Quarkonium measurements at STAR

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for STAR collaboration

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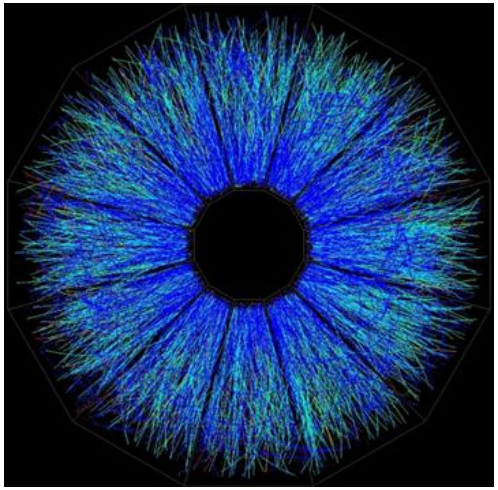

XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects
Marseilles, April 22-26, 2013

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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.

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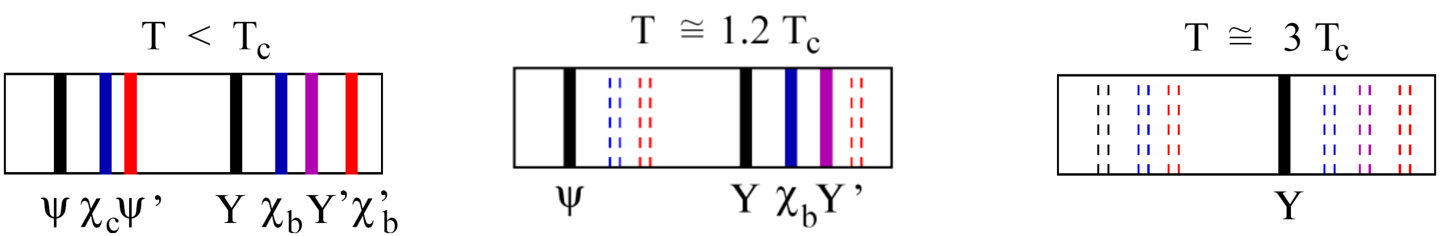
Quarkonium in nuclear matter

- 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 determinate 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

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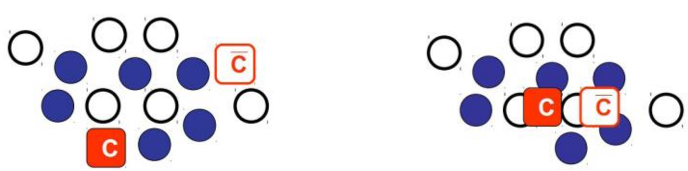
Other important effects

- Quarkonium production mechanism is not well understood.
  - Color-singlet vs. Color-octet?

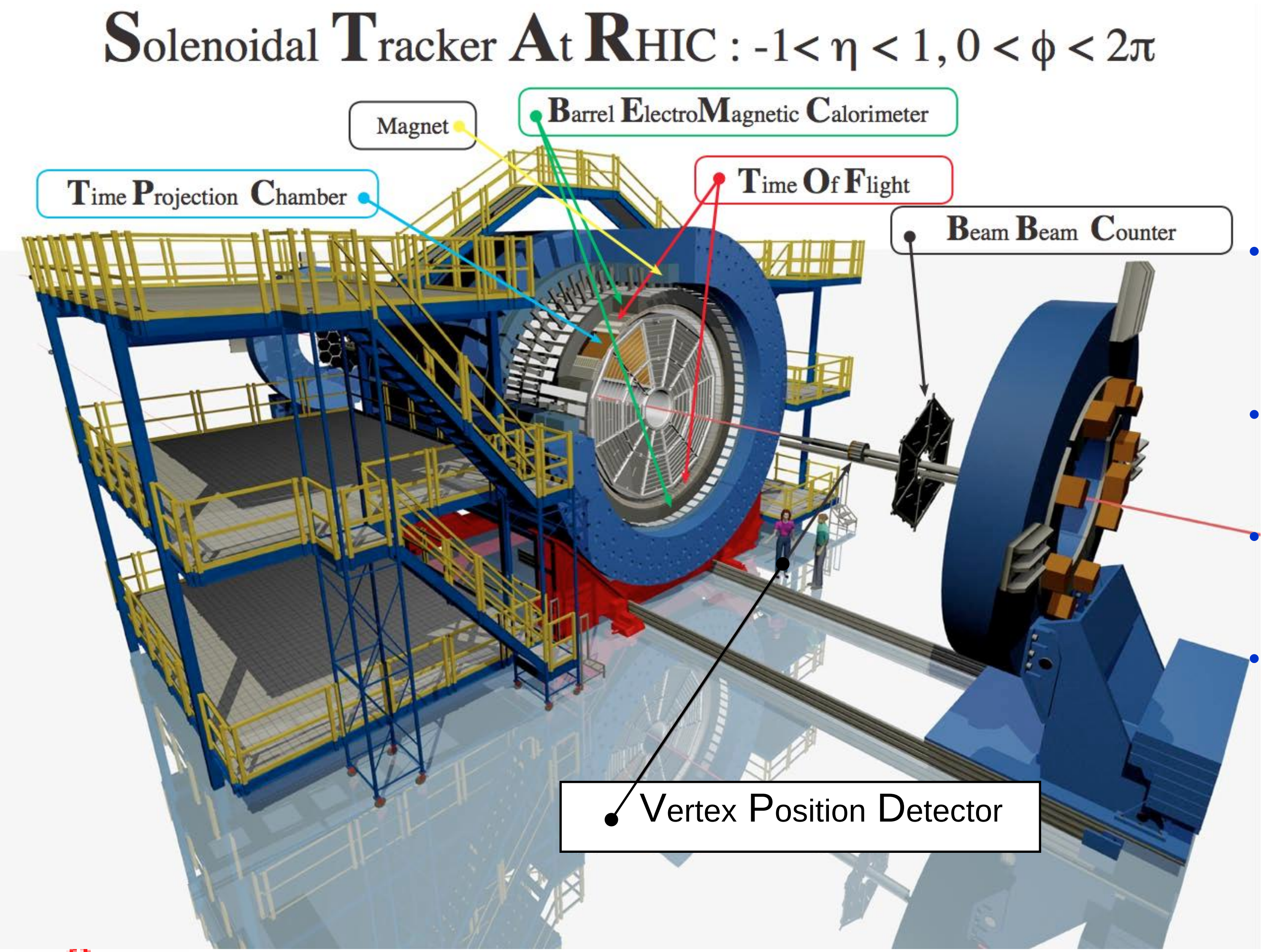
- Observed yields are a mixture of direct production + feeddown
  - E.g. $J/\psi \sim 0.6\ J/\psi$ (Direct) + $\sim 0.3\ \chi_c$ + $\sim 0.1 \psi'$

- 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.



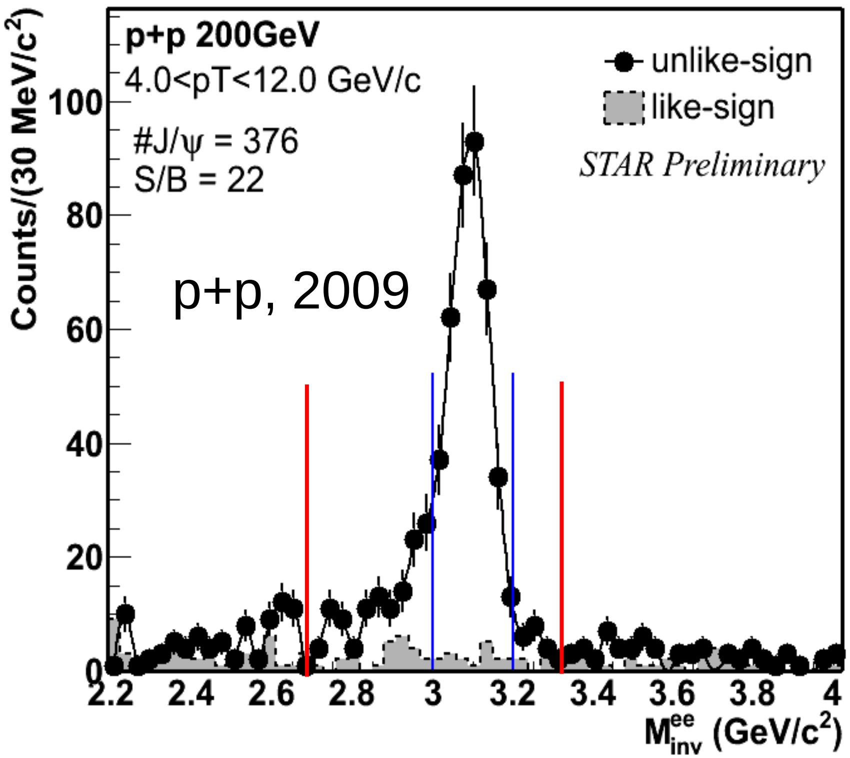
STAR

The STAR Detector

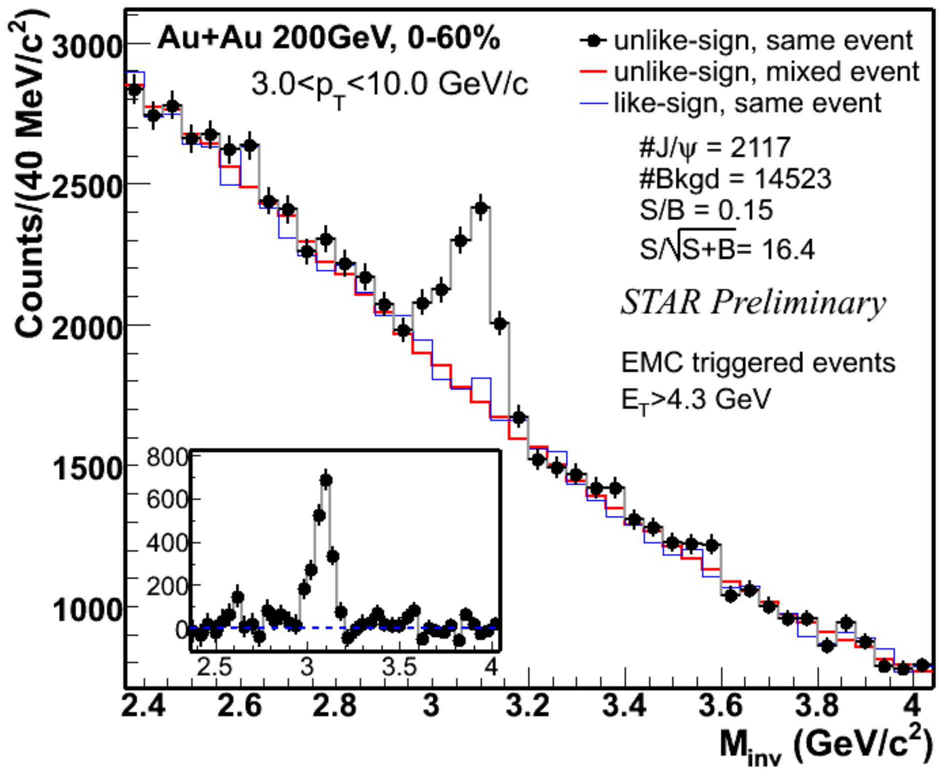


- VPD: minimum bias trigger.
- TPC: PID, tracking.
- TOF: PID.
- BEMC: PID, trigger.

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



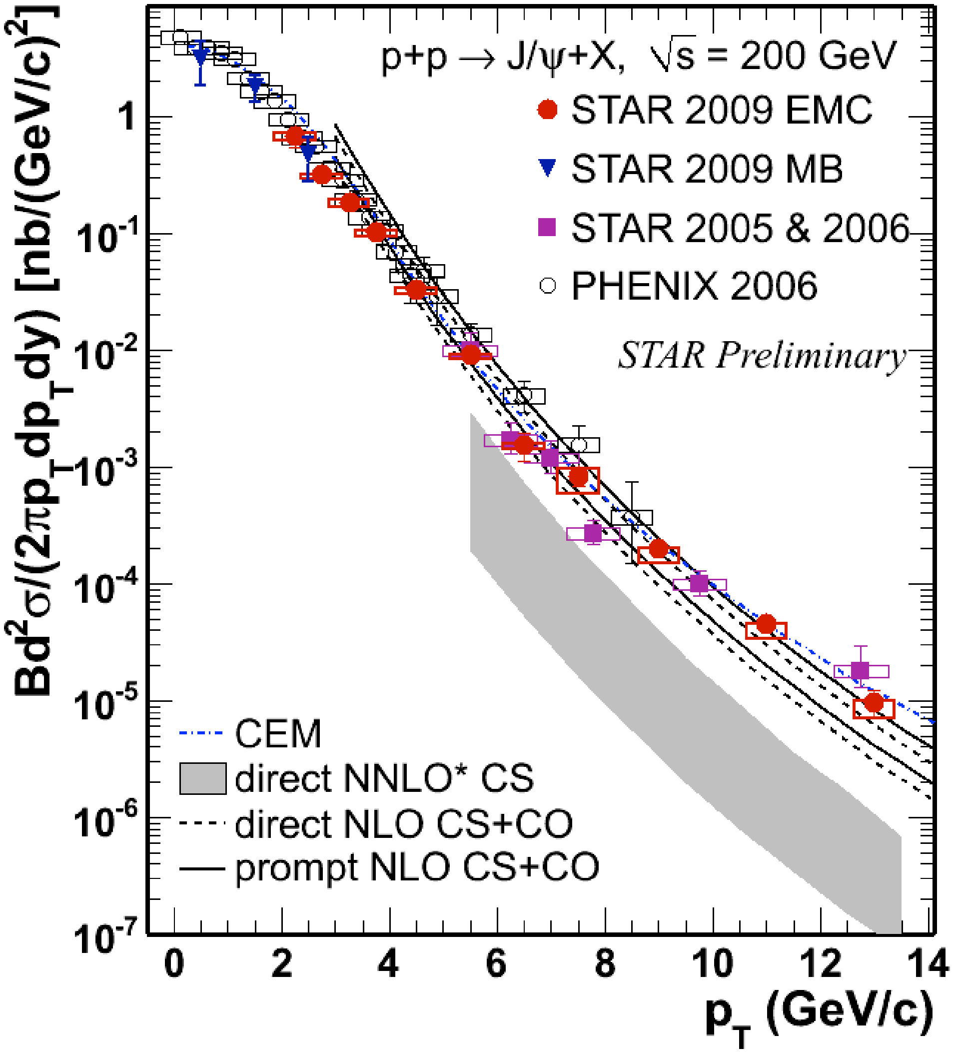
TPC+BEMC



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

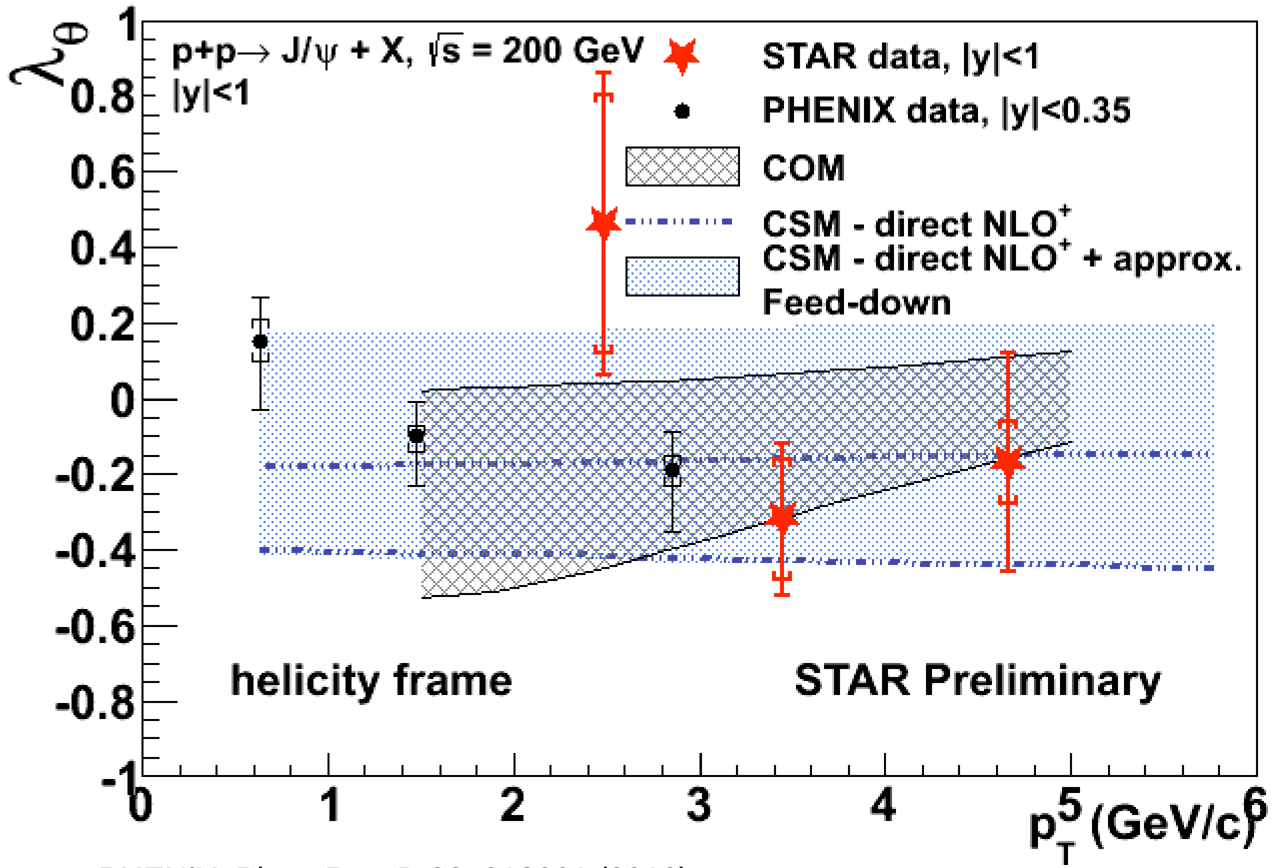


PHENIX: Phys. Rev. D82, 012001 (2010)
STAR 2005&2006: Phys. Rev. C80, 041902(R) (2009)
STAR 2009 EMC : arxiv:1208.2736

- J/ψ p_T extended to 0-14 GeV/c.
- 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

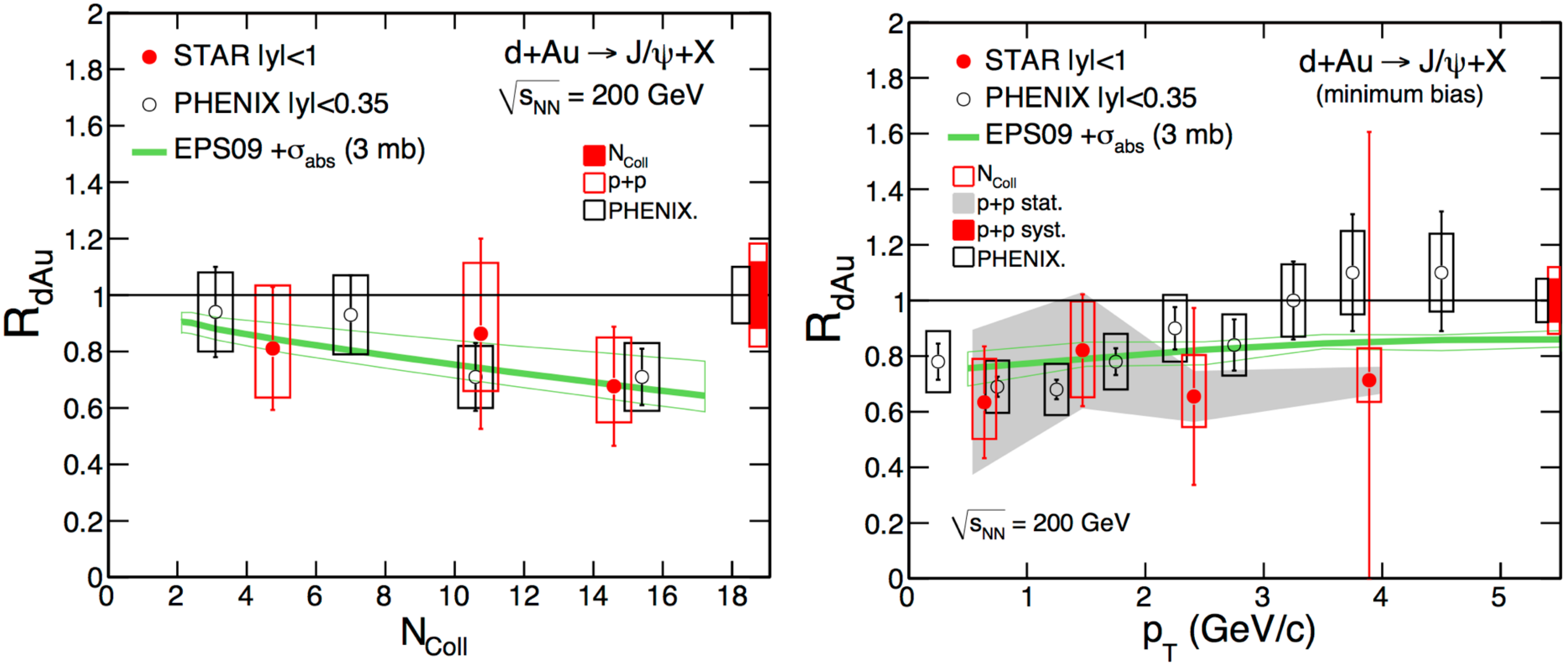
J/ψ polarization



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

- 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 polarization within current uncertainties.
- More precize measurement from p+p 500 GeV expected.

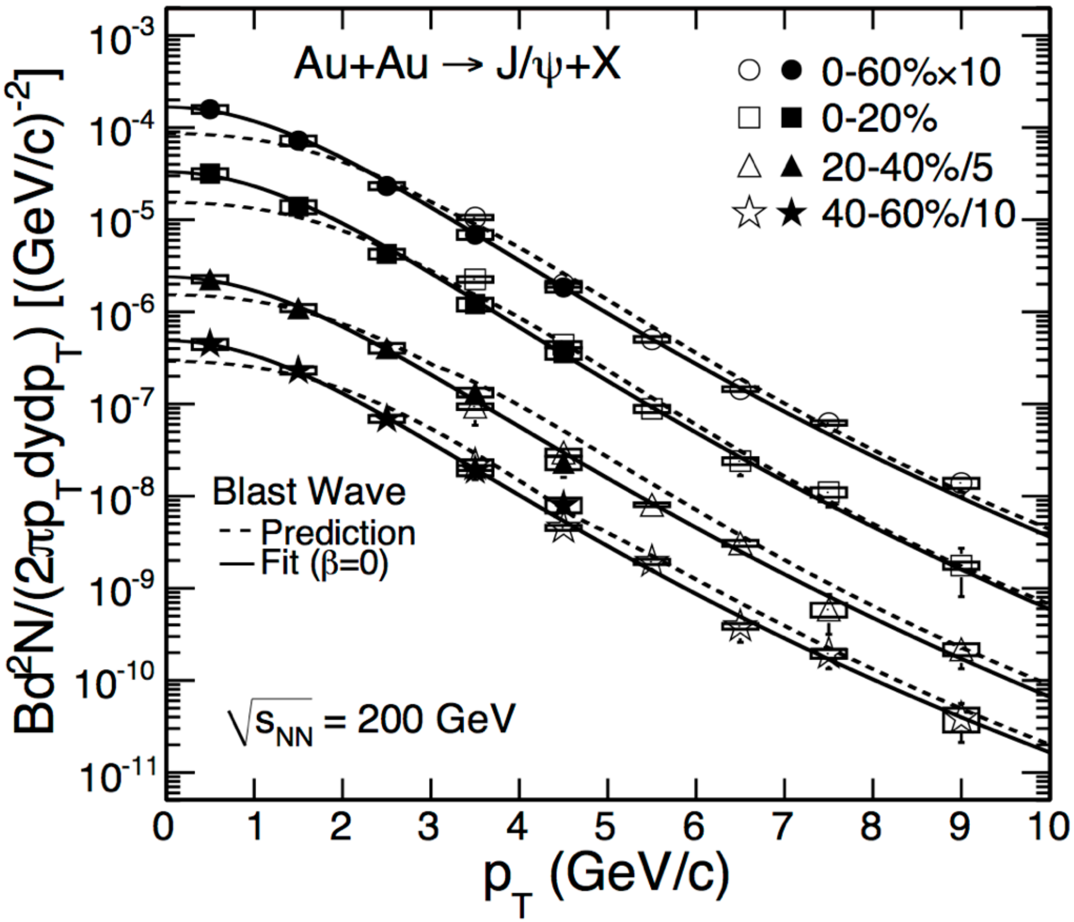
J/ψ in d+Au 200 GeV



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

- 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.
- $\sigma_{abs}^{J/\psi} = 2.8^{+3.5}_{-2.6}(stat.)^{+4.0}_{-2.8}(syst.)^{+1.8}_{-1.1}(EPS09)mb$ fit to the data.

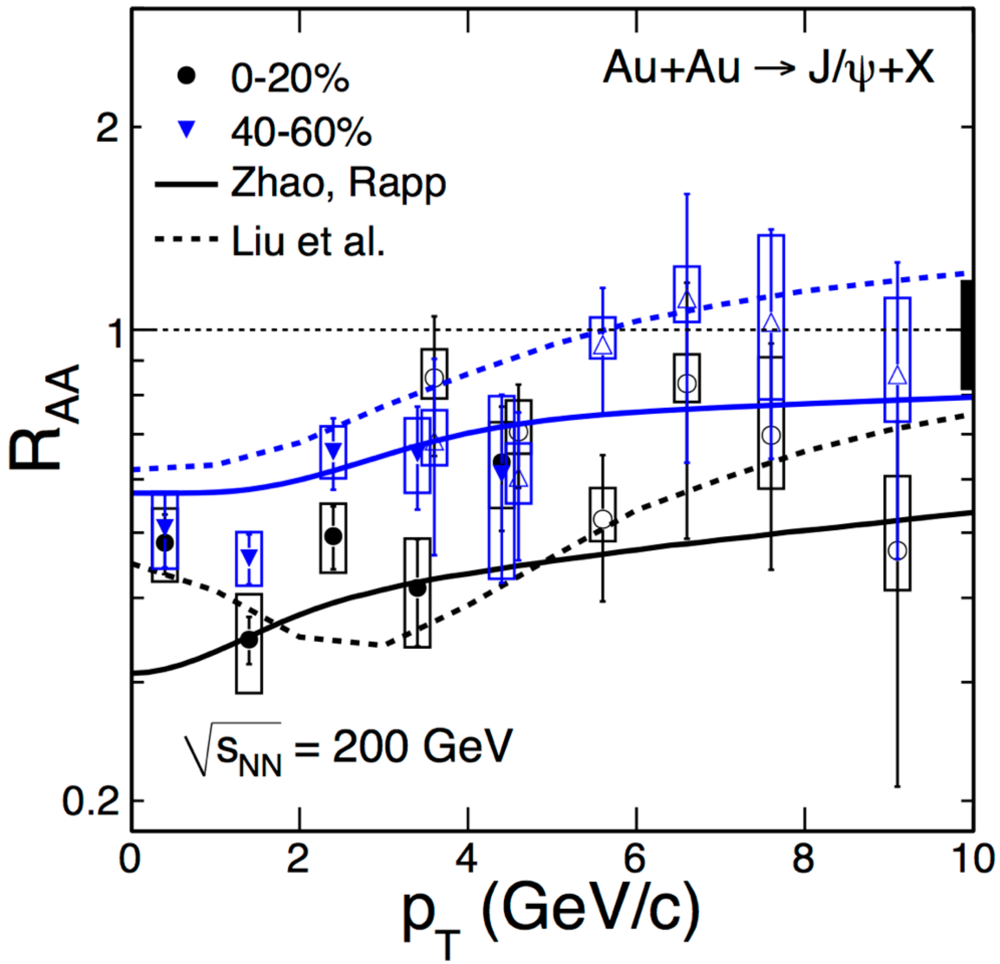
J/ψ spectra in 200GeV Au+Au collisions



- 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



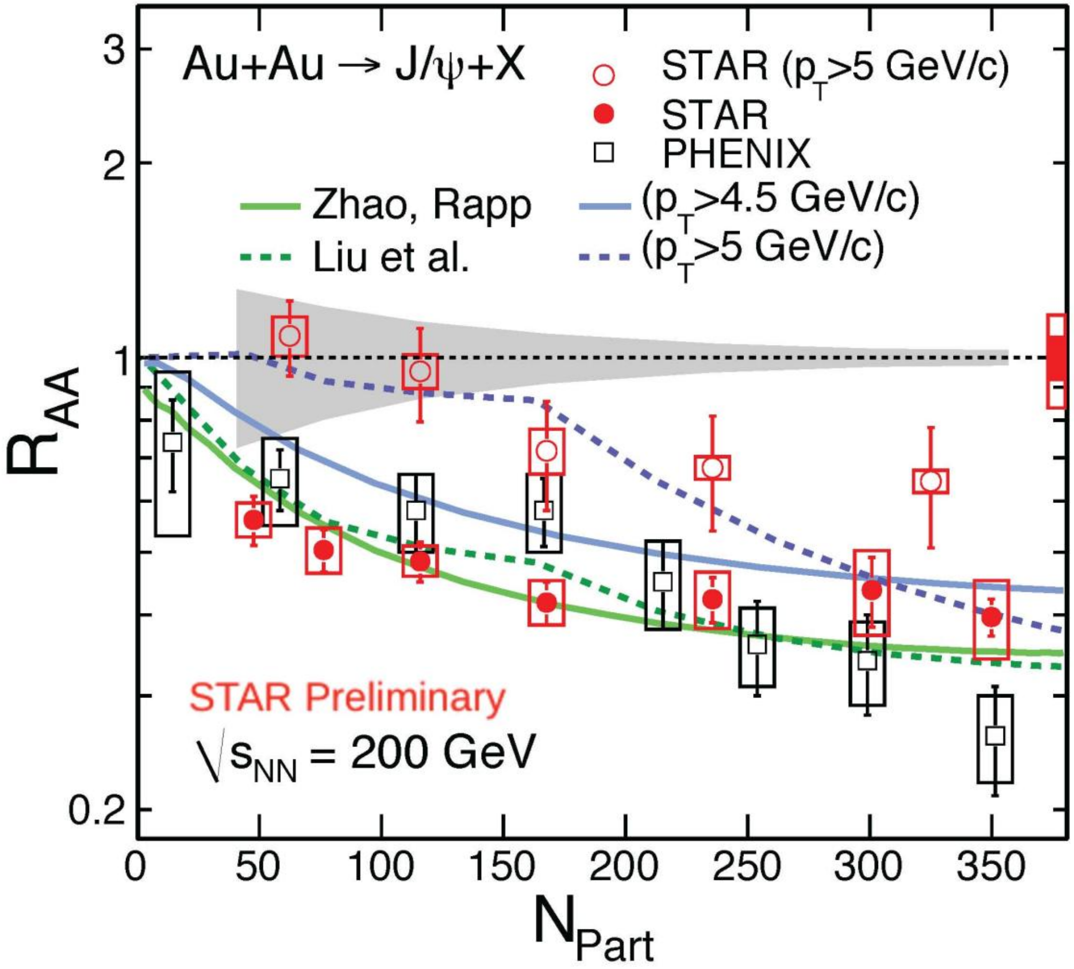
STAR high-pT : arxiv:1208.2736

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

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. Npart



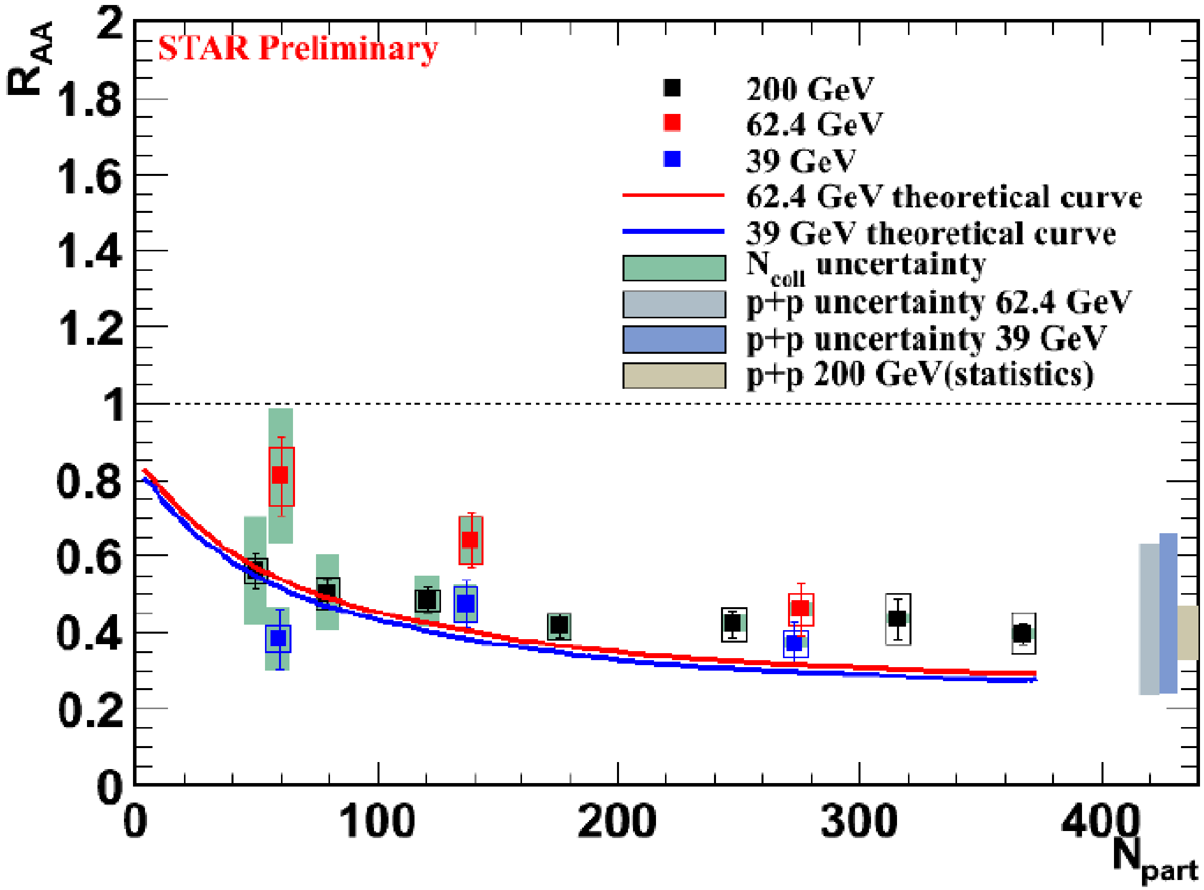
Y. Liu, et al., PLB 678:72 (2009)
X. Zhao and R.Rapp, PRC 82, 064905(2010)

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

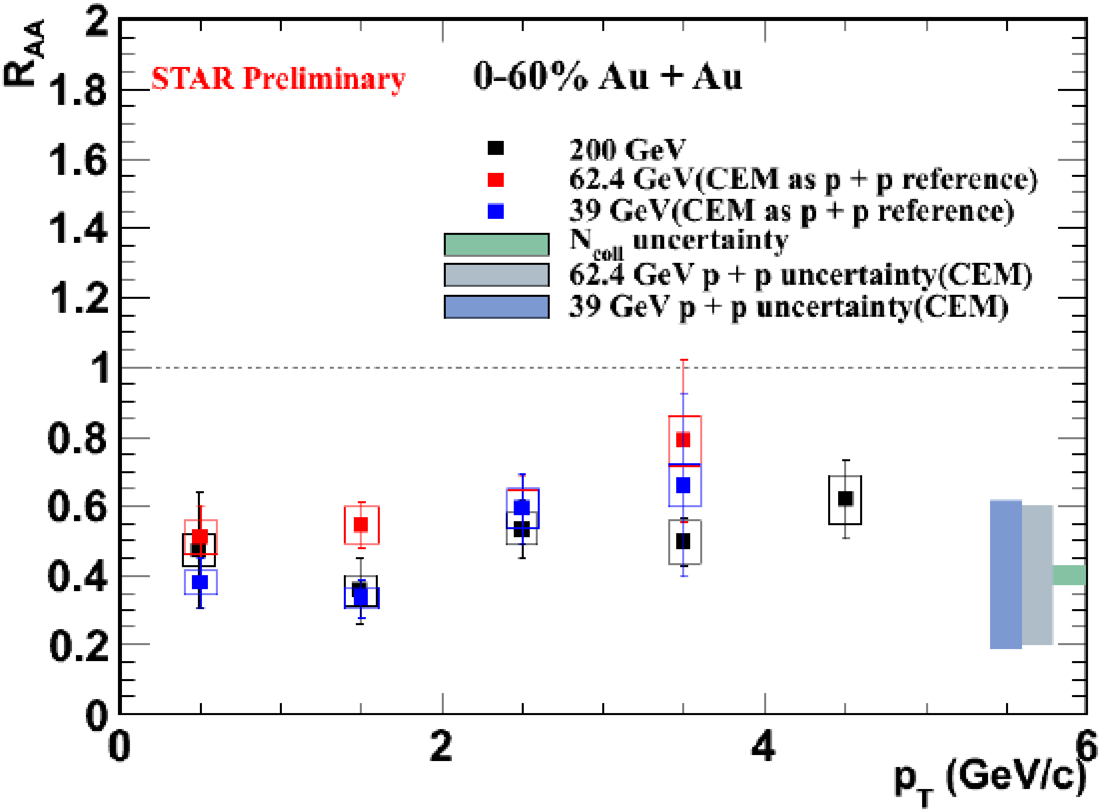
Theoretical curves:

Xingbo Zhao, Ralf Rapp PRC82, 064905 (2010)

Similar suppression from 39 – 200 GeV.

Consistent with theoretical calculation.

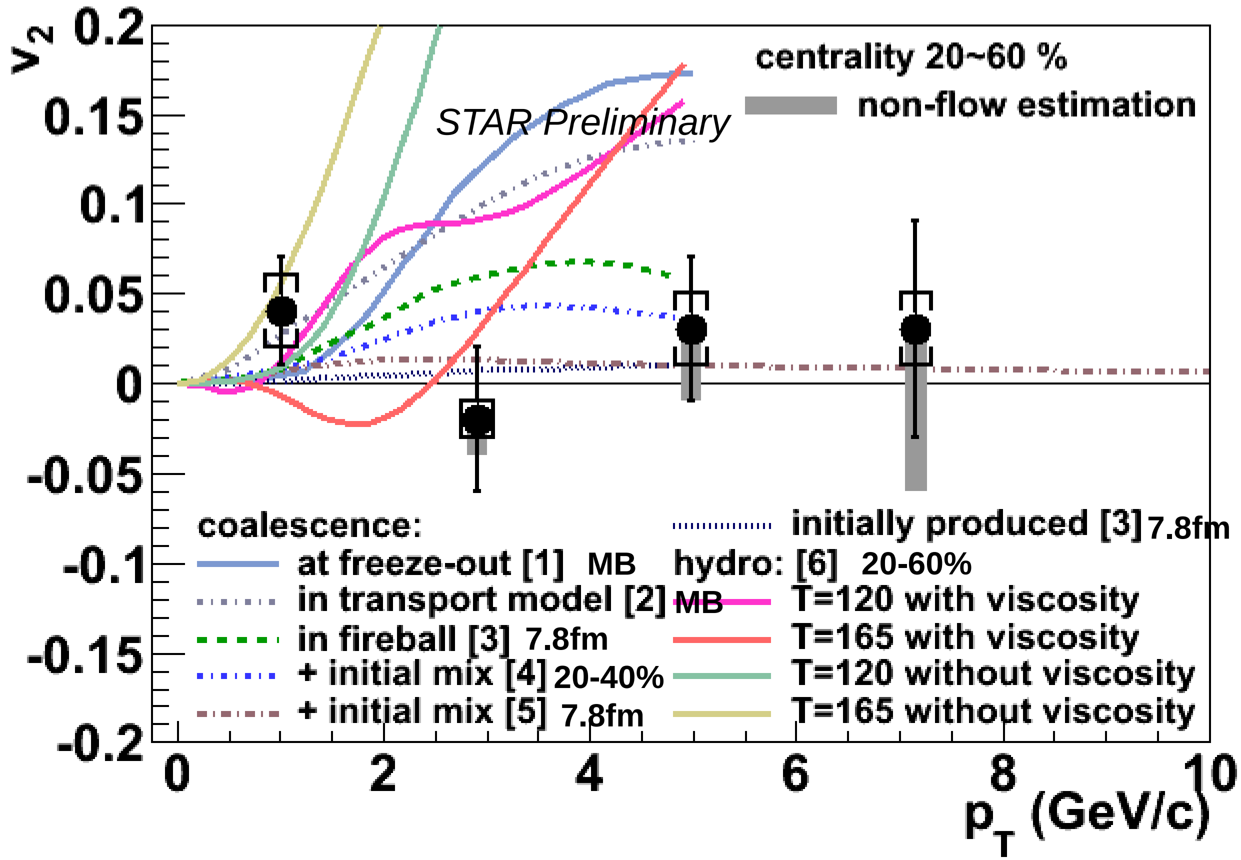
J/ψ suppression at RHIC low energy



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. Phy. A, 834, 317.
[6] U. Heinz, C. Shen, priviate communication.

Upsilons
a cleaner probe of the QGP

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

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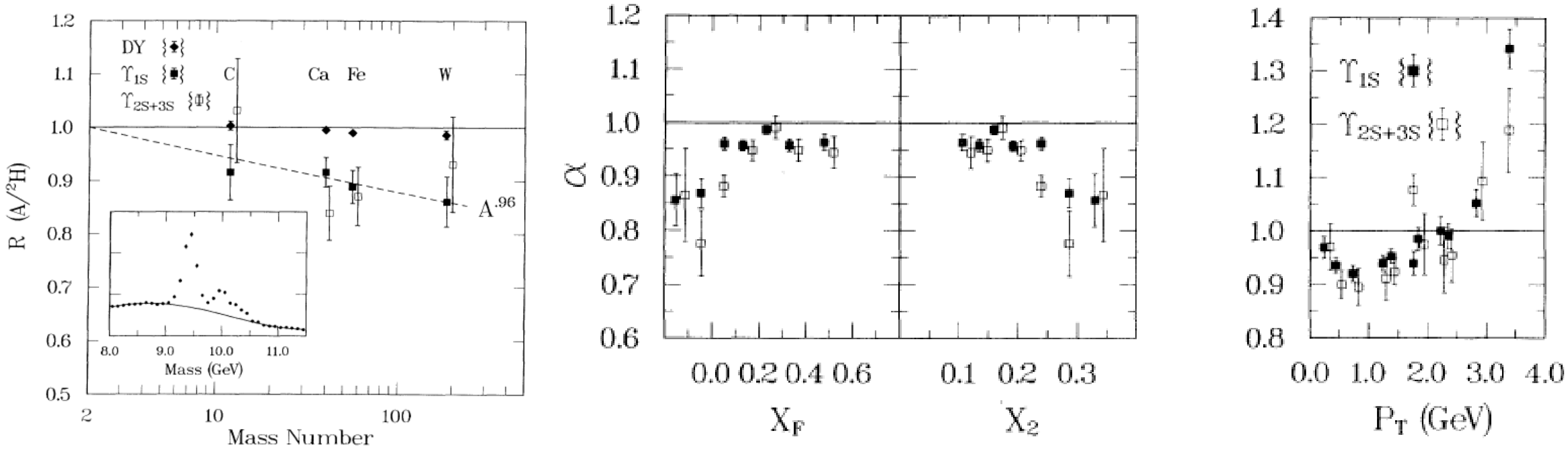
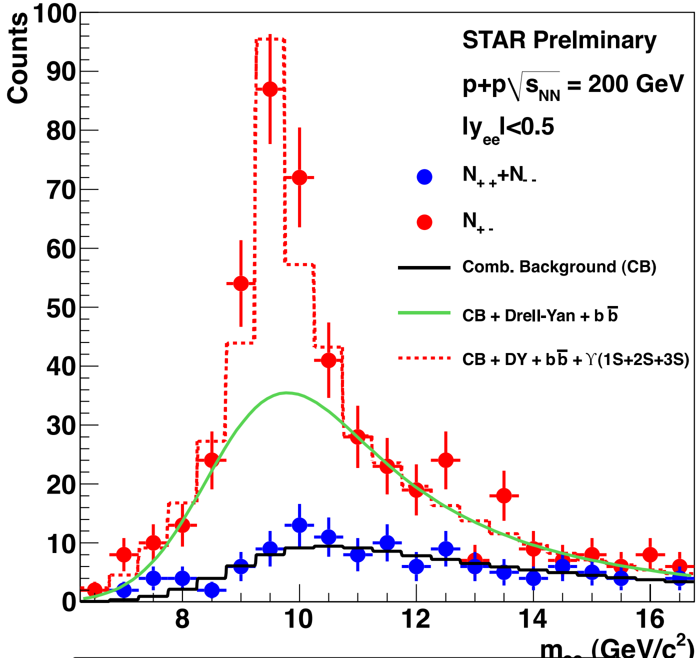
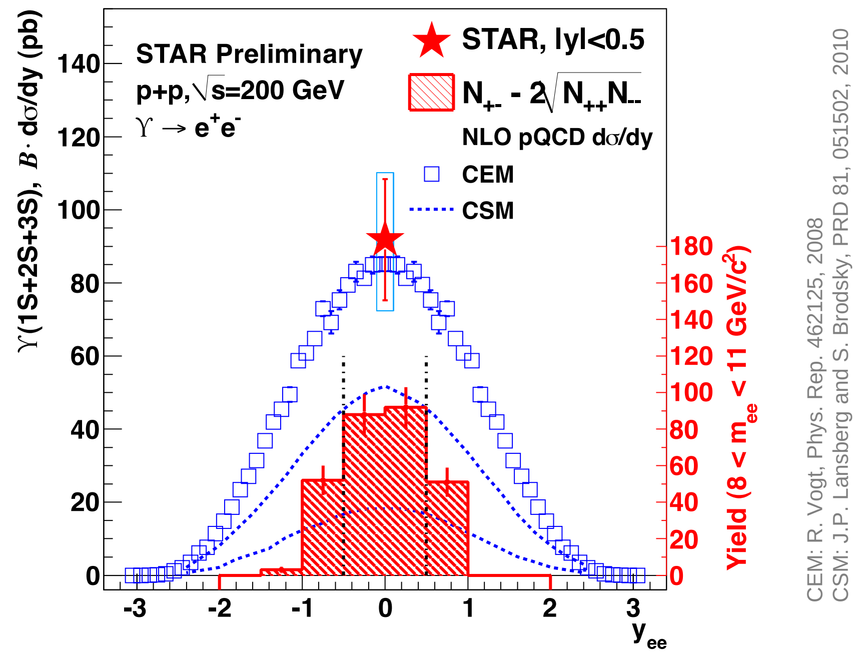
Cold Nuclear Matter Effects

- ϒ : CNM effects established by E776 (√s=38.8 GeV):
  - Magnitude and A dep: ϒ(1S)=ϒ(2S+3S). α can be as low as ~ 0.8.



Υ Comparison to NLO pQCD



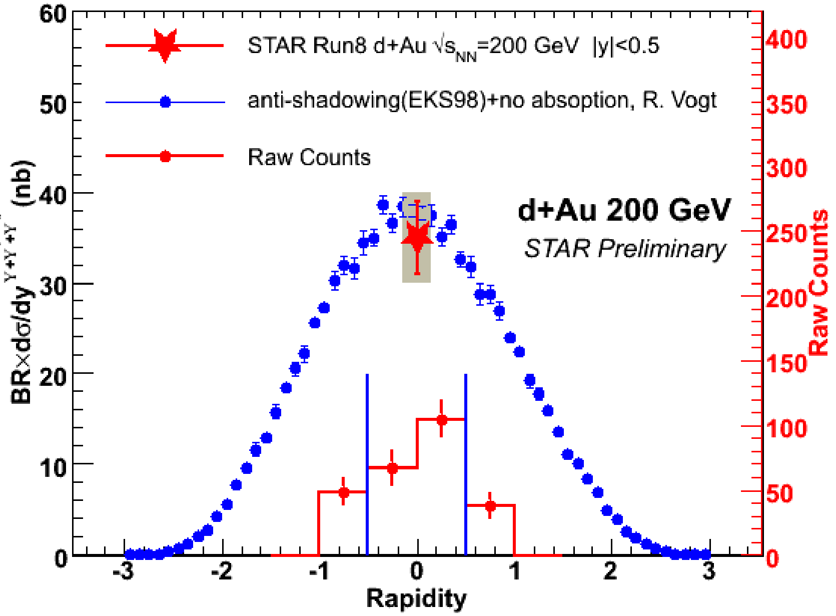


$\int L\,dt$ = 19.7 pb^{-1}
N_{Υ}(total)= 145±26(stat.)

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

- STAR $\sqrt{s}$=200 GeV p+p Υ+Υ′+Υ″→e^+e^- cross section consistent with pQCD Color Evaporation Model (CEM)

Υ in d+Au 200 GeV



$$R_{dAu} = \frac{1}{N_{bin} \times \frac{\sigma_{dAu}}{\sigma_{pp}}} \times \frac{B_{ee} \times \left(\frac{d\sigma_{dAu}}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''}}{B_{ee} \times \left(\frac{d\sigma_{pp}}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''}}$$

σ_{dAu} = 2.2 b σ_{pp} = 42 mb

N_{bin} = 7.5   0.4 for minbias dAu

R_{dAu} =0.78 ± 0.28 ± 0.20

Note: Includes DY and $b\bar{b}$

STAR √s=200 GeV d+Au $\Upsilon+\Upsilon'+\Upsilon''\rightarrow e^+e^-$ cross section consistent with pQCD

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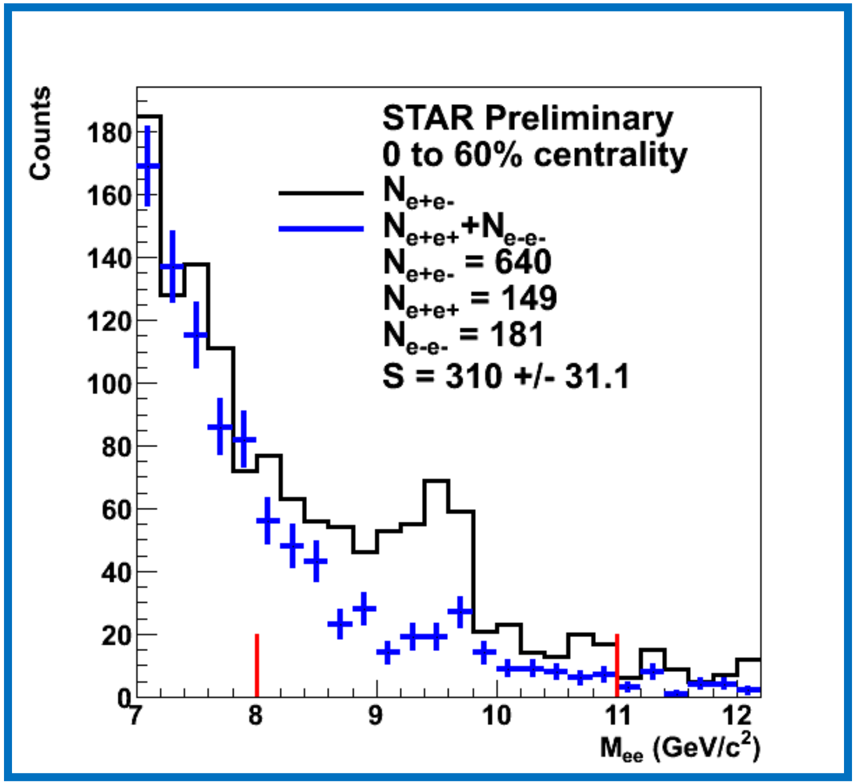
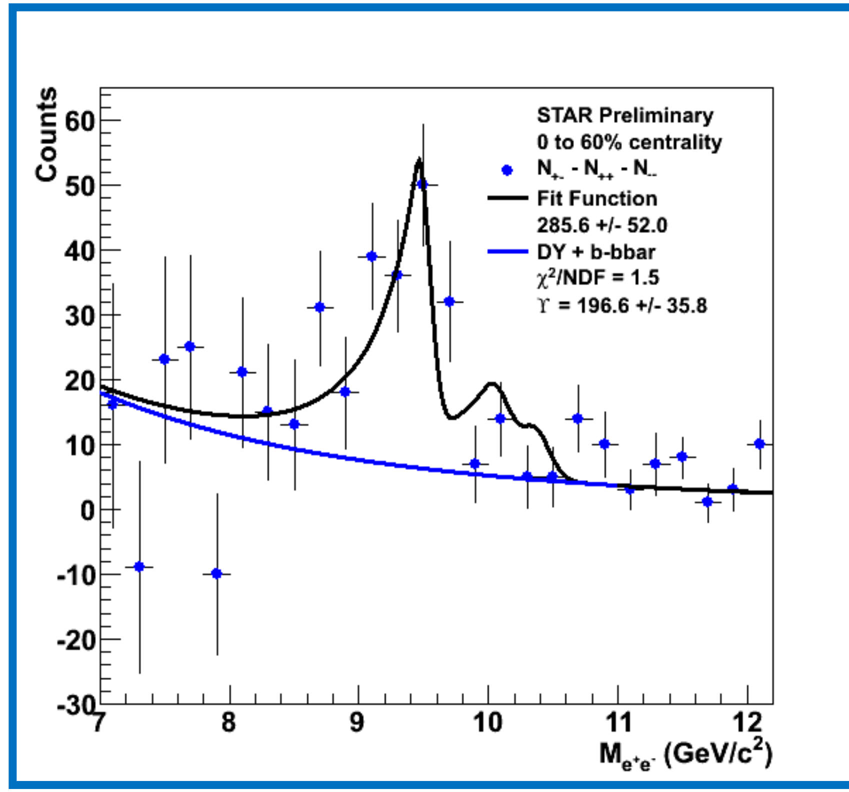
ϒ Signal in Au+Au 200 GeV





Raw yield of $\Upsilon \rightarrow e^+e^-$ with
$|y|<0.5$ = 196.6 ±35.8
= $N_{+-} - N_{--} - N_{++} - \int DY + b\bar{b}$

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

n = 4.59, m_0 = 2.7

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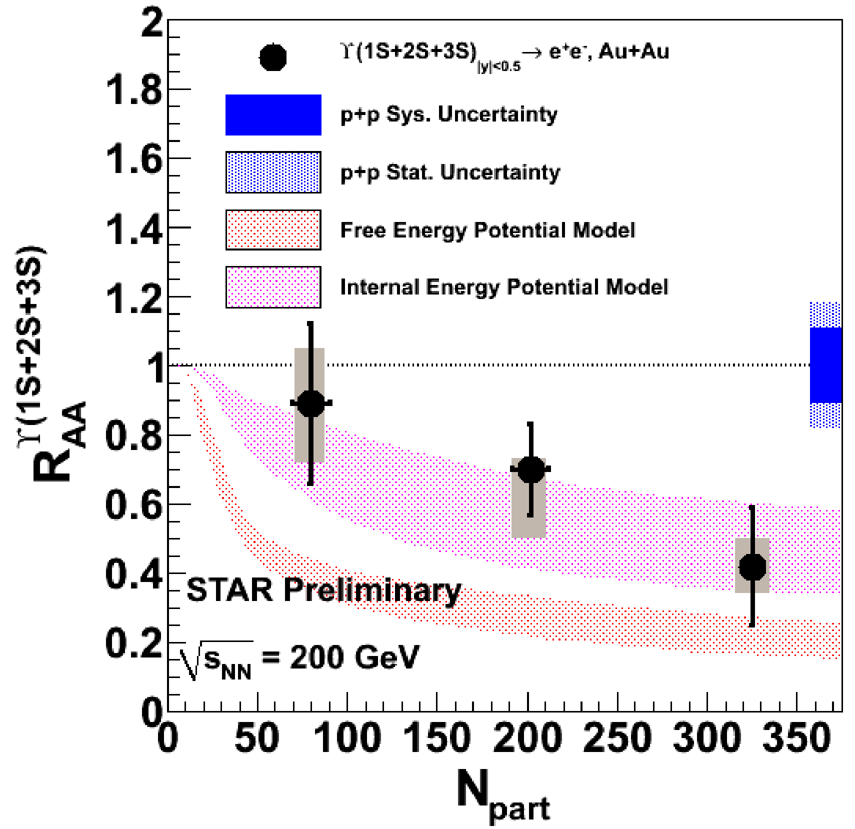
Nuclear modification factor

- Suppression of Υ(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, η/S)
  - Models indicate:
    - $428 < T_0 < 442$ MeV at RHIC
    - for $3 > 4\pi\eta/S > 1$



Model: M. Strickland, PRL 107, 132301 (2011).

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+ $\sigma_{abs J/\psi}$ (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 and d+Au 200GeV**
  - Consistent with pQCD Color Evaporation Model.
  - $R_{dAu} = 0.78 \pm 0.28 \pm 0.20$ (Includes DY and bbar).

- **Upsilon in Au+Au 200GeV**
  - Increasing of ϒ 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.

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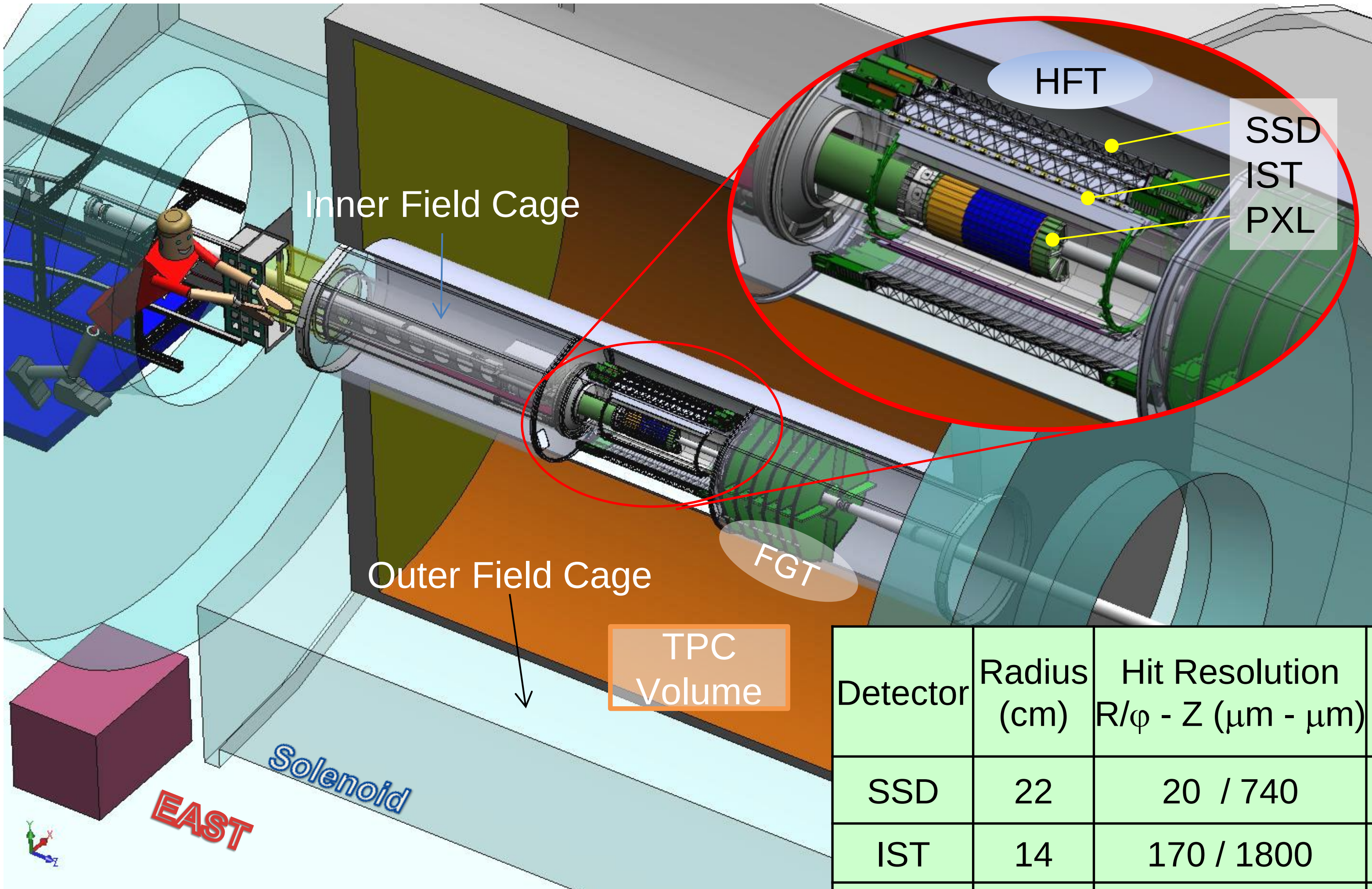
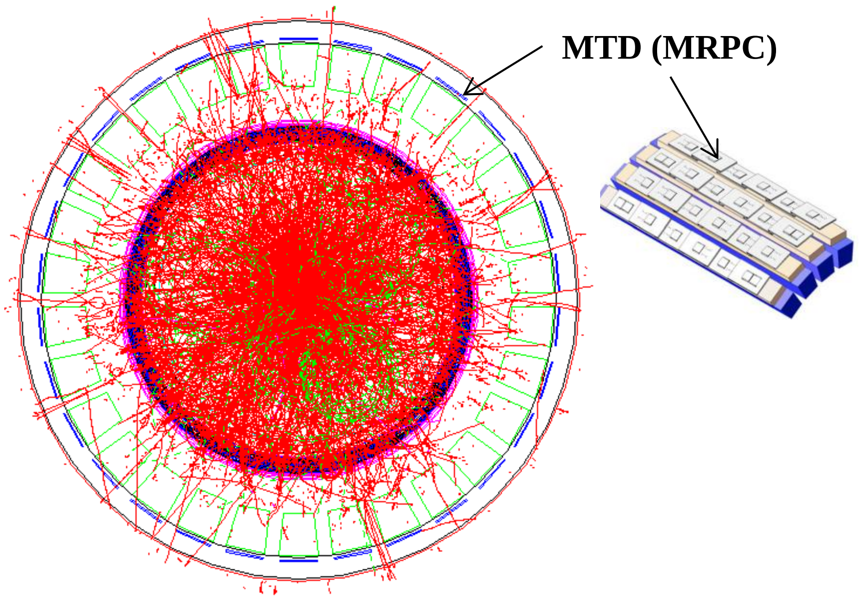
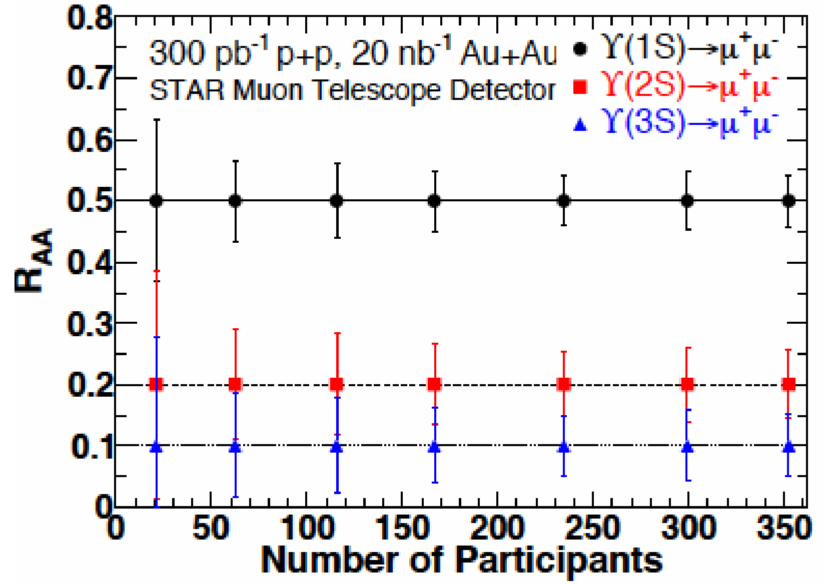
Heavy Flavor Tracker



Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5% X_0
PIXEL	8	12 / 12	~0.4% X_0
	2.5	12 / 12	~0.4% X_0

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 |□|<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 μ+μ-

ϒ in Au+Au 200 GeV, Centrality