Particle Production and Correlations in p(d)A Collisions

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Outline

We'll talk about single-particle production and two-particle correlations in p(d)A collisions:

- Hadron production in p(d)A collisions: going from mid- to forward rapidity at RHIC, transition from Cronin enhancement to suppression.

- Two-particle correlations (first-ever exact calculation!), back-to-back jets.

Hadron Spectra in p(d)A

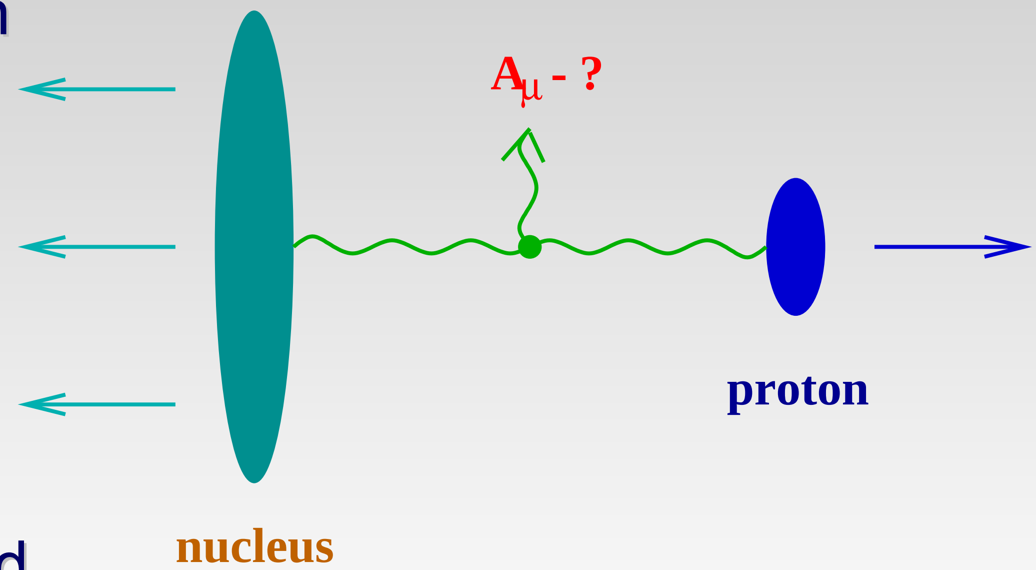
Let’s consider gluon production, it will have all the essential features, and quark production could be done by analogy.

Gluon Production in Proton-Nucleus Collisions (pA): Classical Field

To find the gluon production cross section in pA one has to solve the same classical Yang-Mills equations

$$D_\nu F^{\mu\nu} = J^\mu$$

for two sources – proton and nucleus.

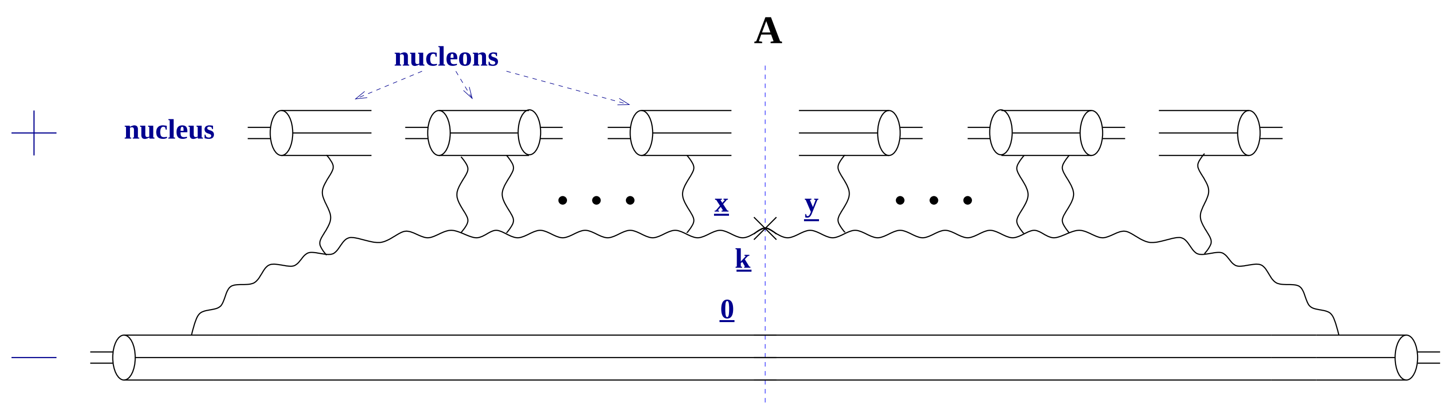


This classical field has been found by Yu. K., A.H. Mueller in '98

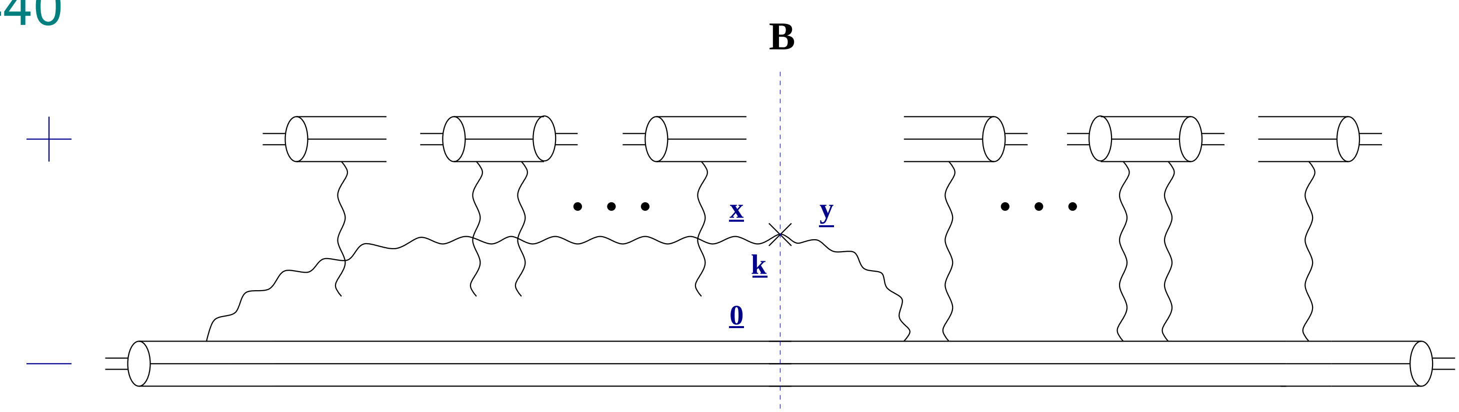
Gluon Production in pA: McLerran-Venugopalan model

The diagrams one has to resum are shown here: they resum powers of

$$\alpha_S^2 A^{1/3}$$



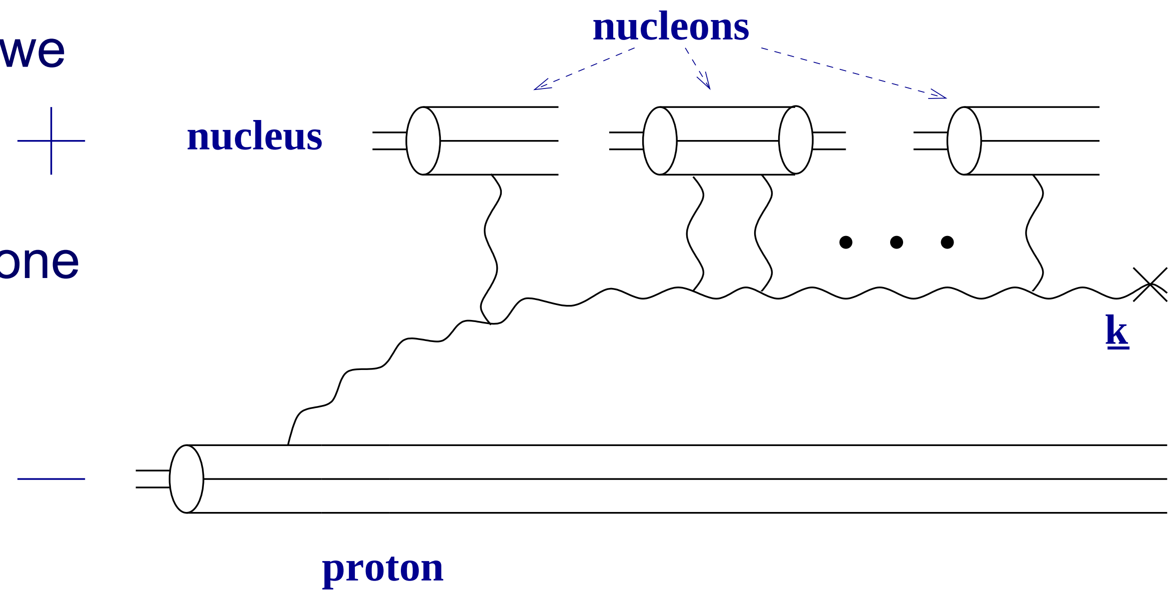
Yu. K., A.H. Mueller, hep-ph/9802440



Gluon Production in pA: McLerran-Venugopalan model

Classical gluon production: we need to resum only the multiple rescatterings of the gluon on nucleons. Here's one of the graphs considered.

Yu. K., A.H. Mueller, hep-ph/9802440



Resulting inclusive gluon production cross section is given by

$$\frac{d\sigma}{d^2k\,dy} = \frac{1}{(2\pi)^2} \int d^2b\, d^2x\, d^2y\, e^{i\underline{k}\cdot(\underline{x}-\underline{y})} \underbrace{\frac{\alpha C_F}{\pi^2} \frac{\underline{x}\cdot\underline{y}}{\underline{x}^2\,\underline{y}^2}}_{\text{proton's wave function}} \left[N_G(\underline{x}) + N_G(\underline{y}) - N_G(\underline{x}-\underline{y}) \right]$$

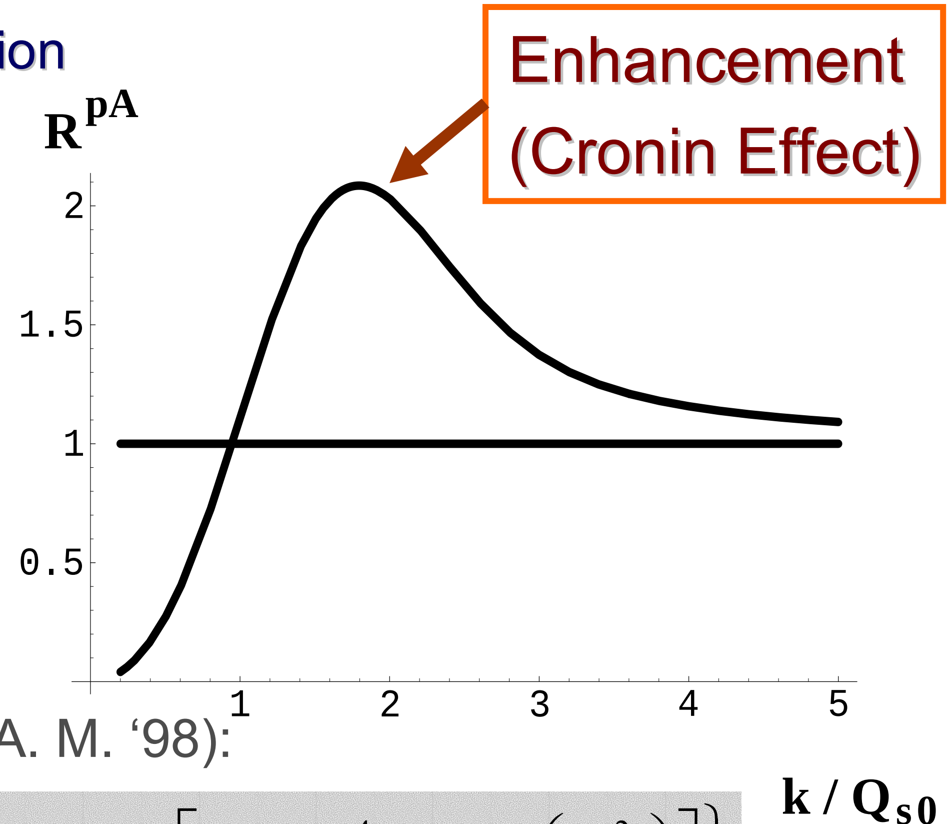
With the gluon-gluon dipole-nucleus forward scattering amplitude

$$N_G(x, Y=0) = 1 - e^{-x^2 Q_s^2/4}$$

McLerran-Venugopalan model: Cronin Effect

To understand how the gluon production in pA is different from independent superposition of *A* proton-proton (pp) collisions one constructs the quantity

$$R^{pA} = \frac{\frac{d\sigma^{pA}}{d^2k\,dy}}{A\,\frac{d\sigma^{pp}}{d^2k\,dy}}$$



We can plot it for the quasi-classical cross section calculated before (Y.K., A. M. '98):

$$R^{pA}(k_T) = \frac{k^4}{Q_S^4}\left\{-\frac{1}{k^2} + \frac{2}{k^2}e^{-k^2/Q_S^2} + \frac{1}{Q_S^2}e^{-k^2/Q_S^2}\left[\ln\frac{Q_S^4}{4\Lambda^2 k^2} + Ei\left(\frac{k^2}{Q_S^2}\right)\right]\right\}$$

Classical gluon production leads to Cronin effect!
Nucleus pushes gluons to higher transverse momentum!

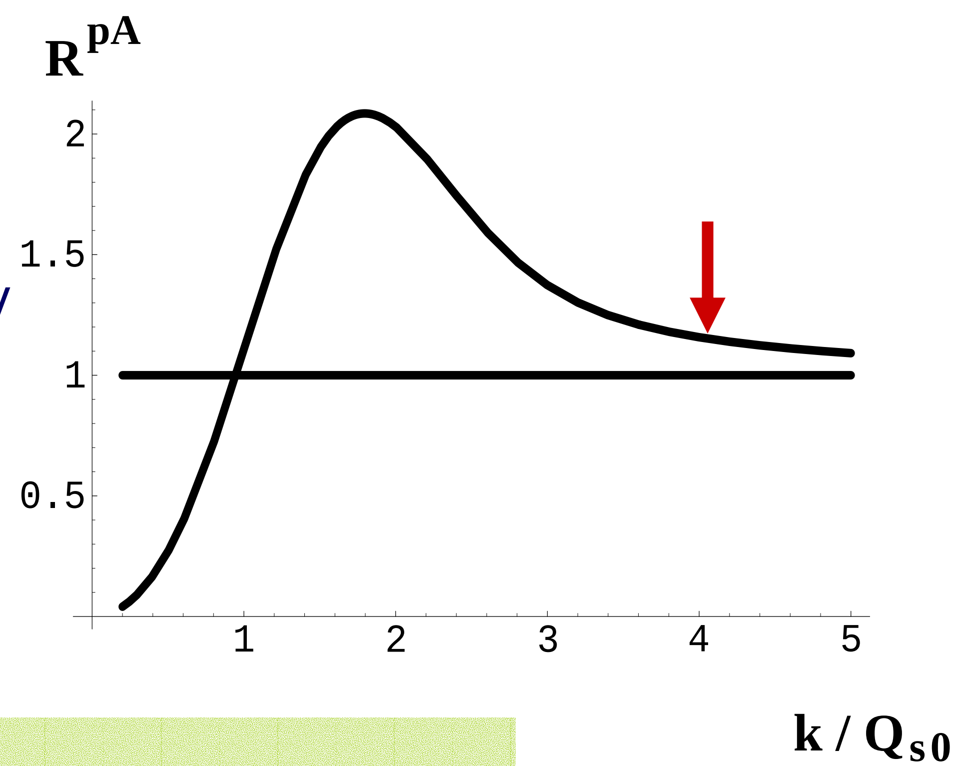
Kharzeev
Yu. K.
Tuchin '03

(see also Kopeliovich et al, '02; Baier et al, '03; Accardi and Gyulassy, '03)

Proof of Cronin Effect

- Plotting a curve is not a proof of Cronin effect: one has to trust the plotting routine.

- To prove that Cronin effect actually does take place one has to study the behavior of R^{pA} at large k_T (cf. Dumitru, Gelis, Jalilian-Marian, quark production, '02-'03):



Note the sign!

$$R^{pA}(k_T) = 1 + \frac{3}{2}\frac{Q_S^2}{k^2}\ln\frac{k^2}{\Lambda^2} + \ldots \quad , \qquad k_T \to \infty$$

R^{pA} approaches 1 from above at high p_T ⇨ there is an enhancement!

Cronin Effect

$$R^{pA}(k_T) = 1 + \frac{3}{2}\frac{Q_S^2}{k^2}\ln\frac{k^2}{\Lambda^2} + \ldots \quad , \qquad k_T \to \infty$$

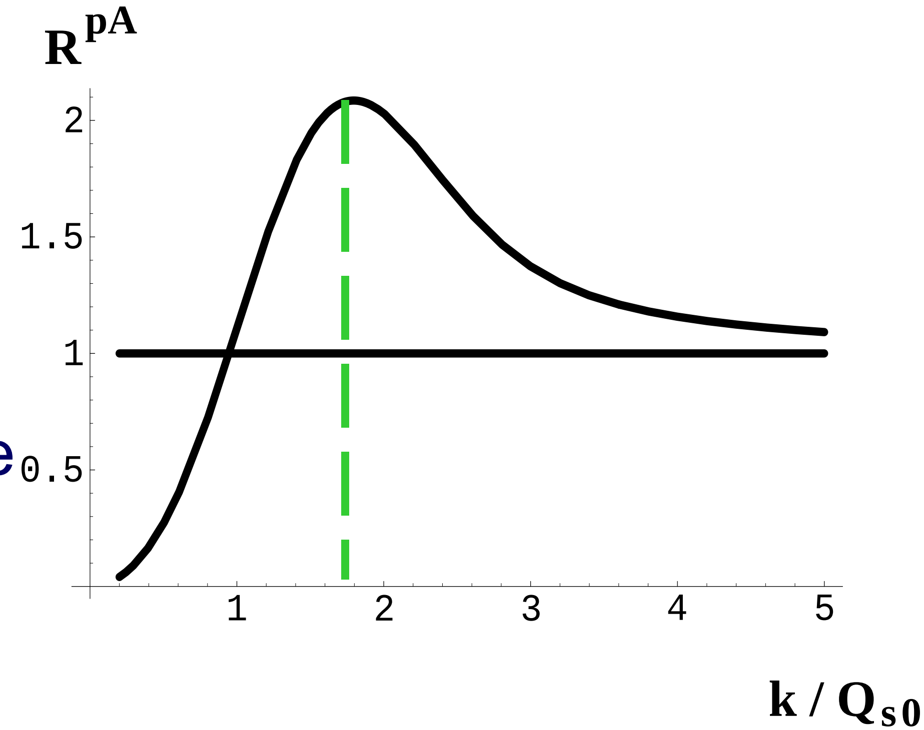
The position of the Cronin maximum is given by

$k_T \sim Q_S \sim A^{1/6}$

as $Q_S^2 \sim A^{1/3}$.

Using the formula above we see that the height of the Cronin peak is

$R^{pA}(k_T = Q_S) \sim \ln Q_S \sim \ln A$.



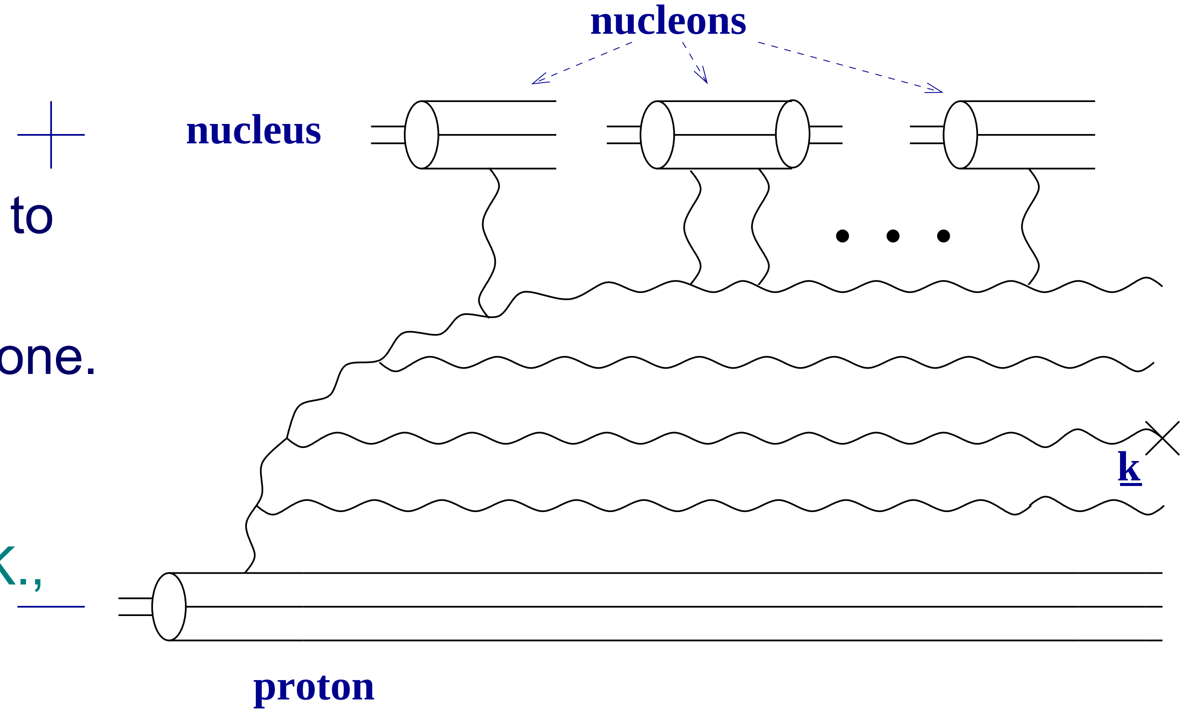
⇨ The height and position of the Cronin maximum are increasing functions of centrality (A)!

Including Quantum Evolution

To understand the energy dependence of particle production in pA one needs to include quantum evolution resumming graphs like this one. This resums powers of

$\alpha \ln 1/x = \alpha Y$.

This has been done in Yu. K., K. Tuchin, hep-ph/0111362.



The rules accomplishing the inclusion of quantum corrections are

Proton's LO wave function ⇨ Proton's BFKL wave function and $N(x, Y=0) \Rightarrow N(x, Y)$

where the dipole-nucleus amplitude N is to be found from (Balitsky, Yu. K.)

$$\frac{\partial N(Y, k^2)}{\partial Y} = \alpha_s K_{BFKL} \otimes N(Y, k^2) - \alpha_s [N(Y, k^2)]^2$$

Including Quantum Evolution

Amazingly enough, gluon production cross section reduces to k_T –factorization expression (Yu. K., Tuchin, '01):

$$\frac{d\sigma^{pA}}{d^2k\,dy} = \frac{2\alpha_S}{C_F}\frac{1}{k^2}\int d^2q\,\phi_p(\underline{q}, Y-y)\,\phi_A(\underline{k}-\underline{q}, y)$$

with the prot ated

distributions'

$\phi^{p,A}(k, y$ $N_G^{p,A}(x, b, y)$

with $N_G^{p,A}$ the le on a p or A.