J/ψ production in PHENIX

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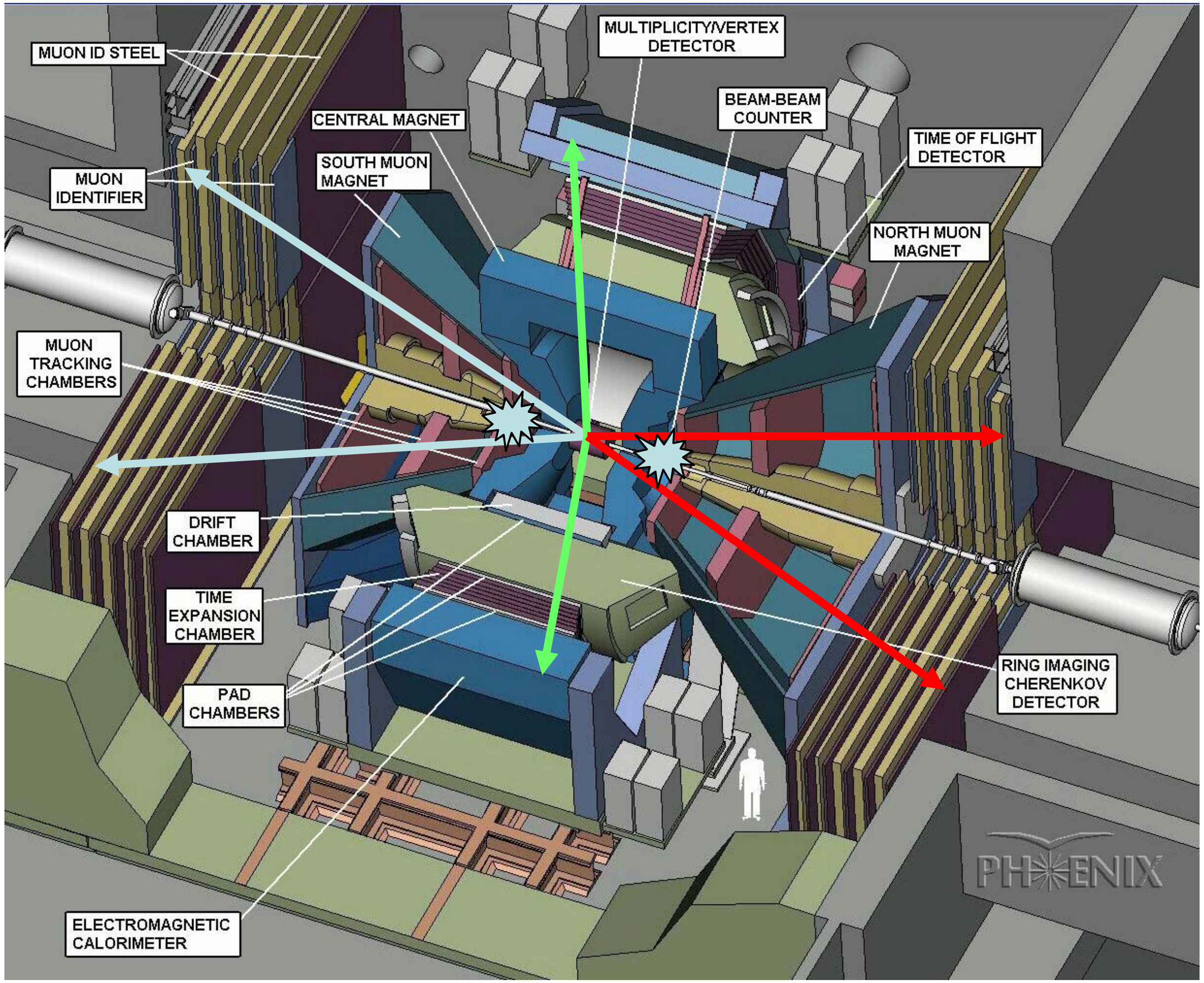
Outline

- No introduction
  - Trying same thing as Helena (and NA60)
  - At higher energy (x10 $\sqrt{s_{NN}}$)
  - With much less statistics…

- J/ψ in proton-proton
- J/ψ in deuteron-gold
- J/ψ in nucleus-nucleus

- No (strong) conclusion

How does PHENIX see the J/ψ ?



$J/\psi \rightarrow e^+e^-$
identified in RICH and EMCal

- $|\eta| < 0.35$
- $p_e > 0.2$ GeV

$J/\psi \rightarrow \mu^+\mu^-$
identified in 2 fwd spectrometers

- $1.2 < |\eta| < 2.4$
- $p_\mu > 2$ GeV

Centrality and vertex given by BBC in $3<|\eta|<3.9$ and ZDC

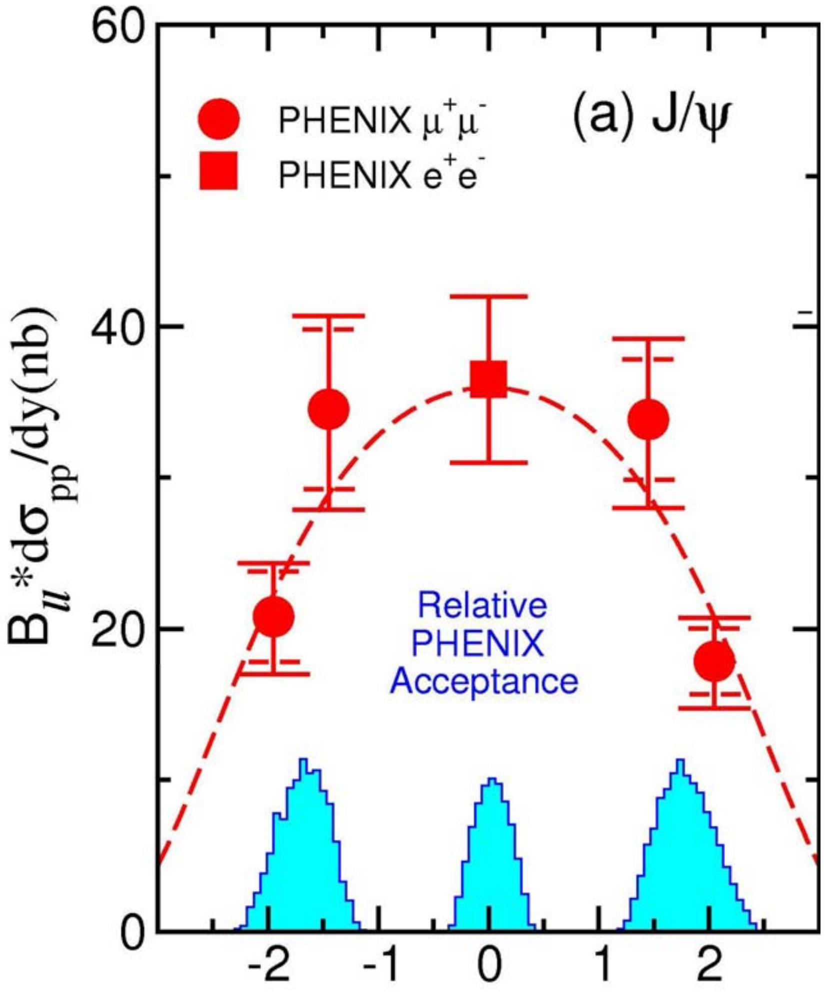
J/ψ in PHENIX

[1] PRL92 (2004) 051802
[2] PRC69 (2004) 014901
[3] PRL96 (2006) 012304
[4] QM05, nucl-ex/0510051

Year	Ions	$\sqrt{s_{NN}}$	Luminosity	Status	J/Ψ (ee + μμ)
2000	Au-Au	130 GeV	1 μb^{-1}	Central (electrons)	0
2001	Au-Au	200 GeV	24 μb^{-1}	Central	13 + 0 [1]
2002	p-p	200 GeV	0.15 pb^{-1}	+ 1 muon arm	46 + 66 [2]
2002	d-Au	200 GeV	2.74 nb^{-1}	Central	360 + 1660 [3]
2003	p-p	200 GeV	0.35 pb^{-1}	+ 2 muon arms	130 + 450 [3]
	Au-Au	200 GeV	240 μb^{-1}	preliminary	~ 1000 + 5000 [4]
2004	Au-Au	63 GeV	9.1 μb^{-1}	analysis	~ 13
	p-p	200 GeV	324 nb^{-1}		
	Cu-Cu	200 GeV	4.8 nb^{-1}	preliminary	~ 1000 + 10000 [4]
2005	Cu-Cu	63 GeV	190 mb^{-1}	analysis	~ 10 + 200
	p-p	200 GeV	3.8 pb^{-1}		~ 1500 + 10000
2006	p-p	200 GeV	??	Running soon	??

J/ψ in proton-proton

Cross section vs rapidity



Total cross section

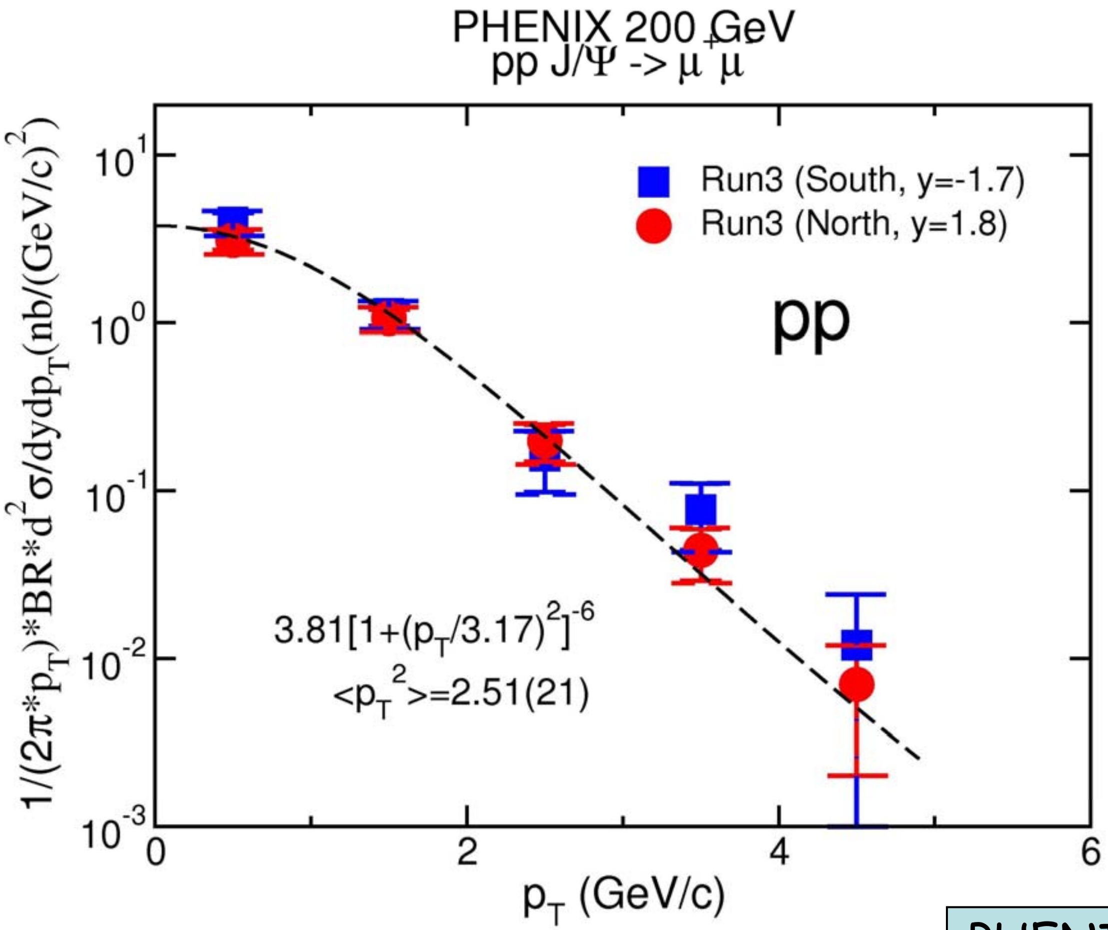
σ (pp → J/ψ)

$2.61 \pm 0.20 \pm 0.26\ \mu b$

- Error from fit (incl. syst and stat)
- Error on absolute normalization

PHENIX, PRL96 (2006) 012304

Cross section versus p_T



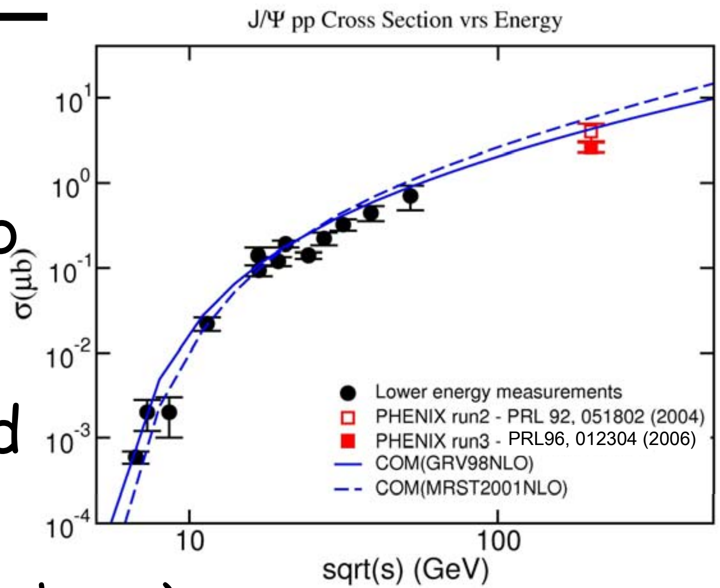
Fit the function

$$\frac{A}{(1+(p_T/B)^2)^6}$$

$\langle p_T^2 \rangle = 2.51 \pm 0.21$ (GeV^2)

PHENIX, PRL96 (2006) 012304

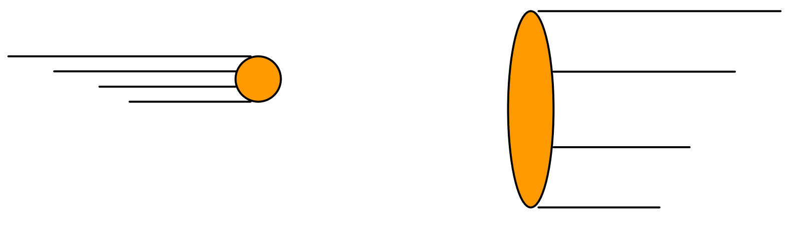
p+p perspectives



- Production mechanism
  - Color Octet Model does the job
- In AA (or dA)
  - Large combinatorial background
  - Low physics background
    - (Drell-Yan or dileptons from open charm)
- p+p is our baseline
  - Nuclear modification factor
- Run5 pp analysis going on
  - > 10 times statistics

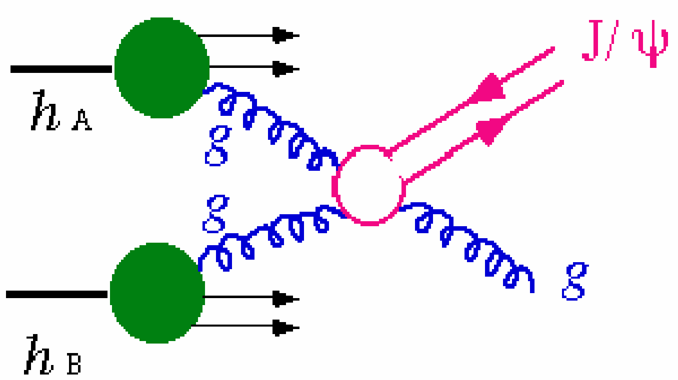
$$R_{AB} = \frac{N_{\psi}^{AB}}{N_{\psi}^{PP} \times \langle N_{coll} \rangle}$$

J/ψ in deuteron-gold



d+Au physics motivation

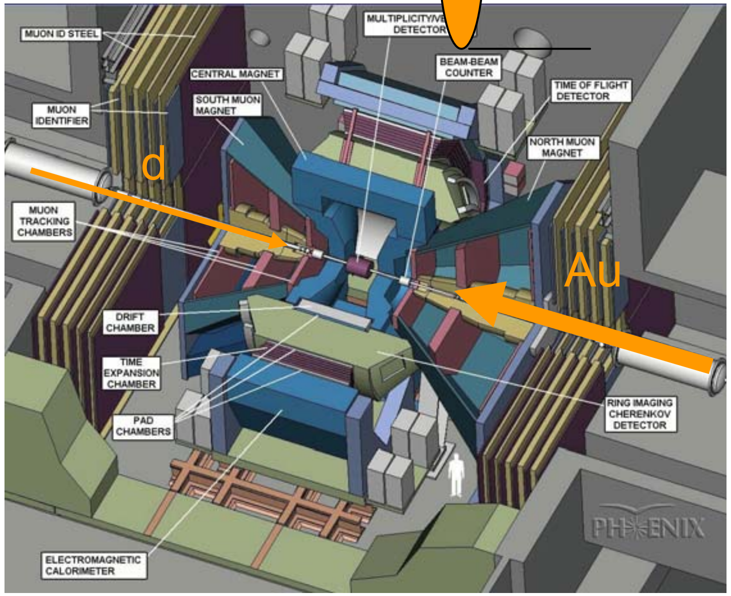
- Goal: disentangle normal "cold" nuclear effects
  - Antishadowing & Shadowing (gluon saturation, color glass ?)
  - Energy loss of initial parton
  - p_T broadening (Cronin effect)
  - J/ψ (or $c\bar{c}$) absorption
  - Something else ?



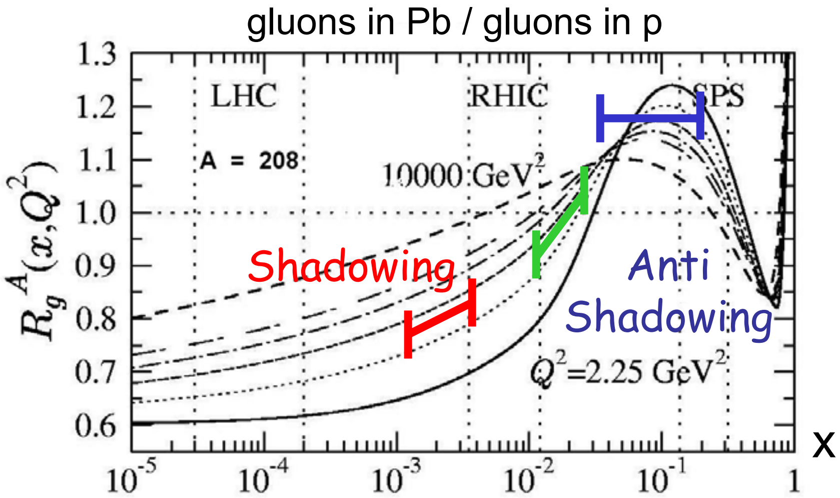
- Tools: d+Au collisions
  - over a broad range of p_T, rapidity and centrality
- Interests:
  - Intrinsically probes interesting nuclear effects
  - Baseline for Au+Au: Why do J/ψ disappear / appear ?

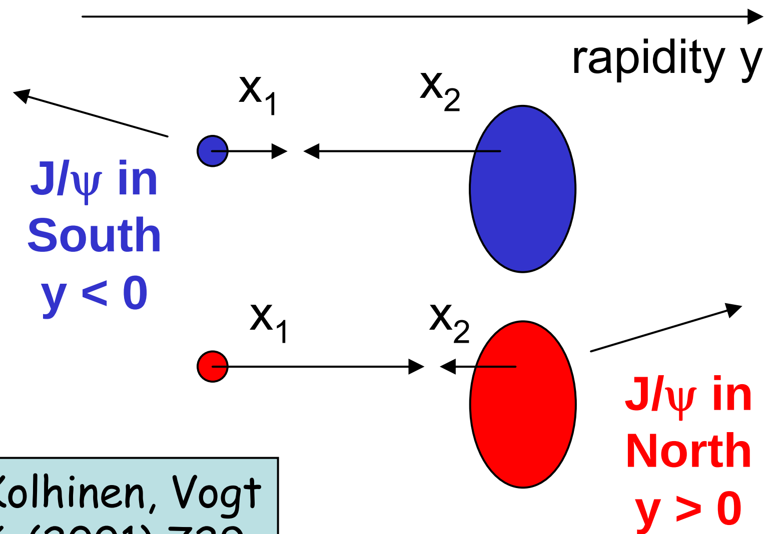
Deuteron → ← Gold

- In PHENIX, J/ψ mostly produced by gluon fusion, and thus sensitive to gluon pdf
- Three rapidity ranges probe different momentum fraction of Au partons
  - South ($y < -1.2$) : large x_2 (in gold) ~ 0.090
  - Central ($y \sim 0$) : intermediate x_2 ~ 0.020
  - North ($y > 1.2$) : small x_2 (in gold) ~ 0.003



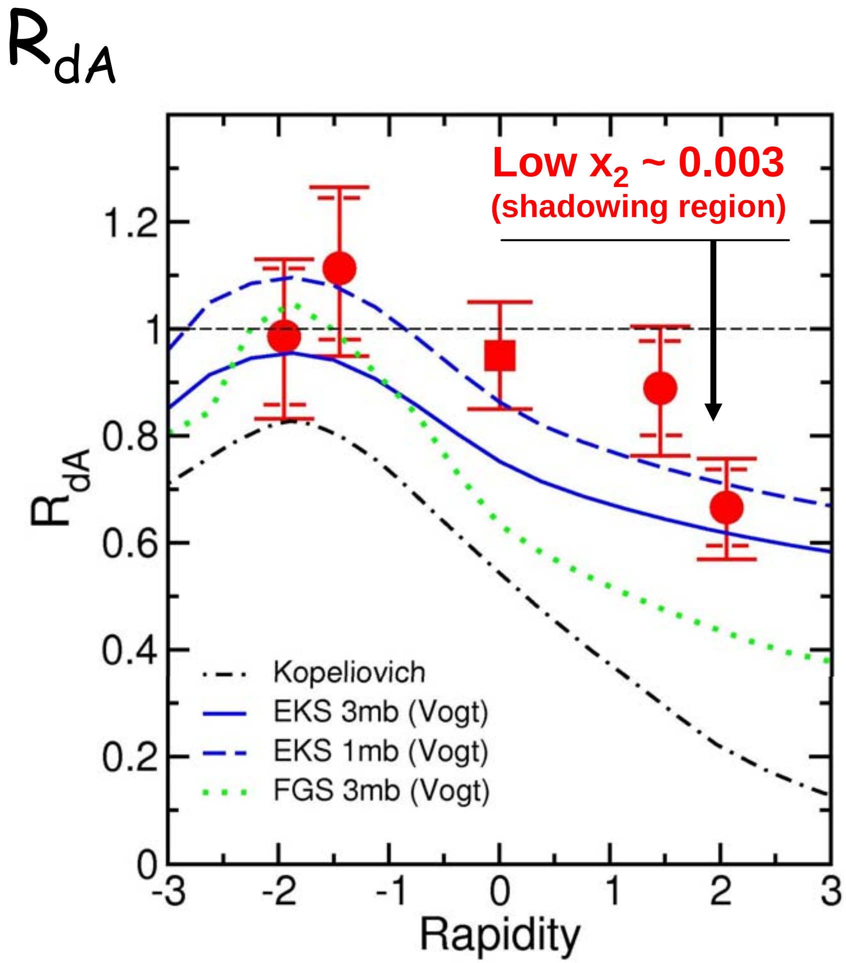
An example of gluon shadowing prediction





Eskola, Kolhinen, Vogt NPA696 (2001) 729

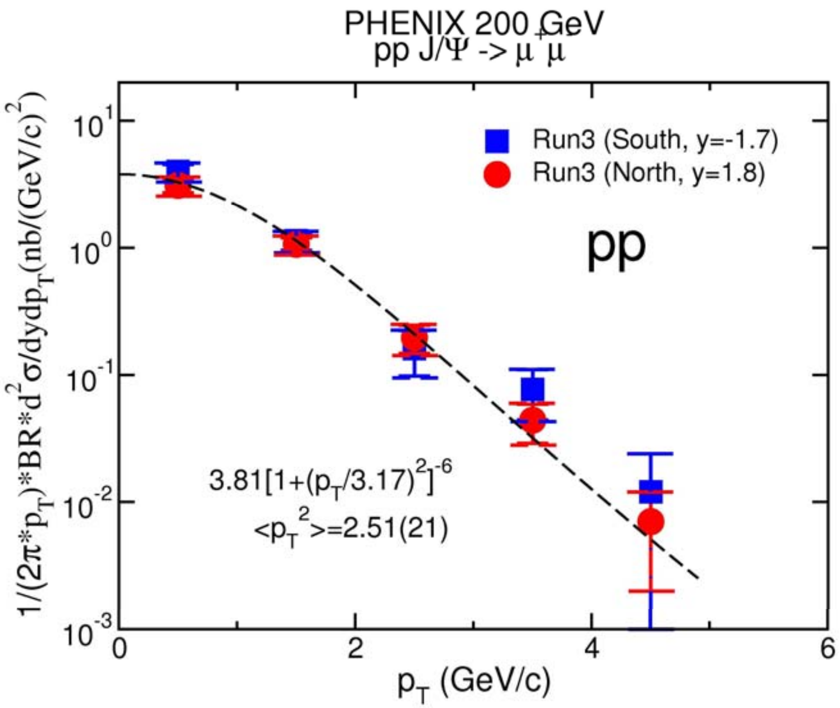
R_{dAu} versus rapidity

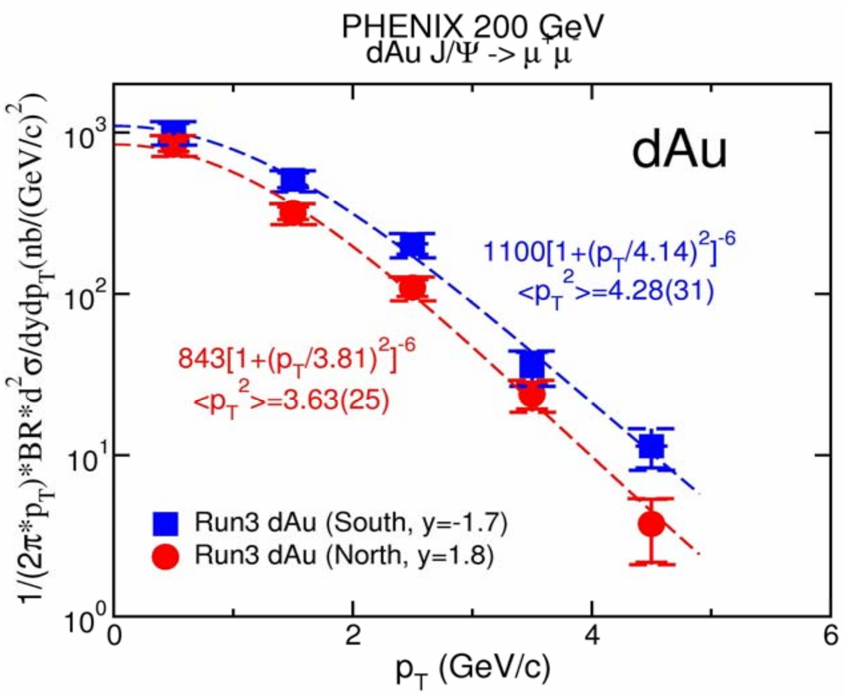


- Data favours
  - (weak) shadowing
    Eskola, Kolhinen, Salgado prescription matches better
  - (weak) absorption
    σ_{abs} ~ 1 to 3 mb
    (4.18 ± 0.35 mb @SPS)
- But with limited statistics difficult to disentangle nuclear effects !

PHENIX, PRL96 (2006) 012304
Klein,Vogt, PRL91 (2003) 142301
Kopeliovich, NPA696 (2001) 669

Cross section versus p_T





PHENIX, PRL96 (2006) 012304

$\Delta\langle p_T^2\rangle = \langle p_T^2\rangle_{dAu} - \langle p_T^2\rangle_{pp}$

Backward: 1.77 ± 0.37 GeV ^{2}

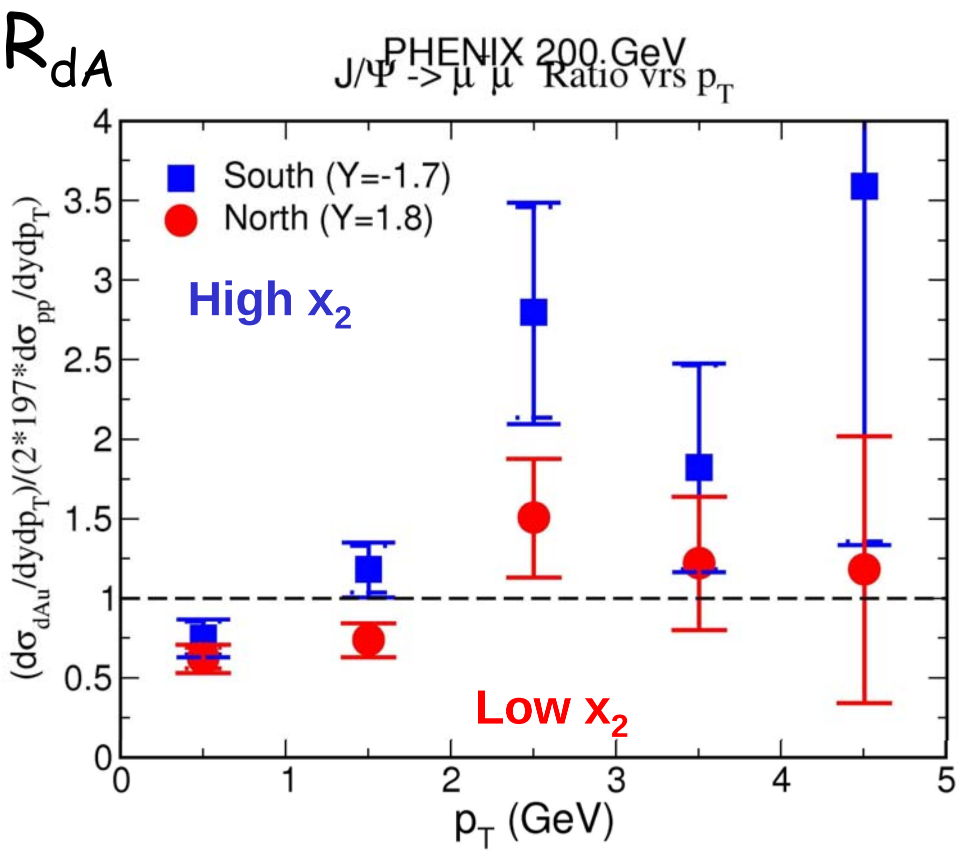
Mid: (-1.28 ± 0.94 GeV ^{2})

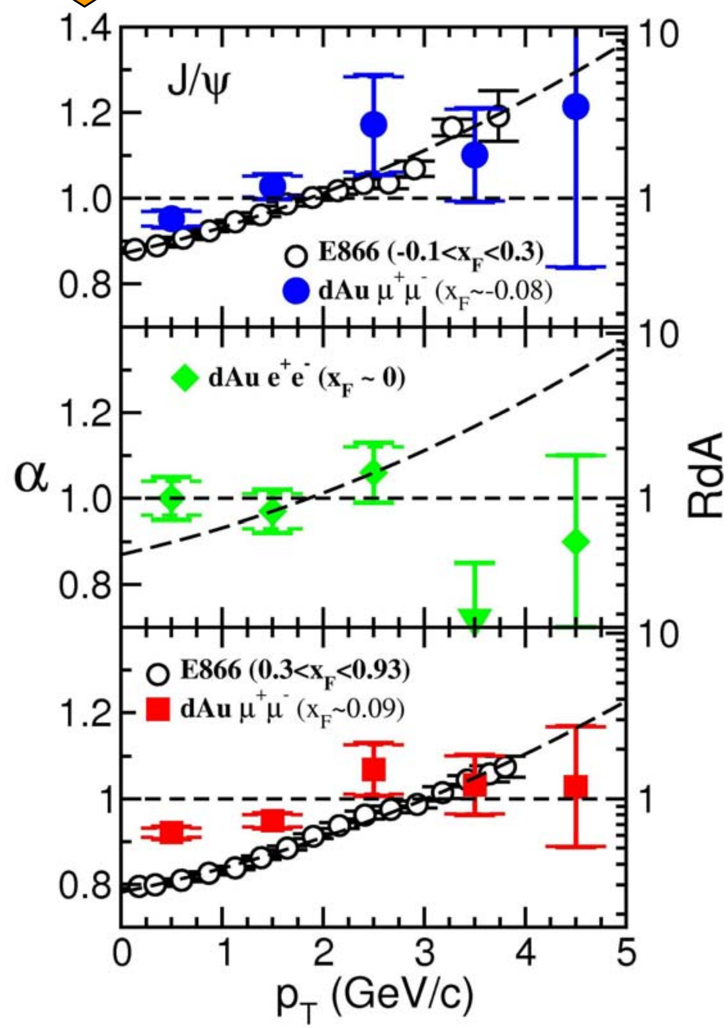
Forward: 1.12 ± 0.35 GeV ^{2}

Some p_T broadening

R_{dAu} versus p_T

$$\sigma_{dA} = \sigma_{pp}(2\times197)^{\alpha}$$

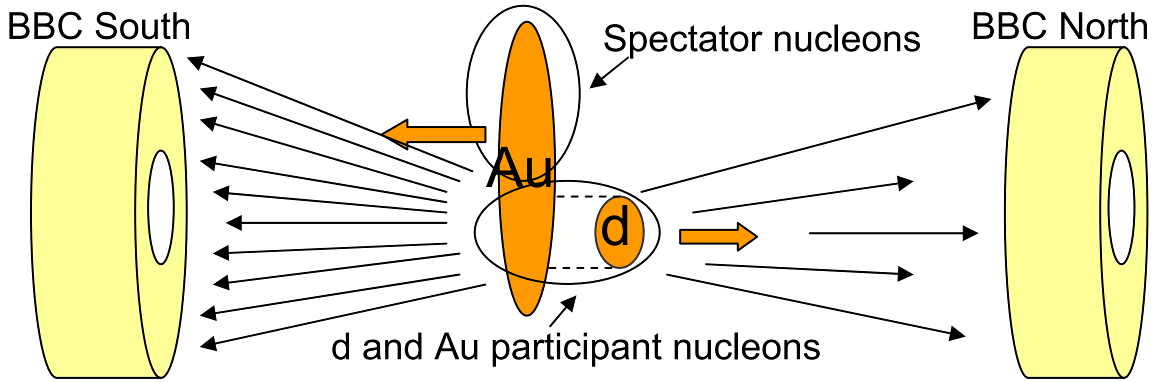




Broadening comparable to lower energy (√s = 39 GeV in E866)

Centrality analysis

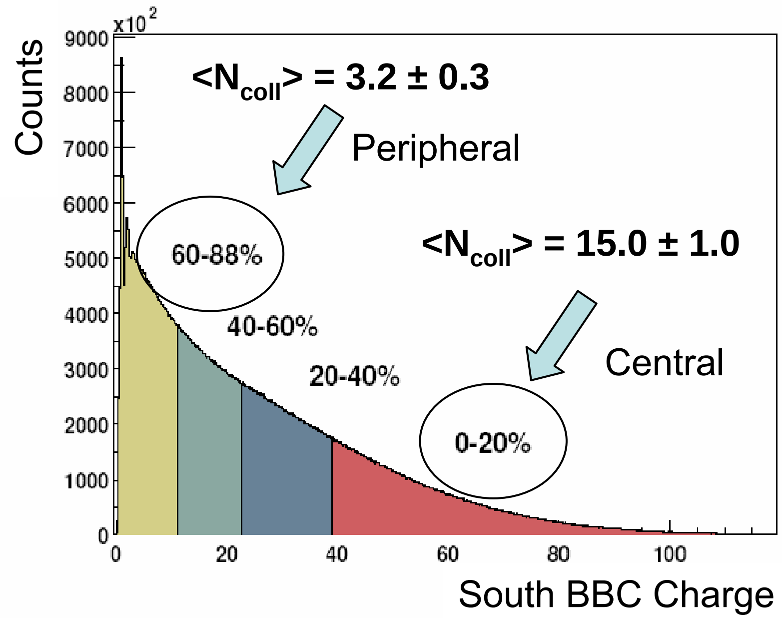
Au breaks up in our south beam counter



- Define 4 centrality classes
- Relate centrality to $\langle N_{coll} \rangle$

through Glauber computation

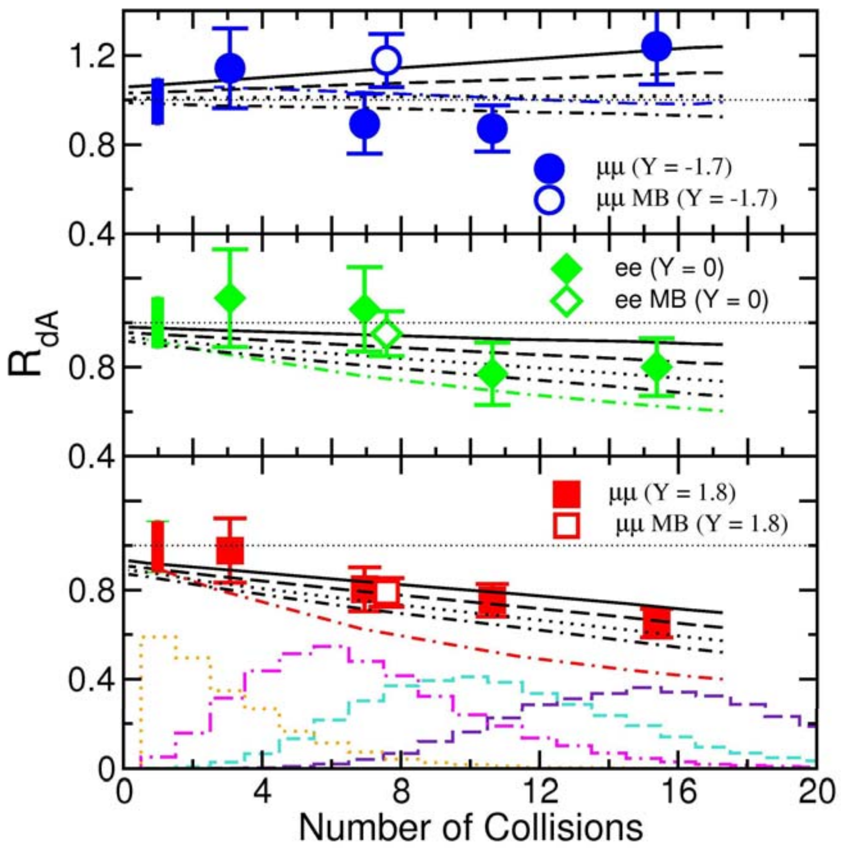
- $\langle N_{coll}^{MB} \rangle = 8.4 \pm 0.7$



R_{dAu} versus N_{coll}

R_{dA}

High x_2 ~ 0.09



Low x_2 ~ 0.003

- Black lines:
  - EKS98 from 0 to 3 mb
- Coloured lines:
  - FGS for 3 mb
- Slopes consistent with shadowing models
  - Especially low x_2

d+Au perspectives

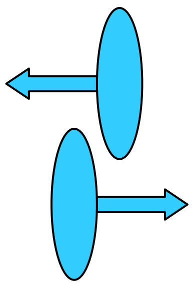
- We have seen small nuclear effects !
  - Weak shadowing / antishadowing
  - Weak absorption (~ 1 to 3 mb)
  - p_T broadening similar to lower energies
- Difficult to disentangle given statistics
  - Need more luminosity !
- But, no large nuclear effect !
  - Good news to see J/ψ suppression in Au-Au !

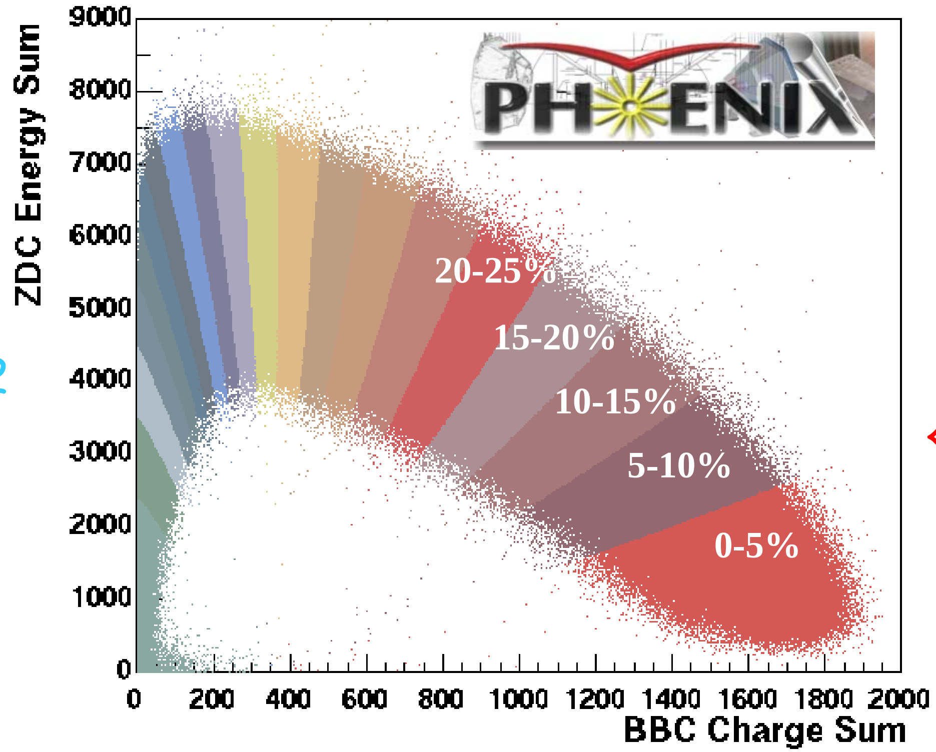
J/ψ in nucleus-nucleus (phenix preliminary)

Centrality analysis

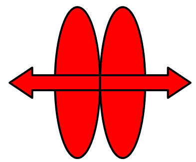
BBC charge versus ZDC energy

Most peripheral
80 – 92.2%
‹ N_{part} › = 6.3 ± 1.2
‹ N_{coll} › = 4.9 ± 1.2



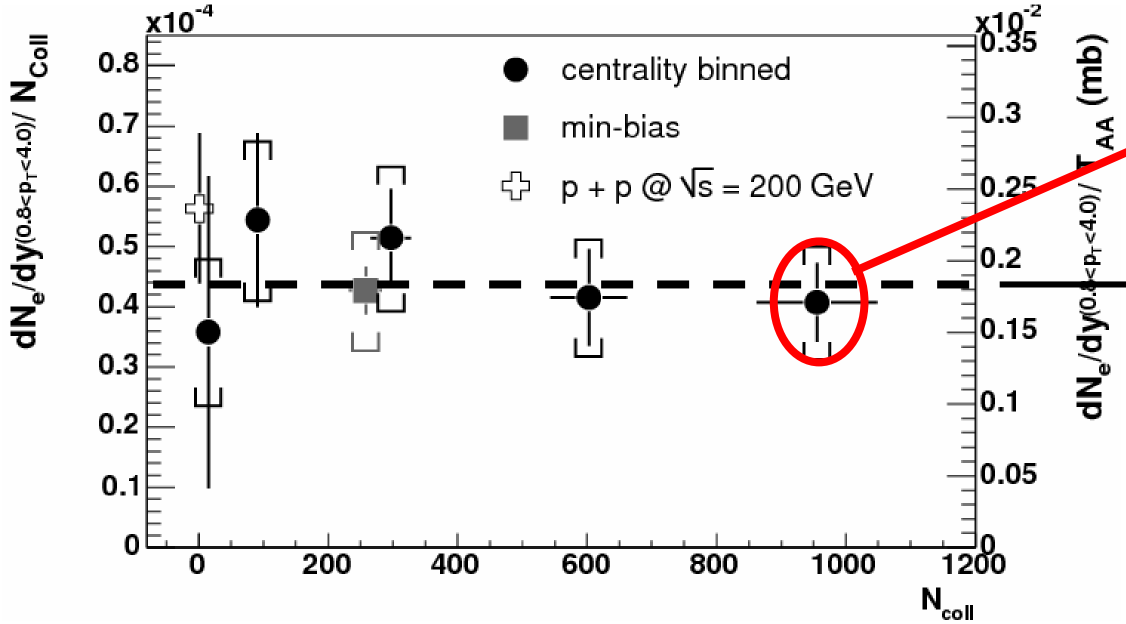


Most central
0 - 5 %
‹ N_{part} › = 351 ± 2.9
‹ N_{coll} › = 1065 ± 105



Quick look to open charm

- Through semileptonic decays (D → e)



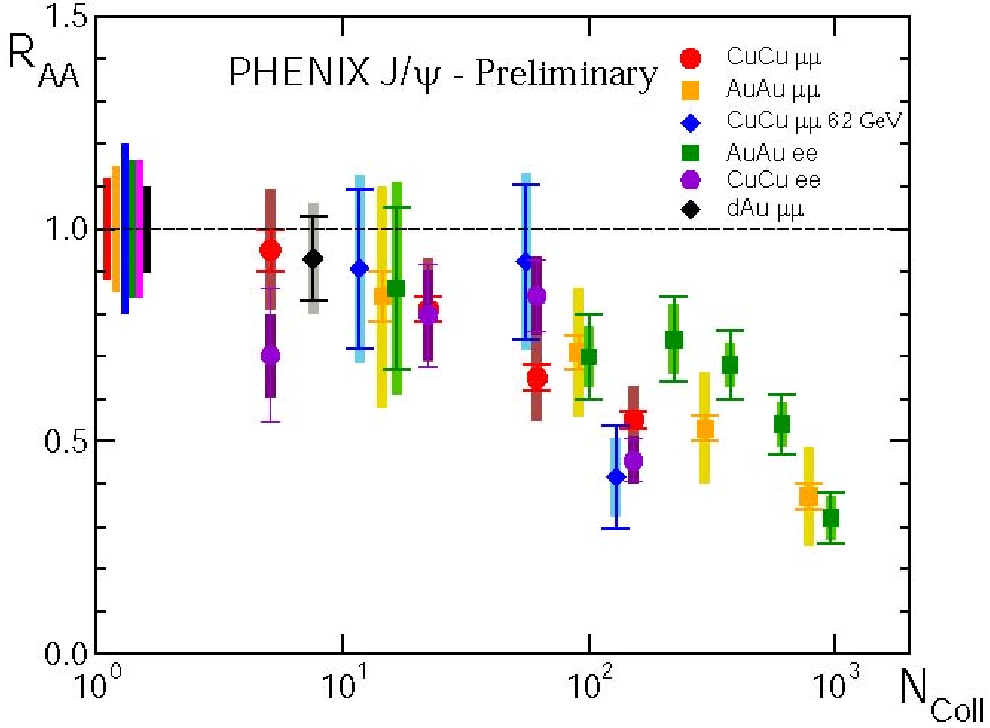
10 to 20 $c\bar{c}$ pairs !
(→ 40 acc. STAR)

N_{coll} scaling

PHENIX, PRL94 (2005) 082301

~25% systematic uncertainties
(without Silicon vertex
detector upgrade)

R_{AA} versus N_{coll}



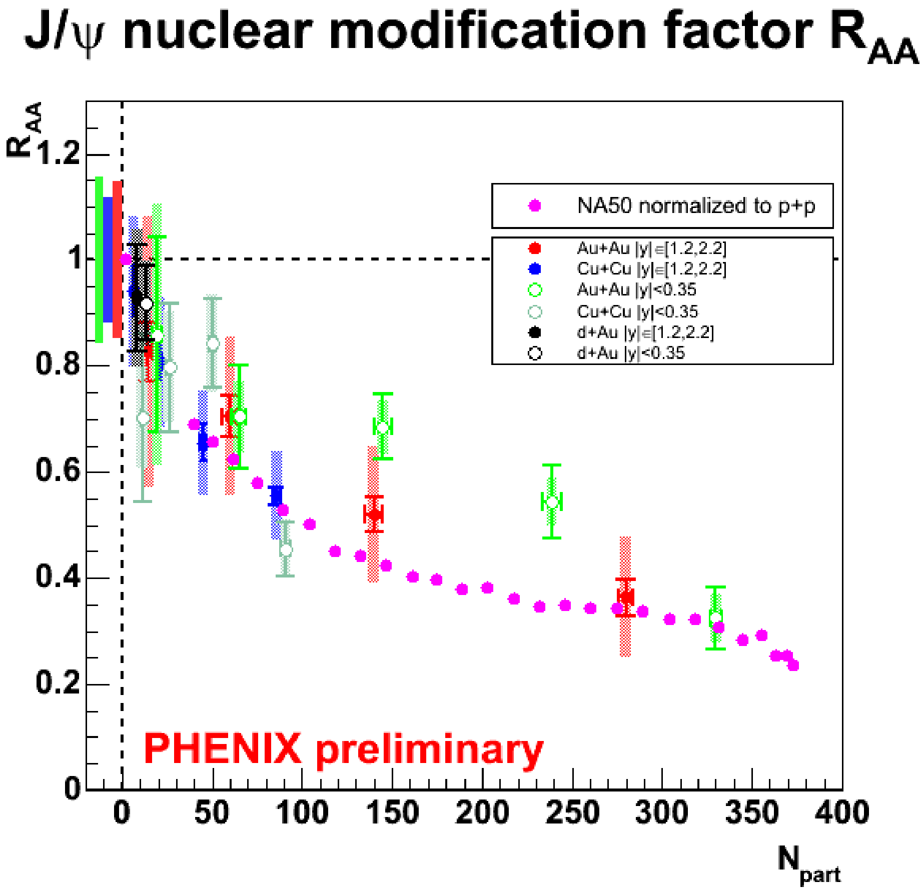
J/ψ → μμ
Muon arm
1.2 < |y| < 2.2

J/ψ → ee
Central arm
-0.35 < y < 0.35

dAu μμ 200 GeV/c	AuAu μμ 200 GeV/c	CuCu μμ 200 GeV/c	AuAu ee 200 GeV/c	CuCu ee 200 GeV/c	CuCu μμ 62 GeV/c

Hugo Pereira da Costa, for PHENIX, QM05, nucl-ex/0510051

Quick comparison to NA50



Same magnitude

- 30% survival prob.

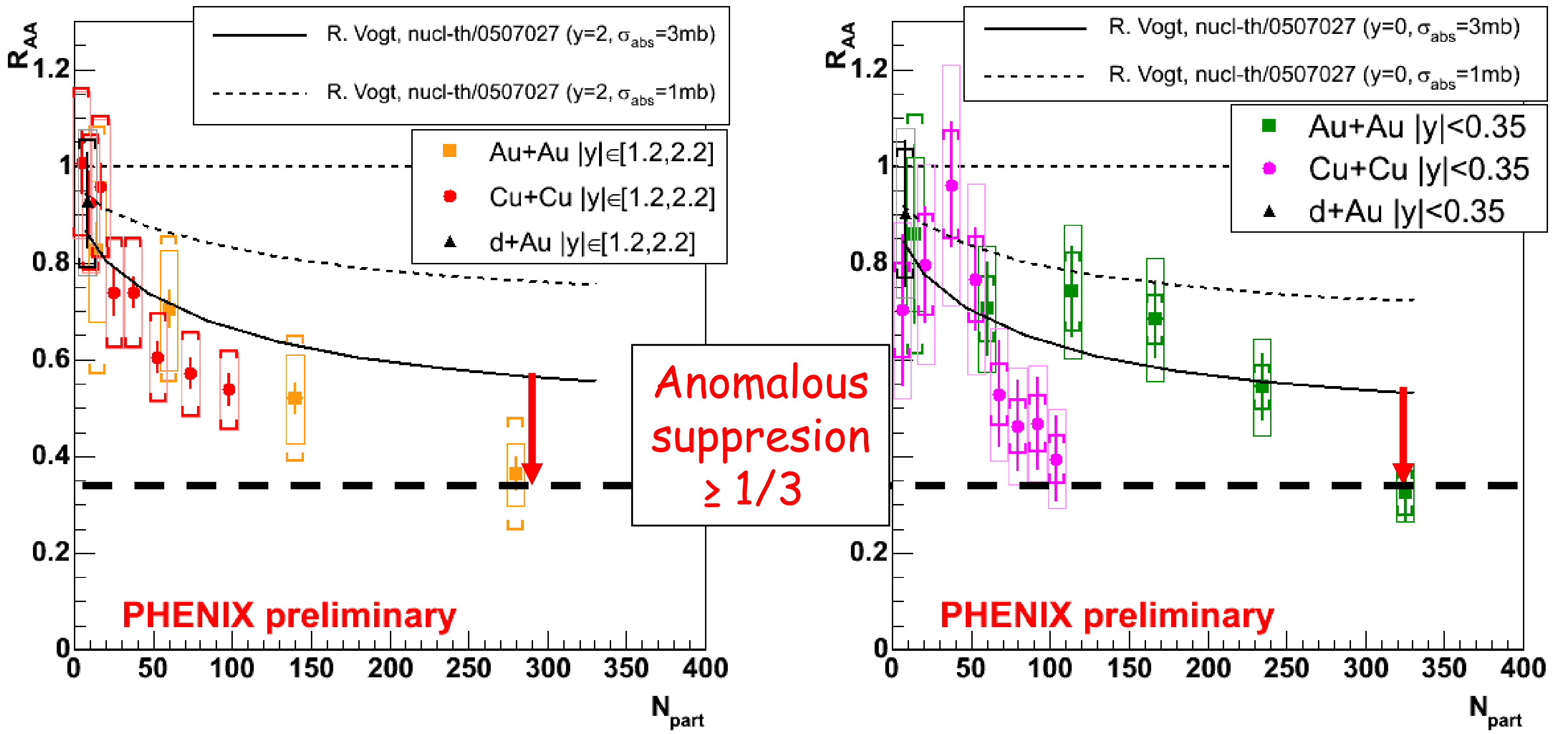
No fundamental reason

Differences:

- Energy density
- Cold / hot nuclear effects balance

Cold nuclear matter effects

- Shadowing + nuclear absorption (crucial !)



PHENIX, QM05, nucl-ex/0510051
Vogt, nucl-th/0507027

" SPS only " effects

- Cold effects + …

—— Comovers (hadrons/partons?)

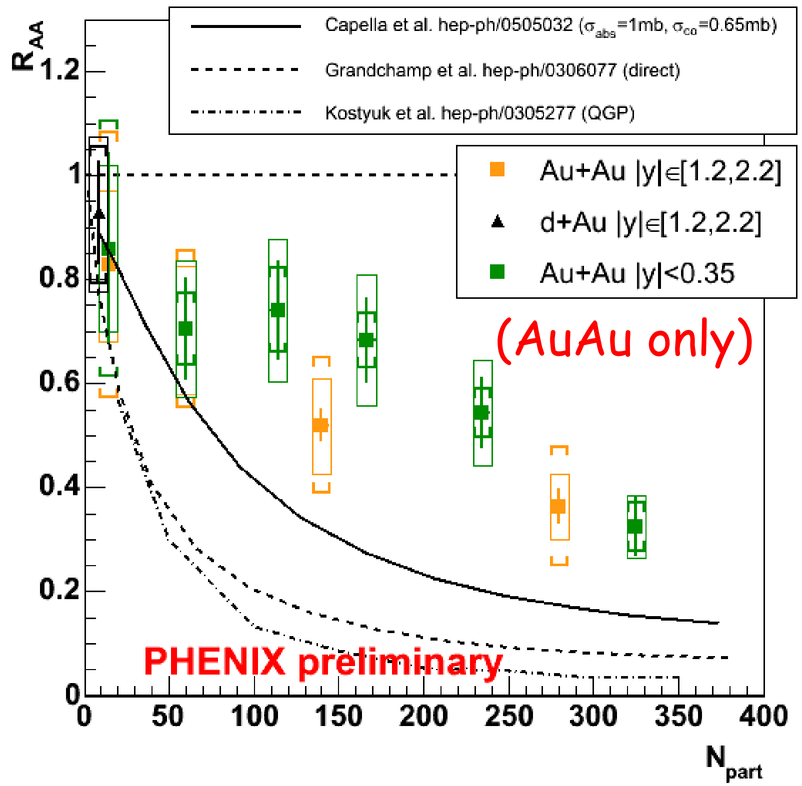
----- Kinetic model ($J/\psi \rightarrow c\,\bar{c}$)

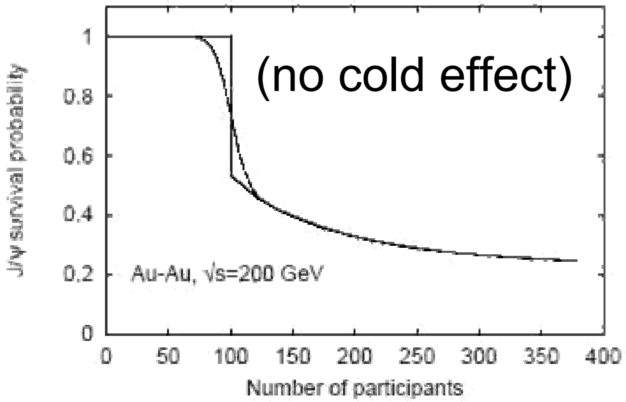
-·-·-·- Thermal plasma

All overestimate suppression !

So does parton percolation

- Onset at N_{part} ~ 90
- Simultaneous $J/\psi + \chi_c + \psi'$





Capella, Ferreiro, EPJC42 (2005) 419
Grandchamp et al, PRL92 (2004) 212301
Kotstyuk et al, PRC68 (2003) 041902
← Digal, Fortuno, Satz, EPJC32 (2004) 547
+ Private communications +

RHIC " new " effects

1st. Variety of recombination & coalescence models

$c\,\bar{c} \rightarrow J/\psi$

(at freeze-out)

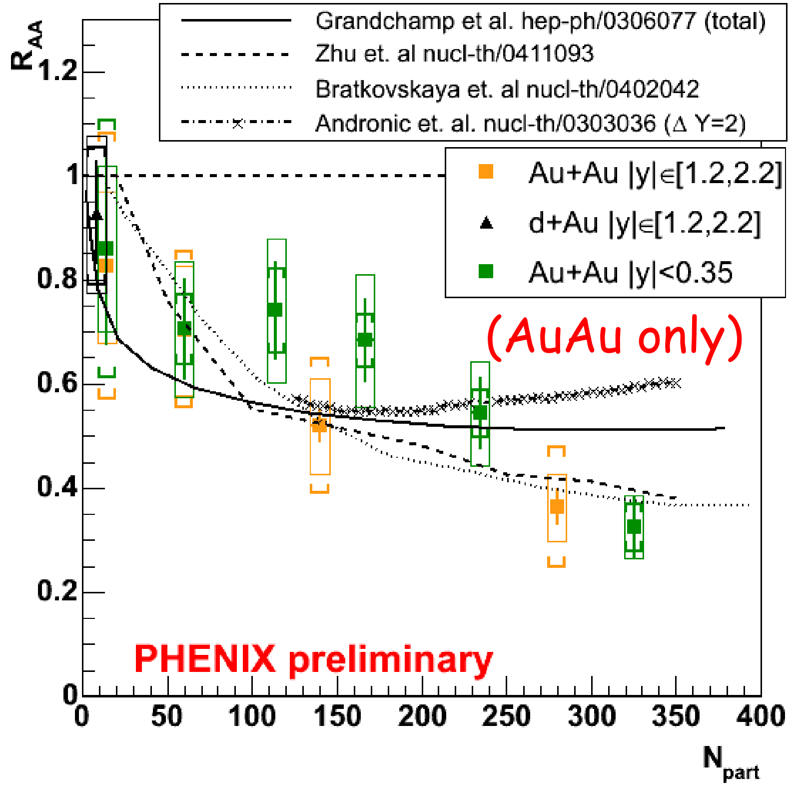
goes as N_{cc}^2

(poorly known)

2nd. One detailed QGP hydro + J/ψ transport (Zhu et al)

(no cold nuclear effects)

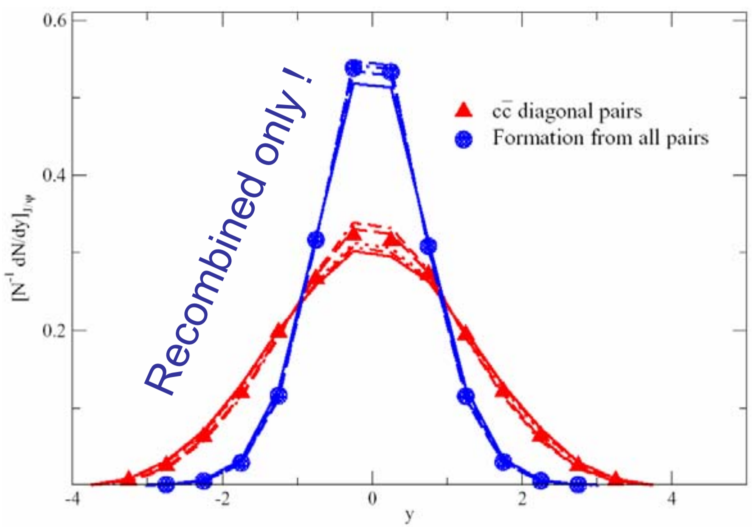
Look at y, p_T...

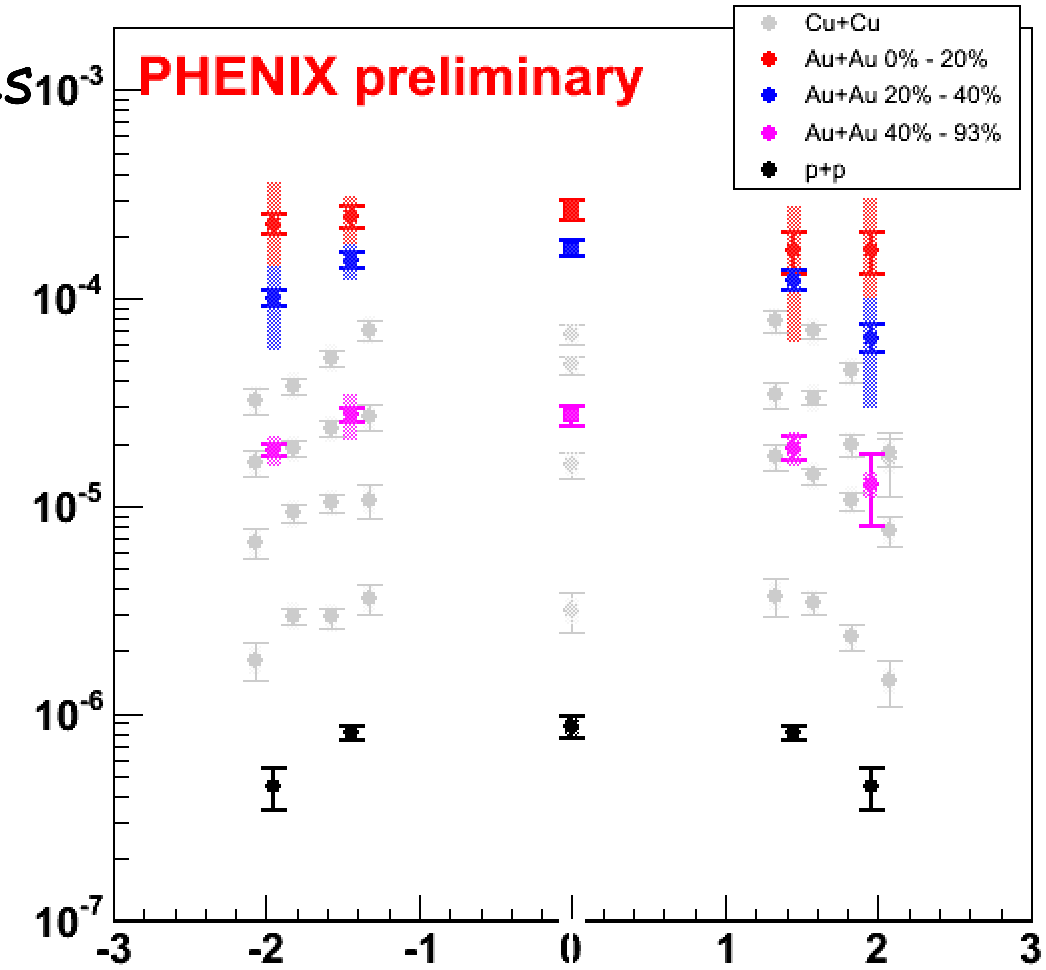


Grandchamp et al, PRL92 (2004) 212301
Zhu, Zhuang, Xu, PLB607 (2005) 107
Bratkoskaya et al, PRC69 (2004) 054903
Andronic et al, PLB571 (2003) 36
+ Private communications +

y shape (vs recombination)

- Recombination emphasizes quark y-distribution
- Quark (open charm) y-distribution unknown
- No significant change in rapidity in data…

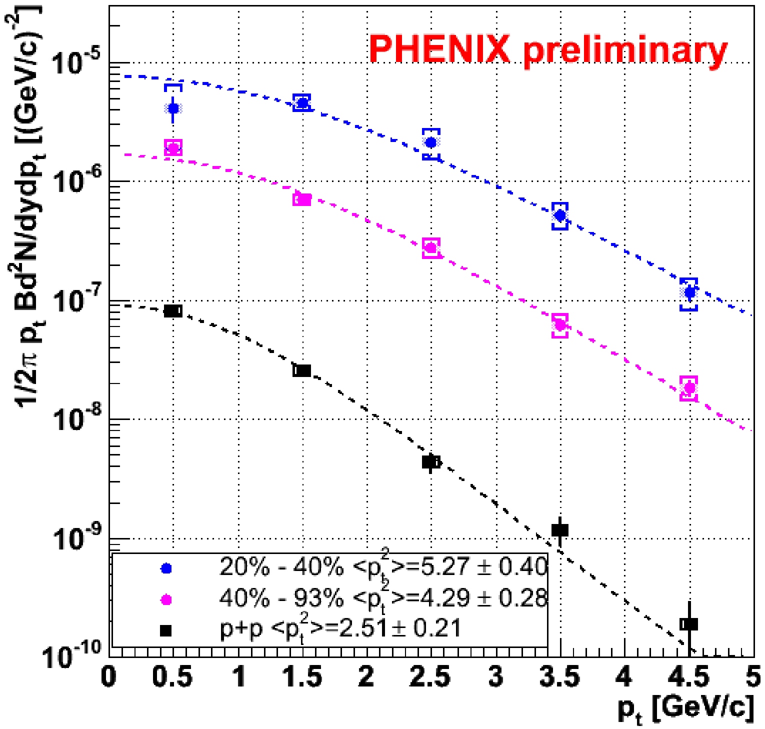




← Thews & Mangano, PRC73 (2006) 014904

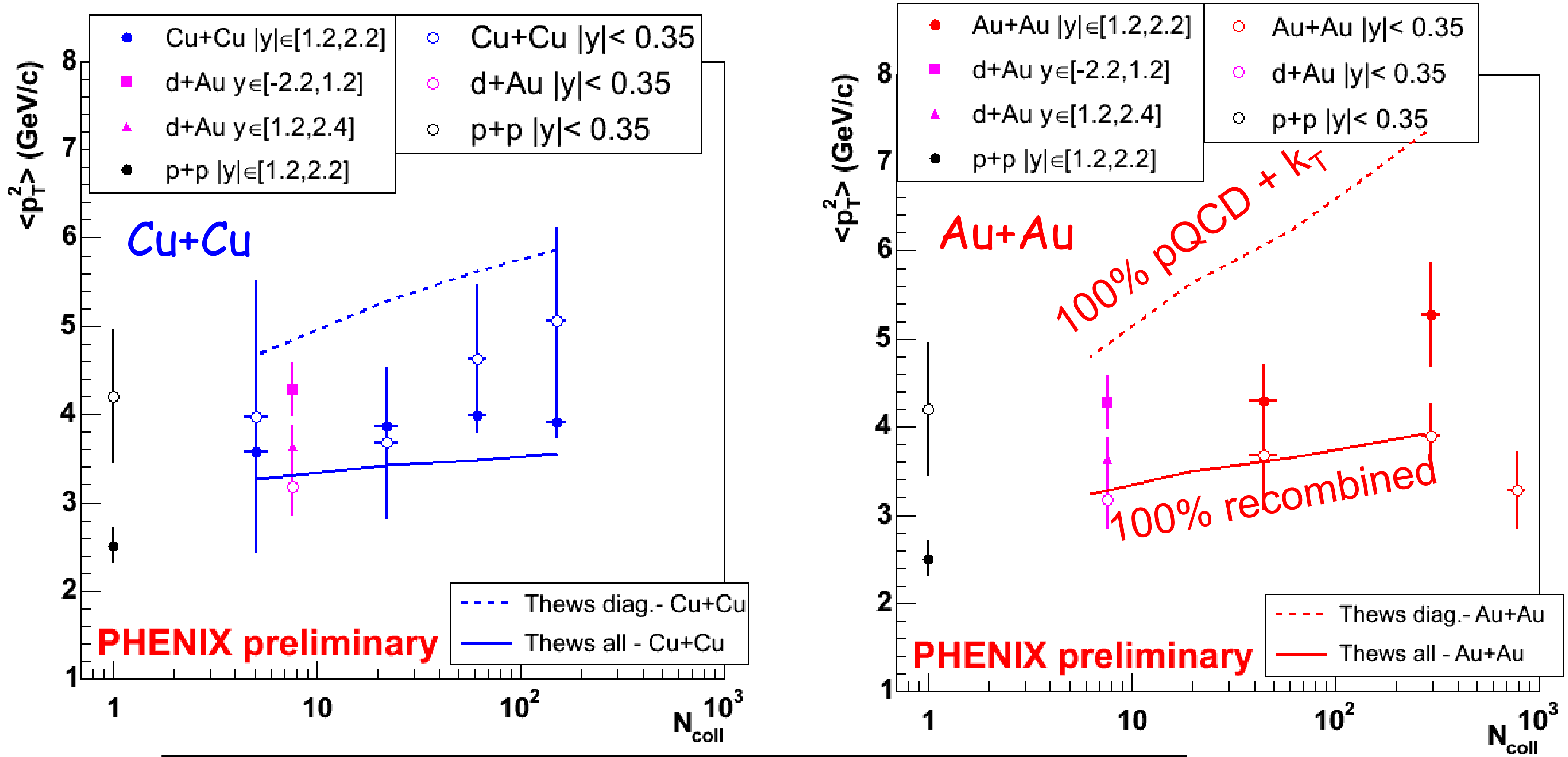
p_T spectra

Au+Au (|y|∈[1.2,2.2])



- In pp:
  - $\langle p_T^2 \rangle = 2.5$ GeV ^{2}
- In AuAu & CuCu:
  - $\langle p_T^2 \rangle = 3 \rightarrow 5.3$ GeV ^{2}

$\langle p_T^2 \rangle$ (vs recombination)

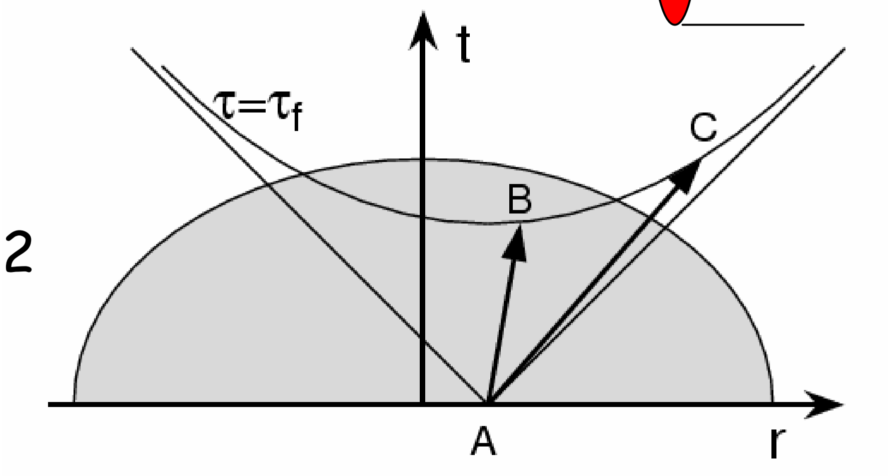


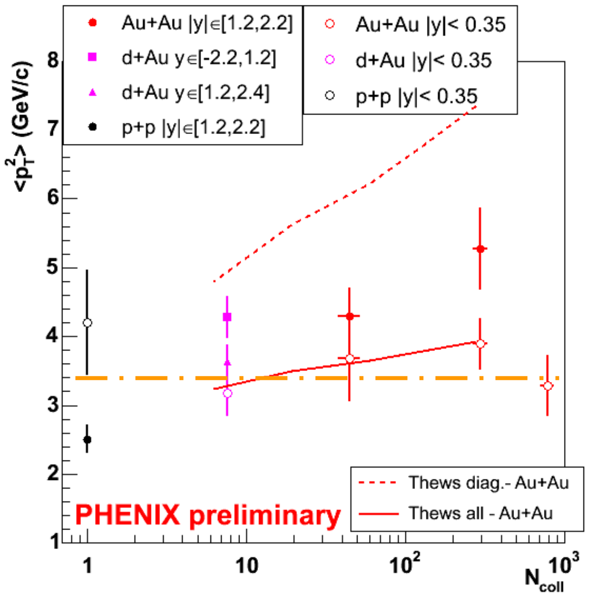
Lines from Thews & Mangano, PRC73 (2006) 014904

- Seems to favor recombination scenario
- But Cronin effect not under control…

<pt²> (vs transport)

- High p_T J/ψ escape
- $\langle p_T^2 \rangle$ up to 3.4 GeV ²
- Ok for midrapidity





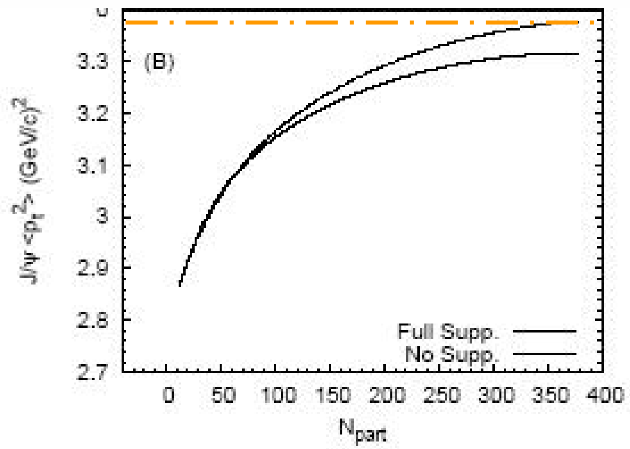
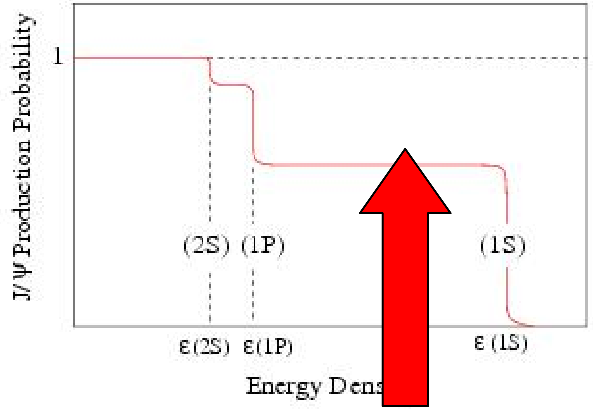


FIG. 2: The J/ψ suppression and $\langle p_t^2 \rangle$ as functions of centrality at RHIC energy.

Zhu, Zhuang, Xu, PLB607 (2005) 107

3^{rd} (simple) explanation

- Amount of anomalous suppression depends on cold nuclear effects amplitude.
- But could be ~1/3
- Compatible to feed-down ratio
  - $J/\psi \sim 0{,}6\ J/\psi + 0{,}3\ \chi_c + 0{,}1\ \psi'$
- Recent lattice $T_d^{\psi} \sim 1.5 - 2.5\ T_c$
  - $\varepsilon \times (T_d^{J/\psi} \sim 2T_c)^4 = 2\ \varepsilon_c \rightarrow \varepsilon_d^{J/\psi} \sim 32\ \varepsilon_c$!
- Wait for LHC ? (and for next talk)



We may still be here

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

Datta & al, hep-lat/0409147
Alberico & al, hep-ph/0507084
Wong, hep-ph/0408020
← Satz, hep-ph/0512217

A-A perspectives

What's new at RHIC ?

1st Recombination ?

- $J/\psi \; \alpha \; (N_{cc})^2$ (but how much is N_{cc} ?)

2nd High p_T J/ψ escape ?

3rd Sequential melting ?

- Only excited states melt. J/ψ still survive !

Lots of ingredients needed to answer…

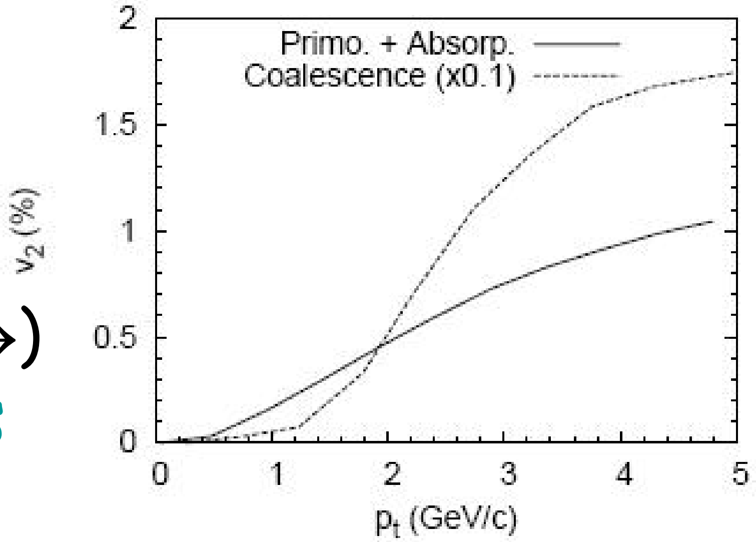
- Cold nuclear effects, open charm,…

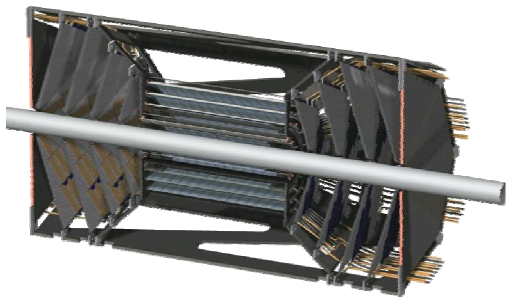
To be continued…

Some steps beyond

- Final AA analysis
  - Smaller systematic ?
  - More centrality bins ?
  - Better pp reference (Run 5)
  - Elliptic flow measurement (→)
- First look at ψ' and upsilons
  - Going on with run 5 pp…
- Better knowledge of dA baseline !
  - Could be run 7 ?
- More AA statistics !
  - Could be run 8 ?
- Better open charm measurements
  - Si VTX upgrade (working on it)

Zhu, Zhuang, Xu, PLB607 (2005) 107





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- Kurchatov Institute, Moscow, Russia
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- Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Vorob'evy Gory, Moscow 119992, Russia
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13 Countries; 62 Institutions; 550 Participants*

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- University of Tennessee (UT), Knoxville, TN 37996, USA
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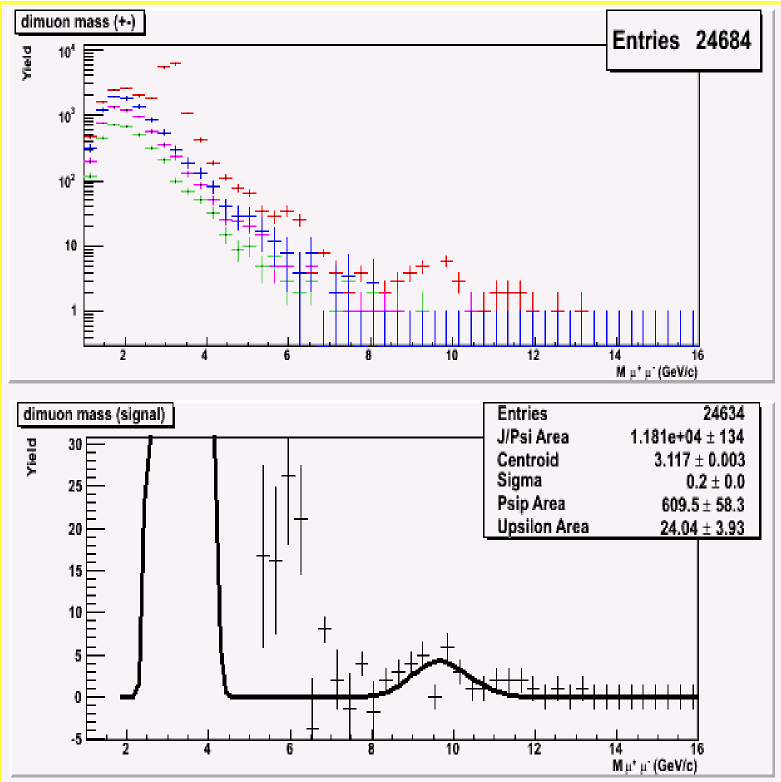
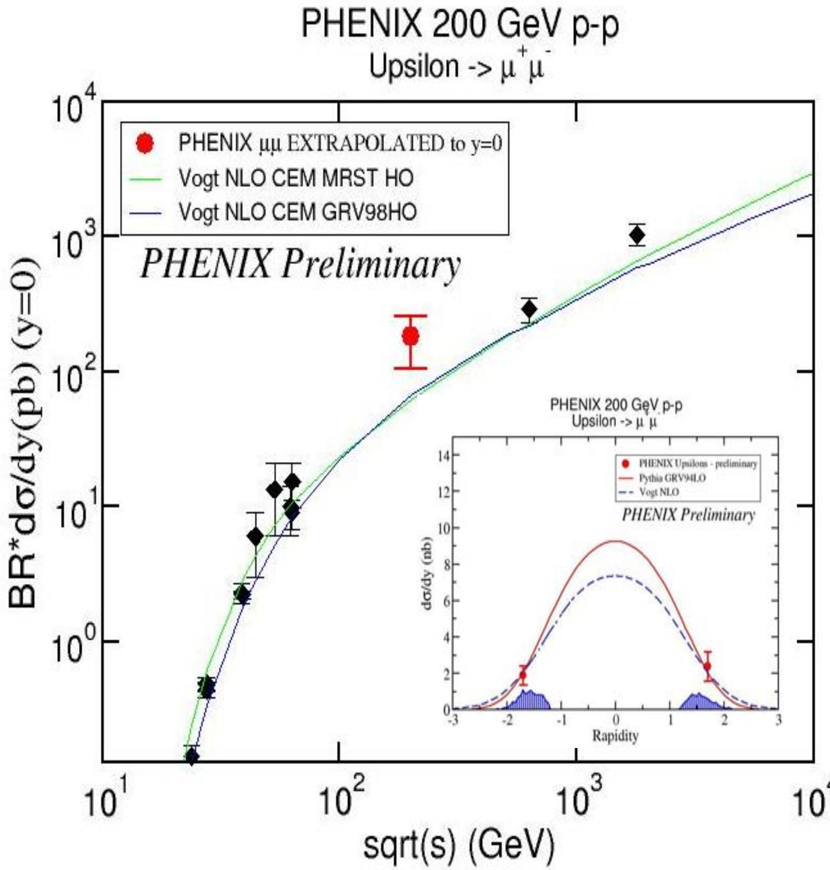
***as of March 2005**

Back up slides

First upsilons…

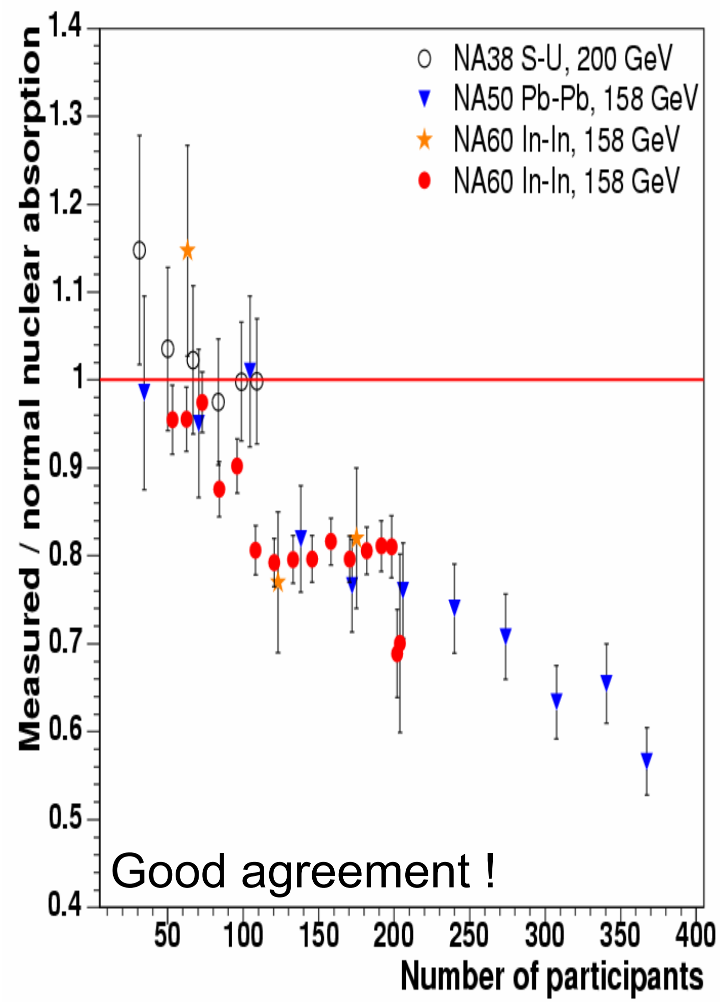


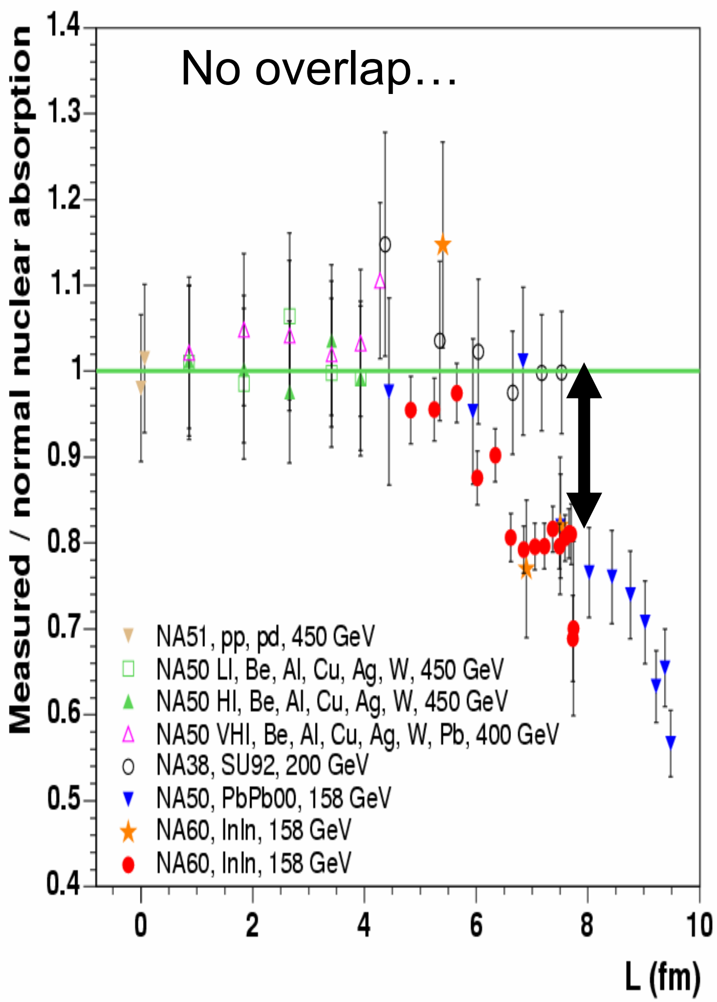


- Run 5 pp (3 pb^{-1})

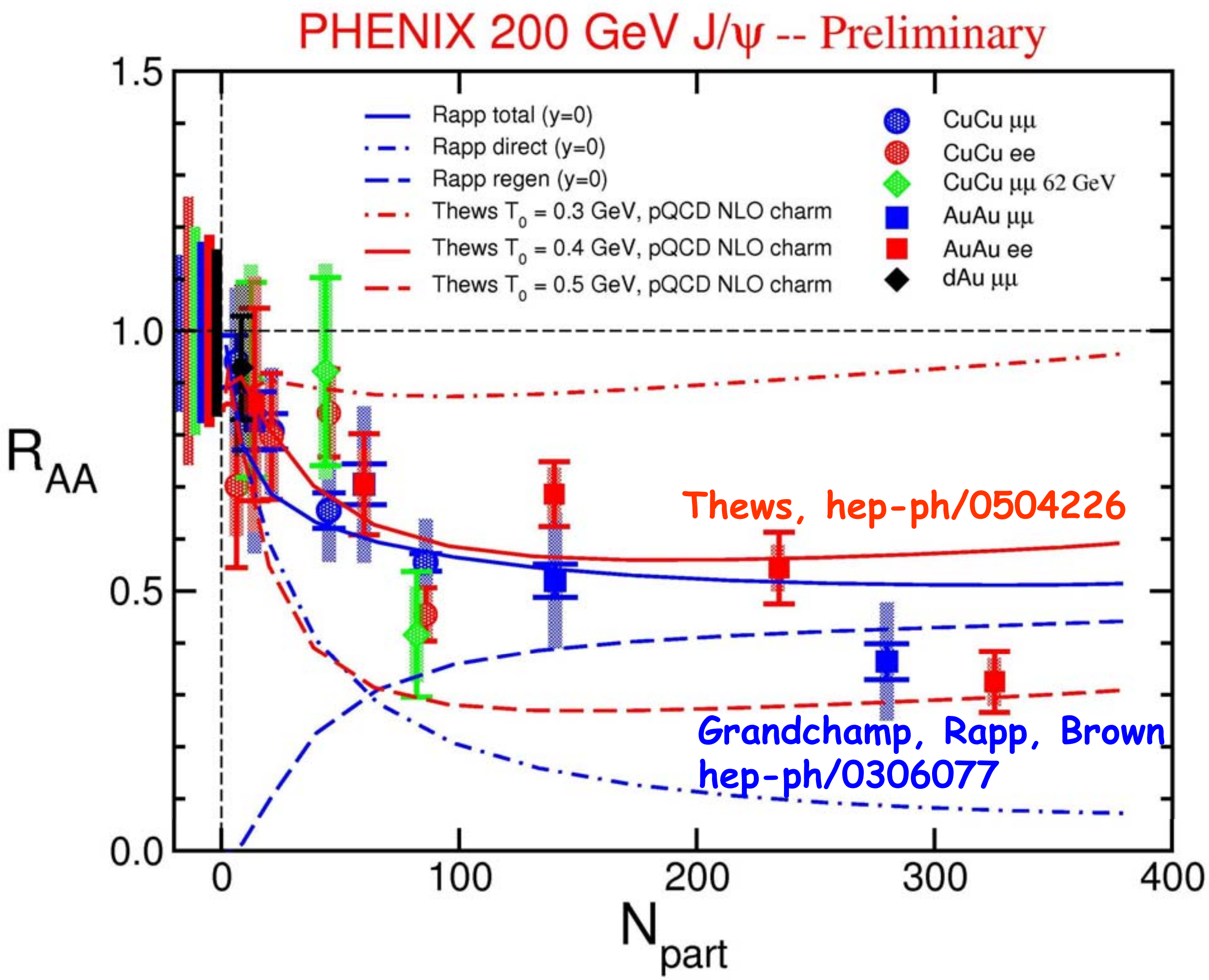
Hie Wei, Quark Matter 2005

NA50 versus NA60 (QM05)

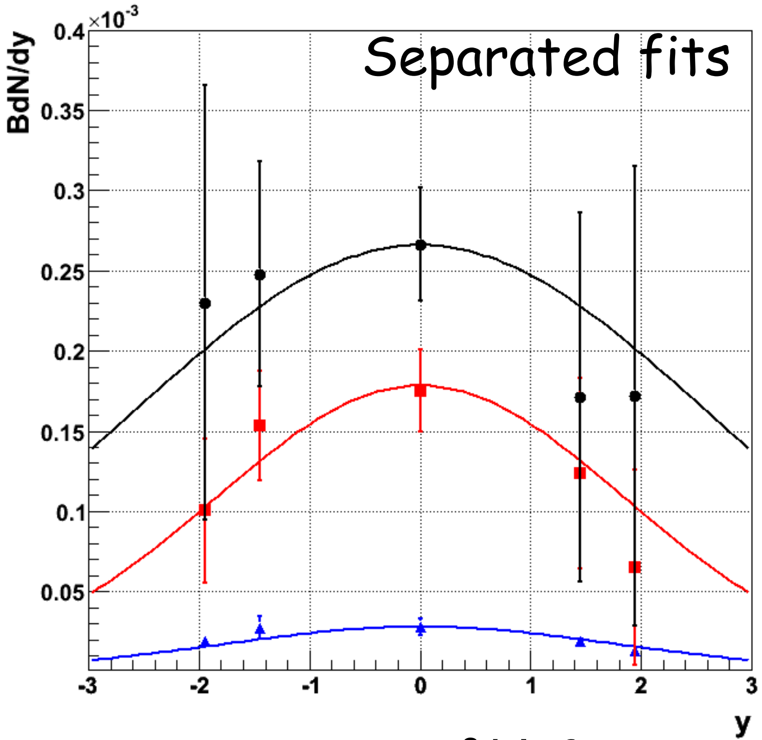




Competing recombination/suppression



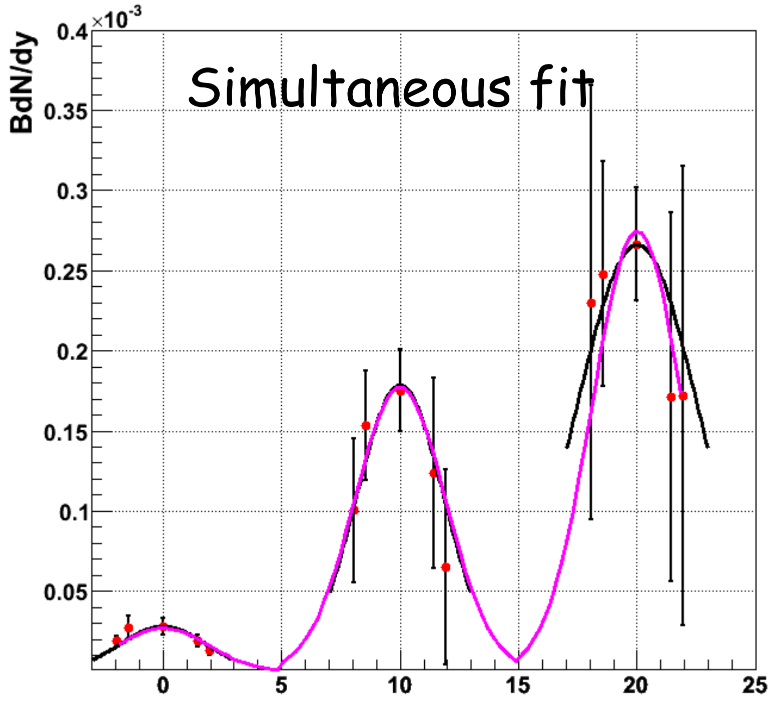
Rapidity width



σ = 2.61 ± 2,54 χ^2/dof = 0.21

σ = 1.85 ± 0,53 χ^2/dof = 0.41

σ = 1.82 ± 1,00 χ^2/dof = 1.39



Width = 1,90 ± 0,32

χ^2/ndl = 0,55

Width pp = 1,75 ± 0,21

No noticeable change in rapidity width

ViNham Tram thesis

More on transport model…

- 2+1D hydro
- Boltzman-type transport
- Local equilibrium
  - (0.8 & 0.6 fm/c)
  - Normal to anomalous
- T_c = 165 MeV
- T_{fo} = 60 MeV
- $g+\Psi \rightarrow cc$
- 40% feeddown
- No in-medium mod.
- No absorption @RHIC

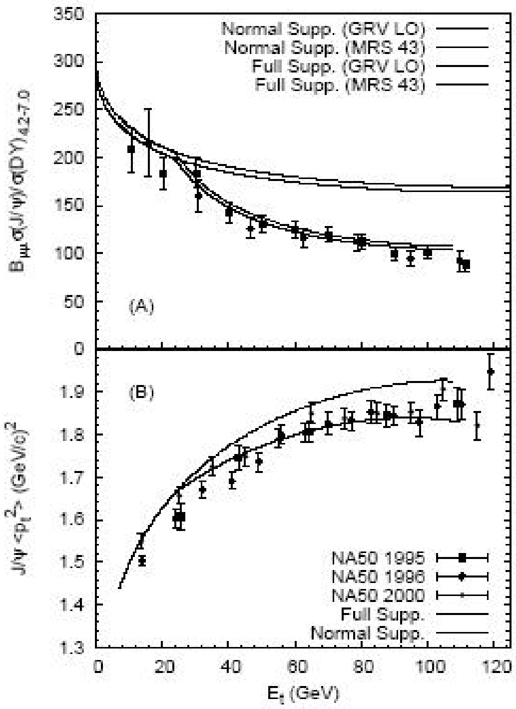


FIG. 1: The J/ψ suppression and $\langle p_t^2 \rangle$ as functions of centrality at SPS energy.

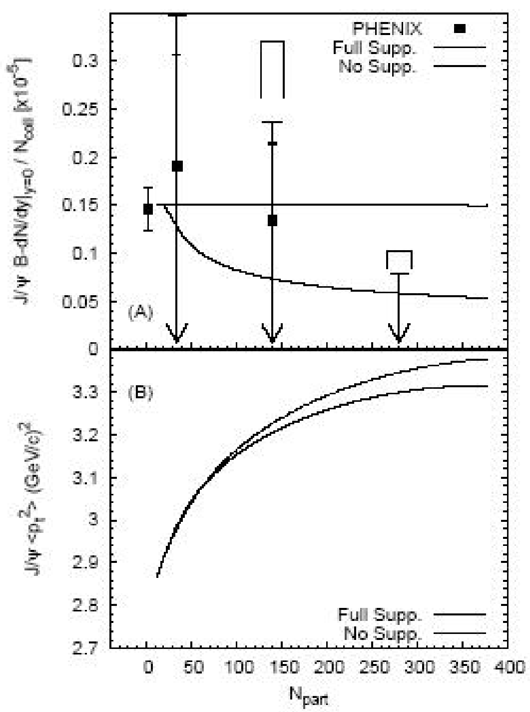
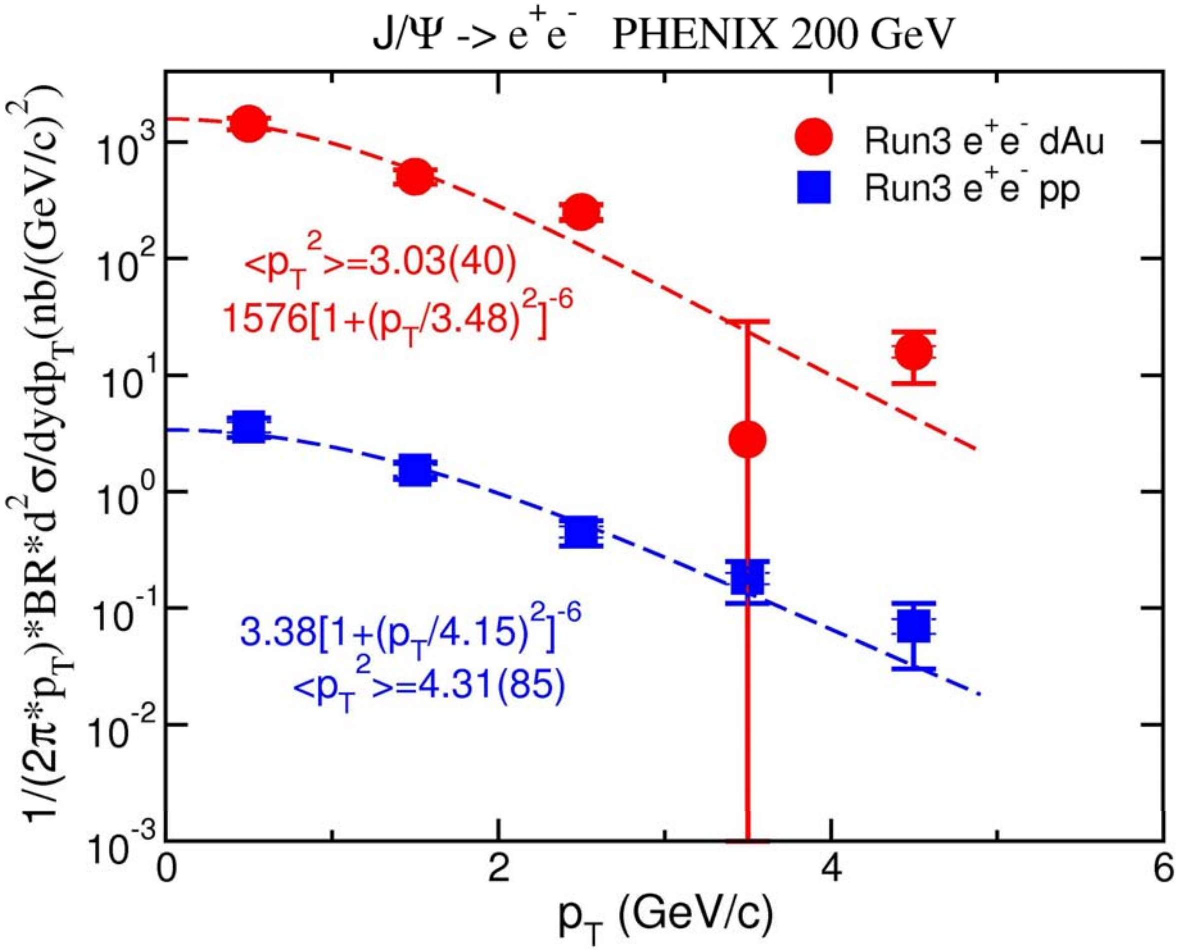


FIG. 2: The J/ψ suppression and $\langle p_t^2 \rangle$ as functions of centrality at RHIC energy.

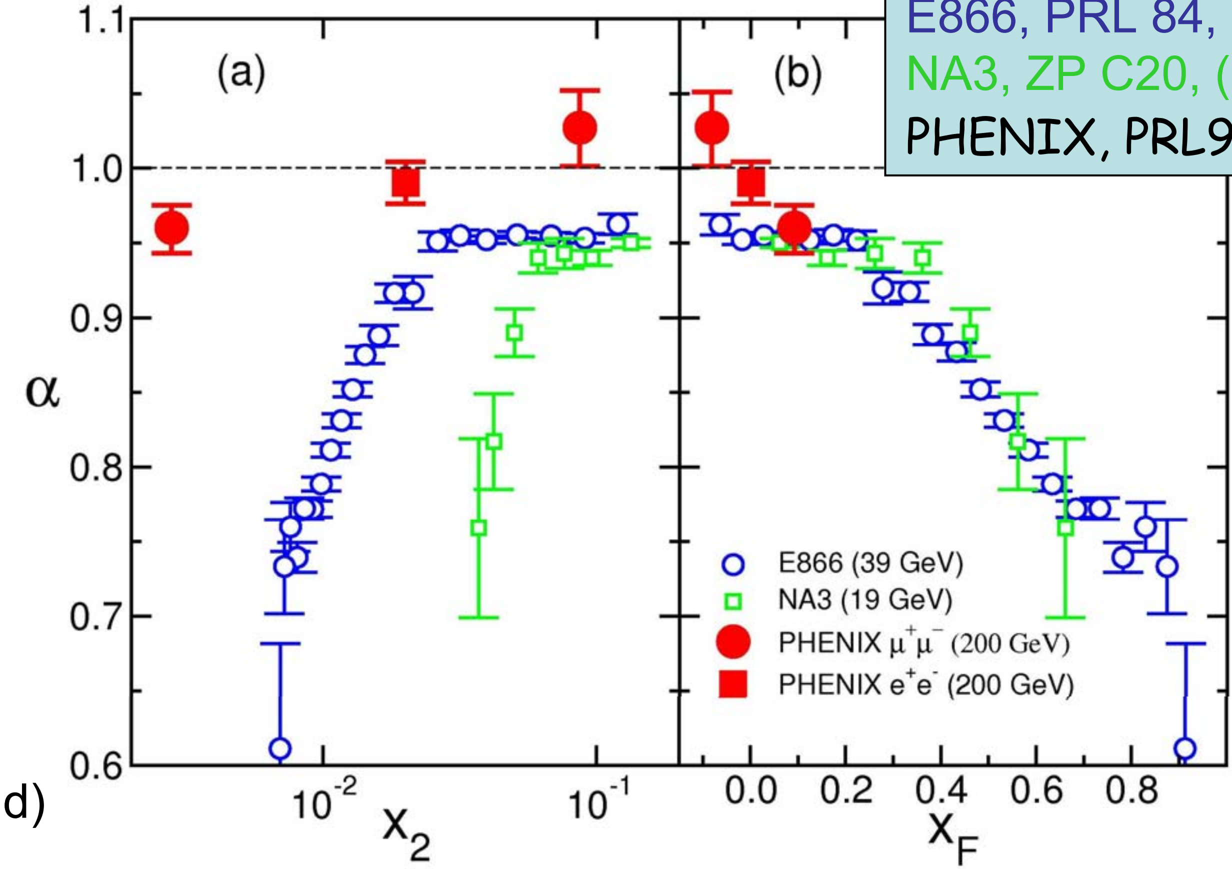
Zhu, Zhuang, Xu, PLB607 (2005) 107

Dielectron pp and dA



α versus X compared to lower $\sqrt{s}$

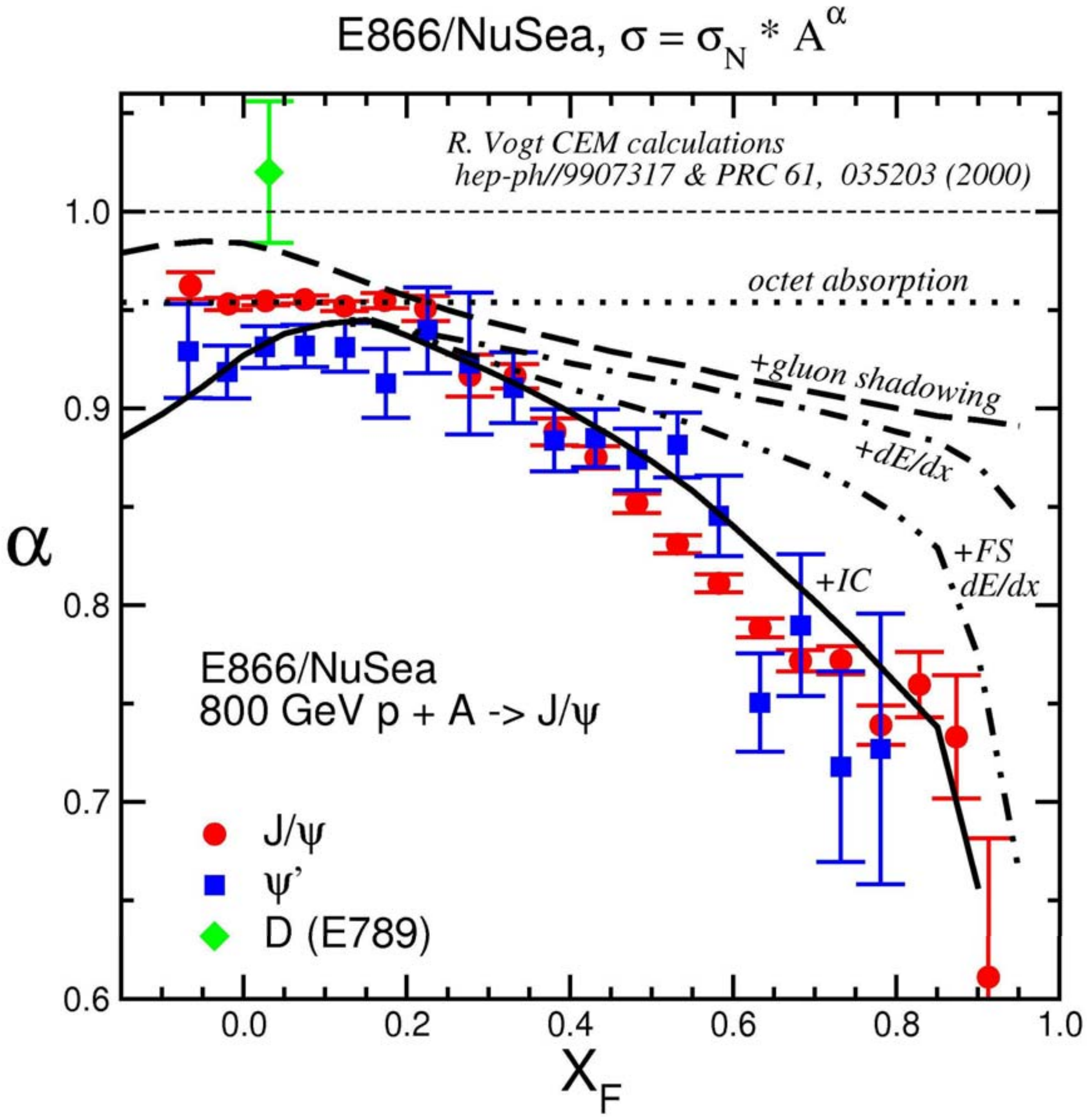
E866, PRL 84, (2000) 3256
NA3, ZP C20, (1983) 101
PHENIX, PRL96 (2006) 012304



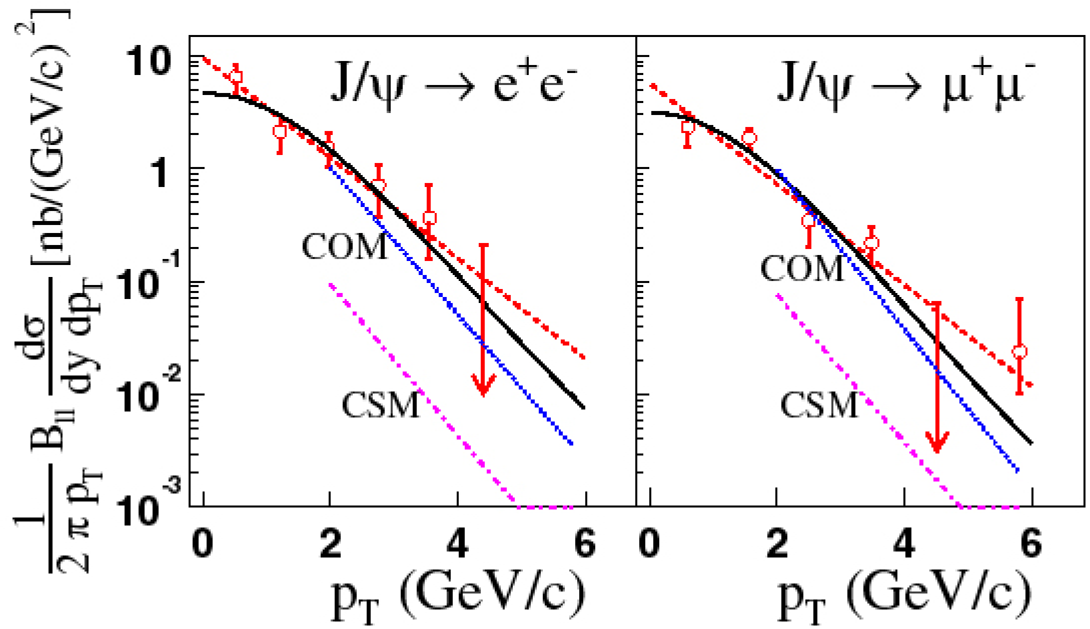
X_2 (in gold) $X_F = X_d - X_{Au}$

- Not universal versus X_2 : shadowing is not the whole story.
- Same versus X_F for diff $\sqrt{s}$. Incident parton energy loss ? (high X_d = high X_F)
- Energy loss expected to be weak at RHIC energy.

How to get x_F scaling ?



J/ψ transverse momentum (run2)



Color Singlet Model

Color Octet Model

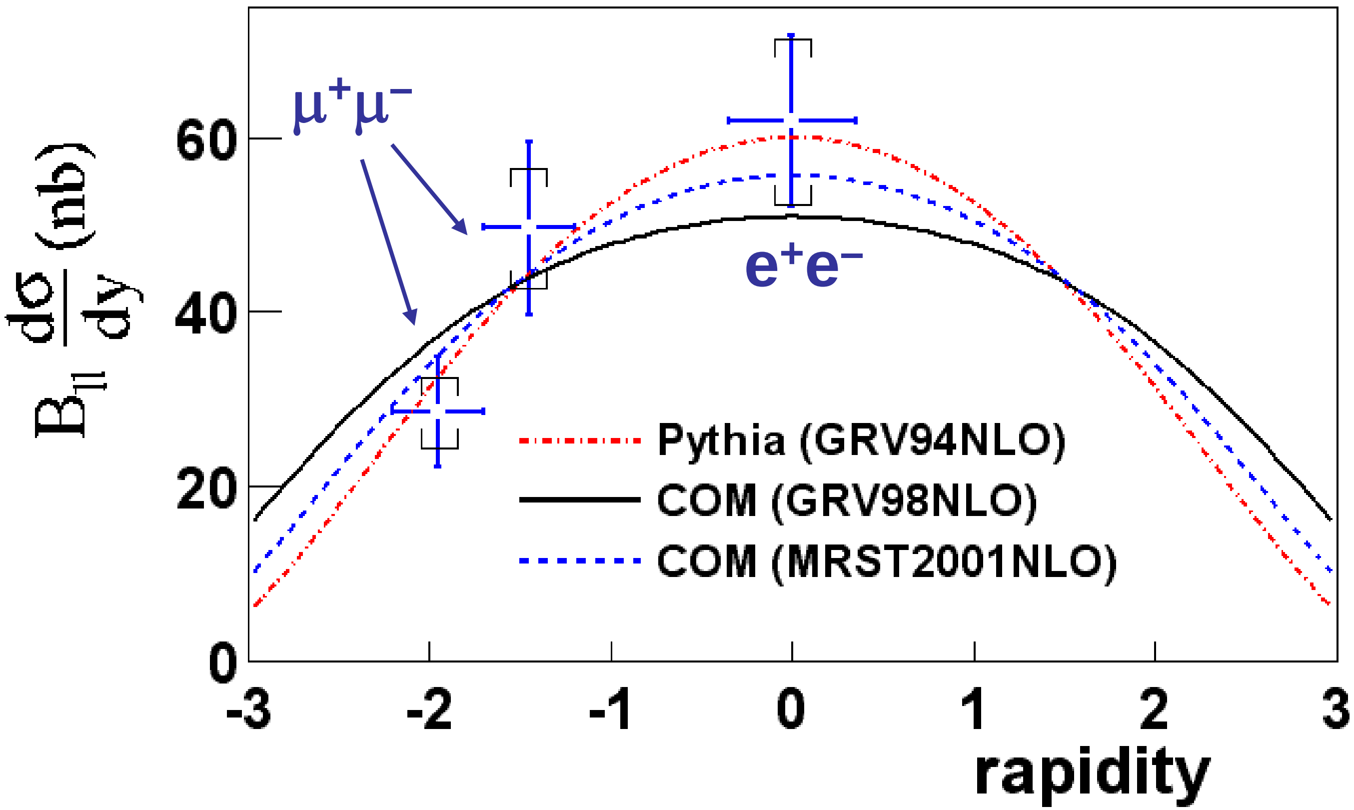
(from Nayak et al. hep/ph 0302095)

COM contribution is dominant, as for high p_T J/Ψ @ Tevatron

Phenomenological + exponential fits of dimuon and dielectron data give mean p_T :

$\langle pT \rangle = 1.80 \pm 0.23$ (stat) ± 0.16 (sys) GeV/c

J/Ψ cross section from run 2



Results consistent with shapes from various models and PDF.

Take the PYTHIA shape to extract our cross-section

Error from absolute normalization

Integrated cross-section :

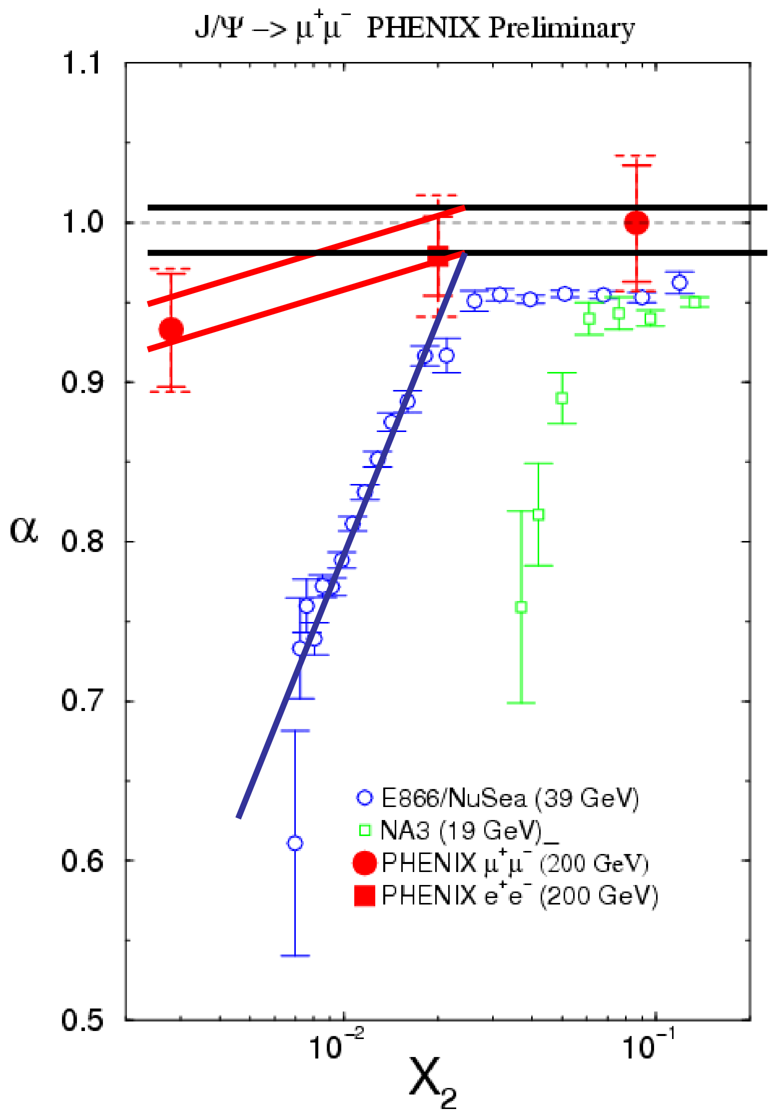
RUN2 234 ± 36 (stat) ± 34 (sys) ± 24(abs) μb

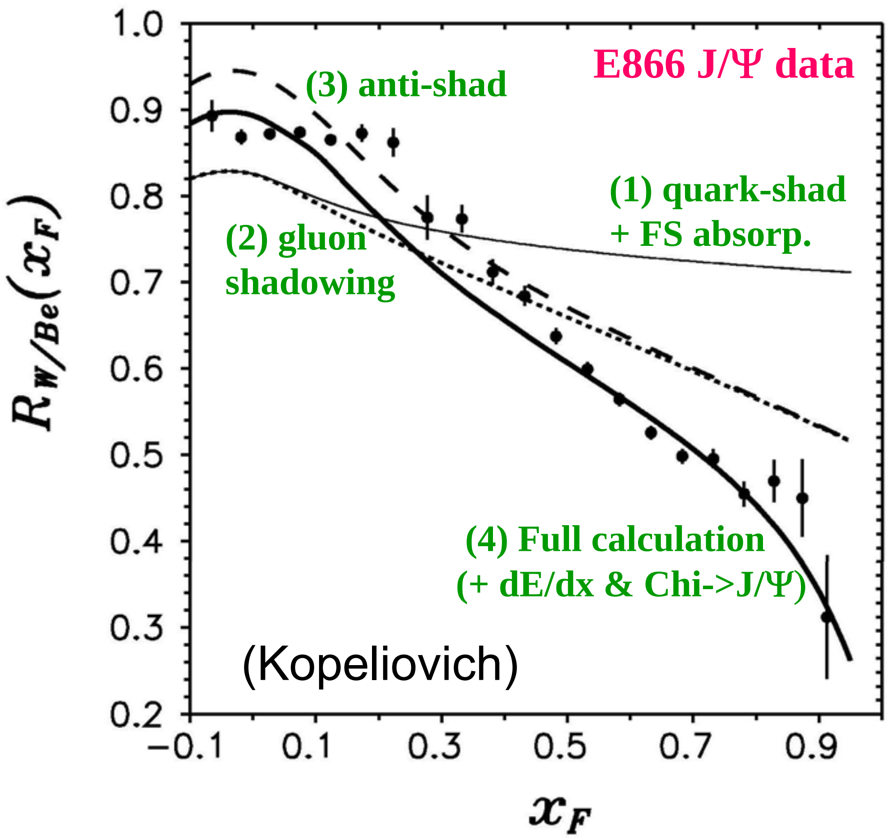
RUN3 159 nb ± 8.5 % (fit) ± 12.3% (abs)

Consistent (1.3 sigma difference)

Naive picture

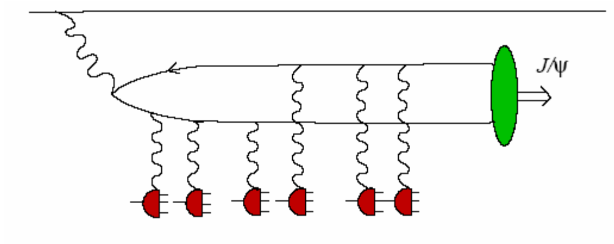
- Less absorption
- Shadowing
- Energy loss

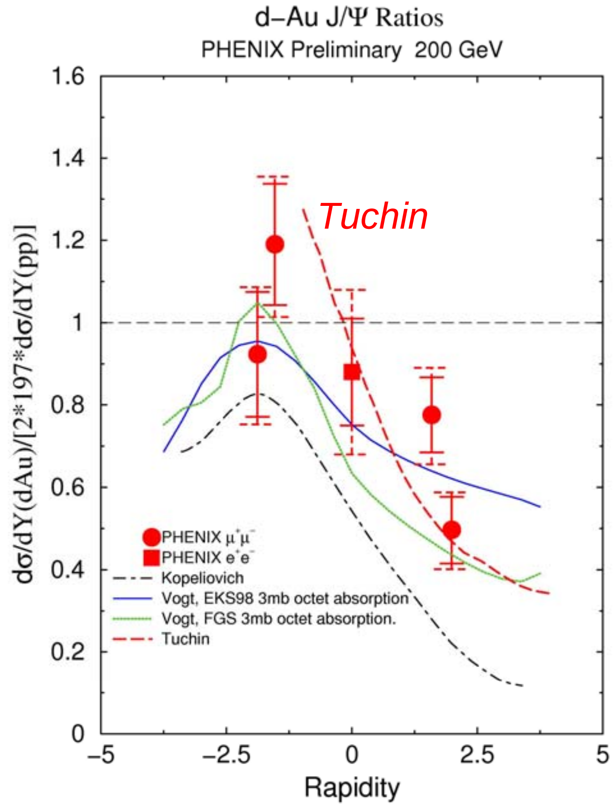




Tuchin & Kharzeev

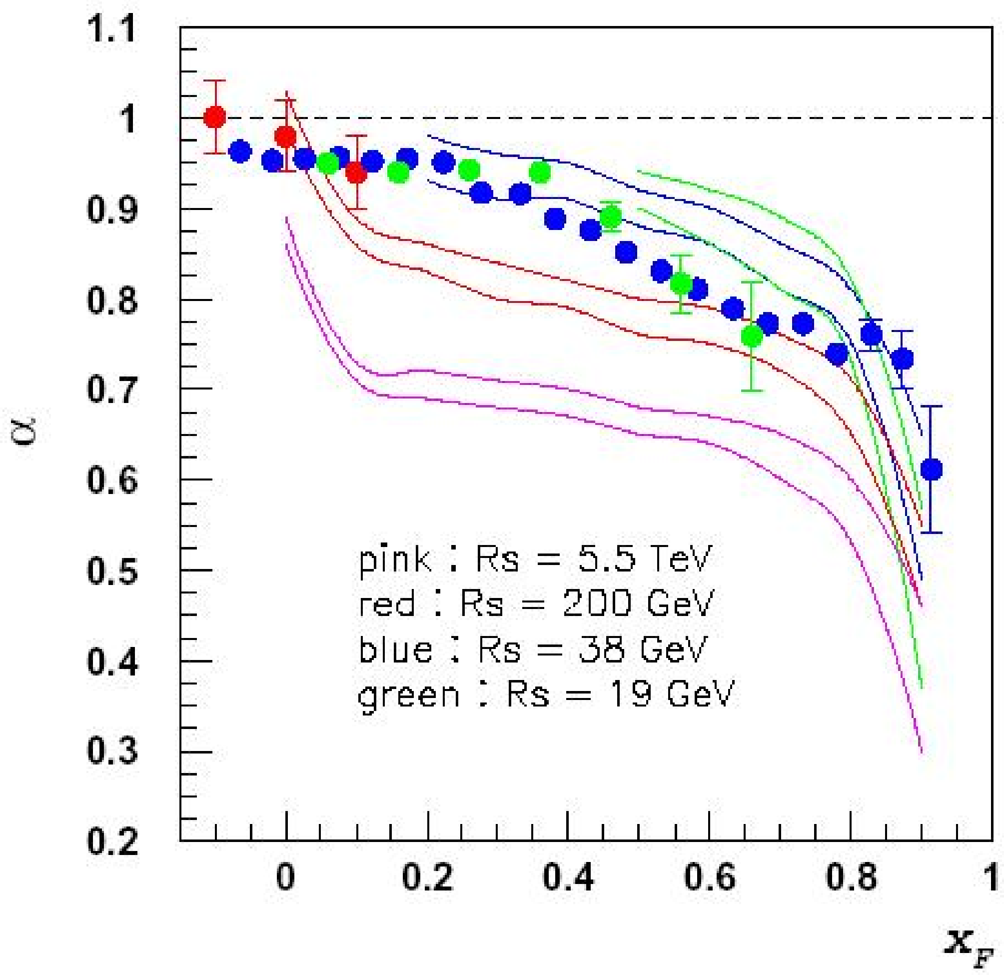
- Hard probes 2004
  - [hep-ph/0504133](hep-ph/0504133)
- Coherent production of charm (open or closed)
  - (y<0 production time to low to make computation)
  - Shadowing from CGC computation…





Tuchin & Kharzeev…

+ absorption for SPS & fermilab



… gold+gold extrapolation …