Quarkonium measurements in heavy-ion collisions at the STAR experiment

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Outline

- **Motivation**
- **STAR experiment**
- **J/ψ measurements in p+Au collisions**
- **ϒ measurements in p+Au and Au+Au collisions**
- **Summary**

Quarkonium: sensitive probe to QGP

Heavy quarkonium: heavy mass (m_c = ~1.5 GeV/c^2, m_b = ~ 4.5 GeV/c^2)
➜ early creation.
long lifetime

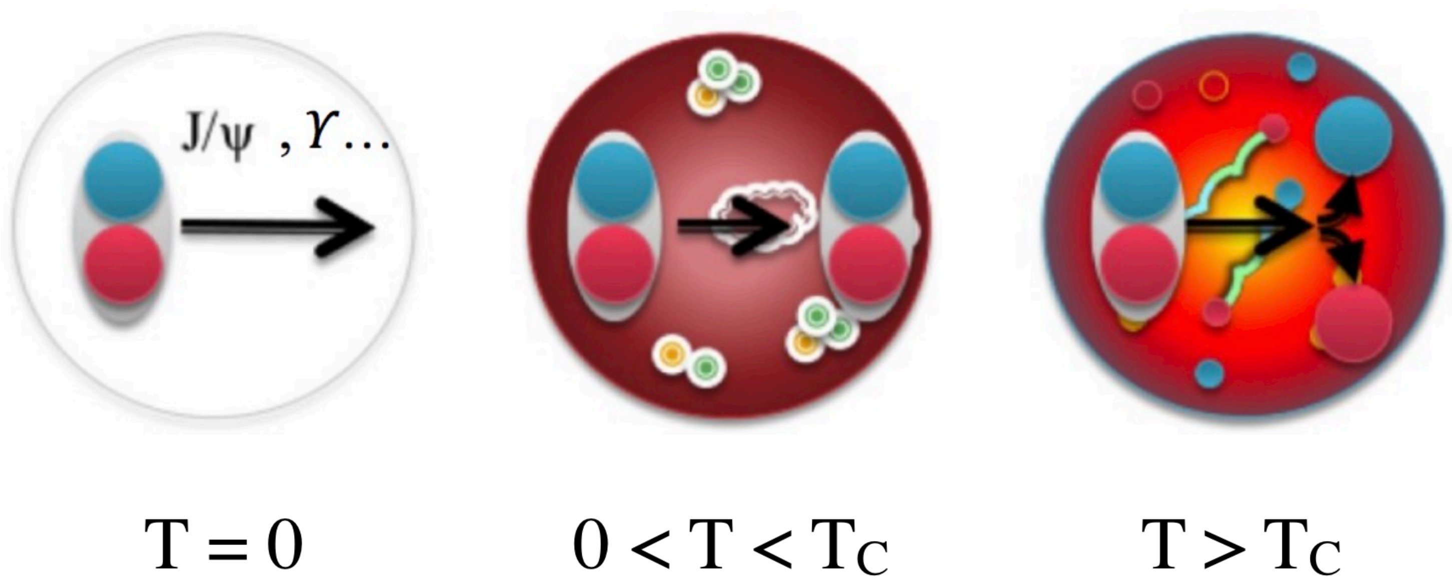


Illustration: A. Rothkopf

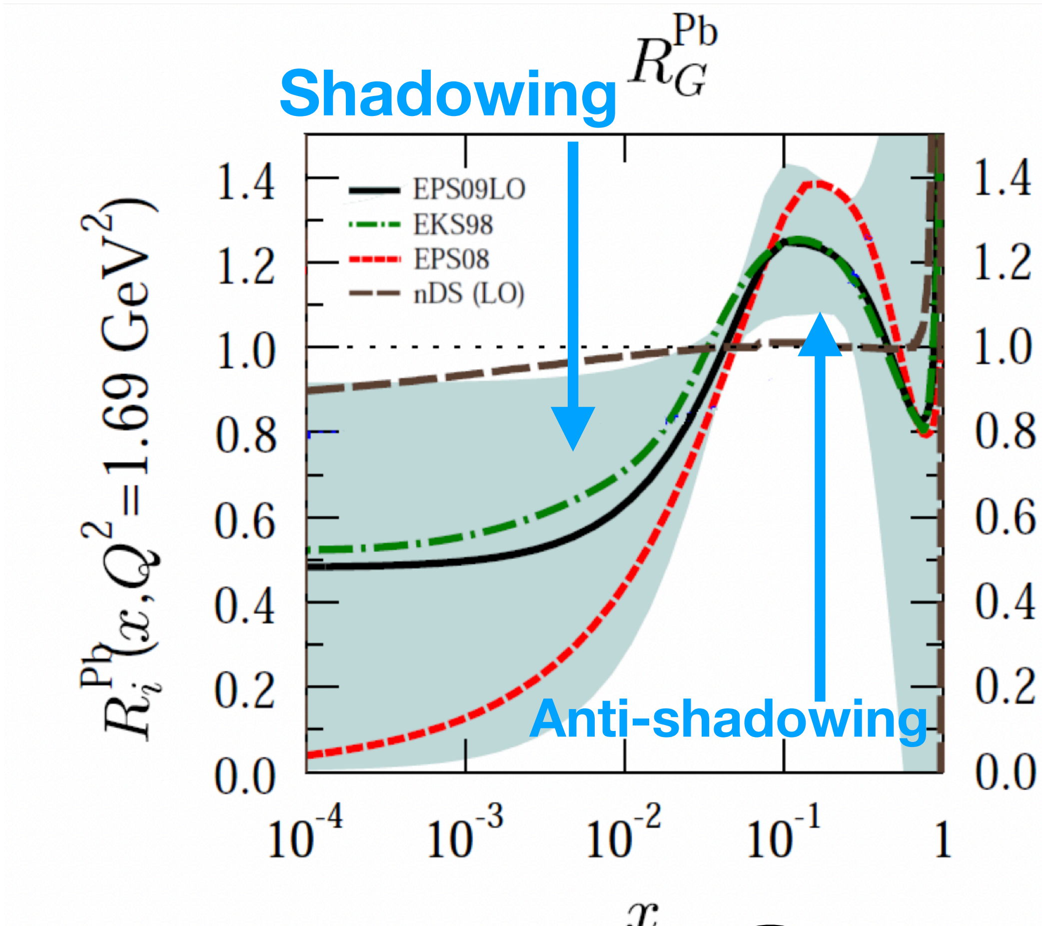
Quarkonium is a sensitive probe of the deconfinement in the QGP: color screening dissociation

Cold nuclear matter effects

- **nPDF effect**

  - Modification of gluon PDF distributions in nucleus

  - Shadowing and Anti-shadowing

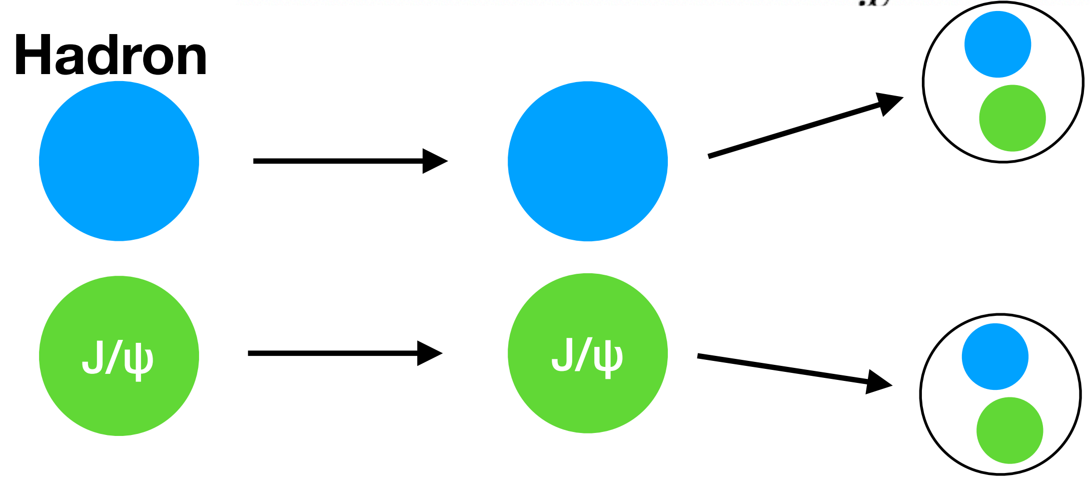


- **Nuclear absorption effect**

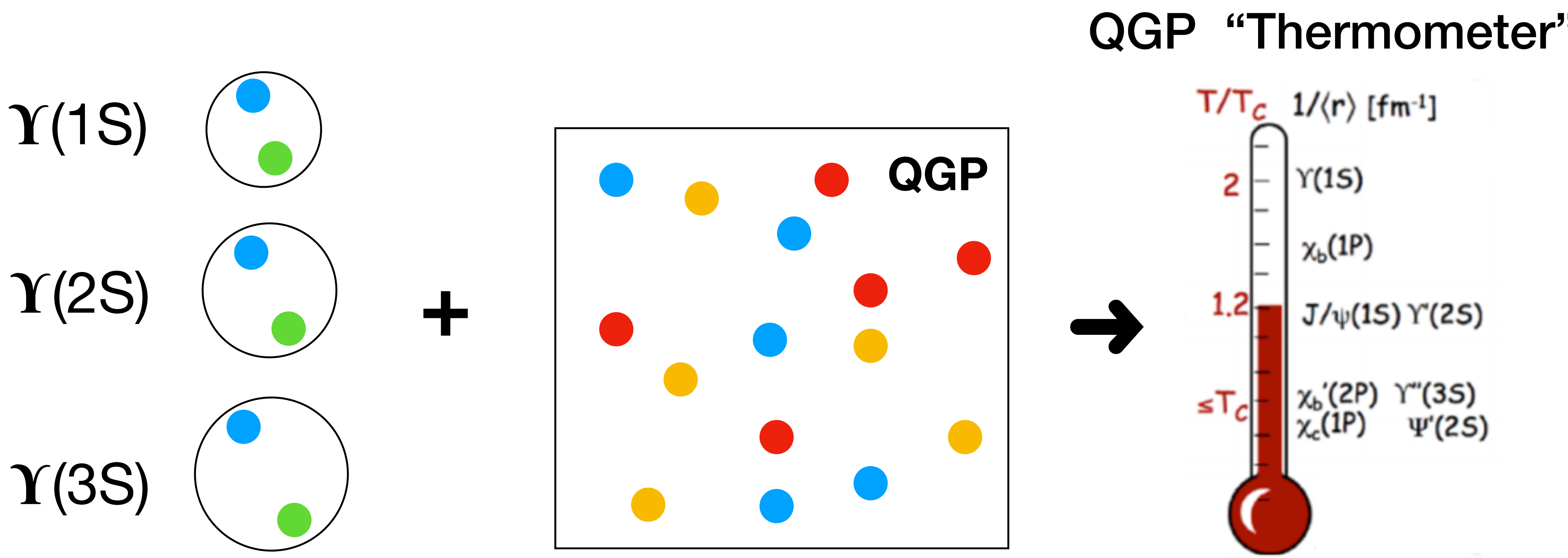
  - Break-up of quarkonium by remnant of incident nuclei.

- **Co-mover effect**

  - Break-up of quarkonium by co-moving hadrons outside of nuclear remnant.



Υ: a cleaner probe at RHIC



Υ is a cleaner probe at RHIC:

- Regeneration is expected to be small

  [A. Emerick, X. Zhao and R. Rapp: EPJ A48, 72 (2012)]
  [X. Du, M. He, and R. Rapp: PRC 96, 054901 (2017)]

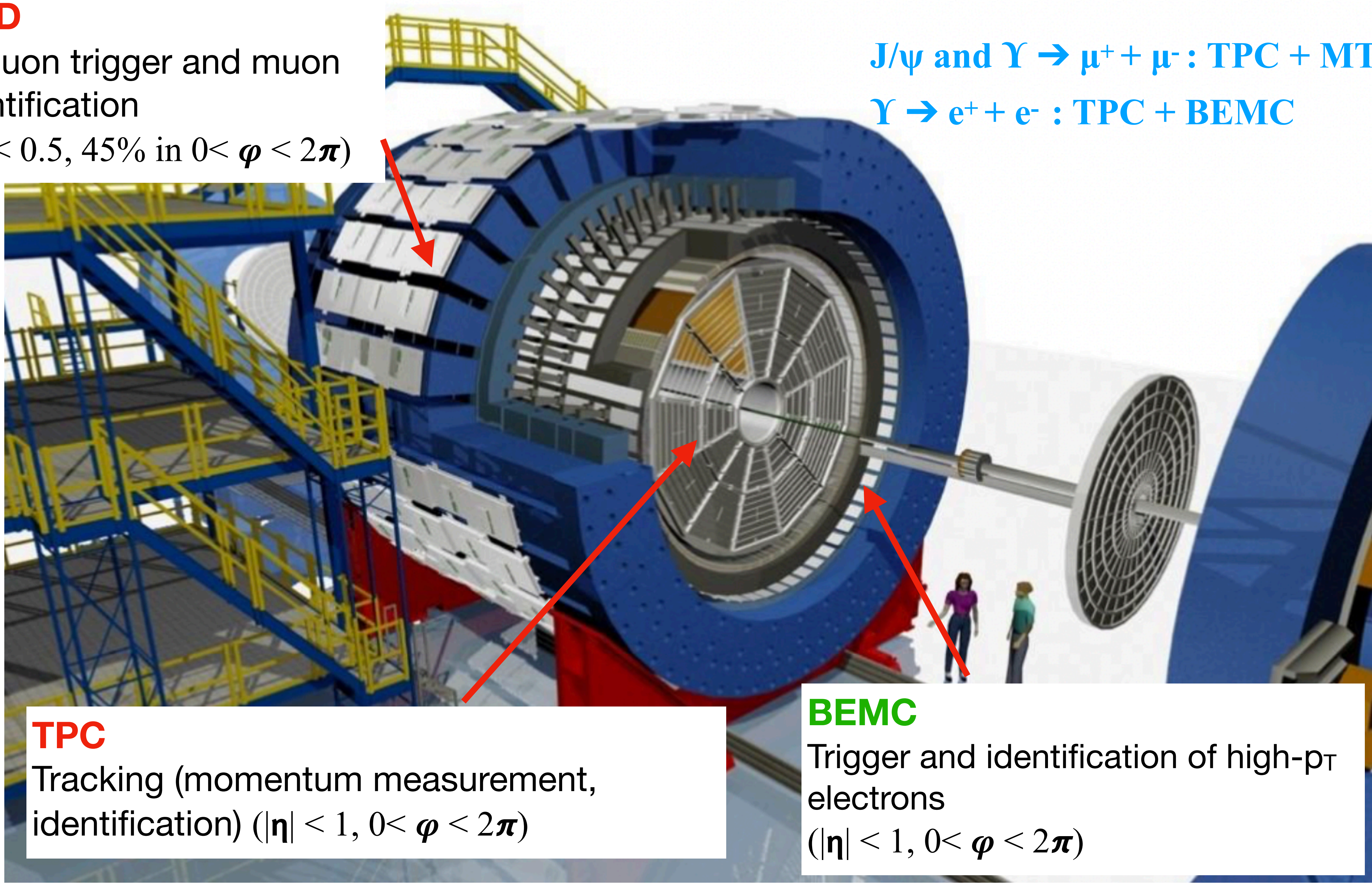
- Co-mover absorption is expected to be small for Υ(1S)

  [Z. Lin and C. Ko: PLB 503, 104 (2001)]

The Solenoidal Tracker at RHIC

MTD
Dimuon trigger and muon identification
($|\eta| < 0.5$, 45% in $0 < \varphi < 2\pi$)

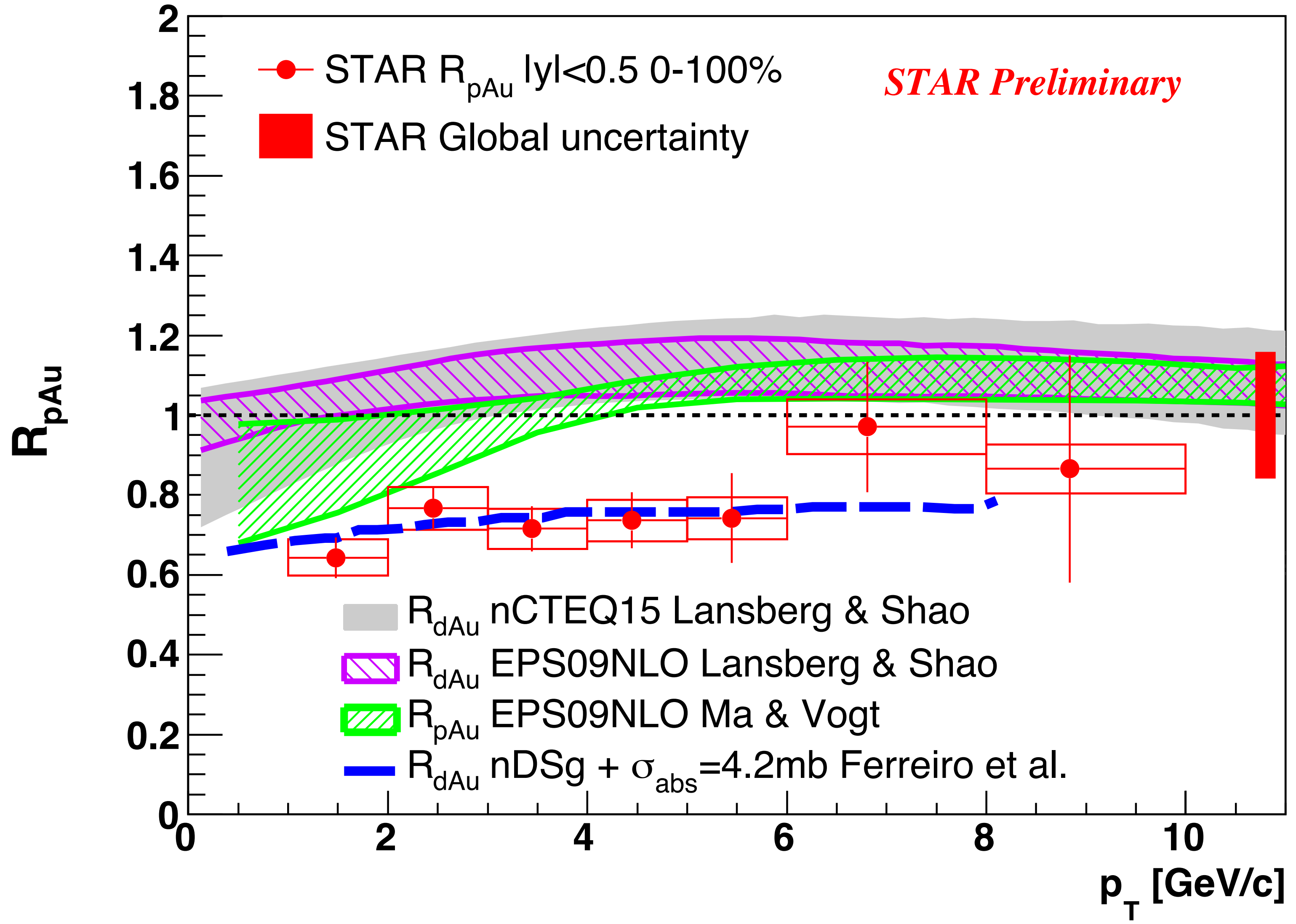
J/ψ and $\Upsilon \rightarrow \mu^+ + \mu^-$: TPC + MTD
$\Upsilon \rightarrow e^+ + e^-$: TPC + BEMC



TPC
Tracking (momentum measurement, identification) ($|\eta| < 1$, $0 < \varphi < 2\pi$)

BEMC
Trigger and identification of high-p_T electrons
($|\eta| < 1$, $0 < \varphi < 2\pi$)

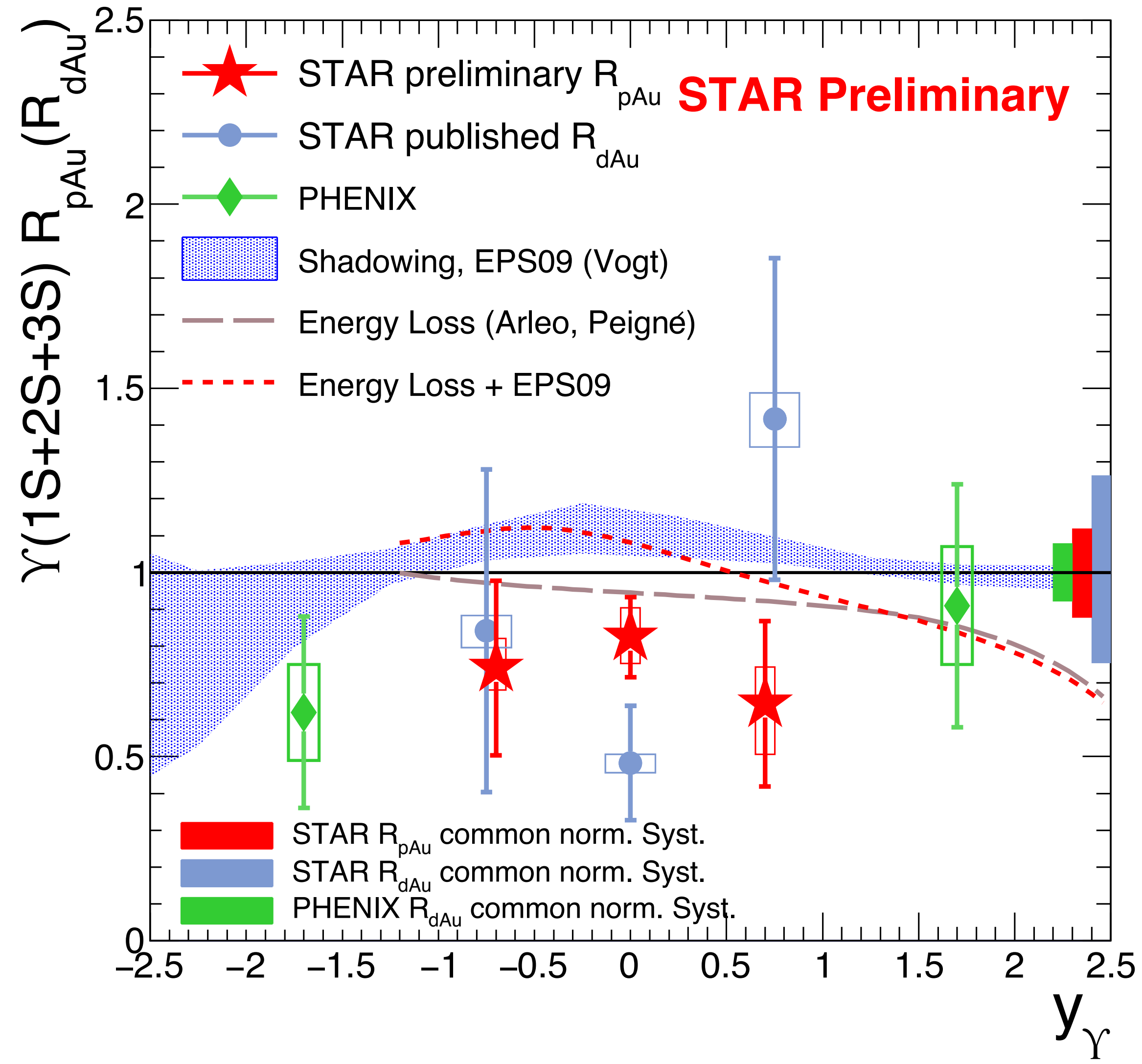
Inclusive J/ψ R_{pA} at $\sqrt{s_{NN}}$ = 200 GeV



EPS09+NLO, Ma & Vogt, Private Comm.
nCTEQ, EPS09+NLO, Lansberg Shao,
Eur.Phys.J. C77 (2017) no.1, 1
Comp. Phys. Comm. 198 (2016) 238-259
Comp. Phys. Comm. 184 (2013) 2562-2570

- Model calculations with only nPDF effect can touch upper limit of data within uncertainties.
- Data favor nPDF effects with additional nuclear absorption.

Inclusive Υ R_{pA} at $\sqrt{s_{NN}}$ = 200 GeV

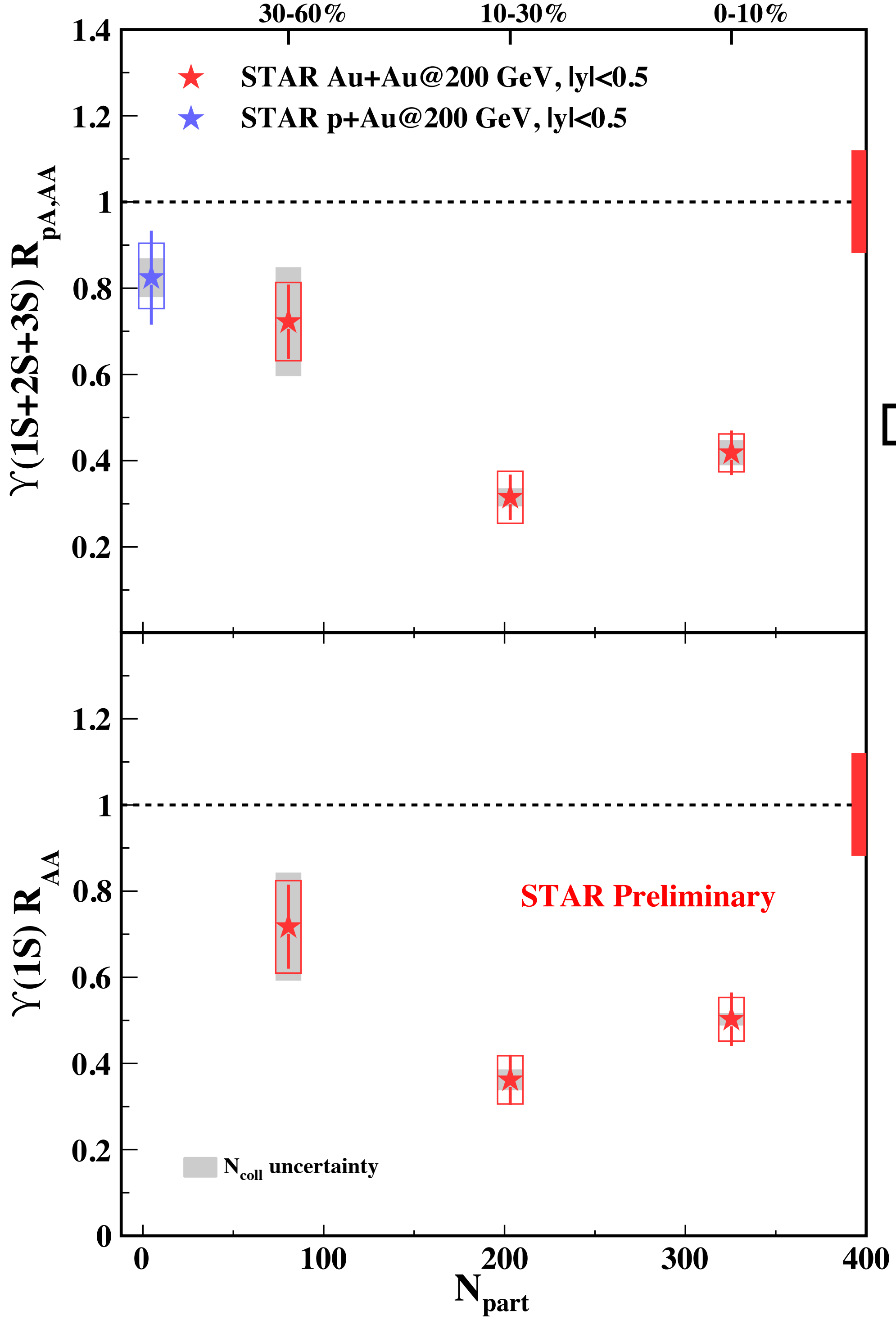


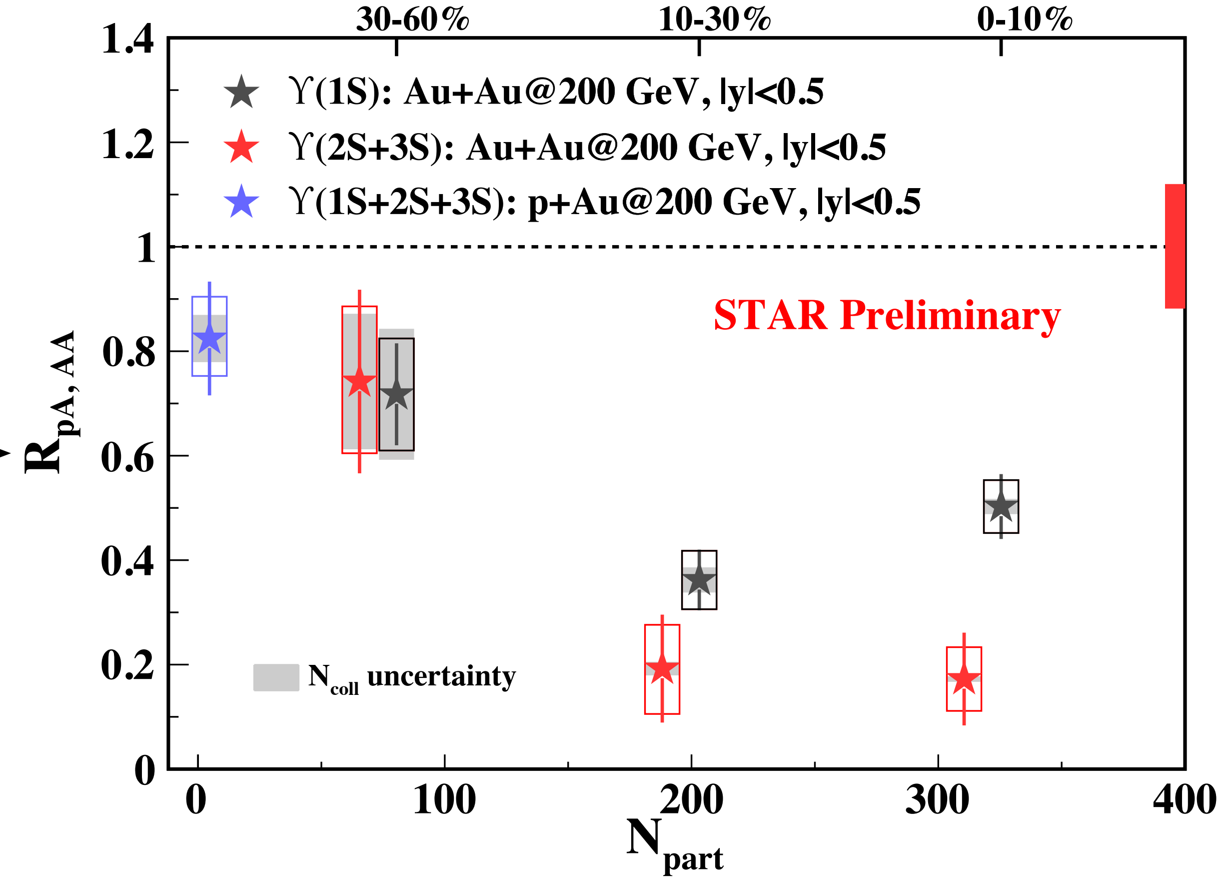
PHENIX: PRC 87 (2013) 044909
STAR: PLB 735 (2014) 127

- Indication of Υ(1S+2S+3S) suppression in p+Au collisions
  - ➜ **Cold nuclear matter effects:**
    R_{pA} (|y|<0.5): 0.82 ± 0.10 (stat.) $^{-0.07}_{+0.08}$ (sys.) ± 0.10 (global)

Inclusive ϒ R_{AA} vs. N_{part} at $\sqrt{s_{NN}}$ = 200 GeV

Combination of dielectron and dimuon channels





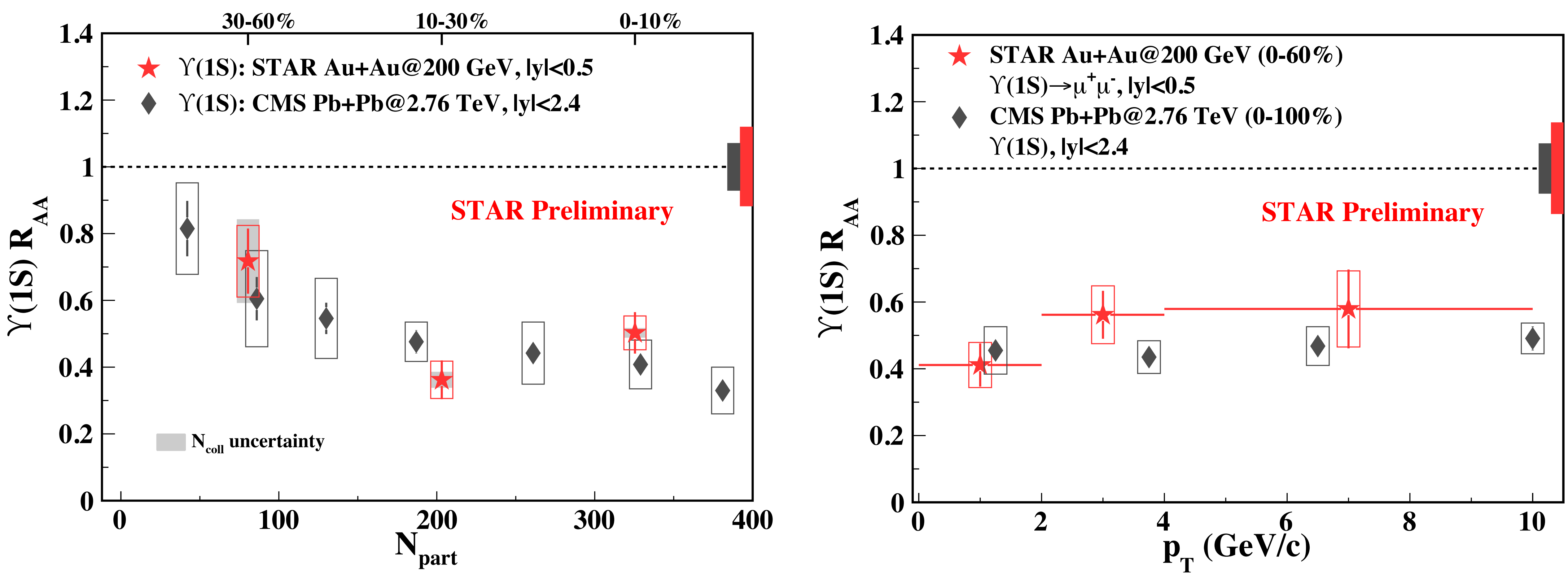
ϒ(1S):

- Stronger suppression towards central collisions

ϒ(2S+3S):

- Stronger suppression in more central collisions
- More suppressed than ϒ(1S) in 0-10% central collisions — sequential melting

ϒ(1S) suppression

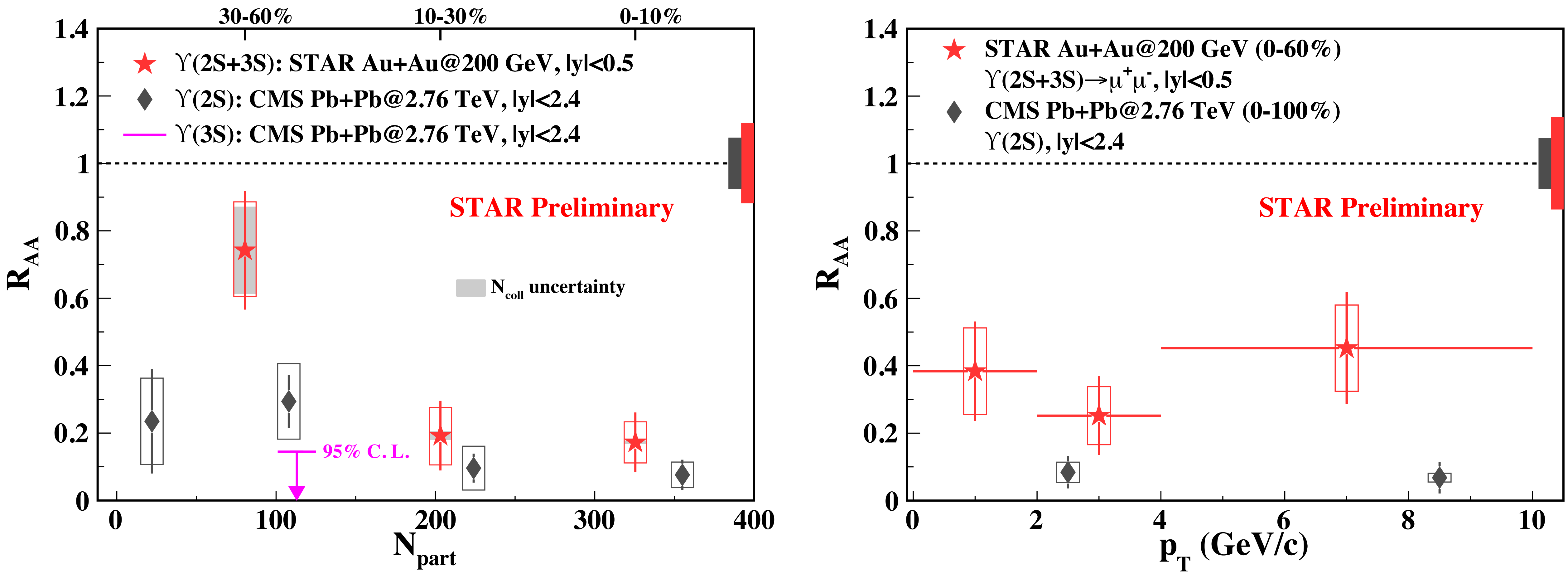


CMS: PLB 770, 357 (2017)

ϒ(1S) suppression is similar at RHIC and LHC and no significant p_T dependence:

- Medium temperature is higher at LHC due to higher collision energy
- Regeneration contribution is larger at LHC
- CNM
- Strong suppression of excited ϒ states that feed-down to ϒ(1S)

ϒ(2S+3S) suppression



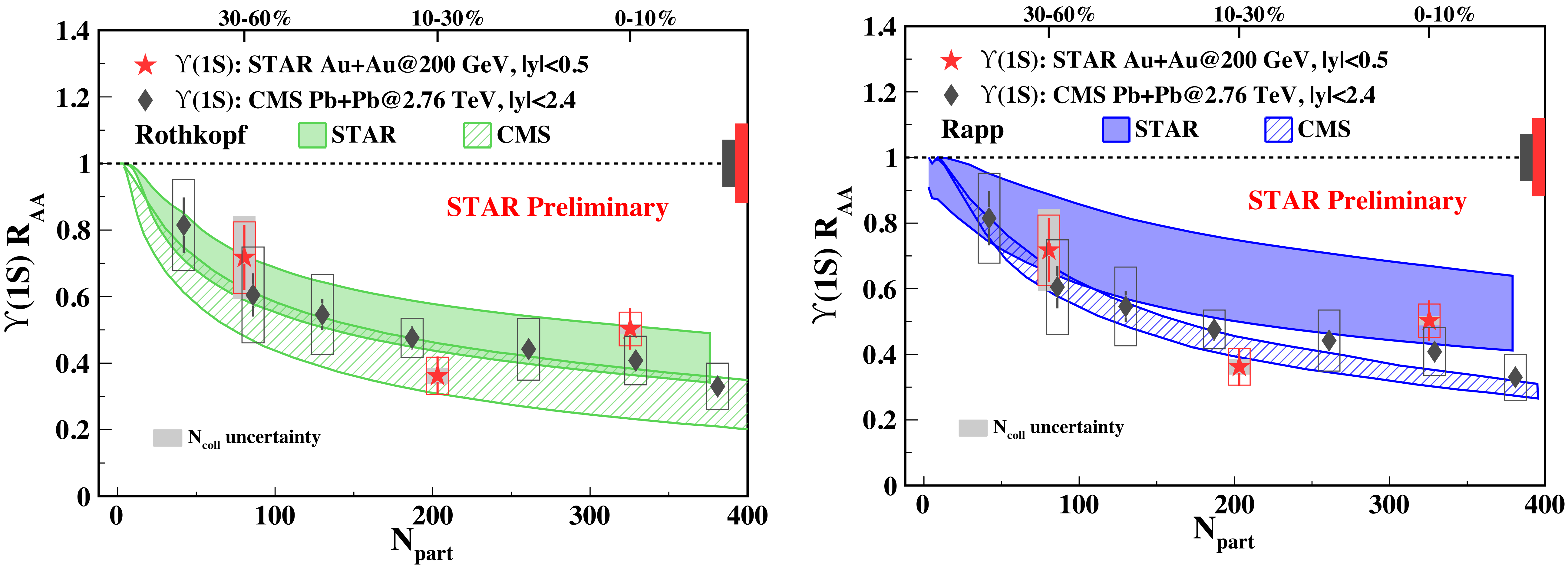
ϒ(2S+3S):

- Indication of less suppression at RHIC than at LHC.

  STAR: ϒ(2S+3S) R_{AA}: 0.35 ± 0.08 (stat.) ± 0.10 (sys.) (0 < p_T < 10 GeV/c, 0-60%)

  CMS: ϒ(2S) R_{AA}: 0.08 ± 0.05 (stat.) ± 0.03 (sys.) (0 < p_T < 5 GeV/c, 0-100%)

ϒ(1S) suppression



[CMS: PLB 770, 357 (2017)]
[B. Krouppa, A. Rothkopf, M. Strickland: PRD 97, 016017 (2018)]
[X. Du, M. He, and R. Rapp: PRC 96, 054901 (2017)]

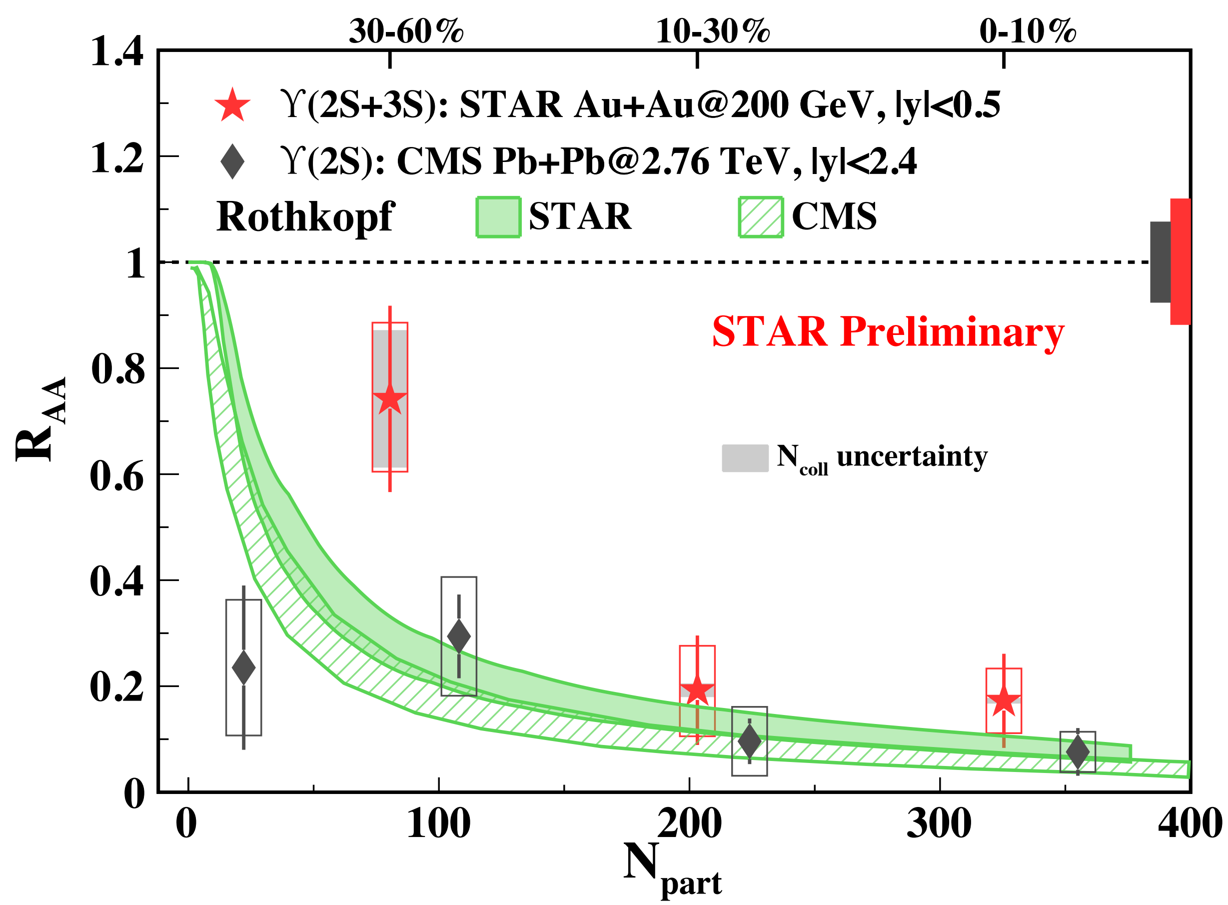
ϒ(1S) R_{AA}:

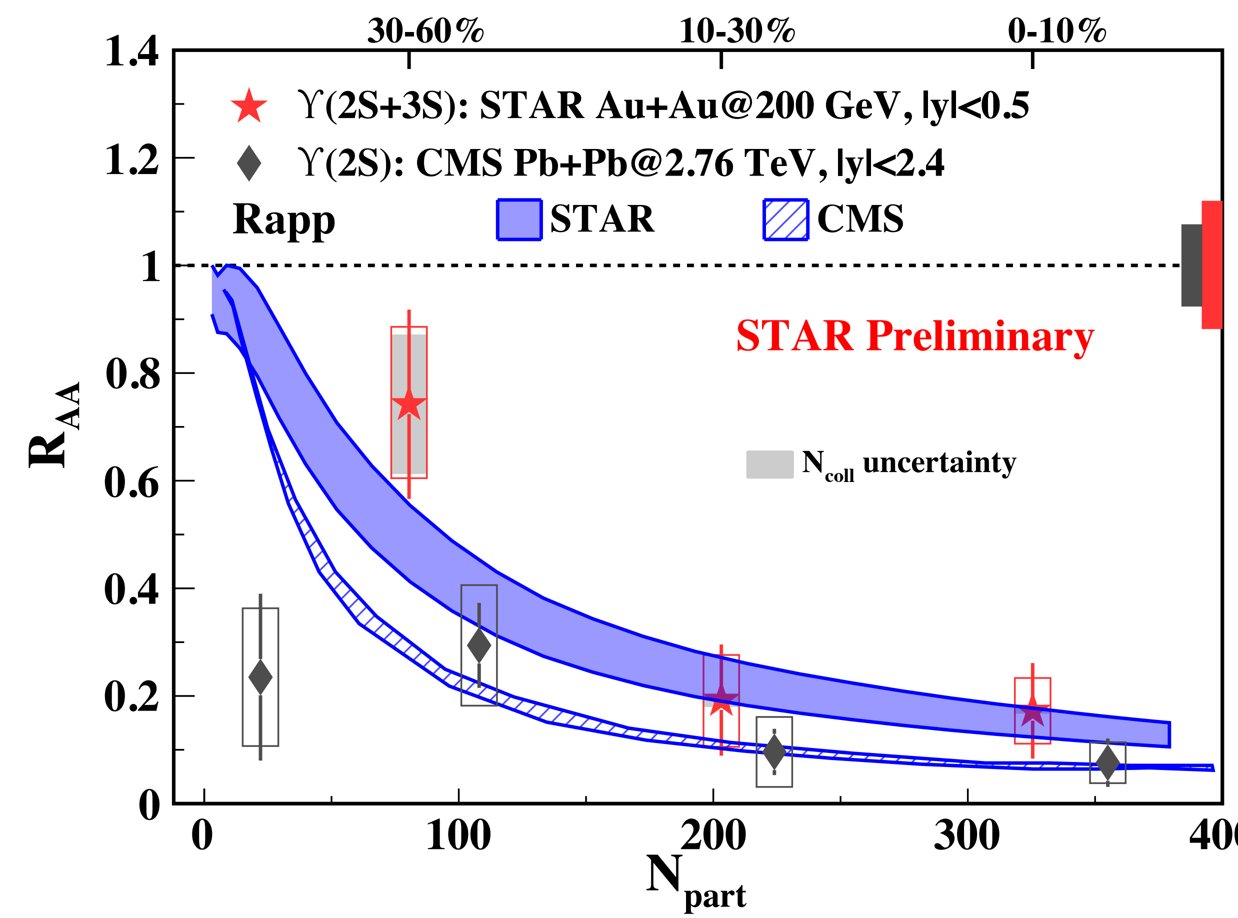
- Both Rothkopf's and Rapp's models describe data

Rothkopf's model: use a lattice-vetted heavy-quark potential

Rapp's model: use in-medium binding energies predicted by thermodynamic T-matrix calculations using internal-energy potentials, from lattice QCD

Υ(2S+3S) suppression





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Υ(2S+3S) R_{AA} :

- Rapp's model describes data
- Rothkopf's model calculation is slightly lower than data in 30-60%

Summary

- **p+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV**
  - Indication of Υ suppression
  - J/ψ R_{pA} favors additional nuclear absorption effect on top of nPDF effect

- **Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV**

The precision of Υ measurements is improved by combining results of dielectron and dimuon channels from dataset taken in different year (2011, 2014 and 2016)

Υ(1S):

- Indication of stronger suppression towards central collisions
- Similar suppression as at LHC
- Both models are consistent with data at RHIC and LHC

Υ(2S+3S):

- More suppressed than Υ(1S) in 0-10% — sequential melting
- Indication of less suppression at RHIC than at the LHC