

Ir f u

cea

saclay

Institut de  
recherche sur les lois  
fondamentales de  
l'univers

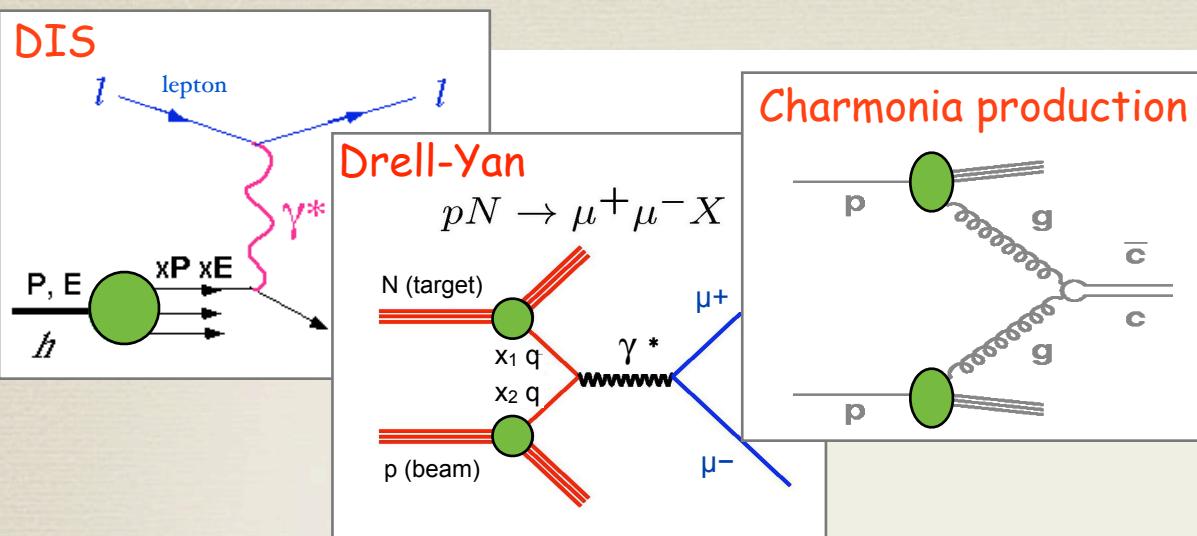
In collaboration with E. G. Ferreiro,  
F. Fleuret & J. P. Lansberg

# ON THE KINEMATICS OF $J/\psi$ PRODUCTION AND ITS INFLUENCE ON CNM EFFECTS

Andry Rakotozafindrabe  
CEA (Saclay) IRFU/SPhN

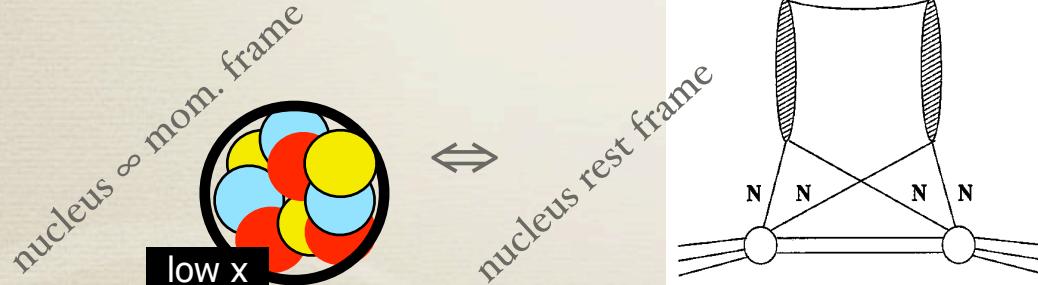
Workshop on nPDF, Annecy 2010

# Shadowing : a cold nuclear matter effect



(Anti-)shadowing :

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



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

Processes used to probe :

nucleon struct. f.

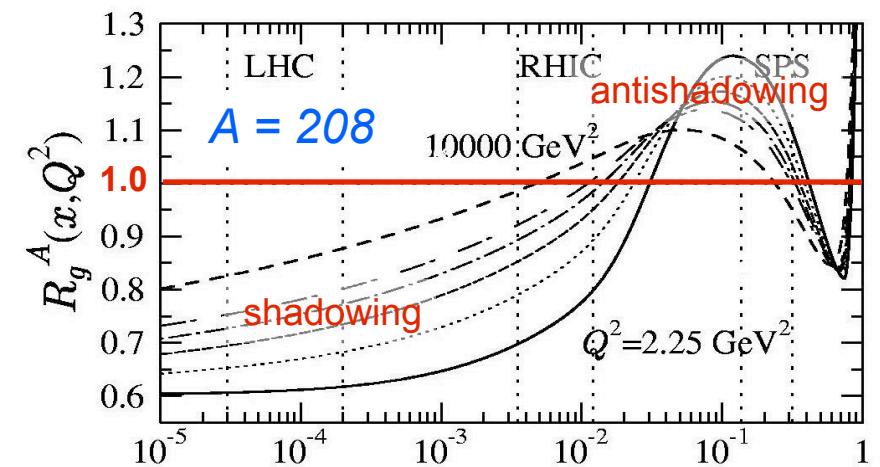
$$F_2 = \sum_i e_i^2 \cdot x f_i(x, Q^2)$$

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

nuclear struct. f. per nucleon

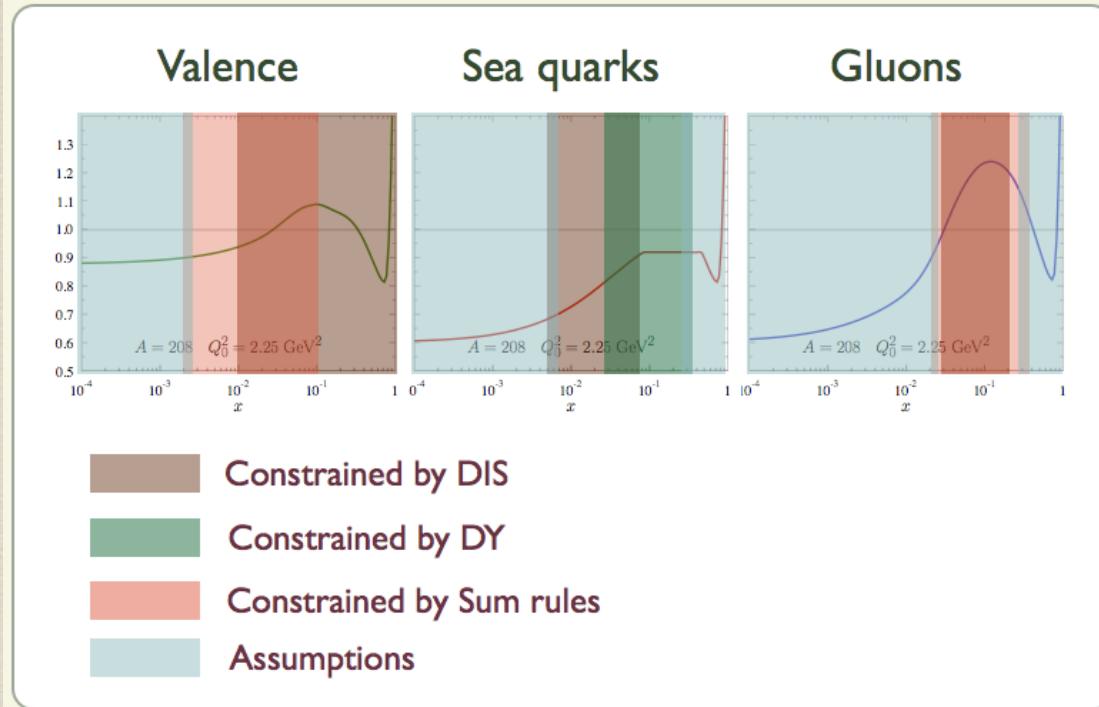


$$R_g^A = \frac{g \text{ PDF} \in \text{bound nucleon}}{g \text{ PDF} \in \text{free nucleon}}$$

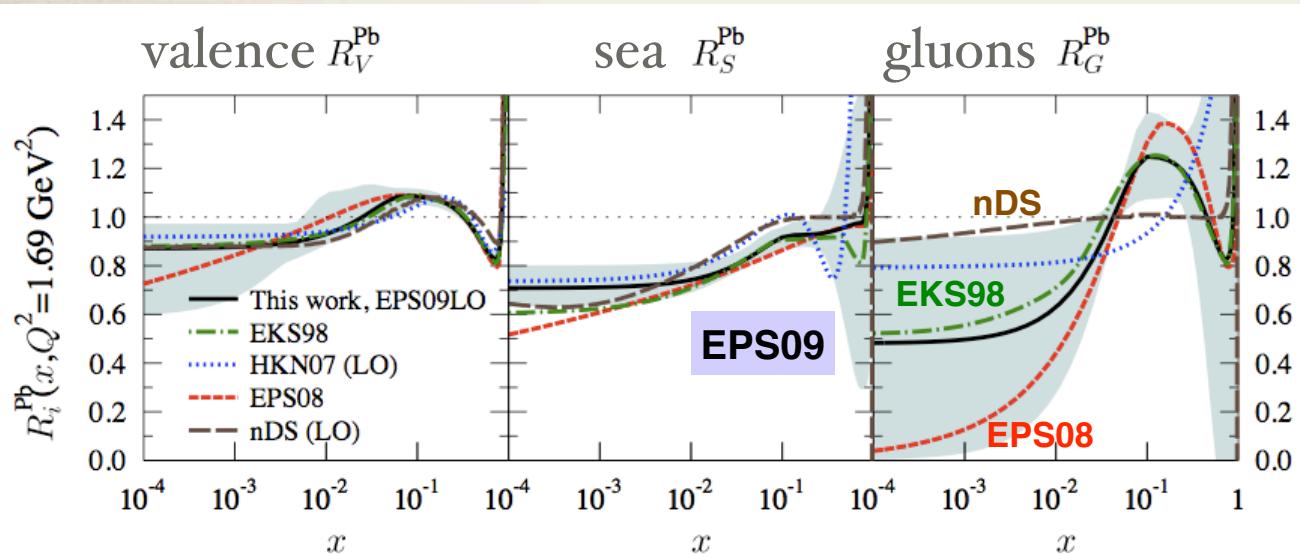
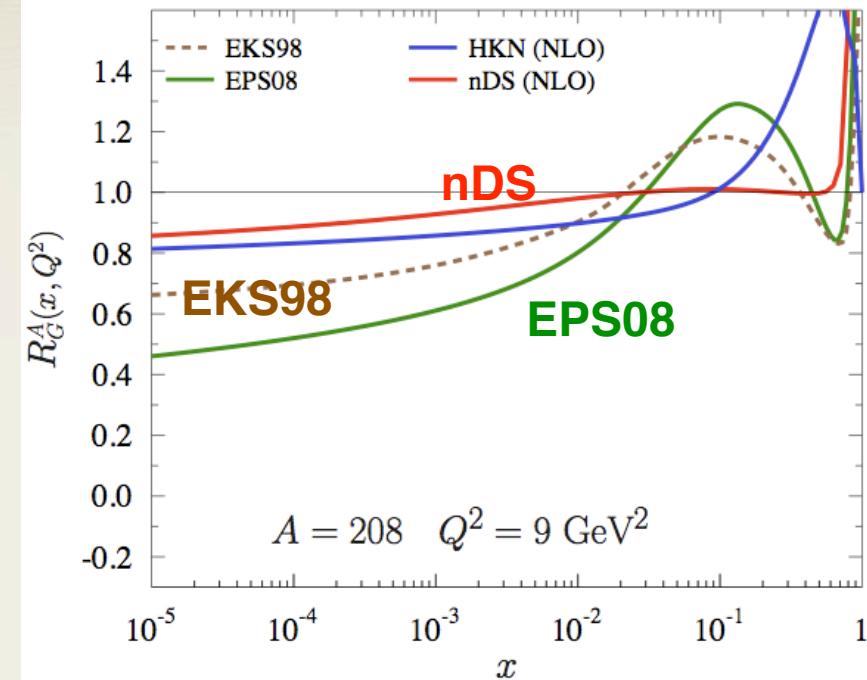


# (Some) nPDFs available on the market

Approximate ranges and constraints in EKS98



Ratios for gluons and Pb nuclei



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

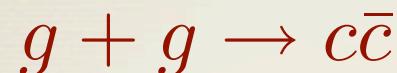
- in A+B: quarkonia production cross-section modified by a shadowing correction factor :

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

- 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**

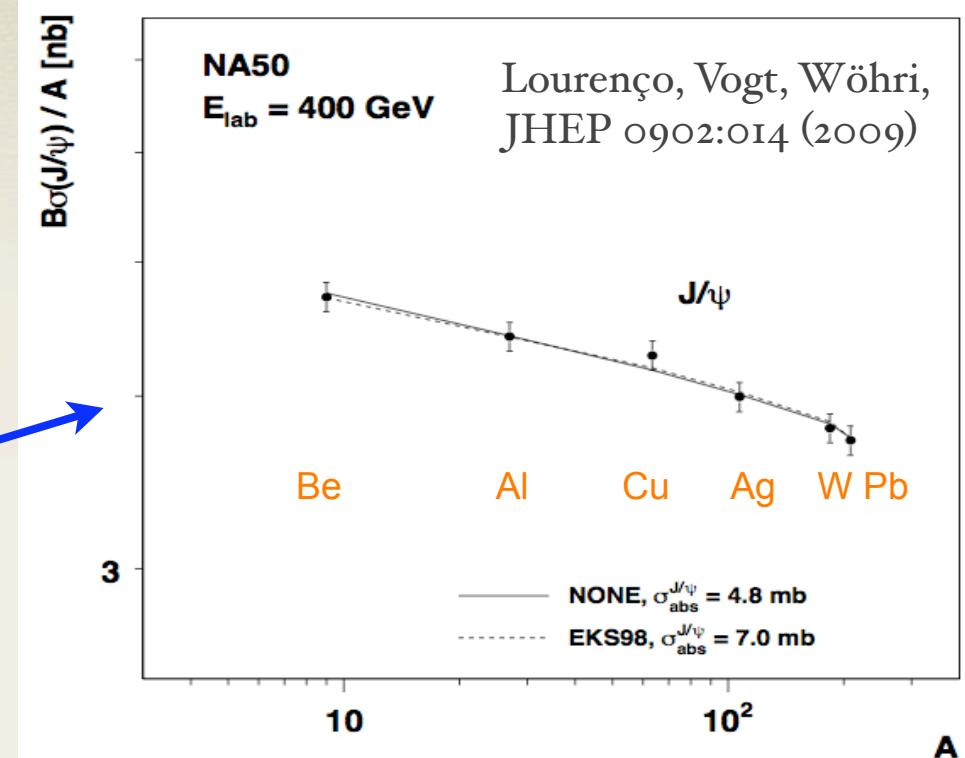
# CNM effects with CEM as prod. model

- Usually CEM LO when looking at the yield integrated over pT :



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

- Massive use at SPS, RHIC, LHC to compute shadowing



# CNM effects with CEM as prod. model

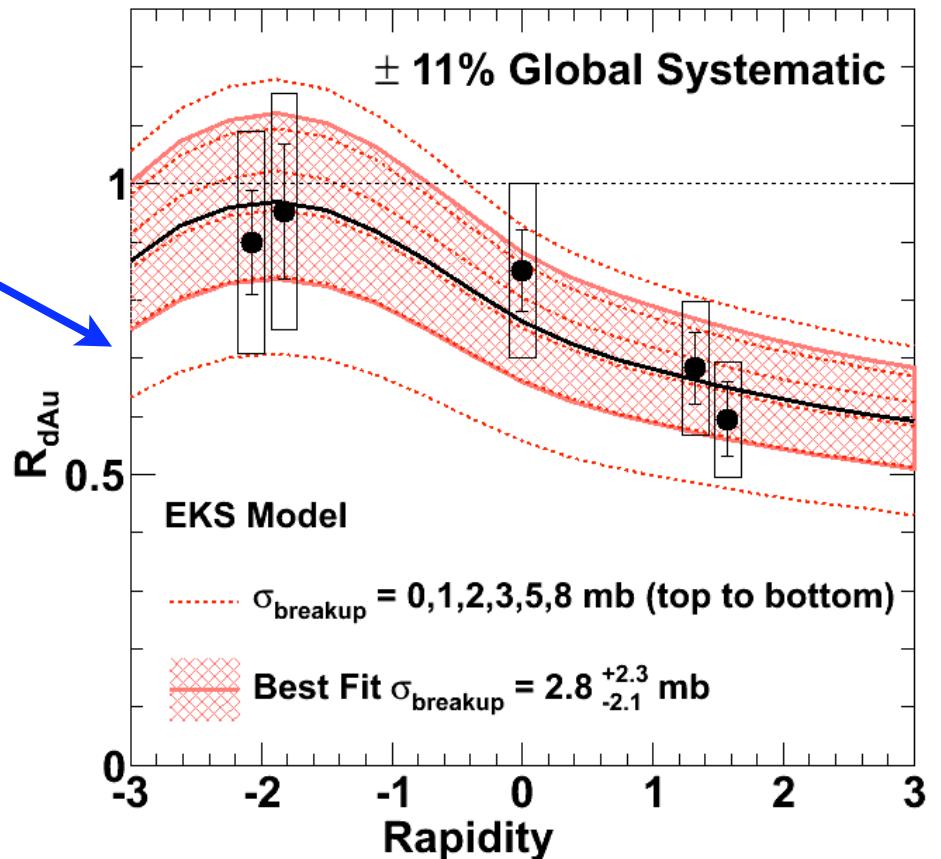
- Usually CEM LO when looking at the yield integrated over pT :

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

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

- Massive use at SPS, RHIC, LHC to compute shadowing

Model from Vogt  
Fits from PHENIX: PRC 77, 024912 (2008) and erratum arXiv:0903.4845 [nucl-ex]



# CNM effects with CEM as prod. model

- Usually CEM LO when looking at the yield integrated over pT :

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

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

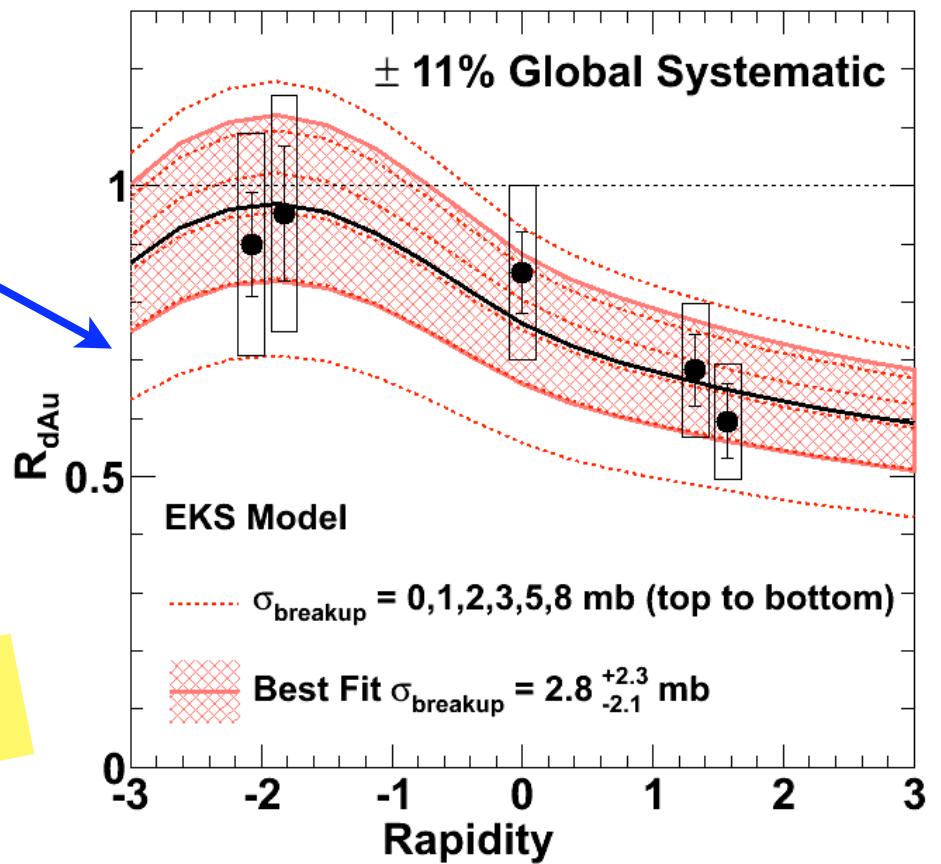
- Massive use at SPS, RHIC, LHC to compute shadowing

- Handy : unequivocal correspondence

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

intrinsic scheme

Model from Vogt  
Fits from PHENIX: PRC 77, 024912 (2008) and erratum arXiv:0903.4845 [nucl-ex]



# s-channel cut CSM

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

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

$2 \rightarrow 2$  process :

more degrees of freedom in the kinematics

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

 extrinsic scheme

# s-channel cut CSM

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

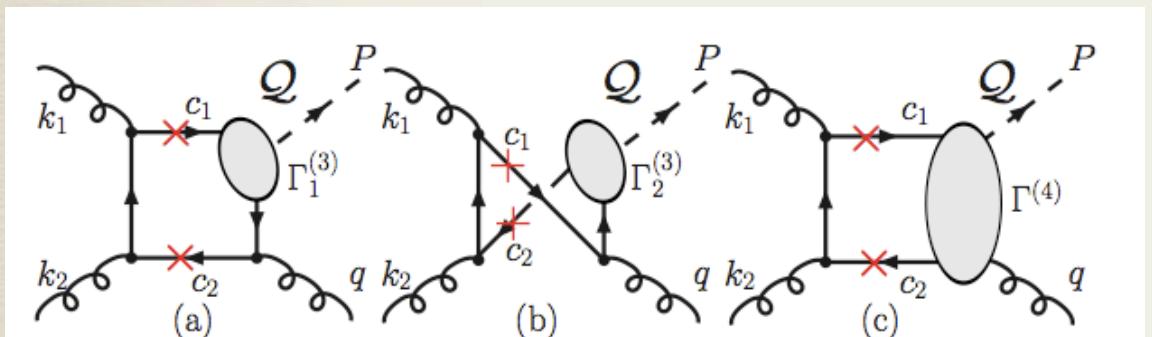
$$y, p_T, x_1 \implies x_2 = \frac{x_1 m_T \sqrt{s} e^{-y} - M^2}{\sqrt{s} (\sqrt{s} x_1 - m_T e^y)}$$

$2 \rightarrow 2$  process :

more degrees of freedom in the kinematics

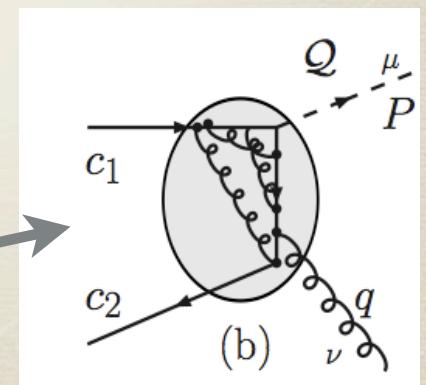
several  $(x_1, x_2) \Leftarrow (y, p_T)$

s-channel cut contributions [I] to the “basic” CSM :



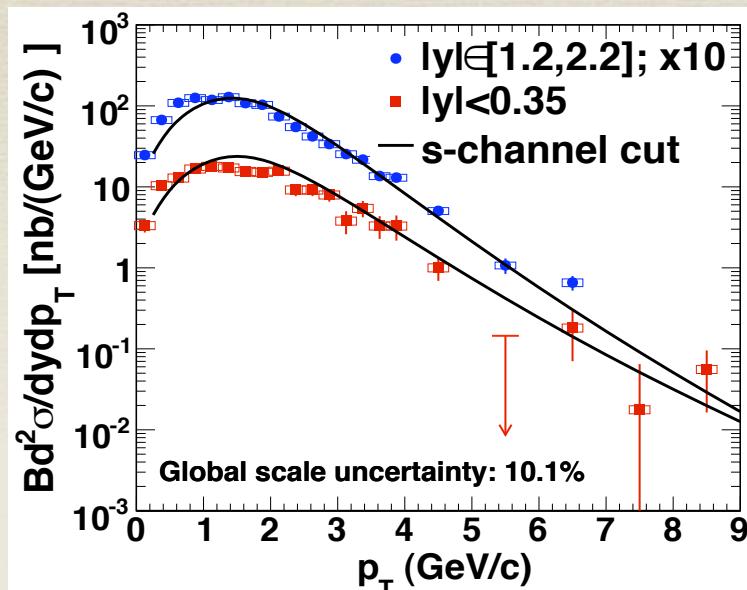
[I] H. Haberzettl et J. P. Lansberg,  
PRL 100, 032006 (2008)

- ✿ 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

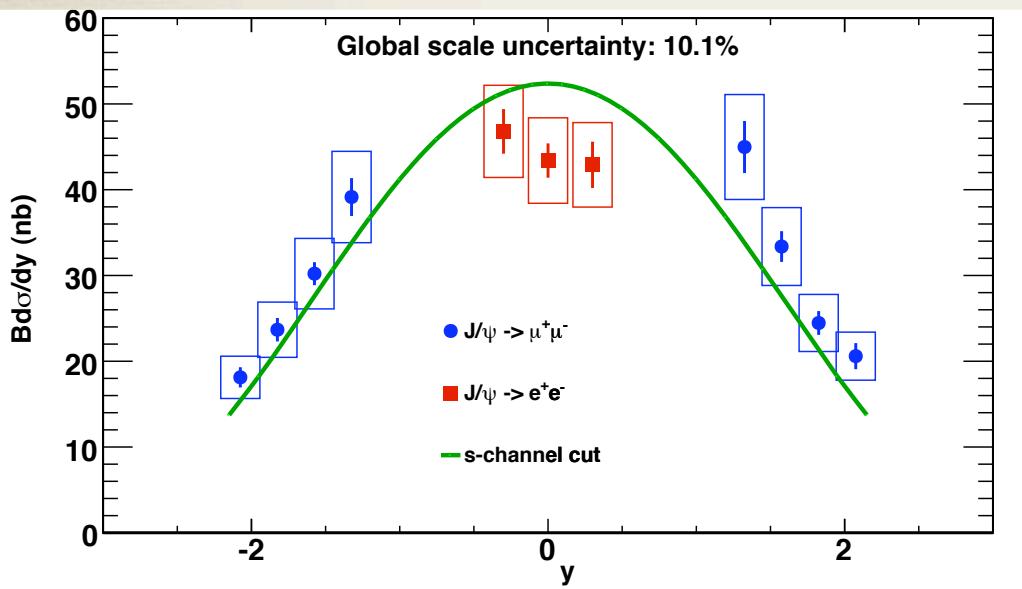


# s-channel cut CSM at RHIC in p+p

yield vs  $p_T$

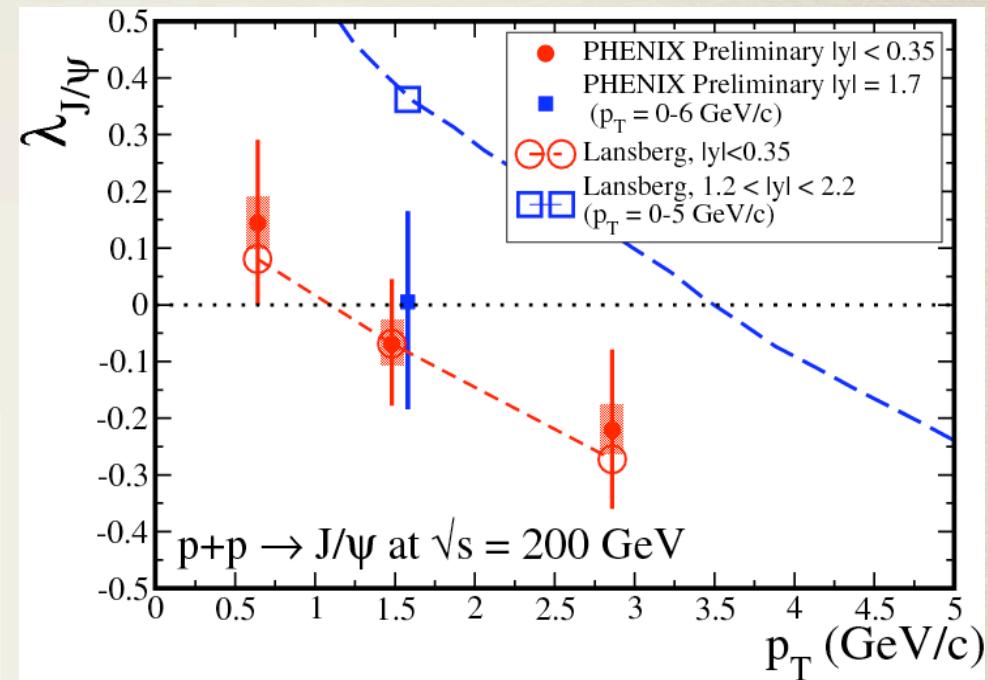


data : phenix run5 p+p spectra



yield vs rapidity

polarisation vs  $p_T$  at mid-y and fwd-y



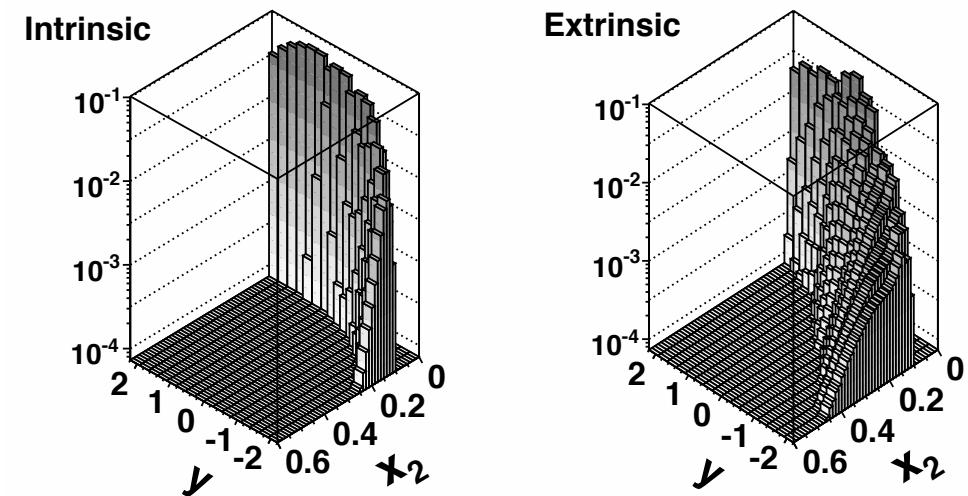
in helicity frame

reasonable model  
from low to  
intermediate  $p_T$

# CEM vs s-channel cut CSM as prod. model : d+Au @ 200 GeV

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

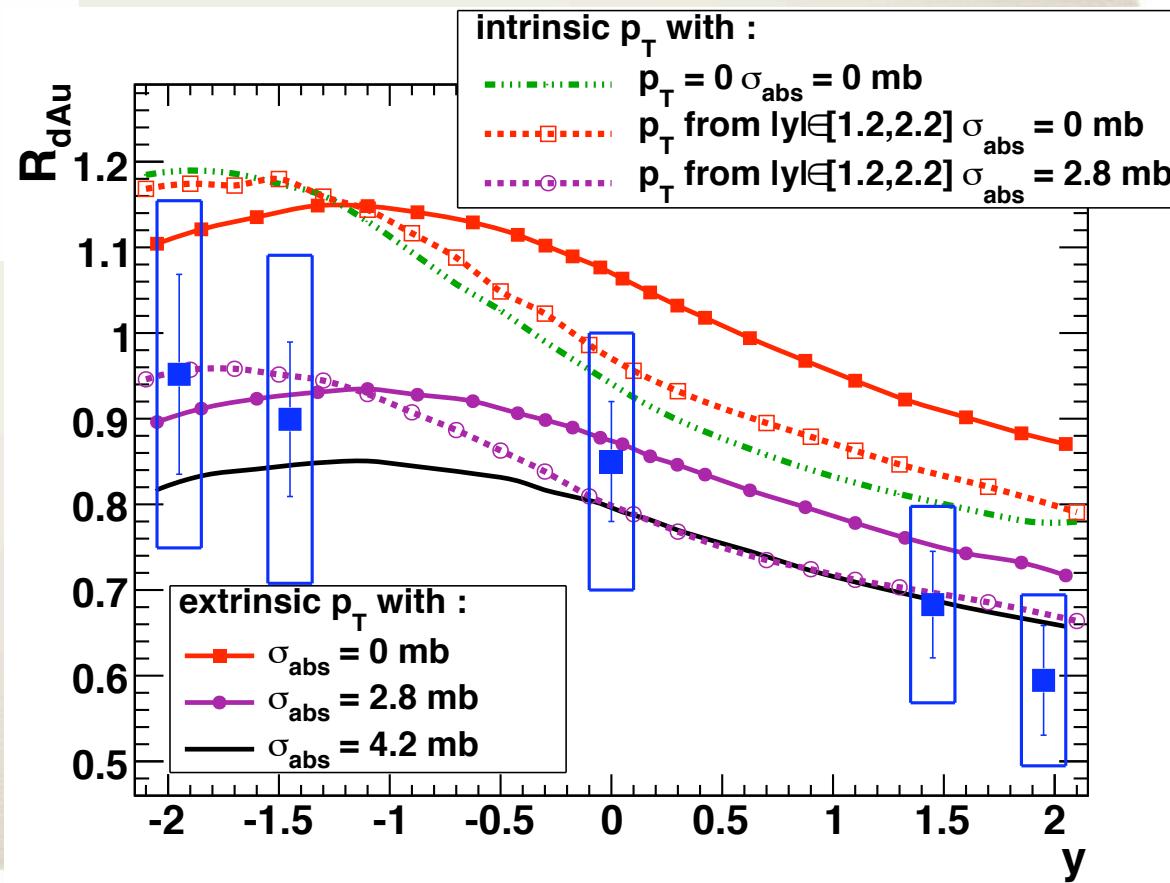
**E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R.**  
**PLB 680, 50-55 (2009)**



Phase-space

2 $\rightarrow$ 2 process :  
different absorption  
cross-section needed

R<sub>dAu</sub> vs rapidity (EKS98)

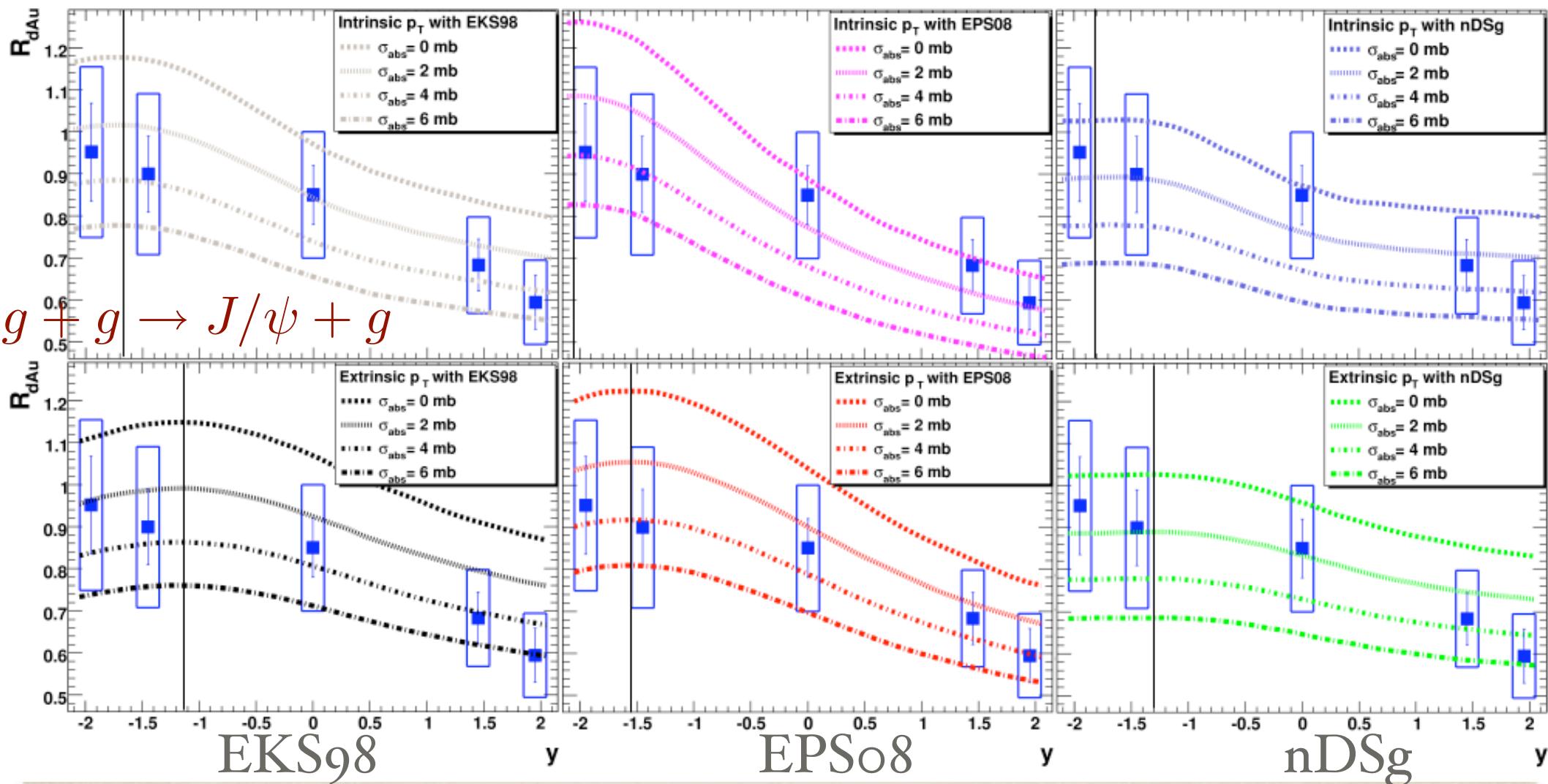


# CEM vs s-channel cut CSM as prod. model : d+Au @ 200 GeV

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R.  
arXiv:0903.4908

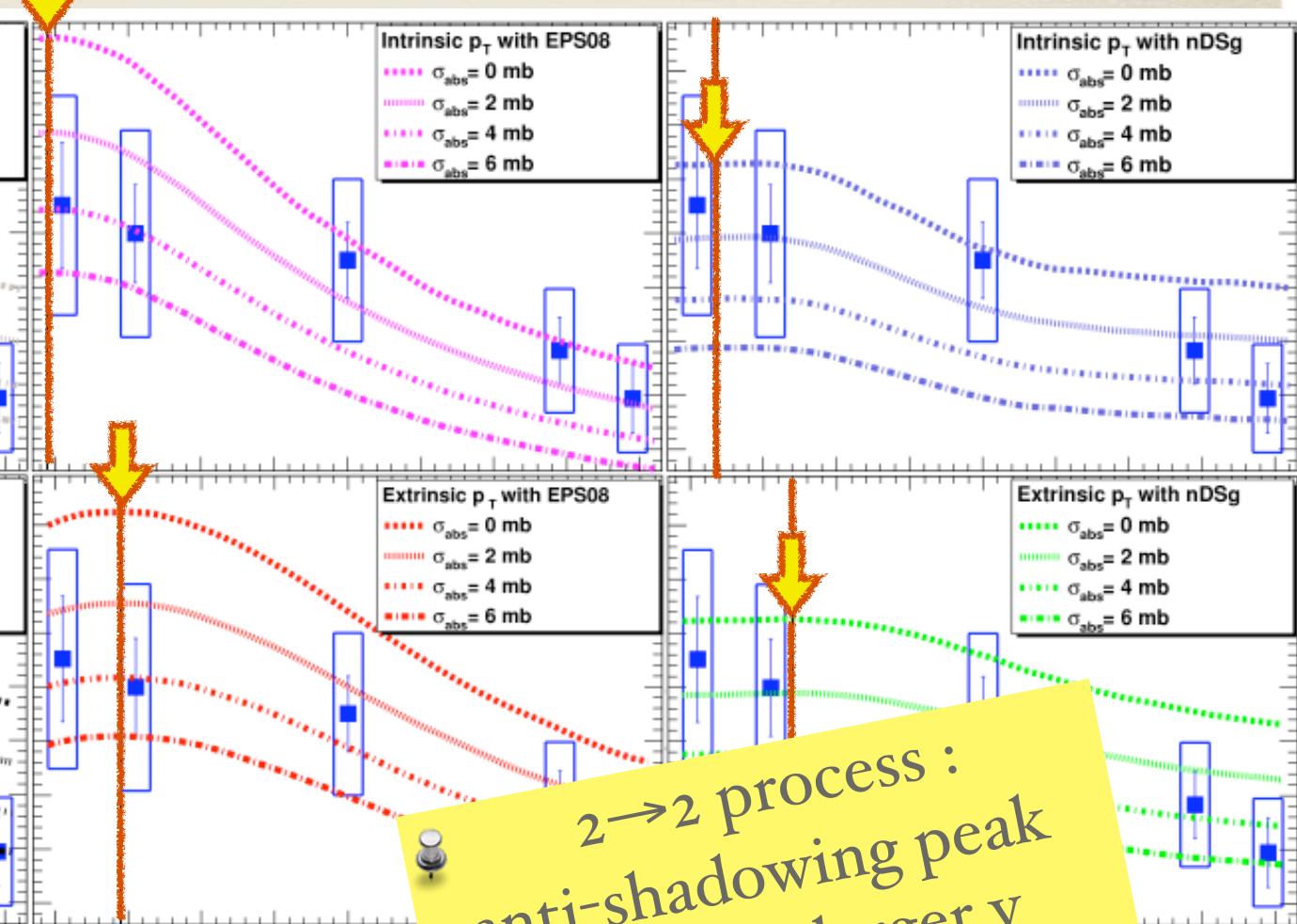
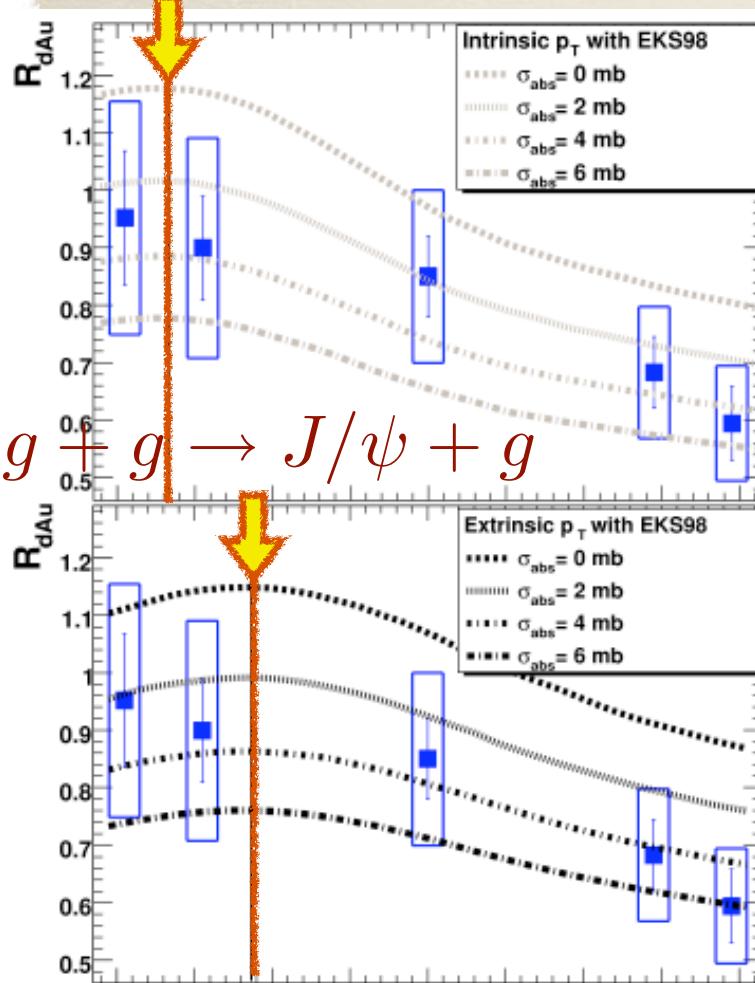
$g + g \rightarrow c\bar{c}$

$R_{dAu}$  vs rapidity



# CEM vs s-channel cut CSM as prod. model : d+Au @ 200 GeV

E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. R.  
arXiv:0903.4908



2 $\rightarrow$ 2 process :  
anti-shielding peak  
shifted to larger y

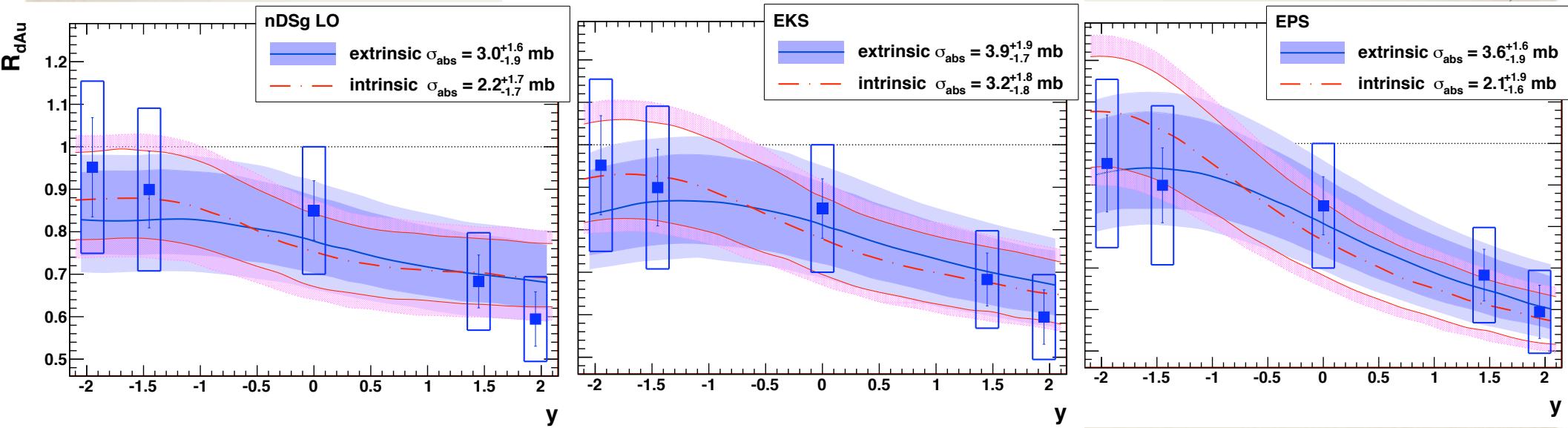
# CEM vs s-channel cut CSM as prod. model : d+Au @ 200 GeV

hard to distinguish  
 $2 \rightarrow 1$  to  $2 \rightarrow 2$  processes  
 with current exp. err.

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

$R_{dAu}$  vs rapidity

nPDF with stronger anti-shadowing



nDSg

EKS98

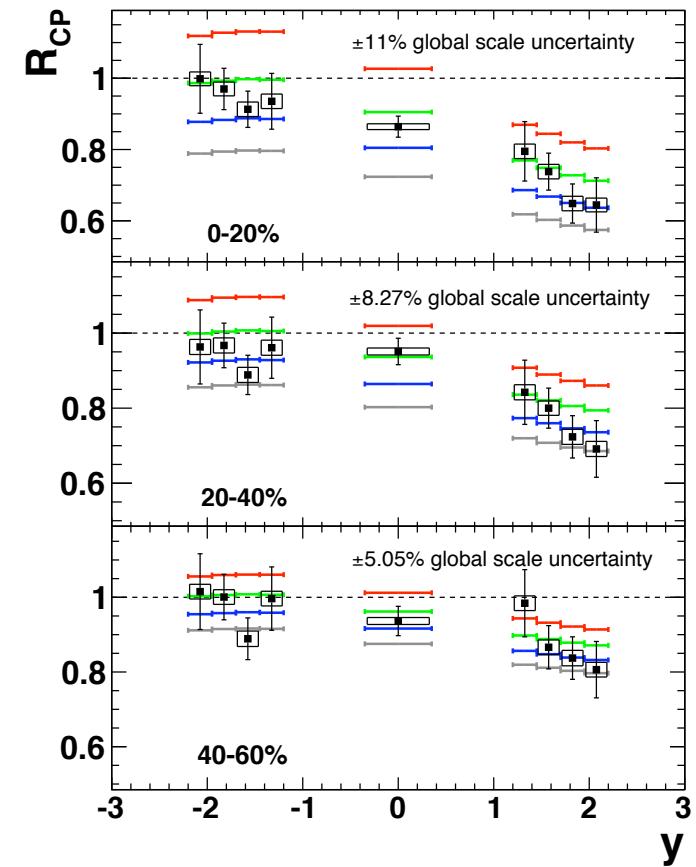
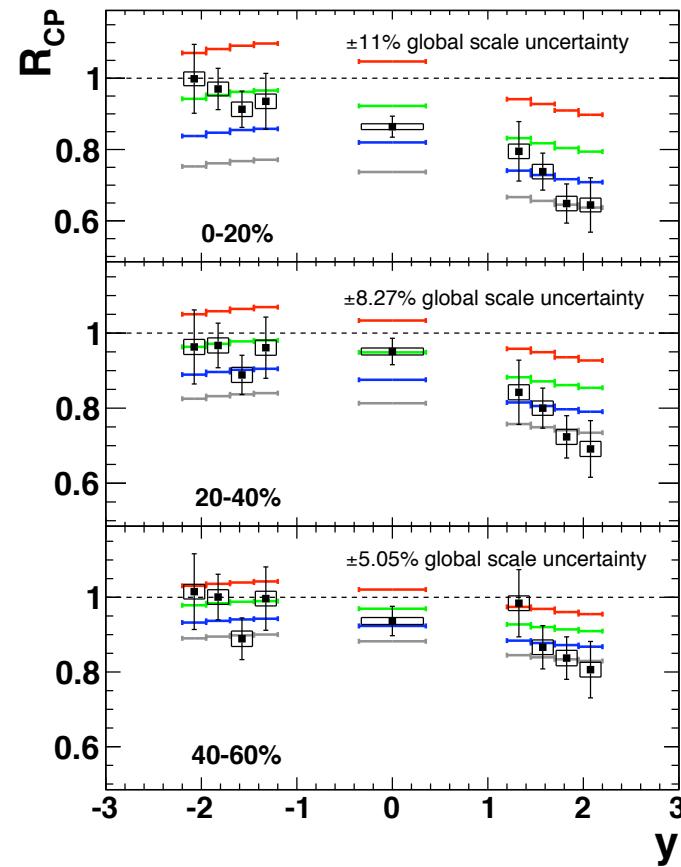
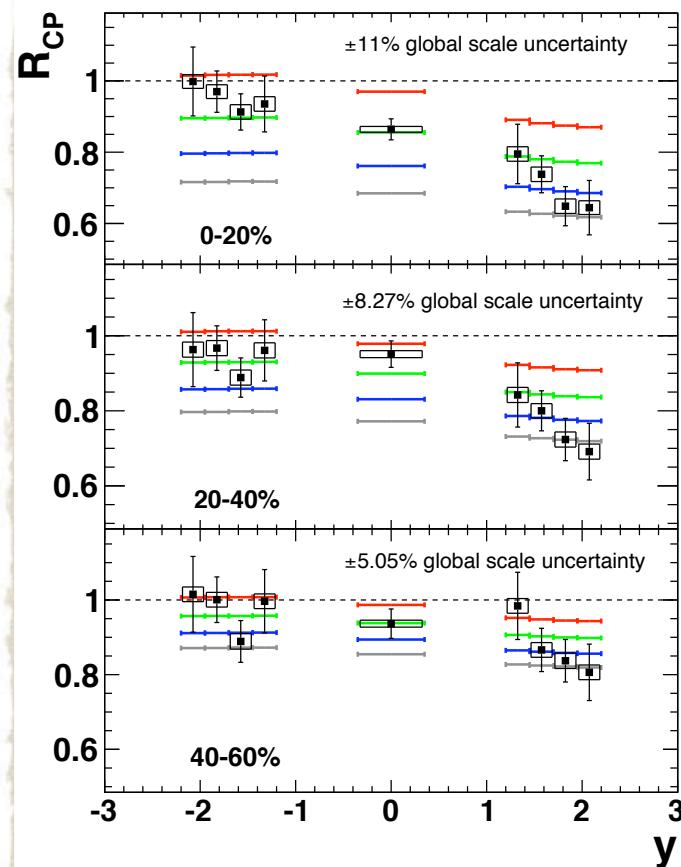
EPS08

# s-channel cut CSM as prod. model : d+Au @ 200 GeV

E. G. Ferreiro, F. Fleuret, J. P. Lansberg  
and A. R., arXiv:0912.4498

absorption : 0, 2, 4, 6 mb

$R_{CP}$  in d+Au vs rapidity



nDSg

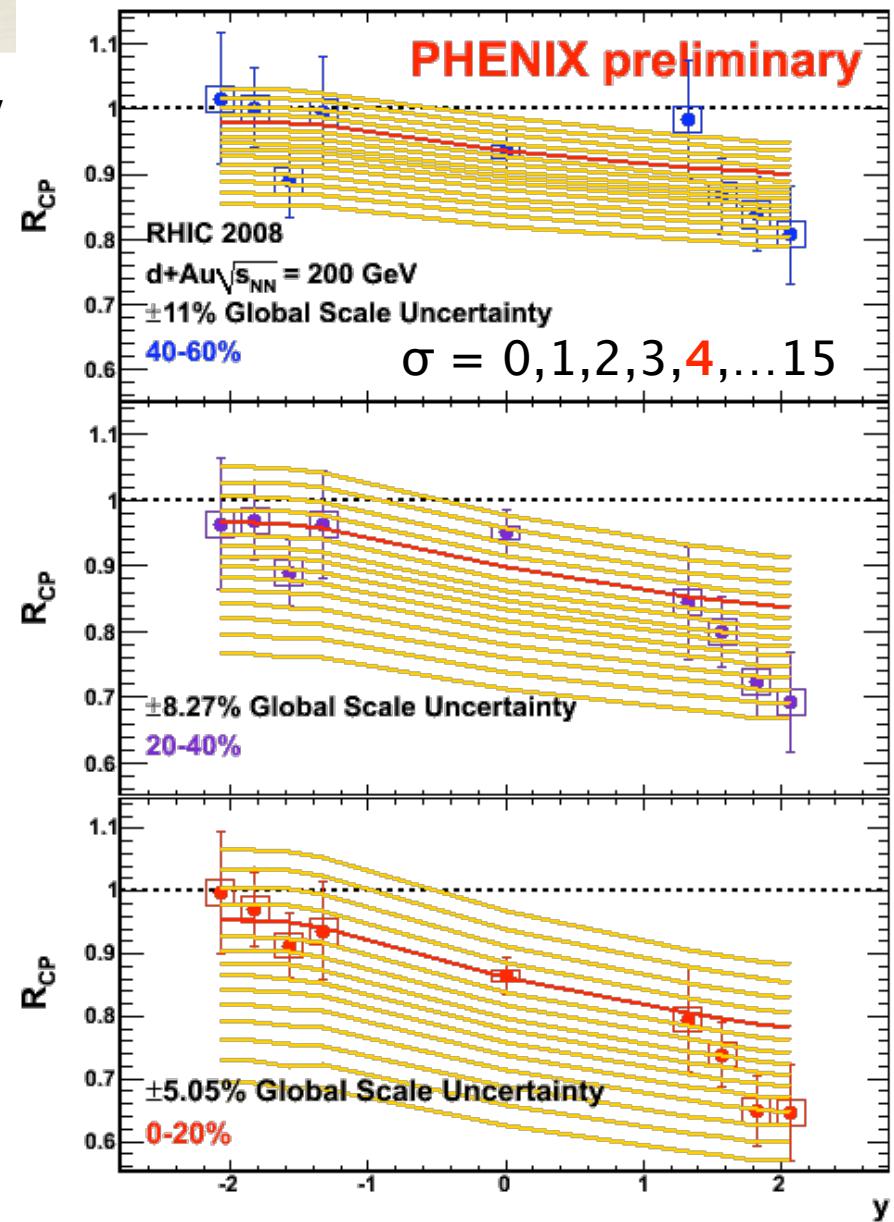
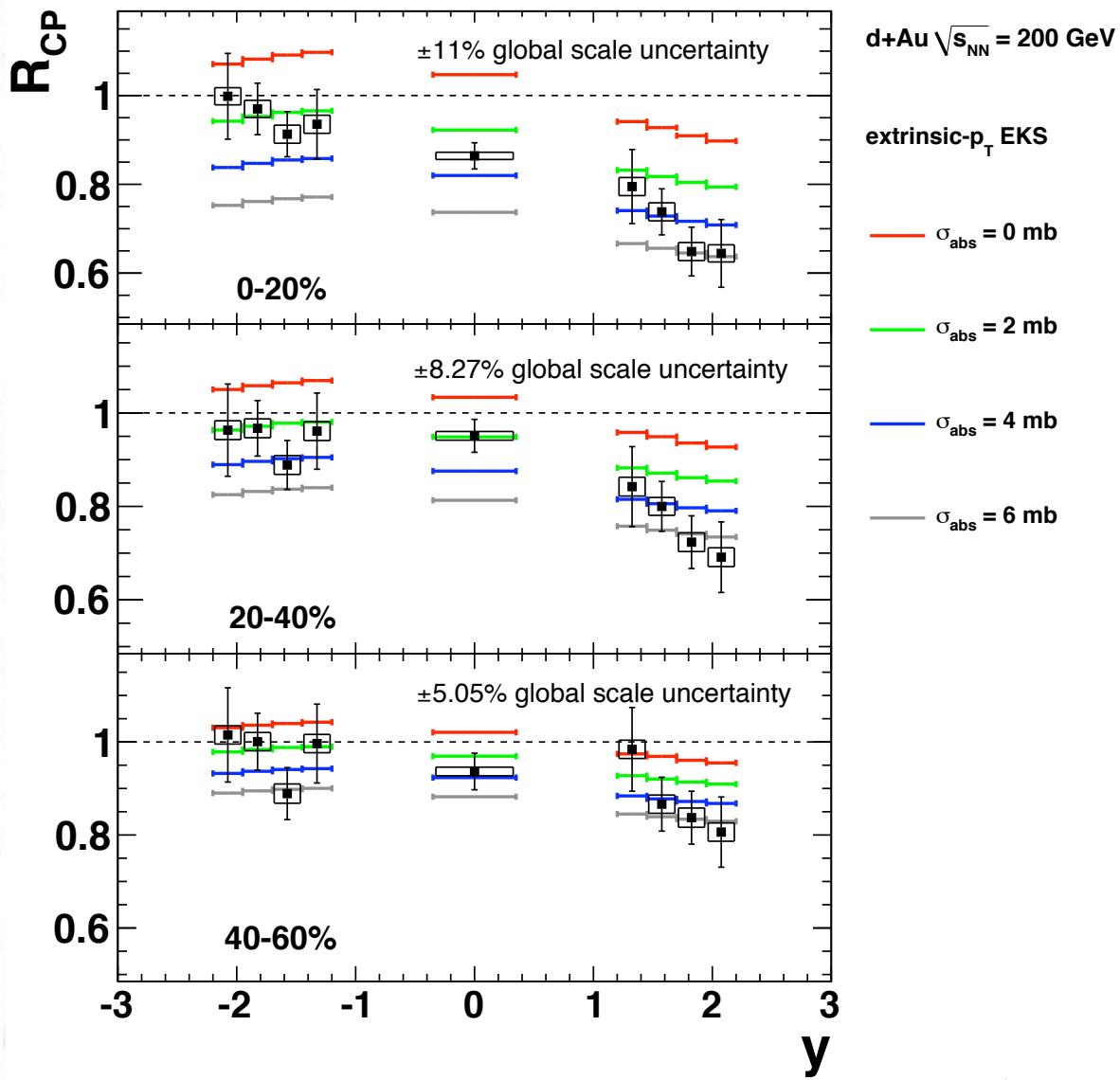
data: PHENIX preliminary

EKS98

EPS08

# A closer look at $R_{CP}$ vs $y$ in d+Au with EKS98

$g + g \rightarrow J/\psi + g$       EKS98       $g + g \rightarrow c\bar{c}$

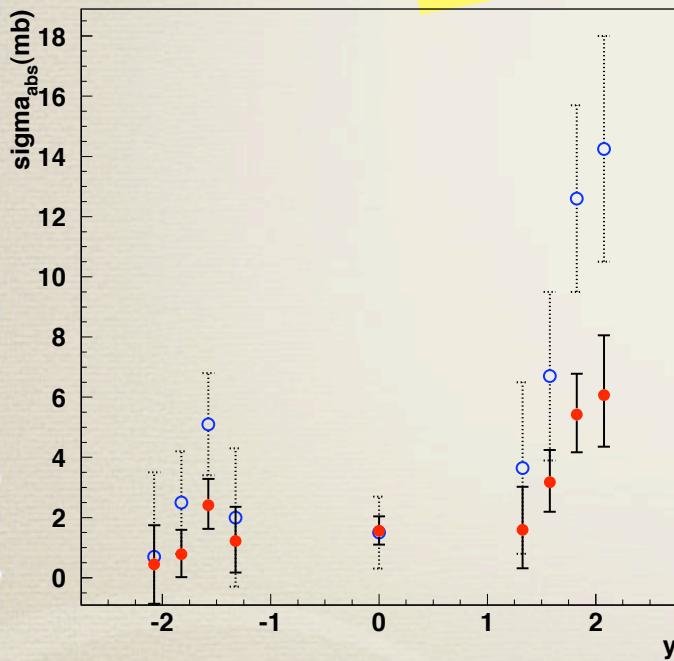


# CEM vs s-channel cut CSM as prod. model : $\sigma_{\text{abs}}(y)$ from Rcp in d+Au @ 200 GeV

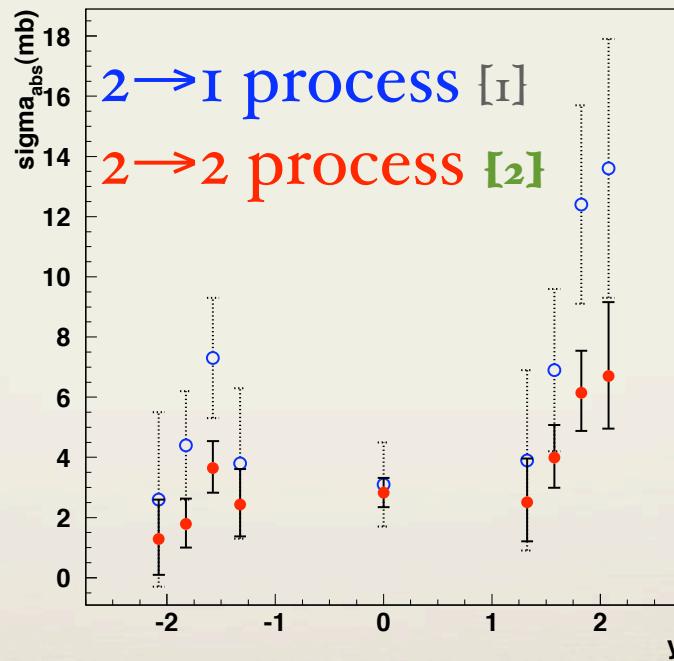
  $\sigma_{\text{abs}}(y)$  much flatter  
for the  $2 \rightarrow 2$  process

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

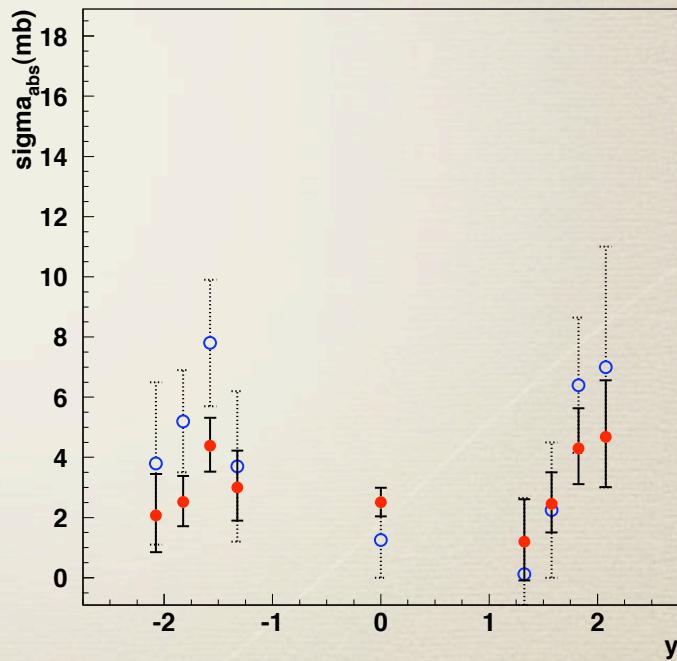
[2] E. G. Ferreiro, F. Fleuret, J. P. Lansberg  
and A. R., arXiv:0912.4498



nDSg



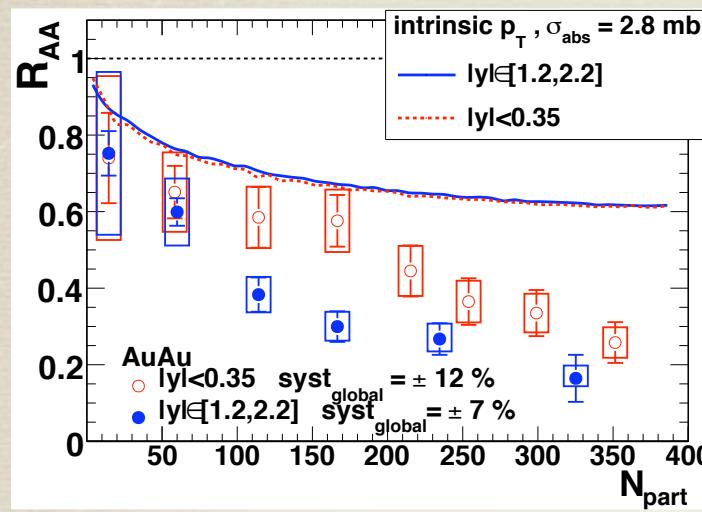
EKS98



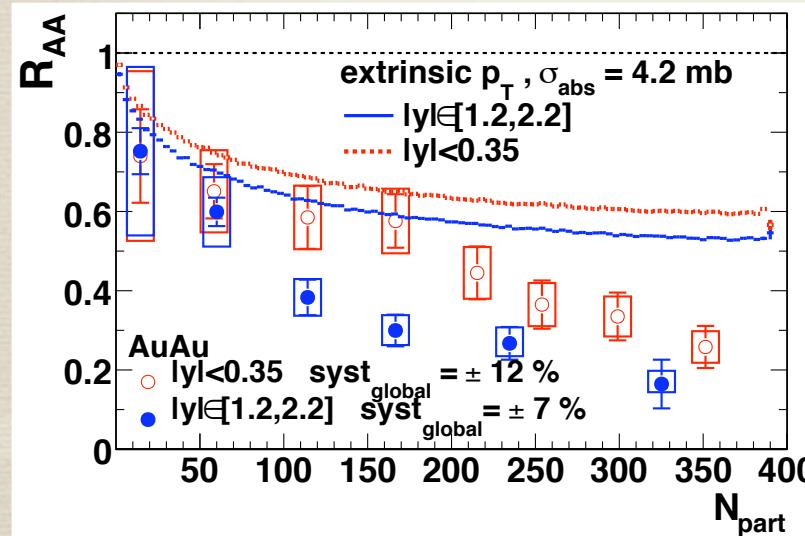
EPS08

# Cold effects in Au+Au

$2 \rightarrow I$  process : mid-y & fwd-y

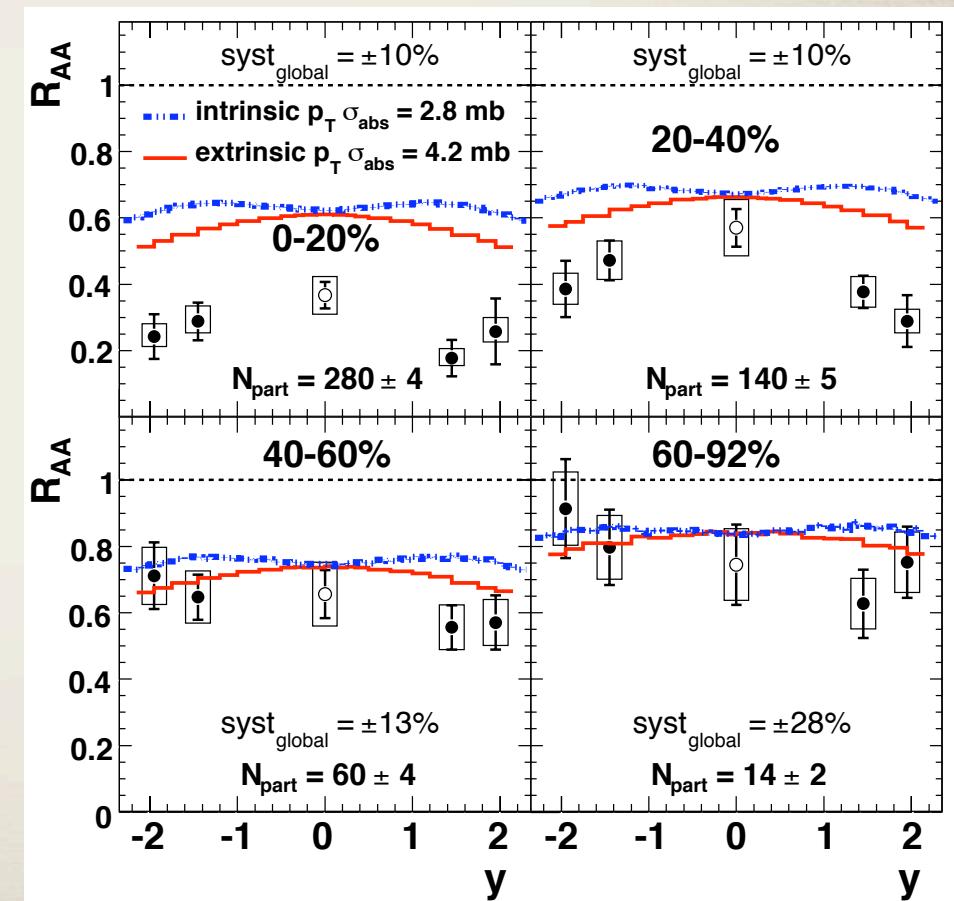


$2 \rightarrow 2$  process : mid-y & fwd-y



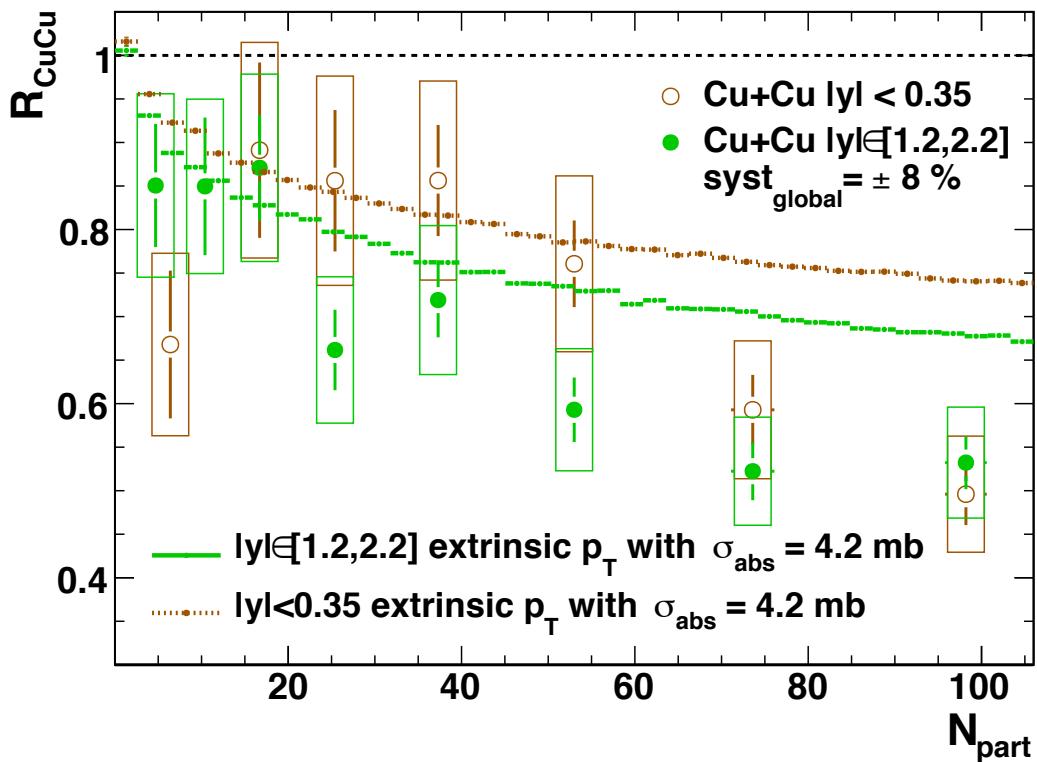
2 → 2 process :  
 less amount of  
 recombination needed  
 $2 \rightarrow I$  VS  $2 \rightarrow 2$  process

using EKS98



# Cold effects in Cu+Cu : extrinsic scheme

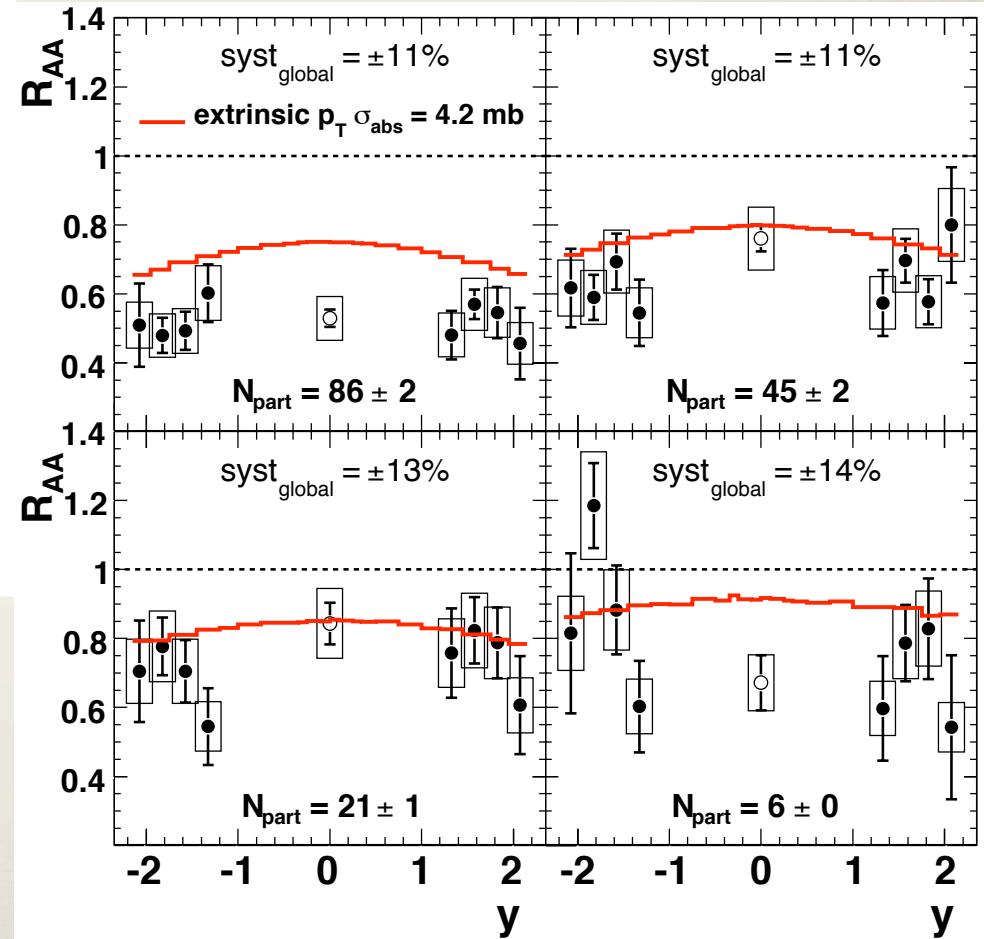
$2 \rightarrow 2$  process : mid-y & fwd-y



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

using EKS98

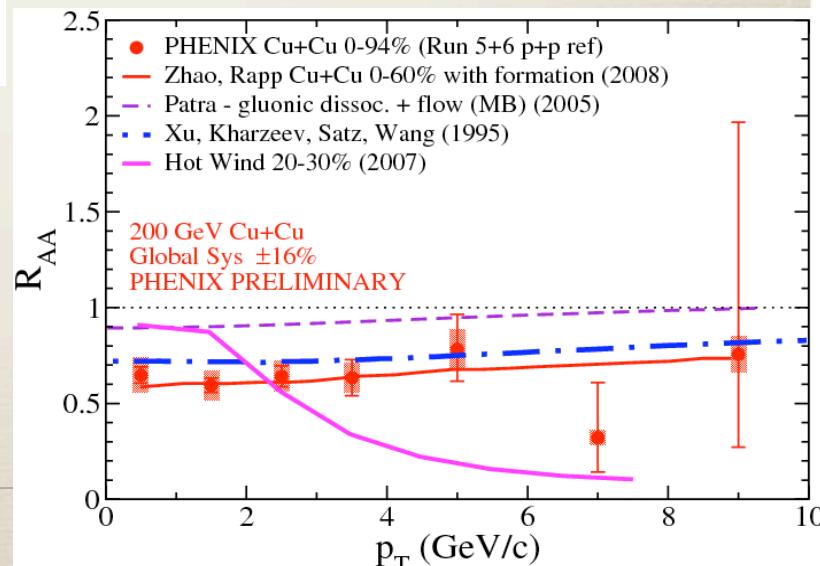
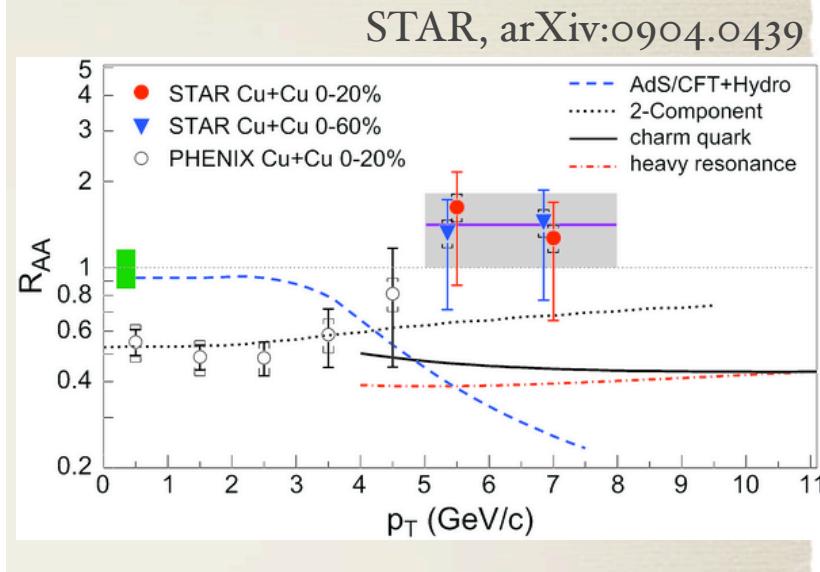
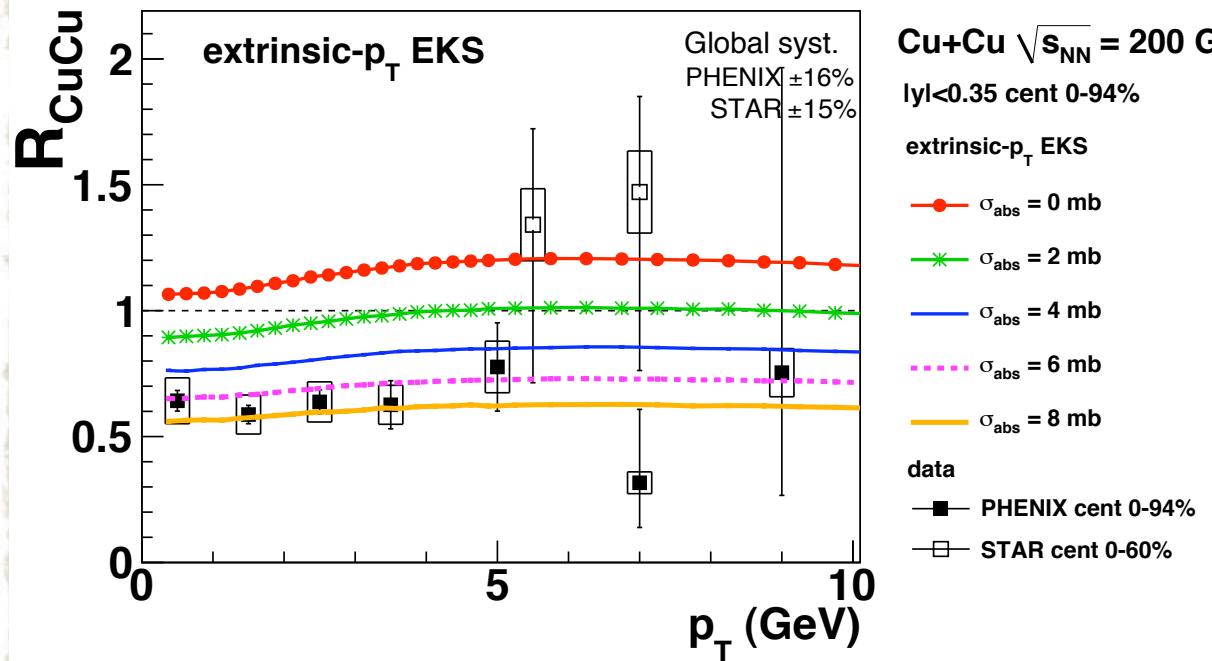
$2 \rightarrow 2$  process



# Cold effects in Cu+Cu : pt dependence in the extrinsic scheme

E. G. Ferreiro, F. Fleuret,  
 J. P. Lansberg  
 and A. R., arXiv:0912.4498

$2 \rightarrow 2$  process EKS98



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

# Conclusion and outlook

- ✿ Shadowing computations can benefit from an improved knowledge of quarkonia production process
  - ✿  $d\sigma/dp_T$  : for now, we use s-channel cut CSM
  - ✿ maybe go to CSM at NLO(\*) or NNLO\*
  - ✿ a piece of the LO was missing  $g + c \rightarrow J/\psi + c$  (20% of the rate, S.J. Brodsky, J.P. Lansberg, arXiv:0908.0754), could be used to study shadowing of  $c$  quark?
- ✿ Absorption x-section derivation from data depends on :
  - ✿ a better prod. model as an input for shadowing computation
  - ✿ nPDF uncertainties

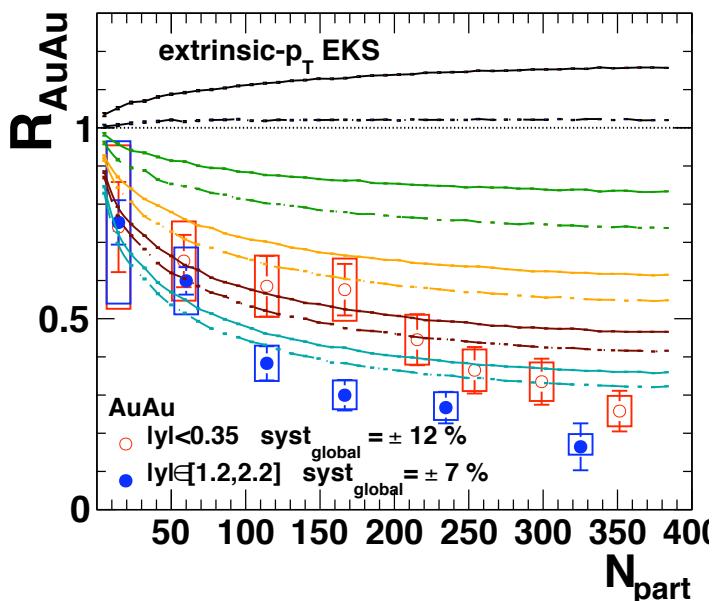
**BACK-UP**

# Cold effects in Au+Au : extrinsic scheme

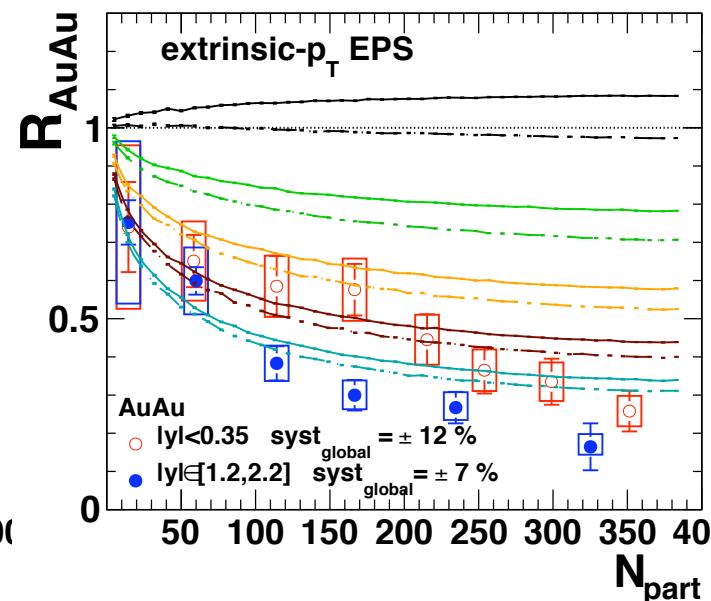
$2 \rightarrow 2$  process

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

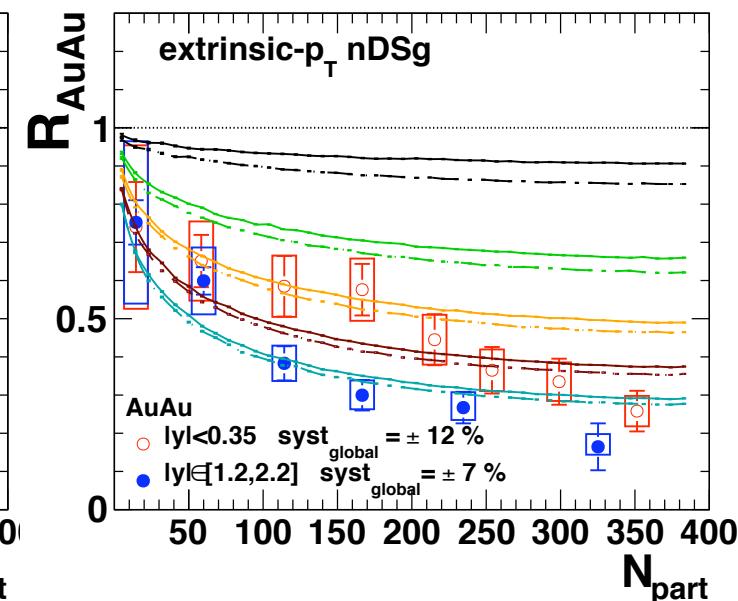
E. G. Ferreiro, F. Fleuret, J. P. Lansberg  
and A. R., arXiv:0912.4498



EKS98



EPS08

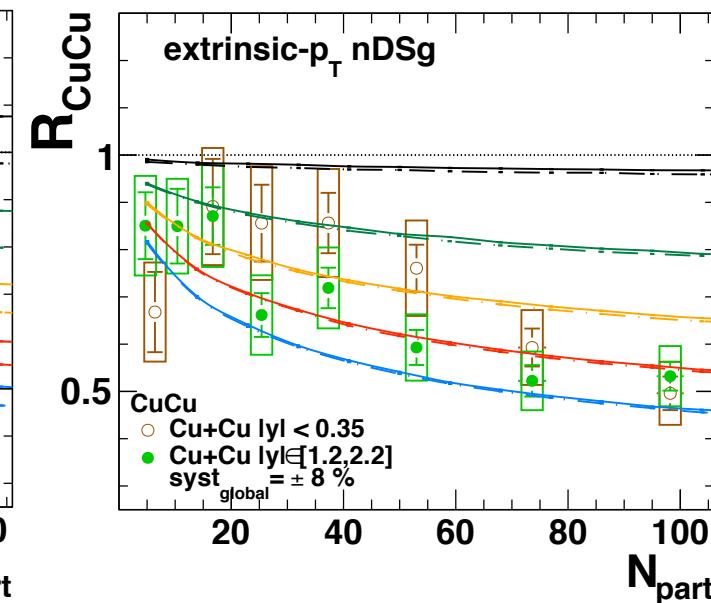
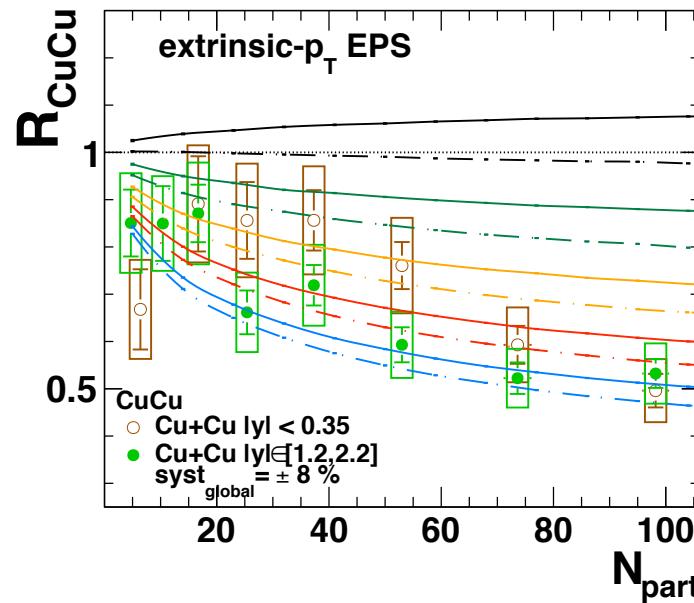
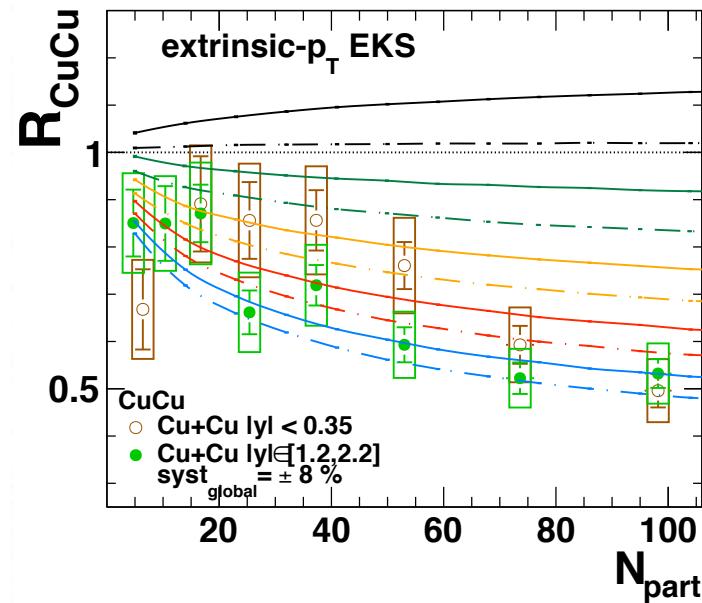


nDSg

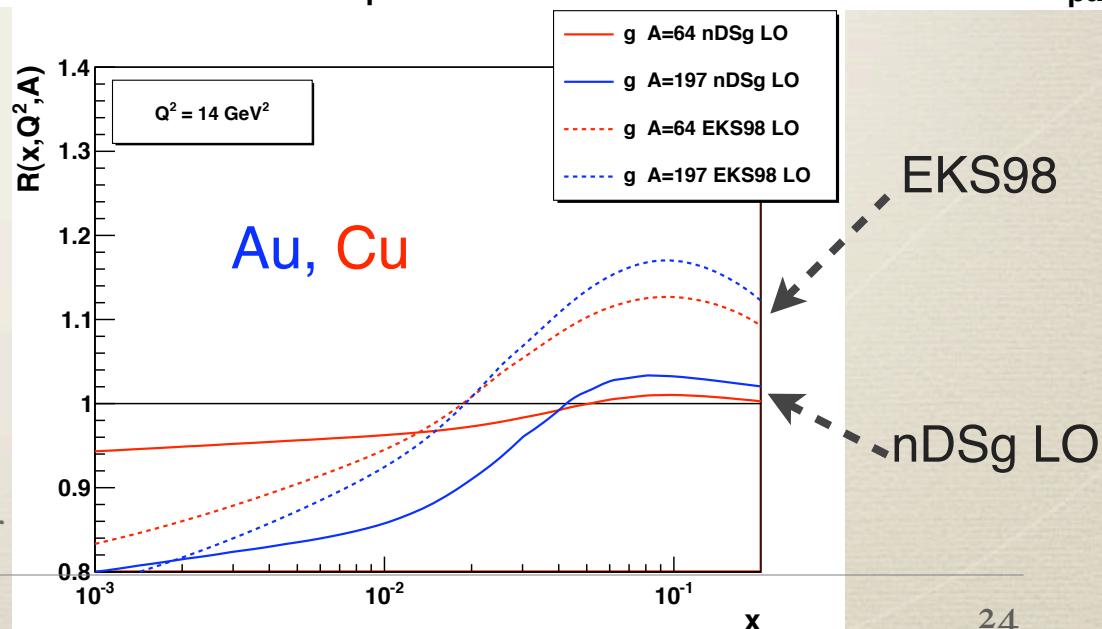
# Cold effects in Cu+Cu : extrinsic scheme

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

E. G. Ferreiro, F. Fleuret, J. P. Lansberg  
and A. R., arXiv:0912.4498



$2 \rightarrow 2$  process



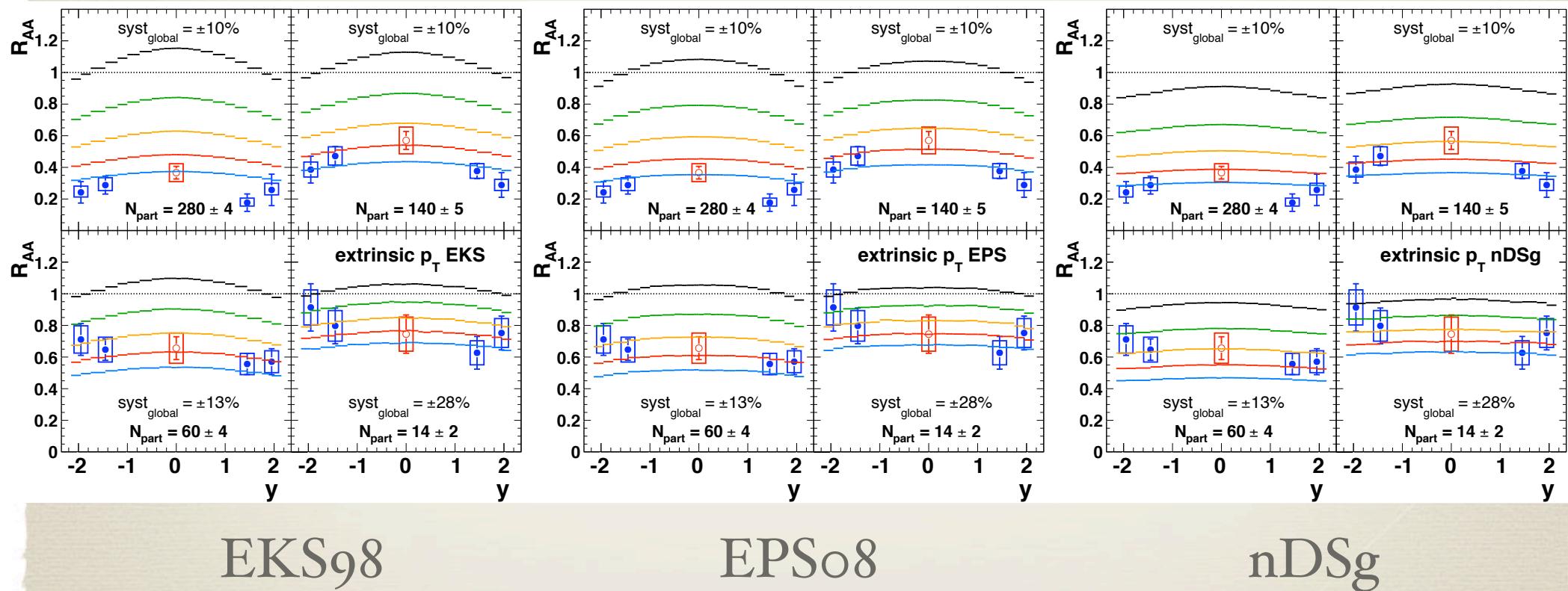
<http://lappweb.in2p3.fr/lapth/npdfgenerator>

# Cold effects in Au+Au : extrinsic scheme

$2 \rightarrow 2$  process

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

E. G. Ferreiro, F. Fleuret, J. P. Lansberg  
and A. R., arXiv:0912.4498



EKS98

EPS08

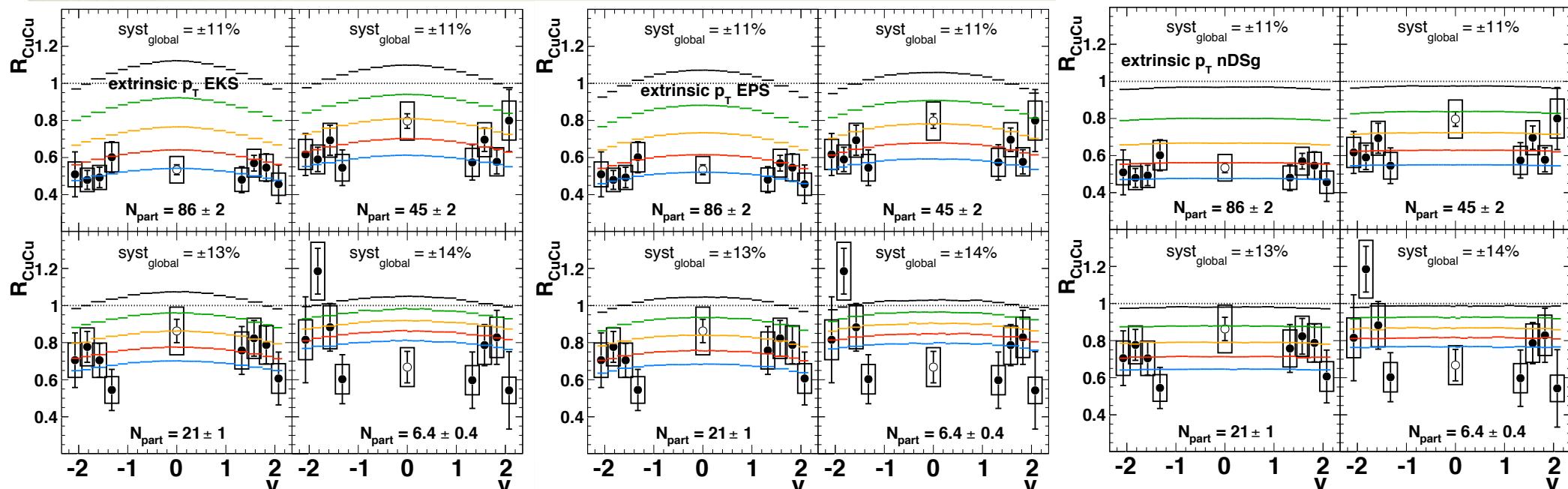
nDSg

# Cold effects in Cu+Cu : extrinsic scheme

$2 \rightarrow 2$  process

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

E. G. Ferreiro, F. Fleuret, J. P. Lansberg  
and A. R., arXiv:0912.4498



EKS98

EPS08

nDSg

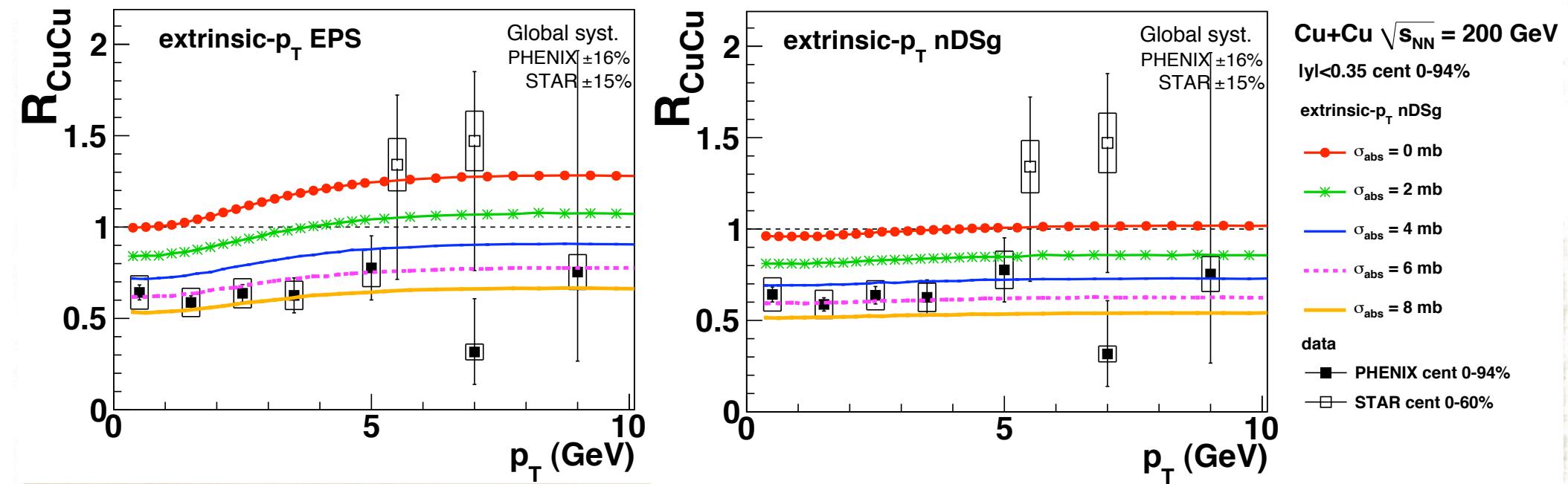
# Cold effects in Cu+Cu : $p_T$ dependence in the extrinsic scheme

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

2 $\rightarrow$ 2 process

EPS08

nDSg

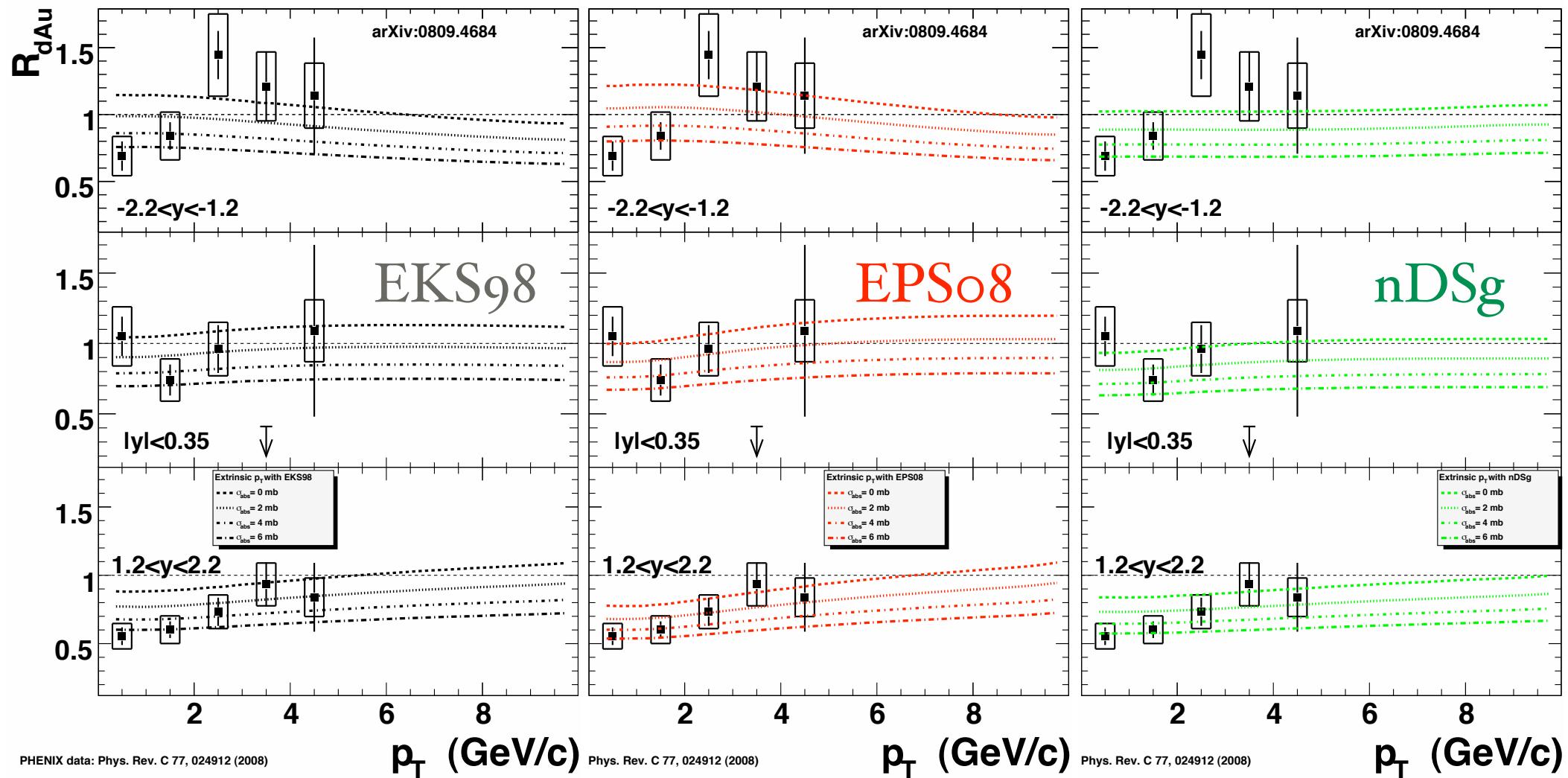


# Cold effects in d+Au : $p_T$ dependence in the extrinsic scheme

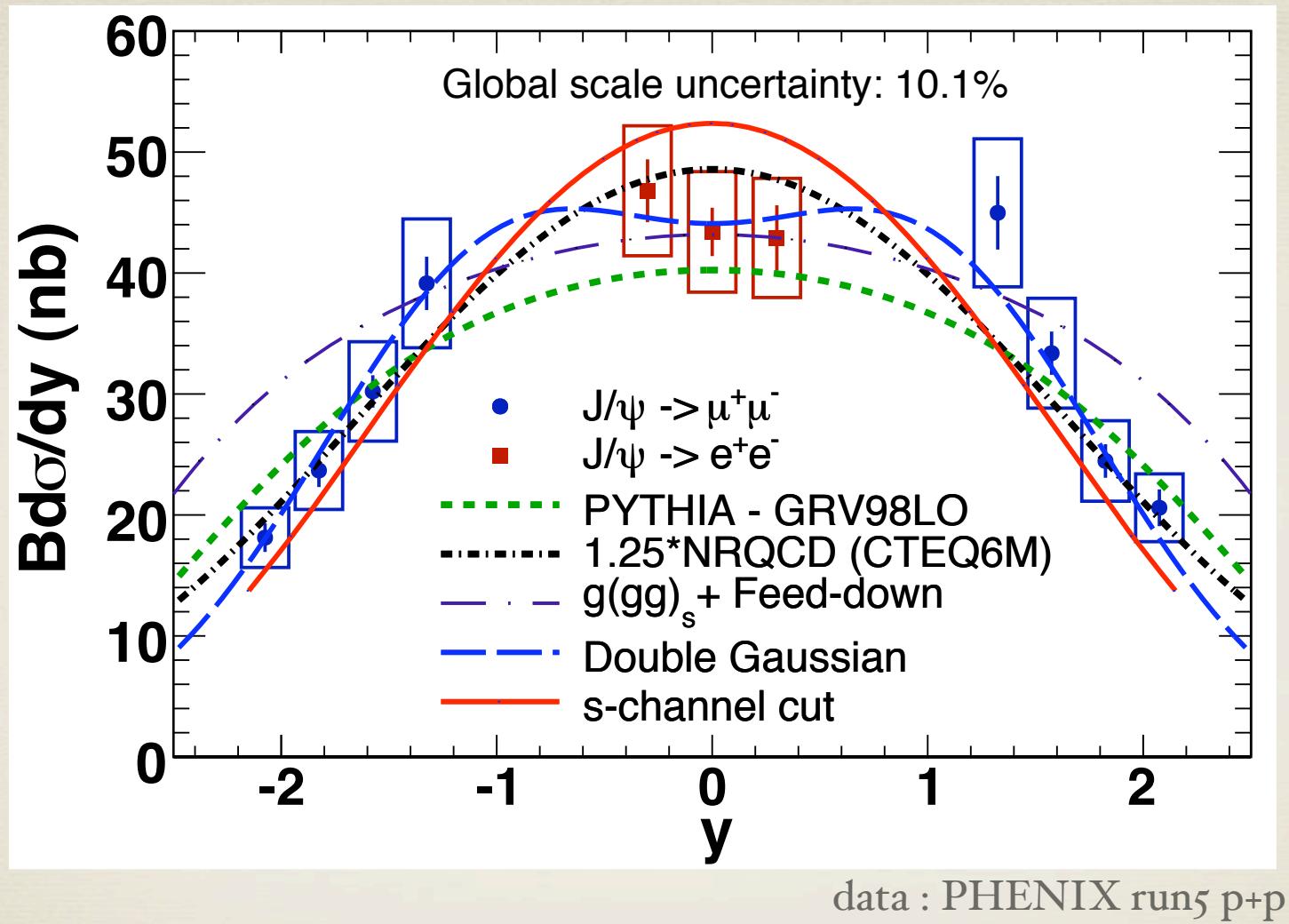
absorption : 0, 2, 4, 6 mb

$2 \rightarrow 2$  process

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



# Various models for the $y$ spectra in $p+p$

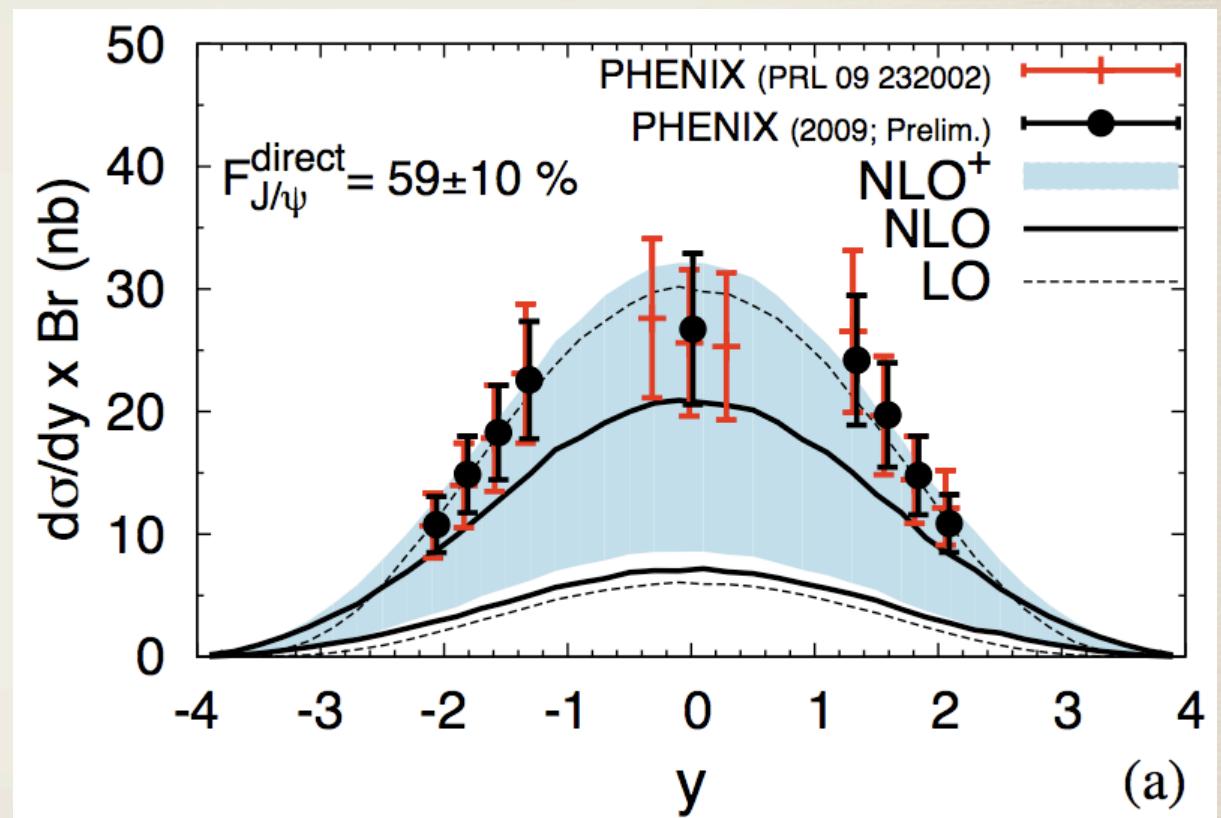


[NRQCD calculation] Cooper, Liu & Nayak, Phys. Rev. Lett. 93, 171801 (2004)

[ $g(gg)_s + \text{Feed-down}$ ] Khoze, Martin, Ryskin Stirling, Eur. Phys. J. C39, 163 (2005)

# CSM LO, NLO, NLO+ $cg$ vs the y spectra in p+p

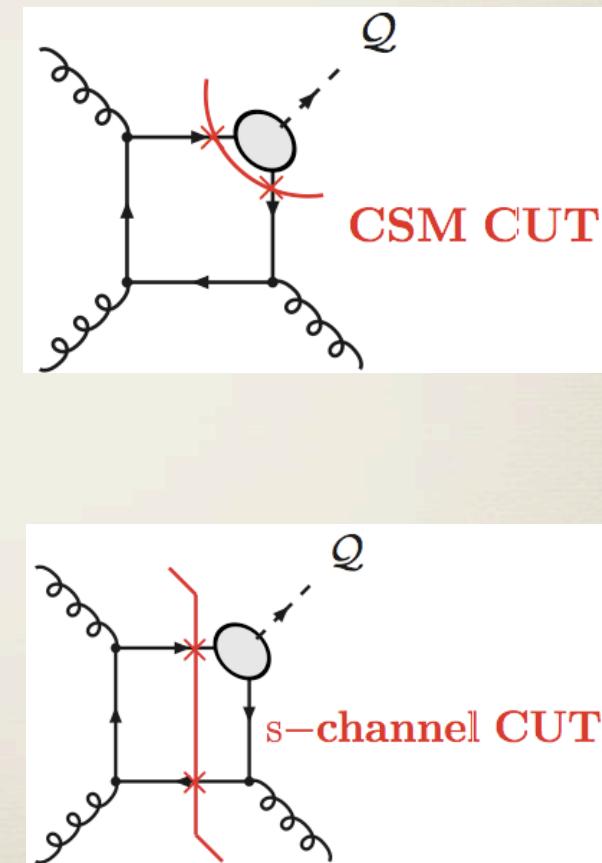
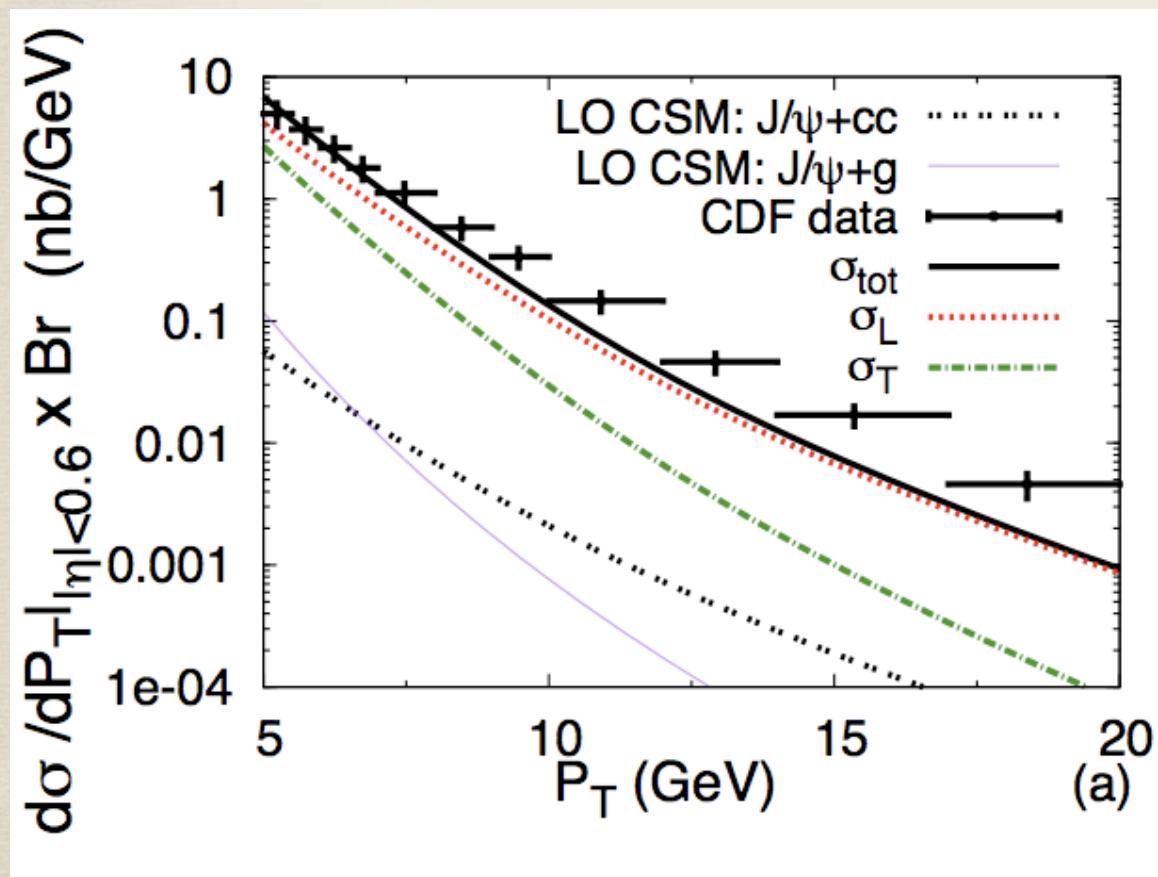
points : y spectra for  
the *direct* J/ $\psi$ ,  
as extrapolated from  
PHENIX spectra



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

# S-channel cut model vs Tevatron pt spectra

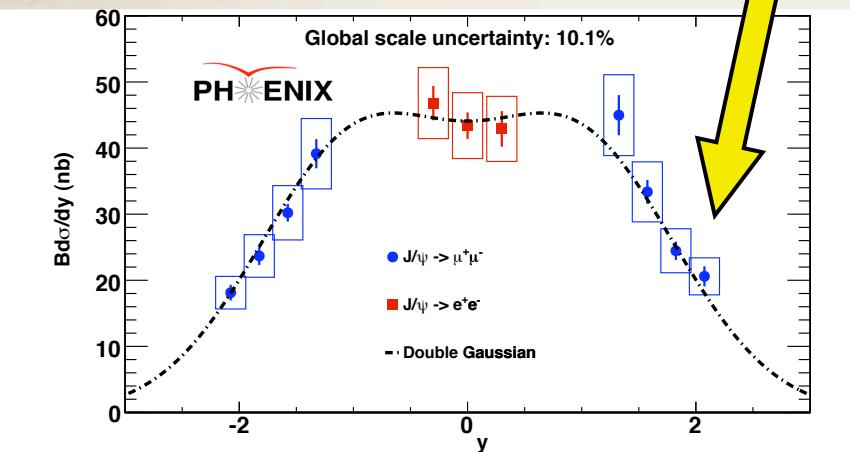
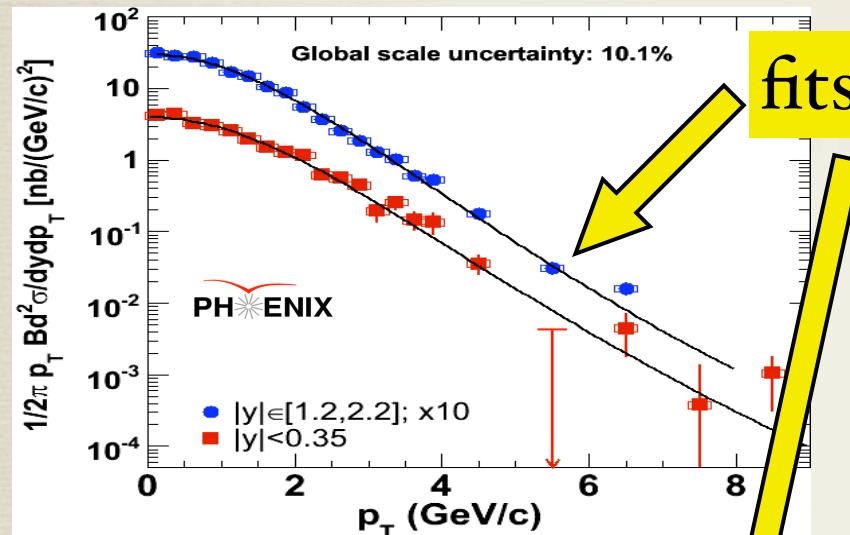
H. Haberzettl et J. P. Lansberg,  
PRL 100, 032006 (2008)



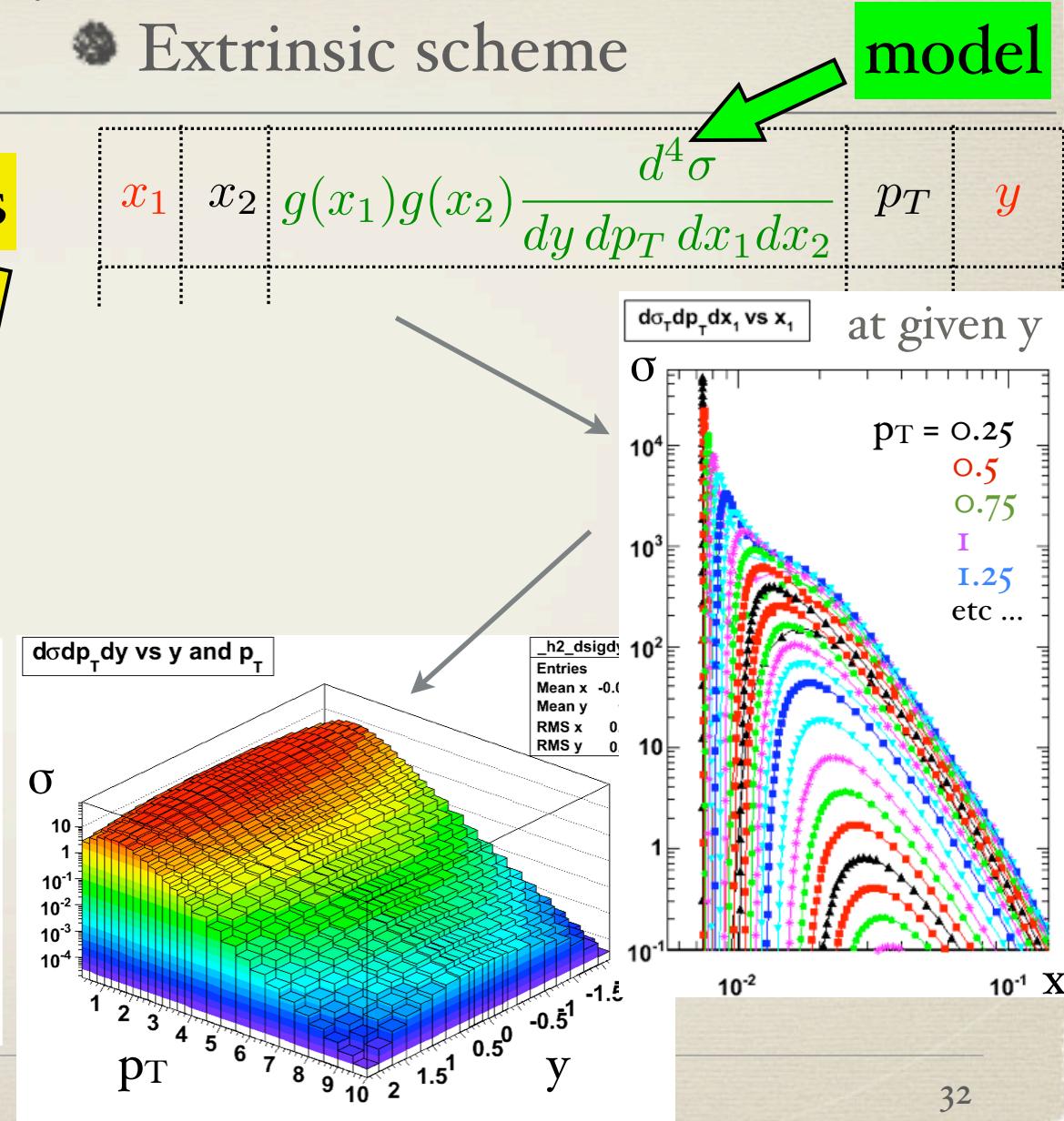
# Adding the pt dependence

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

## Intrinsic scheme



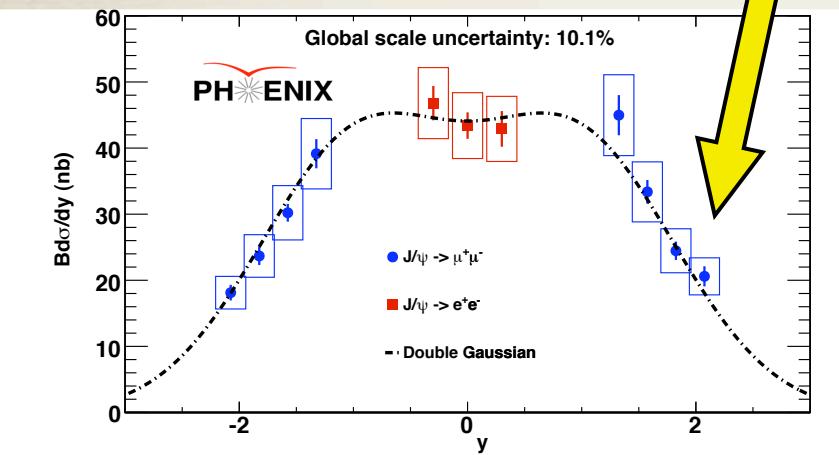
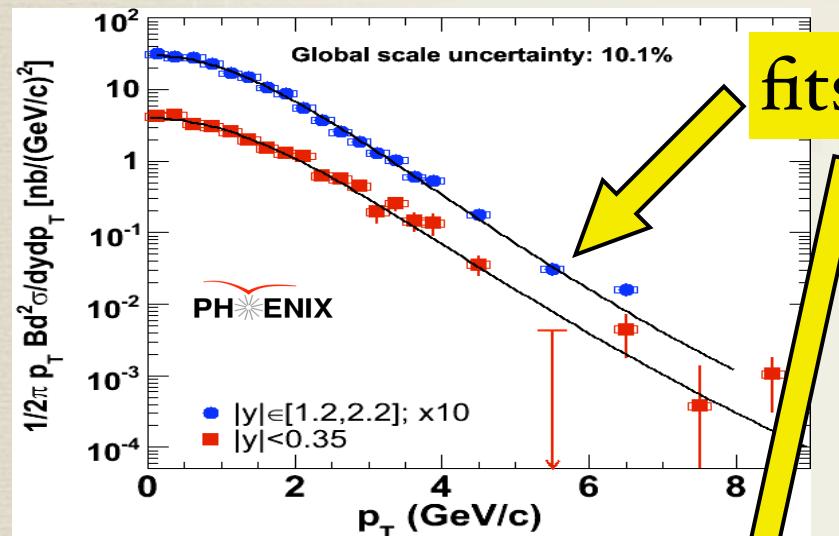
## Extrinsic scheme



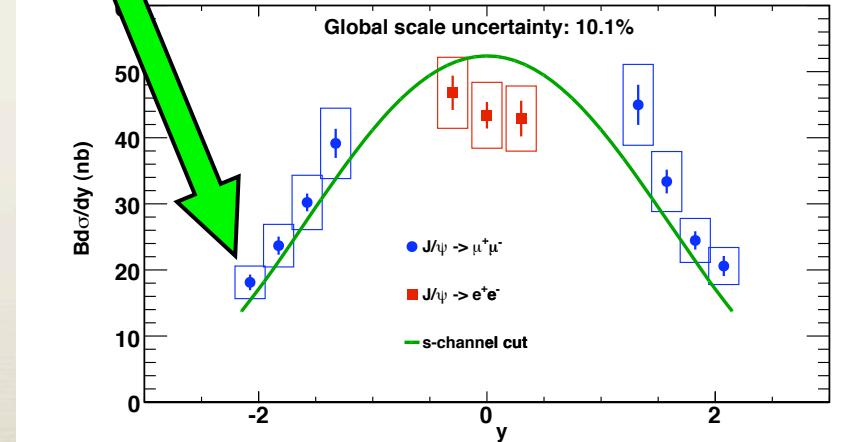
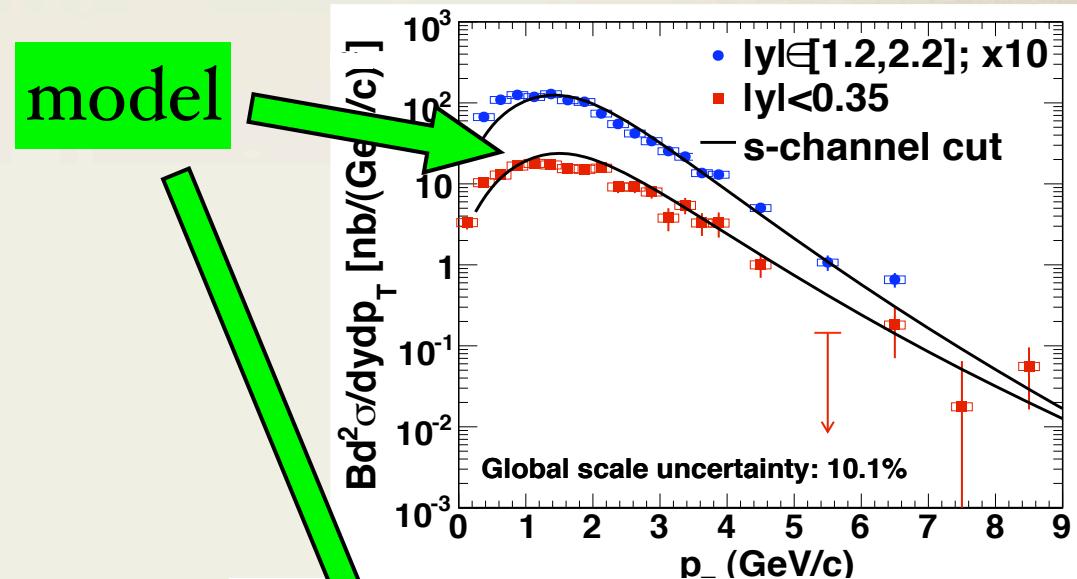
# Adding the pt dependence

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

## Intrinsic scheme



## Extrinsic scheme



# Our Monte-Carlo approach for J/ $\psi$ production

1

2

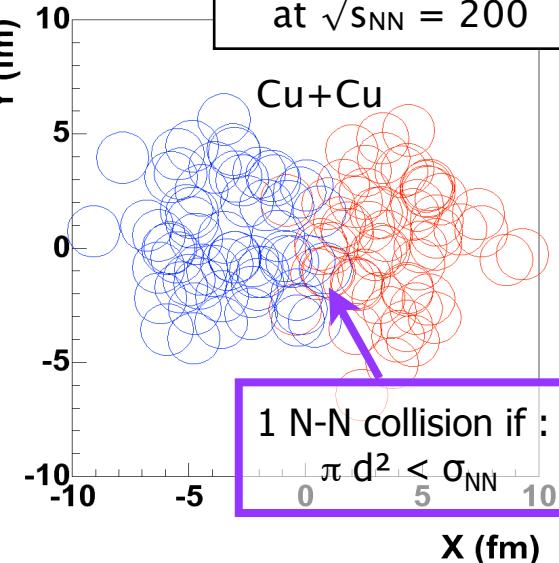
3

## Glauber MC

$$\sigma_{NN} = 42\text{mb}$$

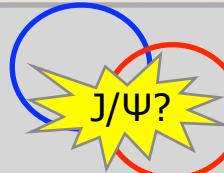
at  $\sqrt{s_{NN}} = 200$

Cu+Cu



Random :

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



2

For each N-N collision

## J/ $\psi$ candidate produced

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

with random :

- $y$  and  $\mathbf{p}_T$
- random  $p_T$  orientation  $\Phi$  uniformly distributed in  $[0, 2\pi]$
- $\mathbf{x}_1, \mathbf{x}_2$  determined from intrinsic or extrinsic scheme

Kinematics for J/ $\psi$  candidate:  
 $y, \mathbf{p}_T, \Phi, M \Rightarrow \mathbf{p}_x, \mathbf{p}_y, \mathbf{p}_z, E$

3

J/ $\psi$  candidate  $\Rightarrow$  real J/ $\psi$  if :

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

computed using EKS

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

# CNM effects at SPS energy with CEM as prod. model

- Usually CEM LO when looking at the yield integrated over  $p_T$ :

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

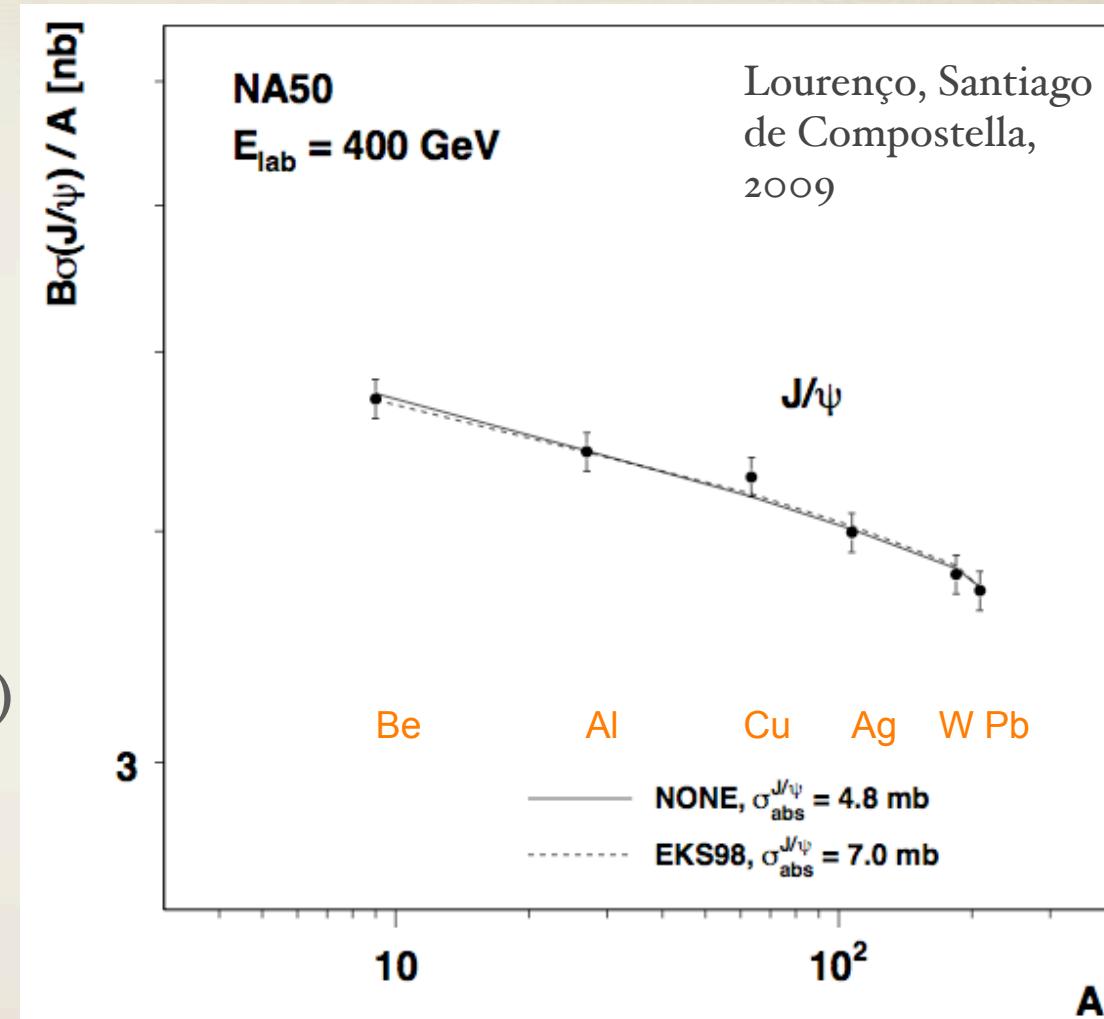
$$x_{1,2} = \frac{m}{\sqrt{s_{NN}}} e^{\pm y}$$

- Absorption cross-section needed on top of the resulting shadowing (NA50)

EKS98  $7.0 \pm 0.7$  mb

nDSg  $4.7 \pm 0.6$  mb

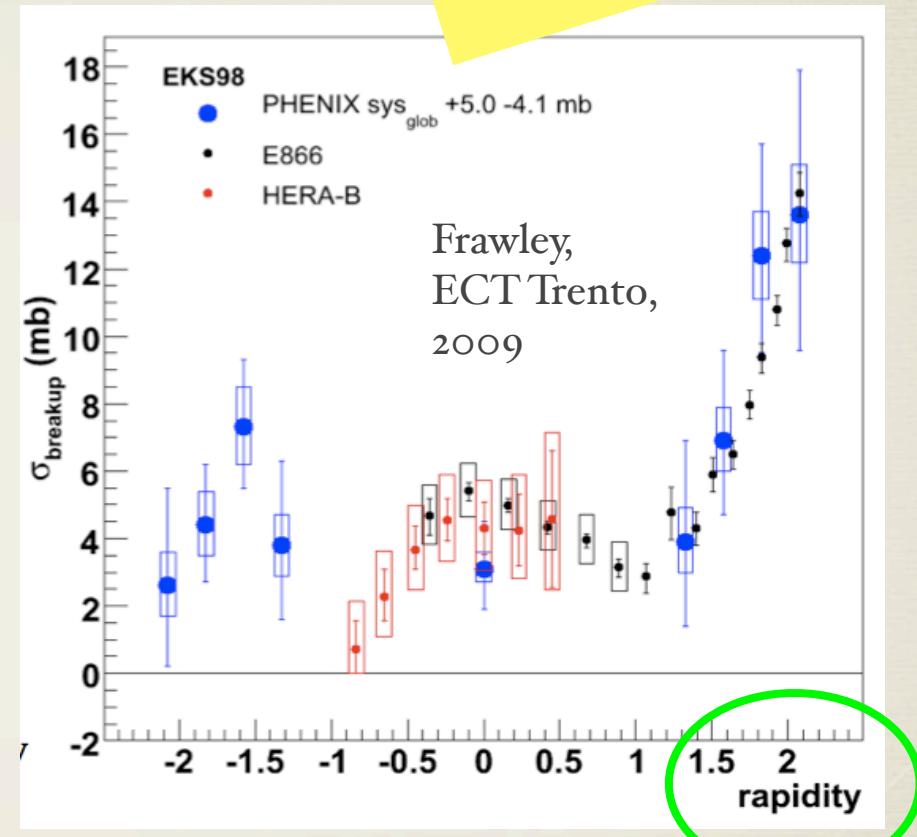
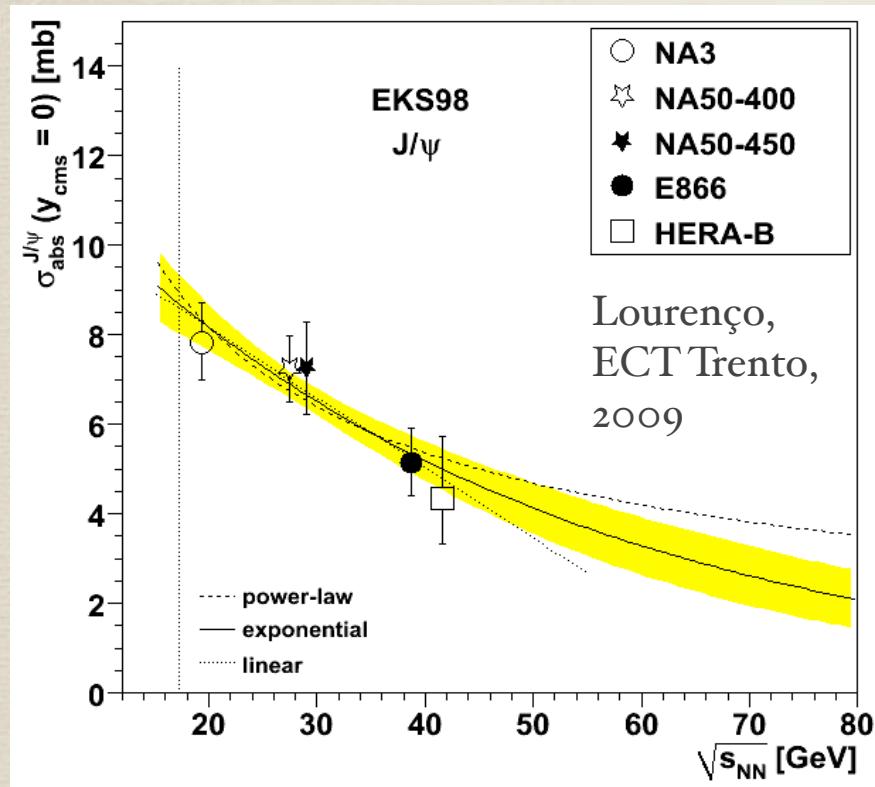
EPS08  $8.0 \pm 0.7$  mb



Lourenço, Vogt, Wöhri, JHEP 0902:014 (2009)

# What about any dependence of $\sigma_{\text{abs}}$ on kinematics ?

investigated assuming  
 $2 \rightarrow 1$  process only !



# What about any dependence of $\sigma_{\text{abs}}$ on kinematics ?

investigated assuming  
 $2 \rightarrow 1$  process only !

