New Measurements of Quarkonium Production at RHIC with the STAR Experiment

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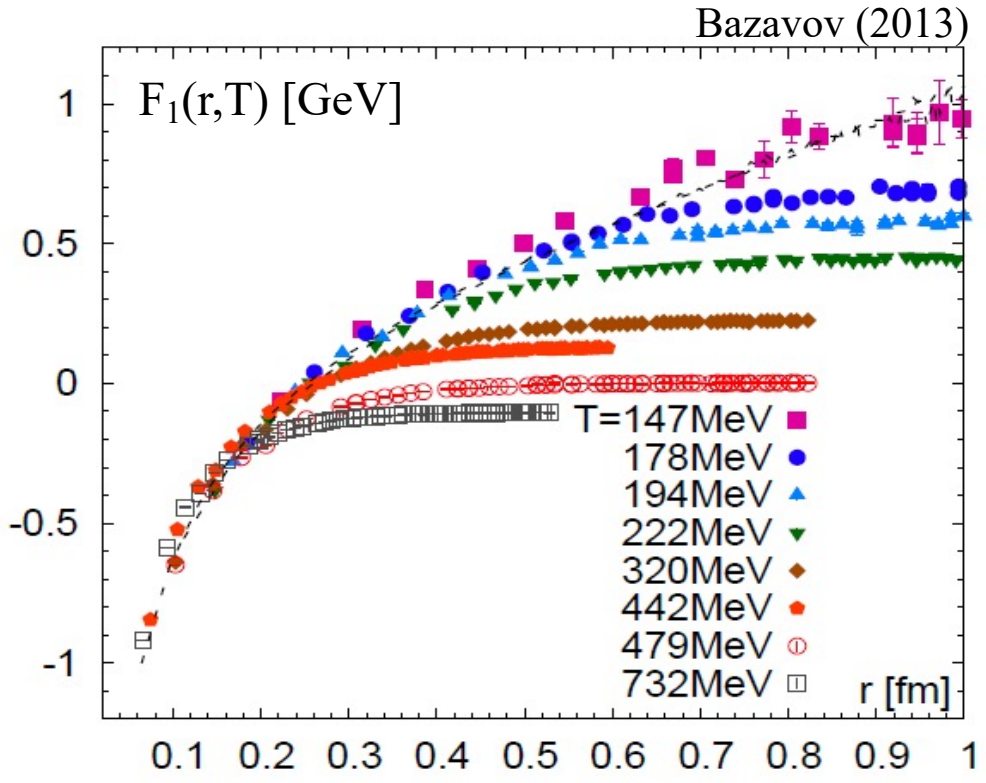
STAR

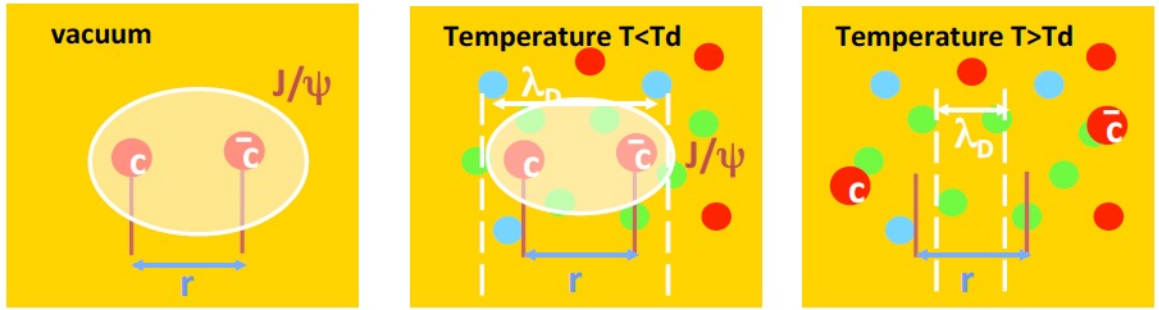
Quarkonium production in A+A collisions



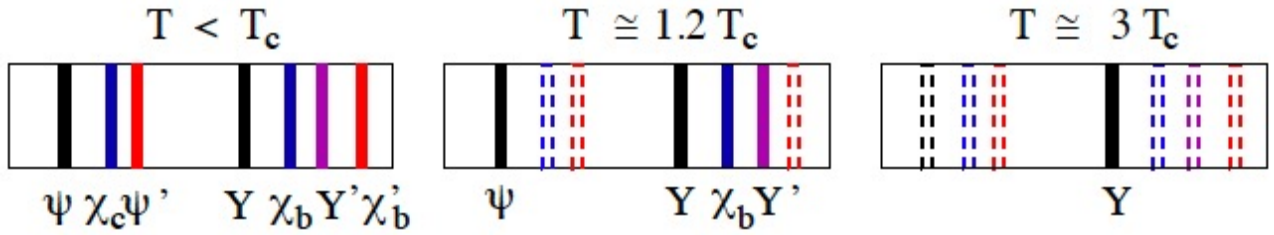
- $Q\bar{Q}$ potential and spectral function modified in the QGP medium with respect to vacuum
- J/ψ dissociation due to color-screening was suggested as a signature of QGP formation
  Matsui and Satz Phys. Lett. B 178 (1986) 416

$$R_{AA} = \frac{Y_{AA}}{\langle N_{coll}\rangle \cdot Y_{pp}} < 1$$

- Different quarkonium binding energies lead to **sequential suppression** with increasing medium temperature -> **QGP thermometer**



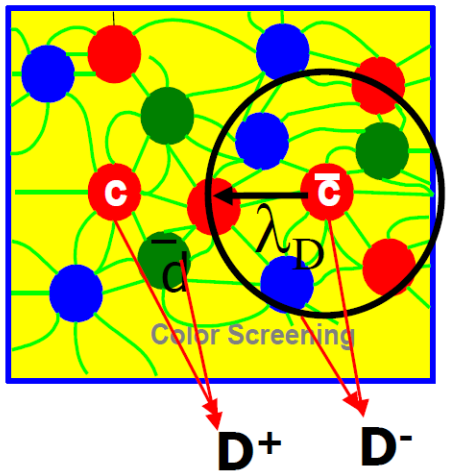
R. Arnaldi



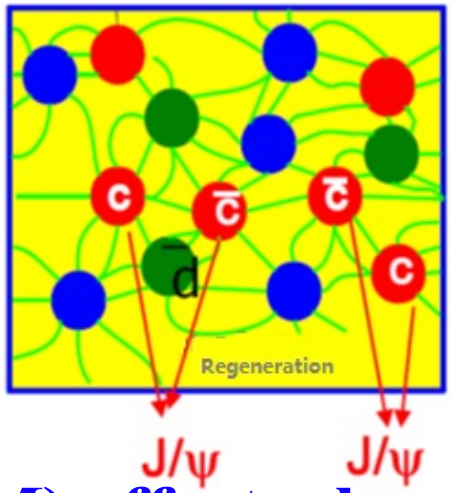
Quarkonium production in A+A collisions

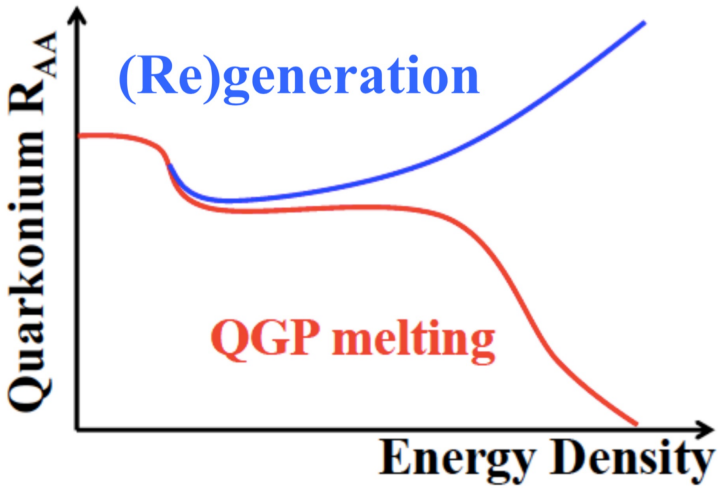
- **Hot Nuclear Matter (HNM) effects: how do they depend on system size and temperature (energy)?**

QGP melting



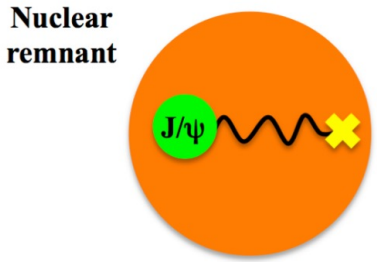
(Re)generation





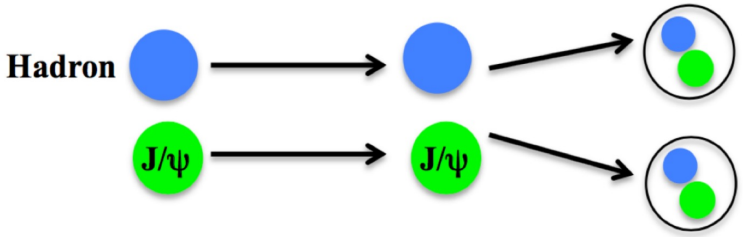
- **Cold Nuclear Matter (CNM) effects: how big are they?**

Nuclear absorption

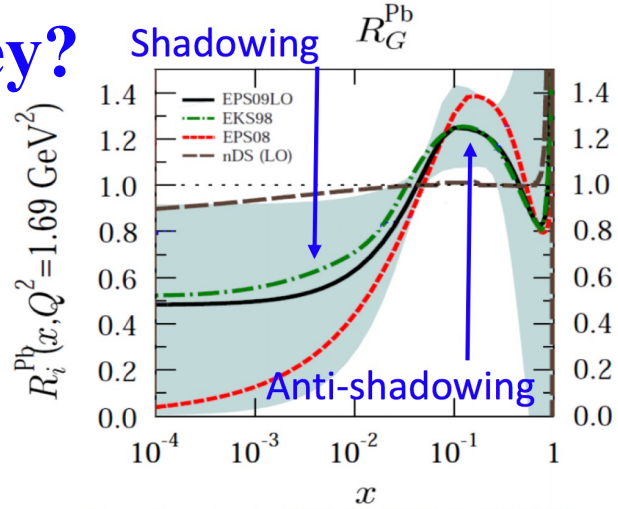


Gavin et al., PRL 78 (1997) 1006

Co-Movers

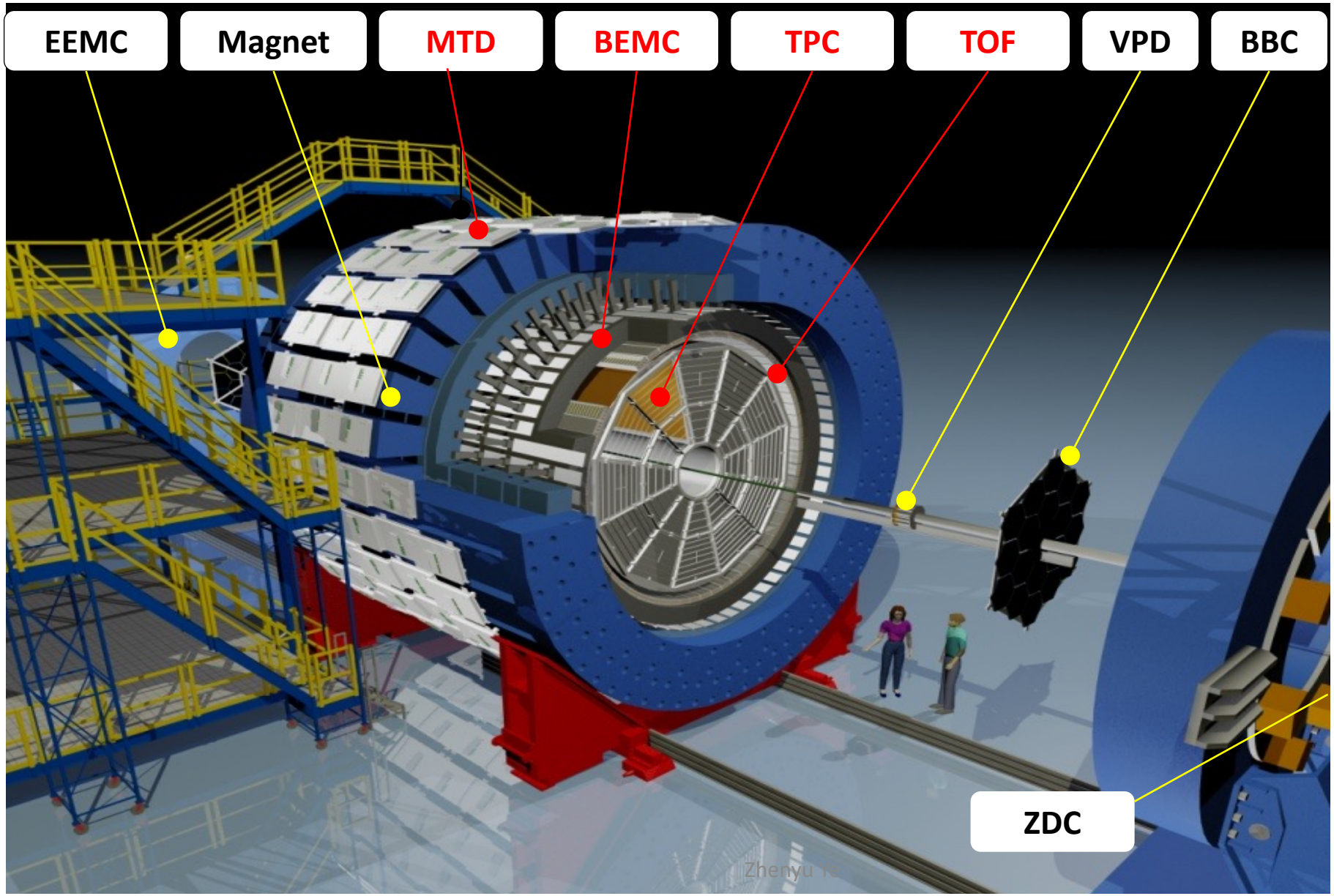


Capella and Ferreiro, EPJC 42 (2005) 419



Ferreiro et al., PRC 81 (2010) 064911

Solenoidal Tracker at RHIC (STAR) Experiment



Tracking, Calorimetry, PID

Solenoidal magnet: $B_z = 0.5$ T

TPC: $|\eta| < 1$

TOF: $|\eta| < 0.9$

BEMC: $|\eta| < 1$

EEMC: $1 < \eta < 2$

MTD: $|\eta| < 0.5$

MB trigger, luminosity

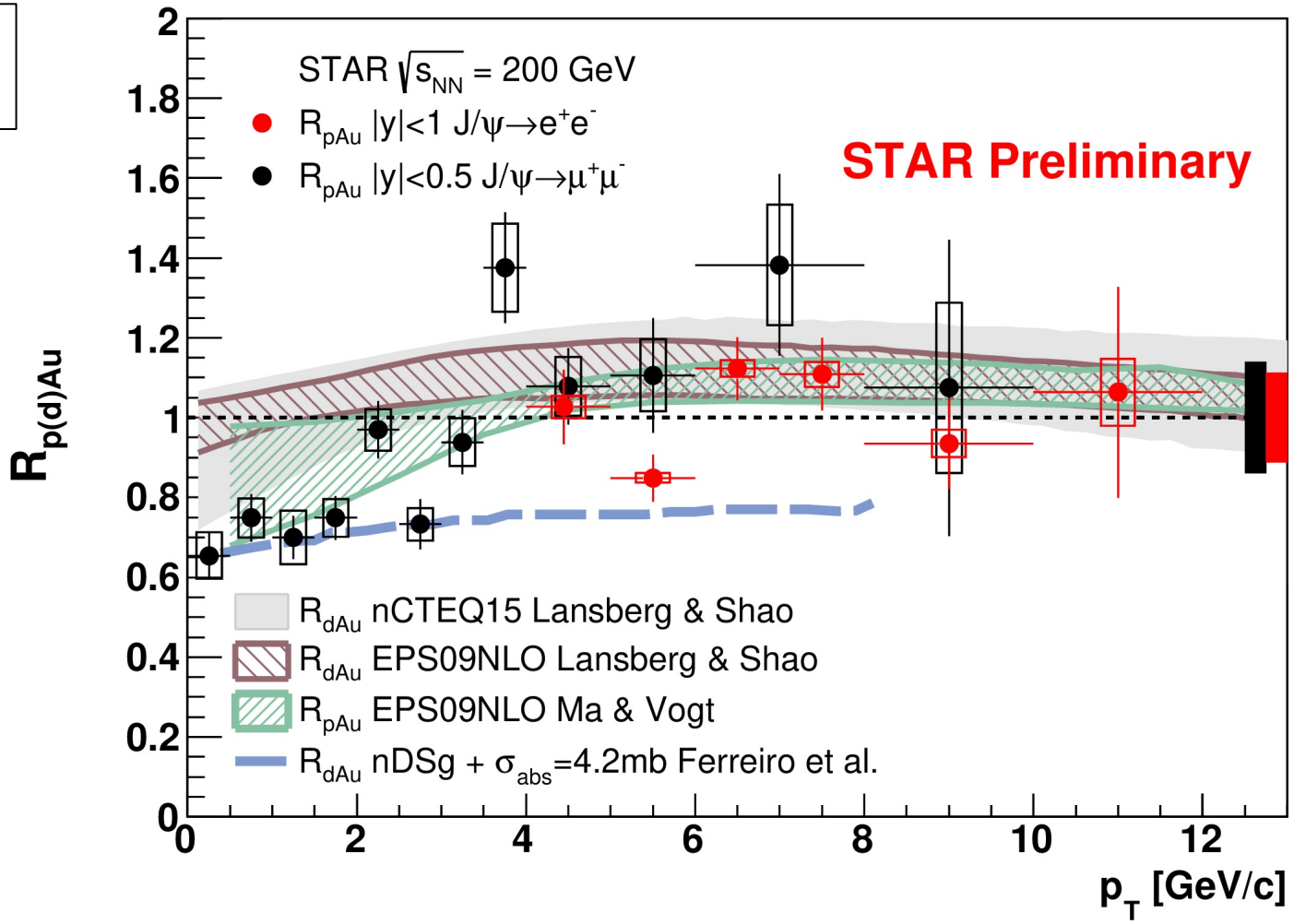
BBC: $3.3 < |\eta| < 5$

VPD: $4.2 < |\eta| < 5$

ZDC: $6.5 < |\eta|$

J/ψ in p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

New: dimuon published
Dielectron preliminary

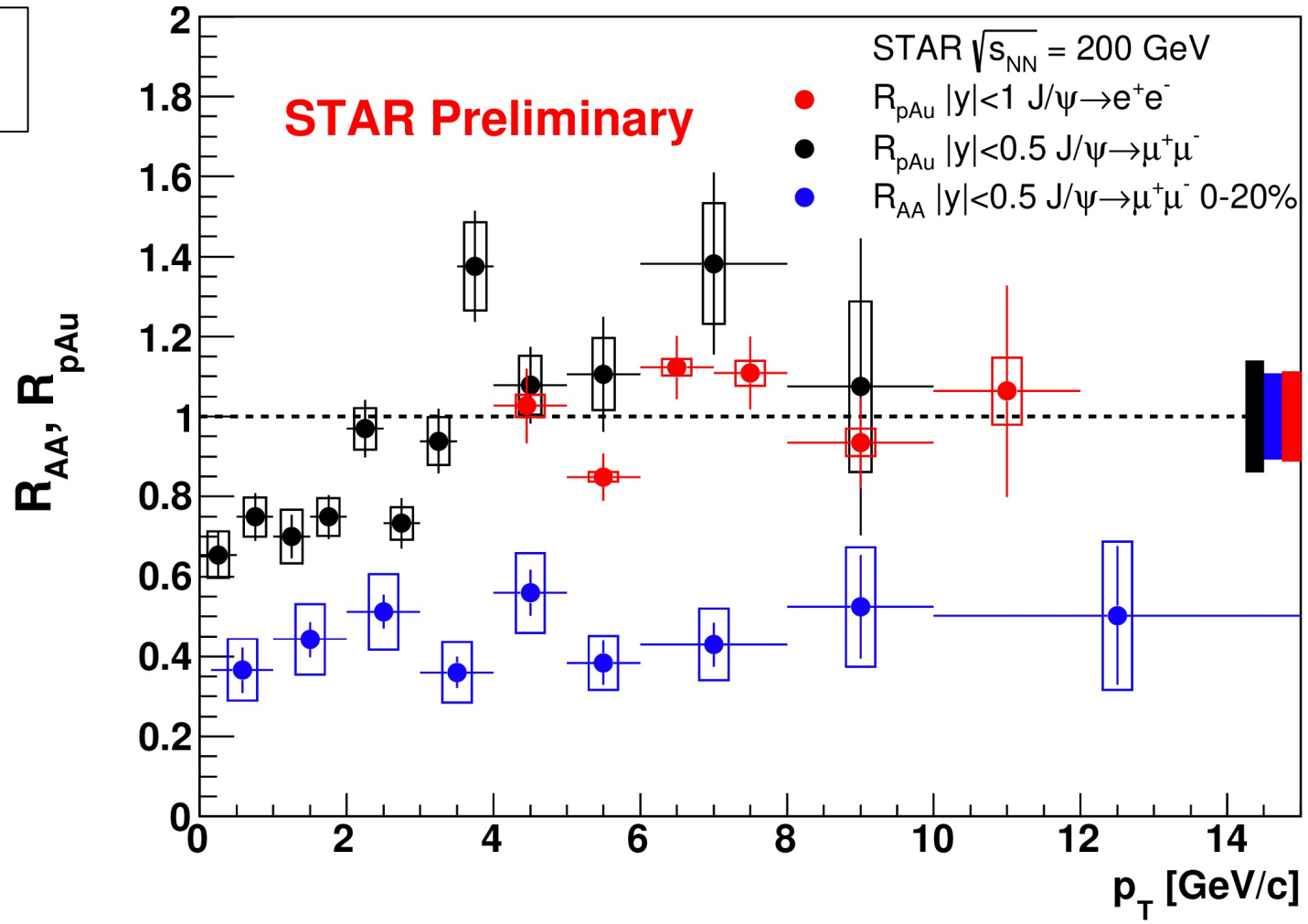


STAR, Phys. Lett. B 825 (2022) 136865
Ma & Vogt, EPS09+NLO, Private Comm.
Lansberg & Shao, Eur.Phys.J. C77 (2017) no.1, 1
Ferreiro et al., Few Body Syst. 53 (2012) 27

- J/ψ R_{pAu}: newly published dimuon results confirm significant CNM effects in p+Au collisions at low p_T; latest high p_T dielectron results with improved precision suggest little CNM effects at high p_T
- Data can be described by model calculations considering nPDF effect only, and disfavors calculation including additional nuclear absorption effect at high p_T

J/ψ in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

New: dimuon published
Dielectron preliminary

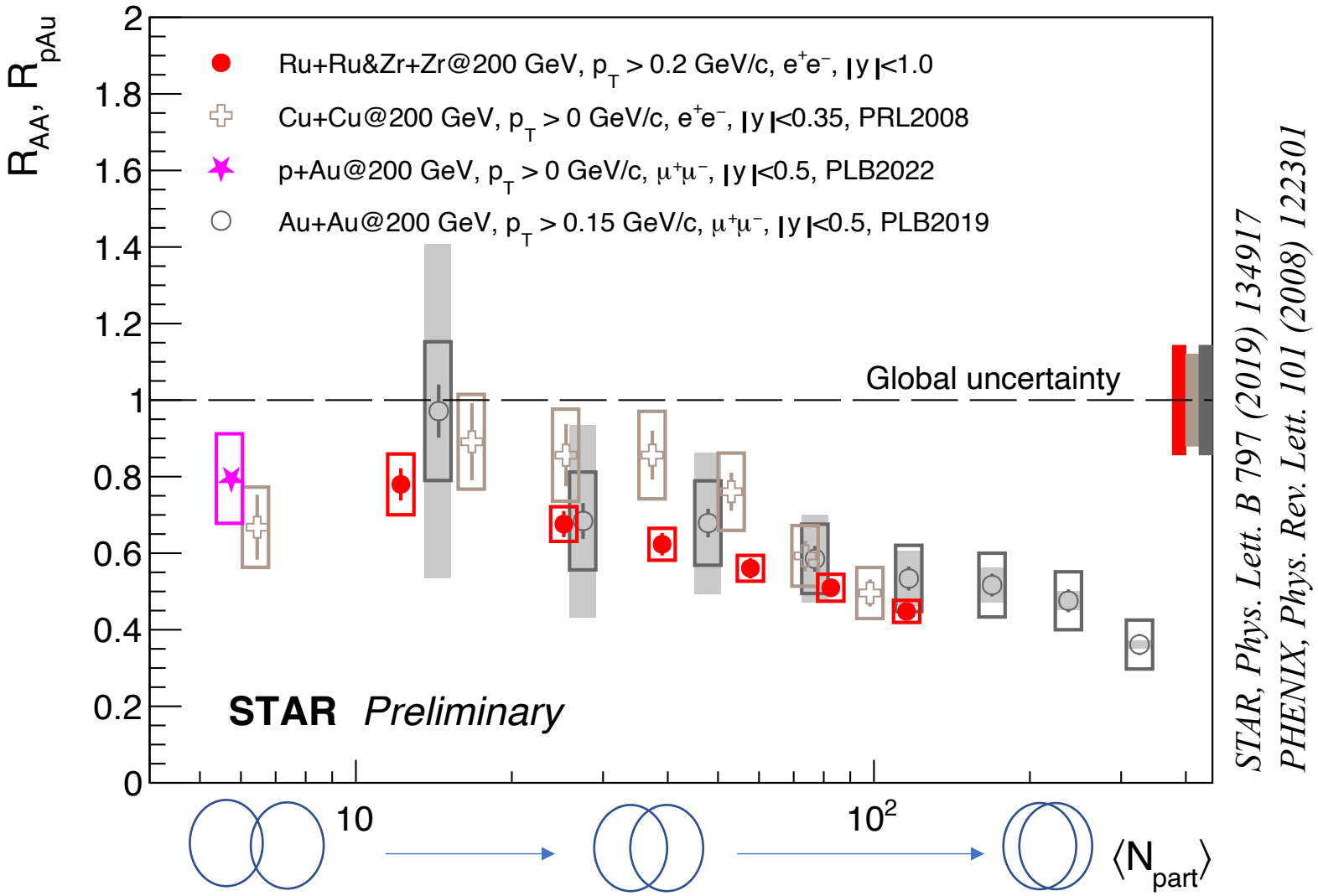


STAR, Phys. Lett. B 825 (2022) 136865
STAR, Phys. Lett. B 797 (2019) 134917

- J/ψ R_{pAu}: newly published dimuon results confirm significant CNM effects in p+Au collisions at low p_T; latest high p_T dielectron results with improved precision suggest little CNM effects at high p_T
- J/ψ R_{AA}: strong suppression at high p_T mostly due to HNM effects

J/ψ in isobar collisions at $\sqrt{s_{NN}} = 200$ GeV

New: isobar R_{AA}

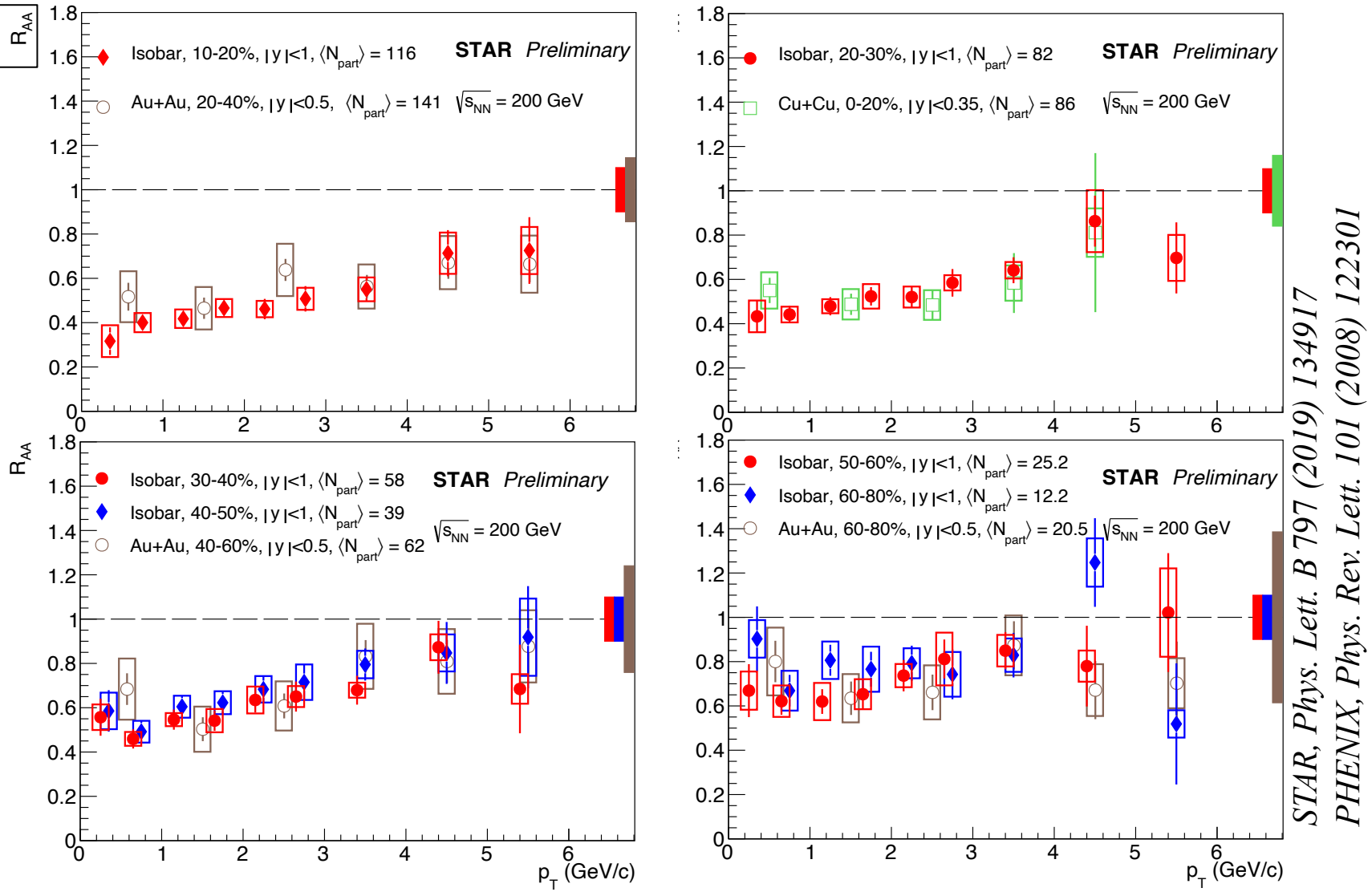


STAR, Phys. Lett. B 797 (2019) 134917
PHENIX, Phys. Rev. Lett. 101 (2008) 122301

- J/ψ R_{AA} vs $\langle N_{part} \rangle$ in ${}^{96}_{44}\mathrm{Ru} + {}^{96}_{44}\mathrm{Ru}$ and ${}^{96}_{40}\mathrm{Zr} + {}^{96}_{40}\mathrm{Zr}$ collisions consistent with those in ${}^{63}_{29}\mathrm{Cu} + {}^{63}_{29}\mathrm{Cu}$ and ${}^{197}_{79}\mathrm{Au} + {}^{197}_{79}\mathrm{Au}$ collisions: no significant A-dependence with same $\langle N_{part} \rangle$

J/ψ in isobar collisions at $\sqrt{s_{NN}} = 200$ GeV

New: isobar R_{AA}

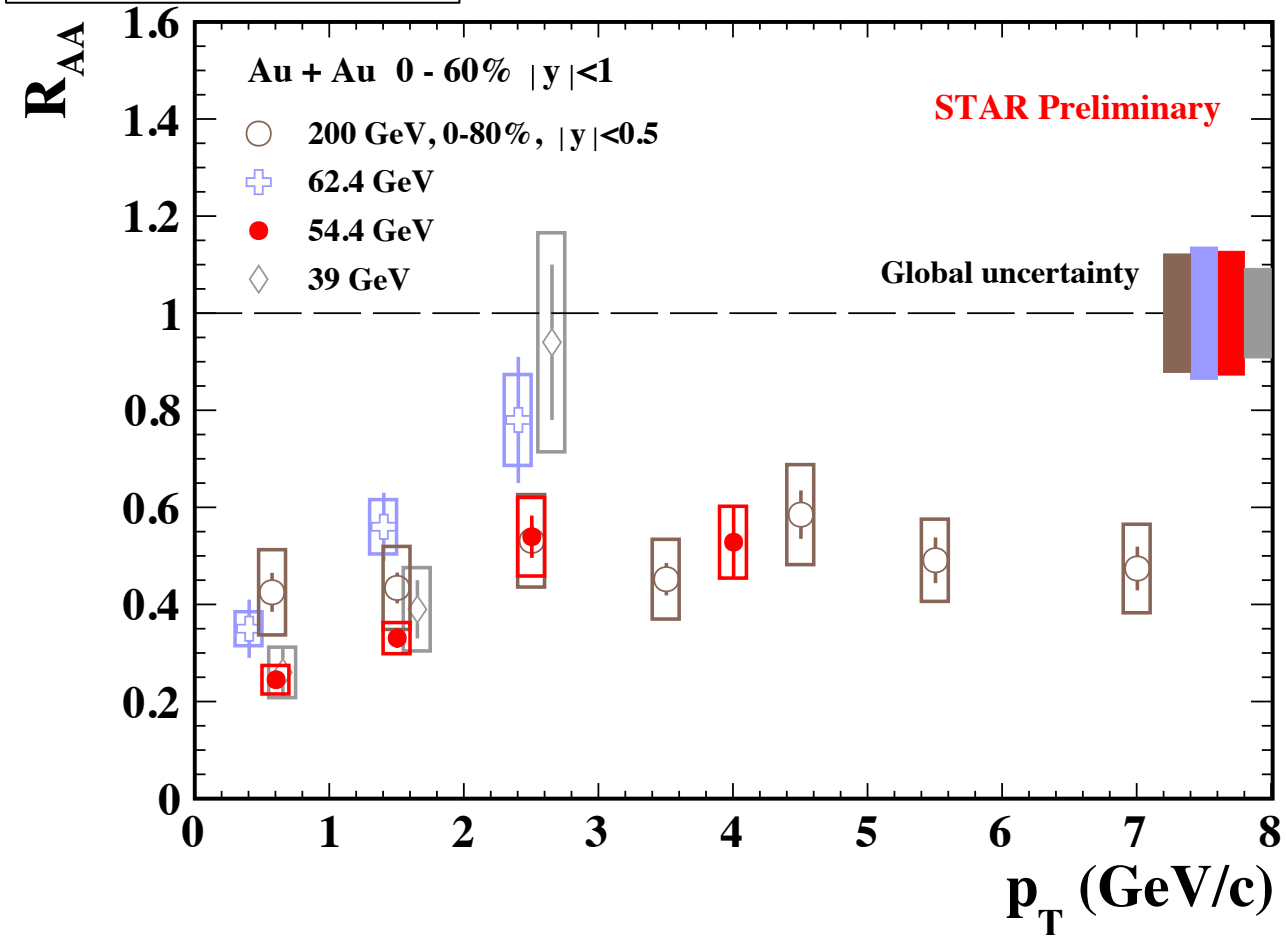


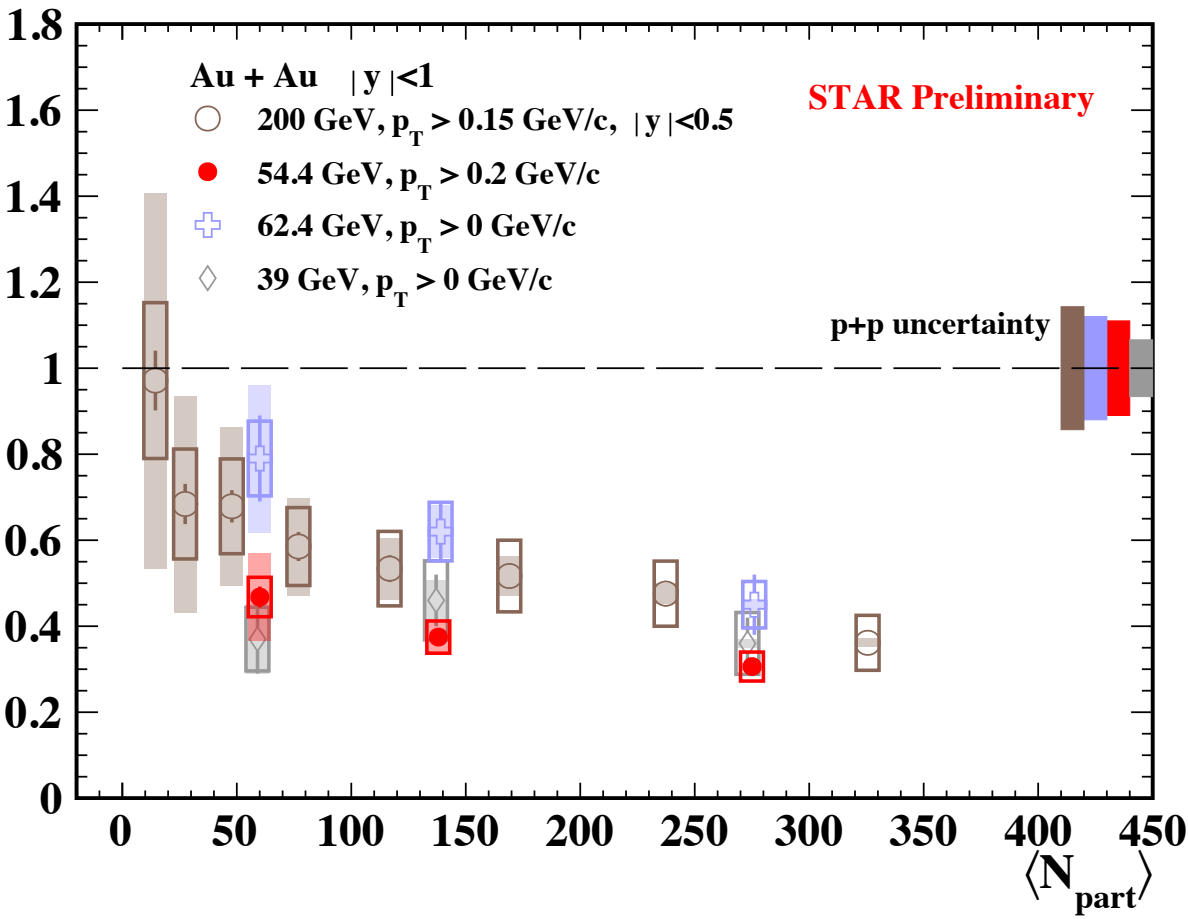
STAR, Phys. Lett. B 797 (2019) 134917
PHENIX, Phys. Rev. Lett. 101 (2008) 122301

- Increasing trend of J/ψ R_{AA} vs p_T in central and mid-central $^{96}_{44}Ru + ^{96}_{44}Ru$ and $^{96}_{40}Zr + ^{96}_{40}Zr$ collisions
- Results are consistent with those in $^{63}_{29}Cu + ^{63}_{29}Cu$ and in $^{197}_{79}Au + ^{197}_{79}Au$ collisions with similar $\langle N_{part} \rangle$

J/ψ in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV

New: 54.4 GeV R_{AA}



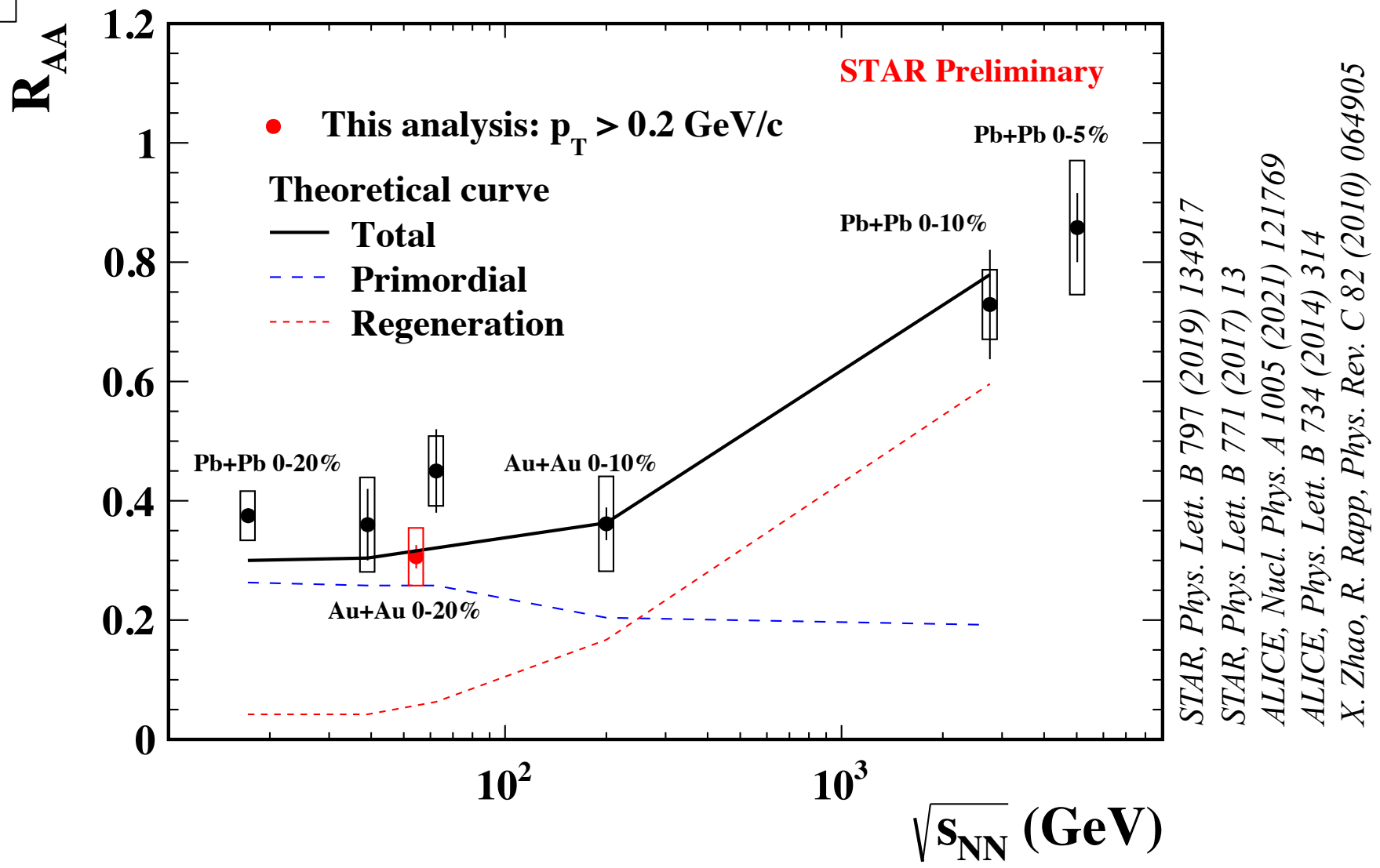


STAR, Phys. Lett. B 797 (2019) 134917
STAR, Phys. Lett. B 771 (2017) 13

- J/ψ R_{AA} increases with p_T for p_T<3 GeV/c at $\sqrt{s_{NN}}$ =39, 54.4 and 62.4 GeV, less p_T dependence at 200 GeV
- J/ψ R_{AA} vs $\langle N_{part} \rangle$: no significant dependence on $\sqrt{s_{NN}}$ between $\sqrt{s_{NN}} = 39 - 200$ GeV

J/ψ in A+A collisions at RHIC and LHC

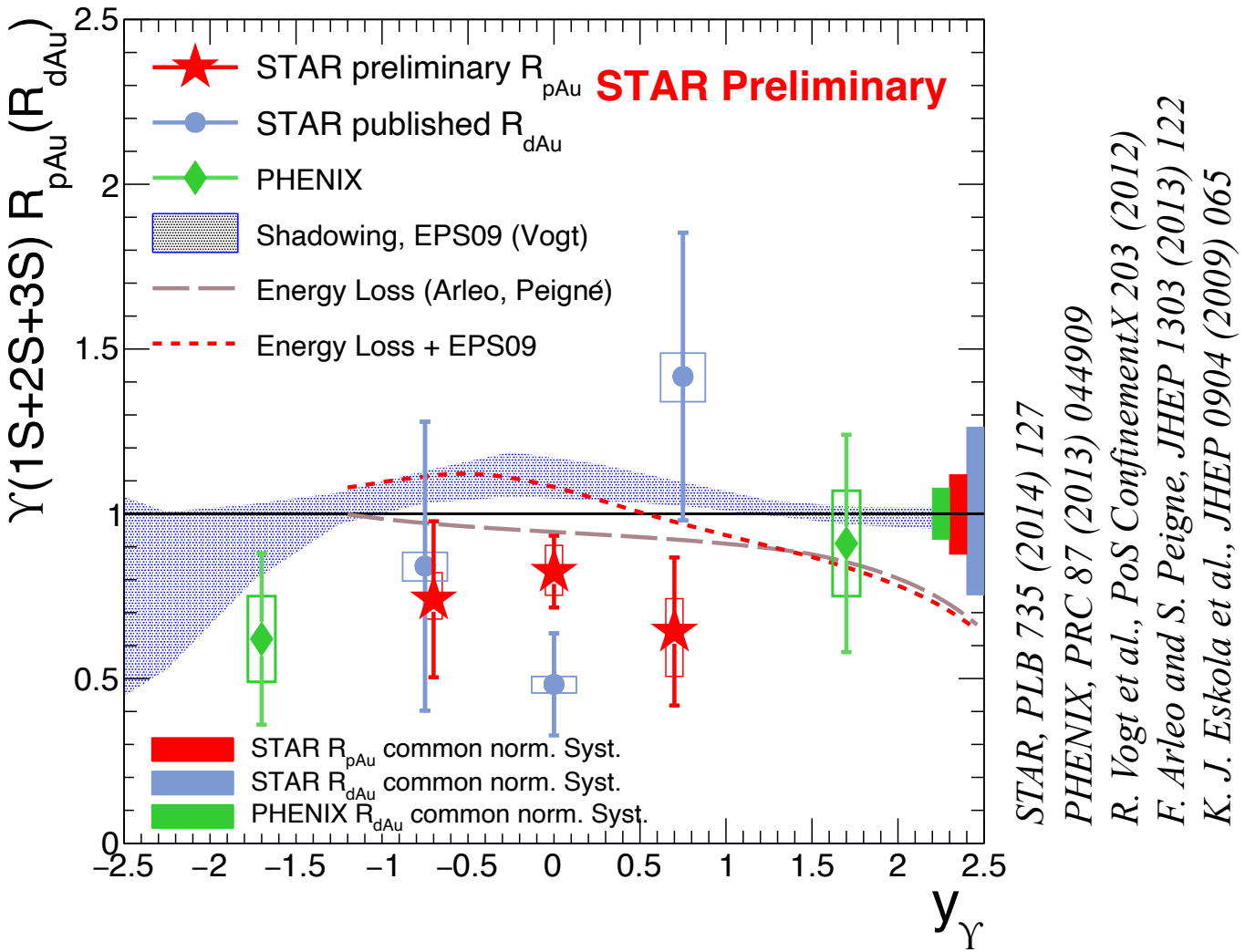
New: 54.4 GeV R_{AA}



STAR, Phys. Lett. B 797 (2019) 134917
STAR, Phys. Lett. B 771 (2017) 13
ALICE, Nucl. Phys. A 1005 (2021) 121769
ALICE, Phys. Lett. B 734 (2014) 314
X. Zhao, R. Rapp, Phys. Rev. C 82 (2010) 064905

- Interplay of dissociation and regeneration can explain the $\sqrt{s_{NN}}$ dependence

ϒ in p+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

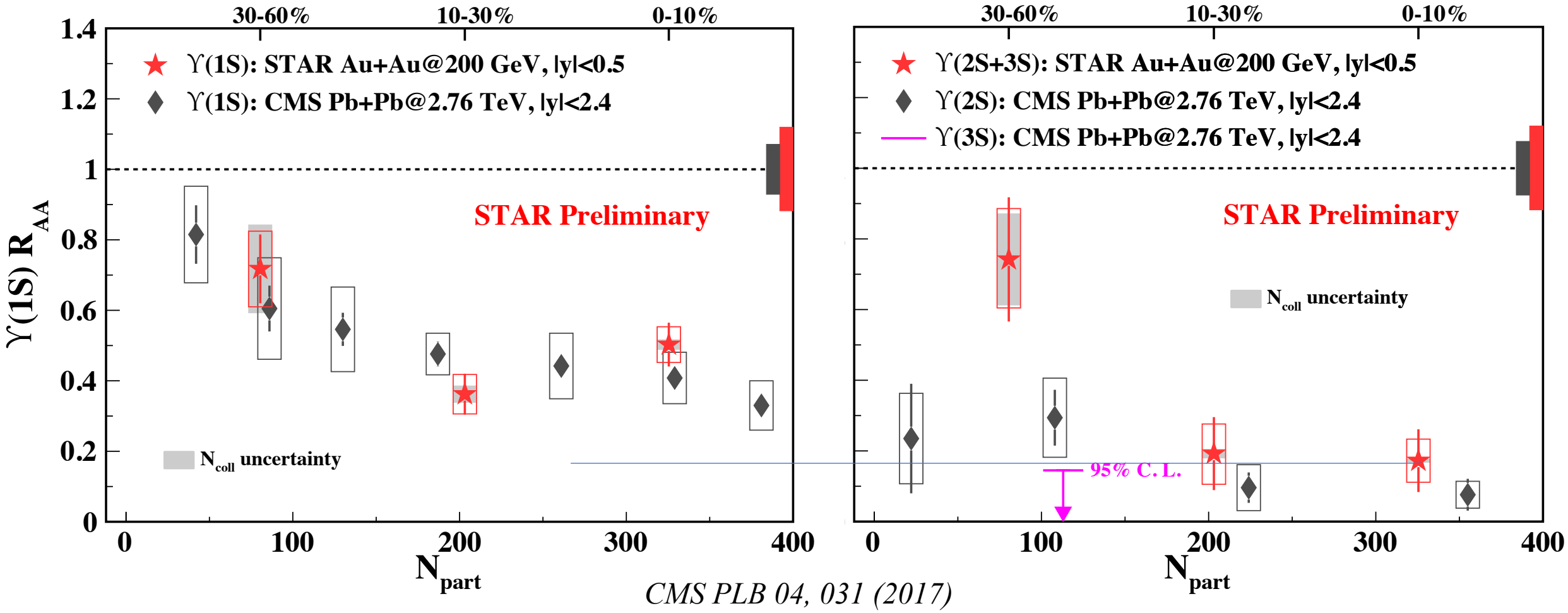


STAR, PLB 735 (2014) 127
PHENIX, PRC 87 (2013) 044909
R. Vogt et al., PoS ConfinementX 203 (2012)
F. Arleo and S. Peigne, JHEP 1303 (2013) 122
K. J. Eskola et al., JHEP 0904 (2009) 065

- Indication of **CNM effects** for Y production at RHIC

$$R_{pAu} = 0.82 \pm 0.10\ (\text{stat.}) \pm 0.08\ (\text{syst.}) \pm 0.10\ (\text{global})$$

ϒ production in A+A collisions at RHIC and LHC

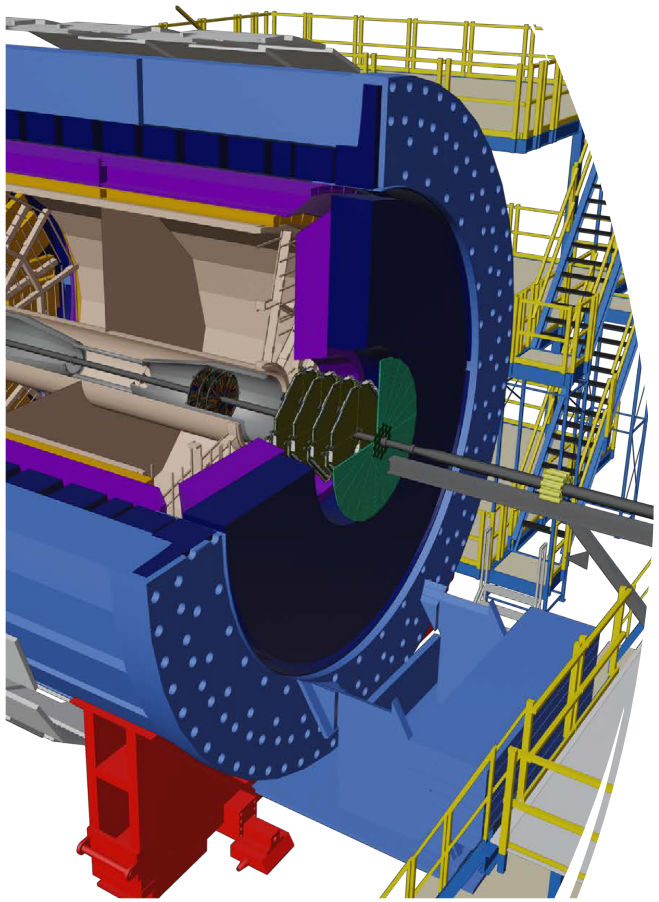


CMS PLB 04, 031 (2017)

- $\Upsilon(2S+3S)$ R_{AA} smaller than $\Upsilon(1S)$ in 0-10%, "**sequential melting**" at RHIC
- ϒ(1S): similar at RHIC and LHC; $\Upsilon(2S+3S)$ R_{AA} might be larger at RHIC than LHC

WG6 May 4: STAR Forward Upgrade

Summary and outlook



- **p+A collisions at $\sqrt{s_{NN}}$ = 200 GeV:**
  - Significant CNM effects for J/ψ at low p_T
  - J/ψ R_{pA} at high p_T consistent with unity
  - Indication of CNM effects on Υ
- **A+A collisions:** evidence of high p_T J/ψ dissociation and Υ sequential suppression
  - No significant A-dependence for J/ψ R_{AA} with similar $\langle N_{part} \rangle$ at 200 GeV
  - No significant energy dependence in J/ψ R_{AA} between 39-200 GeV
- **Not covered:** J/ψ with jet activity in p+p collisions, very low p_T J/ψ in A+A collisions

- **Stay tuned for future Quarkonium results from STAR**
  - Isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV in 2018: J/ψ v_2; high p_T J/ψ and Υ R_{AA} from EMC-triggered sample
  - p+p collisions at $\sqrt{s_{NN}}$ = 510 GeV in 2022 with new forward detectors ($2.5 < \eta < 4$)
  - p+p, p+Au, Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV in 2023-2025 with forward detectors and 2x faster TPC