Rencontres QGP-France, Etretat 19 septembre 2007

Quarkonia & QGP

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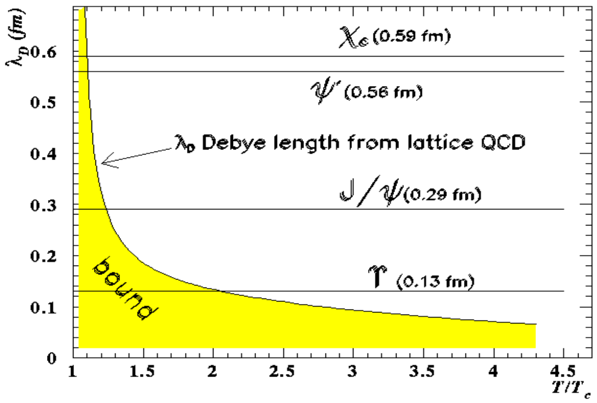
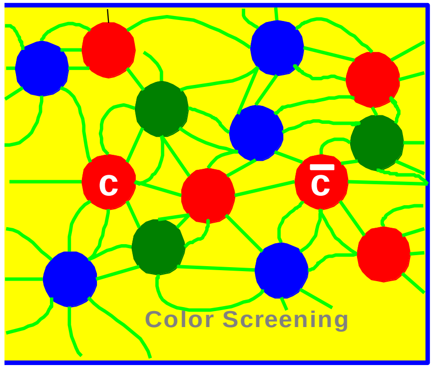
Espagne

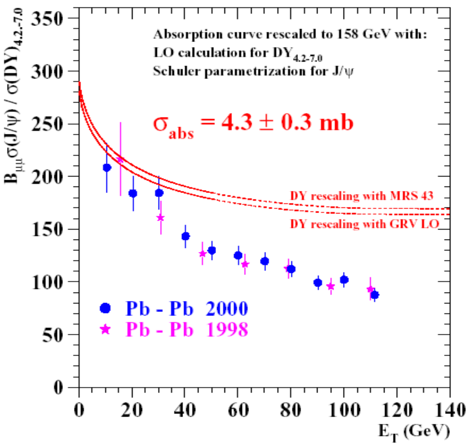
The J/Ψ production: An intringuing story...

Matsui and Satz: J/ψ destruction in a QGP by Debye screening

different states “melting” at different temperatures due to different binding energies.



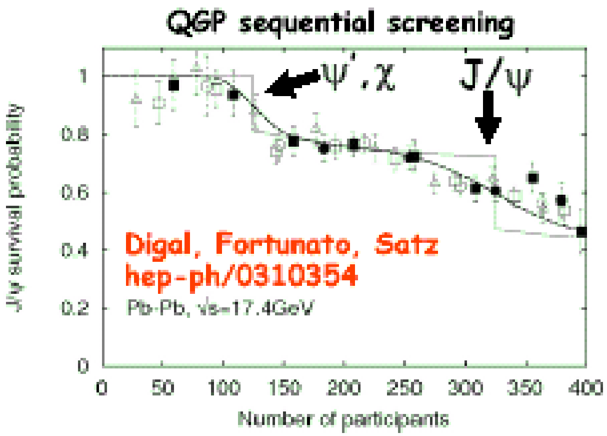


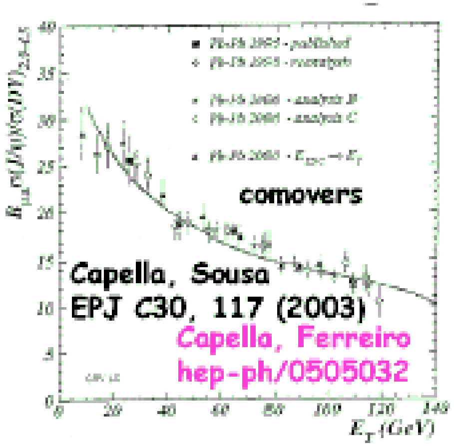


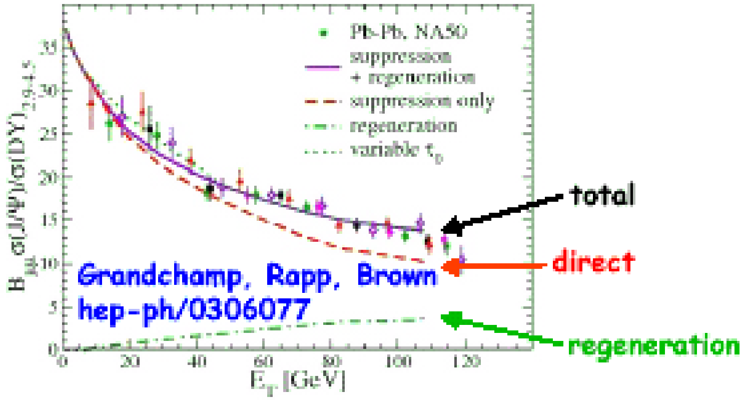
SPS experimental results presented *a compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons are liberated to roam freely.*

NA50 anomalous suppression

Theoretical models at SPS: w or wo QGP?



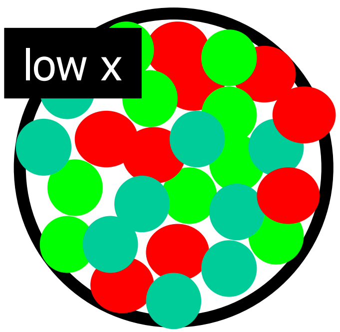


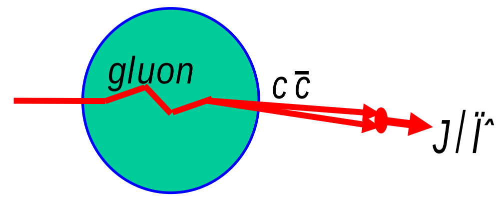


Too many effects...

nuclear absorption

CGC





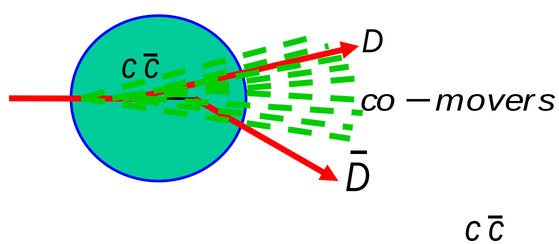
cronin effect

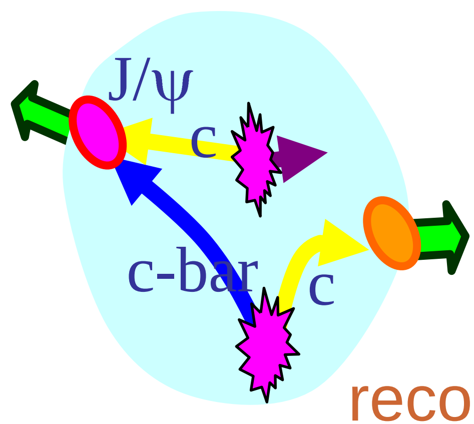
percolation

sequential suppresion

gluon shadowing

hadronic comovers



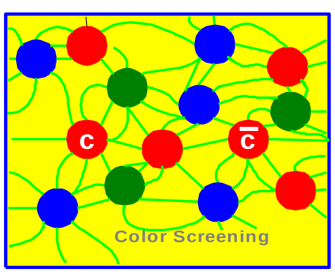


pomeron shadowing

recombination

partonic comovers

QGP



parton saturation

Confusing way to distinguish the effects...

- **initial effects**

nuclear absorption

gluon shadowing

pomeron shadowing

partonic comovers

CGC

percolation

parton saturation

cronin effect

....

- **final effects**

hadronic comovers

QGP

sequential suppresion

recombination

Better: COLD or HOT effects **wo or w QGP**

•cold effects

nuclear absorption

multiple scattering of a pre-resonance c-cbar pair within the nucleons of the nucleus

IMP@SPS, NI@RHIC

gluon shadowing

pomeron shadowing

nuclear structure functions in nuclei $\neq$ superposition of constituents nucleons

FKG, EKS, pomeron CF

IMP@RHIC, NI@SPS

CGC

percolation

parton saturation

recombination effects favoured by the high density of partons become important and lead to eventual saturation of the parton densities

non thermal colour connection

partonic comovers

hadronic comovers

dissociation of the c-cbar pair with the dense medium produced in the collision **partonic or hadronic**

suppression by a dense medium, not thermalized

recombination

•hot effects

QGP

sequential suppresion

recombination

HOT effects: sequential dissociation

screening the J/Ψ in a QGP

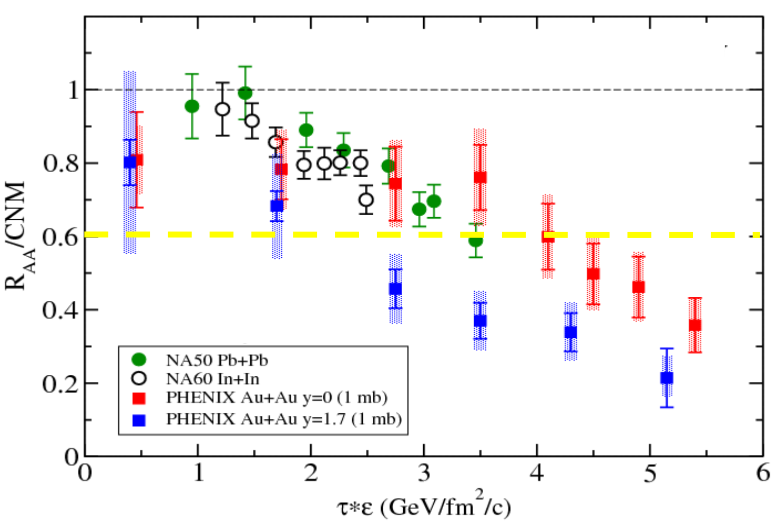
- J/Ψ production:
  - ~ 60% direct production J/Ψ
  - ~ 30% via $\chi_c \rightarrow$ J/Ψ + x
  - ~ 10% via Ψ'→ J/Ψ + x

$S_{J/\Psi} = 0.6\, S_{\Psi} + 0.4\, S_{\chi_c}$

- Temperature of dissociation T_d
  for χ_c and Ψ': $T_d \sim 1.1\, T_c$
  for J/Ψ : $T_d \sim 1.5$ to $2\, T_c$

• Sequential screening of the higher resonances that feed down the J/Ψ

- **J/Ψ itself not screened after all**

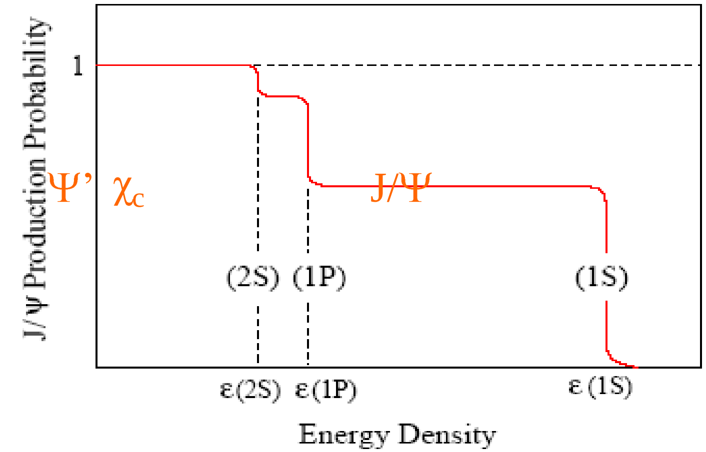


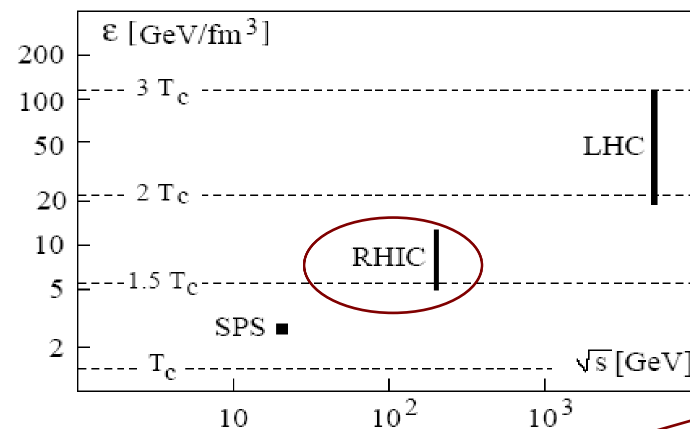
Supported by recent latice calculations:

$T_d \sim 2\, T_c$

Karsch, Kharzeev, Satz, hep-ph/0512239

Sequential dissociation as the temperature (or energy density) increases :





?

Energy density **(τ_0 = 1fm)** vs the max. √s for SPS, RHIC and LHC

HOT effects: QGP, recombination

•statistical coalescence model

Andronic, Braun-Muzinger,Redlich, Stachel, nucl-th/0303036

- screening of primary J/ψ & statistical
- recombination of thermalized c-cbar
- travel of c quarks over significant distance
- presence of a deconfined phase

qgp, recom

•recombination model

Grandchamp, Rapp, Brown, hep-ph/0306077

- screening & in-medium production
- includes effects of chemical equilibrium
- includes effects of thermal equilibrium

qgp, recom

•kinetic model

Thews hep-ph/0504226

- movility of initally produced charm quarks in a space-time region of color deconfinement
- allows formation of heavy quarkonium states via off-diagonal combinations of q & qbar

qgp, recom

•transport in a qgp

Yan, Zhuang, Xu, nucl-th/0608010

- transport equations for the Jpsi
- hydrodynamic equation for the qgp

qgp, w and wo recom

COLD effects: no QGP, recombination

suppression+recombination in a dense medium **wo thermalization**

- hadron string dynamics

Bratkovskaya, Kostyuk, Cassing, Stocker, nucl-th/0402042

- transport approach
- include backward channels for charmonium reproduction by D channels $D + \bar{D} \rightarrow \text{charmonia} + \text{meson}$
- full chemical equilibration not achieved in the transport calculations

no qgp, recom

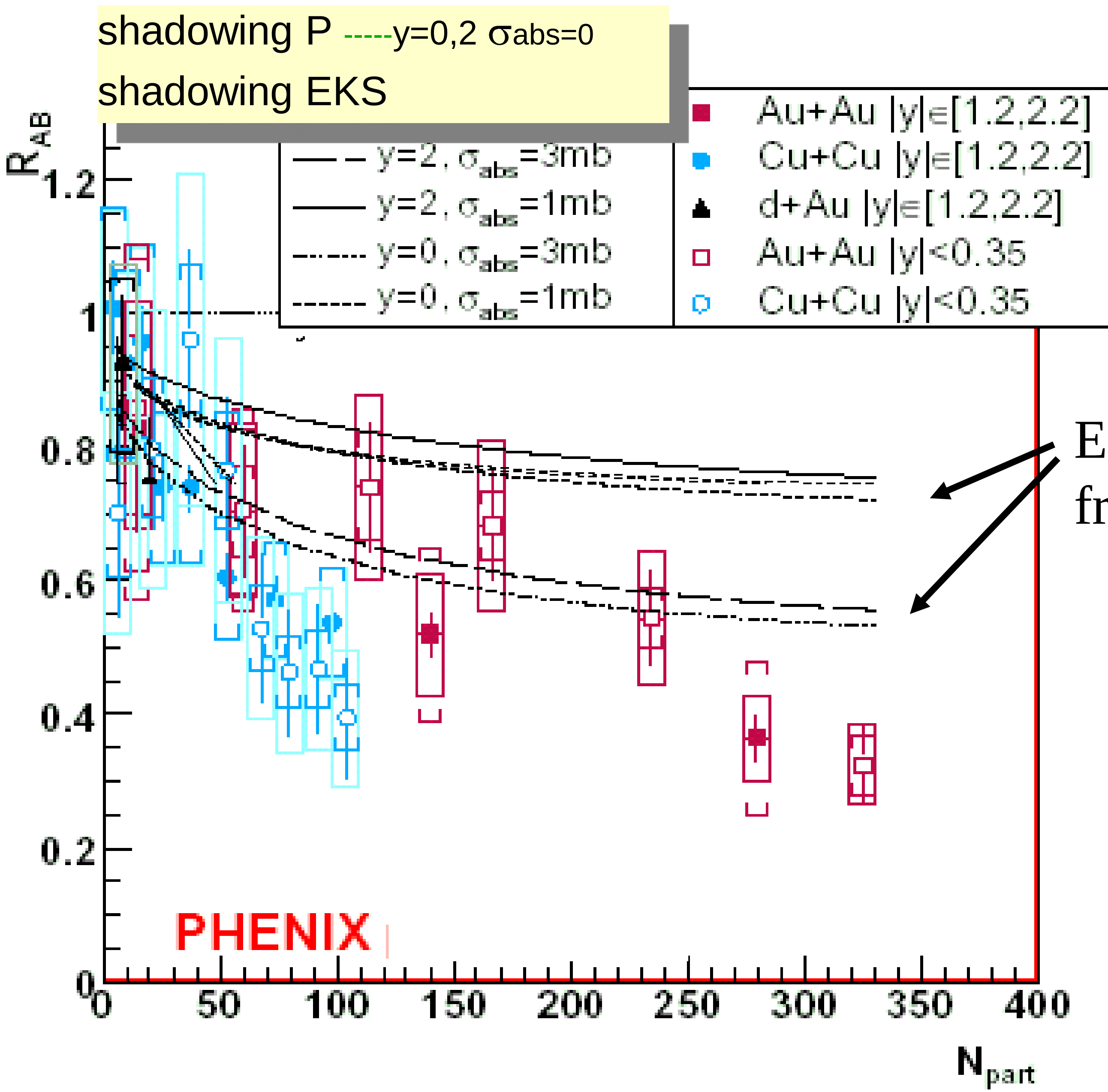
- comovers

K. Tywoniuk, I. C. Arsene, L. Bravina, A. Kaidalov, E. Zabrodin A. Capella, E. G. Ferreiro

- gain and loss diferential equations for:
  dissociation J/Ψ+comovers
  +
  recombination D+Dbar

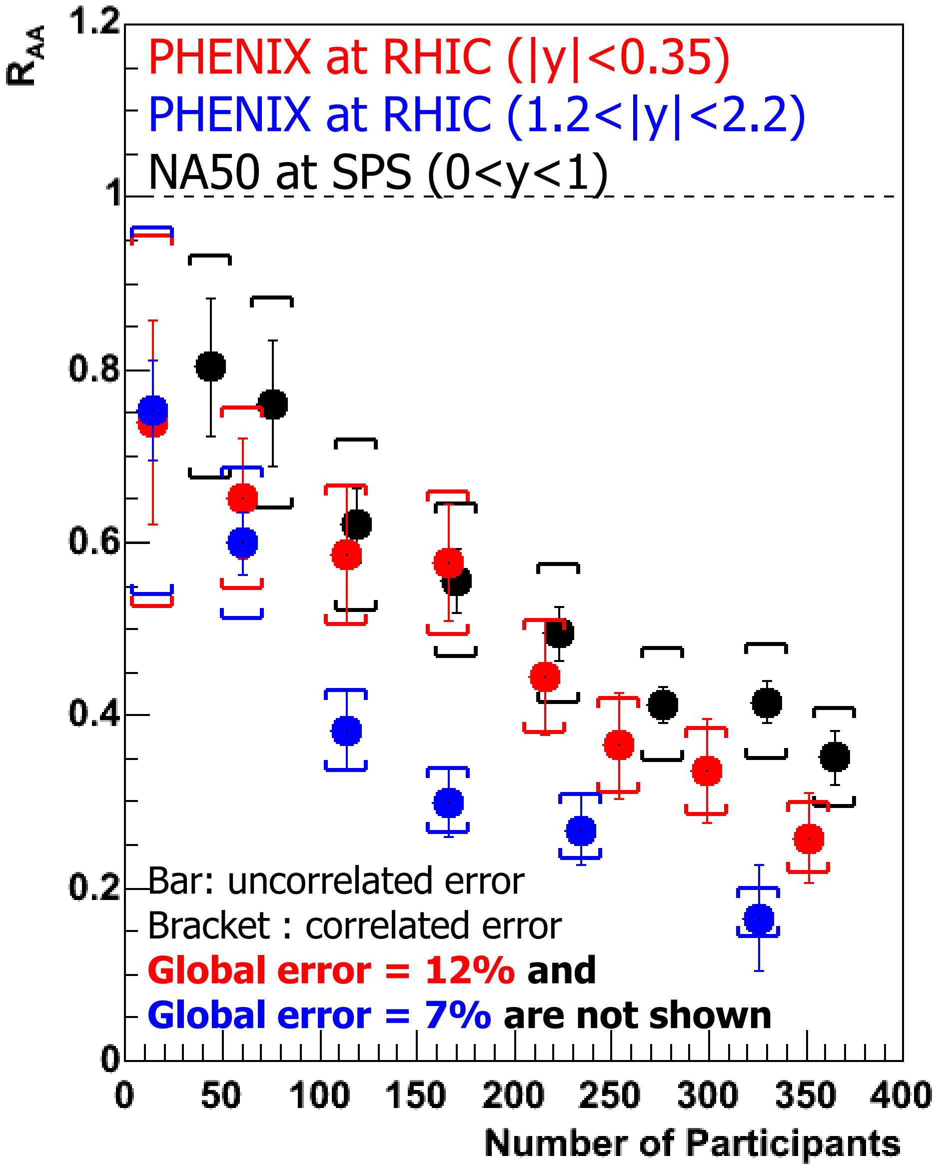
no qgp, recom

The data: R_{AA} vs centrality



Effects *vraiment* froids (Andry)

The data: RAA vs centrality



(Fred)

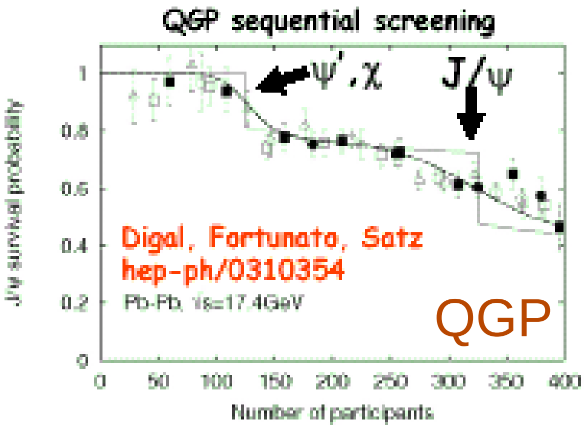
- Similar level of suppression:
  200 GeV Au+Au @ |y|<0.35
  158 GeV/A Pb+Pb @ 0<y<1
- Suppression at forward rapidity greater than at mid-rapidity
- Observed suppression greater than **initial** CNM predictions

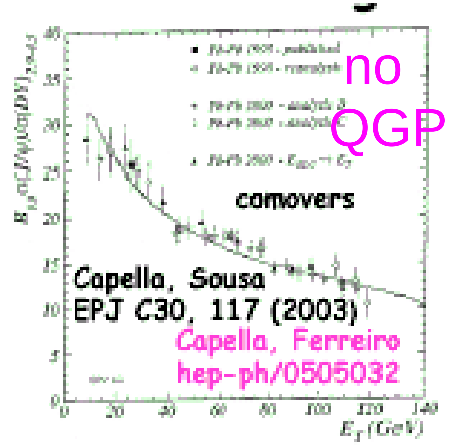
shadowing+nuclear absorption

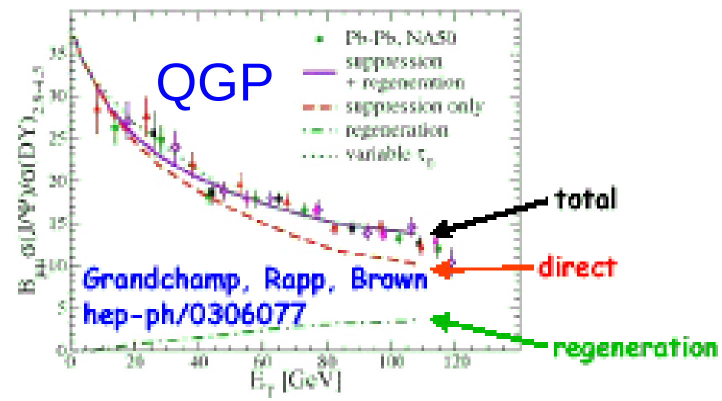
vraiment froids
(Andry)

Suppression by a dense medium:

thermalized or not thermalized, this is the question...





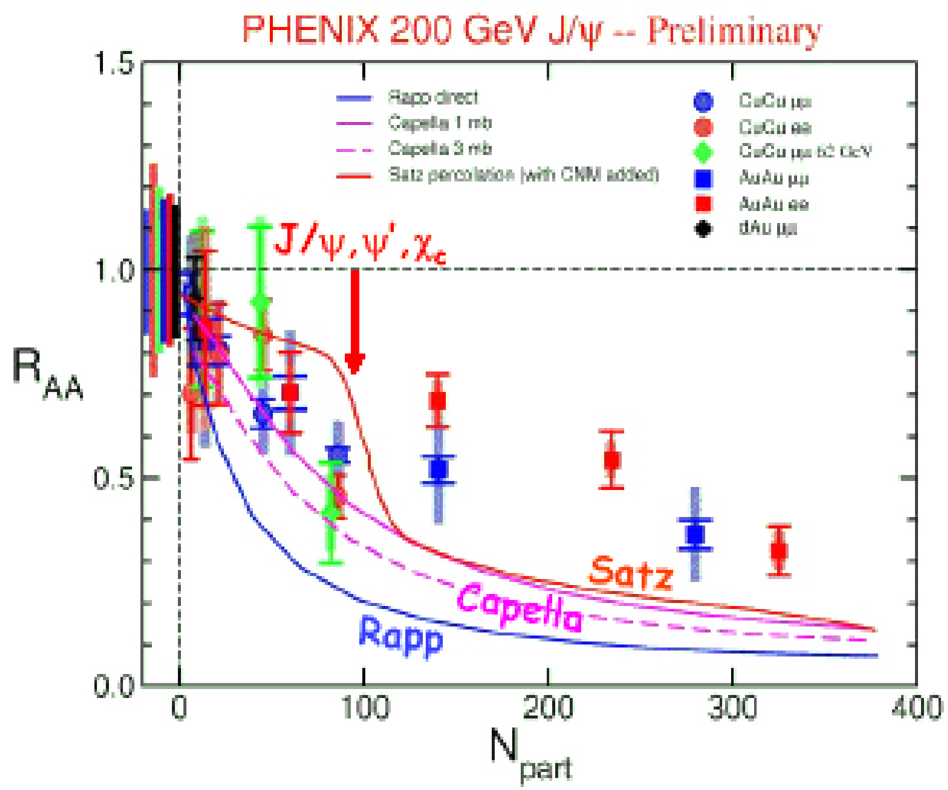


Models that reproduce NA50 results at lower energies predict too much suppression at RHIC!

QGP
- Satz – color screening in QGP (percolation model) with CNM added (EKS shadowing + 1 mb)

no QGP
- Capella – comovers with normal absorption and shadowing

QGP
- Rapp – direct production with CNM effects needs very little regeneration to match NA50 data



It doesn't matter if the medium is hot or not!

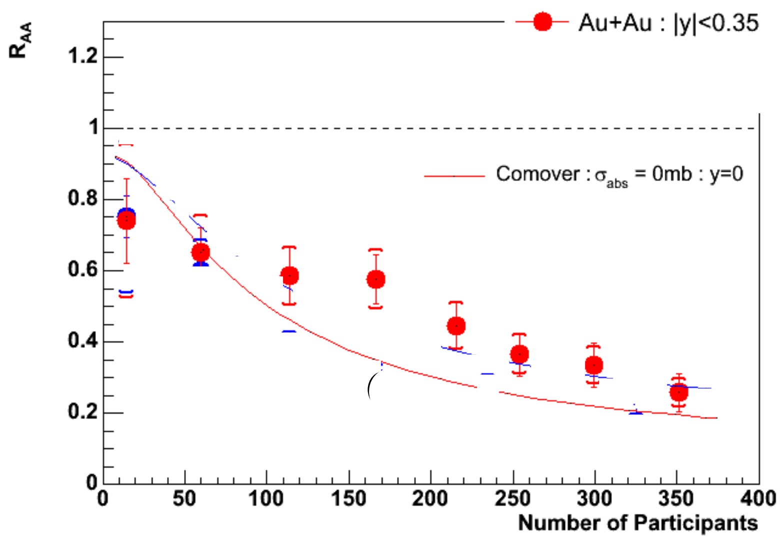
- Suppression models in agreement with SPS data extrapolated at RHIC
  - Unmatched suppression pattern at central rapidity

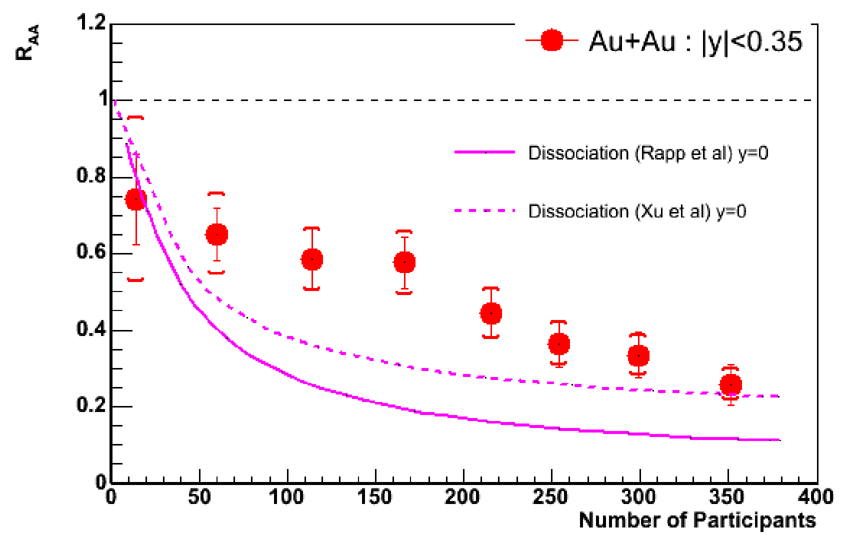
wo QGP

Dissociation by comovers
(Capella et al., hep-ph/0610313)

w QGP

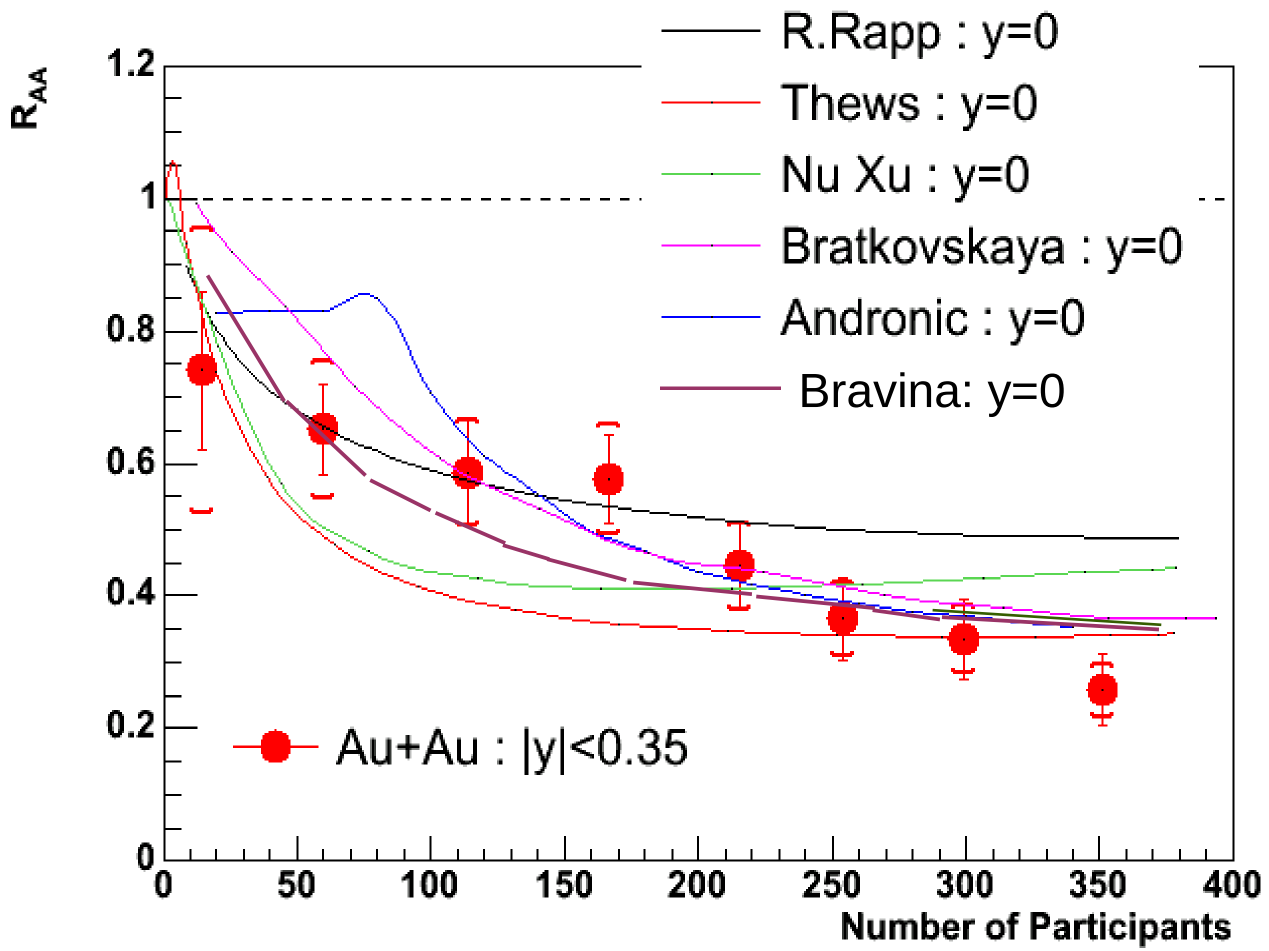
Dissociation by thermal gluons
(R. Rapp et al., nucl-th/0608033
Nu Xu et al., Phys.Rev.Lett. 97 (2006) 232301)





First problem: data Au+Au at central rapidity are not reproduced (wo/w QGP)

Regeneration, this can be the answer ...



R. Rapp *et al.* PRL 92, 212301 (2004) screening & in-medium production

Thews Eur. Phys. J C43, 97 (2005) statistical and kinetic model, deconfinement & recombination

Nu Xu *et al.* Phys.Rev.Lett. 97 (2006) 232301 transport equations & hydro & recombination

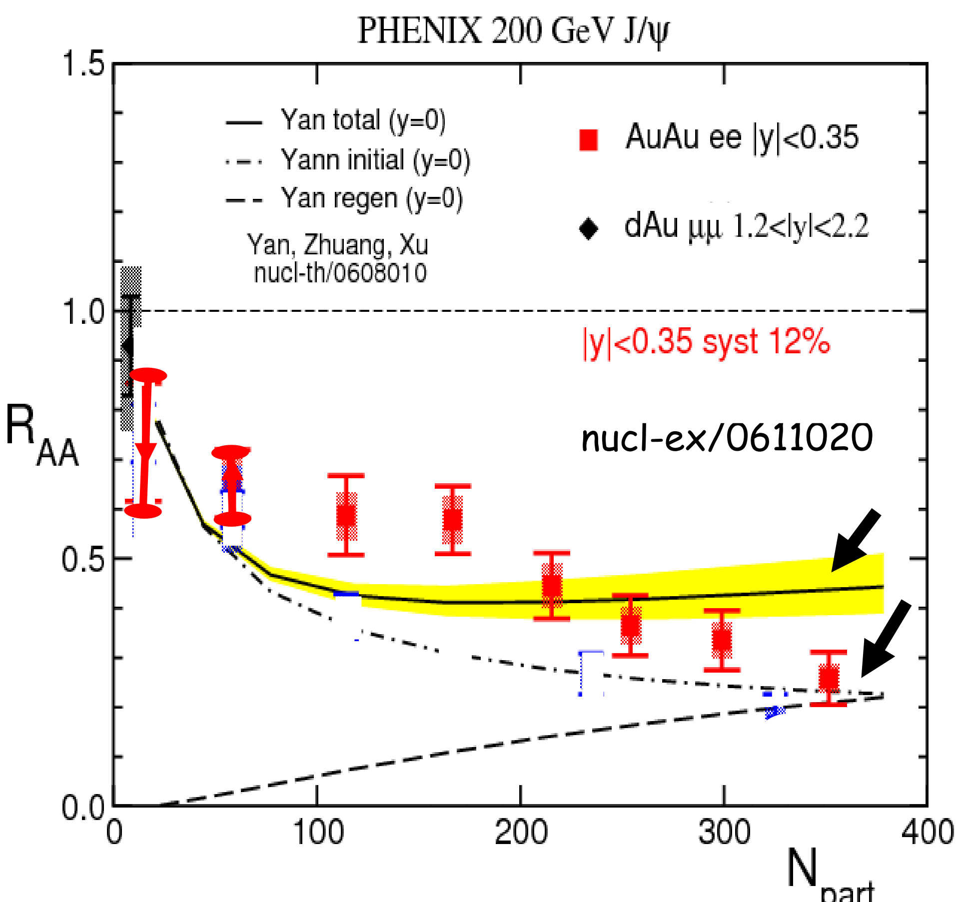
Bratkovskaya *et al.* PRC 69, 054903 (2004) HSD, hadron-string dynamics & recombination **(no QGP)**

Andronic *et al.* nucl-th/0611023 SCM, screening & statistical recombination of thermalized c-cbar

Bravina, comovers: suppression & regeneration **(no QGP)**

or not? some inconvenients of recombination

- indetermination of σ_{cc}^{2}
- the results can be as bad as without recombination:



- it can be present w or wo thermalization **-w or wo QGP-** so is not even a signal of a QGP

wo QGP
hadronic & partonic comovers w suppression+recombination

$$\tau \frac{dN^{J/\psi}}{d\tau}(b,s,y) = -\sigma\left\{N_{J/\psi}N^{co} - N_D N_{\bar{D}}\right\}$$

w QGP
thermal dissociation+recombination

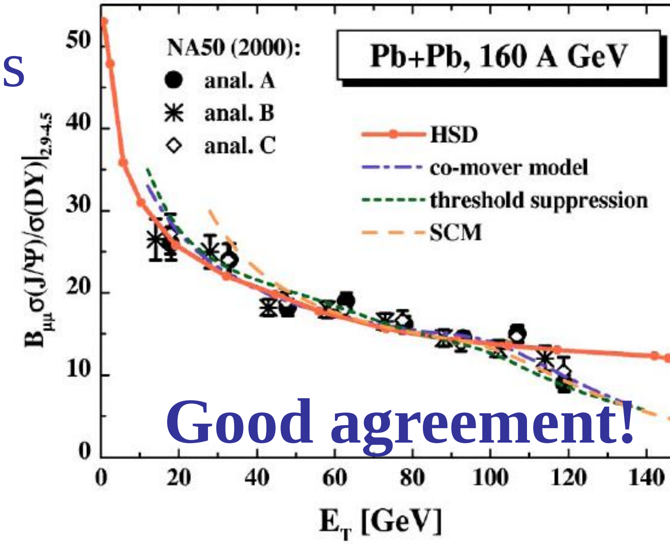
$$\frac{dN_{J/\psi}}{d\tau} = \lambda_F N_c N_{\bar{c}}[V(\tau)]^{-1} - \lambda_D N_{J/\psi}\,\rho_g$$

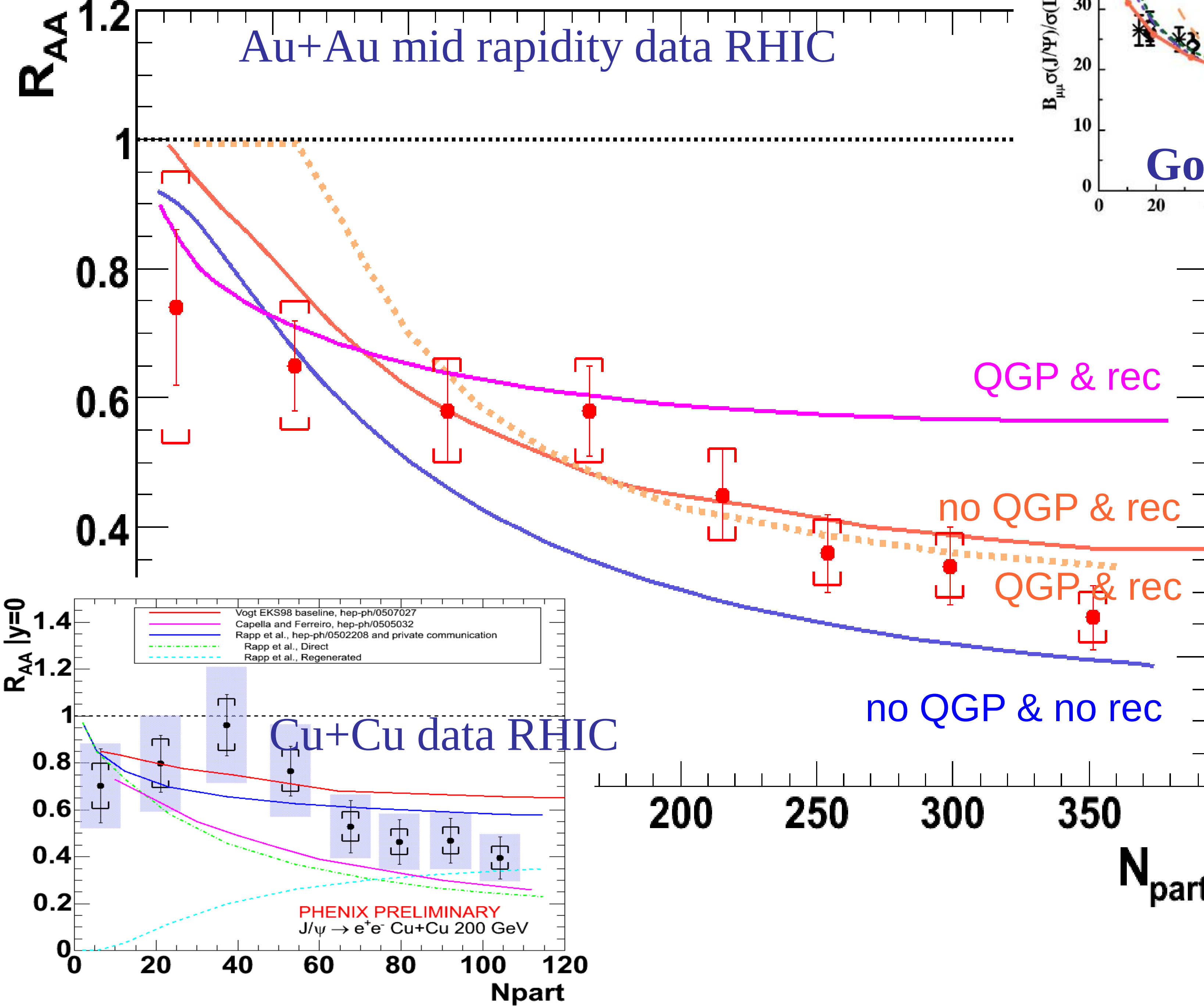
ρ_g the number density of gluons in the medium

reactivity λ = reaction cross section * initial relative velocity $\langle \sigma v_{rel} \rangle$

Model competition

Models at SPS

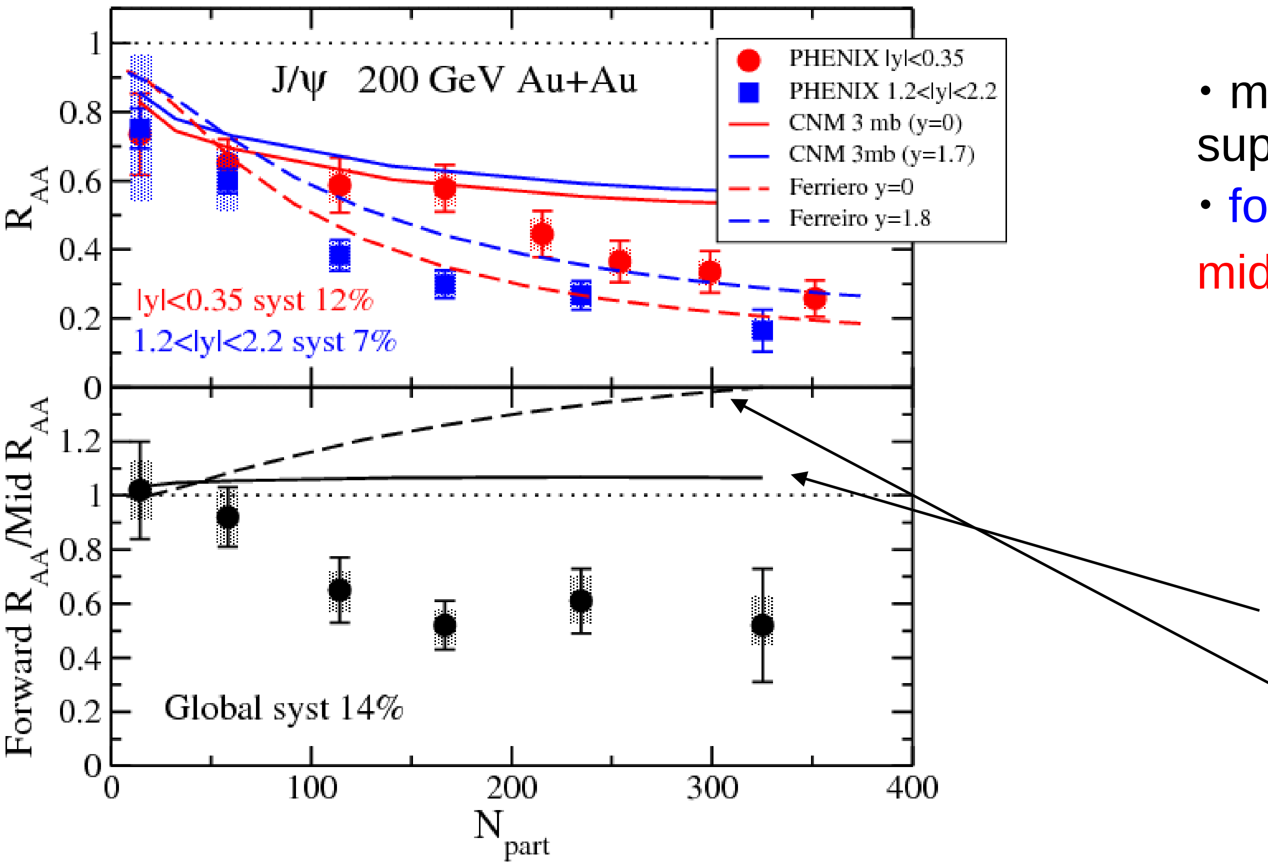




- ______ **recombination**, L.Grandchamp et al, PRL 92, 212301 (2004).
- ________ **HSD**, E.L.Bratkovskaya et al., PRC 71, 044901 (2005).
- ------------ **SCM**, A.Andronic et al., nucl-th/0701079.
- ________ **comover**, A.Capella and E..Ferreiro hep-ph/0610313

Second problem: data Au+Au at mid/forward rapidity

- Opposite suppression behaviour vs rapidity



- most central collisions suppressed to ~0.2
- forward suppressed more than mid-rapidity
  - saturation of forward/mid suppression ratio rapidity @ ~0.6 for $N_{part} \geq 100$?
  - trend opposite to that of CNM (solid lines) and comover (dashed) models

Looking for solutions...

Charmed meson production in the CGC model

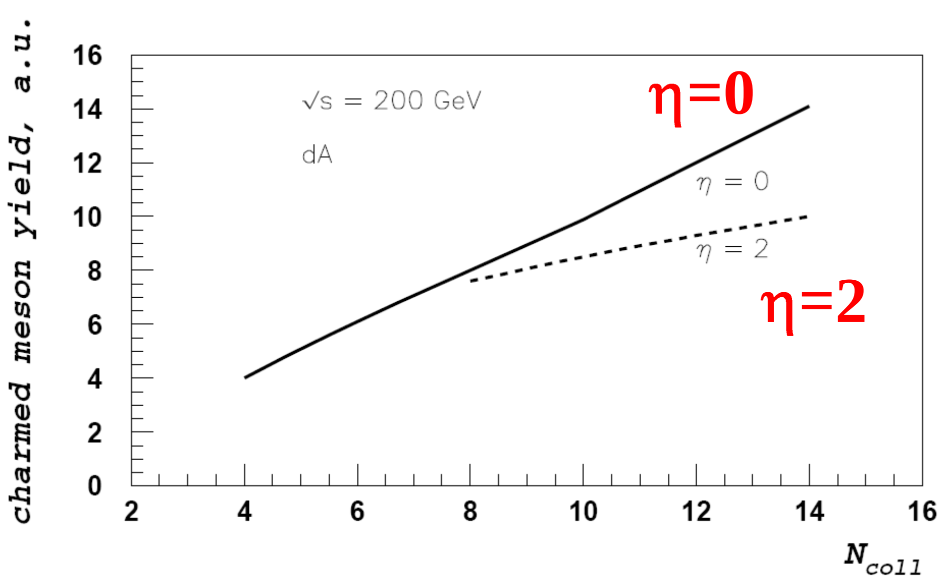
CGC: open charm in central rapidity region at RHIC gets suppressed as a function of rapidity

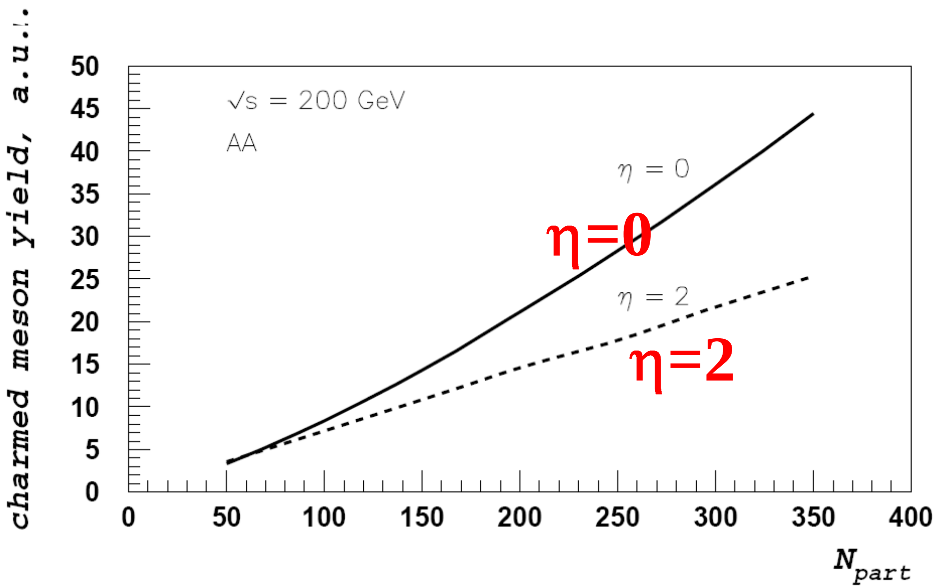
charmed meson yield gets suppressed from y=0 to y=2 both in pA and AA collisions

Cause: saturation scale grows with rapidity $Q_s^2 \simeq 2\, e^{0.3y}\ \mathrm{GeV}^2$

- y=0 $Q_s^2 < m_c^2$ $\frac{dN_{AA}}{d\eta}\Big|_{\eta=0} \sim A^{4/3} \sim N_{\rm coll}\,.$
- y=2 $Q_s^2 > m_c^2$ $\frac{dN_{AA}}{d\eta}\Big|_{\eta\geq 2} \sim A \sim N_{\rm part}$

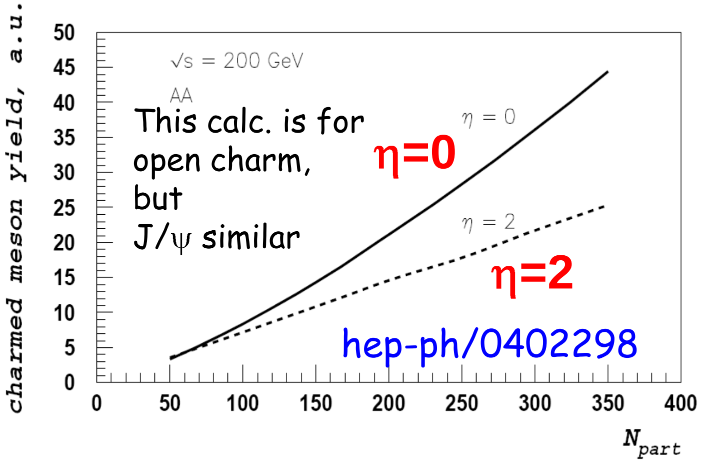
Tuchin, hep-ph/0402298

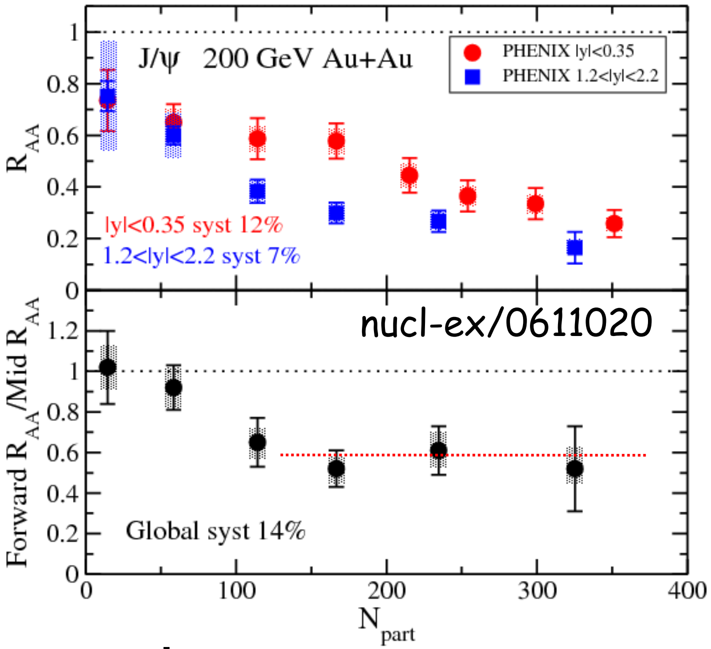




Let's see some results...

QGP Sequential Screening +CGC



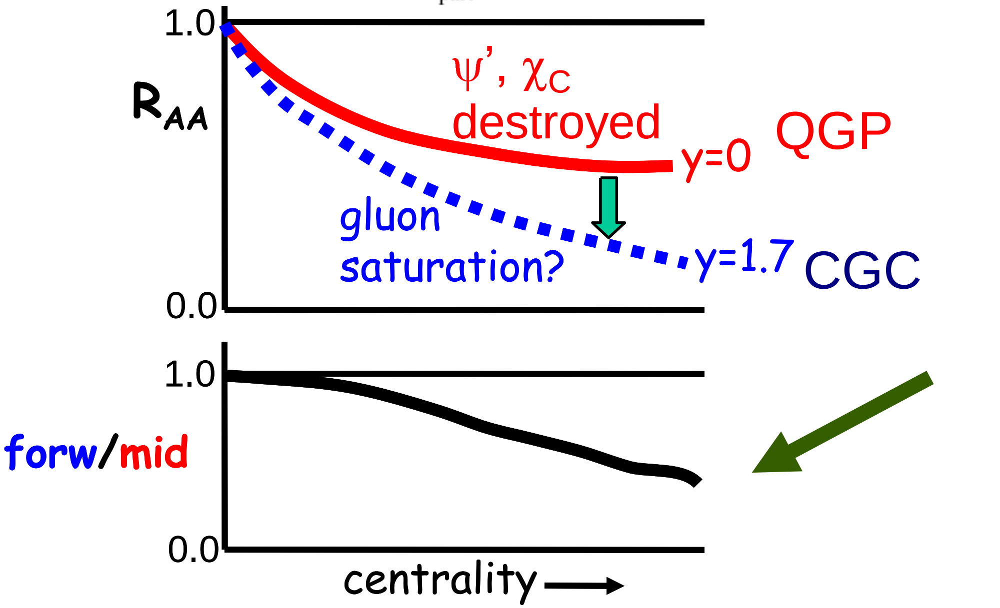


- QGP suppression of ψ', χ_C

+ additional forward suppression from gluon saturation (CGC)

- **BUT** approx. flat forward/mid above Npart ~ 100 seems inconsistent:

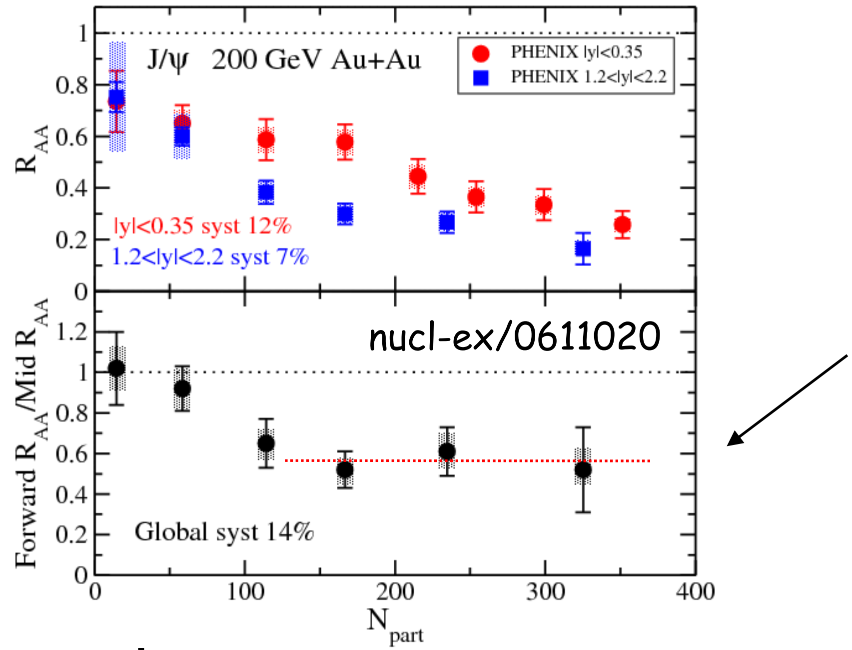
forward should drop more for more central collisions as gluon saturation increases

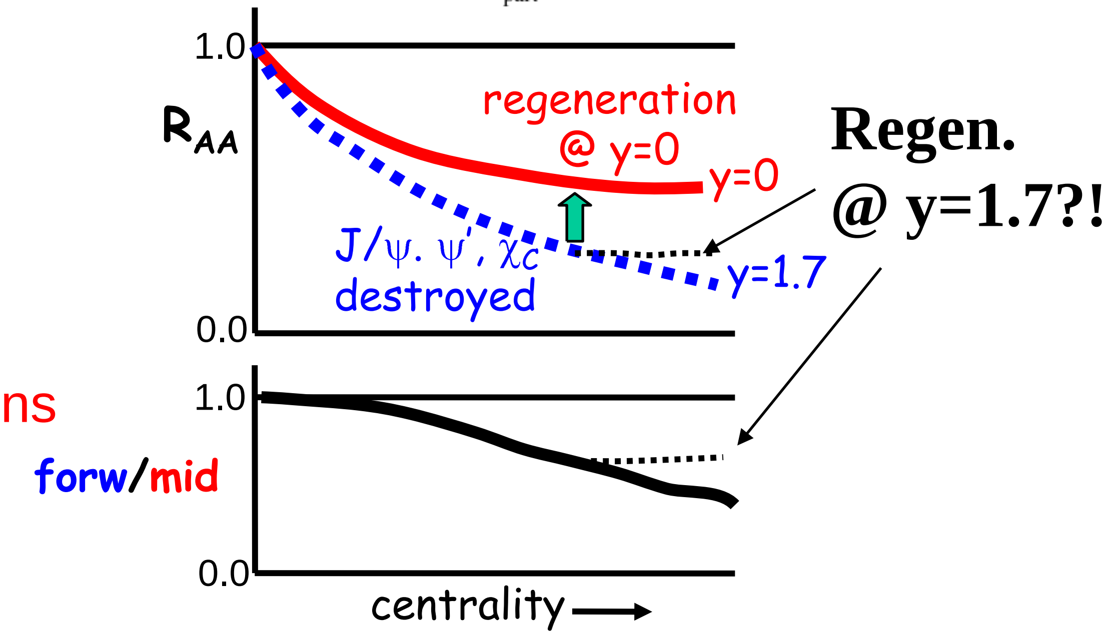


QGP+Regeneration

- both forward & mid rapidity suppressed by QGP – i.e. screening or large gluon density
- mid-rapidity suppression reduced by strong regeneration effect
- but approx. flat forward/mid suppression for Npart>100

seems inconsistent with increasing regeneration & increasing QGP suppression for more central collisions



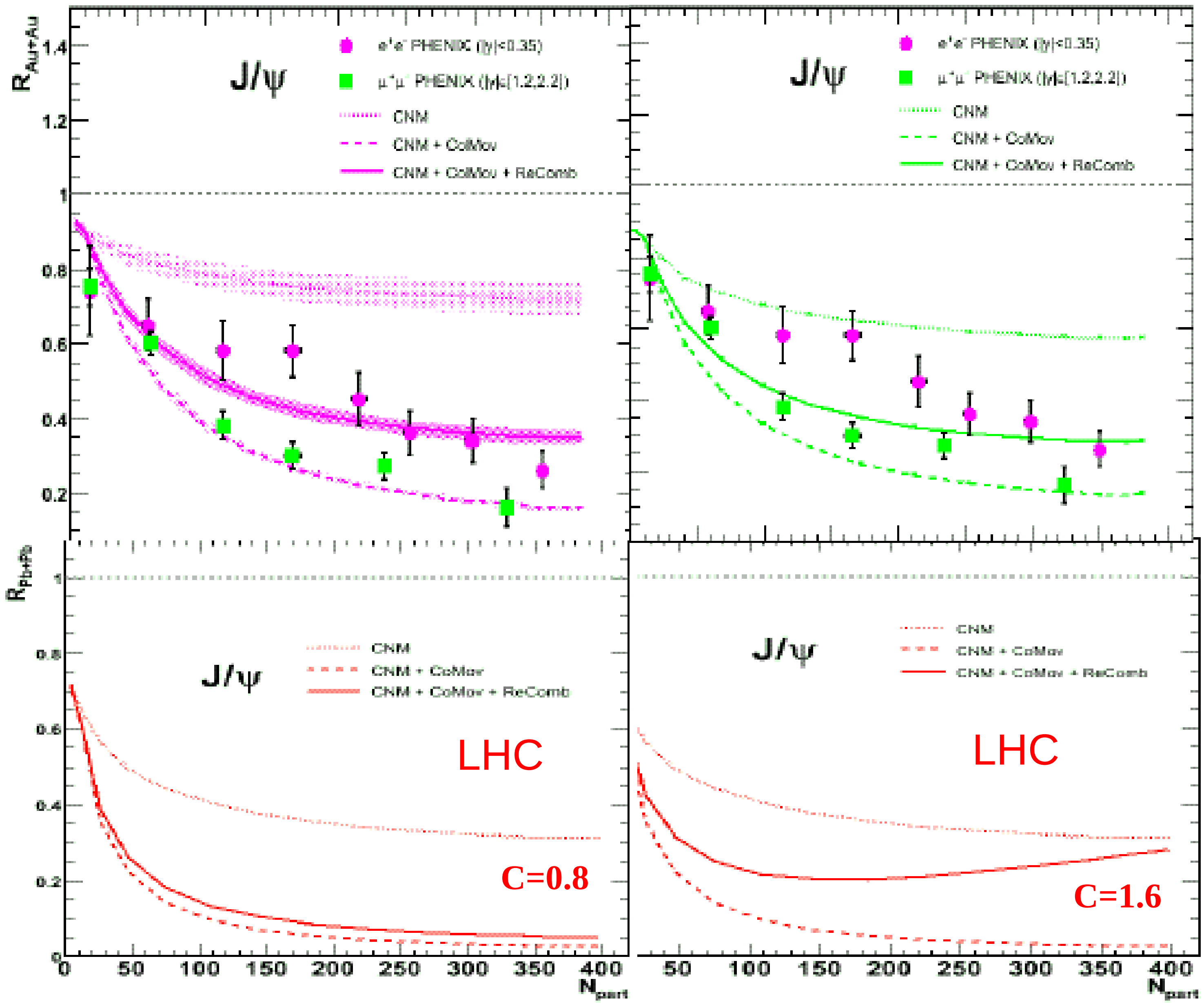


some innovations and predictions...

comovers: **dissociation wo QGP+recombination**

Tywoniuk, Arsene1, Bravina
Kaidalov, Zabrodin

$$\tau \frac{dN^{J/\psi}}{d\tau}(b,s,y) = -\sigma\left\{N_{J/\psi}N^{co} - N_D N_{\bar{D}}\right\} \quad S^{CR}(b,s,y) = \exp\left\{-\sigma\left[N^{co} - C\, n(b,s)\right]\ln\left[\frac{N^{co}}{N_{pp}(0)}\right]\right\}$$



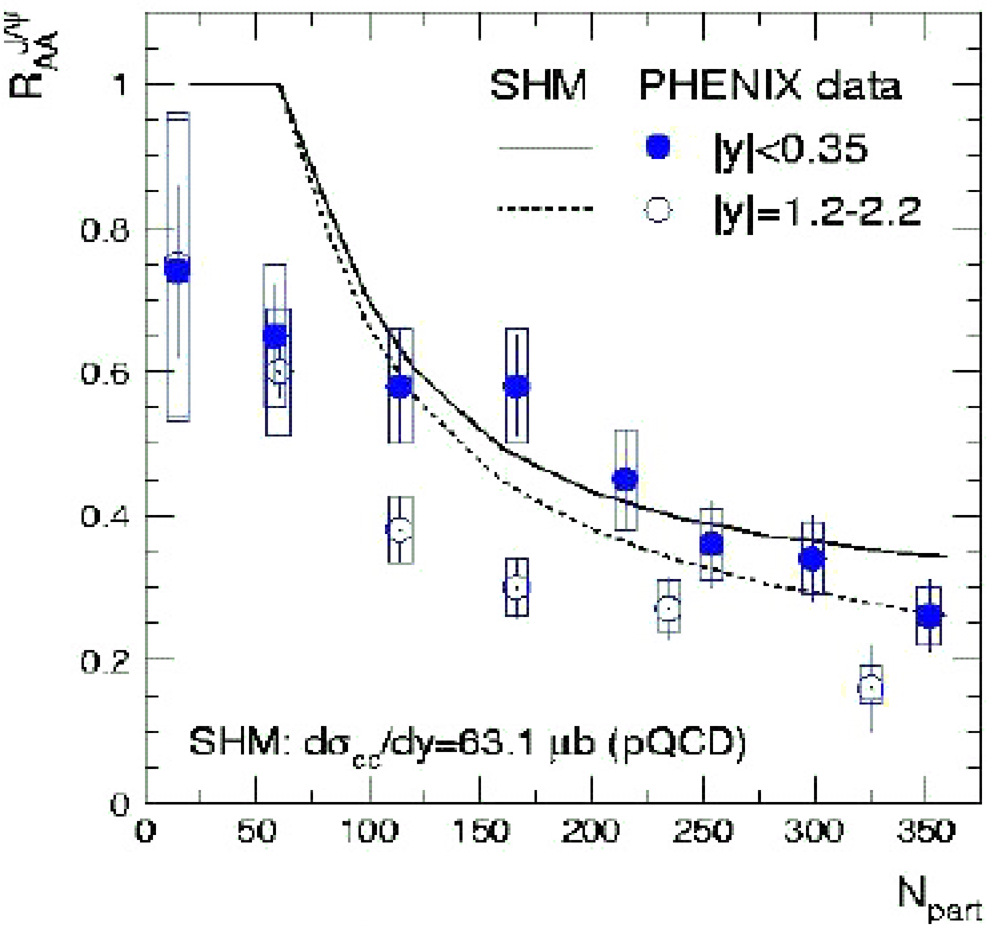
$$C = \frac{\left(dN^D_{pp}/dy\right)^2}{dN^{J/\psi}_{pp}/dy}$$

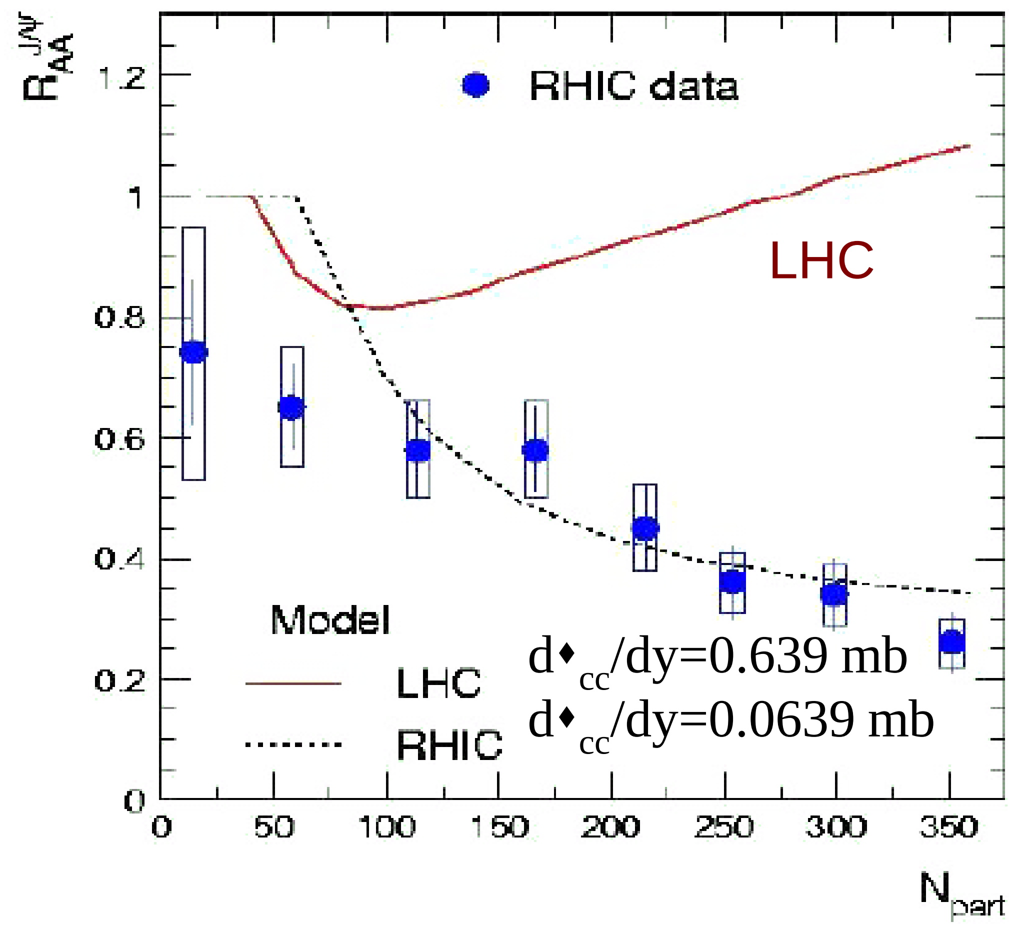
$$\left(d\sigma_{c\bar{c}}/dy\right)_{pp} = 0.8\text{mb}$$

- C_{RHIC}=C_{LHC}
=> small recomb

- C_{RHIC}=C_{LHC}
=> huge recomb
=> enhancement

SCM, Andronic, Braun-Munzinger, Riedlich, Stachel: **QGP+recom**



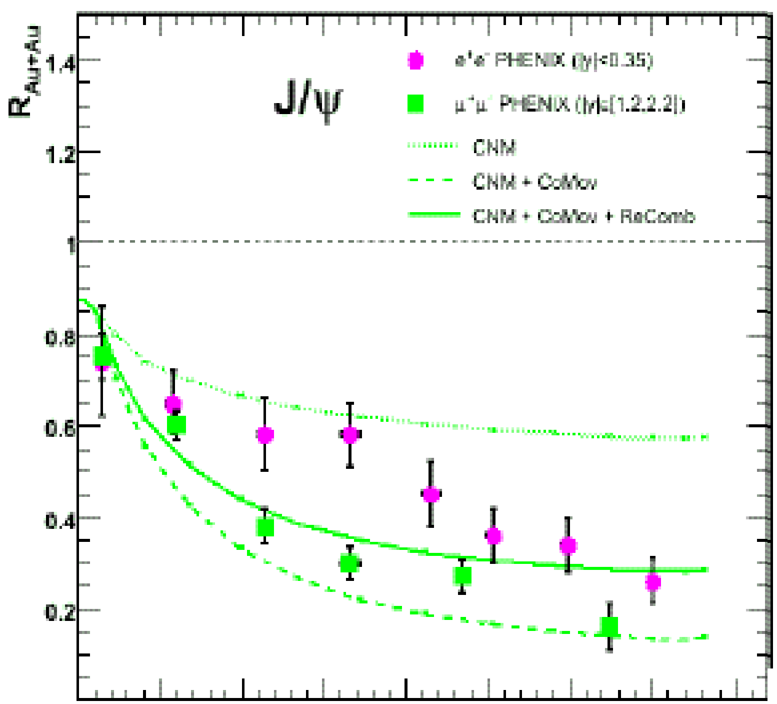


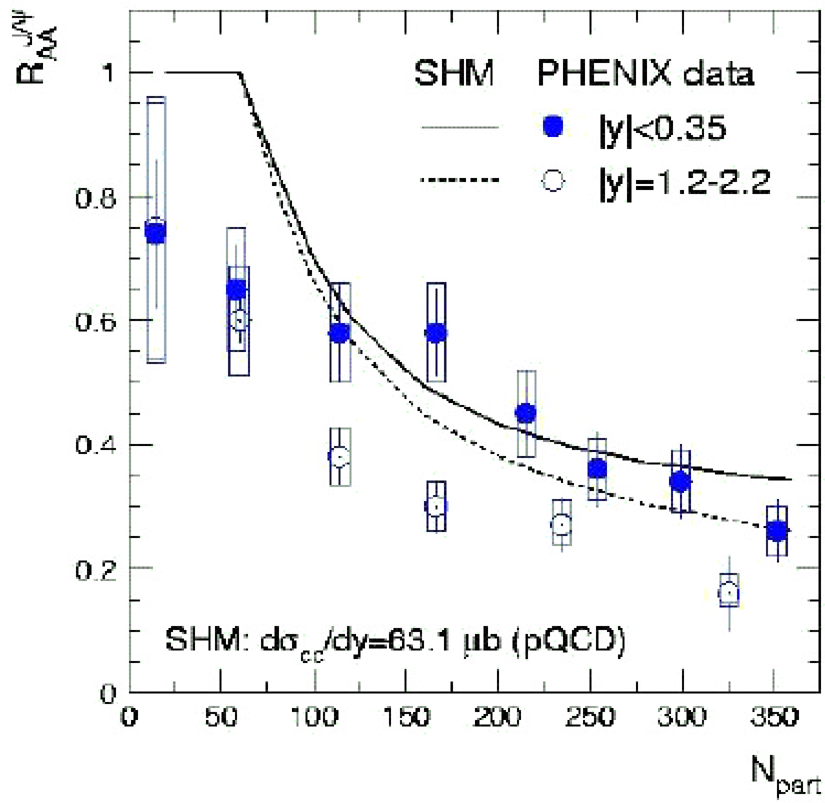
Summary of the parameters used

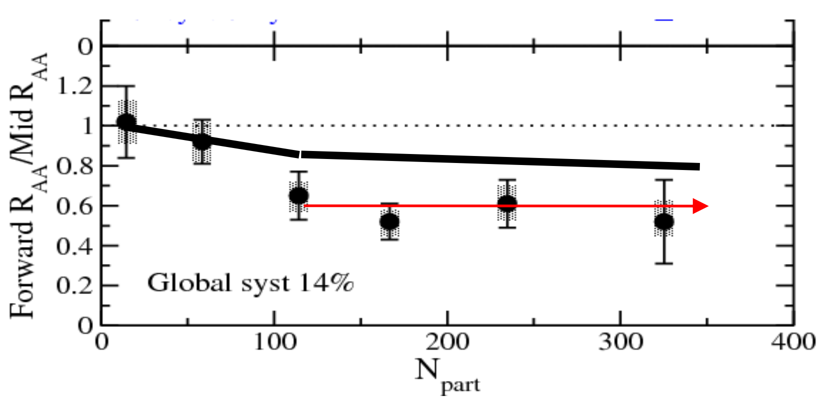
- characteristics at chemical freeze-out:
  - (i) temperature T=161±4 MeV,
  - (ii) baryochemical potential $\mu_b=0.8^{+1.2}_{-0.6}$ MeV
  - (iii) volume corresponding to one unit of rapidity V=6200 fm^3
- charm production cross section: $d\sigma_{cc}^{pp}/dy = 0.64^{+0.64}_{-0.32}$ mb

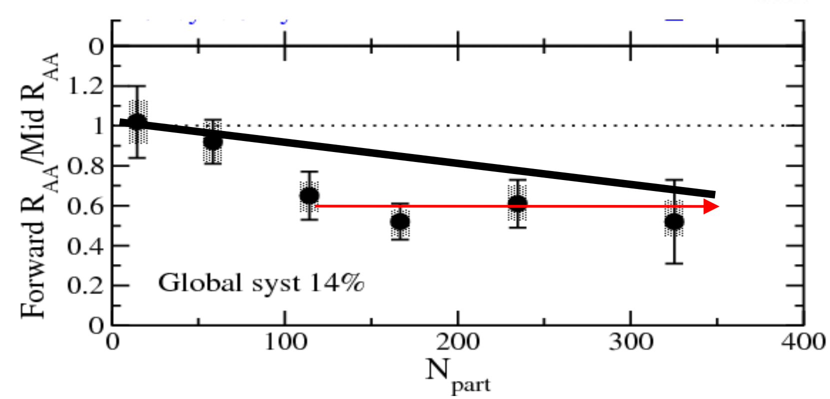
comovers: suppression
+
regeneration

SHM: QGP+regeneration









CONCLUSIONS....

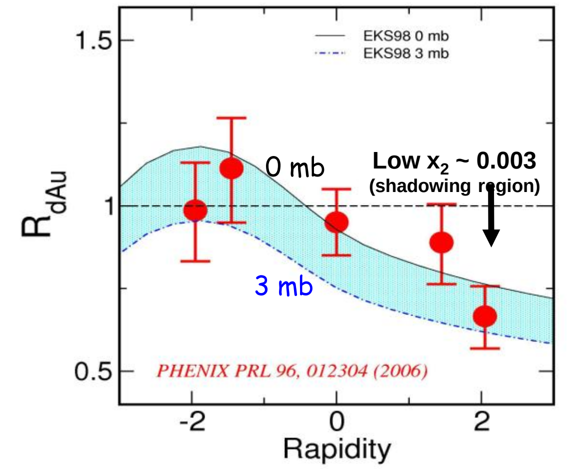
if possible

- Why
Au+Au data y=0 @ RHIC >
Au+Au data y=1.7 @ RHIC?

- Why
Cu+Cu data @ RHIC=Au+Au data @ RHIC for the same Npart?

- Why
data @ RHIC=data @ SPS
for the same Npart?

we need to know much better the initial CNM in d+Au …



nuclear absorption

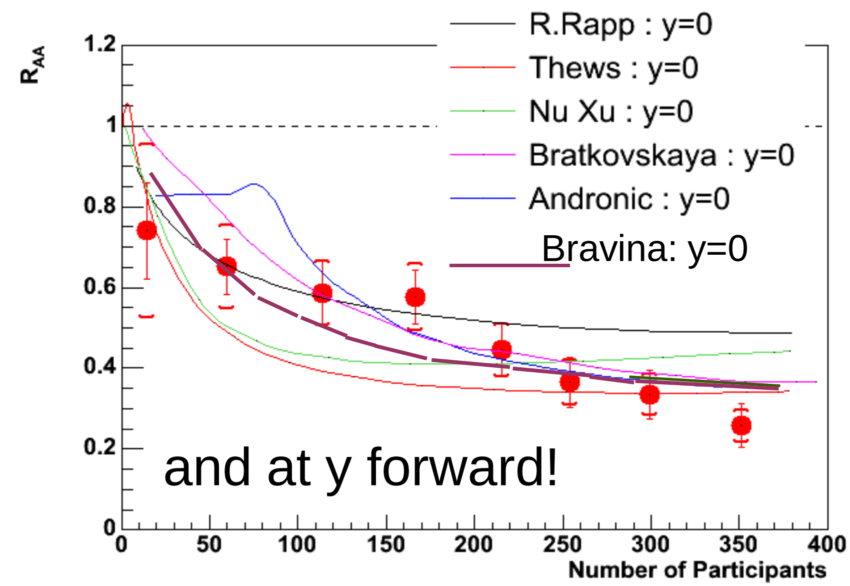
gluon shadowing
pomeron shadowing

CGC
percolation
parton saturation

QGP
sequential suppression
recombination

partonic comovers
hadronic comovers
recombination

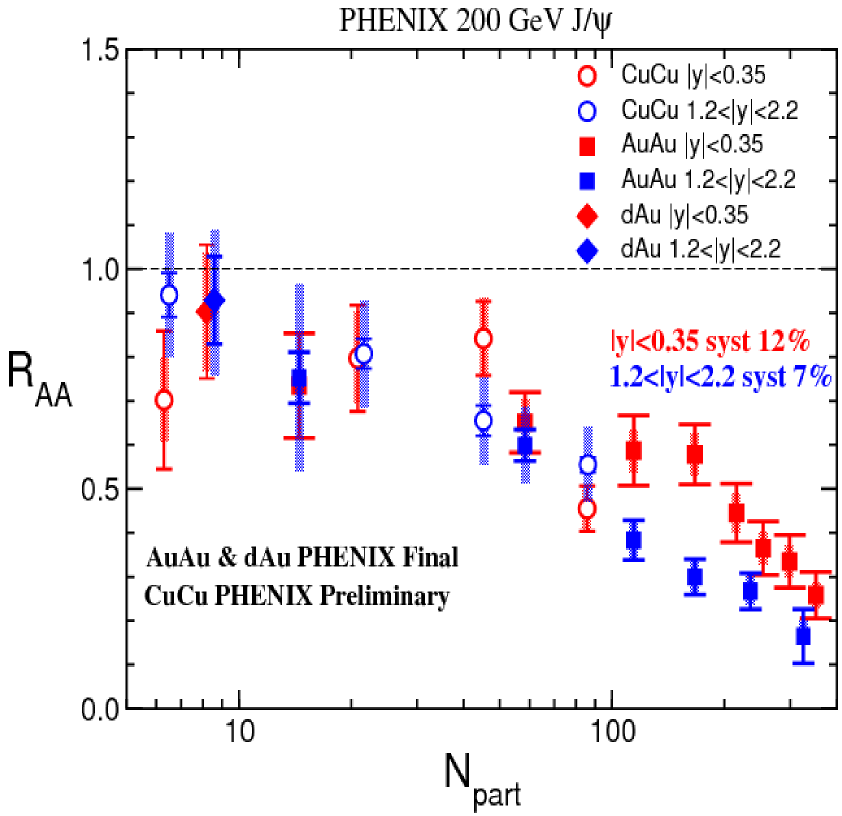
… to reproduce Au+Au at y=0

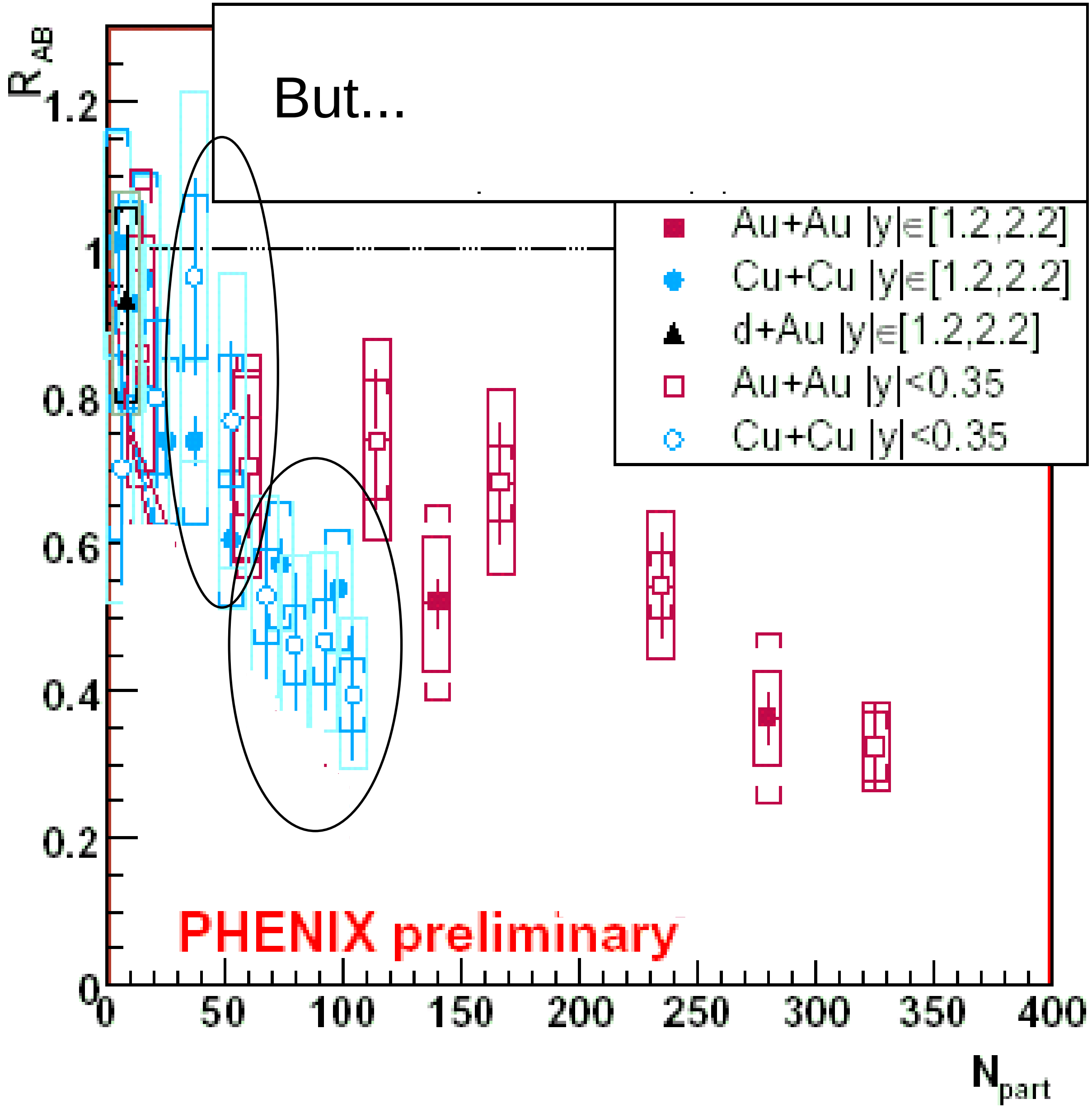


and at y forward!

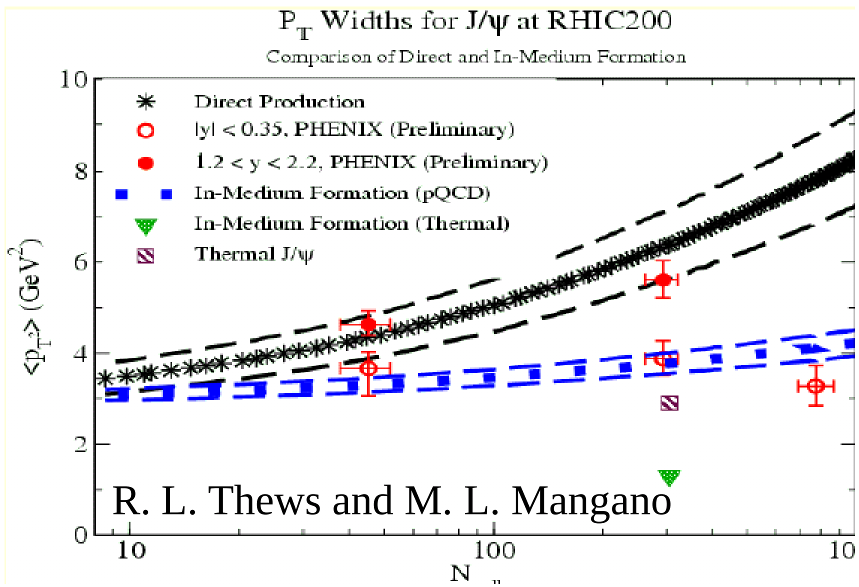
Third problem: data Cu+Cu at mid and forward rapidity

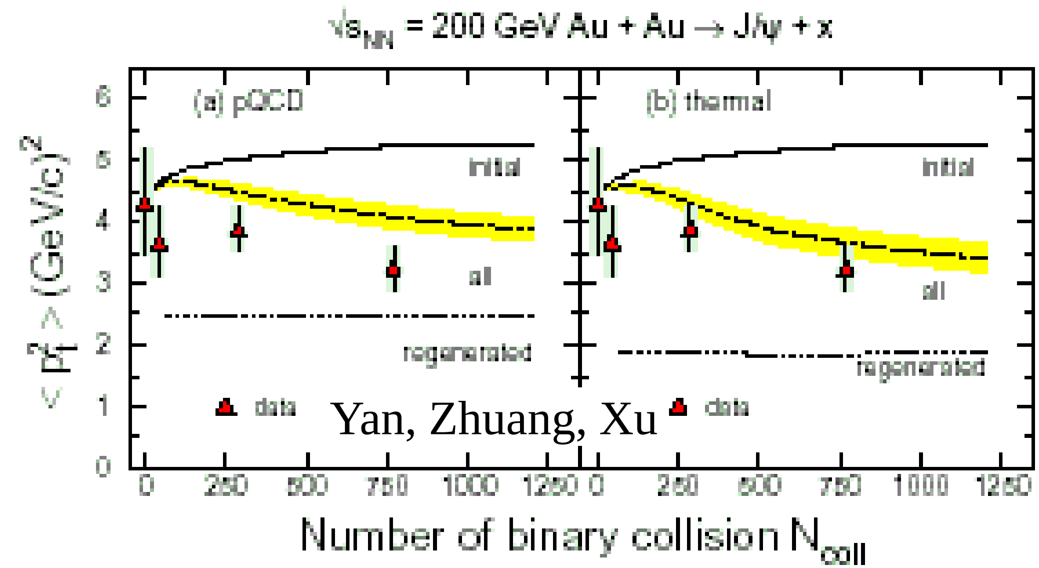
CuCu preliminary results follow AuAu trend vs centrality for N_{part} below ~100

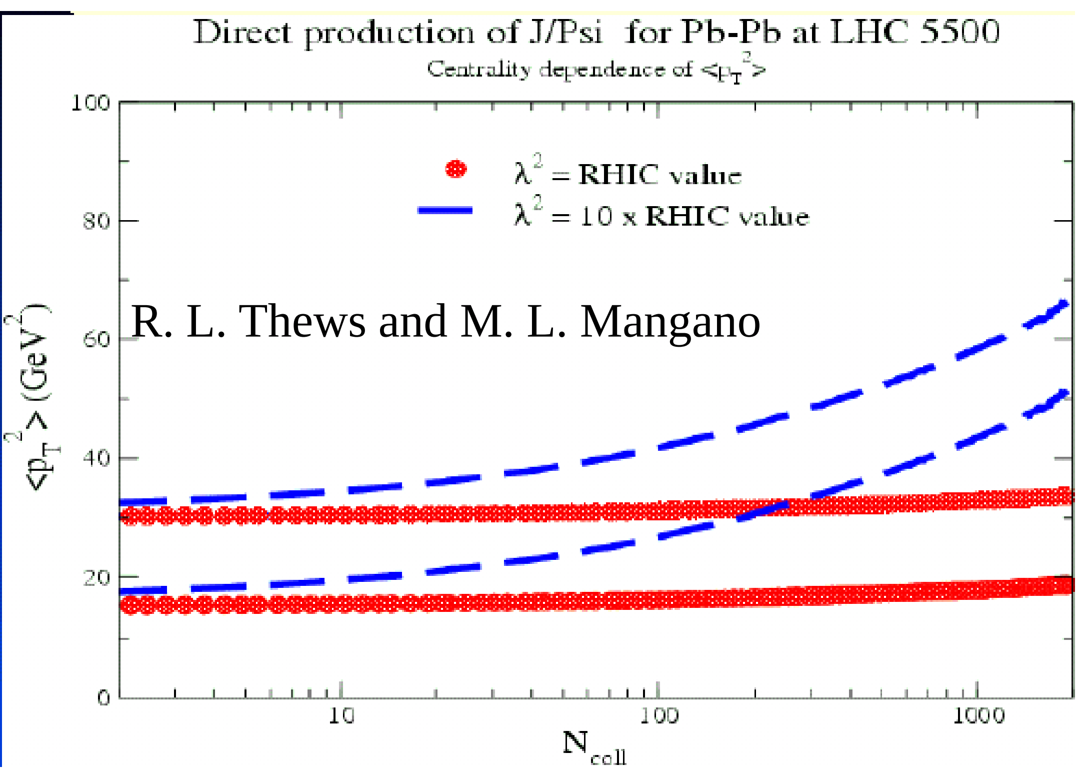


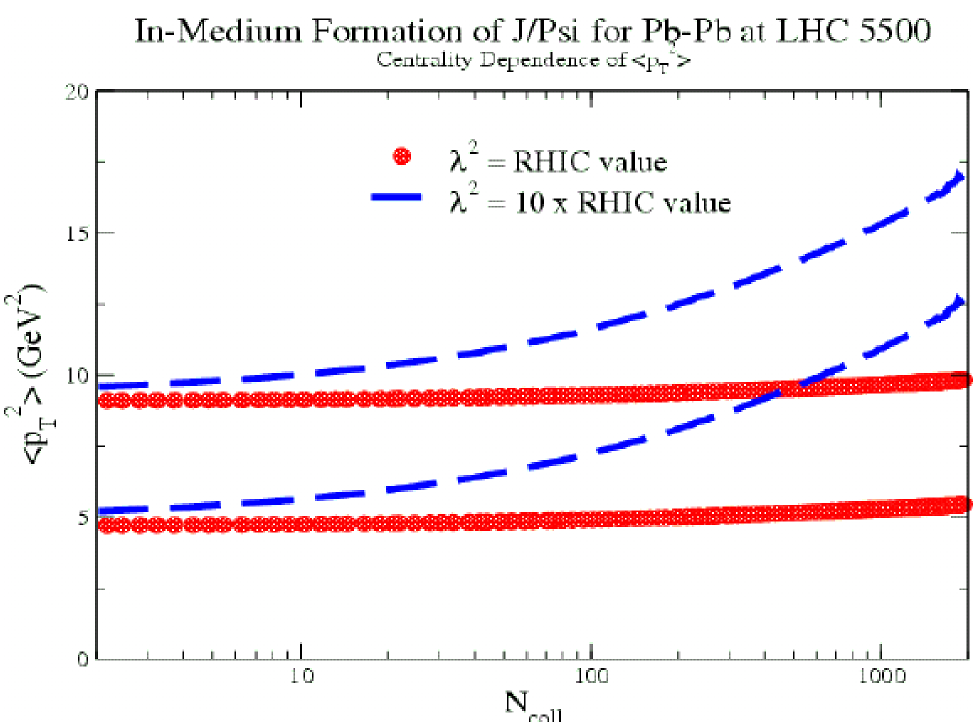


average transverse momentum vs number of collisions

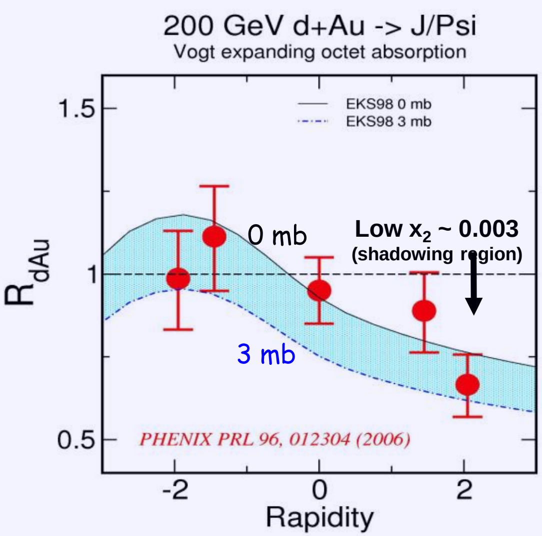








Summary – J/ψ Suppression
A puzzle of two (or more) ingredients

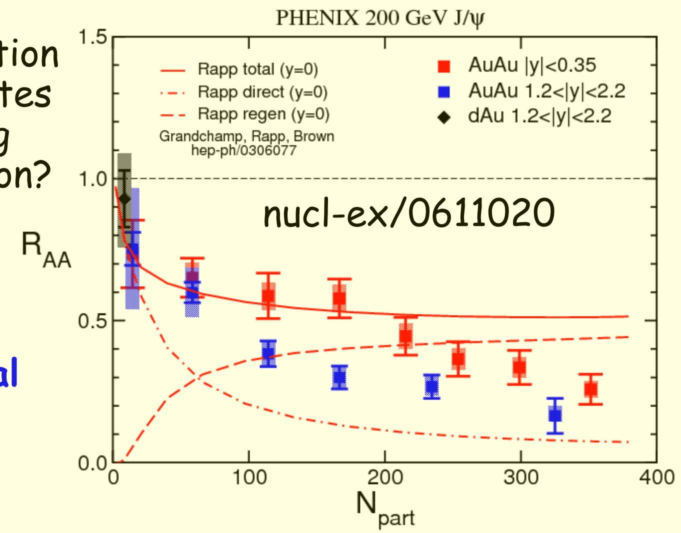


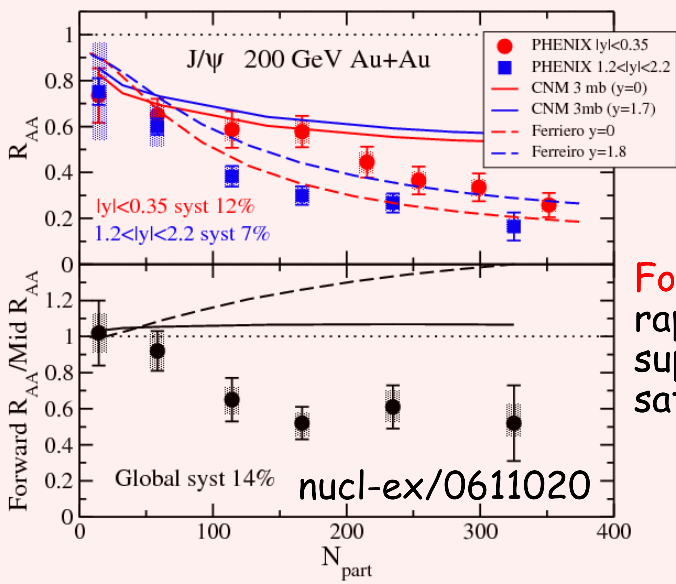
CNM needs better data constraint

Experimental homework

Regeneration compensates for strong destruction?

Theoretical homework

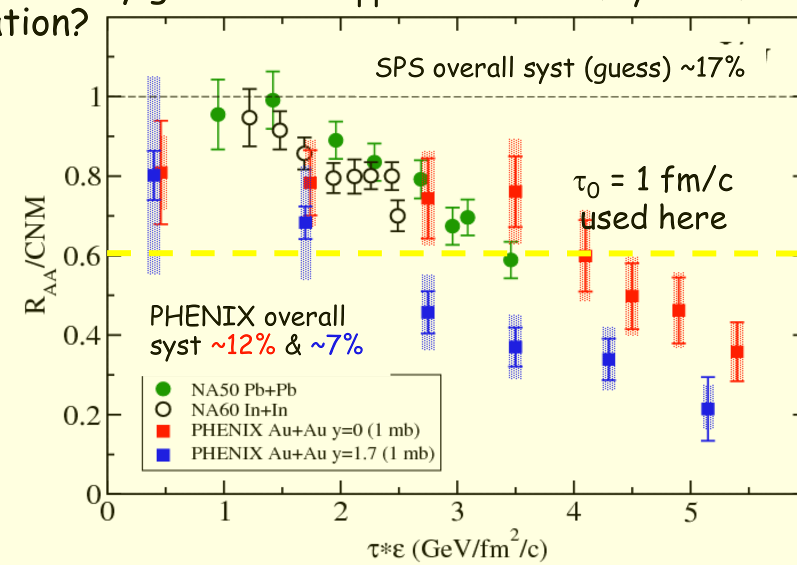




Forward/mid rapidity suppression ratio saturates @~0.6

Sequential screening and forward-y gluon saturation?

difficult to compare RHIC to SPS suppression – but may be similar



Refinement : 3D hydro + sequential dissociation (II)

Gunji et al., hep-ph/0703061 :

- Charmonia
  - initial spatial distribution = from collisions in the Glauber model
  - + free streaming in a full (3D+1) hydro
  - J/Ψ survival probability (R_{AA}/CNM with CNM = shadowing + nuclear absorption σ_{abs} = 1mb)

$$S = (1 - f_{FD})\, S_{\text{direct } J/\Psi} + f_{FD}\, S_{J/\Psi \leftarrow \Psi', \chi c}$$

  - 3 free parameters : feed-down f_{FD} , melting temperatures $T_{J/\Psi}$ and $T_{\Psi',\chi c}$

+ (3D+1) hydro : same setup as the one used to reproduce charged dN/dη measured at RHIC
  - Assuming thermalization for τ ≥ 0.6 fm, initial energy density distribution in the transverse plane, EOS of the medium ($T<T_c$ and $T>T_c$), …

Refinement : 3D hydro + sequential dissociation (II)

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+ (3D+1) hydro

⇒ best fit with :

- $T_{J/\Psi}$ = 2.12 T_c
- $T_{\Psi',\chi c}$ = 1.34 T_c
- f_{FD} = 0.25

0.10 due to uncertainty on σ_{abs} (1 1mb)

Better matching with the data