

NUCLEAR MODIFICATION FACTOR AT LARGE RAPIDITIES AT RHIC

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in collaboration with:

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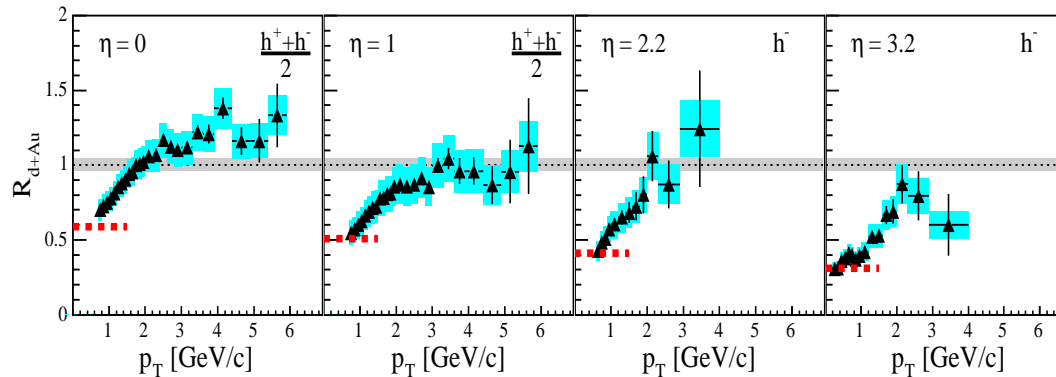
Quark Matter 2005

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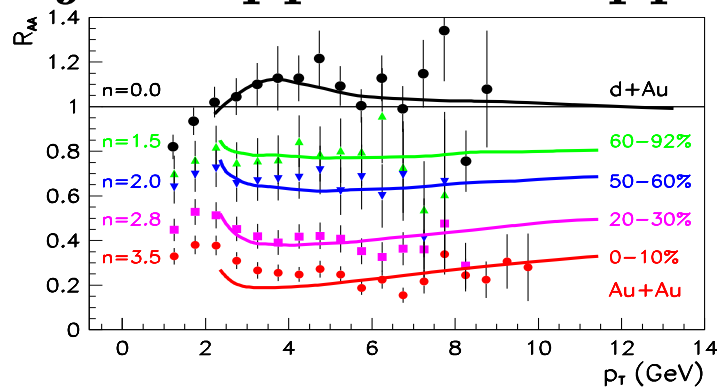
Questions and Motivation

I. We have studied π production in $(pA)dAu$ collision.

- Suppression were found at $\eta > 0$, h^+ , h^- spectra at BRAHMS
- However no suppression at midrapidity at PHENIX.



II. The jet-suppression appears in case of AA collisions



Suppression in π spectra in
 $AuAu$ at RHIC \implies QGP

How interplay the two effects in our modell at $\eta > 0$ for AA' ?

Hunting for Nuclear Effects (Cronin) at High- p_T – R_{AA}

Historically the Cronin effect:

increased particle production in
 $3 \text{ GeV} < p_T < 6 \text{ GeV}$ range (1975)

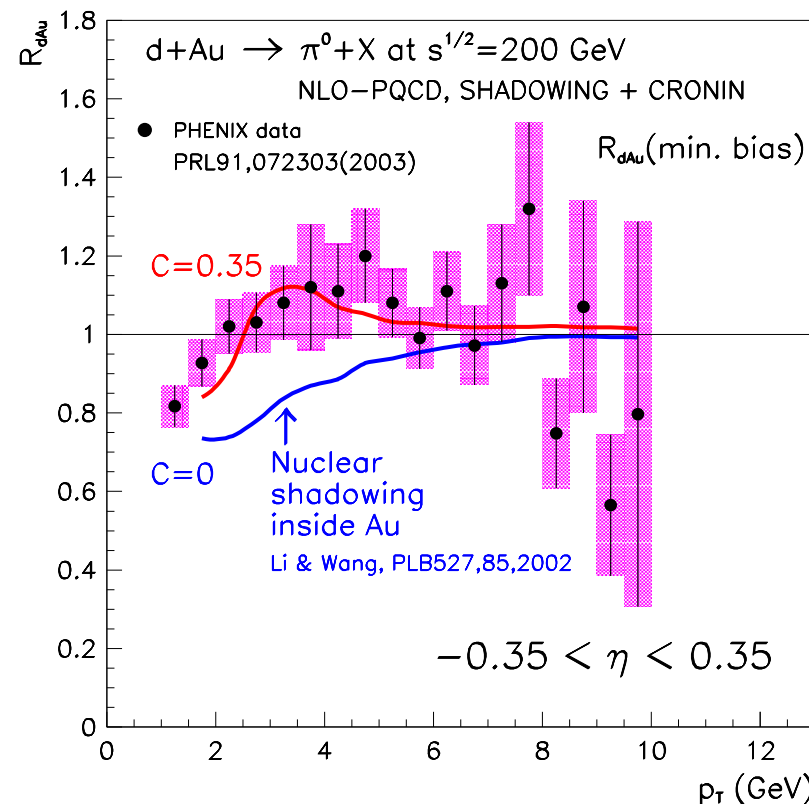
”increased” means more particles
 are produced in pA than expected
 from N_{bin} scaled pp collisions

Nuclear modification factor

→ measuring Cronin effect: $R_{AA} = \frac{1}{N_{bin}} \frac{dN_{AA}/dy d^2p_T}{dN_{pp}/dy d^2p_T}$

→ theoretical def.:

$$R_{AA}^\pi := \frac{d\sigma^{AA' \rightarrow \pi} / d^3p (\text{”shadowing+multiscattering+ jet-quenching”})}{d\sigma^{AA' \rightarrow \pi} / d^3p (\text{”NO nuclear effect”})}$$



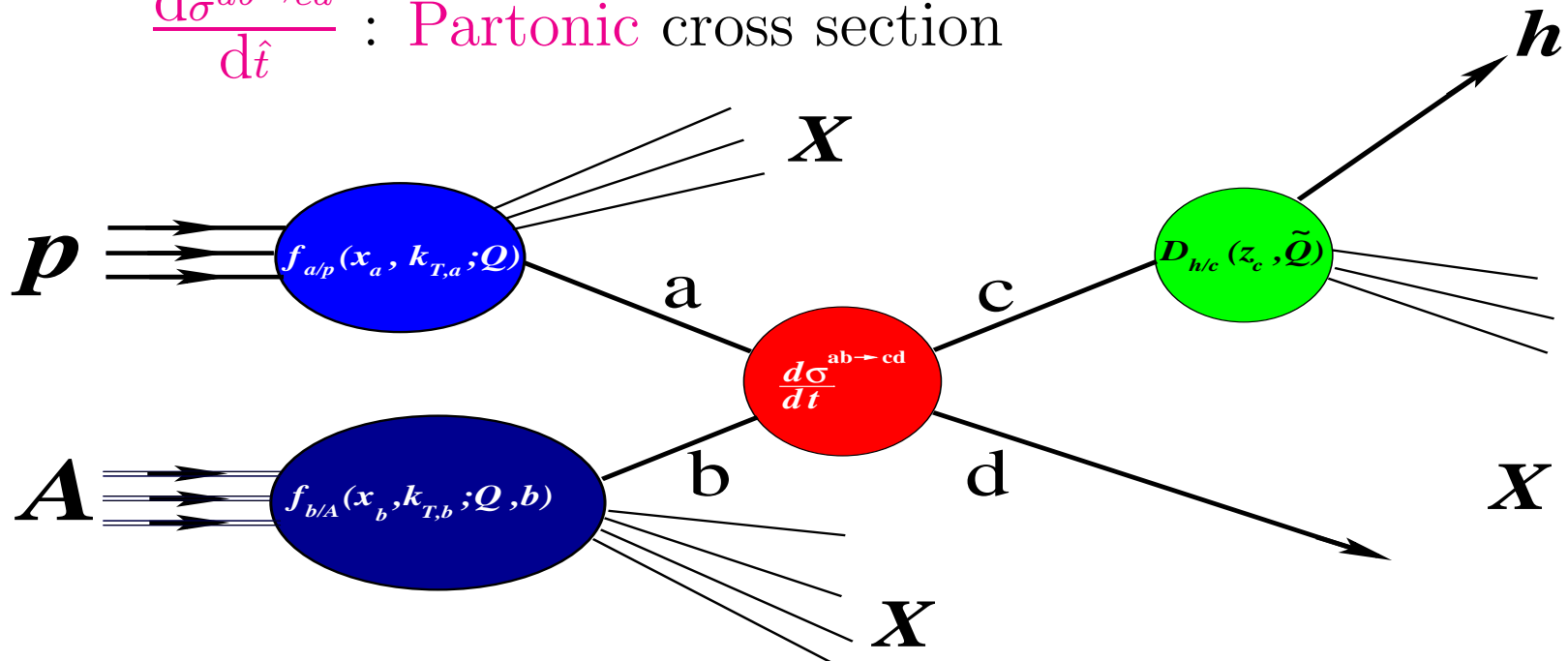
I/1. pQCD Improved Parton Model for pA Collisions

$$E_\pi \frac{d\sigma_\pi^{pA}}{d^3p_\pi} \sim f_{a/p}(x_a, Q^2; k_T) \otimes f_{b/A}(x_b, Q^2; k_T, b) \otimes \frac{d\sigma^{ab \rightarrow cd}}{d\hat{t}} \otimes \frac{D_{\pi/c}(z_c, \hat{Q}^2)}{\pi z_c^2}.$$

$f_{a/A}(x_a, Q^2; k_T, b)$: Parton Dist. Function (PDF), at scale Q^2

$D_{\pi/c}(z_c, \hat{Q}^2)$: Fragmentation Function for π (FF), at scale \hat{Q}^2

$\frac{d\sigma^{ab \rightarrow cd}}{d\hat{t}}$: Partonic cross section



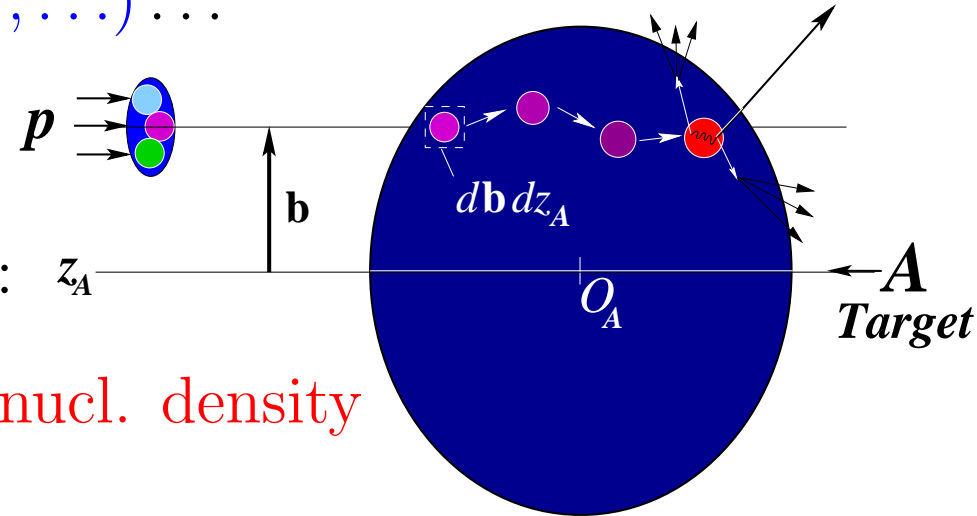
I/2. Collision Geometry and Shadowing in $pA \rightarrow \pi$

$$E_\pi \frac{d\sigma_\pi^{pA}}{d^3p} = \int d^2b t_A(b) \int \dots f_{a/A}(x_a, Q^2; \dots) \dots$$

(a) **Nuclear** thickness function:

$$t_A(b) = \int dz \rho(b, z) \text{ normalized as: } z_A$$

$$A = \int_0^{b_{max}} t_A(b) d^2b, \text{ where } \rho(b, z) \text{ nucl. density}$$



(b) **Nuclear** Shadowing – modified PDFs inside nucleus

$$f_{a/A}(x, Q^2; b) = S_a^A(x, b) \left[\frac{Z}{A} f_{a/p}(x, Q^2) + \left(1 - \frac{Z}{A}\right) f_{a/n}(x, Q^2) \right]$$

$S_a^A(x, b)$: b -dependent or independent shadowing function;
 HIJING: S. Li, X.-N. Wang: Phys.Letts. **B527**,85(2002)
 A atomic- and Z the proton number

I/2. (a) Phenomenological introduction of intrinsic k_T

Introducing intrinsic k_T for colliding partons (G. Fai's talk)

Phenomenological assumption: PDFs are modified

1 dimensional PDFs are changed to 1+2 dimensional ones

$$dx f_{a/p}(x, Q^2) \longrightarrow dx d^2k_T g_{pp}(\vec{k}_T) f_{a/p}(x, Q^2)$$

where $g(\vec{k}_T)$ is a Gauss distribution function :

$$g_{pp}(\vec{k}_T) = \frac{e^{-\vec{k}_T^2 / \langle k_T^2 \rangle}}{\pi \langle k_T^2 \rangle} \quad \text{and} \quad \langle k_T^2 \rangle = \frac{4 \langle k_T \rangle^2}{\pi}$$

Baseline $\langle k_T^2 \rangle$ values for pp : Phys. Rev. **C65** 034903 (2002)
 $\langle k_T^2 \rangle \sim$ value agrees with measured values by PHENIX,

I/2. (a) Multiple Scattering (The Cronin Effect)

Saturated NN collision numbers (in $pA \rightarrow \pi$)

- improve the Glauber model:

$$E_\pi \frac{d\sigma_\pi^{pA}}{d^3p} = \int d^2b t_A(b) E_\pi \frac{d\sigma_\pi^{pp}(\langle k_T^2 \rangle_{pA}, \langle k_T^2 \rangle_{pp})}{d^3p}$$

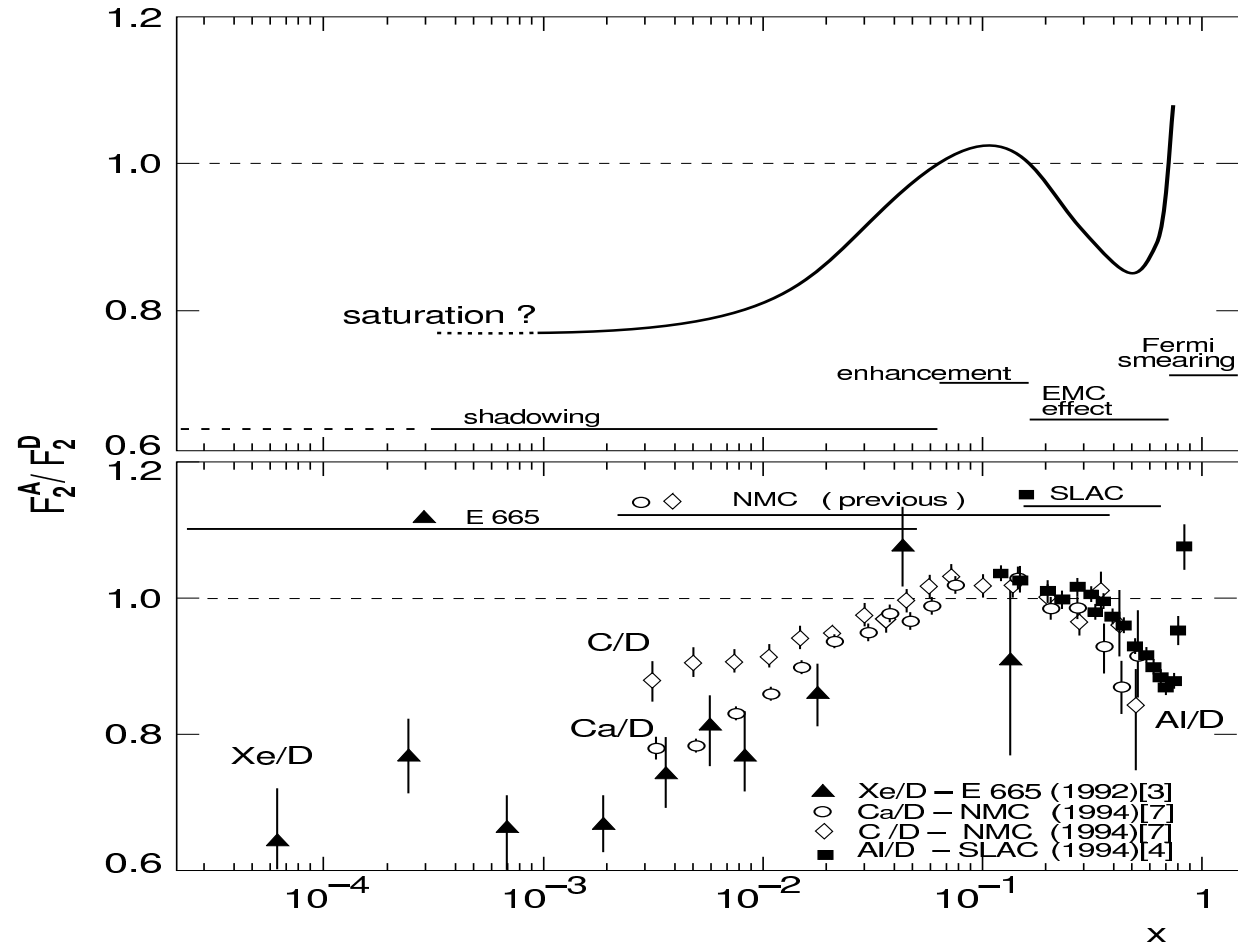
$$\langle k_T^2 \rangle_{pA} = \langle k_T^2 \rangle_{pp} + C h_{pA}(b)$$

Total broadening = pp baseline + nuclear broad.

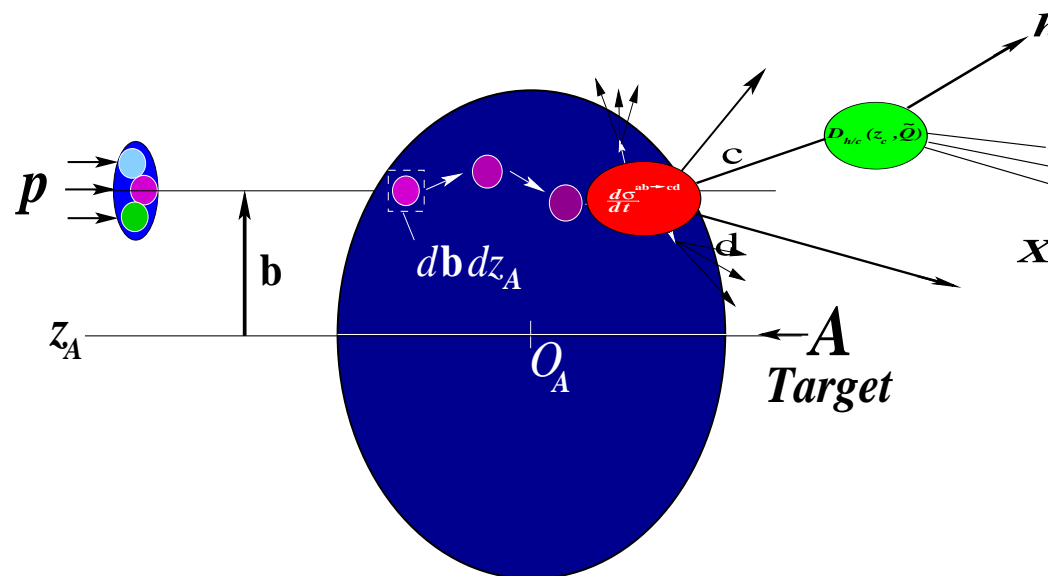
See details in **PRC65** 034903 (2002) and [hep-ph/0212249](#)

- $h(\nu_A(b) - 1)$: number of effective NN collisions $\nu_{max} = 3 - 4$
 C : (average mom. broadening)² / coll. $C \approx 0.35 \text{ GeV}^2$
 $t_A(b)$: nuclear thickness function

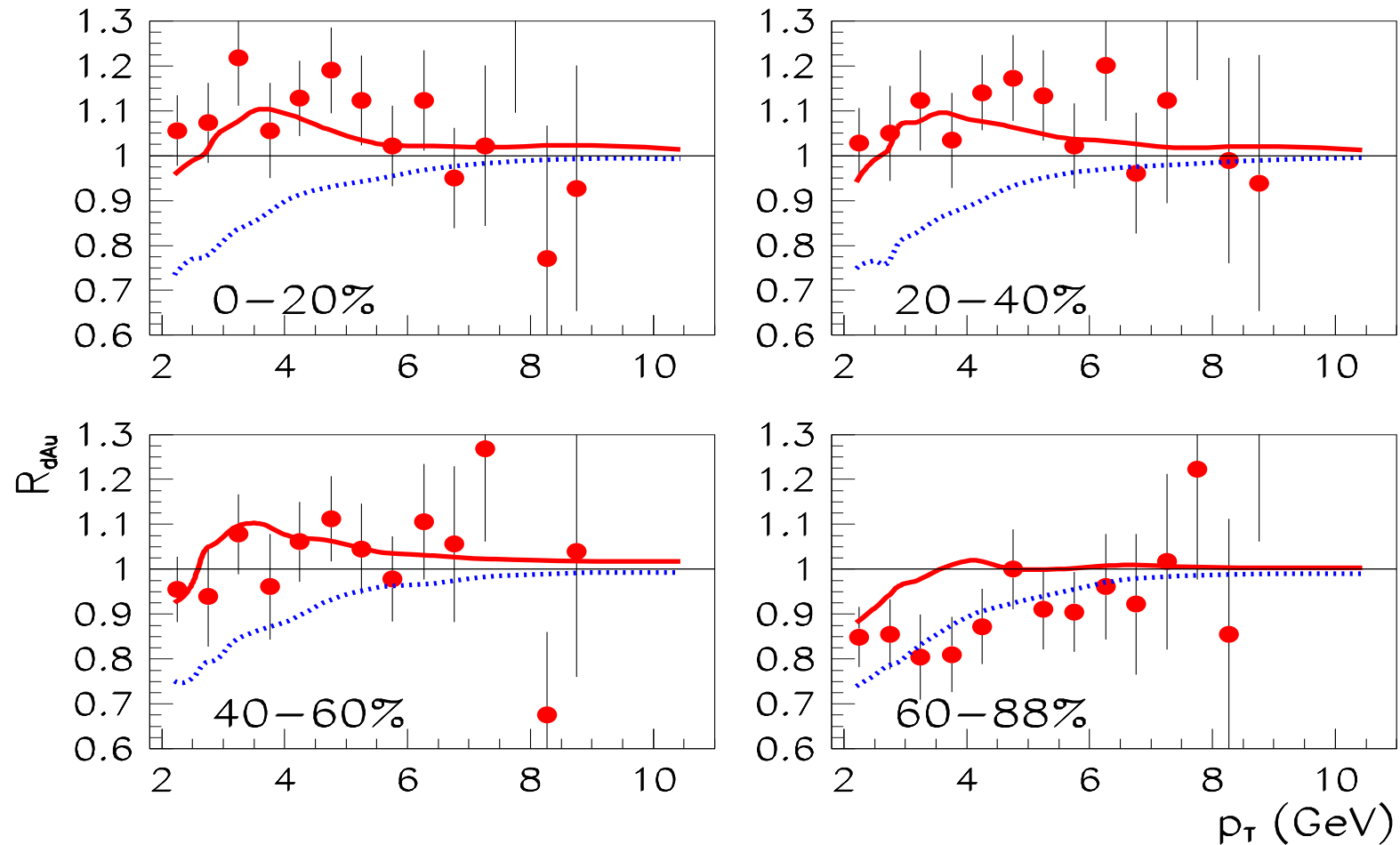
I/2. (b) Phenomenological Shadowing functions



II. APPLICATION OF THE MODEL FOR

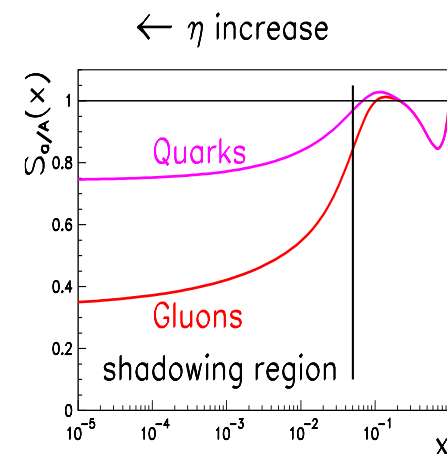
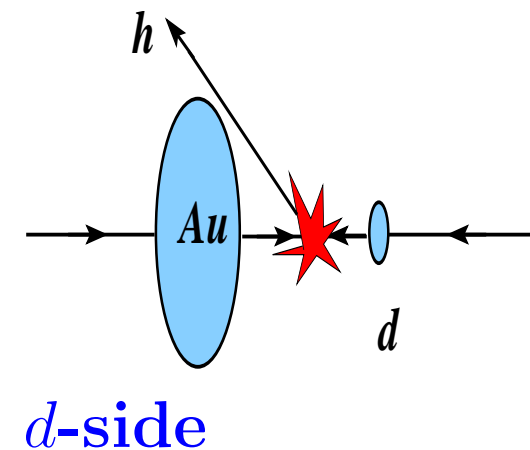
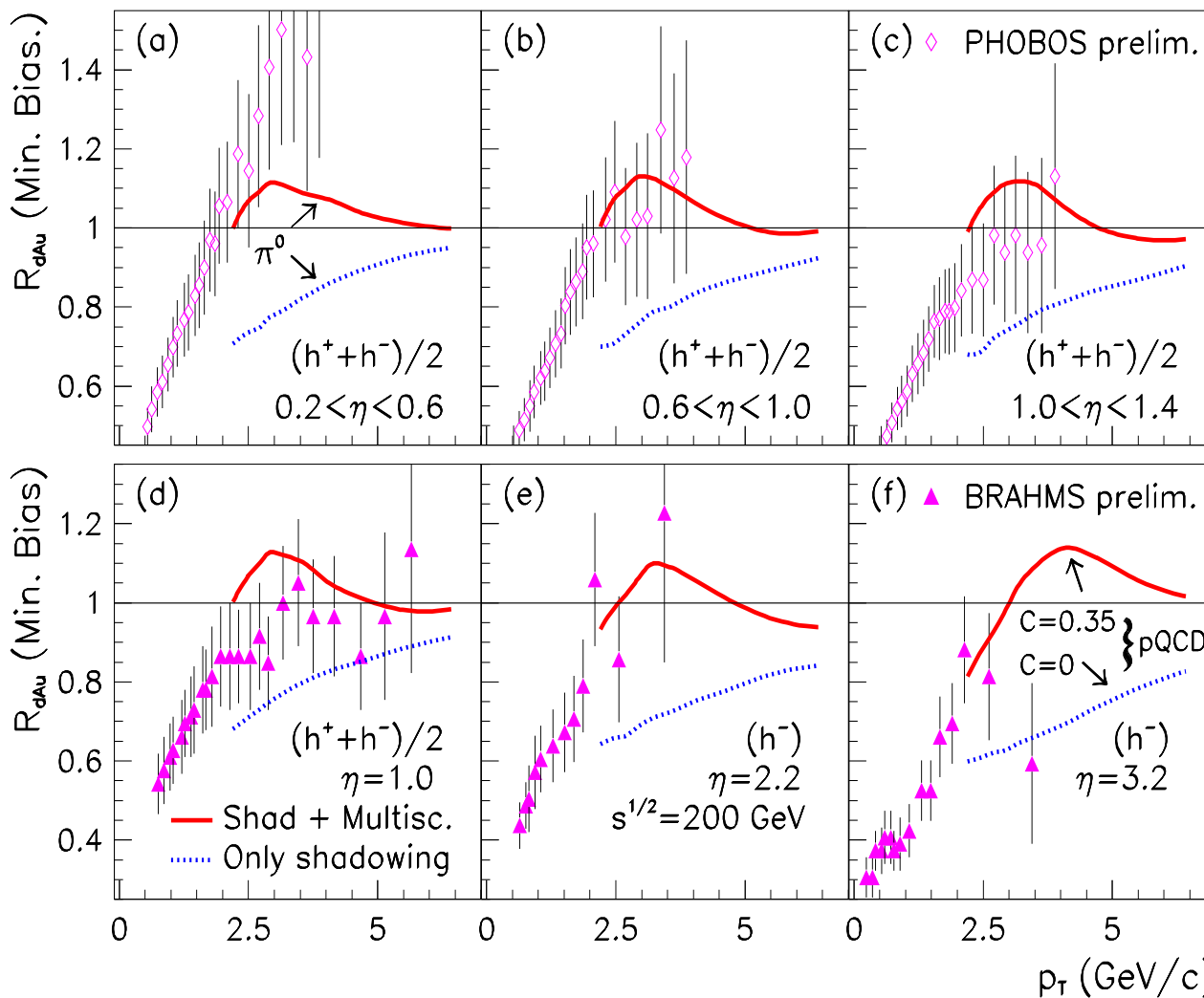


π^0 PRODUCTION IN dAu COLLISIONS

Cronin effect in different Centralities in dAu collision at PHENIX

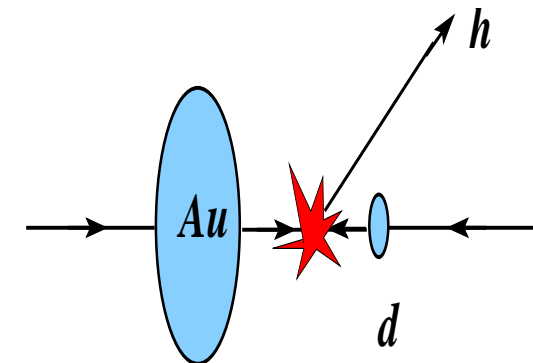
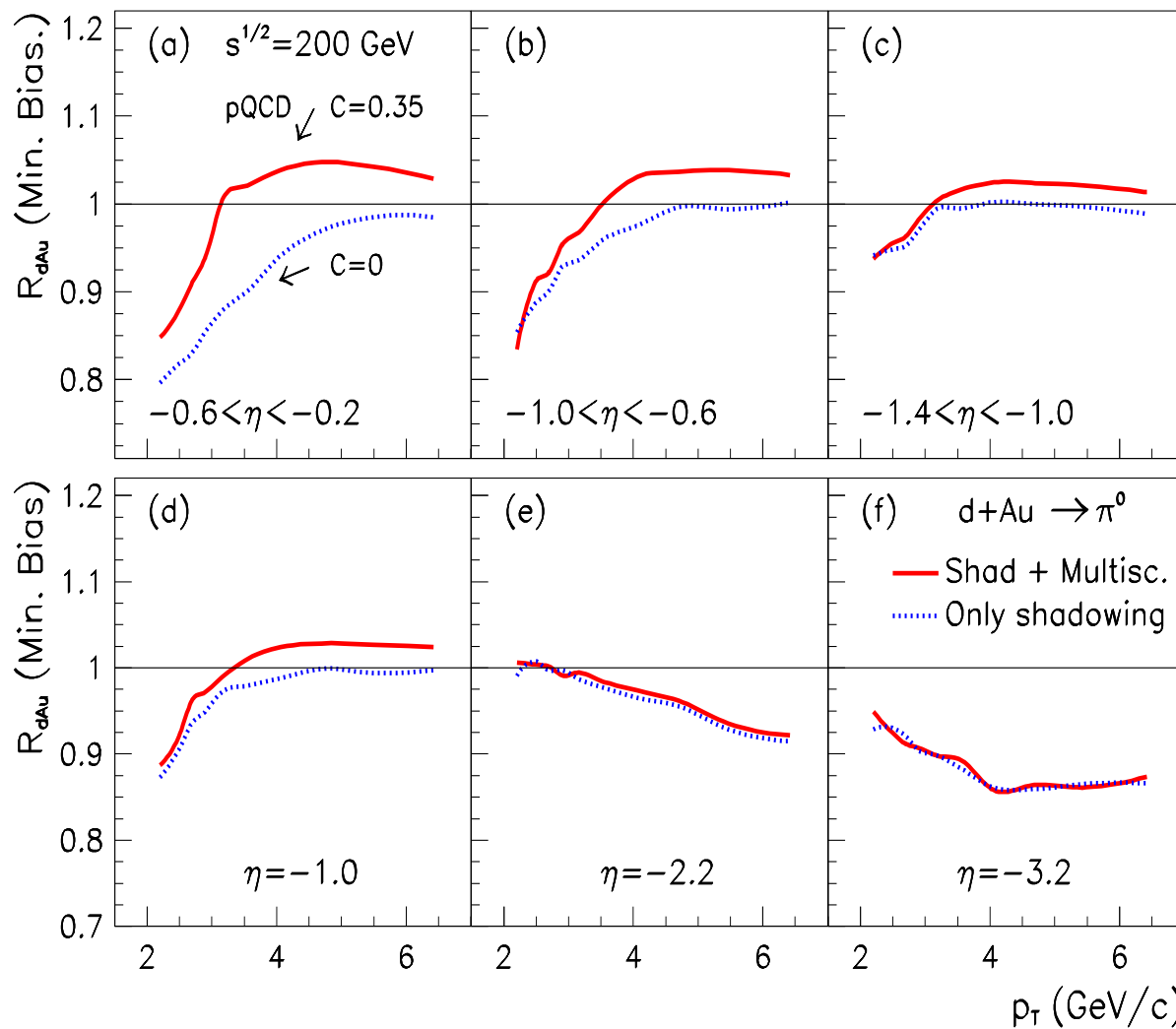
G.G. Barnaföldi *et al.*: J. Phys. G30, S1125

Cronin on min. bias $dAu \rightarrow \pi^0$ at PHOBOS and BRAHMS $\eta > 0$

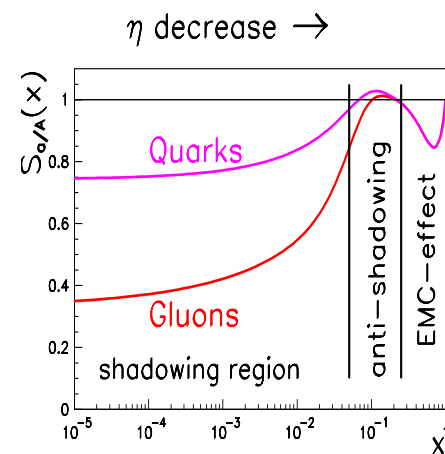


BRAHMS data: nucl-ex/0403005 and **PHOBOS data:** nucl-ex/0406017

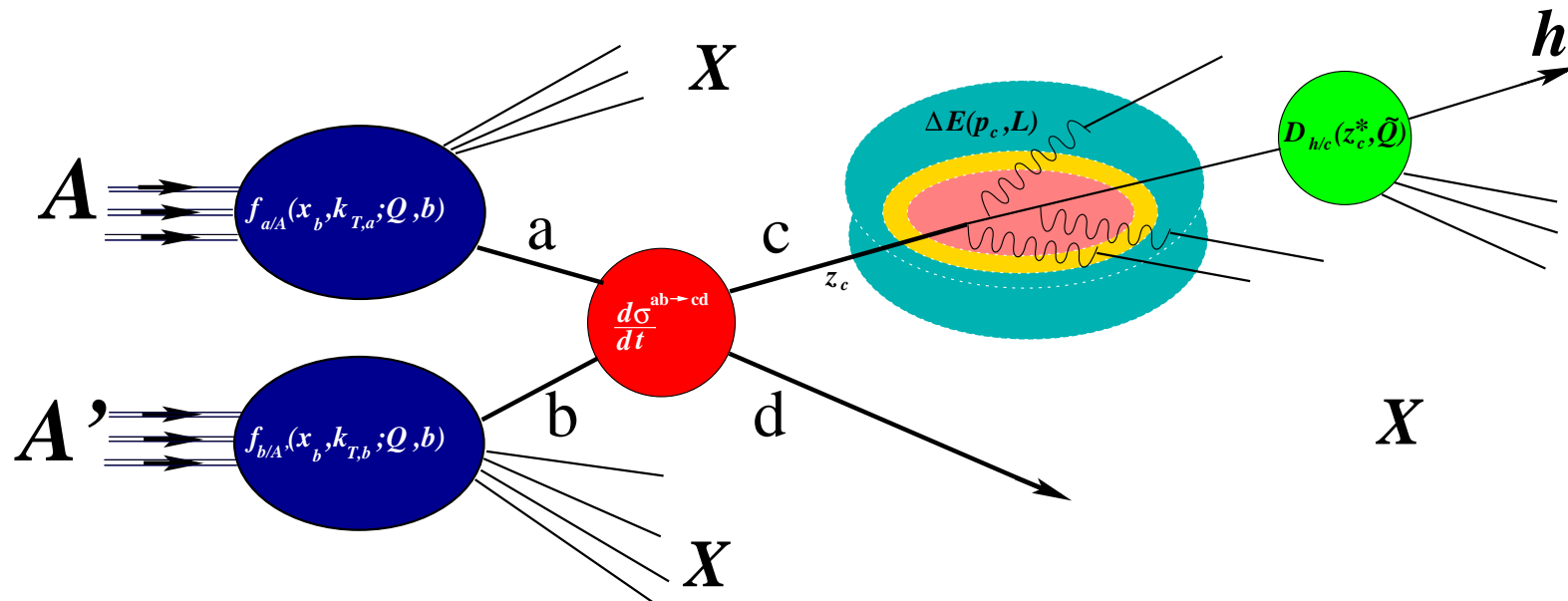
Cronin on min. bias $dAu \rightarrow \pi^0$ as inverted, $\eta < 0$



NO relevant multiscatt. in d . Au -side



III. IMPROVING THE APPLICATION FOR



π^0 PRODUCTION IN AA COLLISIONS

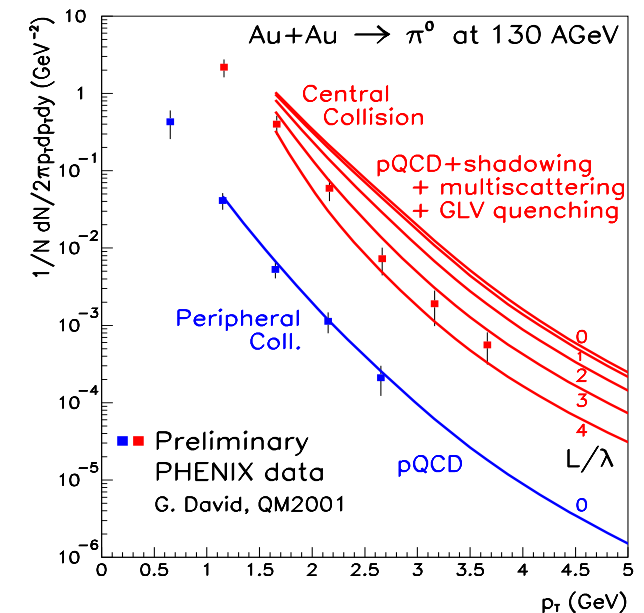
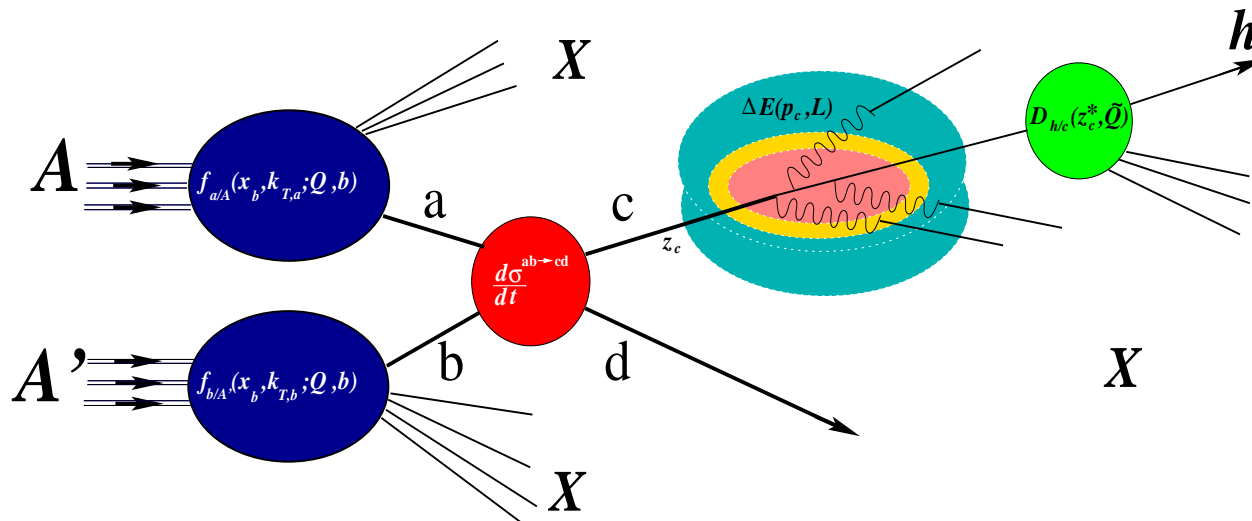
III. A π -suppression in $AuAu$ collisions at RHIC energies

GLV jet-quenching in thin plasma approximation $L \sim \lambda_g$:

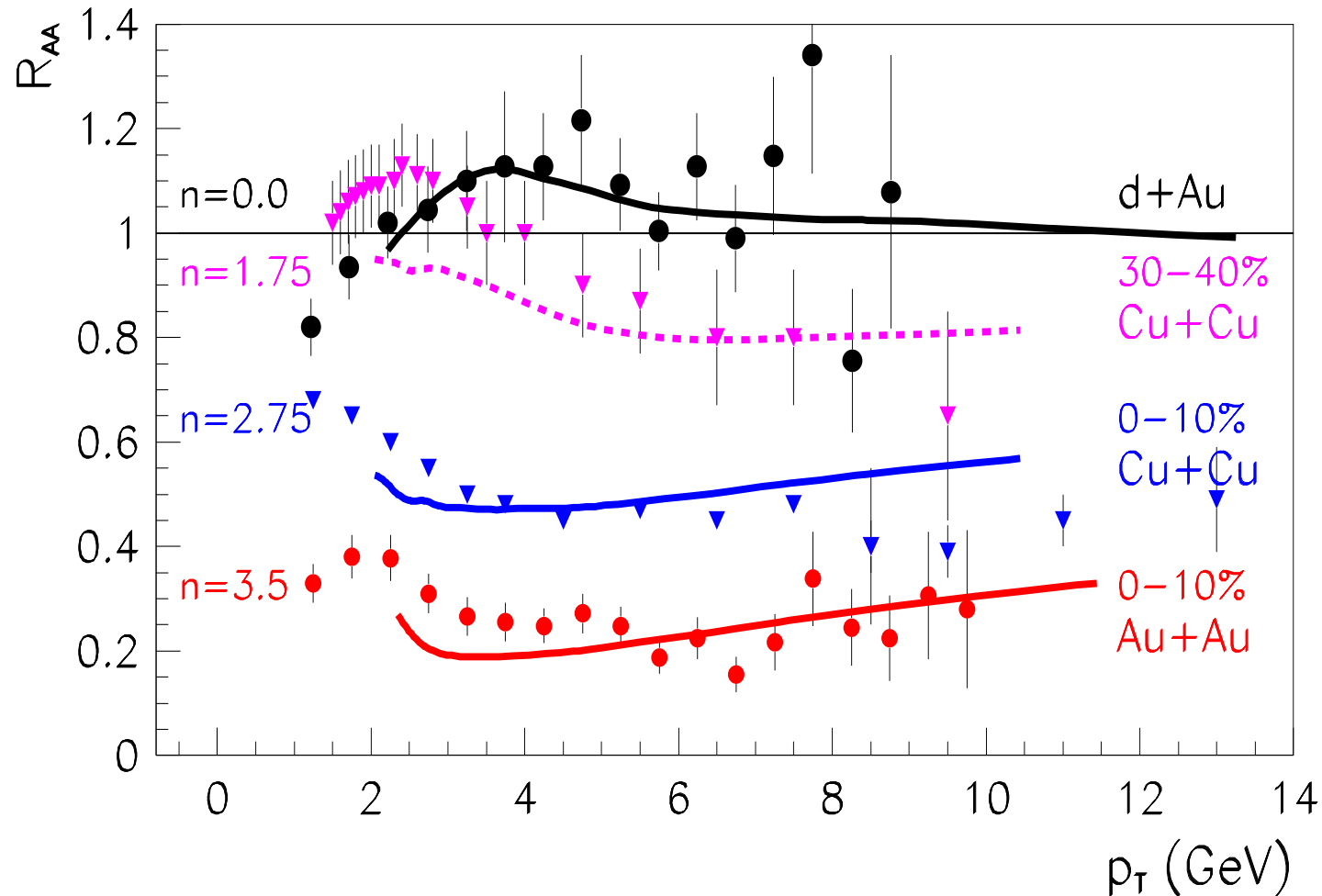
$$\Delta E_{GLV} \sim \frac{L^2 \mu^2}{\lambda_g} \log \frac{E}{\mu}$$

Energy loss of jets decreases the p_c momenta of c before fragmentation:

$$\frac{D_{\pi/c}(z_c, Q'^2)}{\pi z_c^2} \rightarrow \frac{z_c^*}{z_c} \frac{D_{\pi/c}(z_c^*, Q'^2)}{\pi z_c^2}, \quad \text{with } z_c^* = \frac{z_c}{1 - \Delta E/p_c},$$



Calculated $R_{AA}^{\pi^0}$ for central $AuAu$ and $CuCu$ Collisions



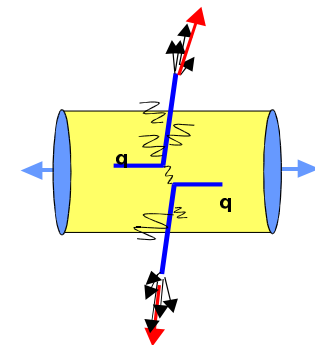
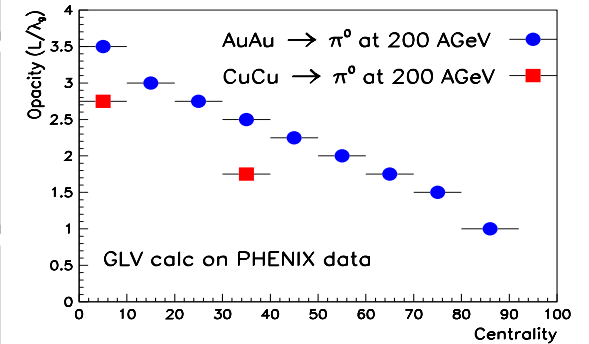
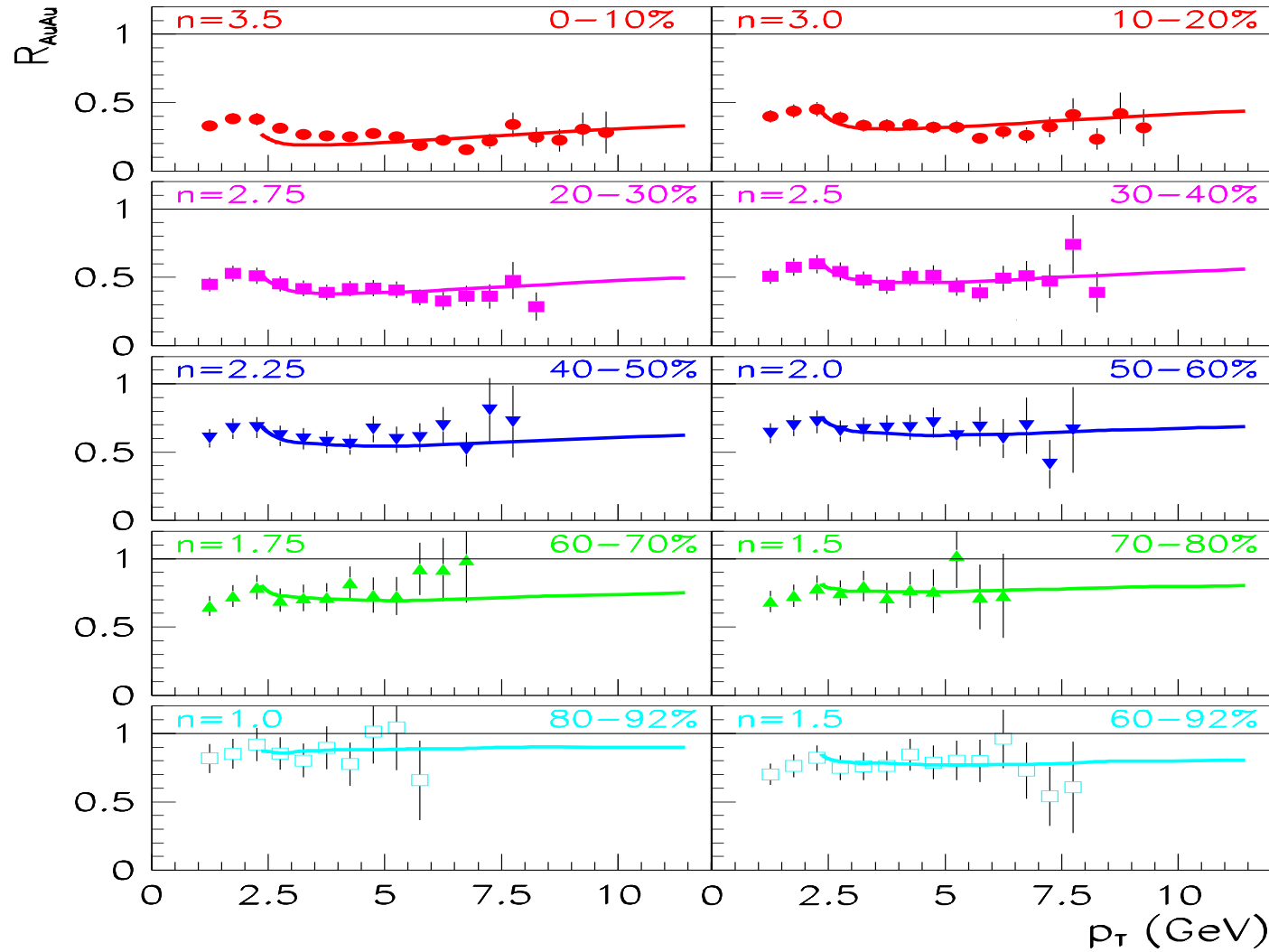
In the smaller
 $CuCu$ system

L/λ is less ~ 0.75

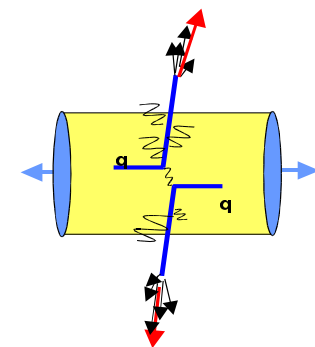
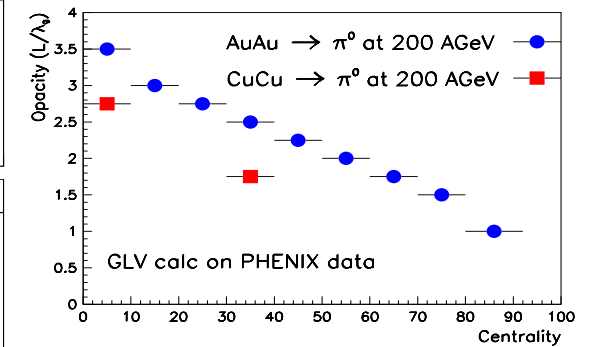
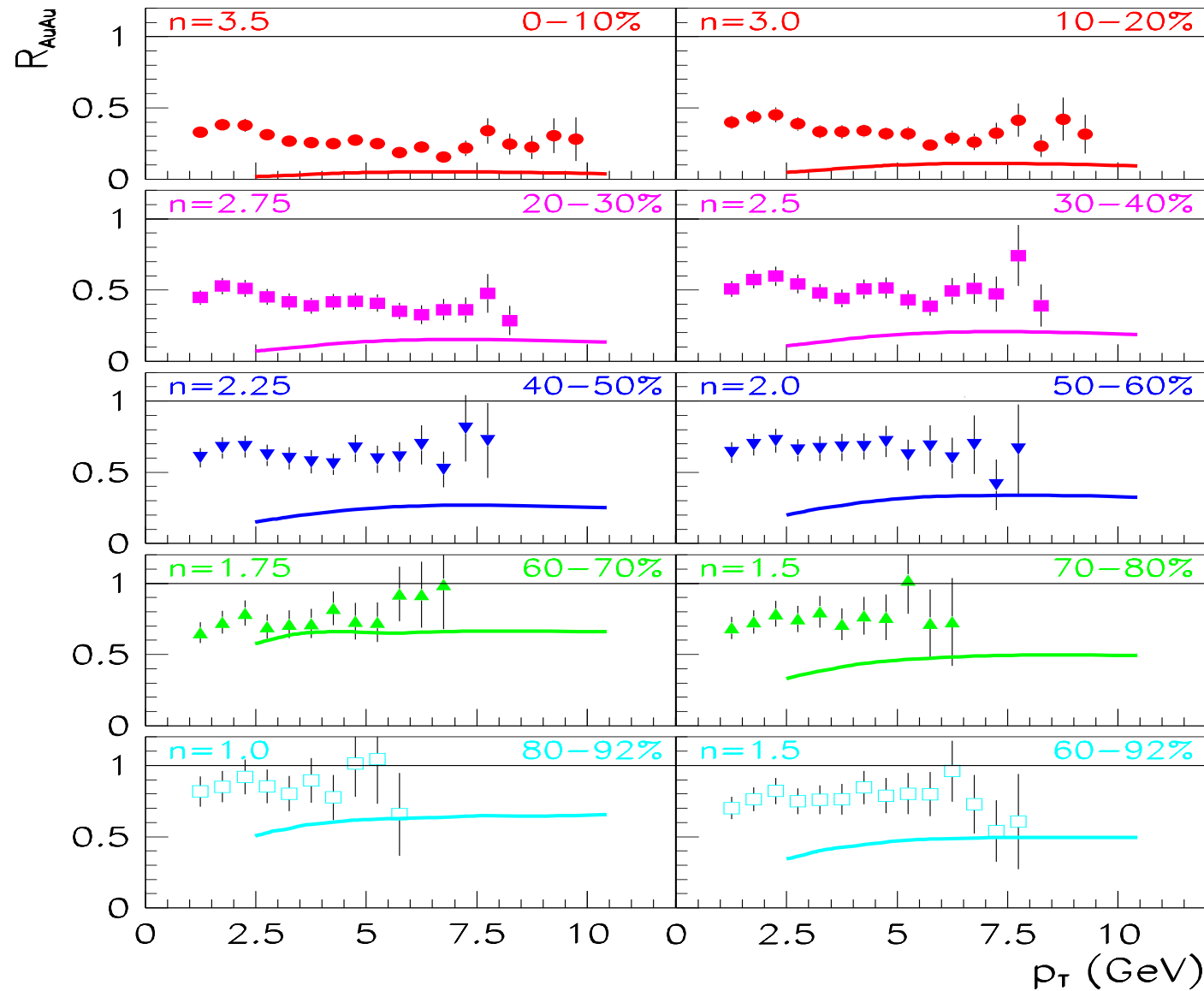
than in $AuAu$.

$AuAu, dAu$ and central $CuCu$ data for π^0 by PHENIX, mid-central $CuCu$ by STAR

Jet-tomography in *AuAu* Collisions at PHENIX ($y = 0$)



Jet-tomography in $AuAu$ Collisions at ($y \approx 2.2$)



Data: by PHENIX at $y = 0$ just for comparison

Comparing π^0 data in $AuAu$ at $\eta = 3.1$ and $y = 0$

$AuAu$ at BRAHMS $\eta = 3.1$ and PHENIX $y = 0$

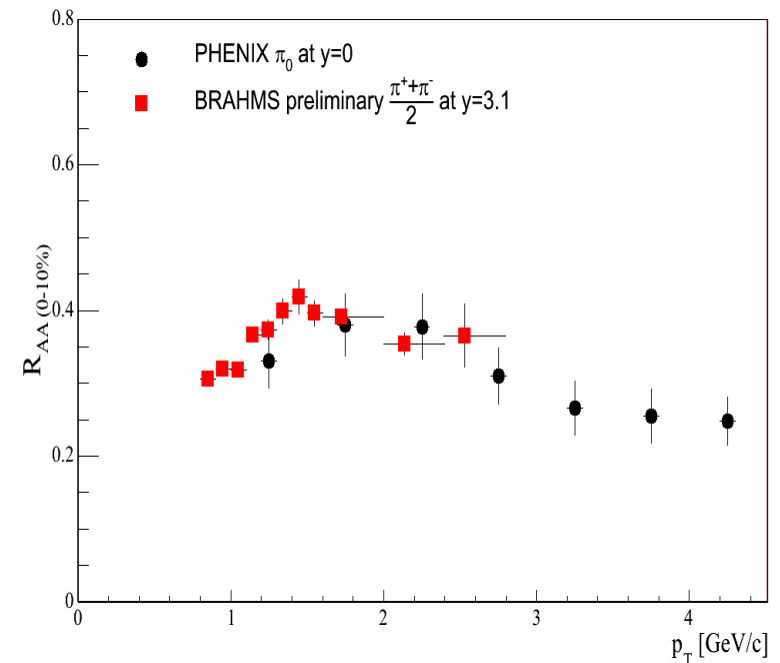
Larger shadowing in dAu at $\eta > 0$

Additional (exp.) information:

– $R_{AuAu}(y = 0) \approx R_{AuAu}(y > 0)$

– $R_{CP} \geq R_{AA'}$

– See D. Rölich's talk



\implies Shadowing effect is stronger

\implies Travelling length getting smaller as going more forward

\implies Smaller L/λ can be extracted in the forward π production

Summary – Outlook

Goal: Extracting the L/λ_g values in AA' in all direction

I. Description of the π^0 production in dAu collisions at all η

- Baseline: pp results for intrinsic- k_T , $\langle k_T^2 \rangle$
- HIJING shad. + Multiscat. + Sat. Galuber model
 - \implies RHIC data well reproduced (min. bias)
 - \implies NO suppression, NO need for extra shadowing
 - \implies For consistency we are waiting for $\eta < 0$ data

II. Results for π^0 in $AuAu$ and $CuCu$ at $\boxed{\eta = 0}$ and $\boxed{\eta > 0}$

- GLV jet-quenching with opacity parameter $n = L/\lambda$
 - \implies As we expected, $R_{AA}(\eta > 0)$ needs smaller L/λ .

... post conference data analysis

- Extracting opacity in the liu of new data
 - \implies At least, but not last: thank You for the nice exp. data