# STAR Quarkonium Program and Future p+A Studies

Anthony Kesich, UC Davis

RHIC/AGS Annual Users Meeting
June 18, 2014

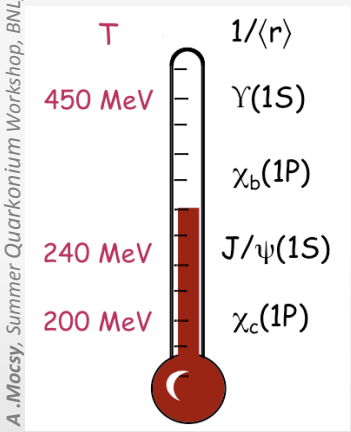
UC DAVIS
UNIVERSITY OF CALIFORNIA

# Outline

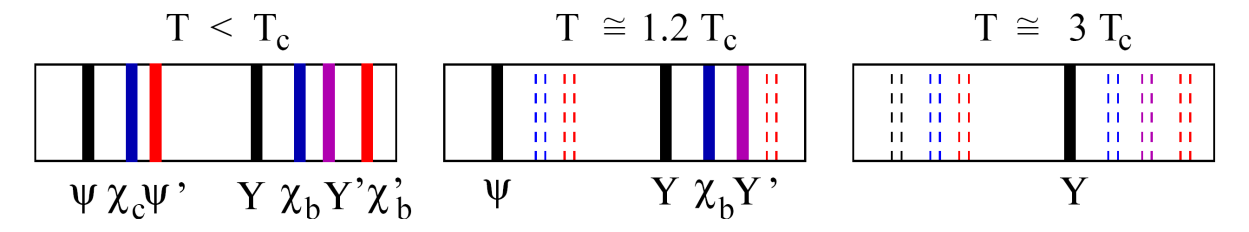
- Significance of Quarkonium Suppression
- STAR
- J/ψ in p+p, d+Au, and A+A
- Upsilon Production
- LHC pPb Quarkonium Results
- Future STAR Programs
- Conclusions

# Quarkonia in QGP

- In 1986, Matsui and Satz propose J/Ψ suppression as a signature of QGP formation
  - Free partons in QGP screen the color field between the charm quark and antiquark
  - The J/Ψ then dissociates into free quarks instead of decaying in vacuum
- Same idea works for the bottom, anti-bottom pair in an Upsilon
- As T increases, the Debye length decreases
- Suppression can be seen as a *Thermometer* of sorts



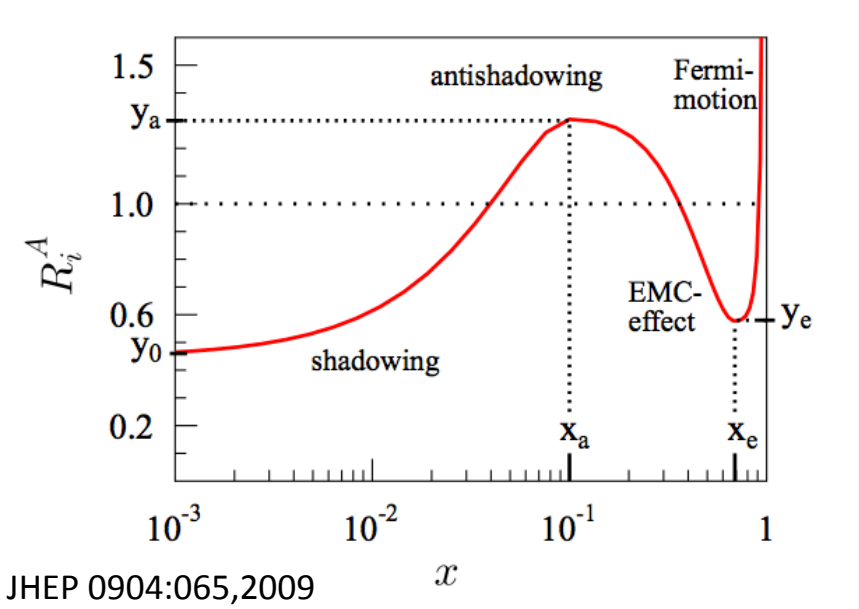

A. Mocsy, Summer Quarkonium Workshop, BNL, 2011




H. Satz, *HP06*

# Sources of CNM Modifications

- Nuclear PDF Modification
  - Shadowing and anti-shadowing
  - Gluon saturation



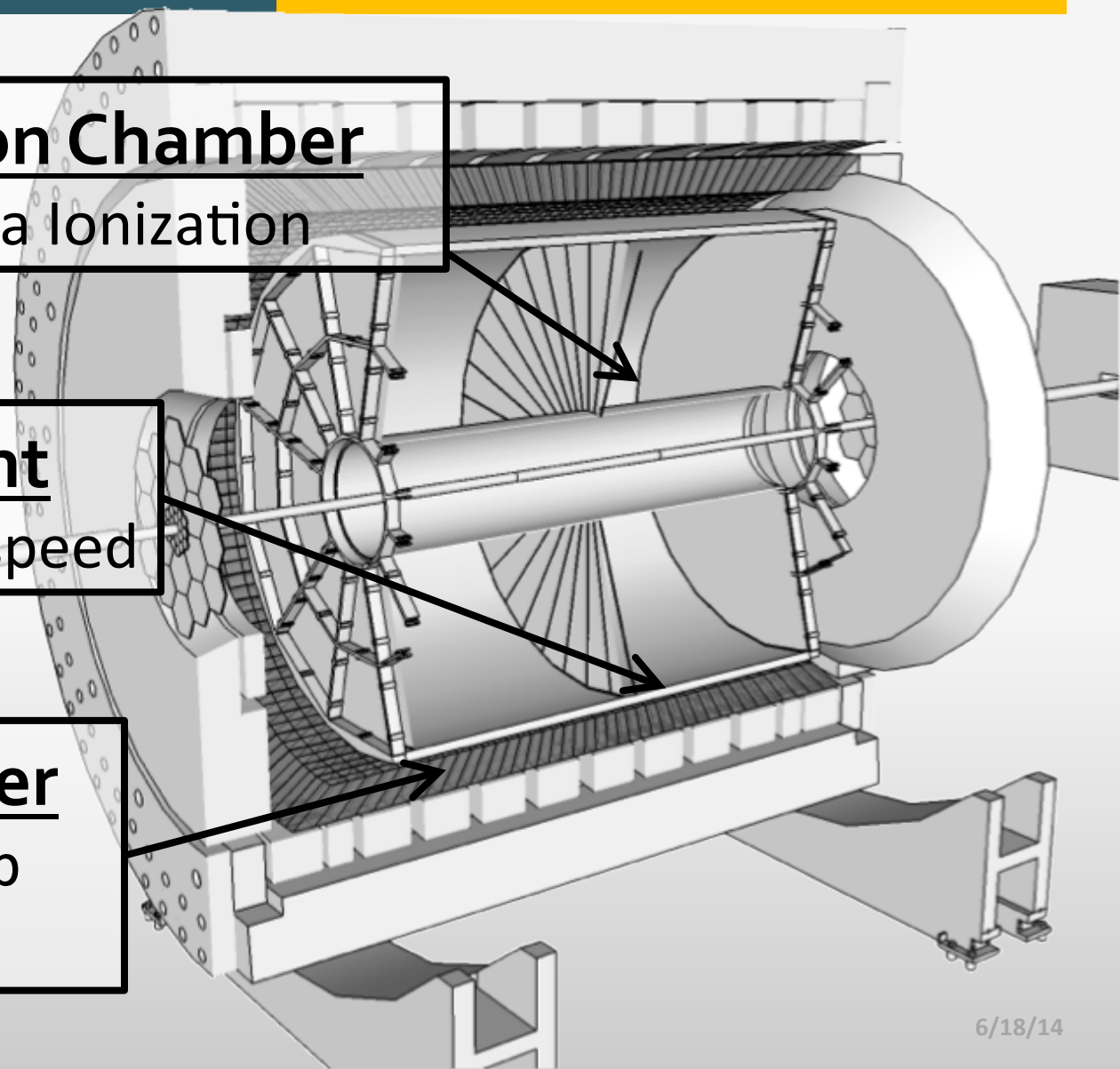
JHEP 0904:065,2009

- Absorption/break-up of pre-quarkonium states by nuclear remnants and co-movers
- Enhancement of $p_T$ spectrum (Cronin effect)

# Other modifications to production

- We observe a mixture of direct production and feeddown
  - J/ψ (observed) ≈ 0.6 (J/ψ direct) + 0.3 ($\chi_c$) + 0.1 (ψ')
  - Also feeddown from B-> J/ψ + X
  - 49% of observed $\Upsilon$(1S) is from excited bottomonium states
- Production mechanism (singlet vs octet vs mix) still unknown
  - Type of pre-quarkonium state can affect nuclear absorption cross section
- Hot medium enhancement
  - Recombination from charm pairs in the medium

# STAR



## Time Projection Chamber

- Tracking and EID via Ionization

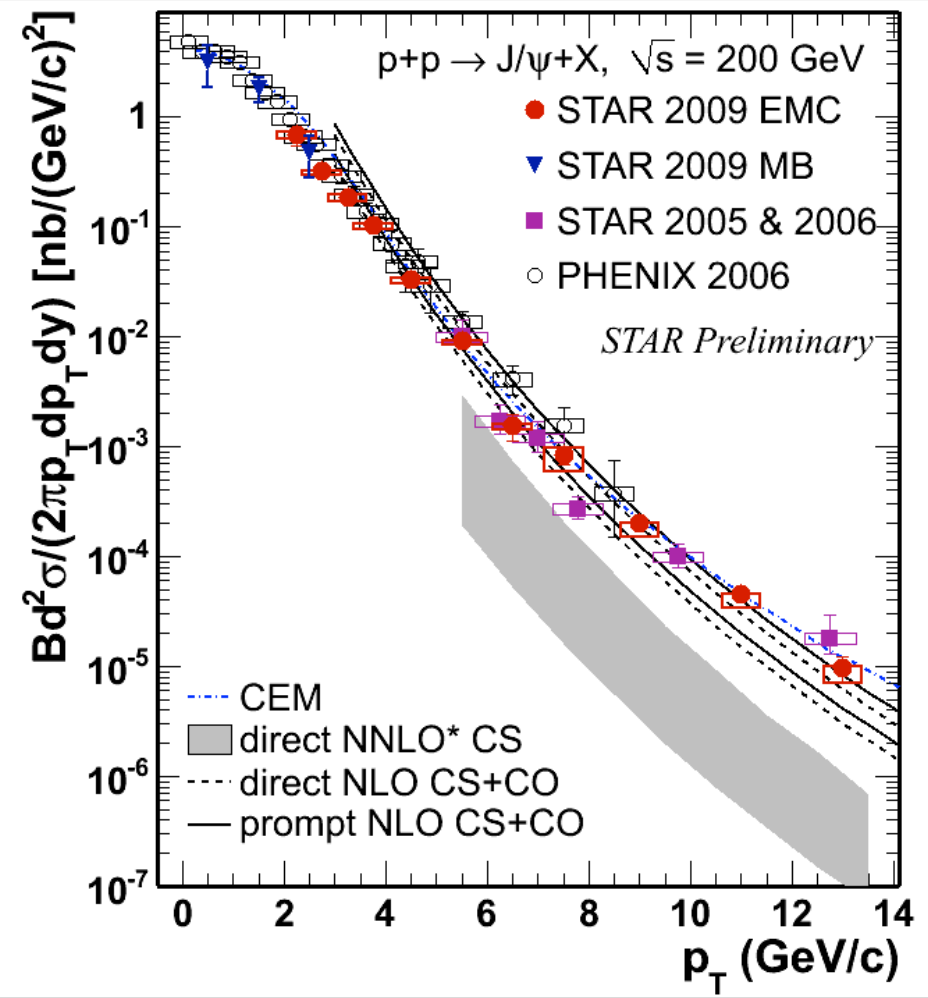
## Time of Flight

- EID thru particle speed

## EM Calorimeter

- Electron ID via E/p
- Event Triggering

# J/ψ in p+p 200 GeV

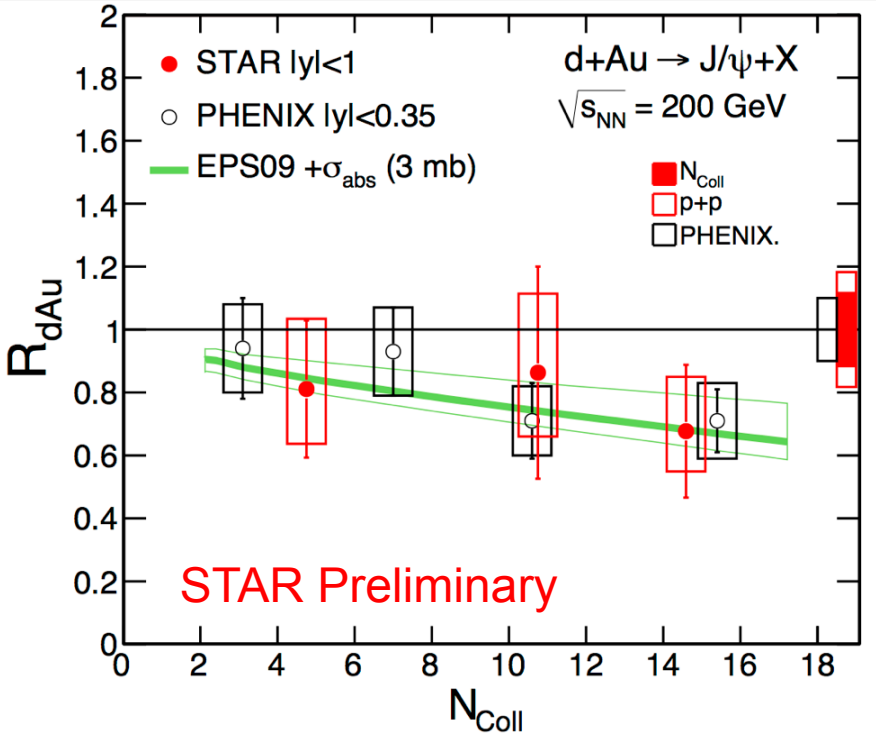


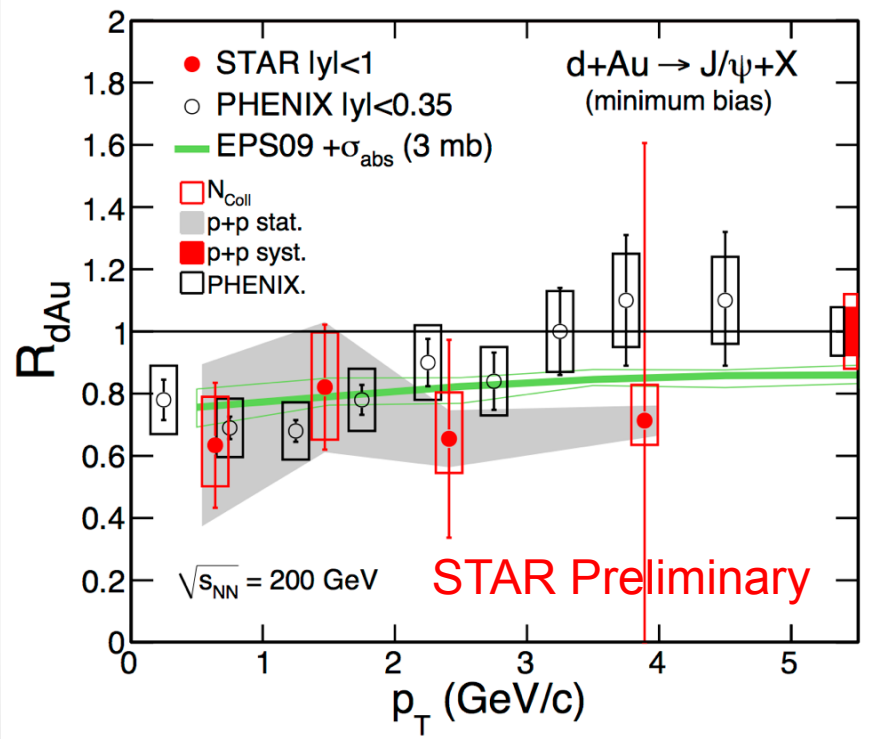

- STAR has strong coverage out to 14 GeV/c
- Prompt NLO CS+CO describes the data
- Prompt CEM does a better job at high-pT

PHENIX: Phys. Rev. D82, 012001 (2010)
STAR 2005&2006: Phys. Rev. C80, 041902(R) (2009)
STAR 2009 EMC : Phys.Lett. B722 (2013)

direct NNLO: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D84, 51 114001 (2011)
CEM:M. Bedjidian et al., hep-ph/0311048, and R.Vogt private communication

# J/ψ in d+Au

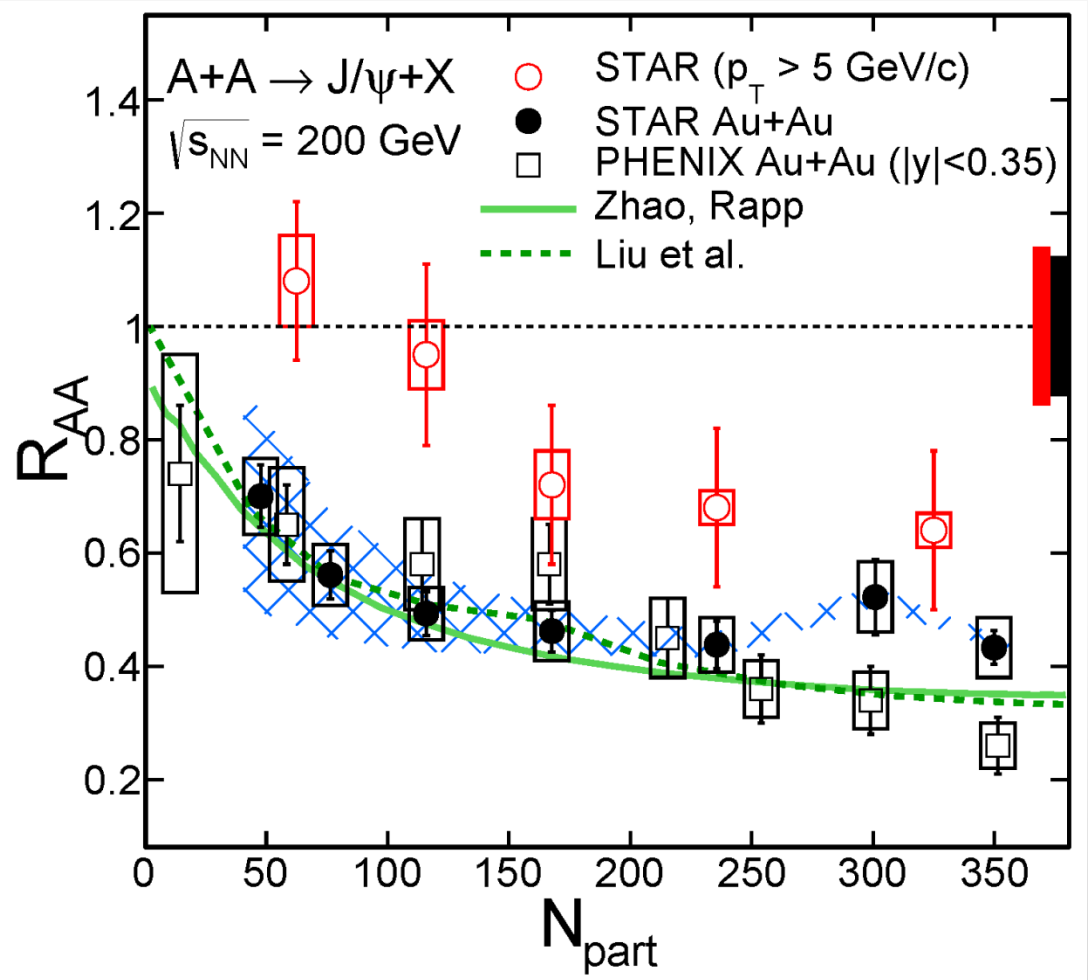



K. Eskola, H. Paukkunen and C. Salgado, Nucl. Phys. A 830, 599 (2009)
R.Vogt, Phys. Rev. C 81, 044903 (2010)

- Prediction assumes shadowing and additional nuclear absorption of 3 mb
- Fit to data gives $\sigma_{abs}=2.8^{+3.5}_{-2.6}$ (stat.) $^{+4.0}_{-2.8}$ (syst.) $^{+1.8}_{-1.1}$ (EPS09) mb
- No sign of Cronin enhancement

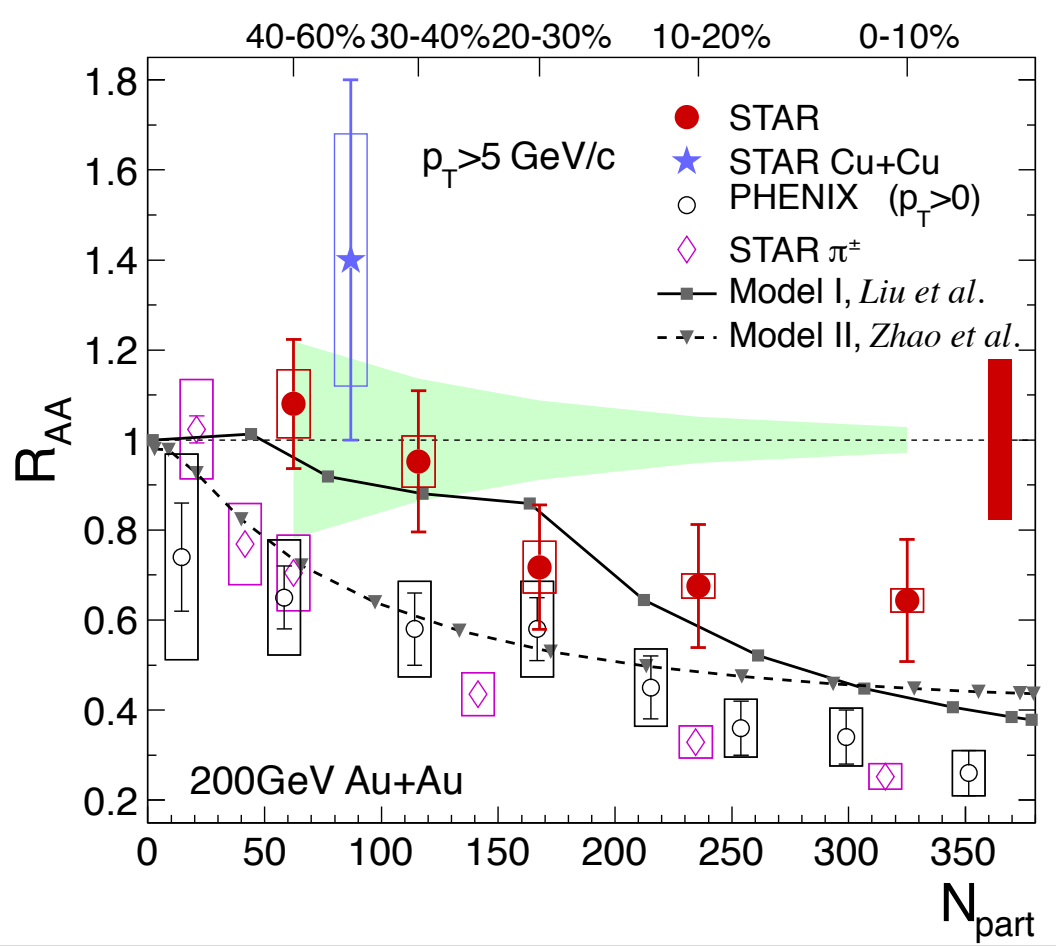
# J/ψ in A+A




- CNM still affects A+A measurements and must be considered
- Zhao and Rapp model assumes $\sigma_{abs}$=7.3±1 mb
  - Includes shadowing
- High-$p_T$ J/ψ interact less with the QGP

Data:
STAR low-pT arXiv:1310.3563
STAR STAR high-pT Phys.Lett. B722 (2013) 55
PHENIX Phys. Rev. Lett. 98, 232301 (2007)
Models:
Y. Liu, et al., PLB 678:72 (2009)
X. Zhao and R.Rapp, PRC 82, 064905(2010)

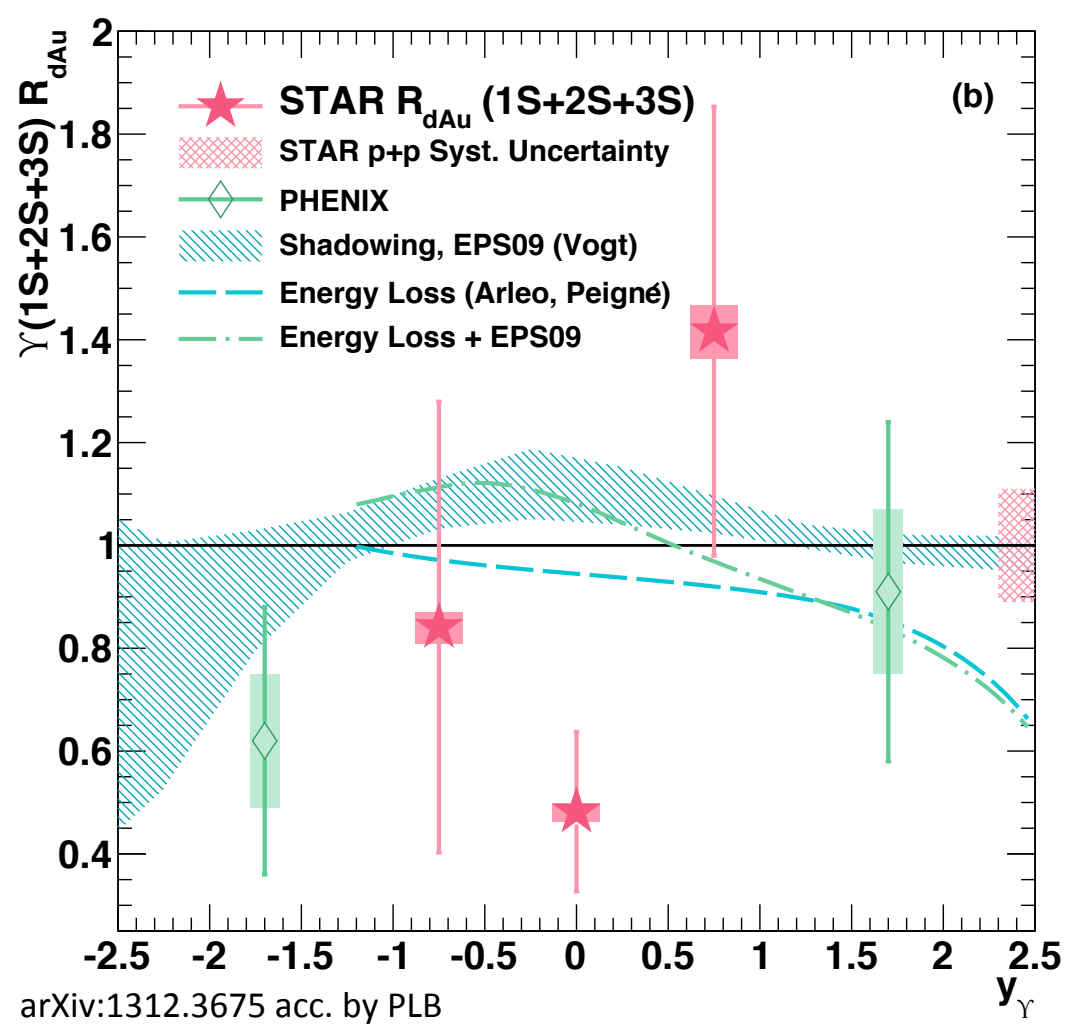
# J/ψ in A+A




- But Zhao and Rapp miss the high-$p_T$ data
- Room for more studies?

Data:
Phys. Lett. B 722 (2013) 55
Models:
Y. Liu, et al., PLB 678:72 (2009)
X. Zhao and R.Rapp, PRC 82, 064905(2010)

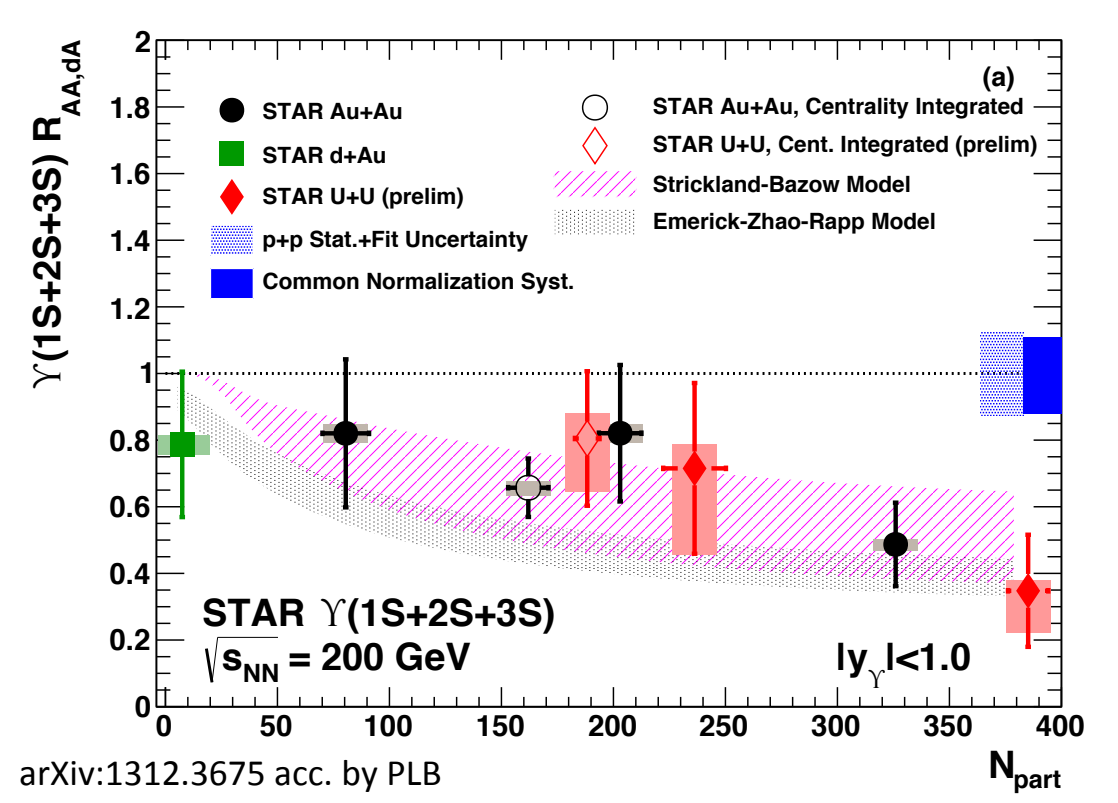
# Upsilons in d+Au




arXiv:1312.3675 acc. by PLB

- STAR and PHENIX results in good agreement with prediction
- Except for at |y|<0.5, in good agreement with just EPS09 and EPS09 + Energy Loss
- Further studies warranted at |y|<0.5
  - Nuclear remnants?
  - Co-movers?

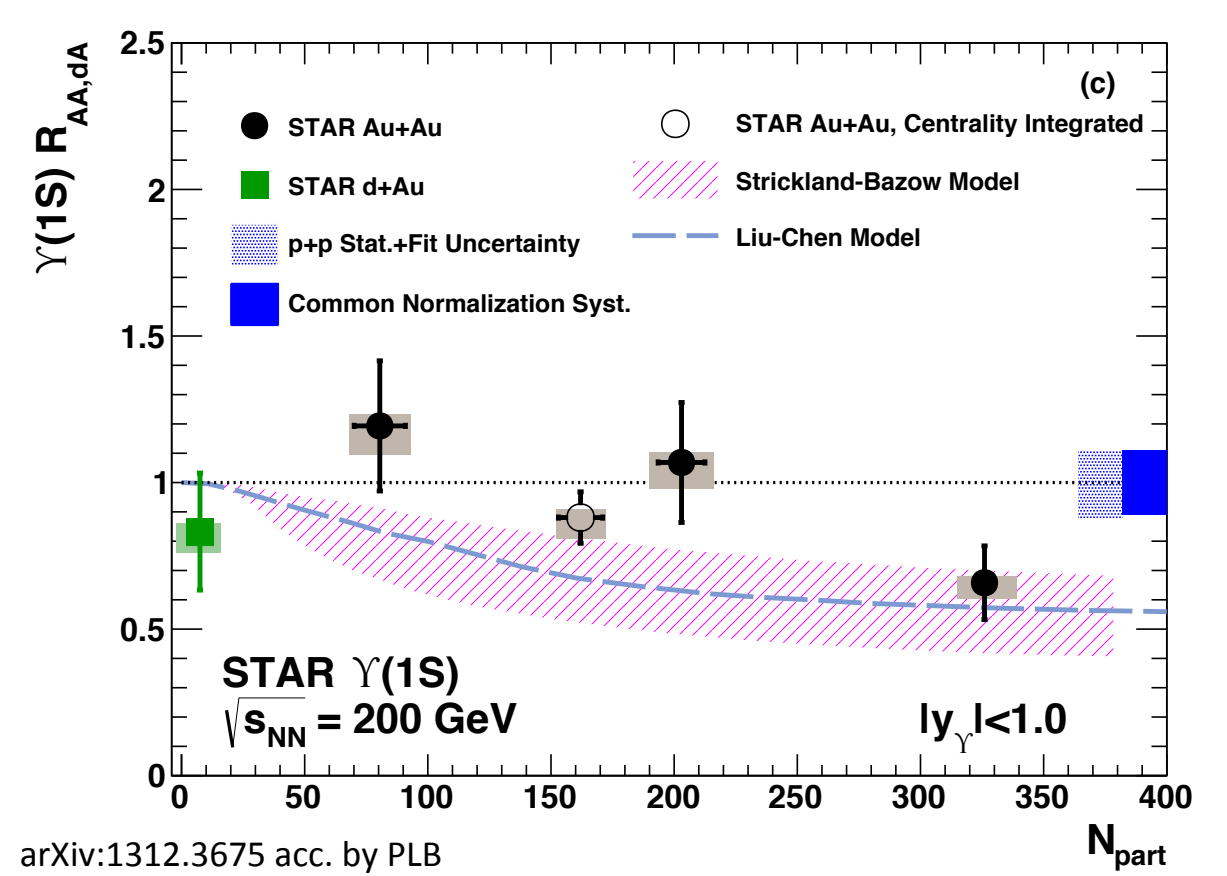
# Upsilon Suppression




arXiv:1312.3675 acc. by PLB

- STAR has measured Upsilons in p+p, d+Au, Au+Au, and U+U
- Results for |y|<1
- Rapp model assumes $\sigma_{abs}$=0-3 mb
- $R_{dAu}$ result suggests minimal-to-no CNM suppression
  - Higher statistics needed

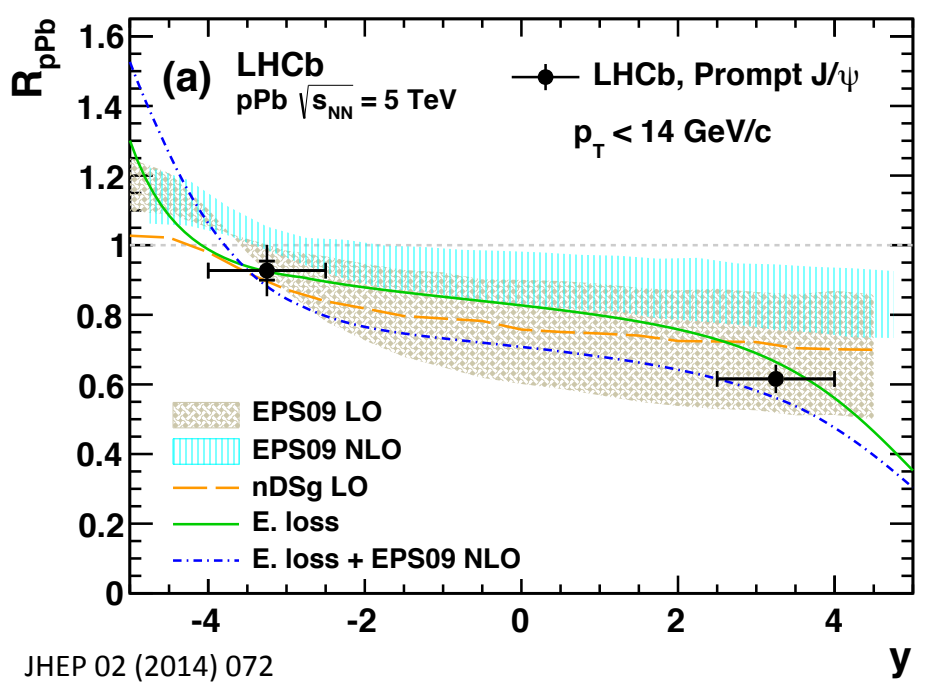
# $\Upsilon$(1S) in Au+Au 200 GeV, $R_{AA}$



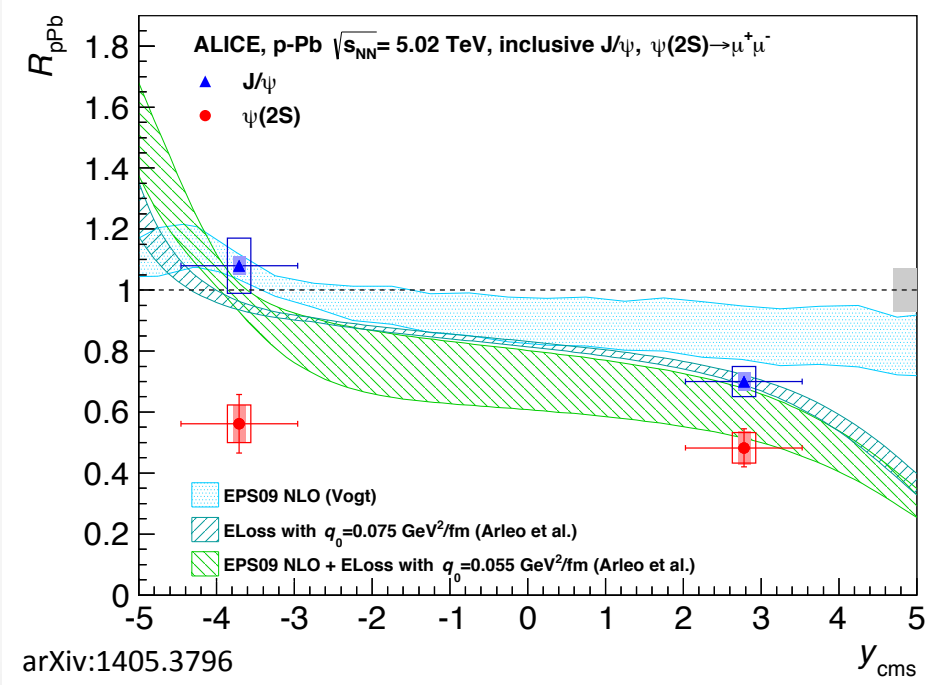

Models from M. Strickland and D. Bazow, arXiv:1112.2761v4
Y. Liu, B. Chen, et. al., arXiv:1009.2585

- $R_{AA}$ of $\Upsilon$(1S) is consistent with 1 in d+Au and peripheral and mid-central Au+Au
- Indication of suppression consistent with model calculation in central Au+Au

# J/ψ in pPb at LHC



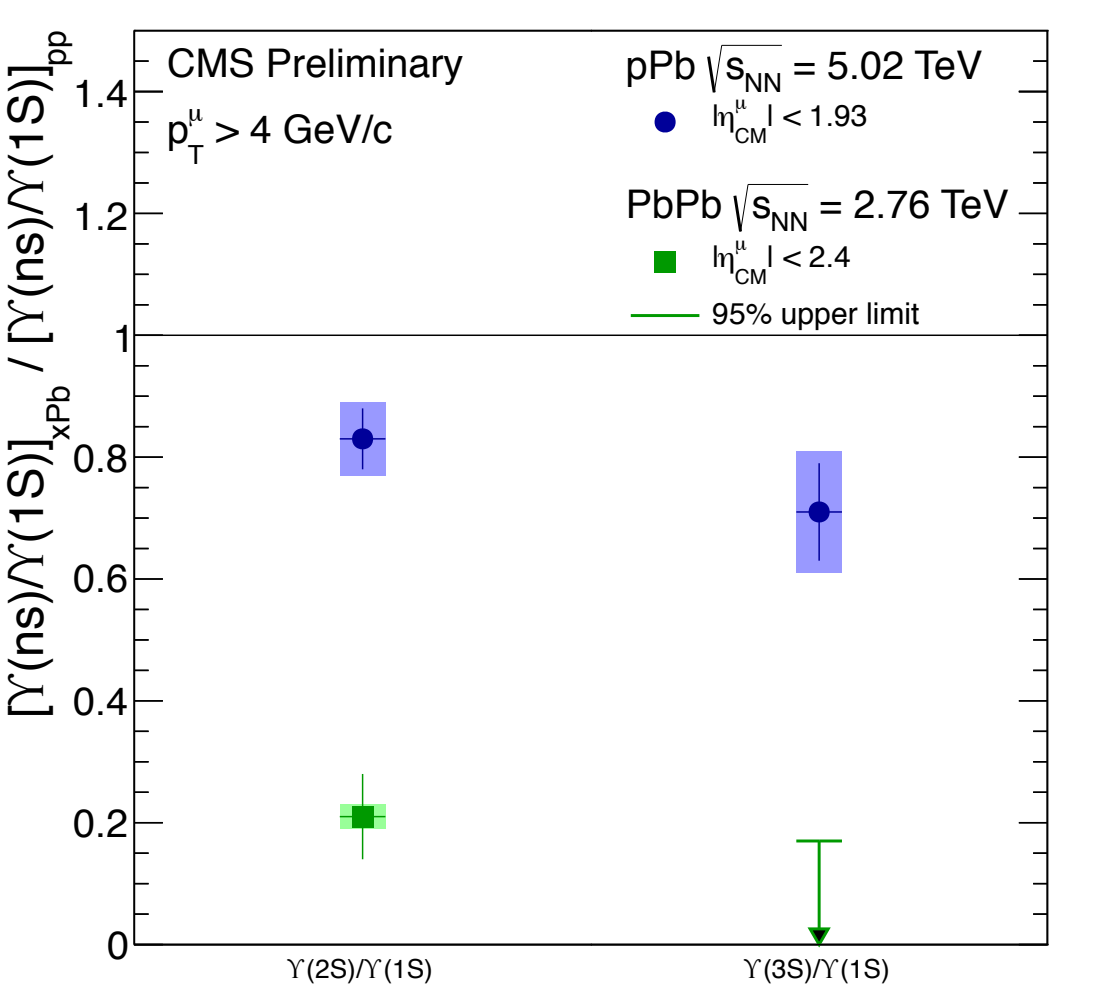

JHEP 02 (2014) 072




arXiv:1405.3796

- LHCb and ALICE results at forward rapidities
- EPS09 can't explain p-going suppression
  - Additional energy loss needed

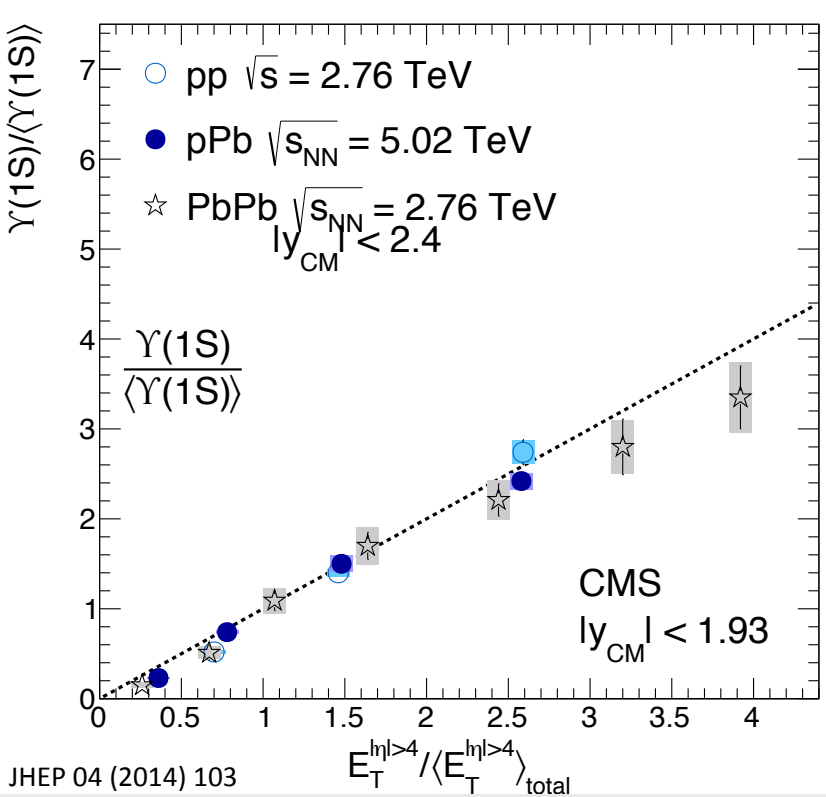
# Upsilons in pPb at CMS

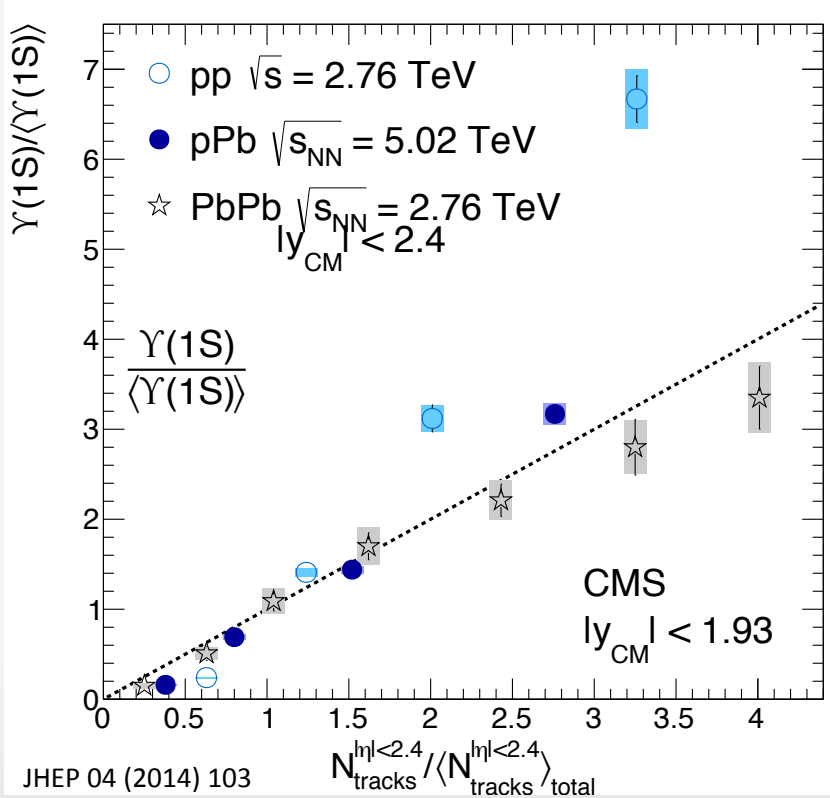



JHEP 04 (2014) 103

- Double Ratios of Upsilon excited-to-ground state as measured by CMS
- Excited state suppression seen in both pPb and PbPb
  - Differential nuclear absorption?

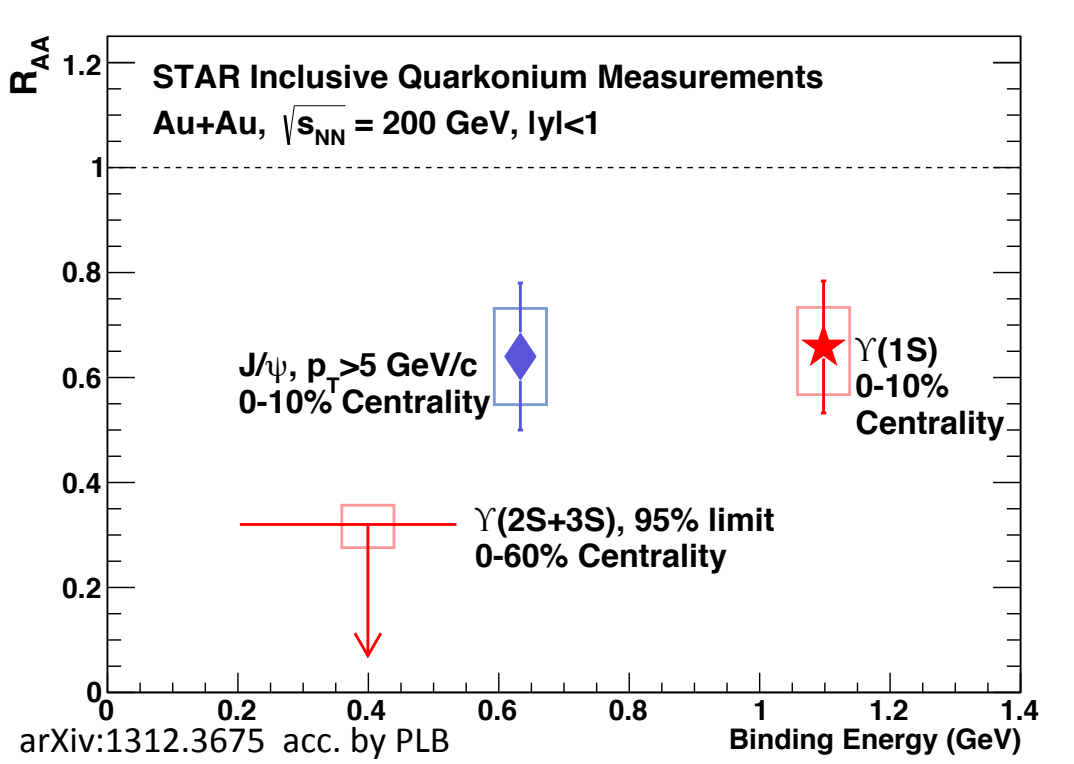
# CMS: Upsilon Production vs. Activity

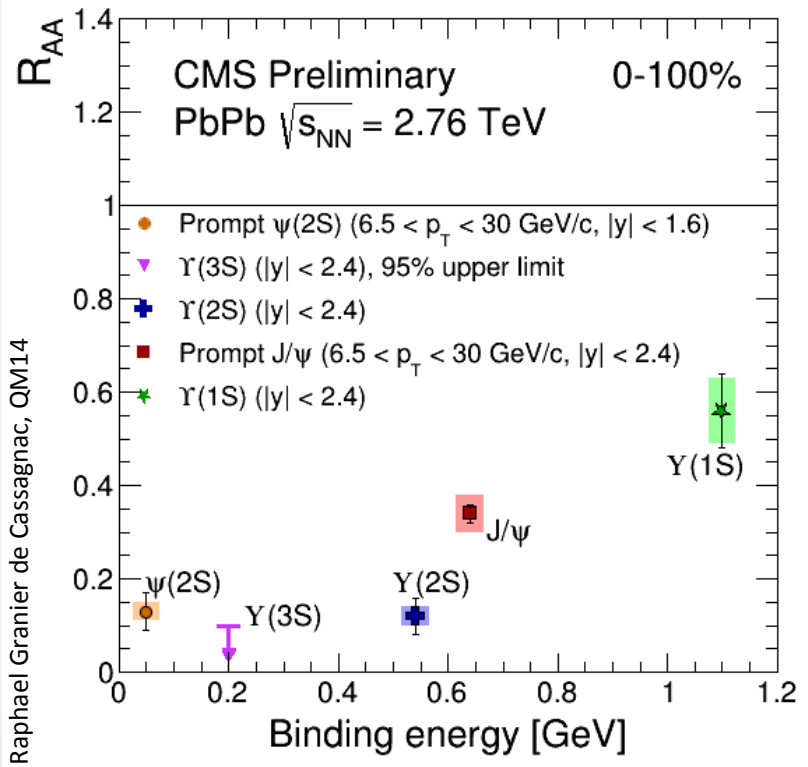



- Activity and Upsilon in different rapidity ranges: standard scaling
- Activity and Upsilon in same rapidity range: enhancement of 1S in p+p (and a hint in d+Au
  - Also seen at CMS for the 2S and hinted at for the 3S

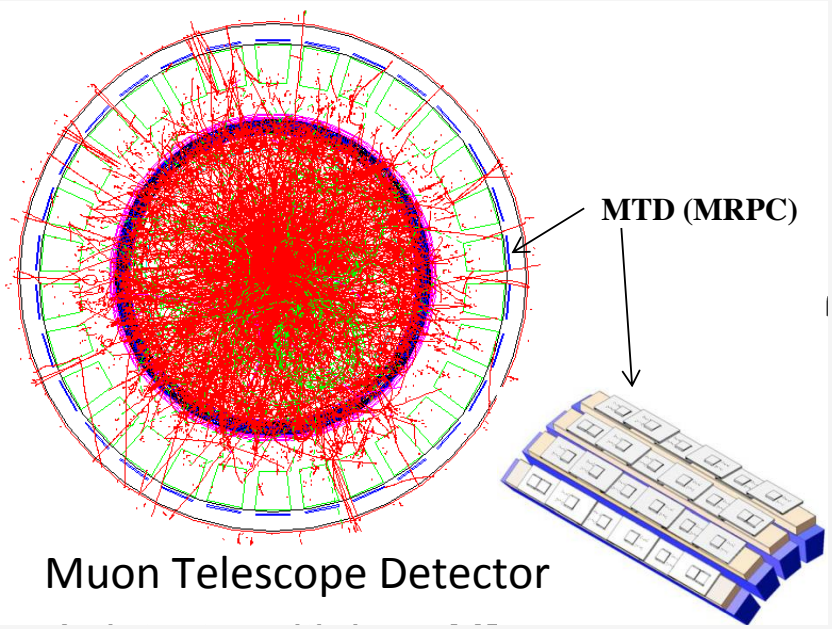
# Binding Energy

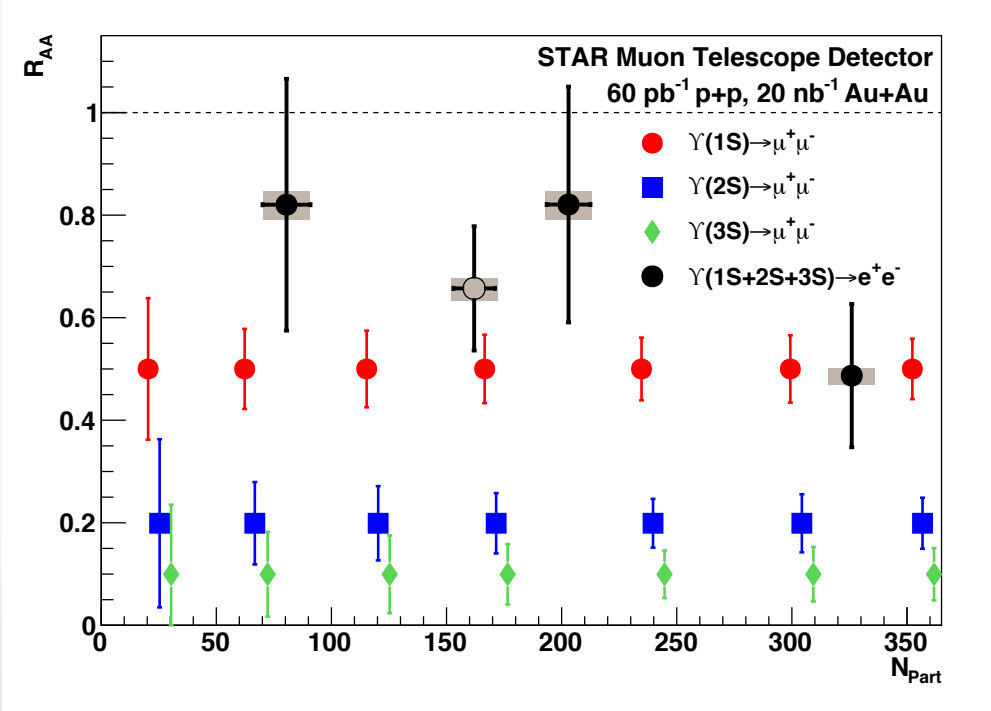


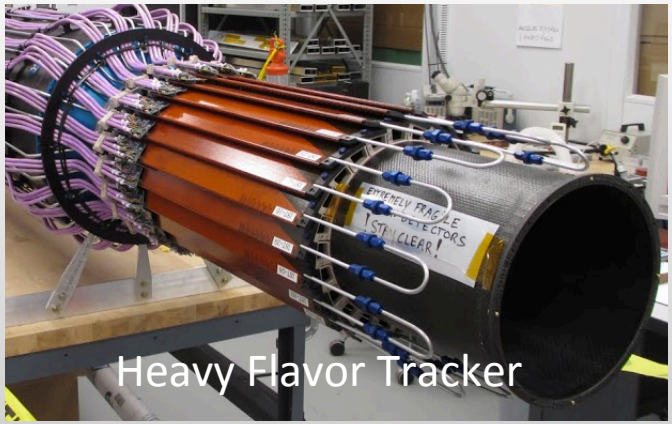

- STAR and CMS quarkonia $R_{AA}$ results show suppression for all states measured
- Increased suppression with decreased binding energy as prediction by Debye screening

# Recent STAR Upgrades

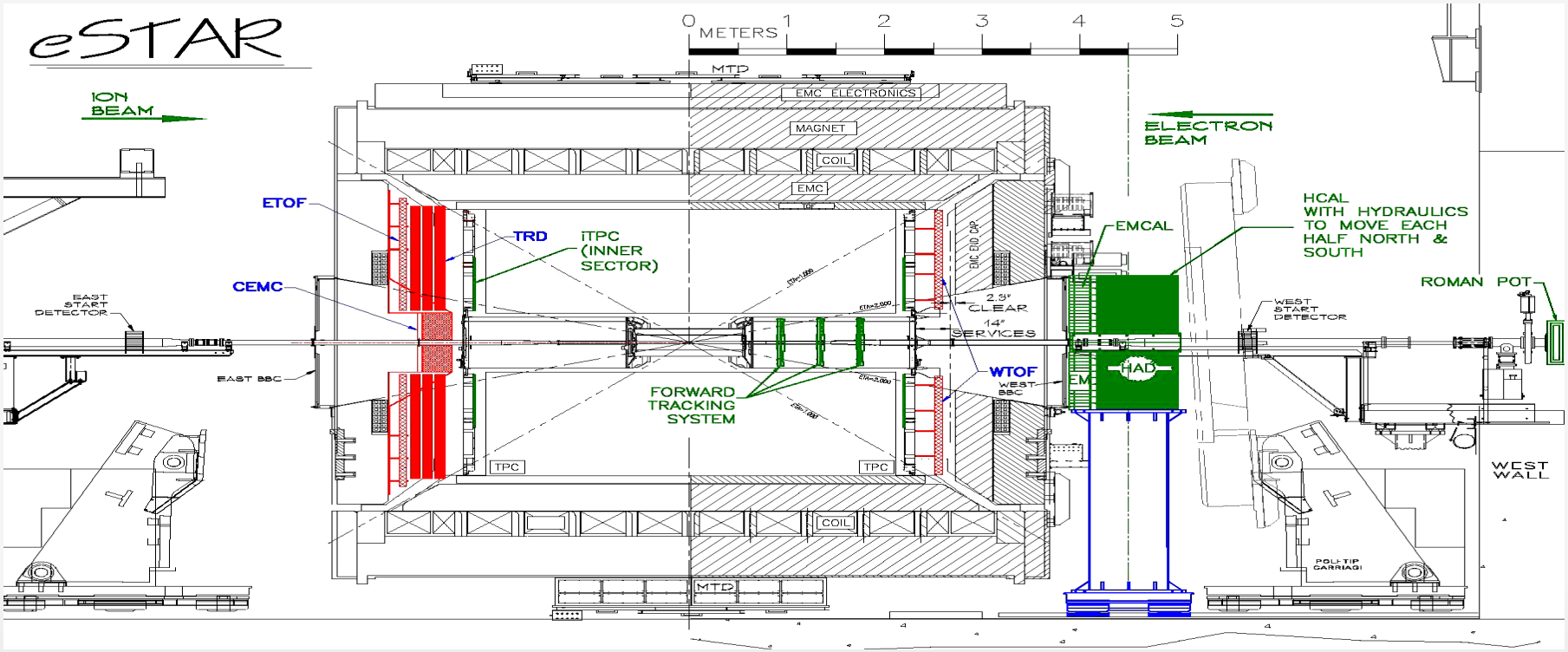



Adapted from J. Bielcik, Hard Probes 2013



# Future STAR Upgrades



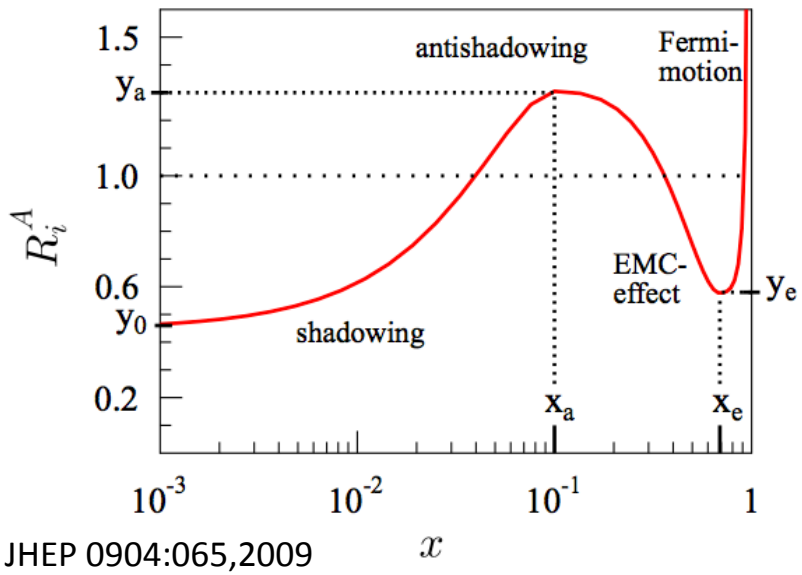

- Planned upgraded to TPC and new forward tracking and ID systems will allow reconstruction of forward quarkonium
  - Allows us to probe into the anti-shadowing region of PDF

# Conclusions

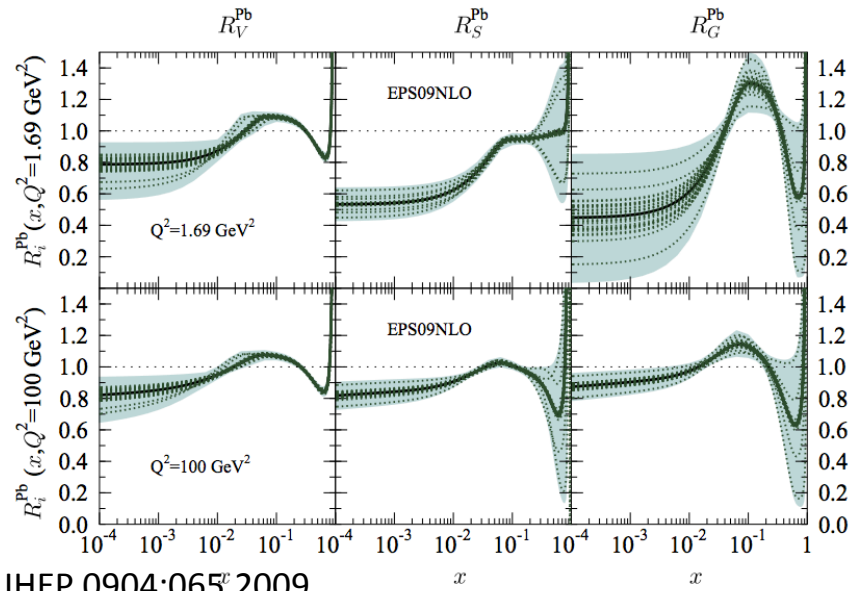
- STAR quarkonium results probe thermal nature of medium
- CNM effects must be quantified before AA results can be fully interpreted
- RHIC and LHC results point to non-negligible nuclear absorption of quarkonium states
- Future d+Au (or p+Au) runs will help constrain CNM effects

# Backup

# EPS09




JHEP 0904:065,2009

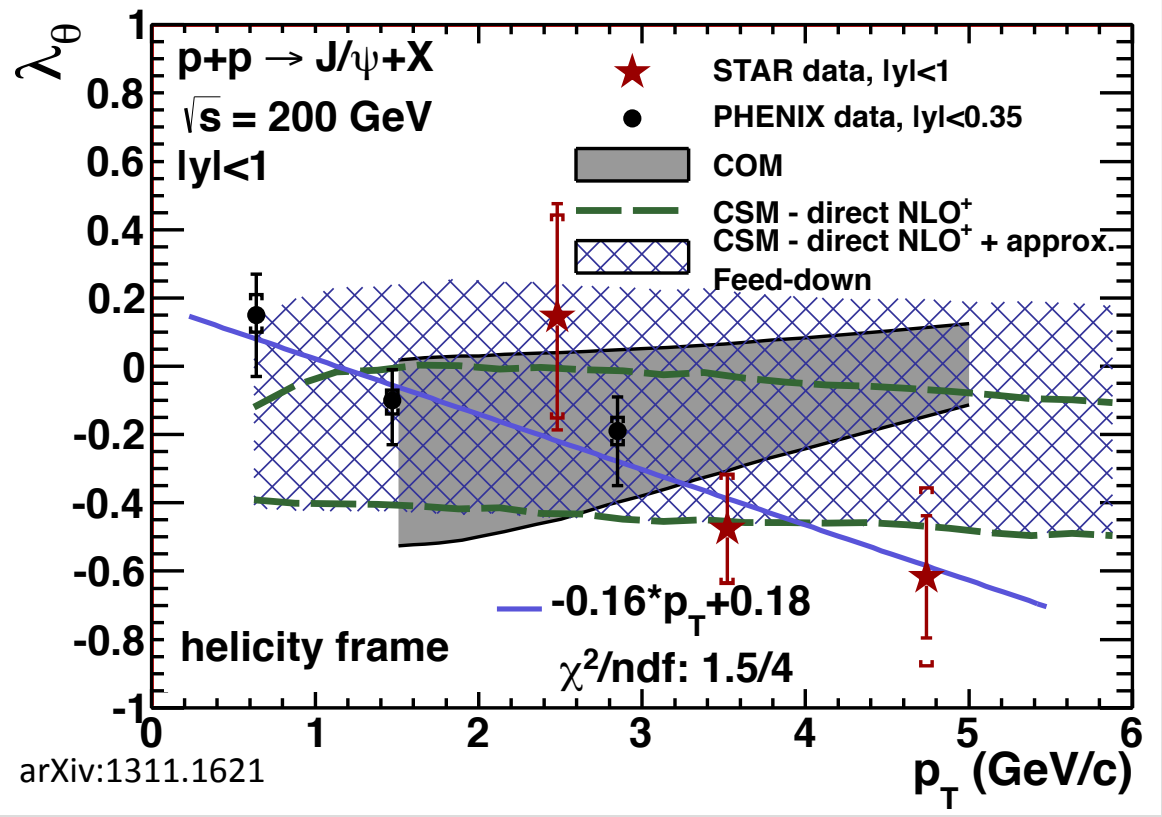



JHEP 0904:065,2009

Lead

- 3 Inputs for the fits:
  - A+l DIS collisions
  - DY leptoproduction in p+A
  - Pion spectra from d+Au and p+p at RHIC

# J/ψ Polarization




arXiv:1311.1621

- |y|<1, 2<pT<6 GeV/c
- STAR+PHENIX consistent with NLO +CSM
  - Higher statistics needed to discriminate
- p+p 500 GeV results will improve precision for future CNM calculations