

# Cold Nuclear Matter Effects on Quarkonium Production at RHIC and the LHC

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# Outline

- 1 Motivations
- 2 On the kinematics of  $J/\psi$  production
- 3 The Glauber Monte Carlo
- 4 Results for  $J/\psi$  at RHIC
- 5 Results for  $\Upsilon$  at RHIC
- 6 EMC effect for gluons
- 7 Results for  $J/\psi$  at the LHC, PbPb collisions
- 8 Conclusions

# Motivations

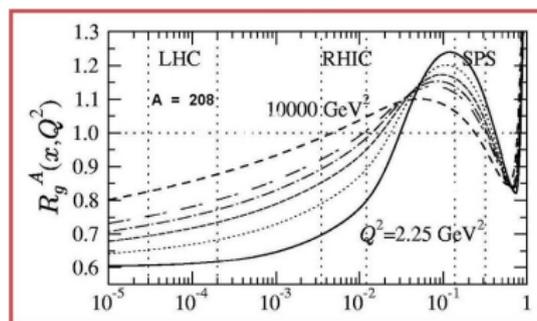
- $J/\psi$  a good probe of QGP produced in **A+A** collisions
- Here we focalise on **p+A** data (no QGP is possible) where only cold nuclear matter (CNM) effects are in play: **shadowing and nuclear absorption**
- At **p+p** level we do not know the specific production kinematics at a partonic level: **CS ( $2 \rightarrow 2$ ) vs CO ( $2 \rightarrow 1$ )**
- **Our goal**: To investigate the CNM effects and the impact of the specific partonic production kinematics

# Shadowing : initial cold nuclear matter effects

- Nuclear shadowing is an initial-state effect on the partons distributions
- Gluon distribution functions are modified by the nuclear environment
- PDFs in nuclei different from the superposition of PDFs of their nucleons

Shadowing effects increases with energy ( $1/x$ ) and decrease with  $Q^2(m_T)$

$$R_i^A(x, \mu_f) = \frac{f_i^A(x, \mu_f)}{A f_i^{\text{nucleon}}(x, \mu_f)} \quad f_i = q, \bar{q}, g$$



# Absorption

Particle spectrum altered by interactions with the nuclear matter they traverse

⇒  $J/\psi$  **suppression** due to final state interactions with spectator nucleons

**Usual parametrisation (Glauber model)** :

$$S_{abs} = \exp(-\rho\sigma_{abs}L)$$

- $\rho$  the nuclear matter density
- $\sigma_{abs}$  the break-up cross section
- $L$  the path length

**Energy dependence** (see E. G. Ferreira talk, Rencontres d'Etretat, 20-23/09)

- **At low energy**: the heavy system undergoes successive interactions with nucleons in its path and has to survive all of them ⇒ **Strong nuclear absorption**
- **At high energy**: the coherence length is large and the projectile interacts with the nucleus as a whole ⇒ **Smaller nuclear absorption**

# On the kinematics of $J/\psi$ production

- CNM -shadowing- effects depends completely on  $J/\psi$  kinematics ( $x, Q^2$ )
- $J/\psi$  kinematics depends on the production mechanism

## Two production mechanisms

- $g + g \rightarrow c\bar{c} \quad 2 \rightarrow 1$

**Intrinsic scheme:** the  $p_T$  of the  $J/\psi$  comes from initial partons

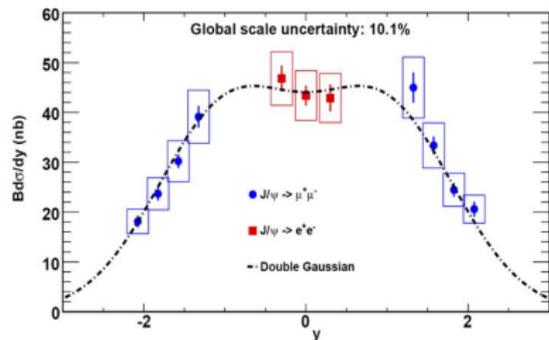
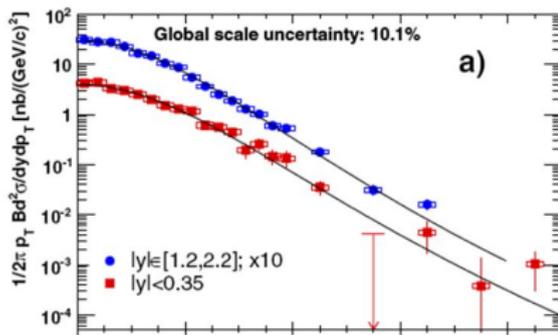
- $g + g \rightarrow c\bar{c} + g \quad 2 \rightarrow 2$

**Extrinsic scheme:** the  $p_T$  of the  $J/\psi$  is balanced by the outgoing gluon

# On the kinematics of $J/\psi$ production

## Intrinsic scheme

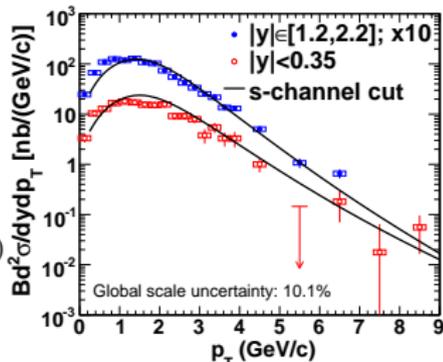
- Intrinsic scheme:  $2 \rightarrow 1$  process CEM @ LO or COM @  $\alpha_s^2$
- $y, p_T$  can be determined using PHENIX  $p + p$  **data**  
Phys. Rev. Lett. 98, 232002 (2007)
- Easy to handle :  $y^{J/\psi}$  and  $p_T^{J/\psi}$  directly give  $x_{1,2}$



# On the kinematics of $J/\psi$ production

## Extrinsic scheme

- We deal with a  $2 \rightarrow 2$  partonic process with collinear initial gluons
- The quadri-momentum conservation results in a complex expression of  $x_2$  as a function of  $(x_1, y, p_T)$  (see next slide)
- Information from the data alone (the  $y$  and  $p_T$  spectra) is **not sufficient to determine  $x_1$  and  $x_2$**
- The models need however **to describe the data at low  $p_T$**
- CSM at LO, COM at  $\alpha_s^3$  and CEM at NLO **do NOT describe the data well** below  $p_T = 2$  GeV
- Models are mandatory to compute the weighting of kinematically allowed  $(x_1, x_2)$
- We choose CSM + s-channel cut at RHIC in  $p + p$  Haberzettl and Lansberg, PRL.100,032006 (2008)
- **A proper description of the kinematics** matters here more than the underlying physics



# On the kinematics of $J/\psi$ production

If  $\mathcal{F}_g^A(x, \vec{r}, z, \mu_f)$  gives the **distribution of a gluon** of mom. fract.  $x$  at a **position  $\vec{r}, z$  in a nucleus  $A$** , the differential cross-section reads:

$$\frac{d\sigma_{AB}}{dy dP_T d\vec{b}} =$$

**2**  $\rightarrow$  **1** kinematics with **intrinsic**  $p_T$

**2**  $\rightarrow$  **2** kinematics with **extrinsic**  $p_T$

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**2  $\rightarrow$  1** kinematics with **intrinsic**  $p_T$

$$\begin{aligned} & \int d\vec{r}_A dz_A dz_B \\ & \times \mathcal{F}_g^A(x_1^0, \vec{r}_A, z_A, \mu_f) \mathcal{F}_g^B(x_2^0, \vec{r}_B, z_B, \mu_f) \\ & \times \sigma_{gg}^{\text{Intr.}}(x_1^0, x_2^0) \\ & \times S_A(\vec{r}_A, z_A) S_B(\vec{r}_B, z_B) \end{aligned}$$

**2  $\rightarrow$  2** kinematics with **extrinsic**  $p_T$

$$\begin{aligned} & \int dx_1 dx_2 \int d\vec{r}_A dz_A dz_B \\ & \times \mathcal{F}_g^A(x_1, \vec{r}_A, z_A, \mu_f) \mathcal{F}_g^B(x_2, \vec{r}_B, z_B, \mu_f) \\ & \times 2\hat{s} P_T \frac{d\sigma_{gg \rightarrow \Upsilon+g}}{d\hat{t}} \delta(\hat{s} - \hat{t} - \hat{u} - M^2) \\ & \times S_A(\vec{r}, z_A) S_B(\vec{r}_B, z_B) \end{aligned}$$

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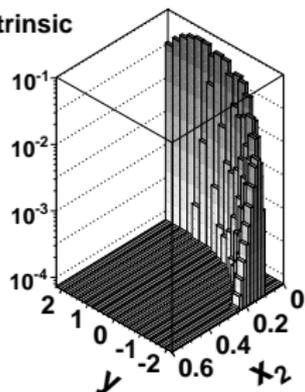
$$x_{1,2} = \frac{m_T}{\sqrt{s_{NN}}} \exp(\pm y) \equiv x_{1,2}^0(y, P_T)$$

**2  $\rightarrow$  2** kinematics with **extrinsic**  $p_T$

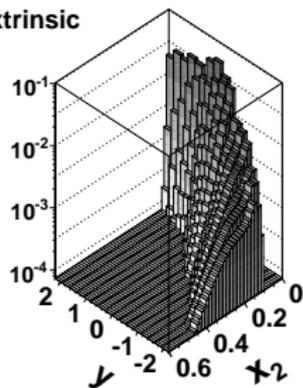
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$$\delta(\cdot) \rightarrow x_2 = \frac{x_1 m_T \sqrt{s_{NN}} e^{-y} - M^2}{\sqrt{s_{NN}} (\sqrt{s_{NN}} x_1 - m_T e^y)}$$

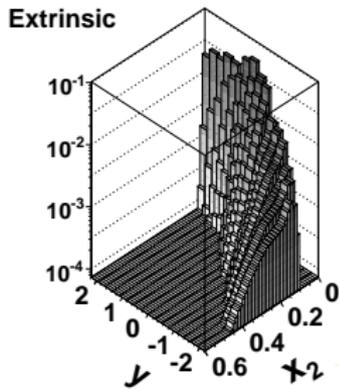
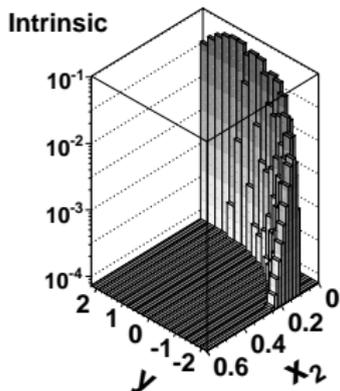
Intrinsic



Extrinsic

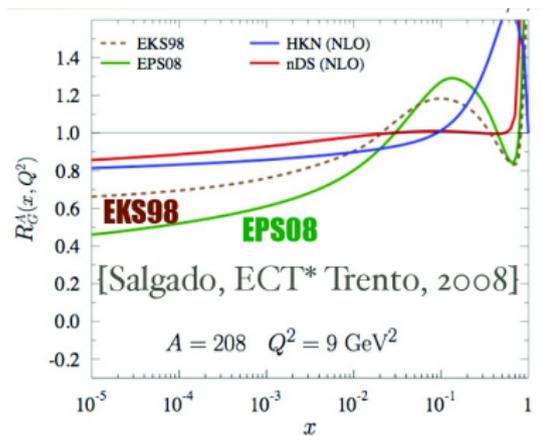


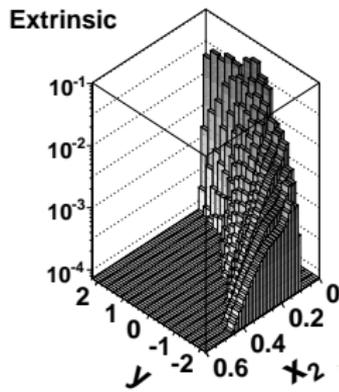
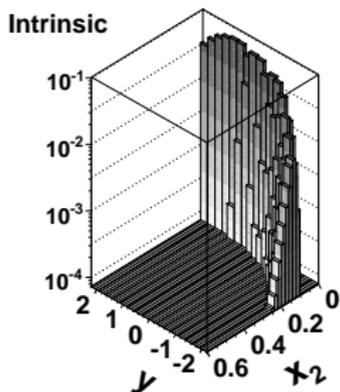
For a given couple  $(y, p_T)$ ,  $x_2$  is larger in the **extrinsic** scheme



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Antishadowing peak at  $\sim 10^{-1}$

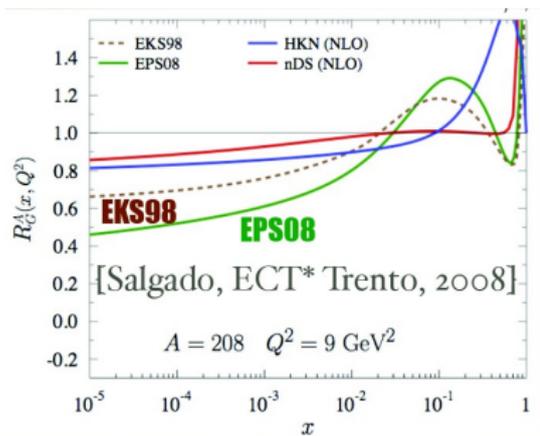




Antishadowing  
peak at  $\sim 10^{-1}$

We expect different shadowing effects  
in both cases.

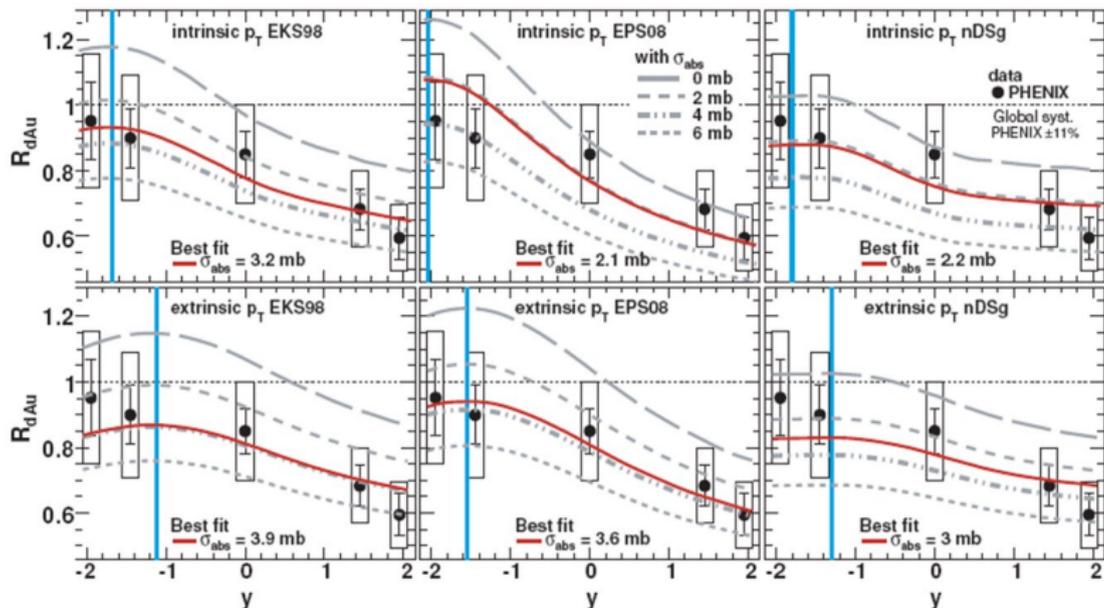
For a given couple  
( $y, p_T$ ),  $x_2$  is larger  
in the extrinsic scheme





Results for  $J/\psi$  at RHIC

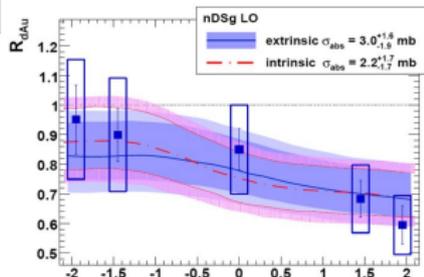
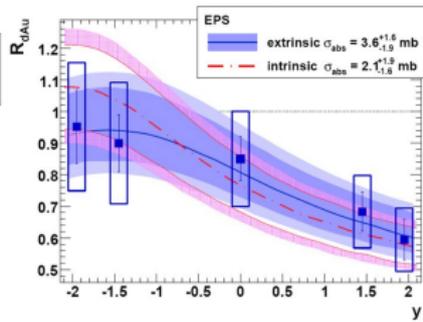
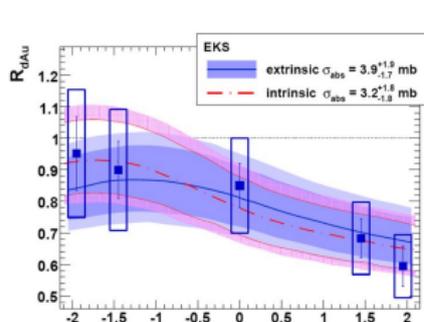
E. G. Ferreiro, F. Fleuret, J.P. Lansberg, A. Rakotozafindrabe, PRC 81, 0649011 (2010).



- shadowing depends on the partonic process:  $2 \rightarrow 1$  or  $2 \rightarrow 2$
- antishadowing peak shifted toward larger  $y$  in the extrinsic case
- in order to reproduce data:  $\sigma_{abs}^{\text{Extrinsic}} > \sigma_{abs}^{\text{Intrinsic}}$

Results for  $J/\psi$  at RHIC

- EKS98: compatible with **intrinsic and extrinsic**
- EPS08: **extrinsic** scheme is **favorized**
- nDSg: intrinsic and extrinsic **equally bad**

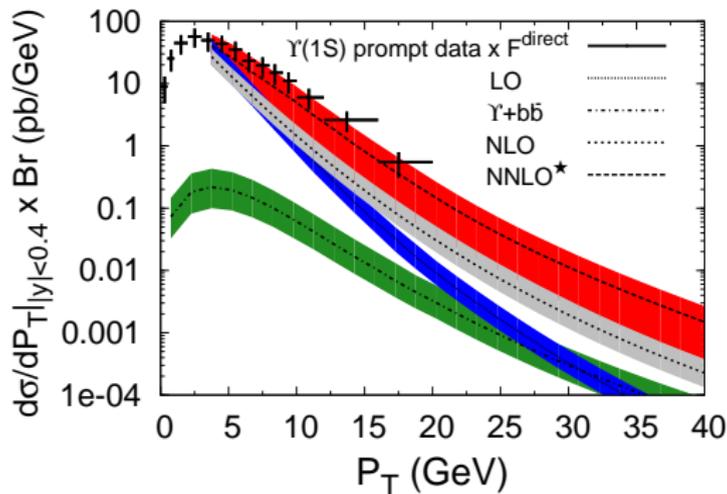


	$\sigma_{\text{abs}}$	$\chi^2_{\text{min}}$
EKS98 Int.	$3.2 \pm 2.4$	0.9
EPS08 Int.	$2.1^{+2.6}_{-2.2}$	1.1
nDSg Int.	$2.2^{+2.6}_{-2.2}$	1.6
EKS98 Ext.	$3.9^{+2.7}_{-2.3}$	1.1
EPS08 Ext.	$3.6^{+2.4}_{-2.5}$	0.5
nDSg Ext.	$3.0^{+2.5}_{-2.4}$	1.4

# $\Upsilon$ : Experimental situation

P. Artoisenet, J. Campbell, J.P. Lansberg, F. Maltoni, Phys. Rev. Lett. 101, 152001 (2008).

Results at 1.8 TeV

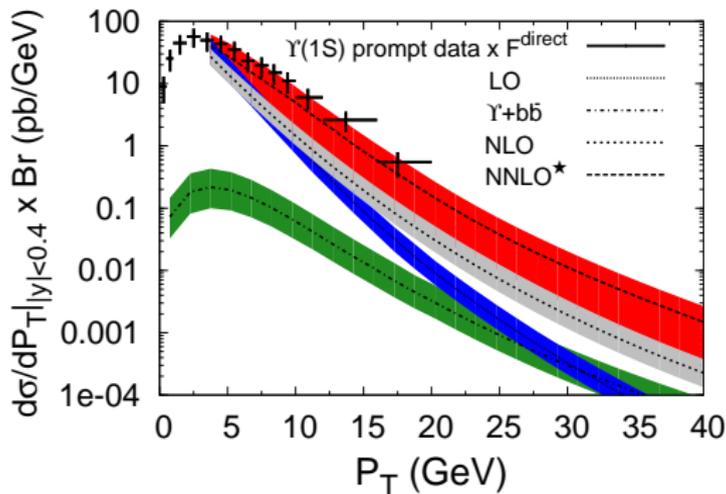


- CSM describes well the data at NNLO\*

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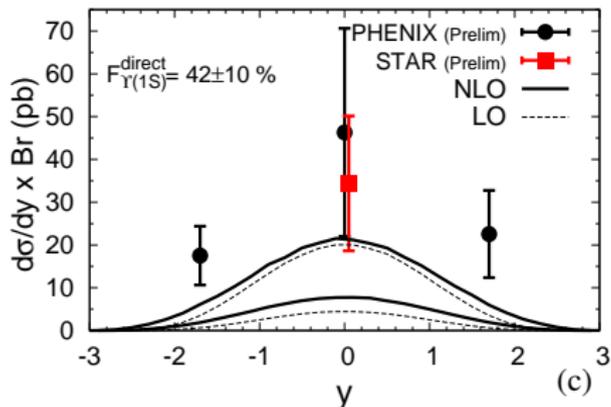


- CSM describes well the data at NNLO\*
- However LO CSM is sufficient to describe low  $p_T$  data

$\Upsilon$ : Experimental situation

S. J. Brodsky and J. P. Lansberg, Phys. Rev. D81, 014004 (2010).

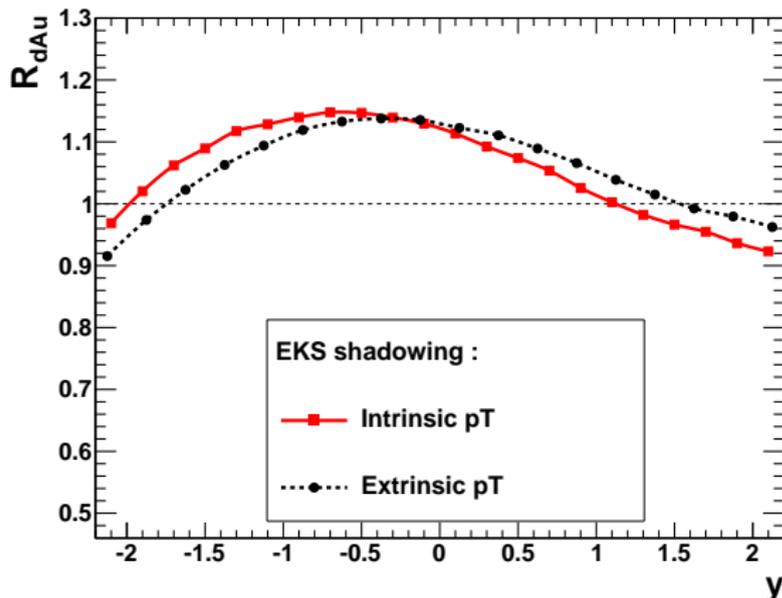
Results at 200 GeV



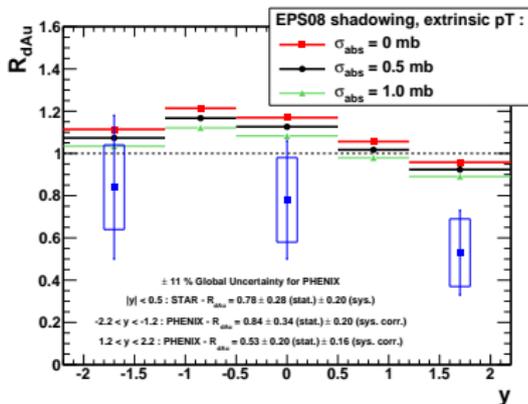
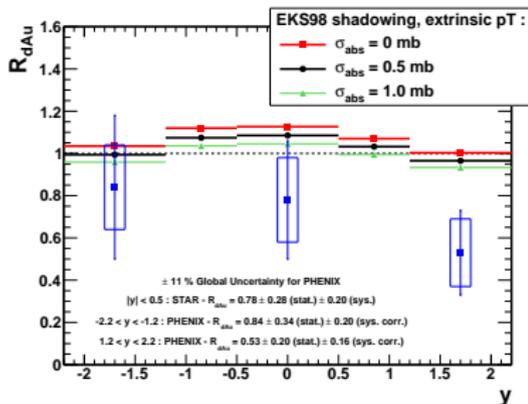
- Upper dashed line,  $m_b = 4.5 \text{ GeV}$ ,  $\mu_r = m_T$ ,  $\mu_F = 2m_T$
- Lower dashed line,  $m_b = 5 \text{ GeV}$ ,  $\mu_r = 2m_T$ ,  $\mu_F = m_T$ ,

Results for dAu at RHIC ( $\Upsilon$ )

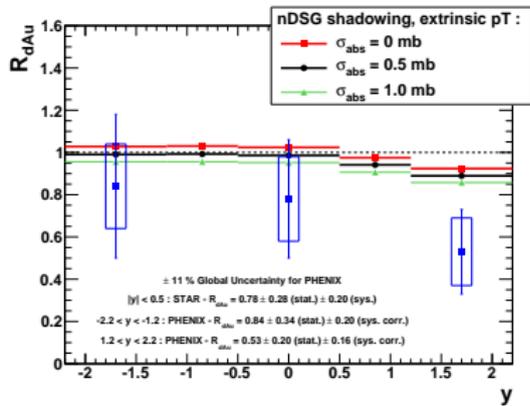
## Intrinsic vs Extrinsic schemes

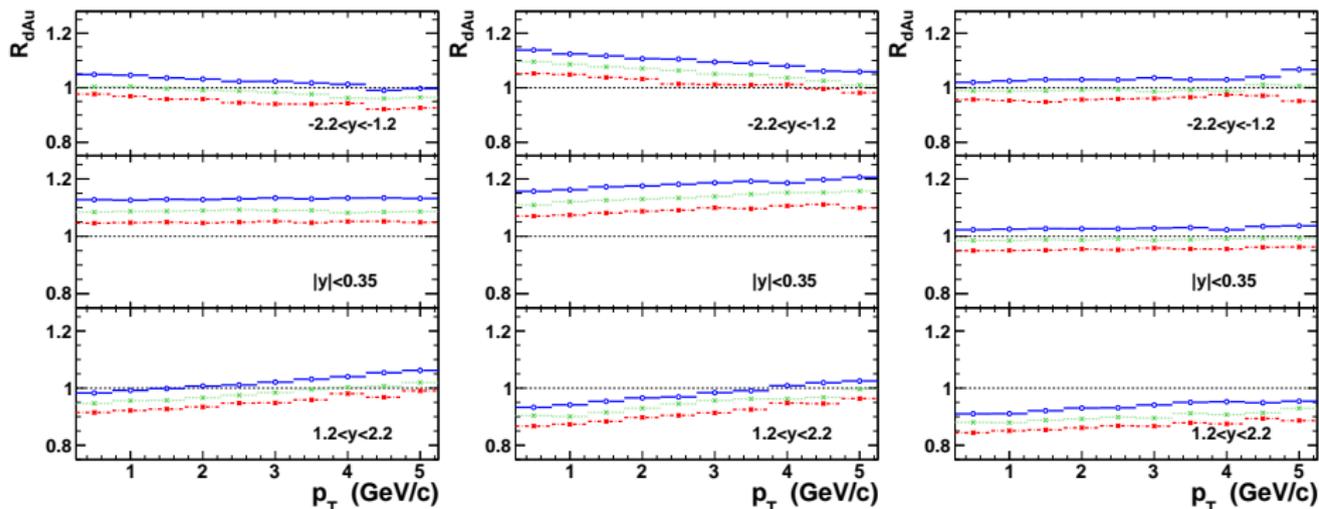


Antishadowing peak **shifted toward larger  $y$**  in the extrinsic case

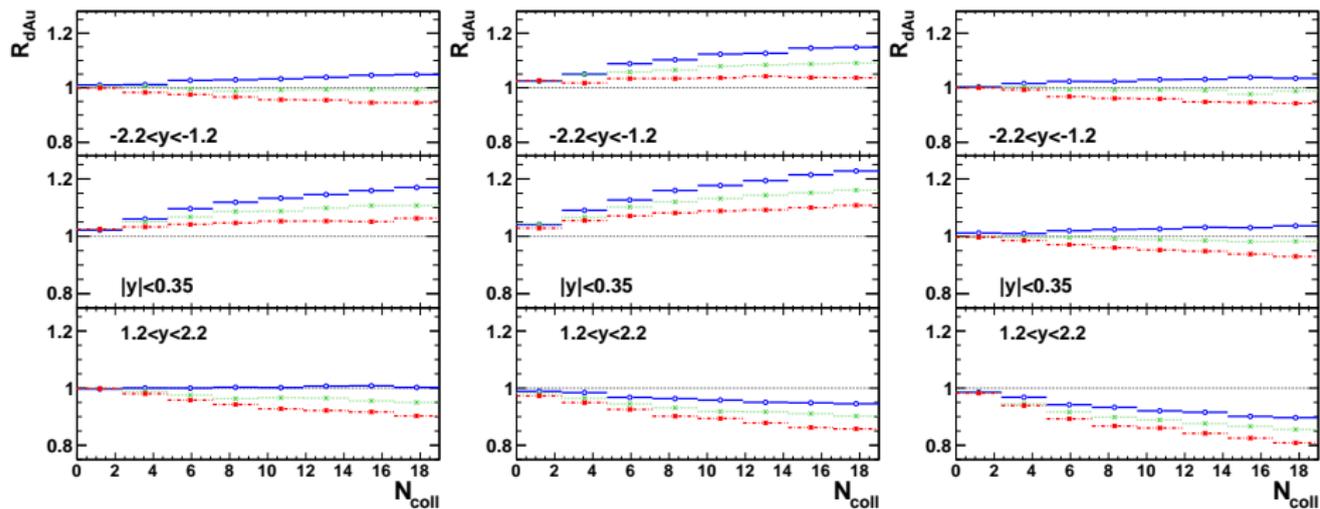
Results for dAu at RHIC ( $\Upsilon$ )

- backward: EMC effect
  - central: antishadowing
  - forward : shadowing  $\approx 1$
- fractional energy loss is needed**



Results for dAu at RHIC ( $\Upsilon$ )

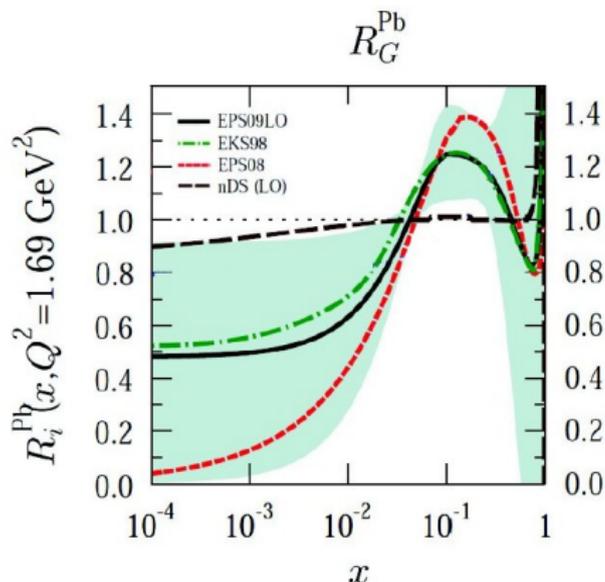
- In blue,  $\sigma_{abs} = 0.0$  mb
- In green,  $\sigma_{abs} = 0.5$  mb
- In red,  $\sigma_{abs} = 1.0$  mb

Results for dAu at RHIC ( $\Upsilon$ )

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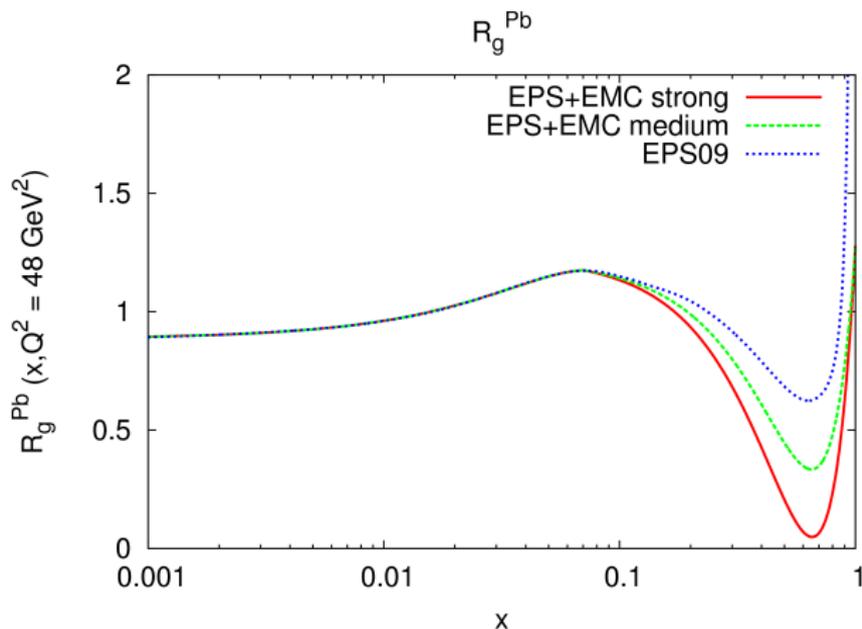
# EMC effect for gluons

- Tension between the theory and the PHENIX points in the backward region
- The backward region correspond to the EMC region ( $x > 0.1$ )
- EMC effect basically unknown for the gluon

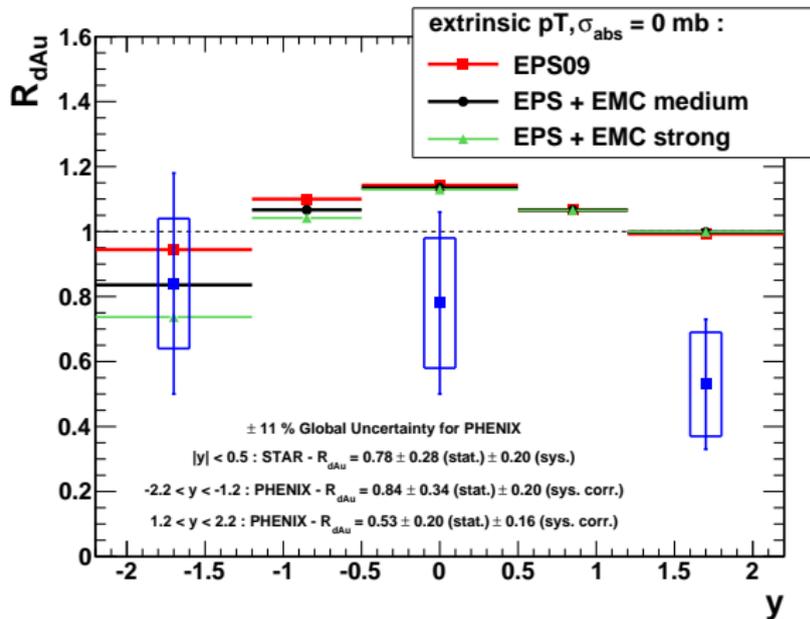


# EMC effect for gluons

- Let us try to increase the suppression of  $g(x)$  in the EMC region
- Keeping momentum conservation :  $\int xg(x) dx = Cst$



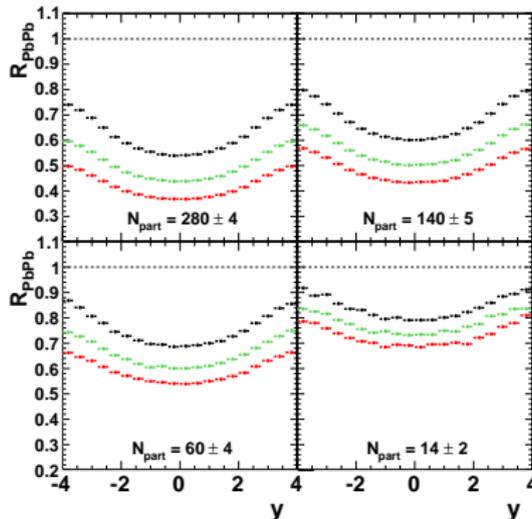
## EMC effect for gluons



Works better

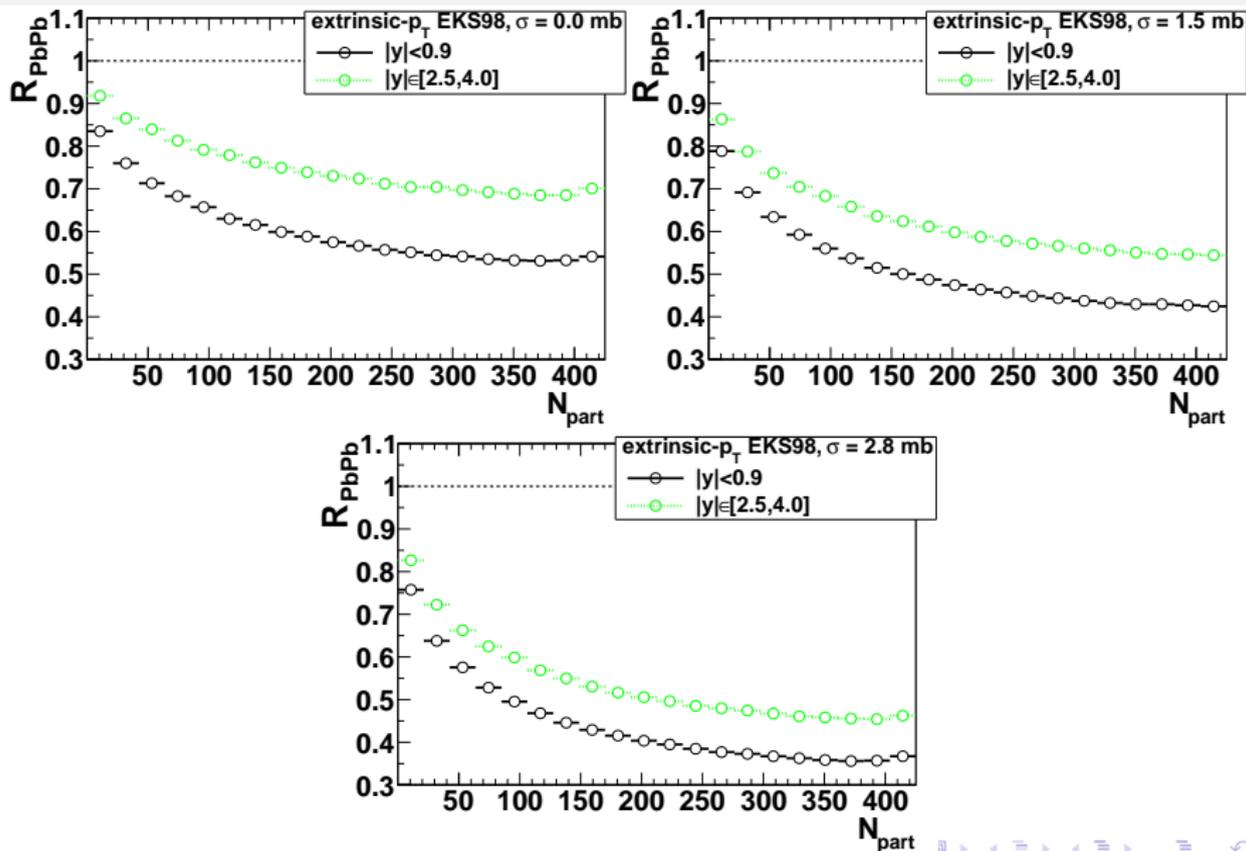
Results for  $J/\psi$  at the LHC, PbPb collisions

$\sqrt{s} = 2.76$  TeV, shadowing: EKS98



In **black**,  $\sigma_{abs} = 0.0$  mb, in **green**,  $\sigma_{abs} = 1.5$  mb, in **red**,  $\sigma_{abs} = 2.8$  mb

**Strong rapidity dependence of  $R_{PbPb}$ !**

Results for  $J/\psi$  at the LHC, PbPb collisions

# Conclusions

- We have studied two schemes : **intrinsic** ( $2 \rightarrow 1$ ) and **extrinsic** ( $2 \rightarrow 2$ ) for different **shadowing and nuclear absorption**
- $J/\psi$  at RHIC  $R_{dAu}$  vs  $y$   $\sigma_{abs}$  **extrinsic**  $>$   $\sigma_{abs}$  **intrinsic**
- $\Upsilon$  antishadowing and EMC region  
 $2 \rightarrow 2$  process  
 need **fractional energy loss**
- $J/\psi$  at LHC  $R_{PbPb}$  vs  $y$  and  $N_{part}$  for EKS98 shadowing  
**Strong rapidity dependence** (inverted w.r.t. RHIC)

## Backup

