Correspondence between CGC and high twist factorization formalisms

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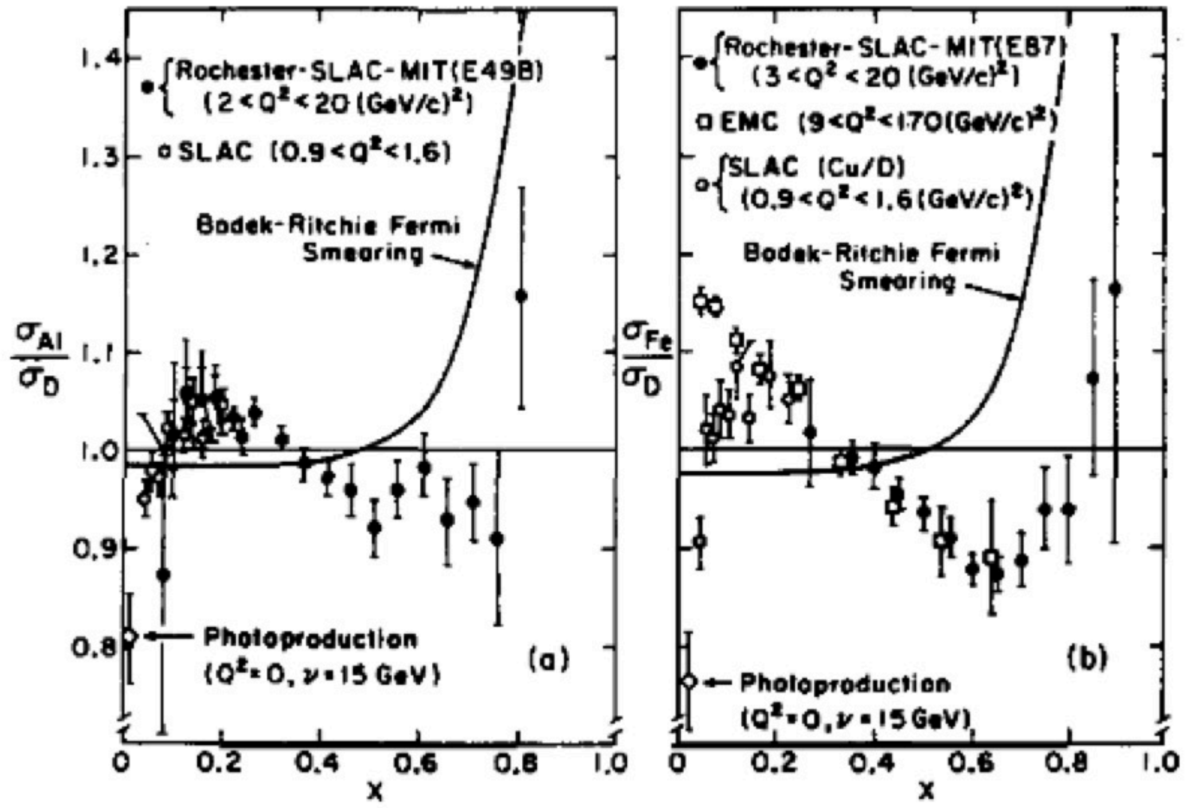
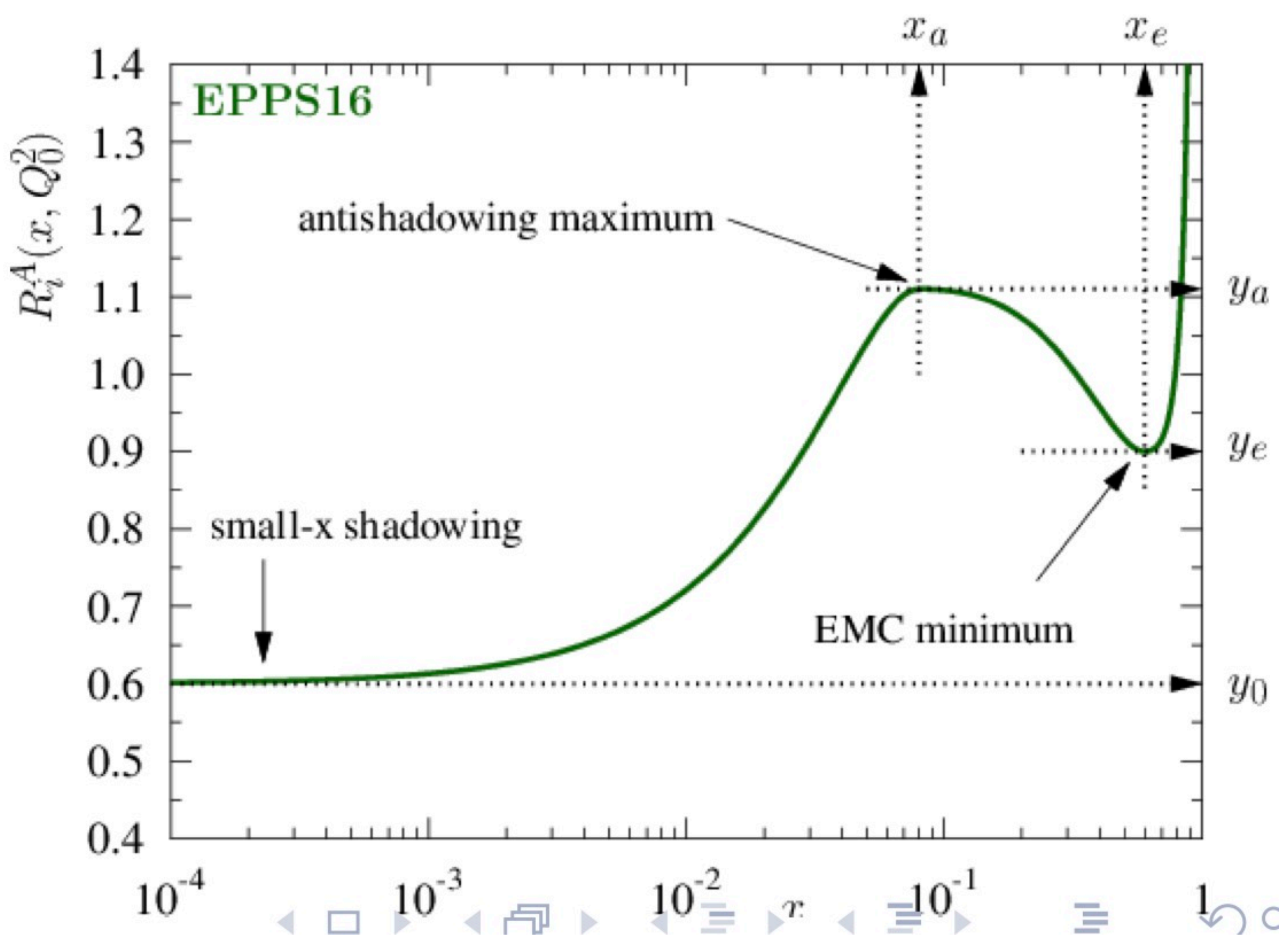
"Old" and long standing problems for cold nuclear matter effect

- Nuclear partonic structure

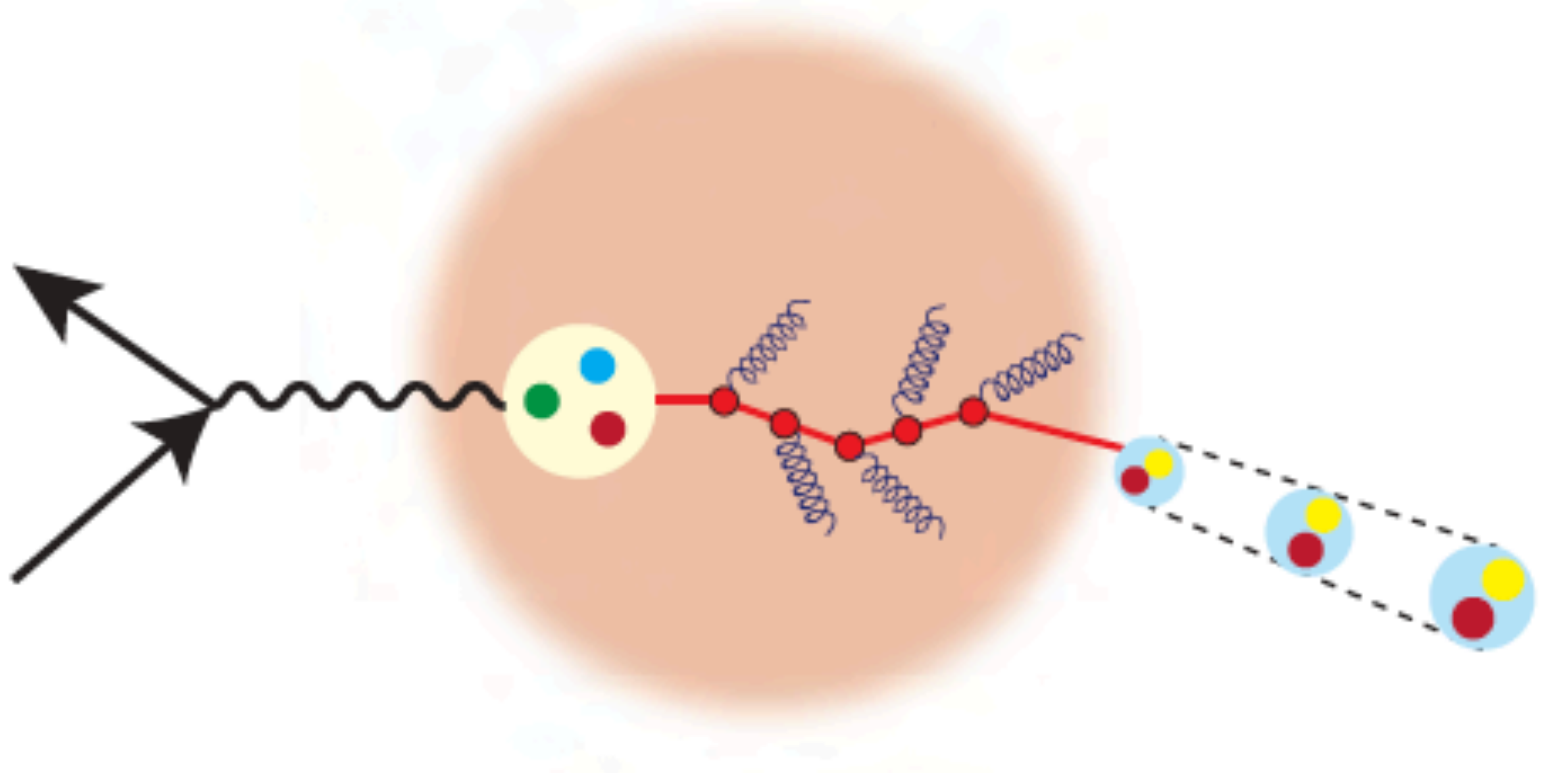
Four Decades of the EMC Effect

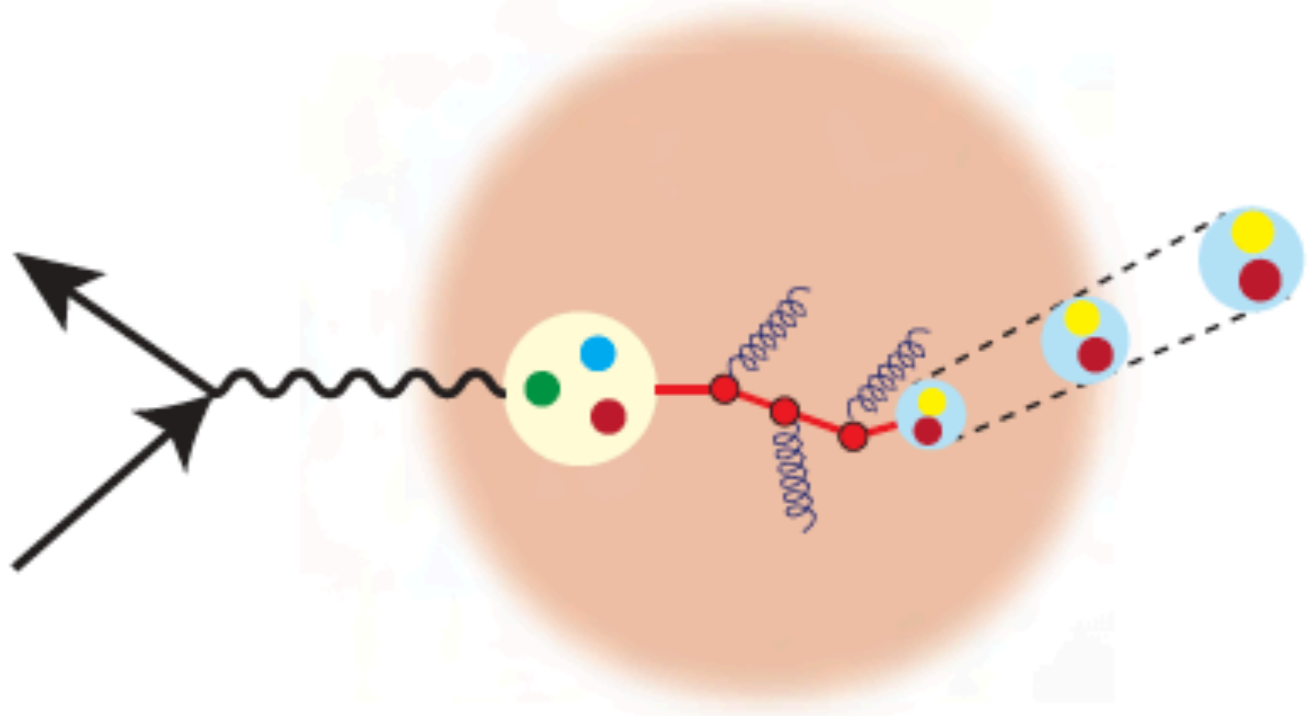




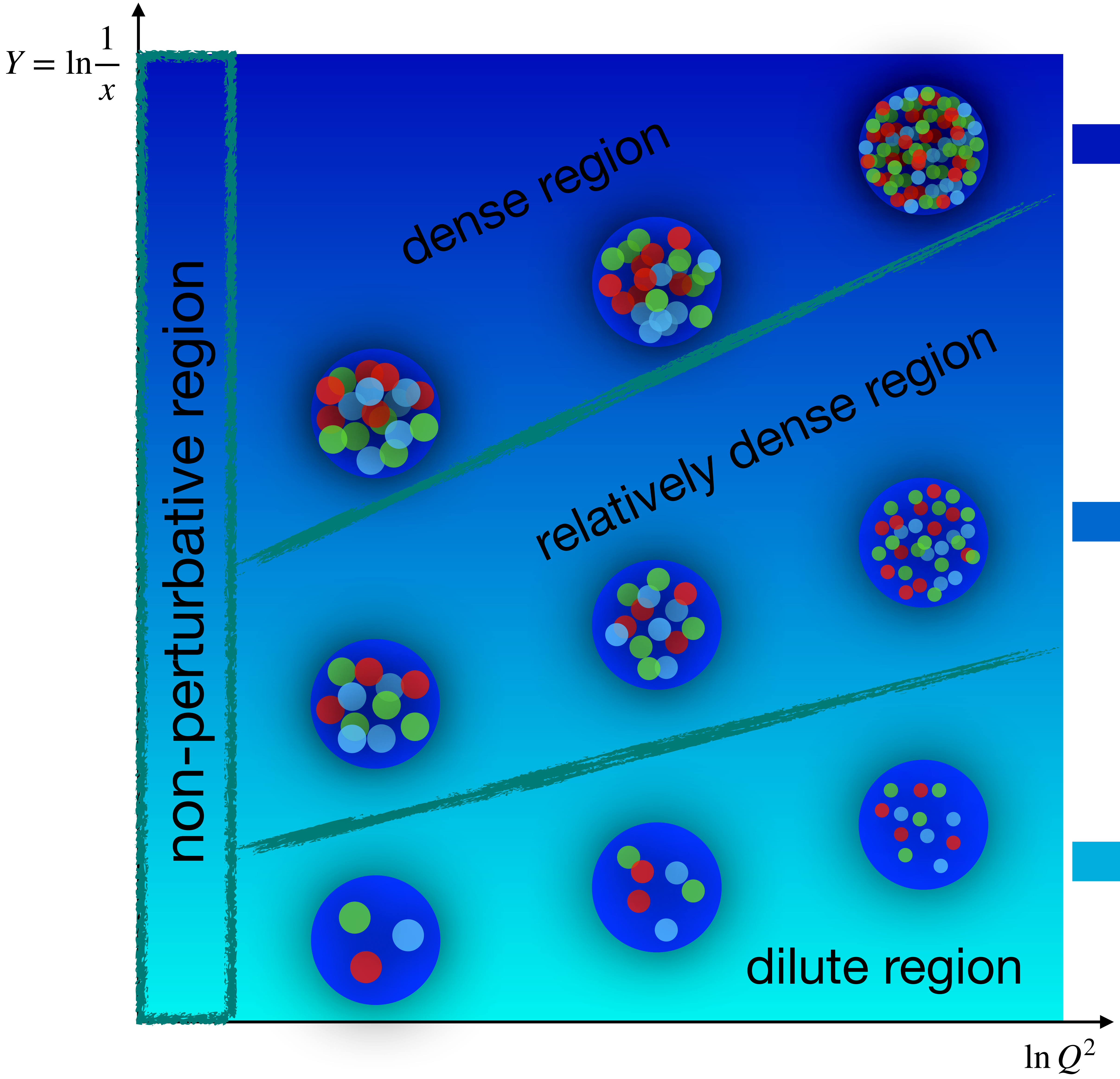
$$R_i^A = \frac{f_{i/A}(x, Q^2)}{f_{i/p}(x, Q^2)}$$

- Quark gluon propagation in nuclear medium





QCD "phase diagram" for nuclei from dilute to dense region



Dense region: $x \ll \mathcal{O}(1)$

Probing length $\lambda \sim 1/xp \gg L \sim A^{1/3}$

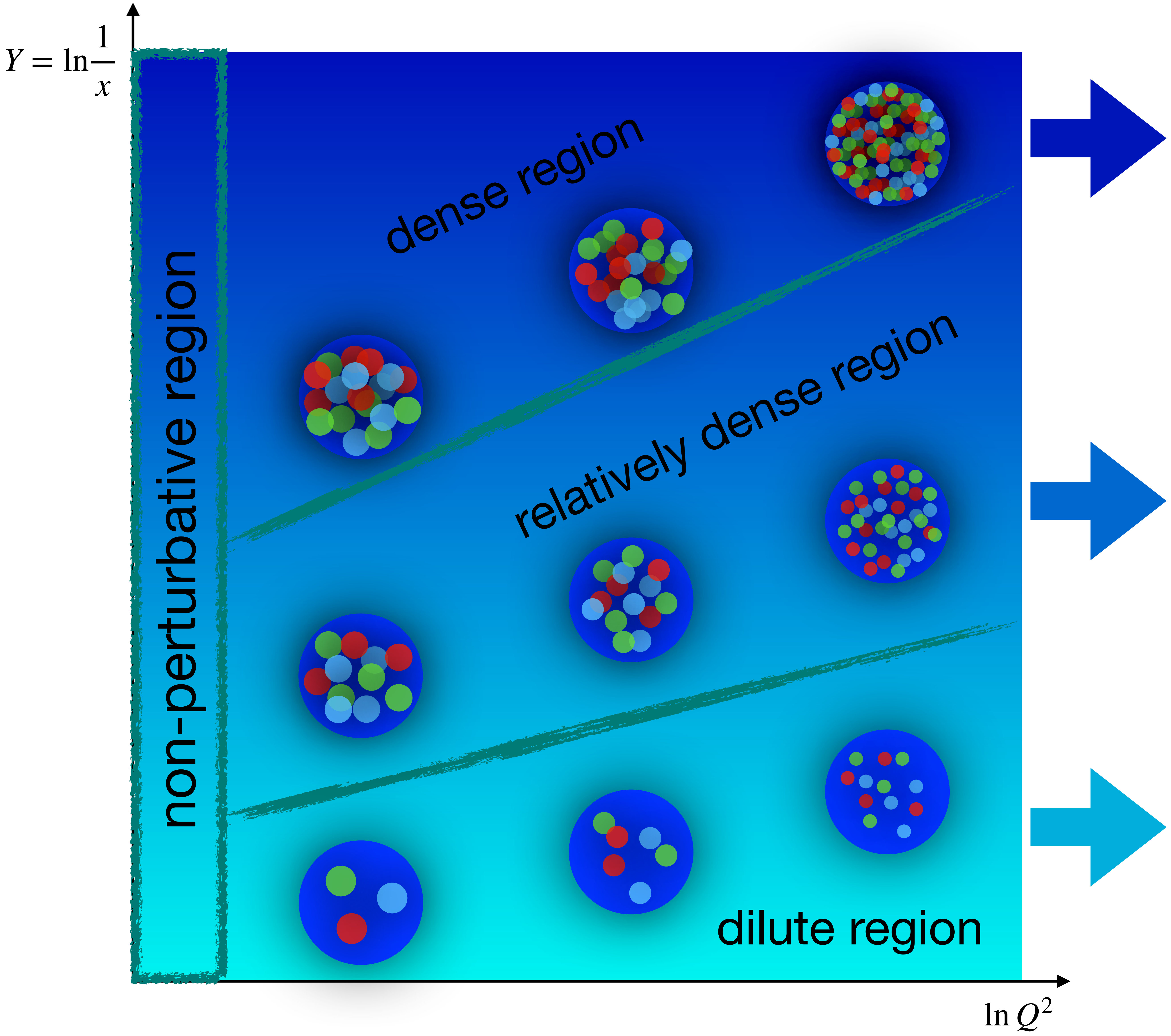
Relatively dense region: $x \lesssim \mathcal{O}(1)$

Probing length $\lambda \sim 1/xp \lesssim L \sim A^{1/3}$

Dilute region: $x \sim \mathcal{O}(1)$

Probing length $\lambda \sim 1/xp \ll L \sim A^{1/3}$

QCD theoretical frameworks from dilute to dense region



Color Glass Condensate (CGC)

Wilson lines, nonlinear BK/JIMWLK evolution

See review: Gelis, Iancu, Venugopalan, 2003

High-twist formalism

Multi-parton correlation, DGLAP-type evolution

Qiu, Stermann, 1991

Kang, Wang, Wang, **Xing**, 2014

Leading twist collinear factorization

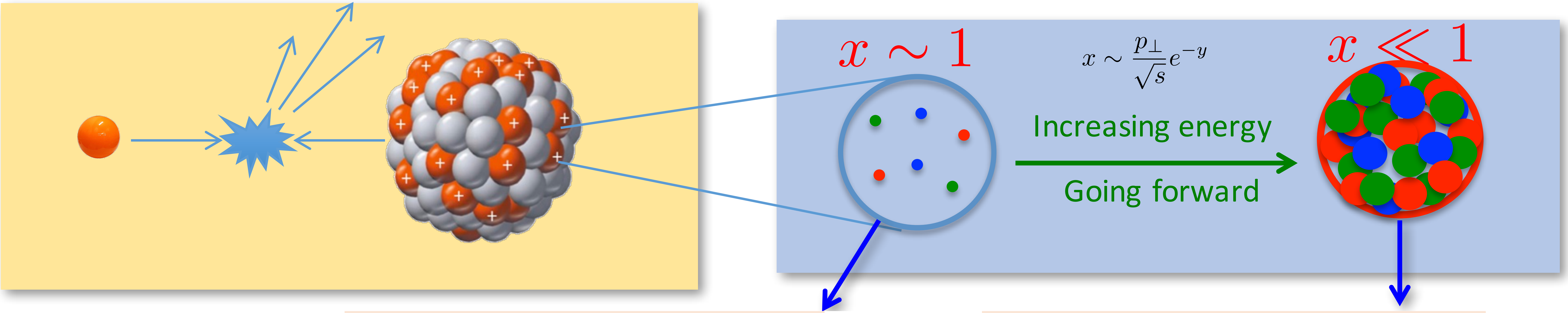
PDF, DGLAP evolution

Collins, Soper, 1981

Scan the phase diagram in proton-nucleus collisions

- Multiple scattering in dilute and dense medium

Probing length: $\lambda \sim \frac{1}{xp}$

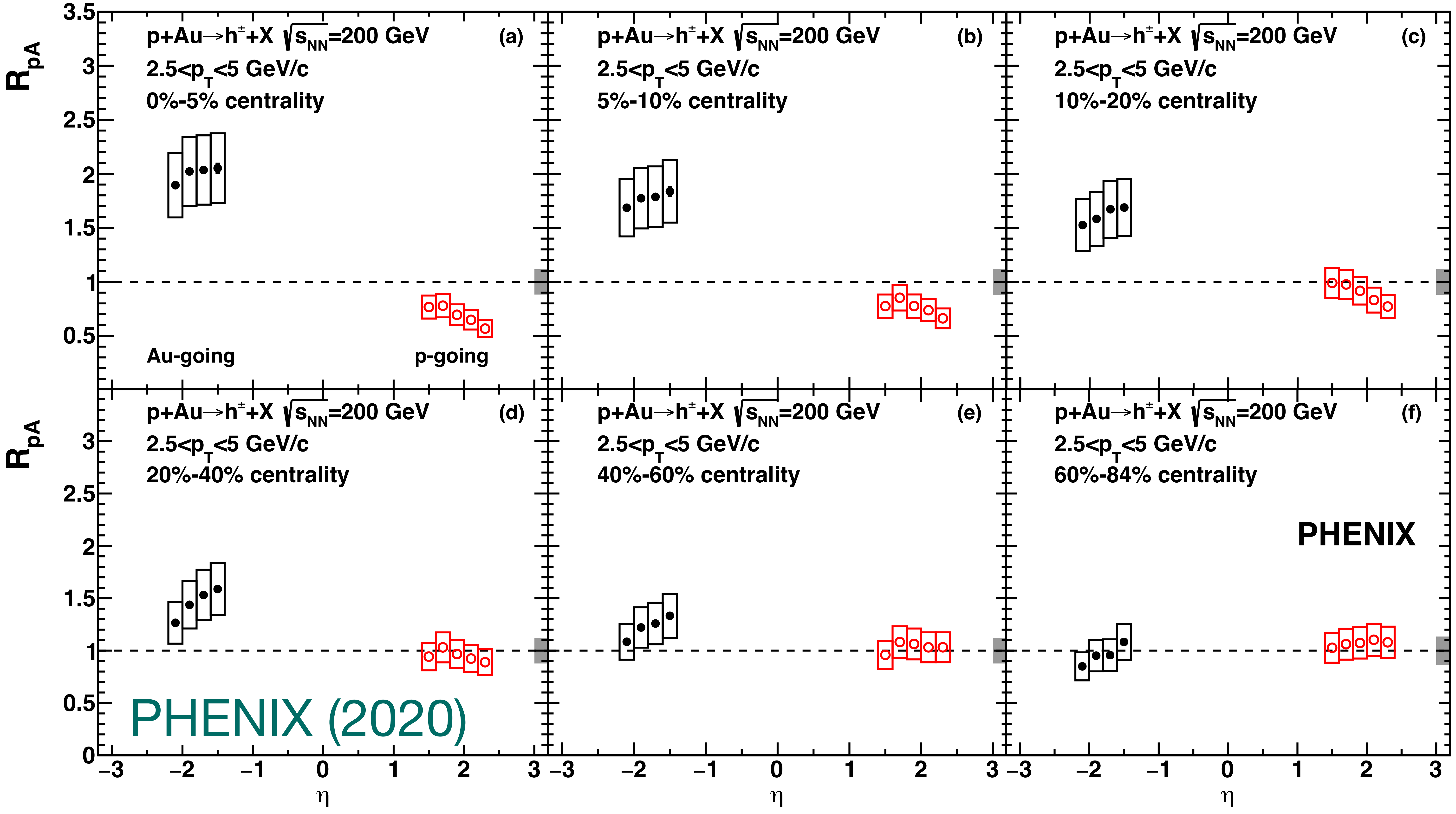


▪ A **dilute** system ▪ Probes interact **independently**	▪ A **dense** system ▪ Probes interact **coherently**

A ← **Backward**   **Forward** → **P**

Scan the phase diagram in proton-nucleus collisions

- Experimental phenomena in dilute and dense medium



Nuclear modification factor

$$R_{pA} = \frac{\sigma_{pA}}{\sigma_{pp}}$$

dilute region: enhancement

dense region: suppression

$$x \sim \frac{p_\perp}{\sqrt{s}} e^{-y}$$

Evidence of CGC?

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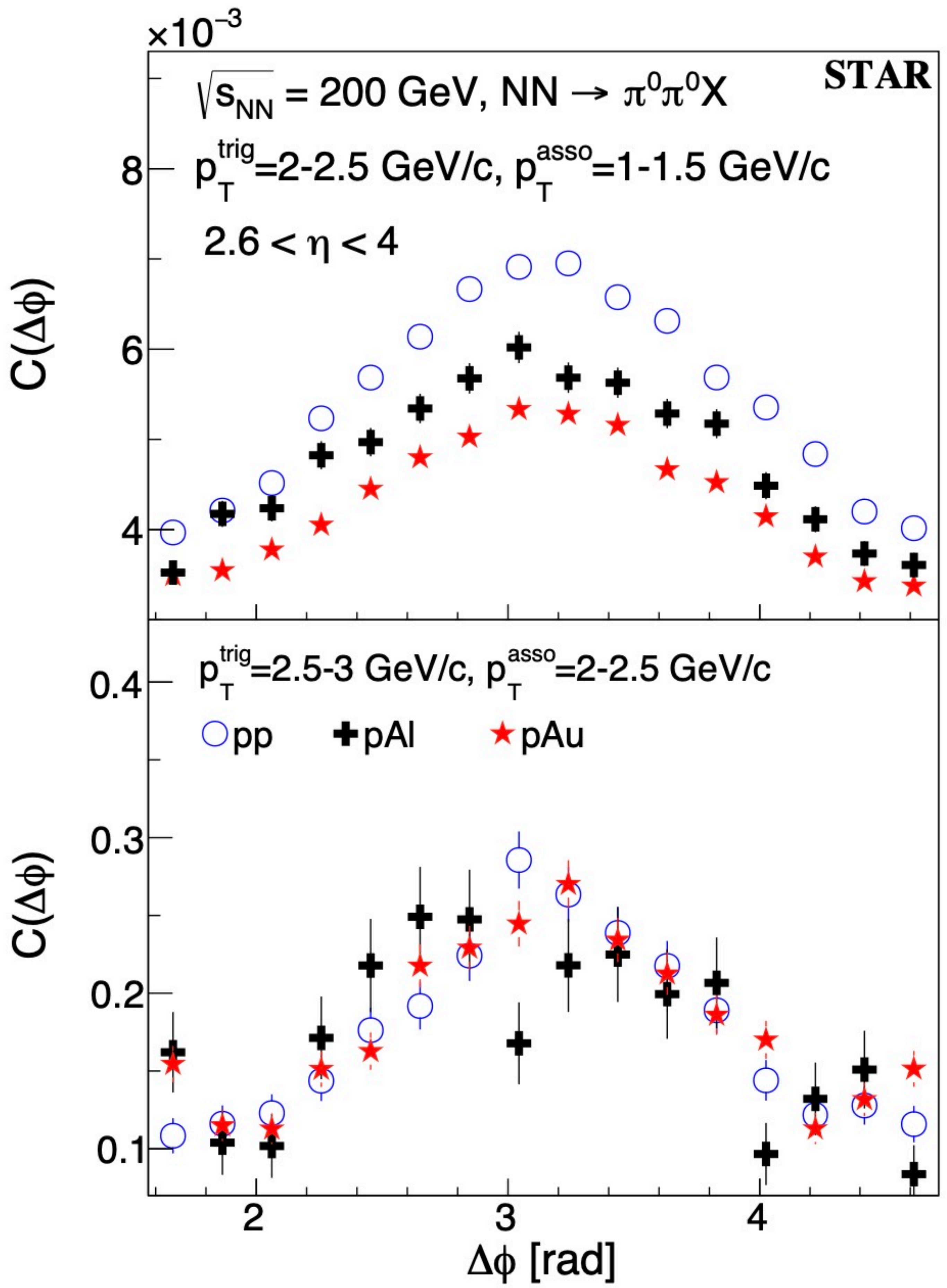
Evidence for Nonlinear Gluon Effects in QCD and Their Mass Number Dependence at STAR

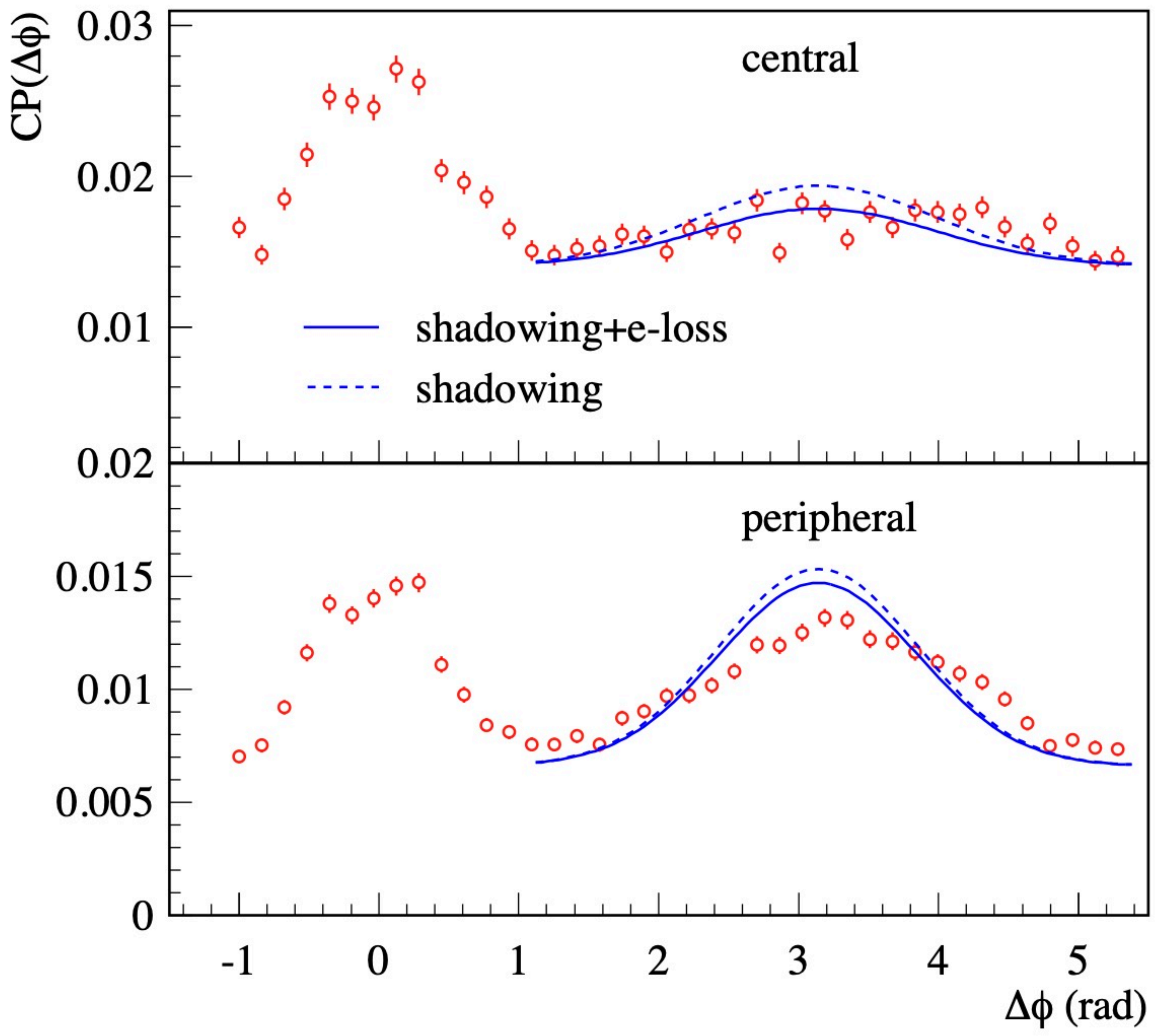
M. S. Abdallah *et al.* (STAR Collaboration)

Phys. Rev. Lett. **129**, 092501 – Published 22 August 2022



Qiu, Vitev, PRL, 2004

Kang, Vitev, **HX**, PRD, 2012



- High-twist calculation also explain the data
- Which framework is correct?

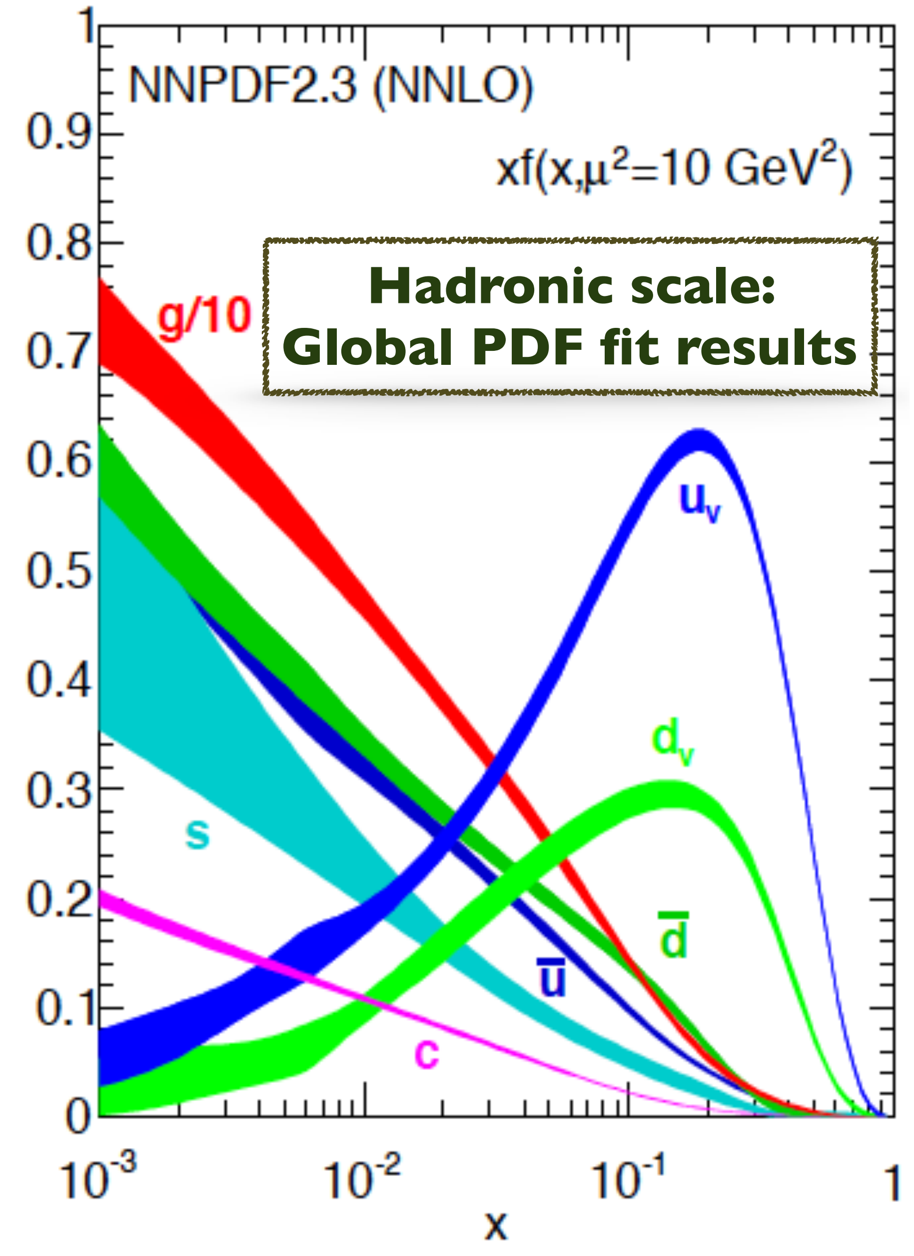
Theoretical framework for multiple scattering expansion

- Generalized factorization theorem

perturbative expansion

Multiple scattering expansion

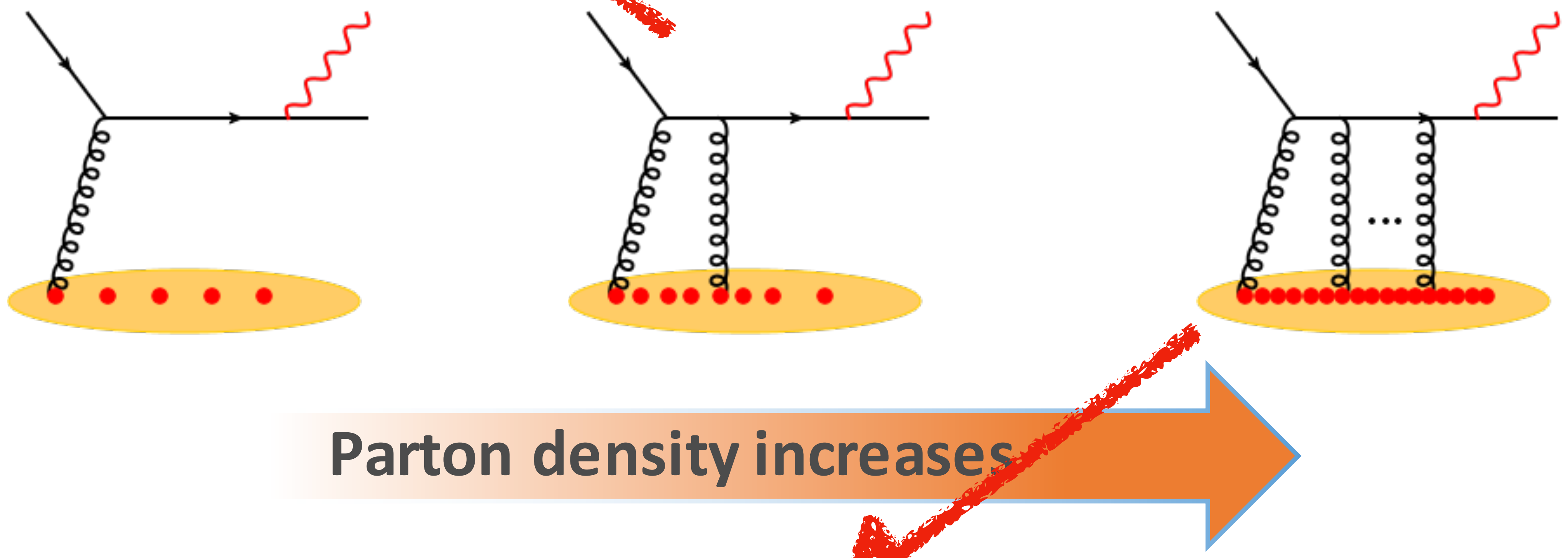
$$
\begin{aligned}
\sigma^h_{phys} = \; & \left[\alpha_s^0 C_2^{(0)} + \alpha_s^1 C_2^{(1)} + \alpha_s^2 C_2^{(2)} + \ldots\right] \otimes T_2(x) \\
& + \frac{1}{Q}\left[\alpha_s^0 C_3^{(0)} + \alpha_s^1 C_3^{(1)} + \alpha_s^2 C_3^{(2)} + \ldots\right] \otimes T_3(x) \\
& + \frac{1}{Q^2}\left[\alpha_s^0 C_4^{(0)} + \alpha_s^1 C_4^{(1)} + \alpha_s^2 C_4^{(2)} + \ldots\right] \otimes T_4(x) \\
& + \ldots
\end{aligned}
$$



twist-4 expansion

- Nuclear enhanced power correction

$$\frac{1}{Q^2} \rightarrow \frac{A^{1/3}}{Q^2}$$

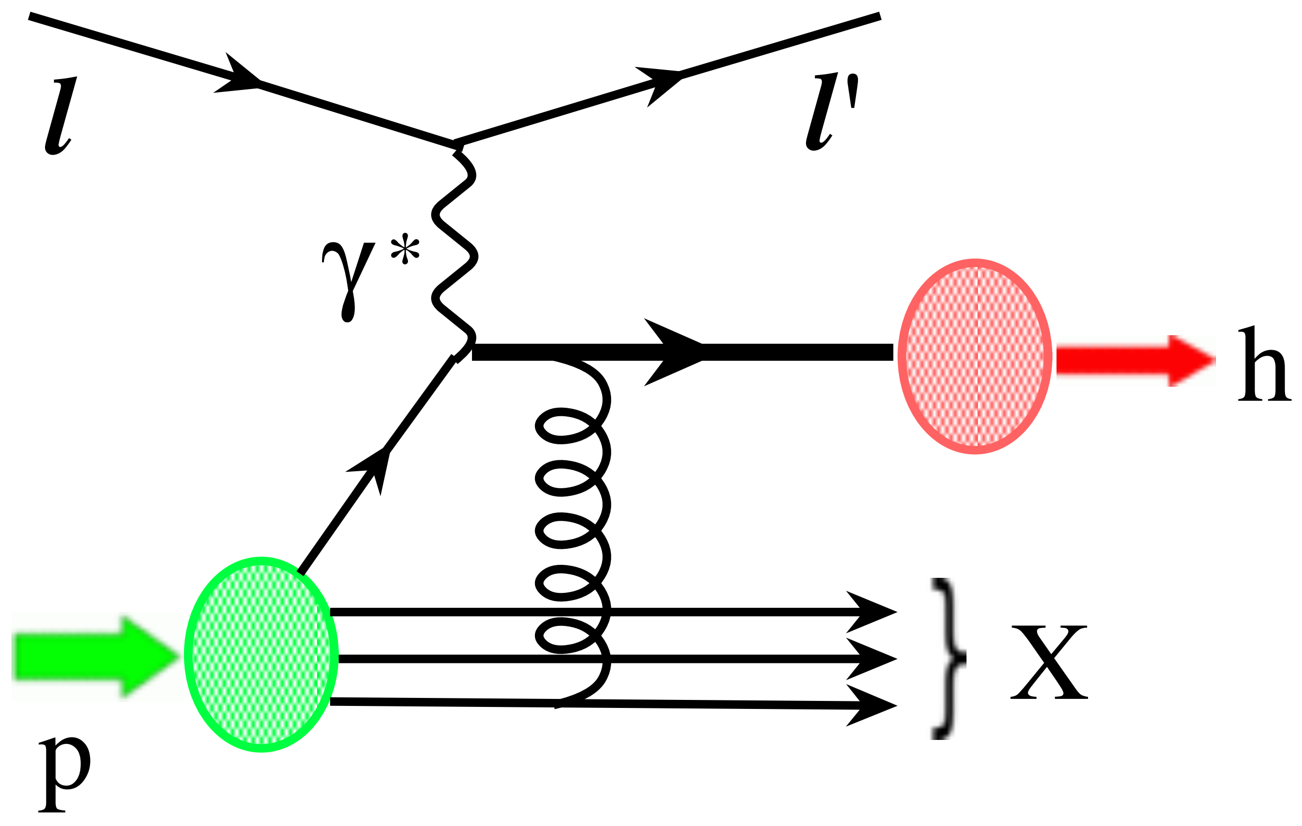


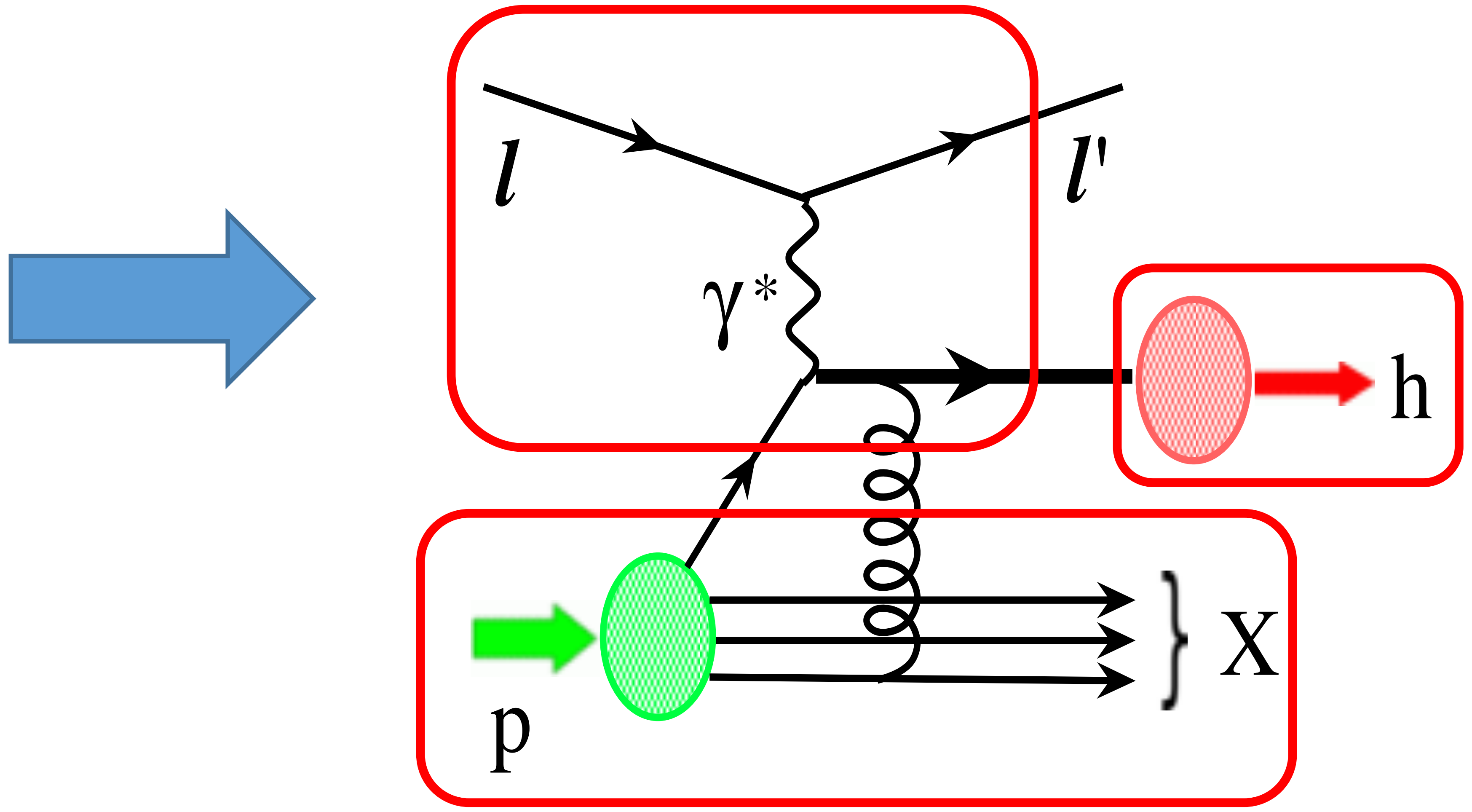
CGC: sum of all multiple scatterings

Incoherent multiple scattering - from dilute to relative dense

- QCD factorization at twist-4

Qiu, Sterman, 1991; Luo, Qiu, Sterman, 1993
Kang, Wang, Wang, **HX,** PRL 2014





$$\frac{d\langle \ell_{hT}^2 \sigma\rangle}{dz_h} \propto D_{q/h}(z,\mu^2)\otimes H^{LO}(x,z)\otimes T_{qg}(x,0,0,\mu^2)$$
$$+\frac{\alpha_s}{2\pi}D_{q/h}(z,\mu^2)\otimes H^{NLO}(x,z,\mu^2)\otimes T_{qg(gg)}(x,0,0,\mu^2)$$

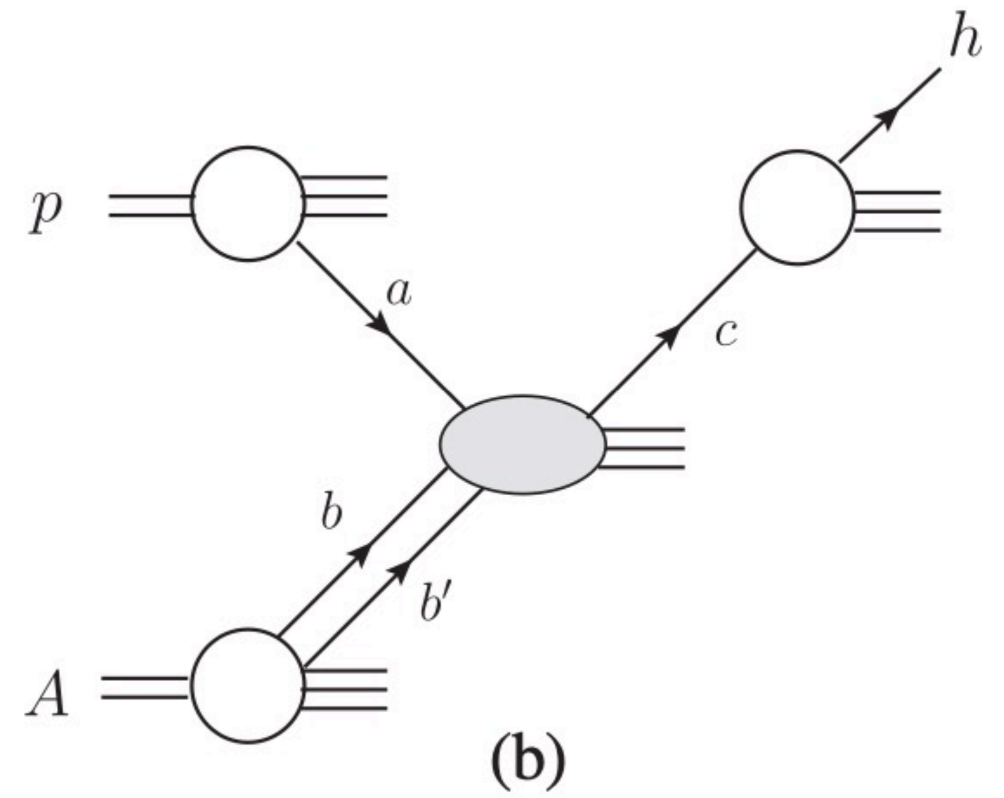
Multiple scattering hard probe and medium properties can be factorized!!!

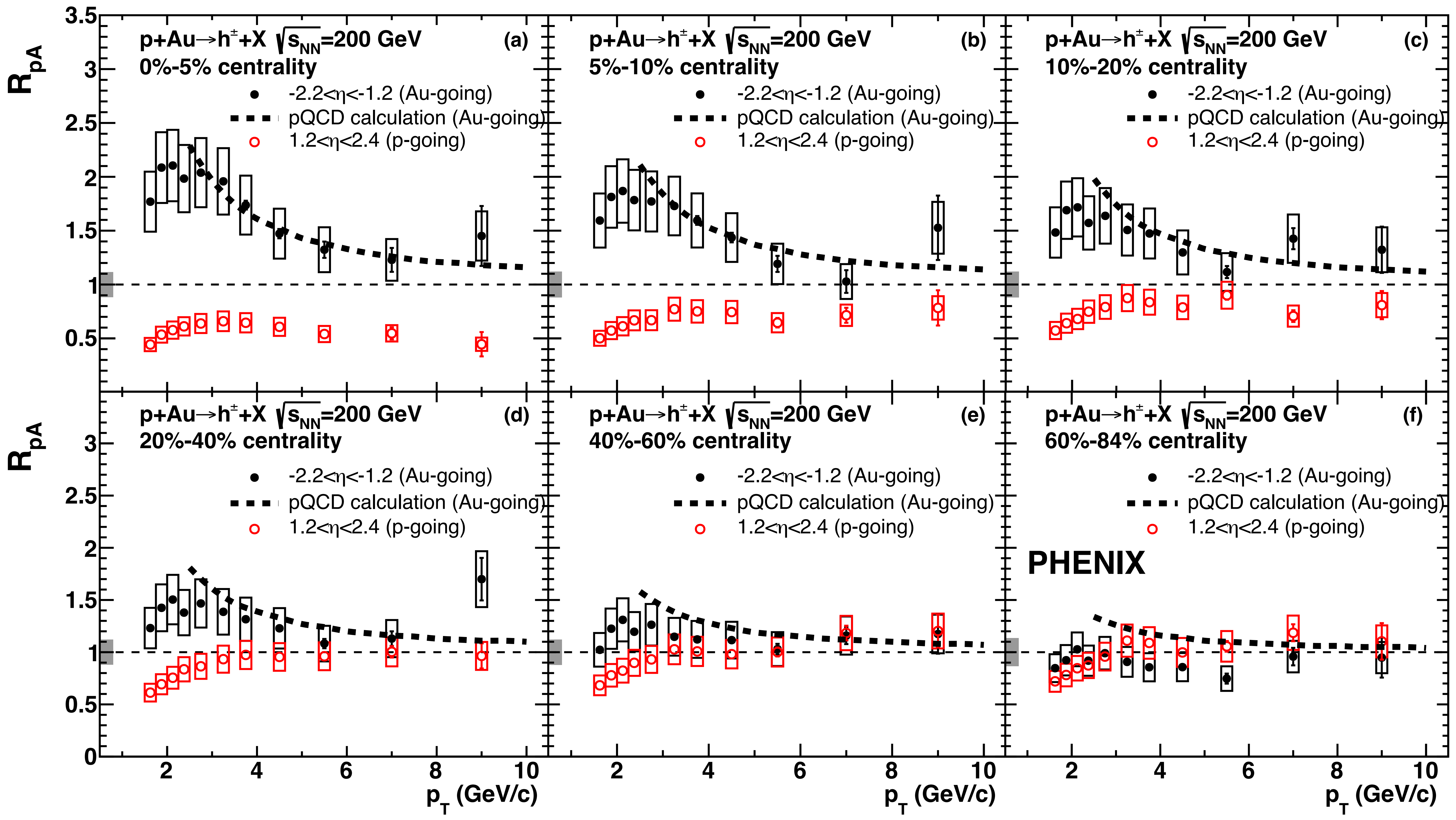
Incoherent multiple scattering - from dilute to relative dense

- Enhancement from twist-4 contribution

$$E_h \frac{d\sigma^{(D)}}{d^3P_h} = \left(\frac{8\pi^2\alpha_s}{N_c^2-1}\right)\frac{\alpha_s^2}{S}\sum_{a,b,c}\int\frac{dz}{z^2}D_{c\to h}(z)\int\frac{dx'}{x'}f_{a/p}(x')\int\frac{dx}{x}\delta(\hat{s}+\hat{t}+\hat{u})$$

$$\times\sum_{i=I,F}\left[x^2\frac{\partial^2 T_{b/A}^{(i)}(x)}{\partial x^2} - x\frac{\partial T_{b/A}^{(i)}(x)}{\partial x} + T_{b/A}^{(i)}(x)\right]c^i H^i_{ab\to cd}(\hat{s},\hat{t},\hat{u})$$



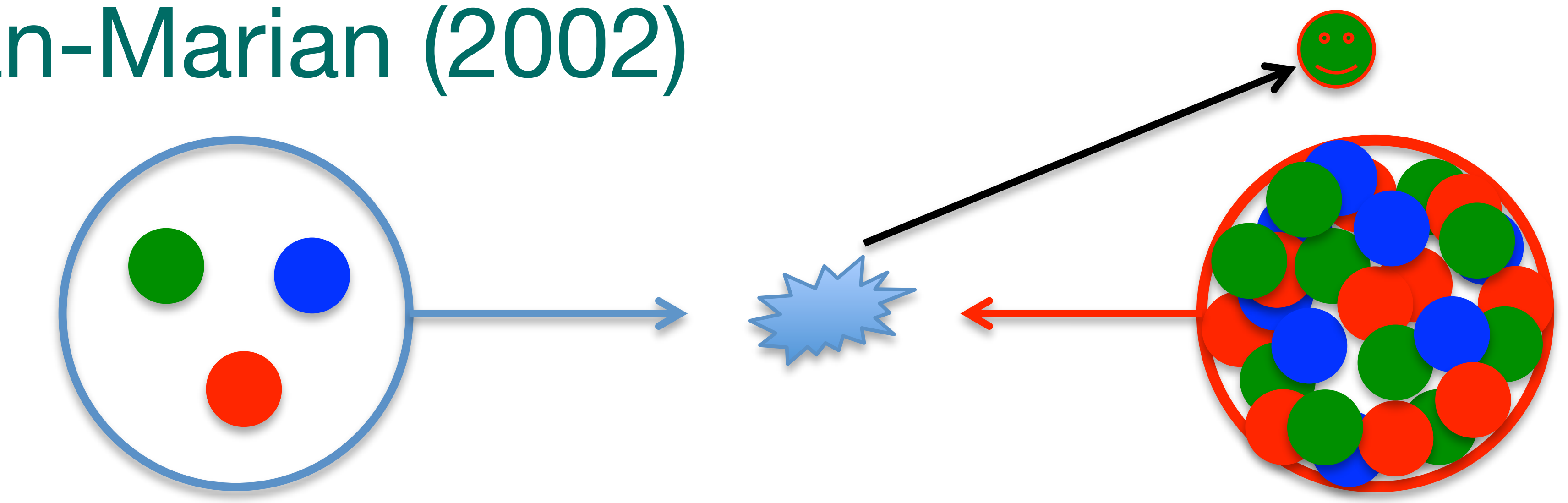


Prediction of nuclear enhancement from incoherent multiple scattering

Kang, Vitev, **HX,** PRD 2014
Li, Kang, **HX**, 2023
PHENIX, PRC, 2020

Coherent multiple scattering - CGC

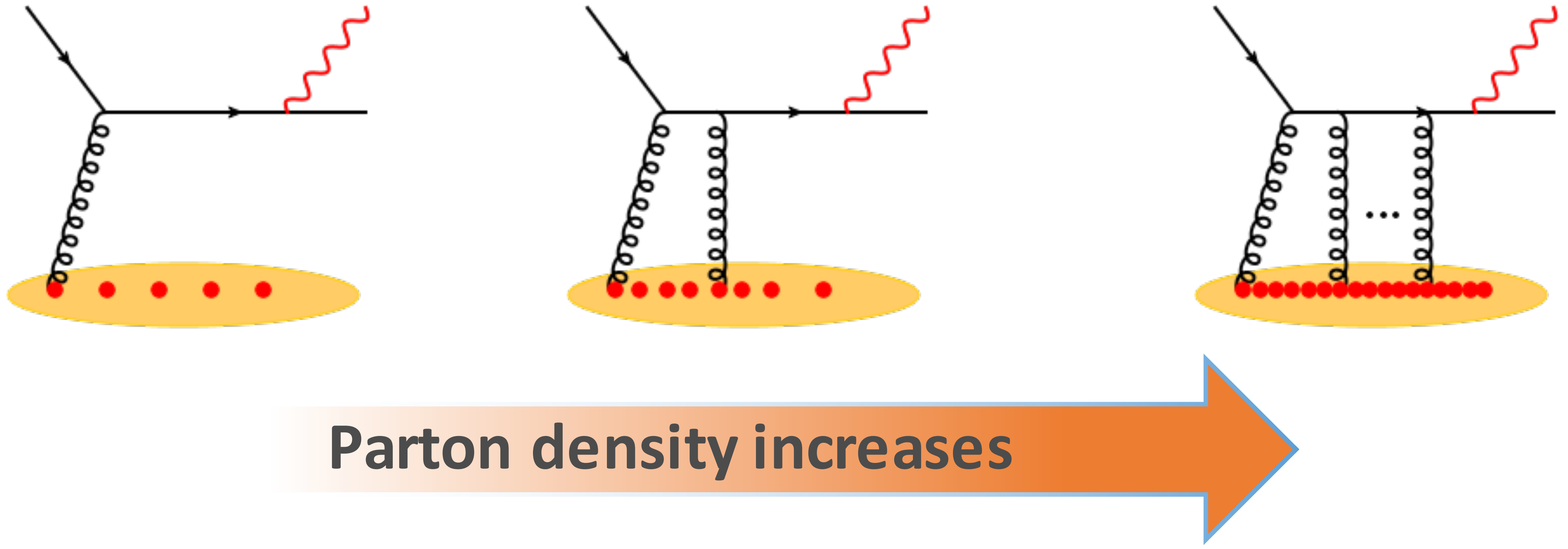
- Hybrid (dilute-dense) factorization — Dumitru, Jalilian-Marian (2002)



$$\sigma \sim x_p f_{q/p}(x_p) \otimes H \otimes \mathcal{F}(x_g, k_\perp) \otimes D_{h/q}(z)$$

$x_p = \frac{p_\perp}{z\sqrt{s}} e^{y}$ → $x_p p_a \gg k_{Ta}$ → Probing valance quark – DGLAP evolution

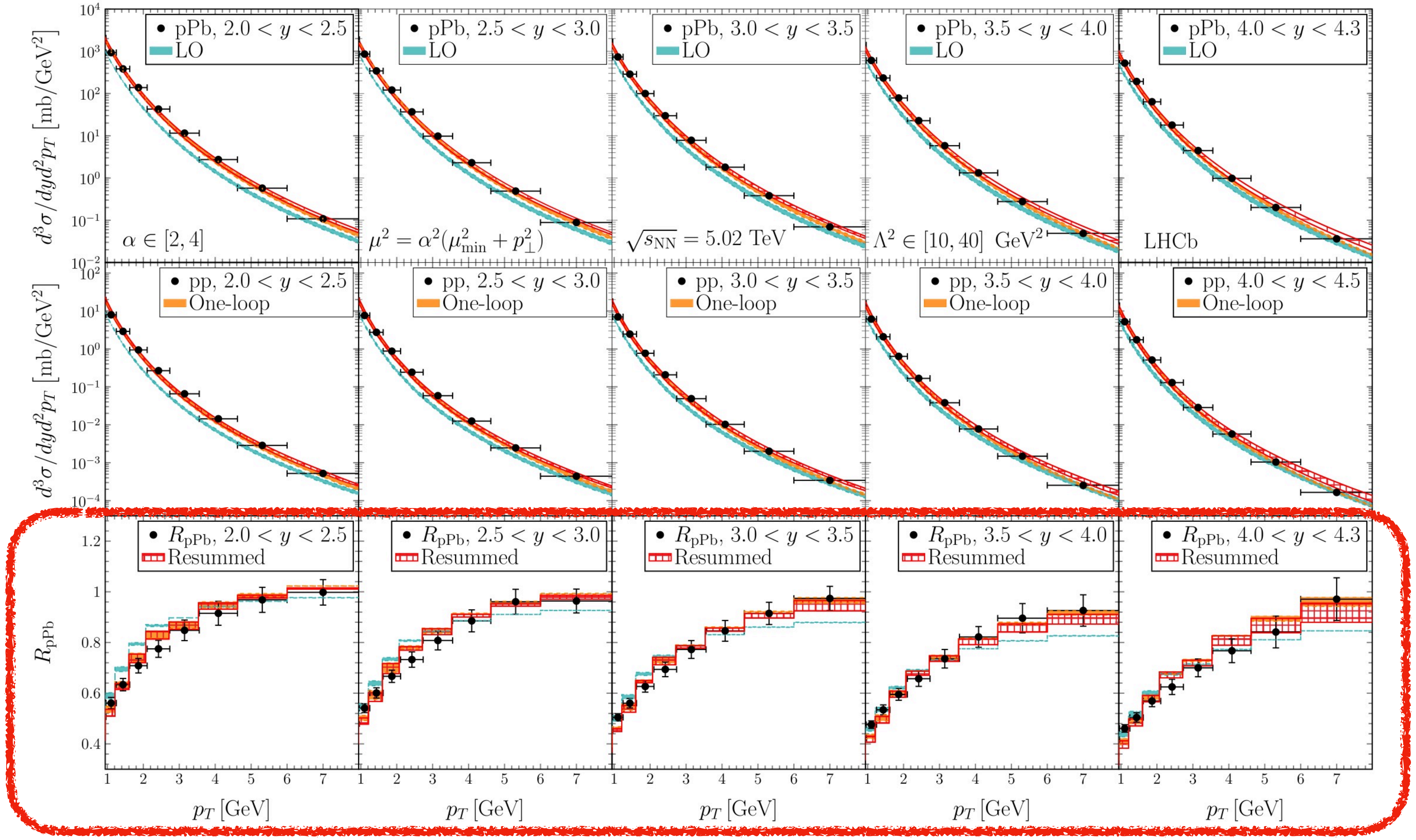
$x_g = \frac{p_\perp}{z\sqrt{s}} e^{-y}$ → $x_g p_b \sim k_{Tb}$ → Probing dense gluon – BK evolution



- All multiple scatterings become equally important, need to be resumed.
- Coherent multiple scattering are encoded in the so-called unintegrated gluon distribution $\mathscr{F}(x_g, k_\perp)$

Coherent multiple scattering - dilute region

- Hybrid (dilute-dense) factorization



Suppression from CGC calculation

Albacete, Marquet, PLB 2010

Dimitri, Jalilian-Marian, PRL 2012

Chirilli, Xiao, Yuan, PRL 2012

Stasto, Xiao, Zaslavsky, PRL 2014

Kang, Vitev, **HX**, PRL 2014

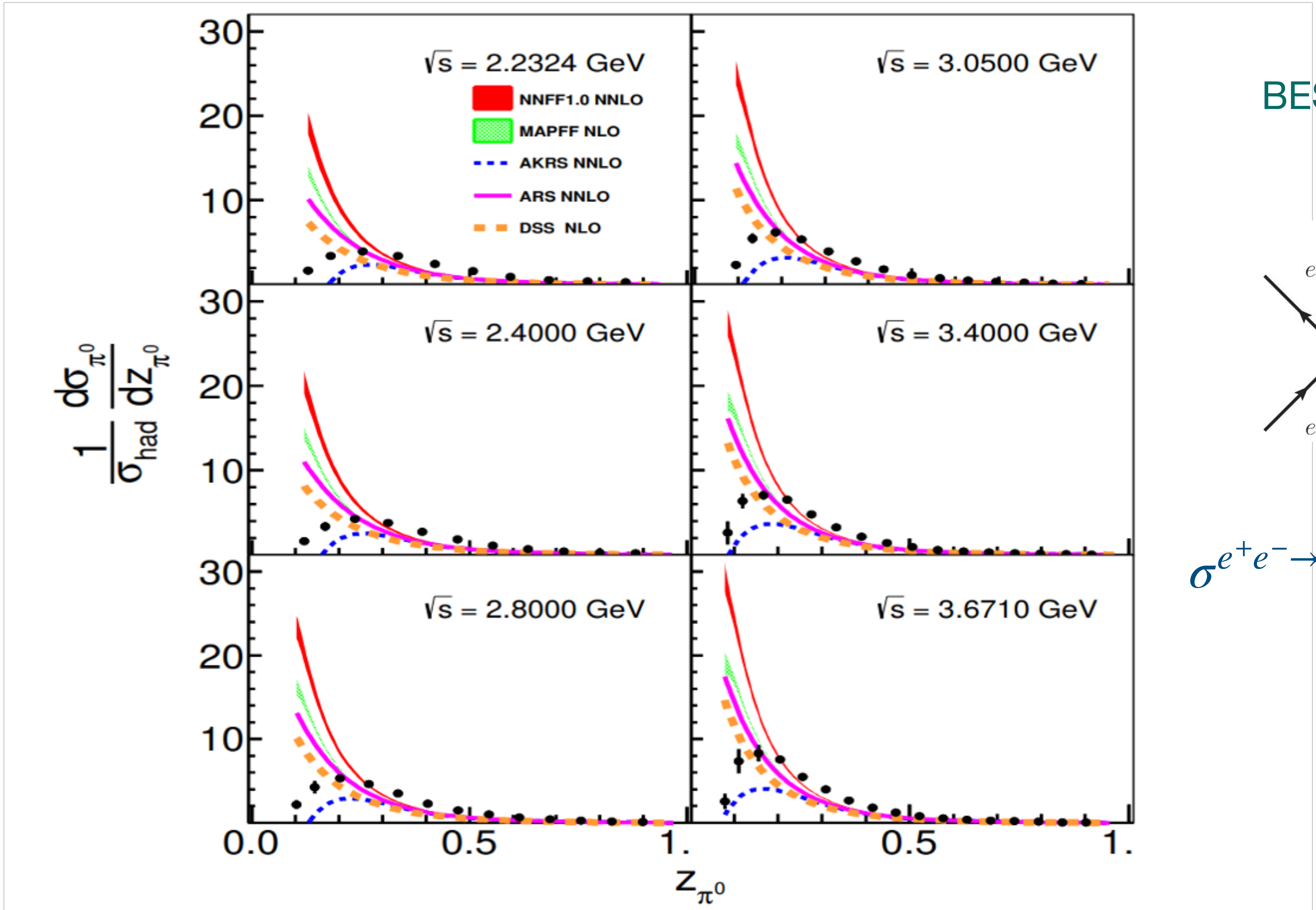
Iancu, Mueller, Triantafyllopoulos, JHEP 2016

Liu, Kang, Liu, PRD 2020

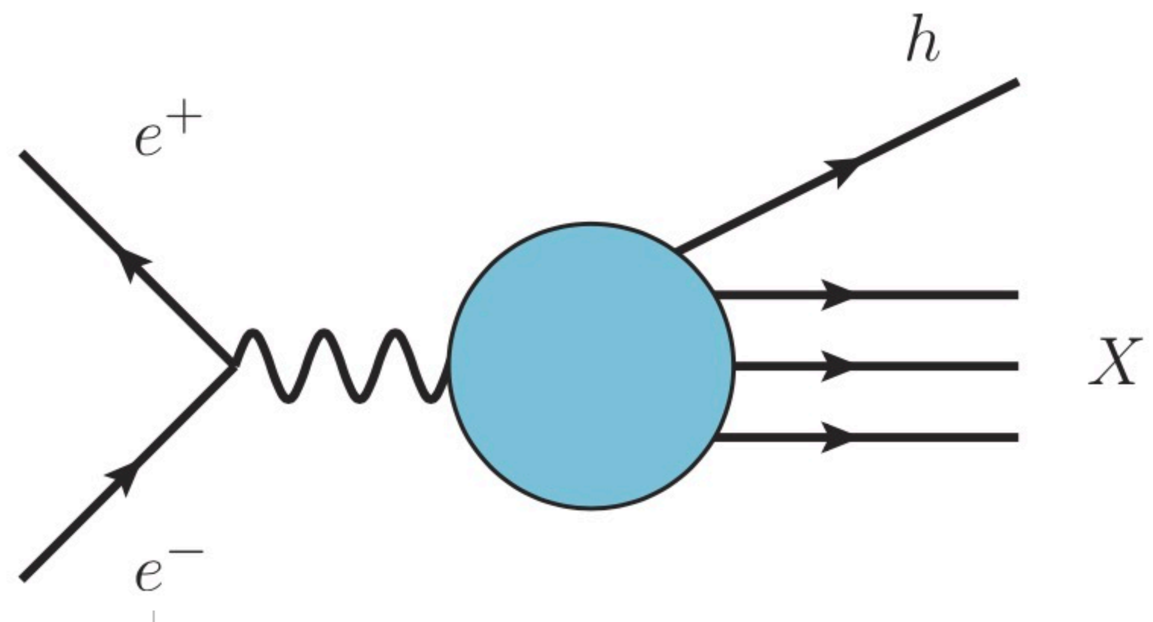
Shi, Wang, Wei, Xiao, PRL 2022

……

The significance of high-twist effect in hadron fragmentation



BESIII, PRL 2023



$$\sigma^{e^+e^-\to hX} = \hat{\sigma}_{e^+e^-\to i} \otimes D_{i\to h}$$

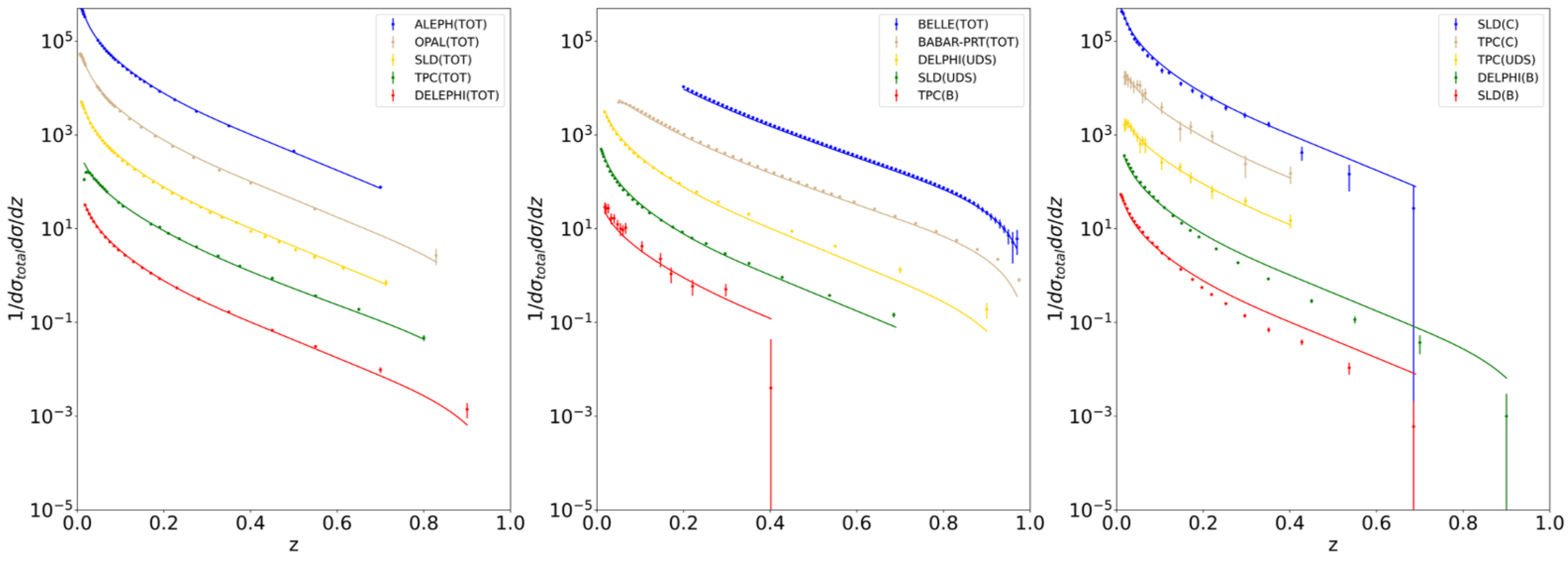
The significance of high-twist effect in low Q^2

Fitting precision	Data points	χ^2	χ^2/dof
NNLO	517	3544.04	6.855
NNLO+HT(1/Q^2)	517	818.97	1.584
NNLO+HT(1/Q^4)	517	806.41	1.560

$$F_2(x,Q^2) = F_2^{LT}(x,Q^2)\left(1 + \frac{C_1(x)}{Q^2} + \frac{C_2(x)}{Q^4}\right)$$

$$C_1(x) = h_0 x^{h_1}(1 + h_2 x)$$

$$C_2(x) = h_3 x^{h_4}(1 + h_5 x)$$



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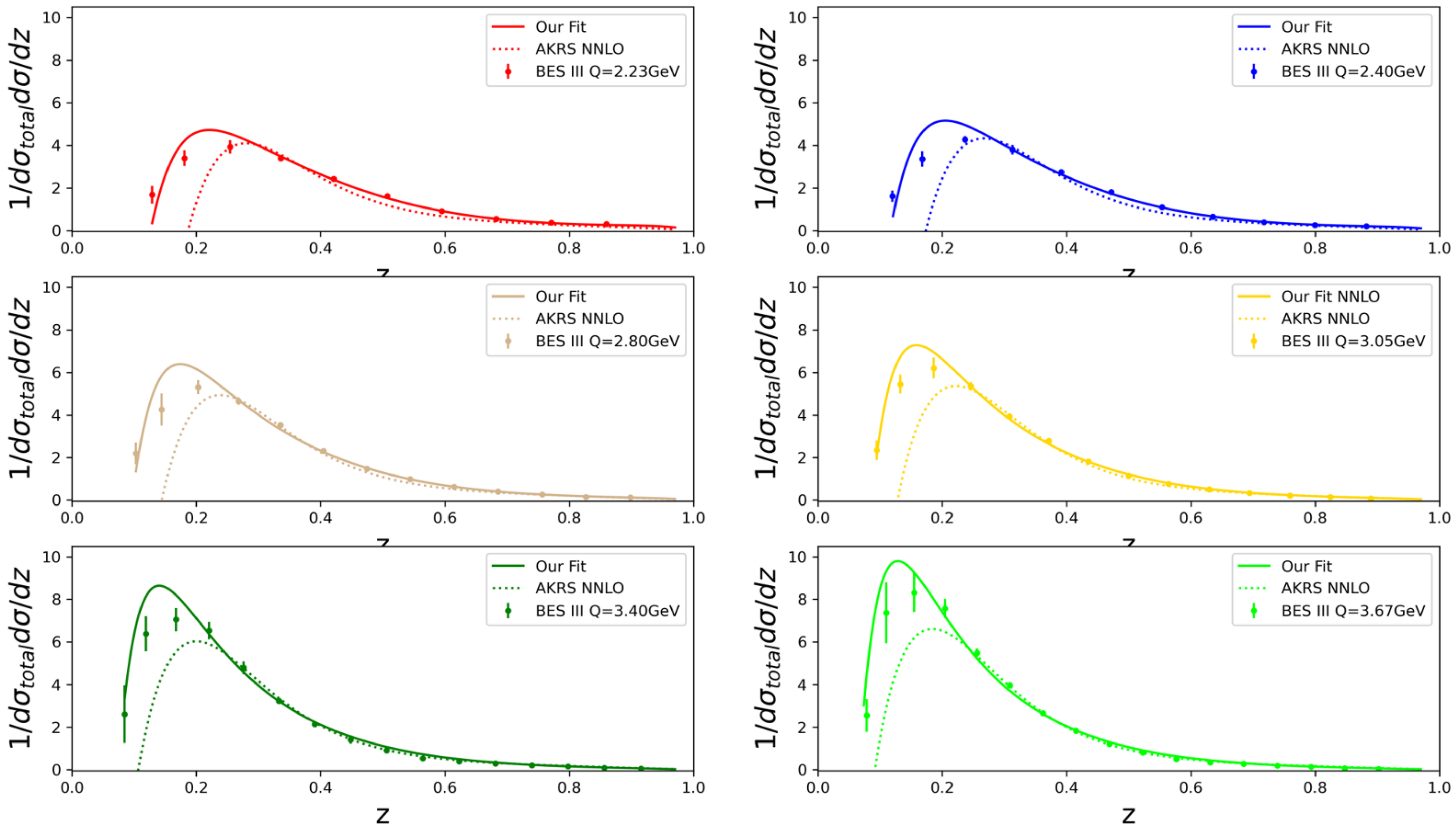
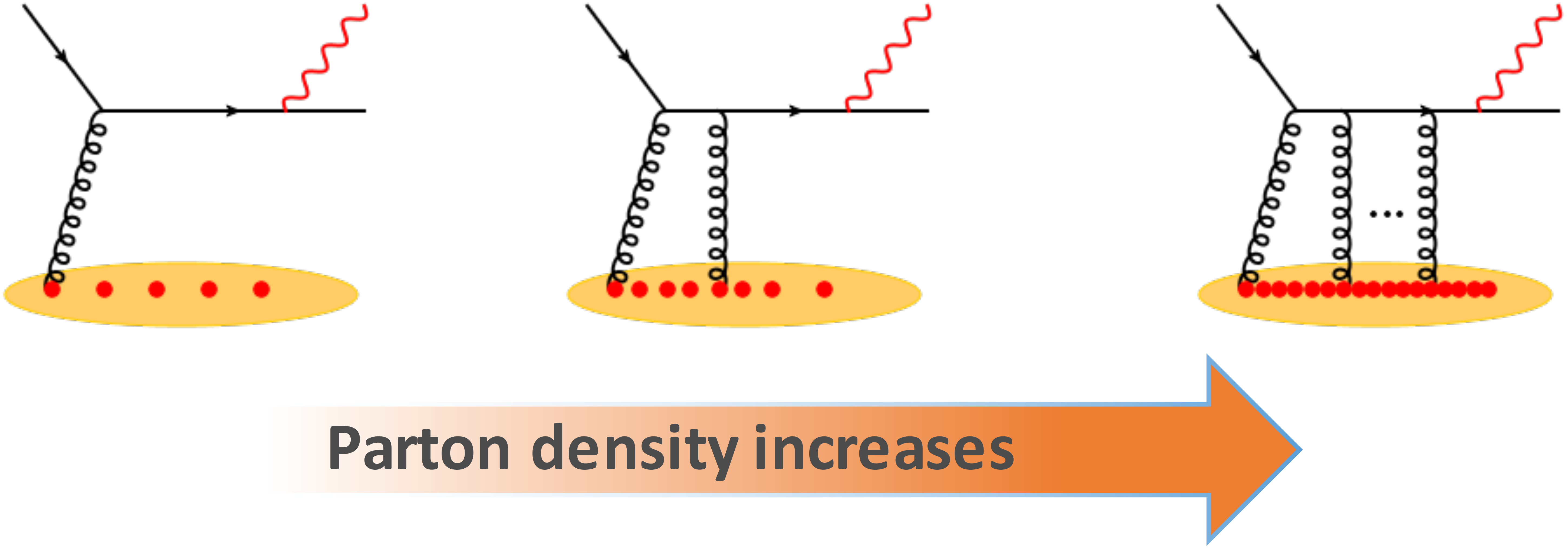


The relation between CGC and high-twist expansion

- Take direct photon production as an example



- Higher twist becomes important at moderate $p_{\gamma\perp}^2$

$$\mathrm{d}\sigma \sim \frac{1}{p_{\gamma\perp}^4}\left[A + B\frac{\langle k_\perp^2\rangle}{p_{\gamma\perp}^2} + C\frac{\langle k_\perp^2\rangle^2}{p_{\gamma\perp}^4}\ldots\right]$$

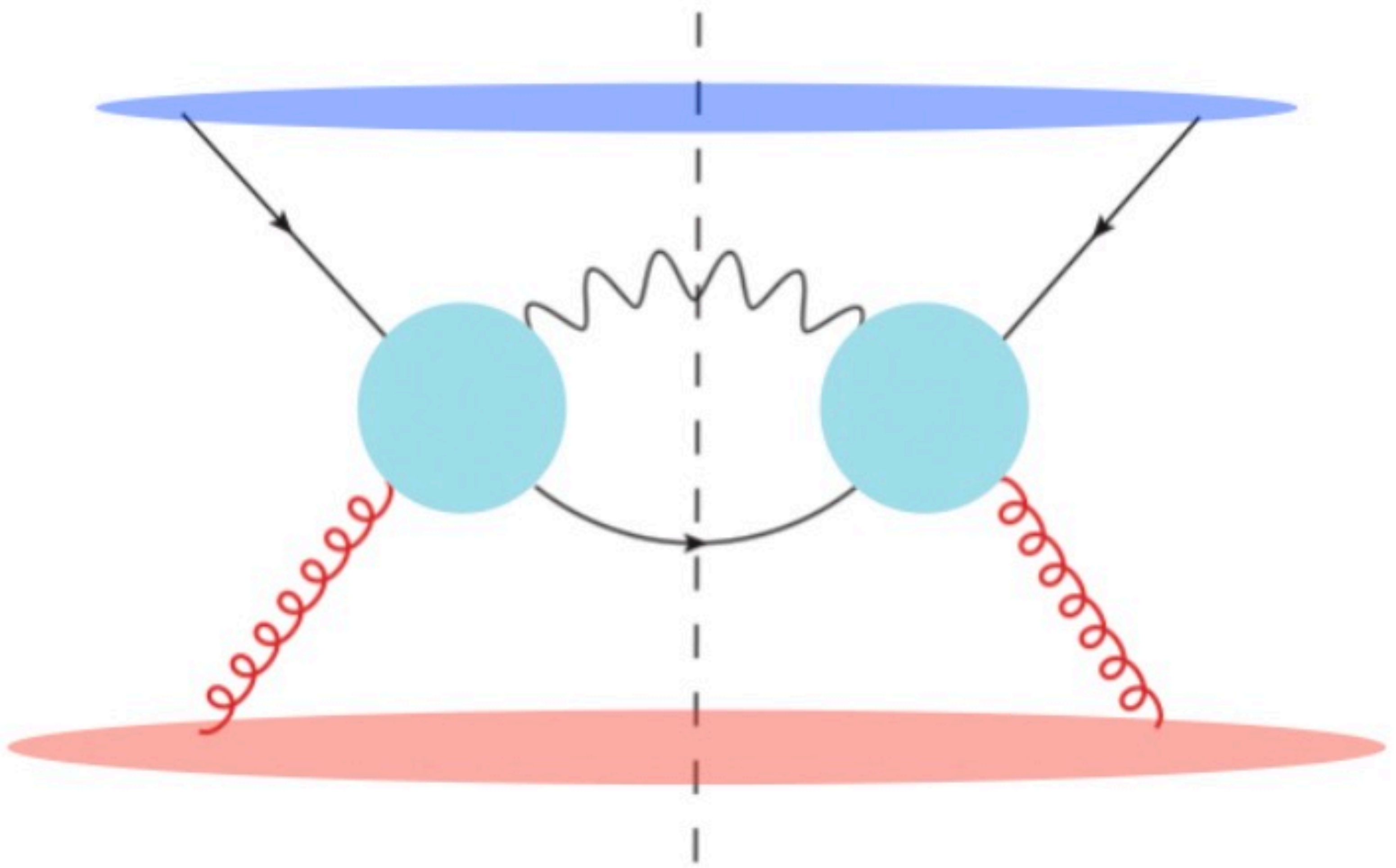
$$\langle k_\perp^2\rangle \sim Q_s^2 \propto A^{1/3}x^{-\lambda}$$

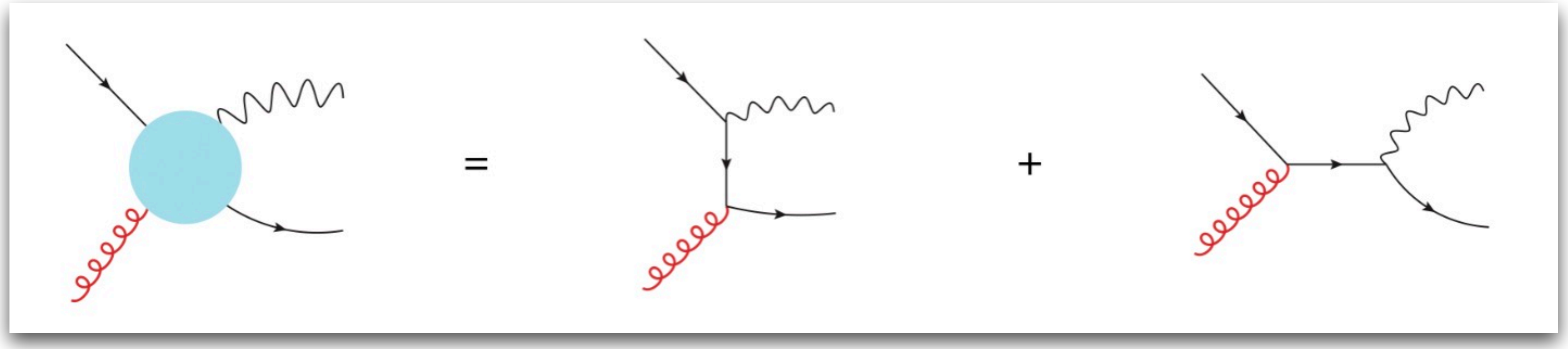
leading twist (twist-2)

Higher twist (twist-4 and twist-6)

Direct photon production in p+A collisions

- Single scattering (q+g channel)





- leading twist collinear factorization

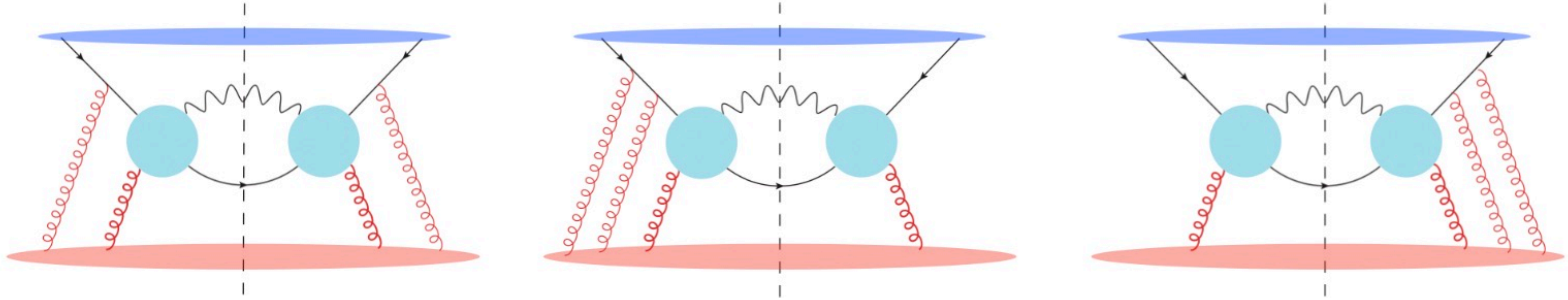
$$E_\gamma \frac{\mathrm{d}\sigma^S_{pA\to\gamma}}{\mathrm{d}^3\boldsymbol{p_\gamma}} = \alpha_{em}\alpha_s \frac{1}{s}\int \frac{\mathrm{d}x_p}{x_p} f(x_p) \int \frac{\mathrm{d}x}{x} f_{g/A}(x)\ H^U_{qg\to q\gamma}(\hat{s},\hat{t},\hat{u})\ \delta(\hat{s}+\hat{t}+\hat{u})$$

$$f_{g/A}(x) = \frac{1}{xP^+}\int \frac{\mathrm{d}y^-}{2\pi}\ e^{-ixP^+y^-}\ \langle P_A|F^{+\omega}(0^-)F^{+}{}_{\omega}(y^-)|P_A\rangle$$

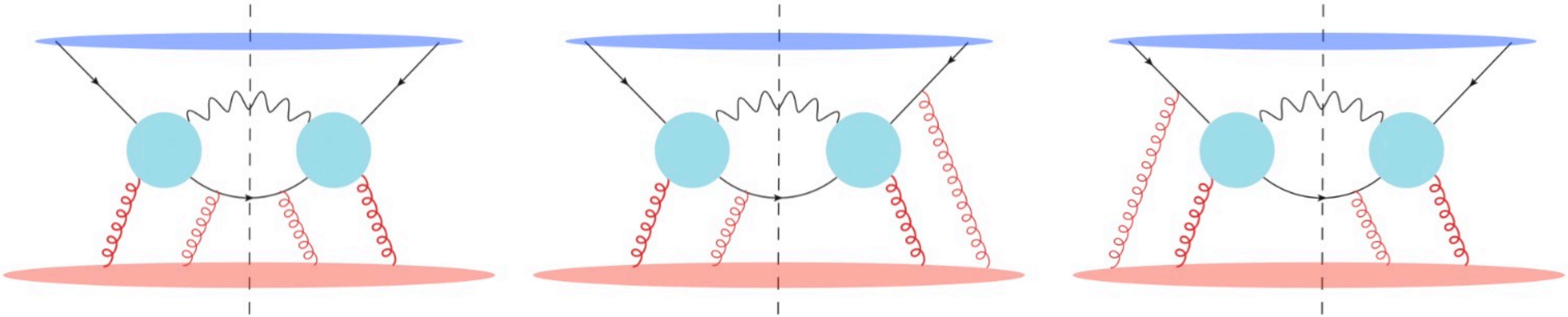
$$H^U_{qg\to q\gamma}(\hat{s},\hat{t},\hat{u}) = \frac{1}{2N_c}[-2(\frac{\hat{t}}{\hat{s}}+\frac{\hat{s}}{\hat{t}})]$$

Looking backward - incoherent multiple scattering from high-twist

- Initial state double scattering and single-triple interference



- Final state double scattering and initial-final interference



Looking backward - incoherent multiple scattering from high-twist

- Complete twist-4 contribution

$$E_\gamma \frac{\mathrm{d}\sigma^D_{qA\to\gamma}}{\mathrm{d}^3\boldsymbol{p}_\gamma} = \int \mathrm{d}x_p f_q(x_p) x_b \frac{4\pi^2\alpha_s^2\alpha_e}{N_c^2} \frac{\xi^2 - 2\xi + 2}{\boldsymbol{p}^6_{\gamma\perp}} \left[\cdots\right]_{x_1=x_b, x_2=x_3=0}$$

$$T(x_1,x_2,x_3) = \int \frac{dy^-}{2\pi}\frac{dy_1^-}{2\pi}\frac{dy_2^-}{2\pi} e^{ix_1P^+y^-} e^{ix_2P^+(y_1^- - y_2^-)} e^{ix_3P^+y_2^-} \frac{1}{xP^+}\left\langle P_A | F^{+\omega}(0^-) F^{+\kappa}(y_2^-) F^+{}_\kappa(y_1^-) F^+{}_\omega(y^-) | P_A \right\rangle$$

result from initial state rescattering

$[\cdots]$ Cuts / Derivatives	Central	Asymmetric
2nd	$\xi^4[x_b^2 \frac{\partial^2 T^{C,I}}{\partial x_1^2}]$	0
1st	$-3\xi^4[x_b \frac{\partial T^{C,I}}{\partial x_1}] + (1-\xi)\xi^3[x_b \frac{\partial T^{C,I}}{\partial x_2}]$	$(1-\xi)\xi^3[x_b \frac{\partial T^{A,I}}{\partial x_2}]$
0th	$4\xi^4 T^{C,I}$	0

- Positive contribution from incoherent multiple scattering

$$E_\gamma \frac{\mathrm{d}\sigma^D_{pA\to\gamma}}{\mathrm{d}^3\boldsymbol{p}_\gamma} = \frac{4\pi^2\alpha_s^2\alpha_e}{N_c}\frac{1}{s}\int\frac{\mathrm{d}x_p}{x_p} f(x_p) \int \frac{\mathrm{d}x}{x} c^I H^U_{qg\to q\gamma}(\hat{s},\hat{t},\hat{u})\, \delta(\hat{s}+\hat{t}+\hat{u})$$

$$\left[x^2 \frac{\partial^2 T^I(x)}{\partial x^2} - x\frac{\partial T^I(x)}{\partial x} + xT^I(x)\right]$$

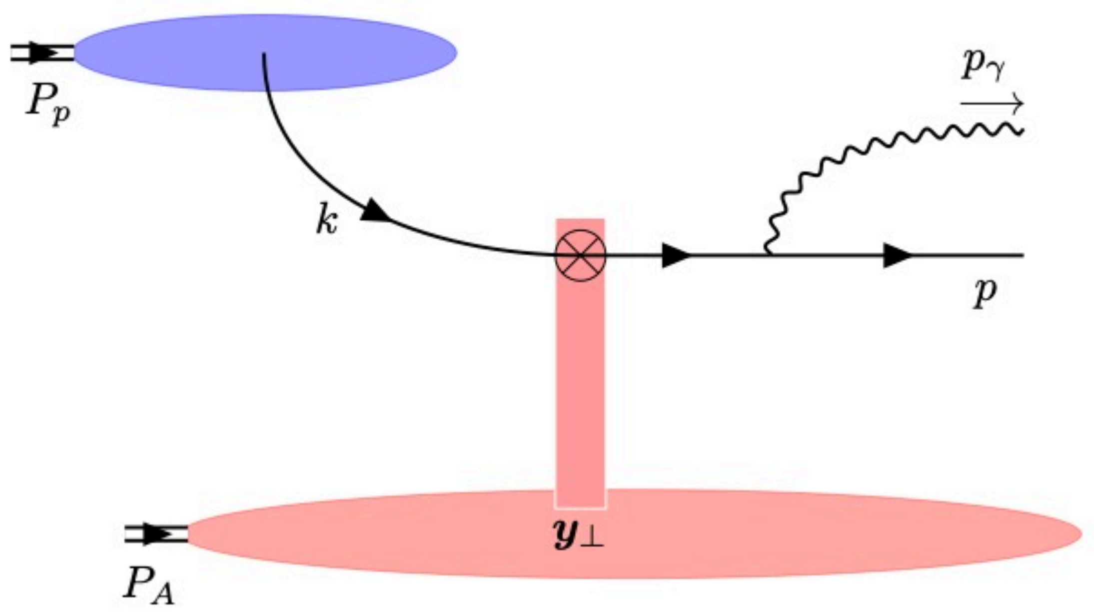
$$c^I = -\frac{1}{\hat{s}} - \frac{1}{\hat{t}}$$

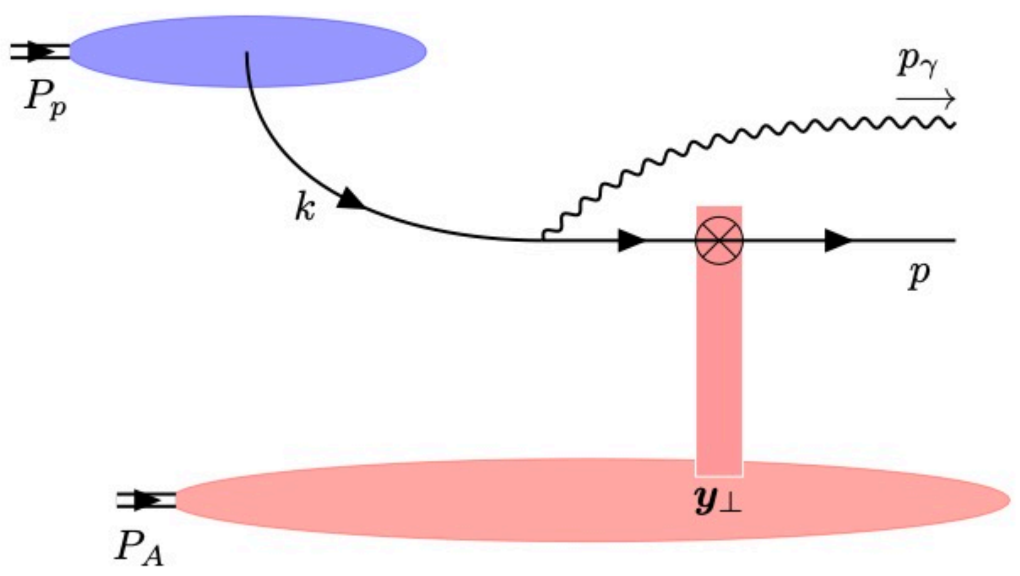
Only initial state rescattering contributes

positive -> nuclear enhancement

Looking forward - coherent multiple scattering from CGC

- Direct photon production with the CGC/saturation framework





- CGC differential cross section

$$\frac{\mathrm{d}\sigma^{p+A\to\gamma+X}}{\mathrm{d}\eta_\gamma \mathrm{d}^2\boldsymbol{p}_{\gamma\perp}} = \frac{\alpha_{\mathrm{em}} e_f^2}{2\pi^2} \int_{x_{p,min}}^1 \mathrm{d}x_p f(x_p) \xi^2 \left[1+(1-\xi)^2\right] \int \mathrm{d}^2\boldsymbol{l}_\perp \frac{\boldsymbol{l}_\perp^2 F(\bar{x}_A, \boldsymbol{l}_\perp)}{(\xi \boldsymbol{l}_\perp - \boldsymbol{p}_{\gamma\perp})^2 \boldsymbol{p}_{\gamma\perp}^2}$$

- Dipole correlator

$$F(x_A, \boldsymbol{l}_\perp) = \int \frac{\mathrm{d}^2\boldsymbol{y}_\perp}{2\pi} \int \frac{\mathrm{d}^2\boldsymbol{y}'_\perp}{2\pi} e^{-i\boldsymbol{l}_\perp\cdot(\boldsymbol{y}_\perp - \boldsymbol{y}'_\perp)} S^{(2)}(x_A; \boldsymbol{y}_\perp, \boldsymbol{y}'_\perp)$$

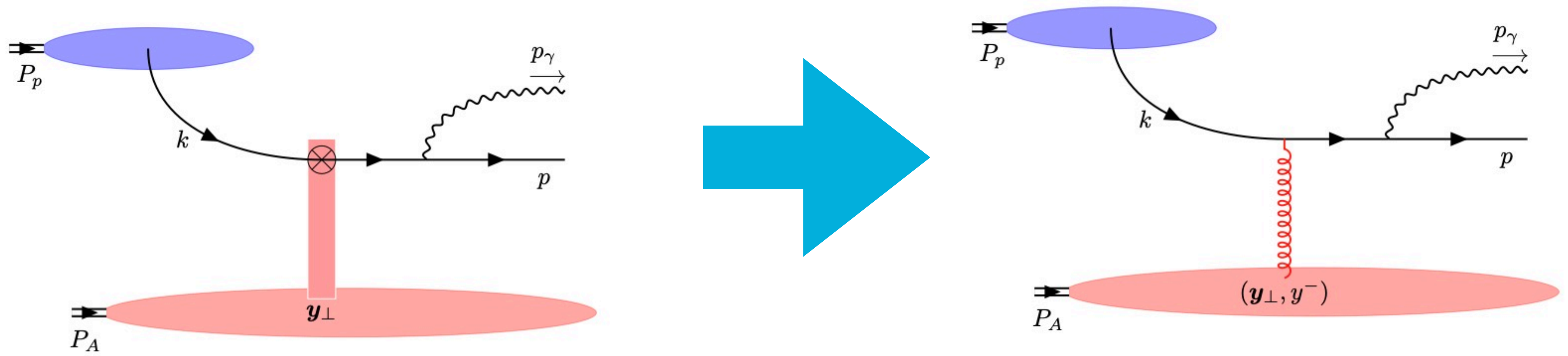
$$S^{(2)}(x_A; \boldsymbol{y}_\perp, \boldsymbol{y}'_\perp) = \frac{1}{N_c} \left\langle \mathrm{Tr}\left[V^\dagger(\boldsymbol{y}'_\perp) V(\boldsymbol{y}_\perp)\right] \right\rangle_{x_A} \qquad V_{ij}(\boldsymbol{y}_\perp) = \mathcal{P} \exp\left(ig \int_{-\infty}^{\infty} \mathrm{d}z^- A^{+,c}(y^-, \boldsymbol{y}_\perp) t^c_{ij} \right)$$

From CGC to leading twist collinear factorization

- Consistency between CGC and single scattering
  - considering large $p_{\gamma\perp}$ to go beyond small-x

$$\frac{1}{(\xi l_\perp - p_{\gamma\perp})^2} \approx \frac{1}{p_{\gamma\perp}^2} + \frac{\xi^2 l_\perp^2}{p_{\gamma\perp}^4} + \dots$$

twist-2 twist-4



  - Twist-2 cross section

$$\frac{d\sigma^{p+A\to\gamma+X}}{d\eta_\gamma d^2\boldsymbol{p}_{\gamma\perp}} = \frac{\alpha_{em} e_f^2 \alpha_s}{N_c} \int_{x_{p,min}}^{1} dx_p f(x_p) \frac{\xi^2\left[1+(1-\xi)^2\right]}{\boldsymbol{p}_{\gamma\perp}^4} \bar{x}_A f_{g/A}(\bar{x}_A)\Big|_{\bar{x}_A\to 0}$$

$$\lim_{x\to 0} x f_{g/A}(x) = \frac{N_c}{2\pi^2\alpha_s}\int d^2\boldsymbol{l}_\perp \boldsymbol{l}_\perp^2 F(x,\boldsymbol{l}_\perp)$$

Baier, Mueller, Schiff, 2004

$$e^{i\bar{x}_A P_A^+ \Delta y} \sim 1 \to \bar{x}_A A^{1/3} \ll 1$$

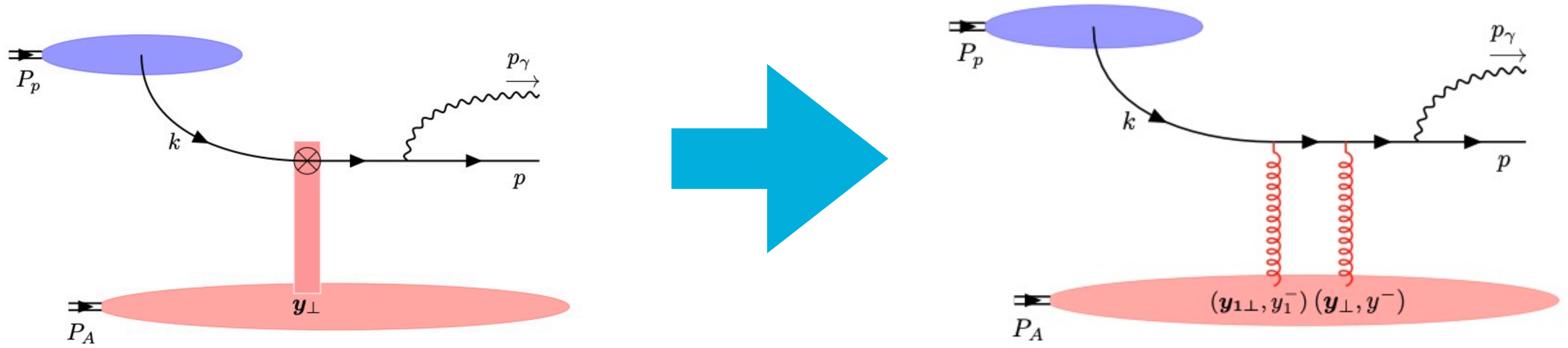
Dropping out the phase in small-x limit

From CGC to twist-4 collinear factorization

- Consistency between CGC and double scattering in small-x limit
  - considering large $p_{\gamma\perp}$ to go beyond small-x

$$\frac{1}{(\xi l_\perp - p_{\gamma\perp})^2} \approx \frac{1}{p_{\gamma\perp}^2} + \frac{\xi^2 l_\perp^2}{p_{\gamma\perp}^4} + \dots$$

twist-2 twist-4



  - Twist-4 cross section

$$\left.\frac{\mathrm{d}\sigma^{p+A\to\gamma+X}}{\mathrm{d}\eta_\gamma \mathrm{d}^2\boldsymbol{p}_{\gamma\perp}}\right|_{\mathrm{NLT}} = \frac{(2\pi)^2\alpha_{\mathrm{em}} e_f^2 \alpha_s^2}{N_c^2} \int_{\frac{p_\gamma^-}{P_p^-}}^1 \mathrm{d}x_p f(x_p) \frac{\xi^4\left[1+(1-\xi)^2\right]}{\boldsymbol{p}_{\gamma\perp}^6} T_{g/A}(\bar{x}_A, 0, 0)\Big|_{\bar{x}_A\to 0}$$

$$\lim_{x\to 0} T_{g/A}(x,0,0) = \frac{2N_c^2}{(2\pi)^4\alpha_s^2}\int \boldsymbol{l}_\perp^4 \mathrm{d}^2\boldsymbol{l}_\perp F(x, \boldsymbol{l}_\perp)$$

matching in the small-x limit if $\lim_{\bar{x}_A\to 0} \bar{x}_A \frac{\partial T_{g/A}(x_1,x_2,x_3)}{\partial x_i}\Big|_{\substack{x_1=\bar{x}_A \\ x_2=0, x_3=0}} \ll \lim_{\bar{x}_A\to 0} T_{g/A}(\bar{x}_A, 0, 0)$

Derivative terms are missing comparing to twist-4 result with finite x !

A unified picture of dilute and dense limits

- Bringing back the longitudinal "sub-eikonal" phase for single scattering

$$\mathrm{d}\sigma \propto \int \mathrm{d}x_p f(x_p)\ \mathcal{H} \otimes \mathcal{T}$$

Expand the Wilson line:

$$(2\pi)\delta(l^- - l'^-)\gamma^- \int \mathrm{d}^2\boldsymbol{y}_\perp e^{-i(\boldsymbol{l}_\perp - \boldsymbol{l}'_\perp)\cdot \boldsymbol{y}_\perp} \int \mathrm{d}y^- e^{i(l^+ - l'^+)y^-} igA_a^+(y^-, \boldsymbol{y}_\perp)(t^a)_{ij}$$

Collinear expansion:

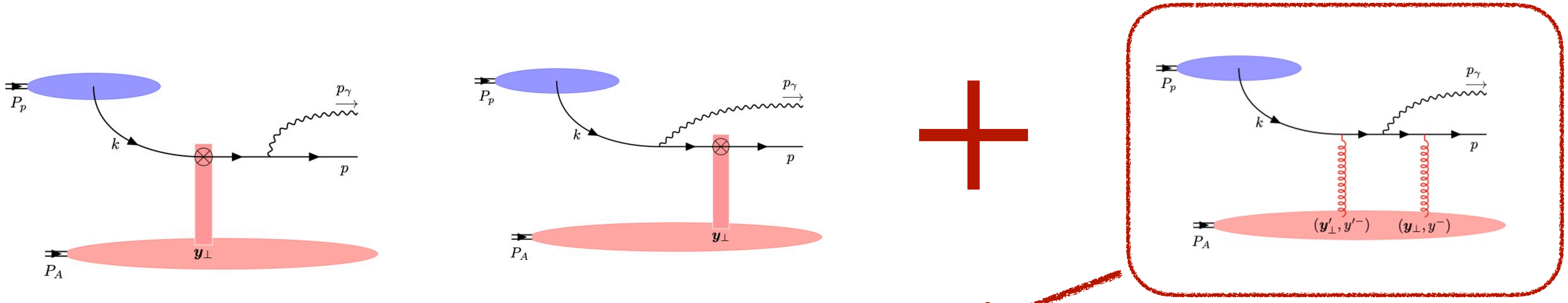
$$\mathcal{H}_2(p_\gamma; y, y') = \frac{8\xi^2\left[1+(1-\xi)^2\right]}{\boldsymbol{p}_{\gamma\perp}^4} e^{i\bar{x}_A P_A^+(y^- - y'^-)} \frac{\partial^2}{\partial \boldsymbol{y}_\perp \cdot \partial \boldsymbol{y}'_\perp} \int \frac{\mathrm{d}^2\boldsymbol{l}_\perp}{(2\pi)^2} e^{-i\boldsymbol{l}_\perp \cdot (\boldsymbol{y}_\perp - \boldsymbol{y}'_\perp)} + \dots .$$

$$\frac{\mathrm{d}\sigma^{p+A\to\gamma+X}}{\mathrm{d}\eta_\gamma \mathrm{d}^2\boldsymbol{p}_{\gamma\perp}} = \frac{\alpha_{\mathrm{em}} e_f^2 \alpha_s}{N_c} \int_{x_{p,min}}^1 \mathrm{d}x_p f(x_p) H(\xi, \boldsymbol{p}_{\gamma\perp}) \bar{x}_A f_{g/A}^{(0)}(\bar{x}_A)$$

Matching exactly to leading-twist result beyond small-x limit

A unified picture of dilute and dense limits

- Missing diagram in CGC



$$\text{phases} = e^{\frac{i}{x_p s}\left[\frac{\boldsymbol{p}_\perp^2}{(1-\xi)}+\frac{\boldsymbol{p}_{\gamma\perp}^2}{\xi}-\boldsymbol{l}_\perp^2\right]P_A^+ y'^-}\, e^{\frac{i}{x_p s}\boldsymbol{l}_\perp^2 P_A^+ y^-}\left\{1 - e^{\frac{i}{x_p s}\frac{\left[\boldsymbol{p}_{\gamma\perp}-\xi \boldsymbol{l}_\perp\right]^2}{\xi(1-\xi)}P_A^+(y^- - y'^-)}\right\}$$

- formation time for photon production: $\tau_{\gamma,\text{form}}^{-1} = \frac{1}{x_p s}\frac{\left[\boldsymbol{p}_{\gamma\perp} - \xi \boldsymbol{l}_\perp\right]^2}{\xi(1-\xi)}P_A^+$

- LPM effect: $\tau_{\gamma,\text{form}} \gg y^- - y'^-$, coherent double scattering cancels, while this diagrams remains a net incoherent double scattering.

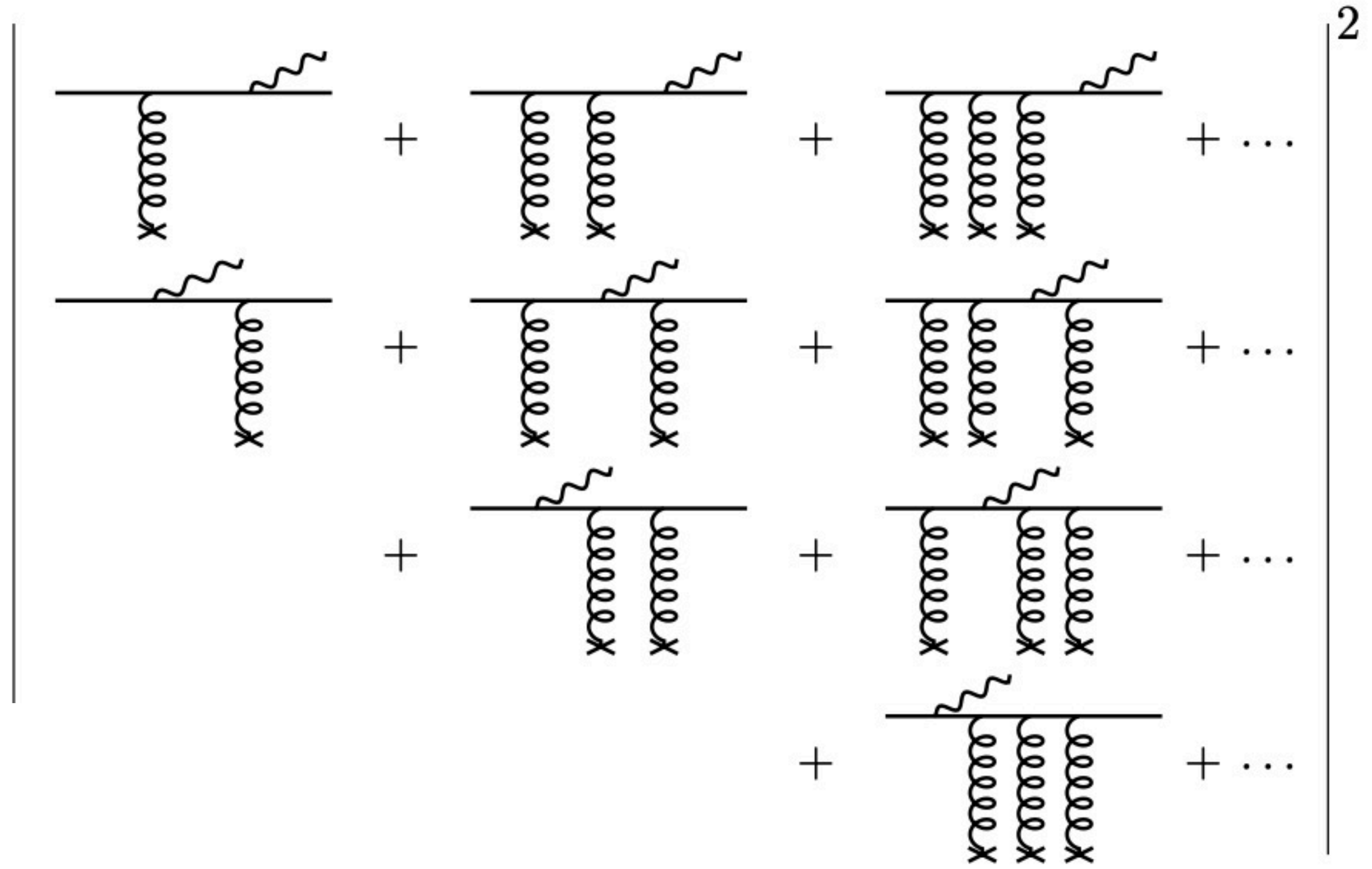
A unified picture of dilute and dense limits

- Consistency between CGC and double scattering

$$\mathrm{d}\sigma \propto \int \mathrm{d}x_p f(x_p)\ \mathcal{H} \otimes \mathcal{T}$$

$$\mathcal{T}(z_1, z_2, z_3, z_4) = \frac{1}{N_c}\langle \mathrm{Tr}\left[A^+(z_1^-, \boldsymbol{z_{1\perp}})A^+(z_2^-, \boldsymbol{z_{2\perp}})A^+(z_3-, \boldsymbol{z_{3\perp}})A^+(z_4^-, \boldsymbol{z_{4\perp}})\right]\rangle$$

$$\mathcal{H}^{coll}_{\mathrm{C,I}}(p_\gamma; y, y', y_1, y_2)$$
$$= 8H(\xi, \boldsymbol{p_{\gamma\perp}})e^{i\bar{x}_A P_A^+(y^- - y'^-)} \frac{\partial\delta^{(2)}(\boldsymbol{y}_\perp - \boldsymbol{y}_{1\perp})}{\partial \boldsymbol{y}_\perp} \cdot \frac{\partial\delta^{(2)}(\boldsymbol{y}'_\perp - \boldsymbol{y}_{2\perp})}{\partial \boldsymbol{y}'_\perp} \times \Big[\delta^{(2)}(\boldsymbol{y}_{1\perp} - \boldsymbol{y}_{2\perp})$$
$$+ \frac{1}{\boldsymbol{p}^2_{\gamma\perp}} \frac{\partial^2\delta^{(2)}(\boldsymbol{y}_{1\perp} - \boldsymbol{y}_{2\perp})}{\partial \boldsymbol{y}_{1\perp} \cdot \partial \boldsymbol{y}_{2\perp}} \left[4\xi^2 + \xi(1-\xi)(i\bar{x}_A P_A^+ \Delta y_{12}^-) - 3\xi^2(i\bar{x}_A P_A^+ \Delta y^-) + \xi^2(i\bar{x}_A P_A^+ \Delta y^-)^2\right]\Big]$$



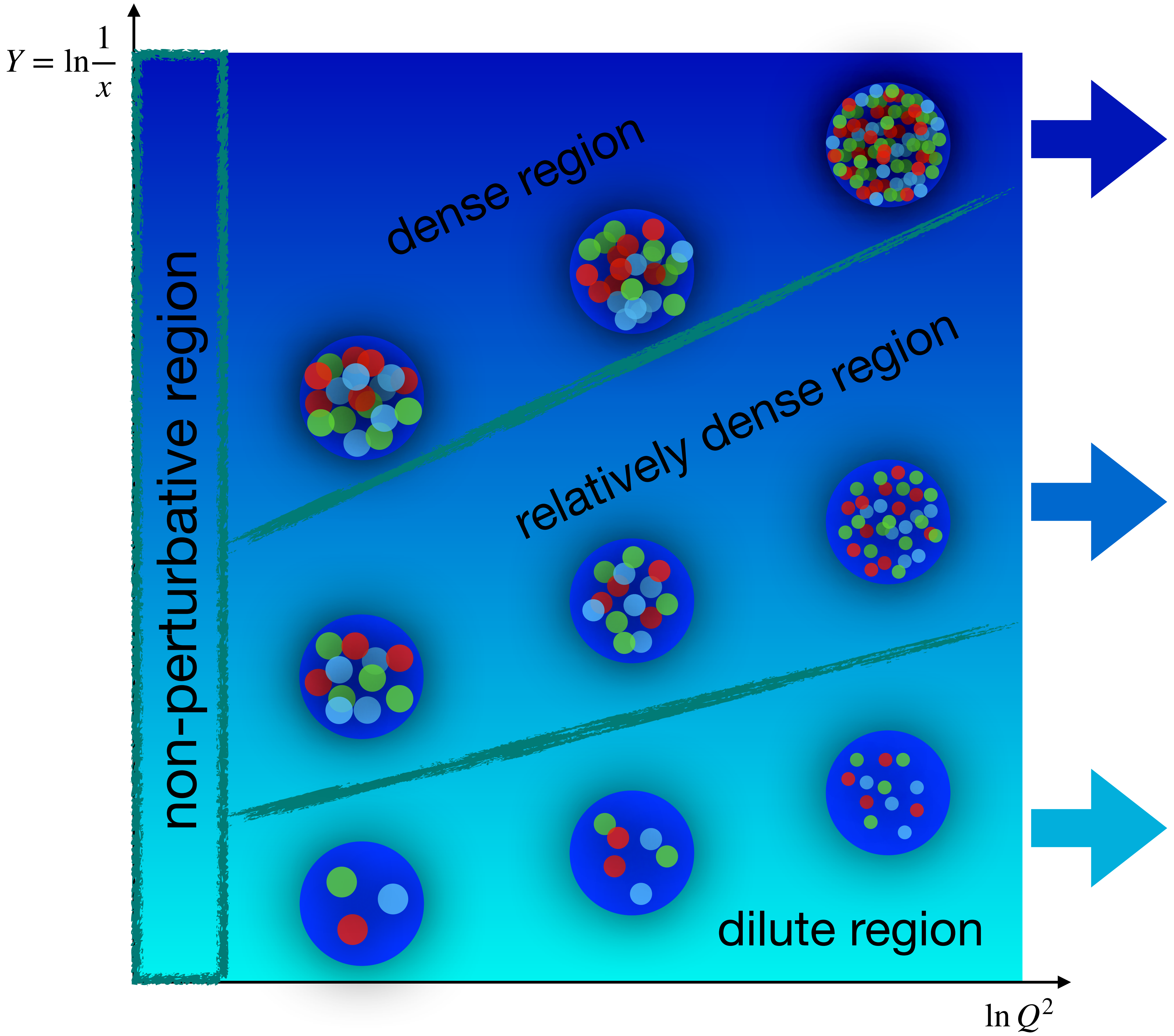
25 diagrams at twist-4

$$\frac{\mathrm{d}\sigma^{p+A\to\gamma+X}_{\mathrm{C,I}}}{\mathrm{d}\eta_\gamma \mathrm{d}^2\boldsymbol{p_{\gamma\perp}}} = \frac{\alpha_{\mathrm{em}} e_f^2 \alpha_{\mathrm{s}}}{N_c} \int_{x_{\min}}^1 \mathrm{d}x_p f(x_p) H(\xi, \boldsymbol{p_{\gamma\perp}}) \bar{x}_A f_{g/A}^{(\mathrm{gauge\ \ link})}(\bar{x}_A)$$
$$+ \frac{(2\pi)^2 \alpha_{\mathrm{em}} e_f^2 \alpha_{\mathrm{s}}^2}{N_c^2 \boldsymbol{p}^2_{\gamma\perp}} \int_{x_{\min}}^1 \mathrm{d}x_p f(x_p) H(\xi, \boldsymbol{p_{\gamma\perp}}) \mathcal{D}_{\mathrm{C,I}}(\xi, \bar{x}_A, x_1, x_2, x_3) T_{\mathrm{C,I}}(x_1, x_2, x_3)\Big|_{\substack{x_1 = \bar{x}_A \\ x_2 = x_3 = 0}}$$

Recover the complete result from twist-4 formalism and the gauge link in PDF!

Summary

Yu Fu, Zhong-Bo Kang, Farid Salazar, Xin-Nian Wang, and Hongxi Xing 2023, to appear soon!



Color Glass Condensate (CGC)

Wilson lines, nonlinear BK/

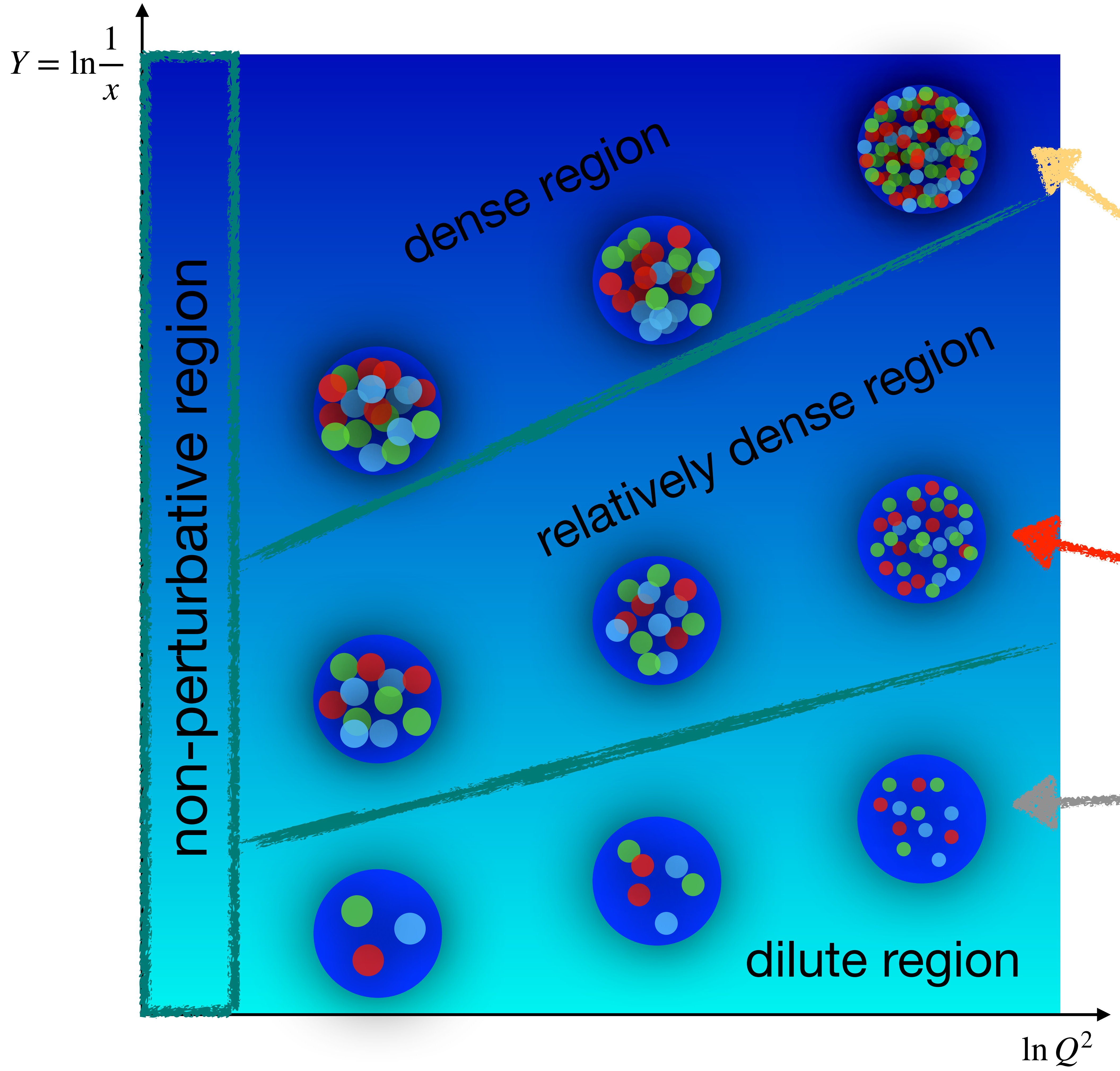
High-twist formalism

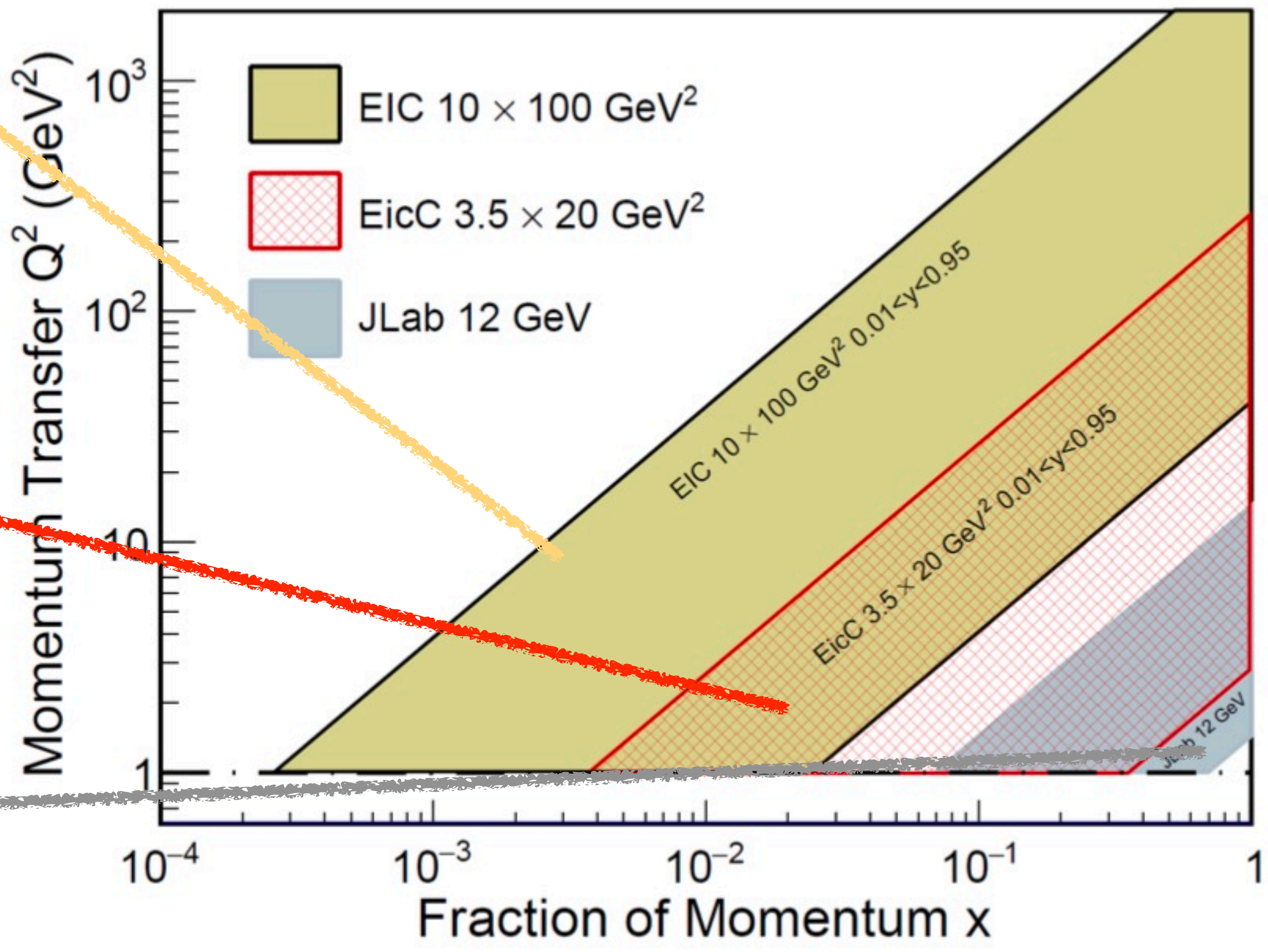
Multi-parton correlation, DGLAP-type evolution

Leading twist collinear factorization

Taking direct photon production in pA collision as an example, we show the consistency between the collinear factorization (dilute) and the extended CGC (dense), and establish a unified picture for dilute-dense dynamics in QCD medium.

Outlook





Mapping out the QCD phase diagram for nuclei with worldwide efforts using a unified theoretical framework!

第四届量子场论研讨会（2024.12）

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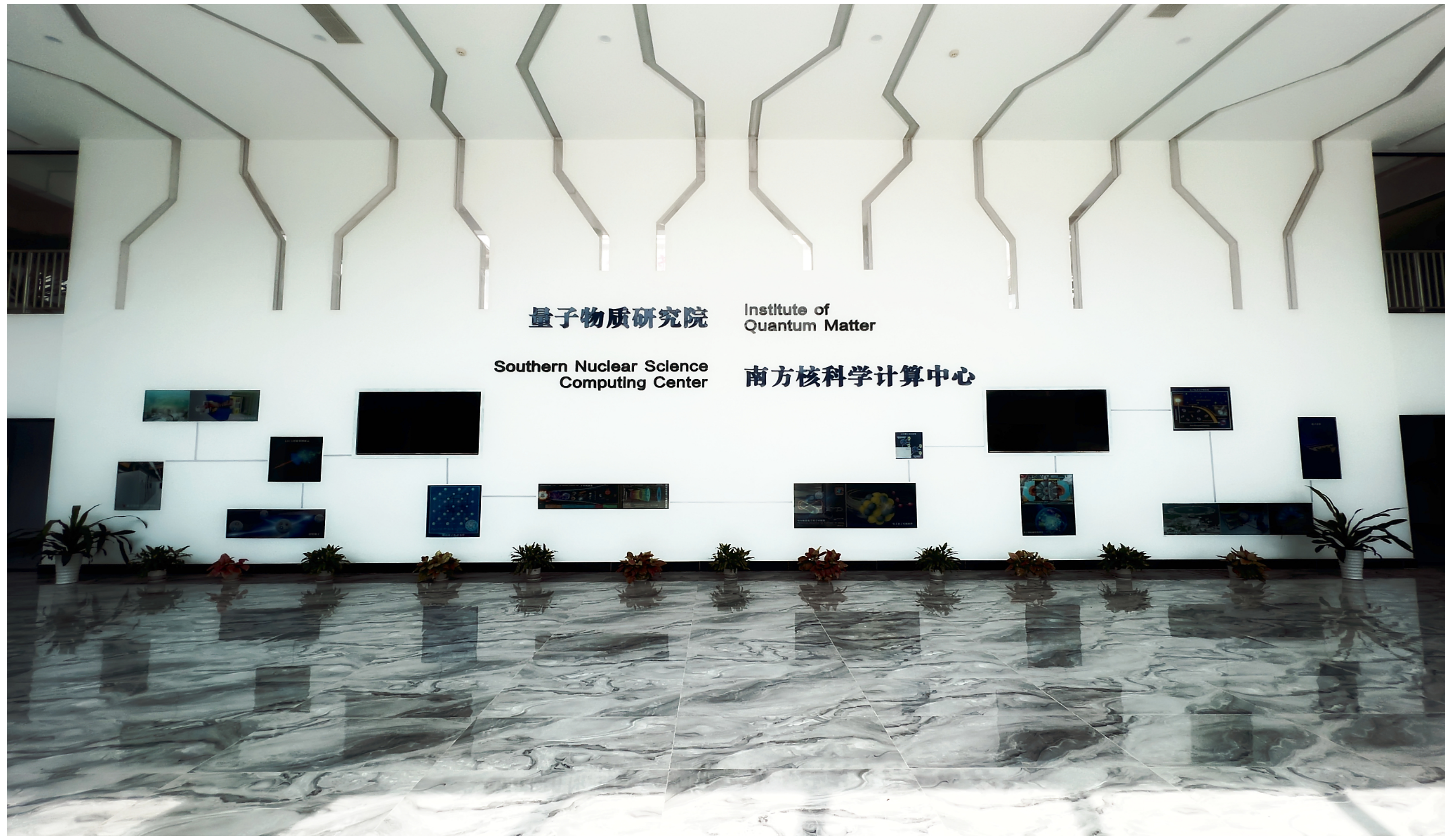

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