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Hot Quarks Workshop - August 2008

Shadowing effects and J/ψ production @ $p_T \neq 0$

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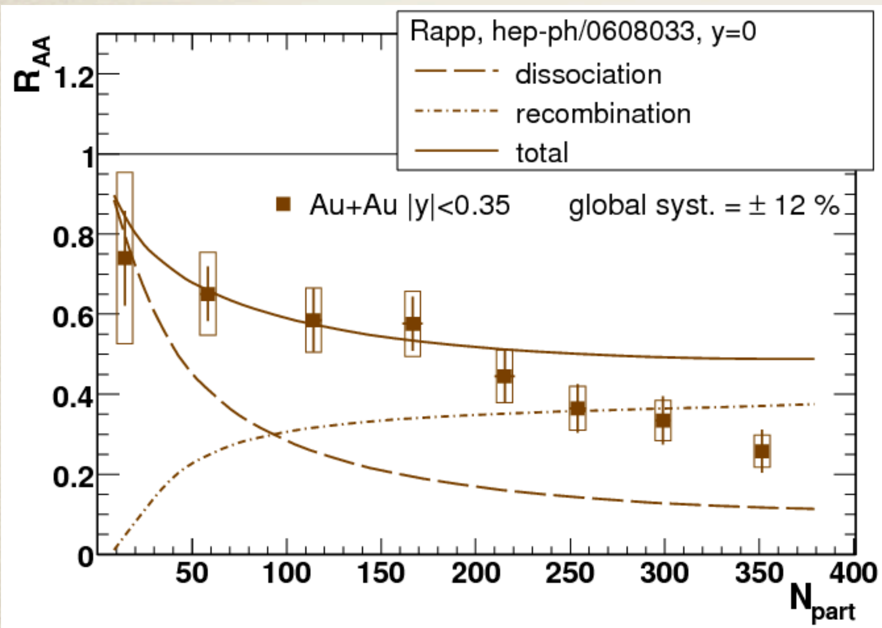
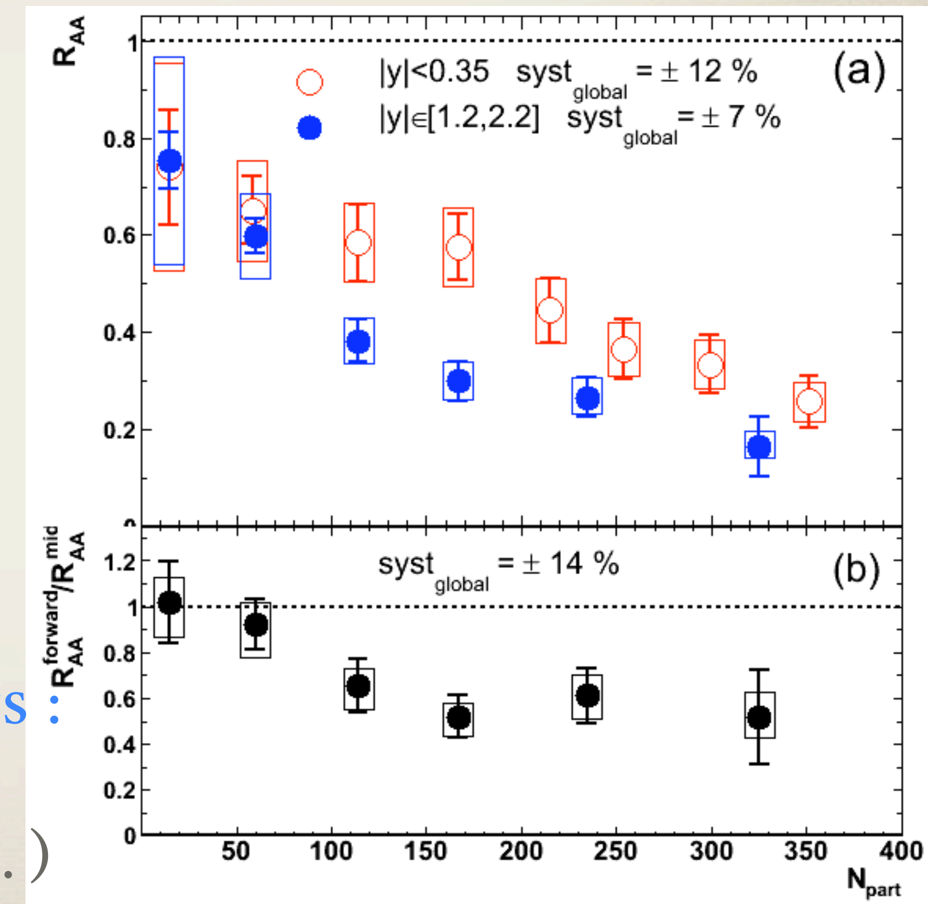
E. G. Ferreiro, F. Fleuret, J.-P. Lansberg and A. R.
paper under preparation

Why are we interested in the J/ψ yield ?

$c\bar{c}$ resonances : early production ⇒ hard probes of the medium

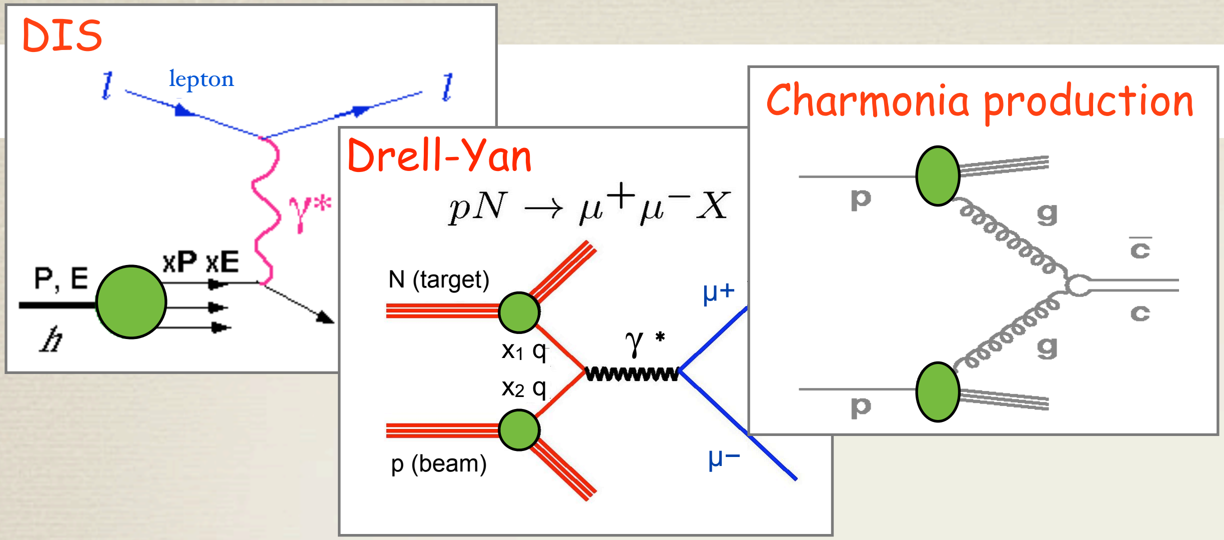
- Hot (QGP) effects :
  - melting/screening, dissociation by hard free *g*
  - secondary in-medium production (recombination)





- Cold nuclear matter (CNM) effects :
  - initial-state (shadowing, ...)
  - final-state (nuclear “absorption”, ...)

Shadowing : a cold *nuclear matter* effect



Processes used to probe :

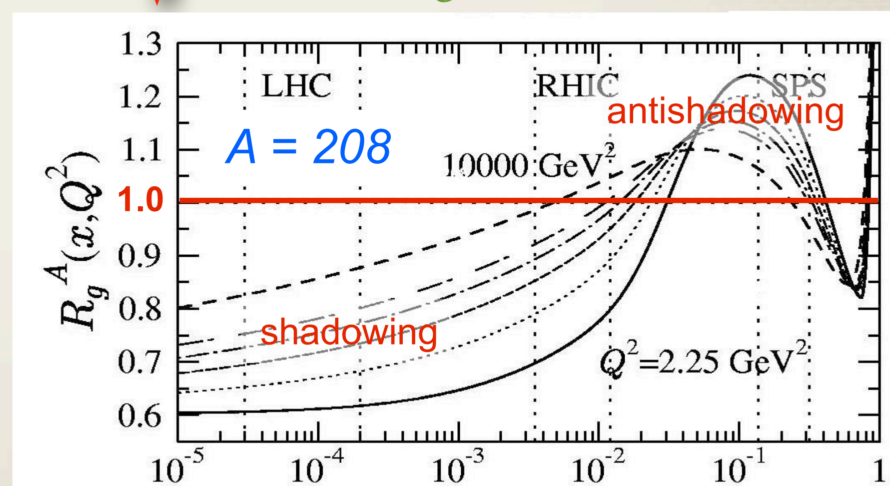
- nucleon struct. f.

$$F_2 = \sum_i e_i^2 \, . \, x f_i(x, Q^2)$$

with $f_i(x, Q^2)$ = PDF and $i = q, \bar{q}, g$

- nuclear struct. f. per nucleon

$$R_g^A = \frac{\text{g PDF} \in \text{bound nucleon}}{\text{g PDF} \in \text{free nucleon}}$$

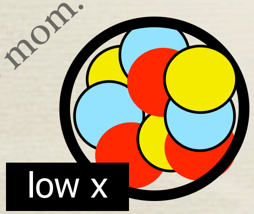


Nucl. Phys. A696 (2001) 729-746

(Anti-)shadowing :

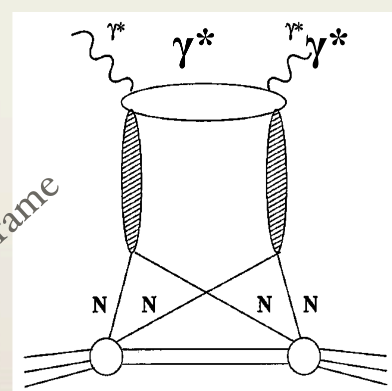
- initial-state effect “calibrated” in d(p)+A
- refers to low-x region
- coherence effect

nucleus ∞ mom. frame



⇔

nucleus rest frame



- (enhances) decreases σ^{pA} wrt $\langle N_{\text{coll}} \rangle \, \sigma^{pp}$

Shadowing models / experiment's goal

- When considering shadowing as the *sole* nuclear effect :

correction factor

$$\sigma^{pA} = R^A_{\text{shadow}} \times \langle N_{\text{coll}} \rangle \, \sigma^{pp}$$

many models on the market : for e.g. EKS-like approach [1, 2, 3]

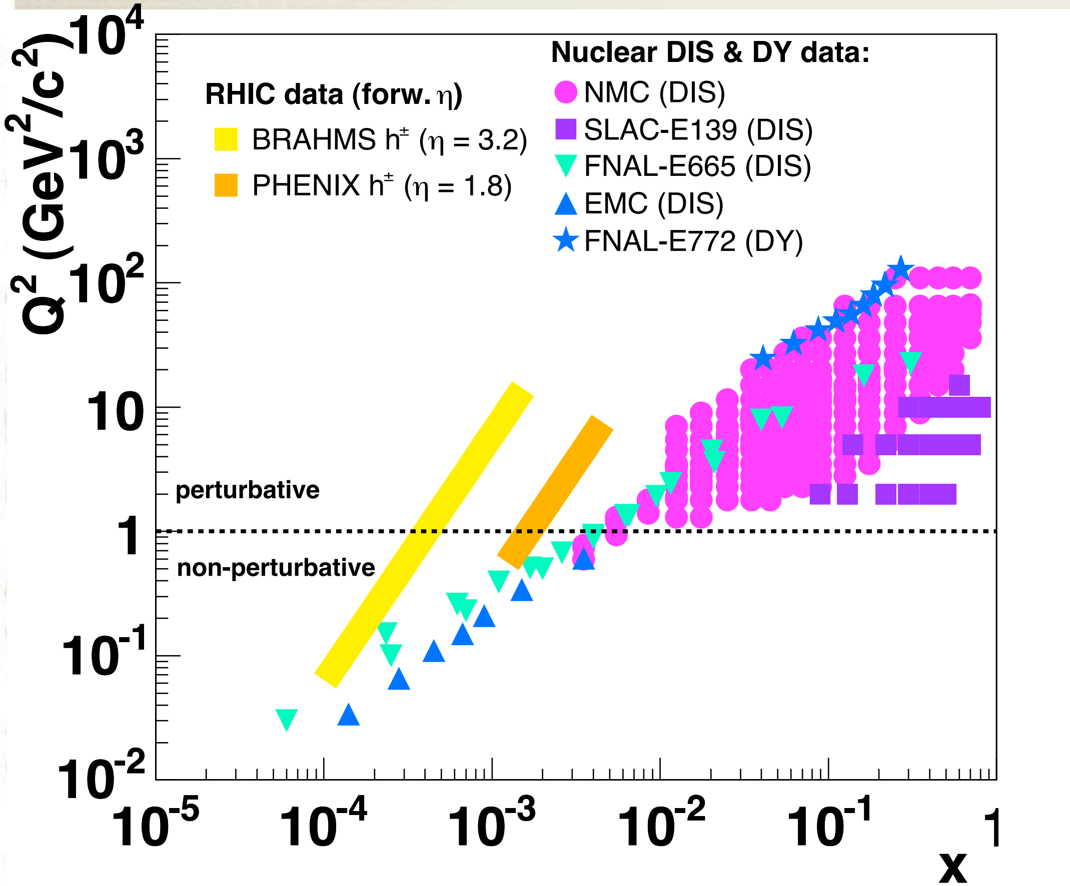
- Favorite experimental observable = nuclear modif. factor :

$$R_{pA} = \frac{dN^{J/\psi}_{pA}}{\langle N_{\text{coll}} \rangle \, dN^{J/\psi}_{pp}}$$

[1] Eskola, Kolhinen & Ruuskanen, Nucl. Phys. B535, 351 (1998)
[2] Eskola, Kolhinen & Salgado, Eur. Phys. J. C9, 61 (1999)
[3] Vogt, Phys. Rev. C71, 054902 (2005)

How is the shadowing predicted?

Range in x, Q^2 covered by the available data



d'Enterria, Eur. Phys. J. A31, 816 (2007)

- EKS-like approach
  - use data to parametrize $R_i^A(x, Q_0^2)$ and DGLAP to get it at $Q^2 > Q_0^2$

$$R^A_{\mathrm{shadow}}(b, x, Q^2) = 1 + \frac{N^A(b)}{< N^A >} \times \left[R_g^A(x, Q^2) - 1\right]$$

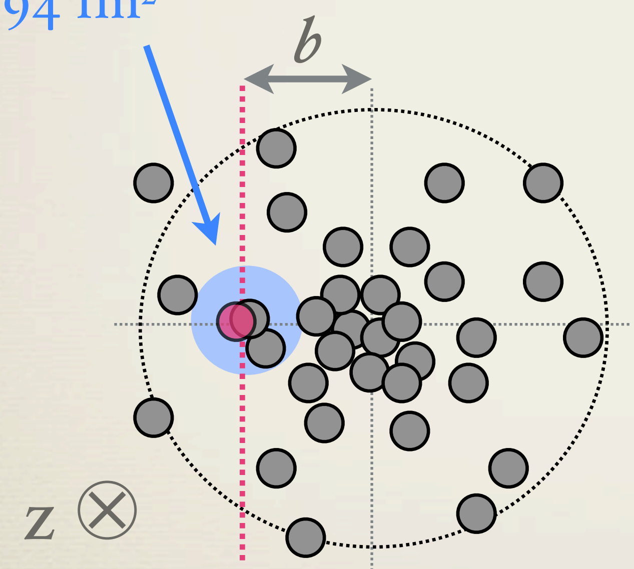
accounts for the gluon PDF modification in nucleus

How is the shadowing predicted?

pA collision

assumption : coherent interaction between parton $i \in$ p and all partons $\in$ A along its path

nucleon tr. size
$\sigma_{\mathrm{tr}} = 3.94$ fm^2



random spatial position of A nucleons following Wood-Saxon density profile

EKS-like approach

- impact parameter dependence :

$$R^A_{\mathrm{shadow}}(b, x, Q^2) = 1 + \frac{N^A(b)}{\langle N^A \rangle} \times \left[R^A_g(x, Q^2) - 1\right]$$

average value of N^A

number of nucleons that contributes to shadowing at b

New !

Adding the p_T dependence

$$(x_1, x_2) \underset{\text{physical constraints}}{\xleftrightarrow{c\bar{c} \text{ hard production process}}} (y, p_T)$$

Intrinsic scheme

E. Ferreiro, F. Fleuret, A. R.

arXiv:0801.4949

- $g + g \rightarrow c\bar{c}$ with intrinsic gluon k_T
- 4-mom conservation :

$$x_{1,2} = \frac{m_T}{\sqrt{s_{NN}}} e^{\pm y}$$

with $m_T = \sqrt{m^2_{J/\psi} + p^2_T}$

- scale chosen accordingly :

$$Q^2 = (2m_c)^2 + (p_T)^2$$

with $m_c = 1.2\,\mathrm{GeV}/c^2$

- input y and p_T spectra from p + p data

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- input y and p_T spectra from p + p data

Extrinsic scheme

E. Ferreiro, F. Fleuret, J.-P. Lansberg, A. R.
(in preparation)

- $g + g \rightarrow c\bar{c} + g$ with collinear inital gluons : p_T is balanced by final gluon
- 4-mom conservation :

$$y, p_T, x_1 \Longrightarrow x_2 = \frac{x_1 m_T \sqrt{s} e^{-y} - M^2}{\sqrt{s}\,(\sqrt{s} x_1 - m_T e^y)}$$

- prod. model successful in p+p needed for a proper weighting of each kinematically allowed (x_1, x_2) :

$$d^4\sigma / dy\, dp_T\, dx_1 dx_2$$

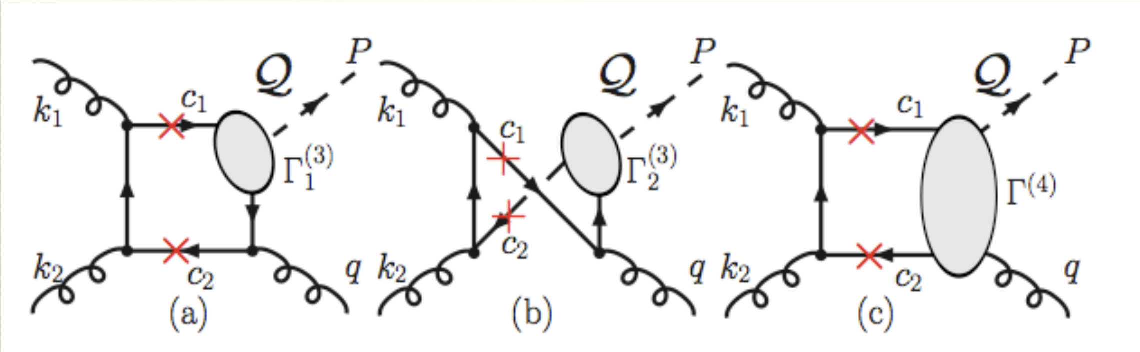
- same scale as in the prod. model :

$$Q^2 = (m_T)^2$$

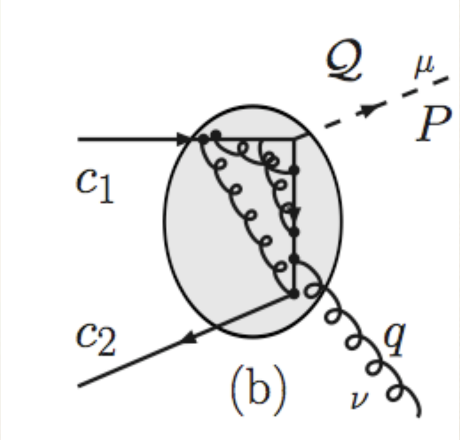
Cross-section calculation in $g + g \to J/\psi + g$

[1] H. Haberzettl et J. P. Lansberg, PRL 100, 032006 (2008)

s-channel cut contributions **[1]** to the "basic" CSM :



- take into account the dynamics of $c\bar{c}$ in the bound state
- need for 4-point coupling $c\bar{c} - J/\psi - g$



- new degrees of freedom constrained by fits
- so far the best description of low-p_T data

Adding the p_T dependence

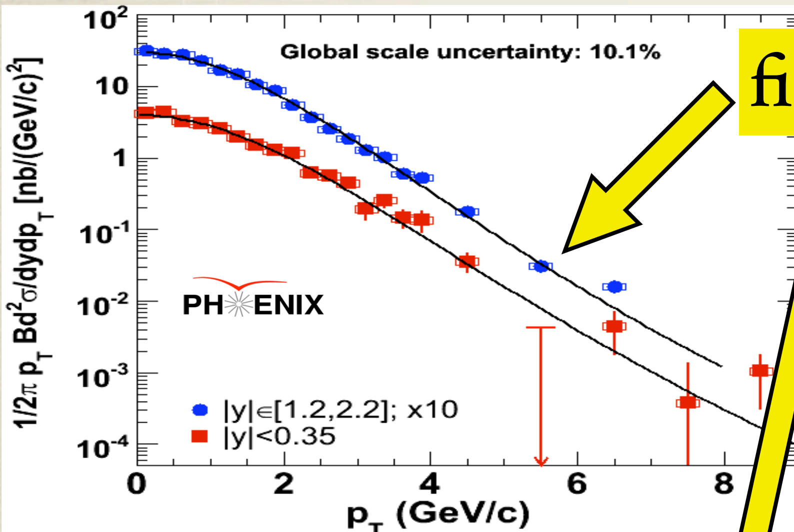
$$(x_1, x_2) \xleftrightarrow[\text{physical constraints}]{c\bar{c}\text{ hard production process}} (y, p_T)$$

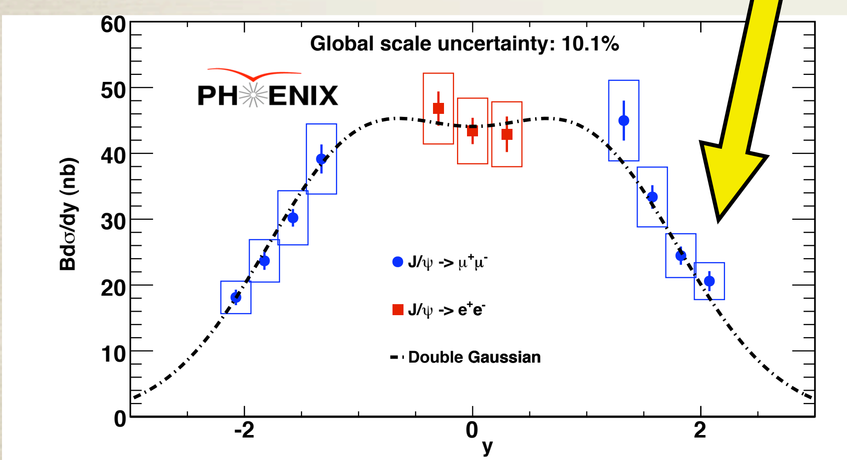
- Intrinsic scheme
- Extrinsic scheme

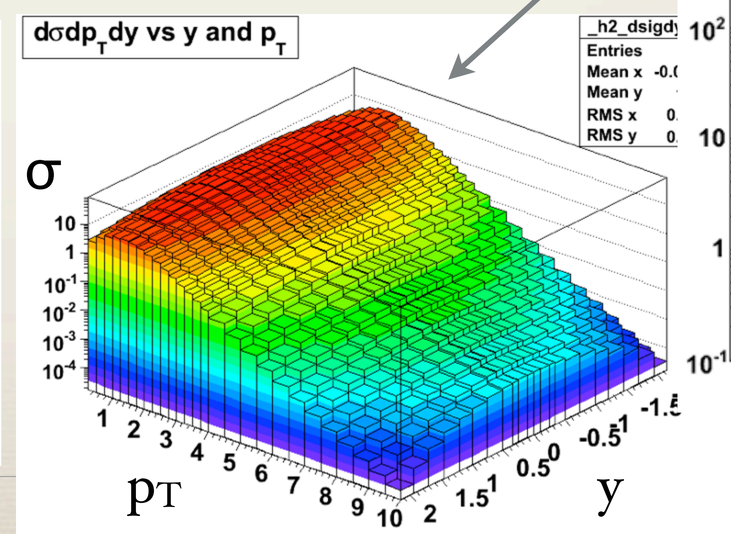
model

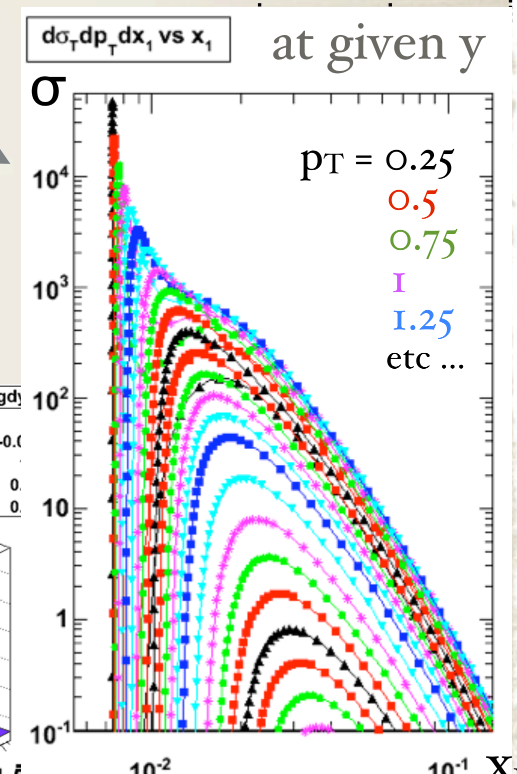
x_1	x_2	$\frac{d^4\sigma}{dy\,dp_T\,dx_1 dx_2}$	p_T	y

fits





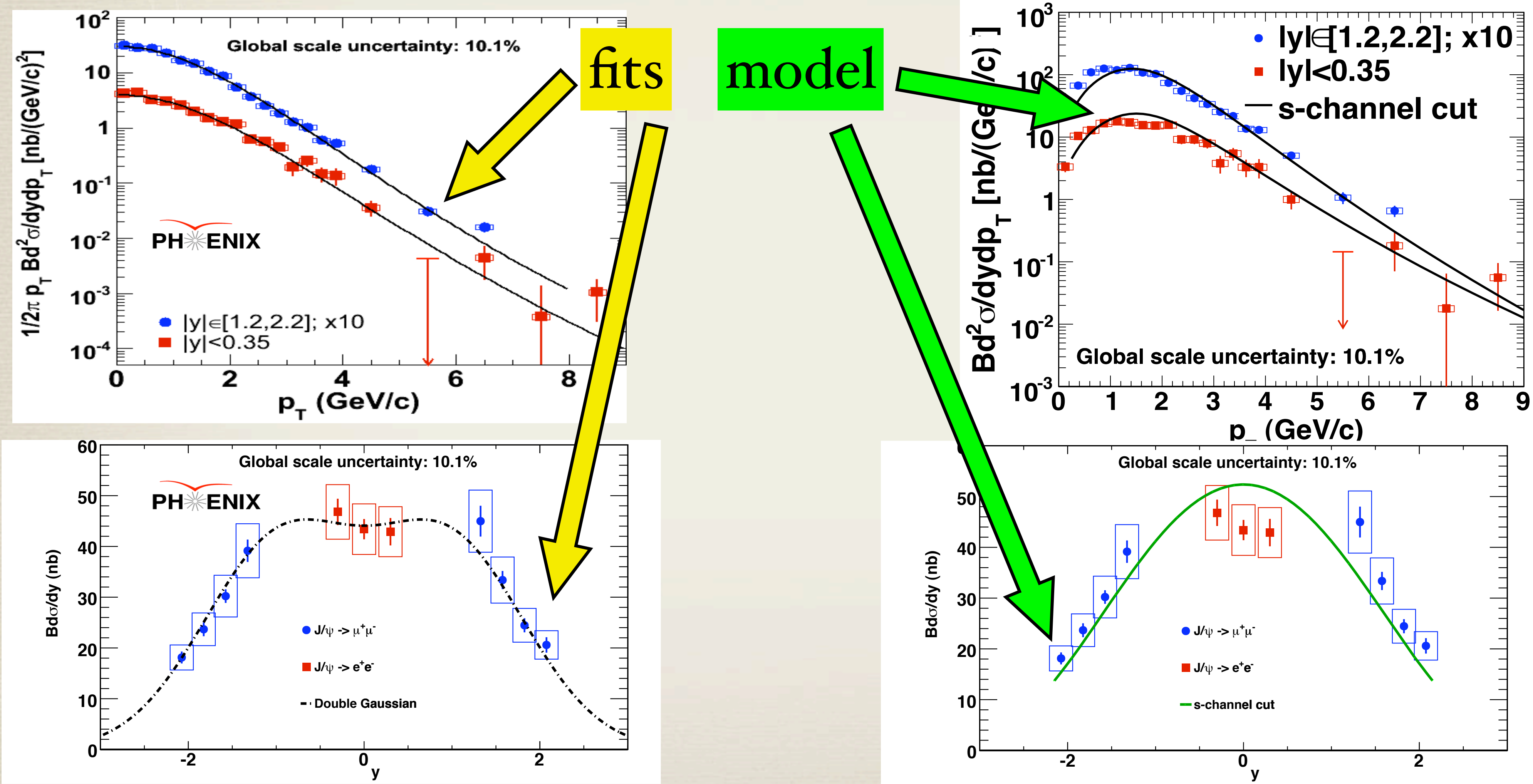




Adding the p_T dependence

$$(x_1, x_2) \xleftrightarrow[\text{physical constraints}]{c\bar{c}\text{ hard production process}} (y, p_T)$$

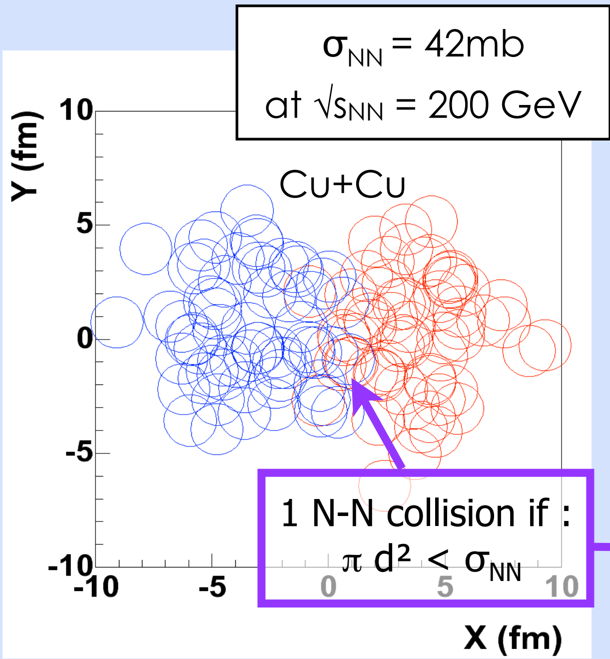
- Intrinsic scheme
- Extrinsic scheme



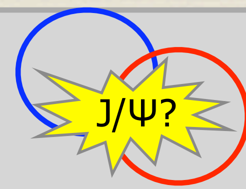
Our Monte-Carlo approach for J/Ψ production

1 — 2 — 3

Glauber MC



Random :
- b according to 2π b db
- position of nucleons $\in$ A, B according to Woods-Saxon



For each N-N collision

J/Ψ candidate produced
- according to $\sigma_{J/\psi} \leq \sigma_{NN}$

with random :
- **y** and $\mathbf{p_T}$
- random p_T orientation $\boldsymbol{\varphi}$ uniformly distributed in $[0, 2\pi]$
- $\mathbf{x_1}$, $\mathbf{x_2}$ determined from intrinsic or extrinsic scheme

Kinematics for J/Ψ candidate:
$y, p_T, \varphi, M \Rightarrow p_x , p_y , p_z , E$

J/Ψ canditate ⇒ real J/Ψ if :

$\text{random}[0,1] < R_{shadow} \times \sigma_{J/\psi} / \sigma_{NN}$

computed using **EKS**

Nuclear modif. factor =
$dN_{\text{real } J/\psi} / dN_{J/\psi \text{ canditate}}$

Our Monte-Carlo approach for J/ψ production

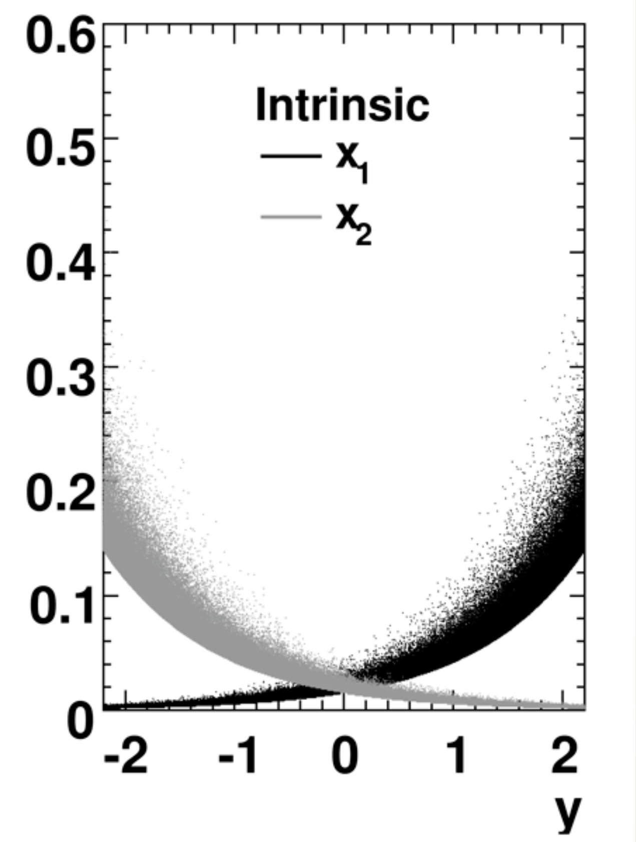
- Physical phase space and relative weighting of x_1, x_2 vs y in d+Au :

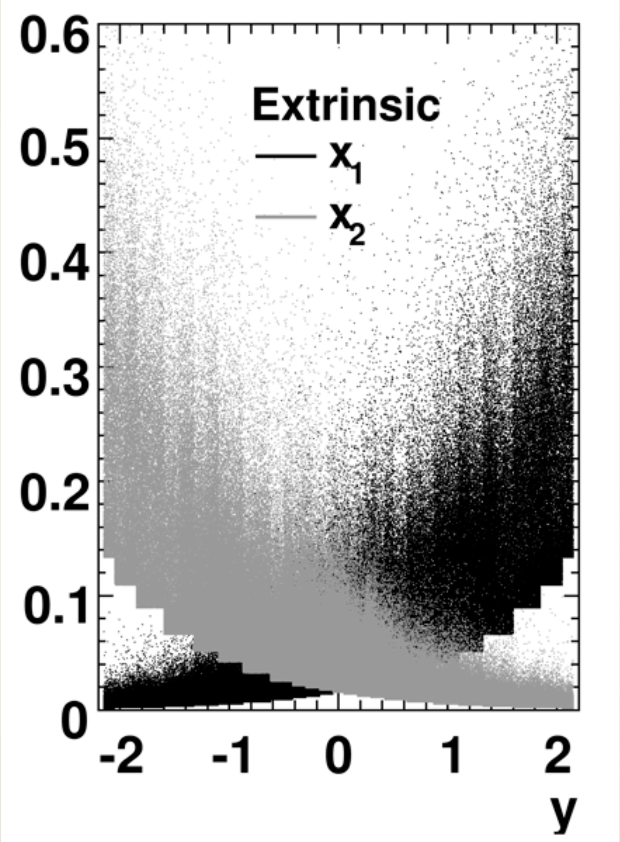
$$g + g \longrightarrow c\bar{c}$$

initial g with intrinsic k_T

$$g + g \longrightarrow c\bar{c} + g$$

collinear initial g ⇒ extrinsic mechanism needed to give $p_T \neq 0$ to the J/ψ

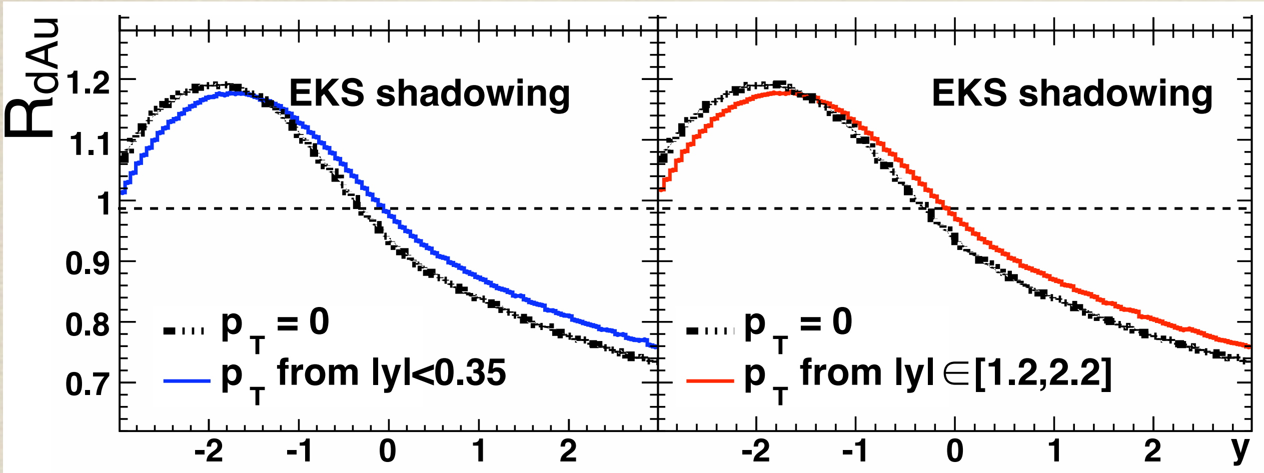




▷ consequence : different shadowing will be obtained !

Results :1) R_{dAu} vs y

p_T = 0 vs intrinsic p_T

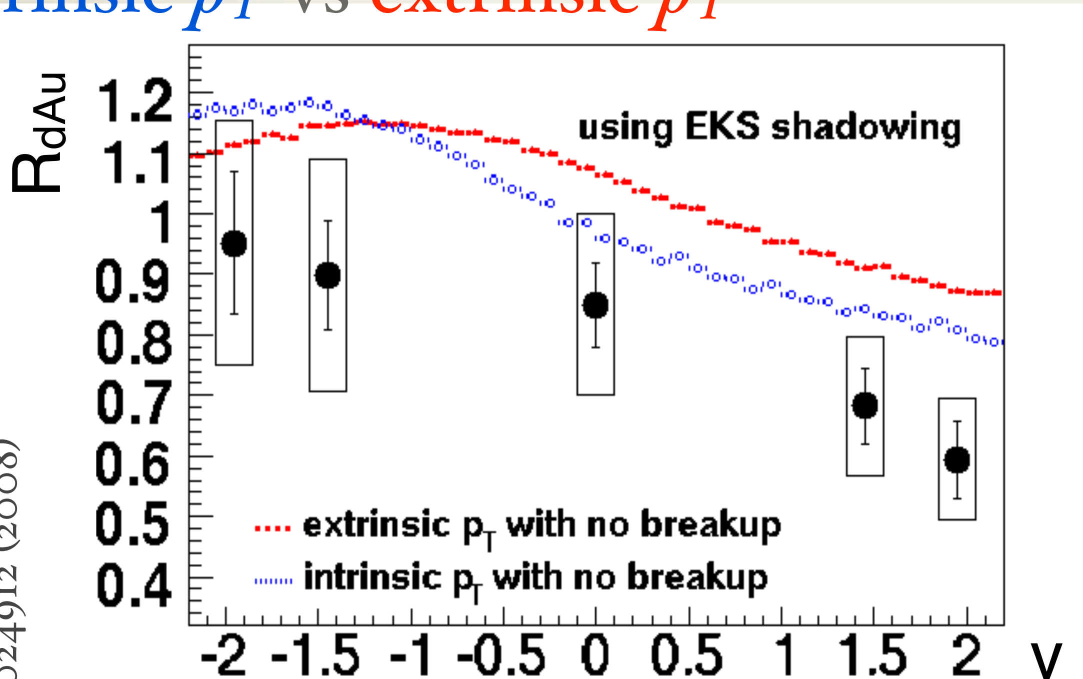


$$x_{1,2} = \frac{m_T}{\sqrt{s_{NN}}} e^{\pm y}$$

- Adding pT via the intrinsic scheme: small effect because

$$\langle p_T \rangle < 2\,\mathrm{GeV}/c < m_{J/\psi}$$

intrinsic p_T vs extrinsic p_T

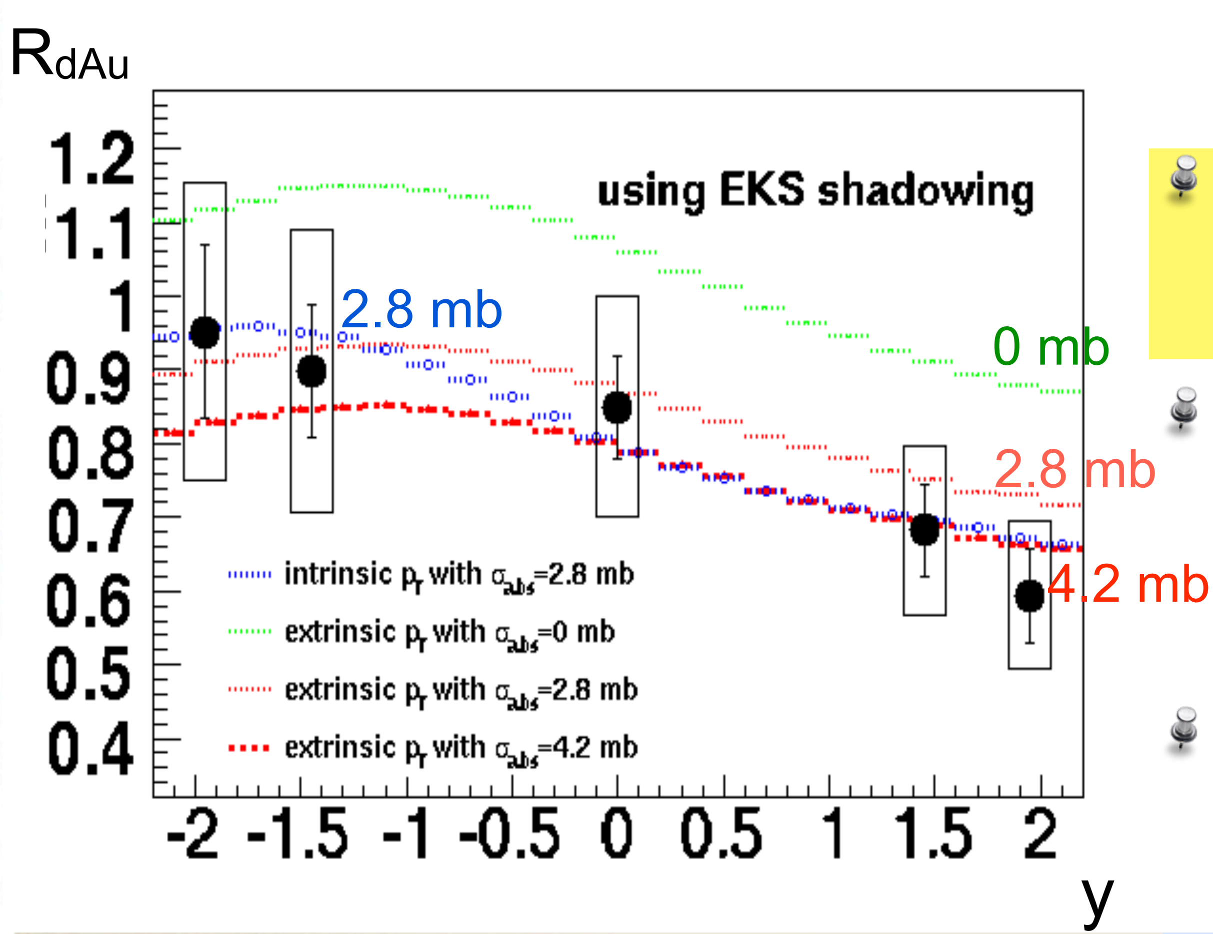


PHENIX d+Au, Phys. Rev. C77, 024912 (2008)

- Intrinsic vs extrinsic : significative differences
- Due to <x₁, x₂> being different in the two schemes
- Need nuclear abs. (final state effect)

Comparison to the data : 1) R_{dAu} vs y

intrinsic p_T vs extrinsic p_T

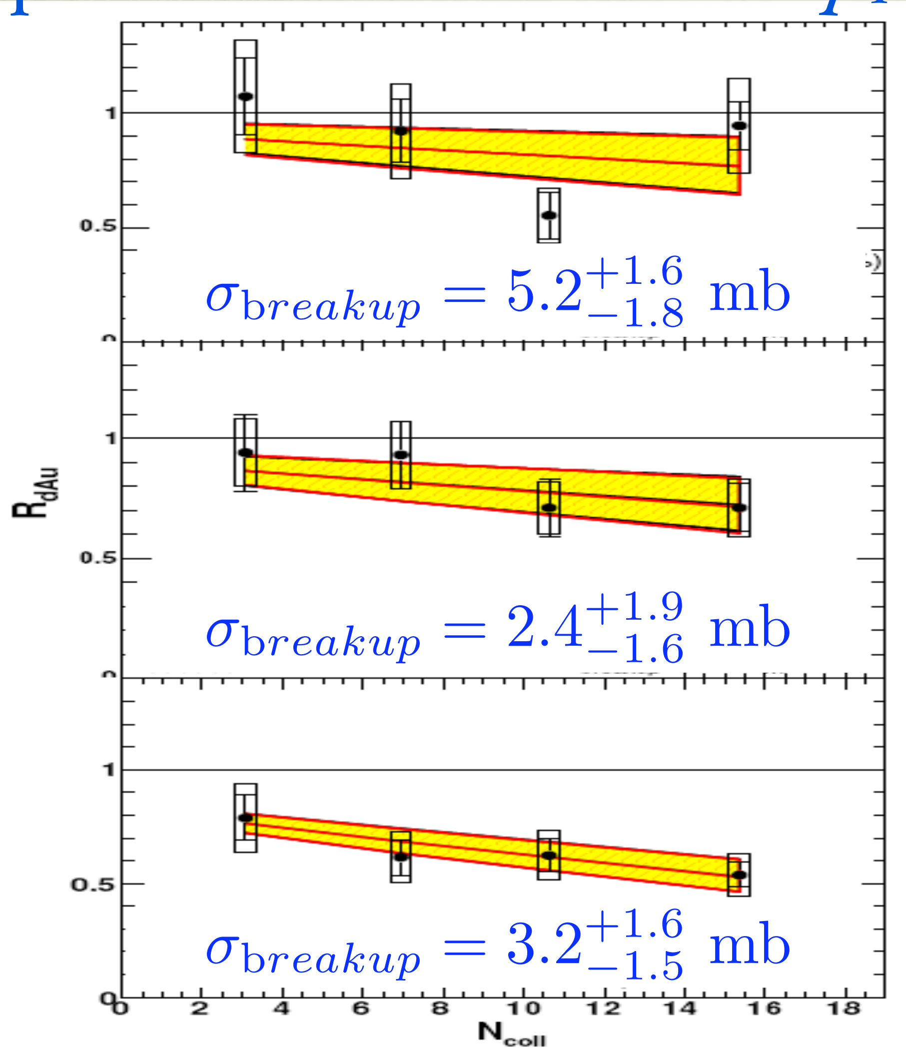


- Good matching obtained for both schemes
- But with diff. values of $\sigma_{\text{break-up}}$
- intrinsic: same $\sigma_{\text{break-up}}$ as the best estimate in PHENIX d+Au paper [1]
- extrinsic: $\sigma_{\text{break-up}}$ matches NA50 (SPS) value at lower energy !

[1] PHENIX d+Au, Phys. Rev. C77, 024912 (2008)

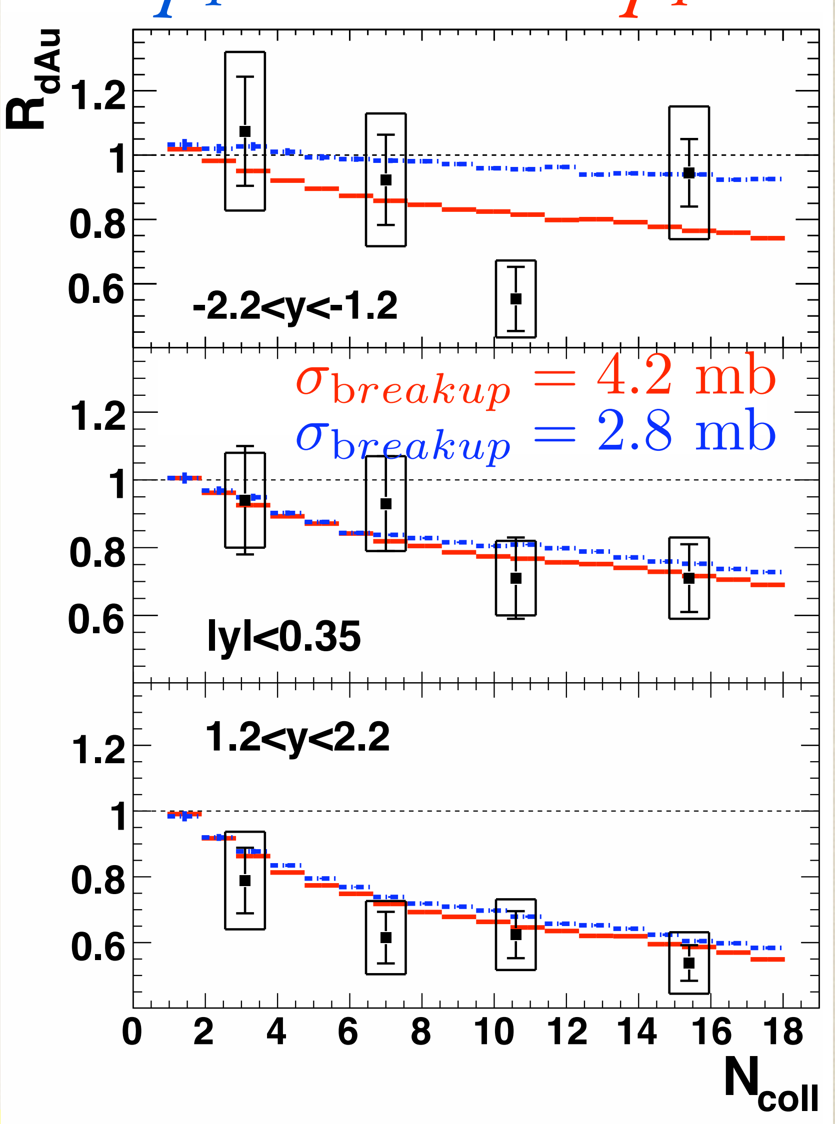
Comparison to the data : 2) R_{dAu} vs N_{coll}

pT = 0 similar to intrinsic p_T



PHENIX d+Au, Phys. Rev. C77, 024912 (2008)

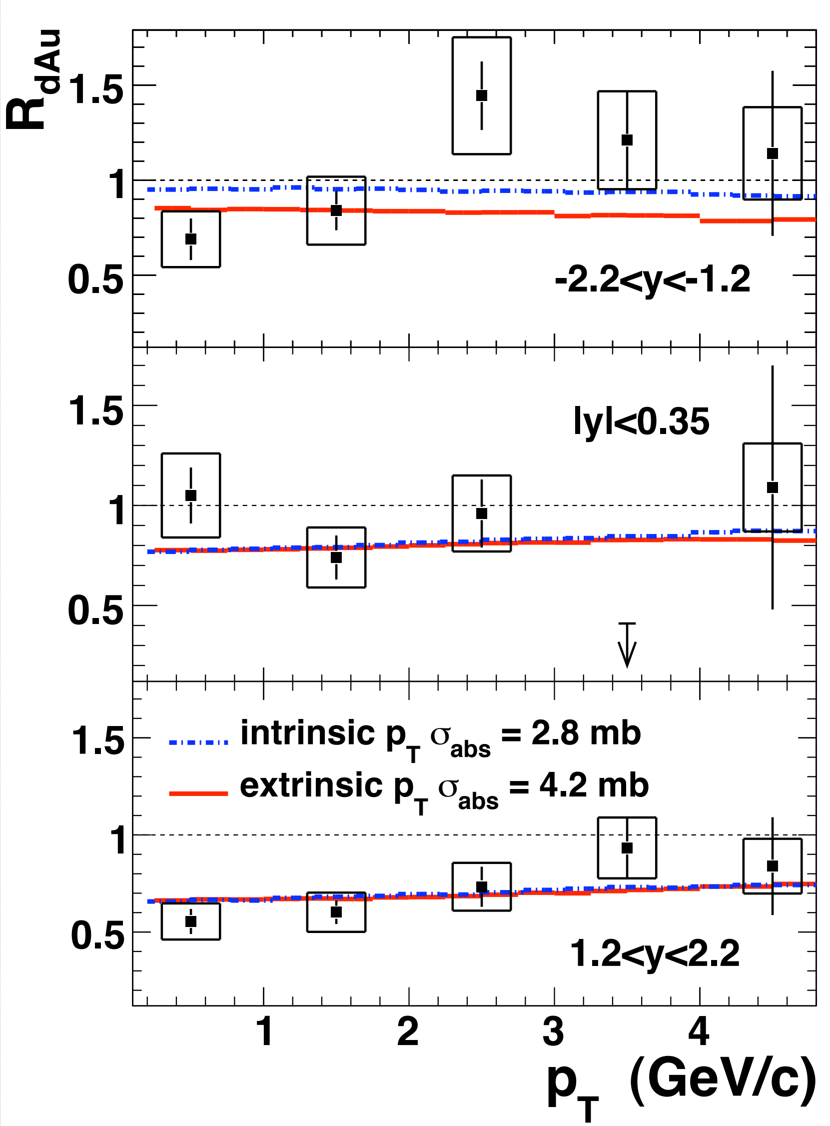
intrinsic p_T vs extrinsic p_T



several $\sigma_{break\text{-}up}$ needed in intrisinc scheme to do the same job as extrinsic scheme with one single $\sigma_{break\text{-}up}$

Comparison to the data : 2) R_{dAu} vs p_T

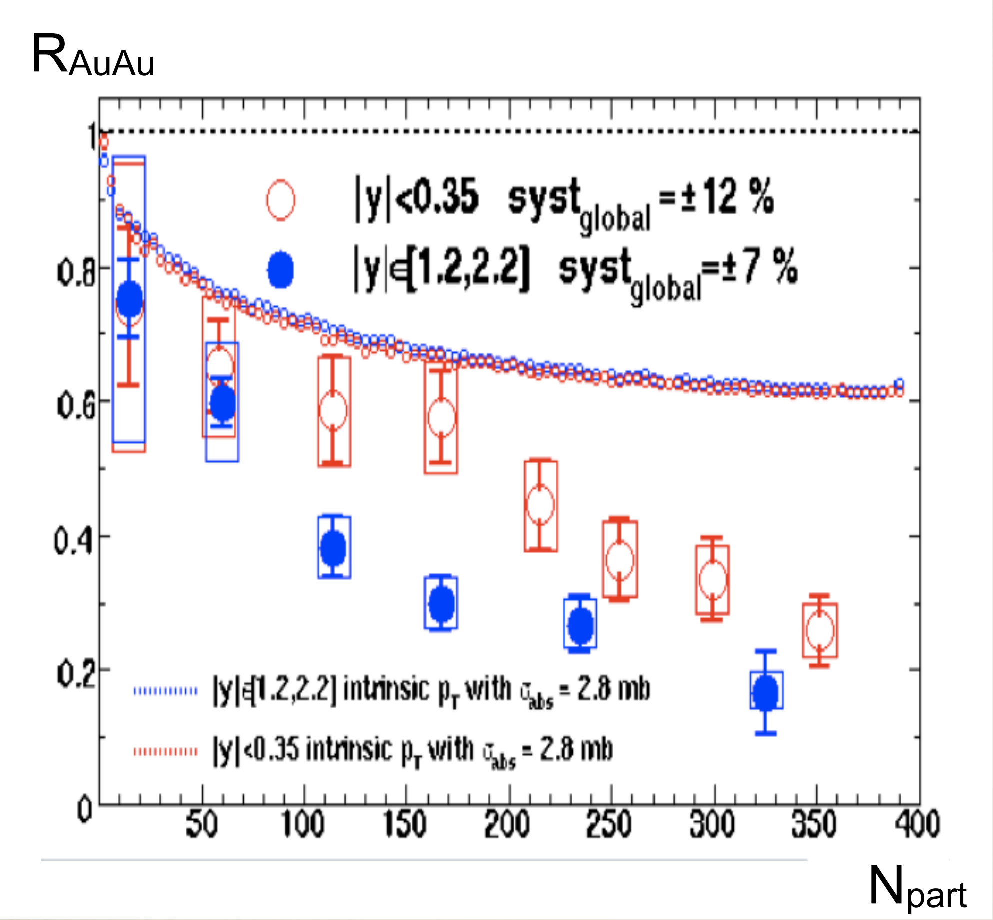
intrinsic p_T vs extrinsic p_T

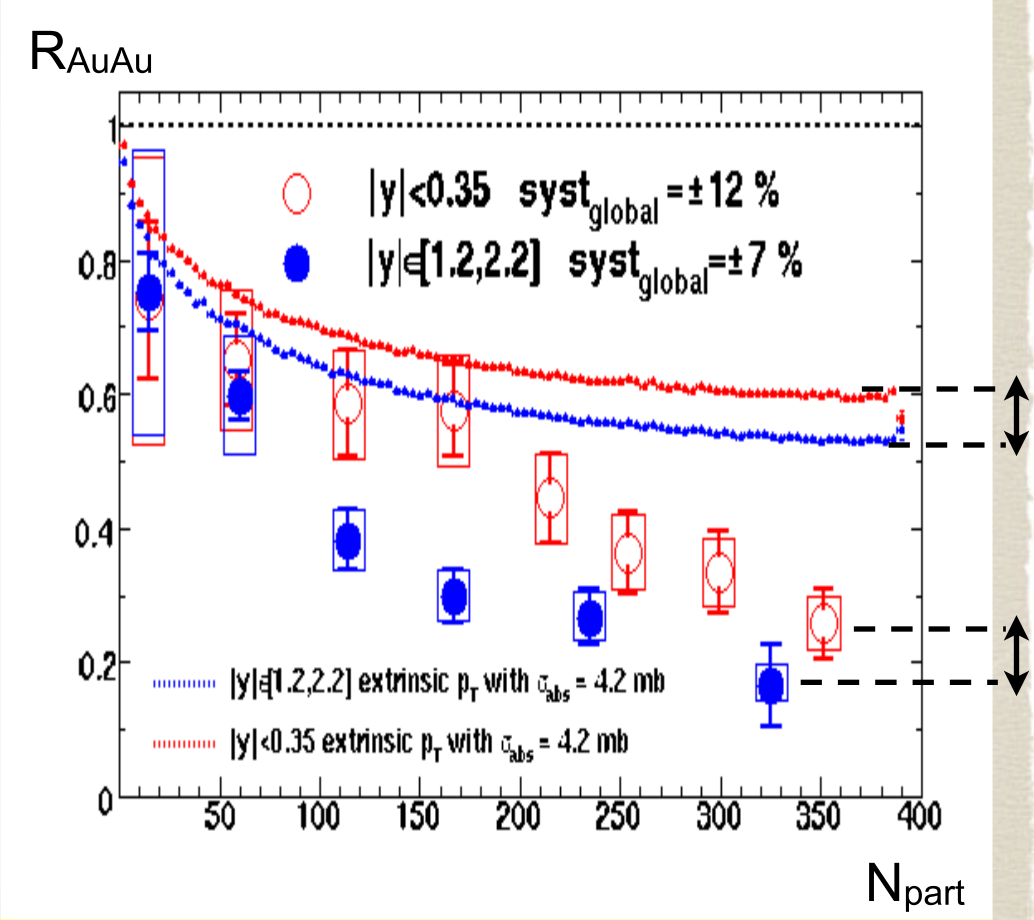


- First predictions of R_{dAu} vs p_T
- some ingredient missing in the model ?
  - like p_T broadening ?
- difficult to conclude
- need more precise data

Cold effects in Au+Au : vs N_{part}

- Intrinsic scheme
- Extrinsic scheme

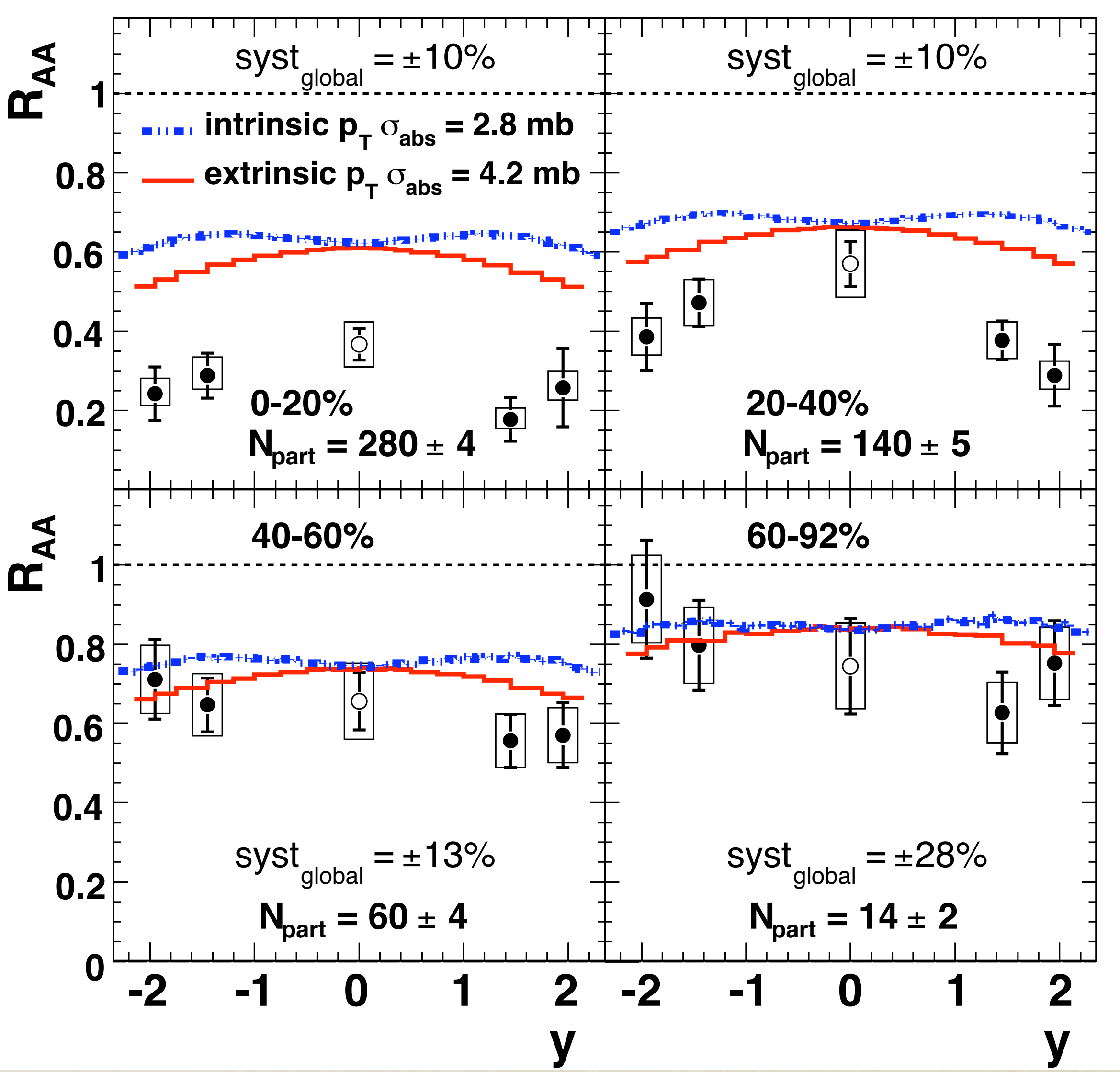




- same CNM effects at both y
- more suppression due to CNM effects at fwd y

Cold effects in Au+Au : vs y

intrinsic p_T vs extrinsic p_T



- Extrinsic scheme :

  less amount of recombination needed

Summary

- Glauber MC (no dynamic)

  + intrinsic or extrinsic scheme for the J/ψ production

  + EKS shadowing model

- First results @ $p_T \neq 0$ for the J/ψ shadowing at RHIC

- Different shadowing obtained in extrinsic scheme $g + g \rightarrow J/\psi + g$

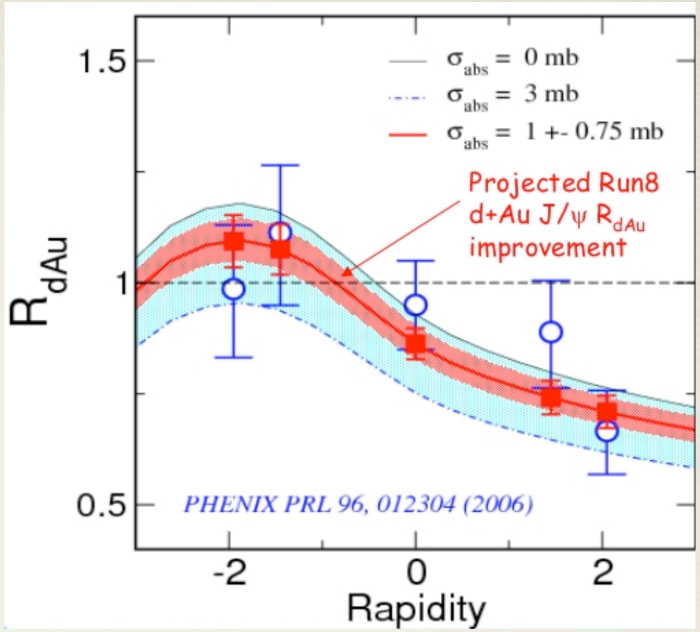
  ☑ more suppression due to CNM effects at $|y|$~1.7 than at $|y|$~0 in AuAu

  ➡ less amount of recombination needed 

- TO DO: in the extrinsic scheme, derive by fits to d+Au data the best break-up cross-section value and the corresponding error

Outlook

- High statistics (> 30×Run3) dAu from RHIC Run8
  - will allow to discriminate intrinsic vs extrinsic schemes

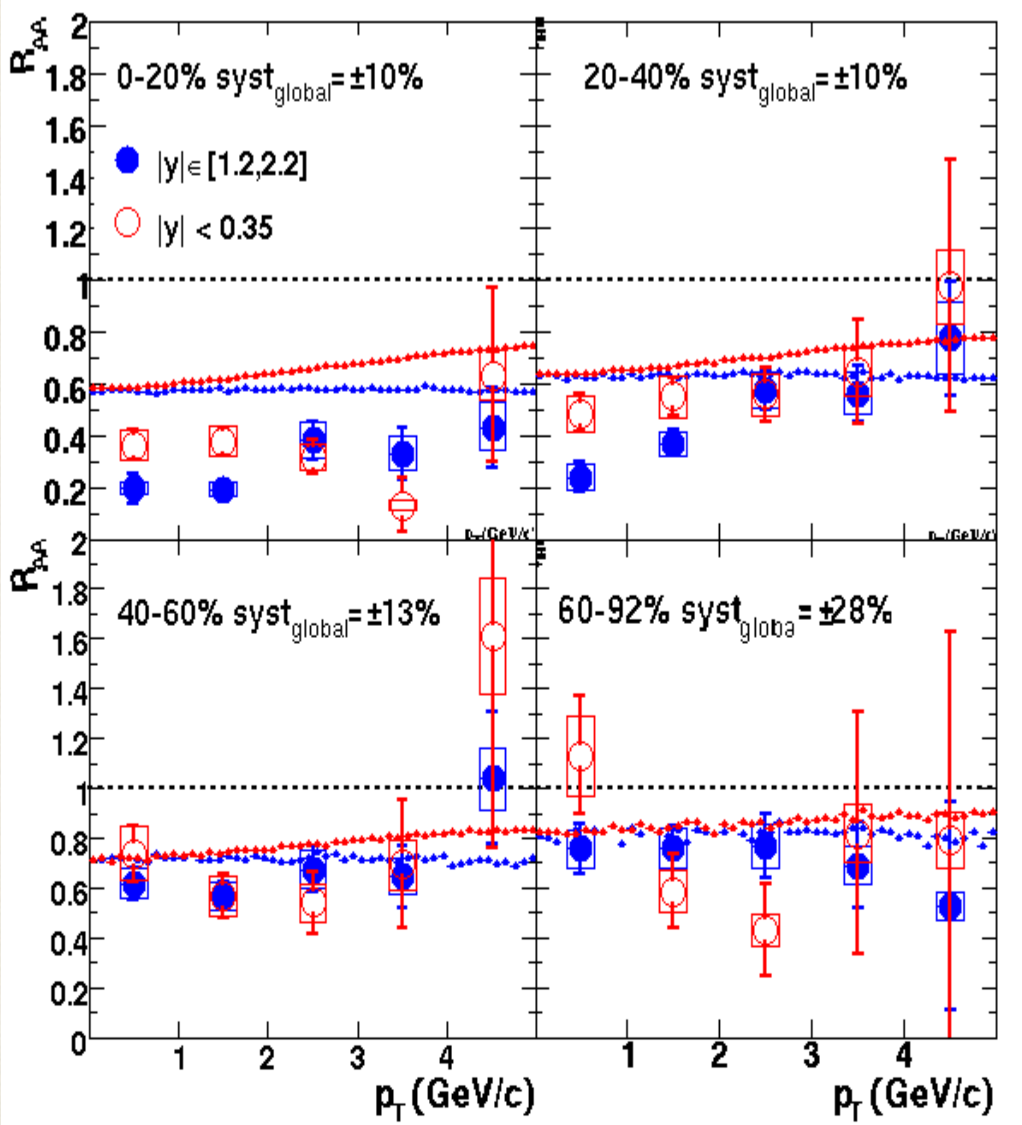


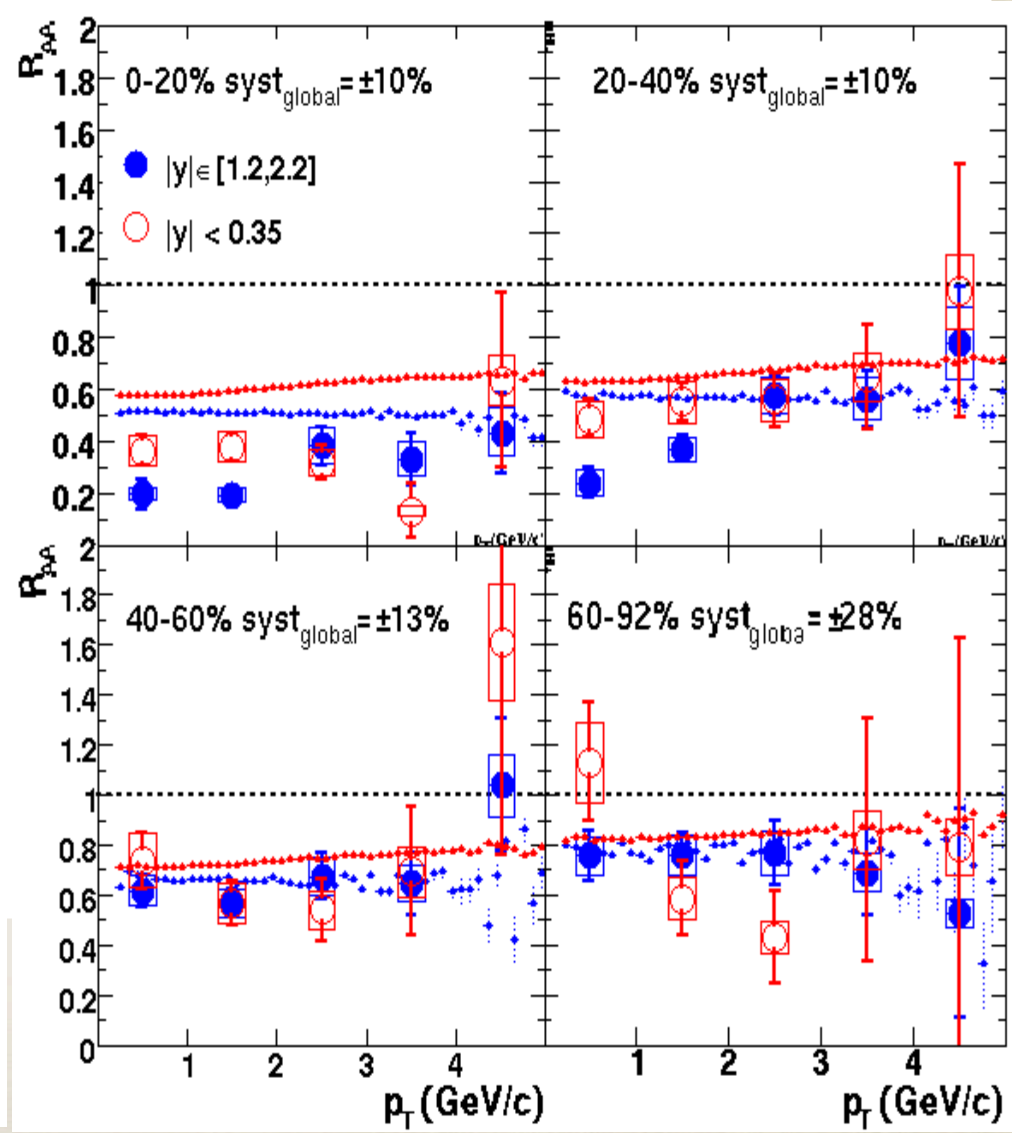
- Recent (x, Q^2) parametrisations of nPDF/A×PDF
  - NLO [de Florian & Sassot, Phys. Rev. D69:074028]
  - EPS08 with updated constrains on low-x gluon PDF from RHIC data [Eskola, Paukkunen & Salgado, arXiv:0802.0139]
- Predictions at LHC energies in the extrinsinc scheme

BACK-UP

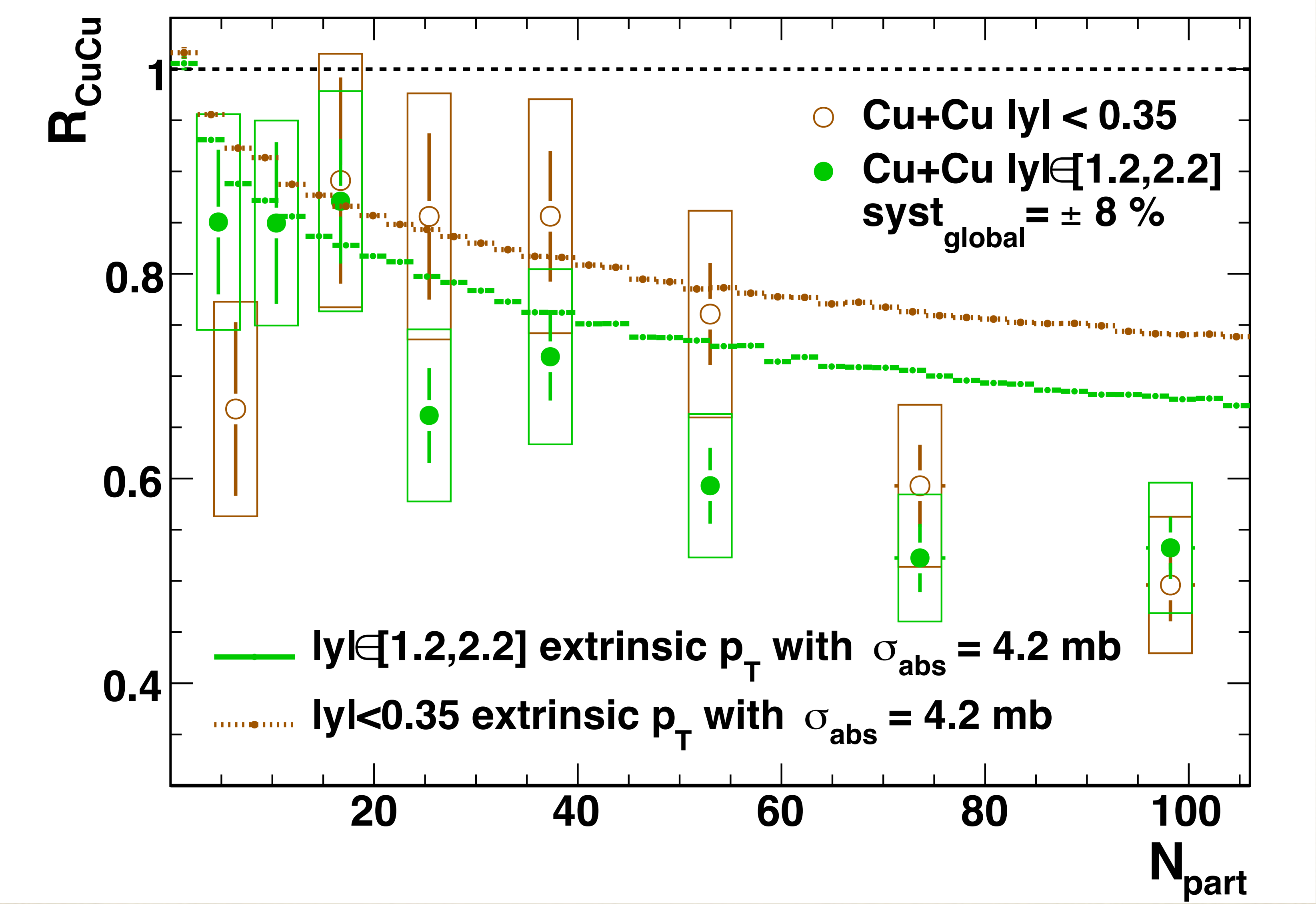
Cold effects in Au+Au : vs p_T

- Intrinsic scheme
- Extrinsic scheme

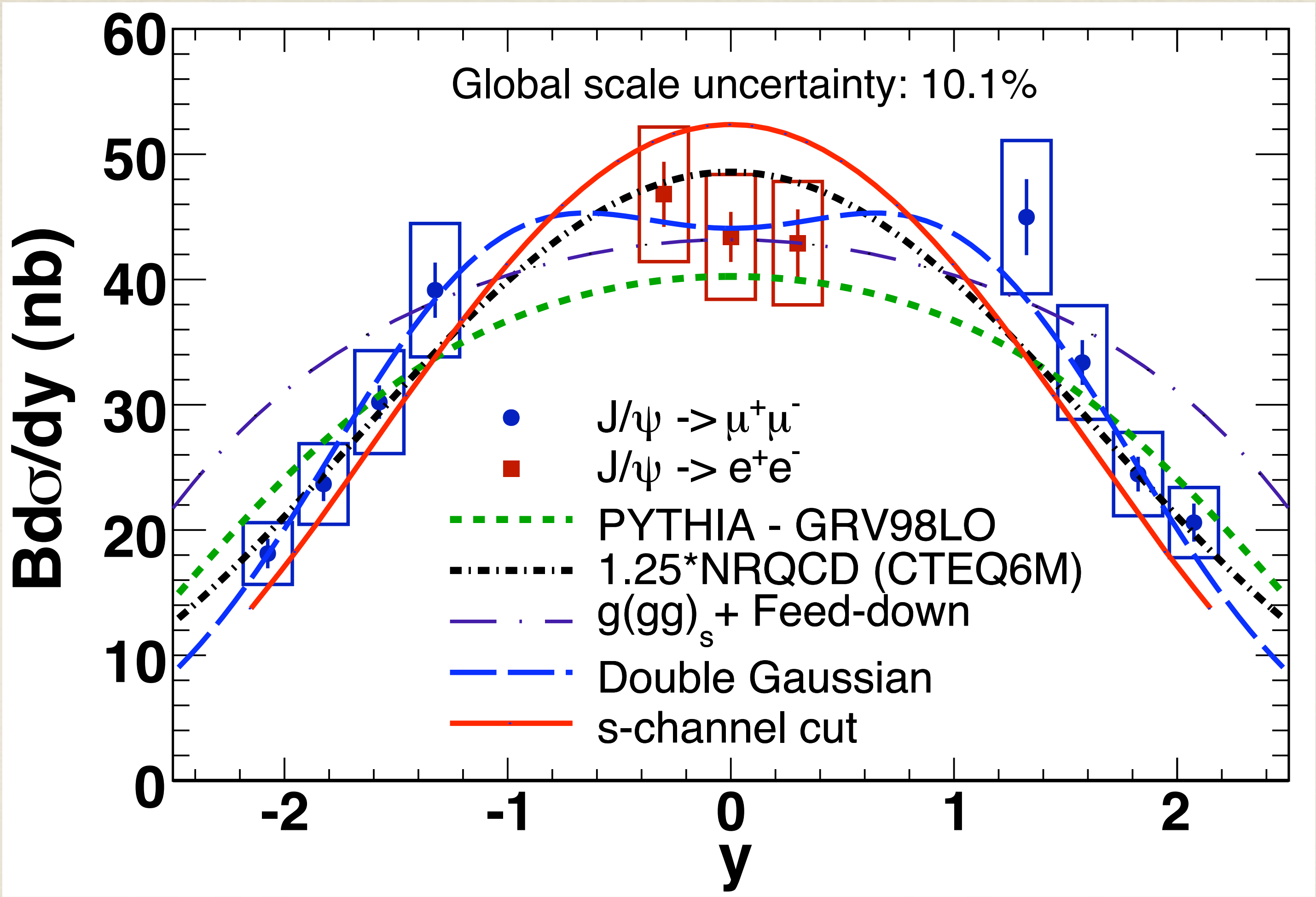




Cold effects in Cu+Cu : extrinsic scheme

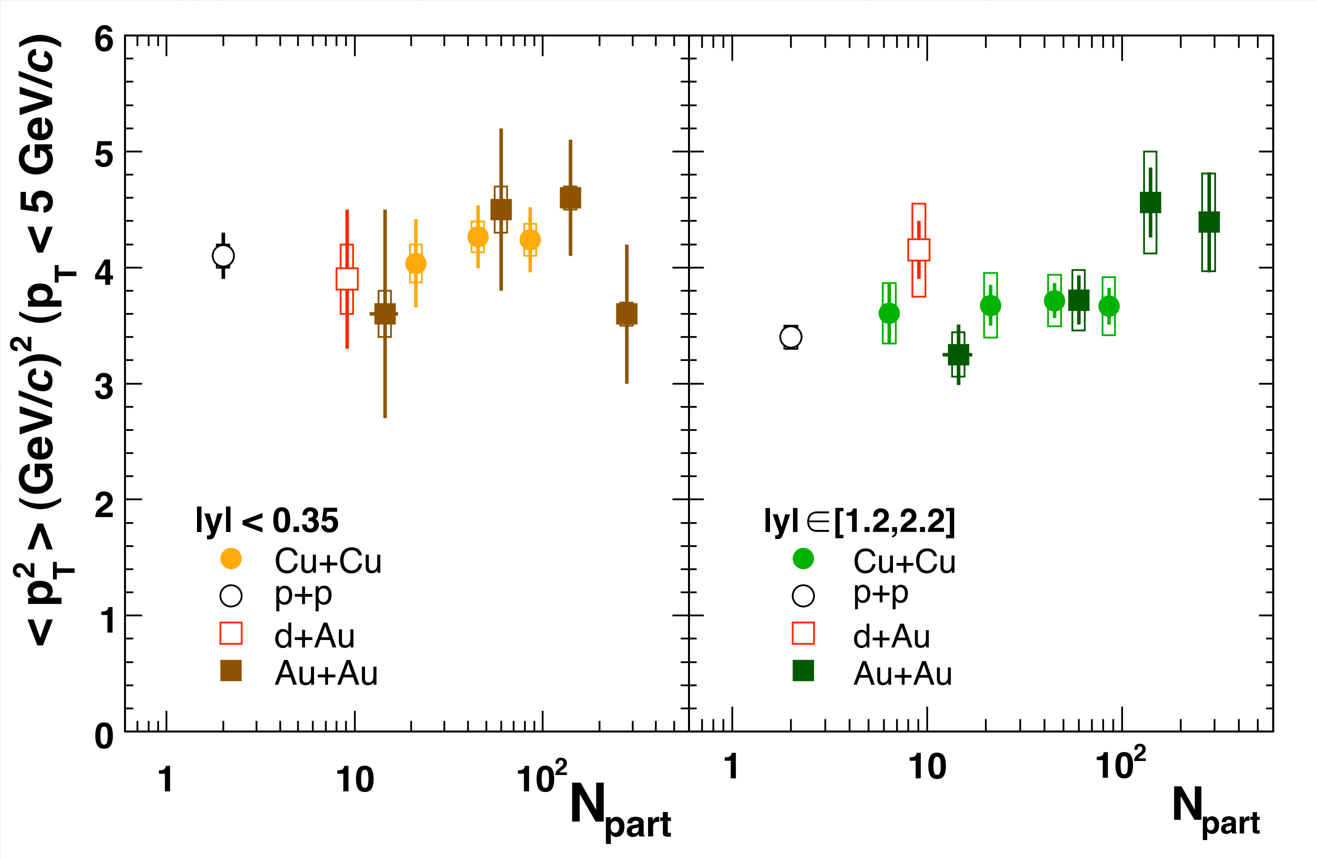


Various models for the y spectra in p+p



[NRQCD calculation] Cooper, Liu & Nayak, Phys. Rev. Lett. 93, 171801 (2004)
[g(gg)$_s$ + Feed-down] Khoze, Martin, Ryskin Stirling, Eur. Phys. J. C39, 163 (2005)

The p_T-broadening picture



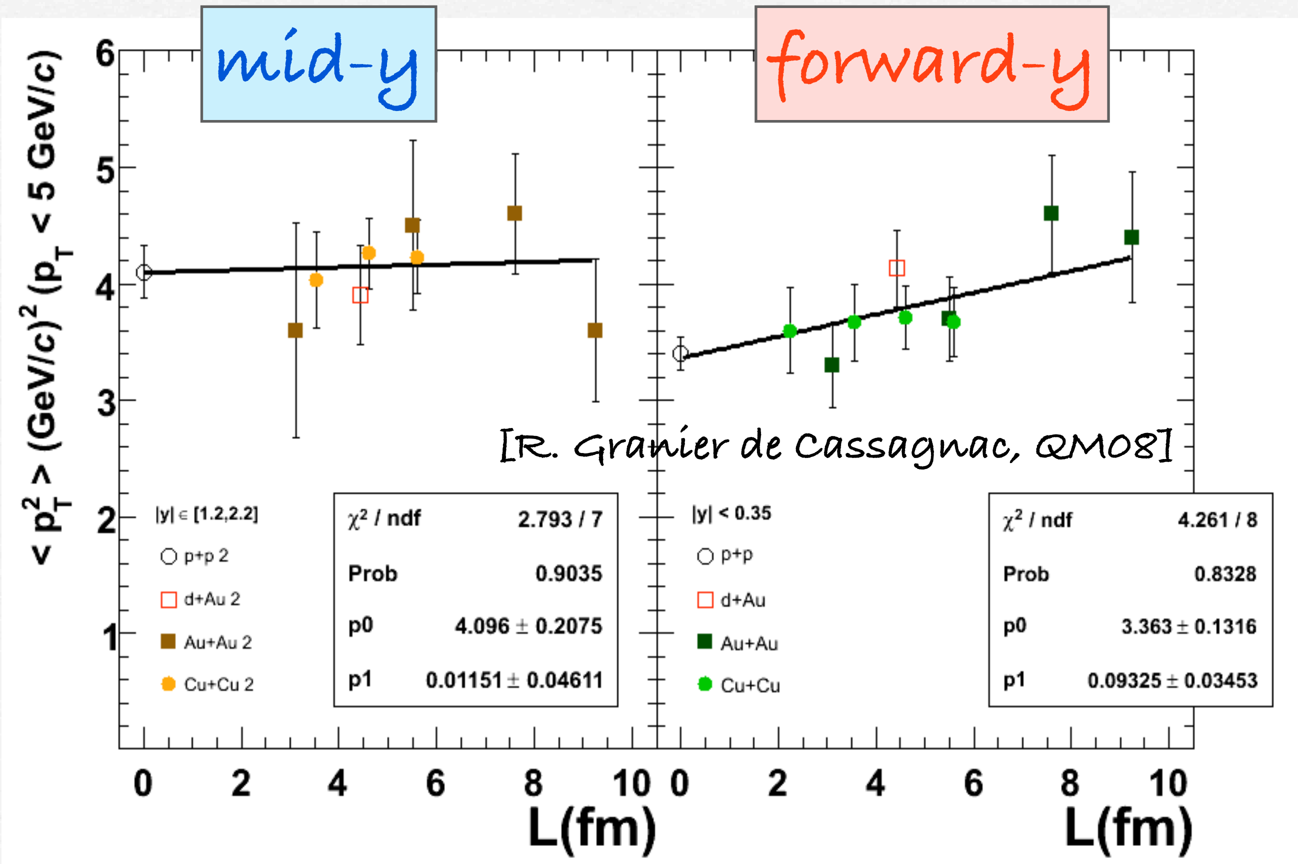
$<p_T^2>$ vs N_{part}

- ☐ flat or moderate broadening
- ☐ if brodened, what origin(s) ?
  - cold effect (shadowing, Cronin)
  - hot effect (recombination)

Bar = pt-to-pt uncorrelated err. (stat. + syst.)

Box = pt-to-pt correlated err. (syst.)

p_T-broadening due to random walk ?



$$\langle p_T^2\rangle_{AA} = \underbrace{\langle p_T^2\rangle_{pp}}_{p0} + \underbrace{\rho_0\,\sigma_{g-\mathrm{N}}\,\Delta p_T^2}_{p1} \times \L_{AA}$$

$<p_T^2>$ vs L

- random walk of the initial gluons in the transverse plane
- at mid-y : slope compatible with zero
  $p1 = 0.011 \pm 0.046$
- at forward-y :
  $p1 = 0.093 \pm 0.034$
  compatible with mid-y