Recent quarkonium results from STAR

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Quarkonium 2014
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CERN

Outline

J/ψ

- p+p, √s = 500 GeV, and Ψ(2S)
- Au+Au, $\sqrt{s_{NN}}$ = 200, 62.4, 39 GeV
- U+U, $\sqrt{s_{NN}}$ = 193 GeV

Upsilon

- p+p, √s = 200 GeV
- d+Au, $\sqrt{s_{NN}}$ = 200 GeV
- Au+Au, $\sqrt{s_{NN}}$ = 200 GeV
- U+U, $\sqrt{s_{NN}}$ = 193 GeV
- Υ(1S) at $\sqrt{s_{NN}}$ = 200 GeV

Quarkonia in STAR Experiment

J/ψ / $\Upsilon \rightarrow e^+ e^- (\mu^+ \mu^-)$

$|\eta| < 1, 0 < \varphi < 2\pi$

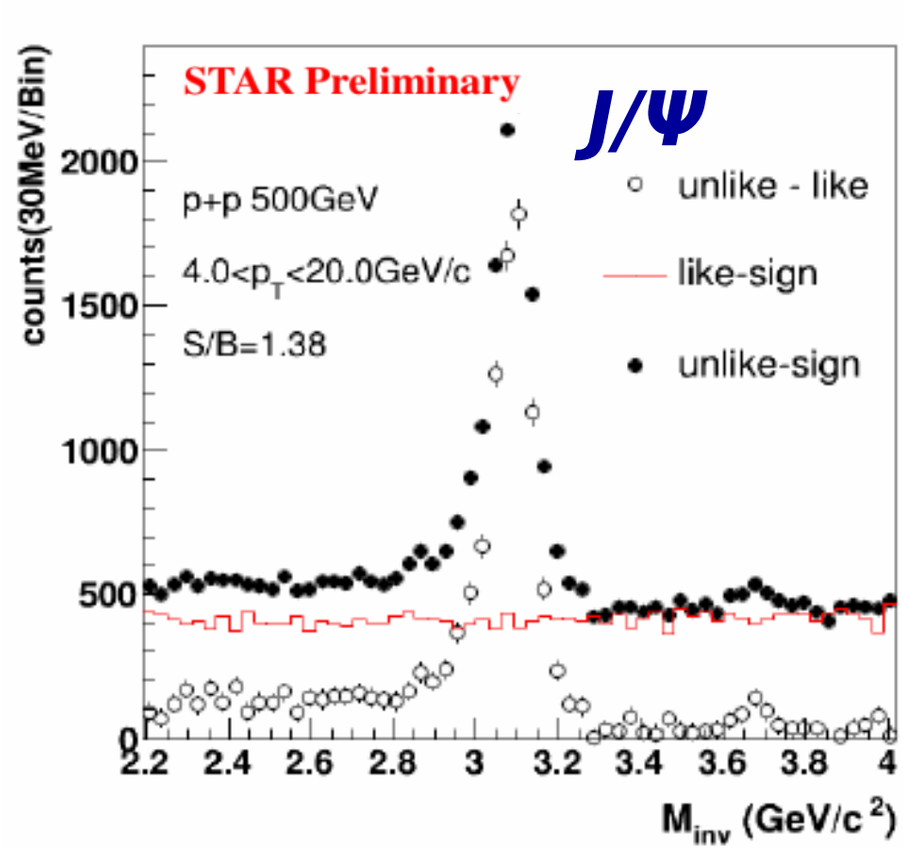
- **VPD - minimum bias trigger**
- **MTD**
- **BEMC – trigger PID: E/p (~1 for electron)**
- **TPC – tracking, PID: dE/dx**
- **TOF – time resolution < 100 ps PID: 1/β**

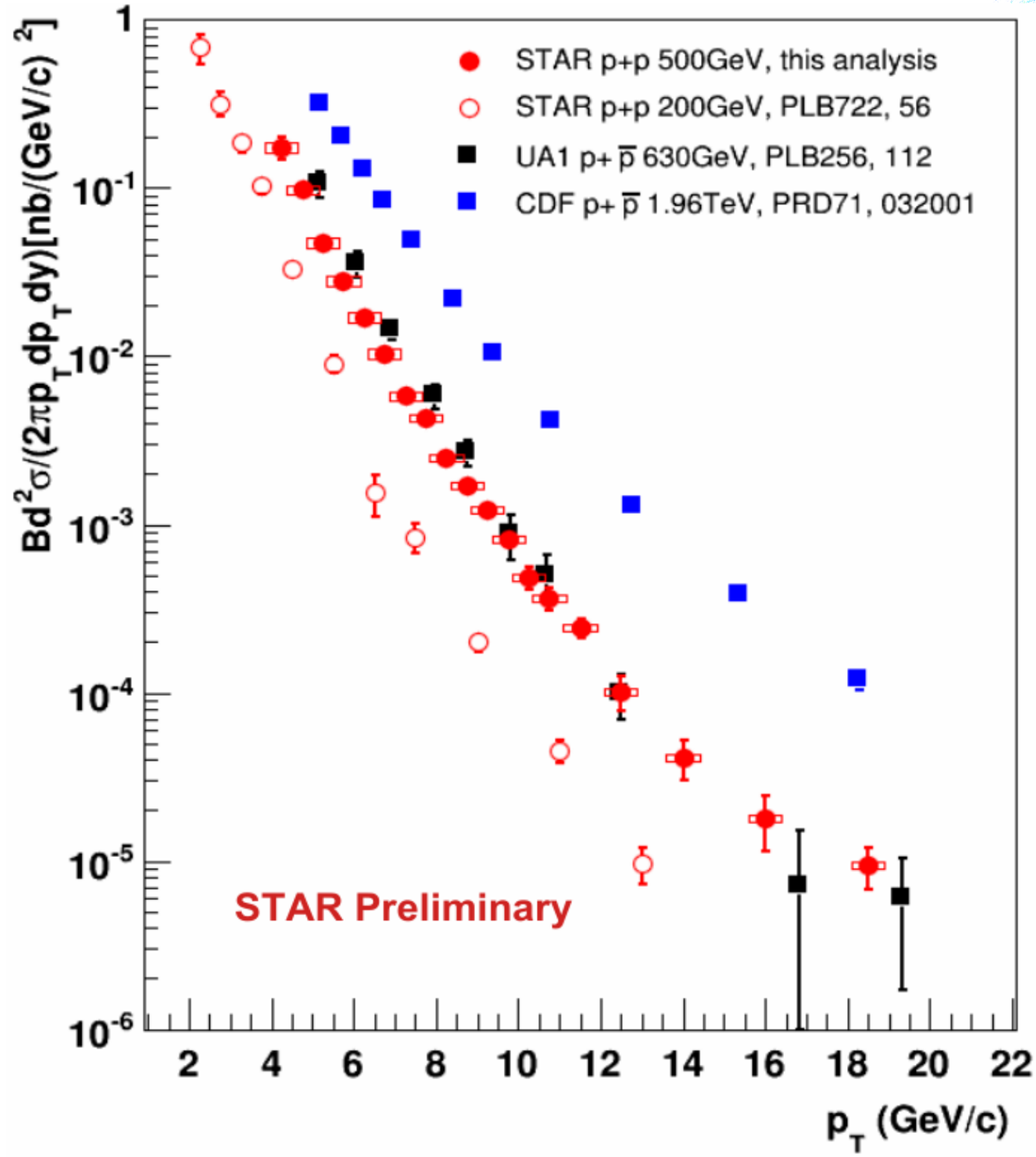
J/ψ

J/Ψ p_T spectrum in p+p 500 GeV

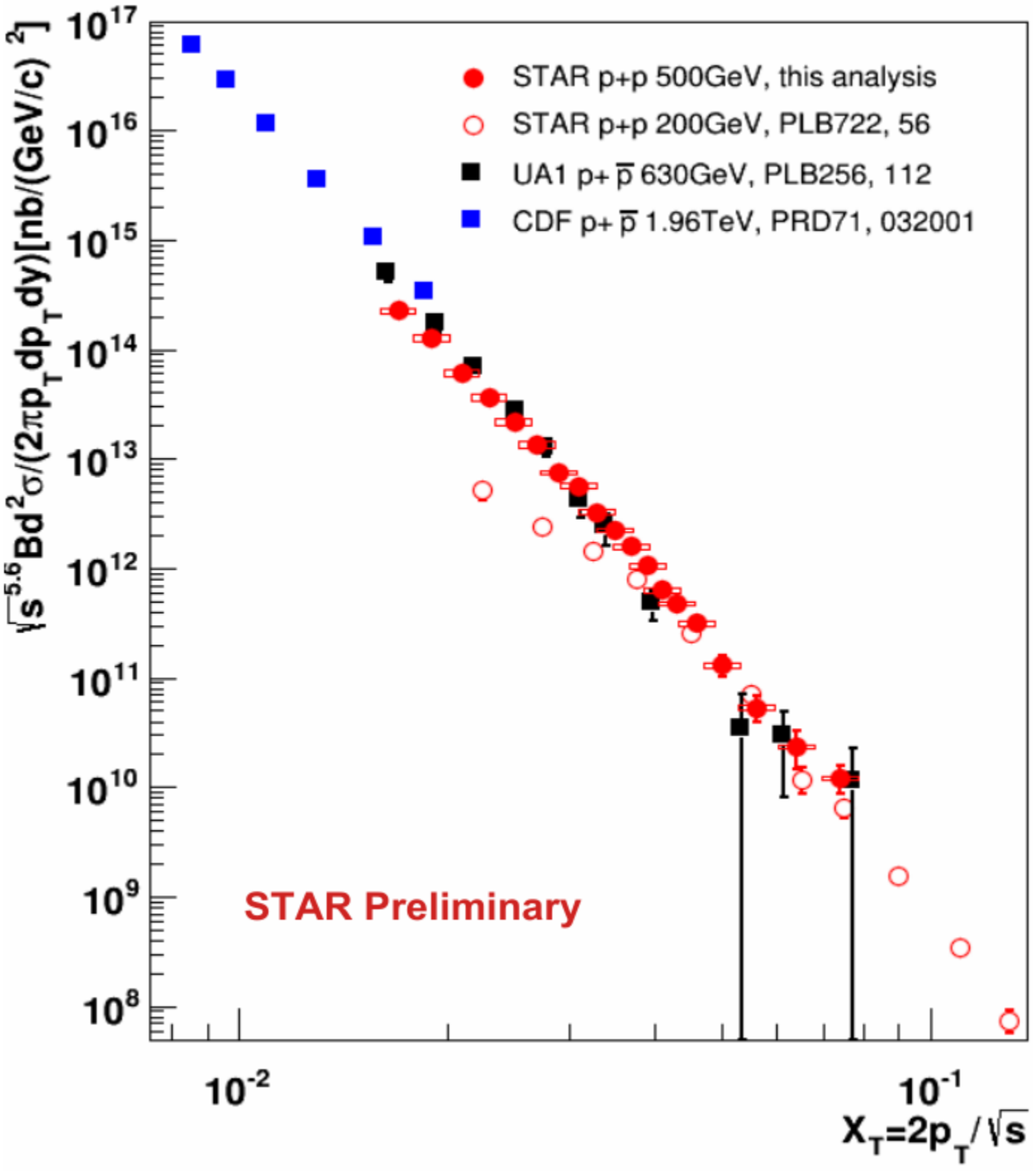
- ✓ Precise J/ψ measurement at new beam energy,

  up to p_T = 20 GeV/c





J/Ψ x_T scaling



$$\frac{d^2\sigma}{2\pi\, p_T\, dp_T\, dy} = g(x_T)/(\sqrt{s})^n$$

- ✓ In p+p 200 GeV J/ψ production follows the x_T scaling of cross-section at mid-rapidity at high p_T, with $n = 5.6 \pm 0.2$ (Phys. Rev. C 80, 041902 (2009))

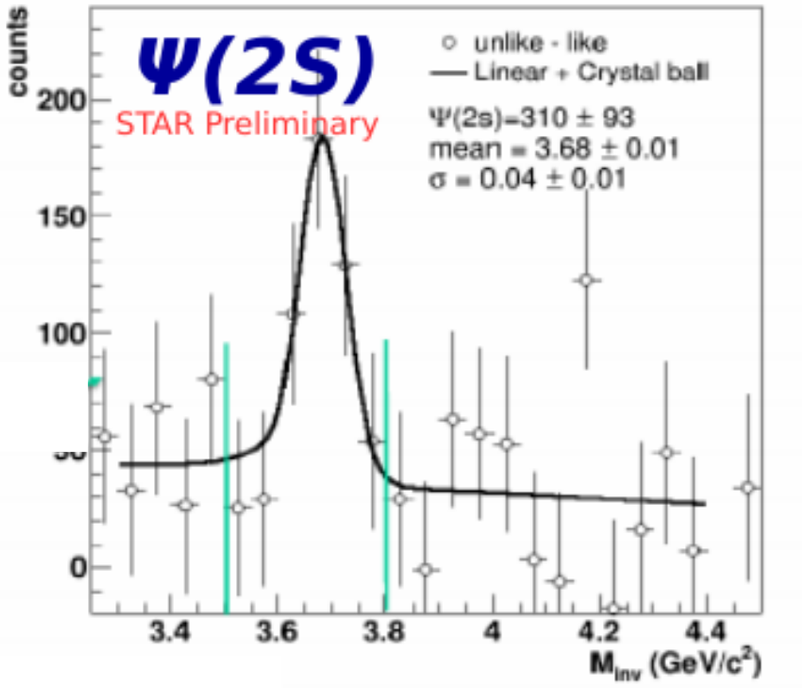
- ✓ x_T scaling observed also in 500 GeV data

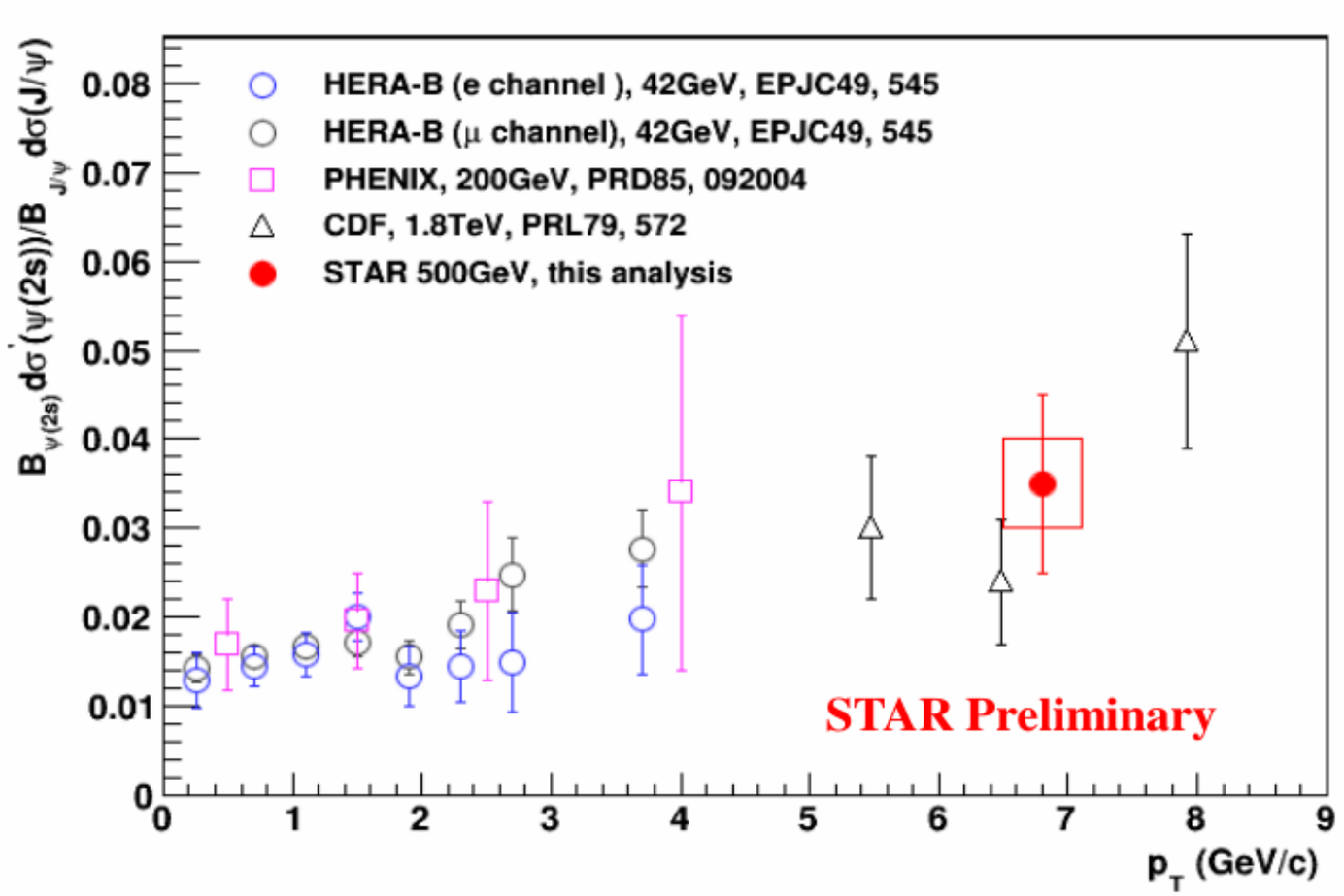
→ x_T scaling breaking - transition from hard to soft process

n – number of constituents taking an active role in hadron production

Ψ(2S) in p+p 500 GeV

- Constrain ψ(2S) feed-down contribution to inclusive J/ψ production



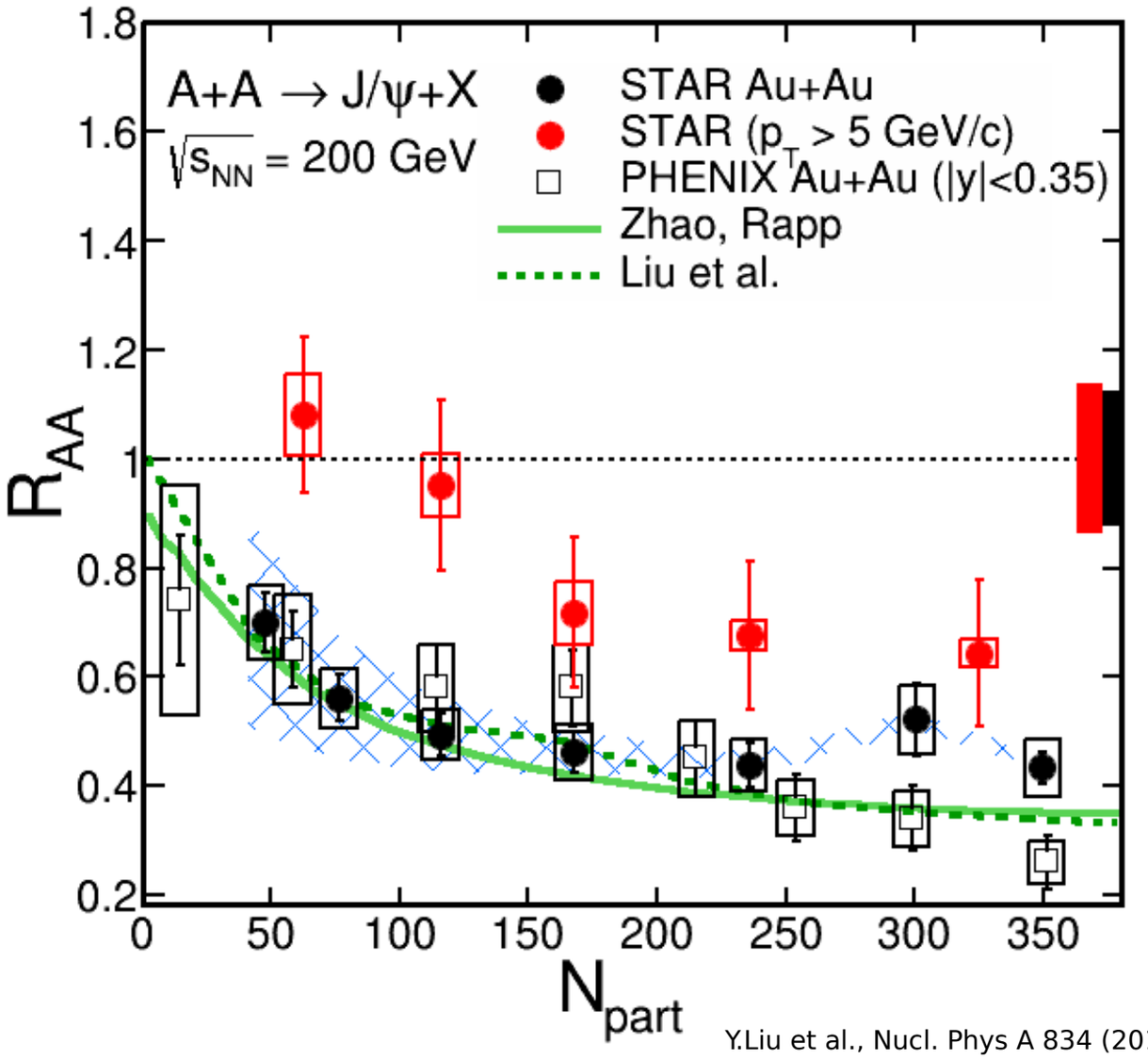


✓ First measurement of (ψ(2S) / J/ψ) ratio in p+p at 500 GeV

➔ Consistent with other experiments

➔ No collision energy dependence observed

J/Ψ R_{AA} in Au+Au 200 GeV



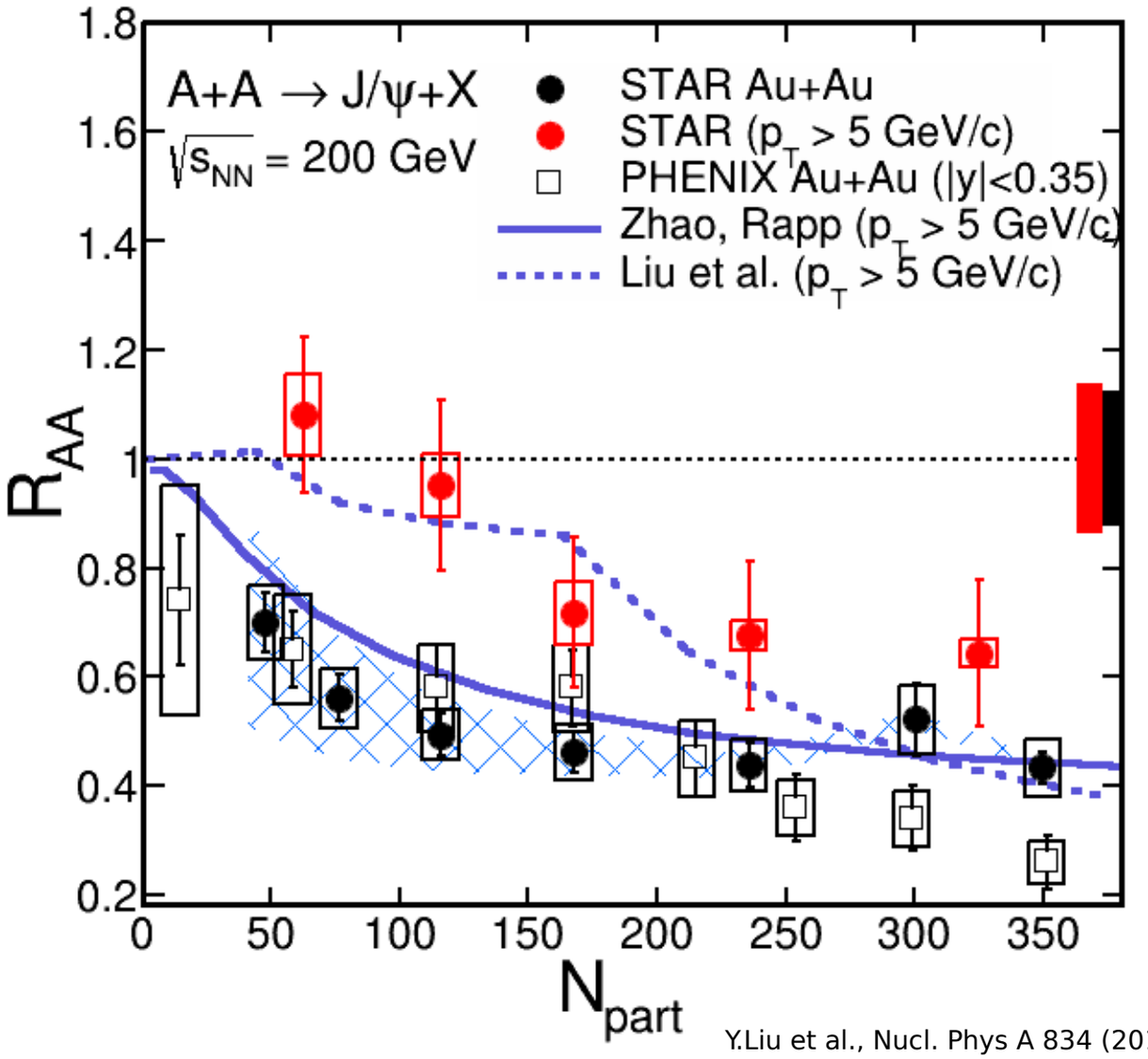
STAR high-p_T : Phys. Lett. B 722 (2013) 55
STAR low-p_T : Phys. Rev. C 90 (2014) 24906

Y.Liu et al., Nucl. Phys A 834 (2010) 317c
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905

- ✓ Suppression increases with collision centrality
- ✓ High-p_T R_{AA} is systematically higher
  - ➢ J/ψ at high-p_T almost not affected by CNM effects and recombination *X .Zhao and R.Rapp, Phys. Rev. C82, 064905 (2010)*
- ✓ High-p_T J/ψ suppressed in central collisions
  - ➔ May indicate QGP effects

- ➔ Both models – *color screening* + *statistical regeneration* - describe the data well at low p_T

J/Ψ R_{AA} in Au+Au 200 GeV



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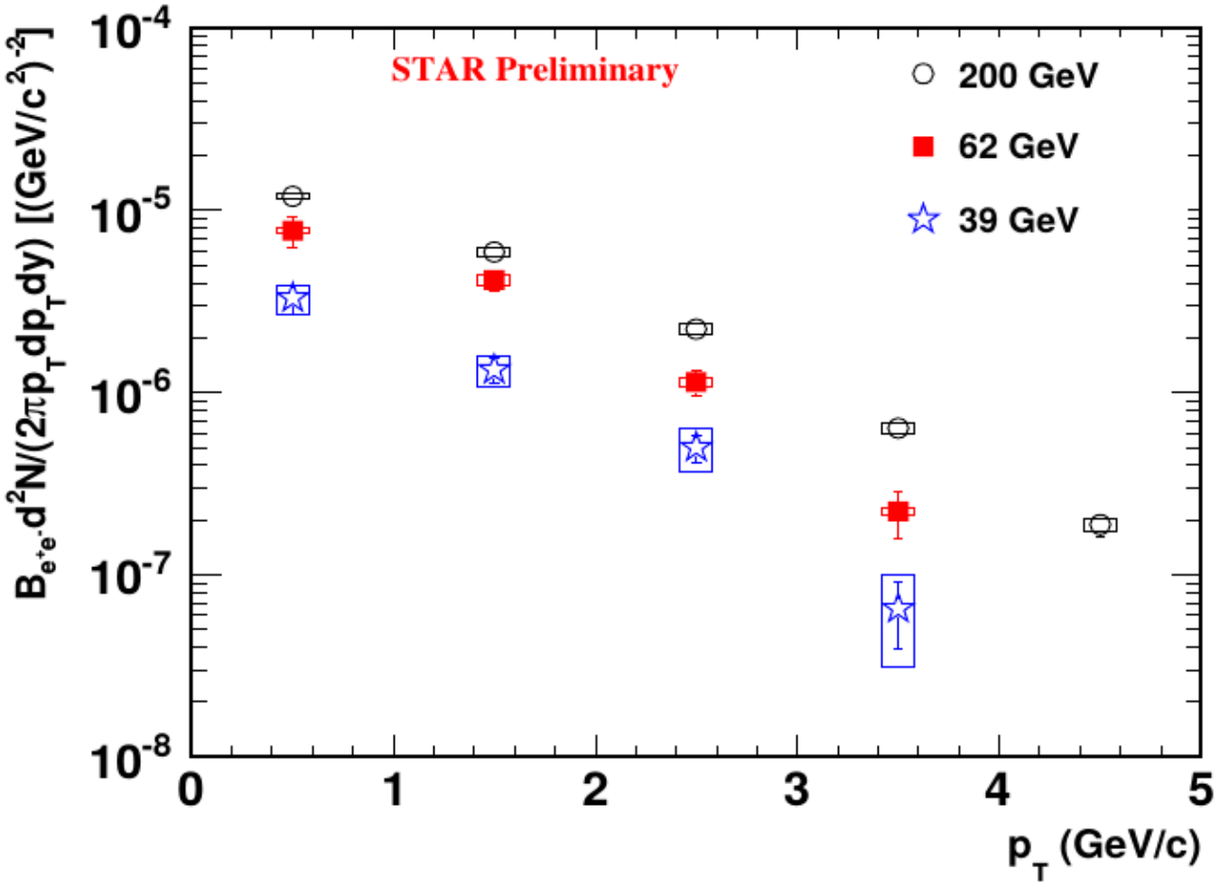
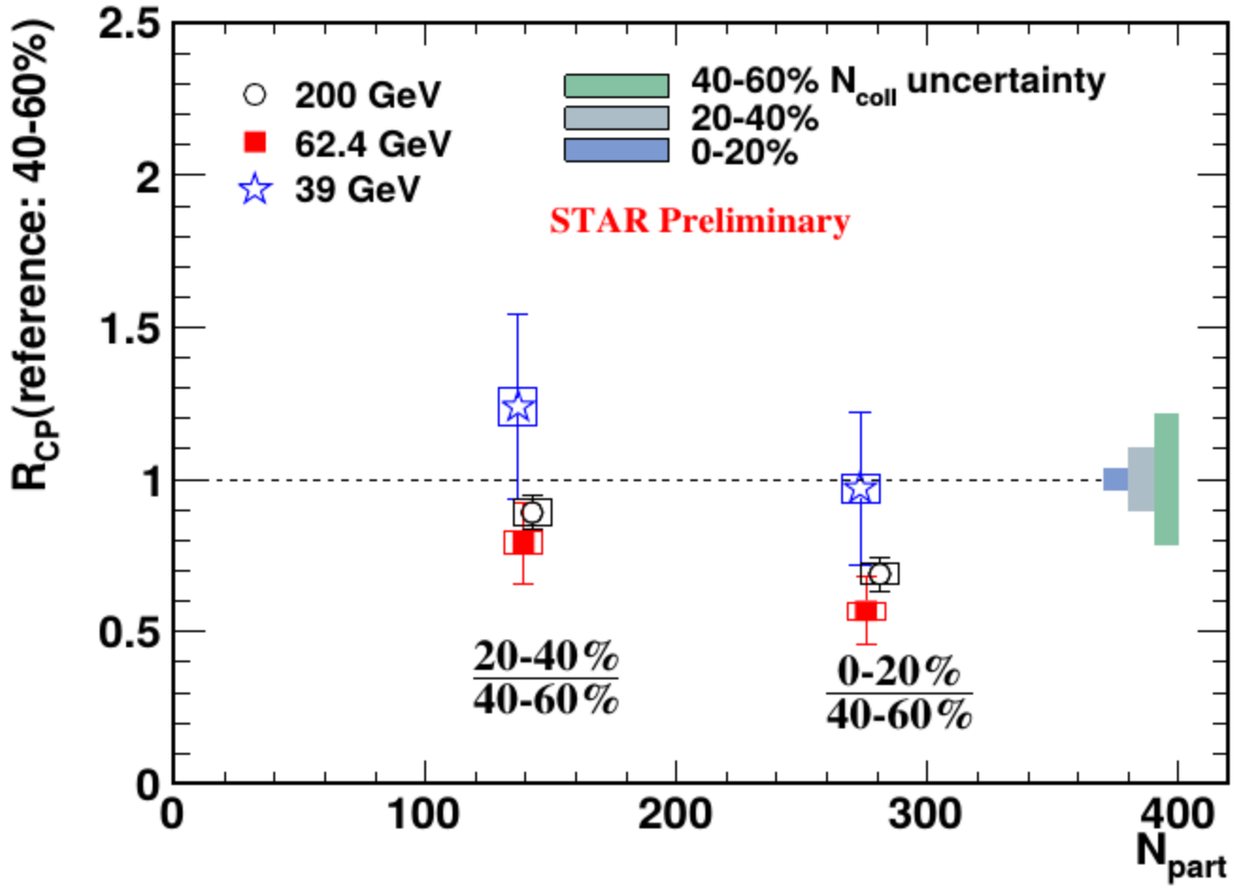
Zhao, Rapp, Phys. Rev. C 82 (2010) 064905

- ➔ At high p_T Liu et al. model describes the data well, while Zhao et. al model underpredicts the R_{AA}

J/Ψ BES results

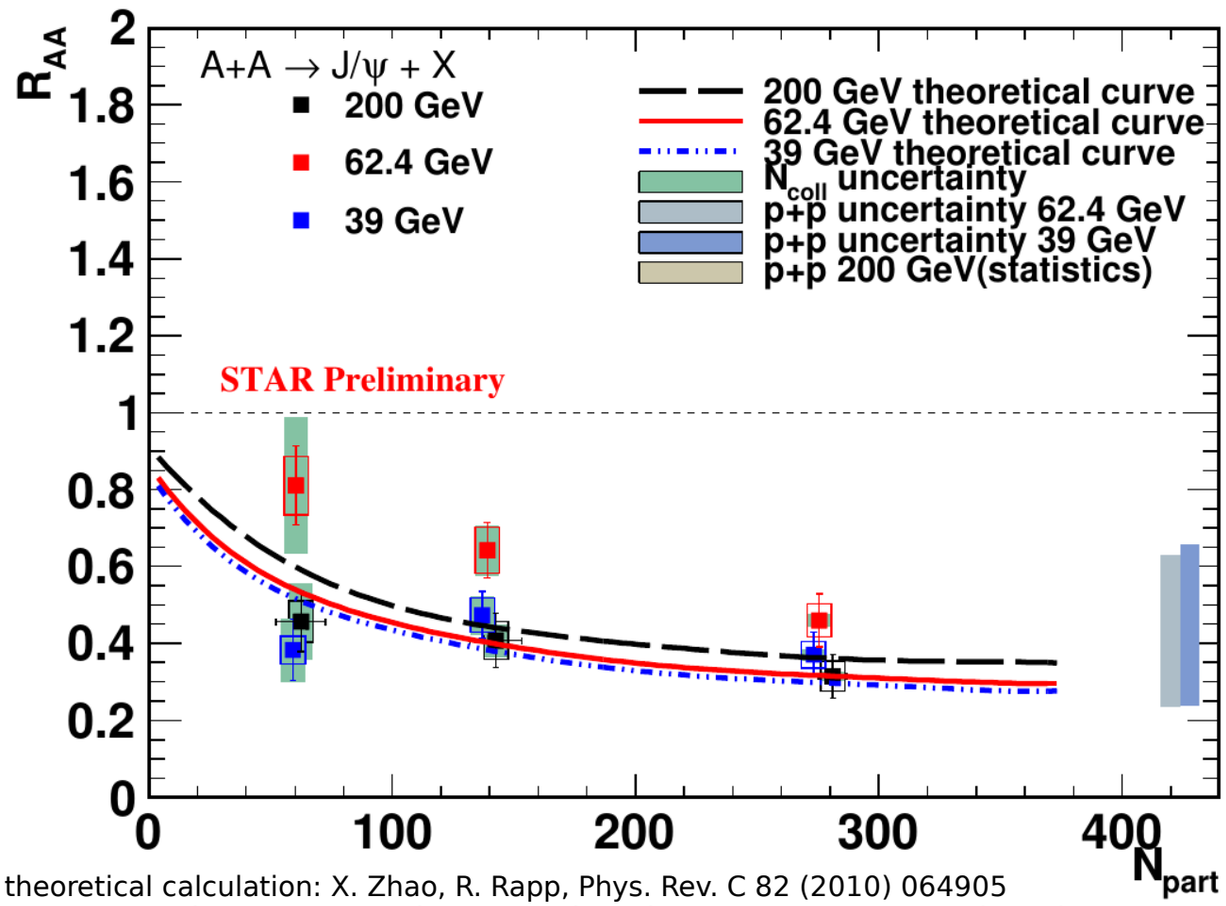


- ✓ Larger invariant yields at larger center-of-mass energy

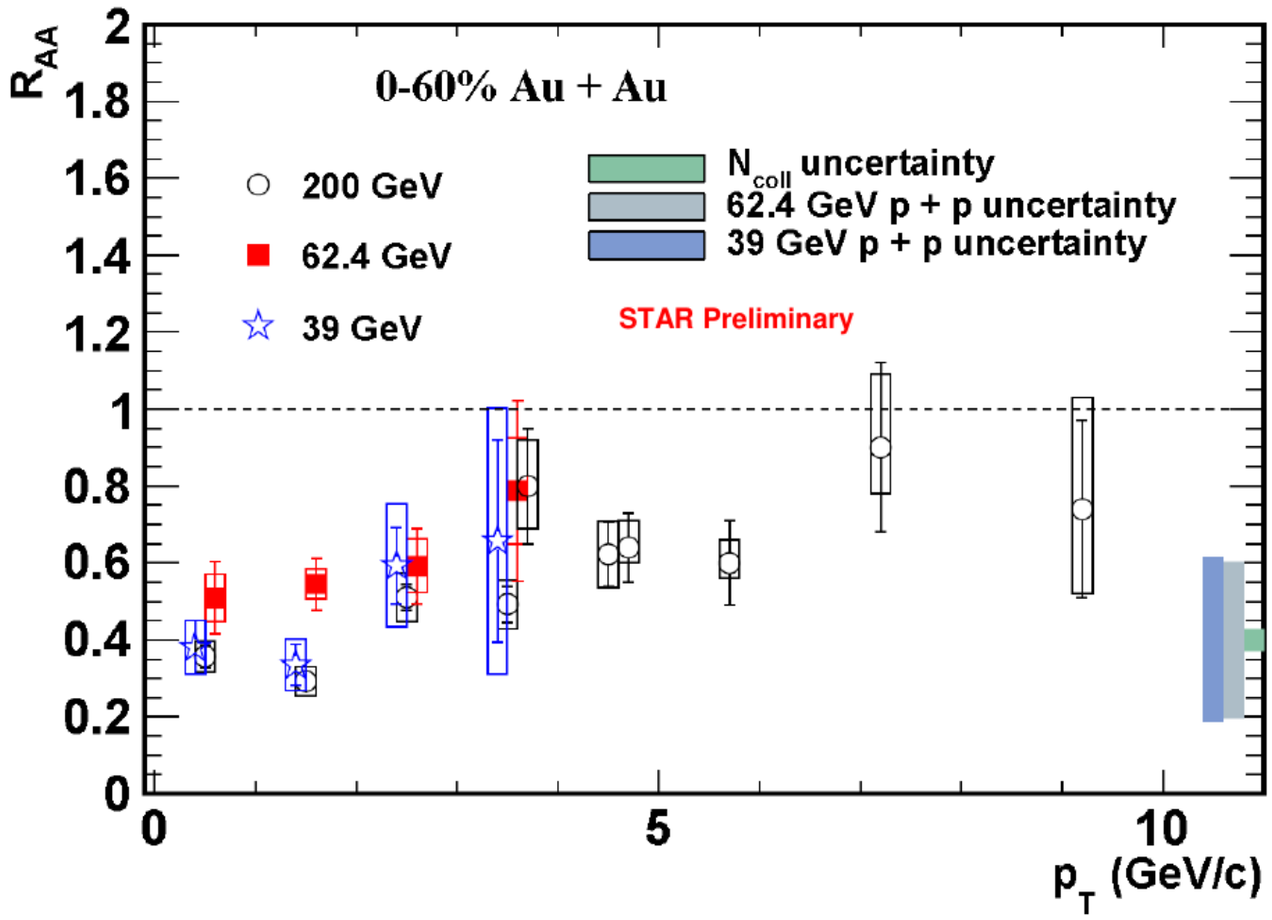


- ✓ Similar R_{CP} in 62.4 and 200 GeV collisions
- ✓ Large uncertainties of 39 GeV result
  - *Reference: 40-60% centrality*

J/ψ R_{AA} from BES



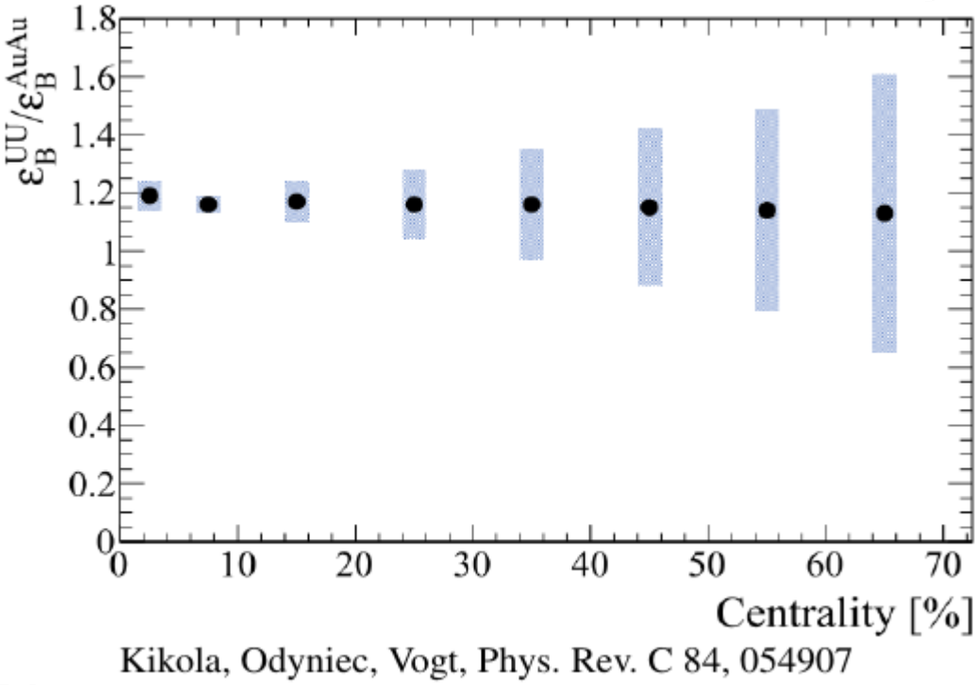
theoretical calculation: X. Zhao, R. Rapp, Phys. Rev. C 82 (2010) 064905
CEM: R. E. Nelson, R. Vogt and A. D. Frawley, Phys. Rev. C 87, 014908 (2013).



- ✓ Suppression observed for all energies: 200, 62.4 and 39 GeV, similar trend in p_T
  - ➔ no strong energy dependence of J/ψ R_{AA} within uncertainties
- ➔ Data agrees with the prediction of the two-component model
  - *p+p reference for 62.4 and 39 GeV data from Color Evaporation Model (CEM) - large theoretical uncertainties*

J/Ψ in U+U 193 GeV

- Higher energy density can be reached in U+U collisions, at the same centrality

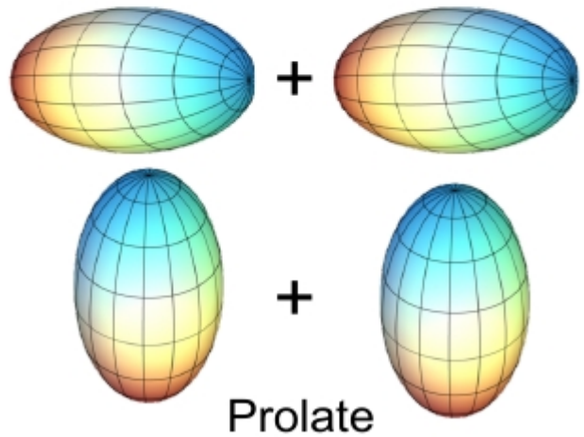


Kikola, Odyniec, Vogt, Phys. Rev. C 84, 054907

Au+Au Collisions

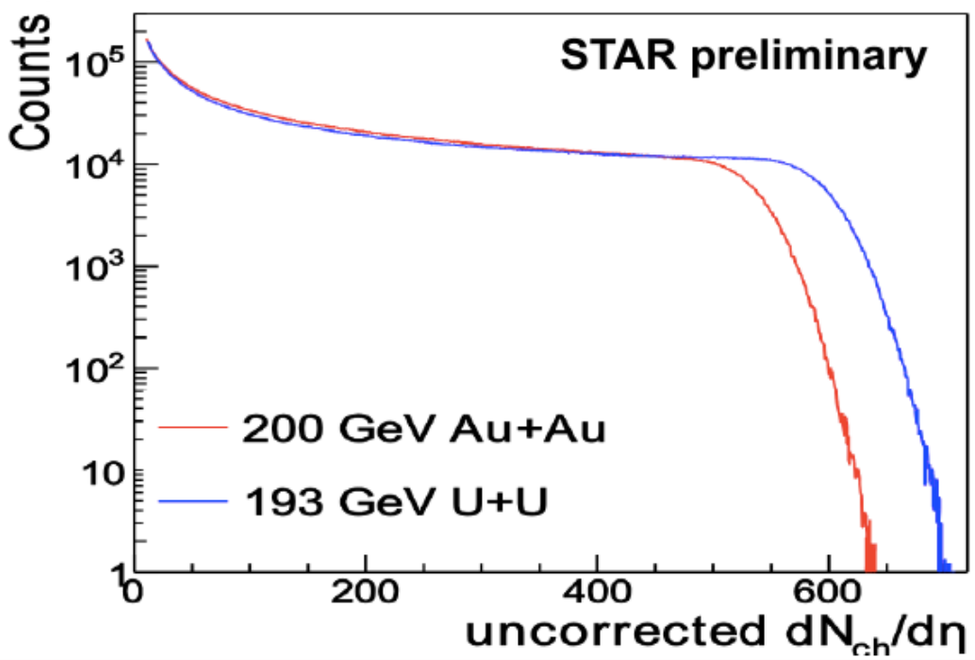
Oblate

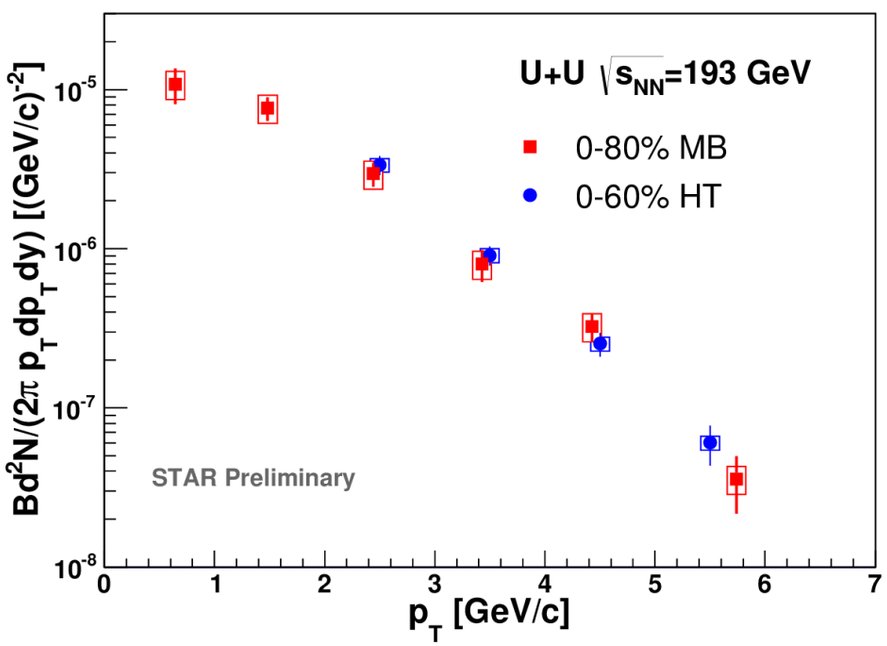
U+U Collisions



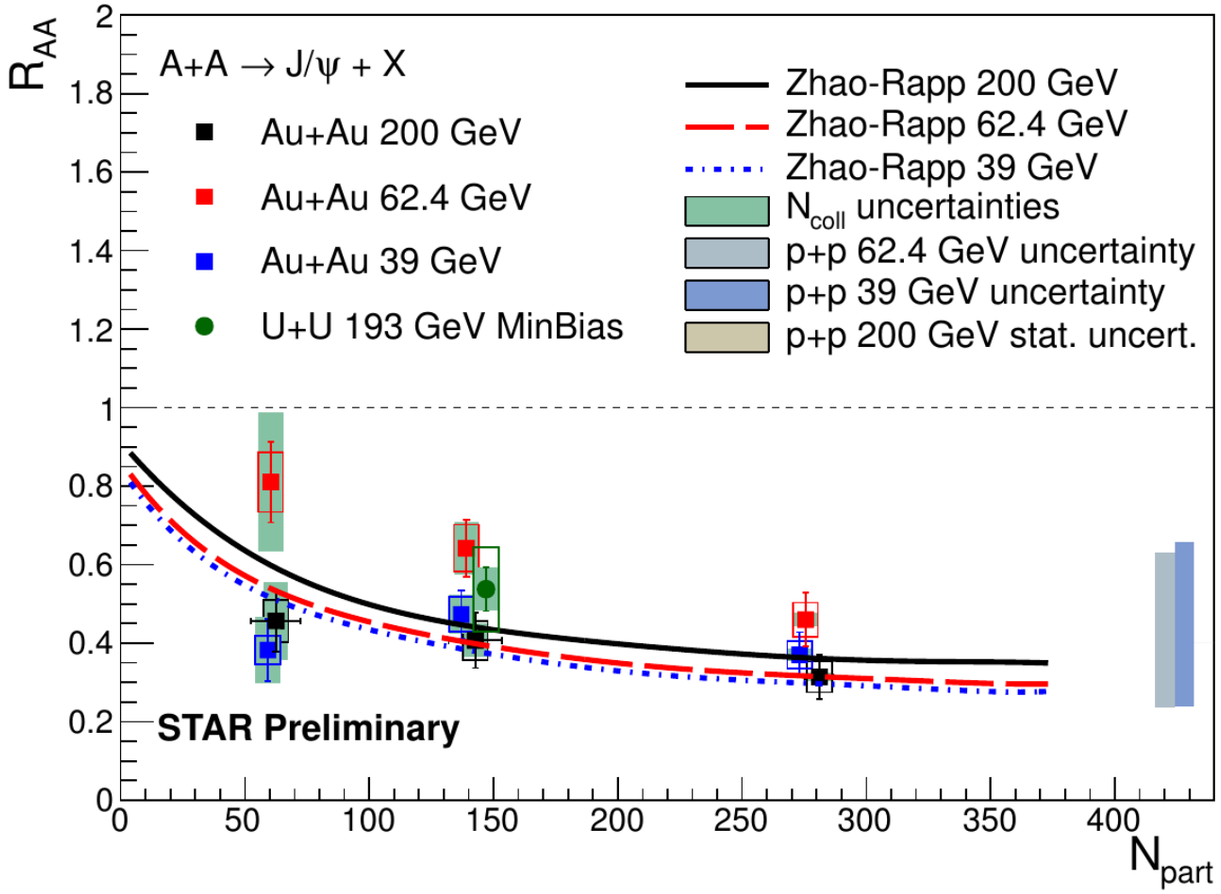
Prolate

- Higher N_{part}



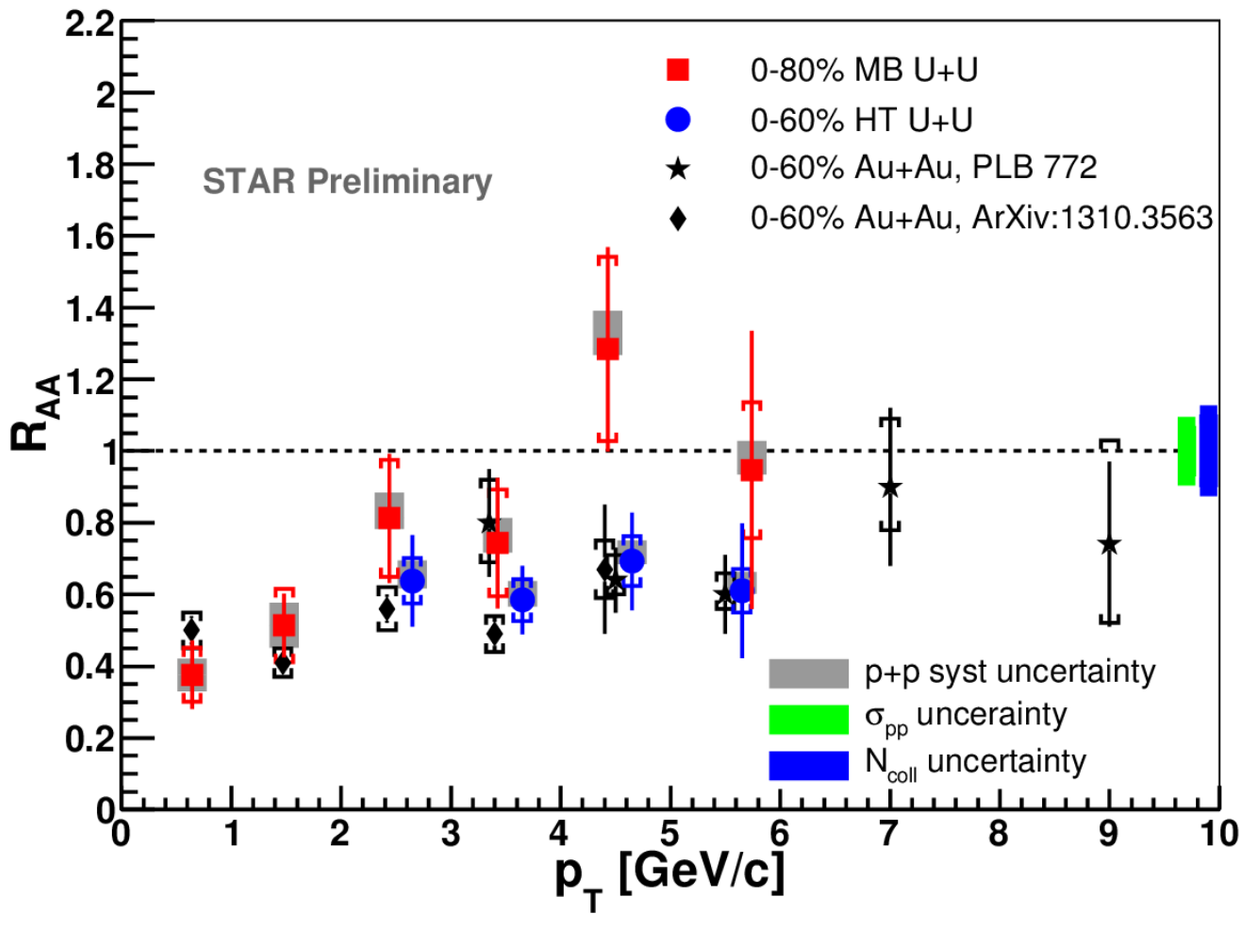


J/Ψ in U+U 193 GeV



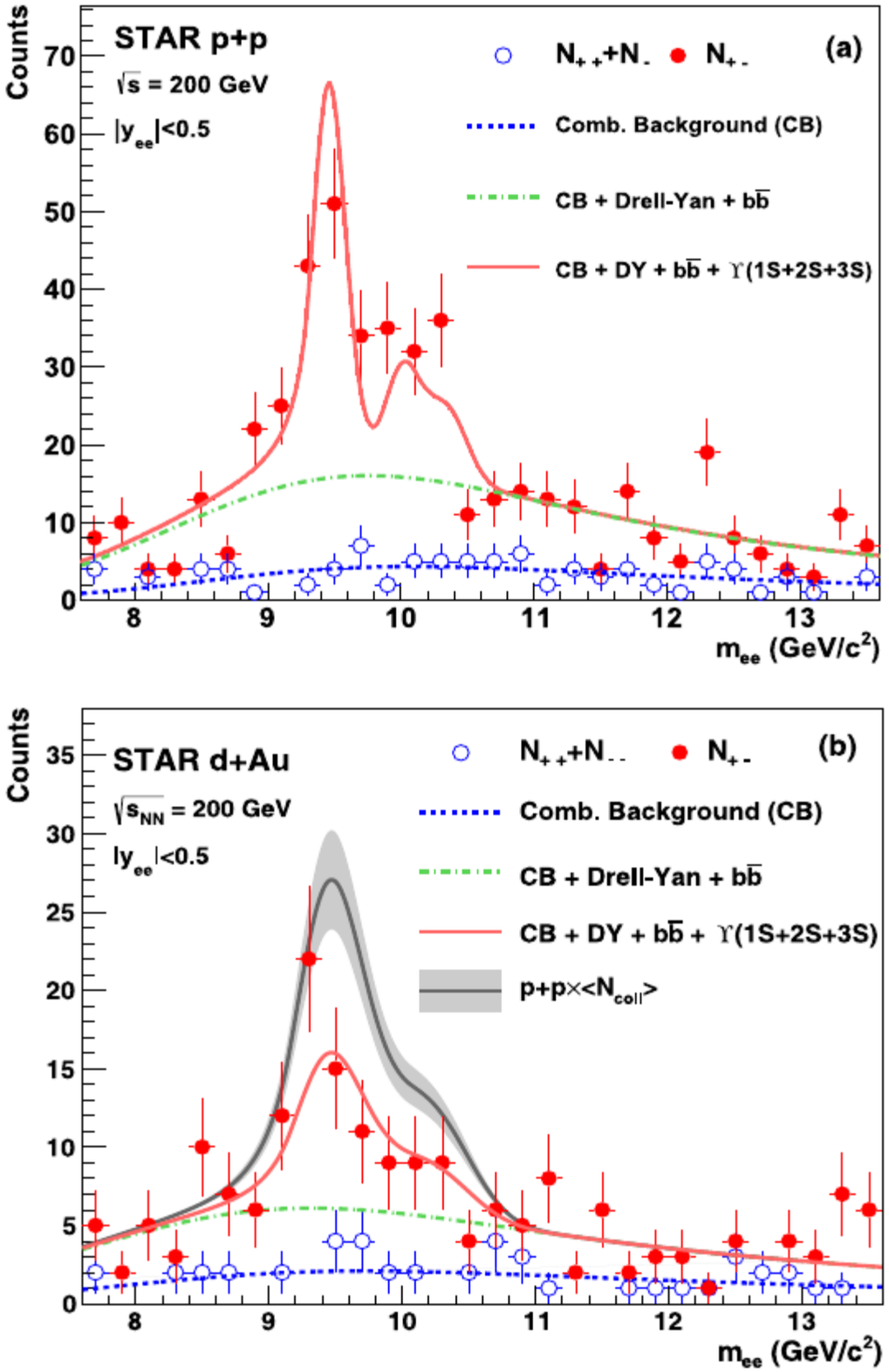
- Similar suppression pattern in U+U and Au+Au collisions, similar p_T trend

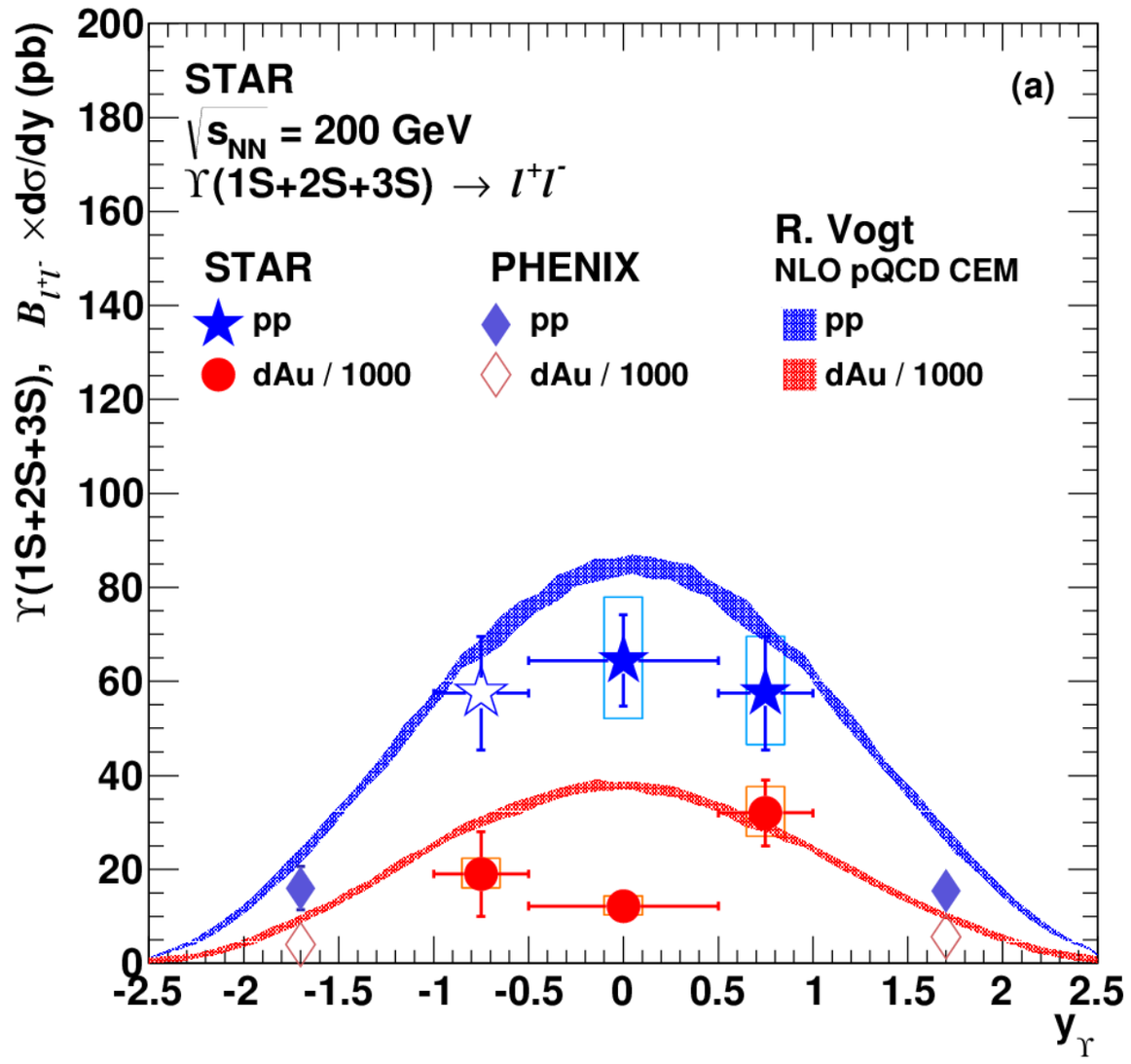
(p+p reference from 200 GeV)



Upsilon

Upsilon in p+p and d+Au 200 GeV

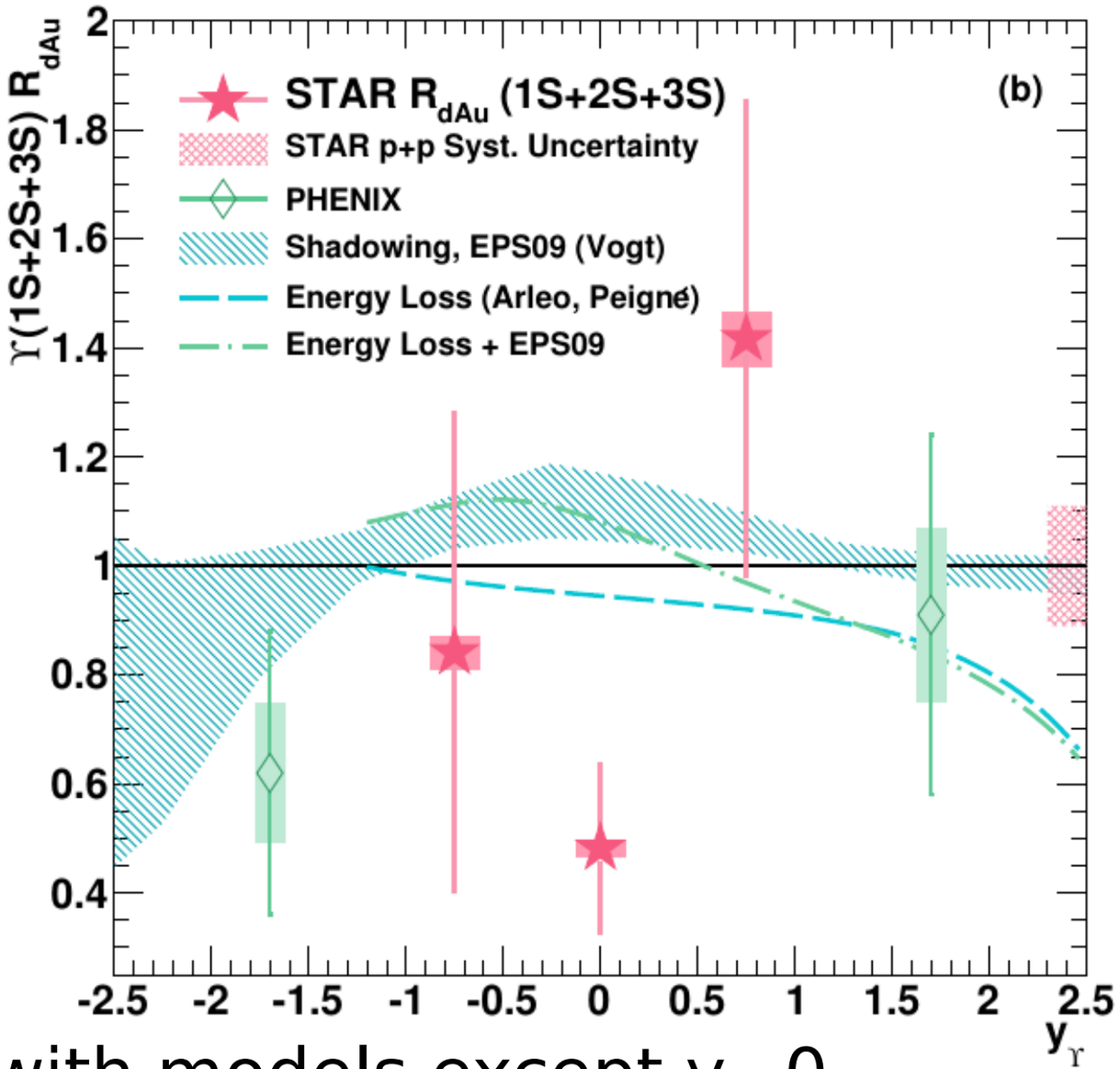




- Consistency with NLO pQCD CEM, except d+Au y~0

R. Vogt, Phys. Rep. 462125, 2008

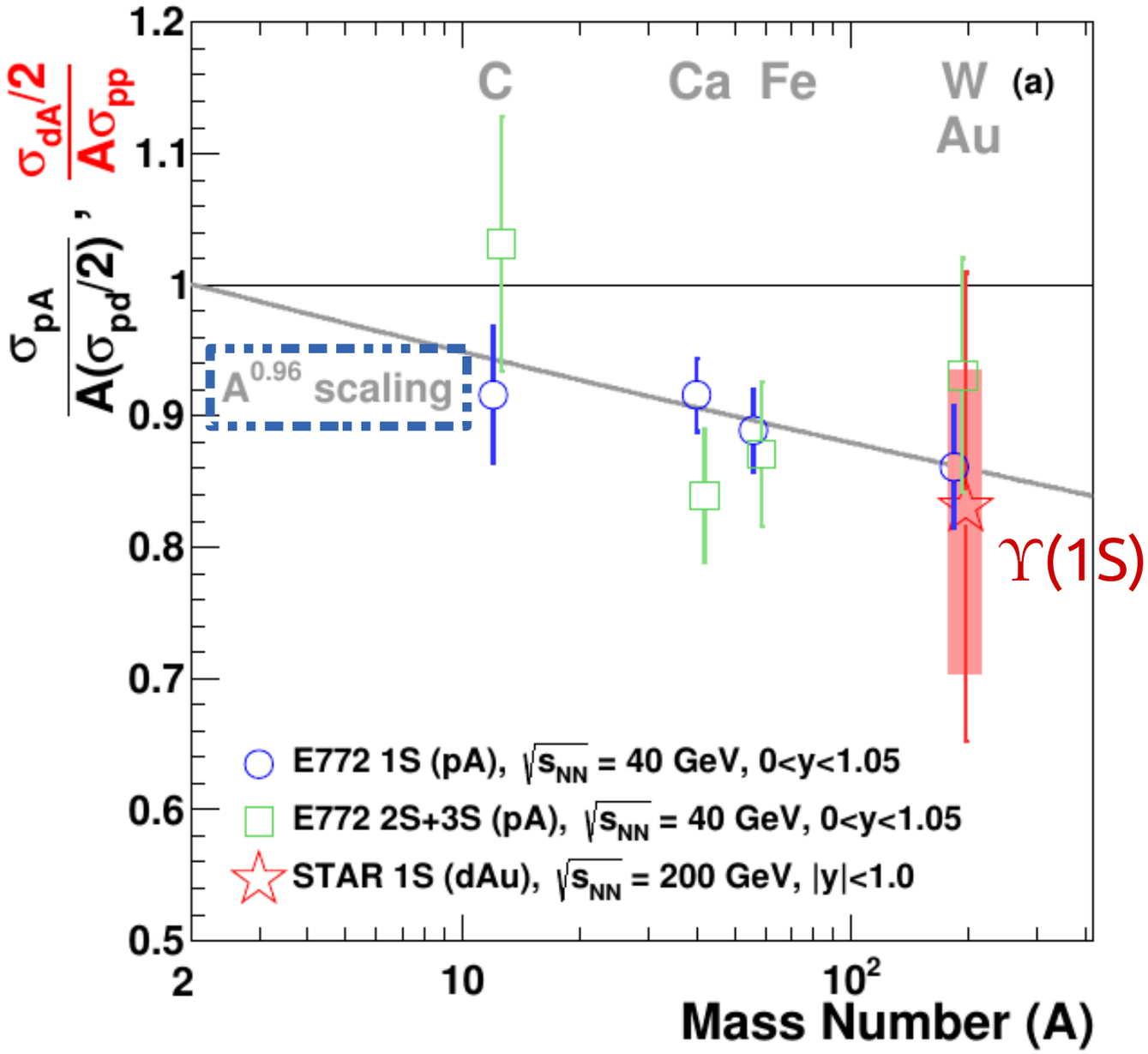
Upsilon in d+Au 200 GeV, CNM effects



- Agreement with models except y~0
- Suppression at y~0, in addition to shadowing and initial state parton energy loss

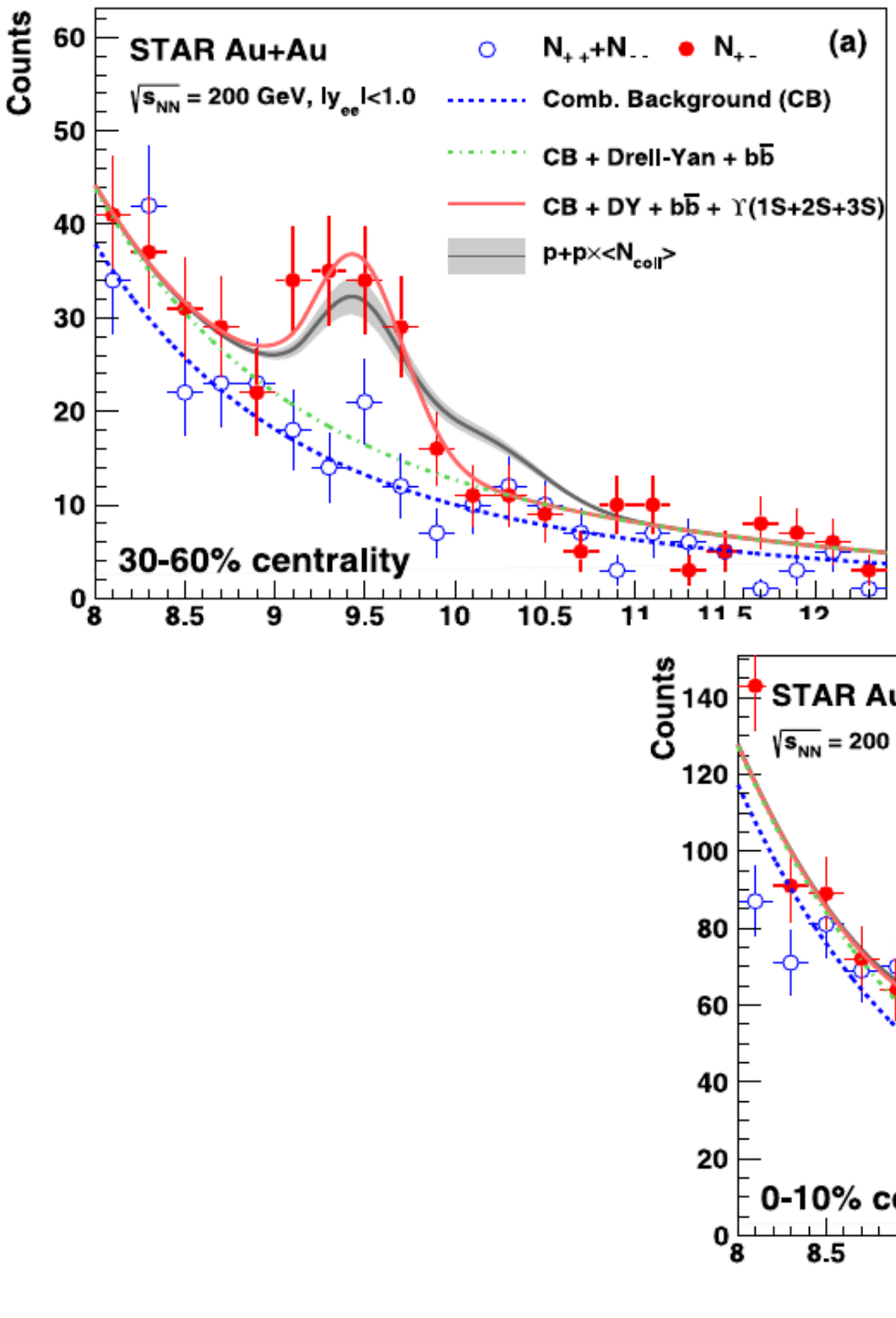
(Υ - negligible co-mover absorption and recombination)

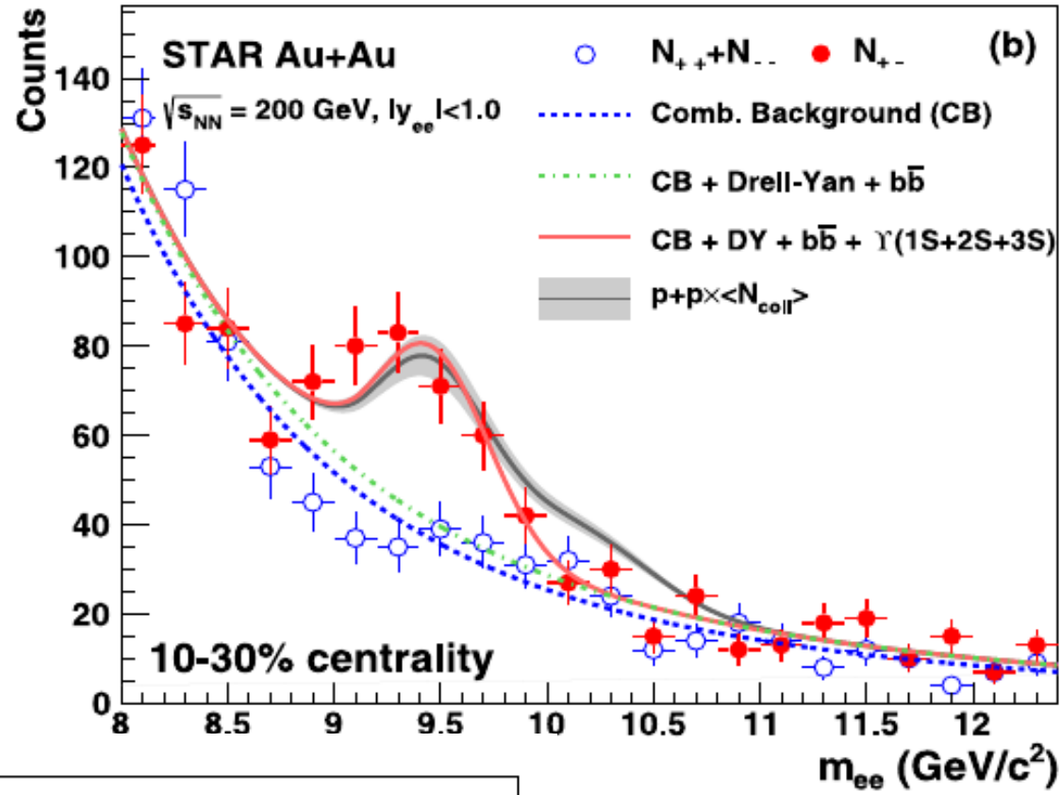
Upsilon in d+Au 200 GeV, CNM effects

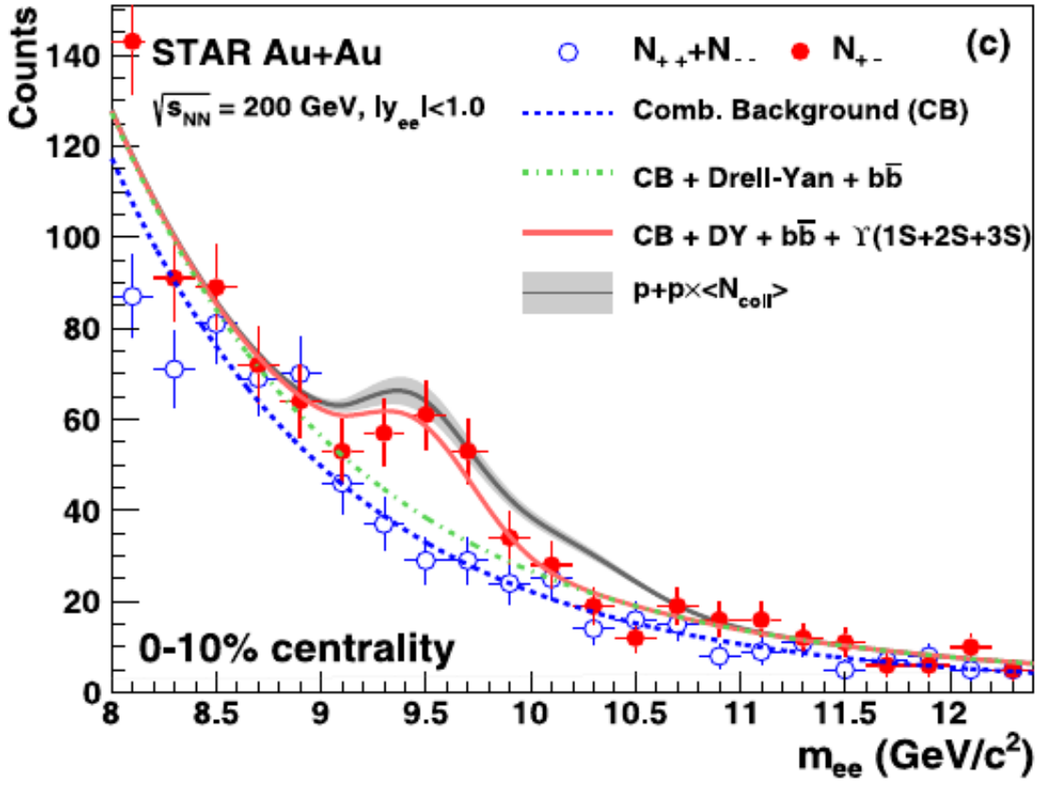


- Similar suppression seen at E772
  - *Better understanding of CNM effects needed*

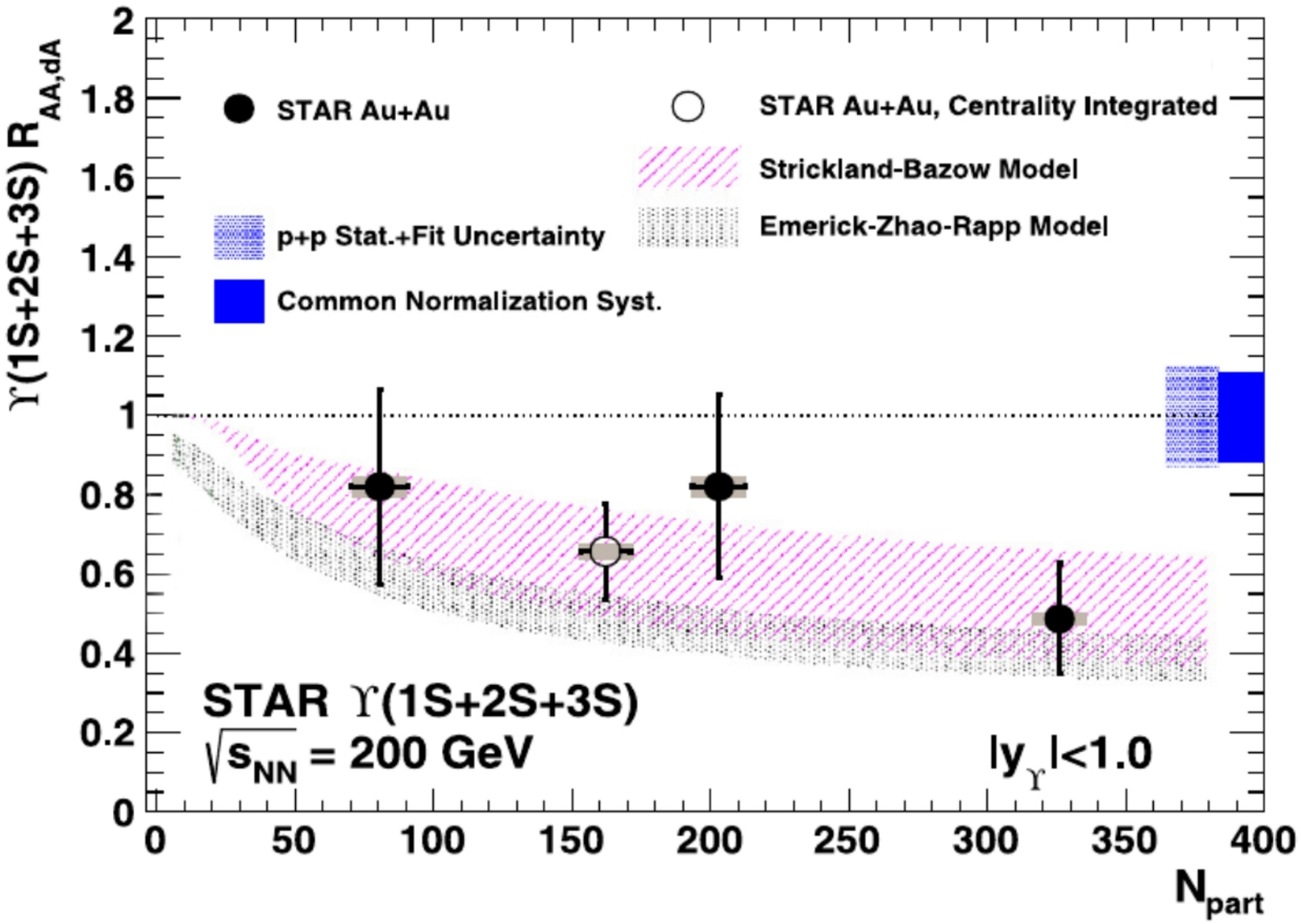
Upsilon signal in Au+Au 200 GeV







Upsilon R_{AA} in Au+Au 200 GeV

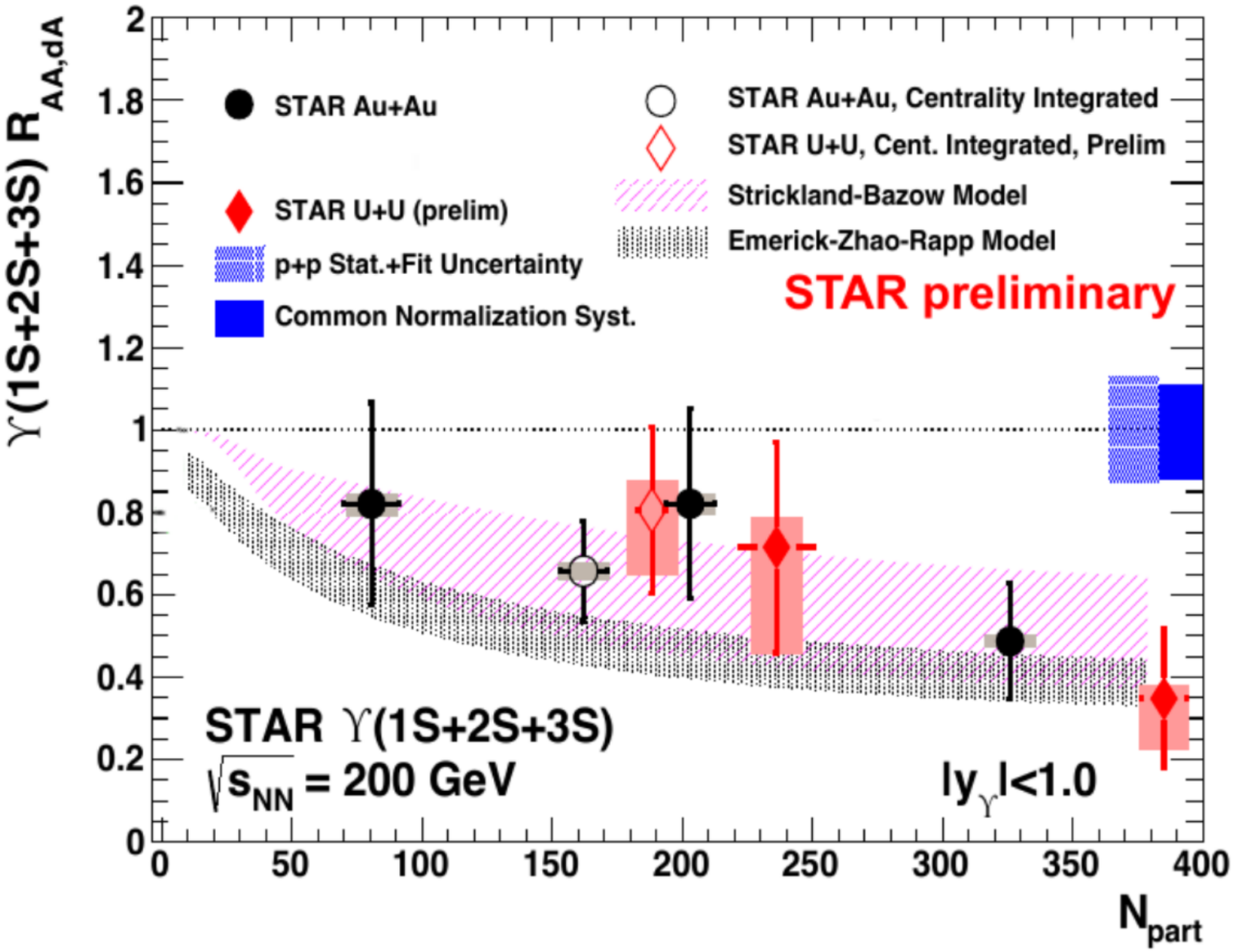


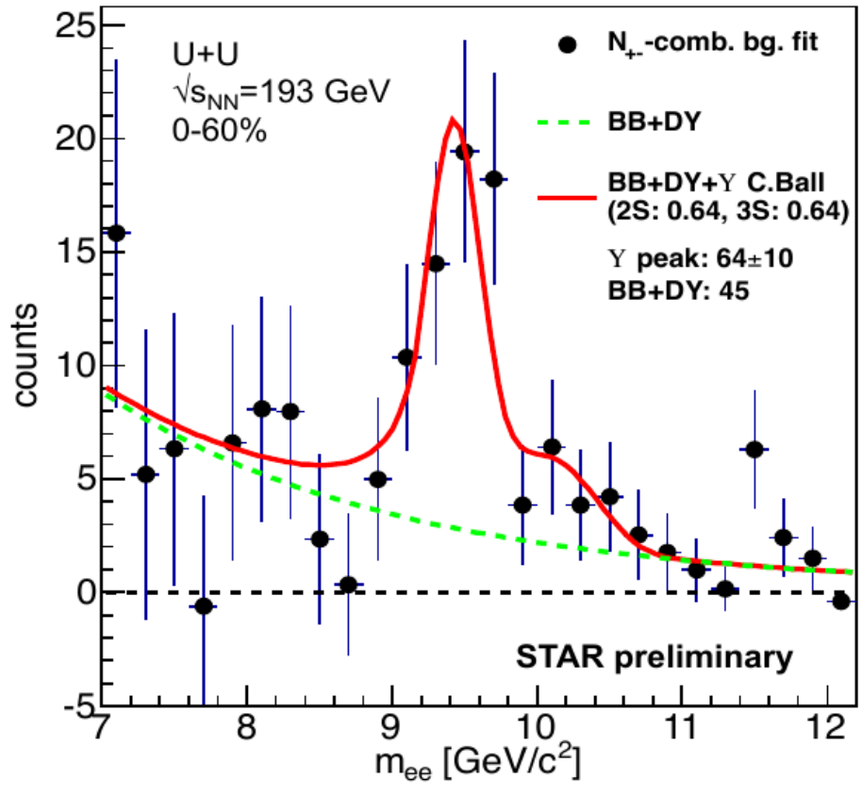
Strickland-Bazow Model
(Nucl. Phys. A879, 25 (2012)):
428 < T < 442 MeV,
internal energy potential

Emerick-Zhao-Rapp Model
(Eur. Phys. J A48, 72 (2012)):
CNM effects included,
strong binding scenario

- ✓ Suppression increases with collision centrality
- ✓ Strong suppression in central collisions
  - ➔ Agreement with models that include presence of QGP

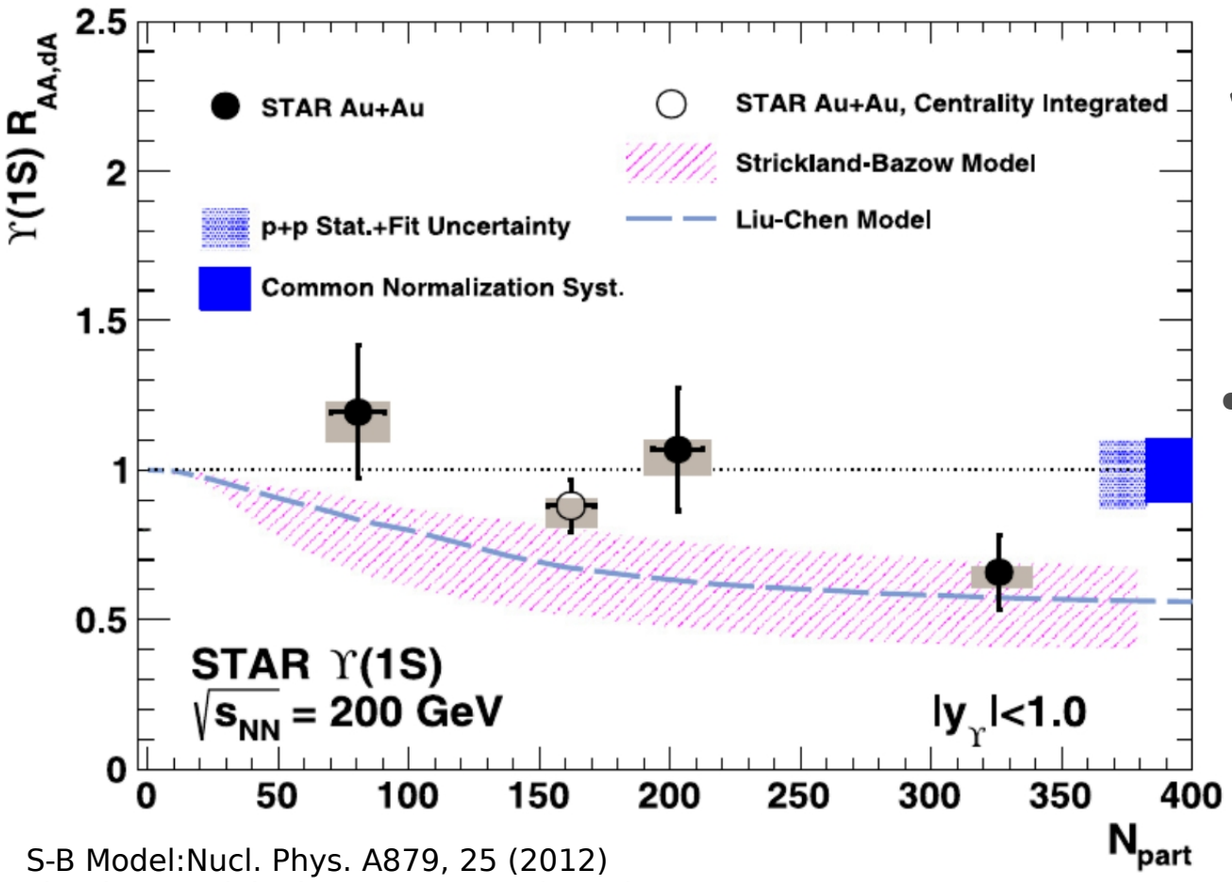
Upsilon in U+U 193 GeV





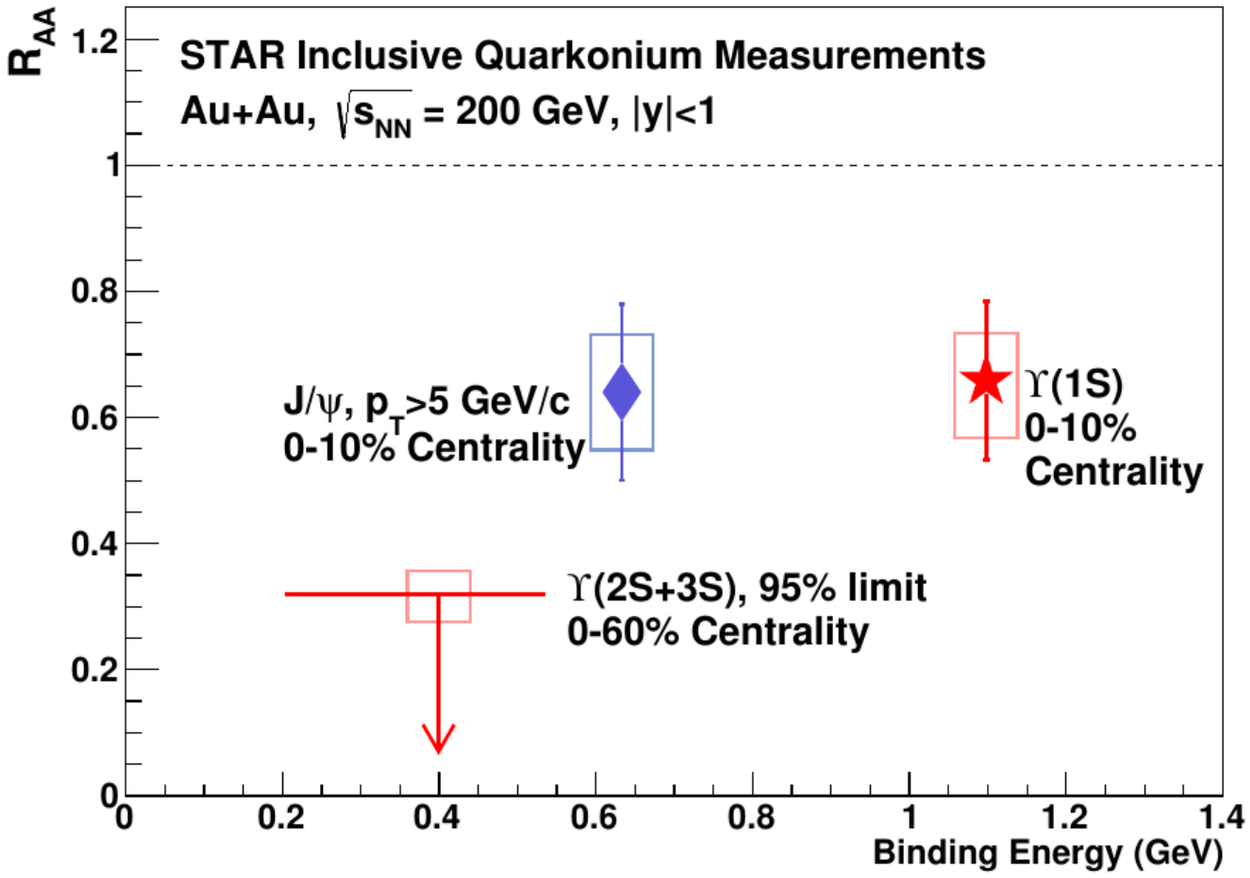
- ✓ The same trend in Au+Au and U+U collisions

Upsilon states suppression in Au+Au



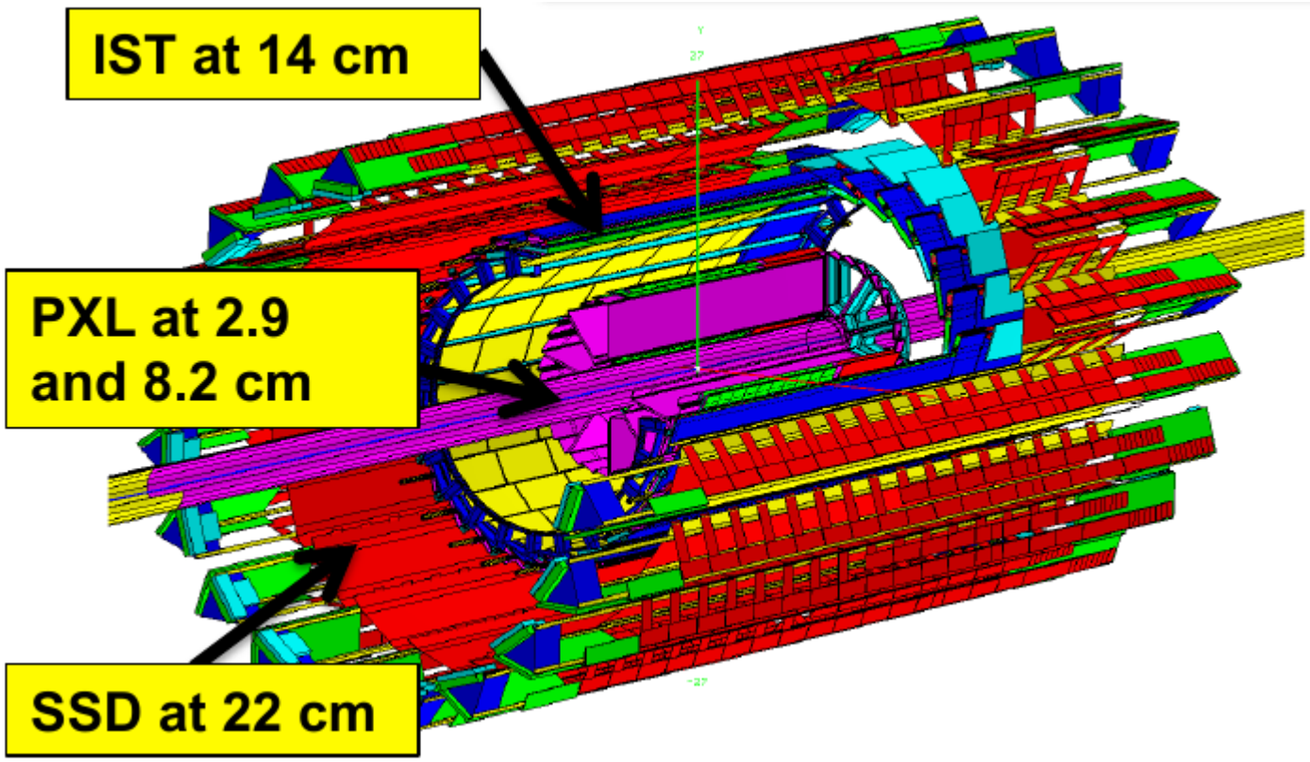
S-B Model:Nucl. Phys. A879, 25 (2012)
Liu-Chen Model: Phys. Lett. B697 (2011) 32

- ✓ Suppression of Υ(1S) in central collisions consistent with model predictions
- *Liu et al. Model* – suppression mostly due to dissociation of the excited states (CNM effects not included)



- Central collisions
  - Indication of complete Υ(2S+3S) suppression
  - Suppression of Υ(1S) similar to high-p_T J/ψ

Heavy Flavor Tracker (HFT)

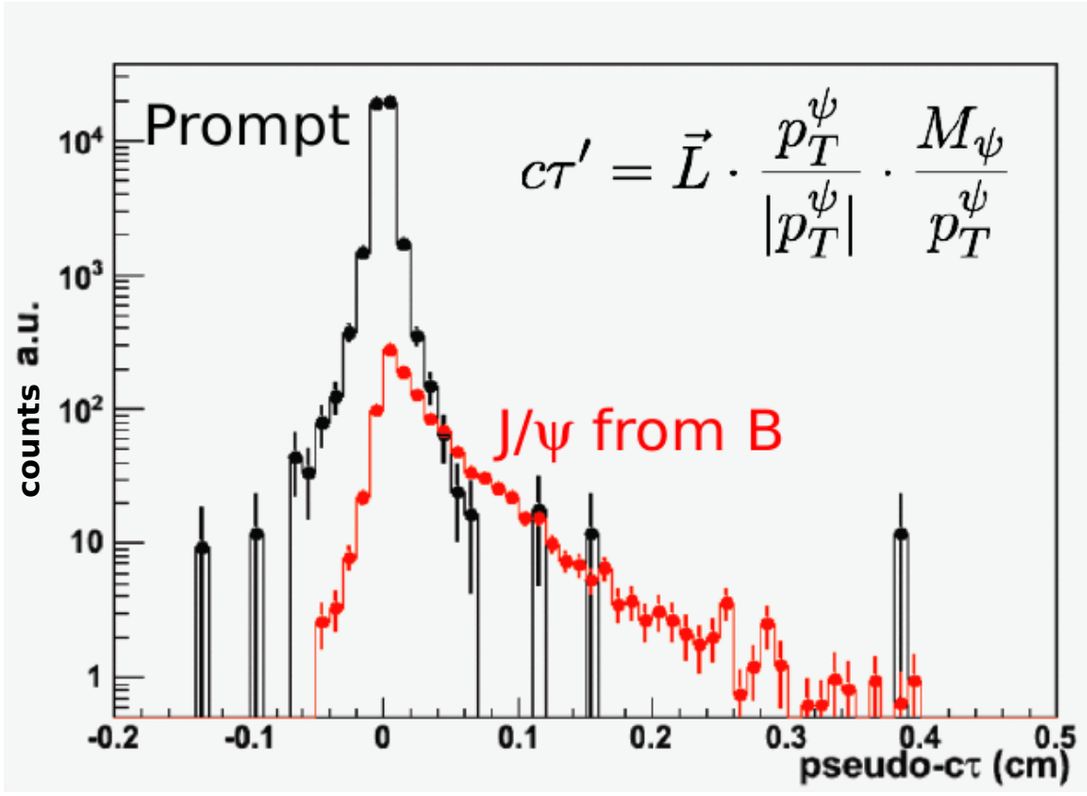


- Inner tracking system with 3 sub-systems
- Direct topological reconstruction of a decay vertex

Precise pointing resolution

$$B \rightarrow J/\psi + X$$

Separate prompt J/ψ production from non-prompt one, from B decays



Fully installed and takes data since 2014

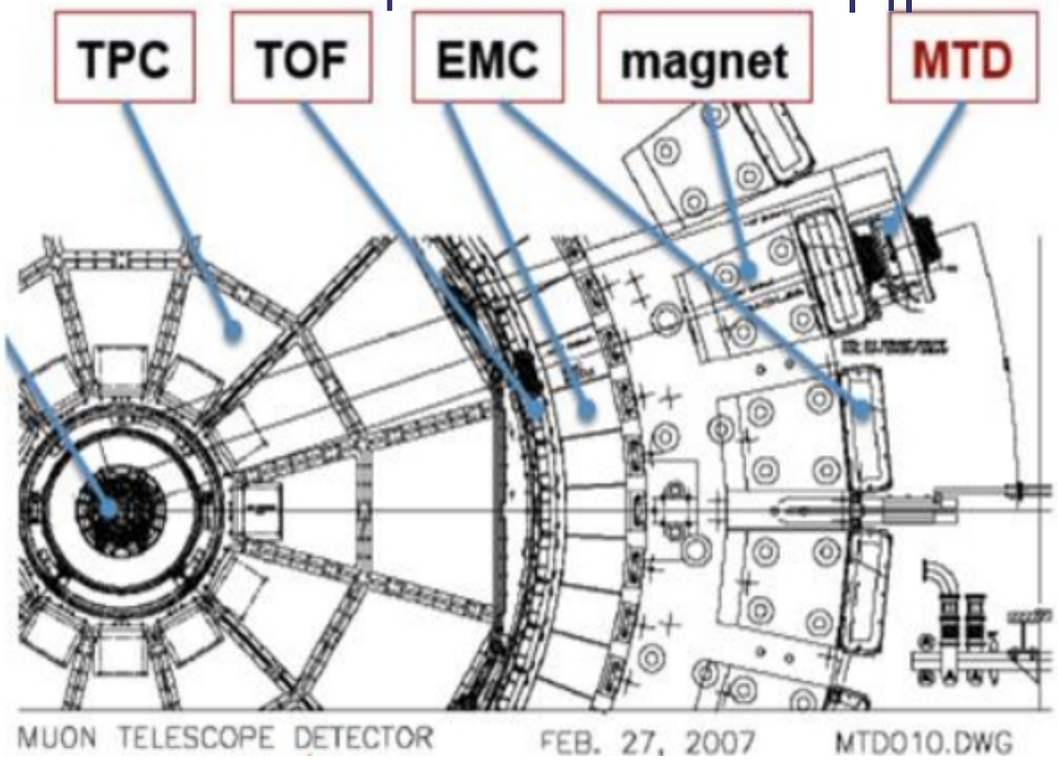
Muon Telescope Detector (MTD)

Precision quarkonium measurements via di-μ channel

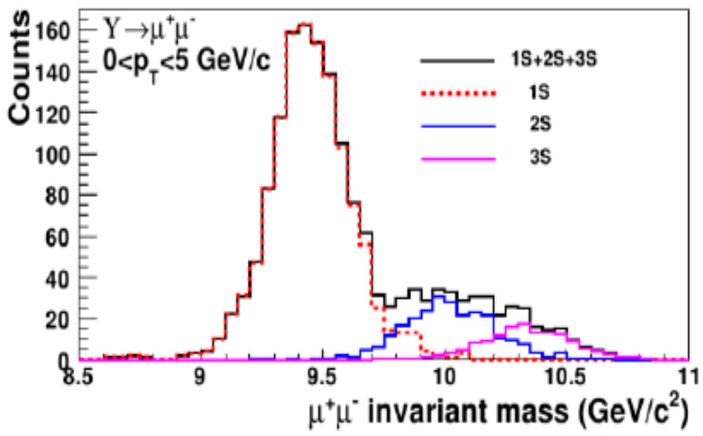
μ advantages over e:

- No γ conversion
- Much less Dalitz decay contribution
- Less affected by radiative loses in the detector material

Acceptance: 45% at |η| < 0.5

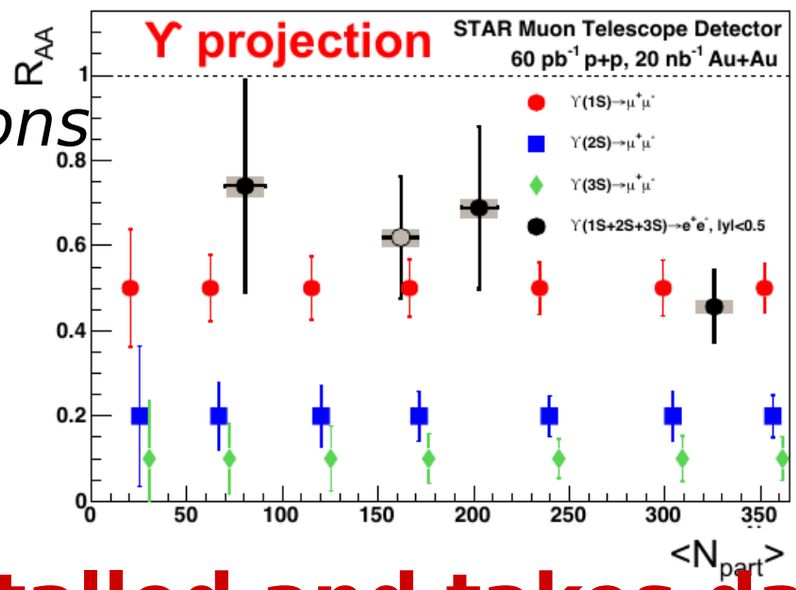


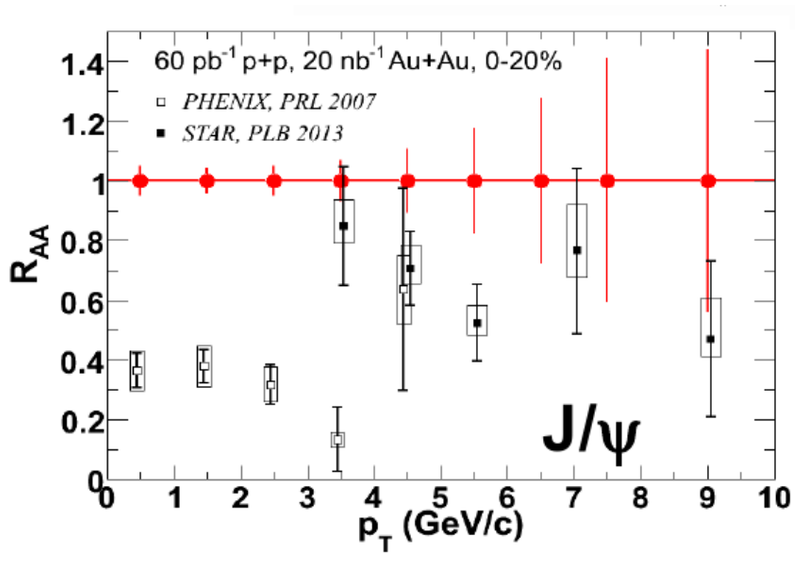
- Multi-gap Resistive Plate Chamber (MRPC) - gas detector
- Long-MRPCs



simulations

- Excellent mass resolution
- Trigger capability for low and high p_T J/ψ in central Au+Au





Fully installed and takes data since 2014

Summary

- No strong energy dependence of J/ψ suppression in Au+Au 200, 62.4, 39 GeV
- Similar J/ψ and ϒ suppression in Au+Au and U+U
- ϒ and high p_T J/ψ suppressed in central Au+Au 200 GeV
- Indication for complete ϒ(2S) and ϒ(3S) suppression in central collisions

  → Signals of the QGP presence

- First ψ(2S) measurement in p+p at 500 GeV

  → No collision energy dependence of (ψ(2S) / J/ψ) ratio seen

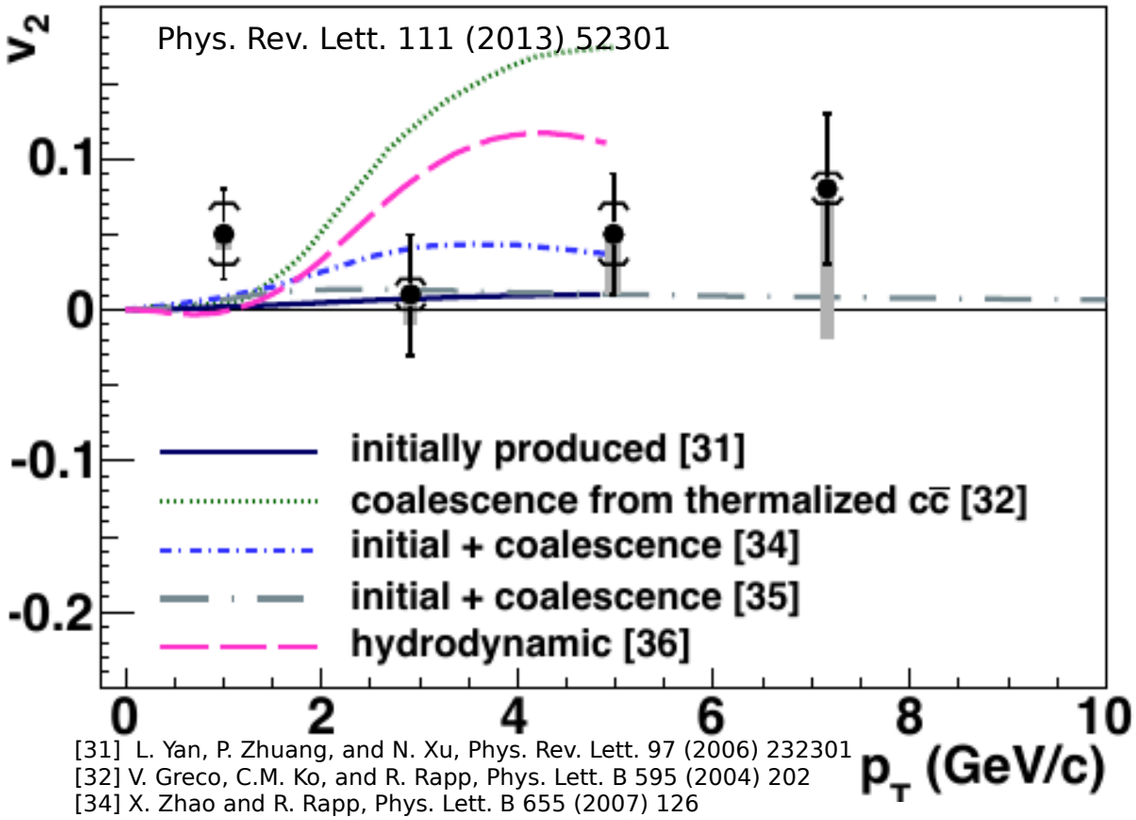
- *HFT and MTD since 2014 – significant improvement of quarkonium measurements*

Thank you !

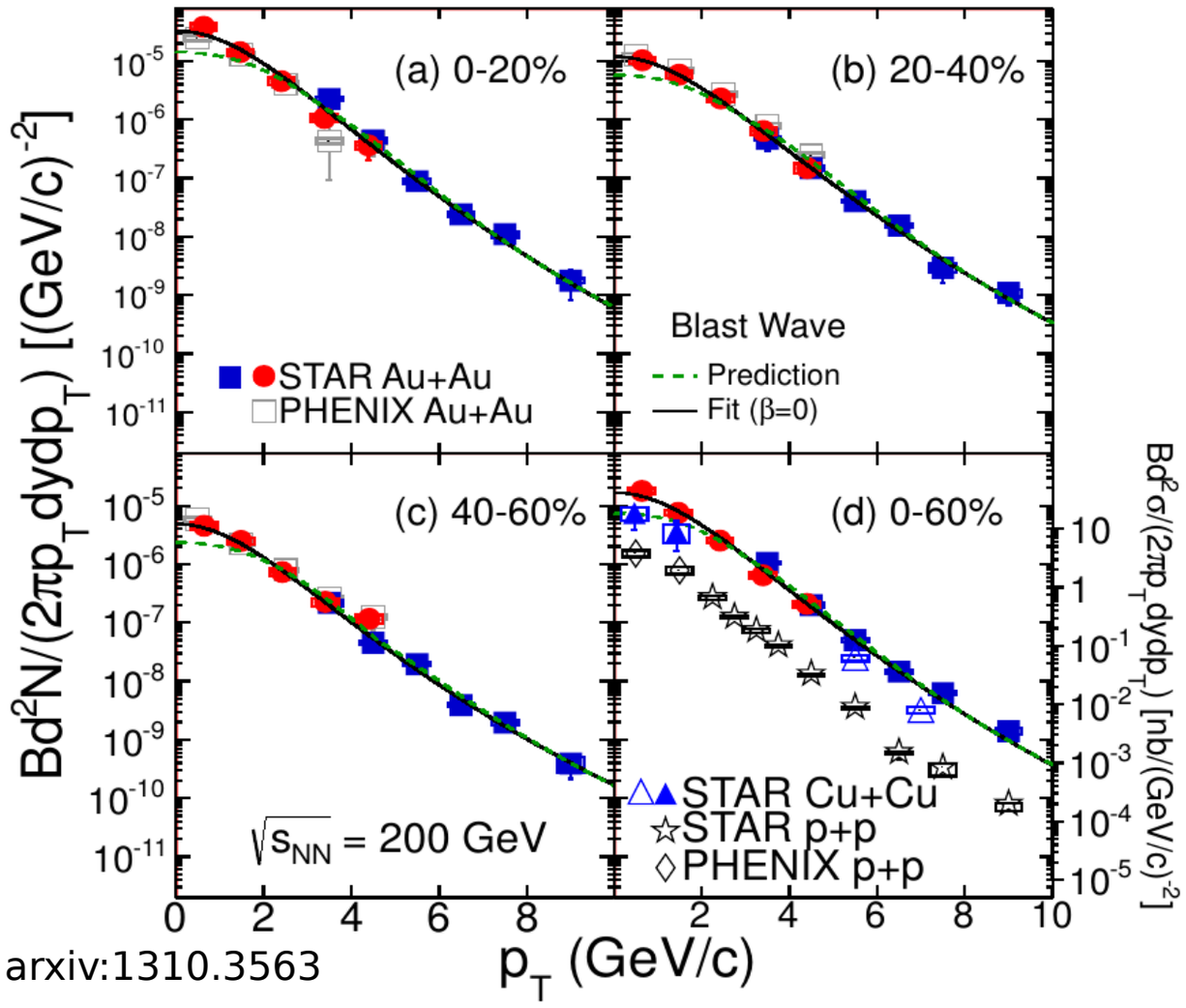
J/Ψ v_2 and p_T spectra in Au+Au 200 GeV

- ✓ J/ψ v_2 is consistent with zero at $p_T > 2$ GeV/c

  ➔ Disfavors the model with J/ψ production via thermalized (anti-)charm coalescence



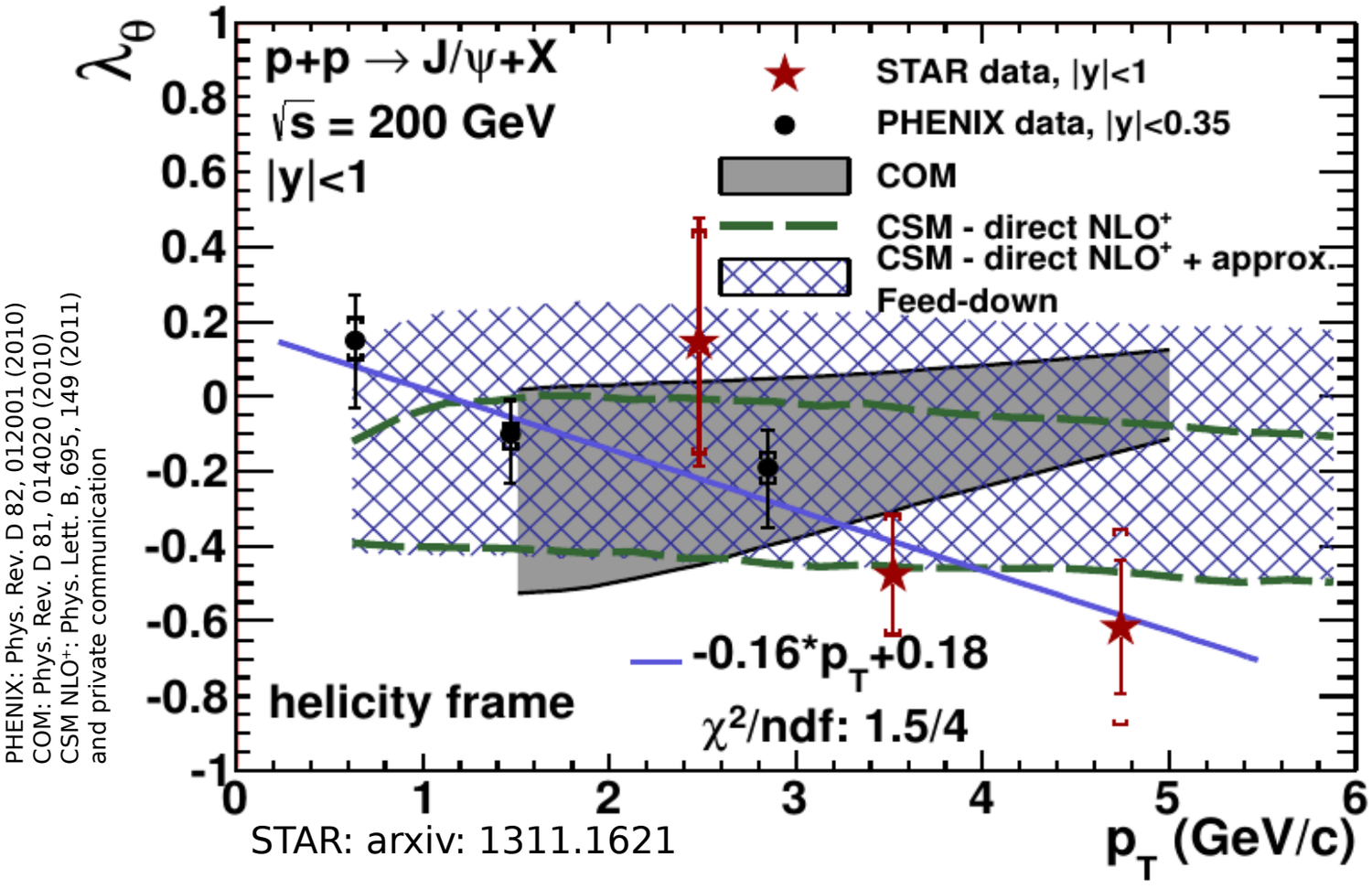
[31] L. Yan, P. Zhuang, and N. Xu, Phys. Rev. Lett. 97 (2006) 232301
[32] V. Greco, C.M. Ko, and R. Rapp, Phys. Lett. B 595 (2004) 202
[34] X. Zhao and R. Rapp, Phys. Lett. B 655 (2007) 126
[35] Y. Liu, N. Xu, and P. Zhuang, Nucl. Phys. A 834 (2010) 317c
[36] U. W. Heinz and C. Chen, private communication (2012)



arxiv:1310.3563

- ✓ At low p_T J/ψ spectra softer than the TBW prediction from light hadron
  - ➔ small radial flow ?
  - ➔ regeneration at low p_T ?

J/Ψ polarization in p+p 200 GeV



The angular distribution integrated over the azimuthal angle:

$$W(cos\theta) \propto 1 + \lambda_\theta cos^2\theta$$

λ_θ – *polarization parameter*

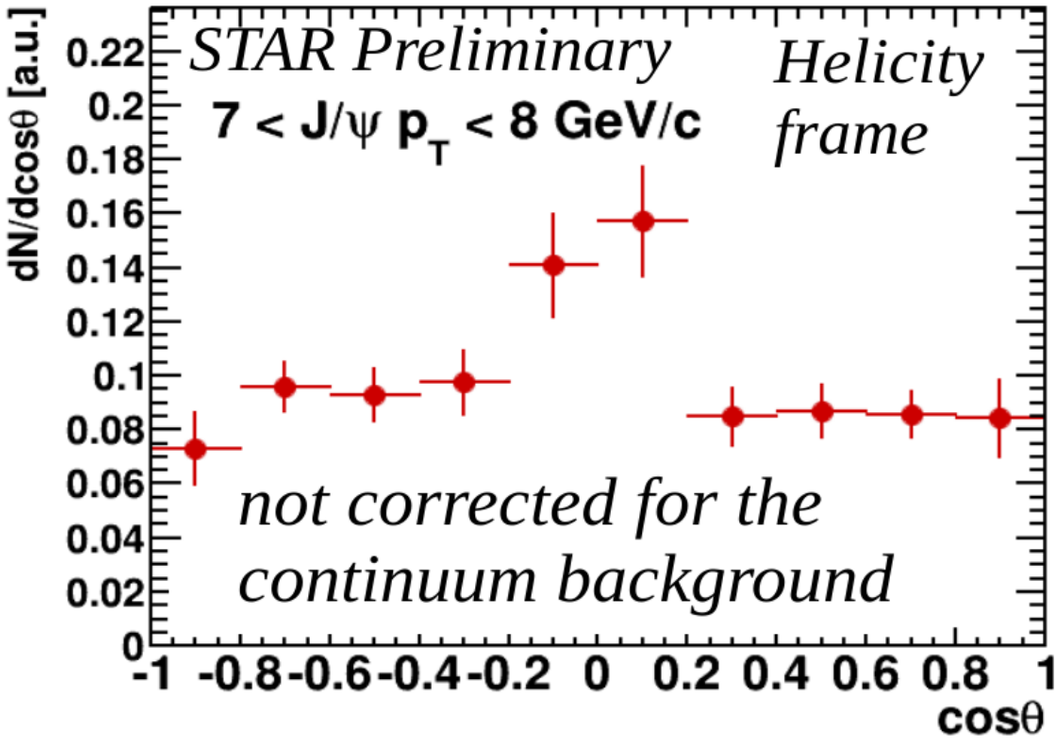
λ_θ = **-1**- longitudinal polarization
λ_θ = **1** - transverse polarization

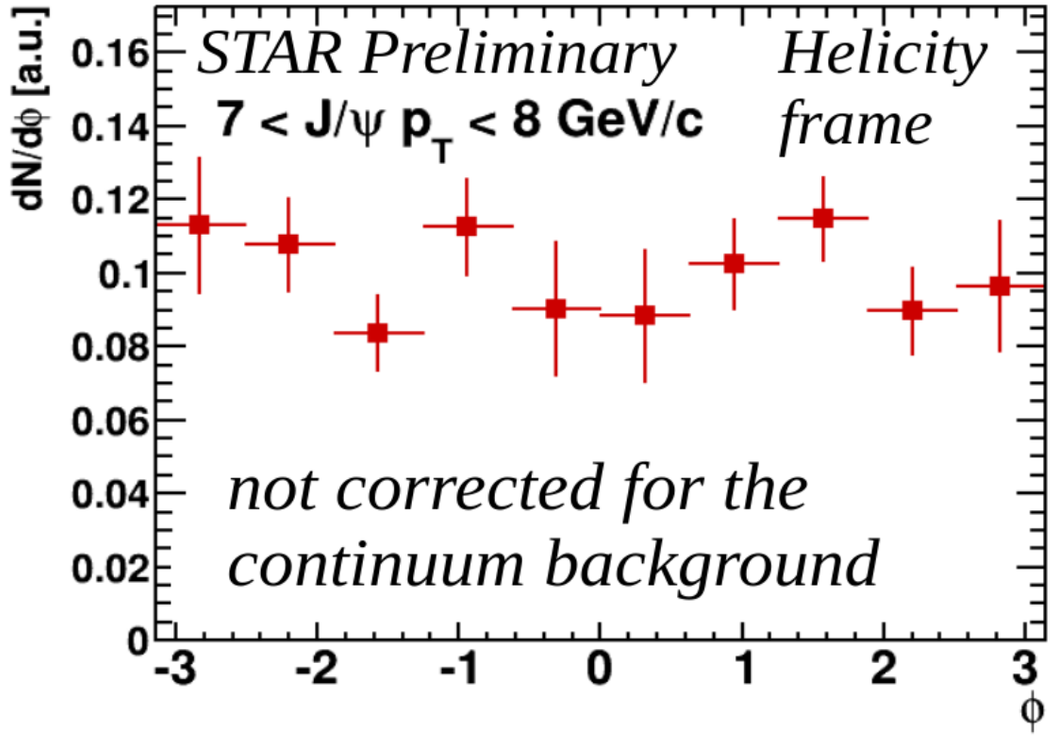
- ✓ Polarization parameter λ_θ is measured in the helicity frame at $|y| < 1$ and $2 < p_T < 6$ GeV/c
  - → RHIC data indicate trend towards longitudinal polarization with increasing p_T
  - → The result is consistent with NLO$^+$ CSM

J/Ψ polarization in p+p 500 GeV

- Information about full decay angular distribution
  - ✓ First J/ψ polarization measurement at √s = 500 GeV from STAR in progress

~22 pb^{-1} vs ~1.8 pb^{-1} (previous analysis)





- ✓ Reconstruction of both θ and φ angles
- ✓ J/ψ signal up to p_T ~ 15 GeV/c, can be divided into several p_T bins