Correspondence between Color Glass Condensate and Higher-Twist Formalism

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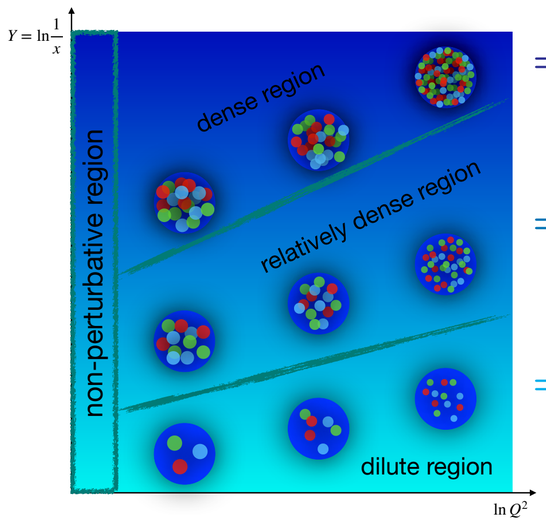
I. Introduction

★ **Anatomy of QCD matter:**



⇒ Color Glass Condensate(**CGC**)
Strong field
BK/JIMWLK evolution

⇒ Higher-Twist(**HT**) formalism
Multiparton correlations
DGLAP type evolution

⇒ Leading twist
Collinear factorization
DGLAP evolution

★ **Motivation:**

▶ Many successes of the HT and CGC were limited to their own domains of validity.

▶ Formalisms should **agree with each other in the overlap region** of validity.

▶There have been tremendous efforts to show the correspondence between CGC and QCD collinear factorization formalism.

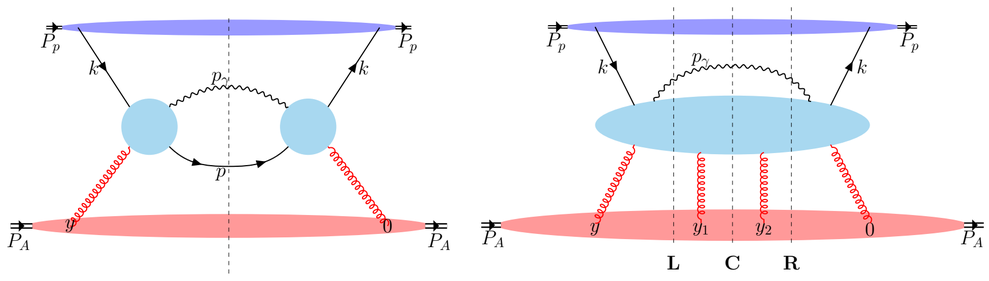
▶ So far, **no consensus has been reached** about the relationship between CGC and HT formalisms.

★ **Goal:**

Clarify the correspondence between CGC and HT formalisms for physical observables using the example of direct photon production.

II. Higher-Twist formalism

• **Direct photon production in HT**:



▷ Leading twist(LT): $E_\gamma \frac{d\sigma^{HT}}{d^3p_\gamma}\big|_{\rm LT} = f_{q/p} \otimes f_{g/A} \otimes H^{(2)}_{q+g\to\gamma+q}$

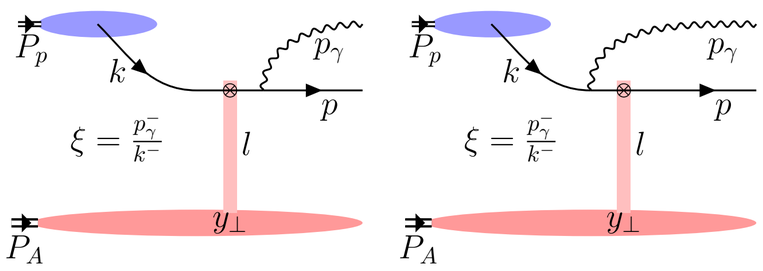
▷ Next-to-leading twist(NLT):

$$E_\gamma \frac{d\sigma^{HT}}{d^3p_\gamma}\big|_{\rm NLT} = f_{q/p} \otimes \left\{ T_{gg}, x\frac{\partial T_{gg}}{\partial x}, x^2\frac{\partial^2 T_{gg}}{\partial x^2} \right\} \otimes H^{(4)}_{q+gg\to\gamma+q}$$

Non-trivial **derivative terms** due to the twist (or power) expansion.

III. Color glass condensate

• **Direct photon production in CGC**:



▷ Final radiation + Initial radiation

$$E_\gamma \frac{d\sigma^{CGC}}{d^3p_\gamma} = f_{q/p}(x_p) \otimes \int d^2l_\perp \frac{l_\perp^2 F(x,l_\perp)}{(\xi l_\perp - p_{\gamma\perp})^2 p_{\gamma\perp}{}^2}$$

Medium properties are encoded in $F(x, l_\perp)$, the **dipole correlator** of Wilson line $V_{ij}(y_\perp) = \mathcal{P}\,\mathbf{exp}\left(ig\int_{-\infty}^{\infty} dy^- A^{+,c}_{\rm cl}(y^-, y_\perp) t^c_{ij}\right)$.

IV. Naive power expansion of CGC

▶ Relation between the gluon correlation and **moment of dipole distribution**:

$$\lim_{x\to 0} T_{gg}(x) = \frac{N_c^2}{2(2\pi)^4\alpha_s^2}\int d^2l_\perp l_\perp^4 F(x, l_\perp)$$

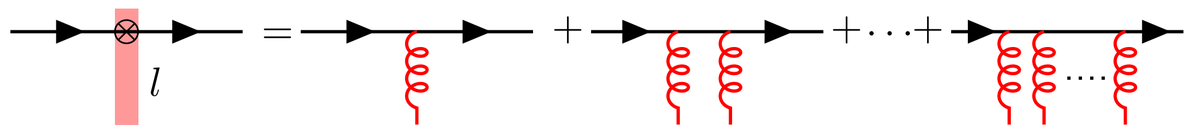
▶ **Direct photon production by power expansion of CGC**:

$$E_\gamma \frac{d\sigma^{CGC}}{d^3p_\gamma}\Big|_{x\to 0} = f_{q/p} \otimes H^{(2)} \otimes \left[x f_{g/A}(x) + \frac{(2\pi)^2\alpha_s}{N_c}\frac{4\xi^2}{p_{\gamma\perp}^2} T_{gg}(x) + \dots \right]_{x\to 0}$$

▶ Can not recover the **derivative terms** in HT at twist-4.

V. Matching between CGC and Higher-Twist

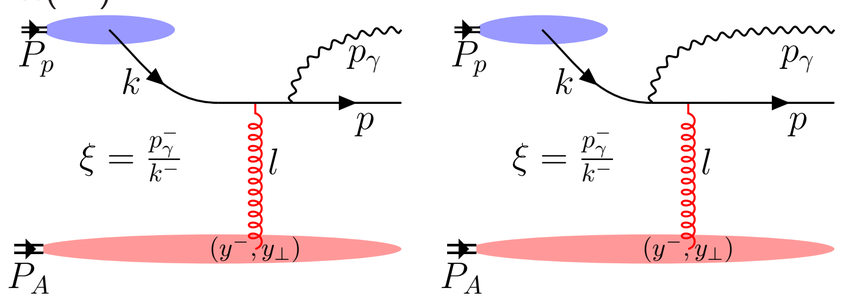
• Expand CGC vertex and bring back **sub-eikonal phase**:



Leading order vertex: $\Gamma(l) \sim \gamma^- \int d^2y_\perp dy^- e^{-il_\perp\cdot y_\perp} e^{il^+y^-} igA^+(y^-, y_\perp)$.

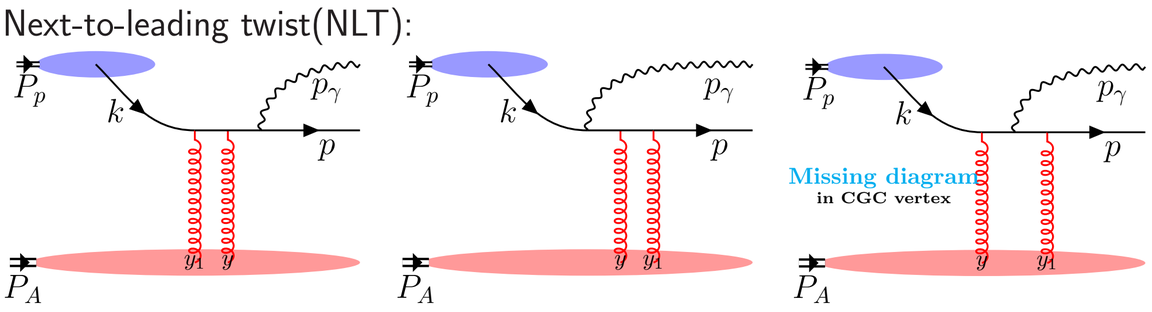
• **Direct photon production in CGC with sub-eikonal phase**:

▷ Leading twist(LT):



Replacing the full CGC vertex by leading order vertex.

▷ Next-to-leading twist(NLT):



"**Missing diagram**" contributes to both initial and final rescattering at twist-4.

▷ The CGC with sub-eikonal phase **matches** to HT at both twist-2 and twist-4:

$$E_\gamma \frac{d\sigma^{\rm CGC_{sub-eik}}}{d^3p_\gamma}\Big|_{\rm LT} = E_\gamma \frac{d\sigma^{HT}}{d^3p_\gamma}\Big|_{\rm LT} \qquad E_\gamma \frac{d\sigma^{\rm CGC_{sub-eik}}}{d^3p_\gamma}\Big|_{\rm NLT} = E_\gamma \frac{d\sigma^{HT}}{d^3p_\gamma}\Big|_{\rm NLT}$$

• **LPM effect**:

▷ "**Missing diagram**" gives phase $\mathbf{1} - e^{i(y^- - y_1^-)/\tau_\gamma}$ with photon formation time $\tau_\gamma \sim x_p P_p^- / p_{\gamma\perp}{}^2$.

▷ At high energy limit, the phase leads to **destructive interference**.

VI. Summary

★ Proved the **consistency between CGC and HT** to twist-4 level.

★ Demonstrated that naive power expansion of CGC only recovers part of the complete HT result at twist-4.

★ Identified two **important missing ingredients in CGC**: sub-eikonal phases and diagrams related to LPM effect.

★ Found the **fourth moment of the dipole distribution** corresponds to twist-4 gluon-gluon correlation function at small-x.

VII. Reference

J.-w. Qiu and G. F. Sterman, Nucl. Phys. B 353, 105(1991). L. D. McLerran and R. Venugopalan, Phys. Rev. D 49,2233(1994). X.-f. Guo and J.-w. Qiu, Phys. Rev. D 53, 6144 (1996). F. Gelis and J. Jalilian-Marian, Phys. Rev. D66, 014021(2002). Y. Fu, Z. Kang, F. Salazar, X.-N. Wang and H. Xing, arXiv:2309.xxxx.

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