Recent quarkonium results from the STAR experiment

Barbara Trzeciak, for the STAR Collaboration
Czech Technical University in Prague

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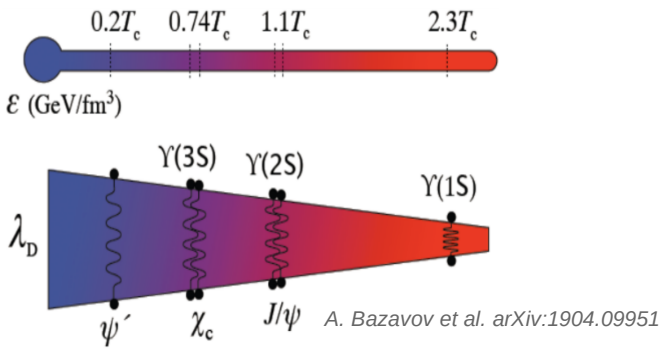
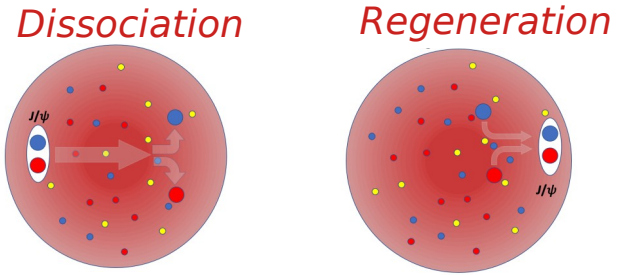
Why quarkonia ?

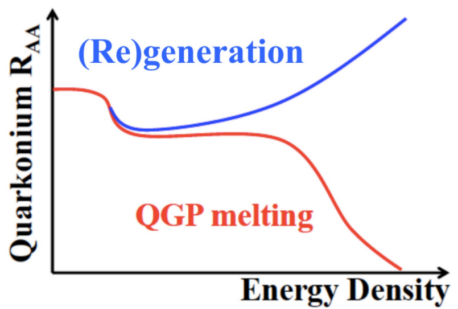
- Heavy-flavor quarks (c,b) produced dominantly in initial hard scatterings

  A+A collisions
- QQbar potential and spectral function modified in the QCD medium w.r.t. vacuum
- **Hot nuclear matter effects:**
  - ➔ **Dissociation** due to color screening and **regeneration**
- **Sequential quarkonium suppression** due to different binding energies



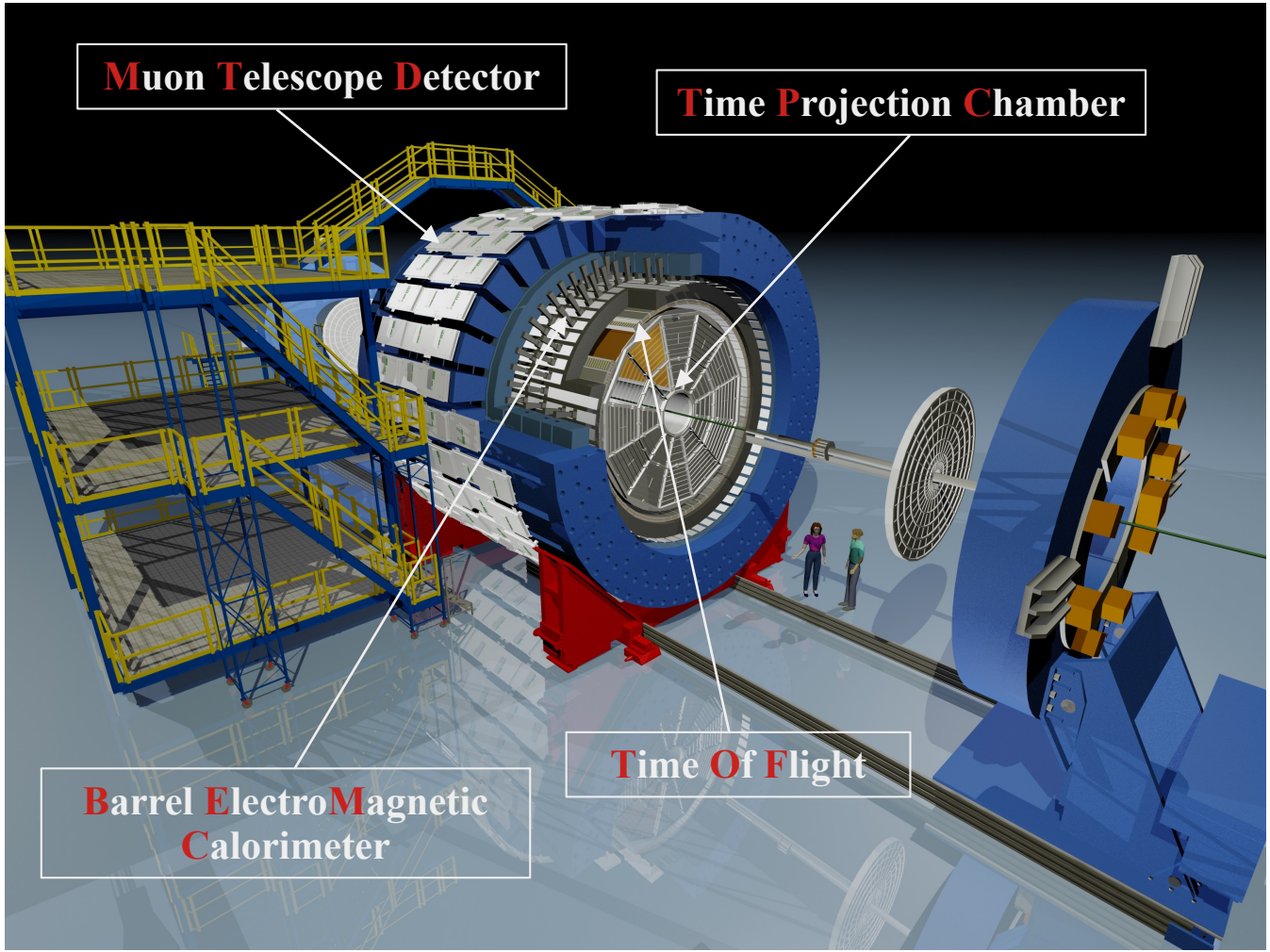
A. Bazavov et al. arXiv:1904.09951





- **Cold nuclear matter effects:**
  - ➔ Modification of PDFs, nuclear absorption, coherent energy loss, co-mover absorption, … - study in **p+A collisions**
- **Production mechanism** – study in ***p+p* collisions**

STAR detector at RHIC



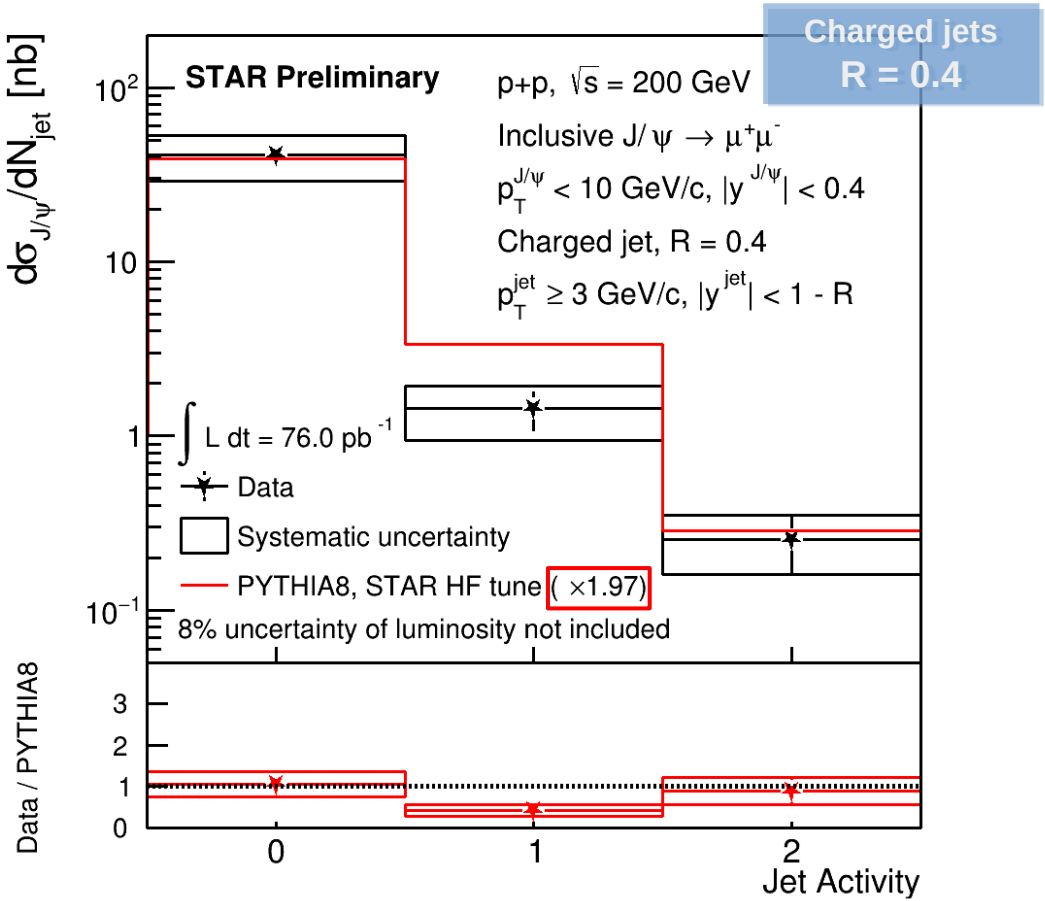
Mid-rapidity sub-detectors

- **TPC**
  - momentum and PID (dE/dx).
- **TOF**
  - time-of-flight and PID (1/β).
- **BEMC**
  - trigger on and identify high p_T electrons.
- **MTD**
  - trigger on and identify muons.

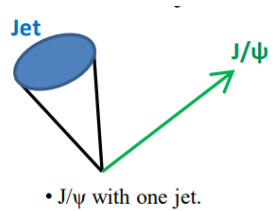
J/ψ production with jet activity in p+p

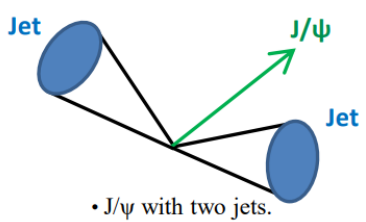
- Constraining J/ψ production mechanism: color singlet vs color octet state

Lansberg, Physics Reports, 889, 1 (2020)



- ➔ Dependence of J/ψ production cross section on jet activity for R = 0.4 jets
- ➔ For the measured kinematics, **Pythia8 predicts larger fraction of J/ψ produced in association with jets than that observed in data**
- ➔ Theoretical model calculations needed

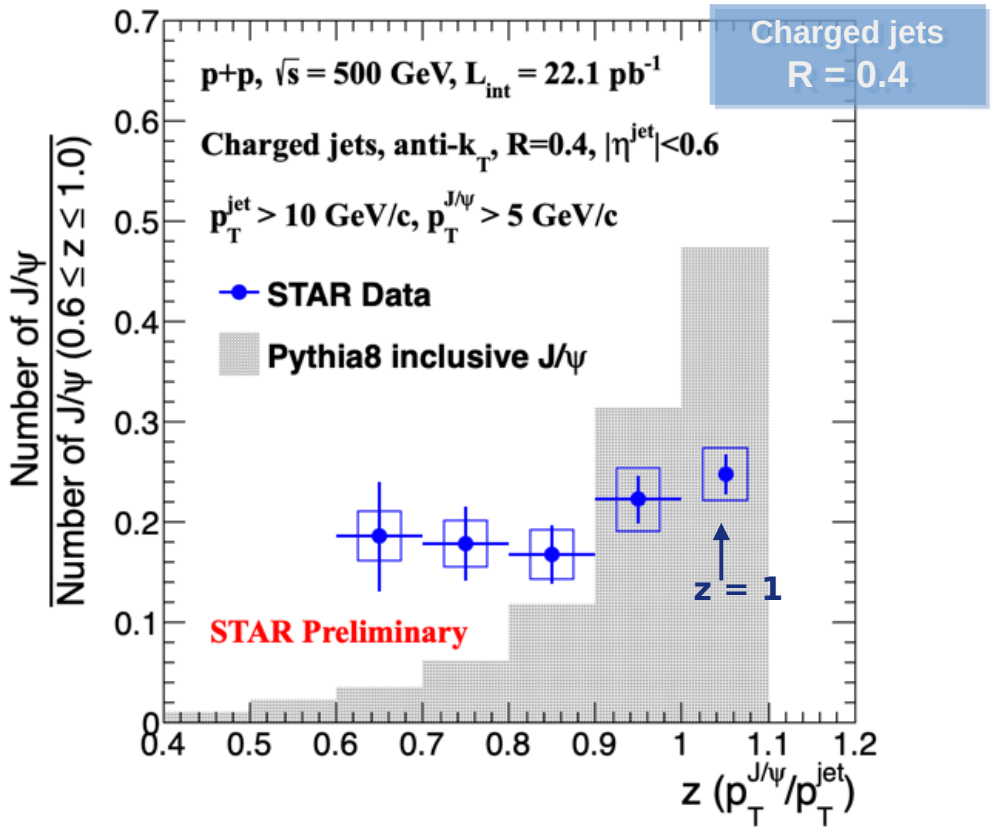


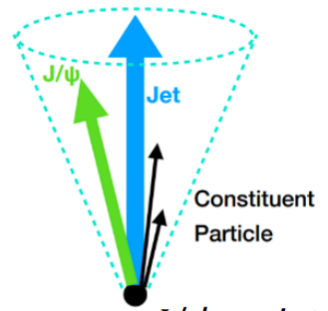


J/ψ production within jets in p+p

- J/ψ production in parton shower ?
- Constraints on Long Distance Matrix Elements in NRQCD

Z. Kang et .al, PRL 119, 032001 (2017)





$$z = p_T^{J/\psi} / p_T^{jet}$$

➔ No significant z dependence observed within uncertainties

➔ **Different trend in data than in Pythia8**

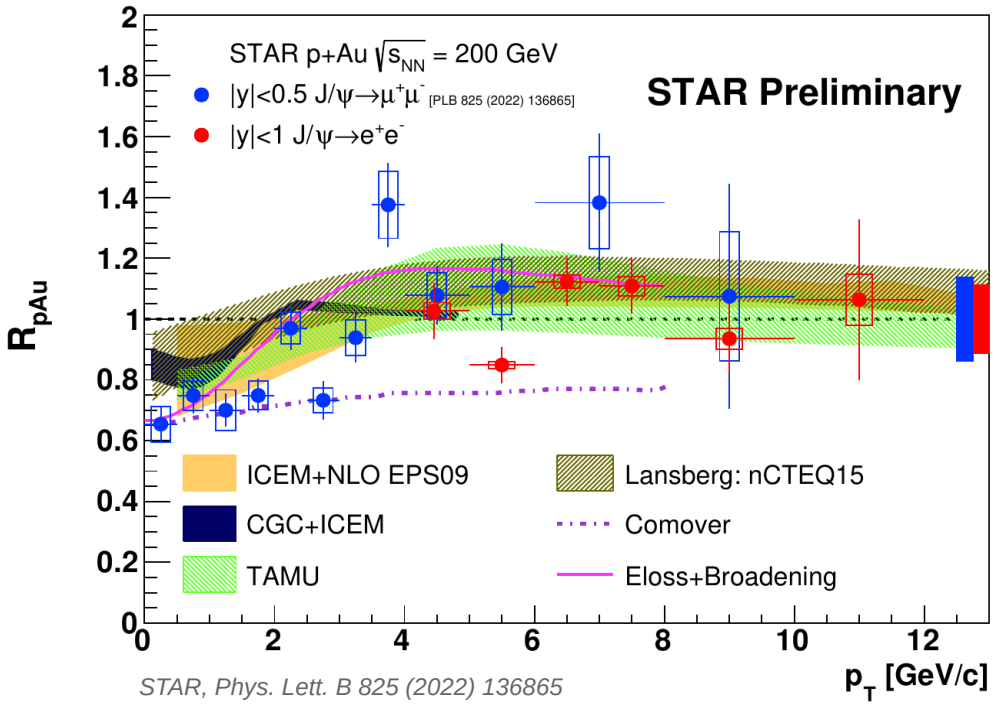
➔ **J/ψ production is less isolated in data than in Pythia8**

CNM effects on J/ψ production

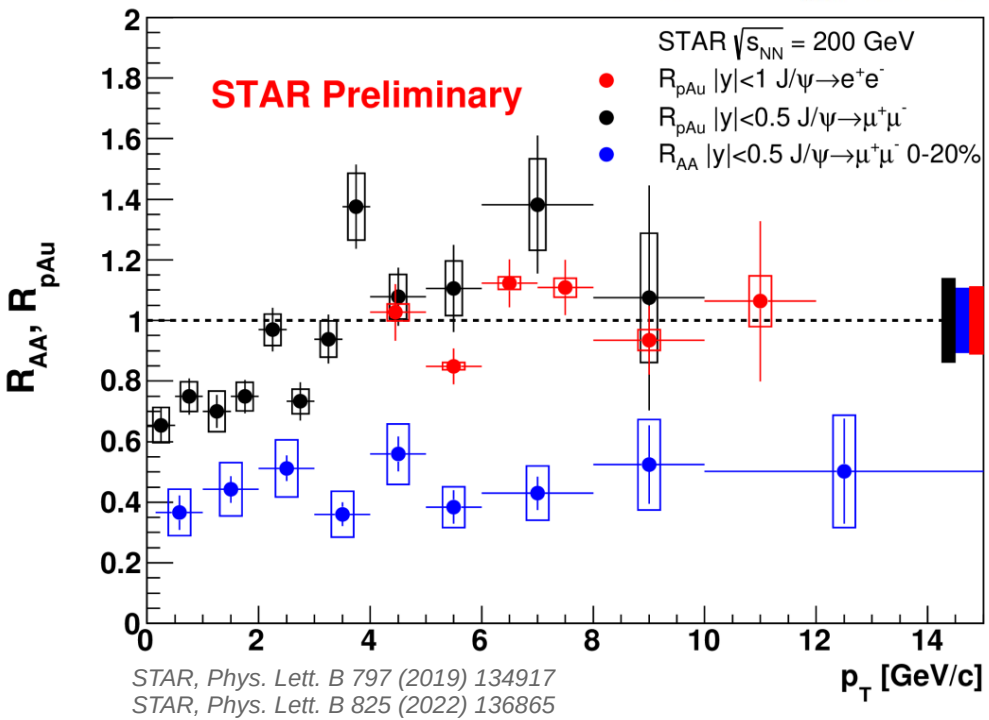
➔ **Low p_T : significant CNM effects**. Consistent with different models.

➔ **High p_T** (> 3 GeV/c): R_{pAu} consistent with unity → **suppression in AA due to QGP effects**

$$R_{AA} = \frac{1}{N_{coll}} \times \frac{dN^2_{AA}/(dp_T dy)}{dN^2_{pp}/(dp_T dy)}$$



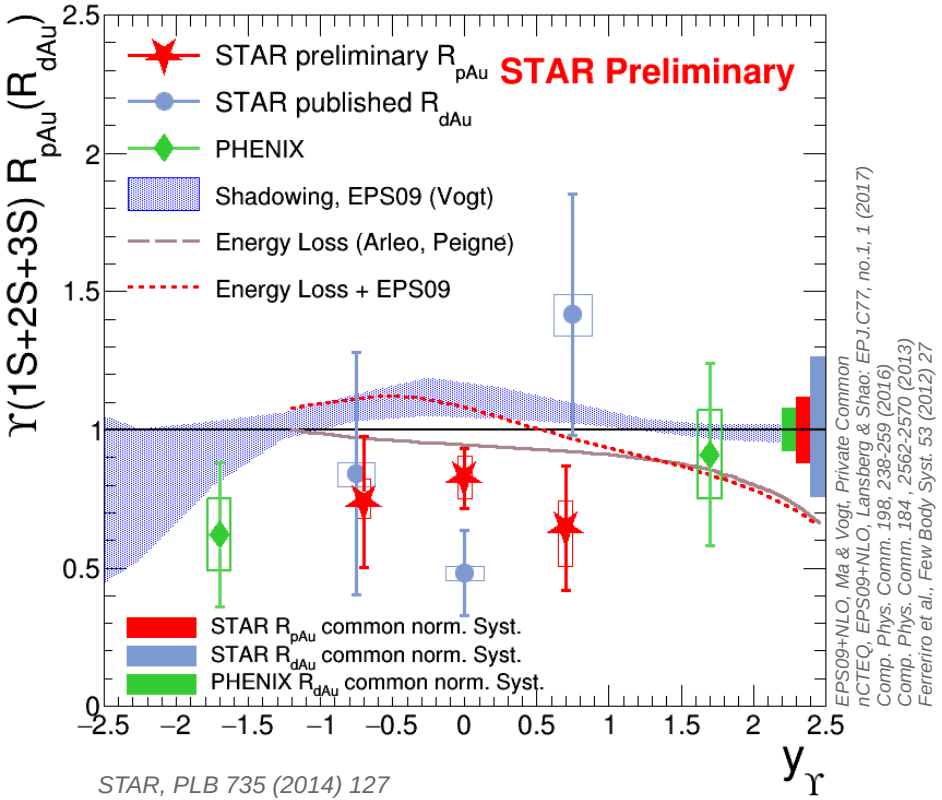
STAR, Phys. Lett. B 825 (2022) 136865



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

CNM effects on ϒ production

- Improved precision in p+Au over previous d+Au results
- **Indication of CNM** effects for ϒ production at RHIC



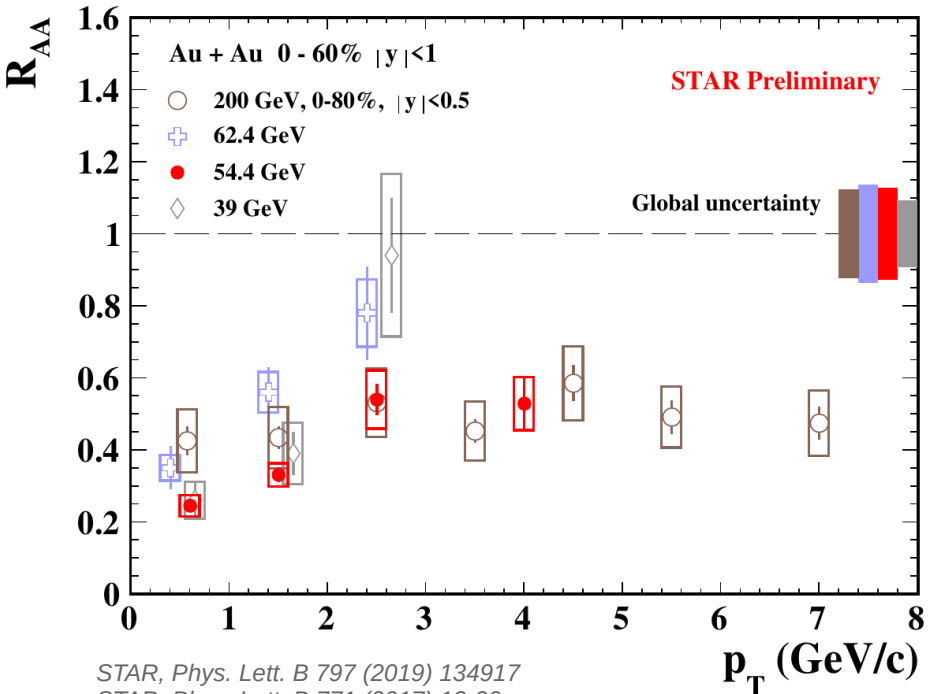
STAR, PLB 735 (2014) 127
PHENIX, PRC 87 (2013) 044909

Energy dependence of J/ψ suppression in Au+Au

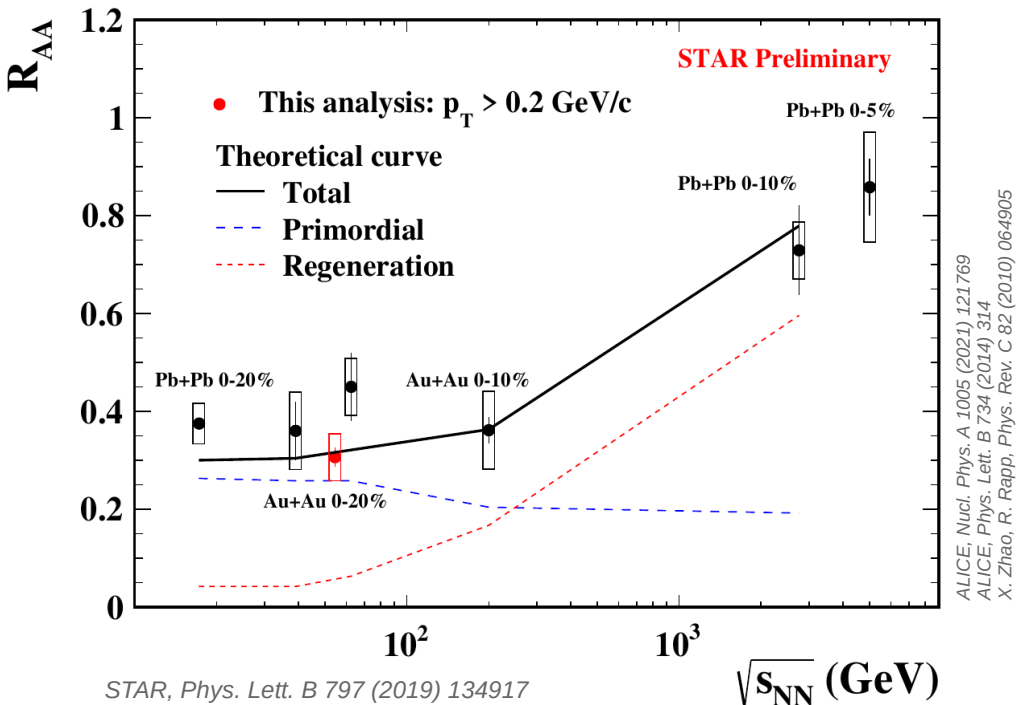
- Improved precision with 54.4 GeV data compared to previous STAR measurements

➔ R_{AA} increases with p_T below 3 GeV/c at 39 - 62.4 GeV, less p_T dependence at 200 GeV

➔ **No significant collision energy dependence** of the J/ψ suppression between 39-200 GeV → **interplay of dissociation and regeneration effects**



STAR, Phys. Lett. B 797 (2019) 134917
STAR, Phys. Lett. B 771 (2017) 13-20

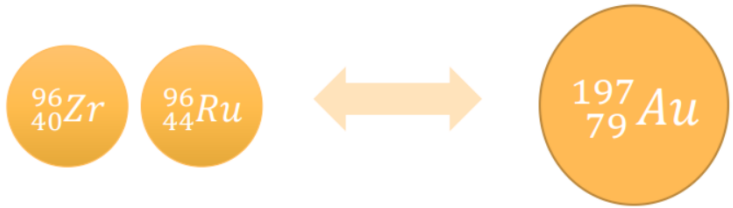


STAR, Phys. Lett. B 797 (2019) 134917
STAR, Phys. Lett. B 771 (2017) 13-20

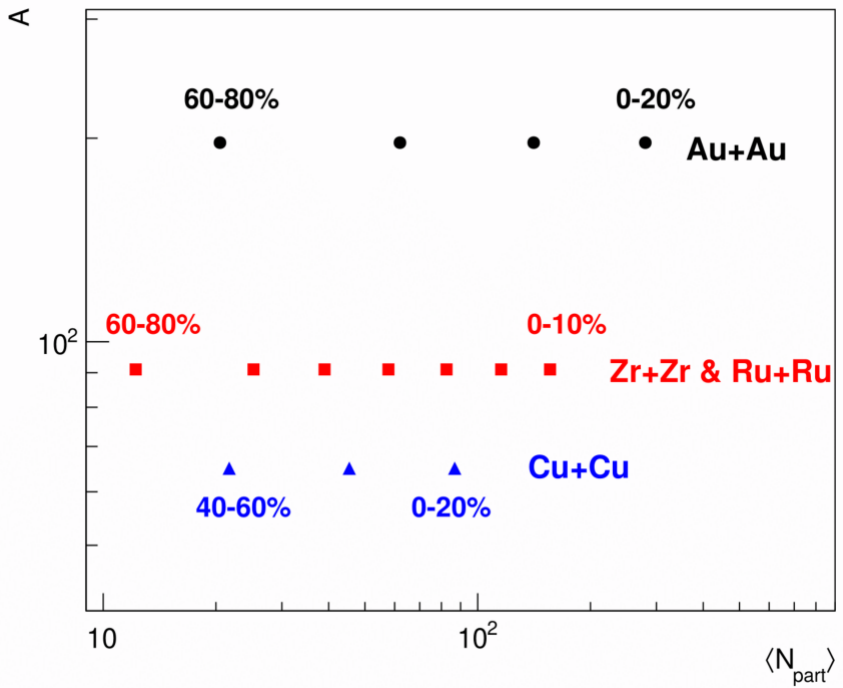
ALICE, Nucl. Phys. A 1005 (2021) 121769
ALICE, Phys. Lett. B 734 (2014) 314
X. Zhao, R. Rapp, Phys. Rev. C 82 (2010) 064905

Isobar collisions at 200 GeV

$^{96}_{44}Ru + {}^{96}_{44}Ru$ and $^{96}_{40}Zr + {}^{96}_{40}Zr$



- Moderate size collision system, between Au+Au and Cu+Cu
- Large sample: ~ 4 billion minimum bias events and high-tower trigger events
- Event Plane Detector (EPD): reduction of non-flow effects in v_2 analysis
- **Study dependence of hot nuclear medium effects on medium size and energy density**

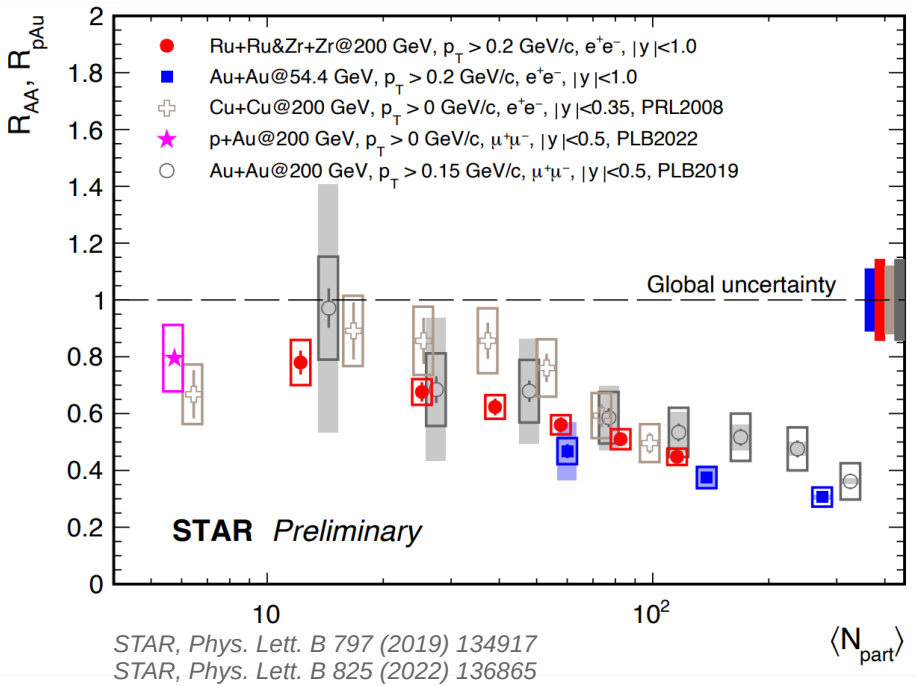


J/ψ suppression and v_2 in isobar collisions

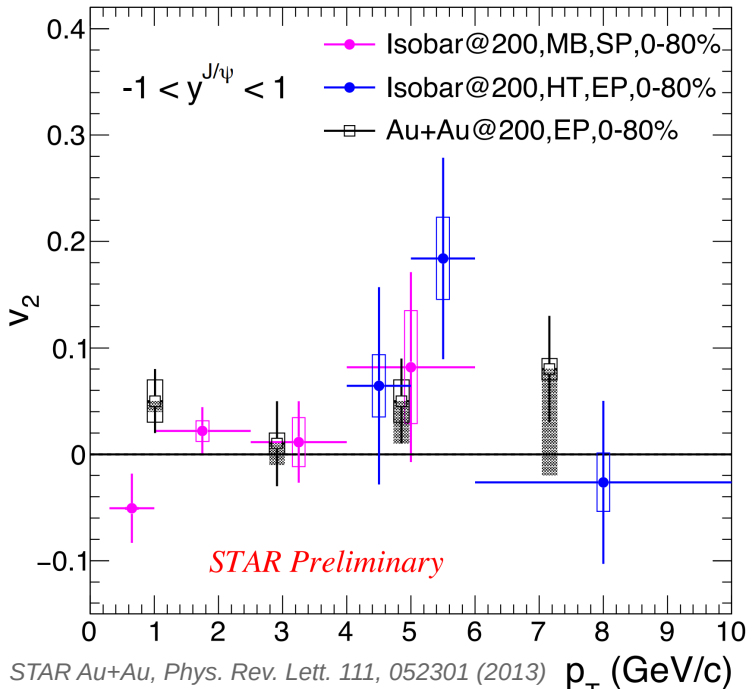
- Dissociation vs regeneration effects: system size and geometry dependence

➔ **No significant collision system and energy dependence** of the J/ψ suppression at similar N_{part}

➔ Elliptic flow (v_2) consistent with zero for p_T < 4 GeV/c at $\sqrt{s_{NN}}$ = 200 GeV → **small regeneration**



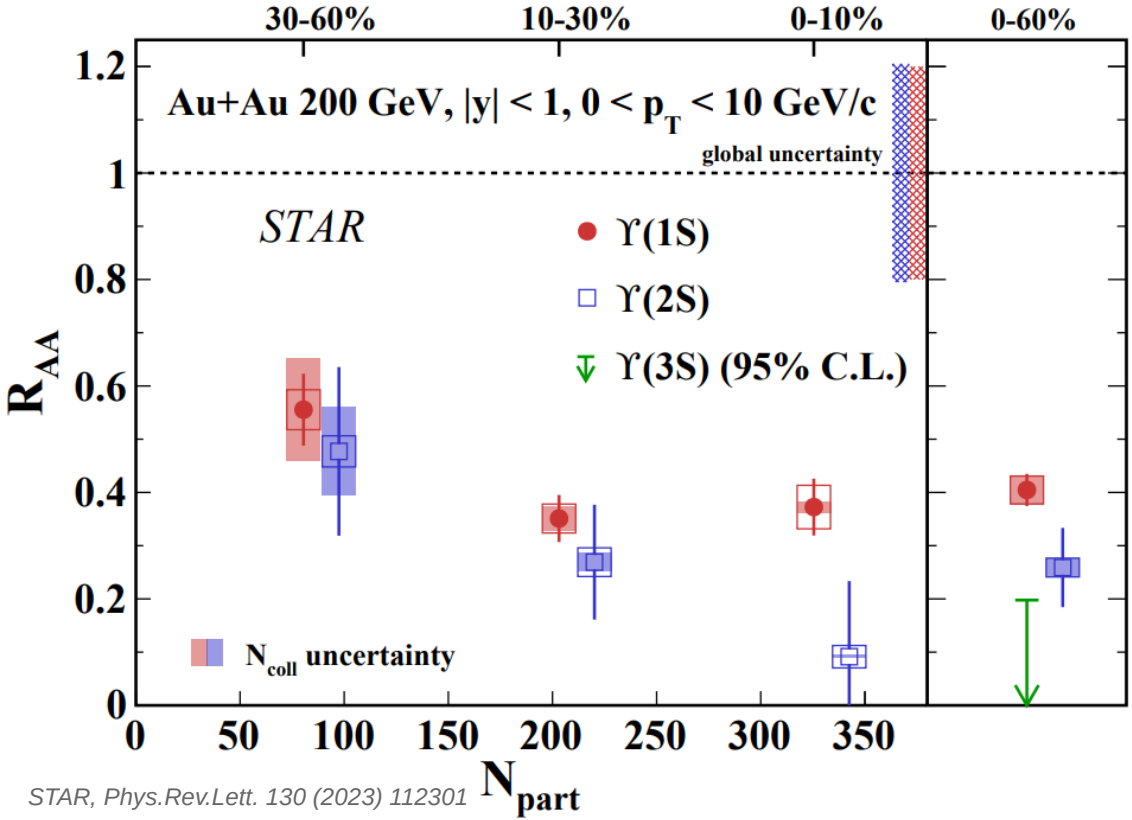
STAR, Phys. Lett. B 797 (2019) 134917
STAR, Phys. Lett. B 825 (2022) 136865



STAR Au+Au, Phys. Rev. Lett. 111, 052301 (2013)

Suppression of ϒ states in Au+Au

- ϒ states as QGP *thermometer*

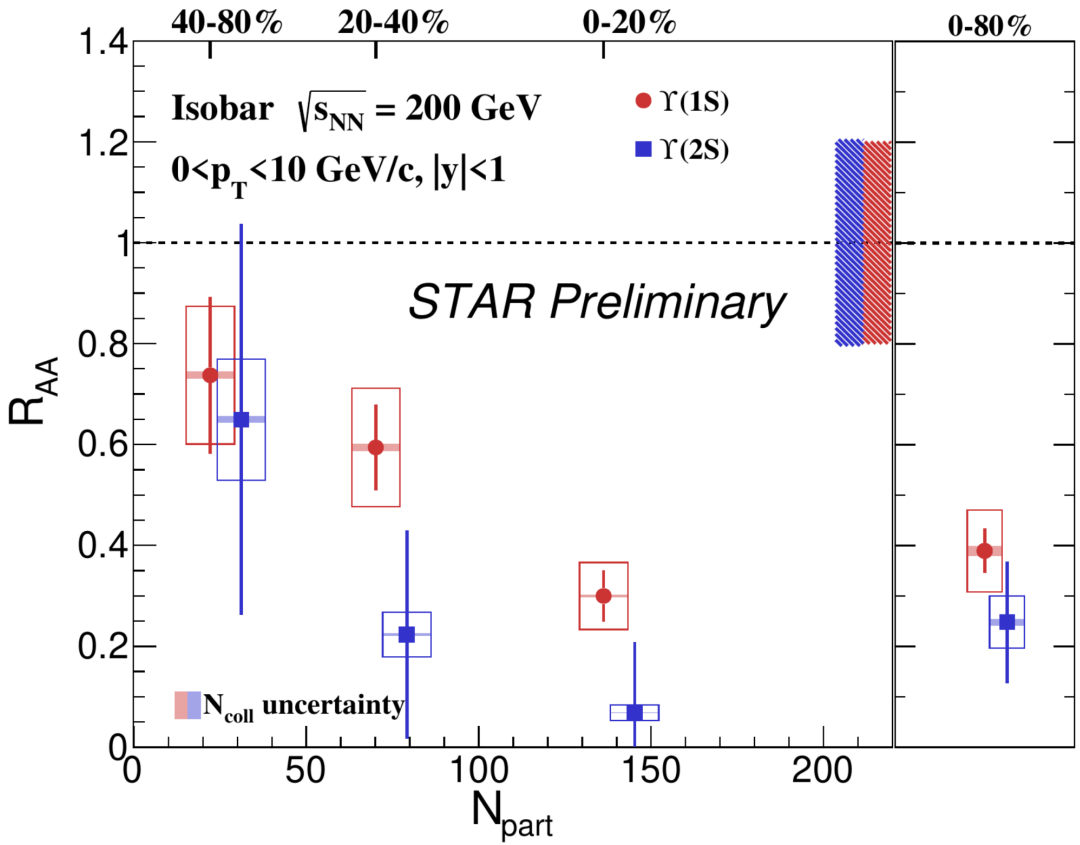


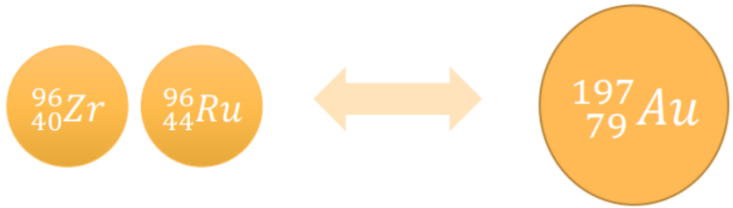
STAR, Phys.Rev.Lett. 130 (2023) 112301

- **Significant suppression of different ϒ states in Au+Au** collisions at 200 GeV
- Increasing suppression in more central collisions
- **Sequential suppression of ϒ states at RHIC**

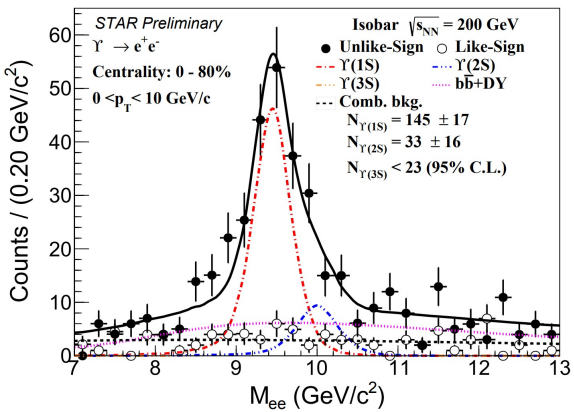
Suppression of ϒ states in Isobar

- ϒ states as QGP *thermometer.*

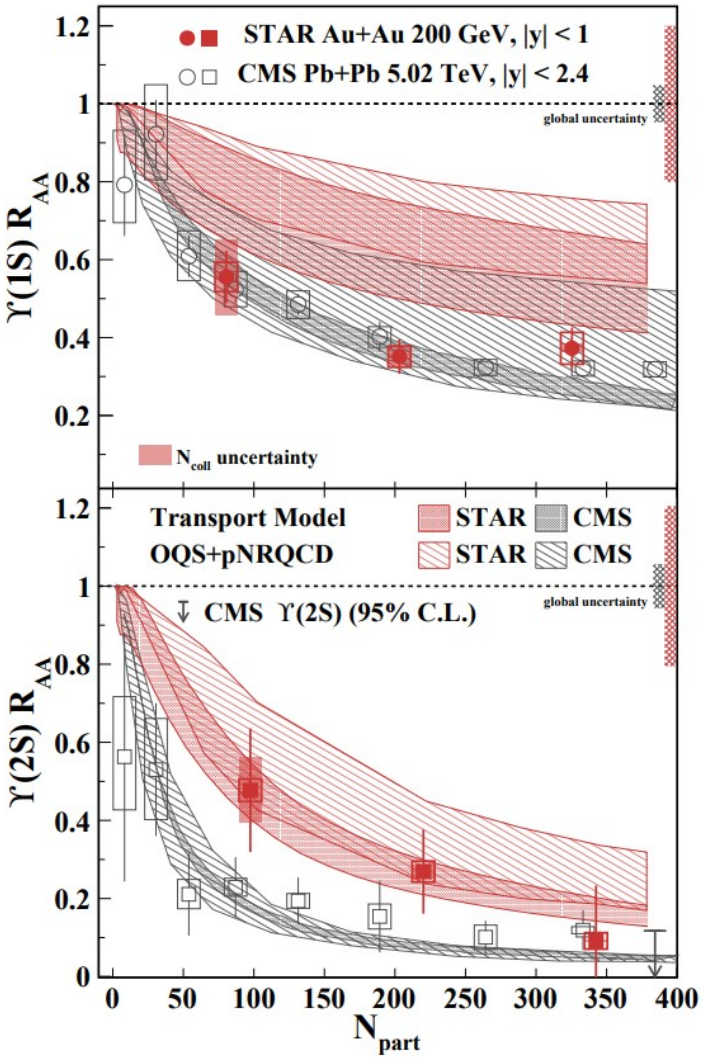




- **Similar R_{AA} for ϒ states in isobar** collisions as in Au+Au at 200 GeV
- Significant suppression, increasing with collision centrality
- Hint of sequential suppression pattern



Energy dependence of ϒ states suppression



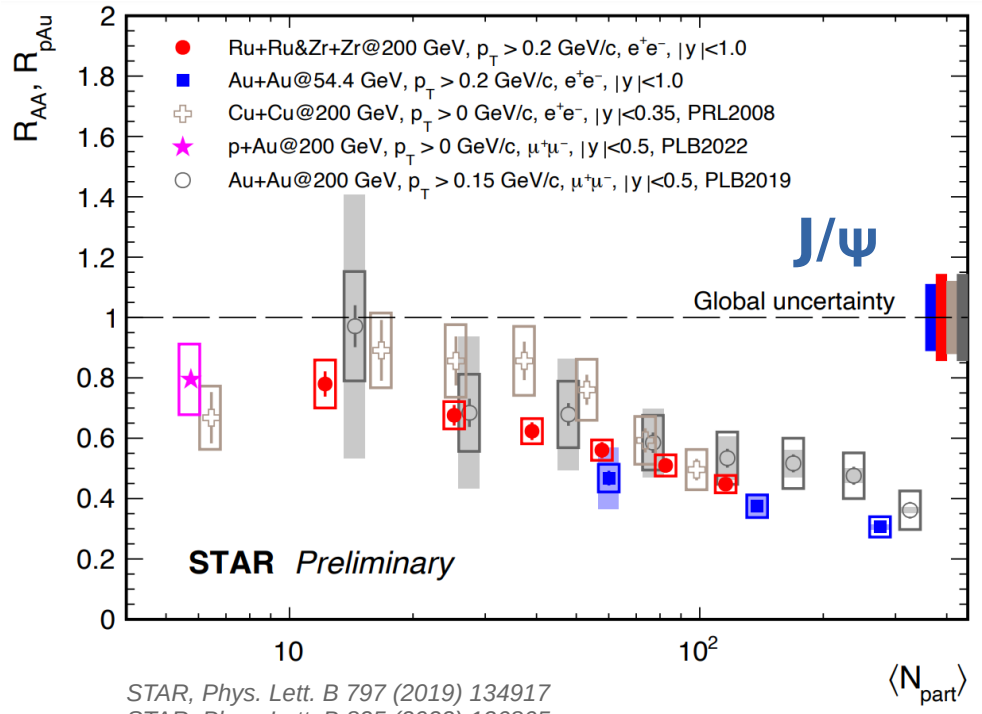
OQS+pNRQCD, JHEP 05 (2021) 136, JHEP 08 (2022) 303
Transport Model, Phys. Rev. C 96 (2017) 054901

- ϒ(1S): **similar magnitude of suppression at RHIC and LHC**
- ϒ(2S): **hint of less suppression at RHIC in peripheral A+A collisions**
- Different model calculations describe ϒ(1S) and ϒ(2S) suppression within uncertainties
  - ϒ(1S) STAR data systematically below the model calculations

STAR, Phys.Rev.Lett. 130 (2023) 112301
CMS, Phys. Lett. B790 (2019) 270–93

System size dependence of quarkonia R_{AA}

➔ **No significant collision species dependence of the suppression at similar $\langle N_{part} \rangle$**



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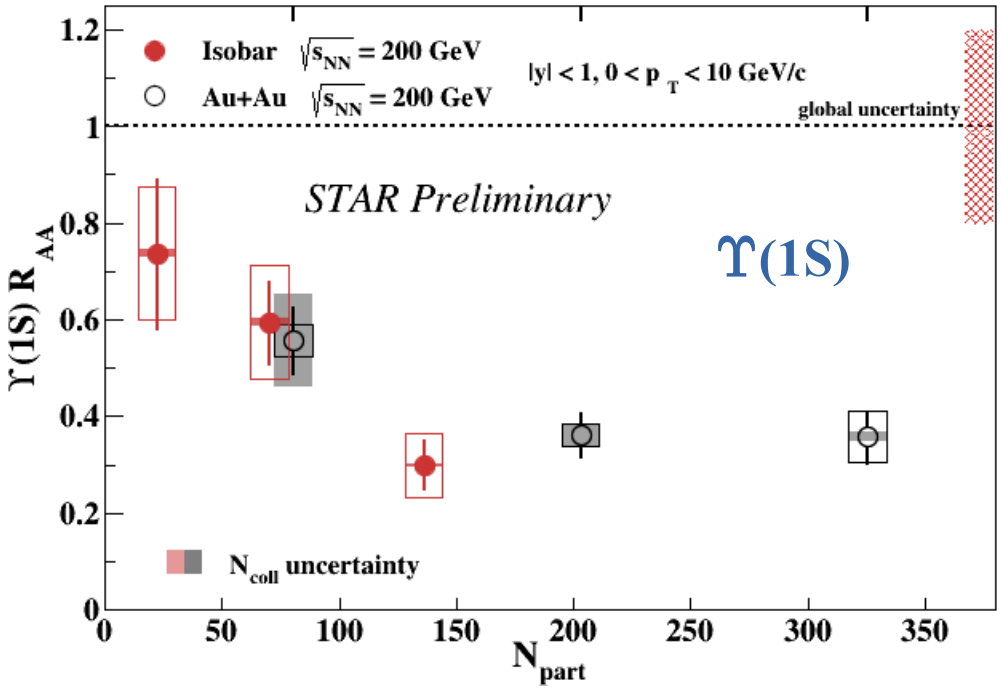
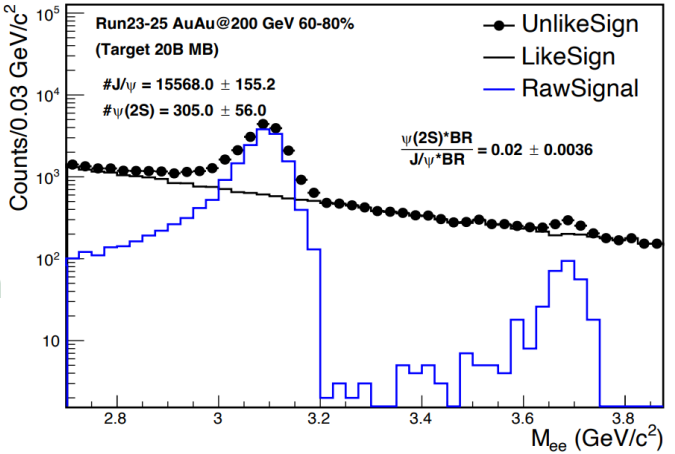


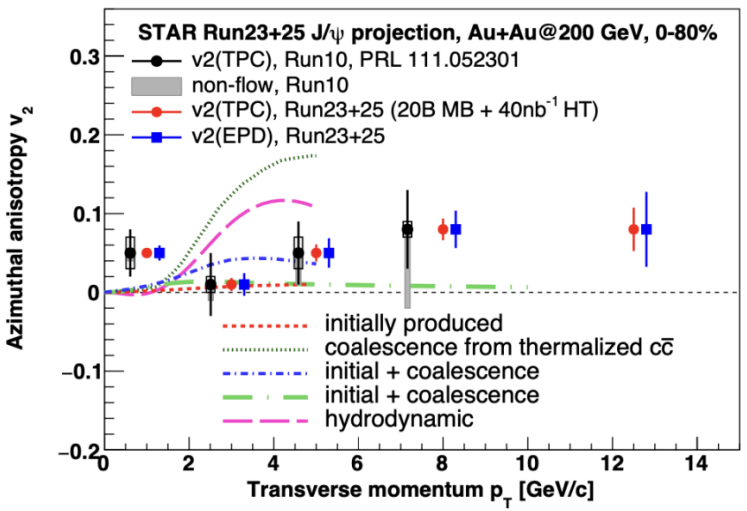
STAR, Phys.Rev.Lett. 130 (2023) 112301

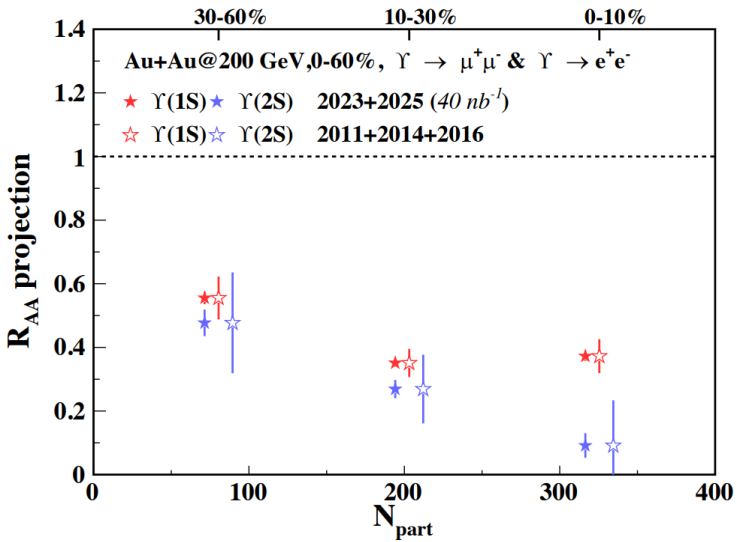
Outlook – 2023 and 25

- **High luminosity Au+Au runs at 200 GeV**

1. ψ(2S) measurement in Au+Au at RHIC.
   - ➔ Regeneration contribution and temperature profile of QGP
2. Improved J/ψ v_2 measurement with reduced non-flow effects
   - ➔ Regeneration contribution and charm quark thermalization
3. Precision ϒ measurements (~30% statistical uncertainty for Υ(3S))
   - ➔ Medium temperature.

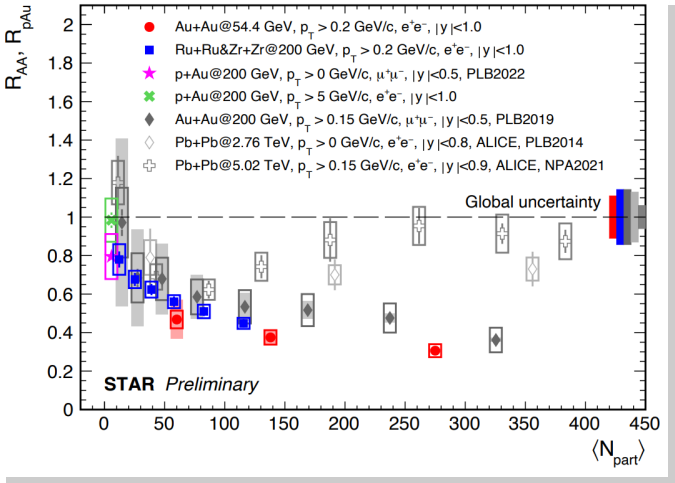


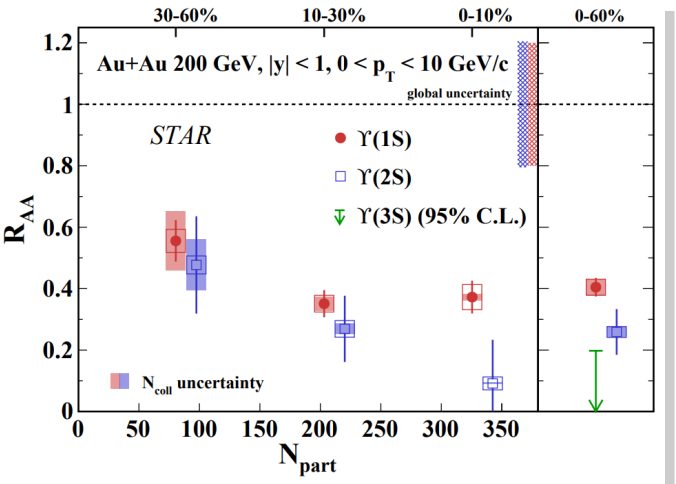




Summary of quarkonia at STAR

1. J/ψ production in jets and vs jet activity: discrepancy between data and Pythia8
2. CNM effects for low-p_T quarkonia
3. J/ψ suppression: no significant collision system and energy dependence
   - Interplay of dissociation and regeneration effects.
4. J/ψ v_2 consistent with zero
   - Indication of small regeneration effects
5. Sequential ϒ suppression at RHIC
   - Thermodynamic properties of the medium
6. Quarkonium suppression driven by N_{part}





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Backup

Outlook – 2023 and 25

- High luminosity Au+Au runs at 200 GeV

➔ Projected kinematic coverage of the heavy-flavor program.