Measurements of the Υ meson production in Au+Au collisions at the STAR experiment

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Outline of the talk

1. Heavy quarkonia as a QGP probe
2. The STAR experiment
3. Latest Υ results in p+p, p+Au, and Au+Au collisions at RHIC
4. Comparison with LHC results and models
5. Summary and outlook

Heavy quarkonia in QGP

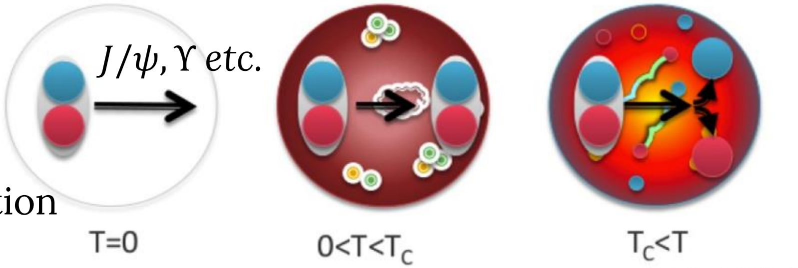
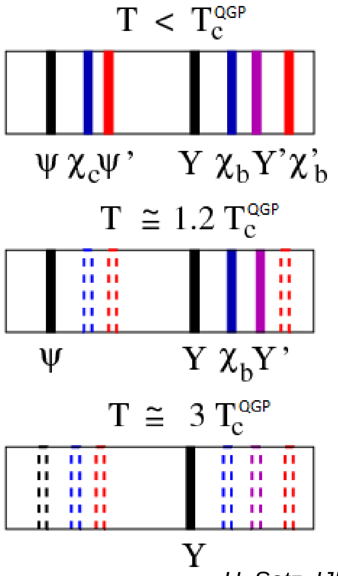


Illustration: A. Rothkopf

- $J/\psi, \Upsilon$ etc. are good candidates to probe QGP
  - $c\bar{c}$, $b\bar{b}$ pairs created mostly before the QGP formation
  - Production cross-section in p+p collisions can be calculated based on pQCD

- Dissociation by colour screening *T. Matsui, H. Satz, PLB 178 (1986) 416*
  - Quarkonium expected to *dissociate* when its radius exceeds the Debye radius: $r_{\mathrm{Debye}} \propto 1/T$

- Sequential melting *A. Mocsy, EPJ C61 (2009) 705*
  - Dissociation depends on the quarkonium binding energy
  - Different states expected to melt at different temperatures
  - QGP *thermometer*



H. Satz, IJMPA 28 (2013)

Other effects also play a role

- Other phenomena complicate the measured quarkonium suppression
- Statistical recombination
  - Coalescence of deconfined quarks at QGP phase boundary

I. Das, QM2015, https://indico.cern.ch/event/355454/contributions/838966/

	RHIC 200 GeV	LHC 2.76 TeV
$\#c\bar{c}$ / event	13	115
$\#b\bar{b}$ / event	0.1	3

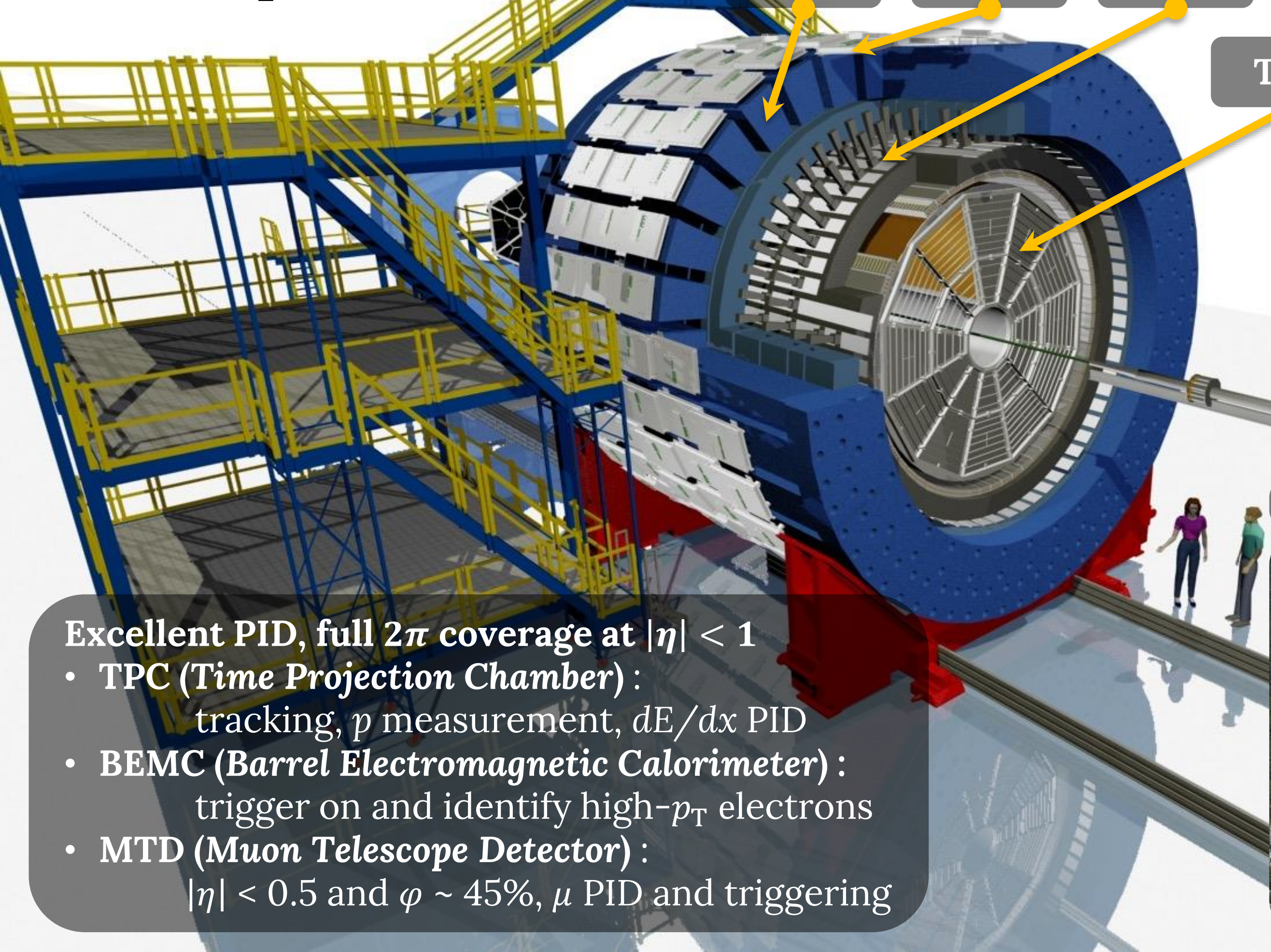
- Cold nuclear matter (CNM) effects
  - Initial state: shadowing, energy loss
  - Final state: inelastic interactions with hadrons
    → nuclear break-up
    → co-mover absorption
  - Can be studied in p+A collisions
- Feed-down

For $\Upsilon's$ at RHIC $\sqrt{s_{\mathrm{NN}}} = 200$ GeV :

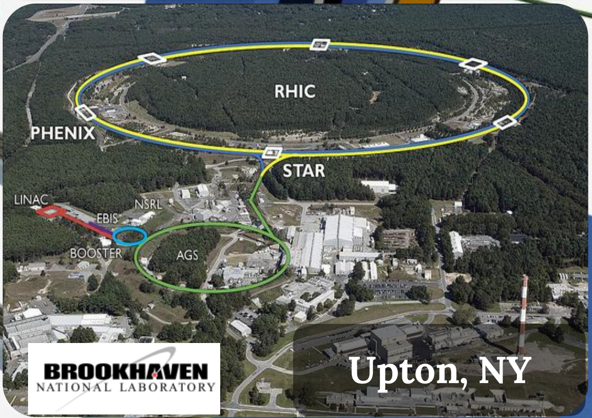
- no recombination *A. Emerick, X. Zhao, R. Rapp, EPJ A48 (2012) 72*
- less co-mover absorption *Z. Lin, C. Ko, PLB 503 (2001) 104*

→ ***cleaner probe!***

STAR experiment



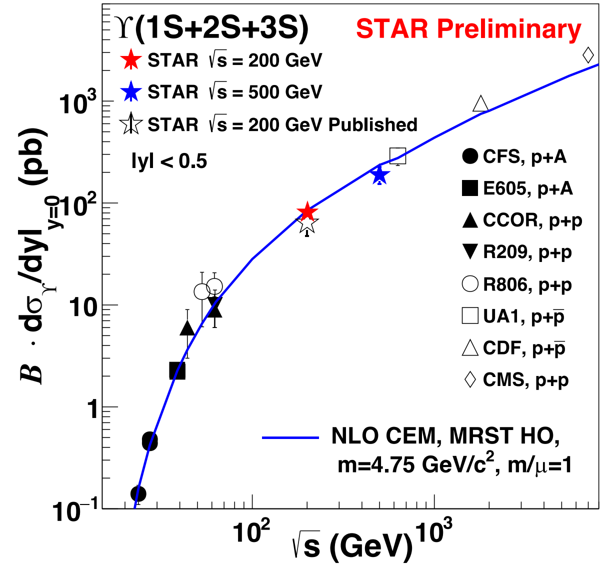
RHIC (*Relativistic Heavy Ion Collider*)

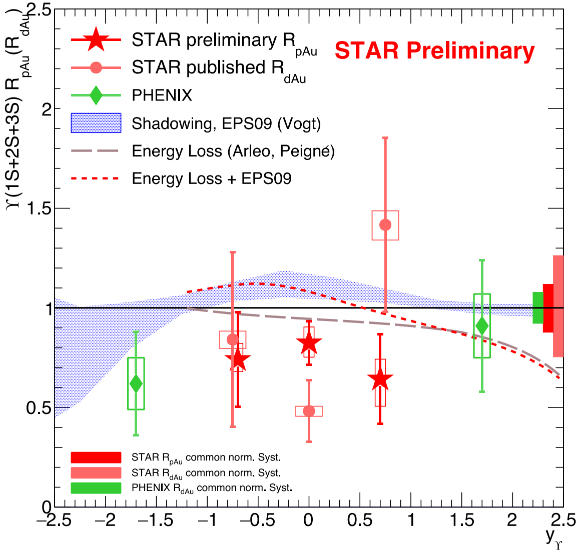


Excellent PID, full 2π coverage at $|\eta| < 1$

- **TPC (*Time Projection Chamber*)** :
  tracking, p measurement, dE/dx PID
- **BEMC (*Barrel Electromagnetic Calorimeter*)** :
  trigger on and identify high-p_T electrons
- **MTD (*Muon Telescope Detector*)** :
  $|\eta| < 0.5$ and φ ~ 45%, μ PID and triggering

Results from p+p and p+Au collisions





- **p+p** : precise baseline for comparison with Au+Au collisions

  → improved precision: $\sigma = 64 \pm 10\,(\text{stat.}) \pm 14\,(\text{syst.})$ pb → $81 \pm 5\,(\text{stat.}) \pm 8\,(\text{syst.})$ pb

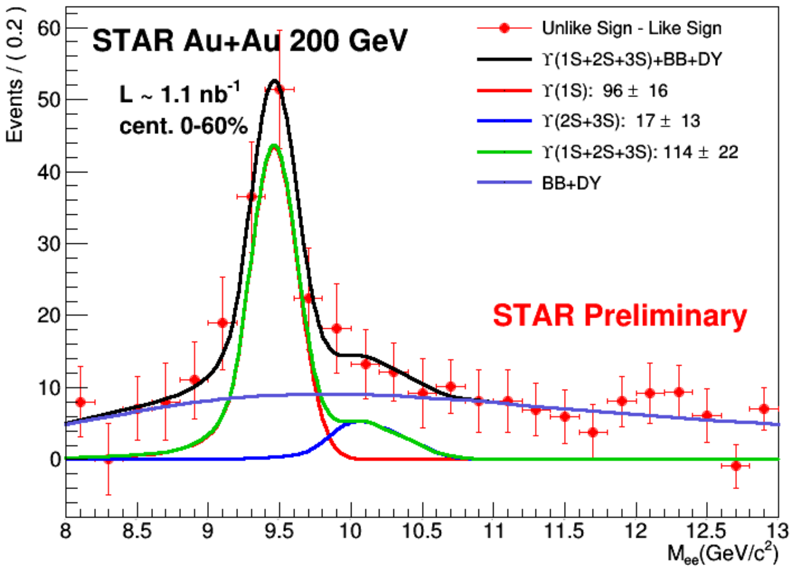
  → consistent with the Colour Evaporation Model (CEM) prediction

  A.Frawley, T.Ullrich, R.Vogt, PR 462 (2008) 125

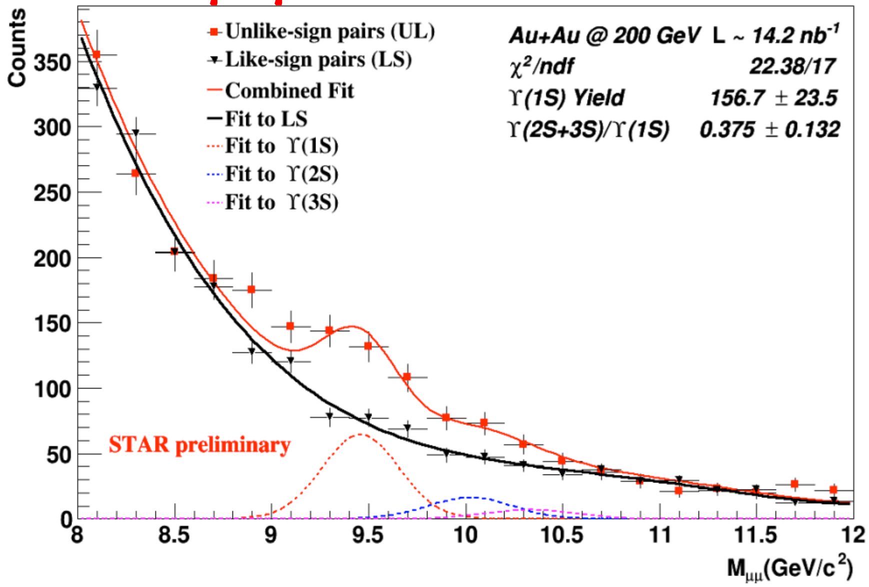
- **p+Au** : quantification of CNM effects with $R_{\text{pAu}} = 0.82 \pm 0.10\,(\text{stat.})\,^{-0.07}_{+0.08}\,(\text{syst.}) \pm 0.10\,(\text{global})$

Signal in Au+Au collisions

$\Upsilon \rightarrow e^+e^-$ *2011 data*



$\Upsilon \rightarrow \mu^+\mu^-$ *2014 data*



- Background sources:

  → combinatorial background (estimated as $N_{l^+l^+} + N_{l^-l^-}$)

  → Drell-Yan di-leptons, $B\bar{B}$ semi-leptonic decays

Results from Au+Au collisions

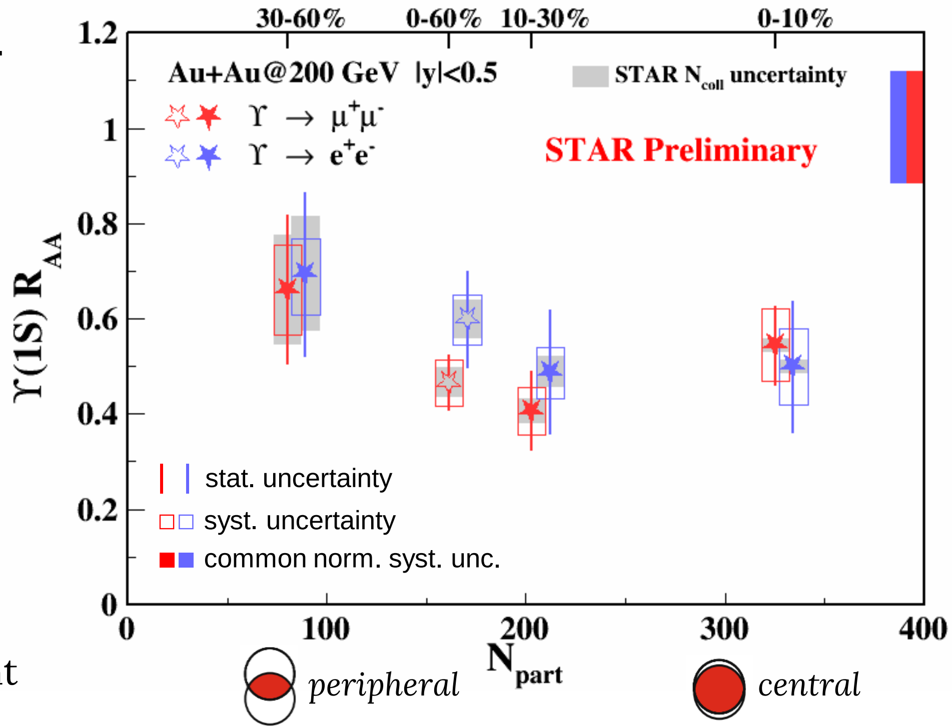
- Nuclear modification factor

  $R_{AA} = \frac{\sigma_{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T dy}{d^2 \sigma_{pp}/dp_T dy}$ as a function of mean number of participants N_{part}

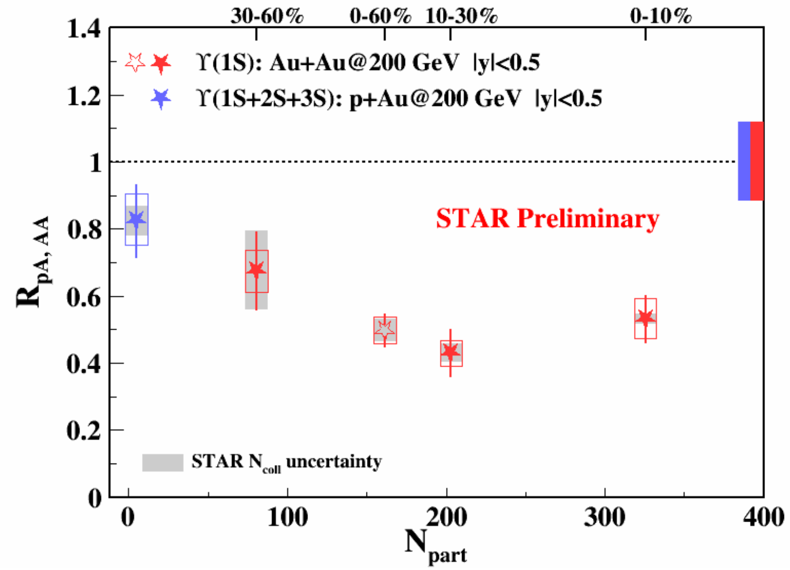
- ☆ is a combination of ★ results

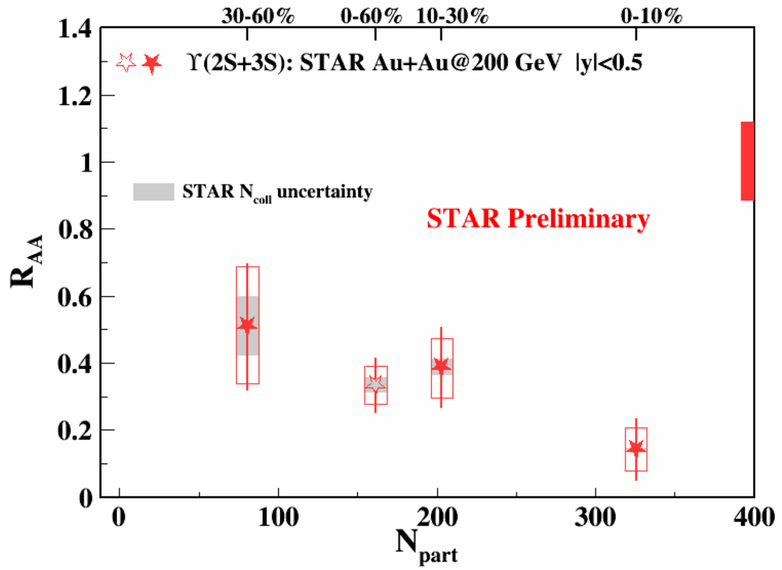
- **Di-muon** and **di-electron** results consistent with each other within the uncertainties

  → ***results combined for increased statistical precision***



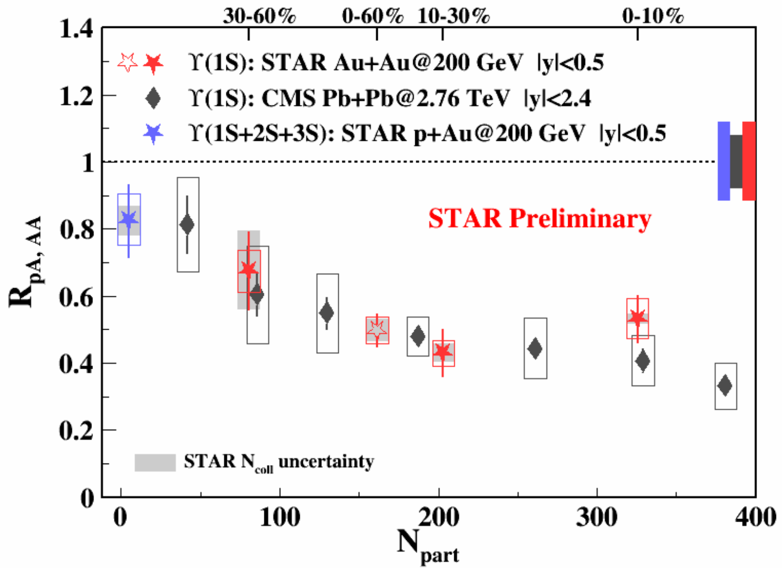
R_{AA} vs. N_{part} at RHIC

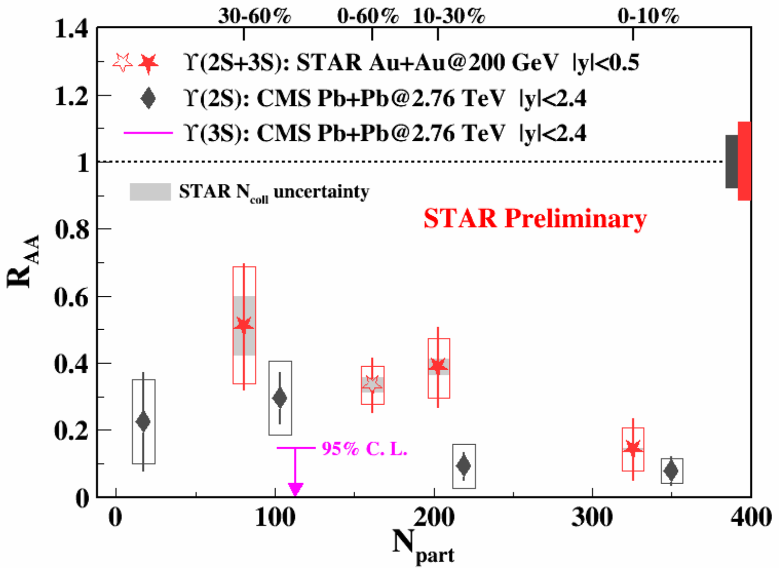




- $\Upsilon(2S), \Upsilon(3S)$ states ***more suppressed*** than $\Upsilon(1S)$ in central collisions

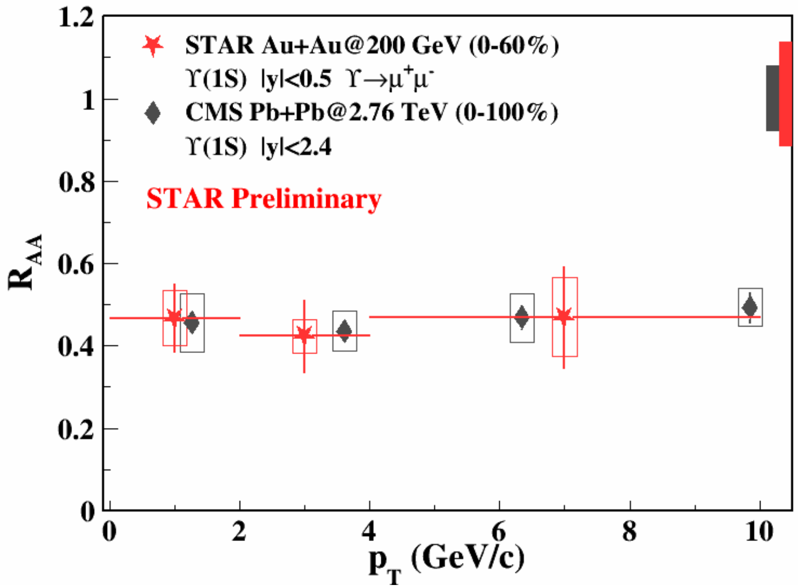
Compare RHIC with LHC

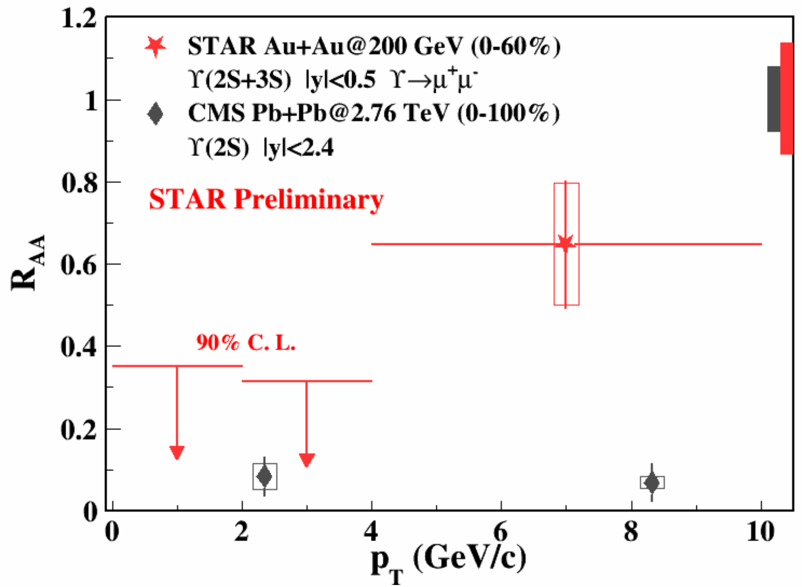




- $\Upsilon(2S), \Upsilon(3S)$ states ***more suppressed*** than $\Upsilon(1S)$ in central collisions
- Comparison with LHC: *CMS, PRL 109 (2012)*
  → solid consistency for $\Upsilon(1S)$
  → hint of ***less suppression*** for $\Upsilon(2S), \Upsilon(3S)$ at RHIC than at LHC

Suppression vs p_T





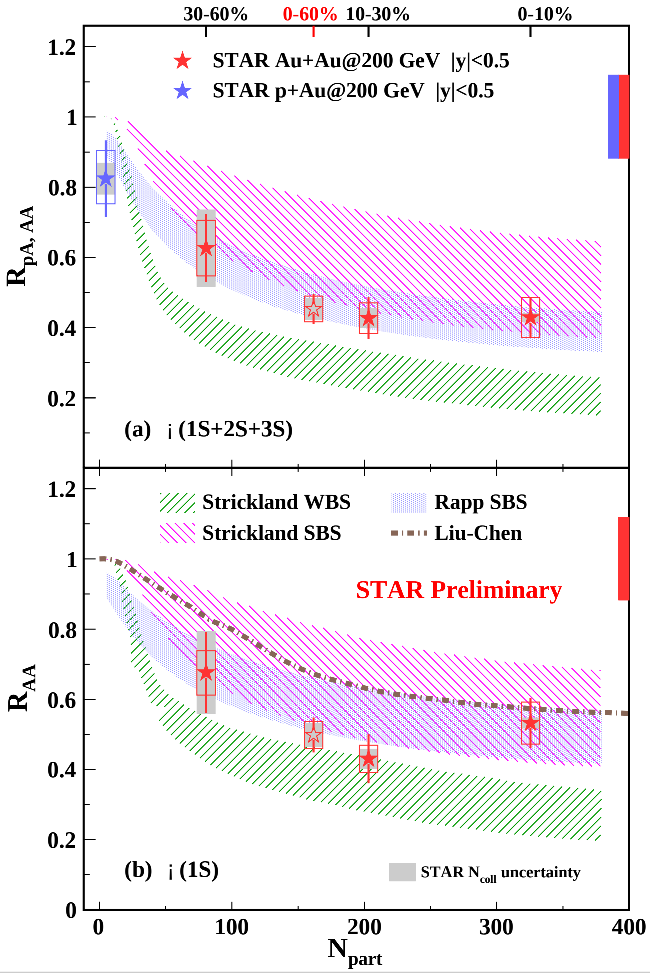
***RHIC** vs. LHC*

- Consistent for $\Upsilon(1S)$
- Signs of ***less suppression*** at high-p_T for $\Upsilon(2S), \Upsilon(3S)$

Comparison with models

- Strickland, Bazov : *NPA 879 (2012) 25*
  - No CNM, no regeneration
  - SBS (Strongly Binding Scenario): fast dissociation–potential based on internal energy
  - WBS (Weakly Binding Scenario): slow dissociation–potential based on free energy
- Liu, Chen, Xu, Zhang : *PLB 697 (2011) 32*
  - No CNM
  - Dissociation only for excited states, suppression of ground state due to feed-down
- Emerick, Zhao, Rapp : *EPJ A48 (2012) 72*
  - Includes CNM, SBS case

→ SBS models favoured by the data



Summary

- **p+p**
  - Improved precision; consistent with the CEM model
- **p+Au**
  - Quantification of the CNM effect: $R_{\mathrm{pAu}} = 0.82 \pm 0.10\,(\mathrm{stat.})\,^{-0.07}_{+0.08}\,(\mathrm{syst.}) \pm 0.10\,(\mathrm{global})$
- **Au+Au**
  - $\Upsilon(1S)$ suppression at RHIC is similar to that at the LHC
  - Direct $\Upsilon(1S)$ may be suppressed; better understanding of CNM effects and feed-down contribution is needed
  - $\Upsilon(2S), \Upsilon(3S)$ more suppressed than $\Upsilon(1S)$ in the most central collisions (sequential melting)
  - $\Upsilon(2S), \Upsilon(3S)$ seem to be less suppressed at RHIC than at LHC
- ***Results can be used to impose constraints on the QGP temperature at RHIC***

Outlook

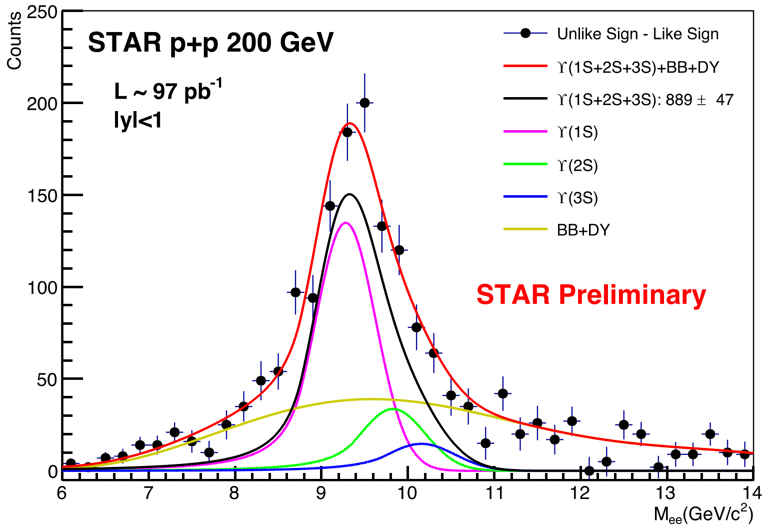
- Analyses from other Au+Au data are underway → increase in statistics by about a factor of 2!

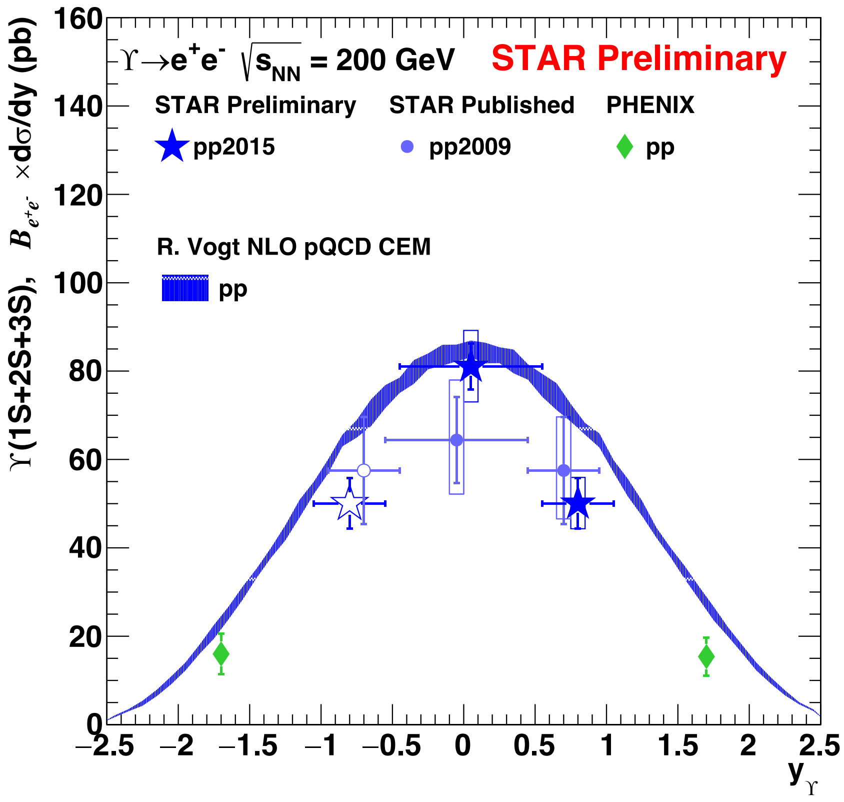
Thanks for your attention!

Back-up slides

Results from p+p

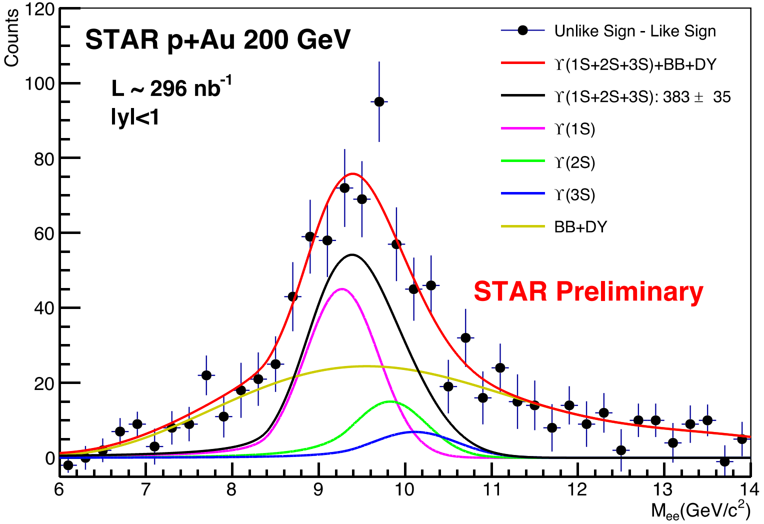
2015 data

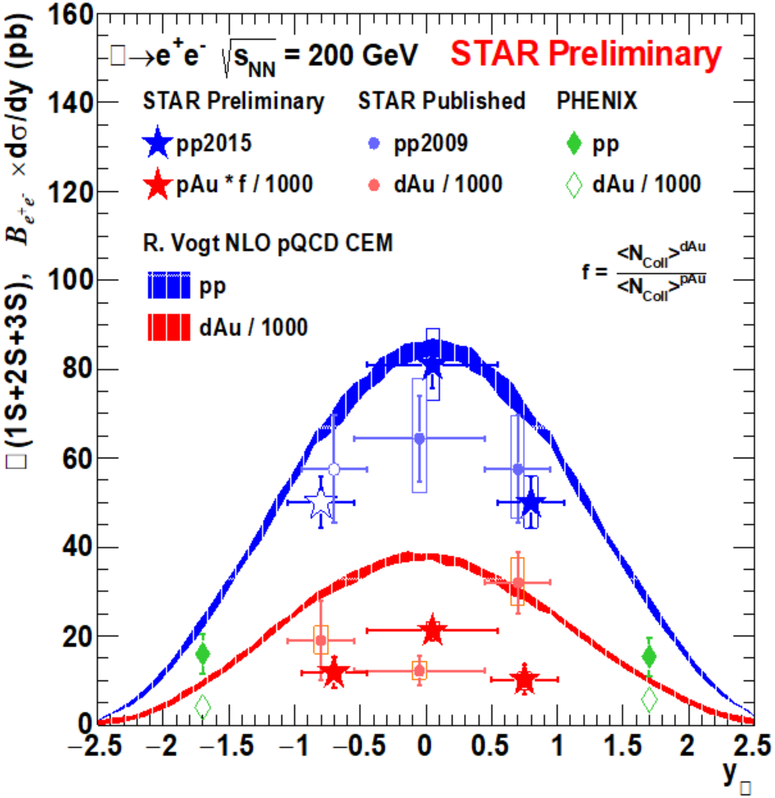




Results from p+Au

2015 data





Excited-to-ground-state ratio