

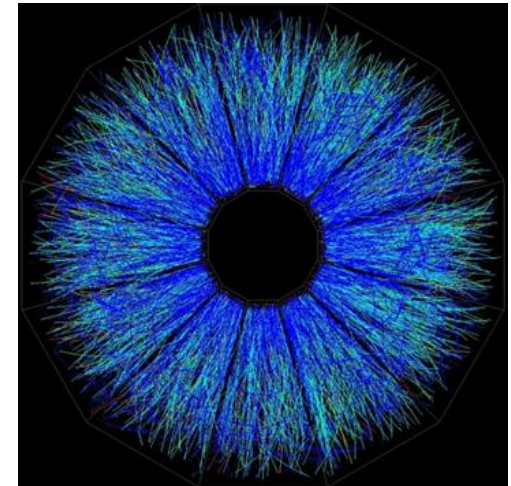


Quarkonium measurements at STAR

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for STAR collaboration

**Czech Technical University
in Prague**



**XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects
Marseilles, April 22-26, 2013**

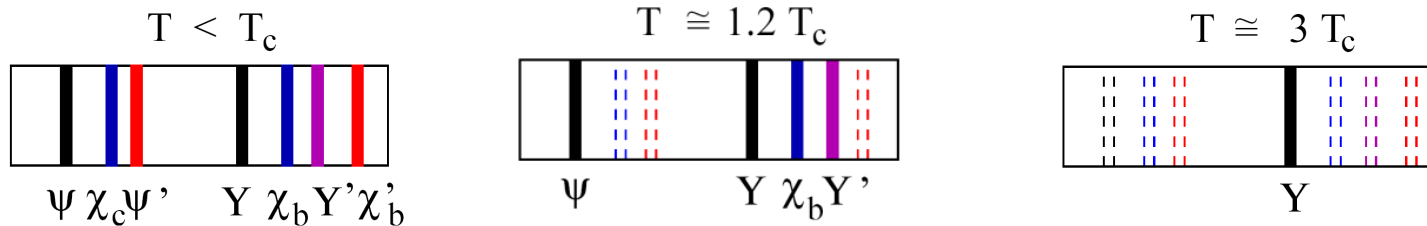
Outline

- Motivation.
- J/ψ production in p+p and d+Au 200GeV.
- J/ψ suppression in Au+Au 39,62,200 GeV.
- Upsilon measurements.
- Summary.



Quarkonium in nuclear matter

- In central Au+Au 200GeV collisions at RHIC hot and dense nuclear matter in form of Quark Gluon Plasma is produced.
- Due to color screening of quark potential in QGP quarkonium dissociation is expected.
- Suppression of different states is determined by medium temperature and their binding energy - QGP thermometer H. Satz, Nucl. Phys. A (783):249-260(2007)



State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ'_b	Υ''
Mass (GeV)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17
r_0 (fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

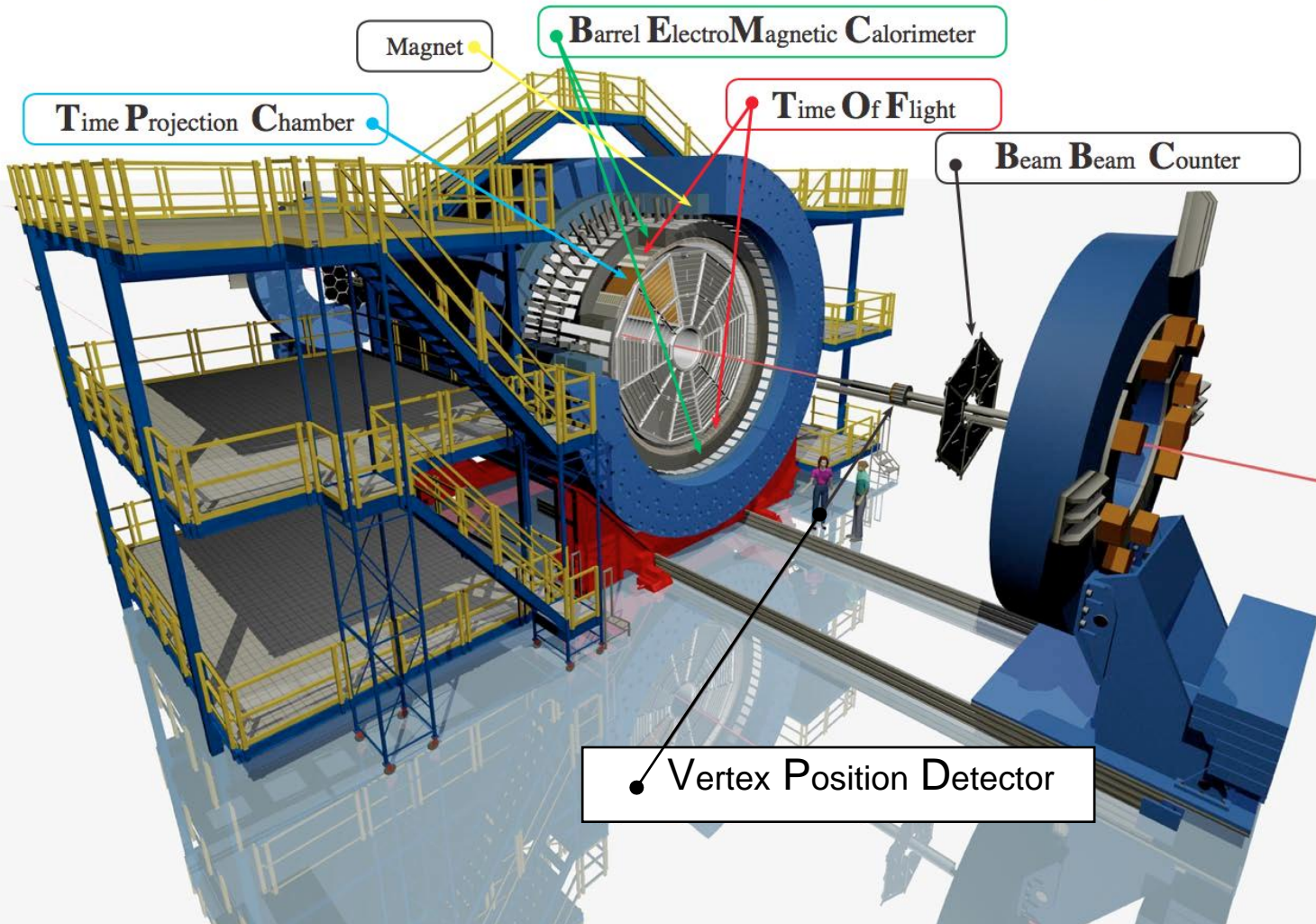
Other important effects

- Quarkonium production mechanism is not well understood.
 - Color-singlet vs. Color-octet?
- Observed yields are a mixture of direct production + feeddown
 - E.g. $J/\psi \sim 0.6 J/\psi$ (Direct) + $\sim 0.3 \chi_c$ + $\sim 0.1 \psi'$
- Suppression and enhancement in the “cold” nuclear medium
 - Nuclear Absorption, Gluon shadowing, initial state energy loss, Cronin effect and gluon saturation.
- Hot/dense medium effect
 - Recombination from uncorrelated charm pairs.



The STAR Detector

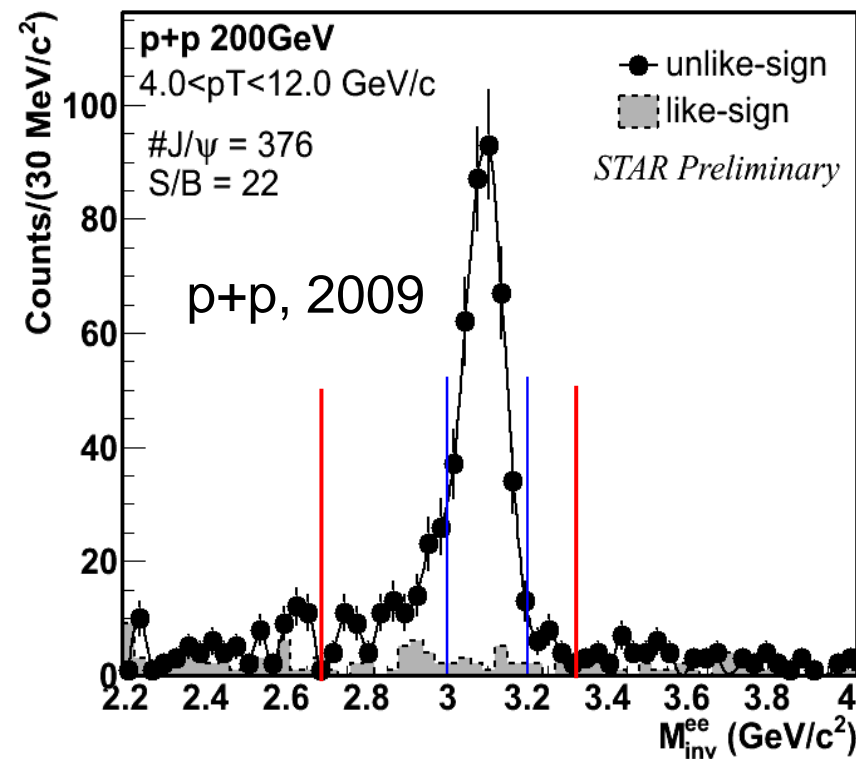
Solenoidal Tracker At RHIC : $-1 < \eta < 1, 0 < \phi < 2\pi$



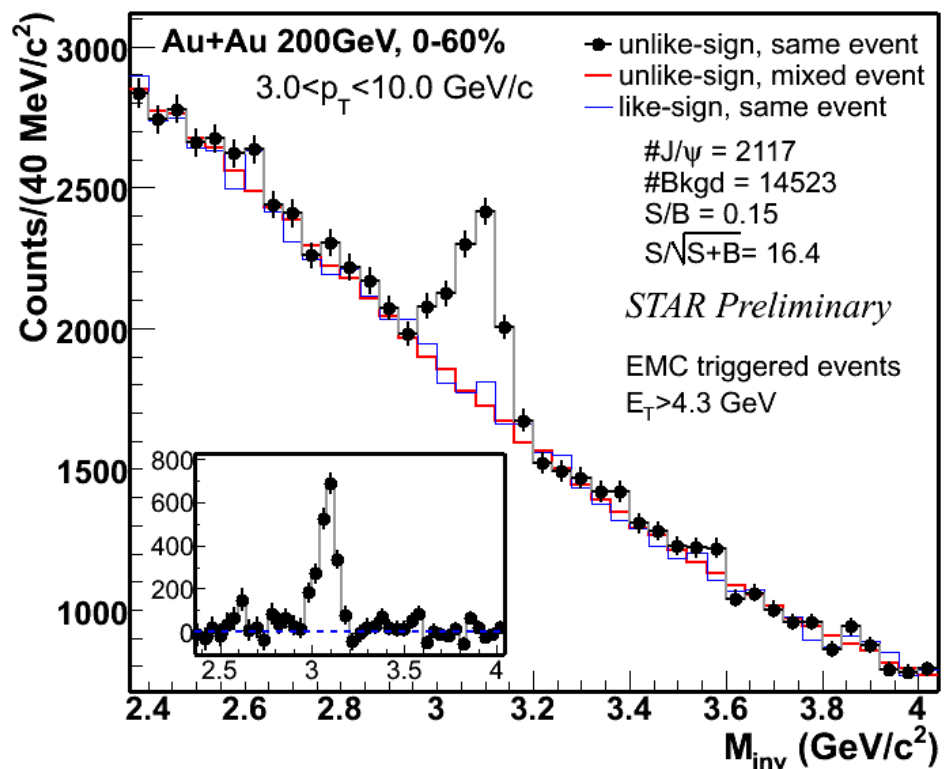
- VPD: minimum bias trigger.
- TPC: PID, tracking.
- TOF: PID.
- BEMC: PID, trigger.



$J/\psi \rightarrow e^+e^-$ signals



TPC+BEMC

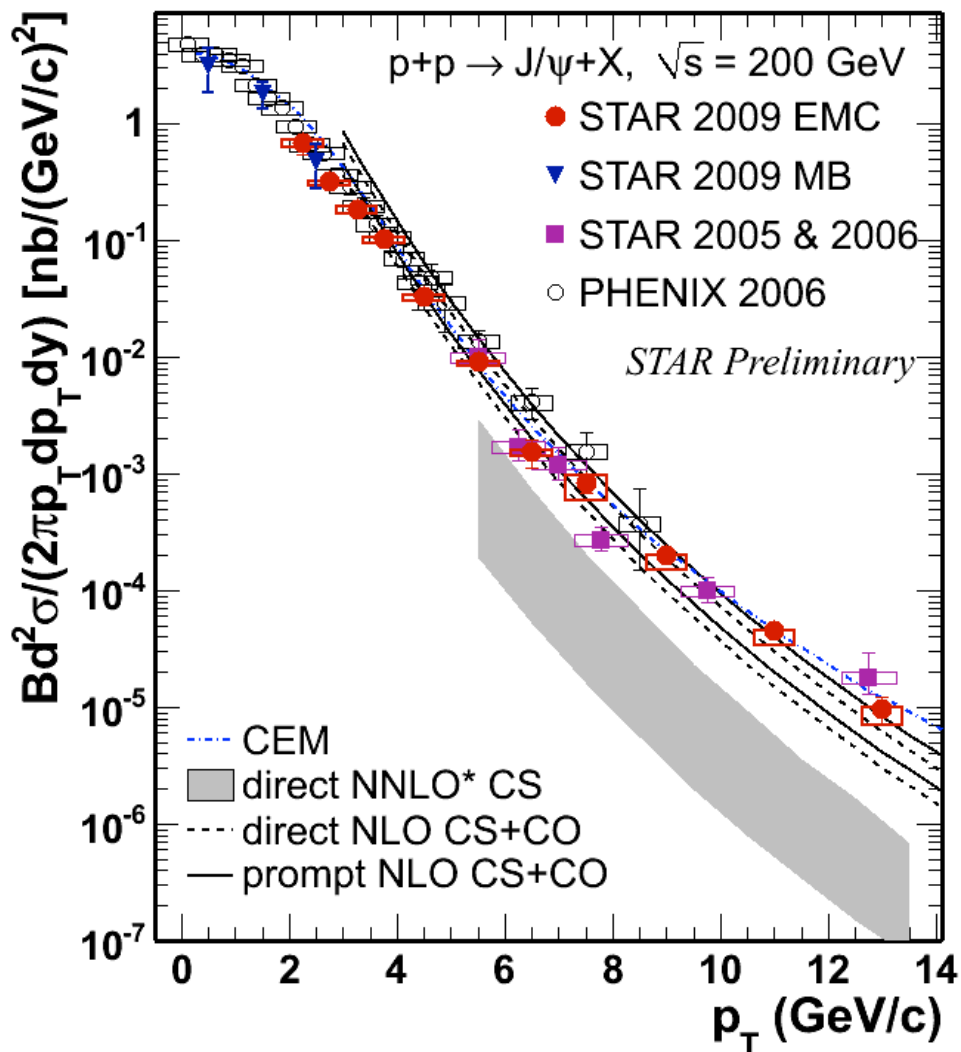


TPC+BEMC+TOF

- Significantly reduced material in 2009 p+p and 2010 Au+Au collisions.
- Clear signal for **high- p_T** in both **p+p** and **Au+Au** 200 GeV collisions.



J/ψ in p+p 200 GeV



PHENIX: Phys. Rev. D82, 012001 (2010)
 STAR 2005&2006: Phys. Rev. C80, 041902(R) (2009)
 STAR 2009 EMC : arxiv:1208.2736

- J/ψ p_T extended to 0-14 GeV/c.
 - Feed-down not subtracted in data
- Prompt NLO CS+CO model describes the data.
- Prompt CEM model describes the high- p_T data.
- Direct NNLO* CS model underpredicts high- p_T part.

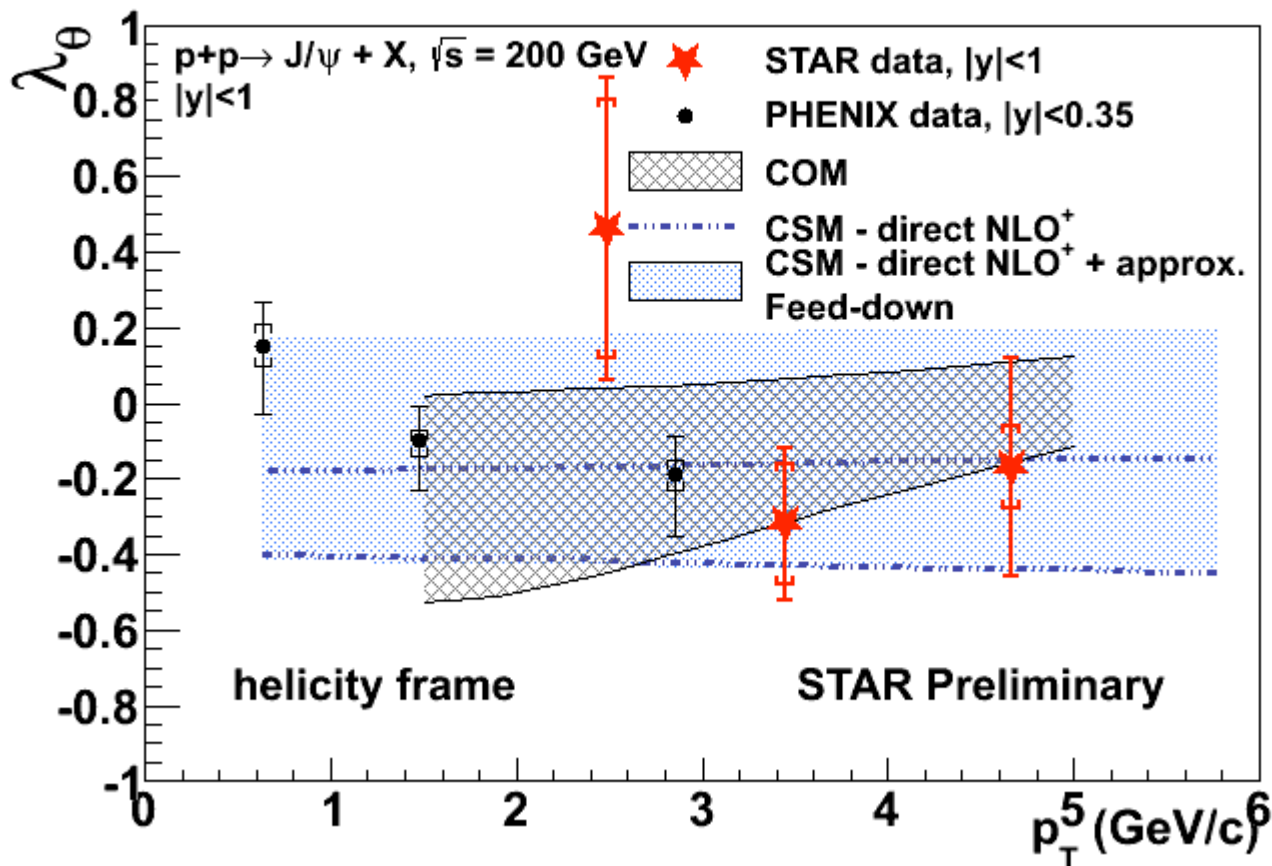
direct NNLO: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication

NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D84, 51 114001 (2011)

CEM:M. Bedjidian et al., hep-ph/0311048, and R.Vogt private communication



J/ψ polarization



- Polarization parameter λ_θ in helicity frame at $|y| < 1$ and $2 < p_T < \sim 5$ GeV/c.

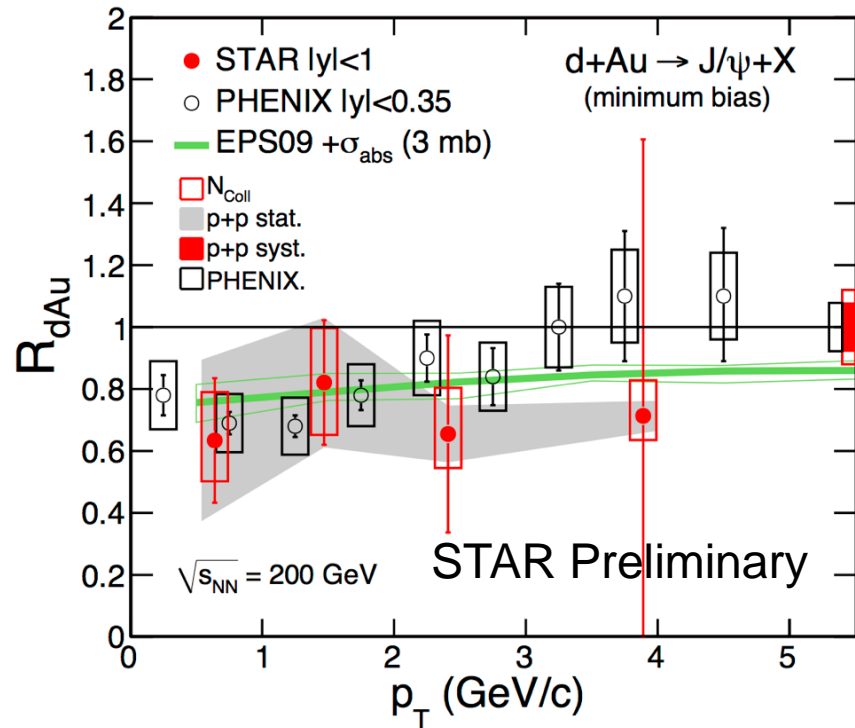
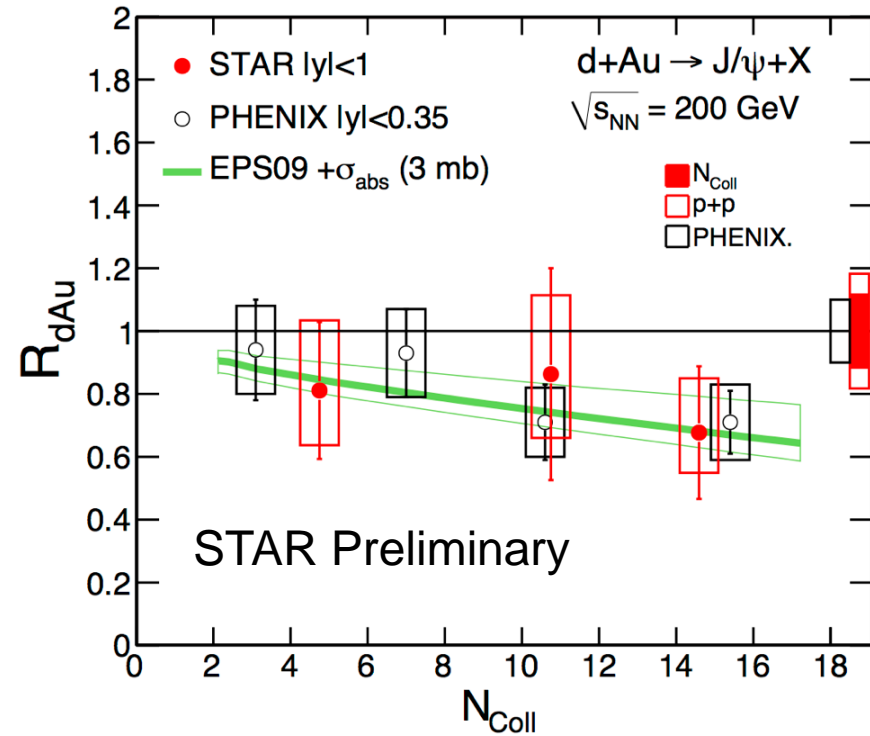
- λ_θ is consistent with NLO+ CSM and COM and with no significant polarization within current uncertainties.

- More precise measurement from p+p 500 GeV expected.

PHENIX: Phys. Rev. D 82, 012001 (2010)
 COM: Phys. Rev. D 81, 014020 (2010)
 CSM NLO+: Phys. Lett. B, 695, 149 (2011)



J/ψ in d+Au 200 GeV

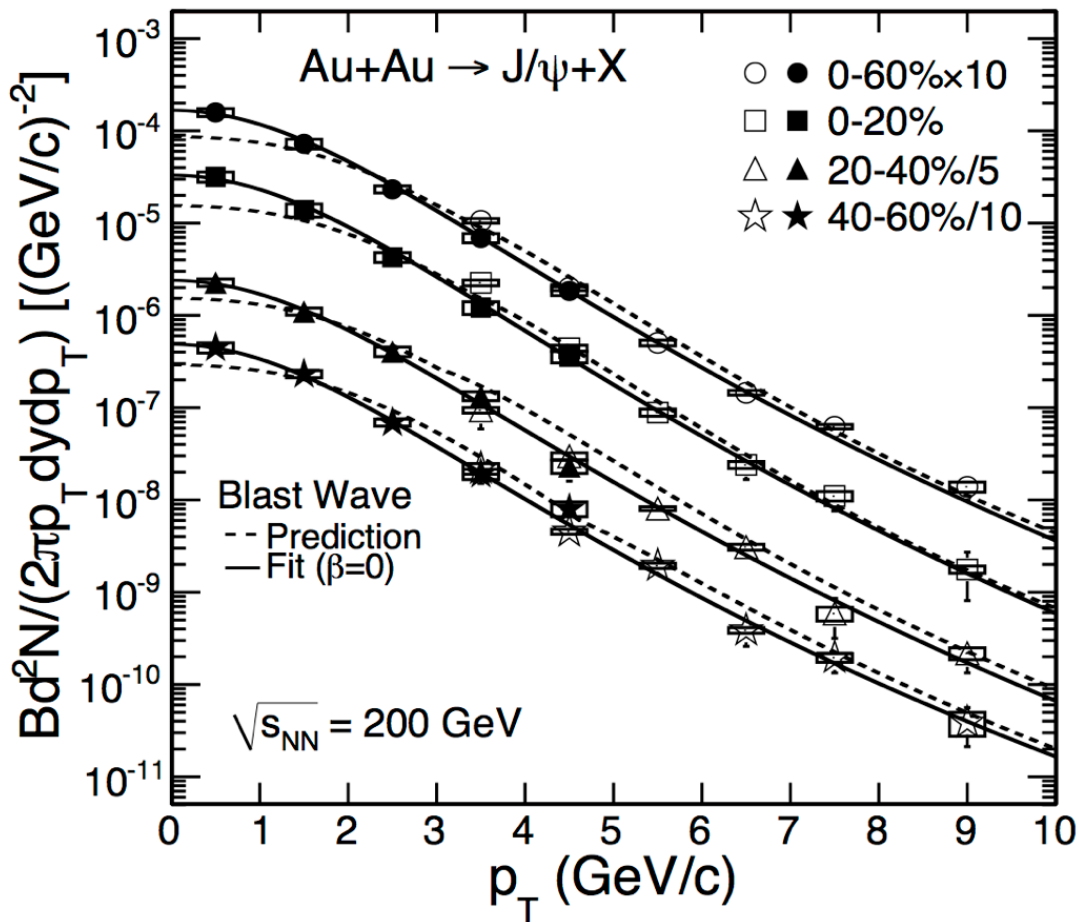


E.Eskola, H.Paukkunenea and C.Salgo, Nucl. Phys. A 830, 599 (2009) R.Vogt, Phys. Rev. C 81, 044903 (2010) PHENIX: arXiv:1204.0777

- Cold nuclear effects are important to interpret the heavy ion results.
- Good agreement with model predictions using EPS09 nPDF parametrization for the shadowing, and J/ψ nuclear absorption cross section.
- $\sigma_{abs}^{J/\psi} = 2.8_{-2.6}^{+3.5} (stat.)_{-2.8}^{+4.0} (syst.)_{-1.1}^{+1.8} (EPS09) mb$ fit to the data.



J/ψ spectra in 200GeV Au+Au collisions



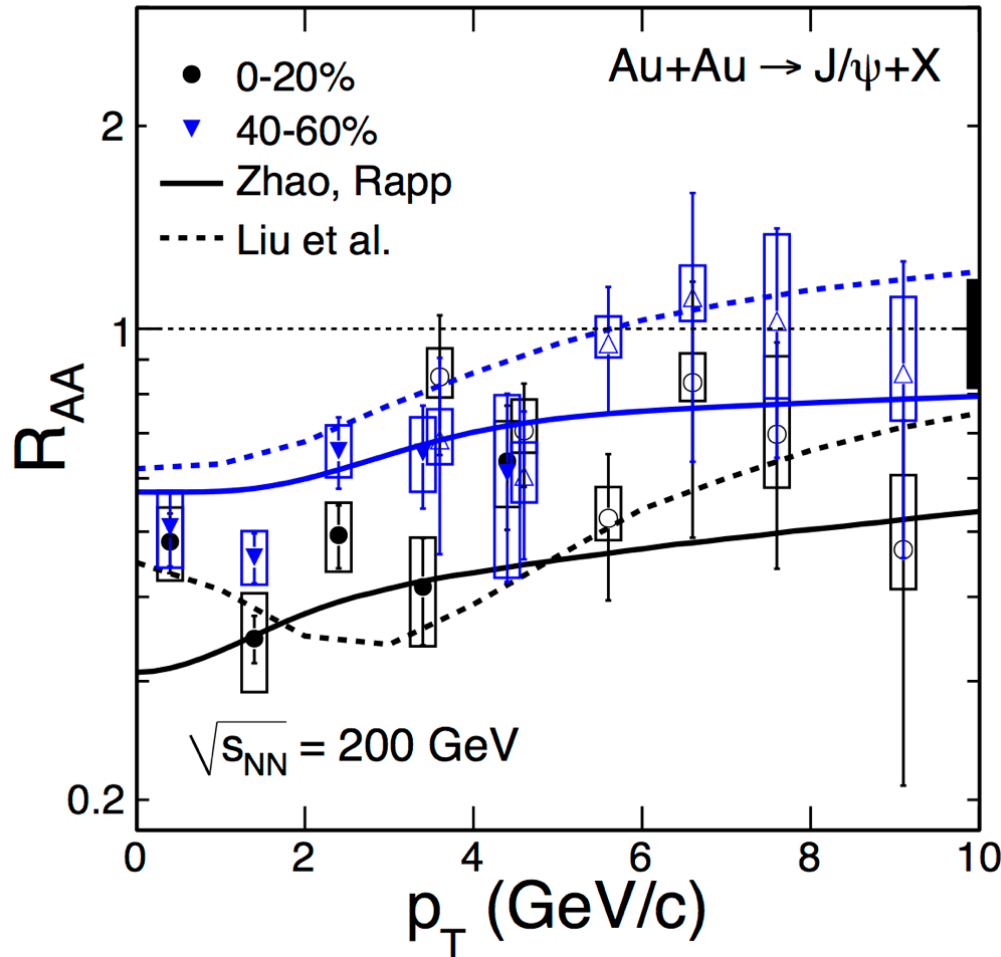
- Large p_T range to 0- 10 GeV/c.
- J/ψ spectra significantly softer at low p_T than the prediction from light hadrons.
 Regeneration at low p_T ?
 Smaller radial flow?

STAR high-pT : arxiv:1208.2736

Tsallis Blast-Wave model: ZBT *et al.*, arXiv:1101.1912; JPG 37, 085104 (2010)



Nuclear modification factor vs. p_T



STAR high- p_T : arxiv:1208.2736

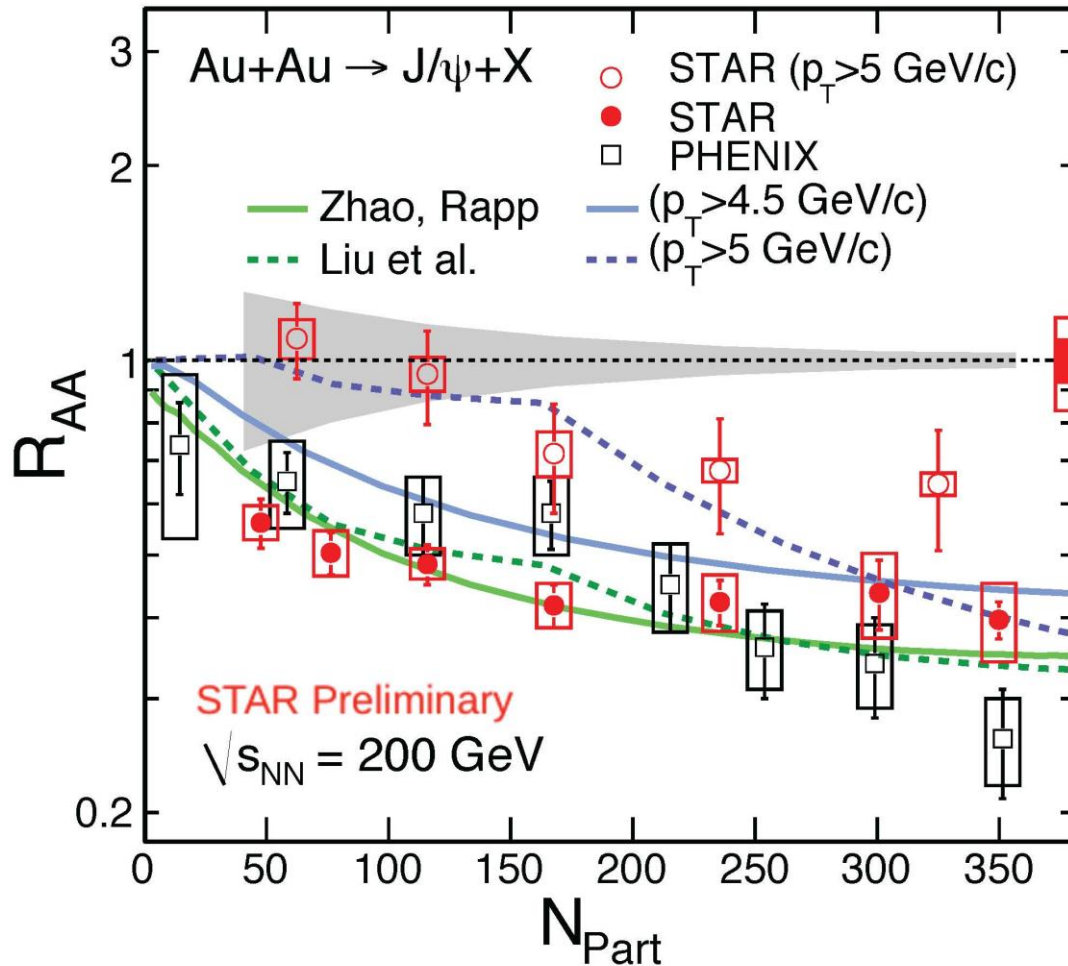
Yunpeng Liu, Zhen Qu, Nu Xu
and Pengfei Zhuang, PLB 678:72
(2009) and private communication

Xingbo Zhao and Ralf Rapp, PRC
82,064905(2010) and private
communication

- Increase from low p_T to high p_T .
- Consistent with unity at high p_T in (semi-) peripheral collisions.
- More suppression in central than in peripheral even at high p_T .



R_{AA} vs. N_{part}



Y. Liu, et al., PLB 678:72 (2009)

X. Zhao and R.Rapp, PRC 82, 064905(2010)

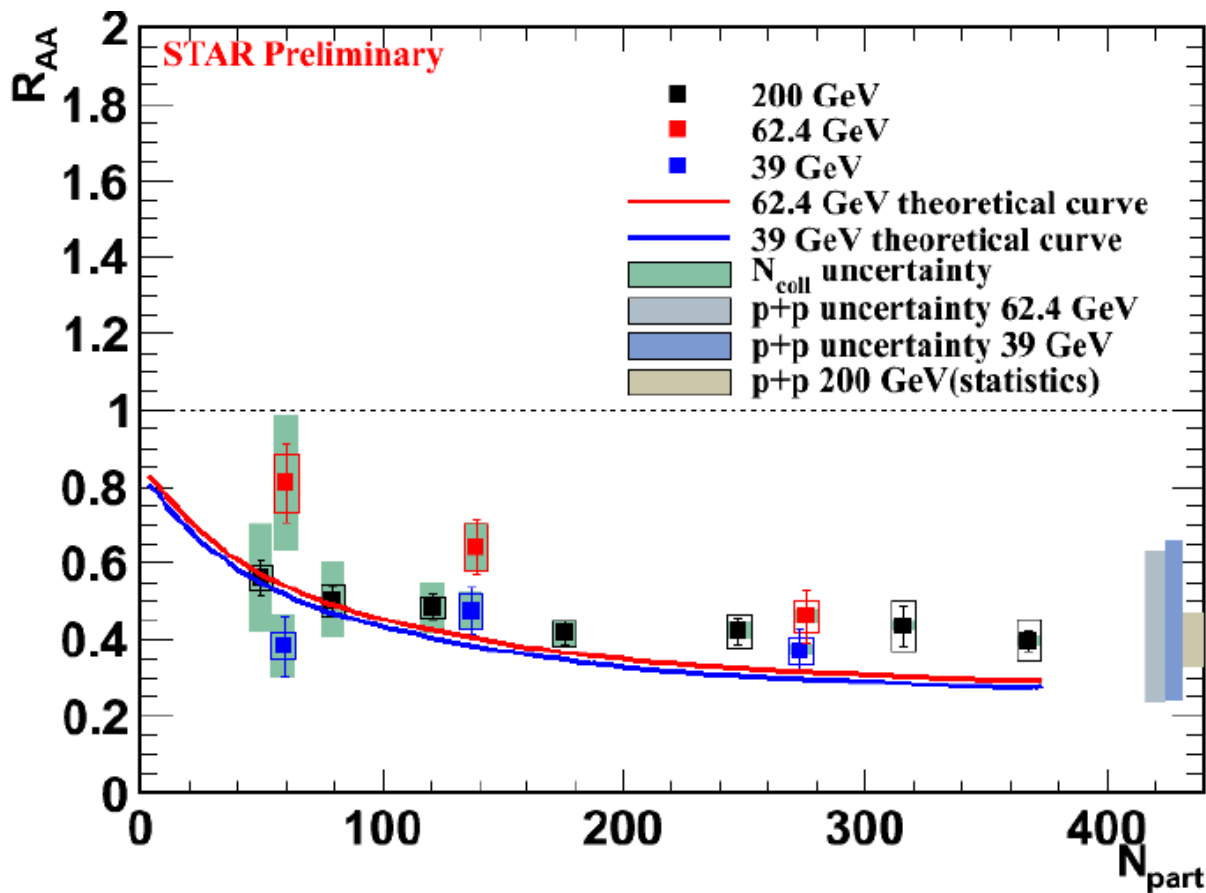
STAR high- p_T : arxiv:1208.2736

- Low- p_T data agrees with two models including color screening and regeneration effects.
- At high- p_T Liu et al. describes data reasonably well.

- Systematically higher at high p_T in all centralities.
- Suppression in central collisions at high p_T .



J/ ψ suppression at RHIC low energy



p+p references for
39 and 62 GeV: CEM
R. Nelson, R. Vogt et al,
arXiv:1210.4610

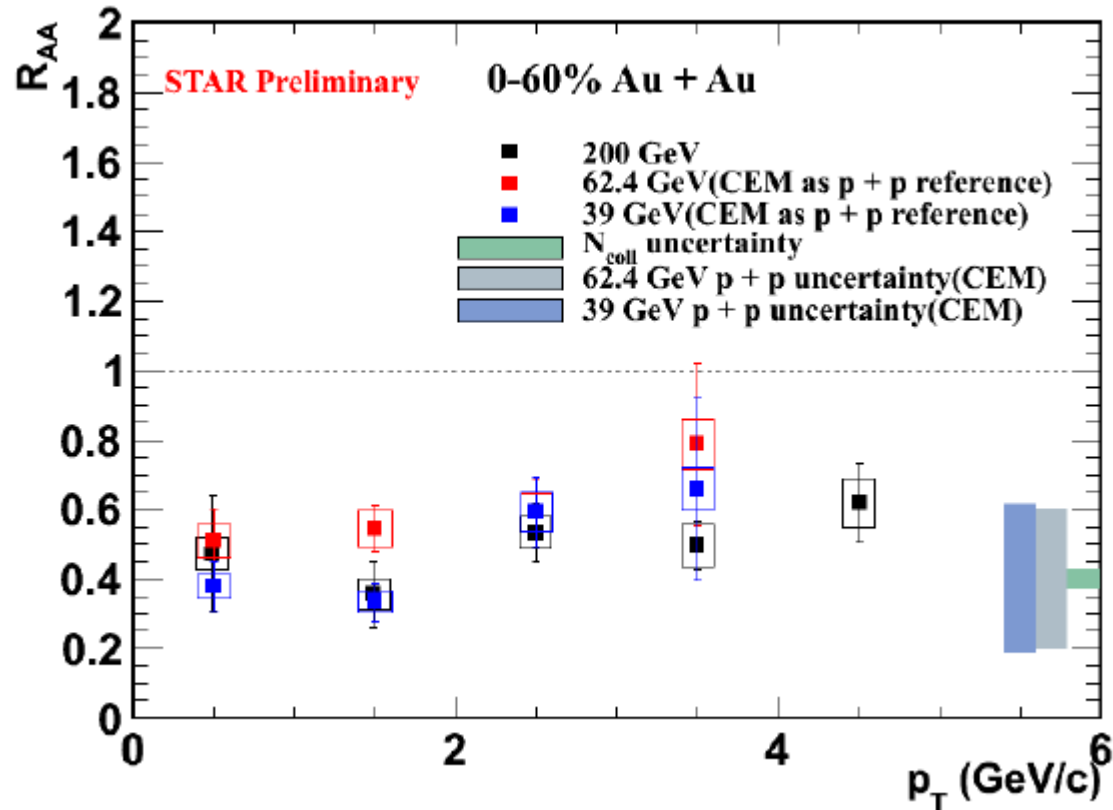
Theoretical curves:
Xingbo Zhao, Ralf Rapp
PRC82, 064905 (2010)

Similar suppression from 39 – 200 GeV.

Consistent with theoretical calculation.



J/ψ suppression at RHIC low energy

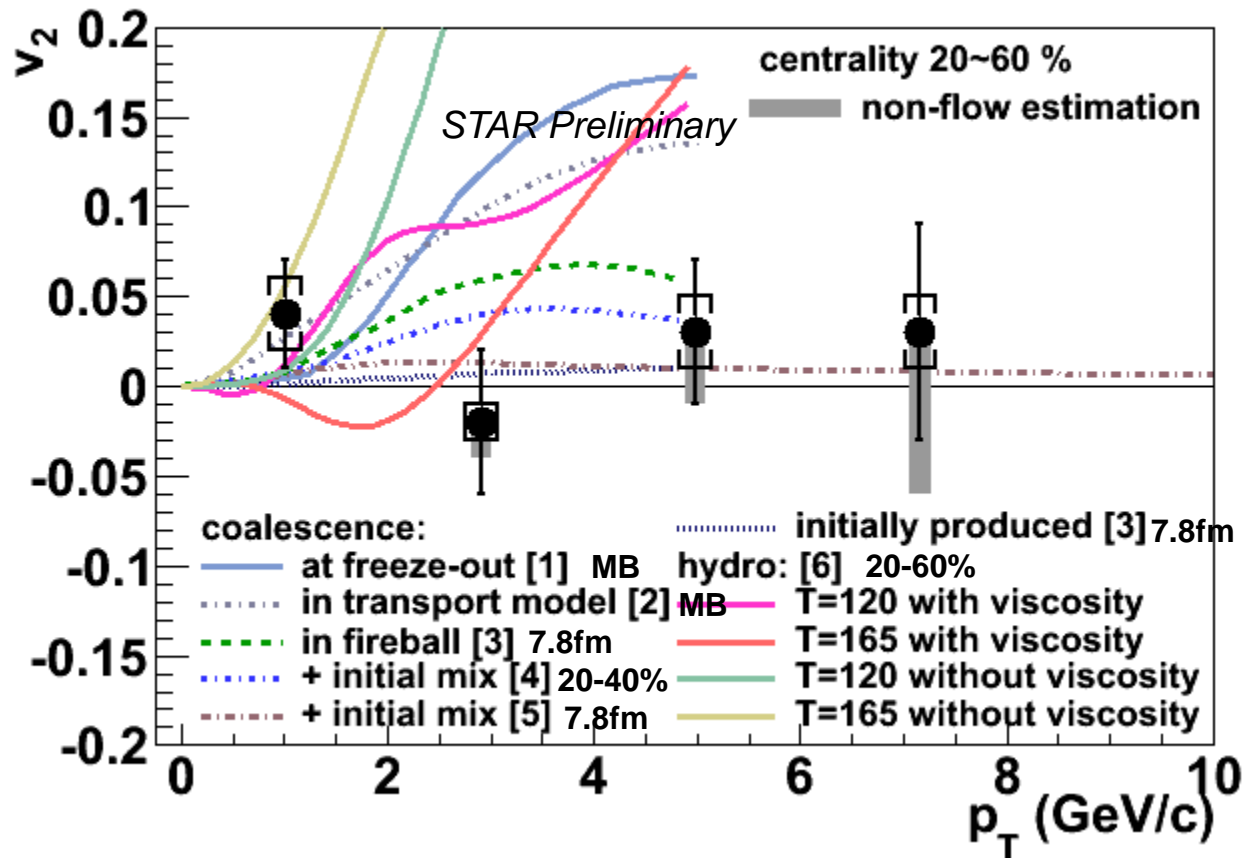


Strong suppression at low- p_T .

No significant beam-energy dependence.



J/ψ elliptic flow v_2



- Consistent with zero, **first hadron** that does **not flow**.
- Disfavor coalescence from thermalized charm quarks at high p_T .

- [1] V. Greco, C.M. Ko, R. Rapp, PLB 595, 202.
- [2] L. Ravagli, R. Rapp, PLB 655, 126.
- [3] L. Yan, P. Zhuang, N. Xu, PRL 97, 232301.
- [4] X. Zhao, R. Rapp, 24th WWND, 2008.
- [5] Y. Liu, N. Xu, P. Zhuang, Nucl. Phys. A, 834, 317.
- [6] U. Heinz, C. Shen, private communication.



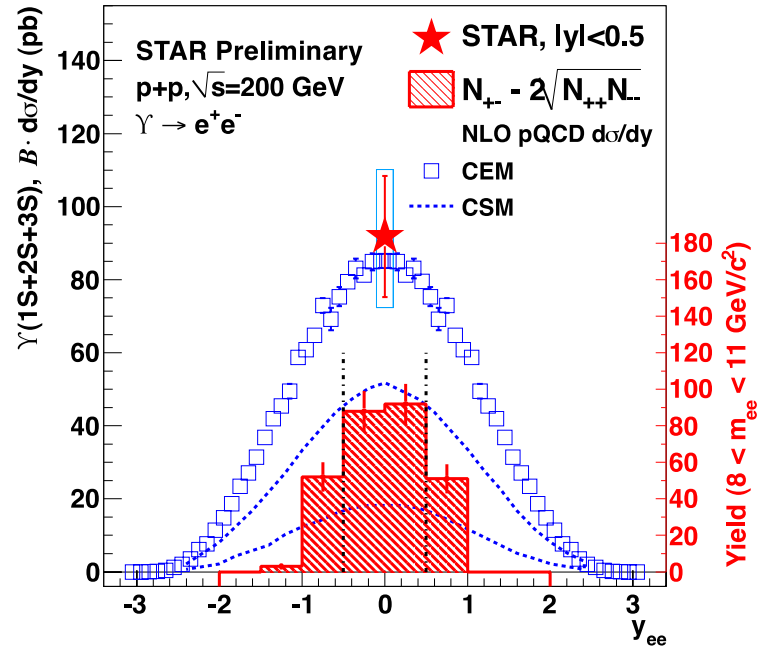
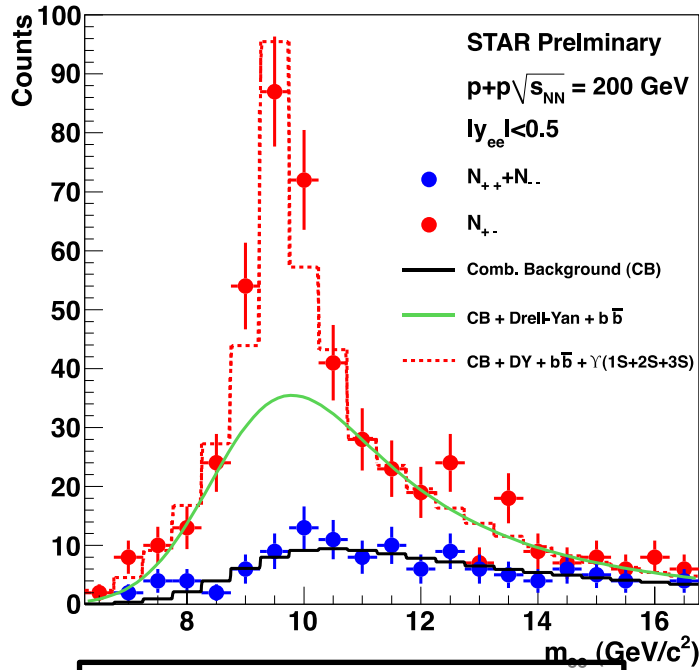
Upsilon

a cleaner probe of the QGP

- Recombination effects
 - J/ψ : Evidence for large effects.
 - Y : Expecting negligible contribution.
 - σ_{cc} @ RHIC: $797 \pm 210^{+208}_{-295}$ μb . (PRD 86, 072013(2012))
 - σ_{bb} @ RHIC: $\sim 1.34 - 1.84$ μb (PRD 83 (2011) 052006)
- Co-mover absorption effects
 - $Y(1S)$: tightly bound, larger kinematic threshold.
 - Expect $\sigma_{abs} \sim 0.2$ mb, 5-10 times smaller than for J/ψ
 - Lin & Ko, PLB 503 (2001) 104
- Cold nuclear matter effects are expected to be small



Y Comparison to NLO pQCD



$$\int L dt = 19.7 \text{ pb}^{-1}$$

$$N_Y(\text{total}) = 145 \pm 26(\text{stat.})$$

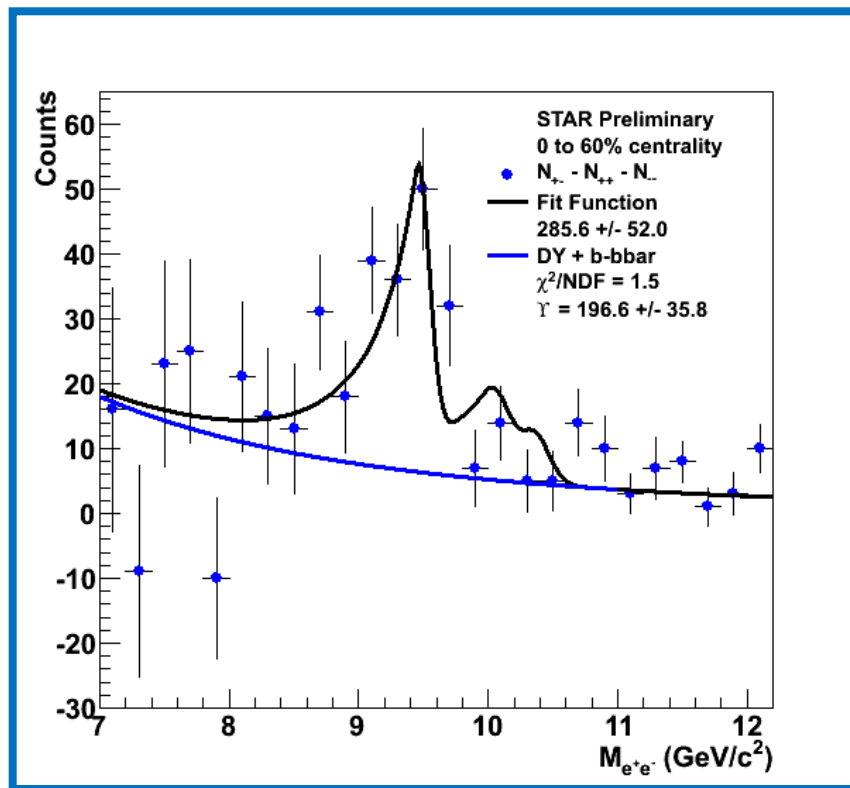
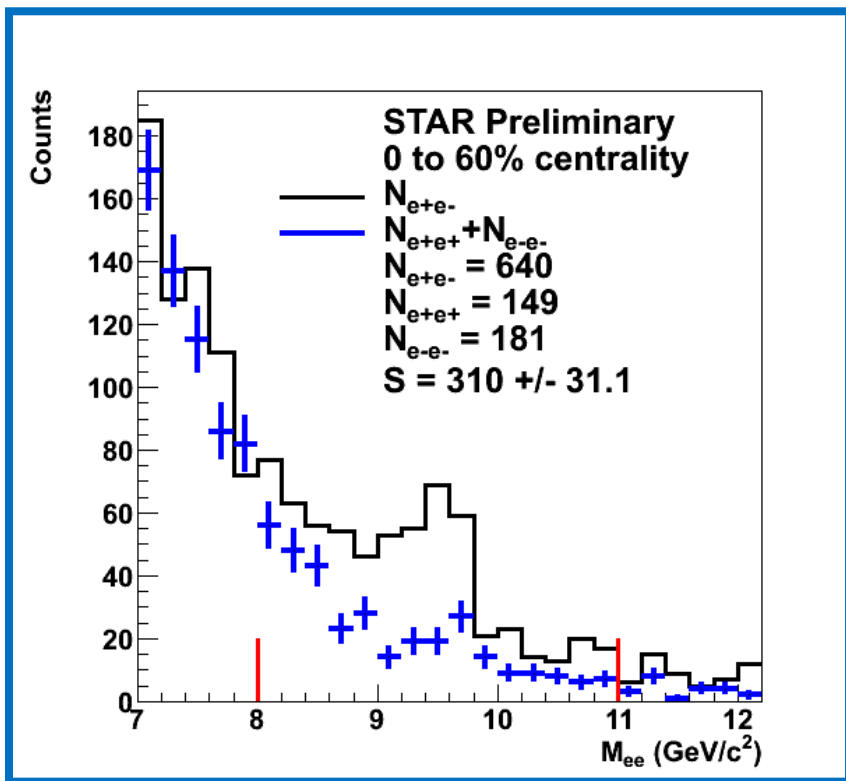
$$\sum_{n=1}^3 \mathcal{B}(nS) \times \sigma(nS) = 91.8 \pm 16.6 \pm 19 \text{ pb}$$

- STAR $\sqrt{s}=200 \text{ GeV}$ $p+p$ $Y+Y'+Y'' \rightarrow e^+e^-$ cross section consistent with pQCD Color Evaporation Model (CEM)

CEM: R. Vogt, Phys. Rep. 462125, 2008
 CSM: J.P. Lansberg and S. Brodsky, PRD 81, 051502, 2010



Y Signal in Au+Au 200 GeV



Raw yield of $Y \rightarrow e^+e^-$ with $|y| < 0.5 = 196.6 \pm 35.8$
 $= N_{+-} - N_{--} - N_{++} - N_{--}$

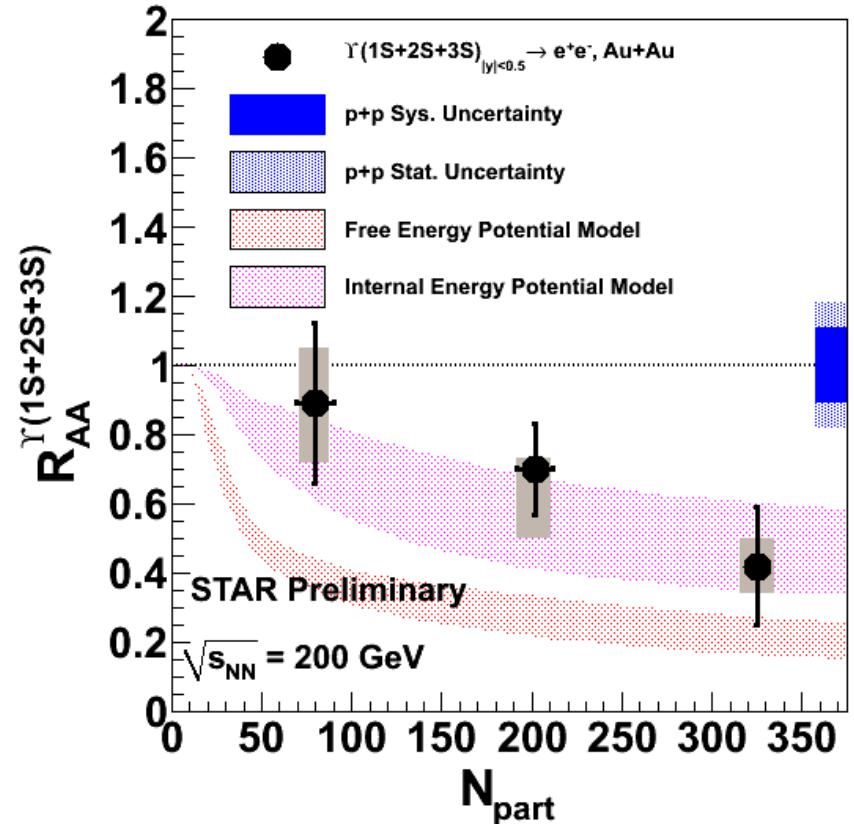
$$\text{Drell-Yan} + b\bar{b} = \frac{A}{\left(1 + \frac{m}{m_0}\right)^n}$$

$n = 4.59, m_0 = 2.7$



Nuclear modification factor

- Suppression of $Y(1S+2S+3S)$ in central Au+Au observed.
- Incorporating lattice-based potentials, including real and imaginary parts
 - A: Free energy
 - Disfavored.
 - B: Internal energy
 - Consistent with data vs. N_{part}
- Includes sequential melting and feed-down contributions
 - ~50% feed-down from χ_b .
- Dynamical expansion, variations in initial conditions ($T_0, \eta/S$)
 - Model parameters used:
 - $428 < T_0 < 442$ MeV at RHIC
 - for $3 > 4\pi\eta/S > 1$

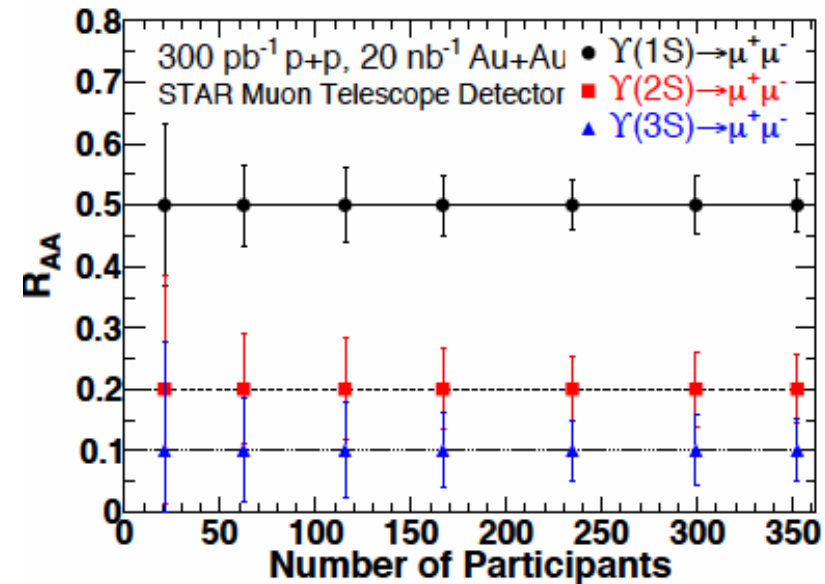
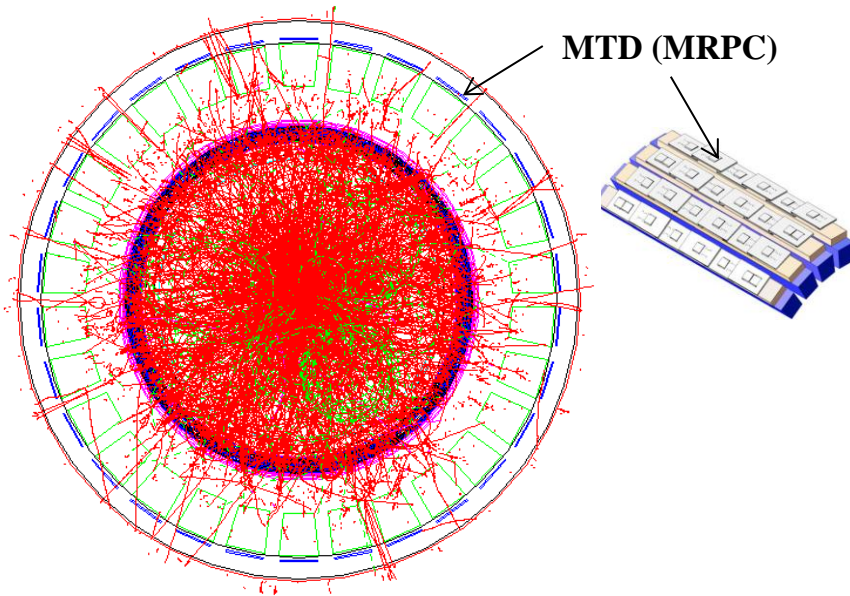


Summary

- **J/ψ in p+p 200GeV**
 - NLO CS+CO and CEM describe the data.
 - No J/ψ polarization observed.
- **J/ψ in d+Au 200GeV**
 - R_{dAu} consistent with the model using EPS09+ $\sigma_{absJ/\psi}$ (3 mb).
- **J/ψ in Au+Au 200GeV**
 - Suppression observed; it increases with collision centrality and decreases with p_T .
 - v_2 consistent with no flow; disfavors the production dominantly by coalescence from thermalized (anti-)charm quarks for $p_T > 2$ GeV/c.
- **J/ψ in Au+Au 39GeV and 62GeV**
 - Similar centrality and p_T dependence like 200 GeV.
- **Upsilon in p+p 200GeV**
 - Consistent with pQCD Color Evaporation Model.
- **Upsilon in Au+Au 200GeV**
 - Increasing of Y suppression vs. centrality.
 - R_{AA} consistent with suppression of feed down from excited states only (~50%).
- **Heavy flavor tracker and Muon telescope detector upgrades.**
 - Significant improvement of STAR quarkonium measurements.

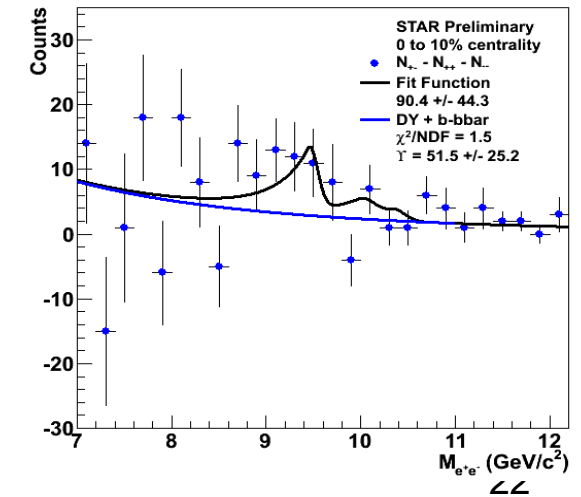
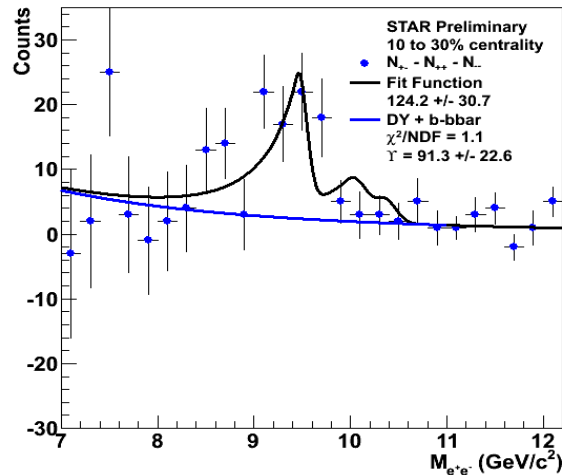
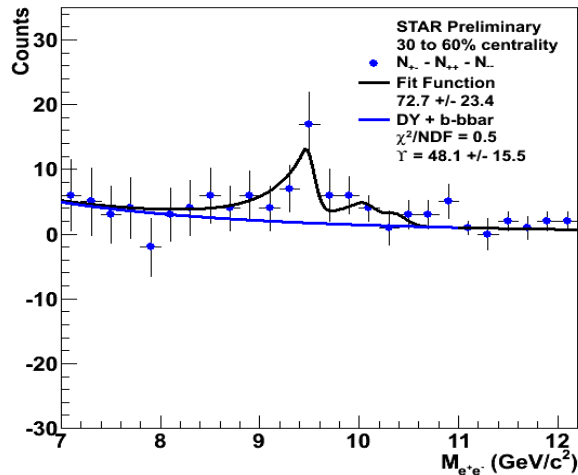
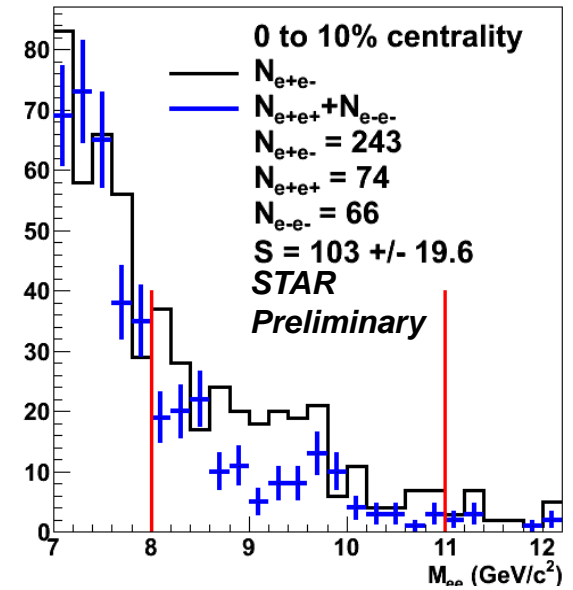
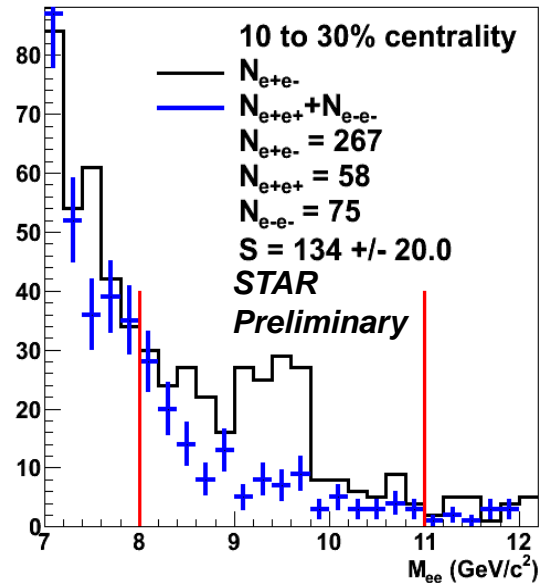
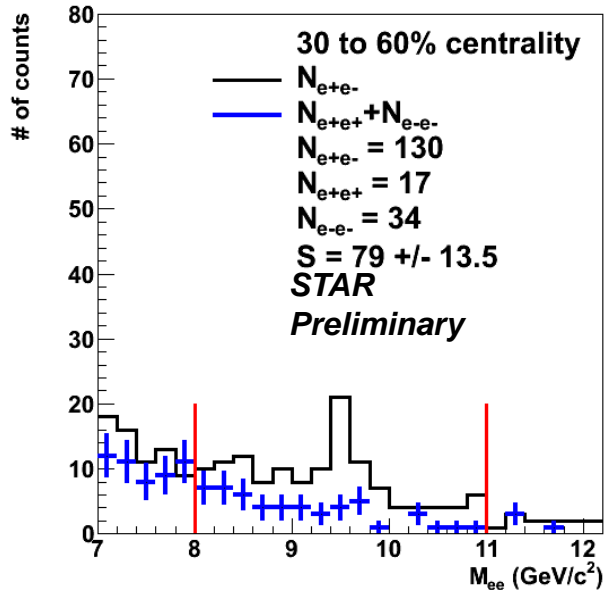


Future: Υ via STAR MTD



- A detector with long-MRPCs
 - Covers the whole iron bars and leave the gaps in between uncovered.
 - Acceptance: 45% at $|\eta| < 0.5$
 - 118 modules, 1416 readout strips, 2832 readout channels
- Long-MRPC detector technology, electronics same as used in STAR-TOF
- Run 2012 -- 10%; 2013 – 60%+; 2014 – 100%: Υ via $\mu^+\mu^-$

Υ in Au+Au 200 GeV, Centrality



Cold Nuclear Matter Effects

- Y : CNM effects established by E776 ($\sqrt{s}=38.8$ GeV):
 - Magnitude and A dep: $Y(1S)=Y(2S+3S)$. α can be as low as ~ 0.8 .

