Toward a unified description of high energy cross sections at both small and large Bjorken x

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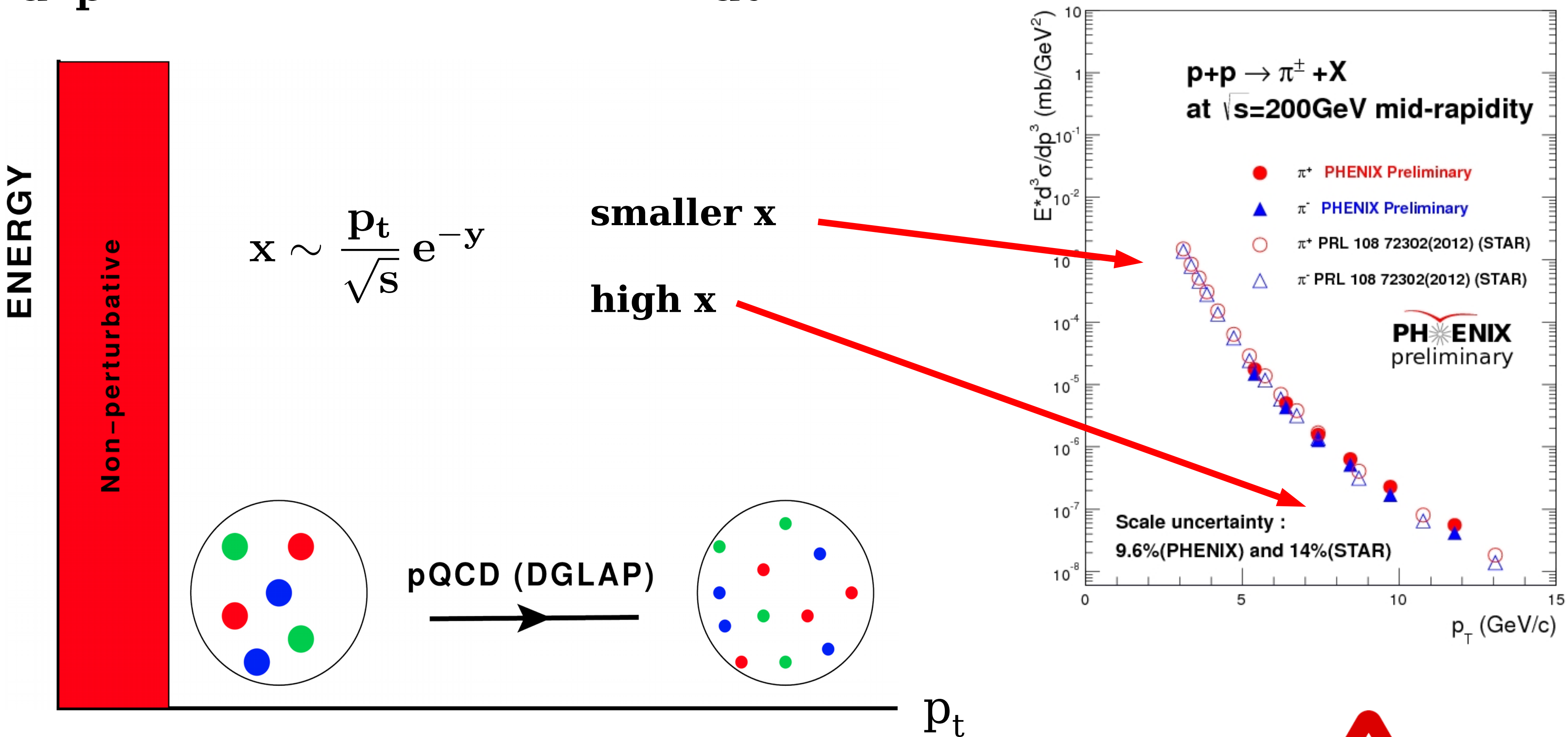
pQCD: the standard paradigm

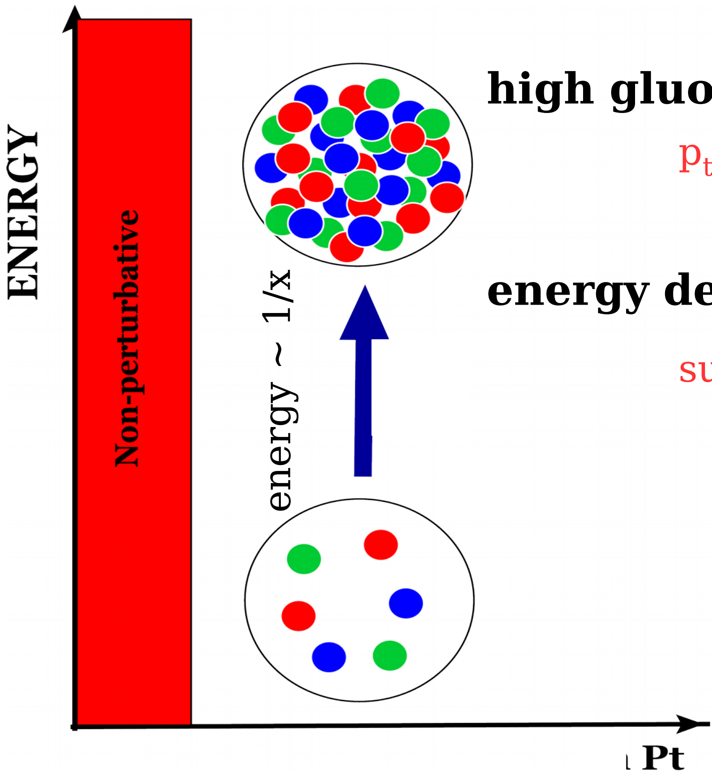
$$E\,\frac{d\sigma}{d^3p} \sim f_1(x, p_t^2) \otimes f_2(x, p_t^2) \otimes \frac{d\sigma}{dt} \otimes D(z, p_t^2)$$

$$x \sim \frac{p_t}{\sqrt{s}}\, e^{-y}$$



bulk of QCD phenomena happens at low p_t (small x)

A hadron/nucleus at high energy: gluon saturation



high gluon density: Eikonal multiple scattering

p_t broadening

energy dependence: x-evolution via JIMWLK/BK

suppression of spectra/away side peaks

$$\mathbf{Q_s^2(x, b_t, A) \sim A^{1/3} \, (\frac{1}{x})^{0.3}}$$

$$Q_s^2(x = 3 \times 10^{-4}) \sim 1 \, GeV^2$$

for a proton target (quarks)

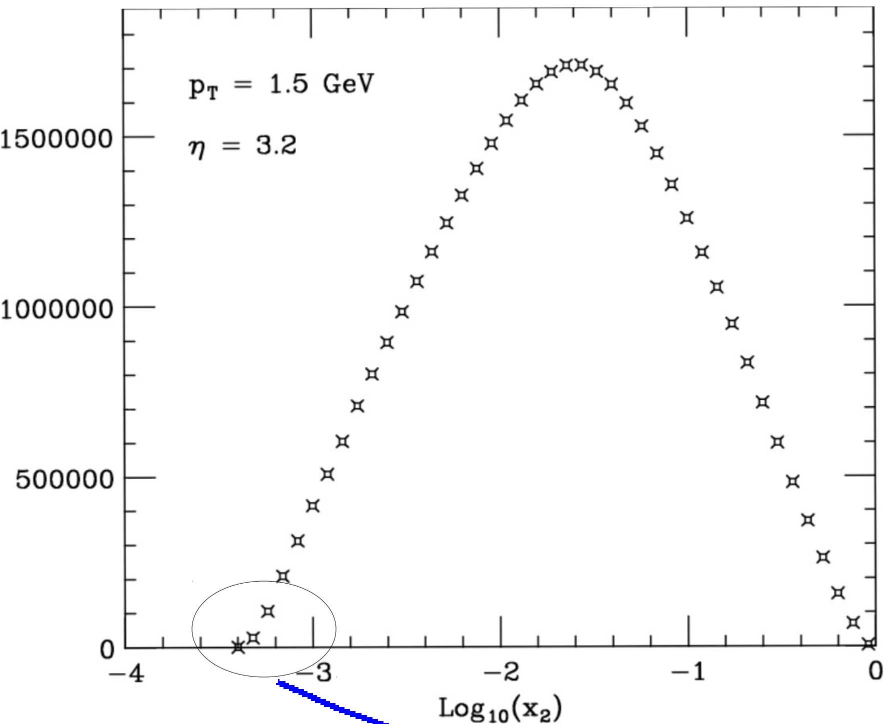
a framework for multi-particle production in QCD at small x/low p_t

Initial conditions for hydro
Thermalization
Long range rapidity correlations
Azimuthal angular correlations
Nuclear modification factor

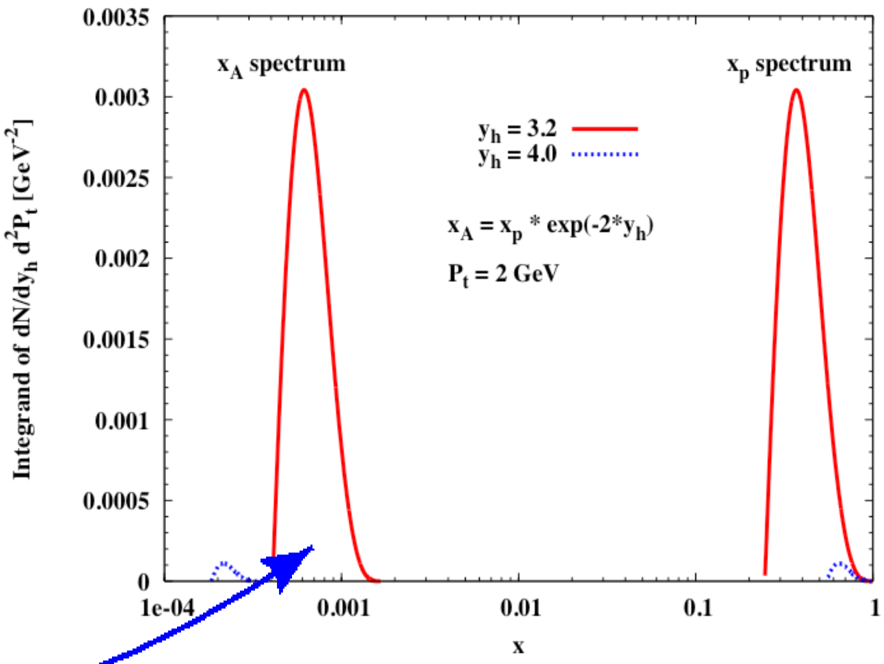
$$\mathbf{x \leq 0.01}$$

Pion production in pp at RHIC: kinematics

collinear factorization — GSV, PLB603 (2004) 173-183



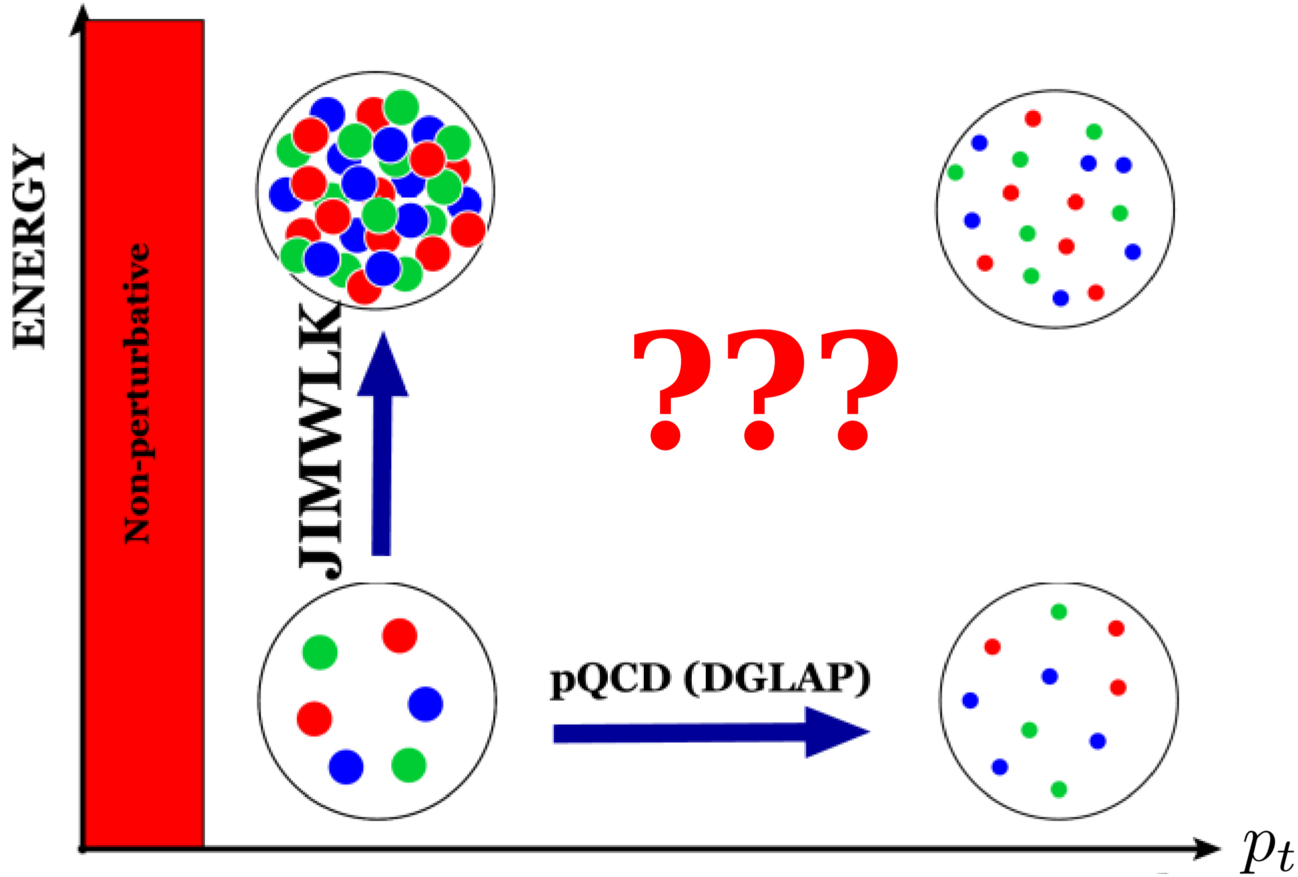
CGC — DHJ, NPA765 (2006) 57-70



$$\int_{x_{min}}^{1} dx\, xG(x,Q^2)\cdots\cdots \longrightarrow x_{min}G(x_{min},Q^2)\cdots$$

this is an extreme approximation with potentially severe consequences!

QCD kinematic phase space



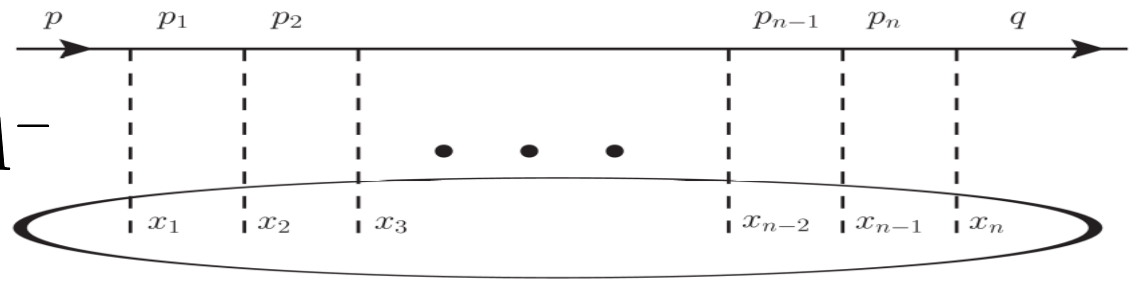
unifying saturation with high p_t (large x) physics?

<u>kinematics of saturation: *where is saturation applicable?*</u>

jet physics, high p_t (polar and azimuthal) angular correlations

cold matter energy loss, spin asymmetries, ...

Eikonal approximation



$$\bar{u}(q)\not{A}\,u(p) \rightarrow p\cdot A \sim p^+\,A^-$$

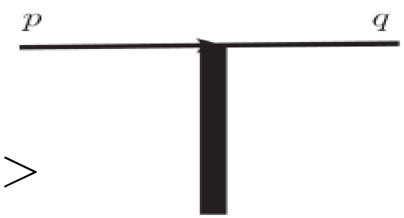
$$A^-_a(x^+, x_\perp) \equiv n^-\,S_a(x^+, x_\perp)$$

$$\begin{aligned} i\mathcal{M}_n \;&=\; 2\pi\delta(p^+ - q^+)\,\bar{u}(q)\,\not{n} \int d^2x_t\, e^{-i(q_t - p_t)\cdot x_t} \\ &\Big\{(ig)^n\,(-i)^n(i)^n \int dx_1^+\,dx_2^+ \cdots dx_n^+\,\theta(x_n^+ - x_{n-1}^+)\cdots\theta(x_2^+ - x_1^+) \\ &\big[S(x_n^+, x_t)\,S(x_{n-1}^+, x_t)\,\cdots S(x_2^+, x_t)S(x_1^+, x_t)\big]\Big\}\,u(p) \end{aligned}$$

$$i\mathcal{M} = \sum_n i\,\mathcal{M}_n$$

$$i\mathcal{M}(p,q) = 2\pi\delta(p^+ - q^+)\,\bar{u}(q)\,\not{n}\int d^2x_t\,e^{-i(q_t-p_t)\cdot x_t}\;[V(x_t) - 1]\;u(p)$$

with $V(x_t) \equiv \hat{P}\,\exp\left\{ig\int_{-\infty}^{+\infty} dx^+\,n^-\,S_a(x^+, x_t)\,t_a\right\}$

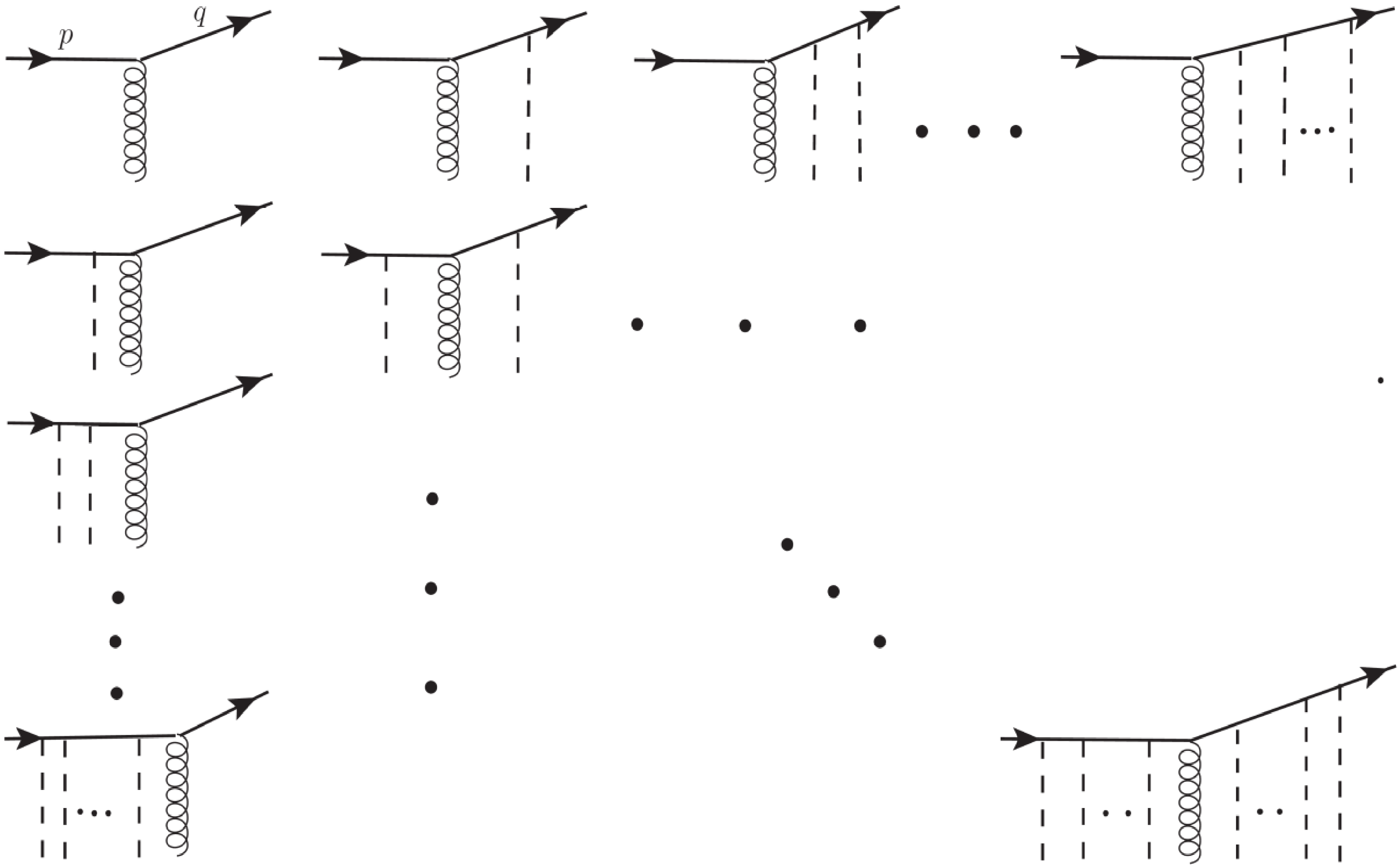


DIS, proton-nucleus collisions involve $< Tr\,V(x_\perp)\,V^\dagger(y_\perp) >$

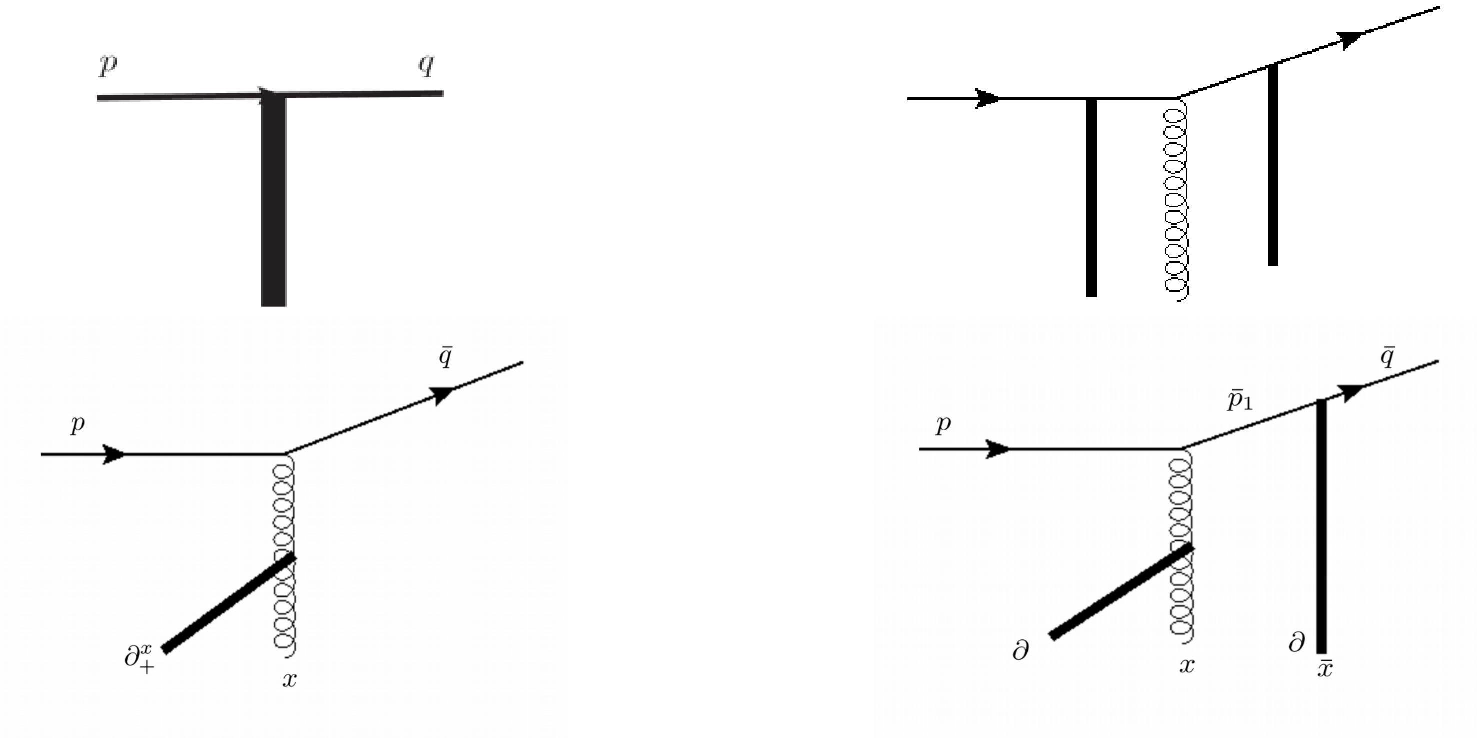
scattering from small x modes of the target can cause only a *small angle deflection*

include large x gluons of target: large angle deflection of quark

$$A^\mu_a(x^+, x^-, x_\perp)$$


p
q

full amplitude: $\mathbf{i}\mathcal{M} = \mathbf{i}\mathcal{M}_{\mathbf{eik}} + \mathbf{i}\mathcal{M}_{\mathbf{1}} + \mathbf{i}\mathcal{M}_{\mathbf{2}} + \mathbf{i}\mathcal{M}_{\mathbf{3}}$



small x (eikonal) limit:

$$A^\mu(x) \quad \rightarrow \quad n^- \, S(x^+, x_t)$$
$$n \cdot \bar{q} \quad \rightarrow \quad n \cdot p$$

$$i\mathcal{M} \longrightarrow i\mathcal{M}_{eik}$$

other components of target field contribute
new combinations of Wilson lines
helicity amplitudes: A_{LL}
target geometry: v_n at intermediate p_t

SUMMARY

CGC is a systematic approach to high energy collisions

CGC breaks down at large x (high p_t)

- ***a significant portion of EIC phase space is at large x***
- ***transition from DGLAP physics to CGC***

Toward a unified formalism:

- ***quark scattering from small and large x fields***
  - *particle production in pp, pA in both small and large x (p_t) kinematics*
- ***spin asymmetries***
- ***DIS structure functions***