# *Quarkonia production in the STAR experiment*

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# Outline

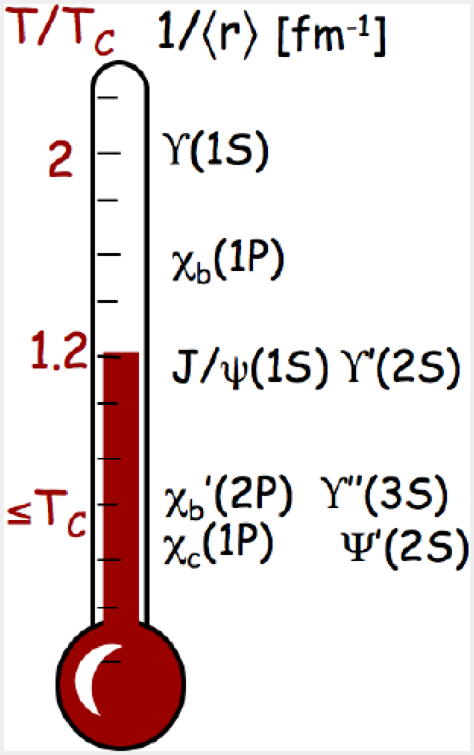
- Motivation
- J/ψ production in p+p, d+Au and Au+Au collisions at 200 GeV
  - spectra, polarization, $R_{AA}$, elliptic flow
- ϒ in p+p and Au+Au collisions at 200 GeV
  - cross section, $R_{AA}$
- Summary

# Quarkonia at RHIC - Motivation

*Charmonia*: $J/\psi$, $\psi'$, $\chi_c$ *Bottomonia:* $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, $\chi_b$

- ✓ Quarkonia suppression in QGP in heavy-ion collisions due to color screening
- ✓ Suppression of different states is determined by $T_C$ and their binding energy - QGP thermometer

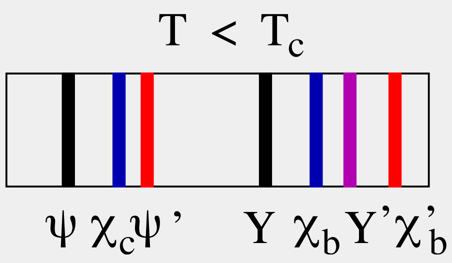
*The QGP Thermometer*




A .Mocsy, Eur. Phys. J. C61, 705-710 (2009)

*Screening radius:*

$$r_D(T) \propto 1/T$$

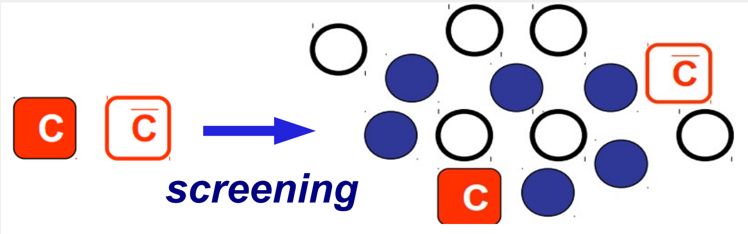



*Quarkonia spectral lines as thermometer*

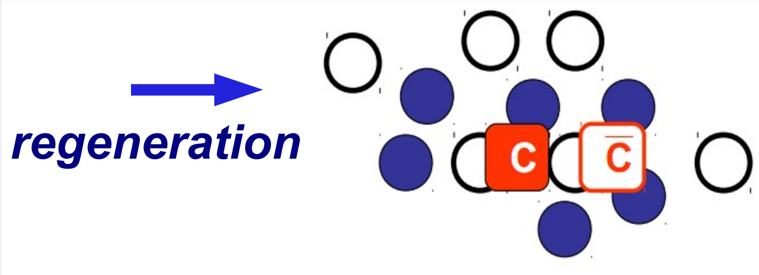
H.Satz, Nucl. Phys. A 783, 249 (2007)

# Quarkonia at RHIC - Motivation (2)

- ✓ But there are more complications:
  - ➡ Still unknown quarkonia Production Mechanism
  - ➡ Cold Nuclear Matter Effects, e.g. nuclear shadowing, Cronin effect, nuclear absorption




  - ➡ Other Hot Nuclear Matter Effects, e.g regeneration



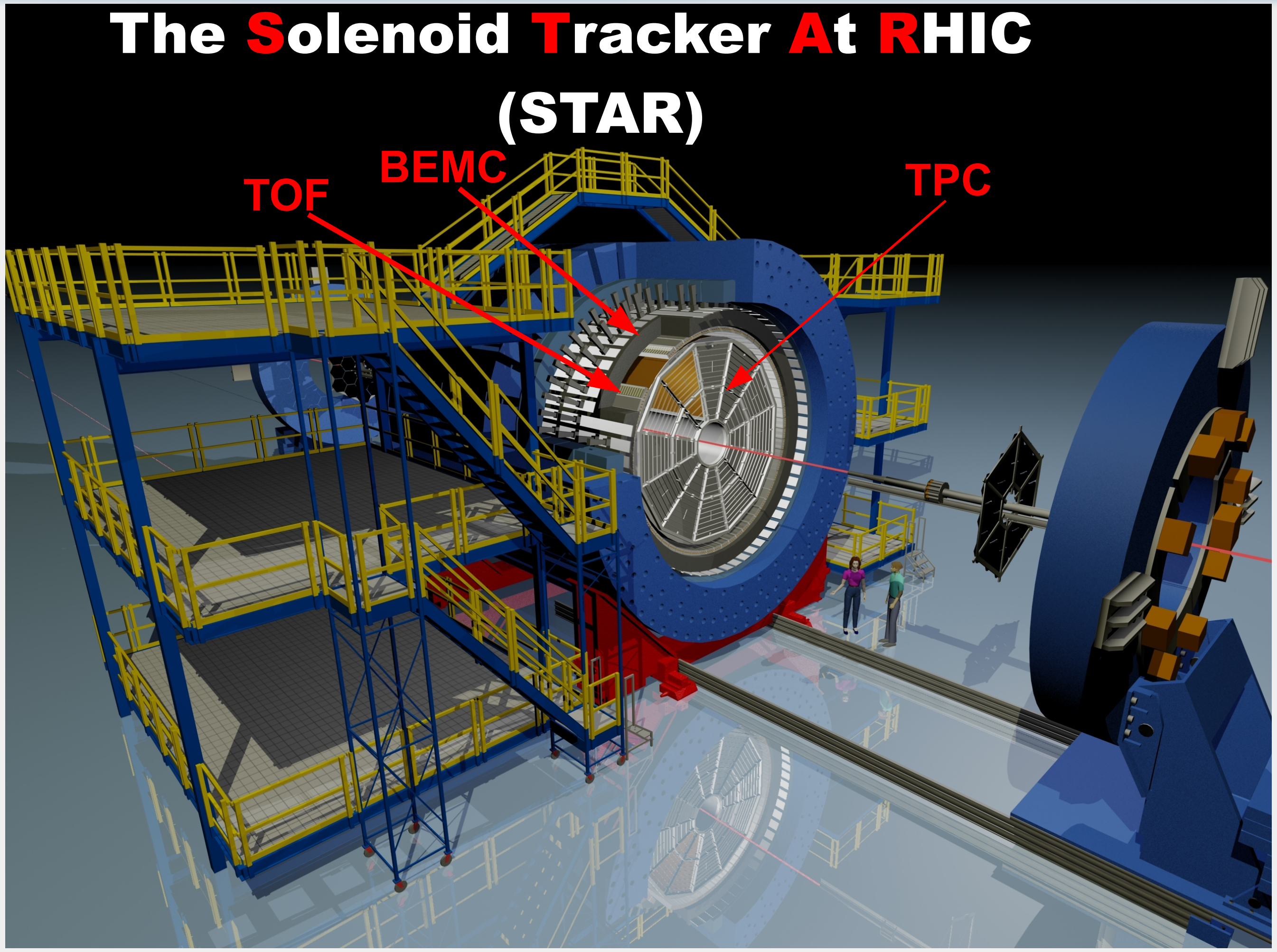

- ✓ $\Upsilon$ very rare but a cleaner probe compare to $J/\psi$: negligible co-mover absorption and recombination

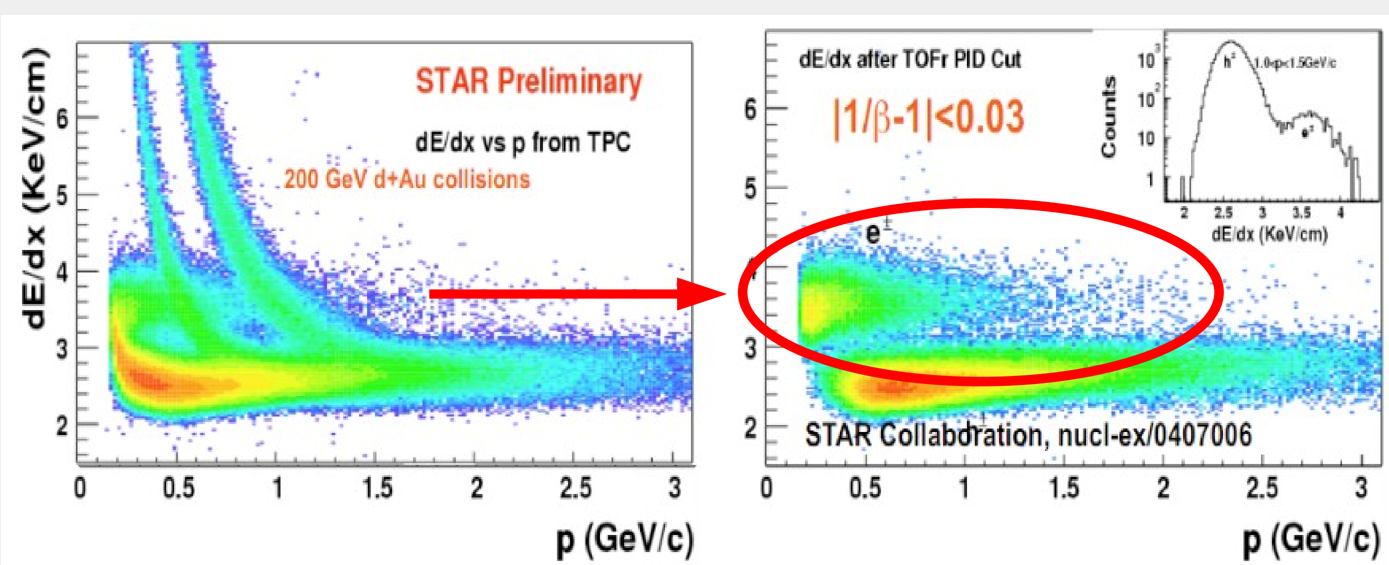
- ✓ *Measure quarkonia production for different colliding systems, centralities and collision energies*
  - ➡ $p_T$ spectra, $R_{AA}$, polarization, elliptic flow ...

$$R_{AA} = \frac{1}{N_{coll}} \frac{dN/dy_{A+A}}{dN/dy_{p+p}}$$

# STAR EXPERIMENT, PID

$J/\psi \rightarrow e^{+}e^{-}$ (BR 5.9%)   $\Upsilon \rightarrow e^{+}e^{-}$ (BR 2.4%)

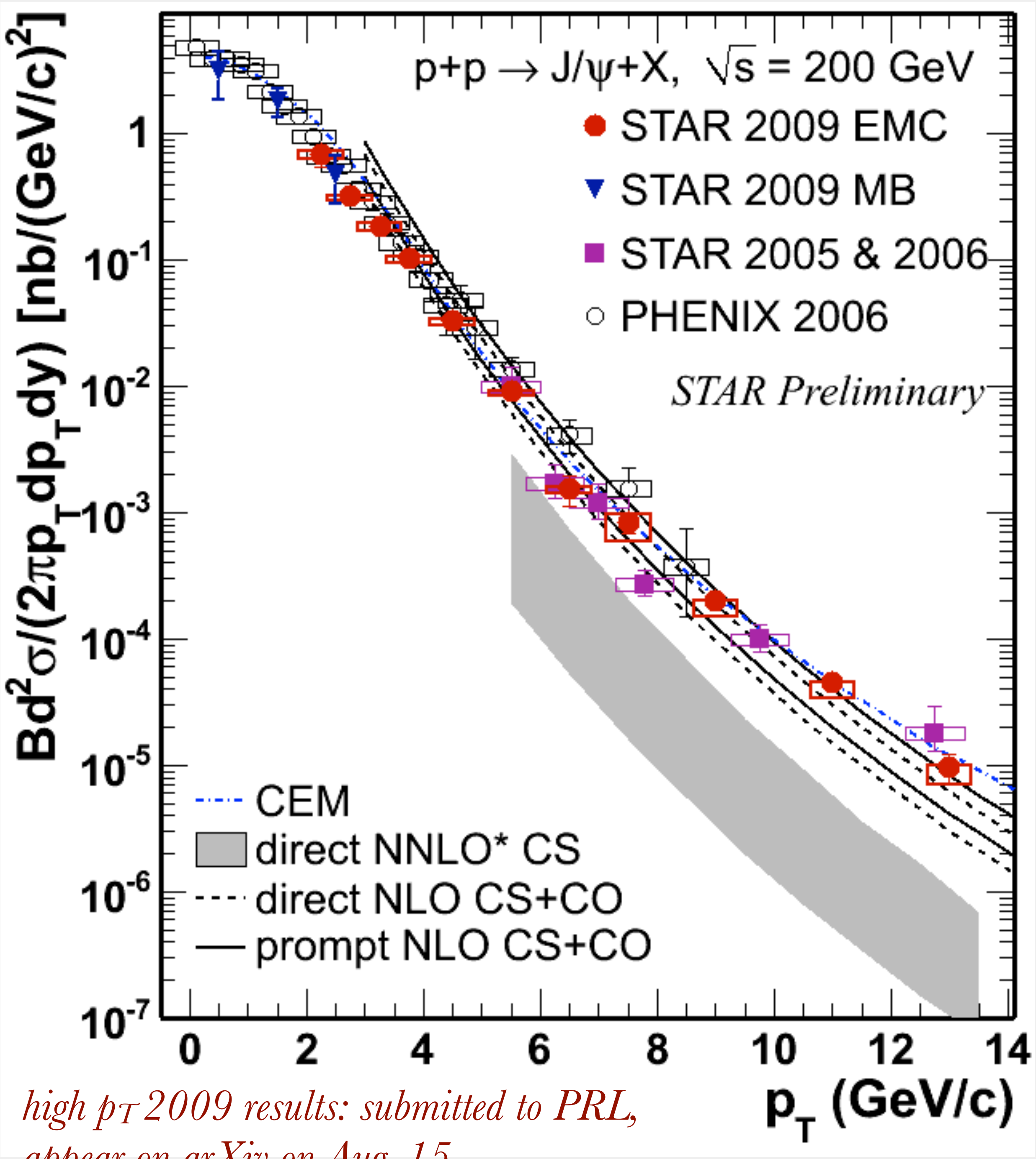



- ✓ Large acceptance:
  - ➡ $|\eta| < 1,\ 0 < \phi < 2\pi$
- ✓ Time Projection Chamber (***TPC***)
  - ➡ Tracking: $p_T$, $\eta$, $\phi$
  - ➡ dE/dx: **PID**
- ✓ Time of Flight (***TOF***)
  - ➡ Timing resolution < 100 ps
  - ➡ $1/\beta$: **PID**
- ✓ Barrel Electromagnetic Calorimeter (***BEMC***)
  - ➡ Tower $\Delta\eta$ x $\Delta\phi$ = 0.05 x 0.05
  - ➡ Energy: E/p ~ 1 (for electrons) **PID**
  - ➡ **Trigger**

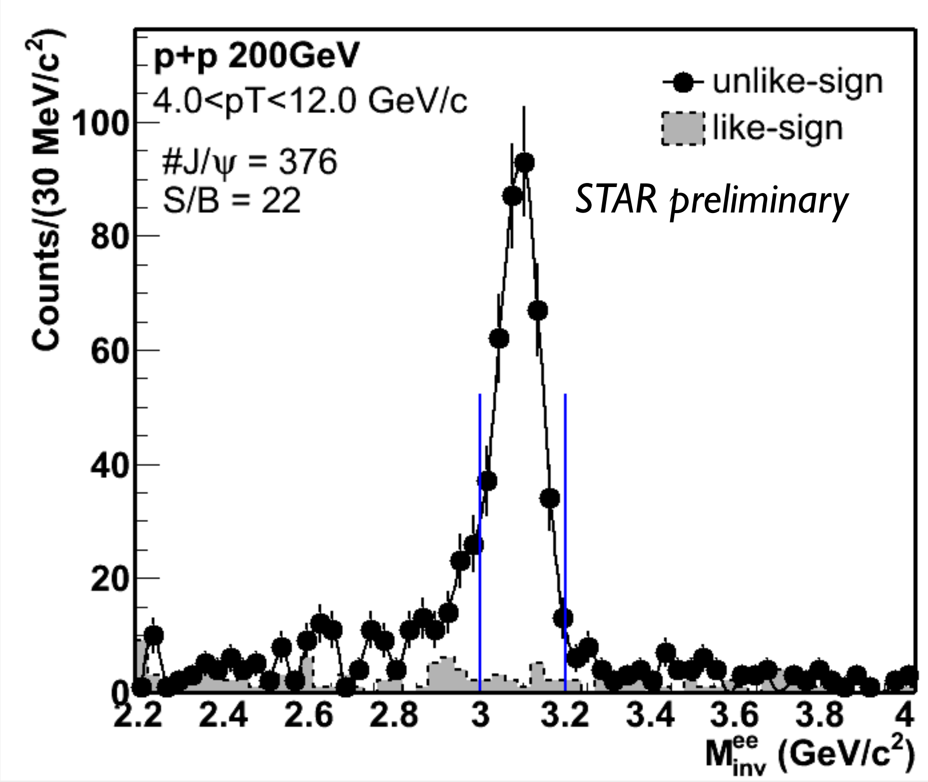
# J/ψ spectra in p+p collisions at 200 GeV

STAR results consistent with PHENIX results, $p_T$ extended up to 14 GeV/c




*high $p_T$ 2009 results: submitted to PRL, appear on arXiv on Aug. 15*

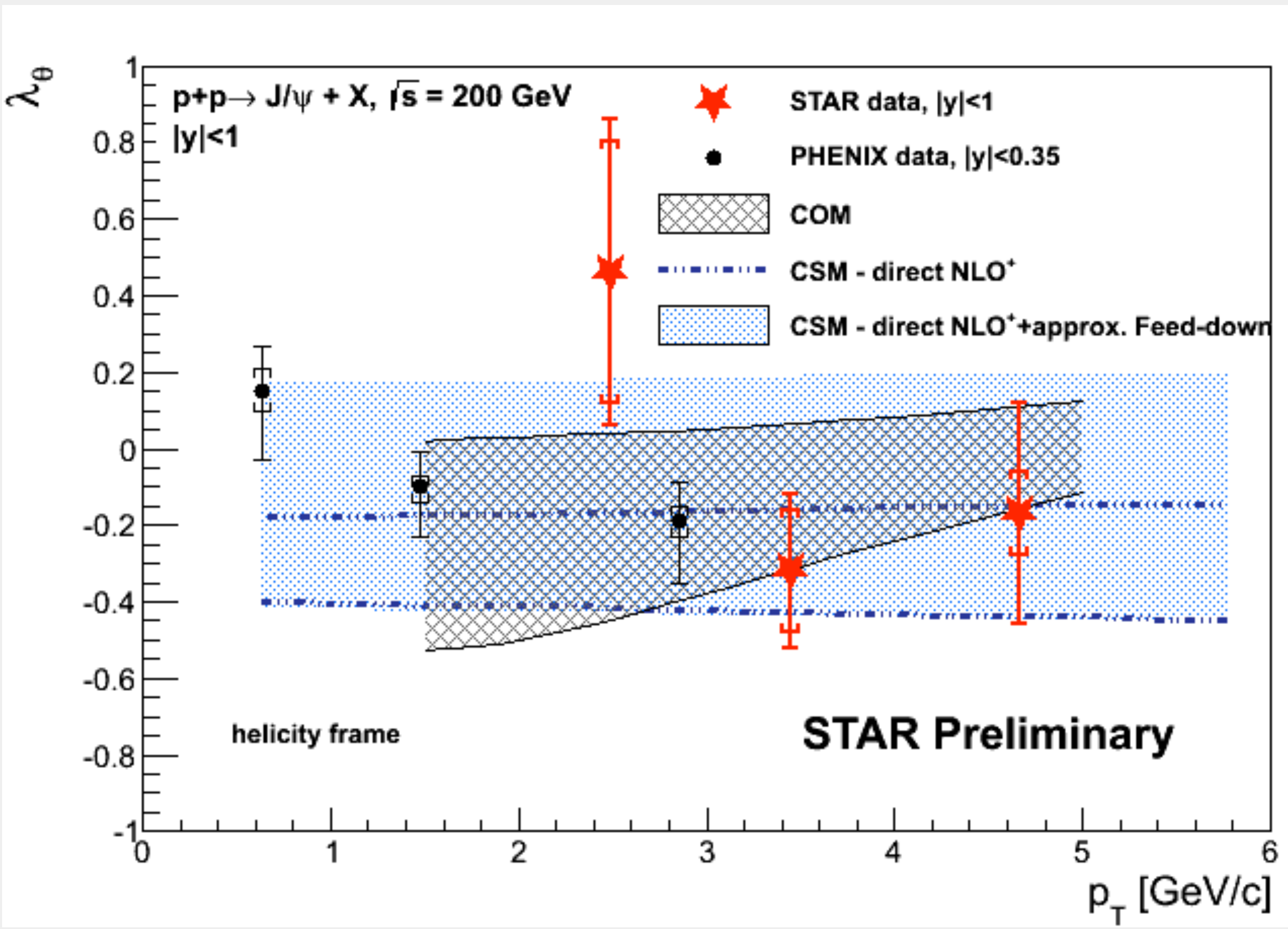
- ✓ Direct NNLO* CS model misses high-$p_T$ part
- ✓ NLO CS+CO model describes the data
- ✓ CEM model can reasonable well describe the $p_T$ spectra

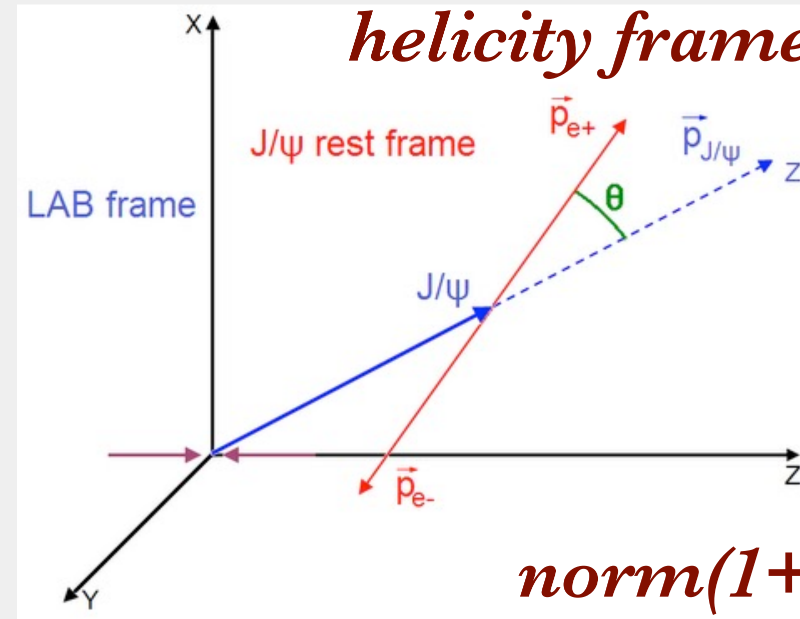



*PHENIX: Phys. Rev. D 82, 012001 (2010)*
*STAR: Phys. Rev. C80, 041902(R) (2009)*
*direct NNLO: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication*
*NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D84, 51 114001 (2011)*
*CEM: M. Bedjidian et al., hep-ph/0311048, and R.Vogt private communication*

# J/ψ polarization in p+p collisions at 200 GeV

Discrimination power between different J/ψ production models at high-$p_T$

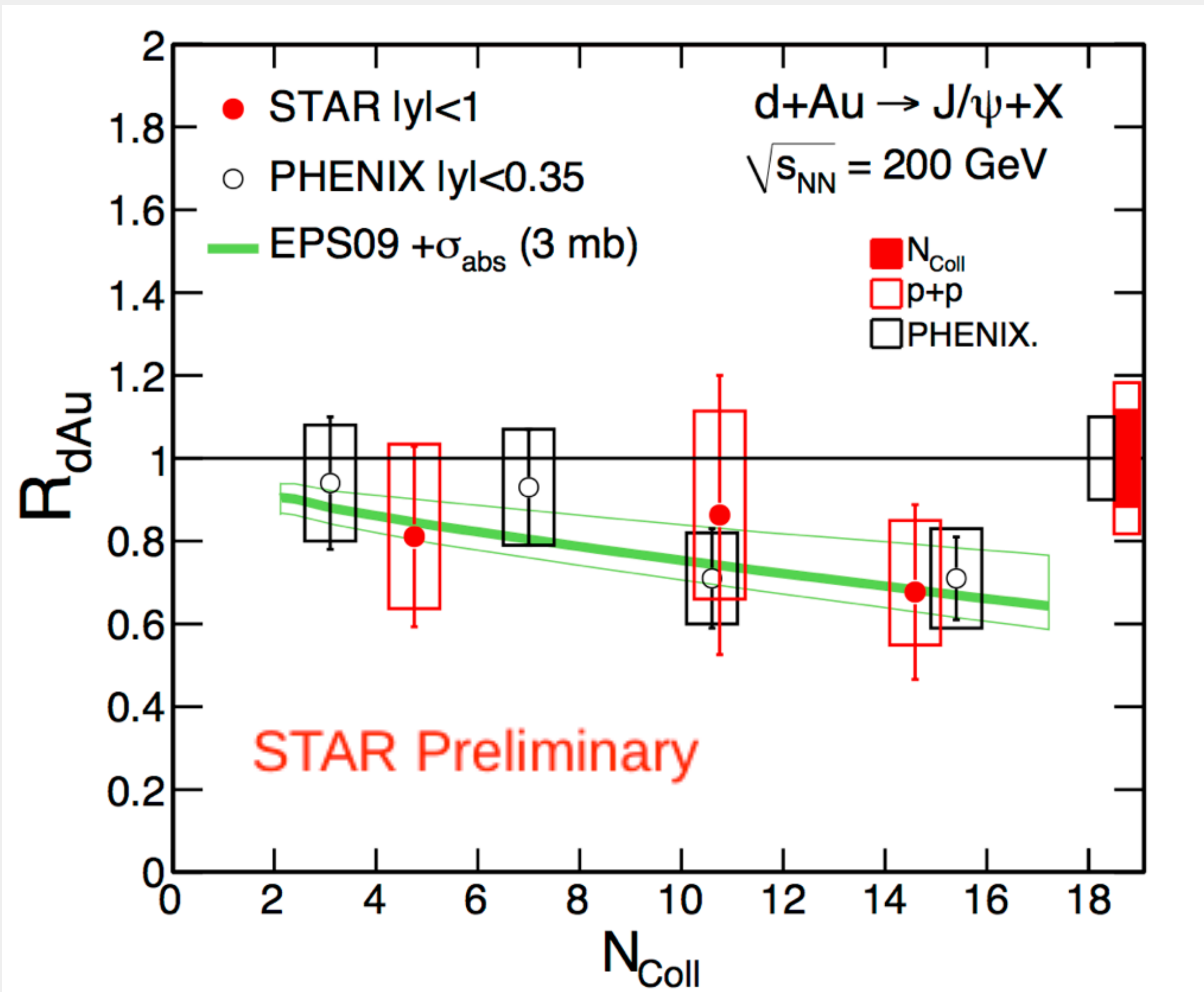


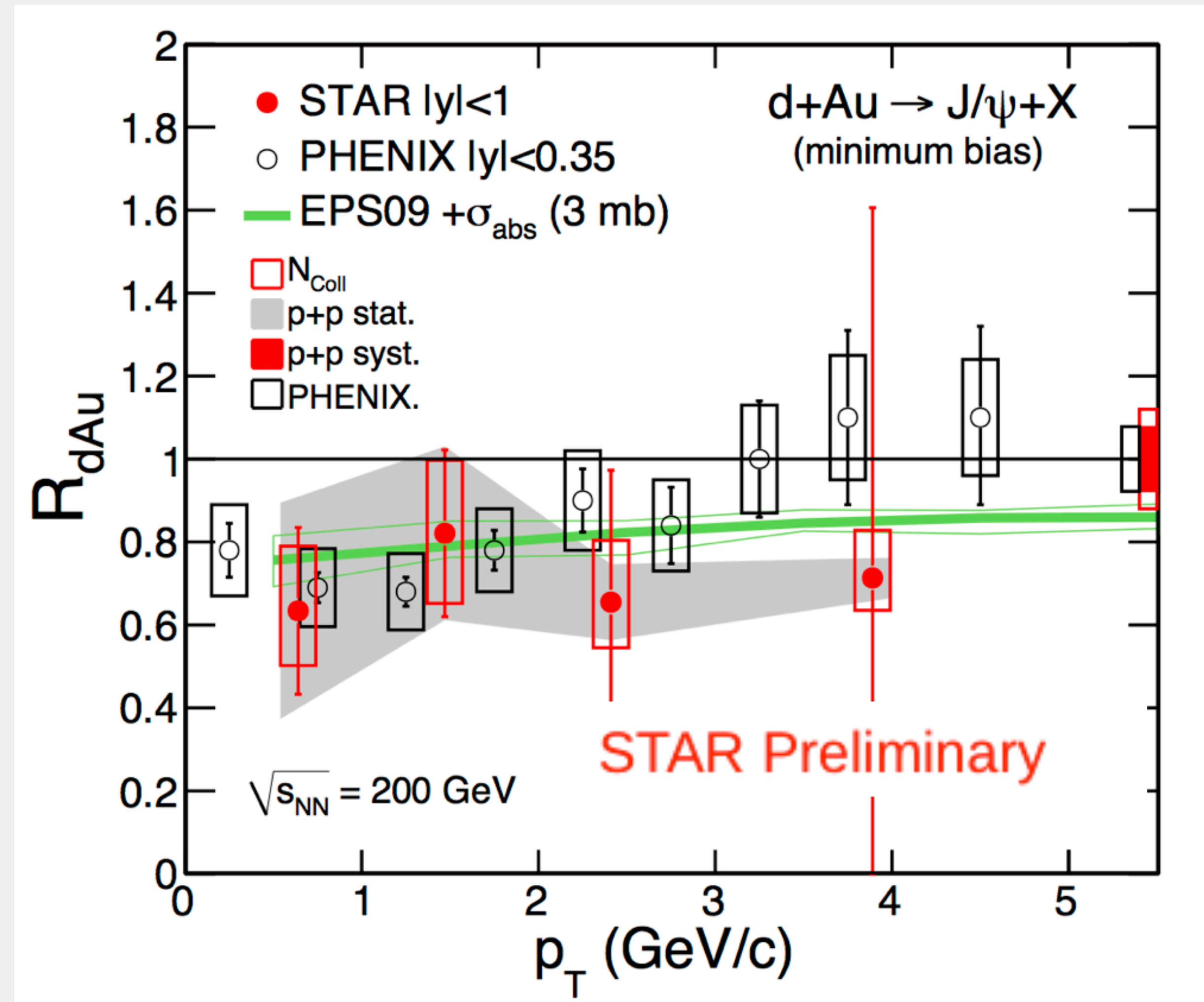

PHENIX: *Phys. Rev. D 82, 012001 (2010)*
COM: *Phys. Rev. D 81, 014020 (2010)*
CSM NLO+: *Phys. Lett. B, 695, 149 (2011)*

- ✓ Polarization parameter $\lambda_\theta$ is measured in helicity frame at $|y| < 1$ and $2 < p_T < 6$ GeV/c
- ✓ $\lambda_\theta$ is consistent with NLO+ CSM and COM models predictions, and with no polarization within current uncertainties

# J/ψ $R_{AA}$ in d+Au collisions at 200 GeV

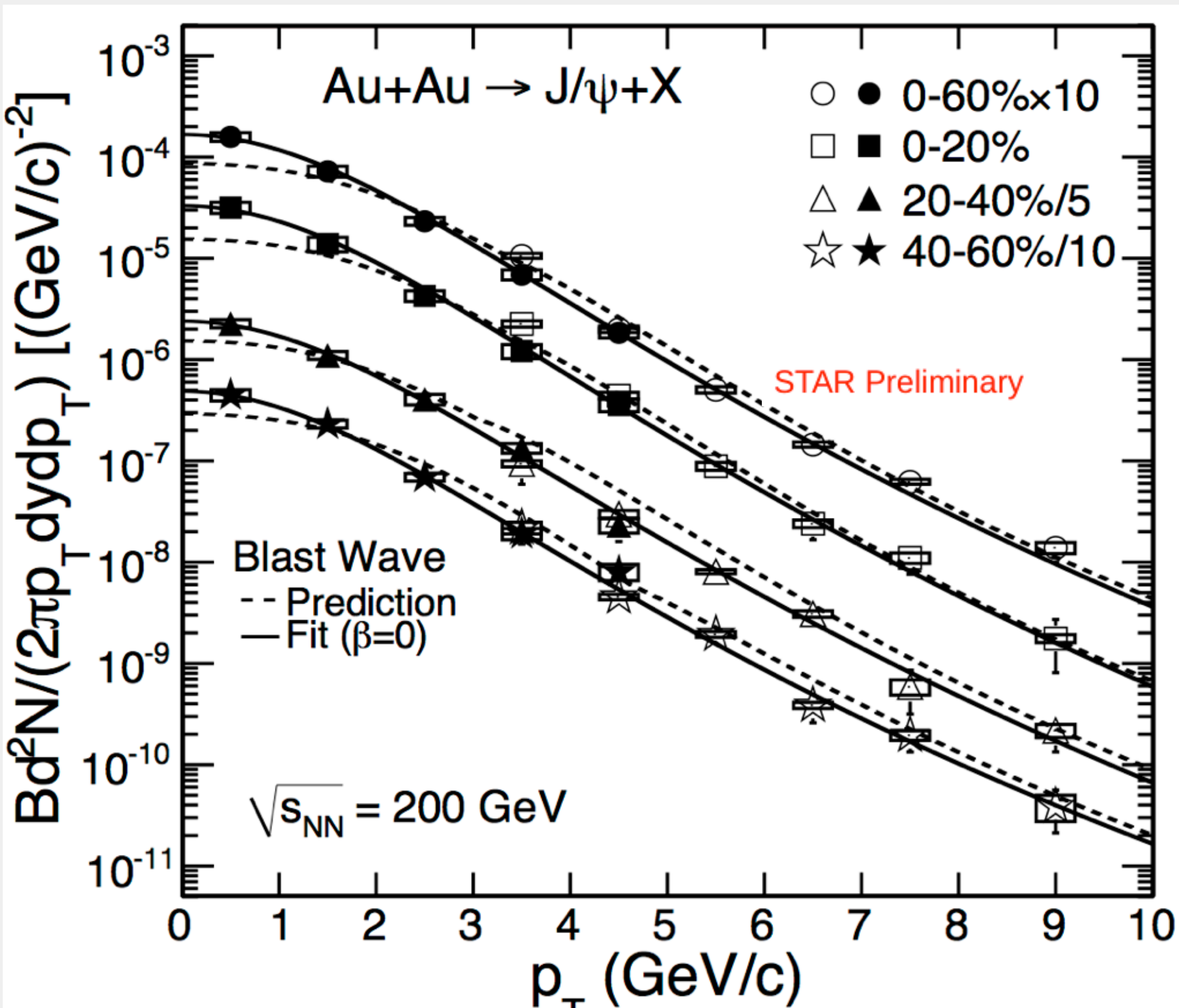



E.Eskola, H.Paukkunenea and C.Salgo, Nucl. Phys. A 830, 599 (2009)
R.Vogt, Phys. Rev. C 81, 044903 (2010)




- ✓ Measurement of J/ψ in d+Au collisions provides information on CNM effects
- ✓ Good agreement with model predictions using EPS09 nPDF parametrization for the shadowing, and a 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
- ✓ STAR results consistent with PHENIX measurements

# J/ψ spectra in Au+Au collisions at 200 GeV

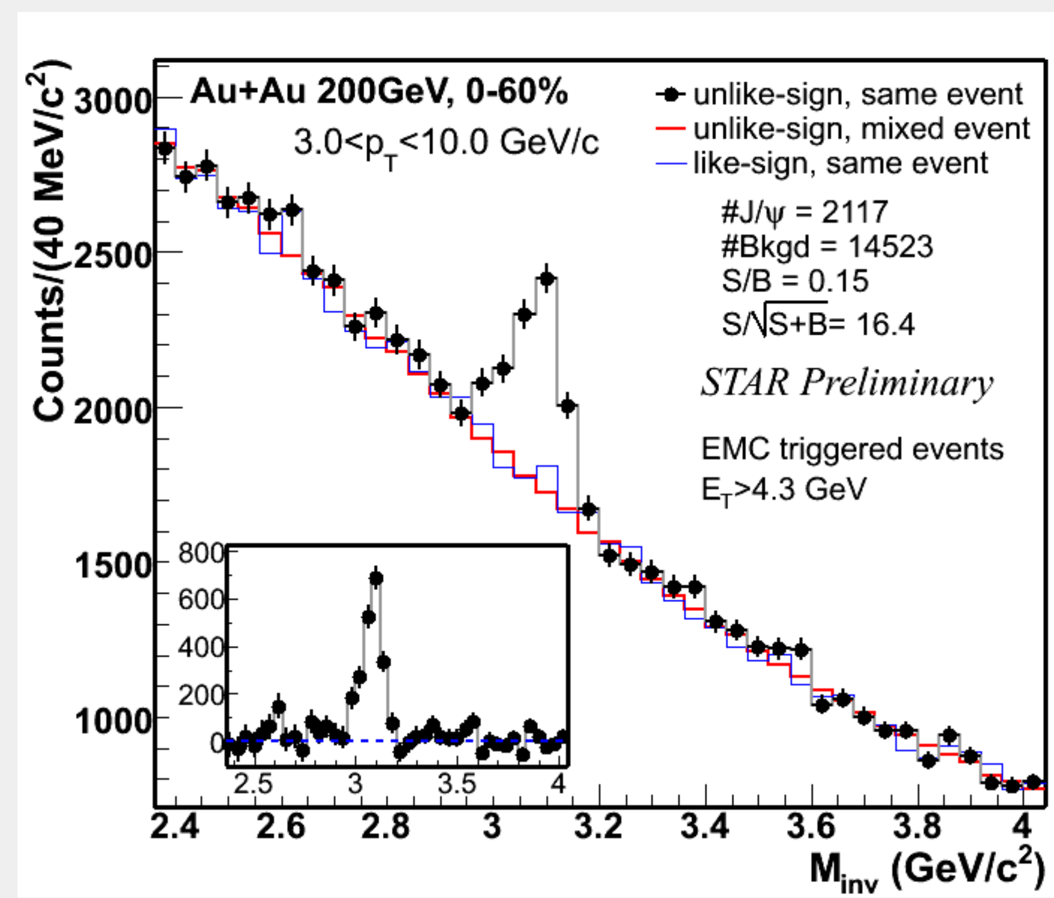



- ✓ Softer spectra than light hadron prediction at low $p_T$

*smaller radial flow* ?

*regeneration at low $p_T$* ?

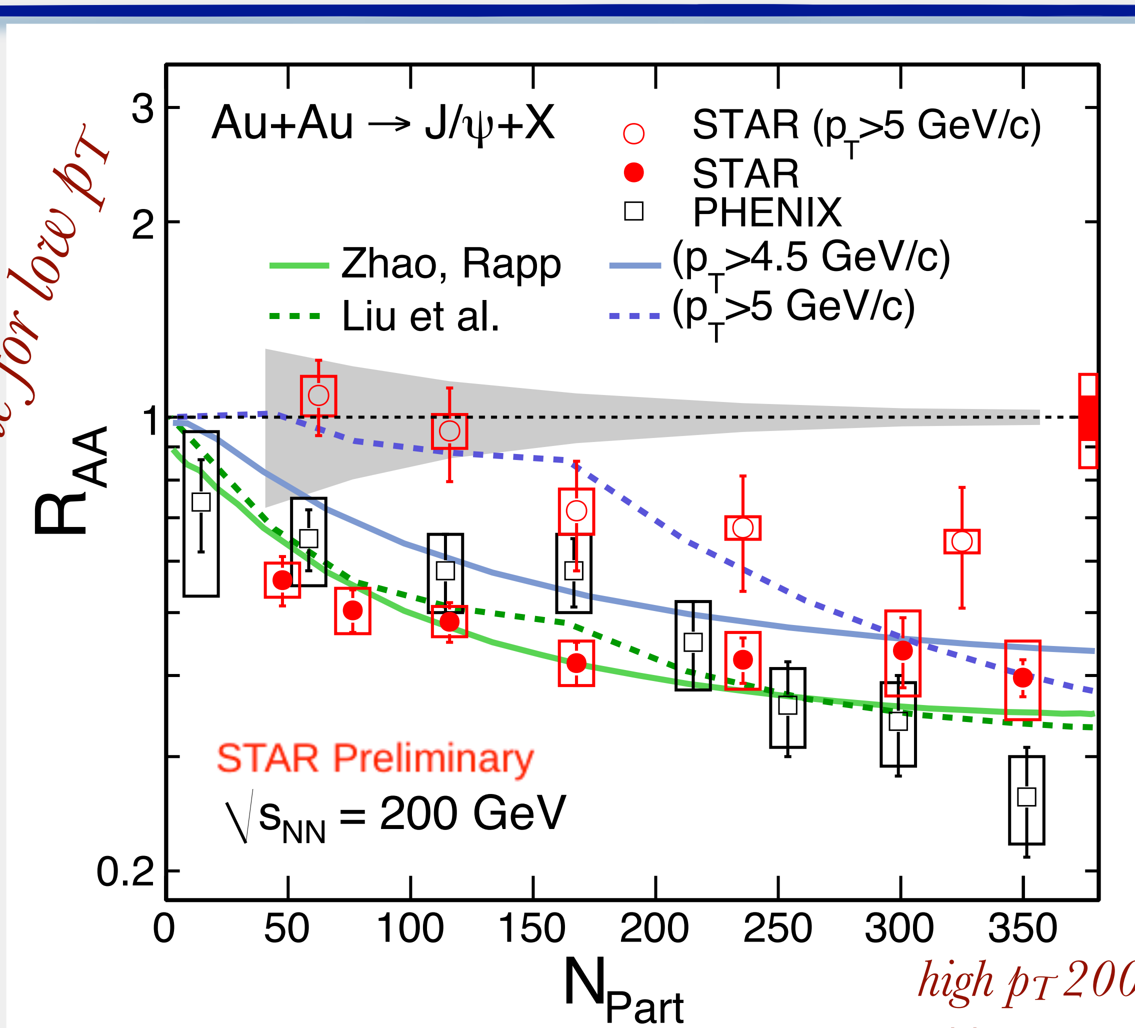
*high $p_T$ 2009 results: submitted to PRL, appear on arXiv on Aug. 15*



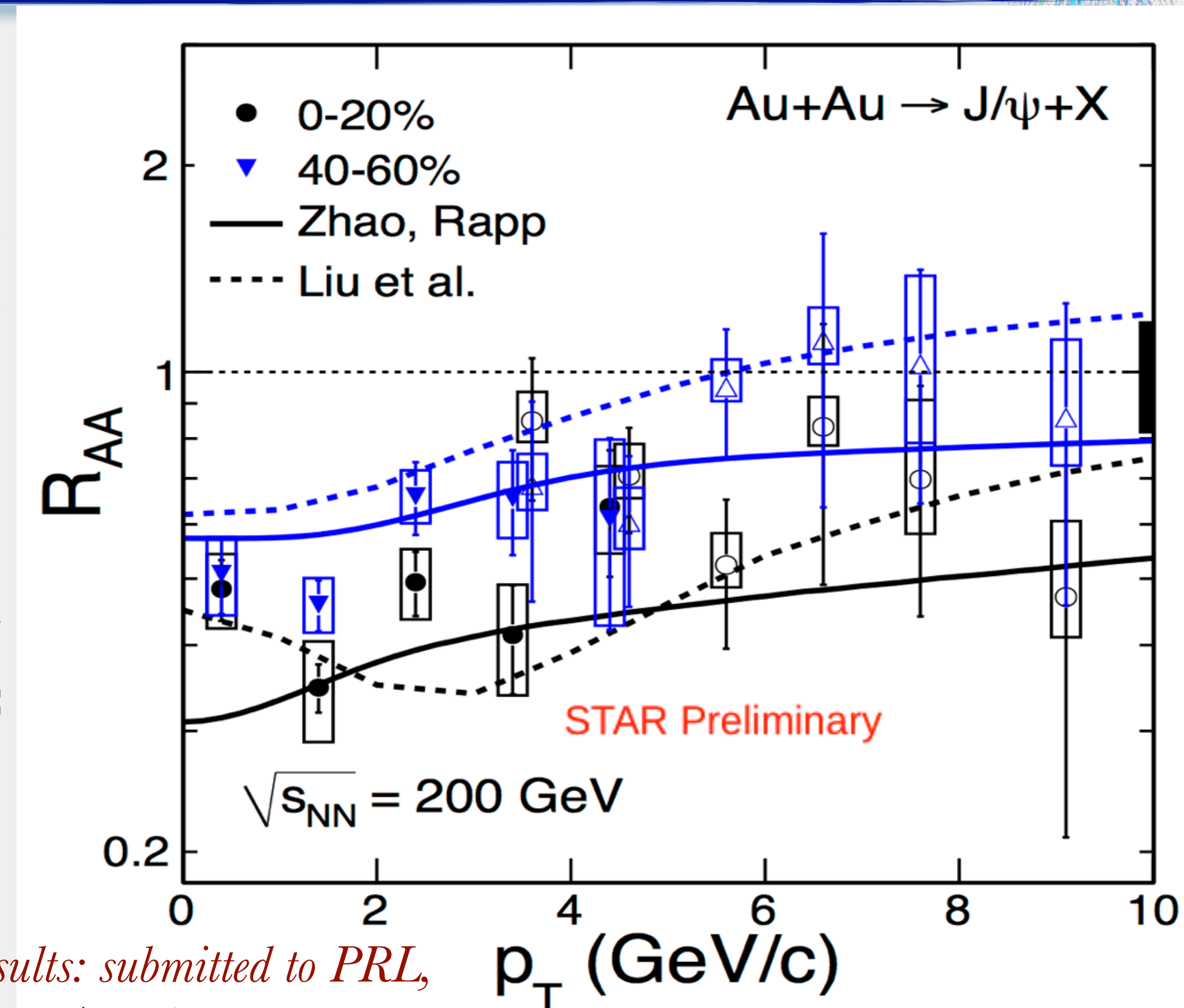

*Tsallis Blast-Wave model: Z.Tang et al., arXiv: 1101.1912, JPG 37, 08194 (2010)*

# J/ψ $R_{AA}$ in Au+Au collisions at 200 GeV

*new p+p 2009 baseline for low $p_T$*




*Y.Liu et al., Phys. Lett. B, 678:72 (2009)*
*Zhao, Rapp, Phys. Rev. C 82, 064905 (2010)*

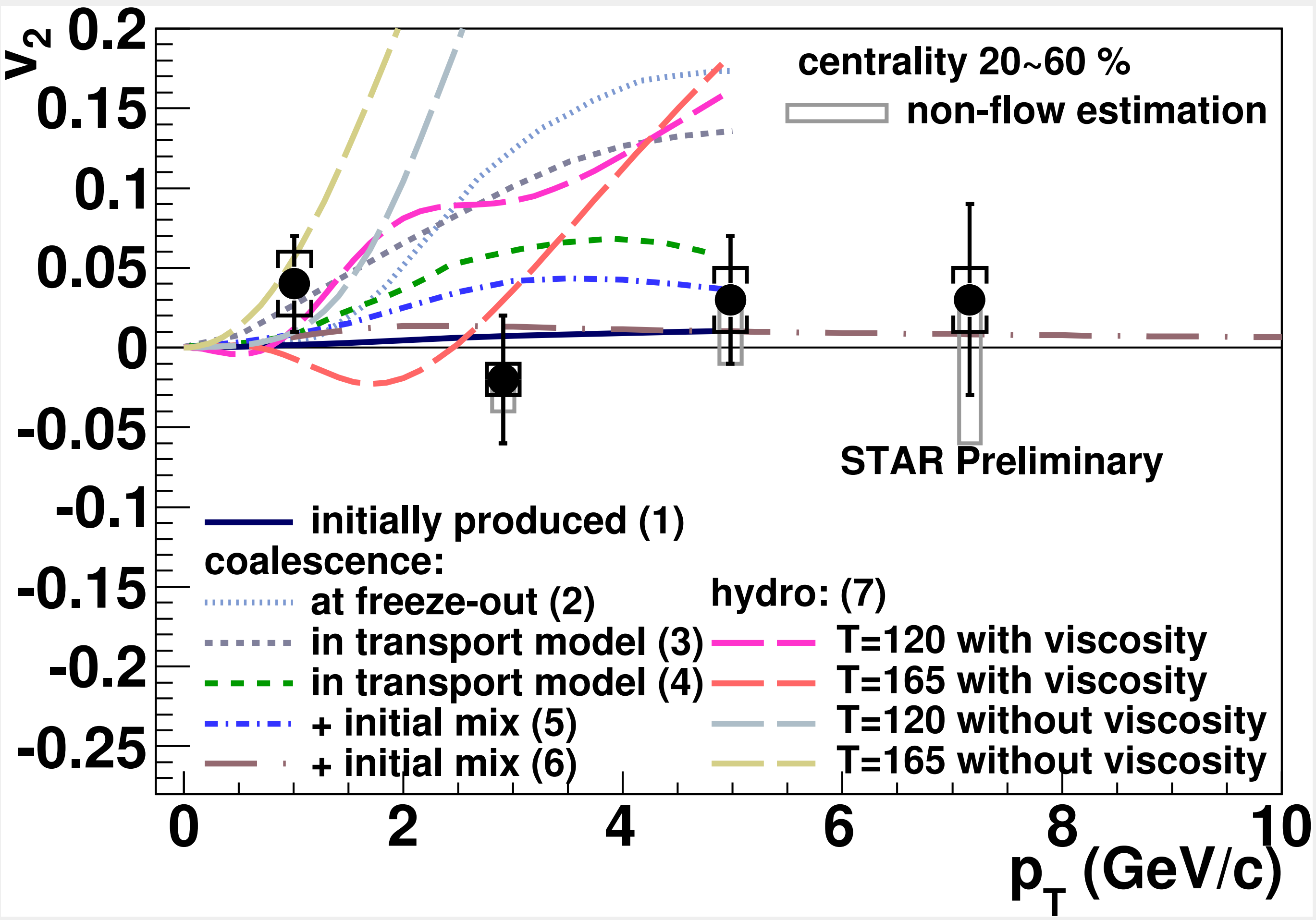



*high $p_T$ 2009 results: submitted to PRL, appear on arXiv on Aug. 15*

- ✓ J/ψ suppression increases with collision centrality
- ✓ J/ψ suppression decreases with $p_T$ across the centrality range
- ✓ At low $p_T$ data agree with two models including color screening and regeneration effects
- ✓ At high $p_T$ Liu et al. model describes data reasonable well, while Zhao and Rapp model underpredicts $R_{AA}$ at $N_{part}$ > 70

# J/ψ $v_2$ in semi-central Au+Au collisions at 200 GeV

The J/ψ $v_2$ measurement is crucial for the test of charm quark recombination effect

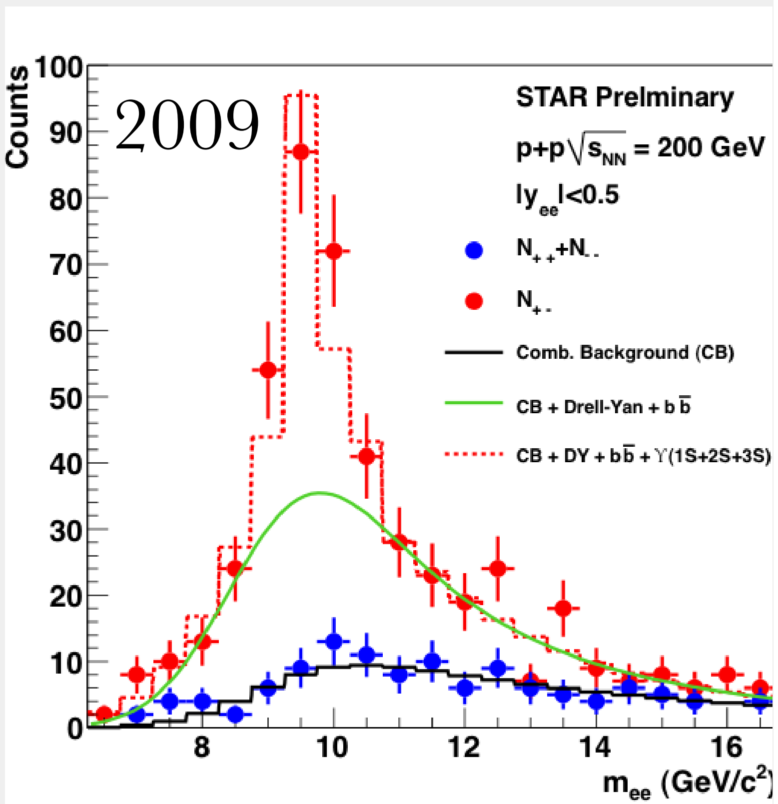


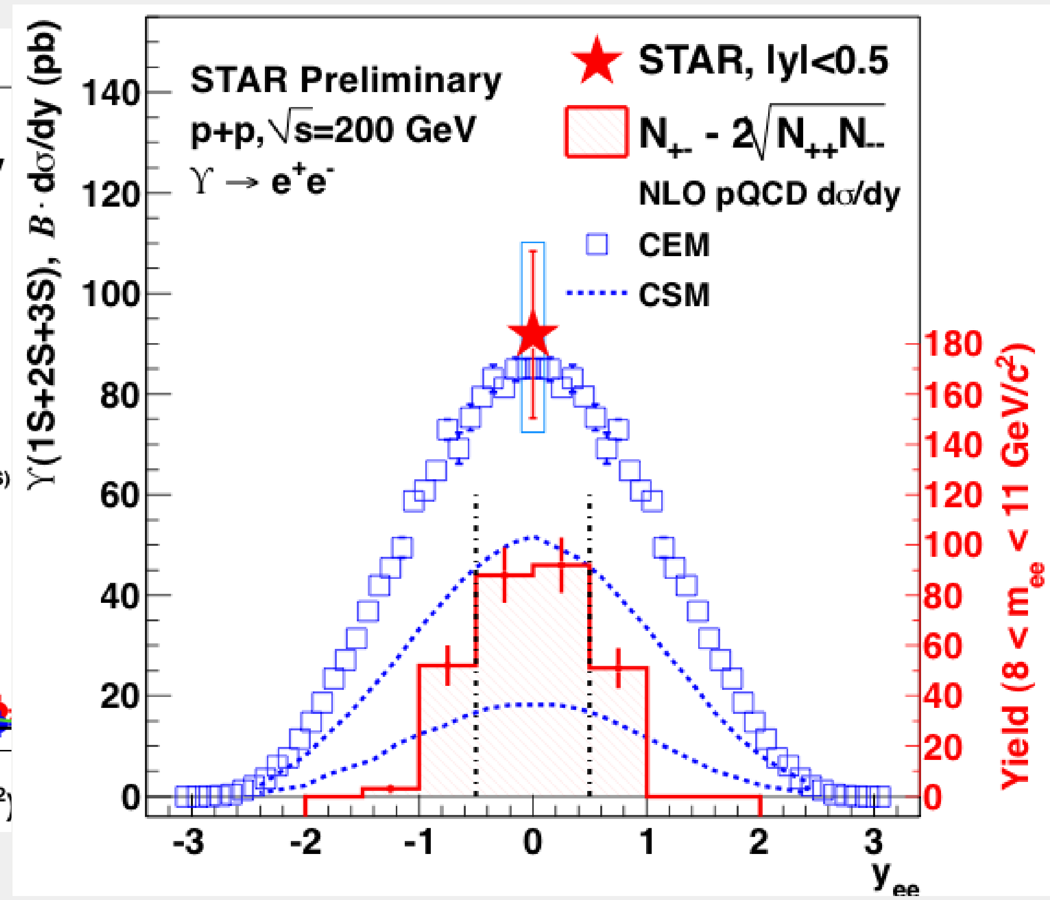

*(1) (4) Phys. Rev. Lett. 97, 232301 (2006)*
*(2) Phys. Lett. B595, 202 (2004)*
*(3) Phys. Lett. B655, 126 (2008)*
*(5) X.Zhao, R.Rapp, 24th WWND (2008)*
*(6) Nucl. Phys. A834, 317 (2010)*
*(7) U.Heinz, C. Shen, private communication*

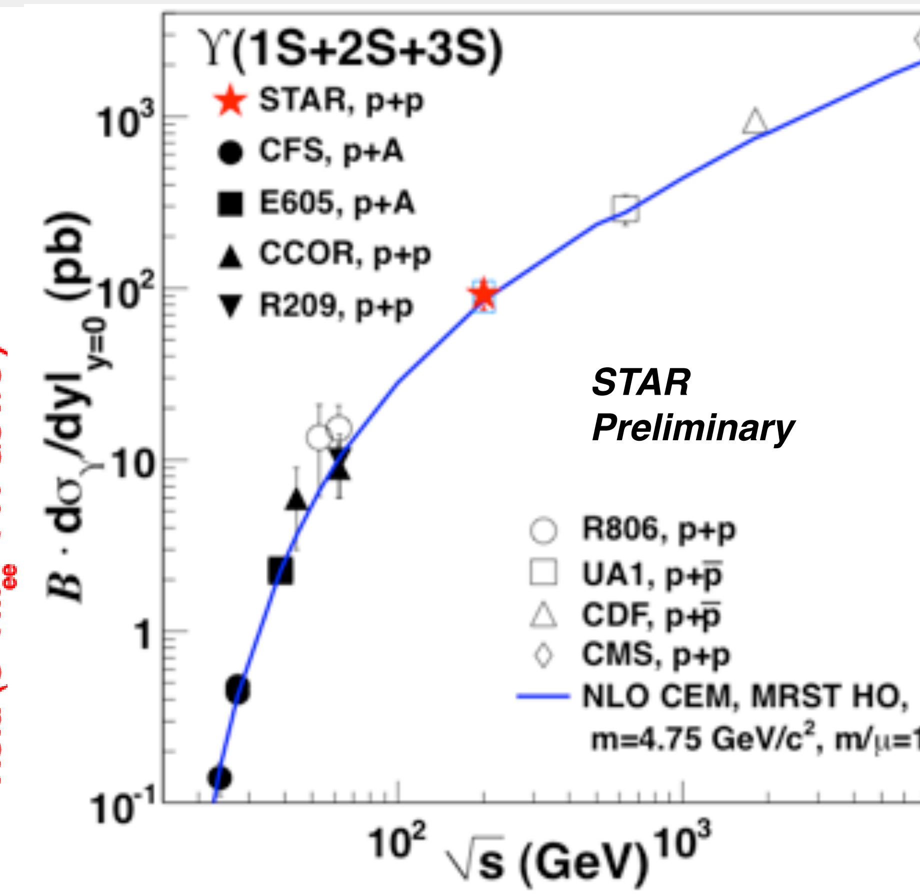
- ✓ J/ψ $v_2$ is consistent with non flow at $p_T$ > 2 GeV/c - disfavors the case when J/ψ is produced dominantly by coalescence from thermalized (anti-)charm quarks

| Models | $\chi^2$/ndf | P-value |
|---|---|---|
| Initially produced | 1.8/3 | 6.2e-1 |
| Coalescence at freezeout | 22.6/3 | 4.9e-5 |
| Coalescence In transport | 13.9/3 | 3.0e-3 |
| Coalescence In transport | 4.8/3 | 1.8e-1 |
| Coalescence +initial mix | 2.9/3 | 4.0e-1 |
| Coalescence +initial mix | 1.8/4 | 7.7e-1 |
| Hydro T=120 w/viscosity | 16.5/3 | 9.2e-4 |
| Hydro T=165w/ viscosity | 14.9/3 | 1.9e-03 |
| Hydro T=120 w/o viscosity | 191.6/3 | 2.7e-41 |
| Hydro T=165w/o viscosity | 237.3/3 | 0.0 |

# Υ(1S+2S+3S) in p+p collisions at 200 GeV




STAR preliminary

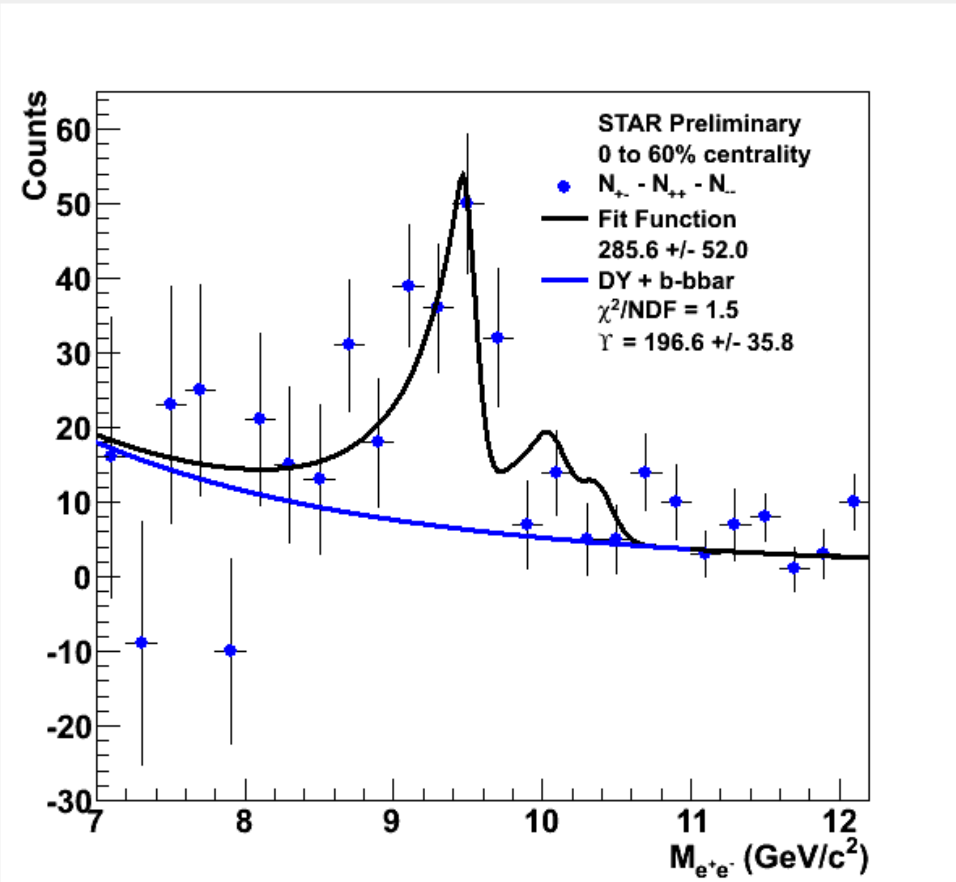
$$\sum_{n=1}^{3} \mathcal{B}(nS) \times \sigma(nS) = 91.8 \pm 16.6 \pm 19 \text{ pb}$$

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

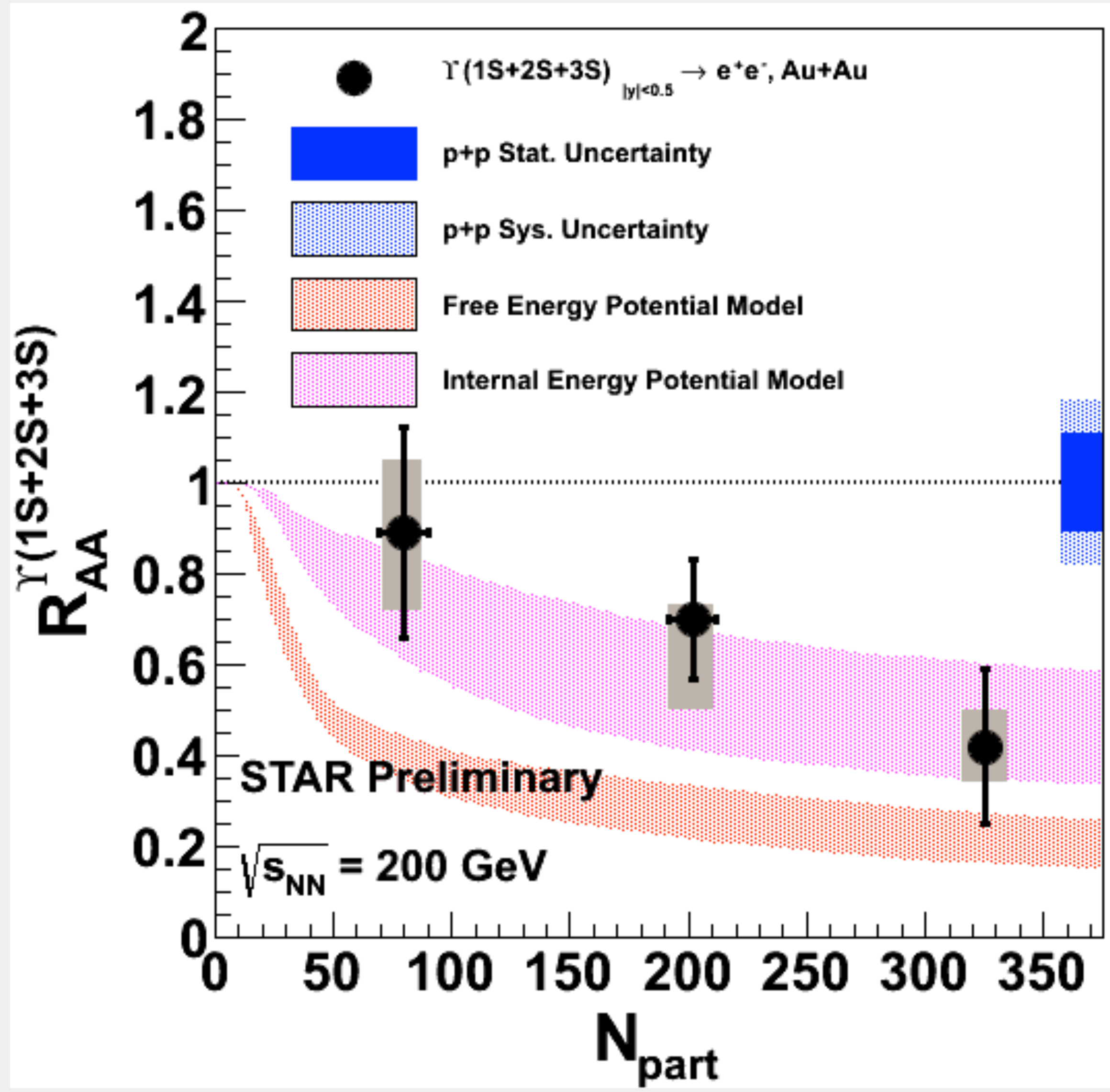
Benefit from high DAQ rate and dedicated Upsilon trigger
**improved statistics**

✓ p+p Υ(1S+2S+3S)→$e^+e^-$ cross section consistent with pQCD and world data trend

# Υ(1S+2S+3S) $R_{AA}$ in Au+Au collisions at 200 GeV




Raw yield of Υ→e+e- with $|y|<0.5$ = 197 ± 36




*Model: M.Strickland and D. Baxow, arXiv:1112.2761v4*

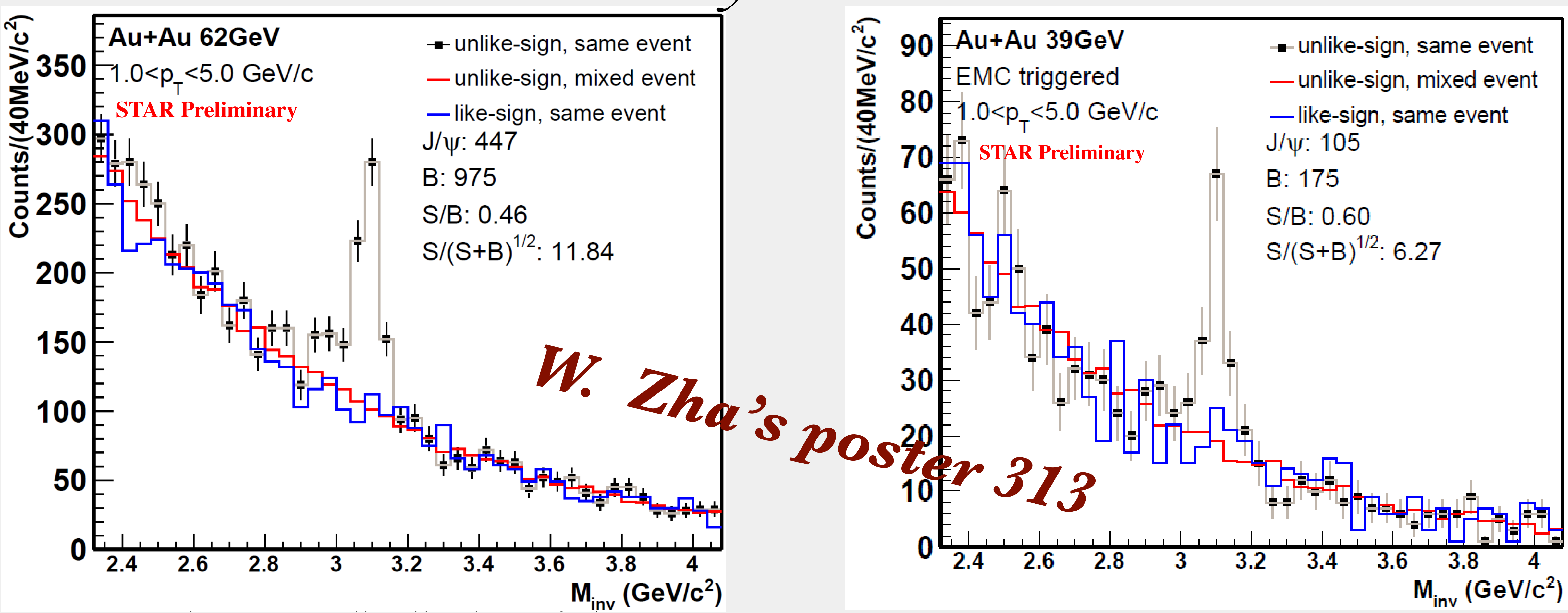
- ✓ Comparison with dynamic model with fireball expansion and quarkonium feed-down, calculation included variation of initial $\eta/S$ and $T_0$
- ✓ Results are consistent with complete melting of 3S and very strong suppression of 2S in central collisions in this model

# Summary

- ➡ $\Upsilon$(1S+2S+3S) Au+Au results consistent with the model that predicts complete melting of 3S and strong 2S suppression
- ➡ p+p $\Upsilon$(1S+2S+3S) $\rightarrow e^+e^-$ cross section consistent with pQCD and world data trend
- ➡ $J/\psi$ suppression in Au+Au collisions increases with centrality and decreases with $p_T$ - at high $p_T$ suppression only for central collisions
- ➡ $J/\psi$ $v_2$ consistent with zero at $p_T > 2$ GeV/c - disfavors the case when $J/\psi$ is produced dominantly by coalescence from thermalized (anti-)charm quarks at higher $p_T$
- ➡ $J/\psi$ $R_{dAu}$ consistent with the model using EPS09+ $\sigma_{abs}^{J/\psi}$ (3 mb)
- ➡ NLO CS+CO and CEM models describe $J/\psi$ $p_T$ spectrum in p+p collisions
- ➡ $J/\psi$ polarization in p+p collisions consistent with NLO$^+$ CSM and COM models predictions, and with no polarization

# J/ψ in Au+Au collisions at 62.4 GeV and 39 GeV

*Analysis status*




*Invariant mass distributions for 0-60 % centrality*

- ✓ Clear J/ψ signal at different $p_T$ and centrality bins in Au+Au collisions at 62.4 GeV and 39 GeV
- ✓ Measurement of J/ψ $R_{CP}$ for different centralities and energies will be done

*Thank you!*