Heavy Ion Physics @ eRHIC

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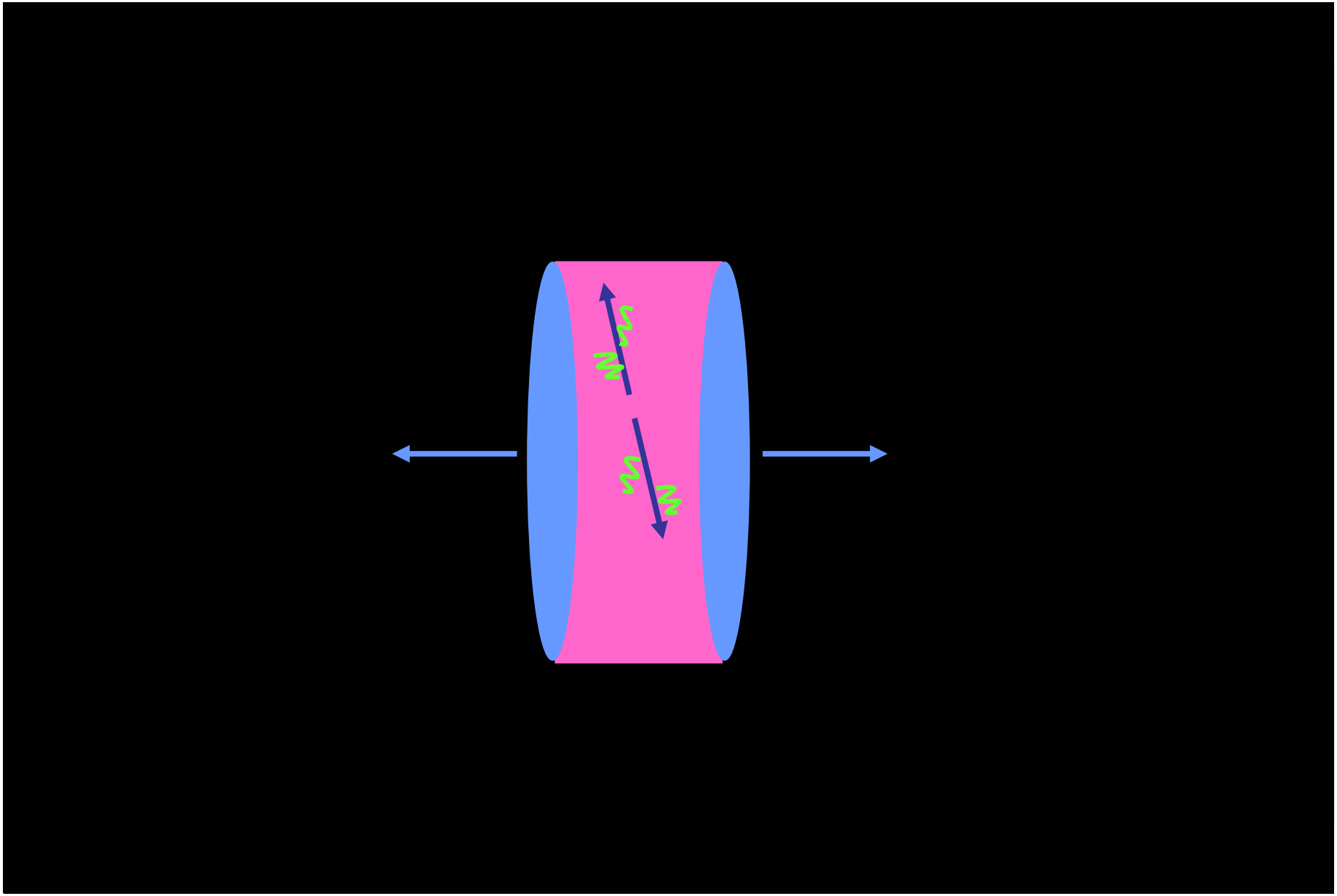
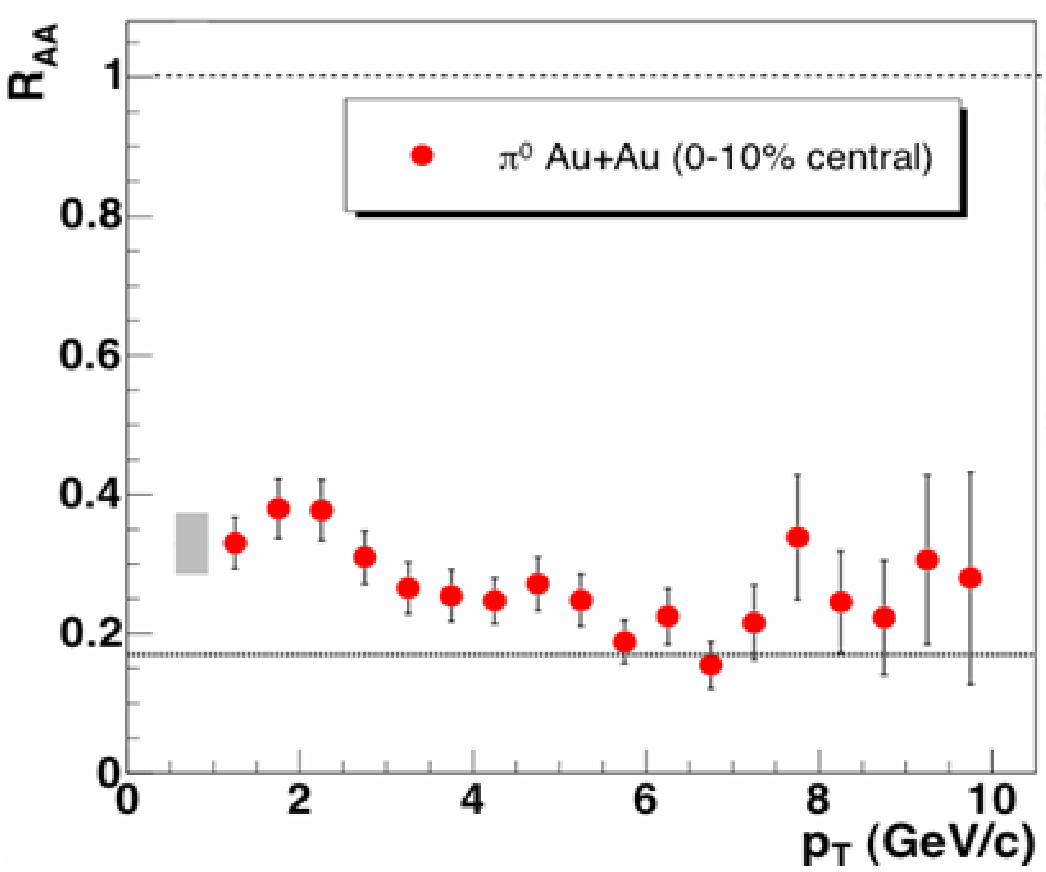
QCD in Nuclei

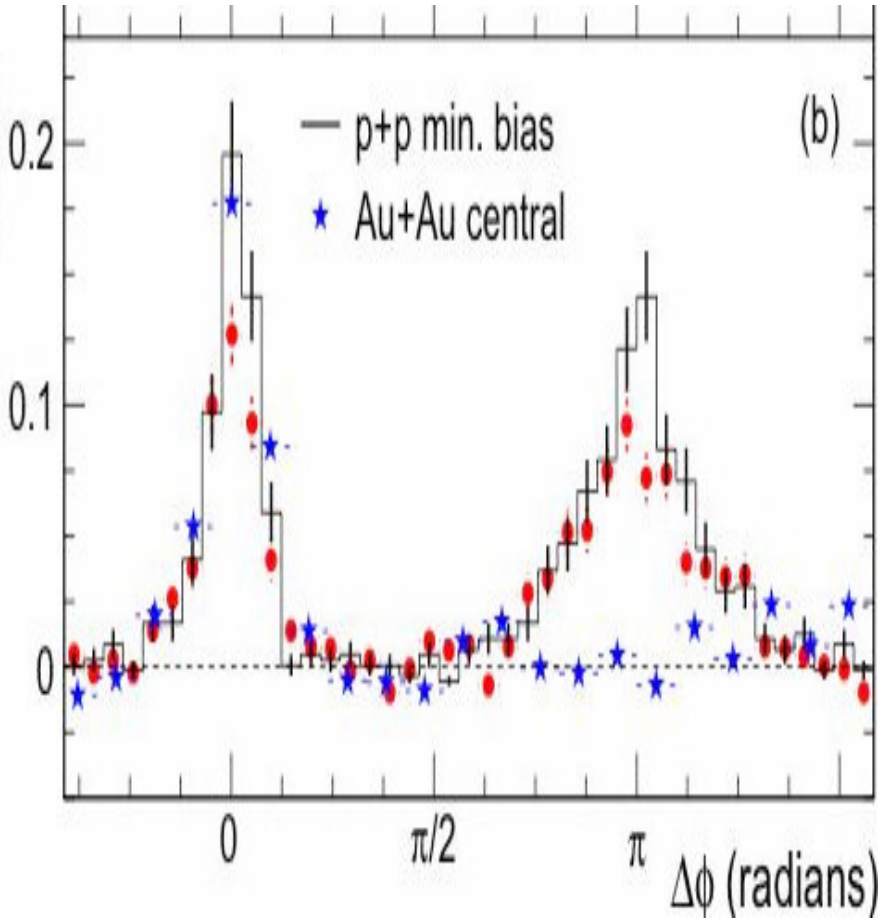
- *Gluonic matter under extreme conditions*
  - *Inclusive:*
    - F_2 , F_L , xG,
  - *Semi inclusive/diffractive:*
    - F^D , *vector meson production, …*
- *Hadronization in the media, energy loss, p_t broadening, …*
- *…….*

The Search for Quark Gluon Plasma



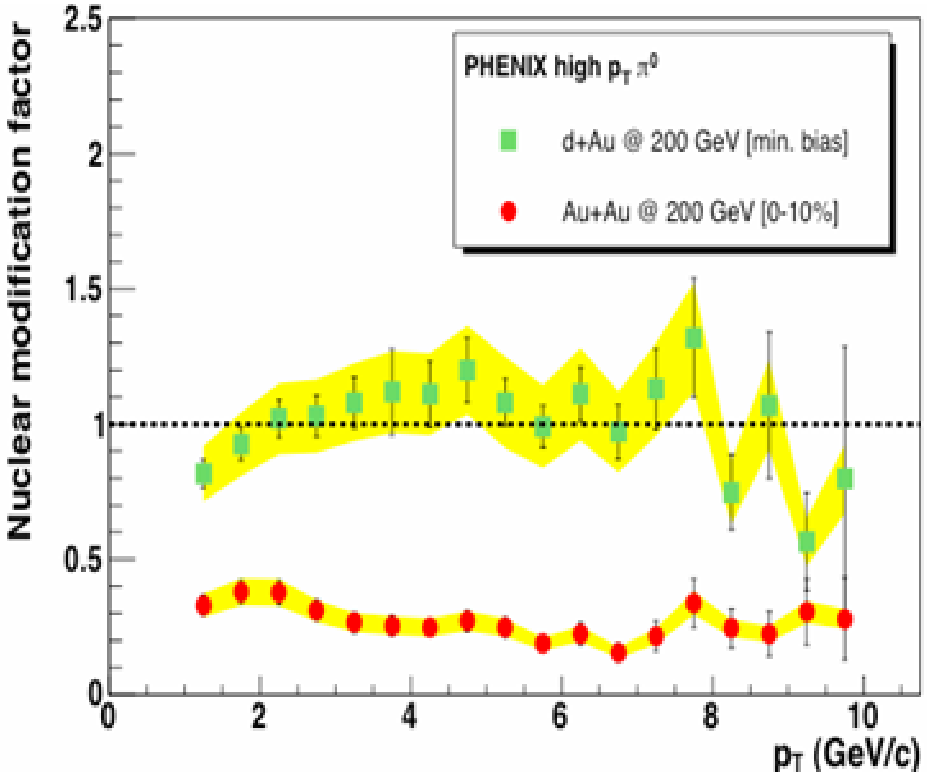
Gold-Gold Collisions at RHIC

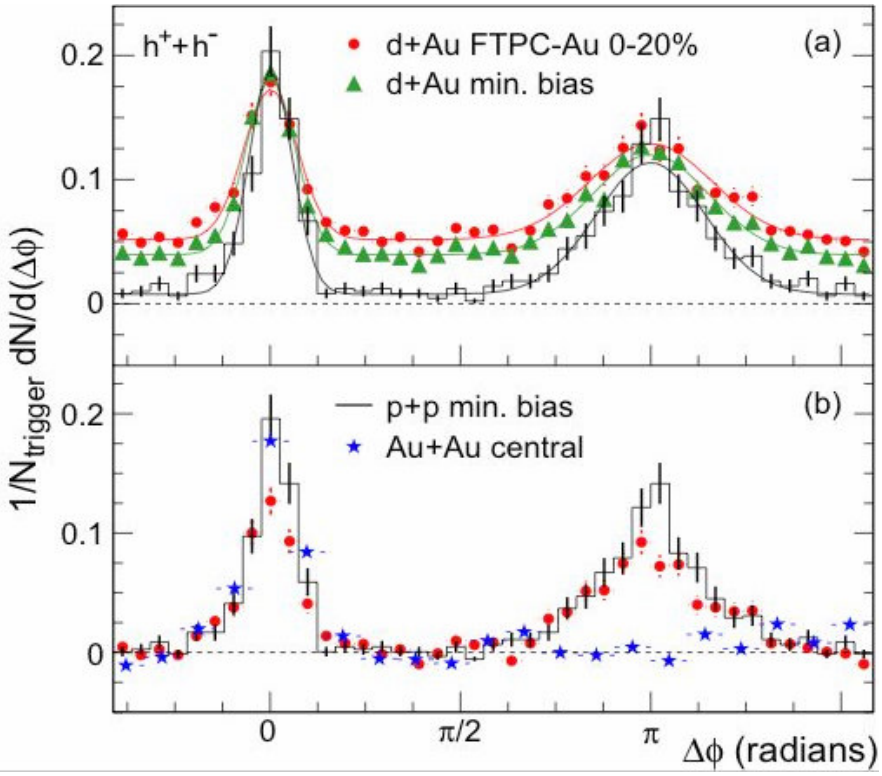




Suppression of single hadron production
Disappearance of back to back correlations

Deuteron-Gold Collisions at RHIC: mid-rapidity





Medium effects overwhelm initial state effects

Kinematics: $x_{bj} > 10^{-2}$ for $p_t > 2$ GeV

Nuclear structure functions measured in DIS

Gluons are less constrained

From mid to forward rapidity at RHIC

Kinematics: $\sqrt{s} = 200\,\mathrm{GeV}$

$$x_{projectile} \sim \frac{p_t}{\sqrt{s}} e^{y} \qquad x_{target} \sim \frac{p_t}{\sqrt{s}} e^{-y}$$

Consider $p_t = 2\,\mathrm{GeV}$

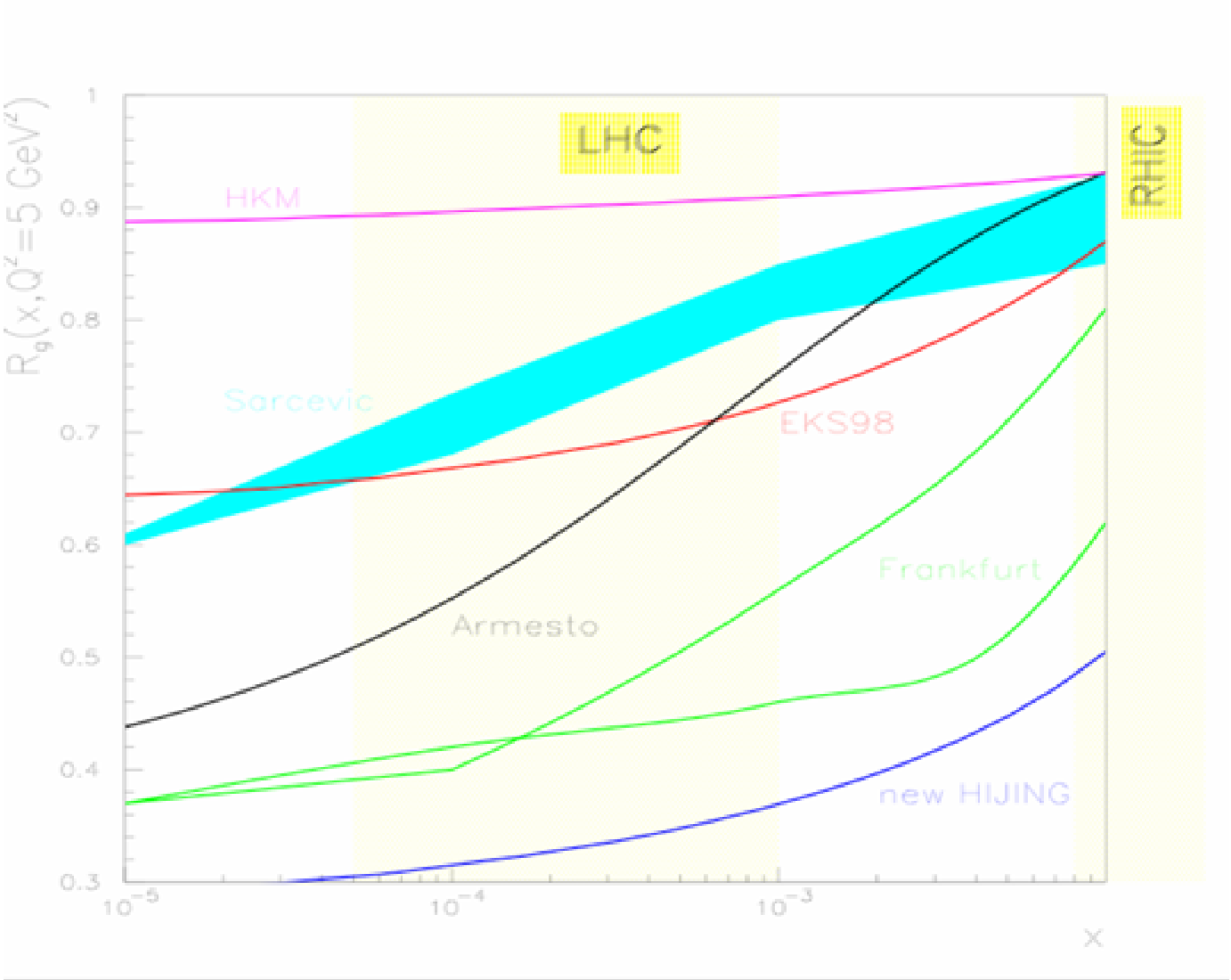
Mid rapidity:

$$y = 0: \quad x_{projectile} = x_{target} \sim 10^{-2}$$

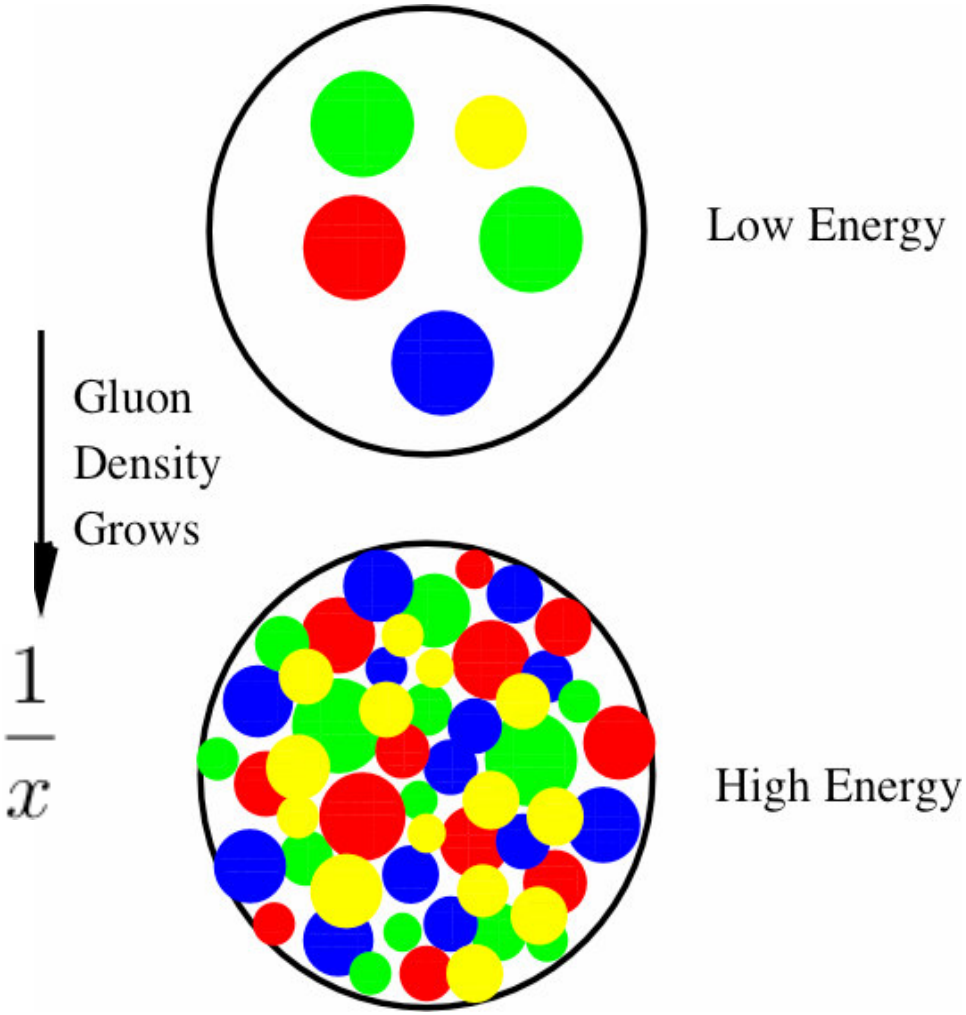
Forward rapidity RHIC: ***(similar to mid rapidity LHC)***

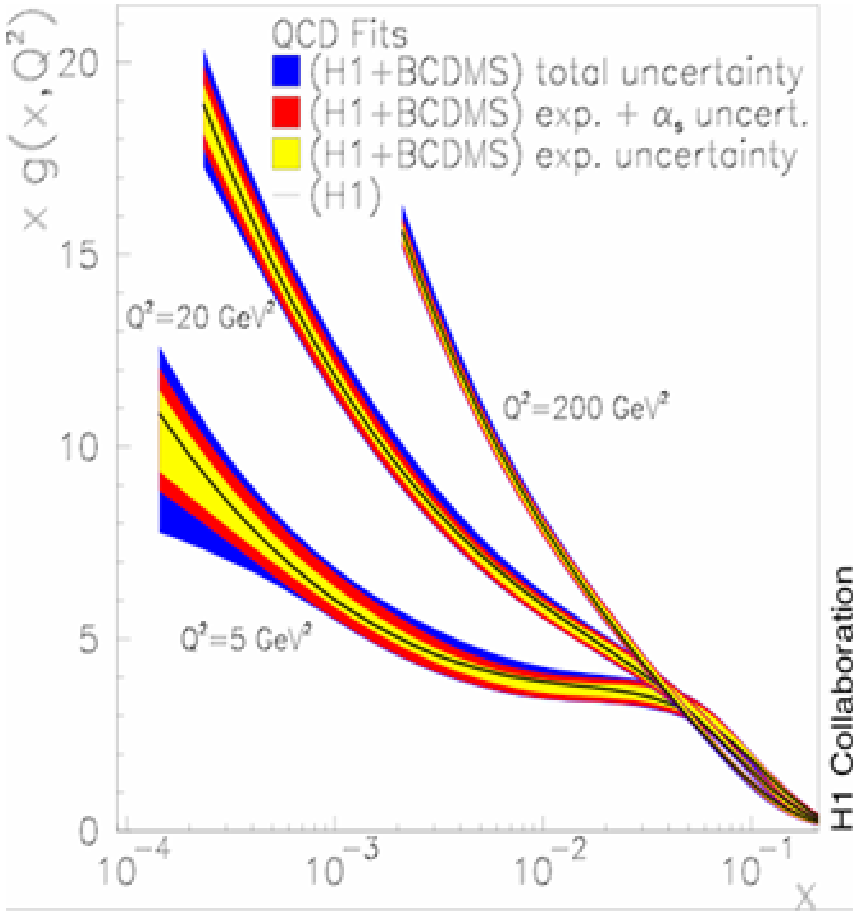
$$y = 4: \quad x_{projectile} \sim 0.5 \quad x_{target} \sim 2 \times 10^{-4}$$

Modification of Gluons in Nuclei



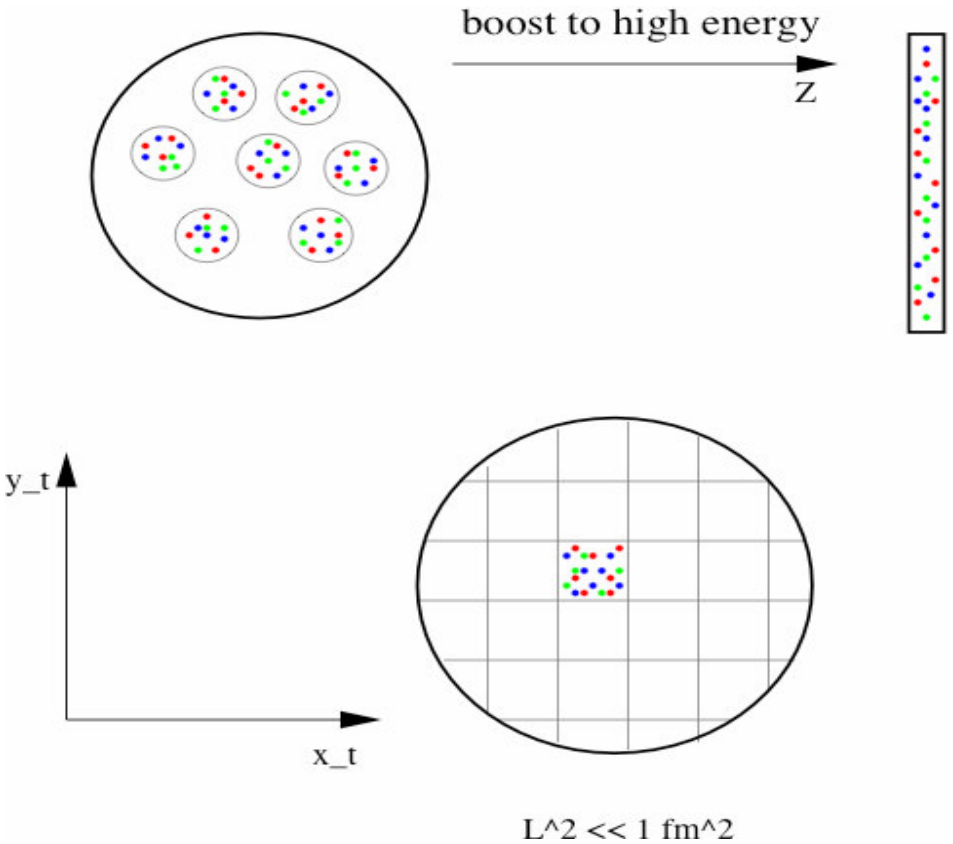
The Color Glass Condensate

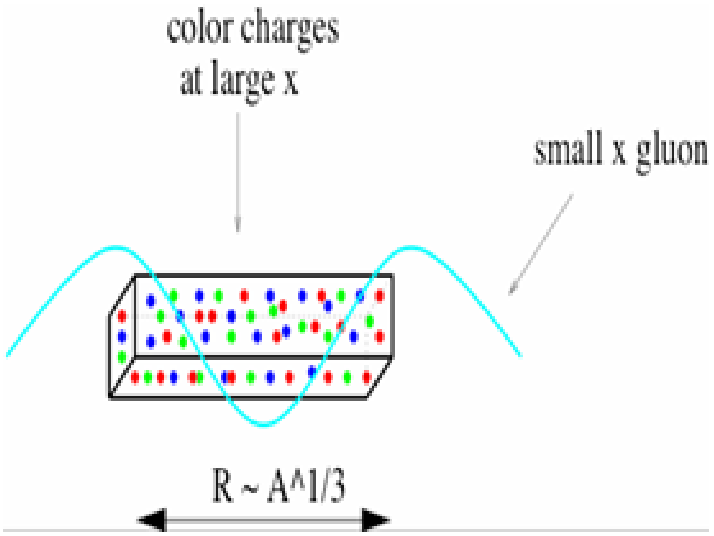




CGC: An Effective Theory of QCD at high energy

Consider large nucleus in the IMF frame: $P^+ \to \infty$





One large component of the current-others suppressed by $\frac{1}{P+}$

Wee partons see a large density of valence color charges at small transverse resolutions

The effective action

$$S = -\frac{1}{4}\int d^4x\, G^2 \longrightarrow \text{Yang-Mills}$$

coupling of color charges to gluon fields

$$+ \frac{i}{N_c}\int d^2x_t\, dx^-\, \delta(x^-)\,\mathrm{tr}\;\rho(x_t)\, U_{-\infty,\infty}[A^-](x^-, x_t)$$

$$+ i\int d^2x_t F[\rho^a(x_t)] \longrightarrow$$

weight function for color charge configurations

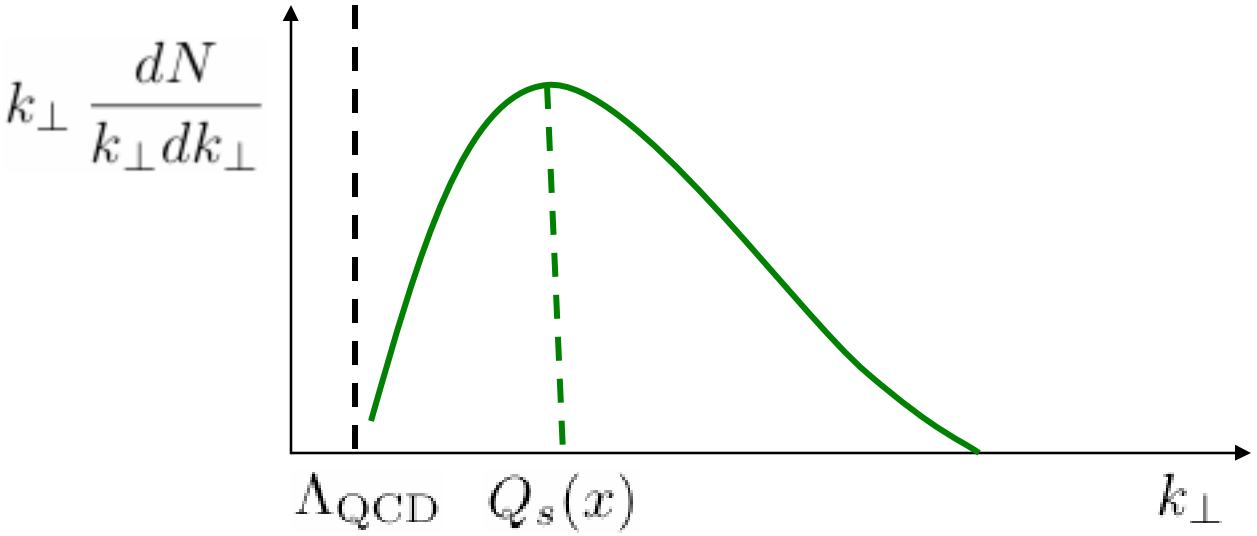
where

$$U[A^-] \equiv \hat{P}\, e^{-ig\int dx^+\, A_a^-\, T_a}$$

MV:

$$F[\rho] \to \frac{\rho^2}{\mu^2} \qquad \mathrm{tr}\,\rho\,\mathrm{U} \to \rho\mathrm{A}^-$$

Hadron/NUCLEUS at high energY is a Color Glass Condensate



- ✓ Gluons are colored
- ✓ Random sources evolving on time scales much larger than natural time scales-very similar to spin glasses
- ✓ Bosons with large occupation $\# \sim \frac{1}{\alpha_S}$ - form a condensate
- ✓ Typical momentum of gluons is Q_s

$$Q_s\,(x, A, b_t) >> \Lambda_{QCD}$$

Wilson RG at small x

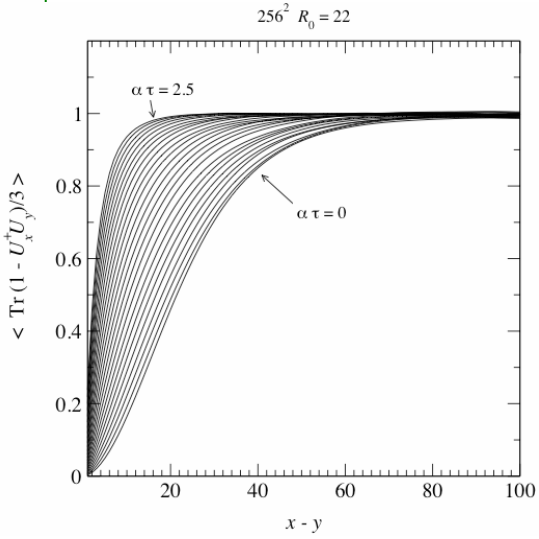
$$\sigma^a(x)[\rho] = < \delta\rho_Y^a(x) >_\rho \; ; \; \chi^{ab}(x,y)[\rho] = < \delta\rho_Y^a(x)\delta\rho_Y^b(y) >_\rho$$

$$\sigma^a(x) = \frac{1}{2}\int d^2y \frac{\delta\chi^{ab}(x,y)}{\delta\rho_Y^b(y)}$$

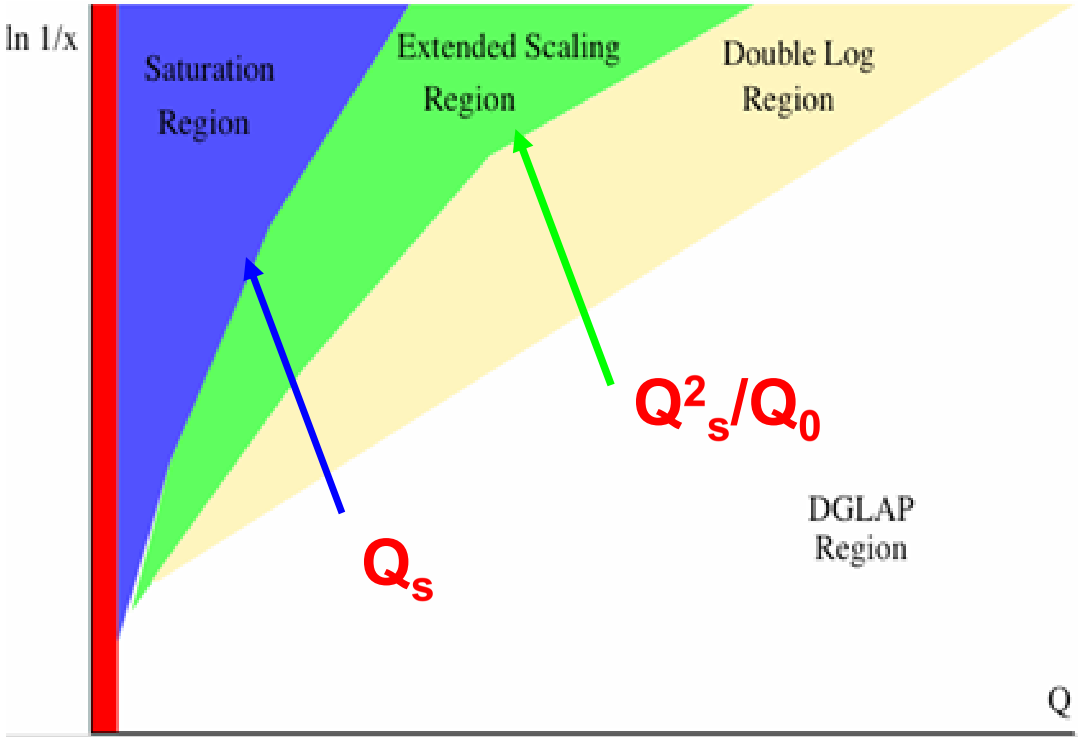
$$\frac{\partial W_x[\rho]}{\partial \ln(1/x)} = \frac{1}{2}\int_{x_\perp,y_\perp} \frac{\delta}{\delta\rho_x^a(x_\perp)}\chi^{ab}(x_\perp,y_\perp)[\rho]\frac{\delta}{\delta\rho_x^b(y_\perp)}W_x[\rho]$$

JIMWLK equations describe evolution of all N-point correlation functions of Wilson lines with energy (log 1/x)

recover BFKL in the low density regime



A New Paradigm of QCD



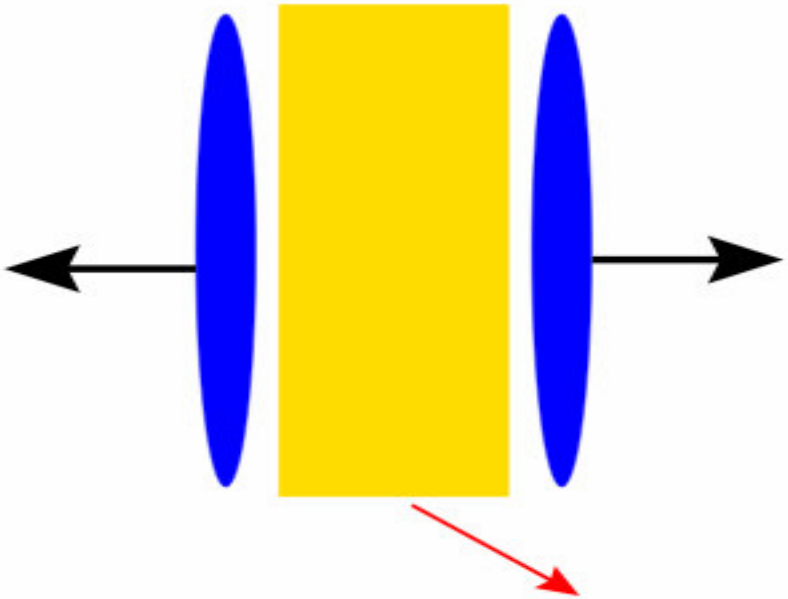
Saturation region: dense system of gluons

Extended scaling region: dilute system - anomalous dimension

Double Log: BFKL meets DGLAP

DGLAP: collinearly factorized pQCD

Colliding Sheets of CGC at High Energies



Initial energy and multiplicity of produced gluons depend on $\mathbf{Q_s}$

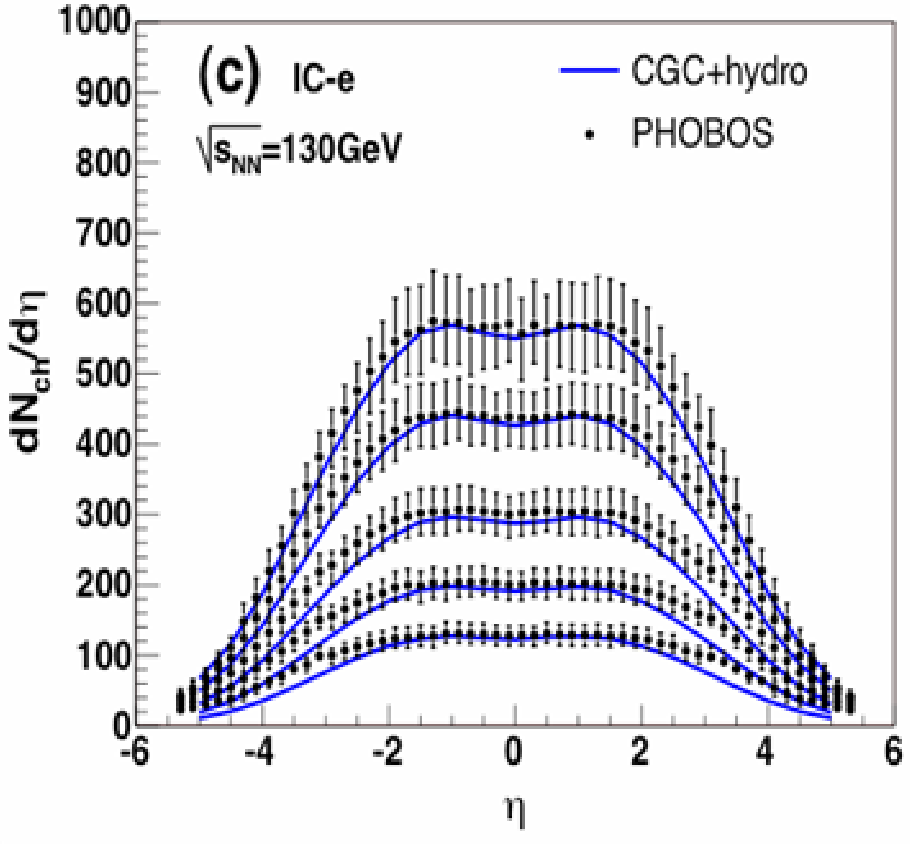
$$\frac{1}{\pi R^2}\frac{dE_\perp}{d\eta} = \frac{0.25}{g^2}Q_s^3$$

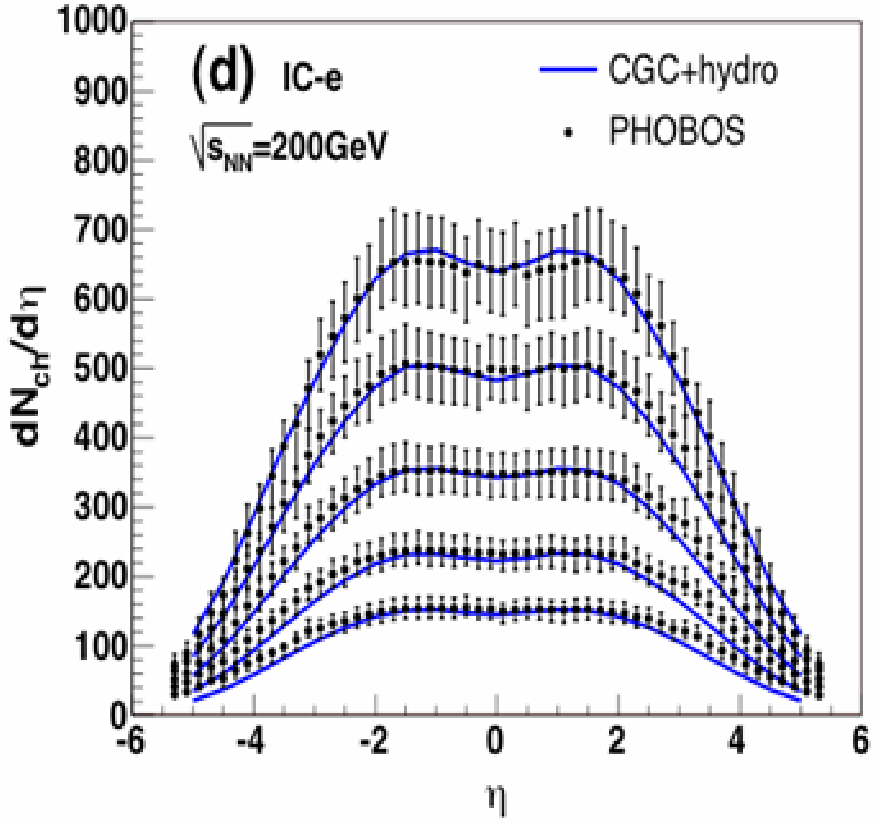
$$\frac{1}{\pi R^2}\frac{dN}{d\eta} = \frac{0.3}{g^2}Q_s^2$$

Thermalization? Instabilities, ….

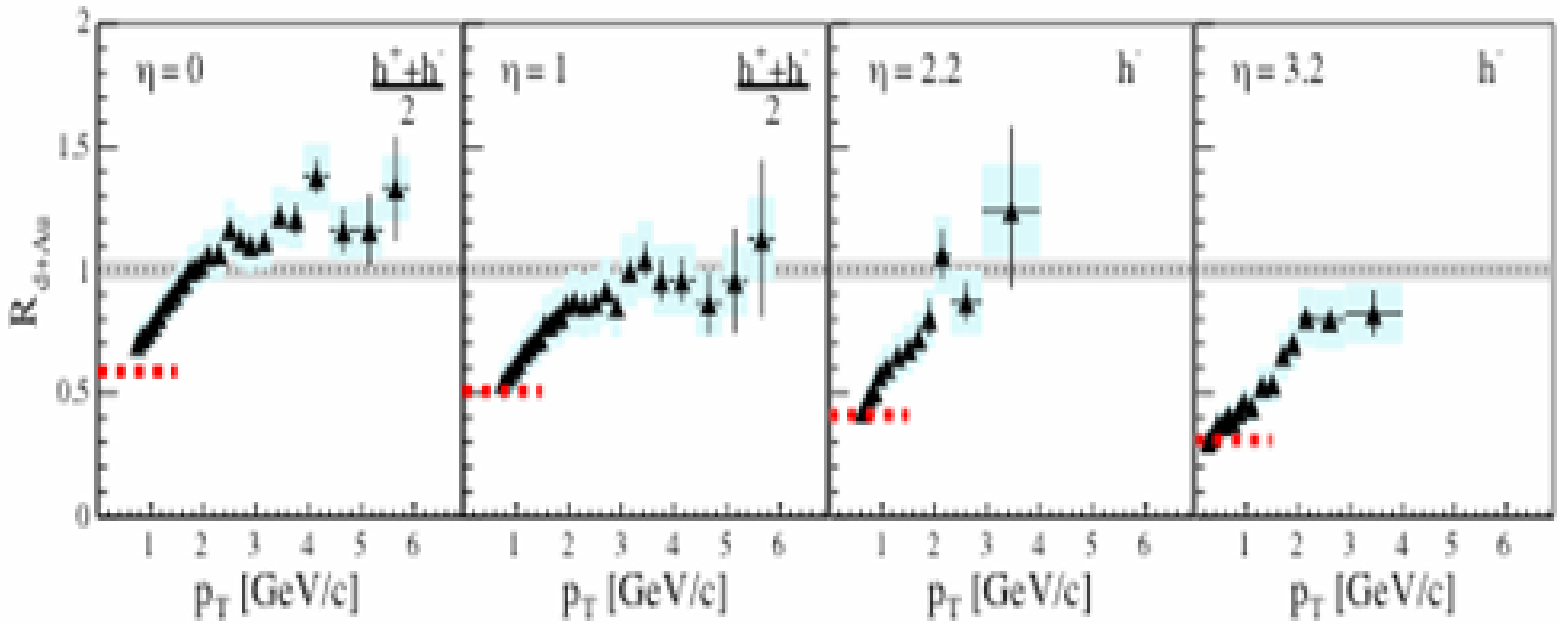
Colliding Sheets of CGC at High Energies

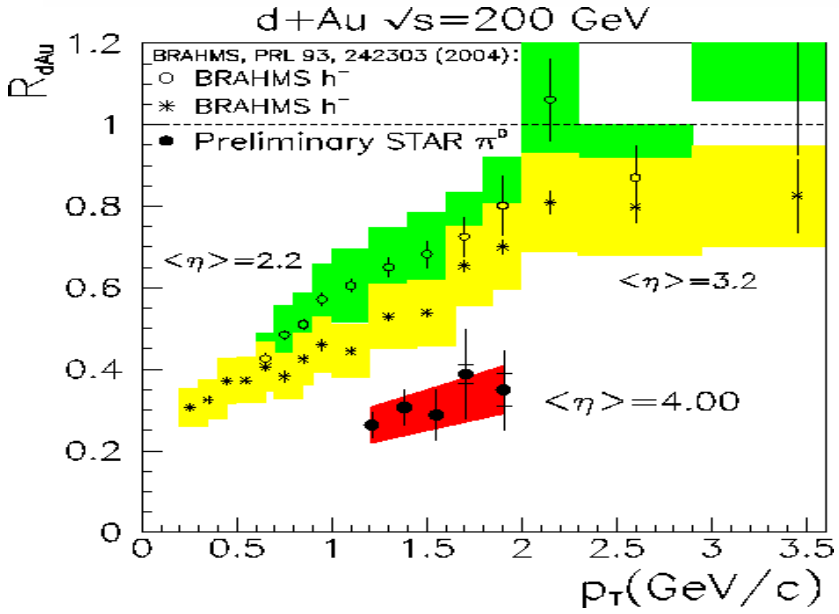
adding final state effects: hydro, energy loss





From mid to forward rapidity at RHIC

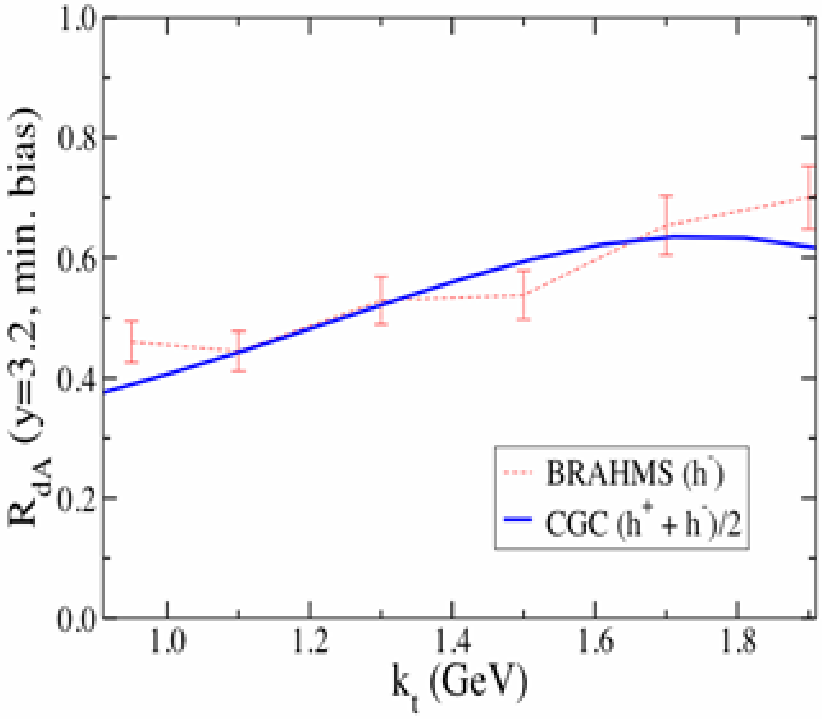


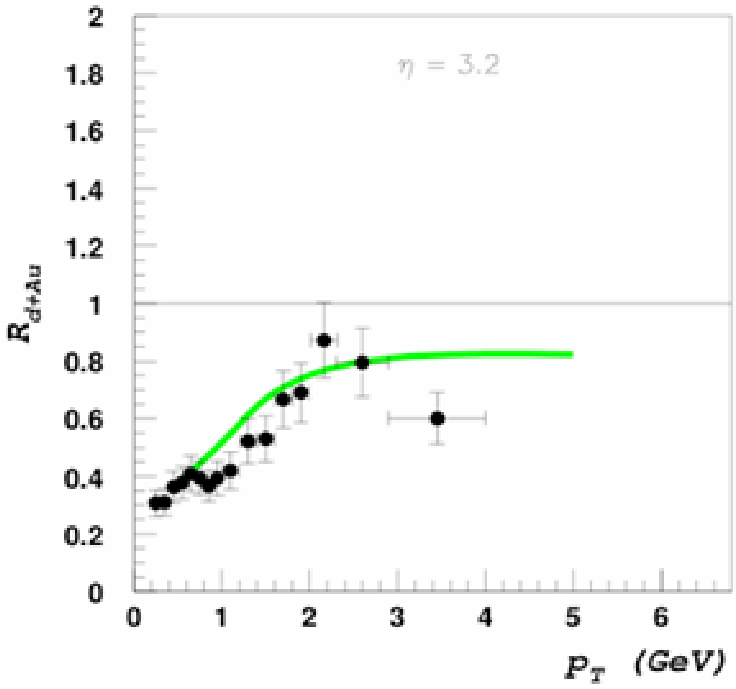


predictions by CGC: suppress (due to evolution in x)

all others: enhancement !

Hadron Production in dA at RHIC



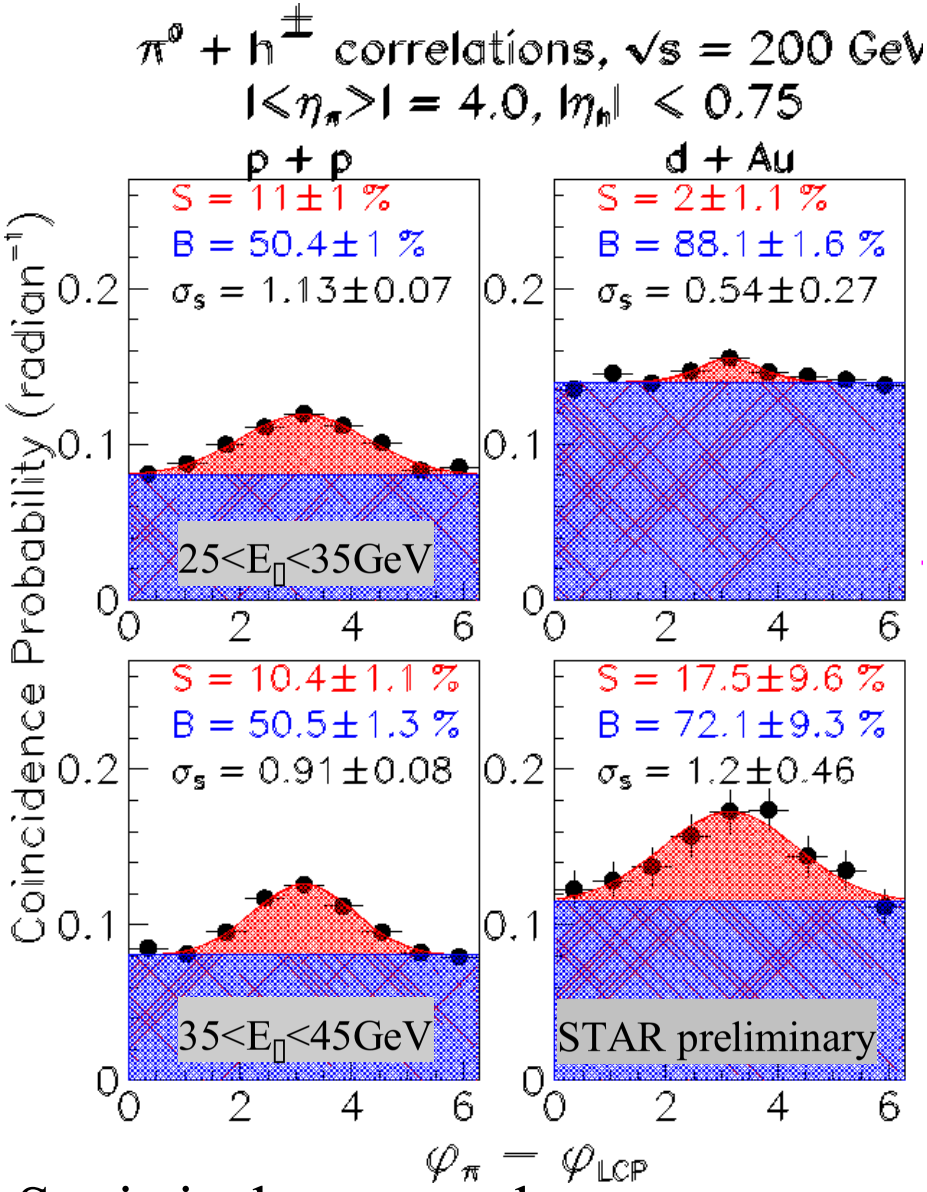


JJM

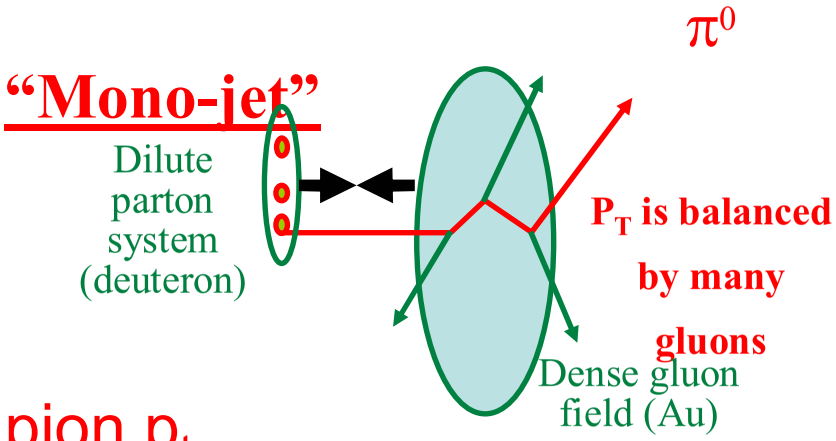
KKT

Caution: other models can now fit the data !

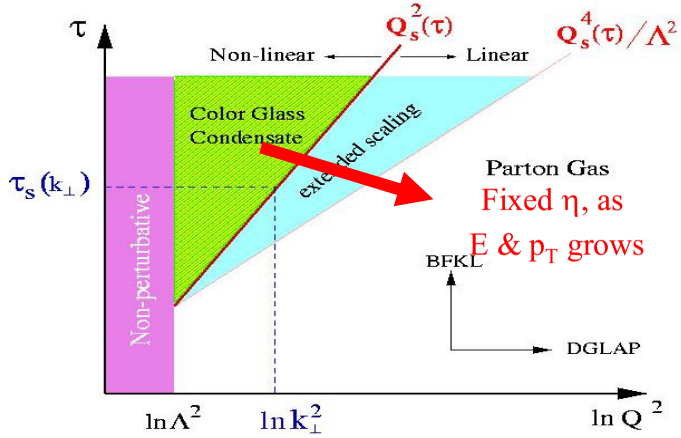
d-Au: two particle correlations



Statistical errors only

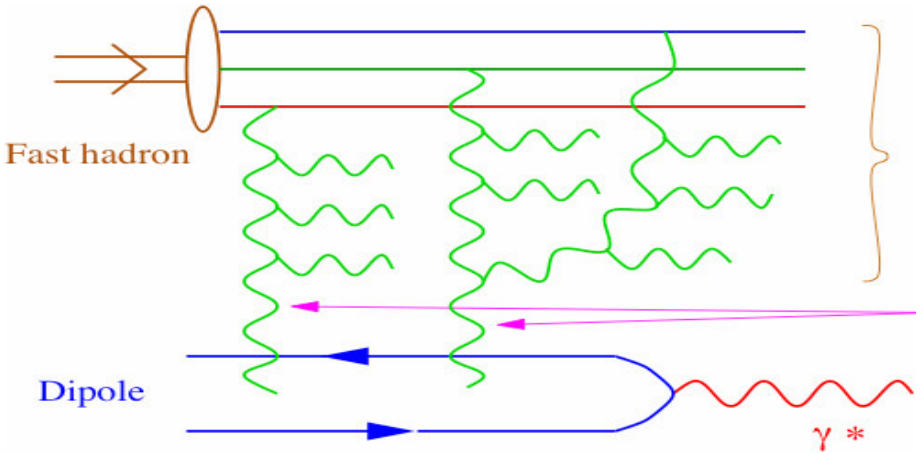


pion p_t increasing



DIS Structure Functions

$$F_2 = \frac{Q^2}{4\pi^2 \alpha_{em}} \sigma^{\gamma^* p}$$

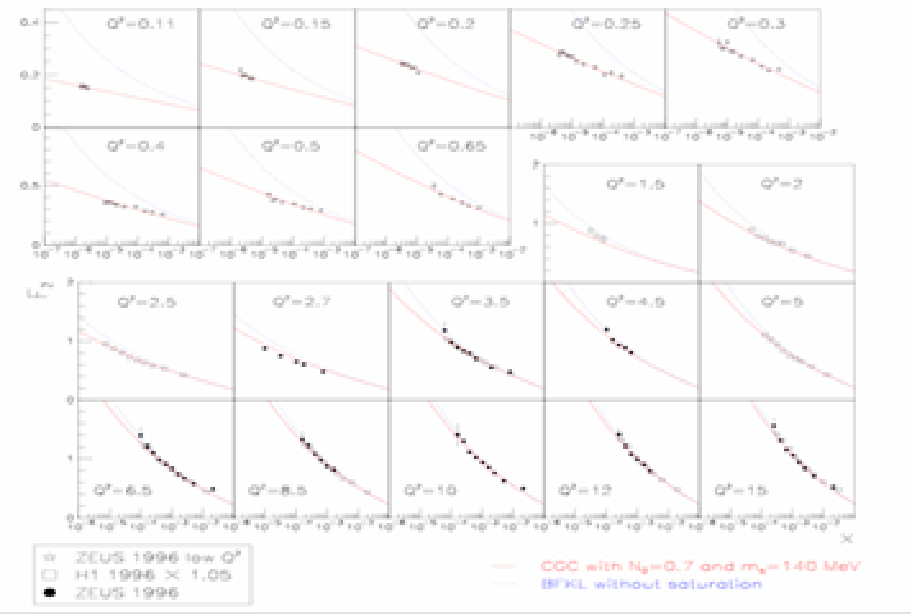


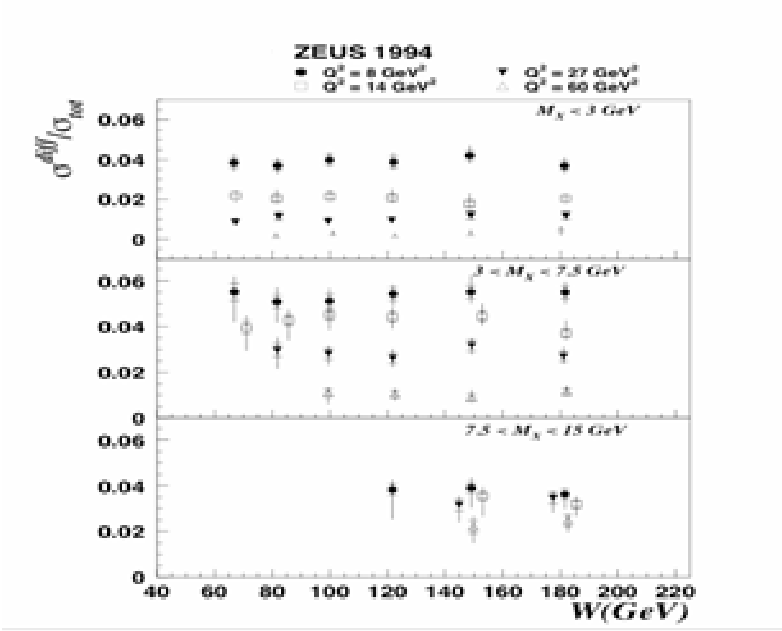
$$\sigma^{\gamma^* p} = \int_0^1 dz \int d^2 r_t \, d^2 b_t |\Psi(z, r_t, Q^2)|^2 \, \sigma_{dipole}(x, r_t, b_t)$$

$$\sigma_{dipole}(x, r_t, b_t) \equiv \frac{2}{N_c} Tr < 1 - U(x_t) \, U^\dagger(y_t) >_x$$

similar relations for F_L , F^D, …
applications to:
DIS at HERA
DIS on nuclei: NMC,…

CGC at HERA ?



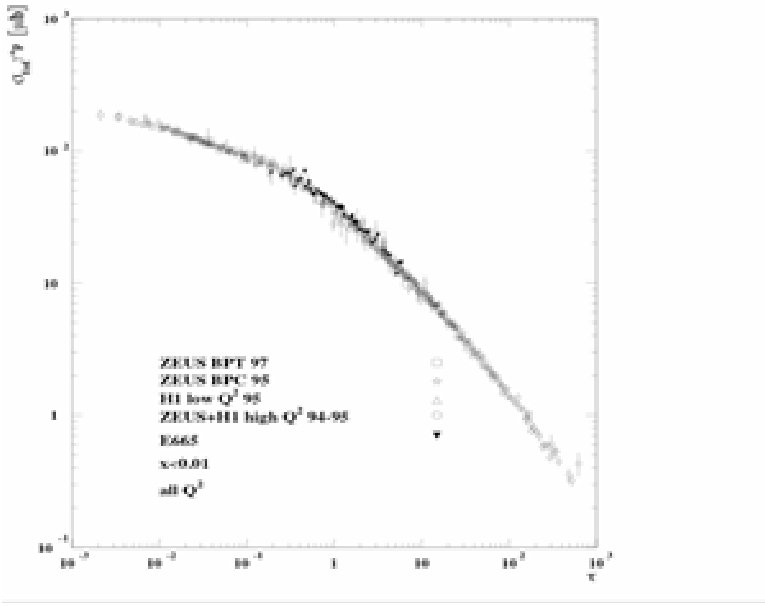


Structure Functions

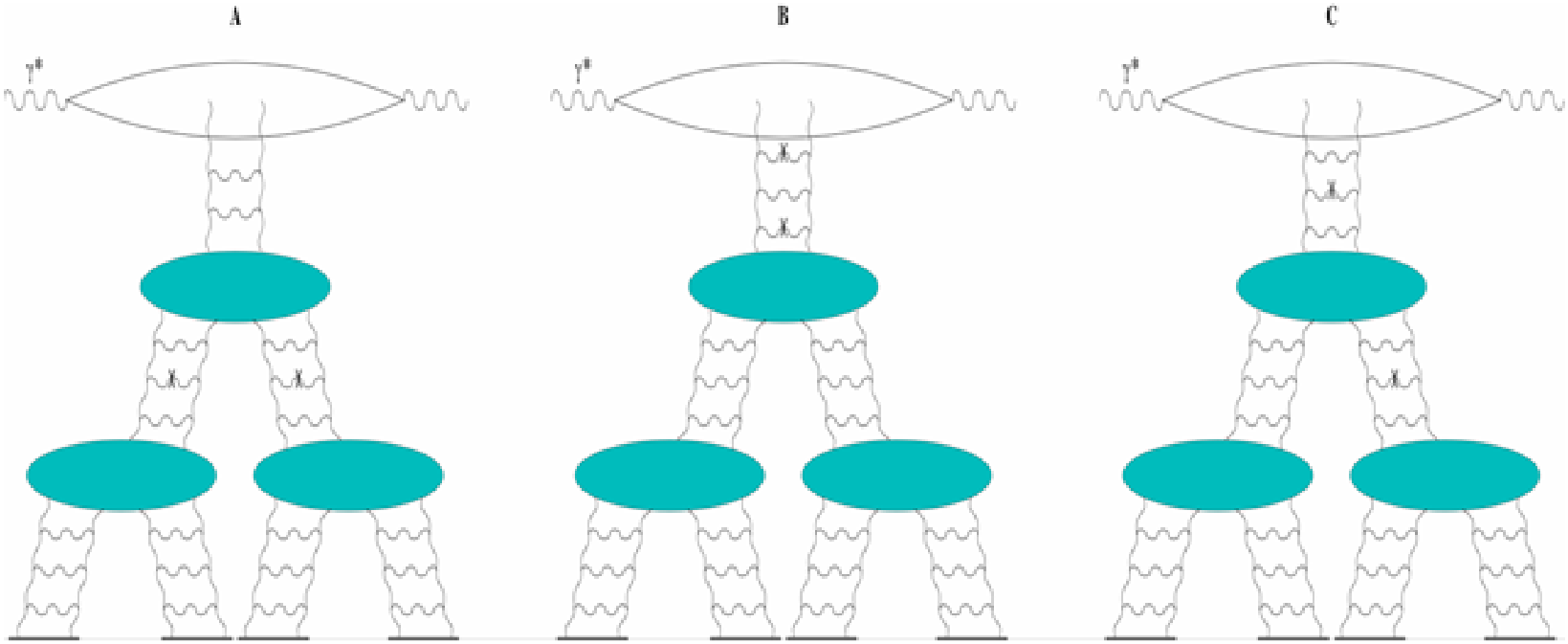
$\sigma^{diff}/\sigma^{tot}$ energy dependence

Geometric Scaling

Vector mesons



Two Hadron Production in DIS



two hadrons are far apart in rapidity: study correlations

AGK + fans is violated, first known case !

Summary

★ We may be probing small x QCD at RHIC

- Mid Rapidity AA:
  - Multiplicities,…
- Forward Rapidity dA:
  - Single inclusive hadron production
  - Two particle correlations

★ **We need eRHIC: *precision* + *kinematics***

- **Independent, large lever arms in x, Q**
- **Ability to vary energy:**
  - **F_L (very sensitive probe of CGC)**
- **Diffraction**
- **…….**

CONCLUSIONS

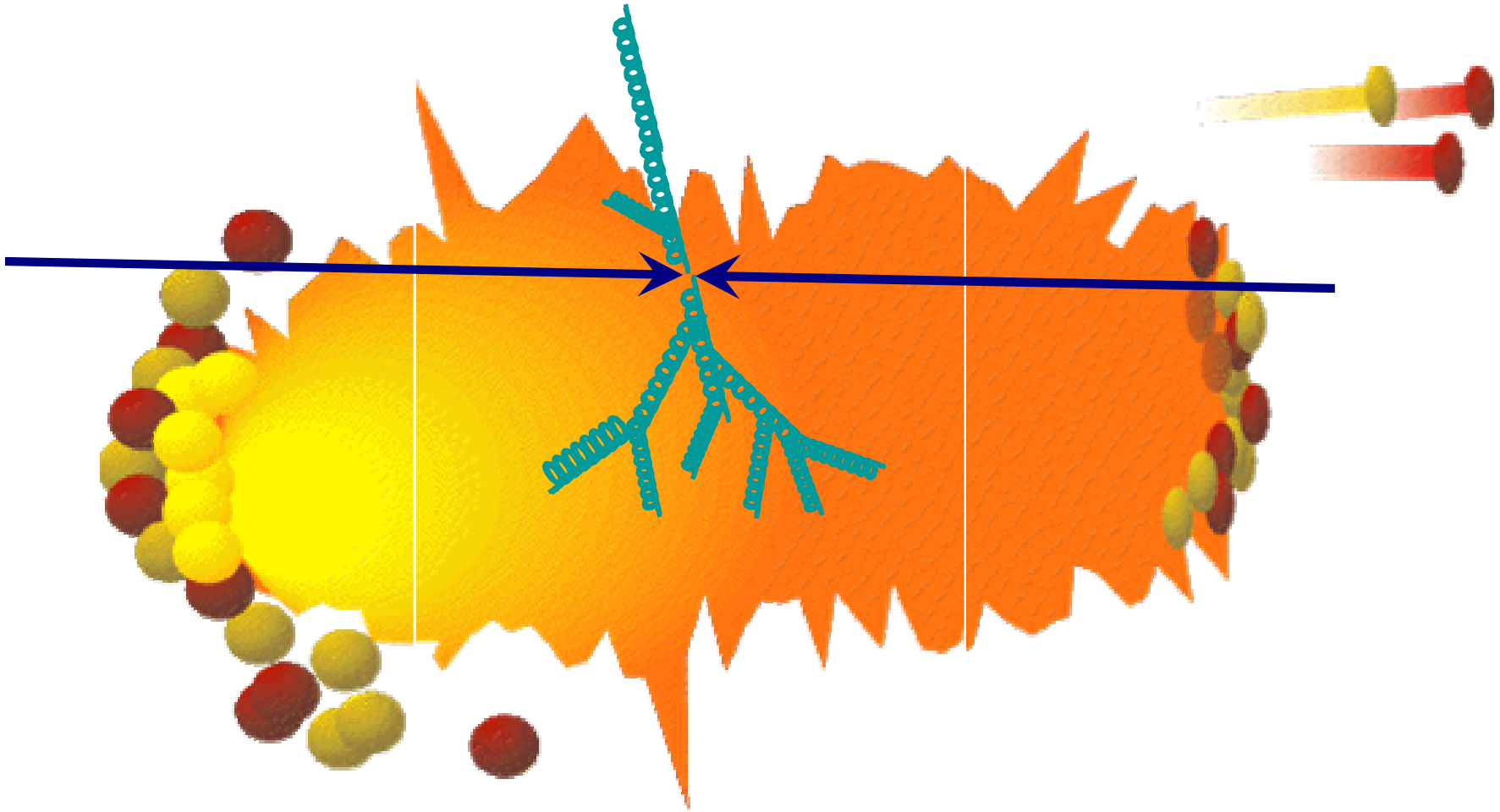
NEED eRHIC FOR A QUANTITATIVE UNDERSTANDING OF CGC

MUST DISENTANGLE CGC AND QGP

eRHIC IS ESSENTIAL FOR A QUANTITATIVE UNDERSTANDING OF QGP AT LHC

EXTRA SLIDES

Back to Back Correlations



$$U(x_t) = \hat{P} e^{ig \int_{-\infty}^{\infty} dx^- \, A_a^+(x^-, x_t) \, t_a}$$