Measurements of Υ Production and Nuclear Modification Factor at STAR

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For the STAR Collaboration

Outline

- Motivation for measuring Upsilons
- The Solenoidal Tracker At RHIC and its triggers
- Υ production cross section in p+p
- Υ production in d+Au
- Υ Nuclear Modification Factor in Au+Au
- LHC Results
- Conclusions

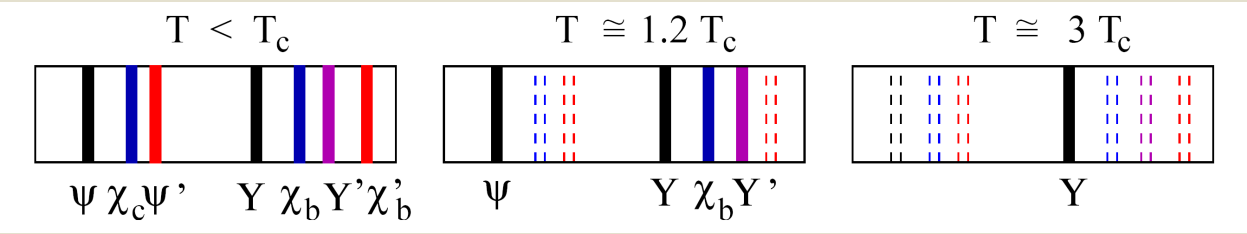
Goal: Quarkonia states in A+A

Charmonia: J/Ψ, Ψ', χ_c Bottomonia: $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, χ_B

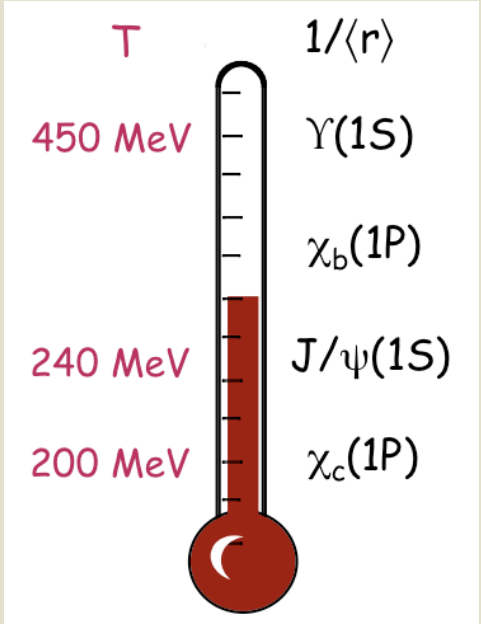
<u>Key Idea:</u> Quarkonia Melt in the plasma

- Color screening of static potential between heavy quarks
- Suppression of states is determined by T_C and their binding energy
- Lattice QCD: Evaluation of spectral functions $\Rightarrow T_{melting}$
- Originaly proposed by Matsui & Satz (1986)

When do states melt?



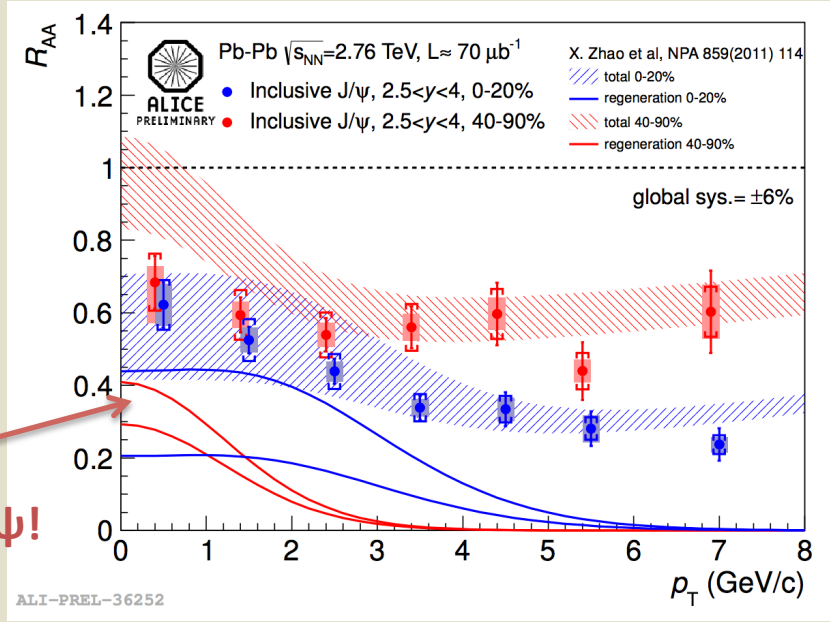
H. Satz, *HP06*



A. Mocsy, Summer Quarkonium Workshop, BNL, 2011

Why do ϒ at RHIC instead of J/Ψ?

- A cleaner probe compared to J/Ψ
  - co-mover absorption → negligible
  - recombination → negligible
    - σ_{cc} = ~800 μb
    - $\sigma_{bb=}$ ~ 2μb
- Challenge: low rate, rare probe
  - Large acceptance detector
  - Efficient trigger



Regeneration of J/ψ!

R. Arnaldi, arXiv:1211.2578v1 [nucl-ex]

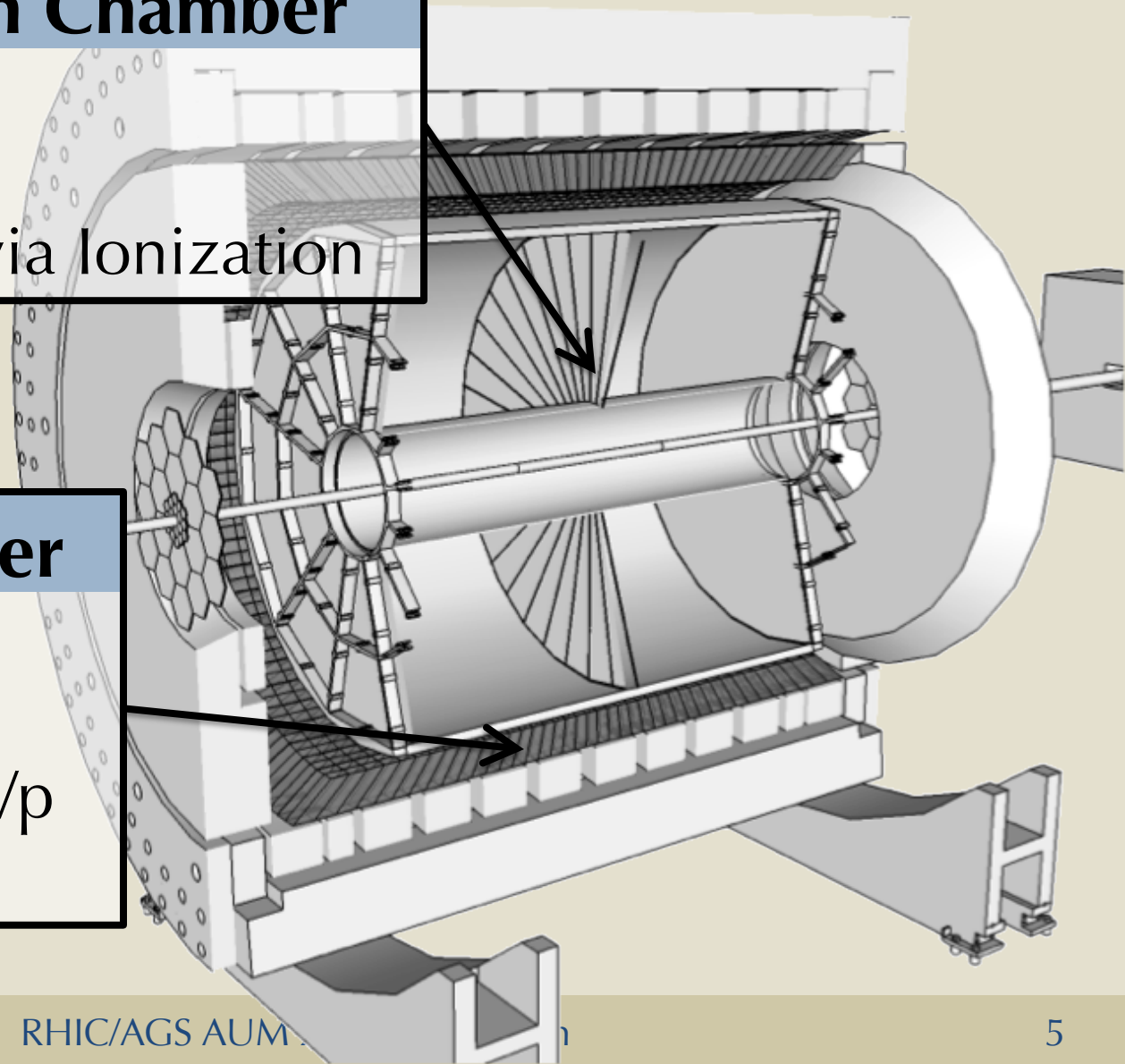
STAR

Time Projection Chamber

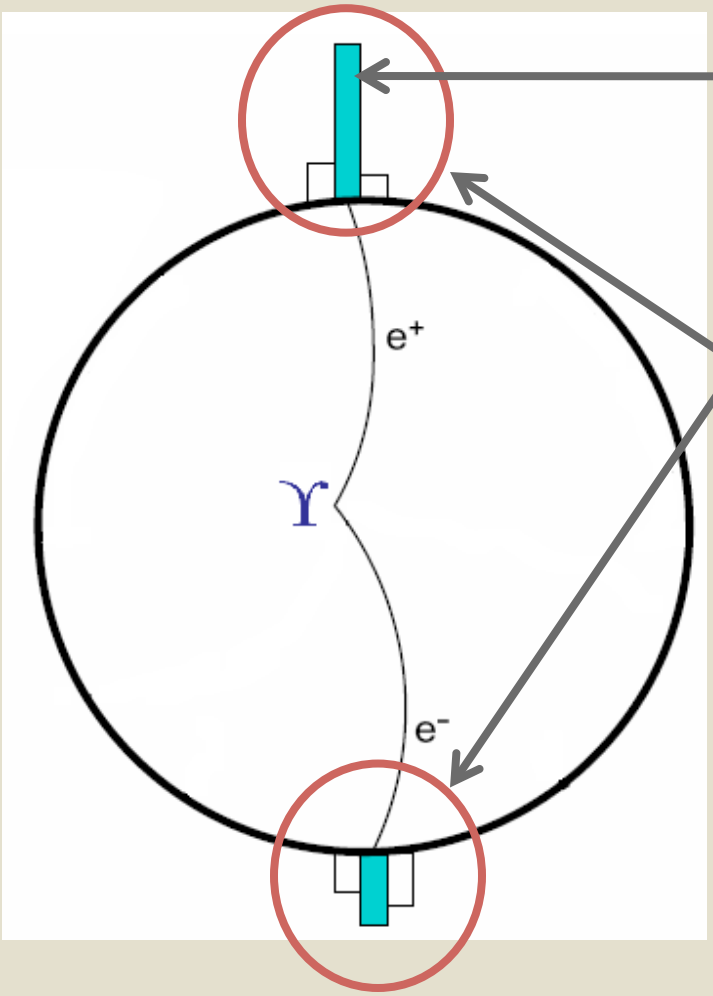
- $|\eta| < 1$
- Full ϕ coverage
- Tracking and EID via Ionization

EM Calorimeter

- $|\eta| < 1$
- Full ϕ coverage
- Electron ID via E/p
- Event Triggering



Triggering on Υ decays



Level 0 Trigger (p+p,d+Au,Au+Au):

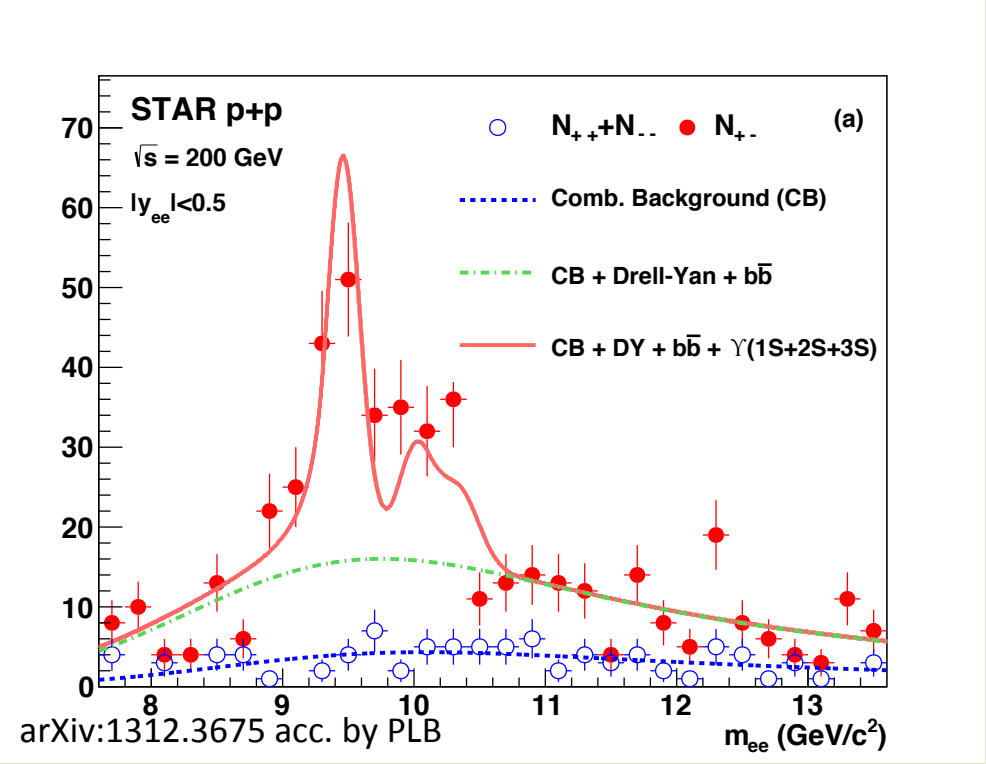
- Hardware-based
- Fires on at least one high tower

Level 2 Trigger (p+p,d+Au):

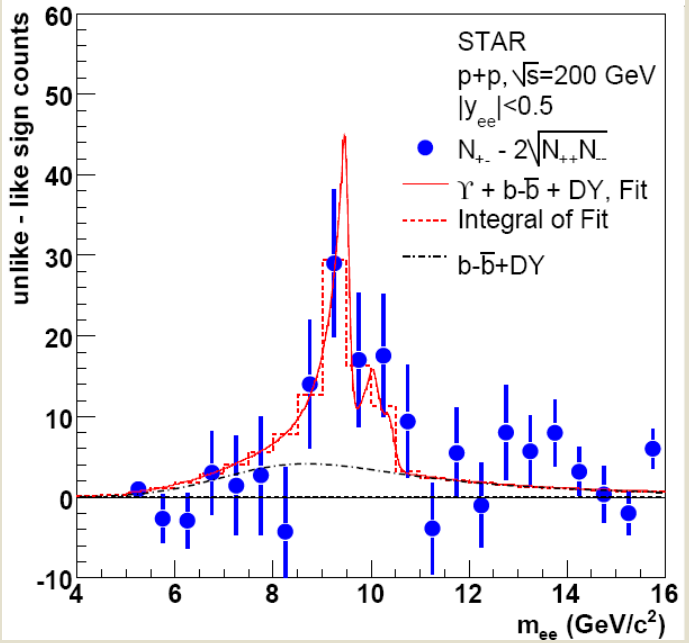
- Software-based
- Calculates:
  - Cluster energies
  - Opening angle
  - Mass

High rejection rate allowed us to sample entire luminosity

Υ in p+p 200 GeV



arXiv:1312.3675 acc. by PLB



Phys. Rev. D **82** (2010) 12004

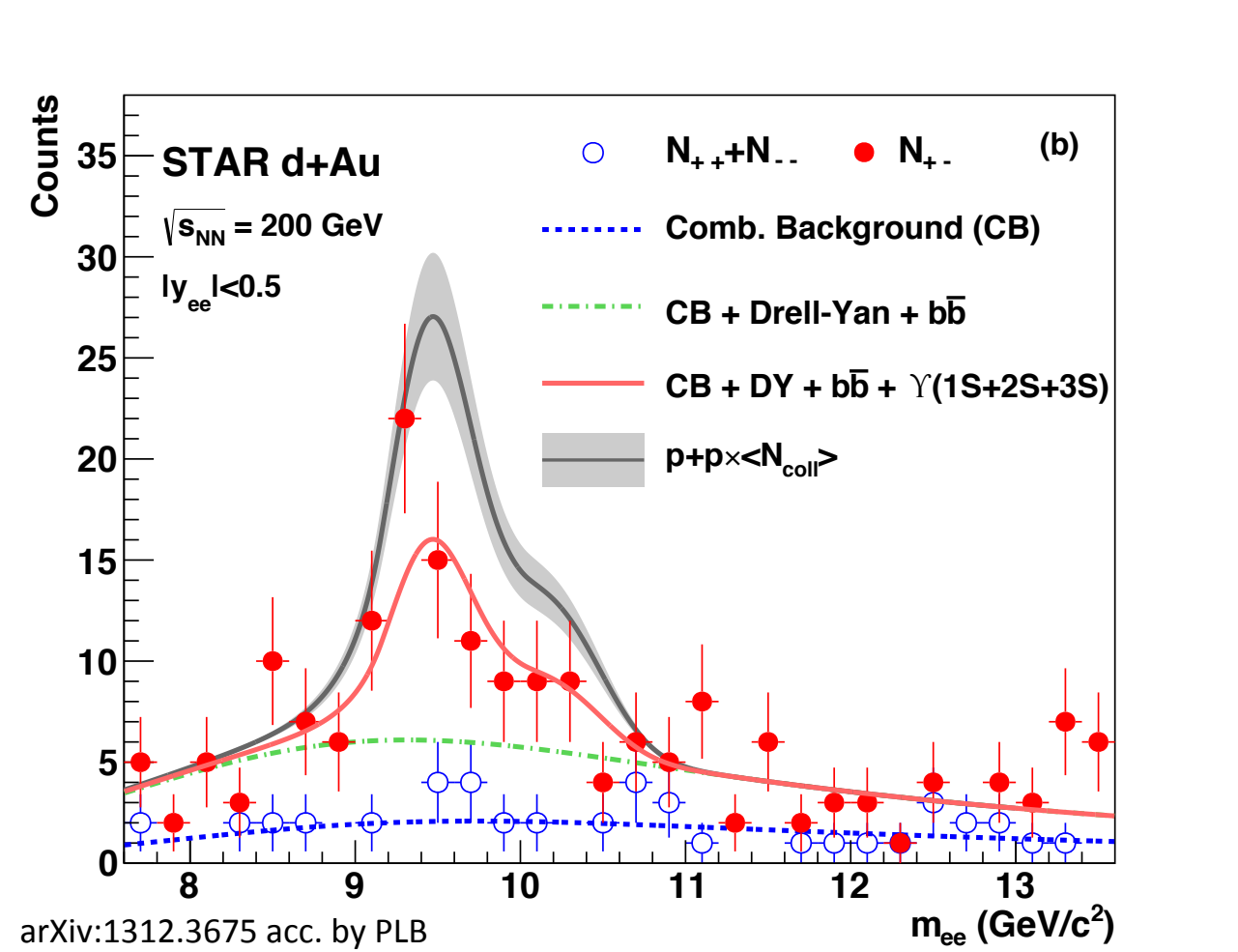
Statistical error reduced by a factor of 2!

For |y|<0.5:

$$\sum_{n=1}^{3} \mathcal{B}(n\mathrm{S}) \times \frac{d\sigma(n\mathrm{S})}{dy} = 64 \pm 10^{+14}_{-12}\ \mathrm{pb}$$

$\int L\,dt = 20.0\ \mathrm{pb}^{-1}$
$N_\Upsilon(\mathrm{total}) = 152 \pm 23(\mathrm{stat.} + \mathrm{fit})$

ϒ in d+Au 200 GeV

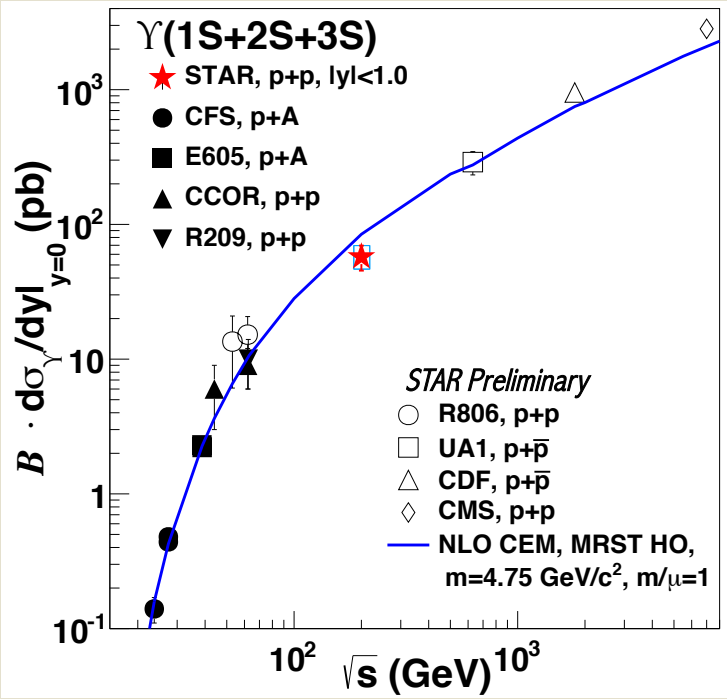


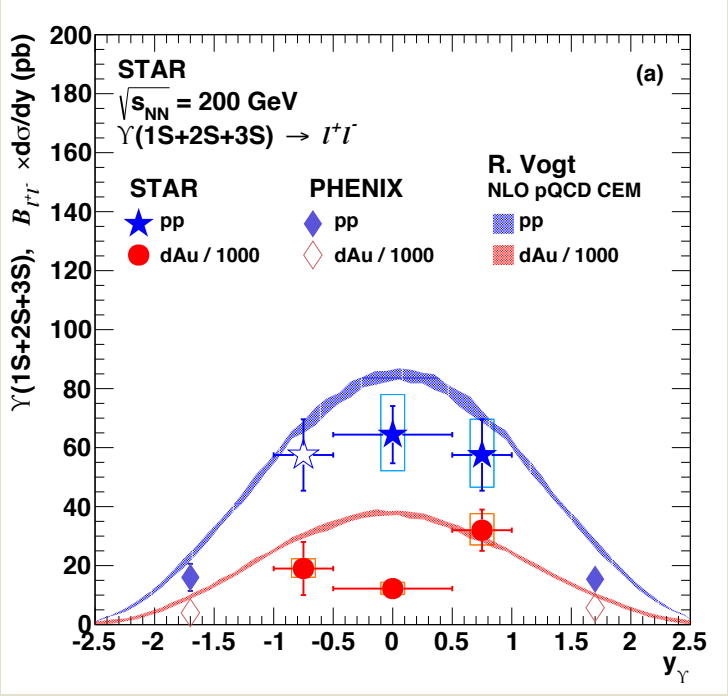
$$\sum_{n=1}^{3} \mathcal{B}(n\mathrm{S}) \times \frac{d\sigma(n\mathrm{S})}{dy} = 12.2 \pm 3.4^{+2.1}_{-1.9}\ \mathrm{nb}$$

$\int L\,dt = 28.1\ \mathrm{nb}^{-1}$

$N_{\Upsilon} = 46 \pm 13$ (stat. + fit)

ϒ in p+p 200 GeV, Comparisons



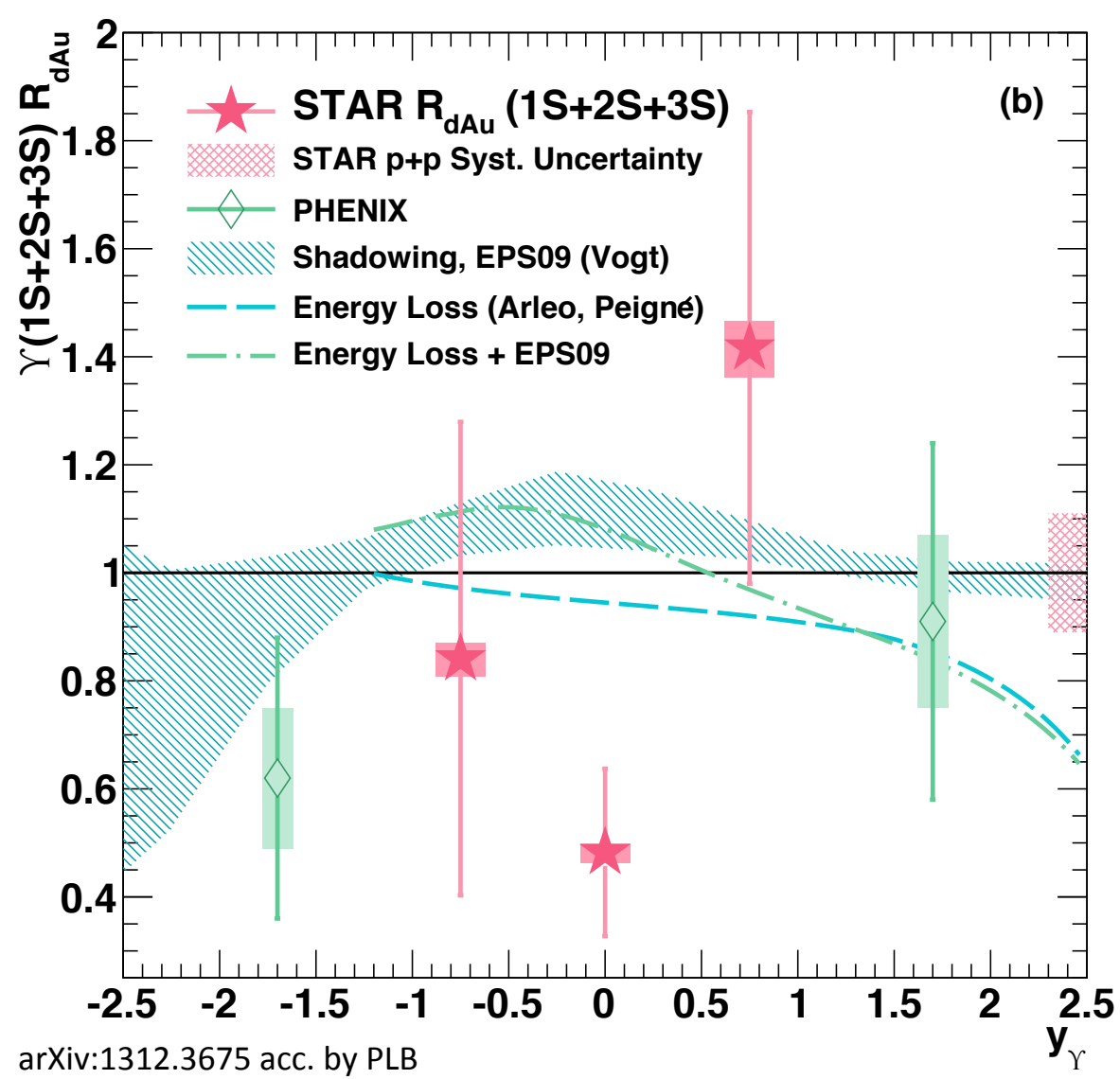


arXiv:1312.3675 acc. by PLB

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

STAR √s=200 GeV p+p ϒ+ϒ′+ϒ″→e^+e^- cross section compared to pQCD and world data trend

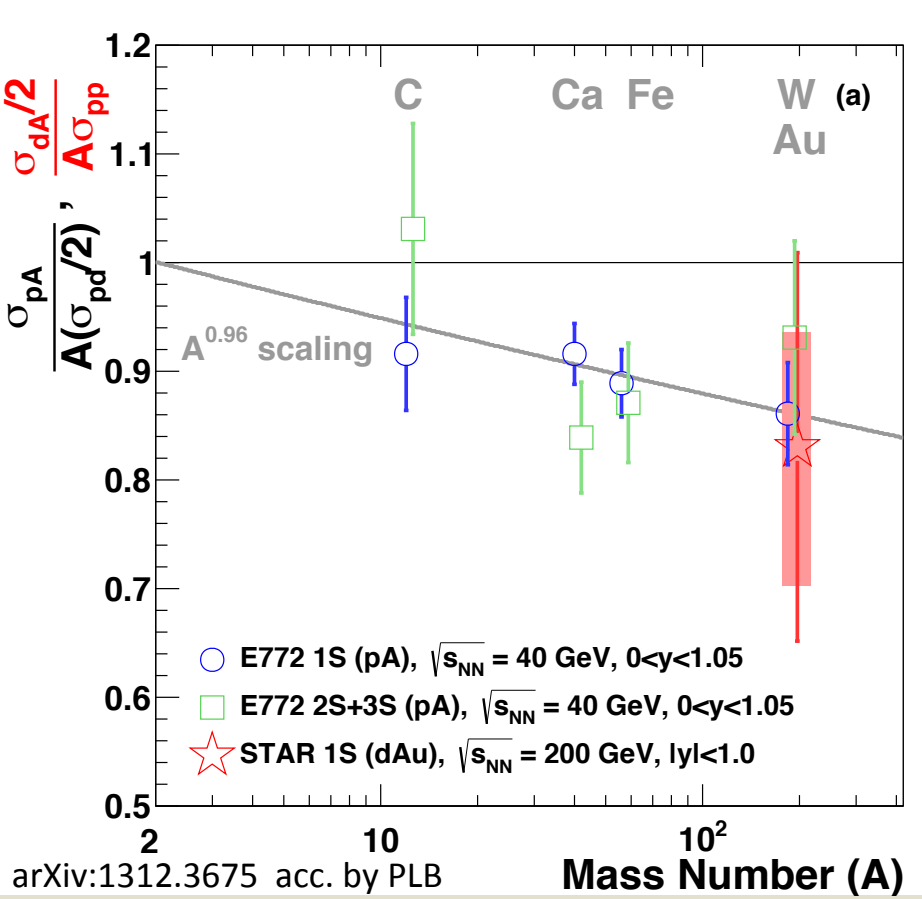
R_{dAu} vs Rapidity



arXiv:1312.3675 acc. by PLB

- STAR results consistent with predictions and with unity except for mid-rapidity
- PHENIX results also consistent with predictions
- Indication of suppression at y=0 unexpected, but further studies needed

Comparison to E772 Results



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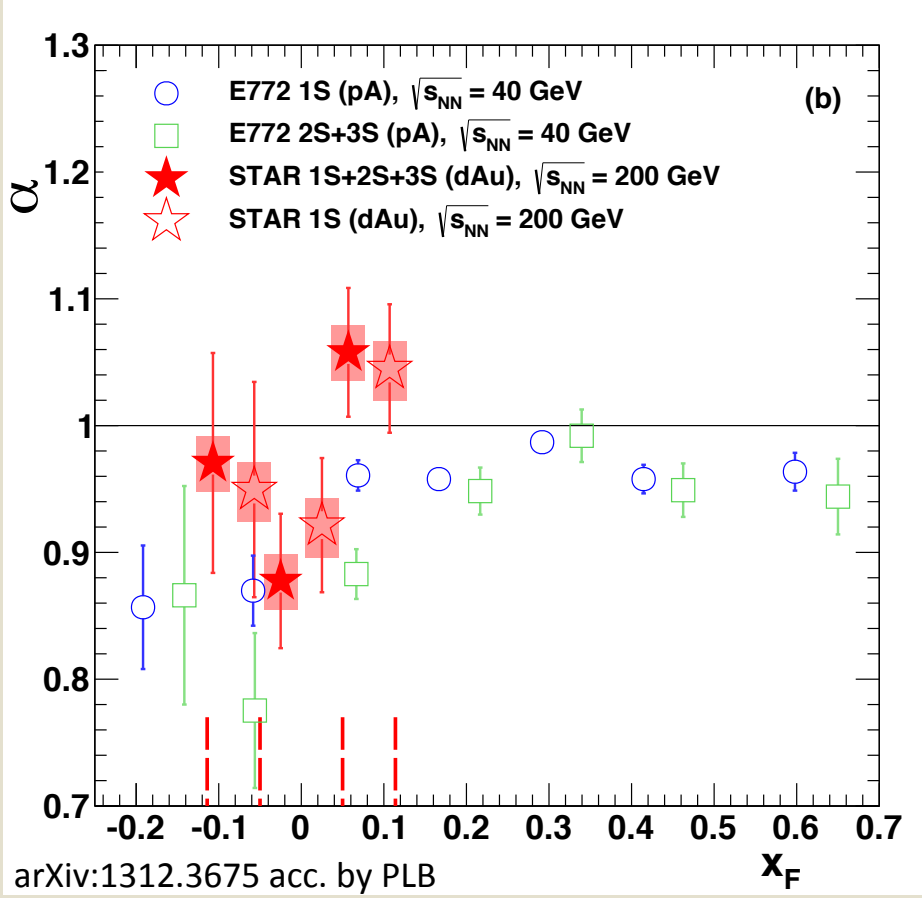
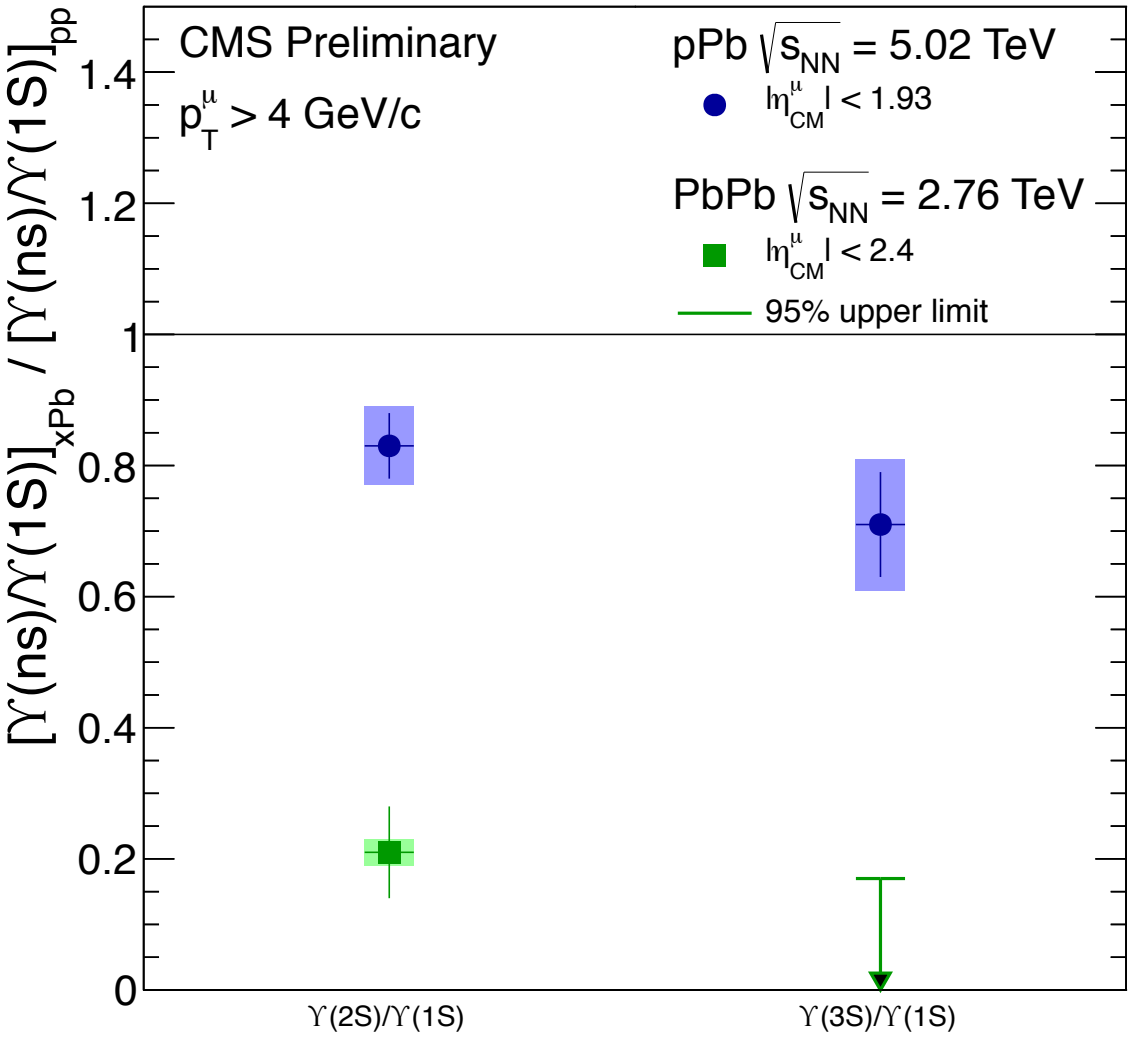


arXiv:1312.3675 acc. by PLB

- Upsilon suppression in CM seen before at E772
- STAR results mostly in agreement with E772

CMS Upsilon pPb Results



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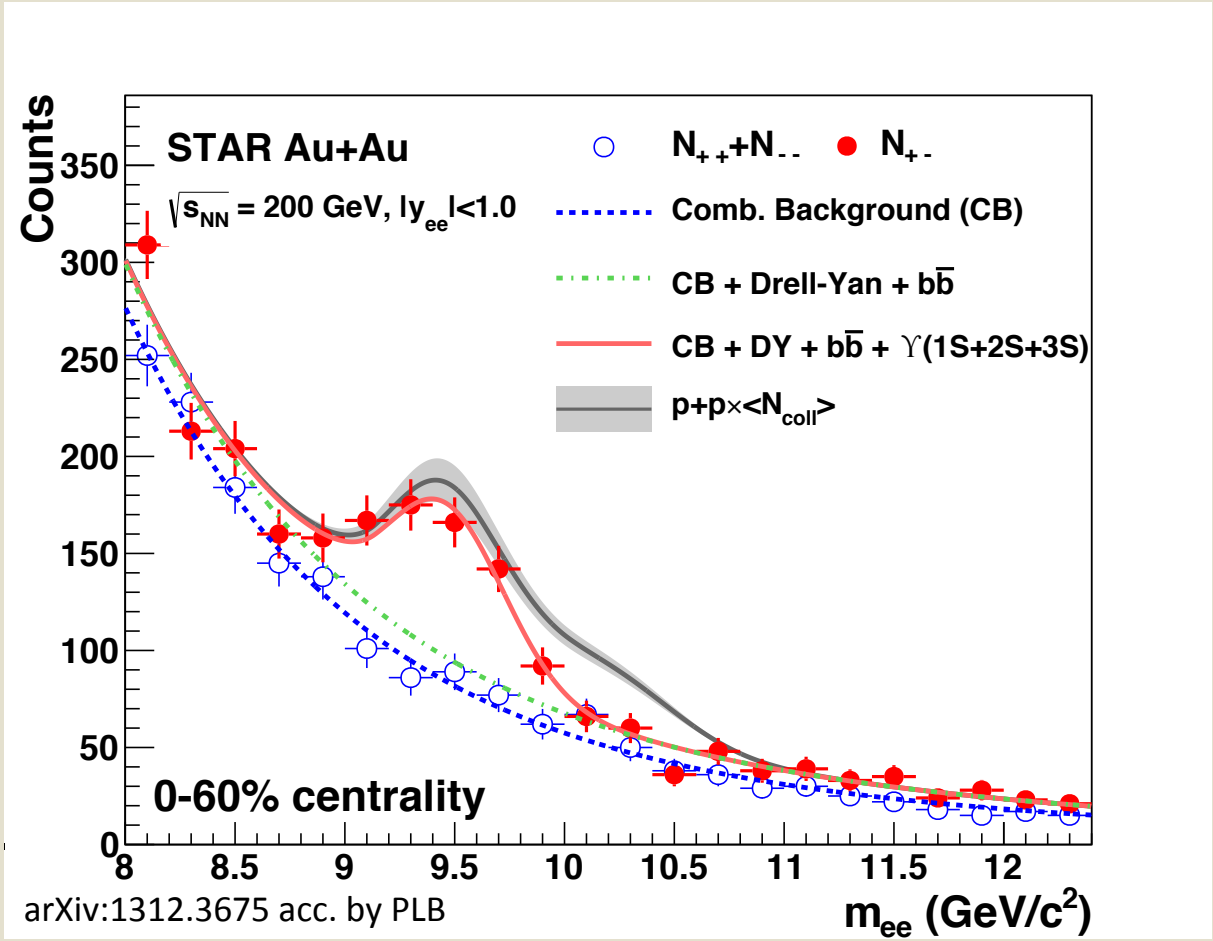
- Double ratio of excited states to the ground state
- Large to complete suppression in PbPb
- Slight relative suppression in pPb
  - Indication of nuclear absorption or breakup?

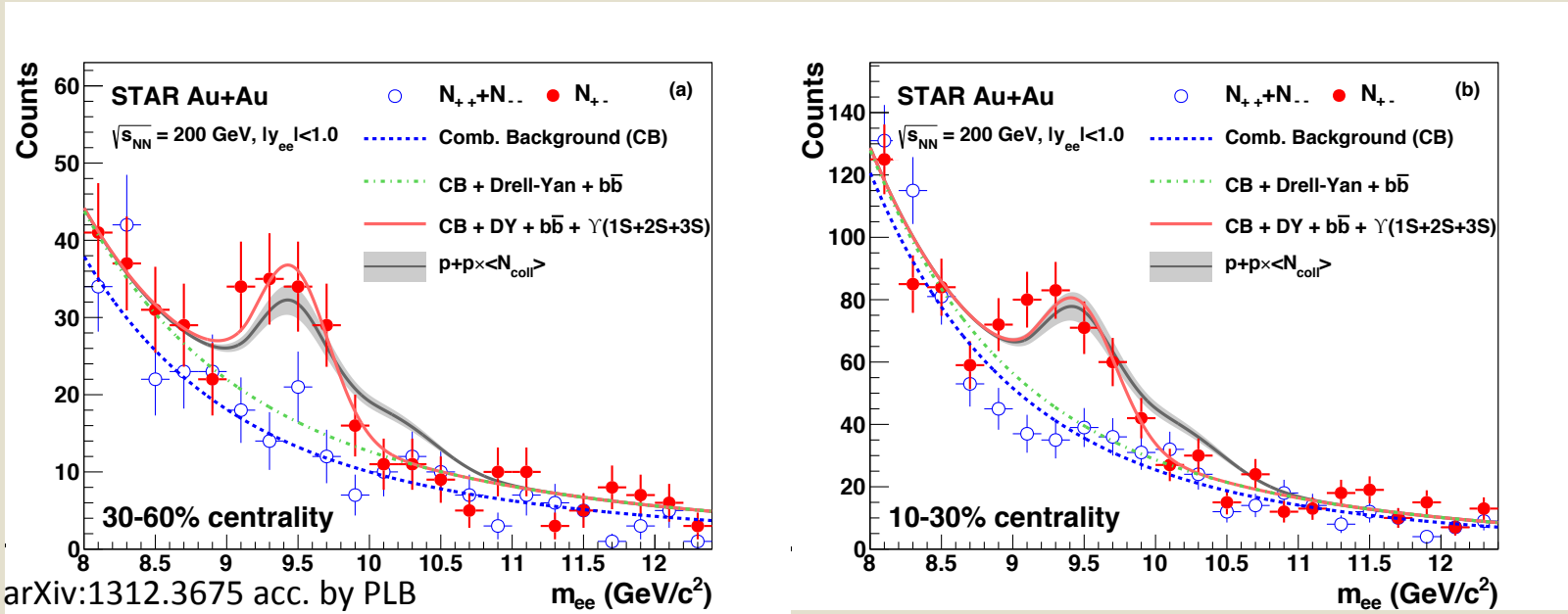
ϒ in Au+Au 200 GeV



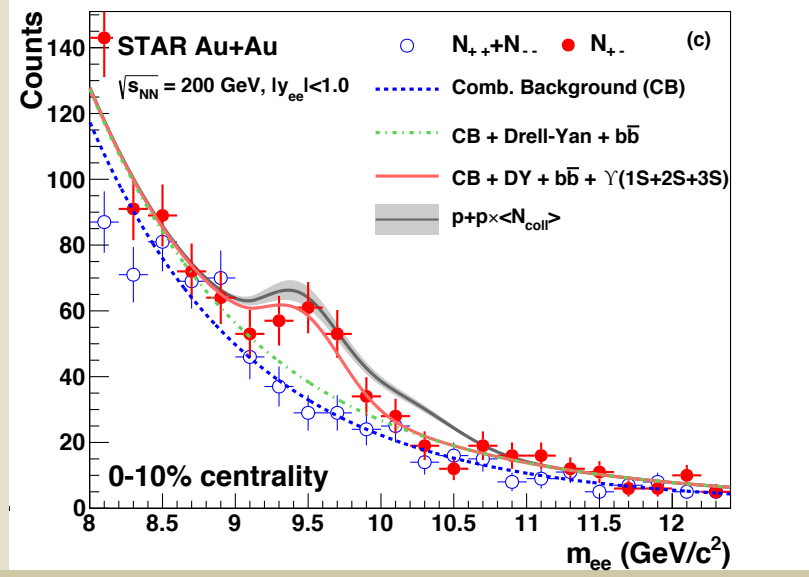
Raw yield of $\Upsilon \rightarrow e^+e^-$ with $|y|<1.0 = 254 \pm 29$

$\int L\, dt = 1075\ \mu b^{-1}$

ϒ in Au+Au 200 GeV, Centrality

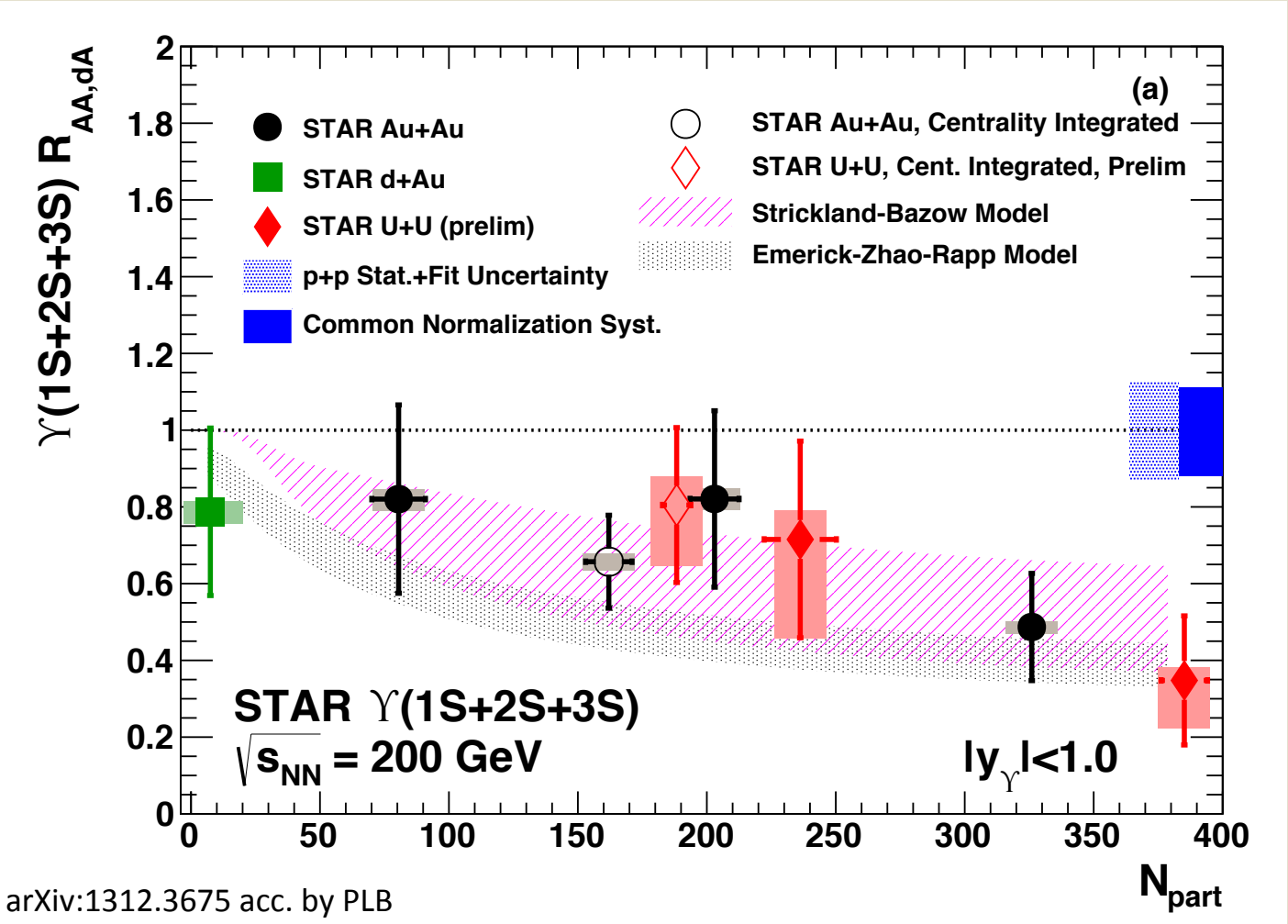


arXiv:1312.3675 acc. by PLB



- AuAu signal split into three centrality bins
- Grey curve indicates line shape if no suppression

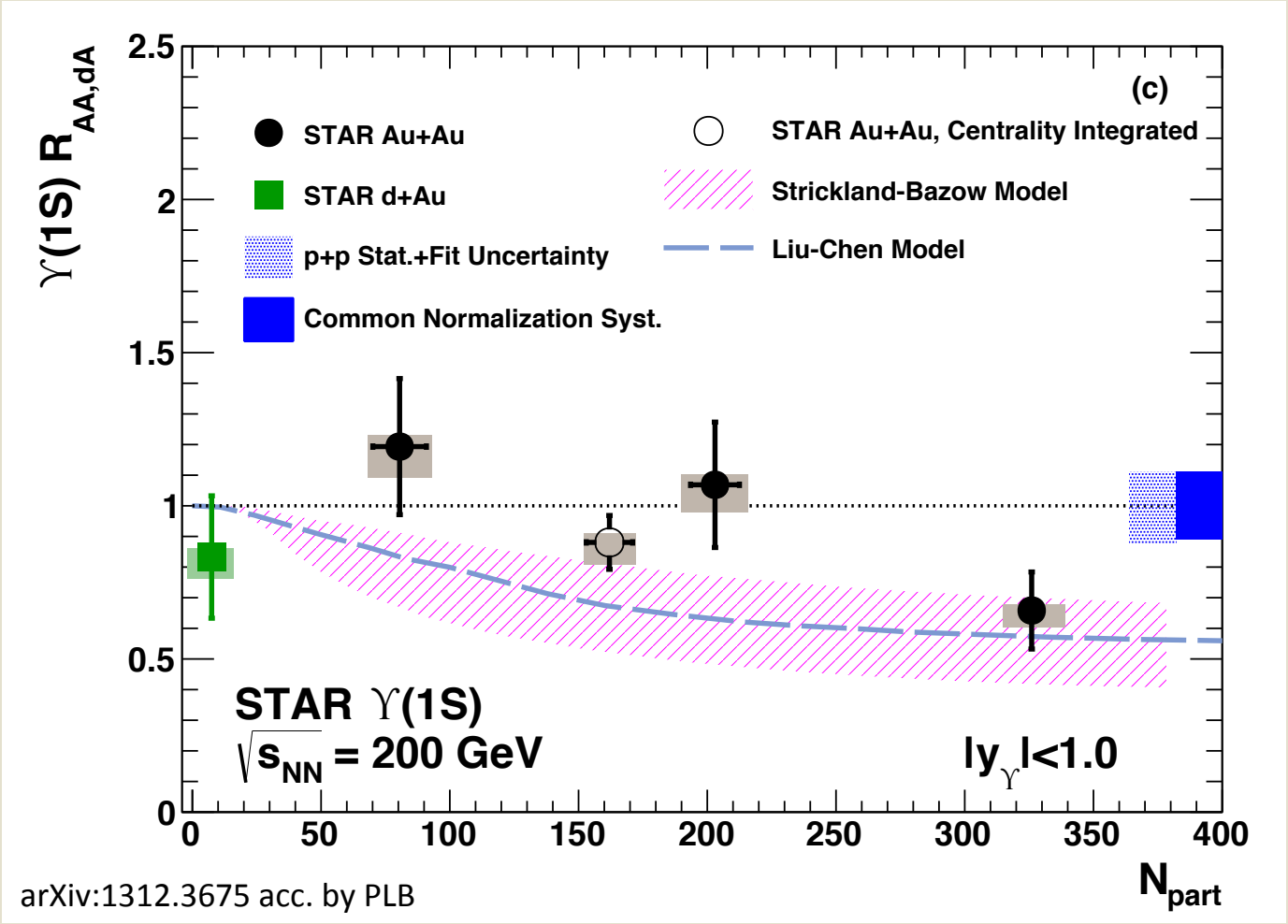
Υ in Au+Au 200 GeV, R_{AA}



Models from M. Strickland and D. Bazow, arXiv:1112.2761v4
A. Emerick et al., Eur. Phys. J. A48 (2012) 72

- Consistent increase in suppression with greater N_{part} in both Au+Au and U+U
- Strickland models predict temperature range of 428 MeV < T < 442 MeV

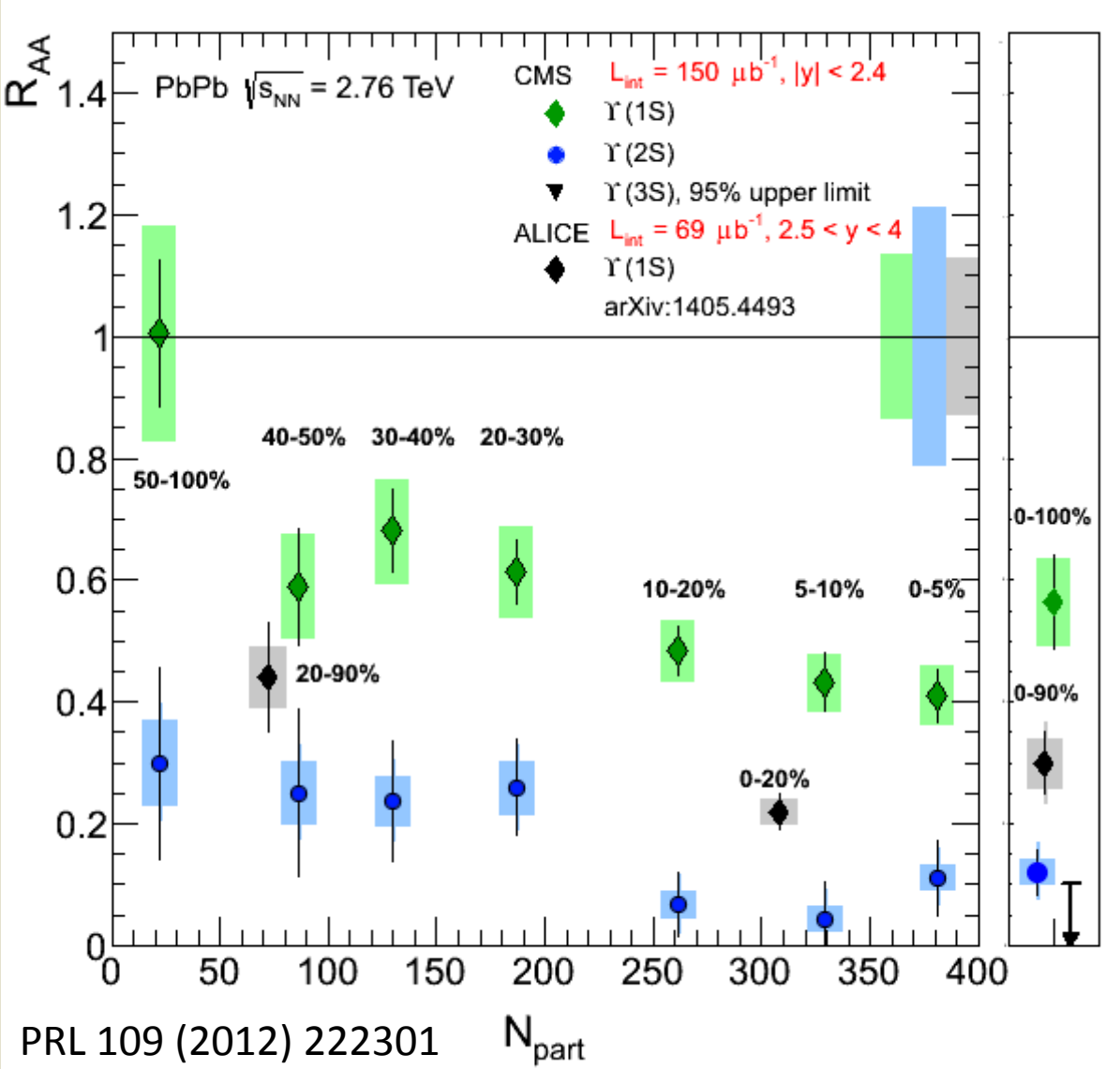
$\Upsilon(1S)$ in Au+Au 200 GeV, R_{AA}



Models from M. Strickland and D. Bazow, Nuclear Physics A 879, 25-58 (2012
Y. Liu, B. Chen, et. al., arXiv:1009.2585

- R_{AA} of $\Upsilon(1S)$ is consistent with 1 in dAu and peripheral and mid-central AuAu
- Indication of suppression consistent with model calculation in central AuAu

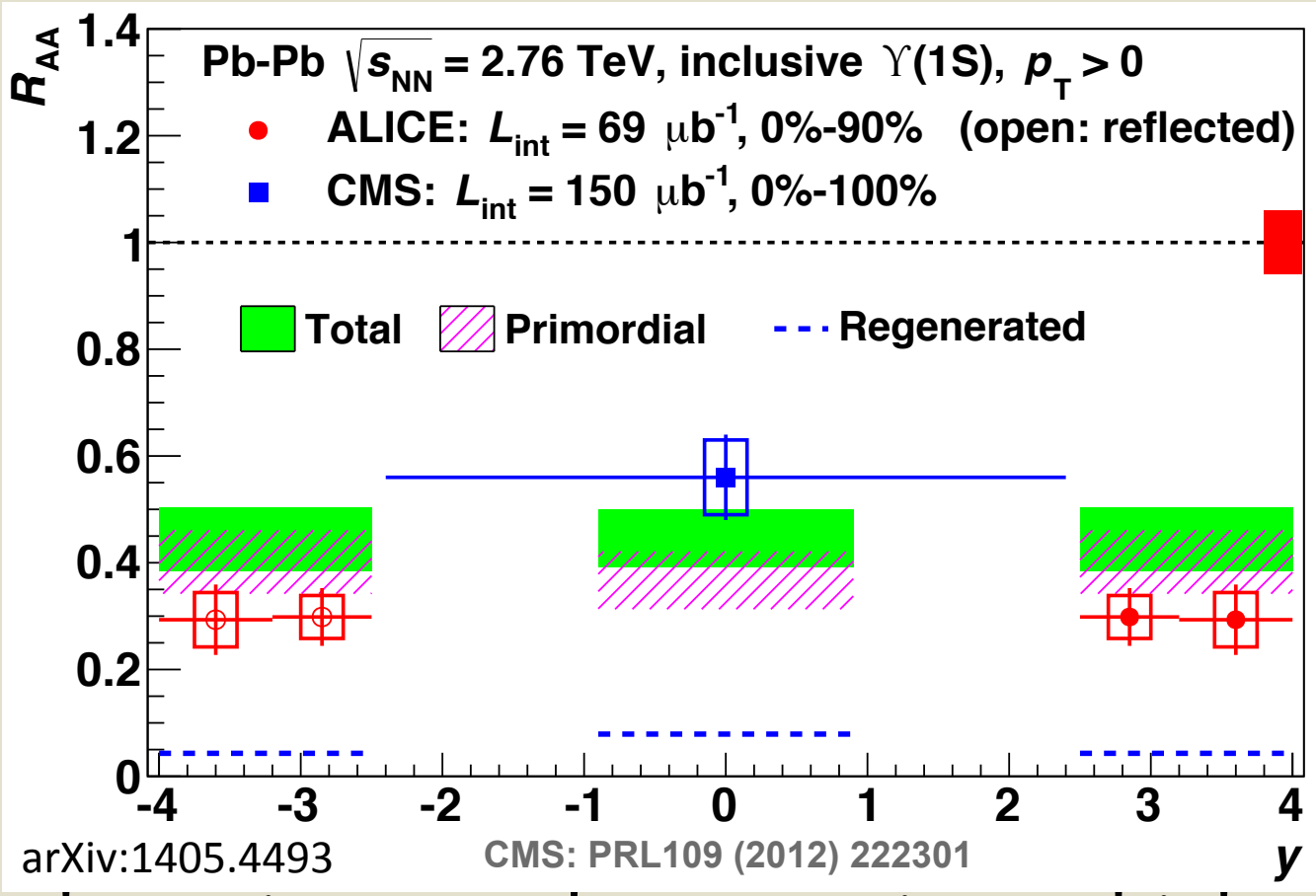
CMS Upsilon PbPb Results



PRL 109 (2012) 222301

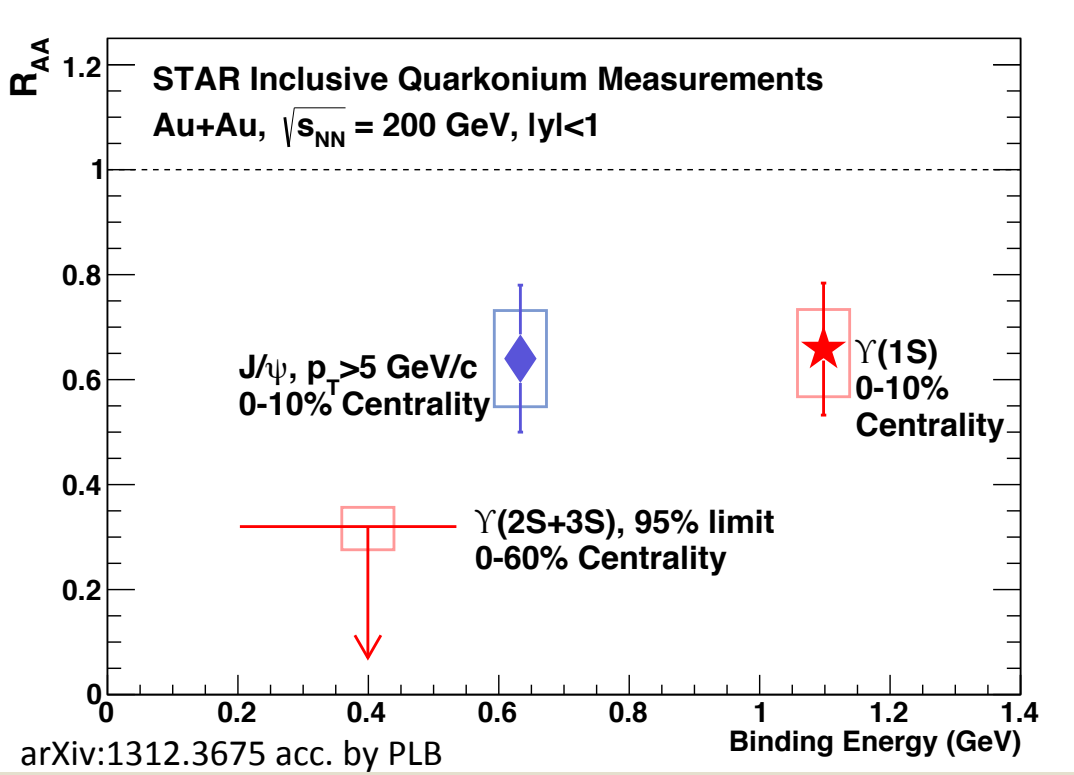
- CMS also sees increasing suppression with more central collisions
- Results are consistent with predictions within statistics
- Suppression level comparable to STAR

LHC: R_{AA} vs Rapidity

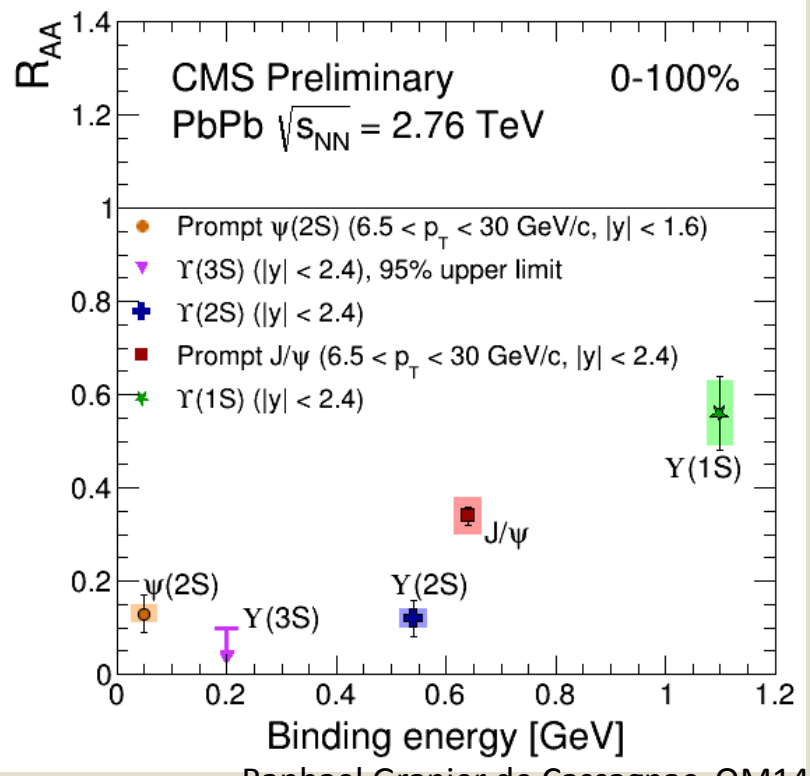


- LHC shows increased suppression at higher y
  - Unexpected and opposite of predictions
- Role of CNM or Regeneration?

Binding Energy



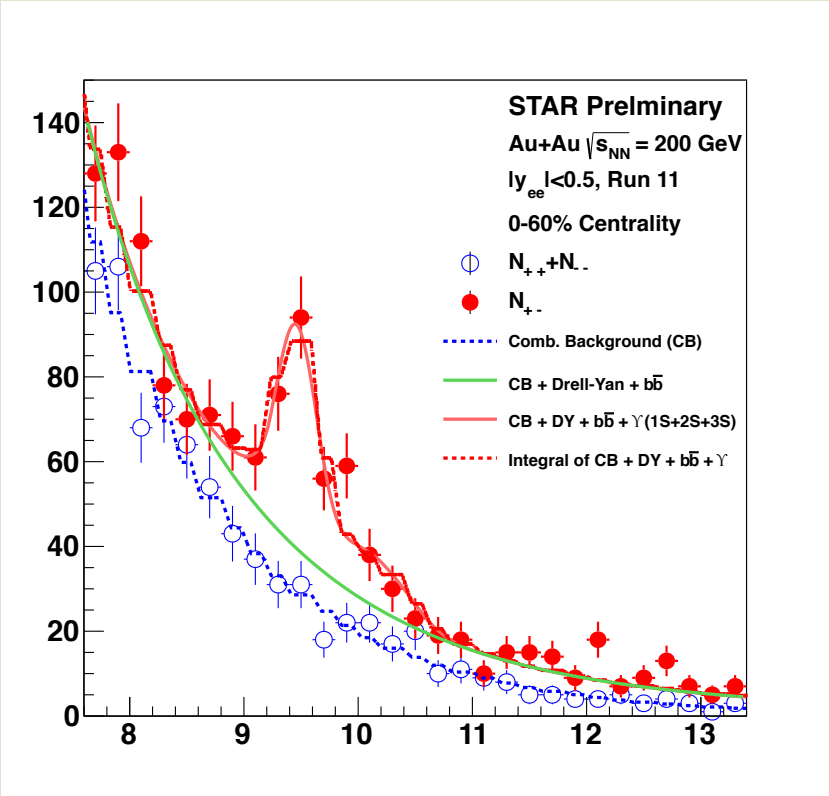
arXiv:1312.3675 acc. by PLB



Raphael Granier de Cassagnac, QM14

- STAR and CMS quarkonia R_{AA} results show suppression for all states measured
- Increased suppression with decreased binding energy as prediction by Debye screening

Outlook

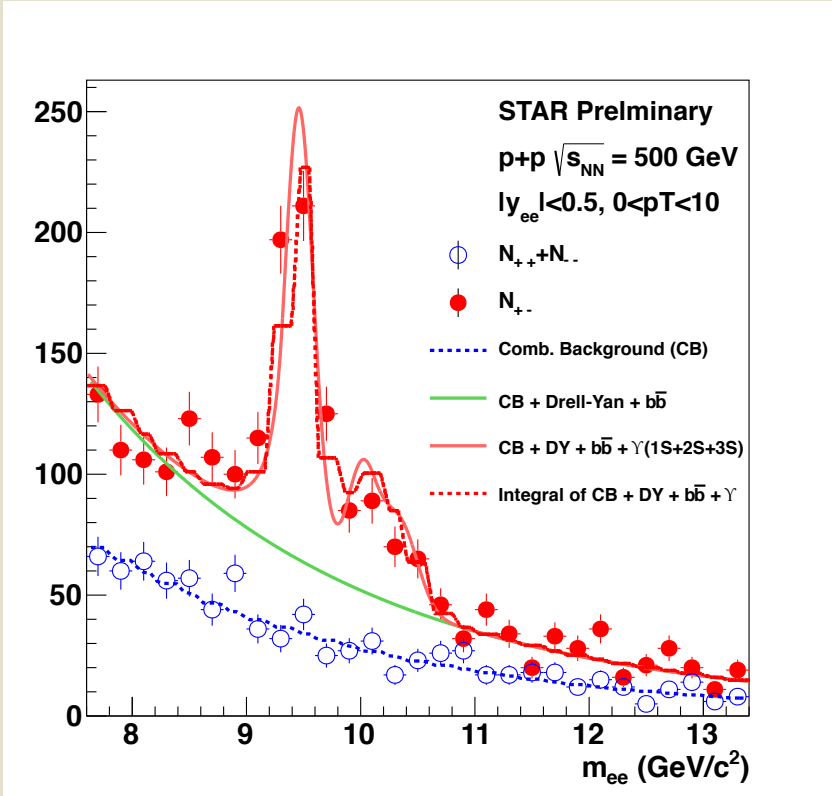


Au+Au @ 200 GeV, 2011

- Same setup as in 2010
- ~2800 ub^{-1}

Au+Au @ 200 GeV, 2014

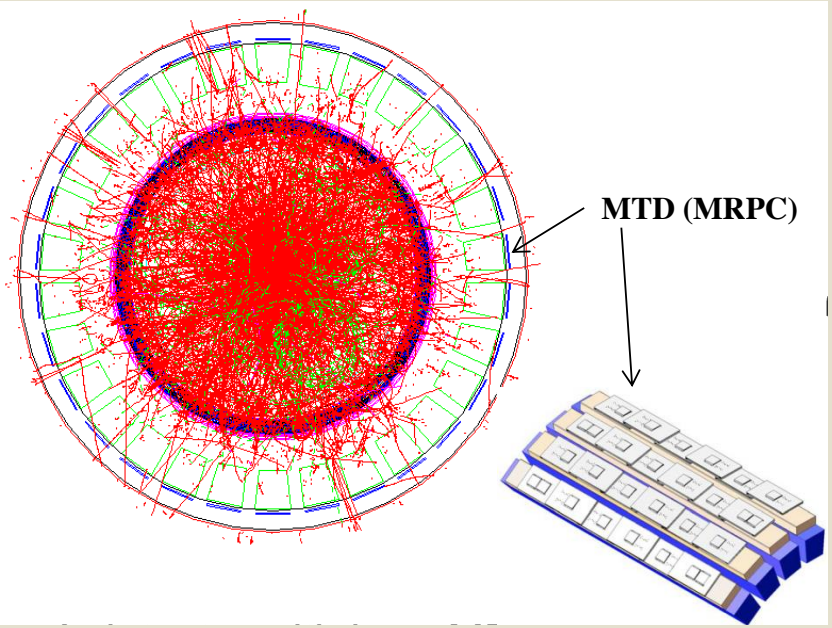
- ~13.8 nb^{-1} sampled by MTD
- MTD and HFT full installed

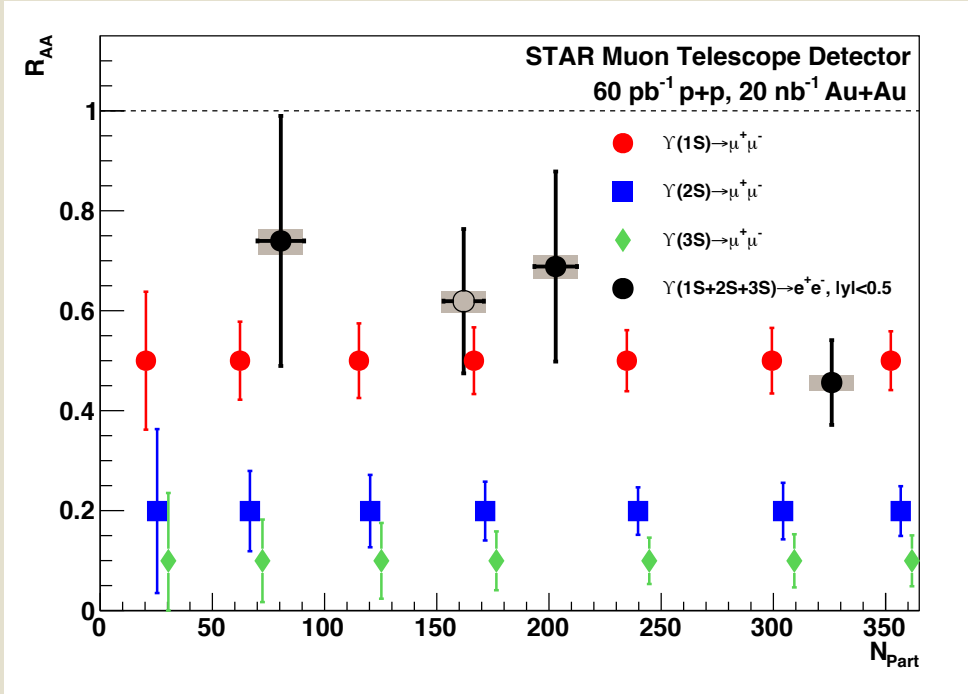


p+p @ 500 GeV, 2011

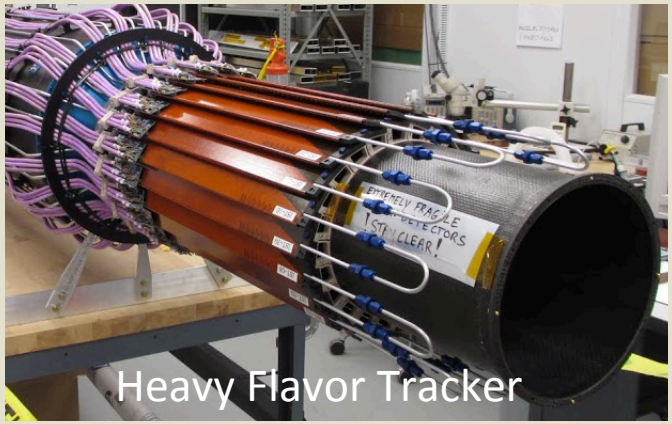
- High energy doubles Upsilon cross section
- Excited-to-ground ratio
- P_T spectrum
- Preliminary results available soon
- ~22 pb^{-1}

Outlook





Adapted from J. Bielcik, Hard Probes 2013



Conclusions

- Measured Υ production in p+p, d+Au, and Au+Au collisions at 200 GeV
- Au+Au results consistent with 2S and 3S suppression
- d+Au results hint at additional suppression beyond model calculations
  - Further studies warranted
- New muon channel will enhance and compliment our electron measurements

Thank you