Irfu
cea
saclay
Institut de recherche sur les lois fondamentales de l'Univers

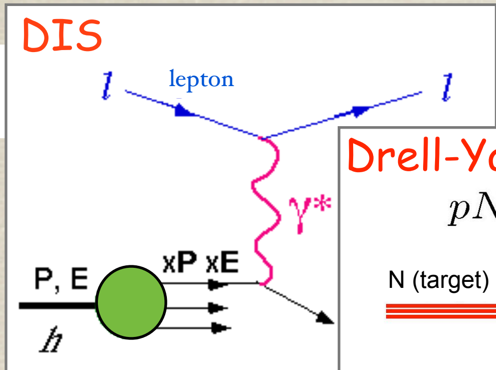
In collaboration with E. G. Ferreiro, F. Fleuret, J. P. Lansberg & N. Matagne

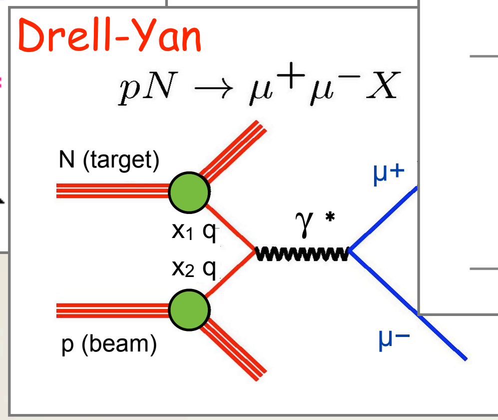
CNM effects on Quarkonium production : from RHIC to LHC

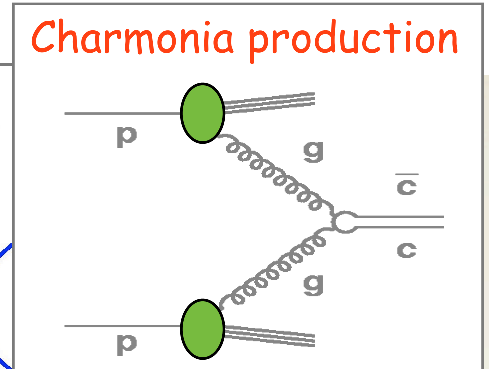
Andry Rakotozafindrabe
CEA (Saclay) IRFU/SPhN

Rencontres Ions Lourds, July 26th, 2011

Shadowing : a cold *nuclear matter* effect







Processes used to probe :

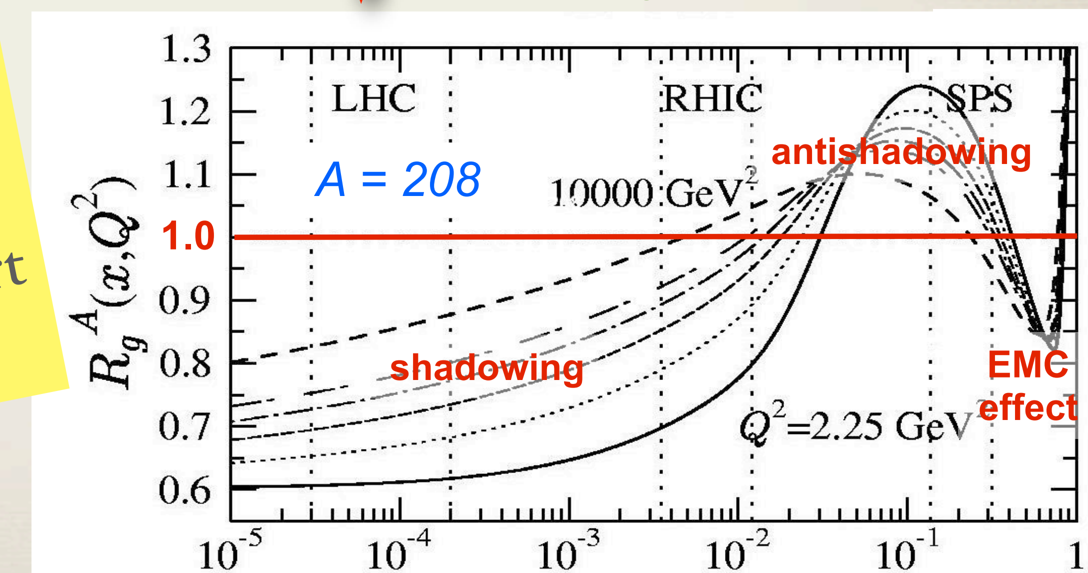
- nucleon struct. f.

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

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

- nuclear struct. f. per nucleon

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

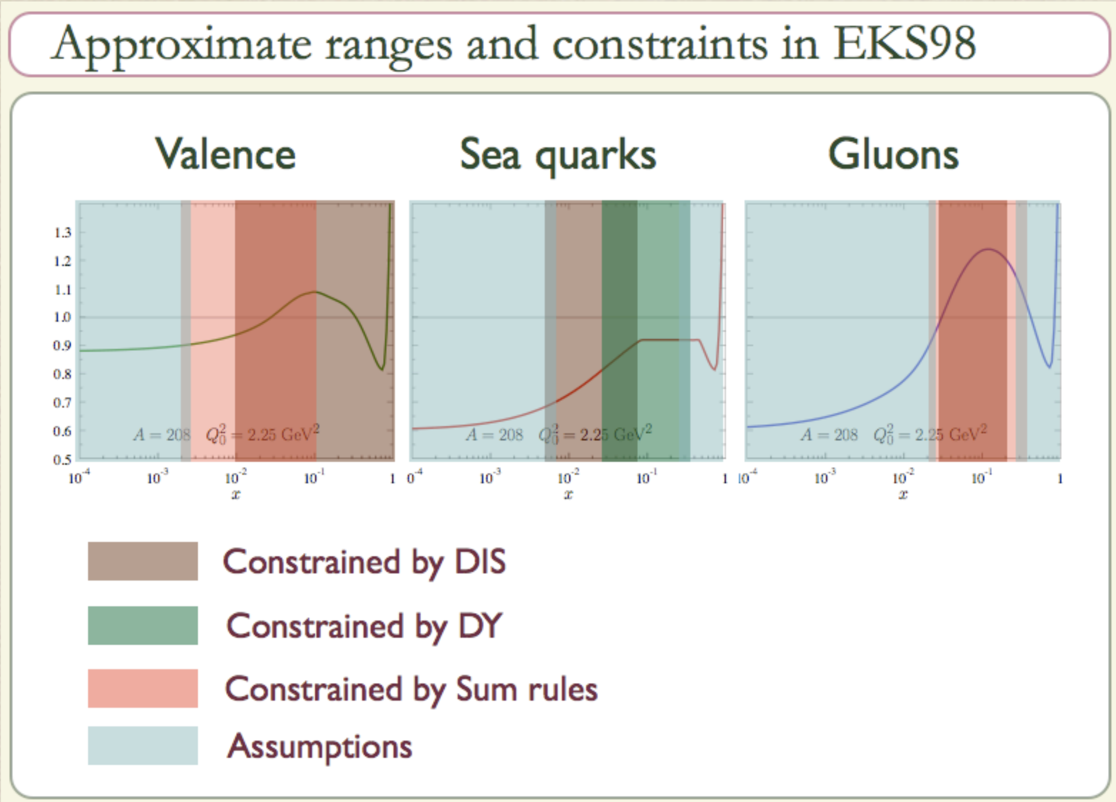


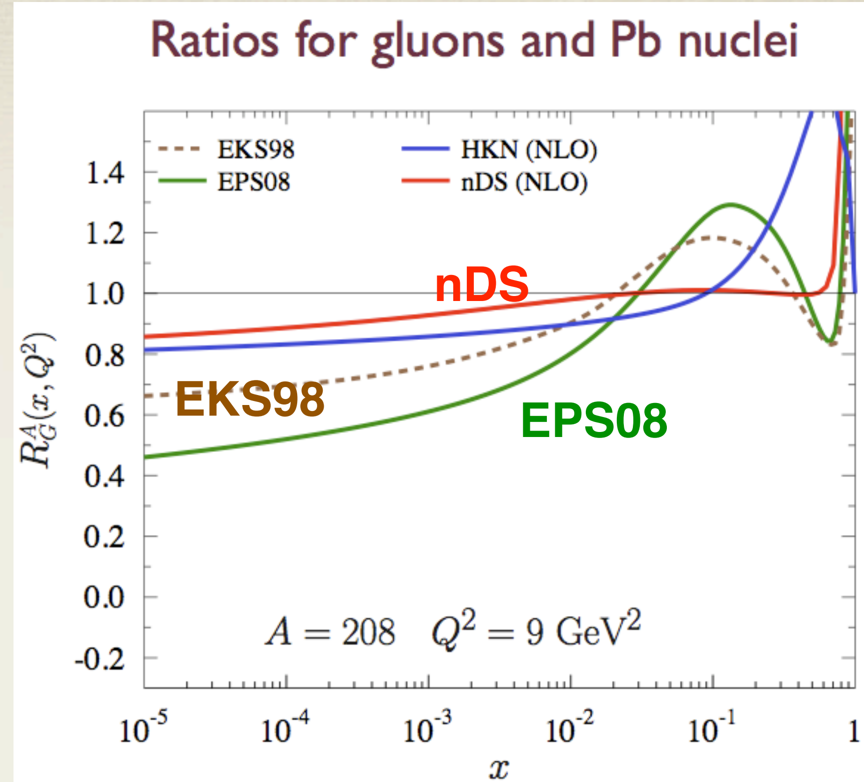
Nucl. Phys. A696 (2001) 729-746

(Anti-)shadowing :

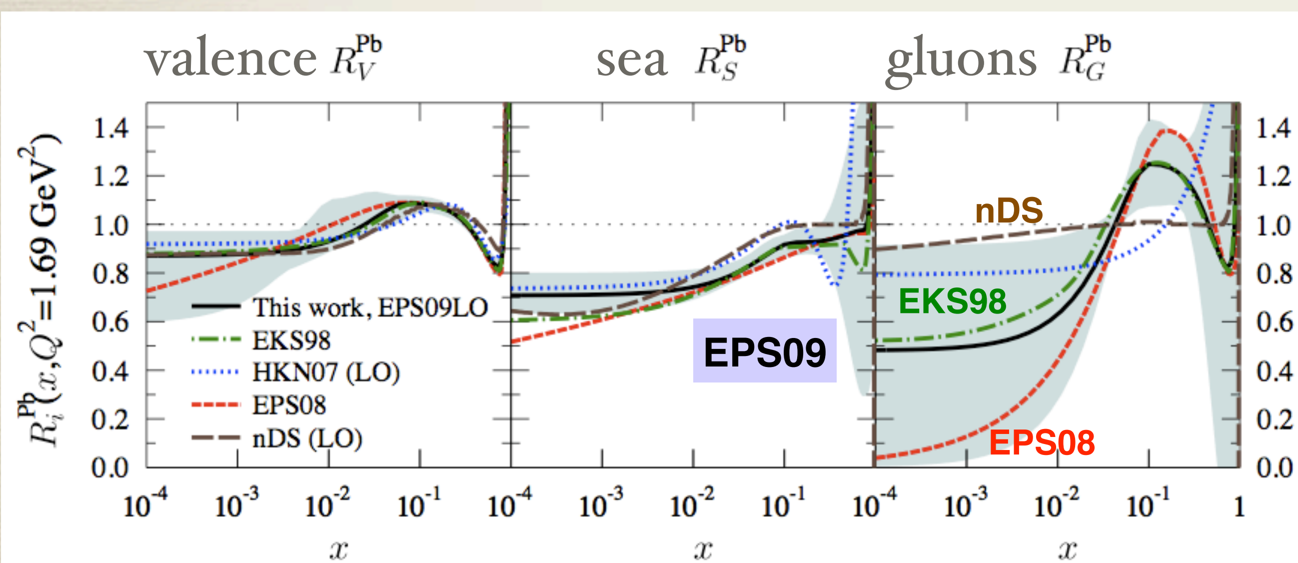
- initial-state effect "calibrated" in d(p)+A
- (enhances) decreases σ^{pA} wrt $\langle N_{\rm coll} \rangle\, \sigma^{pp}$

(Some) nPDFs available on the market





C. Salgado, ECT Trento July 2008



nDS(g), EKS98 and EPS08 span the uncertainty on nPDF

Eskola, Paukkunen, Salgado, JHEP 0904:065 (2009)

Shadowing computation

- in A+B: quarkonia production cross-section modified by a **shadowing correction factor** :

$$\mathcal{F}(R_g^A(x_1, Q^2)) \times \mathcal{F}(R_g^B(x_2, Q^2))$$

- **4-mom conservation relates** (x_1, x_2) **to quarkonia** (y, p_T)
- production models (CEM, NRQCD, CSM ...) in p+p gives quarkonia thanks to **various processes, each with:**
  - **a given phase-space in** (x_1, x_2, y, p_T)
  - a given weight (differential cross-section) for each point in this phase-space

☑ different production models may result in quite different shadowings

How prod. models can differ ?

- intrinsic scheme
  $2 \longrightarrow 1$ process

$$g + g \longrightarrow c\bar{c} \text{ or } b\bar{b}$$

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

- ☑ Handy : unequivocal correspondence

$$(x_1, x_2) \Leftrightarrow (y, p_T)$$

- Quarkonia p_T comes from initial partons
- e.g. CEM LO

- extrinsic scheme
  $2 \longrightarrow 2$ process

$$g + g \longrightarrow \{J/\psi, \Upsilon\} + g$$

more degrees of freedom in the kinematics :

- ☑ several $(x_1, x_2) \Leftarrow (y, p_T)$

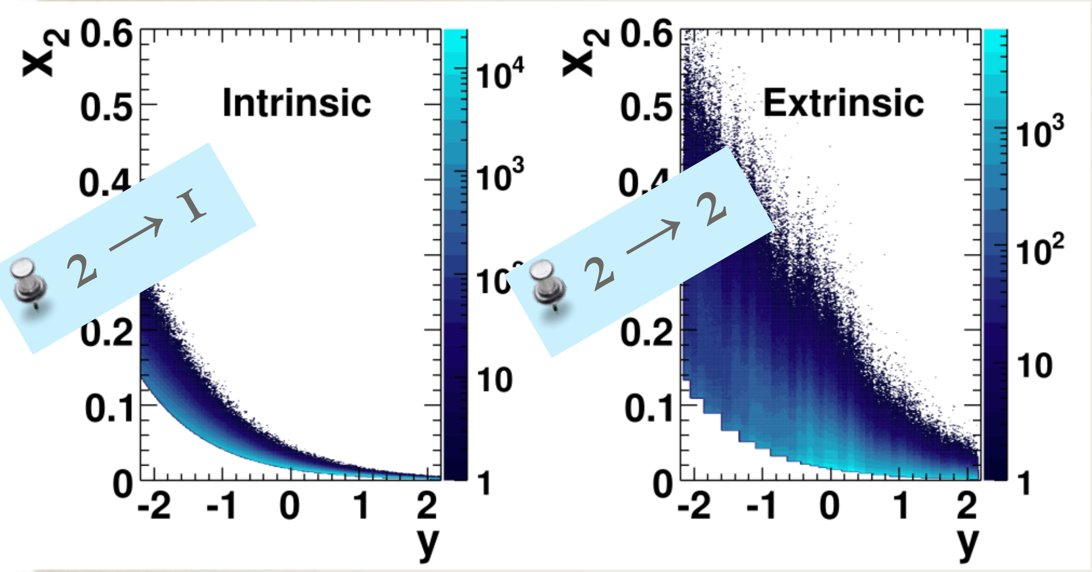
$$y, p_T, x_1 \Longrightarrow x_2 = \frac{x_1 m_T \sqrt{s} e^{-y} - M^2}{\sqrt{s}\,(\sqrt{s} x_1 - m_T e^y)}$$

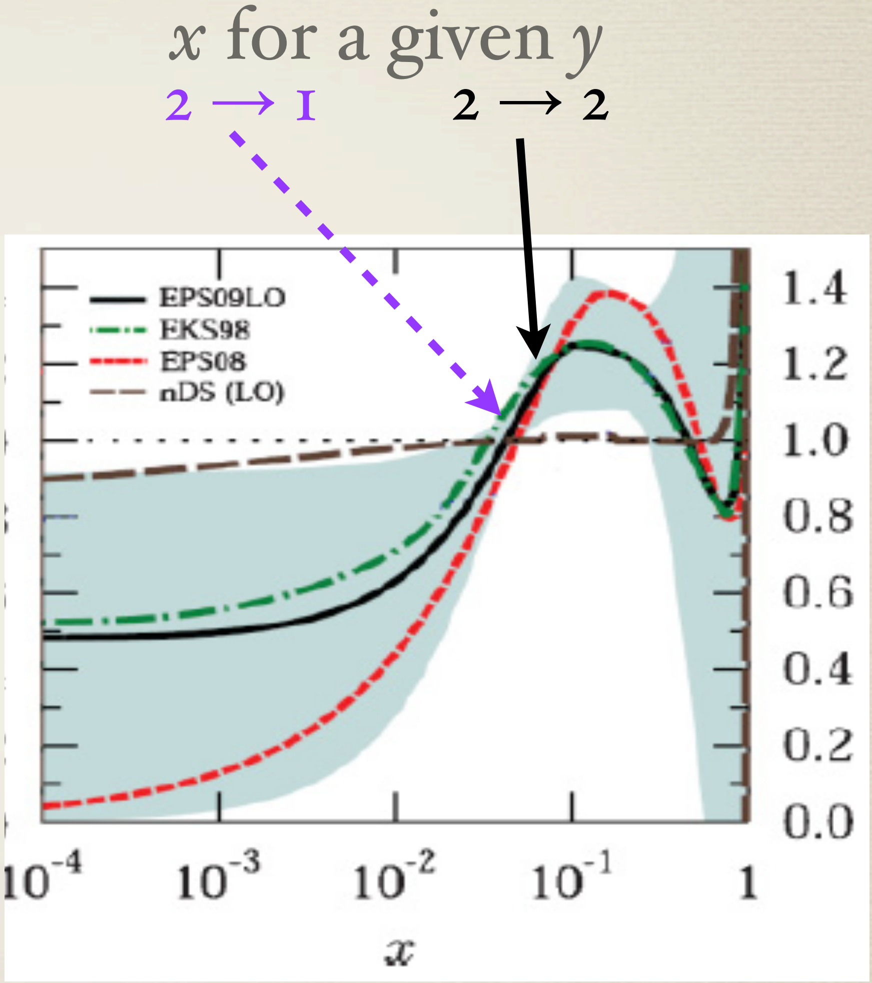
- Quarkonia p_T is balanced by the outgoing gluon
- e.g. CSM LO, COM LO

☑ Use reasonably good models in p+p to compute CNM effects in p+A, A+A

CNM effects at RHIC : J/ψ in dAu

$g + g \to c\bar{c}$ $\qquad$ $g + g \to J/\psi + g$





- for a given y, <x> is larger in the 2 → 2 process

CNM effects at RHIC : J/ψ in dAu

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R.
PRC 81 (2010) 064911

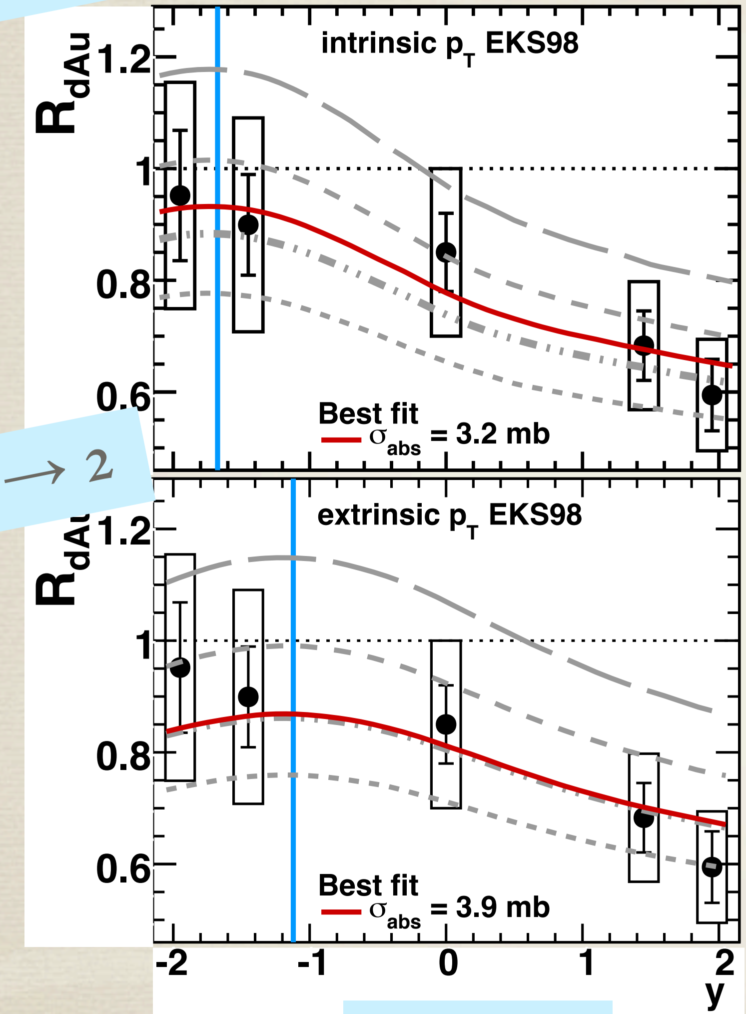
R_{dAu} vs rapidity

- $2 \to 1$

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

- $2 \to 2$

$g + g \to J/\psi + g$



- EKS98

- for a given y, x is larger in the $2 \to 2$ process
- ✓ *larger* absorption cross-section needed
- ✓ antishadowing peak shifted to larger y

- systematic effects seen for *all* nPDFs

CNM effects at RHIC : J/ψ in dAu

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R.
PRC 81 (2010) 064911

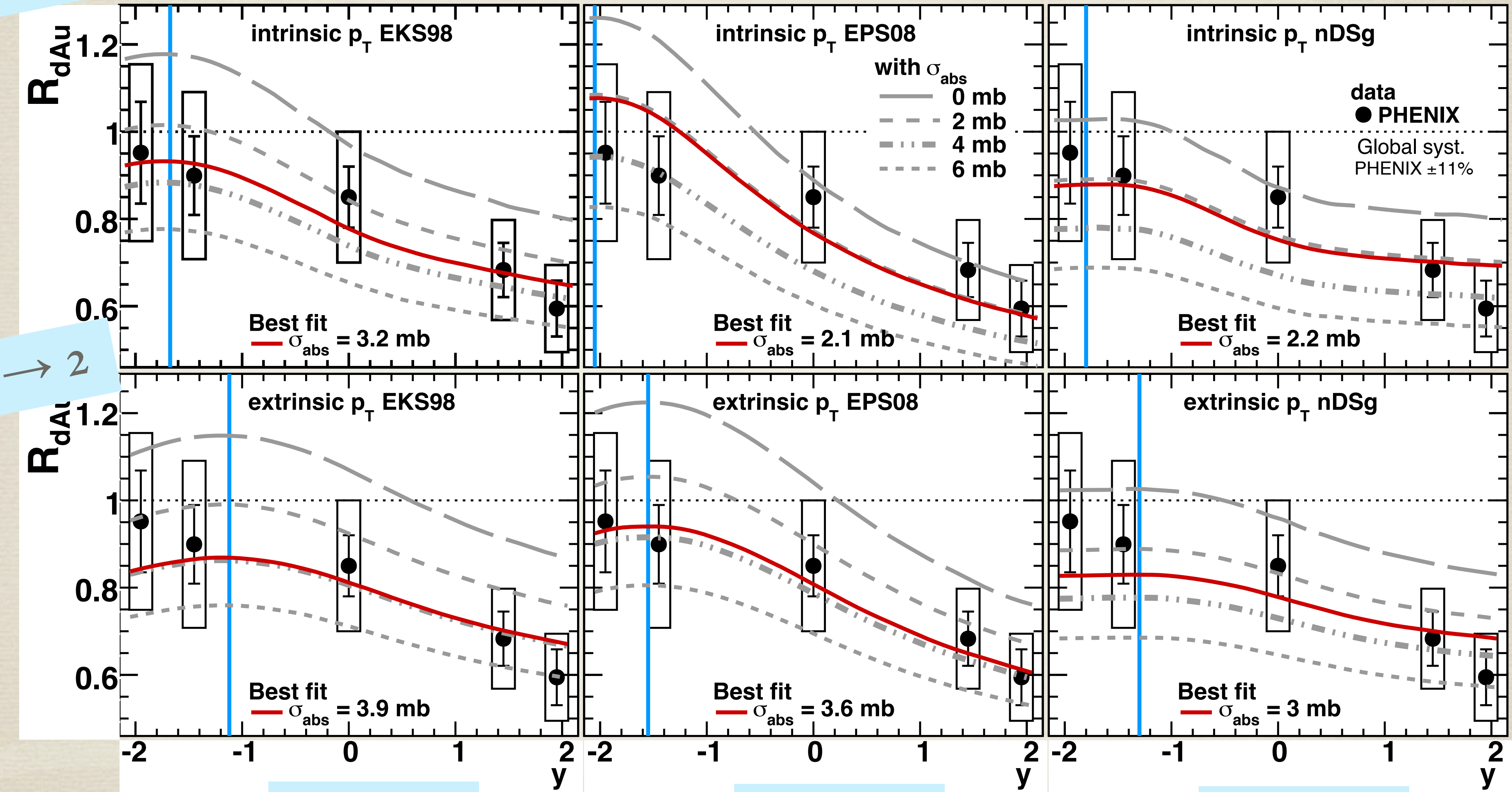
R_{dAu} vs rapidity

$2 \rightarrow 1$

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

$2 \rightarrow 2$

$g + g \rightarrow J/\psi + g$



EKS98 EPS08 nDSg

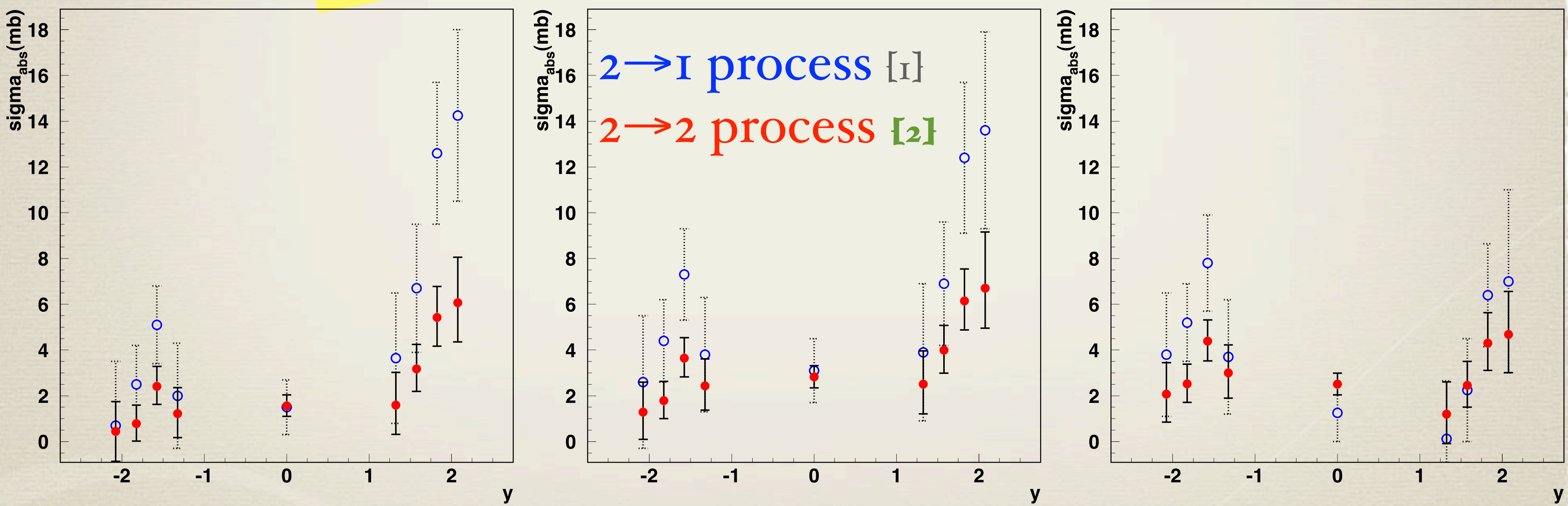
CEM vs s-channel cut CSM as prod. model :

$\sigma_{abs}(y)$ from Rcp in dAu @ 200 GeV

$\sigma_{abs}(y)$ much flatter for the 2→2 process

[1] A. D. Frawley, INT, Seattle USA, June 2009

[2] E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R., PRC 81 (2010) 064911

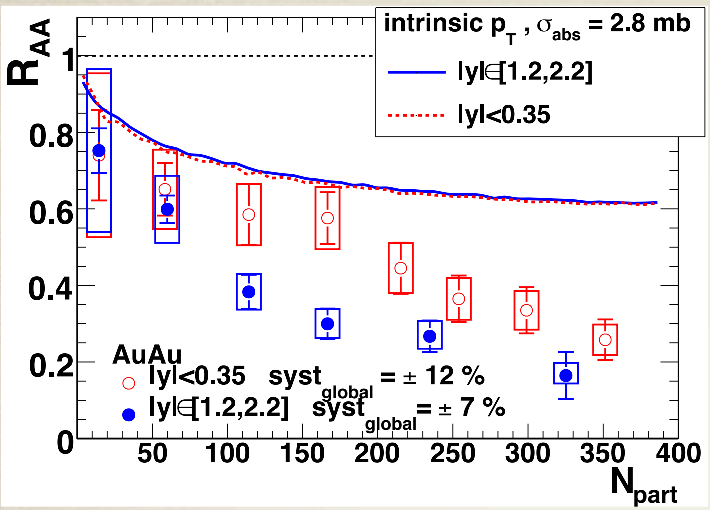


nDSg EKS98 EPS08

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R.
PLB 680, 50-55 (2009)

CNM effects : J/ψ in AuAu @ 200 GeV

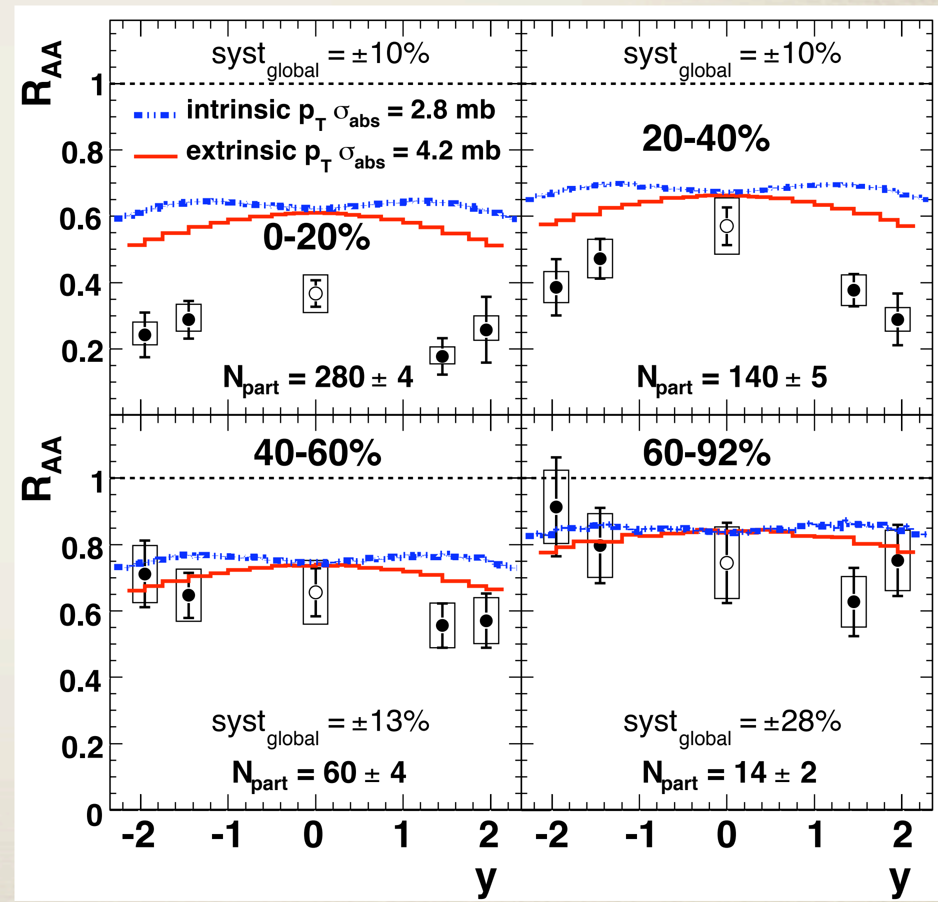
2→1 process : mid-y & fwd-y



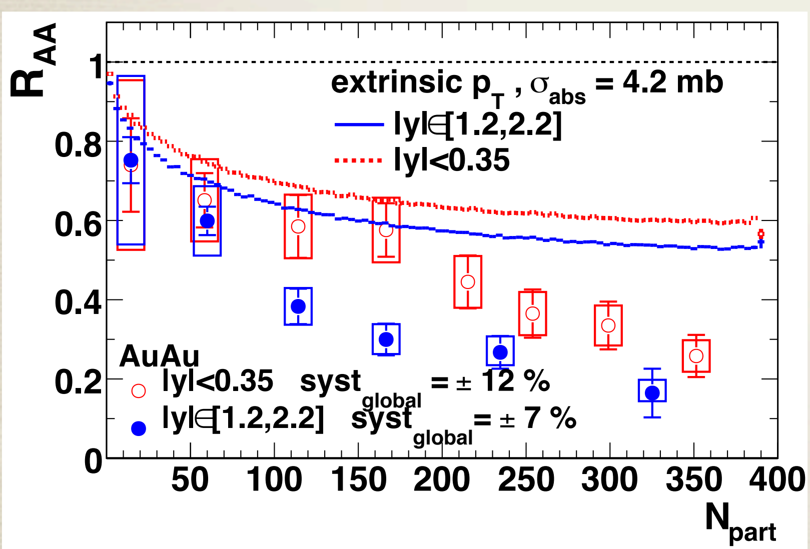
2→2 process :
less amount of recombination needed

using EKS98

2 → 1 vs 2 → 2 process



2→2 process : mid-y & fwd-y



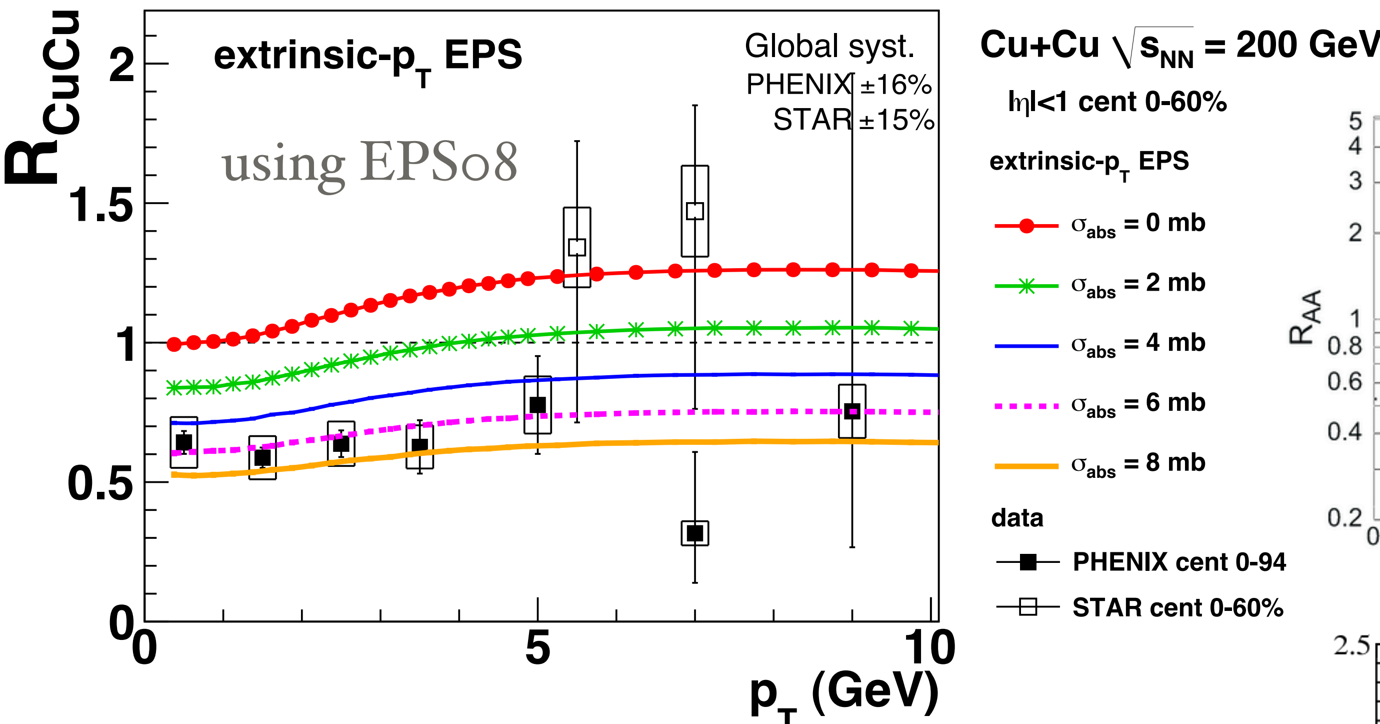
CNM effects at RHIC : J/ψ R_{CuCu} vs p_T

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R. Rakotozafindrabe

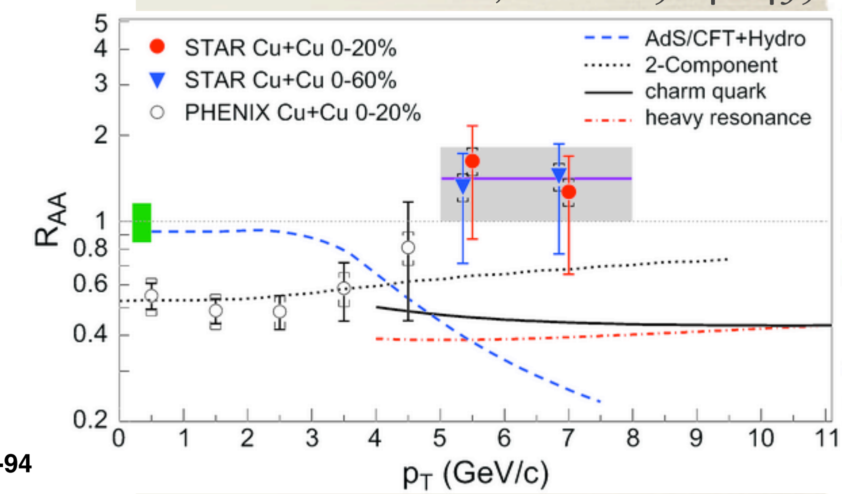
PRC 81 (2010) 064911

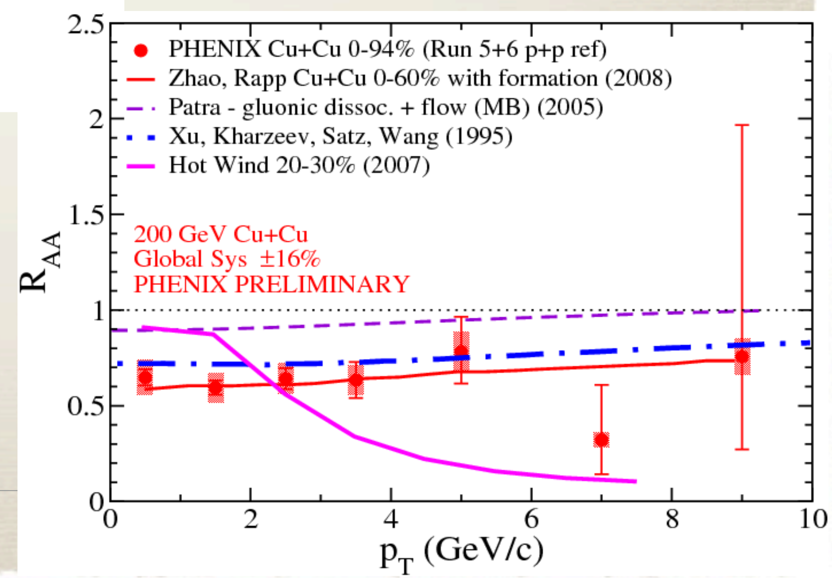
- $2 \rightarrow 2$ process

using EPS08



STAR, arXiv:0904.0439



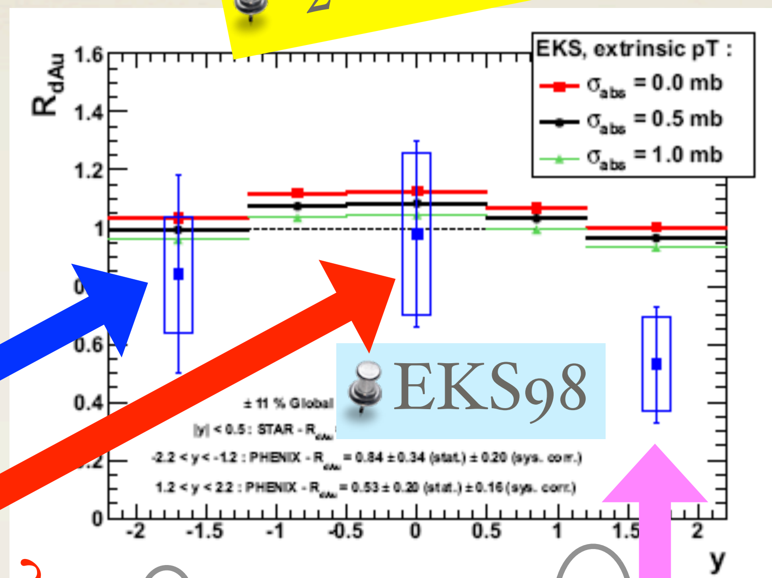


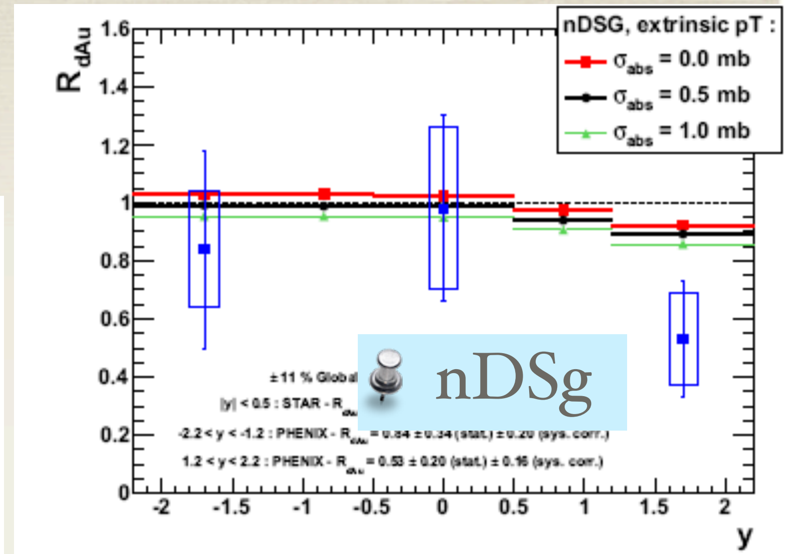
- CNM effects with $2 \rightarrow 2$ process as input also in the game

CNM effects at RHIC : Υ in dAu

E. G. Ferreiro, F. Fleuret,
J. P. Lansberg, N. Matagne and A. R.
in preparation

$2 \rightarrow 2$ process

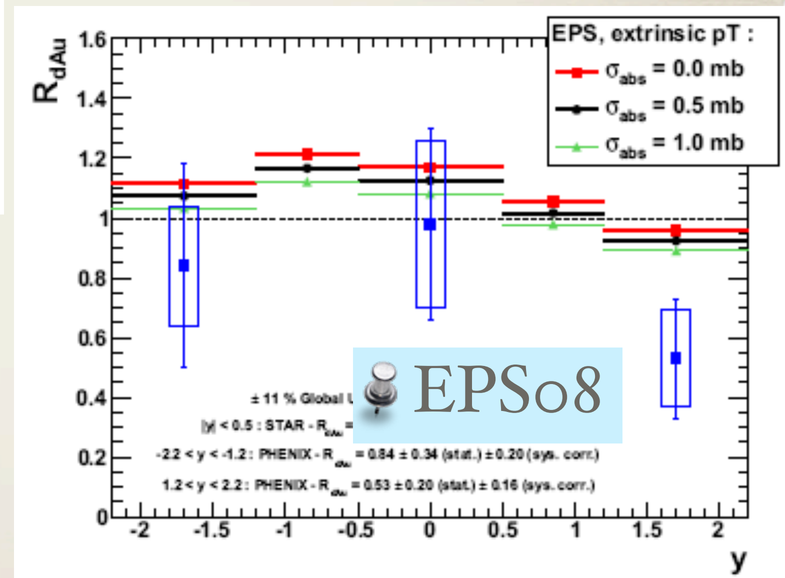


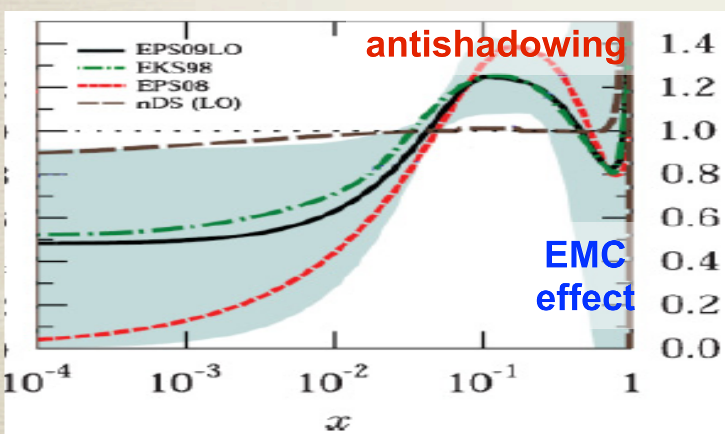


EMC effect ?

antishadowing ?

energy loss ?





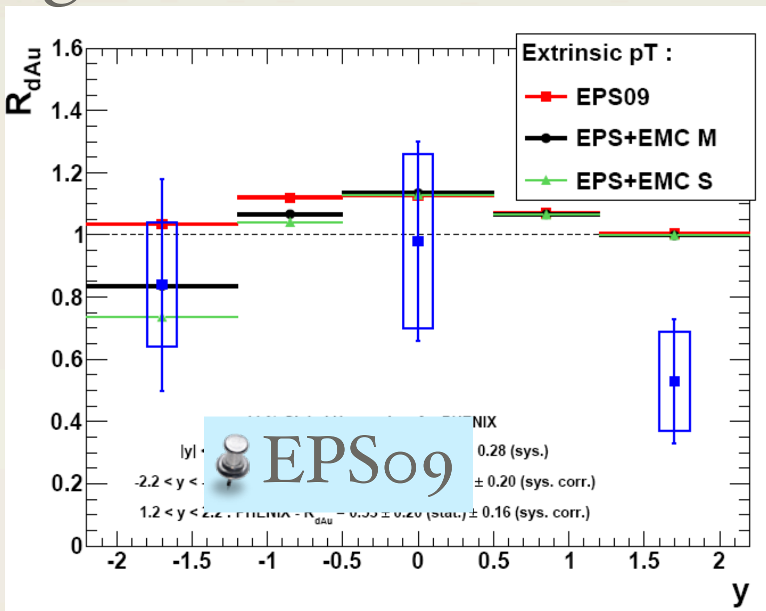
Data:
STAR Preliminary, Nucl. Phys. A830 (2009) 235c
PHENIX Preliminary, H. Pereira Da Costa, talk at The Rencontres de Moriond, March 2010

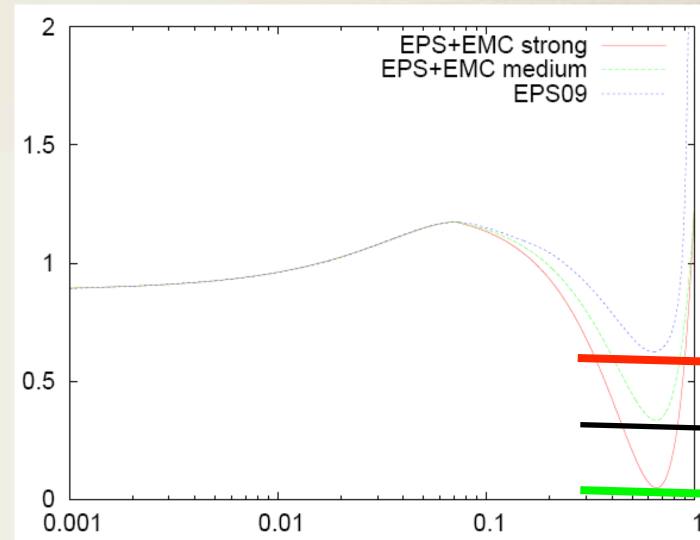
CNM effects at RHIC : Υ in dAu

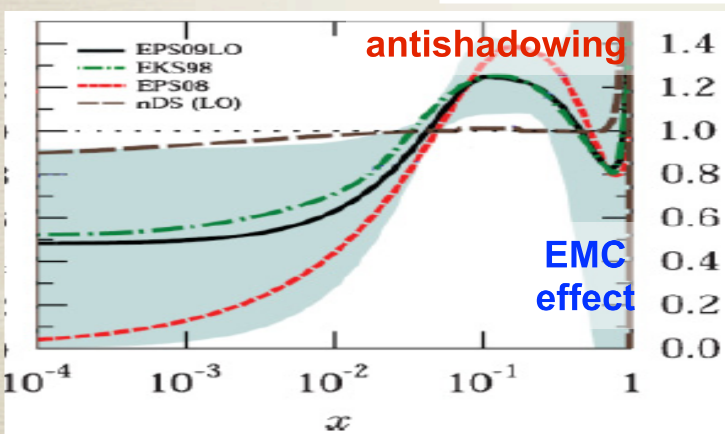
$2 \longrightarrow 2$ process

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

E. G. Ferreiro, F. Fleuret, J. P. Lansberg, N. Matagne and A. R., in preparation





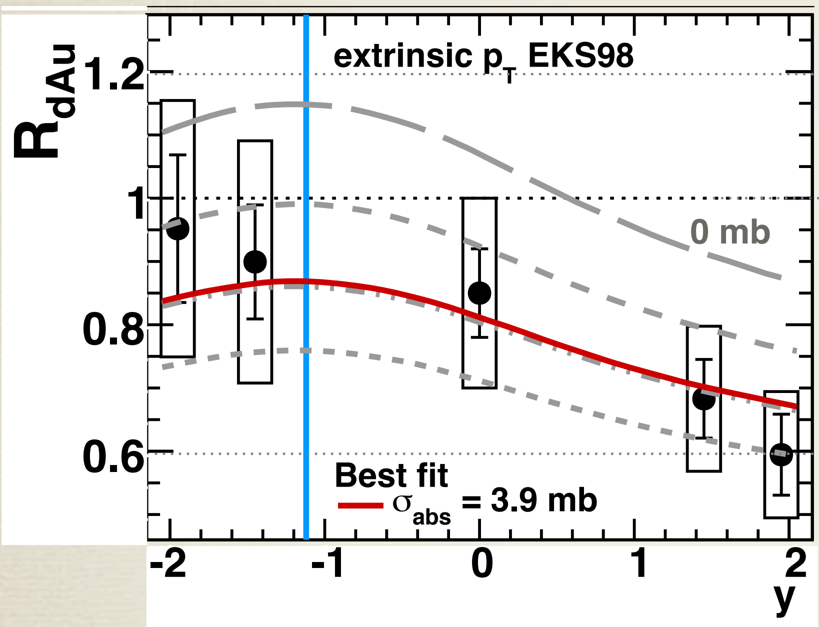


Data:
STAR Preliminary, Nucl. Phys. A830 (2009) 235c
PHENIX Preliminary, H. Pereira Da Costa, talk at The Rencontres de Moriond, March 2010

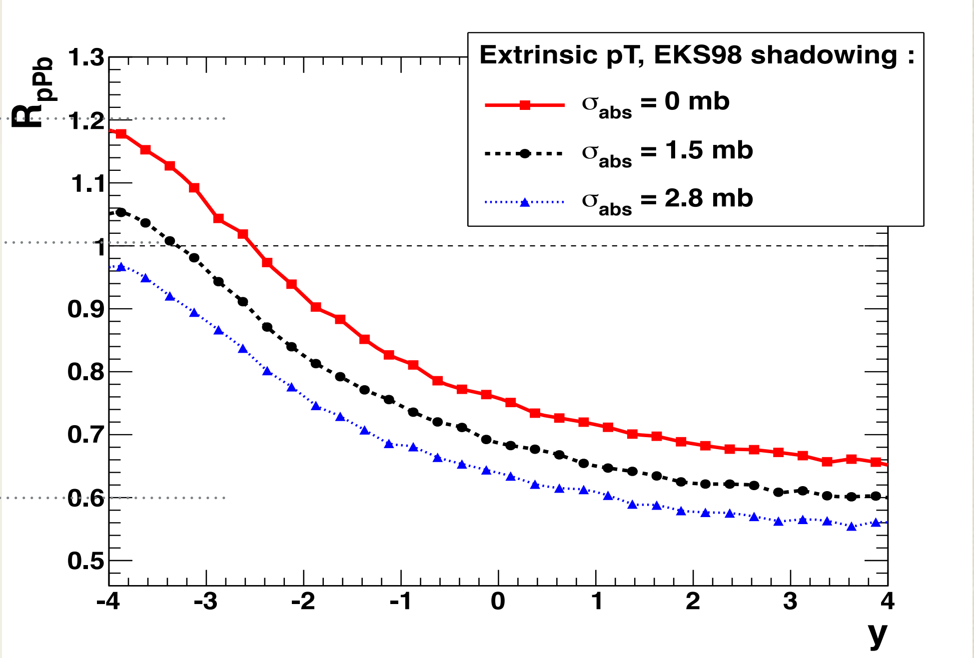
CNM effects from RHIC to LHC

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

$2 \longrightarrow 2$ process



RHIC dAu @ 200 GeV



LHC pPb @ 2.76 TeV

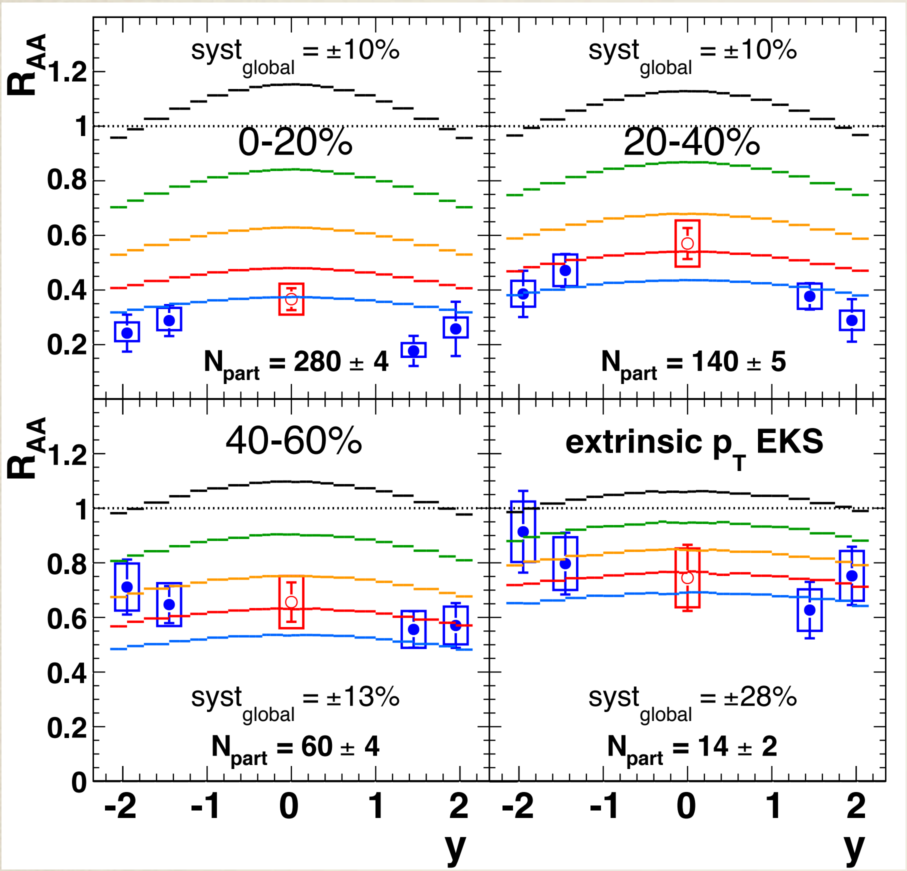
LHC : much smaller x, antshadowing peak at much lower y

CNM effects from RHIC to LHC

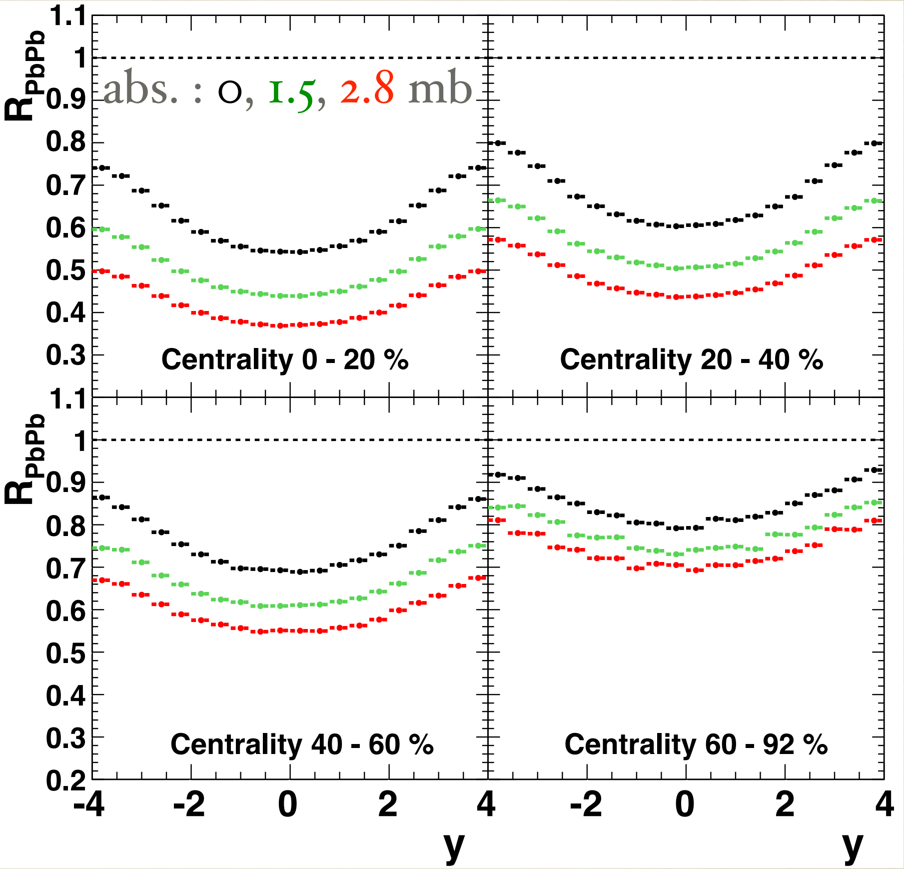
absorption : 0, 2, 4, 6, 8 mb

2 ⟶ 2 process

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



RHIC AuAu @ 200 GeV



LHC PbPb @ 2.76 TeV

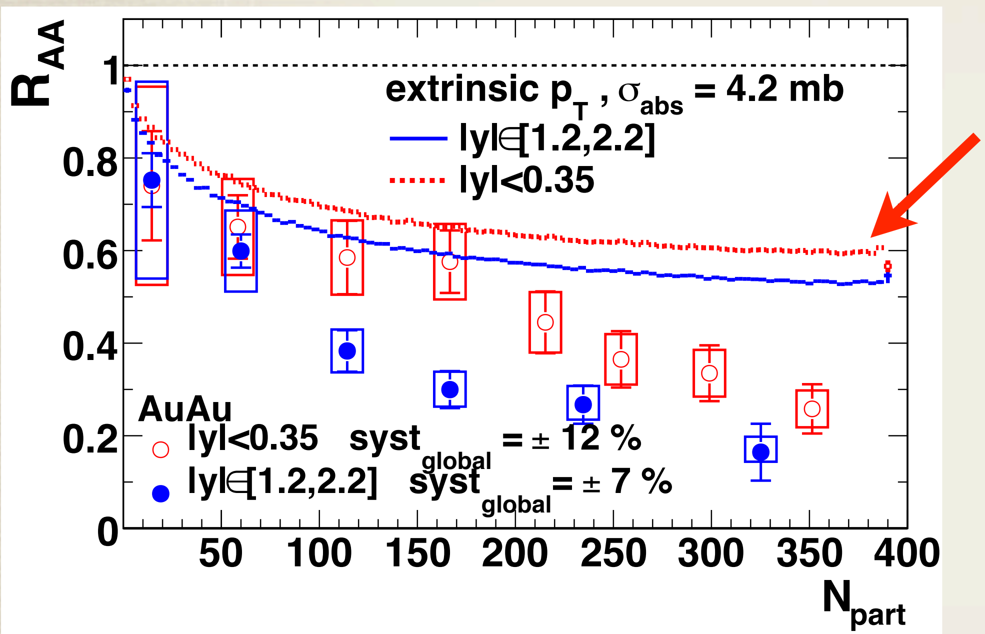
☑ LHC : opposite shape for the y dependence per centrality bin

CNM effects from RHIC to LHC

2 → 2 process

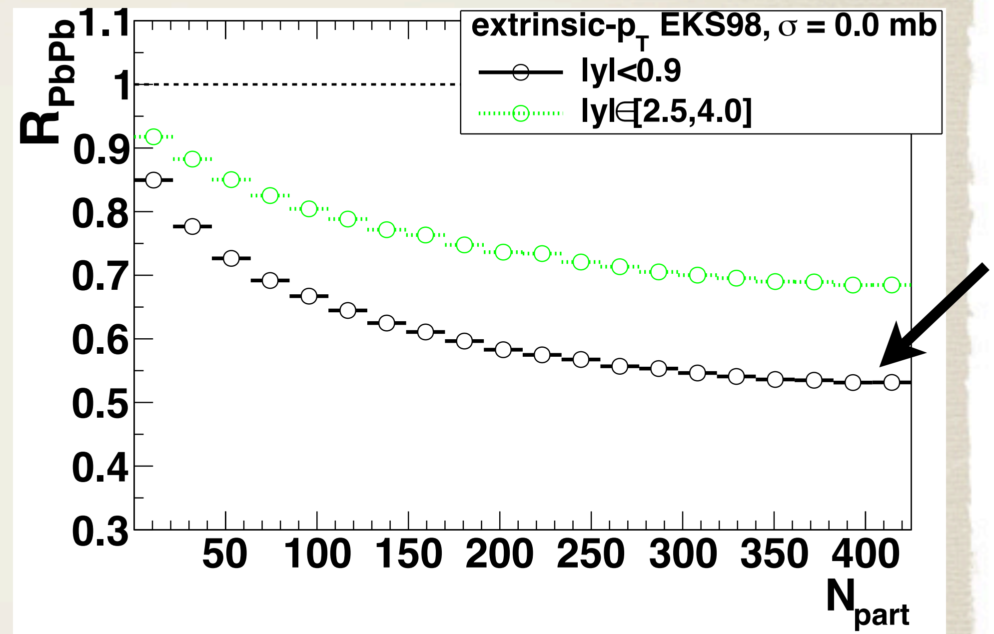
E. G. Ferreiro, F. Fleuret, J. P. Lansberg, N. Matagne and A. R., Nucl. Phys. A 855 (2011) 327-330

mid-y & fwd-y



RHIC AuAu @ 200 GeV

mid-y & fwd-y



LHC PbPb @ 2.76 TeV

☑ LHC : CNM effects go in the opposite way as should go the recombination, with more suppression at mid-y than at fwd-y.

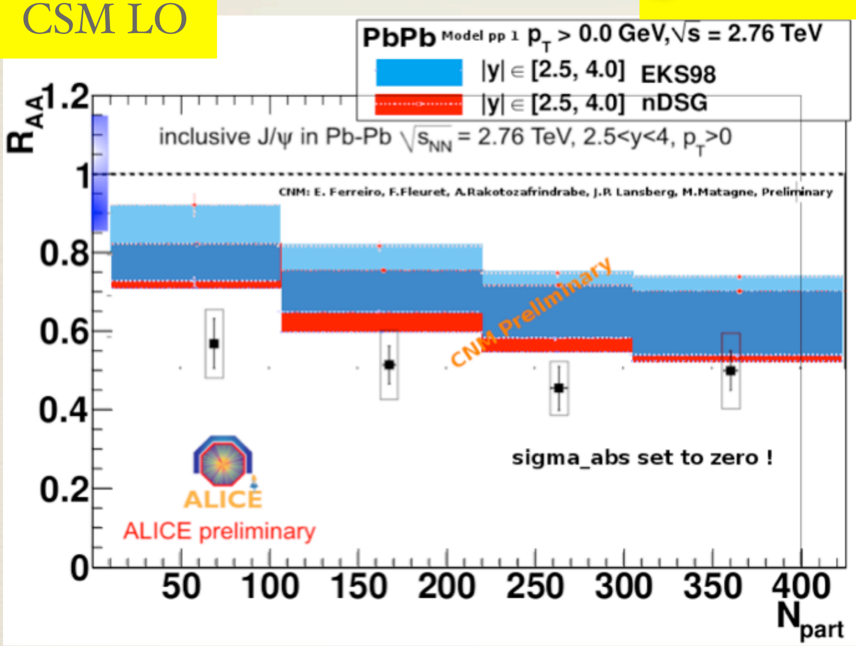
CNM effects at LHC : *J/ψ* in PbPb

Two models (prompt/direct J/ψ) + nPDF and μ_F uncertainties vs inclusive J/ψ R_{AA} :

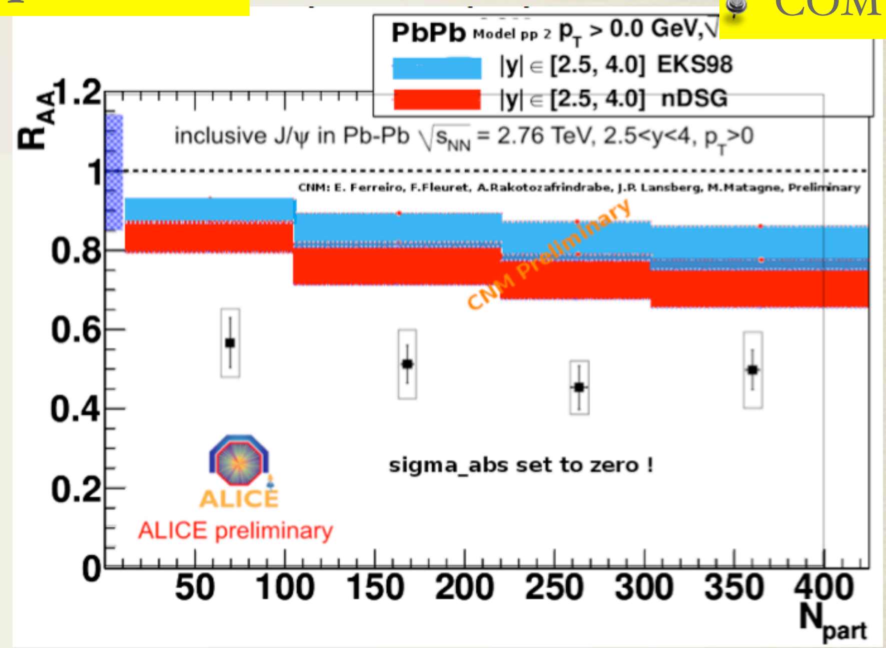
2 ⟶ 2 process

E. G. Ferreiro, F. Fleuret, J. P. Lansberg, N. Matagne and A. R., in preparation

CSM LO

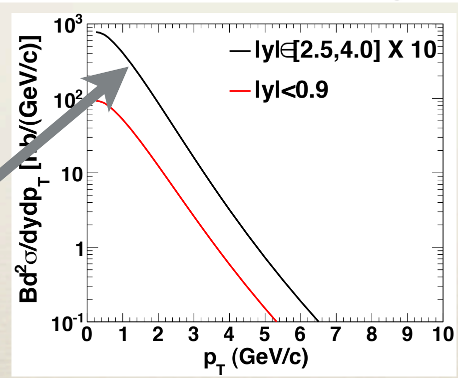


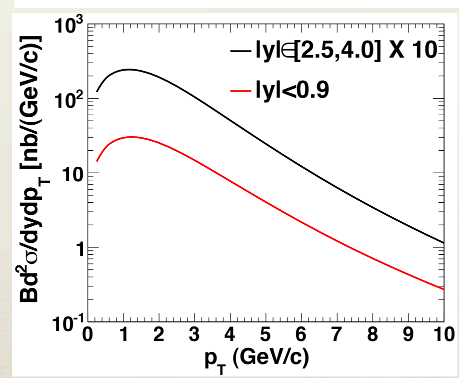
COM LO



p_T spectra in p+p

closer to 2 ⟶ 1 process





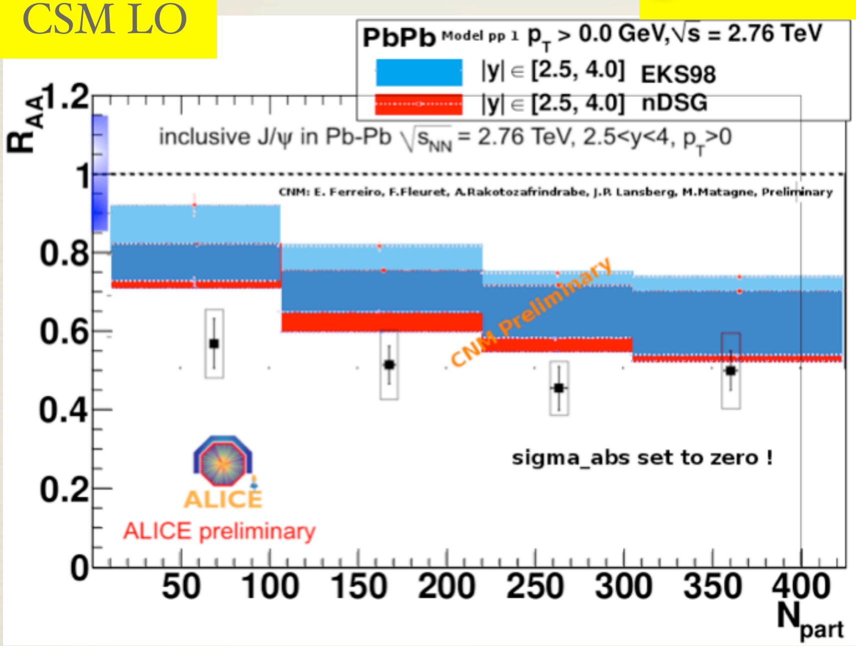
CNM effects at LHC : J/ψ in PbPb

Two models (prompt/direct J/ψ) + nPDF and μ_F uncertainties vs inclusive J/ψ R_{AA} :

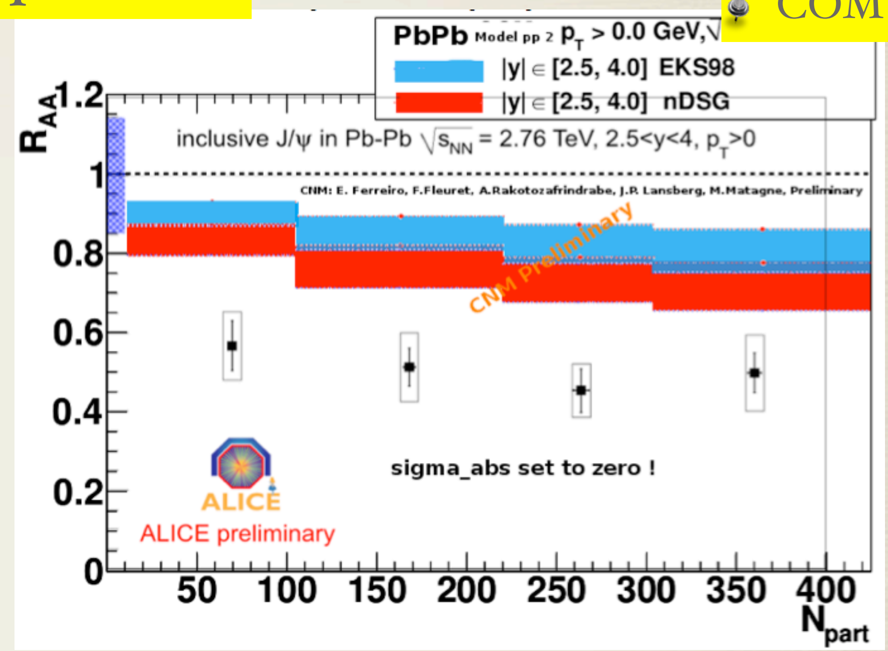
2 ⟶ 2 process

E. G. Ferreiro, F. Fleuret, J. P. Lansberg, N. Matagne and A. R., in preparation

CSM LO



COM LO



- ☑ Alice data dominated by low p_T J/ψ
- ☑ PbPb suppression : about the same or slightly more than CNM effects

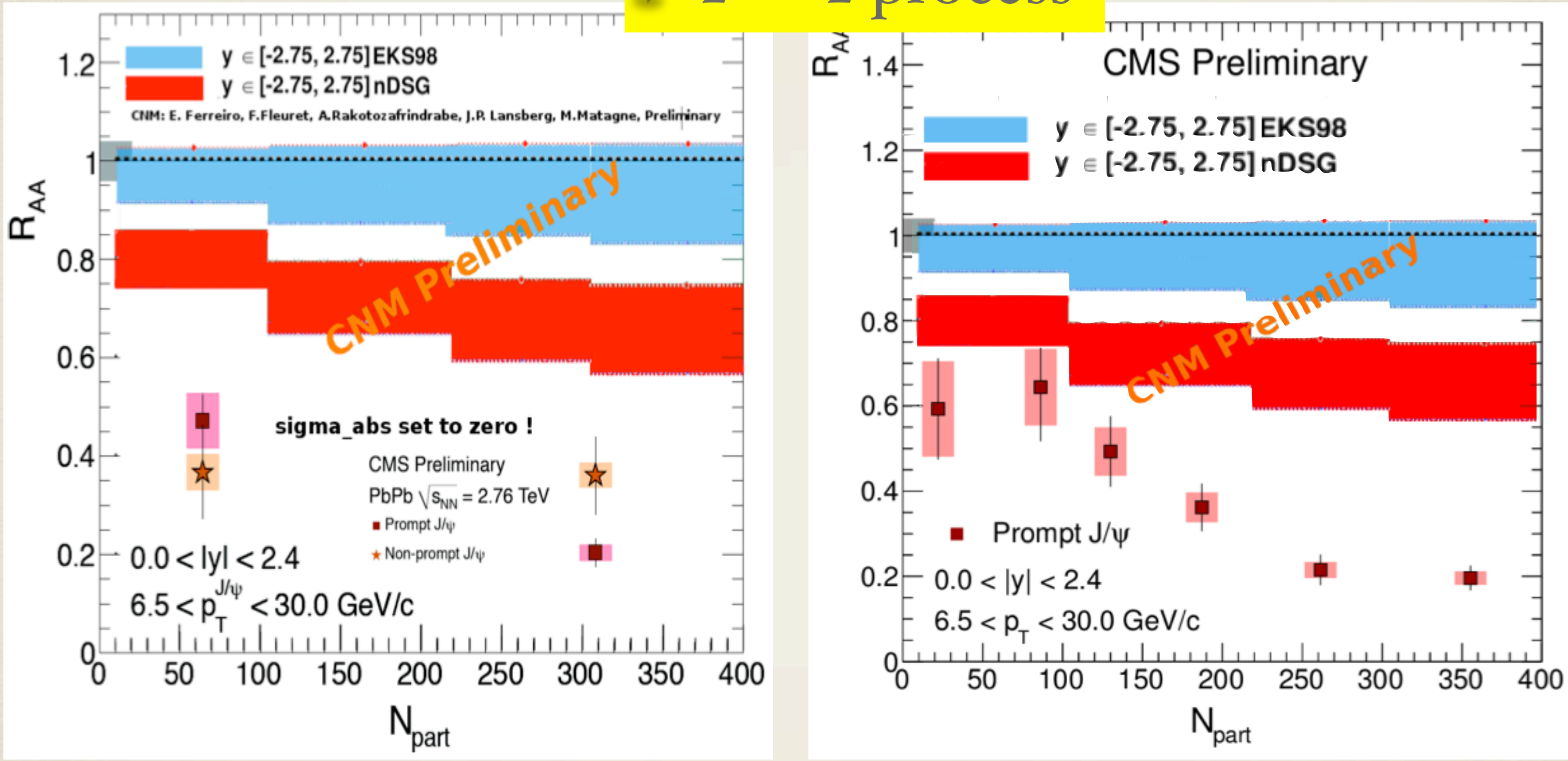
➡ hint of a large recombination effect as expected at low p_T ?

CNM effects at LHC : J/ψ in PbPb

Going to mid-y, adding a pT cut > 6.5 GeV/c to the most conservative model and to the data :

$2 \longrightarrow 2$ process

E. G. Ferreiro, F. Fleuret, J. P. Lansberg, N. Matagne and A. R., in preparation



PbPb suppression goes much further than CNM effects

➡ confirms that recombination is small at high p_T ?

Conclusion and outlook (1/2)

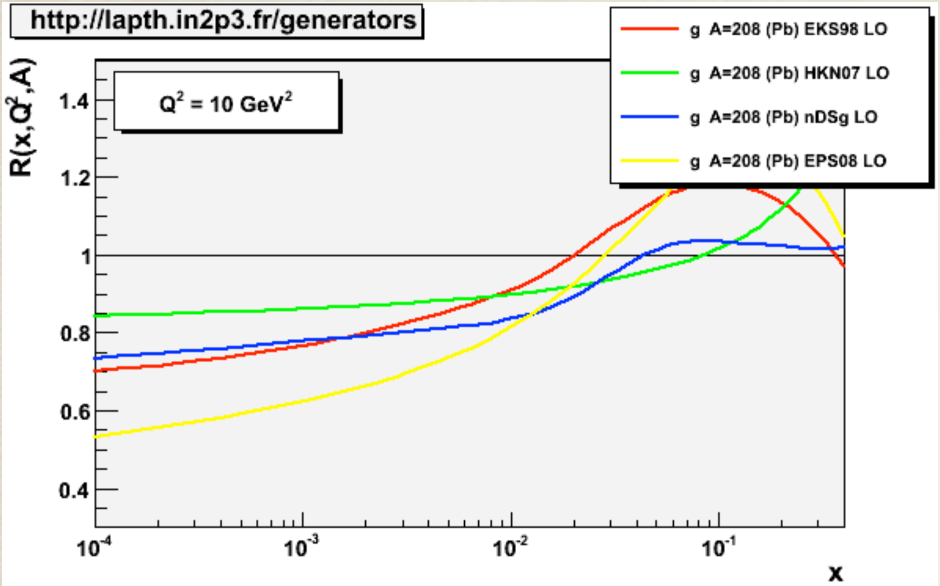
- Shadowing computations can benefit from an improved knowledge of quarkonia production process
- Within the extrinsic sheme (2 to 2 process) :
  - more complex kinematics
  - for a given y, x is larger => larger absorption cross-section needed to match RHIC data, and antishadowing peak shifted to larger y
  - Upsilon could be used as a tool to explore antishadowing and EMC effect

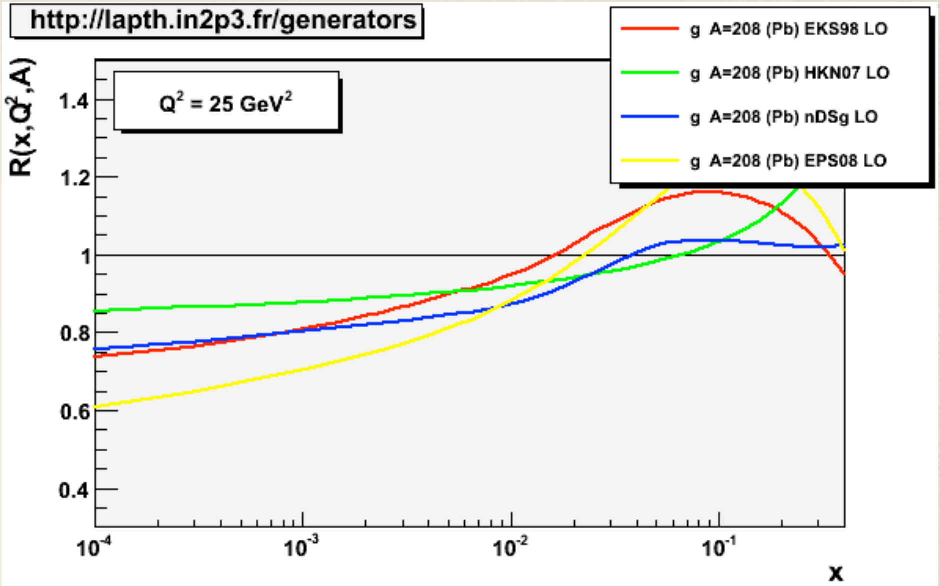
Conclusion and outlook (2/2)

- Shadowing computations suffer from large uncertainties. Especially large is the uncertainty due to μ_F for the J/ψ.
- Hints of recombination at low p_T, and of a negligible recombination at large p_T.
- It will be difficult to understand the present suppression pattern of the J/ψ if we do not reduce these uncertainties on shadowing computations.
  - pA run with a good precision on the *y*, p_T and centrality dependence
  - move to heavier quarkonium states at LHC ?

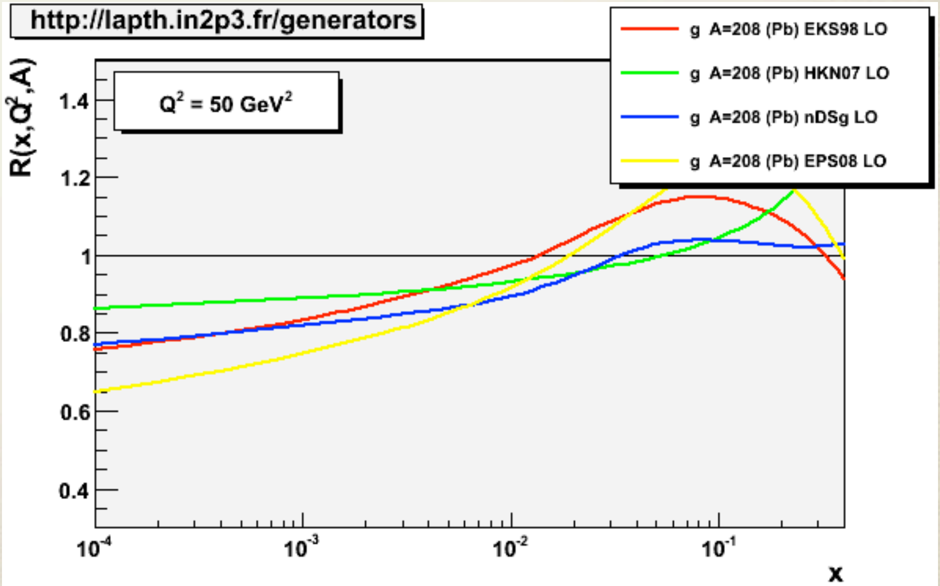
BACK-UP

nPDF for Pb



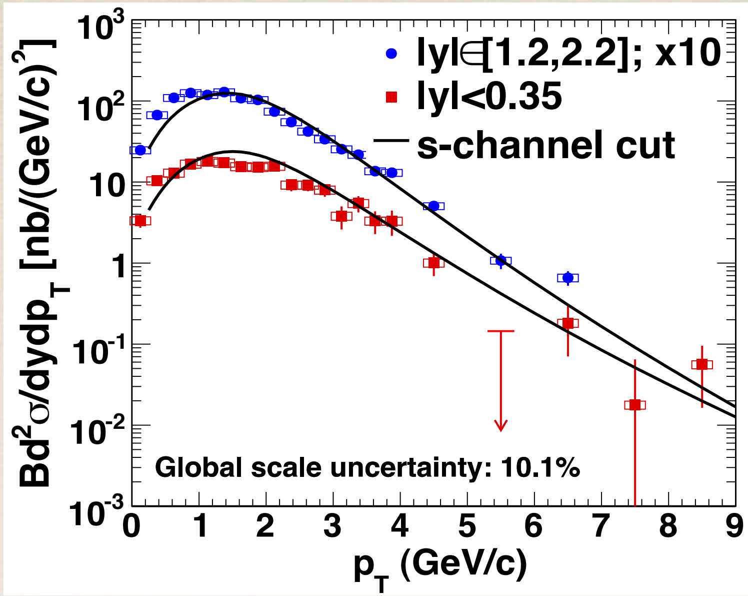


EKS98
HKN07
nDSg
EPS08

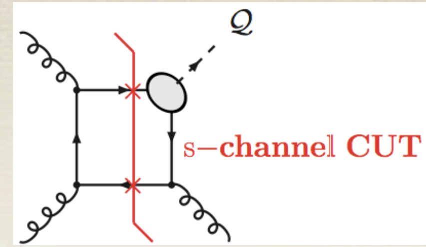


CSM + s-channel cut at RHIC in p+p

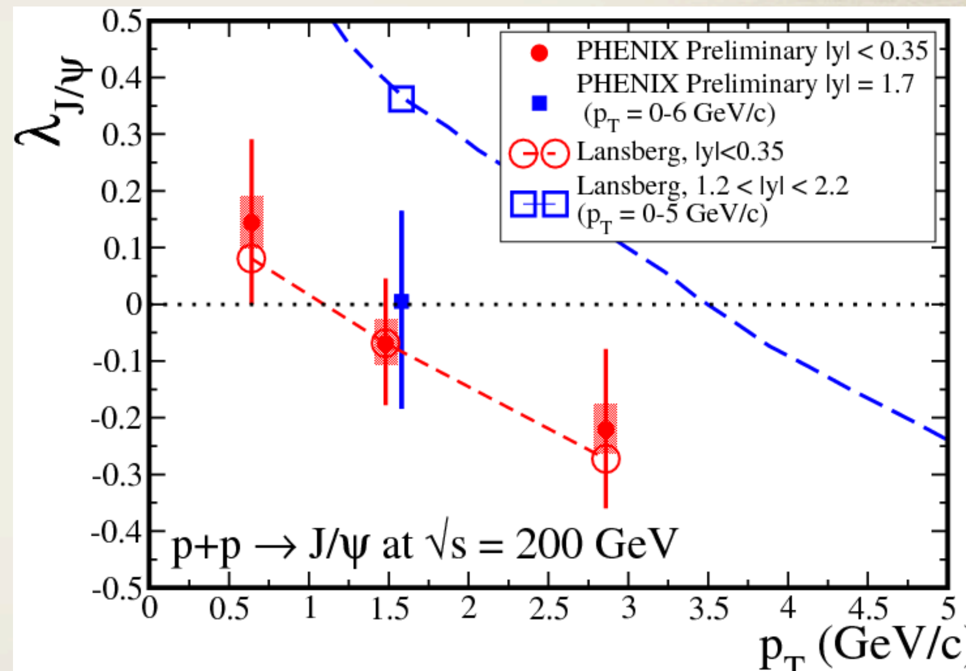
yield vs p_T



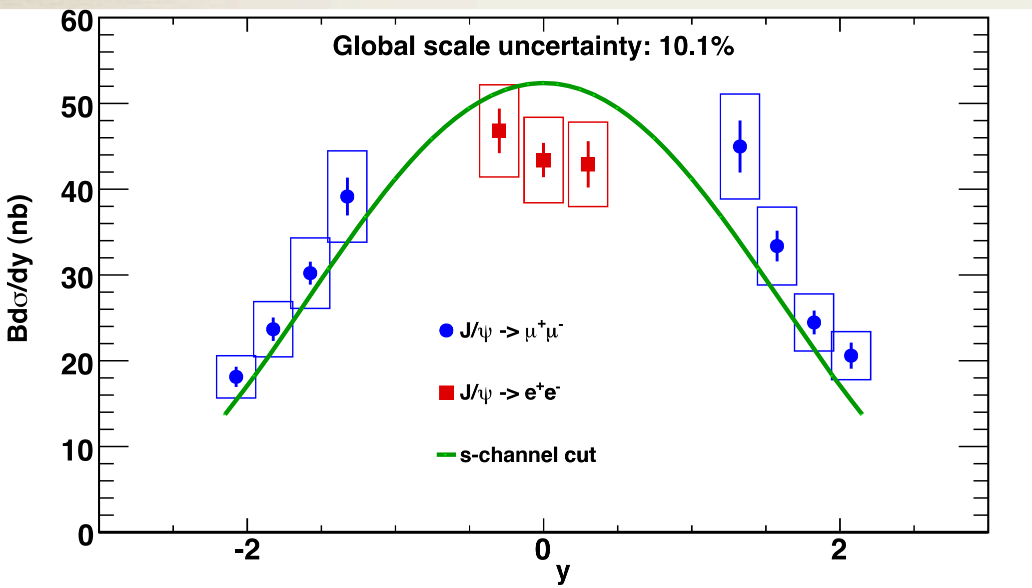
data : phenix run5 p+p spectra



polarisation vs p_T at mid-y and fwd-y



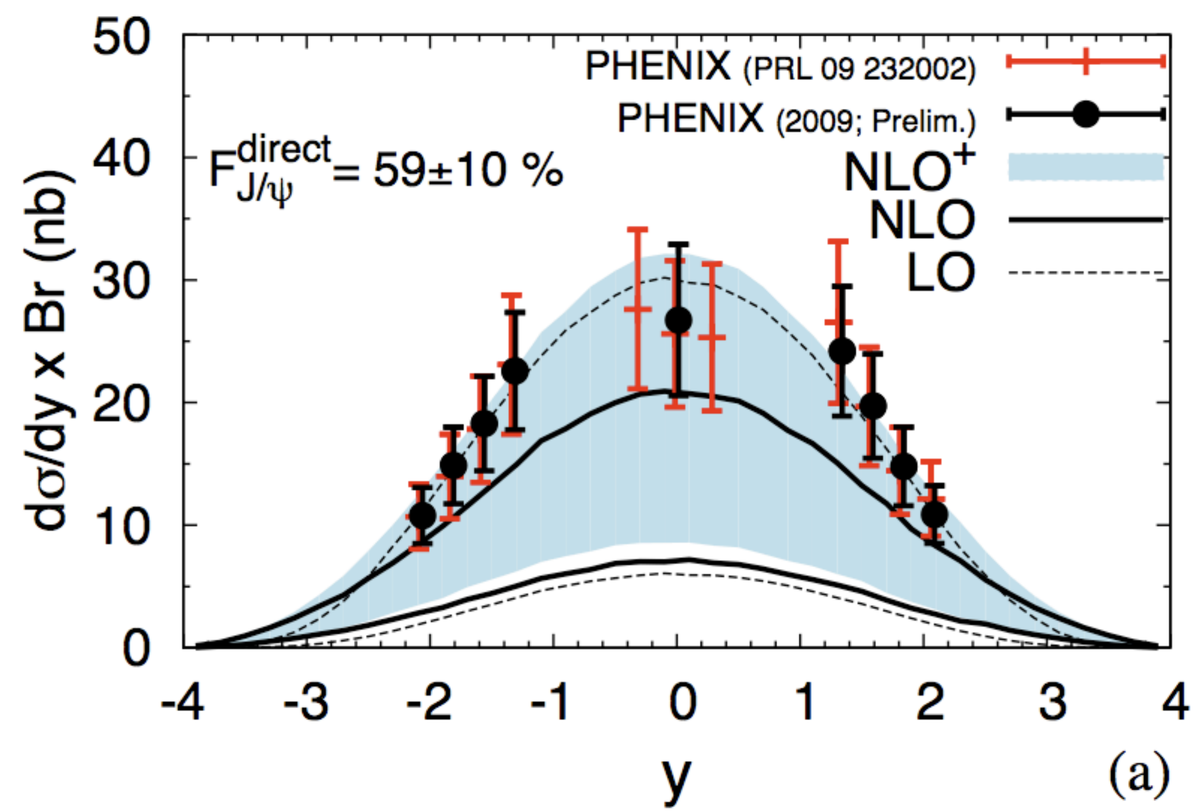
in helicity frame



yield vs rapidity

CSM LO, NLO, NLO+cg vs the y spectra in p+p at RHIC

direct J/ψ



points : y spectra for the *direct* J/ψ, as extrapolated from PHENIX spectra

S. J. Brodsky and J. P. Lansberg, arXiv:0908.0754

The y spectra in p+p at RHIC

J/ψ

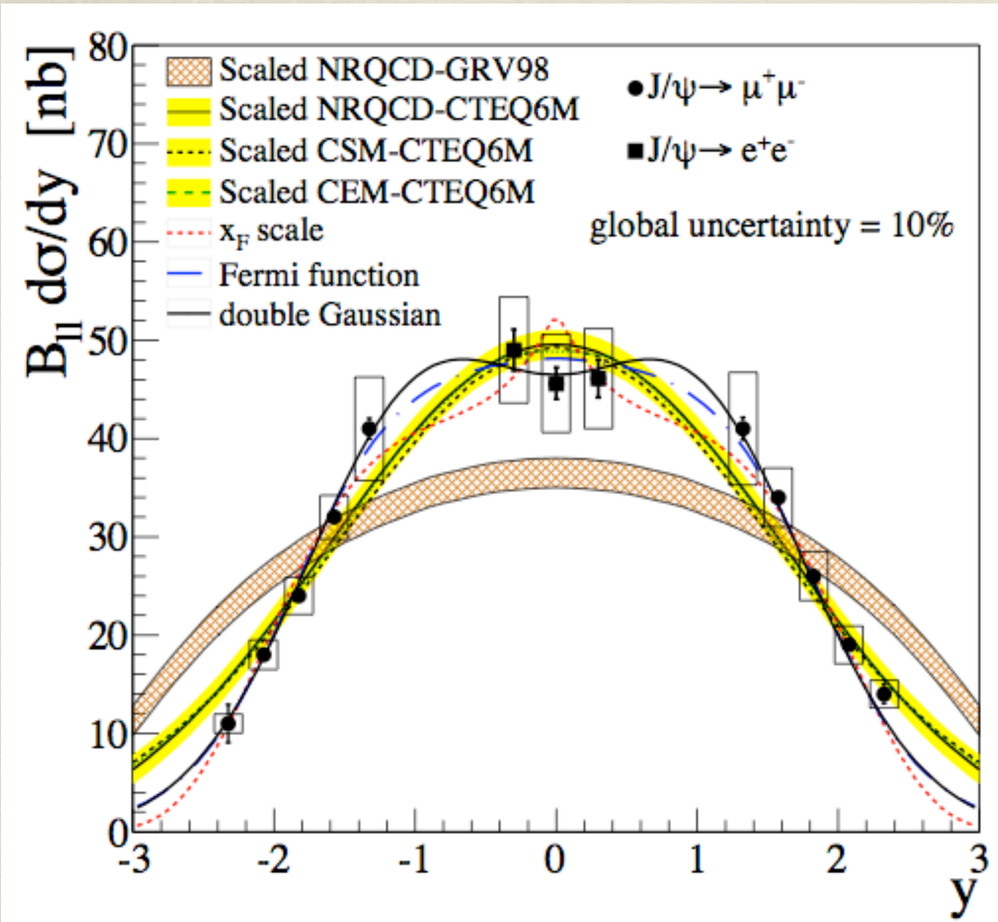
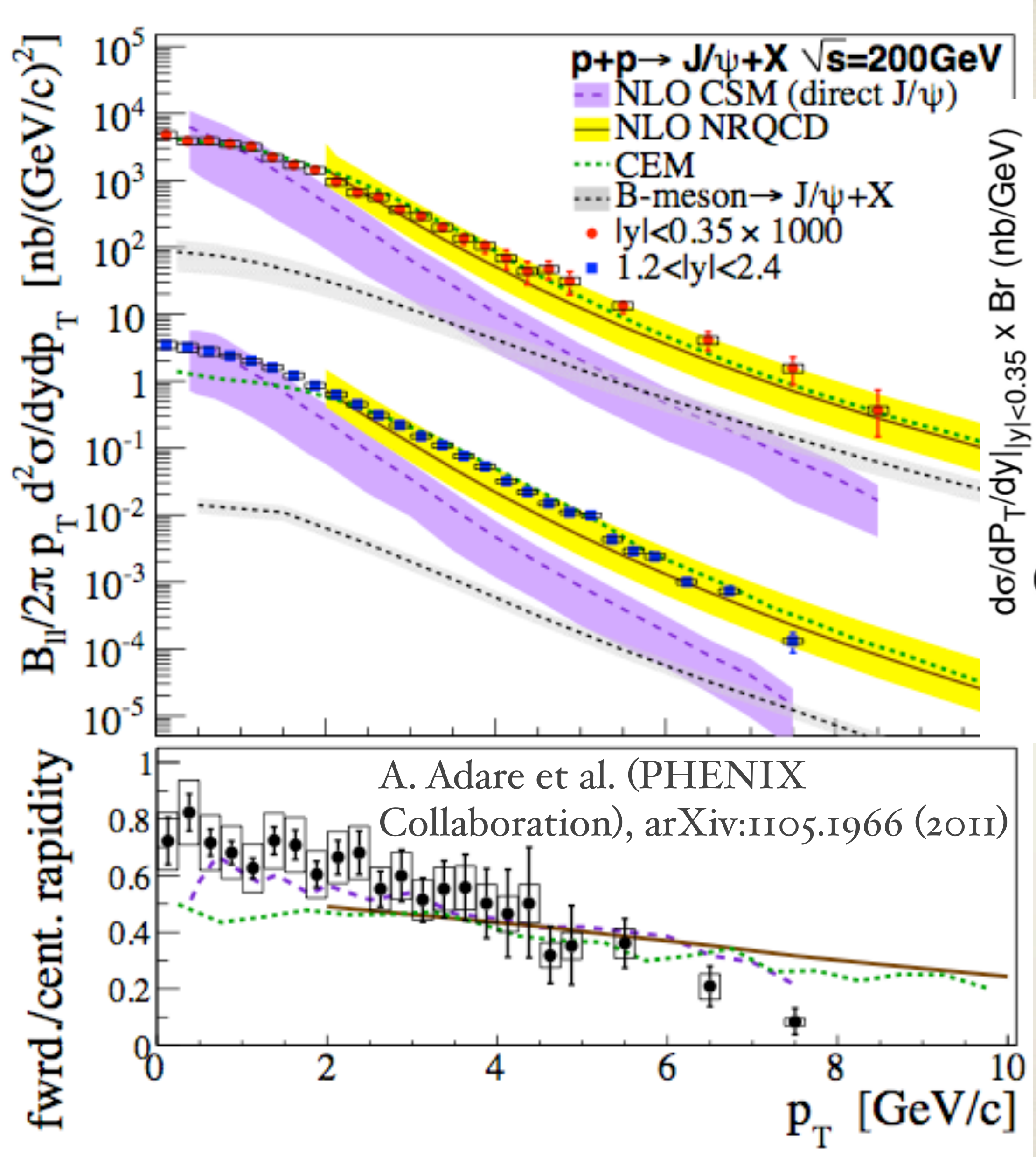


TABLE V: Comparison of the measured J/ψ cross section with the three models considered in this text. Direct J/ψ cross sections are obtained assuming that the χ_c and ψ' feed-down fractions measured at midrapidity are the same at forward rapidity. Type A, type B and type C errors are quadratically summed in the measured result.

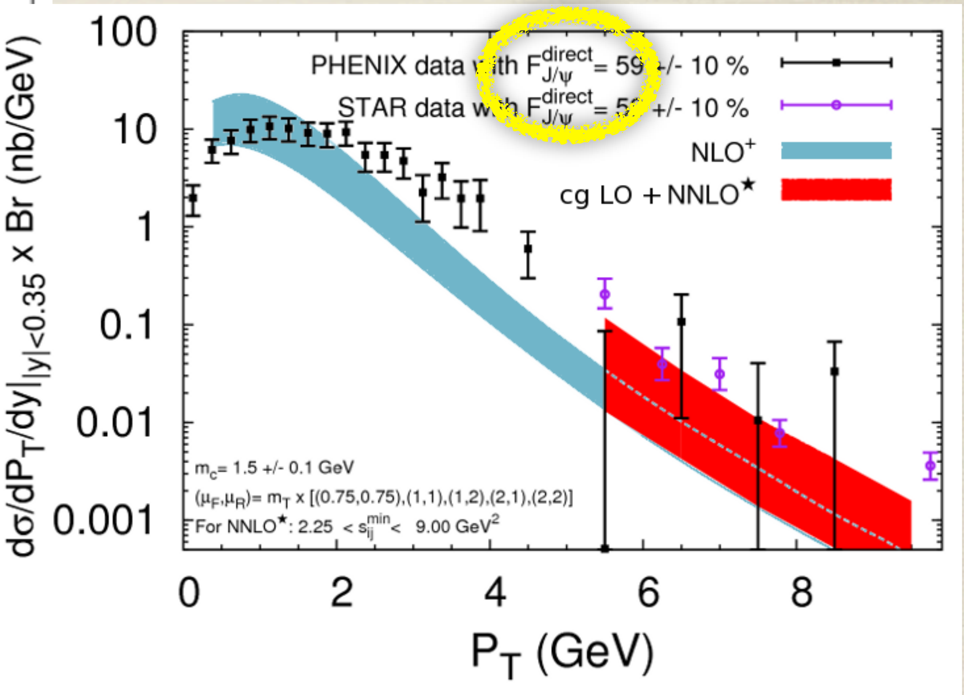
	direct J/ψ	inclusive
CEM	-	169 ± 30 nb
NLO CSM	53 ± 26 nb	-
LO NRQCD	-	140 ± 5 nb
Measured	105 ± 26 nb	181 ± 22 nb

A. Adare et al. (PHENIX Collaboration), arXiv:1105.1966 (2011)

The p_T spectra in p+p at RHIC



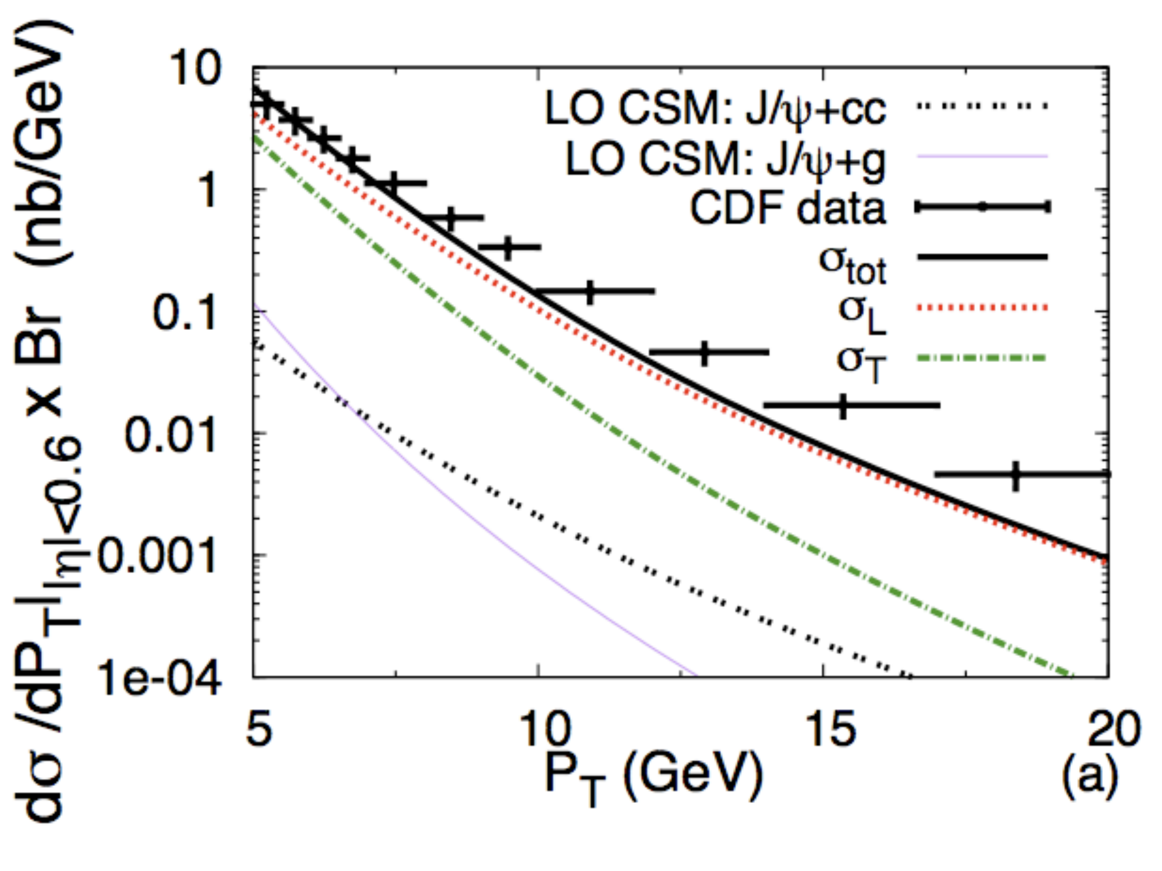
A. Adare et al. (PHENIX Collaboration), arXiv:1105.1966 (2011)

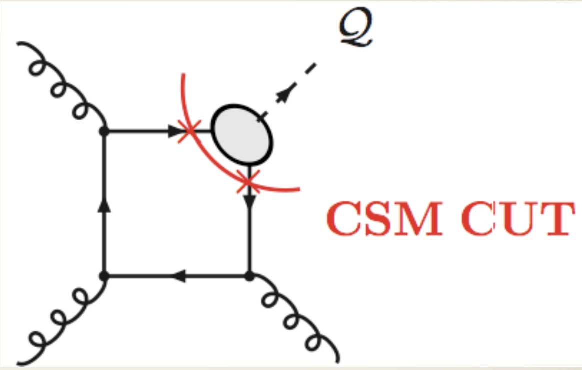


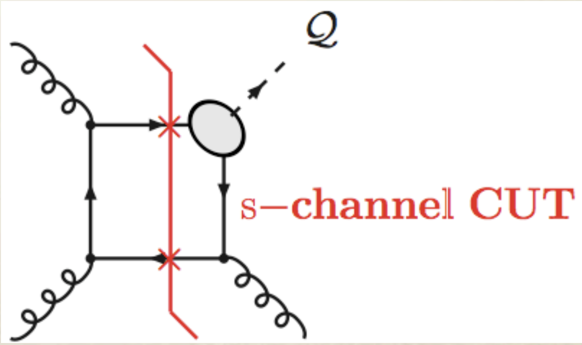
Brodsky, Lansberg, PRD 81:051502 (R) (2010)

S-channel cut model vs Tevatron p_T spectra

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







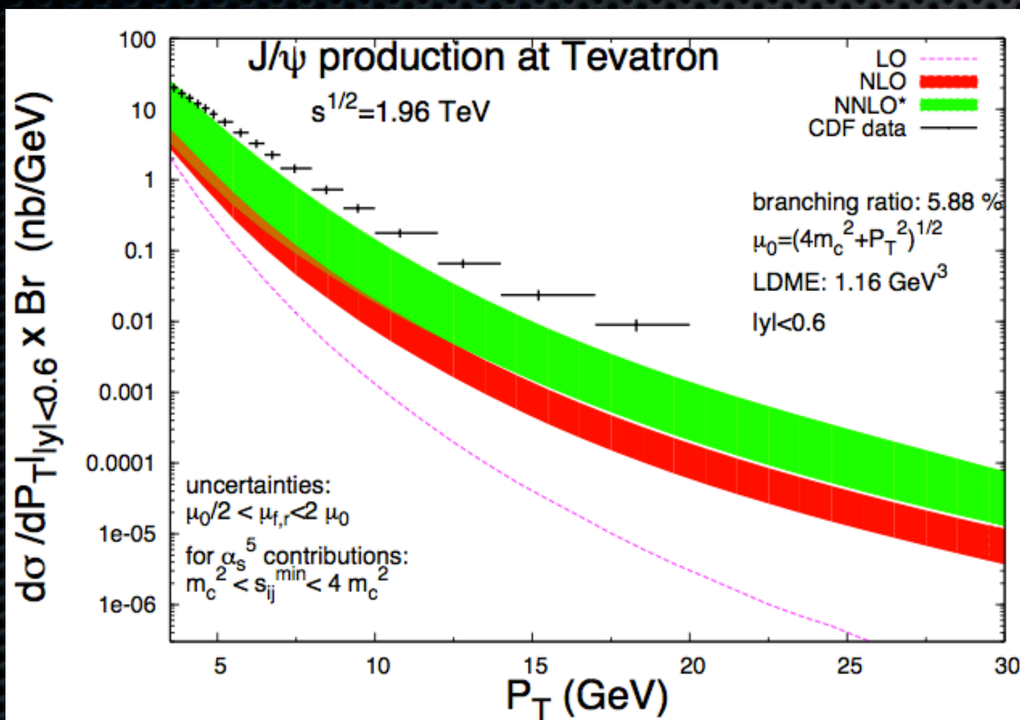
«Clean» exp. results ...
... not so clear underlying theory

CDF

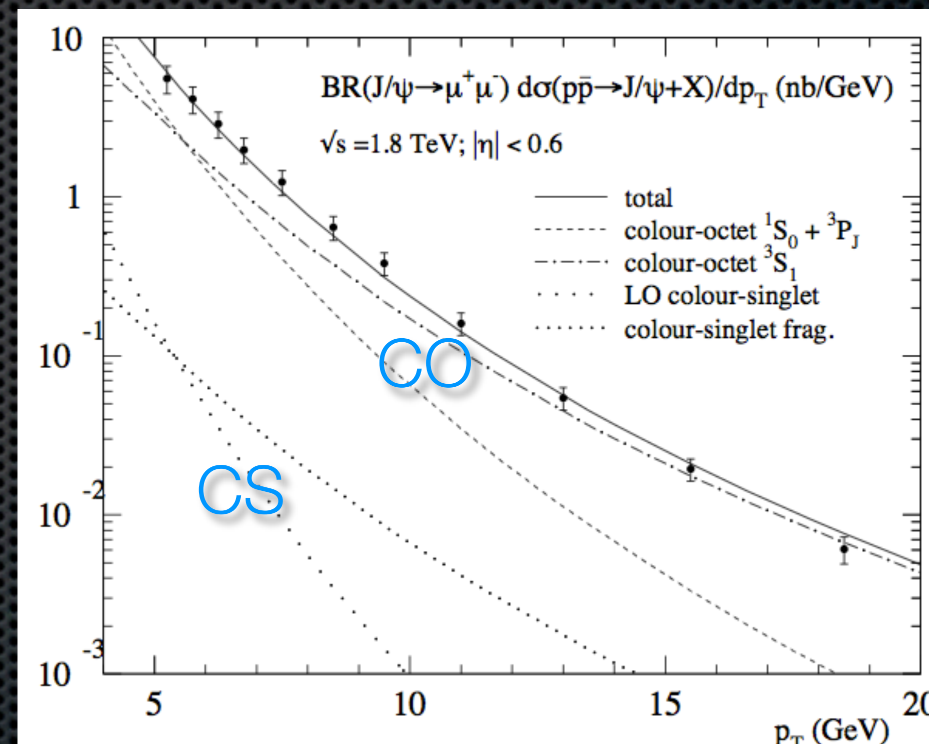
Artoisenet, Lansberg, Maltoni, PLB 653:60 (2007); Campbell, Maltoni, Tramontano, PRL 98:252002 (2007); Gong, Wang, PRL 100:232001 (2008)

Artoisenet, Campbell, Lansberg, Maltoni, Tramontano (in progress) Kramer, Prog. Part. Nucl. Phys. 47:141 (2001)

CSM NNLO*



NRQCD - CO dominance



Direct *J/ψ* vs p_T :

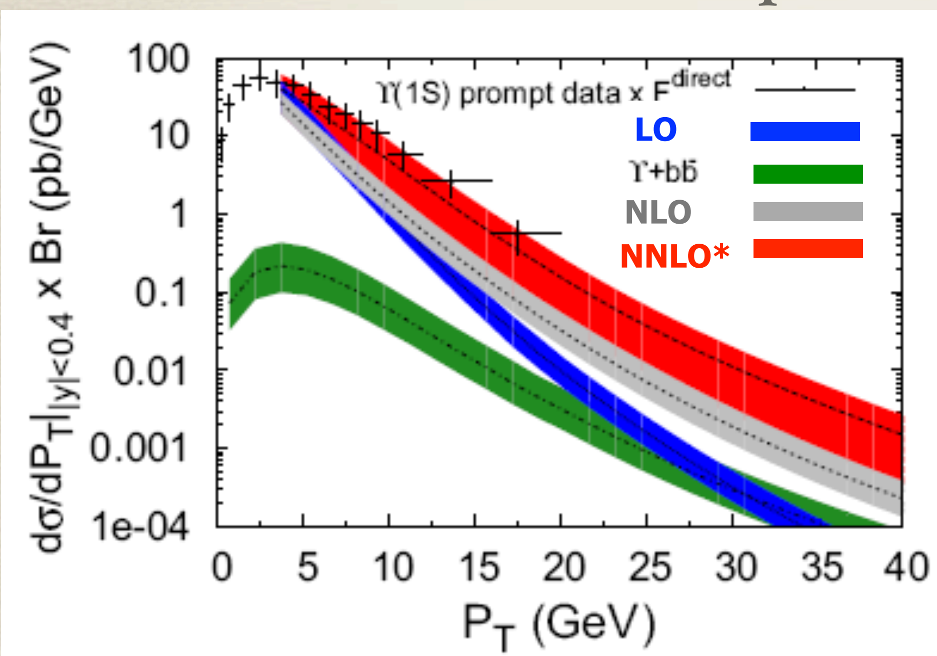
- not satisfactory for CSM even with higher order corrections included
- good agreement for NRQCD, *with matrix elements tuned with CDF data*

CSM @ LO and higher orders

$\Upsilon(1S)$

P. Artoisenet, J. Campbell, J.P. Lansberg, F. Maltoni, PRL 101 (2008) 152001.
D. Acosta et al. (CDF Collaboration), PRL 88 (2002) 161802.

Tevatron (1.8 TeV):
CSM LO sufficient to describe low p_T data



STAR preliminary [STAR Collaboration, J. Phys. G 34 (2007) S947.]

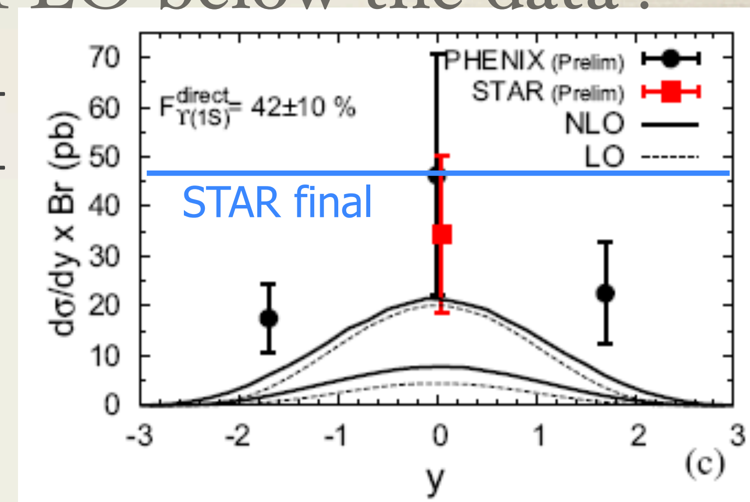
$$BR \times (d\sigma/dy)_{y=0} = 91 \pm 28\,(\text{stat.}) \pm 22\,(\text{syst.})$$

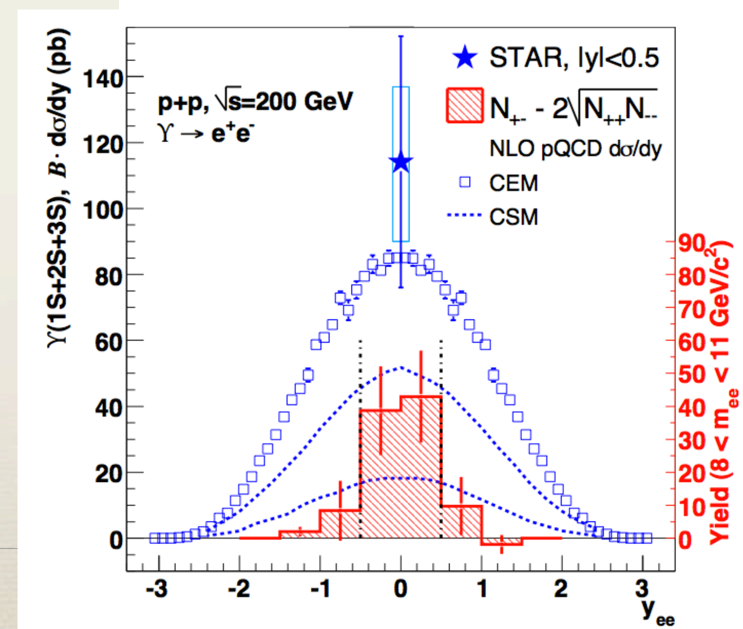
STAR final [STAR Collaboration, arXiv:1001.2745.]

$$BR \times (d\sigma/dy)_{y=0} = 114 \pm 38^{+23}_{-24}$$

RHIC (200 GeV):
CSM LO below the data ?

S.J. Brodsky, J.P. Lansberg, PRD 81 (2010) 014004.

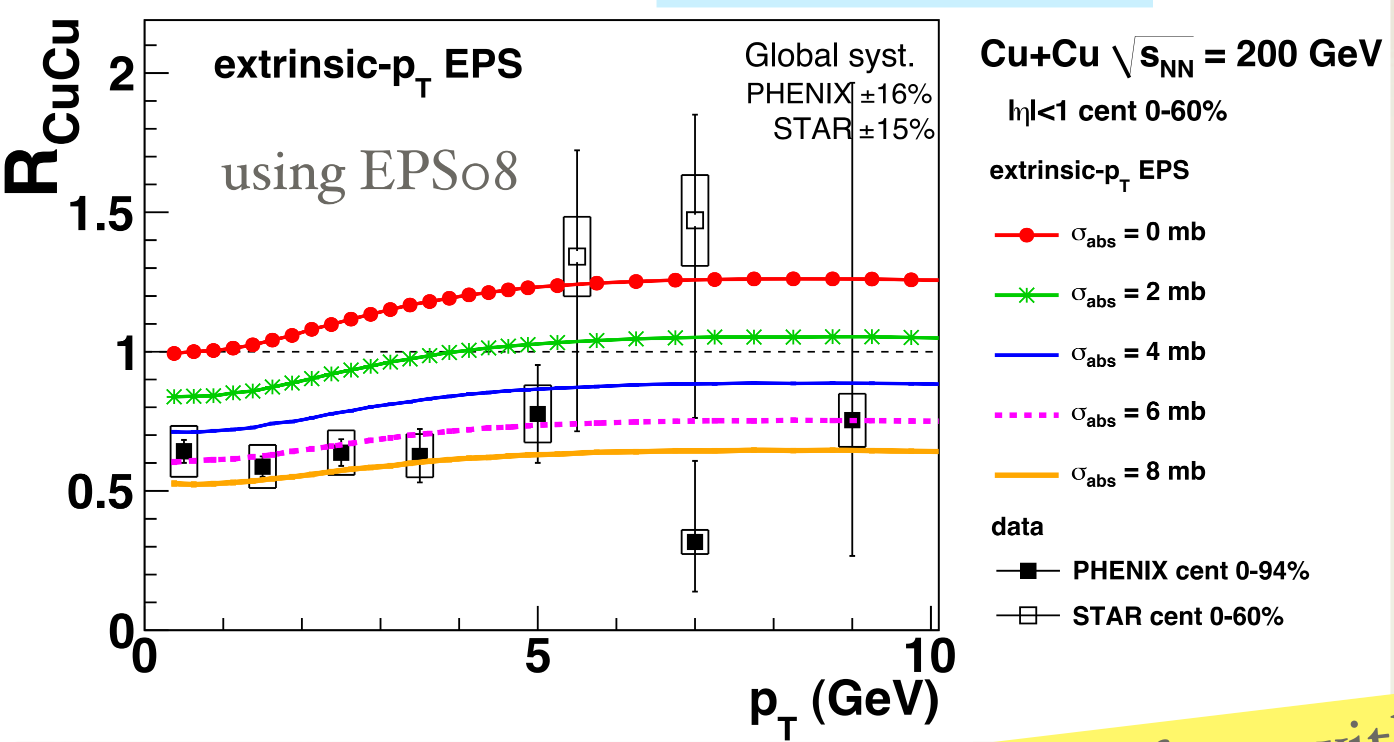




CNM effects at RHIC : J/ψ R_{CuCu} vs p_T

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R.
PRC 81 (2010) 064911

- $2 \longrightarrow 2$ process



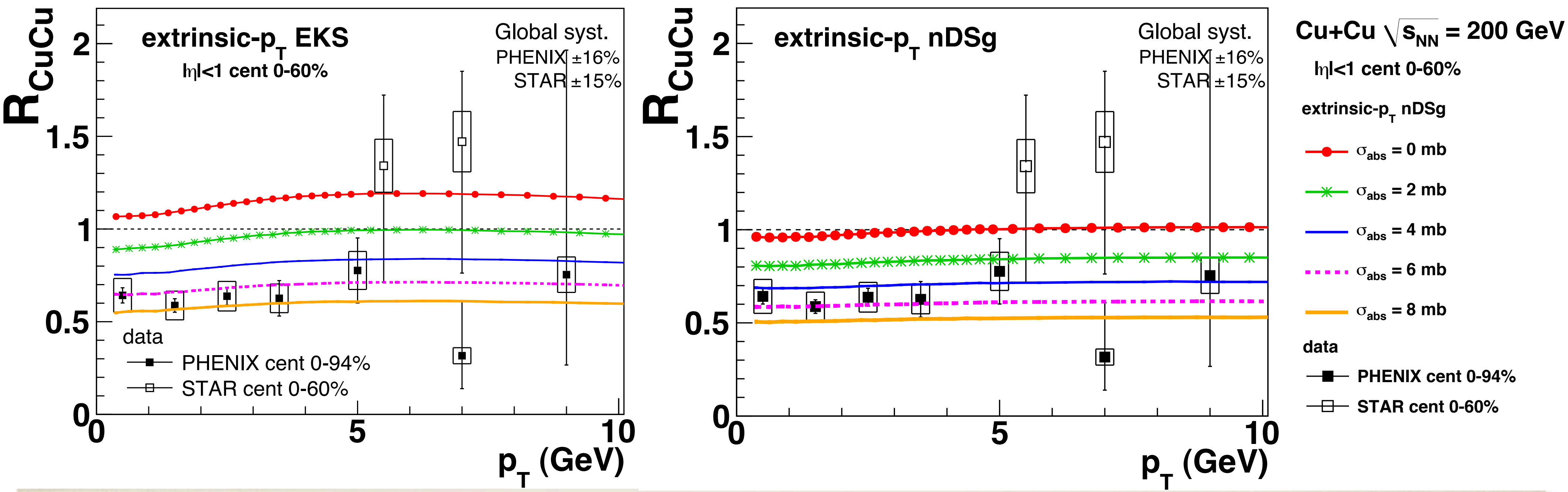
- CNM effects with 2→2 process as input also in the game
- Less suppression due to shadowing with increasing p_T

CNM effects : J/ψ R_{CuCu} vs p_T

$2 \rightarrow 2$ process

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R. PRC 81 (2010) 064911

EKS98 nDSg

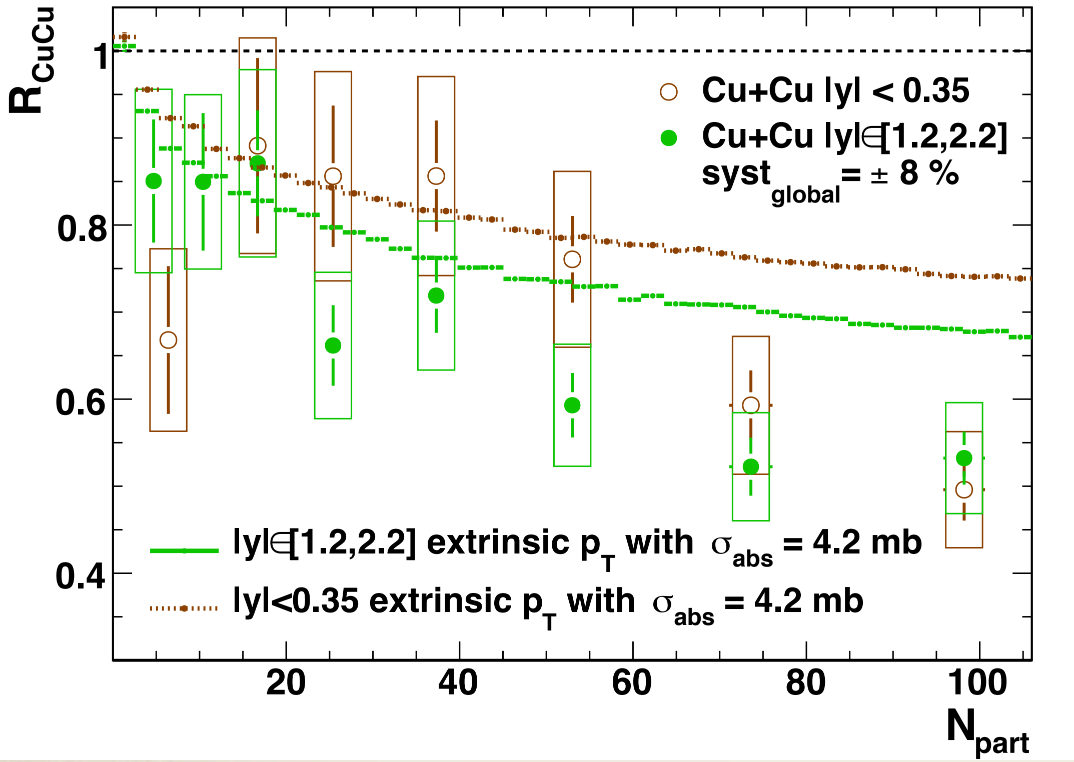


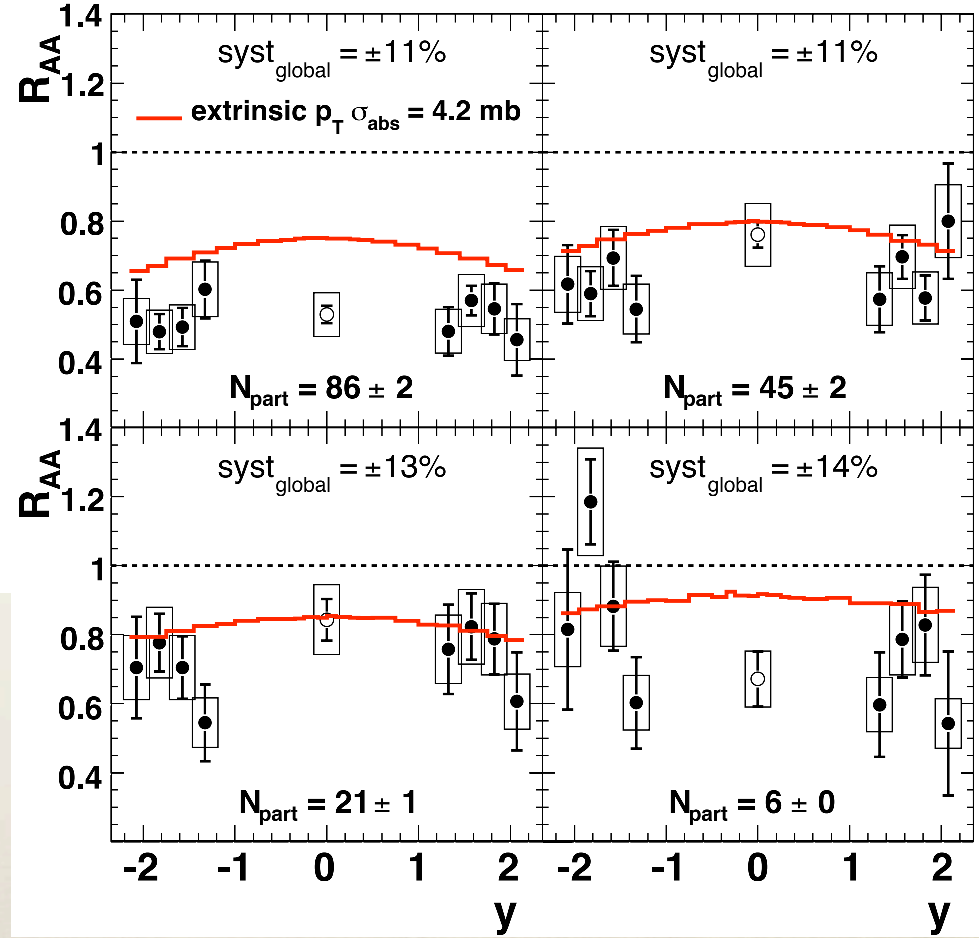
CNM effects at RHIC : *J/ψ* in CuCu

2→2 process : mid-y & fwd-y

2 → 2 process

using EKS98





E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R. PLB 680, 50-55 (2009)

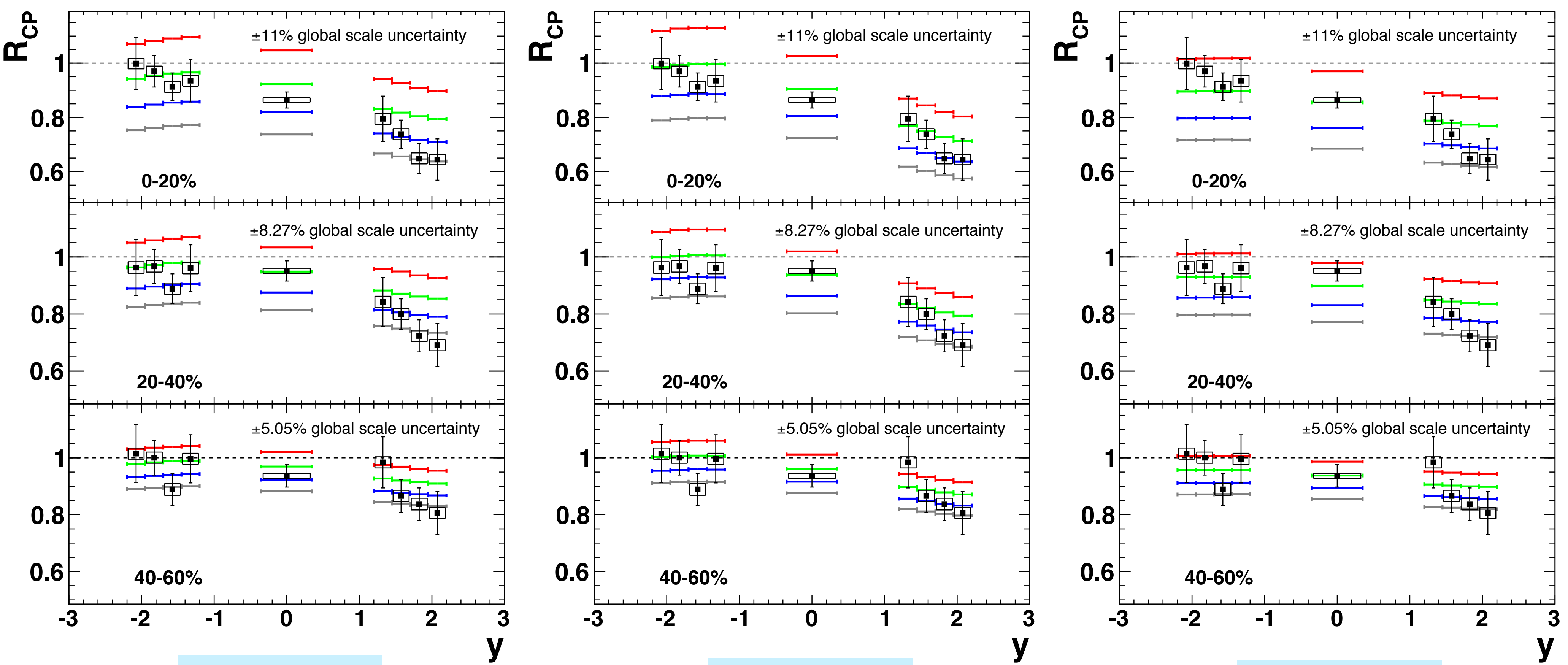
CNM effects at RHIC : J/ψ in dAu

2 → 2 process

E. G. Ferreiro, F. Fleuret, J. P. Lansberg
and A. R., PRC 81 (2010) 064911

absorption : 0, 2, 4, 6 mb

R_{CP} in d+Au vs rapidity

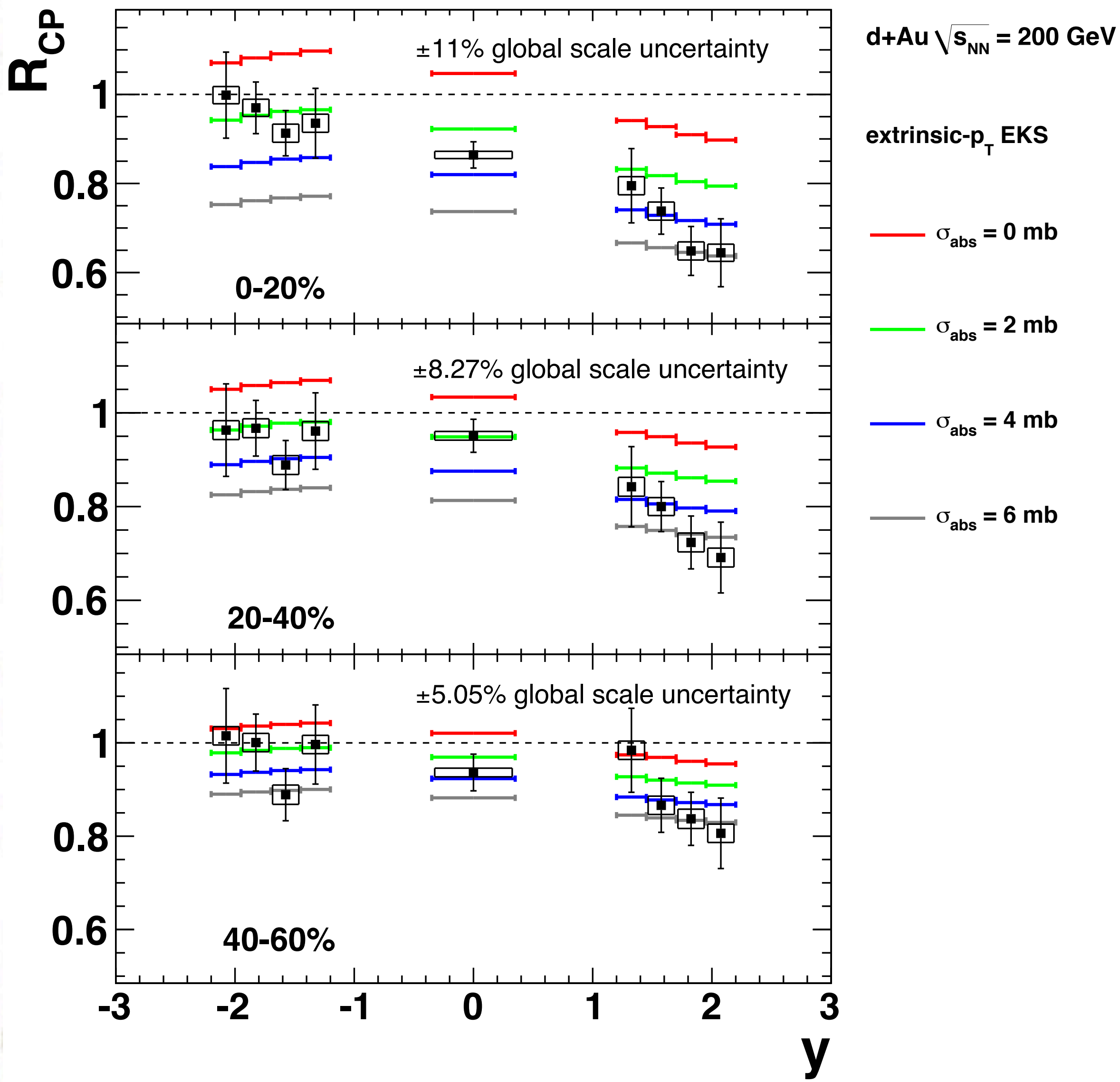


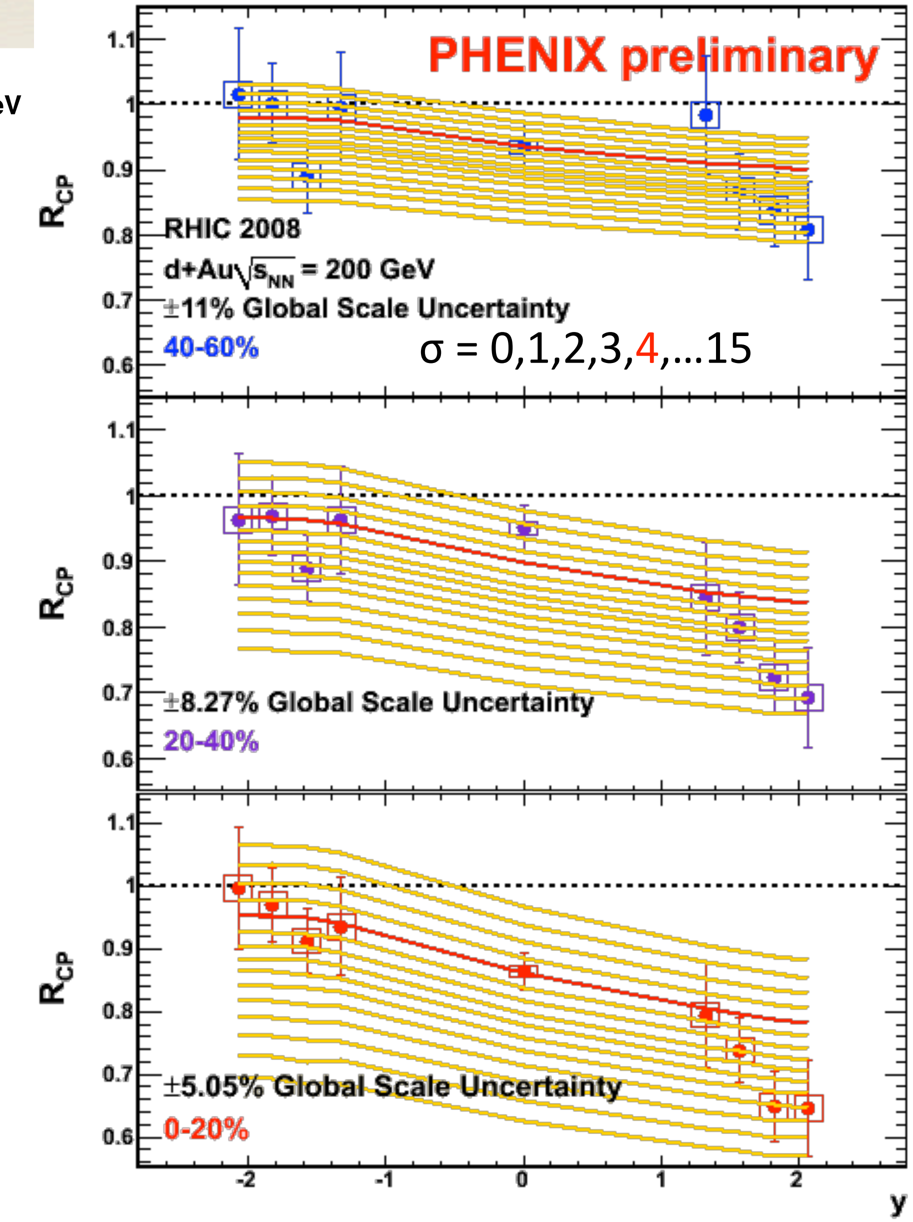
EKS98 EPS08 nDSg

data: PHENIX preliminary

A closer look at RCP vs y in dAu with EKS98

$g + g \rightarrow J/\psi + g$ $\quad$ $g + g \rightarrow c\bar{c}$



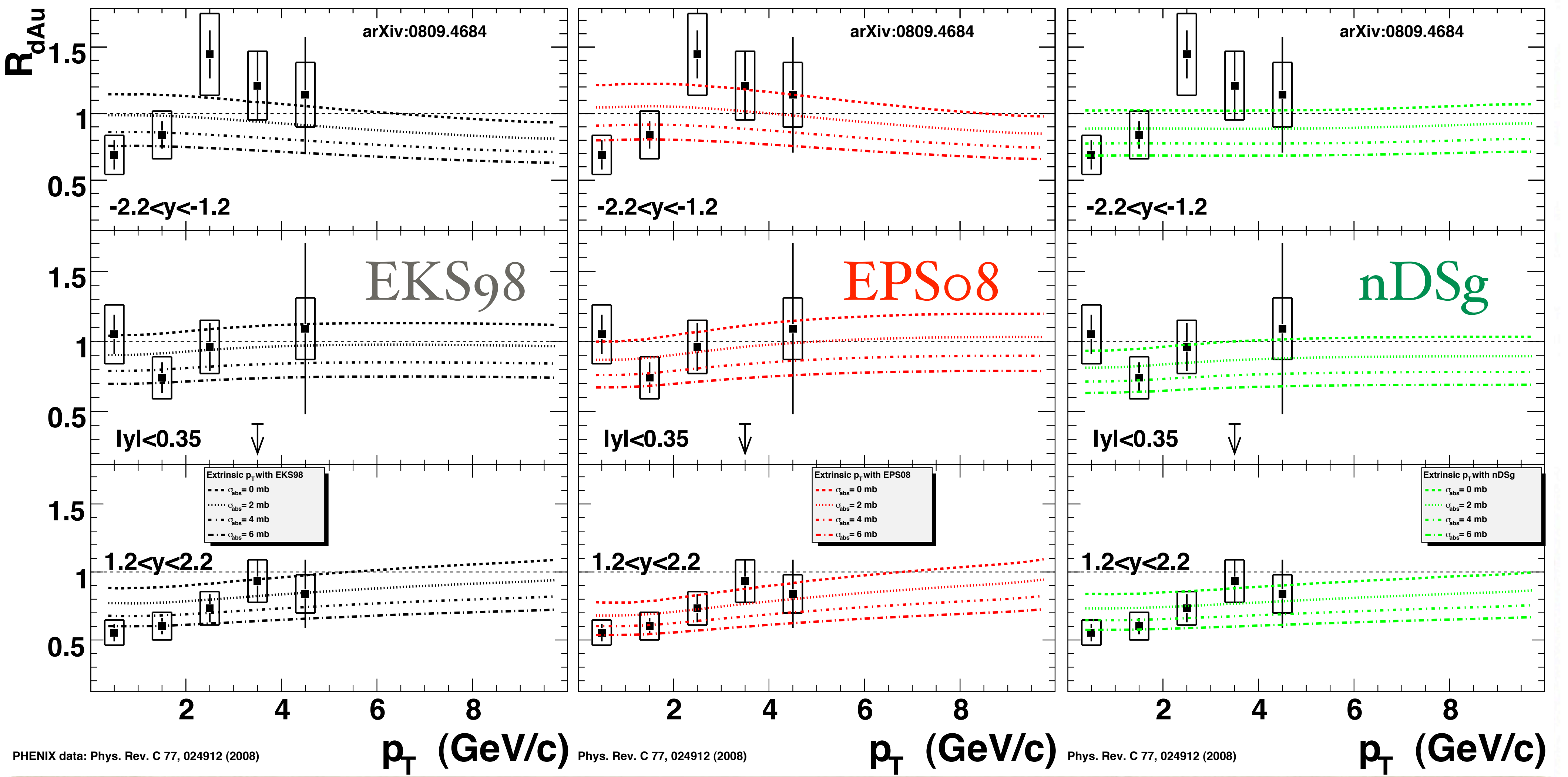


CNM effects : J/ψ R_{dAu} vs p_T

2 → 2 process

absorption : 0, 2, 4, 6 mb

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R. PLB 680, 50-55 (2009)

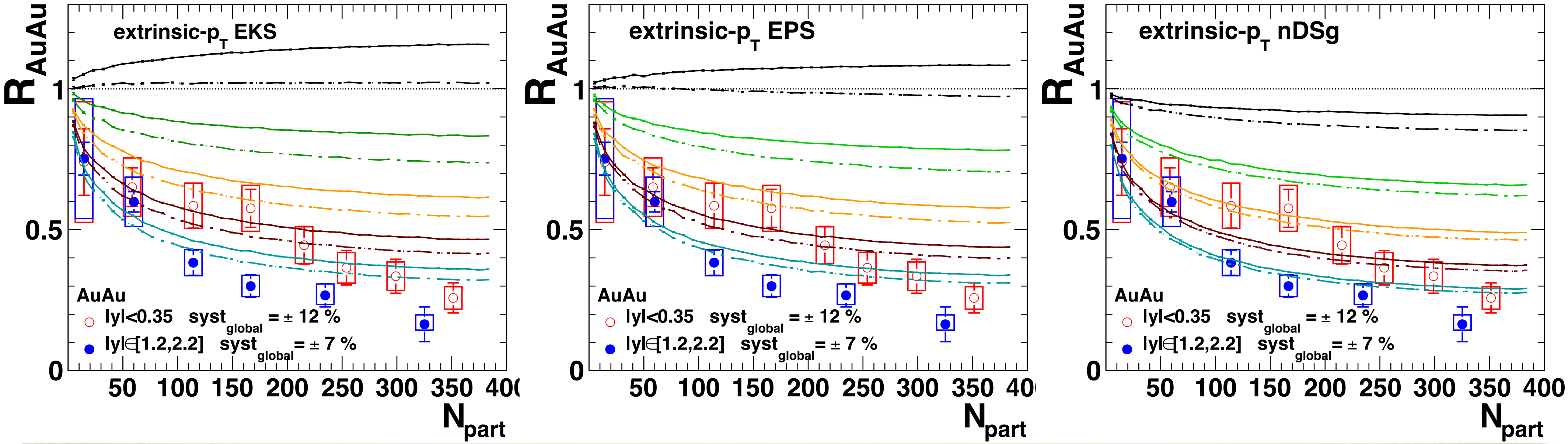


CNM effects : J/ψ in AuAu

$2 \rightarrow 2$ process

absorption : 0, 2, 4, 6, 8 mb

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R., PRC 81 (2010) 064911



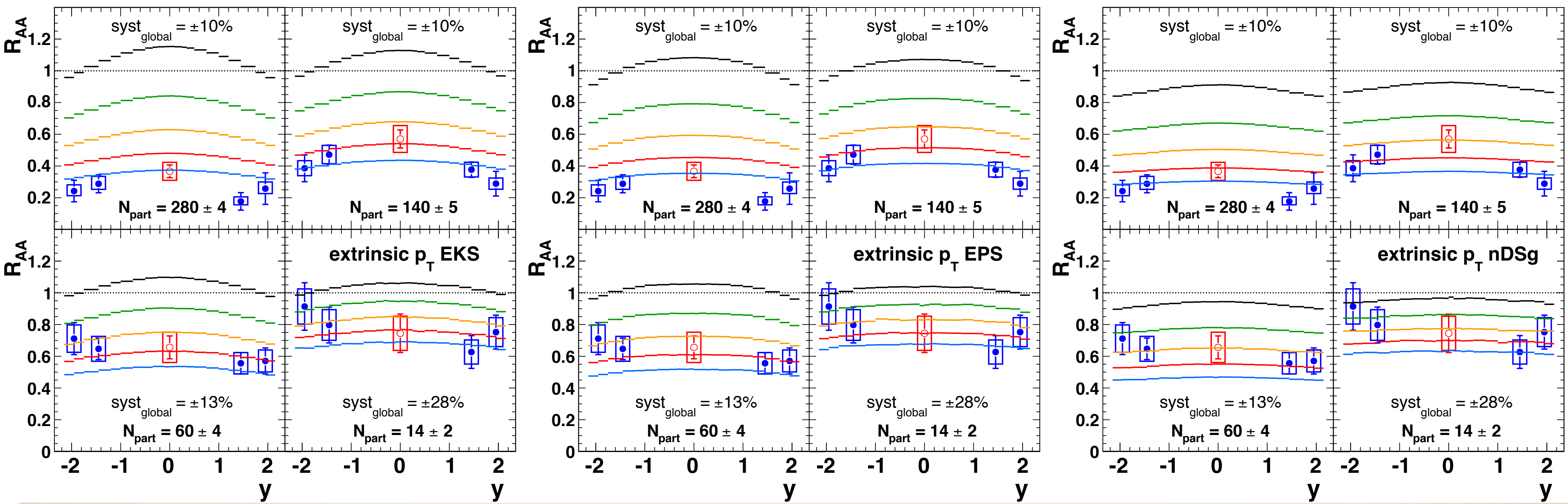
EKS98 EPS08 nDSg

CNM effects : J/ψ in AuAu

$2 \rightarrow 2$ process

absorption : 0, 2, 4, 6, 8 mb

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R., PRC 81 (2010) 064911



EKS98 EPS08 nDSg

Adding the p_T dependence

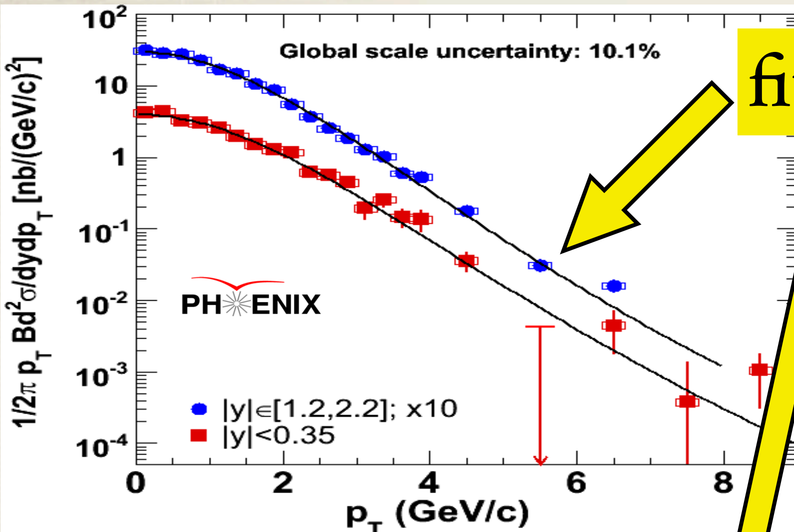
$$(x_1, x_2) \xleftrightarrow[\text{physical constraints}]{c\bar{c}\text{ hard production process}} (y, p_T)$$

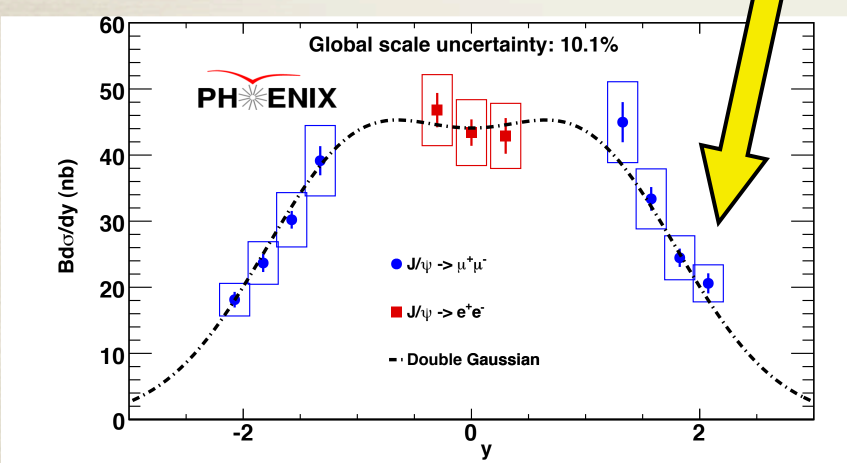
- Intrinsic scheme
- Extrinsic scheme

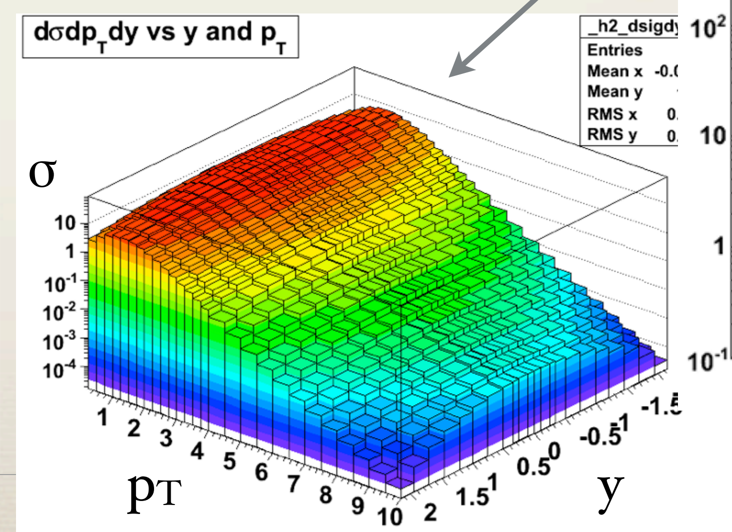
model

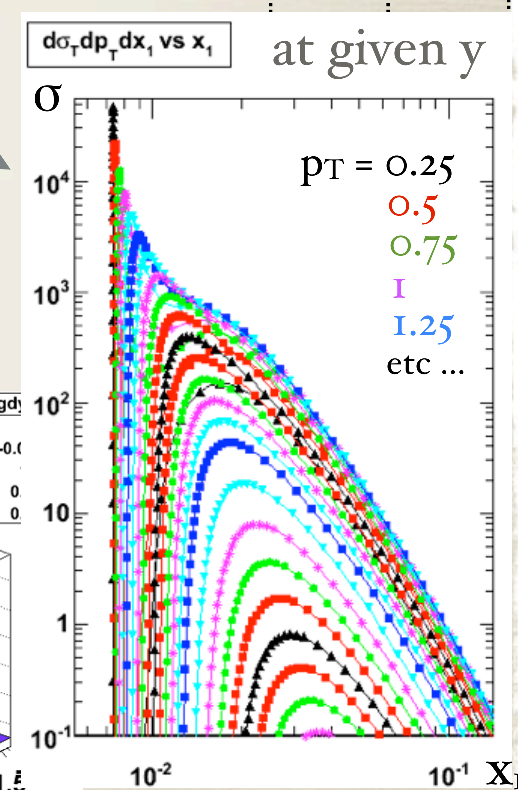
x_1	x_2	$g(x_1)g(x_2)\dfrac{d^4\sigma}{dy\,dp_T\,dx_1 dx_2}$	p_T	y

fits









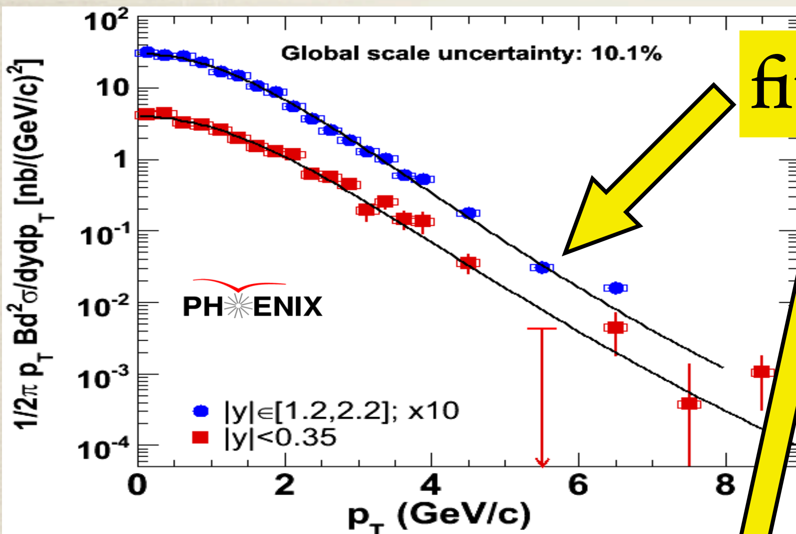
Adding the p_T dependence

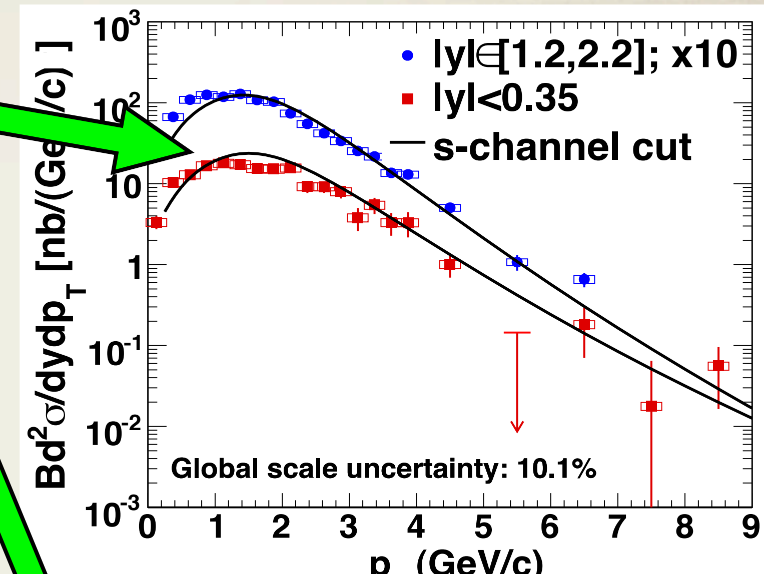
$$(x_1, x_2) \xleftrightarrow[\text{physical constraints}]{c\bar{c}\ \text{hard production process}} (y, p_T)$$

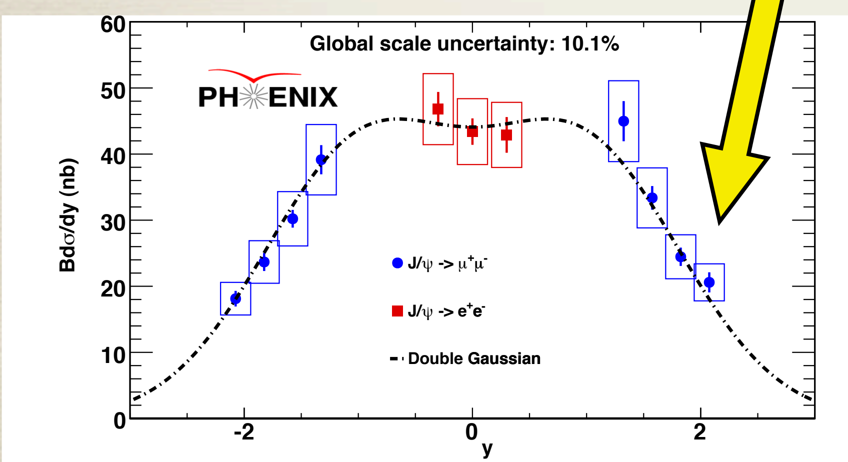
- Intrinsic scheme
- Extrinsic scheme

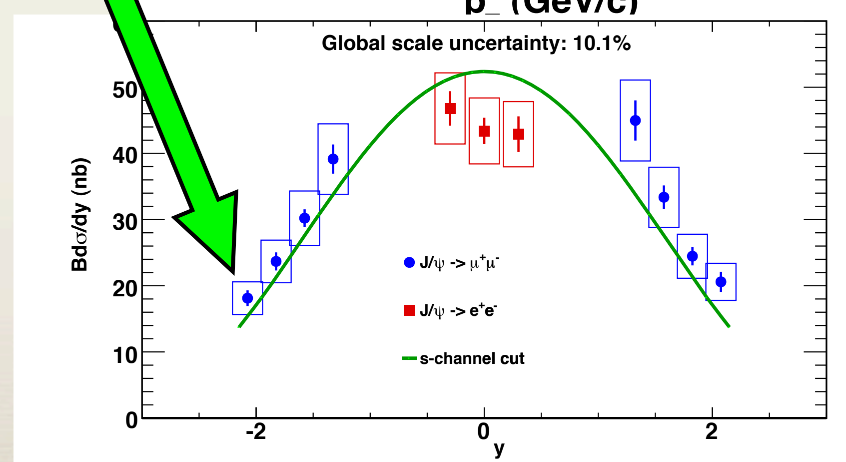
fits

model





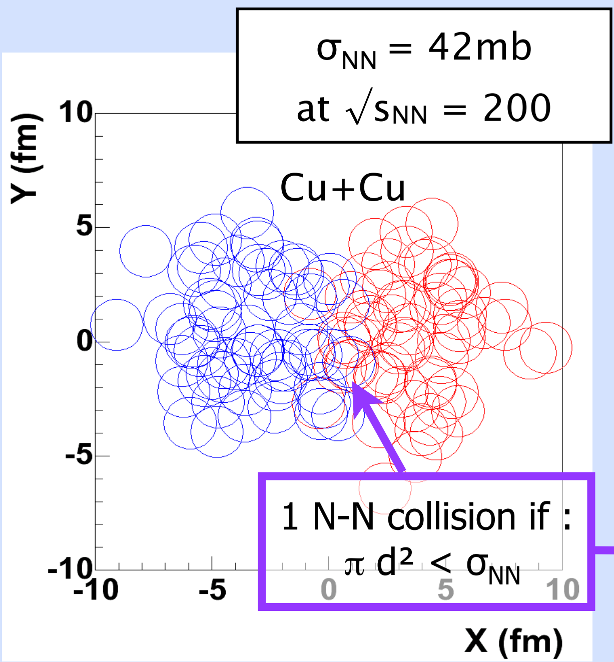




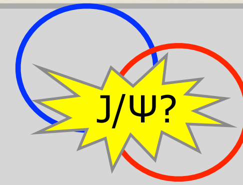
Our Monte-Carlo approach for J/ψ production

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, 2π]
- $\mathbf{x_1}$, $\mathbf{x_2}$ determined from intrinsic or extrinsic scheme

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

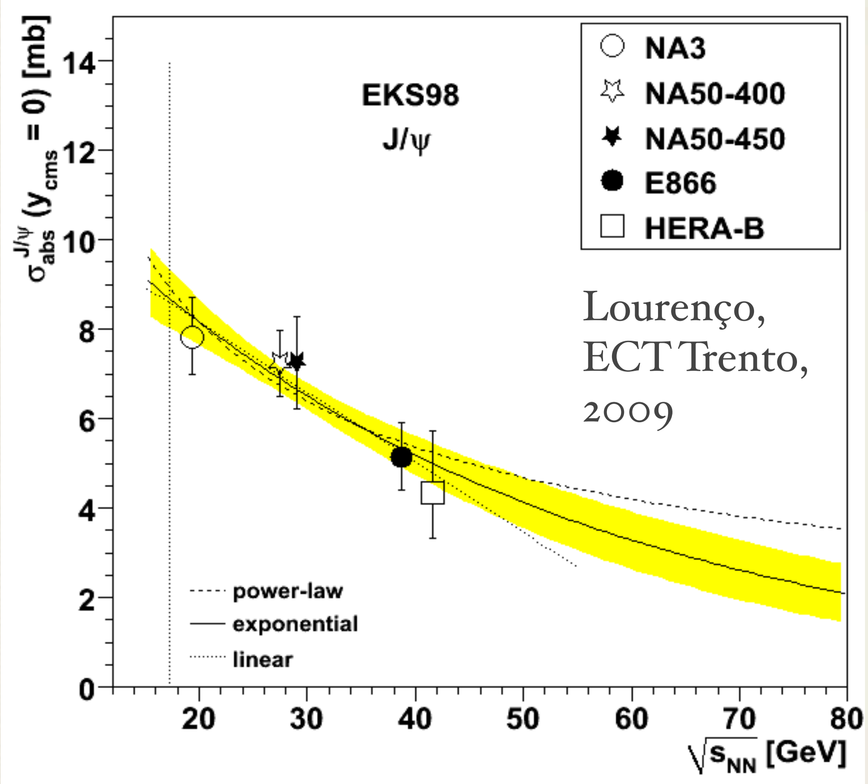
J/Ψ canditate ⇒ real J/Ψ if :
random[0,1] < $R_{shadow} \times \sigma_{J/\psi} / \sigma_{NN}$

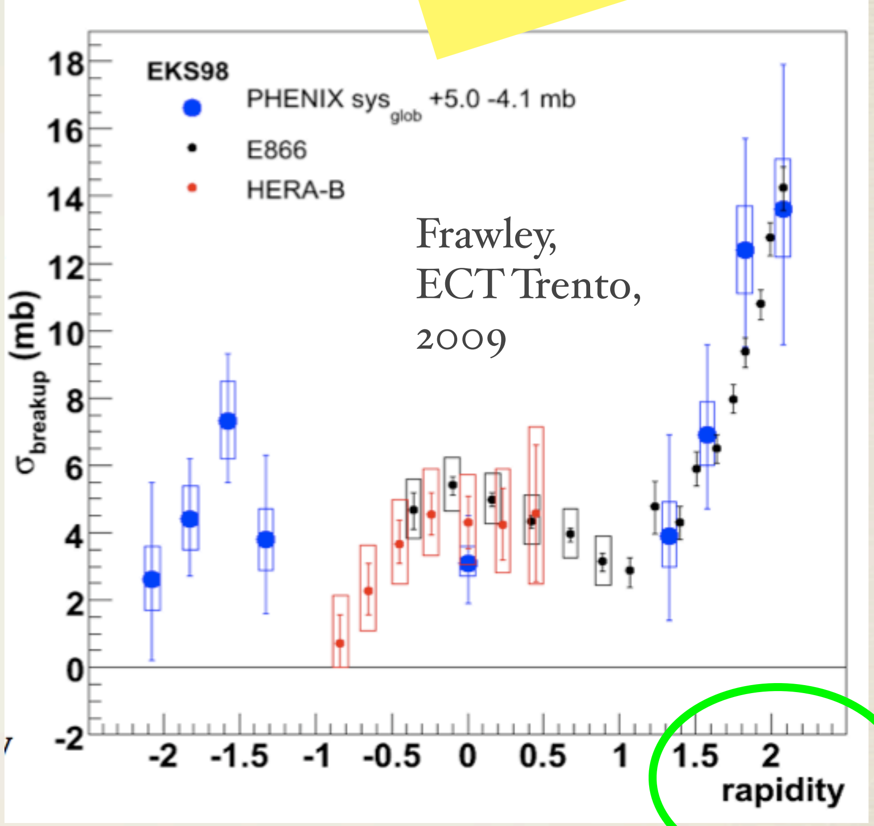
computed using **EKS**

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

What about any dependence of σ_{abs} on kinematics ?

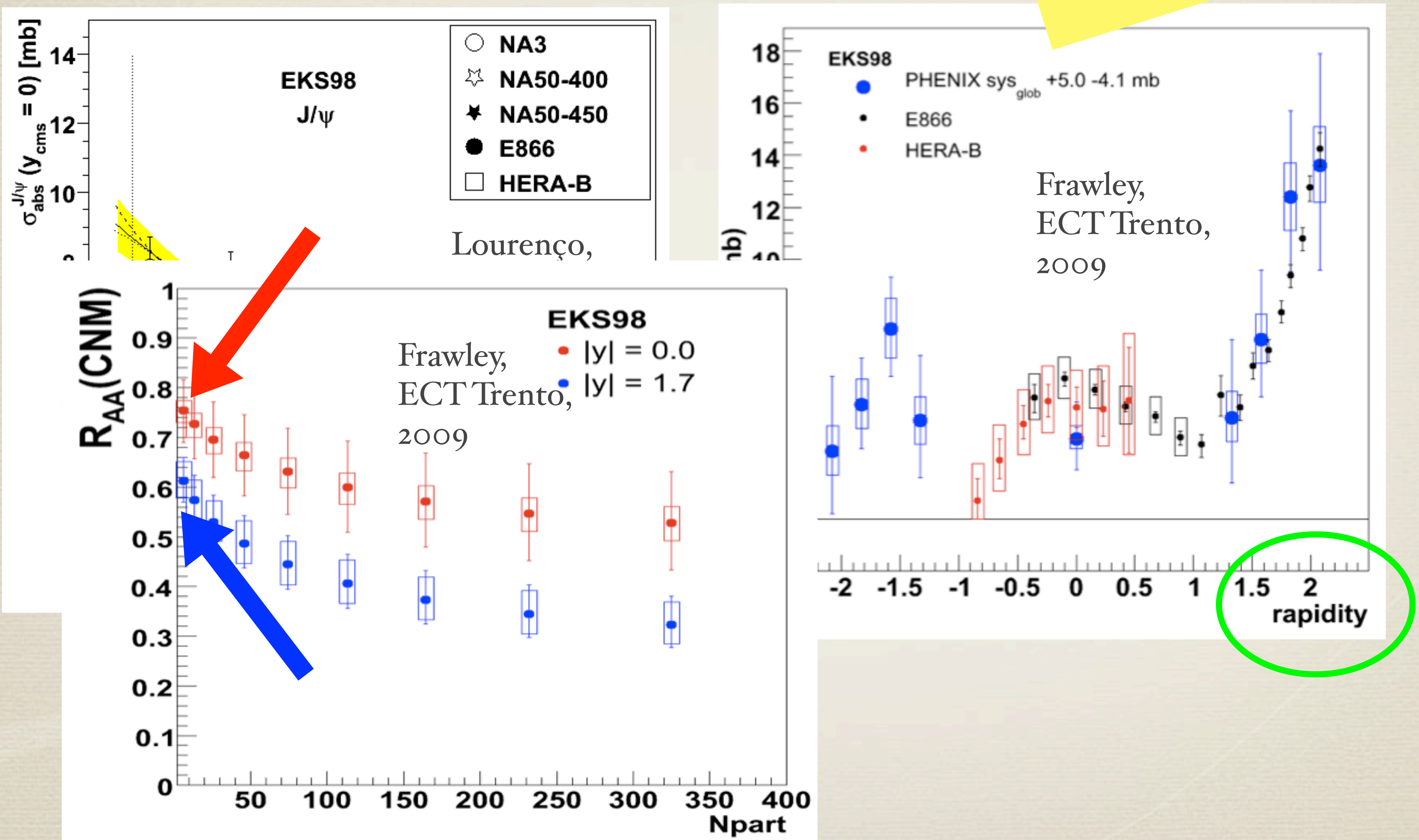
investigated assuming 2→1 process only !





What about any dependence of σ_{abs} on kinematics ?

investigated assuming 2→1 process only !



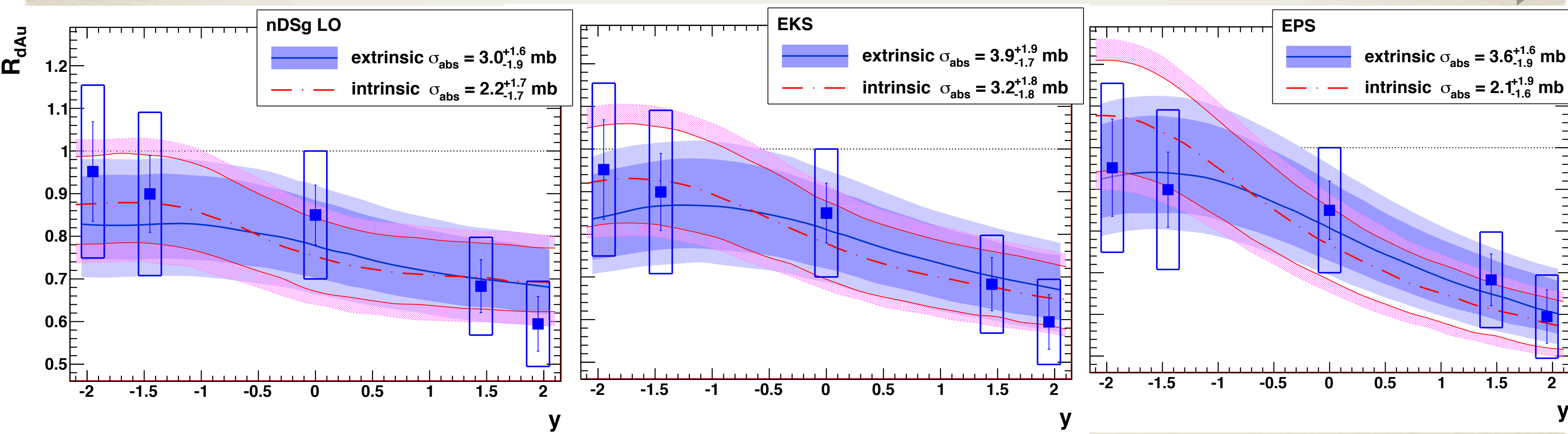
Data constrains on the value of the effective σ_{abs}

A.R., E. G. Ferreiro, F. Fleuret and J. P. Lansberg, arXiv:1002.2351

hard to distinguish $2\rightarrow1$ to $2\rightarrow2$ processes with current exp. err.

R_{dAu} vs rapidity

nPDF with stronger anti-shadowing



nDSg | EKS98 | EPS08