L.N.Lipatov (1940-2017)

The picture is from M.Shifman's live journal.

On correlators of Reggeon fields in high energy QCD

Bondarenko Sergey

sergeyb@ariel.ac.il

Physics Department
Ariel University
Israel

Based on:
S.Bondarenko, L.Lipatov and A.Prygarin,
Eur.Phys.J. C **77**, no. 8, 527 (2017) arXiv:1706.00278 ;
S. Bondarenko, L. Lipatov, S. Pozdnyakov and A. Prygarin,
Eur.Phys.J. C **77**, no. 9, 630 (2017), arXiv:1708.05183 ;
S. Bondarenko, M. Zubkov,
Eur.Phys.J. C **78** (2018) no.8, 617, arXiv:1801.08066;
S. Bondarenko, S. Pozdnyakov,
Phys.Lett.B **783**, 207 (2018) arXiv:1803.04131;
S. Bondarenko, S. Pozdnyakov,
Int.J.Mod.Phys. A **33** (2018) no.35, 1850204, arXiv:1806.02563.

DIS 2019 TORINO 8-12 April

Effective action setup

- Consider QCD action with added sources of longitudinal gluons:

$$S_{eff} = -\int d^4x \left(\frac{1}{4} F^a_{\mu\nu} F^{\mu\nu}_a + tr\left[v_+ J^+(v_+) - A_+ j^+_{reg} + v_- J^-(v_-) - A_- j^-_{reg} \right] \right)$$

The real currents $J^{\pm}_a(v_\pm)$ under a variation wiht respect to the gluon fields behave as

$$\delta\left(v_\pm J^\pm(v_\pm)\right) = (\delta v_\pm)\, j^{ind}_\mp(v_\pm) = (\delta v_\pm)\, j^\pm(v_\pm)$$

where induced currents posses the covariant conservation property:

$$\left(D_\pm j^{ind}_\mp(v_\pm)\right)^a = \left(D_\pm j^\pm(v_\pm)\right)^a = 0$$

Additionally we require:

$$v_{+\,cl} = A_+\,, \quad v_{-\,cl} = A_-\,, \quad \partial_- A_+ = \partial_+ A_- = 0$$

and that is enough (almost) for the determination of the form of $J^{\pm}_a(v_\pm)$ currents.

Effective action setup

- The construction above is equivalent to the construction of the Lipatov's gauge-invariant action local in rapidity interval $(y_0 - \eta, y_0 + \eta)$ for the gluon-reggeon interactions with $A_\pm$ as reggeon fields similar to the Gribov's RFT:

$$S_{eff} = - \int d^4 x \left(\frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a + tr \left[(\mathcal{T}_+(v_+) - A_+) j^+_{reg} + (\mathcal{T}_-(v_-) - A_-) j^-_{reg} \right] \right)$$

$$\mathcal{T}_\pm(v_\pm) = \frac{1}{g} \partial_\pm O(x^\pm, v_\pm) = v_\pm O(x^\pm, v_\pm) ,$$

$$j^\pm_{reg\, a} = \frac{1}{C(R)} \partial_i^2 A^\pm_a , \quad \partial_- A_+ = \partial_+ A_- = 0 ,$$

where $C(R)$ is the eigenvalue of Casimir operator in the representation R, $C(R) = N$ in the case of adjoint representation and O as some operators of Wilson lines. See in:

L. N. Lipatov, Nucl. Phys. B 452, 369 (1995); Phys. Rept. 286, (1997) 131; B.Ioffe, V.Fadin and L.Lipatov, "Perturbative QCD".

Effective action setup

- In the simplest case:

$$O_x \;=\; P\, e^{g \int_{-\infty}^{x^+} dx'^+ \, v_+(x'^+)} \,, \;\; O_x^T \;=\; P\, e^{g \int_{x^+}^{\infty} dx'^+ \, v_+(x'^+)} \,.$$

are usual ordered exponentials and

$$\delta\,\left(v_+\, J^+\right) \;=\delta\, tr[\,\left(\, v_{+x}\, O_x\, \partial_i^2\, A^+\,\right)\,] \;=\; -\,\delta v_+^a\; tr[\,T_a\, O\, T_b\, O^T\,]\;\left(\partial_i^2\, A_b^+\right)\;.$$

- Correspondingly, the new gluon-reggeon vertices are arising in the action; it can be used for the diagrammatic construction of the amplitudes with gluon and reggeon fields: *L. N. Lipatov, Nucl. Phys. Proc. Suppl.* **99A**, *175 (2001); M. A. Braun and M. I. Vyazovsky, Eur. Phys. J. C* **51**, *103 (2007); M. A. Braun, L. N. Lipatov, M. Y. Salykin and M. I. Vyazovsky, Eur. Phys. J. C* **71**, *1639 (2011); M. Hentschinski and A. Sabio Vera, Phys. Rev. D* **85**, *056006 (2012); G. Chachamis, M. Hentschinski, J. D. Madrigal Martnez and A. Sabio Vera and etc.*

Regge Field Theory (RFT) construction

- Expanding around the classical solutions

$$v_i^a \to v_{i\,cl}^a + \varepsilon_i^a\,, \quad v_+^a \to v_{+\,cl}^a + \varepsilon_+^a$$

and integrating over the fluctuations we obtain Regge Field Theory (RFT) effective action:

- $$\Gamma = -\int d^4x\,(\,s_1[g,\,A_+,\,A_-] + g\,s_2[g,\,A_+,\,A_-] + \cdots)$$

which can be considered as generating functional of the Reggeons interaction vertices:

$$\Gamma = \sum_{n,m=1} \left(A_+^{a_1} \cdots A_+^{a_n}\, K_{b_1 \cdots b_m}^{a_1 \cdots a_n}\, A_-^{b_1} \cdots A_-^{b_m} \right)$$

- The perturbative order and precision of the effective vertices (kernels) K in Γ are determined by QCD degrees of freedom only. It is possible to fix the precision and consider the corrections from the RFT sector exclusively.

Lipatov's effective action from another angle of view

- Consider two Lipatov's operators interactin in eikonal approximation and averaged over the gluon fields:

$$
\begin{aligned}
Z[J] \quad &= \quad \frac{1}{Z'} \int Dv \exp\Big(\imath\, S^0[v] \,+\, \frac{\imath}{2\,C(R)} \int d^4x\, \mathcal{T}_+\, \partial_\perp^2\, \mathcal{T}_- \,+ \\
&+ \quad \frac{\imath}{2\,C(R)} \int d^4x\, J_-(x^-,\, x_\perp)\, \mathcal{T}_+ \,+\, \frac{\imath}{2\,C(R)} \int d^4x\, J_+(x^+,\, x_\perp)\, \mathcal{T}_- \Big)
\end{aligned}
$$

with

$$
\mathcal{T}_\pm(v_\pm) \,=\, \frac{1}{g}\, \partial_\pm\, O(v_\pm) \,=\, v_\pm\, O(v_\pm)\,,
$$

S. Bondarenko, M. Zubkov, arXiv:1801.08066; E. Verlinde and H. Verlinde, QCD at high energies and two-dimensional field theory, preprint PUPT 1319, IASSNS-HEP 92/30, 1993; I. Ya. Arefeva, Large N QCD at high energies as two-dimensional field theory, preprint SMI-5-93.

This reformulation of the Lipatov's effective action be used for establishing of a connection between the correlators of the Reggeon fields and Wilson lines (Balitsky-JIMWLK approach).

Schwinger-Dyson equations for the correlators

- Lipatov's effective action generating functional variation with respect to Reggeon fields:

$$\delta\, Z[J] \;=\; \int DA\, \delta A^a_\pm \left(\frac{\delta \Gamma[A]}{\delta A^a_\pm} - \int dx^\mp\, J^a_\mp(x^\mp,\, x_\perp) \right) \exp\Big(\imath \Gamma[A] - \imath \int d^4x\, J^a_-\, A^a_+ - \\ - \;\imath \int d^4x\, J^a_+\, A^a_- \Big) = 0$$

- One-field correlator:

$$< \frac{\delta \Gamma[A]}{\delta A^a_\pm} >= 0$$

provides

$$< A^a_\pm(x,\, \eta) >= \sum_{n=1} \Big(\tilde{K}(\eta; x,\, x_1 \cdots,\, x_n) \Big)^{a\, a_1 \cdots a_n} < A^{a_1}_\pm(x_1) \cdots A^{a_n}_\pm(x_n) >,$$

The BFKL like evolution is obtained by taking the derivative with respect to the η:

$$\frac{\partial}{\partial \eta} < A^a_\pm >= \frac{\partial}{\partial \eta} \left(\sum_{n=1} \Big(\tilde{K}(\eta) \Big)^{a\, a_1 \cdots a_a} < A^{a_1}_\pm \cdots A^{a_n}_\pm > \right)$$

Schwinger-Dyson equations for correlators of Reggeons

- Taking derivative with respect to currents:

$$< \frac{\delta \Gamma[A]}{\delta A_{\pm}^{a_1}} A_{\pm}^{a_2} - \imath \, \delta^{a_1 \, a_2} \, \delta_{\pm 1 \, \pm 2} \, \delta(x_{\perp 1} - x_{\perp 2}) >= 0 \, .$$

that provides

$$\partial_{\perp 1}^2 < A_{\pm}^{a_1} A_{\mp}^{a_2} >= - \imath \, \delta^{a_1 \, a_2} \, \delta_{\pm 1 \, \pm 2} \, \delta(x_{\perp 1} - x_{\perp 2}) + \left(K_{b_1}^{a_1} \right)_{\mp}^{\pm} < A_{\pm}^{b_1} A_{\mp}^{a_2} > + \cdots$$

- In general we have:

$$< A_{\pm}^{a} A_{\pm}^{a_1} \cdots A_{\pm}^{a_m} >= \sum_{n=1} \left(\hat{K}(\eta) \right)^{a \, b_1 \cdots b_n} < A_{\pm}^{b_1} \cdots A_{\pm}^{b_n} A_{\pm}^{a_1} \cdots A_{\pm}^{a_m} >$$

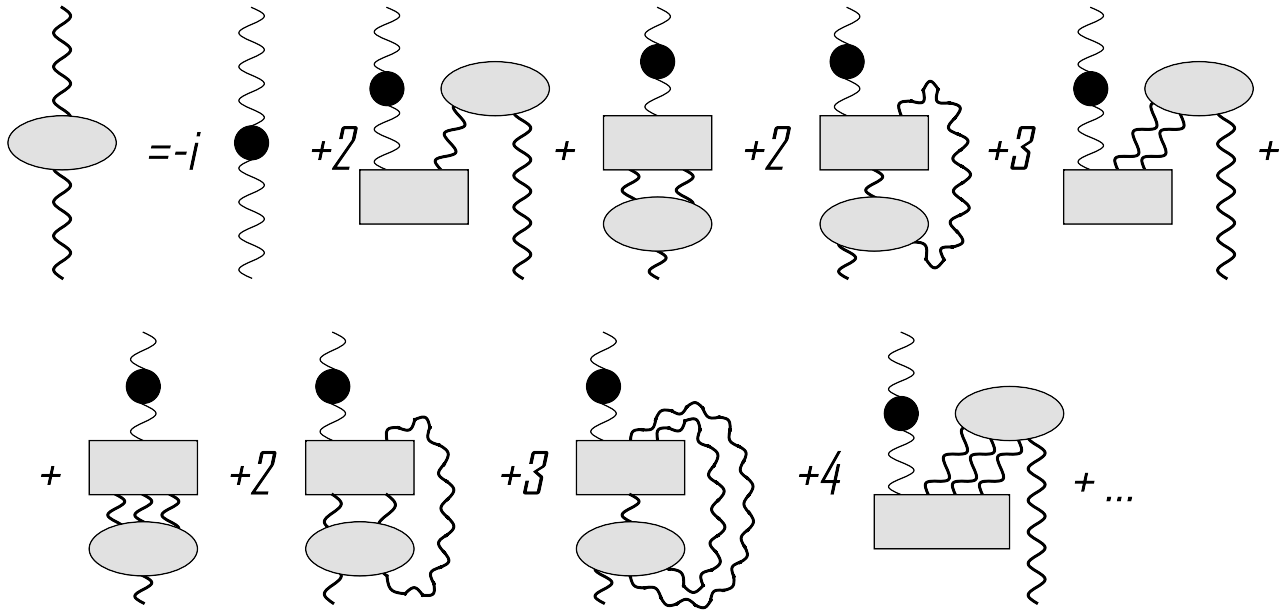
or in the form of evolution equation:

$$\frac{\partial}{\partial \eta} < A_{\pm}^{a} A_{\pm}^{a_1} \cdots A_{\pm}^{a_m} >= \frac{\delta}{\delta \eta} \sum_{n=1} \left(\hat{K}(\eta) \right)^{a \, b_1 \cdots b_n} < A_{\pm}^{b_1} \cdots A_{\pm}^{b_n} A_{\pm}^{a_1} \cdots A_{\pm}^{a_m} >$$

Schwinger-Dyson equations for correlators of two Reggeons

- For two Reggeon fields correlator we have:

$$
\begin{aligned}
\partial_\perp^2 < \mathcal{B}_+^{a} \mathcal{B}_-^{a_1} > &= -\imath\, \delta^{a a_1} + (K_{a}^{\ a_2})_-^+ < \mathcal{B}_+^{a_2} \mathcal{B}_-^{a_1} > + 2\, (K_{a\, a_2})_{--} < \mathcal{B}_-^{a_2} \mathcal{B}_-^{a_1} > + \\
+ \quad & (K_{a}^{\ a_2\, a_3})_-^{++} < \mathcal{B}_+^{a_3} \mathcal{B}_+^{a_2} \mathcal{B}_-^{a_1} > + 2\, (K_{a\, a_3}^{\ a_2})_{--}^+ < \mathcal{B}_+^{a_2} \mathcal{B}_-^{a_3} \mathcal{B}_-^{a_1} > + \\
+ \quad & 3\, (K_{a\, a_2\, a_3})_{---} < \mathcal{B}_-^{a_3} \mathcal{B}_-^{a_2} \mathcal{B}_-^{a_1} > + (K_{a}^{\ a_2\, a_3\, a_4})_-^{+++} < \mathcal{B}_+^{a_2} \mathcal{B}_+^{a_3} \mathcal{B}_+^{a_4} \mathcal{B}_-^{a_1} > + \\
+ \quad & 2\, (K_{a\, a_2}^{\ a_3\, a_4})_{--}^{++} < \mathcal{B}_+^{a_3} \mathcal{B}_+^{a_4} \mathcal{B}_-^{a_2} \mathcal{B}_-^{a_1} > + 3\, (K_{a\, a_2\, a_3}^{\ a_4})_{---}^+ < \mathcal{B}_+^{a_4} \mathcal{B}_-^{a_3} \mathcal{B}_-^{a_2} \mathcal{B}_-^{a_1} > + \\
+ \quad & 4\, (K_{a\, a_2\, a_3\, a_4})_{----} < \mathcal{B}_-^{a_4} \mathcal{B}_-^{a_3} \mathcal{B}_-^{a_2} \mathcal{B}_-^{a_1} > + \cdots
\end{aligned}
$$



QCD propagator of reggeized gluons

- "Usual" reggeized correlator (two first terms in r.h.s. of above expression):

$$\partial_\perp^2 \; < A_+^a \, A_-^{a_1} > = \; - \imath \, \delta^{\, a a_1} \; + \; (K_a^{\; a_2})_-^+ \; < A_+^{a_2} \, A_-^{a_1} >$$

or in terms of propagator

$$< A_+^a(x^+, x_\perp) A_-^b(y^-, y_\perp) > = \; \imath \, \delta(x^+) \, \delta(y^-) \, \delta^{ab} \, D(x_\perp, y_\perp)$$

$$D_{xy}^{ac} \; = \; D_{xy\,0}^{ac} \; - \int d^4 z \int d^4 w \, D_{xz\,0}^{ab} \left(\sum_{k=1} K_{zw\,k}^{bd} \right) D_{wy}^{dc}$$

The equation after Fourier transform:

$$\tilde{D}^{ab}(p_\perp, \eta) \; = \; \frac{\delta^{ab}}{p_\perp^2} \; + \; \epsilon(p_\perp^2) \int_0^\eta d\eta' \; \tilde{D}^{ab}(p_\perp, \eta')$$

$$\tilde{D}^{ab}(p_\perp, \eta) \; = \; \frac{\delta^{ab}}{p_\perp^2} \, e^{\, \eta \, \epsilon(p_\perp^2)} \, , \quad \epsilon(p_\perp^2) \; = \; - \frac{\alpha_s \, N}{4 \, \pi^2} \int d^2 k_\perp \, \frac{p_\perp^2}{k_\perp^2 \; (\, p_\perp \; - \; k_\perp \,)^2}$$

One loop RFT (bare QCD) propagator of reggeized gluons

- We can take into account LO RFT contribution to the propagator with bare QCD vertices:

$$\left(K^{abc}_{xyz}\right)^{++-}_{0} = \frac{1}{2}\, g\, f^{abc} \left(\tilde{G}^{+\,0}_{x^+\,y^+} - \tilde{G}^{+\,0}_{y^+\,x^+}\right) \delta^2(z_\perp - x_\perp)\, \delta^2(z_\perp - y_\perp)\, \partial^2_{i\,z}$$

$$\left(K^{abc}_{xyz}\right)^{+--}_{0} = -\, g\, f^{abc} \left(\tilde{G}^{-\,0}_{y^-\,z^-} - \tilde{G}^{-\,0}_{z^-\,y^-}\right) \delta^2(y_\perp - x_\perp)\, \delta^2(z_\perp - x_\perp)\, \partial^2_{i\,x}$$

obtaining

$$\begin{aligned}
&\partial^2_{\perp\,x} < A^a_+(x^+, x_\perp) A^{a_1}_-(y^-, y_\perp) > = -\imath\, \delta^{a a_1}\, \delta(x^+)\, \delta(y^-)\, \delta^2(x_\perp - y_\perp) \; + \\
+ \quad & \int d^2 z_\perp \int dz_1^+ d^2 z_{1\perp} \\
& K^{b_1 b_2 a}_{++-}(x^+, z_\perp; z_1^+, z_{1\perp}; x_\perp) \; < A^{b_1}_+(x^+, z_\perp) A^{b_2}_+(z_1^+, z_{1\perp}) A^{a_1}_-(y^-, y_\perp) > \; + \\
+ \quad & \int d^2 z_\perp \int dz_1^- d^2 z_{1\perp} \\
& K^{b_1 b_2 a}_{+--}(z_\perp; z_1^-, z_{1\perp}; x^-, x_\perp) < A^{b_1}_+(x^+, z_\perp) A^{b_2}_-(z_1^-, z_{1\perp}) A^{a_1}_-(y^-, y_\perp) >
\end{aligned}$$

One loop RFT (bare QCD) propagator of reggeized gluons

- Have to consider 4-d Regeon fields:

$$A_+(x^+, x_\perp) \to \mathcal{B}_+(x^+, x^-, x_\perp) = A_+(x^+, x_\perp) + \mathcal{D}_+(x^+, x^-, x_\perp)$$

$$A_-(x^-, x_\perp) \to \mathcal{B}_-(x^+, x^-, x_\perp) = A_-(x^-, x_\perp) + \mathcal{D}_-(x^+, x^-, x_\perp)$$

$$\mathcal{D}_+(x^+, x^- = 0, x_\perp) = \mathcal{D}_-(x^+ = 0, x^-, x_\perp) = 0$$

that provides:

$$\partial^2_{\perp\, x} < \mathcal{D}^a_+(x^+, x^-, x_\perp) A^{a_1}_-(y^-, y_\perp) > = \int d^2 z_\perp \int dz_1^+ d^2 z_{1\perp}$$

$$K^{b_1 b_2 a}_{++-}(x^+, z_\perp; z_1^+, z_{1\perp}; x_\perp) < A^{b_1}_+(x^+, z_\perp) A^{b_2}_+(z_1^+, z_{1\perp}) A^{a_1}_-(y^-, y_\perp) > +$$

$$+ \int d^2 z_\perp \int dz_1^- d^2 z_{1\perp}$$

$$K^{b_1 b_2 a}_{+--}(z_\perp; z_1^-, z_{1\perp}; x^-, x_\perp) < A^{b_1}_+(x^+, z_\perp) A^{b_2}_-(z_1^-, z_{1\perp}) A^{a_1}_-(y^-, y_\perp) >$$

One loop RFT (bare QCD) propagator of reggeized gluons

- Three field correlator:

$$\partial^2_{\perp\, x} < A^a_+(x^+, x_\perp) A^{a_1}_+(y^+, y_\perp) A^{a_2}_-(z^-, z_\perp) > =$$
$$\int d^2 w_\perp dw_1^- d^2 w_{1\perp} K^{a_4 a a_3}_{+--}(w_\perp; x^-, x_\perp; w_1^-, w_{1\perp})$$
$$< A^{a_4}_+(x^+, w_\perp) A^{a_1}_+(y^+, y_\perp) A^{a_2}_-(z^-, z_\perp) A^{a_3}_-(w_1^-, w_{1\perp}) >$$

and four field correlator

$$\begin{aligned} & < A^{a_4}_+(x^+, w_\perp) A^{a_1}_+(y^+, y_\perp) A^{a_2}_-(z^-, z_\perp) A^{a_3}_-(w_1^-, w_{1\perp}) > = \\ = \quad & \imath \delta^{a_4 a_3} \delta(x^+) \delta(w_1^-) D_0(w_\perp, w_{1\perp}) < A^{a_1}_+ A^{a_2}_- > + \\ + \quad & \imath \delta^{a_4 a_2} \delta(x^+) \delta(z^-) D_0(w_\perp, z_\perp) < A^{a_1}_+ A^{a_3}_- > \end{aligned}$$

we obtain

$$< A^a_+(x^+, x_\perp) A^{a_1}_+(y^+, y_\perp) A^{a_2}_-(z^-, z_\perp) > = -\imath \int d^2 w_\perp \int dw_1^- d^2 w_{1\perp} \int d^2 w_{2\perp}$$
$$D_0(x_\perp, w_\perp)\, K^{a_2 a a_3}_{+--}(w_{2\perp}; x^-, w_\perp; w_1^-, w_{1\perp})\, D_0(w_{2\perp}, z_\perp)$$
$$< A^{a_1}_+(y^+, y_\perp) A^{a_3}_-(w_1^-, w_{1\perp}) > \delta(x^+)\, \delta(z^-)\,,$$

One loop RFT (bare QCD) propagator of reggeized gluons

- In terms of propagators:

$$< A^a_+(x^+, x_\perp) A^b_-(y^-, y_\perp) > = \imath\, \delta(x^+)\, \delta(y^-)\, \delta^{ab}\, D(x_\perp, y_\perp)$$

$$< \mathcal{D}^a_+(x^+, x^-, x_\perp) A^{a_1}_-(y^-, y_\perp) > = \imath\, \mathcal{G}^{aa_1}_+(x^+, x^-, x_\perp; y^-, y_\perp)\,,$$

finally we obtain

$$\begin{aligned}
& \mathcal{G}^{aa_1}_+(x^+, x^-, x_\perp; y^-, y_\perp) = \\
= \quad & -\frac{\imath}{2}\, g^2\, N\, \delta^{aa_1} \left(\tilde{G}^{+\,0}_{x^+\,0} - \tilde{G}^{+\,0}_{0\,x^+}\right) \left(\tilde{G}^{-\,0}_{x^-\,0} - \tilde{G}^{-\,0}_{0\,x^-}\right) \left(D_0(x_\perp, y_\perp)\, D(x_\perp, y_\perp) - \right. \\
- \quad & \int d^2 w_\perp \int d^2 z_\perp\, D_0(x_\perp, z_\perp) \left(\partial^2_{iz}\, \partial^2_{iw}\, D_0(z_\perp, w_\perp)\right) D_0(w_\perp, z_\perp)\, D(w_\perp, y_\perp) - \\
- \quad & \left. \int d^2 w_\perp \int d^2 z_\perp D_0(x_\perp, z_\perp) \left(\partial^2_{iz} \partial^2_{iw} D_0(z_\perp, w_\perp)\right) D_0(w_\perp, y_\perp) D(w_\perp, z_\perp) \right) \delta(x^+) \delta(y^-)
\end{aligned}$$

The only first term provides non-zero contribution.

One loop RFT (bare QCD) propagator of reggeized gluons

- We have introducing rapidity variable $y = \frac{1}{2}\ln(\Lambda k_+)$

$$\tilde{\mathcal{G}}_+^{aa_1}(p_+, p_\perp; x^-; \eta) = g^2\, N \delta^{aa_1} \left(\tilde{G}^{-\,0}_{x^-\,0} - \tilde{G}^{-\,0}_{0\,x^-}\right) \int \frac{dy}{2\pi} \int \frac{d^2k_\perp}{(2\pi)^2} \frac{e^{(\eta - y)\epsilon(k_\perp^2)}}{k_\perp^2\,(p_\perp - k_\perp)^2}$$

and taking $\eta \to Y = Y = \ln(s/s_0)$ we obtain:

$$\tilde{\mathcal{G}}_+^{aa_1}(p_+, p_\perp; x^-; Y) = \frac{g^2 N}{4\pi^3} \delta^{aa_1} \left(\tilde{G}^{-\,0}_{x^-\,0} - \tilde{G}^{-\,0}_{0\,x^-}\right) \int d^2k_\perp \frac{\left(e^{\epsilon(k_\perp^2)Y} - 1\right)}{k_\perp^2\,(p_\perp - k_\perp)^2 \epsilon(k_\perp^2)}$$

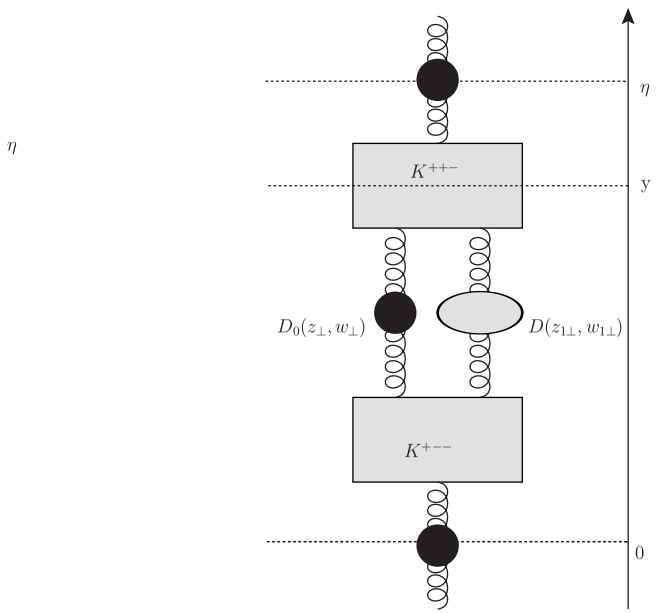
that after the integration on k provides:

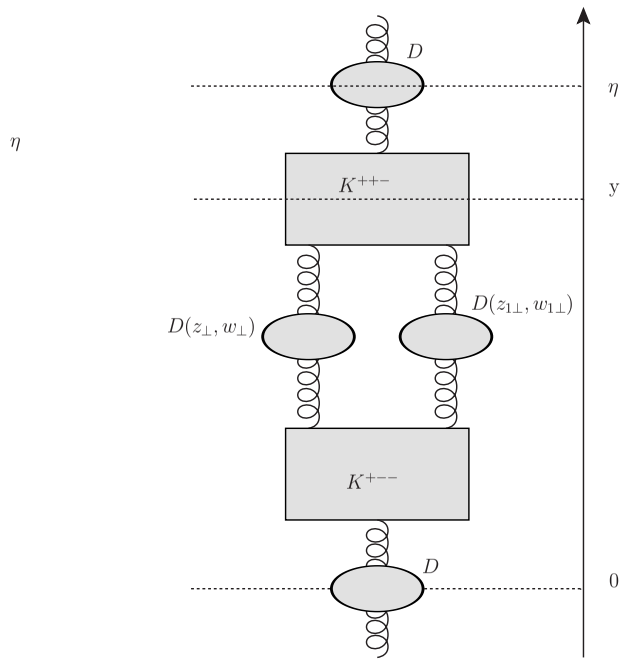
$$\tilde{\mathcal{G}}_+^{aa_1}(p_+, p_\perp; x^-; Y) = \frac{2\,\delta^{aa_1}}{p_\perp^2} \left(1 - e^{\epsilon(p_\perp^2)\,Y} - \int_0^{-\,\epsilon(p_\perp^2)\,Y} \frac{dy}{y}\left(e^{-y} - 1\right)\right) \left(\tilde{G}^{-\,0}_{x^-\,0} - \tilde{G}^{-\,0}_{0\,x^-}\right)$$

One loop RFT propagator of reggeized gluons with one loop QCD correction

- Including one QCD loop in all the correlators:

$$\tilde{\mathcal{G}}_{+}^{a a_1}(p_+, p_\perp; x^-; Y) = \frac{2\,\delta^{a a_1}}{p_\perp^2}\left(e^{\epsilon(p_\perp^2)\,Y} - e^{2\,\epsilon(p_\perp^2)\,Y} - \int_{-\epsilon(p_\perp^2)\,Y}^{-2\,\epsilon(p_\perp^2)\,Y} \frac{dy}{y}\left(e^{-y} - 1\right)\right)\left(\tilde{G}^{-\,0}_{x^-\,0} - \tilde{G}^{-\,0}_{0\,x^-}\right)$$





Conclusion:

- Lipatov's effective action provides systematical calculations of unitary corrections to the scattering amplitudes at high energy in the framework of the QCD RFT;

Conclusion:

- Lipatov's effective action provides systematical calculations of unitary corrections to the scattering amplitudes at high energy in the framework of the QCD RFT;
- First source of the corrections are QCD loops contributions to the vertices of the effective action;

Conclusion:

- Lipatov's effective action provides systematical calculations of unitary corrections to the scattering amplitudes at high energy in the framework of the QCD RFT;
- First source of the corrections are QCD loops contributions to the vertices of the effective action;
- Additional source of the unitary corrections are the Regge Field Theory (RFT) loop's contributions. Lipatov's effective action can be considered as QCD variant of RFT and provides the base for these RFT calculations;

Conclusion:

- Lipatov's effective action provides systematical calculations of unitary corrections to the scattering amplitudes at high energy in the framework of the QCD RFT;
- First source of the corrections are QCD loops contributions to the vertices of the effective action;
- Additional source of the unitary corrections are the Regge Field Theory (RFT) loop's contributions. Lipatov's effective action can be considered as QCD variant of RFT and provides the base for these RFT calculations;
- Formulated as RFT, the Lipatov's effective action provides non-linear unitary corrections to the correlators of Reggeon fields on the base of Dyson-Schwinger hierarchy of equations for the correlators (similar to Balitsky hierarchy) ;

Conclusion:

- Lipatov's effective action provides systematical calculations of unitary corrections to the scattering amplitudes at high energy in the framework of the QCD RFT;
- First source of the corrections are QCD loops contributions to the vertices of the effective action;
- Additional source of the unitary corrections are the Regge Field Theory (RFT) loop's contributions. Lipatov's effective action can be considered as QCD variant of RFT and provides the base for these RFT calculations;
- Formulated as RFT, the Lipatov's effective action provides non-linear unitary corrections to the correlators of Reggeon fields on the base of Dyson-Schwinger hierarchy of equations for the correlators (similar to Balitsky hierarchy) ;
- These non-linear corrections are not small and violate the reggeization of usual QCD propagator of reggeized gluons;

Conclusion:

- Lipatov's effective action provides systematical calculations of unitary corrections to the scattering amplitudes at high energy in the framework of the QCD RFT;
- First source of the corrections are QCD loops contributions to the vertices of the effective action;
- Additional source of the unitary corrections are the Regge Field Theory (RFT) loop's contributions. Lipatov's effective action can be considered as QCD variant of RFT and provides the base for these RFT calculations;
- Formulated as RFT, the Lipatov's effective action provides non-linear unitary corrections to the correlators of Reggeon fields on the base of Dyson-Schwinger hierarchy of equations for the correlators (similar to Balitsky hierarchy) ;
- These non-linear corrections are not small and violate the reggeization of usual QCD propagator of reggeized gluons;
- There are interesting problems concerning the structure of Pomeron and properties of QCD RFT as field theory and etc.

One loop RFT propagator of reggeized gluons with one loop QCD correction

- Part of one-loop triple Reggeon vertex:

$$
\begin{aligned}
& -2\,\imath\, K^{a\,b\,c}_{x\,y\,z\,1,\,2} = \\
= \quad & -\frac{\imath\, g^3\, N}{2\,(2\pi)^5}\, f_{abc}\, \partial^2_{i\,y} \\
& \left(\theta(z^+ - x^+) \delta^2_{x_\perp\, y_\perp} \int \frac{dk_-}{k_-} \int d^2k_\perp \int d^2k_{1\perp} \frac{k^2_{1\perp}}{k^2_\perp\, (k_\perp - k_{1\perp})^2}\, e^{-\imath\,(x^i - z^i) k_{1\,i}} \right) + \\
+ \quad & \frac{\imath\, g^3\, N}{2\,(2\pi)^5}\, f_{abc}\, \partial^2_{i\,y} \\
& \left(\theta(x^+ - z^+)\, \delta^2_{z_\perp\, y_\perp} \int \frac{dk_-}{k_-} \int d^2k_\perp \int d^2k_{1\perp} \frac{k^2_{1\perp}}{k^2_\perp\, (k_\perp - k_{1\perp})^2}\, e^{-\imath\,(z^i - x^i)\, k_{1\,i}} \right)
\end{aligned}
$$