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## I. AXIAL

### A. Gluon propagator in the light-like gauge

The general expression for Feynman gluon propagator in the light-like gauge  $p_2^\mu A_\mu = 0$  in the background field (??) has the form

$$i\langle T\{A_\mu^a(x)A_\nu^b(y)\}\rangle = (x|(g_{\mu i}^\perp - \frac{p_{2\mu}}{p_*}p_i) \frac{1}{P^2 + i\epsilon} (\delta_\nu^i - p^i \frac{p_{2\nu}}{p_*}) - \frac{p_{2\mu}p_{2\nu}}{p_*^2}|y)^{ab} \quad (1)$$

Using the expression (??) for  $\frac{1}{P^2 + i\epsilon}$  we get

$$\begin{aligned} \langle T\{A_\mu^a(x)A_\nu^b(y)\}\rangle &= \left[ -\theta(x_* - y_*) \int_0^\infty \frac{d\alpha}{2\alpha} + \theta(y_* - x_*) \int_{-\infty}^0 \frac{d\alpha}{2\alpha} \right] e^{-i\alpha(x-y)\bullet} \\ &\times (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s}x_*} (g_{\mu i}^\perp - \frac{2p_{2\mu}}{\alpha s}p_i) \mathcal{O}_\alpha(x_*, y_*; p_\perp) (\delta_\nu^i - p^i \frac{2p_{2\nu}}{\alpha s}) e^{i\frac{p_\perp^2}{\alpha s}y_*} |y_\perp)^{ab} + i(x| \frac{p_{2\mu}p_{2\nu}}{p_*^2} |y)^{ab} \end{aligned} \quad (2)$$

For the complex conjugate amplitude one obtains in a similar way

$$-i\langle \tilde{T}\{A_\mu^a(x)A_\nu^b(y)\}\rangle = (x|(g_{\mu i}^\perp - \frac{p_{2\mu}}{p_*}p_i) \frac{1}{P^2 - i\epsilon} (\delta_\nu^i - p^i \frac{p_{2\nu}}{p_*}) - \frac{p_{2\mu}p_{2\nu}}{p_*^2}|y)^{ab} \quad (3)$$

and

$$\begin{aligned} \langle \tilde{T}\{A_\mu^a(x)A_\nu^b(y)\}\rangle &= \left[ -\theta(y_* - x_*) \int_0^\infty \frac{d\alpha}{2\alpha} + \theta(x_* - y_*) \int_{-\infty}^0 \frac{d\alpha}{2\alpha} \right] e^{-i\alpha(x-y)\bullet} \\ &\times (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s}x_*} (g_{\mu i}^\perp - \frac{2p_{2\mu}}{\alpha s}p_i) \mathcal{O}_\alpha(x_*, y_*; p_\perp) (\delta_\nu^i - p^i \frac{2p_{2\nu}}{\alpha s}) e^{i\frac{p_\perp^2}{\alpha s}y_*} |y_\perp)^{ab} - i(x| \frac{p_{2\mu}p_{2\nu}}{p_*^2} |y)^{ab} \end{aligned} \quad (4)$$

where we used Eq. (??) for  $\frac{1}{P^2 - i\epsilon}$ .

The ‘‘cut’’ propagator in the background field  $A_\bullet(x_*, x_\perp)$  is given by Eq. (??)

$$\begin{aligned} \langle \tilde{A}_\mu^a(x)A_\nu^b(y)\rangle &= - (x|(g_{\mu i}^\perp - \frac{p_{2\mu}}{p_*}p_i) \frac{1}{P^2 - i\epsilon} p^2 2\pi\delta(p^2)\theta(p_0)p^2 \frac{1}{P^2 + i\epsilon} (\delta_\nu^i - p^i \frac{p_{2\nu}}{p_*}) |y)^{ab} \end{aligned} \quad (5)$$

Using Eq. (??) for scalar propagator we obtain

$$\begin{aligned} \langle \tilde{A}_\mu^a(x)A_\nu^b(y)\rangle &= - \int_0^\infty \frac{d\alpha}{2\alpha} e^{-i\alpha(x-y)\bullet} \\ &\times (x_\perp | (g_{\mu i}^\perp - \frac{2p_{2\mu}}{\alpha s}p_i) e^{-i\frac{p_\perp^2}{\alpha s}x_*} \tilde{\mathcal{O}}(x_*, \infty) \mathcal{O}(\infty, y_*) e^{i\frac{p_\perp^2}{\alpha s}y_*} (\delta_\nu^i - p^i \frac{2p_{2\nu}}{\alpha s}) |y_\perp)^{ab} \end{aligned} \quad (6)$$

where, as usual,  $\tilde{\mathcal{O}}$  is built of the  $\tilde{A}$  fields in the left functional integral in Eq. (??).

### B. Viz xigs

$$S_\Phi = \Omega \int d^4z F_{\mu\nu}^a(z) F^{a\mu\nu}(z) \Phi(z) = \frac{4\Omega}{s} \int d^4z F_{*i}^a(z) F_{\bullet}^{ai}(z) \Phi(z) = \frac{4\Omega}{s} \int d^4z \partial_* A_i^a(z) F_{\bullet}^{ai}(z) \Phi(z) \quad (7)$$

$$\begin{aligned}
\langle A_\mu^a(x) e^{iS_A+iS_\Phi} \rangle &= i\Omega \frac{4}{s} \int d^4y \langle A_\mu^a(x) \partial_* A_i^b(y) F_{\bullet}^{bi}(y) e^{iS_A} \rangle \Phi(y) \\
&= \Omega \frac{4}{s} \int d^4y \langle x | [(g_{\mu j}^\perp - \frac{p_{2\mu} p_j}{p_*}) \frac{1}{P^2 + i\epsilon} (\delta_\nu^j - p^j \frac{p_{2\nu}}{p_*}) - \frac{p_{2\mu} p_{2\nu}}{p_*^2}] i p_* |y\rangle^{ab} \delta_i^\nu F_{\bullet}^{bi}(y) \Phi(y) \\
&= 2i\Omega \int d^4y F_{\bullet}^{bi}(y_*, y_\perp) \Phi(y) \frac{\partial}{\partial y_\bullet} \left[ -\theta(x_* - y_*) \int_0^\infty \frac{\tilde{d}\alpha}{2\alpha} + \theta(y_* - x_*) \int_{-\infty}^0 \frac{\tilde{d}\alpha}{2\alpha} \right] e^{-i\alpha(x-y)_\bullet} \\
&\times (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} x_*} (g_{\mu i}^\perp - \frac{2p_{2\mu} p_i}{\alpha s}) \mathcal{O}_\alpha(x_*, y_*; p_\perp) e^{i\frac{p_\perp^2}{\alpha s} y_*} |y_\perp\rangle^{ab} ] \\
&\simeq \Omega \int d^4y \left[ \theta(x_* - y_*) \int_0^\infty \tilde{d}\alpha - \theta(y_* - x_*) \int_{-\infty}^0 \tilde{d}\alpha \right] e^{-i\alpha(x-y)_\bullet} (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} x_*} (g_{\mu i}^\perp - \frac{2p_{2\mu} p_i}{\alpha s}) |y_\perp\rangle [x_*, y_*]_y^{ab} F_{\bullet}^{bi}(y_*, y_\perp) \Phi(y) ] \\
&= i\Omega \frac{4}{s} \int d^4y \left[ \langle A_\mu^a(x) \partial_* A_i^{b,\alpha>0}(y_\bullet, y_\perp) e^{iS_{\text{QCD}}} \rangle [\infty, y_*]_y^{bc} F_{\bullet}^{ci}(y_*, y_\perp) + \langle A_\mu^a(x) \partial_* A_i^{b,\alpha<0}(y_\bullet, y_\perp) e^{iS_{\text{QCD}}} \rangle [-\infty, y_*]_y^{bc} F_{\bullet}^{ci}(y_*, y_\perp) \right] \Phi(y)
\end{aligned} \tag{8}$$

## II. IN THE BF

### ПРОПАГАТОР

$$\begin{aligned}
\langle A_\mu^a(x) A_\nu^b(y) \rangle &= \left[ -\theta(x_* - y_*) \int_0^\infty \frac{\tilde{d}\alpha}{2\alpha} + \theta(y_* - x_*) \int_{-\infty}^0 \frac{\tilde{d}\alpha}{2\alpha} \right] e^{-i\alpha(x-y)_\bullet} \{ (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} (x-y)_*} \\
&\times [\mathcal{G}_{\mu\nu}^{ab}(x_*, y_*; p_\perp) + \mathcal{Q}_{\mu\nu}^{ab}(x_*, y_*; p_\perp)] |y_\perp\rangle + (y_\perp | \bar{\mathcal{Q}}_{\mu\nu}^{ab}(x_*, y_*; p_\perp) e^{-i\frac{p_\perp^2}{\alpha s} (x-y)_*} |x_\perp\rangle \}
\end{aligned} \tag{9}$$

### GDE

$$\begin{aligned}
\mathcal{G}_{\mu\nu}(x_*, y_*; p_\perp) &= \\
&= g_{\mu\nu}[x_*, y_*] + g \int_{y_*}^{x_*} dz_* \left( -\frac{2i}{\alpha s^2} (z-y)_* g_{\mu\nu} \{ 2p^j [x_*, z_*] F_{\bullet j}(z_*) - i[x_*, z_*] D^j F_{\bullet j}(z_*) \} \right. \\
&+ \frac{4}{\alpha s^2} (\delta_\mu^j p_{2\nu} - \delta_\nu^j p_{2\mu}) [x_*, z_*] F_{\bullet j}(z_*) \left. \right) [z_*, y_*] \\
&+ \frac{8g^2}{\alpha s^3} \int_{y_*}^{x_*} dz_* \int_{y_*}^{z_*} dz'_* [i g_{\mu\nu} (z' - y)_* - \frac{2}{\alpha s} p_{2\mu} p_{2\nu}] [x_*, z_*] F_{\bullet j}(z_*) [z_*, z'_*] F_{\bullet}^j(z'_*) [z'_*, y_*] \\
\mathcal{Q}_{\mu\nu}^{ab}(x_*, y_*; p_\perp) &= -\frac{4ig}{\alpha^2 s^3} p_{2\mu} p_{2\nu} \int_{y_*}^{x_*} dz_* ([x_*, z_*] D^j F_{\bullet j}(z_*) [z_*, y_*])^{ab} \\
&+ \frac{g^2}{\alpha s^2} \int_{y_*}^{x_*} dz_* \int_{y_*}^{z_*} dz'_* \bar{\psi}(z_*) [z_*, x_*] t^a [x_*, y_*] t^b [y_*, z'_*] \gamma_\mu^\perp \not{p}_1 \gamma_\nu^\perp \psi(z'_*), \\
\bar{\mathcal{Q}}_{\mu\nu}^{ab}(x_*, y_*; p_\perp) &= -\frac{g^2}{\alpha s^2} \int_{y_*}^{x_*} dz_* \int_{z_*}^{x_*} dz'_* \bar{\psi} \gamma_\nu^\perp \not{p}_1 \gamma_\mu^\perp [z_*, y_*] t^b [y_*, x_*] t^a [x_*, z'_*] \psi(z'_*)
\end{aligned} \tag{10}$$

As we mentioned, this formula is correct for the point  $y$  inside the shock wave and the point  $x$  inside or outside.

Without quarks

$$\begin{aligned}
\langle A_\mu^a(x) F_{\bullet i}^b(y) \rangle &= i \left[ -\theta(x_* - y_*) \int_0^\infty \frac{\tilde{d}\alpha}{2\alpha} + \theta(y_* - x_*) \int_{-\infty}^0 \frac{\tilde{d}\alpha}{2\alpha} \right] e^{-i\alpha(x-y)_\bullet} (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} (x-y)_*} \left[ \alpha \frac{s}{2} \mathcal{G}_{\mu i}^{ab}(x_*, y_*; p_\perp) - \mathcal{G}_{\mu*}^{ab}(x_*, y_*; p_\perp) p_i \right] |y_\perp\rangle = \\
&= i \left[ -\theta(x_* - y_*) \int_0^\infty \frac{\tilde{d}\alpha}{2\alpha} + \theta(y_* - x_*) \int_{-\infty}^0 \frac{\tilde{d}\alpha}{2\alpha} \right] e^{-i\alpha(x-y)_\bullet} (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} (x-y)_*} \{ [x_*, y_*] \left( \frac{\alpha s}{2} g_{\mu i} - p_{2\mu} p_i \right) - \frac{2p_{2\mu}}{s} \int_{y_*}^{x_*} dz_* [x_*, z_*] F_{\bullet i}(z_*) [z_*, y_*] \} |y_\perp\rangle
\end{aligned} \tag{12}$$

### A. Viz xigs

$$\begin{aligned}
\langle A_\mu^a(x) e^{iS_A+iS_\Phi} \rangle &= i\Omega \frac{4}{s} \int d^4y \langle A_\mu^a(x) (\partial_* A_i^b - \partial_i A_*^b(y)) F_{\bullet}^{bi}(y) e^{iS_A} \rangle \Phi(y) = \frac{4\Omega}{s} \left[ \theta(x_* - y_*) \int_0^\infty \frac{d\alpha}{2\alpha} \right. \\
&\quad \left. - \theta(y_* - x_*) \int_{-\infty}^0 \frac{d\alpha}{2\alpha} \right] e^{-i\alpha(x-y)\cdot} (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} x_*} \{ [x_*, y_*] (\alpha \frac{s}{2} g_{\mu i} - p_{2\mu} p_i) - \frac{2}{s} p_{2\mu} \int_{y_*}^{x_*} dz_* [x_*, z_*] F_{\bullet} (z_*) [z_*, y_*] \} | y_\perp)^{ab} F_{\bullet i}^b(y_*) \Phi(y) \\
&= \frac{4\Omega}{s} \left[ \theta(x_* - y_*) \int_0^\infty \frac{d\alpha}{2\alpha} - \theta(y_* - x_*) \int_{-\infty}^0 \frac{d\alpha}{2\alpha} \right] e^{-i\alpha(x-y)\cdot} (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} x_*} \{ [x_*, y_*] (\alpha \frac{s}{2} g_{\mu i} - p_{2\mu} p_i) - ip_{2\mu} (\partial_i [x_*, y_*]) \} | y_\perp)^{ab} F_{\bullet i}^b(y_*) \Phi(y) \\
&= \frac{4\Omega}{s} \left[ \theta(x_* - y_*) \int_0^\infty \frac{d\alpha}{2\alpha} - \theta(y_* - x_*) \int_{-\infty}^0 \frac{d\alpha}{2\alpha} \right] e^{-i\alpha(x-y)\cdot} (x_\perp | e^{-i\frac{p_\perp^2}{\alpha s} x_*} (\alpha \frac{s}{2} g_{\mu i} - p_{2\mu} p_i) [x_*, y_*] | y_\perp)^{ab} F_{\bullet i}^b(y_*) \Phi(y) \\
&= i\Omega \frac{4}{s} \int d^4y [\langle A_\mu^a(x) (\partial_* A_i - \partial_i A_*)^{b, \alpha > 0}(y_\bullet, y_\perp) \rangle [\infty, y_*]_{y_\perp}^{bc} F_{\bullet}^{ci}(y_*, y_\perp) + \langle A_\mu^a(x) (\partial_* A_i - \partial_i A_*)^{b, \alpha < 0}(y_\bullet, y_\perp) \rangle [-\infty, y_*]_{y_\perp}^{bc} F_{\bullet}^{ci}(y_*, y_\perp)] \Phi(y) \\
&= i\Omega \frac{4}{s} \int d^4y [\langle A_\mu^a(x) F_{*i}^{b, \alpha > 0}(y_\bullet, y_\perp) \rangle [\infty, y_*]_{y_\perp}^{bc} F_{\bullet}^{ci}(y_*, y_\perp) + \langle A_\mu^a(x) F_{*i}^{b, \alpha < 0}(y_\bullet, y_\perp) \rangle [-\infty, y_*]_{y_\perp}^{bc} F_{\bullet}^{ci}(y_*, y_\perp)] \Phi(y) \tag{13}
\end{aligned}$$

### III. LVERTEX

$A_\bullet(x_*, x_\perp), B_*(x_\bullet, x_\perp)$

$$\begin{aligned}
D^\mu \mathcal{G}_{\mu i} &= -\frac{2}{s} f^{abc} (B_*^b \partial_i A_\bullet^c + A_\bullet^b \partial_i B_*^c) \\
D^\mu \mathcal{G}_{\mu \bullet} &= \frac{2}{s} f^{abc} [B_*^b \partial_\bullet A_\bullet^c - \frac{s}{2} (\frac{1}{\partial_*} B_*^b) \partial_\perp^2 A_\bullet^c] + \frac{2}{s} f^{abm} f^{cdm} A_\bullet^b B_*^c A_\bullet^d \\
D^\mu \mathcal{G}_{\mu * } &= \frac{2}{s} f^{abc} [A_\bullet^b \partial_* B_*^c - \frac{s}{2} (\frac{1}{\partial_\bullet} A_\bullet^b) \partial_\perp^2 B_*^c] + \frac{2}{s} f^{abm} f^{cdm} B_*^b A_\bullet^c B_*^d \tag{14}
\end{aligned}$$

Chek:

$$\begin{aligned}
\partial^\nu D^\mu \mathcal{G}_{\mu\nu} &= \frac{2}{s} f^{abc} \left[ -\partial_i (B_*^b \partial_i A_\bullet^c + A_\bullet^b \partial_i B_*^c) \right. \\
&\quad \left. + \partial_* [B_*^b \partial_\bullet A_\bullet^c - \frac{s}{2} (\frac{1}{\partial_*} B_*^b) \partial_\perp^2 A_\bullet^c] + \frac{2}{s} f^{abm} f^{cdm} A_\bullet^b \partial_* B_*^c A_\bullet^d + \partial_\bullet [A_\bullet^b \partial_* B_*^c - \frac{s}{2} (\frac{1}{\partial_\bullet} A_\bullet^b) \partial_\perp^2 B_*^c] + \frac{2}{s} f^{abm} f^{cdm} B_*^b \partial_\bullet A_\bullet^c B_*^d \right] \tag{15}
\end{aligned}$$

If  $\alpha\beta s \gg \perp^2$  the Lipatov vertex reduces to usual one.

$$\begin{aligned}
&C_*^a(\alpha) B_*^b(\alpha_1) B_*^c(-\alpha - \alpha_1) \bar{\psi} \left( t^a \frac{1}{\alpha + i\epsilon} t^b \frac{1}{\alpha + \alpha_1 + i\epsilon} t^c - t^a \frac{1}{\alpha + i\epsilon} t^c \frac{1}{\alpha_1 - i\epsilon} t^b + t^b \frac{1}{\alpha_1 + i\epsilon} t^a \frac{1}{\alpha + \alpha_1 + i\epsilon} t^c \right. \\
&\quad \left. + t^c \frac{1}{\alpha + \alpha_1 - i\epsilon} t^a \frac{1}{\alpha_1 - i\epsilon} t^b - t^b \frac{1}{\alpha_1 + i\epsilon} t^c \frac{1}{\alpha - i\epsilon} t^a + t^c \frac{1}{\alpha + \alpha_1 - i\epsilon} t^b \frac{1}{\alpha - i\epsilon} t^a \right) \hat{p}_1 \psi \\
&= C_*^a(\alpha) B_*^b(\alpha_1) B_*^c(-\alpha - \alpha_1) \bar{\psi} \left( t^a t^b t^c \frac{1}{(\alpha + i\epsilon)(\alpha + \alpha_1 + i\epsilon)} - t^a t^c t^b \left[ \frac{1}{(\alpha + i\epsilon)(\alpha + \alpha_1)} + \frac{1}{(\alpha_1 - i\epsilon)(\alpha + \alpha_1)} \right] \right. \\
&\quad \left. + t^b t^a t^c \frac{1}{(\alpha_1 + i\epsilon)(\alpha + \alpha_1 + i\epsilon)} + t^c t^a t^b \frac{1}{(\alpha + \alpha_1 - i\epsilon)(\alpha_1 - i\epsilon)} - t^b t^c t^a \left[ \frac{1}{(\alpha - i\epsilon)(\alpha + \alpha_1)} + \frac{1}{(\alpha_1 + i\epsilon)(\alpha + \alpha_1)} \right] \right. \\
&\quad \left. + t^c t^b t^a \frac{1}{(\alpha + \alpha_1 - i\epsilon)(\alpha - i\epsilon)} \right) \hat{p}_1 \psi = C_*^a(\alpha) B_*^b(\alpha_1) B_*^c(-\alpha - \alpha_1) \bar{\psi} \left( \frac{[t^a, [t^b, t^c]]}{\alpha(\alpha + \alpha_1)} + \frac{[t^b, [t^a, t^c]]}{\alpha_1(\alpha + \alpha_1)} \right) \hat{p}_1 \psi \\
&\sim C_*^a(\alpha, \beta) B_*^b(\alpha_1) B_*^c(-\alpha - \alpha_1) \partial^2 A_\bullet^n(-\beta) \left[ \frac{f^{amn} f^{bcm}}{\alpha(\alpha + \alpha_1)} + \frac{f^{acm} f^{bmn}}{\alpha_1(\alpha + \alpha_1)} \right] \tag{17}
\end{aligned}$$

Zapishem po-drugomu

$$\begin{aligned}
&\sim C_*^k(\alpha_1 + \alpha_2) B_*^a(-\alpha_1) B_*^b(-\alpha_2) \bar{\psi} \left( \frac{[t^a, [t^b, t^k]]}{\alpha_1(\alpha_1 + \alpha_2)} + \frac{[t^b, [t^a, t^k]]}{\alpha_2(\alpha_1 + \alpha_2)} \right) \hat{p}_1 \psi \\
&\sim C_*^c(\alpha_1 + \alpha_2, \beta) B_*^a(-\alpha_1) B_*^b(-\alpha_2) \partial^2 A_\bullet^n(-\beta) \left[ \frac{f^{amn} f^{bcm}}{\alpha_1(\alpha_1 + \alpha_2)} + \frac{f^{acm} f^{bmn}}{\alpha_2(\alpha_1 + \alpha_2)} \right] \tag{18}
\end{aligned}$$

## 1. Lvertices

$$-i\langle\psi(x)\bar{\psi}(y)\rangle_{A_*} = \frac{2}{s}\langle\psi(x)\bar{\psi}(z)\rangle\hat{p}_1 A_*(z)\langle\psi(z)\bar{\psi}(y)\rangle - \frac{2}{s}\langle\psi(x)\bar{\psi}(z)\rangle A_*(z)\langle z|\frac{1}{P_*}|z'\rangle A_*(z')\hat{p}_1\langle\psi(z')\bar{\psi}(y)\rangle \quad (19)$$

$$S_{\text{eff}} = \frac{2}{s}\int d^4z \bar{\psi}(z)\hat{p}_1 A_*\psi(z) - \frac{2}{s}\int d^4z d^4z' \bar{\psi}(z)\hat{p}_1 A_*(z)\langle z|\frac{1}{P_*+i\epsilon}|z'\rangle A_*(z')\langle\psi(z')\rangle \quad (20)$$

Y HAC  $A_* = B_* + C_*$  U HADO expand do 3x powers of  $C_*$ .

First term of expansion (the lvertex)

$$\begin{aligned} S_{\text{eff}} &= \frac{2}{s}\int d^4z \bar{\psi}(z)\hat{p}_1 C_*\psi(z) - \frac{2}{s}\int d^4z d^4z' \bar{\psi}(z)\hat{p}_1 [C_*(z)\langle z|\frac{1}{p_*+B_*+i\epsilon}|z'\rangle B_*(z') + B_*(z)\langle z|\frac{1}{p_*+B_*+i\epsilon}|z'\rangle C_*(z') \\ &- B_*(z)\langle z|\frac{1}{p_*+B_*+i\epsilon}C_*\frac{1}{p_*+B_*+i\epsilon}|z'\rangle B_*(z')]\psi(z') \\ &= \frac{2i}{s}\int d^4z \int dz'_\bullet \bar{\psi}(z_*, z_\perp)\hat{p}_1 \{\theta(z_\bullet > z'_\bullet)C_*(z)[z_\bullet, z'_\bullet]_z B_*(z'_\bullet, z_\perp) + \theta(z_\bullet > z'_\bullet)B_*(z_\bullet, z_\perp)[z_\bullet, z'_\bullet]_z C_*(z) \\ &- \int dz'_\bullet d''_\bullet \theta(z_\bullet > z'_\bullet)\theta(z'_\bullet > z''_\bullet)B_*(z_\bullet, z_\perp)[z_\bullet, z'_\bullet]_z C_*(z')[z'_\bullet, z''_\bullet]_z B_*(z''_\bullet, z_\perp)\}\bar{\psi}(z_*, z_\perp) \\ &= \frac{2}{s}\int d^4z \int dz'_\bullet \bar{\psi}(z_*, z_\perp)\hat{p}_1 \{[-\infty, z_\bullet]C_*(z)[z_\bullet, -\infty] - C_*(z)\}\bar{\psi}(z_*, z_\perp) \end{aligned} \quad (21)$$

Po-drugomu

$$\begin{aligned} S_{\text{eff}} &= \frac{2}{s}\int d^4z \bar{\psi}(z)\hat{p}_1 A_*\psi(z) - \frac{2}{s}\int d^4z d^4z' \bar{\psi}(z)\hat{p}_1 A_*(z)\langle z|\frac{1}{P_*+i\epsilon}|z'\rangle A_*(z')\langle\psi(z')\rangle \\ &= \frac{2}{s}\int d^4z d^4z' \bar{\psi}(z)\hat{p}_1 [p_* - (z|p_*\frac{1}{P_*+i\epsilon}p_*|z')]\langle\psi(z')\rangle = -\frac{s}{2}\int d^4z dz'_\bullet \theta(z_\bullet - z'_\bullet)\bar{\psi}(z_*, z_\perp)\hat{p}_1 \frac{\partial}{\partial z_\bullet} \frac{\partial}{\partial z'_\bullet} [z_\bullet, z'_\bullet]_z \psi(z_*, z_\perp) \\ &= \int d^2z_\perp dz_* dz'_\bullet \bar{\psi}(z_*, z_\perp)[\infty, z_\bullet]_z C_*(z)[z_\bullet, -\infty]_z \psi(z_*, z_\perp) \end{aligned} \quad (22)$$

bikoz

$$\frac{\partial}{\partial z_\bullet} \frac{\partial}{\partial z'_\bullet} \text{Pexp}\left\{i\frac{2}{s}\int_{z'_\bullet}^{z_\bullet} dz''_\bullet (B_* + C_*)\right\} = \frac{\partial}{\partial z_\bullet} \frac{\partial}{\partial z'_\bullet} i\frac{2}{s}\int_{z'_\bullet}^{z_\bullet} dz''_\bullet [z_\bullet, z''_\bullet]_z C_*(z'') [z''_\bullet, z'_\bullet] \quad (24)$$

Eq. (22) korrespondz 2

$$\begin{aligned} &\int dz_* \left( t^a t^b t^c \int_{z_*}^\infty dz'_* \int_{z_*}^{z'_*} dz''_* + t^a t^c t^b \int_{z_*}^\infty dz'_* \int_{-\infty}^{z_*} dz''_* + t^c t^a t^b \int_{-\infty}^{z_*} dz'_* \int_{-\infty}^{z'_*} dz''_* \right) e^{-i\alpha_1 z'_\bullet - i\alpha_2 z''_\bullet - i\alpha z_\bullet} B_\bullet^a(\alpha_1) B_\bullet^b(\alpha_2) C_\bullet^c(\alpha) \\ &= \delta(\alpha_1 + \alpha_2 + \alpha) \left[ -\frac{t^a t^b t^c}{(\alpha_1 - i\epsilon)(\alpha_1 + \alpha_2 - i\epsilon)} + \frac{t^a t^c t^b}{(\alpha_1 - i\epsilon)(\alpha_2 + i\epsilon)} - \frac{t^c t^a t^b}{(\alpha_2 + i\epsilon)(\alpha_1 + \alpha_2 + i\epsilon)} \right] B_\bullet^a(\alpha_1) B_\bullet^b(\alpha_2) C_\bullet^c(\alpha) \end{aligned} \quad (25)$$

Perepishem fla (16)

$$\begin{aligned} &C_*^c(\alpha) B_*^a(\alpha_1) B_*^b(\alpha_2) = -\alpha - \alpha_1 \bar{\psi} \left( t^c \frac{1}{-\alpha_1 - \alpha_2 + i\epsilon} t^a \frac{1}{-\alpha_2 + i\epsilon} t^b + t^c \frac{1}{-\alpha_1 - \alpha_2 + i\epsilon} t^b \frac{1}{-\alpha_1 + i\epsilon} t^a + t^a \frac{1}{\alpha_1 + i\epsilon} t^c \frac{1}{-\alpha_2 + i\epsilon} t^b \right. \\ &+ t^b \frac{1}{\alpha_2 + i\epsilon} t^c \frac{1}{-\alpha_1 + i\epsilon} t^a + t^a \frac{1}{\alpha_1 + i\epsilon} t^b \frac{1}{\alpha_1 + \alpha_2 + i\epsilon} t^c + t^b \frac{1}{\alpha_2 + i\epsilon} t^a \frac{1}{\alpha_1 + \alpha_2 + i\epsilon} t^c \left. \right) \hat{p}_1 \psi \\ &= C_*^c(\alpha) B_*^a(\alpha_1) B_*^b(\alpha_2) \bar{\psi} \left( \frac{t^c t^a t^b}{(\alpha_2 - i\epsilon)(\alpha_1 + \alpha_2 - i\epsilon)} + \frac{t^c t^b t^a}{(\alpha_1 - i\epsilon)(\alpha_1 + \alpha_2 - i\epsilon)} \right. \\ &+ \frac{t^a t^c t^b}{(\alpha_1 + i\epsilon)(-\alpha_2 + i\epsilon)} + \frac{t^b t^c t^a}{(\alpha_2 + i\epsilon)(-\alpha_1 + i\epsilon)} + \frac{t^a t^b t^c}{(\alpha_1 + i\epsilon)(\alpha_1 + \alpha_2 + i\epsilon)} + \left. \frac{t^b t^a t^c}{(\alpha_1 + i\epsilon)(\alpha_1 + \alpha_2 + i\epsilon)} \right) \hat{p}_1 \psi \\ &= C_*^c(\alpha) B_*^a(\alpha_1) B_*^b(\alpha_2) \bar{\psi} \left( \frac{[[t^c, t^a], t^b]}{\alpha_2(\alpha_1 + \alpha_2)} + \frac{[[t^c, t^b], t^a]}{\alpha_1(\alpha_1 + \alpha_2)} \right) \hat{p}_1 \psi \\ &\sim C_*^c(\alpha, \beta) B_*^a(\alpha_1) B_*^b(\alpha_2) \partial^2 A_\bullet^n(-\beta) \left[ \frac{f^{acm} f^{bmn}}{\alpha_2(\alpha_1 + \alpha_2)} + \frac{f^{bcm} f^{amn}}{\alpha_1(\alpha_1 + \alpha_2)} \right] \end{aligned} \quad (26)$$

Nau, gipoteza dlya retarded fankshns

$$\int d^2 z_{\perp} dz_* dz_{\bullet} \bar{\psi}(z_*, z_{\perp}) [-\infty, z_{\bullet}]_z C(z) [z_{\bullet}, -\infty]_z \psi(z_*, z_{\perp}) \quad (27)$$

korrespondz 2

$$\begin{aligned} & \int dz_* \left( t^a t^b t^c \int_{z_*}^{-\infty} dz'_* \int_{z_*}^{z'_*} dz''_* + t^a t^c t^b \int_{z_*}^{-\infty} dz'_* \int_{-\infty}^{z_*} dz''_* + t^c t^a t^b \int_{-\infty}^{z_*} dz'_* \int_{-\infty}^{z'_*} dz''_* \right) e^{-i\alpha_1 z'_{\bullet} - i\alpha_2 z''_{\bullet} - i\alpha z_{\bullet}} B_{\bullet}^a(\alpha_1) B_{\bullet}^b(\alpha_2) C_{\bullet}^c(\alpha) \\ &= \delta(\alpha_1 + \alpha_2 + \alpha) \left[ -\frac{t^a t^b t^c}{(\alpha_1 + i\epsilon)(\alpha_1 + \alpha_2 + i\epsilon)} + \frac{t^a t^c t^b}{(\alpha_1 + i\epsilon)(\alpha_2 + i\epsilon)} - \frac{t^c t^a t^b}{(\alpha_2 + i\epsilon)(\alpha_1 + \alpha_2 + i\epsilon)} \right] B_{\bullet}^a(\alpha_1) B_{\bullet}^b(\alpha_2) C_{\bullet}^c(\alpha) \\ &= \delta(\alpha_1 + \alpha_2 + \alpha) \left[ -\frac{t^a [t^b, t^c]}{(\alpha_1 + i\epsilon)(\alpha_1 + \alpha_2 + i\epsilon)} - \frac{[t^c, t^a] t^b}{(\alpha_2 + i\epsilon)(\alpha_1 + \alpha_2 + i\epsilon)} \right] B_{\bullet}^a(\alpha_1) B_{\bullet}^b(\alpha_2) C_{\bullet}^c(\alpha) \end{aligned} \quad (28)$$

UTOFO

$$\begin{aligned} D^{\mu} \mathcal{G}_{\mu i} &= -\frac{2}{s} f^{abc} (B_*^b \partial_i A_*^c + A_*^b \partial_i B_*^c) \\ D^{\mu} \mathcal{G}_{\mu \bullet} &= \frac{2}{s} \bar{D}_{\bullet}^{aa'} f^{a'bc} B_*^b A_*^c - \left( \frac{1}{\bar{P}_* + i\epsilon} B_* \right)^{ab} \partial_{\perp}^2 A_*^b = \frac{2}{s} \bar{D}_{\bullet}^{ab} \bar{G}_{* \bullet}^b - \left( \frac{1}{\bar{P}_* + i\epsilon} B_* \right)^{ab} \partial_{\perp}^2 A_*^b \\ D^{\mu} \mathcal{G}_{\mu * } &= \frac{2}{s} \bar{D}_{* }^{aa'} f^{a'bc} A_{\bullet}^b B_*^c - \left( \frac{1}{\bar{P}_{\bullet} + i\epsilon} A_{\bullet} \right)^{ab} \partial_{\perp}^2 B_*^b = -\frac{2}{s} \bar{D}_{* }^{ab} \bar{G}_{* \bullet}^b - \left( \frac{1}{\bar{P}_{\bullet} + i\epsilon} A_{\bullet} \right)^{ab} \partial_{\perp}^2 B_*^b \\ D^{\mu} \mathcal{G}_{\mu \nu} &= \bar{D}^{\mu} \bar{G}_{\mu \nu} - \partial^2 \bar{A}_{\mu} - l_{\mu}, \quad l_{\mu}^a \equiv \frac{2}{s} p_{1\mu} \left( \frac{1}{\bar{P}_{\bullet}} \bar{A}_{\bullet} \right)^{ab} \partial_{\perp}^2 \bar{A}_*^b + \frac{2}{s} p_{2\mu} \left( \frac{1}{\bar{P}_*} \bar{A}_* \right)^{ab} \partial_{\perp}^2 \bar{A}_{\bullet}^b \end{aligned} \quad (29)$$

Chek:

$$\begin{aligned} \bar{D}^{\nu} D^{\mu} \mathcal{G}_{\mu \nu} &= \frac{2}{s} f^{abc} \left[ -\partial^i (B_*^b \partial_i A_*^c + A_*^b \partial_i B_*^c) \right. \\ &+ \frac{2}{s} (\bar{D}_*)^{aa'} \left[ \frac{2}{s} \bar{D}_{\bullet}^{a'b} \bar{G}_{* \bullet}^b - \left( \frac{1}{\bar{P}_* + i\epsilon} B_* \right)^{a'b} \partial_{\perp}^2 A_{\bullet}^b \right] + \frac{2}{s} (\bar{D}_{\bullet})^{aa'} \left[ -\frac{2}{s} \bar{D}_{* }^{a'b} \bar{G}_{* \bullet}^b - \left( \frac{1}{\bar{P}_{\bullet} + i\epsilon} A_{\bullet} \right)^{a'b} \partial_{\perp}^2 B_*^b \right] \\ &= \frac{4}{s^2} [\bar{D}_*, \bar{D}_{\bullet}]^{ab} \bar{G}_{* \bullet}^b - \frac{2}{s} f^{abc} \partial_i (B_*^b \partial_i A_*^c + A_*^b \partial_i B_*^c) - \frac{2}{s} f^{abc} (B_*^b \partial_{\perp}^2 A_*^c + A_*^b \partial_{\perp}^2 B_*^c) = 0 \end{aligned} \quad (30)$$

## 2. Exersize with scalar quarks

Vertex:  $\bar{\phi}_k(x) \phi_k(x) \Phi(x)$

$$\begin{aligned} i \bar{\phi}_A^m(x) \phi_C^m(x) \int d^4 z \bar{\phi}_C^k(z) \{p^{\mu}, A_{\mu}\}_{kl} \phi_B^l(z) &= \int d^4 z \bar{\phi}_A^m(x) (z) 2\alpha \frac{1}{m^2 + p^2 - \alpha\beta s - i\epsilon} |x\rangle_{mk} A_{\bullet}^{kl}(z_*, z_{\perp}) \phi_B^l(z) \\ \stackrel{\alpha \geq 0}{=} - \int d^4 z \bar{\phi}_A^m(x_*, x_{\perp}) (x) \frac{2}{\beta s + i\epsilon} |z\rangle A_{\bullet}^{kl}(z_*, z_{\perp}) \phi_B^l(z_{\bullet}, z_{\perp}) &= -\frac{2}{s} \int dz_* \bar{\phi}_A^k(x_*, x_{\perp}) A_{\bullet}^{kl}(z_*, x_{\perp}) \int \frac{\bar{d}\beta}{\beta + i\epsilon} e^{-i\beta(x_* - z_*)} \phi_B^l(x_{\bullet}, x_{\perp}) \\ = \bar{\phi}_A^k(x_*, x_{\perp}) \frac{2i}{s} \int_{-\infty}^{x_*} dz_* A_{\bullet}^{kl}(z_*, x_{\perp}) \phi_B^l(x_{\bullet}, x_{\perp}) &\rightarrow \bar{\phi}_A^k(x_*, x_{\perp}) [x_*, -\infty]_x^{kl} \phi_B^l(x_{\bullet}, x_{\perp}) \end{aligned} \quad (31)$$

which agrees with

$$\bar{\phi}^k(x) \langle \phi^k(x) \phi^l(y) \rangle_A = \bar{\phi}^k(x) [x_*, -\infty]^{kl} (x) \frac{i}{p^2 + i\epsilon} |y\rangle \Rightarrow \bar{\phi}_A^k(x) [\phi_B^k(x) + \phi_C^k(x)] = \int d^4 z \bar{\phi}_A^k(x) (x) \frac{1}{P^2 + i\epsilon} p^2 |z\rangle^{kl} \phi_B^l(z) \quad (32)$$

First order in  $B_*$

$$\begin{aligned} & \int d^4 z d^4 z' (x) \frac{1}{(p+A)^2 + i\epsilon} \{p, A\} |z'\rangle^{kl} \phi_B^l(z') (x) \frac{1}{(p+A)^2 + i\epsilon} \{p+A, B\} |z\rangle^{km} \phi_A^m(z) \\ \stackrel{\alpha \geq 0}{=} [x_*, -\infty]_x^{kl} \phi_B^l(x_{\bullet}, x_{\perp}) \frac{1}{s} (x) \frac{1}{P^2 + i\epsilon} \{P_{\bullet}, B_*\} |z\rangle^{km} \phi_A^m(z) \\ = \bar{\phi}_A^k(x_*, x_{\perp}) \frac{2i}{s} \int_{-\infty}^{x_*} dz_* A_{\bullet}^{kl}(z_*, x_{\perp}) \phi_B^l(x_{\bullet}, x_{\perp}) &\rightarrow \bar{\phi}_A^k(x_*, x_{\perp}) [x_*, -\infty]_x^{kl} \phi_B^l(x_{\bullet}, x_{\perp}) \end{aligned} \quad (33)$$

### A. Gluon in the bF gauge

Split the fields in up, down, and ‘‘eikonal’’  $A \rightarrow A + B + C$ . The field  $B$  (up) do not depend on  $z_*$  (at least, the dependence is negligible). Similarly, fields  $A$  (down) do not depend on  $z_\bullet$ . The propagator of  $C$  fields will be local in  $x_\perp$ .

$$F_{\mu\nu} = (A + B)_{\mu\nu} + (D_\mu C_\nu - \mu \leftrightarrow \nu) - i[C_\mu, C_\nu], \quad (A + B)_{\mu\nu} \equiv A_{\mu\nu} + B_{\mu\nu} - i[A_\mu, B_\nu] - i[B_\mu, A_\nu] \quad (34)$$

$$\begin{aligned} -\frac{1}{4}F_{\mu\nu}^a F^{a\mu\nu} - \frac{1}{2}[(D_\mu C_\mu]^2 &= -\frac{1}{2}\text{Tr}\{(A_{\mu\nu} + B_{\mu\nu} - i[A_\mu, B_\nu] - i[B_\mu, A_\nu])^2\} \\ + 2\text{Tr}\{C^\nu D^\mu (A + B)_{\mu\nu}\} - \frac{1}{2}\text{Tr}\{C^\mu (D^2 g_{\mu\nu} - 2i[(A + B)_{\mu\nu}], C^\nu)\} - 2i\text{Tr}\{D^\mu C_\nu [C^\mu, C^\nu]\} + \dots \end{aligned} \quad (35)$$

Linear term

$$2\text{Tr}\{C^\nu D^\mu (A + B)_{\mu\nu}\} = C^{a\nu} (D^\mu (A + B)_{\mu\nu})^a \quad (36)$$

$$\begin{aligned} C_\alpha^a(x) &\rightarrow A_\alpha^a(x) + B_\alpha^a(x) + i \int dz \langle C_\alpha^a(x) C^{b\nu}(x) \rangle (D^\mu (A + B)_{\mu\nu})^b \\ &= A_\alpha^a(x) + B_\alpha^a(x) + \int dz (x | \left( \frac{1}{P^2 g_{\alpha\nu} + 2i(A + B)_{\alpha\nu}} \right)^{ab} (D^\mu (A + B)_{\mu\nu})^b | z) \end{aligned} \quad (37)$$

Now we keep all orders in  $A$  but only one in  $B$ . By kinematics, this only  $B$  must be from  $(D^\mu (A + B)_{\mu\nu})$  since pure  $A$ 's cannot produce  $C$  gluon. Thus,

$$(D^\mu (A + B)_{\mu\nu}) \rightarrow (D^2 g_{\nu\mu} - 2iA_{\nu\mu})^{ab} B^{b\mu} - D_\nu D_\mu B^\mu \quad (38)$$

Also,  $B$  alone cannot produce  $C$  gluon so the term  $(\partial^2 g_{\nu\mu} - \partial_\mu \partial_\nu) B^\mu$  must be subtracted, so

$$(D^\mu (A + B)_{\mu\nu})^b \rightarrow (D^2 g_{\nu\mu} - 2iA_{\nu\mu})^{bc} B^{c\mu} - (D_\nu D_\mu B^\mu)^b - (\partial^2 g_{\nu\mu} - \partial_\mu \partial_\nu) B^{b\mu} \quad (39)$$

and we get

$$\begin{aligned} A_\alpha^a(x) + B_\alpha^a(x) + C_\alpha^a(x) &\rightarrow A_\alpha^a(x) + B_\alpha^a(x) + i \int dz \langle C_\alpha^a(x) C^{b\nu}(z) \rangle (D^\mu (A + B)_{\mu\nu})^b(z) = A_\alpha^a(x) + B_\alpha^a(x) \\ + \int dz (x | \left( \frac{1}{P^2 g_{\alpha\nu} + 2iA_{\alpha\nu}} \right)^{ab} (D^2 g_{\nu\Omega} - 2iA_{\nu\Omega} - D_\nu D_\Omega)^{bc} | z) B^{c\Omega}(z) &- \int dz (x | \left( \frac{1}{P^2 g_{\alpha\nu} + 2iA_{\alpha\nu}} \right)^{ab} (\partial^2 g_{\nu\Omega} - \partial_\nu \partial_\Omega | z) B^{b\Omega}(z) \\ = A_\alpha^a(x) + \int dz (x | P_\alpha \frac{1}{P^2} P^\mu | x)^{ab} B_\mu^b(z) - \int dz (x | \left( \frac{1}{P^2 g_{\alpha\nu} + 2iA_{\alpha\nu}} \right)^{ab} (\partial^2 g_{\nu\Omega} - \partial_\nu \partial_\Omega | z) B^{b\Omega}(z) &+ O(D^\mu A_{\mu\nu}) \end{aligned} \quad (40)$$

If  $\alpha = *$

$$\begin{aligned} &\int dz (x | P_* \frac{1}{P^2 + i\epsilon} P^\Omega | x)^{ab} B_\Omega^b(z) - \int dz (x | \frac{1}{P^2 + i\epsilon} (\partial^2 p_{2\Omega} - \partial_\Omega \partial_*) | z)^{ab} B^{b\mu}(z) \\ &= \int dz (x | \frac{\alpha}{P^2} P_\bullet | z)^{ab} B_*^m(z) - \int dz (x | \frac{1}{P^2} (\partial^2 - \frac{2}{s} \partial_\bullet \partial_*) | z)^{ab} B_*^b(z) \\ &= \int dz (x | \frac{\alpha}{P^2} P_\bullet | z)^{ab} B_*^m(z) + \int dz (x | \frac{1}{P^2} (\alpha p_\bullet - p_\perp^2) | z)^{ab} B_*^b(z) = B_*^a(x) - \int dz (x | \frac{\alpha}{P^2 + i\epsilon} A_\bullet | x)^{ab} B_*^b(z) \end{aligned} \quad (41)$$

Decompose  $B_*(z_\bullet) = B_*^{\alpha>0} + B_*^{\alpha<0} = B^+(z_\bullet) + B^-(z_\bullet)$

$$\begin{aligned} &\int dz (x | \frac{\alpha}{P^2 + i\epsilon} A_\bullet | z)^{ab} B_*^{b+}(z) + \int dz (z | \frac{\alpha}{P^2 + i\epsilon} A_\bullet | x)^{ab} B_*^{b-}(z) \\ &= \frac{1}{2} \int dz (z | \frac{1}{P_\bullet + i\epsilon} A_\bullet | z)^{ab} B_*^{b+}(z) + \frac{1}{2} \int dz (x | \frac{1}{P_\bullet - i\epsilon} A_\bullet | z)^{ab} B_*^{m-}(z) \\ &= \frac{1}{2} B_*^a(x) + \frac{is}{4} \int dz \frac{\partial}{\partial z_*} (x | \frac{1}{P_\bullet + i\epsilon} | z)^{ab} B_*^{b+}(z) + \frac{is}{4} \int dz \frac{\partial}{\partial z_*} (x | \frac{1}{P_\bullet - i\epsilon} | z)^{ab} B_*^{m-}(z) \\ &= \frac{1}{2} B_*^a(x) + \frac{1}{2} \int dz_* \frac{\partial}{\partial z_*} \theta(x_* - z_*) [x_*, z_*]^{ab} B_*^{b+}(x_\bullet, x_\perp) - \frac{1}{2} \int dz_* \frac{\partial}{\partial z_*} [x_*, z_*]^{ab} \theta(z_* - x_*) B_*^{b-}(x_\bullet, x_\perp) \\ &= \frac{1}{2} B_*^a(x) - \frac{1}{2} [x_*, -\infty]^{ab} B_*^{b+}(x_\bullet, x_\perp) - \frac{1}{2} \int dz_* [x_*, \infty]^{ab} B_*^{b-}(x_\bullet, x_\perp) \end{aligned} \quad (42)$$



ΓDE DBOŮKA?

Ice again in the leading order in  $B$ :

$$D^\mu(A+B)_{\mu*} = (D_A^\mu - i[B^\mu])(A_{\mu*} + D_\mu^A B_* - D_*^A B_\mu) + O(B^2) = D_A^2 B_* - \frac{2}{s} D_*^A D_{\bullet}^A B_* \quad (43)$$

$$\begin{aligned} C_*^a(x) &\rightarrow A_*^a(x) + B_*^a(x) + i \int dz \langle C_*^a(x) C^{\mu b}(x) \rangle (D^\mu(A+B)_{\mu\nu})^b \\ &= B_*^a(x) + \int dz (x | \frac{1}{(p+A)^2} | z)^{ab} (D^\mu(A+B)_{\mu*} - (A=0))^b(z) = B_*^a(x) - \int dz (x | \frac{1}{(p+A)^2} (\{p, A\} - \alpha A_{\bullet}) | z)^{ab} B_*(z) \\ &= B_*^a(x) - \int dz (x | \frac{1}{2\alpha P_{\bullet} + i\epsilon} (2\alpha A_{\bullet} - \alpha A_{\bullet}) | z)^{ab} B_*(z) = B_*^a(x) - \int dz (x | \frac{1}{P_{\bullet} + i\epsilon\alpha} (A_{\bullet} - \frac{1}{2} A_{\bullet}) | z)^{ab} B_*(z) \end{aligned} \quad (44)$$

$$\int dz (x | \frac{1}{P_{\bullet} + i\epsilon\alpha} A_{\bullet} | z)^{ab} B_*(z)$$

$$\begin{aligned} \int dz (x | \frac{1}{P_{\bullet} + i\epsilon\alpha} A_{\bullet} | z)^{ab} B_*(z) &= \int dz (x | \frac{1}{P_{\bullet} + i\epsilon} A_{\bullet} | z)^{ab} B_*^{b+}(z) + \int dz (z | \frac{1}{P_{\bullet} - i\epsilon} A_{\bullet} | x)^{ab} B_*^{b-}(z) \\ &= \int dz (z | \frac{1}{P_{\bullet} + i\epsilon} A_{\bullet} | z)^{ab} B_*^{b+}(z) + \int dz (x | \frac{1}{P_{\bullet} - i\epsilon} A_{\bullet} | z)^{ab} B_*^{m-}(z) \\ &= B_*^a(x) + \frac{is}{4} \int dz \frac{\partial}{\partial z_*} (x | \frac{1}{P_{\bullet} + i\epsilon} | z)^{ab} B_*^{b+}(z) + \frac{is}{2} \int dz \frac{\partial}{\partial z_*} (x | \frac{1}{P_{\bullet} - i\epsilon} | z)^{ab} B_*^{m-}(z) \\ &= B_*^a(x) + \int dz_* \frac{\partial}{\partial z_*} \theta(x_* - z_*) [x_*, z_*]^{ab} B_*^{b+}(x_{\bullet}, x_{\perp}) - \int dz_* \frac{\partial}{\partial z_*} [x_*, z_*]^{ab} \theta(z_* - x_*) B_*^{b-}(x_{\bullet}, x_{\perp}) \\ &= B_*^a(x) - [x_*, -\infty]^{ab} B_*^{b+}(x_{\bullet}, x_{\perp}) - \int dz_* [x_*, \infty]^{ab} B_*^{b-}(x_{\bullet}, x_{\perp}) = B_*^a(x) - [x_*, -\infty\alpha]^{ab} B_*^b(x_{\bullet}, x_{\perp}) \end{aligned} \quad (45)$$

## B. Lorentz gauge

$$D^\mu G_{\mu\nu} = D^\mu A_{\mu\nu} + D^\mu B_{\mu\nu} \Rightarrow (D^2 g_{\mu\nu} - 2iG_{\mu\nu}^{A+B} - D_\mu D_\nu) C^\nu = (D^\mu G_{\mu\nu})^{A+B} - D^\mu A_{\mu\nu} - D^\mu B_{\mu\nu} \quad (46)$$

Lorentz gauge  $\partial^\mu C_\mu = 0$

$$C_\mu = \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iG_{\mu\nu} - P_\mu A_\nu} | z) [(D^\mu G_{\mu\nu})^{A+B} - D^\mu A_{\mu\nu} - D^\mu B_{\mu\nu}](z) \quad (47)$$

In the leading order in  $B$

$$\begin{aligned} C_\mu &= - \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu} - P_\mu A_\nu} | z) [(P^2 g_{\nu\Omega} + 2iA_{\nu\Omega} - P_\nu P_\Omega - p^2 g_{\nu\Omega} + p_\nu p_\Omega) | z] B^\Omega(z) \\ &= - \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu} - P_\mu A_\nu} | z) [(P^2 g_{\nu\Omega} + 2iA_{\nu\Omega} - P_\nu A_\Omega - p^2 g_{\nu\Omega}) | z] B^\Omega(z) \\ &= - B_\mu + \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu} - P_\mu A_\nu} p^2 | z) B_\nu(z) = - B_\mu + \frac{2}{s} \int dz (x | \frac{1}{P^2 g_{\mu\bullet} + 2iA_{\mu\bullet} - P_\mu A_{\bullet}} p^2 | z) B_*(z) \quad (48) \\ C_* &= - B_* + \int dz (x | \frac{1}{P^2 - \frac{2}{s} P_* A_{\bullet}} p^2 | z) B_*(z) = - B_* + \int dz (x | \frac{1}{P_{\bullet} - \frac{1}{2} A_{\bullet} - i\epsilon\alpha} p_{\bullet} | z) B_*(z) \end{aligned} \quad (49)$$

### C. Background-Lorentz gauge

$$(\partial_\mu - iA_\mu - iB_\mu)C^\mu = 0 \Rightarrow$$

$$C_\mu^a = \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iG_{\mu\nu}} | z)^{ab} [(D^\mu G_{\mu\nu})^{A+B} - D^\mu A_{\mu\nu} - D^\mu B_{\mu\nu}]^b(z) \quad (50)$$

In the leading order in  $B$

$$\begin{aligned} C_\mu^a &= - \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu}} | z) [(P^2 g_{\nu\Omega} + 2iA_{\nu\Omega} - P_\nu P_\Omega - p^2 g_{\nu\Omega} + p_\nu p_\Omega) | z]^{ab} B^{b\Omega}(z) \\ &= - \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu}} | z) [(P^2 g_{\nu\Omega} + 2iA_{\nu\Omega} - P_\nu A_\Omega - p^2 g_{\nu\Omega}) | z] B^\Omega(z) \\ &= -B_\mu + \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu}} p^2 | z) B_\nu(z) + \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu}} P_\nu A_\Omega | z) B_\Omega(z) \\ &= -B_\mu + \frac{2}{s} \int dz (x | \frac{1}{P^2 g_{\mu\bullet} + 2iA_{\mu\bullet} - i\epsilon} p^2 | z)^{ab} B_*^b(z) + \frac{2}{s} \int dz (x | \frac{1}{P^2 g_{\mu\nu} + 2iA_{\mu\nu} - i\epsilon} P_\nu A_\bullet | z)^{ab} B_*^b(z) \quad (51) \end{aligned}$$

$$\begin{aligned} C_*^a &= -B_*^a + \int dz (x | \frac{1}{P^2 + i\epsilon} p^2 | z)^{ab} B_*^b(z) + \int dz (x | \frac{1}{P^2 + i\epsilon} \alpha A_\bullet | z)^{ab} B_*^b(z) \quad (52) \\ &= -\frac{1}{2} \int dz (x | \frac{1}{P_\bullet + i\epsilon \alpha} A_\bullet | z)^{ab} B_*^b(z) \\ \Rightarrow C_*(x) &= \frac{i}{s} \int_{-\infty}^{x_*} dz_* [x_*, z_*]_x [A_\bullet(z_*, x_\perp), B_*(x_\bullet, x_\perp)] [z_*, x_*]_x = -\frac{1}{2} B_*(x_\bullet, x_\perp) + \frac{1}{2} [x_*, -\infty \alpha]_x B_*(x_\bullet, x_\perp) [-\infty \alpha, x_*]_x \end{aligned}$$

In the first order in  $A$  and  $B$

$$C_* = - \int dz (x | \frac{1}{p^2 + i\epsilon} (2\alpha A_\bullet - \alpha A_\bullet) | z) B_*(z) \Leftrightarrow C_*^a = -i f^{abc} \int dz (x | \frac{1}{p^2 + i\epsilon} (2\alpha A_\bullet^b - \alpha A_\bullet^b)(z) B_*^c(z) \quad (53)$$

ΦΟΡΜΥΛΑ

$$P_\mu \frac{1}{P^2 g_{\mu\nu} + 2iG_{\mu\nu}} = \frac{1}{P^2} P_\nu + \frac{1}{P^2} D^\alpha G_{\alpha\beta} \frac{1}{P^2 g_{\beta\nu} + 2iG_{\beta\nu}} \quad (54)$$

#### 1. From 3-gluon vertex

Vershina

$$\begin{aligned} \exp \left\{ -ig \int dz f^{mnl} A_\mu^m A_\nu^n (D^\mu A^\nu)^l \right\} &= \exp \left\{ \frac{g}{3!} \int \dot{d} k_1 \dot{d} k_2 A_\mu^m(k_1) A_\nu^n(k_2) A_\Omega^l(-k_1 - k_2) f^{mnl} \Gamma^{\mu\nu\Omega}(k_1, k_2, -k_1 - k_2) \right\} \\ \Gamma_{\mu\nu;\Omega}(k_1, k_2) &\equiv \Gamma_{\mu\nu\Omega}(k_1, k_2, -k_1 - k_2) = (k_1 - k_2)_\Omega g_{\mu\nu} + (2k_2 + k_1)_\mu g_{\nu\Omega} + (-2k_1 - k_2)_\nu g_{\Omega\mu} \quad (55) \end{aligned}$$

$$\begin{aligned} \langle C_\alpha^a(x) \exp \left\{ \frac{g}{3!} \int \dot{d} k_1 \dot{d} k_2 (A + B + C)_\mu^m(k_1) (A + B + C)_\nu^n(k_2) (A + B + C)_\Omega^l(-k_1 - k_2) f^{mnl} \Gamma^{\mu\nu\Omega}(k_1, k_2, -k_1 - k_2) \right\} \rangle \\ &= f^{mnl} \int \dot{d} k_1 \dot{d} k_2 \langle C_\alpha(x) C_\Omega^l(-k_1 - k_2) \rangle \frac{g}{2} (A + B)_\mu^m(k_1) (A + B)_\nu^n(k_2) \Gamma^{\mu\nu\Omega}(k_1, k_2, -k_1 - k_2) \\ &= g f^{mnl} \int \dot{d} k_1 \dot{d} k_2 \langle C_\alpha(x) C_\Omega^l(-k_1 - k_2) \rangle A_\mu^m(k_1) B_\nu^n(k_2) \Gamma^{\mu\nu\Omega}(k_1, k_2, -k_1 - k_2) \\ &= -i \frac{2}{s} g f^{mnl} \int \dot{d} k_1 \dot{d} k_2 \frac{e^{-i(k_1+k_2)x}}{(k_1+k_2)^2} [(2\alpha_1 + \alpha_2)p_1 - (2\beta_2 + \beta_1)p_2 + (k_1 - k_2)^\perp]_\alpha A_\bullet^m(k_1) B_*^n(k_2) \\ &= -i \frac{2}{s} g f^{mnl} \int \dot{d} k_1 \dot{d} k_2 \frac{e^{-i\alpha_2 x_\bullet - i\beta_1 x_* + i(k_1+k_2, x)_\perp}}{\alpha_2 \beta_1 s - (k_1+k_2)_\perp^2 + i\epsilon} [\alpha_2 p_1 - \beta_1 p_2 + (k_1 - k_2)^\perp]_\alpha A_\bullet^m(k_{1\perp}, \beta_k) B_*^n(k_2) \\ &= \frac{2}{is} g f^{mnl} \int \dot{d} k_1^\perp \dot{d} k_2^\perp \frac{e^{-i\alpha_2(x-z_2)_\bullet - i\beta_1(x-z_1)_* + i(k_1+k_2, x)_\perp - i(k_1, z_1)_\perp - i(k_2, z_2)_\perp}}{\alpha_2 \beta_1 s - (k_1+k_2)_\perp^2 + i\epsilon} [\alpha_2 p_1 - \beta_1 p_2 + (k_1 - k_2)^\perp]_\alpha A_\bullet^m(z_1) B_*^n(z_2) dz_{1*} dz_{2\bullet} \dot{d} \alpha_2 \dot{d} \beta_1 \end{aligned}$$

Assumption: drop  $(k_1 + k_2)_\perp^2$  in the denominator

$$\begin{aligned}
&= \frac{2}{is} g f^{mnl} \int \bar{d} k_1^\perp \bar{d} k_2^\perp e^{-i\alpha_2(x-z_2)_\bullet - i\beta_1(x-z_1)_* + i(k_1+k_2, x)_\perp - i(k_1, z_1)_\perp - i(k_2, z_2)_\perp} \frac{[\alpha_2 p_1 - \beta_1 p_2 + (k_1 - k_2)_\perp]^\alpha}{\alpha_2 \beta_1 s + i\epsilon} A_\bullet^m(z_1) B_*^n(z_2) dz_{1*} dz_{2\bullet} \bar{d} \alpha_2 \bar{d} \beta_1 \\
&= \frac{2}{is^2} g f^{mnl} \int dz_{1*} dz_{2\bullet} \bar{d} \alpha_2 \bar{d} \beta_1 e^{-i\alpha_2(x-z_2)_\bullet - i\beta_1(x-z_1)_*} \left( \left[ \frac{p_1}{\beta_1 + i\epsilon \alpha_2} - \frac{p_2}{\alpha_2 + i\epsilon \beta_1} \right] A_\bullet^m(x_\perp, z_{1*}) B_*^n(x_\perp, z_{2\bullet}) \right. \\
&+ \left. \frac{i}{\alpha_2 \beta_1 + i\epsilon} [(\partial_\alpha^\perp A_\bullet^m(x_\perp, z_{1*})) B_*^n(x_\perp, z_{2\bullet}) - A_\bullet^m(x_\perp, z_{1*}) \partial_\alpha^\perp B_*^n(x_\perp, z_{2\bullet})] \right) \tag{56}
\end{aligned}$$

$$\begin{aligned}
C_*^a(x) &= \frac{1}{is} g f^{mnl} \int dz_{1*} dz_{2\bullet} \bar{d} \alpha_2 \bar{d} \beta_1 e^{-i\alpha_2(x-z_2)_\bullet - i\beta_1(x-z_1)_*} \frac{1}{\beta_1 + i\epsilon \alpha_2} A_\bullet^m(x_\perp, z_{1*}) B_*^n(x_\perp, z_{2\bullet}) \\
&= -\frac{1}{s} f^{amn} \int_{-\infty}^{x_*} dz_* A_\bullet^m(x_\perp, z_*) B_*^{n+}(x_\perp, x_\bullet) + \frac{1}{s} f^{amn} \int_{x_*}^{\infty} dz_* A_\bullet^m(x_\perp, z_*) B_*^{n-}(x_\perp, x_\bullet) \\
&= \frac{1}{2} ([x_*, -\infty]_x^{(1)})^{an} B_*^{n+}(x_\perp, x_\bullet) + \frac{1}{2} ([x_*, \infty]_x^{(1)})^{an} B_*^{n-}(x_\perp, x_\bullet) = \frac{1}{2} ([x_*, -\infty \alpha]_x^{(1)})^{ab} B_*^b(x_\perp, x_\bullet) \tag{57}
\end{aligned}$$

#### D. Scalars

Linear term

$$\begin{aligned}
\bar{\phi}_C[(p+A+B)^2 - (p+B)^2] \phi_B + \bar{\phi}_C[(p+A+B)^2 - (p+A)^2] \phi_A + \bar{\phi}_B[(p+A+B)^2 - (p+B)^2] \phi_C + \bar{\phi}_A[(p+A+B)^2 - (p+B)^2] \phi_C \\
= \bar{\phi}_C(\{p+A, B\} + B^2) \phi_A + \bar{\phi}_C(\{p+B, A\} + A^2) \phi_B + \bar{\phi}_A(\{p+A, B\} + B^2) \phi_C + \bar{\phi}_B(\{p+B, A\} + A^2) \phi_C \tag{58}
\end{aligned}$$

In the first order in  $B_*$

$$\begin{aligned}
\phi_A(x) + i\phi_C \int dz \bar{\phi}_C[(p+A+B)^2 - (p+A)^2] \phi_A(z) &= \phi_A(x) - \int dz (x | \frac{1}{(p+A+B)^2 + i\epsilon} | z) [(p+A+B)^2 - (p+A)^2] \phi_A(z) \\
&= \int dz (x | \frac{1}{(p+A+B)^2 + i\epsilon} (p+A)^2 | z) \phi_A(z) = \phi_A(x) - \int dz \phi_A(x) (x | \frac{1}{(p+A)^2 + i\epsilon} \{p+A, B\} | z) \phi_A(z) \\
&= \phi_A(x) - \frac{2}{s} \int dz (x | \frac{1}{\alpha} | z) B_*(z) \phi_A(z) + \frac{1}{s} \int dz (x | \frac{1}{\alpha P_\bullet + i\epsilon} | z) [A_\bullet, B_*] \phi_A(z) \\
&= [x_\bullet, \infty \beta]_x^{(1)} \phi_A(x_*, x_\perp) + \frac{1}{s} \int dz (x | \frac{1}{\alpha P_\bullet + i\epsilon} | z) [A_\bullet, B_*] \phi_A(z) \\
&= [x_\bullet, \infty \beta]_x^{(1)} \phi_A(x_*, x_\perp) + \frac{1}{s} \int dz (x | \frac{1}{\alpha P_\bullet + i\epsilon} [A_\bullet, B_*] \frac{1}{P_\bullet + i\epsilon \alpha} A_\bullet | z) \phi_A(z) + \frac{1}{s} \int dz (x | \frac{1}{\alpha P_\bullet + i\epsilon} A_\bullet | z) B_*(z) \phi_A(z) \tag{59}
\end{aligned}$$

Dobavka:

$$\begin{aligned}
C_*(x) &= \frac{i}{s} \int_{-\infty}^{x_*} dz_* [x_*, z_*]_x [A_\bullet(z_*, x_\perp), B_*(x_\bullet, x_\perp)] [z_*, x_*]_x = -\frac{1}{2} B_*(x_\bullet, x_\perp) + \frac{1}{2} [x_*, -\infty \alpha]_x B_*(x_\bullet, x_\perp) [-\infty \alpha, x_*]_x \\
\frac{2i}{s} \int dz_\bullet C_*(z_\bullet) \phi_A(x_*, x_\perp) &= \frac{1}{s} \int dz_\bullet ([z_*, -\infty]_x B_*(x_\perp, z_\bullet) [z_*, -\infty]_x - B_*(z_\perp, x_\bullet)) \phi_A(x_*, x_\perp) \tag{60}
\end{aligned}$$

$$\begin{aligned}
\bar{\phi}_B(x) + i \int dz \bar{\phi}_B(z) [(p+A+B)^2 - (p+B)^2] \phi_C(z) \bar{\phi}_C &= \bar{\phi}_B(x) - \int dz \bar{\phi}_B(z) (z [(p+A+B)^2 - (p+B)^2]) \frac{1}{(p+A+B)^2 + i\epsilon} |x) \\
&= \int dz \bar{\phi}_B(z) (z | (p+B)^2 \frac{1}{(p+A+B)^2 + i\epsilon} |x) \\
&= \int dz \bar{\phi}_B(z) (z | p^2 \left[ \frac{1}{(p+A)^2} - \frac{1}{(p+A)^2 + i\epsilon} \{p+A, B\} \frac{1}{(p+A)^2 + i\epsilon} \right] |x) + \int dz \bar{\phi}_B(z) (z | \{p, B\} \frac{1}{(p+A)^2 + i\epsilon} |x) \\
&= \int dz \bar{\phi}_B(z) (z | p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} - \frac{1}{s} p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} \{P_\bullet, B_*\} \frac{1}{\alpha P_\bullet + i\epsilon} |x) + \frac{1}{s} \int dz \bar{\phi}_B(z) (z | \{p_\bullet, B_*\} \frac{1}{\alpha P_\bullet + i\epsilon} |x) \\
&= \int dz \bar{\phi}_B(z) (z | p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} |x) + \frac{1}{s} \int dz \bar{\phi}_B(z) (z | p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} [A_\bullet, B_*] \frac{1}{\alpha P_\bullet + i\epsilon} |x) \\
&= \bar{\phi}_B(x_\bullet, x_\perp) [-\infty, x_*] + \frac{1}{s} \int dz \bar{\phi}_B(z) (z | p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} [A_\bullet, B_*] \frac{1}{\alpha P_\bullet + i\epsilon} |x) \\
&= \bar{\phi}_B(x_\bullet, x_\perp) [-\infty, x_*] + \frac{1}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) B_*(z_\bullet, x_\perp) [-\infty, x_*]_x - \frac{1}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) [-\infty, x_*]_x B_*(z_\bullet, x_\perp) \quad (61)
\end{aligned}$$

1 mo term

$$\begin{aligned}
\bar{\phi}_B(x) + i \int dz \bar{\phi}_B(z) [(p+A+B+C)^2 - (p+B)^2] \phi_C(z) \bar{\phi}_C &\ni \int dz \bar{\phi}_B(z) (z | 2\alpha C_\bullet \frac{1}{(p+A)^2 + i\epsilon} |x) \\
&= \\
&= \quad (62)
\end{aligned}$$

CYMMA

$$\begin{aligned}
&\bar{\phi}_B(x_\bullet, x_\perp) [-\infty, x_*] [x_\bullet, \infty]_x^{(1)} \phi_A(x_*, x_\perp) + \frac{1}{s} \bar{\phi}_B(x_\bullet, x_\perp) \int dz (x | \frac{1}{\alpha P_\bullet + i\epsilon} |z) [A_\bullet, B_*] \phi_A(z) \\
&+ \frac{1}{s} \int dz \bar{\phi}_B(z) (z | p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} [A_\bullet, B_*] \frac{1}{\alpha P_\bullet + i\epsilon} |x) \phi_A(x_*, x_\perp) + B_* \leftrightarrow C_* \\
&= \frac{1}{2} \bar{\phi}_B(x_\bullet, x_\perp) [x_\bullet, \infty]_x^{(1)} [-\infty, x_*]_x \phi_A(x_*, x_\perp) + \frac{1}{2} \bar{\phi}_B(x_\bullet, x_\perp) [-\infty, x_*]_x [x_\bullet, \infty]_x^{(1)} \phi_A(x_*, x_\perp) \\
&+ \left[ \frac{1}{s} \bar{\phi}_B(x_\bullet, x_\perp) \int dz (x | \frac{1}{\alpha P_\bullet + i\epsilon} |z) [A_\bullet, B_*] \phi_A(z) + \frac{1}{s} \int dz \bar{\phi}_B(z) (z | p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} [A_\bullet, B_*] \frac{1}{\alpha P_\bullet + i\epsilon} |x) \phi_A(x_*, x_\perp) + B_* \leftrightarrow C_* \right] \\
&= \bar{\phi}_B(x_\bullet, x_\perp) [x_\bullet, \infty]_x^{(1)} [-\infty, x_*]_x \phi_A(x_*, x_\perp) + \frac{1}{2} \bar{\phi}_B(x_\bullet, x_\perp) \left( \frac{1}{\alpha} B_*(x) [-\infty, x_*]_x - [-\infty, x_*]_x \frac{1}{\alpha} B_*(x) \right) \phi_A(x_*, x_\perp) \\
&+ \left[ \frac{1}{s} \bar{\phi}_B(x_\bullet, x_\perp) \int dz (x | \frac{1}{\alpha P_\bullet + i\epsilon} |z) [A_\bullet, B_*] \phi_A(z) + \frac{1}{s} \int dz \bar{\phi}_B(z) (z | p \cdot \frac{1}{P_\bullet + i\epsilon\alpha} [A_\bullet, B_*] \frac{1}{\alpha P_\bullet + i\epsilon} |x) \phi_A(x_*, x_\perp) + B_* \leftrightarrow \mathbb{G} \right] \quad (63)
\end{aligned}$$

1. Zabył

$$\begin{aligned}
e^{i \int dz' C^\mu D_\mu G^{\mu\nu}(z')} e^{i \int dz \bar{\phi}_B \{p+A+B, C\} \phi_C} \bar{\phi}_C(x) &= - \int dz' D_\mu G^{a\mu\nu} \langle C^\nu(z') C_\Omega(z) \rangle^{ab} \bar{\phi}_B \{p+A+B, t^b\} \langle \phi_C(z) \bar{\phi}_C(x) \rangle \\
&= - \int dz \bar{\phi}_B(z) \{p+A, C^{(1)}(z)\} \langle \phi_C(z) \bar{\phi}_C(x) \rangle = - \int dz \bar{\phi}_B(z) (z | \{p+A, C^{(1)}\} \frac{1}{(p+A)^2 + i\epsilon} |x) \\
&= \frac{2}{s} \int dz \bar{\phi}_B(z) C_*(z) (z | 2P_\bullet \frac{1}{2\alpha P_\bullet + i\epsilon} |x) = \frac{2}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) C_*(z_\bullet, x_\perp) \quad (64)
\end{aligned}$$

## 2. Cbu

From Eq. (51) we get

$$\begin{aligned}
C_{\bullet}^a &= \frac{2}{s} \int dz (x | \frac{1}{P^2 g_{\bullet\bullet} + 2iA_{\bullet\bullet} - i\epsilon} p^2 + \frac{2}{s} \frac{1}{P^2 g_{\bullet\bullet} + 2iA_{\bullet\bullet} - i\epsilon} P_{\bullet} A_{\bullet} + \frac{1}{P^2 g_{\bullet i} + 2iA_{\bullet i} - i\epsilon} P_i A_{\bullet} + \frac{1}{P^2} P_{\bullet} A_{\bullet} | z)^{ab} B_{\bullet}^b(z) \\
&= \frac{2}{s} \int dz (x | \frac{4}{P^2} A_{\bullet i} \frac{1}{P^2} A_{\bullet}^i \frac{1}{P^2} \alpha(2p_{\bullet} + A_{\bullet}) - 2i \frac{1}{P^2} A_{\bullet i} \frac{1}{P^2} p^i A_{\bullet} + \frac{1}{2\alpha P^2} (2\alpha P_{\bullet} - p_{\perp}^2 + p_{\perp}^2) A_{\bullet} | z)^{ab} B_{\bullet}^b(z) \\
&= \frac{2}{s} \int dz (x | \frac{1}{\alpha^2} \frac{1}{P_{\bullet}} A_{\bullet i} \frac{1}{P_{\bullet}} A_{\bullet}^i \frac{1}{P_{\bullet}} \alpha(2p_{\bullet} + A_{\bullet}) - \frac{i}{2\alpha^2} \frac{1}{P_{\bullet}} A_{\bullet i} \frac{1}{P_{\bullet}} p^i A_{\bullet} + \frac{1}{2\alpha} A_{\bullet} + \frac{1}{4\alpha P_{\bullet}} p_{\perp}^2 A_{\bullet} | z)^{ab} B_{\bullet}^b(z) \\
&\simeq \int dz (x | \frac{1}{\alpha s} A_{\bullet} | z)^{ab} B_{\bullet}^b = \frac{1}{2} [x_{\bullet}, -\infty \beta]_x^{ab} A_{\bullet}^b(x_{\bullet}, x_{\perp}) - \frac{1}{2} A_{\bullet}^a(x_{\bullet}, x_{\perp})
\end{aligned} \tag{65}$$

## IV. SCALARS AGAIN

Scalars move in the “external” field  $(A + B + C)_{\mu}$

## 3. Fi A

$$\begin{aligned}
&\phi_A(x) + i\phi_C \int dz \bar{\phi}_C [(p + A + B + C)^2 - (p + A)^2] \phi_A(z) \\
&= \phi_A(x) - \int dz (x | \frac{1}{(p + A + B + C)^2 + i\epsilon} | z) [(p + A + B + C)^2 - (p + A)^2] \phi_A(z) \\
&= \int dz (x | \frac{1}{(p + A + B + C)^2 + i\epsilon} (p + A)^2 | z) \phi_A(z) = \phi_A(x) - \int dz (x | \frac{1}{(p + A)^2 + i\epsilon} \{p + A, B + C\} | z) \phi_A(z) \\
&= \phi_A(x) - \int dz (x | \frac{1}{(p + A)^2 + i\epsilon} (\frac{4}{s} P_{\bullet} (B_{\bullet} + C_{\bullet}) - \frac{2}{s} [P_{\bullet}, B_{\bullet} + C_{\bullet}] + 2\alpha C_{\bullet} + \{p_i, C^i\}) | z) \phi_A(z) \\
&= \phi_A(x) - \int dz (x | \frac{1}{(p + A)^2 + i\epsilon} (\frac{4}{s} P_{\bullet} (B_{\bullet} + C_{\bullet}) - \frac{2}{s} [P_{\bullet}, B_{\bullet} + C_{\bullet}] + 2[\alpha, C_{\bullet}] + \{p_i, C^i\}) | z) \phi_A(z)
\end{aligned} \tag{66}$$

Since

$$C_{\bullet}^a = -\frac{1}{2} \int dz (x | \frac{1}{P_{\bullet} + i\epsilon\alpha} A_{\bullet} | z)^{ab} B_{\bullet}^b(z), \quad C_{\bullet}^a = \int dz (x | \frac{1}{\alpha s} A_{\bullet} | z)^{ab} B_{\bullet}^b \tag{67}$$

we get

$$\begin{aligned}
P_{\bullet}^{ab} (B_{\bullet} + C_{\bullet})^b &= \frac{1}{2} A_{\bullet}^{ab} B_{\bullet}^b \Rightarrow [P_{\bullet}, B_{\bullet} + C_{\bullet}] = \frac{1}{2} [A_{\bullet}, B_{\bullet}] \\
2\alpha C_{\bullet}^a &= \frac{1}{s} A_{\bullet}^{ab} B_{\bullet}^b \Rightarrow [\alpha, C_{\bullet}] = \frac{1}{s} [A_{\bullet}, B_{\bullet}]
\end{aligned} \tag{68}$$

$$\Rightarrow \{p^{\mu} + A^{\mu}, B_{\mu} + C_{\mu}\} \simeq \frac{4}{s} (p + A)_{\bullet} (B_{\bullet} + C_{\bullet}) \tag{69}$$

and there4

$$\begin{aligned}
&\phi_A(x) + i\phi_C \int dz \bar{\phi}_C [(p + A + B + C)^2 - (p + A)^2] \phi_A(z) \\
&= \phi_A(x) - \int dz (x | \frac{1}{(p + A)^2 + i\epsilon} \frac{4}{s} P_{\bullet} (B_{\bullet} + C_{\bullet}) | z) \phi_A(z) = \phi_A(x) - \frac{2}{s} \int dz (x | \frac{1}{\alpha P_{\bullet} + i\epsilon} P_{\bullet} (B_{\bullet} + C_{\bullet}) | z) \phi_A(z)
\end{aligned} \tag{70}$$

$$(x|\frac{1}{\alpha P_{\bullet} + i\epsilon}|z) = -i\delta(x_{\perp} - z_{\perp})[x_*, z_*] \left( \theta(x_* - z_*) \int_{\sigma}^{\infty} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} - \theta(z_* - x_*) \int_{-\infty}^{-\sigma} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} \right) \quad (71)$$

$$(x|P_{\bullet} \frac{1}{\alpha P_{\bullet}}|z) = \frac{s}{2} \delta(x_{\perp} - z_{\perp}) \delta(x_* - z_*) \left[ \int_{\sigma}^{\infty} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} + \int_{-\infty}^{-\sigma} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} \right] = -\frac{is}{4} \delta(x_{\perp} - z_{\perp}) \delta(x_* - z_*) \epsilon(x_{\bullet} - z_{\bullet})$$

$$(x|\frac{1}{P_{\bullet} + i\epsilon\alpha}|z) = -i\delta(x_{\perp} - z_{\perp})[x_*, z_*] \left( \theta(x_* - z_*) \int_{\sigma}^{\infty} d\alpha e^{-i\alpha(x-z)\bullet} - \theta(z_* - x_*) \int_{-\infty}^{-\sigma} d\alpha e^{-i\alpha(x-z)\bullet} \right)$$

$$\begin{aligned} \int_{\sigma}^{\infty} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} &= -\frac{i\pi}{2} - \ln \sigma(x_{\bullet} - z_{\bullet} - i\epsilon) - C + O(\sigma(x-z)\bullet) \\ \int_{-\infty}^{-\sigma} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} &= -\frac{i\pi}{2} + \ln \sigma(x_{\bullet} - z_{\bullet} + i\epsilon) + C + O(\sigma(x-z)\bullet) \end{aligned} \quad (72)$$

ДАЛЕЕ,

$$\frac{2}{s} \int dz (x|P_{\bullet} \frac{1}{\alpha P_{\bullet}}|z) [B_*(z) + C_*(z)] \phi_A(z) = \frac{1}{2} \int dz_{\bullet} \left[ \int_{\sigma}^{\infty} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} \right. \quad (73)$$

$$\times (B_*^+(z_{\bullet}, x_{\perp}) + [x_*, -\infty] B_*^+(z_{\bullet}, x_{\perp}) [-\infty, x_*]) + \int_{-\infty}^{-\sigma} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} (B_*^-(z_{\bullet}, x_{\perp}) + [x_*, \infty] B_*^-(z_{\bullet}, x_{\perp}) [\infty, x_*]) \left. \right] \phi_A(x)$$

$$= -\frac{i}{2} \int_{-\infty}^{x_{\bullet}} dz_{\bullet} (B_*(z_{\bullet}) + [x_*, -\infty] B_*(z_{\bullet}) [-\infty, x_*]) \phi_A(x) + \frac{i}{2} \int_{x_{\bullet}}^{\infty} dz_{\bullet} (B_*(z_{\bullet}) + [x_*, -\infty] B_*(z_{\bullet}) [-\infty, x_*]) \phi_A(x)$$

$$+ \frac{1}{2} [x_*, -\infty] \int dz_{\bullet} \int_{-\infty}^{-\sigma} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} (U_x^{\dagger} B_*^-(z_{\bullet}, x_{\perp}) U_x - B_*^-(z_{\bullet}, x_{\perp})) [-\infty, x_*] \phi_A(x) \quad (74)$$

where we uzd

$$B_*(x) + C_*(x) = \frac{1}{2} B_*^+(x_{\bullet}, x_{\perp}) + \frac{1}{2} [x_*, -\infty] B_*^+(x_{\bullet}, x_{\perp}) [-\infty, x_*] + \frac{1}{2} B_*^-(x_{\bullet}, x_{\perp}) + \frac{1}{2} [x_*, \infty] B_*^-(x_{\bullet}, x_{\perp}) [\infty, x_*] \quad (75)$$

УТОГО

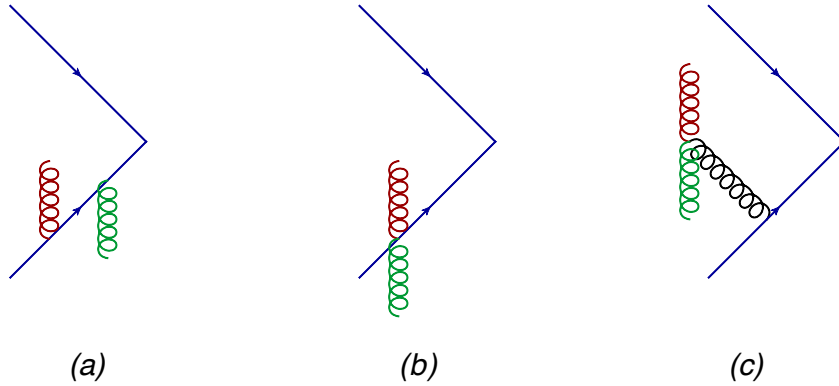


FIG. 1. Niz.

$$\begin{aligned} \phi_A(x) + i\phi_C \int dz \bar{\phi}_C [(p+A+B+C)^2 - (p+A)^2] \phi_A(z) &= \phi_A(x) - \frac{2}{s} \int dz (x|\frac{1}{\alpha P_{\bullet} + i\epsilon} P_{\bullet} (B_* + C_*)|z) \phi_A(z) \\ &= \phi_A(x) + \frac{i}{s} \int_{-\infty}^{x_{\bullet}} dz_{\bullet} (B_*(z_{\bullet}) + [x_*, -\infty] B_*(z_{\bullet}) [-\infty, x_*]) \phi_A(x) - \frac{i}{s} \int_{x_{\bullet}}^{\infty} dz_{\bullet} (B_*(z_{\bullet}) + [x_*, -\infty] B_*(z_{\bullet}) [-\infty, x_*]) \phi_A(x) \\ &- \frac{1}{s} [x_*, -\infty] \int dz_{\bullet} \int_{-\infty}^{-\sigma} \frac{d\alpha}{\alpha} e^{-i\alpha(x-z)\bullet} (U_x^{\dagger} B_*^-(z_{\bullet}, x_{\perp}) U_x - B_*^-(z_{\bullet}, x_{\perp})) [-\infty, x_*] \phi_A(x) \end{aligned} \quad (76)$$

4. *Fi Be*

$$\begin{aligned}
& \bar{\phi}_B(x) + i \int dz \bar{\phi}_B(z) [(p+A+B+C)^2 - (p+B)^2] \phi_C(z) \bar{\phi}_C(x) \\
&= \bar{\phi}_B(x) - \int dz \bar{\phi}_B(z) (z | [(p+A+B+C)^2 - (p+B)^2] \frac{1}{(p+A+B+C)^2 + i\epsilon} | x) \\
&= \int dz \bar{\phi}_B(z) (z | (p+B)^2 \frac{1}{(p+A+B+C)^2 + i\epsilon} | x) = \int dz \bar{\phi}_B(z) (z | p^2 \frac{1}{(p+A)^2 + i\epsilon} | x) \\
&+ \int dz \bar{\phi}_B(z) (z | \{p, B\} \frac{1}{(p+A)^2 + i\epsilon} - p^2 \frac{1}{(p+A)^2} \{p+A, B+C\} \frac{1}{(p+A)^2} | x) \\
&= \int dz \bar{\phi}_B(z) (z | p \frac{1}{P_\bullet + i\epsilon\alpha} | x) + \int dz \bar{\phi}_B(z) (z | -\frac{4}{s} p \bullet C_* \frac{1}{(p+A)^2 + i\epsilon} | x) \\
&= i \frac{s}{2} \int dz \bar{\phi}_B(z) \frac{\partial}{\partial z_*} (z | \frac{1}{P_\bullet + i\epsilon\alpha} | x) - i \int dz \bar{\phi}_B(z) \frac{\partial}{\partial z_*} C_*(z) (z | \frac{1}{\alpha P_\bullet + i\epsilon} | x) \\
&= \frac{s}{2} \int dz \bar{\phi}_B(z) \delta(x_\perp - z_\perp) \frac{\partial}{\partial z_*} [z_*, x_*] \left( \theta(z_* - x_*) \int_\sigma^\infty \dot{d}\alpha e^{-i\alpha(z-x)\bullet} - \theta(x_* - z_*) \int_{-\infty}^{-\sigma} \dot{d}\alpha e^{-i\alpha(z-x)\bullet} \right) \\
&- \int dz \delta(x_\perp - z_\perp) \bar{\phi}_B(z) \frac{\partial}{\partial z_*} C_*(z) [z_*, x_*] \left( \theta(z_* - x_*) \int_\sigma^\infty \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(z-x)\bullet} - \theta(x_* - z_*) \int_{-\infty}^{-\sigma} \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(z-x)\bullet} \right) \\
&= \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) [\infty, x_*] \int_\sigma^\infty \dot{d}\alpha e^{-i\alpha(z-x)\bullet} - \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) [-\infty, x_*] \int_{-\infty}^{-\sigma} \dot{d}\alpha e^{-i\alpha(z-x)\bullet} \\
&- \frac{2}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) C_*(z_* = \infty, z_\bullet, x_\perp) [\infty, x_*] \int_\sigma^\infty \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(z-x)\bullet} \\
&+ \frac{2}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) C_*(z_* = -\infty, z_\bullet, x_\perp) [-\infty, x_*] \int_{-\infty}^{-\sigma} \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(z-x)\bullet} \\
&= \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) [\infty, x_*] \int_\sigma^\infty \dot{d}\alpha e^{-i\alpha(z-x)\bullet} - \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) [-\infty, x_*] \int_{-\infty}^{-\sigma} \dot{d}\alpha e^{-i\alpha(z-x)\bullet} \\
&- \frac{1}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \{U_x B_*^+(z_\bullet, x_\perp) U_x^\dagger - B_*^+(z_\bullet, x_\perp)\} [\infty, x_*] \int_\sigma^\infty \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(z-x)\bullet} \\
&+ \frac{1}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \{U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp)\} [-\infty, x_*] \int_{-\infty}^{-\sigma} \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(z-x)\bullet} \tag{77}
\end{aligned}$$

bikoz

$$\begin{aligned}
C_*(x) &= -\frac{1}{2} B_*^+(x_\bullet, x_\perp) + \frac{1}{2} [x_*, -\infty] B_*^+(x_\bullet, x_\perp) [-\infty, x_*] - \frac{1}{2} B_*^-(x_\bullet, x_\perp) + \frac{1}{2} [x_*, \infty] B_*^-(x_\bullet, x_\perp) [\infty, x_*] \tag{78} \\
\Rightarrow C_*(x_* = \infty) &= -\frac{1}{2} B_*^+(x_\bullet, x_\perp) + \frac{1}{2} U_x B_*^+(x_\bullet, x_\perp) U_x^\dagger, \quad C_*(x_* = -\infty) = -\frac{1}{2} B_*^-(x_\bullet, x_\perp) + \frac{1}{2} U_x^\dagger B_*^-(x_\bullet, x_\perp) U_x
\end{aligned}$$

From LSZ:

$$\int dx_\bullet e^{i\alpha_H x} \mathcal{O}(x_\bullet) \Rightarrow \mathcal{O}(x_\bullet) = \int_0^\infty \dot{d}\alpha \mathcal{O}(\alpha) e^{-i\alpha x}$$

$\Rightarrow$  the third term in the r.h.s. of Eq. (77) does not contribute

$$\begin{aligned}
& \Rightarrow \bar{\phi}_B(x) + i \int dz \bar{\phi}_B(z) [(p+A+B+C)^2 - (p+B)^2] \phi_C(z) \bar{\phi}_C(x) \\
&= \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) [\infty, x_*] \int_\sigma^\infty \dot{d}\alpha e^{-i\alpha(z-x)\bullet} - \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) [-\infty, x_*] \int_{-\infty}^{-\sigma} \dot{d}\alpha e^{-i\alpha(z-x)\bullet} \\
&+ \frac{1}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \{U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp)\} [-\infty, x_*] \int_{-\infty}^{-\sigma} \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(z-x)\bullet}
\end{aligned}$$

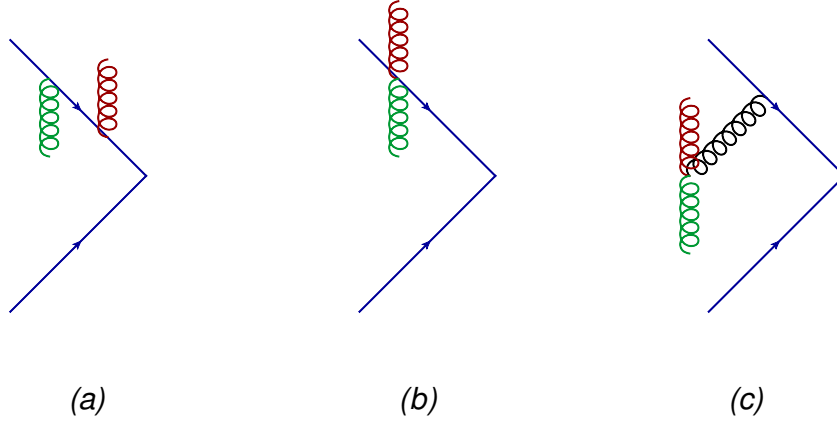


FIG. 2. BEPX.

## 5. CYMMA

Trivial term

$$\begin{aligned}
& \left( \int dz_{\bullet} \bar{\phi}_B(z_{\bullet}, x_{\perp}) [\infty, x_*] \int_{\sigma}^{\infty} \dot{d}\alpha e^{-i\alpha(z-x)_{\bullet}} - \int dz_{\bullet} \bar{\phi}_B(z_{\bullet}, x_{\perp}) [-\infty, x_*] \int_{-\infty}^{-\sigma} \dot{d}\alpha e^{-i\alpha(z-x)_{\bullet}} \right) \phi_A(x_*, x_{\perp}) \\
\stackrel{\text{LSZ}}{=} & - \int dz_{\bullet} \bar{\phi}_B(z_{\bullet}, x_{\perp}) [-\infty, x_*] \int_{-\infty}^{-\sigma} \dot{d}\alpha e^{-i\alpha(z-x)_{\bullet}} \phi_A(x_*, x_{\perp}) = \int dz_{\bullet} \bar{\phi}_B(z_{\bullet}, x_{\perp}) [-\infty, x_*] \int_{\sigma}^{\infty} \dot{d}\alpha e^{-i\alpha(x-z)_{\bullet}} \phi_A(x_*, x_{\perp}) \\
= & \bar{\phi}_B^+(x_{\bullet}, x_{\perp}) [-\infty, x_*] \phi_A(x_*, x_{\perp}) \tag{79}
\end{aligned}$$

The term in Fig. 3

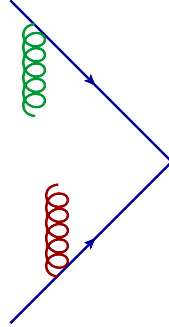


FIG. 3. Figa.

$$\begin{aligned}
\text{Fig.3} &= - \int dz \bar{\phi}_B(z) [(p+A)^2 - p^2] \phi_C(z) \bar{\phi}_C(x) \phi_C(x) \int dz' \bar{\phi}_C [(p+A+B+C)^2 - (p+A)^2] \phi_A(z') \\
&= \int dz_{\bullet} \bar{\phi}_B(z_{\bullet}, x_{\perp}) [\infty, x_*] \int_{\sigma}^{\infty} \dot{d}\alpha e^{-i\alpha(z-x)_{\bullet}} - \int dz_{\bullet} \bar{\phi}_B(z_{\bullet}, x_{\perp}) [-\infty, x_*] \int_{-\infty}^{-\sigma} \dot{d}\alpha e^{-i\alpha(z-x)_{\bullet}} \\
&\times \left\{ \frac{i}{s} \int_{-\infty}^{x_{\bullet}} dz'_{\bullet} (B_*(z'_{\bullet}) + [x_*, -\infty] B_*(z'_{\bullet}) [-\infty, x_*]) \phi_A(x) - \frac{i}{s} \int_{x_{\bullet}}^{\infty} dz'_{\bullet} (B_*(z'_{\bullet}) + [x_*, -\infty] B_*(z'_{\bullet}) [-\infty, x_*]) \phi_A(x) \right. \\
&\left. - \frac{1}{s} [x_*, -\infty] \int dz'_{\bullet} \int_{-\infty}^{-\sigma} \frac{\dot{d}\alpha}{\alpha} e^{-i\alpha(x-z')_{\bullet}} (U_x^{\dagger} B_*^-(z'_{\bullet}, x_{\perp}) U_x - B_*^-(z'_{\bullet}, x_{\perp})) [-\infty, x_*] \phi_A(x) \right\} \tag{80}
\end{aligned}$$



In the leading order in  $A_\bullet$ .

$$\begin{aligned} \text{Fig.3} &= \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \frac{2i}{s} \int_{x_*}^{\infty} dz_* A_\bullet(z_*, x_\perp) \int_\sigma^{\infty} \bar{d}\alpha e^{-i\alpha(z-x)_\bullet} - \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \int_{-\infty}^{x_*} dz_* A_*^*(z_*, x_\perp) \int_{-\infty}^{-\sigma} \bar{d}\alpha e^{-i\alpha(z-x)_\bullet} \\ &\times \left\{ \frac{2i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet B_*(z_\bullet) \phi_A(x) - \frac{2i}{s} \int_{x_\bullet}^{\infty} dz_\bullet B_*(z_\bullet) \phi_A(x) \right\} \end{aligned}$$

First term  $\sim B_*$

$$\begin{aligned} \text{Fig.2} &= \{ \bar{\phi}_B(x) + i \int dz \bar{\phi}_B(z) [(p+A+B+C)^2 - (p+B)^2] \phi_C(z) \bar{\phi}_C(x) \} \phi_A(x) \\ &+ \bar{\phi}_B(x) \{ \phi_A(x) + i \phi_C \int dz \bar{\phi}_C [(p+A+B+C)^2 - (p+A)^2] \phi_A(z) \} - \bar{\phi}_B(x) \phi_A(x) \\ &= \frac{1}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \{ U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp) \} [-\infty, x_*] \int_{-\infty}^{-\sigma} \frac{\bar{d}\alpha}{\alpha} e^{-i\alpha(z-x)_\bullet} \phi_A(x) \\ &+ \frac{i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \left( \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) [\infty, x_*] \int_\sigma^{\infty} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} - \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) [-\infty, x_*] \int_{-\infty}^{-\sigma} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} \right) \\ &\quad \times (B_*(z_\bullet) + [x_*, -\infty] B_*(z_\bullet) [-\infty, x_*]) \phi_A(x) \\ &- \frac{i}{s} \int_{x_\bullet}^{\infty} dz_\bullet \left( \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) [\infty, x_*] \int_\sigma^{\infty} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} - \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) [-\infty, x_*] \int_{-\infty}^{-\sigma} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} \right) \\ &\quad \times (B_*(z_\bullet) + [x_*, -\infty] B_*(z_\bullet) [-\infty, x_*]) \phi_A(x) \\ &- \frac{1}{s} \left( \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) [\infty, x_*] \int_\sigma^{\infty} \bar{d}\alpha' e^{-i\alpha'(z'-x)_\bullet} - \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) [-\infty, x_*] \int_{-\infty}^{-\sigma} \bar{d}\alpha' e^{-i\alpha'(z'-x)_\bullet} \right) \\ &\quad \times [x_*, -\infty] \int dz_\bullet \int_{-\infty}^{-\sigma} \frac{\bar{d}\alpha}{\alpha} e^{-i\alpha(x-z)_\bullet} (U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp)) [-\infty, x_*] \phi_A(x) \quad (81) \end{aligned}$$

After LSZ

$$\begin{aligned} &\{ \bar{\phi}_B(x) + i \int dz \bar{\phi}_B(z) [(p+A+B+C)^2 - (p+B)^2] \phi_C(z) \bar{\phi}_C(x) \} \phi_A(x) \quad (82) \\ &+ \bar{\phi}_B(x) \{ \phi_A(x) + i \phi_C \int dz \bar{\phi}_C [(p+A+B+C)^2 - (p+A)^2] \phi_A(z) \} - \bar{\phi}_B(x) \phi_A(x) \\ &= \frac{1}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \{ U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp) \} [-\infty, x_*] \int_{-\infty}^{-\sigma} \frac{\bar{d}\alpha}{\alpha} e^{-i\alpha(z-x)_\bullet} \phi_A(x) \\ &- \frac{i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) \int_{-\infty}^{-\sigma} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} \cdot ([-\infty, x_*] B_*(z_\bullet) + B_*(z_\bullet) [-\infty, x_*]) \phi_A(x) \\ &+ \frac{i}{s} \int_{x_\bullet}^{\infty} dz_\bullet \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) \int_{-\infty}^{-\sigma} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} \cdot ([-\infty, x_*] B_*(z_\bullet) + B_*(z_\bullet) [-\infty, x_*]) \phi_A(x) \\ &+ \frac{1}{s} \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) \int_{-\infty}^{-\sigma} \bar{d}\alpha' e^{-i\alpha'(z'-x)_\bullet} \cdot \int dz_\bullet \int_{-\infty}^{-\sigma} \frac{\bar{d}\alpha}{\alpha} e^{-i\alpha(x-z)_\bullet} \cdot (U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp)) [-\infty, x_*] \phi_A(x) \end{aligned}$$

In the leading order in  $A_\bullet$ .

$$\begin{aligned} \text{Fig.2} &= \frac{1}{s} \int dz_\bullet \bar{\phi}_B(z_\bullet, x_\perp) \{ U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp) \} [-\infty, x_*] \int_{-\infty}^{-\sigma} \frac{\bar{d}\alpha}{\alpha} e^{-i\alpha(z-x)_\bullet} \phi_A(x) \\ &- \frac{i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) \int_{-\infty}^{-\sigma} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} \cdot ([-\infty, x_*] B_*(z_\bullet) + B_*(z_\bullet) [-\infty, x_*]) \phi_A(x) \\ &+ \frac{i}{s} \int_{x_\bullet}^{\infty} dz_\bullet \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) \int_{-\infty}^{-\sigma} \bar{d}\alpha e^{-i\alpha(z'-x)_\bullet} \cdot ([-\infty, x_*] B_*(z_\bullet) + B_*(z_\bullet) [-\infty, x_*]) \phi_A(x) \\ &+ \frac{1}{s} \int dz'_\bullet \bar{\phi}_B(z'_\bullet, x_\perp) \int_{-\infty}^{-\sigma} \bar{d}\alpha' e^{-i\alpha'(z'-x)_\bullet} \cdot \int dz_\bullet \int_{-\infty}^{-\sigma} \frac{\bar{d}\alpha}{\alpha} e^{-i\alpha(x-z)_\bullet} \cdot (U_x^\dagger B_*^-(z_\bullet, x_\perp) U_x - B_*^-(z_\bullet, x_\perp)) [-\infty, x_*] \phi_A(x) \end{aligned}$$

## V. POLE

### A. Scalar model

$$\int D\phi \phi(x) e^{iS(\phi)} = 0, \quad S(\phi) = \int d^4x \left[ -\frac{1}{2}\phi(\partial^2 + m^2)\phi - \frac{\Omega}{4!}\phi^4 \right] \quad (83)$$

Sdvg  $\phi \rightarrow \phi + \bar{\phi}$

$$\int D\phi [\bar{\phi}(x) + \phi(x)] e^{iS(\phi)} = 0, \quad S(\phi) = S(\bar{\phi}) - \frac{1}{2}\phi(\partial^2 + m^2 + \frac{\Omega}{2}\bar{\phi}^2)\phi - \phi(\partial^2 + m^2 + \frac{\Omega}{6}\bar{\phi}^2)\bar{\phi} - \frac{\Omega}{6}\phi^3\bar{\phi} - \frac{\Omega}{4!}\phi^4 \quad (84)$$

Nado

$$\int D\phi \phi(x) e^{i \int d^4x \left( -\frac{1}{2}\phi(\partial^2 + m^2 + \frac{\Omega}{2}\bar{\phi}^2)\phi - \phi(\partial^2 + m^2 + \frac{\Omega}{6}\bar{\phi}^2)\bar{\phi} - \frac{\Omega}{6}\phi^3\bar{\phi} - \frac{\Omega}{4!}\phi^4 \right)} \quad (85)$$

Sdvg  $\phi \rightarrow \phi - \tilde{\phi}$ .

$$\begin{aligned} & \exp \left\{ i \int d^4x \left( -\frac{1}{2}(\phi - \tilde{\phi})\square(\phi - \tilde{\phi}) - (\phi - \tilde{\phi})\left(\square - \frac{\Omega}{3}\bar{\phi}^2\right)\bar{\phi} - \frac{\Omega}{6}(\phi - \tilde{\phi})^3\bar{\phi} - \frac{\Omega}{4!}(\phi - \tilde{\phi})^4 \right) \right\} \\ &= \exp \left\{ i \int d^4x \left( -\frac{1}{2}\tilde{\phi}\square\tilde{\phi} + \tilde{\phi}\left(\square - \frac{\Omega}{3}\bar{\phi}^2\right)\bar{\phi} + \frac{\Omega}{6}\tilde{\phi}^3\bar{\phi} - \frac{\Omega}{4!}\tilde{\phi}^4 \right) \right. \\ & \left. + i \int d^4x \left( -\frac{1}{2}\phi(\square - \Omega\tilde{\phi}\bar{\phi} + \frac{\Omega}{2}\tilde{\phi}^2)\phi - \phi(\square\bar{\phi} - \frac{\Omega}{3}\bar{\phi}^3 + \frac{\Omega}{2}\tilde{\phi}\bar{\phi}^2 + \frac{\Omega}{6}\tilde{\phi}^3) + \frac{\Omega}{6}(\bar{\phi} - \tilde{\phi})\phi^3 - \frac{\Omega}{4!}\phi^4 \right) \right\} = \text{free} \quad (86) \end{aligned}$$

where  $\square \equiv \partial^2 + m^2 + \frac{\Omega}{2}\bar{\phi}^2$ .

ПО-ДРПТОМЪ: ВО ВНЕУИИЕМ ПОЛЕ  $\bar{\phi}$

$$\begin{aligned} & \int D\phi \phi(x) e^{i \int d^4x \left( -\frac{1}{2}\phi\square\phi - \phi\left(\square - \frac{\Omega}{3}\bar{\phi}^2\right)\bar{\phi} - \frac{\Omega}{6}\phi^3\bar{\phi} - \frac{\Omega}{4!}\phi^4 \right)} \quad (87) \\ &= -i \int D\phi e^{i \int d^4x \left( -\frac{1}{2}\phi\square\phi \right)} \phi(x) \int d^4z \left[ \phi\left(\square - \frac{\Omega}{3}\bar{\phi}^2\right)\bar{\phi}(z) + \frac{\Omega}{6}\bar{\phi}\phi^3(z) \int d^4z' d^4z'' \phi\left(\square - \frac{\Omega}{3}\bar{\phi}^2\right)\bar{\phi}(z')\phi\left(\square - \frac{\Omega}{3}\bar{\phi}^2\right)\bar{\phi}(z'') \right] \\ &= -\bar{\phi} + \frac{\Omega}{3}\frac{1}{\square}\bar{\phi}^3 - \frac{\Omega}{3}\frac{1}{\square}\bar{\phi}^3 + \dots \quad (88) \end{aligned}$$

#### 1. Shifts?

Suppose  $\partial^\mu \bar{A}_\mu = 0$

$$\int DA (A_\mu + \bar{A}_\mu)(x) e^{iS(A+\bar{A}) + i \int d^4z \frac{1}{2}(\bar{D}^\alpha A_\alpha^a)^2} = \int DA A_\mu(x) e^{iS(A)} e^{i \int d^4z \frac{1}{2}(\bar{D}^\alpha A_\alpha^a)^2} = 0 \quad (89)$$

If  $\bar{A}_\mu = \bar{\aleph}_\mu^\dagger$

$$\int DA (A_\mu + \bar{\aleph}_\mu^\dagger)(x) e^{iS(A+\bar{\aleph}^\dagger)} e^{i \int d^4z \frac{1}{2}(\bar{D}^\alpha A_\alpha^a)^2} = \bar{\aleph}_\mu^\dagger(x) + \int DA A_\mu(x) e^{i \int d^4z \left( \frac{1}{2}A_\alpha^a(\bar{D}^2)^{ab}A^{ab} - g f^{abc}\bar{D}^\alpha A^{a\beta}A_\alpha^b A_\beta^c \right)} \quad (90)$$

In abelian theory in the  $A_0 = 0$  gauge the shift  $A_i \rightarrow A_i + \partial_i \Omega(\vec{x})$  is allowed since both  $(\partial_0 \delta_{ik} - W_{ik})\partial_k \Omega(t, \vec{x})|_{t=\infty} = 0$  and  $(\partial_0 \delta_{ik} + W_{ik})\partial_k \Omega(t, \vec{x})|_{t=-\infty} = 0$  vanish (here  $W_{ik} \equiv \frac{\partial^2 \delta_{ik} - \partial_i \partial_k}{\sqrt{-\partial^2}}$ ). This is the redundant gauge symmetry which should be eliminated.

In Feynman gauge  $\partial^2 \Omega = 0 \Leftrightarrow \Omega = \int \frac{d^3k}{|k|} (a_k e^{-i|k|x_0 + i\vec{k}\cdot\vec{x}} + a_k^* e^{i|k|x_0 - i\vec{k}\cdot\vec{x}})$

## B. Gauge field

$$\bar{A}_\mu = \Omega_\mu^\dagger + \Delta_\mu$$

$$\int DA A_\mu(x) e^{iS(A+\bar{A})} = e^{iS(\bar{A})} \int DA A_\mu(x) e^{i\int d^4z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta} - \bar{D}^\alpha \bar{D}^\beta)^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right)} \quad (91)$$

$$\bar{D}_\xi \bar{G}^{a\xi\alpha} = (D_\Omega^2 g_{\alpha\xi} - D_\alpha^\Omega D_\xi^\Omega) \Delta^\xi \quad (92)$$

$$\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta} - \bar{D}^\alpha \bar{D}^\beta = D_\Omega^2 g_{\alpha\beta} - D_\alpha^\Omega D_\beta^\Omega - i\{D_\xi^\Omega, \Delta^\xi\} g_{\alpha\beta} - 2i((\bar{D}^\alpha \Delta^\beta) - \alpha \leftrightarrow \beta) + i\Delta_\alpha D_\beta^\Omega - D_\alpha^\Omega \Delta_\beta$$

### 1. $bF$

$$\int DA A_\mu^a(x) e^{i\int d^4z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right)} \quad (93)$$

$$= \int d^4z (x | \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} | z)^{ab} \bar{D}_\xi \bar{G}^{b\xi\beta}(z) = - \int d^4z (x | \frac{1}{P_\Omega^2 g_{\alpha\beta} + \{P_\xi^\Omega, \Delta^\xi\} g_{\alpha\beta} + 2i((\bar{D}^\alpha \Delta^\beta) - \alpha \leftrightarrow \beta)} | z) (P_\Omega^2 g_{\beta\xi} - P_\beta^\Omega P_\xi^\Omega) \Delta^\xi$$

$$= -\Delta_\alpha(x) + (x | \frac{1}{P_\Omega^2} P_\alpha^\Omega P_\xi^\Omega | z) \Delta^\xi(z) \quad (94)$$

$$A_\mu^{(0)} = \bar{A}_\mu = \Omega_\mu^\dagger + \Delta_\mu \quad A_\mu^{(1)}(x) = -\Delta_\mu + \tilde{A}_\mu^{(1)} = -\left(g_{\mu\nu} - \frac{P_\mu^\Omega P_\nu^\Omega}{P_\Omega^2}\right) \Delta^\nu, \quad \tilde{A}_\mu^{(1)} \equiv \int dz (x | \frac{1}{P_\Omega^2} P_\mu^\Omega P_\xi^\Omega | z) \Delta^\xi(z)$$

$$A_\mu^{(0)}(x) + A_\mu^{(1)}(x) = \Omega_\mu^\dagger + \int dz (x | \frac{1}{P_\Omega^2} P_\mu^\Omega P_\xi^\Omega | z) \Delta^\xi(z) \Rightarrow F_{\mu\nu}^{(0+1)} = \int dz \bar{D}_\mu^\Omega (x | \frac{1}{P_\Omega^2} P_\nu^\Omega P_\xi^\Omega | z) \Delta^\xi(z) - \mu \leftrightarrow \nu = 0 \quad (95)$$

### 2. Second order

$$D_\mu^{ab} f^{bmn} \Delta_\alpha^m \Delta_\beta^n = f^{amn} (D_\mu \Delta_\alpha)^m \Delta_\beta^n + f^{amn} \Delta_\alpha^m (D_\mu \Delta_\beta)^n$$

$$D_\mu [\Delta_\alpha, \Delta_\beta] = \partial_\mu [\Delta_\alpha, \Delta_\beta] - ig [A_\mu, [\Delta_\alpha, \Delta_\beta]] \\ = [\partial_\mu \Delta_\alpha, \Delta_\beta] + [\Delta_\alpha, \partial_\mu \Delta_\beta] - ig [\Delta_\alpha, [A_\mu, \Delta_\beta]] + ig [\Delta_\beta, [A_\mu, \Delta_\alpha]] = [D_\mu \Delta_\alpha, \Delta_\beta] + [\Delta_\alpha, D_\mu \Delta_\beta] \quad (96)$$

$$\bar{G}_{\xi\alpha}^a = \bar{D}_\xi^\Omega \Delta_\alpha^a - \bar{D}_\alpha^\Omega \Delta_\xi^a + g f^{abc} \Delta_\xi^b \Delta_\alpha^c \quad (97)$$

$$\bar{D}^\xi \bar{G}_{\xi\alpha}^a = (\bar{D}_\Omega^{ab\xi} - g f^{abc} \Delta^c) (\bar{D}_\xi^\Omega \Delta_\alpha^b - \bar{D}_\alpha^\Omega \Delta_\xi^b + g f^{bmn} \Delta_\xi^m \Delta_\alpha^n)$$

$$= (\bar{D}_\Omega^2 g_{\xi\alpha} - \bar{D}_\xi^\Omega \bar{D}_\alpha^\Omega) \Delta^\xi + g f^{abc} [2\Delta_\xi^b (\bar{D}_\Omega^\xi \Delta_\alpha)^c - \Delta_\alpha^b (\bar{D}_\Omega^\xi \Delta_\xi)^c - \Delta_\xi^b (\bar{D}_\alpha^\Omega \Delta^\xi)^c]$$

$$\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta} - \bar{D}^\alpha \bar{D}^\beta = \bar{D}_\Omega^2 g_{\alpha\beta} - \bar{D}_\alpha^\Omega \bar{D}_\beta^\Omega - i\{\bar{D}_\xi^\Omega, \Delta^\xi\} g_{\alpha\beta} - 2i((\bar{D}^\alpha \Delta^\beta) - \alpha \leftrightarrow \beta) + i\Delta_\alpha \bar{D}_\beta^\Omega - \bar{D}_\alpha^\Omega \Delta_\beta + O(\Delta^2)$$

$$A_\mu = \Omega_\mu^\dagger + \Delta_\mu + A_\mu^{(1)} + A_\mu^{(2)} = \Omega_\mu^\dagger + \tilde{A}_\mu^{(1)} + A_\mu^{(2)} \Rightarrow F_{\mu\nu} = \bar{D}_\mu^\Omega \tilde{A}_\nu^{(1)} + \bar{D}_\mu^\Omega A_\nu^{(2)} - \mu \leftrightarrow \nu - i[\tilde{A}_\mu^{(1)}, \tilde{A}_\nu^{(1)}]$$

$$\int DA A_\mu^a(x) e^{i\int d^4z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right)} \quad (98)$$

$$= \int d^4z \left[ (x | \frac{1}{\bar{P}^2 g_{\mu\beta} + 2i\bar{G}_{\mu\beta}} | z)^{ab} \bar{D}_\xi \bar{G}^{b\xi\beta}(z) - i(x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} A_\xi^{1b} A_\mu^{1c}(z) + (x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} A^{1b\xi} (\bar{D}_\xi^\Omega A_\mu^{1c} - \bar{D}_\mu^\Omega A_\xi^{1c})(z) \right] =$$

$$= \int d^4z (x | \frac{1}{P_\Omega^2 g_{\mu\beta} + \{P_\xi^\Omega, \Delta^\xi\} g_{\mu\beta} + 2i((\bar{D}_\mu^\Omega \Delta_\beta) - \mu \leftrightarrow \beta)} | z)^{aa'} [- (P_\Omega^2 g_{\beta\xi} - P_\beta^\Omega P_\xi^\Omega)^{a'b} \Delta^{b\xi} + g f^{a'bc} [2\Delta_\xi^b \bar{D}_\Omega^\xi \Delta_\beta^c - \Delta_\beta^b (\bar{D}_\Omega^\xi \Delta_\xi)^c - \Delta_\xi^b (\bar{D}_\beta^\Omega \Delta^\xi)^c]$$

$$= -\Delta_\mu^a(x) + (x | \frac{P_\mu^\Omega P_\xi^\Omega}{P_\Omega^2} | z)^{ab} \Delta^{b\xi}(z) + (x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} [2\Delta_\xi^b \bar{D}_\Omega^\xi \Delta_\mu^c - \Delta_\mu^b (\bar{D}_\Omega^\xi \Delta_\xi)^c - \Delta_\xi^b (\bar{D}_\mu^\Omega \Delta^\xi)^c]$$

$$- (x | \frac{1}{P_\Omega^2} [\{P_\xi^\Omega, \Delta^\xi\} g_{\mu\beta} + 2i(\bar{D}_\mu^\Omega \Delta_\beta - \mu \leftrightarrow \beta)] | z)^{ab} A^{1b\xi}(z) - i(x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} A_\xi^{1b} A_\mu^{1c}(z) + (x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} A^{1b\xi} (\bar{D}_\xi^\Omega A_\mu^{1c} - \bar{D}_\mu^\Omega A_\xi^{1c})(z)$$

$\int d^4 z$  is assumed

$$\begin{aligned} \tilde{A}_\nu^{(1)} + A_\nu^{(2)} &= (x|\frac{P_\nu^\Omega P_\Omega^\xi}{P_\Omega^2}|z)^{ab} \Delta^{b\xi}(z) - i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^{1b} \Delta_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} [\Delta_\xi^b \bar{D}_\Omega^\xi \Delta_\nu^c - \Delta_\xi^b (\bar{D}_\nu^\Omega \Delta_\xi^c)](z) \\ &- (x|\frac{1}{P_\Omega^2} [\{\bar{P}_\Omega^\xi, \Delta_\xi\} g_{\nu\beta} + 2i(\bar{D}_\nu^\Omega \Delta_\beta - \bar{D}_\beta^\Omega \Delta_\nu)]|z)^{ab} A^{1b\beta}(z) - i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} A_\xi^{1b} A_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} A^{1b\xi} (\bar{D}_\xi^\Omega A_\nu^{1c} - \bar{D}_\nu^\Omega A_\xi^{1c})(z) \\ &= (x|\frac{P_\nu^\Omega P_\Omega^\xi}{P_\Omega^2}|z)^{ab} \Delta^{b\xi}(z) - i(x|\frac{P_\nu^\Omega}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta^{b\xi} A_\xi^{1c}(z) - i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} \tilde{A}^{1b\xi} (\bar{D}_\xi^\Omega \tilde{A}_\nu^{1c} - \bar{D}_\nu^\Omega \tilde{A}_\xi^{1c})(z) \end{aligned} \quad (99)$$

where we used  $\tilde{A}_\mu^1 = \Delta_\mu + A_\mu^1$  and

$$\begin{aligned} &- (x|\frac{1}{P_\Omega^2} [\{\bar{P}_\Omega^\xi, \Delta_\xi\} g_{\nu\beta} + 2i(\bar{D}_\nu^\Omega \Delta_\beta - \nu \leftrightarrow \beta)]|z)^{ab} A^{1b\beta}(z) \\ &= - (x|\frac{\bar{P}_\Omega^\xi}{P_\Omega^2}|z)^{aa'} \Delta_\xi^{a'c} A_\nu^{1c}(z) - i(x|\frac{1}{P_\Omega^2}|z)^{aa'} \Delta_\xi^{a'c} \bar{D}_\xi^\Omega A_\nu^{1c}(z) - 2i(x|\frac{1}{P_\Omega^2}|z)^{aa'} \bar{D}_\nu^\Omega \Delta_\beta^{a'b} A^{1b\beta}(z) + 2i(x|\frac{1}{P_\Omega^2}|z)^{aa'} \bar{D}_\beta^\Omega \Delta_\nu^{a'b} A^{1b\beta}(z) \\ &= -i(x|\frac{\bar{P}_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^b A_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^b \bar{D}_\xi^\Omega A_\nu^{1c}(z) - 2(x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} A^{1b\xi} \bar{D}_\nu^\Omega \Delta_\xi^c(z) + 2(x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} \bar{D}_\xi^\Omega \Delta_\nu^c A^{1b\xi}(z) \end{aligned} \quad (100)$$

and

$$\begin{aligned} &\left[ -i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} (\Delta_\xi^b + A_\xi^{1b}) (\Delta_\nu^c + A_\nu^{1c})(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} (\Delta_\xi^b + A^{1b\xi}) (\bar{D}_\xi^\Omega \Delta_\nu^c + \bar{D}_\xi^\Omega A_\nu^{1c} - \bar{D}_\nu^\Omega \Delta_\xi^c - \bar{D}_\nu^\Omega \tilde{A}_\xi^{1c})(z) \right]_{\Delta \otimes A^1} \\ &= -i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} [\Delta_\xi^b A_\nu^{1c} + A_\xi^{1b} \Delta_\nu^c](z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^b (\bar{D}_\xi^\Omega A_\nu^{1c} - \bar{D}_\nu^\Omega A_\xi^{1c})(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} A^{1b\xi} (\bar{D}_\xi^\Omega \Delta_\nu^c - \bar{D}_\nu^\Omega \Delta_\xi^c)(z) \\ &= -i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^b A_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^b (\bar{D}_\xi^\Omega A_\nu^{1c} - \bar{D}_\nu^\Omega A_\xi^{1c})(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} A^{1b\xi} (2\bar{D}_\xi^\Omega \Delta_\nu^c - \bar{D}_\nu^\Omega \Delta_\xi^c)(z) \\ &= i(x|\frac{P_\nu^\Omega}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta^{b\xi} A_\xi^{1c} - i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^b A_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta_\xi^b \bar{D}_\xi^\Omega A_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} A^{1b\xi} (2\bar{D}_\xi^\Omega \Delta_\nu^c - 2\bar{D}_\nu^\Omega \Delta_\xi^c)(z) \end{aligned} \quad (101)$$

(bikoz  $\bar{D}_\xi^\Omega A^{1\xi} = 0$ ).

The result is

$$\begin{aligned} \int DA [\tilde{A}_\nu^a(x) + A_\nu^a(x)] e^{i\int d^4 z (\frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\beta^c)} &= \Omega_\nu^a + \int d^4 z (x|\frac{P_\nu^\Omega \bar{P}_\Omega^\xi}{P_\Omega^2}|z)^{ab} \Delta_\xi^b(z) \\ &- \int d^4 z \left[ i(x|\frac{P_\nu^\Omega}{P_\Omega^2}|z)^{aa'} f^{a'bc} \Delta^{b\xi} A_\xi^{1c} + i(x|\frac{P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\nu^{1c}(z) \right] \end{aligned} \quad (102)$$

bikoz  $(\bar{D}_\xi^\Omega \tilde{A}_\nu^{1c} - \bar{D}_\nu^\Omega \tilde{A}_\xi^{1c}) = 0$

Nau  $A_\mu = \Omega_\mu^\dagger + \tilde{A}_\mu^{(1)} + A_\mu^{(2)} \Rightarrow F_{\mu\nu} = \bar{D}_\mu^\Omega \tilde{A}_\nu^{(1)} + \bar{D}_\nu^\Omega A_\mu^{(2)} - \mu \leftrightarrow \nu - i[\tilde{A}_\mu^{(1)}, \tilde{A}_\nu^{(1)}]$  sou

$$\begin{aligned} \int DA F_{\mu\nu}^a(x) e^{i\int d^4 z (\frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\beta^c)} & \\ &= \int d^4 z \left[ - (x|\frac{P_\mu^\Omega P_\Omega^\xi}{P_\Omega^2}|z)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\nu^{1c}(z) - \mu \leftrightarrow \nu \right] + f^{abc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(x) \\ &= \int d^4 z \left[ (x|\frac{D_\xi^\Omega}{P_\Omega^2}|z)^{aa'} f^{a'bc} (\bar{D}_\mu^\Omega \tilde{A}^{1b\xi}) \tilde{A}_\nu^{1c}(z) - \mu \leftrightarrow \nu \right] + f^{abc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(x) \\ &= \int d^4 z \left[ (x|\frac{\bar{D}_\xi^\Omega}{P_\Omega^2}|z)^{aa'} f^{a'bc} (\bar{D}_\xi^\Omega \tilde{A}_\mu^{1b}) \tilde{A}_\nu^{1c}(z) - \mu \leftrightarrow \nu \right] + f^{abc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(x) \\ &= \int d^4 z \left[ (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} (\bar{D}_\Omega^2 \tilde{A}_\mu^{1b}) \tilde{A}_\nu^{1c}(z) + (x|\frac{1}{P_\Omega^2}|z)^{aa'} f^{a'bc} (\bar{D}_\xi^\Omega \tilde{A}_\mu^{1b}) \bar{D}_\Omega^\xi \tilde{A}_\nu^{1c}(z) - \mu \leftrightarrow \nu \right] + f^{abc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(x) \\ &= \int d^4 z \left[ (x|\frac{\bar{D}_\Omega^2}{2P_\Omega^2}|z)^{aa'} f^{a'bc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(z) + (x|\frac{1}{2P_\Omega^2}|z)^{aa'} f^{a'bc} (\bar{D}_\Omega^2 \tilde{A}_\mu^{1b}) \tilde{A}_\nu^{1c}(z) - (x|\frac{1}{2P_\Omega^2}|z)^{aa'} f^{a'bc} \tilde{A}_\mu^{1b} \bar{D}_\Omega^2 \tilde{A}_\nu^{1c}(z) - \mu \leftrightarrow \nu \right] + f^{abc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(x) \\ &= -f^{abc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(x) + \int d^4 z \left[ (x|\frac{1}{2P_\Omega^2}|z)^{aa'} f^{a'bc} (\bar{D}_\Omega^2 \tilde{A}_\mu^{1b}) \tilde{A}_\nu^{1c}(z) + (x|\frac{1}{2P_\Omega^2}|z)^{aa'} f^{a'bc} \tilde{A}_\nu^{1b} \bar{D}_\Omega^2 \tilde{A}_\mu^{1c}(z) - \mu \leftrightarrow \nu \right] + f^{abc} \tilde{A}_\mu^{1b} \tilde{A}_\nu^{1c}(x) = 0 \end{aligned} \quad (103)$$

4E U T D.

ЕУЇЄ ПА3:  $\bar{A}_\mu = i\Omega\partial_\mu\Omega^\dagger + \delta A_\mu$

$$\int DA A_\mu^a(x) e^{i\int d^4z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right)} \quad (104)$$

$$= -\delta A_\mu^a(x) + \int d^4z \left[ \left( x \left| \frac{P_\mu^\Omega P_\xi^\Omega}{P_\Omega^2} \right| z \right)^{ab} \delta A^{b\xi}(z) - i \left( x \left| \frac{P_\mu^\Omega}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \delta A^{b\xi} \tilde{A}_\xi^{1c}(z) - i \left( x \left| \frac{P_\Omega^\xi}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) \right]$$

$$\text{gde } \tilde{A}_\xi^{1a} \equiv \int d^4z \left( x \left| \frac{P_\xi^\Omega \bar{P}_\Omega^\eta}{P_\Omega^2} \right| z \right)^{ab} \delta A_\eta^b(z)$$

### 3. Gauge matrix

$$\Omega_\mu^\dagger = i\Omega\partial_\mu\Omega^\dagger \Rightarrow \Omega_\mu^\dagger + \tilde{A}_\mu^{(1)} = i(1 - \Omega\delta\Omega^\dagger)\Omega\partial_\mu\Omega^\dagger(1 + \Omega\delta\Omega^\dagger) \Rightarrow$$

$$\tilde{A}_\mu^{(1)} = (i\partial_\mu + [\Omega_\mu^\dagger])\Omega\delta\Omega^\dagger \Rightarrow \tilde{A}_\mu^{1a} = (P_\mu^\Omega)^{ab}(\Omega\delta\Omega^\dagger)^b$$

where  $(\Omega\delta\Omega^\dagger)^b \equiv 2\text{tr}\{t^b\Omega\delta\Omega^\dagger\}$ . Wi get

$$\begin{aligned} (\Omega\delta\Omega^\dagger)^a &= \int dz \left( x \left| \frac{\bar{P}_\Omega^\xi}{P_\Omega^2} \right| z \right)^{ab} \Delta_\xi^b(z) = \Omega_x^{ac} \int dz \left( x \left| \frac{P_\Omega^\xi}{P_\Omega^2} \right| z \right) \Omega_z^{\dagger cb} \Delta_\xi^b(z) \\ &\Rightarrow \delta\Omega_x^\dagger \Omega_x = \int dz \left( x \left| \frac{P_\Omega^\xi}{P_\Omega^2} \right| z \right) \Omega_z^\dagger \Delta_\xi(z) \Omega_z \end{aligned} \quad (105)$$

Second order  $(\Omega_\mu^\dagger \equiv \Omega i\partial_\mu \Omega^\dagger)$

$$\begin{aligned} &\Omega[1 - \delta_1\Omega^\dagger\Omega - \delta_2\Omega^\dagger\Omega + \frac{1}{2}(\delta_1\Omega^\dagger\Omega)^2]i\partial_\mu[1 + \delta_1\Omega^\dagger\Omega + \delta_2\Omega^\dagger\Omega + \frac{1}{2}(\delta_1\Omega^\dagger\Omega)^2]\Omega^\dagger \\ &= [1 - \Omega\delta_1\Omega^\dagger - \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2]\Omega i\partial_\mu\Omega^\dagger[1 + \Omega\delta_1\Omega^\dagger + \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2] \\ &= [1 - \Omega\delta_1\Omega^\dagger - \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2]\Omega_\mu^\dagger[1 + \Omega\delta_1\Omega^\dagger + \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2] \\ &\quad + [1 - \Omega\delta_1\Omega^\dagger - \Omega\delta_2\Omega^\dagger][i\partial_\mu(\Omega\delta_1\Omega^\dagger) + i\partial_\mu(\Omega\delta_2\Omega^\dagger) + \frac{1}{2}i\partial_\mu(\Omega\delta_1\Omega^\dagger)^2] \\ &= \Omega_\mu^\dagger + (i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_1\Omega^\dagger) + (i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_2\Omega^\dagger) + \frac{1}{2}[(i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_1\Omega^\dagger), \Omega\delta_1\Omega^\dagger] \end{aligned} \quad (106)$$

YPAHEHUE  $((i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_1\Omega^\dagger) = \tilde{A}_\mu^{(1)})$

$$\begin{aligned} &2\text{tr}\{t^a \left( \Omega_\mu^\dagger + (i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_1\Omega^\dagger) + (i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_2\Omega^\dagger) + \frac{1}{2}[(i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_1\Omega^\dagger), \Omega\delta_1\Omega^\dagger] \right)\} \\ &= \Omega_\mu^a + \int d^4z \left( x \left| \frac{P_\mu^\Omega \bar{P}_\Omega^\xi}{P_\Omega^2} \right| z \right)^{ab} \Delta_\xi^b(z) + \int d^4z \left[ i \left( x \left| \frac{P_\mu^\Omega}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \Delta^{b\xi} A_\xi^{1c}(z) - i \left( x \left| \frac{P_\Omega^\xi}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) \right] \\ &\Rightarrow 2\text{tr}\{t^a \left( (i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_2\Omega^\dagger) + \frac{1}{2}[\tilde{A}_\mu^{(1)}, \Omega\delta_1\Omega^\dagger] \right)\} = (P_\mu^\Omega)^{ab}(\Omega\delta_2\Omega^\dagger)^b + \frac{i}{2}f^{abc}\tilde{A}_\mu^{1b}(\Omega\delta_1\Omega^\dagger)^c \\ &= \int d^4z \left[ i \left( x \left| \frac{P_\mu^\Omega}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \Delta^{b\xi} \tilde{A}_\xi^{1c}(z) - i \left( x \left| \frac{P_\Omega^\xi}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) \right] \\ &\Rightarrow (P_\mu^\Omega)^{ab}(\Omega\delta_2\Omega^\dagger)^b = \int d^4z \left[ -i \left( x \left| \frac{P_\mu^\Omega}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \Delta^{b\xi} \tilde{A}_\xi^{1c}(z) - i \left( x \left| \frac{P_\Omega^\xi}{P_\Omega^2} \right| z \right)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) \right] - \frac{i}{2}f^{abc}\tilde{A}_\mu^{1b}(\Omega\delta_1\Omega^\dagger)^c \end{aligned} \quad (107)$$

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$$\begin{aligned}
& i f^{abc} \tilde{A}_\mu^{1b} (\Omega \delta_1 \Omega^\dagger)^c + i (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) = i f^{abc} \tilde{A}_\mu^{1b} (\Omega \delta_1 \Omega^\dagger)^c + i (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (P_\xi^\Omega)^{bm} (\Omega \delta_1 \Omega^\dagger)^m \tilde{A}_\mu^{1c}(z) \\
& = i f^{abc} \tilde{A}_\mu^{1b} (\Omega \delta_1 \Omega^\dagger)^c + i f^{abc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\mu^{1c}(z) - i (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b (P_\xi^\Omega \tilde{A}_\mu^{1c}(z)) = -i (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b i \bar{D}_\mu^\Omega \tilde{A}_\xi^{1c}(z) \\
& = -i (x | \frac{P_\Omega^\xi P_\mu^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\xi^{1c}(z) + i (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} \tilde{A}_\mu^{1b} \tilde{A}_\xi^{1c}(z) \\
& \Rightarrow -i (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) = \frac{i}{2} f^{abc} \tilde{A}_\mu^{1b} (\Omega \delta_1 \Omega^\dagger)^c + \frac{i}{2} (x | \frac{P_\Omega^\xi P_\mu^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\xi^{1c}(z) \tag{108} \\
& \Rightarrow \text{Eq. (107) takes the form}
\end{aligned}$$

$$\begin{aligned}
(P_\mu^\Omega)^{ab} (\Omega \delta_2 \Omega^\dagger)^b &= \int d^4 z \left[ -i (x | \frac{P_\mu^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} \tilde{A}_\xi^{1c}(z) + \frac{i}{2} (x | \frac{P_\Omega^\xi P_\mu^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\xi^{1c}(z) \right] \\
\Rightarrow (\Omega \delta_2 \Omega^\dagger)^a &= \int d^4 z \left[ -i (x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} \tilde{A}_\xi^{1c}(z) + \frac{i}{2} (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\xi^{1c}(z) \right]
\end{aligned}$$

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$$\begin{aligned}
(x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} \tilde{A}_\xi^{1c}(z) &= (x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} (P_\xi^\Omega (\Omega \delta_1 \Omega^\dagger))^c(z) \\
&= (x | \frac{\bar{P}_\Omega^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} (\Omega \delta_1 \Omega^\dagger)^c(z) - (x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\bar{P}_\xi^\Omega \Delta^{b\xi}) (\Omega \delta_1 \Omega^\dagger)^c(z) \\
&= (x | \frac{\bar{P}_\Omega^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} (\Omega \delta_1 \Omega^\dagger)^c(z) - (x | \frac{1}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\bar{P}_\xi^\Omega \tilde{A}^{1b\xi}) (\Omega \delta_1 \Omega^\dagger)^c(z) \\
&= (x | \frac{\bar{P}_\Omega^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} (\Omega \delta_1 \Omega^\dagger)^c(z) - (x | \frac{\bar{P}_\Omega^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} \tilde{A}^{1b\xi} (\Omega \delta_1 \Omega^\dagger)^c(z) = - (x | \frac{\bar{P}_\Omega^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} A^{1b\xi} (\Omega \delta_1 \Omega^\dagger)^c(z)
\end{aligned}$$

$\Rightarrow$  UMEEM

$$(\Omega \delta_2 \Omega^\dagger)^a = \int dz \left[ -i (x | \frac{\bar{P}_\Omega^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} (\Omega \delta_1 \Omega^\dagger)^c(z) - \frac{i}{2} (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\xi^{1c}(z) \right]$$

#### 4. Symmetric raz

$\bar{A}$  - arbitrary.  $\bar{A}_\mu + \Delta_\mu = \Omega_\mu = \text{pure gauge}$

$$\begin{aligned}
& \int DA A_\mu^\alpha(x) e^{i \int d^4 z (\frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c)} \tag{109} \\
& = \int d^4 z (x | \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i \bar{G}_{\alpha\beta}} | z)^{ab} \bar{D}_\xi \bar{G}^{b\xi\beta}(z) = \int d^4 z (x | \frac{1}{\bar{P}_\Omega^2 g_{\alpha\beta} - \{P_\xi^\Omega, \Delta^\xi\} g_{\alpha\beta} - 2i((\bar{D}^\alpha \Delta^\beta) - \alpha \leftrightarrow \beta)} | z)^{ab} (P_\Omega^2 g_{\beta\xi} - P_\beta^\Omega P_\xi^\Omega) \Delta^\xi \\
& = \Delta_\alpha(x) - (x | \frac{1}{P_\Omega^2} P_\alpha^\Omega P_\xi^\Omega | z) \Delta^\xi(z)
\end{aligned}$$

$$\int DA (\bar{A}_\mu^\alpha(x) + A_\mu^\alpha(x)) e^{i \int d^4 z (\frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c)} \tag{110}$$

$$= \bar{A}_\mu^\alpha(x) + \Delta_\alpha(x) - (x | \frac{1}{P_\Omega^2} P_\alpha^\Omega P_\xi^\Omega | z) \Delta^\xi(z) \tag{111}$$

Using Eq. (104) we get

$$\begin{aligned}
& \int DA A_\mu^\alpha(x) e^{i \int d^4 z (\frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c)} \tag{112} \\
& = \Delta_\mu^\alpha(x) + \int d^4 z \left[ - (x | \frac{P_\mu^\Omega P_\xi^\Omega}{P_\Omega^2} | z)^{ab} \Delta^{b\xi}(z) - i (x | \frac{P_\mu^\Omega}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} \tilde{A}_\xi^{1c}(z) - i (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) \right]
\end{aligned}$$

$$\text{gde } \tilde{A}_\xi^{1a} \equiv \int d^4 z (x | \frac{P_\xi^\Omega P_\Omega^\eta}{P_\Omega^2} | z)^{ab} \Delta_\eta^b(z)$$

### 5. Symmetric dua

$$\begin{aligned} \bar{D}^\xi \bar{G}_{\xi\alpha}^a &= (\partial^{ab\xi} - g f^{abc} \bar{A}^{c\xi})(\partial_\xi \bar{A}_\alpha^b - \partial_\alpha \bar{A}_\xi^b + g f^{bmn} \bar{A}_\xi^m \bar{A}_\alpha^n) - \\ &= (\partial^2 g_{\xi\alpha} - \partial_\xi \partial_\alpha) \bar{A}^{a\xi} + g f^{abc} [2 \bar{A}_\xi^b (\partial^\xi \bar{A}_\alpha)^c - \bar{A}_\alpha^b (\partial^\xi \bar{A}_\xi)^c - \bar{A}_\xi^b (\partial_\alpha \bar{A}^\xi)^c] - g^2 f^{abc} \bar{A}^{c\xi} f^{bmn} \bar{A}_\xi^m \bar{A}_\alpha^n \\ \bar{P}^2 g^{\alpha\beta} + 2i \bar{G}^{\alpha\beta} &= (p^2 + \{p^\xi, \bar{A}_\xi\} + \bar{A}^2) g_{\alpha\beta} + 2i \bar{G}^{\alpha\beta} \end{aligned}$$

$$\int DA A_\mu^a(x) e^{i \int d^4 z (\frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c)} = \int d^4 z (x | \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i \bar{G}^{\alpha\beta}} | z)^{ab} \bar{D}_\xi \bar{G}^{b\xi\alpha}(z) \quad (113)$$

$$\begin{aligned} &= \int d^4 z (x | \frac{1}{(p^2 + \{p^\xi, \bar{A}_\xi\} + \bar{A}^2) g_{\alpha\beta} + 2i \bar{G}^{\alpha\beta}} ( - (p^2 g_{\xi\alpha} - p_\xi p_\alpha) \bar{A}^\xi + g f^{abc} [2 \bar{A}_\xi^b (\partial^\xi \bar{A}_\alpha)^c - \bar{A}_\alpha^b (\partial^\xi \bar{A}_\xi)^c - \bar{A}_\xi^b (\partial_\alpha \bar{A}^\xi)^c] ) \\ &= -\bar{A}_\alpha + \int dz (x | \frac{p_\alpha p_\xi}{p^2} | z) \bar{A}^\xi(z) \end{aligned} \quad (114)$$

### 6. bF gauge for arbitrary $\bar{A}$

At  $\Omega^\dagger = 1$  and  $\Delta \rightarrow \bar{A}$  the Eq. (99) gives  $\tilde{A}_\nu^{(1)} = (x | \frac{p_\nu p_\xi}{p^2} | z)^{ab} \bar{A}^{b\xi}(z)$  and

$$A_\nu^{(1)} + A_\nu^{(2)} = -\bar{A}_\nu(x) + (x | \frac{p_\nu p_\xi}{p^2} | z) \bar{A}^{a\xi}(z) - i (x | \frac{p_\nu}{p^2} | z) f^{abc} \bar{A}^{b\xi} \bar{A}_\xi^{1c}(z) - i (x | \frac{p_\xi}{p^2} | z) f^{abc} \tilde{A}_\xi^{1b} \tilde{A}_\nu^{1c}(z)$$

By inspection of f-la (141) at  $\Omega^\dagger = 1$  and  $\Delta \rightarrow \bar{A}$  we see that if  $\partial^\xi \bar{A}_\xi = 0$  vi get  $\tilde{A}_\xi^{(1)} = \int dz (x | \frac{p_\xi p_\eta}{p^2} | z) \bar{A}_\eta(z) = 0$  so

$$\int DA (\bar{A}_\mu^a(x) + A_\mu^a(x)) e^{i \int d^4 z (\frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c)} = 0 \quad (115)$$

### C. In 2 dimensions

$i\Omega \partial_* \Omega^\dagger = A_\bullet \Rightarrow \Omega^\dagger = [\pm\infty, x_*]$ ,  $A_\bullet(x_*) = i[x_*, \pm\infty] \partial_\bullet [\pm\infty, x_*]$ . We take  $\Omega^\dagger(x_*) = [-\infty, x_*]$  and  $\Delta_* = B_*$

$$\begin{aligned} (\Omega \delta_1 \Omega^\dagger)^a &= \int dz (x | \frac{\bar{P}_\Omega^\xi}{P_\Omega^2} | z)^{ab} \Delta_\xi^b(z) = \Omega_x^{ac} \int dz (x | \frac{p^\xi}{p^2 + i\epsilon p_0} | z) \Omega_z^{\dagger cb} \Delta_\xi^b(z) = \Omega_{x_*}^{ac} \frac{2}{s} \int dz_* dz_\bullet (x | \frac{1}{\alpha + i\epsilon} | z) \Omega_{z_*}^{\dagger cb} \Delta_*^b(z_\bullet) \\ &= \frac{1}{s} \int dz_\bullet (x | \frac{1}{\alpha + i\epsilon} | z) B_*^a(z_\bullet) = -i \frac{1}{s} \int_{-\infty}^{x_\bullet} dz_\bullet B_*^a(z_\bullet) \Rightarrow \Omega \delta_1 \Omega^\dagger = \frac{1}{2} [-\infty, x_\bullet]^{(1)} \end{aligned} \quad (116)$$

$$\tilde{A}_*^{(1)} = \frac{1}{2} B_*, \quad \tilde{A}_\bullet^{(1)} = i \frac{1}{s} \int_{-\infty}^{x_\bullet} dz_\bullet [B_*(z_\bullet), A_\bullet(x_*)]$$

Chek:  $\partial_* \tilde{A}_\bullet + D_\bullet \tilde{A}_* = D_\bullet B_*$

$$\begin{aligned} (\Omega \delta_2 \Omega^\dagger)^a &= \int dz \left[ -i (x | \frac{\bar{P}_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} \Delta^{b\xi} (\Omega \delta_1 \Omega^\dagger)^c(z) - \frac{i}{2} (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\xi^{1c}(z) \right] \\ &= \frac{2}{s} \int dz \left[ -\frac{i}{2} (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} B_\bullet^b (\Omega \delta_1 \Omega^\dagger)^c(z) - \frac{i}{2} (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_*^{1c}(z) \right] \\ &= \frac{i}{2} f^{abc} \frac{4}{s^2} \int_{-\infty}^{x_*} dz_\bullet \int_{-\infty}^{z_*} dz'_\bullet B_*^b(z_\bullet) B_*^c(z'_\bullet) - \frac{i}{2} f^{abc} \frac{2}{s} (x | \frac{P_\Omega^\xi}{P_\Omega^2} | z)^{aa'} f^{a'bc} (\Omega \delta_1 \Omega^\dagger)^b \tilde{A}_\bullet^{1c}(z) \end{aligned}$$

## 1. Exampel po-drugomu

$$\begin{aligned}
x &= (x_*, x_\bullet), \quad x_R = (-x_*, x_\bullet), \quad x_L = (x_*, -x_\bullet) \\
\Omega^\dagger &= \theta(x_*)\theta(x_\bullet)[x, -\infty x] + \theta(x_*)\theta(-x_\bullet)[x, -\infty x_R] + \theta(-x_*)\theta(x_\bullet)[x, -\infty x_L] + \theta(-x_*)\theta(-x_\bullet)[x, \infty x] \\
\Omega_\mu^\dagger &= A_\mu(x) + \theta(x_*)\theta(x_\bullet) \int_{-\infty}^1 t dt [x, tx] x^\rho G_{\rho\mu}(tx)[tx, x] + \dots
\end{aligned}$$

2. Trial  $\Lambda$ 

$$\Omega(x) = [x, 0], \quad \Omega_\mu = i[x, 0]\partial_\mu[0, x] = -i(\partial_\mu\Omega)\Omega^\dagger$$

$$\begin{aligned}
\Omega_\mu &= \bar{A}_\mu(x) - \int_0^1 t dt [x, tx] x^\rho G_{\rho\mu}(tx)[tx, x] \\
\Rightarrow \Delta_\mu &= - \int_0^1 t dt [x, tx] x^\rho G_{\rho\mu}(tx)[tx, x]
\end{aligned}$$

From f-la (104)

$$\begin{aligned}
&\int DA A_\mu^\alpha(x) e^{i\int d^4z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right)} \\
&= \Delta_\mu^\alpha(x) + \int d^4z \left[ (x| - \frac{P_\mu^\Omega P_\xi^\Omega}{P_\Omega^2} |z)^{ab} \Delta^{b\xi}(z) - i(x| \frac{P_\mu^\Omega}{P_\Omega^2} |z)^{aa'} f^{a'bc} \Delta^{b\xi} \tilde{A}_\xi^{1c}(z) - i(x| \frac{P_\Omega^\xi}{P_\Omega^2} |z)^{aa'} f^{a'bc} \tilde{A}_\xi^{1b} \tilde{A}_\mu^{1c}(z) \right]
\end{aligned} \tag{117}$$

gde  $\tilde{A}_\xi^{1a} \equiv \int d^4z (x| \frac{P_\xi^\Omega P_\Omega^\eta}{P_\Omega^2} |z)^{ab} \Delta_\eta^b(z)$  which corresponds to  $\Omega_\mu^\dagger = i\Omega^\dagger \partial_\mu \Omega \Rightarrow$

$$\Omega_\mu + \tilde{A}_\mu^{(1)} = i(1 - \delta\Omega\Omega^\dagger)\Omega\partial_\mu\Omega^\dagger(1 + \delta\Omega\Omega^\dagger)$$

$\Rightarrow$

$$\Omega^\dagger = (1 - \delta_1\Omega\Omega^\dagger)\Omega, \quad \tilde{A}_\mu^{(1)} = (i\partial_\mu + [\Omega_\mu])\delta\Omega\Omega^\dagger \Rightarrow \tilde{A}_\mu^{1a} = (P_\mu^\Omega)^{ab}(\delta\Omega\Omega^\dagger)^b$$

where  $(\Omega^\dagger\delta\Omega)^b \equiv 2\text{tr}\{t^b\Omega^\dagger\delta\Omega\}$ . Wi get

$$\begin{aligned}
(\delta\Omega\Omega^\dagger)^a &= \int dz (x| \frac{P_\Omega^\xi}{P_\Omega^2} |z)^{ab} \Delta_\xi^b(z) = \Omega_x^{ac} \int dz (x| \frac{p_\xi}{p^2} |z) \Omega_z^{\dagger cb} \Delta_\xi^b(z) \\
\Rightarrow \Omega_x^\dagger \delta\Omega_x &= - \int_0^1 t dt \int dz (x| \frac{p_\xi}{p^2} |z) [0, tz] z^\rho G_{\rho\xi}(tz)[tz, 0]
\end{aligned} \tag{118}$$

$$\Omega_x^\dagger \delta\Omega_x = \int dz (x| \frac{p_\xi}{p^2} |z) \tag{119}$$

Second order ( $\Omega_\mu^\dagger \equiv \Omega i\partial_\mu \Omega^\dagger$ )

$$\begin{aligned}
&\Omega[1 - \delta_1\Omega^\dagger\Omega - \delta_2\Omega^\dagger\Omega + \frac{1}{2}(\delta_1\Omega^\dagger\Omega)^2]i\partial_\mu[1 + \delta_1\Omega^\dagger\Omega + \delta_2\Omega^\dagger\Omega + \frac{1}{2}(\delta_1\Omega^\dagger\Omega)^2]\Omega^\dagger \\
&= [1 - \Omega\delta_1\Omega^\dagger - \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2]\Omega i\partial_\mu\Omega^\dagger [1 + \Omega\delta_1\Omega^\dagger + \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2] \\
&= [1 - \Omega\delta_1\Omega^\dagger - \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2]\Omega_\mu^\dagger [1 + \Omega\delta_1\Omega^\dagger + \Omega\delta_2\Omega^\dagger + \frac{1}{2}(\Omega\delta_1\Omega^\dagger)^2] \\
&\quad + [1 - \Omega\delta_1\Omega^\dagger - \Omega\delta_2\Omega^\dagger][i\partial_\mu(\Omega\delta_1\Omega^\dagger) + i\partial_\mu(\Omega\delta_2\Omega^\dagger) + \frac{1}{2}i\partial_\mu(\Omega\delta_1\Omega^\dagger)^2] \\
&= \Omega_\mu^\dagger + (i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_1\Omega^\dagger) + (i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_2\Omega^\dagger) + \frac{1}{2}[(i\partial_\mu + [\Omega_\mu^\dagger])(\Omega\delta_1\Omega^\dagger), \Omega\delta_1\Omega^\dagger]
\end{aligned} \tag{120}$$



## 3. Background-Lorentz gauge

$$(\partial_\mu - iA_\mu - iB_\mu)C^\mu = 0 \Rightarrow$$

$$C_\mu^a = \int dz (x) \frac{1}{P_{A+B}^2 g_{\mu\nu} + 2i\bar{G}_{\mu\nu}^{A+B}} |z|^{ab} [(D^\mu G_{\mu\nu})^{A+B} - D^\mu A_{\mu\nu} - D^\mu B_{\mu\nu}]^b(z) \quad (121)$$

For  $\bar{A} = \frac{2}{s}A_\bullet(x_*, x_\perp) + \frac{2}{s}B_*(x_\bullet, x_\perp)$  we get  $D^\mu A_{\mu\nu} + D^\mu B_{\mu\nu} = \partial^2 \bar{A}$

If  $\bar{A}_\mu + \Delta_\mu = \Omega_\mu =$  pure gauge from Eq. (109) we get

$$\begin{aligned} & \int DA A_\mu^a(x) e^{i\int dz (\frac{1}{2}A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\beta^c - A_\xi^a \partial^2 \bar{A}^{\alpha\xi})} \\ &= \int dz (x) \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} |z|^{ab} (\bar{D}_\xi \bar{G}^{b\xi\beta}(z) - \partial^2 \bar{A}^{b\beta}(z)) \\ &= \int dz (x) \frac{1}{\bar{P}_\Omega^2} [(P_\Omega^2 g_{\alpha\xi} - P_\alpha^\Omega P_\xi^\Omega) |z| \Delta^\xi(z) - (x) \frac{1}{\bar{P}_\Omega^2} p^2 |z| \bar{A}_\alpha^b(z)] \\ &= \Delta_\alpha(x) - \int dz (x) \frac{1}{\bar{P}_\Omega^2} P_\alpha^\Omega P_\xi^\Omega |z| \Delta^\xi(z) - \int dz (x) \frac{1}{\bar{P}_\Omega^2} p^2 |z| \bar{A}_\alpha^b(z) = \Omega_\alpha^\dagger - \int dz (x) \frac{1}{\bar{P}_\Omega^2} p^2 |z| \bar{A}_\alpha^b(z) \\ &- \int dz (x) \frac{1}{\bar{P}_\Omega^2} p^2 |z| \bar{A}_\alpha^b(z) = \frac{4i}{s} p_{1\alpha} \int dz \frac{\partial}{\partial z_*} (x) \frac{1}{\bar{P}_\Omega^2} p_* |z| \bar{A}_*^b(z) + \frac{4i}{s} p_{2\alpha} \int dz \frac{\partial}{\partial z_\bullet} (x) \frac{1}{\bar{P}_\Omega^2} p_\bullet |z| \bar{A}_\bullet^b(z) \end{aligned} \quad (122)$$

## VI. PURE GAUGE IN 2D

$$\begin{aligned} \bar{G}_{\xi\alpha}^a &= \partial_\xi \bar{A}_\alpha^a - \partial_\alpha \bar{A}_\xi^a + g f^{abc} \bar{A}_\xi^b \bar{A}_\alpha^c \\ \bar{D}^\xi \bar{G}_{\xi\alpha}^a - (\partial^2 g_{\xi\alpha} - \partial_\xi \partial_\alpha) \bar{A}^\xi &= (\partial^{ab\xi} - g f^{abc} \bar{A}^{c\xi}) (\partial_\xi \bar{A}_\alpha^b - \partial_\alpha \bar{A}_\xi^b + g f^{bmn} \bar{A}_\xi^m \bar{A}_\alpha^n) - (\partial^2 g_{\xi\alpha} - \partial_\xi \partial_\alpha) \bar{A}^\xi \\ &= g f^{abc} [2\bar{A}_\xi^b (\partial^\xi \bar{A}_\alpha)^c - \bar{A}_\alpha^b (\partial^\xi \bar{A}_\xi)^c - \bar{A}_\xi^b (\partial_\alpha \bar{A}^\xi)^c] + O(g^2) = g f^{abc} [\partial^\xi (\bar{A}_\xi^b \bar{A}_\alpha^c) + \bar{A}^{b\xi} (\partial_\xi \bar{A}_\alpha^c - \partial_\alpha \bar{A}_\xi^c)] - g^2 f^{abc} \bar{A}^{c\xi} f^{bmn} \bar{A}_\xi^m \bar{A}_\alpha^n \\ \bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta} - \bar{D}^\alpha \bar{D}^\beta &= \partial^2 g_{\alpha\beta} - \partial_\alpha \partial_\beta - i\{\partial_\xi, \bar{A}^\xi\} g_{\alpha\beta} - 2i((\bar{D}^\alpha \bar{A}^\beta) - \alpha \leftrightarrow \beta) + i\bar{A}_\alpha \partial_\beta - \partial_\alpha \bar{A}_\beta + O(\bar{A}^2) \end{aligned} \quad (123)$$

Trivial order

$$\begin{aligned} & \int DA A_\nu^a(x) e^{i\int dz (\frac{1}{2}A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\beta^c - \frac{1}{2}A_\alpha^a \partial^2 \bar{A}^{\alpha\alpha})} = \\ &= \int d^4 z (x) \frac{1}{p^2} |z| f^{abc} [\partial^\xi (\bar{A}_\xi^b \bar{A}_\nu^c) + \bar{A}^{b\xi} (\partial_\xi \bar{A}_\nu^c - \partial_\nu \bar{A}_\xi^c)] \stackrel{\partial_\mu \bar{A}_\nu = \partial_\nu \bar{A}_\mu}{=} \int d^4 z (x) \frac{1}{p^2} |z| f^{abc} \partial^\xi (\bar{A}_\xi^b \bar{A}_\nu^c(z)) \end{aligned} \quad (124)$$

Since  $\bar{G}_{\mu\nu}^a = g f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c \xrightarrow{x \rightarrow \infty} 0$  and  $\bar{A}^\xi \partial_\xi \bar{A}_\nu \xrightarrow{x \rightarrow \infty} 0$

$$\begin{aligned} G_{\mu\nu}^a(\bar{A} + A) &= -i \int d^2 z (x) \frac{p_\mu}{p^2} |z| f^{abc} \bar{A}_\xi^b \partial^\xi \bar{A}_\nu^c(z) - \mu \leftrightarrow \nu + g f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c = \int d^2 z (x) \frac{1}{p^2} |z| f^{abc} \partial_\mu \bar{A}_\xi^b \partial^\xi \bar{A}_\nu^c(z) - \mu \leftrightarrow \nu + g f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c \\ &= \int d^2 z (x) \frac{1}{p^2} |z| f^{abc} \partial_\xi \bar{A}_\mu^b \partial^\xi \bar{A}_\nu^c(z) - \mu \leftrightarrow \nu + g f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c = \frac{1}{2} \int d^2 z (x) \frac{\partial^2}{p^2} |z| f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c(z) - \mu \leftrightarrow \nu + g f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c = 0 \end{aligned} \quad (125)$$

A. LO in  $\bar{G}$ 

With our  $\bar{A}$

$$\begin{aligned} \bar{G}_{\xi\alpha}^a &= g f^{abc} \bar{A}_\xi^b \bar{A}_\alpha^c \\ \bar{D}^\xi \bar{G}_{\xi\alpha}^a - (\partial^2 g_{\xi\alpha} - \partial_\xi \partial_\alpha) \bar{A}^\xi &= (\partial^{ab\xi} - g f^{abc} \bar{A}^{c\xi}) g f^{bmn} \bar{A}_\xi^m \bar{A}_\alpha^n = g \bar{D}^{ab\xi} f^{bmn} (\bar{A}_\xi^m \bar{A}_\alpha^n) = g f^{amn} \bar{A}_\xi^m (\bar{D}^\xi \bar{A}_\alpha)^n \end{aligned} \quad (126)$$

$$\begin{aligned}
A_\alpha^{(1)a} &\equiv \int DA A_\alpha^a(x) e^{i \int d^2z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{\alpha\beta} A_\beta^b - A_\alpha^a \partial^2 \bar{A}^{a\alpha} \right)} = \\
&= \int d^2z (x | \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i \bar{G}_{\alpha\beta}} | z)^{aa'} f^{a'bc} \bar{A}_\xi^b (\bar{D}^\xi \bar{A}_\beta)^c(z) = \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} \bar{A}_\xi^b (\bar{D}^\xi \bar{A}_\alpha)^c(z) + O(\bar{G}^2) \quad (127)
\end{aligned}$$

$\Rightarrow$

$$A_\bullet^{(1)a} = \frac{2i}{s} \int d^2z (x | \frac{P_\bullet}{\bar{P}^2} | z) G_{\bullet*}(z), \quad A_*^{(1)a} = -\frac{2i}{s} \int d^2z (x | \frac{P_*}{\bar{P}^2} | z) G_{\bullet*}(z) \quad (128)$$

$$\begin{aligned}
G_{\mu\nu}^a(\bar{A} + A^{(1)}) &\simeq G_{\mu\nu}^a(\bar{A}) + (\bar{D}_\mu A_\nu^{(1)} - \mu \leftrightarrow \nu)^a = \int d^2z (x | \frac{\bar{D}_\mu}{\bar{P}^2} | z)^{aa'} f^{a'bc} \bar{A}_\xi^b (\bar{D}^\xi \bar{A}_\nu)^c(z) - \mu \leftrightarrow \nu + g f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c \\
&= \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [(\bar{D}_\mu \bar{A}_\xi)^b (\bar{D}^\xi \bar{A}_\nu)^c(z) + (\bar{A}_\xi)^b (\bar{D}_\mu \bar{D}^\xi \bar{A}_\nu)^c(z)] - \mu \leftrightarrow \nu + g f^{abc} \bar{A}_\mu^b \bar{A}_\nu^c \\
&= \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [(\bar{D}_\mu \bar{A}_\xi - \bar{D}_\xi \bar{A}_\mu)^b (\bar{D}^\xi \bar{A}_\nu)^c(z) - (\bar{A}^\xi)^b (D^2 g_{\mu\xi} - \bar{D}_\mu \bar{D}^\xi) \bar{A}_\nu^c(z)] - \mu \leftrightarrow \nu \quad (129)
\end{aligned}$$

$$\text{Y HAC } \bar{D}_*^a \bar{A}_\bullet^b = \bar{G}_{* \bullet}^a.$$

$$\begin{aligned}
G_{\bullet*}^a(\bar{A} + A^{(1)}) &= \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} \quad (130) \\
&\times [(\bar{D}_\bullet \bar{A}_\xi - \bar{D}_\xi \bar{A}_\bullet)^b (\bar{D}^\xi \bar{A}_*)^c(z) - (\bar{A}^\xi)^b (D^2 g_{\bullet\xi} - \bar{D}_\bullet \bar{D}^\xi) \bar{A}_*^c(z) - (\bar{D}_* \bar{A}_\xi - \bar{D}_\xi \bar{A}_*)^b (\bar{D}^\xi \bar{A}_\bullet)^c(z) + (\bar{A}^\xi)^b (D^2 g_{*\xi} - \bar{D}_* \bar{D}^\xi) \bar{A}_\bullet^c(z)] \\
&= \frac{2}{s} \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [(\bar{D}_\bullet \bar{A}_* - \bar{D}_* \bar{A}_\bullet)^b (\bar{D}_\bullet \bar{A}_*)^c(z) - (\bar{D}_* \bar{A}_\bullet - \bar{D}_\bullet \bar{A}_*)^b (\bar{D}_* \bar{A}_\bullet)^c(z) \\
&\quad - (\bar{A}_\bullet)^b (\bar{D}_* \bar{D}_\bullet \bar{A}_* + \bar{D}_*^2 \bar{A}_\bullet)^c(z) + (\bar{A}_*)^b (\bar{D}_\bullet \bar{D}_* \bar{A}_\bullet + \bar{D}_\bullet^2 \bar{A}_*)^c(z)] \\
&= \frac{2}{s} \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [- (\bar{A}_\bullet)^b (\bar{D}_* \bar{D}_\bullet \bar{A}_* + \bar{D}_*^2 \bar{A}_\bullet)^c(z) + (\bar{A}_*)^b (\bar{D}_\bullet \bar{D}_* \bar{A}_\bullet + \bar{D}_\bullet^2 \bar{A}_*)^c(z)] \\
&= \frac{2}{s} \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [(\bar{A}_\bullet)^b (\bar{P}_* \bar{P}_\bullet \bar{A}_* + \bar{P}_*^2 \bar{A}_\bullet)^c(z) - (\bar{A}_*)^b (\bar{P}_\bullet \bar{P}_* \bar{A}_\bullet + \bar{P}_\bullet^2 \bar{A}_*)^c(z)] \\
&= \frac{2}{s} \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [(\bar{A}_\bullet)^b (\bar{P}_* \bar{A}_\bullet)^{cd} \bar{A}_*^d(z) + (\bar{A}_\bullet)^b (\bar{P}_* \bar{A}_*)^{cd} \bar{A}_\bullet^d(z) - (\bar{A}_*)^b (\bar{P}_\bullet \bar{A}_*)^{cd} \bar{A}_\bullet^d(z) + (\bar{A}_*)^b (\bar{P}_\bullet \bar{A}_\bullet)^{cd} \bar{A}_*^d(z)] \\
&= \frac{2}{s} \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [(\bar{A}_\bullet)^b (i \bar{D}_* \bar{A}_\bullet)^{cd} \bar{A}_*^d(z) + i (\bar{A}_\bullet)^b \bar{A}_\bullet^{cd} \partial_* \bar{A}_*^d(z) + (\bar{A}_\bullet)^b (i \partial_* \bar{A}_*)^{cd} \bar{A}_\bullet^d(z) - (\bullet \leftrightarrow *)] \\
&= \frac{2i}{s} \int d^2z (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} [\bar{A}_\bullet^b \bar{G}_{* \bullet}^{cd} \bar{A}_*^d(z) + \bar{A}_*^b \bar{G}_{\bullet*}^{cd} \bar{A}_\bullet^d(z)] \quad (131)
\end{aligned}$$

ПО-DПЫТОМЬ: from Eq. (127) we get

$$\begin{aligned}
A_\alpha^{(1)a} &= -i \int d^2z (x | \frac{1}{\bar{P}^2} \bar{P}^\xi | z)^{aa'} f^{a'bc} \bar{A}_\xi^b \bar{A}_\alpha^c(z) + O(\bar{G}^2) = \\
\Rightarrow A_\bullet^{(1)a} &= \frac{2i}{s} \int d^2z (x | \frac{1}{\bar{P}^2} \bar{P}_\bullet | z) \bar{G}_{\bullet*}(z), \quad A_*^{(1)a} = -\frac{2i}{s} \int d^2z (x | \frac{1}{\bar{P}^2} \bar{P}_* | z)^{ab} G_{\bullet*}^b(z) + O(\bar{G}^2) \quad (132)
\end{aligned}$$

$\Rightarrow$

$$G_{\bullet*}^a(\bar{A} + A^{(1)}) \simeq G_{\bullet*}^a(\bar{A}) + \bar{D}_\bullet A_*^{(1)} - \bar{D}_* A_\bullet^{(1)} = \bar{G}_{\bullet*}^a - \frac{2}{s} \int d^2z (x | \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_* + \bar{P}_* \frac{1}{\bar{P}^2} \bar{P}_\bullet | z)^{ab} \bar{G}_{\bullet*}^b(z) = O(\bar{G}^2) \quad (133)$$

B. NLO:  $\bar{G}^2$ 

$$\begin{aligned}
A_\alpha^{(1+2)a} &\equiv A_\alpha^{(1)a} + A_\alpha^{(2)a} = \int DA A_\alpha^a(x) e^{i\int d^2z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c - A_\alpha^a \partial^2 \bar{A}^{a\alpha} \right)} = \\
&= \int d^2z \left[ -i(x) \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} \bar{P}^\xi |z\rangle^{ab} \bar{G}_{\xi\beta}^b(z) \right. \\
&- i(x) \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} \bar{P}^\xi |z\rangle^{aa'} f^{a'bc} A_\xi^{(1)b} A_\beta^{(1)b} - (x) \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} |z\rangle^{aa'} f^{a'bc} A^{(1)b\xi} (\bar{D}_\beta A_\xi^{(1)b} - \bar{D}_\xi A_\beta^{(1)b}) \left. \right] + O(\bar{G}^3) \\
&= \int d^2z \left[ -i(x) \frac{1}{\bar{P}^2} \bar{P}^\xi |z\rangle^{ab} \bar{G}_{\xi\alpha}^b(z) - 2(x) \frac{1}{\bar{P}^2} \bar{G}_{\alpha\beta} \frac{1}{\bar{P}^2} \bar{P}^\xi |z\rangle^{ab} \bar{G}_{\xi\beta}^b(z) \right. \\
&- i(x) \frac{1}{\bar{P}^2} \bar{P}^\xi |z\rangle^{aa'} f^{a'bc} A_\xi^{(1)b} A_\alpha^{(1)c} - (x) \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} A^{(1)b\xi} (\bar{D}_\alpha A_\xi^{(1)c} - \bar{D}_\xi A_\alpha^{(1)c}) \left. \right] + O(\bar{G}^3) \tag{134}
\end{aligned}$$

$$\begin{aligned}
A_\bullet^{(1+2)a} &= \int d^2z \left[ -\frac{2i}{s} (x) \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{ab} \bar{G}_{\bullet\bullet}^b(z) + \frac{8}{s^2} (x) \frac{1}{\bar{P}^2} \bar{G}_{\bullet\bullet} \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{ab} \bar{G}_{\bullet\bullet}^b(z) \right. \\
&- \frac{2i}{s} (x) \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{aa'} f^{a'bc} A_\bullet^{(1)b} A_\bullet^{(1)c} - \frac{2}{s} (x) \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} A_\bullet^{(1)b} (\bar{D}_\bullet A_\bullet^{(1)c} - \bar{D}_\bullet A_\bullet^{(1)c}) \left. \right] + O(\bar{G}^3) \\
A_\star^{(2)a} &= \int d^2z \left[ \frac{2i}{s} (x) \frac{1}{\bar{P}^2} \bar{P}_\star |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) + \frac{8}{s^2} (x) \frac{1}{\bar{P}^2} \bar{G}_{\star\bullet} \frac{1}{\bar{P}^2} \bar{P}_\star |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) \right. \\
&+ \frac{2i}{s} (x) \frac{1}{\bar{P}^2} \bar{P}_\star |z\rangle^{aa'} f^{a'bc} A_\star^{(1)b} A_\bullet^{(1)c} + \frac{2}{s} (x) \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} A_\star^{(1)b} (\bar{D}_\bullet A_\star^{(1)c} - \bar{D}_\star A_\bullet^{(1)c}) \left. \right] + O(\bar{G}^3) \tag{135}
\end{aligned}$$

$$\begin{aligned}
G_{\mu\nu}^a (\bar{A} + A^{(1)} + A^{(2)}) &= \bar{G}_{\mu\nu}^a + (\bar{D}_\mu A_\nu^{(1)} - \mu \leftrightarrow \nu)^a + (\bar{D}_\mu A_\nu^{(2)} - \mu \leftrightarrow \nu)^a + g f^{abc} A_\mu^{(1)b} A_\nu^{(1)c} + O(\bar{G}^3) \\
G_{\star\bullet}^a (\bar{A} + A^{(1)} + A^{(2)}) &= \bar{G}_{\star\bullet}^a + (\bar{D}_\star A_\bullet^{(1+2)} - \bar{D}_\bullet A_\star^{(1+2)})^a + g f^{abc} A_\star^{(1)b} A_\bullet^{(1)c} + O(\bar{G}^3) \tag{136}
\end{aligned}$$

Potochnee

$$\begin{aligned}
G_{\star\bullet}^a (\bar{A}) + \bar{D}_\star A_\bullet^{(1)} - \bar{D}_\bullet A_\star^{(1)} & \tag{137} \\
= \bar{G}_{\star\bullet}^a - \frac{2}{s} \int d^2z (x) \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_\star + \bar{P}_\star \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) &= \frac{2}{s} \int d^2z (x) \frac{1}{\bar{P}^2} \bar{P}_\bullet \bar{G}_{\star\bullet} \bar{P}_\star \frac{1}{\bar{P}^2} + \frac{1}{\bar{P}^2} \bar{P}_\star \bar{G}_{\star\bullet} \bar{P}_\bullet \frac{1}{\bar{P}^2} |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) + O(\bar{G}^3)
\end{aligned}$$

DALEE

$$\begin{aligned}
(\bar{D}_\star A_\bullet^{(1+2)} - \bar{D}_\bullet A_\star^{(1+2)})^a &= \int d^2z \left[ -\frac{2}{s} (x) \bar{P}_\star \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) - \frac{8i}{s^2} (x) \bar{P}_\star \frac{1}{\bar{P}^2} \bar{G}_{\star\bullet} \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) \right. \\
&- \frac{2}{s} (x) \bar{P}_\star \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{aa'} f^{a'bc} A_\star^{(1)b} A_\bullet^{(1)c} + \frac{2i}{s} (x) \bar{P}_\star \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} A_\bullet^{(1)b} (\bar{D}_\bullet A_\star^{(1)c} - \bar{D}_\star A_\bullet^{(1)c}) \\
&- \frac{2}{s} (x) \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_\star |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) + \frac{8i}{s^2} (x) \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{G}_{\star\bullet} \frac{1}{\bar{P}^2} \bar{P}_\star |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) \\
&- \frac{2}{s} (x) \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_\star |z\rangle^{aa'} f^{a'bc} A_\star^{(1)b} A_\bullet^{(1)c} + \frac{2i}{s} (x) \bar{P}_\bullet \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} A_\star^{(1)b} (\bar{D}_\bullet A_\star^{(1)c} - \bar{D}_\star A_\bullet^{(1)c}) \left. \right] + O(\bar{G}^3) \tag{138}
\end{aligned}$$

Bikoz  $\bar{D}_\bullet A_\star^{(1)} - \bar{D}_\star A_\bullet^{(1)} = \bar{G}_{\star\bullet}$

$$\begin{aligned}
(\bar{D}_\star A_\bullet^{(1+2)} - \bar{D}_\bullet A_\star^{(1+2)})^a &= -f^{abc} A_\star^{(1)b} A_\bullet^{(1)c} + \int d^2z \left[ -\frac{2}{s} (x) \bar{P}_\star \frac{1}{\bar{P}^2} \bar{P}_\bullet + \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_\star |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) \right. \tag{139} \\
&+ \frac{8i}{s^2} (x) \frac{1}{\bar{P}^2} (\bar{P}_\bullet \bar{G}_{\star\bullet} \bar{P}_\star - \bar{P}_\star \bar{G}_{\star\bullet} \bar{P}_\bullet) \frac{1}{\bar{P}^2} |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) - \frac{2i}{s} (x) \bar{P}_\star \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} \bar{G}_{\star\bullet}^b A_\bullet^{(1)c} - \frac{2i}{s} (x) \bar{P}_\bullet \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} \bar{G}_{\star\bullet}^b A_\star^{(1)c} \left. \right] + O(\bar{G}^3) \\
&= -f^{abc} A_\star^{(1)b} A_\bullet^{(1)c} - \bar{G}_{\star\bullet}^a + \int d^2z \left[ \frac{4i}{s^2} (x) \frac{1}{\bar{P}^2} (\bar{P}_\bullet \bar{G}_{\star\bullet} \bar{P}_\star - \bar{P}_\star \bar{G}_{\star\bullet} \bar{P}_\bullet) \frac{1}{\bar{P}^2} |z\rangle^{ab} \bar{G}_{\star\bullet}^b(z) \right. \\
&- \frac{4}{s^2} (x) \bar{P}_\star \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} \bar{G}_{\star\bullet}^b(z) \int dz' (z) \frac{1}{\bar{P}^2} \bar{P}_\bullet |z'\rangle^{cd} G_{\star\bullet}^d(z') + \frac{4}{s^2} (x) \bar{P}_\bullet \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} \bar{G}_{\star\bullet}^b(z) \int dz' (z) \frac{1}{\bar{P}^2} \bar{P}_\star |z'\rangle^{cd} G_{\star\bullet}^d(z') \left. \right] + O(\bar{G}^3) \\
&= -\bar{G}_{\star\bullet}^a - f^{abc} A_\star^{(1)b} A_\bullet^{(1)c} + O(\bar{G}^3) \tag{140} \\
&\Rightarrow G_{\mu\nu}^a (\bar{A} + A^{(1)} + A^{(2)}) = O(\bar{G}^3) \text{ for any } \frac{1}{\bar{P}^2 \pm i\epsilon} \text{ or } \frac{1}{\bar{P}^2 \pm i\epsilon p_0}
\end{aligned}$$

### C. Pure gauge in a simple way

$$\bar{A}^\mu = \frac{2}{s} p_1^\mu \bar{A}_\bullet(x_*) + \frac{2}{s} p_2^\mu \bar{A}_*(x_\bullet), \quad \bar{G}_{*\bullet}^a(x_*, x_\bullet) = f^{abc} \bar{A}_*(x_\bullet) \bar{A}_\bullet^c(x_*)$$

Rewrite Eq. (134)

$$\begin{aligned} A_\alpha^{(1+2)a} &\equiv A_\alpha^{(1)a} + A_\alpha^{(2)a} = \int DA A_\alpha^a(x) e^{i \int d^2 z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\beta^c - A_\alpha^a \partial^2 \bar{A}^{a\alpha} \right)} = \\ &= \int d^2 z \left[ -i(x) \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i \bar{G}_{\alpha\beta}} \bar{P}^\xi |z\rangle^{ab} \bar{G}_{\xi\beta}^b(z) \right. \\ &- i(x) \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i \bar{G}_{\alpha\beta}} \bar{P}^\xi |z\rangle^{aa'} f^{a'bc} A_\xi^{(1)b} A_\beta^{(1)b} - (x) \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i \bar{G}_{\alpha\beta}} |z\rangle^{aa'} f^{a'bc} A^{(1)b\xi} (\bar{D}_\beta A_\xi^{(1)b} - \bar{D}_\xi A_\beta^{(1)b}) \left. \right] + O(\bar{G}^3) \\ &= \int d^2 z \left[ -i(x) \frac{1}{\bar{P}^2} \bar{P}^\xi |z\rangle^{ab} \bar{G}_{\xi\alpha}^b(z) - 2(x) \frac{1}{\bar{P}^2} \bar{G}_{\alpha\beta} \frac{1}{\bar{P}^2} \bar{P}^\xi |z\rangle^{ab} \bar{G}_{\xi\beta}^b(z) \right. \\ &- i(x) \frac{1}{\bar{P}^2} \bar{P}^\xi |z\rangle^{aa'} f^{a'bc} A_\xi^{(1)b} A_\alpha^{(1)c} - (x) \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} A^{(1)b\xi} (\bar{D}_\alpha A_\xi^{(1)c} - \bar{D}_\xi A_\alpha^{(1)c}) \left. \right] + O(\bar{G}^3) \end{aligned} \quad (141)$$

$$\frac{1}{\bar{P}^2} = \frac{s}{4 \bar{P}_\bullet \bar{P}_*} + \frac{i}{2 \bar{G}_{*\bullet}} \simeq \frac{s}{4 \bar{P}_\bullet \bar{P}_*} - \frac{is}{8 \bar{P}_\bullet \bar{P}_*} \bar{G}_{*\bullet} \frac{1}{\bar{P}_\bullet \bar{P}_*} + O(\bar{G}^2)$$

From Eq. (141) we get

$$\begin{aligned} A_\bullet^{(1+2)a} &= \int d^2 z \left[ -\frac{2i}{s} (x) \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) + \frac{8}{s^2} (x) \frac{1}{\bar{P}^2} \bar{G}_{*\bullet} \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) \right. \\ &- \frac{2i}{s} (x) \frac{1}{\bar{P}^2} \bar{P}_\bullet |z\rangle^{aa'} f^{a'bc} A_*^{(1)b} A_\bullet^{(1)c} - \frac{2}{s} (x) \frac{1}{\bar{P}^2} |z\rangle^{aa'} f^{a'bc} A_\bullet^{(1)b} \bar{G}_{*\bullet}^c \left. \right] + O(\bar{G}^3) \\ &= \int d^2 z \left[ -\frac{i}{2} (x) \frac{1}{\bar{P}_*} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) - \frac{1}{4} (x) \frac{1}{\bar{P}_\bullet \bar{P}_*} \bar{G}_{*\bullet} \frac{1}{\bar{P}_*} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) + \frac{1}{2} (x) \frac{1}{\bar{P}_\bullet \bar{P}_*} \bar{G}_{*\bullet} \frac{1}{\bar{P}_*} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) \right. \\ &- \frac{i}{2} (x) \frac{1}{\bar{P}_*} |z\rangle^{aa'} f^{a'bc} A_*^{(1)b} A_\bullet^{(1)c} - \frac{1}{4} (x) \frac{1}{\bar{P}_\bullet \bar{P}_*} \bar{G}_{*\bullet} \frac{1}{\bar{P}_*} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) \left. \right] + O(\bar{G}^3) \\ &= \int d^2 z \left[ -\frac{i}{2} (x) \frac{1}{\bar{P}_*} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) - \frac{i}{2} (x) \frac{1}{\bar{P}_*} |z\rangle^{aa'} f^{a'bc} A_*^{(1)b} A_\bullet^{(1)c} \right] \end{aligned} \quad (142)$$

$\Rightarrow$

$$A_\bullet^{(1)a} = -\frac{i}{2} \int d^2 z (x) \frac{1}{\bar{P}_*} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z), \quad A_\bullet^{(2)a} = -\frac{i}{2} \int d^2 z (x) \frac{1}{\bar{P}_*} |z\rangle^{aa'} f^{a'bc} A_*^{(1)b} A_\bullet^{(1)c} \quad (143)$$

Similarly,

$$A_*^{(1)a} = \frac{i}{2} \int d^2 z (x) \frac{1}{\bar{P}_\bullet} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z), \quad A_*^{(2)a} = \frac{i}{2} \int d^2 z (x) \frac{1}{\bar{P}_\bullet} |z\rangle^{aa'} f^{a'bc} A_*^{(1)b} A_\bullet^{(1)c} \quad (144)$$

Now

$$(\bar{D}_* A_\bullet^{(1+2)} - \bar{D}_\bullet A_*^{(1+2)})^a = -\bar{G}_{*\bullet}^a - f^{abc} A_*^{(1)b} A_\bullet^{(1)c} \Leftrightarrow \bar{G}_{*\bullet} (\bar{A} + A^{(1)} + A^{(2)}) = O(\bar{G}^3) \quad (145)$$

is evident.

### D. Pure gauge for the retarded propagators

$$\begin{aligned} A_\bullet^{(1)a} &= -\frac{i}{2} \int d^2 z (x) \frac{1}{\bar{P}_* + i\epsilon} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) = \frac{i}{2} \int_{-\infty}^{x_\bullet} dz_\bullet ([x_\bullet, z_\bullet] A_*(z_\bullet))^{ab} \bar{A}_\bullet^b(x_*) \simeq -\frac{1}{2} f^{abc} \int_{-\infty}^{x_\bullet} dz_\bullet A_*^b(z_\bullet) \bar{A}_\bullet^c(x_*) \\ A_*^{(1)a} &= \frac{i}{2} \int d^2 z (x) \frac{1}{\bar{P}_\bullet} |z\rangle^{ab} \bar{G}_{*\bullet}^b(z) = \frac{i}{2} \int_{-\infty}^{x_*} dz_* ([x_*, z_*] A_\bullet(z_*))^{ab} \bar{A}_*^b(x_\bullet) \end{aligned} \quad (146)$$

$$\begin{aligned} \frac{2}{s}\bar{D}_*\bar{D}_*\theta(x_*-z_*)[x_*,z_*]\theta(x_\bullet-z_\bullet)[x_\bullet,z_\bullet] &= \frac{s}{2}\delta(x_*-z_*)\delta(x_\bullet-z_\bullet) = \delta^{(2)}(x-z) \\ (x|\frac{1}{\bar{P}_*\bar{P}_\bullet+i\epsilon p_0}|z) &= (x|\frac{1}{(\bar{P}_*+i\epsilon)(\bar{P}_\bullet+i\epsilon)}|z) = -\frac{2}{s}\theta(x_*-z_*)[x_*,z_*]\theta(x_\bullet-z_\bullet)[x_\bullet,z_\bullet] \end{aligned} \quad (147)$$

$$\begin{aligned} \bar{A}_\bullet(x_*)+A_\bullet^{(1)a}(x) &= [x_*,-\infty]i\partial_\bullet[-\infty,x_*]-\frac{i}{2}\int d^2z(x|\bar{P}_\bullet\frac{1}{\bar{P}_*\bar{P}_\bullet+i\epsilon p_0}|z)^{ab}\bar{G}_{*\bullet}^b(z) = \Omega i\partial_\bullet\Omega^\dagger \\ \Omega^\dagger &= [-\infty,x_*(1+\delta\Omega^\dagger)] \Rightarrow \delta\Omega^a = -\frac{i}{2}\int d^2z(x|\frac{1}{\bar{P}_*\bar{P}_\bullet+i\epsilon p_0}|z)^{ab}\bar{G}_{*\bullet}^b(z) \\ \Rightarrow \delta\Omega^\dagger &= \frac{i}{2}\int_{-\infty}^{x_*}d\frac{2}{s}z_*\int_{-\infty}^{x_\bullet}d\frac{2}{s}z_\bullet[x_*,z_*][x_\bullet,z_\bullet]\bar{G}_{*\bullet}[z_\bullet,x_\bullet][z_*,x_*] \end{aligned} \quad (148)$$

1.  $A\Omega_0^\dagger = [-\infty, x]$  model

$$\begin{aligned} [x,-\infty]i\partial_\bullet[-\infty,x] &\equiv [x,-\infty]\frac{is}{2}\frac{\partial}{\partial x_*}[-\infty,x] = \bar{A}_\bullet(x) + \frac{2}{s}x_\bullet\int_{-\infty}^1 tdt[x,tx]G_{*\bullet}(tx)[tx,x] \\ [x,-\infty]i\partial_*[-\infty,x] &\equiv [x,-\infty]\frac{is}{2}\frac{\partial}{\partial x_\bullet}[-\infty,x] = \bar{A}_*(x) - \frac{2}{s}x_*\int_{-\infty}^1 tdt[x,tx]G_{*\bullet}(tx)[tx,x] \end{aligned} \quad (149)$$

$$\begin{aligned} \bar{A}_\bullet(x_*)+A_\bullet^{(1)a}(x) &= \bar{A}_\bullet(x_*) - \frac{i}{2}\int d^2z(x|\bar{P}_\bullet\frac{1}{\bar{P}_*\bar{P}_\bullet+i\epsilon p_0}|z)^{ab}\bar{G}_{*\bullet}^b(z) = \Omega i\partial_\bullet\Omega^\dagger \\ \Omega^\dagger &= [-\infty,x](1+\delta\Omega^\dagger) \Rightarrow (i\partial_\bullet + [\bar{A}_\bullet])\delta\Omega^a = -\frac{i}{2}\int d^2z(x|\bar{P}_\bullet\frac{1}{\bar{P}_*\bar{P}_\bullet+i\epsilon p_0}|z)^{ab}\bar{G}_{*\bullet}^b(z) - \frac{2}{s}x_\bullet\int_{-\infty}^1 tdt[x,tx]^{ab}G_{*\bullet}^b(tx) \\ \Rightarrow \delta\Omega^a &= -\frac{i}{2}\int d^2z(x|\frac{1}{\bar{P}_*\bar{P}_\bullet+i\epsilon p_0}|z)^{ab}\bar{G}_{*\bullet}^b(z) + \frac{ix^2}{s}\int_{-\infty}^1 tdt[x,tx]^{ab}G_{*\bullet}^b(tx) + O(D_\bullet G_{*\bullet}) \\ &= \frac{i}{2}\int d\frac{2}{s}z_*\int d\frac{2}{s}z_\bullet[x_*,z_*][x_\bullet,z_\bullet]\bar{G}_{*\bullet}(z_*,z_\bullet)[z_\bullet,x_\bullet][z_*,x_*] + ? \end{aligned} \quad (150)$$

## E. Propagator

$$\begin{aligned} &\int DA A_\mu^m(x)A_\nu^n(y)e^{i\int d^2z(\frac{1}{2}A_\alpha^a(\bar{D}^2g^{\alpha\beta}-2i\bar{G}^{\alpha\beta})^{ab}A_\beta^b+A_\alpha^a\bar{D}_\xi\bar{G}^{\alpha\xi}-gf^{abc}\bar{D}^\alpha A^{a\beta}A_\alpha^bA_\beta^c)} \\ &\ni -igf^{abc}\int DA A_\mu^m(x)A_\nu^n(y)\int dz\bar{D}^\alpha A^{a\beta}A_\alpha^bA_\beta^c(z)e^{i\int d^2z'(\frac{1}{2}A_\alpha^a(\bar{D}^2g^{\alpha\beta}-2i\bar{G}^{\alpha\beta})^{ab}A_\beta^b+A_\alpha^a\bar{D}_\xi\bar{G}^{\alpha\xi})} \\ &= -igf^{abc}\int dz\left[\langle A_\mu^m(x)A^{b\alpha}(z)\rangle_{\bar{A}}\langle A^{c\beta}(z)A_\nu^n(y)\rangle_{\bar{A}}(\bar{D}_\alpha A_\beta^{(1)a}-\bar{D}_\beta A_\alpha^{(1)a}) \right. \\ &+ \left. \langle A_\mu^m(x)(\bar{D}^\alpha A^{a\beta}-\bar{D}^\beta A^{a\alpha})(z)\rangle_{\bar{A}}A_\alpha^{(1)b}\langle A_\beta^c(z)A_\nu^n(y)\rangle_{\bar{A}} + \langle A_\mu^m(x)A_\beta^c(z)\rangle_{\bar{A}}A_\alpha^{(1)b}\langle(\bar{D}^\alpha A^{a\beta}-\bar{D}^\beta A^{a\alpha})(z)A_\nu^n(y)\rangle_{\bar{A}}\right] \\ &= if^{abc}\int dz(x|\frac{1}{\bar{P}^2g_{\mu\alpha}+2i\bar{G}_{\mu\alpha}}|z)^{mb}(\bar{D}_\alpha A_\beta^{(1)a}-\bar{D}_\beta A_\alpha^{(1)a})(z|\frac{1}{\bar{P}^2g_{\beta\nu}+2i\bar{G}_{\beta\nu}}|y)^{cn} \\ &- f^{abc}\int dz(x|\frac{1}{\bar{P}^2g_{\mu\beta}+2i\bar{G}_{\mu\beta}}\bar{P}_\alpha-\frac{1}{\bar{P}^2g_{\mu\beta}+2i\bar{G}_{\mu\beta}}\bar{P}_\beta|z)^{ma}A_\alpha^{(1)b}(z|\frac{1}{\bar{P}^2g_{\beta\nu}+2i\bar{G}_{\beta\nu}}|y)^{cn} \\ &+ f^{abc}\int dz(x|\frac{1}{\bar{P}^2g_{\mu\beta}+2i\bar{G}_{\mu\beta}}|z)^{mc}A_\alpha^{(1)b}(z)(x|\bar{P}_\alpha\frac{1}{\bar{P}^2g_{\beta\nu}+2i\bar{G}_{\beta\nu}}-\bar{P}_\beta\frac{1}{\bar{P}^2g_{\alpha\nu}+2i\bar{G}_{\alpha\nu}}|z)^{an} \end{aligned} \quad (151)$$

$$\begin{aligned}
&= - \int dz (x | \frac{1}{\bar{P}^2 g_{\mu\alpha} + 2i\bar{G}_{\mu\alpha}} | z)^{mb} (\bar{D}_\alpha A_\beta^{(1)} - \bar{D}_\beta A_\alpha^{(1)})^{bc} (z | \frac{1}{\bar{P}^2 g_{\beta\nu} + 2i\bar{G}_{\beta\nu}} | y)^{cn} \\
&+ i \int dz (x | \frac{1}{\bar{P}^2 g_{\mu\beta} + 2i\bar{G}_{\mu\beta}} \bar{P}_\alpha - \frac{1}{\bar{P}^2 g_{\mu\alpha} + 2i\bar{G}_{\mu\alpha}} \bar{P}_\beta | z)^{ma} A_\alpha^{(1)ac} (z) (z | \frac{1}{\bar{P}^2 g_{\beta\nu} + 2i\bar{G}_{\beta\nu}} | y)^{cn} \\
&+ i \int dz (x | \frac{1}{\bar{P}^2 g_{\mu\beta} + 2i\bar{G}_{\mu\beta}} | z)^{mc} A_\alpha^{(1)ca} (z) (x | \bar{P}_\alpha \frac{1}{\bar{P}^2 g_{\beta\nu} + 2i\bar{G}_{\beta\nu}} - \bar{P}_\beta \frac{1}{\bar{P}^2 g_{\alpha\nu} + 2i\bar{G}_{\alpha\nu}} | z)^{an} \\
&= i \int dz (x | \frac{1}{\bar{P}^2 g_{\mu\alpha} + 2i\bar{G}_{\mu\alpha}} [\{\bar{P}_\xi, A^{(1)\xi}\} g_{\alpha\beta} + 2i(\bar{D}_\alpha A_\beta^{(1)} - \bar{D}_\beta A_\alpha^{(1)})] \frac{1}{\bar{P}^2 g_{\beta\nu} + 2i\bar{G}_{\beta\nu}} | y)^{mn} \\
&- i \int dz (x | \frac{1}{\bar{P}^2 g_{\mu\alpha} + 2i\bar{G}_{\mu\alpha}} A_\alpha^{(1)} \bar{P}_\beta \frac{1}{\bar{P}^2 g_{\beta\nu} + 2i\bar{G}_{\beta\nu}} | y)^{mn} - i \int dz (x | \frac{1}{\bar{P}^2 g_{\mu\beta} + 2i\bar{G}_{\mu\beta}} \bar{P}_\beta A_\alpha^{(1)} \frac{1}{\bar{P}^2 g_{\alpha\nu} + 2i\bar{G}_{\alpha\nu}} | z)^{mn} \quad (152)
\end{aligned}$$

## VII. CHOBA

### ΠΡΟΔΥΕΜ

$$\begin{aligned}
\frac{1}{2}(\bar{D}^\mu - iX^\mu)^{ma} A_\mu^a (\bar{D}^\nu - iX^\nu)^{mb} A_\nu^b &= \frac{1}{2}(\bar{D}^\mu A_\mu)^a (\bar{D}^\nu A_\nu)^a + f^{abc} (\bar{D}^\xi A_\xi)^a X_\eta^b A^{c\eta} + \frac{1}{2} A_\mu^a (X^\mu X^\nu)^{ab} A_\nu^b \\
&= \frac{1}{2}(\bar{D}^\mu A_\mu)^a (\bar{D}^\nu A_\nu)^a - i(\bar{D}^\xi A_\xi)^a X_\eta^b A^{b\eta} + \frac{1}{2} A_\mu^a (X^\mu X^\nu)^{ab} A_\nu^b \quad (153)
\end{aligned}$$

$$\Box_{\mu\nu}^{ab} = \bar{P}^2 g_{\mu\nu} + 2i\bar{G}_{\mu\nu} + \bar{P}_\mu X_\nu + X_\mu \bar{P}_\nu + X_\mu X_\nu \Leftrightarrow \bar{P}^2 g_{\mu\nu} + 2i\bar{G}_{\mu\nu} + 2X_\mu \bar{P}_\nu + X_\mu X_\nu \quad (154)$$

bikoz

$$\int dz A^{a\mu} \bar{P}_\mu^{aa'} X_\nu^{a'b} A^{b\nu}(z) = \int dz A^{b\nu} X_\nu^{ba'} \bar{P}_\mu^{a'a} A^{a\mu}(z) = \int dz A^{a\mu} X_\mu^{aa'} \bar{P}_\nu^{a'b} A^{b\nu}(z)$$

$$\begin{aligned}
\bar{C}_\mu^m(x) &= \int DA A_\mu^m(x) e^{i \int d^2z (-\frac{1}{4}[G_{\mu\nu}^a(A+\bar{A})]^2 - \frac{1}{2}[(\bar{D}_\mu - i\bar{C}_\mu)A^\mu]^2)} \\
&= \int DA A_\mu^m(x) e^{i \int d^2z (-\frac{1}{4}\bar{G}^{\alpha\mu\nu} \bar{G}_{\mu\nu}^\alpha - \frac{1}{2}A^{\alpha\alpha} \Box_{\alpha\beta} A^{\beta b} + A_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha A^{\alpha\beta} A_\alpha^b A_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} A^{\alpha\alpha} A^{b\beta} A_\alpha^c A_\beta^d)} \\
&\stackrel{A \rightarrow A+\bar{C}}{=} \int DA [A_\mu^m(x) + \bar{C}_\mu^m(x)] e^{i \int d^2z (-\frac{1}{4}\bar{G}^{\alpha\mu\nu} \bar{G}_{\mu\nu}^\alpha - \frac{1}{2}\bar{C}^{\alpha\alpha} \Box_{\alpha\beta} \bar{C}^{\beta b} + \bar{C}_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha \bar{C}^{\alpha\beta} \bar{C}_\alpha^b \bar{C}_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} \bar{C}^{\alpha\alpha} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d)} \\
&\times \exp i \int dz \left\{ A^{\alpha\alpha} \left( -\Box_{\alpha\beta}^{ab} \bar{C}^{b\beta} + (\bar{D}\bar{G})_\alpha^a + f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} - \bar{C}_\alpha^b \bar{D}^\beta \bar{C}_\beta^c) - f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \right) \right. \\
&+ \frac{1}{2} A^{\alpha\alpha} \left( -\Box_{\alpha\beta} - 2i(\bar{D}_\alpha \bar{C}_\beta) + 2\bar{C}_\beta \bar{P}_\alpha - 2g_{\alpha\beta} (\bar{C}^\xi \bar{P}_\xi) - g_{\alpha\beta} \bar{C}_\xi \bar{C}^\xi + \bar{C}_\beta \bar{C}_\alpha - [\bar{C}_\alpha, \bar{C}_\beta] \right) A^{b\beta} \\
&\left. - g f^{abc} (\bar{D}_\alpha - i\bar{C}_\alpha)^{aa'} A_\beta^{a'} A^{c\alpha} A^{d\beta} - \frac{g^2}{4} f^{abm} f^{cdm} A^{\alpha\alpha} A^{b\beta} A_\alpha^c A_\beta^d \right\} \quad (155)
\end{aligned}$$

### ΗΑΪΔΕΜ UKC

$$\begin{aligned}
&\frac{1}{2} A^{\alpha\alpha} \left( -\Box_{\alpha\beta} - 2i(\bar{D}_\alpha \bar{C}_\beta) + 2\bar{C}_\beta \bar{P}_\alpha - 2g_{\alpha\beta} (\bar{C}^\xi \bar{P}_\xi) - g_{\alpha\beta} \bar{C}_\xi \bar{C}^\xi + \bar{C}_\beta \bar{C}_\alpha - [\bar{C}_\alpha, \bar{C}_\beta] \right)^{ab} A^{b\beta} \quad (156) \\
&= \frac{1}{2} A^{\alpha\alpha} \left( -\bar{P}^2 g_{\alpha\beta} - 2i\bar{G}_{\alpha\beta} - 2X_\alpha \bar{P}_\beta - X_\alpha X_\beta - 2i\bar{D}_\alpha \bar{C}_\beta + 2\bar{C}_\beta \bar{P}_\alpha - 2g_{\alpha\beta} (\bar{C}^\xi \bar{P}_\xi) - g_{\alpha\beta} \bar{C}_\xi \bar{C}^\xi + \bar{C}_\beta \bar{C}_\alpha - [\bar{C}_\alpha, \bar{C}_\beta] \right)^{ab} A^{b\beta} \\
&= \frac{1}{2} A^{\alpha\alpha} \left( -(\bar{P} + \bar{C})^2 g_{\alpha\beta} - 2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha \bar{C}_\beta - \bar{D}_\beta \bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta]) + \bar{C}_\alpha \bar{C}_\beta - 2[\bar{P}_\beta, \bar{C}_\alpha] + 2\bar{C}_\beta \bar{P}_\alpha - 2X_\alpha \bar{P}_\beta - X_\alpha X_\beta \right)^{ab} A^{b\beta} \\
&= \frac{1}{2} A^{\alpha\alpha} \left( -(\bar{P} + \bar{C})^2 g_{\alpha\beta} - 2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha \bar{C}_\beta - \bar{D}_\beta \bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta]) \right)^{ab} A^{b\beta}
\end{aligned}$$

ΠΡΟ ΥΛΟΘΕΤΟΥΜΕΝΟ  $X_\mu = \bar{C}_\mu$  az ekspekted.

UTAK, the gauge-fixing term is

$$\begin{aligned}
\frac{1}{2}(\bar{D}^\mu - i\bar{C}^\mu)^{ma} A_\mu^a (\bar{D}^\nu - i\bar{C}^\nu)^{mb} A_\nu^b &= \frac{1}{2}(\bar{D}^\mu A_\mu)^a (\bar{D}^\nu A_\nu)^a + f^{abc} (\bar{D}^\xi A_\xi)^a \bar{C}_\eta^b A^{c\eta} + \frac{1}{2} A_\mu^a (\bar{C}^\mu \bar{C}^\nu)^{ab} A_\nu^b \\
&= \frac{1}{2}(\bar{D}^\mu A_\mu)^a (\bar{D}^\nu A_\nu)^a - i(\bar{D}^\xi A_\xi)^a \bar{C}_\eta^b A^{b\eta} + \frac{1}{2} A_\mu^a (\bar{C}^\mu \bar{C}^\nu)^{ab} A_\nu^b \quad (157)
\end{aligned}$$

SO

$$\square_{\mu\nu}^{ab} = \bar{P}^2 g_{\mu\nu} + 2i\bar{G}_{\mu\nu} + \bar{P}_\mu \bar{C}_\nu + \bar{C}_\mu \bar{P}_\nu + \bar{C}_\mu \bar{C}_\nu \quad (158)$$

$$\begin{aligned} \bar{C}_\mu^m(x) &= \int DA A_\mu^m(x) e^{i\int d^2z \left( -\frac{1}{4}[G_{\mu\nu}^a(A+\bar{A})]^2 - \frac{1}{2}[(\bar{D}_\mu - i\bar{C}_\mu)A^\mu]^2 \right)} \\ &= \int DA A_\mu^m(x) e^{i\int d^2z \left( -\frac{1}{4}\bar{G}^{a\mu\nu}\bar{G}_{\mu\nu}^a - \frac{1}{2}A^{\alpha a}\square_{\alpha\beta}^{ab}A^{\beta b} + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} A^{\alpha a} A^{b\beta} A_\alpha^c A_\beta^d \right)} \\ &\stackrel{A \rightarrow A+\bar{C}}{=} \int DA [A_\mu^m(x) + \bar{C}_\mu^m(x)] e^{i\int d^2z \left( -\frac{1}{4}\bar{G}^{a\mu\nu}\bar{G}_{\mu\nu}^a - \frac{1}{2}\bar{C}^{\alpha a}(\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{\beta b} + \bar{C}_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha \bar{C}^{a\beta} \bar{C}_\alpha^b \bar{C}_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} \bar{C}^{\alpha a} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \right)} \\ &\times \exp i \int dz \left\{ A^{\alpha a} \left( -(\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab} \bar{C}^{b\beta} + (\bar{D}\bar{G})_\alpha^a + f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \right) \right. \\ &- \frac{1}{2} A^{\alpha a} \left( (\bar{P} + \bar{C})^2 g_{\alpha\beta} + 2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha \bar{C}_\beta - \bar{D}_\beta \bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta]) \right)^{ab} A^{b\beta} \\ &\left. - g f^{abc} (\bar{D}_\alpha - i\bar{C}_\alpha)^{aa'} A_{\beta'}^{a'} A^{\alpha c} A^{d\beta} - \frac{g^2}{4} f^{abm} f^{cdm} A^{\alpha a} A^{b\beta} A_\alpha^c A_\beta^d \right\} \quad (159) \end{aligned}$$

UMEEM YP-E HA  $\bar{C}_\mu$  B BUDE

$$(\bar{P}^2 g_{\alpha\beta} + 2ig\bar{G}_{\alpha\beta})^{ab} \bar{C}^{b\beta} = \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \quad (160)$$

B КОМПОНЕНТАХ

$$\begin{aligned} 2(\bar{P}_\bullet \bar{P}_\bullet)^{ab} \bar{C}_\bullet^b &= \bar{D}_\bullet^{ab} \bar{G}_\bullet^b + i\bar{C}_\bullet^{ab} \bar{C}_\bullet^b + g\bar{D}_\bullet^{aa'} (f^{a'bc} \bar{C}_\bullet^b \bar{C}_\bullet^c) + 2g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_\bullet^c \bar{C}_\bullet^d \\ 2(\bar{P}_\bullet \bar{P}_\bullet)^{ab} \bar{C}_\bullet^b &= -\bar{D}_\bullet^{ab} \bar{G}_\bullet^b - i\bar{C}_\bullet^{ab} \bar{C}_\bullet^b - g\bar{D}_\bullet^{aa'} (f^{a'bc} \bar{C}_\bullet^b \bar{C}_\bullet^c) + 2g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_\bullet^c \bar{C}_\bullet^d \quad (161) \end{aligned}$$

ПЕРЕПИШЕМ НА  $\delta YDUUEE$ 

$$\begin{aligned} 2(\bar{P}_\bullet \bar{P}_\bullet)^{ab} \bar{C}_\bullet^b &= \bar{D}_\bullet^{ab} \bar{G}_\bullet^b + i\bar{C}_\bullet^{ab} \bar{C}_\bullet^b + g\bar{D}_\bullet^{aa'} (f^{a'bc} \bar{C}_\bullet^b \bar{C}_\bullet^c) + 2g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_\bullet^c \bar{C}_\bullet^d \\ \Rightarrow (\bar{P}_\bullet \bar{P}_\bullet + \bar{P}_\bullet \bar{P}_\bullet)^{ab} \bar{C}_\bullet^b &= \bar{D}_\bullet^{ab} \bar{G}_\bullet^b + 2i\bar{C}_\bullet^{ab} \bar{C}_\bullet^b + g f^{abc} \bar{D}_\bullet \bar{C}_\bullet^c + g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c + 2g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_\bullet^c \bar{C}_\bullet^d \\ \Rightarrow (\mathcal{P}_\bullet \bar{P}_\bullet + \mathcal{P}_\bullet \bar{P}_\bullet)^{ab} \bar{C}_\bullet^b &= -f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c - f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c + \bar{D}_\bullet^{ab} \bar{G}_\bullet^b + 2i\bar{C}_\bullet^{ab} \bar{C}_\bullet^b - g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c + g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c + 2g f^{abc} \bar{C}_\bullet^b \bar{D}_\bullet \bar{C}_\bullet^c - g^2 f^{abm} f^{klc} \bar{C}_\bullet^b \bar{C}_\bullet^k \bar{C}_\bullet^l \\ &= \bar{D}_\bullet^{ab} \bar{G}_\bullet^b - 2i\bar{C}_\bullet^{ab} \bar{G}_\bullet^b + g f^{abc} \bar{C}_\bullet^b (\bar{D}_\bullet \bar{C}_\bullet^c - \bar{D}_\bullet \bar{C}_\bullet^c - f^{ckl} \bar{C}_\bullet^k \bar{C}_\bullet^l) = \bar{D}_\bullet^{ab} \bar{G}_\bullet^b - i\bar{C}_\bullet^{ab} \bar{G}_\bullet^b = \mathcal{D}_\bullet^{ab} \bar{G}_\bullet^b \quad (162) \end{aligned}$$

where  $\mathcal{A}_\bullet \equiv \bar{A}_\bullet + \bar{C}_\bullet$ ,  $\mathcal{P}_\bullet = \bar{P}_\bullet + \bar{C}_\bullet$  and similarly for  $\ast$ HADO expand do  $\bar{G}_\bullet^3$ . ПАЗδUBAEM  $\bar{C} = \bar{C}_1 + \bar{C}_2 + \bar{C}_3$ ΦΟΡΜΥΛΑ:  $\bar{P}_\bullet \frac{1}{\bar{P}_\bullet \bar{P}_\bullet \pm i\epsilon} \bar{P}_\bullet = \bar{P}_\bullet \frac{1}{\bar{P}_\bullet \bar{P}_\bullet \pm i\epsilon} \bar{P}_\bullet = 1$  (ΠΡΟ ΛΙΟΔΟΜ ΟΔΧΟΔΕ ΣΙΝΓΥΛΛΑΡΗΟΤΗ).)

$$\begin{aligned} \bar{C}_\bullet^1 &= -\frac{i}{2\bar{P}_\bullet \bar{P}_\bullet} \bar{P}_\bullet \bar{G}_\bullet^* \Leftrightarrow \bar{C}_\bullet^{1a}(x) = -\frac{i}{2} \int d^2z (x | \frac{1}{\bar{P}_\bullet \bar{P}_\bullet} \bar{P}_\bullet | z)^{ab} \bar{G}_\bullet^b(z) \Rightarrow \bar{D}_\bullet \bar{C}_\bullet^1 = -\frac{1}{2} \bar{G}_\bullet^* \\ \bar{C}_\bullet^1 &= \frac{i}{2\bar{P}_\bullet \bar{P}_\bullet} \bar{P}_\bullet \bar{G}_\bullet^* \Leftrightarrow \bar{C}_\bullet^{1a}(x) = \frac{i}{2} \int d^2z (x | \frac{1}{\bar{P}_\bullet \bar{P}_\bullet} \bar{P}_\bullet | z)^{ab} \bar{G}_\bullet^b(z) \Rightarrow \bar{D}_\bullet \bar{C}_\bullet^1 = \frac{1}{2} \bar{G}_\bullet^* \quad (163) \end{aligned}$$

$$\begin{aligned} (x | \frac{1}{\bar{P}_\bullet \bar{P}_\bullet + i\epsilon p_\bullet} \bar{P}_\bullet | z) &= (x | \frac{1}{\bar{P}_\bullet + i\epsilon} | z) = -i\delta(x_\bullet - z_\bullet) \theta(x_\bullet - z_\bullet) [x_\bullet, z_\bullet]^{\bar{A}_\bullet} \\ (x | \frac{1}{\bar{P}_\bullet \bar{P}_\bullet + i\epsilon p_\bullet} \bar{P}_\bullet | z) &= (x | \frac{1}{\bar{P}_\bullet + i\epsilon} | z) = -i\delta(x_\bullet - z_\bullet) \theta(x_\bullet - z_\bullet) [x_\bullet, z_\bullet]^{\bar{A}_\bullet} \quad (164) \end{aligned}$$

ЕСЛИ  $\bar{A}_\bullet(x_\bullet) \rightarrow 0$  ПРИ  $x_\bullet \rightarrow \pm\infty$ , ТО

$$\begin{aligned} \bar{C}_\bullet^{(1)}(x) &= -\frac{i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet [x_\bullet, z_\bullet]^{A_\bullet} [\bar{A}_\bullet(x_\bullet), \bar{A}_\bullet(z_\bullet)] [z_\bullet, x_\bullet]^{A_\bullet} \Rightarrow \bar{C}_\bullet^{(1)}(x_\bullet, x_\bullet = \pm\infty) = \bar{C}_\bullet^{(1)}(x_\bullet = -\infty, x_\bullet) = 0 \\ \bar{C}_\bullet^{(1)}(x) &= \frac{i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet [x_\bullet, z_\bullet]^{A_\bullet} [\bar{A}_\bullet(z_\bullet), \bar{A}_\bullet(x_\bullet)] [z_\bullet, x_\bullet]^{A_\bullet} \Rightarrow \bar{C}_\bullet^{(1)}(x_\bullet, x_\bullet = \pm\infty) = \bar{C}_\bullet^{(1)}(x_\bullet = -\infty, x_\bullet) = 0 \quad (165) \end{aligned}$$

АНАЛОГУНО,  $\bar{C}_\bullet^{(1)}(x_\bullet = -\infty, x_\bullet) = \bar{C}_\bullet^{(1)}(x_\bullet = \pm\infty, x_\bullet) = 0$

$$\begin{aligned}
2(\bar{P}_* \bar{P}_*)^{ab} \bar{C}_*^{(2)b} &= i\bar{G}_{**}^{ab} \bar{C}_*^{(1)b} + g\bar{D}_*^{aa'} (f^{a'bc} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c}) - g f^{abc} \bar{C}_*^{(1)b} \bar{G}_{**}^c \Rightarrow \bar{C}_*^{(2)a} = -\frac{i}{2} \left( \frac{1}{\bar{P}_* \bar{P}_*} \bar{P}_* \right)^{aa'} f^{a'bc} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \\
2(\bar{P}_* \bar{P}_*)^{ab} \bar{C}_*^{(2)b} &= -i\bar{G}_{**}^{ab} \bar{C}_*^{(2)b} - g\bar{D}_*^{aa'} (f^{a'bc} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c}) + g f^{abc} \bar{C}_*^{(1)b} \bar{G}_{**}^c \Rightarrow \bar{C}_*^{(2)a} = \frac{i}{2} \left( \frac{1}{\bar{P}_* \bar{P}_*} \bar{P}_* \right)^{aa'} f^{a'bc} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \quad (166)
\end{aligned}$$

$$G_{**}^a (\bar{A} + \bar{C}^{(1)} + \bar{C}^{(2)}) = \bar{G}_{**}^a + (\bar{D}_* \bar{C}_*^{(1)} - \bar{D}_* \bar{C}_*^{(1)})^a + (\bar{D}_* \bar{C}_*^{(2)} - \bar{D}_* \bar{C}_*^{(2)})^a + f^{abc} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} = 0 \quad (167)$$

HAM HADO EUĬ

$$\bar{D}_* \bar{C}_*^{(2)a} = -\frac{1}{2} f^{abc} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c}, \quad \bar{D}_* \bar{C}_*^{(2)a} = \frac{1}{2} f^{abc} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \quad (168)$$

Similarly to Eq. (165)  $\bar{C}_*^{(2)}(x_* = -\infty, x_*) = \bar{C}_*^{(2)}(x_*, x_* = -\infty) = 0$

ТРЕТУЇ ПОРАДОК

$$\begin{aligned}
2(\bar{P}_* \bar{P}_*)^{ab} \bar{C}_*^{(3)b} &= i\bar{G}_{**}^{ab} \bar{C}_*^{(2)b} + g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) + 2g f^{abc} \bar{C}_*^{(1)b} \bar{D}_* \bar{C}_*^{(2)c} + 2g f^{abc} \bar{C}_*^{(2)b} \bar{D}_* \bar{C}_*^{(1)c} - g^2 f^{abm} f^{cdm} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \bar{C}_*^{(1)d} \\
&= g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) + 2g f^{abc} \bar{C}_*^{(1)b} \bar{D}_* \bar{C}_*^{(2)c} - g^2 f^{abm} f^{cdm} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \bar{C}_*^{(1)d} = g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) \\
\Rightarrow \bar{C}_*^{(3)a} &= -\frac{i}{2} \left( \frac{1}{\bar{P}_* \bar{P}_*} \bar{P}_* \right)^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) \quad (169)
\end{aligned}$$

Similarly

$$\begin{aligned}
2(\bar{P}_* \bar{P}_*)^{ab} \bar{C}_*^{(3)b} &= -i\bar{G}_{**}^{ab} \bar{C}_*^{(2)b} - g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) + 2g f^{abc} \bar{C}_*^{(1)b} \bar{D}_* \bar{C}_*^{(2)c} + 2g f^{abc} \bar{C}_*^{(2)b} \bar{D}_* \bar{C}_*^{(1)c} - g^2 f^{abm} f^{cdm} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \bar{C}_*^{(1)d} \\
&= -g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) + 2g f^{abc} \bar{C}_*^{(1)b} \bar{D}_* \bar{C}_*^{(2)c} - g^2 f^{abm} f^{cdm} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \bar{C}_*^{(1)d} = -g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) \\
\Rightarrow \bar{C}_*^{(3)a} &= \frac{i}{2} \left( \frac{1}{\bar{P}_* \bar{P}_*} \bar{P}_* \right)^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) \quad (170)
\end{aligned}$$

HAM SYDET HADO

$$\bar{D}_* \bar{C}_*^{(3)a} = -\frac{1}{2} f^{abc} (\bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) \quad (171)$$

Again,  $\bar{C}_*^{(3)}(x_* = \pm\infty, x_*) = \bar{C}_*^{(3)}(x_*, x_* = \pm\infty) = 0 \Rightarrow \bar{C}_*(x_* = \pm\infty, x_*) = \bar{C}_*(x_*, x_* = \pm\infty) = 0$

$$\Rightarrow (\bar{A} + \bar{C})_*(x_*, x_* = -\infty) = \bar{A}_*(x_*), \quad (\bar{A} + \bar{C})_*(x_* = -\infty, x_*) = \bar{A}_*(x_*) \quad (172)$$

ΦΟΡΜΥΛΑ:

$$\frac{1}{2} \bar{G}_{**}^a + \bar{D}_* \bar{C}_*^{(1)a} + \bar{D}_* \bar{C}_*^{(2)a} + \bar{D}_* \bar{C}_*^{(3)a} + \frac{1}{2} f^{abc} (\bar{C}_*^{(1)b} \bar{C}_*^{(1)c} + \bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) = 0$$

И ПОЭТОМУ

$$\begin{aligned}
F_{**}^a (\bar{A} + \bar{C}^{(1)} + \bar{C}^{(2)} + \bar{C}^{(3)}) &= \bar{G}_{**}^a + (\bar{D}_* \bar{C}_*^{(1)} - \bar{D}_* \bar{C}_*^{(1)})^a + (\bar{D}_* \bar{C}_*^{(2)} - \bar{D}_* \bar{C}_*^{(2)})^a + (\bar{D}_* \bar{C}_*^{(3)} - \bar{D}_* \bar{C}_*^{(3)})^a + f^{abc} (\bar{C}_*^{(1)b} \bar{C}_*^{(1)c} + \bar{C}_*^{(1)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(1)c}) = 0 \quad (173)
\end{aligned}$$

ΗΑΔΛΥΔΕΗΕ

$$\bar{D}_* \bar{C}_*^{(i)} + \bar{D}_* \bar{C}_*^{(i)} = 0 \Leftrightarrow (i\partial_\mu + [\bar{A}_\mu, ) \bar{C}^\mu = (i\partial_\mu + [\bar{A}_\mu, + [\bar{C}_\mu, ) \bar{C}^\mu = 0 \quad (174)$$

4Ў ПОРАДОК (see Eqs. (167) and (171))

$$\begin{aligned}
2(\bar{P}_* \bar{P}_*)^{ab} \bar{C}_*^{(4)b} &= i\bar{G}_{**}^{ab} \bar{C}_*^{(3)b} + g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(3)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(3)b} \bar{C}_*^{(1)c}) + 2g f^{abc} \bar{C}_*^{(1)b} \bar{D}_* \bar{C}_*^{(3)c} + 2g f^{abc} \bar{C}_*^{(2)b} \bar{D}_* \bar{C}_*^{(2)c} + 2g f^{abc} \bar{C}_*^{(3)b} \bar{D}_* \bar{C}_*^{(1)c} \\
&- g^2 f^{abm} f^{cdm} \bar{C}_*^{(2)b} \bar{C}_*^{(1)c} \bar{C}_*^{(1)d} - g^2 f^{abm} f^{cdm} \bar{C}_*^{(1)b} \bar{C}_*^{(2)c} \bar{C}_*^{(1)d} - g^2 f^{abm} f^{cdm} \bar{C}_*^{(1)b} \bar{C}_*^{(1)c} \bar{C}_*^{(2)d} \\
&= g\bar{D}_*^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(3)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(3)b} \bar{C}_*^{(1)c}) \\
\Rightarrow \bar{C}_*^{(4)a} &= -\frac{i}{2} \left( \frac{1}{\bar{P}_* \bar{P}_*} \bar{P}_* \right)^{aa'} f^{a'bc} (\bar{C}_*^{(1)b} \bar{C}_*^{(3)c} + \bar{C}_*^{(2)b} \bar{C}_*^{(2)c} + \bar{C}_*^{(3)b} \bar{C}_*^{(1)c}) \quad (175)
\end{aligned}$$



$$\Rightarrow \bar{D}_* \bar{C}_\bullet^{(4)} = -\frac{1}{2} f^{abc} (\bar{C}_*^{(1)b} \bar{C}_\bullet^{(3)c} + \bar{C}_*^{(2)b} \bar{C}_\bullet^{(2)c} + \bar{C}_*^{(3)b} \bar{C}_\bullet^{(1)c}), \quad \bar{D}_\bullet \bar{C}_*^{(4)} = \frac{1}{2} f^{abc} (\bar{C}_*^{(1)b} \bar{C}_\bullet^{(3)c} + \bar{C}_*^{(2)b} \bar{C}_\bullet^{(2)c} + \bar{C}_*^{(3)b} \bar{C}_\bullet^{(1)c}) \quad (176)$$

U II $\Rightarrow$ TOMY

$$F_{*\bullet}^a (\bar{A} + \bar{C}^{(1)} + \bar{C}^{(2)} + \bar{C}^{(3)} + \bar{C}^{(4)}) \quad (177)$$

$$= \bar{C}_{*\bullet}^a + (\bar{D}_* \bar{C}_\bullet^{(1)} - \bar{D}_\bullet \bar{C}_*^{(1)})^a + (\bar{D}_* \bar{C}_\bullet^{(2)} - \bar{D}_\bullet \bar{C}_*^{(2)})^a + (\bar{D}_* \bar{C}_\bullet^{(3)} - \bar{D}_\bullet \bar{C}_*^{(3)})^a + (\bar{D}_* \bar{C}_\bullet^{(4)} - \bar{D}_\bullet \bar{C}_*^{(4)})^a \\ + f^{abc} (\bar{C}_*^{(1)b} \bar{C}_\bullet^{(1)c} + \bar{C}_*^{(1)b} \bar{C}_\bullet^{(2)c} + \bar{C}_*^{(2)b} \bar{C}_\bullet^{(1)c} + \bar{C}_*^{(1)b} \bar{C}_\bullet^{(3)c} + \bar{C}_*^{(2)b} \bar{C}_\bullet^{(2)c} + \bar{C}_*^{(3)b} \bar{C}_\bullet^{(1)c}) = 0 \quad (178)$$

and

$$\bar{D}_* \bar{C}_\bullet = \frac{i}{2} [\bar{C}_*, \bar{C}_\bullet] - \frac{1}{2} \bar{G}_{*\bullet} = -\bar{D}_\bullet \bar{C}_* \quad (179)$$

NB: we never used any assumptions on  $\bar{A}_\bullet$  and  $\bar{A}_*$

### VIII. $\Omega$

Here  $\bar{A}_\bullet(z_*)$  and  $\bar{A}_*(z_\bullet)$

#### 1. $\Omega$ do $\bar{A}^3$

$$\Omega(x_*, x_\bullet) = 1 + i \int_{-\infty}^{x_*} d_{-s}^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d_{-s}^2 x'_* d_{-s}^2 x''_* \theta(x' - x'')_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) + i \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet \bar{A}_*(x'_\bullet) \\ - \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet d_{-s}^2 x''_\bullet \theta(x' - x'')_\bullet \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d_{-s}^2 x'_* \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \quad (180)$$

$$\Omega^\dagger(x_*, x_\bullet) = 1 - i \int_{-\infty}^{x_*} d_{-s}^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d_{-s}^2 x'_* d_{-s}^2 x''_* \theta(x' - x'')_* \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*) - i \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet \bar{A}_*(x'_\bullet) \\ - \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet d_{-s}^2 x''_\bullet \theta(x' - x'')_\bullet \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d_{-s}^2 x'_* \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \quad (181)$$

Trivial chek:

$$\Omega^\dagger(x_*, x_\bullet) \Omega(x_*, x_\bullet) = \left[ 1 - i \int_{-\infty}^{x_*} d_{-s}^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d_{-s}^2 x'_* d_{-s}^2 x''_* \theta(x' - x'')_* \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*) - i \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet \bar{A}_*(x'_\bullet) \right. \\ \left. - \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet d_{-s}^2 x''_\bullet \theta(x' - x'')_\bullet \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d_{-s}^2 x'_* \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \right] \\ \times \left[ 1 + i \int_{-\infty}^{x_*} d_{-s}^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d_{-s}^2 x'_* d_{-s}^2 x''_* \theta(x' - x'')_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) + i \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet \bar{A}_*(x'_\bullet) \right. \\ \left. - \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet d_{-s}^2 x''_\bullet \theta(x' - x'')_\bullet \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d_{-s}^2 x'_* \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \right] = 1 \quad (182)$$

Non-trivial chek:

$$i \partial_\bullet \Omega^\dagger(x_*, x_\bullet) = \bar{A}_\bullet(x_*) - i \int_{-\infty}^{x_*} d_{-s}^2 x'_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) - \frac{i}{2} \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet (\bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*)) \\ \Rightarrow \Omega i \partial_\bullet \Omega^\dagger(x_*, x_\bullet) = \left[ 1 + i \int_{-\infty}^{x_*} d_{-s}^2 x'_* \bar{A}_\bullet(x'_*) + i \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet \bar{A}_*(x'_\bullet) \right] \\ \times \left[ \bar{A}_\bullet(x_*) - i \int_{-\infty}^{x_*} d_{-s}^2 x'_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) - \frac{i}{2} \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet (\bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*)) \right] \\ = \bar{A}_\bullet(x_*) - \frac{i}{2} \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet [\bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet)] \Rightarrow (\Omega i \partial_\bullet \Omega^\dagger)^a(x_*, x_\bullet) = \bar{A}_\bullet^a(x_*) - \frac{1}{2} f^{abc} \int_{-\infty}^{x_\bullet} d_{-s}^2 x'_\bullet \bar{A}_*^b(x'_\bullet) \bar{A}_\bullet^c(x_*) \quad (183)$$

which agrees with Eq. (146)

$$\delta\omega = -\frac{1}{2}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\bar{A}_\bullet(x'_*)\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\bar{A}_\bullet(x'_*)) = -\frac{1}{s}\int d^2z \theta(x_* - z_*)\theta(x_\bullet - z_\bullet)\{\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)\} \quad (184)$$

Next step

$$\begin{aligned} & \Omega^\dagger(x_*, x_\bullet)\Omega(x_*, x_\bullet) \\ & \supseteq \frac{i}{2}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* \bar{A}_\bullet(x'_*) (\bar{A}_\bullet(x''_*)\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\bar{A}_\bullet(x''_*)) \\ & - \frac{i}{2}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\bar{A}_\bullet(x'_*)\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\bar{A}_\bullet(x'_*)) \bar{A}_\bullet(x''_*) \\ & - i\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{x'_*}^{x_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) \bar{A}_*(x'_*) + i\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \bar{A}_*(x'_*) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) \\ & = \frac{i}{2}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* ([\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)]\bar{A}_*(x'_*) + \bar{A}_*(x'_*)[\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)]) \end{aligned} \quad (185)$$

Guess

$$\begin{aligned} \Omega(x_*, x_\bullet) & = 1 + i\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d\frac{2}{s}x'_* d\frac{2}{s}x''_* \theta(x' - x'')_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) + i\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \bar{A}_*(x'_*) \\ & - \int_{-\infty}^{x_*} d\frac{2}{s}x'_* d\frac{2}{s}x''_* \theta(x' - x'')_\bullet \bar{A}_*(x'_*) \bar{A}_*(x''_*) - \frac{1}{2}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\bar{A}_\bullet(x'_*)\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\bar{A}_\bullet(x'_*)) \\ & - \frac{i}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* ([\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)]\bar{A}_*(x'_*) + \bar{A}_*(x'_*)[\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)]) \\ & - \frac{i}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* ([\bar{A}_*(x'_*), \bar{A}_*(x''_*)]\bar{A}_*(x'_*) + \bar{A}_*(x'_*)[\bar{A}_*(x'_*), \bar{A}_*(x''_*)]) + ? \end{aligned} \quad (186)$$

$$\begin{aligned} \Omega^\dagger(x_*, x_\bullet) & = 1 - i\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d\frac{2}{s}x'_* d\frac{2}{s}x''_* \theta(x' - x'')_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) - i\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \bar{A}_*(x'_*) \\ & - \int_{-\infty}^{x_*} d\frac{2}{s}x'_* d\frac{2}{s}x''_* \theta(x' - x'')_\bullet \bar{A}_*(x'_*) \bar{A}_*(x''_*) - \frac{1}{2}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\bar{A}_\bullet(x'_*)\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\bar{A}_\bullet(x'_*)) \\ & - \frac{i}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* ([\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)]\bar{A}_*(x'_*) + \bar{A}_*(x'_*)[\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)]) \\ & - \frac{i}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* ([\bar{A}_*(x'_*), \bar{A}_*(x''_*)]\bar{A}_*(x'_*) + \bar{A}_*(x'_*)[\bar{A}_*(x'_*), \bar{A}_*(x''_*)]) \\ & + \frac{i}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\{\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)\}\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\{\bar{A}_\bullet(x'_*), \bar{A}_\bullet(x''_*)\}) \\ & + \frac{i}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\{\bar{A}_*(x'_*), \bar{A}_*(x''_*)\}\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\{\bar{A}_*(x'_*), \bar{A}_*(x''_*)\}) \end{aligned} \quad (187)$$

$$\begin{aligned} i\partial_\bullet\Omega^\dagger(x_*, x_\bullet) & = \bar{A}_\bullet(x_*) - i\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) - \frac{i}{2}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\bar{A}_\bullet(x_*)\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\bar{A}_\bullet(x_*)) \\ & + \frac{1}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* ([\bar{A}_\bullet(x_*), \bar{A}_\bullet(x'_*)]\bar{A}_*(x'_*) + \bar{A}_*(x'_*)[\bar{A}_\bullet(x_*), \bar{A}_\bullet(x'_*)]) \\ & + \frac{1}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* ([\bar{A}_*(x'_*), \bar{A}_*(x''_*)]\bar{A}_*(x_*) + \bar{A}_*(x_*)[\bar{A}_*(x'_*), \bar{A}_*(x''_*)]) \\ & - \frac{1}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x_*} d\frac{2}{s}x'_* (\{\bar{A}_\bullet(x_*), \bar{A}_\bullet(x'_*)\}\bar{A}_*(x'_*) + \bar{A}_*(x'_*)\{\bar{A}_\bullet(x_*), \bar{A}_\bullet(x'_*)\}) \\ & - \frac{1}{4}\int_{-\infty}^{x_*} d\frac{2}{s}x'_* \int_{-\infty}^{x'_*} d\frac{2}{s}x''_* (\{\bar{A}_*(x'_*), \bar{A}_*(x''_*)\}\bar{A}_*(x_*) + \bar{A}_*(x_*)\{\bar{A}_*(x'_*), \bar{A}_*(x''_*)\}) \end{aligned} \quad (188)$$

$$\begin{aligned}
\Omega(x_*, x_\bullet) i \partial_\bullet \Omega^\dagger(x_*, x_\bullet) &= \left[ 1 + i \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d \frac{2}{s} x'_* d \frac{2}{s} x''_* \theta(x' - x'') \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x'') + i \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \bar{A}_*(x'_\bullet) \right. \\
&- \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet d \frac{2}{s} x''_\bullet \theta(x' - x'') \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \\
&\times \left[ \bar{A}_\bullet(x_*) - i \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) - \frac{i}{2} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet (\bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*)) \right. \\
&+ \frac{1}{4} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet ([\bar{A}_\bullet(x_*), \bar{A}_\bullet(x'_*)] \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) [\bar{A}_\bullet(x_*), \bar{A}_\bullet(x'_*)]) \\
&+ \frac{1}{4} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \int_{-\infty}^{x_*} d \frac{2}{s} x''_* ([\bar{A}_*(x'_\bullet), \bar{A}_*(x''_*)] \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x_*) [\bar{A}_*(x'_\bullet), \bar{A}_*(x''_*)]) + X3 \left. \right] \\
&- \frac{1}{4} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet (\{\bar{A}_\bullet(x_*)\} \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \{\bar{A}_\bullet(x_*)\}) \\
&- \frac{1}{4} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \int_{-\infty}^{x_*} d \frac{2}{s} x''_* (\{\bar{A}_*(x'_\bullet)\} \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x_*) \{\bar{A}_*(x'_\bullet)\}) \quad (189) \\
&= \frac{1}{2} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \bar{A}_\bullet(x'_*) (\bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*)) + \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \int_{-\infty}^{x_*} d \frac{2}{s} x''_* \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \\
&+ \frac{1}{2} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \int_{-\infty}^{x_*} d \frac{2}{s} x''_* \bar{A}_*(x'_\bullet) (\bar{A}_\bullet(x_*) \bar{A}_*(x''_*) + \bar{A}_*(x''_*) \bar{A}_\bullet(x_*)) - \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet d \frac{2}{s} x''_* \theta(x' - x'') \bar{A}_*(x'_\bullet) \bar{A}_*(x''_*) \bar{A}_\bullet(x_*) \\
&- \frac{1}{2} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \bar{A}_\bullet(x_*) \\
&+ \frac{1}{4} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet ([\bar{A}_\bullet(x_*)\} \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) [\bar{A}_\bullet(x_*)\}) \\
&- \frac{1}{4} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet (\{\bar{A}_\bullet(x_*)\} \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \{\bar{A}_\bullet(x_*)\}) \\
&+ \frac{1}{4} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \int_{-\infty}^{x_*} d \frac{2}{s} x''_* ([\bar{A}_*(x'_\bullet)\} \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x_*) [\bar{A}_*(x'_\bullet)\}) \\
&- \frac{1}{4} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \int_{-\infty}^{x_*} d \frac{2}{s} x''_* (\{\bar{A}_*(x'_\bullet)\} \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x_*) \{\bar{A}_*(x'_\bullet)\}) \\
&= - \frac{1}{2} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet d \frac{2}{s} x''_* \theta(x' - x'') \bullet [\bar{A}_*(x'_\bullet), [\bar{A}_*(x''_\bullet), \bar{A}_\bullet(x_*)]] \quad \text{az it shud bi} \quad (190)
\end{aligned}$$

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$$\begin{aligned}
\Omega^\dagger(x_*, x_\bullet) &= 1 - i \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d \frac{2}{s} x'_* d \frac{2}{s} x''_* \theta(x' - x'') \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x'') - i \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet \bar{A}_*(x'_\bullet) \\
&- \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet d \frac{2}{s} x''_\bullet \theta(x' - x'') \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \\
&+ \frac{i}{2} \int_{-\infty}^{x_*} d \frac{2}{s} x'_* d \frac{2}{s} x''_* \theta(x' - x'') \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x'_*)) \\
&+ \frac{i}{2} \int_{-\infty}^{x_\bullet} d \frac{2}{s} x'_\bullet d \frac{2}{s} x''_* \theta(x' - x'') \int_{-\infty}^{x_*} d \frac{2}{s} x''_* (\bar{A}_*(x'_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_*(x'_*)) \quad (191)
\end{aligned}$$

$$\begin{aligned}
\Omega(x_*, x_\bullet) &= 1 + i \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d\frac{2}{s} x'_* d\frac{2}{s} x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) + i \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet \bar{A}_*(x'_\bullet) \\
&\quad - \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet d\frac{2}{s} x''_\bullet \theta(x'_\bullet - x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \\
&\quad - \frac{i}{2} \int_{-\infty}^{x_*} d\frac{2}{s} x'_* d\frac{2}{s} x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*)) \\
&\quad - \frac{i}{2} \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet d\frac{2}{s} x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_*} d\frac{2}{s} x'_* (\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_*))
\end{aligned} \tag{192}$$

$$\begin{aligned}
\Omega^\dagger(x_*, x_\bullet) &= 1 - i \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d\frac{2}{s} x'_* d\frac{2}{s} x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*) - i \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet \bar{A}_*(x'_\bullet) \\
&\quad - \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet d\frac{2}{s} x''_\bullet \theta(x'_\bullet - x''_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \\
&\quad + \frac{i}{2} \int_{-\infty}^{x_*} d\frac{2}{s} x'_* d\frac{2}{s} x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet (\bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*)) \\
&\quad + \frac{i}{2} \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet d\frac{2}{s} x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_*} d\frac{2}{s} x'_* (\bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_*))
\end{aligned} \tag{193}$$

$$\begin{aligned}
i\partial_\bullet \Omega^\dagger(x_*, x_\bullet) &= \bar{A}_\bullet(x_*) - i \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x_*) - \frac{i}{2} \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet (\bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*)) \\
&\quad - \frac{1}{2} \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) \bar{A}_\bullet(x'_*)) \\
&\quad - \frac{1}{2} \int_{-\infty}^{x_\bullet} d\frac{2}{s} x'_\bullet d\frac{2}{s} x''_\bullet \theta(x'_\bullet - x''_\bullet) (\bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet))
\end{aligned} \tag{194}$$





$$\begin{aligned}
\Omega(x_*, x_\bullet) i\partial_\bullet \Omega^\dagger(x_*, x_\bullet) &= \left[ 1 + i \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) + i \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet \bar{A}_*(x'_\bullet) \right. \\
&- \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) - \frac{1}{2} \int_{-\infty}^{x_*} d_s^2 x'_* \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) \\
&- \frac{i}{2} \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_\bullet)) \\
&- \left. \frac{i}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_*} d_s^2 x'_* (\bar{A}_*(x'_*) \bar{A}_*(x''_*) \bar{A}_\bullet(x'_\bullet) + \bar{A}_\bullet(x'_\bullet) \bar{A}_*(x''_*) \bar{A}_*(x'_\bullet)) \right] \\
&\times \left[ \bar{A}_\bullet(x_*) - i \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) - \frac{i}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet (\bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*)) \right. \\
&- \frac{1}{2} \int_{-\infty}^{x_*} d_s^2 x'_* \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet (\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) \bar{A}_\bullet(x_*)) \\
&- \left. \frac{1}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) (\bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet)) + i\partial_\bullet X3^\dagger \right] \\
&= - \frac{i}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_*} d_s^2 x'_* (\bar{A}_*(x'_*) \bar{A}_*(x''_*) \bar{A}_\bullet(x'_\bullet) + \bar{A}_\bullet(x'_\bullet) \bar{A}_*(x''_*) \bar{A}_*(x'_\bullet)) \bar{A}_\bullet(x_*) \\
&\quad + i \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_*(x'_*) \bar{A}_*(x''_*) \bar{A}_\bullet(x'_\bullet) \bar{A}_\bullet(x_*) \\
&+ \frac{i}{4} \int_{-\infty}^{x_*} d_s^2 x'_* \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet \int_{-\infty}^{x_*} d_s^2 x''_* (\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*)) (\bar{A}_\bullet(x_*) \bar{A}_*(x''_*) + \bar{A}_*(x''_*) \bar{A}_\bullet(x_*)) \\
&- \frac{i}{2} \int_{-\infty}^{x_*} d_s^2 x'_* \int_{-\infty}^{x_\bullet} d_s^2 x''_\bullet \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_*(x'_*) (\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x''_*) + \bar{A}_*(x''_*) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*)) \\
&- \frac{i}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x'_*) (\bar{A}_*(x''_*) \bar{A}_*(x'_*) \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x_*) \bar{A}_*(x''_*) \bar{A}_*(x'_*)) + i\partial_\bullet X3^\dagger \\
&= \frac{i}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_*} d_s^2 x'_* [[\bar{A}_*(x'_*), \bar{A}_\bullet(x'_*)], [\bar{A}_*(x''_*), \bar{A}_\bullet(x_*)]] \tag{202}
\end{aligned}$$

$$\begin{aligned}
i\partial_\bullet X3^\dagger &= \frac{i}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_*} d_s^2 x'_* \\
&\times \left[ \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x_*) - \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x_*) - \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) \right. \\
&- \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x_*) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) - \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \\
&+ 4\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) + 4\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x_*) - 8\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \\
&- 2\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) - 2\bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) - 2\bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x_*) \\
&- 2\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) - 2\bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) - 2\bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) - 2\bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) \\
&+ 4\bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) + 4\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) + 4\bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x'_\bullet) + 4\bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \\
&+ \left. 4\bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x_*) + 4\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \right] \tag{203}
\end{aligned}$$

$$\begin{aligned}
X3_1^\dagger &= \frac{1}{4} \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) (2\bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x'_*) + 2\bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_*) \\
&+ \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) - \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) - \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_*) \tag{204} \\
&= \frac{1}{4} \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \\
&\times (2\bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x'_*) + 2\bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_*) - [\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x''_\bullet)] [\bar{A}_\bullet(x'_*) \bar{A}_*(x'_*)]) \tag{205}
\end{aligned}$$

$$\begin{aligned}
i\partial_\bullet(X3^\dagger - X3_1^\dagger) &= \frac{i}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_\bullet} d_s^2 x'_* \\
&\times \left[ -\bar{A}_\bullet(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x_*) + \bar{A}_\bullet(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x_*) + \bar{A}_*(x'_\bullet) \bar{A}_*(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x_*) - \bar{A}_*(x'_\bullet) \bar{A}_*(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x_*) \right. \\
&\left. - \bar{A}_*(x''_\bullet) \bar{A}_*(x_*) \bar{A}_*(x'_\bullet) \bar{A}_*(x'_*) + \bar{A}_*(x_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x'_*) + \bar{A}_*(x''_\bullet) \bar{A}_*(x_*) \bar{A}_*(x'_\bullet) \bar{A}_*(x'_*) - \bar{A}_*(x_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x'_*) \right]
\end{aligned} \tag{206}$$

$\Rightarrow$

$$\begin{aligned}
(X3^\dagger - X3_1^\dagger) &= \frac{1}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \\
&\times \left[ \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x'_*) - \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x'_*) - \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \right. \\
&\left. - \bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_*) - \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_*) \bar{A}_\bullet(x'_*) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x'_*) \bar{A}_*(x'_*) \bar{A}_*(x''_\bullet) + \bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_*) \bar{A}_\bullet(x''_\bullet) \right] \\
&= \frac{1}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) ([\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)][\bar{A}_*(x''_\bullet), \bar{A}_\bullet(x'_*)] + [\bar{A}_*(x''_\bullet), \bar{A}_\bullet(x'_*)][\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_*)])
\end{aligned} \tag{207}$$

УТОГО

$$\begin{aligned}
X3^\dagger &= \frac{1}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \left( 4\bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x'_*) + 4\bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_*) \right. \\
&\left. - 2[\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)][\bar{A}_\bullet(x'_\bullet) \bar{A}_*(x'_*)] - [\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)][\bar{A}_\bullet(x'_\bullet), \bar{A}_*(x'_*)] - [\bar{A}_\bullet(x'_\bullet), \bar{A}_*(x'_*)][\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_*)] \right)
\end{aligned} \tag{208}$$

$$\begin{aligned}
X3 &= \frac{1}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \left( 4\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) + 4\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \right. \\
&\left. - 2[\bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet)][\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)] - [\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)][\bar{A}_\bullet(x'_\bullet), \bar{A}_*(x''_\bullet)] - [\bar{A}_\bullet(x'_\bullet), \bar{A}_*(x''_\bullet)][\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)] \right)
\end{aligned} \tag{209}$$

$$\begin{aligned}
\Omega(x_*, x_\bullet) &= 1 + i \int_{-\infty}^{x_\bullet} d_s^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_*) + i \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet \bar{A}_*(x'_\bullet) \\
&- \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) - \frac{1}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet \int_{-\infty}^{x_\bullet} d_s^2 x''_\bullet (\bar{A}_\bullet(x'_\bullet) \bar{A}_*(x''_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_\bullet)) \\
&- \frac{i}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet (\bar{A}_\bullet(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_\bullet) + \bar{A}_*(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \bar{A}_\bullet(x'_\bullet)) \\
&- \frac{i}{2} \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \int_{-\infty}^{x_\bullet} d_s^2 x'_* (\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_*) + \bar{A}_\bullet(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_*(x'_*)) + O(\bar{A}_*^3 \bar{A}_\bullet) + O(\bar{A}_\bullet^3 \bar{A}_*) \\
&+ \frac{1}{8} \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) \left( 4\bar{A}_\bullet(x'_*) \bar{A}_\bullet(x''_\bullet) \bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) + 4\bar{A}_*(x'_\bullet) \bar{A}_*(x''_\bullet) \bar{A}_\bullet(x'_\bullet) \bar{A}_\bullet(x''_\bullet) \right. \\
&\left. - 2[\bar{A}_\bullet(x'_*) \bar{A}_*(x''_\bullet)][\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)] - [\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)][\bar{A}_\bullet(x'_\bullet), \bar{A}_*(x''_\bullet)] - [\bar{A}_\bullet(x'_\bullet), \bar{A}_*(x''_\bullet)][\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x'_\bullet)] \right)
\end{aligned} \tag{210}$$

Guess:

$$\begin{aligned}
\Omega(x_*, x_\bullet) &= \frac{1}{2} [-\infty, x_*] [-\infty, x_\bullet] + \frac{1}{2} [-\infty, x_\bullet] [-\infty, x_*] - \frac{1}{4} [[-\infty, x_\bullet], [-\infty, x_*]] [[-\infty, x_\bullet], [-\infty, x_*]] \\
&+ \frac{1}{4} \int_{-\infty}^{x_\bullet} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \int_{-\infty}^{x_\bullet} d_s^2 x'_\bullet d_s^2 x''_\bullet \theta(x'_\bullet - x''_\bullet) [[\bar{A}_\bullet(x'_\bullet), \bar{A}_*(x'_\bullet)], [\bar{A}_\bullet(x''_\bullet), \bar{A}_*(x''_\bullet)]]
\end{aligned} \tag{211}$$



IX.  $\bar{C}_i$  IN THE 1ST ORDER IN  $p_\perp$ 

From Eq. (160) we get

$$\begin{aligned} (\bar{P}^2 g_{\alpha\beta} + 2ig\bar{G}_{\alpha\beta})^{ab} \bar{C}^{b\beta} &= \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b - \partial^2 \bar{A}_\alpha^a + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \\ \Leftrightarrow [(\bar{P} + \bar{C})^2]^{ab} \bar{C}_\alpha^b &= -2ig\bar{G}_{\alpha\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b - \partial^2 \bar{A}_\alpha^a - g f^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} = (\bar{D} - i\bar{C})^{ab\xi} \bar{G}_{\xi\alpha}^b - \partial^2 \bar{A}_\alpha^a - ig\bar{G}_{\alpha\beta}^{ab} \bar{C}^{b\beta} - g f^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} \end{aligned} \quad (212)$$

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$$\begin{aligned} (\bar{P}^2 g_{\alpha\beta} + 2ig\bar{G}_{\alpha\beta})^{ab} \bar{C}^{b\beta} &= \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + \bar{Y}\gamma_\alpha t^a \Upsilon \Rightarrow \\ [(\bar{P} + \bar{C})^2]^{ab} \bar{C}_\alpha^b &= -2ig\bar{G}_{\alpha\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + \bar{Y}\gamma_\alpha t^a \Upsilon - g f^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} = (\bar{D} - i\bar{C})^{ab\xi} \bar{G}_{\xi\alpha}^b + \bar{Y}\gamma_\alpha t^a \Upsilon - ig\bar{G}_{\alpha\beta}^{ab} \bar{C}^{b\beta} - g f^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} \end{aligned} \quad (213)$$

$$[(\bar{P} + \bar{C})^2]^{ab} \bar{C}_\alpha^b = (\bar{P}^2)^{ab} \bar{C}_\alpha^b - 2g f^{abc} \bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c + g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + f^{abc} \bar{C}_\alpha^b \bar{D}^\beta \bar{C}_\beta^c, \quad (214)$$

$$2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha \bar{C}_\beta - \bar{D}_\beta \bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta])^{ab} \bar{C}_\beta^b = 2i\bar{G}_{\alpha\beta} \bar{C}_\beta^b - 2g f^{abc} \bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c + 2g f^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} + 2g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d$$

Eq. (212) in components

$$\begin{aligned} (2\bar{P}_* \bar{P}_* - \frac{s}{2} p_\perp^2)^{ab} \bar{C}_\bullet^b &= \bar{D}_\bullet^{ab} \bar{G}_{\bullet\bullet}^b + i\bar{G}_{\bullet\bullet}^{ab} \bar{C}_\bullet^b - is\bar{G}_{\bullet\bullet}^{ab} \bar{C}^{bi} + g\bar{D}_\bullet^{aa'} (f^{a'bc} \bar{C}_*^b \bar{C}_*^c) \\ &\quad + 2g f^{abc} \bar{C}_\bullet^b \bar{D}_* \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_*^c \bar{C}_*^d + \frac{s}{2} g f^{abc} (2\bar{C}_i^b \partial^i \bar{C}_\bullet^c - \bar{C}_i^b \bar{D}_* \bar{C}^{ci}) - \frac{s}{2} g^2 f^{abm} f^{cdm} \bar{C}^{bi} \bar{C}_\bullet^c \bar{C}_i^d, \\ (2\bar{P}_* \bar{P}_* - \frac{s}{2} p_\perp^2)^{ab} \bar{C}_*^b &= -\bar{D}_*^{ab} \bar{G}_{\bullet\bullet}^b - i\bar{G}_{\bullet\bullet}^{ab} \bar{C}_*^b - is\bar{G}_{\bullet\bullet}^{ab} \bar{C}^{bi} - g\bar{D}_*^{aa'} (f^{a'bc} \bar{C}_*^b \bar{C}_*^c) \\ &\quad + 2g f^{abc} \bar{C}_*^b \bar{D}_* \bar{C}_*^c - g^2 f^{abm} f^{cdm} \bar{C}_*^b \bar{C}_*^c \bar{C}_*^d + g f^{abc} (2\bar{C}_i^b \partial^i \bar{C}_*^c - \bar{C}_i^b \bar{D}_* \bar{C}^{ci}) - g^2 f^{abm} f^{cdm} \bar{C}^{bi} \bar{C}_*^c \bar{C}_i^d, \\ (\bar{P}_* \bar{P}_* + \bar{P}_* \bar{P}_* - \frac{s}{2} p_\perp^2) \bar{C}_i^b &= \bar{D}_*^{ab} \bar{G}_{\bullet\bullet}^b + \bar{D}_\bullet^{ab} \bar{G}_{*i}^b + 2ig(\bar{C}_{\bullet\bullet}^{ab} \bar{C}_*^b + \bar{G}_{*i}^{ab} \bar{C}_\bullet^b) + g f^{abc} (2\bar{C}_*^b \bar{D}_* \bar{C}_i^c + 2\bar{C}_\bullet^b \bar{D}_* \bar{C}_i^c - \bar{C}_\bullet^b \partial_i \bar{C}_*^c - \bar{C}_*^b \partial_i \bar{C}_\bullet^c) \\ &\quad - g^2 f^{abm} f^{cdm} (\bar{C}_\bullet^b \bar{C}_i^c \bar{C}_*^d + \bar{C}_*^b \bar{C}_i^c \bar{C}_\bullet^d) + \frac{s}{2} g f^{abc} (2\bar{C}_j^b \partial^j \bar{C}_i^c - \bar{C}_j^b \partial_i \bar{C}^{cj}) - g^2 f^{abm} f^{cdm} \bar{C}^{bj} \bar{C}_i^c \bar{C}_j^d \end{aligned} \quad (215)$$

In the leading order in  $\partial_i$

$$\begin{aligned} (\bar{P}_* \bar{P}_* + \bar{P}_* \bar{P}_*) \bar{C}_i^b &= \bar{D}_*^{ab} \bar{G}_{\bullet\bullet}^b + \bar{D}_\bullet^{ab} \bar{G}_{*i}^b + 2ig(\bar{G}_{\bullet\bullet}^{ab} \bar{C}_*^b + \bar{G}_{*i}^{ab} \bar{C}_\bullet^b) + g f^{abc} (2\bar{C}_*^b \bar{D}_* \bar{C}_i^c + 2\bar{C}_\bullet^b \bar{D}_* \bar{C}_i^c - \bar{C}_\bullet^b \partial_i \bar{C}_*^c - \bar{C}_*^b \partial_i \bar{C}_\bullet^c) - g^2 f^{abm} f^{cdm} (\bar{C}_\bullet^b \bar{C}_i^c \bar{C}_*^d + \bar{C}_*^b \bar{C}_i^c \bar{C}_\bullet^d) \\ \Leftrightarrow [(\bar{P} + \bar{C})_* (\bar{P} + \bar{C})_\bullet + (\bar{P} + \bar{C})_\bullet (\bar{P} + \bar{C})_*] \bar{C}_i^b &= (\bar{D} - i\bar{C})^{ab} \bar{G}_{\bullet\bullet}^b + (\bar{D} - i\bar{C})^{ab} \bar{G}_{*i}^b + g f^{abc} (\bar{C}_*^b \bar{G}_{\bullet\bullet}^c + \bar{C}_\bullet^b \bar{G}_{*i}^c) - g f^{abc} (\bar{C}_\bullet^b \partial_i \bar{C}_*^c + \bar{C}_*^b \partial_i \bar{C}_\bullet^c) \\ \Leftrightarrow [(\bar{P} + \bar{C})_* (\bar{P} + \bar{C})_\bullet + (\bar{P} + \bar{C})_\bullet (\bar{P} + \bar{C})_*] \bar{C}_i^b &= (\bar{D} - i\bar{C})^{ab} \bar{G}_{\bullet\bullet}^b + (\bar{D} - i\bar{C})^{ab} \bar{G}_{*i}^b - g f^{abc} [\bar{C}_\bullet^b \partial_i (\bar{A} + \bar{C})_*^c + \bar{C}_*^b \partial_i (\bar{A} + \bar{C})_\bullet^c] \end{aligned} \quad (216)$$

EUĬĚ PA3: YPABHEHUE HA  $\bar{C}_i$

$$\begin{aligned} [(\bar{P} + \bar{C})^2]^{ab} \bar{C}_i^b &= -2ig\bar{G}_{i\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi i}^b - \partial^2 \bar{A}_i^a - g f^{abc} \bar{C}_\beta^b \partial_i \bar{C}^{c\beta} \\ &= -g f^{abc} \bar{C}_\beta^b \partial_i \bar{C}^{c\beta} - g f^{abc} \bar{A}_\beta^b \partial_i \bar{A}^{c\beta} - 2g f^{abc} \bar{C}^{b\xi} \partial_i \bar{A}_\xi^c = -g f^{abc} (\bar{A} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} + \partial_i (f^{abc} \bar{A}^{b\xi} \bar{C}_\xi^c) \\ &= -g f^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} - \partial_i \partial^\xi (\bar{A} + \bar{C})_\xi^a + i\partial_i (\bar{A}_\xi^{ab} \bar{C}^{b\xi}) = -g f^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} = ig(\bar{P} + \bar{C})_\beta^{ab} \partial_i (\bar{A} + \bar{C})^{b\beta} \\ \Rightarrow (\Omega p^2 \Omega^\dagger)^{ab} \bar{C}_i^b &= -(\Omega p_\beta \Omega^\dagger)^{ab} \partial_i (\Omega \partial_\beta \Omega^\dagger)^b = -i\Omega^{ab} \partial^2 (2\text{Tr}\{t^b (\partial_i \Omega^\dagger) \Omega\}) \end{aligned} \quad (217)$$

gde  $\bar{A}_\bullet + \bar{C}_\bullet = i\Omega \partial_\bullet \Omega^\dagger$  and  $\bar{A}_* + \bar{C}_* = i\Omega \partial_* \Omega^\dagger$

Wi uzd  $\Phi\text{OPMY}\Lambda\Lambda$

$$\begin{aligned} \Omega^{ab} \partial_\mu ((\partial_\nu \Omega^\dagger) \Omega)^b &= \Omega^{ab} \partial_\mu (2\text{Tr}\{t^b (\partial_\nu \Omega^\dagger) \Omega\}) = 2\text{Tr}\{t^b \Omega \partial_\mu \partial_\nu \Omega^\dagger + t^b (\partial_\nu \Omega) \partial_\mu \Omega^\dagger\} = \partial_\nu 2\text{Tr}\{t^b \Omega \partial_\mu \Omega^\dagger\} \\ \Rightarrow \Omega^{\dagger ab} \partial_i (\Omega \partial_\bullet \Omega^\dagger)^b &= \partial_\bullet (\partial_i \Omega^\dagger \Omega)^a \quad \text{and} \quad \Omega^{\dagger ab} \partial_i (\Omega \partial_* \Omega^\dagger)^b = \partial_* (\partial_i \Omega^\dagger \Omega)^a \end{aligned} \quad (218)$$

Solution of Eq. (217)

$$\begin{aligned} 2\mathcal{P}_* \mathcal{P}_* \bar{C}_i &= i(\mathcal{P}_* \partial_i \mathcal{A}_\bullet + \mathcal{P}_* \partial_i \mathcal{A}_*) \Rightarrow \bar{C}_i^a = -i \int d^4 z \Omega_x^{ab} (x | \frac{1}{p^2} | z) \partial^2 ((\partial_i \Omega^\dagger) \Omega)^b \\ &= -is \int d^4 z \Omega_x^{ab} (x | \frac{1}{p^2} | z) \frac{\partial}{\partial z_*} \frac{\partial}{\partial z_\bullet} ((\partial_i \Omega_z^\dagger) \Omega_z)^b = (\Omega i \partial_i \Omega^\dagger)^a + \frac{4}{s} \Omega_x^{ab} \int d^2 z_\perp dz_\bullet (x | \frac{p_*}{p^2} | z) ((\partial_i \Omega_z^\dagger) \Omega_z)^b \Big|_{z_*=-\infty} \\ &\quad + \frac{4}{s} \Omega_x^{ab} \int d^2 z_\perp dz_* (x | \frac{p_\bullet}{p^2} | z) ((\partial_i \Omega_z^\dagger) \Omega_z)^b \Big|_{z_\bullet=-\infty} - 2i\Omega_x^{ab} \int d^2 z_\perp (x | \frac{1}{p^2} | z) ((\partial_i \Omega_z^\dagger) \Omega_z)^b \Big|_{z_* = z_\bullet = -\infty} \\ &= (\Omega i \partial_i \Omega^\dagger)^a - i\Omega_x^{ab} [(\partial_i \Omega^\dagger(x_\perp, x_\bullet, -\infty_*) \Omega(x_\perp, x_\bullet, -\infty_*)) \\ &\quad - i\Omega_x^{ab} [(\partial_i \Omega^\dagger(x_\perp, x_*, -\infty_\bullet) \Omega(x_\perp, x_*, -\infty_\bullet)) + i\Omega_x^{ab} [(\partial_i \Omega^\dagger(x_\perp, -\infty_*, -\infty_\bullet) \Omega(x_\perp, -\infty_*, -\infty_\bullet))] \end{aligned} \quad (219)$$

$$\bar{C}_i^a = (\Omega i \partial_i \Omega^\dagger)^a + i \Omega_x^{ab} ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_i [x_*, -\infty_*]_x^{\bar{A}\bullet})^b + i \Omega_x^{ab} ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_i [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^b \quad (220)$$

Properti:

$$\bar{C}_i(x) \xrightarrow{x_* \rightarrow -\infty} 0, \quad \bar{C}_i(x) \xrightarrow{x_\bullet \rightarrow -\infty} 0 \quad (221)$$

Now

$$\begin{aligned} F_{\bullet i}^a &= \partial_\bullet \bar{C}_i^a - \partial_i (\bar{A}_\bullet + \bar{C}_\bullet)^a - i (\bar{A} + \bar{C})^{ab} \bar{C}_i^b = \Omega^{am} \partial_\bullet (\Omega^{\dagger mb} \bar{C}_i^b) - i \partial_i (\Omega \partial_\bullet \Omega^\dagger)^a \\ &= \Omega^{ab} \partial_\bullet \left( i ((\partial_i \Omega^\dagger) \Omega_x)^b - i [(\partial_i \Omega^\dagger (x_\perp, x_*, -\infty_\bullet) \Omega(x_\perp, x_*, -\infty_\bullet))]^b \right) - i \partial_i (\Omega \partial_\bullet \Omega^\dagger)^a \\ &= -i \Omega_x^{ab} \partial_\bullet \left( [\partial_i \Omega^\dagger (x_\perp, x_*, -\infty_\bullet)] \Omega(x_\perp, x_*, -\infty_\bullet) \right)^b \equiv -i \Omega_x^{ab} \partial_\bullet 2\text{Tr} \{ t^b [\partial_i \Omega^\dagger (x_\perp, x_*, -\infty_\bullet)] \Omega(x_\perp, x_*, -\infty_\bullet) \} \end{aligned} \quad (222)$$

At  $x_\bullet = -\infty$   $(\bar{A}_\bullet + \bar{C}_\bullet)(x_*, x_\bullet = -\infty) = \bar{A}_\bullet(x_*)$  so

$$\Omega(x_\perp, x_*, -\infty_\bullet) = [x_*, -\infty_*]_x^{\bar{A}\bullet} \Rightarrow (\partial_i \Omega^\dagger (x_\perp, x_*, -\infty_\bullet) \Omega(x_\perp, x_*, -\infty_\bullet)) = \frac{2i}{s} \int_{-\infty}^{x_*} dz_* [-\infty_*, z_*]_x^{\bar{A}\bullet} \bar{G}_{\bullet i}^c(x_\perp, z_*) [z_*, -\infty_*]_x^{\bar{A}\bullet} \quad (223)$$

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$$F_{\bullet i}^a(x) = \Omega_x^{ab} 2\text{Tr} \{ t^b [-\infty_*, x_*]_x^{\bar{A}\bullet} \bar{G}_{\bullet i}^c(x_\perp, x_*) [x_*, -\infty_*]_x^{\bar{A}\bullet} \} = \Omega_x^{ab} [-\infty_*, x_*]_x^{\bar{A}\bullet bc} \bar{G}_{\bullet i}^c(x_\perp, x_*) \quad (224)$$

and there4

$$\Rightarrow F_{*i}^{a(\bar{A}+\bar{C})}(x) F_{\bullet}^{ai(\bar{A}+\bar{C})}(x) = \bar{G}_{*i}^a(x_\perp, x_\bullet) ([x_\bullet, -\infty_\bullet]_{x_\perp}^{\bar{A}\bullet}) [-\infty_*, x_*]_{x_\perp}^{\bar{A}\bullet} \bar{G}_{\bullet i}^c(x_\perp, x_*) \quad (225)$$

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$$\begin{aligned} [(\bar{P} + \bar{C})^2]^{ab} \bar{C}_i^b &= -2ig \bar{G}_{i\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi i}^b + \bar{\Upsilon} \gamma_i t^a \Upsilon - g f^{abc} \bar{C}_\beta^b \partial_i \bar{C}^{c\beta} \\ &= -g f^{abc} (\bar{A} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} + \partial_i (f^{abc} \bar{A}^{b\xi} \bar{C}_\xi^c) + \bar{\Upsilon} \gamma_i t^a \Upsilon \\ &= -g f^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} - \partial_i \partial^\xi (\bar{A} + \bar{C})_\xi^a + i \partial_i (\bar{A}_\xi^a \bar{C}^{b\xi}) + \bar{\Upsilon} \gamma_i t^a \Upsilon \\ &= ig (\bar{P} + \bar{C})_\beta^{ab} \partial_i (\bar{A} + \bar{C})^{b\beta} + \bar{\Upsilon} \gamma_i t^a \Upsilon \end{aligned} \quad (226)$$

### 3. First order in $\bar{A}_\bullet, \bar{A}_*$

$$\begin{aligned} \bar{C}_\bullet^{1a}(x) &= -\frac{i}{2} \int dz(x) \frac{1}{p_* + i\epsilon} |z) \bar{G}_{\bullet}^a(z) = -\frac{i}{2} f^{abc} \int dz(x) \frac{1}{p_* + i\epsilon} |z) \bar{A}_*^b \bar{A}_\bullet^c(z), \\ \bar{C}_*^{1a}(x) &= \frac{i}{2} \int d^2 z(x) \frac{1}{p_\bullet + i\epsilon} |z) \bar{G}_{*}^a(z) = \frac{i}{2} f^{abc} \int dz(x) \frac{1}{p_* + i\epsilon} |z) \bar{A}_*^b \bar{A}_\bullet^c(z), \\ \bar{C}_i^{1a}(x) &= \frac{1}{2} \int dz(x) \frac{1}{p_* p_\bullet + i\epsilon p_0} |z) (\bar{D}_* \bar{G}_{\bullet i}^a(z) + \bar{D}_\bullet \bar{G}_{*i}^a(z)) = -\frac{1}{2} f^{abc} \int dz(x) \frac{1}{p_* p_\bullet + i\epsilon p_0} |z) (A_\bullet^b \partial_i A_*^c + A_*^b \partial_i A_\bullet^c) \\ F_{\bullet i}^{(1)a}(x) &= \frac{i}{2} f^{abc} \int dz(x) \frac{1}{p_* + i\epsilon} |z) (\bar{A}_\bullet^b \partial_i \bar{A}_*^c + \bar{A}_*^b \partial_i \bar{A}_\bullet^c) + \frac{i}{2} f^{abc} \int dz(x) \frac{1}{p_* + i\epsilon} |z) \partial_i (\bar{A}_*^b \bar{A}_\bullet^c(z)) \\ &= i f^{abc} \int dz(x) \frac{1}{p_* + i\epsilon} |z) \bar{A}_*^b \partial_i \bar{A}_\bullet^c(z) = f^{abc} \int_{-\infty}^{x_\bullet} d\frac{2}{s} z_\bullet \bar{A}_*^b(z_\bullet) \partial_i \bar{A}_\bullet^c(x_*) = -f^{abc} \int_{-\infty}^{x_\bullet} d\frac{2}{s} z_\bullet \bar{A}_*^b(z_\bullet) \bar{G}_{\bullet i}^c(x_*) \\ F_{*i}^{(1)m}(x) &= i f^{mcd} \int dz(x) \frac{1}{p_\bullet + i\epsilon} |z) \bar{A}_\bullet^a \partial_i \bar{A}_*^b(z) = -f^{mab} \int_{-\infty}^{x_*} d\frac{2}{s} z_* \partial_i \bar{A}_*^a(x_\bullet) \bar{A}_\bullet^b(z_*) = f^{mab} \int_{-\infty}^{x_*} d\frac{2}{s} z_* \bar{G}_{*i}^a(x_\bullet) \bar{A}_\bullet^b(z_*) \\ \Rightarrow F_{\bullet}^{(1)ai} F_{*i}^{(1)a}(x) &= f^{mab} f^{mcd} \bar{G}_{*i}^{ai}(x_\bullet) i \int_{-\infty}^{x_*} d\frac{2}{s} z_* \bar{A}_\bullet^b(z_*) i \int_{-\infty}^{x_\bullet} d\frac{2}{s} z_\bullet \bar{A}_*^c(z_\bullet) \bar{G}_{\bullet i}^d(x_*) \end{aligned} \quad (227)$$

A HA CAMOM DEAE (see Eq. (225))

$$F_{\bullet}^{(1)ai} F_{*i}^{(1)a}(x) = f^{mac} f^{mbd} \bar{G}_{*i}^a(x_\bullet) i \int_{-\infty}^{x_\bullet} d\frac{2}{s} z_\bullet \bar{A}_*^c(z_\bullet) i \int_{-\infty}^{x_*} d\frac{2}{s} z_* \bar{A}_\bullet^b(z_*) \bar{G}_{\bullet i}^d(x_*)$$

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$$f^{mab} f^{mcd} - f^{mac} f^{mbd} = - f^{adm} f^{bcm} \quad (228)$$

$$\begin{aligned} \bar{C}_\bullet^{1a}(x) &= -\frac{i}{2} \int dz(x) \frac{1}{P_* + i\epsilon} |z|^{ab} \bar{G}_{*\bullet}^b(z), \quad \bar{C}_*^{1a}(x) = \frac{i}{2} \int d^2z(x) \frac{1}{P_* + i\epsilon} |z|^{ab} \bar{G}_{*\bullet}^b(z), \\ \bar{C}_i^{1a}(x) &= \frac{1}{2} \int dz(x) \frac{1}{P_* P_\bullet + i\epsilon p_0} |z|^{ab} (\bar{D}_* \bar{G}_{\bullet i}^b(z) + \bar{D}_\bullet \bar{G}_{*i}^b(z) + 2ig \bar{G}_{\bullet i}^{ab} \bar{C}_*^{(1)b} + 2ig \bar{G}_{*i}^{ab} \bar{C}_\bullet^{(1)b}) \\ F_{\bullet i}^{(1)a}(x) &= \bar{D}_\bullet \bar{C}_i^{1a}(x) - \partial_i \bar{C}_\bullet^{1a} = -\frac{i}{2} (x) \frac{1}{P_* + i\epsilon} |z|^{ab} (\bar{D}_* \bar{G}_{\bullet i}^b(z) + \bar{D}_\bullet \bar{G}_{*i}^b(z)) + \frac{1}{2} \int dz(x) p_i \frac{1}{P_* + i\epsilon} |z|^{ab} \bar{G}_{*\bullet}^b(z) \\ &+ \frac{i}{2} \int dz(x) \frac{1}{P_* + i\epsilon} \bar{G}_{\bullet i} \frac{1}{P_\bullet + i\epsilon} |z|^{ab} \bar{G}_{*\bullet}^b = \\ &f^{mab} f^{mcd} \bar{C}_*^{ai}(x_\bullet) i \int_{-\infty}^{x_*} d\frac{2}{s} z_* \bar{A}_\bullet^b(z_*) i \int_{-\infty}^{x_*} d\frac{2}{s} z_\bullet \bar{A}_*^c(z_\bullet) \bar{G}_{\bullet i}^d(x_*) \\ &+ \frac{i}{2} \bar{F}_*^{ai} \int dz(x) \frac{1}{P_* + i\epsilon} \bar{G}_{\bullet i} \frac{1}{P_\bullet + i\epsilon} |z|^{ab} \bar{F}_*^b - \frac{i}{2} \bar{F}_\bullet^{ai} \int dz(x) \frac{1}{P_\bullet + i\epsilon} \bar{G}_{*i} \frac{1}{P_* + i\epsilon} |z|^{ab} \bar{F}_\bullet^b \\ &\stackrel{?}{=} f^{mac} f^{mbd} \bar{C}_*^a(x_\bullet) i \int_{-\infty}^{x_*} d\frac{2}{s} z_\bullet \bar{A}_*^c(z_\bullet) i \int_{-\infty}^{x_*} d\frac{2}{s} z_* \bar{A}_\bullet^b(z_*) \bar{G}_{\bullet i}^d(x_*) \end{aligned} \quad (229)$$

From Eq. (192)

$$\Omega(x) = [x_\bullet, -\infty][x_*, -\infty] + \frac{i}{2} \int_{-\infty}^{x_*} d\frac{2}{s} z_* \int_{-\infty}^{x_*} d\frac{2}{s} z_\bullet \bar{G}_{*\bullet}(z) + O(\bar{A}^3) \quad (230)$$

and from Eq. (224)

$$F_{\bullet i}^a(x) = \Omega_x^{ab} [-\infty_*, x_*]_x^{(\bar{A}\bullet)ab} \bar{F}_{\bullet i}^b(x_\perp, x_*) = [-\infty_*, x_\bullet]_x^{(\bar{A}\bullet)bc} \bar{C}_{\bullet i}^c(x_\perp, x_*) - \frac{1}{2} f^{abc} \int_{-\infty}^{x_*} d\frac{2}{s} z_* \int_{-\infty}^{x_*} d\frac{2}{s} z_\bullet \bar{G}_{*\bullet}(z) \bar{C}_{\bullet i}^c(x_\perp, x_*) \quad (231)$$

HAÜDĚM  $F_{ik}^{(1)}$ 

$$\bar{C}_i^a = (\Omega_i \partial_i \Omega^\dagger)^a + C_{1i}^a + C_{2i}^a, \quad C_{1i}^a = i \Omega_x^{ab} ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_i [x_*, -\infty_*]_x^{\bar{A}\bullet})^b, \quad C_{2i}^a = i \Omega_x^{ab} ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_i [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^b \quad (232)$$

$$\Omega^{\dagger aa'} F_{ik}^{a'}(x) = \Omega^{\dagger aa'} (\Omega \partial_i \Omega^\dagger)^{a'b} (C_1 + C_2)_k^b - i \leftrightarrow k + \Omega^{\dagger aa'} f^{a'bc} (C_1 + C_2)_i^b (C_1 + C_2)_k^c \quad (233)$$

$$\begin{aligned} &= i 2 \text{Tr} t^a (\partial_i [-\infty_*, x_*]_x^{\bar{A}\bullet}) \partial_k [x_*, -\infty_*]_x^{\bar{A}\bullet} + i 2 \text{Tr} t^a (\partial_i [-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet}) \partial_k [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet} - i \leftrightarrow k \\ &- f^{abc} ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_i [x_*, -\infty_*]_x^{\bar{A}\bullet})^b ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_k [x_*, -\infty_*]_x^{\bar{A}\bullet})^c - f^{abc} ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_i [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^b ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_k [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^c \\ &- f^{abc} ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_i [x_*, -\infty_*]_x^{\bar{A}\bullet})^b ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_k [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^c - f^{abc} ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_i [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^b ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_k [x_*, -\infty_*]_x^{\bar{A}\bullet})^c \\ &= - f^{abc} ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_i [x_*, -\infty_*]_x^{\bar{A}\bullet})^b ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_k [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^c - f^{abc} ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_i [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^b ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_k [x_*, -\infty_*]_x^{\bar{A}\bullet})^c \\ &\Rightarrow \end{aligned}$$

$$F_{ik}^{(1)a}(x) = - \Omega_x^{aa'} f^{a'bc} \{ ([-\infty_*, x_*]_x^{\bar{A}\bullet} \partial_i [x_*, -\infty_*]_x^{\bar{A}\bullet})^b ([-\infty_\bullet, x_\bullet]_x^{\bar{A}\bullet} \partial_k [x_\bullet, -\infty_\bullet]_x^{\bar{A}\bullet})^c - i \leftrightarrow k \} \quad (234)$$

### A. Eff action

$$\begin{aligned} &-\frac{1}{4} \bar{G}^{a\mu\nu} \bar{G}_{\mu\nu}^a - \frac{1}{2} \bar{C}^{\alpha\alpha} (\bar{P}^2 g_{\alpha\beta} + 2i \bar{G}_{\alpha\beta})^{ab} \bar{C}^{\beta b} + \bar{C}_\alpha \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha \bar{C}^{a\beta} \bar{C}_\alpha^b \bar{C}_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} \bar{C}^{a\alpha} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \\ &= -\frac{1}{4} \bar{G}^{a\mu\nu} \bar{G}_{\mu\nu}^a - \frac{1}{2} \bar{C}_\alpha^a g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c + \frac{1}{2} g f^{abc} \bar{C}_\alpha^b \bar{C}_\beta^d \bar{D}_\alpha \bar{C}^{\beta c} + \frac{1}{2} \bar{C}_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} - g f^{abc} \bar{D}^\alpha \bar{C}^{a\beta} \bar{C}_\alpha^b \bar{C}_\beta^c + \frac{g^2}{4} f^{abm} f^{cdm} \bar{C}^{a\alpha} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \\ &= -\frac{1}{4} \bar{G}^{a\mu\nu} \bar{G}_{\mu\nu}^a + \frac{1}{2} g f^{abc} \bar{C}_\alpha^a \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{\beta c} + \frac{1}{2} \bar{C}_\alpha^a \bar{D}_\xi \bar{G}^{\alpha\xi} + \frac{g^2}{4} f^{abm} f^{cdm} \bar{C}^{a\alpha} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \\ &= -\frac{1}{4} [\bar{G}^{\alpha\alpha\beta} + \bar{D}^\alpha \bar{C}^{\alpha\beta} - \bar{D}^\beta \bar{C}^{\alpha\alpha} + g f^{akl} \bar{C}^{k\alpha} \bar{C}^{l\beta}] [\bar{C}_\alpha^a + \bar{D}_\alpha \bar{C}_\beta^a - \bar{D}_\beta \bar{C}_\alpha^a + g f^{acd} \bar{C}^{ca} \bar{C}^{d\beta}] + ? \end{aligned} \quad (235)$$

## X. IN 4 DIMENSIONS

$$A_\mu^{(1+2+\dots)} \equiv \int DA A_\mu(x) e^{i \int d^4 z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i \bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a (\bar{D}_\xi \bar{G}^{\alpha\xi} - \partial^2 \bar{A}_\alpha^a - l_\alpha^a) - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right)} \quad (236)$$

gde (cm. Eq. (29))

$$l_\mu^a \equiv \frac{2}{s} p_{1\mu} \left( \frac{1}{P_\bullet} \bar{A}_\bullet \right)^{ab} \partial_\perp^2 \bar{A}_*^b + \frac{2}{s} p_{2\mu} \left( \frac{1}{P_*} \bar{A}_* \right)^{ab} \partial_\perp^2 \bar{A}_\bullet^b \quad (237)$$

Y HAC  $\partial^\xi \bar{A}_\xi = 0$

$$\bar{D}^\xi \bar{G}_{\xi\bullet}^a - \partial^2 \bar{A}_\bullet^a = \frac{2}{s} \bar{D}_\bullet \bar{G}_{*\bullet}^a, \quad \bar{D}^\xi \bar{G}_{\xi*}^a - \partial^2 \bar{A}_*^a = -\frac{2}{s} \bar{D}_* \bar{G}_{*\bullet}^a, \quad \bar{D}^\xi \bar{G}_{\xi i}^a = \frac{2}{s} \bar{D}_* \bar{G}_{\bullet i}^a + \frac{2}{s} \bar{D}_\bullet \bar{G}_{*i}^a \quad (238)$$

$$A_\alpha^{(1)a} \equiv \int d^4 z (x | \frac{1}{\bar{P}^2} | z)^{ab} (\bar{D}^\xi \bar{G}_{\xi\alpha}^a - l_\alpha^a)^b(z) \quad (239)$$

$$\begin{aligned} A_*^{(1)a} &= \int d^4 z (x | \frac{1}{\bar{P}^2} | z)^{ab} \left[ -\frac{2}{s} \bar{D}_* \bar{G}_{*\bullet}^b(z) - \left( \frac{1}{\bar{P}_\bullet} \bar{A}_\bullet \right)^{bc} \partial_\perp^2 \bar{A}_*^c \right] = \int d^4 z \left[ \frac{2i}{s} (x | \frac{1}{\bar{P}^2} \bar{P}_* | z)^{ab} \bar{G}_{*\bullet}^b(z) - (x | \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_\bullet} \bar{A}_\bullet | z)^{ab} \partial_\perp^2 \bar{A}_*^b \right] \\ A_\bullet^{(1)a} &= \int d^4 z (x | \frac{1}{\bar{P}^2} | z)^{ab} \left[ \frac{2}{s} \bar{D}_\bullet \bar{G}_{*\bullet}^b(z) - \left( \frac{1}{\bar{P}_*} \bar{A}_* \right)^{bc} \partial_\perp^2 \bar{A}_\bullet^c \right] = \int d^4 z \left[ -\frac{2i}{s} (x | \frac{1}{\bar{P}^2} \bar{P}_\bullet | z)^{ab} \bar{G}_{*\bullet}^b(z) - (x | \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_*} \bar{A}_* | z)^{ab} \partial_\perp^2 \bar{A}_\bullet^b \right] \\ A_i^{(1)a} &= \frac{2}{s} \int d^4 z (x | \frac{1}{\bar{P}^2} | z)^{ab} [\bar{D}_* \bar{G}_{\bullet i}^a + \bar{D}_\bullet \bar{G}_{*i}^a](z) + O(\bar{G}^2) = \frac{2}{s} \int d^4 z (x | \frac{1}{\bar{P}^2} | z)^{ab} [2\bar{D}_\bullet \bar{G}_{*i}^a - \partial_i \bar{G}_{*\bullet}^a](z) + O(\bar{G}^2) \quad (240) \end{aligned}$$

$$\begin{aligned} G_{*\bullet}^a(\bar{A} + A^{(1)}) &= \bar{G}_{*\bullet}^a + \int d^4 z \left[ -\frac{2}{s} (x | \bar{P}_* \frac{1}{\bar{P}^2} \bar{P}_\bullet + \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_* | z)^{ab} \bar{G}_{*\bullet}^b(z) + i (x | \bar{P}_* \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_*} \bar{A}_* | z)^{ab} \partial_\perp^2 \bar{A}_\bullet^b - i (x | \bar{P}_\bullet \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_\bullet} \bar{A}_\bullet | z)^{ab} \partial_\perp^2 \bar{A}_*^b \right] \\ &= \int d^4 z \left[ -\frac{1}{s} (x | [\bar{P}_*, [\bar{P}_\bullet, \frac{1}{\bar{P}^2}]] + [\bar{P}_\bullet, [\bar{P}_*, \frac{1}{\bar{P}^2}]] - \frac{i}{2\bar{P}^2} \{p^i, \{\bar{P}^\xi, \bar{G}_{\xi i}\}\} \frac{1}{\bar{P}^2} | z)^{ab} \bar{G}_{*\bullet}^b(z) + (x | \frac{1}{\bar{P}^2} | z)^{ab} \partial_\perp^2 \bar{G}_{*\bullet}^b(z) \right. \\ &\quad \left. - (x | \frac{1}{\bar{P}^2} | z)^{ab} f^{a'bc} [\bar{A}_*^b \partial_\perp^2 \bar{A}_\bullet^c + (\partial_\perp^2 \bar{A}_\bullet^b) \bar{A}_*^c] + (x | \frac{1}{\bar{P}^2} \{p^\xi, \bar{G}_{*\xi}\} \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_*} \bar{A}_* | z)^{ab} \partial_\perp^2 \bar{A}_\bullet^b - (x | \frac{1}{\bar{P}^2} \{p^\xi, \bar{G}_{*\xi}\} \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_\bullet} \bar{A}_\bullet | z)^{ab} \partial_\perp^2 \bar{A}_*^b \right] \\ &= \int d^4 z \left[ (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} \bar{G}_{*i}^b(z) \bar{G}_{\bullet i}^c(z) - \frac{1}{s} (x | [\bar{P}_*, [\bar{P}_\bullet, \frac{1}{\bar{P}^2}]] + [\bar{P}_\bullet, [\bar{P}_*, \frac{1}{\bar{P}^2}]] - \frac{i}{2\bar{P}^2} \{p^i, \{\bar{P}^\xi, \bar{G}_{\xi i}\}\} \frac{1}{\bar{P}^2} | z)^{ab} \bar{G}_{*\bullet}^b(z) \right. \\ &\quad \left. + (x | \frac{1}{\bar{P}^2} \{p^\xi, \bar{G}_{*\xi}\} \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_*} \bar{A}_* | z)^{ab} \partial_\perp^2 \bar{A}_\bullet^b - (x | \frac{1}{\bar{P}^2} \{p^\xi, \bar{G}_{*\xi}\} \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_\bullet} \bar{A}_\bullet | z)^{ab} \partial_\perp^2 \bar{A}_*^b \right] \quad (241) \end{aligned}$$

bikoz  $\frac{2}{s} \bar{P}_* \frac{1}{\bar{P}^2} \bar{P}_\bullet + \frac{2}{s} \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_* = 1 + \frac{1}{s} [\bar{P}_\bullet, [\bar{P}_*, \frac{1}{\bar{P}^2}]] + \frac{1}{s} [\bar{P}_*, [\bar{P}_\bullet, \frac{1}{\bar{P}^2}]] + \frac{1}{2} \{p_\perp^2, \frac{1}{\bar{P}^2}\}$ .

If  $\bar{G}_{\bullet i} = \frac{s}{2} \Omega U_i \Omega^\dagger \delta(x_*)$  and  $\bar{G}_{*i} = \frac{s}{2} \Omega V_i \Omega^\dagger \delta(x_*)$ , the first term

$$\int d^4 z \left[ (x | \frac{1}{\bar{P}^2} | z)^{aa'} f^{a'bc} \bar{G}_{*i}^b(z) \bar{G}_{\bullet i}^c(z) = -i \int d^2 z_\perp (x | \frac{1}{\bar{P}^2} \Omega^\dagger | 0, z_\perp)^{ab} [U_i, V^i]^b \right] \quad (242)$$

agrees with Eq. (52) from hep-ph/9812311

$$\begin{aligned} G_{*i}^a(\bar{A} + A^{(1)}) &= -\partial_i (\bar{A}_* + A_*^{(1)}) + \bar{D}_* A_i^{(1)} = \bar{G}_{*i}^a + \bar{D}_* A_i^{(1)} - \partial_i A_*^{(1)} \\ &= \bar{G}_{*i}^a - \int d^4 z \left[ \frac{2}{s} (x | p_i \frac{1}{\bar{P}^2} \bar{P}_* | z)^{ab} \bar{G}_{*\bullet}^b(z) - i (x | p^i \frac{1}{\bar{P}^2} \frac{1}{\bar{P}_\bullet} \bar{A}_\bullet | z)^{ab} \partial_\perp^2 \bar{A}_*^b + \frac{4}{s} (x | \bar{P}_* \frac{1}{\bar{P}^2} \bar{A}_\bullet | z)^{ab} \bar{G}_{*i}^b(z) - \frac{2}{s} (x | \bar{P}_* \frac{1}{\bar{P}^2} p_i | z) \bar{G}_{*\bullet}^b(z) \right] \end{aligned}$$

If we throw away  $p_\perp^2$

1. NLO at  $d = 4$ 

From Eq. (134) and (29)

$$\begin{aligned}
A_\alpha^{(1+2)a} &\equiv A_\alpha^{(1)a} + A_\alpha^{(2)a} = \int DA A_\alpha^a(x) e^{i\int d^4z \left( \frac{1}{2} A_\alpha^a (\bar{D}^2 g^{\alpha\beta} - 2i\bar{G}^{\alpha\beta})^{ab} A_\beta^b + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c - A_\alpha^a I^{a\alpha} \right)} = \\
&= \int d^4z \left[ (x| \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} |z)^{ab} \left[ (\bar{D}^\xi \bar{G}_{\xi\beta} - \partial^2 \bar{A}_\beta)^b(z) - \frac{2}{s} p_{2\beta} \left( \frac{1}{P_*} \bar{A}_* \right)^{ab} \partial_\perp^2 \bar{A}_\bullet^b - \frac{2}{s} p_{1\beta} \left( \frac{1}{P_\bullet} \bar{A}_\bullet \right)^{ab} \partial_\perp^2 \bar{A}_*^b \right] \right. \\
&\quad \left. - i(x| \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} \bar{P}^\xi |z)^{aa'} f^{a'bc} A_\xi^{(1)b} A_\beta^{(1)b} - (x| \frac{1}{\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta}} |z)^{aa'} f^{a'bc} A^{(1)b\xi} (\bar{D}_\beta A_\xi^{(1)b} - \bar{D}_\xi A_\beta^{(1)b}) \right] \\
&= \bar{A}_\alpha^{(1)} + \int d^2z \left[ -2i(x| \frac{1}{\bar{P}^2} \bar{G}_{\alpha\beta} \frac{1}{\bar{P}^2} |z)^{ab} (\bar{D}^\xi \bar{G}_{\xi\beta} - \partial^2 \bar{A}_\beta)^b(z) - \frac{2}{s} p_{2\beta} \left( \frac{1}{P_*} \bar{A}_* \right)^{ab} \partial_\perp^2 \bar{A}_\bullet^b - \frac{2}{s} p_{1\beta} \left( \frac{1}{P_\bullet} \bar{A}_\bullet \right)^{ab} \partial_\perp^2 \bar{A}_*^b \right] \\
&\quad - i(x| \frac{1}{\bar{P}^2} \bar{P}^\xi |z)^{aa'} f^{a'bc} A_\xi^{(1)b} A_\alpha^{(1)c} - (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A^{(1)b\xi} (\bar{D}_\alpha A_\xi^{(1)c} - \bar{D}_\xi A_\alpha^{(1)c}) \left] \right.
\end{aligned} \tag{243}$$

$$\begin{aligned}
A_*^{(1+2)a} &= \frac{2i}{s} \int d^4z (x| \frac{1}{\bar{P}^2} \bar{P}_* |z)^{ab} \bar{G}_{*\bullet}^b(z) + \frac{2}{s} \int d^4z \left[ \frac{4}{s} (x| \frac{1}{\bar{P}^2} \bar{G}_{*\bullet} \frac{1}{\bar{P}^2} \bar{P}_* |z)^{ab} \bar{G}_{*\bullet}^b(z) - 2i(x| \frac{1}{\bar{P}^2} \bar{G}_*^i \frac{1}{\bar{P}^2} |z)^{ab} (\bar{D}_* \bar{G}_{*\bullet}^b + \bar{D}_\bullet \bar{G}_{*i}^b)(z) \right. \\
&\quad \left. - i(x| \frac{1}{\bar{P}^2} P_* |z)^{aa'} f^{a'bc} A_\bullet^{(1)b} A_*^{(1)c}(z) - \frac{is}{2} (x| \frac{1}{\bar{P}^2} p^i |z)^{aa'} f^{a'bc} A_i^{(1)b} A_*^{(1)c}(z) \right. \\
&\quad \left. - (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A_*^{(1)b} (\bar{D}_* A_\bullet^{(1)c} - \bar{D}_\bullet A_*^{(1)c})(z) - \frac{s}{2} (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A^{(1)bi} (\bar{D}_* A_i^{(1)c} - \partial_i A_*^{(1)c})(z) \right] \\
&= A_*^{(1)a} + \frac{2}{s} \int d^4z \left[ \frac{4}{s} (x| \frac{1}{\bar{P}^2} \bar{G}_{*\bullet} \frac{1}{\bar{P}^2} \bar{P}_* |z)^{ab} \bar{G}_{*\bullet}^b(z) - 2i(x| \frac{1}{\bar{P}^2} \bar{G}_*^i |z) \frac{s}{2} A_i^{(1)b}(z) \right. \\
&\quad \left. - i(x| \frac{1}{\bar{P}^2} P_* |z)^{aa'} f^{a'bc} A_\bullet^{(1)b} A_*^{(1)c}(z) - \frac{is}{2} (x| \frac{1}{\bar{P}^2} p^i |z)^{aa'} f^{a'bc} A_i^{(1)b} A_*^{(1)c}(z) \right. \\
&\quad \left. + \frac{2}{s} (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A_*^{(1)b}(z) (z| \bar{P}_* \frac{1}{\bar{P}^2} \bar{P}_\bullet + \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_* |z')^{cc'} \bar{G}_{*\bullet}^{c'}(z') - \frac{s}{2} (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A^{(1)bi} (\bar{D}_* A_i^{(1)c} - \partial_i A_*^{(1)c})(z) \right] \\
&= A_*^{(1)a} + \frac{2}{s} \int d^4z \left[ -i(x| \frac{1}{\bar{P}^2} \bar{G}_{*\bullet} |z)^{ab} A_*^{(1)b}(z) - i(x| \frac{1}{\bar{P}^2} P_* |z)^{aa'} f^{a'bc} A_\bullet^{(1)b} A_*^{(1)c}(z) \right. \\
&\quad \left. - 2i(x| \frac{1}{\bar{P}^2} \bar{G}_*^i |z) \frac{s}{2} A_i^{(1)b}(z) - \frac{is}{2} (x| \frac{1}{\bar{P}^2} p^i |z)^{aa'} f^{a'bc} A_i^{(1)b} A_*^{(1)c}(z) - \frac{s}{2} (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A^{(1)bi} (\bar{D}_* A_i^{(1)c} - \partial_i A_*^{(1)c})(z) \right. \\
&\quad \left. + \frac{1}{s} (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A_*^{(1)b}(z) (z| \{p_\perp^2, \frac{1}{\bar{P}^2}\} |z')^{cc'} \bar{G}_{*\bullet}^{c'}(z') \right]
\end{aligned}$$

Similarly,

$$\begin{aligned}
A_\bullet^{(1+2)a} &= A_\bullet^{(1)a} + \frac{2}{s} \int d^4z \left[ i(x| \frac{1}{\bar{P}^2} \bar{G}_{*\bullet} |z)^{ab} A_\bullet^{(1)b}(z) + i(x| \frac{1}{\bar{P}^2} P_\bullet |z)^{aa'} f^{a'bc} A_\bullet^{(1)b} A_*^{(1)c}(z) \right. \\
&\quad \left. - 2i(x| \frac{1}{\bar{P}^2} \bar{G}_\bullet^i |z) \frac{s}{2} A_i^{(1)b}(z) - \frac{is}{2} (x| \frac{1}{\bar{P}^2} p^i |z)^{aa'} f^{a'bc} A_i^{(1)b} A_\bullet^{(1)c}(z) - \frac{s}{2} (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A^{(1)bi} (\bar{D}_\bullet A_i^{(1)c} - \partial_i A_\bullet^{(1)c})(z) \right] \\
&\quad - \frac{1}{s} (x| \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A_\bullet^{(1)b}(z) (z| \{p_\perp^2, \frac{1}{\bar{P}^2}\} |z')^{cc'} \bar{G}_{*\bullet}^{c'}(z') \left] \right.
\end{aligned}$$

ПОЕТОМЪ

$$\begin{aligned}
\bar{D}_* A_\bullet^{(1+2)a} - \bar{D}_\bullet A_*^{(1+2)a} &= -\frac{2}{s} \int d^4z (x| \bar{P}_* \frac{1}{\bar{P}^2} \bar{P}_\bullet + \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{P}_* |z)^{ab} \bar{G}_{*\bullet}^b \\
&+ \frac{2}{s} \int d^4z \left[ (x| \bar{P}_* \frac{1}{\bar{P}^2} \bar{G}_{*\bullet} |z)^{ab} A_\bullet^{(1)b}(z) + (x| \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{G}_{*\bullet} |z)^{ab} A_*^{(1)b}(z) + (x| \bar{P}_* \frac{1}{\bar{P}^2} P_\bullet + \bar{P}_\bullet \frac{1}{\bar{P}^2} P_* |z)^{aa'} f^{a'bc} A_\bullet^{(1)b} A_*^{(1)c}(z) \right. \\
&\quad \left. - 2(x| \bar{P}_* \frac{1}{\bar{P}^2} \bar{G}_\bullet^i |z) \frac{s}{2} A_i^{(1)b}(z) - \frac{s}{2} (x| \bar{P}_* \frac{1}{\bar{P}^2} p^i |z)^{aa'} f^{a'bc} A_i^{(1)b} A_\bullet^{(1)c}(z) + i \frac{s}{2} (x| \bar{P}_* \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A^{(1)bi} (\bar{D}_\bullet A_i^{(1)c} - \partial_i A_\bullet^{(1)c})(z) \right] \\
&\quad + 2(x| \bar{P}_\bullet \frac{1}{\bar{P}^2} \bar{G}_*^i |z) \frac{s}{2} A_i^{(1)b}(z) + \frac{s}{2} (x| \bar{P}_\bullet \frac{1}{\bar{P}^2} p^i |z)^{aa'} f^{a'bc} A_i^{(1)b} A_*^{(1)c}(z) - i \frac{s}{2} (x| \bar{P}_\bullet \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A^{(1)bi} (\bar{D}_* A_i^{(1)c} - \partial_i A_*^{(1)c})(z) \left] \right. \\
&\quad \left. + i \frac{1}{s} (x| P_* \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A_\bullet^{(1)b}(z) (z| \{p_\perp^2, \frac{1}{\bar{P}^2}\} |z')^{cc'} \bar{G}_{*\bullet}^{c'}(z') + i \frac{1}{s} (x| P_\bullet \frac{1}{\bar{P}^2} |z)^{aa'} f^{a'bc} A_*^{(1)b}(z) (z| \{p_\perp^2, \frac{1}{\bar{P}^2}\} |z')^{cc'} \bar{G}_{*\bullet}^{c'}(z') \right] \tag{244}
\end{aligned}$$

## XI. C KBAPKAMU

$\partial_{\perp}^2 A_{\bullet} \text{ MA}\Lambda\text{O} \Leftrightarrow \partial_{\perp}^2 A_{\bullet} \sim m_{\perp}^2 \Rightarrow \psi_A \sim m_{\perp}$ . Similarly,  $\partial_{\perp}^2 B_{\bullet} \sim m_{\perp}^2 \Rightarrow \psi_B \sim m_{\perp}$

$$\begin{aligned}
\bar{\psi}_B(x_{\bullet}) - \int d^2 z \bar{\psi}_B(z_{\bullet}) (z | (\hat{A} + \hat{C}) \frac{1}{(\hat{p} + \hat{A} + \hat{B} + \hat{C})} | x) &= \int d^2 z \bar{\psi}_B(z_{\bullet}) (z | (\hat{p} + \hat{B}) \frac{1}{(\hat{p} + \hat{A} + \hat{B} + \hat{C})} | x) \\
&= \int d^2 z \bar{\psi}_B(z_{\bullet}) \hat{p}_2 \left( \frac{\partial}{\partial z_{\bullet}} - \overleftarrow{\frac{\partial}{\partial z_{\bullet}}} \right) (z | \frac{1}{(\hat{p} + \hat{A} + \hat{B} + \hat{C})} | x) = i \int d^2 z \bar{\psi}_B(z_{\bullet}) \hat{p}_2 \left( \frac{\partial}{\partial z_{\bullet}} - \overleftarrow{\frac{\partial}{\partial z_{\bullet}}} \right) \Omega(z) (z | \frac{1}{\hat{p} - i\epsilon p_0} | x) \Omega^{\dagger}(x) \\
&= \frac{i}{s} \int d^2 z \bar{\psi}_B(z_{\bullet}) \hat{p}_2 \left( \frac{\partial}{\partial z_{\bullet}} - \overleftarrow{\frac{\partial}{\partial z_{\bullet}}} \right) \Omega(z) (z | \frac{\hat{p}_1}{\beta - i\epsilon} | x) \Omega^{\dagger}(x) = \frac{1}{s} \bar{\psi}_B(x_{\bullet}) \Omega(-\infty_{\bullet}, x_{\bullet}) \Omega^{\dagger}(x_{\bullet}, x_{\bullet}) \hat{p}_2 \hat{p}_1
\end{aligned} \tag{245}$$

Similarly

$$\begin{aligned}
\psi_A(x_{\bullet}) - \int dz (x | \frac{1}{\hat{p} + \hat{A} + \hat{B} + \hat{C}} (\hat{B} + \hat{C}) | z) \psi_A(z_{\bullet}) &= \int dz (x | \frac{1}{\hat{p} + \hat{A} + \hat{B} + \hat{C}} (\hat{p} + \hat{A}) | z) \psi_A(z_{\bullet}) \\
&= - \int dz i \frac{\partial}{\partial z_{\bullet}} (x | \frac{1}{\hat{p} + \hat{A} + \hat{B} + \hat{C}} | z) \hat{p}_1 \psi_A(z_{\bullet}) = - \Omega_x \int dz i \frac{\partial}{\partial z_{\bullet}} (x | \frac{1}{\hat{p}} | z) \Omega_z^{\dagger} \hat{p}_1 \psi_A(z_{\bullet}) = - \Omega_x \int dz i \frac{\partial}{\partial z_{\bullet}} (x | \frac{\hat{p}_2}{\alpha s + i\epsilon} | z) \Omega_z^{\dagger} \hat{p}_1 \psi_A(z_{\bullet}) \\
&= - \frac{1}{s} \Omega_x \int dz_{\bullet} \frac{\partial}{\partial z_{\bullet}} \theta(x_{\bullet} - z_{\bullet}) \Omega^{\dagger}(z_{\bullet}, x_{\bullet}, x_{\perp}) \hat{p}_2 \hat{p}_1 \psi_A(x_{\bullet}, x_{\perp}) = \frac{\hat{p}_2 \hat{p}_1}{s} \Omega_x \Omega^{\dagger}(-\infty_{\bullet}, x_{\bullet}, x_{\perp}) \psi_A(x_{\bullet}, x_{\perp})
\end{aligned} \tag{246}$$

$$\begin{aligned}
&\frac{1}{s^2} \bar{\psi}_B(x_{\bullet}) \Omega(-\infty_{\bullet}, x_{\bullet}) \Omega^{\dagger}(x_{\bullet}, x_{\bullet}) \hat{p}_2 \hat{p}_1 \gamma_{\mu}^{\perp} \hat{p}_2 \hat{p}_1 \Omega(x_{\bullet}, x_{\bullet}) \Omega^{\dagger}(-\infty_{\bullet}, x_{\bullet}) \psi_A(x_{\bullet}) \\
&= \bar{\psi}_B(x_{\bullet}) \Omega(-\infty_{\bullet}, x_{\bullet}) \gamma_{\mu}^{\perp} \Omega^{\dagger}(-\infty_{\bullet}, x_{\bullet}) \psi_A(x_{\bullet})
\end{aligned} \tag{247}$$

In the first order in  $\partial_{\perp}$

$$\begin{aligned}
\xi(x) = \psi_A(x) - \int dz (x | \frac{1}{\hat{p} + \hat{A} + \hat{B} + \hat{C}} (\hat{B} + \hat{C}) | z) \psi_A(z) &= - \Omega_x \int dz i \frac{\partial}{\partial z_{\bullet}} (x | \frac{\hat{p}_2}{\alpha s + i\epsilon} + \frac{\hat{p}_{\perp}}{\alpha \beta s + i\epsilon p_0} | z) \Omega_z^{\dagger} \hat{p}_1 \psi_A(z) \\
&= \Omega_x [-\infty, x_{\bullet}]_x^{\hat{A}_{\bullet}} \psi_A(x) + \Omega_x \int_{-\infty}^{x_{\bullet}} d \frac{2}{s} z_{\bullet} (\hat{\partial}_{\perp} [-\infty, z_{\bullet}]_x^{\hat{A}_{\bullet}}) \hat{p}_1 \psi_A(z_{\bullet}, x_{\perp}, x_{\bullet})
\end{aligned} \tag{248}$$

Chek:

$$\begin{aligned}
(i \hat{\partial} + \hat{A} + \hat{B} + \hat{C}) \xi(x) &= \Omega_x i \hat{\partial} \Omega_x^{\dagger} \xi(x) = \Omega_x [-\infty, x_{\bullet}]_x^{\hat{A}_{\bullet}} \left( \frac{2}{s} \hat{p}_2 (i \hat{\partial}_{\bullet} + \hat{A}_{\bullet}) + \frac{2}{s} \hat{p}_1 i \hat{\partial}_{\bullet} + i \hat{\partial}_{\perp} \right) \psi_A(x) \\
&+ \Omega_x (i \hat{\partial}_{\perp} [-\infty, x_{\bullet}]_x^{\hat{A}_{\bullet}}) \psi_A(x) + \Omega_x i \hat{p}_2 \frac{\partial}{\partial x_{\bullet}} \int_{-\infty}^{x_{\bullet}} d \frac{2}{s} z_{\bullet} (\hat{\partial}_{\perp} [-\infty, z_{\bullet}]_x^{\hat{A}_{\bullet}}) \hat{p}_1 \psi_A(z_{\bullet}, x_{\perp}, x_{\bullet}) + \mathcal{O}\left(\left(\frac{k_{\perp}^{\text{gluon}}}{k_{\perp}^{\text{quark}}}\right)^2\right) \\
&= \Omega_x (i \hat{\partial}_{\perp} [-\infty, x_{\bullet}]_x^{\hat{A}_{\bullet}}) \left(1 - \frac{\hat{p}_2 \hat{p}_1}{s}\right) \psi_A(x) = \mathcal{O}\left(\left(\frac{k_{\perp}^{\text{gluon}}}{k_{\perp}^{\text{quark}}}\right)^2\right)
\end{aligned} \tag{249}$$

Similarly

$$\psi_B(x) - \int dz (x | \frac{1}{\hat{p} + \hat{A} + \hat{B} + \hat{C}} (\hat{A} + \hat{C}) | z) \psi_B(z) = \Omega_x [-\infty, x_{\bullet}]_x^{\hat{A}_{\bullet}} \psi_B(x) + \Omega_x \int_{-\infty}^{x_{\bullet}} d \frac{2}{s} z_{\bullet} (\hat{\partial}_{\perp} [-\infty, z_{\bullet}]_x^{\hat{A}_{\bullet}}) \hat{p}_2 \psi_A(z_{\bullet}, x_{\perp}, x_{\bullet}) \tag{250}$$

### 2. Conservation of em current?

$$\begin{aligned}
\partial^{\mu} \bar{\psi}_A \gamma_{\mu} \psi_A &= \bar{\psi}_A (\overleftarrow{\hat{\partial}} + \hat{\partial}) \psi_A = \bar{\psi}_A (\overleftarrow{\hat{\partial}} + i \hat{A} + \hat{\partial} - i \hat{A}) \psi_A = 0 \\
\partial^{\mu} \bar{\psi}_B \gamma_{\mu} \psi_B &= \bar{\psi}_B (\overleftarrow{\hat{\partial}} + \hat{\partial}) \psi_B = \bar{\psi}_B (\overleftarrow{\hat{\partial}} + i \hat{B} + \hat{\partial} - i \hat{B}) \psi_B = 0 \\
\partial^{\mu} (\bar{\psi}_A + \bar{\psi}_B) \gamma_{\mu} (\psi_A + \psi_B) &= i \bar{\psi}_B (\hat{A} - \hat{B}) \psi_A - i \bar{\psi}_A (\hat{A} - \hat{B}) \psi_B \neq 0?
\end{aligned} \tag{251}$$

## A. ОδΩΛΑΪΑ ΗΑΥΚΑ

$$\square_{\mu\nu}^{ab} = \bar{P}^2 g_{\mu\nu} + 2i\bar{G}_{\mu\nu} + \bar{P}_\mu \bar{C}_\nu + \bar{C}_\mu \bar{P}_\nu + \bar{C}_\mu \bar{C}_\nu \quad (252)$$

$$\xi \equiv \xi_a(x_\bullet, x_\perp) + \xi_b(x_*, x_\perp),$$

$$\frac{2\hat{p}_1}{s} (i\partial_* + \bar{A}_*(x_\bullet, x_\perp))\xi_a(x_\bullet, x_\perp) + i\gamma_i \partial^i \xi_a(x_\bullet, x_\perp) = 0, \quad \frac{2\hat{p}_2}{s} (i\partial_\bullet + \bar{A}_\bullet(x_*, x_\perp))\xi_b(x_*, x_\perp) + i\gamma_i \partial^i \xi_b(x_*, x_\perp) = 0 \quad (253)$$

Approximately  $\hat{p}_1 \xi_a = \hat{p}_2 \xi_b = 0$  (up 2  $p_\perp^2$ )

$$\begin{aligned} \bar{C}_\mu^m(x) &= \int DA A_\mu^m(x) e^{i\int dz \left( -\frac{1}{4}[G_{\mu\nu}^a(A+\bar{A})]^2 - \frac{1}{2}[(\bar{D}_\mu - i\bar{C}_\mu)A^\mu]^2 \right) + (\bar{\psi} + \bar{\xi})(\hat{P} + \hat{A})(\psi + \xi)} \\ &= \int DAD\bar{\psi}D\psi A_\mu^m(x) \exp \left\{ i \int dz \left( -\frac{1}{4}\bar{G}^{a\mu\nu}\bar{G}_{\mu\nu}^a - \frac{1}{2}A^{a\alpha}\square_{\alpha\beta}^{ab}A^{\beta b} + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d \right) \right. \\ &\quad \left. + \bar{\xi}\hat{P}\xi + \bar{\xi}\hat{A}\xi + \bar{\xi}\hat{P}\psi + \bar{\psi}\hat{P}\xi + \bar{\xi}\hat{A}\psi + \bar{\psi}\hat{A}\xi + \bar{\psi}\hat{P}\psi + \bar{\psi}\hat{A}\psi \right\} \end{aligned} \quad (254)$$

gde

$$\partial_\perp^2 \bar{A}_\bullet^a(x_*, x_\perp) = g\bar{\xi}_b t^a \gamma_\bullet \xi_b(x_*, x_\perp), \quad \partial_\perp^2 \bar{A}_*^a(x_\bullet, x_\perp) = g\bar{\xi}_a t^a \gamma_* \xi_a(x_\bullet, x_\perp) \quad (255)$$

$$\int dx \bar{\xi}\hat{P}\xi(x) = \int dx (\bar{\xi}_a + \bar{\xi}_b) \left[ \left( i \frac{\partial}{\partial x_\bullet} + \frac{2}{s} \bar{A}_*(x_\bullet, x_\perp) \right) \hat{p}_1 + \left( i \frac{\partial}{\partial x_*} + \frac{2}{s} \bar{A}_\bullet(x_*, x_\perp) \right) \hat{p}_2 + i\gamma_i \frac{\partial}{\partial x_i} \right] (\xi_a + \xi_b) \quad (256)$$

$$\begin{aligned} \chi(x) &= \int DA \psi(x) e^{i\int dz \left( -\frac{1}{4}[G_{\mu\nu}^a(A+\bar{A})]^2 - \frac{1}{2}[(\bar{D}_\mu - i\bar{C}_\mu)A^\mu]^2 \right) + (\bar{\psi} + \bar{\chi})(\hat{P} + \hat{A})(\psi + \xi)} \\ &= \int DA A_\mu^m(x) \exp \left\{ i \int dz \left( -\frac{1}{4}\bar{G}^{a\mu\nu}\bar{G}_{\mu\nu}^a - \frac{1}{2}A^{a\alpha}\square_{\alpha\beta}^{ab}A^{\beta b} + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d \right) \right. \\ &\quad \left. + \bar{\xi}\hat{P}\xi + \bar{\xi}\hat{A}\xi + \bar{\xi}\hat{P}\psi + \bar{\psi}\hat{P}\xi + \bar{\xi}\hat{A}\psi + \bar{\psi}\hat{A}\xi + \bar{\psi}\hat{P}\psi + \bar{\psi}\hat{A}\psi \right\} \end{aligned} \quad (257)$$

Sdvg  $A \rightarrow A + \bar{C}$ ,  $\psi \rightarrow \psi + \chi$

$$\int DA A_\mu^m(x) \psi(y) e^{i\int dz \left( -\frac{1}{4}[G_{\mu\nu}^a(A+\bar{A})]^2 - \frac{1}{2}[(\bar{D}_\mu - i\bar{C}_\mu)A^\mu]^2 \right) + (\bar{\psi} + \bar{\chi})(\hat{P} + \hat{A})(\psi + \xi)} \quad (258)$$

$$\begin{aligned} &\int DA [A_\mu^m(x) + \bar{C}_\mu^m(x)] [\psi(y) + \chi(y)] \\ &\times e^{i\int dz \left( -\frac{1}{4}\bar{G}^{a\mu\nu}\bar{G}_{\mu\nu}^a - \frac{1}{2}\bar{C}^{a\alpha}(\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} + \bar{C}_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - g f^{abc} \bar{D}^\alpha \bar{C}^{a\beta} \bar{C}_\alpha^b \bar{C}_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} \bar{C}^{a\alpha} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + (\bar{\xi} + \bar{\chi})(\hat{P} + \hat{C})(\xi + \chi) \right)} \\ &\times \exp i \int dz \left\{ A^{a\alpha} \left( -(\bar{P}^2 g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} + (\bar{D}\bar{G})_\alpha^a + f^{abc}(2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + (\bar{\xi} + \bar{\chi})\gamma_\alpha t^a (\xi + \chi) \right) \right. \\ &\quad \left. + \bar{\psi}(\hat{P} + \hat{C})(\xi + \chi) + (\bar{\xi} + \bar{\chi})(\hat{P} + \hat{C})\psi \right. \\ &\quad \left. - \frac{1}{2}A^{a\alpha} \left( (\bar{P} + \bar{C})^2 g_{\alpha\beta} + 2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha \bar{C}_\beta - \bar{D}_\beta \bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta]) \right)^{ab} A^{b\beta} + \bar{\psi}(\hat{P} + \hat{C})\psi + (\bar{\xi} + \bar{\chi})\hat{A}\psi + \bar{\psi}\hat{A}(\xi + \chi) \right. \\ &\quad \left. - g f^{abc} (\bar{D}_\alpha - i\bar{C}_\alpha)^{aa'} A_{\beta'}^a A^{\alpha\alpha'} A^{d\beta} - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d + \bar{\psi}\hat{A}\psi \right\} \end{aligned} \quad (259)$$

UMEEM YP-E (226) HA  $\bar{C}_\mu$  U  $\chi, \bar{\chi}$  B BUDE ( $\Upsilon = \xi + \chi$ )

$$\begin{aligned} (\bar{P}^2 g_{\alpha\beta} + 2ig\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} &= \bar{D}^{ab\xi}\bar{G}_{\xi\alpha}^b + g f^{abc}(2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + \bar{\Upsilon}\gamma_\alpha t^a \Upsilon \\ (\hat{P} + \hat{C})\Upsilon &= 0, \quad \bar{\Upsilon}(\hat{P} + \hat{C}) = 0 \end{aligned} \quad (260)$$

$$\begin{aligned}
[(\bar{P} + \bar{C})^2]^{ab} \bar{C}_\alpha^b &= -2ig\bar{G}_{\alpha\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b - gf^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} + \bar{\Upsilon} t^a \gamma_\alpha \Upsilon + f^{abc} \bar{C}_\alpha^b \bar{D}^\beta \bar{C}_\beta^c \\
&= ? - gf^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} - gf^{abc} \bar{A}_\beta^b \bar{D}_\alpha \bar{A}^{c\beta} - 2gf^{abc} \bar{C}^{b\xi} \partial_i \bar{A}_\xi^c = -gf^{abc} (\bar{A} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} + \partial_i (f^{abc} \bar{A}^{b\xi} \bar{C}_\xi^c) \\
&= -gf^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} - \partial_i \partial^\xi (\bar{A} + \bar{C})_\xi^a + i\partial_i (\bar{A}_\xi^{ab} \bar{C}^{b\xi}) = -gf^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} = ig(\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{b\beta} \\
&\Rightarrow (\Omega p^2 \Omega^\dagger)^{ab} \bar{C}_i^b = -(\Omega p_\beta \Omega^\dagger)^{ab} \partial_i (\Omega \partial_\beta \Omega^\dagger)^b = -i\Omega^{ab} \partial^2 (2\text{Tr}\{t^b (\partial_i \Omega^\dagger) \Omega\})
\end{aligned} \tag{261}$$

S kvarkami

$$\begin{aligned}
(\bar{P}^2 g_{\alpha\beta} + 2ig\bar{G}_{\alpha\beta})^{ab} \bar{C}^{b\beta} &= \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + gf^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + \bar{\Upsilon} \gamma_\alpha t^a \Upsilon \Rightarrow \\
[(\bar{P} + \bar{C})^2]^{ab} \bar{C}_\alpha^b &= -2ig\bar{G}_{\alpha\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + \bar{\Upsilon} \gamma_\alpha t^a \Upsilon - gf^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} = (\bar{D} - i\bar{C})^{ab\xi} \bar{G}_{\xi\alpha}^b + \bar{\Upsilon} \gamma_\alpha t^a \Upsilon - ig\bar{G}_{\alpha\beta}^{ab} \bar{C}^{b\beta} - gf^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}
\end{aligned} \tag{262}$$

$$\begin{aligned}
[(\bar{P} + \bar{C})^2]^{ab} \bar{C}_\alpha^b &= (\bar{P}^2)^{ab} \bar{C}_\alpha^b - 2gf^{abc} \bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c + g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + f^{abc} \bar{C}_\alpha^b \bar{D}^\beta \bar{C}_\beta^c, \\
2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha \bar{C}_\beta - \bar{D}_\beta \bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta])^{ab} \bar{C}_\beta^b &= 2i\bar{G}_{\alpha\beta}^{ab} \bar{C}_\beta^b - 2gf^{abc} \bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c + 2gf^{abc} \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} + 2g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d
\end{aligned} \tag{263}$$

EUĬĬ PA3: YPABHEHUE (226) HA  $\bar{C}_i$

$$\begin{aligned}
[(\bar{P} + \bar{C})^2]^{ab} \bar{C}_i^b &= -2ig\bar{G}_{i\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi i}^b - gf^{abc} \bar{C}_\beta^b \partial_i \bar{C}^{c\beta} + \bar{\Upsilon} t^a \gamma_i \Upsilon + f^{abc} \bar{C}_i^b \bar{D}^\beta \bar{C}_\beta^c \\
&= -gf^{abc} \bar{C}_\beta^b \partial_i \bar{C}^{c\beta} - gf^{abc} \bar{A}_\beta^b \partial_i \bar{A}^{c\beta} - 2gf^{abc} \bar{C}^{b\beta} \partial_i \bar{A}_\beta^c + f^{abc} \bar{C}_i^b \bar{D}^\beta \bar{C}_\beta^c + \bar{\Upsilon} t^a \gamma_i \Upsilon \\
&= -gf^{abc} (\bar{A} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} + \partial_i (f^{abc} \bar{A}^{b\beta} \bar{C}_\beta^c) + f^{abc} \bar{C}_i^b \bar{D}^\beta \bar{C}_\beta^c + \bar{\Upsilon} t^a \gamma_i \Upsilon \\
&= -gf^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} - \partial_i \partial^\beta (\bar{A} + \bar{C})_\beta^a + i\partial_i (\bar{A}_\beta^{ab} \bar{C}^{b\beta}) + f^{abc} \bar{C}_i^b \bar{D}^\beta \bar{C}_\beta^c + \bar{\Upsilon} t^a \gamma_i \Upsilon \\
&= -gf^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} - \partial_i \bar{D}^\beta \bar{C}_\beta^a + f^{abc} \bar{C}_i^b \bar{D}^\beta \bar{C}_\beta^c + \bar{\Upsilon} t^a \gamma_i \Upsilon = ig\mathcal{P}_\beta^{ab} \partial_i \mathcal{A}^{b\beta} + \bar{\Upsilon} t^a \gamma_i \Upsilon - \mathcal{D}_i \bar{D}^\beta \bar{C}_\beta^a \\
&\Rightarrow \mathcal{P}^2 \mathcal{A}_i = ig\mathcal{P}_\beta^{ab} \partial_i \mathcal{A}^{b\beta} + \bar{\Upsilon} t^a \gamma_i \Upsilon - \mathcal{D}_i \bar{D}^\beta \bar{C}_\beta^a
\end{aligned} \tag{264}$$

In the leading order

$$(\Omega p^2 \Omega^\dagger)^{ab} \bar{C}_i^b = -(\Omega p_\beta \Omega^\dagger)^{ab} \partial_i (\Omega \partial_\beta \Omega^\dagger)^b = -i\Omega^{ab} \partial^2 (2\text{Tr}\{t^b (\partial_i \Omega^\dagger) \Omega\}) \tag{265}$$

B KOMΠOHEHTAX

$$\begin{aligned}
\bar{P}^2 \bar{C}_\bullet^a &= \bar{D}^{ab\xi} \bar{G}_{\xi\bullet}^b - 2ig\bar{G}_{\bullet\beta}^{ab} \bar{C}^{b\beta} + gf^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\bullet^c - \bar{C}_\beta^b \bar{D}_\bullet \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\bullet^c \bar{C}_\beta^d + (\bar{\xi} + \bar{\chi}) \gamma_\bullet t^a (\bar{\xi} + \bar{\chi}) \\
(\hat{P} + \hat{C})(\bar{\xi} + \bar{\chi}) &= 0, \quad (\bar{\xi} + \bar{\chi})(\hat{P} + \hat{C}) = 0
\end{aligned} \tag{266}$$

$$\begin{aligned}
\frac{2}{s} (\mathcal{P}_* \mathcal{P}_\bullet + \mathcal{P}_\bullet \mathcal{P}_*)^{ab} \bar{C}_i^b &= -(\partial_\perp^2 g_{ij} + \partial_i \partial_j) \bar{C}^{aj} + gf^{abc} (2\bar{C}_j^b \partial^j \bar{C}_i^c - \bar{C}_j^b \partial_i \bar{C}^{cj}) - g^2 f^{abm} f^{cdm} \bar{C}_j^b \bar{C}_i^c \bar{C}^{dj} \\
&+ \bar{\Upsilon} t^a \gamma_i \Upsilon + \frac{2}{s} (\bar{D}_* \bar{G}_{\bullet i} + \bar{D}_\bullet \bar{G}_{*i}) - \frac{2}{s} gf^{abc} (\bar{C}_*^b \partial_i \bar{C}_\bullet^c + \bar{C}_\bullet^b \partial_i \bar{C}_*^c) \\
&= -\mathcal{D}^j F_{ij}^a + f^{abc} \bar{C}_i^b \partial^j \bar{C}_j^c + \bar{\Upsilon} t^a \gamma_i \Upsilon + \frac{2}{s} (\bar{D}_* \bar{G}_{\bullet i} + \bar{D}_\bullet \bar{G}_{*i}) - \frac{2}{s} gf^{abc} (\bar{C}_*^b \partial_i \bar{C}_\bullet^c + \bar{C}_\bullet^b \partial_i \bar{C}_*^c)
\end{aligned} \tag{267}$$

CPABHU C YP. (226)

$$\begin{aligned}
[(\bar{P} + \bar{C})^2]^{ab} \bar{C}_i^b &= -2ig\bar{G}_{i\beta}^{ab} \bar{C}^{b\beta} + \bar{D}^{ab\xi} \bar{G}_{\xi i}^b - \partial^2 \bar{A}_i^a - gf^{abc} \bar{C}_\beta^b \partial_i \bar{C}^{c\beta} \\
&= -gf^{abc} \bar{C}_\beta^b \partial_i \bar{C}^{c\beta} - gf^{abc} \bar{A}_\beta^b \partial_i \bar{A}^{c\beta} - 2gf^{abc} \bar{G}^{b\xi} \partial_i \bar{A}_\xi^c = -gf^{abc} (\bar{A} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} + \partial_i (f^{abc} \bar{A}^{b\xi} \bar{C}_\xi^c) \\
&= -gf^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} - \partial_i \partial^\xi (\bar{A} + \bar{C})_\xi^a + i\partial_i (\bar{A}_\xi^{ab} \bar{C}^{b\xi}) = -gf^{abc} (\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{c\beta} = ig(\bar{P} + \bar{C})_\beta^b \partial_i (\bar{A} + \bar{C})^{b\beta}
\end{aligned}$$

$$\begin{aligned}
(2(\bar{P} \cdot \bar{P}_*) - \frac{s}{2} p_\perp^2)^{ab} \bar{C}_\bullet^b &= \bar{D}_\bullet^{ab} \bar{G}_{*\bullet}^b + i\bar{G}_{*\bullet}^{ab} \bar{C}_\bullet^b + g\bar{D}_\bullet^{aa'} (f^{a'bc} \bar{C}_*^b \bar{C}_\bullet^c) + 2gf^{abc} \bar{C}_\bullet^b \bar{D}_* \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_\bullet^c \bar{C}_*^d \\
&+ \frac{s}{2} \left[ f^{abc} (2g\bar{G}_{\bullet i}^b \bar{C}^{ci} + 2\bar{C}_i^b \partial^i \bar{C}_\bullet^c - \bar{C}_i^b \bar{D}_\bullet \bar{C}^{ci}) + g^2 f^{abm} f^{cdm} \bar{C}_i^b \bar{C}_\bullet^c \bar{C}^{di} + \bar{\xi}_a t^a \hat{p}_1 \xi_b + \bar{\xi}_b t^a \hat{p}_1 \xi_a + \bar{\xi}_a t^a \hat{p}_1 \xi_a + \bar{\xi} t^a \hat{p}_1 \chi + \bar{\chi} t^a \hat{p}_1 \xi + \bar{\chi} t^a \hat{p}_1 \chi \right]
\end{aligned}$$

$$\begin{aligned}
2(\bar{P} \cdot \bar{P}_*)^{ab} \bar{C}_\bullet^b &= \bar{D}_\bullet^{ab} \bar{G}_{*\bullet}^b + i\bar{G}_{*\bullet}^{ab} \bar{C}_\bullet^b + g\bar{D}_\bullet^{aa'} (f^{a'bc} \bar{C}_*^b \bar{C}_\bullet^c) + 2gf^{abc} \bar{C}_\bullet^b \bar{D}_* \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_\bullet^c \bar{C}_*^d \\
&- \frac{s}{2} \partial_\perp^2 (\bar{A}_\bullet^a + \bar{C}_\bullet^a) + \frac{s}{2} \left[ f^{abc} (2g\bar{G}_{\bullet i}^b \bar{C}^{ci} + 2\bar{C}_i^b \partial^i \bar{C}_\bullet^c - \bar{C}_i^b \bar{D}_\bullet \bar{C}^{ci}) + g^2 f^{abm} f^{cdm} \bar{C}_i^b \bar{C}_\bullet^c \bar{C}^{di} + (\bar{\xi} + \bar{\chi}) t^a \hat{p}_1 (\bar{\xi} + \bar{\chi}) \right] \\
&= \bar{D}_\bullet^{ab} \bar{G}_{*\bullet}^b + i\bar{G}_{*\bullet}^{ab} \bar{C}_\bullet^b + g\bar{D}_\bullet^{aa'} (f^{a'bc} \bar{C}_*^b \bar{C}_\bullet^c) + 2gf^{abc} \bar{C}_\bullet^b \bar{D}_* \bar{C}_\bullet^c - g^2 f^{abm} f^{cdm} \bar{C}_\bullet^b \bar{C}_\bullet^c \bar{C}_*^d \\
&+ \frac{s}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i (\bar{A}_\bullet^b + \bar{C}_\bullet^b) - i\frac{s}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{s}{2} (\bar{\xi} + \bar{\chi}) t^a \hat{p}_1 (\bar{\xi} + \bar{\chi})
\end{aligned} \tag{268}$$



where we uzd

$$F_{\bullet i}^a = \mathcal{D}_{\bullet}^{ab} \bar{C}_i^b - \partial_i A_{\bullet}^a = (\partial_{\bullet} - i\bar{A}_{\bullet} - i\bar{C}_{\bullet}) \bar{C}_i - \partial_i (\bar{A}_{\bullet} + \bar{C}_{\bullet})$$

$$\begin{aligned} & 2(\bar{P}_{\bullet} + \bar{C}_{\bullet})(\bar{P}_{\bullet} + \bar{C}_{\bullet})^{ab} \bar{C}_{\bullet}^b = \\ & = \bar{D}_{\bullet}^{ab} \bar{G}_{\bullet}^b + i\bar{G}_{\bullet}^{ab} \bar{C}_{\bullet}^b + g\bar{D}_{\bullet}^{aa'} (f^{a'bc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c) + 2gf^{abc} \bar{C}_{\bullet}^b \bar{D}_{\bullet} \bar{C}_{\bullet}^c - g^2 f^{abm} f^{cdm} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c \bar{C}_{\bullet}^d \\ & + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i (\bar{A}_{\bullet}^b + \bar{C}_{\bullet}^b) - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} \bar{\Upsilon} t^a \hat{p}_1 \Upsilon + 2(D_{\bullet})^{aa'} f^{a'bc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c - 2gf^{abc} \bar{C}_{\bullet}^b \bar{D}_{\bullet} \bar{C}_{\bullet}^c + 2g^2 f^{abm} f^{cdm} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c \bar{C}_{\bullet}^d \\ & = (\bar{D} - i\bar{C})^{ab} \bar{G}_{\bullet}^b + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i (\bar{A}_{\bullet}^b + \bar{C}_{\bullet}^b) - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} \bar{\Upsilon} t^a \hat{p}_1 \Upsilon + (D_{\bullet})^{aa'} f^{a'bc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c + g^2 f^{abm} f^{cdm} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c \bar{C}_{\bullet}^d \\ & = -i\mathcal{P}_{\bullet}^{ab} \bar{G}_{\bullet}^b + \frac{S}{2} (-D^i F_{\bullet i}^{ab} + \bar{\Upsilon} t^a \hat{p}_1 \Upsilon) - \frac{iS}{2} \mathcal{P}_{\bullet}^{ab} \partial^i \bar{C}_i^b - i(\mathcal{P}_{\bullet})^{aa'} g f^{a'bc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c = 2(\mathcal{P}_{\bullet} \mathcal{P}_{\bullet})^{ab} \bar{C}_{\bullet}^b \\ & = -i\mathcal{P}_{\bullet}^{ab} \bar{G}_{\bullet}^b + i\mathcal{P}_{\bullet}^{ab} F_{\bullet i}^b - \frac{iS}{2} \mathcal{P}_{\bullet}^{ab} \partial^i \bar{C}_i^b - i(\mathcal{P}_{\bullet})^{aa'} g f^{a'bc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c + \frac{S}{2} (\mathcal{D}_{\bullet}^{ab} F_{\bullet i}^b - \mathcal{D}^i F_{\bullet i}^{ab} + \bar{\Upsilon} t^a \hat{p}_1 \Upsilon) \\ & \Rightarrow \end{aligned} \tag{269}$$

$$2\mathcal{P}_{\bullet}^{ab} \bar{C}_{\bullet}^b = i(F_{\bullet i}^a - \bar{G}_{\bullet}^a) - \frac{iS}{2} \partial^i \bar{C}_i^a + igf^{abc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c \Leftrightarrow 2\bar{P}_{\bullet}^{ab} \bar{C}_{\bullet}^b = i(F_{\bullet i}^a - \bar{G}_{\bullet}^a) - \frac{iS}{2} \partial^i \bar{C}_i^a - igf^{abc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c \tag{270}$$

$$2\mathcal{P}_{\bullet}^{ab} \bar{C}_{\bullet}^b = -i(F_{\bullet i}^a - \bar{G}_{\bullet}^a) - \frac{iS}{2} \partial^i \bar{C}_i^a - igf^{abc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c \Leftrightarrow 2\bar{P}_{\bullet}^{ab} \bar{C}_{\bullet}^b = -i(F_{\bullet i}^a - \bar{G}_{\bullet}^a) - \frac{iS}{2} \partial^i \bar{C}_i^a + igf^{abc} \bar{C}_{\bullet}^b \bar{C}_{\bullet}^c$$

### 1. $\bar{c}_{\bullet}$ and $\bar{c}_{\bullet}$ .

Define

$$\bar{C}_{\bullet} = \tilde{C}_{\bullet} + \bar{c}_{\bullet}, \quad \mathcal{A} \equiv \bar{A}_{\bullet} + \tilde{C}_{\bullet} = \Omega^{\dagger} i \partial_{\bullet} \Omega, \quad \mathcal{A} \equiv \bar{A}_{\bullet} + \tilde{C}_{\bullet} = \Omega^{\dagger} i \partial_{\bullet} \Omega \tag{271}$$

$$\begin{aligned} & 2(\bar{P}_{\bullet} \bar{P}_{\bullet})^{ab} \bar{c}_{\bullet}^b = \\ & = i\bar{G}_{\bullet}^{ab} \bar{c}_{\bullet}^b + g\bar{D}_{\bullet}^{aa'} f^{a'bc} (\tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c + \bar{c}_{\bullet}^b \tilde{C}_{\bullet}^c) + 2gf^{abc} (\tilde{C}_{\bullet}^b \bar{D}_{\bullet} \bar{c}_{\bullet}^c + \bar{c}_{\bullet}^b \bar{D}_{\bullet} \tilde{C}_{\bullet}^c) - g^2 f^{abm} f^{cdm} (\tilde{C}_{\bullet}^b \tilde{C}_{\bullet}^c \bar{c}_{\bullet}^d + \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c \tilde{C}_{\bullet}^d + \bar{c}_{\bullet}^b \tilde{C}_{\bullet}^c \tilde{C}_{\bullet}^d) \\ & + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i (\bar{A}_{\bullet}^b + \tilde{C}_{\bullet}^b) - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} (\bar{\xi} + \bar{\chi}) t^a \hat{p}_1 (\bar{\xi} + \bar{\chi}) \end{aligned} \tag{272}$$

$$\begin{aligned} & \Rightarrow 2(\bar{P}_{\bullet} + \tilde{C}_{\bullet})(\bar{P}_{\bullet} + \tilde{C}_{\bullet})^{ab} \bar{c}_{\bullet}^b = -2f^{abc} \tilde{C}_{\bullet}^b \bar{D}_{\bullet} \bar{c}_{\bullet}^c - 2\bar{D}_{\bullet}^{aa'} (f^{a'bc} \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) - 2f^{abm} f^{cdm} \tilde{C}_{\bullet}^b \tilde{C}_{\bullet}^c \bar{c}_{\bullet}^d \\ & + i\bar{G}_{\bullet}^{ab} \bar{c}_{\bullet}^b + g\bar{D}_{\bullet}^{aa'} f^{a'bc} (\tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c + \bar{c}_{\bullet}^b \tilde{C}_{\bullet}^c) + 2gf^{abc} (\tilde{C}_{\bullet}^b \bar{D}_{\bullet} \bar{c}_{\bullet}^c + \bar{c}_{\bullet}^b \bar{D}_{\bullet} \tilde{C}_{\bullet}^c) - g^2 f^{abm} f^{cdm} (\tilde{C}_{\bullet}^b \tilde{C}_{\bullet}^c \bar{c}_{\bullet}^d + \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c \tilde{C}_{\bullet}^d + \bar{c}_{\bullet}^b \tilde{C}_{\bullet}^c \tilde{C}_{\bullet}^d) \\ & + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i (\bar{A}_{\bullet}^b + \tilde{C}_{\bullet}^b) - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} (\bar{\xi} + \bar{\chi}) t^a \hat{p}_1 (\bar{\xi} + \bar{\chi}) \\ & = i\bar{G}_{\bullet}^{ab} \bar{c}_{\bullet}^b - g\bar{D}_{\bullet}^{aa'} (f^{a'bc} \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) - g\bar{D}_{\bullet}^{aa'} (f^{a'bc} \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) + 2gf^{abc} \bar{c}_{\bullet}^b \bar{D}_{\bullet} \tilde{C}_{\bullet}^c - g^2 f^{abm} f^{cdm} (\tilde{C}_{\bullet}^b \tilde{C}_{\bullet}^c \bar{c}_{\bullet}^d - \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c \tilde{C}_{\bullet}^d + \bar{c}_{\bullet}^b \tilde{C}_{\bullet}^c \tilde{C}_{\bullet}^d) \\ & + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i (\bar{A}_{\bullet}^b + \tilde{C}_{\bullet}^b) - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} (\bar{\xi} + \bar{\chi}) t^a \hat{p}_1 (\bar{\xi} + \bar{\chi}) \\ & = -f^{abc} \bar{G}_{\bullet}^b \bar{c}_{\bullet}^c - g\bar{D}_{\bullet}^{aa'} (f^{a'bc} \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) - g\mathcal{D}_{\bullet}^{aa'} (f^{a'bc} \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) + 2gf^{abc} \bar{c}_{\bullet}^b \bar{D}_{\bullet} \tilde{C}_{\bullet}^c - g^2 f^{abm} f^{cdm} \bar{c}_{\bullet}^b \tilde{C}_{\bullet}^c \tilde{C}_{\bullet}^d \\ & + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i \bar{A}_{\bullet}^b - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} (\bar{\xi} + \bar{\chi}) t^a \hat{p}_1 (\bar{\xi} + \bar{\chi}) \\ & = -g\bar{D}_{\bullet}^{aa'} (f^{a'bc} \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) - g\mathcal{D}_{\bullet}^{aa'} (f^{a'bc} \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i \bar{A}_{\bullet}^b - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} \bar{\Upsilon} t^a \hat{p}_1 \Upsilon \end{aligned} \tag{273}$$

$$\text{wæ wi uzd } \bar{D}_{\bullet} \tilde{C}_{\bullet} = -\frac{1}{2} f^{abc} \tilde{C}_{\bullet}^b \tilde{C}_{\bullet}^c - \frac{1}{2} \bar{G}_{\bullet}^a$$

$$\begin{aligned} 2\mathcal{P}_{\bullet} \mathcal{P}_{\bullet} \bar{c}_{\bullet}^a & = -g\bar{D}_{\bullet}^{aa'} f^{a'bc} (\tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c + \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i \bar{A}_{\bullet}^b - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} \bar{\Upsilon} t^a \hat{p}_1 \Upsilon \\ 2\mathcal{P}_{\bullet} \mathcal{P}_{\bullet} \bar{c}_{\bullet}^a & = -g\bar{D}_{\bullet}^{aa'} f^{a'bc} (\tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c + \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) + \frac{S}{2} (\partial_i - i\bar{C}_i)^{ab} \partial^i \bar{A}_{\bullet}^b - i\frac{S}{2} F_{\bullet i}^{ab} \bar{C}_i^c + \frac{S}{2} \bar{\Upsilon} t^a \hat{p}_1 \Upsilon \end{aligned} \tag{274}$$

$$\begin{aligned} \bar{c}_{\bullet}^a & = \frac{i}{2\mathcal{P}_{\bullet} \mathcal{P}_{\bullet}} \bar{\mathcal{P}}_{\bullet}^{aa'} f^{a'bc} (\tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c + \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) + \frac{S}{4\mathcal{P}_{\bullet} \mathcal{P}_{\bullet}} [(\partial_i - i\bar{C}_i)^{ab} \partial^i \bar{A}_{\bullet}^b - iF_{\bullet i}^{ab} \bar{C}_i^c + \bar{\Upsilon} t^a \hat{p}_1 \Upsilon] \\ \bar{c}_{\bullet}^a & = \frac{i}{2\mathcal{P}_{\bullet} \mathcal{P}_{\bullet}} \bar{\mathcal{P}}_{\bullet}^{aa'} f^{a'bc} (\tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c + \tilde{C}_{\bullet}^b \bar{c}_{\bullet}^c) + \frac{S}{4\mathcal{P}_{\bullet} \mathcal{P}_{\bullet}} [(\partial_i - i\bar{C}_i)^{ab} \partial^i \bar{A}_{\bullet}^b - iF_{\bullet i}^{ab} \bar{C}_i^c + \bar{\Upsilon} t^a \hat{p}_1 \Upsilon] \end{aligned} \tag{275}$$

⇒

$$\begin{aligned}
\mathcal{P}_* \bar{c}_*^a &= \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c + \tilde{C}_*^c \bar{c}_*^b) + \frac{s}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] \\
&= \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c + \tilde{C}_*^c \bar{c}_*^b) + \frac{s}{4 \mathcal{P}_*} [-\mathcal{D}^i F_{*i}^a + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] - \frac{is}{4} \partial^i \bar{C}_i \\
\mathcal{P}_* \bar{c}_*^a &= \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c + \tilde{C}_*^c \bar{c}_*^b) + \frac{s}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] \\
&= \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c + \tilde{C}_*^c \bar{c}_*^b) + \frac{s}{4 \mathcal{P}_*} [-\mathcal{D}^i F_{*i}^a + \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon] - \frac{is}{4} \partial^i \bar{C}_i
\end{aligned} \tag{276}$$

⇒

$$\begin{aligned}
\bar{P}_* \bar{c}_*^a &= \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c - \tilde{C}_*^c \bar{c}_*^b) + \frac{s}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] \\
&= \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c - \tilde{C}_*^c \bar{c}_*^b) + \frac{s}{4 \mathcal{P}_*} [-\mathcal{D}^i F_{*i}^a + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] - \frac{is}{4} \partial^i \bar{C}_i = \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c - \tilde{C}_*^c \bar{c}_*^b) + \frac{i}{2} F_{*i}^{1a} - \frac{is}{4} \partial^i \bar{C}_i \\
\bar{P}_* \bar{c}_*^a &= \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c - \tilde{C}_*^c \bar{c}_*^b) + \frac{s}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon] = \frac{i}{2} g f^{abc} (\tilde{C}_*^b \bar{c}_*^c - \tilde{C}_*^c \bar{c}_*^b) - \frac{i}{2} F_{*i}^{1a} - \frac{is}{4} \partial^i \bar{C}_i \\
\Rightarrow \bar{P}_* \bar{c}_*^a + \bar{P}_* \bar{c}_*^a &= \frac{s}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] + \frac{s}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon]
\end{aligned} \tag{277}$$

$$\begin{aligned}
&\Rightarrow \frac{2}{s} (\bar{P}_* \bar{c}_* + \bar{P}_* \bar{c}_*)^a + i \partial^i \bar{C}_i \\
&= \frac{1}{2 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon - \mathcal{D}_* \partial^i \bar{C}_i] + \frac{1}{2 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ac} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon - \mathcal{D}_* \partial^i \bar{C}_i] \\
&= -\frac{1}{2 \mathcal{P}_*} [\mathcal{D}^i F_{*i}^a - \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] - \frac{1}{2 \mathcal{P}_*} [\mathcal{D}^i F_{*i}^a + \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon] = 0 \quad \text{due to formula 290}
\end{aligned} \tag{278}$$

$$\begin{aligned}
F_{*i} &= \mathcal{D}_* \bar{C}_i - \partial_i \mathcal{A}_*, \quad [\mathcal{D}_*, \mathcal{D}_i] = -i F_{*i} \\
\Rightarrow (\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ac} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon - \mathcal{D}_* \partial^i \bar{C}_i &= \mathcal{D}_i^{ab} (\mathcal{D}_* \bar{C}_i - F_{*i}^b) - i F_{*i}^{ac} \bar{C}_i^c - (\mathcal{D}_* \mathcal{D}^i)^{ab} \bar{C}_i^b + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon \\
&= i F_{*i}^{ab} \bar{C}_i^b - \mathcal{D}^i F_{*i}^a - i F_{*i}^{ac} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon = -\mathcal{D}^i F_{*i}^a + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon
\end{aligned} \tag{279}$$

From Eq. (276) we get

$$\begin{aligned}
F_{*i}^{(1)} &= \mathcal{D}_* \bar{c}_* - \mathcal{D}_* \bar{c}_* = -\frac{is}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] + \frac{is}{4 \mathcal{P}_*} [(\partial_i - i \bar{C}_i)^{ab} \partial^i \mathcal{A}_*^b - i F_{*i}^{ab} \bar{C}_i^c + \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon] \\
&= -\frac{is}{4 \mathcal{P}_*} [-\mathcal{D}^i F_{*i}^a + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon + \mathcal{D}_* \partial^i \bar{C}_i^a] + \frac{is}{4 \mathcal{P}_*} [-\mathcal{D}^i F_{*i}^a + \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon + \mathcal{D}_* \partial^i \bar{C}_i^a] = \frac{is}{4 \mathcal{P}_*} [\mathcal{D}^i F_{*i}^a - \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] - \frac{is}{4 \mathcal{P}_*} [\mathcal{D}^i F_{*i}^a - \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon]
\end{aligned} \tag{280}$$

Useful f-las

$$F_{*i} = \Omega_x [-\infty_*, x_*]_{x_*}^{\bar{A} \bullet} \bar{G}_{*i}^{\bar{A} \bullet} (x_*, x_\perp) [x_*, -\infty_*]_{x_*}^{\bar{A} \bullet} \Omega_x^\dagger, \quad ([-\infty_*, x_*]_{x_*}^{\bar{A} \bullet} \bar{G}_{*i}^{\bar{A} \bullet} (x_*, x_\perp) [x_*, -\infty_*]_{x_*}^{\bar{A} \bullet})^{ab} = -i f^{abc} ([-\infty_*, x_*]_{x_*}^{\bar{A} \bullet})^{cd} \bar{G}_{*i}^{\bar{A} \bullet} (x_*, x_\perp) \tag{281}$$

$$F_{*i}^{(1)a} = (\Omega_x [-\infty_*, x_*]_{x_*}^{\bar{A} \bullet})^{ab} \bar{G}_{*i}^{\bar{A} \bullet} (x_*, x_\perp) \tag{282}$$

From Eq. (220)

$$\bar{C}_i(x) = \Omega_x i \partial_i \Omega_x^\dagger + i \Omega_x [-\infty_*, x_*]_{x_*}^{\bar{A} \bullet} (\partial_i [x_*, -\infty_*]_{x_*}^{\bar{A} \bullet}) \Omega_x^\dagger + i \Omega_x [-\infty_\bullet, x_\bullet]_{x_\bullet}^{\bar{A} *} (\partial_i [x_\bullet, -\infty_\bullet]_{x_\bullet}^{\bar{A} *}) \Omega_x^\dagger \tag{283}$$

$$\left( \frac{is}{4 \mathcal{P}_* \mathcal{P}_*} F_{*i} \right)^{ab} F_*^{bi} = \left( \frac{-s}{4 \mathcal{P}_* \mathcal{P}_*} \right)^{aa'} f^{a'bc} F_{*i}^b F_*^{ci} = -\frac{s}{4} f^{abc} \bar{C}_i^{1a} \bar{C}_i^{2bi} \tag{284}$$

Dlya prichinnogo obxoda (see Eq. (333))

$$\tilde{\Upsilon} t^a \hat{p}_1 \Upsilon = (\Omega_x \Omega_x^\dagger (x_*, -\infty_\bullet, x_\perp))^{am} \bar{\xi}_b t^m \hat{p}_1 \xi_b = (\Omega_x [-\infty_*, x_*]_{x_*}^{\bar{A} \bullet})^{am} \bar{\xi}_b t^m \hat{p}_1 \xi_b \tag{285}$$

EU,Ë PA3 (see Eq. (271) for definitions)

$$\bar{C}_i^a = (\Omega i \partial_i \Omega^\dagger)^a + i \Omega_x^{ab} ([-\infty_*, x_*]_{x_*}^{\bar{A} \bullet} \partial_i [x_*, -\infty_*]_{x_*}^{\bar{A} \bullet})^b + i \Omega_x^{ab} ([-\infty_\bullet, x_\bullet]_{x_\bullet}^{\bar{A} *} \partial_i [x_\bullet, -\infty_\bullet]_{x_\bullet}^{\bar{A} *})^b = \Omega_i^a + \bar{C}_i^{1a} + \bar{C}_i^{2a} \tag{286}$$

$$\begin{aligned}
2\mathcal{P}_*\mathcal{P}_*\bar{c}_*^a &= -g\bar{\mathcal{D}}_*^{aa'}f^{a'bc}(\tilde{C}_*^b\bar{c}_*^c + \tilde{C}_*^b\bar{c}_*^c) - \frac{s}{2}\mathcal{D}^iF_{*i}^a + \frac{s}{2}\tilde{\Upsilon}t^a\hat{p}_1\Upsilon + \frac{s}{2}\mathcal{D}_*\mathcal{D}^i\bar{C}_i^a \\
2\mathcal{P}_*\mathcal{P}_*\bar{c}_*^a &= -g\bar{\mathcal{D}}_*^{aa'}f^{a'bc}(\tilde{C}_*^b\bar{c}_*^c + \tilde{C}_*^b\bar{c}_*^c) - \frac{s}{2}\mathcal{D}^iF_{*i}^a + \frac{s}{2}\tilde{\Upsilon}t^a\hat{p}_1\Upsilon + \frac{s}{2}\mathcal{D}_*\mathcal{D}^i\bar{C}_i^a
\end{aligned} \tag{287}$$

⇒ Equation:

$$\begin{aligned}
\mathcal{P}_*\bar{c}_*^a &= \frac{i}{2}gf^{abc}(\tilde{C}_*^b\bar{c}_*^c + \tilde{C}_*^b\bar{c}_*^c) + \frac{s}{4\mathcal{P}_*}[-\mathcal{D}^iF_{*i}^a + \tilde{\Upsilon}t^a\hat{p}_1\Upsilon] - \frac{is}{4}\partial^i\bar{C}_i = \frac{i}{2}gf^{abc}(\tilde{C}_*^b\bar{c}_*^c + \tilde{C}_*^b\bar{c}_*^c) + \frac{i}{2}F_{*i}^{1a} - \frac{is}{4}\partial^i\bar{C}_i \\
\mathcal{P}_*\bar{c}_*^a &= \frac{i}{2}gf^{abc}(\tilde{C}_*^b\bar{c}_*^c + \tilde{C}_*^b\bar{c}_*^c) + \frac{s}{4\mathcal{P}_*}[-\mathcal{D}^iF_{*i}^a + \tilde{\Upsilon}t^a\hat{p}_2\Upsilon] - \frac{is}{4}\partial^i\bar{C}_i = \frac{i}{2}gf^{abc}(\tilde{C}_*^b\bar{c}_*^c + \tilde{C}_*^b\bar{c}_*^c) - \frac{i}{2}F_{*i}^{1a} - \frac{is}{4}\partial^i\bar{C}_i
\end{aligned} \tag{288}$$

From Eq. (285), (281), (282), and (333) we get

$$\begin{aligned}
\mathcal{D}^iF_{*i}^m - \tilde{\Upsilon}t^m\hat{p}_1\Upsilon &= (\partial_i - i\Omega^i - iC_{(1)}^i - iC_{(2)}^i)^{ma}F_{*i}^a - (\Omega(x)[- \infty_*, x_*]_{x_*}^{\bar{A}\bullet})^{ma}\bar{\xi}_{bt}^a\hat{p}_1\xi_b = \Omega_x^{ma}\left(\partial^i[- \infty_*, x_*]_{\bar{A}\bullet}^{ab}\bar{G}_{*i}^b\right. \\
&+ \left.([- \infty_*, x_*]_{\bar{A}\bullet}(\partial^i[x_*, - \infty_*]_{\bar{A}\bullet}^{\bar{A}\bullet})[- \infty_*, x_*]_{\bar{A}\bullet}) + \left([- \infty_*, x_*]_{\bar{A}\bullet}(\partial^i[x_*, - \infty_*]_{\bar{A}\bullet}^{\bar{A}\bullet})[- \infty_*, x_*]_{\bar{A}\bullet}\right)^{ab}\bar{G}_{*i}^b - [- \infty_*, x_*]_{\bar{A}\bullet}^{ab}\bar{\xi}_{bt}^b\hat{p}_1\xi_b\right) \\
&= \Omega_x^{ma}\left([- \infty_*, x_*]_{\bar{A}\bullet}(\partial^i[x_*, - \infty_*]_{\bar{A}\bullet}^{\bar{A}\bullet})[- \infty_*, x_*]_{\bar{A}\bullet}\right)^{ab}\bar{G}_{*i}^b(x_*) = \Omega_x^{ma}f^{abc}\int_{-\infty}^{x_*}d\frac{2}{s}z_*[- \infty_*, z_*]_{\bar{A}\bullet}^{bk}\bar{G}_{*i}^k(z_*)[- \infty_*, x_*]_{\bar{A}\bullet}^{cl}\bar{G}_{*i}^{li}(x_*) \\
&= if^{abc}\left(\frac{1}{\mathcal{P}_*}F_{*i}^a\right)^bF_{*i}^{ci}
\end{aligned} \tag{289}$$

$$\begin{aligned}
\Rightarrow \frac{s}{4\mathcal{P}_*}(\mathcal{D}^iF_{*i}^m - \tilde{\Upsilon}t^m\hat{p}_1\Upsilon) &= \frac{s}{4}\Omega_x^{ma}f^{abc}\int_{-\infty}^{x_*}d\frac{2}{s}z_*[- \infty_*, z_*]_{\bar{A}\bullet}^{bk}\bar{G}_{*i}^k(z_*)\frac{1}{\mathcal{P}_*}[- \infty_*, x_*]_{\bar{A}\bullet}^{cl}\bar{G}_{*i}^{li}(x_*) \\
&= \Omega_x^{ma}\left(-\frac{isf^{abc}}{4}\right)\int_{-\infty}^{x_*}d\frac{2}{s}z_*[- \infty_*, z_*]_{\bar{A}\bullet}^{bk}\bar{G}_{*i}^k(z_*)\int_{-\infty}^{x_*}d\frac{2}{s}z_*[- \infty_*, z_*]_{\bar{A}\bullet}^{cl}\bar{G}_{*i}^{li}(z_*) = \frac{is}{4}f^{mabc}\left(\frac{1}{\mathcal{P}_*}F_{*i}^a\right)^b\left(\frac{1}{\mathcal{P}_*}F_{*i}^a\right)^c = -\frac{s}{4\mathcal{P}_*}(\mathcal{D}^iF_{*i}^m - \tilde{\Upsilon}t^m\hat{p}_2\Upsilon)
\end{aligned} \tag{290}$$

From Eqs. (280), (298) and (290) we get

$$F_{*i}^{(1)a} = -\frac{s}{2}f^{abc}\left(\frac{1}{\mathcal{P}_*}F_{*i}^a\right)^b\left(\frac{1}{\mathcal{P}_*}F_{*i}^a\right)^c = \Omega_x^{aa'}(-if^{a'bc})\int_{-\infty}^{x_*}d\frac{2}{s}z_*[- \infty_*, z_*]_{\bar{A}\bullet}^{bk}\bar{G}_{*i}^k(z_*)\int_{-\infty}^{x_*}d\frac{2}{s}z_*[- \infty_*, z_*]_{\bar{A}\bullet}^{cl}\bar{G}_{*i}^{li}(z_*) \tag{291}$$

$$\Rightarrow \mathcal{D}_*F_{*i}^a = \frac{s}{4}[\mathcal{D}^iF_{*i}^a - \tilde{\Upsilon}t^a\hat{p}_1\Upsilon] - \frac{is}{4\mathcal{P}_*}\mathcal{D}_*[\mathcal{D}^iF_{*i}^a - \tilde{\Upsilon}t^a\hat{p}_2\Upsilon] = \frac{s}{2}[\mathcal{D}^iF_{*i}^a - \tilde{\Upsilon}t^a\hat{p}_1\Upsilon] \Rightarrow \mathcal{D}^\mu F_{*\mu}^a = \tilde{\Upsilon}t^a\hat{p}_1\Upsilon \tag{292}$$

ПРЕДПОЛОЖИТЕЛ'НО,  $\mathcal{D}^\mu F_{*\mu}^a = -\tilde{\Upsilon}t^a\gamma_\nu\Upsilon$  ВО ВСЕХ ПОПАДКАХ ПО  $\partial_\perp$

$$\begin{aligned}
\mathcal{P}_*\bar{c}_*^a &= \frac{1}{2}\tilde{C}_*^{ab}\bar{c}_*^b + \frac{1}{2}\tilde{C}_*^{ab}\bar{c}_*^b + \frac{i}{2}F_{*i}^{1a} - \frac{is}{4}\partial^i\bar{C}_i^a \\
\mathcal{P}_*\bar{c}_*^a &= \frac{1}{2}\tilde{C}_*^{ab}\bar{c}_*^b + \frac{1}{2}\tilde{C}_*^{ab}\bar{c}_*^b - \frac{i}{2}F_{*i}^{1a} - \frac{is}{4}\partial^i\bar{C}_i^a
\end{aligned} \tag{293}$$

$$\begin{aligned}
\bar{c}_*^{(0)a} &= \left(\frac{i}{2\mathcal{P}_*}\right)^{ab}F_{*i}^{1b}, \quad \bar{c}_*^{(0)a} = -\left(\frac{i}{2\mathcal{P}_*}\right)^{ab}F_{*i}^{1b}, \\
\bar{c}_*^{(1)a} &= \frac{i}{4}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{i}{4}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \left(\frac{is}{4\mathcal{P}_*}\right)^{ab}\partial^i\bar{C}_i^b \\
\bar{c}_*^{(1)a} &= \frac{i}{4}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{i}{4}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \left(\frac{is}{4\mathcal{P}_*}\right)^{ab}\partial^i\bar{C}_i^b \\
\bar{c}_*^{(2)a} &= \frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{is}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}\partial^i\bar{C}_i^b \\
&+ \frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{is}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}\partial^i\bar{C}_i^b \\
\bar{c}_*^{(2)a} &= -\frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} + \frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{is}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}\partial^i\bar{C}_i^b \\
&- \frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} + \frac{i}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}F_{*i}^{1b} - \frac{is}{8}\left(\frac{1}{\mathcal{P}_*}\tilde{C}_*\frac{1}{\mathcal{P}_*}\right)^{ab}\partial^i\bar{C}_i^b
\end{aligned} \tag{294}$$

$$\begin{aligned}
\bar{c}_\bullet^{(3)a} &= \frac{i}{16} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} - \frac{i}{16} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} - \frac{is}{16} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} \partial^i \bar{C}_i^b \\
&+ \frac{i}{16} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} - \frac{i}{16} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} - \frac{is}{16} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} \partial^i \bar{C}_i^b \\
&- \frac{i}{16} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} + \frac{i}{8} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} - \frac{is}{8} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} \partial^i \bar{C}_i^b \\
&- \frac{i}{8} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} + \frac{i}{8} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} F_{*\bullet}^{1b} - \frac{is}{8} \left( \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \tilde{C}_* \frac{1}{\mathcal{P}_*} \right)^{ab} \partial^i \bar{C}_i^b
\end{aligned} \tag{295}$$

$$\bar{c} = c + d$$

$$\begin{aligned}
(2\mathcal{P}_* - \tilde{C}_*)^{ab} d_\bullet^b &= \tilde{C}_\bullet^{ab} d_\bullet^b - \frac{is}{2} \partial^i \bar{C}_i^a \Rightarrow d_\bullet^a = \left( \mathcal{P}_* \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( -\frac{is}{2} \partial^i \bar{C}_i^b \right) \\
(2\mathcal{P}_\bullet - \tilde{C}_\bullet)^{ab} d_\bullet^a &= \tilde{C}_*^{ab} d_\bullet^a - \frac{is}{2} \partial^i \bar{C}_i^a \Rightarrow d_\bullet^a = \left( \mathcal{P}_* \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( -\frac{is}{2} \partial^i \bar{C}_i^b \right)
\end{aligned} \tag{296}$$

$$\begin{aligned}
(2\mathcal{P}_* - \tilde{C}_*)^{ab} c_\bullet^b &= \tilde{C}_\bullet^{ab} c_\bullet^b + iF_{*\bullet}^{1a} \Rightarrow c_\bullet^a = \left( (\mathcal{P}_\bullet - \tilde{C}_\bullet) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) + X_1 \\
(2\mathcal{P}_\bullet - \tilde{C}_\bullet)^{ab} c_\bullet^a &= \tilde{C}_*^{ab} c_\bullet^a - iF_{*\bullet}^{1a} \Rightarrow c_\bullet^a = - \left( (\mathcal{P}_* - \tilde{C}_*) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) - X_2
\end{aligned} \tag{297}$$

Чек:

$$\begin{aligned}
& \left( (2\mathcal{P}_* - \tilde{C}_*) (\mathcal{P}_\bullet - \tilde{C}_\bullet) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) + \tilde{C}_\bullet^{ab} \left( (\mathcal{P}_* - \tilde{C}_*) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) \\
&= \left( (2\mathcal{P}_* \mathcal{P}_\bullet - 2\mathcal{P}_* \tilde{C}_\bullet - \tilde{C}_* \mathcal{P}_\bullet + \tilde{C}_* \tilde{C}_\bullet + \tilde{C}_\bullet \mathcal{P}_* - \tilde{C}_\bullet \tilde{C}_*) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) = \frac{i}{2} F_{*\bullet}^{1a} + \dots
\end{aligned} \tag{298}$$

$$\begin{aligned}
& \left( (2\mathcal{P}_\bullet - \tilde{C}_\bullet) (\mathcal{P}_* - \tilde{C}_*) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) + \tilde{C}_*^{ab} \left( (\mathcal{P}_\bullet - \tilde{C}_\bullet) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) \\
&= \left( (2\mathcal{P}_\bullet \mathcal{P}_* - 2\mathcal{P}_\bullet \tilde{C}_* - \tilde{C}_\bullet \mathcal{P}_* + \tilde{C}_\bullet \tilde{C}_* + \tilde{C}_* \mathcal{P}_\bullet - \tilde{C}_\bullet \tilde{C}_\bullet) \frac{1}{2\mathcal{P}_* \mathcal{P}_* - \tilde{C}_* \mathcal{P}_* - \tilde{C}_\bullet \mathcal{P}_*} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) = \frac{i}{2} F_{*\bullet}^{1a} + \dots
\end{aligned} \tag{299}$$

bikoz

$$2\mathcal{P}_* \mathcal{P}_\bullet - 2\mathcal{P}_* \tilde{C}_\bullet - \tilde{C}_* \mathcal{P}_\bullet + \tilde{C}_* \tilde{C}_\bullet + \tilde{C}_\bullet \mathcal{P}_* - \tilde{C}_\bullet \tilde{C}_* - (2\mathcal{P}_* \mathcal{P}_\bullet - \tilde{C}_* \mathcal{P}_\bullet - \tilde{C}_\bullet \mathcal{P}_*) = -2[\mathcal{P}_*, \tilde{C}_\bullet] + [\tilde{C}_*, \tilde{C}_\bullet] = i\tilde{G}_{*\bullet} \tag{300}$$

due to Eq. (179).

$$\text{ПРОВЕРУМ АНЗАТЦ } (\mathcal{Z} \equiv 2\mathcal{P}_* \mathcal{P}_\bullet - \tilde{C}_* \mathcal{P}_\bullet - \tilde{C}_\bullet \mathcal{P}_* = \bar{P}_* \mathcal{P}_\bullet + \bar{P}_\bullet \mathcal{P}_*)$$

$$\begin{aligned}
c_\bullet^a &= \left( (\mathcal{P}_\bullet - \tilde{C}_\bullet) \frac{1}{\mathcal{Z}} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) - \left( \mathcal{P}_\bullet \frac{1}{\mathcal{Z}} i\tilde{G}_{*\bullet} \frac{1}{\mathcal{Z}} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) \\
c_\bullet^a &= - \left( (\mathcal{P}_* - \tilde{C}_*) \frac{1}{\mathcal{Z}} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) - \left( \mathcal{P}_* \frac{1}{\mathcal{Z}} i\tilde{G}_{*\bullet} \frac{1}{\mathcal{Z}} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right)
\end{aligned} \tag{301}$$

ОТ УР. (288) ДО УР. (303) КОЕ-ГДЕ НЕТЫ ДВОЕК В ЗНАМЕНАТЕЛЕ

$$\begin{aligned}
(2\mathcal{P}_* - \tilde{C}_*)^{ab} c_\bullet^b - \tilde{C}_\bullet^{ab} c_\bullet^b &= \left( (2\mathcal{P}_* - \tilde{C}_*) (\mathcal{P}_\bullet - \tilde{C}_\bullet) + \tilde{C}_\bullet (\mathcal{P}_* - \tilde{C}_*) \right) \frac{1}{\mathcal{Z}} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) \\
- \left( (2\mathcal{P}_* - \tilde{C}_*) \mathcal{P}_\bullet \frac{1}{\mathcal{Z}} i\tilde{G}_{*\bullet} \frac{1}{\mathcal{Z}} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) &+ \left( \tilde{C}_\bullet \mathcal{P}_* \frac{1}{\mathcal{Z}} i\tilde{G}_{*\bullet} \frac{1}{\mathcal{Z}} \right)^{ab} \left( \frac{i}{2} F_{*\bullet}^{1b} \right) = \frac{i}{2} F_{*\bullet}^{1b}
\end{aligned} \tag{302}$$

РЕШЕНИЕ УРАВНЕНИЙ (288)

$$\begin{aligned}
\bar{c}_\bullet^a &= i \left( \bar{P}_\bullet \frac{1}{\mathcal{Z}} \right)^{ab} F_{*\bullet}^{1b} - i \left( \mathcal{P}_\bullet \frac{1}{\mathcal{Z}} i\tilde{G}_{*\bullet} \frac{1}{\mathcal{Z}} \right)^{ab} F_{*\bullet}^{1b} - \frac{is}{2} \left( \mathcal{P}_\bullet \frac{1}{\mathcal{Z}} \right)^{ab} \partial^i \bar{C}_i^b \\
\bar{c}_*^a &= -i \left( \bar{P}_* \frac{1}{\mathcal{Z}} \right)^{ab} F_{*\bullet}^{1b} - i \left( \mathcal{P}_* \frac{1}{\mathcal{Z}} i\tilde{G}_{*\bullet} \frac{1}{\mathcal{Z}} \right)^{ab} F_{*\bullet}^{1b} - \frac{is}{2} \left( \mathcal{P}_* \frac{1}{\mathcal{Z}} \right)^{ab} \partial^i \bar{C}_i^b
\end{aligned} \tag{303}$$

где  $\mathcal{Z} \equiv \bar{P}_* \mathcal{P}_\bullet + \bar{P}_\bullet \mathcal{P}_* = \mathcal{P}_\bullet \bar{P}_* + \mathcal{P}_* \bar{P}_\bullet$ ,  $\mathcal{P} = \bar{P} + \tilde{A}$ ,  $\tilde{A}_\bullet = \bar{A}_\bullet + \tilde{C}_\bullet = i\Omega \partial_\bullet \Omega^\dagger$ ,  $\tilde{A}_* = i\Omega \partial_* \Omega^\dagger$

Чек:  $\mathcal{P}_* \bar{c}_\bullet - \mathcal{P}_\bullet \bar{c}_* = iF_{*\bullet}^{(1)}$ ,  $\bar{P}_* \bar{c}_\bullet + \bar{P}_\bullet \bar{c}_* = -\frac{is}{2} \partial^i \bar{C}_i$

2.  $F_{\bullet i}$  BO BTOFOM ПОРАДКЕ

В ПЕРВОМ ПОРАДКЕ  $\mathcal{P}_{\bullet} \equiv p_{\bullet} + \mathcal{A}_{\bullet}$ ,  $\mathcal{A}_{\bullet} \equiv \bar{A}_{\bullet} + \tilde{C}_{\bullet}$ ,  $\mathcal{A}_i \equiv \tilde{C}_i = \Omega_i + C_{1i} + C_{2i}$ , and

$$2\mathcal{P}_{\bullet}\mathcal{P}_{\bullet}\tilde{C}_i = i(\mathcal{P}_{\bullet}\partial_i\mathcal{A}_{\bullet} + \mathcal{P}_{\bullet}\partial_i\mathcal{A}_{\bullet})$$

В СЛЕДУЮЩЕМ ПОРАДКЕ

$$\bar{C}_i = \tilde{C}_i + \bar{c}_i, \quad F_{\bullet i} = F_{\bullet i}^{(1)} + F_{\bullet i}^{(2)} = \mathcal{D}_{\bullet}\bar{C}_i - \partial_i\mathcal{A}_{\bullet} + \mathcal{D}_{\bullet}\bar{c}_i - \mathcal{D}_i\bar{c}_{\bullet} \quad (304)$$

УЗ УР. Eq. (226) ПОЛУЧАЕМ

$$\begin{aligned} & (2\mathcal{P}_{\bullet}\mathcal{P}_{\bullet})^{ab}\bar{c}_i^b \quad (305) \\ &= (-\{\mathcal{P}_{\bullet}, \bar{c}_{\bullet}\} - \{\mathcal{P}_{\bullet}, \bar{c}_{\bullet}\} + \frac{s}{2}(p + \bar{C})_{\perp}^2)^{ab}\bar{C}_i^b - f^{abc}(\bar{c}_{\bullet}^b\partial_i\mathcal{A}_{\bullet}^c + \bar{c}_{\bullet}^b\partial_i\mathcal{A}_{\bullet}^c) - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b + \frac{is}{2}\mathcal{P}_j^{ab}\partial_i\tilde{C}^{bj} + \frac{s}{2}\tilde{\Upsilon}\gamma_i t^a \Upsilon \\ &= (-\mathcal{P}_{\bullet}\bar{c}_{\bullet} - \mathcal{P}_{\bullet}\bar{c}_{\bullet} - \frac{s}{2}\mathcal{P}_j\mathcal{P}_j)^{ab}\bar{C}_i^b + f^{abc}(\bar{c}_{\bullet}^b F_{\bullet i}^{(1)c} + \bar{c}_{\bullet}^b F_{\bullet i}^{(1)c}) - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b + \frac{is}{2}\mathcal{P}_j^{ab}\partial_i\tilde{C}^{bj} + \frac{s}{2}\tilde{\Upsilon}\gamma_i t^a \Upsilon \\ &= (-\mathcal{P}_{\bullet}\bar{c}_{\bullet} - \mathcal{P}_{\bullet}\bar{c}_{\bullet})^{ab}\bar{C}_i^b + f^{abc}(\bar{c}_{\bullet}^b F_{\bullet i}^{(1)c} + \bar{c}_{\bullet}^b F_{\bullet i}^{(1)c}) - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b - \frac{s}{2}\mathcal{D}^j F_{ij}^{(1)a} + \frac{s}{2}\tilde{\Upsilon}\gamma_i t^a \Upsilon = \\ &= (\mathcal{P}_{\bullet}\bar{C}_i)^{ab}\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} - \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} + ((\mathcal{D}_{\bullet} - i\bar{c}_{\bullet})F_{\bullet i}^{(1+2)a} + (\mathcal{D}_{\bullet} - i\bar{c}_{\bullet})F_{\bullet i}^{(1+2)a} + \frac{s}{2}\mathcal{D}^j F_{ji}^{(1)a} + \frac{s}{2}\tilde{\Upsilon}\gamma_i t^a \Upsilon) \\ &= (\mathcal{P}_{\bullet}\bar{C}_i)^{ab}\bar{c}_{\bullet}^b + (\mathcal{P}_{\bullet}\bar{C}_i)^{ab}\bar{c}_{\bullet}^b + i\mathcal{P}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b + i\mathcal{P}_{\bullet}^{ab}\partial_i\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} - \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} = (\mathcal{P}_{\bullet}\mathcal{P}_i)^{ab}\bar{c}_{\bullet}^b + (\mathcal{P}_{\bullet}\mathcal{P}_i)^{ab}\bar{c}_{\bullet}^b - \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} - \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} \quad (306) \end{aligned}$$

$$(2\mathcal{P}_{\bullet}\mathcal{P}_{\bullet})^{ab}\bar{c}_i^b = (\mathcal{P}_{\bullet}\mathcal{P}_i)^{ab}\bar{c}_{\bullet}^b + (\mathcal{P}_{\bullet}\mathcal{P}_i)^{ab}\bar{c}_{\bullet}^b - f^{abc}(F_{\bullet i}^{(1)b}\bar{c}_{\bullet}^c + F_{\bullet i}^{(1)b}\bar{c}_{\bullet}^c) + \frac{s}{2}\mathcal{D}^j F_{ji}^{(1)a} + \frac{s}{2}\tilde{\Upsilon}\gamma_i t^a \Upsilon \quad (307)$$

$$\begin{aligned} & \Rightarrow (2\mathcal{P}_{\bullet}\mathcal{P}_{\bullet})^{ab}\bar{c}_i^b = (\mathcal{P}_{\bullet}\mathcal{P}_i + iF_{\bullet i}^{(1)})^{ab}\bar{c}_{\bullet}^b + (\mathcal{P}_{\bullet}\mathcal{P}_i + iF_{\bullet i}^{(1)})^{ab}\bar{c}_{\bullet}^b + \frac{s}{2}\mathcal{D}^j F_{ji}^{(1)a} + \frac{s}{2}\tilde{\Upsilon}\gamma_i t^a \Upsilon \\ &= (2\mathcal{P}_{\bullet}\mathcal{P}_i)^{ab}\bar{c}_{\bullet}^b + 2iF_{\bullet i}^{(1)ab}\bar{c}_{\bullet}^b + \mathcal{D}_i F_{\bullet i}^{(1)} + \frac{s}{2}\mathcal{D}^j F_{ji}^{(1)a} + \frac{s}{2}\tilde{\Upsilon}\gamma_i t^a \Upsilon \quad (308) \end{aligned}$$

$\Rightarrow$

$$F_{\bullet i}^{(2)a} = -i\mathcal{P}_{\bullet}^{ab}\bar{c}_i^b + i\mathcal{P}_i^{ab}\bar{c}_{\bullet}^b = \left(\frac{1}{\mathcal{P}_{\bullet}}F_{\bullet i}^{(1)}\right)^{ab}\bar{c}_{\bullet}^b - \left(\frac{i}{2\mathcal{P}_{\bullet}}\right)^{ab}\mathcal{D}_i F_{\bullet i}^{(1)} - \left(\frac{is}{4\mathcal{P}_{\bullet}}\right)^{ab}(\mathcal{D}^j F_{ji}^{(1)a} + \tilde{\Upsilon}\gamma_i t^a \Upsilon) \quad (309)$$

Check of YM equations for the field

$$A_{\bullet}^{[2]a} = \bar{A}_{\bullet} + \tilde{C}_{\bullet} + \bar{c}_{\bullet}, \quad A_{\bullet}^{[2]a} = \bar{A}_{\bullet} + \tilde{C}_{\bullet} + \bar{c}_{\bullet}, \quad A_i^{[3]a} = \tilde{C}_i + \bar{c}_i, \quad \Upsilon^{[1]} = \Omega_x([-\infty_{\bullet}, x_{\bullet}]_x^{\hat{A}_{\bullet}} \xi_a(x) + [-\infty_{\bullet}, x_{\bullet}]_x^{\hat{A}_{\bullet}} \xi_b(x)) \quad (310)$$

$$\begin{aligned} & \mathcal{D}_{\bullet} F_{\bullet i}^{(1)a} + \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} - i\bar{c}_{\bullet} F_{\bullet i}^{(1)a} = -\frac{1}{2}\mathcal{D}_i F_{\bullet i}^{(1)a} - \frac{s}{4}(\mathcal{D}^j F_{ji}^{(1)a} + \tilde{\Upsilon}\gamma_i t^a \Upsilon), \\ & \mathcal{D}_{\bullet} F_{\bullet i}^{(1)a} + \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} - i\bar{c}_{\bullet} F_{\bullet i}^{(1)a} = \frac{1}{2}\mathcal{D}_i F_{\bullet i}^{(1)a} - \frac{s}{4}(\mathcal{D}^j F_{ji}^{(1)a} + \tilde{\Upsilon}\gamma_i t^a \Upsilon) \\ & \Rightarrow \frac{2}{s}[\mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} - i\bar{c}_{\bullet} F_{\bullet i}^{(1)a} + \mathcal{D}_{\bullet} F_{\bullet i}^{(2)a} - i\bar{c}_{\bullet} F_{\bullet i}^{(1)a}] + \mathcal{D}^j F_{ji}^{(1)a} = -\tilde{\Upsilon}\gamma_i t^a \Upsilon \\ & \Rightarrow D^{\mu} F_{\mu i}^{[3]a} = \tilde{\Upsilon}\gamma_i t^a \Upsilon + O(\partial_{\perp}^4) \quad (311) \end{aligned}$$

For  $\bullet$  projection, rewrite Eq. (292)

$$\mathcal{D}_{\bullet} F_{\bullet i}^{[2]a} = \frac{s}{4}[\mathcal{D}^j F_{\bullet i}^{[1]a} - \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] - \frac{is}{4\mathcal{P}_{\bullet}}\mathcal{D}_{\bullet}[\mathcal{D}^i F_{\bullet i}^{[1]a} - \tilde{\Upsilon} t^a \hat{p}_2 \Upsilon] = \frac{s}{2}[\mathcal{D}^i F_{\bullet i}^{[1]a} - \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon] \Rightarrow \mathcal{D}^{\mu} F_{\bullet \mu}^a = \tilde{\Upsilon} t^a \hat{p}_1 \Upsilon + O(\partial_{\perp}^3) \quad (312)$$

GDE  $F_{\bullet i}^{[1]a}$  ДАЕТЦА ФОРМУЛОЎ (224)

3. First order in  $\bar{A}_\bullet, \bar{A}_*$ 

$$\begin{aligned}
\bar{C}_\bullet^{1a}(x) &= -\frac{i}{2} \int dz(x) \left| \frac{1}{p_* + i\epsilon p_\bullet} \right| z \bar{G}_{*\bullet}^a(z) = -\frac{i}{2} f^{abc} \int dz(x) \left| \frac{1}{p_* + i\epsilon p_\bullet} \right| z \bar{A}_*^b \bar{A}_\bullet^c(z), \\
\bar{C}_*^{1a}(x) &= \frac{i}{2} \int d^2z(x) \left| \frac{1}{p_\bullet + i\epsilon p_*} \right| z \bar{G}_{*\bullet}^a(z) = \frac{i}{2} f^{abc} \int dz(x) \left| \frac{1}{p_* + i\epsilon p_\bullet} \right| z \bar{A}_*^b \bar{A}_\bullet^c(z), \\
\bar{C}_i^{1a}(x) &= \frac{1}{2} \int dz(x) \left| \frac{1}{p_* p_\bullet + i\epsilon} \right| z (\bar{D}_* \bar{G}_{*\bullet}^a(z) + \bar{D}_\bullet \bar{G}_{*i}^a(z)) = -\frac{1}{2} f^{abc} \int dz(x) \left| \frac{1}{p_* p_\bullet + i\epsilon} \right| z (A_\bullet^b \partial_i A_*^c + A_*^b \partial_i A_\bullet^c) \\
F_{\bullet i}^{1a}(x) &= \frac{i}{2} f^{abc} \int dz(x) \left| \frac{1}{p_* + i\epsilon p_\bullet} \right| z (\bar{A}_\bullet^b \partial_i \bar{A}_*^c + \bar{A}_*^b \partial_i \bar{A}_\bullet^c) + \frac{i}{2} f^{abc} \int dz(x) \left| \frac{1}{p_* + i\epsilon p_\bullet} \right| z \partial_i (\bar{A}_*^b \bar{A}_\bullet^c(z)) = i f^{abc} \int dz(x) \left| \frac{1}{p_* + i\epsilon p_\bullet} \right| z \bar{A}_*^b \partial_i \bar{A}_\bullet^c(z) \\
F_{*i}^{1a}(x) &= i f^{abc} \int dz(x) \left| \frac{1}{p_\bullet + i\epsilon p_*} \right| z \bar{A}_\bullet^b \partial_i \bar{A}_*^c(z) \\
\int dx F_{*i}^{1a} F_{\bullet i}^{1ai}(x) &= -\frac{4}{s} f^{mab} f^{mcd} \int dz dz' \left| \frac{1}{p^2 + i\epsilon} \right| z' \bar{A}_*^a \partial_i \bar{A}_\bullet^b(z) \bar{A}_\bullet^c \partial_i \bar{A}_*^d(z')
\end{aligned} \tag{313}$$

4. Two  $\partial_\perp$ 's, one  $\bar{A}_\bullet$  and one  $\bar{A}_*$ 

$$\begin{aligned}
\bar{C}_i^{1a}(x) &= \frac{2}{s} \int dz(x) \left| \frac{1}{p^2 + i\epsilon p_0} \right| z (\bar{D}_* \bar{G}_{*\bullet}^a(z) + \bar{D}_\bullet \bar{G}_{*i}^a(z)) = -\frac{2}{s} f^{abc} \int dz(x) \left| \frac{1}{p^2 + i\epsilon p_0} \right| z (A_\bullet^b \partial_i A_*^c + A_*^b \partial_i A_\bullet^c) \\
F_{\bullet i}^{(1)}(x) &= -\int dz(x) \left| \frac{1}{p_* + i\epsilon} \right| z \bar{A}_*^{ab} \bar{G}_{*\bullet}^b(z) \Rightarrow \partial^i F_{\bullet i}^{(1)} = \int dz(x) \left| \frac{1}{p_* + i\epsilon} \right| z \bar{G}_{*\bullet}^{ab} \bar{G}_{*\bullet}^{bi}(z) - \int dz(x) \left| \frac{1}{p_* + i\epsilon} \right| z \bar{A}_*^{ab} \partial^i \bar{G}_{*\bullet}^b(z)
\end{aligned} \tag{314}$$

From Eq. (272) we get

$$\begin{aligned}
\bar{c}_\bullet^a(x) &= -\int dz(x) \left| \frac{1}{p^2 + i\epsilon p_0} \right| z [\partial_\perp^2 (\bar{A}_\bullet + \bar{C}_\bullet)(z) - \bar{\Upsilon} t^a \hat{p}_1 \Upsilon(z)], \quad \bar{c}_*^a(x) = -\int dz(x) \left| \frac{1}{p^2 + i\epsilon p_0} \right| z \partial_\perp^2 \bar{C}_*(z) \\
\bar{D}_* \bar{c}_\bullet^a(x) &= \frac{s}{8} \int dz(x) \left| \frac{1}{p_\bullet + i\epsilon p_0} \right| z \partial_\perp^2 \frac{1}{P_* + i\epsilon} \bar{G}_{*\bullet}^a(z) \simeq \frac{s}{8} \int dz(x) \left| \frac{1}{(p_\bullet + i\epsilon)(p_* + i\epsilon)} \right| z \partial_\perp^2 \bar{G}_{*\bullet}^a(z)
\end{aligned} \tag{315}$$

## B. Quark fields in the target and projectile

## 1. In the target

$\bar{A}_\bullet(x_*, x_\perp)$  and  $\xi_b(x_*, x_\perp)$ .  
Dirac:

$$\frac{2}{s} \hat{p}_2 (i\partial_\bullet + \bar{A}_\bullet) \xi_b(x_*, x_\perp) + i\gamma^i \partial_i \xi_b(x_*, x_\perp) = 0 \tag{316}$$

PA3 $\delta$ UBAEM

$$\xi = \xi^{(1)} + \xi^{(2)} \quad \xi^{(1)} \equiv \frac{\hat{p}_2 \hat{p}_1}{s} \xi, \quad \xi^{(2)} \equiv \frac{\hat{p}_1 \hat{p}_2}{s} \xi$$

YP-E DUPAKA:

$$\begin{aligned}
\frac{2}{s} \hat{p}_2 (i\partial_\bullet + \bar{A}_\bullet) \xi_b^{(2)}(x_*, x_\perp) + i\gamma^i \partial_i \xi_b^{(1)}(x_*, x_\perp) &= 0, \quad i\gamma^i \partial_i \xi_b^{(2)}(x_*, x_\perp) = 0 \\
(i\partial_\bullet + \bar{A}_\bullet) \xi_b^{(2)}(x_*, x_\perp) &= i\gamma_i \partial^i \hat{p}_1 \xi_b^{(1)}(x_*, x_\perp)
\end{aligned} \tag{317}$$

Solution of the free Dirac (Weyl) equation

$$\nu^\alpha = \int \frac{d^3p}{(2\pi)^3} (c(p)(p \cdot \bar{\sigma}) \sigma_0]^\alpha_\beta \varphi^\beta e^{-ipx} + d^*(p)[(p \cdot \bar{\sigma}) \sigma_0]^\alpha_\beta \kappa^\beta e^{ipx}) \tag{318}$$

$$p_x + ip_y \equiv \tilde{p}, \quad p_x - ip_y = \tilde{p}^*$$

$$\bar{\sigma}_\mu p^\mu = \begin{pmatrix} p_0 + p_z & p_x - ip_y \\ p_x + ip_y & p_0 - p_z \end{pmatrix} = \sqrt{s} \begin{pmatrix} \frac{p_\perp^2}{\beta_s} & \frac{\tilde{p}^*}{\sqrt{s}} \\ \frac{\tilde{p}}{\sqrt{s}} & \beta \end{pmatrix}, \quad \sigma_\mu p^\mu = \begin{pmatrix} p_0 - p_z & -p_x + ip_y \\ -p_x - ip_y & p_0 + p_z \end{pmatrix} = \sqrt{s} \begin{pmatrix} \beta & -\frac{\tilde{p}^*}{\sqrt{s}} \\ -\frac{\tilde{p}}{\sqrt{s}} & \frac{p_\perp^2}{\beta_s} \end{pmatrix} \quad (319)$$

$$\bar{\sigma}_\mu p^\mu \sigma_0 \begin{pmatrix} 1 \\ 0 \end{pmatrix} = 2p_0 \cos \frac{\theta}{2} \begin{pmatrix} \cos \frac{\theta}{2} \\ e^{i\phi} \sin \frac{\theta}{2} \end{pmatrix}, \quad \bar{\sigma}_\mu p^\mu \sigma_0 \begin{pmatrix} 0 \\ 1 \end{pmatrix} = 2p_0 \sin \frac{\theta}{2} e^{-i\phi} \begin{pmatrix} \cos \frac{\theta}{2} \\ e^{i\phi} \sin \frac{\theta}{2} \end{pmatrix} \quad (320)$$

$$\nu^\alpha(x) = \int \frac{d^3 p}{(2\pi)^3} \begin{pmatrix} \frac{p_\perp^2}{\beta_s} & \frac{\tilde{p}^*}{\sqrt{s}} \\ \frac{\tilde{p}}{\sqrt{s}} & \beta \end{pmatrix} \left( c(p) \begin{pmatrix} 1 \\ 0 \end{pmatrix} e^{-ipx} + d^*(p) \begin{pmatrix} 0 \\ 1 \end{pmatrix} e^{ipx} \right) \quad (321)$$

$$\nu_\alpha^*(x) = \int \frac{d^3 p}{(2\pi)^3} [d^*(p)(0,1)e^{-ipx} + c^*(p)(1,0)e^{ipx}] \begin{pmatrix} \frac{p_\perp^2}{\beta_s} & \frac{\tilde{p}^*}{\sqrt{s}} \\ \frac{\tilde{p}}{\sqrt{s}} & \beta \end{pmatrix} \quad (322)$$

(see Eqs. (6.93)-(6.98) from AQM)

If  $A_\bullet$  does not depend on  $x_\perp$

$$\nu_\alpha(x) = [x_*, -\infty]^{A_\bullet} \int \frac{d^3 p}{(2\pi)^3} \begin{pmatrix} \frac{p_\perp^2}{\beta_s} & \frac{\tilde{p}^*}{\sqrt{s}} \\ \frac{\tilde{p}}{\sqrt{s}} & \beta \end{pmatrix} \left( c(p) \begin{pmatrix} 1 \\ 0 \end{pmatrix} e^{-ipx} + d^*(p) \begin{pmatrix} 0 \\ 1 \end{pmatrix} e^{ipx} \right) \quad (323)$$

$$\bar{\sigma}_\mu p_1^\mu = \sqrt{s} \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \quad = \sigma_\mu p_2^\mu \quad \sigma_\mu p_1^\mu = \sqrt{s} \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}, \quad = \bar{\sigma}_\mu p_2^\mu \quad \frac{\bar{p}_1 p_2}{s} = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \quad \frac{\bar{p}_2 p_1}{s} = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \quad (324)$$

$$\nu_\alpha^{(1)}(x) = \frac{\bar{p}_2 p_1}{s} \nu_\alpha(x) = \text{big}, \quad \nu_\alpha^{(2)}(x) = \frac{\bar{p}_1 p_2}{s} \nu_\alpha(x) = \text{small} \quad (325)$$

### U3 DUAΓPAMM

$$\left\{ 1 + \left( \frac{\hat{p}_1}{s} + \frac{\hat{k}_\perp}{k_\perp^2} \beta_k \right) \hat{p}_2 ([x_*, -\infty] - 1) \right\} u(k) e^{-ikx} = \left\{ 1 + \frac{\hat{k}}{k_\perp^2} \beta_k \hat{p}_2 ([x_*, -\infty] - 1) \right\} u(k) e^{-ikx} = [x_*, -\infty] u(k) e^{-ikx} \quad (326)$$

If  $A_\bullet$  depends on  $x_\perp$ , in the first order in  $\partial_\perp$  we get

$$\begin{aligned} & \left( \frac{2}{s} (i\partial_\bullet + \bar{A}_\bullet) \hat{p}_2 + \frac{2}{s} i\partial_* \hat{p}_1 + i\partial_i \gamma^i \right) \left\{ \left( 1 - i \frac{\beta_k \hat{p}_2}{k_\perp^2} \gamma_j \partial^j \right) [x_*, -\infty]_x + 2i \frac{k^j}{k_\perp^2} \beta_k \int_{-\infty}^{x_*} d\frac{2}{s} z_* (x_* - z_*) [x_*, z_*]_x F_{\bullet j}(z_*, x_\perp) [z_*, -\infty]_x \right\} u(k) e^{-ikx} \\ &= \left\{ i\gamma^i \partial_i [x_*, -\infty]_x - (\alpha_k \hat{p}_1 + k_i \gamma^i) i \frac{\beta_k \hat{p}_2}{k_\perp^2} \gamma_j \partial^j [x_*, -\infty]_x - 2\hat{p}_2 \frac{k^j}{k_\perp^2} \beta_k \int_{-\infty}^{x_*} d\frac{2}{s} z_* [x_*, z_*]_x F_{\bullet j}(z_*, x_\perp) [z_*, -\infty]_x \right\} u(k) e^{-ikx} \\ &= \left\{ i\gamma^i \partial_i [x_*, -\infty]_x - (\alpha_k \hat{p}_1 + \hat{k}_\perp) i \frac{\beta_k \hat{p}_2}{k_\perp^2} \gamma_j \partial^j [x_*, -\infty]_x - 2\hat{p}_2 \frac{k^j}{k_\perp^2} \beta_k i \partial_j [x_*, -\infty]_x \right\} u(k) e^{-ikx} + \mathcal{O}(\partial_i \partial_j) \\ &= \left\{ i\gamma^i \partial_i [x_*, -\infty]_x - i(\gamma^j \partial_j - \frac{\hat{p}_2 \hat{p}_1}{s} \gamma^j \partial_j - 2 \frac{k^j}{k_\perp^2} \beta_k \hat{p}_2 \partial_j + \beta_k \hat{p}_2 \gamma^j \frac{\hat{k}_\perp}{k_\perp^2} \partial_j) [x_*, -\infty]_x - 2\hat{p}_2 \frac{k^j}{k_\perp^2} \beta_k i \partial_j [x_*, -\infty]_x \right\} u(k) e^{-ikx} \\ &= \left\{ (\gamma^j \frac{\hat{p}_2 \hat{p}_1}{s} + \beta_k \gamma^j \hat{p}_2 \frac{\hat{k}_\perp}{k_\perp^2}) i \partial_j [x_*, -\infty]_x \right\} u(k) e^{-ikx} = \frac{\gamma^j \hat{p}_2 \hat{p}_1}{k_\perp^2} \beta_k (\alpha_k \hat{p}_1 + \hat{k}_\perp) u(k) e^{-ikx} i \partial_j [x_*, -\infty]_x = 0 + \mathcal{O}(\partial_i \partial_j) \end{aligned} \quad (327)$$

УТОГО В ПЕРВОМ ПОРЯДКЕ ПО  $\partial_i \bar{A}_\bullet$  ПОЛУЧАЕМ

$$\begin{aligned} \xi_b(x) &= \int dk_\perp d\beta_k \left\{ \left( [x_*, -\infty]_x - \frac{\beta_k \hat{p}_2}{k_\perp^2} \gamma^j \int_{-\infty}^{x_*} d\frac{2}{s} z_* [x_*, z_*]_x F_{\bullet j}(z_*, x_\perp) [z_*, -\infty]_x \right) \right. \\ &+ 2i \frac{k^j}{k_\perp^2} \beta_k \int_{-\infty}^{x_*} d\frac{2}{s} z_* (x_* - z_*) [x_*, z_*]_x F_{\bullet j}(z_*, x_\perp) [z_*, -\infty]_x \left. \right\} (c_1 u(k) e^{-i \frac{k_\perp^2}{\beta_k s} x_\bullet - i \beta_k x_* + i(k, x)_\perp} + c_2 v(k) e^{i \frac{k_\perp^2}{\beta_k s} x_\bullet + i \beta_k x_* - i(k, x)_\perp}) \\ &= [x_*, -\infty]_x \xi_b^{\text{free}}(x) - \frac{2\hat{p}_2}{s} (i\gamma_j \partial^j [x_*, -\infty]_x) \frac{\partial_\bullet}{\partial_\perp^2} \xi_b^{\text{free}}(x) + \frac{4i}{s} \int_{-\infty}^{x_*} d\frac{2}{s} z_* (x_* - z_*) [x_*, z_*]_x F_{\bullet j}(z_*, x_\perp) [z_*, -\infty]_x \frac{\partial^j \partial_\bullet}{\partial_\perp^2} \xi_b^{\text{free}}(x) + \mathcal{O}(\partial_i \partial_j A_\bullet) \end{aligned} \quad (328)$$

It looks like the light-cone expansion in powers of  $\frac{k_{\perp}^{\text{gluon}}}{k_{\perp}^{\text{quark}}}$ .

$$\text{PA3}\delta\text{UEHUE } \xi^{\text{free}} = \xi_{\text{free}}^{(1)} + \xi_{\text{free}}^{(2)}, \quad \xi^{(1)} \equiv \frac{\hat{p}_2 \hat{p}_1}{s} \xi, \quad \xi^{(2)} \equiv \frac{\hat{p}_1 \hat{p}_2}{s} \xi, \quad \xi_{\text{free}}^{(1)} \sim 1, \quad \xi_{\text{free}}^{(2)} \sim \frac{k_{\perp}}{\sqrt{s}}$$

$$\xi_{(2)}^b = [x_*, -\infty] \xi_{\text{free}}^{(2)b} + \frac{4i}{s} \int_{-\infty}^{x_*} d\frac{z}{s} z_* (x_* - z_*) [x_*, z_*]_x F_{\bullet j}(z_*, x_{\perp}) [z_*, -\infty]_x \frac{\partial^j \partial_{\bullet}}{\partial_{\perp}^2} \xi_{\text{free}}^{(2)b}(x) + \mathcal{O}\left(\left(\frac{k_{\perp}^{\text{gluon}}}{k_{\perp}^{\text{quark}}}\right)^2\right)$$

$$\xi_{(1)}^b = [x_*, -\infty] \xi_{\text{free}}^{(1)b} - \frac{2\hat{p}_2}{s} (i\gamma_j \partial^j [x_*, -\infty]_x) \frac{\partial_{\bullet}}{\partial_{\perp}^2} \xi_{\text{free}}^{(2)b}(x) + \mathcal{O}\left(\left(\frac{k_{\perp}^{\text{gluon}}}{k_{\perp}^{\text{quark}}}\right)^2\right) \quad (329)$$

$$\text{3AC, } \xi_{(2)}^b = \mathcal{O}\left(\left(\frac{k_{\perp}^{\text{gluon}}}{k_{\perp}^{\text{quark}}}\right)\right) \xi_{(1)}^b$$

## 2. In the projectile

$\bar{A}_{\bullet}(x_{\bullet}, x_{\perp})$  and  $\xi_a(x_{\bullet}, x_{\perp})$   
 PA3\delta UBAEM

$$\xi = \xi^{(1)} + \xi^{(2)} \quad \xi^{(1)} \equiv \frac{\hat{p}_2 \hat{p}_1}{s} \xi, \quad \xi^{(2)} \equiv \frac{\hat{p}_1 \hat{p}_2}{s} \xi$$

YP-E DUPAKA:

$$\begin{aligned} \frac{2}{s} \hat{p}_1 (i\partial_* + \bar{A}_*) \xi_a(x_{\bullet}, x_{\perp}) + i\gamma^i \partial_i \xi_a(x_{\bullet}, x_{\perp}) &= 0 \\ \frac{2}{s} \hat{p}_1 (i\partial_* + \bar{A}_*) \xi_a^{(1)}(x_{\bullet}, x_{\perp}) + i\gamma^i \partial_i \xi_a^{(2)}(x_{\bullet}, x_{\perp}) &= 0, \quad i\gamma^i \partial_i \xi_a^{(1)}(x_{\bullet}, x_{\perp}) = 0 \end{aligned} \quad (330)$$

## C. КЛАСС. YP-E КВАРКОВ

### 1. КЛАСС. YP-E В ПЕРВОМ ПОПАДКЕ ПО $p_{\perp}$

$\bar{C}_* = \Omega^{\dagger} i\partial_* \Omega - \bar{A}_*$  where  $\Omega$  is given by Eq. (210). From that equation we C that

$$\Omega(x_{\bullet}, -\infty_*, x_{\perp}) = [x_{\bullet}, -\infty_{\bullet}]_{x_{\perp}}^{\bar{A}_*}, \quad \Omega(x_*, -\infty_{\bullet}, x_{\perp}) = [x_*, -\infty_*]_{x_{\perp}}^{\bar{A}_{\bullet}} \quad (331)$$

In the leading order

$$(\hat{P} + \hat{C})\Upsilon(x) = \Omega_x i\hat{\partial} \Omega_x^{\dagger} \Upsilon(x) = 0 \quad (332)$$

The solution is given by Eq. (248) and (250)

$$\begin{aligned} \Upsilon(x) &\equiv \xi(x) + \chi(x) = \Omega(x)[- \infty_{\bullet}, x_{\bullet}]_x^{\hat{A}_*} \xi_a(x) + \Omega(x)[- \infty_*, x_*]_x^{\hat{A}_{\bullet}} \xi_b(x) \\ &= \Omega(x)[- \infty_{\bullet}, x_{\bullet}]_x^{\hat{A}_*} \frac{\hat{p}_1 \hat{p}_2}{s} \xi_a(x) + \Omega(x)[- \infty_*, x_*]_x^{\hat{A}_{\bullet}} \frac{\hat{p}_2 \hat{p}_1}{s} \xi_b(x) + \mathcal{O}\left(\left(\frac{k_{\perp}^{\text{gluon}}}{k_{\perp}^{\text{quark}}}\right)\right) \end{aligned} \quad (333)$$

Chek of the solution:

$$\begin{aligned} (\hat{P} + \hat{C})\Upsilon(x) &= \Omega(x) i\hat{\partial} [- \infty_{\bullet}, x_{\bullet}]_x^{\hat{A}_*} \xi_a(x) + \Omega(x) i\hat{\partial} [- \infty_*, x_*]_x^{\hat{A}_{\bullet}} \xi_b(x) = \\ &= \Omega_x [- \infty_{\bullet}, x_{\bullet}]_x^{\hat{A}_*} \left( \frac{2}{s} \hat{p}_1 (i\partial_* + \hat{A}_*) + \frac{2}{s} \hat{p}_2 i\partial_{\bullet} + i\hat{\partial}_{\perp} \right) \xi_a(x) + \Omega_x [- \infty_*, x_*]_x^{\hat{A}_{\bullet}} \left( \frac{2}{s} \hat{p}_2 (i\partial_{\bullet} + \hat{A}_{\bullet}) + \frac{2}{s} \hat{p}_1 i\partial_* + i\hat{\partial}_{\perp} \right) \xi_b(x) \end{aligned} \quad (334)$$

Boundary conditions

$$\begin{aligned} \left. [\xi(x) + \chi(x)] \right|_{x_{\bullet} = -\infty} &= \Omega(x_*, -\infty_{\bullet}, x_{\perp}) [- \infty_*, x_*]_x^{\hat{A}_{\bullet}} \xi_b(x) = \xi_b(x) \\ \left. [\xi(x) + \chi(x)] \right|_{x_* = -\infty} &= \Omega(x_{\bullet}, -\infty_*, x_{\perp}) [- \infty_{\bullet}, x_{\bullet}]_x^{\hat{A}_*} \xi_a(x) = \xi_a(x) \end{aligned} \quad (335)$$

where we uzd Eq. (331).



## XII. AFTER GAUGE TRANSFORMATION WITH $\Omega(x)$

### A. ODHO ПОЛЕ $\bar{A}_i(x_\bullet)$

Gauge transformation  $\bar{A}(x_\bullet, x_\perp) \rightarrow V(x_\bullet, x_\perp)$

$$\begin{aligned}
\bar{A}_*(x_\bullet, x_\perp) &\rightarrow [-\infty_\bullet, x_\bullet]_{x_\perp}^{\bar{A}_*} (i\partial_* + \bar{A}_*) [x_\bullet, -\infty_\bullet]_{x_\perp}^{\bar{A}_*} = 0 = V_* \\
\bar{A}_i(x_\bullet, x_\perp) &\rightarrow [-\infty_\bullet, x_\bullet]_{x_\perp}^{\bar{A}_*} (i\partial_i + 0) [x_\bullet, -\infty_\bullet]_{x_\perp}^{\bar{A}_*} = [-\infty_\bullet, x_\bullet]_{x_\perp}^{\bar{A}_*} i\partial_i [x_\bullet, -\infty_\bullet]_{x_\perp}^{\bar{A}_*} \equiv V_i(x_\bullet, x_\perp) \\
V_{ik} &= \partial_i \bar{A}_k(x_\bullet, x_\perp) - \partial_k \bar{A}_i(x_\bullet, x_\perp) - i[\bar{A}_i(x_\bullet, x_\perp), \bar{A}_k(x_\bullet, x_\perp)] = 0 \\
V_{*i} &= \partial_* V_i(x_\bullet, x_\perp) = [-\infty_\bullet, x_\bullet]_{x_\perp}^{\bar{A}_*} \bar{G}_{*i}(x_\perp, x_\bullet) [x_\bullet, -\infty_\bullet]_{x_\perp}^{\bar{A}_*}, \quad V_\bullet = V_{\bullet i} = 0
\end{aligned} \tag{336}$$

$$\begin{aligned}
&\int DA e^{ifdz(-\frac{1}{4}[G_{\mu\nu}^a]^2 + \bar{\psi}\hat{P}\psi)} e^{ifd^2z_\perp d_s^2z_\bullet} A_i^a(z)\bar{V}_{*i}^a(z_\bullet, z_\perp) \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \\
&\Rightarrow \int DA e^{ifdz(-\frac{1}{4}[G_{\mu\nu}^a(A+V)]^2 - \frac{1}{2}(\bar{D}_\mu A^\mu)^2) + (\bar{\psi} + \bar{\xi})(\hat{P} + \hat{V})(\psi + \xi)} e^{ifd^2z_\perp d_s^2z_\bullet} A_i^a(z)\bar{V}_{*i}^a(z_\bullet, z_\perp) \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \\
&= \int DAD\bar{\psi}D\psi A_\mu^m(x) \exp \left\{ i \int dz \left( -\frac{1}{2} A^{a\alpha} (P^2 g_{\alpha\beta} + 2iV_{\alpha\beta})^{ab} A^{\beta b} + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - gf^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right. \right. \\
&\quad \left. \left. - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d + \bar{\xi}\hat{P}\xi + \bar{\xi}\hat{A}\xi + \bar{\xi}\hat{P}\psi + \bar{\psi}\hat{P}\xi + \bar{\xi}\hat{A}\psi + \bar{\psi}\hat{A}\xi + \bar{\psi}\hat{P}\psi + \bar{\psi}\hat{A}\psi \right) \right\}
\end{aligned} \tag{337}$$

DPYTOE ПОЛЕ

$$\begin{aligned}
\bar{A}_\bullet(x_*, x_\perp) &\rightarrow [-\infty_*, x_*]_{x_\perp}^{\bar{A}_\bullet} (i\partial_\bullet + \bar{A}_\bullet) [x_*, -\infty_*]_{x_\perp}^{\bar{A}_\bullet} = 0 = U_* \\
\bar{A}_i(x_*, x_\perp) &\rightarrow [-\infty_*, x_*]_{x_\perp}^{\bar{A}_\bullet} (i\partial_i + 0) [x_*, -\infty_*]_{x_\perp}^{\bar{A}_\bullet} = [-\infty_*, x_*]_{x_\perp}^{\bar{A}_\bullet} i\partial_i [x_*, -\infty_*]_{x_\perp}^{\bar{A}_\bullet} \equiv U_i(x_*, x_\perp) \\
U_{ik} &= \partial_i \bar{A}_k(x_\bullet, x_\perp) - \partial_k \bar{A}_i(x_\bullet, x_\perp) - i[\bar{A}_i(x_\bullet, x_\perp), \bar{A}_k(x_\bullet, x_\perp)] = 0 \\
U_{\bullet i} &= \partial_\bullet U_i(x_\bullet, x_\perp) = [-\infty_*, x_*]_{x_\perp}^{\bar{A}_\bullet} \bar{G}_{\bullet i}(x_\perp, x_*) [x_*, -\infty_*]_{x_\perp}^{\bar{A}_\bullet}, \quad U_\bullet = U_{\bullet i} = 0
\end{aligned} \tag{338}$$

### B. CYMMA DBYX ПОЛЕЎ

$$\begin{aligned}
&\int DA e^{ifdz(-\frac{1}{4}[G_{\mu\nu}^a(A+V+U)]^2 - \frac{1}{2}(\bar{D}_\mu A^\mu)^2) + (\bar{\psi} + \bar{\xi})(\hat{P} + \hat{V} + \hat{U})(\psi + \xi)} e^{ifd^2z_\perp d_s^2z_\bullet} A_i^a(z)\bar{V}_{*i}^a(z_\bullet, z_\perp) \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} e^{ifd^2z_\perp d_s^2z_\bullet} A_i^a(z)\bar{U}_{\bullet i}^a(z_*, z_\perp) \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \\
&= \int DAD\bar{\psi}D\psi A_\mu^m(x) \exp \left\{ i \int dz \left( -\frac{1}{4} \bar{G}^{a\mu\nu} \bar{G}_{\mu\nu}^a - \frac{1}{2} A^{a\alpha} (P^2 g_{\alpha\beta} + 2iV_{\alpha\beta})^{ab} A^{\beta b} + A_\alpha^a \bar{D}_\xi \bar{G}^{a\xi\alpha} - gf^{abc} \bar{D}^\alpha A^{a\beta} A_\alpha^b A_\beta^c \right. \right. \\
&\quad \left. \left. - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d + \bar{\xi}\hat{P}\xi + \bar{\xi}\hat{A}\xi + \bar{\xi}\hat{P}\psi + \bar{\psi}\hat{P}\xi + \bar{\xi}\hat{A}\psi + \bar{\psi}\hat{A}\xi + \bar{\psi}\hat{P}\psi + \bar{\psi}\hat{A}\psi \right) \right\}
\end{aligned} \tag{339}$$

$$\begin{aligned}
\bar{G}_{\mu\nu} &= U_{\mu\nu} + V_{\mu\nu} - i[U_\mu, V_\nu] - i[V_\mu, U_\nu] \Rightarrow \bar{G}_{*\bullet} = 0, \quad \bar{G}_{\bullet i} = U_{\bullet i}, \quad \bar{G}_{*i} = V_{*i}, \quad \bar{G}_{ik} = -i[U_i, V_k] - i[V_i, U_k] \\
\bar{D}^i \bar{G}_{i\bullet} - (\partial_i - i[U_i, U_\bullet]) U_{i\bullet} &= -i\partial_\bullet [U_i, V^i], \quad \bar{D}^i \bar{G}_{i*} - (\partial_i - i[V_i, V_{i*}]) V_{i*} = i\partial_* [U_i, V^i]
\end{aligned} \tag{340}$$

From (282)

$$F_{\bullet i}^{(1)}(x) = \Omega_x U_{\bullet i}(x_\perp, x_*) \Omega_x^\dagger, \quad F_{*i}^{(1)}(x) = \Omega_x V_{*i}(x_\perp, x_\bullet) \Omega_x^\dagger \tag{341}$$

From Eq. (220)

$$\bar{C}_i^a = (\Omega i\partial_i \Omega^\dagger)^a + i\Omega_x^{ab} ([-\infty_*, x_*]_{x_\perp}^{\bar{A}_\bullet} \partial_i [x_*, -\infty_*]_{x_\perp}^{\bar{A}_\bullet})^b + i\Omega_x^{ab} ([-\infty_\bullet, x_\bullet]_{x_\perp}^{\bar{A}_*} \partial_i [x_\bullet, -\infty_\bullet]_{x_\perp}^{\bar{A}_*})^b = \Omega_i^a + \Omega(U_i + V_i) \Omega^\dagger \tag{342}$$

From Eqs. (234) and (280)

$$F_{*\bullet}^{(1)}(x) = \Omega_x [U_i, V^i] \Omega^\dagger(x), \quad F_{ik}^{(1)}(x) = -i\Omega_x [U_i, V_k] \Omega^\dagger(x) - i \leftrightarrow k \tag{343}$$

Consider  $\Omega$  applied to  $\mathcal{A}_\bullet = \bar{A}_\bullet + \bar{C}_\bullet$ ,  $\mathcal{A}_* = \bar{A}_* + \bar{C}_*$  and  $\mathcal{A}_i = \bar{C}_i$

$$\Omega_x^\dagger \mathcal{A}_\bullet \Omega(x) + i\Omega_x^\dagger \partial_\bullet \Omega(x) = \Omega_x^\dagger \mathcal{A}_* \Omega(x) + i\Omega_x^\dagger \partial_* \Omega(x) = 0, \quad \Omega_x^\dagger \mathcal{A}_i \Omega(x) + i\Omega_x^\dagger \partial_i \Omega(x) = U_i + V_i \tag{344}$$

## C. General sdvig

$$\int DAD\bar{\psi}D\psi A_\mu^m(x)\psi(y)e^{i\int dz\left(-\frac{1}{4}[G_{\mu\nu}^a(A+\bar{A})]^2-\frac{1}{2}[(\bar{D}_\mu-i\bar{C}_\mu)A^\mu]^2+(\bar{\psi}+\bar{\xi})(\hat{P}+\hat{A})(\psi+\xi)\right)} \quad (345)$$

Sdvig  $A \rightarrow A + \bar{C}$ ,  $\psi \rightarrow \psi + \chi$ . Notation:  $\Upsilon = \xi + \chi$ ,  $\mathbb{A} = \bar{A} + \bar{C}$

$$\begin{aligned} &= \int DAD\bar{\psi}D\psi [A_\mu^m(x) + \bar{C}_\mu^m(x)][\psi(y) + \chi(y)] \\ &\times e^{i\int dz\left(-\frac{1}{4}\bar{G}^{a\mu\nu}\bar{G}_{\mu\nu}^a - \frac{1}{2}\bar{C}^{a\alpha}(\bar{P}^2g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} + \bar{C}_\alpha^a\bar{D}_\xi\bar{G}^{a\xi\alpha} - g^{abc}\bar{D}^\alpha\bar{C}^{a\beta}\bar{C}_\alpha^b\bar{C}_\beta^c - \frac{g^2}{4}f^{abm}f^{cdm}\bar{C}^{a\alpha}\bar{C}^{b\beta}\bar{C}_\alpha^c\bar{C}_\beta^d + (\bar{\xi}+\bar{\chi})(\hat{P}+\hat{C})(\xi+\chi)\right)} \\ &\times \exp i\int dz\left\{A^{a\alpha}\left(-(\bar{P}^2g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} + (\bar{D}\bar{G})_\alpha^a + f^{abc}(2\bar{C}_\beta^b\bar{D}^\beta\bar{C}_\alpha^c - \bar{C}_\beta^b\bar{D}_\alpha\bar{C}^{c\beta}) - f^{abm}f^{cdm}\bar{C}^{b\beta}\bar{C}_\alpha^c\bar{C}_\beta^d + (\bar{\xi}+\bar{\chi})\gamma_\alpha t^a(\xi+\chi)\right)\right. \\ &+ \bar{\psi}(\hat{P}+\hat{C})(\xi+\chi) + (\bar{\xi}+\bar{\chi})(\hat{P}+\hat{C})\psi \\ &- \frac{1}{2}A^{a\alpha}\left((\bar{P}+\bar{C})^2g_{\alpha\beta} + 2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha\bar{C}_\beta - \bar{D}_\beta\bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta])\right)^{ab}A^{b\beta} + \bar{\psi}(\hat{P}+\hat{C})\psi + (\bar{\xi}+\bar{\chi})\hat{A}\psi + \bar{\psi}\hat{A}(\xi+\chi) \\ &\left.- g^{abc}(\bar{D}_\alpha - i\bar{C}_\alpha)^{aa'}A_\beta^{a'}A^{c\alpha}A^{d\beta} - \frac{g^2}{4}f^{abm}f^{cdm}A^{a\alpha}A^{b\beta}A_\alpha^cA_\beta^d + \bar{\psi}\hat{A}\psi\right\} \\ &= \int DAD\bar{\psi}D\psi [A_\mu^m(x) + \bar{C}_\mu^m(x)][\psi(y) + \chi(y)]e^{i\int dz\left[-\frac{1}{4}\mathbb{G}^{a\mu\nu}\mathbb{G}_{\mu\nu}^a + \Upsilon\hat{P}\Upsilon - \frac{1}{2}(\mathbb{D}^\beta\bar{C}_\beta^a)^2\right]} \\ &\times e^{i\int dz A^{a\alpha}\left[-(\mathbb{P}^2g_{\alpha\beta} + 2i\mathbb{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} - i\bar{C}_\beta^{ab}\mathbb{D}_\alpha\bar{C}_\beta^b + (\bar{D}\bar{G})_\alpha^a + \Upsilon\gamma_\alpha t^a\Upsilon + \bar{\psi}\hat{P}\Upsilon + \Upsilon\hat{P}\psi + i\bar{C}_\alpha^{ab}\bar{D}_\beta\bar{C}_\beta^b\right]} \\ &\times e^{i\int dz\left[-\frac{1}{2}A^{a\alpha}(\mathbb{P}^2g_{\alpha\beta} + 2i\mathbb{G}_{\alpha\beta})A^{b\beta} + \bar{\psi}\hat{P}\psi + \Upsilon\hat{A}\psi + \bar{\psi}\hat{A}\Upsilon - g^{abc}A^{a\alpha}A^{b\beta}\mathbb{D}_\alpha A_\beta^c - \frac{g^2}{4}f^{abm}f^{cdm}A^{a\alpha}A^{b\beta}A_\alpha^cA_\beta^d + \bar{\psi}\hat{A}\psi\right]} \quad (346) \end{aligned}$$

whæ wi uzd

$$\begin{aligned} &-(\bar{P}^2g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} + f^{abc}(2\bar{C}_\beta^b\bar{D}^\beta\bar{C}_\alpha^c - \bar{C}_\beta^b\bar{D}_\alpha\bar{C}^{c\beta}) - f^{abm}f^{cdm}\bar{C}^{b\beta}\bar{C}_\alpha^c\bar{C}_\beta^d \\ &= -\left((\bar{P}+\bar{C})^2g_{\alpha\beta} + 2i(\bar{G}_{\alpha\beta} + \bar{D}_\alpha\bar{C}_\beta - \bar{D}_\beta\bar{C}_\alpha - i[\bar{C}_\alpha, \bar{C}_\beta])\right)^{ab}\bar{C}^{b\beta} - i\bar{C}_\beta^{ab}\mathbb{D}_\alpha\bar{C}_\beta^b + i\bar{C}_\alpha^{ab}\bar{D}_\beta\bar{C}_\beta^b \\ &= -(\mathbb{P}^2g_{\alpha\beta} + 2i\mathbb{G}_{\alpha\beta}(\mathbb{A}))^{ab}\bar{C}^{b\beta} - i\bar{C}_\beta^{ab}\mathbb{D}_\alpha\bar{C}_\beta^b + i\bar{C}_\alpha^{ab}\bar{D}_\beta\bar{C}_\beta^b \equiv -(\mathbb{P}^2g_{\alpha\beta} + 2i\mathbb{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} - i\bar{C}_\beta^{ab}\mathbb{D}_\alpha\bar{C}_\beta^b + i\bar{C}_\alpha^{ab}\bar{D}_\beta\bar{C}_\beta^b \end{aligned} \quad (347)$$

and (without paying attention to boundaries)

$$\begin{aligned} &-\frac{1}{4}\bar{G}^{a\mu\nu}\bar{G}_{\mu\nu}^a - \frac{1}{2}\bar{C}^{a\alpha}(\bar{P}^2g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} + \bar{C}_\alpha^a\bar{D}_\xi\bar{G}^{a\xi\alpha} - g^{abc}\bar{D}^\alpha\bar{C}^{a\beta}\bar{C}_\alpha^b\bar{C}_\beta^c - \frac{g^2}{4}f^{abm}f^{cdm}\bar{C}^{a\alpha}\bar{C}^{b\beta}\bar{C}_\alpha^c\bar{C}_\beta^d + \Upsilon(\hat{P}+\hat{C})\Upsilon \\ &= -\frac{1}{4}\mathbb{G}^{a\mu\nu}\mathbb{G}_{\mu\nu}^a + \Upsilon\hat{P}\Upsilon - \frac{1}{2}(\mathbb{D}^\beta\bar{C}_\beta^a)^2 \quad (348) \end{aligned}$$

$$\begin{aligned} &D^\xi G_{\xi\mu}^a(\bar{A} + \bar{C}) = (\bar{D}^\xi - i\bar{C}^\xi)^{ab}(\bar{G}_{\xi\mu}^b + \bar{D}_\xi\bar{C}_\mu^b - \bar{D}_\mu\bar{C}_\xi^b - i\bar{C}_\xi^{bc}\bar{C}_\mu^c) = \bar{D}^\xi\bar{G}_{\xi\mu}^a + (\bar{D}^2g_{\mu\xi} - 2i\bar{G}_{\mu\xi})^{ab}\bar{C}^{b\xi} - \bar{D}_\mu\bar{D}^\xi\bar{C}_\xi^a \\ &- i(\bar{D}^\xi\bar{C}_\xi)^{ab}\bar{C}_\mu^b - i\bar{C}_\xi^{ab}\bar{D}^\xi\bar{C}_\mu^b - i\bar{C}^{\xi ab}\bar{D}_\xi\bar{C}_\mu^b + i\bar{C}^{\xi ab}(\bar{D}_\mu - i\bar{C}_\mu)\bar{C}_\xi^b \\ &= \bar{D}^\xi\bar{G}_{\xi\mu}^a + (\bar{D}^2g_{\mu\xi} - 2i\bar{G}_{\mu\xi})^{ab}\bar{C}^{b\xi} - (\bar{D}_\mu - i\bar{C}_\mu)\bar{D}^\xi\bar{C}_\xi^a + i\bar{C}^{\xi ab}(\bar{D}_\mu - i\bar{C}_\mu)\bar{C}_\xi^b - 2i\bar{C}^{\xi ab}\bar{D}_\xi\bar{C}_\mu^b \\ &= -(\bar{D}_\mu - i\bar{C}_\mu)\bar{D}^\xi\bar{C}_\xi^a - (\bar{P}^2g_{\mu\beta} + 2i\bar{G}_{\mu\beta})^{ab}\bar{C}^{b\beta} + (\bar{D}\bar{G})_\mu^a + f^{abc}(2\bar{C}_\beta^b\bar{D}^\beta\bar{C}_\mu^c - \bar{C}_\beta^b\bar{D}_\mu\bar{C}^{c\beta}) - f^{abm}f^{cdm}\bar{C}^{b\beta}\bar{C}_\mu^c\bar{C}_\beta^d \quad (349) \end{aligned}$$

wich agriiz wiz Eq. (160).

Another rewriting:

$$D^\xi G_{\xi\mu}^a(\bar{A} + \bar{C}) + (\bar{D}_\mu - i\bar{C}_\mu)\bar{D}^\xi\bar{C}_\xi^a = -(\bar{P}^2g_{\mu\beta} + 2i\bar{G}_{\mu\beta})^{ab}\bar{C}^{b\beta} + (\bar{D}\bar{G})_\mu^a + i\bar{C}^{\xi ab}(\bar{D}_\mu - i\bar{C}_\mu)\bar{C}_\xi^b - 2i\bar{C}^{\xi ab}\bar{D}_\xi\bar{C}_\mu^b \quad (350)$$

If  $\bar{C}$  and  $\chi$  are the solutions of Eq. (260)

$$\begin{aligned} &(\bar{P}^2g_{\alpha\beta} + 2i\bar{G}_{\alpha\beta})^{ab}\bar{C}^{b\beta} = \bar{D}^{ab\xi}\bar{G}_{\xi\alpha}^b + g^{abc}(2\bar{C}_\beta^b\bar{D}^\beta\bar{C}_\alpha^c - \bar{C}_\beta^b\bar{D}_\alpha\bar{C}^{c\beta}) - g^2f^{abm}f^{cdm}\bar{C}^{b\beta}\bar{C}_\alpha^c\bar{C}_\beta^d + (\bar{\xi}+\bar{\chi})\gamma_\alpha t^a(\xi+\chi) \\ &(\hat{P}+\hat{C})(\xi+\chi) = 0, \quad (\bar{\xi}+\bar{\chi})(\hat{P}+\hat{C}) = 0 \quad (351) \end{aligned}$$

we get

$$\begin{aligned}
& \int DAD\bar{\psi}D\psi A_\mu^m(x)\psi(y)e^{i\int dz\left(-\frac{1}{4}[G_{\mu\nu}^a(A+\bar{A})]^2-\frac{1}{2}[(\bar{D}_\mu-i\bar{C}_\mu)A^\mu]^2\right)+(\bar{\psi}+\bar{\chi})(\hat{P}+\hat{A})(\psi+\xi)} \\
&= \int DAD\bar{\psi}D\psi [A_\mu^m(x)+\bar{C}_\mu^m(x)][\psi(y)+\chi(y)]e^{i\int dz\left(-\frac{1}{4}G^{a\mu\nu}G_{\mu\nu}^a+\bar{\Upsilon}\hat{P}\Upsilon\right)} \\
&\times e^{i\int dz\left[-\frac{1}{2}A^{a\alpha}(\mathbb{P}^2g_{\alpha\beta}+2iG_{\alpha\beta})A^{b\beta}+\bar{\psi}\hat{P}\psi+\bar{\Upsilon}\hat{A}\psi+\bar{\psi}\hat{A}\Upsilon-gf^{abc}A^{a\alpha}A^{b\beta}\mathbb{D}_\alpha A_\beta^c-\frac{g^2}{4}f^{abm}f^{cdm}A^{a\alpha}A^{b\beta}A_\alpha^cA_\beta^d+\bar{\psi}\hat{A}\psi\right]} = (\mathbb{A}(x)-\bar{A}(x))(\Upsilon(y)-\xi(y)) \\
&\times \int DAD\bar{\psi}D\psi e^{i\int dz\left(-\frac{1}{4}G^{a\mu\nu}G_{\mu\nu}^a+\bar{\Upsilon}\hat{P}\Upsilon\right)} e^{i\int dz\left[-\frac{1}{2}A^{a\alpha}(\mathbb{P}^2g_{\alpha\beta}+2iG_{\alpha\beta})A^{b\beta}+\bar{\psi}\hat{P}\psi+\bar{\Upsilon}\hat{A}\psi+\bar{\psi}\hat{A}\Upsilon-gf^{abc}A^{a\alpha}A^{b\beta}\mathbb{D}_\alpha A_\beta^c-\frac{g^2}{4}f^{abm}f^{cdm}A^{a\alpha}A^{b\beta}A_\alpha^cA_\beta^d+\bar{\psi}\hat{A}\psi\right]}
\end{aligned} \tag{352}$$

We can solve Eq. (351)

$$\begin{aligned}
& (\bar{P}^2g_{\mu\xi}+2i\bar{G}_{\mu\xi})^{ab}\bar{C}^b\xi+(\bar{D}_\mu-i\bar{C}_\mu)\bar{D}^\xi\bar{C}_\xi^a-i\bar{C}^{\xi ab}(\bar{D}_\mu-i\bar{C}_\mu)\bar{C}_\xi^b+2i\bar{C}^{\xi ab}\bar{D}_\xi\bar{C}_\mu^b-(\bar{D}\bar{G})_\mu^a=(\bar{\xi}+\bar{\chi})\gamma_\mu t^a(\xi+\chi) \\
&\Leftrightarrow D^\xi G_{\xi\mu}^a(\bar{A}+\bar{C})+(\bar{D}_\mu-i\bar{C}_\mu)\bar{D}^\xi\bar{C}_\xi^a=(\bar{\xi}+\bar{\chi})\gamma_\mu t^a(\xi+\chi)
\end{aligned} \tag{353}$$

by iterations  $\bar{C}_\xi = \Omega_\xi - \bar{A}_\xi + s_\xi$ ,  $\chi = \Omega_\xi - \xi + \lambda$ . At the first step we get

$$D_\Omega^2 s_\mu^a - i s_\mu^{ab} D_\Omega^\xi (\Omega_\xi - \bar{A}_\xi)^b = -D_\mu^\Omega D_\Omega^\xi (\Omega_\xi - \bar{A}_\xi) + \bar{\xi} \Omega^\dagger t^a \gamma_\mu \Omega_\xi \tag{354}$$

For our  $\Omega$  we have

$$D_\Omega^\xi (\Omega_\xi - \bar{A}_\xi)^a = \partial_\xi (\Omega_\xi - \bar{A}_\xi)^a - i (\Omega_\xi)^{ab} (\Omega_\xi - \bar{A}_\xi)^b = \partial_\xi \Omega_\xi + i (\Omega_\xi)^{ab} \bar{A}_\xi^b = \bar{D}_\xi^{ab} \Omega^{\xi b} = \bar{D}_\xi^{ab} (\Omega^\xi - \bar{A}^\xi)^b = \partial^i \Omega_i \tag{355}$$

so the equation turns 2

$$[\partial^2 + i(\partial^i \tilde{\Omega}_i)]^{ab} (\Omega^\dagger s_\mu)^b = -\partial_\mu \partial^i \tilde{\Omega}_i + \bar{\xi} t^a \gamma_\mu \xi \tag{356}$$

$$\text{gde } \tilde{\Omega}_\mu \equiv \Omega^\dagger i \partial_\mu \Omega$$

#### D. First iteration

If  $\bar{A}_i = 0$  for projectile and target, for self-consistency we must require

$$\bar{\xi}_a \gamma_i \xi_a = \partial_\bullet \bar{G}_{*i} = 0, \quad \bar{\xi}_b \gamma_i \xi_b = \partial_* \bar{G}_{\bullet i} = 0 \tag{357}$$

First iteration ( $\Omega_i \equiv \Omega^\dagger i \partial_i \Omega$ )

$$\begin{aligned}
\tilde{C}_\parallel &= \Omega i \partial_\parallel \Omega^\dagger - \bar{A}_\parallel, \\
\tilde{C}_i^a &= \Omega_x^{ab} (U_i + V_i - \Omega_i - \Sigma_i)^b, \quad \Sigma_i \equiv \frac{s}{4} \int_{-\infty}^{x_*} d\frac{z}{s} \int_{-\infty}^{x_\bullet} d\frac{z}{s} [\bar{\Sigma}^a(z_\bullet, x_\perp) t^b \gamma_i \Sigma_b(z_*, x_\perp) + \bar{\Sigma}^b(z_*, x_\perp) t^b \gamma_i \Sigma_a(z_\bullet, x_\perp)] \\
\tilde{\Upsilon} &= \Omega(x) (\Sigma^a + \Sigma^b), \quad \Sigma_a(x_\bullet, x_\perp) = [-\infty_\bullet, x_\bullet]_x^{\hat{A}_*} \xi_a(x), \quad \Sigma_b(x_\bullet, x_\perp) = [-\infty_*, x_*]_x^{\hat{A}_\bullet} \xi_b(x)
\end{aligned} \tag{358}$$

is a solution of equations (226), (248) and (250)

$$\begin{aligned}
[\mathcal{P}_* \mathcal{P}_\bullet + \mathcal{P}_\bullet \mathcal{P}_*]^{ab} \tilde{C}_\bullet^b &= -i \tilde{C}_\bullet^{ab} \mathcal{D}_\bullet \tilde{C}_*^b - i \tilde{C}_*^{ab} \mathcal{D}_\bullet \tilde{C}_\bullet^b + \bar{D}_\bullet \bar{G}_{**}^a \\
[\mathcal{P}_* \mathcal{P}_\bullet + \mathcal{P}_\bullet \mathcal{P}_*]^{ab} \tilde{C}_*^b &= -i \tilde{C}_*^{ab} \mathcal{D}_* \tilde{C}_\bullet^b - i \tilde{C}_\bullet^{ab} \mathcal{D}_* \tilde{C}_*^b - \bar{D}_* \bar{G}_{**}^a \\
[\mathcal{P}_* \mathcal{P}_\bullet + \mathcal{P}_\bullet \mathcal{P}_*]^{ab} \tilde{C}_i^b &= ig [\mathcal{P}_*^{ab} \partial_i \mathcal{A}_\bullet^b + \mathcal{P}_\bullet^{ab} \partial_i \mathcal{A}_*^b] + \frac{s}{2} \Omega^{ab} (\bar{\Sigma}_a \gamma_i t^b \Sigma_b + \bar{\Sigma}_b \gamma_i t^b \Sigma_a) \\
\hat{P} \Upsilon(x) &= \Omega^\dagger (\hat{U} \Sigma_a + \hat{V} \Sigma_b)
\end{aligned} \tag{359}$$

with initial conditions

$$\begin{aligned}
\tilde{C}_\mu(x_* \rightarrow -\infty) = \tilde{C}_\mu(x_* \rightarrow -\infty) = 0 &\Leftrightarrow \mathcal{A}_*(-\infty, x_\bullet, x_\perp) = \mathcal{A}_*(x_\bullet, x_\perp), \quad \mathcal{A}(x_*, -\infty, x_\perp) = \mathcal{A}_\bullet(x_\bullet, x_\perp), \\
\mathcal{A}_i(-\infty, x_\bullet, x_\perp) = \mathcal{A}_i(x_*, -\infty, x_\perp) = 0, \quad \Upsilon(-\infty, x_\bullet, x_\perp) = \xi_a(x_\bullet, x_\perp), \quad \Upsilon(x_*, -\infty, x_\perp) = \xi_b(x_*, x_\perp)
\end{aligned} \tag{360}$$

Here  $\mathcal{A}_* = \bar{A}_* + \tilde{C}_*$ ,  $\mathcal{P}_* = \bar{P}_* + \tilde{C}_*$ , and  $\mathcal{A}_\bullet = \bar{A}_\bullet + \tilde{C}_\bullet$ ,  $\mathcal{P}_\bullet = \bar{P}_\bullet + \tilde{C}_\bullet$  and

$$\left(\hat{p} + \frac{2}{s} \hat{p}_1 \bar{A}_\bullet\right) \xi_a(x_*, x_\perp) = \left(\hat{p} + \frac{2}{s} \hat{p}_2 \bar{A}_\bullet\right) \xi_b(x_*, x_\perp) = 0 \Rightarrow (\hat{p} + \hat{V}) \Sigma_a = (\hat{p} + \hat{U}) \Sigma_b = 0 \tag{361}$$

gde  $\hat{U} \equiv \gamma_i U^i$ ,  $\hat{V} \equiv \gamma_i V^i$

$$\begin{aligned} \mathcal{G}_{*\bullet} &= 0, \quad \mathcal{G}_{*i} = \Omega(V_{*i} - \partial_* \Sigma_i) \Omega^\dagger, \quad \mathcal{G}_{\bullet i} = \Omega(U_{\bullet i} - \partial_{\bullet} \Sigma_i) \Omega^\dagger, \\ \mathcal{G}_{ik} &= \Omega(-i[U_i, V_k] - i[V_i, U_k] - (\mathbb{D}_i \Sigma_k - i \leftrightarrow k) - i[\Sigma_i, \Sigma_k]) \Omega^\dagger \end{aligned} \quad (362)$$

gde

$$\Sigma_i^a(x) \equiv \int_{-\infty}^{x_*} d\frac{2}{s} z_* \int_{-\infty}^{x_{\bullet}} d\frac{2}{s} z_{\bullet} [\bar{\Sigma}^a(z_{\bullet}, x_{\perp}) t^b \gamma_i \Sigma_b(z_*, x_{\perp}) + \bar{\Sigma}^b(z_*, x_{\perp}) t^b \gamma_i \Sigma_a(z_{\bullet}, x_{\perp})] \quad (363)$$

$$\mathcal{G}_{\bullet i}(x) \xrightarrow{x_{\bullet} \rightarrow \pm \infty} \bar{G}_{\bullet i}(x_*, x_{\perp}), \quad \mathcal{G}_{*i}(x) \xrightarrow{x_* \rightarrow \pm \infty} \bar{G}_{*i}(x_{\bullet}, x_{\perp}), \quad \Sigma_i^a(x) \xrightarrow{x_* \rightarrow \pm \infty} 0 \quad (364)$$

### 1. Sdvg $A \rightarrow A + \mathcal{A}$

$$\begin{aligned} & \int d^4 x \left( -\frac{1}{4} [G_{\mu\nu}(A + \mathcal{A})]^2 + \frac{1}{2} (\mathcal{D}^\mu A_\mu + \mathcal{D}^\mu \tilde{C}_\mu)^2 + (\bar{\Upsilon} + \bar{\psi})(\hat{D} + \hat{A})(\Upsilon + \psi) \right) \\ &= \int d^4 x \left( -\frac{1}{4} \mathcal{G}_{\mu\nu}^2 + \frac{1}{2} (\bar{D}^\mu \tilde{C}_\mu)^2 + A_\alpha^a (\mathcal{D}_\mu \mathcal{G}^{a\mu\alpha} + \bar{\Upsilon} \gamma_\alpha t^a \Upsilon - \mathcal{D}^\alpha \bar{D}^\mu \tilde{C}_\mu^a) + \bar{\psi} \hat{D} \Upsilon + \bar{\Upsilon} \hat{D} \psi + \frac{1}{2} A_\mu^a (\mathcal{D}^2 g^{\mu\nu} - 2i \mathcal{G}^{\mu\nu})^{ab} A_\nu^b \right. \\ &- g f^{abc} A^{a\alpha} A^{b\beta} \mathcal{D}_\alpha A_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d + \bar{\psi} \hat{A} \psi \left. \right) \\ &+ \int d\frac{2}{s} x_{\bullet} dx_{\perp} [A^{ai}(\infty, x_{\bullet}, x_{\perp}) \mathcal{G}_{*i}^a(\infty, x_{\bullet}, x_{\perp}) - (\infty \rightarrow -\infty)] + \int d\frac{2}{s} x_* dx_{\perp} [A^{ai}(x_*, \infty, x_{\perp}) \mathcal{G}_{\bullet i}^a(x_*, \infty, x_{\perp}) - (\infty \rightarrow -\infty)] \end{aligned} \quad (365)$$

### 2. Gauge transformation

$$\text{Gauge transformation: } \mathbb{A}_\mu = \Omega^\dagger i \partial_\mu \Omega + \Omega^\dagger \mathcal{A}_\mu \Omega, \quad A_{\text{new}}^{\text{quant}} = \Omega^\dagger A^{\text{quant}} \Omega$$

$$\begin{aligned} \mathbb{A}_{\bullet} &= \mathbb{A}_* = 0, \quad \mathbb{A}_i = U_i + V_i - \Sigma_i, \quad G_{*\bullet}(\mathbb{A}) = 0, \\ G_{*i}(\mathbb{A}) &= V_{*i} - \partial_* \Sigma_i, \quad G_{\bullet i}(\mathbb{A}) = U_{\bullet i} - \partial_{\bullet} \Sigma_i, \quad G_{ik}(\mathbb{A}) = -i[U_i, V_k] - i[V_i, U_k] - (\mathbb{D}_i \Sigma_k - i \leftrightarrow k) - i[\Sigma_i, \Sigma_k] \\ D^\mu G_{\mu i}(\mathbb{A}) &= \frac{2}{s} \partial_* G_{\bullet i}(\mathbb{A}) + \frac{2}{s} \partial_{\bullet} G_{*i}(\mathbb{A}) + (\partial^k - i \mathbb{A}^k) G_{ki}(\mathbb{A}) = -\bar{\Upsilon} \gamma_i t^a \Upsilon + (\partial^k - i \mathbb{A}^k) G_{ki}(\mathbb{A}), \\ D^\mu G_{\mu \bullet}(\mathbb{A}) &= -(\partial^i - i \mathbb{A}^i) G_{\bullet i}(\mathbb{A}), \quad D^\mu G_{\mu *}( \mathbb{A}) = -(\partial^i - i \mathbb{A}^i) G_{*i}(\mathbb{A}) \end{aligned} \quad (366)$$

gde

$$\Upsilon = \Sigma_a + \Sigma_b = [-\infty_{\bullet}, x_{\bullet}]_{x_{\perp}}^{\hat{A}_*} \xi_a(x) + [-\infty_*, x_*]_{x_{\perp}}^{\hat{A}_{\bullet}} \xi_b(x) \quad (367)$$

so

$$\bar{\Upsilon} \gamma_{\bullet} t^a \Upsilon = \bar{\Sigma}^b t^a \gamma_{\bullet} \Sigma_b, \quad \bar{\Upsilon} \gamma_* t^a \Upsilon = \bar{\Sigma}^a t^a \gamma_* \Sigma_a, \quad \bar{\Upsilon} \gamma_i t^a \Upsilon = \bar{\Sigma}_a t^a \gamma_i \Sigma_b + \bar{\Sigma}_b t^a \gamma_i \Sigma_b \quad (368)$$

Sdvg  $A \rightarrow A + \mathbb{A}$ ,  $\psi \rightarrow \psi + \Upsilon$  (bez surface terms):

$$\begin{aligned} & \int d^4 x \left( -\frac{1}{4} [G_{\mu\nu}(A + \mathbb{A})]^2 + \frac{1}{2} (\mathbb{D}^\mu A_\mu)^2 + (\bar{\Upsilon} + \bar{\psi})(\hat{D} + \hat{A})(\Upsilon + \psi) \right) \\ &= \int d^4 x \left( -\frac{1}{4} \mathcal{G}_{\mu\nu}^2 + A_\alpha^a (\mathbb{D}_\mu \mathcal{G}^{a\mu\alpha} + \bar{\Upsilon} \gamma_\alpha t^a \Upsilon) + \bar{\psi} \hat{D} \Upsilon + \bar{\Upsilon} \hat{D} \psi + \frac{1}{2} A_\mu^a (\mathbb{D}^2 g^{\mu\nu} - 2i \mathcal{G}^{\mu\nu})^{ab} A_\nu^b \right. \\ &- g f^{abc} A^{a\alpha} A^{b\beta} \mathbb{D}_\alpha A_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d + \bar{\psi} \hat{A} \psi \left. \right) \end{aligned} \quad (369)$$

УУЕМ  $\mathcal{C}$  and  $\Upsilon$  TAKUE 4TO

$$\mathcal{C}(x)\Psi(y) = \int DAD\bar{\psi}D\psi A(x)\psi(y)e^{\int d^4x \left( -\frac{1}{4}[G_{\mu\nu}(A+\mathbb{A})]^2 + \frac{1}{2}(\mathbb{D}^\mu A_\mu)^2 + (\bar{\Psi}+\bar{\psi})(\hat{\mathbb{D}}+\hat{A})(\Psi+\psi) \right)} \quad (370)$$

ТОГДА  $\mathcal{A} = \mathbb{A} + \mathcal{C}$  и  $\Upsilon = \Psi + \bar{\Psi}$  - ПЕУЕНУЕ  $\Upsilon$ - $\bar{\Psi}$

$$\begin{aligned} & \delta \left\{ \int d^4x \left( -\frac{1}{4}[G_{\mu\nu}(A+\mathbb{A}+\mathcal{C})]^2 + \frac{1}{2}[\mathbb{D}^\mu(A_\mu+\mathcal{C}_\mu)]^2 + (\bar{\Psi}+\bar{\Psi}+\bar{\psi})(\hat{\mathbb{D}}+\hat{\mathcal{C}}+\hat{A})(\Psi+\Psi+\psi) \right) \right\} = 0 \\ & \Rightarrow \mathbb{D}^\mu \mathcal{G}_{\mu\nu}^a + \mathbb{D}_\nu \mathbb{D}^\mu \mathcal{C}_\mu^a + \bar{\Upsilon} \gamma_\nu t^a \Upsilon = 0, \quad \hat{\mathcal{D}}\Upsilon = 0 \end{aligned} \quad (371)$$

HADO ПРОВЕРУТ'  $\mathbb{D}^\mu \mathcal{C}_\mu = 0$  (order by order?)

Formulas

$$\begin{aligned} & D^\mu G_{\mu\bullet}(\mathbb{A}) + t^a(\bar{\Sigma}_b \gamma_\bullet t^a \Sigma_b) = -\partial^i G_{\bullet i}(\mathbb{A}) + i[\mathbb{A}^i, G_{\bullet i}(\mathbb{A})] + t^a(\bar{\Sigma}_b \gamma_\bullet t^a \Sigma_b) \\ & = -\partial^i([-\infty_*, x_*]_{x_\perp}^{\bar{A}\bullet} \bar{G}_{\bullet i}(x_\perp, x_*)[x_*, -\infty_*]_{x_\perp}^{\bar{A}\bullet}) + i[U^i + V^i - \Sigma^i, U_{\bullet i} - \partial_\bullet \Sigma_i] + t^a(\bar{\Sigma}_b \gamma_\bullet t^a \Sigma_b) \\ & = -[-\infty_*, x_*]_{x_\perp}^{\bar{A}\bullet} \partial^i \bar{G}_{\bullet i}(x_\perp, x_*)[x_*, -\infty_*]_{x_\perp}^{\bar{A}\bullet} - i \int_{-\infty}^{x_*} d_s^2 z_* [-\infty_*, z_*]_{x_\perp}^{\bar{A}\bullet} \bar{G}_{\bullet i}(x_\perp, z_*)[z_*, x_*]_{x_\perp}^{\bar{A}\bullet} \bar{G}_{\bullet i}(x_\perp, x_*)[x_*, -\infty_*]_{x_\perp}^{\bar{A}\bullet} \\ & + i \int_{-\infty}^{x_*} d_s^2 z_* [-\infty_*, x_*]_{x_\perp}^{\bar{A}\bullet} \bar{G}_{\bullet i}(x_\perp, x_*)[x_*, z_*]_{x_\perp}^{\bar{A}\bullet} \bar{G}_{\bullet i}(x_\perp, z_*)[z_*, -\infty_*]_{x_\perp}^{\bar{A}\bullet} + t^a(\bar{\xi}_b [x_*, -\infty_*]_{x_\perp}^{\bar{A}\bullet} \hat{p}_1 t^a [-\infty_*, x_*]_{x_\perp}^{\bar{A}\bullet} \xi_b) + i[U^i, U_{\bullet i}] \\ & + i[V^i - \Sigma^i, U_{\bullet i} - \partial_\bullet \Sigma_i] = i[V^i, U_{\bullet i}] - i[\Sigma^i, U_{\bullet i}] - i[V^i, \partial_\bullet \Sigma_i] + i[\Sigma^i, \partial_\bullet \Sigma_i] \end{aligned} \quad (372)$$

Similarly

$$D^\mu G_{\mu*}(\mathbb{A}) + t^a(\bar{\Sigma}_a \gamma_* t^a \Sigma_a) = i[U^i, V_{*i}] - i[\Sigma^i, V_{*i}] - i[U^i, \partial_* \Sigma_i] + i[\Sigma^i, \partial_* \Sigma_i] \quad (373)$$

Also,

$$\begin{aligned} & D^\mu G_{\mu i}^a(\mathbb{A}) + t^a(\bar{\Upsilon} \gamma_i t^a \Upsilon) = (\partial^k - i\mathbb{A}^k)G_{ki}(\mathbb{A}) + \frac{2}{s}\partial_* G_{\bullet i}(\mathbb{A}) + \frac{2}{s}\partial_\bullet G_{*i}(\mathbb{A}) + [\bar{\Sigma}^a t^b \gamma_i \Sigma_b + \bar{\Sigma}^b t^b \gamma_i \Sigma_a] \\ & = (\partial^k - iU^k - iV^k + i\Sigma^k)(i[U_i, V_k] + i[V_i, U_k]) \\ & + (\mathbb{D}_i \Sigma_k - i \leftrightarrow k) + i[\Sigma_i, \Sigma_k] - [\bar{\Sigma}^a(x_\bullet, x_\perp) t^b \gamma_i \Sigma_b(x_*, x_\perp) + \bar{\Sigma}^b(x_*, x_\perp) t^b \gamma_i \Sigma_a(x_\bullet, x_\perp)] + [\bar{\Sigma}^a t^b \gamma_i \Sigma_b + \bar{\Sigma}^b t^b \gamma_i \Sigma_a] \\ & = (\partial^k - i\mathbb{A}^k)G_{ki}(\mathbb{A}) = i\mathbb{D}_k^{ab}([U_i, V^k] + i[V_i, U^k])^b + O(\partial_\perp^4) \end{aligned} \quad (374)$$

ЧА4ААА  $\delta E3$  КВАРКОВ (4  $\frac{1}{p_* p_\bullet}$  C Eq. (147))

$$\begin{aligned} A_\bullet^{[2]}(x) &= \frac{1}{p_\parallel^2} \mathbb{D}^\mu G_{\mu\bullet} = \frac{s}{4p_* p_\bullet} \mathbb{D}^\mu G_{\mu\bullet} = \frac{is}{4p_* p_\bullet} [V^i, U_{\bullet i}] = \frac{i}{2} \int_{-\infty}^{x_\bullet} dz_\bullet [U^i(x_*, x_\perp), V_i(z_\bullet, z_\perp)] \\ A_*^{[2]}(x) &= \frac{1}{p_\parallel^2} \mathbb{D}^\mu G_{\mu*} = \frac{s}{4p_* p_\bullet} \mathbb{D}^\mu G_{\mu*} = \frac{is}{4p_* p_\bullet} [U^i, V_{\bullet i}] = \frac{i}{2} \int_{-\infty}^{x_*} dz_* [V^i(x_\bullet, x_\perp), U_i(z_*, z_\perp)] \\ A_i^{[3]a}(x) &= \frac{1}{p_\parallel^2} \mathbb{D}^\mu G_{\mu i}^a + 2i \frac{1}{p_\parallel^2} G_{*i}^{ab} \frac{1}{p_\parallel^2} \mathbb{D}^\mu G_{\mu\bullet}^b + 2i \frac{1}{p_\parallel^2} G_{\bullet i}^{ab} \frac{1}{p_\parallel^2} \mathbb{D}^\mu G_{\mu*}^b \\ &= \frac{s}{4p_* p_\bullet} \mathbb{D}^k G_{ki}^a + \frac{is^2}{8} \frac{1}{p_* p_\bullet} G_{*i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu\bullet}^b + \frac{is^2}{8} \frac{1}{p_* p_\bullet} G_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu*}^b \end{aligned} \quad (375)$$

$$\begin{aligned} F_{\bullet i}^{[3]} &= \partial_\bullet \frac{1}{p_\parallel^2} \mathbb{D}^\mu G_{\mu i} - \mathbb{D}_i \frac{1}{p_\parallel^2} \mathbb{D}^j G_{j\bullet} + \frac{s}{4} \frac{1}{p_*} G_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu*}^b + \frac{s}{4} \frac{1}{p_*} G_{*i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu\bullet}^b \\ &= -\frac{is}{4p_*} \mathbb{D}^k G_{ki} - \mathbb{D}_i \frac{s}{4p_* p_\bullet} \mathbb{D}^\mu G_{\mu\bullet} + \frac{s}{4} \frac{1}{p_*} G_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu*}^b + \frac{s}{4} \frac{1}{p_*} G_{*i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu\bullet}^b \\ &\Rightarrow F_{\bullet i}(A) = G_{\bullet i} + F_{\bullet i}^{[3]} = G_{\bullet i} - \frac{is}{4p_*} \mathbb{D}^k G_{ki} - \mathbb{D}_i \frac{s}{4p_* p_\bullet} \mathbb{D}^\mu G_{\mu\bullet} + \frac{s}{4} \frac{1}{p_*} G_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu*}^b + \frac{s}{4} \frac{1}{p_*} G_{*i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu\bullet}^b \\ &= G_{\bullet i} - \frac{is}{4p_*} \mathbb{D}^k G_{ki} - \frac{s}{4p_* p_\bullet} \mathbb{D}_i \mathbb{D}^\mu G_{\mu\bullet} + \frac{s}{4} \frac{1}{p_*} G_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu G_{\mu*}^b - \frac{s}{4} \frac{1}{p_* p_\bullet} G_{\bullet i}^{ab} \frac{1}{p_\bullet} \mathbb{D}^\mu G_{\mu\bullet}^b \end{aligned}$$

$$\begin{aligned}
D_* F_{\bullet i}^a(A) &= \partial_* \mathbb{G}_{\bullet i}^a + \partial_* F_{\bullet i}^{[3]a} - i A_*^{[2]ab} \mathbb{G}_{\bullet i}^b = \partial_* F_{\bullet i}^{[3]a} + i \mathbb{G}_{\bullet i}^{ab} A_*^{[2]b} \\
&= -\frac{s}{4} \mathbb{D}^k \mathbb{G}_{ki}^a - \partial_* \mathbb{D}_i \frac{s}{4 p_* p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu\bullet} - i \mathbb{G}_{\bullet i}^{ab} \frac{s}{4 p_* p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu*}^b - i \frac{s}{4} \mathbb{G}_{*i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + i \frac{s}{4} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu*}^b \\
&= -\frac{s}{4} \mathbb{D}^k \mathbb{G}_{ki}^a - \partial_* \mathbb{D}_i \frac{s}{4 p_* p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu\bullet} - i \frac{s}{4} \mathbb{G}_{*i}^{ab} \frac{1}{p_* p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b = -\frac{s}{4} \mathbb{D}^k \mathbb{G}_{ki}^a + i \mathbb{D}_i \frac{s}{4 p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu*} \\
D_\bullet F_{*i}^a(A) &= -\frac{s}{4} \mathbb{D}^k \mathbb{G}_{ki}^a + i \mathbb{D}_i \frac{s}{4 p_*} \mathbb{D}^\mu \mathbb{G}_{\mu*}
\end{aligned} \tag{376}$$

From Eq. (375)

$$\frac{s}{4 p_*} \mathbb{D}^\mu \mathbb{G}_{\mu*} + \frac{s}{4 p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu\bullet} = i \partial_* A_\bullet^{[2]}(x) + i \partial_\bullet A_*^{[2]}(x) = 0 \tag{377}$$

and therefore

$$\frac{2}{s} D_* F_{\bullet i}^a(A) + \frac{2}{s} D_\bullet F_{*i}^a(A) + \mathbb{D}^k \mathbb{G}_{ki}^a = i \mathbb{D}_i \left( \frac{1}{2 p_*} \mathbb{D}^\mu \mathbb{G}_{\mu*} + \frac{1}{2 p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu\bullet} \right) = O(\partial_\perp^4)$$

$$\begin{aligned}
& -\frac{is}{4 p_*} \mathbb{D}^k \mathbb{G}_{ki} - \mathbb{D}_i \frac{s}{4 p_* p_\bullet} \mathbb{D}^\mu \mathbb{G}_{\mu\bullet} \\
&= \frac{s}{4 p_*} (\partial^k - i U^k - i V^k) ([U_i, V_k] + [V_i, U_k]) - (p_i + U_i + V_i) \frac{s}{4 p_* p_\bullet} [V^k, U_{\bullet k}] \\
&= -\frac{1}{2} \int_{-\infty}^{x_\bullet} d \frac{2}{s} z_\bullet (i \partial^k + U^k + V^k)^{ab} ([U_i, V_k] + [V_i, U_k])^b(x_*, z_\bullet) + \frac{1}{2} (i \partial_i + U_i(x) + V_i(x))^{ab} \int_{-\infty}^{x_\bullet} d \frac{2}{s} z_\bullet [V^k(z_\bullet), U_k(x_\bullet)]^b
\end{aligned} \tag{378}$$

### C KBAPKAMU

$$\begin{aligned}
A_\bullet^{[2]}(x) &= \frac{s}{4 p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet} + t^a (\bar{\Sigma}_b \gamma_\bullet t^a \Sigma_b)) = \frac{i}{2} \int_{-\infty}^{x_\bullet} dz_\bullet [U^i(x_*, x_\perp), V_i(z_\bullet, z_\perp)] + O(\partial_\perp^4) \\
A_*^{[2]}(x) &= \frac{s}{4 p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*} + t^a (\bar{\Sigma}_a \gamma_* t^a \Sigma_a)) = \frac{i}{2} \int_{-\infty}^{x_*} dz_* [V^i(x_\bullet, x_\perp), U_i(z_*, z_\perp)] + O(\partial_\perp^4) \\
A_i^{[3]a}(x) &= \frac{1}{p_\parallel^2} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) + 2i \frac{1}{p_\parallel^2} \mathbb{G}_{*i}^{ab} \frac{1}{p_\parallel^2} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\Sigma}_b \gamma_\bullet t^b \Sigma_b) + 2i \frac{1}{p_\parallel^2} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_\parallel^2} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\Sigma}_a \gamma_* t^b \Sigma_a) \\
&= \frac{s}{4 p_* p_\bullet} \mathbb{D}^k \mathbb{G}_{ki}^a + \frac{is^2}{8} \frac{1}{p_* p_\bullet} \mathbb{G}_{*i}^{ab} \frac{1}{p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\mathbb{Y}} \gamma_\bullet t^b \mathbb{Y}) + \frac{is^2}{8} \frac{1}{p_* p_\bullet} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\mathbb{Y}} \gamma_* t^b \mathbb{Y})
\end{aligned} \tag{379}$$

gde wi uzd  $\bar{\Sigma}_a \gamma_\bullet t^b \Sigma_a = \bar{\Sigma}_b \gamma_* t^b \Sigma_b = 0$

$$\begin{aligned}
F_{\bullet i}^{[3]} &= \\
&= -\frac{is}{4 p_*} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \mathbb{D}_i \frac{s}{4 p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^a + \bar{\mathbb{Y}} \gamma_\bullet t^a \mathbb{Y}) + \frac{s}{4} \frac{1}{p_*} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\mathbb{Y}} \gamma_* t^b \mathbb{Y}) + \frac{s}{4} \frac{1}{p_*} \mathbb{G}_{*i}^{ab} \frac{1}{p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\mathbb{Y}} \gamma_\bullet t^b \mathbb{Y}) \\
&\Rightarrow D_* F_{\bullet i}^a(A) = \partial_* \mathbb{G}_{\bullet i}^a + \partial_* F_{\bullet i}^{[3]a} - i A_*^{[2]ab} \mathbb{G}_{\bullet i}^b = -\partial_* \partial_\bullet \Sigma_i + \partial_* F_{\bullet i}^{[3]a} + i \mathbb{G}_{\bullet i}^{ab} A_*^{[2]b} \\
&= -\partial_* \bar{\partial}_\bullet \Sigma_i - \frac{s}{4} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \partial_* \mathbb{D}_i \frac{s}{4 p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^a + \bar{\mathbb{Y}} \gamma_\bullet t^a \mathbb{Y}) - i \mathbb{G}_{\bullet i}^{ab} \frac{s}{4 p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\mathbb{Y}} \gamma_* t^b \mathbb{Y}) \\
&\quad - i \mathbb{G}_{*i}^{ab} \frac{s}{4 p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\mathbb{Y}} \gamma_\bullet t^b \mathbb{Y}) + i \frac{s}{4} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_* p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\mathbb{Y}} \gamma_* t^b \mathbb{Y}) \\
&= -\frac{s}{4} (\bar{\Sigma}^a t^a \gamma_i \Sigma_b + \bar{\Sigma}^b t^a \gamma_i \Sigma_a) - \frac{s}{4} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) + i \mathbb{D}_i \frac{s}{4 p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^a + \bar{\mathbb{Y}} \gamma_\bullet t^a \mathbb{Y})
\end{aligned} \tag{380}$$

## 3. Lvertex

$$\begin{aligned}
A_{\bullet}^{[2]}(x) &= \frac{1}{p^2} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet} + t^a (\bar{\Sigma}_b \gamma_{\bullet} t^a \Sigma_b)) = i \int d^4 z (x | \frac{1}{p^2} | z) ([V^i, U_{\bullet i}] - [\Sigma^i, U_{\bullet i}] - [V^i, \partial_{\bullet} \Sigma_i] + [\Sigma^i, \partial_{\bullet} \Sigma_i]) \\
A_{*}^{[2]}(x) &= \frac{1}{p^2} (\mathbb{D}^\mu \mathbb{G}_{\mu*} + t^a (\bar{\Sigma}_a \gamma_{*} t^a \Sigma_a)) = i \int d^4 z (x | \frac{1}{p^2} | z) ([U^i, V_{*i}] - [\Sigma^i, V_{*i}] - [U^i, \partial_{*} \Sigma_i] + [\Sigma^i, \partial_{*} \Sigma_i]) \\
A_i^{[3]a}(x) &= \frac{1}{p^2} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\Upsilon} \gamma_i t^a \Upsilon) + 2i \frac{1}{p^2} \mathbb{G}_{*i}^{ab} \frac{1}{p^2} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\Sigma}_b \gamma_{\bullet} t^b \Sigma_b) + 2i \frac{1}{p^2} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p^2} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\Sigma}_a \gamma_{*} t^b \Sigma_a) \quad (381)
\end{aligned}$$

E. EUIË PA3: ΠΑΡΑΜΕΤΡ  $\partial_{\perp}$ 

First approximation:

$$\begin{aligned}
\mathbb{A}_{\bullet} &= \mathbb{A}_{*} = 0, \quad \mathbb{A}_i = U_i + V_i, \quad G_{*\bullet}(\mathbb{A}) = 0, \\
G_{*i}(\mathbb{A}) &= V_{*i}, \quad G_{\bullet i}(\mathbb{A}) = U_{\bullet i}, \quad G_{ik}(\mathbb{A}) = -i[U_i, V_k] - i[V_i, U_k] \\
\Upsilon &= \Sigma_a + \Sigma_b = \Sigma_a = [-\infty_{\bullet}, x_{\bullet}]_{x_{\bullet}}^{\hat{A}_{*}} \xi_a(x), \quad \Sigma_b = [-\infty_{*}, x_{*}]_{x_{*}}^{\hat{A}_{\bullet}} \xi_b(x) \quad (382)
\end{aligned}$$

## СВОÏСТВА САМОСОГЛАСОВАННОСТУ

$$\begin{aligned}
\bar{\Upsilon} \gamma_{\bullet} t^a \Upsilon &= \bar{\Sigma}^b t^a \gamma_{\bullet} \Sigma_b, \quad \bar{\Upsilon} \gamma_{*} t^a \Upsilon = \bar{\Sigma}^a t^a \gamma_{*} \Sigma_a, \quad \bar{\Upsilon} \gamma_i t^a \Upsilon = \bar{\Sigma}_a t^a \gamma_i \Sigma_b + \bar{\Sigma}_b t^a \gamma_i \Sigma_b, \\
\partial^i \mathbb{G}_{\bullet i}^a &= \bar{\Sigma}_a \gamma_{\bullet} t^a \Sigma_a, \quad \partial^i \mathbb{G}_{*i}^a = \bar{\Sigma}_b \gamma_{*} t^a \Sigma_b \quad (383)
\end{aligned}$$

$$\begin{aligned}
D^\mu G_{\mu i}(\mathbb{A}) &= \frac{2}{s} \partial_{*} G_{\bullet i}(\mathbb{A}) + \frac{2}{s} \partial_{\bullet} G_{*i}(\mathbb{A}) + (\partial^k - i\mathbb{A}^k) G_{ki}(\mathbb{A}) = (\partial^k - i\mathbb{A}^k) G_{ki}(\mathbb{A}), \\
D^\mu G_{\mu\bullet}(\mathbb{A}) &= -(\partial^i - i\mathbb{A}^i) G_{\bullet i}(\mathbb{A}), \quad D^\mu G_{\mu*}(\mathbb{A}) = -(\partial^i - i\mathbb{A}^i) G_{*i}(\mathbb{A}), \quad (384)
\end{aligned}$$

Sdvg  $A \rightarrow A + \mathbb{A}$ ,  $\psi \rightarrow \psi + \Upsilon$  (bez surface terms):

$$\begin{aligned}
&\int d^4 x \left( -\frac{1}{4} [G_{\mu\nu}(A + \mathbb{A})]^2 + \frac{1}{2} (\mathbb{D}^\mu A_\mu)^2 + (\bar{\Upsilon} + \bar{\psi})(\hat{\mathbb{D}} + \hat{A})(\Upsilon + \psi) \right) \\
&= \int d^4 x \left( -\frac{1}{4} \mathcal{G}_{\mu\nu}^2 + A_\alpha^a (\mathbb{D}_\mu \mathcal{G}^{a\mu\alpha} + \bar{\Upsilon} \gamma_\alpha t^a \Upsilon) + \bar{\psi} \hat{\mathbb{D}} \Upsilon + \bar{\Upsilon} \hat{\mathbb{D}} \psi + \frac{1}{2} A_\mu^a (\mathbb{D}^2 g^{\mu\nu} - 2i \mathcal{G}^{\mu\nu})^{ab} A_b^b \right. \\
&\quad \left. - g f^{abc} A^{a\alpha} A^{b\beta} \mathbb{D}_\alpha A_\beta^c - \frac{g^2}{4} f^{abm} f^{cdm} A^{a\alpha} A^{b\beta} A_\alpha^c A_\beta^d + \bar{\psi} \hat{A} \psi \right) \quad (385)
\end{aligned}$$

УЩЕМ  $\mathcal{C}$  and  $\Upsilon$  ТАКЖЕ 4ТО

$$\mathcal{C}(x) \Psi(y) = \int DAD\bar{\psi}D\psi A(x) \psi(y) e^{\int d^4 x \left( -\frac{1}{4} [G_{\mu\nu}(A + \mathbb{A})]^2 + \frac{1}{2} (\mathbb{D}^\mu A_\mu)^2 + (\bar{\Upsilon} + \bar{\psi})(\hat{\mathbb{D}} + \hat{A})(\Upsilon + \psi) \right)} \quad (386)$$

ТОГДА  $\mathcal{A} = \mathbb{A} + \mathcal{C}$  и  $\Upsilon = \Psi + \Upsilon$  - РЕШЕНИЕ УР-Û

$$\begin{aligned}
&\delta \left\{ \int d^4 x \left( -\frac{1}{4} [G_{\mu\nu}(A + \mathbb{A} + \mathcal{C})]^2 + \frac{1}{2} [\mathbb{D}^\mu (A_\mu + \mathcal{C}_\mu)]^2 + (\bar{\Upsilon} + \bar{\Psi} + \bar{\psi})(\hat{\mathbb{D}} + \hat{\mathcal{C}} + \hat{A})(\Upsilon + \Psi + \psi) \right) \right\} = 0 \\
&\Rightarrow \mathcal{D}^\mu \mathcal{G}_{\mu\nu}^a + \mathbb{D}_\nu \mathbb{D}^\mu \mathcal{C}_\mu^a + \bar{\Upsilon} \gamma_\nu t^a \Upsilon = 0, \quad \hat{\mathcal{D}} \Upsilon = 0 \quad (387)
\end{aligned}$$

HADO ПРОБЕРУТ'  $\mathbb{D}^\mu \mathcal{C}_\mu = 0$  (order by order?)

ΛΙΗΕÛΗÛÛ 4ΛΕΗ Β ΗΠΤΕΓΡΑΛΕ (385)

$$\begin{aligned}
D^\mu G_{\mu\bullet}(\mathbb{A}) + t^a (\bar{\Upsilon} \gamma_{\bullet} t^a \Upsilon) &= -\partial^i G_{\bullet i}(\mathbb{A}) + i[\mathbb{A}^i, G_{\bullet i}(\mathbb{A})] + t^a (\bar{\Sigma}_b \gamma_{\bullet} t^a \Sigma_b) = i[V^i, U_{\bullet i}] \\
D^\mu G_{\mu*}(\mathbb{A}) + t^a (\bar{\Upsilon} \gamma_{*} t^a \Upsilon) &= -\partial^i G_{*i}(\mathbb{A}) + i[\mathbb{A}^i, G_{*i}(\mathbb{A})] + t^a (\bar{\Sigma}_b \gamma_{*} t^a \Sigma_b) = i[U^i, V_{*i}] \\
D^\mu G_{\mu i}(\mathbb{A}) &= -\mathbb{D}^k G_{ik}(\mathbb{A}) = i(\partial^k - i[U_k + V_k])([U_i, V_k] + [V_i, U_k]) \quad (388)
\end{aligned}$$

ПОЛЕ  $\mathcal{C}_\mu$

$$\begin{aligned}
\mathcal{C}_\bullet &= A_\bullet^{[2]}(x) = \frac{s}{4p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet} + t^a (\bar{\Sigma}_b \gamma_\bullet t^a \Sigma_b)) = \frac{i}{2} \int_{-\infty}^{x_\bullet} dz_\bullet [U^i(x_*, x_\perp), V_i(z_\bullet, z_\perp)] + O(\partial_\perp^4) \\
\mathcal{C}_* &= A_*^{[2]}(x) = \frac{s}{4p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*} + t^a (\bar{\Sigma}_a \gamma_* t^a \Sigma_a)) = \frac{i}{2} \int_{-\infty}^{x_*} dz_* [V^i(x_\bullet, x_\perp), U_i(z_*, z_\perp)] + O(\partial_\perp^4) \\
\mathcal{C}_i &= A_i^{[3]a}(x) = \frac{1}{p_\perp^2} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) + 2i \frac{1}{p_\perp^2} \mathbb{G}_{*i}^{ab} \frac{1}{p_\perp^2} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\Sigma}_b \gamma_\bullet t^b \Sigma_b) + 2i \frac{1}{p_\perp^2} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_\perp^2} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\Sigma}_a \gamma_* t^b \Sigma_a) \\
&= \frac{s}{4p_*p_\bullet} (\mathbb{D}^k \mathbb{G}_{ki}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \frac{s^2}{8} \frac{1}{p_*p_\bullet} \mathbb{G}_{*i}^{ab} \frac{1}{p_*p_\bullet} [V^j, U_{\bullet j}]^b - \frac{s^2}{8} \frac{1}{p_*p_\bullet} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_*p_\bullet} [U^j, V_{*j}]^b \\
&= \frac{s}{4p_*p_\bullet} (\mathbb{D}^k \mathbb{G}_{ki}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - i \frac{s^2}{8} \frac{1}{p_*p_\bullet} V_{*i}^{ab} \frac{1}{p_*} [U^j, V_j]^b + i \frac{s^2}{8} \frac{1}{p_*p_\bullet} U_{\bullet i}^{ab} \frac{1}{p_\bullet} [U^j, V_j]^b
\end{aligned} \tag{389}$$

Check  $\mathbb{D}^\mu \mathcal{C}_\mu = 0$ :

$$\frac{2}{s} \partial_* \mathcal{C}_\bullet + \frac{2}{s} \partial_\bullet \mathcal{C}_* = 0, \quad \frac{2}{s} \partial_* \mathcal{C}_\bullet + \frac{2}{s} \partial_\bullet \mathcal{C}_* + \mathbb{D}^i \mathcal{C}_i = O(\partial_\perp^4) \tag{390}$$

$$\begin{aligned}
F_{\bullet i}^{[3]} &= \partial_\bullet A_i^{[3]}(x) - \mathbb{D}_i A_\bullet^{[2]}(x) \\
&= -\frac{is}{4p_*} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \mathbb{D}_i \frac{s}{4p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^a + \bar{\mathbb{Y}} \gamma_\bullet t^a \mathbb{Y}) + \frac{s}{4p_*} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\mathbb{Y}} \gamma_* t^b \mathbb{Y}) + \frac{s}{4p_*} \mathbb{G}_{*i}^{ab} \frac{1}{p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\mathbb{Y}} \gamma_\bullet t^b \mathbb{Y}) \\
&= \frac{is}{4p_*} (\mathbb{D}^k \mathbb{G}_{ik}^a - \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) + \mathbb{D}_i \frac{s}{4p_*} \frac{1}{p_\bullet} [U^j, V_j]^b + \frac{s}{4p_*} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_\bullet} [U^j, V_j]^b
\end{aligned} \tag{391}$$

$$\begin{aligned}
D_* F_{\bullet i}^a(A) &= \partial_* \mathbb{G}_{\bullet i}^a + \partial_* F_{\bullet i}^{[3]a} - i A_*^{[2]ab} \mathbb{G}_{\bullet i} = -\partial_* F_{\bullet i}^{[3]a} + i \mathbb{G}_{\bullet i}^{ab} A_*^{[2]b} \\
&= -\frac{s}{4} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \partial_* \mathbb{D}_i \frac{s}{4p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^a + \bar{\mathbb{Y}} \gamma_\bullet t^a \mathbb{Y}) - i \mathbb{G}_{\bullet i}^{ab} \frac{s}{4p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\mathbb{Y}} \gamma_* t^b \mathbb{Y}) \\
&\quad - i \mathbb{G}_{*i}^{ab} \frac{s}{4p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^b + \bar{\mathbb{Y}} \gamma_\bullet t^b \mathbb{Y}) + i \frac{s}{4} \mathbb{G}_{\bullet i}^{ab} \frac{1}{p_*p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu*}^b + \bar{\mathbb{Y}} \gamma_* t^b \mathbb{Y}) \\
&= -\frac{s}{4} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) + i \mathbb{D}_i \frac{s}{4p_\bullet} (\mathbb{D}^\mu \mathbb{G}_{\mu\bullet}^a + \bar{\mathbb{Y}} \gamma_\bullet t^a \mathbb{Y}) = \frac{s}{4} (\mathbb{D}^k \mathbb{G}_{ik}^a - \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \frac{is}{4} \mathbb{D}_i [U^j, V_j]
\end{aligned} \tag{392}$$

We get YM equation:

$$\begin{aligned}
\mathcal{D}_* \mathcal{F}_{\bullet i}^a &\equiv D_* F_{\bullet i}^a(A) = -\frac{s}{4} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \frac{s}{4} \mathbb{D}_i [V^j, U_j] + O(\partial_\perp^4) \\
\mathcal{D}_\bullet \mathcal{F}_{*i}^a &\equiv D_\bullet F_{*i}^a(A) = -\frac{s}{4} (\mathbb{D}^\mu \mathbb{G}_{\mu i}^a + \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y}) - \frac{s}{4} \mathbb{D}_i [U^j, V_j] + O(\partial_\perp^4) \\
\Rightarrow \frac{2}{s} (\mathcal{D}_* \mathcal{F}_{\bullet i}^a + \mathcal{D}_\bullet \mathcal{F}_{*i}^a) &= -\mathbb{D}^k \mathbb{G}_{ki}^a - \bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y} + O(\partial_\perp^4) \Rightarrow \mathcal{D}^\mu \mathcal{F}_{\mu i} = -\bar{\mathbb{Y}} \gamma_i t^a \mathbb{Y} + O(\partial_\perp^4)
\end{aligned} \tag{393}$$

### XIII. FEYNMAN OXOD

$$(x | \frac{1}{p^2 + i\epsilon} | z) = \frac{i}{4\pi} \ln[-(x-z)_* + i\epsilon(x-z)_\bullet] + \frac{i}{4\pi} \ln[(x-z)_\bullet - i\epsilon(x-z)_*] + \text{const} \tag{394}$$

Cutoffs: we are solving YM equation in a region where  $(x-z)_\perp^2 \ll m_\perp^{-2}$  where  $m_\perp^{-2}$  is a characteristic transverse size of  $\bar{A}_*$  and/or  $\bar{A}_\bullet$ . Let  $a$  be the characteristic  $\alpha$ 's in  $\bar{A}_\bullet$  and  $b$  be the characteristic  $\beta$ 's in  $\bar{A}_*$ .

TOFDA:

$$(x | \frac{1}{p^2 + i\epsilon} | z) = \frac{i}{4\pi} \ln[-b(x-z)_* + i\epsilon(x-z)_\bullet] + \frac{i}{4\pi} \ln[a(x-z)_\bullet - i\epsilon(x-z)_*] \tag{395}$$



if  $abs \gg m_{\perp}^2$  (see Eq. (416)) and

$$(x|\frac{1}{p^2+i\epsilon}|z) = \frac{i}{4\pi} \ln[-\frac{4}{s}(x-z)_*(x-z)_{\bullet}m_{\perp}^2+i\epsilon] = \frac{i}{4\pi} \ln[-\frac{2m_{\perp}}{\sqrt{s}}(x-z)_*+i\epsilon(x-z)_{\bullet}] + \frac{i}{4\pi} \ln[\frac{2m_{\perp}}{\sqrt{s}}(x-z)_{\bullet}-i\epsilon(x-z)_*] \quad (396)$$

if  $abs \ll m_{\perp}^2$ . so

$$\begin{aligned} (x|\frac{1}{\bar{P}_*\bar{P}_{\bullet}+i\epsilon}\bar{P}_*|z) &= (x|\frac{1}{\bar{P}_{\bullet}+i\epsilon p_*}|z) = -\frac{(2\pi)^{-1}}{x_{\bullet}-z_{\bullet}-i\epsilon(x-z)_*}[x_*, z_*]^{A_{\bullet}} \\ (x|\frac{1}{\bar{P}_{\bullet}\bar{P}_*+i\epsilon}\bar{P}_{\bullet}|z) &= (x|\frac{1}{\bar{P}_*+i\epsilon p_{\bullet}}|z) = -\frac{(2\pi)^{-1}}{x_*-z_*-i\epsilon(x-z)_{\bullet}}[x_{\bullet}, z_{\bullet}]^{A_*} \end{aligned} \quad (397)$$

(cf. Eq. (147)).

$$\begin{aligned} (x|\frac{1}{\bar{P}_{\bullet}\bar{P}_*+i\epsilon}|y) &= (x|\frac{1}{\bar{P}_*+i\epsilon p_{\bullet}}|z)(z|\frac{1}{\bar{P}_{\bullet}+i\epsilon p_*}|y) = \frac{1}{4\pi^2} \int dz \frac{[x_{\bullet}, z_{\bullet}]^{A_*}}{x_*-z_*-i\epsilon(x-z)_*} \frac{[z_*, y_*]^{A_{\bullet}}}{z_{\bullet}-y_{\bullet}-i\epsilon(z-y)_{\bullet}} \\ &= \frac{1}{4\pi^2} \int dz \left( \frac{[x_{\bullet}, z_{\bullet}]^{A_*}}{x_*-z_*-i\epsilon} - 2\pi i \theta(z-x)_{\bullet} \delta(x_*-z_*) \right) \left( \frac{[z_*, y_*]^{A_{\bullet}}}{z_{\bullet}-y_{\bullet}-i\epsilon} - 2\pi i \theta(y-z)_* \delta(z_{\bullet}-y_{\bullet}) \right) \\ (x|\frac{1}{\bar{P}_*\bar{P}_{\bullet}+i\epsilon}|y) &= (x|\frac{1}{\bar{P}_{\bullet}+i\epsilon p_*}|z)(z|\frac{1}{\bar{P}_*+i\epsilon p_{\bullet}}|y) = \frac{1}{4\pi^2} \int dz \frac{[x_*, z_*]^{A_{\bullet}}}{x_{\bullet}-z_{\bullet}-i\epsilon(x-z)_*} \frac{[z_{\bullet}, y_{\bullet}]^{A_*}}{z_*-y_*-i\epsilon(z-y)_{\bullet}} \end{aligned} \quad (398)$$

ECAU  $\bar{A}_*(x_{\bullet}) \rightarrow 0$  PPU  $x_{\bullet} \rightarrow \pm\infty$ , TO

$$\begin{aligned} \bar{C}_*^{(1)}(x) &= -\frac{1}{2\pi s} \int dz_* dz_{\bullet} \frac{1}{x_{\bullet}-z_{\bullet}-i\epsilon(x-z)_*} [x_*, z_*]^{A_{\bullet}} [\bar{A}_*(z_{\bullet}), \bar{A}_{\bullet}(z_*)] [z_*, x_*]^{A_{\bullet}} \Rightarrow \bar{C}_*^{(1)}(x_*, x_{\bullet} = \pm\infty) = 0 \\ \bar{C}_*^{(1)}(x_{\bullet}, x_* = \infty) &=? -\frac{1}{2\pi} \int dz_{\bullet} \frac{1}{x_{\bullet}-z_{\bullet}+i\epsilon} ([\infty_*, -\infty_*]^{A_{\bullet}} - 1)^{ab} \bar{A}_*^b(z_{\bullet}) \end{aligned} \quad (399)$$

ОПЕРДЕЛЕНИЕ

$$\begin{aligned} A_{\bullet}^{(+)}(x_*) &= -\frac{i}{2\pi} \int dz_* \frac{1}{x_*-z_*-i\epsilon} A_{\bullet}(z_*), & A_{\bullet}^{(-)}(x_*) &= \frac{i}{2\pi} \int dz_* \frac{1}{x_*-z_*+i\epsilon} A_{\bullet}(z_*) \\ A_*^{(+)}(x_{\bullet}) &= -\frac{i}{2\pi} \int dz_{\bullet} \frac{1}{x_{\bullet}-z_{\bullet}-i\epsilon} A_*(z_{\bullet}), & A_*^{(-)}(x_{\bullet}) &= \frac{i}{2\pi} \int dz_{\bullet} \frac{1}{x_{\bullet}-z_{\bullet}+i\epsilon} A_*(z_{\bullet}) \end{aligned} \quad (400)$$

$$\begin{aligned} (\bar{A}_{\bullet} + \bar{C}_{\bullet}^{(1)})(x_*) &= \bar{A}_{\bullet}^{(+)}(x_*) + \frac{i}{2} \int_{-\infty}^{x_{\bullet}} d\frac{2}{s} x'_{\bullet} [\bar{A}_*(x'_{\bullet}), \bar{A}_{\bullet}^{(+)}(x_*)] + \bar{A}_{\bullet}^{(-)}(x_*) - \frac{i}{2} \int_{x_{\bullet}}^{\infty} d\frac{2}{s} x'_{\bullet} [\bar{A}_*(x'_{\bullet}), \bar{A}_{\bullet}^{(-)}(x_*)] \\ (\bar{A}_* + \bar{C}_*^{(1)})(x_{\bullet}) &= \bar{A}_*^{(+)}(x_{\bullet}) + \frac{i}{2} \int_{-\infty}^{x_*} d\frac{2}{s} x'_* [\bar{A}_{\bullet}(x'_*), \bar{A}_*^{(+)}(x_{\bullet})] + \bar{A}_*^{(-)}(x_{\bullet}) - \frac{i}{2} \int_{x_*}^{\infty} d\frac{2}{s} x'_* [\bar{A}_{\bullet}(x'_*), \bar{A}_*^{(-)}(x_{\bullet})] \end{aligned} \quad (401)$$

### 1. $F_{\bullet i}$

Solution of Eq. (217)

$$\bar{C}_i^a = -i \int d^4 z \Lambda_x^{ab} (x|\frac{1}{p^2+i\epsilon}|z) \partial^2 ((\partial_i \Lambda^{\dagger}) \Lambda)^b = -\frac{4i}{s} \int d^4 z \Lambda_x^{ab} (x|\frac{1}{p^2}|z) \partial_* \partial_{\bullet} ((\partial_i \Lambda_z^{\dagger}) \Lambda_z)^b \quad (402)$$

$$\begin{aligned} \bar{C}_i^a &= -i \int d^4 z \Lambda_x^{ab} (x|\frac{1}{p^2}|z) \partial^2 ((\partial_i \Lambda^{\dagger}) \Lambda)^b \\ &= -is \int d^4 z \Lambda_x^{ab} (x|\frac{1}{p^2}|z) \frac{\partial}{\partial z_*} \frac{\partial}{\partial z_{\bullet}} ((\partial_i \Lambda_z^{\dagger}) \Lambda_z)^b = (\Lambda_i \partial_i \Lambda^{\dagger})^a - \frac{4}{s} \Lambda_x^{ab} \int d^2 z_{\perp} dz_{\bullet} (x|\frac{p_*}{p^2}|z) ((\partial_i \Lambda_z^{\dagger}) \Lambda_z)^b \Big|_{z_*=-\infty}^{z_*=\infty} \\ &\quad - \frac{4}{s} \Lambda_x^{ab} \int d^2 z_{\perp} dz_* (x|\frac{p_{\bullet}}{p^2}|z) ((\partial_i \Lambda_z^{\dagger}) \Lambda_z)^b \Big|_{z_{\bullet}=-\infty}^{z_{\bullet}=\infty} - 2i \Lambda_x^{ab} \int d^2 z_{\perp} (x|\frac{1}{p^2}|z) ((\partial_i \Lambda_z^{\dagger}) \Lambda_z)^b \Big|_{z_*=-\infty}^{z_*=\infty} \Big|_{z_{\bullet}=-\infty}^{z_{\bullet}=\infty} \end{aligned} \quad (403)$$

Now

$$\begin{aligned}
F_{\bullet i}^a(x) &= \partial_{\bullet} \bar{C}_i^a - \partial_i (\bar{A}_{\bullet} + \bar{C}_{\bullet})^a - i(\bar{A} + \bar{C})_{\bullet}^{ab} \bar{C}_i^b = \Lambda^{am} \partial_{\bullet} (\Lambda^{\dagger mb} \bar{C}_i^b) - i \partial_i (\Lambda \partial_{\bullet} \Lambda^{\dagger})^a \\
&= -\frac{4}{s} \Lambda_x^{ab} \int dz (x | \frac{p_{\bullet}}{p^2 + i\epsilon} | z) \partial_{\bullet} \partial_{\bullet} ((\partial_i \Lambda_z^{\dagger}) \Lambda_z)^b - i \partial_i (\Lambda \partial_{\bullet} \Lambda^{\dagger})^a = -\frac{4}{s} \Lambda_x^{ab} \int dz (x | \frac{p_{\bullet}}{p^2 + i\epsilon} | z) \partial_{\bullet} \Lambda^{\dagger bc} \partial_i (\Lambda_z \partial_{\bullet} \Lambda_z^{\dagger})^c - i \partial_i (\Lambda \partial_{\bullet} \Lambda^{\dagger})^a \\
&= -\frac{4}{s} \Lambda_x^{ab} \int dz_{\bullet} (x | \frac{p_{\bullet}}{p^2 + i\epsilon} | z) \Lambda_z^{\dagger bc} \partial_i (\Lambda_z \partial_{\bullet} \Lambda_z^{\dagger})^c \Big|_{z_{\bullet}=-\infty}^{z_{\bullet}=\infty} = -\frac{4}{s} \Lambda_x^{ab} \int dz_{\bullet} (x | \frac{p_{\bullet}}{p^2 + i\epsilon} | z) \partial_{\bullet} (\partial_i \Lambda_z^{\dagger} \Lambda_z)^b \Big|_{z_{\bullet}=-\infty}^{z_{\bullet}=\infty} \\
&= \frac{1}{2\pi} \Lambda_x^{ab} \int dz_{\bullet} \left( \frac{1}{x_{\bullet} - z_{\bullet} + i\epsilon} \Lambda_z^{\dagger bc} \partial_i (\Lambda_z \partial_{\bullet} \Lambda_z^{\dagger})^c \Big|_{z_{\bullet}=\infty} - \frac{1}{x_{\bullet} - z_{\bullet} - i\epsilon} \Lambda_z^{\dagger bc} \partial_i (\Lambda_z \partial_{\bullet} \Lambda_z^{\dagger})^c \Big|_{z_{\bullet}=-\infty} \right) \\
&= \frac{1}{2\pi} \Lambda_x^{ab} \int dz_{\bullet} \left( \frac{1}{x_{\bullet} - z_{\bullet} + i\epsilon} \partial_{\bullet} (\partial_i \Lambda_z^{\dagger} \Lambda_z)^b \Big|_{z_{\bullet}=\infty} - \frac{1}{x_{\bullet} - z_{\bullet} - i\epsilon} \partial_{\bullet} (\partial_i \Lambda_z^{\dagger} \Lambda_z)^b \Big|_{z_{\bullet}=-\infty} \right) \tag{404}
\end{aligned}$$

where we used eq. (218).

U ΠOΞTOMY

$$\begin{aligned}
&\int dx F_{\bullet i}^a(x) F_{\bullet}^{ai}(x) \\
&= -\int dz_{\bullet} \partial_{\bullet} (\partial_i \Lambda_z^{\dagger} \Lambda_z)^a \Big|_{z_{\bullet}=-\infty}^{z_{\bullet}=\infty} \int dz'_{\bullet} (z_{\bullet}, z_{\bullet} | \frac{1}{p_{\bullet} p_{\bullet} + i\epsilon} | z'_{\bullet}, z'_{\bullet}) \partial_{\bullet} (\partial_i \Lambda_z^{\dagger} \Lambda_z)^a \Big|_{z'_{\bullet}=-\infty}^{z'_{\bullet}=\infty} \tag{405}
\end{aligned}$$

## 2. Action

$$\bar{A} + \bar{C} \equiv \mathcal{A}, \quad \chi + \xi \equiv \Upsilon$$

$$\begin{aligned}
&\int d^4x \left( -\frac{1}{4} [G_{\mu\nu}^a(A + \bar{A})]^2 - \frac{1}{2} [(\bar{D}_{\mu} - i\bar{C}_{\mu}) A^{\mu}]^2 \right) + (\bar{\psi} + \bar{\Upsilon})(\hat{P} + \hat{A})(\psi + \Upsilon) \\
&\Rightarrow \int d^4x \left( -\frac{1}{4} [G_{\mu\nu}^a(A + \mathcal{A})]^2 - \frac{1}{2} (\mathbb{D}^{\mu} A_{\mu} + \bar{D}^{\mu} \bar{C}_{\mu})^2 + \bar{\Upsilon}(\hat{P} + \hat{A})\Upsilon \right) \\
&= \int d^4x \left( -\frac{1}{4} (\mathcal{G}_{\mu\nu}^a)^2 - \mathcal{G}_{\mu\nu}^a \mathcal{D}^{\mu} A^{\nu} - A^{a\mu} \frac{1}{2} (\mathcal{D}^2 g_{\mu\nu} - 2i\mathcal{G}_{\mu\nu})^{ab} A^{b\nu} - (\mathcal{D}^{\mu} A_{\mu}^a) \bar{D}^{\nu} \bar{C}_{\nu}^a - \frac{1}{2} (\bar{D}^{\mu} \bar{C}_{\mu}^a)^2 + (\bar{\psi} + \bar{\Upsilon})(\hat{P} + \hat{A})(\psi + \Upsilon) \right) \\
&= \int d^4x \left( -\frac{1}{4} (\mathcal{G}_{\mu\nu}^a)^2 - \frac{1}{2} (\bar{D}^{\mu} \bar{C}_{\mu}^a)^2 + A^{a\nu} (\mathcal{D}^{\mu} \mathcal{G}_{\mu\nu}^a + \mathcal{D}^{\nu} \bar{D}^{\mu} \bar{C}_{\mu}^a) - A^{a\mu} \frac{1}{2} (\mathcal{D}^2 g_{\mu\nu} - 2i\mathcal{G}_{\mu\nu})^{ab} A^{b\nu} + (\bar{\psi} + \bar{\Upsilon})(\hat{P} + \hat{A})(\psi + \Upsilon) \right) \\
&- \int d^2_s x_{\bullet} dx_{\perp} (\mathcal{G}_{\bullet\mu}^a A^{a\mu} + A_{\bullet}^a \bar{D}^{\mu} \bar{C}_{\mu}^a) \Big|_{x_{\bullet}=-\infty}^{x_{\bullet}=\infty} - \int d^2_s x_{\bullet} dx_{\perp} (\mathcal{G}_{\bullet\mu}^a A^{a\mu} + A_{\bullet}^a \bar{D}^{\mu} \bar{C}_{\mu}^a) \Big|_{x_{\bullet}=-\infty}^{x_{\bullet}=\infty} \tag{406}
\end{aligned}$$

Classical equations:  $\hat{P}\Upsilon \equiv (\bar{P} + \bar{C})(\xi + \chi) = 0$  and

$$\begin{aligned}
&\mathcal{D}^{\mu} \mathcal{G}_{\mu\nu}^a + \mathcal{D}^{\nu} \bar{D}^{\mu} \bar{C}_{\mu}^a + \bar{\Upsilon} t^a \gamma_{\nu} \Upsilon = 0 \\
&\Leftrightarrow (\bar{P}^2 g_{\alpha\mu} + 2i\bar{G}_{\alpha\mu})^{ab} \bar{C}^{c\mu} = \bar{D}^{\mu} \bar{G}_{\mu\alpha}^a + f^{abc} \bar{C}^{b\mu} (2\bar{D}_{\mu} \bar{C}_{\alpha}^c - \bar{D}_{\alpha} \bar{C}_{\mu}^c) + f^{abm} f^{cdm} \bar{C}^{b\mu} \bar{C}_{\mu}^c \bar{C}_{\alpha}^d + \bar{\Upsilon} t^a \gamma_{\alpha} \Upsilon \tag{407}
\end{aligned}$$

which coincides with Eqs. (160).

The action from Eq. (259) has the form

$$\int d^4x \left( -\frac{1}{4} (\mathcal{G}_{\mu\nu}^a)^2 - \frac{1}{2} (\bar{D}^{\mu} \bar{C}_{\mu}^a)^2 \right) \tag{408}$$

$$\begin{aligned}
(\bar{P}^2 g_{\alpha\beta} + 2ig\bar{G}_{\alpha\beta})^{ab} \bar{C}^{b\beta} &= \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + g f^{abc} (2\bar{C}_{\beta}^b \bar{D}^{\beta} \bar{C}_{\alpha}^c - \bar{C}_{\beta}^b \bar{D}_{\alpha} \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_{\alpha}^c \bar{C}_{\beta}^d + (\bar{\xi} + \bar{\chi}) \gamma_{\alpha} t^a (\xi + \chi) \\
(\hat{P} + \hat{C})(\xi + \chi) &= 0, \quad (\bar{\xi} + \bar{\chi})(\hat{P} + \hat{C}) = 0 \tag{409}
\end{aligned}$$

## 3. Self-consistency of $\bar{D}^{\mu} \bar{C}_{\mu} = 0$

$$\begin{aligned}
\mathcal{D}^{\mu} \mathcal{G}_{\mu\alpha}^a &= (\bar{D}^{\mu} - i\bar{C}^{\mu})^{ab} (\bar{G}_{\mu\alpha}^b + \bar{D}_{\mu} \bar{C}_{\alpha}^b - \bar{D}_{\alpha} \bar{C}_{\mu}^b + f^{bmn} \bar{C}_{\mu}^m \bar{C}_{\alpha}^n) \\
&= \bar{D}^{\mu} \bar{G}_{\mu\alpha}^a + (\bar{D}^2 g_{\alpha\mu} - 2i\bar{G}_{\alpha\mu})^{ab} \bar{C}^{c\mu} + f^{abk} f^{mkn} \bar{C}^{\mu b} \bar{C}_{\mu}^m \bar{C}_{\alpha}^n + f^{amn} \bar{C}_{\mu}^m (\bar{D}^{\mu} \bar{C}_{\alpha}^n - \bar{D}_{\alpha} \bar{C}^{\mu n}) \\
&\Rightarrow (\bar{P}^2 g_{\alpha\mu} + 2i\bar{G}_{\alpha\mu})^{ab} \bar{C}^{c\mu} = \bar{D}^{\mu} \bar{G}_{\mu\alpha}^a + f^{abc} \bar{C}_{\mu}^b (\bar{D}^{\mu} \bar{C}_{\alpha}^c - \bar{D}_{\alpha} \bar{C}^{\mu c}) + f^{abm} f^{cdm} \bar{C}^{b\mu} \bar{C}_{\mu}^c \bar{C}_{\alpha}^d + f^{abc} \bar{C}_{\alpha}^b \bar{D}^{\mu} \bar{C}_{\mu}^c + \bar{\Upsilon} t^a \gamma_{\alpha} \Upsilon \\
&\Leftrightarrow (\bar{P}^2 g_{\alpha\mu} + 2i\bar{G}_{\alpha\mu})^{ab} \bar{C}^{c\mu} = \bar{D}^{\mu} \bar{G}_{\mu\alpha}^a + f^{abc} \bar{C}^{b\mu} (2\bar{D}_{\mu} \bar{C}_{\alpha}^c - \bar{D}_{\alpha} \bar{C}_{\mu}^c) + f^{abm} f^{cdm} \bar{C}^{b\mu} \bar{C}_{\mu}^c \bar{C}_{\alpha}^d + \bar{\Upsilon} t^a \gamma_{\alpha} \Upsilon \tag{410}
\end{aligned}$$

A.  $\mathbf{Iz} \bar{D}^\mu \bar{C}_\mu$  zero?

$$\begin{aligned}
\bar{C}^{a\mu} &= \left( \frac{1}{\bar{P}^2 g_{\mu\alpha} + 2ig\bar{G}_{\mu\alpha}} \right)^{ma} \left( \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + (\bar{\xi} + \bar{\chi}) \gamma_\alpha t^a (\xi + \chi) \right) \\
\Rightarrow \bar{D}_\mu \bar{C}^{m\mu} &= \left( \frac{1}{\bar{P}^2} \bar{D}^\alpha \right)^{ma} \left( \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abn} f^{cdn} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + (\bar{\xi} + \bar{\chi}) \gamma_\alpha t^a (\xi + \chi) \right) \\
&- i \left( \frac{1}{\bar{P}^2} \bar{D}^\lambda \bar{G}_{\lambda\rho} \frac{1}{\bar{P}^2 g_{\rho\alpha} + 2i\bar{G}_{\rho\alpha}} \right)^{ma} \left( \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abn} f^{cdn} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + (\bar{\xi} + \bar{\chi}) \gamma_\alpha t^a (\xi + \chi) \right) \\
&= \left( \frac{1}{\bar{P}^2} \right)^{mn} \left[ g f^{nbc} \left( 2\bar{D}^\alpha \bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c + 2\bar{C}_\beta^b \bar{D}^\alpha \bar{D}^\beta \bar{C}_\alpha^c - \bar{D}^\alpha \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta} - \bar{C}_\beta^b \bar{D}^2 \bar{C}^{c\beta} - g^2 f^{nbl} f^{cdl} \bar{D}^\alpha \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d \right) \right. \\
&- \left. g^2 f^{nbl} f^{cdl} \bar{C}^{b\beta} (\bar{D}^\alpha \bar{C}_\alpha^c \bar{C}_\beta^d + \bar{C}_\alpha^c \bar{D}^\alpha \bar{C}_\beta^d) + (\bar{\xi} + \bar{\chi}) (\hat{D}^\leftarrow t^n + t^n \hat{D}) (\xi + \chi) \right] \quad (411) \\
&- i \left( \frac{1}{\bar{P}^2} \bar{D}^\lambda \bar{G}_{\lambda\rho} \frac{1}{\bar{P}^2 g_{\rho\alpha} + 2i\bar{G}_{\rho\alpha}} \right)^{ma} \left( \bar{D}^{ab\xi} \bar{G}_{\xi\alpha}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\alpha^c - \bar{C}_\beta^b \bar{D}_\alpha \bar{C}^{c\beta}) - g^2 f^{abn} f^{cdn} \bar{C}^{b\beta} \bar{C}_\alpha^c \bar{C}_\beta^d + (\bar{\xi} + \bar{\chi}) \gamma_\alpha t^a (\xi + \chi) \right)
\end{aligned}$$

where wi uzd Eq. (54)

1. Two  $\partial_\perp$ 's, one  $\bar{A}_\bullet$  and one  $\bar{A}_*$

$$\begin{aligned}
\bar{C}_i^{1a}(x) &= \frac{2}{s} \int dz(x) \frac{1}{p^2 + i\epsilon p_0} |z\rangle (\bar{D}_* \bar{G}_{\bullet i}^a(z) + \bar{D}_\bullet \bar{G}_{* i}^a(z)) = -\frac{2}{s} f^{abc} \int dz(x) \frac{1}{p^2 + i\epsilon p_0} |z\rangle (A_\bullet^b \partial_i A_*^c + A_*^b \partial_i A_\bullet^c) \\
F_{\bullet i}^{(1)}(x) &= -\int dz(x) \frac{1}{p_* + i\epsilon} |z\rangle \bar{A}_*^{ab} \bar{G}_{\bullet i}^b(z) \Rightarrow \partial^i F_{\bullet i}^{(1)} = \int dz(x) \frac{1}{p_* + i\epsilon} |z\rangle \bar{G}_{* i}^{ab} \bar{G}_{\bullet i}^b(z) - \int dz(x) \frac{1}{p_* + i\epsilon} |z\rangle \bar{A}_*^{ab} \partial^i \bar{G}_{\bullet i}^b(z) \\
\bar{c}_*^a(x) &= -\int dz(x) \frac{1}{p^2 + i\epsilon p_0} |z\rangle \partial_\perp^2 \bar{C}_\bullet(z) \\
\bar{D}_* \bar{c}_\bullet^a(x) &= \frac{s}{8} \int dz(x) \frac{1}{p_\bullet + i\epsilon p_0} |z\rangle \partial_\perp^2 \frac{1}{\bar{P}_* + i\epsilon} \bar{G}_{*\bullet}(z) \simeq \frac{s}{8} \int dz(x) \frac{1}{(p_\bullet + i\epsilon)(p_* + i\epsilon)} |z\rangle \partial_\perp^2 \bar{G}_{*\bullet}(z) \quad (412)
\end{aligned}$$

B.  $\Lambda$  do  $\bar{A}^2$

ПОПУТКА

$$\begin{aligned}
&\Lambda i \partial_\bullet \Lambda^\dagger(x_*, x_\bullet) \quad (413) \\
&= \left[ 1 + i \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \bar{A}_\bullet^{(+)}(x'_*) - i \int_{x_*}^{\infty} d\frac{2}{s} x'_* \bar{A}_\bullet^{(-)}(x'_*) - \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \int_{-\infty}^{x'_*} d\frac{2}{s} x''_* \bar{A}_\bullet^{(+)}(x''_*) \bar{A}_\bullet^{(+)}(x'_*) + \int_{x_*}^{\infty} d\frac{2}{s} x'_* \int_{-\infty}^{x'_*} d\frac{2}{s} x''_* \bar{A}_\bullet^{(+)}(x''_*) \bar{A}_\bullet^{(-)}(x'_*) \right. \\
&\quad \left. + \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \int_{x'_*}^{\infty} d\frac{2}{s} x''_* \bar{A}_\bullet^{(-)}(x''_*) \bar{A}_\bullet^{(+)}(x'_*) - \int_{x_*}^{\infty} d\frac{2}{s} x'_* \int_{x'_*}^{\infty} d\frac{2}{s} x''_* \bar{A}_\bullet^{(-)}(x''_*) \bar{A}_\bullet^{(-)}(x'_*) \right] \\
&\times i \partial_\bullet \left[ 1 - i \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \bar{A}_\bullet^{(+)}(x'_*) + i \int_{x_*}^{\infty} d\frac{2}{s} x'_* \bar{A}_\bullet^{(-)}(x'_*) - \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \int_{-\infty}^{x'_*} d\frac{2}{s} x''_* \bar{A}_\bullet^{(+)}(x''_*) \bar{A}_\bullet^{(+)}(x'_*) + \int_{x_*}^{\infty} d\frac{2}{s} x'_* \int_{-\infty}^{x'_*} d\frac{2}{s} x''_* \bar{A}_\bullet^{(+)}(x''_*) \bar{A}_\bullet^{(-)}(x'_*) \right. \\
&\quad \left. + \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \int_{x'_*}^{\infty} d\frac{2}{s} x''_* \bar{A}_\bullet^{(-)}(x''_*) \bar{A}_\bullet^{(+)}(x'_*) - \int_{x_*}^{\infty} d\frac{2}{s} x'_* \int_{x'_*}^{\infty} d\frac{2}{s} x''_* \bar{A}_\bullet^{(-)}(x''_*) \bar{A}_\bullet^{(-)}(x'_*) \right] \\
&= \left[ 1 + i \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \bar{A}_\bullet^{(+)}(x'_*) - i \int_{x_*}^{\infty} d\frac{2}{s} x'_* \bar{A}_\bullet^{(-)}(x'_*) \right] \left[ \bar{A}_\bullet(x_*) \right. \\
&- \left. i \int_{-\infty}^{x_*} d\frac{2}{s} x''_* \bar{A}_\bullet^{(+)}(x''_*) \bar{A}_\bullet^{(+)}(x_*) - i \int_{-\infty}^{x_*} d\frac{2}{s} x''_* \bar{A}_\bullet^{(+)}(x''_*) \bar{A}_\bullet^{(-)}(x_*) + i \int_{x_*}^{\infty} d\frac{2}{s} x''_* \bar{A}_\bullet^{(-)}(x''_*) \bar{A}_\bullet^{(+)}(x_*) + i \int_{x_*}^{\infty} d\frac{2}{s} x''_* \bar{A}_\bullet^{(-)}(x''_*) \bar{A}_\bullet^{(-)}(x_*) \right] \\
&= \left[ 1 + i \int_{-\infty}^{x_*} d\frac{2}{s} x'_* \bar{A}_\bullet^{(+)}(x'_*) - i \int_{x_*}^{\infty} d\frac{2}{s} x'_* \bar{A}_\bullet^{(-)}(x'_*) \right] \left[ \bar{A}_\bullet(x_*) - i \int_{-\infty}^{x_*} d\frac{2}{s} x''_* \bar{A}_\bullet^{(+)}(x''_*) \bar{A}_\bullet(x_*) + i \int_{x_*}^{\infty} d\frac{2}{s} x''_* \bar{A}_\bullet^{(-)}(x''_*) \bar{A}_\bullet(x_*) \right] = \bar{A}_\bullet(x_*)
\end{aligned}$$

$$\Lambda^\dagger = \Omega^\dagger(1 + \delta\lambda)$$

$$\begin{aligned} \Lambda i\partial_\bullet \Lambda^\dagger(x_*, x_\bullet) &= (1 - \delta\lambda)\Omega i\partial_\bullet \Omega^\dagger(1 + \delta\lambda) = \bar{A}_\bullet + \bar{C}_\bullet + (i\partial_\bullet + [\bar{A}_\bullet + \bar{C}_\bullet])\delta\lambda \\ &= \bar{A}_\bullet - \frac{i}{2} \int d^2z (x|\bar{P}_\bullet \frac{1}{\bar{P}_* \bar{P}_\bullet + i\epsilon p_0} |z)^{ab} \bar{G}_{*\bullet}^b(z) + (i\partial_\bullet + [\bar{A}_\bullet + \bar{C}_\bullet])\delta\lambda = \bar{A}_\bullet - \frac{i}{2} \int d^2z (x|\bar{P}_\bullet \frac{1}{\bar{P}_* \bar{P}_\bullet + i\epsilon} |z)^{ab} \bar{G}_{*\bullet}^b(z) \\ \Rightarrow \bar{P}_\bullet \delta\lambda^a &= \frac{i}{2} \int d^2z (x|\bar{P}_\bullet \frac{1}{\bar{P}_* \bar{P}_\bullet + i\epsilon p_0} - \bar{P}_\bullet \frac{1}{\bar{P}_* \bar{P}_\bullet + i\epsilon} |z)^{ab} \bar{G}_{*\bullet}^b(z) \\ \Rightarrow \delta\lambda &= \frac{2}{s} \int d^2z (x|\frac{1}{p^2 + i\epsilon p_0} - \frac{1}{p^2 + i\epsilon} |z)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \int d^2z (x|\delta(p_\bullet) \frac{1}{p_*} |z)(c_1 \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + c_2 \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet)) \end{aligned} \quad (414)$$

$$\begin{aligned} \delta\lambda &= -i \frac{2}{s} \int d^2z (x|2\pi\delta(p^2)\theta(-p_0)|z)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] = \frac{i}{2\pi s} \int d^2z \ln(-\frac{4}{s}(x-z)_*(x-z)_\bullet - i\epsilon(x-z)_0)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \\ &= \frac{i}{\pi s^2} \int dz_* dz_\bullet \{ \ln(-(x-z)_* - i\epsilon) + \ln((x-z)_\bullet + i\epsilon) \} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \int d^2z (x|\delta(p_*) \frac{1}{p_\bullet} |z)(d_1 \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + d_2 \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet)) \end{aligned} \quad (415)$$

Cutoffs:

$$\begin{aligned} \delta\lambda &= -i \frac{2}{s} \int d^2z (x|2\pi\delta(p^2)\theta(-p_0)|z)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] = -i \int d^2z \int \bar{d}\alpha \bar{d}\beta e^{-i\alpha(x-z)_\bullet - i\beta(x-z)_*} 2\pi\delta(\alpha\beta s)\theta(-p_0)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \\ &= -\frac{2\pi i}{s} \int d^2z \int \bar{d}\alpha \bar{d}\beta e^{i\alpha(x-z)_\bullet + i\beta(x-z)_*} \left( \frac{\theta(\beta)}{\beta} \delta(\alpha)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \frac{\theta(\alpha)}{\alpha} \delta(\beta)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \frac{\theta(\alpha)}{\alpha} \delta(\beta) X3 \right) \\ &= -\frac{2i}{s^2} \int dz_* dz_\bullet \int_a^\infty \frac{\bar{d}\alpha}{\alpha} e^{i\alpha(x-z)_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \frac{2i}{s^2} \int dz_* dz_\bullet \int_b^\infty \frac{\bar{d}\beta}{\beta} e^{i\beta(x-z)_*} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \\ &= \frac{i}{\pi s^2} \int dz_* dz_\bullet \{ \ln b(x_* - z_* + i\epsilon)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \ln a(x_\bullet - z_\bullet + i\epsilon)([\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + X3) \} \end{aligned} \quad (416)$$

Similarly

$$\begin{aligned} \delta\lambda &= \\ &= \frac{i}{\pi s^2} \int dz_* dz_\bullet \{ -\ln a(x_\bullet - z_\bullet + i\epsilon)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \ln b(x_* - z_* + i\epsilon)([\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + X3') \} \end{aligned} \quad (417)$$

Guess

$$\delta\lambda = \frac{i}{\pi s^2} \int dz_* dz_\bullet \{ -\ln a(x_\bullet - z_\bullet + i\epsilon)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \ln b(x_* - z_* + i\epsilon)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \} \quad (418)$$

U TOFDA

$$\Omega^\dagger(1 + \delta\lambda) = 1 - \frac{2}{s^2} \int_{-\infty}^{x_*} dz_* \int_{-\infty}^{x_\bullet} dz_\bullet (\bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet) + \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*)) \quad (419)$$

$$+ \frac{i}{\pi s^2} \int dz_* dz_\bullet \{ -\ln a(x_\bullet - z_\bullet + i\epsilon)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \ln b(x_* - z_* + i\epsilon)[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \} \quad (420)$$

$$\begin{aligned} \ln(x_\bullet - z_\bullet - i\epsilon(x-z)_*) &= \ln(x_\bullet - z_\bullet + i\epsilon) - 2\pi i \theta(x_* - z_*) \theta(z_\bullet - x_\bullet) \\ \ln(-(x-z)_\bullet + i\epsilon(x-z)_*) &= \ln(-x_\bullet + z_\bullet - i\epsilon) + 2\pi i \theta(x_* - z_*) \theta(x_\bullet - z_\bullet) \end{aligned} \quad (421)$$

$\Rightarrow$

$$\Omega^\dagger(1 + \delta\lambda) = 1 - \frac{2}{s^2} \int_{-\infty}^{x_*} dz_* \int_{-\infty}^{x_\bullet} dz_\bullet (\bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet) + \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*)) \quad (422)$$

$$\begin{aligned} &+ \frac{i}{\pi s^2} \int dz_* dz_\bullet \{ -\ln a(x_\bullet - z_\bullet + i\epsilon) \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + \ln a(x_\bullet - z_\bullet + i\epsilon) \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet) + 2\pi i \theta(x_* - z_*) \theta(x_\bullet - z_\bullet) \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet) \\ &+ \ln b(x_* - z_* + i\epsilon) \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) - \ln b(x_* - z_* + i\epsilon) \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet) + 2\pi i \theta(x_* - z_*) \theta(x_\bullet - z_\bullet) \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) \} \end{aligned} \quad (423)$$

ЕЦЇ ПОПУТКА:

$$\Lambda^\dagger(x_*, x_\bullet) = \Lambda_{(1)}(1 + \delta\lambda) = 1 - i \int_{-\infty}^{x_*} \frac{d^2 z_\bullet}{s} \bar{A}_*(z_\bullet) - i \int_{-\infty}^{x_*} \frac{d^2 x'_\bullet}{s} \bar{A}_\bullet(x'_\bullet) + \delta\lambda \quad (424)$$

$$\begin{aligned}
\Lambda i\partial_\bullet \Lambda^\dagger(x_*, x_\bullet) &= (1 - \delta\lambda)\Lambda_{(1)} i\partial_\bullet \Lambda_{(1)}^\dagger (1 + \delta\lambda) = \bar{A}_\bullet + \frac{2i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{A}_*(z_\bullet) \bar{A}_\bullet(x_*) + i\partial_\bullet \delta\lambda = \bar{A}_\bullet - \frac{i}{2} \int d^2z (x|\bar{P}_\bullet \frac{1}{\bar{P}_* \bar{P}_\bullet + i\epsilon} |z)^{ab} \bar{G}_{*\bullet}^b(z) \\
\Rightarrow i\partial_\bullet \delta\lambda &= -\frac{2}{s} \int d^2z (x|\frac{p_\bullet}{p^2 + i\epsilon} |z) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \frac{2i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{A}_*(z_\bullet) \bar{A}_\bullet(x_*) \\
&= \frac{1}{4\pi} \int d^2z \frac{1}{x_* - z_* - i\epsilon(x-z)_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \frac{2i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{A}_*(z_\bullet) \bar{A}_\bullet(x_*) = \\
\Rightarrow \delta\lambda &= -\frac{2}{s} \int d^2z (x|\frac{1}{p^2 + i\epsilon} |z) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \frac{4}{s^2} \int_{-\infty}^{x_\bullet} dz_\bullet \int_{\pm\infty}^{x_*} dz_* \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + f(x_\bullet) \\
&= -\frac{i}{2\pi s} \int d^2z \ln(-a(x-z)_\bullet + i\epsilon(x-z)_*) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \frac{i}{2\pi s} \int d^2z \ln(-a(x-z)_* + i\epsilon(x-z)_\bullet) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \\
&+ \int d^2z (x|\delta(p_\bullet) \frac{1}{p_*} |z) (c_1 \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + c_2 \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet)) - \frac{4}{s^2} \int_{-\infty}^{x_\bullet} dz_\bullet \int_{-\infty}^{x_*} dz_* \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) \\
&= -\frac{i}{2\pi s} \int d^2z \ln(-a(x-z)_\bullet - i\epsilon) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \frac{i}{2\pi s} \int d^2z \ln(-a(x-z)_* - i\epsilon) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \\
&+ \int d^2z \left\{ (x|\delta(p_\bullet) \frac{1}{p_*} |z) (c_1 \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + c_2 \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet)) - \frac{1}{s} \theta(x_* - z_*) \theta(x_\bullet - z_\bullet) (\bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet)) \right\}
\end{aligned}$$

Similarly

$$\begin{aligned}
\Lambda i\partial_* \Lambda^\dagger(x_*, x_\bullet) &= (1 - \delta\lambda)\Lambda_{(1)} i\partial_* \Lambda_{(1)}^\dagger (1 + \delta\lambda) = \bar{A}_* + (i\partial_* + [\bar{A}_*, \cdot])\delta\lambda = \bar{A}_* + \frac{i}{2} \int d^2z (x|\bar{P}_* \frac{1}{\bar{P}_* \bar{P}_\bullet + i\epsilon} |z)^{ab} \bar{G}_{*\bullet}^b(z) \\
\Rightarrow \delta\lambda &= \frac{i}{2\pi s} \int d^2z \ln(-a(x-z)_\bullet - i\epsilon) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + \frac{i}{2\pi s} \int d^2z \ln(-a(x-z)_* - i\epsilon) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \\
&+ \int d^2z \left\{ (x|\delta(p_*) \frac{1}{p_\bullet} |z) (c_2 \bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + c_1 \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet)) - \frac{1}{s} \theta(x_* - z_*) \theta(x_\bullet - z_\bullet) (\bar{A}_*(z_\bullet) \bar{A}_\bullet(z_*) + \bar{A}_\bullet(z_*) \bar{A}_*(z_\bullet)) \right\} \\
&\Rightarrow (\text{cf. Eq. (184)})
\end{aligned}$$

$$\begin{aligned}
\delta\lambda &= \frac{i}{2\pi s} \int d^2z \left[ (\ln[-a(x-z)_\bullet - i\epsilon] - \ln[-b(x-z)_* - i\epsilon]) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] + 2\pi i \theta(x_* - z_*) \theta(x_\bullet - z_\bullet) \{ \bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*) \} \right] \\
&= \delta\omega + \frac{i}{2\pi s} \int d^2z \left[ (\ln[-a(x-z)_\bullet - i\epsilon] - \ln[-b(x-z)_* - i\epsilon]) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \right] \quad (425)
\end{aligned}$$

Chek

$$\begin{aligned}
\Lambda_\bullet^{(1)}(x) = \bar{C}_\bullet^{(1)}(x) &= -\frac{2}{s} \int d^2z (x|\frac{p_\bullet}{p^2 + i\epsilon} |z) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] = \frac{1}{2\pi s} \int dz_* dz_\bullet [x_\bullet, z_\bullet]^{A_*} \frac{[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)]}{x_* - z_* - i\epsilon(x-z)_\bullet} [z_\bullet, x_\bullet]^{A_*}, \\
\Lambda_*^{(1)}(x) = \bar{C}_*^{(1)}(x) &= -\frac{1}{2\pi s} \int dz_* dz_\bullet \frac{1}{x_\bullet - z_\bullet - i\epsilon(x-z)_*} [x_*, z_*]^{A_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_*, x_*]^{A_\bullet}. \quad (426)
\end{aligned}$$

$$\begin{aligned}
\bar{C}_\bullet^{(1)}(x) &= \frac{2i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{A}_*(z_\bullet) \bar{A}_\bullet(x_*) + i\partial_\bullet \delta\lambda \quad (427) \\
&= \frac{2i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \bar{A}_*(z_\bullet) \bar{A}_\bullet(x_*) + \frac{1}{4\pi} \int d^2z \frac{1}{(x-z)_* + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - \frac{i}{s} \int_{-\infty}^{x_\bullet} dz_\bullet \{ \bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*) \} = \text{r.h.s. of Eq. (426)}
\end{aligned}$$

### C. $\Lambda$ do $\bar{A}^3$

$$\Lambda = \Omega M \Rightarrow \Lambda_\mu = i\Lambda \partial_\mu \Lambda^\dagger = i\Omega M \partial_\mu M^\dagger \Omega^\dagger = i\Omega \partial_\mu \Omega^\dagger + \Omega i(M \partial_\mu M^\dagger) \Omega^\dagger \Rightarrow iM \partial_\mu M^\dagger = \Omega^\dagger (\Lambda_\mu - \Omega_\mu) \Omega \quad (428)$$

1. do  $\bar{A}^2$ 

$$\begin{aligned} \Lambda_\bullet - \Omega_\bullet &= -\frac{i}{2} \int d_s^2 z_\bullet \left( \theta(x_\bullet - z_\bullet) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(x_*)] + \frac{i}{2\pi} \int dz_* \frac{1}{x_* - z_* - i\epsilon(x-z)_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \right) \\ &= \frac{1}{4\pi} \int d_s^2 z_\bullet dz_* \frac{1}{x_* - z_* + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \quad \Rightarrow \quad i \frac{s}{2} \frac{\partial}{\partial x_*} M^\dagger = \frac{1}{4\pi} \int d_s^2 z_\bullet dz_* \frac{1}{x_* - z_* + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \end{aligned} \quad (429)$$

Similarly,

$$\Lambda_* - \Omega_* = \frac{-1}{4\pi} \int d_s^2 z_\bullet dz_* \frac{1}{x_\bullet - z_\bullet + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \quad \Rightarrow \quad i \frac{s}{2} \frac{\partial}{\partial x_\bullet} M^\dagger = -\frac{1}{4\pi} \int d_s^2 z_\bullet dz_* \frac{1}{x_\bullet - z_\bullet + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \quad (430)$$

$\Rightarrow$

$$M^\dagger - 1 = \frac{i}{2\pi s} \int d^2 z \left( \ln[-a(x-z)_\bullet - i\epsilon] - \ln[-b(x-z)_* - i\epsilon] \right) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \quad (431)$$

2. do  $\bar{A}^3$ 

$$\begin{aligned} \Lambda_\bullet - \Omega_\bullet &= -\frac{i}{2} \int d_s^2 z_\bullet [x_\bullet, z_\bullet]^{A_*} \left( \theta(x_\bullet - z_\bullet) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(x_*)] + \frac{i}{2\pi} \int dz_* \frac{1}{x_* - z_* - i\epsilon(x-z)_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \right) [z_\bullet, x_\bullet]^{A_*} \\ &= \frac{1}{4\pi} \int d_s^2 z_\bullet dz_* [x_\bullet, z_\bullet]^{A_*} \frac{1}{x_* - z_* + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_\bullet, x_\bullet]^{A_*} \\ &\Rightarrow iM\partial_\bullet M^\dagger = \frac{1}{4\pi} \left[ 1 - i \int_{-\infty}^{x_\bullet} d_s^2 z'_\bullet \bar{A}_*(z'_\bullet) - i \int_{-\infty}^{x_*} d_s^2 z'_* \bar{A}_\bullet(z'_*) \right] \int d_s^2 z_\bullet dz_* \\ & [x_\bullet, z_\bullet]^{A_*} \frac{1}{x_* - z_* + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_\bullet, x_\bullet]^{A_*} \left[ 1 + i \int_{-\infty}^{x_\bullet} d_s^2 z'_\bullet \bar{A}_*(z'_\bullet) + i \int_{-\infty}^{x_*} d_s^2 z'_* \bar{A}_\bullet(z'_*) \right] \\ &= \frac{1}{4\pi} \left[ 1 - i \int_{-\infty}^{x_*} d_s^2 z'_* \bar{A}_\bullet(z'_*) \right] \int d_s^2 z_\bullet dz_* \frac{1}{x_* - z_* + i\epsilon} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \left[ 1 + i \int_{-\infty}^{x_*} d_s^2 z'_* \bar{A}_\bullet(z'_*) \right] \\ &+ \frac{1}{4\pi} \int d_s^2 z_\bullet dz_* \frac{1}{x_* - z_* + i\epsilon} \left[ 1 - i \int_{-\infty}^{z_\bullet} d_s^2 z'_\bullet \bar{A}_*(z'_\bullet) \right] [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \left[ 1 + i \int_{-\infty}^{z_\bullet} d_s^2 z'_\bullet \bar{A}_*(z'_\bullet) \right] \\ &\Rightarrow M^\dagger \ni -\frac{i}{2\pi s} \int d^2 z [-\infty_\bullet, z_\bullet]^{A_*} \ln[-b(x-z)_* - i\epsilon] [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_\bullet, \infty_\bullet]^{A_*} \\ & - \frac{1}{2\pi s} \int d^2 z \int_{-\infty}^{x_*} d_s^2 z'_* \ln \frac{x_* - z_* - i\epsilon}{z'_* - z_* - i\epsilon} [\bar{A}_\bullet(z'_*), [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)]] \end{aligned} \quad (432)$$

Guess

$$\begin{aligned} M^\dagger - 1 &= -\frac{i}{2\pi s} \int d^2 z [-\infty_\bullet, z_\bullet]_{(1)}^{A_*} \ln[-b(x-z)_* - i\epsilon] [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_\bullet, \infty_\bullet]_{(1)}^{A_*} - \frac{1}{2\pi s} \int d^2 z \int_{-\infty}^{x_*} d_s^2 z'_* \ln \frac{x_* - z_* + i\epsilon}{z'_* - z_* + i\epsilon} [\bar{A}_\bullet(z'_*), [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)]] \\ &+ \frac{i}{2\pi s} \int d^2 z [-\infty_*, z_*]_{(1)}^{A_\bullet} \ln[-a(x-z)_\bullet - i\epsilon] [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_*, \infty_*]_{(1)}^{A_\bullet} + \frac{1}{2\pi s} \int d^2 z \int_{-\infty}^{x_\bullet} d_s^2 z'_\bullet \ln \frac{x_\bullet - z_\bullet + i\epsilon}{z'_\bullet - z_\bullet + i\epsilon} [\bar{A}_*(z'_\bullet), [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)]] \end{aligned} \quad (433)$$

Check (see Eq. (426) and Eq. (165)) :

$$\begin{aligned}
& \left[ 1 + i \int_{-\infty}^{x_\bullet} d^2_s z'_\bullet \bar{A}_*(z'_\bullet) + i \int_{-\infty}^{x_*} d^2_s z'_* \bar{A}_\bullet(z'_*) \right] i \frac{s}{2} \left( \frac{\partial}{\partial x_\bullet} M^\dagger \right) \left[ 1 - i \int_{-\infty}^{x_\bullet} d^2_s z'_\bullet \bar{A}_*(z'_\bullet) - i \int_{-\infty}^{x_*} d^2_s z'_* \bar{A}_\bullet(z'_*) \right] + \Omega_* \quad (434) \\
& = \left[ 1 + i \int_{-\infty}^{x_\bullet} d^2_s z'_\bullet \bar{A}_*(z'_\bullet) + i \int_{-\infty}^{x_*} d^2_s z'_* \bar{A}_\bullet(z'_*) \right] \left\{ - \frac{1}{4\pi} \int d^2 z \frac{1}{(x-z)_\bullet + i\epsilon} [-\infty_*, z_*]_{(1)}^{A_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_*, \infty_*]_{(1)}^{A_\bullet} \right. \\
& + \left. \frac{i}{4\pi} \int d^2 z \frac{1}{x_\bullet - z_\bullet + i\epsilon} \int_{-\infty}^{x_\bullet} d^2_s z'_\bullet [\bar{A}_*(z'_\bullet), [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)]] \right\} \left[ 1 - i \int_{-\infty}^{x_\bullet} d^2_s z'_\bullet \bar{A}_*(z'_\bullet) - i \int_{-\infty}^{x_*} d^2_s z'_* \bar{A}_\bullet(z'_*) \right] + \Omega_* \\
& = - \frac{1}{4\pi} \int d^2 z \frac{1}{(x-z)_\bullet + i\epsilon} [x_*, z_*]^{A_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_*, x_*]^{A_\bullet} - \frac{i}{s} \int_{-\infty}^{x_*} dz_* [x_*, z_*]^{A_\bullet} [\bar{A}_*(x_\bullet), \bar{A}_\bullet(z_*)] [z_*, x_*]^{A_\bullet} \\
& = - \frac{1}{4\pi} \int d^2 z \frac{1}{(x-z)_\bullet - i\epsilon(x-z)_*} [x_*, z_*]^{A_\bullet} [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] [z_*, x_*]^{A_\bullet}
\end{aligned}$$

#### D. $\Lambda$ do $\bar{A}_*^2 \bar{A}_\bullet^2$

From Eq. (166) and Eq. (426)

$$\begin{aligned}
\Lambda_\bullet^{(2)a} & = - \frac{i}{2} \left( \frac{1}{\bar{P}_\bullet \bar{P}_*} \bar{P}_\bullet \right)^{aa'} f^{a'bc} \Lambda_*^{(1)b} \Lambda_\bullet^{(1)c} \quad (435) \\
\Rightarrow \Lambda_\bullet^{(2)} & = - \frac{1}{2} \int dz (x | \frac{1}{p_* + i\epsilon p_\bullet} | y) [\Lambda_*^{(1)}(y), \Lambda_\bullet^{(1)}(y)] = \frac{1}{4\pi} \int dy \frac{1}{x_* - y_* - i\epsilon(x-y)_\bullet} [\Lambda_*^{(1)}(y), \Lambda_\bullet^{(1)}(y)] \\
& = - \frac{1}{64\pi^3} \int dy dz dz' \frac{1}{x_* - y_* - i\epsilon(x-y)_\bullet} \frac{1}{y_\bullet - z_\bullet - i\epsilon(y-z)_*} \frac{1}{y_* - z'_* - i\epsilon(y-z')_\bullet} [[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(z'_*)]] \\
& = - \frac{1}{64\pi^3} \int dy dz dz' \left[ \frac{1}{x_* - y_* + i\epsilon} + 2\pi i \delta(x_* - y_*) \theta(x_\bullet - y_\bullet) \right] \left[ \frac{1}{y_\bullet - z_\bullet + i\epsilon} + 2\pi i \delta(y_\bullet - z_\bullet) \theta(y_* - z_*) \right] \\
& \times \left[ \frac{1}{y_* - z'_* + i\epsilon} + 2\pi i \delta(y_* - z'_*) \theta(y_\bullet - z'_\bullet) \right] [[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(z'_*)]] \\
& = - \frac{1}{64\pi^3} \int dy dz dz' \frac{1}{x_* - y_* + i\epsilon} \frac{1}{y_\bullet - z_\bullet - i\epsilon} \frac{1}{y_* - z'_* + i\epsilon} [[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(z'_*)]] \\
& - \frac{i}{32\pi^2} \int_{-\infty}^{x_\bullet} d^2_s y_\bullet \int dz dz' \frac{1}{y_\bullet - z_\bullet - i\epsilon} \frac{1}{x_* - z'_* + i\epsilon} [[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(z'_*)]] \\
& - \frac{i}{32\pi^2} \int dy dz' \int_{-\infty}^{y_*} d^2_s z_* \frac{1}{x_* - y_* + i\epsilon} \frac{1}{y_* - z'_* + i\epsilon} [[\bar{A}_*(y_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(z'_*)]] \\
& - \frac{i}{32\pi^2} \int dy dz \int_{-\infty}^{y_\bullet} d^2_s z'_\bullet \frac{1}{x_* - y_* + i\epsilon} \frac{1}{y_\bullet - z_\bullet - i\epsilon} [[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(y_*)]] \\
& + \frac{1}{16\pi} \int dy \int_{-\infty}^{y_\bullet} d^2_s z'_\bullet \int_{-\infty}^{y_*} d^2_s z_* \frac{1}{x_* - y_* + i\epsilon} [[\bar{A}_*(y_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(y_*)]] \\
& + \frac{1}{16\pi} \int dz \int_{-\infty}^{x_\bullet} d^2_s y_\bullet \int_{-\infty}^{y_\bullet} d^2_s z'_\bullet \frac{1}{y_\bullet - z_\bullet + i\epsilon} [[\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(x_*)]] \\
& + \frac{1}{16\pi} \int dz' \int_{-\infty}^{x_\bullet} d^2_s y_\bullet \int_{-\infty}^{x_*} d^2_s z_* \frac{1}{y_* - z'_* + i\epsilon} [[\bar{A}_*(y_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(z'_*)]] \\
& + \frac{i}{8} \int_{-\infty}^{x_*} d^2_s y_\bullet \int_{-\infty}^{x_*} d^2_s z_* \int_{-\infty}^{y_\bullet} d^2_s z'_\bullet [[\bar{A}_*(y_\bullet), \bar{A}_\bullet(z_*)], [\bar{A}_*(z'_\bullet), \bar{A}_\bullet(x_*)]]
\end{aligned}$$

From Eq. (201)

$$\begin{aligned}
\Lambda_{\bullet}^{(2)} - \Omega_{\bullet}^{(2)} &= -\frac{1}{64\pi^3} \int dy dz dz' \frac{1}{x_* - y_* - i\epsilon(x-y)_{\bullet}} \frac{1}{y_{\bullet} - z_{\bullet} - i\epsilon(y-z)_{*}} \frac{1}{y_* - z'_* - i\epsilon(y-z')_{\bullet}} [[\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(z'_{*})]] \\
&- \frac{i}{8} \int_{-\infty}^{x_{\bullet}} d\frac{2}{s} y_{\bullet} d\frac{2}{s} x''_{\bullet} \theta(y_{\bullet} - x''_{\bullet}) \int_{-\infty}^{x_*} d\frac{2}{s} z_* [[\bar{A}_{*}(y_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(x''_{\bullet}), \bar{A}_{\bullet}(x_{*})]] \\
&= -\frac{1}{64\pi^3} \int dy dz dz' \frac{1}{x_* - y_* + i\epsilon} \frac{1}{y_{\bullet} - z_{\bullet} - i\epsilon} \frac{1}{y_* - z'_* + i\epsilon} [[\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(z'_{*})]] \\
&- \frac{i}{32\pi^2} \int_{-\infty}^{x_{\bullet}} d\frac{2}{s} y_{\bullet} \int dz dz' \frac{1}{y_{\bullet} - z_{\bullet} - i\epsilon} \frac{1}{x_* - z'_* + i\epsilon} [[\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(z'_{*})]] \\
&- \frac{i}{32\pi^2} \int dy dz' \int_{-\infty}^{y_*} d\frac{2}{s} z'_* \frac{1}{x_* - y_* + i\epsilon} \frac{1}{y_* - z'_* + i\epsilon} [[\bar{A}_{*}(y_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(z'_{*})]] \\
&- \frac{i}{32\pi^2} \int dy dz \int_{-\infty}^{y_{\bullet}} d\frac{2}{s} z'_{\bullet} \frac{1}{x_* - y_* + i\epsilon} \frac{1}{y_{\bullet} - z_{\bullet} - i\epsilon} [[\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(y_{*})]] \\
&+ \frac{1}{16\pi} \int dy \int_{-\infty}^{y_{\bullet}} d\frac{2}{s} z'_{\bullet} \int_{-\infty}^{y_*} d\frac{2}{s} z_* \frac{1}{x_* - y_* + i\epsilon} [[\bar{A}_{*}(y_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(y_{*})]] \\
&+ \frac{1}{16\pi} \int dz \int_{-\infty}^{x_{\bullet}} d\frac{2}{s} y_{\bullet} \int_{-\infty}^{y_{\bullet}} d\frac{2}{s} z'_{\bullet} \frac{1}{y_{\bullet} - z_{\bullet} + i\epsilon} [[\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(x_{*})]] \\
&+ \frac{1}{16\pi} \int dz' \int_{-\infty}^{x_{\bullet}} d\frac{2}{s} y_{\bullet} \int_{-\infty}^{x_*} d\frac{2}{s} z_* \frac{1}{y_* - z'_* + i\epsilon} [[\bar{A}_{*}(y_{\bullet}), \bar{A}_{\bullet}(z_{*}), [\bar{A}_{*}(z'_{\bullet}), \bar{A}_{\bullet}(z'_{*})]]
\end{aligned}$$

#### XIV. DOUBLE FUNTEGRAL

Fields  $A$  to the right of the cut, fields  $\tilde{A}$  to the left.

$$\langle \tilde{A}_{\mu}^a(x) A_{\nu}^b(y) \rangle \stackrel{bF}{=} - (x | \frac{1}{\tilde{P}^2 g_{\mu\xi} + 2i\tilde{G}_{\mu\xi} - i\epsilon} p^2 2\pi\delta(p^2)\theta(p_0) p^2 \frac{1}{\tilde{P}^2 \delta_{\nu}^{\xi} + 2i\tilde{G}_{\nu}^{\xi} + i\epsilon} | y)^{ab} \quad (436)$$

##### 1. How we get retarded propagator

$$\begin{aligned}
\int D\bar{\phi} D\phi \phi(x) e^{-iS(\bar{\phi}) - i\tilde{J}\bar{\phi}} e^{iS(\phi) + iJ\phi} &= - \int dz (x | \frac{1}{p^2 + i\epsilon} | z) J(z) - i \int dz (x | 2\pi\delta(p^2)\theta(-p_0) | z) \tilde{J}(z) \\
&= \int dz \frac{i}{4\pi^2[-(x-z)^2 + i\epsilon]} J(z) - \int dz \frac{i}{4\pi^2[-(x-z)^2 - i\epsilon(x-z)_0]} J(z) \\
\int D\bar{\phi} D\phi \tilde{\phi}(x) e^{-iS(\bar{\phi}) - i\tilde{J}\bar{\phi}} e^{iS(\phi) + iJ\phi} &= i \int dz (x | 2\pi\delta(p^2)\theta(p_0) | z) J(z) - \int dz (x | \frac{1}{p^2 - i\epsilon} | z) \tilde{J}(z) - \\
&= \int dz \frac{i}{4\pi^2[-(x-z)^2 + i\epsilon(x-z)_0]} J(z) - \int dz \frac{i}{4\pi^2[-(x-z)^2 - i\epsilon]} \tilde{J}(z) \quad (437)
\end{aligned}$$

so if  $J = \tilde{J}$

$$\phi(x) = \tilde{\phi}(x) = - \int dz (x | \frac{1}{p^2 + i\epsilon p_0} | z) J(z) = \frac{1}{4\pi^2} \int dz 2\pi\delta((x-z)^2)\theta(x_0 - z_0) J(z) \quad (438)$$

#### A. In two (longitudinal) dimensions

Eq. (161)

$$\begin{aligned}
2(\bar{P}\cdot\bar{P})^{ab}\bar{C}_{\bullet}^b &= \bar{D}_{\bullet}^{ab}\bar{G}_{\bullet}^b + i\bar{G}_{\bullet}^{ab}\bar{C}_{\bullet}^b + g\bar{D}_{\bullet}^{aa'}(f^{a'bc}\bar{C}_{\bullet}^b\bar{C}_{\bullet}^c) + 2gf^{abc}\bar{C}_{\bullet}^b\bar{D}_{\bullet}^c\bar{C}_{\bullet}^c - g^2f^{abm}f^{cdm}\bar{C}_{\bullet}^b\bar{C}_{\bullet}^c\bar{C}_{\bullet}^d \\
2(\bar{P}\cdot\bar{P})^{ab}\bar{C}_{*}^b &= -\bar{D}_{*}^{ab}\bar{G}_{\bullet}^b - i\bar{G}_{\bullet}^{ab}\bar{C}_{*}^b - g\bar{D}_{*}^{aa'}(f^{a'bc}\bar{C}_{*}^b\bar{C}_{\bullet}^c) + 2gf^{abc}\bar{C}_{*}^b\bar{D}_{\bullet}^c\bar{C}_{*}^c - g^2f^{abm}f^{cdm}\bar{C}_{*}^b\bar{C}_{*}^c\bar{C}_{\bullet}^d \quad (439)
\end{aligned}$$



and same

$$\begin{aligned} 2(\bar{P}_* \bar{P}_*)^{ab} \bar{C}_*^b &= \bar{D}_*^{ab} \bar{G}_*^b + i \bar{G}_*^{ab} \bar{C}_*^b + g \bar{D}_*^{aa'} (f^{a'bc} \bar{C}_*^b \bar{C}_*^c) + 2g f^{abc} \bar{C}_*^b \bar{D}_* \bar{C}_*^c - g^2 f^{abm} f^{cdm} \bar{C}_*^b \bar{C}_*^c \bar{C}_*^d \\ 2(\bar{P}_* \bar{P}_*)^{ab} \bar{C}_*^b &= -\bar{D}_*^{ab} \bar{G}_*^b - i \bar{G}_*^{ab} \bar{C}_*^b - g \bar{D}_*^{aa'} (f^{a'bc} \bar{C}_*^b \bar{C}_*^c) + 2g f^{abc} \bar{C}_*^b \bar{D}_* \bar{C}_*^c - g^2 f^{abm} f^{cdm} \bar{C}_*^b \bar{C}_*^c \bar{C}_*^d \end{aligned} \quad (440)$$

РЕУНЕНУЕ

$$\begin{aligned} \bar{C}_*^{1a}(x) &= -\frac{i}{2} \int d^2 z \left[ (x | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) + \frac{is}{4} (x | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} p^4 2\pi \delta(p^2) \theta(-p_0) \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) \right] \\ \bar{C}_*^{1a}(x) &= \frac{i}{2} \int d^2 z \left[ (x | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) + \frac{is}{4} (x | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} p^4 2\pi \delta(p^2) \theta(-p_0) \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) \right] \\ \bar{C}_*^{1a}(x) &= -\frac{i}{2} \int d^2 z \left[ (x | \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) - \frac{is}{4} (x | \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} p^4 2\pi \delta(p^2) \theta(p_0) \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) \right] \\ \bar{C}_*^{1a}(x) &= \frac{i}{2} \int d^2 z \left[ (x | \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) - \frac{is}{4} (x | \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} p^4 2\pi \delta(p^2) \theta(p_0) \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_* | z)^{ab} \bar{G}_*^b(z) \right] \end{aligned} \quad (441)$$

НА  $\infty$ -ТУ (СМ. УР-Е (397))

$$(x | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_* | z) = (x | \frac{1}{\bar{P}_* + i\epsilon p_\bullet} | z) = -\frac{(2\pi)^{-1}}{x_\bullet - z_\bullet - i\epsilon(x - z)_\bullet} [x_\bullet, z_\bullet]^{\bar{A}_\bullet} \quad (442)$$

СВОЎСТВО

$$\begin{aligned} &(x | \bar{P}_* \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} p_\bullet^2 p_\bullet^2 2\pi \delta(p^2) \theta(-p_0) \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_* | z) \\ &= (x | [P_* - \bar{P}_* \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} (\bar{P}_* A_* + A_* p_*)] 2\pi \delta(p^2) \theta(-p_0) [\bar{P}_* - (p_\bullet \bar{A}_* + \bar{A}_* \bar{P}_*) \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_*] | y) \\ &= (x | \bar{P}_* \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} A_* p_* 2\pi \delta(p^2) \theta(-p_0) p_\bullet \bar{A}_* \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_* | y) = 0 \end{aligned} \quad (443)$$

У ПОЭТОМУ (СР. С ФОРМУЛОЎ (163))

$$\bar{D}_\bullet \bar{C}_*^{(1)} = -\bar{D}_* \bar{C}_\bullet^{(1)} = \frac{1}{2} \bar{G}_{* \bullet}, \quad \bar{D}_\bullet \bar{C}_*^{(1)} = -\bar{D}_* \bar{C}_\bullet^{(1)} = \frac{1}{2} \bar{G}_{* \bullet} \quad (444)$$

1. Wightman propagators in 2d

$$\begin{aligned} (x | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_* | z) &= (x | \frac{1}{\bar{P}_\bullet + i\epsilon p_*} | z) = -\frac{(2\pi)^{-1} [x_\bullet, z_\bullet]^{A_\bullet}}{x_\bullet - z_\bullet - i\epsilon(x - z)_\bullet}, & (x | \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_* | z) &= \frac{(2\pi)^{-1} [x_\bullet, z_\bullet]^{A_\bullet}}{x_\bullet - z_\bullet + i\epsilon(x - z)_\bullet} \\ (x | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | z) &= (x | \frac{1}{\bar{P}_* + i\epsilon p_\bullet} | z) = -\frac{(2\pi)^{-1} [x_\bullet, z_\bullet]^{\bar{A}_\bullet}}{x_\bullet - z_\bullet - i\epsilon(x - z)_\bullet}, & (x | \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_\bullet | z) &= \frac{(2\pi)^{-1} [x_\bullet, z_\bullet]^{\bar{A}_\bullet}}{x_\bullet - z_\bullet + i\epsilon(x - z)_\bullet} \end{aligned} \quad (445)$$

$$\begin{aligned} &(z | 2\pi \delta(p^2) \theta(p_0) | z') (z' | p_* p_\bullet \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) = (z | 2\pi \delta(p^2) \theta(p_0) | z') (z' | [\bar{P}_* - (p_\bullet \bar{A}_* + \bar{A}_* \bar{P}_*) \frac{1}{\bar{P}_* \bar{P}_* - i\epsilon} \bar{P}_\bullet] | y) \\ &\equiv (z | 2\pi \delta(p^2) \theta(p_0) p_\bullet | z') (z' | p_* \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) + i \int dz'_\bullet (z | 2\pi \delta(p^2) \theta(p_0) | z') (z' | p_* \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) \Big|_{z'_\bullet = -\infty}^{z'_\bullet = \infty} \\ &= i \int dz'_\bullet (z | 2\pi \delta(p^2) \theta(p_0) p_\bullet | z') (z' | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) \Big|_{z'_\bullet = -\infty}^{z'_\bullet = \infty} + i \int dz'_\bullet (z | 2\pi \delta(p^2) \theta(p_0) | z') (z' | p_* \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) \Big|_{z'_\bullet = -\infty}^{z'_\bullet = \infty} \\ &= i \int dz'_\bullet (z | 2\pi \delta(p^2) \theta(p_0) p_\bullet | z') (z' | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) \Big|_{z'_\bullet = -\infty}^{z'_\bullet = \infty} + i \int dz'_\bullet (z | 2\pi \delta(p^2) \theta(p_0) p_* | z') (z' | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) \Big|_{z'_\bullet = -\infty}^{z'_\bullet = \infty} \\ &= i \int dz'_\bullet (z | 2\pi \delta(p^2) \theta(p_0) p_\bullet | z') (z' | \frac{1}{\bar{P}_* \bar{P}_* + i\epsilon} \bar{P}_\bullet | y) \Big|_{z'_\bullet = -\infty}^{z'_\bullet = \infty} \end{aligned} \quad (446)$$

$$\begin{aligned}
& (x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} p_\bullet p_* 2\pi\delta(p^2)\theta(p_0)p_\bullet p_* \frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|z) \\
& \equiv (x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} [1 - (p_\bullet A_* + P_* A_\bullet)] 2\pi\delta(p^2)\theta(p_0) [\bar{P}_\bullet - (p_\bullet \bar{A}_* + \bar{A}_\bullet \bar{P}_*)] \frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} \bar{P}_\bullet|y) \\
& = i \int dz'_* (x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} [1 - (p_\bullet A_* + P_* A_\bullet)] 2\pi\delta(p^2)\theta(p_0)p_\bullet|z')(z'|\frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|y)|_{z'_*=-\infty}^{z'_*=\infty} \\
& = i \int dz'_* d^2z (x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} p_\bullet p_*|z)(z|2\pi\delta(p^2)\theta(p_0)p_\bullet|z')(z'|\frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|y)|_{z'_*=-\infty}^{z'_*=\infty} \\
& = \int dz'_* dz_* (x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} p_\bullet|z)(z|2\pi\delta(p^2)\theta(p_0)p_\bullet|z')(z'|\frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|y)|_{z_*=-\infty}^{z_*=\infty}|_{z'_*=-\infty}^{z'_*=\infty} \quad (447)
\end{aligned}$$

$$\begin{aligned}
(x|\frac{1}{p^2 - i\epsilon}|z) &= -\frac{i}{4\pi} \ln[-(x-z)_* - i\epsilon(x-z)_\bullet] - \frac{i}{4\pi} \ln[(x-z)_\bullet + i\epsilon(x-z)_*] = -\frac{i}{4\pi} \ln[-(x-z)_*(x-z)_\bullet - i\epsilon] \\
&= -\frac{i}{4\pi} \ln[-(x-z)_* + i\epsilon] - \frac{1}{2} \theta(x-z)_* \theta(x-z)_\bullet - \frac{i}{4\pi} \ln[(x-z)_\bullet - i\epsilon] + \frac{1}{2} \theta(x-z)_* \theta(x-z)_\bullet \\
(x|2\pi\delta(p^2)\theta(p_0)|z) &= -\frac{1}{4\pi} \ln[-(x-z)_* + i\epsilon] - \frac{1}{4\pi} \ln[(x-z)_\bullet - i\epsilon] = -\frac{i}{4\pi} \ln[-(x-z)_*(x-z)_\bullet + i\epsilon(x-z)_0] \\
(x|2\pi\delta(p^2)\theta(p_0)p_\bullet|z) &= -\frac{is}{8\pi} \frac{1}{x_* - z_* - i\epsilon}, \quad (x|2\pi\delta(p^2)\theta(-p_0)p_\bullet|z) = -\frac{is}{8\pi} \frac{1}{x_* - z_* + i\epsilon} \\
(x|\frac{1}{p^2 + i\epsilon p_0}|z) &= -\frac{1}{2} \theta(x_* - z_*) \theta(x_\bullet - z_\bullet) \\
(x|\frac{1}{p^2 - i\epsilon}|z) - (x|\frac{1}{p^2 + i\epsilon p_0}|z) &= (x|2\pi i \delta(p^2)\theta(p_0)|z) \quad (448)
\end{aligned}$$

$$\begin{aligned}
& \int dz'_* (z|2\pi\delta(p^2)\theta(p_0)p_\bullet|z')(z'|\frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|y)|_{z'_*=-\infty}^{z'_*=\infty} \\
& = \frac{is}{16\pi^2} \int dz'_* \frac{1}{(z_* - z'_* - i\epsilon)[z'_* - y_* - i\epsilon(z' - y)_\bullet]} [z'_*, y_\bullet]^{A_*} \Big|_{z'_*=-\infty}^{z'_*=\infty} = -\frac{s}{8\pi(z_* - y_* - i\epsilon)} [\infty_\bullet, y_\bullet]^{A_*} \\
& \Rightarrow -\int dz'_* dz_* (x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} p_\bullet|z)(z|2\pi\delta(p^2)\theta(p_0)p_\bullet|z')(z'|\frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|y)|_{z_*=-\infty}^{z_*=\infty}|_{z'_*=-\infty}^{z'_*=\infty} \\
& = \frac{s}{8\pi} \int dz_* (x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} p_\bullet|z)|_{z_*=-\infty}^{z_*=\infty} \frac{[\infty_\bullet, y_\bullet]^{A_*}}{z_* - y_* - i\epsilon}
\end{aligned}$$

$$(x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon}|y) = -\frac{i}{4\pi} [x_\bullet, y_\bullet] \ln[-(x-y)_* - i\epsilon(x-y)_\bullet] + \text{solution of } \bar{P}_\bullet\bar{P}_*(\dots) = 0$$

$$\begin{aligned}
(x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} p_\bullet p_* 2\pi\delta(p^2)\theta(p_0)p_\bullet p_* \frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|y) &= -\frac{is}{8\pi(x_* - y_* - i\epsilon)} [x_\bullet, \infty_\bullet]^{A_*} [\infty_\bullet, y_\bullet]^{A_*} \\
(x|\frac{1}{\bar{P}_*\bar{P}_\bullet - i\epsilon} p_\bullet p_* 2\pi\delta(p^2)\theta(p_0)p_\bullet p_* \frac{1}{\bar{P}_*\bar{P}_\bullet + i\epsilon} \bar{P}_*|y) &= -\frac{is}{8\pi(x_\bullet - y_\bullet - i\epsilon)} [x_*, \infty_*]^{A_\bullet} [\infty_*, y_*]^{A_\bullet} \quad (449)
\end{aligned}$$

Check of Eq. (443)

$$\bar{P}_*(x|\frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} p_\bullet p_* 2\pi\delta(p^2)\theta(p_0)p_\bullet p_* \frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} \bar{P}_\bullet|z) = -\frac{is}{8\pi(x_* - y_* - i\epsilon)} \bar{P}_*[x_\bullet, \infty_\bullet]^{A_*} [\infty_\bullet, y_\bullet]^{A_*} = 0 \quad (450)$$

ΕΥΞΕ ΔΒΑ ΠΡΟΠΑΓΑΤΟΡΑ

$$\begin{aligned}
(x|\frac{1}{\bar{P}_\bullet\bar{P}_* + i\epsilon} p_\bullet p_* 2\pi\delta(p^2)\theta(-p_0)p_\bullet p_* \frac{1}{\bar{P}_\bullet\bar{P}_* - i\epsilon} \bar{P}_\bullet|y) &=? -\frac{is}{8\pi(x_* - y_* + i\epsilon)} [x_\bullet, \infty_\bullet]^{A_*} [\infty_\bullet, y_\bullet]^{A_*} \\
(x|\frac{1}{\bar{P}_*\bar{P}_\bullet + i\epsilon} p_\bullet p_* 2\pi\delta(p^2)\theta(-p_0)p_\bullet p_* \frac{1}{\bar{P}_*\bar{P}_\bullet - i\epsilon} \bar{P}_*|y) &=? -\frac{is}{8\pi(x_\bullet - y_\bullet + i\epsilon)} [x_*, \infty_*]^{A_\bullet} [\infty_*, y_*]^{A_\bullet} \quad (451)
\end{aligned}$$

## 2. Cheks

Na  $\infty$ -ti: from Eq. (441) we get

$$\begin{aligned}
\bar{C}_{\bullet}^{1a}(x) &= -\frac{i}{2} \int d^2 z \left[ (x | \frac{1}{\bar{P}_{\bullet} \bar{P}_{*} + i\epsilon} \bar{P}_{\bullet} | z)^{ab} \bar{G}_{* \bullet}^b(z) + \frac{is}{4} (x | \frac{1}{\bar{P}_{\bullet} \bar{P}_{*} + i\epsilon} p^4 2\pi \delta(p^2) \theta(-p_0) \frac{1}{\bar{P}_{\bullet} \bar{P}_{*} - i\epsilon} \bar{P}_{\bullet} | z)^{ab} \bar{G}_{* \bullet}^b(z) \right] \\
&= \frac{i}{4\pi} \int d^2 z \left[ \frac{1}{x_* - z_* - i\epsilon(x-z)_{\bullet}} ([x_{\bullet}, z_{\bullet}]^{\bar{A}^*})^{ab} \bar{G}_{* \bullet}^b(z) - \frac{1}{x_* - z_* + i\epsilon} ([x_{\bullet}, \infty_{\bullet}]^{\bar{A}^*} [\infty_{\bullet}, z_{\bullet}]^{\bar{A}^*})^{ab} \bar{G}_{* \bullet}^b(z) \right] \\
\bar{C}_{\bullet}^{1a}(x) &= -\frac{i}{2} \int d^2 z \left[ -\frac{is}{4} (x | \frac{1}{\bar{P}_{\bullet} \bar{P}_{*} - i\epsilon} p^4 2\pi \delta(p^2) \theta(p_0) \frac{1}{\bar{P}_{\bullet} \bar{P}_{*} + i\epsilon} \bar{P}_{\bullet} | z)^{ab} \bar{G}_{* \bullet}^b(z) + (x | \frac{1}{\bar{P}_{\bullet} \bar{P}_{*} - i\epsilon} \bar{P}_{\bullet} | z)^{ab} \bar{G}_{* \bullet}^b(z) \right] \\
&= \frac{i}{4\pi} \int d^2 z \left[ \frac{1}{x_* - z_* - i\epsilon} ([x_{\bullet}, \infty_{\bullet}]^{\bar{A}^*} [\infty_{\bullet}, z_{\bullet}]^{\bar{A}^*})^{ab} \bar{G}_{* \bullet}^b(z) - \frac{1}{x_* - z_* + i\epsilon(x-z)_{\bullet}} ([x_{\bullet}, z_{\bullet}]^{\bar{A}^*})^{ab} \bar{G}_{* \bullet}^b(z) \right] \quad (452)
\end{aligned}$$

If  $x_* \rightarrow \infty$  both  $\bar{C}_{\bullet}^{1a}(x), \bar{C}_{\bullet}^{1a}(x) \rightarrow 0$ , if  $x_* \sim 1$  and  $x_{\bullet} \rightarrow \infty$  they coincide.

Another check:  $\bar{A} = \bar{A} = A$

$$\bar{C}_{\bullet}^{1a}(x) = \bar{C}_{\bullet}^{1a}(x) = -\frac{1}{2} \int d^2 z \delta(x_* - z_*) \theta(x_{\bullet} - z_{\bullet}) ([x_{\bullet}, z_{\bullet}]^{A^*})^{ab} G_{* \bullet}^b(z) \quad (453)$$

which coincide with Eq. (163).

B. Matrix  $\aleph$ 

$$\aleph^{\dagger(0)} = 1 + i \int_{x_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{\bullet}(x'_*) + i \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(x'_{\bullet}), \quad \tilde{\aleph}^{\dagger(0)} = 1 + i \int_{x_*}^{\infty} d^2 \frac{z'}{s} \bar{\bar{A}}_{\bullet}(x'_*) + i \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{\bar{A}}_{*}(x'_{\bullet}) \quad (454)$$

First order

$$\begin{aligned}
i(\aleph \partial_{\bullet} \aleph^{\dagger})^a &= \bar{A}_{\bullet}^a + \frac{i}{4\pi} \int d^2 z \left[ \frac{1}{x_* - z_* - i\epsilon(x-z)_{\bullet}} ([x_{\bullet}, z_{\bullet}]^{\bar{A}^*})^{ab} \bar{G}_{* \bullet}^b(z) - \frac{1}{x_* - z_* + i\epsilon} ([x_{\bullet}, \infty_{\bullet}]^{\bar{A}^*} [\infty_{\bullet}, z_{\bullet}]^{\bar{A}^*})^{ab} \bar{G}_{* \bullet}^b(z) \right] \\
\Rightarrow i(\aleph \partial_{\bullet} \aleph^{\dagger}) &= \bar{A}_{\bullet} + \frac{1}{4\pi} \int d^2 z \left( \frac{1}{x_* - z_* - i\epsilon(x-z)_{\bullet}} [\bar{A}_{*}, \bar{A}_{\bullet}](z) - \frac{1}{x_* - z_* + i\epsilon} [\bar{\bar{A}}_{*}, \bar{\bar{A}}_{\bullet}](z) \right) \quad (455)
\end{aligned}$$

Probuem

$$\begin{aligned}
\aleph^{\dagger} &= 1 + i \int_{x_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{\bullet}(z_*) + i \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z_{\bullet}) - \int_{x_*}^{\infty} d^2 \frac{z'}{s} \int_{z_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{\bullet}(z'_*) \bar{A}_{\bullet}(z_*) - \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{z_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z'_*) \bar{A}_{*}(z_{\bullet}) \\
&- \frac{i}{2\pi s} \int d^2 z (\ln(x_* - z_* - i\epsilon(x-z)_{\bullet}) [\bar{A}_{*}, \bar{A}_{\bullet}](z) - \ln(x_* - z_* + i\epsilon) [\bar{\bar{A}}_{*}, \bar{\bar{A}}_{\bullet}](z)) + X3 \\
\Rightarrow i\partial_{\bullet} X3 &= i \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z_{\bullet}) \bar{A}_{\bullet}(x_*) \quad (456) \\
X3 &= -\int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{x_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z_{\bullet}) \bar{A}_{\bullet}(z_*) = -\frac{1}{2} \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{x_*}^{\infty} d^2 \frac{z'}{s} \{ \bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_*) \} - \frac{1}{2} \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{x_*}^{\infty} d^2 \frac{z'}{s} [\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_*)] \\
&\Rightarrow \\
\aleph^{\dagger} &= 1 + i \int_{x_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{\bullet}(z_*) + i \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z_{\bullet}) - \int_{x_*}^{\infty} d^2 \frac{z'}{s} \int_{z_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{\bullet}(z'_*) \bar{A}_{\bullet}(z_*) - \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{z_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z'_*) \bar{A}_{*}(z_{\bullet}) \\
&- \frac{1}{2} \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{x_*}^{\infty} d^2 \frac{z'}{s} \{ \bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_*) \} - \frac{i}{4\pi} \int d^2 \frac{z'}{s} d^2 \frac{z'}{s} (\ln(x_* - z_* - i\epsilon) [\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_*)] - \ln(x_* - z_* + i\epsilon) [\bar{\bar{A}}_{*}(z_{\bullet}), \bar{\bar{A}}_{\bullet}(z_*)]) \\
\text{Adding the } * \leftrightarrow \bullet \text{ term we get} \\
\aleph^{\dagger}(x_*, x_{\bullet}) &= 1 + i \int_{x_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{\bullet}(z_*) + i \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z_{\bullet}) - \int_{x_*}^{\infty} d^2 \frac{z'}{s} \int_{z_*}^{\infty} d^2 \frac{z'}{s} \bar{A}_{\bullet}(z'_*) \bar{A}_{\bullet}(z_*) - \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{z_{\bullet}}^{\infty} d^2 \frac{z'}{s} \bar{A}_{*}(z'_*) \bar{A}_{*}(z_{\bullet}) \\
&- \frac{1}{2} \int_{x_{\bullet}}^{\infty} d^2 \frac{z'}{s} \int_{x_*}^{\infty} d^2 \frac{z'}{s} \{ \bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_*) \} \quad (457) \\
&- \frac{i}{4\pi} \int d^2 \frac{z'}{s} d^2 \frac{z'}{s} \{ (\ln(x_* - z_* - i\epsilon) - \ln(x_{\bullet} - z_{\bullet} - i\epsilon)) [\bar{A}_{*}(z_{\bullet}), \bar{A}_{\bullet}(z_*)] - (\ln(x_* - z_* + i\epsilon) - \ln(x_{\bullet} - z_{\bullet} + i\epsilon)) [\bar{\bar{A}}_{*}(z_{\bullet}), \bar{\bar{A}}_{\bullet}(z_*)] \}
\end{aligned}$$

Check:  $\bar{A} = \bar{\bar{A}}$

$$\begin{aligned} \aleph^\dagger &= 1 + i \int_{x_*}^\infty d_s^2 z_* \bar{A}_\bullet(z_*) + i \int_{x_\bullet}^\infty d_s^2 z_\bullet \bar{A}_*(z_\bullet) - \int_{x_*}^\infty d_s^2 z_* \int_{z_*}^\infty d_s^2 z'_* \bar{A}_\bullet(z'_*) \bar{A}_\bullet(z_*) - \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{z_\bullet}^\infty d_s^2 z'_\bullet \bar{A}_*(z'_\bullet) \bar{A}_*(z_\bullet) \\ &- \frac{1}{2} \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{x_*}^\infty d_s^2 z_* \{ \bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*) \} - \frac{1}{2} \int d_s^2 z_* d_s^2 z_\bullet (\theta(x_* - z_*) - \theta(x_\bullet - z_\bullet)) [ \bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*) ] \end{aligned}$$

Reminder:

$$\begin{aligned} \Omega^\dagger &= \left[ 1 - i \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*) - i \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_*(x'_*) \right. \\ &\quad \left. - \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_*(x''_*) \bar{A}_*(x'_*) - \frac{1}{2} \int_{-\infty}^{x_*} d_s^2 x'_* \int_{-\infty}^{x_*} d_s^2 x''_* (\bar{A}_\bullet(x'_*) \bar{A}_*(x''_*) + \bar{A}_*(x'_*) \bar{A}_\bullet(x''_*)) \right] \end{aligned}$$

From Eqs. (193) and (192) we see that

$$\Omega(\infty_\bullet, \infty_*) \Omega^\dagger(x_*, x_\bullet) = \left[ 1 + i \int d_s^2 x'_* \bar{A}_\bullet(x'_*) - \int d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*) + i \int d_s^2 x'_* \bar{A}_*(x'_*) \right. \quad (458)$$

$$\left. - \int d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_*(x''_*) \bar{A}_*(x'_*) - \frac{1}{2} \int d_s^2 x'_* d_s^2 x''_* (\bar{A}_\bullet(x'_*) \bar{A}_*(x''_*) + \bar{A}_*(x'_*) \bar{A}_\bullet(x''_*)) \right]$$

$$\times \left[ 1 - i \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_\bullet(x'_*) - \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_\bullet(x''_*) \bar{A}_\bullet(x'_*) - i \int_{-\infty}^{x_*} d_s^2 x'_* \bar{A}_*(x'_*) \right.$$

$$\left. - \int_{-\infty}^{x_*} d_s^2 x'_* d_s^2 x''_* \theta(x'_* - x''_*) \bar{A}_*(x''_*) \bar{A}_*(x'_*) - \frac{1}{2} \int_{-\infty}^{x_*} d_s^2 x'_* \int_{-\infty}^{x_*} d_s^2 x''_* (\bar{A}_\bullet(x'_*) \bar{A}_*(x''_*) + \bar{A}_*(x'_*) \bar{A}_\bullet(x''_*)) \right]$$

$$\begin{aligned} &\Rightarrow \int d_s^2 x'_* d_s^2 x''_* \left\{ -\frac{1}{2} [1 + \theta(x_\bullet - x'_*) \theta(x_* - x'_*)] (\bar{A}_\bullet(x'_*) \bar{A}_*(x''_*) + \bar{A}_*(x'_*) \bar{A}_\bullet(x''_*)) + \theta(x_\bullet - x'_*) \bar{A}_\bullet(x'_*) \bar{A}_*(x''_*) + \theta(x_* - x'_*) \bar{A}_*(x'_*) \bar{A}_\bullet(x''_*) \right\} \\ &= \int d_s^2 x'_* d_s^2 x''_* \left( -\frac{1}{2} \theta(x'_* - x_\bullet) \theta(x'_* - x_*) \{ \bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*) \} + \frac{1}{2} (\theta(x_* - x'_*) - \theta(x_\bullet - x'_*)) [ \bar{A}_*(x'_*), \bar{A}_\bullet(x''_*) ] \right) \end{aligned}$$

$\Rightarrow$

$$\aleph^\dagger(\bar{A} = \bar{A}) = \Omega(\infty_*, \infty_\bullet) \Omega^\dagger(x_*, x_\bullet) \quad (459)$$

Similarly

$$i(\tilde{\aleph} \partial_\bullet \tilde{\aleph}^\dagger)^a = \bar{\bar{A}}_\bullet + \frac{1}{4\pi} \int d^2 z \left( \frac{1}{x_* - z_* - i\epsilon} [\bar{A}_*, \bar{A}_\bullet](z) - \frac{1}{x_* - z_* + i\epsilon(x - z)_\bullet} [\bar{\bar{A}}_*, \bar{\bar{A}}_\bullet](z) \right) \quad (460)$$

$$\text{compare 2} \quad i(\aleph \partial_\bullet \aleph^\dagger)^a = \bar{A}_\bullet + \frac{1}{4\pi} \int d^2 z \left( \frac{1}{x_* - z_* - i\epsilon(x - z)_\bullet} [\bar{A}_*, \bar{A}_\bullet](z) - \frac{1}{x_* - z_* + i\epsilon} [\bar{\bar{A}}_*, \bar{\bar{A}}_\bullet](z) \right)$$

$$\begin{aligned} \tilde{\aleph}^\dagger &= 1 + i \int_{x_*}^\infty d_s^2 z_* \bar{\bar{A}}_\bullet(z_*) + i \int_{x_\bullet}^\infty d_s^2 z_\bullet \bar{\bar{A}}_*(z_\bullet) - \int_{x_*}^\infty d_s^2 z_* \int_{z_*}^\infty d_s^2 z'_* \bar{\bar{A}}_\bullet(z'_*) \bar{\bar{A}}_\bullet(z_*) - \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{z_\bullet}^\infty d_s^2 z'_\bullet \bar{\bar{A}}_*(z'_\bullet) \bar{\bar{A}}_*(z_\bullet) \\ &- \frac{i}{2\pi s} \int d^2 z (\ln(x_* - z_* - i\epsilon) [\bar{\bar{A}}_*, \bar{\bar{A}}_\bullet](z) - \ln(x_* - z_* + i\epsilon(x - z)_\bullet) [\bar{\bar{A}}_*, \bar{\bar{A}}_\bullet](z)) + \tilde{X}3 \end{aligned}$$

$$\Rightarrow i\partial_\bullet \tilde{X}3 = i \int_{x_\bullet}^\infty d_s^2 z_\bullet \bar{\bar{A}}_*(z_\bullet) \bar{\bar{A}}_\bullet(x_*) \quad (461)$$

$$\tilde{X}3 = - \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{x_*}^\infty d_s^2 z_* \bar{\bar{A}}_*(z_\bullet) \bar{\bar{A}}_\bullet(z_*) = - \frac{1}{2} \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{x_*}^\infty d_s^2 z_* \{ \bar{\bar{A}}_*(z_\bullet), \bar{\bar{A}}_\bullet(z_*) \} - \frac{1}{2} \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{x_*}^\infty d_s^2 z_* [ \bar{\bar{A}}_*(z_\bullet), \bar{\bar{A}}_\bullet(z_*) ]$$

$\Rightarrow$

$$\begin{aligned} \aleph^\dagger(x_*, x_\bullet) &= 1 + i \int_{x_*}^\infty d_s^2 z_* \bar{\bar{A}}_\bullet(z_*) + i \int_{x_\bullet}^\infty d_s^2 z_\bullet \bar{\bar{A}}_*(z_\bullet) - \int_{x_*}^\infty d_s^2 z_* \int_{z_*}^\infty d_s^2 z'_* \bar{\bar{A}}_\bullet(z'_*) \bar{\bar{A}}_\bullet(z_*) - \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{z_\bullet}^\infty d_s^2 z'_\bullet \bar{\bar{A}}_*(z'_\bullet) \bar{\bar{A}}_*(z_\bullet) \\ &- \frac{1}{2} \int_{x_\bullet}^\infty d_s^2 z_\bullet \int_{x_*}^\infty d_s^2 z_* \{ \bar{\bar{A}}_*(z_\bullet), \bar{\bar{A}}_\bullet(z_*) \} \end{aligned} \quad (462)$$

$$- \frac{i}{4\pi} \int d_s^2 z_* d_s^2 z_\bullet \{ (\ln(x_* - z_* - i\epsilon) - \ln(x_\bullet - z_\bullet - i\epsilon)) [ \bar{\bar{A}}_*(z_\bullet), \bar{\bar{A}}_\bullet(z_*) ] - (\ln(x_* - z_* + i\epsilon) - \ln(x_\bullet - z_\bullet + i\epsilon)) [ \bar{\bar{A}}_*(z_\bullet), \bar{\bar{A}}_\bullet(z_*) ] \}$$

Compare 2 Eq. (457):

$$\begin{aligned}
\aleph^\dagger &= 1 + i \int_{x_*}^\infty d^2 z_* \frac{2}{s} \bar{A}_\bullet(z_*) + i \int_{x_\bullet}^\infty d^2 z_\bullet \frac{2}{s} \bar{A}_*(z_\bullet) - \int_{x_*}^\infty d^2 z_* \int_{z_*}^\infty d^2 z'_* \frac{2}{s} \bar{A}_\bullet(z'_*) \bar{A}_\bullet(z_*) - \int_{x_\bullet}^\infty d^2 z_\bullet \int_{z_\bullet}^\infty d^2 z'_\bullet \frac{2}{s} \bar{A}_*(z'_\bullet) \bar{A}_*(z_\bullet) \\
&- \frac{1}{2} \int_{x_*}^\infty d^2 z_* \frac{2}{s} \int_{x_*}^\infty d^2 z_* \frac{2}{s} \{ \bar{A}_*(z_*), \bar{A}_\bullet(z_*) \} \\
&- \frac{i}{4\pi} \int d^2 z_* \frac{2}{s} d^2 z_\bullet \frac{2}{s} \{ (\ln(x_* - z_* - i\epsilon) - \ln(x_\bullet - z_\bullet - i\epsilon)) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] - (\ln(x_* - z_* + i\epsilon) - \ln(x_\bullet - z_\bullet + i\epsilon)) [\bar{A}_*(z_\bullet), \bar{A}_\bullet(z_*)] \}
\end{aligned} \tag{463}$$

1.  $\bar{C}_i$  and  $\bar{\tilde{C}}_i$

YP-E (217)

$$\begin{aligned}
(\aleph p^2 \aleph^\dagger)^{ab} \bar{C}_i^b &= - (\aleph p_\beta \aleph^\dagger)^{ab} \partial_i (\aleph \partial_\beta \aleph^\dagger)^b = - i \aleph^{ab} \partial^2 (2 \text{Tr} \{ t^b (\partial_i \aleph^\dagger) \aleph \}) \\
(\tilde{\aleph} p^2 \tilde{\aleph}^\dagger)^{ab} \bar{\tilde{C}}_i^b &= - (\tilde{\aleph} p_\beta \tilde{\aleph}^\dagger)^{ab} \partial_i (\tilde{\aleph} \partial_\beta \tilde{\aleph}^\dagger)^b = - i \tilde{\aleph}^{ab} \partial^2 (2 \text{Tr} \{ t^b (\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph} \})
\end{aligned} \tag{464}$$

gde  $\bar{A}_\bullet + \bar{C}_\bullet = i \aleph \partial_\bullet \aleph^\dagger$  and  $\bar{A}_* + \bar{C}_* = i \aleph \partial_* \aleph^\dagger$ . Also, we used f-la (218).

ПО АНАЛОГИИ С УРАВНЕНИЕМ (219)

$$\begin{aligned}
\bar{C}_i^a &= -i \int d^2 z \aleph_x^{ab} (x | \frac{1}{p^2 + i\epsilon} | z) \partial^2 ((\partial_i \aleph^\dagger) \aleph)^b + \int d^4 z \aleph_x^{ab} (x | 2\pi \delta(p^2) \theta(-p_0) | z) \partial^2 ((\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph})^b \\
\bar{\tilde{C}}_i^a &= -i \int d^2 z \tilde{\aleph}_x^{ab} (x | \frac{1}{p^2 - i\epsilon} | z) \partial^2 ((\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph})^b - \int d^4 z \tilde{\aleph}_x^{ab} (x | 2\pi \delta(p^2) \theta(p_0) | z) \partial^2 ((\partial_i \aleph^\dagger) \aleph)^b
\end{aligned} \tag{465}$$

$$\begin{aligned}
\bar{C}_i^a &= -i \int d^2 z \aleph_x^{ab} (x | \frac{1}{p^2 + i\epsilon} | z) \partial^2 ((\partial_i \aleph^\dagger) \aleph)^b + \int d^2 z \aleph_x^{ab} (x | 2\pi \delta(p^2) \theta(-p_0) | z) \partial^2 ((\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph})^b \\
&= -is \int d^2 z \aleph_x^{ab} (x | \frac{1}{p^2} | z) \frac{\partial}{\partial z_*} \frac{\partial}{\partial z_\bullet} ((\partial_i \aleph^\dagger) \aleph_z)^b + s \int d^2 z \aleph_x^{ab} (x | 2\pi \delta(p^2) \theta(-p_0) | z) \frac{\partial}{\partial z_*} \frac{\partial}{\partial z_\bullet} ((\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph})^b \\
&= (\aleph i \partial_i \aleph^\dagger)^a + \frac{4}{s} \aleph_x^{ab} \int d^2 z_\perp dz_\bullet (x | \frac{p_*}{p^2 + i\epsilon} | z) ((\partial_i \aleph^\dagger) \aleph_z)^b \Big|_{z_*=-\infty}^{z_*=\infty} + \frac{4}{s} \aleph_x^{ab} \int d^2 z_\perp dz_* (x | \frac{p_\bullet}{p^2 + i\epsilon} | z) ((\partial_i \aleph^\dagger) \aleph_z)^b \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \\
&- 2i \aleph_x^{ab} \int d^2 z_\perp (x | \frac{1}{p^2 + i\epsilon} | z) ((\partial_i \aleph^\dagger) \aleph_z)^b \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \Big|_{z_*=-\infty}^{z_*=\infty} \\
&+? \frac{4i}{s} \aleph_x^{ab} \int d^2 z_\perp dz_\bullet (x | 2\pi \delta(p^2) \theta(-p_0) p_* | z) ((\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph}_z)^b \Big|_{z_*=-\infty}^{z_*=\infty} +? \frac{4i}{s} \aleph_x^{ab} \int d^2 z_\perp dz_* (x | 2\pi \delta(p^2) \theta(-p_0) p_\bullet | z) ((\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph}_z)^b \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \\
&+? 2 \aleph_x^{ab} \int d^2 z_\perp (x | 2\pi \delta(p^2) \theta(-p_0) | z) ((\partial_i \tilde{\aleph}^\dagger) \tilde{\aleph}_z)^b \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \Big|_{z_*=-\infty}^{z_*=\infty}
\end{aligned} \tag{466}$$

## XV. BFKL?

### A. ВКЛАД КВАРКОВ

$$\begin{aligned}
(\hat{P} + \hat{C}) \Upsilon &\equiv (\hat{p} + \hat{A} + \hat{B} + \hat{C}) (\xi_a + \xi_b + \chi) = 0 \Rightarrow \\
\chi &= - \frac{1}{\hat{P} + \hat{C}} (\hat{B} + \hat{C}) \xi_a - \frac{1}{\hat{P} + \hat{C}} (\hat{A} + \hat{C}) \xi_b
\end{aligned} \tag{467}$$

$$\Upsilon(x) = -i \int dz_\bullet d^2 z_\perp (x | \frac{1}{\hat{P} + \hat{C}} | z) \Big|_{z_*=-\infty}^{z_*=\infty} \gamma_* \xi_a(z_\bullet) - i \int dz_* d^2 z_\perp (x | \frac{1}{\hat{P} + \hat{C}} | z) \Big|_{z_\bullet=-\infty}^{z_\bullet=\infty} \gamma_\bullet \xi_b(z_*) \tag{468}$$

In the leading order

$$\begin{aligned}
\chi(x) &= -\int d^4z (x|\frac{1}{\hat{p}}|z)\gamma_*\hat{A}_\bullet(z_*)\xi_a(z_\bullet) - \int d^4z (x|\frac{1}{\hat{p}}|z)\gamma_*\hat{A}_*(z_\bullet)\xi_b(z_*) \\
&= -\int dz_*dz_\bullet (x||\frac{1}{p_\bullet + i\epsilon p_*}|z||)A_\bullet(z_*, x_\perp)\xi_a(z_\bullet, x_\perp) - \int dz_*dz_\bullet (x||\frac{1}{p_* + i\epsilon p_\bullet}|z||)A_*(z_\bullet, x_\perp)\xi_b(z_*, x_\perp) \\
&= \frac{1}{2\pi}\int dz_*dz_\bullet \frac{1}{x_\bullet - z_\bullet - i\epsilon(x-z)_*}A_\bullet(z_*, x_\perp)\xi_a(z_\bullet, x_\perp) + \frac{1}{2\pi}\int dz_*dz_\bullet \frac{1}{x_* - z_* - i\epsilon(x-z)_\bullet}A_*(z_\bullet, x_\perp)\xi_b(z_*, x_\perp) \\
\bar{\chi}(x) &= \frac{1}{2\pi}\int dz_*dz_\bullet \bar{\xi}_a(z_\bullet, x_\perp)A_\bullet(z_*, x_\perp)\frac{1}{z_\bullet - x_\bullet - i\epsilon(z-x)_*} + \frac{1}{2\pi}\int dz_*dz_\bullet \bar{\xi}_b(z_*, x_\perp)A_*(z_\bullet, x_\perp)\frac{1}{z_* - x_* - i\epsilon(z-x)_\bullet}
\end{aligned} \tag{469}$$

### 1. Double counting?

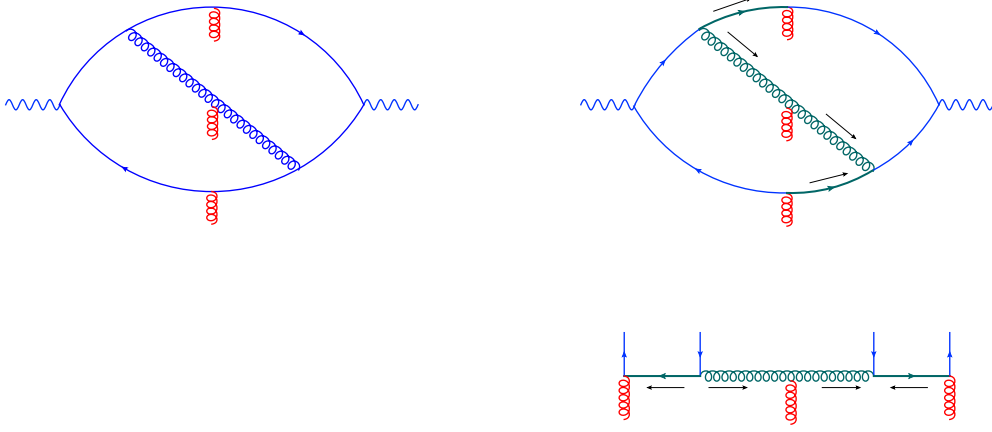


FIG. 4. Problem: projectile fields or central “C” fields? Arrows denote direction of  $\alpha$ 's.

### B. $F_{\mu\nu}$ up to one $A_\bullet$ and one $A_*$

From Eq. (260)

$$\begin{aligned}
p^2\bar{C}_*^a &= \bar{D}^\xi\bar{G}_{\xi_*}^a + \bar{\xi}_a\gamma_*t^a\xi_a + \bar{\xi}_a\gamma_*t^a\chi + \bar{\chi}\gamma_*t^a\xi_a = -\frac{2}{s}\partial_*\bar{G}_{* \bullet}^a + \bar{\xi}_a\gamma_*t^a\chi + \bar{\chi}\gamma_*t^a\xi_a, \\
&= -\frac{2}{s}\partial_*\bar{G}_{* \bullet}^a + \frac{1}{2\pi}\int dz_*dz_\bullet \left[ \frac{\bar{\xi}_a(x_\bullet, x_\perp)\hat{p}_2t^aA_\bullet(z_*, x_\perp)\xi_a(z_\bullet, x_\perp)}{x_\bullet - z_\bullet - i\epsilon(x-z)_*} + \frac{\bar{\xi}_a(z_\bullet, x_\perp)A_\bullet(z_*, x_\perp)t^a\hat{p}_2\xi_a(x_\bullet, x_\perp)}{z_\bullet - x_\bullet - i\epsilon(z-x)_*} \right] \\
&= -\frac{2}{s}\partial_*\bar{G}_{* \bullet}^a + \frac{1}{2\pi}\int dz_*dz_\bullet \text{V.p.} \frac{1}{x_\bullet - z_\bullet} [\bar{\xi}_a(x_\bullet, x_\perp)\hat{p}_2t^at^b\xi_a(z_\bullet, x_\perp) - \bar{\xi}_a(z_\bullet, x_\perp)t^bt^a\hat{p}_2\xi_a(x_\bullet, x_\perp)] \int dz_*A_\bullet(z_*, x_\perp) \\
&\quad + \frac{1}{2}f^{abc}\bar{\xi}_at^b\hat{p}_2\xi_a(x_\bullet, x_\perp) \int dz_*\epsilon(x_* - z_*)A_\bullet^c(z_*, x_\perp) \\
p^2\bar{C}_\bullet^a &= \bar{D}^\xi\bar{G}_{\xi_\bullet}^a + \bar{\xi}_b\gamma_\bullet t^a\xi_b + \bar{\xi}_b\gamma_\bullet t^a\chi + \bar{\chi}\gamma_\bullet t^a\xi_b = \frac{2}{s}\partial_\bullet\bar{G}_{* \bullet}^a + \bar{\xi}_b\gamma_\bullet t^a\chi + \bar{\chi}\gamma_\bullet t^a\xi_b, \\
p^2\bar{C}_i^a &= \bar{D}^\xi\bar{G}_{\xi_i}^a = \frac{2}{s}(\bar{D}_* \bar{G}_{*i} + \bar{D}_\bullet \bar{G}_{*i}) = -\frac{2}{s}f^{abc}(\bar{A}_\bullet^b\partial_i\bar{A}_*^c + \bar{A}_*^b\partial_i\bar{A}_\bullet^c)
\end{aligned} \tag{470}$$

$$\begin{aligned}
\bar{C}_*^{(1)a}(x) &= \frac{2i}{s}\int d^4z (x|\frac{p_*}{p^2 + i\epsilon}|z)\bar{G}_{* \bullet}^a(z), \quad \bar{C}_\bullet^{(1)a}(x) = -\frac{2i}{s}\int d^4z (x|\frac{p_\bullet}{p^2 + i\epsilon}|z)\bar{G}_{* \bullet}^a(z), \\
\bar{C}_i^{(1)a} &= -\frac{2}{s}f^{abc}\int d^4z (x|\frac{1}{p^2 + i\epsilon}|z)(\bar{A}_\bullet^b\partial_i\bar{A}_*^c + \bar{A}_*^b\partial_i\bar{A}_\bullet^c)(z)
\end{aligned} \tag{471}$$

$$\begin{aligned}
F_{*\bullet}^{(1)a}(x) &= \bar{G}_{*\bullet}(x) - \frac{4}{s} \int d^4 z (x | \frac{p_* p_\bullet}{p^2 + i\epsilon} | z) \bar{G}_{*\bullet}^a(z) = \int d^4 z (x | \frac{1}{p^2 + i\epsilon} | z) \partial_\perp^2 \bar{G}_{*\bullet}^a(z) \\
F_{\bullet i}^{(1)a}(x) &= \bar{G}_{\bullet i}^a(x) + \frac{2i}{s} f^{abc} \int d^4 z (x | \frac{p_\bullet}{p^2 + i\epsilon} | z) (\bar{A}_\bullet^b \partial_i \bar{A}_*^c + \bar{A}_*^b \partial_i \bar{A}_\bullet^c)(z) + \frac{2}{s} \int d^4 z (x | \frac{p_\bullet p_i}{p^2 + i\epsilon} | z) \bar{G}_{*\bullet}^a(z) \\
&= \bar{G}_{\bullet i}^a(x) + \frac{4i}{s} f^{abc} \int d^4 z (x | \frac{p_\bullet}{p^2 + i\epsilon} | z) \bar{A}_*^b \partial_i \bar{A}_\bullet^c(z) \\
F_{*i}^{(1)a}(x) &= \bar{G}_{*i}^a(x) + \frac{4i}{s} f^{abc} \int d^4 z (x | \frac{p_*}{p^2 + i\epsilon} | z) \bar{A}_\bullet^b \partial_i \bar{A}_*^c(z) \\
F_{ij}^{(1)a}(x) &= -\frac{4}{s} f^{abc} \int d^4 z (x | \frac{1}{p^2 + i\epsilon} | z) (\partial_i \bar{A}_*^b \partial_j \bar{A}_\bullet^c(z) - i \leftrightarrow j)
\end{aligned} \tag{472}$$

1.  $F_{\bullet i}$  up to  $\bar{A}_\bullet^2 \bar{A}_*$

From Eq. (260)

$$\begin{aligned}
\bar{P}^2 \bar{C}_i^a + \frac{4ig}{s} (\bar{G}_{i\bullet}^{ab} \bar{C}_*^b + \bar{G}_{i*}^{ab} \bar{C}_\bullet^b) &= \bar{D}^{ab\xi} \bar{G}_{\xi i}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_i^c - \bar{C}_\beta^b \partial_i \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_i^c \bar{C}_\beta^d + \bar{\Upsilon} \gamma_i t^a \xi \\
\Rightarrow p^2 \bar{C}_i^{(2)a} &= -\frac{4}{s} (\bar{A}_* p_\bullet + \bar{A}_\bullet p_*)^{ab} \bar{C}_i^{(1)b} + \frac{4ig}{s} (\bar{G}_{\bullet i}^{ab} \bar{C}_*^{(1)b} + \bar{G}_{*i}^{ab} \bar{C}_\bullet^{(1)b}) + \bar{\xi}_a \gamma_i t^a \xi_b + \bar{\xi}_b \gamma_i t^a \xi_a \\
\Rightarrow \bar{C}_i^{(2)a}(x) &= \frac{8}{s^2} \int d^4 z (x | \frac{1}{p^2} (\bar{A}_* \frac{p_\bullet}{p^2} + \bar{A}_\bullet \frac{p_*}{p^2}) | z)^{aa'} f^{a'bc} (\bar{A}_\bullet^b \partial_i \bar{A}_*^c + \bar{A}_*^b \partial_i \bar{A}_\bullet^c)(z) + \frac{8}{s^2} \int d^4 z (x | \frac{1}{p^2} (\bar{G}_{*i} \frac{p_\bullet}{p^2} - \bar{G}_{\bullet i} \frac{p_*}{p^2}) | z)^{ab} \bar{G}_{*\bullet}^b(z) \\
&\quad + \int d^4 z (x | \frac{1}{p^2} (\bar{\xi}_a \gamma_i t^a \xi_b + \bar{\xi}_b \gamma_i t^a \xi_a)
\end{aligned} \tag{473}$$

$$\begin{aligned}
\bar{P}^2 \bar{C}_\bullet^a + 2ig \bar{G}_{\bullet\xi}^{ab} \bar{C}^{b\xi} &= \bar{D}^{ab\xi} \bar{G}_{\xi\bullet}^b + g f^{abc} (2\bar{C}_\beta^b \bar{D}^\beta \bar{C}_\bullet^c - \bar{C}_\beta^b \partial_\bullet \bar{C}^{c\beta}) - g^2 f^{abm} f^{cdm} \bar{C}^{b\beta} \bar{C}_\bullet^c \bar{C}_\beta^d + \bar{\xi}_b \gamma_\bullet t^a \xi_b \\
\Rightarrow \bar{P}^2 \bar{C}_\bullet^a + 2ig \bar{G}_{\bullet\xi}^{ab} \bar{C}^{b\xi} &= -\frac{2i}{s} \bar{A}_\bullet^a \bar{G}_{\bullet*}^b \Rightarrow p^2 \bar{C}_\bullet^{(2)a} = -\frac{4}{s} \bar{A}_\bullet p_* \bar{C}_\bullet^{(1)a} - 2ig \bar{G}_{\bullet i}^{ab} \bar{C}^{(1)bi} - \frac{2i}{s} \bar{A}_\bullet^a \bar{G}_{*\bullet}^b \\
\Rightarrow \bar{C}_\bullet^{(2)a}(x) &= -\frac{2i}{s} \int d^4 z (x | \frac{1}{p^2} \bar{A}_\bullet \frac{1}{p^2} | z)^{ab} \partial_\perp^2 \bar{G}_{*\bullet}^b(z) + \frac{4i}{s} \int d^4 z (x | \frac{1}{p^2} \bar{G}_{\bullet i} \frac{1}{p^2} | z)^{aa'} f^{a'bc} (\bar{A}_\bullet^b \partial^i \bar{A}_*^c + \bar{A}_*^b \partial^i \bar{A}_\bullet^c)(z)
\end{aligned} \tag{474}$$

$$\begin{aligned}
F_{\bullet i}^{(2)a}(x) &= \partial_\bullet \bar{C}_i^{(2)a}(x) - i \bar{A}_\bullet^a \bar{C}_i^{(1)b}(x) - \partial_i \bar{C}_\bullet^{(2)a}(x) \\
&= -\frac{8i}{s^2} \int d^4 z (x | \frac{p_\bullet}{p^2} \bar{A}_\bullet \frac{p_*}{p^2} | z)^{aa'} f^{a'bc} (\bar{A}_\bullet^b \partial_i \bar{A}_*^c + \bar{A}_*^b \partial_i \bar{A}_\bullet^c)(z) + \frac{8i}{s^2} \int d^4 z (x | \frac{p_\bullet}{p^2} \bar{G}_{\bullet i} \frac{p_*}{p^2} | z)^{ab} \bar{G}_{*\bullet}^b(z) \\
&\quad - i \int d^4 z (x | \frac{p_\bullet}{p^2} (\bar{\xi}_a \gamma_i t^a \xi_b + \bar{\xi}_b \gamma_i t^a \xi_a) + \frac{2i}{s} \bar{A}_\bullet^{aa'} \int d^4 z (x | \frac{1}{p^2} | z) f^{a'bc} (\bar{A}_\bullet^b \partial_i \bar{A}_*^c + \bar{A}_*^b \partial_i \bar{A}_\bullet^c)(z) \\
&\quad + \frac{2}{s} \int d^4 z (x | \frac{p_i}{p^2} \bar{A}_\bullet \frac{1}{p^2} | z)^{ab} \partial_\perp^2 \bar{G}_{*\bullet}^b(z) - \frac{4}{s} \int d^4 z (x | \frac{p_i}{p^2} \bar{G}_{\bullet j} \frac{1}{p^2} | z)^{aa'} f^{a'bc} (\bar{A}_\bullet^b \partial^j \bar{A}_*^c + \bar{A}_*^b \partial^j \bar{A}_\bullet^c)(z) \\
&= -\frac{2i}{s} \int d^4 z (x | \frac{p_\perp^2}{p^2} \bar{A}_\bullet \frac{1}{p^2} | z)^{aa'} f^{a'bc} (\bar{A}_\bullet^b \partial_i \bar{A}_*^c + \bar{A}_*^b \partial_i \bar{A}_\bullet^c)(z) + \frac{2i}{s} \int d^4 z \bar{G}_{\bullet i}^{ab}(x) (x | \frac{1}{p^2} | z) \bar{G}_{*\bullet}^b(z) \\
&\quad + \frac{2i}{s} \int d^4 z (x | \frac{p_\perp^2}{p^2} \bar{G}_{\bullet i} \frac{1}{p^2} | z)^{ab} \bar{G}_{*\bullet}^b(z) - i \int d^4 z (x | \frac{p_\bullet}{p^2} (\bar{\xi}_a \gamma_i t^a \xi_b + \bar{\xi}_b \gamma_i t^a \xi_a) \\
&\quad + \frac{2}{s} \int d^4 z (x | \frac{p_i}{p^2} \bar{A}_\bullet \frac{1}{p^2} | z)^{ab} \partial_\perp^2 \bar{G}_{*\bullet}^b(z) - \frac{4}{s} \int d^4 z (x | \frac{p_i}{p^2} \bar{G}_{\bullet j} \frac{1}{p^2} | z)^{aa'} f^{a'bc} (\bar{A}_\bullet^b \partial^j \bar{A}_*^c + \bar{A}_*^b \partial^j \bar{A}_\bullet^c)(z)
\end{aligned} \tag{475}$$

2. Action

$$\int d^4 x \bar{G}_*^{ai}(x) F_{\bullet i}^{(2)a}(x) = \tag{476}$$