J/ψ production in Au+Au collisions at $\sqrt{s}$ = 200 GeV measured by PHENIX at RHIC

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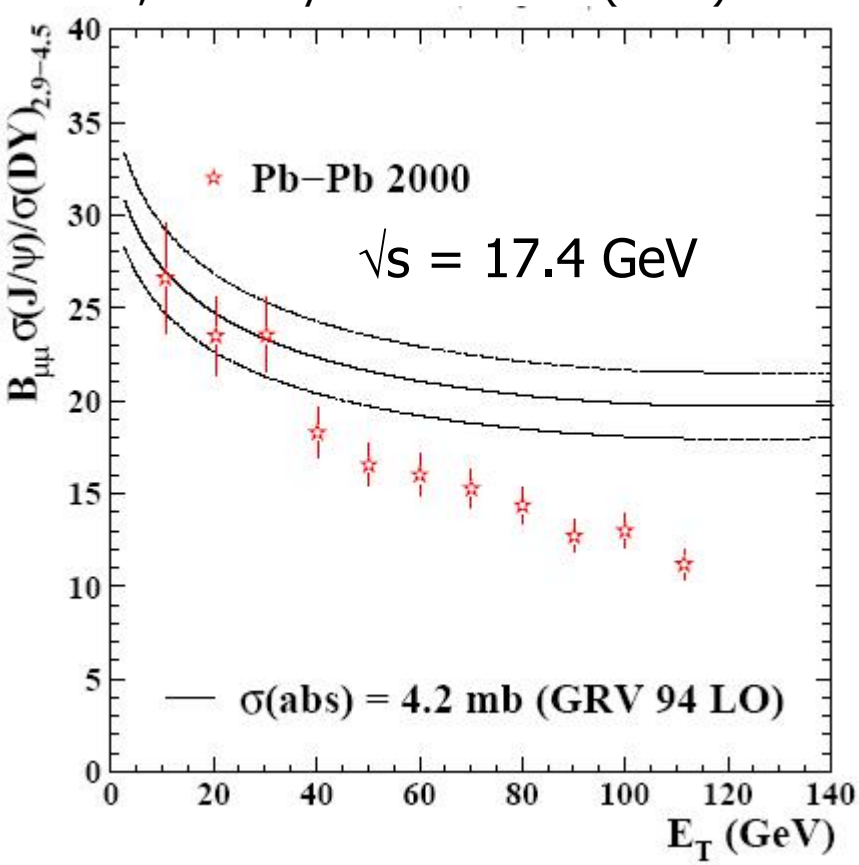
Motivation in A+A collisions

- J/Ψ production used as a probe of formed medium
- Anomalous suppression expected in case of QGP formation
- Observed by NA50 (and NA60) at SPS
- Alternative explanation (dense hadronic syst…)

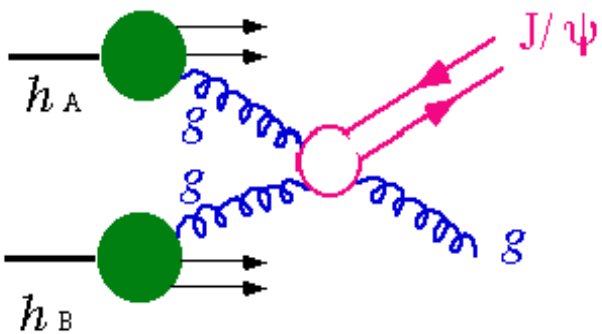
NA50, Eur. Phys. Journal C39 (2005) 335



Look for the effect at higher collision energy @ RHIC √s =200 GeV

J/Ψ hadro-production at RHIC

- J/Ψ production dominated by gluon fusion
- Feed-down from higher mass resonances:



χ_c (~30 %) et Ψ′ (~10 %)

p+p : J/Ψ production used as reference

AA production ~ pp x N_{coll}

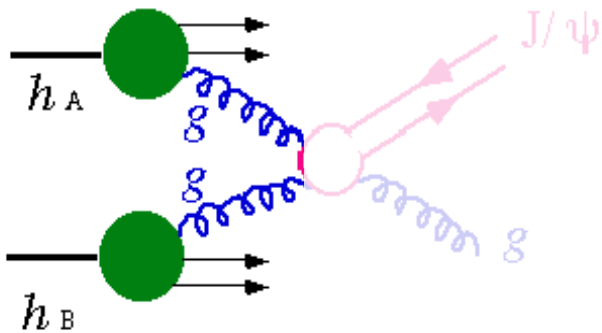
* N_{coll} number of binary collisions

$$R_{AB} = \frac{dN^{AB}/dy}{dN^{PP}/dy \times \langle N_{coll} \rangle}$$

Cold nuclear effects in J/Ψ production

– Initial state:

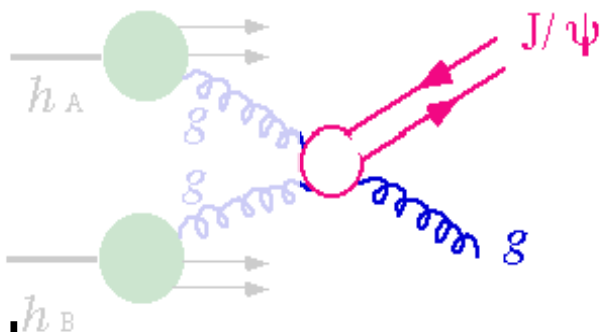
- Gluon (anti)-shadowing,
- p_T broadening (Cronin effect)



– Final state:

- Nuclear absorption

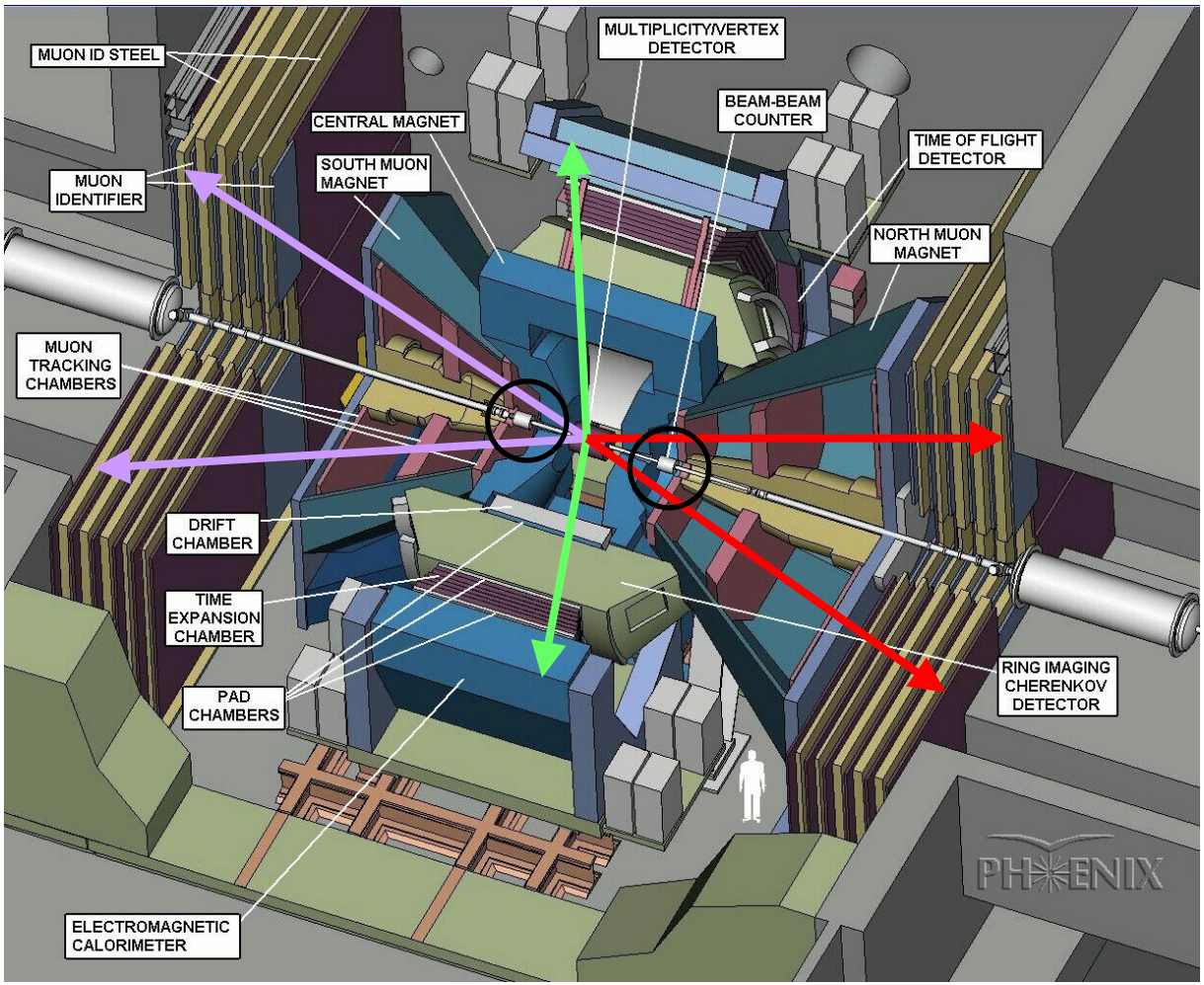
$$c\bar{c} + N \rightarrow open\,charm$$



AA production ≠ pp x N_{coll}

d+Au : disentangle cold nuclear effects

J/Ψ measurement in PHENIX



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

identified in RICH and EMCal

Tracking with momentum measurement in drift chamber, pixel pad chambers

- $|y| < 0.35$
- $P_e > 0.2$ GeV/c
- $\Delta\Phi = \pi$

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

identified with penetration depth / momentum match

tracking momentum measurement with cathode strip chambers

South :

- $-2.2 < y < -1.2$

North :

- $1.2 < y < 2.4$

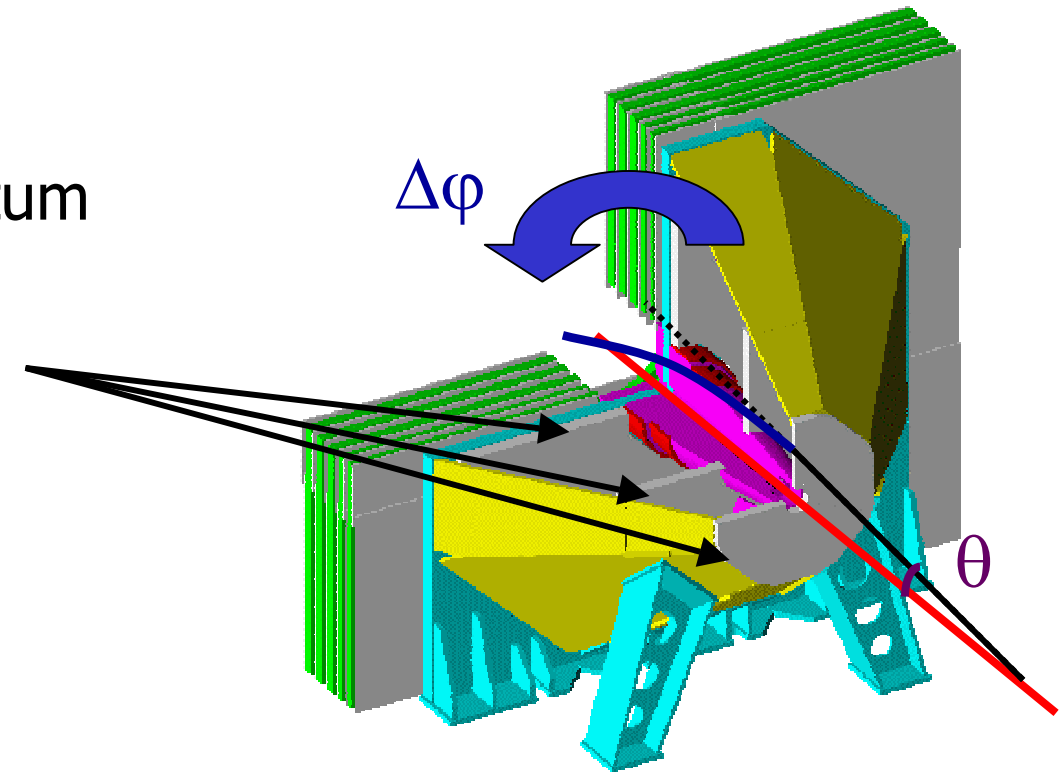
- $P_\mu > 2$ GeV/c
- $\Delta\Phi = 2\pi$

Muon arm: spectrometer + identifier

Radial magnetic field : $\Delta\varphi$

$\Delta\varphi$ & $\theta \Rightarrow$ particle momentum

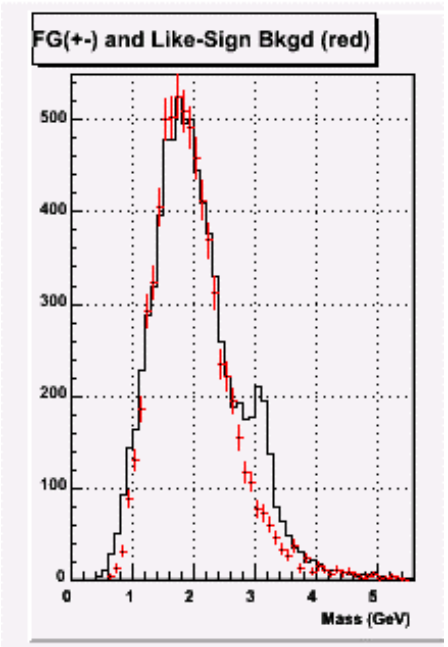
3 tracking stations

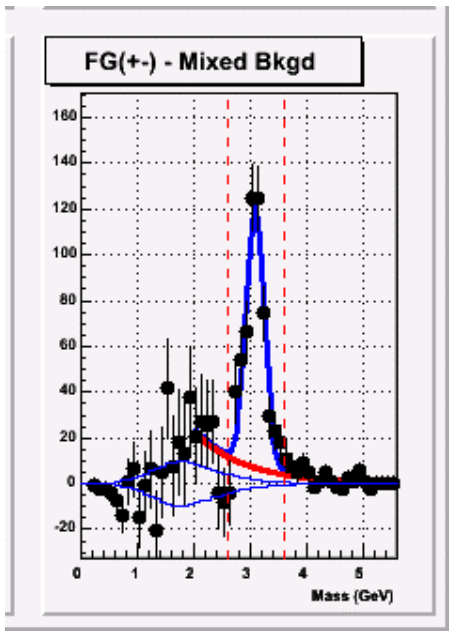


5 « gaps » per arm

vertical & horizontal orientation (~ 9 cm pitch)

J/Ψ Signal extraction





- Invariant mass μμ

$$M = \sqrt{(E_{\mu 1} + E_{\mu 2})^2 - (\vec{P}_{\mu 1} + \vec{P}_{\mu 2})^2}$$

  - Opposite signs
  - Like sign
- J/Ψ Signal obtained by combinatorial background subtraction:

  Signal = N_{+-} - $\text{background}_{\text{combinatorial}}$

- gaussian fit (J/ψ) + exponential
- *acceptance and inefficiencies corrections*

→ Cross section

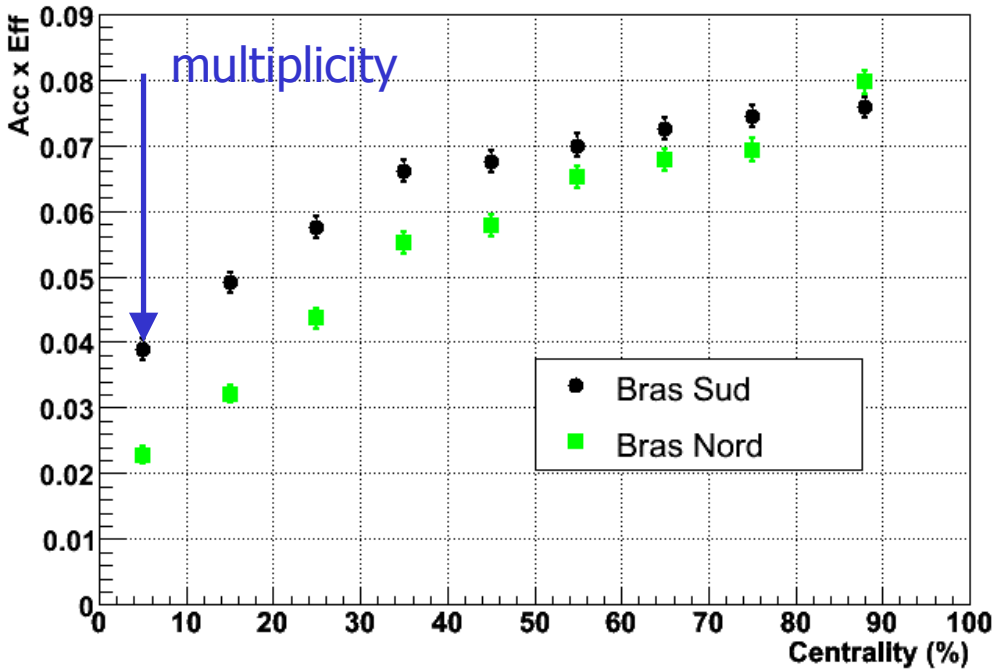
Acceptance & efficiency corrections

- J/Ψ with PYTHIA over 4π sr
- Embed into real minimum bias data
  - Perfect z vertex matching
  - realistic detector response (gain, HV)
- Efficiency determination
  - As a function of different kinematic variables
  - Strong centrality dependence

acceptance & level 2 & reconstruction & analysis cuts

Final corrections

- Acceptance,
- Level 2,
- Pattern Reconstruction
- Analysis cuts



North and South multiplicity different

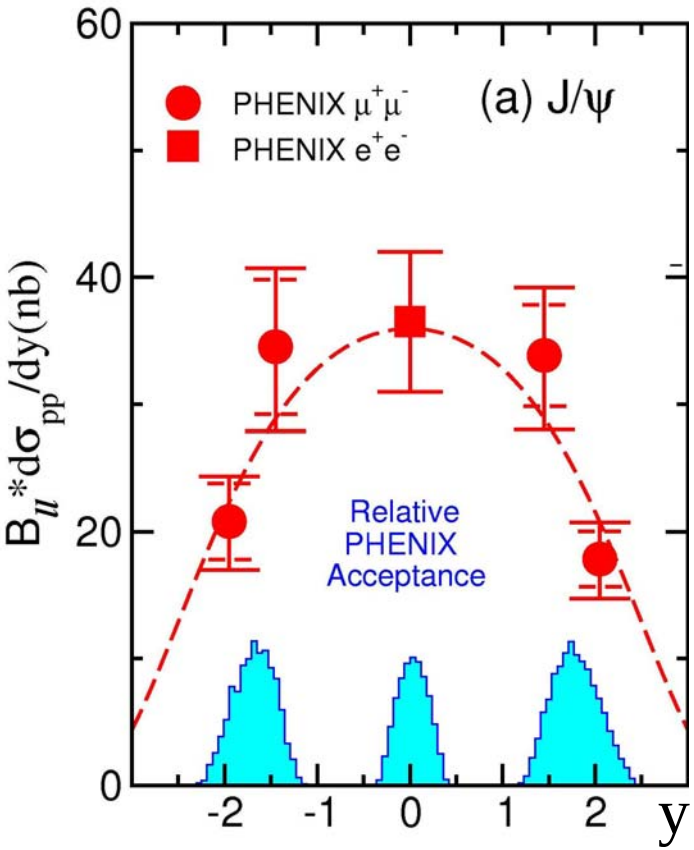
PHENIX data taking at RHIC

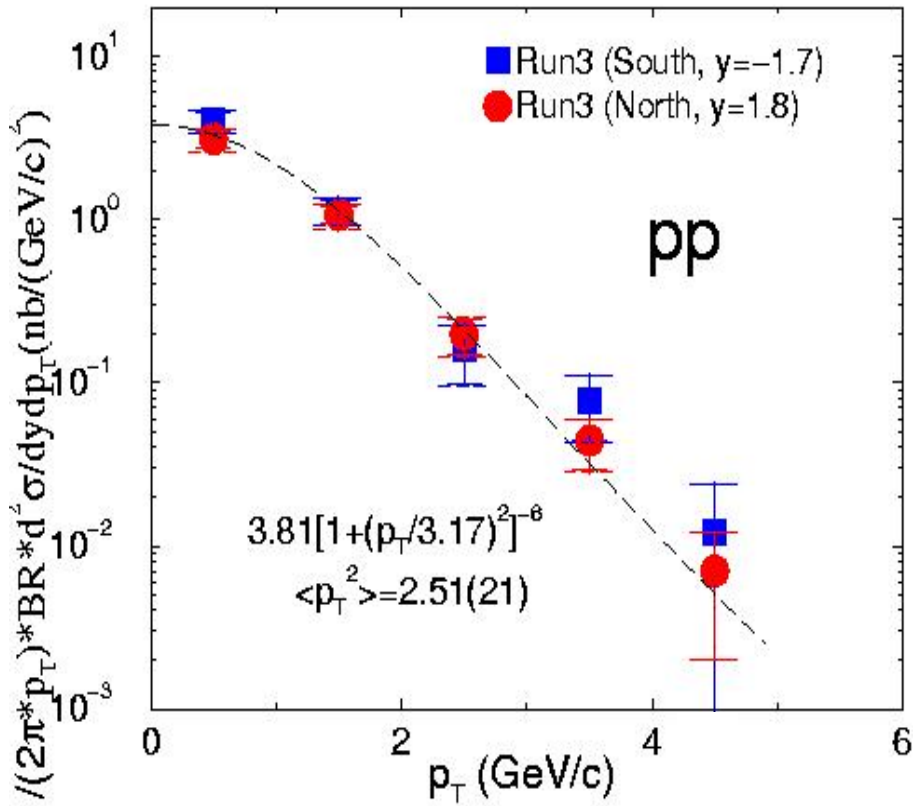
Year	System (ions)@√s	Int. luminosity	J/Ψ (ee + μμ)
2001	Au + Au @ 130 GeV	1 μb^{-1}	
2002	p + p @ 200 GeV	0,15 pb^{-1}	46 + 66
	Au + Au @ 200 GeV	24 μb^{-1}	13 (ee)
2003	p + p @ 200 GeV d+Au @200 Gev	350 nb^{-1} 2,74 nb^{-1}	100 + 420 300 + 1400
2004	Au + Au @ 200 GeV	240 μb^{-1}	~800 + ~5000
	Au + Au @ 63 GeV p + p @ 200 GeV	9.1 μb^{-1} 324 nb^{-1}	13 (ee)
2005	Cu + Cu @ 200 Gev Cu + Cu @ 63 Gev p + p @ 200 GeV	3,06 nb^{-1} 190 mb^{-1} 3,8 pb^{-1}	900 + 10 000 ~200 (μμ) ~11200 (μμ)
2006	p + p @ 200 GeV		

Baseline
p+p and d+Au in RUN3 (2003)
Final results (Phys. Rev. Lett. 96, 012304)

J/Ψ production in p+p

Phys. Rev. Lett. 96, 012304





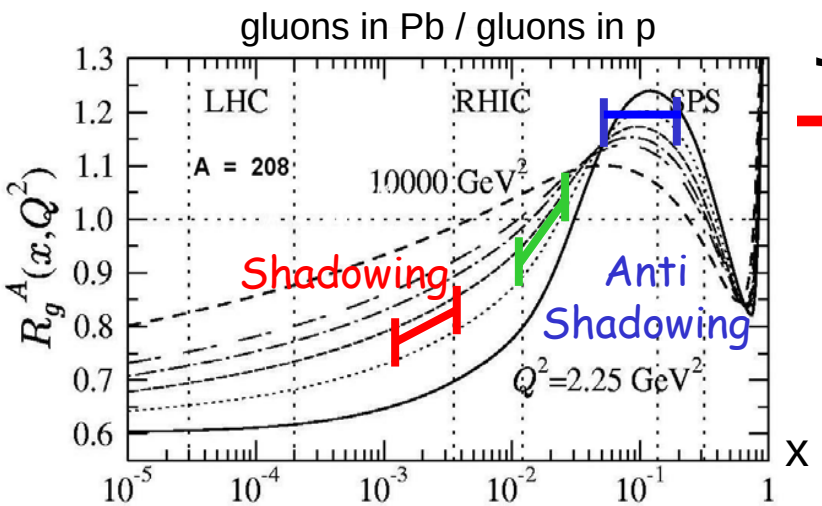
$$\frac{1}{2\pi p_t}\frac{d\sigma}{dp_t} = A[1+(p_t/B)^2]^{-6}$$

Total cross section in p+p

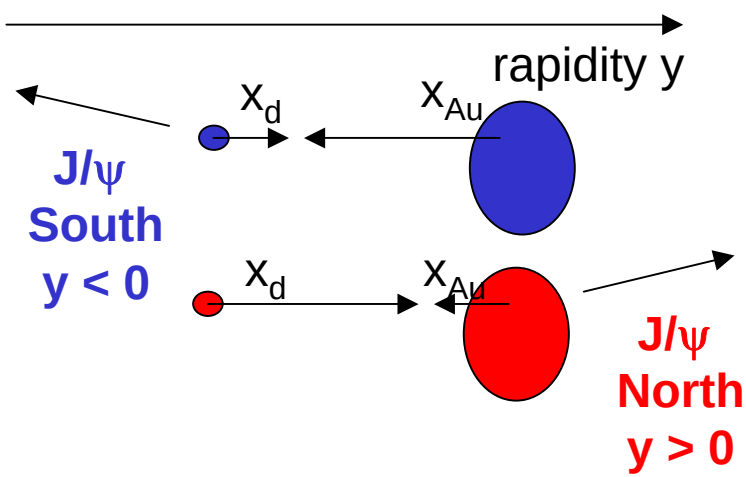
$\sigma = 2.61 \pm 0.20 \pm 0.26$ μb

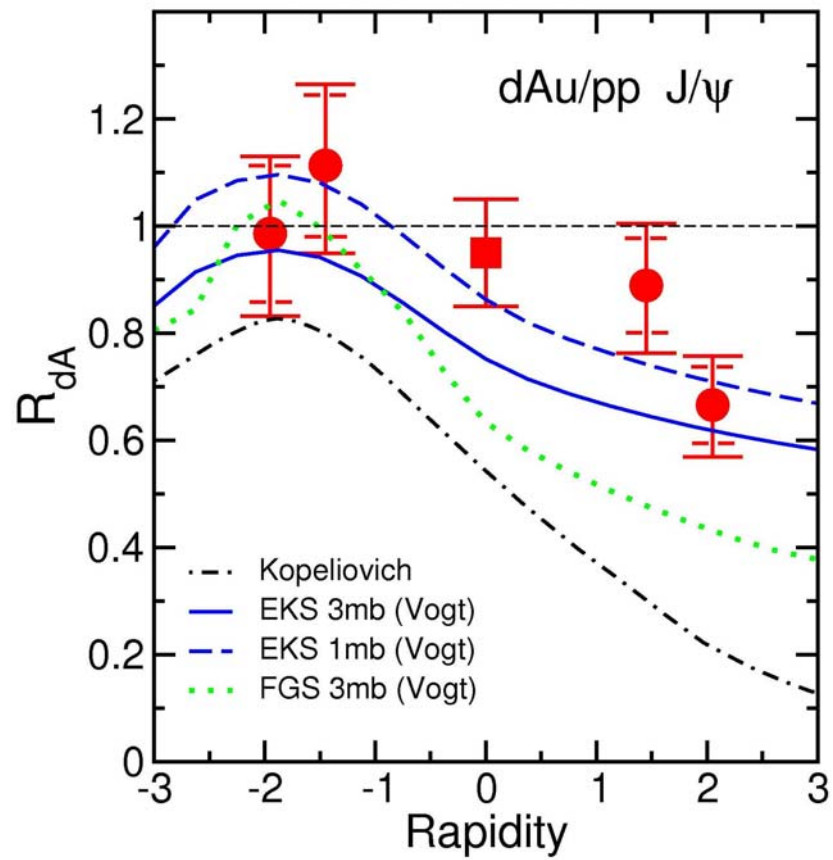
$\langle p_t^2 \rangle = 2.51\ (\mathrm{GeV/c})^2$

J/Ψ production in d+Au



Nucl. Phys. A696 (2001) 729-746





y < -1.2 : large x_{Au} ~ 0.090

y ~ 0 : intermediate x_{Au} ~ 0.020

y > 1.2 : low x_{Au} ~ 0.003

$$R_{dA} = \frac{\sigma_{dAu}}{(2 \times 197 \times \sigma_{pp})}$$

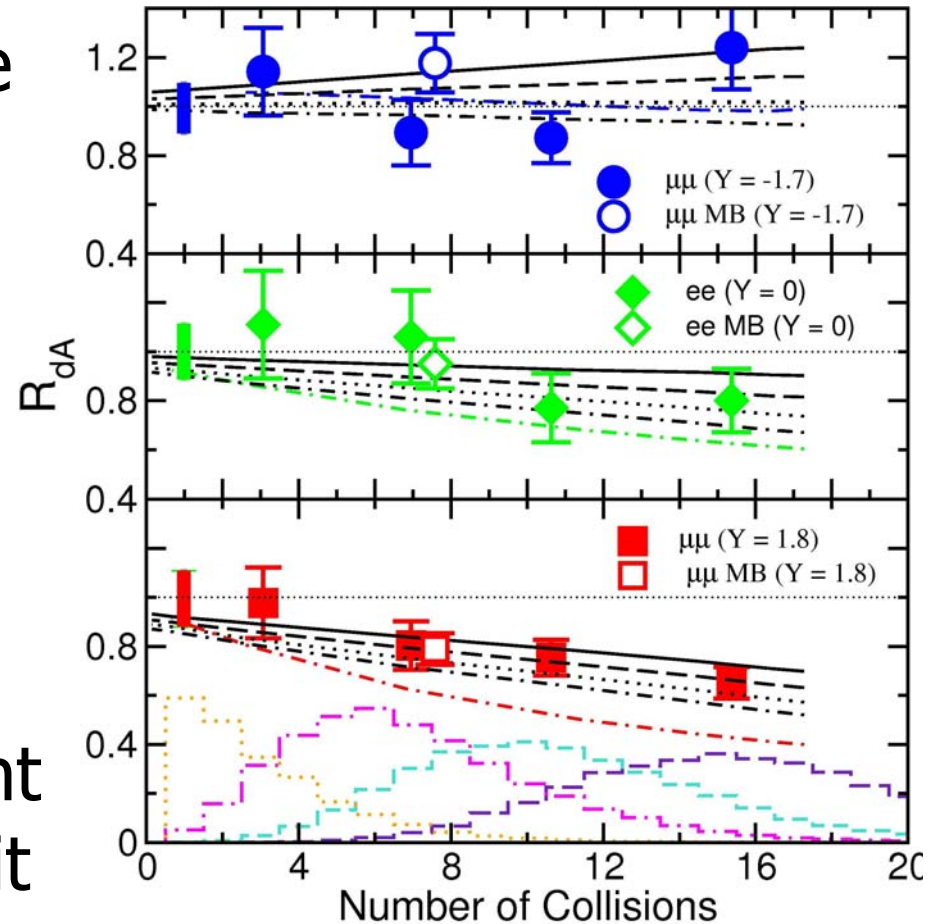
J/Ψ production in d+Au vs centrality

Small centrality dependence

Models with absorption + shadowing

- shadowing EKS98
- σ^{abs} = 0 to 3 mb

σ^{abs} = 1 mb good agreement
σ^{abs} = 3 mb is an upper limit

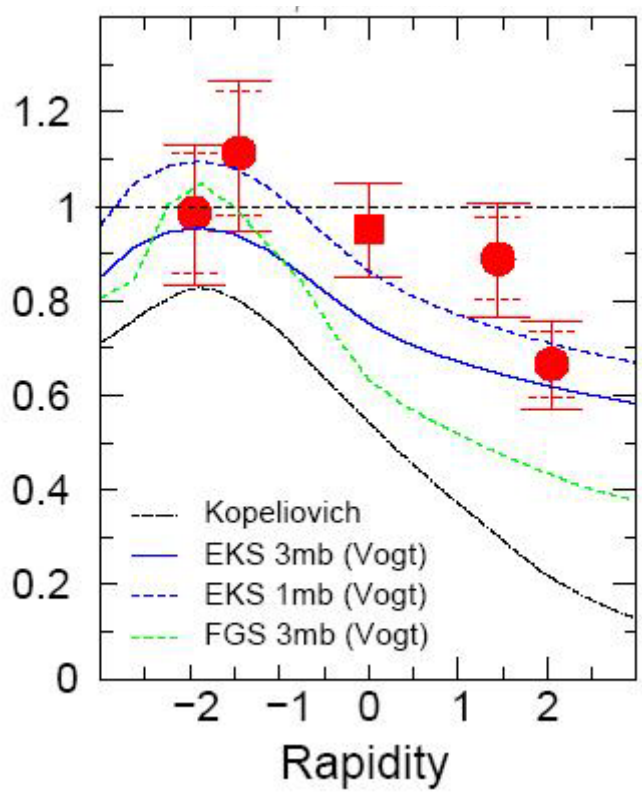


Cold nuclear effects at RHIC

- Cold nuclear effects observed
  - Weak shadowing and weak nuclear absorption observed (1 to 3mb max)
  - Weak p_T broadening

    $<pt^2> = 4.28 +/-0.31 (GeV/c)^2$

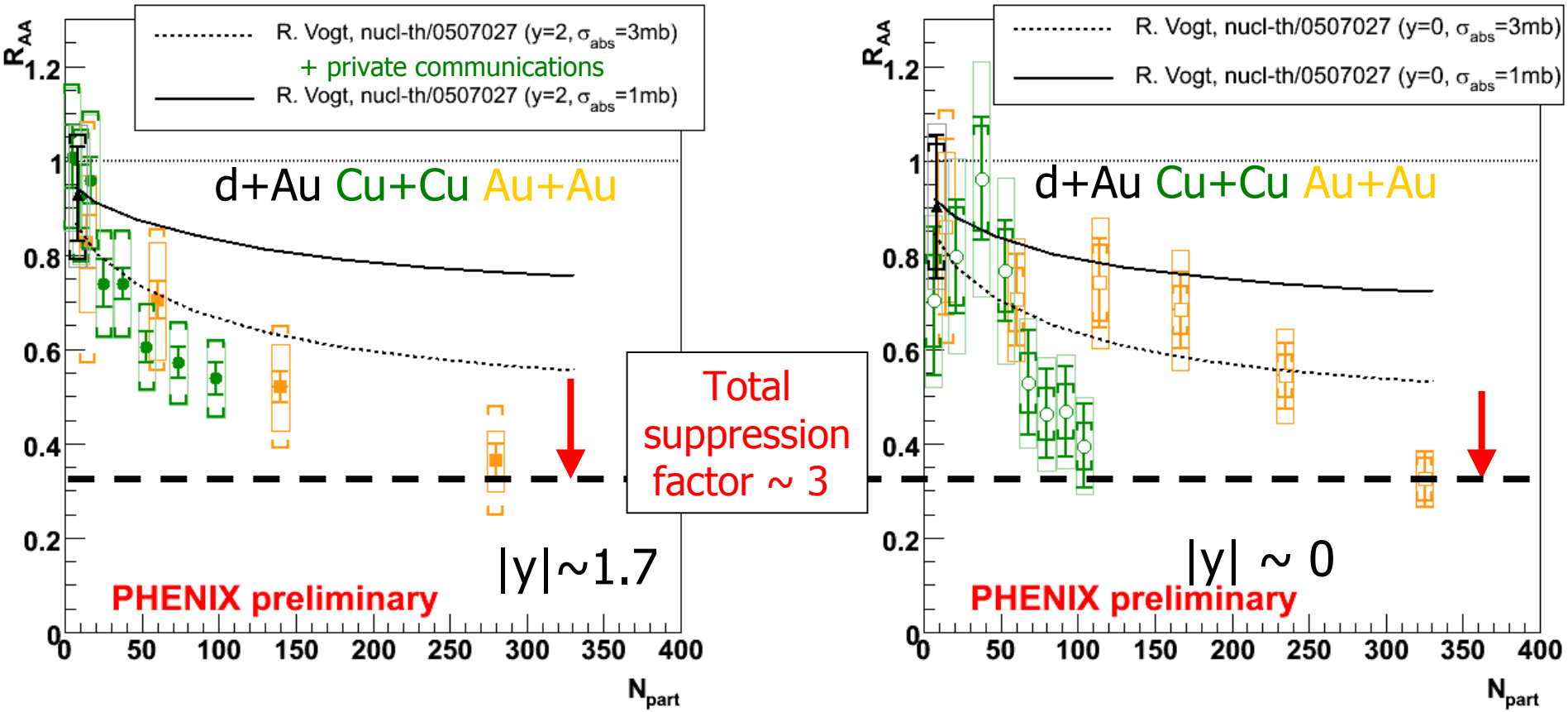
    $<pt^2> = 3.63 +/- 0.25 (GeV/c)^2$



- Models including (shadowing + absorption) correctly describe data

J/Ψ production in heavy ions collisions
Preliminary results

R_{AA} vs N_{part} Au+Au and Cu+Cu



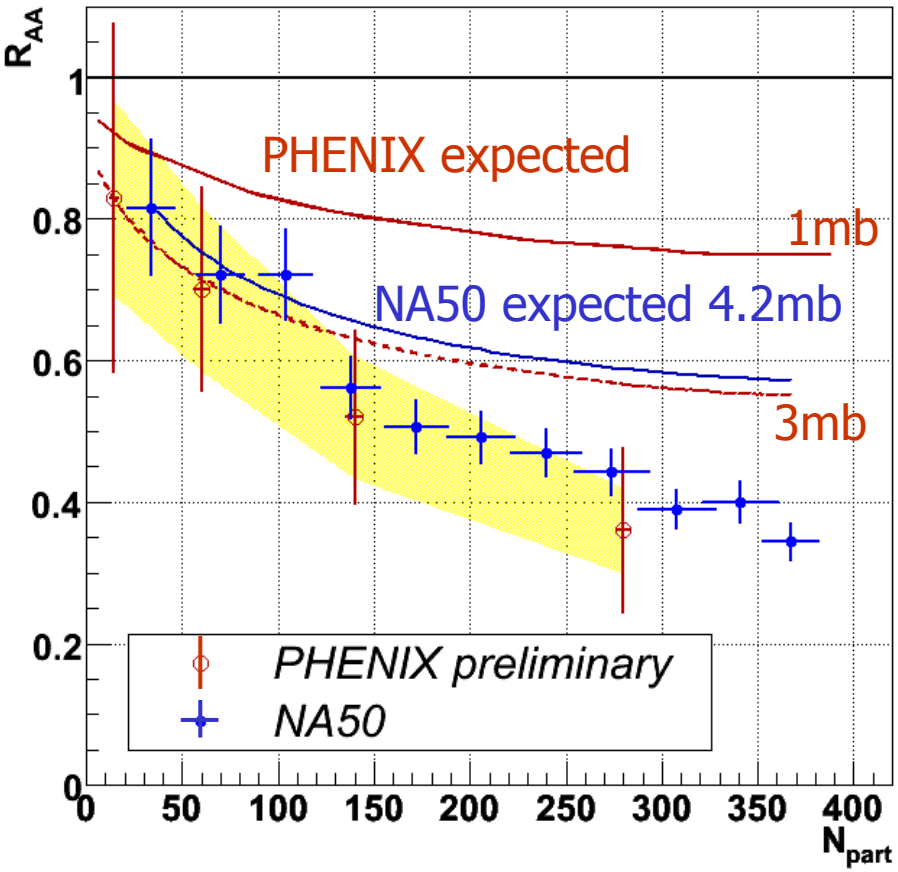
Cold nuclear effects alone:

shadowing and σ_{abs} = 1 mb (solid) and 3 mb (dashed, upper limit)

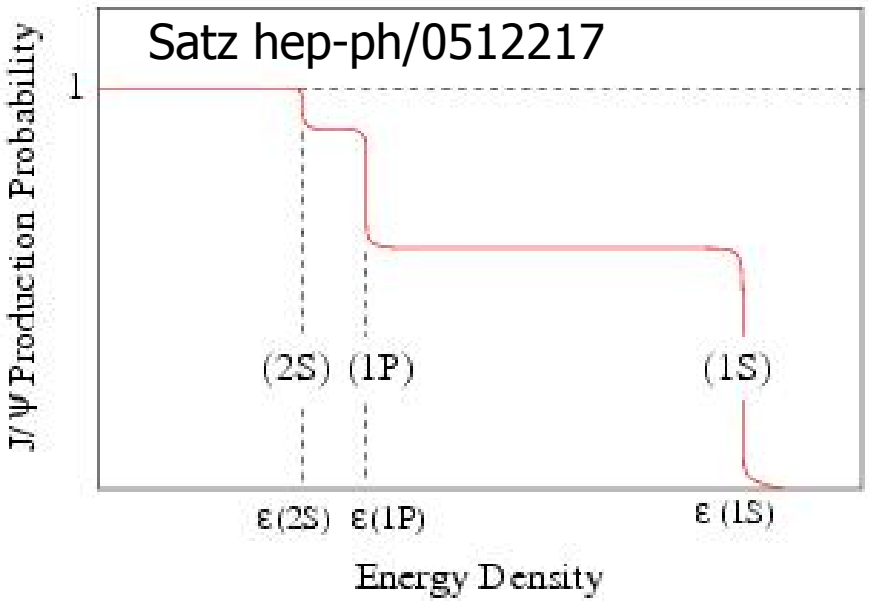
Suppression beyond cold nuclear effect: anomalous suppression ?

Bars: statistical errors, brackets: systematics, boxes: common errors

Raw comparison to NA50 data



Comparison with NA50 data presented wrt N_{part} and normalized to NA51 p+p point.



- But nuclear effects are supposed to be different at SPS vs RHIC
- Need to better constrain cold nuclear effects at RHIC

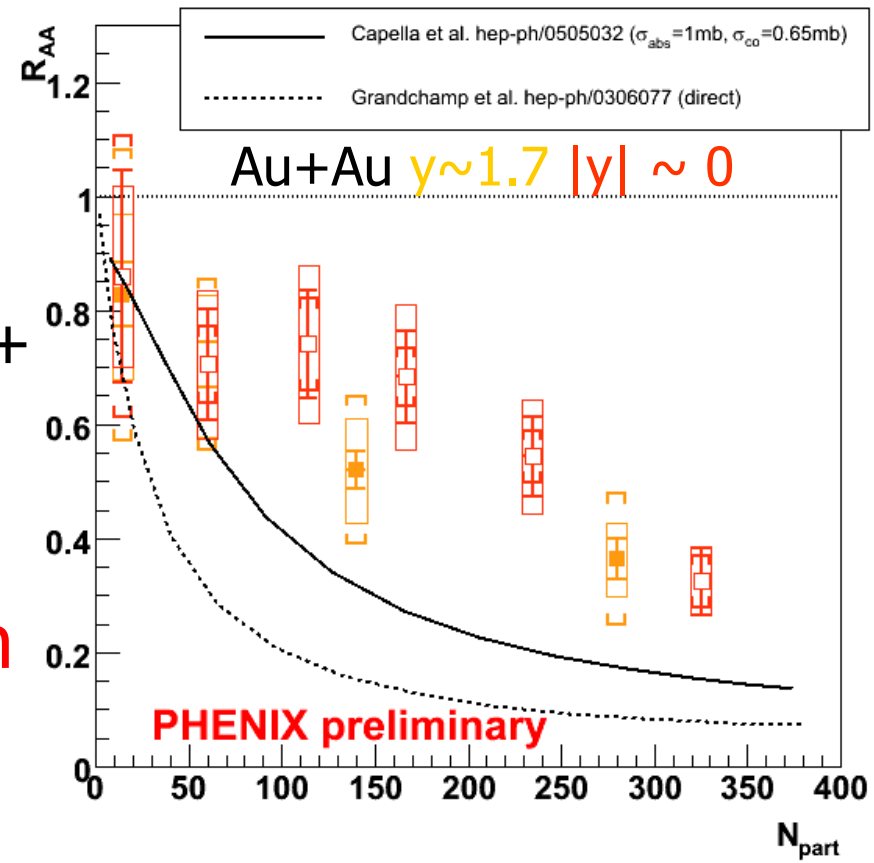
Suppression models

Models accounting for NA50 data extrapolated at √s = 200 GeV:

- Comovers + normal absorption + shadowing (solid)
- QGP suppression (dashed)

Overestimate the suppression observed at RHIC

(other available predictions give same results)



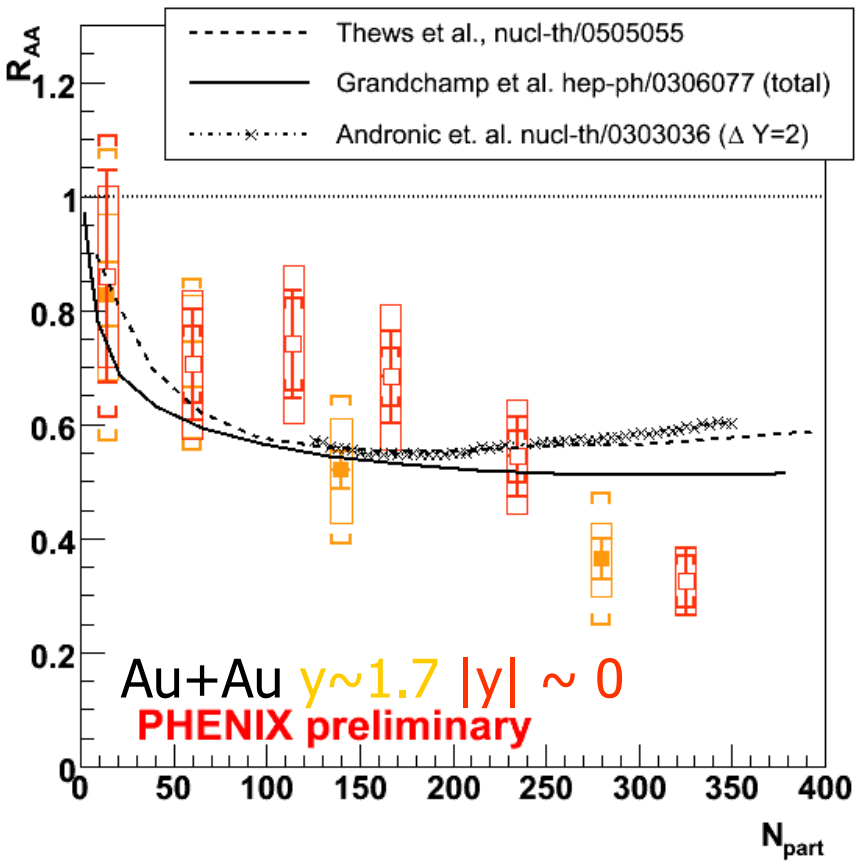
+ private communications

Regeneration models

QGP suppression+regeneration

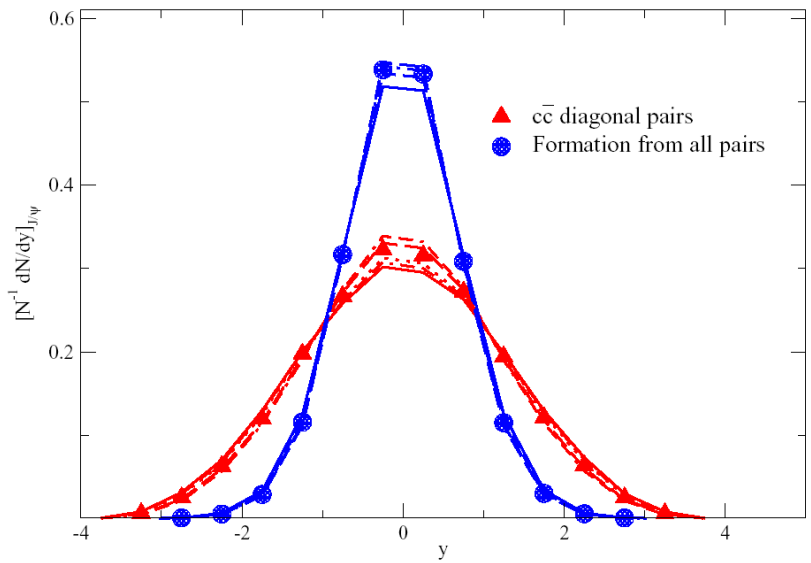
reasonable agreement but regeneration goes as $\sigma_{c\bar{c}}^{2}$ (not precisely measured yet)

If regeneration scenario, huge effect expected at LHC



+ private communications

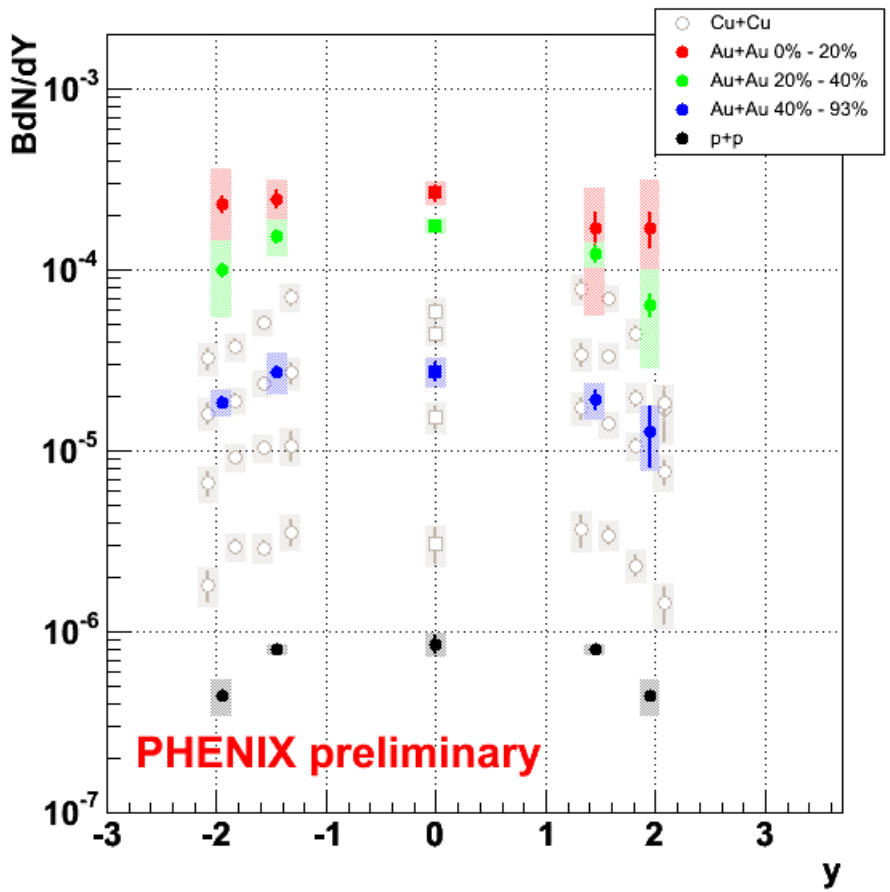
Regeneration model: rapidity distribution



Idea* : Charm quark production favored at y~0.

=> Rapidity distribution of recombined J/ψ is supposed to be peaked at y=0

R.L. Thews et. al. nucl-th/0505055

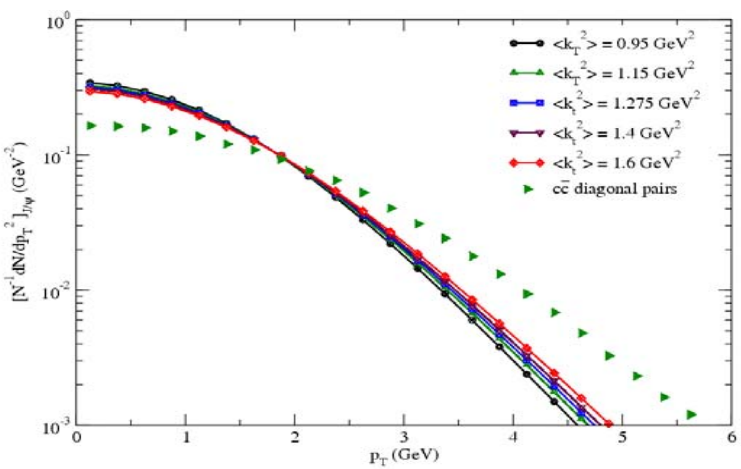


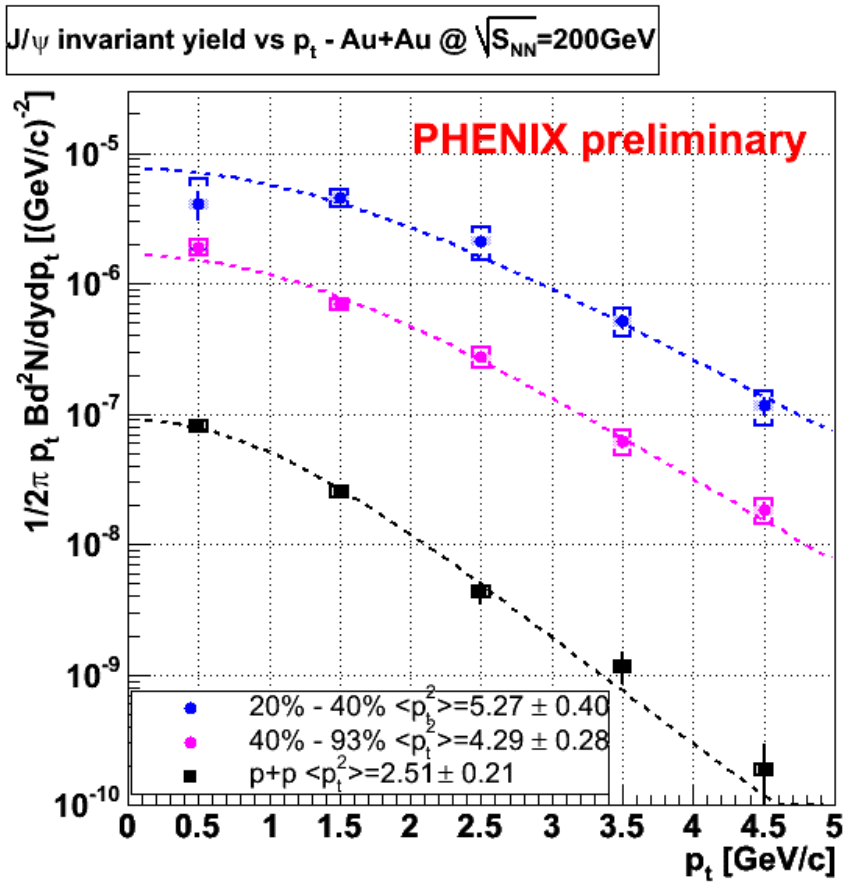
No significant modification of the y distribution observed

Regeneration model : p_t distribution

Idea* : charm quark production (pQCD) favored at low pt

=>Recombined J/ψ at low pt favored

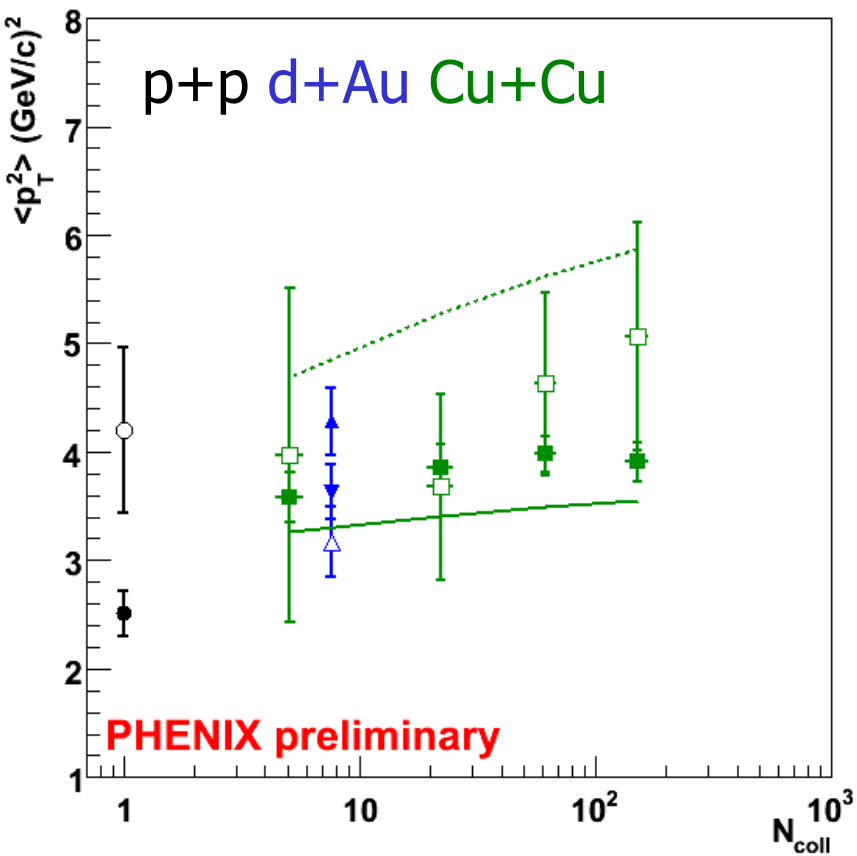


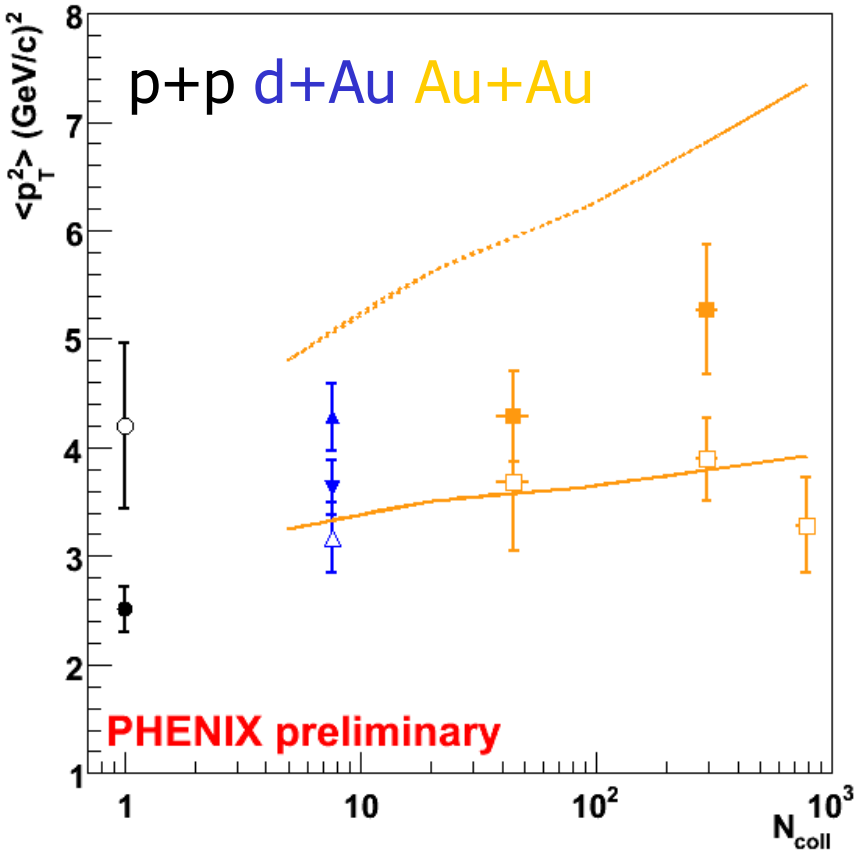


*R.L. Thews et. al. nucl-th/0505055

Regeneration model : $<pt^2>$ vs N_{coll}

Open markers: |y| < 0.35 Filled markers: y ~2





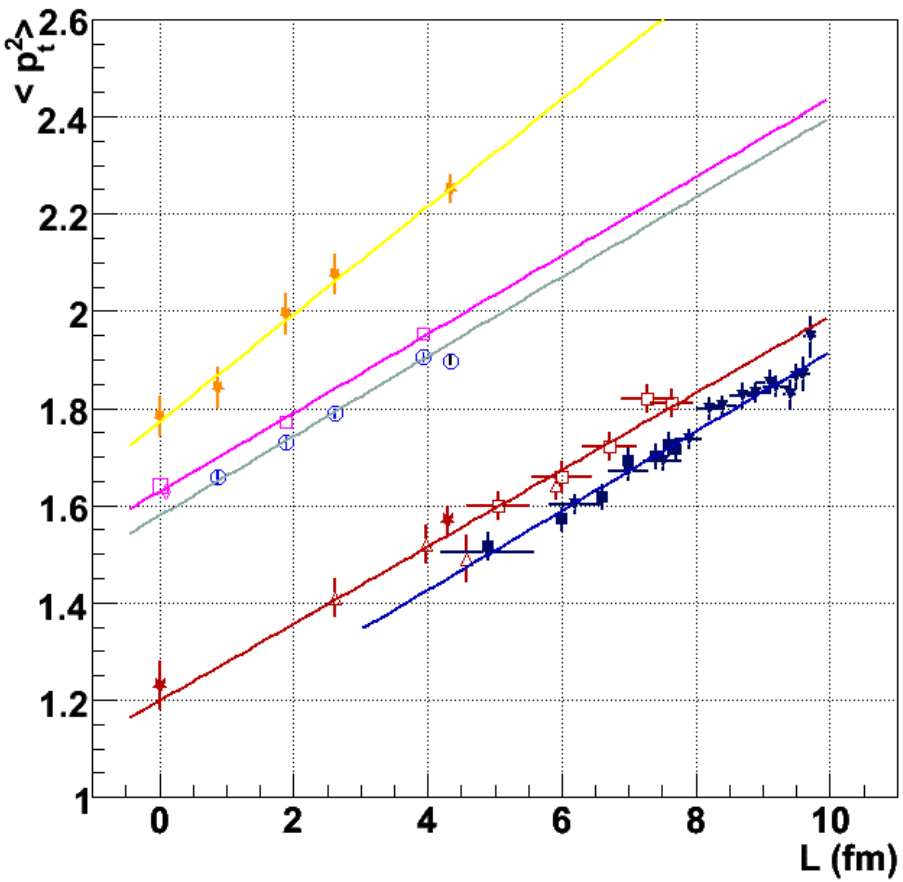
Lines are a prediction with/without recombination*

Mixture of recombined and non recombined ?

*R.L. Thews et. al. nucl-th/0505055

Cronin effect

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



$\sqrt{s}$ =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

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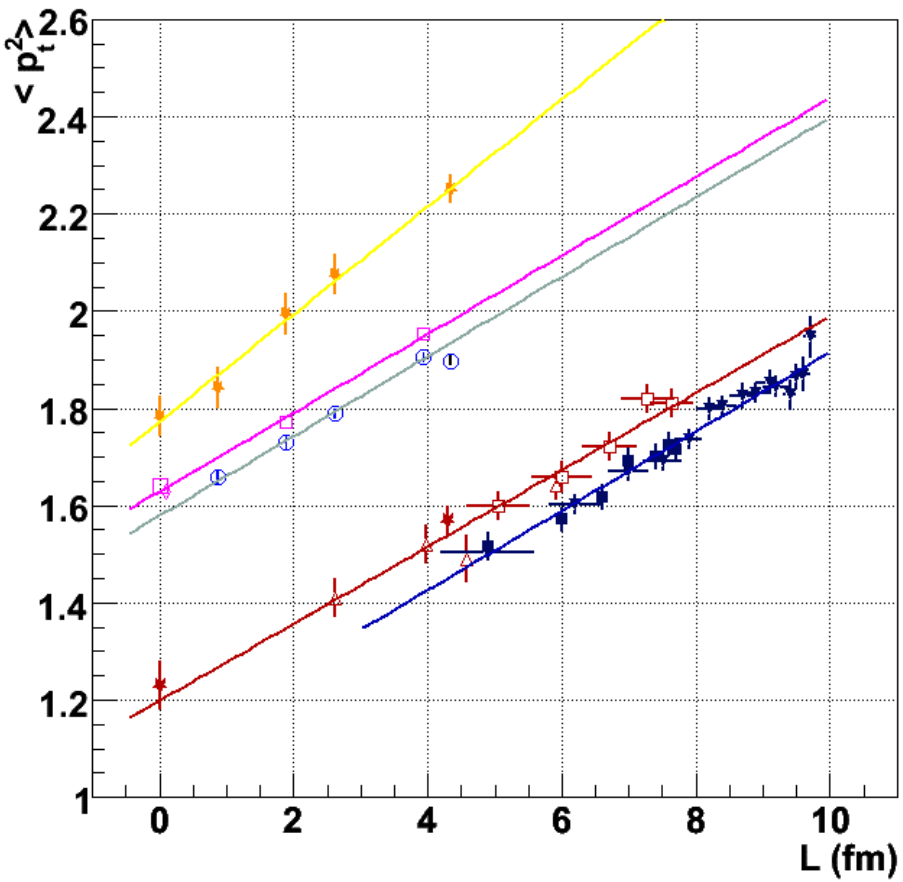

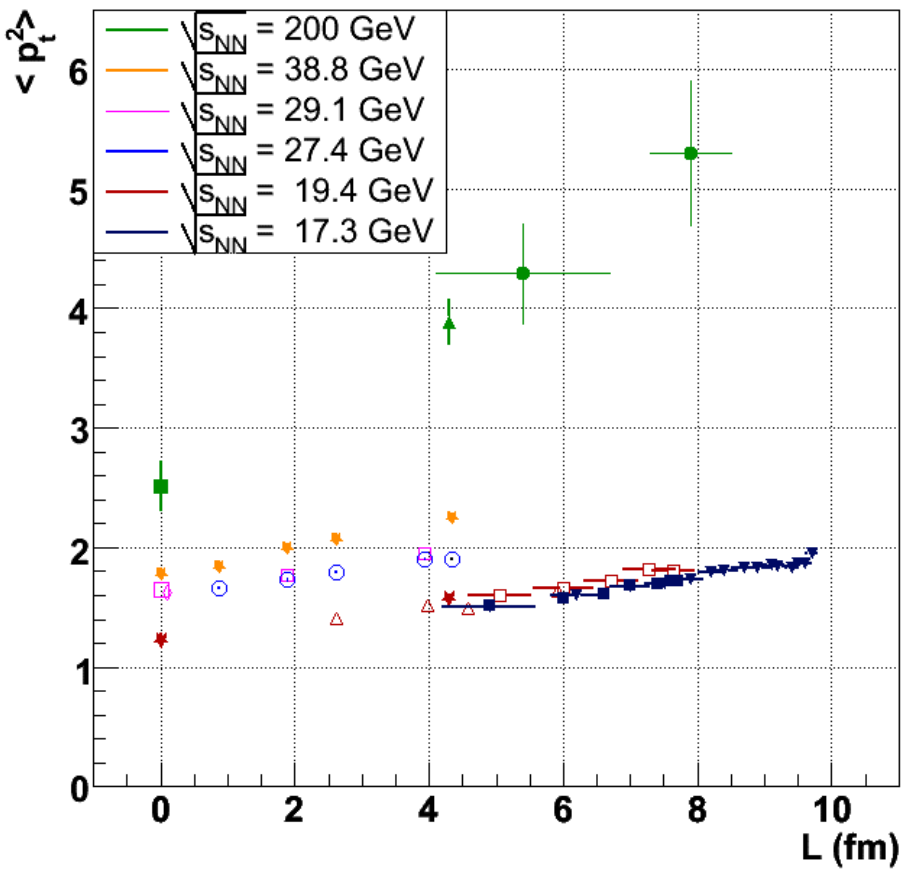

Extrapolation curve from PHENIX J/ψ results in p+p and d+Au

Cronin effect

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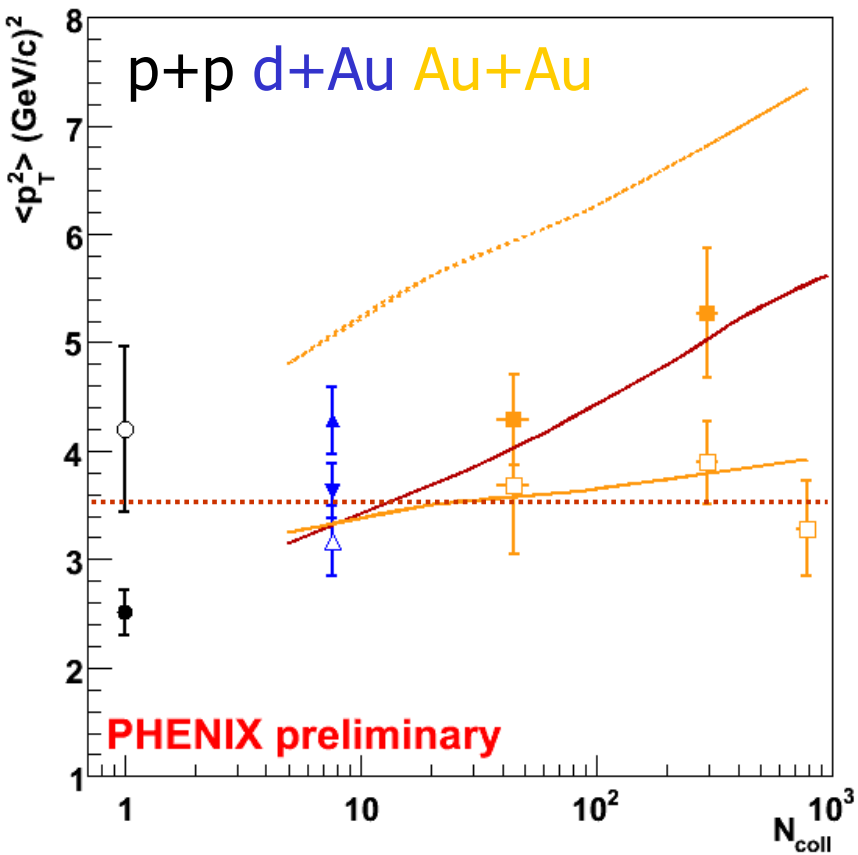
Extrapolation curve from PHENIX J/ψ results in p+p and d+Au

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



Summary & Outlook

J/ψ measured in p+p, d+Au : cold nuclear effects

Weak shadowing and weak absorption (1 to 3 mb at max)

Au+Au :

- suppression at RHIC beyond cold nuclear effects
- models that explain NA50 measurements overestimate suppression at RHIC
- « raw » suppression measured at RHIC and SPS have similar amplitudes. χ_c suppression only ? If yes, J/ψ at LHC !
- J/ψ transport + QGP suppression ?
- regeneration needed ? y, p_t distribution ?

More precision at RHIC :

- Need more accurate d+Au & A+A data with higher luminosity and better measurements (silicon vertex upgrade)
- Need accurate charm cross section to constrain regeneration models (silicon vertex upgrade)

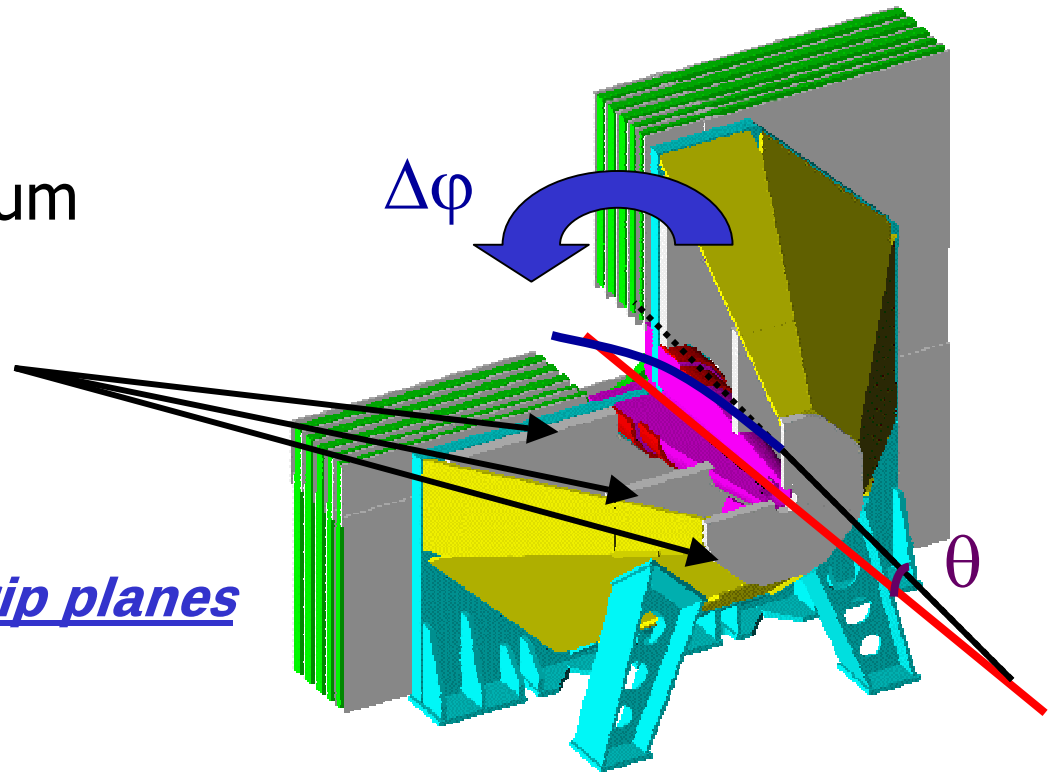
Back up slides

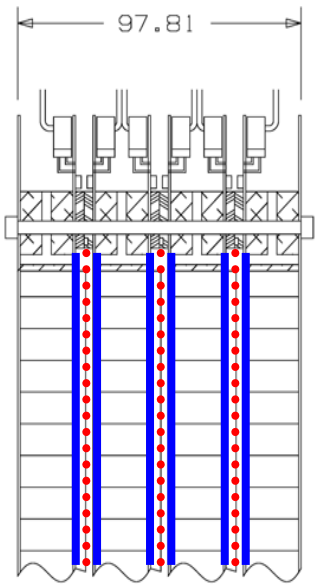
Muon spectrometers

Radial magnetic field : $\Delta\varphi$

$\Delta\varphi$ & $\theta \Rightarrow$ particle momentum

3 tracking stations





gap :

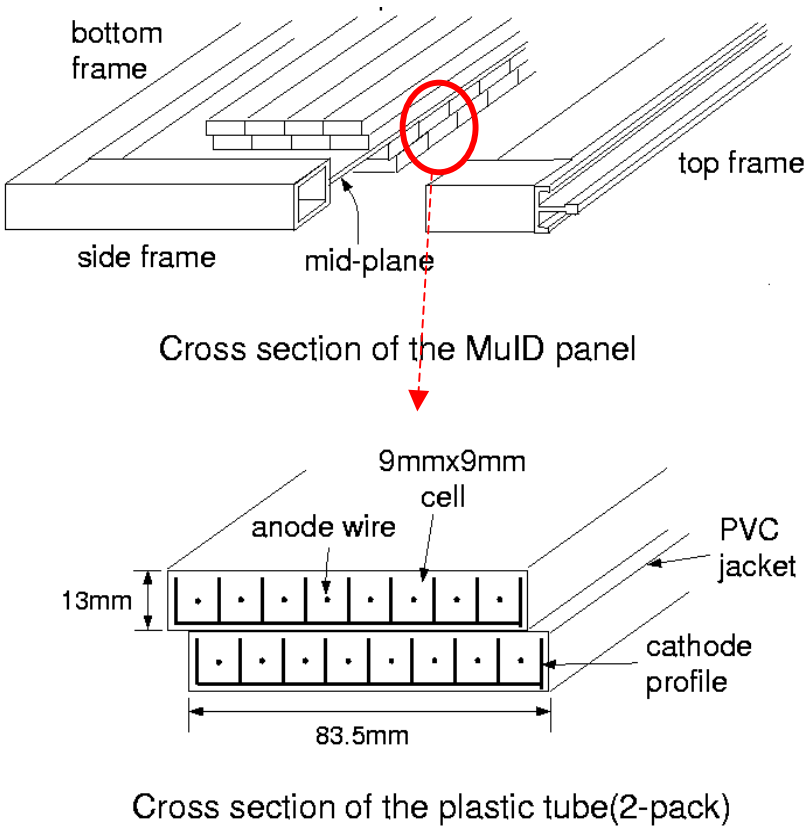
- 2 ***cathode-strip planes***
- anode plane

gaz mixture: Ar 50%, CO_2 30% et CF_4 20%

HV ~ 1800 V

(6+6+4) planes/arm ~ 22 000 readout channels

Muon identifiers



5 « gaps » per arm

vertical & horizontal orientation (~ 9 cm pitch)

Pattern reconstruction algorithm

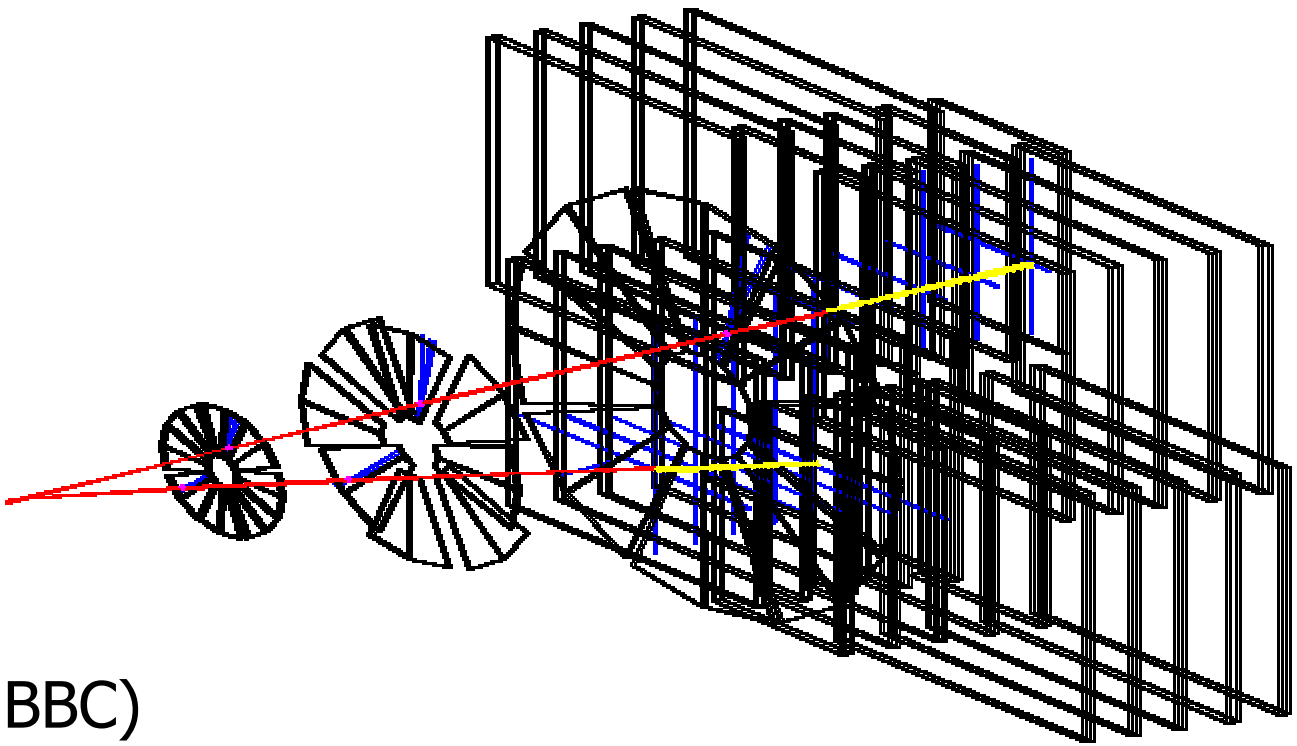
MuID : roads

MuTr : stubs

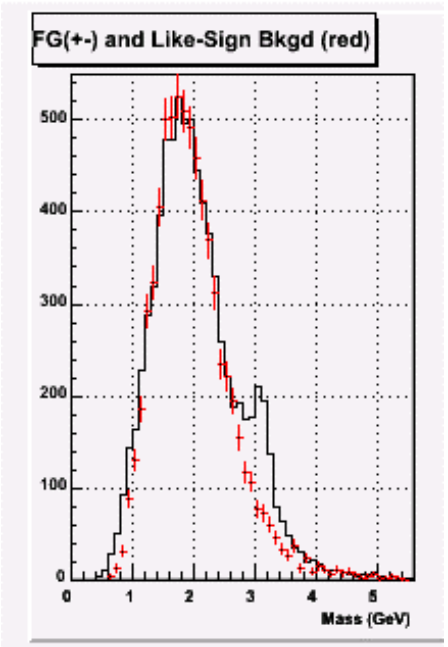
tracks

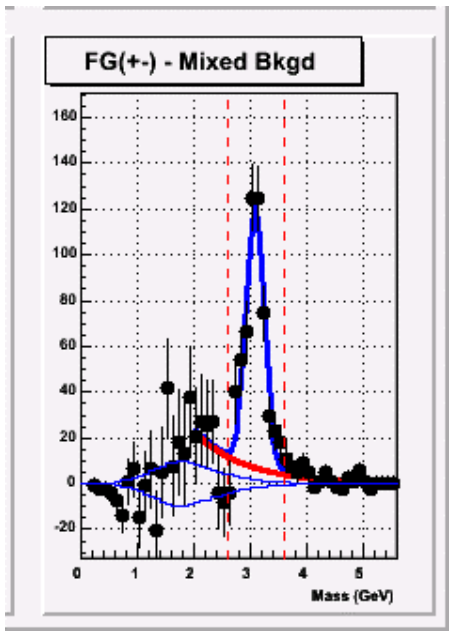
z vertex fit (+ BBC)

Kalman Filter – road-association



J/Ψ Signal extraction





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- Embed into real minimum bias data
  - Perfect z vertex matching
  - realistic detector response (gain, HV)
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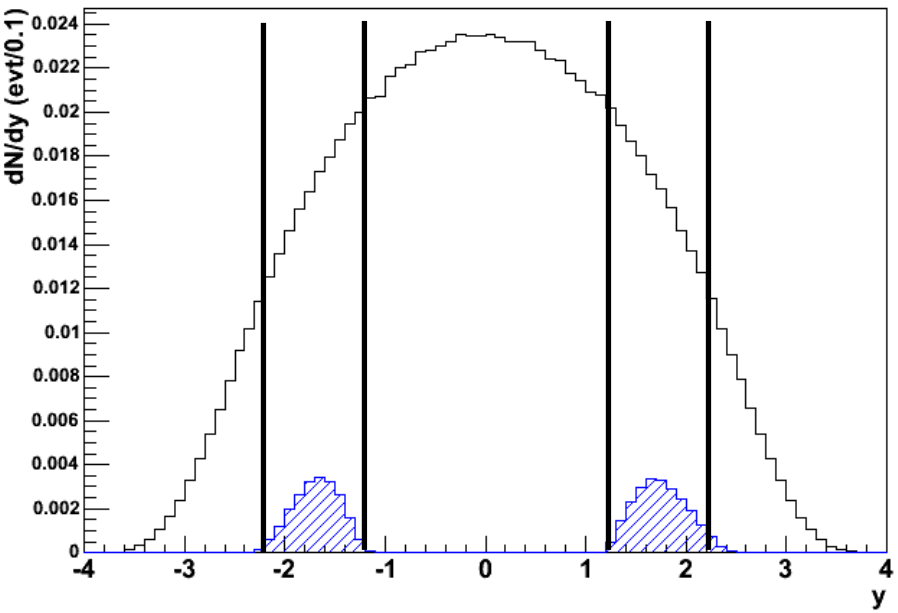
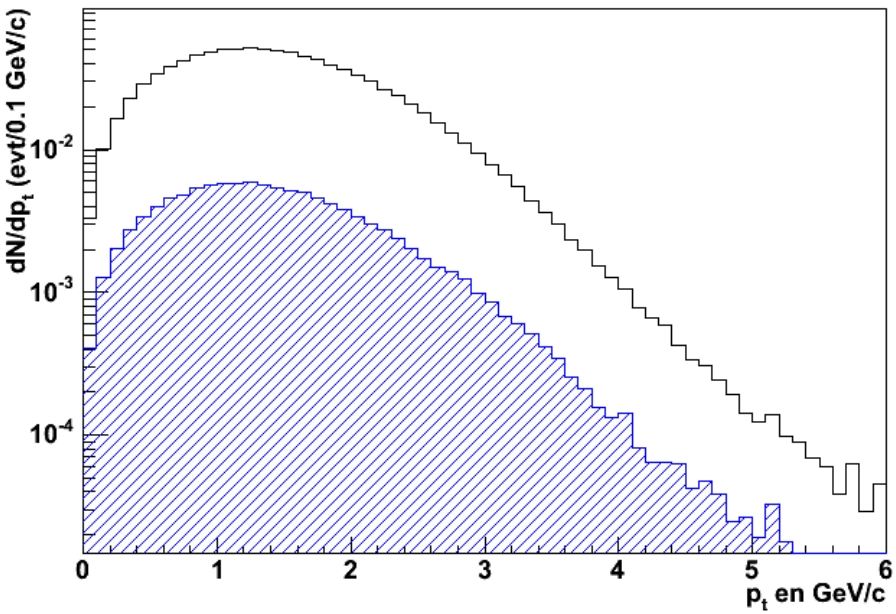
acceptance & level 2 & reconstruction & analysis cuts

Acceptance





Initial Distribution (PYTHIA)

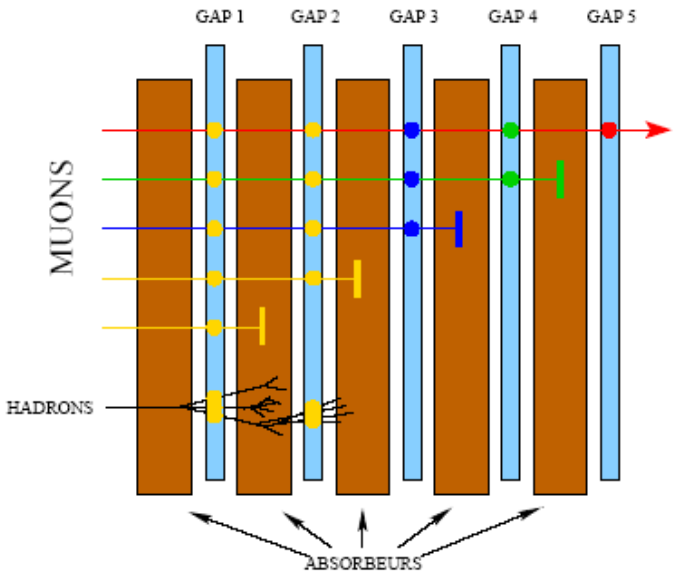
J/Ψ into detector acceptance

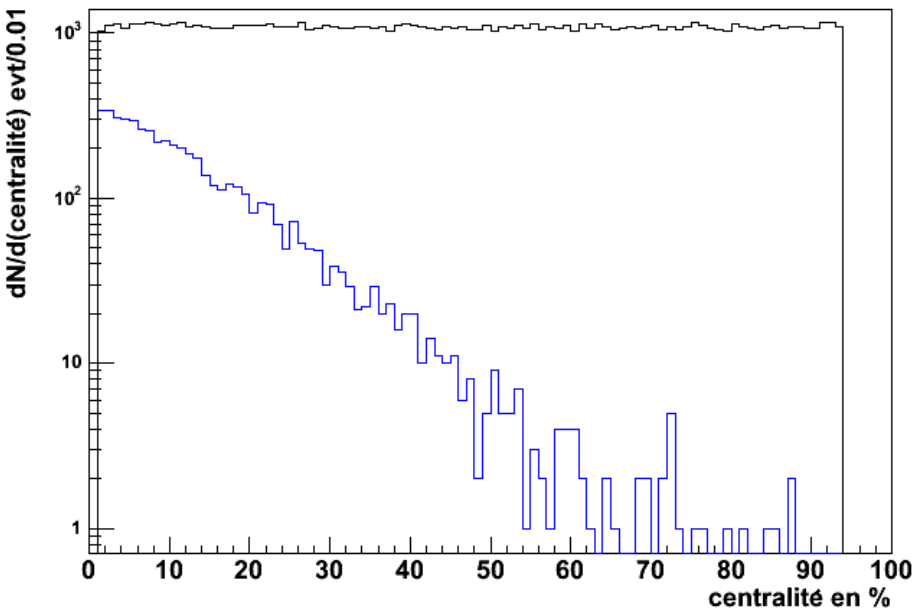
} ~ 13% per arm

(1,2< |y|< 2,2)

Level 2 offline trigger (offline)

- Based on a fast simplified tracking in MuID
  - 2 deep roads + nhits >= 8 hits
  - Cut on road slope (θ>12°)
  - And pairs opening angle (>19,2°)





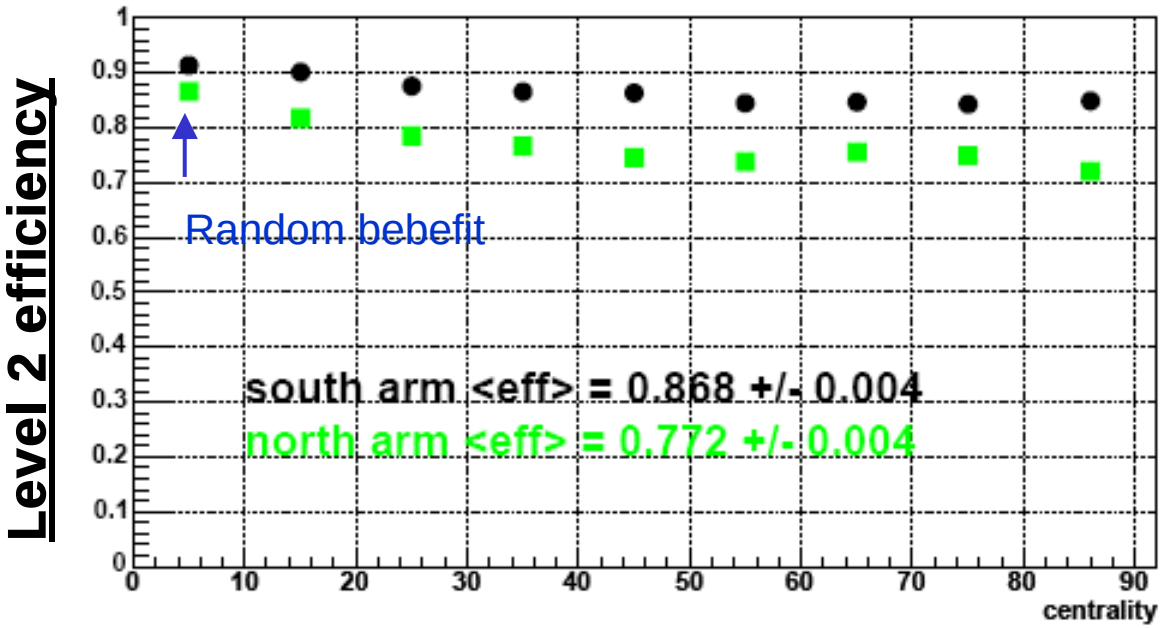
- Performance

- <Rejection power> : 40/arm

- Production time is 3 to 4 times faster than for MB events

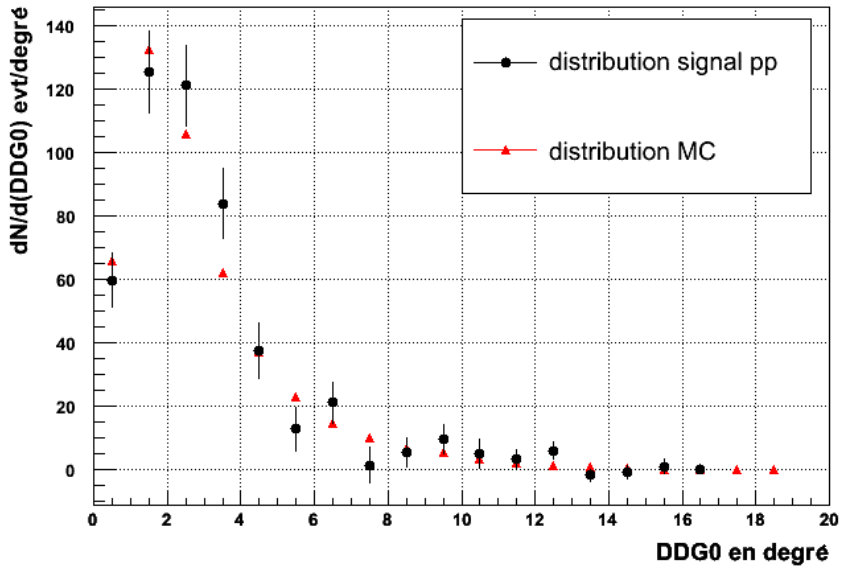
Level 2 offline trigger (offline)

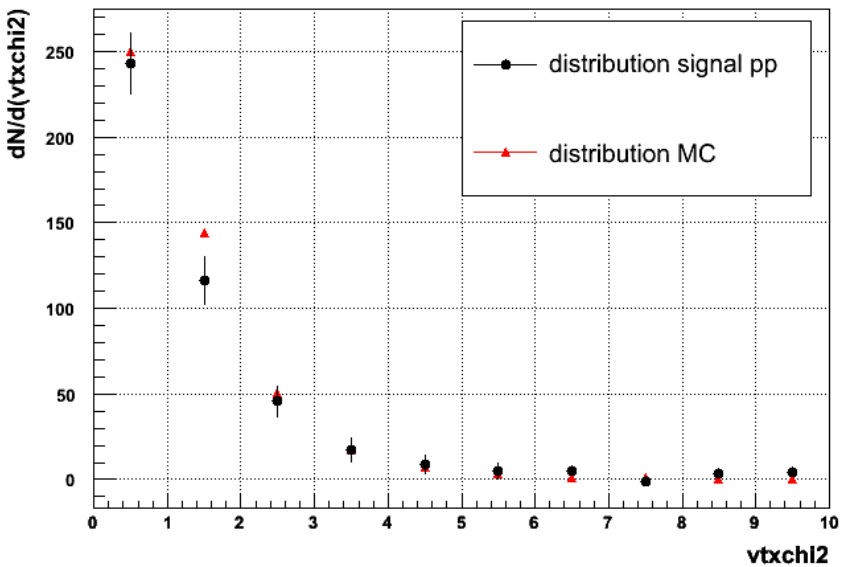
< J/Ψ Efficiency> ~ 87 % (south) and 77 % (north)

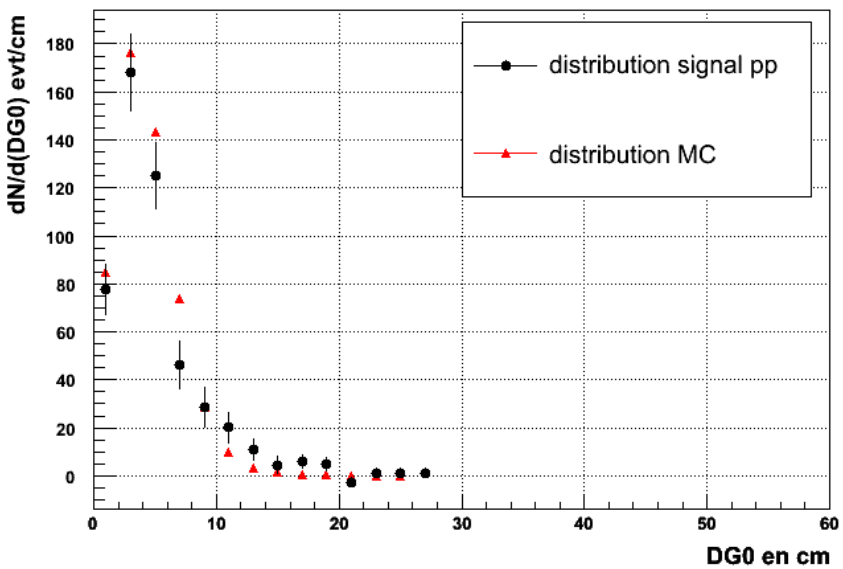


Analysis cuts

Analysis cuts based on track quality
Signal and MC distributions are consistent

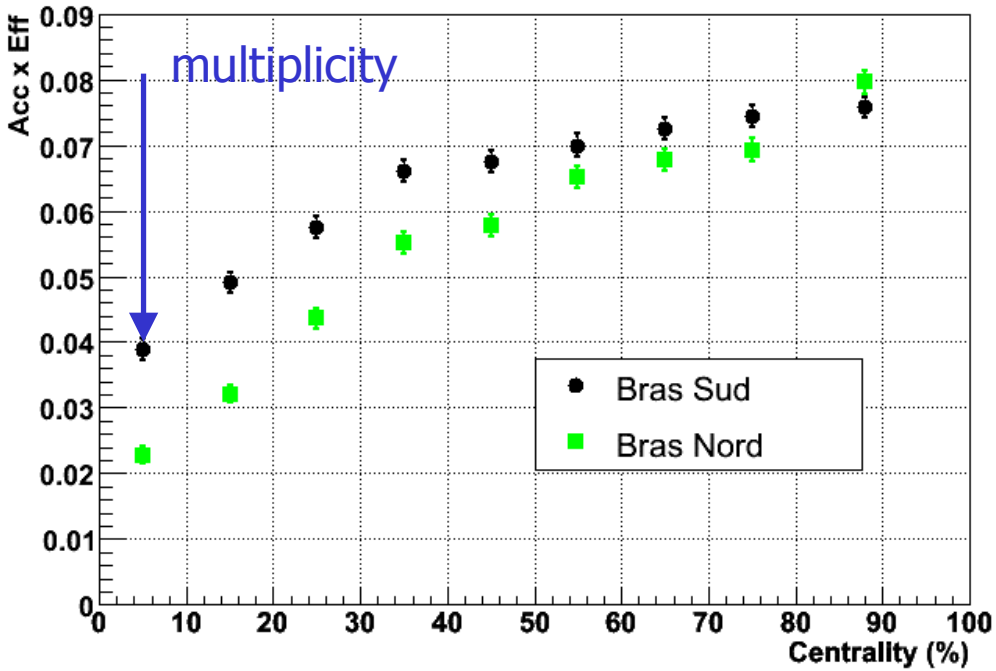






Final corrections

- Acceptance,
- Level 2,
- Pattern Reconstruction
- Analysis cuts



North and South multiplicity different

Centrality determination

Experimental measurement :

1. Pair BBC detect charged particles (secondary particles) at $3<|\eta|<3.9$,
2. Pair of ZDC detects forward-going neutrons (spectators).

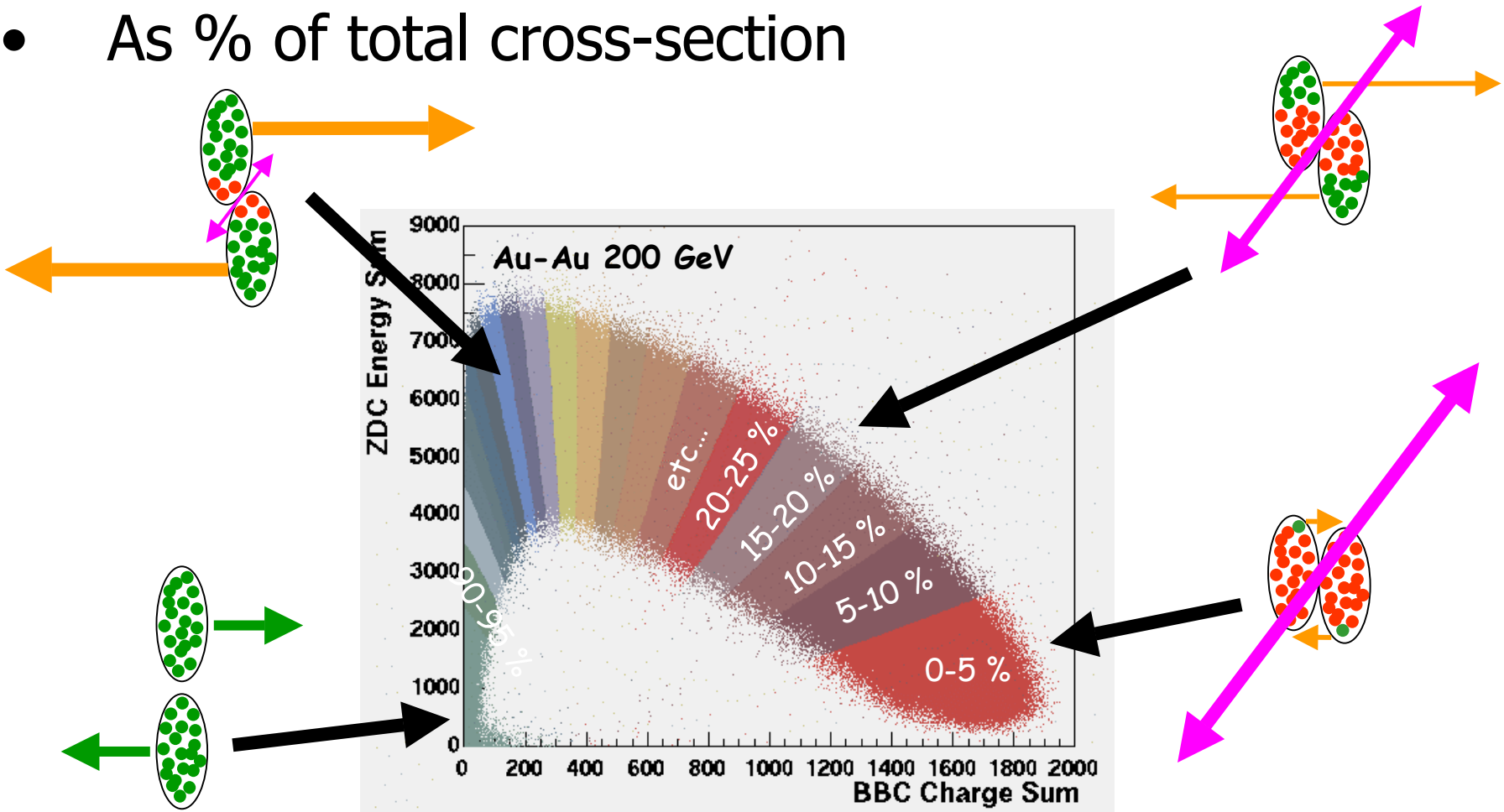
For different configurations

- d+Au collisions : BBC in the Au-going direction
- Cu+Cu collisions : BBC
- Au+Au collisions : BBC and ZDC correlation

Glauber model (Woods-Saxon function) links experimental measurements $\Leftrightarrow$ impact parameter, N_{part} and N_{coll}

Centrality measurement in Au+Au (200 GeV)

- ZDC (spectator neutrons) / BBC (secondary particles) correlation
- As % of total cross-section



J/ψ transport and gluon interactions model

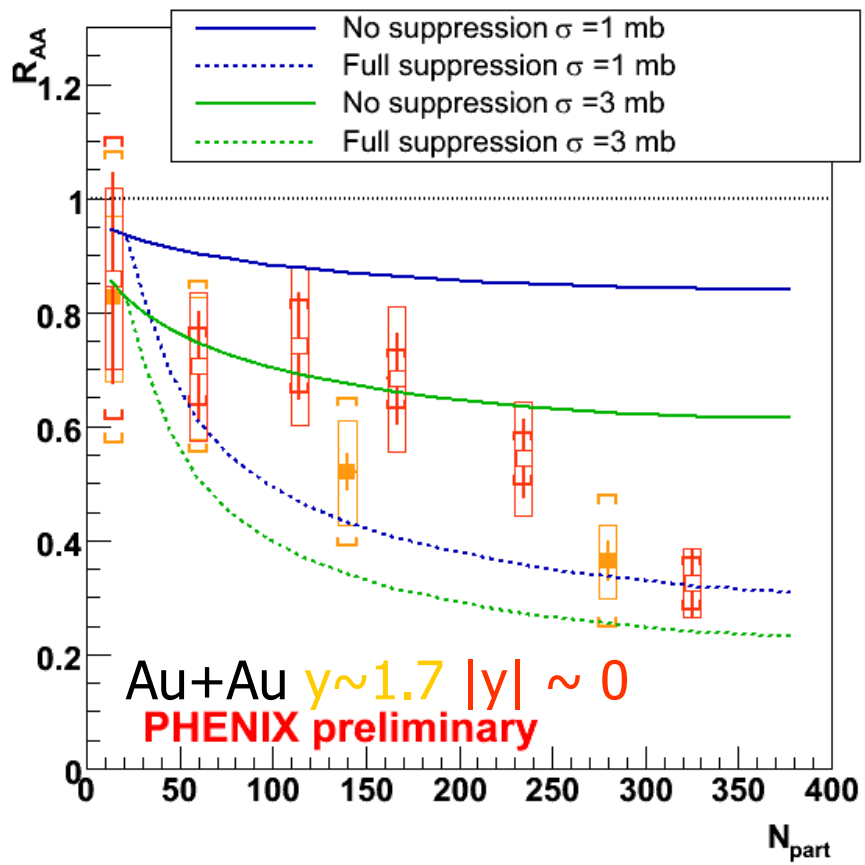
Detailed QGP hydro +

J/ψ transport +

normal nuclear absorption:

- σ^{abs} = 1 mb
- σ^{abs} = 3 mb
- Curves for y=2, but y=0 similar

Better agreement

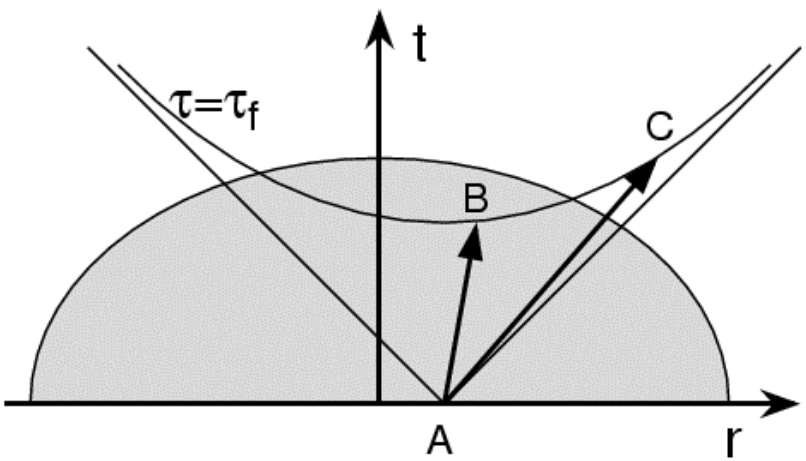


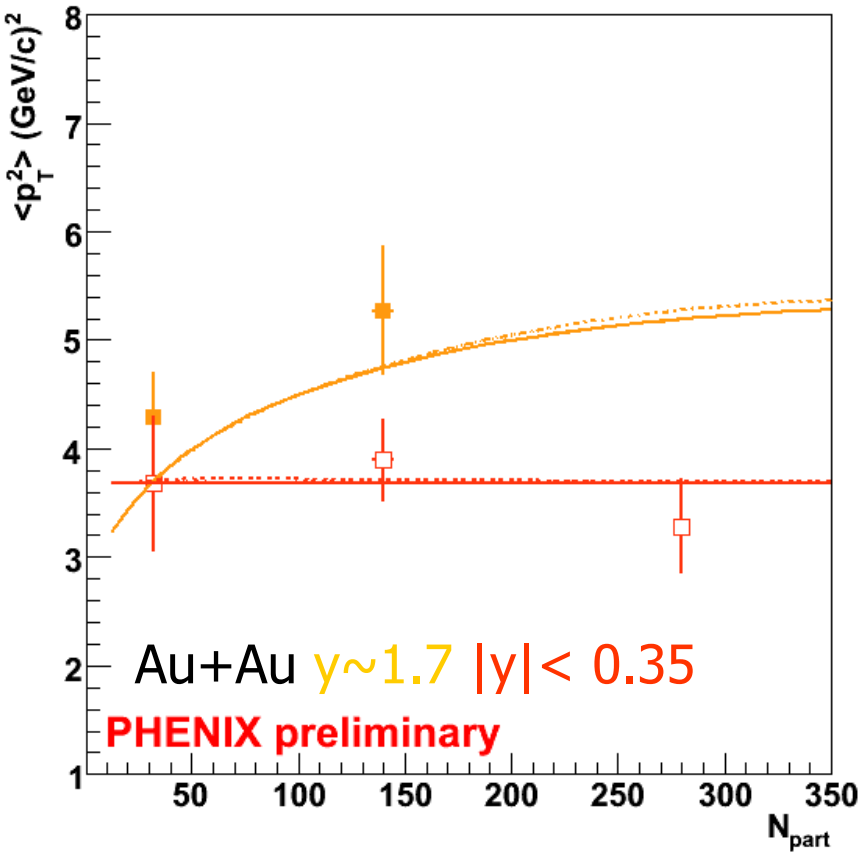
Zhu, Zhuang, Xu, PLB607 (2005) 107

+ private communications

J/ψ transport model : $<pt^2>$ vs N_{part}

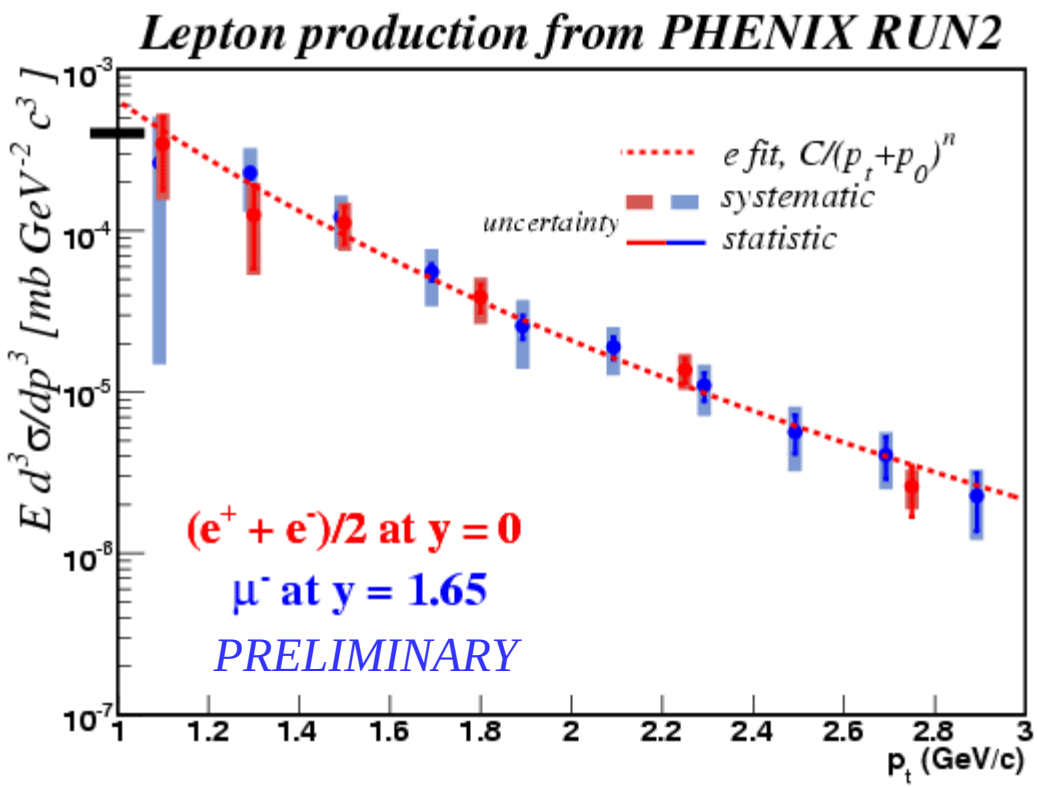
- Competition:
  - High p_T J/ψ production favored (due to Cronin) *and* are more suppressed in a QGP
  - High p_T J/ψ escape



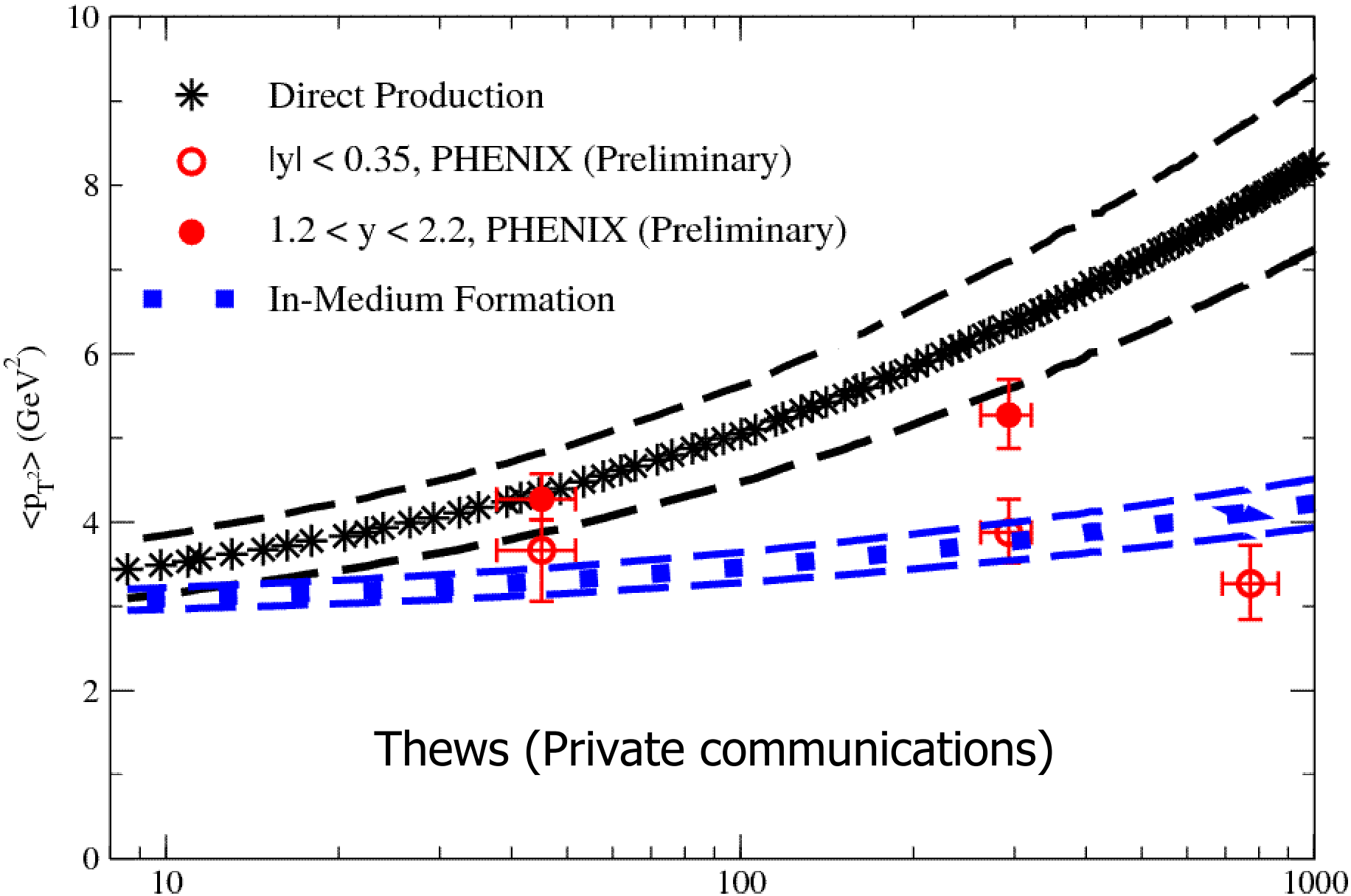


Note the Cronin enhancement observed at mid rapidity is weak

Final Non-photonic e & Preliminary Prompt μ Invariant Cross section



In medium production and recombinaison



Thews (Private communications)