J/ψ and Υ production in proton-nucleus collisions: lessons from RHIC for the 2012 proton-lead LHC run

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IPN Orsay, Université Paris-Sud

July 6, 2012 – **ICHEP 2012** – Melbourne, Australia

on behalf of E.G. Ferreiro, F. Fleuret, N. Matagne and A. Rakotozafindrabe

Part I

Background

Quarkonium production cross section in pA collisions

We shall assume here that

- collinear factorisation applies: use of nPDF
  (for instance, saturation, if any, to be mimicked by gluon shadowing)
- pA collisions are described by a probabilistic Glauber approach
- other nuclear effects in an effective absorption x-section
  (should be compatible with the bound-state size, though)

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What we want to learn:

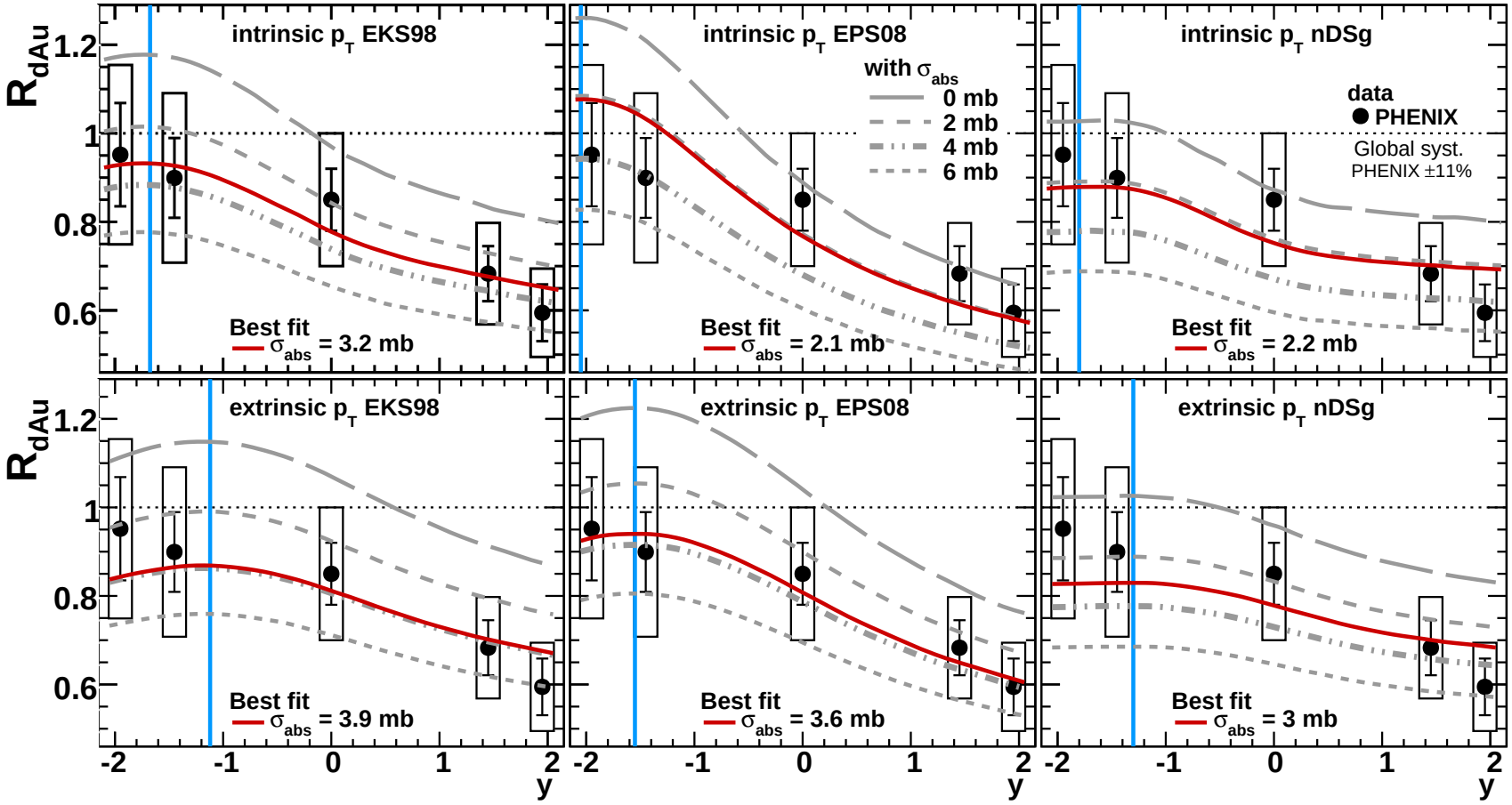
- whether all the nuclear effects can be encompassed in nPDFs
  (+ maybe an (effective) x-section for nuclear absorption)
- how large the nuclear effects –likely to affect AA production– are
  baseline to be subtracted
- genuine new information on QCD

Part II

J/ψ production in $(p, d)A$ and AA collisions

Nuclear modification factor for J/ψ in dAu collisions at RHIC

E.G. Ferreiro, F. Fleuret, J.P.L., A. Rakotozafindrabe, PLB 680:50,2009, PRC 81:064911, 2010; PHENIX PRC 77: 024912, 2008



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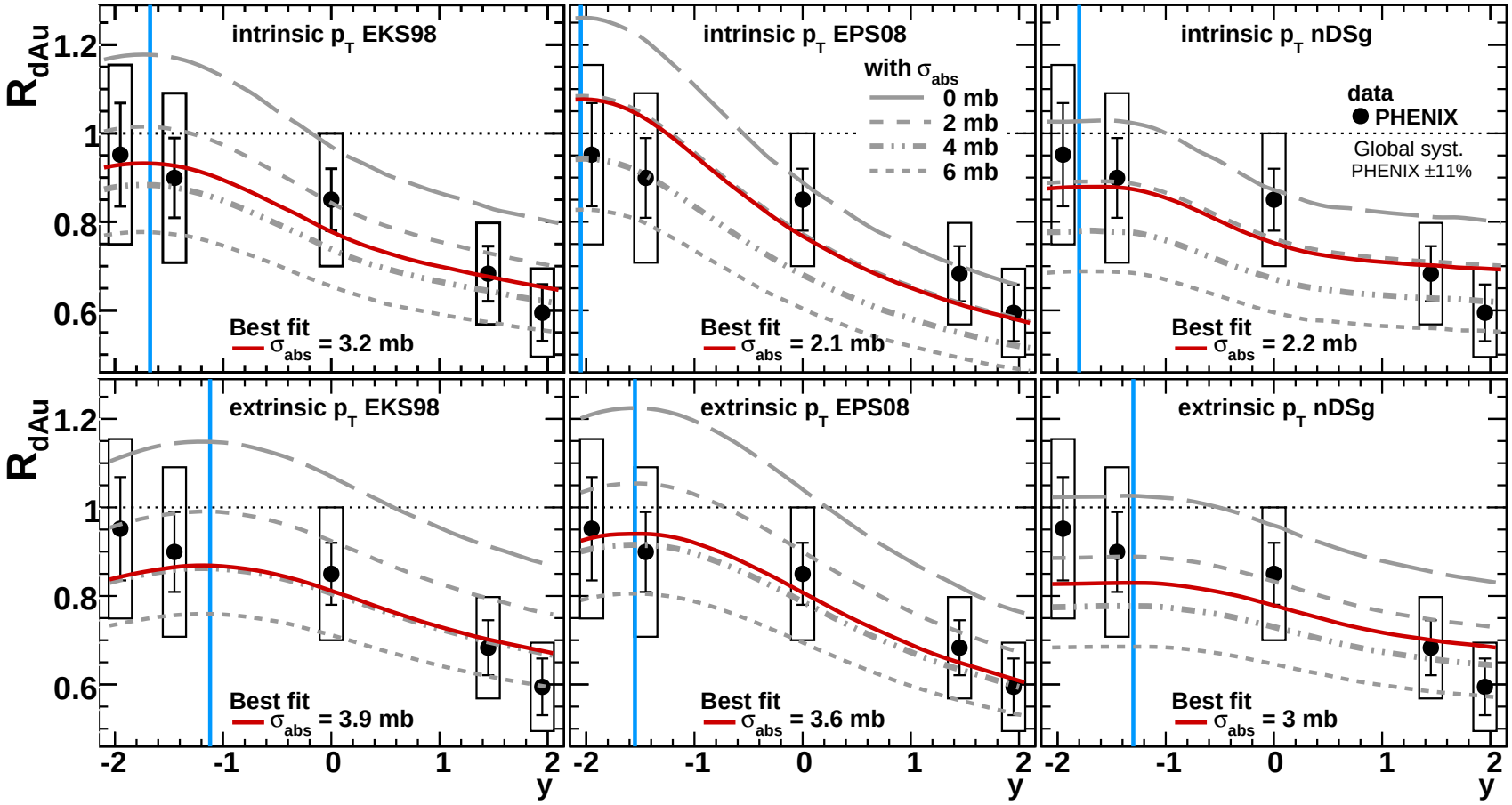

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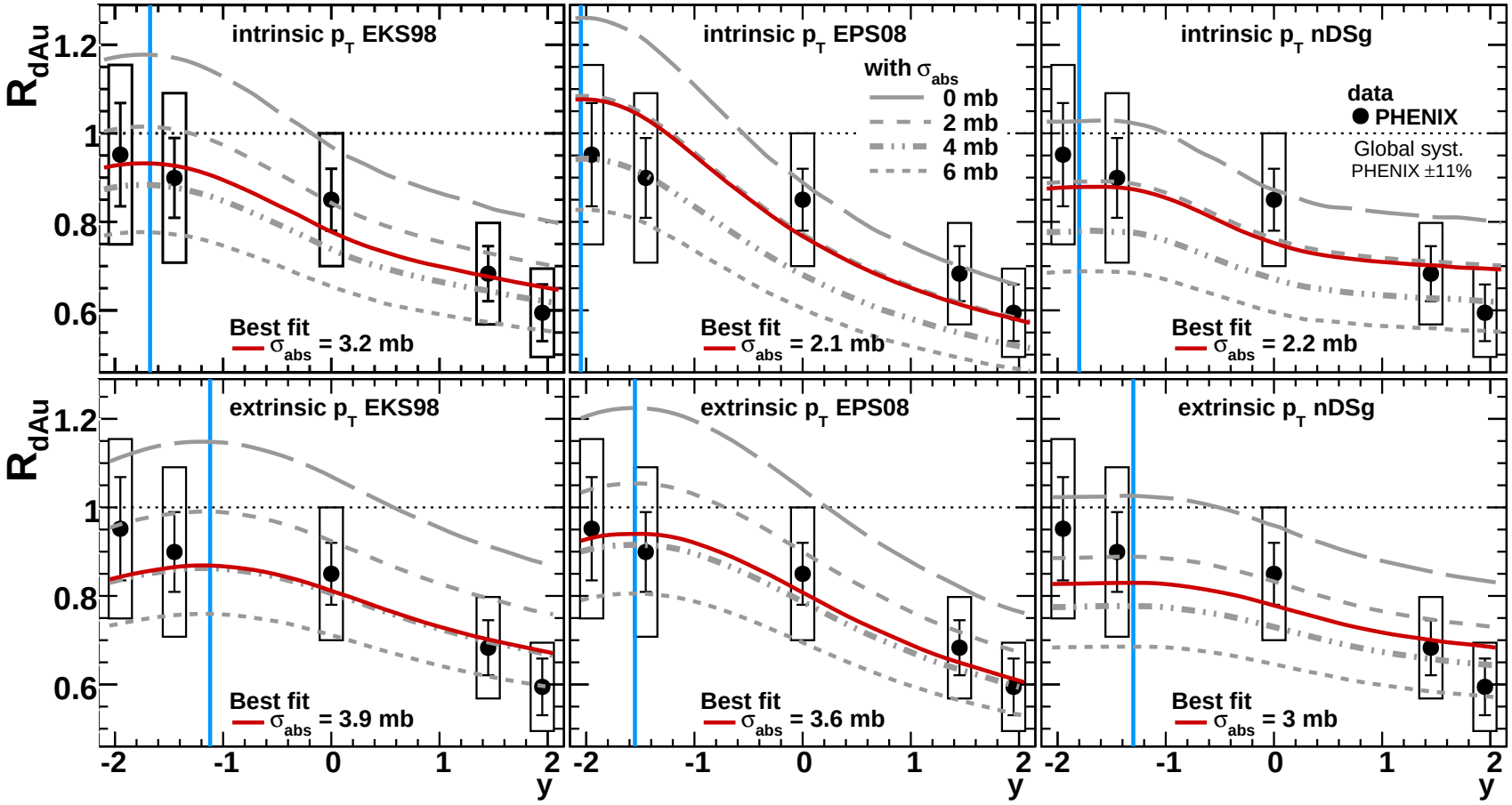
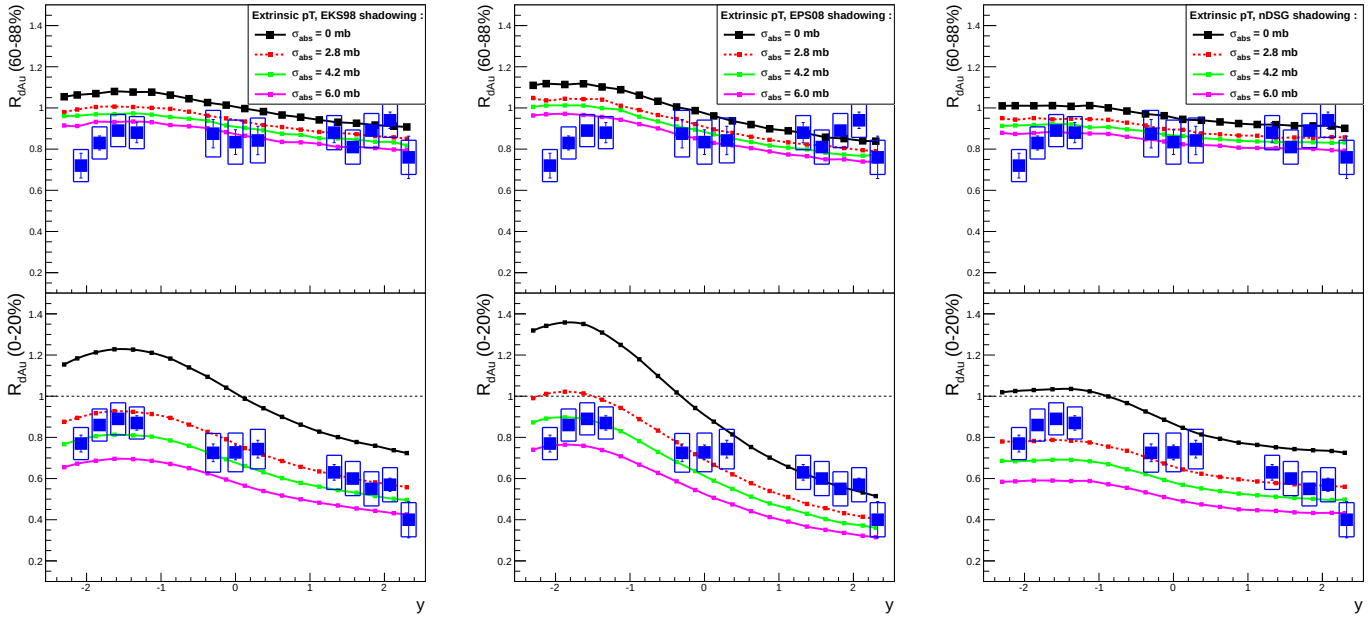


- The shadowing impact does depend on the kinematics: $\underbrace{2 \to 1}_{\text{intrinsic}}$ vs $\underbrace{2 \to 2}_{\text{extrinsic}}$
- Shift of the rapidity distribution (see the vertical blue line)

Comparison with the most recent PHENIX data

E.G. Ferreiro, F. Fleuret, J.P.L., N. Matagne A. Rakotozafindrabe, FBS 53: 27, 2012; PHENIX PRL 107: 142301, 2011



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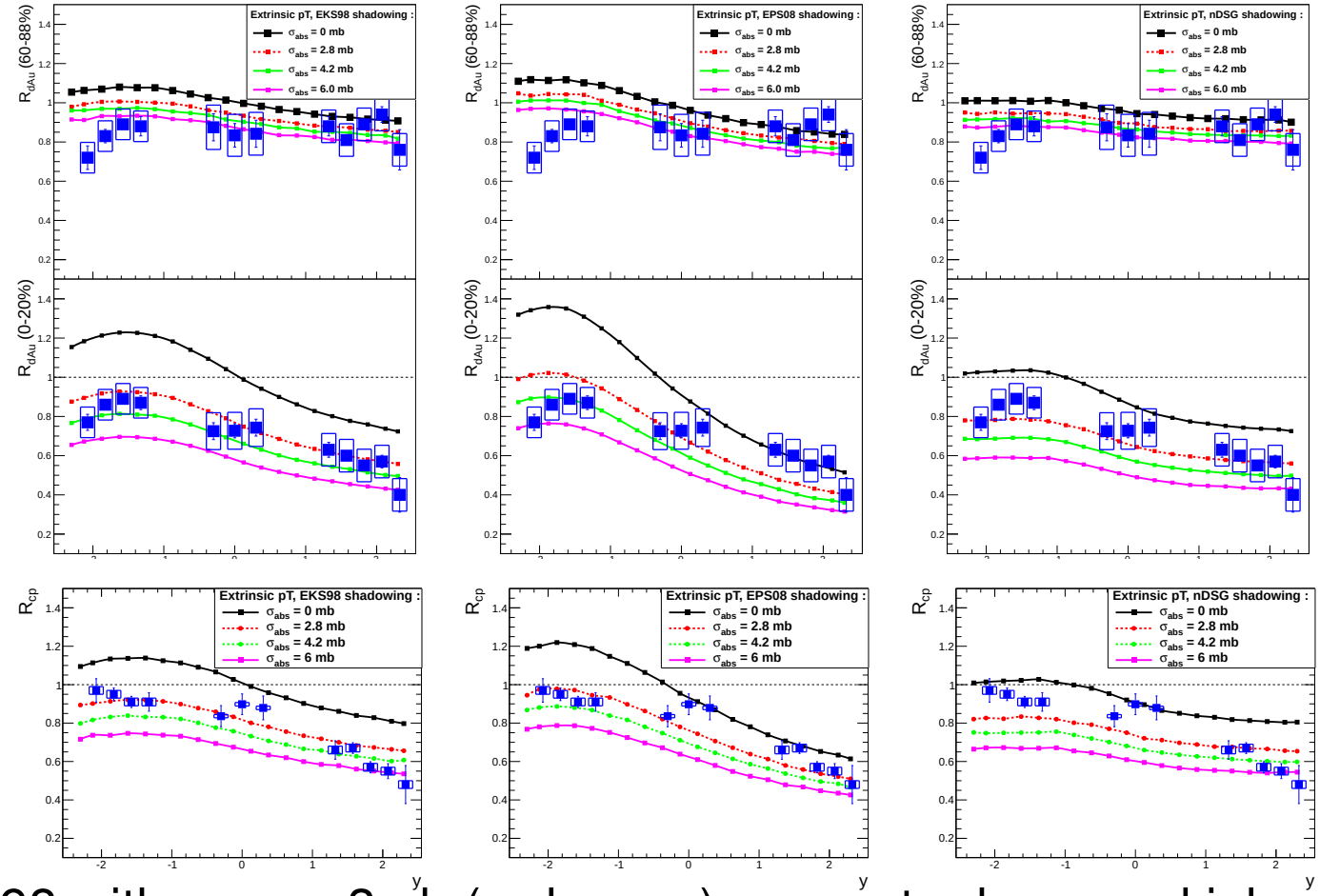

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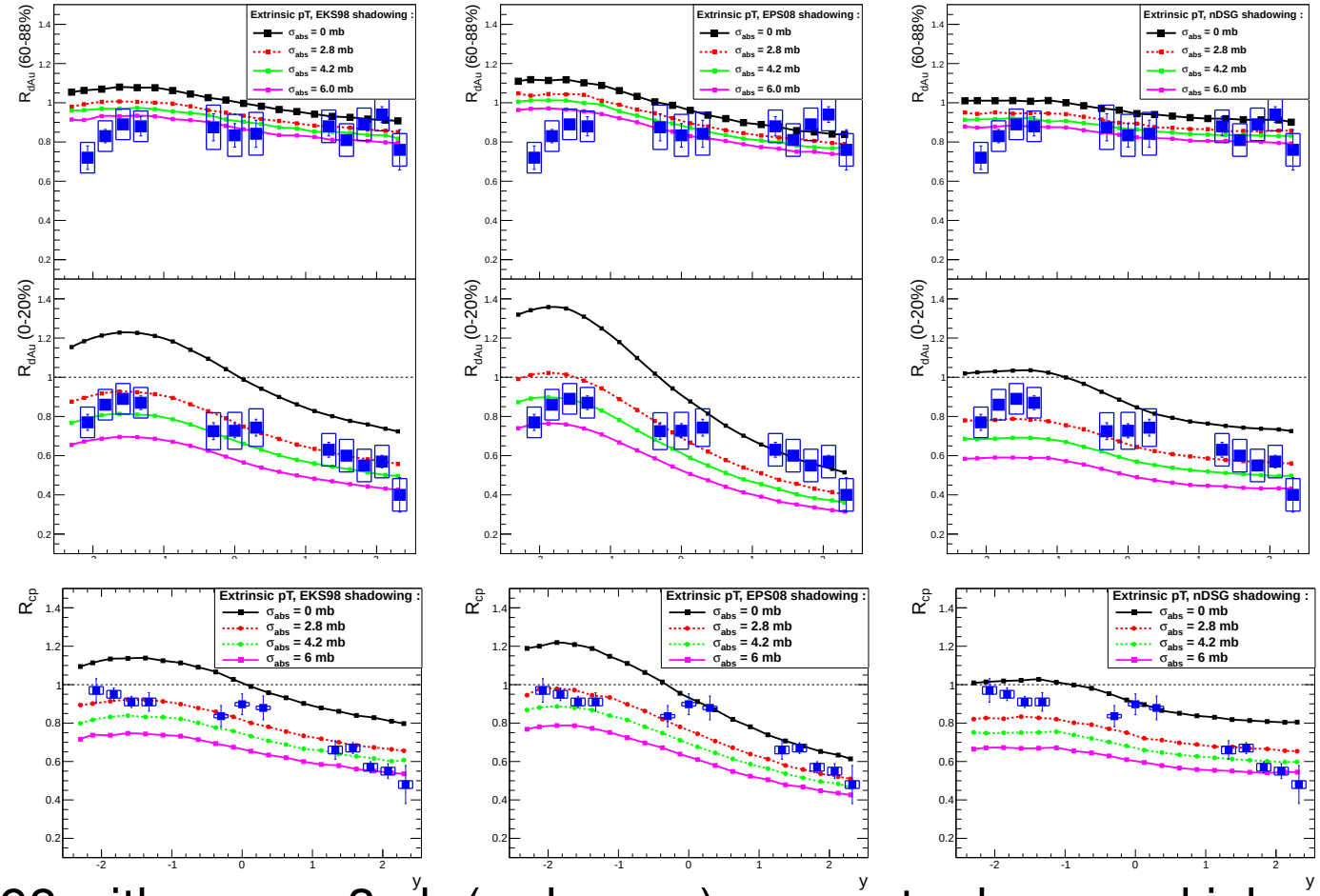
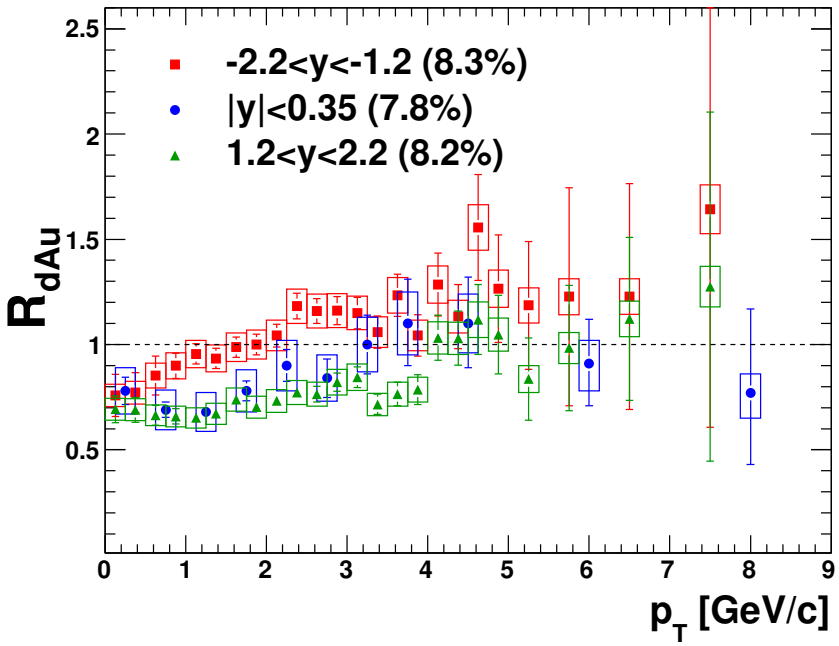


- EKS98 with $\sigma_{abs} \simeq 3$mb (red curve) seems to do a good job
- Less true when one looks at R_{CP} (EPS08 (i.e. strong shadowing) better)
- Lesson for the LHC: R_{CP} can be quite instructive
  - even when one has R_{pA}

$R_{d\mathrm{Au}}$ vs P_T: new PHENIX data

E.G. Ferreiro, F. Fleuret, J.P.L., N. Matagne A. Rakotozafindrabe, FBS 53: 27, 2012; PHENIX: 1204.0777



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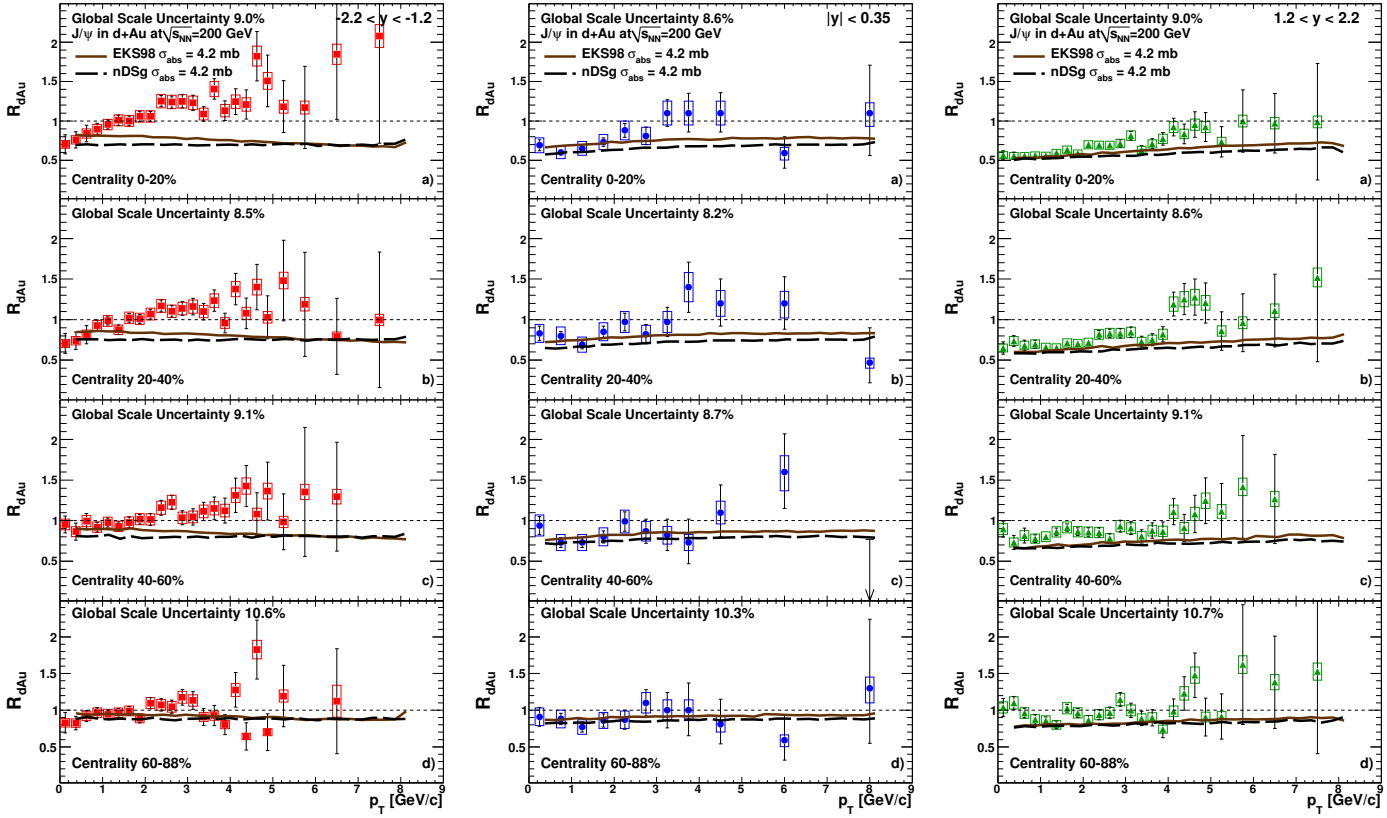

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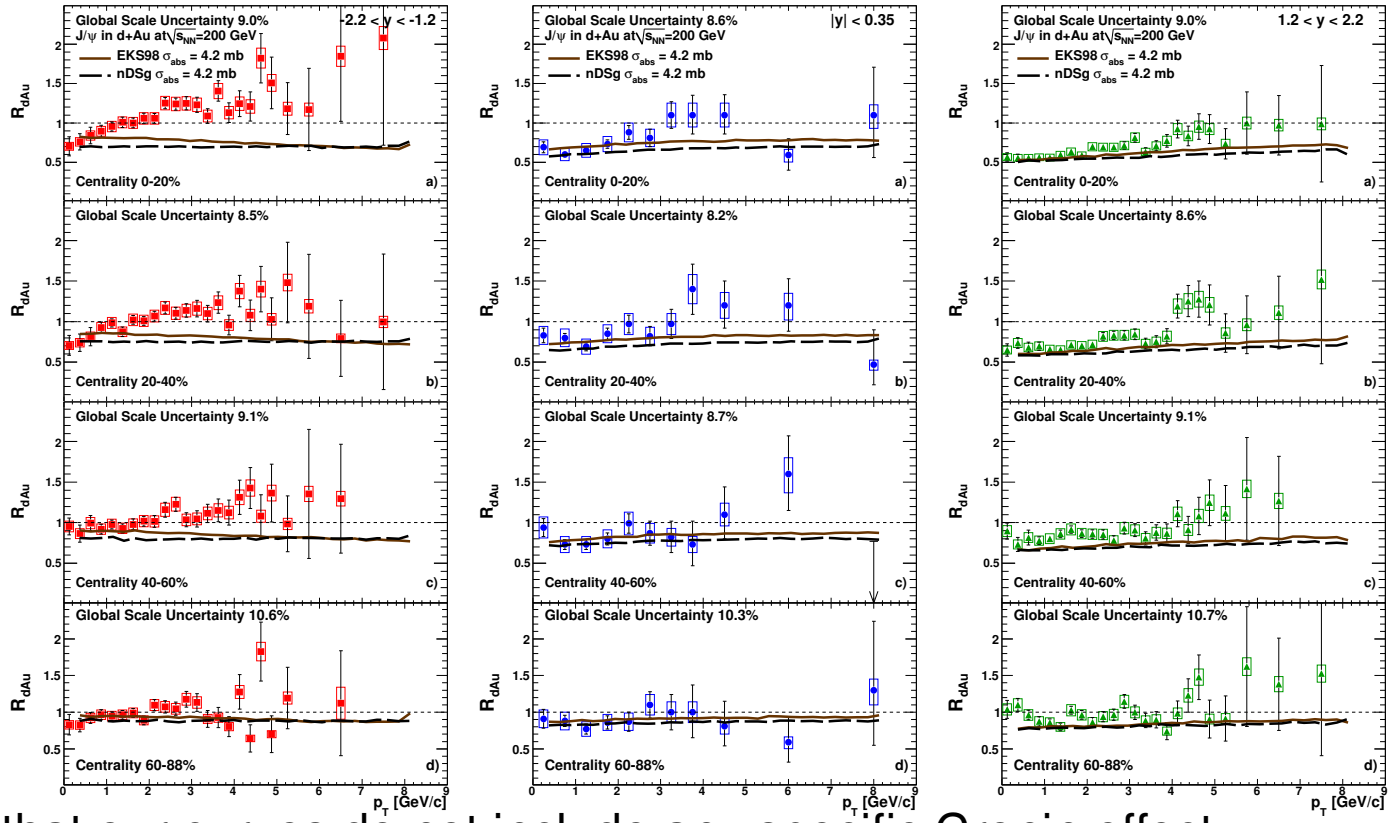

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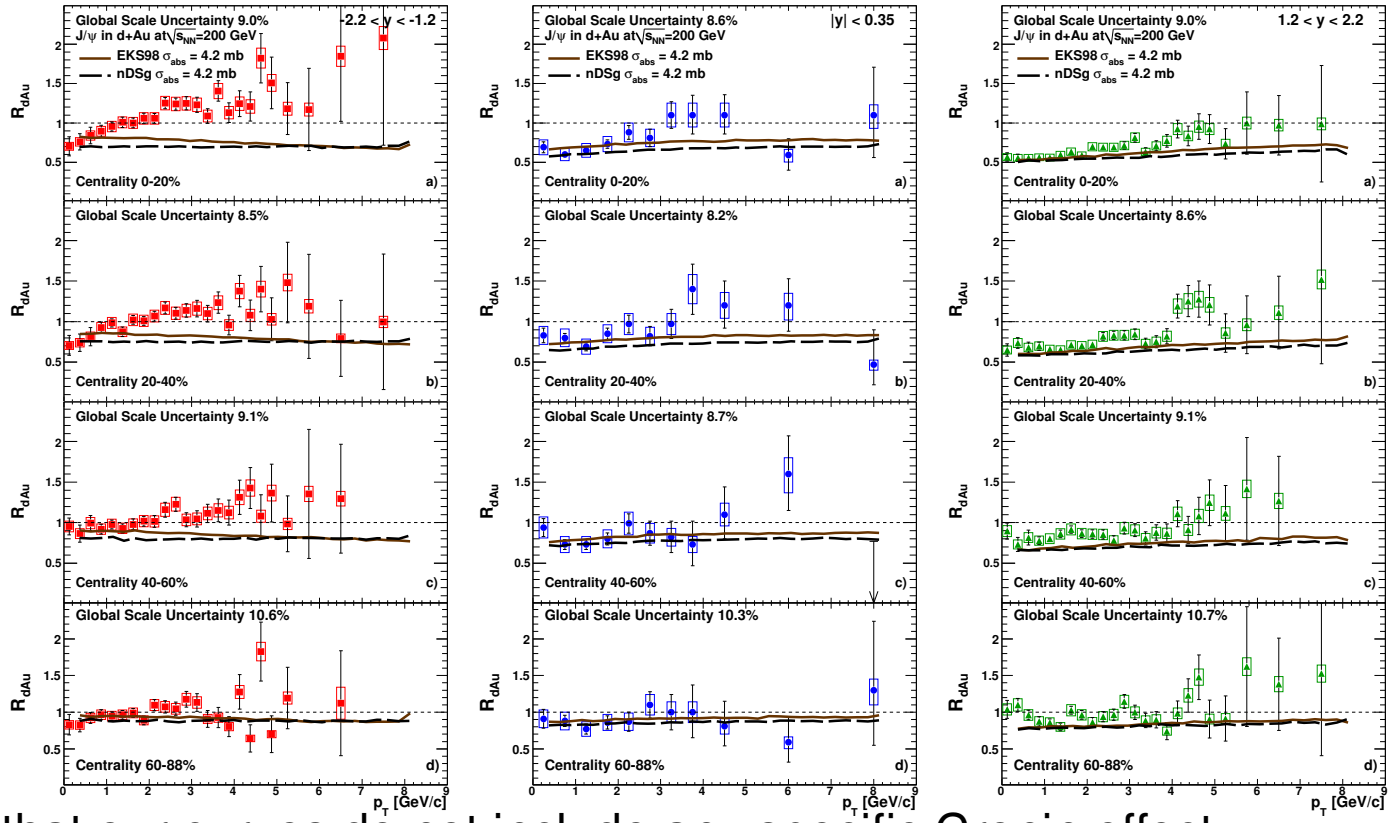

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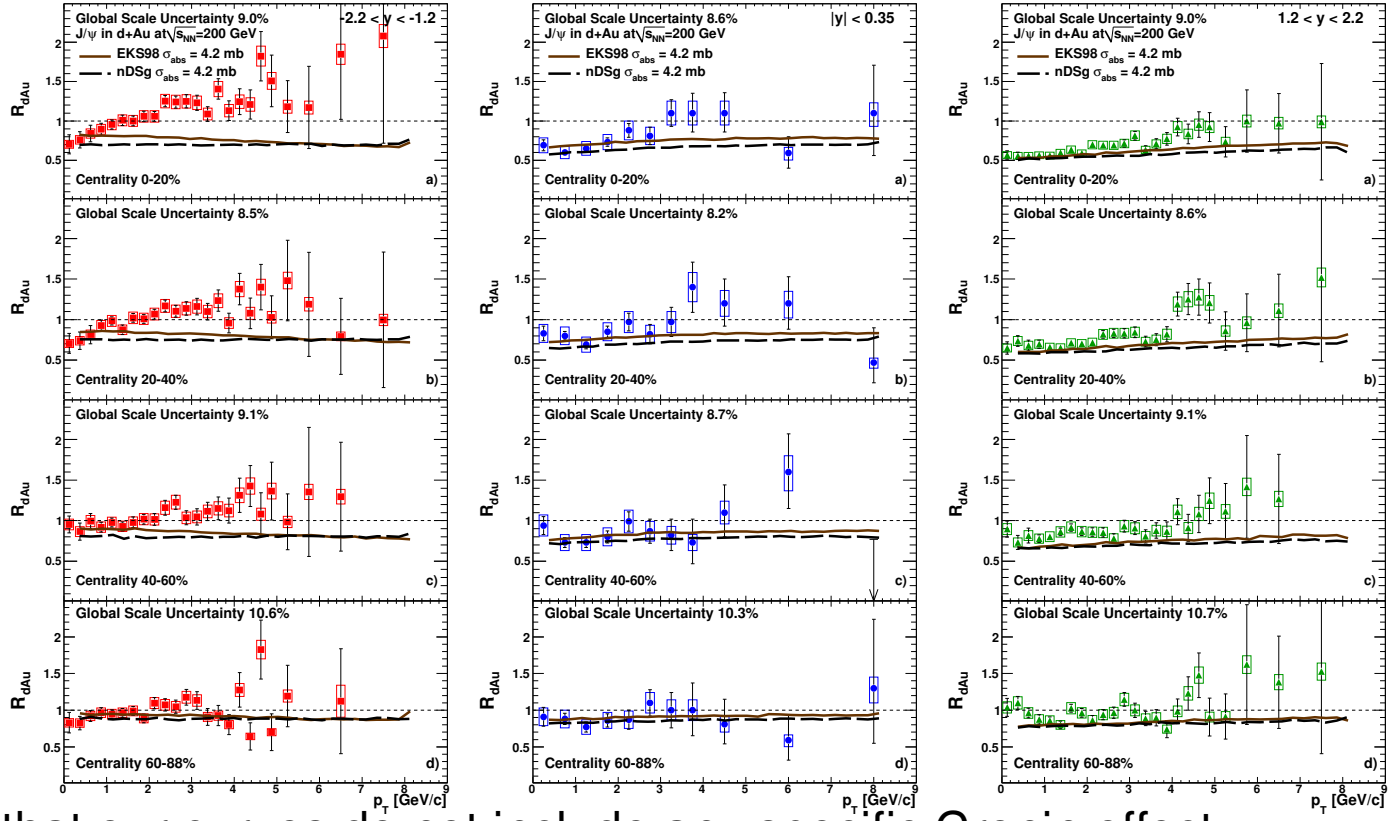

- Note that our curves do not include any specific Cronin effect
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- Cronin effect stronger in the backward region ?
- Unexpected nPDF effect ? It would be nice to see [-2.2:-1.7] & [-1.7:-1.2]

Rapidity dependence in AuAu

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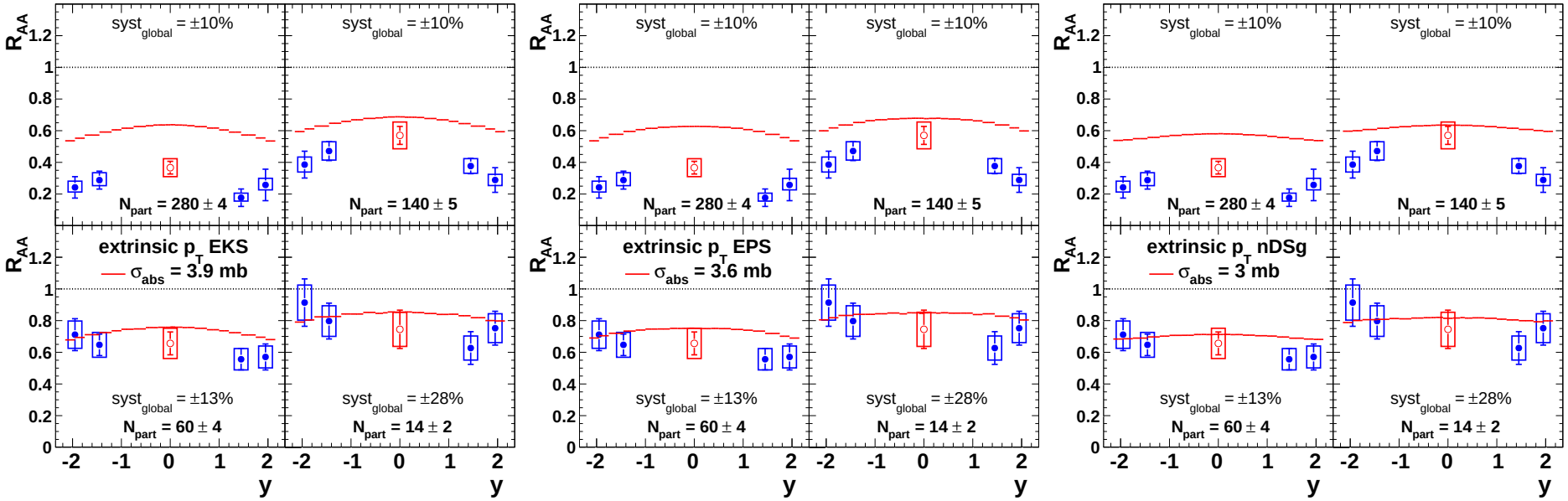

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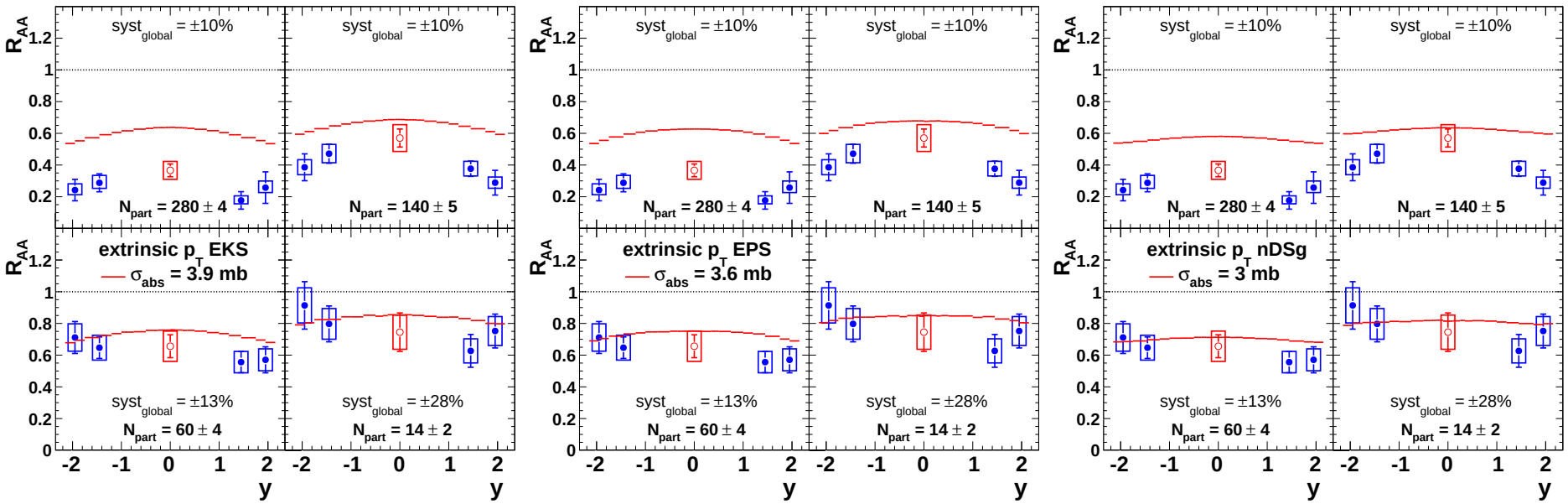

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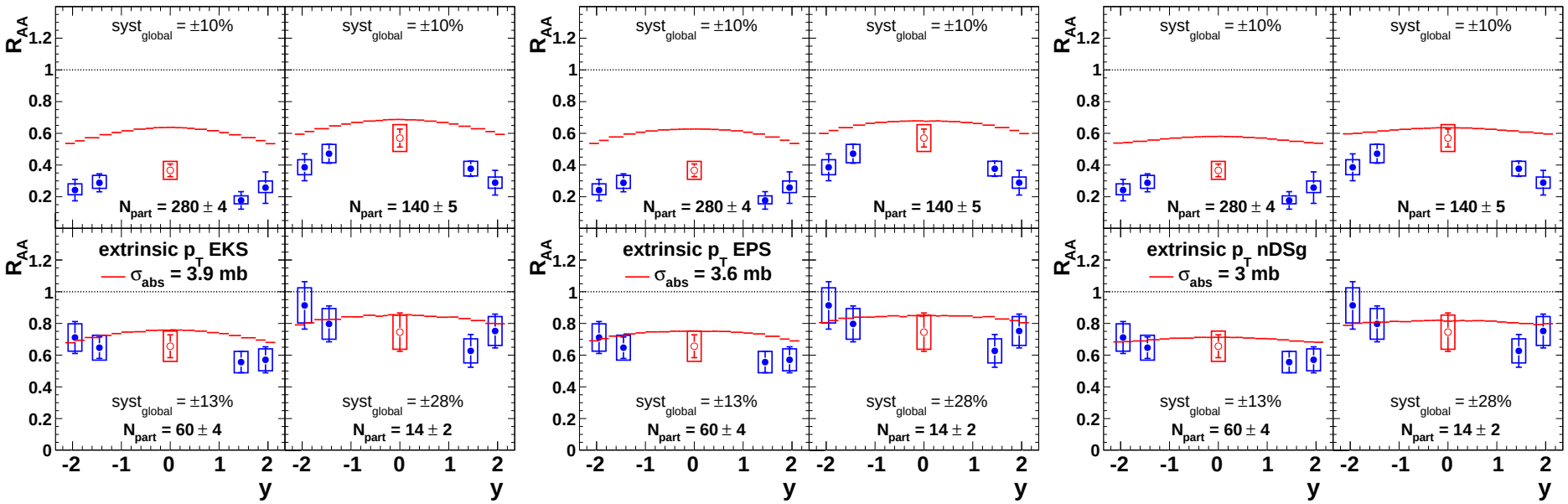

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- Can account for a part of the y-dependence of the most central data

Rapidity dependence in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

E.G. Ferreiro, F. Fleuret, J.P.L., N. Matagne, A. Rakotozafindrabe, Nucl. Phys. A 855 (2011) 327-330

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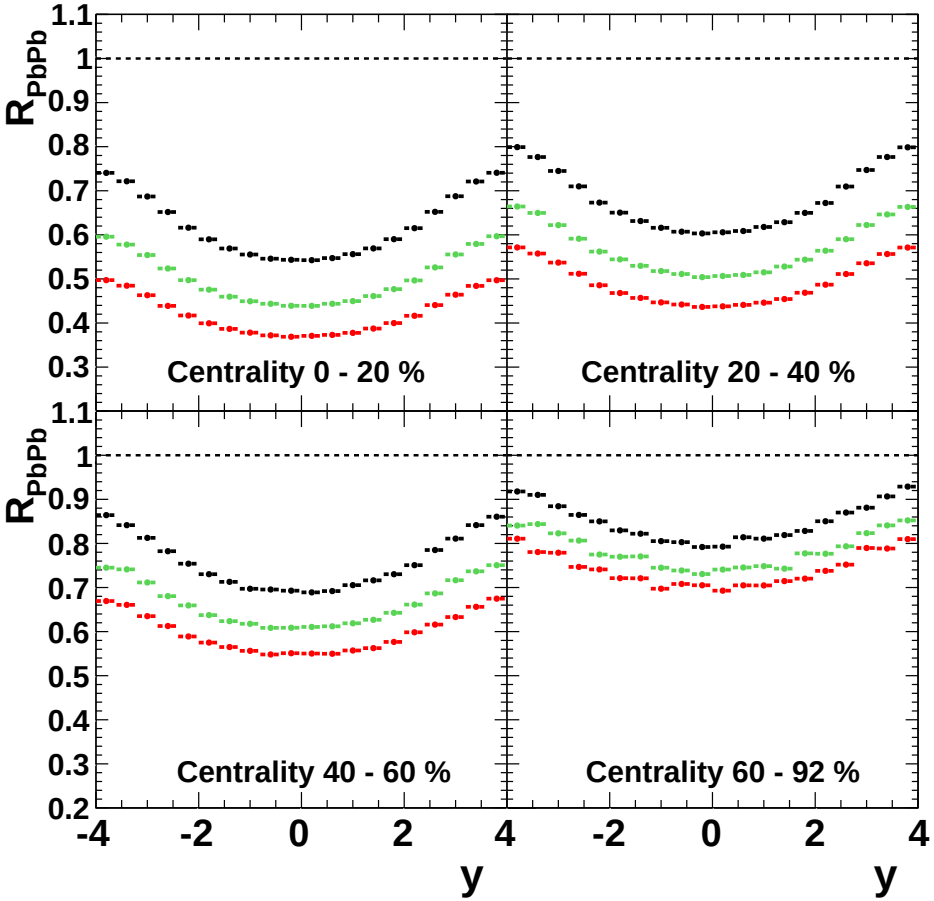

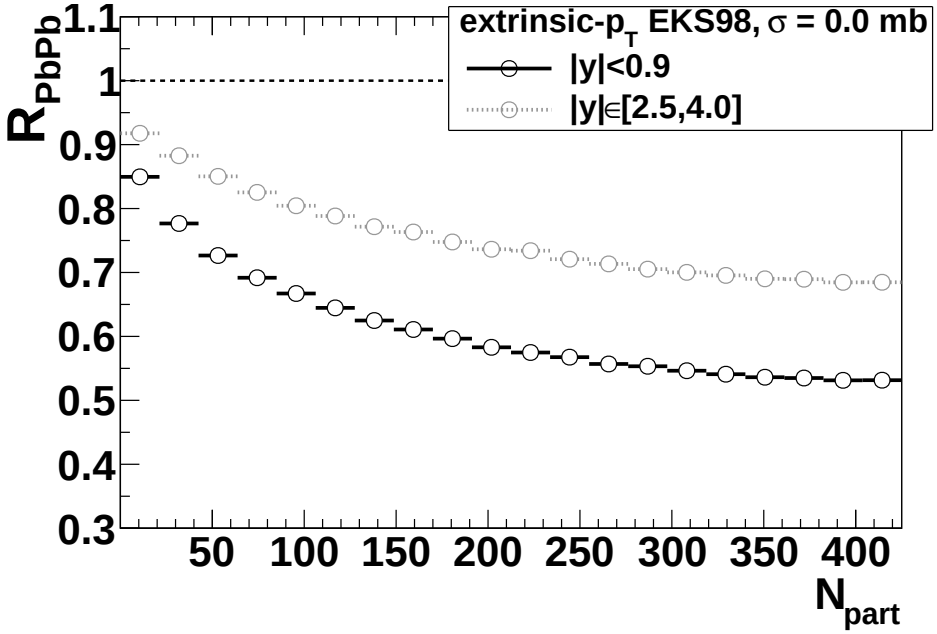

In black, $\sigma_{abs}^{eff} = 0.0$ mb, in green, $\sigma_{abs}^{eff} = 1.5$ mb, in red, $\sigma_{abs}^{eff} = 2.8$ mb

Strong rapidity dependence of R_{PbPb}!

Opposite to that at RHIC energy!

CNM vs data at $\sqrt{s_{NN}} = 2.76$ TeV

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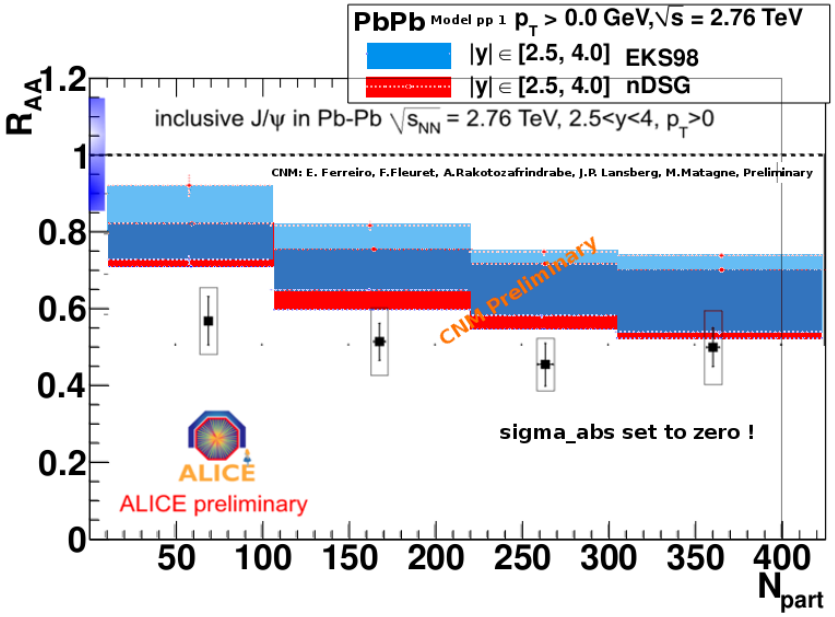
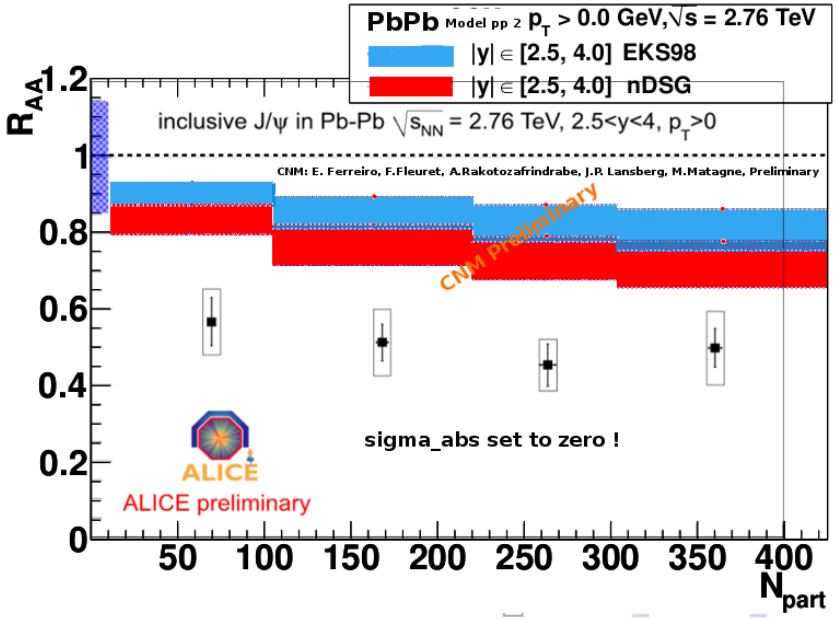
Without P_T cut and forward (ALICE acceptance):





CNM vs data at $\sqrt{s_{NN}} = 2.76$ TeV with a P_T cut

With $P_T > 6.5$ GeV cut and mostly central (CMS/ATLAS acceptance)

CMS, JHEP 1205 (2012) 063

[1] Note: we consider the shadowing with M1 to be exaggerated: Q^2 too small, too much weight on small P_T, i.e. small x

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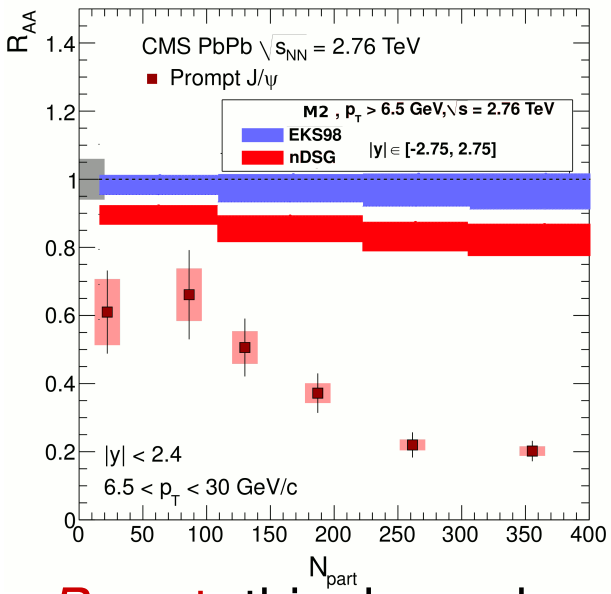

- Non trivial effect of the P_T cut: this depends on the nPDF set

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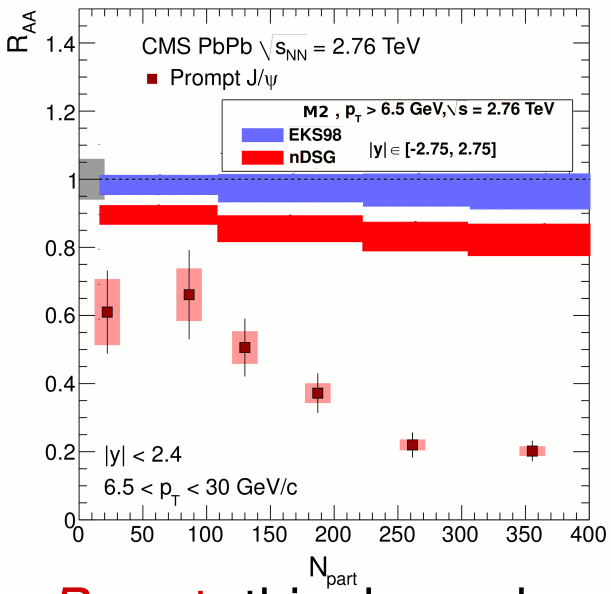

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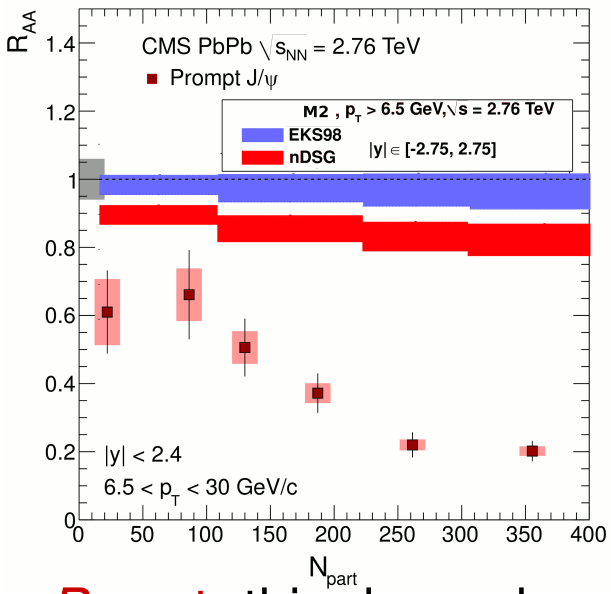

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- Without P_T cut with M1[1], EKS98 $\sim$ nDSg and strong suppression
- With a P_T cut with M2,
  EKS98 (slight/no suppression) $\nsim$ nDSg (still significant suppression)

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Part III

Υ production in p/dA and AA collisions

Absorption: Υ vs. J/ψ

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- at $y < 0$, $t_f \leq r_{\text{Au}}$, fully formed in the nucleus: e.g. $\sigma^{\Upsilon(2S)}_{abs} \geq 4\sigma^{\Upsilon(1S)}_{abs}$
  Yet, equal suppression found by E772 in the backward region:

$$\Rightarrow \sigma^{\Upsilon(2S)}_{abs} - \sigma^{\Upsilon(1S)}_{abs} \text{ small} \Rightarrow \boxed{\sigma^{\Upsilon(1S)}_{abs} \text{ small}}$$

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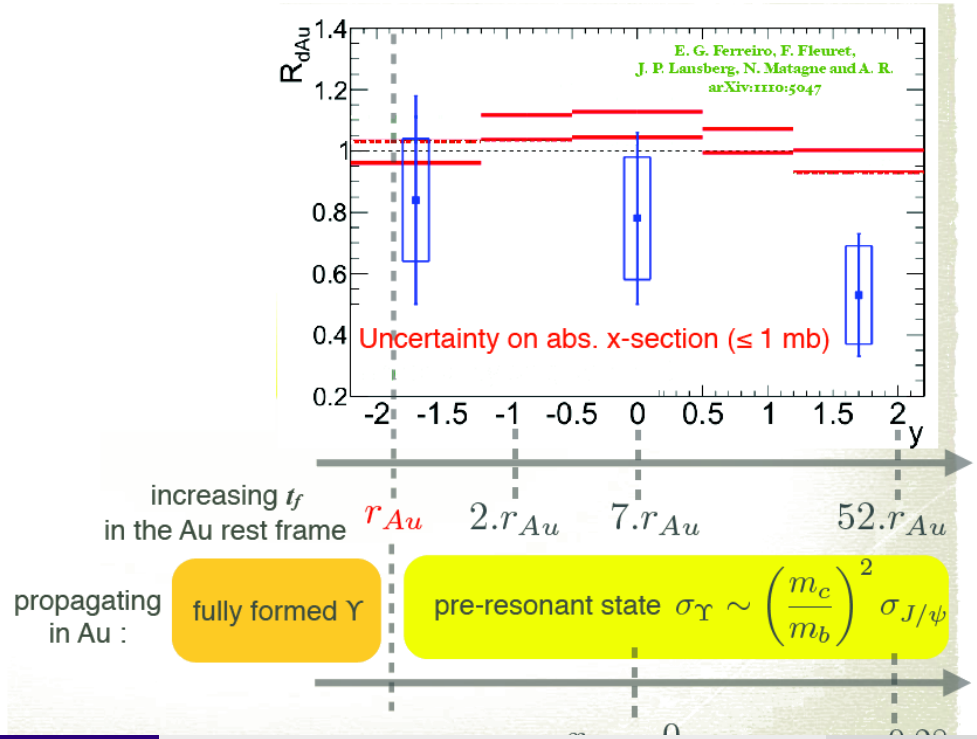
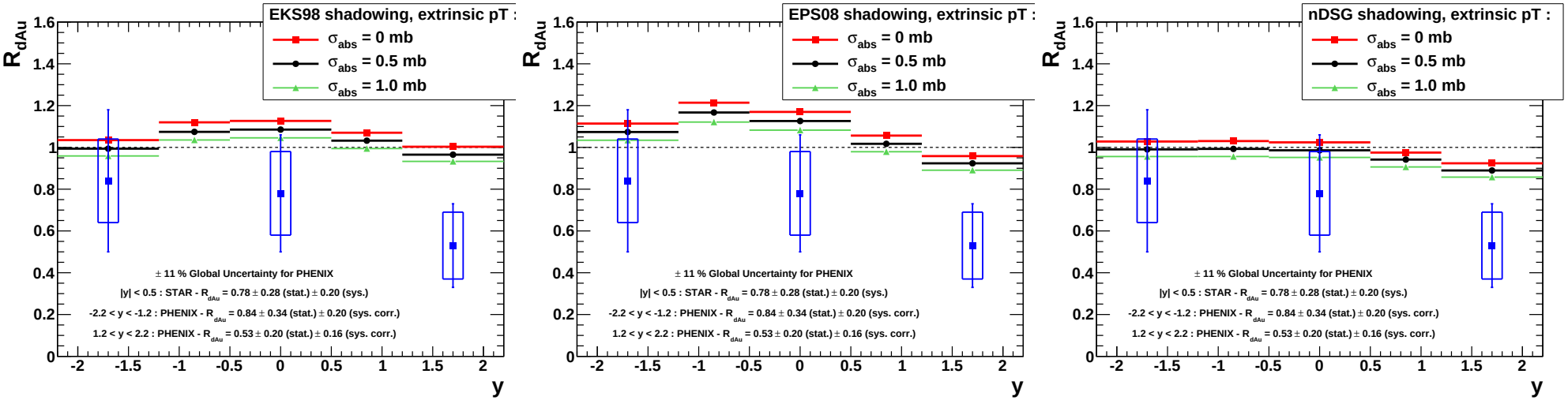
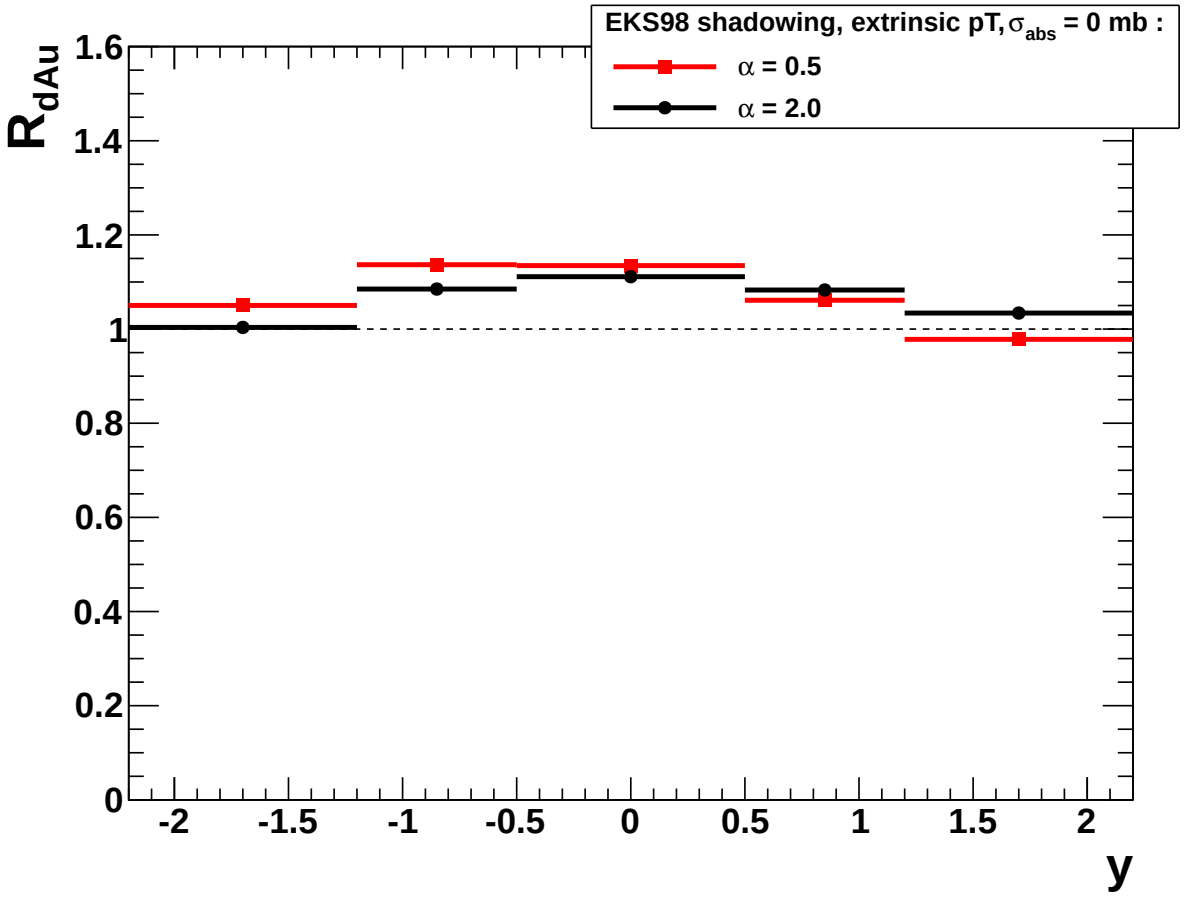


nPDF uncertainty on Υ production in *d*Au collisions



- Similar trend for the three nPDFs (EKS98, EPS08, nDSg)
  (nDSg shadowing as strong as EKS since its Q^2 evolution is slow)
- Uncertainty from the nPDFs larger than our conservative estimate for that from the absorption x-section (0-1 mb)
- A priori, uncertainties smaller than for J/ψ

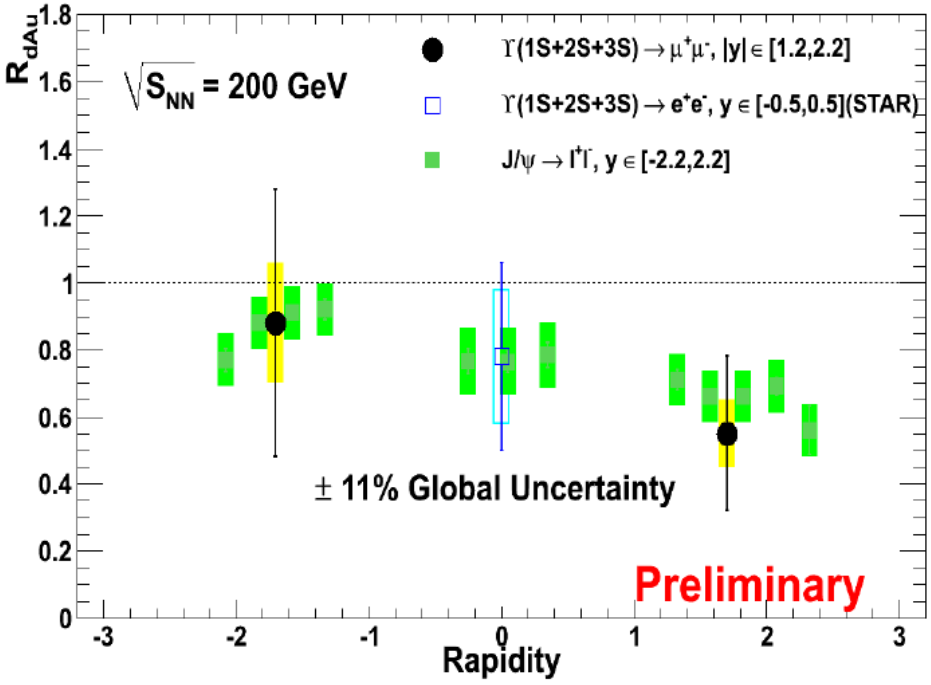
(Factorisation) scale dependence of Υ production in dAu



$$Q = \mu_F = \alpha \times m_T$$

$\rightarrow$ Scale uncertainty for Υ is smaller than for J/ψ

Υ vs J/ψ: different effects, same suppression ?



T. Frawley, Hard Probes 2012

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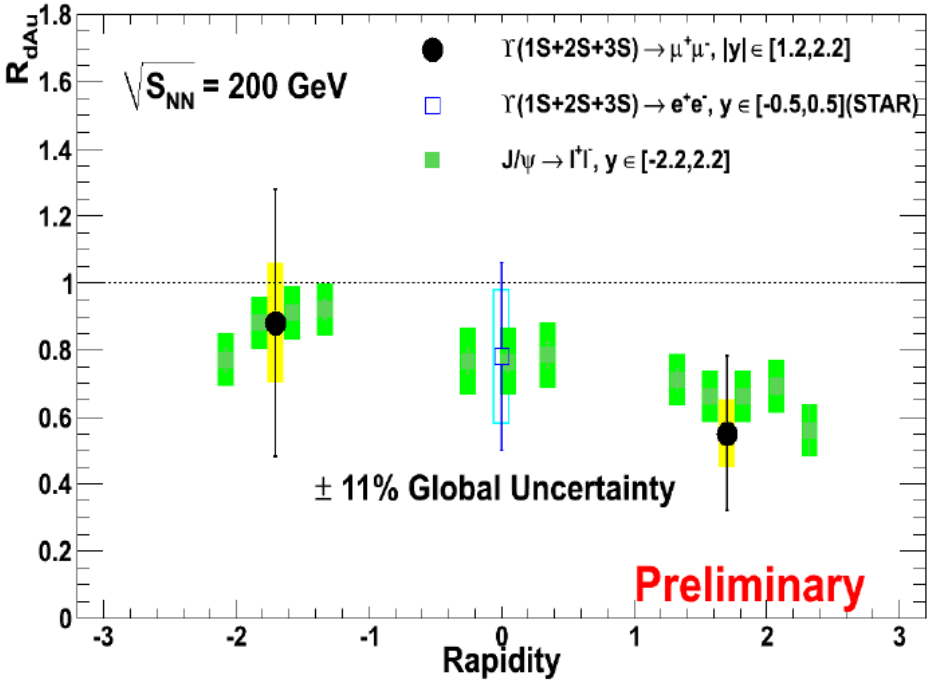

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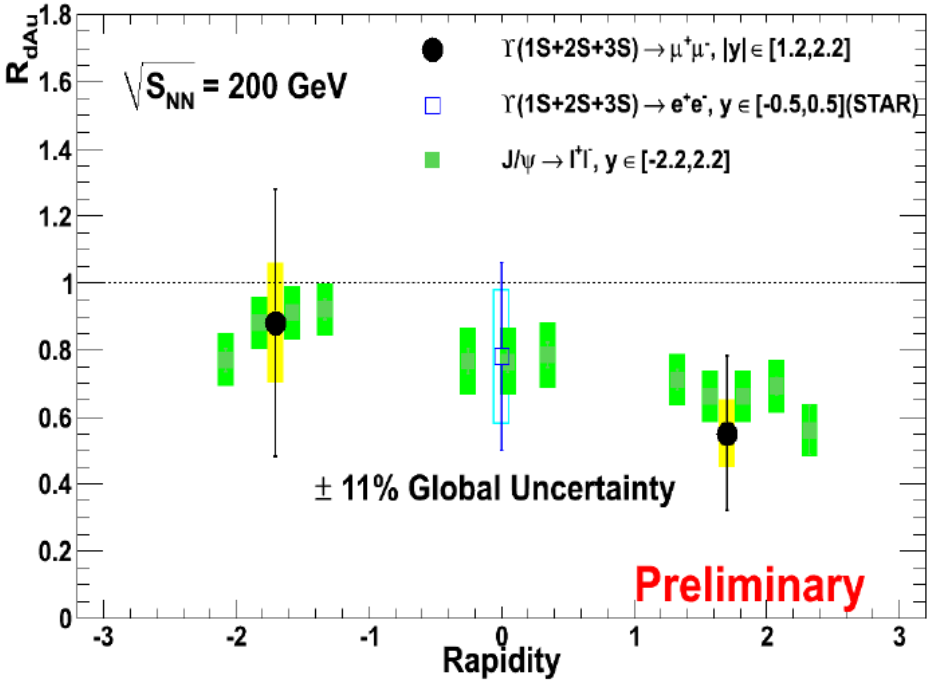

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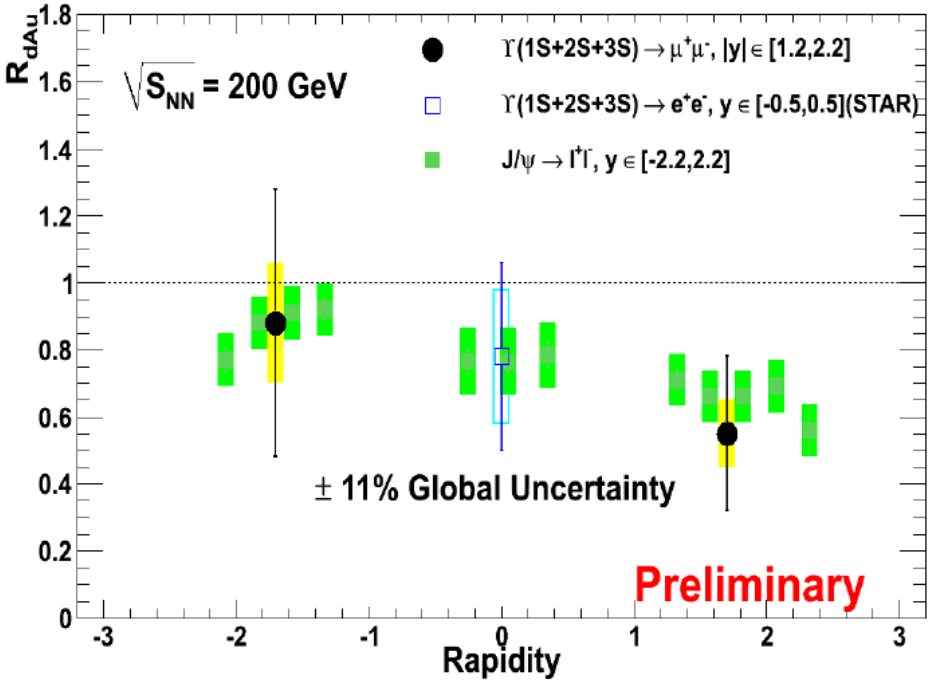

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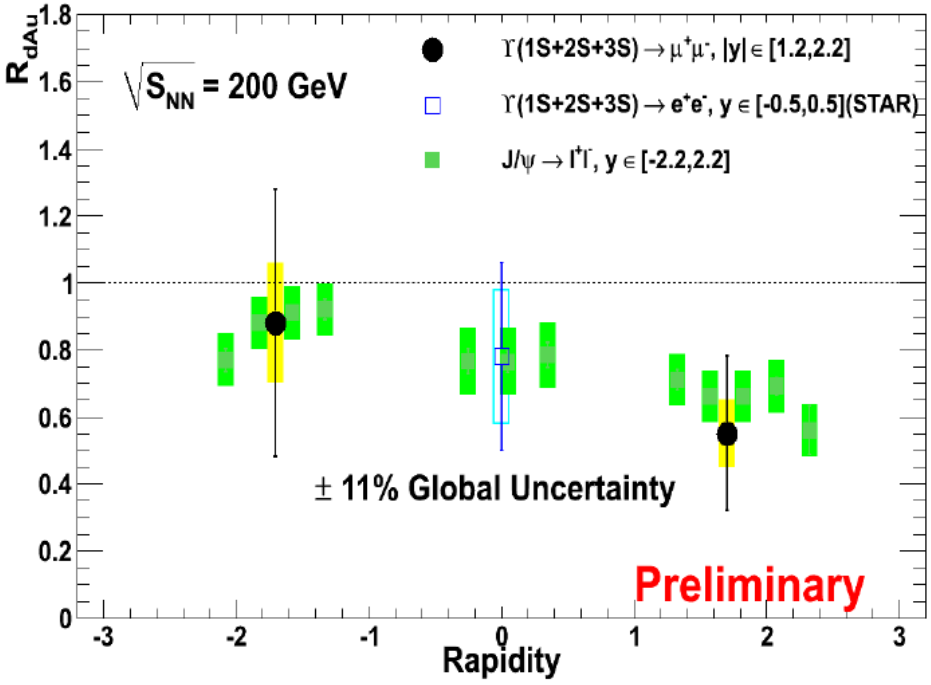

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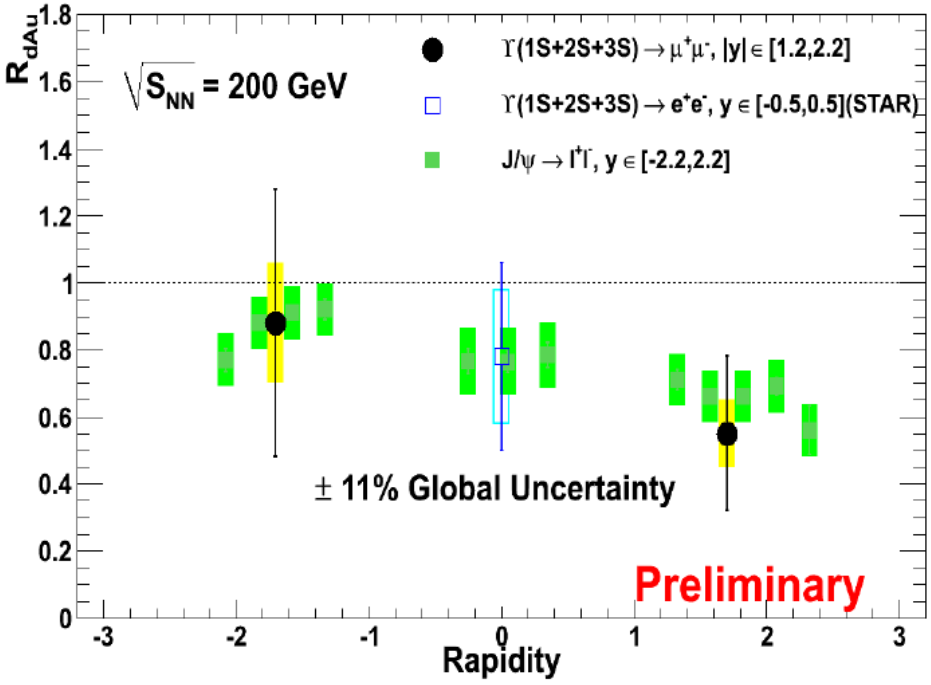
Υ vs J/ψ: different effects, same suppression ?



T. Frawley, Hard Probes 2012

- A priori same behaviour, but
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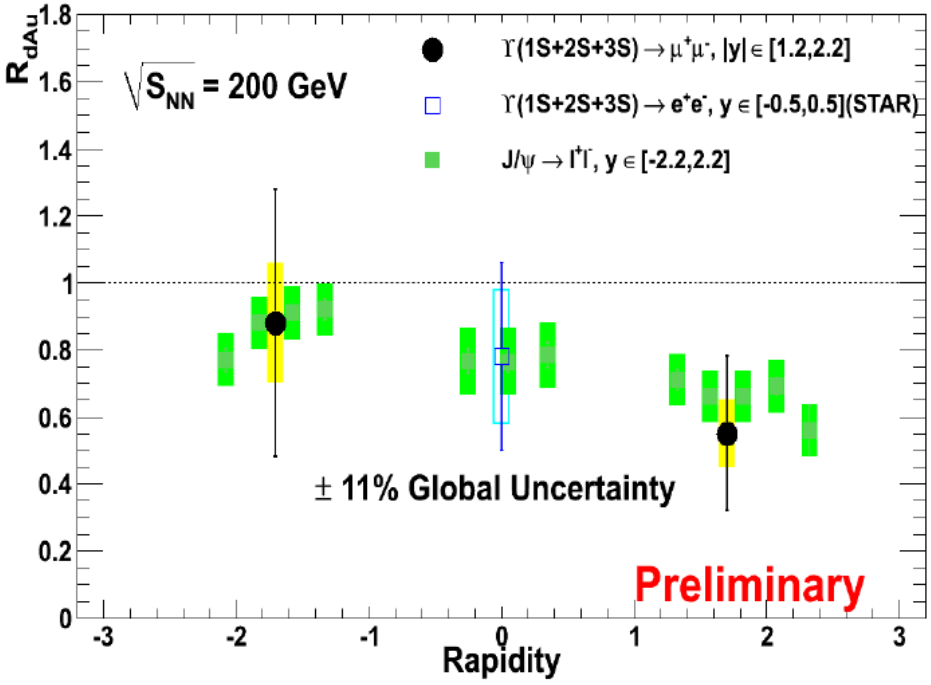

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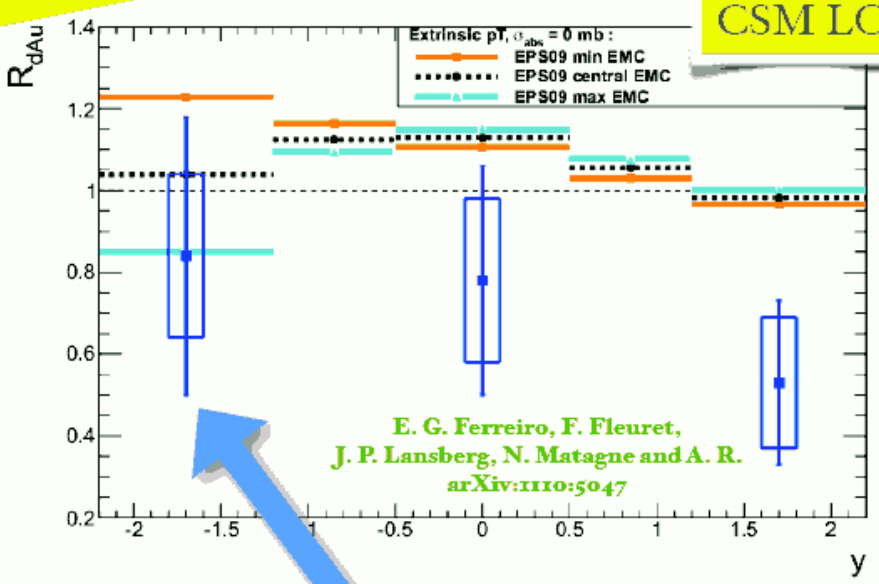
- Backward Υ's sit in the EMC region
- Note, however, than the error bars are large

Υ production in *d*Au at RHIC and the gluon EMC effect

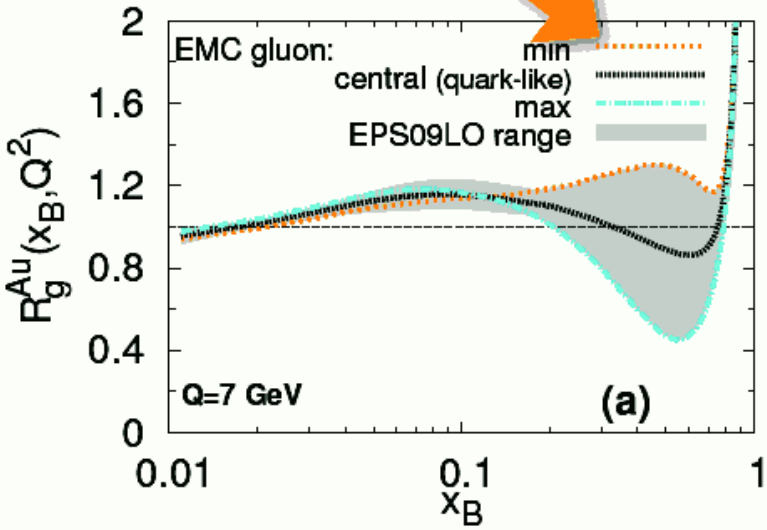
Let us focus in the EMC region and pick the EPS09 sets that are the limiting cases in this region :

$2 \to 2$ process

CSM LO



min. disfavoured



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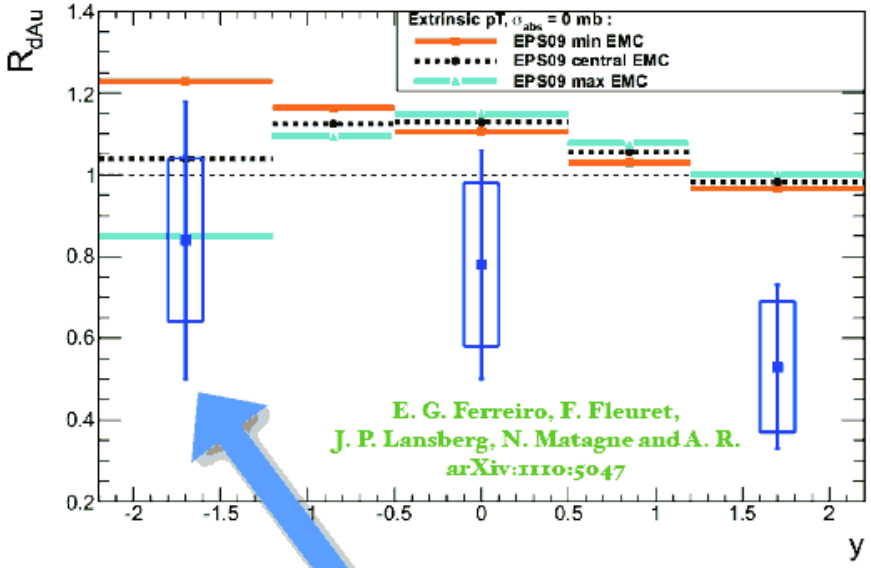

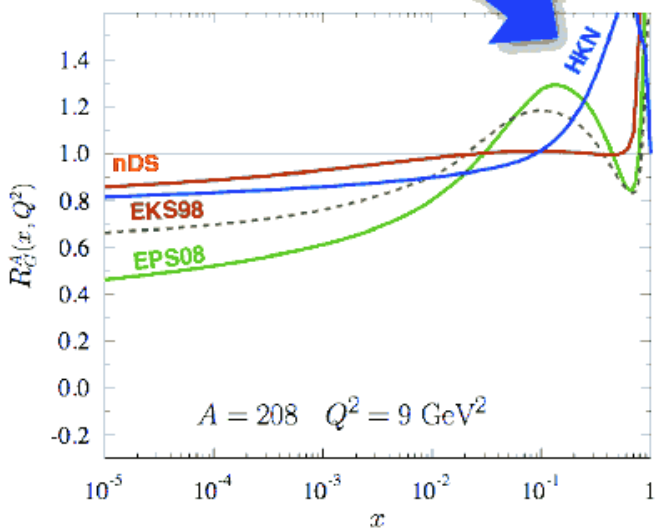

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Υ production in *d*Au at RHIC in the mid and forward region

E. G. Ferreiro, F. Fleuret,
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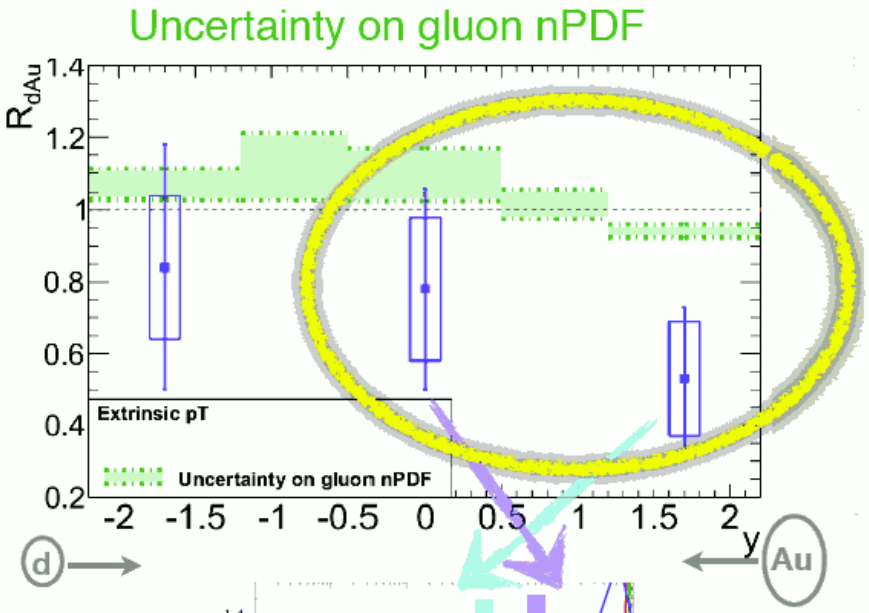
arXiv:1110:5047

Typical gluon nPDF parametrisations induce a **flat rapidity dependence** w.r.t. data



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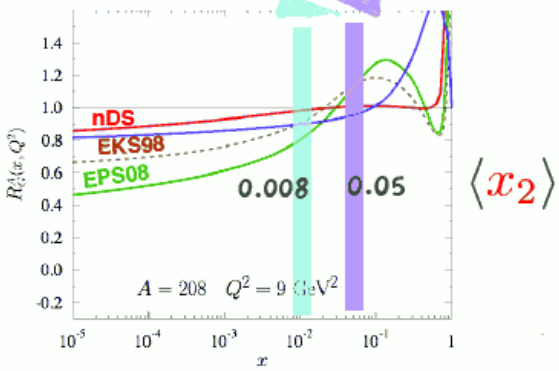

Data:
STAR Preliminary, Nucl. Phys. A855 (2011) 440,
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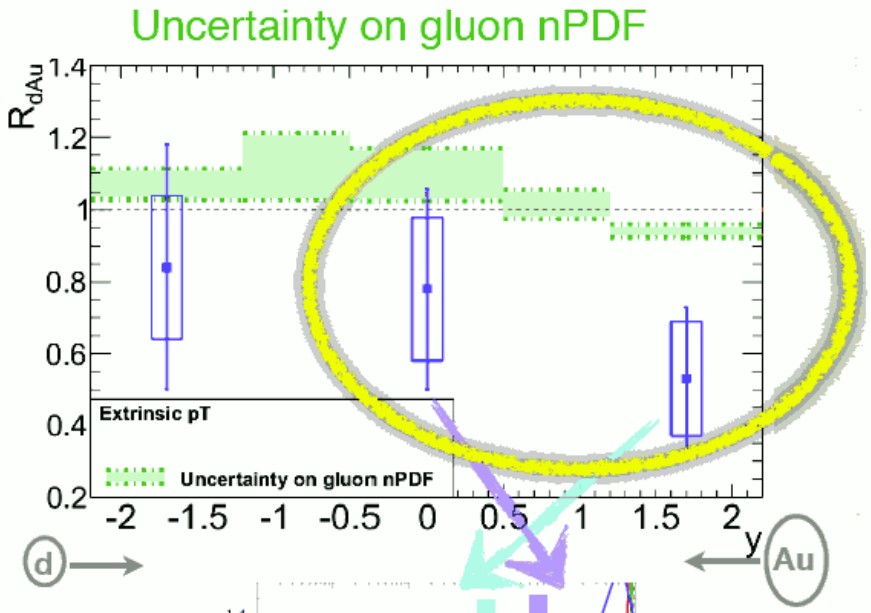

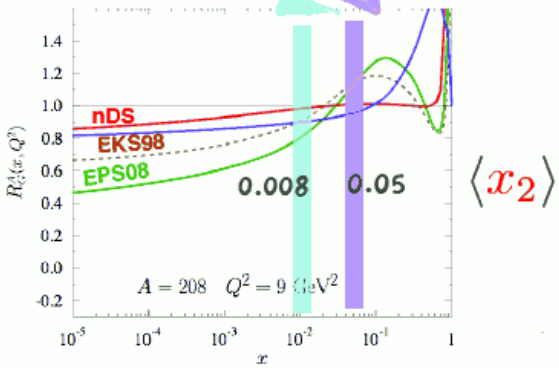

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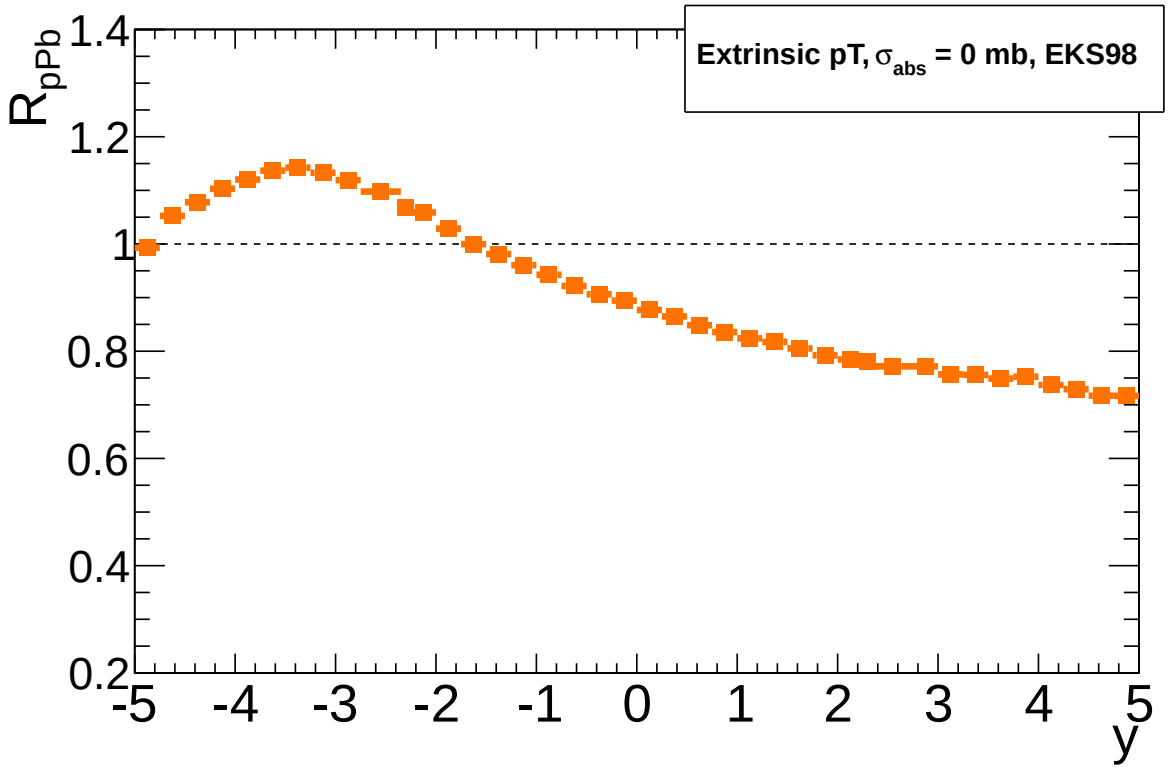
→ Fractional Energy loss à la Arleo-Peigné ?

What's next: Υ at 5 TeV



- Shadowing and antishadowing effects:expected to be significant
- Rules of thumb: $Q^2_{\Upsilon} \simeq 10 \times Q^2_{J/\psi}$ but also $x_2^{\Upsilon} \simeq 3 \times x_2^{J/\psi}$
- Let's keep in mind that Q is nothing but μ_F which we do not know

Part IV

Conclusions

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- R_{CP} should not be overlooked: no need for a *pp* baseline, avoid Δy & info on impact-parameter d.o.f.
- Υ offer a new playground: smaller uncertainties and a priori new effects
- At RHIC, Υ suppression shows the same trend as for J/ψ, this is unnatural...

Part V

Backup

On the kinematics of quarkonium 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:

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

2 $\rightarrow$ **1** kinematics with instrinsic p_T	**2** $\rightarrow$ **2** kinematics with extrinsic p_T

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

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2 → 1 kinematics with instrinsic p_T

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

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

2 → 2 kinematics with extrinsic p_T

$$\int dx_1\, dx_2 \int d\vec{r}_A dz_A dz_B$$
$$\times\ \mathcal{F}_g^A(x_1, \vec{r}_A, z_A, \mu_f)\mathcal{F}_g^B(x_2, \vec{r}_B, z_B, \mu_f)$$
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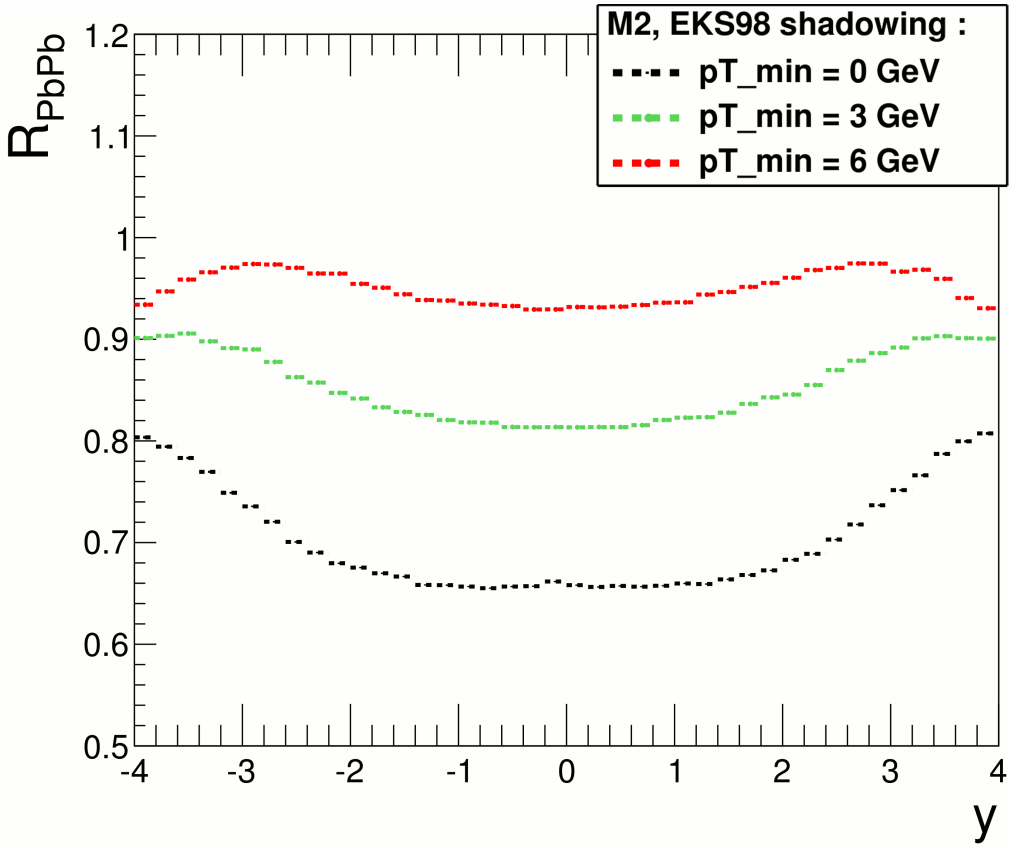
$$\times\ S_A(\vec{r}, z_A)S_B(\vec{r}_B, z_B)$$

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

The P_T cut matters

E.G. Ferreiro, F. Fleuret, J.P.L., N. Matagne, A. Rakotozafindrabe, Nucl. Phys. A 855 (2011) 327-330 + in progress



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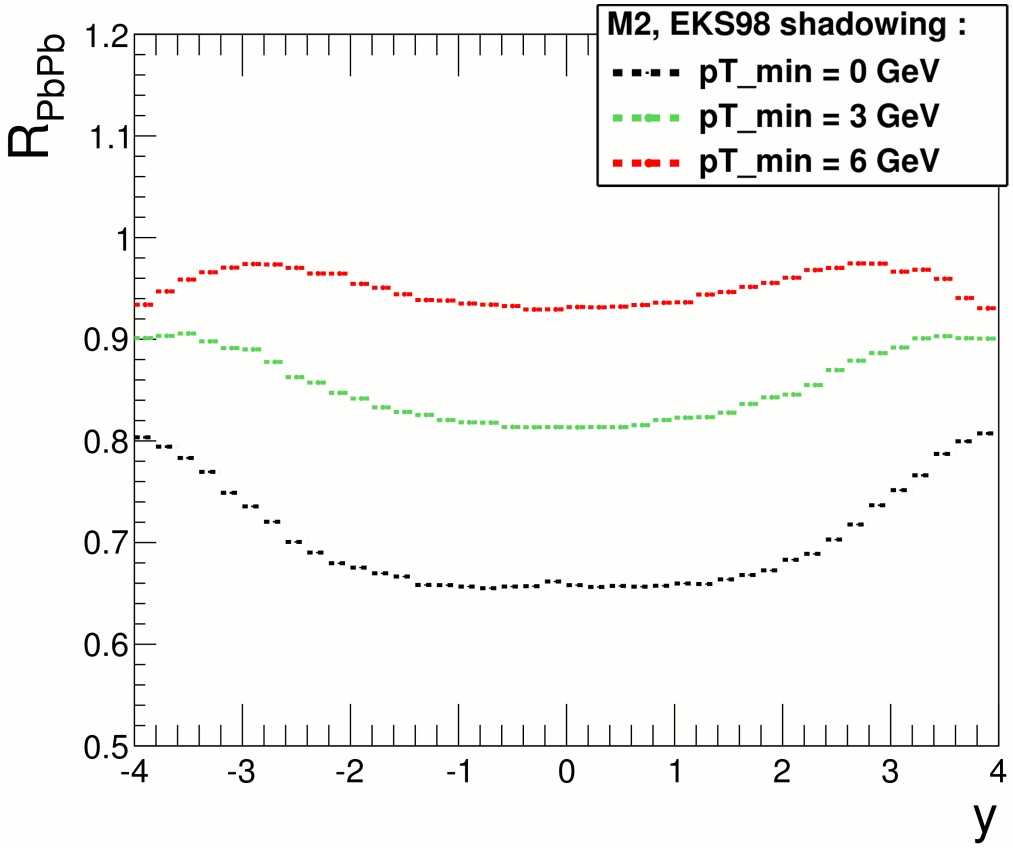

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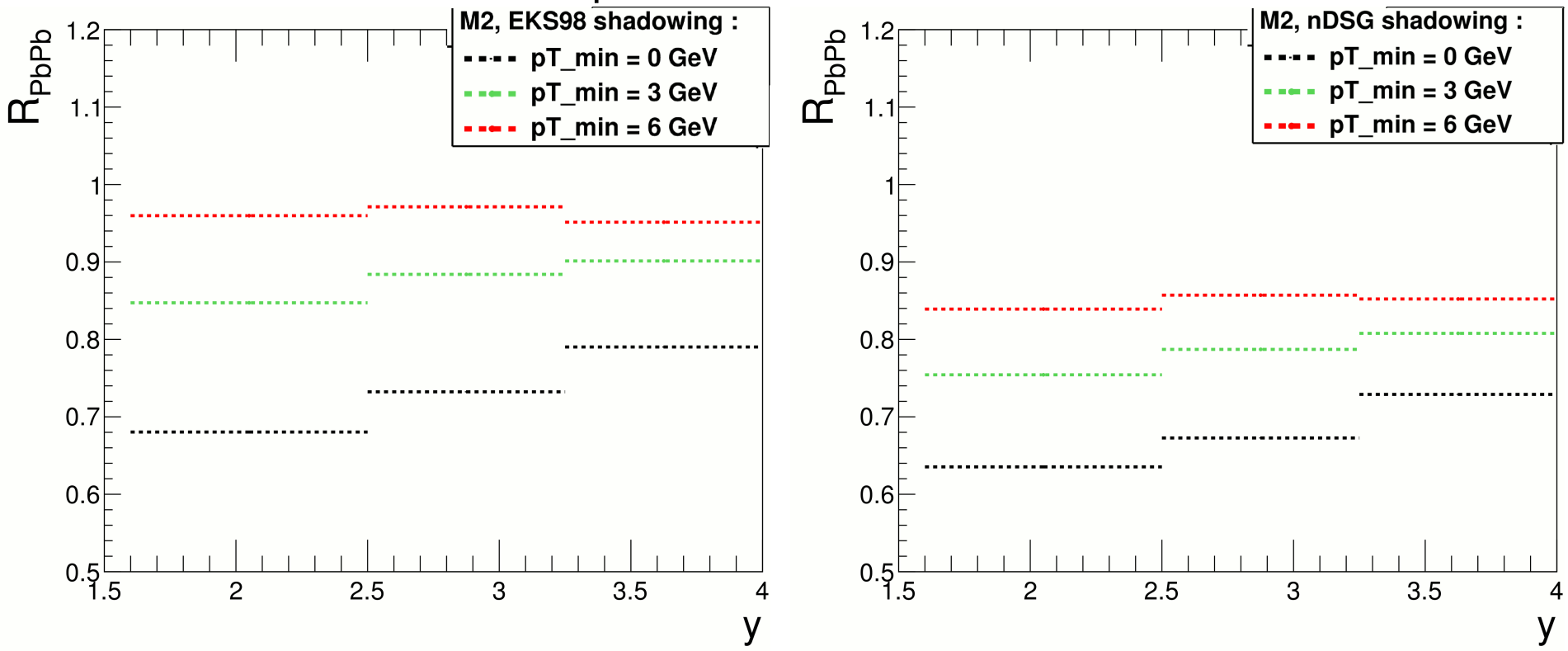

- For larger P_T cuts, the shadowing decreases (less true with nDSg)
  - $Q^2 \equiv \mu_F^2 \sim \sqrt{M^2 + P_T^2}$ — nDSg mild Q^2 evolution
  - But also, when $P_T \nearrow$, $x_{1,2} \nearrow$ — nDSg flatter than EKS98 for $x \leq 0.1$

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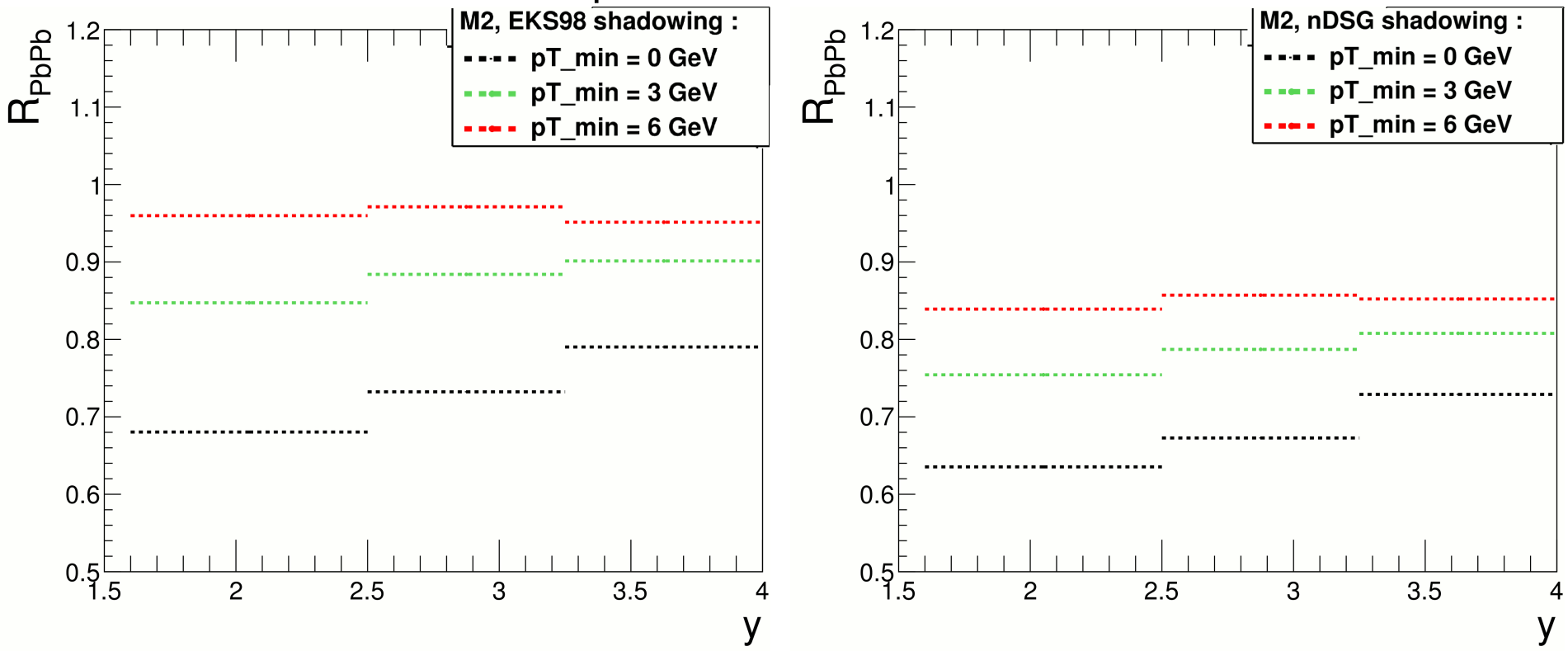

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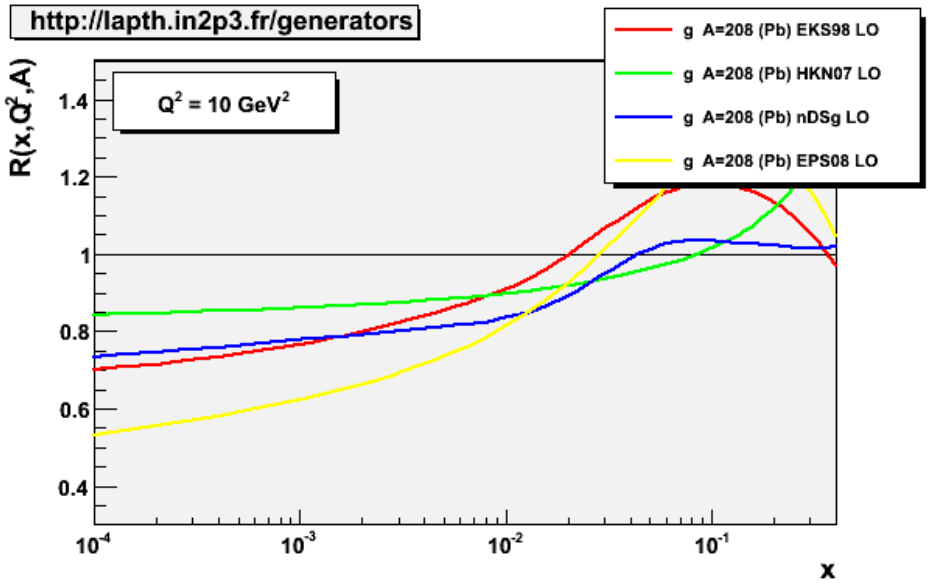
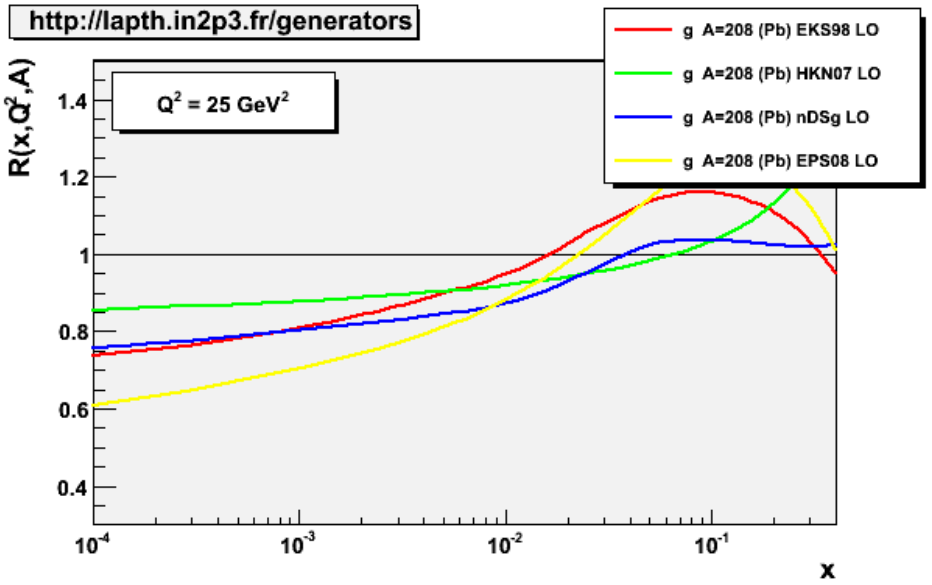
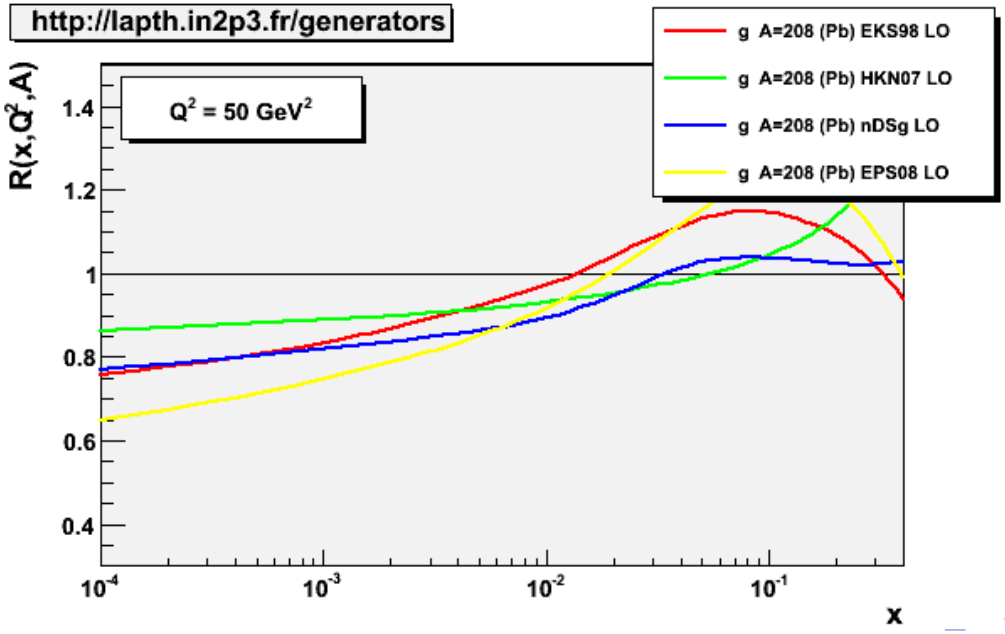
  - But also, when $P_T \nearrow$, $x_{1,2} \nearrow$ — nDSg flatter than EKS98 for $x \leq 0.1$
- Non trivial modification of the y-dependence

Gluon shadowing at different scales for Pb ions



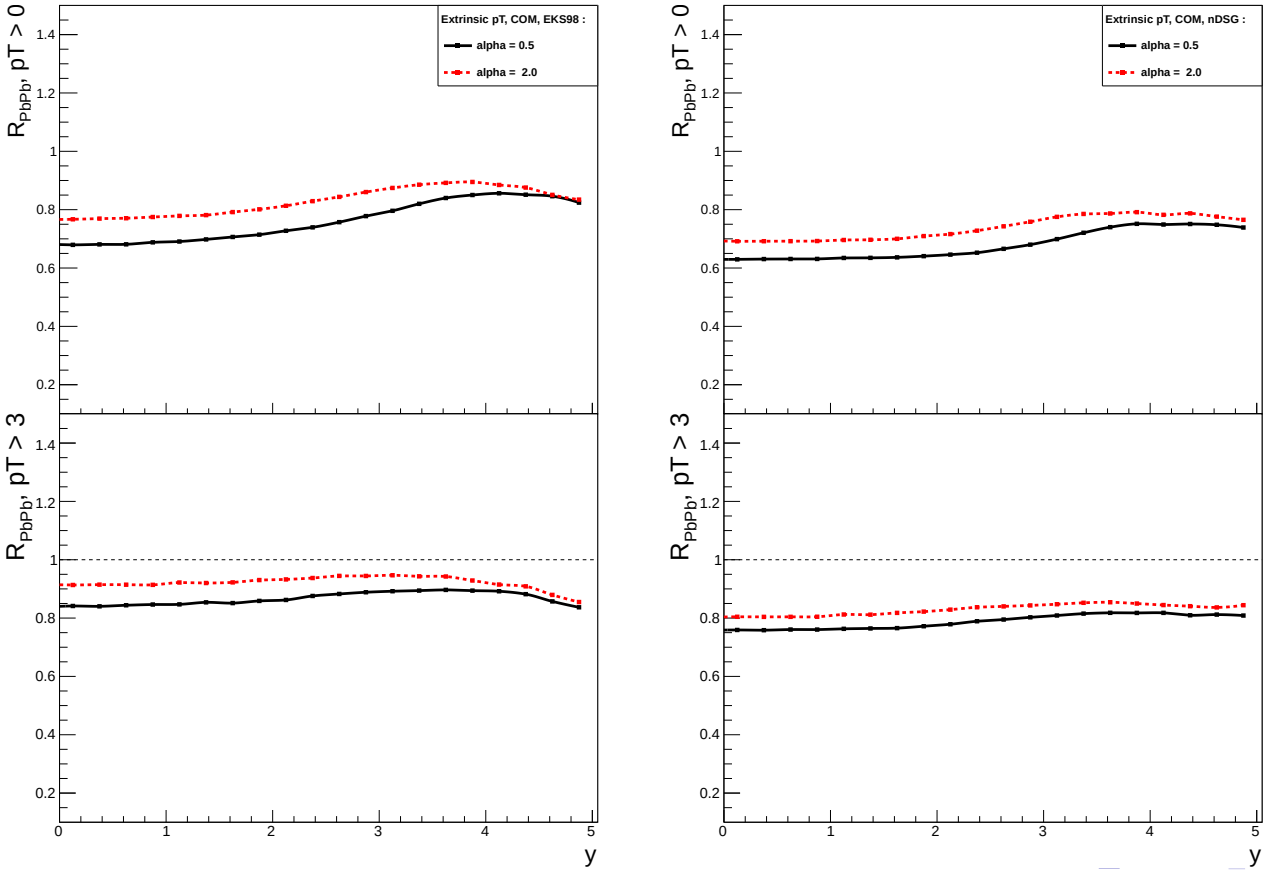




The P_T cut matters

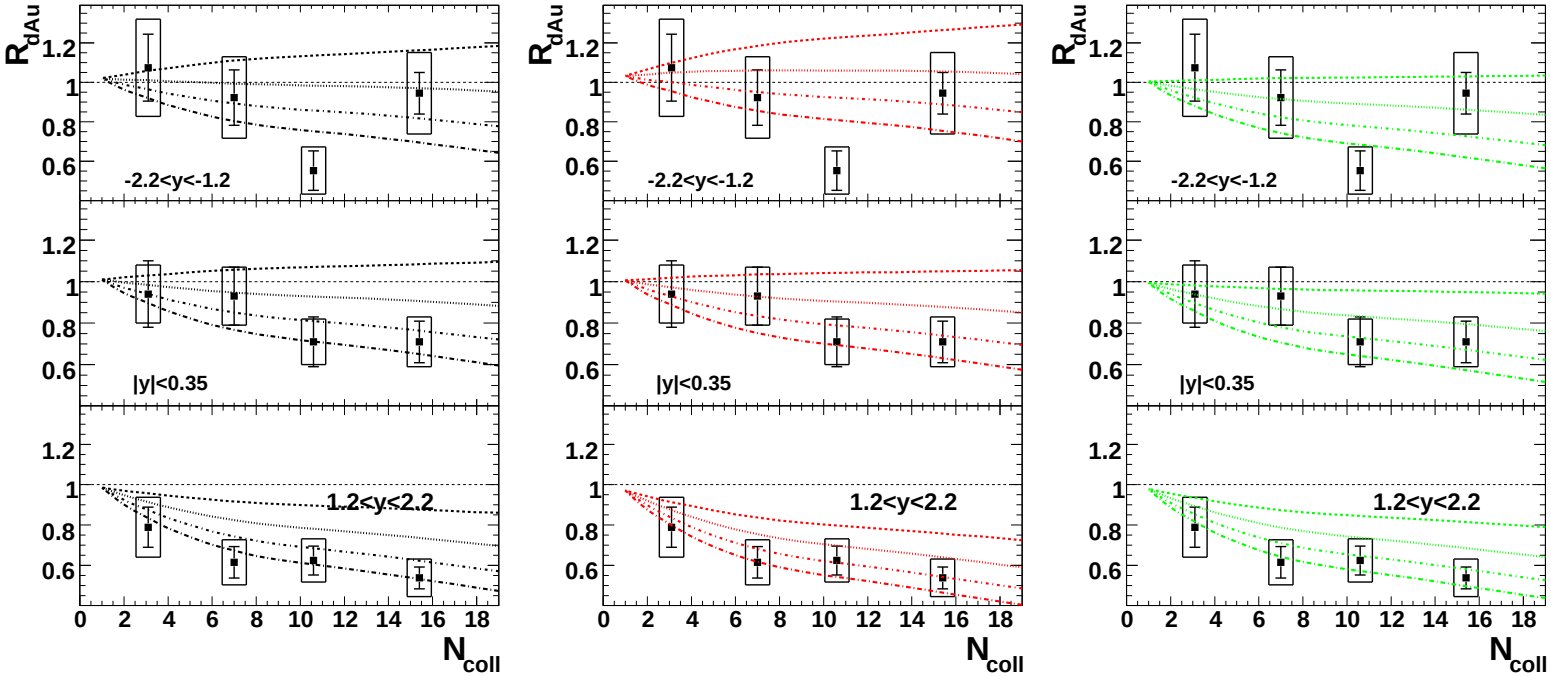
E.G. Ferreiro, F. Fleuret, J.P.L., N. Matagne, A. Rakotozafindrabe, Nucl. Phys. A 855 (2011) 327-330 + in progress

- CMS could not go below $P_T = 3$ GeV,
  and only in the slightly forward region
- Can one expect a big difference for the CNM when a cut $P_T \geq 3$ GeV is applied ? not really ...



Centrality dependence in *d*Au

E.G. Ferreiro, F. Fleuret, J.P.L., A. Rakotozafindrabe, PLB 680:50,2009, PRC 81, 064911 (2010)



(a) EKS98 (b) EPS08 (c) nDSg

- Backward region $-2.2 < y < 1.2$: the gluon in the Au is very energetic (large x) $\rightarrow$ antishadowing
- Central region $-0.35 < y < 0.35$: the gluon in the Au is energetic (mid x) $\rightarrow$ slight shadowing
- Forward region $1.2 < y < 2.2$: the gluon in the Au is not energetic (small x) $\rightarrow$ stronger shadowing