J/ψ production in

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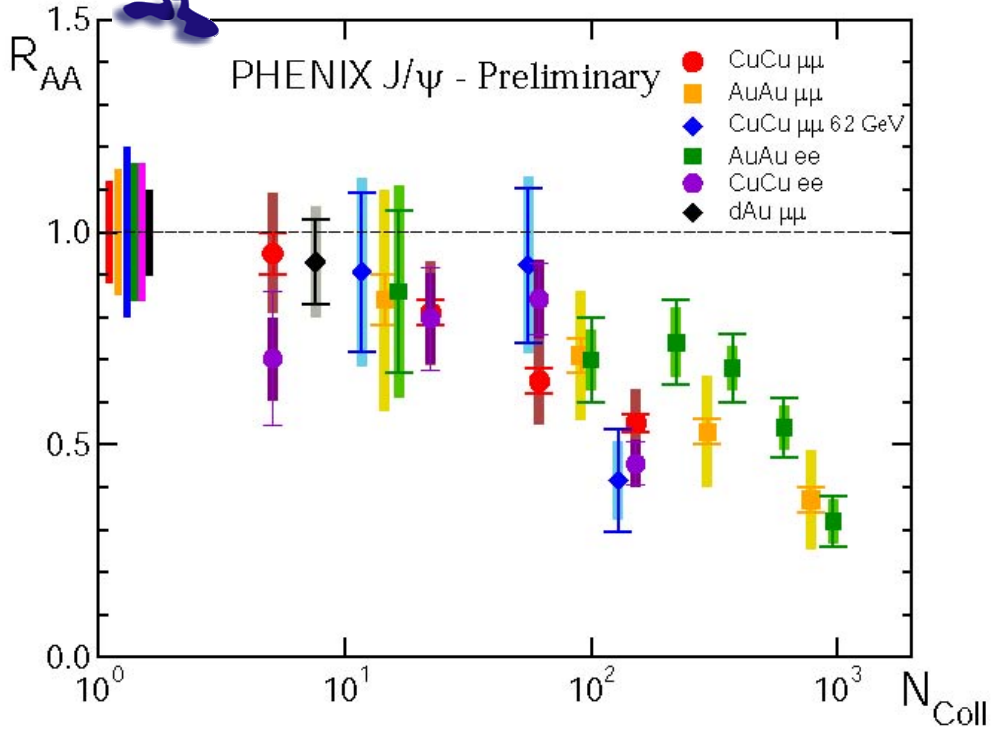
LLR – École polytechnique / IN2P3
For the PHENIX collaboration

Hot Quarks 2006
Villasinius, Sardinia, May 20th

J/ψ in nucleus-nucleus (phenix preliminary = QM05)

R_{AA} versus N_{coll}



J/ψ → μμ
Muon arm
1.2 < |y| < 2.2

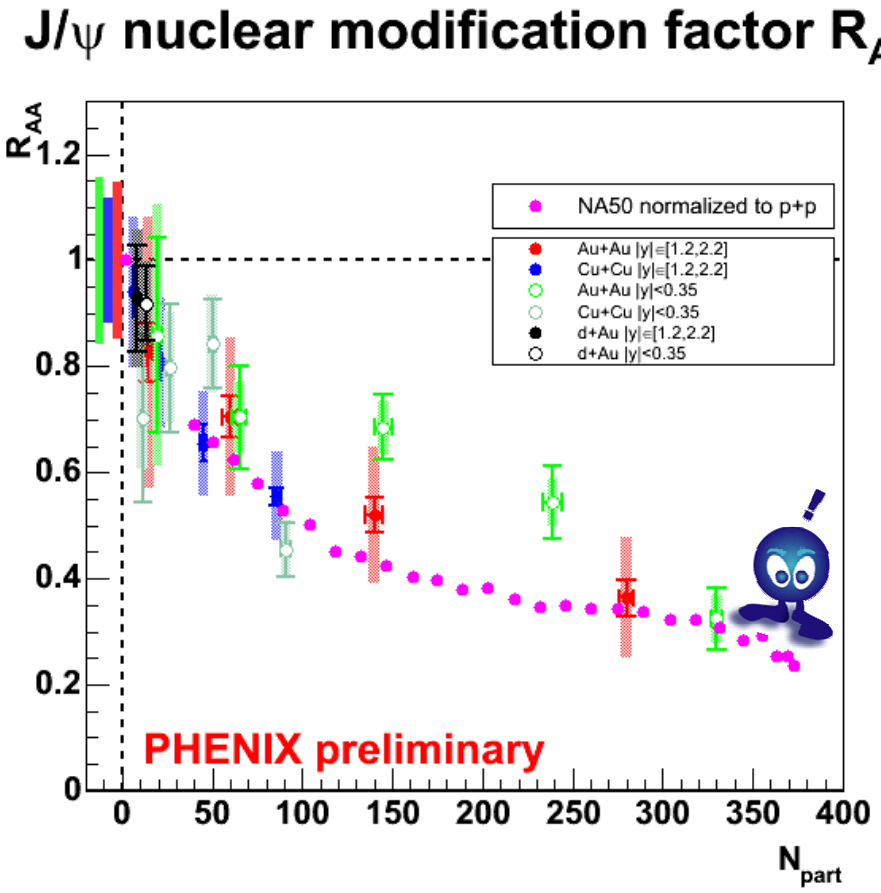
J/ψ → ee
Central arm
-0.35 < y < 0.35

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

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

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

Quick comparison to NA50



Same magnitude

- 30% survival prob.

No fundamental reason

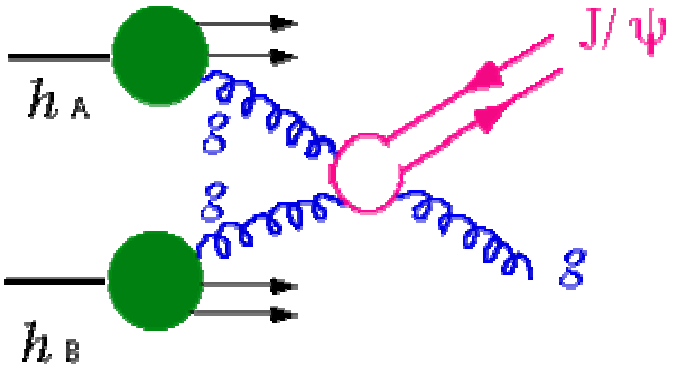
Differences:

- Higher energy density
  - (x10 beam energies)
- Balance between cold & hot nuclear effects ?

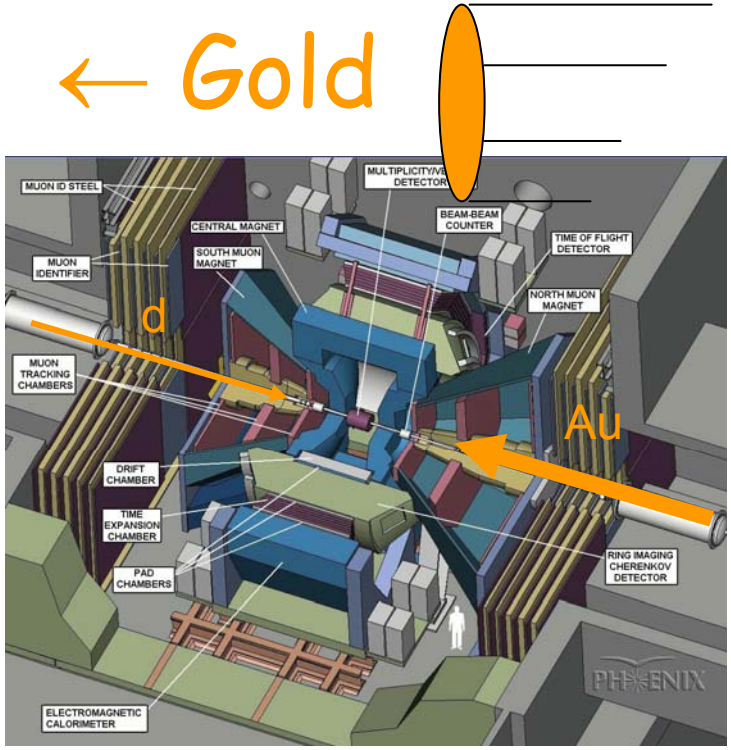
J/ψ in deuteron-gold
PRL96 (2006) 012304

Cold nuclear matter effects

- Various "cold" effects:
  - Shadowing  or anti-shadowing 
    (gluon saturation, Color Glass Condensate…)
  - Energy loss of initial parton
  - p_T broadening (Cronin effect)
  - J/ψ (or $c\bar{c}$) absorption
  - Something else ?

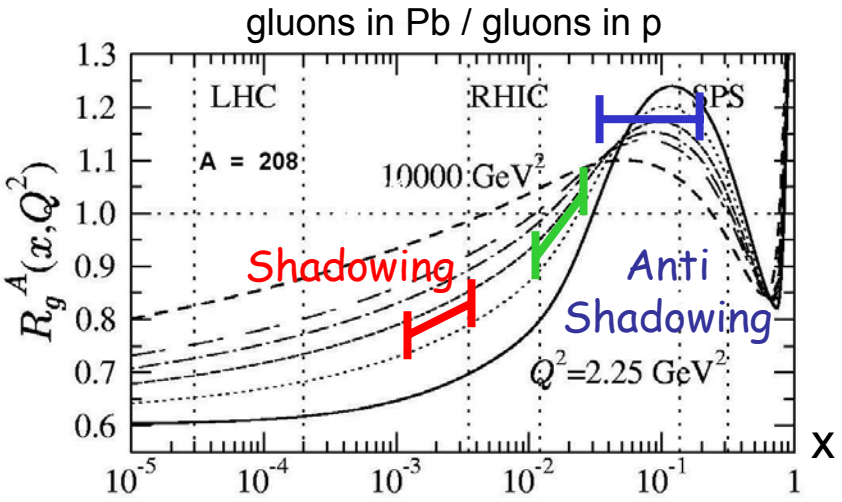


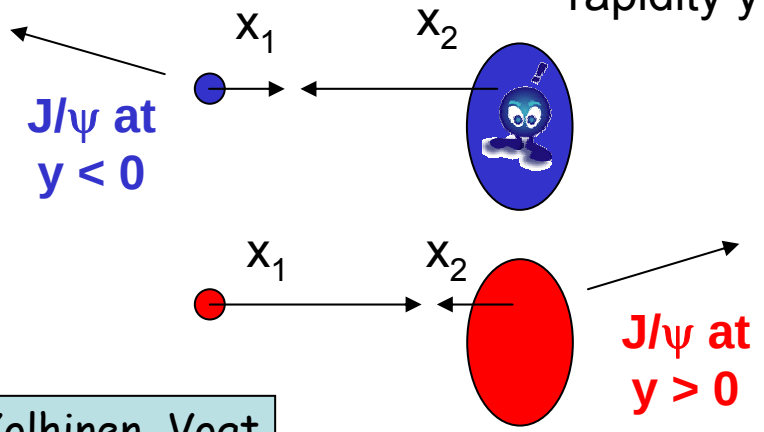
Deuteron → ← Gold



- 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 ~ 0) : intermediate x_2 ~ 0.020
  - North (y > 1.2) : small x_2 (in gold) ~ 0.003

An example of gluon shadowing prediction

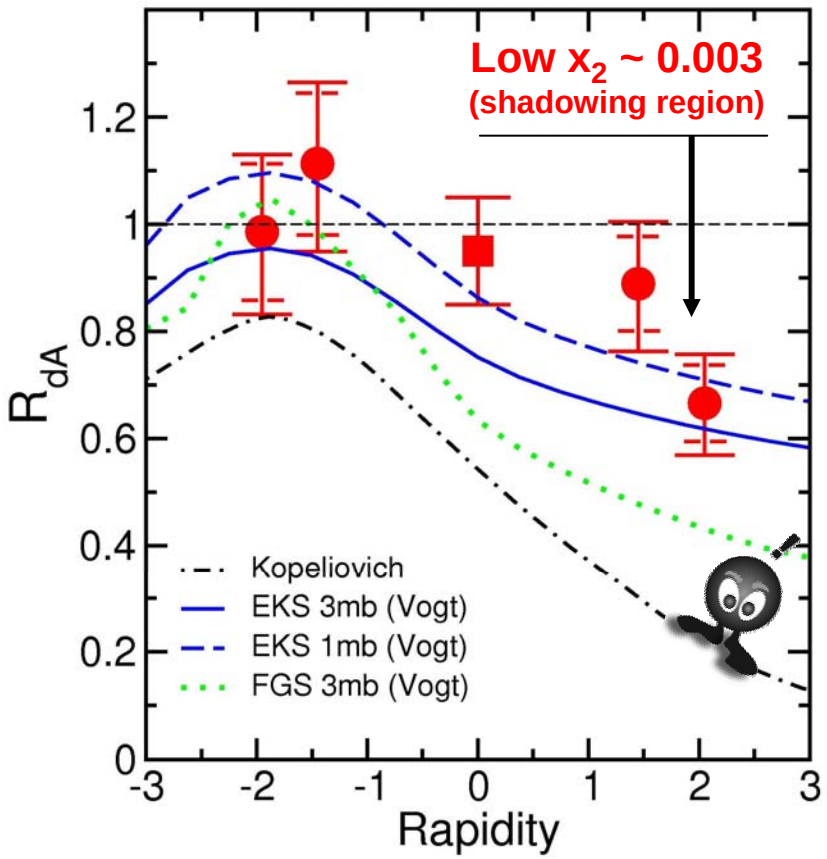




Eskola, Kolhinen, Vogt NPA696 (2001) 729

R_{dAu} versus rapidity

R_{dA}



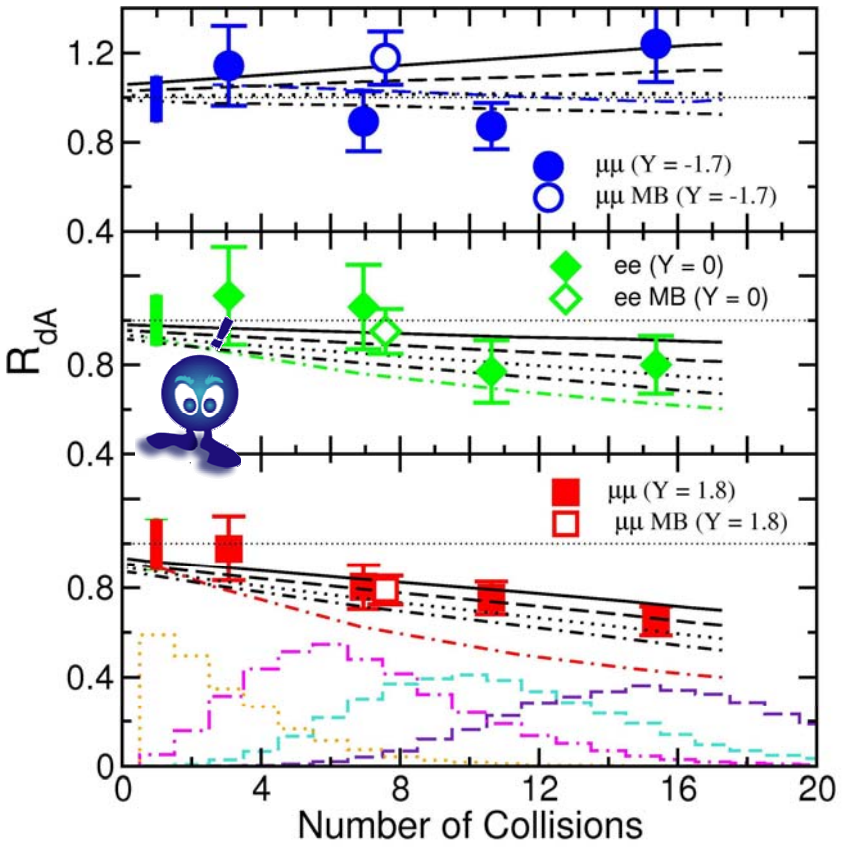
- Data favours
  - (weak) shadowing
    Eskola, Kolhinen, Salgado prescription matches better
  - (weak) absorption
    σ_{abs} ~ 1 to 3 mb
    (4.18 ± 0.35 mb @SPS)
- But with limited statistics difficult to disentangle nuclear effects !

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

R_{dAu} versus N_{coll}

R_{dA}

High x_2 ~ 0.09

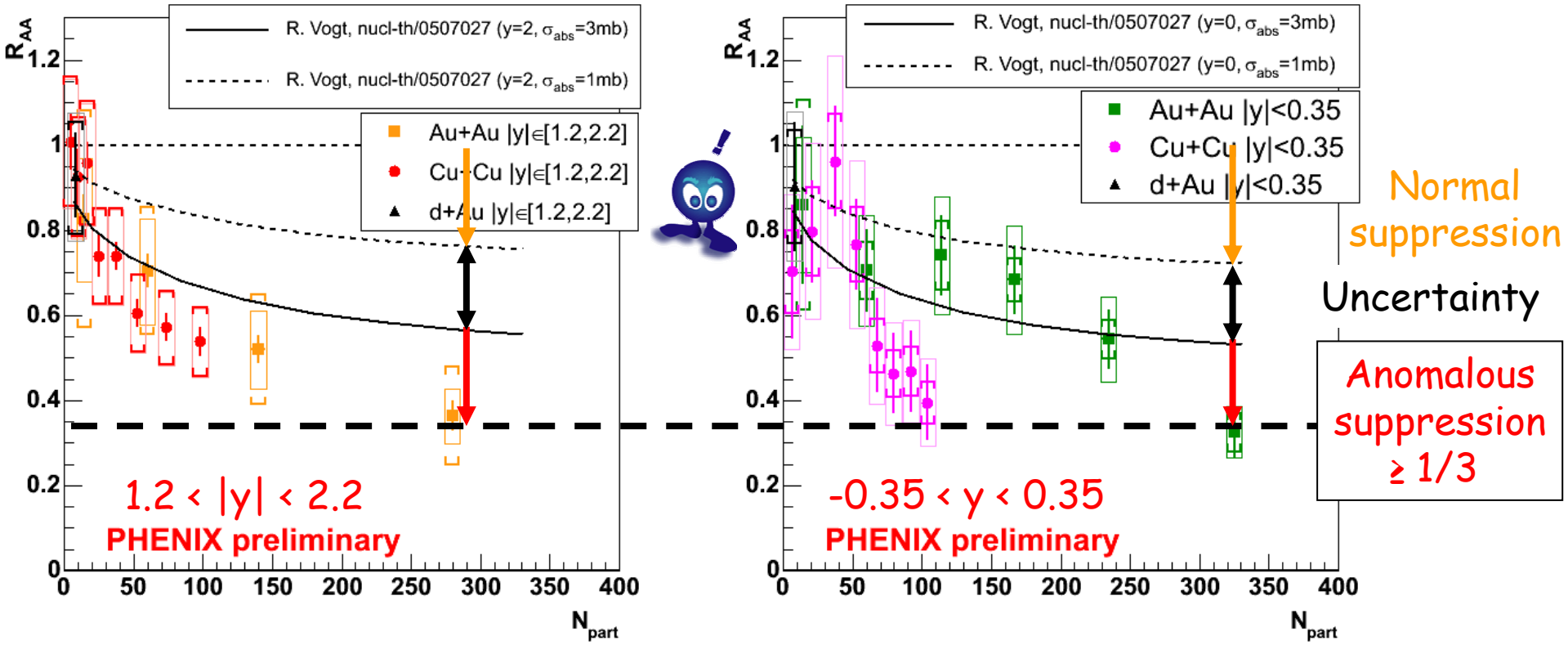


Low x_2 ~ 0.003

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

Cold nuclear matter effects

- Shadowing + nuclear absorption (crucial !)



Error bar code : bars = statistical,
bracket = systematic, box : global.

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

"NA50 only" effects

- Cold effects + …

——— Comovers (hadrons/partons?)

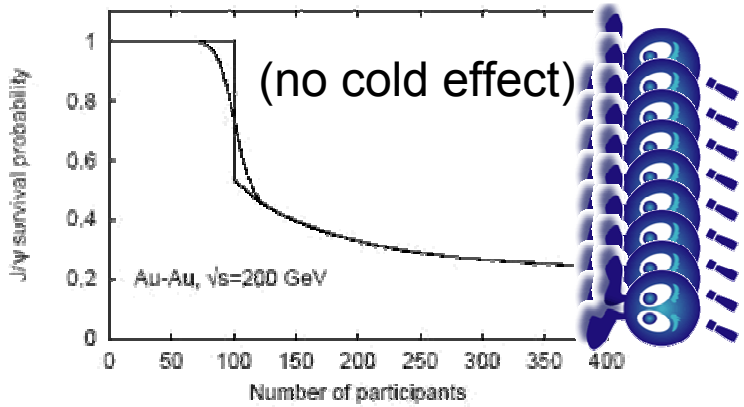
- - - - - Kinetic model ($J/\psi \rightarrow c\,\bar{c}$)

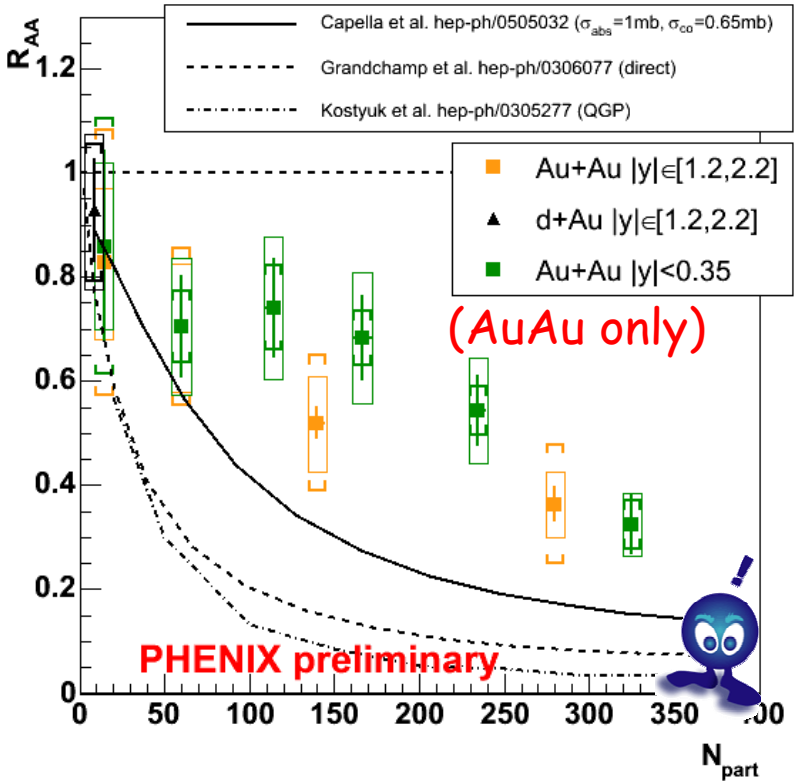
-·-·-·- Thermal plasma

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

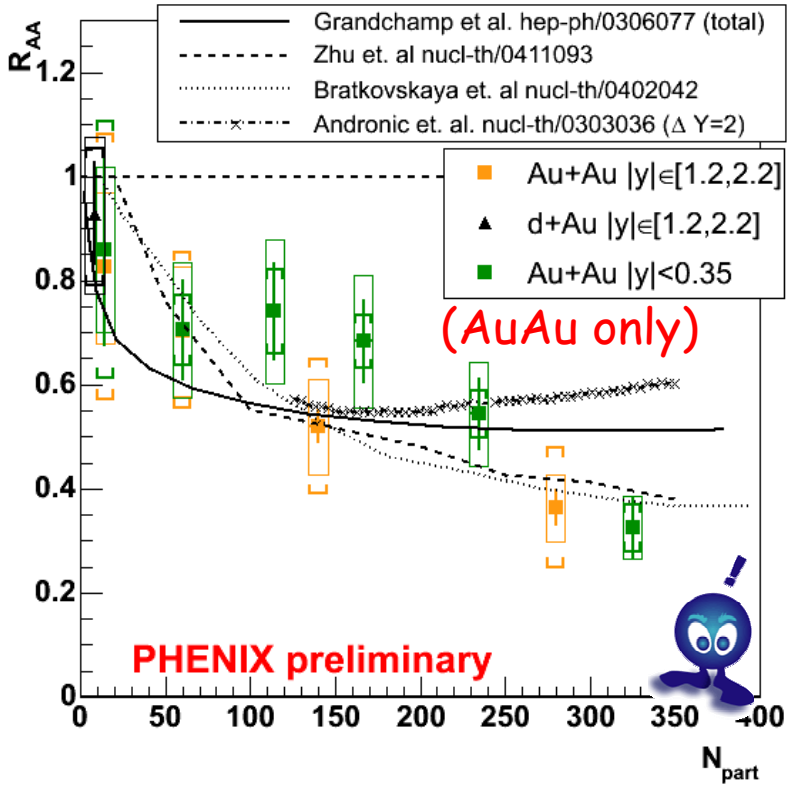
- $c\,\bar{c} \rightarrow J/\psi$ (at freeze-out)
- goes as N_{cc}^2 (poorly known)

(other models not displayed)

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

(here without cold nuclear effects, see later…)

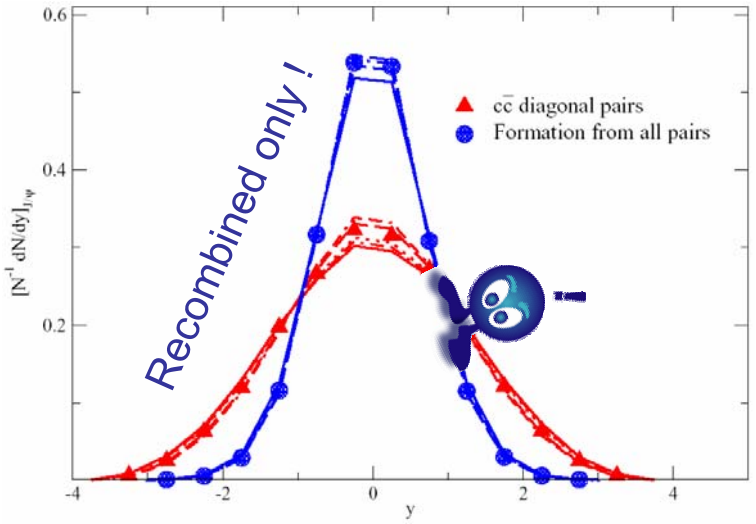
Look at y, p_T…

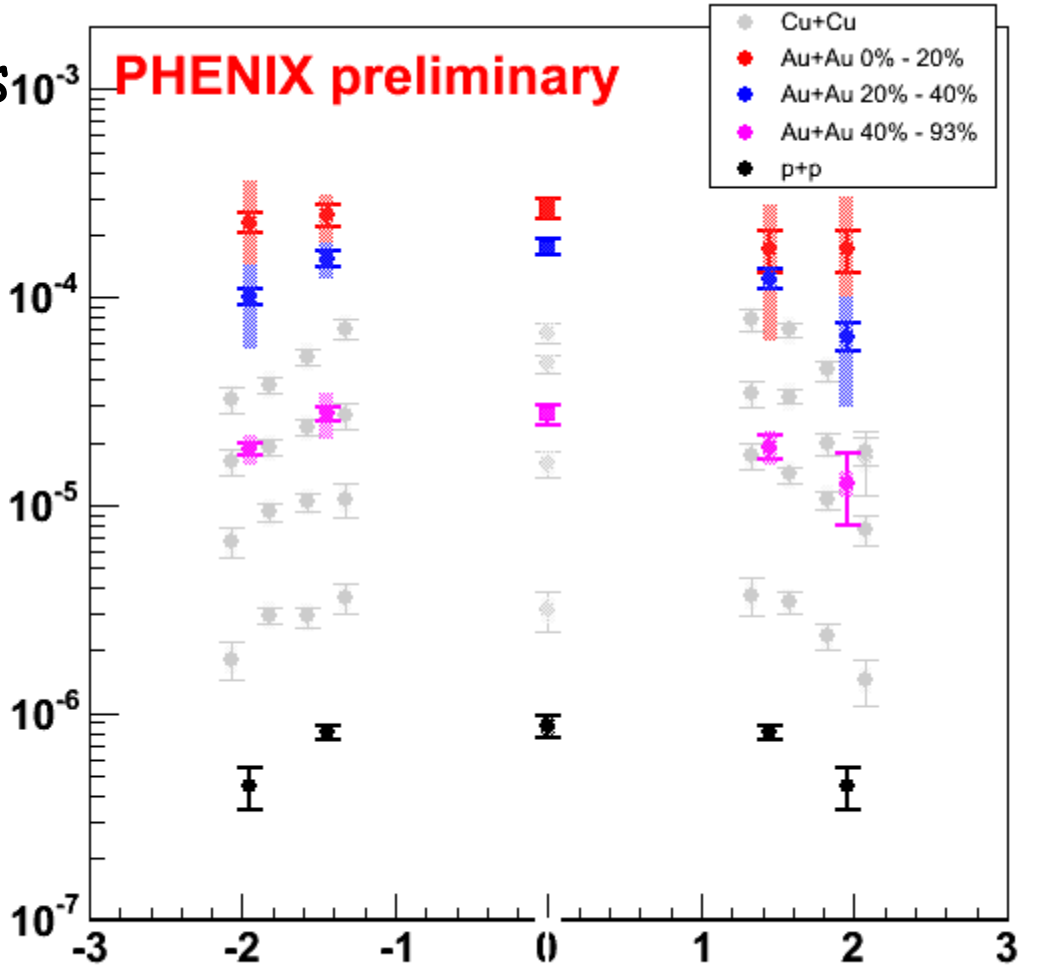


Grandchamp et al, PRL92 (2004) 212301
Bratkoskaya et al, PRC69 (2004) 054903
Andronic et al, PLB571 (2003) 36
Zhu, Zhuang, Xu, PLB607 (2005) 107
+ Private communications +

y shape (vs recombination)

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



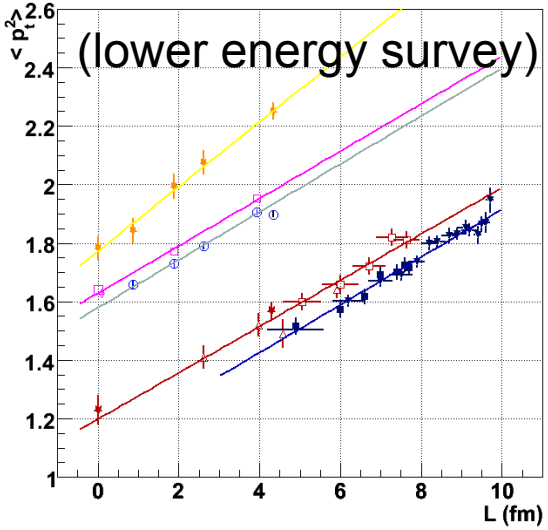


← Thews & Mangano, PRC73 (2006) 014904c

$\langle p_T^2 \rangle$ (vs Cronin effect)

$\langle p_T^2 \rangle_{AA} = \langle p_T^2 \rangle_{pp} + \rho\ \sigma\ \Delta p_T^2 \times L$ [nuclear matter thickness]

(random walk of initial gluons)

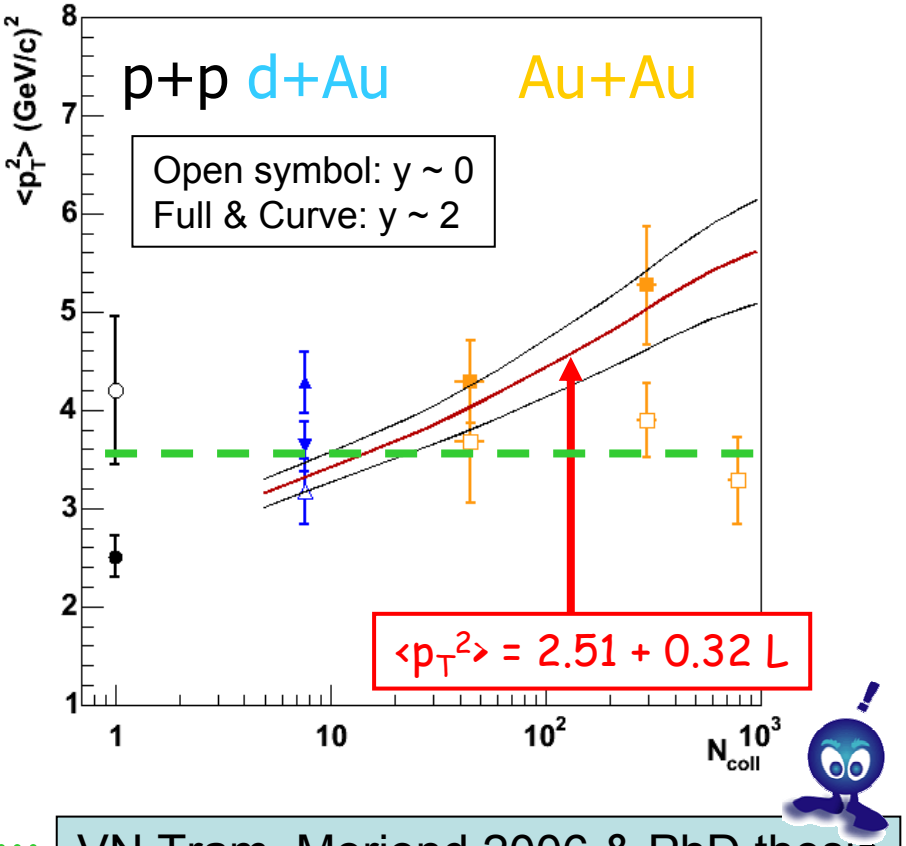


$\rho\ \sigma\ \Delta p_T^2$ from pp and dA →

L <-> N_{coll} conversion

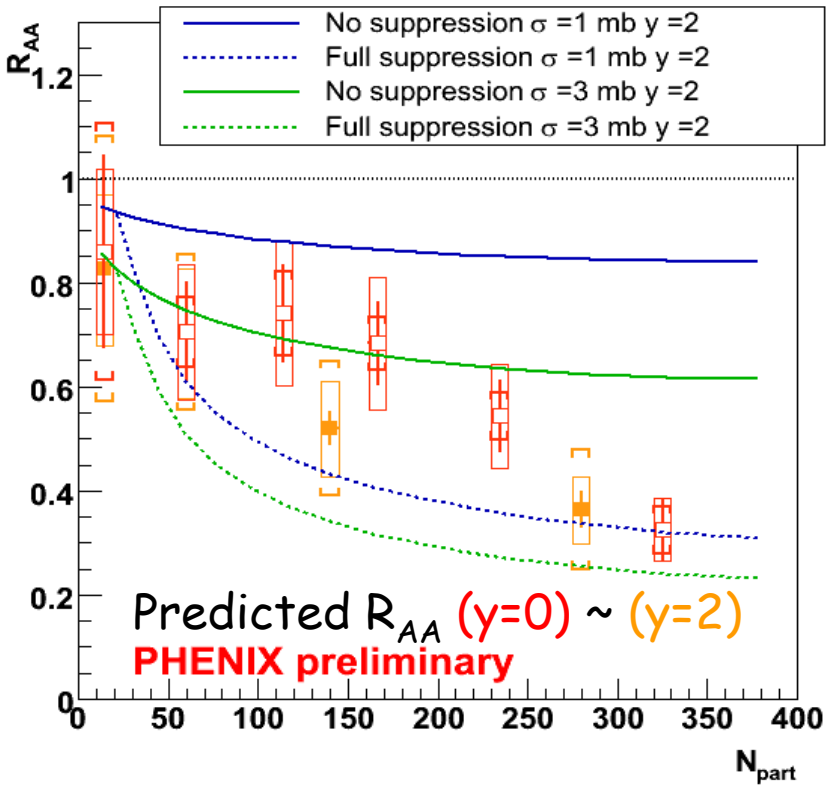
Negligible broadening @ y=0 !?...

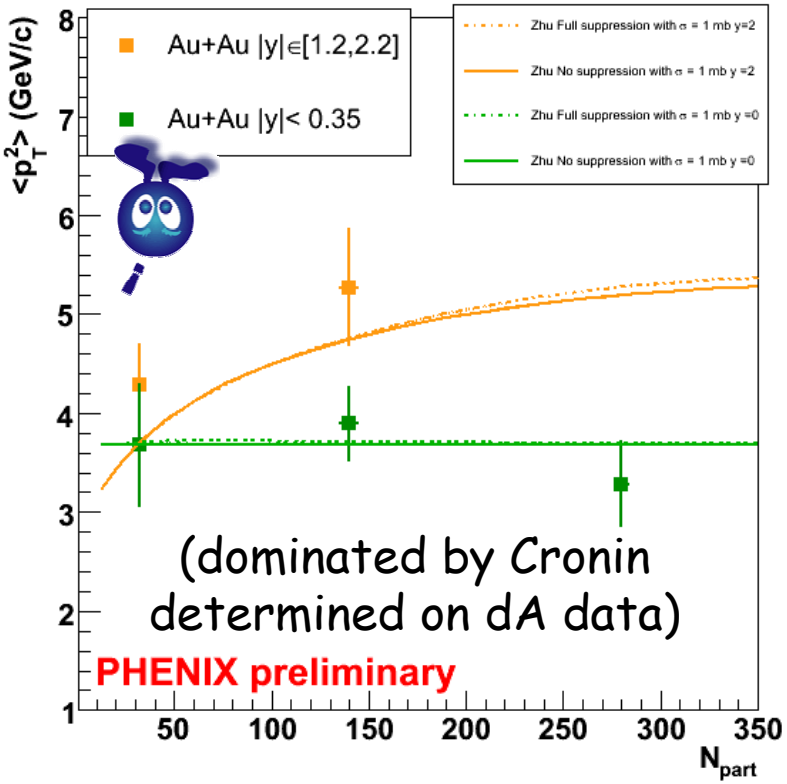
(open symbols)



VN Tram, Moriond 2006 & PhD thesis

2nd. Zhu et al (updated)



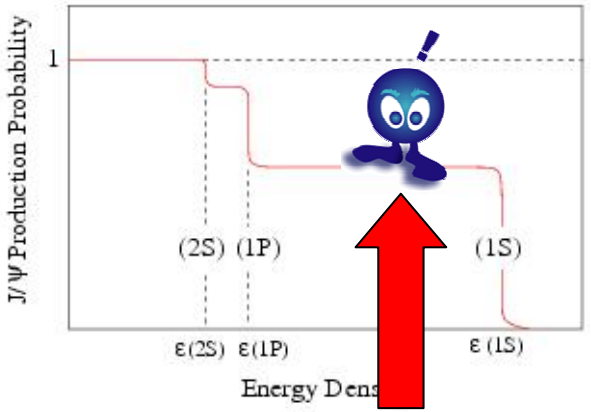


+ Nuclear absorption (1 or 3 mb)
+ Cronin effect from our dAu

Zhu, Zhuang, Xu,
PLB607 (2005) 107
+ private communication

3rd (simple) explanation

- Amount of anomalous suppression depends on cold nuclear effects amplitude
- But could as low as 30 to 40%
- 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 ?



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

Conclusions (1)

For now, 3 models to "explain" the data:

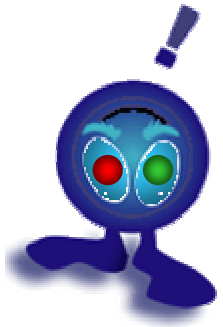
1st Recombination ?

- But no sign of y or p_T^2 modifications…
- J/ψ α $(N_{cc})^2$ (but how much is N_{cc} ?)

2nd J/ψ detailed transport in hydro QGP

3rd Sequential melting ?

- J/ψ may still survive @ RHIC…



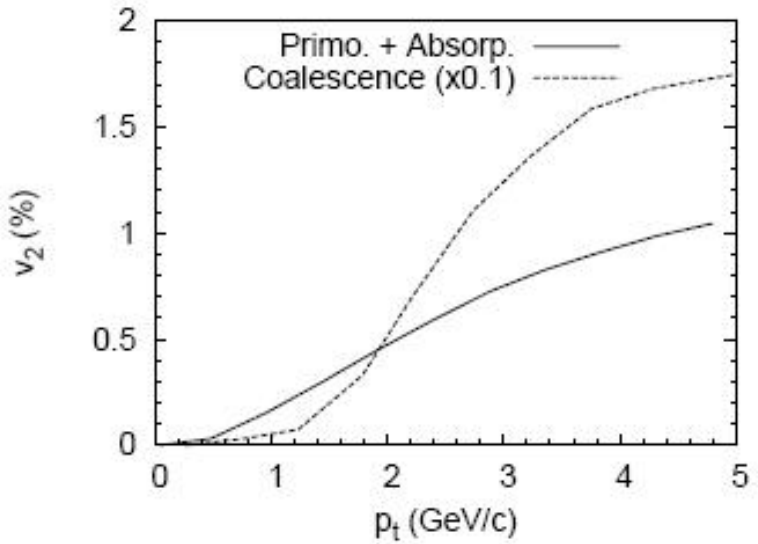
All assume a QGP…

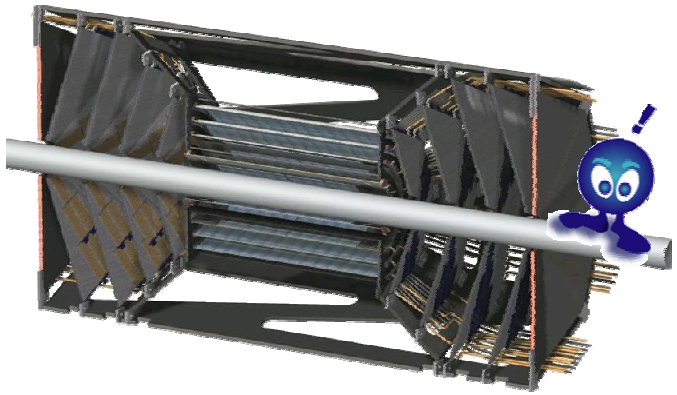
Conclusions (2)

What do we need to answer ?

- Final AA analysis
  - A bit more data & more bins !
  - With a better pp ref (run 5)
  - With J/ψ elliptic flow ? →
- More dA ! Better handle cold nuclear effects…
- More AA ! With open charm, ψ',…
- First look at ψ' and upsilons
  - Going on with run 5 pp…
- Better open charm measurements
  - Si VTX upgrade →
- LHC !

Zhu, Zhuang, Xu, PLB607 (2005) 107





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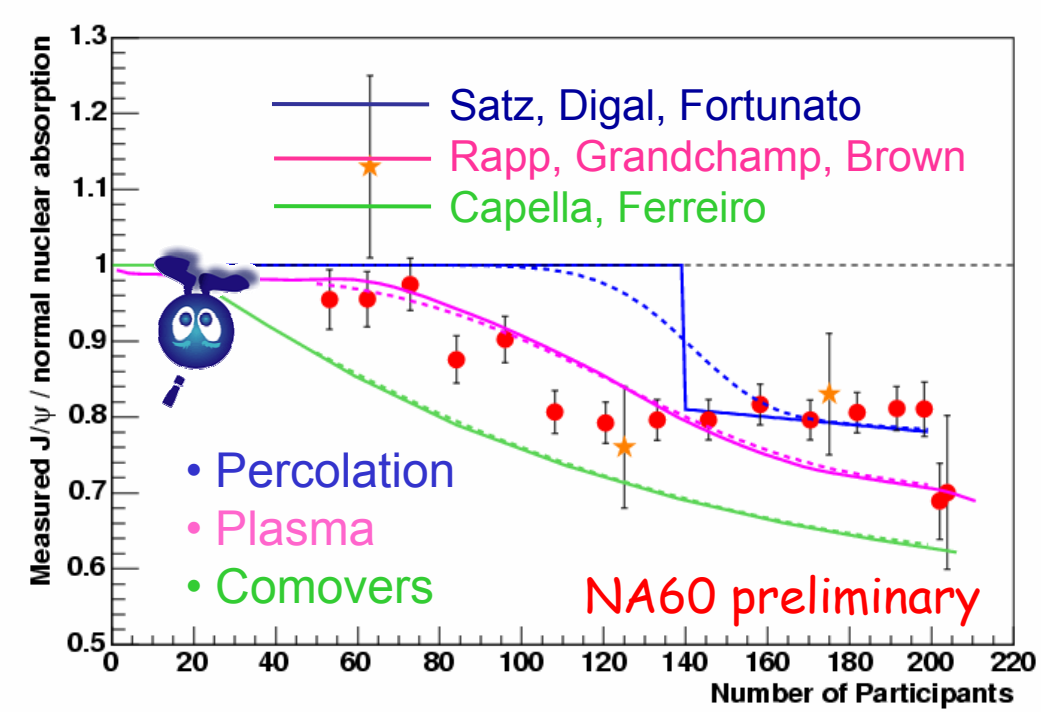
***as of March 2005**

Back up slides

Quick look at NA60

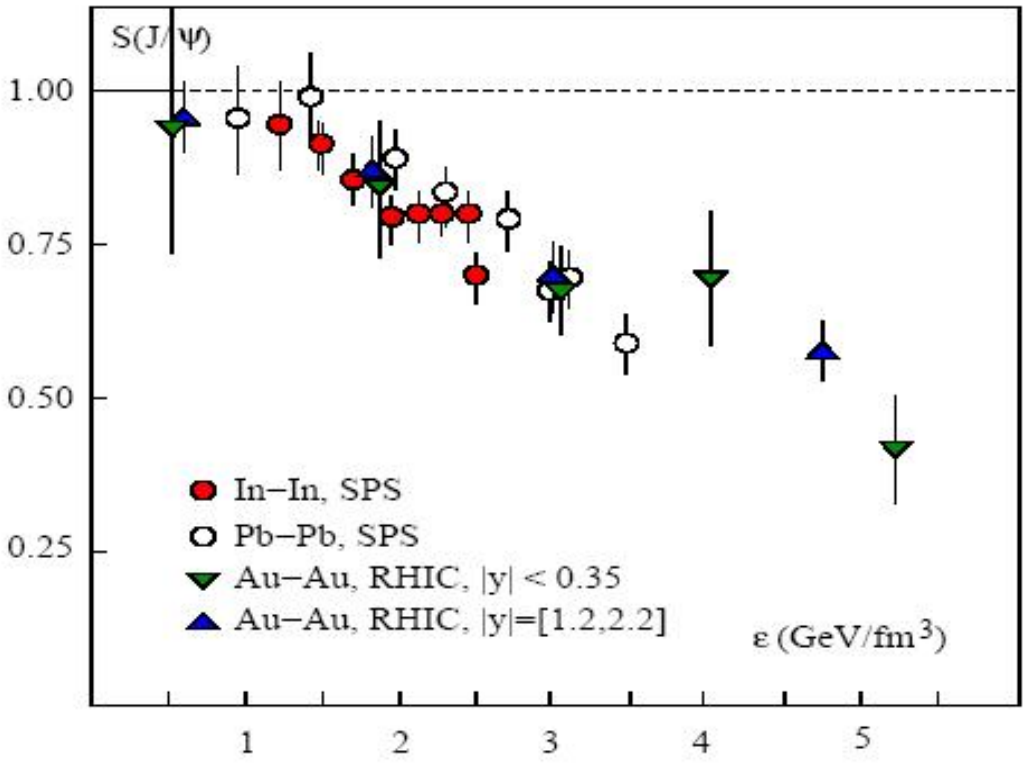
- In In-In collisions, preliminary plateau also rules out percolation, comovers and available plasma

Roberta Arnaldi, QM05



3rd Sequential melting

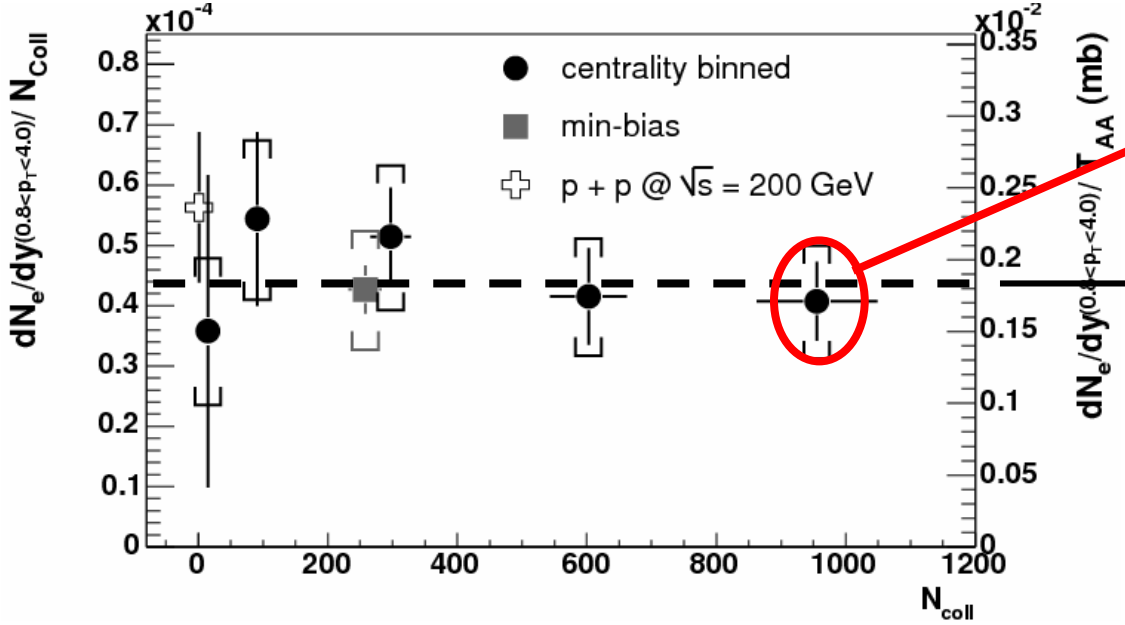
- Sequential melting
  - J/ψ survival only
- Cold nuclear matter effects derived from dAu data for RHIC
- Axis cannot be energy density since same τ^0 (1fm/c) is assume for SPS and RHIC !
  - Larger at SPS
  - Smaller at RHIC



Karsch, Kharzeev & Satz hep-ph/0512239

Quick look to open charm

- Through semileptonic decays (D → e)



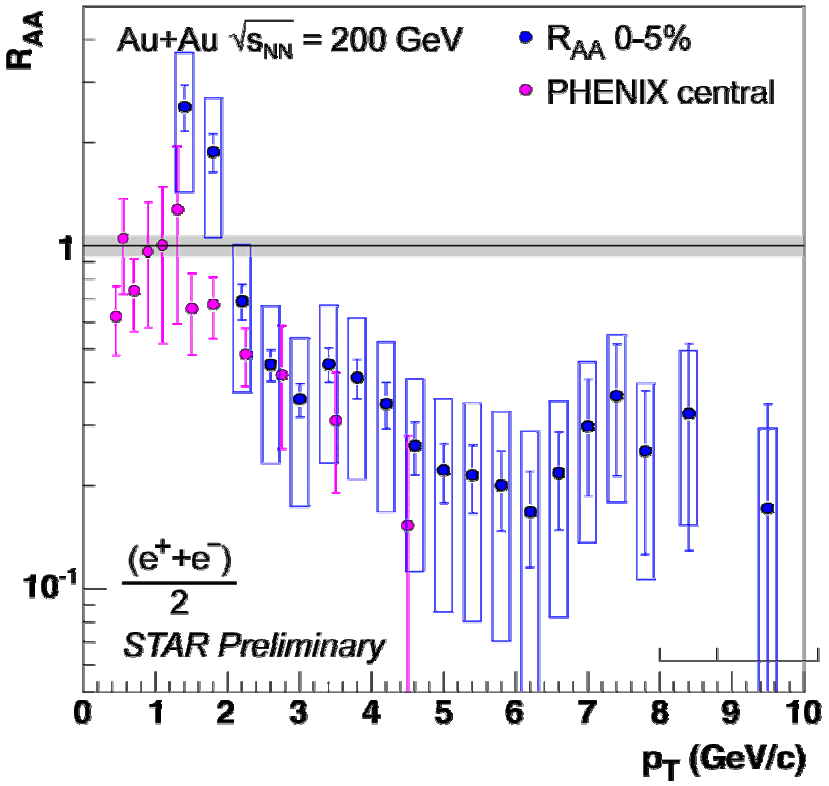
10 to 20 $c\bar{c}$ pairs !
(→ 40 acc. STAR)

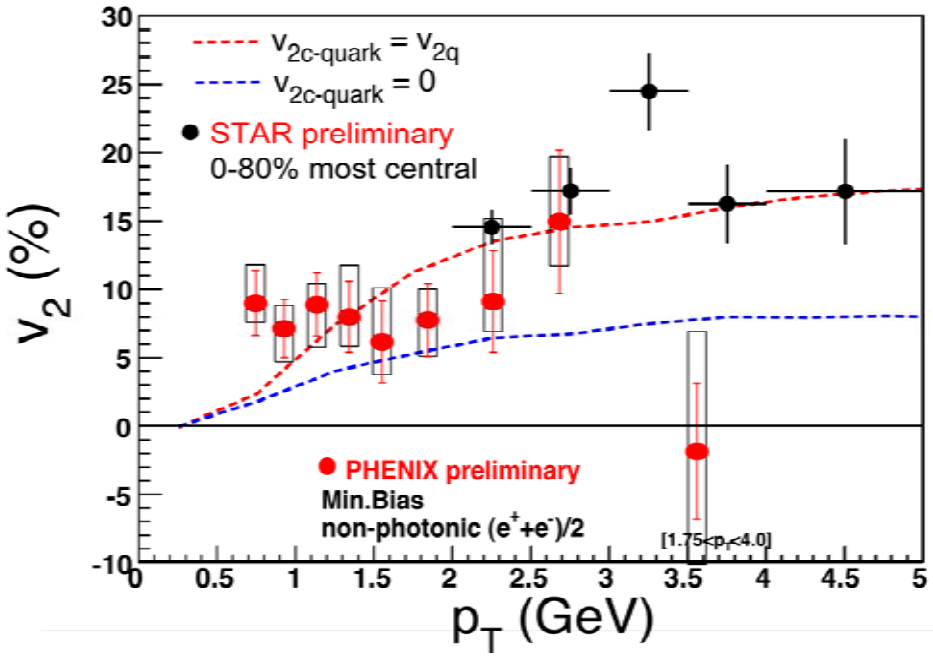
N_{coll} scaling

PHENIX, PRL94 (2005) 082301

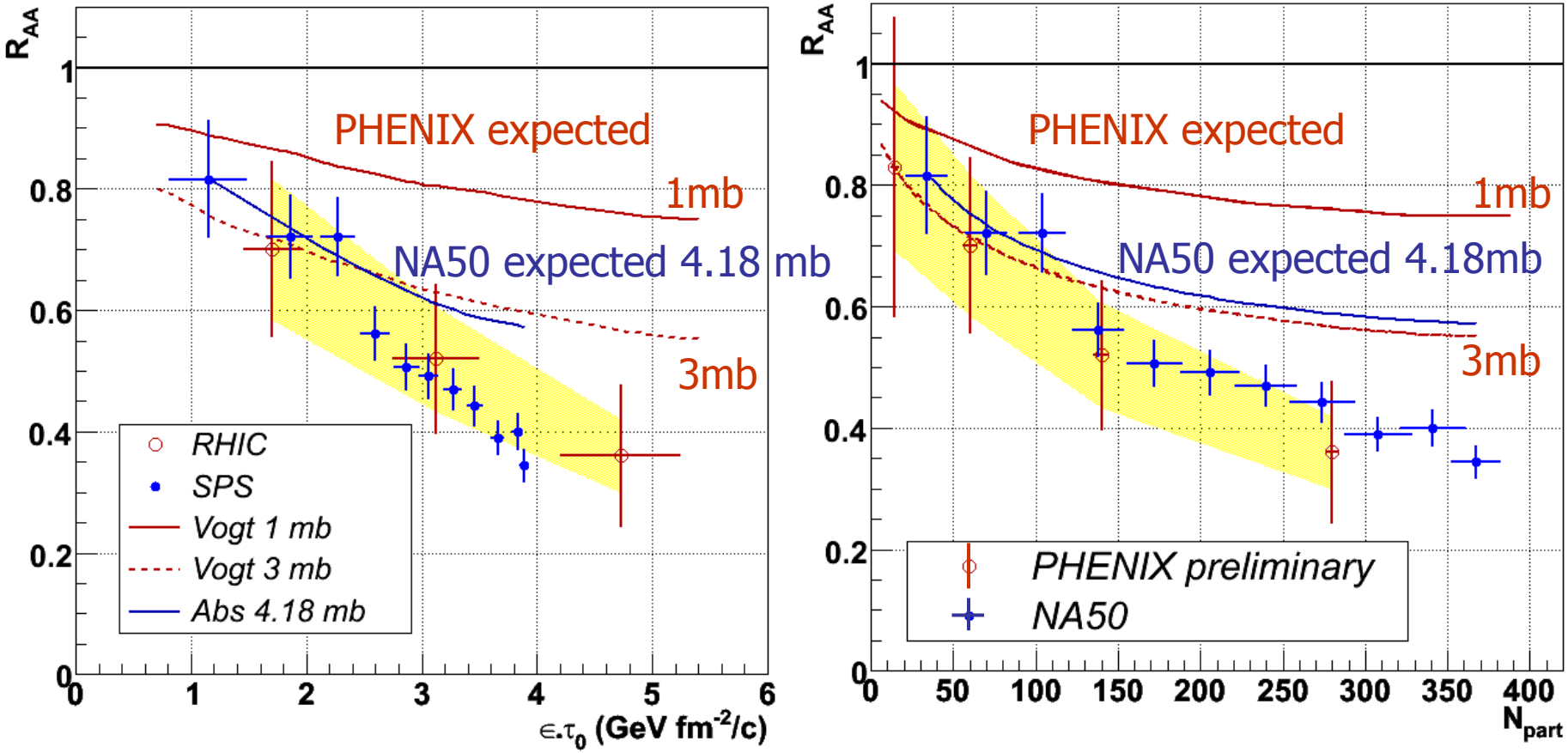
~25% systematic uncertainties (without Silicon vertex detector upgrade)

Charm quench & flow



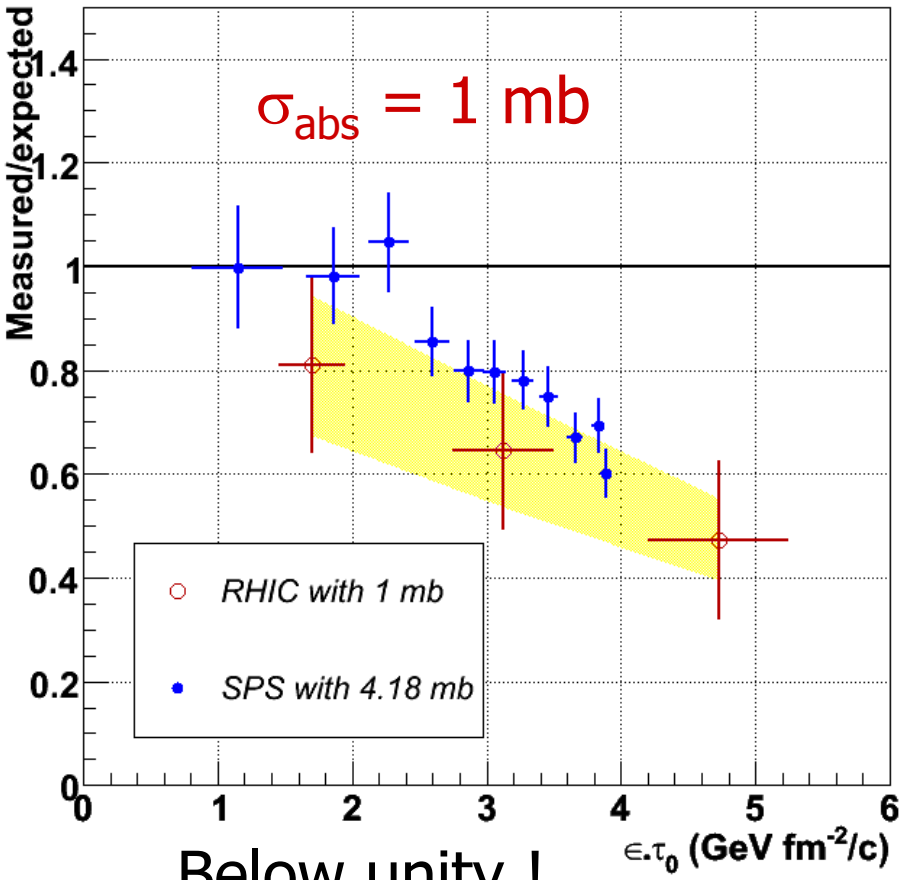


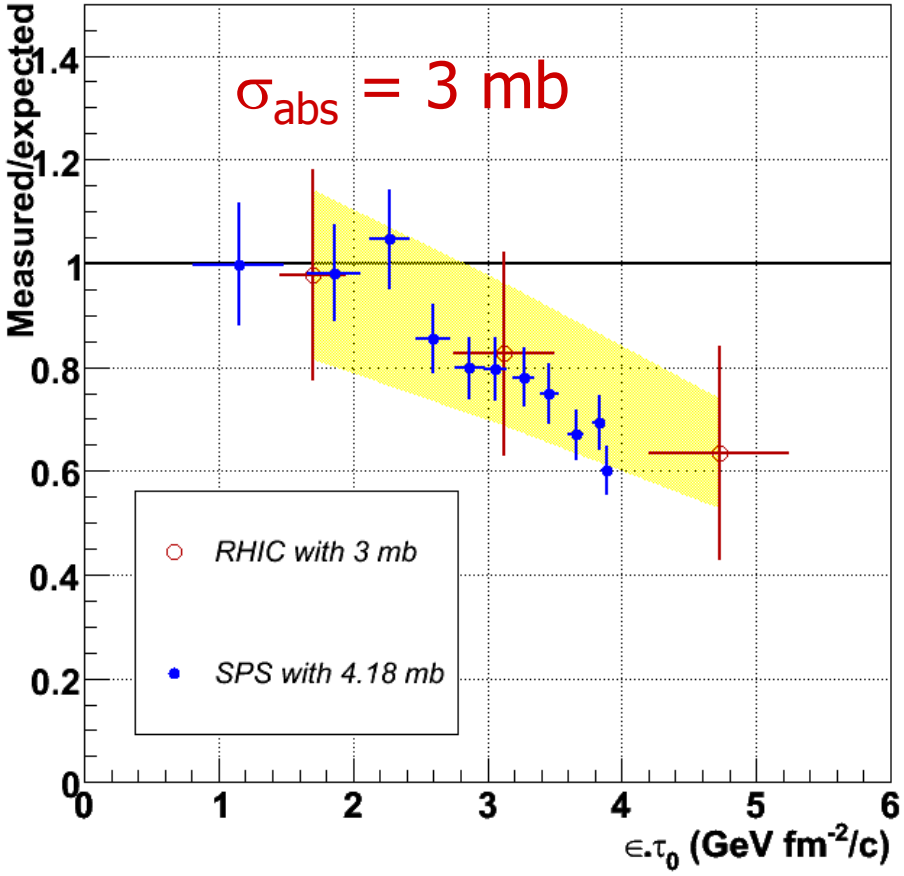
Na50/Phenix comparisons



Consistent suppression amplitude observed
but cold nuclear effects may be different

measured/expected vs ε_{Bj} ($\times \tau_0$) !

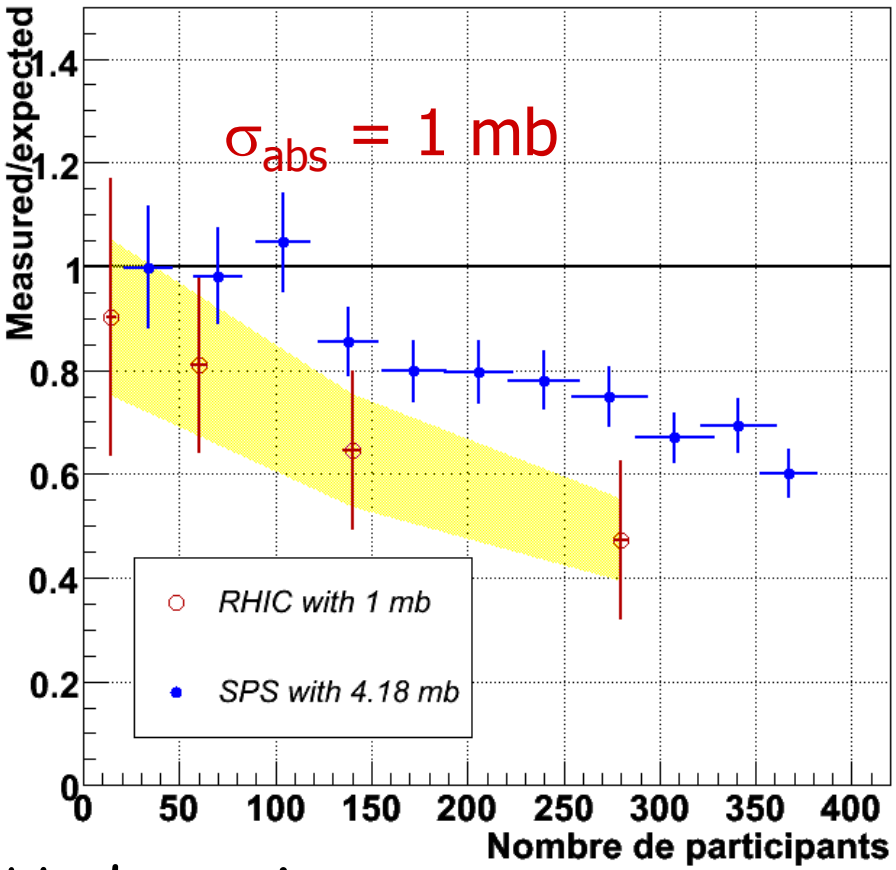


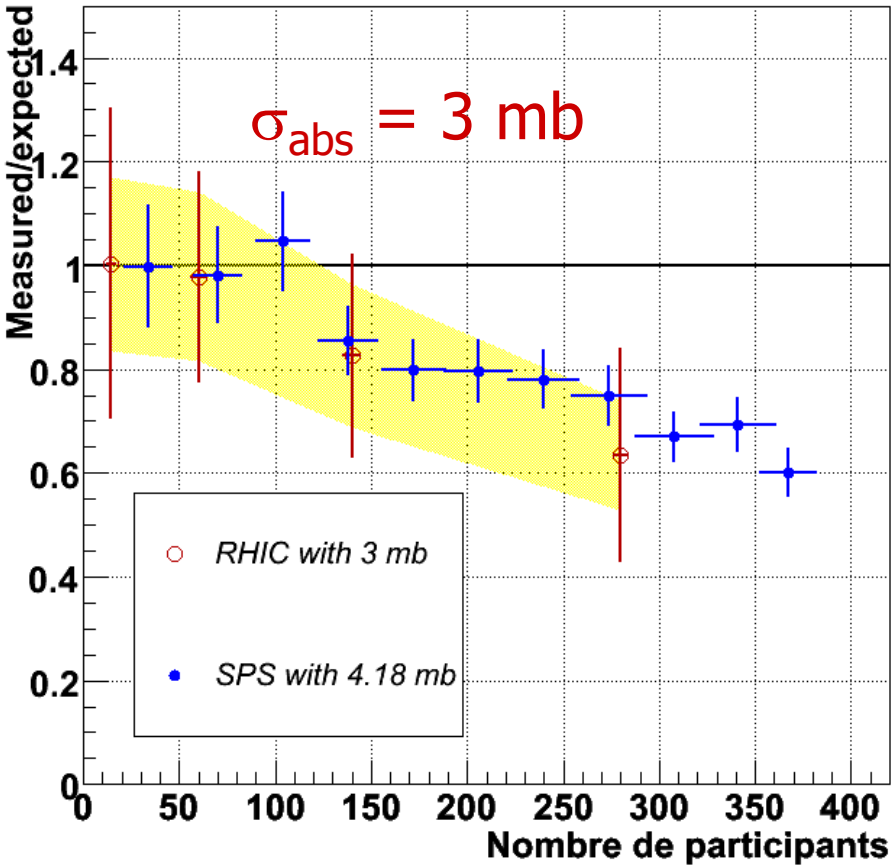


Below unity !

Suppression amplitude consistent within error bars

measured/expected vs N_{part}

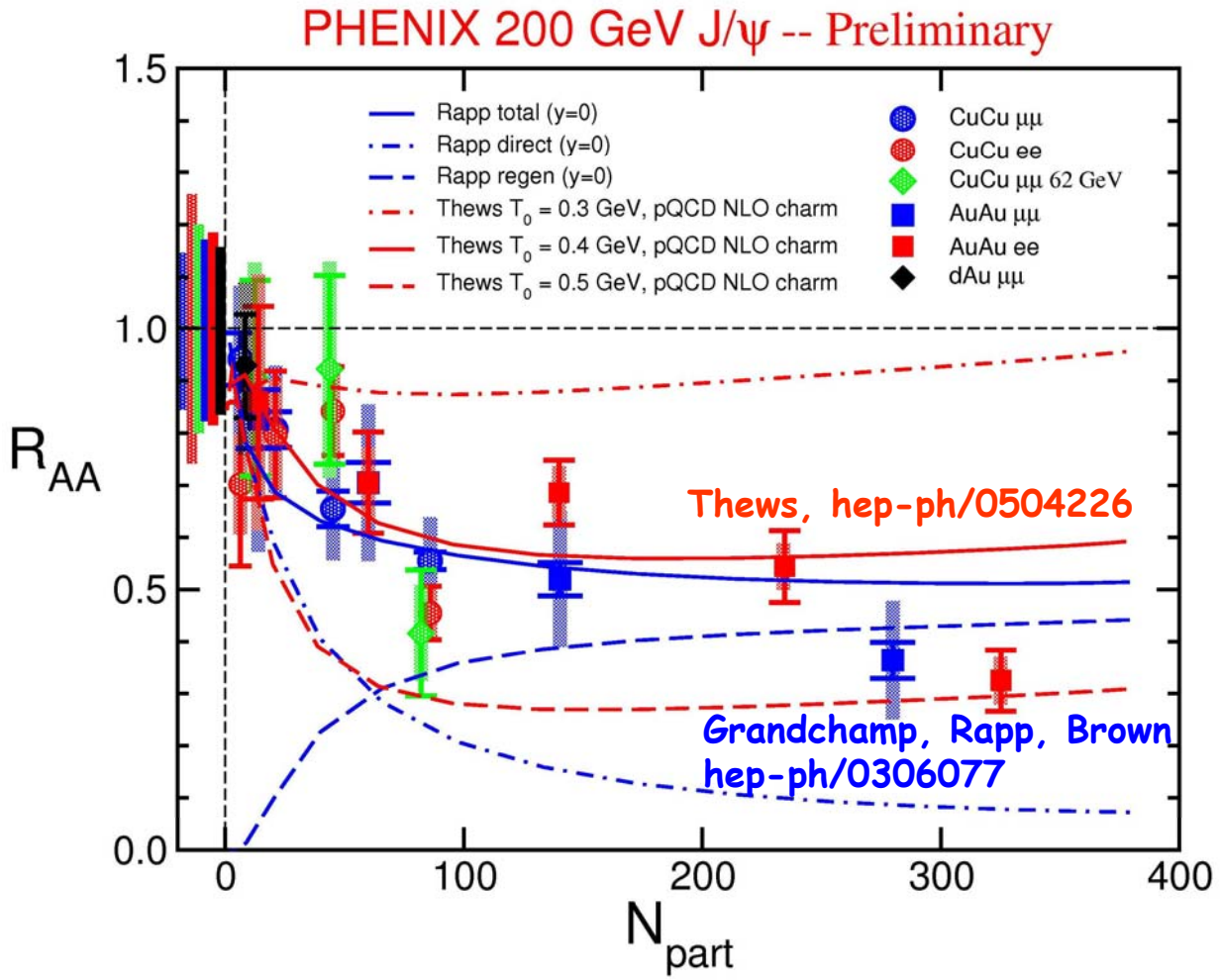




Under unity

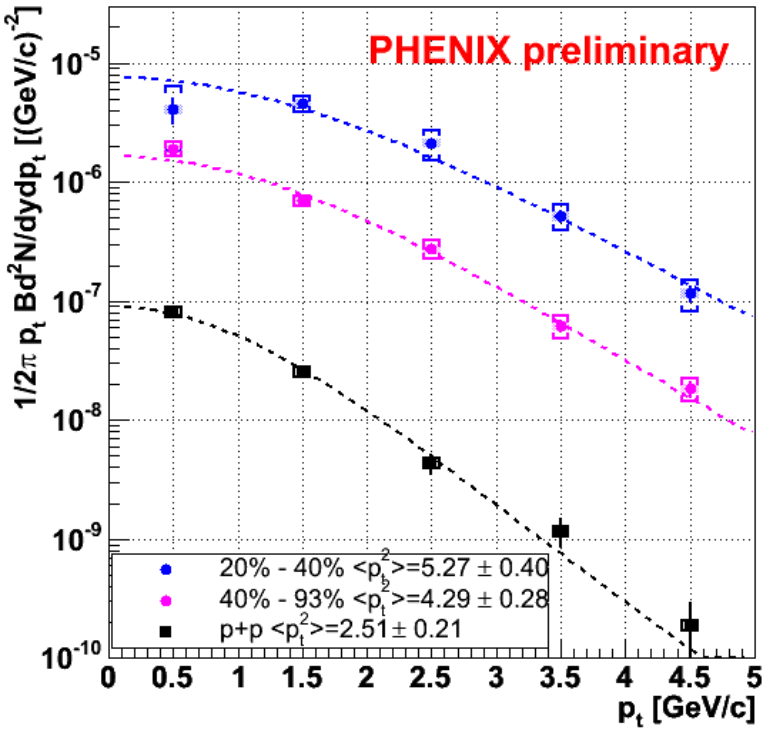
Larger difference when 1mb but compatible within error bars

recombination/suppression



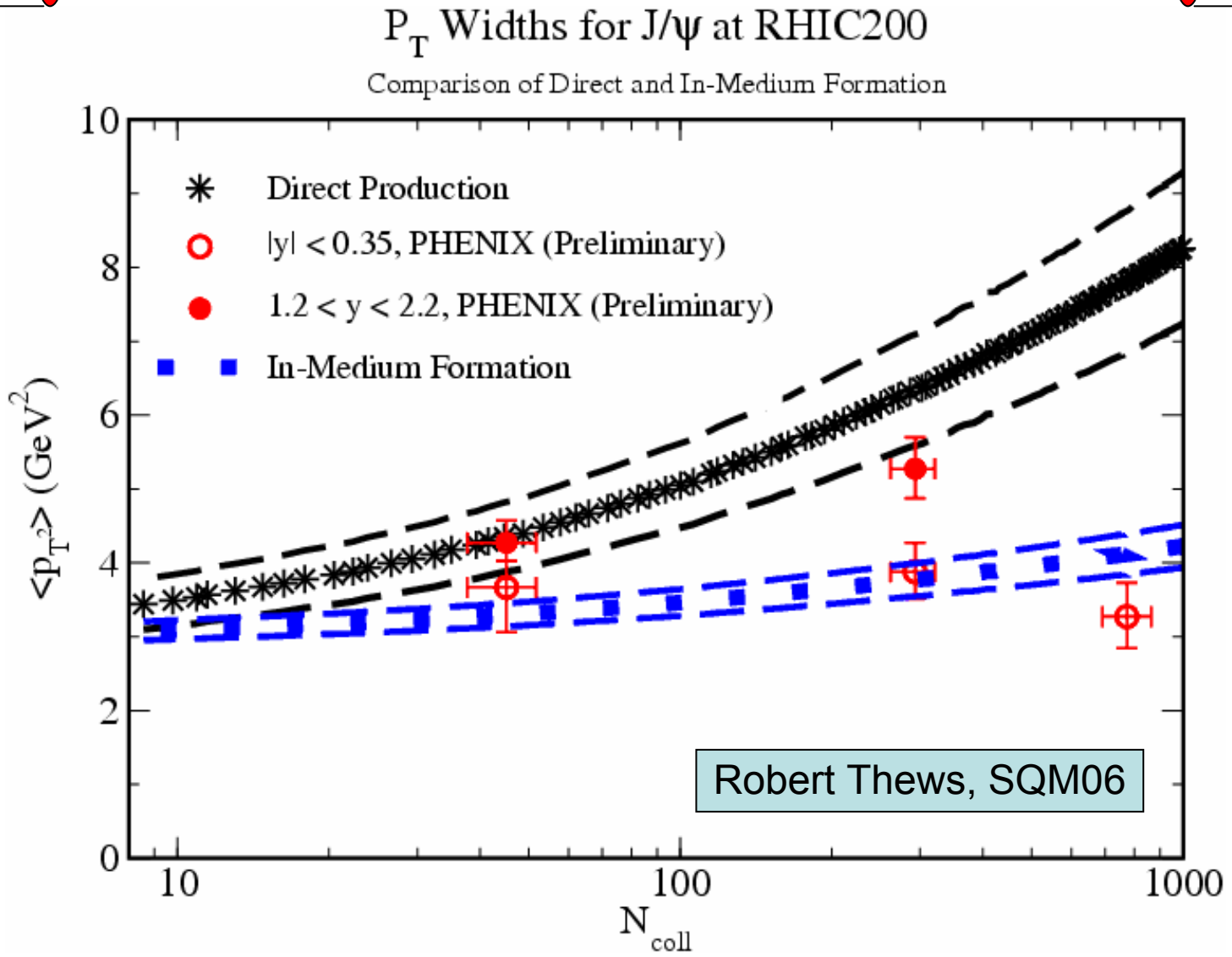
p_T spectra

Au+Au ($|y| \in [1.2,2.2]$)

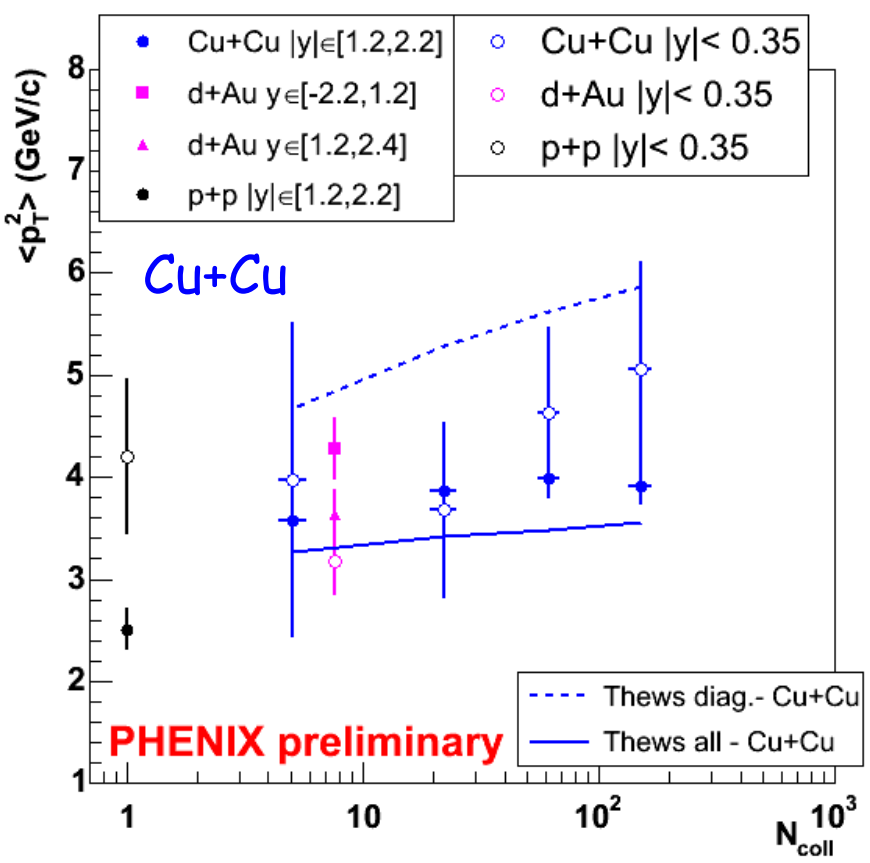


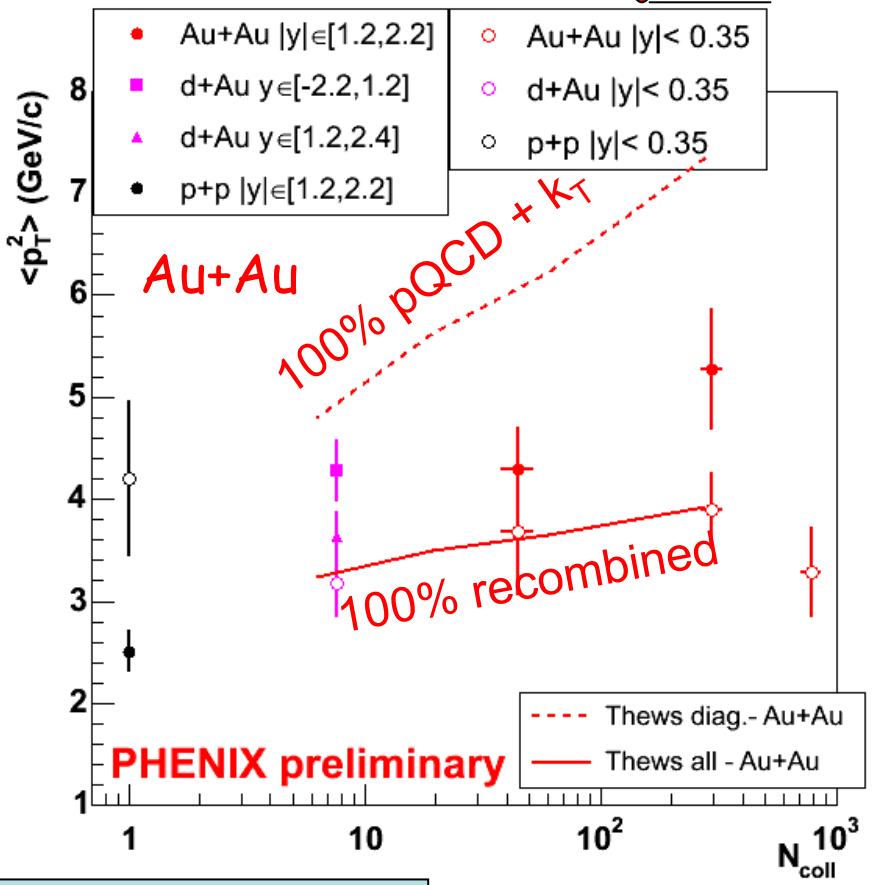
- In pp:
  - $\langle p_T^2 \rangle = 2.5\ GeV^2$
- In AuAu & CuCu:
  - $\langle p_T^2 \rangle = 3 \rightarrow 5.3\ GeV^2$

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



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



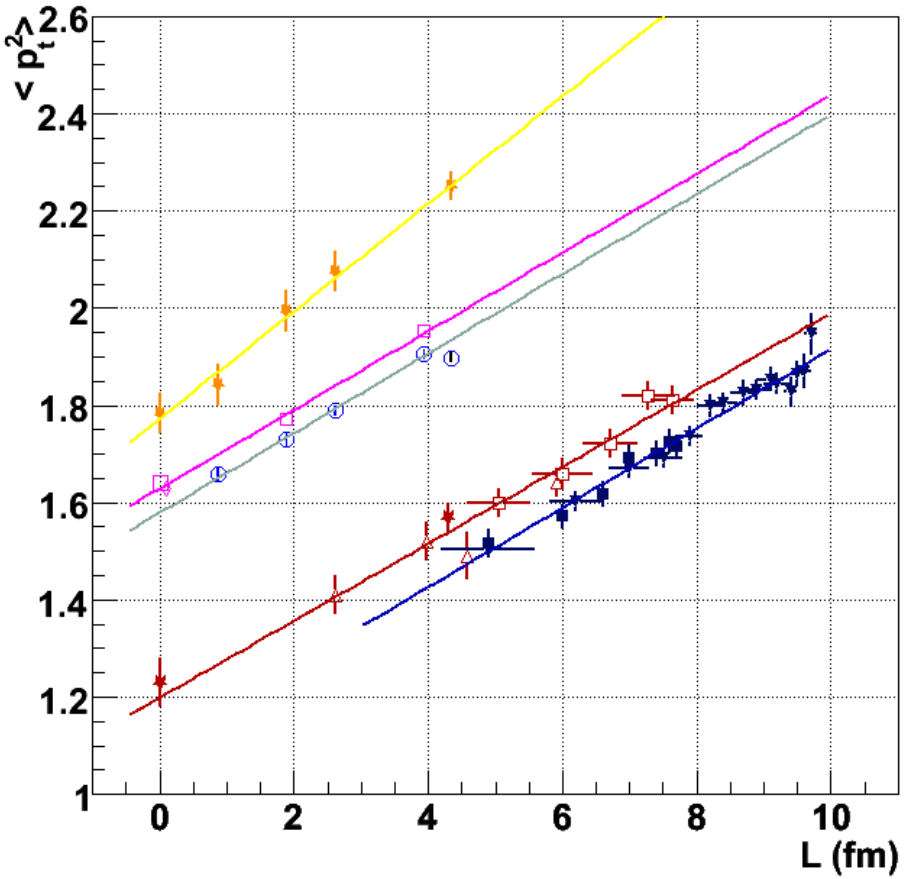


Lines from Thews & Mangano, PRC73 (2006) 014904

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

Cronin effect

Scattering of initial gluons of nucleon before ccbar formation
random walk : $\langle p_t^2 \rangle_{AA} = \langle p_t^2 \rangle_{pp} + \rho\sigma\Delta(\langle p_t^2 \rangle) L_{AA}$



$\sqrt{s}$ =17.3 GeV : NA50/60 Pb+Pb, In+In

$\sqrt{s}$ = 19.4 GeV : NA3 p+p, NA38 p+Cu, p+U,O+U, S+U

$\sqrt{s}$ = 27.4 GeV : NA50 p+Be, p+Al, p+Cu, p+W

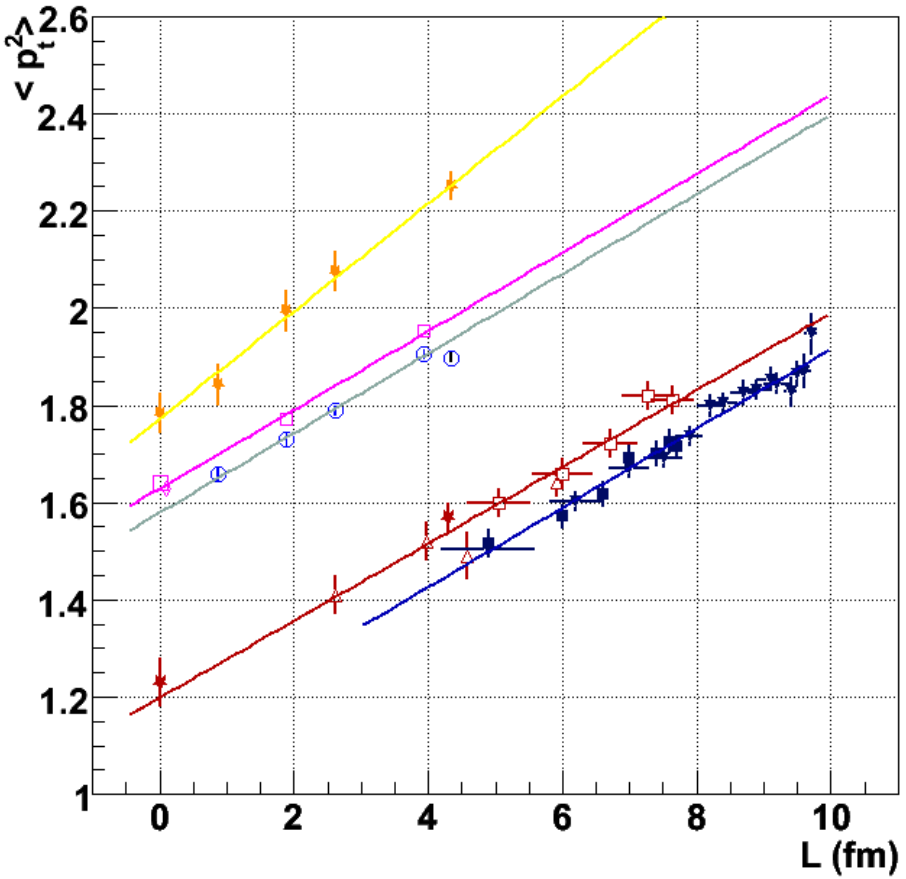
$\sqrt{s}$ = 29.1 GeV :NA51 p+p, p+d, NA50 p+Al, p+W

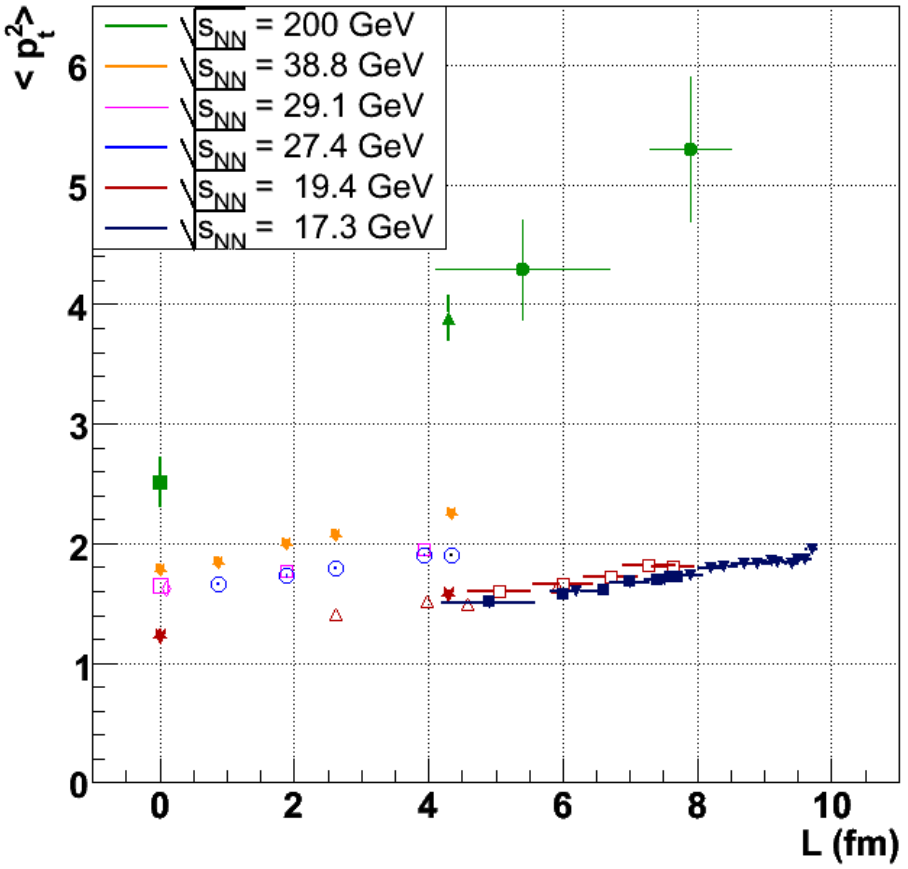
$\sqrt{s}$ = 38.8 GeV : E866/789/771

ρ nuclear density, σ elastic gluon-nucleon scattering cross section, $\Delta(\langle p_t^2 \rangle)$ kick given by each scattering and L average thickness of nuclear matter

Cronin effect

Cronin : $\langle p_t^2 \rangle_{AA} = \langle p_t^2 \rangle_{pp} + \rho\sigma\Delta(\langle p_t^2 \rangle) L_{AA}$





Extrapolation curve from PHENIX J/ψ results in p+p and d+Au

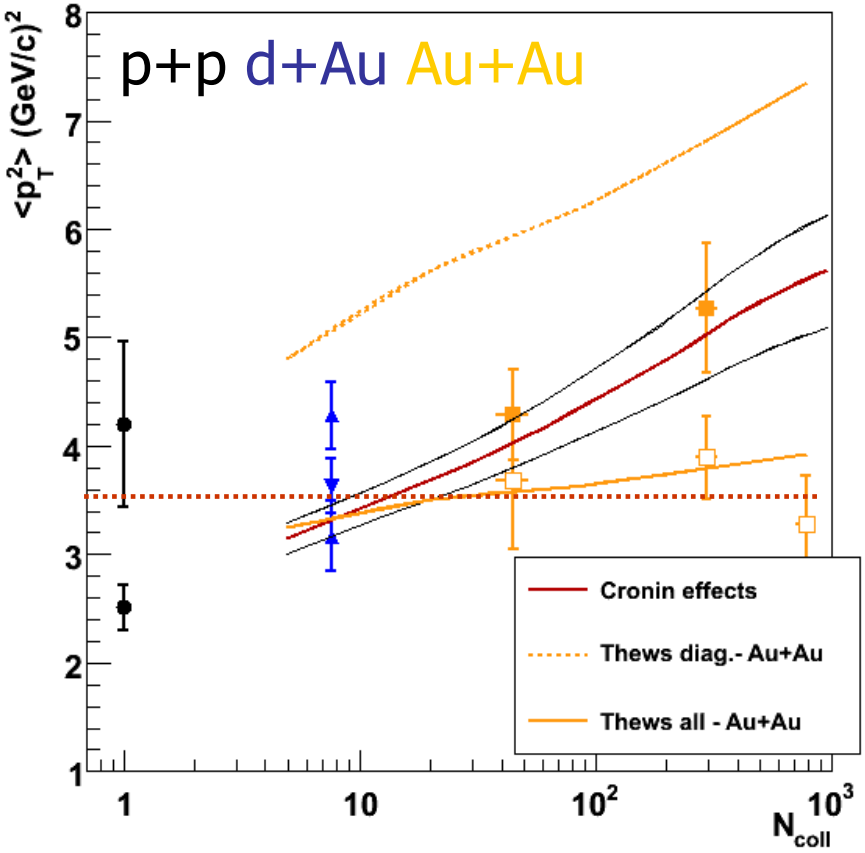
Cronin effect

Cronin : $\langle p_t^2 \rangle_{AA} = \langle p_t^2 \rangle_{pp} + \rho\sigma\Delta(\langle p_t^2 \rangle) L_{AA}$

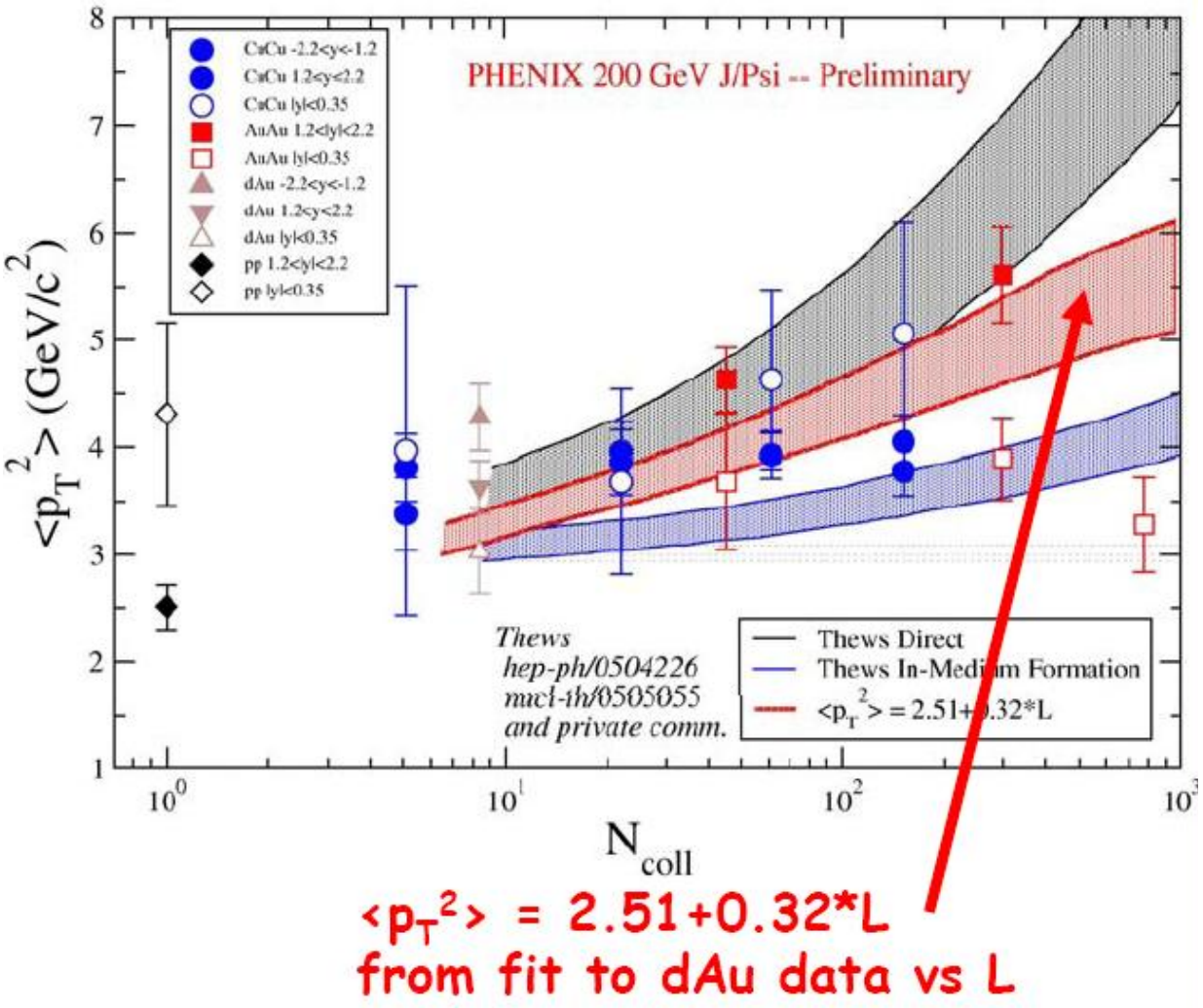
Extrapolation curve from PHENIX J/ψ results in p+p and d+Au

At forward rapidity, $\langle p_t^2 \rangle$ variation compatible with this Cronin extrapolation

At mid rapidity, measurements in p+p and d+Au indicate a weak Cronin effect



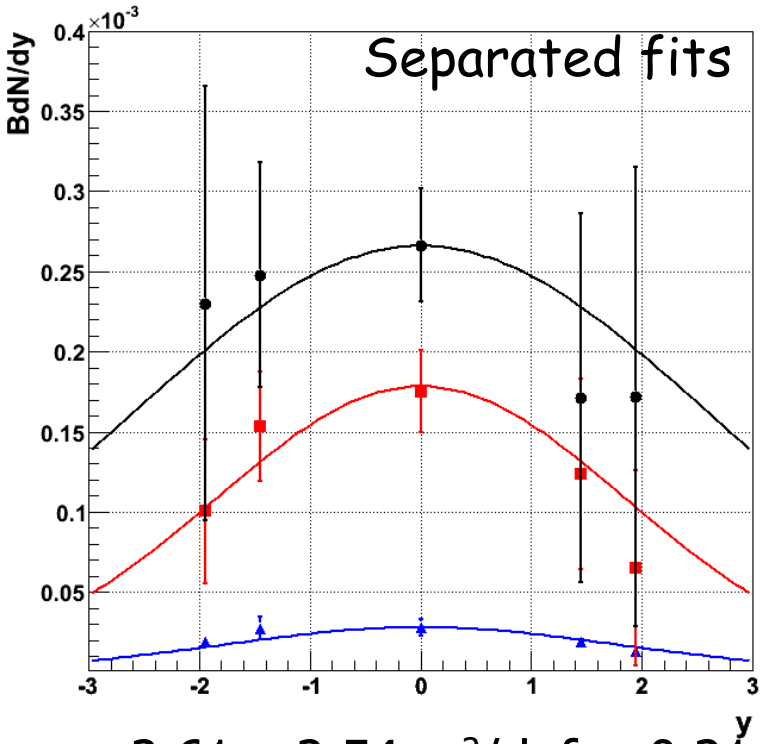
A busy plot about $\langle p_T^2 \rangle$

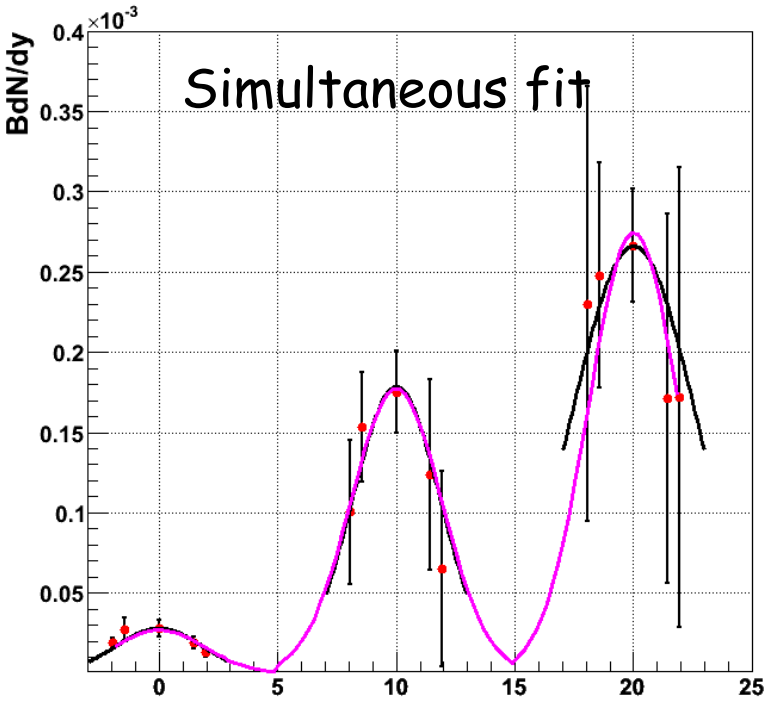


$\langle p_T^2 \rangle = 2.51 + 0.32 * L$
from fit to dAu data vs L

(curves to be compared with AA @ $1.2<|y|<2.2$)

Rapidity width





$\sigma = 2.61 \pm 2.54$ $\chi^2/dof = 0.21$

$\sigma = 1.85 \pm 0.53$ $\chi^2/dof = 0.41$

$\sigma = 1.82 \pm 1.00$ $\chi^2/dof = 1.39$

Width = 1.90 ± 0.32

$\chi^2/ndl = 0.55$

Width pp = 1.75 ± 0.21

No noticeable change in rapidity width

VN 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+Ψ → cc
- 40% feeddown
- No in-medium mod
- No absorption @RHIC (here)

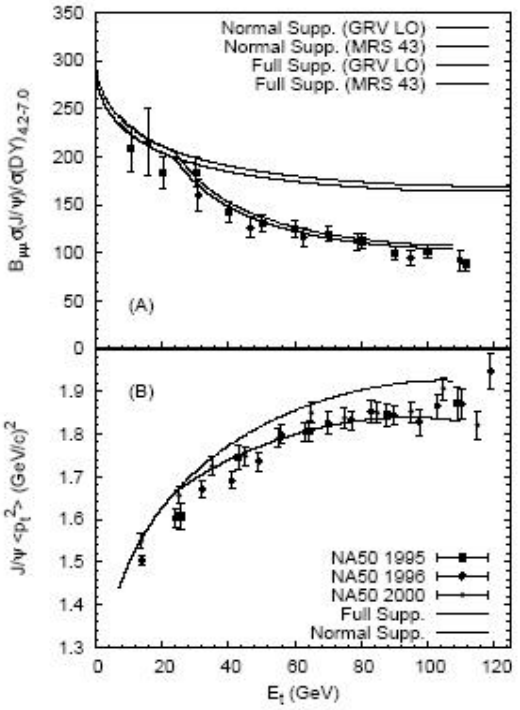


FIG. 1: The J/ψ suppression and $\langle p_t^2 \rangle$ as functions of centrality at SPS energy.

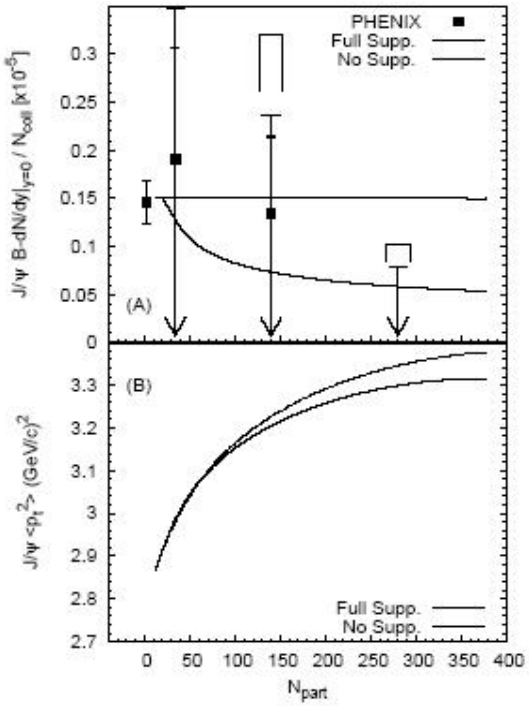
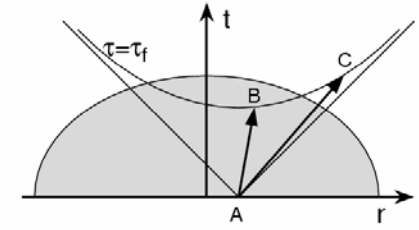
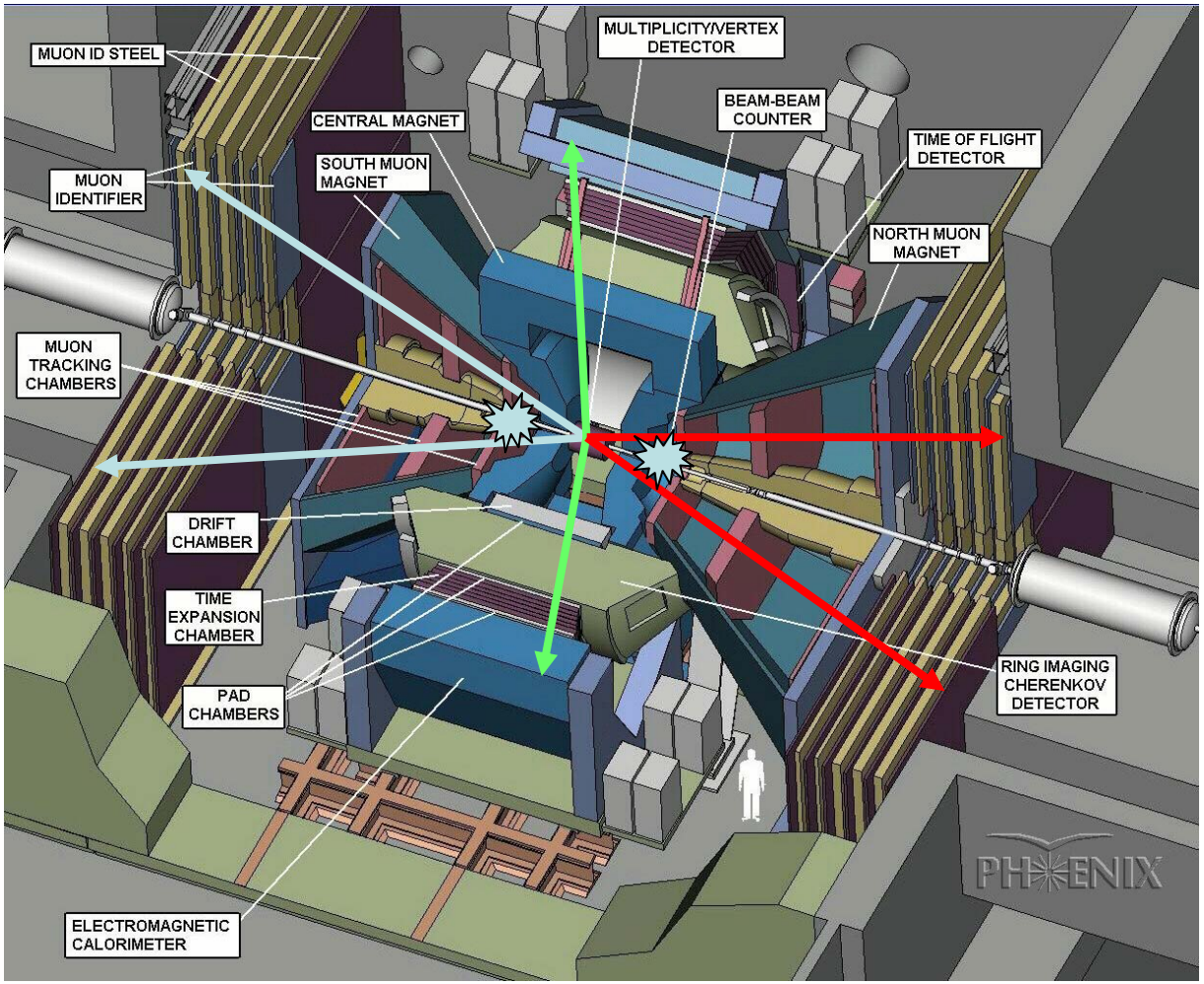


FIG. 2: The J/ψ suppression and $\langle p_t^2 \rangle$ as functions of centrality at RHIC energy.



Zhu, Zhuang, Xu, PLB607 (2005) 107

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

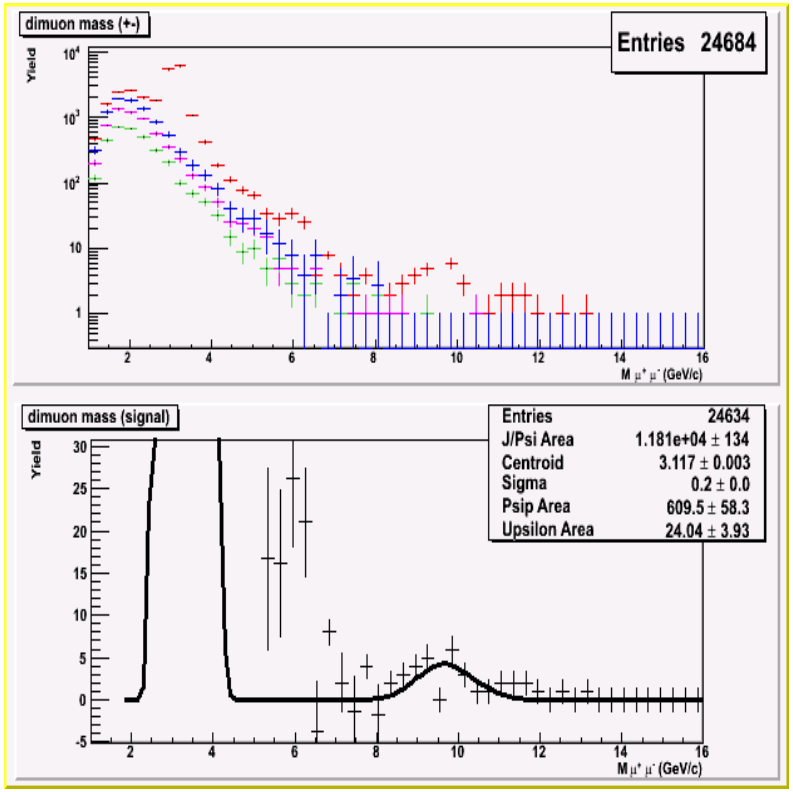
Centrality and vertex given by BBC in $3<|\eta|<3.9$ and ZDC

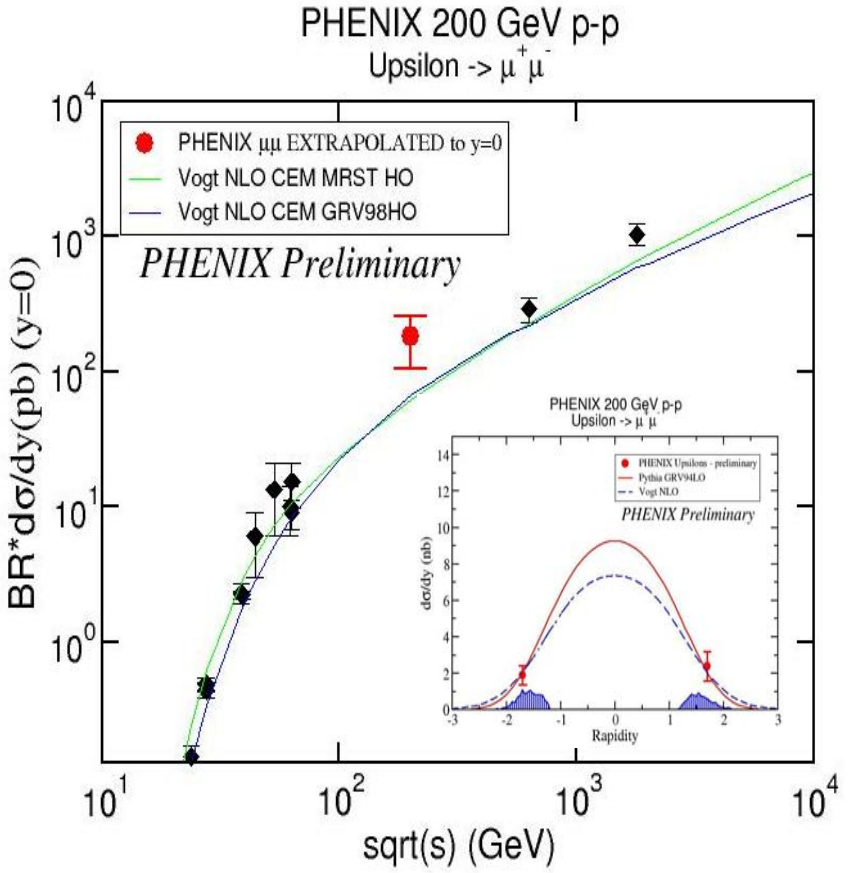
J/ψ in PHENIX

[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…	??

First upsilons…



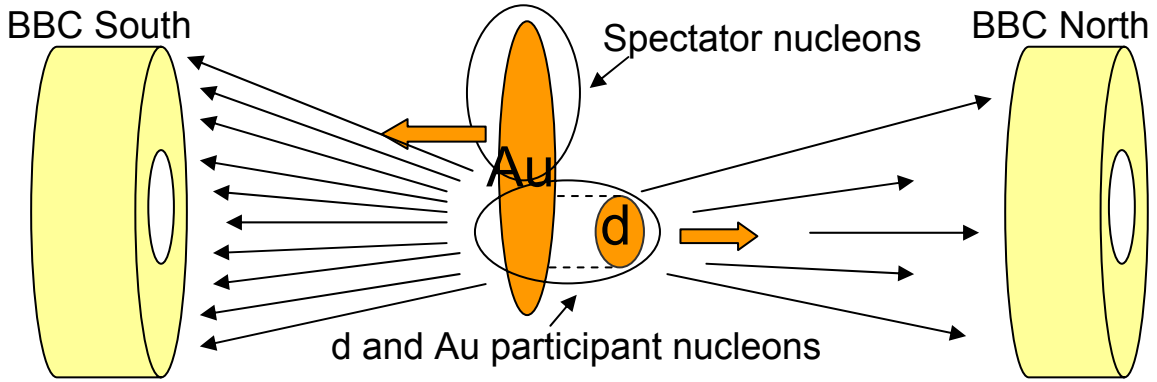


- Run 5 pp (3 pb^{-1})

Hie Wei, Quark Matter 2005

Centrality analysis

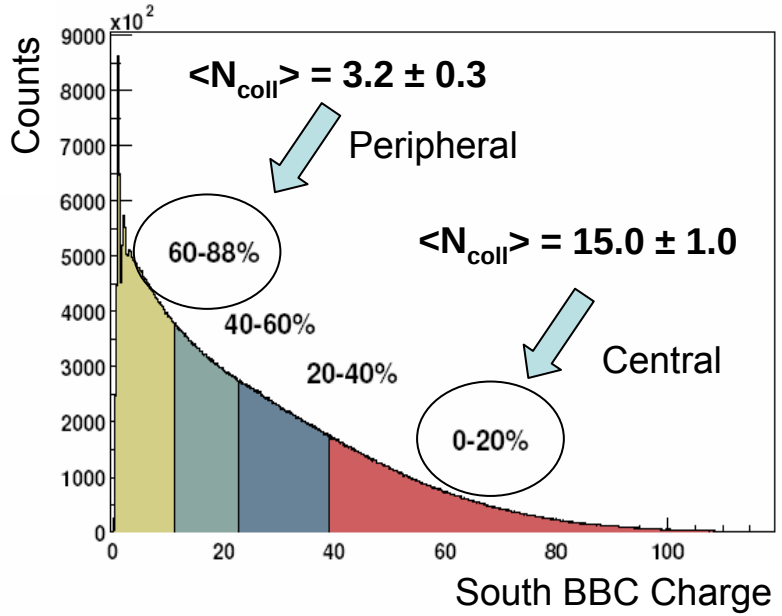
Au breaks up in our south beam counter



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

through Glauber computation

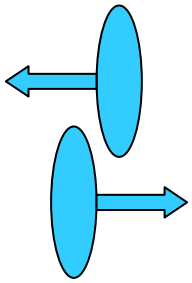
- $\langle N_{coll}^{MB} \rangle = 8.4 \pm 0.7$

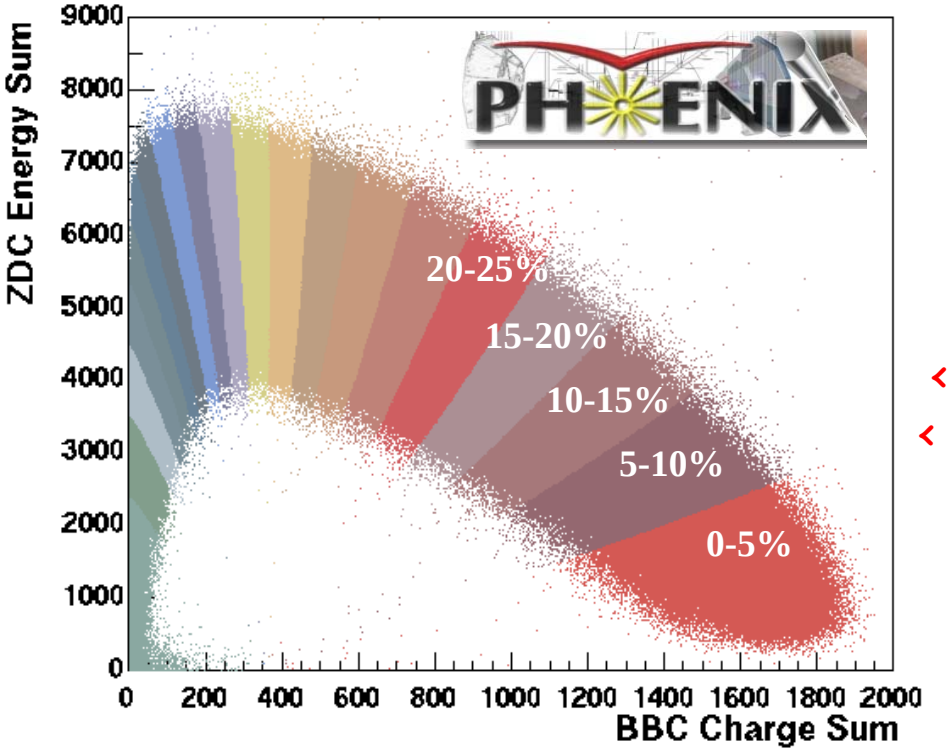


Centrality analysis

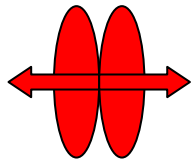
BBC charge versus ZDC energy

Most peripheral
80 – 92.2%
$\langle N_{part} \rangle = 6.3 \pm 1.2$
$\langle N_{coll} \rangle = 4.9 \pm 1.2$

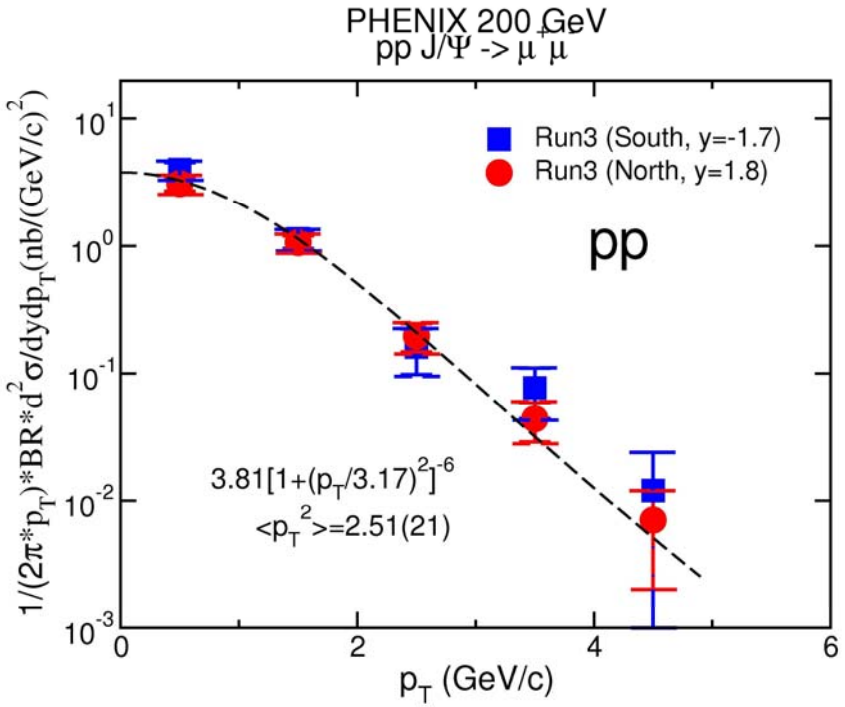


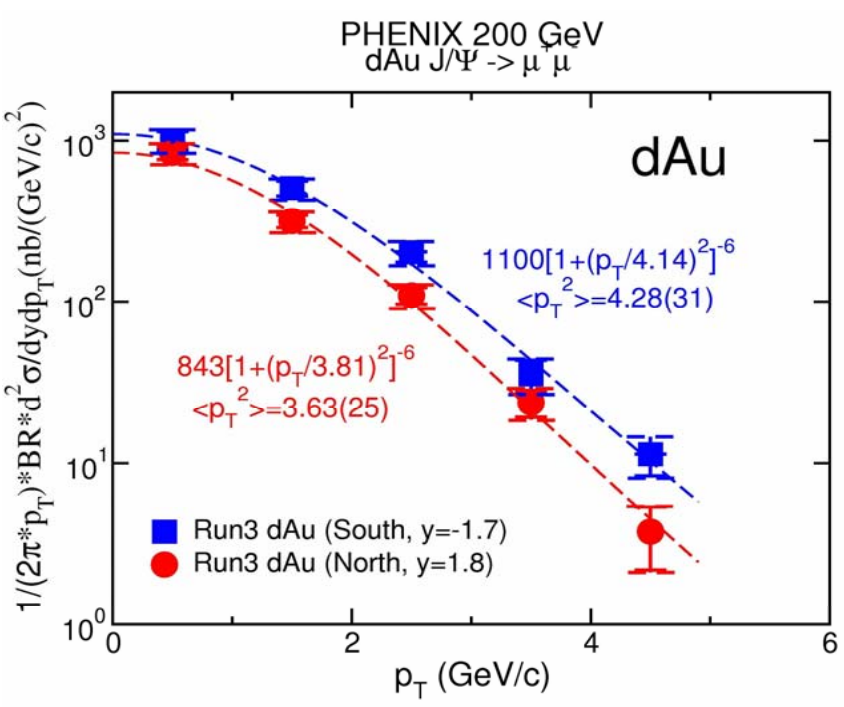


Most central
0 - 5 %
$\langle N_{part} \rangle = 351 \pm 2.9$
$\langle N_{coll} \rangle = 1065 \pm 105$



Cross section versus p_T





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

Backward: 1.77 ± 0.37 GeV ^{2}

Mid: (-1.28 ± 0.94 GeV ^{2})

Forward: 1.12 ± 0.35 GeV ^{2}

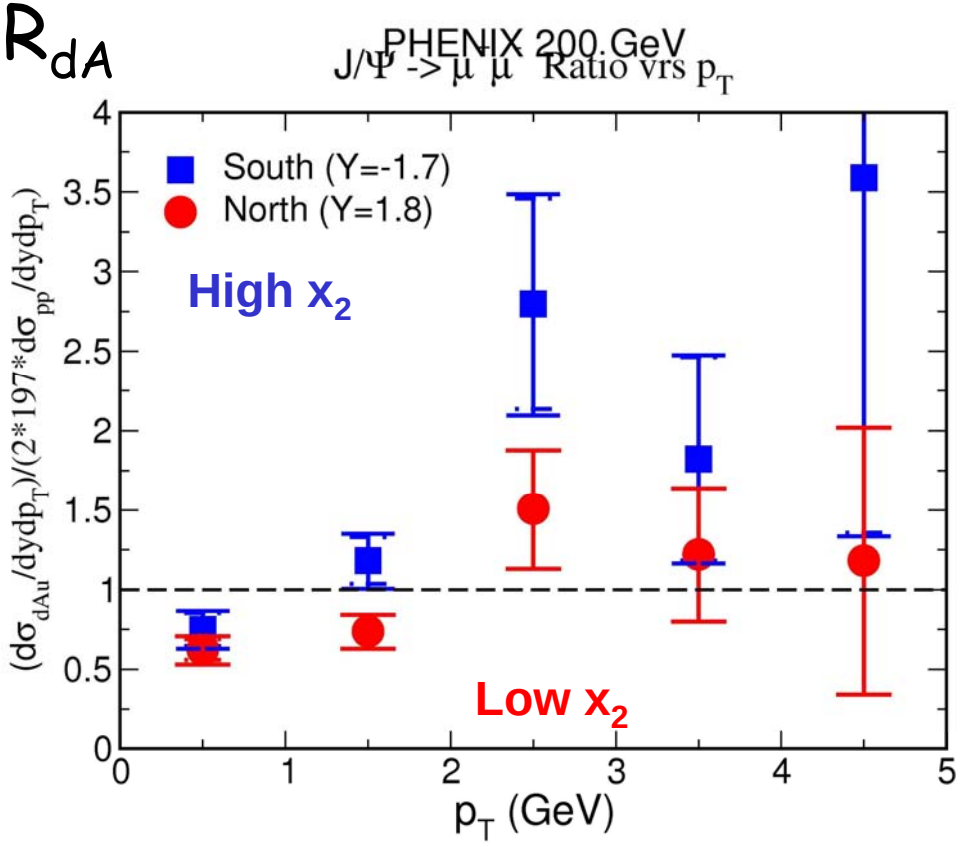
PHENIX, PRL96 (2006) 012304

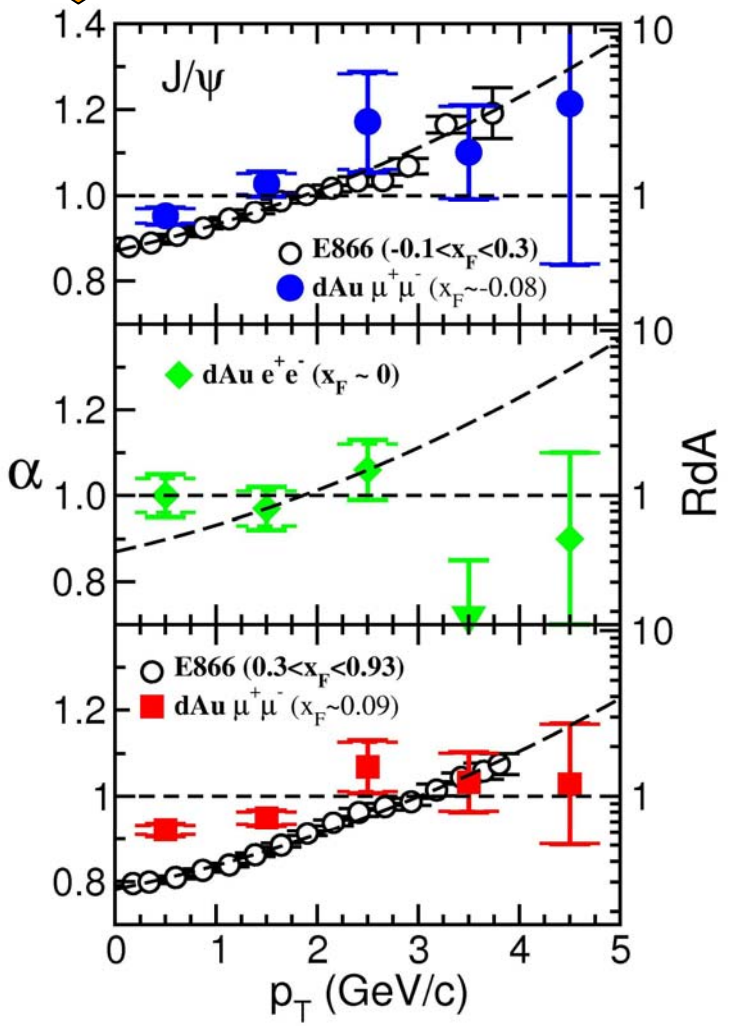
Some p_T broadening

R_{dAu} versus p_T

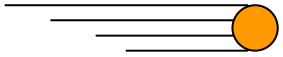
$$\sigma_{dA} = \sigma_{pp}(2\times197)^{\alpha}$$

R_{dA}

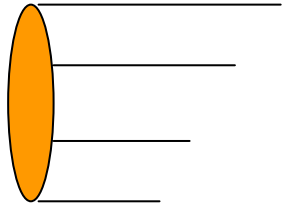




Broadening comparable to lower energy ($\sqrt{s}$ = 39 GeV in E866)



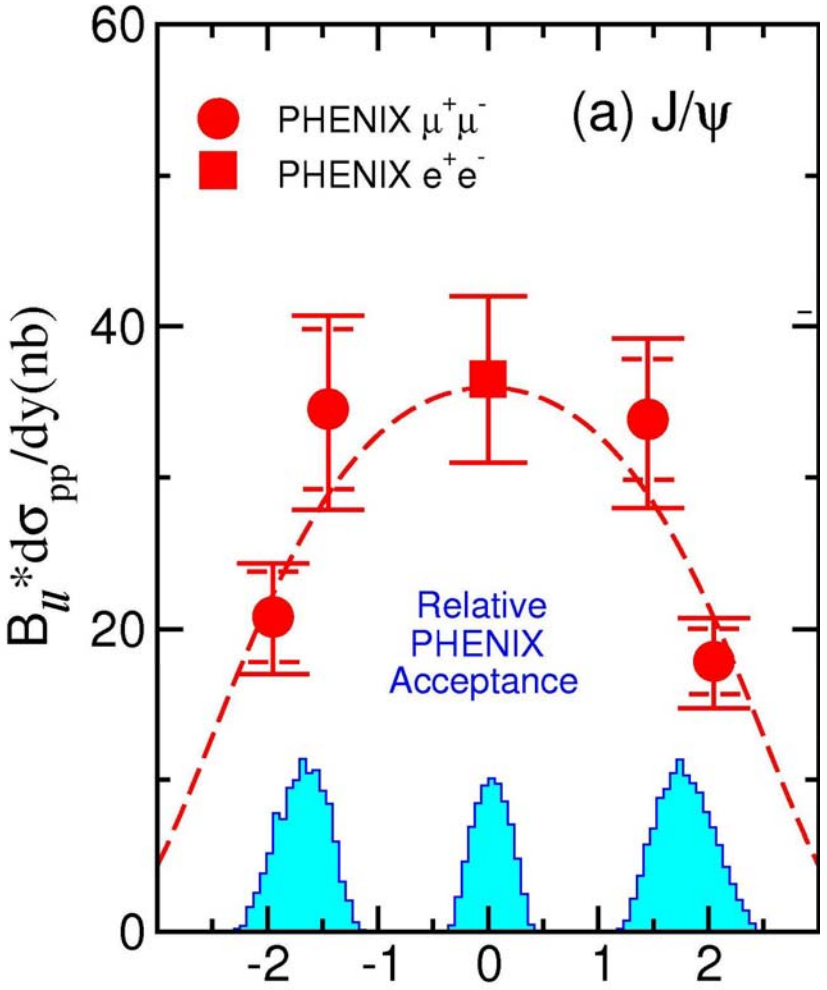
d+Au perspectives



- 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 proton-proton

Cross section vs rapidity



Total cross section

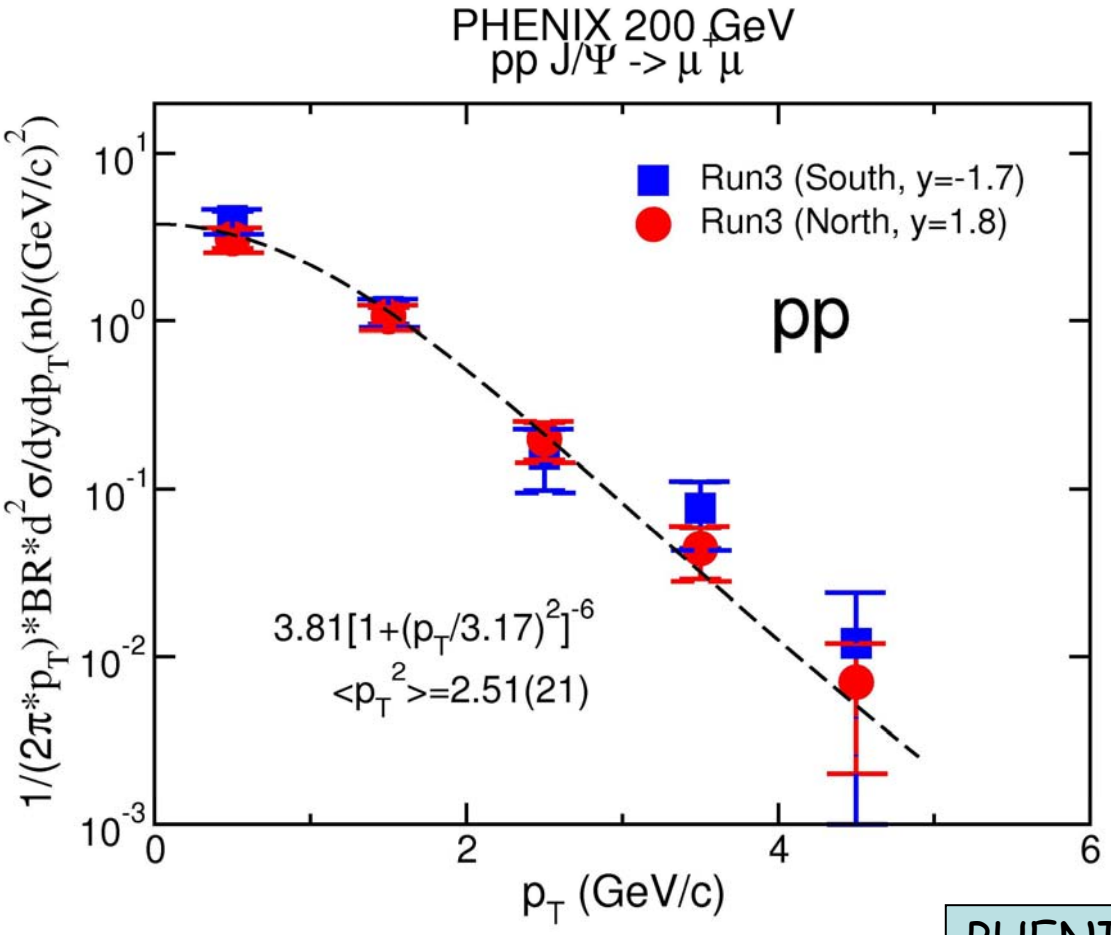
$\sigma (pp \rightarrow J/\psi)$

$2.61 \pm 0.20 \pm 0.26$ μb

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

PHENIX, PRL96 (2006) 012304

Cross section versus p_T



Fit the function

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

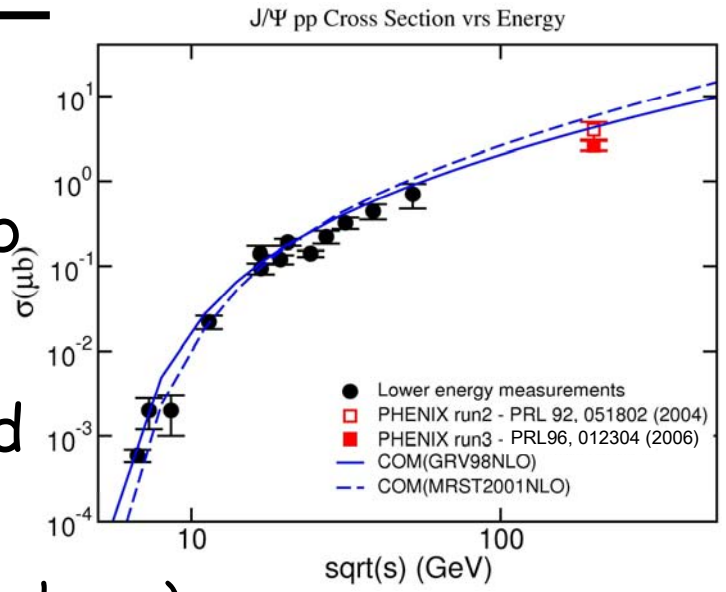
$\langle p_T^2 \rangle = 2.51 \pm 0.21$ (GeV^2)

PHENIX, PRL96 (2006) 012304

p+p perspectives

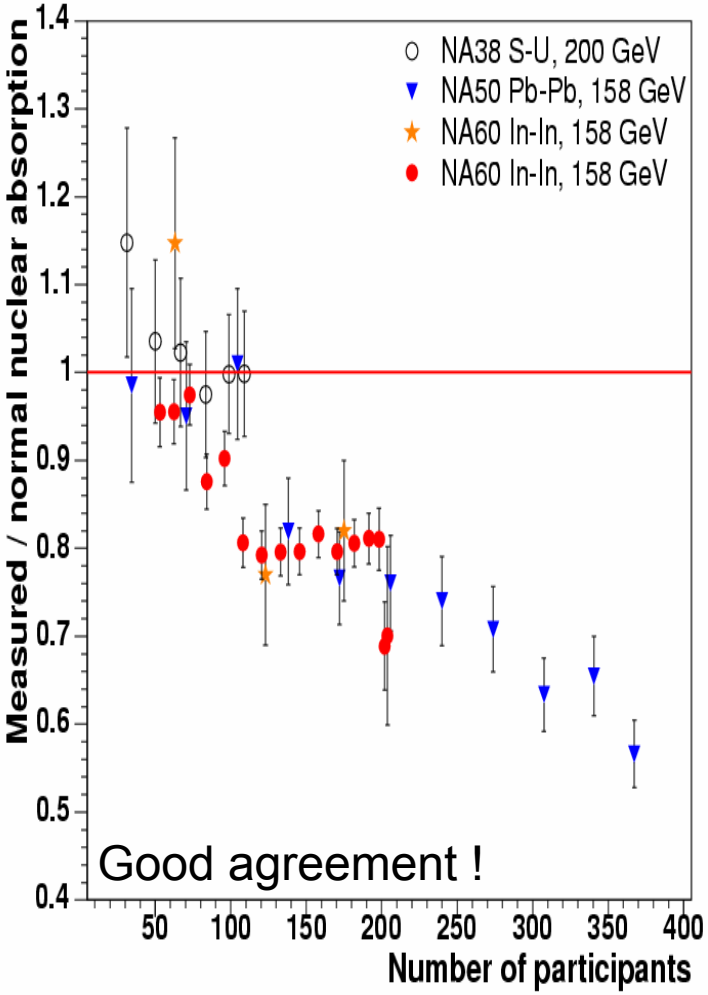
- Production mechanism
  - Color Octet Model does the job
- In AA (or dA)
  - Large combinatorial background
  - Low physics background
    - (Drell-Yan or dileptons from open charm)
- p+p is our baseline
  - Nuclear modification factor
- Run5 pp analysis going on

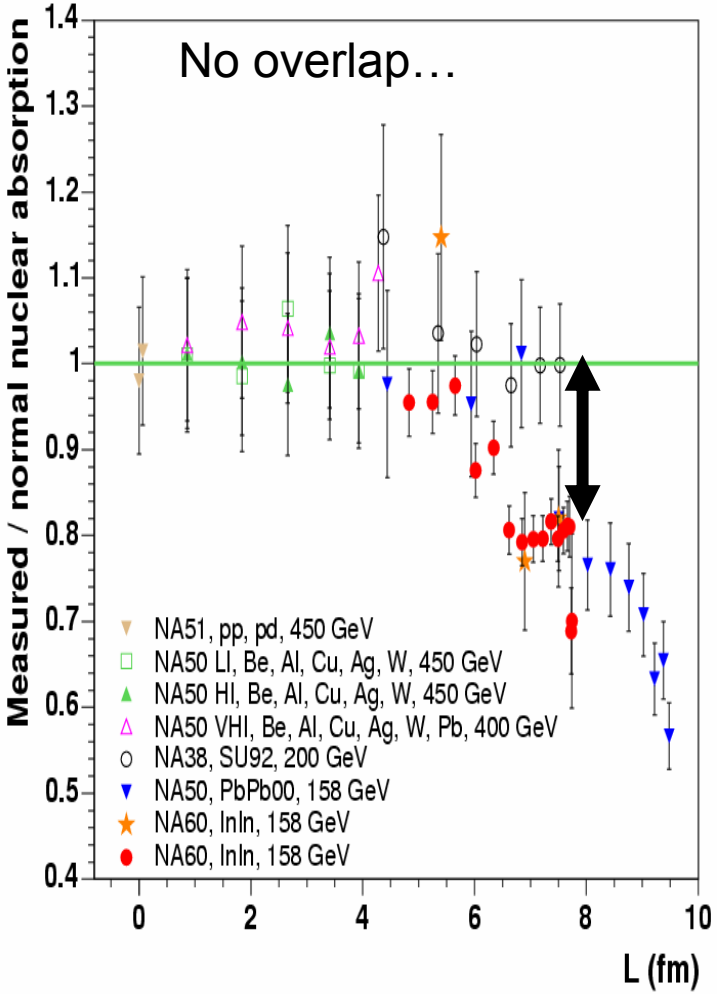
  > 10 times statistics



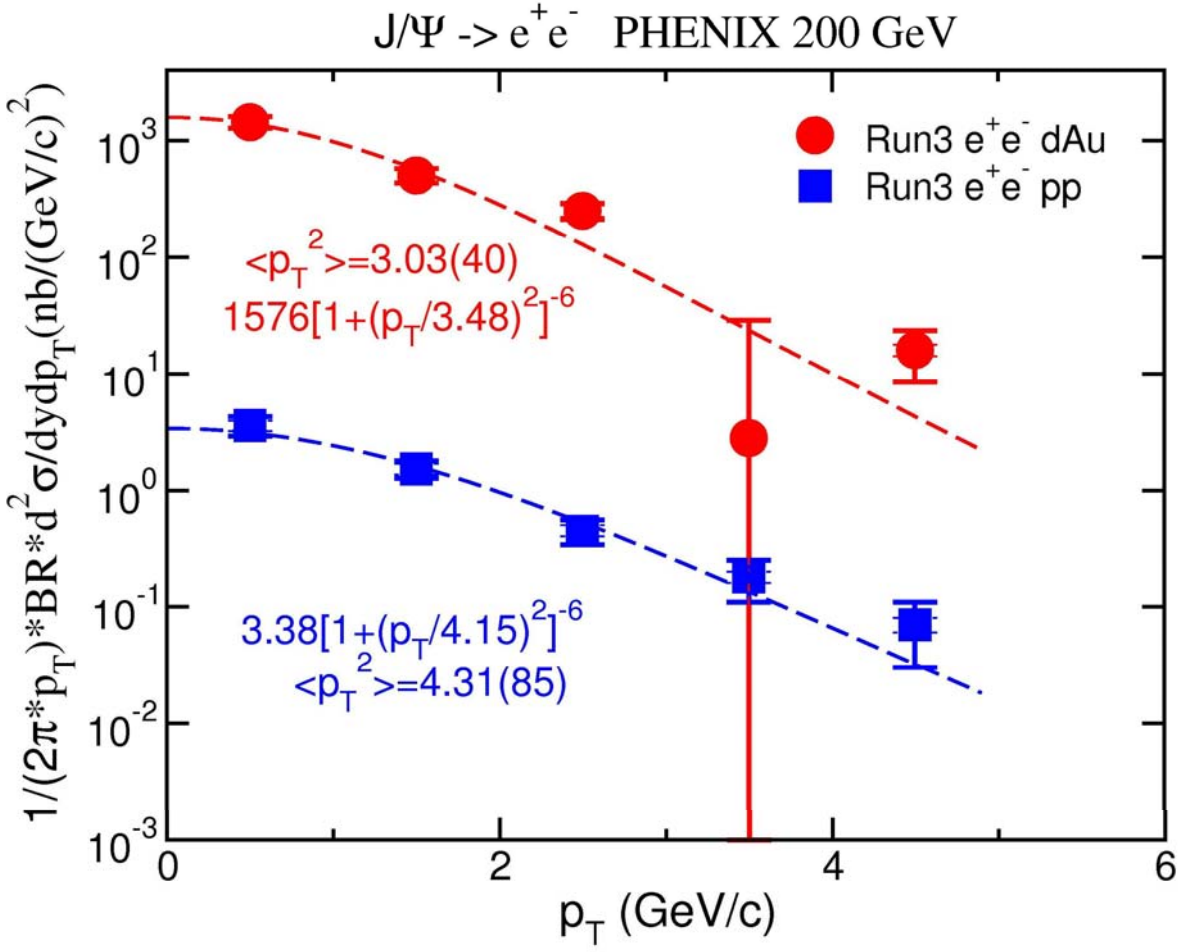
$$R_{AB} = \frac{N_{\psi}^{AB}}{N_{\psi}^{PP} \times \langle N_{coll} \rangle}$$

NA50 versus NA60 (QM05)



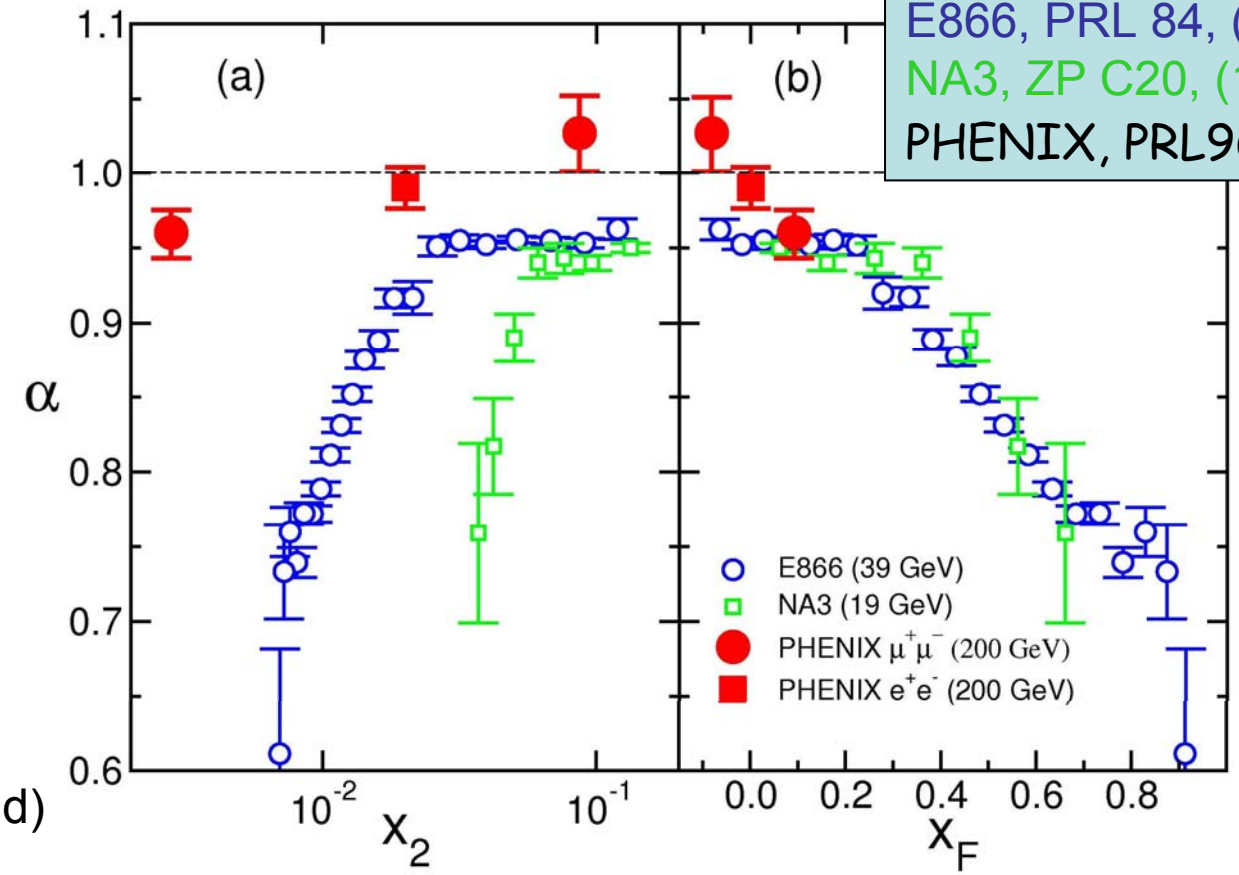


Dielectron pp and dA



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

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

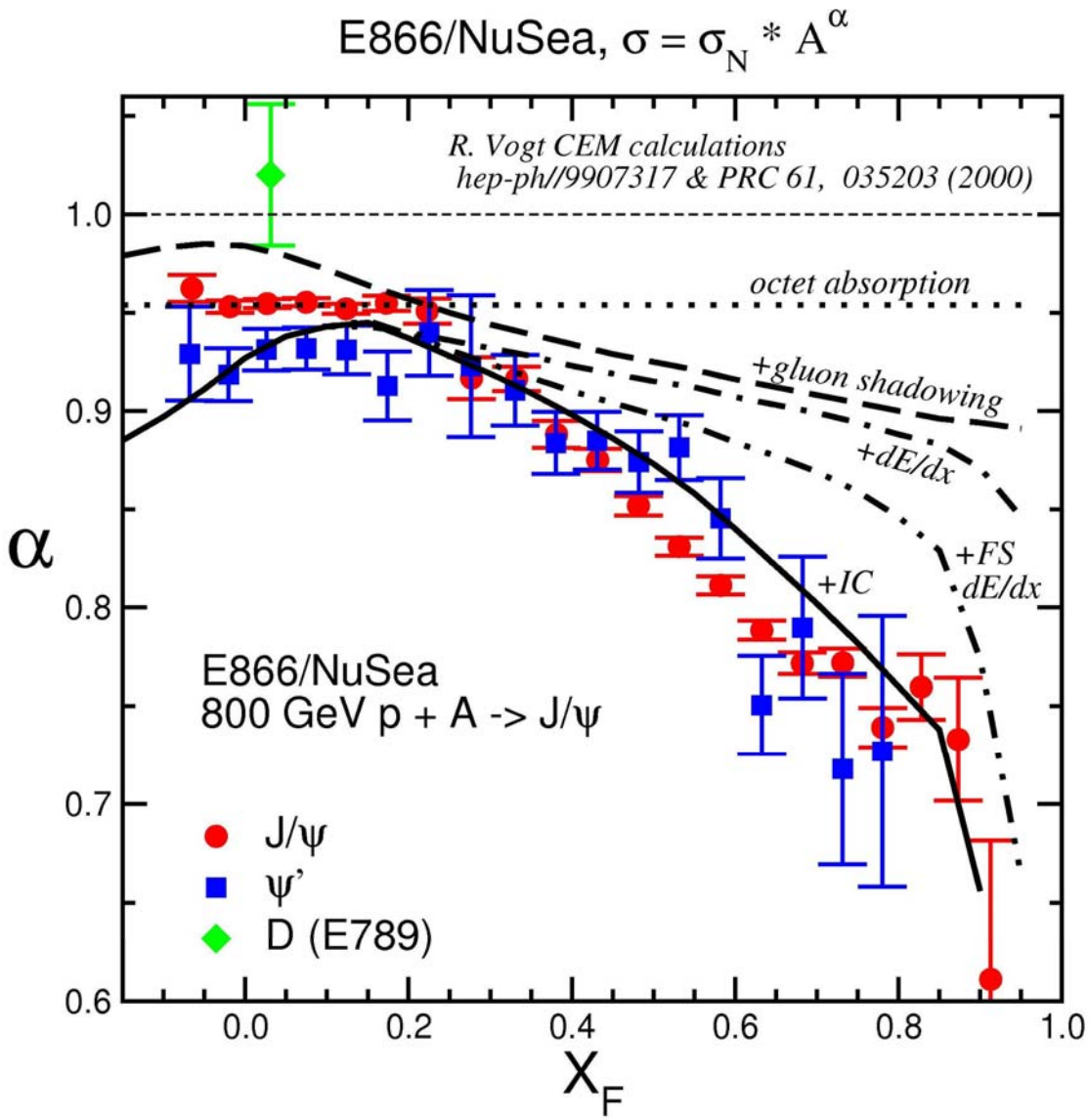


X_2 (in gold)

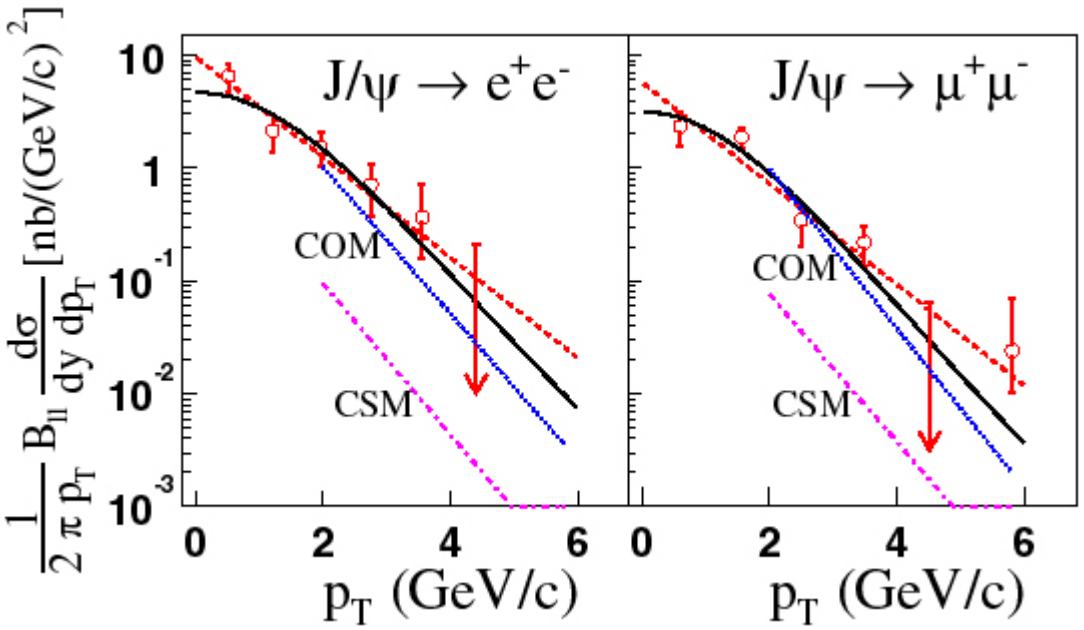
$X_F = X_d - X_{Au}$

- 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

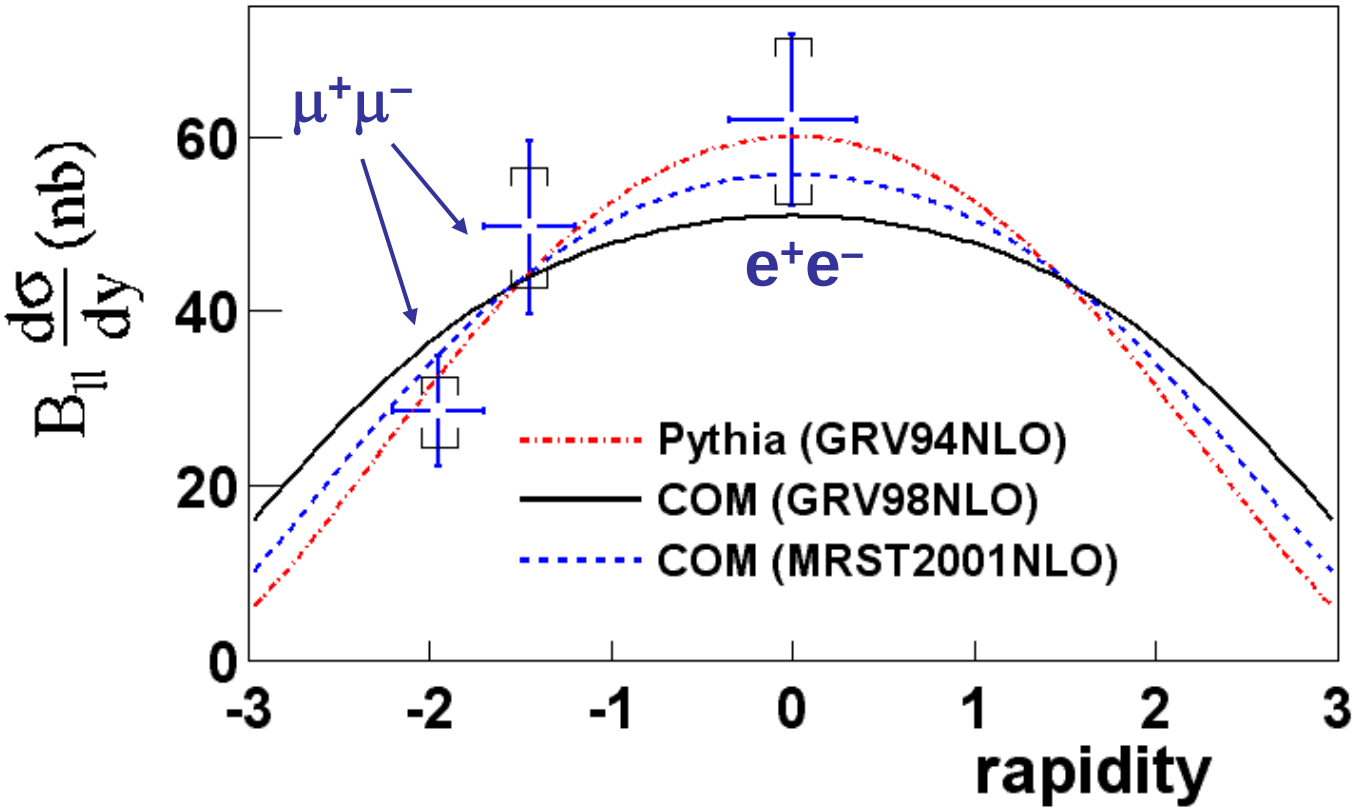
(from Nayak et al. hep/ph 0302095)

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

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

$\langle p_T \rangle$ = 1.80 ± 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 :

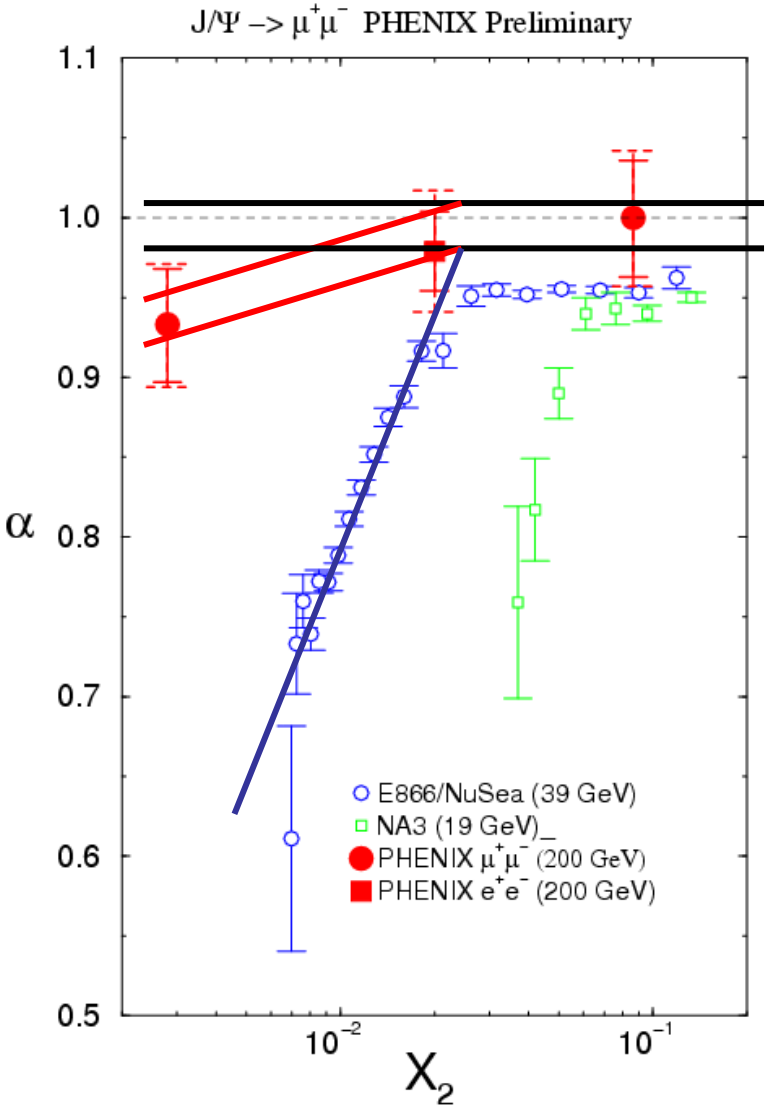
RUN2 234 ± 36 (stat) ± 34 (sys) ± 24(abs) μb

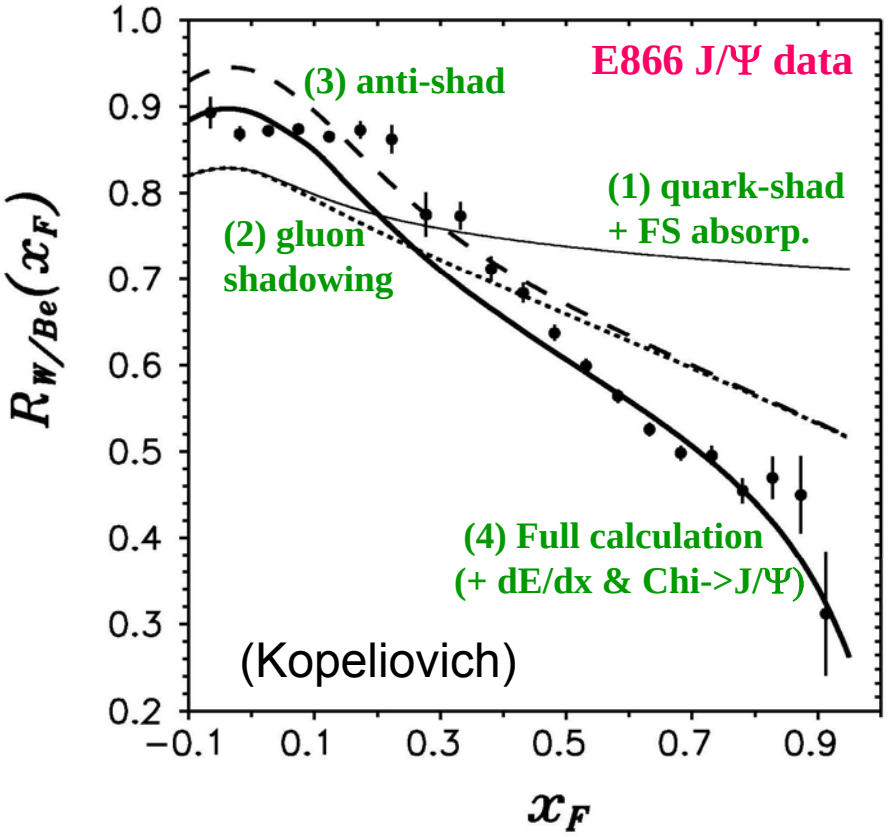
RUN3 159 nb ± 8.5 % (fit) ± 12.3% (abs)

} Consistent (1.3 sigma difference)

Naive picture

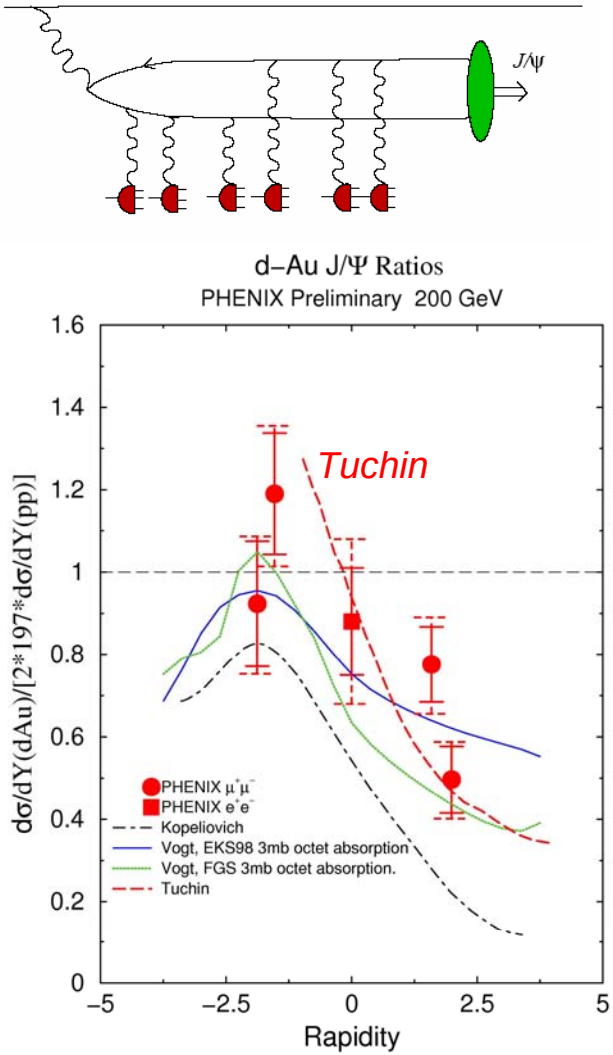
- Less absorption
- Shadowing
- Energy loss





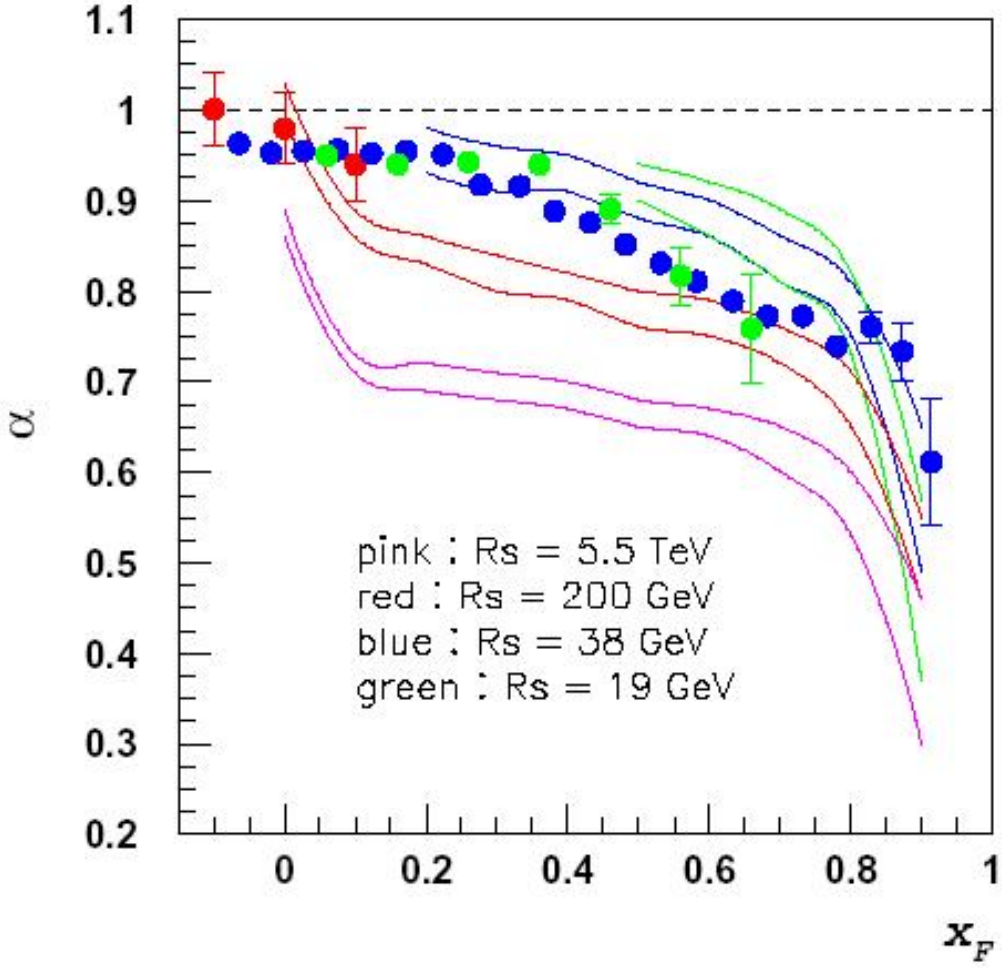
Tuchin & Kharzeev

- Hard probes 2004
  - hep-ph/0504133
- 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 …