Measurements of the Υ meson production in Au+Au collisions by 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 $\sqrt{s_{\mathrm{NN}}} = 200$ GeV
4. Comparison with LHC results and models
5. Summary and outlook

Heavy quarkonia in QGP

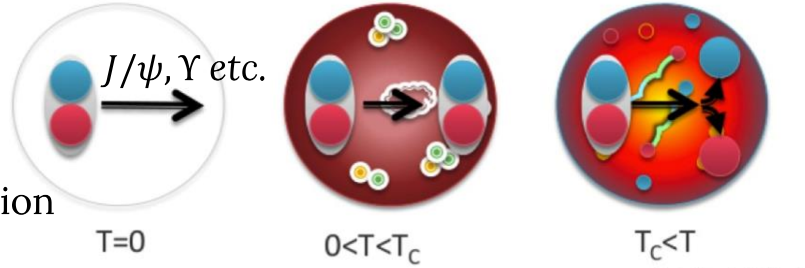
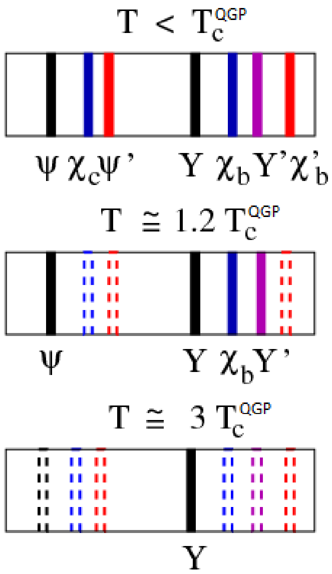


Illustration: A. Rothkopf

- $J/\psi, \Upsilon$ etc. are good candidates to probe QGP
  - $c\bar{c}$, $b\bar{b}$ pairs created mostly before the QGP formation
  - Quarkonium production cross-section can be calculated reasonably well in p+p collisions
- Dissociation by colour screening *T. Matsui, H. Satz, PLB 178 (1986) 416*
  - Quarkonium expected to *dissociate* if its radius is greater than 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 interpretation of the measured quarkonium suppression
- Statistical recombination
  - Coalescence of deconfined quarks at QGP phase boundary
- Cold nuclear matter (CNM) effects
  - Initial state: nPDF, energy loss
  - Final state: inelastic interactions with hadrons
  - → nuclear break-up
  - → co-mover absorption
  - Can be studied in p+A collisions
- Feed-down

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

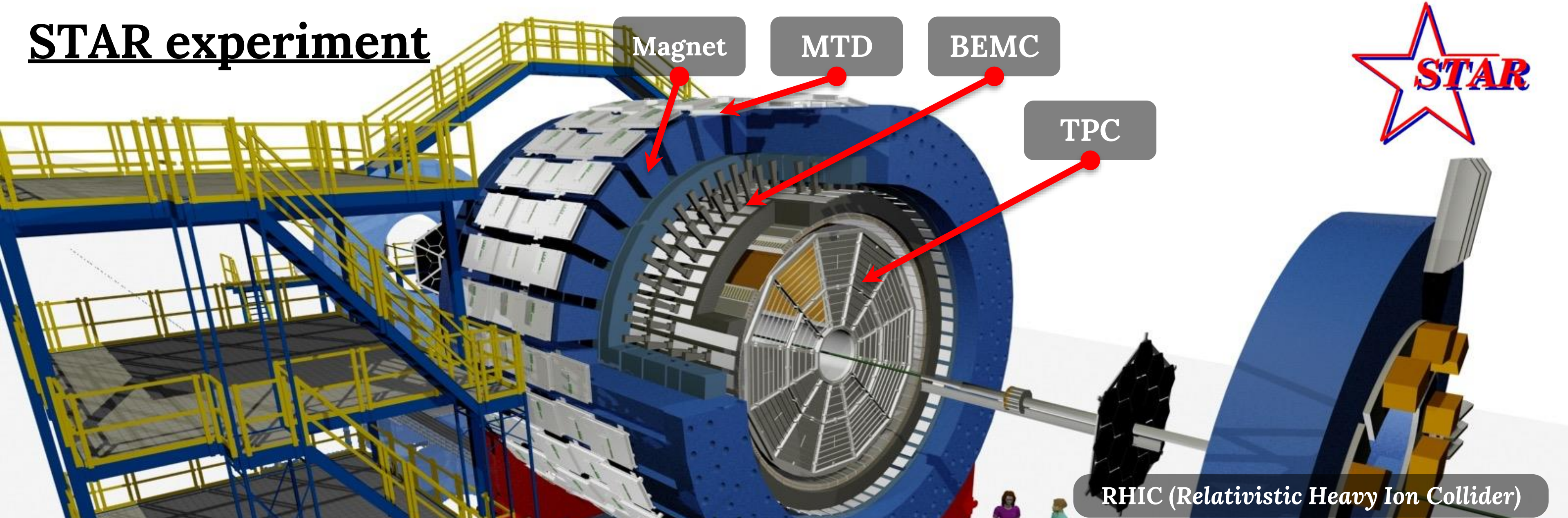
	RHIC 200 GeV	LHC 2.76 TeV
$\#c\bar{c}$ / event	13	115
$\#b\bar{b}$ / event	0.1	3

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!***

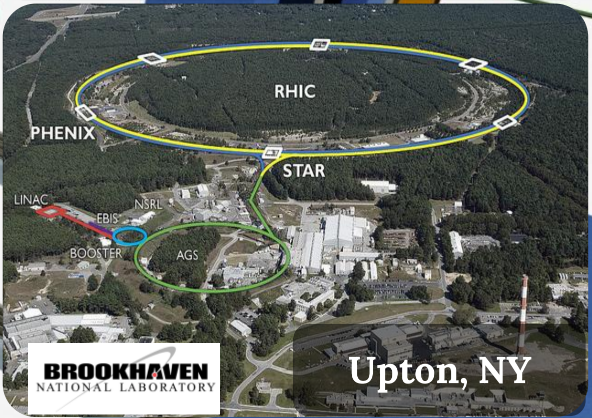
STAR experiment



Excellent PID, full 2π coverage at $|\eta| < 1$ (except MTD)

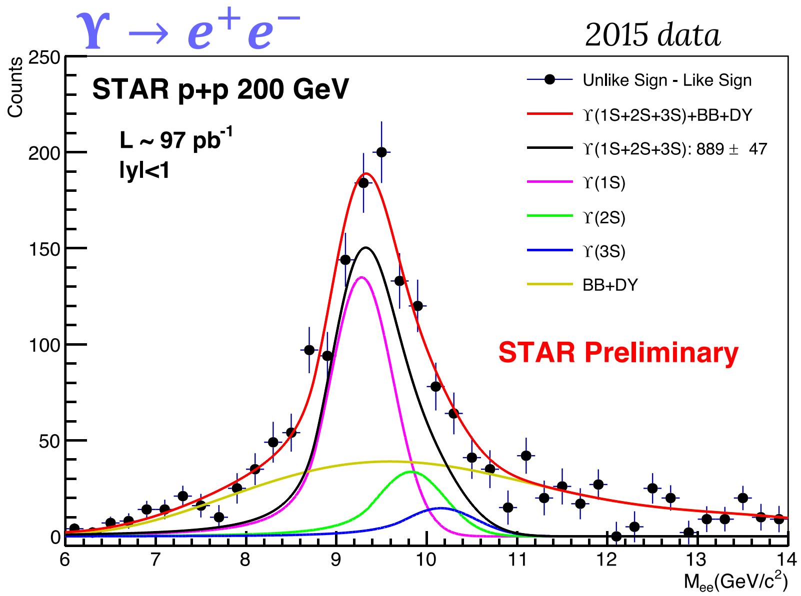
- **TPC (*Time Projection Chamber*)** :
  tracking, momentum measurement, dE/dx PID
- **BEMC (*Barrel Electromagnetic Calorimeter*)** :
  trigger on and identify high-p_T electrons
- **MTD (*Muon Telescope Detector*)** :
  $|\eta| < 0.5$ and φ ~ 45%, muon PID and triggering

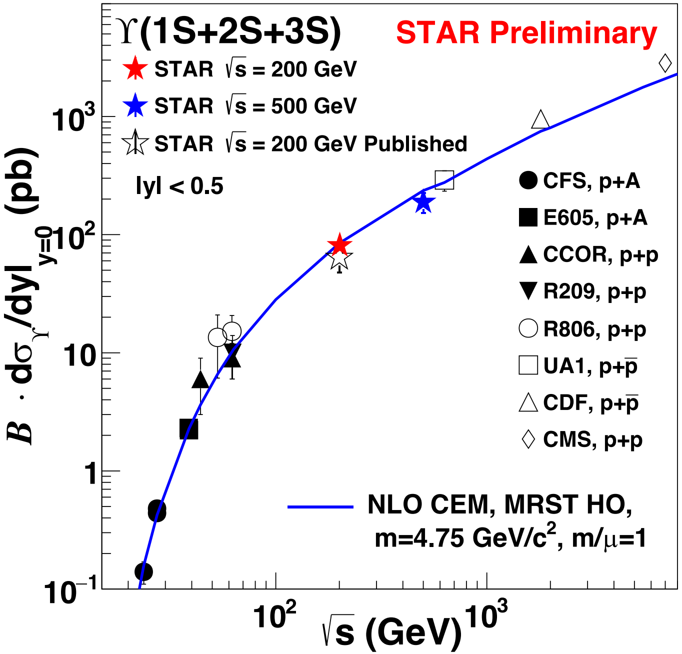
RHIC (*Relativistic Heavy Ion Collider*)



Upton, NY

Results from p+p collisions





- Precise baseline for comparison with Au+Au collisions

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

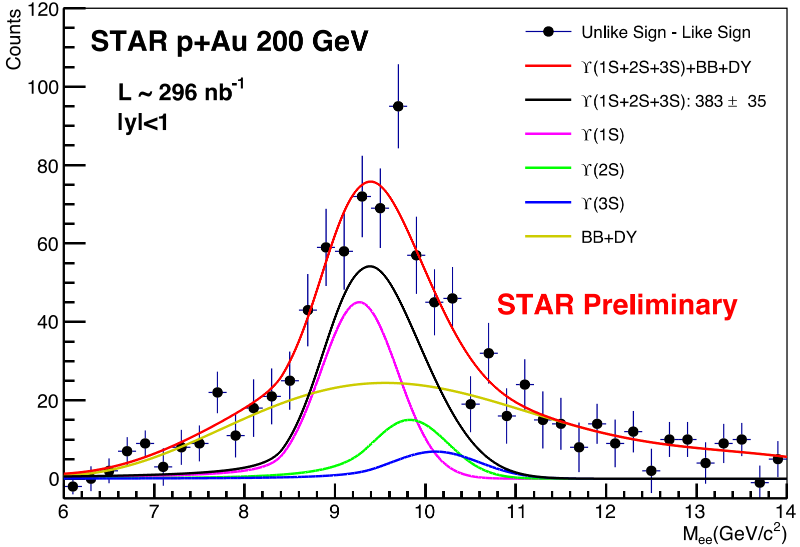
→ consistent with the Colour Evaporation Model (CEM) prediction

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

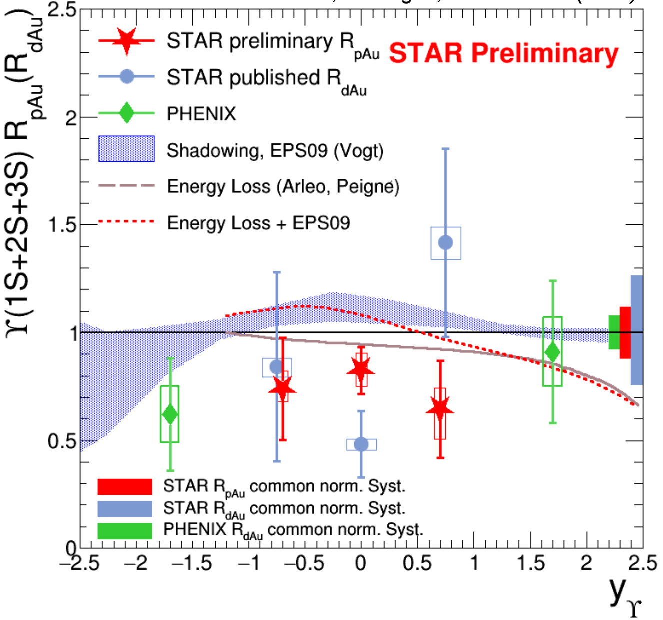
Results from p+Au collisions

$\Upsilon \to e^+e^-$

2015 data



STAR, PLB 735 (2014) 127
PHENIX, PRC 87 (2013)
F. Arleo, S. Peigné, JHEP03 122 (2013)



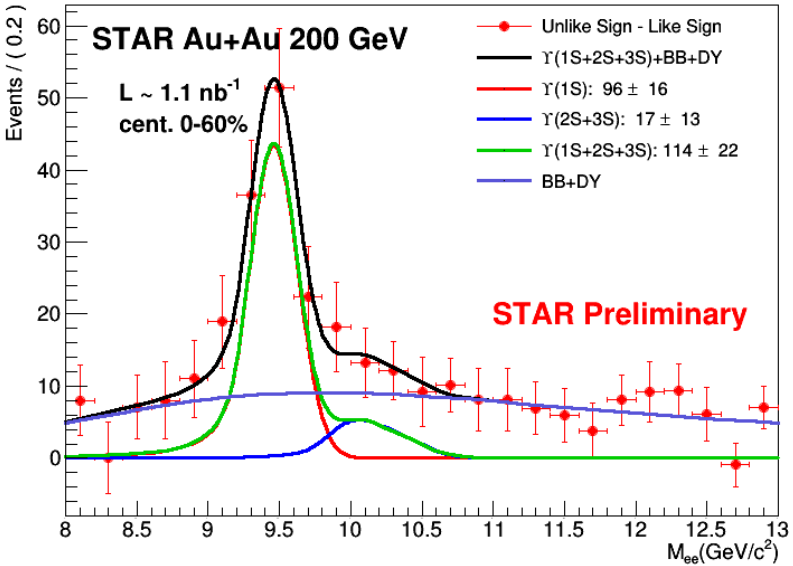
- Quantification of CNM effects with nuclear modification factor

$$\boldsymbol{R_{\mathrm{pAu}}(|y| < 0.5) = 0.82 \pm 0.10\,(\mathrm{stat.})\,^{-0.07}_{+0.08}\,(\mathrm{syst.}) \pm 0.10\,(\mathrm{global})}$$

Signal in Au+Au collisions

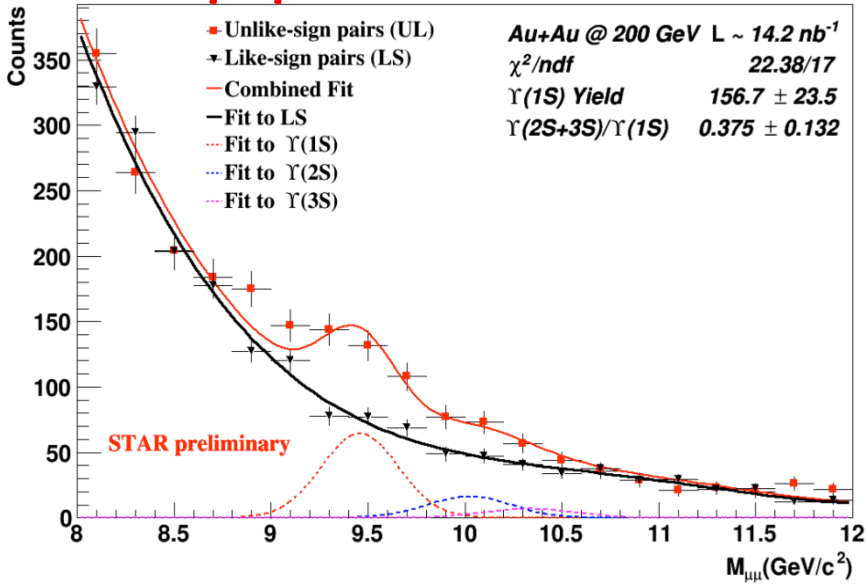
$\Upsilon \rightarrow e^+e^-$

2011 data



$\Upsilon \rightarrow \mu^+\mu^-$

2014 data



- Background sources:

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

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

Results from Au+Au collisions

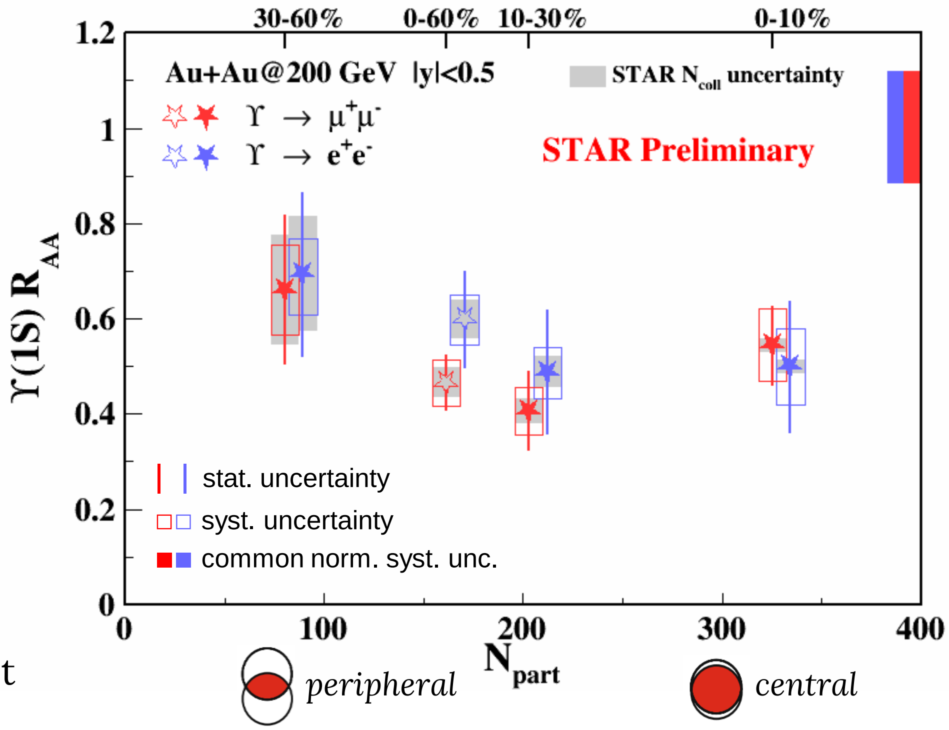
- Nuclear modification factor

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

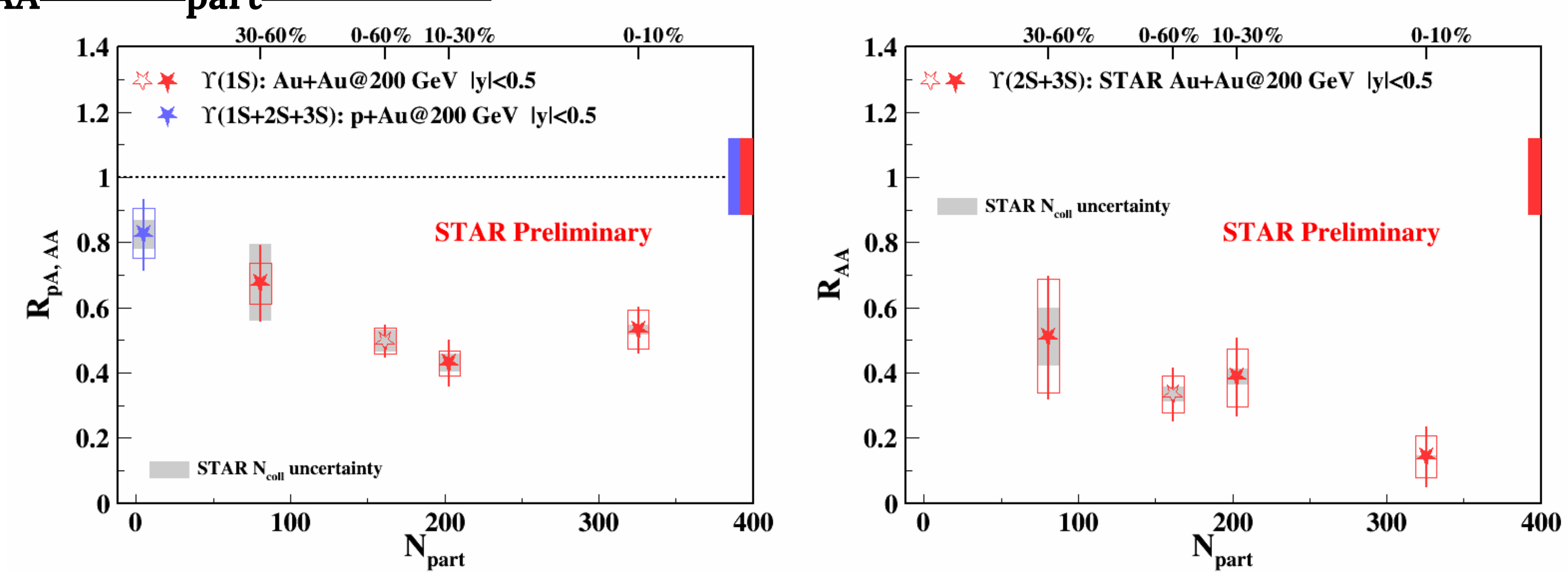
- ☆ is a combination of ★ results

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

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

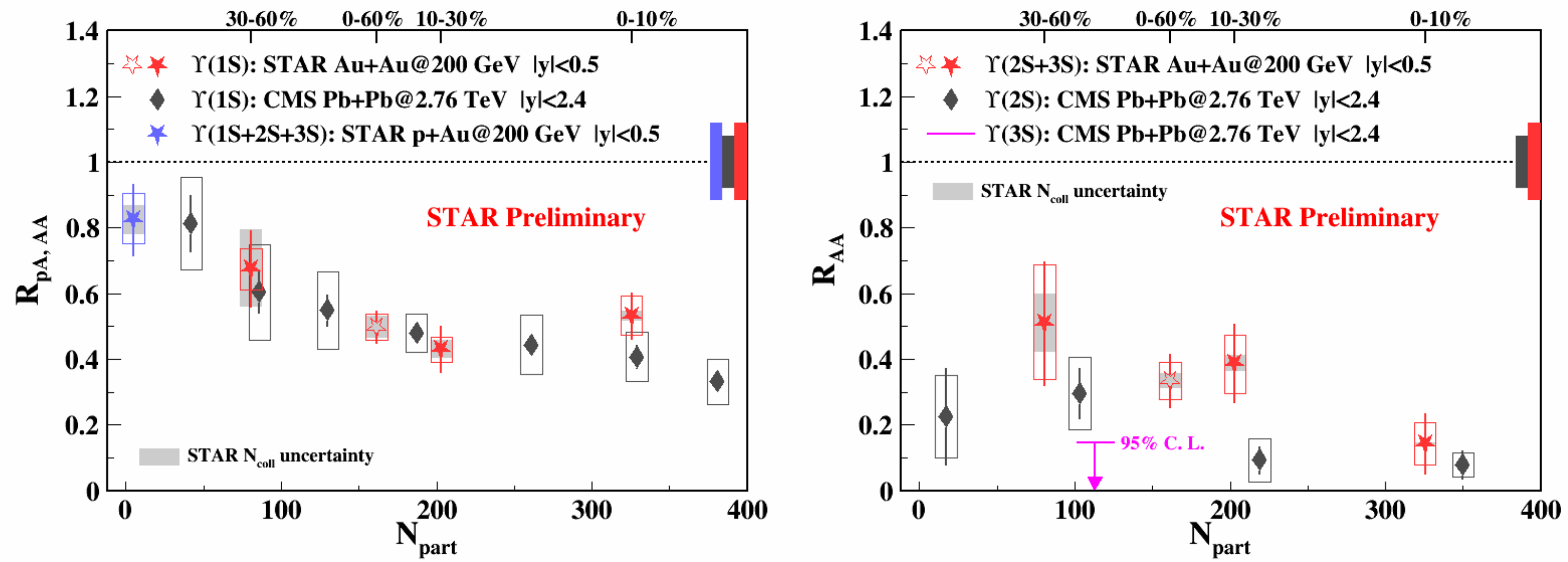


R_{AA} vs. N_{part} at RHIC



- $\Upsilon(2S{+}3S)$ ***more suppressed*** than $\Upsilon(1S)$ in central collisions

Compare RHIC with LHC

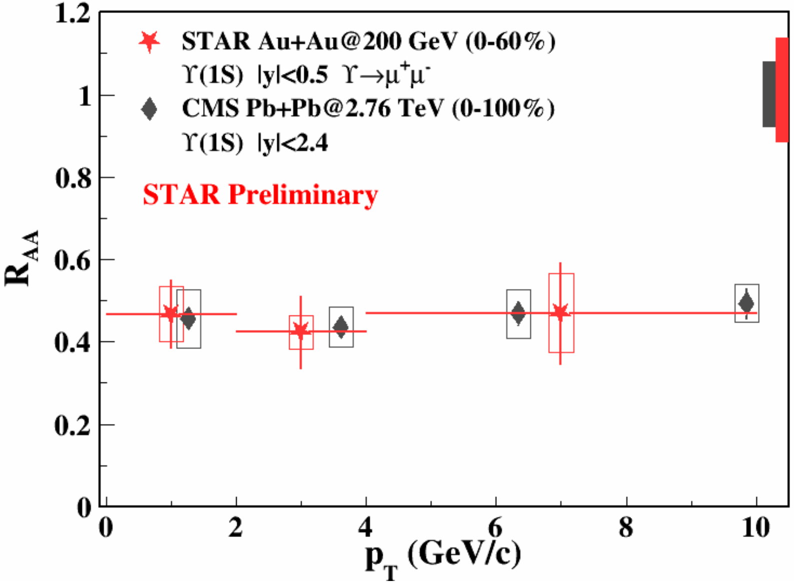


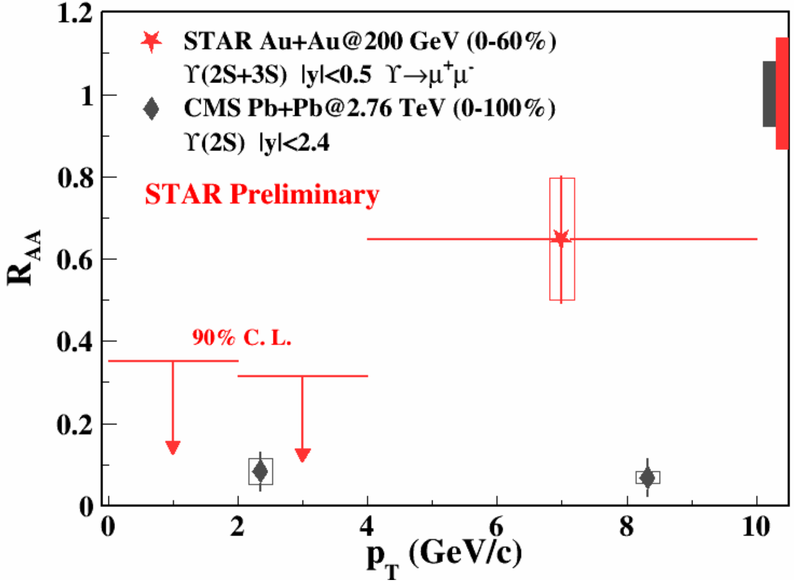
- $\Upsilon(2S{+}3S)$ ***more suppressed*** than $\Upsilon(1S)$ in central collisions
- Comparison with LHC: *CMS, PLB 770 (2017) 357*

  → comparable suppression for inclusive $\Upsilon(1S)$

  → hint of ***less suppression*** for $\Upsilon(2S{+}3S)$ at RHIC than at LHC

Suppression vs. p_{T}





RHIC vs. LHC

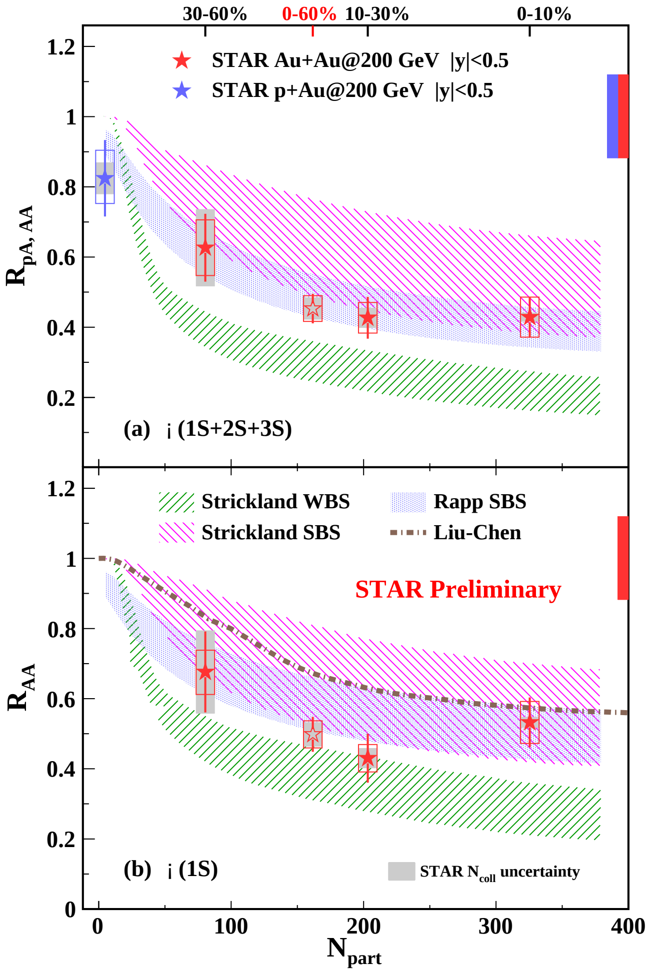
CMS, PLB 770 (2017) 357

- Comparable suppression for inclusive $\Upsilon(1S)$
- Signs of ***less suppression*** at high-p_{T} for $\Upsilon(2S{+}3S)$

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, SBS case
    - 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: $R_{\mathrm{pAu}}(|y| < 0.5) = 0.82 \pm 0.10\ (\mathrm{stat.})\ {}^{-0.07}_{+0.08}\ (\mathrm{syst.}) \pm 0.10\ (\mathrm{global})$
- **Au+Au**
    - Inclusive $\Upsilon(1S)$ suppressed at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV
    - $\Upsilon(2S+3S)$ more suppressed than $\Upsilon(1S)$ in the most central collisions (sequential melting)
    - Inclusive $\Upsilon(1S)$ suppression at RHIC is similar to that at the LHC
    - $\Upsilon(2S+3S)$ seem to be less suppressed at RHIC than at the LHC
- ***Results can be used to impose constraints on the QGP temperature at RHIC***

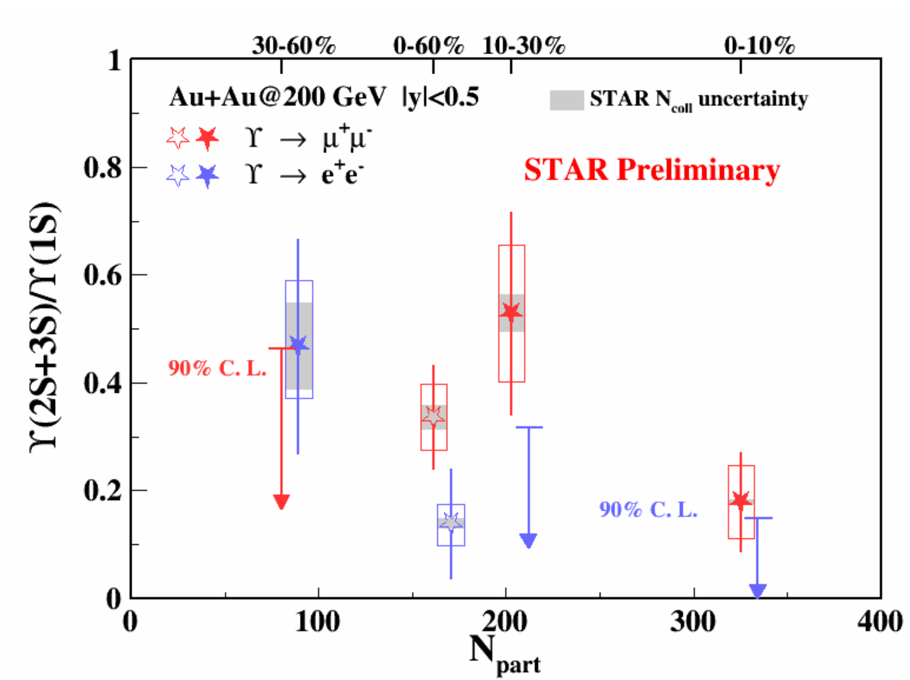
Outlook

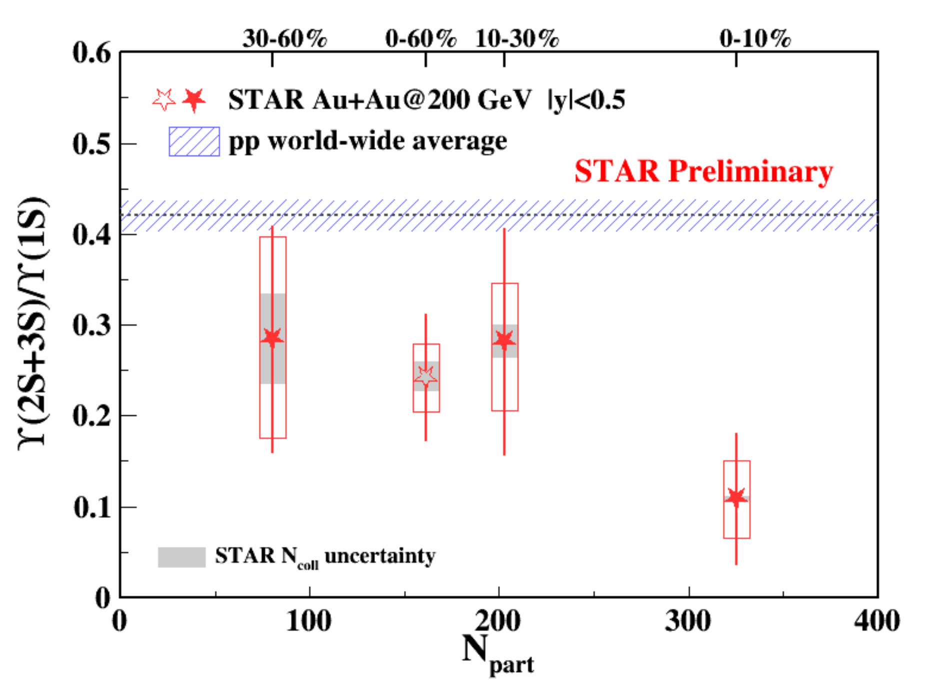
- Analyses using other Au+Au data are underway → increase in statistics by about a factor of 2

Thanks for your attention!

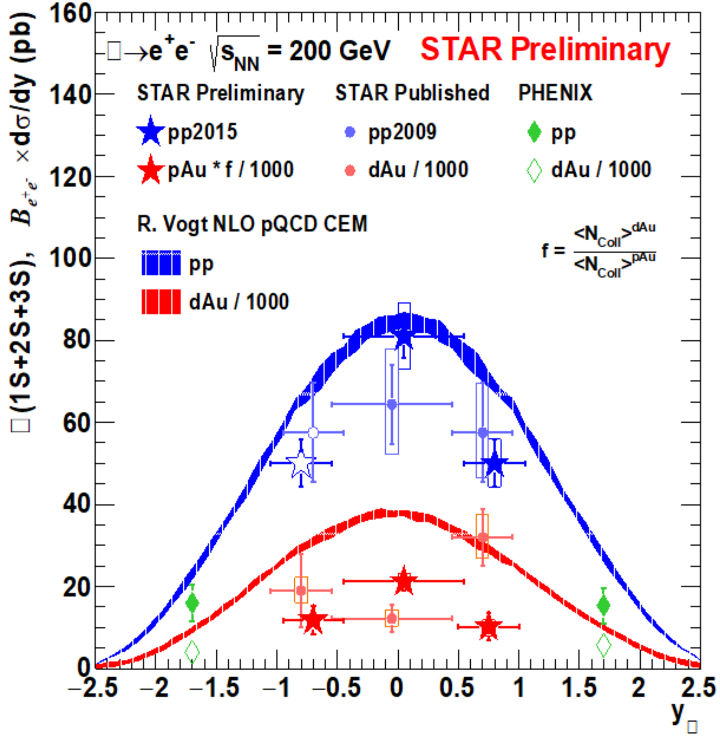
Back-up slides

Excited-to-ground-state ratio





Rapidity dependence



Runs

system:	**p+p**	**p+Au / d+Au**	**Au+Au**
published:	2009	2008	2010
shown:	2015	2015	2011+2014