Quarkonia Results from PHENIX & STAR

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BNL RHIC/AGS Users Mtg – 27 May 2008

- Quarkonia & Deconfinement
- PHENIX A+A Results
- Cold Nuclear Matter (CNM)
- Production Issues
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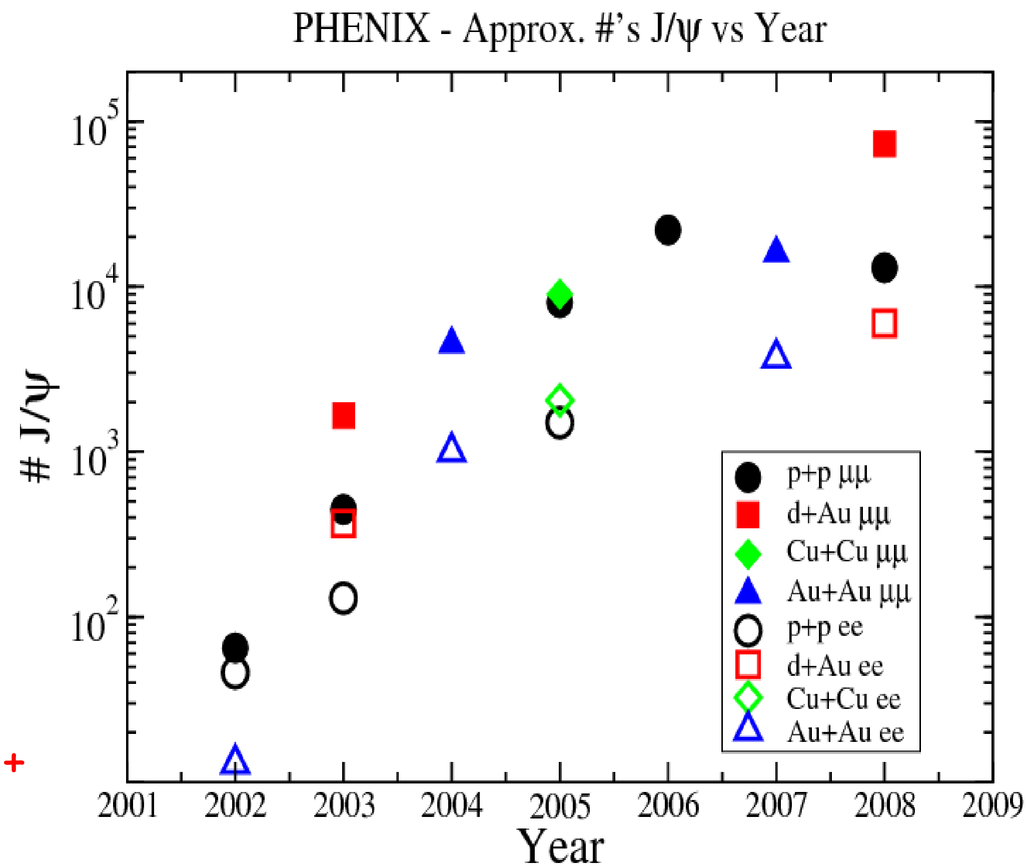
- Flow & Transverse Momentum
- Heavier Quarkonia
- Future

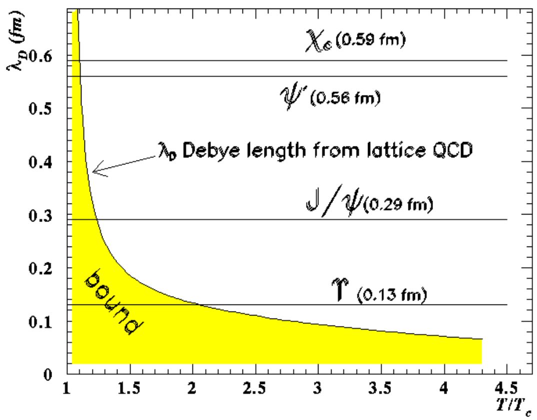


thanks to all my PHENIX colleagues + Consentino, Das & Tang from STAR!

Deconfinement and Quarkonia

For the hot-dense medium (sQGP) created in A+A collisions at RHIC:

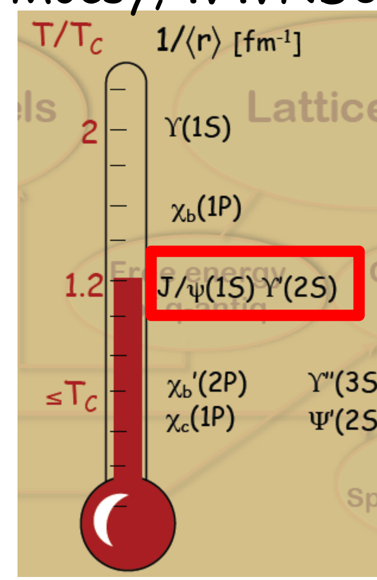
- Large quark energy loss in the medium implies high densities
- Flow scales with number of quarks
- Is there deconfinement? → look for Quarkonia screening



Debye screening predicted to destroy J/ψ's in a sQGP with other states "melting" at different temperatures due to different sizes or binding energies.

RHIC: T/T_C ~ 1.9 or higher

Mocsy, WWND08



Different lattice calculations do not agree on whether the J/ψ is screened or not – measurements will have to tell!

Satz, hep-ph/0512217

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

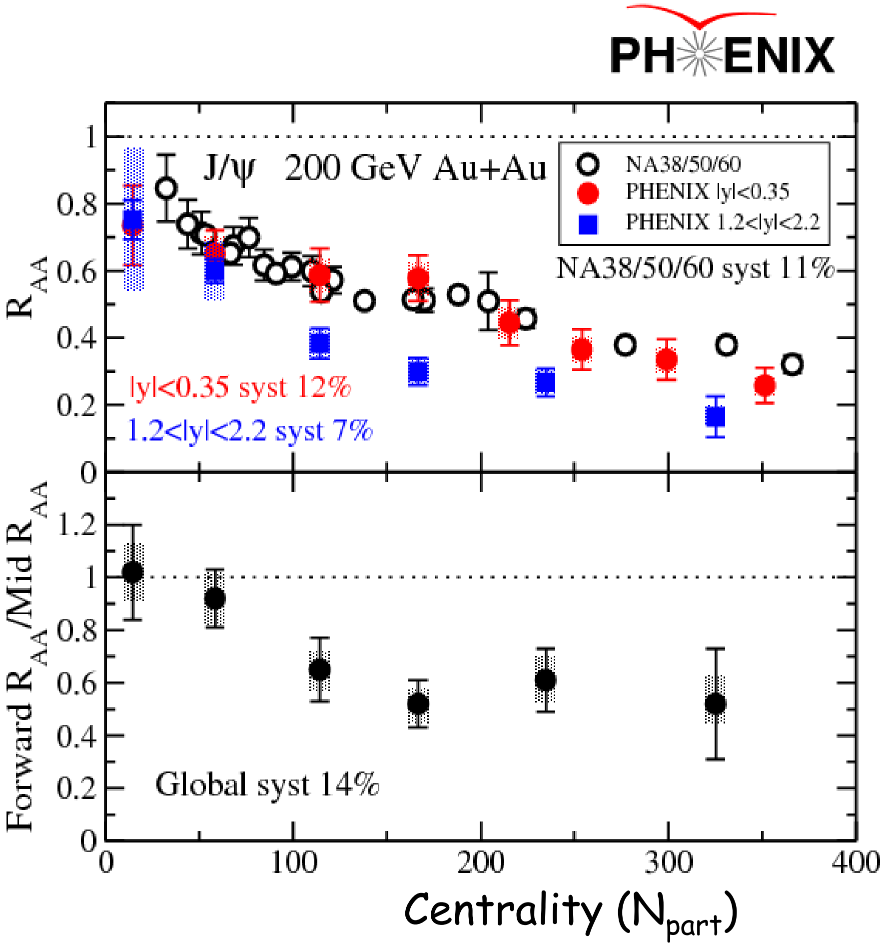
PHENIX A+A Data and Features

PHENIX Au+Au data shows suppression at mid-rapidity about the same as seen at the SPS at lower energy

- but stronger suppression at forward rapidity.
- Forward/Mid R_{AA} ratio looks flat above a centrality with N_{part} = 100

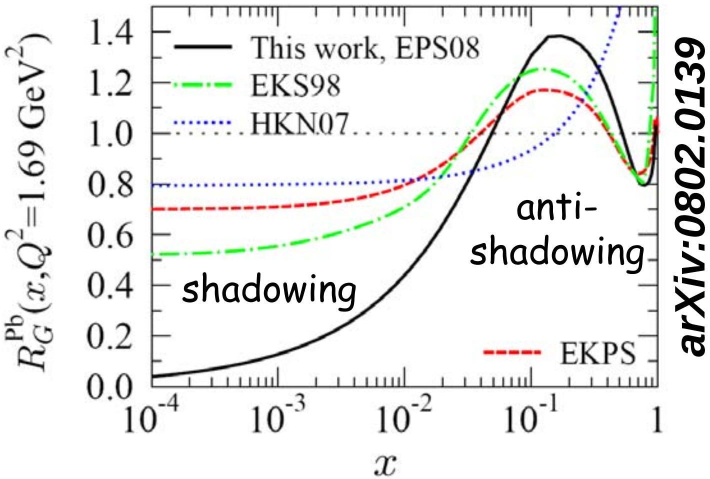
Several scenarios may contribute:

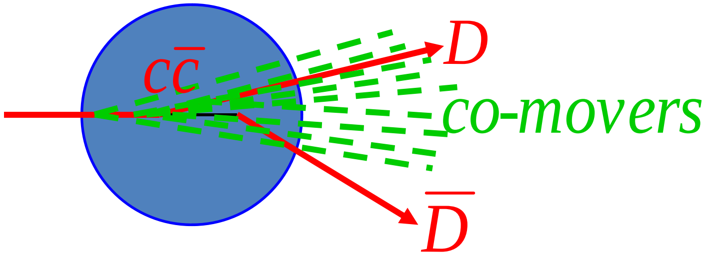
- Cold nuclear matter (CNM) effects
  - in any case are always present
- Sequential suppression
  - sQGP screening only of χ_C & ψ'- removing their feed-down contribution to J/ψ at both SPS & RHIC
- Regeneration models
  - give enhancement that compensates for screening



What CNM effects are important?
(CNM = Cold Nuclear Matter)

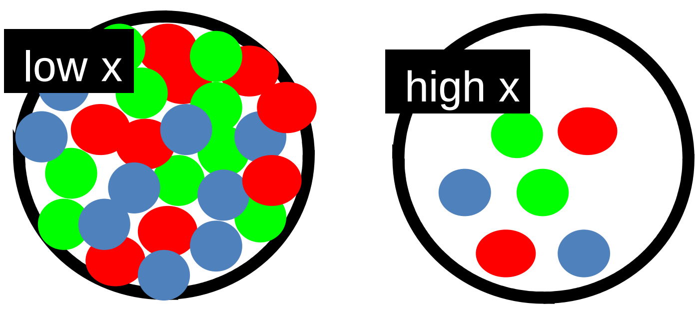
Traditional shadowing from fits to DIS or from coherence models



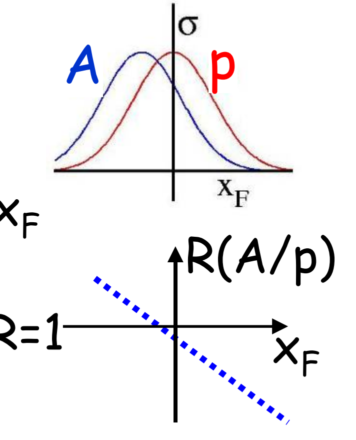


Absorption (or dissociation) of $c\bar{c}$ into two D mesons by nucleus or co-movers

Gluon saturation from non-linear gluon interactions for the high density at small x; amplified in a nucleus.



Energy loss of incident gluon shifts effective x_F and produces nuclear suppression which increases with x_F



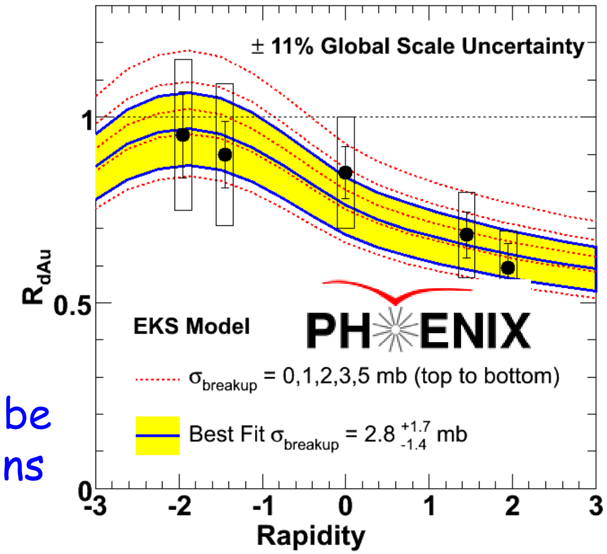
Nuclear Dependence Nomenclature – Ratio (R_{dAu}, R_{AA}) and Alpha (α)

$R_{dAu} = \alpha = 1$ if every N-N collision in a Nucleus contributes as if it were in a free nucleon

$$R_{dAu} = \frac{d\sigma^{dAu}/dy}{2\times 197\cdot(d\sigma^{pp}/dy)}$$

$$= \frac{dN^{dAu}/dy}{\langle n_{coll}^{dAu}\rangle dN^{pp}/dy}$$

$\langle n_{coll}\rangle$ from Glauber model calc. – can also be used for centrality bins

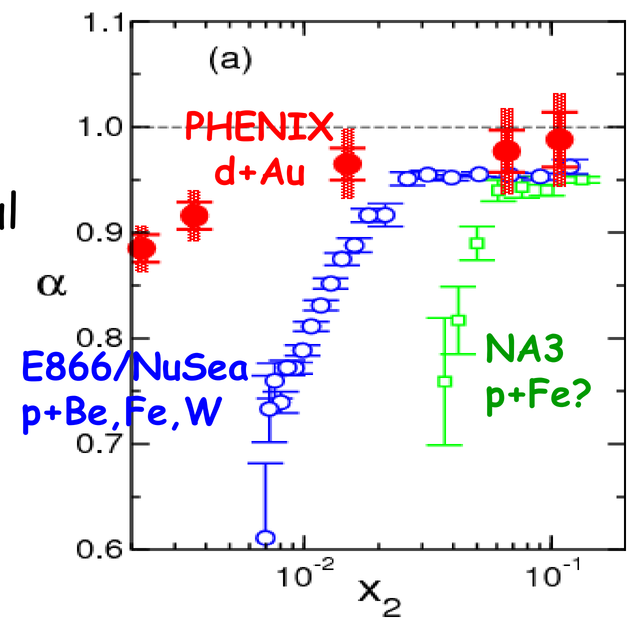


Where dN^{dAu}/dy is an invariant yield w/o absolute normalization factors that would be needed for a cross section (lower systematical uncertainties)

Alternatively, a power law with α – especially useful when comparing expts that used different nuclear targets

$$\sigma_{pA} = \sigma_{pp} A^{\alpha}$$

$$\alpha = 1 + \ln(R_{pA})/\ln(A)$$



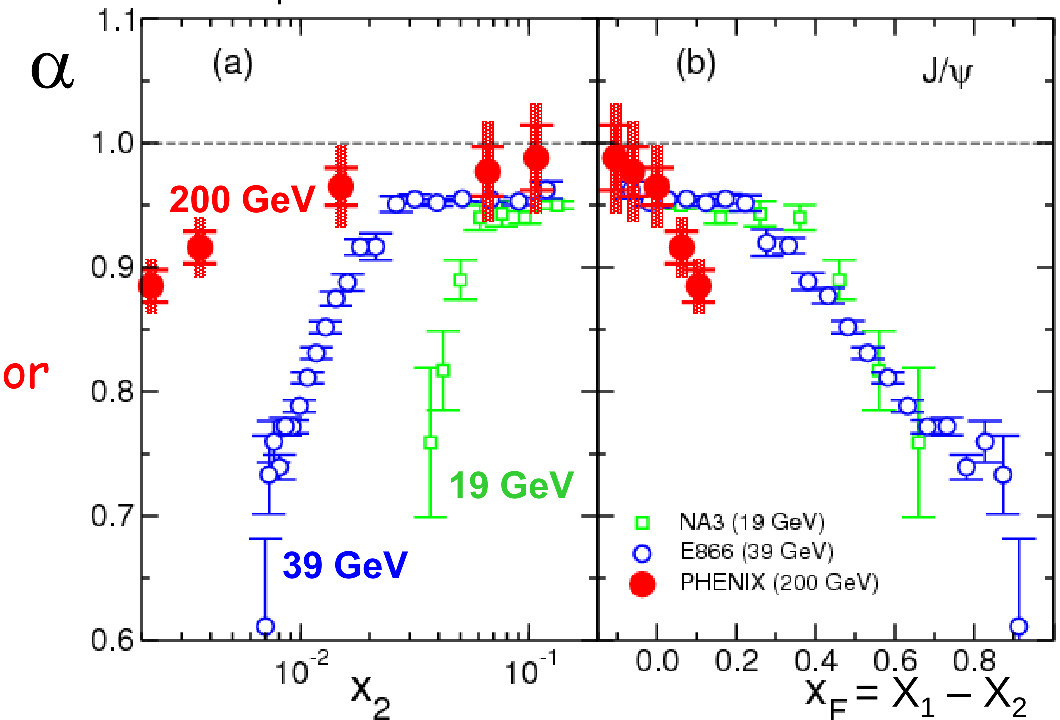
CNM Physics – PHENIX, E866, NA3 Comparison

New Analysis of Run3 d+Au with new 2005 p+p baseline
PRC 77,024912(2008)

Compared to E866/NuSea p+A results & lower-energy NA3 at CERN

$$\sigma_A = \sigma_N A^{\alpha}$$

J/ψ α for different √s collisions



(x_2 is x in the nucleus)

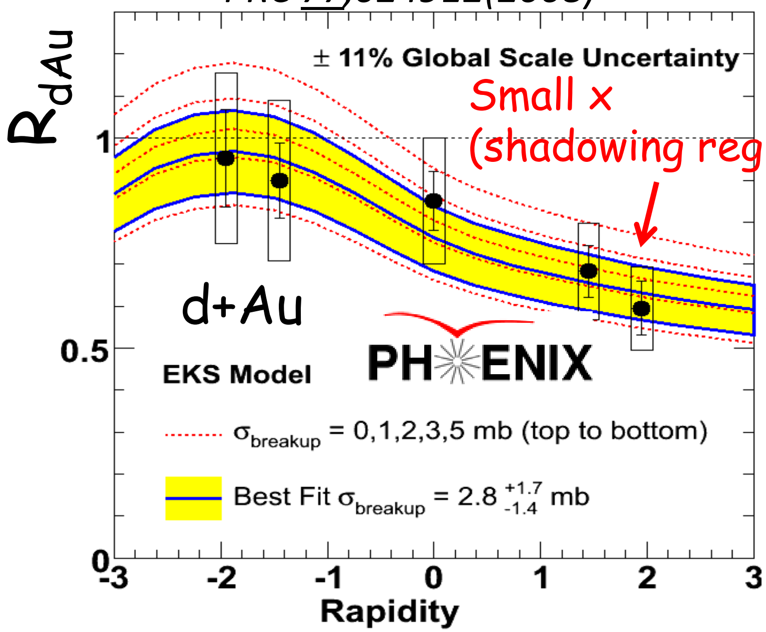
Not universal vs x_2 as expected for shadowing, but closer to scaling with x_F, why?

- initial-state gluon energy loss?
- gluon saturation?

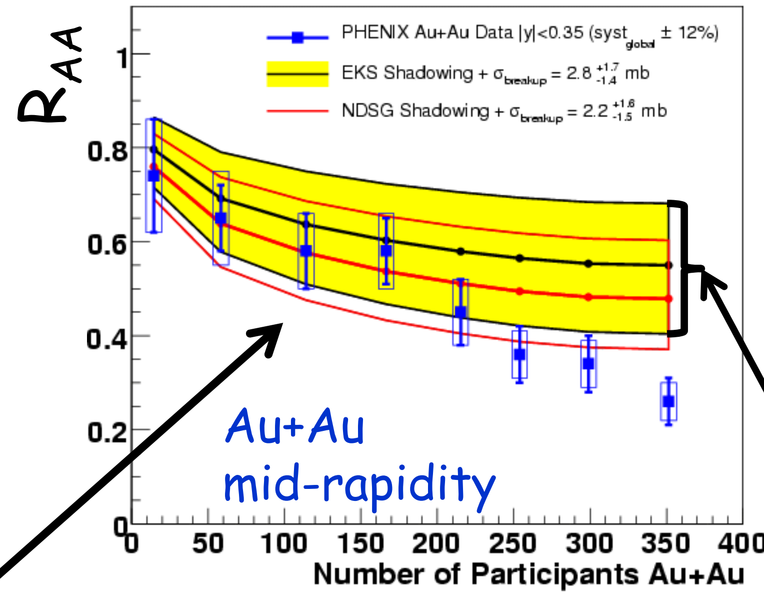
Present CNM Constraints on A+A data

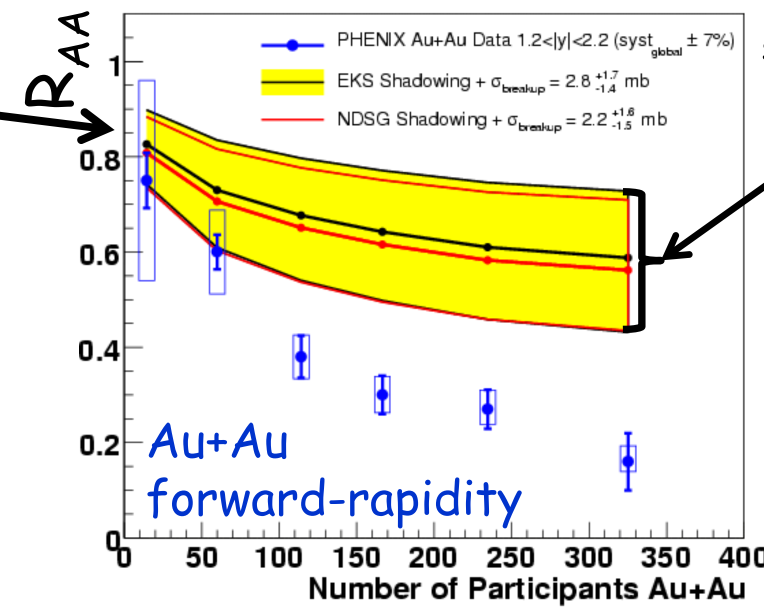
CNM effects (EKS shadowing + dissociation from fits to d+Au data, with R. Vogt calculations) give large fraction of observed Au+Au suppression, especially at mid-rapidity

PRC 77,024912(2008)



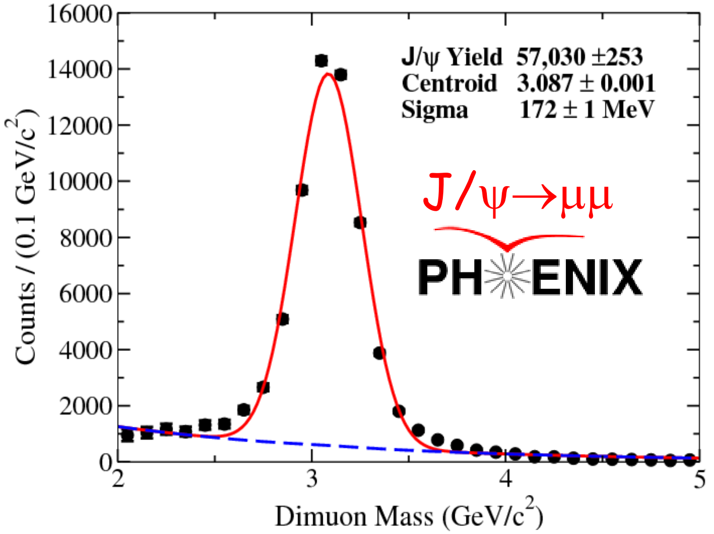
more accurate d+Au constraint badly needed



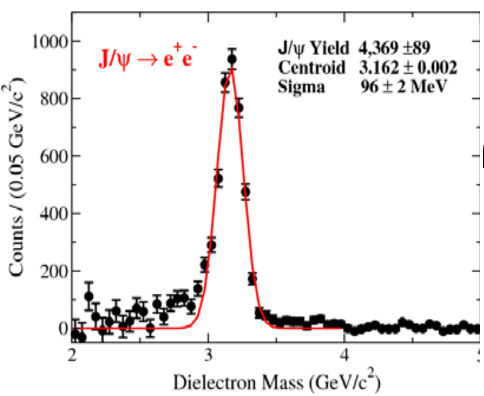


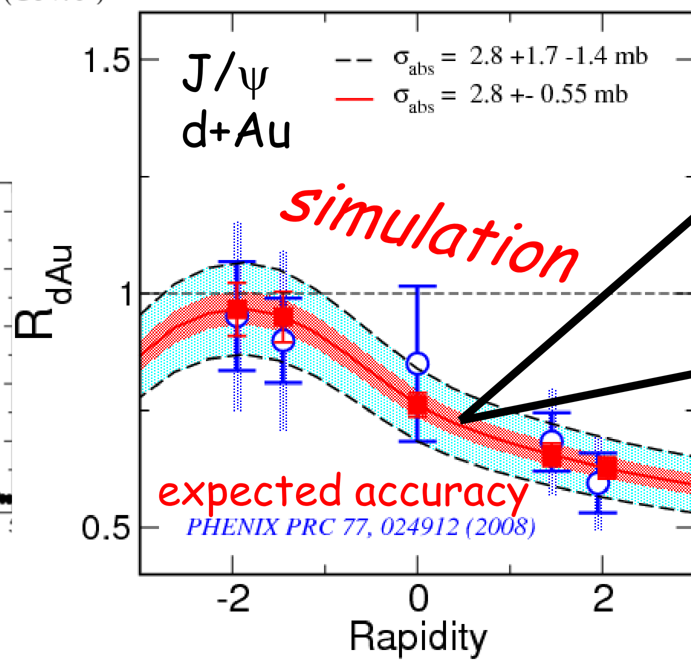
EKS shadowing band

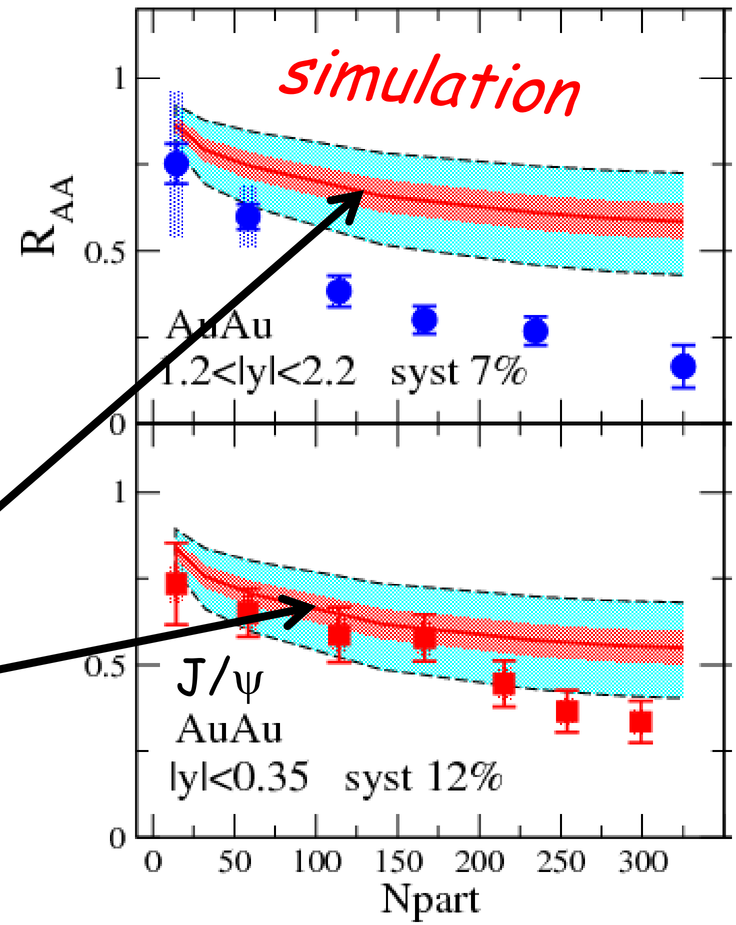
CNM Constraints from New Run8 d+Au J/ψ Data



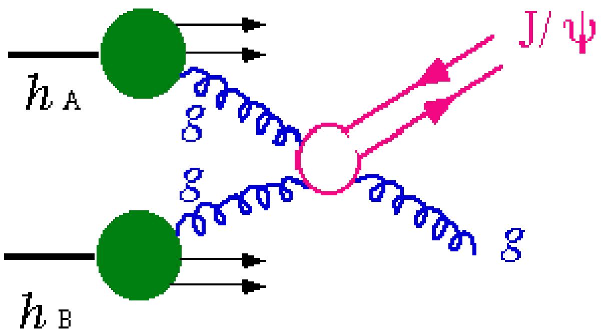
Expected improvement in CNM constraints (red) compared to Run3 (blue)





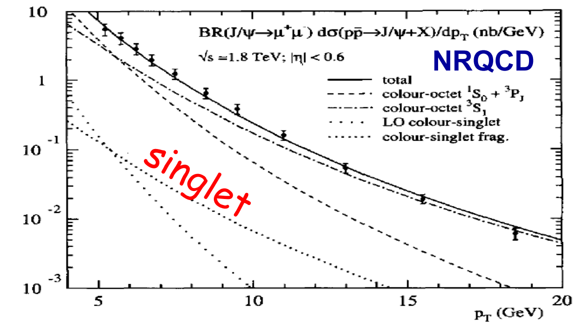


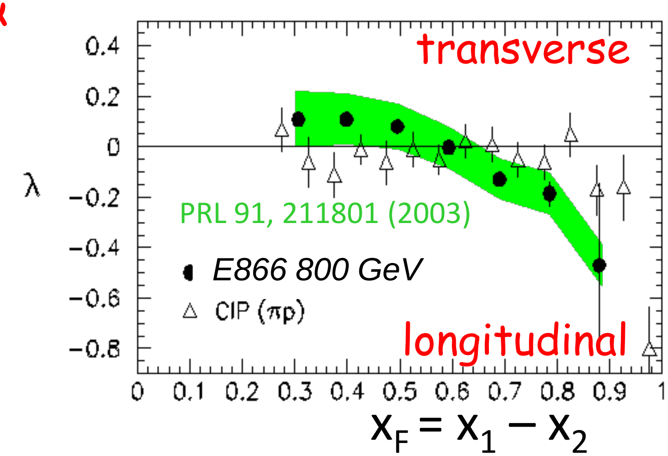
What about Production?
Lets look at p+p Collisions



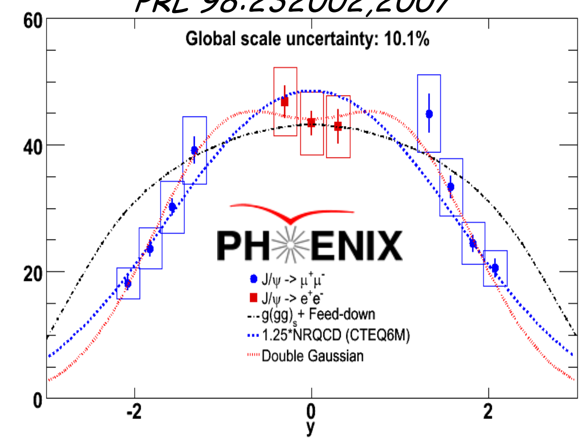
Quarkonia Production is Also an Issue

- gluon fusion dominates
- but is $c\bar{c}$ produced in a color-singlet or –octet state?
    - important for CNM effects
- difficult to get both absolute cross section & polarization correct
    - singlet models under-predict cross sections
    - octet models get cross section but predict transverse polarization at large p_T - but small longitudinal polarization was seen (E866, CDF)
    - recently a new singlet model seems to get both correct (*Haberzettl, Lansberg, PRL 100, 032006 (2008)*)
- Latest PHENIX data starting to define rapidity dependence

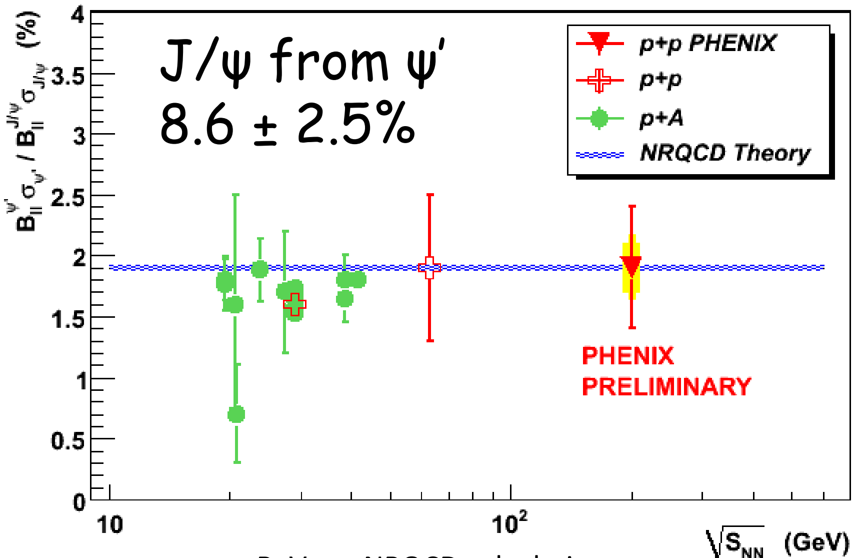




PRL 98:232002,2007

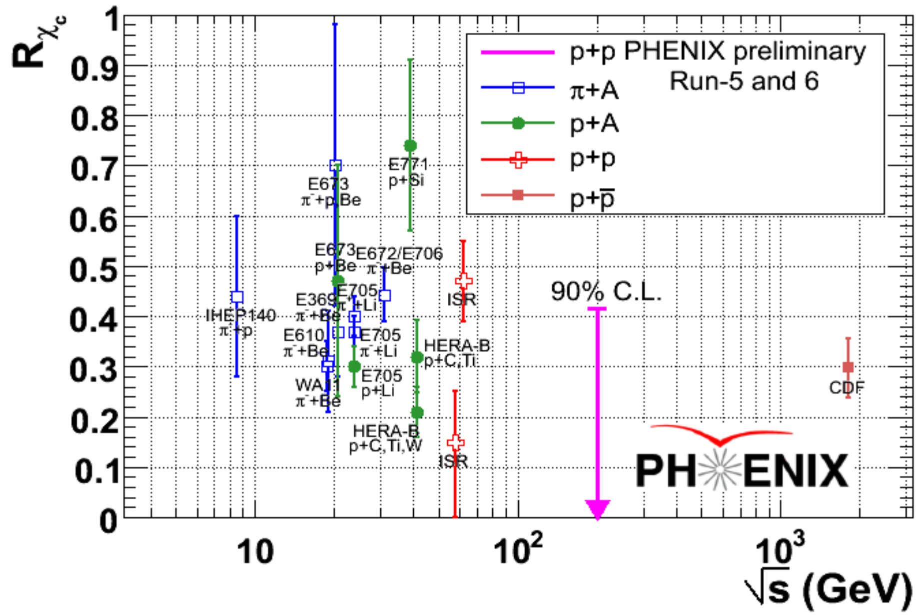


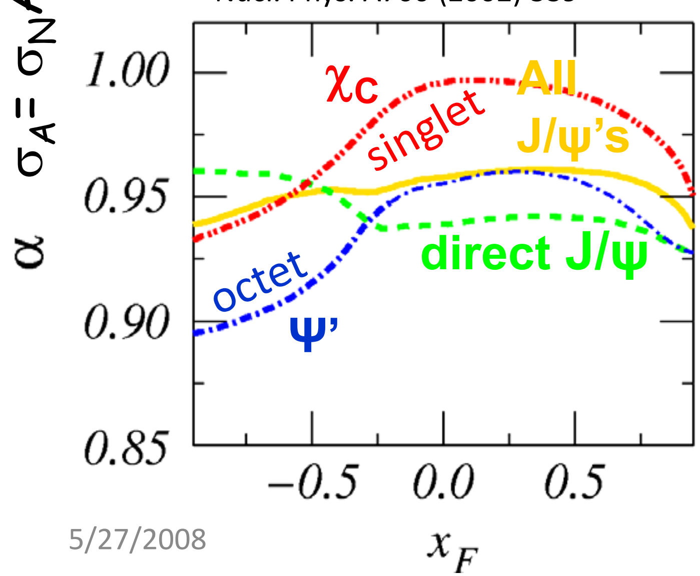
Complications due to substantial feed-down from higher mass resonances (ψ', χ_c)



R. Vogt, NRQCD calculations
Nucl. Phys. A700 (2002) 539

J/ψ from χ_c < 42% (90% CL)



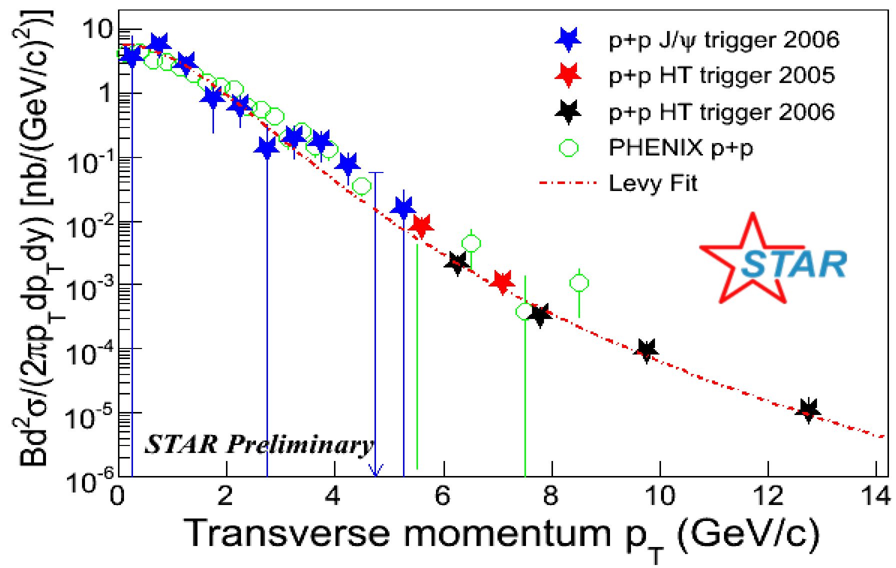


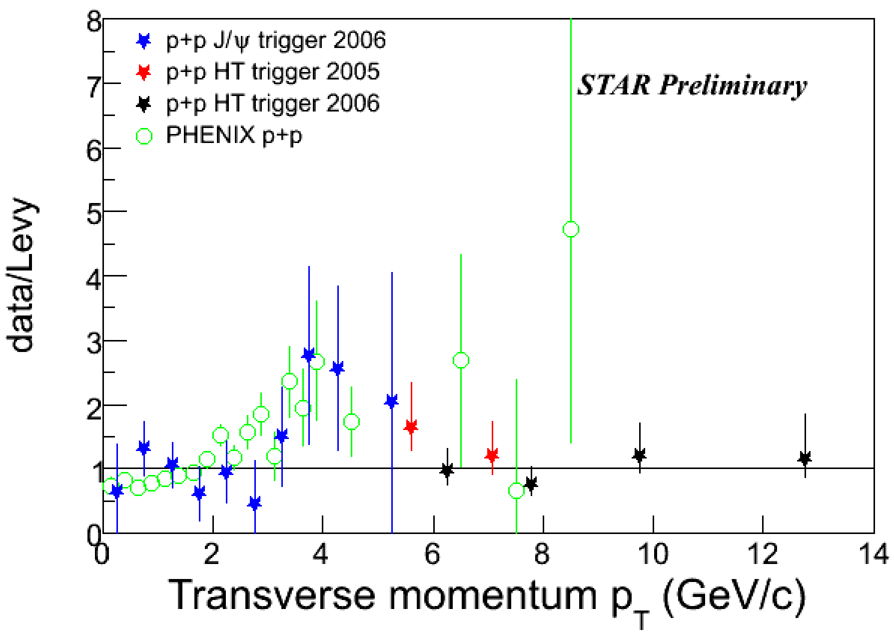
Nuclear dependence of (parent) resonance, e.g. χ_C is probably different than that of the J/ψ

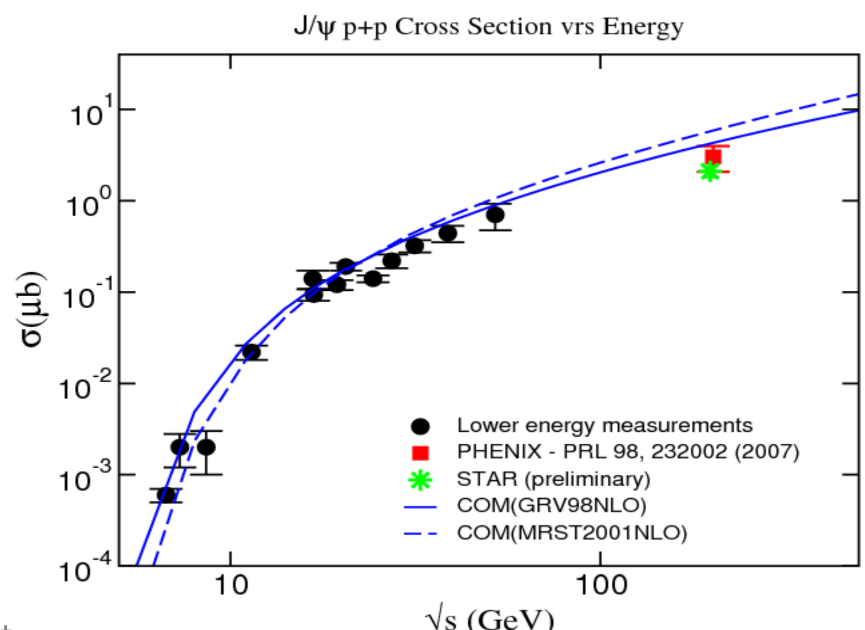
Also measure of
B → J/ψ - 4^{+3}_{-2} %
(but will be strongest at high-p_T)

Consistency of STAR and PHENIX

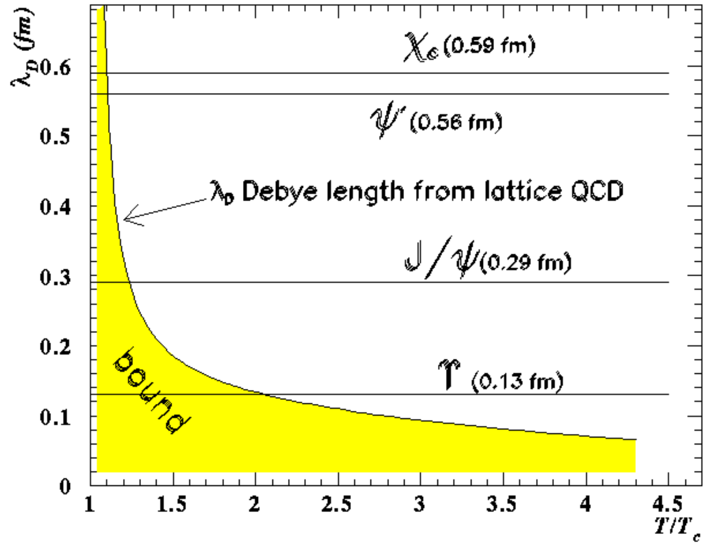
STAR beginning to measure J/ψ, especially at larger p_T
- consistent with PHENIX measurements







And Now back to A+A and the sQGP

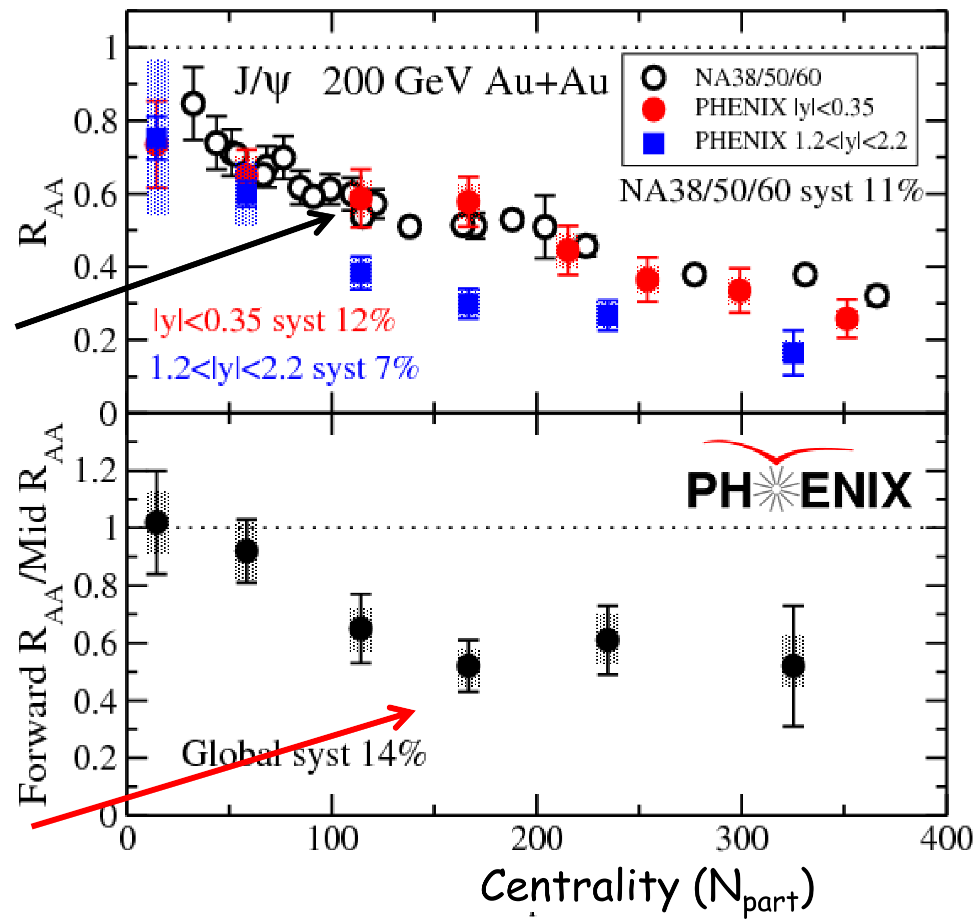


sQGP Effects on Quarkonia
Sequential Screening and Gluon Saturation

Some recent lattice calculations suggest J/ψ not screened at all

- suppression then comes only via feed-down from screened χ_C & ψ′
- then the situation would be the same at lower energies (NA38/50/60) as for RHIC mid-rapidity
- and the stronger suppression at forward rapidity at RHIC could come from gluon saturation

- *Can this picture explain flat forward/mid-rapidity R_{AA} super-ratio?*



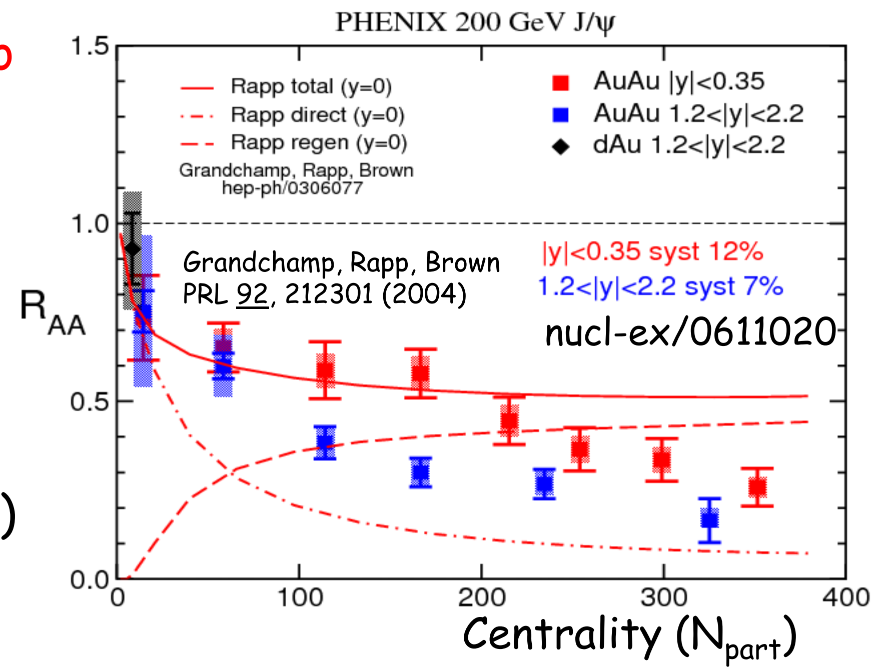
sQGP effects on Quarkonia
Regeneration – Compensating for Screening

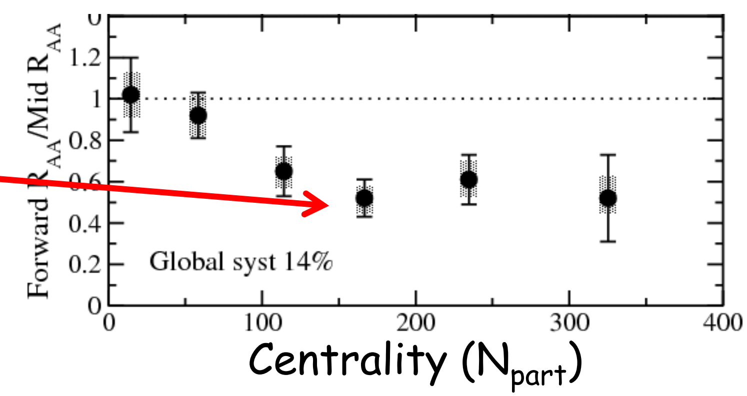
- larger gluon density at RHIC expected to give stronger suppression than SPS
- but larger charm production at RHIC gives larger regeneration

- forward rapidity lower than mid due to smaller open-charm density there
- very sensitive to poorly known open-charm cross sections (FVTX will help here)

- expect inherited flow from open charm
- regeneration would be HUGE at the LHC!

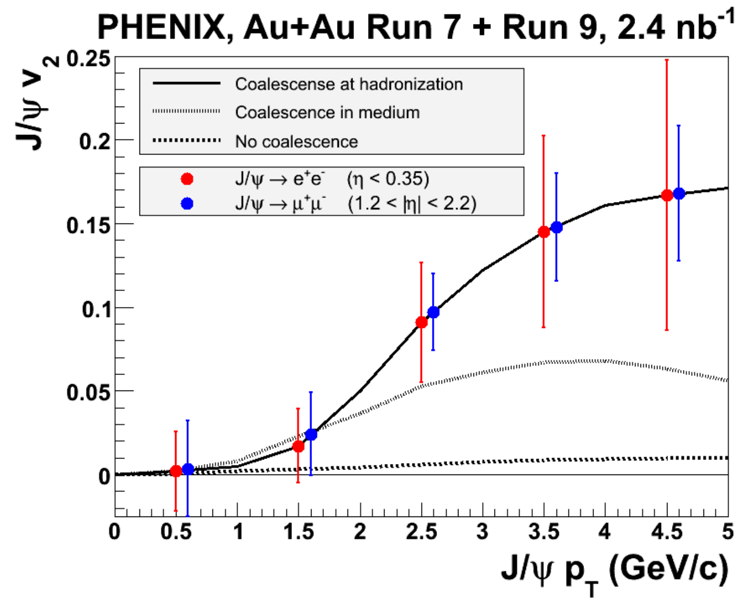
- *can the two compensating components (screening & regeneration) which may have diff. centrality dependences, give a flat forward/mid-rapidity R_{AA}?*



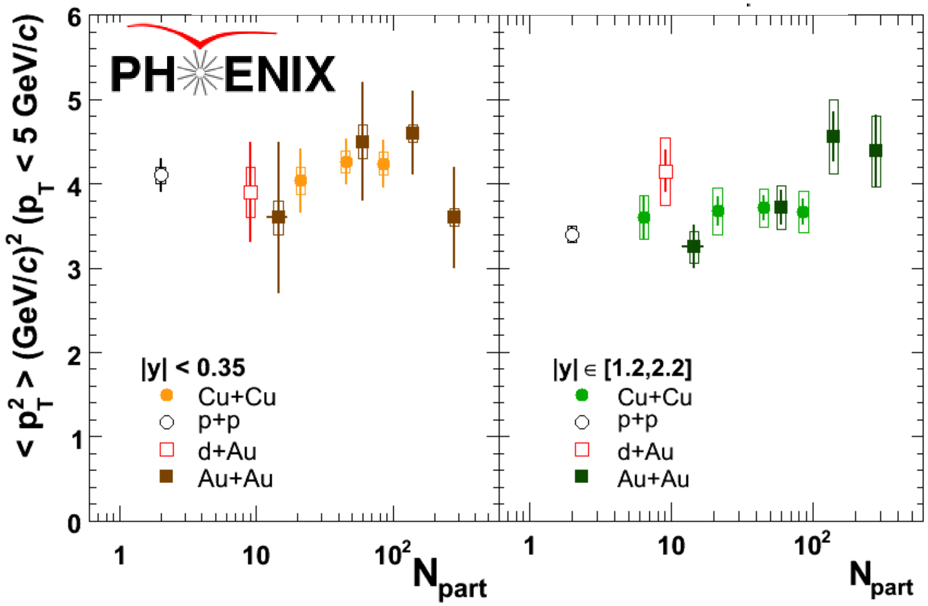


sQGP effects on Quarkonia - J/ψ flow & p_T Broadening

- J/ψ's from regeneration should inherit the already observed large charm-quark elliptic flow
- First J/ψ flow measurement by PHENIX
- also need to measure open-charm flow at forward rapidity
- Projection for Run9+7 (2.4 nb^{-1}) with dimuons (blue) & dielectrons (red)



- CNM effects broaden p_T
  - initial-state mult. scatt. for both gluons
- but regeneration should narrow p_T
  - square of small-p_T peaked open-charm cross section
- *AA data same as pp & relatively flat with centrality*



Reaching Higher p_T for J/ψ - probing for the "hot wind?"

Approximate ratios by combining PHENIX & STAR data reach higher p_T & appear to be consistent with R_{AA}=0.9±0.2 at high p_T

- but also consistent with lower p_T data at R_{AA} = 0.52
- & regeneration models
- & rough projection from d+Au
- but not with gluon dissociation + flow (*Patra, nucl-th/0503034 2005*)

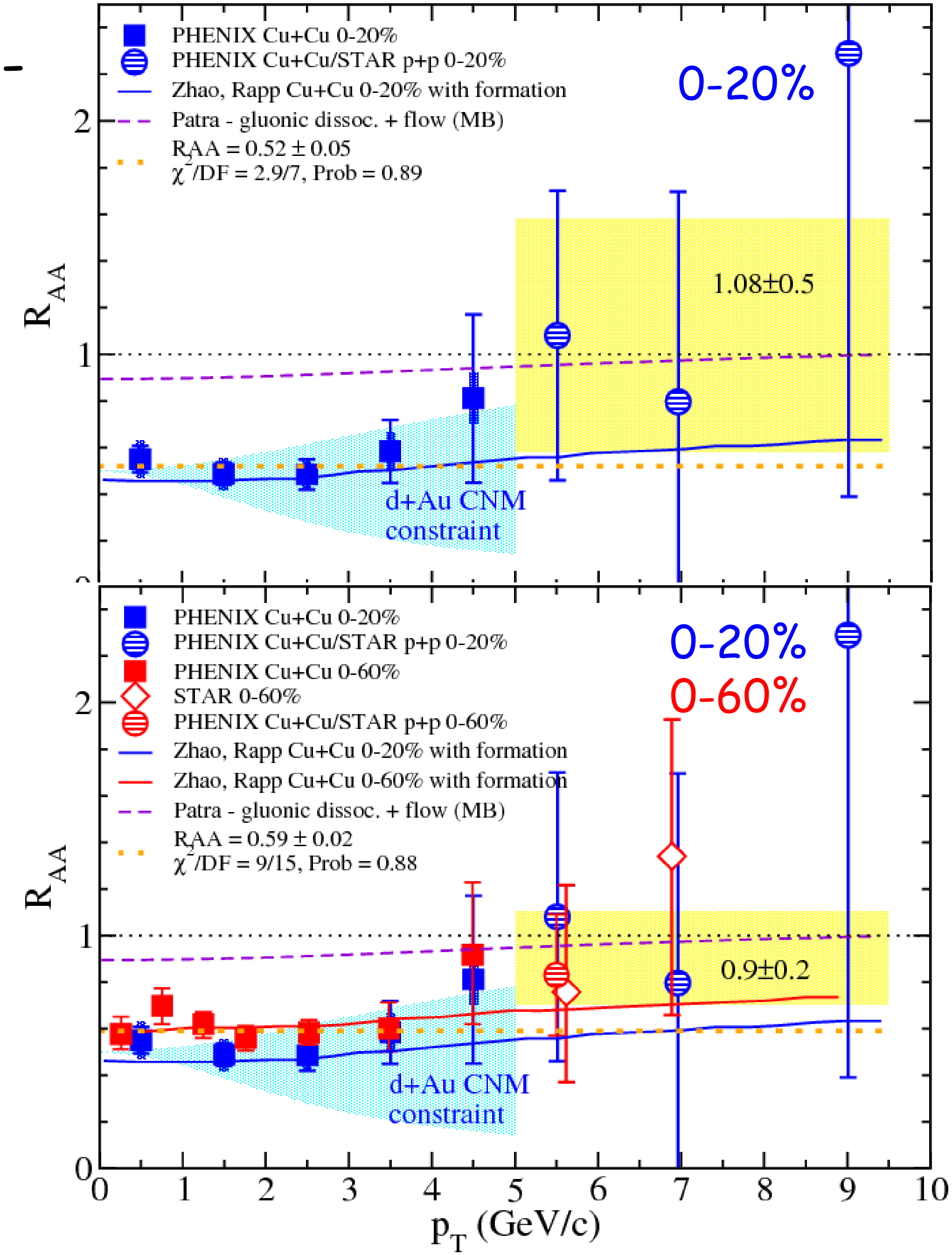
Most models expect a decrease in R_{AA} at high p_T:

AdS/CFT ("hot wind"):

H. Liu, K. Rajagopal and U.A. Wiedemann, PRL 98, 182301(2007) and hep-ph/0607062

Regeneration (2-compenent):

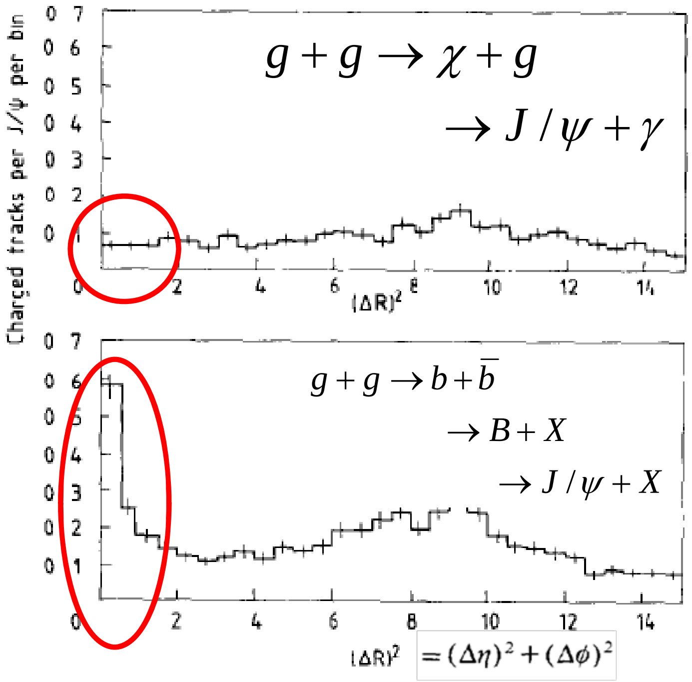
X. Zhao and R. Rapp, hep-ph/07122407
Private communication



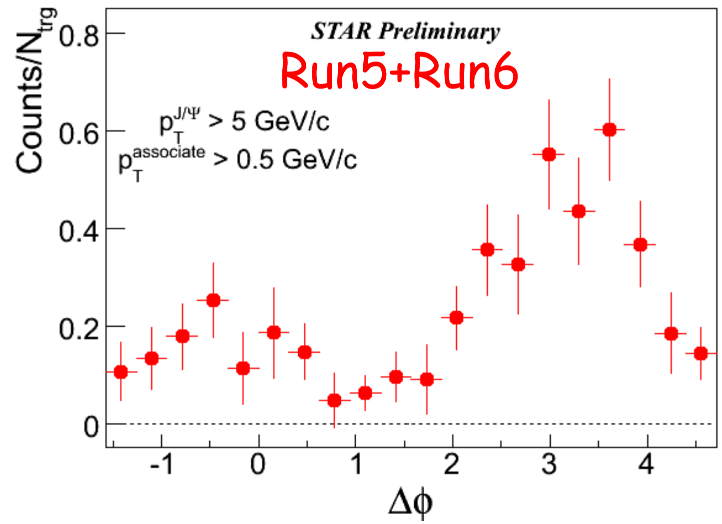
Disentangle Contributions via Correlations

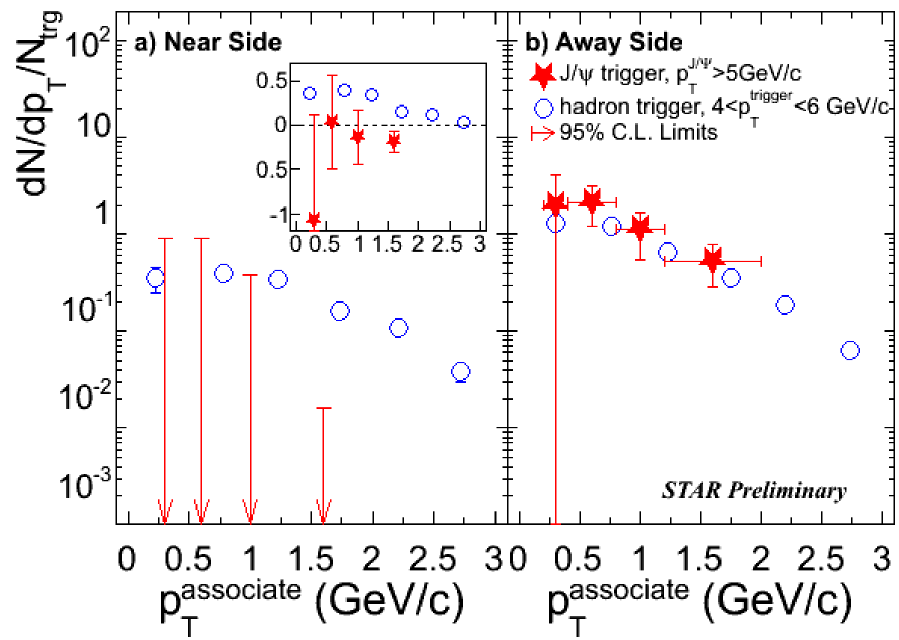
PLB 200, 380 (1988), 256, 112 (1991)

UA1 simulations



J/ψ-hadron correlation sensitive to source of J/ψ





Away-side - consistent with gluon or light-quark fragmentation

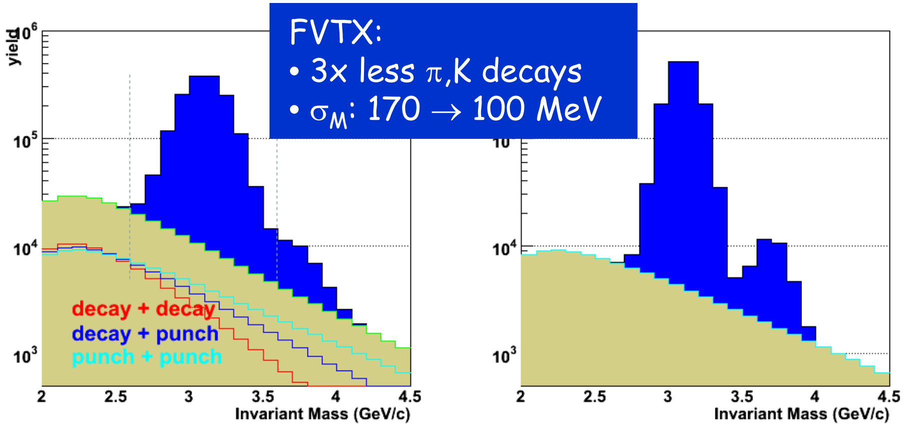
Near-side – consistent with no associated hadron production

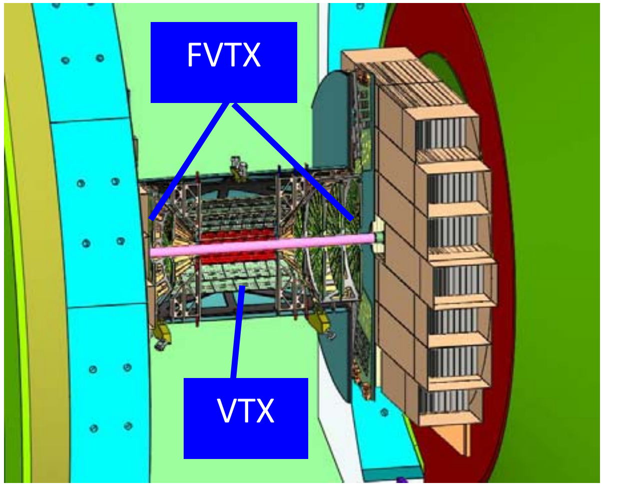
- B → J/ψ not important (at this p_T)

PHENIX Upgrades & RHIC Luminosity Advances

Vertex detectors (VTX,FVTX) + higher luminosity will give:

- ψ' measurement with reduced combinatoric background + sharper mass resolution
- precise open-heavy measurements to constrain regeneration picture
- hadrons at forward rapidity





Rates for a 12-week Au+Au run at highest RHIC (stoch. cooled) luminosities (muon arms + FVTX)

J/ψ	ψ'	Υ	$B \rightarrow J/\psi\ X$
121k	2.2k	600	3.4k

19 nb^{-1} Au+Au delivered

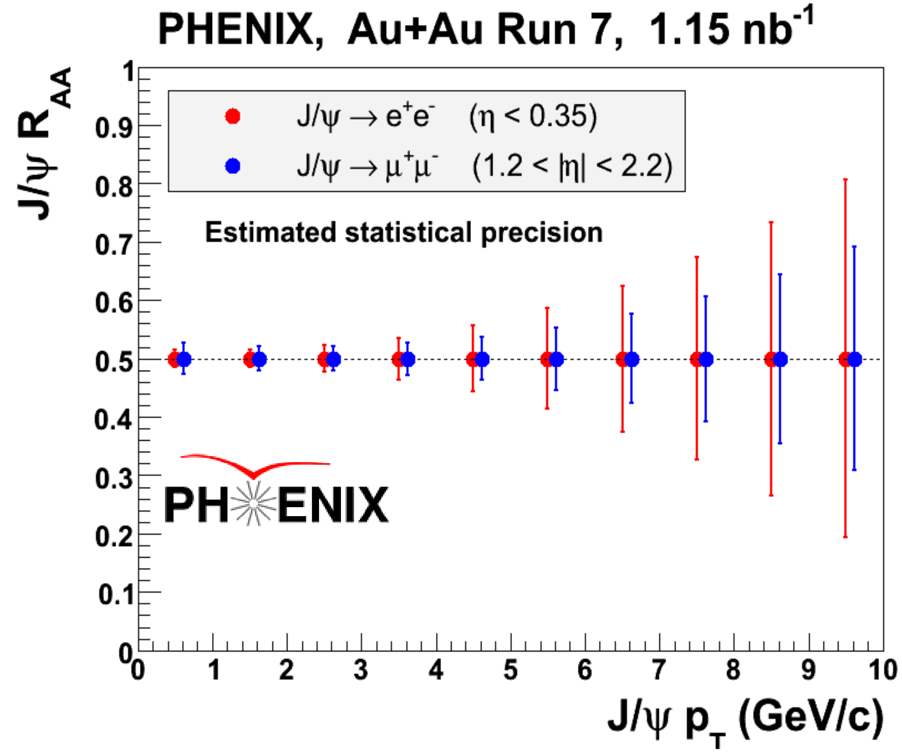
Recent Quarkonia Yields in PHENIX & STAR

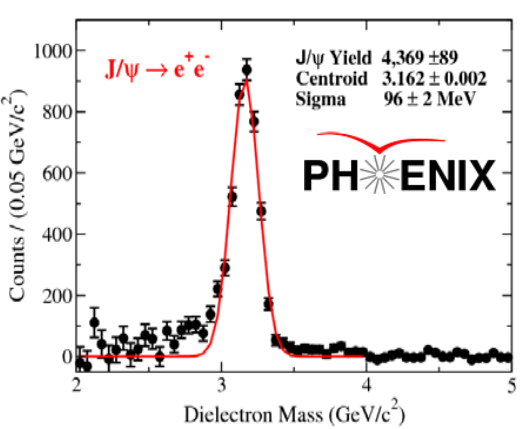
					J/ψ		Υ	
Run	species	Expt.	Lumi	p_T	ee	μμ	ee	μμ
2005	pp	PHENIX	3.8 pb^{-1}		400	1250		27
		STAR	3 pb^{-1}	>2.5	22			
	CuCu	PHENIX	3 nb^{-1}		2k	9k		
		STAR	0.9 nb^{-1}	> 3.75	17			
2006	pp	PHENIX	10.7 pb^{-1}		1.5k	22k		
		STAR	0.4 pb^{-1}		~150			
			11 pb^{-1}	> 4	40			
			9 pb^{-1}				42	
2007	AuAu	PHENIX	0.81 nb^{-1}		3.7k	16k		
		STAR	0.3 nb^{-1}				70	
2008	dAu	PHENIX	80 nb^{-1}		6k	73k		~200
	pp		5.2 pb^{-1}			13k		

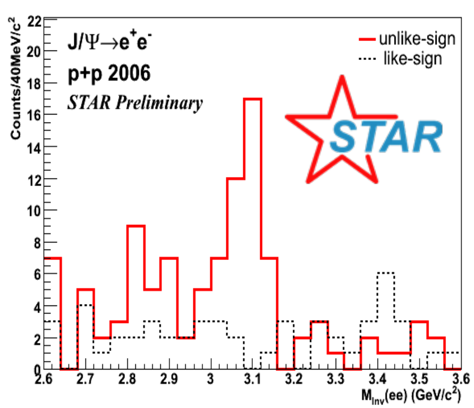
Increasing the Reach in p_T for J/ψ

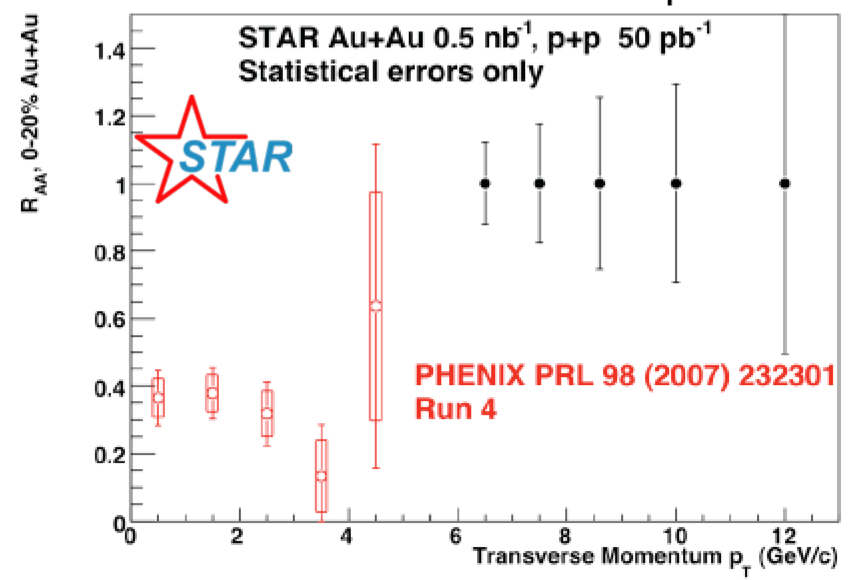
J/ψ projections from PHENIX & STAR – note that:

- 1.15 nb^{-1} at R_{AA}=0.5 is roughly equivalent to 0.5 nb^{-1} at R_{AA}=1, in terms of statistical uncertainty
- so fractional uncertainties shown here imply similar precision from both expts.

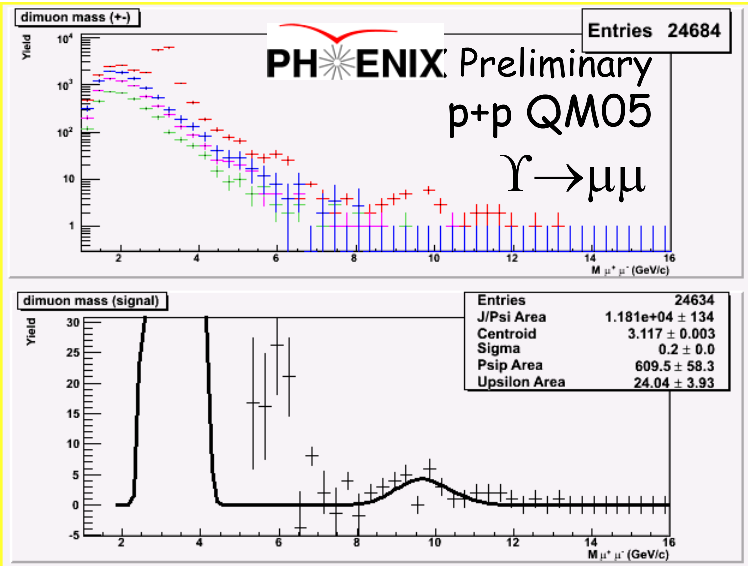


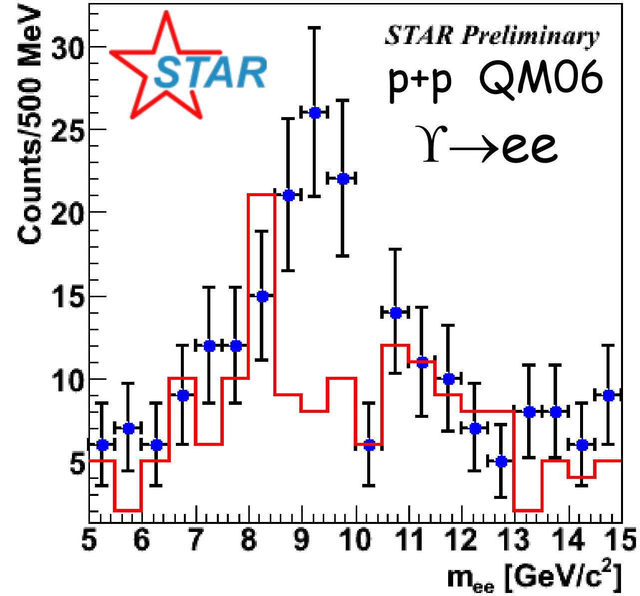


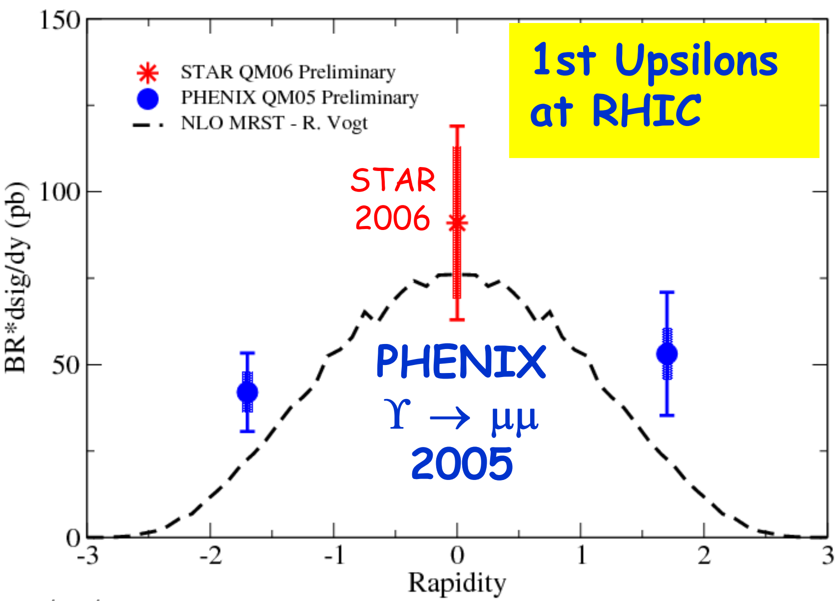


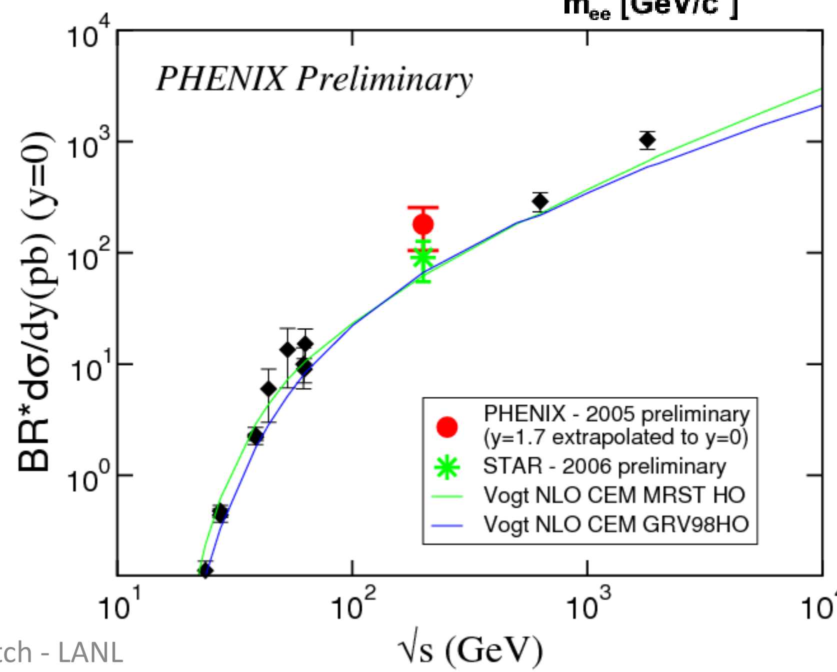


PHENIX & STAR Preliminary Υ p+p Cross Sections









The Upsilon Challenge

Expectations for Υ's in the sQGP:

- Υ_{1s} survives
- Υ_{2s} may melt
- Υ_{3s} melts

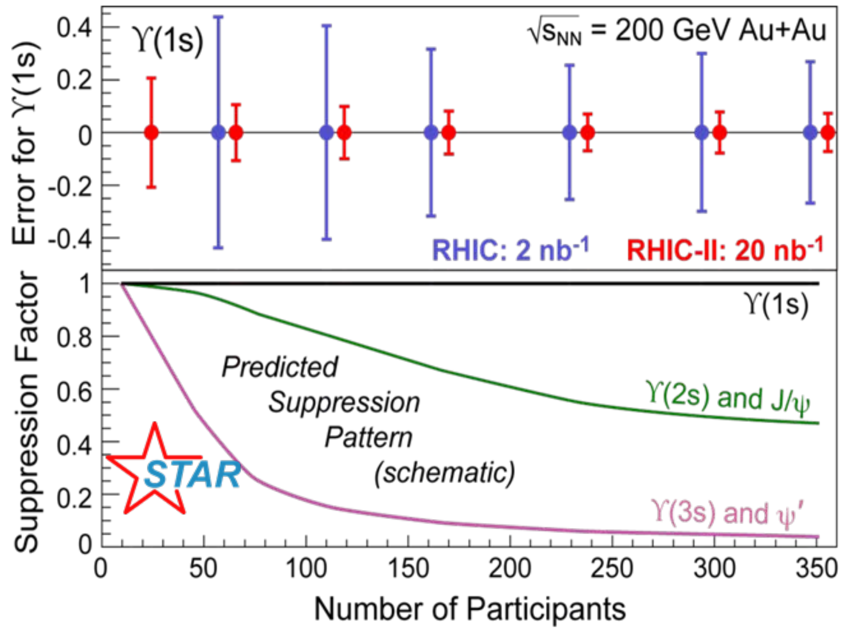
- Recombination small (at RHIC)
- STAR has large acceptance

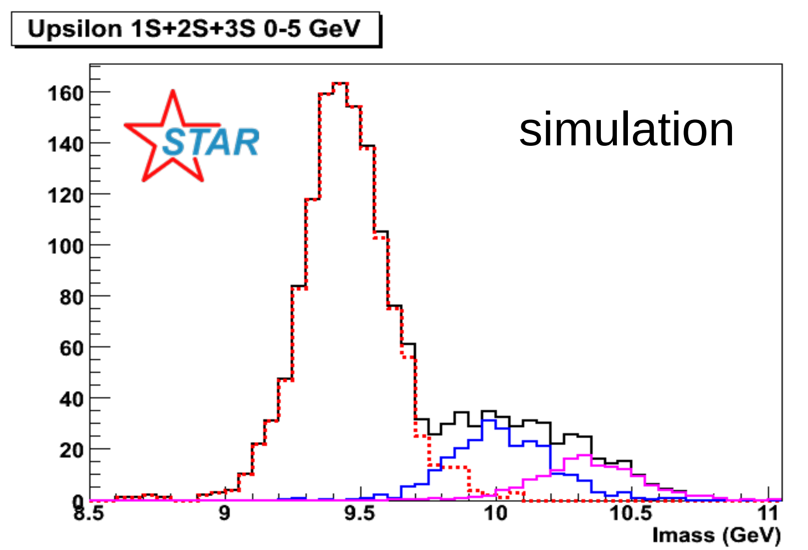
But Υ's are certainly a challenge:

- very low rates - luminosity critical
- difficult to separate the 3 states

PHENIX expectations:

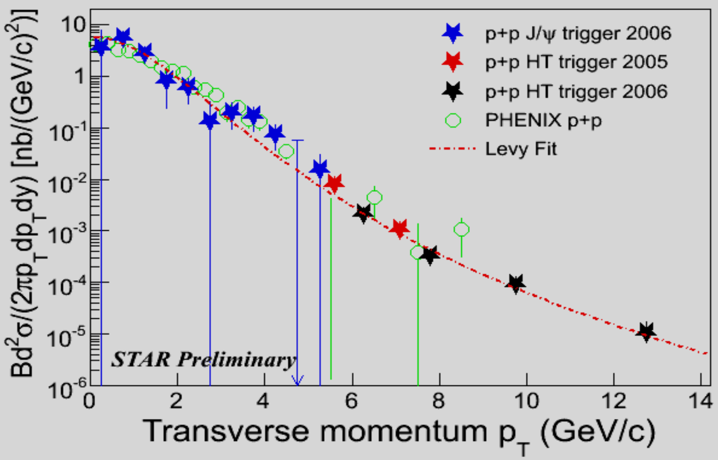
- 600 $\Upsilon_{1s+2s+3s}$ for 19 nb^{-1} Au+Au delivered
- 700 $\Upsilon_{1s+2s+3s}$ for 360 pb^{-1} p+p delivered



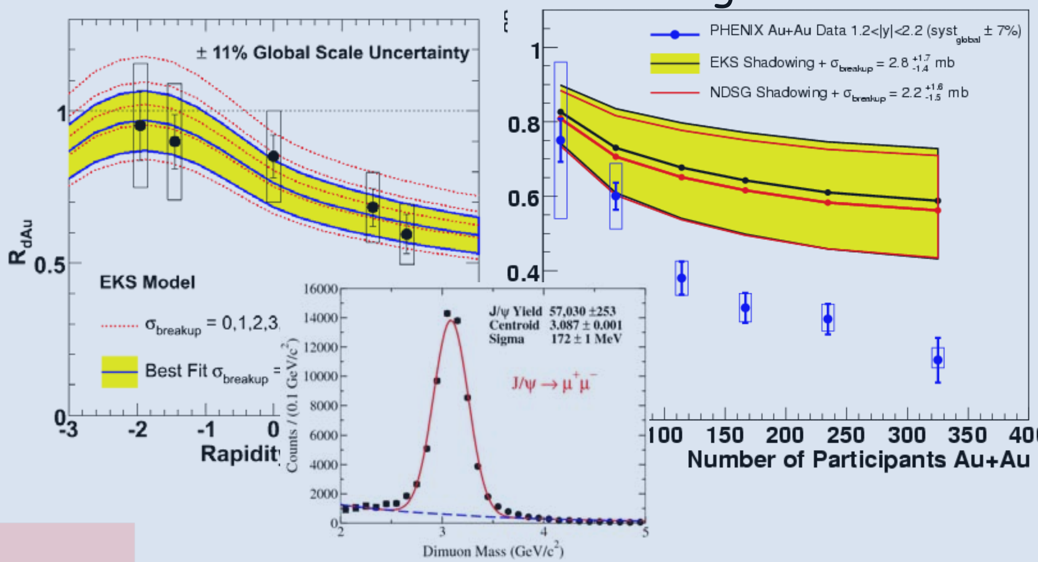


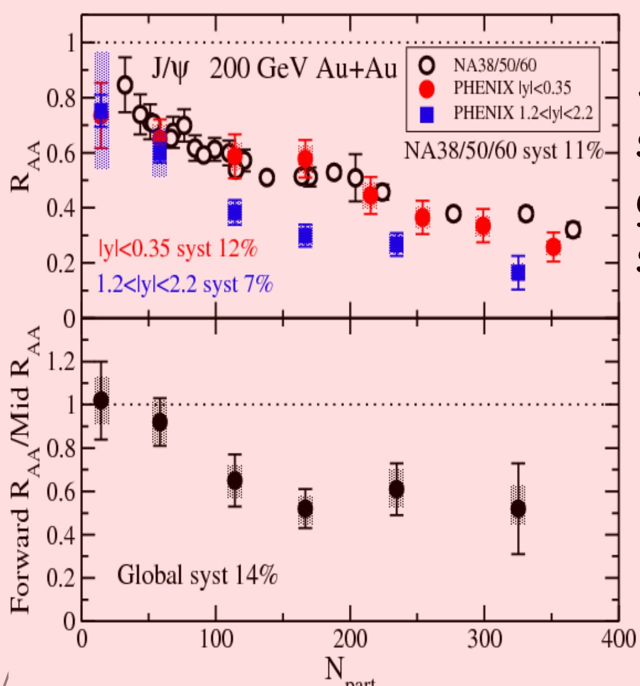
Quarkonia Results from RHIC – Summary

Pushing J/ψ to higher-p_T



Better CNM baseline coming from Run8!





Sequential screening & gluon saturation

flow from regeneration is difficult to see