STAR quarkonium measurements in heavy ion collisions

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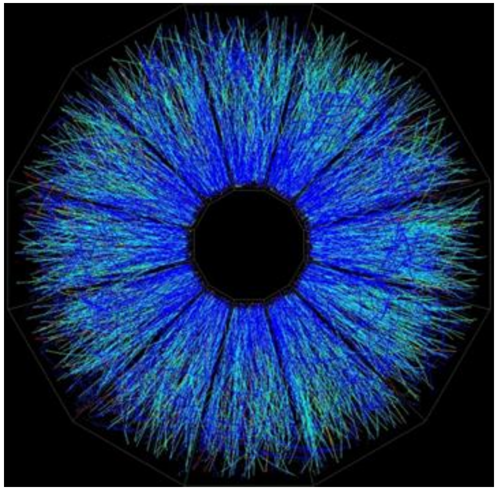
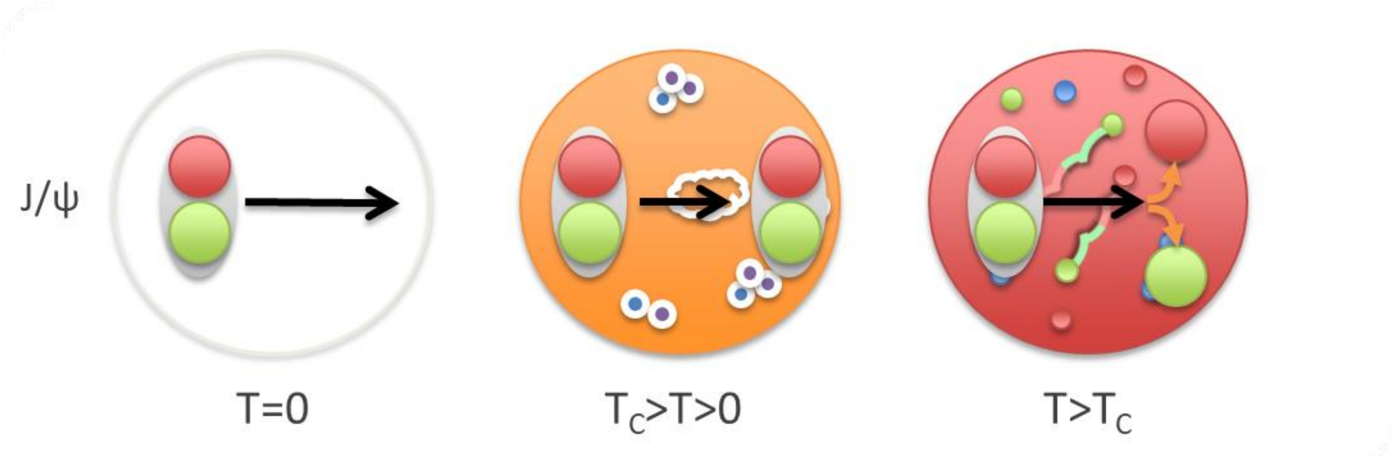


QWG 2019 – The 13-th International Workshop on Heavy Quarkonium
13-17 May 2019 Torino, Italy

Quarkonium in nuclear matter

- In heavy ion collisions at RHIC hot and dense quark gluon plasma is created
- Heavy-flavor quarks are good probes for studying QGP
  - $m_{c,b} >> T_C, \Lambda_{QCD}, m_{u,d,s}$: produced dominantly by high-Q^2 scatterings in the early stage
- Due to color screening of quark-antiquark potential in QGP quarkonium dissociation is expected

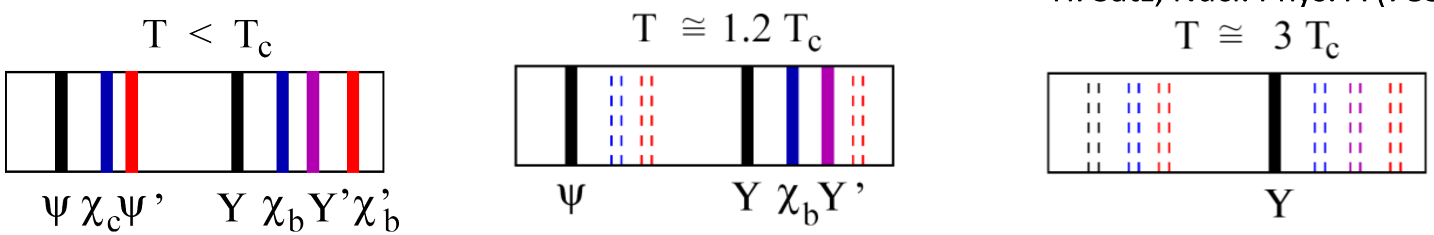


A.Rothkopf HP12

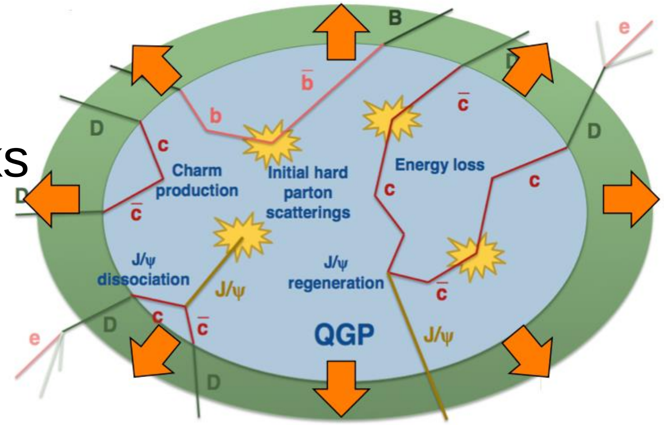
Quarkonium in nuclear matter

- Sequential melting: suppression of different states is determined by medium temperature and their binding energies - QGP thermometer

H. Satz, Nucl. Phys. A (783):249-260(2007)



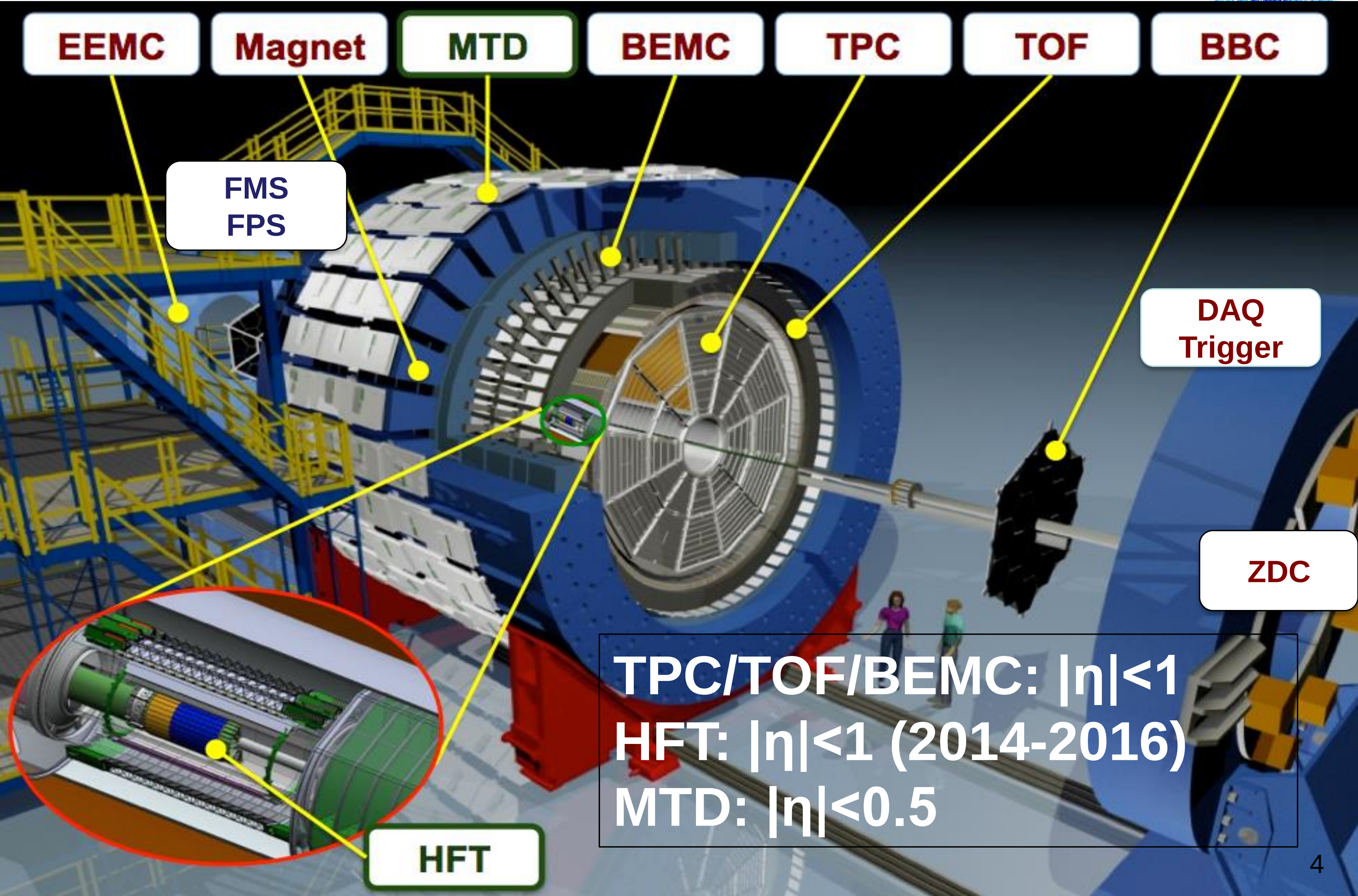
- Hot nuclear matter effects
  - Dissociation
  - Regeneration from deconfined quarks
  - Medium-induced energy loss
  - Formation time effect



https://indico.cern.ch/event/443462/images/6069-hf_cartoon1.png

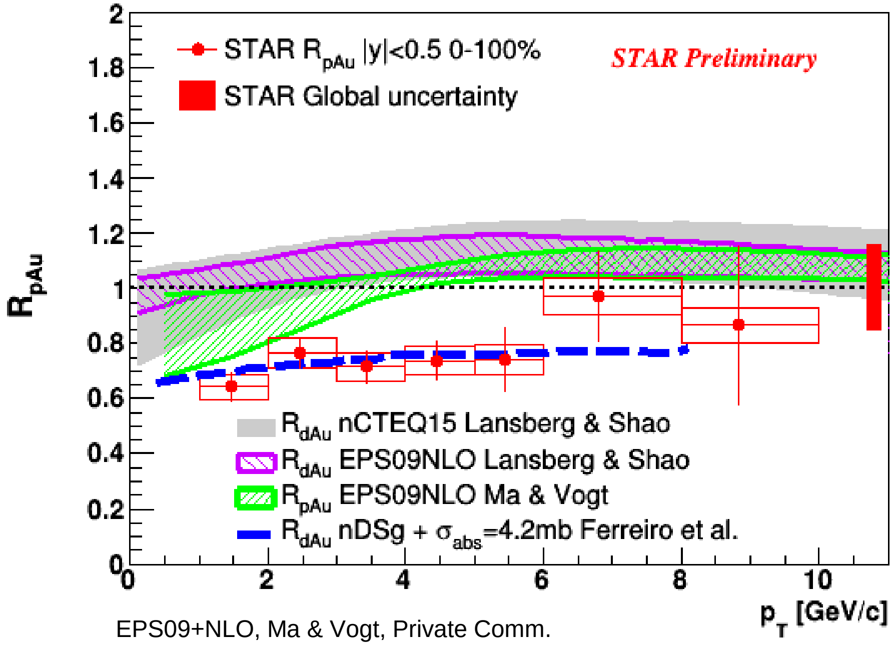
- Cold nuclear matter effects (CNM)
  - Nuclear absorption, gluon shadowing, initial state energy loss, Cronin effect and gluon saturation.
- Feed-down from excited states and B-hadrons

STAR experiment

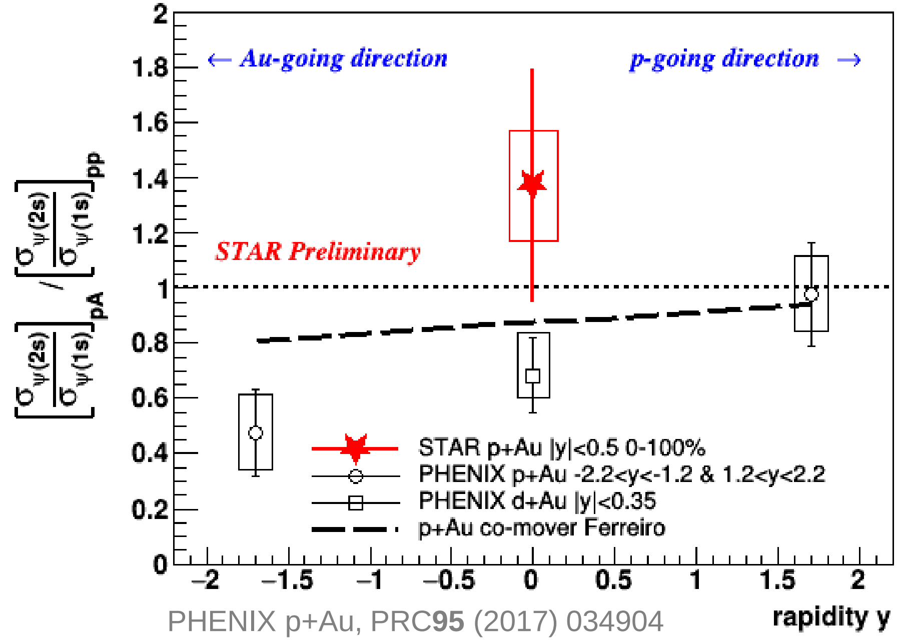


TPC/TOF/BEMC: $|\eta|<1$
HFT: $|\eta|<1$ (2014-2016)
MTD: $|\eta|<0.5$

J/ψ and ψ(2s) production in 200 GeV p+Au collisions



EPS09+NLO, Ma & Vogt, Private Comm.
nCTEQ, EPS09+NLO, Lansberg & Shao, Eur. Phys. J. C77 (2017) 1
Comp. Phys. Comm. 198 (2016) 238, Comp. Phys. Comm. 184 (2013) 2562
Ferreriro et al., Few Body Syst. 53 (2012) 27

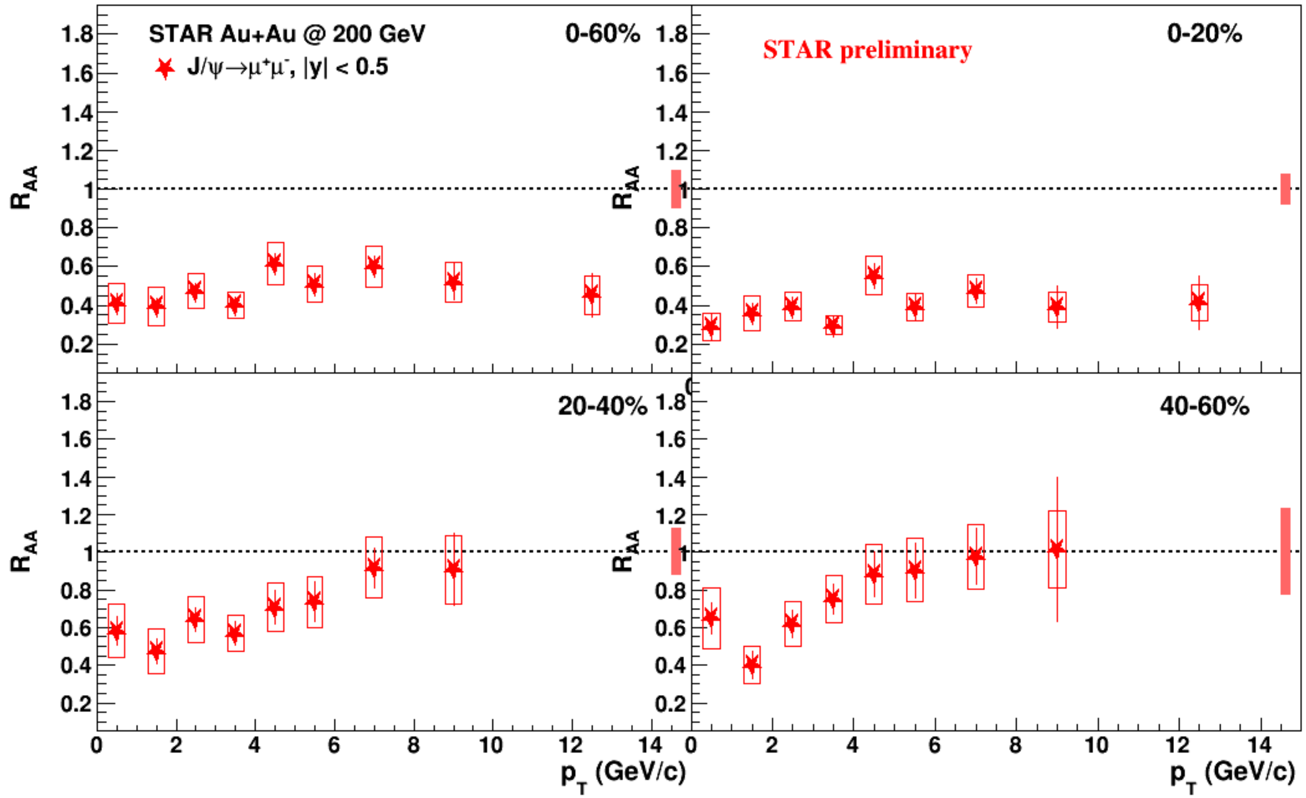


PHENIX p+Au, PRC**95** (2017) 034904
PHENIX d+Au, PRL**111** (2013) 202301
Co-mover calculation, Ferreiro, private comm.

- Models with only nPDF effects can reach upper uncertainty limit of the data at low and high p_T, but underpredicts the suppression at p_T of 3-6 GeV/c
  - Additional nuclear absorption is favored by data

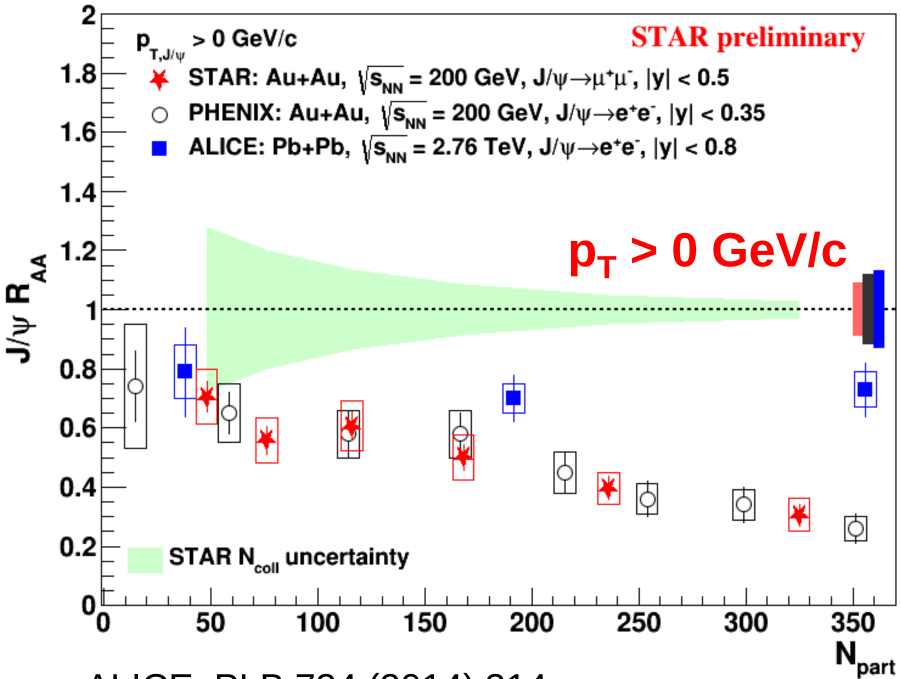
- First ψ(2S) to J/ψ double ratio measurement from STAR between p+Au and p+p at midrapidity at RHIC: **1.37 ±0.42(stat.) ±0.19(syst.)**

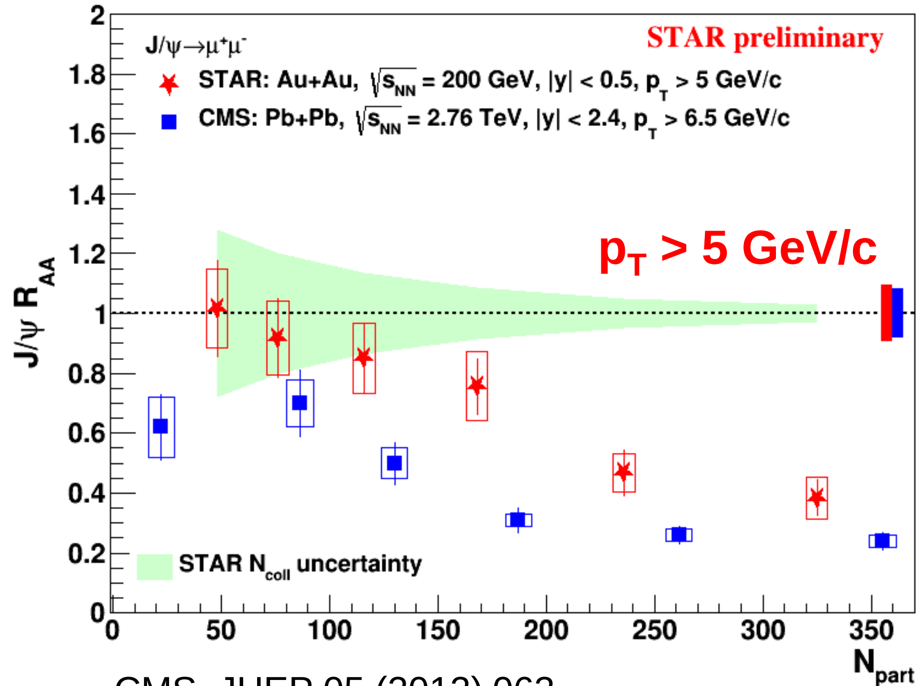
J/ψ production in 200 GeV Au+Au collisions



- R_{AA} increases from ~0.5 to 1.0 at high-p_T in 20-40% and 40-60% centrality, most likely due to CNM, formation time effects and B-hadron feed-down
- No obvious p_T dependence for 0-20% and 0-60% centrality
  - Suppression at low p_T is interplay of dissociation, Cold Nuclear Matter effects and regeneration
  - Suppression at high p_T is mainly due to dissociation, other effects are small

J/ψ production in 200 GeV Au+Au collisions





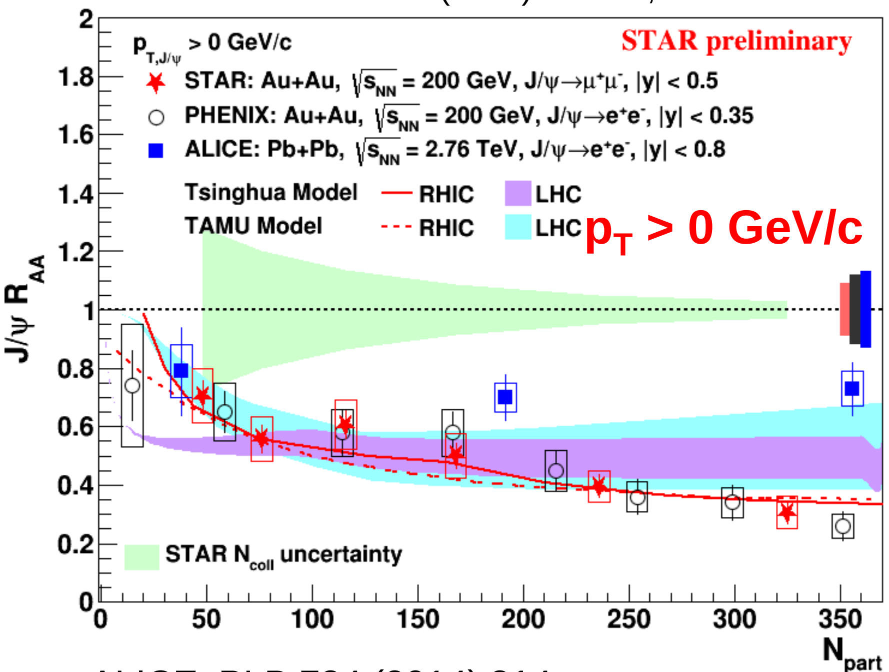
ALICE, PLB 734 (2014) 314
PHENIX, PRL 98 (2007) 232301

CMS, JHEP 05 (2012) 063

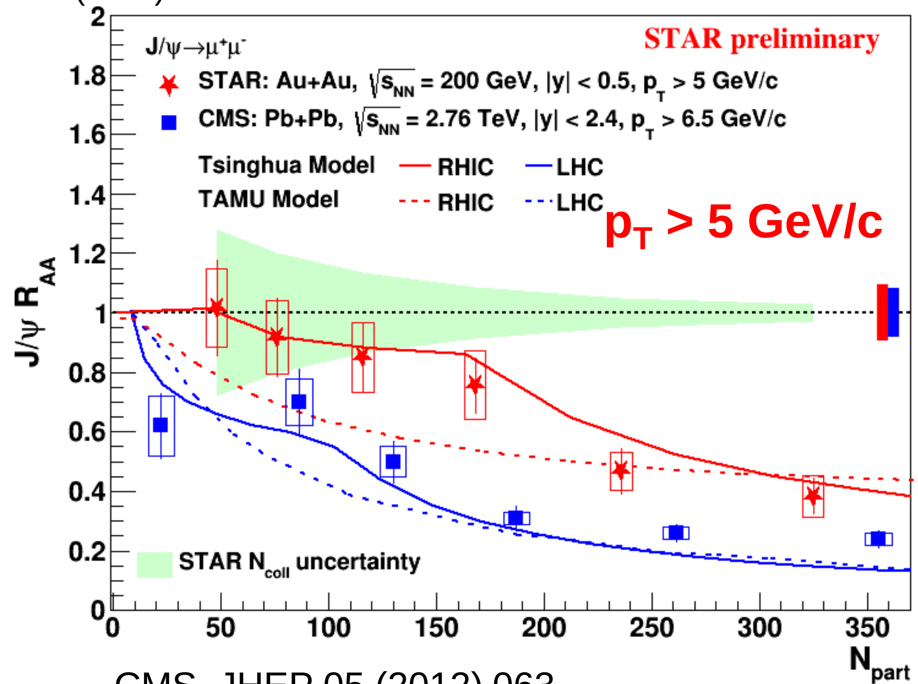
- Suppression in central collisions at low p_T:
  - dissociation, Cold Nuclear Matter effects, regeneration
- Suppression in central collisions at high p_T: due to dissociation
- LHC vs RHIC:
  - More regeneration at the LHC leads to less suppression at low p_T
  - Higher temperature at the LHC, higher dissociation leads to more suppression at high p_T

J/ψ production in 200 GeV Au+Au collisions

Tsinghua at RHIC: PLB 678 (2009) 72, Tsinghua at LHC: PRC 89 (2014) 054911
TAMU at RHIC: PRC 82 (2010) 064905, TAMU at LHC: NPA 859 (2011) 114



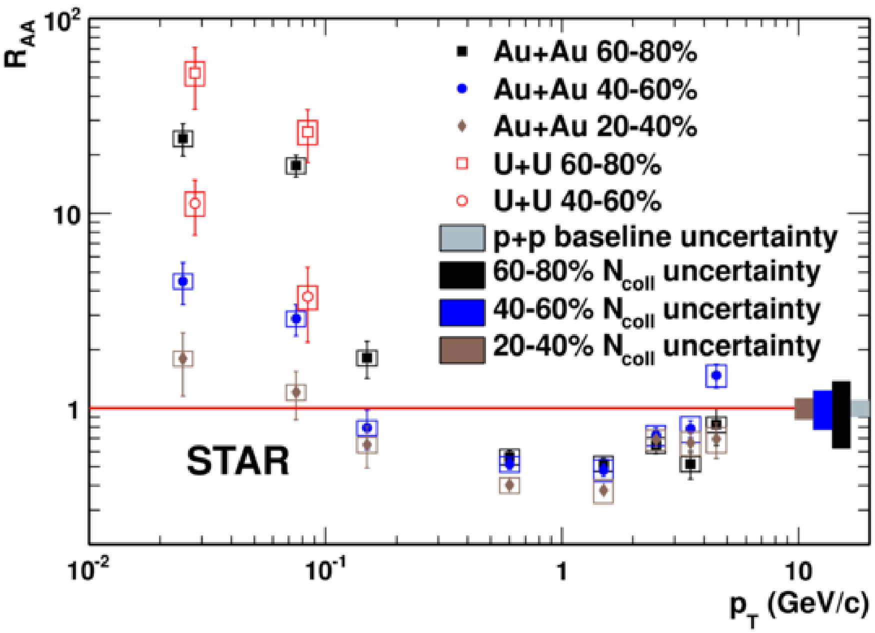
ALICE, PLB 734 (2014) 314
PHENIX, PRL 98 (2007) 232301

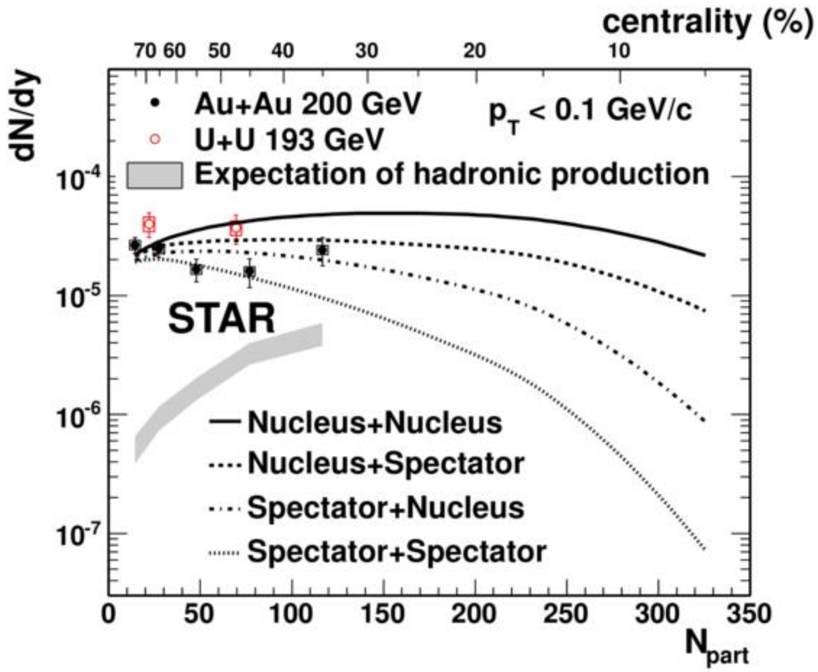


CMS, JHEP 05 (2012) 063

- Models (dissociation + regeneration effects) can describe centrality dependence at RHIC, but overestimate suppression at the LHC at low p_T
- At high p_T both models can qualitatively describe data at RHIC and the LHC

J/ψ production at very low p_T





STAR arxiv.org:1904.11658 (submitted to PRL)
model W.Zha PRC 97, 044910 (2018)

- Large enhancement at low p_T in peripheral collisions
  - Cannot be explained by hadronic production (color screening, CNM, regeneration)
- Coherent photoproduction of J/ψ can qualitatively explain the observation
  - In semicentral collisions data favor model configuration Nucleus+Spectator and Spectator+Nucleus as photon and Pomeron emitters

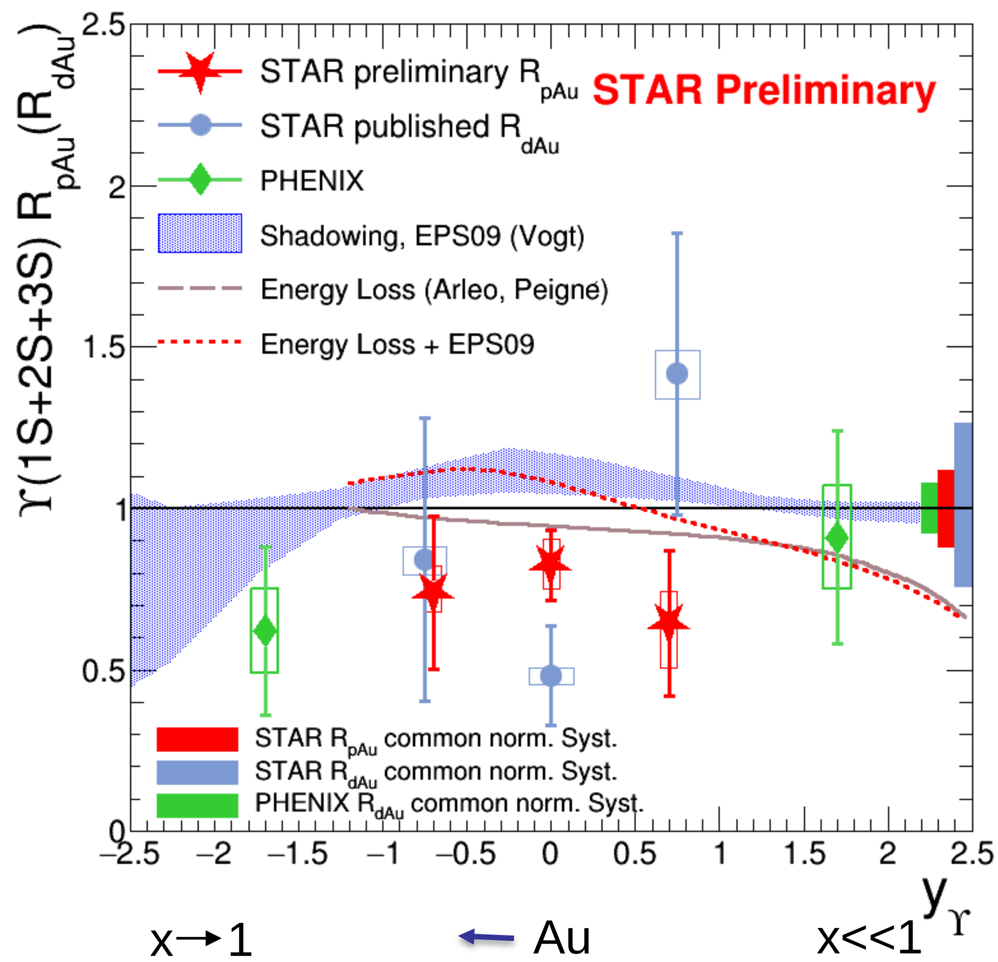
Bottomonia Υ(1S), Υ(2S), Υ(3S)

- Recombination effects
  - J/ψ : Evidence for large effects at the LHC.
  - Υ: Expecting negligible contribution.

    $\sigma_{c\bar{c}}$ @ RHIC: 797 ± 210 $^{+208}_{-295}$ μb. (PRD 86, 072013(2012))

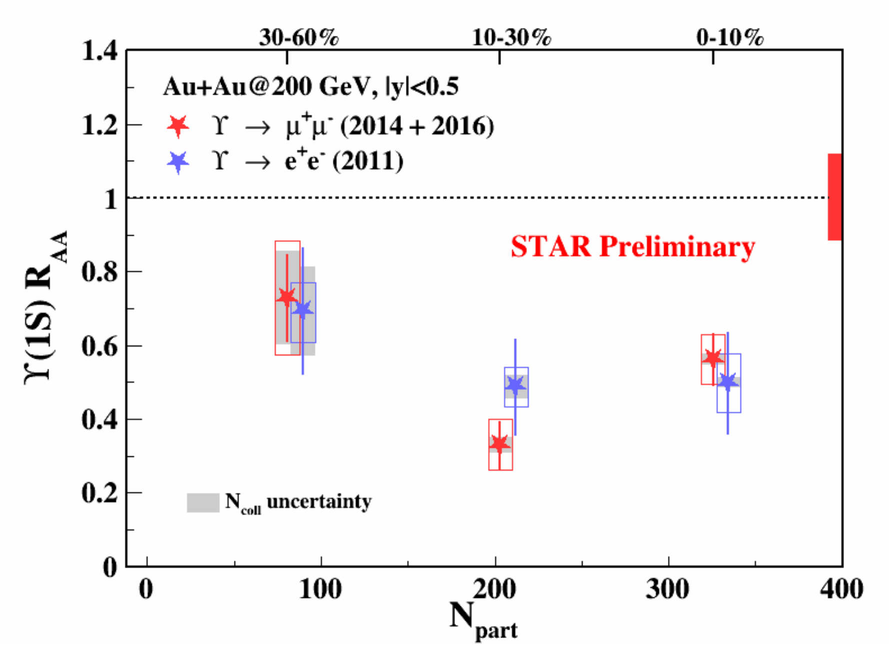
    $\sigma_{b\bar{b}}$ @ RHIC: ~ 1.34 – 1.84 μb (PRD 83 (2011) 052006)
- Co-mover absorption effects
  - Υ (1S) : tightly bound, larger kinematic threshold.
    - Expect σ ~ 0.2 mb, 5-10 times smaller than for J/ψ
      - Lin & Ko, PLB 503 (2001) 104

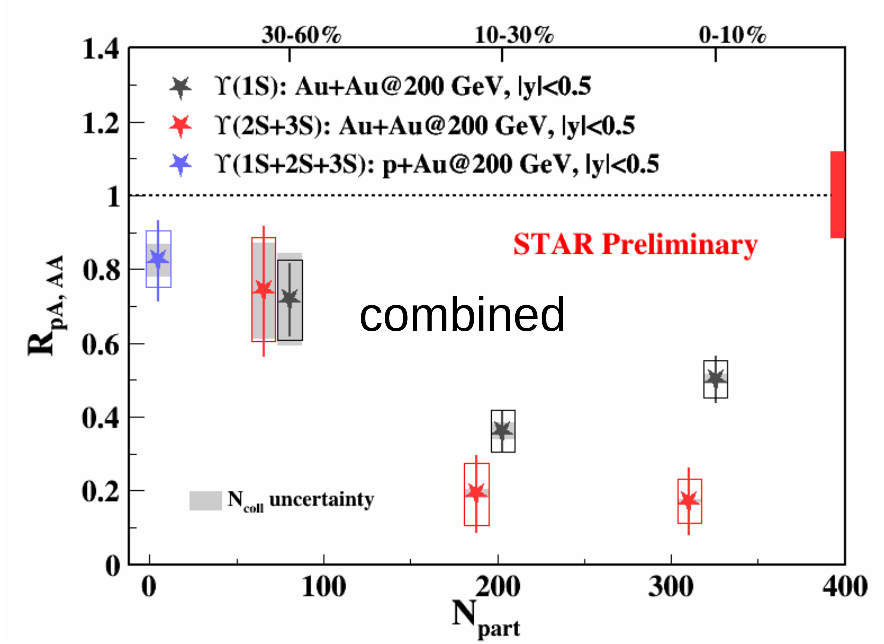
ϒ(1S,2S,3S) in 200 GeV p+Au collisions



- Indication of ϒ(1S,2S,3S) suppresion in p+Au collisions
- $R_{pAu}|_{|y|<0.5} = 0.82 \pm 0.10(\text{stat.})^{+0.08}_{-0.07}(\text{syst.}) \pm 0.10(\text{glob.})$
- Suppression due to CNM effects - beyond expectation from nPDFs only

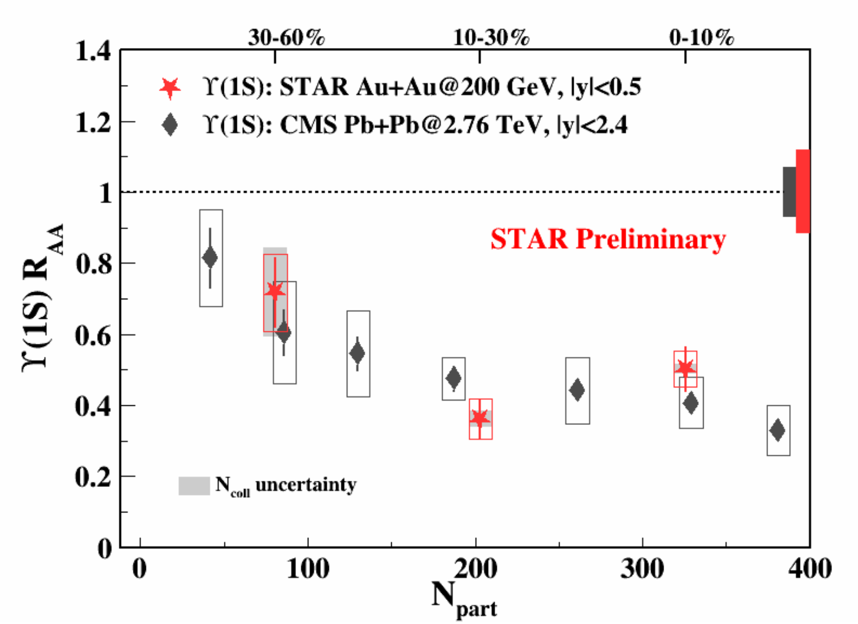
ϒ(1S,2S,3S) in 200 GeV Au+Au collisions

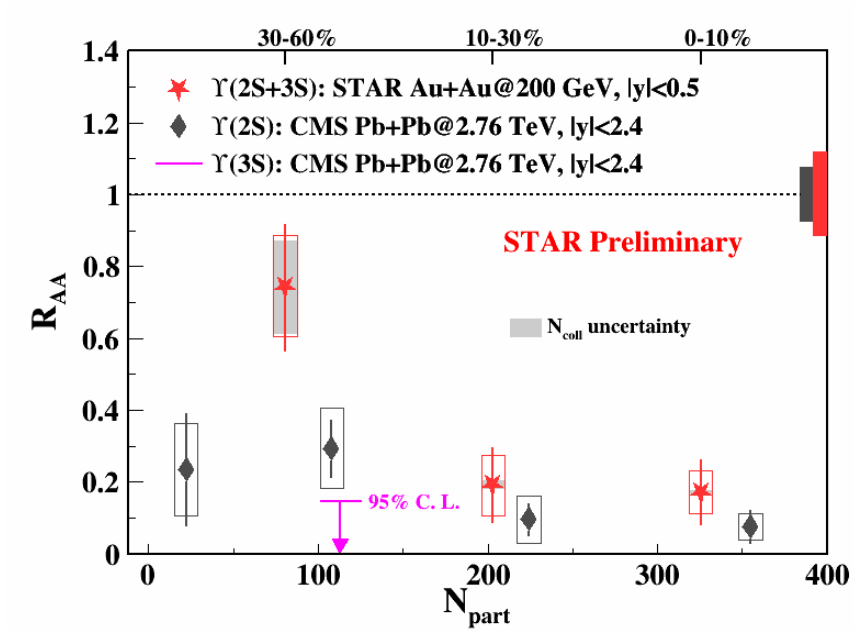




- Dielectron and dimuon results consistent with each other
- Stronger suppression of ϒ(2S + 3S) than ϒ(1S) in central coll.
  - Consistent with sequential melting expectations

ϒ at RHIC and LHC





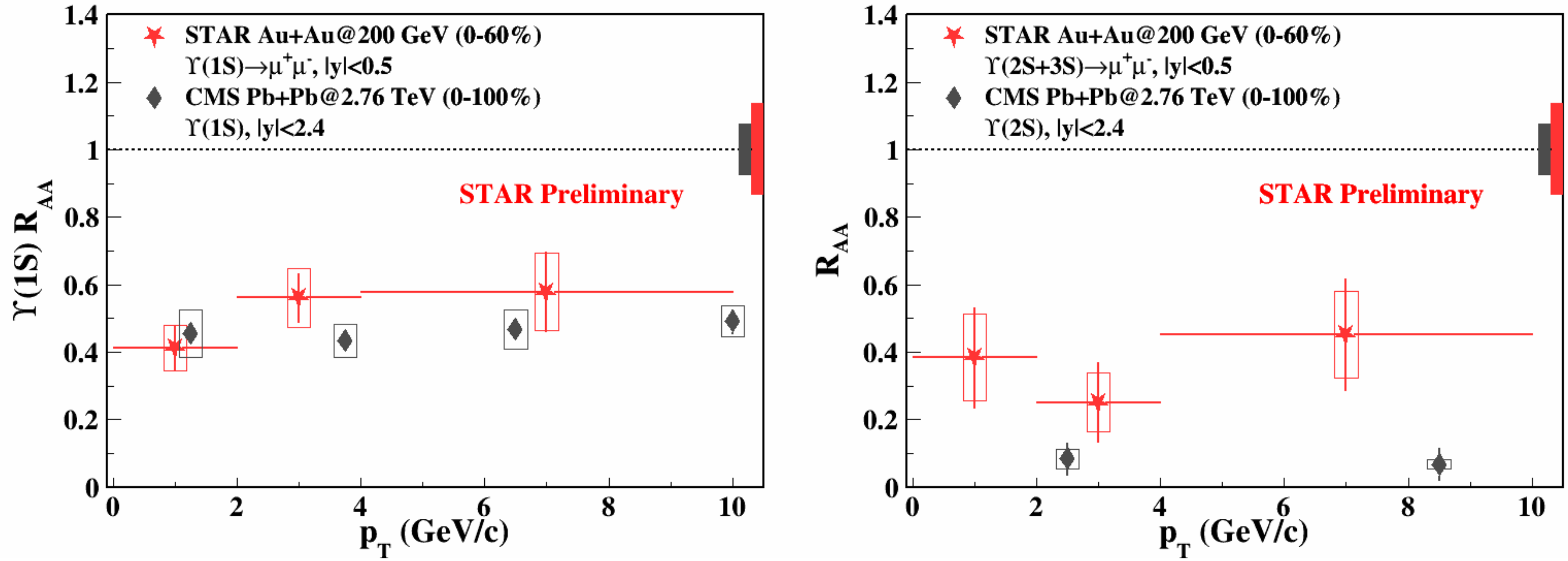
Phys. Lett. B 770(2017) 357

- Similar suppression for ϒ(1S), despite higher medium temperature at the LHC
  - Regeneration? Larger at the LHC than at RHIC
  - CNM effects

- Indication of smaller suppression for ϒ(2S+3S) at RHIC than at the LHC

Υ(1S), Υ(2S,3S) R_{AA} vs p_T

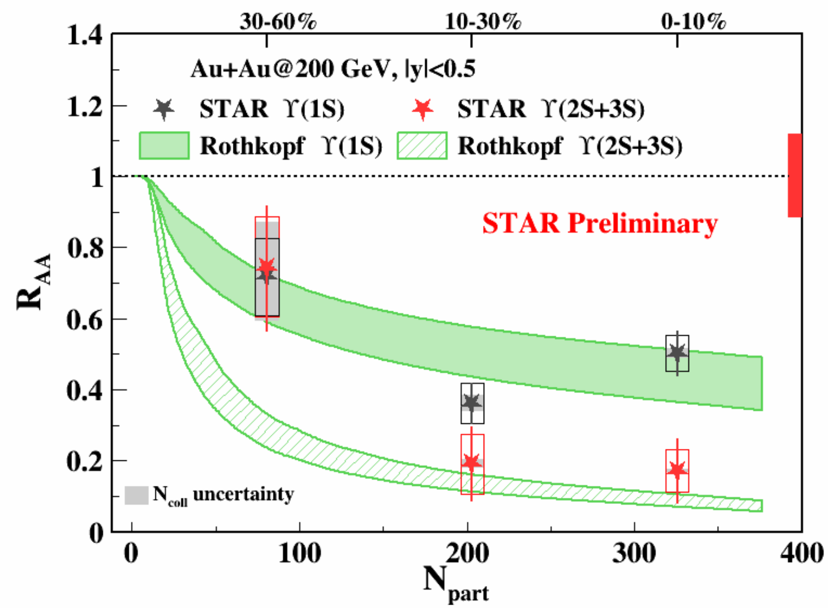
Phys. Lett. B 770(2017) 357



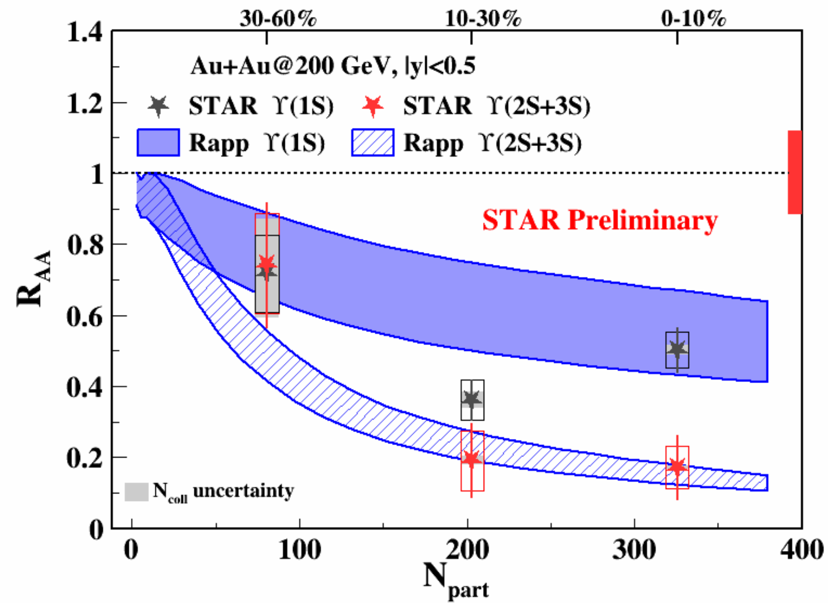
- Consistent with no p_T dependence
- Similar suppression for Υ(1S) at RHIC and the LHC
- Indication of smaller suppression for Υ(2S+3S) at RHIC than at the LHC

Data to model comparison

- Krouppa, Rothkopf, Strickland
  Phys. Rev. D **97**, 016017
- Lattice QCD-vetted potential for heavy quarks in hydrodynamic-modeled medium
- No regeneration, no CNM effects



- De, He, Rapp
  Phys. Rev. C 96, 054901
- Quarkonium in-medium binding energy described by thermodynamic T-matrix calculations with internal energy potential (strongly bound scenario)
- Includes both regeneration and CNM efects

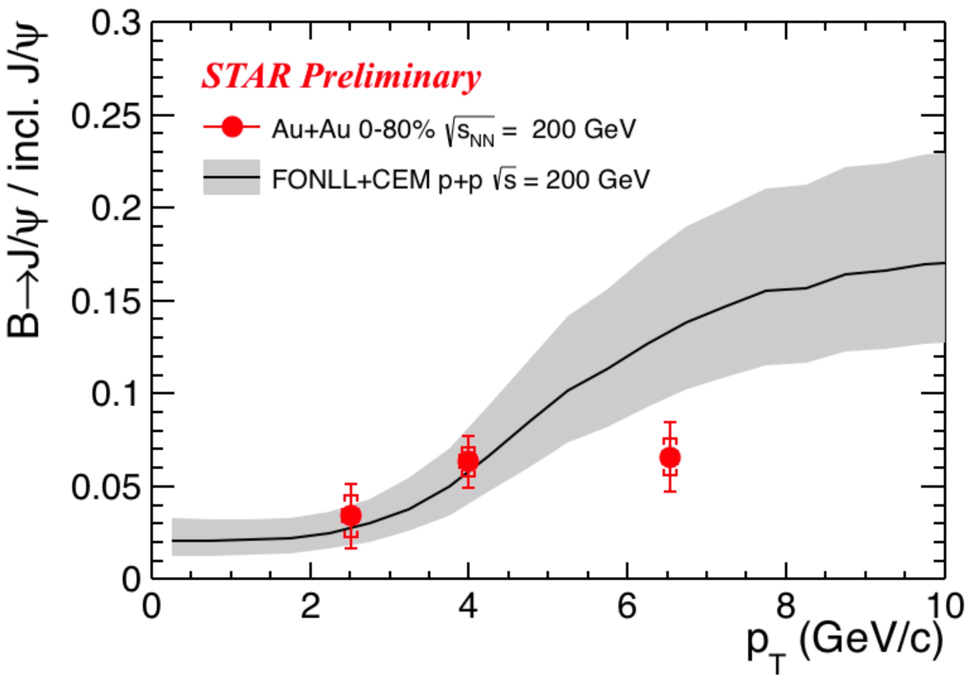


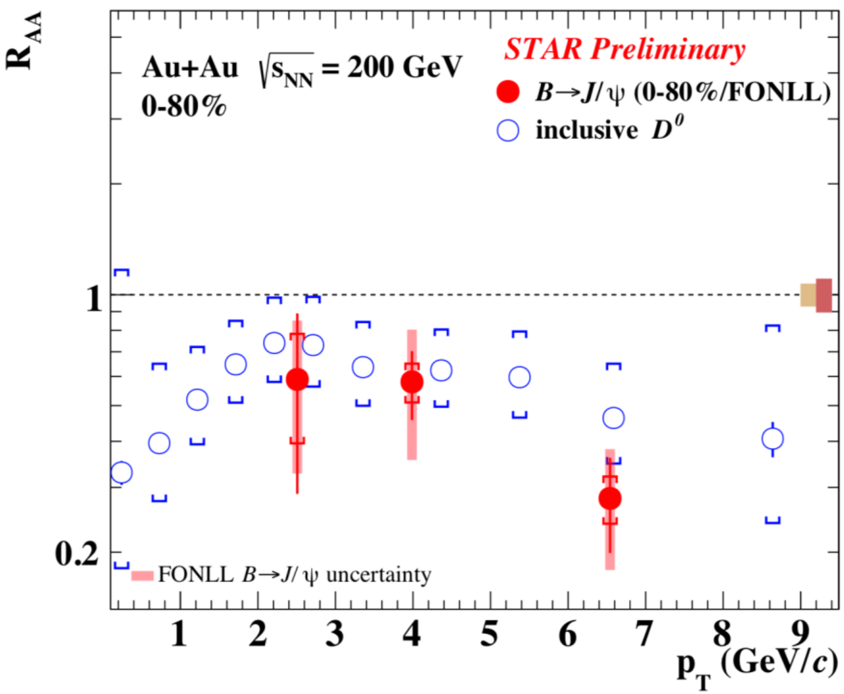
- ϒ(1S) well described;
- ϒ(2S+3S) underestimates data in 30-60% centrality by Rothkopf model

Summary

- **J/ψ in p+Au at 200GeV**
  - R_{pAu} favors additional nuclear absorption on top of nPDF
- **J/ψ in Au+Au at 200GeV**
  - R_{AA} described qualitatively by models including dissociation and regeneration
  - Suppression observed at p_T>5 GeV/c due to dissociation
  - Low p_T (<100MeV) enhancement consistent with coherent photoproduction
- ϒ production in **p+Au at 200 GeV**
  - Indication of ϒ(1S,2S,3S) suppression
- ϒ production in **Au+Au at 200GeV**
  - Stronger suppression of ϒ(2S + 3S) than ϒ(1S)
  - Consistent with sequential melting
  - No p_T dependence of suppresion observed

Nuclear modification of non-prompt J/ψ





- Non-prompt J/ψ fraction in Au+Au 200GeV of about 0.03-0.06 extracted
- Strong suppression of B → J/ψ at high p_T (> 5 GeV/c) observed