J/Ψ production in pp, dA and AA collisions at $\sqrt{S_{NN}}$ = 200 GeV by the PHENIX experiment at RHIC

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Heavy Ion Forum, July 19, 2006

Outline

- Motivation
- Experimental setup
- p+p collisions
- d+Au collisions
- Cu+Cu and Au+Au collisions

Motivation (1)

J/Ψ is produced at the early stage of the collision via gluon fusion

~60 % direct J/Ψ

~30 % via $\chi_c \rightarrow$ J/Ψ + x

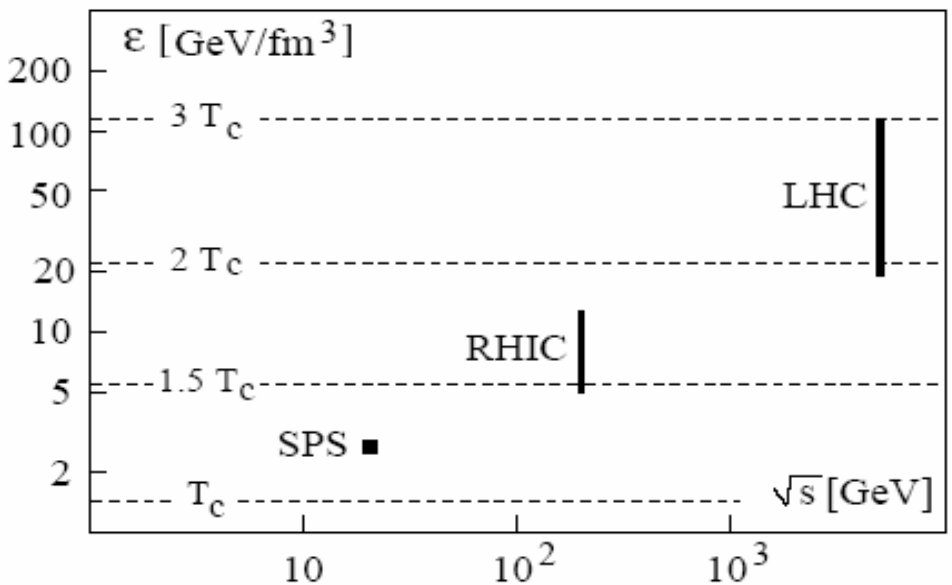
~10 % via Ψ'$\rightarrow$ J/Ψ + x

Sensitive to the formation of a quark gluon plasma via color screening.

Dissociation temperature:

for χ_c and Ψ': $T_d \sim 1.1\ T_c$

for J/Ψ : $T_d \sim 1.5$ to $2\ T_c$



Motivations (2)

But it is also sensitive to **initial state effects** such as shadowing

and **final state effects** such as:

- normal nuclear absorption
- interaction with comovers (partonic and/or hadronic)
- recombination of charm quarks.

Studying J/Ψ requires

- good p+p reference for baseline
- test experiment using pA (or dA) to control cold nuclear matter effects
- correct extrapolation from dA to AA
- measurement in AA collisions
  (nuclear modification factor, pt and rapidity spectrum)

Experimental Setup

BNL Facility

length: 3.83 km

Capable of colliding *any* nuclear species

Energy:

500 GeV for p-p

200 GeV for Au-Au (per N-N collision)

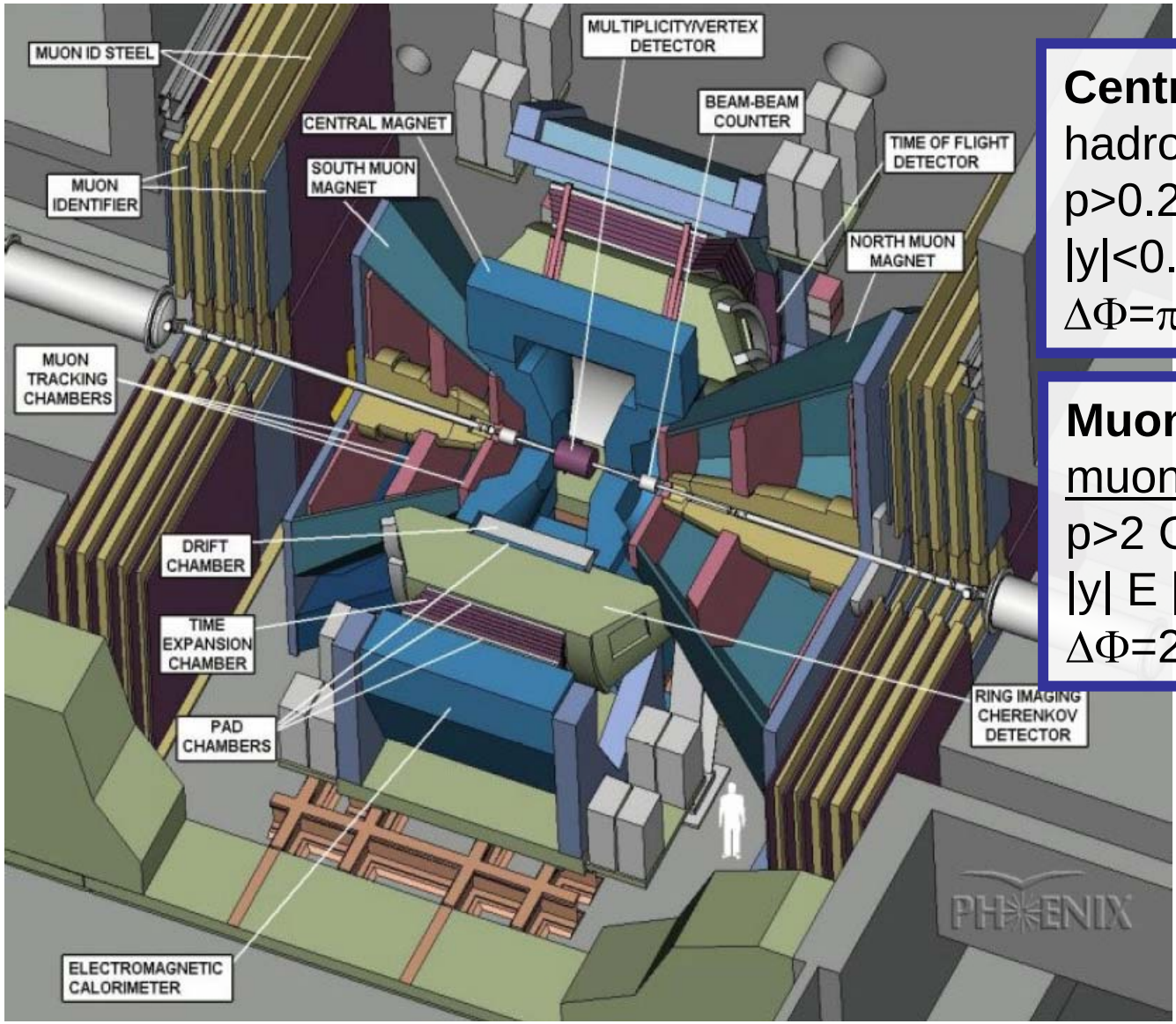
protons: Linac → Booster → AGS → RHIC

ions: Tandems → Booster → AGS → RHIC

Collision species and energy

Run	Year	Species	Energy (GeV)	# J/Ψ (ee+μμ)
01	2000	Au+Au	130	0
02	2001/2002	Au+Au p+p	200 200	13 + 0 46 + 66
03	2002/2003	d+Au p+p	200 200	360 + 1660 130 + 450
04	2003/2004	Au+Au Au+Au	200 62	~ 1000 + 5000 13 + 0
05	2004/2005	Cu+Cu Cu+Cu Cu+Cu p+p	200 62 22.5 200	~ 1000 + 10000 10 + 200 ~ 1500 + 10000
06	2006	p+p p+p p+p	200 62 500	~ 3000 + 30000

The PHENIX detector

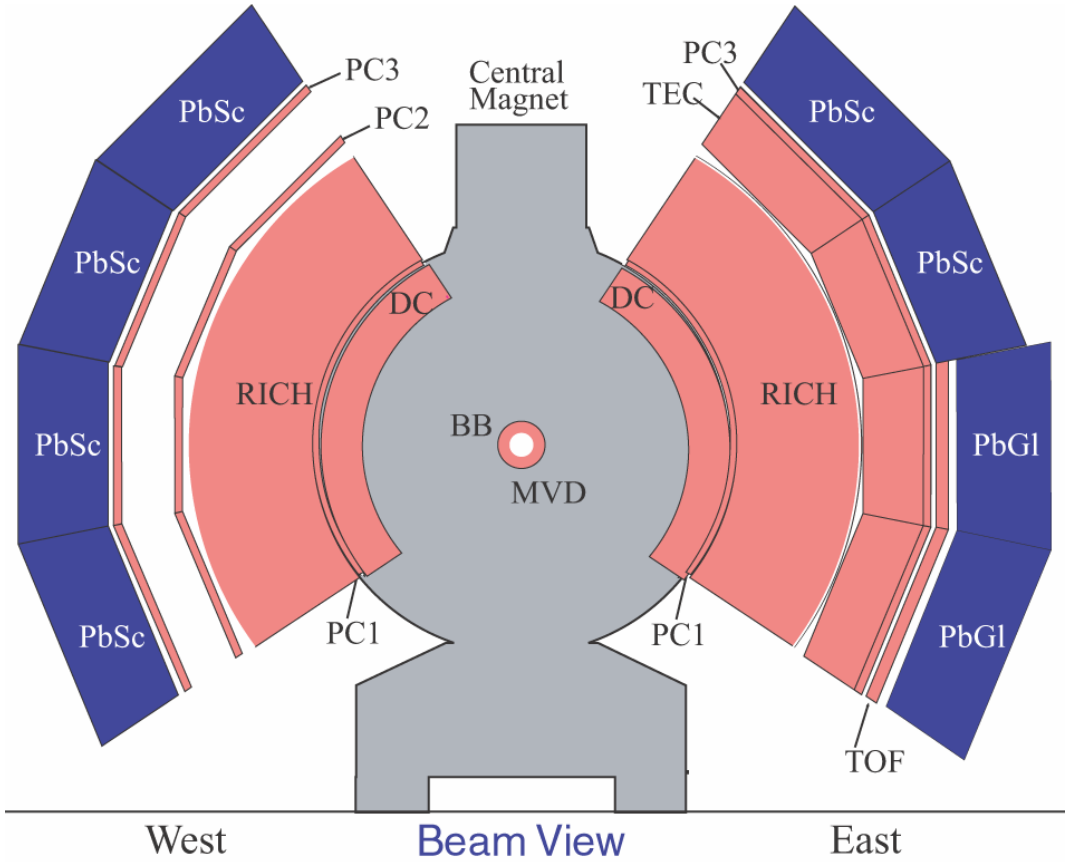


Central arm
hadrons; photons; <u>electrons</u>
p>0.2 GeV/c
|y|<0.35
$\Delta\Phi=\pi$

Muon arms
<u>muons</u>
p>2 GeV/c
|y| E [1.2,2.4]
$\Delta\Phi=2\pi$

J/Ψ measurement at mid rapidity

$J/\Psi \rightarrow e^+e^-$

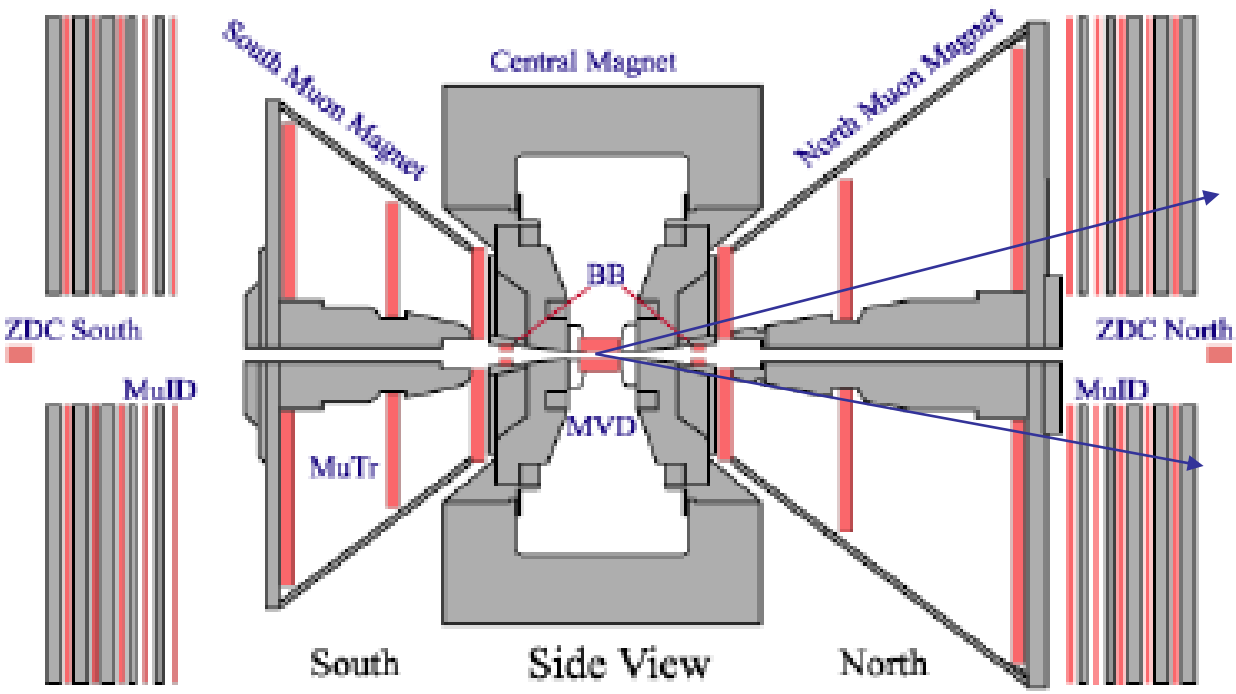


Drift chambers for momentum measurement

RICH and EMCal for electron identification and trigger (level1 and offline level2)

J/Ψ measurement at forward rapidity

$J/\Psi \rightarrow \mu^+\mu^-$



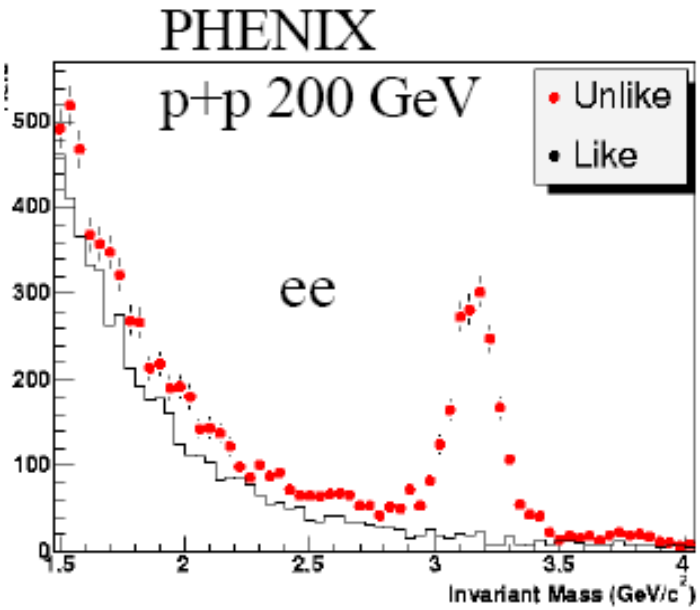
Front absorber to stop hadrons

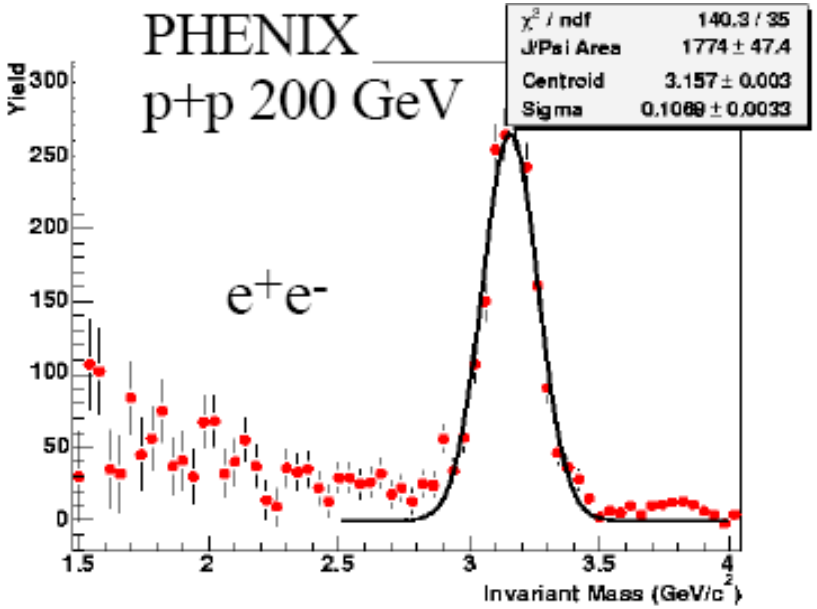
3 muon tracker stations of cathode strip chambers with radial magnetic field for momentum measurement

5 muon identifier planes (X and Y) and absorber, for muon selection and trigger

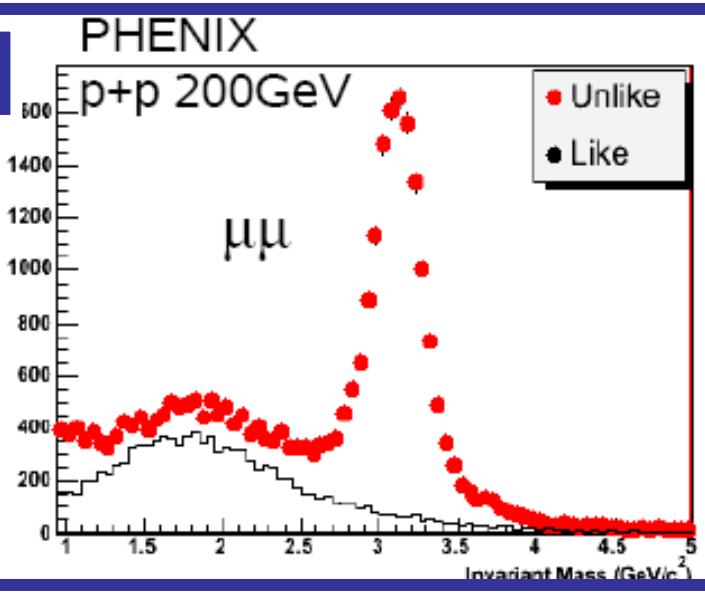
Dilepton invariant mass spectrum (run6 pp)

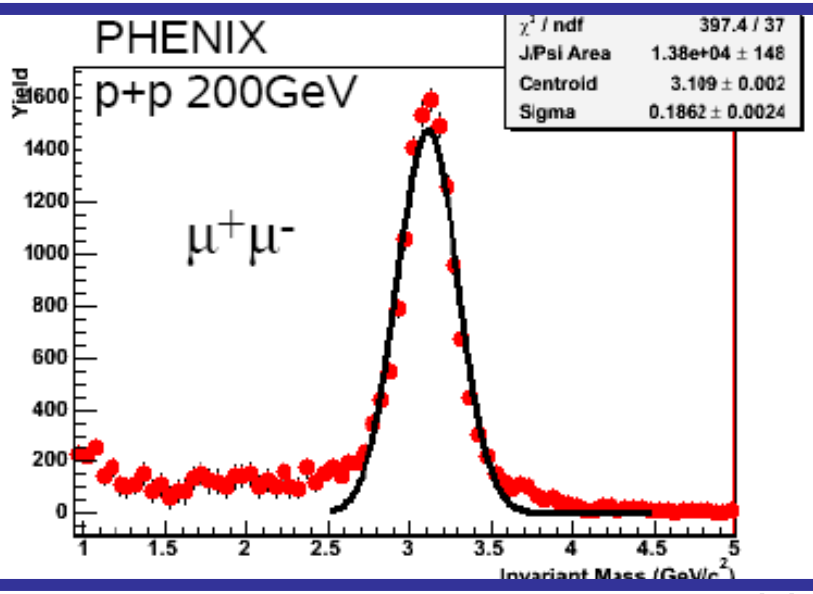
J/Ψ→ e^+e^-



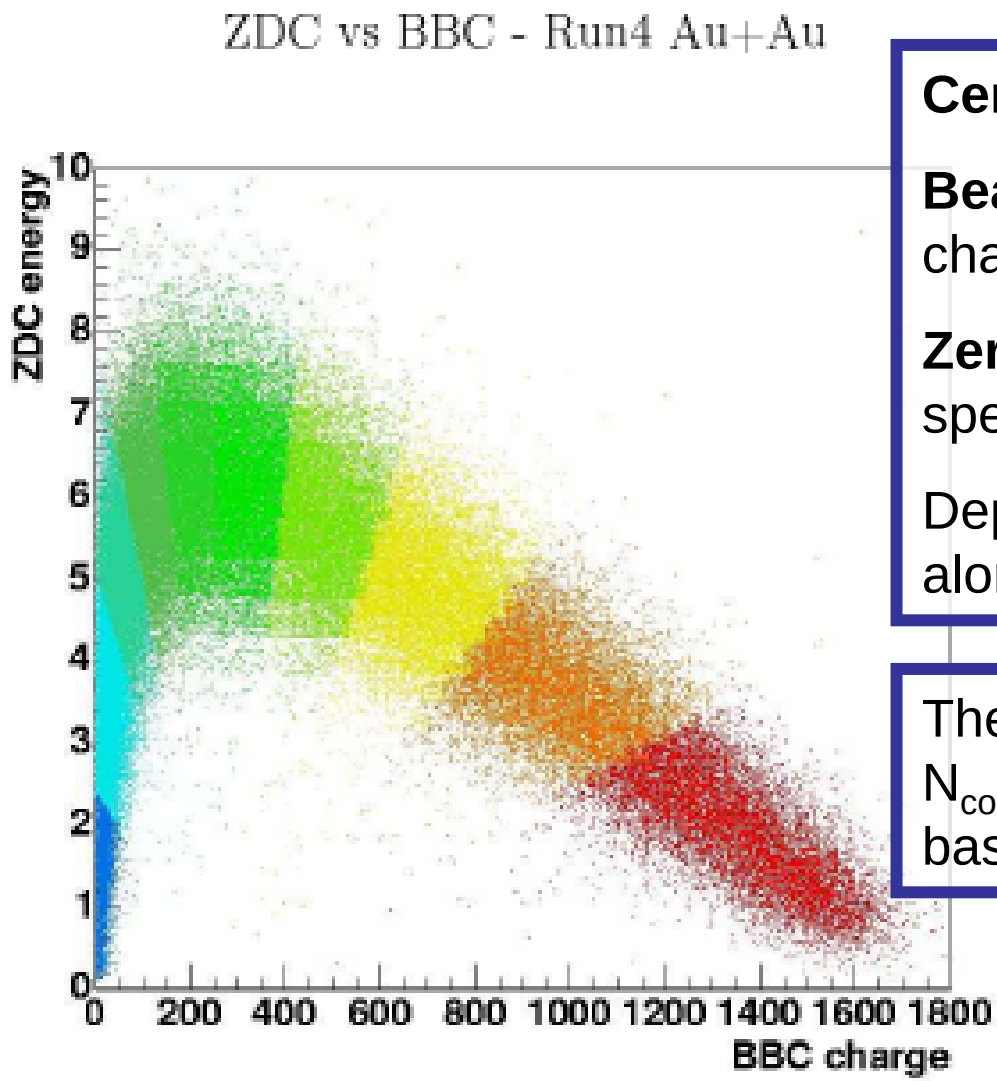


J/Ψ→ $\mu^+\mu^-$





Collision centrality determination



Centrality measurement using:

Beam beam counters to count charged particles at forward rapidity

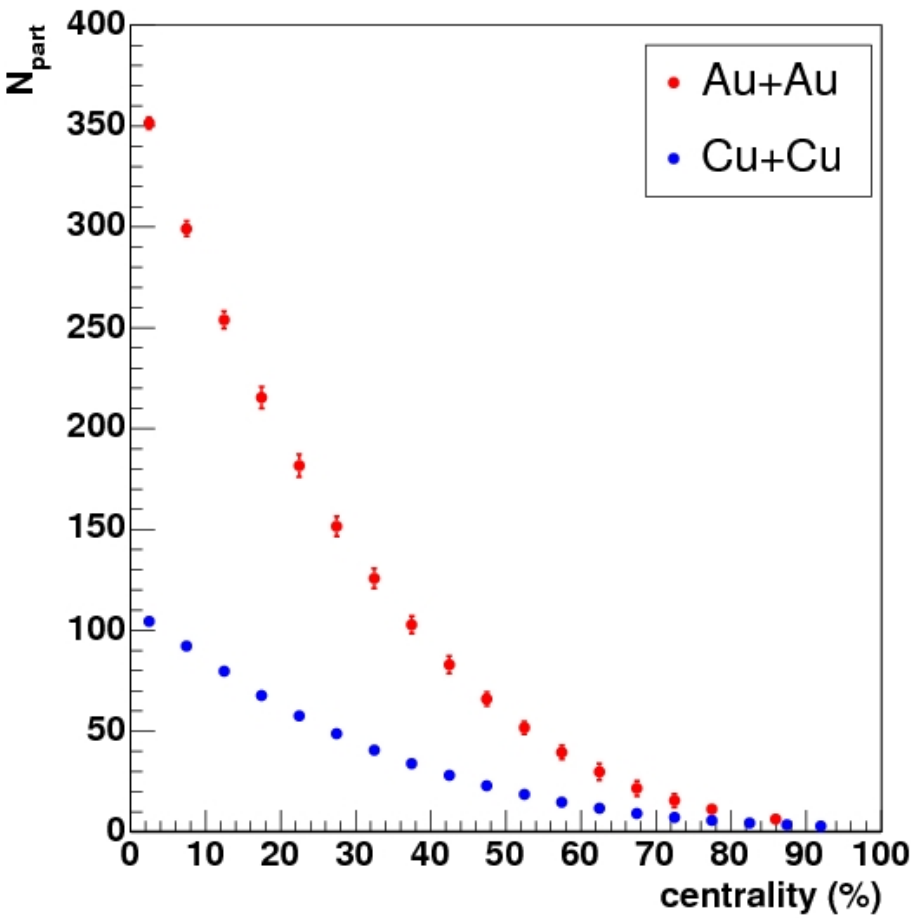
Zero degree calorimeters to count spectator neutrons

Depending on the run either BBC alone or BBC + ZDC are used

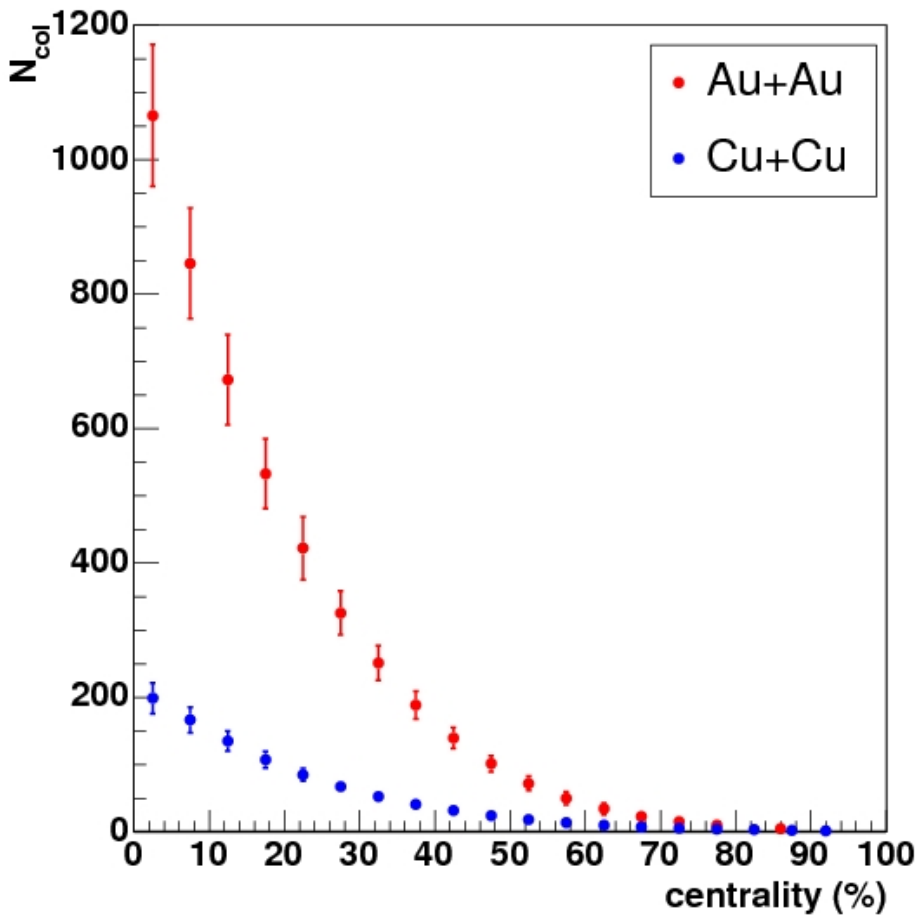
The centrality is mapped into N_{part}, N_{col}, b, etc. using a simulation based on a **Glauber** model.

Collision centrality (2)

N_{part} vs centrality (5% bins)



N_{col} vs centrality (5% bins)



J/Ψ yield and nuclear modification factor

J/Psi invariant production yield:

$$BdN_{J/\Psi}/dy = \frac{N_{J/\Psi}}{\Delta y . A \varepsilon_{J/\Psi} . \varepsilon^{J/\Psi}_{BBC}} \frac{\varepsilon^{MB}_{BBC}}{N_{MB}}$$

Nuclear modification factor:

$$R_{AA} = \frac{\text{yield in AA}}{N_{col} . \text{ yield in pp}}$$

N_{col} = number of equivalent nucleon-nucleon collisions

J/Ψ production in p+p collisions

J/Ψ yield as a function of rapidity

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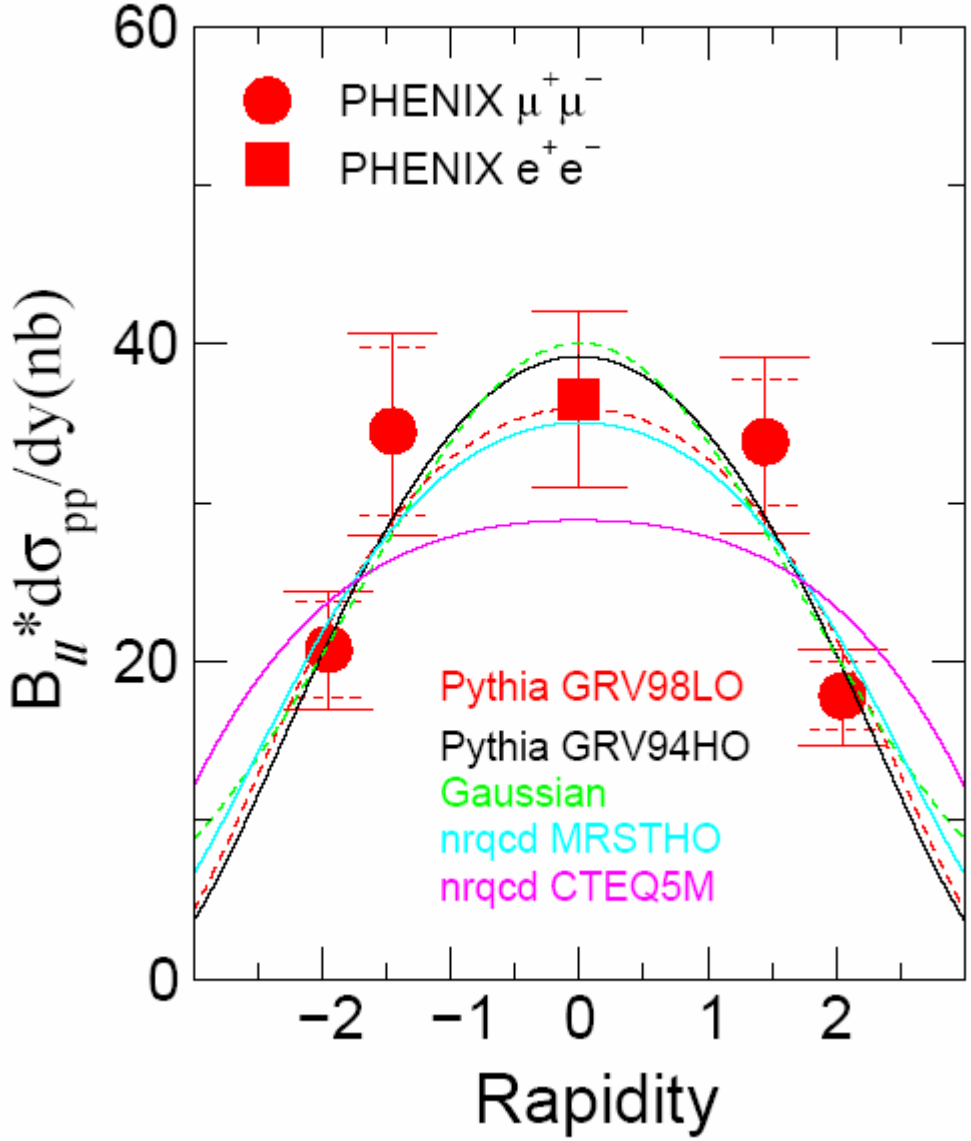

Measurement from Run3 p+p data.

Line shapes obtained from PYTHIA using different parton distribution functions.

$\sigma(pp \rightarrow J/\Psi) = 2.61 \pm 0.20 \pm 0.26 \mu b$

Total cross section, energy dependence

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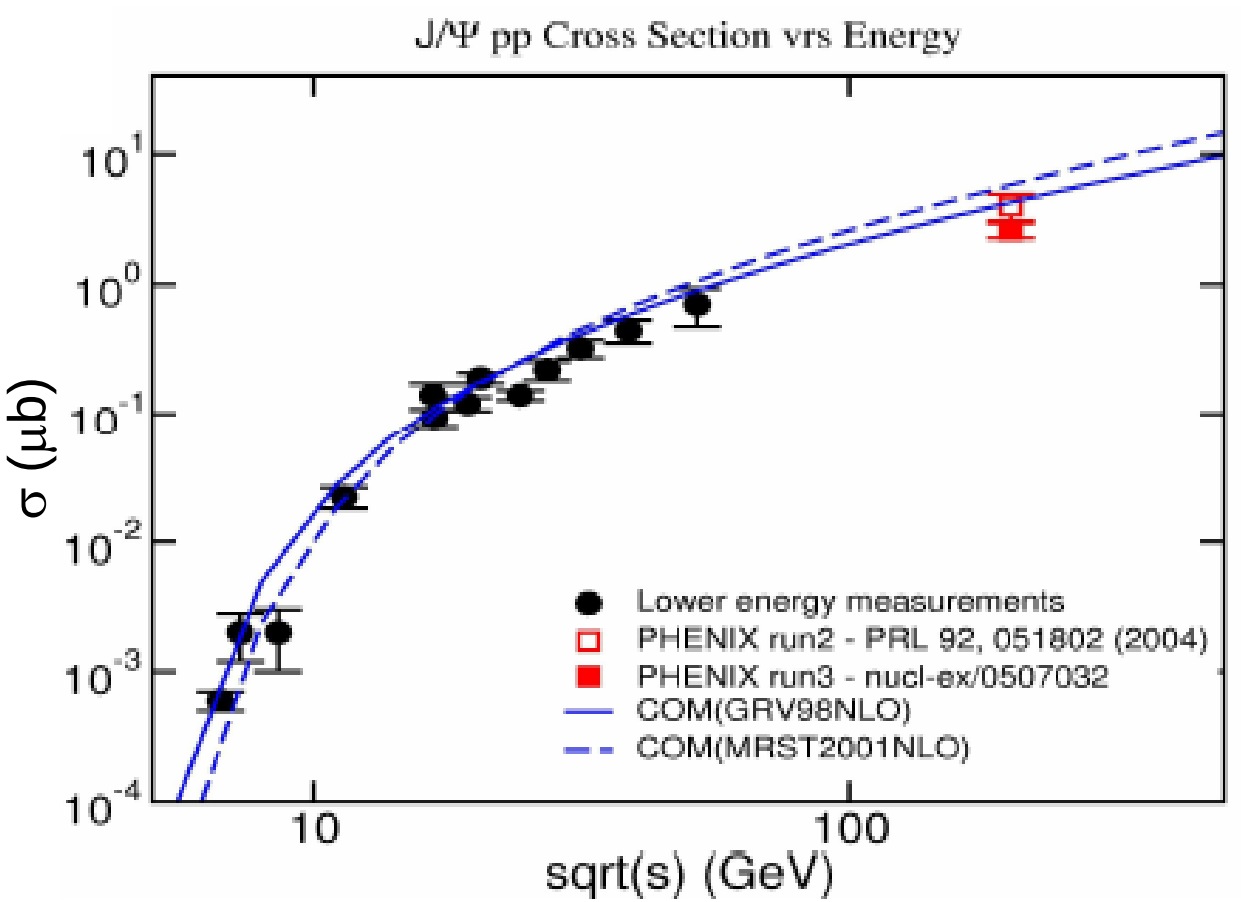

J/Ψ yield as a function of transverse momentum

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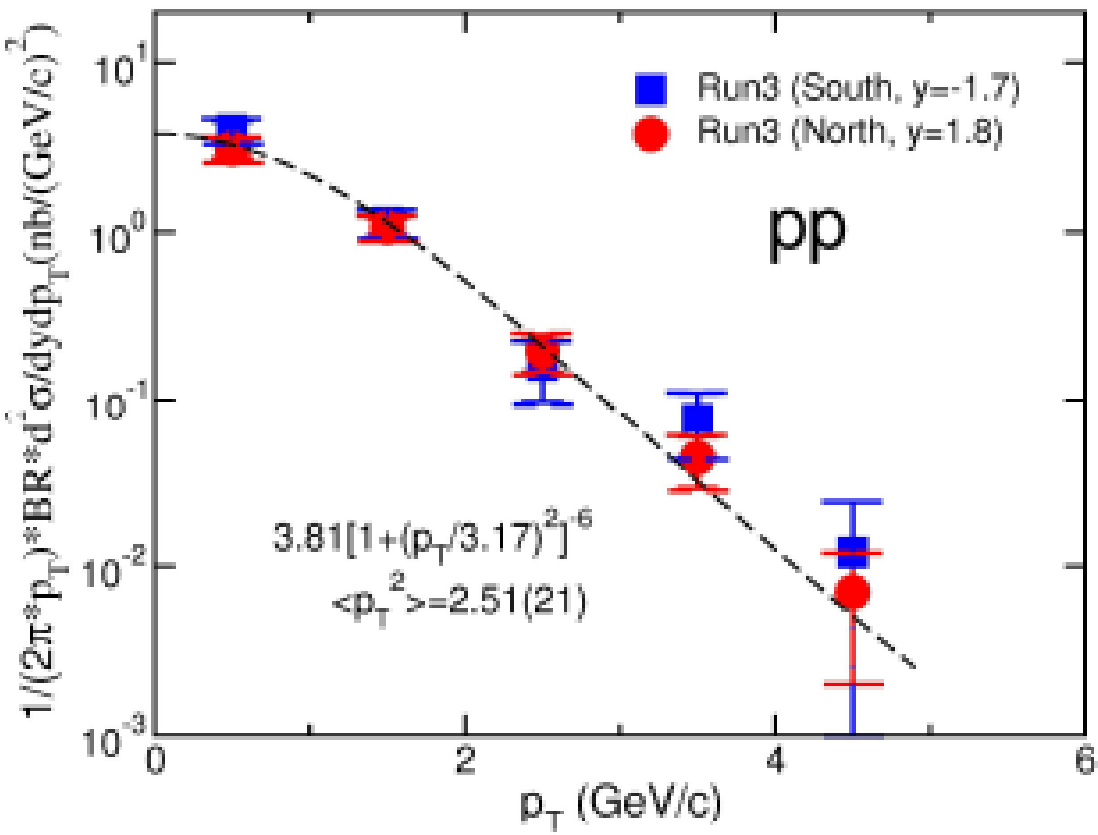

p_t spectrum at forward rapidity

Fit using:

$$p_0.[1+ (p_t/p_1)^2]^{-6}$$

$$\langle p_t^2 \rangle = 2.51 \pm 0.21 \text{ GeV}^2$$

J/Ψ production in d+Au collisions

R_{dAu} as a function of rapidity

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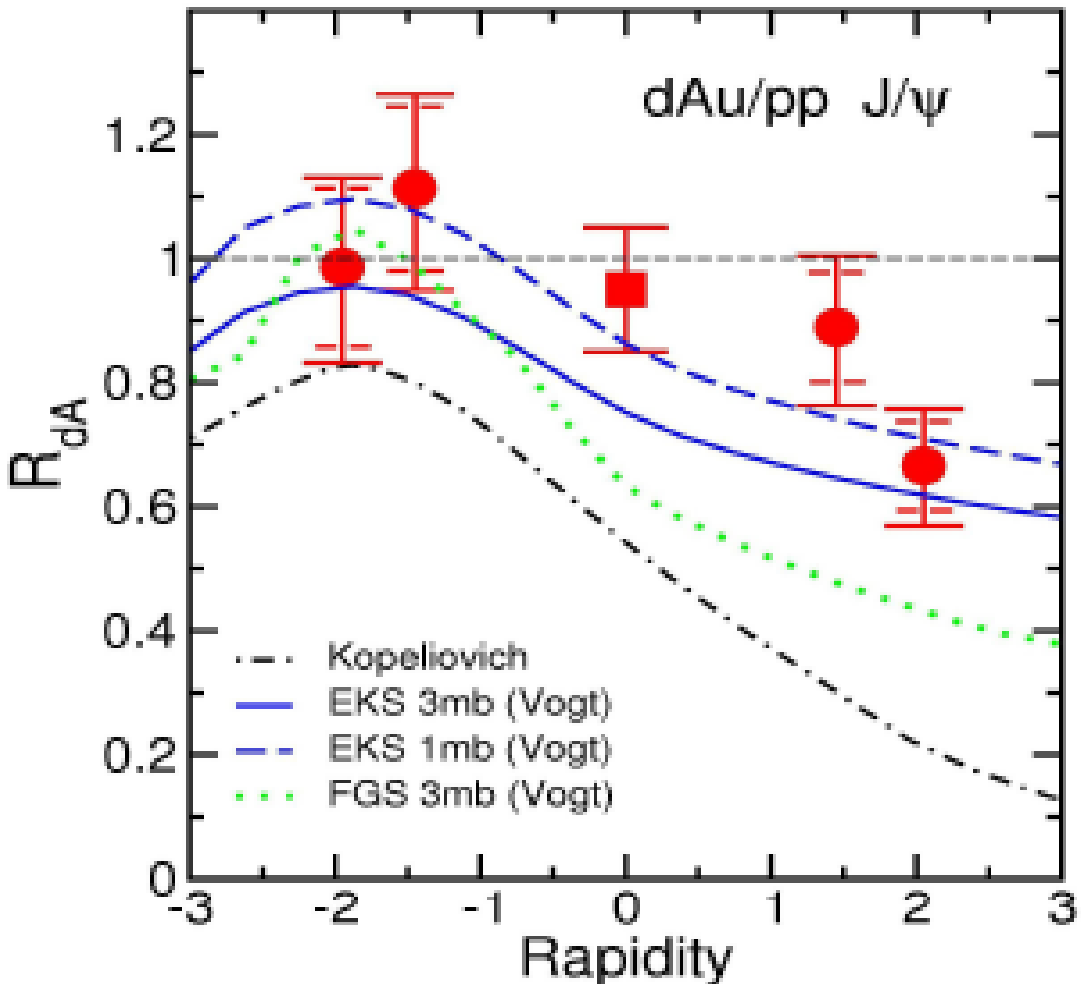


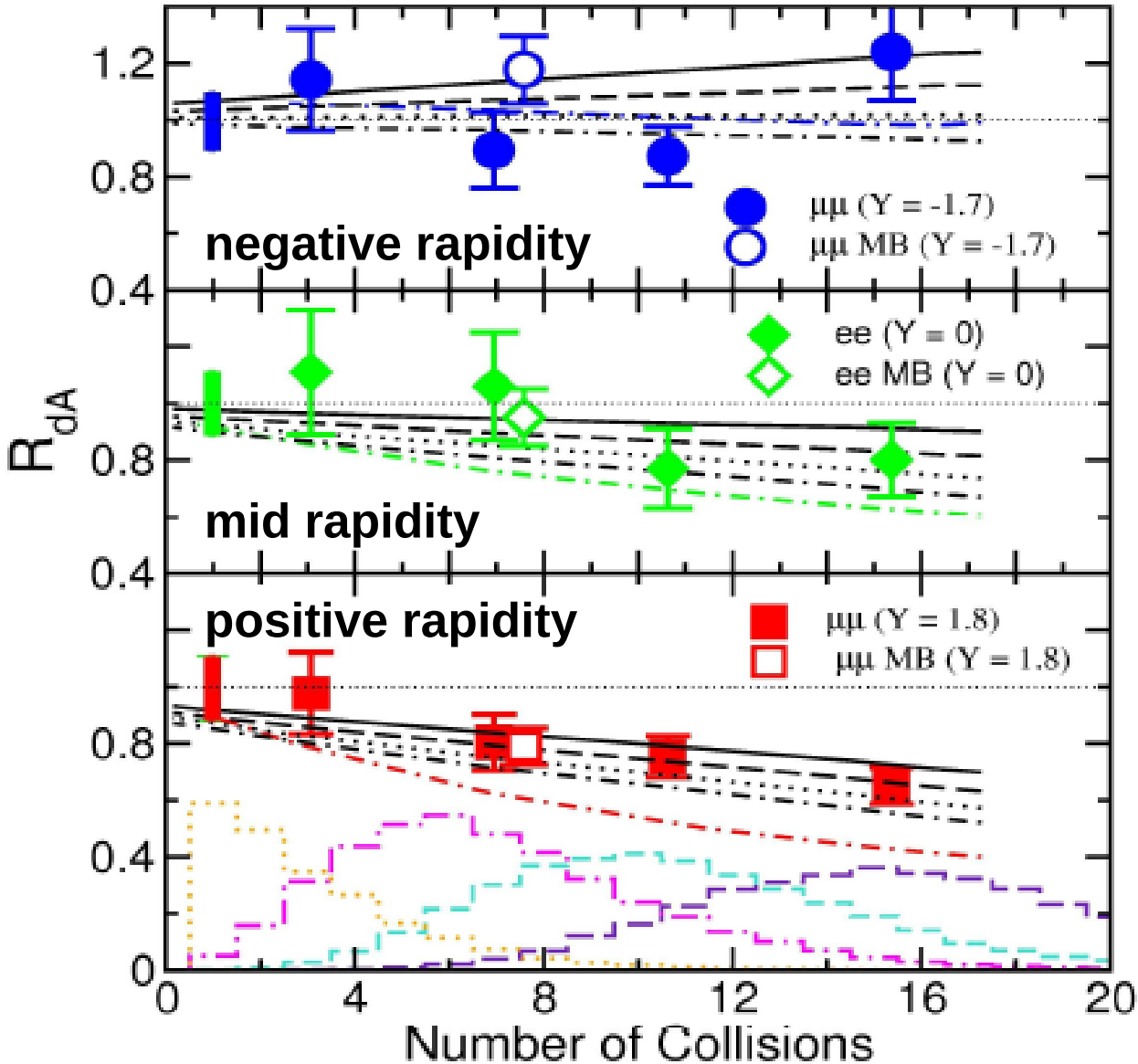
y<0 (deuteron side)
large x_{Au} (~0.09)
anti-shadowing region

y>0 (gold side)
small x_{Au} (~0.003)
shadowing region

Compared to various parameterization for the nuclear shadowing + a nuclear absorption cross-section.

R_{dA} vs y is consistent with EKS shadowing and a weak absorption (1-3mb)

Centrality dependence



Black lines:
EKS98 0-3mb

Colored lines:
FGS 3mb

Slopes are consistent with EKS shadowing

Extrapolation from dA to AA collisions

Different approaches:

1. A model of shadowing and nuclear absorption as used in previous slides (here EKS shadowing and 1 to 3mb nuclear absorption) extrapolated to AA (Ramona Vogt, nucl-th/0507027)

2. A phenomenological fit on the d+Au data to get σ_{diss} for each rapidity and use $\exp-[\sigma_{diss}(y) + \sigma_{diss}(-y)]n_0L$ for AA. (Karsh, Kharzeev and Satz, PLB637(2006)75)
   - $\sigma_{diss}(y=1.8) = 3.1 \pm 0.2$ mb
   - $\sigma_{diss}(y=0) = 1.2 \pm 0.4$ mb
   - $\sigma_{diss}(y=-1.7) = -0.1 \pm 0.2$ mb

3. A direct extrapolation of measured R_{dA} to AA using a simulation based on Glauber model (R. Granier de Cassagnac, private communication)

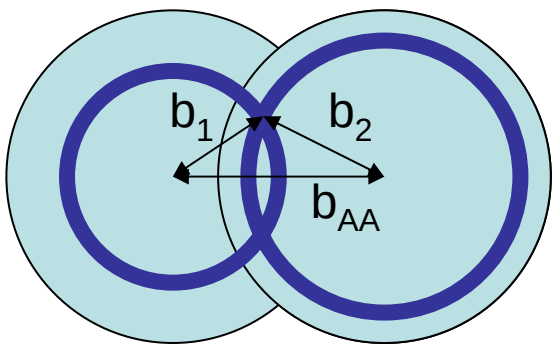
Direct extrapolation of measured R_{dA} to AA

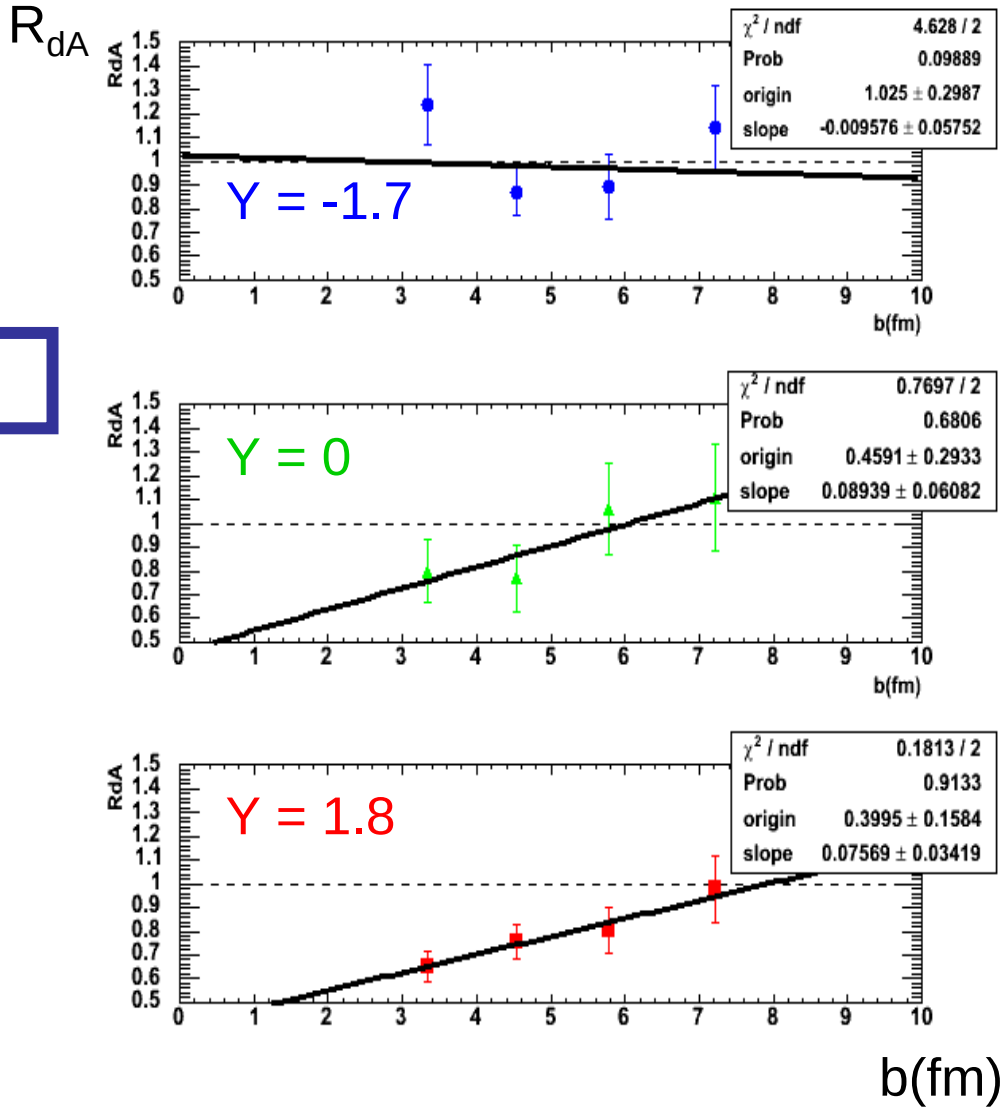
Use a simple fit of RdA vs b

Plug $R_{dA}(b)$ into an AA Glauber simulation:

$$R_{AA}(y,b_{AA}) = \Sigma[R_{da}(-y,b_1).R_{dA}(y,b_2)]$$

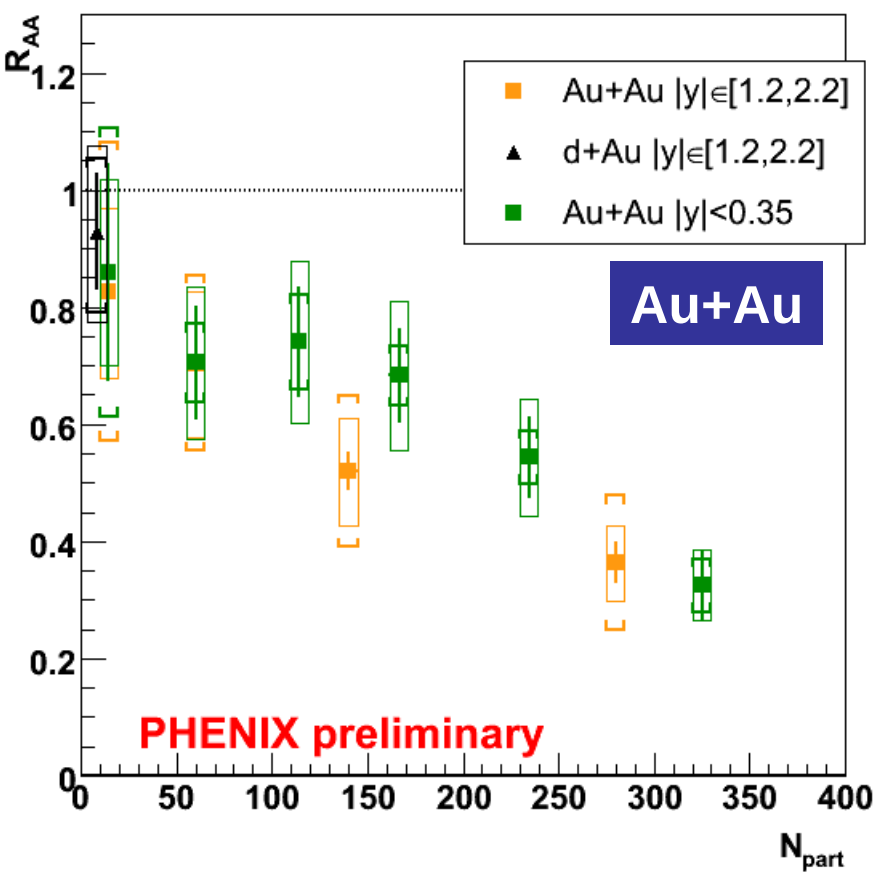
where b_1 and b_2 are determined for each nucleon-nucleon collision in the simulation at a given b_{AA}.

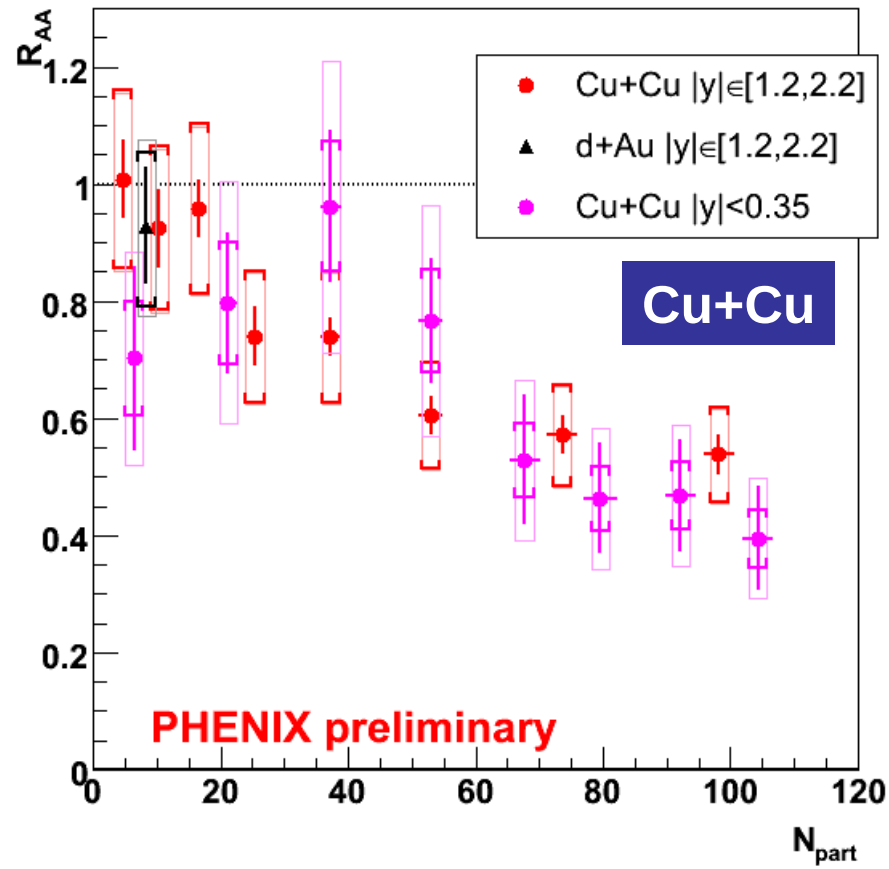




J/Ψ production in Cu+Cu and Au+Au collisions

Nuclear modification factor



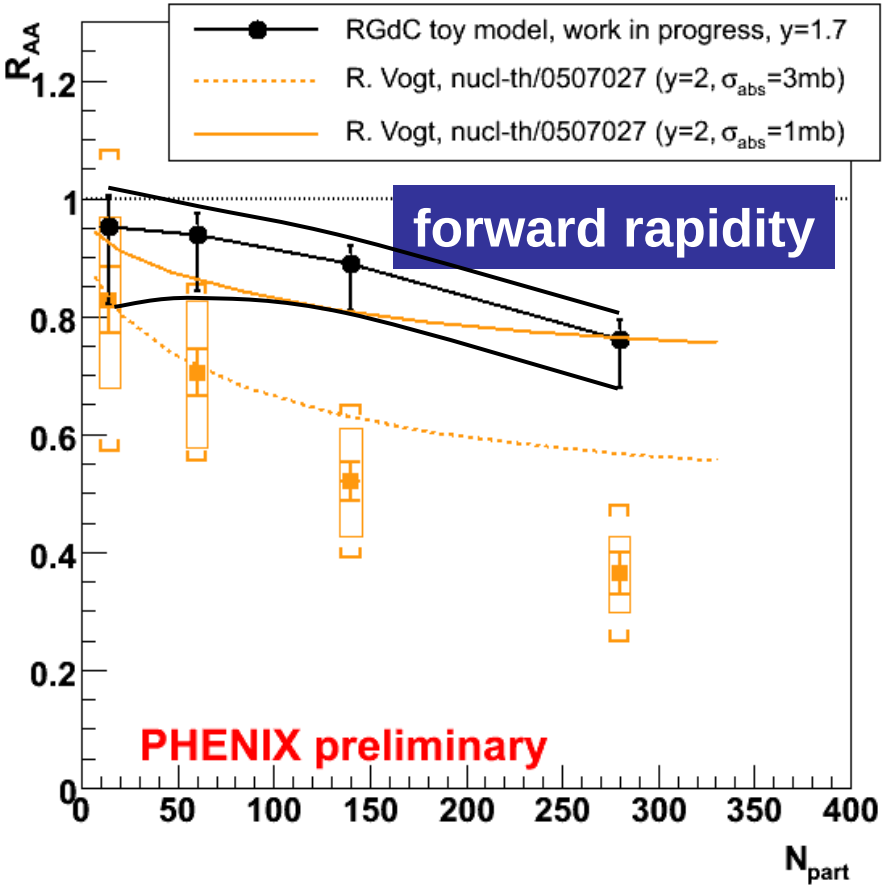


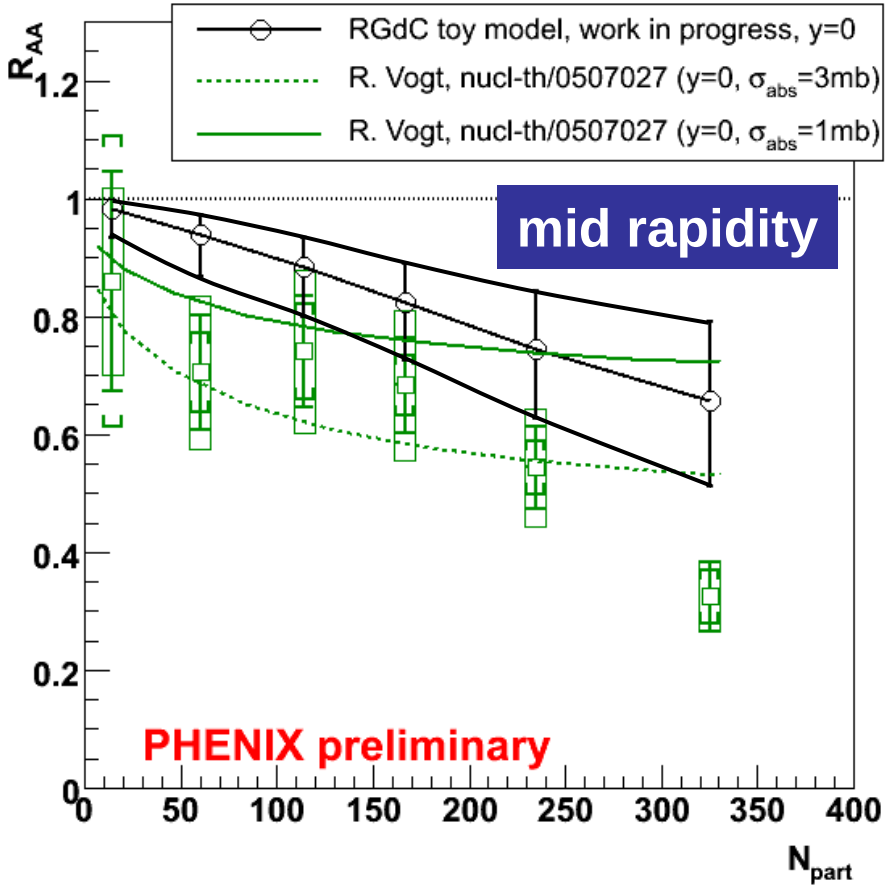
Bars are statistical errors

Brackets are point to point systematic errors

Boxes are global errors

Cold nuclear matter effects



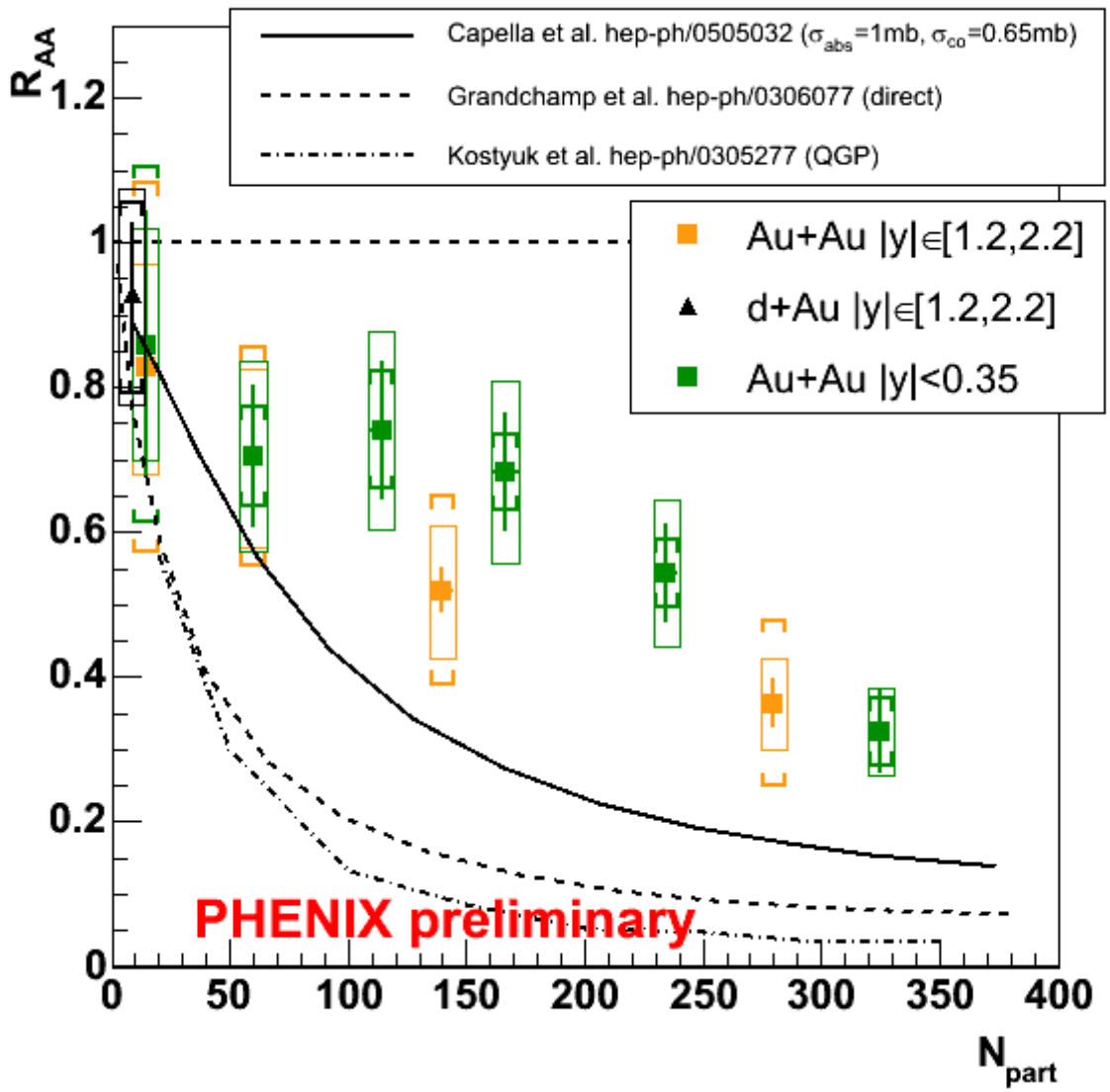


Black line is from R. Granier de Cassagnac, using RdA.
Error bars are from RdA measurement.

Orange and green lines are from R. Vogt, using 1 and 3mb normal absorption

Both methods miss the most central points

Suppression extrapolated from SPS



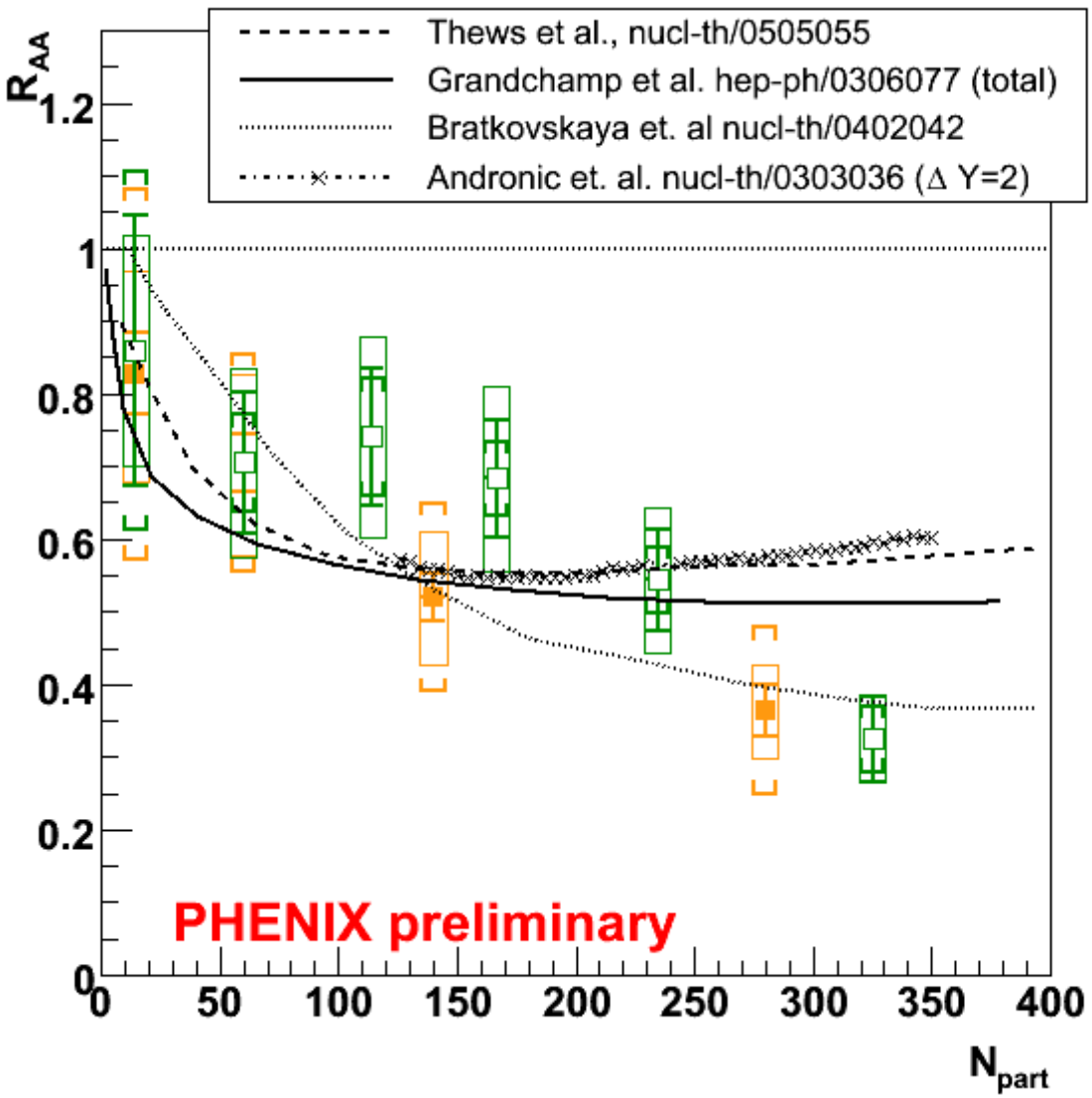
Comovers

Kinetic $J/\Psi \rightarrow c\bar{c}$

Thermal plasma

All models overestimate the suppression observed at RHIC

Suppression + recombination

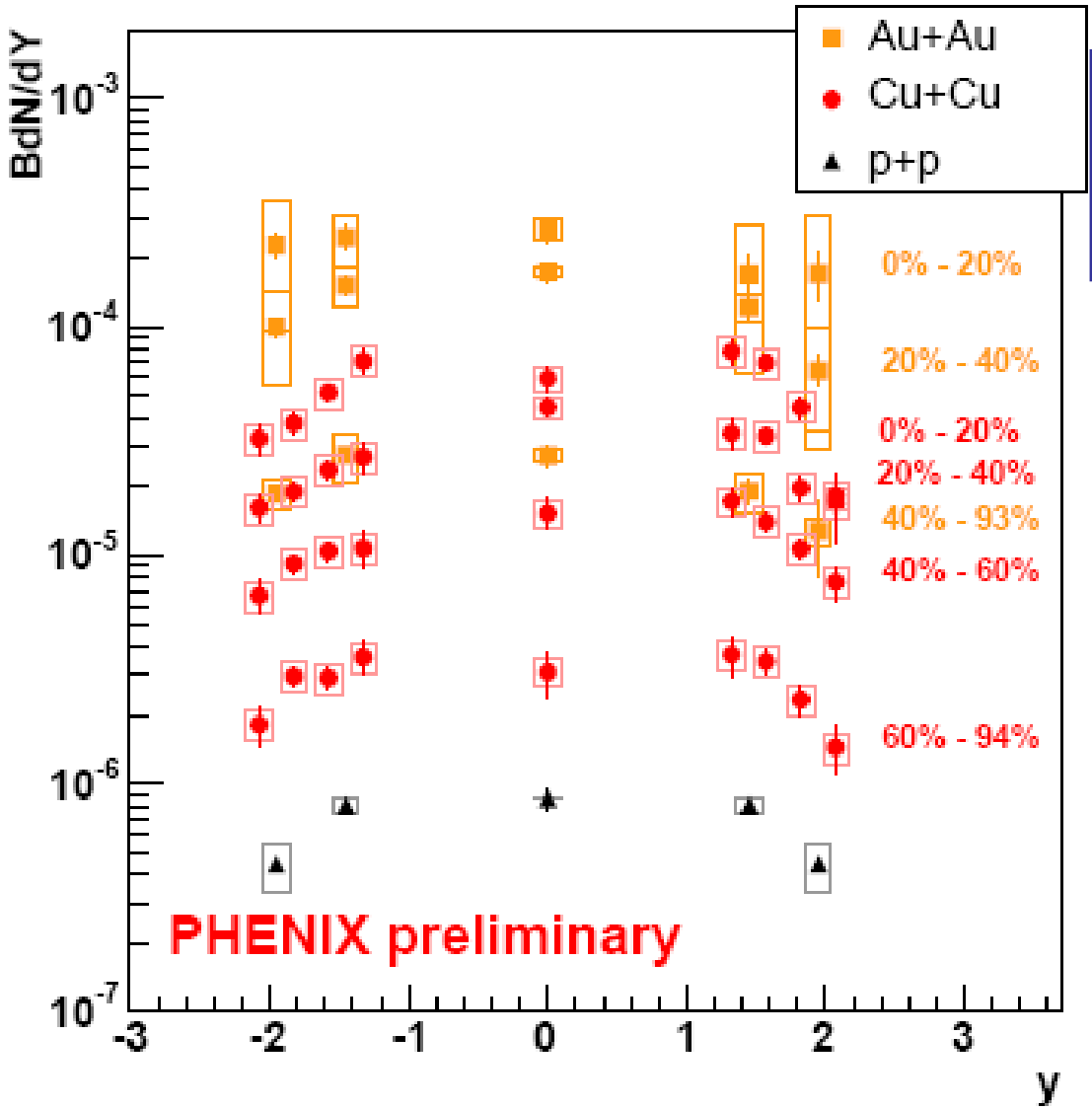


Better **qualitative** agreement achieved if turning on coalescence or recombination.

But:

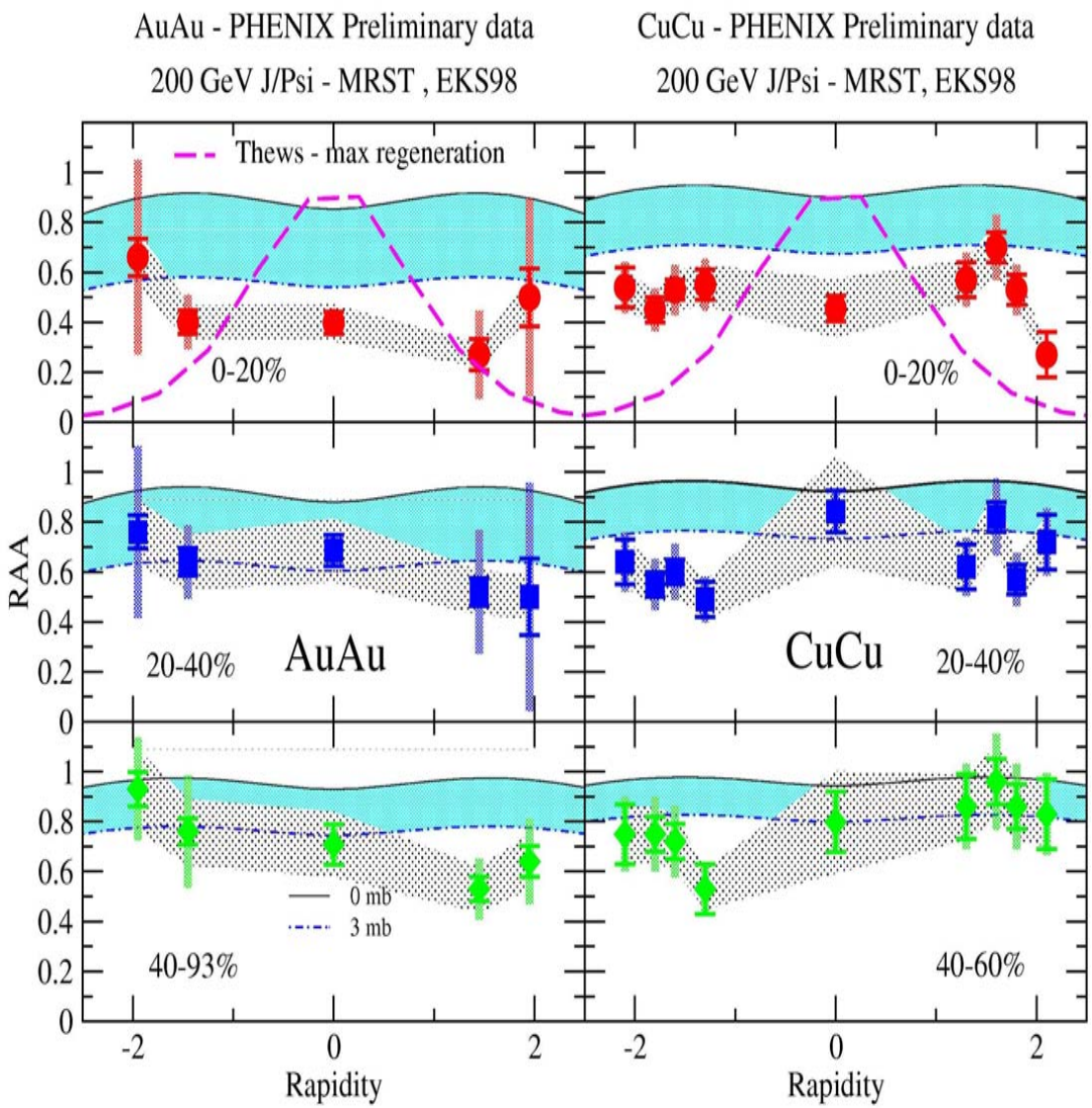
- most models apply only at mid rapidity.
- most models miss the most central points, as was the case when comparing to cold nuclear matter effects.

J/Ψ yield as a function of rapidity



No clear change in the rapidity shape as a function of centrality.

J/Ψ R_{AA} as a function of rapidity



Blue bands are cold nuclear matter prediction from Vogt, (EKS + 3mb absorption).

Dashed purple line are expected R_{AA} vs y for recombined J/Ψs

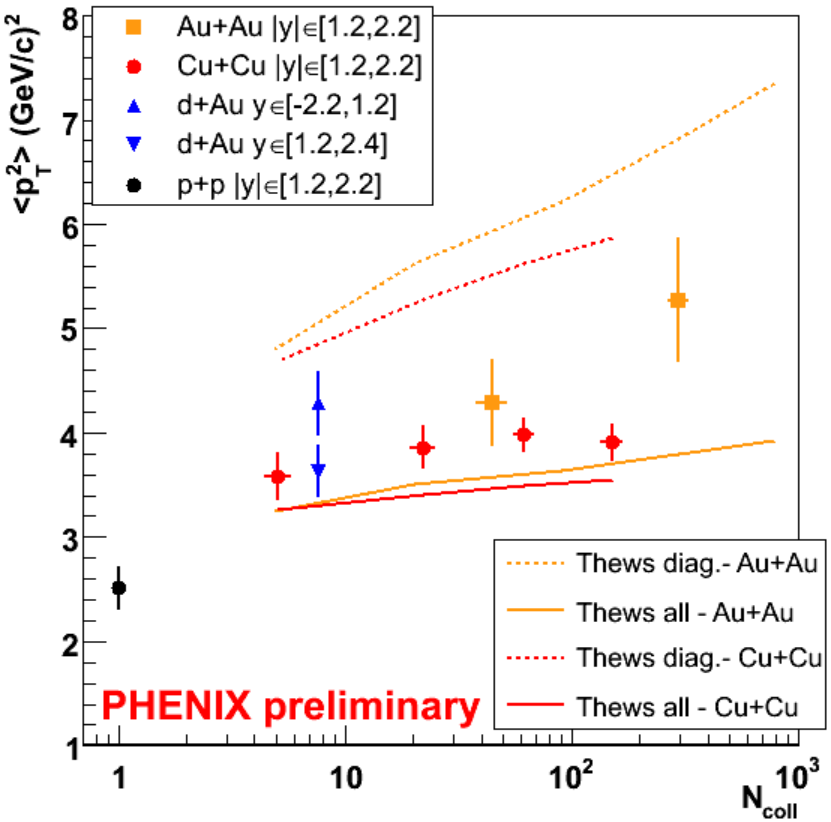
Grey bands are error from p+p

No clear change in the rapidity shape as a function of centrality.

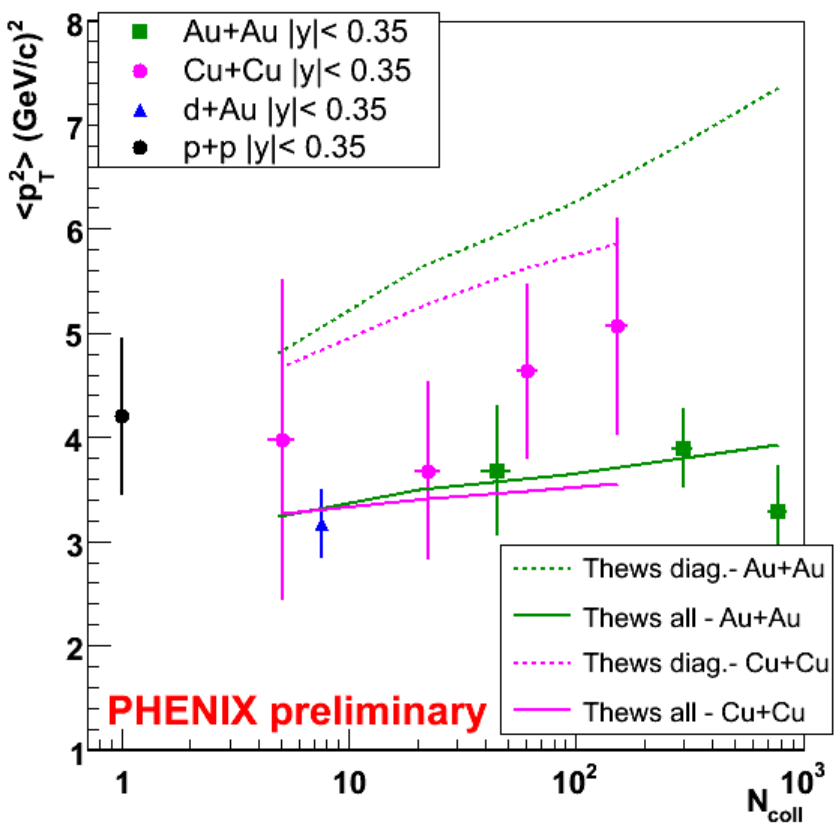
nucl-th/0507027

J/Ψ mean p_t^2 (1)

forward rapidity

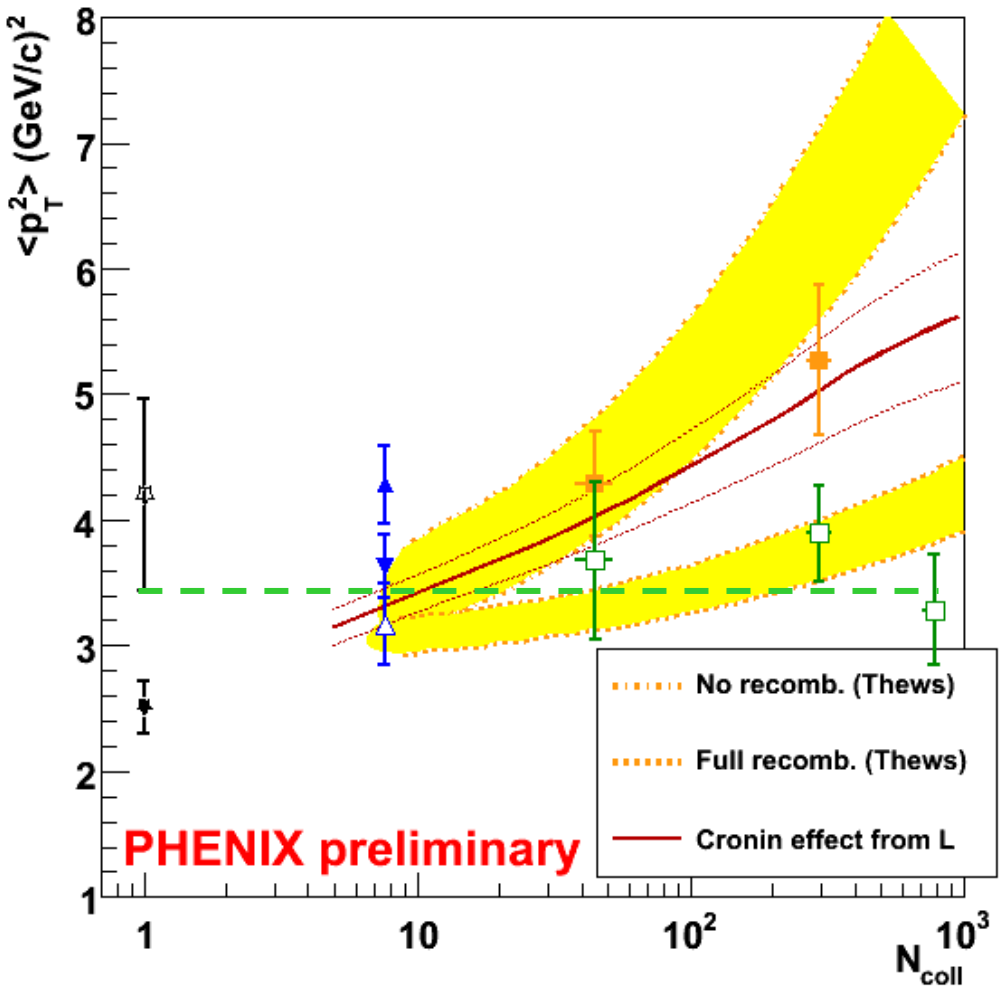


mid rapidity



Early comparison to Thews predictions, for direct J/Ψ (dashed line) and recombined J/Ψ (full line)

J/Ψ mean p_t^2 (2)



VN Tram, Moriond 2006 & PhD thesis
Thews and Mangano, PRC73 (2006) 014904c

black is p+p

blue is d+Au

green, and orange are Au+Au

Open symbol is for mid rapidity

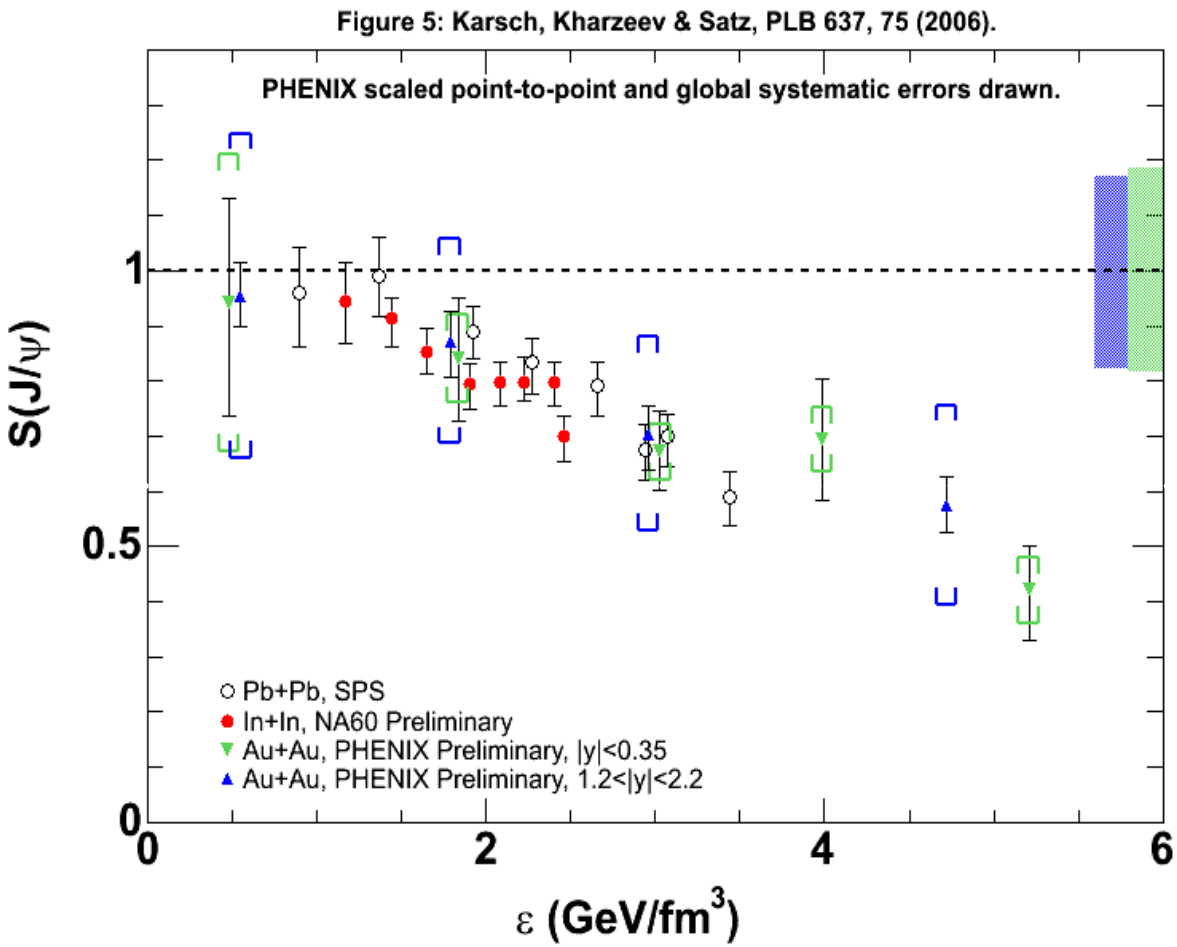
Full symbol is for forward rapidity

Yellow bands are from Thews

Brown line is a Cronin effect extrapolation from p+p and d+Au at forward rapidity

mid rapidity values are consistent with no p_t broadening.

Comparison to SPS



PHENIX points are referred to a fit of d+Au cold nuclear effects.

Both NA60 and PHENIX points are preliminary

Large uncertainties in the determination of ε for both SPS and RHIC.

The comparison indicates that RHIC an SPS follow the same pattern and are consistent with sequential melting of Ψ', χc and (not yet observed) direct J/Ψ.

Conclusion

Conclusion (1)

PHENIX has measured a J/Ψ suppression in Au+Au and Cu+Cu beyond what one would expect by extrapolating cold d+Au nuclear effects.

Simple extrapolation from SPS overestimate the suppression

Plugging in additional mechanisms (coalescence) do a better job.

Comparison between SPS and RHIC results is hard due to the choice of a common *x* axis (energy density should be the correct variable) and proper accounting for cold nuclear matter effects. It indicates a common pattern when plotted against the energy density.

Conclusion (2) Todo list

For experimentalists :

Produce **final** results;
detail the errors on the measurement and how to use them;
use a better p+p reference;
have better control on cold nuclear effects in d+Au and how to extrapolate to Au+Au.

For theoreticians :

give predictions not only for R_{AA} but also p_t and y spectrum;
give predictions for the different rapidity windows measured;
and for the different systems (so far Cu+Cu and Au+Au)
account for the cold nuclear effects measured in d+Au;
take the experimental error bars seriously;
produce theoretical error bars.

Conclusion (3)

Near future:

Final Run4 Au+Au results should be available for QM2006, with better control over systematic errors, and normalized to Run5 p+p.
Should allow for more acurate R_{AA} vs rapidity and p_t

Future RHIC runs (PHENIX Beam Use Proposal):

Run7: high luminosity Au+Au (200GeV) and p+p
Run8: high luminosity d+Au (200GeV) and p+p
Run9: energy scan with Au+Au

Future measurements:

Need accurate open charm measurement (for coalescence models).
Ψ', χ_c and Y would help.
Need RHIC II and detector upgrades.