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

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Outline

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2. On the kinematics of J/ψ production
3. Results for J/ψ at RHIC
4. Results for Υ at RHIC
5. EMC effect for gluons
6. Results for J/ψ at the LHC, PbPb collisions
7. Conclusions

Motivations

- J/ψ 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:

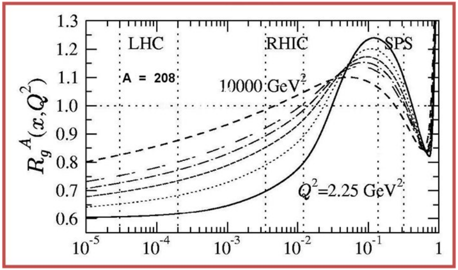
  shadowing and nuclear absorption
- At **p+p** level we do not know the specific production kinematics at a partonic level: **color singlet ($2 \to 2$) vs color octet models ($2 \to 1$)**
- **Our goal**: To investigate the CNM effects and the impact of the specific partonic production kinematics

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 $Q^2(m_T)$

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



Absorption

Particle spectrum altered by interactions with the nuclear matter they traverse
⇒ J/ψ **suppression** due to final state interactions with spectator nucleons
Usual parametrisation (Glauber model) :

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

- ρ the nuclear matter density
- σ_{abs} the break-up cross section
- L the path length

Energy dependence **(see E. G. Ferreiro 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/ψ production

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

Two production mechanisms

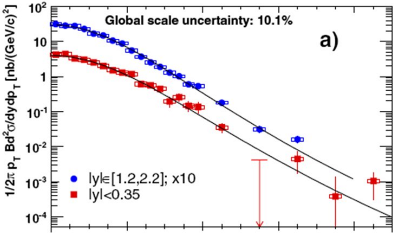
- $g + g \rightarrow c\bar{c}$ $2 \rightarrow 1$
  Instrinsic scheme: the p_T of the J/ψ comes from initial partons
- $g + g \rightarrow c\bar{c} + g$ $2 \rightarrow 2$
  Extrinsic scheme: the p_T of the J/ψ is balanced by the outgoing gluon

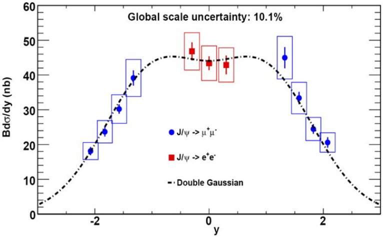
On the kinematics of J/ψ production

Instrinsic scheme

- Intrinsic scheme: $2 \to 1$ process color evaporation model @ LO or color octet model @ α_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 $x_{1,2}$

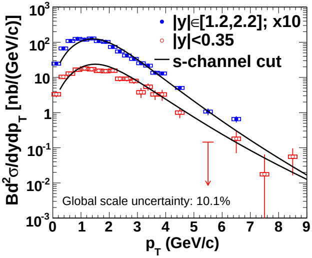




On the kinematics of J/ψ production

Extrinsic scheme

- **$2 \to 2$** partonic process with collinear initial gluons
- Momentum conservation results in a complex expression of x_2 as a function of (x_1, y, p_T) (see next slide)
- Data alone is **not sufficient to determine x_1 and x_2**
- Models are mandatory to compute the weighting of kinematically allowed (x_1, x_2)
- One needs **to describe the data at low p_T**
- LO CSM, COM at @ α_s^3 and NLO CEM **do NOT describe the data well for $p_T < 2$ GeV**
- 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/ψ 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:

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

$\boxed{\mathbf{2} \rightarrow \mathbf{1} \text{ kinematics with intrinsic } p_T}$ | $\boxed{\mathbf{2} \rightarrow \mathbf{2} \text{ kinematics with extrinsic } p_T}$

On the kinematics of J/ψ production

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2 → 1 kinematics with intrinsic p_T	**2 → 2** kinematics with extrinsic p_T
$\int d\vec{r}_A\,dz_A\,dz_B$	$\int dx_1\,dx_2 \int d\vec{r}_A dz_A dz_B$
$\times\ \mathcal{F}_g^A(x_1^0,\vec{r}_A,z_A,\mu_f)\mathcal{F}_g^B(x_2^0,\vec{r}_B,z_B,\mu_f)$	$\times\ \mathcal{F}_g^A(x_1,\vec{r}_A,z_A,\mu_f)\mathcal{F}_g^B(x_2,\vec{r}_B,z_B,\mu_f)$
$\times\ \sigma_{gg}^{\mathrm{Intr.}}(x_1^0,x_2^0)$	$\times\ 2\hat{s}P_T\frac{d\sigma_{gg\to\Upsilon+g}}{d\hat{t}}\delta(\hat{s}-\hat{t}-\hat{u}-M^2)$
$\times\ S_A(\vec{r}_A,z_A)\,S_B(\vec{r}_B,z_B)$	$\times\ S_A(\vec{r},z_A)S_B(\vec{r}_B,z_B)$

On the kinematics of J/ψ 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:

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

$2 \to 1$ kinematics with intrinsic p_T

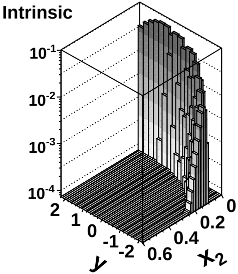
$$\int d\vec{r}_A\, dz_A\, dz_B$$
$$\times\ \mathcal{F}_g^A(x_1^0, \vec{r}_A, z_A, \mu_f)\mathcal{F}_g^B(x_2^0, \vec{r}_B, z_B, \mu_f)$$
$$\times\ \sigma_{gg}^{\mathrm{Intr.}}(x_1^0, x_2^0)$$
$$\times\ S_A(\vec{r}_A, z_A)\, S_B(\vec{r}_B, z_B)$$

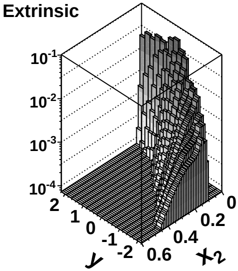
$$\boxed{x_{1,2} = \frac{m_T}{\sqrt{s_{NN}}} \exp(\pm y) \equiv x_{1,2}^0(y, P_T)}$$

$2 \to 2$ kinematics with extrinsic p_T

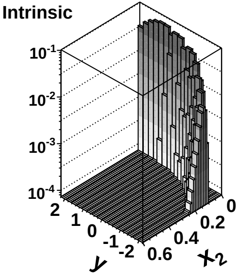
$$\int dx_1\, dx_2 \int d\vec{r}_A dz_A dz_B$$
$$\times\ \mathcal{F}_g^A(x_1, \vec{r}_A, z_A, \mu_f)\mathcal{F}_g^B(x_2, \vec{r}_B, z_B, \mu_f)$$
$$\times\ 2\hat{s} P_T \frac{d\sigma_{gg\to\Upsilon+g}}{d\hat{t}} \delta(\hat{s} - \hat{t} - \hat{u} - M^2)$$
$$\times\ S_A(\vec{r}, z_A) S_B(\vec{r}_B, z_B)$$

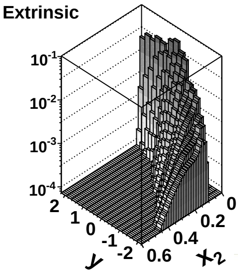
$$\boxed{\delta(..) \to x_2 = \frac{x_1 m_T \sqrt{s_{NN}} e^{-y} - M^2}{\sqrt{s_{NN}}(\sqrt{s_{NN}} x_1 - m_T e^{y})}}$$


Intrinsic


Extrinsic

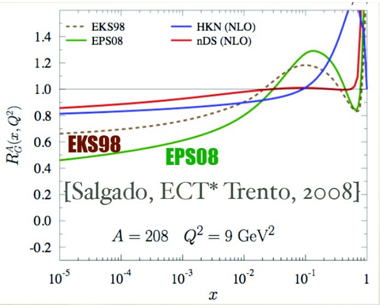
For a given couple (y, p_T), x_2 is larger in the extrinsic scheme



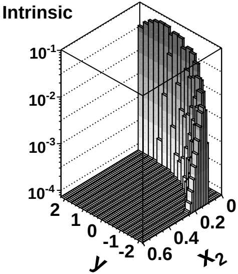


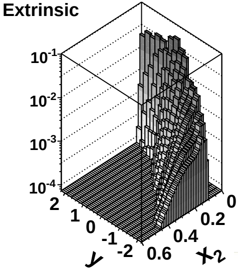
For a given couple (y, p_T), x_2 is larger in the extrinsic scheme

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



[Salgado, ECT* Trento, 2008]

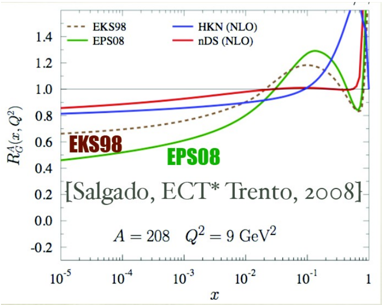




For a given couple (y, p_T), x_2 is larger in the extrinsic scheme

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

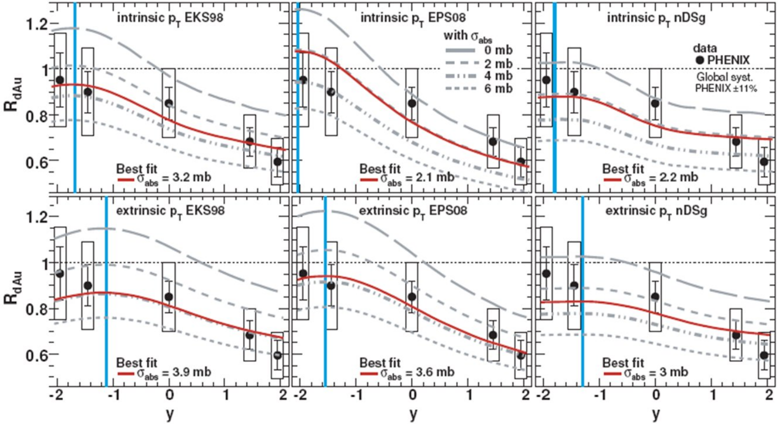
We expect different shadowing effects in both cases.



[Salgado, ECT* Trento, 2008]

Results for J/ψ at RHIC

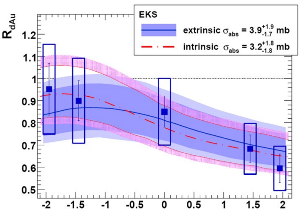
E. G. Ferreiro, F. Fleuret, J.P. Lansberg, A. Rakotozafindrabe, PRC 81, 0649011 (2010).

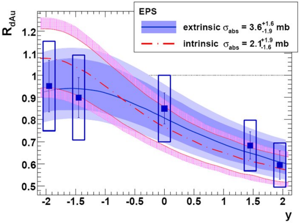


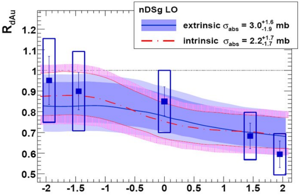
- shadowing depends on the partonic process: $2 \to 1$ or $2 \to 2$
- antishadowing peak shifted toward larger y in the extrinsic case
- in order to reproduce data: σ_{abs} **Extrinsic** $> \sigma_{abs}$ **Instrinsic**

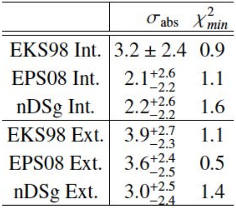
Results for J/ψ at RHIC

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







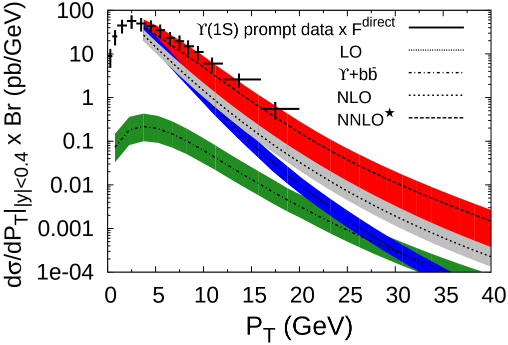


	σ_{abs}	χ^2_{min}
EKS98 Int.	3.2 ± 2.4	0.9
EPS08 Int.	$2.1^{+2.6}_{-2.2}$	1.1
nDSg Int.	$2.2^{+2.6}_{-2.2}$	1.6
EKS98 Ext.	$3.9^{+2.7}_{-2.3}$	1.1
EPS08 Ext.	$3.6^{+2.4}_{-2.5}$	0.5
nDSg Ext.	$3.0^{+2.5}_{-2.4}$	1.4

Υ: 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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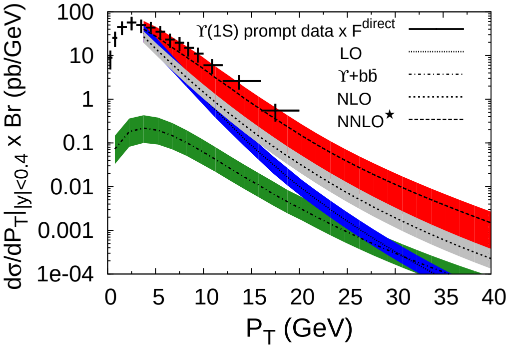
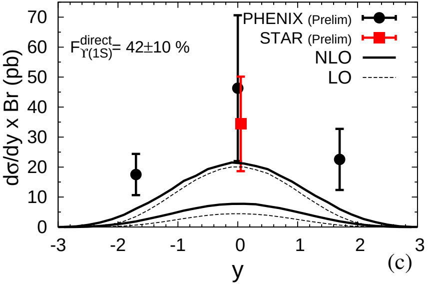


- CSM describes well the data at NNLO*
- However LO CSM is sufficient to describe low p_T data

Υ: Experimental situation

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

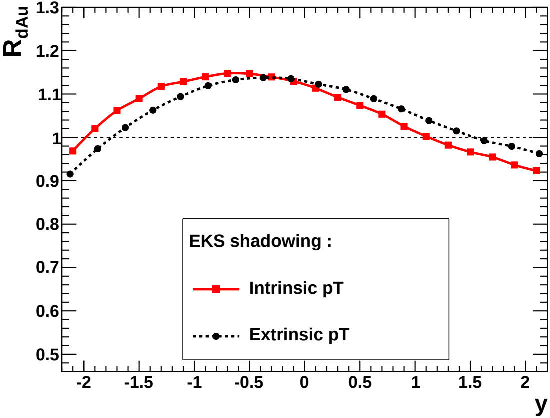
Results at 200 GeV



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

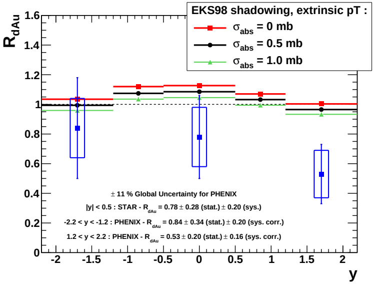
Results for dAu at RHIC (Υ)

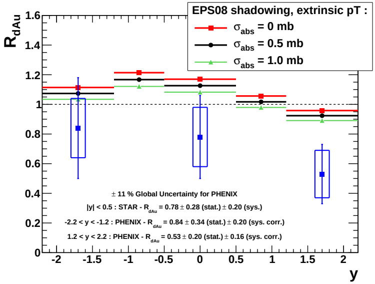
Intrinsic vs Extrinsic schemes



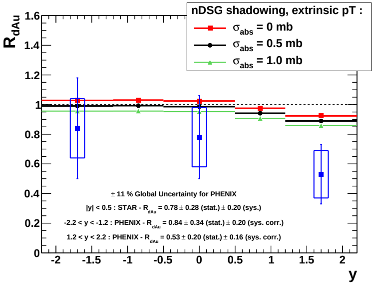
Antishadowing peak **shifted toward larger y** in the extrinsic case

Results for dAu at RHIC (Υ)



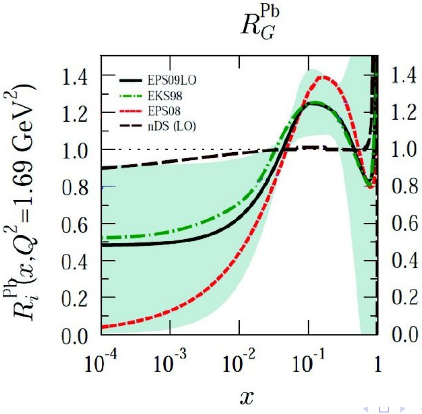


- backward: EMC effect
- central: antishadowing
- forward : shadowing ≈ 1
  fractional energy loss is needed ($\Delta E \propto E$)



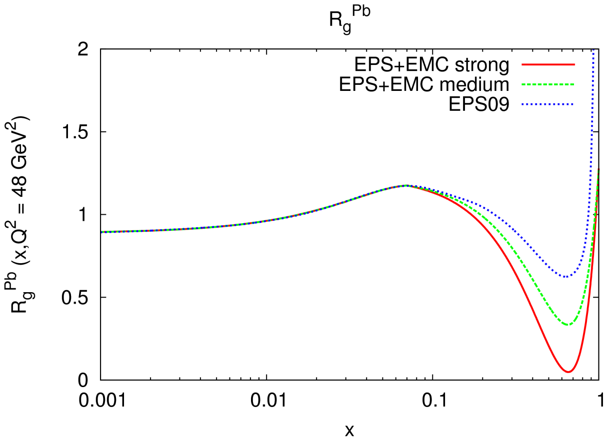
EMC effect for gluons

- 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

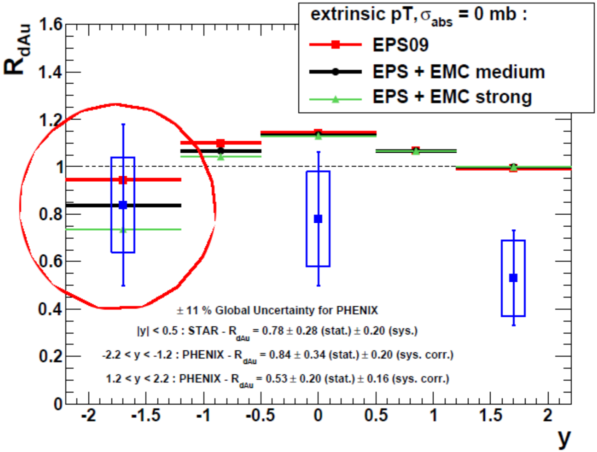


EMC effect for gluons

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



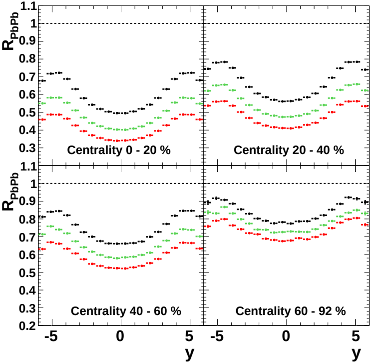
EMC effect for gluons



Works better

Results for J/ψ at the LHC, PbPb collisions

$\sqrt{s} = 5.5$ TeV, shadowing: EKS98



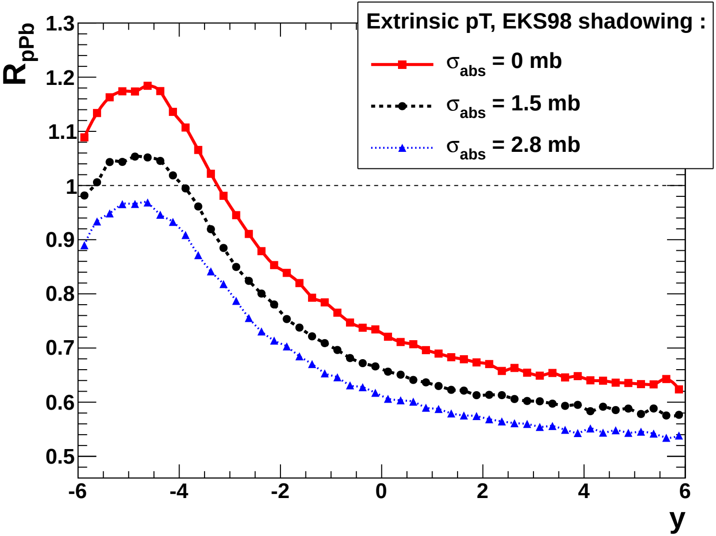
In **black**, $\sigma_{abs} = 0.0$ mb, in green, $\sigma_{abs} = 1.5$ mb, in red, $\sigma_{abs} = 2.8$ mb

Strong rapidity dependence of R_{PbPb}!

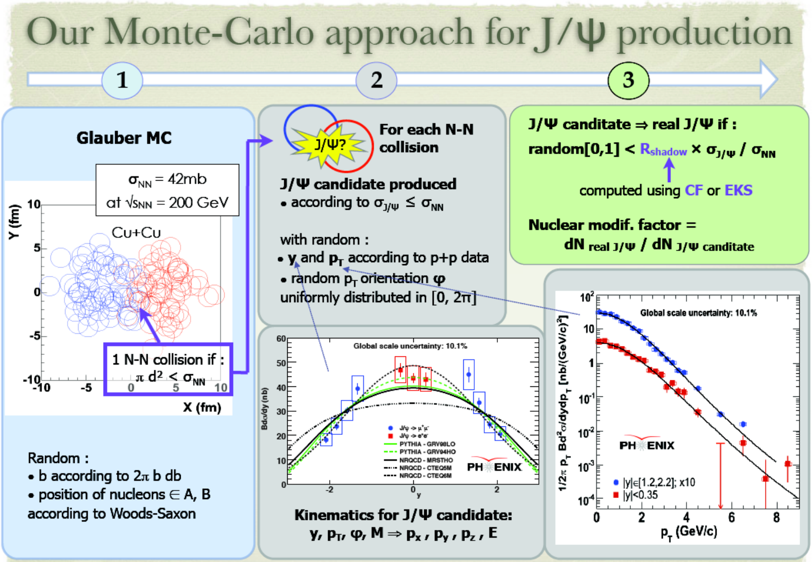
Conclusions

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

Backup


R_{pPb}
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
-6
-4
-2
0
2
4
6
y
Extrinsic pT, EKS98 shadowing :
σ_{abs} = 0 mb
σ_{abs} = 1.5 mb
σ_{abs} = 2.8 mb

The Glauber Monte Carlo



Our Monte-Carlo approach for J/Ψ production

1

Glauber MC

σ_{NN} = 42mb at $\sqrt{s_{NN}}$ = 200 GeV

1 N-N collision if : $\pi d^2 < \sigma_{NN}$

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

2

For each N-N collision

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

with random :
- **y** and **p_T** according to p+p data
- random p_T orientation **φ** uniformly distributed in [0, 2π]

Kinematics for J/Ψ candidate:
y, p_T, φ, M ⇒ p_x , p_y , p_z , E

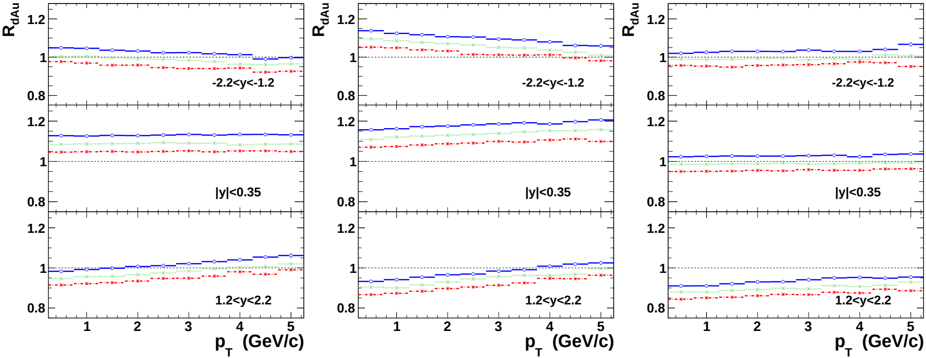
3

J/Ψ canditate ⇒ real J/Ψ if :
random[0,1] < R_{shadow} × $\sigma_{J/\psi}$ / σ_{NN}

computed using CF or EKS

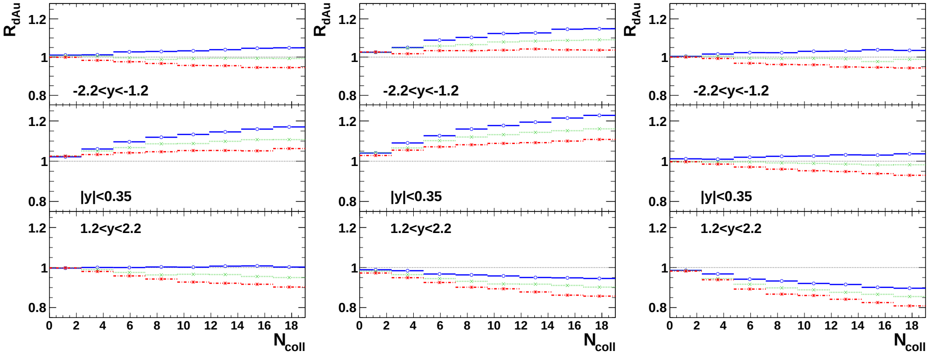
Nuclear modif. factor = dN $_{real\ J/\psi}$ / dN $_{J/\psi\ canditate}$

Results for dAu at RHIC (Υ)



- 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 (Υ)



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Results for J/ψ at the LHC, PbPb collisions