Review on J/ψ suppressions

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PHENIX & CMS experiments

Santiago de Compostela
2009, February 4th

The normal introduction

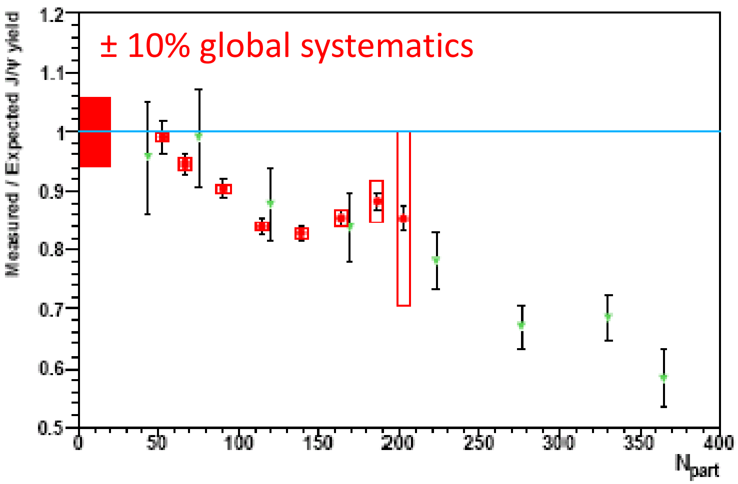
Matsui & Satz, PLB178 (1986) 416

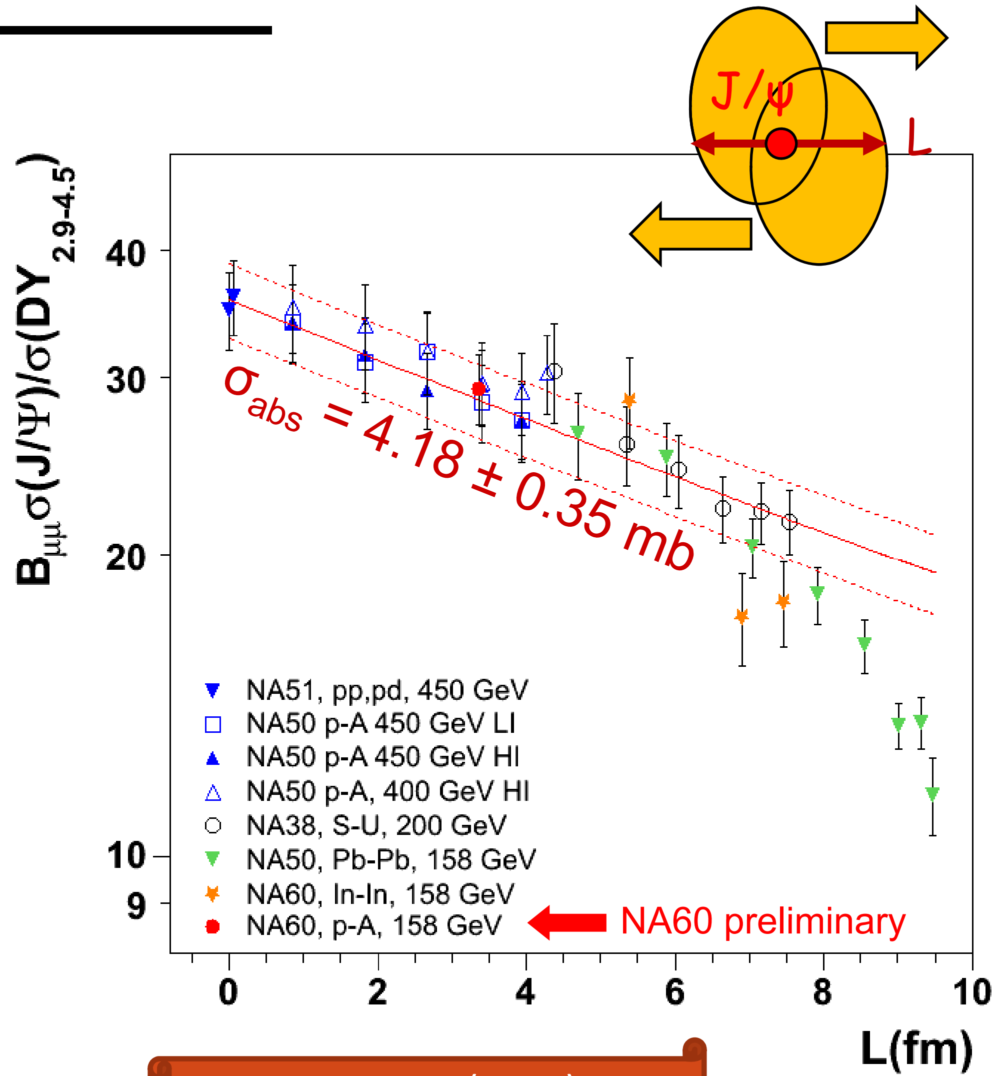
- In 1986, Matsui & Satz predicted an "unambiguous" signature of QGP
  - Onset of quarkonia melting above a certain temperature / energy density threshold
- Example of assumed T_d (but theorists still working on it):

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

Cold and hot matters @ SPS

- Normal nuclear absorption alone does a splendid job describing pA, SU and peripheral InIn and PbPb:
  - $\sigma_{abs} = 4.18 \pm 0.35$ mb
- Beyond is "anomalous suppression"
  - InIn looks like an onset



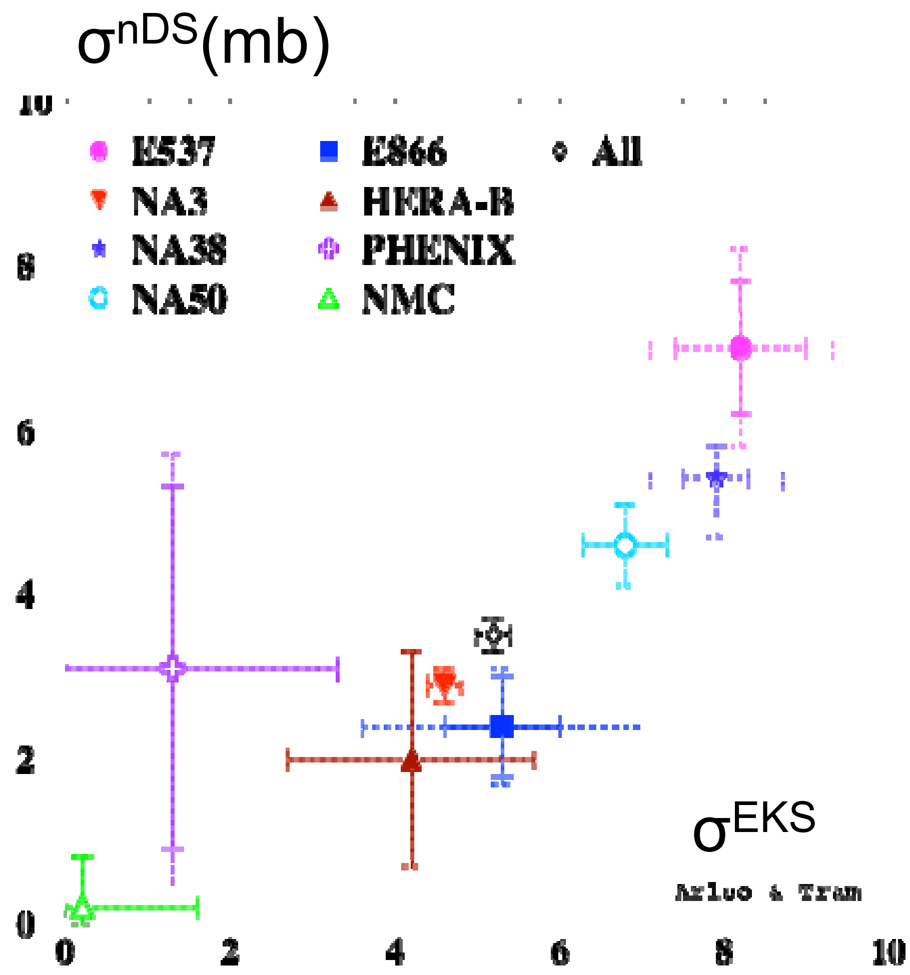


NA50, EPJ C39 (2005) 335
NA60, PRL99 (2007) 132302

C. Lourenzo
P. Faccioli,
P. Martins

Still open questions at SPS…

- Interplay shadowing – absorption →
- √s dependence of absorption?
  - Lourenço et al, arxiv:0901:3054.
- NA60, pA @ 168 GeV?
  - HP08? QM09?
- Unexplained rapidity dependence in pA?
  - Eur.Phys.J.C48:329,2006



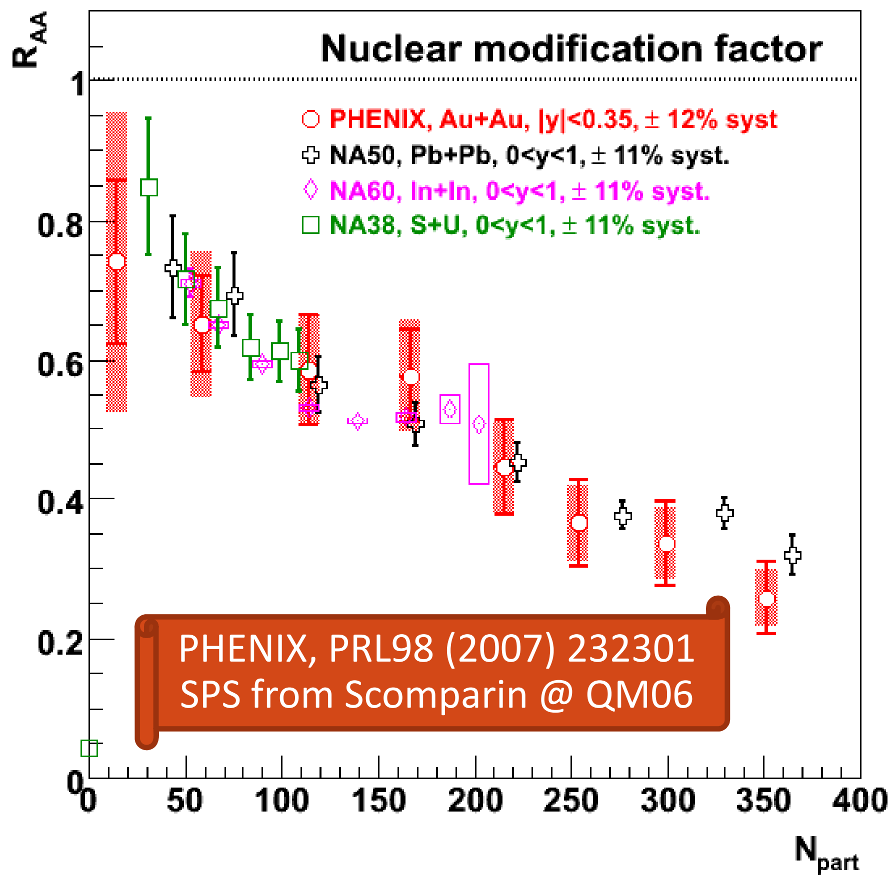
Tram & Arleo, EPJ. C 55, 449-461 (2008)

However, J/ψ behave pretty much like the predicted golden QGP signature @ SPS

What about RHIC?

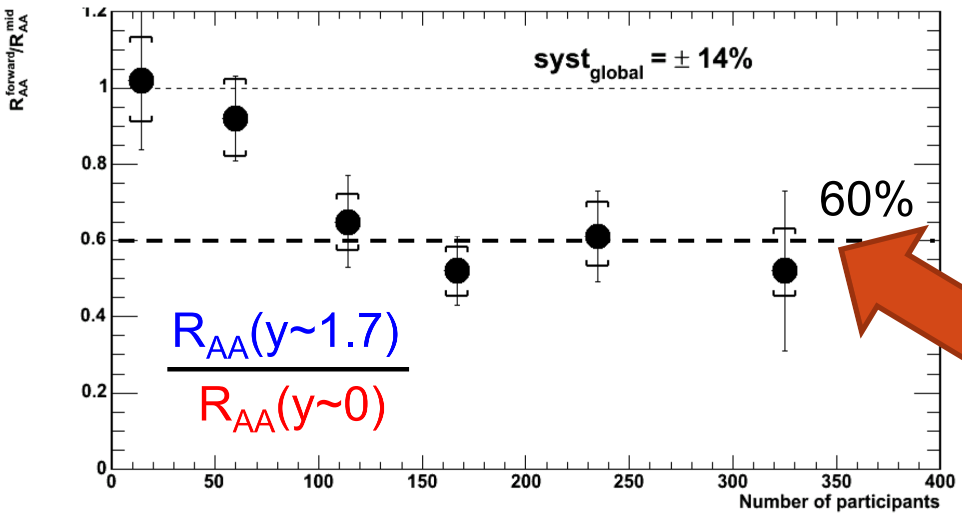
R_{AuAu} (y≈0 in PHENIX) ≈ R_{PbPb} (@ SPS)

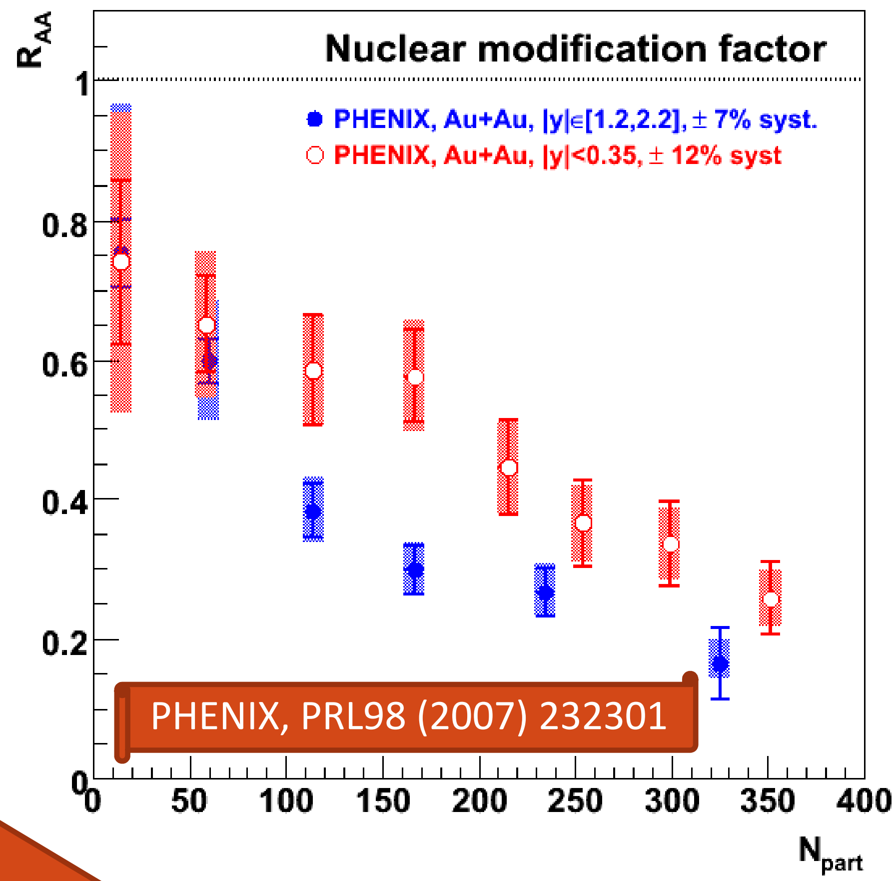
- Lower rapidity R_{AA} looks surprisingly similar, while there are obvious differences:
  - At a given N_{part}, different energy densities…
  - Cold nuclear matter effects ($x_{Bjorken}$, σ_{abs}…)
  - …



R_{AuAu} (y≈1.7) < R_{AuAu} (y≈0) in PHENIX

- @ RHIC, more J/ψ suppression at forward rapidity !
- While energy density should be smaller…





What is this further 40% suppression due to ?

@ RHIC, more suppression at forward rapidity!

Two possible theoretical explanations…

A. One hot: coalescence, regeneration

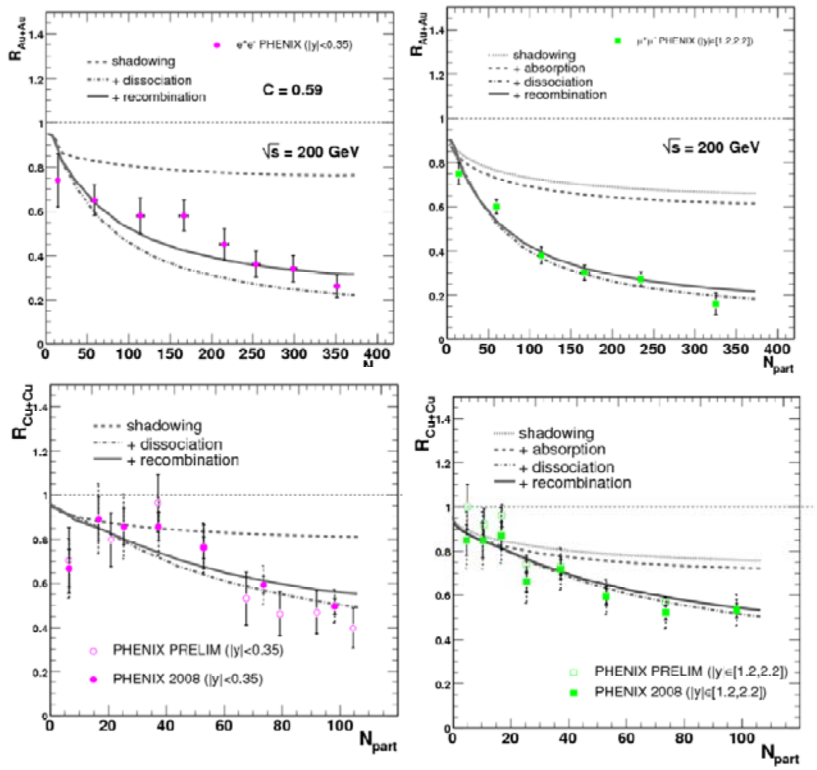
B. One cold: saturation, shadowing

A. Hot coalescence, regeneration

- Large variety of approaches, all justify:
  - $R_{AA}(y=0) > R_{AA}(y=1.7)$
  - (more c quarks to recombine at y=0)

Latest references
R. Thews et al, EPJ C43, 97 (2005)
Yan, Zhuang, Xu, PRL97, 232301 (2006)
A. Andronic et al., NPA789, 334 (2007)
Ravagli, Rapp, PLB655, 126 (2007)
Zhao, Rapp, PLB664, 253 (2008)
A. Capella et al., EPJ C58, (2008) →
O. Linnyk et al., NPA807, 79 (2008)
(Apologies if I forgot somebody)

- As an example

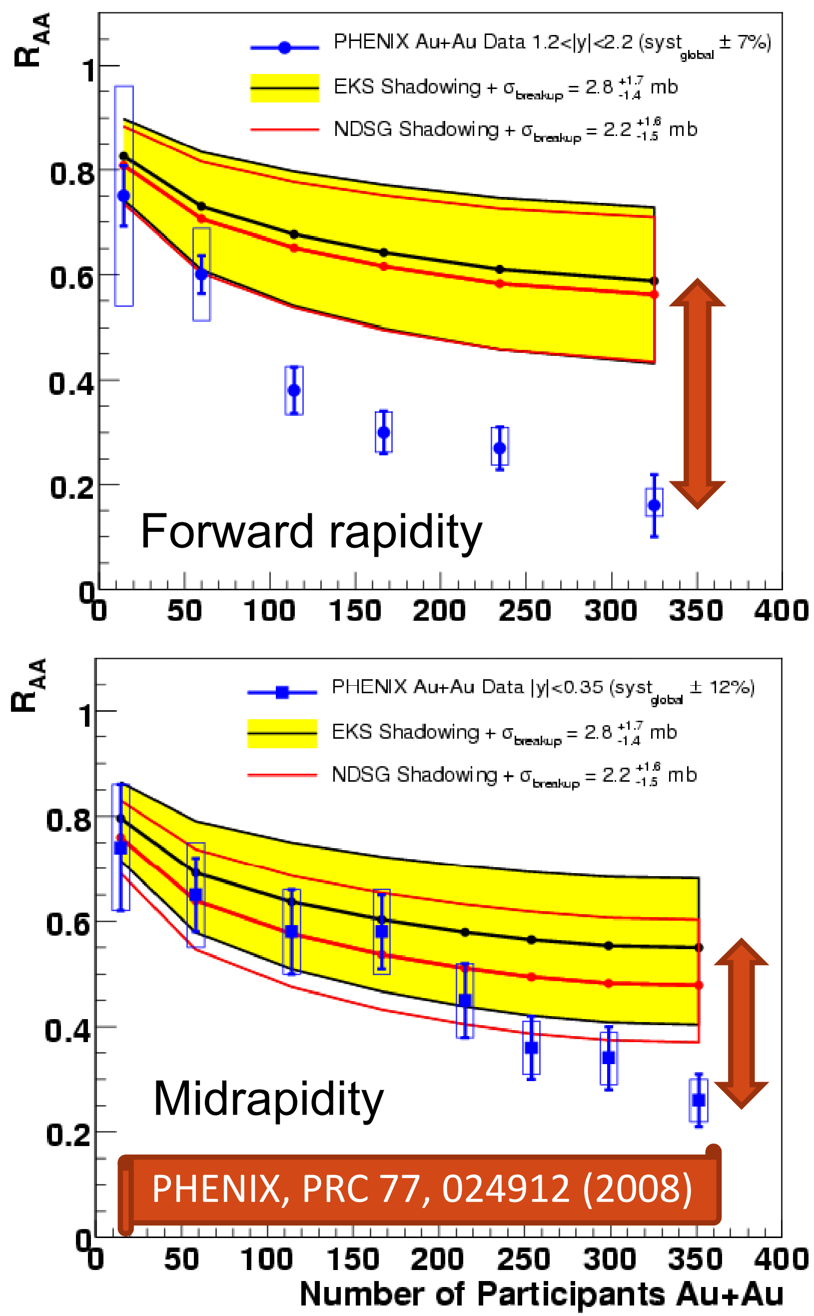


Capella, Ferreiro, Tywoniuk et al.
Fitting Cu+Cu, Au+Au,
Mid and forward rapidity

B. Cold matter

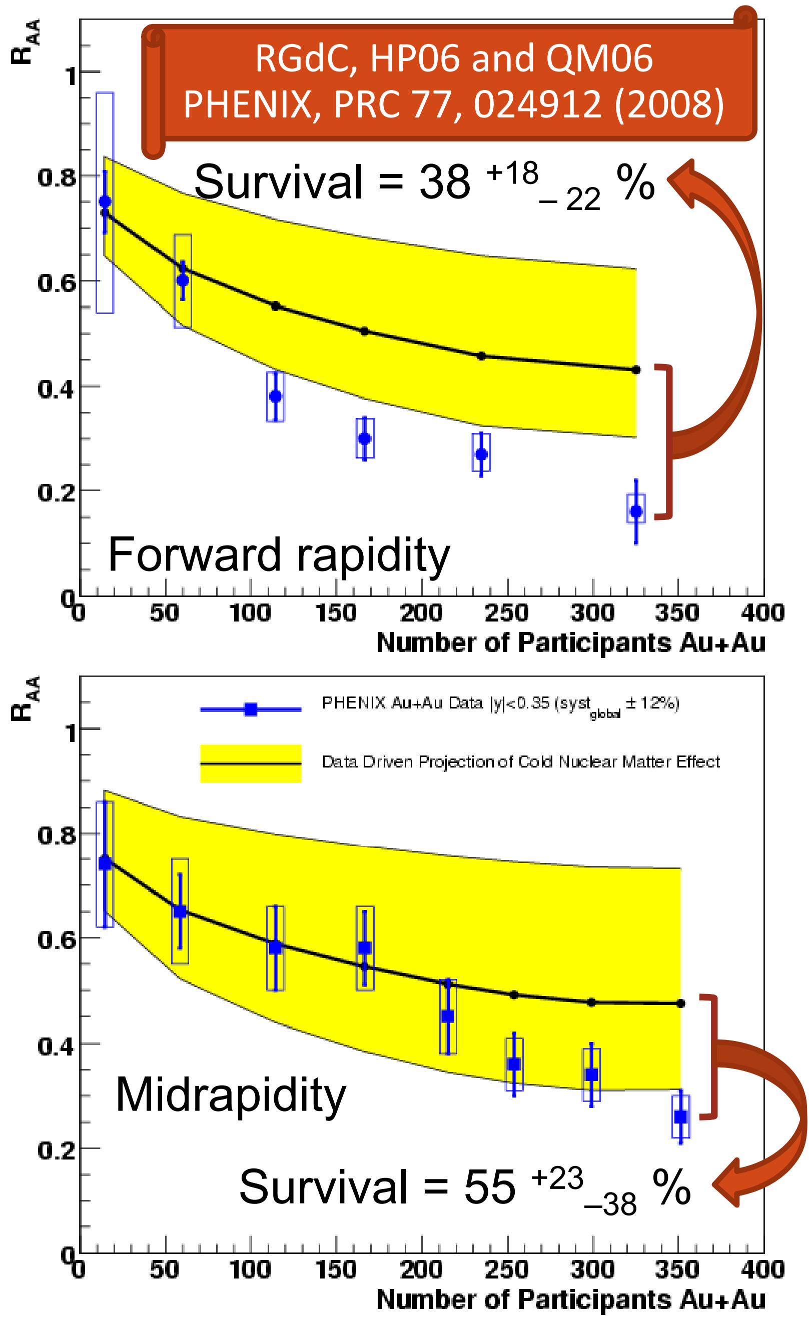
More with E. Ferreiro

- Assuming two shadowing schemes, derive a breakup cross sections from $R_{dA}(y)$
  - $\sigma_{EKS} \approx 2.8\ ^{+1.7}_{-1.4}$ mb
  - $\sigma_{NDSG} \approx 2.2\ ^{+1.6}_{-1.5}$ mb
  - ¡ Error is underestimated !
  - (A. Linden-Levy @SQM08)
  - Proper error on σ is > 2 mb
- And extrapolate to AuAu collisions →
  - (Also available for CuCu)
  - Mid and forward are correlated through shadowing scheme
  - <u>If you believe this shadowing,</u> large anomalous suppression, larger at forward rapidity.



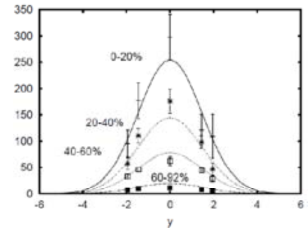
B. Cold matter

- More model independent…
- In a Glauber data-driven model, propagate what we know from R_{dA}(y,centrality)
  - $R_{AA}(y,b) = \Sigma_i R_{dA}(-y,b^i_1) \times R_{dA}(+y,b^i_2)$
  - No shadowing nor absorption schemes
  - Mid and forward are not correlated, less model dependent → larger uncertainties (especially @ y≈0)
- Anomalous suppression, at least at forward rapidity!
- Anomalous suppression could be identical at midrapidity
- (No dCu, so no CuCu)

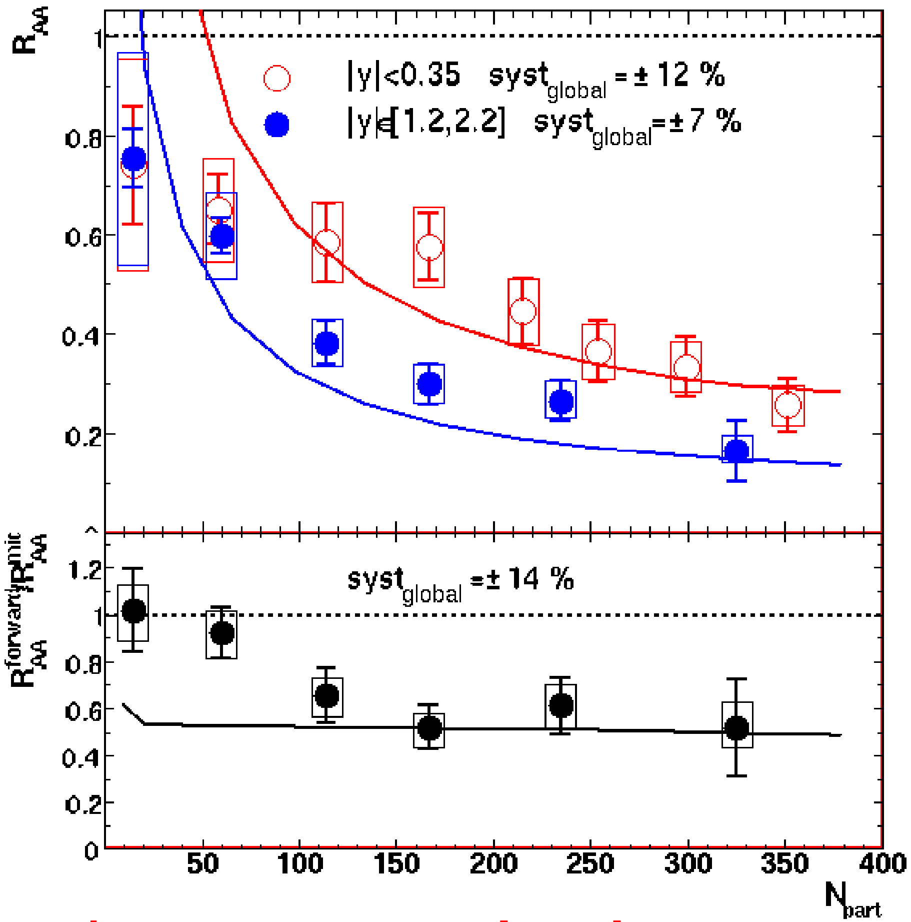


B. Recent CGC news

Kharzeev, Levin, Nardi, Tuchin
arXiv: 0808.2954 & 0809.2933



- Gluon saturation could further suppress forward J/ψ in AuAu
  - First numerical estimate
  - Absolute amount of suppression is fitted to the AuAu data!
  - Waiting forward to new dAu data to fit them first
  - However, rapidity dependence should be ok
  - But it fails to reproduce peripheral data →
  - Anyway…



→ Not proven that J/ψ anomalous suppression is different at mid and forward rapidity!

How to disentangle these two scenarios experimentally?

Two possible theoretical explanations…

A. One hot: coalescence, regeneration

B. One cold: saturation, shadowing

How to move forward experimentally?

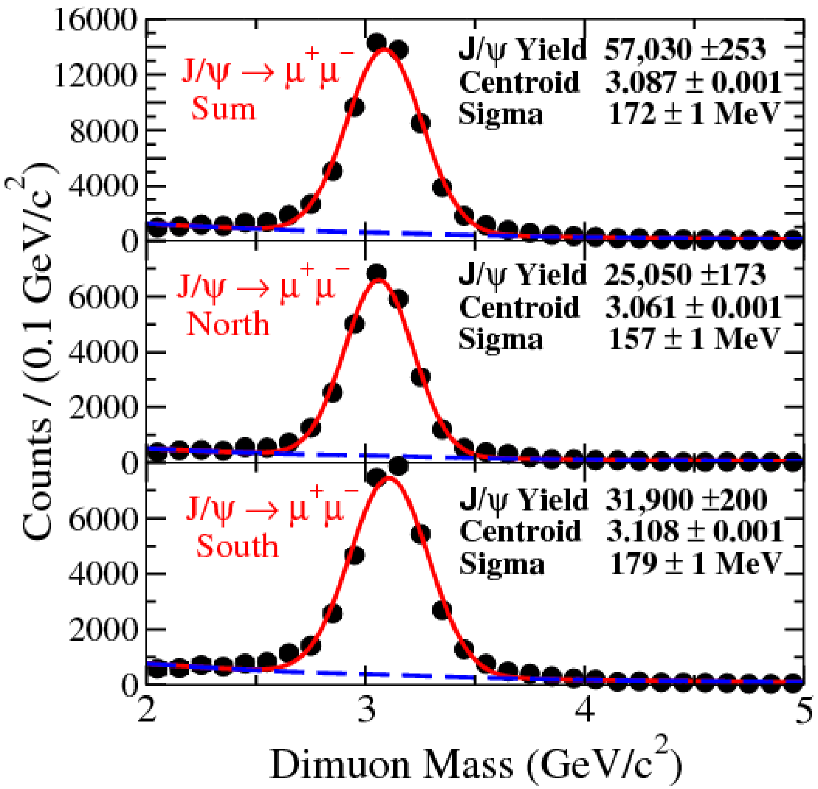
RGdC, Quarkonia in hot and cold matters, Quark Matter 08

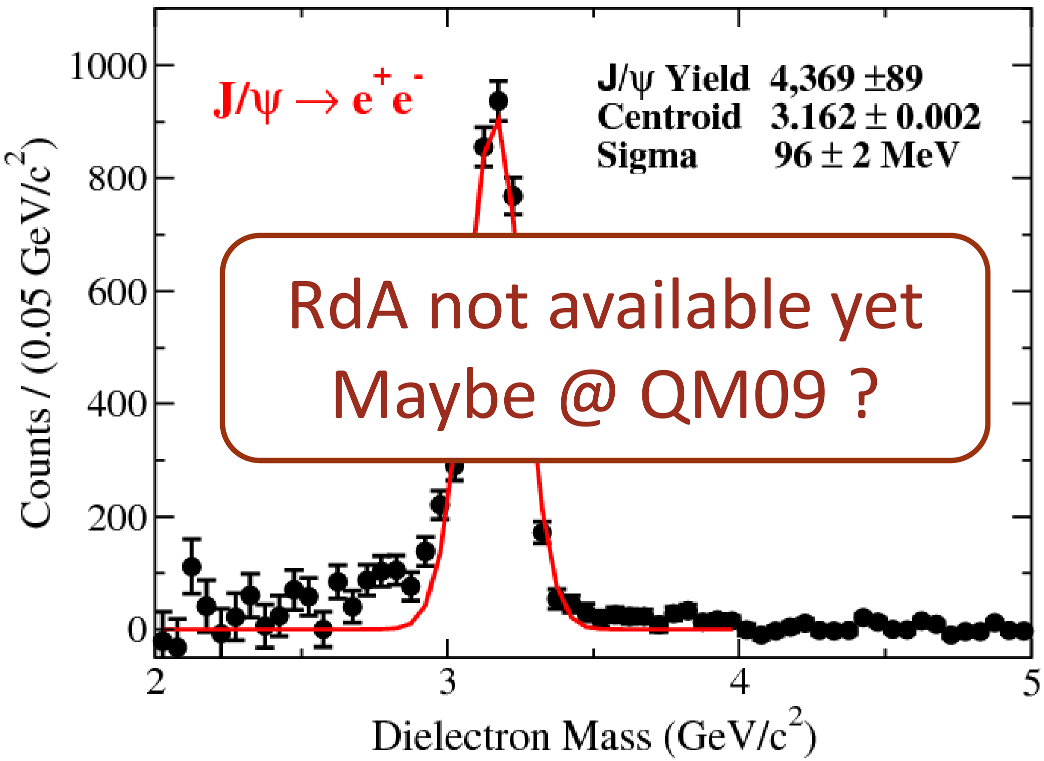
1.	Calm down?	(Better pA/dA reference)
2.	Be more open?	(Measure cc to constrain regen.)
3.	Broaden interest?	(in transverse momentum)
4.	Let it flow?	(elliptically)
5.	Get excited?	(ψ', χ_c)
6.	Get high?	(in mass, looking at upsilons)
7.	Be upset?	(and search for onset)
8.	Give up?	And move to the LHC?

Some progress on all these points at this meeting !

1. We need a better reference

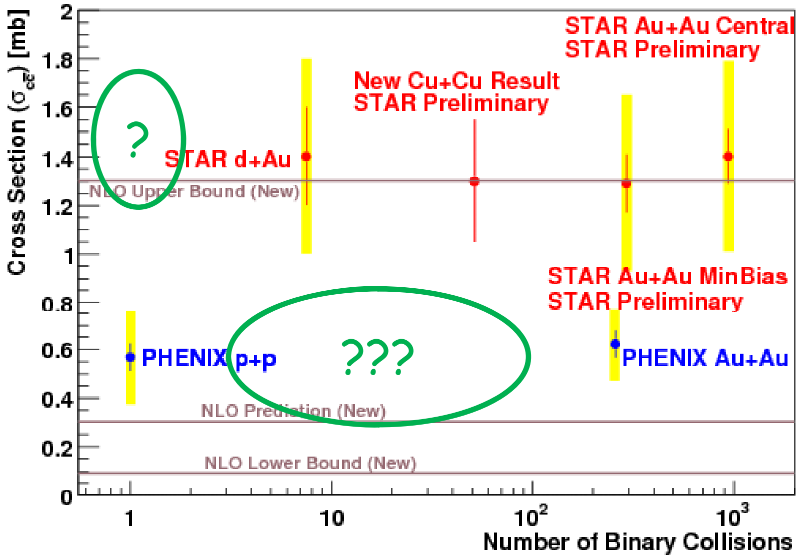
- Already a lot more dAu data on tape (run8 ≈ 30 x run3) that should further help constraining cold matter effects

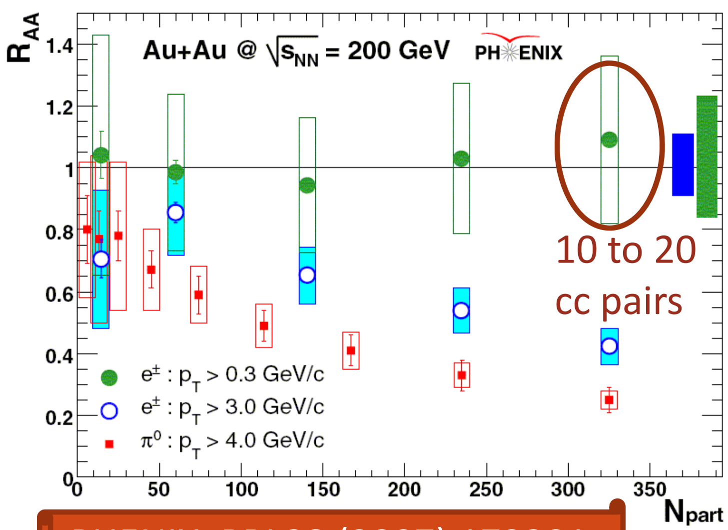




RdA not available yet
Maybe @ QM09 ?

2. Measuring open charm…





PHENIX, PRL98 (2007) 172301

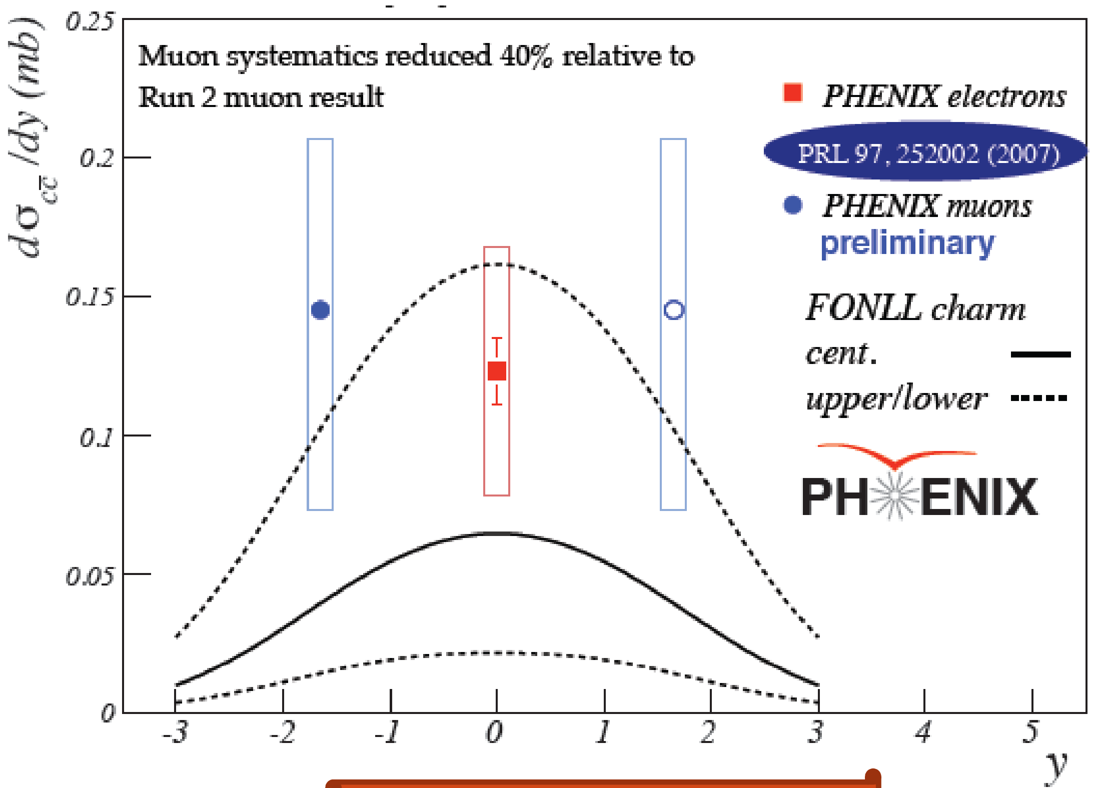
… could constrain both

- Regeneration α $(N_{cc})^2$
- Initial state effect (shadowing…) common to J/ψ

- A factor of 2 difference between experiments
- ≈25% systematic error
- But binary scaling (within uncertainties…)

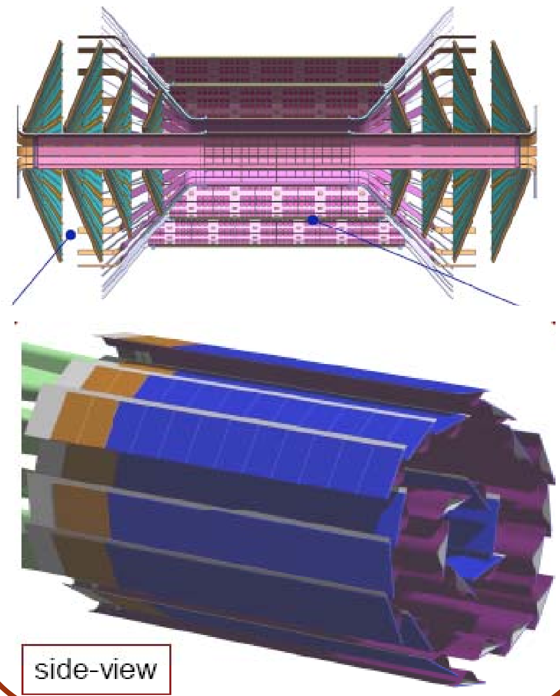
2. Open charm vs rapidity

- Only pp, and very poorly known



D. Hornback, PHENIX, QM08

To know more about open charm, wait for silicon upgrades in Phenix and Star



Look at other observables

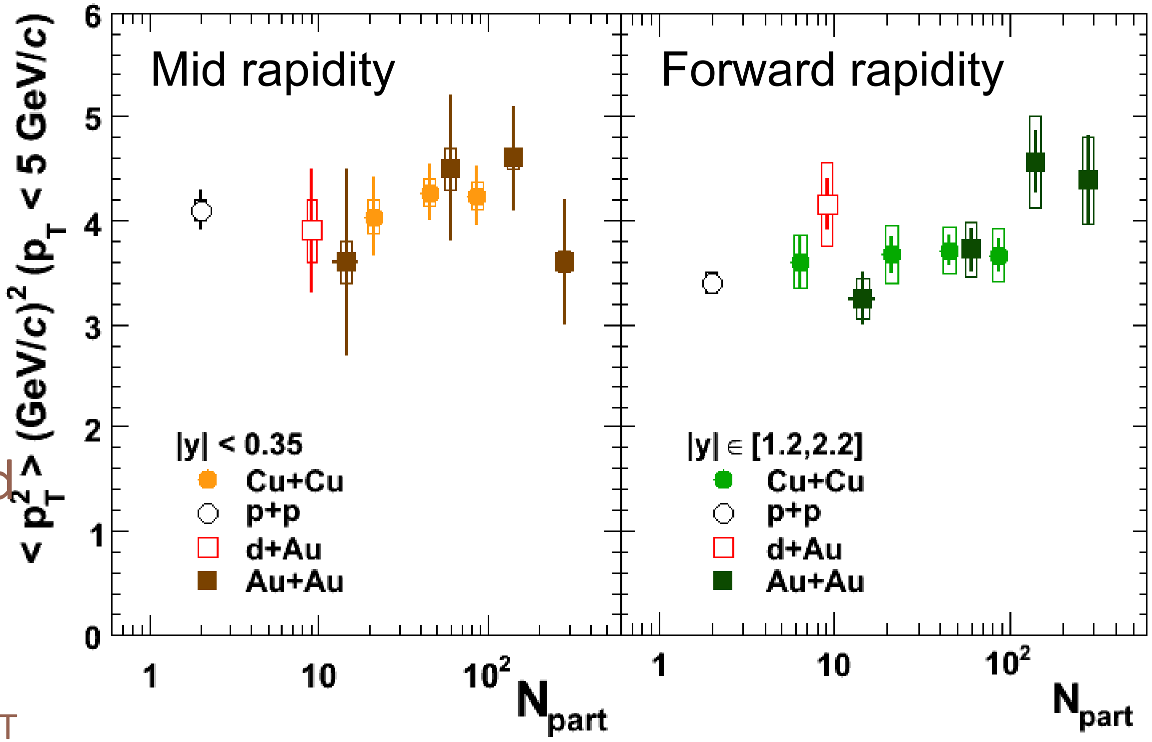
3. p_T (broadening)
4. Elliptic flow

3. p_T broadening @ RHIC ? vs N_{part} ?

PHENIX, PRL 101, 122301 (2008)

- Widely unknown initial charm production:
  - Recombined R_{AA} are poorly constrained…
- Instead look at p_T:
  - Hot: Inherited p_T should be lower than initial
  - Cold: Cronin effect should broaden initial p_T
- Cronin goes like:

  $<p_T^2>_{AB} = <p_T^2>_{pp} + \alpha \times L$



- No strong $<p_T^2>$ dependence…
- Modest rise at forward rapidity
- Could be broadening
- No need for recombination here

3. p_T broadening @ RHIC ? vs thickness ?

- Widely unknown initial charm production:
  - Recombined R_{AA} are poorly constrained…
- Instead look at p_T:
  - Hot: Inherited p_T should be lower than initial
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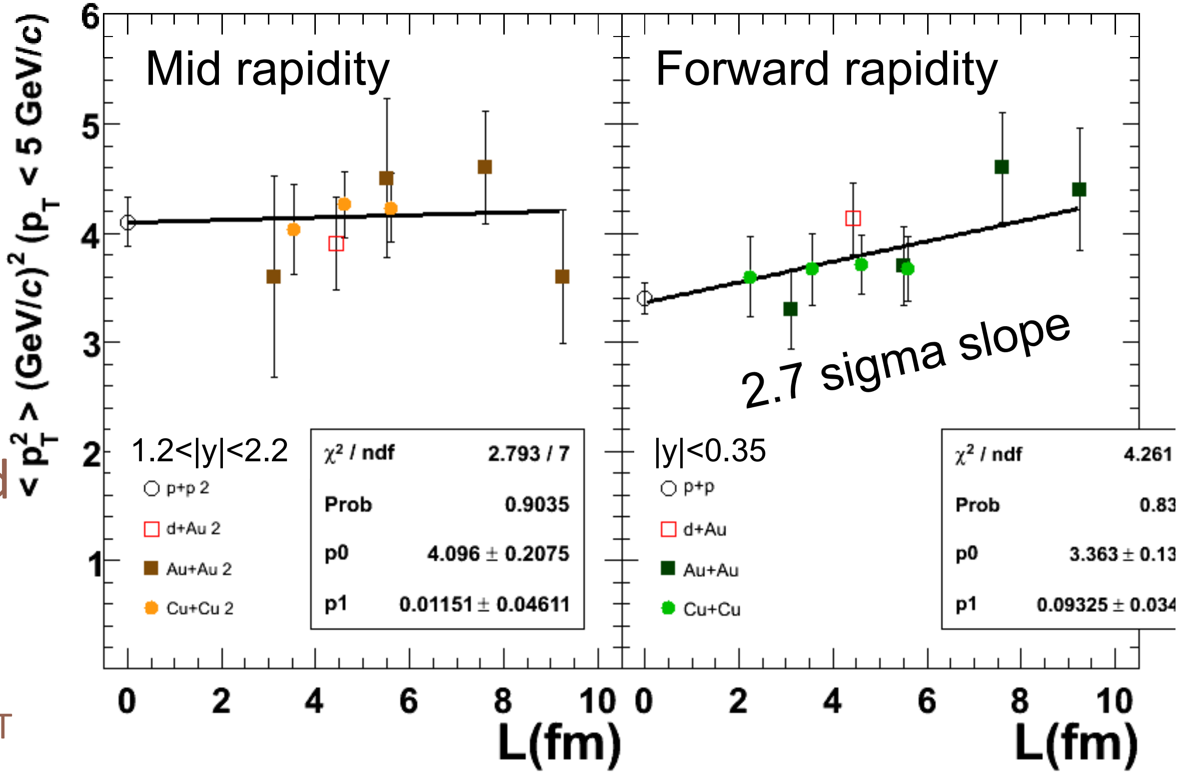
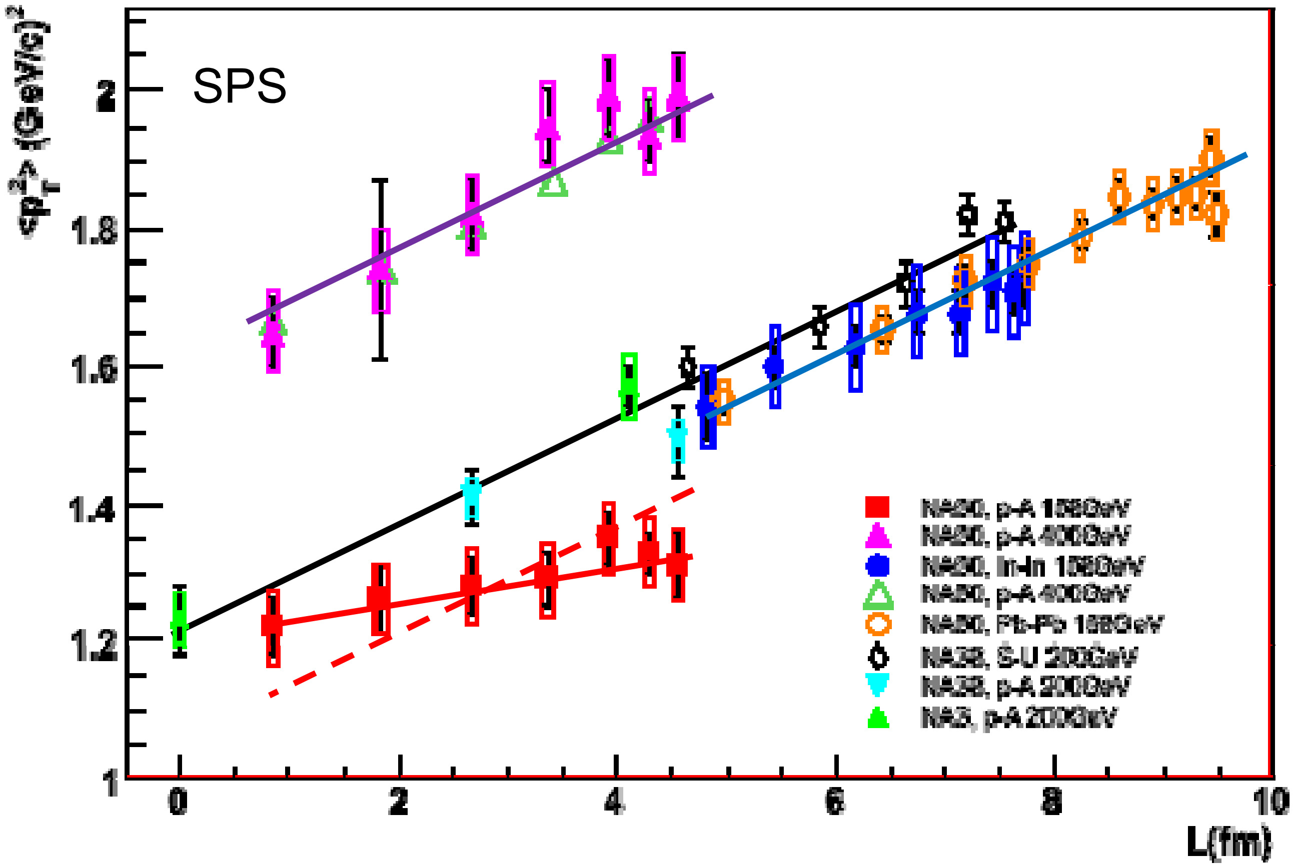


- No strong $<p_T^2>$ dependence…
- Modest rise at forward rapidity
- Could be broadening
- No need for recombination here

3. p_T broadening @ SPS ?

- Tested on many systems…

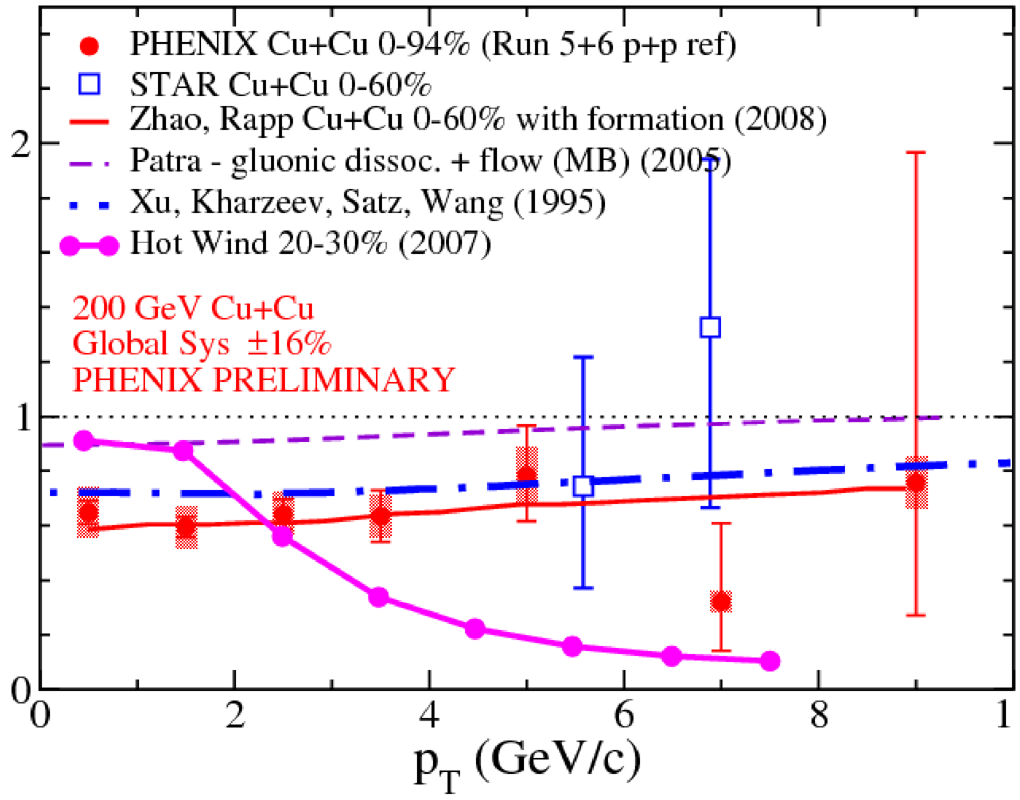


Cortese (NA60), Hard probes 08
+ homemade powerpoint fits

3. Reaching higher p_T

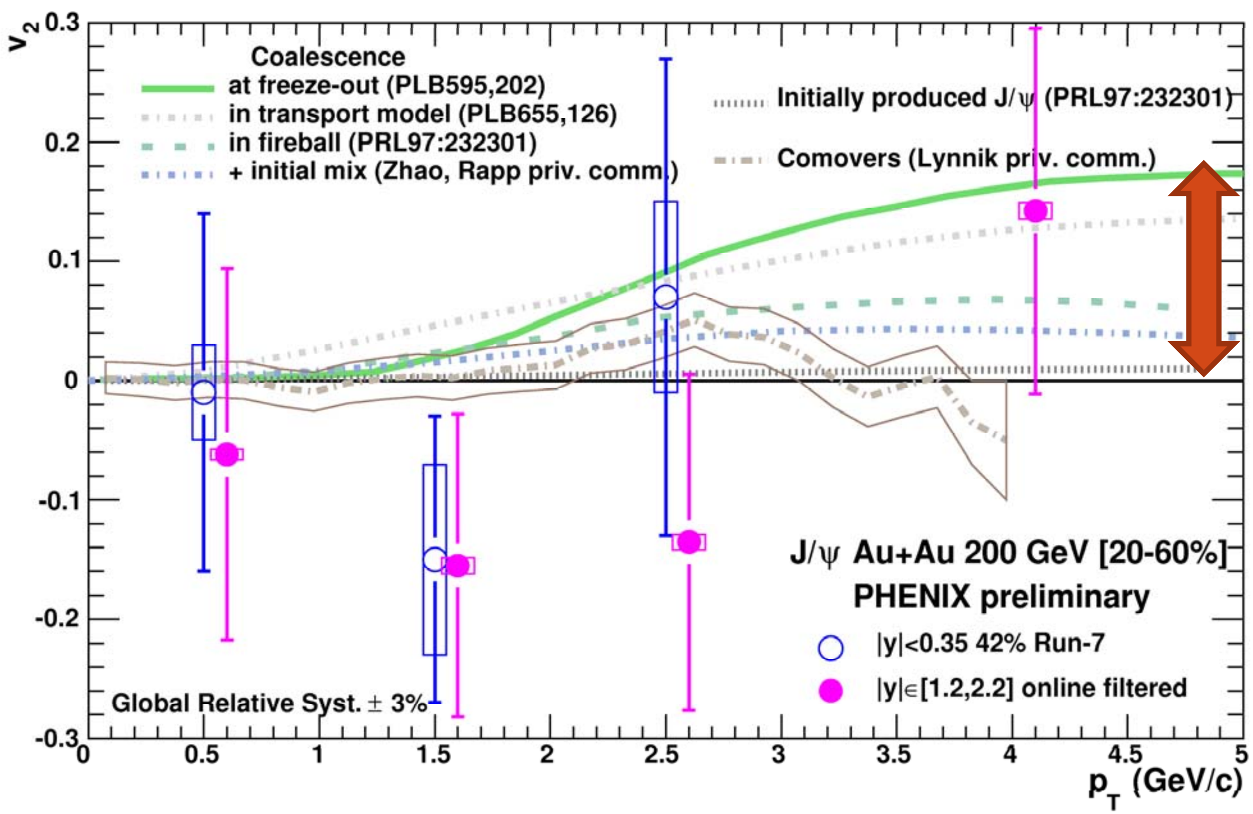
- At QM08, some excitement about STAR's high p_T
  R_{CuCu} (high p_T) ≈ 1

- Hot wind scenario → 0
  - Screening length from AdS/CFT
- Several reasons for RAA to grow at high p_T
  - Cronin effect
  - Bottom contribution
  - Leakage
  - (Anti)shadowing



4. J/ψ elliptic flow in PHENIX

- If recombined, J/ψ should inherit the (rather large) charm quark elliptic flow. First measurement:

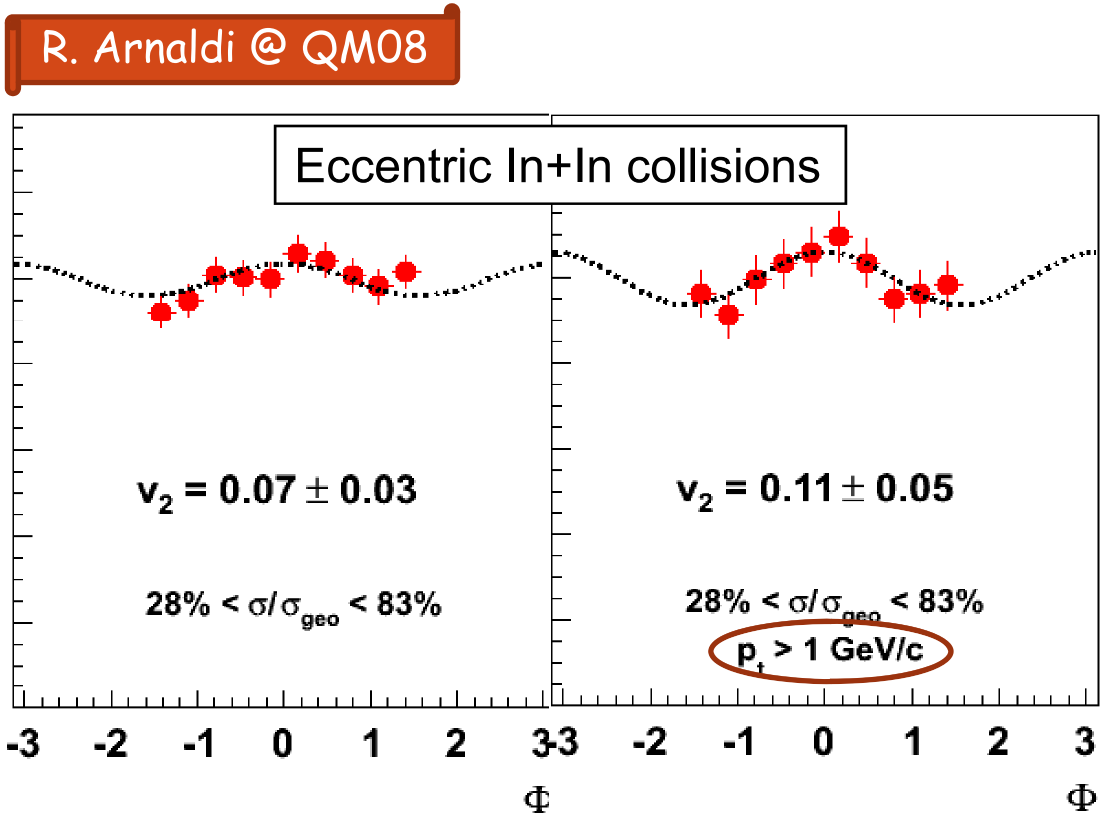


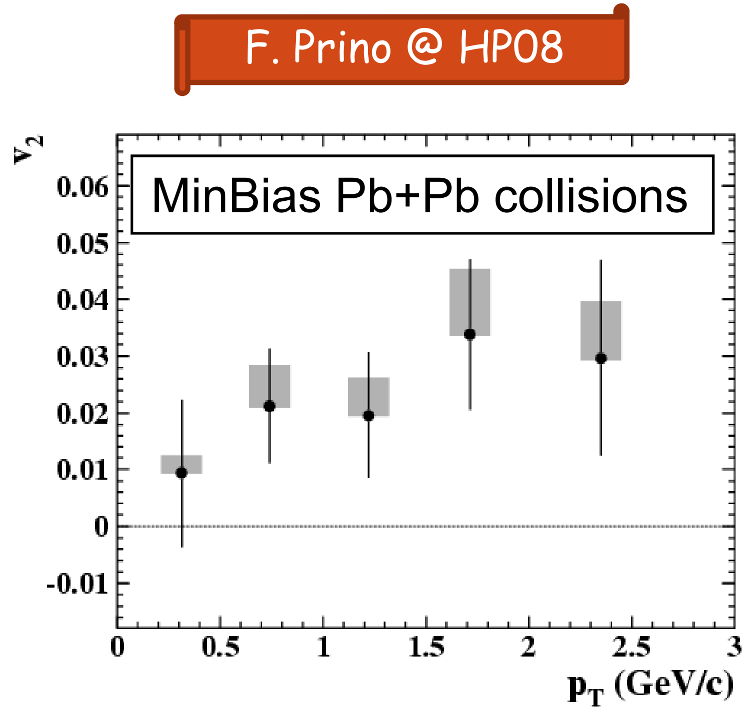
C. Silvestre @ QM08
E.T. Atomssa @ HP08

Various levels of recombination…

Will require RHIC II for a discriminating measurement

4. But also J/ψ elliptic flow @ SPS





- Cannot be due to recombination
  - (≈0.05 cc pairs in In+In)
- Needs confirmation and understanding

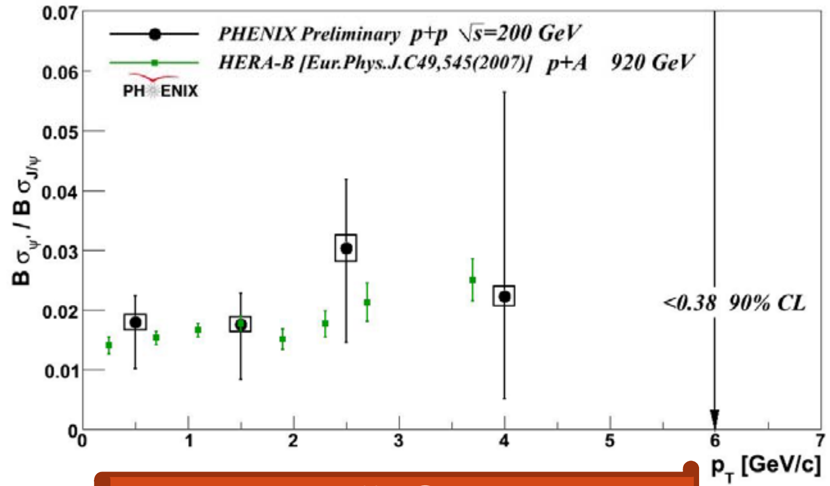
Look at other quarkonia

5. Excited charmonia
6. Upsilons

5. Excited states (=feed down to J/ψ)

- Excited states should…
  - A. melt if J/ψ suppression is cold effects + sequential melting
  - B. also regenerate if J/ψ do (and maybe even more)
- Unfortunately only pp
  - → Feeddown ratio

- ψ from ψ' = 8.6 ± 2.5%

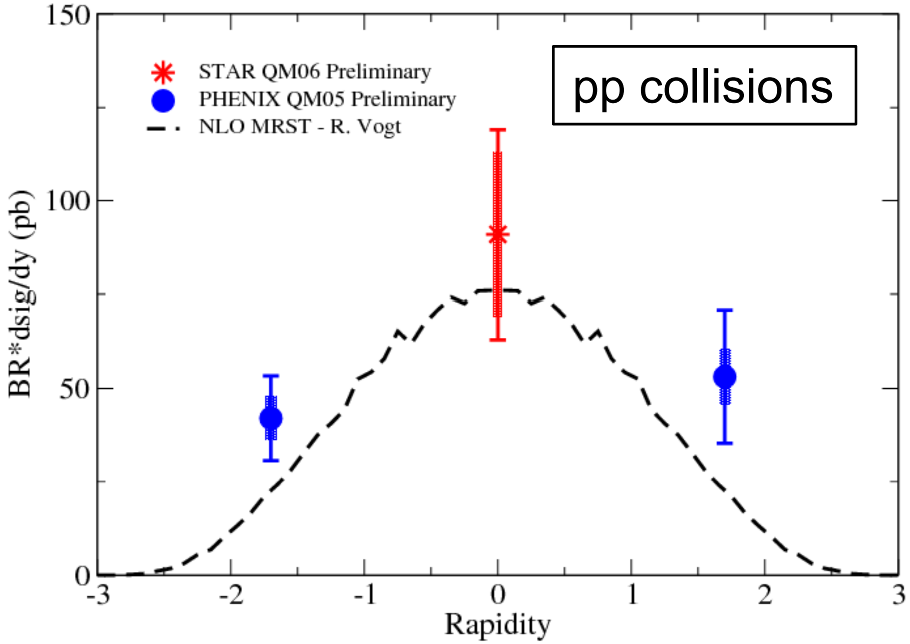


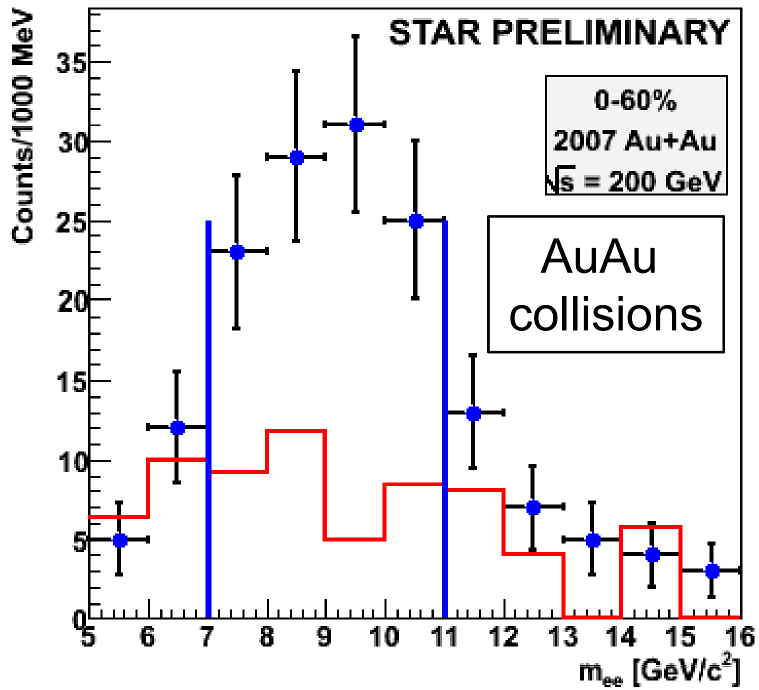
M. Donadelli @ PANIC08

- ψ from χ_c < 42% (90%CL)
- Beauty cross section → ψ from B = 4^{+3}_{-2} %

6. Bottomonia

D. Das @ QM08





- Suffer less from cold matter
  - (x=0.02 to 0.1=EKS antishadowing)
  - can be checked with run8 d+Au
- Should measure (unseparated) excited states melting…

Some news on
on ψ' and Upsilons
in AA collisions
at QM09?

What else ?

---

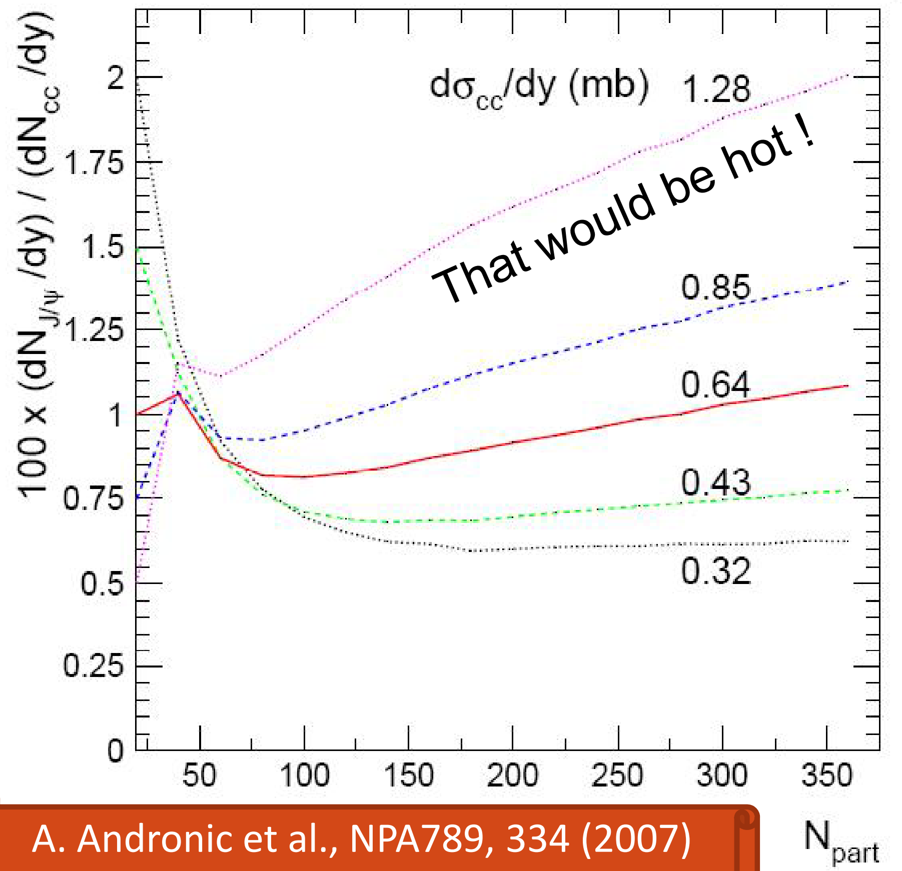
7. ~~Look for onsets~~

8. Go to LHC, the uncharted territory

8. J/ψ at LHC ?

- A new story will begin
  - ↓ More J/ψ melting
  - ↓ Larger shadowing / saturation effects
  - ↑ Larger recombination (maybe 200 cc pairs)
- If recombination prevails → golden signal
- If not, expect same or worse difficulties as at RHIC…

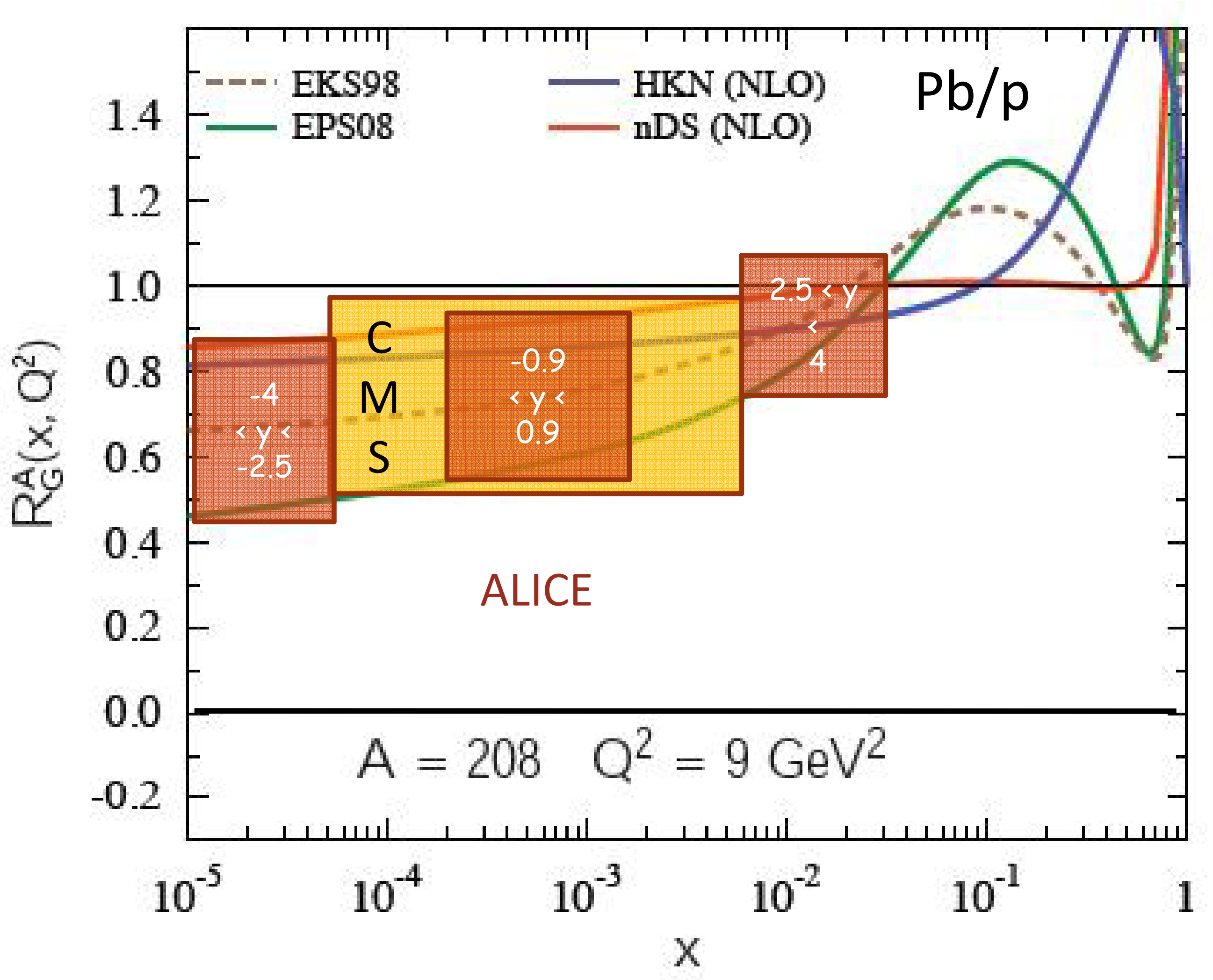
- Example of prediction



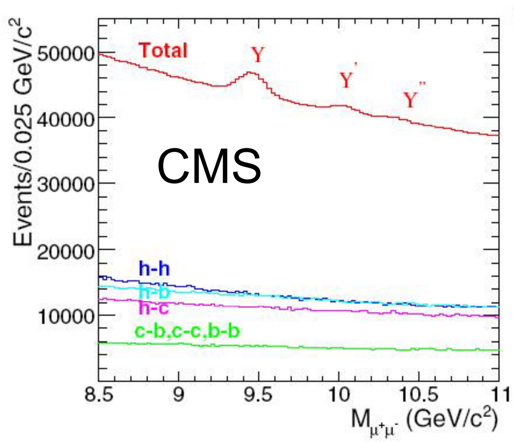
A. Andronic et al., NPA789, 334 (2007)
A. Andronic, Quark Matter 2008

8. Quick look at shadowing on J/ψ

- (emmited gluons and pT are neglected)
- A factor of ≈2x2 uncertainty on charm production from current shadowing knowledge



8. More quarkonia @ LHC



- A lot of Upsilons
  - Υ' and Υ'' should be suppressed
  - Υ shouldn't (apart from 50% χ_b feeddown)

Signal	ALICE	$\|\eta\|$	CMS	$\|\eta\|$	ATLAS	$\|\eta\|$
$J/\psi \to \mu^+\mu^-$	677,000	$2.5-4$	184,000	< 2.4	$8,000-100,000$	< 2.5
$J/\psi \to e^+e^-$	121,100	< 0.9				
$\psi' \to \mu^+\mu^-$	18,900	$2.5-4$	≈ 3,700 (10 σ) ?		$1,400-1,800$	< 2.5
$\psi' \to e^+e^-$						
$\Upsilon \to \mu^+\mu^-$	9,600	$2.5-4$	37,700	< 2.4	15,000 (21,200)	< 2.0 (< 2.5)
$\Upsilon \to e^+e^-$	1,800	< 0.9				
$D^0 \to K^\pm\pi^\mp$	13,000	< 0.9				

Pb-Pb 0,5 nb^{-1}

Frawley, Ullrich, Vogt, Phys Rept 462 (2008) 125

Anomalous conclusions

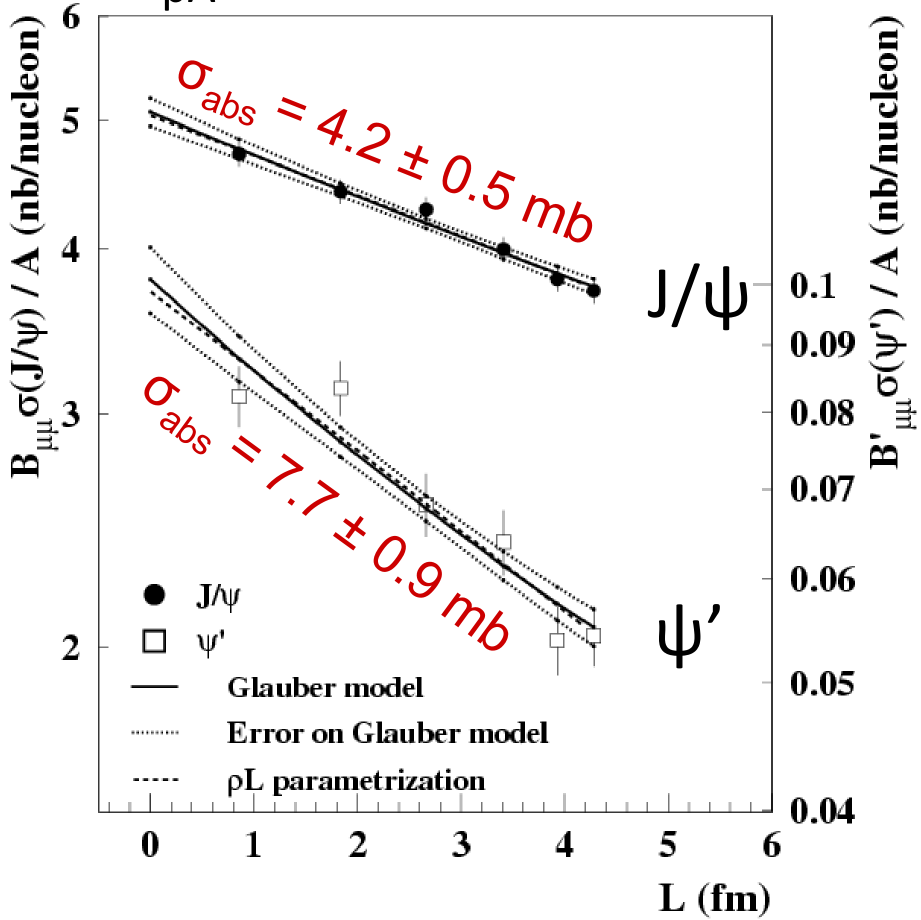
- Three years ago, in Santiago (Feb 10th 2006)
  - "No strong conclusion" we had the RHIC preliminary Au+Au result, but the rapidity dependence of R_{AA} was not clear yet…
- Today, one strong conclusion:
  - "J/ψ production is not (well and yet) understood at RHIC"
- Forward/mid rapidity difference could be due to:
  A. Regeneration / coalescence of cc pairs?
  B. Gluon shadowing / saturation?
- However, conservative cold matter approaches still gives significant anomalous suppression at least at forward rapidity…
  - The hot matter is deconfining some quarkonia
- More to come soon
  - dAu data ! Upsilon, ψ' in AA collisions and LHC…

That’s all folks

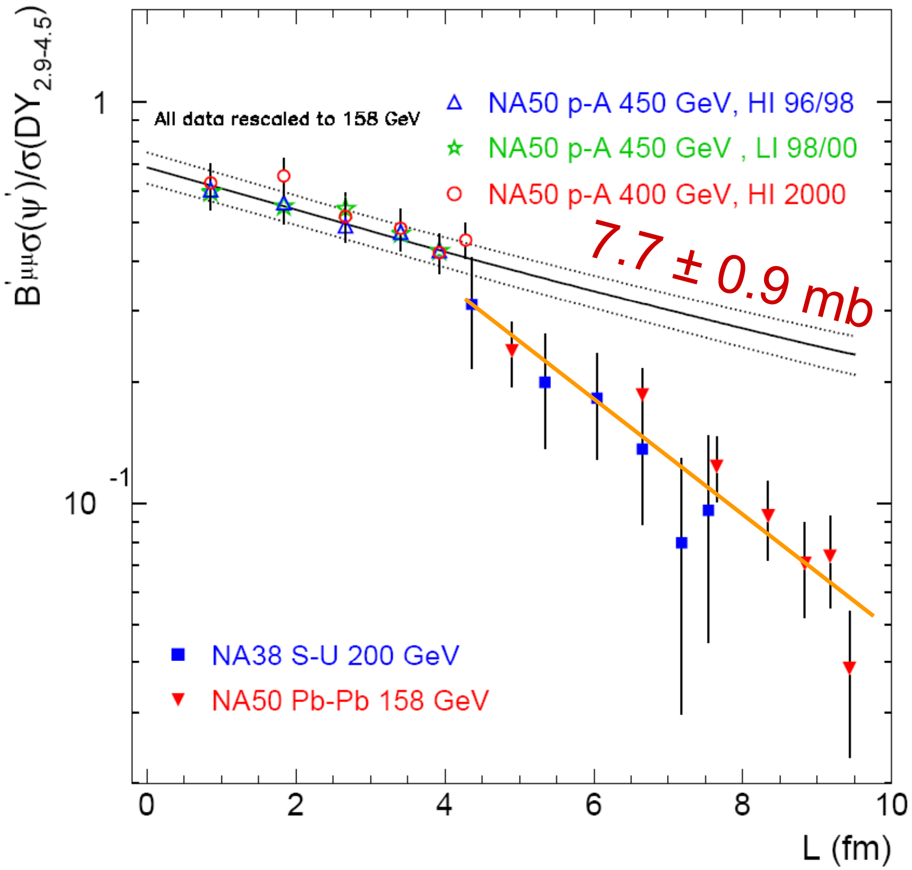
And the next speaker is…

What about ψ' ?

ψ_{pA} / A



ψ'/Drell-Yan

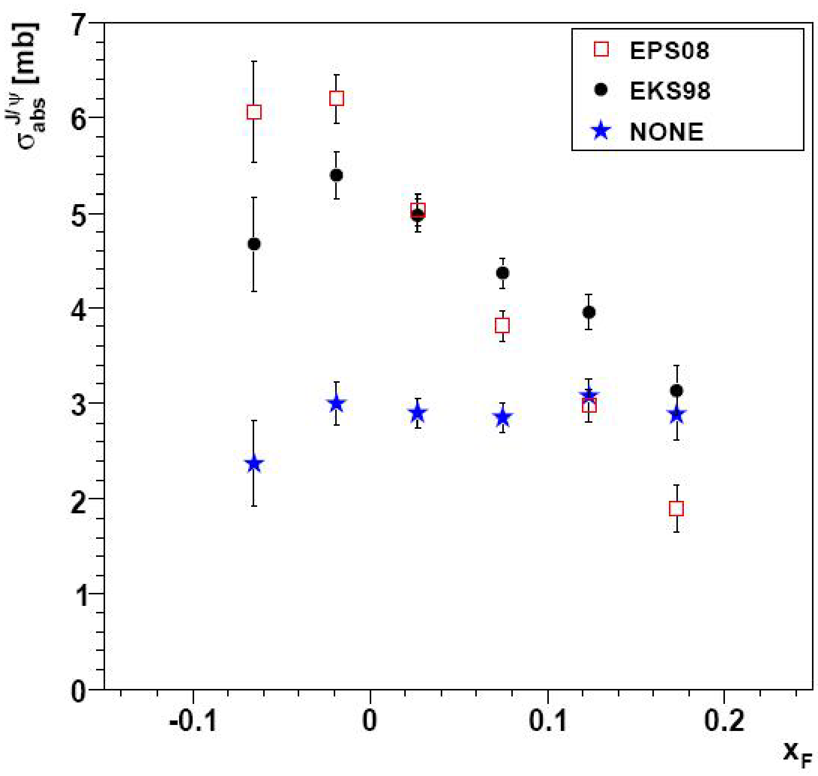


- ψ' are more absorbed than J/ψ

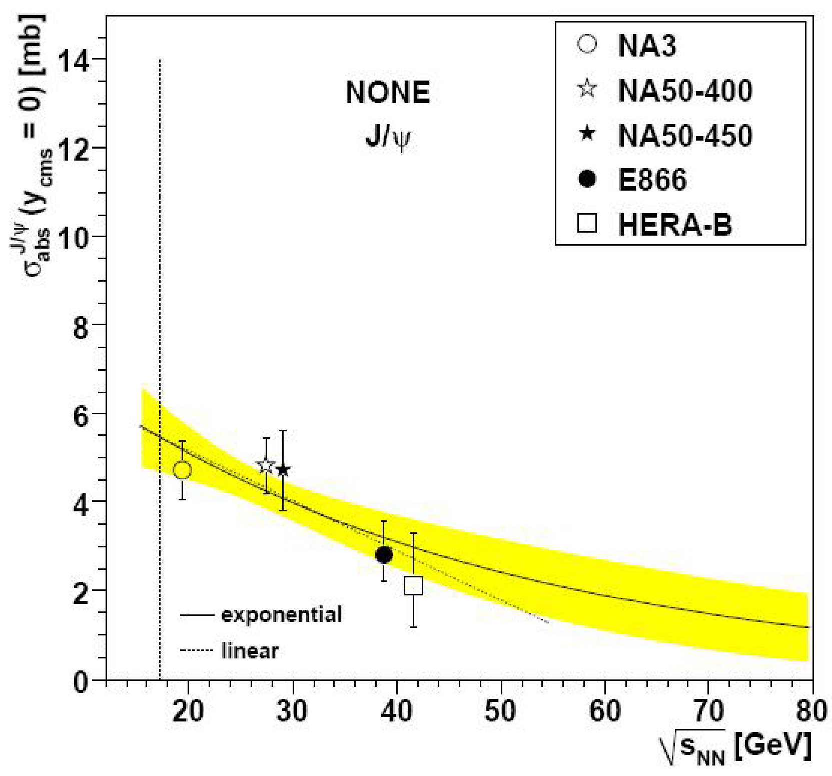
NA50, EPJC48 (2006) 329
NA50, EPJC49 (2007) 559

Lourenço et al, arxiv:0901.3054

E866 : flat with x_F if no shadowing is assumed…

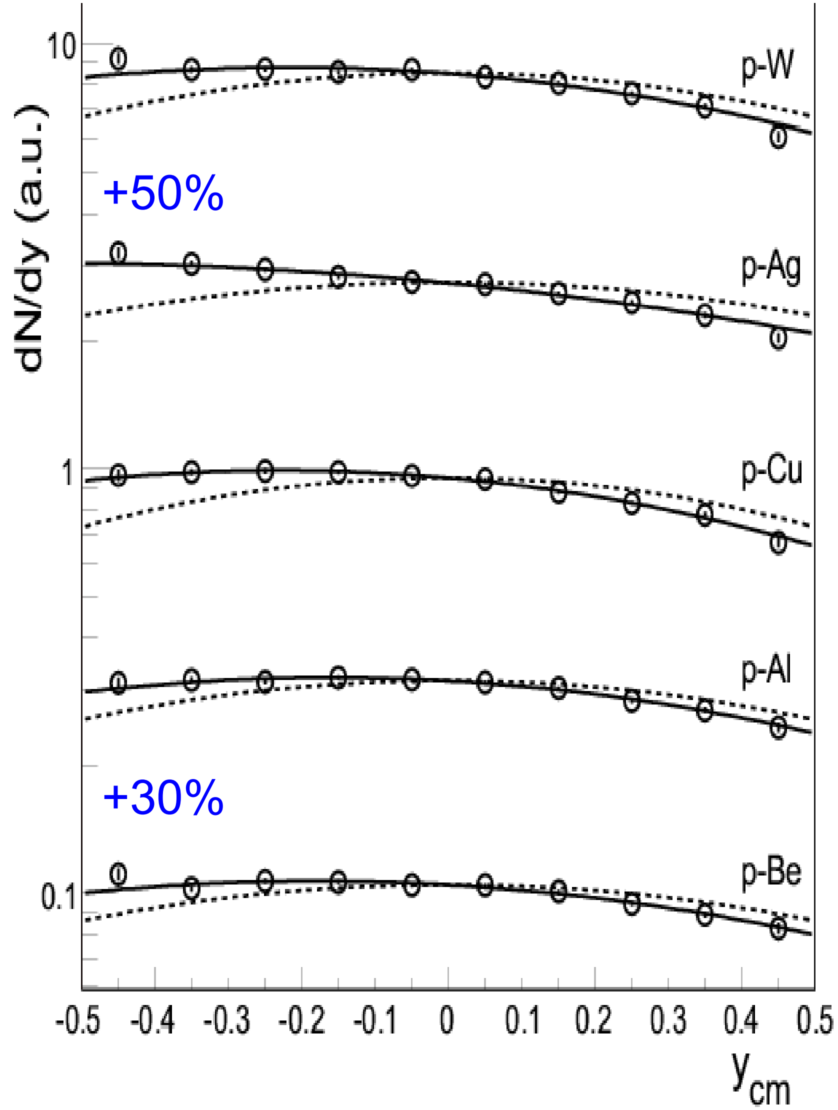


√s dependence of σ_{abs}: even with no shadowing, little



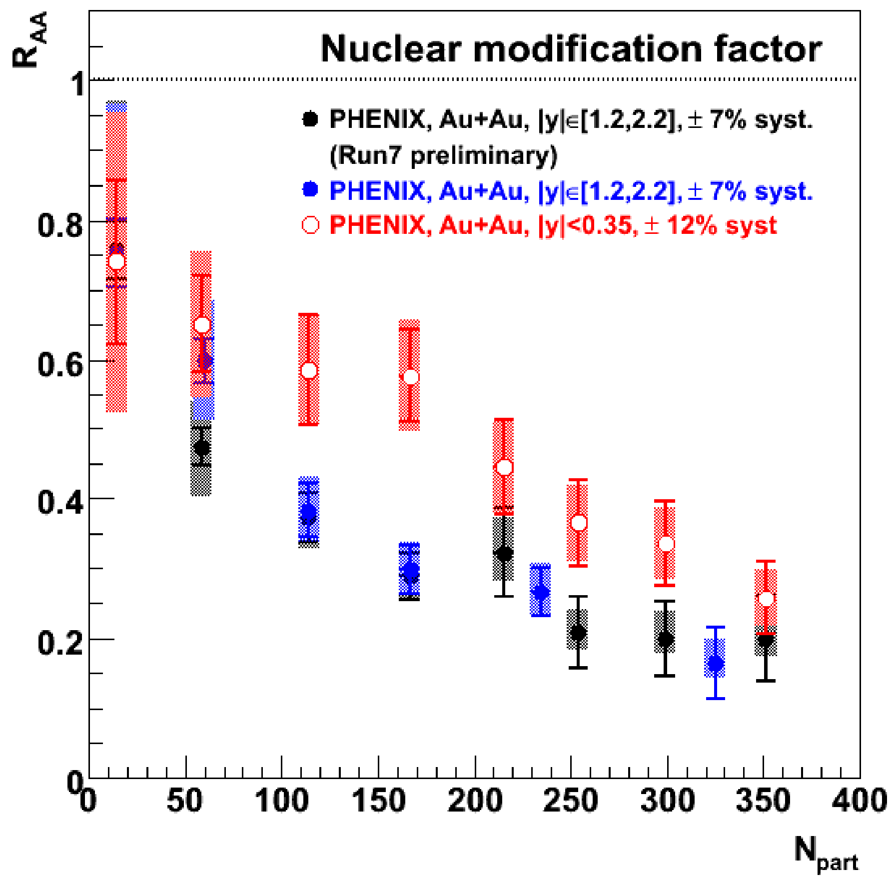
J/ψ in pA, NA50

- In pA, an unsolved rapidity dependence…
- EPJ…



R_{AuAu} (run 4) = R_{AuAu} (run 7)

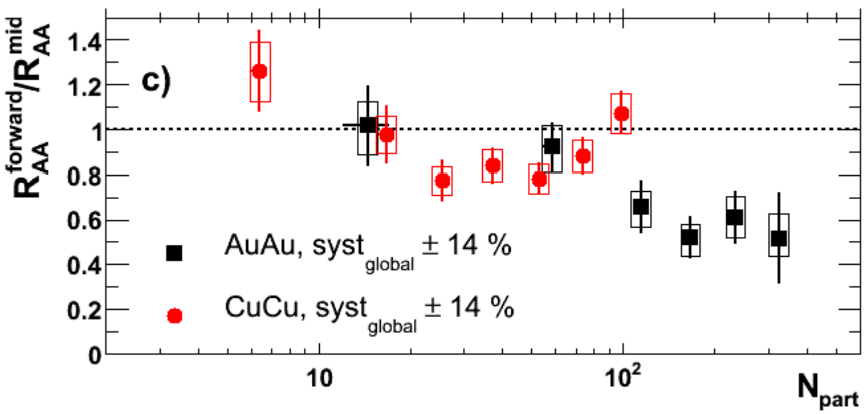
- Forward rapidity only (for now)
- More bins at higher centrality
- Confirm the trend
  - $R_{AA}(y\approx1.7) < R_{AA}(y\approx0)$

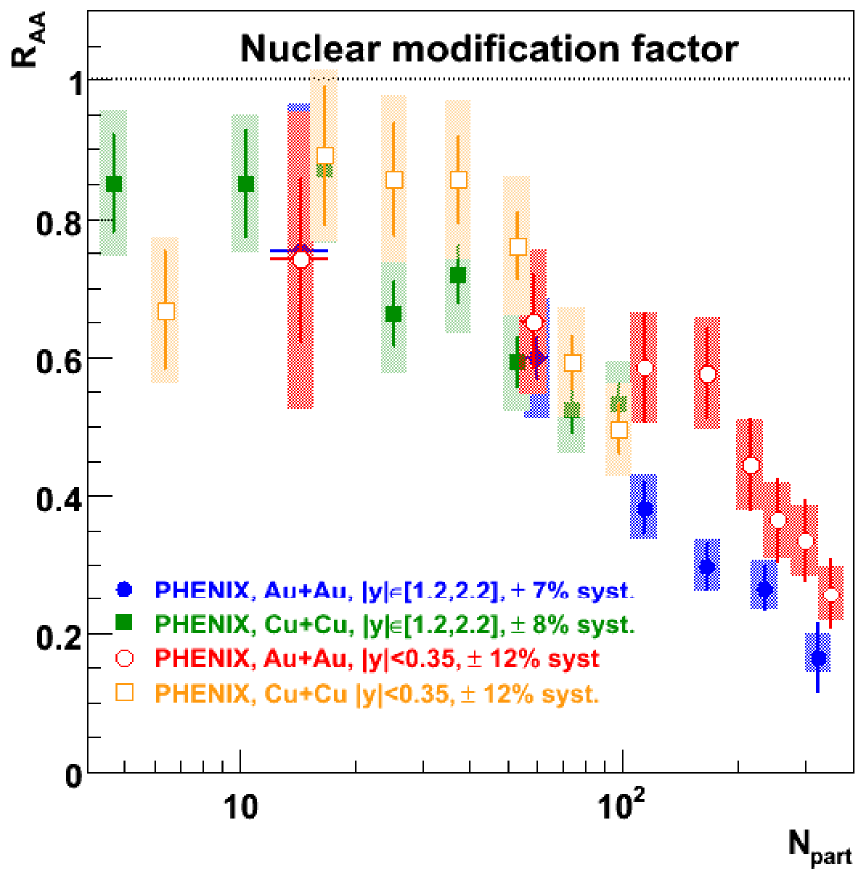


R_{AuAu} vs R_{CuCu} @RHIC

- Final CuCu analysis
- Slightly below 1 in CuCu

$$\frac{R_{AA}(y\sim1.7)}{R_{AA}(y\sim0)}$$





PHENIX, arXiv:0801.0220

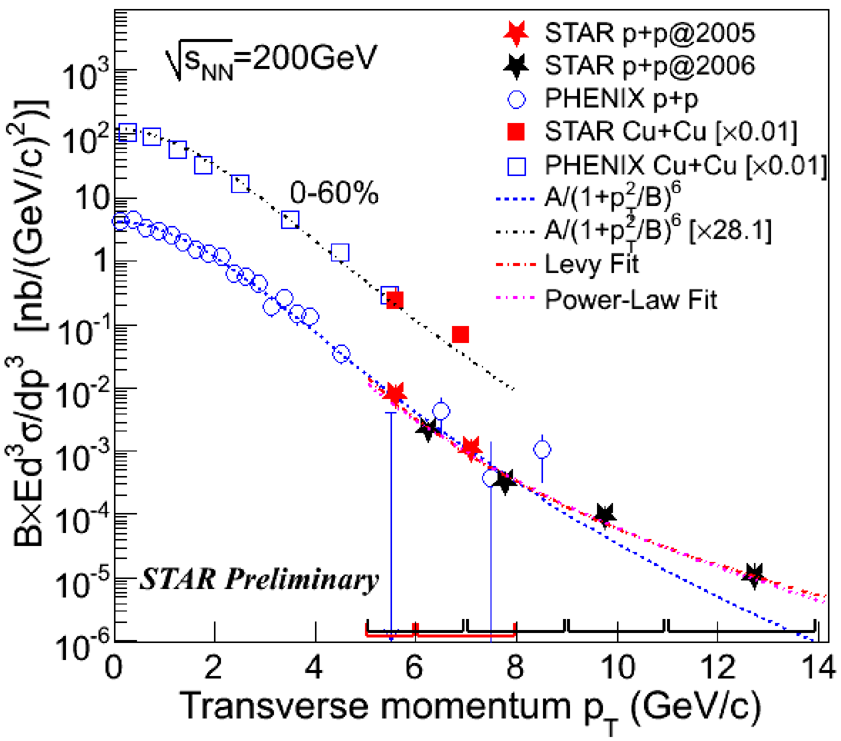
s loin, et avec les
s de Ralf and Co.
+ PHENIX !

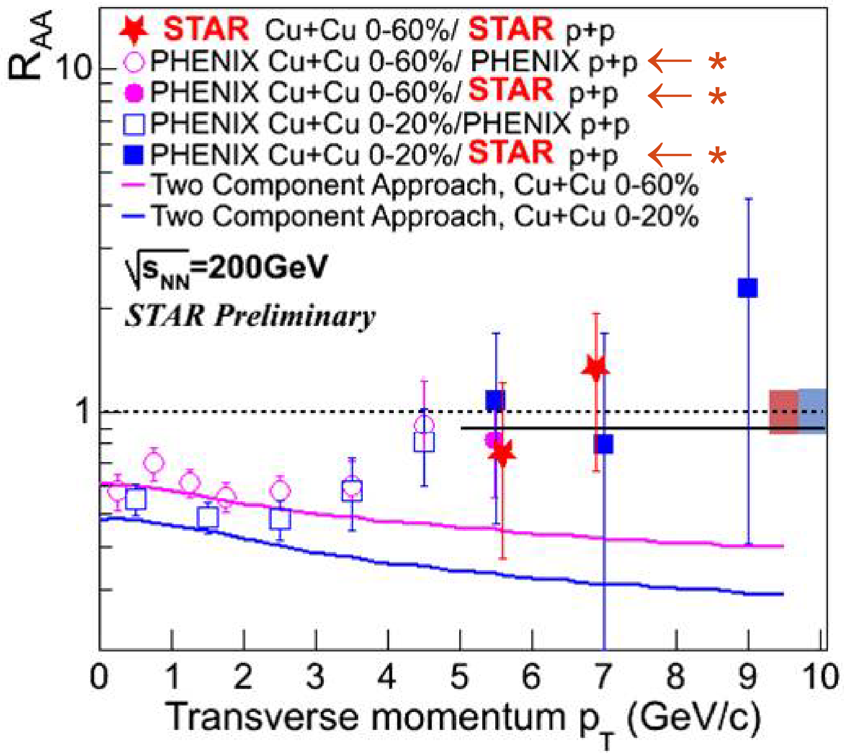
R_{CuCu} (STAR, high p_T) ≈ 1

2 sigma J/ψ signal in Cu+Cu

STAR = PHENIX charm spectra ☺

R_{CuCu} raising with p_T

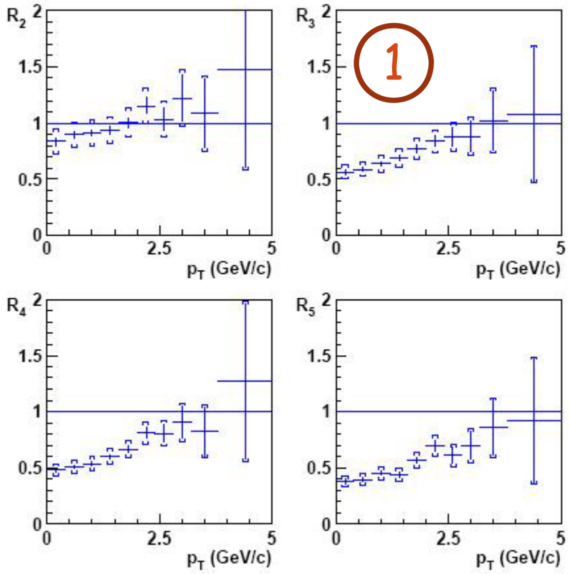


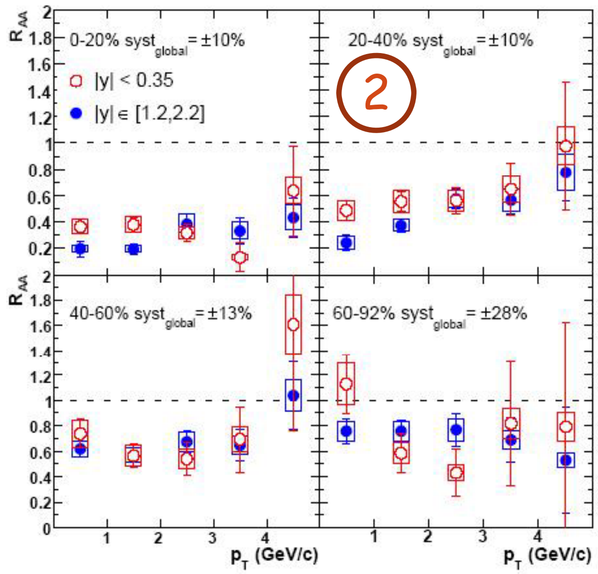


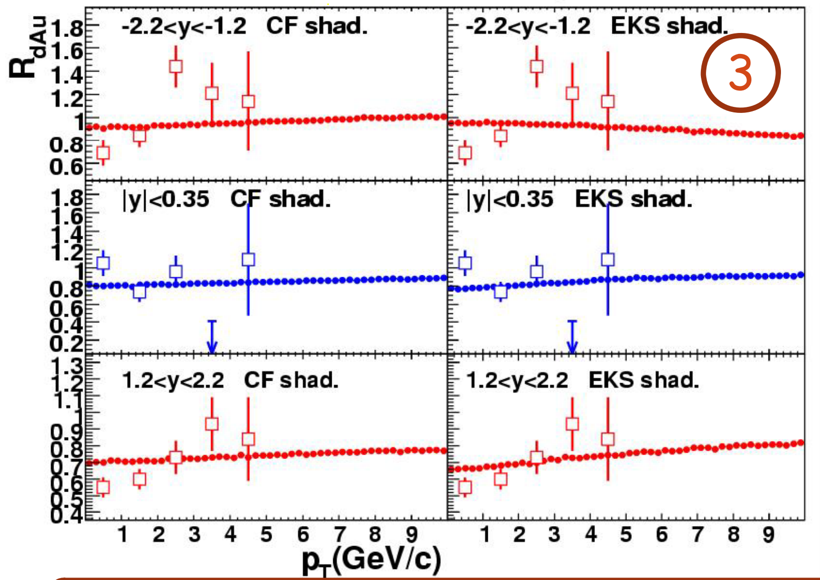
* These are not phenix results yet, but could become as soon as the two experiments talk to each others ☺

Various $R_{XY}(p_T)$

- Several (hints of) $R_{AA}(p_T)$
  1. R_{CP} PbPb (NA50)
  2. R_{AuAu} (PHENIX)
  3. R_{dAu} (PHENIX)
- Several potential reasons:
  - Leakage effect, J/ψ escape
    - High p_T J/ψ forming beyond QGP
  - Cronin effect
  - Raising x_{Bj} = less shadowing
    - 0.02 to 0.05 from 0 to 9 GeV/c
    - See discussion in →
- Think about it…





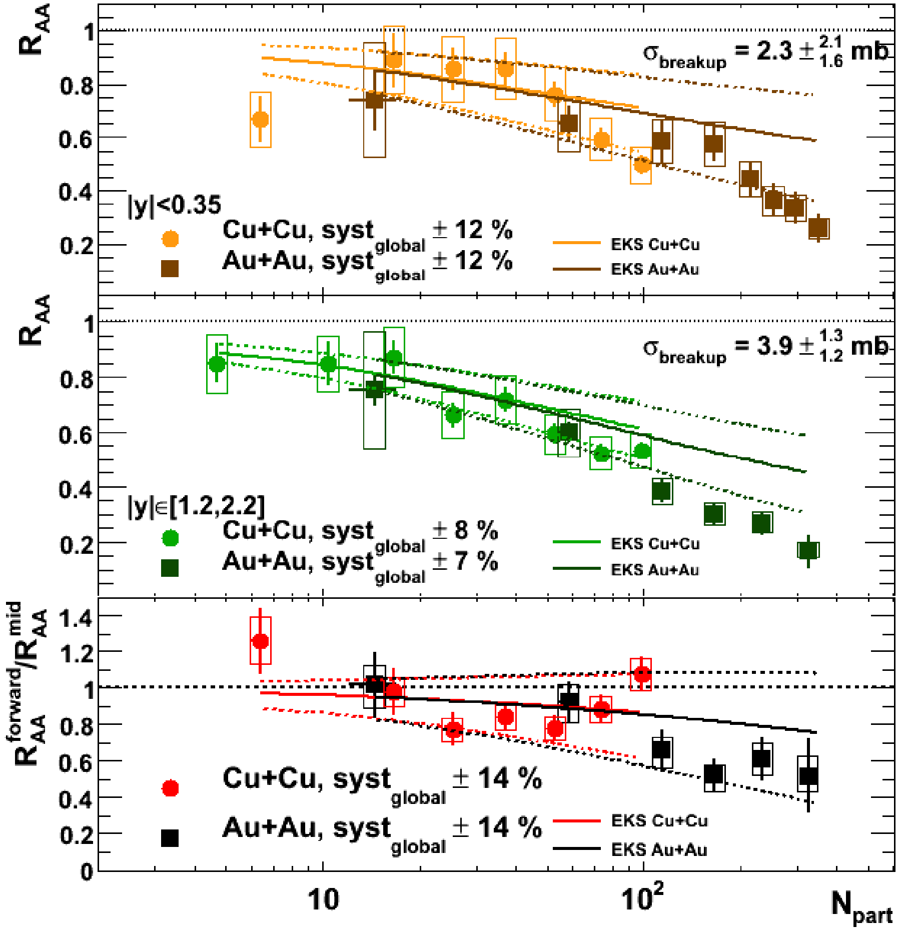


PHENIX, arxiv:0711.3917 compared to Ferreiro, Fleuret, Rakotozafindrabe, arxiv: 0801.4949

2. Cold matter again ?

- Fitting an effective break-up cross section (depending on y) and extrapolate to CuCu and AuAu…

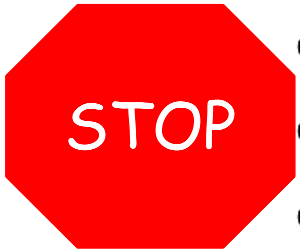
- Do you agree that we have poor handle on the cold nuclear matter effect?

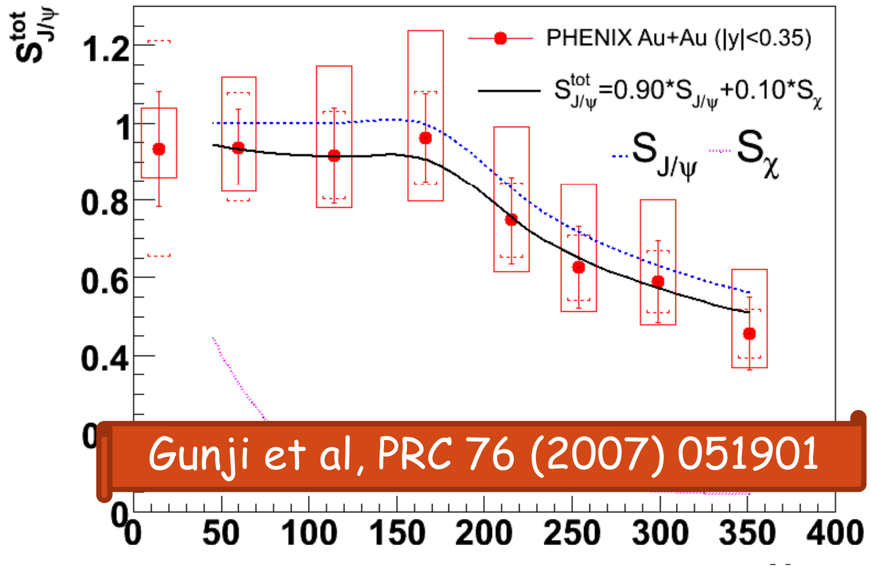


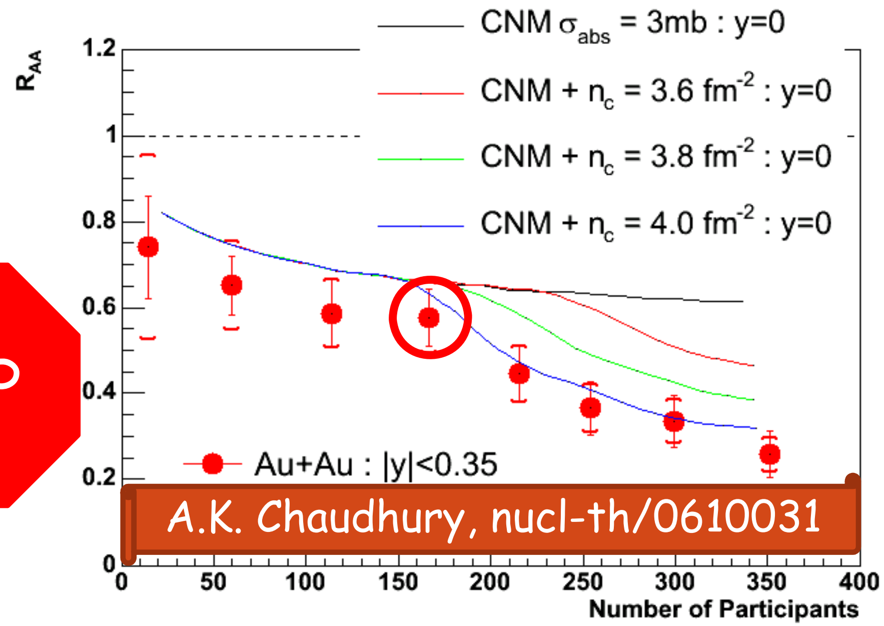
PHENIX, arxiv:0801.0220

7. Search for an onset?

- Onset curves fit the midrapidity AuAu data…
  - Chaudhury, nucl-th/0610031
  - Gunji et al, hep-ph/0703061
    - (after CNM subtraction)
- But so do smooth curves !
  - Nagle nucl-ex/0705.1712
- Density threshold @ y=0 is incompatible with SPS onset
  - Linnyk & al, nucl-th/0705.4443
- No onset @ y=1.7 ?
- Wait for run7 analysis & CNM constraints!

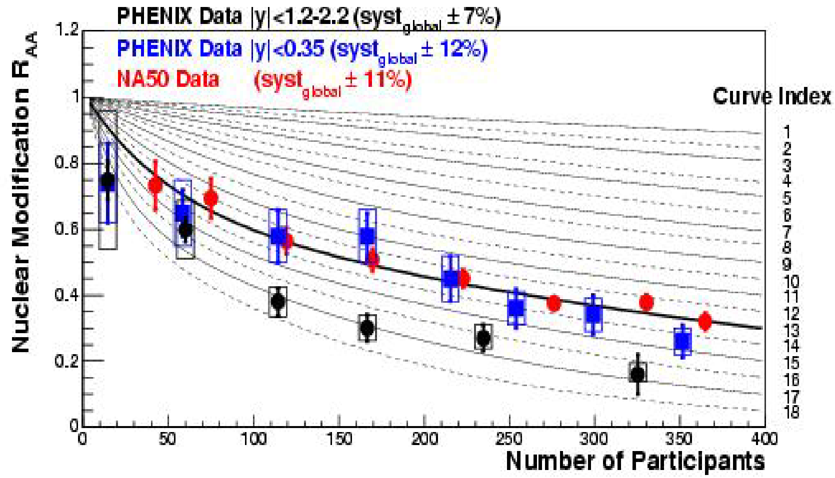


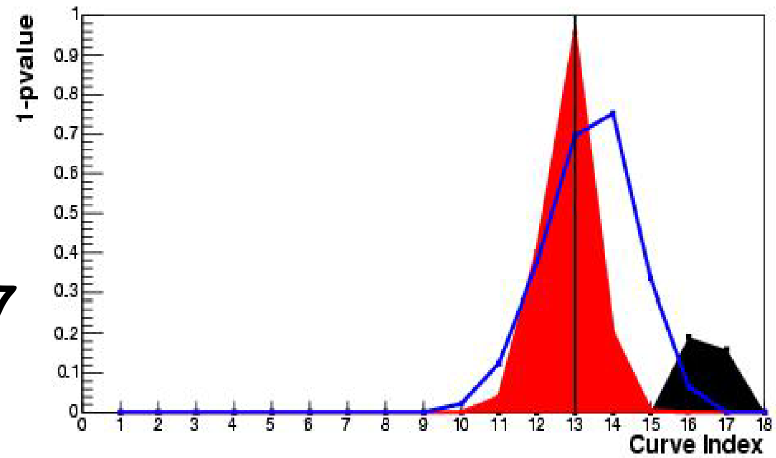




Density threshold ? No !

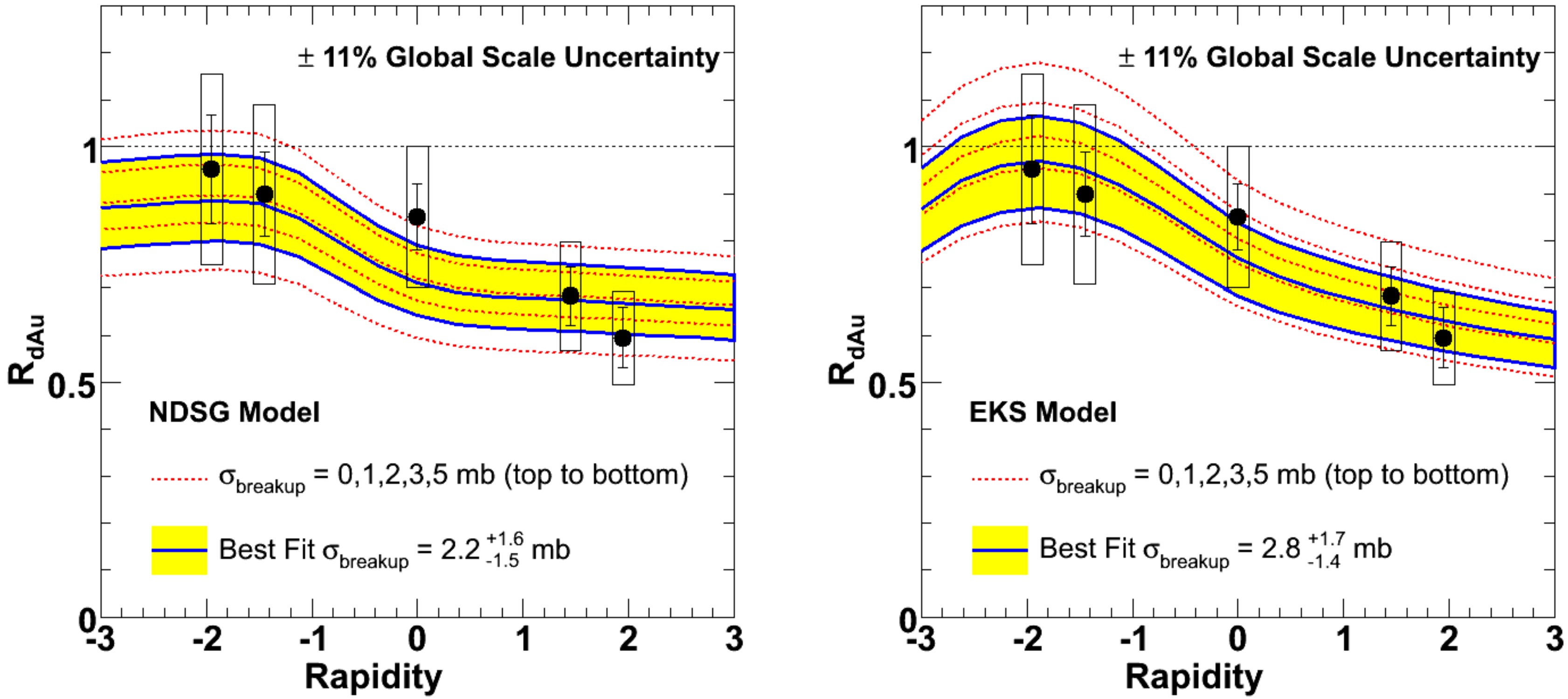
- Onset curves fit the midrapidity data…
  - Chaudhury, nucl-th/0610031
  - Gunji et al, hep-ph/0703061 (after CNM subtraction)
- So do smooth curves !
  - Nagle nucl-ex/0705.1712
- Density threshold @ y=0 is incompatible with SPS onset or larger suppression @ y=1.7
  - Linnyk & al, nucl-th/0705.4443



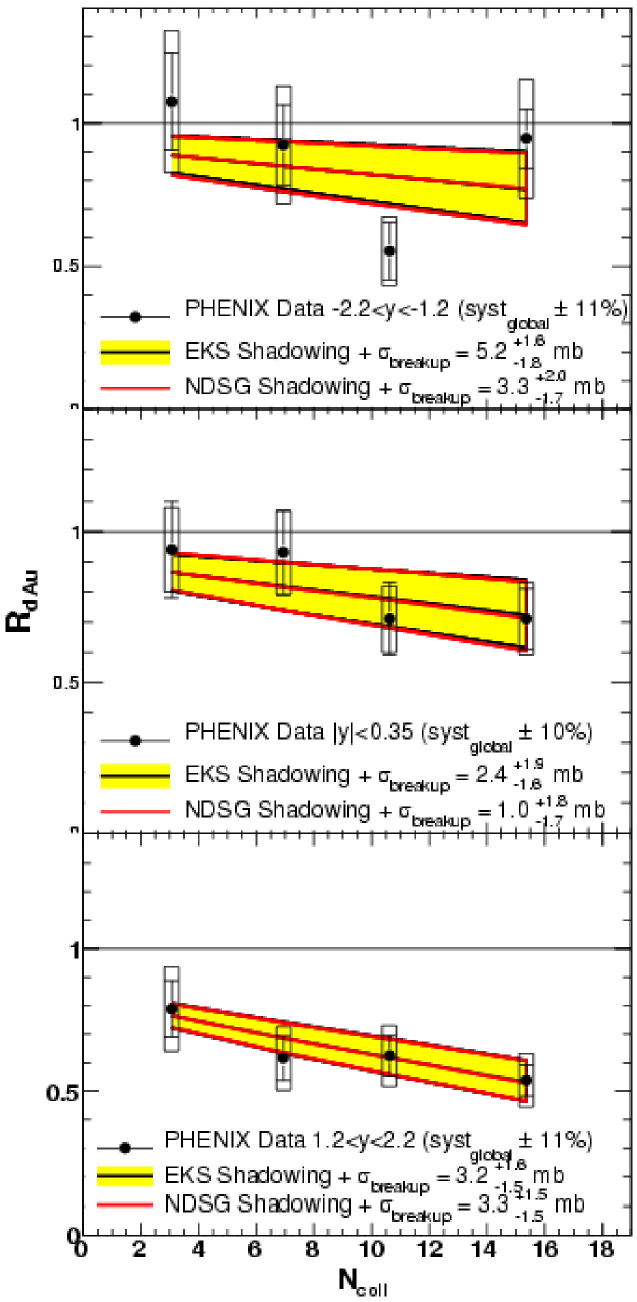


J. Nagle, nucl-ex/0705.1712

RdAu(y)

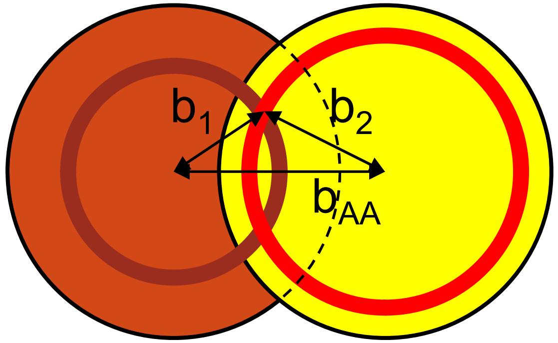

± 11% Global Scale Uncertainty
R_{dAu}
NDSG Model
$\sigma_{breakup}$ = 0,1,2,3,5 mb (top to bottom)
Best Fit $\sigma_{breakup} = 2.2^{+1.6}_{-1.5}$ mb
Rapidity
± 11% Global Scale Uncertainty
R_{dAu}
EKS Model
$\sigma_{breakup}$ = 0,1,2,3,5 mb (top to bottom)
Best Fit $\sigma_{breakup} = 2.8^{+1.7}_{-1.4}$ mb
Rapidity

RdAu(centrality,y)



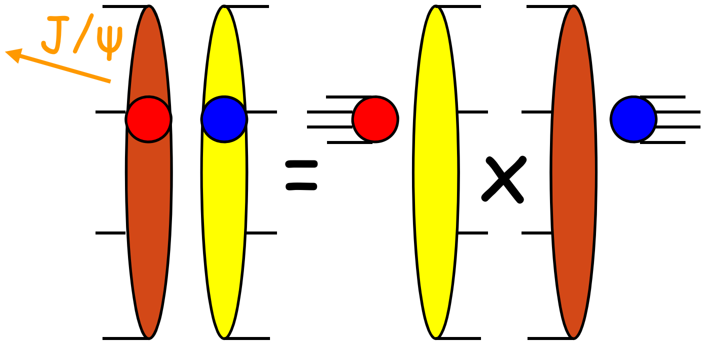
From dA to AA @ RHIC

- For a given A+A collision at b_{AA}, Glauber provides a set of N+N collisions occurring at b_i^1 and b_i^2



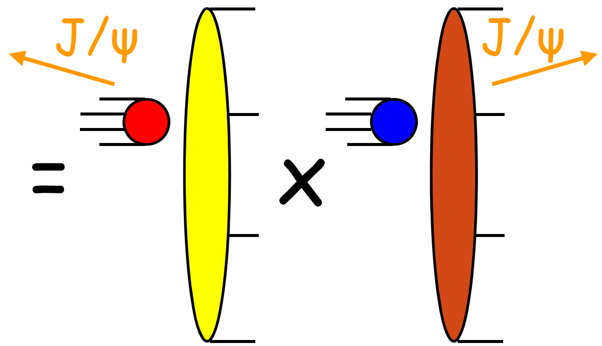
- One minimal assumption is rapidity factorization: $R_{AA}(|y|,b_{AA}) =$

  $\Sigma_{collisions}\ [R_{dA}(-y,b_i^1) \times R_{dA}(+y,b_i^2)] / N_{coll}$



- Works (at least) for absorption & shadowing since production

  ~ pdf1 x pdf2 x exp $-\rho\sigma(L_1+L_2)$



RGdC, hep-ph/0701222

Heavy flavor elliptic flow

- Also a surprise!
- Now, do bees fly?
  - Need the b/c+b in AA to properly estimate the b flow…
- (todo : average the 2 datasets cause they have different stat/syst balance)