Quarkonium Experiments in Heavy-Ion Collisions

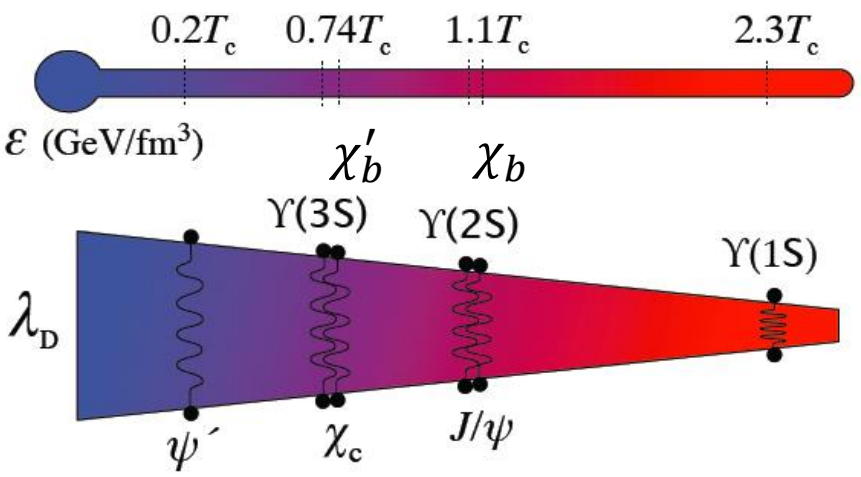
Zebo Tang（唐泽波）

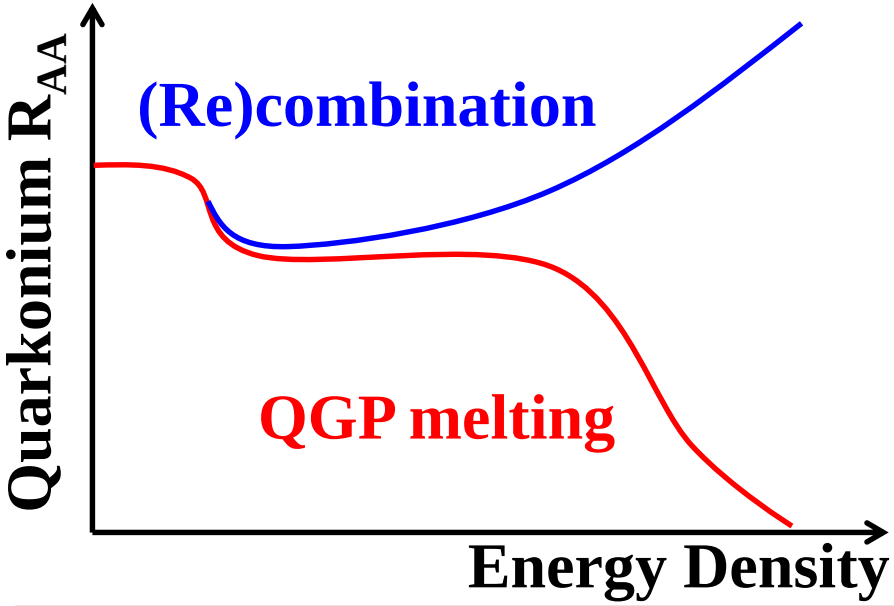
University of Science and Technology of China (USTC)

Collaborative Innovation Center for Particles and Interactions 强子对撞物理协同创新中心

1958 中国科学技术大学 University of Science and Technology of China

Quarkonium as a sensitive probe of QGP





- Quarkonium production suppressed due to color-screening/melting in the QGP
- Different quarkonium states provide distance scales to probe QGP (sequential suppression)
- Quaroknium production enhanced due to (re)combination during QGP evolution or hadronization

In reality

Quarkonium production modified by cold nuclear matter (CNM) effects on top of hot matter effects

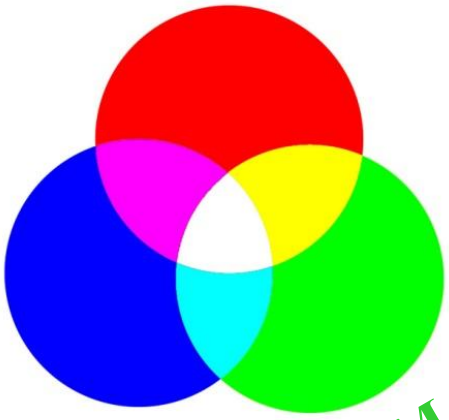
Quarkonium production in heavy-ion collisions are the interplay of color-screening/melting, (re)combination and CNM effects

Experimental solutions:

pA: CNM effects, reference

AA:

- Multiple dimensional
  Centrality, p_T, rapidity…
  Collision energy, system
- Different states
  J/ψ, ψ(2S),ϒ(1S, 2S, 3S)

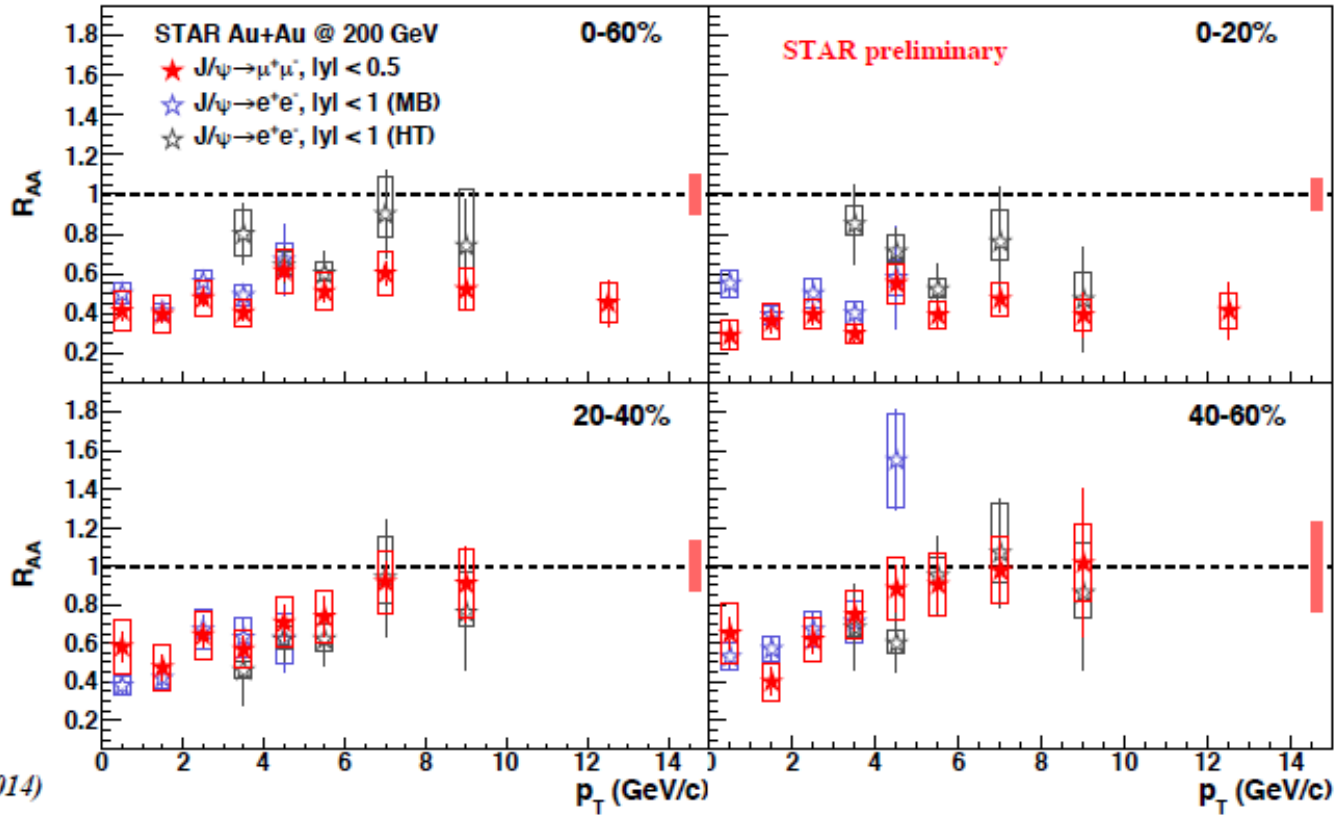


Experiments

Accelerator	Detector	Mid-y	Forward	Notes
RHIC	PHENIX	e^+e^-	$\mu^+\mu^-$	Decommissioned
	STAR	e^+e^- $\mu^+\mu^-$		
LHC	ALICE	e^+e^-	$\mu^+\mu^-$	
	ATLAS	$\mu^+\mu^-$		High p_T muon
	CMS	$\mu^+\mu^-$		High p_T muon
	LHCb		$\mu^+\mu^-$	pPb and peripheral PbPb

J/ψ Results

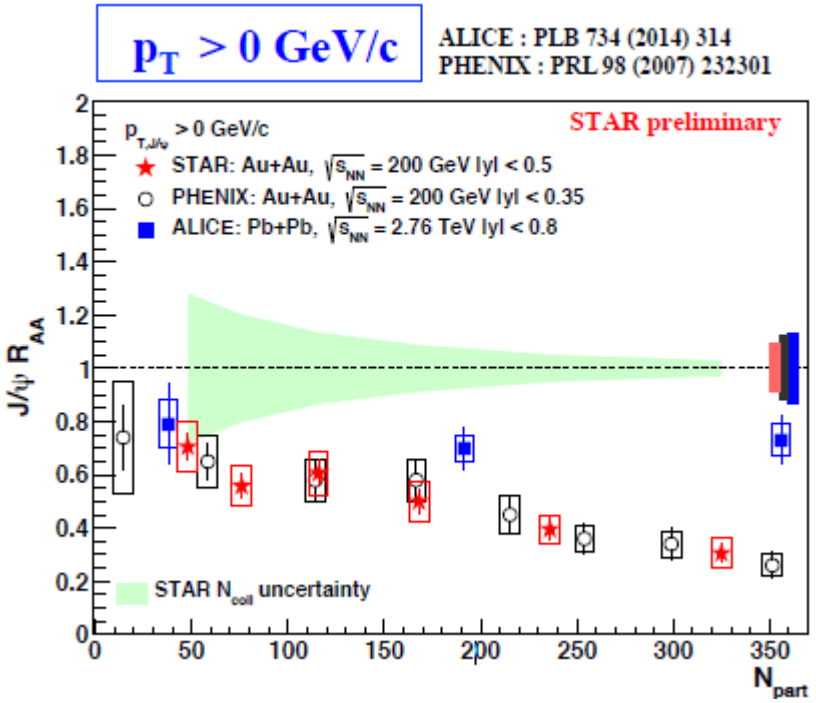
STAR new results from $\mu^+\mu^-$

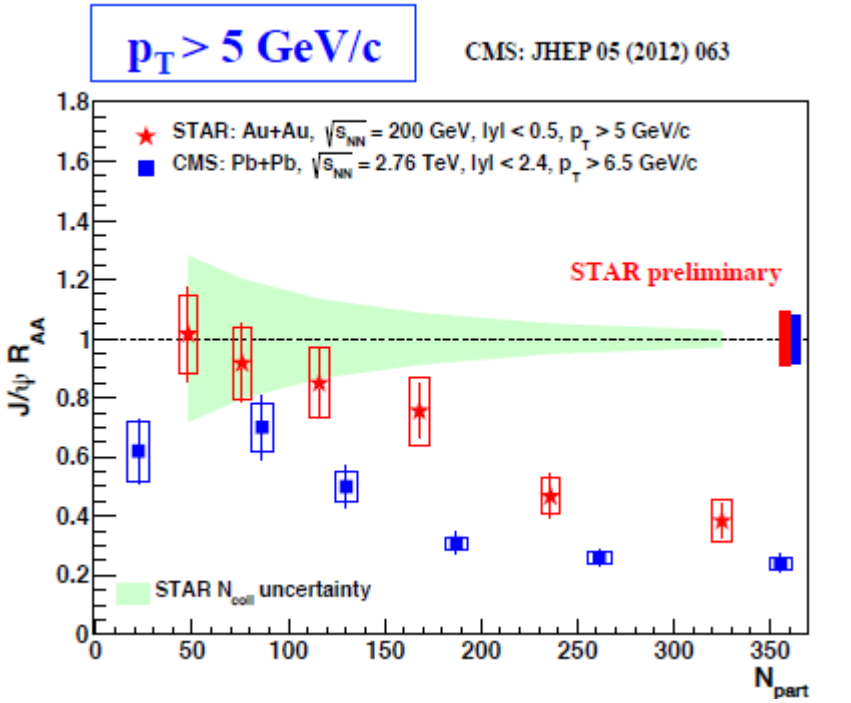


Di-electron:
STAR PLB 722 (2013) 55
STAR PRC 90, 024906 (2014)

- Confirmed previously published e^+e^- results
- Improved precision and p_T converge

Centrality dependence





Low-p_T: SPS ~ RHIC < LHC

More collision energies?

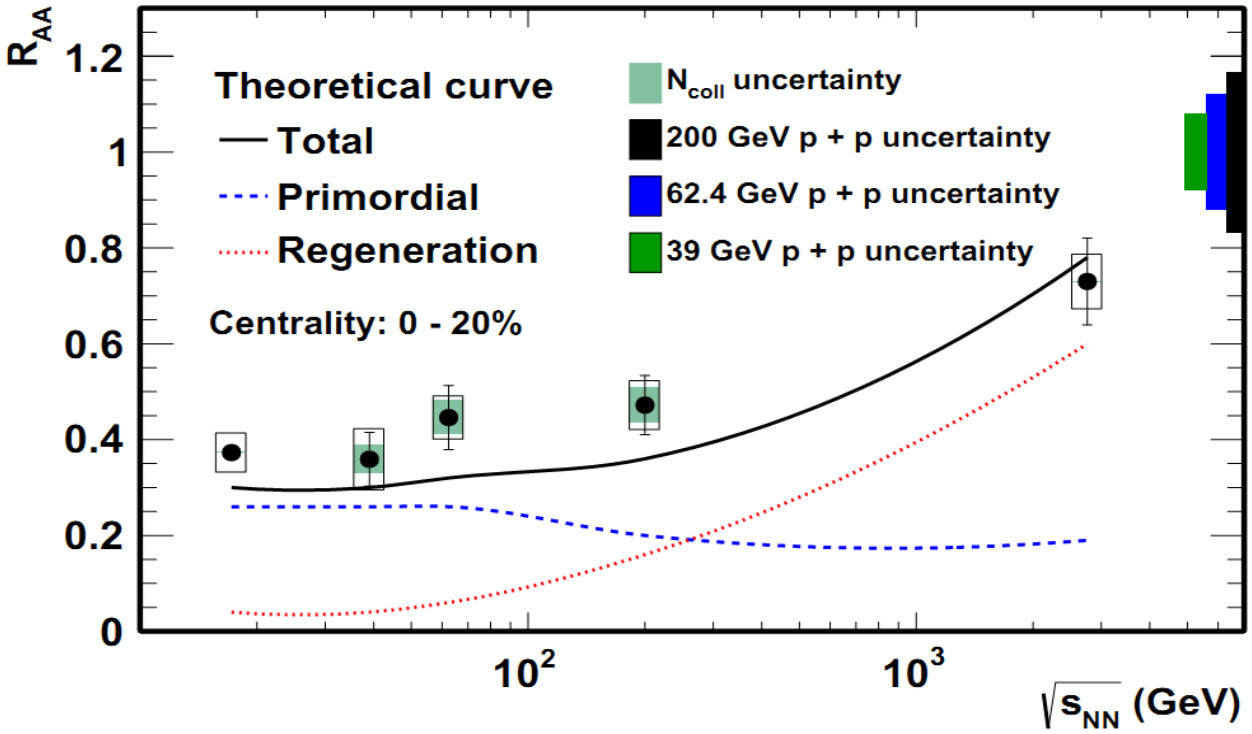
High-p_T: (Re)combination less important

Stronger suppression at LHC than at RHIC

Higher collision energy?

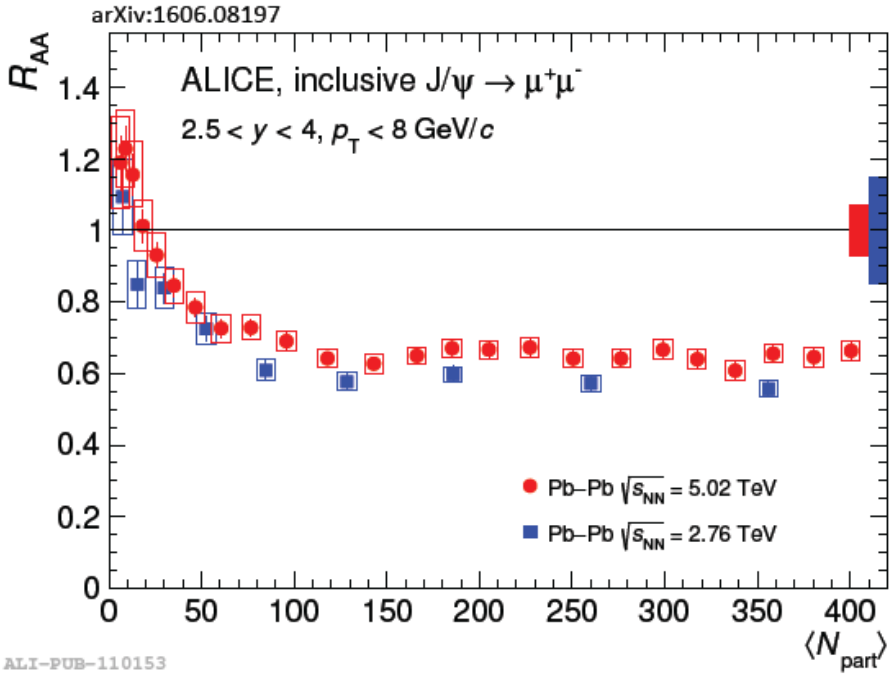
Beam energy dependence

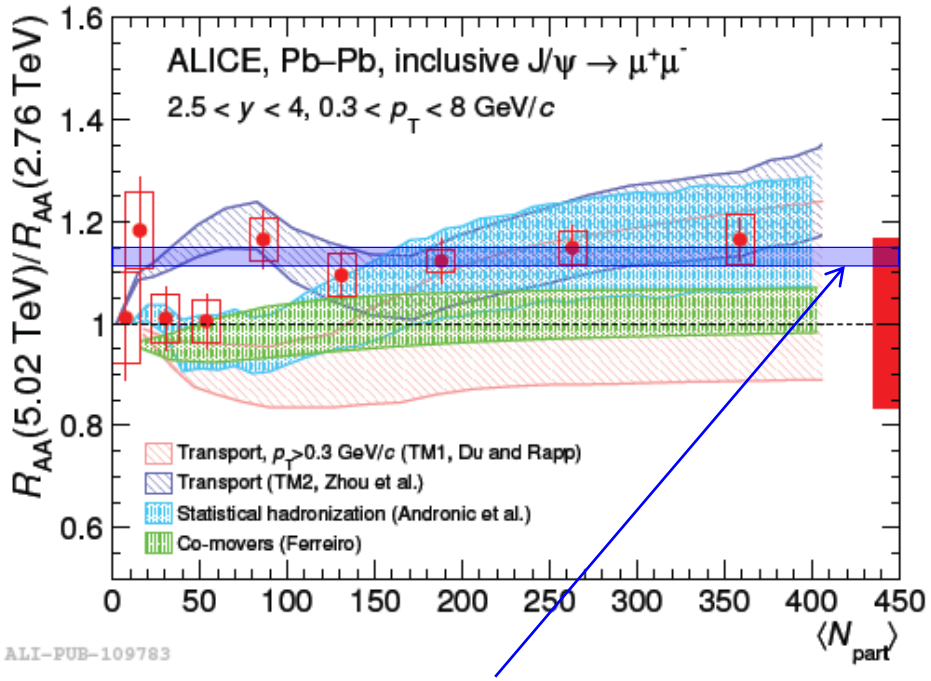
STAR, arXiv:1607.07517 , submitted to PLB



- SPS→RHIC: Gradually increase
- RHIC→LHC: Significantly increase
- Consistently described by transport model

Low-p_T J/ψ in PbPb at 5 TeV

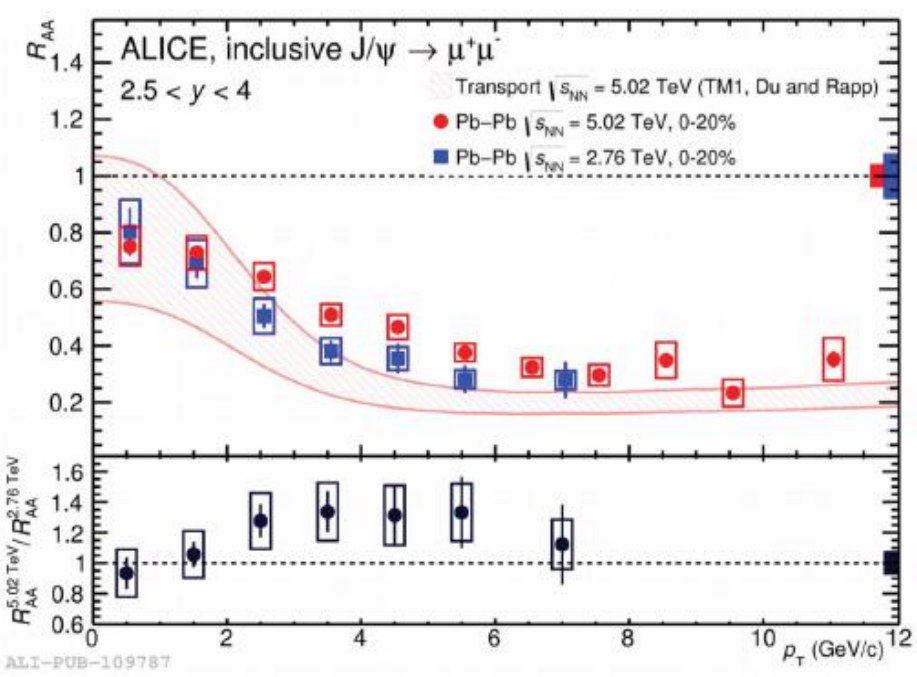




0-90%: $1.13 \pm 0.02(\text{stat.}) \pm 0.18(\text{syst.})$

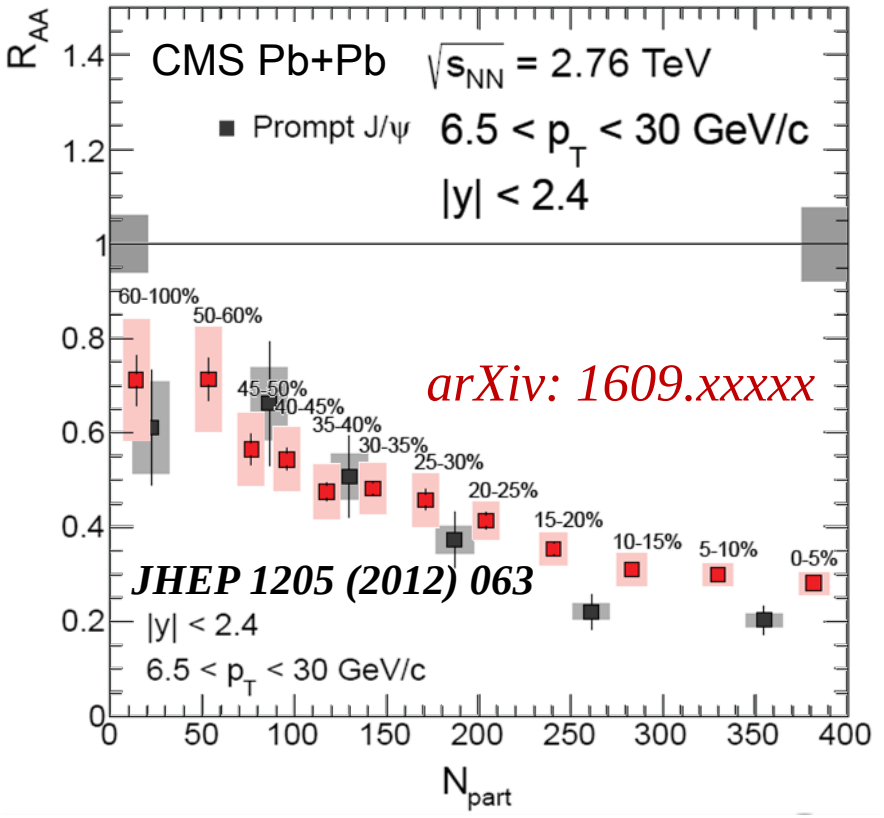
- J/ψ at low-p_T at forward rapidity
- Less suppression at 5 TeV than 2.76 TeV
- But consistent within normalization uncertainties dominated by 2.76 TeV pp reference extrapolation

p_T dependence



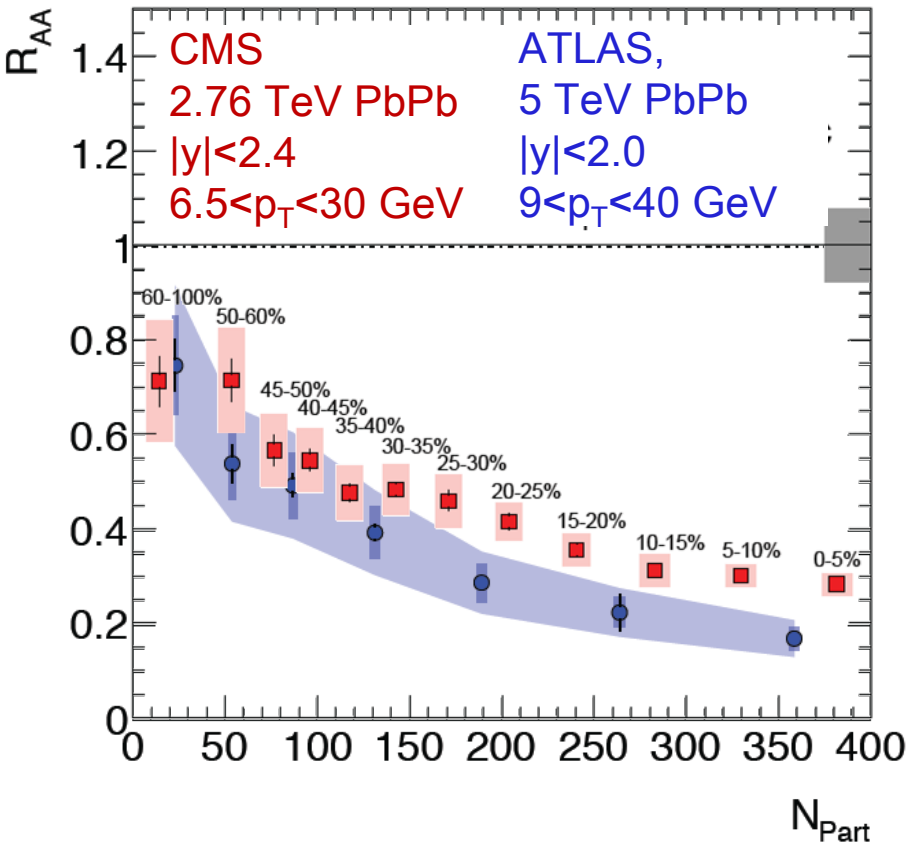
- "Hint" of increase from 2.76→5 TeV at $2<p_T<6$ GeV/c
- (Re)combination of flowing charm?

High-p_T J/ψ in PbPb at 2.76TeV



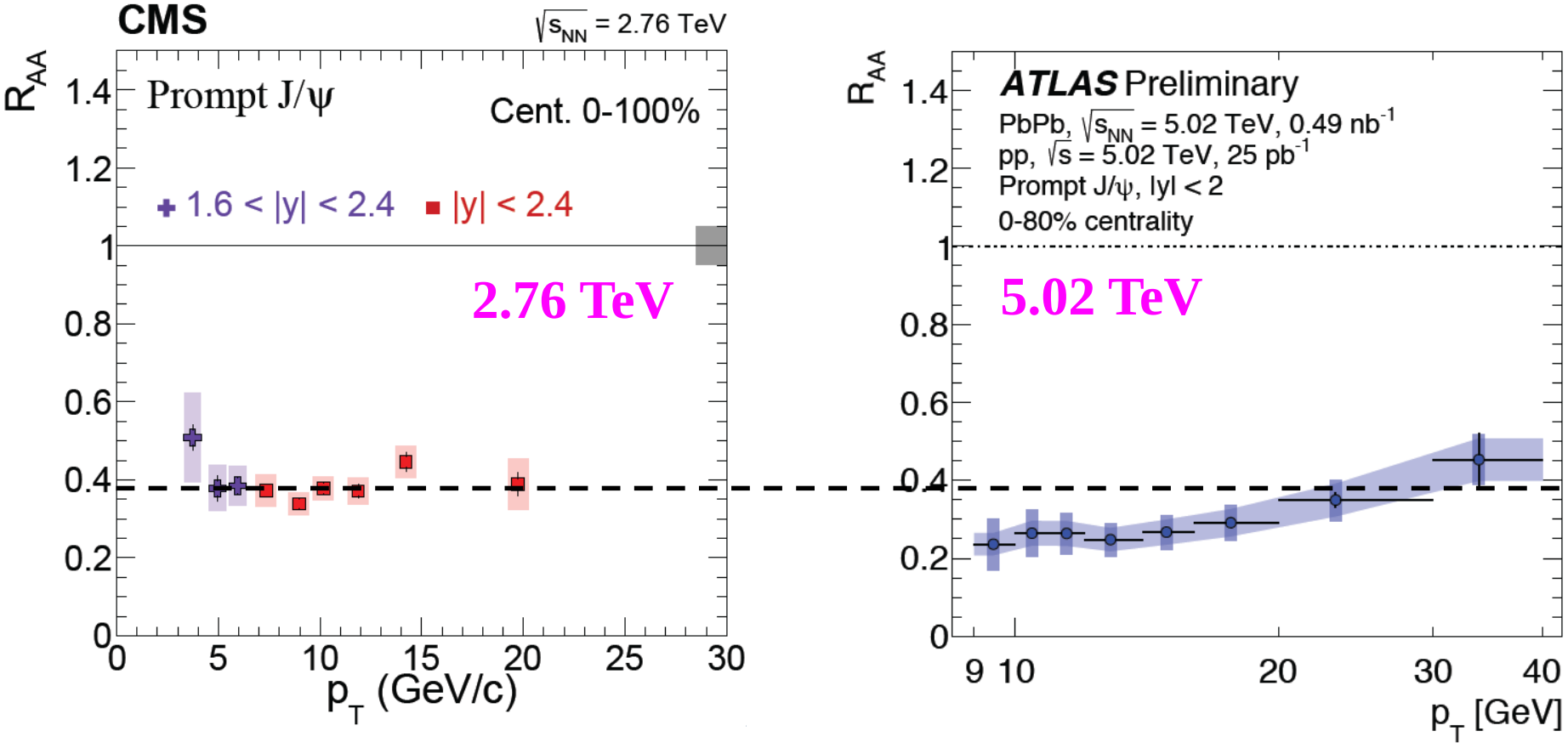
- CMS final results on J/ψ in Pb+Pb at 2.76 TeV
- Better precision with finer centrality bins

High-p_T J/ψ in PbPb at 5 TeV



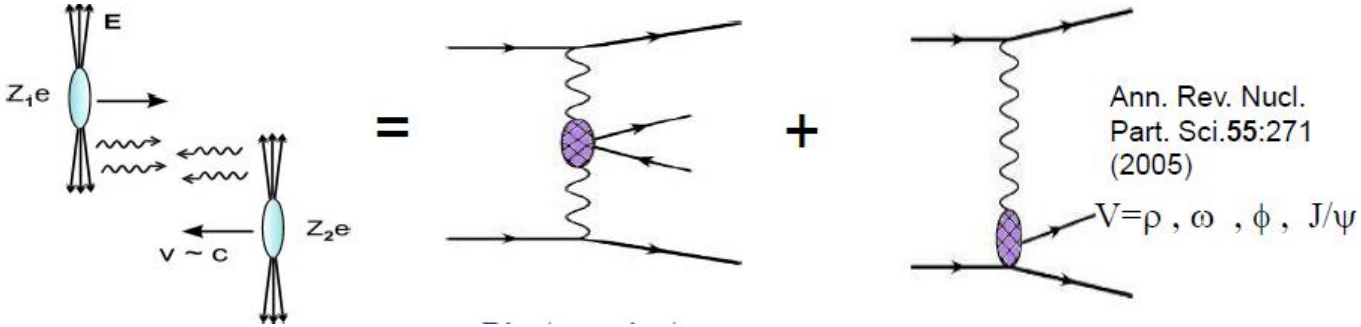
- Stronger suppression of high-p_T J/ψ at 5 TeV than 2.76 TeV
- Because of different p_T cut?

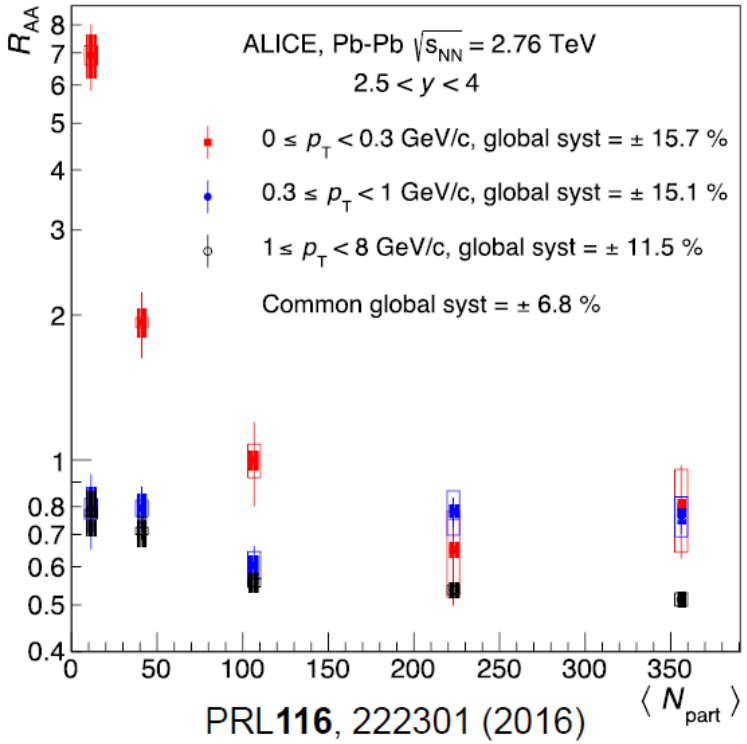
p_T dependence



- Flat at $5<p_T<\sim15$ GeV/c and then increase with p_T
- Stronger suppression at higher beam energy in overlapping p_T

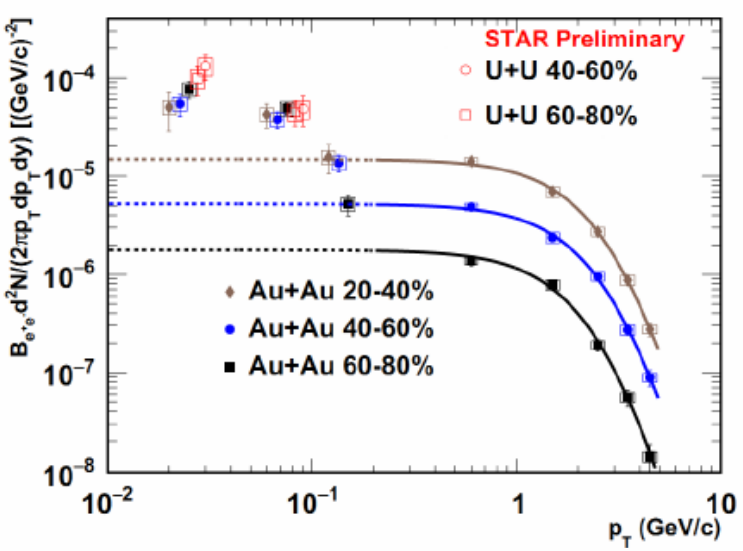
Very low-p_T J/ψ in peripheral AA

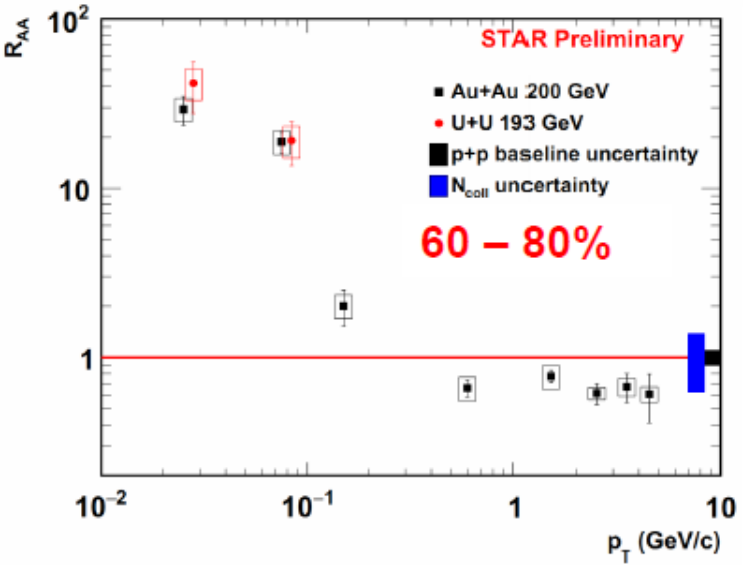


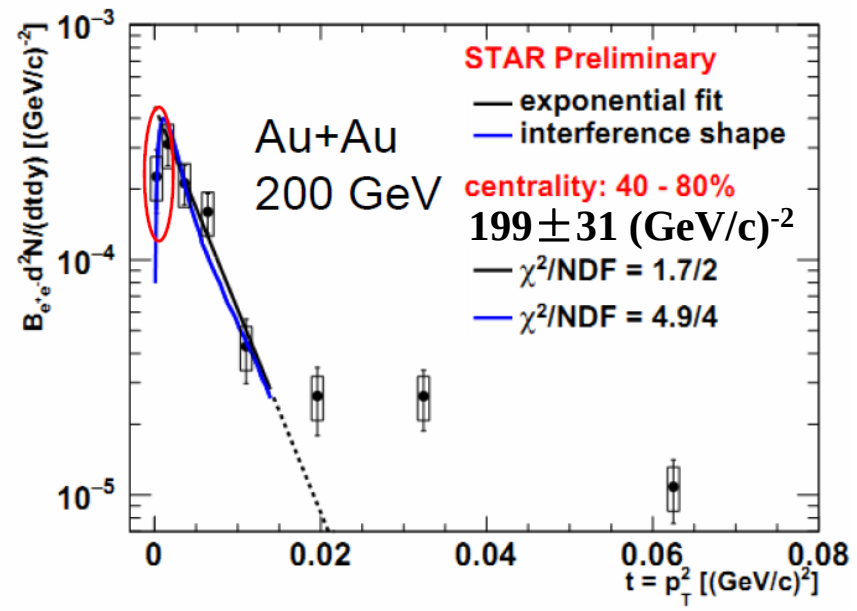


- Significant enhancement at very low p_T in (semi-)peripheral PbPb Collisions
- A domain where re(combination) is negligible
- At rest in the created medium

Very low-p_T J/ψ at STAR





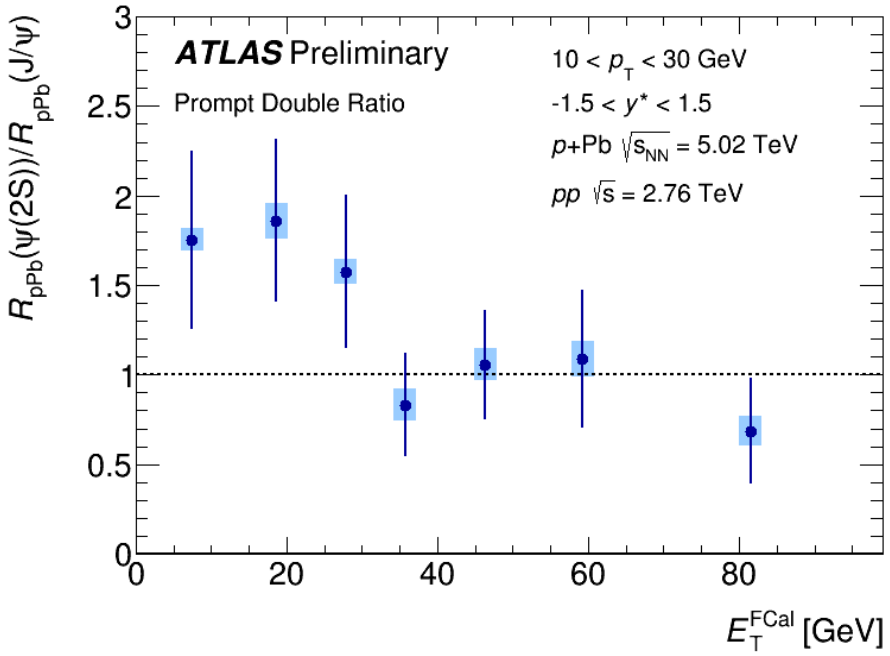


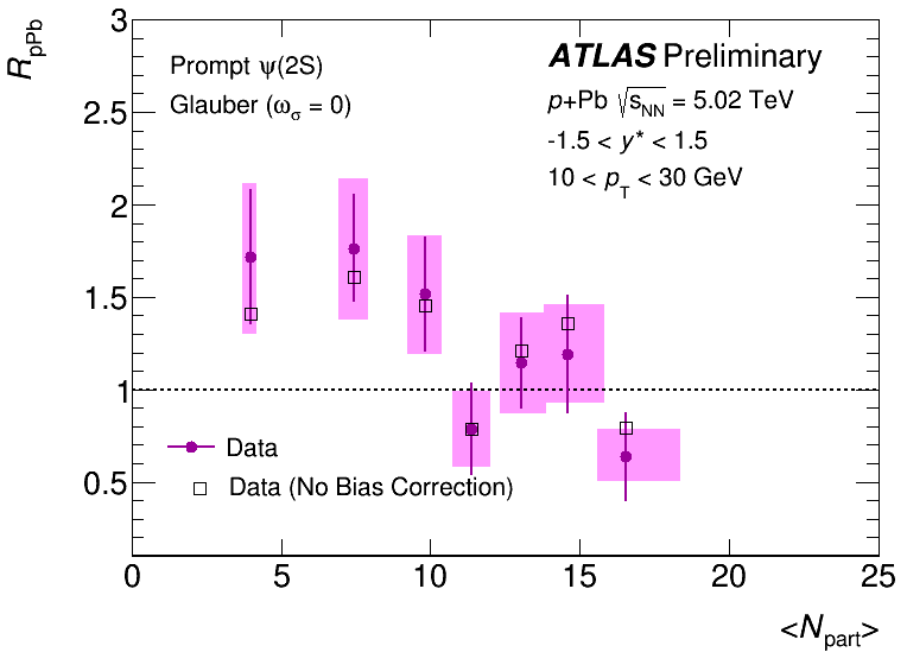
- Excess observed at p_T<0.1 GeV, no obvious centrality dependence
- *t* distribution consistent with interference, slope consistent with that of ρ in UPC

ψ(2S) Results

High-p_T ψ(2S) in pPb

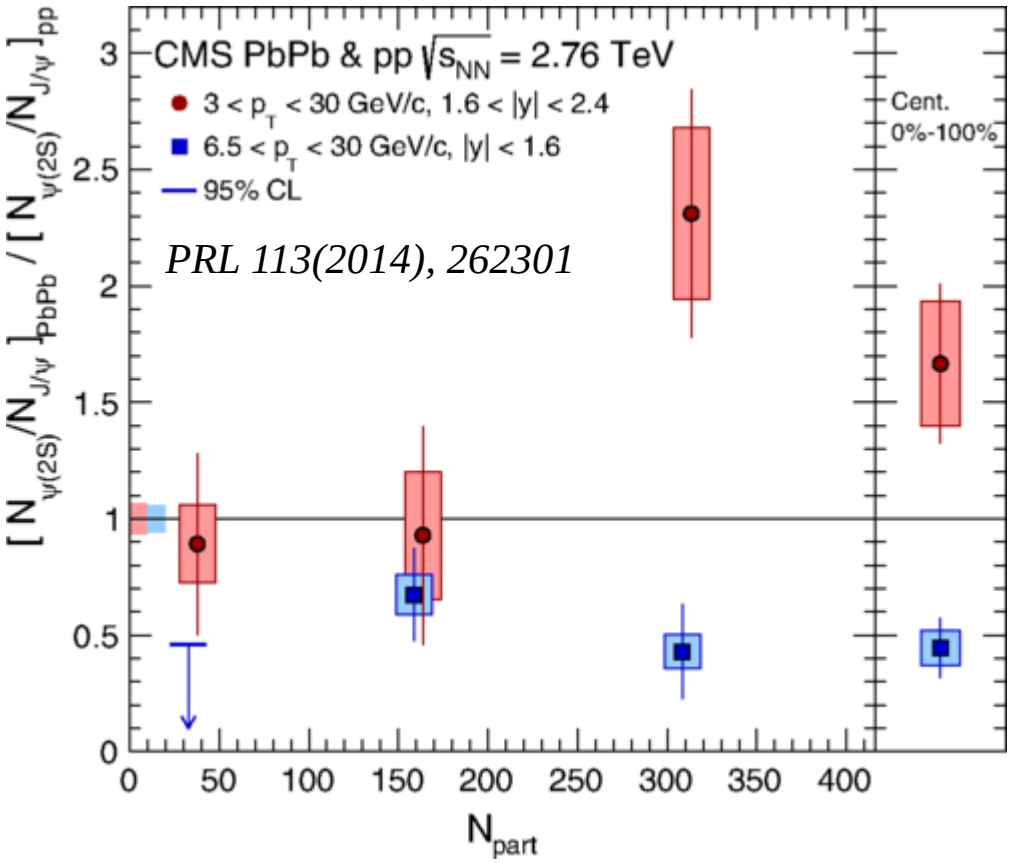
ATLAS-CONF-2015-023





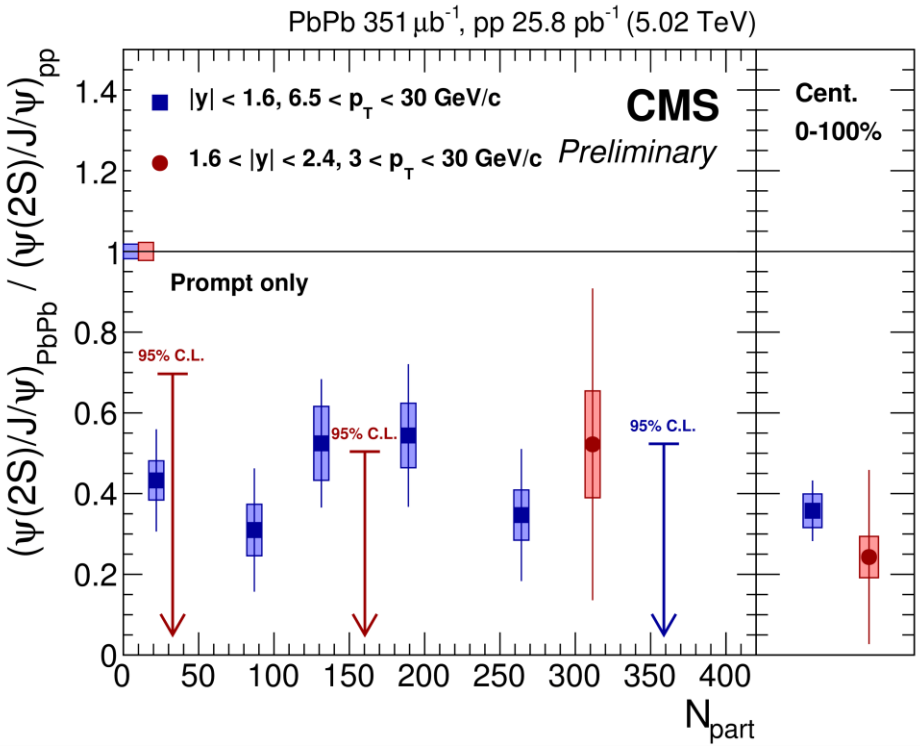
- Similar suppression in central collisions
- Hints of less suppression in peripheral collisions

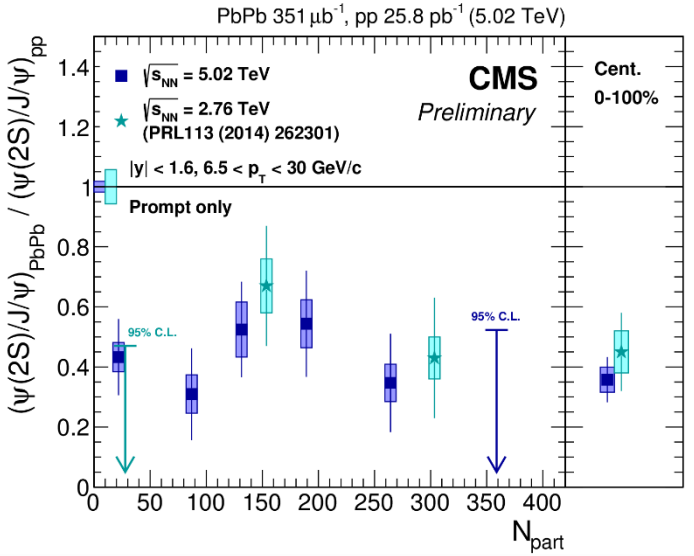
ψ(2S) in PbPb at 2.76 TeV

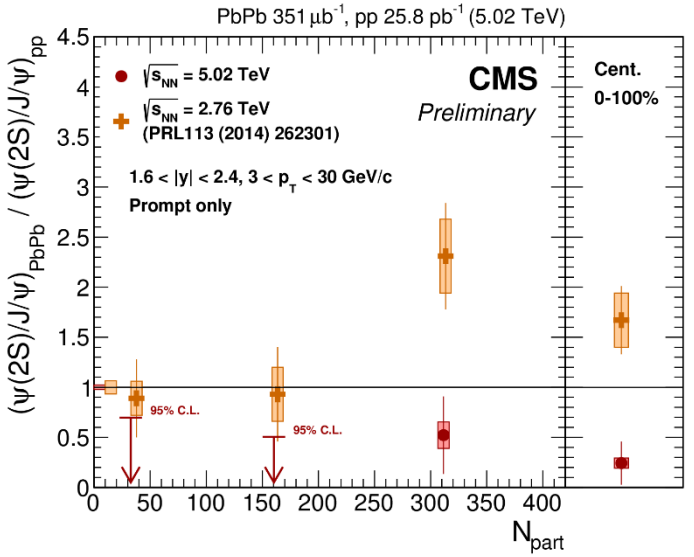


- Relative more suppression at p_T>6.5 GeV/c
- Relative enhancement at p_T>3 GeV/c

ψ(2S) in PbPb at 5 TeV

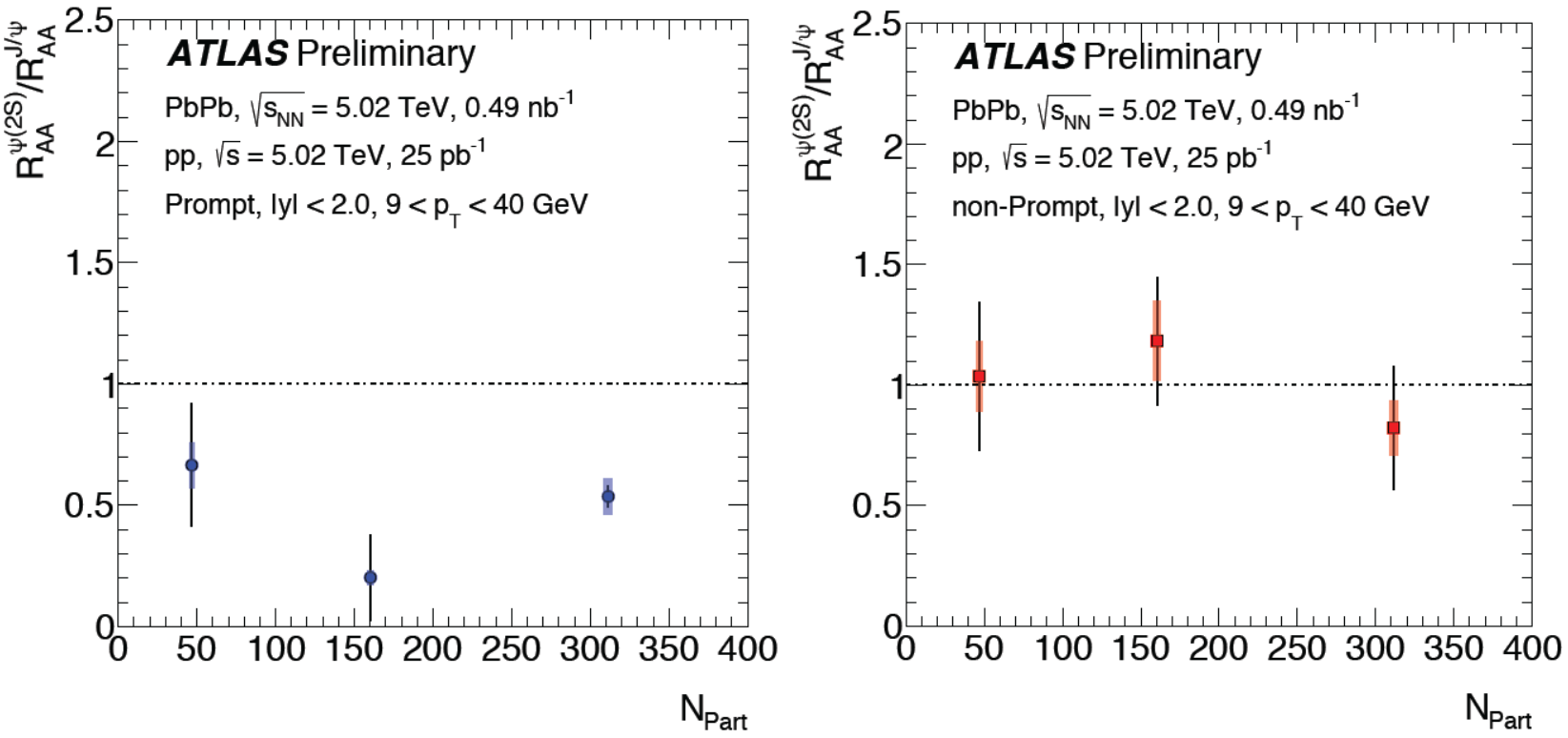






- Centrality independent suppression
- Consistent between two energies, but ~3σ difference in central collisions
- Precision need to be improved

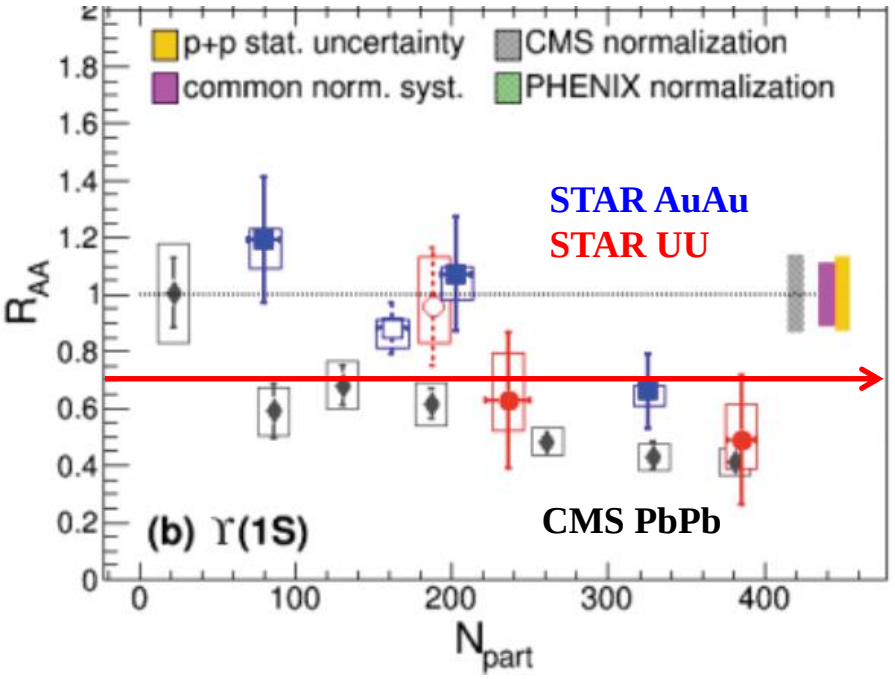
High-p_T ψ(2S) in PbPb

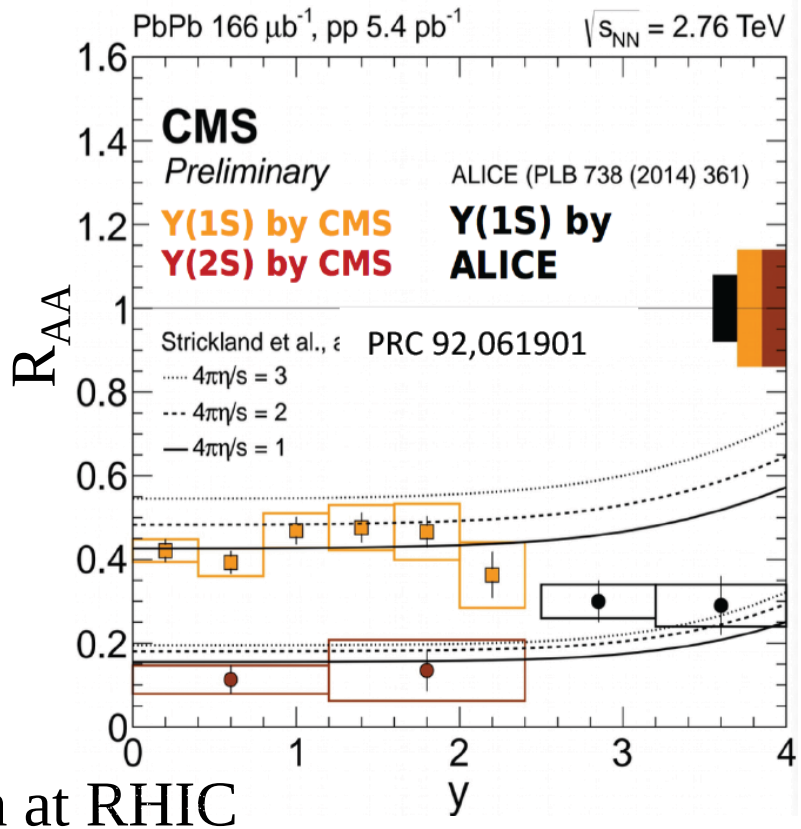


- Significantly stronger suppression with respect to J/ψ
- Same suppression for non-prompt ψ(2S) and J/ψ

Υ(1S, 2S, 3S) Results

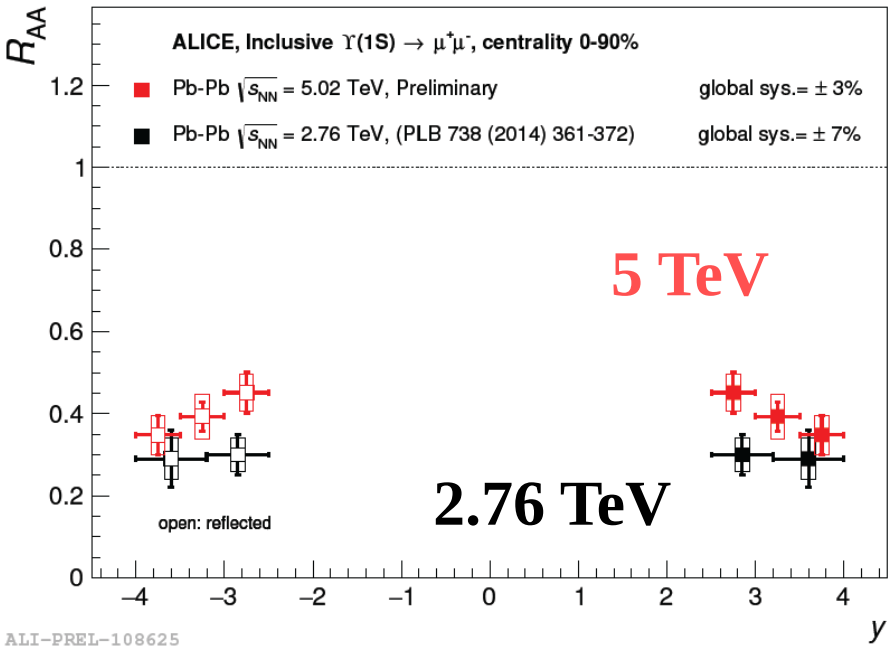
ϒ(1S) in AA

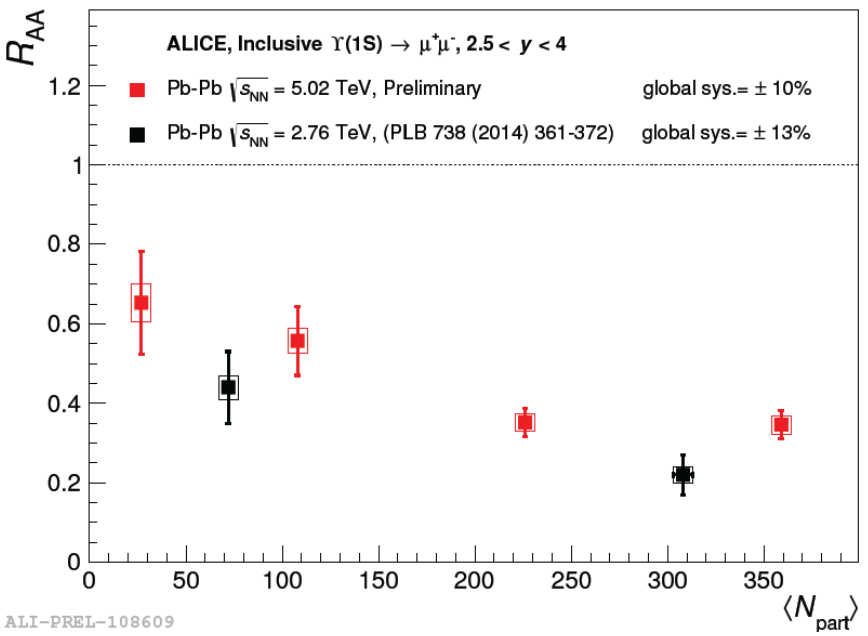




- Stronger suppression at LHC than at RHIC
- Suppression of direct ϒ(1S) in central collisions?
- More suppression at forward rapidity than mid-rapidity (Re)combination?

Υ(1S) in PbPb at 5 TeV



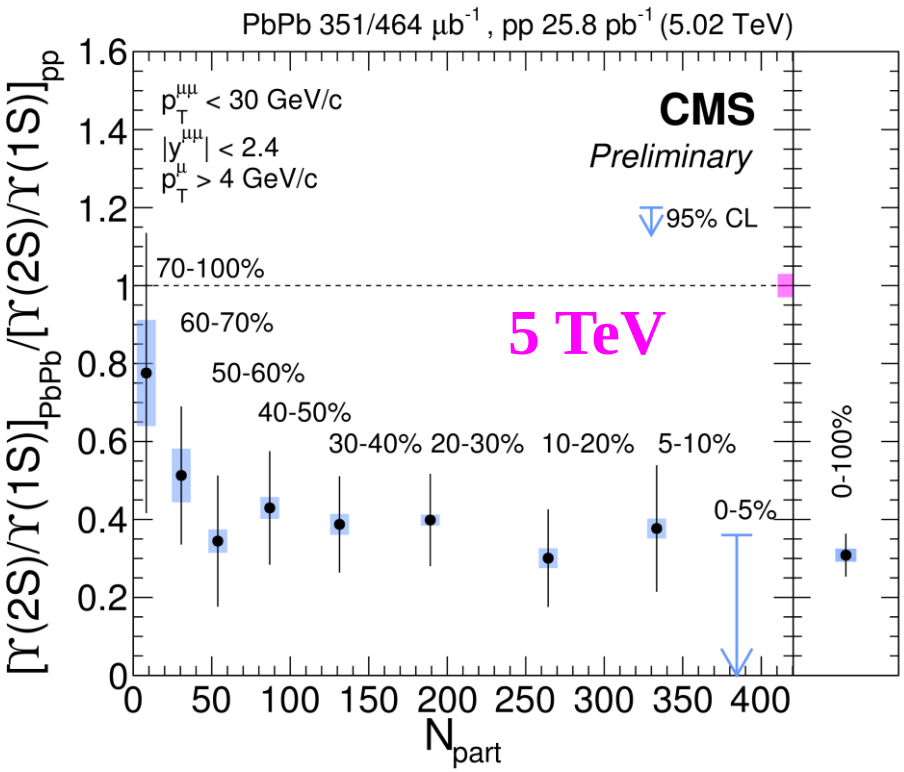


- Hints of stronger suppression in more forward rapidity
- Hints of less suppression at higher beam energy

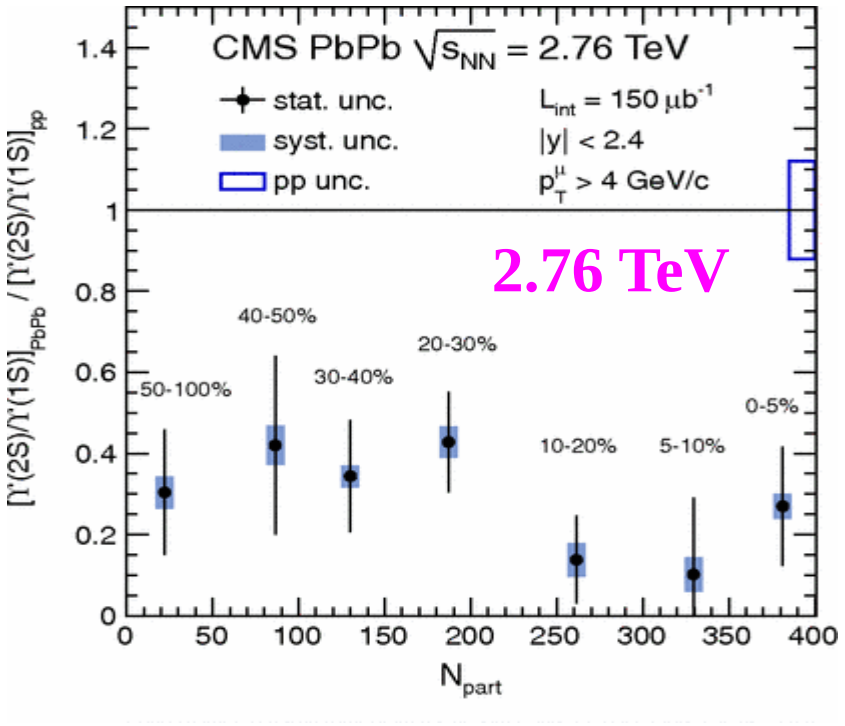
  Ratio(0-90%) = 1.3 ± 0.2(stat.) ± 0.2(syst.)

  ~1σ higher than unity

Υ(2S) in PbPb



CMS, PRL109 (2012), 222301

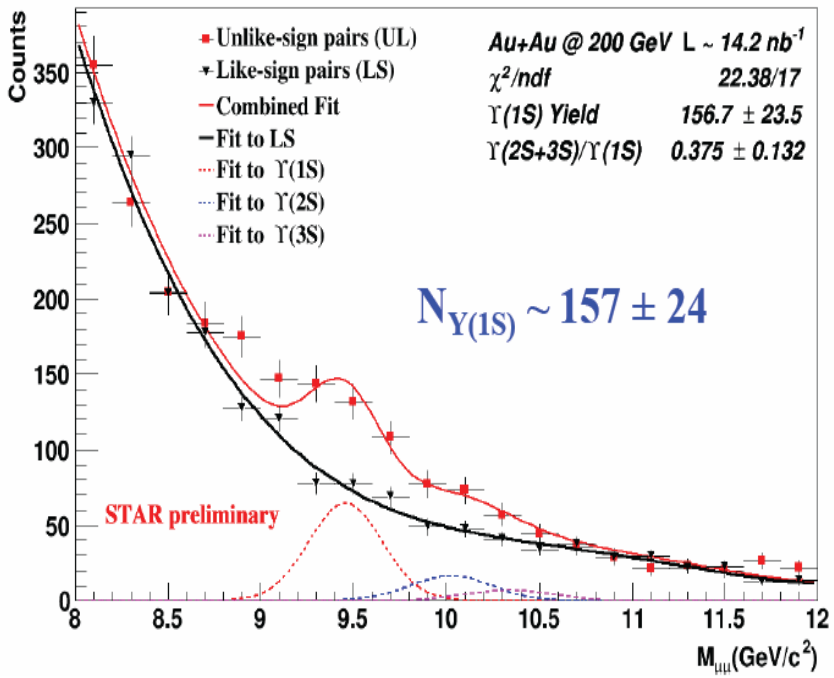


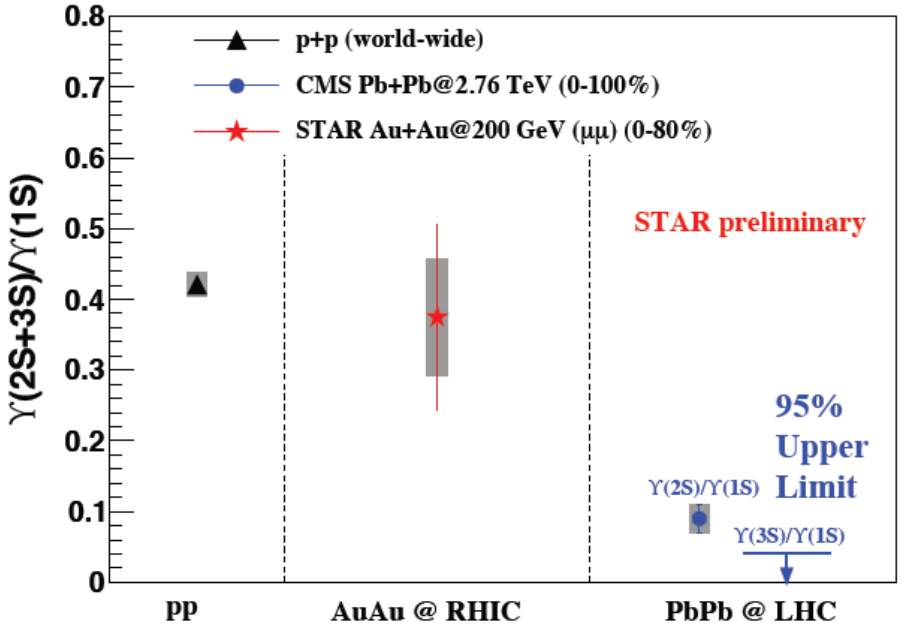
$0.308 \pm 0.055(\text{stat.}) \pm 0.017(\text{syst.})$

$0.21 \pm 0.07(\text{stat.}) \pm 0.02(\text{syst.})$

- Double ratio ~1σ higher at 5 TeV than at 2.76 TeV

Υ(2S+3S) in AuAu at RHIC

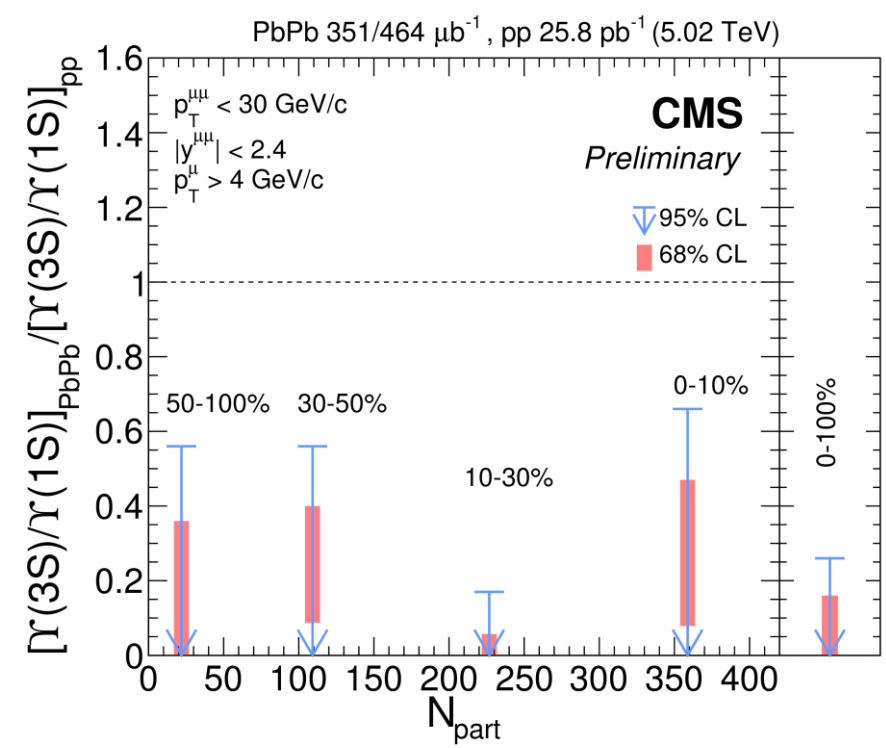




World-wide PRC 88(2013) 067901
CMS : PRL 109(2012) 222301
CMS : JHEP 04 (2014) 103

- ~1.5σ higher at 0.2 TeV than at 2.76 TeV

Υ(3S) in PbPb



- Double Ratio < 0.26 (95% CL) at 5 TeV
- Double Ratio < 0.17 (95% CL) at 2.76 TeV

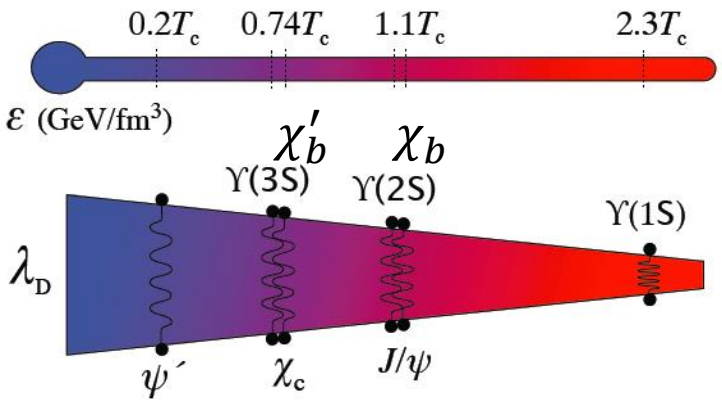
Summary (1/2)

J/ψ

- Low-p_T: Suppression decreases from 0.2 to 5 TeV
  (Re)combination
- High-p_T: Suppression increases from 0.2 to 5 TeV
  QGP melting
- Very low-p_T: Enhancement due to photo-production

ψ(2S)÷J/ψ

- Double ratio at high-p_T:
  ~1 in pPb for promt
  ≪1 in PbPb for prompt
  ~1 in PbPb for non-prompt
  QGP melting

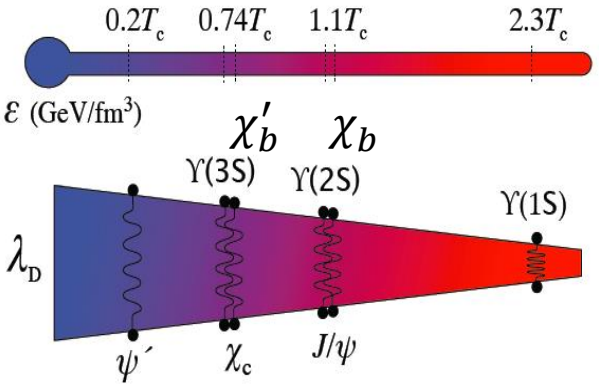


Summary (2/2)

ϒ(1S)

- ϒ(1S)@LHC vs. J/ψ@ RHIC (low-βγ)

  QGP melting + (Re)combination



ϒ(2S, 3S) ÷ ϒ(1S)

- Strong suppression in PbPb

  QGP melting

- Hints of decrease then increase from 0.2→2.76→5 TeV

  (Re)combination also plays a role?

  ~1-1.5σ effect, statistical uncertainty dominant

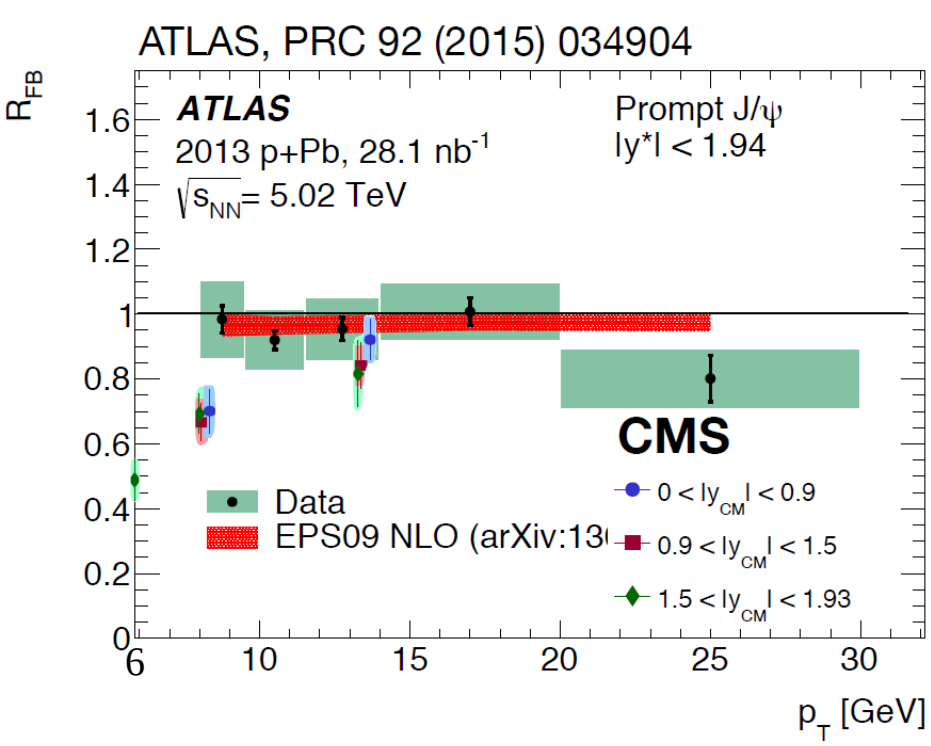
More data needed to be more precise!

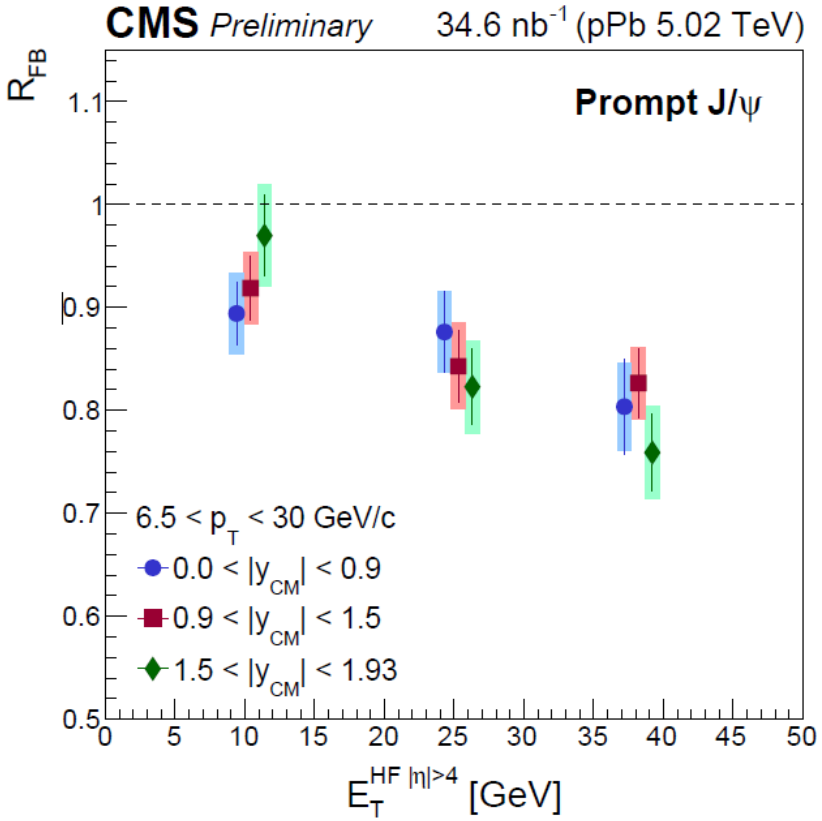
All the observed features can be explained in QGP melting + (Re)combination picture

Thank you!

Backup slides

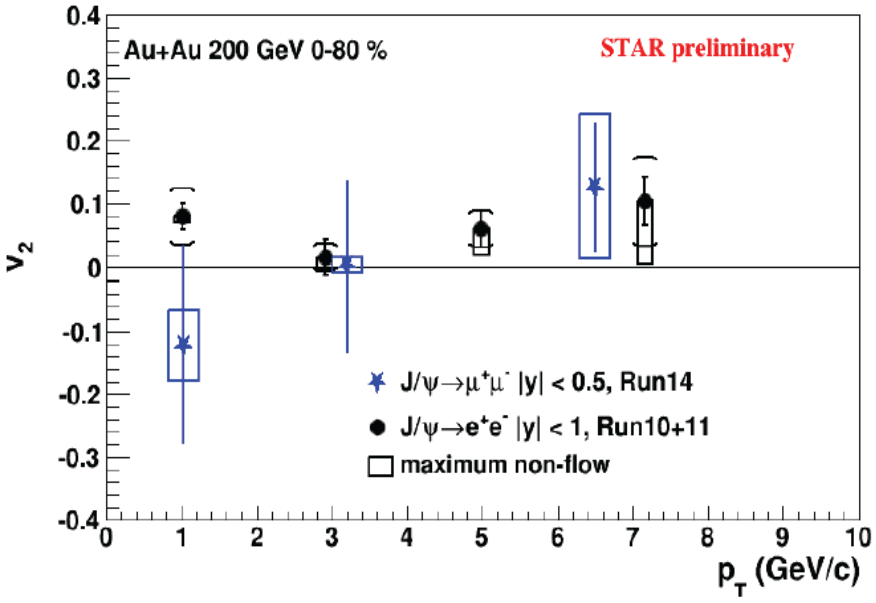
High-p_T J/ψ in pPb

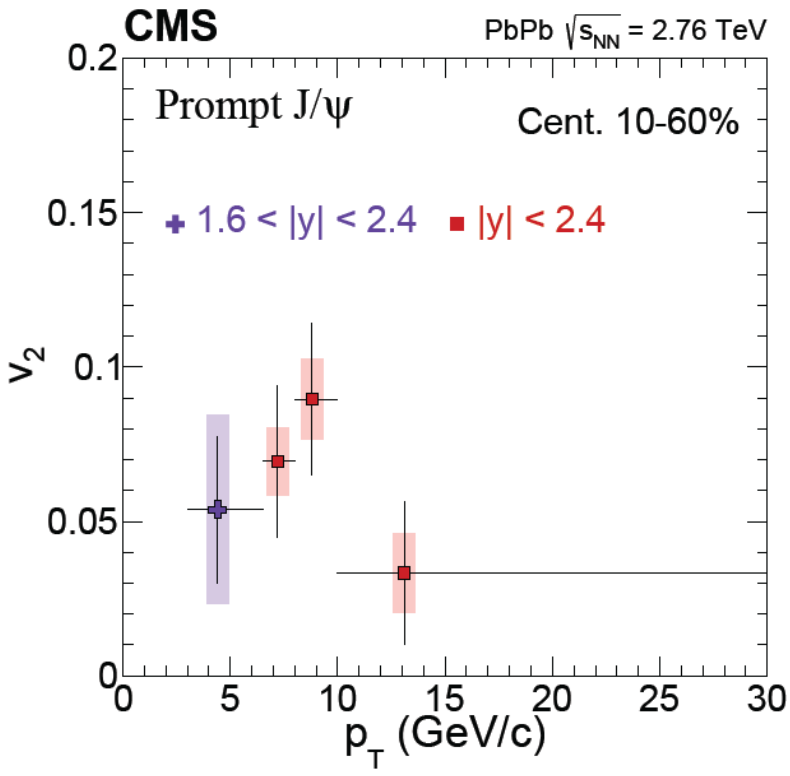




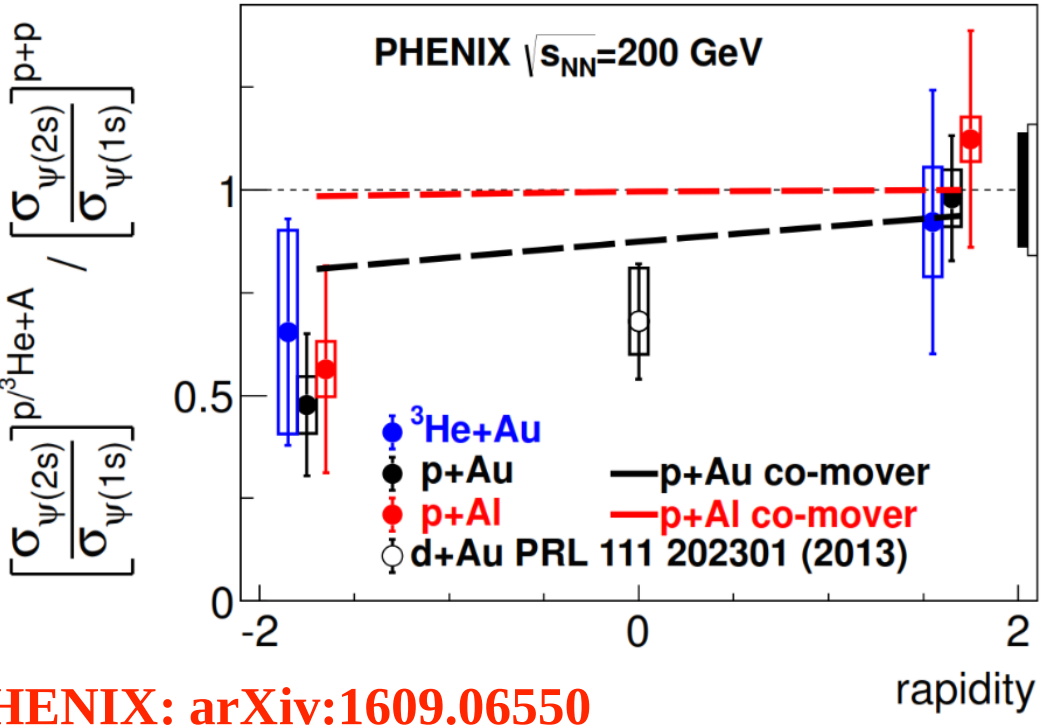
- Suppression at p_T<10 GeV/c observed by CMS
- Suppression increases with event activity at forward
- Tension between ATLAS and CMS at p_T<10 GeV/c

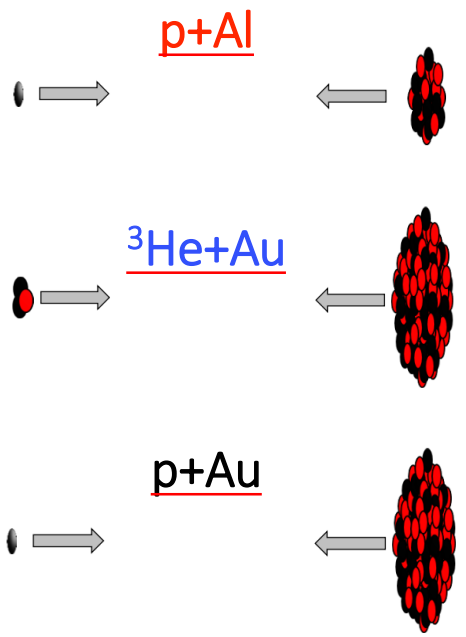
J/ψ elliptic flow





ψ(2S) in pA at RHIC

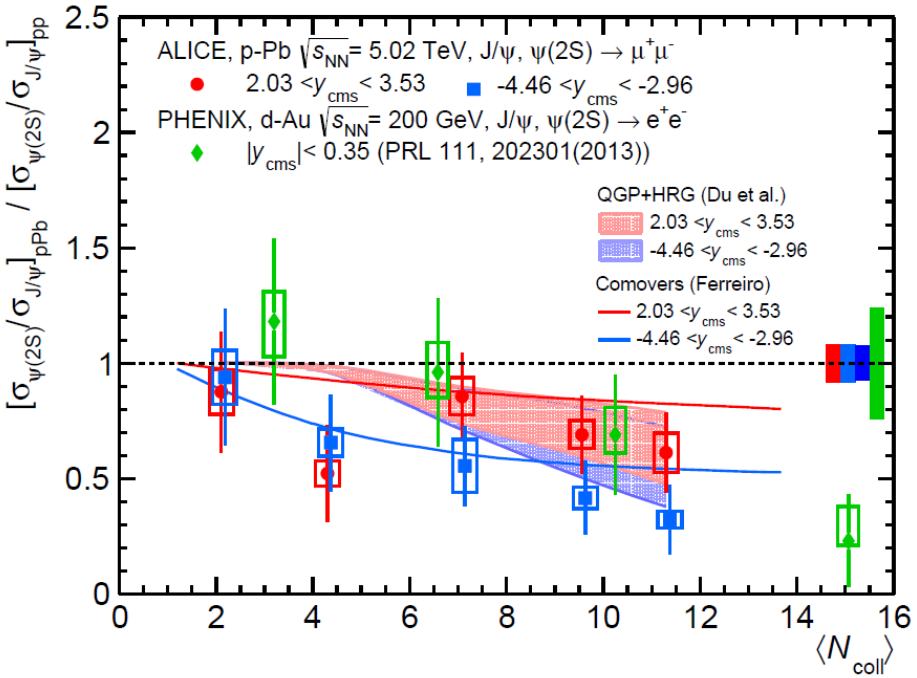




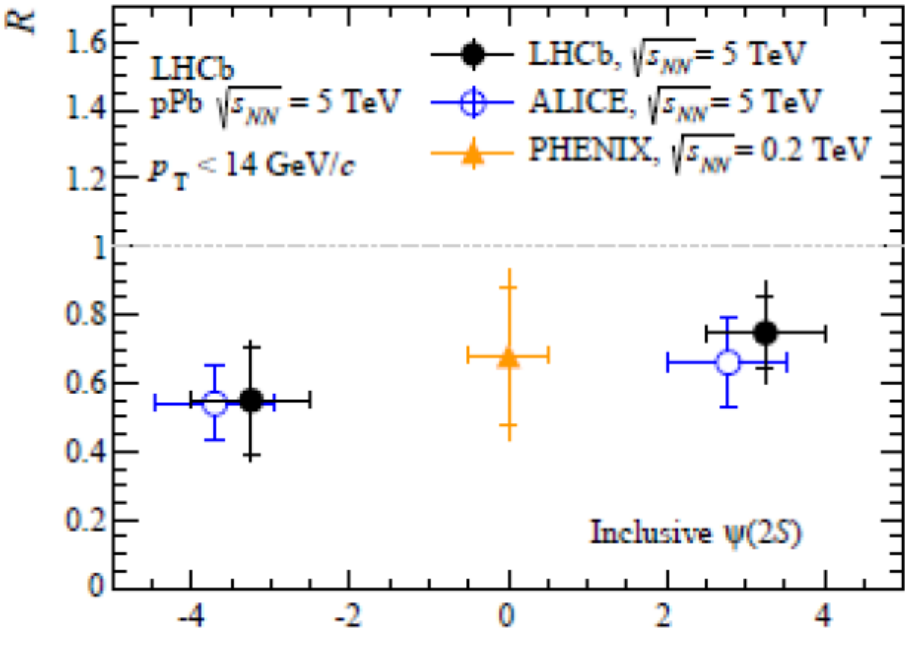
PHENIX: arXiv:1609.06550

- Indication of stronger suppression with respect to J/ψ on A-going

ψ(2S) in pPb at LHC



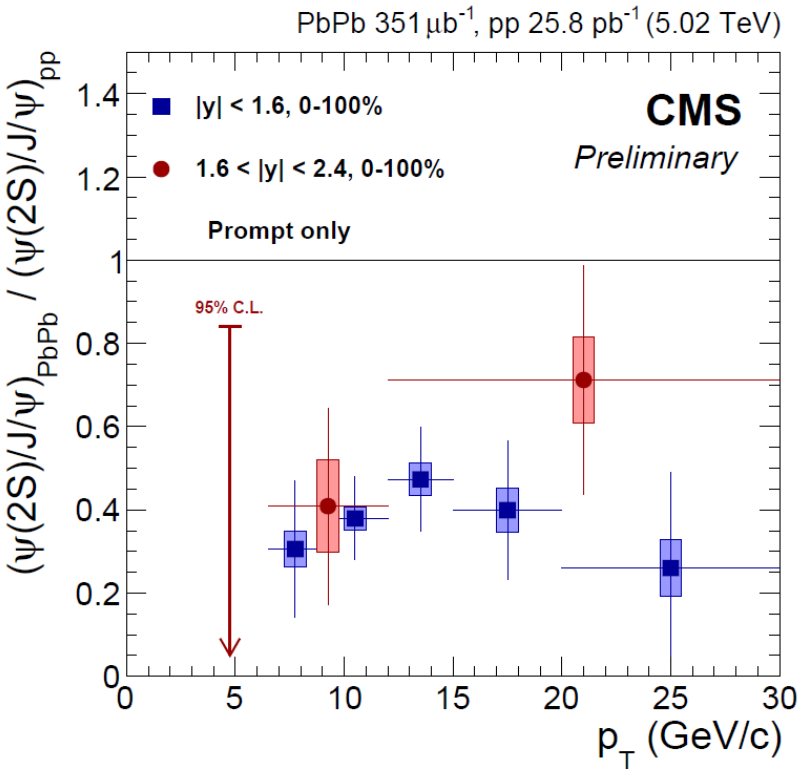
ALICE, JHEP 1606(2016) 50

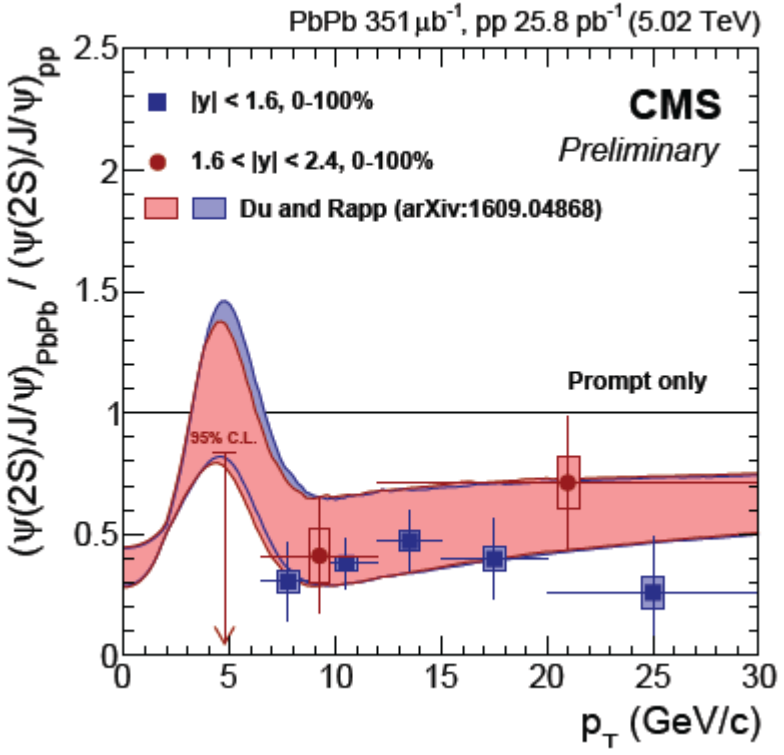


LHCb, JHEP 1603 (2016) 133

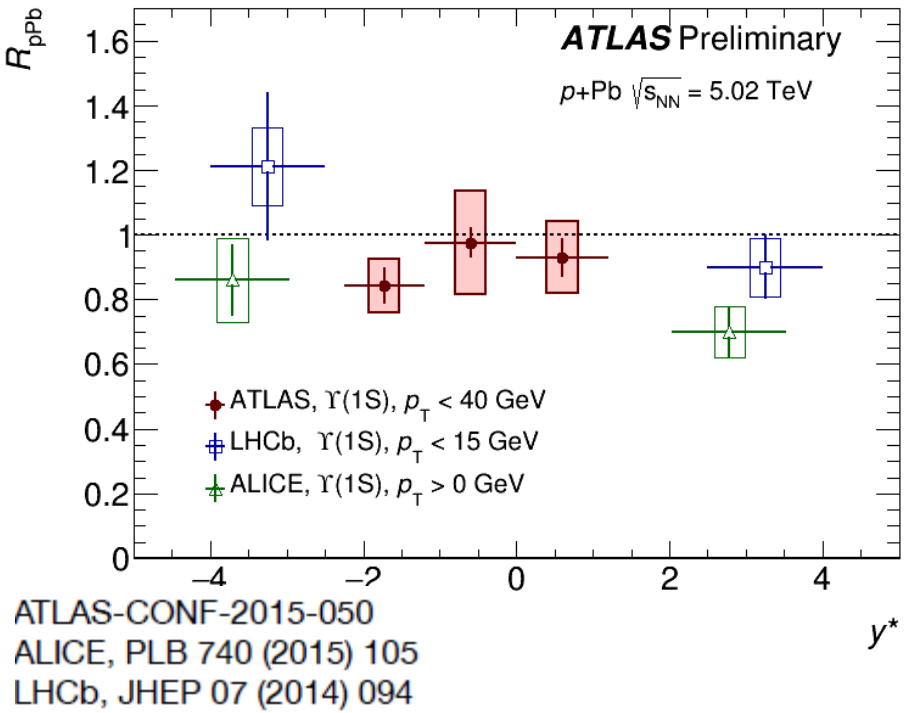
- ψ(2S) more suppressed than J/ψ in both forward and backward
- Comover interaction model describes reasonable well

ψ(2S) in PbPb


PbPb 351 μb-1, pp 25.8 pb-1 (5.02 TeV)
|y| < 1.6, 0-100%
1.6 < |y| < 2.4, 0-100%
CMS
Preliminary
Prompt only
95% C.L.
(ψ(2S)/J/ψ)PbPb / (ψ(2S)/J/ψ)pp
pT (GeV/c)


PbPb 351 μb-1, pp 25.8 pb-1 (5.02 TeV)
|y| < 1.6, 0-100%
1.6 < |y| < 2.4, 0-100%
Du and Rapp (arXiv:1609.04868)
CMS
Preliminary
Prompt only
95% C.L.
(ψ(2S)/J/ψ)PbPb / (ψ(2S)/J/ψ)pp
pT (GeV/c)

ϒ in pPb



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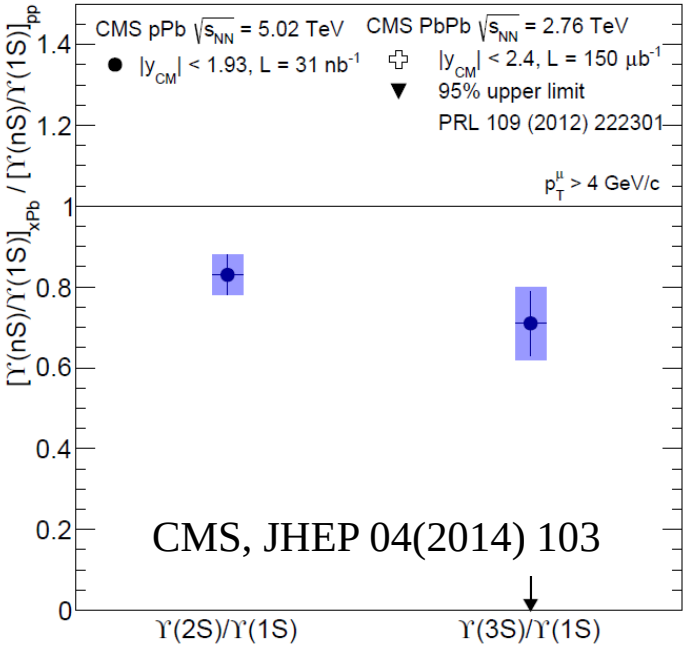
ALICE, PLB 740 (2015) 105
LHCb, JHEP 07 (2014) 094



- Suppression observed on p-going for ϒ(1S)
- More suppression for excited states