Recent Quarkonia Measurements at PHENIX

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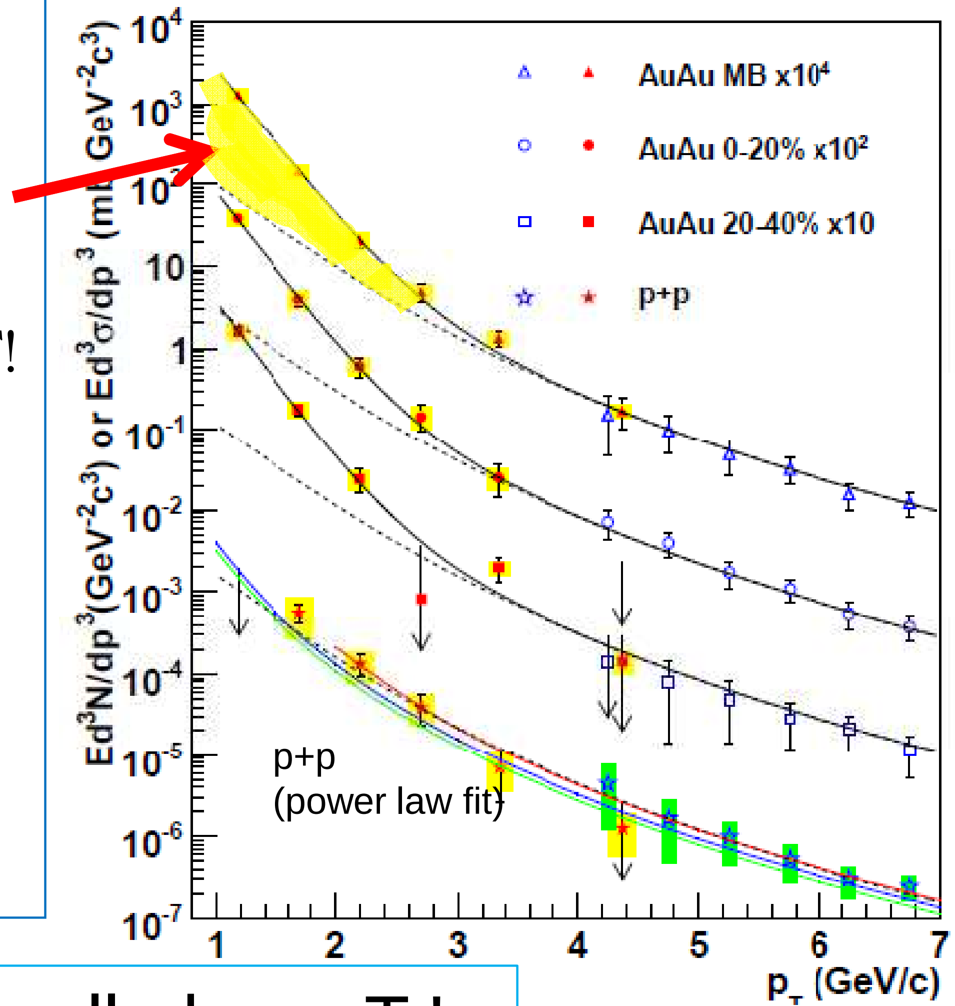
Thermal photons in Au+Au

- Au+Au has large excess of photons above scaled p+p expectation.
- If slope ∝ 1/T, this is an experimental lower bound on T!
- Fits to low p_T give $T = 221 \pm 23(\text{stat}) \pm 18(\text{sys})$ MeV
- Data agrees with hydro models using T_i = 300-600 MeV
  Eur. Phys. J. C 46, 451-464 (2006)

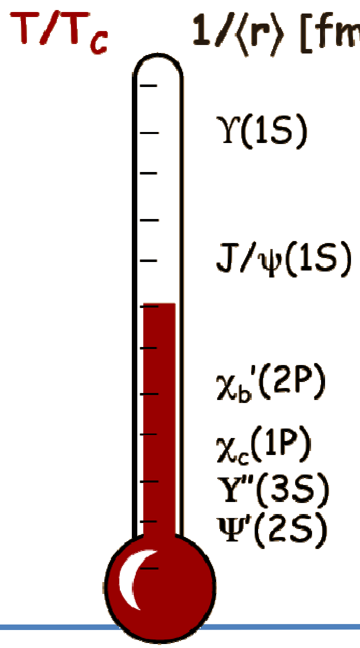


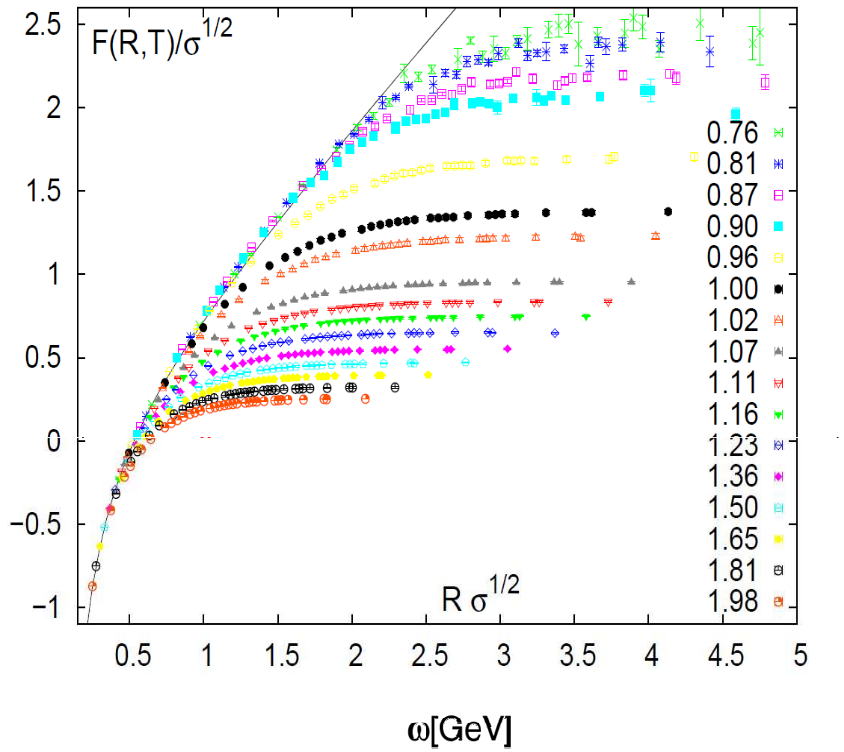
The matter appears to be well above T_c!

nucl-ex/0804.4168v1

Predictions inspired by LQCD.

- Potential model (F from lattice)
  Not clear whether U is better.
- Or study spectral functions (similar results on the lattice).
- Sets upper limits for quarkonia melting temperatures





hep-ph/0706.2183v2

state	χ_c	ψ'	J/ψ	Υ'	χ_b	Υ
T_{dis}	$\leq T_c$	$\leq T_c$	$1.2T_c$	$1.2T_c$	$1.3T_c$	$2T_c$

Understanding suppression.

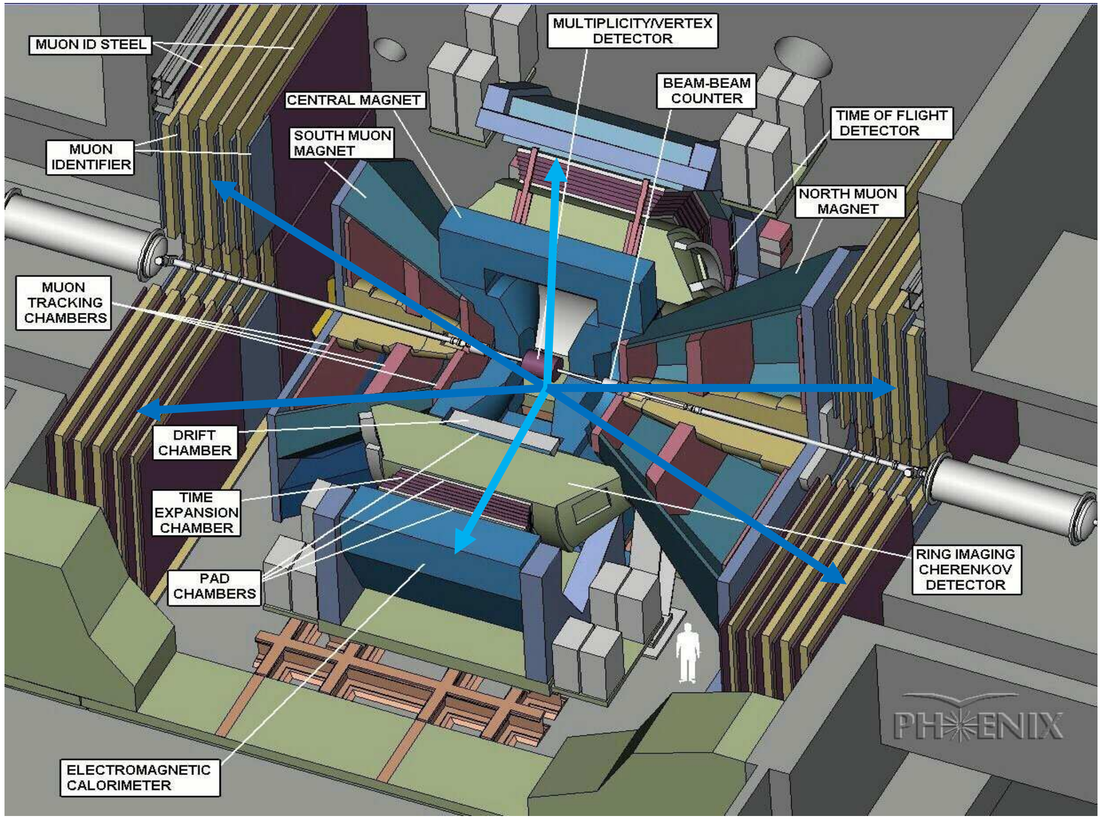
- Production mechanisms.
- Feed down from higher states.
- Cold nuclear matter effects.
- Regeneration (coalescence) of uncorrelated pairs.

Without rigorous book keeping of all the effects I believe we are lost

Measuring quarkonia in PHENIX

Central Arms:
Hadrons, photons, electrons

- $J/\psi \rightarrow e^+e^-$; $\psi' \rightarrow e^+e^-$; $\chi_c \rightarrow e^+e^-\gamma$;
- $|\eta| < 0.35$
- $p_e > 0.2$ GeV/c
- $\Delta\phi = \pi$ (2 arms x $\pi/2$)



Forward rapidity Arms:
Muons

- $J/\psi \rightarrow \mu^+\mu^-$
- $1.2 < |\eta| < 2.2$
- $p_\mu > 1$ GeV/c
- $\Delta\phi = 2\pi$

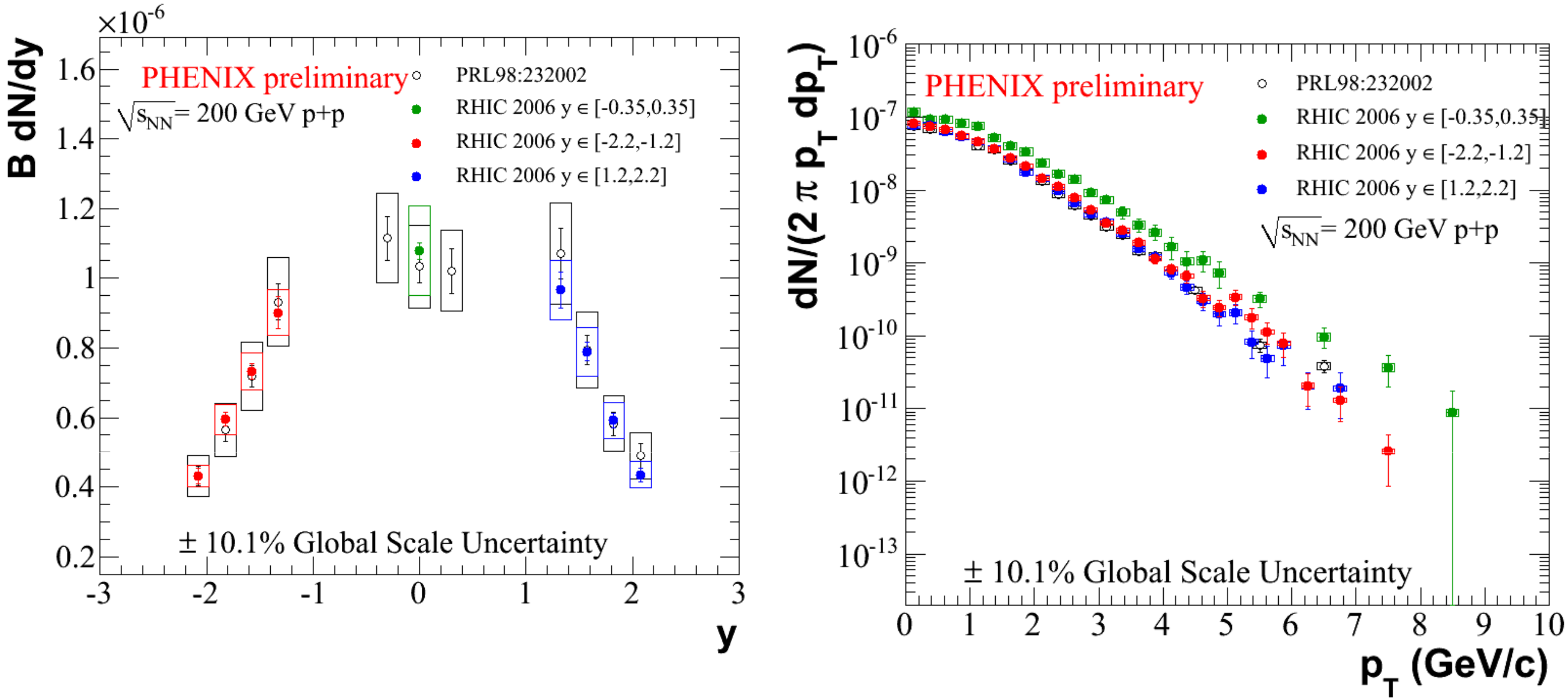
Global detectors:
Beam-Beam Counter (BBC)
Zero Degree Calorimeter (ZDC)
Reaction Plane Detector (RxNP)

RHIC physical runs, 2000-2010

System	$\sqrt{s_{NN}}$, GeV
Au+Au	7, 9, 39, 62, 130, 200
d+Au	200
Cu+Cu	22, 62, 200
p↑+p↑	22, 62, 200, 500

P+P RESULTS FROM PHENIX

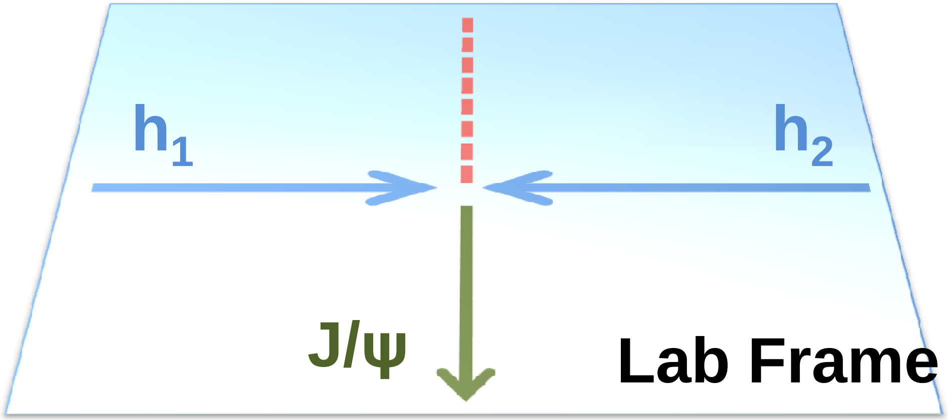
J/ψ p+p spectra

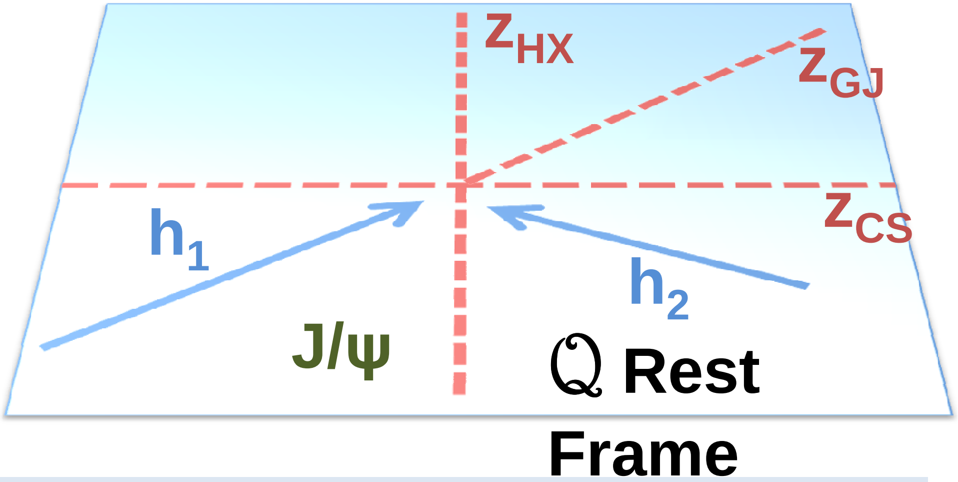


- Powerful data set to test production models.
- Baseline for HI Data.
- Final result coming that combines run-6 and run-8 (~2x these stat.)

J/ψ Polarization I

Adapted from **P. Faccioli**

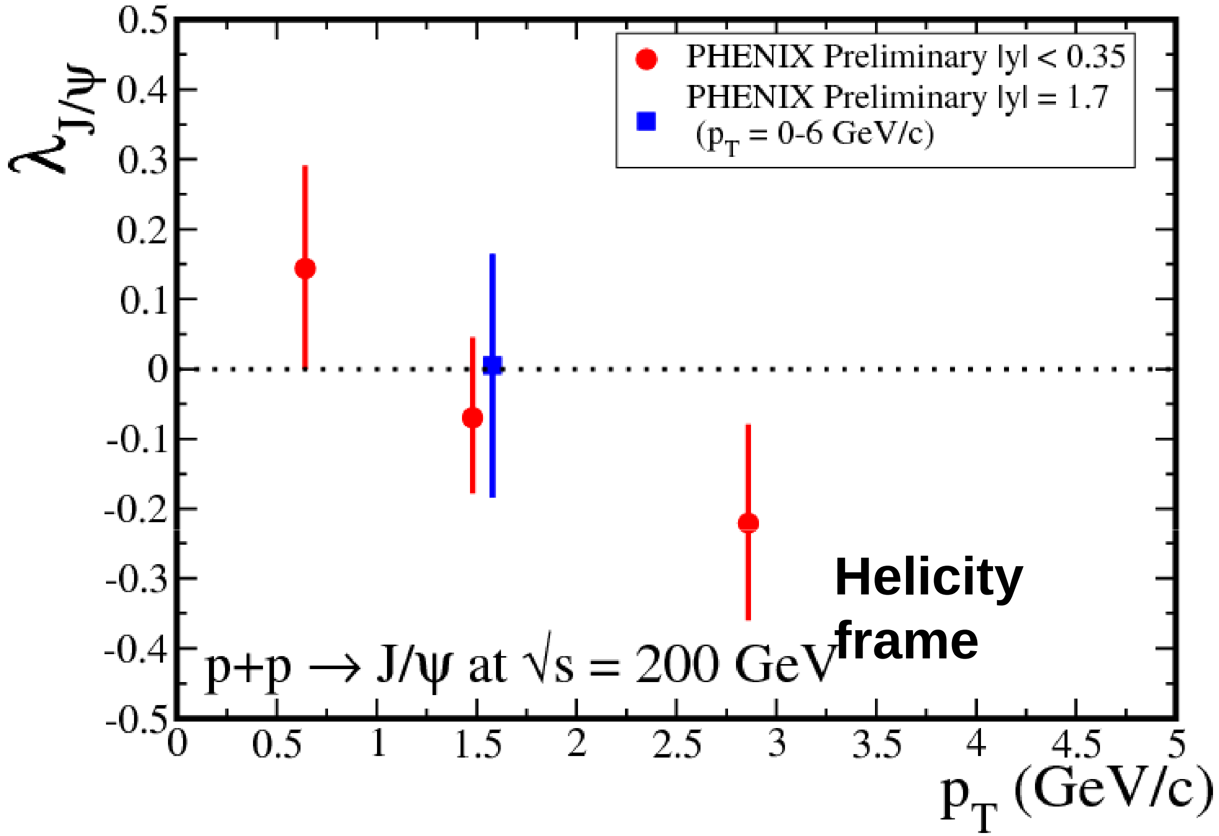




Measure l+ direction with respect to:

1. Helicity (HX): Q momentum in rest *frame*
2. Gottfried-Jackson (GJ): direction of *h_1 or h_2 in* Q *rest frame*
3. Collins-Soper (CS): bisector between *h_1 and (–)h_2 directions in* Q rest frame → ~ direction of relative velocity of colliding partons.

J/ψ Polarization II

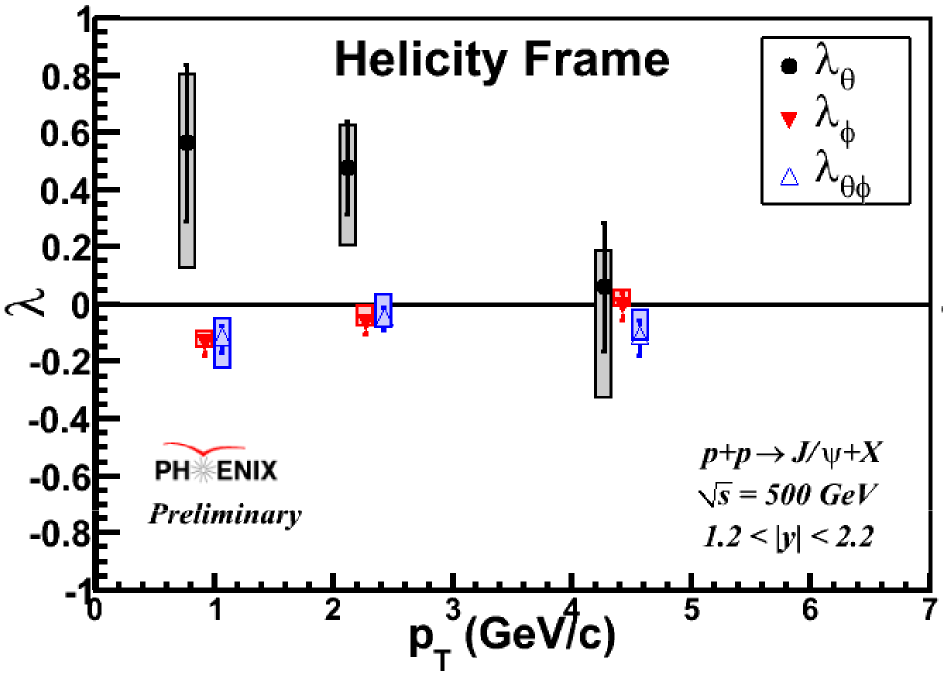


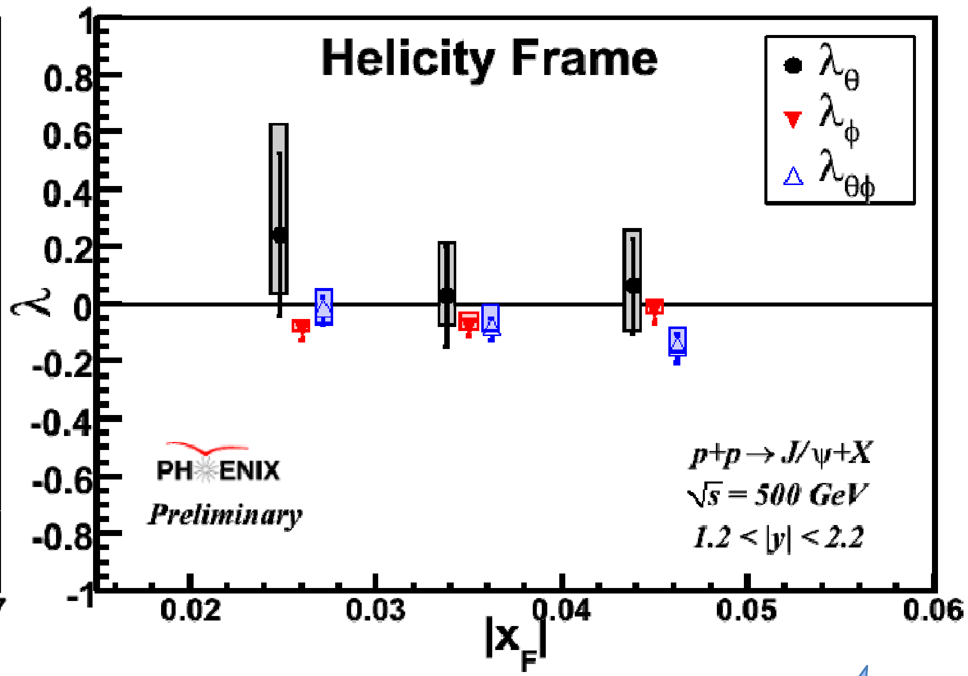
$$\frac{dN}{d\cos\theta} = A(1+\lambda\cos^2\theta)$$

λ>0 transverse
λ<0 longitudinal

- PHENIX acceptance limited in other frames.

J/ψ Polarization III





NEW

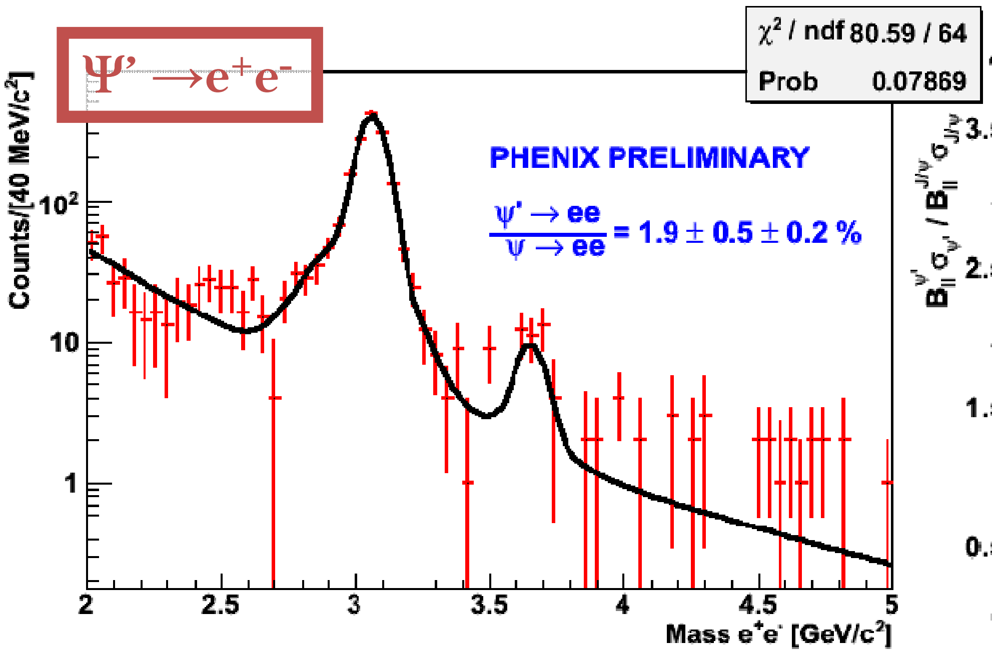
- 500 GeV and 200 GeV polarization measured.
- Full angular distribution measured at 500 GeV.

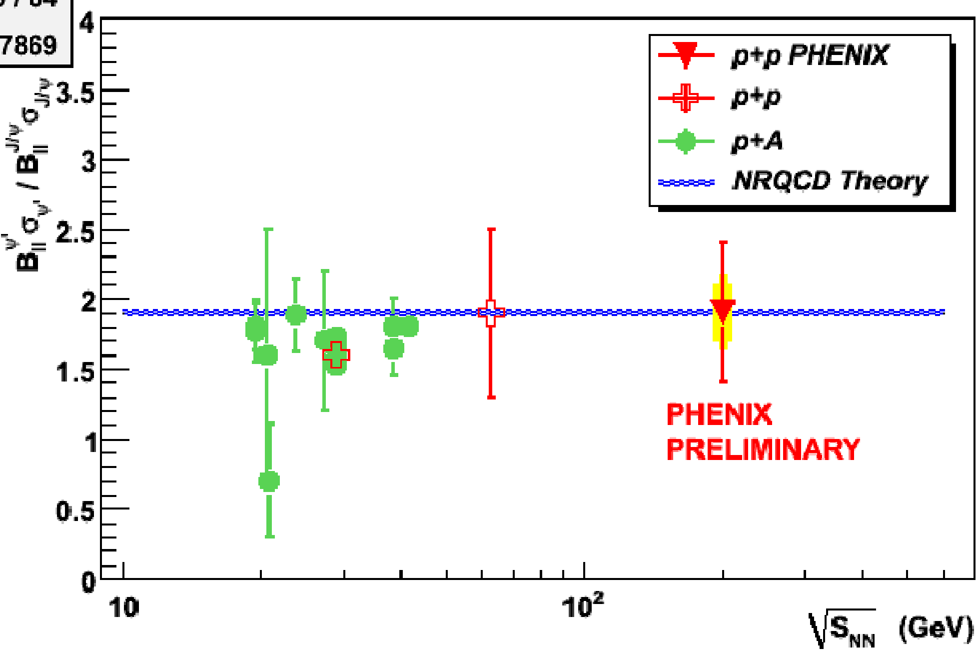
Feed down from ψ' (p+p)

R(ψ') =8.6±2.5% PHENIX (QM08)

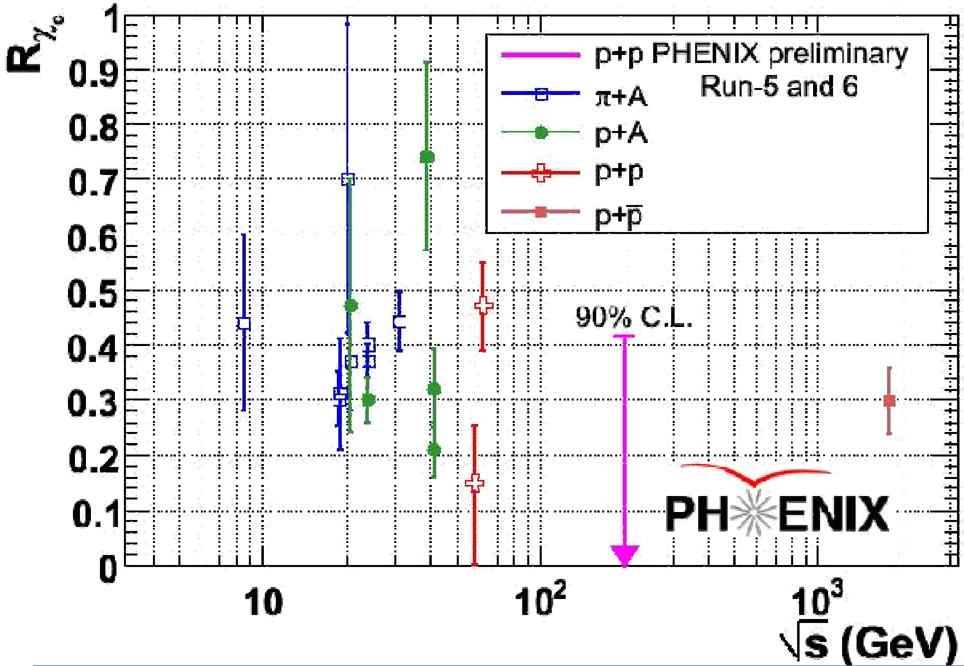
R(ψ') =8.0±2.0% from the lattice (Phys.Rev.D64:094015)

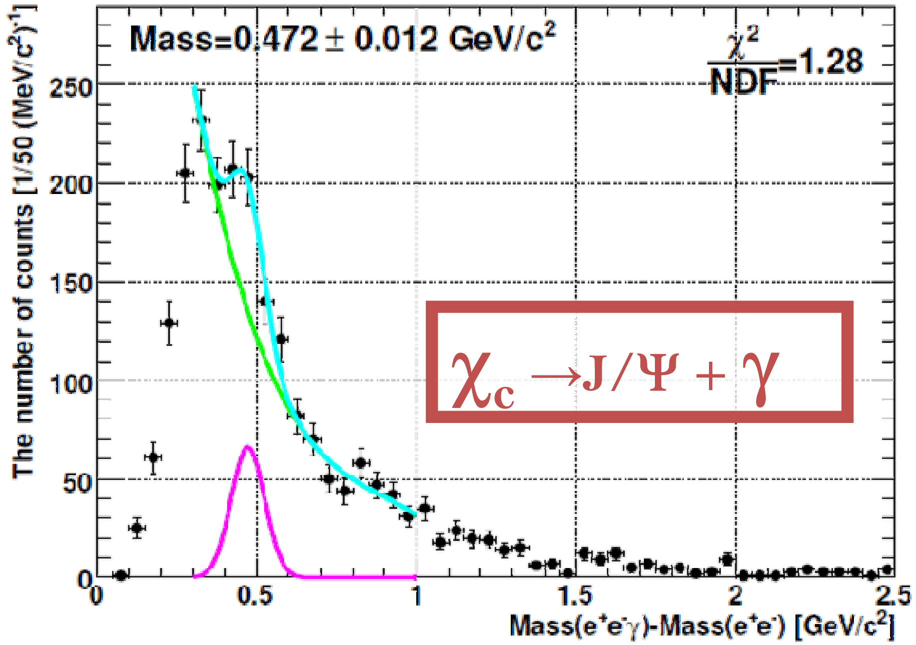
R(ψ') =8.1±0.3% from average of world data (hep-ph/0809.2153v1)





Feed down from χ_c (p+p)





R(χ_c) <42% (90%C.L.) PHENIX

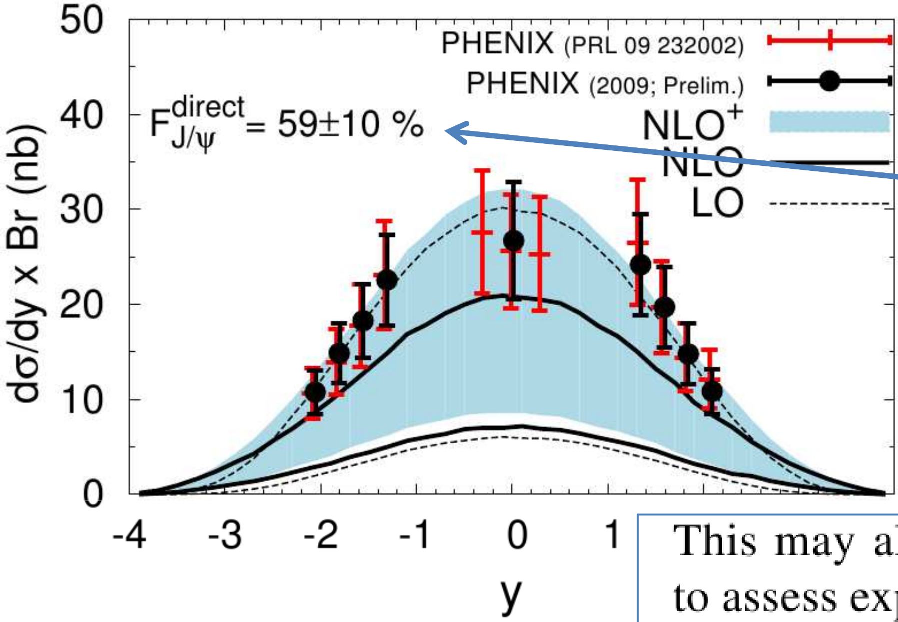
R (χ_c) = 30% ± 8.0 Lattice (Phys.Rev.D64:094015)

R (χ_c) = 25% ± 5.0 World average (hep-ph/0809.2153v1)

(final Hera-b : 18% ± 2.8% hep-ex/08087.2167v1)

- If the χ_c melts in Au +Au 200GeV collisions 20-40% of the J/Ψ disappear !

Phys. Rev. D81:051502

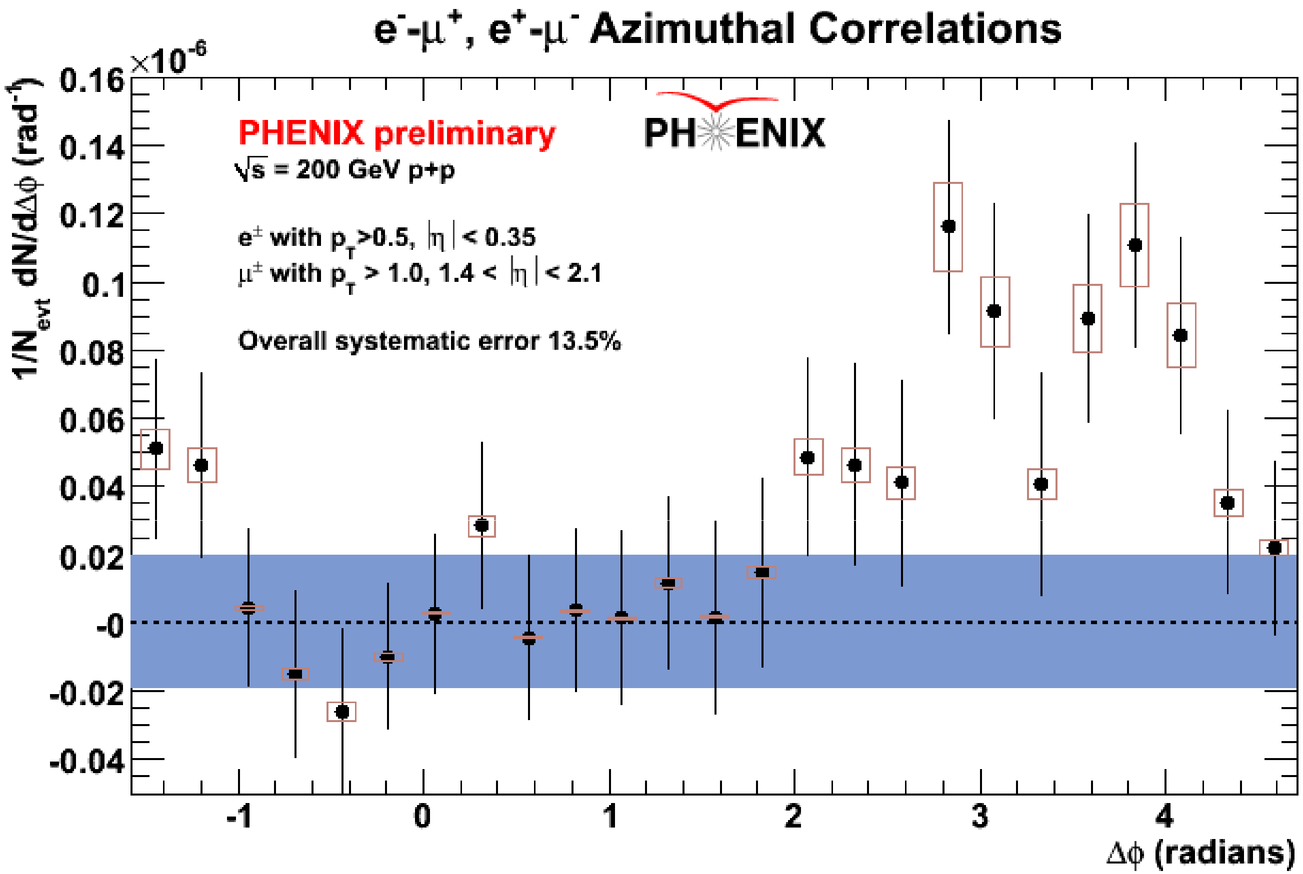


Note: PHENIX 90% CL for χ_C is ~40%. So the PHENIX data may actually need F~50% (moves points down a bit more)

This may also impact the J/ψ yield in this region. In order to assess experimentally the importance of cg fusion, whether from the usual CSM or from CTM effects, the measurement of J/ψ in association with D meson would be illuminating, as has been noted in ref. [14] for $J/\psi + c\bar{c}$. More accessible is the study of the azimuthal correlation of $J/\psi + e$ in the central region by PHENIX and STAR and of $J/\psi + \mu$ in the forward region by PHENIX. The key signature for such subprocesses is the observation a lepton excess opposite in azimuthal angle ϕ to the detected J/ψ.

CSM with cg fusion has another experimental signature too look for!

e-μ correlations



•This signal (if it exists) must be in this data.
•Can PHENIX actually extract this and confirm or rule it out?

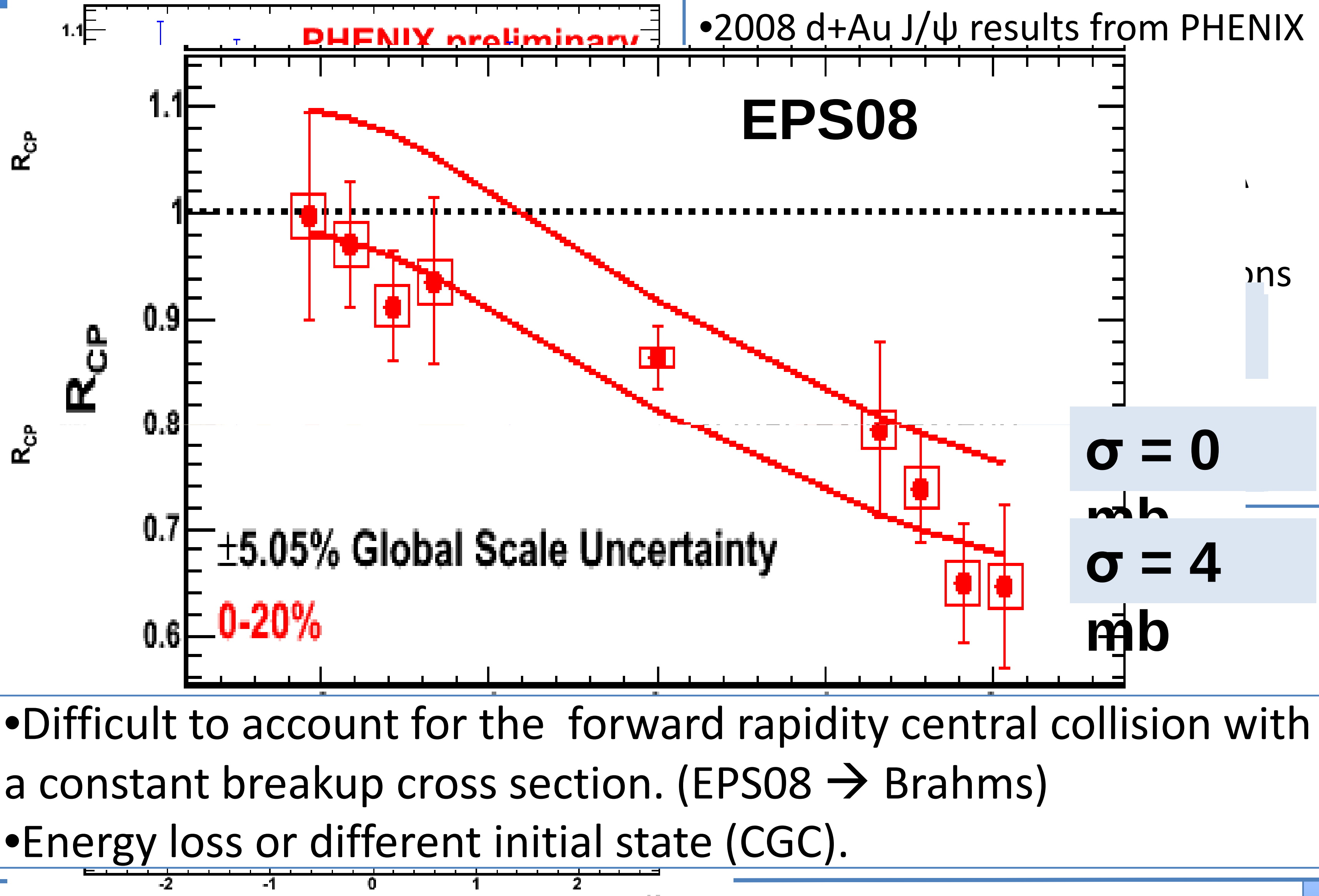
Production Summary

- Production mechanism of quarkonia is still not settled.
  - 2 → 1?
  - 1 → 1 ?
  - What is the x1, x2 mapping (smeared out as in extrinsic?)
- S-channel cut is small (Braaten et al. arxiv:0907.0025v2)
- CSM Still in the game (Brodskey and Lansberg)
  - Needs to confront p_T spectrum
  - No polarization shown in this paper.
- NRQD (pT>5 GeV/c)
  - Still completely off on the polarization
- CEM
  - Nice comparison to pT spectra
  - No possibility to calculate
- Azimuthal correlations could be another tool to differentiate production mechanisms.
  - Theory needs to calculate these. Experiment needs to measure them.

CNM RESULTS FROM PHENIX

Breakup cross section

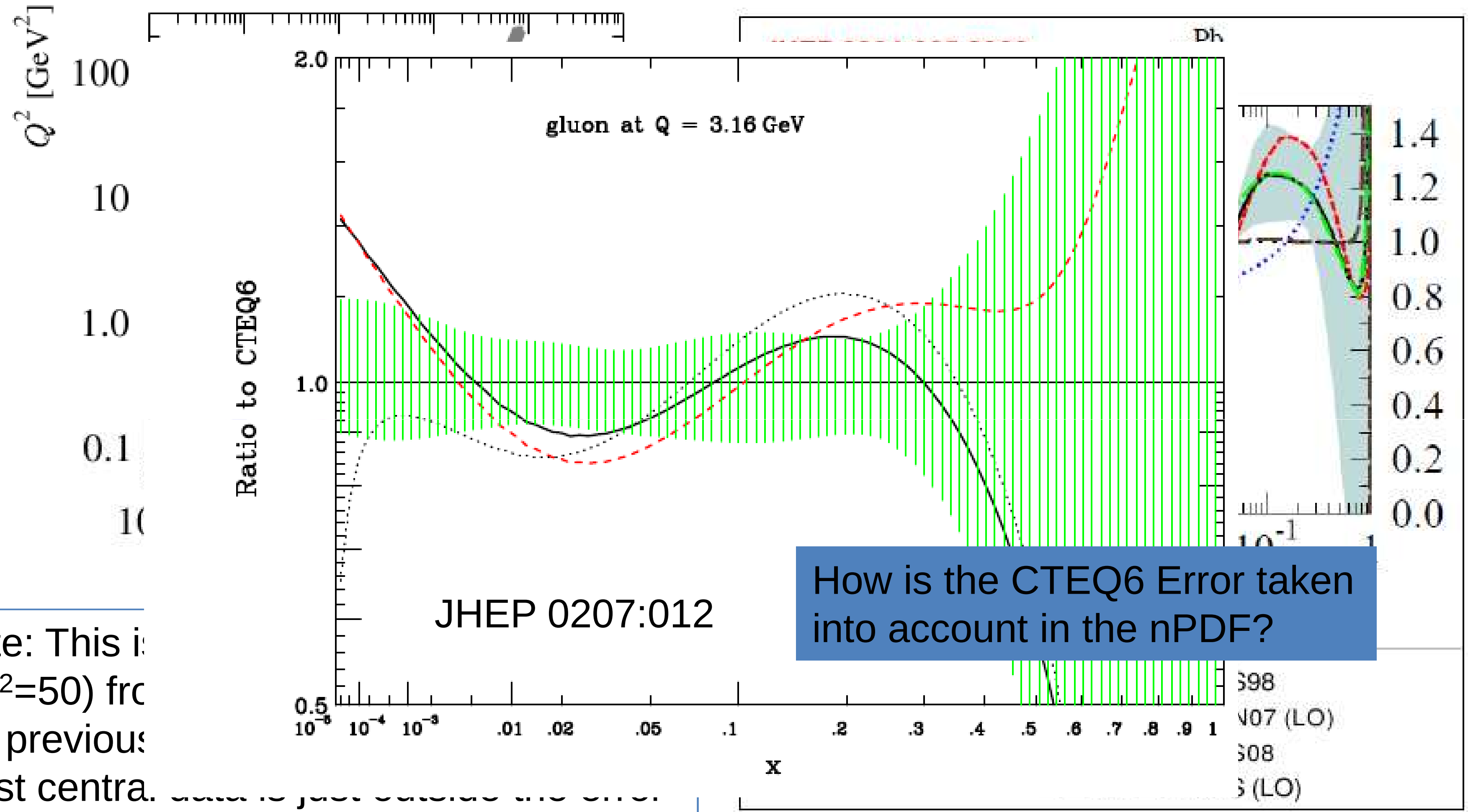
•2008 d+Au J/ψ results from PHENIX



•Difficult to account for the forward rapidity central collision with a constant breakup cross section. (EPS08 → Brahms)

•Energy loss or different initial state (CGC).

EPS09 G(x) nPDF



How is the CTEQ6 Error taken into account in the nPDF?

Note: This i
($\Delta\chi^2$=50) frc
the previou
most centra
band. (arxiv:0902.4154)

Energy Loss?

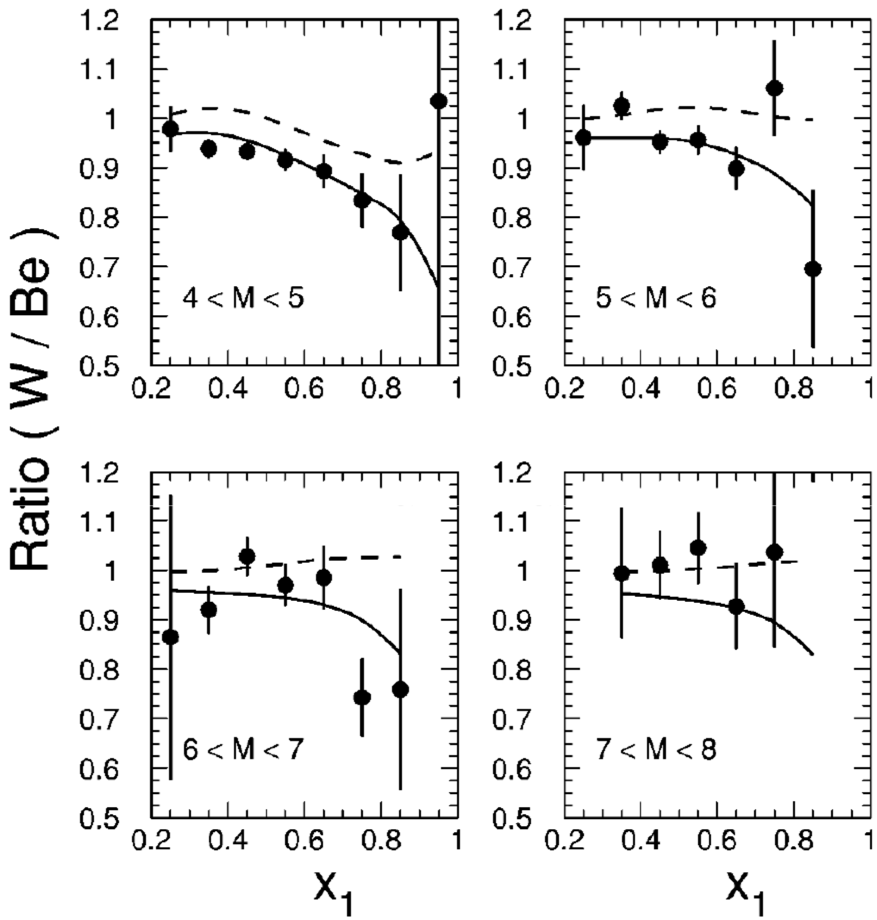
Drell-Yan at E772 and E866

Energy loss calculated in target rest frame.

dE/dx = 2.73 ± 0.37 ± 0.5 GeV/fm (from hadronization)
dE/dx ~ 0.2 GeV/fm (from gluon radiation)

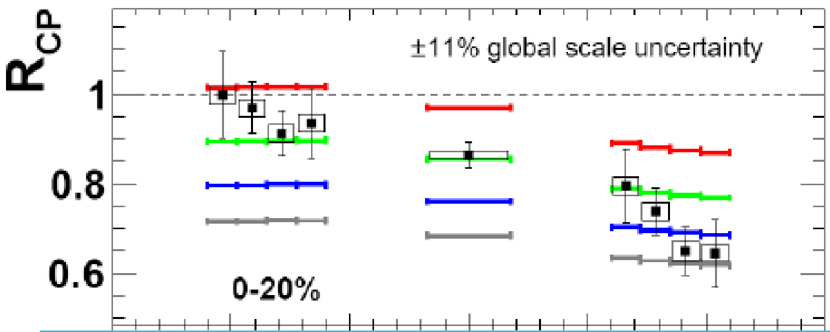
Changes the x of the incoming quark and therefore changes shadowing? How is this extended to gluons? What path length dependance to use?

"This is the first observation of a non-zero energy loss effect in such experiments."



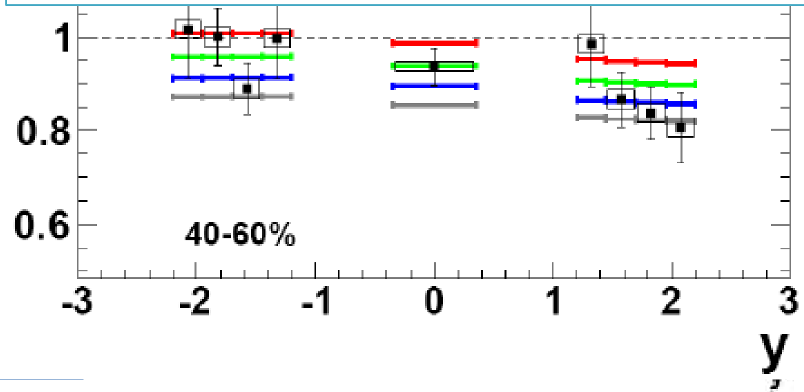
Johnson, Kopeliovich, Potashnikova, E772 et al.
Phys. Rev.C 65, 025203 (2002) hep-ph/0105195
Phys. Rev. Lett. 86, 4487 (2001) hep=ex/0010051

Production model?



Intrinsic 2 → 1

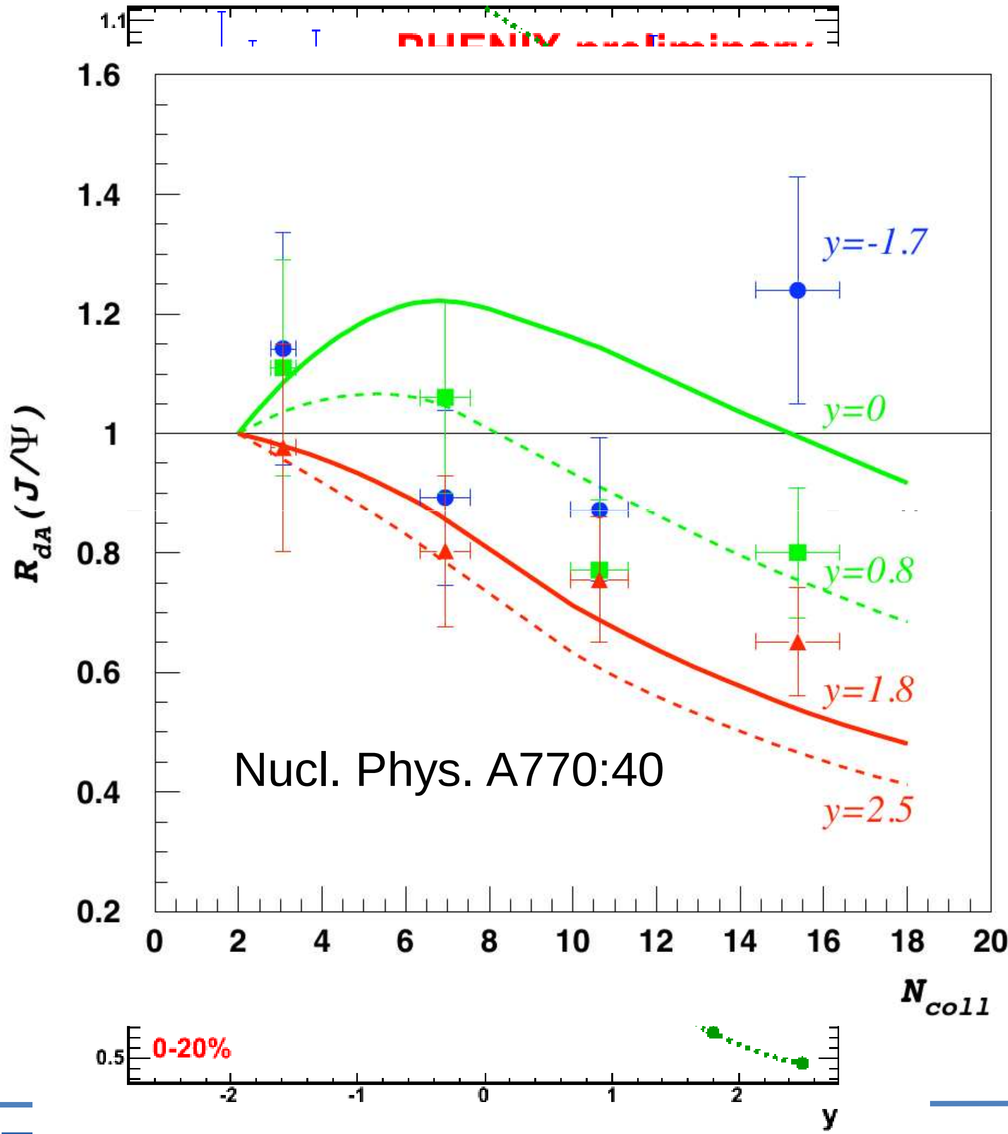
- Softens the result
- Does not completely describe forward suppression (shadowing model dependent)
- What does this look like for CSM+IC? (arXiv:0908.0754)



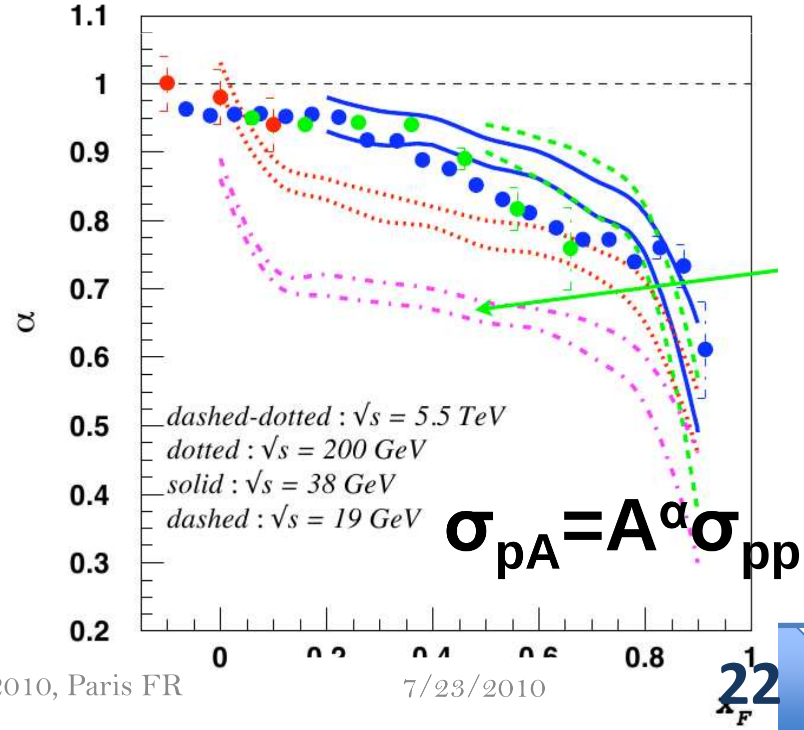
$$x_2 = \frac{x_1 m_T \sqrt{s_{NN}} e^{-y} - M^2}{\sqrt{s_{NN}}(\sqrt{s_{NN}} x_1 - m_T e^{y})}$$

Lansberg et al. arXiv:0912.4498

Coherent Multiple Scattering (CGC)?



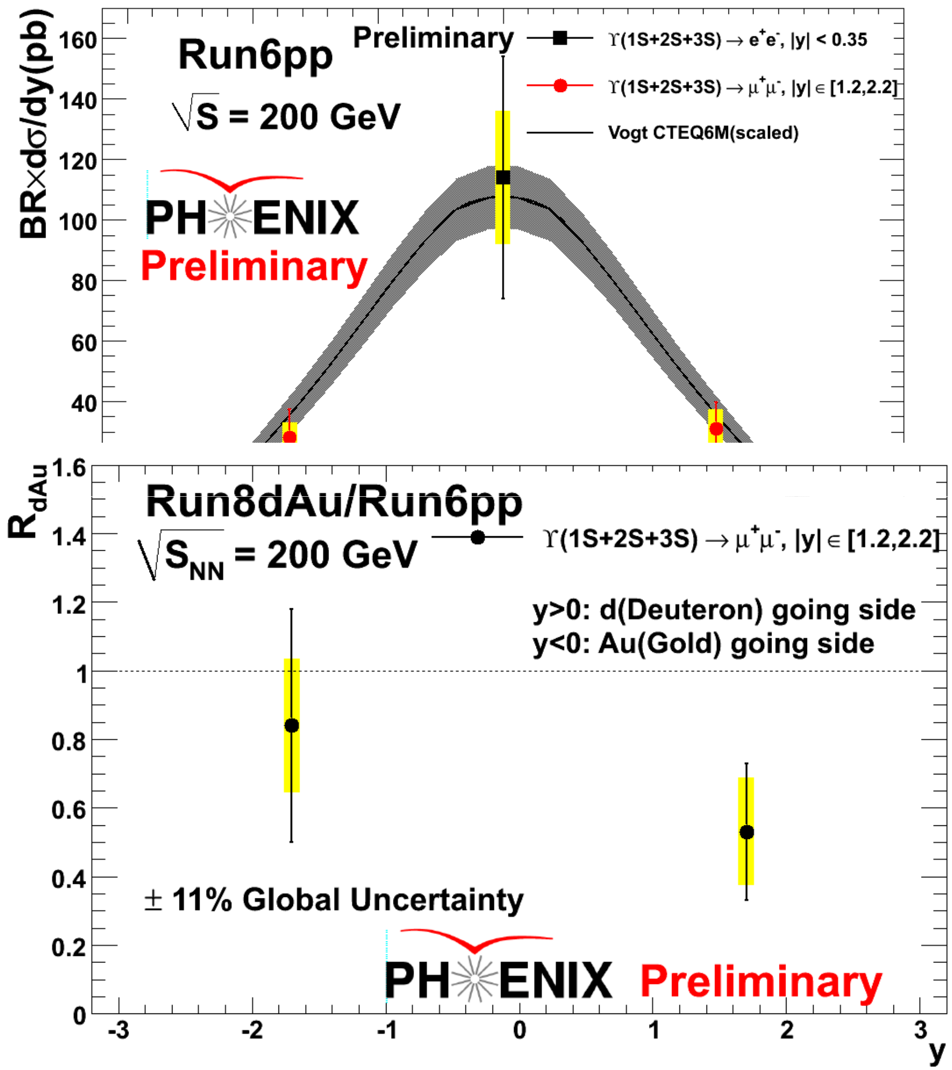
- Also calculate the backward rapidity? (anti-shadowing as conservation of momentum)
- Note: Not valid for low energy data at the SPS?

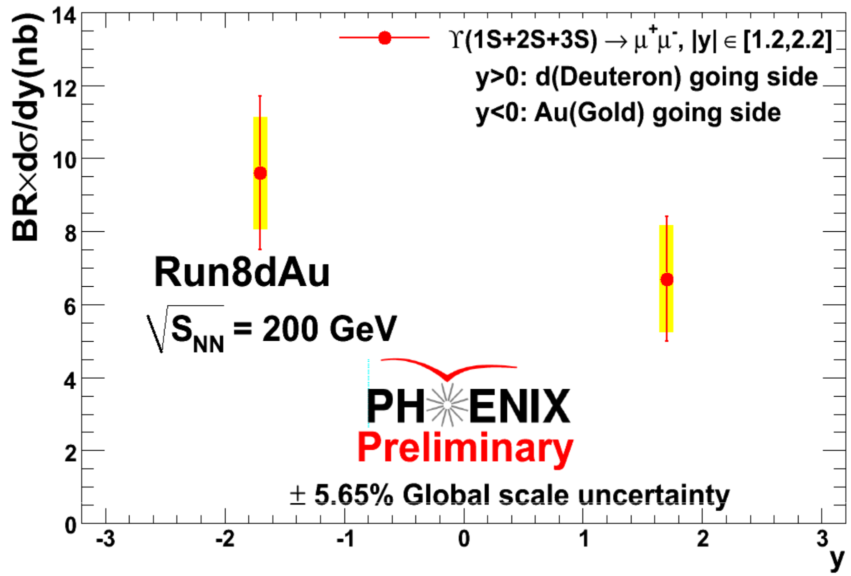


J/ψ CNM Suppression Summary

- Very difficult to test our data when nPDF are so poorly constrained.
- Up to this point initial state energy loss has been ignored (we have to put it in).
- What leverage do we have to differentiate between the CGC initial state and normal shadowing (are they different?).

Υ CNM Suppression

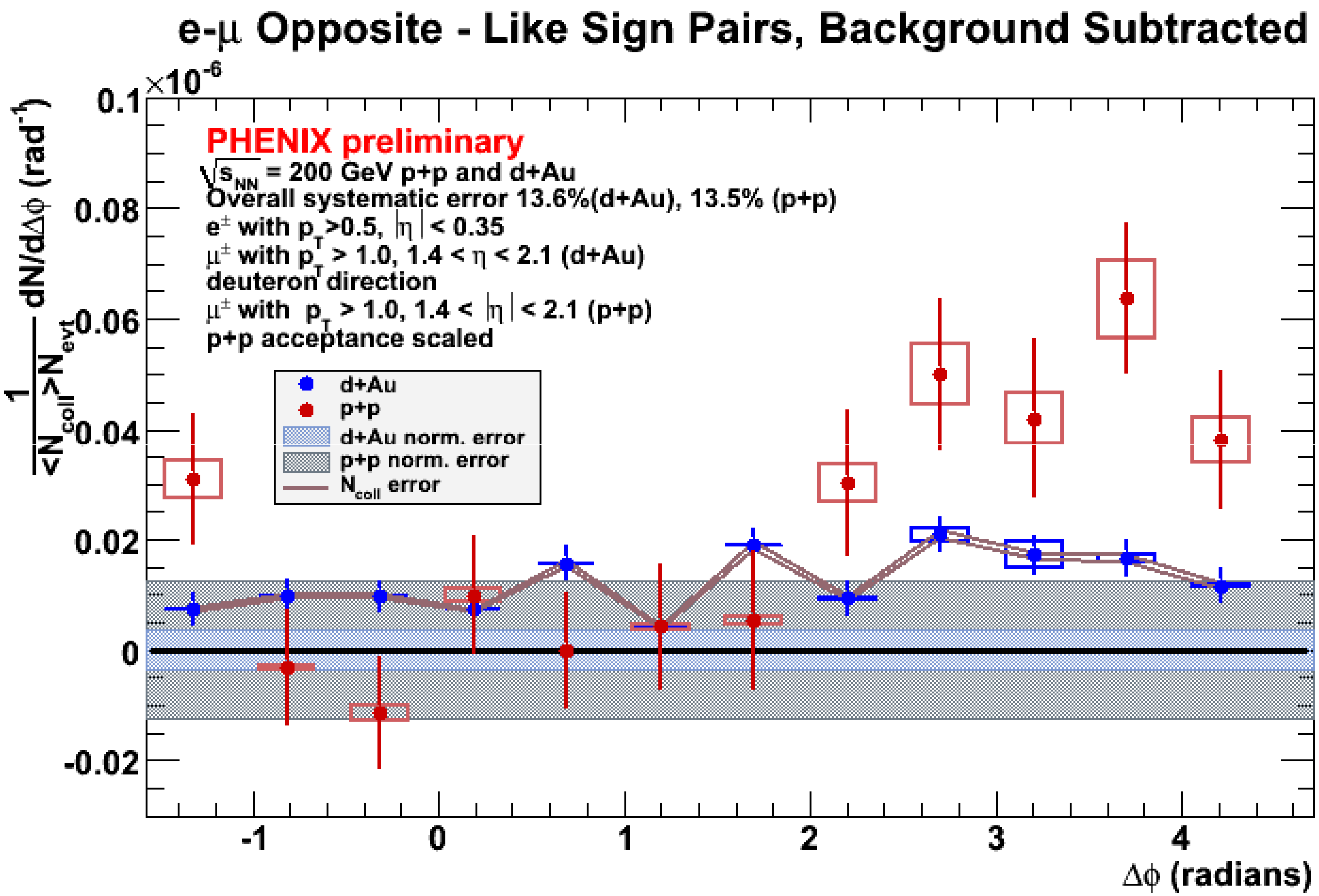




$R_{dAu}[1.2,2.2] = 0.53 \pm 0.20(\text{sta}) \pm 0.16(\text{sys})$

NEW

e-μ correlations in CNM



NEW

CNM Summary

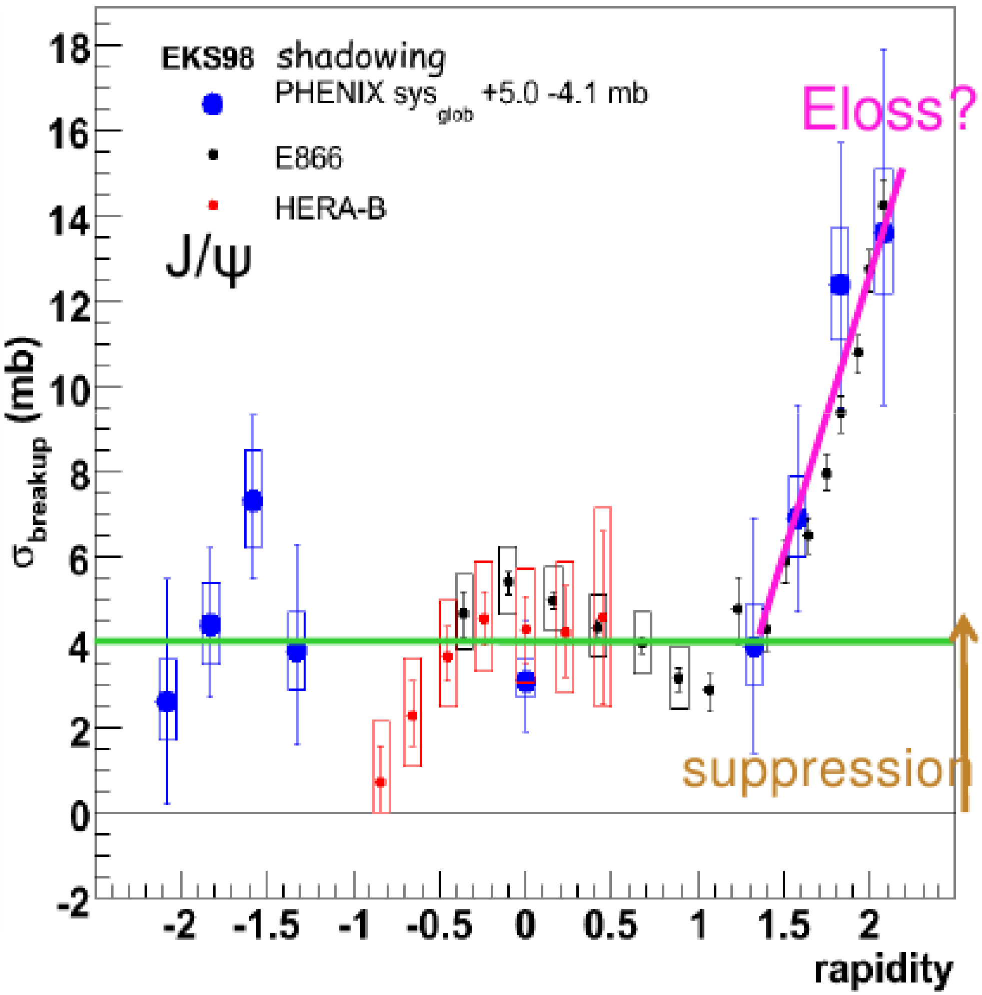
- Clearly missing some physics. (σ(y))
  - Similar trend in lower energy data.
- Energy loss is in DY data at lower energy should be in the RHIC data too.
  - However gluon rather than quark
- Or, is the initial state completely coherent?
  - Only applicable in a forward limit
  - Can the CGC calculation be extended to other regions?
- Possible that suppression is seen in the e-μ correlations that contains some of the CSM IC signal (if it exists).

ANOMALOUS SUPPRESSION

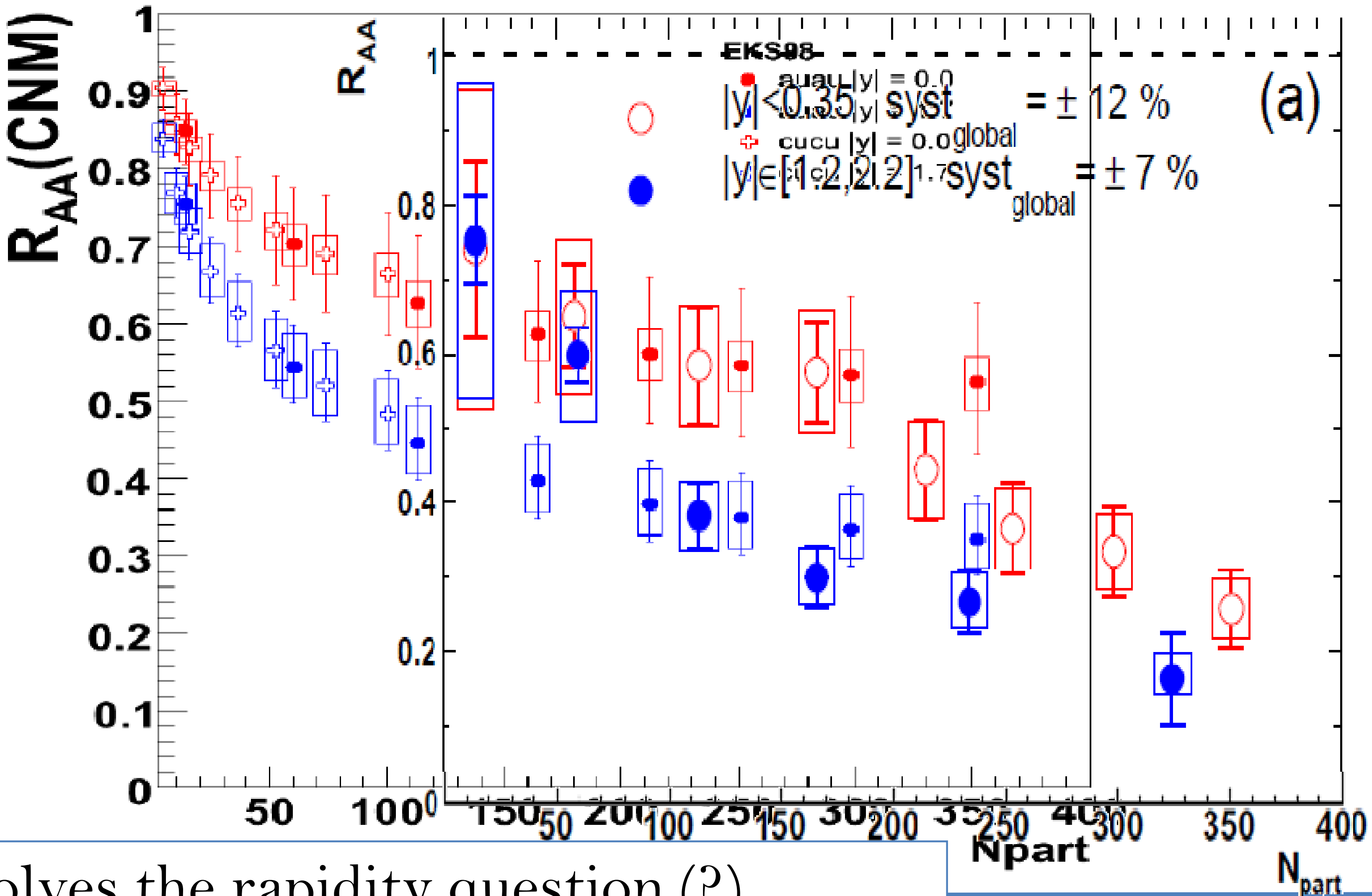
Rapidity dependence!

- Extract best fit to R_{CP} at a given rapidity versus centrality.
- Based on predictions from R. Vogt.
- Parameterizes all the effect that shadowing is missing.
- Same shape at lower energy (initial state energy loss).

A. Frawley ECT, Trento

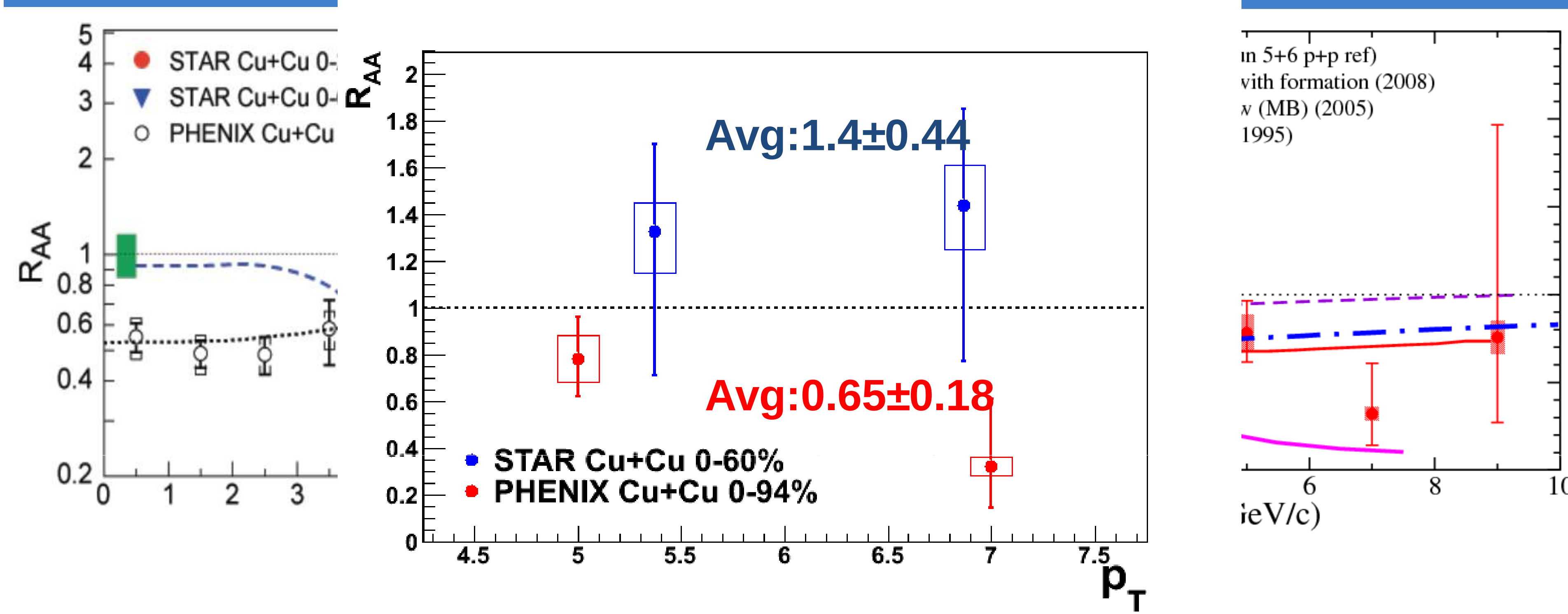


Prediction for HI



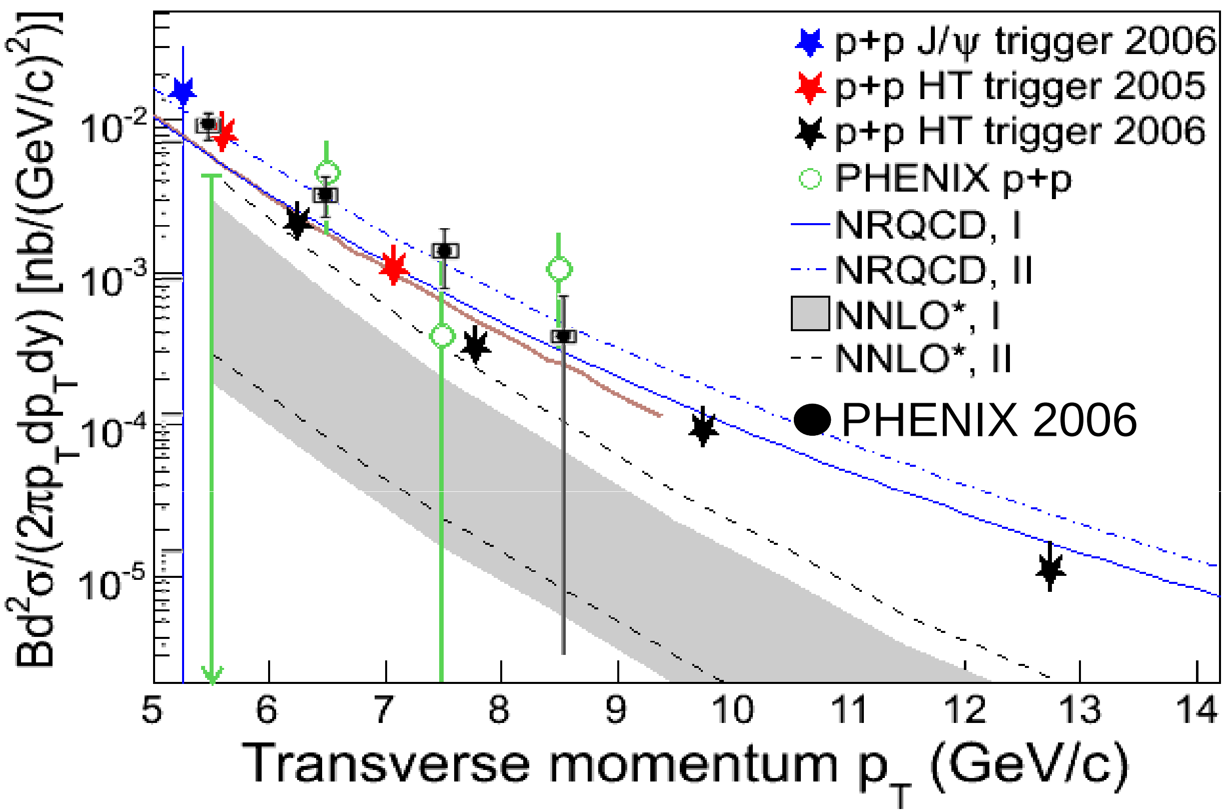
- Resolves the rapidity question.(?)

High p_T R_{AA}



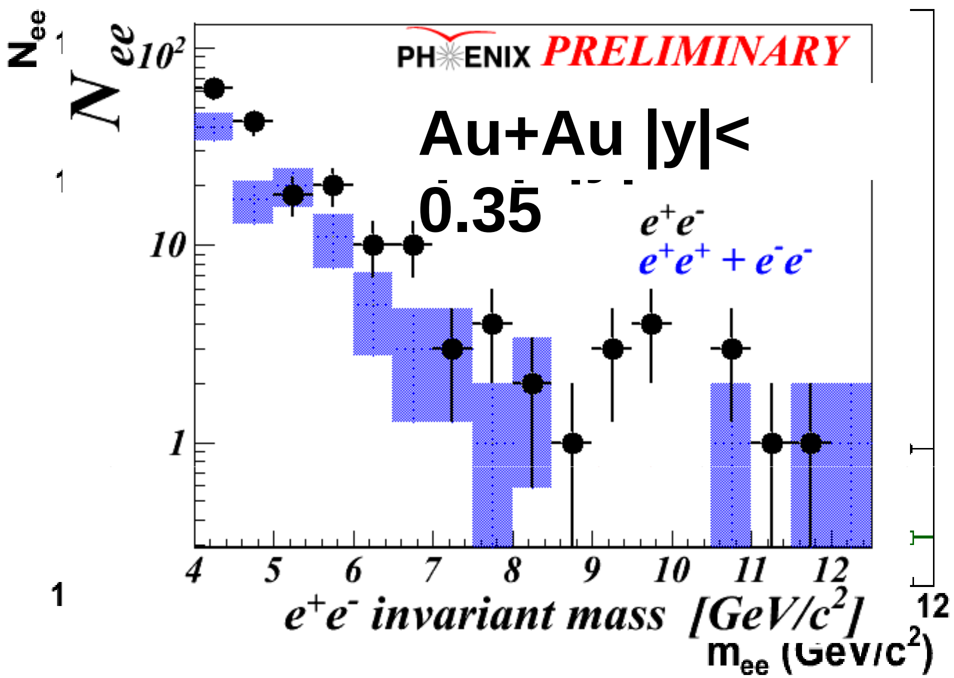
•Data are consistent at ~ 1 σ level.
•PHENIX data would appear to remain constant over pT.
•STAR predicts binary scaling (overstated conclusion).

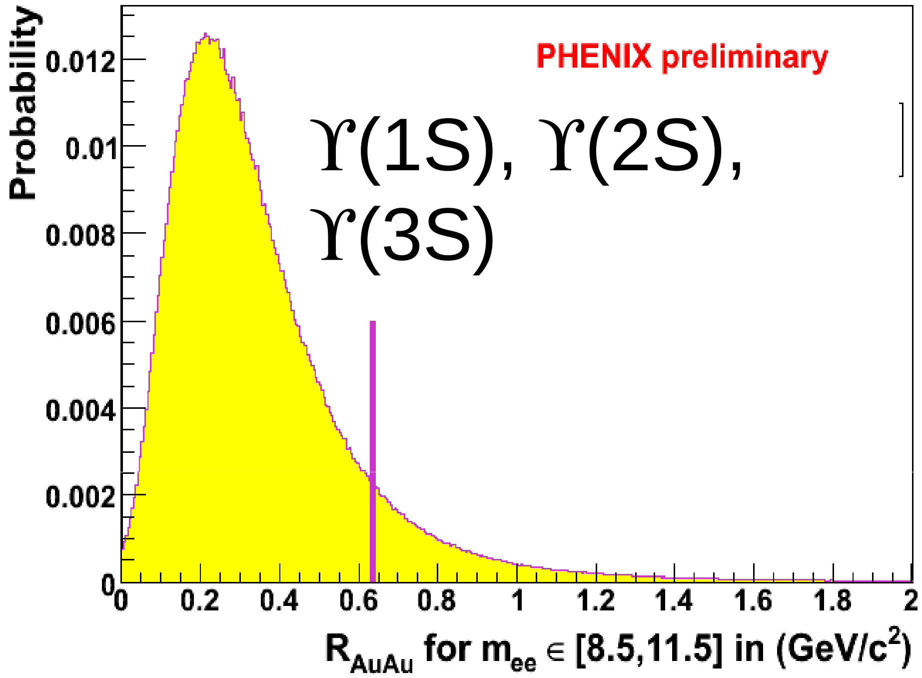
RHIC at high p_T



- STAR p+p baseline lower than PHENIX at high p_T.
- Is the STAR data internally consistent?
- Different rapidity ranges being compared on previous slide?

Υ Anomolous Suppression





- Poisson probability analysis to set an upper limit.
- Upper limit $R_{AA} < 0.64$ 90% CL for Upsilon atRHIC.
- Need Run-8 d+Au value for CNM baseline.

Anomalous Suppression Summary

- The million dollar high pT question
  - 2007 Au+Au data coming with
- Disagreement between star and phenix baseline?
  - Is it worth beating this drum anymore since the data have huge error bars.
- PHENIX rapidity difference in Au+Au collisions can be accounted for by an effective breakup cross section.
  - Parameterizes all the physics that is missing

BACKUP