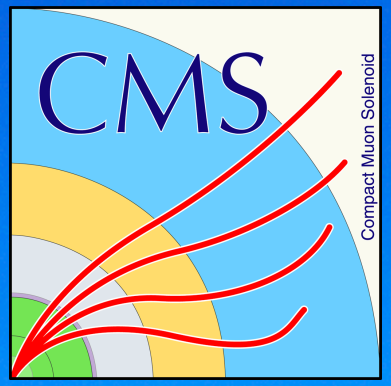
Suppression of the upsilon excited states measured with CMS

Soohwan Lee
Korea University



Saclay heavy ion seminar 24 Nov, 2022

Quarkonia inside QGP

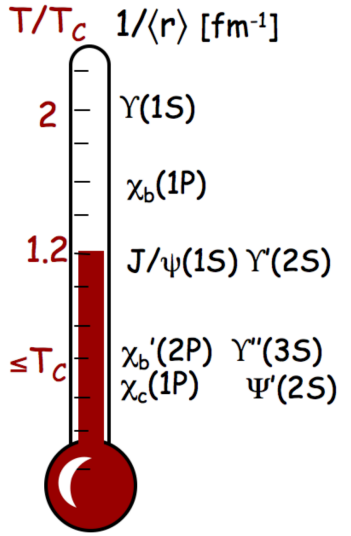
- Bottomonia are good probes to study the QGP

☑ Produced mostly from initial hard scattering

☑ Heavier mass allows more reliable NRQCD calculation compared to charmonium

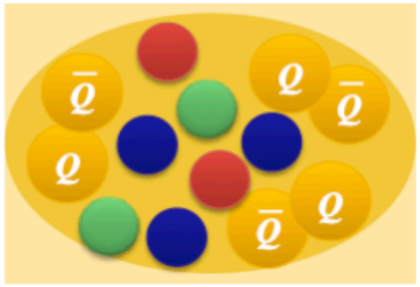
☑ Sensitive to in medium effects

(color screening, dissociation, recombination)

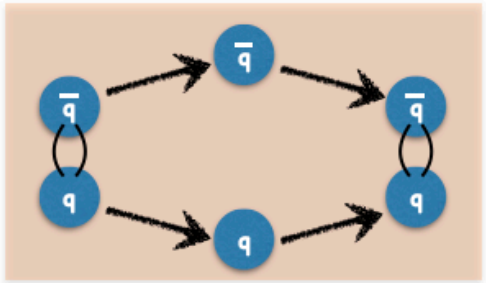


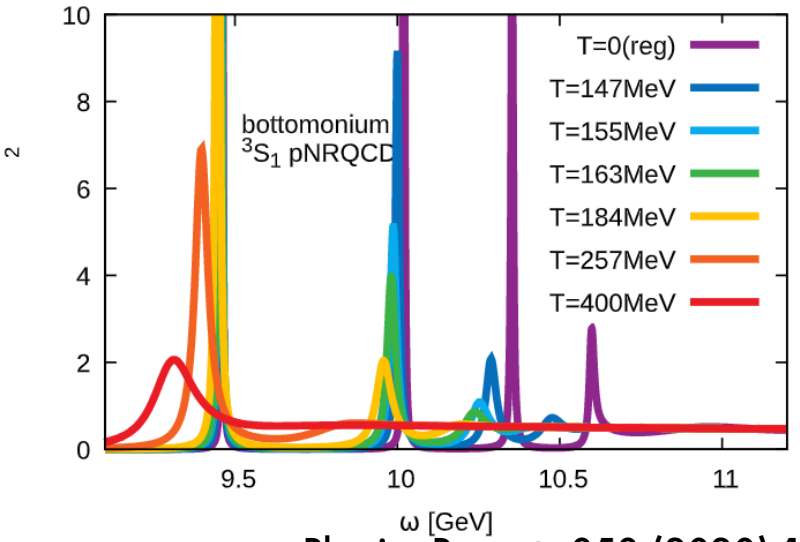
EPJC 61 (2009) 705-710

- Uncorrelated



- Correlated

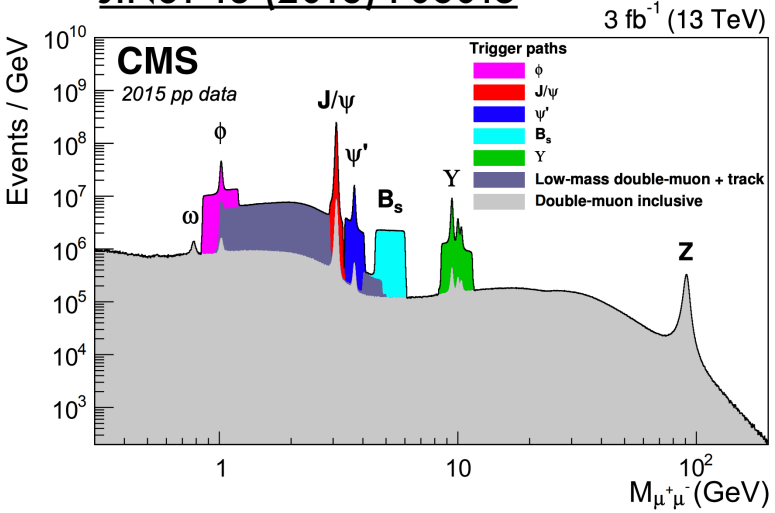




Physics Reports 858 (2020) 1

The CMS detector

JINST 13 (2018) P06015

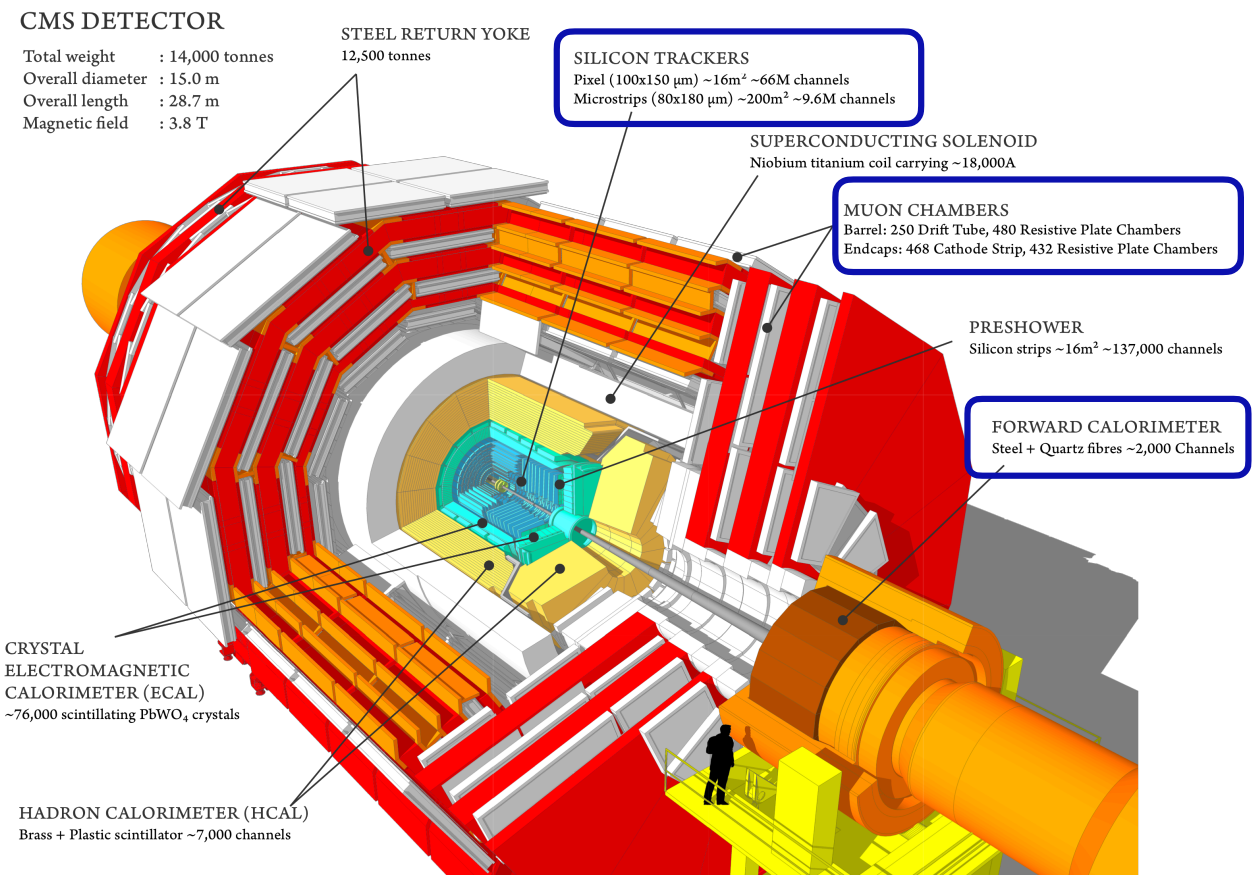


detector for bottomonium measurement in HI collisions.

Wide p_T range of muon(> $\mathcal{O}(100)$ GeV)

Good momentum resolution

Large cover of muon reconstruction

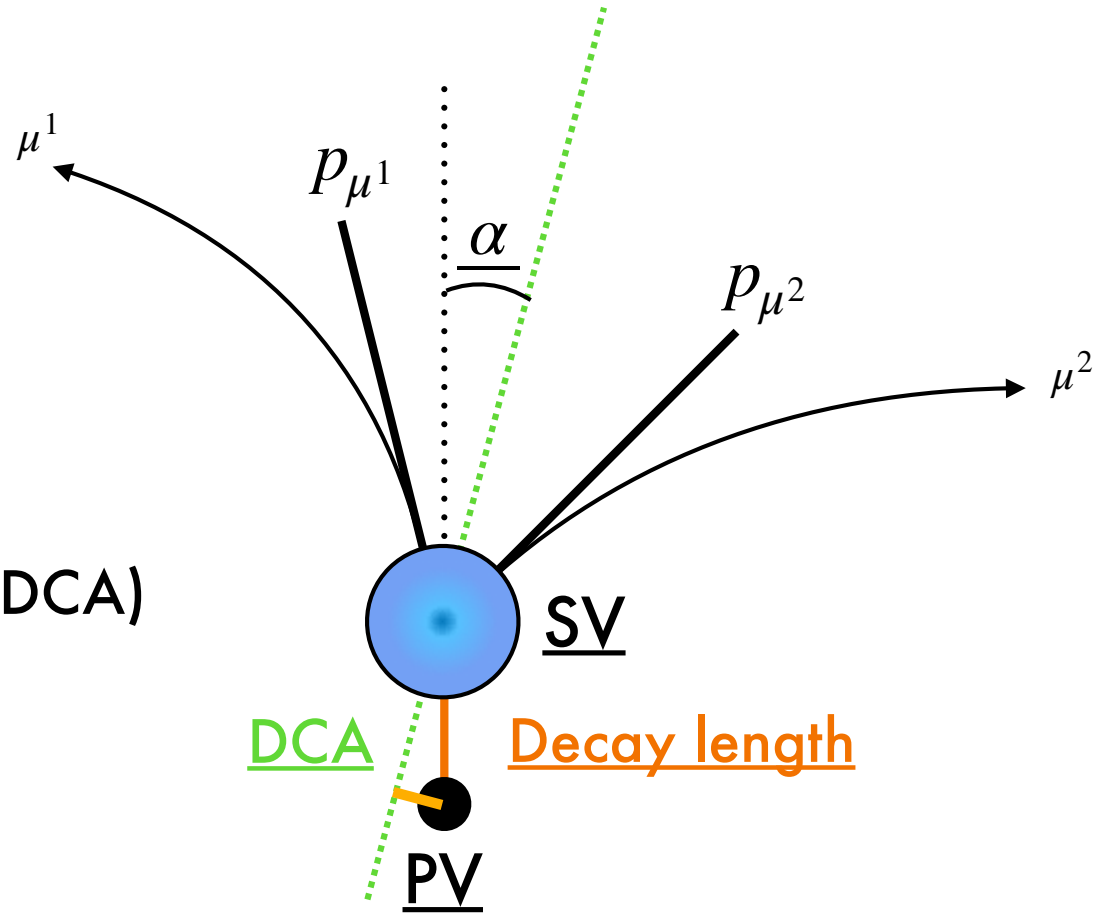


Signal extraction

Signal (dimuon from Y(nS)) enhancement with MVA selection(BDT) for PbPb data

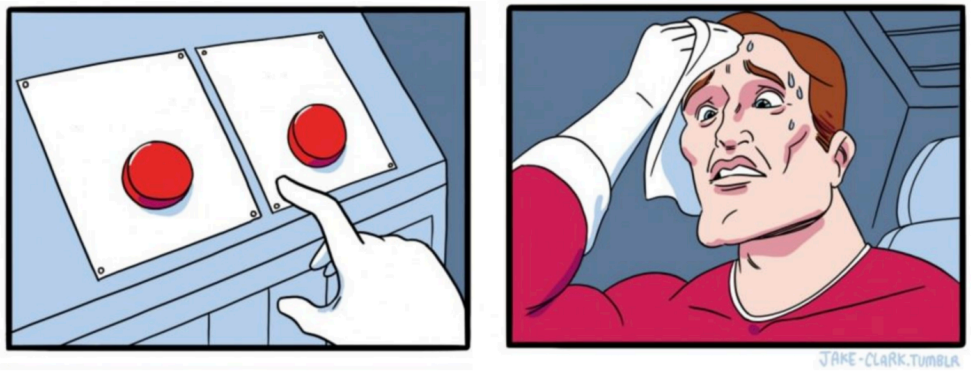
Trained with Signal MC and background (side band data) for classification

- Pointing angle α
- Distance to closest approach (DCA)
- Vertex related information



Classification through BDT

image credit: imgflip



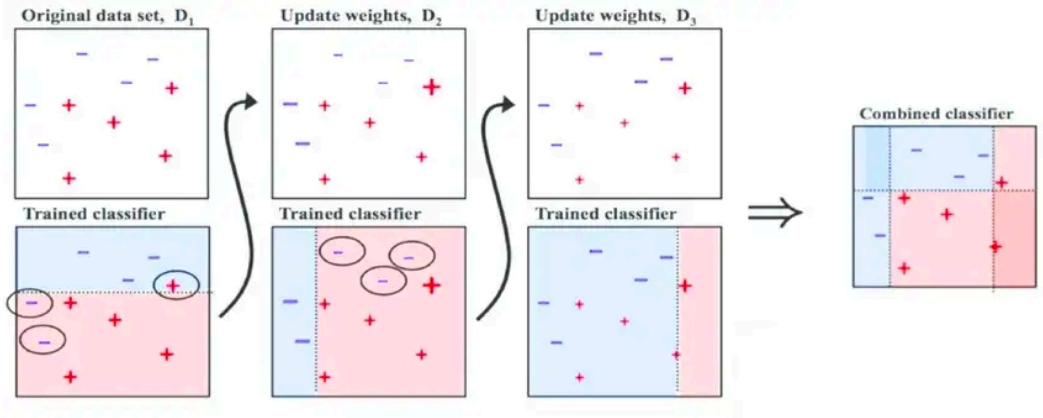
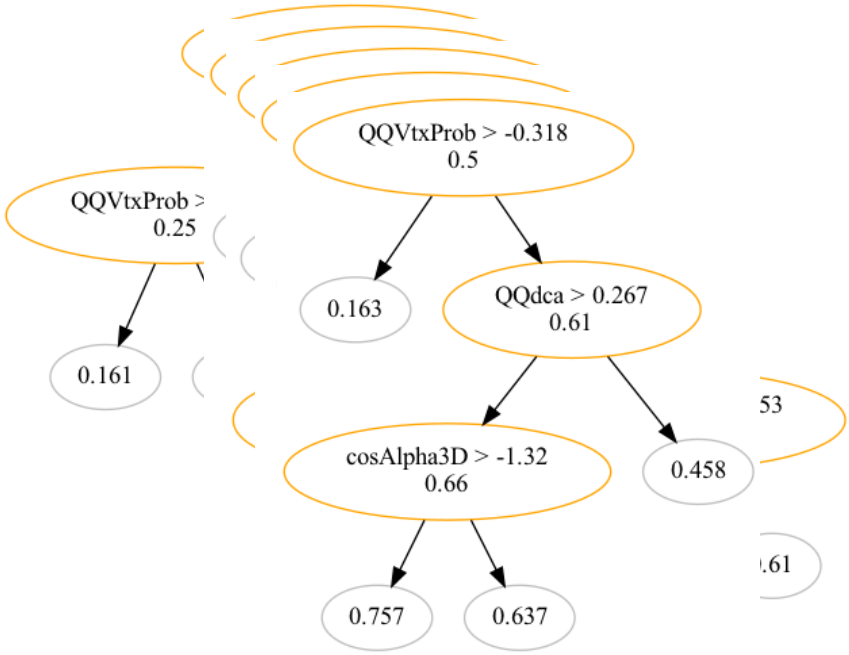


image credit: Ashish Patel

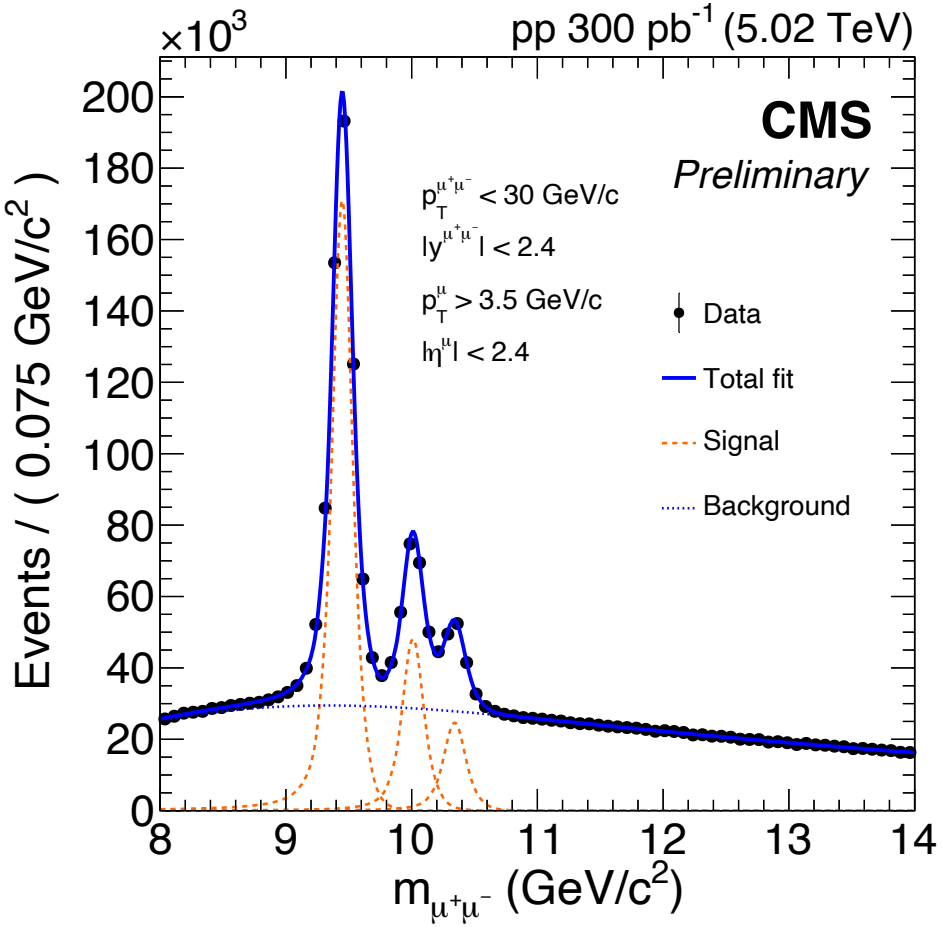


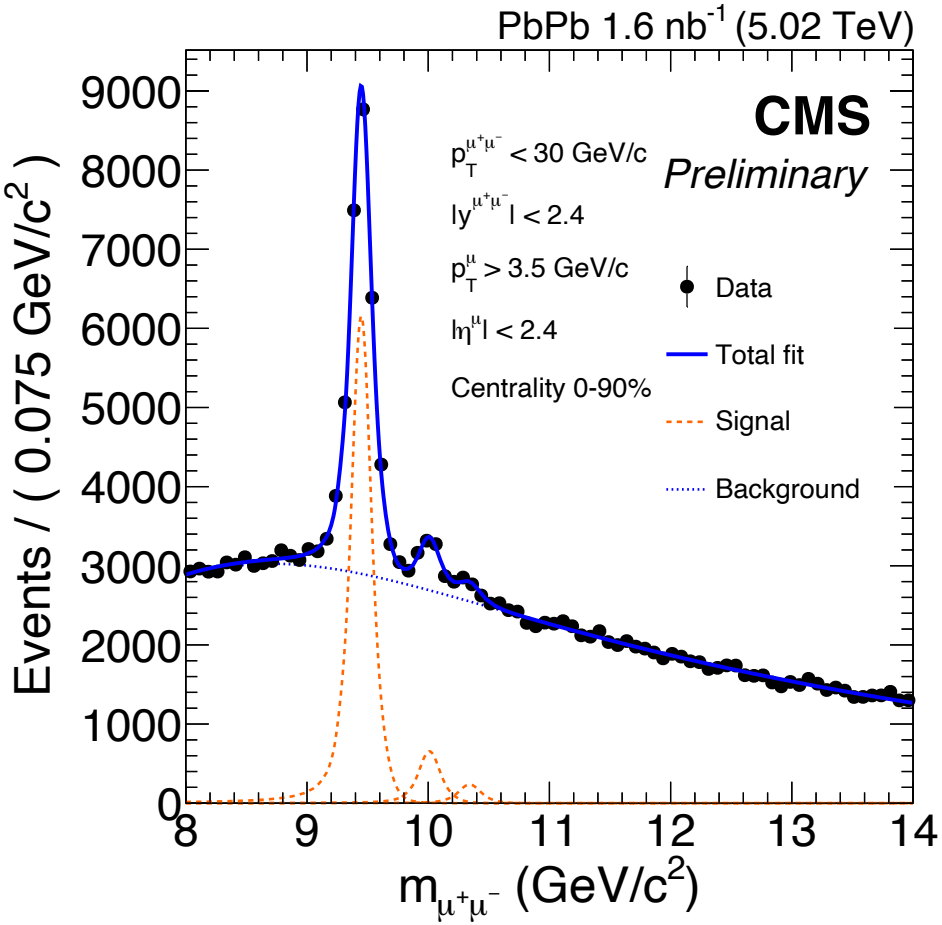
Example of weighted decision trees

- BDT is a N-dimension regression with ensemble learning
  - Hard for one tree, but the forest of weighted trees do a good job in learning

Dimuon mass spectra

CMS-PAS-HIN-21-007

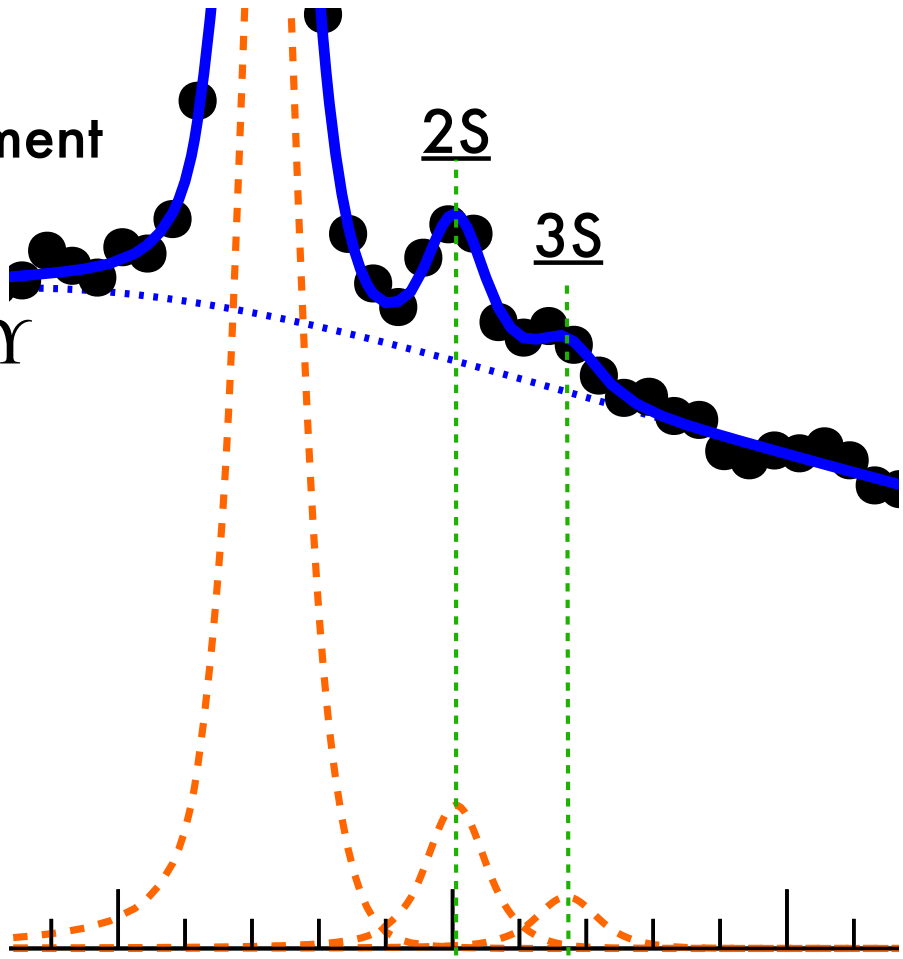




- Distribution fitted to 3 Crystal Ball signal + background

Observation of Y(3S)

- Clear peak after background reduction
- 5σ significance of non-zero Υ measurement in the integrated p_T, centrality dataset
  - Evidence to reject total meltdown of Υ (3S)



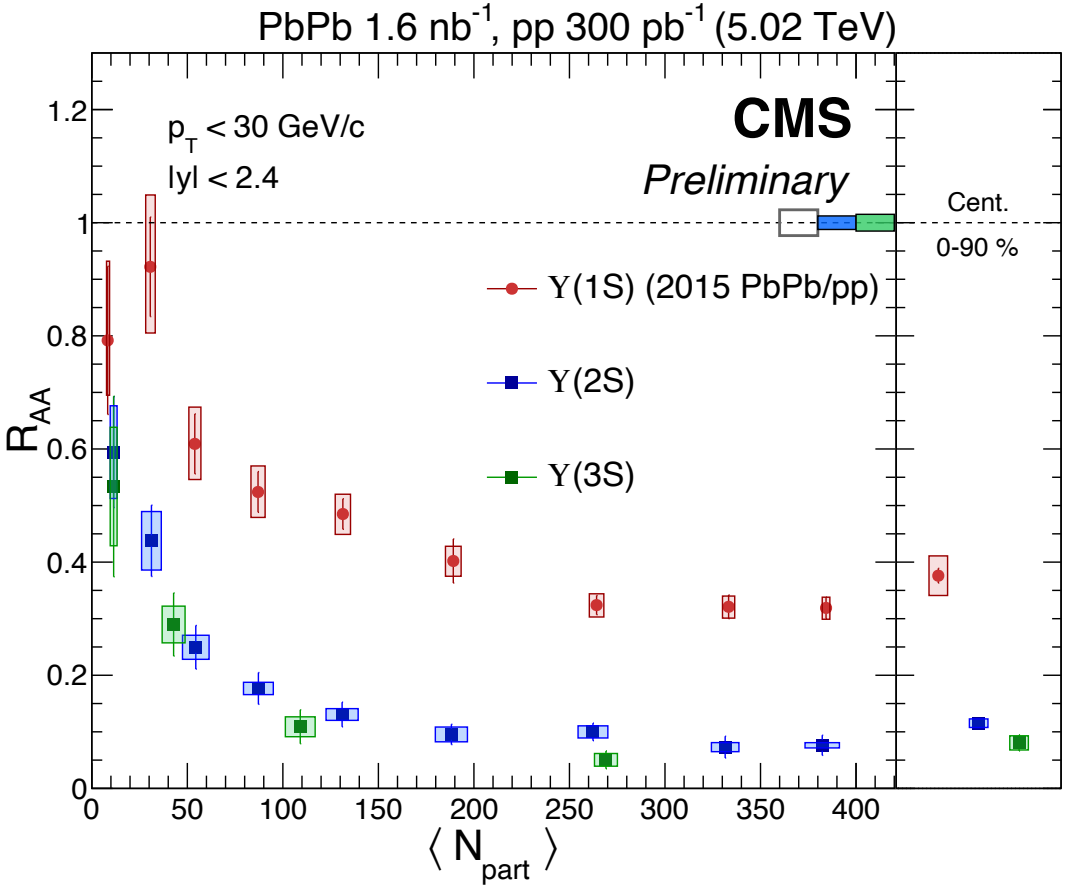
Systematic uncertainties

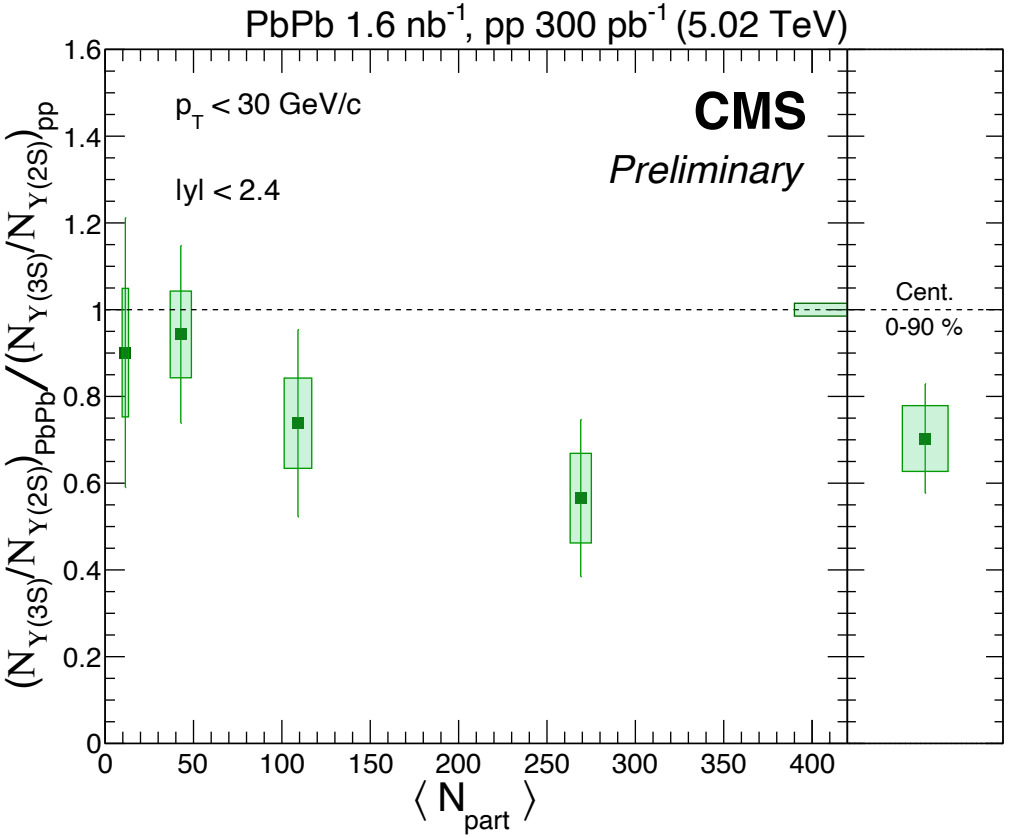
CMS-PAS-HIN-21-007

	Yield				Ratio	
	Υ(2S) (%)		Υ(3S) (%)		Υ(3S)/Υ(2S) (%)	
Source	pp	PbPb	pp	PbPb	pp	PbPb
BDT selection	-	0.3-9.0	-	1.5-18.6	-	1.2-22.8
Background PDF	0.1-1.4	0.3-11.7	0.2-1.6	1.4-21.4	<0.5	0.6-17.6
Signal PDF	0.1-1.1	0.5-2.6	0.4-1.1	0.1-2.5	0.3-0.6	0.1-3.0
Signal parameter	0.1-1.2	0.0-3.8	0.1-1.6	0.3-3.7	0.05-1.4	0.1-0.9
Event selection	-	0.0-0.5	-	0.2-13.1	-	0.1-13.6
Correction factors	<0.1	<0.5	<0.1	<0.4	<2.0	
T&P	0.9-1.0	3.8-4.5	0.9-1.1	3.8-4.4	-	
Total uncertainty	1.0-1.8	3.9-13.5	1.1-2.2	6.0-22.2	0.4-1.5	4.1-23.8

- Most uncertainty comes from background distribution shape and BDT selection
- 5σ significance obtained encompassing all yield related uncertainty

Results



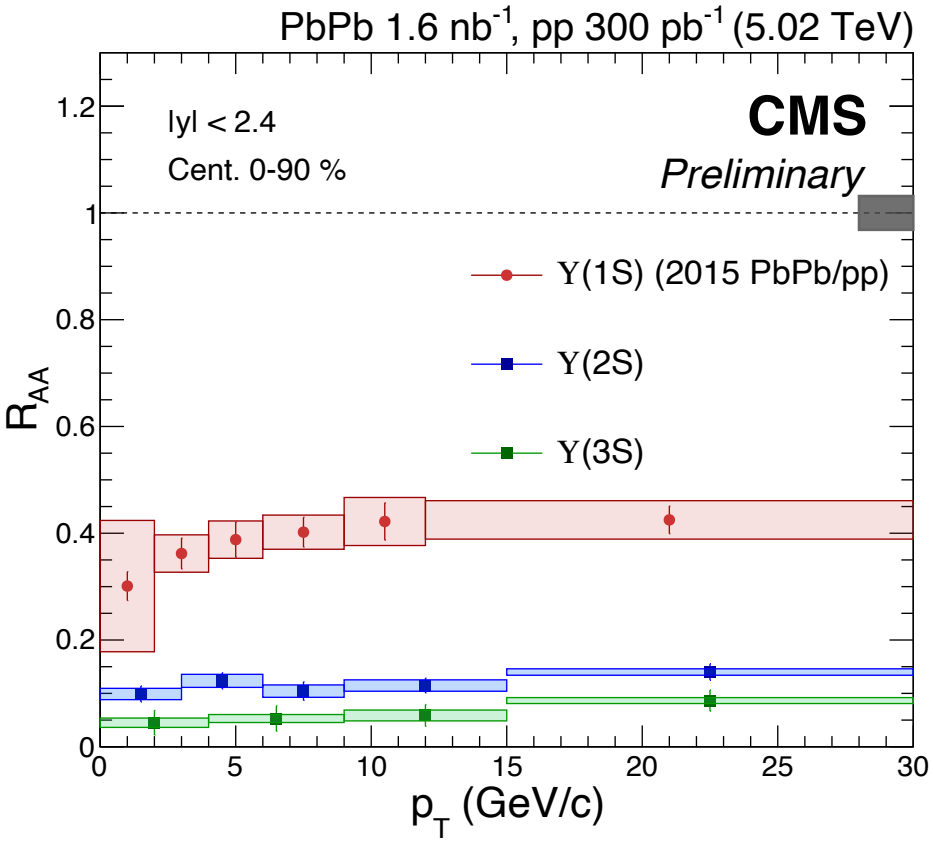


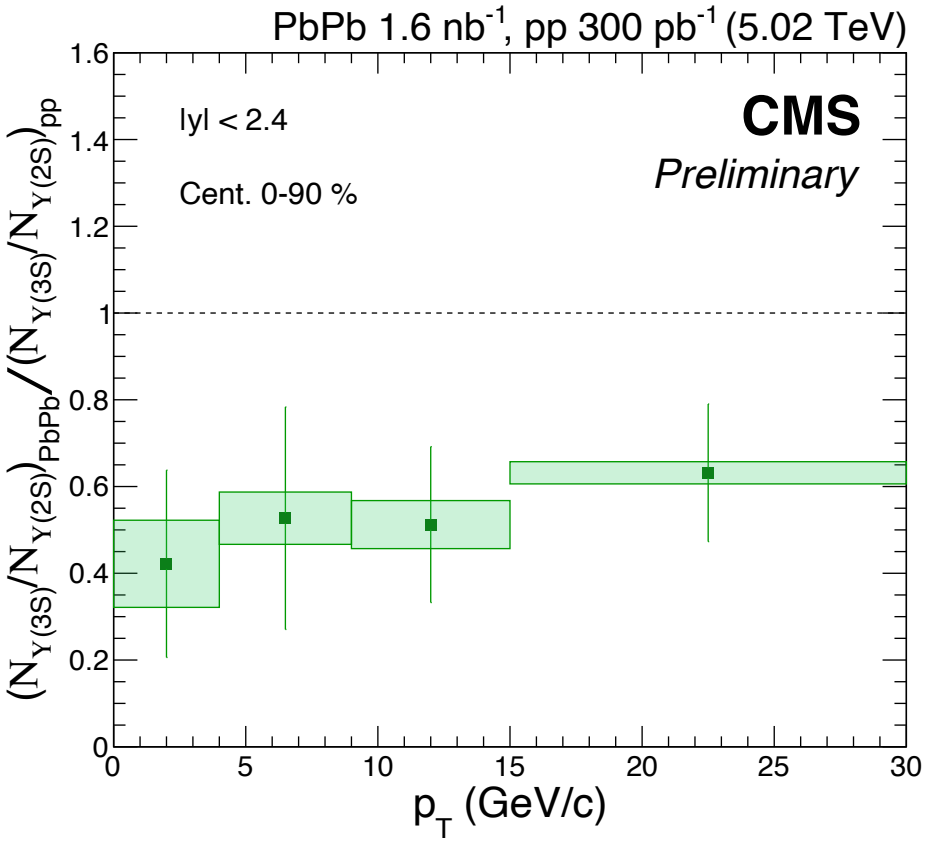
CMS-PAS-HIN-21-007

$$R_{AA}(p_T, y) = \frac{d^2N^{AA}_{\Upsilon,corr}/dp_T dy}{\langle T_{AA}\rangle d^2\sigma^{PP}_{\Upsilon}/dp_T dy}$$

- Sequential suppression visual in the plots
  - Comparison more visible in double ratio
  - Suppression of all Υ toward head-on collision

Results

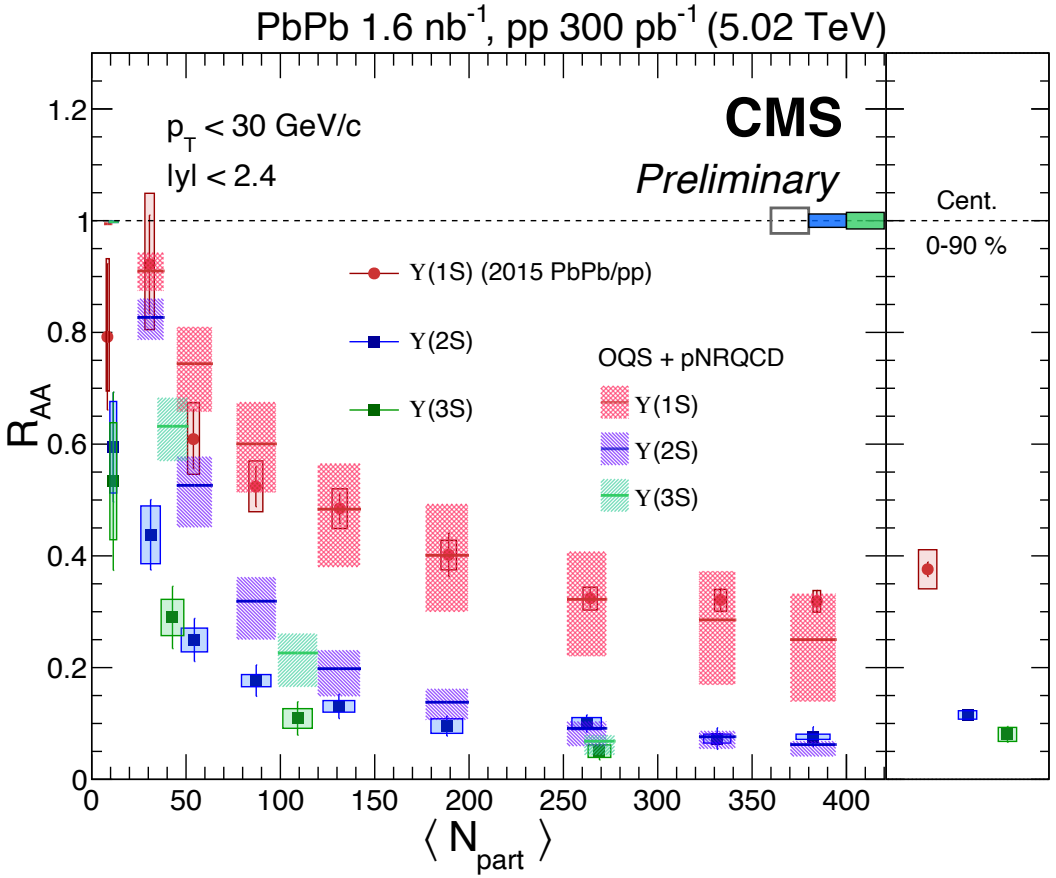


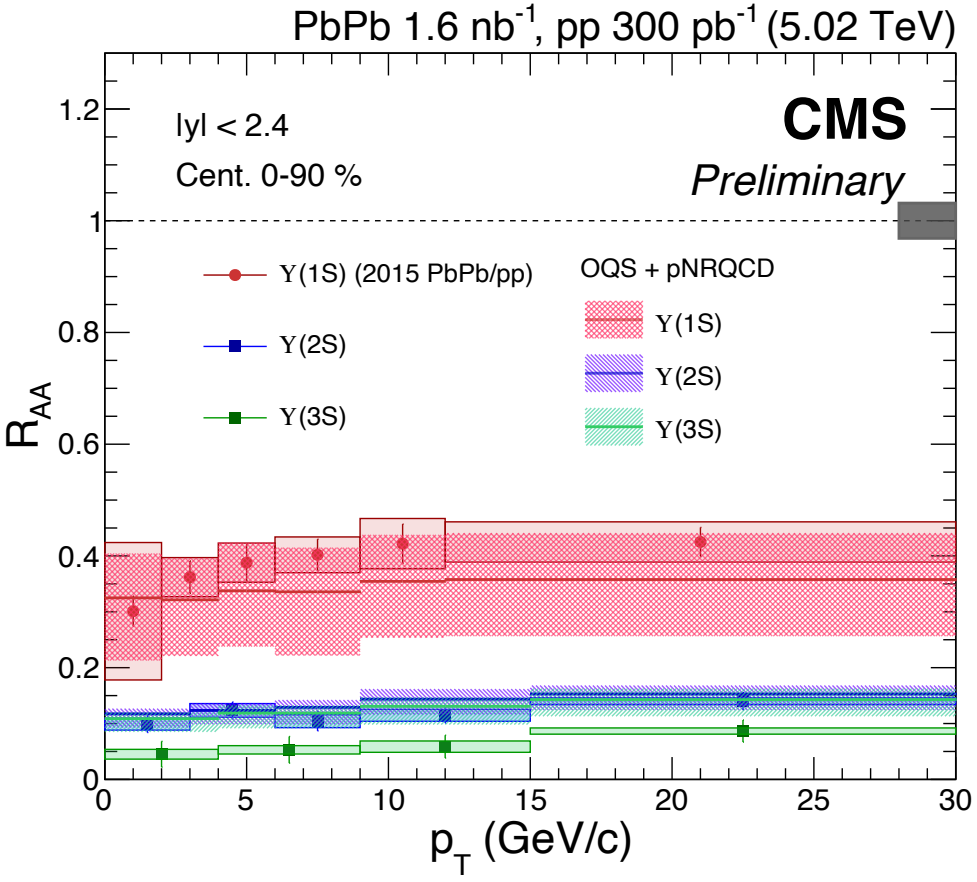


CMS-PAS-HIN-21-007

- Suppression hierarchy consistent in the measured p_T interval
- Compatible with constant trend for all measurement

Comparison with OQS





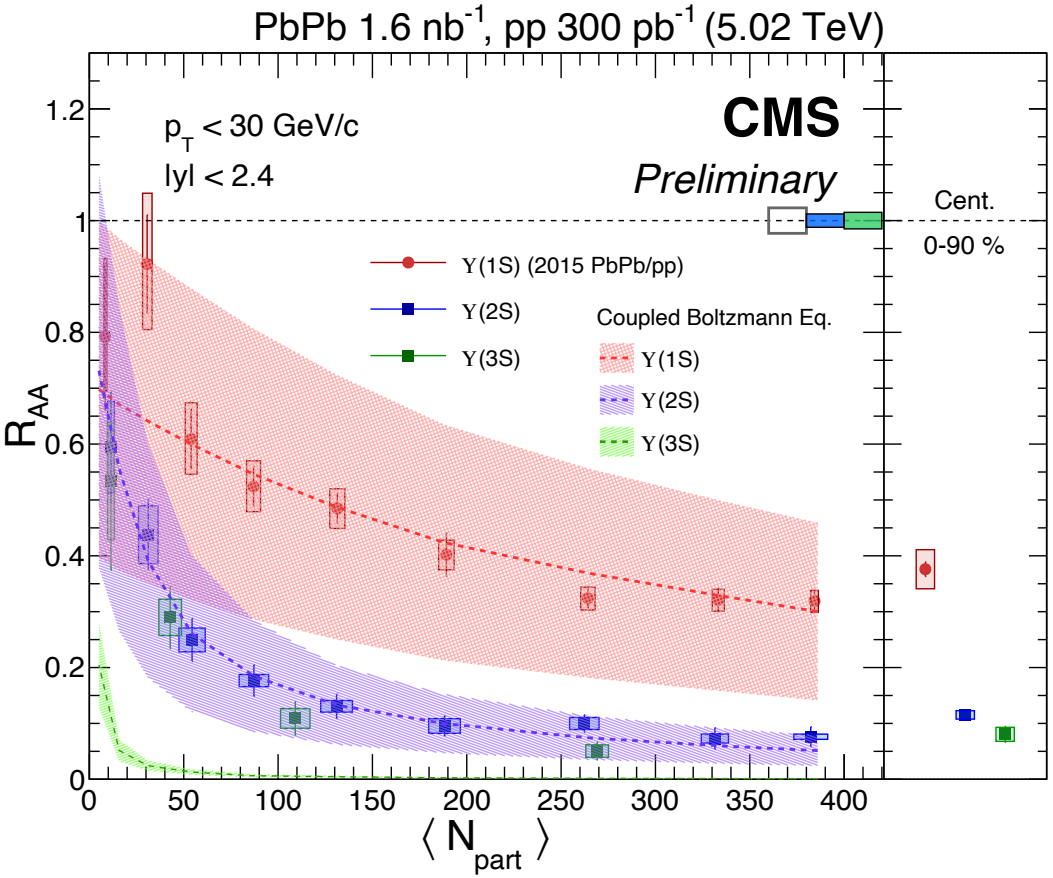
PRD 104 094049

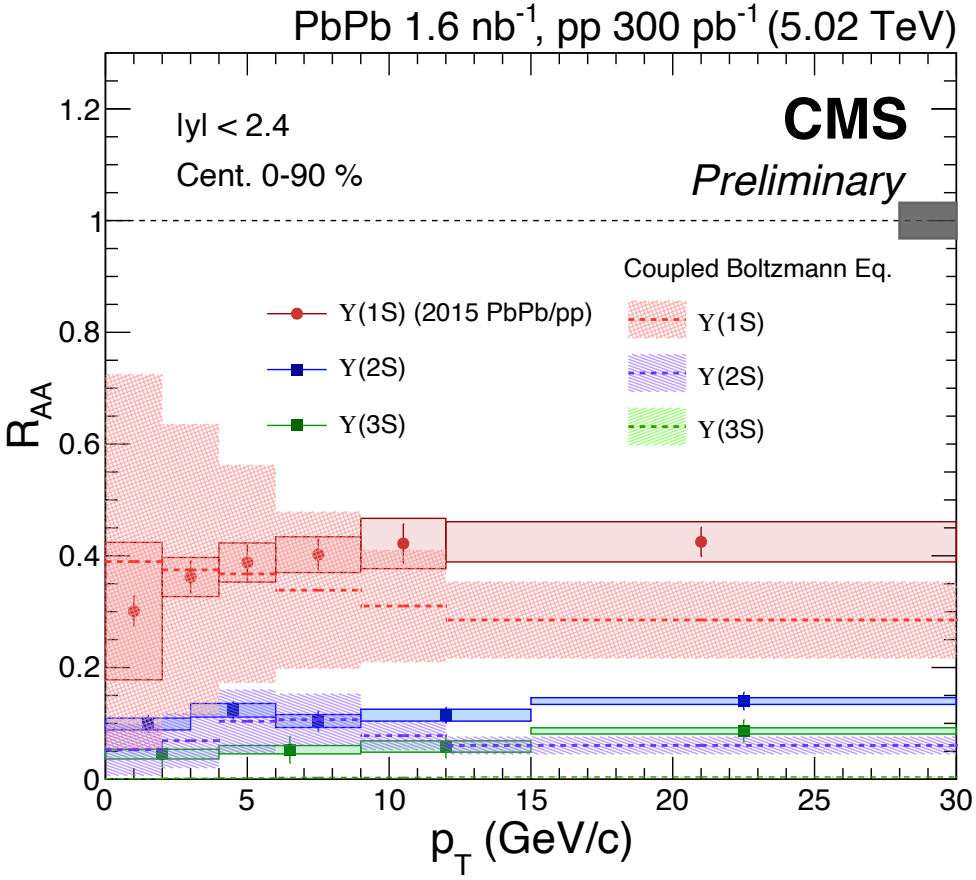
CMS-PAS-HIN-21-007

Open quantum system + potential NRQCD

- Dissociation & regeneration
- No CNM effects
- Similar R_{AA} for the excited states
- Feed down contributions included

Comparison with Boltzmann theory





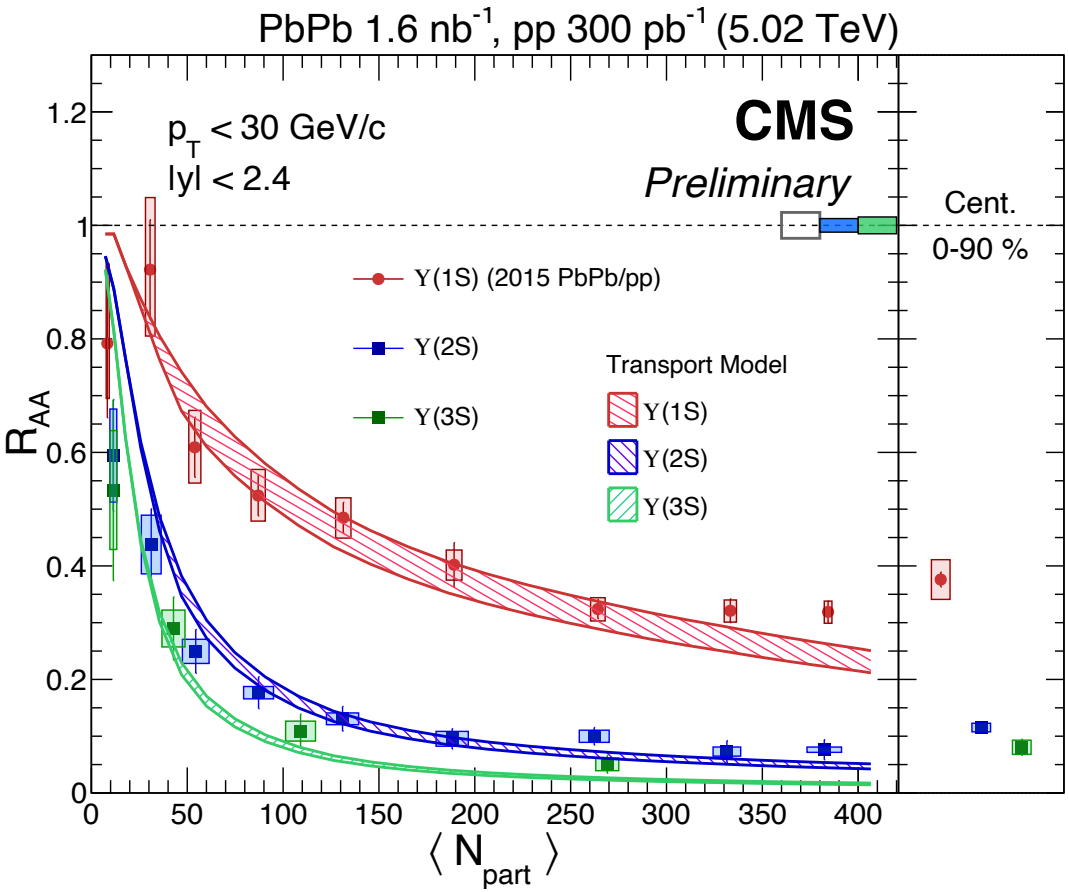
JHEP 01(2021) 046

CMS-PAS-HIN-21-007

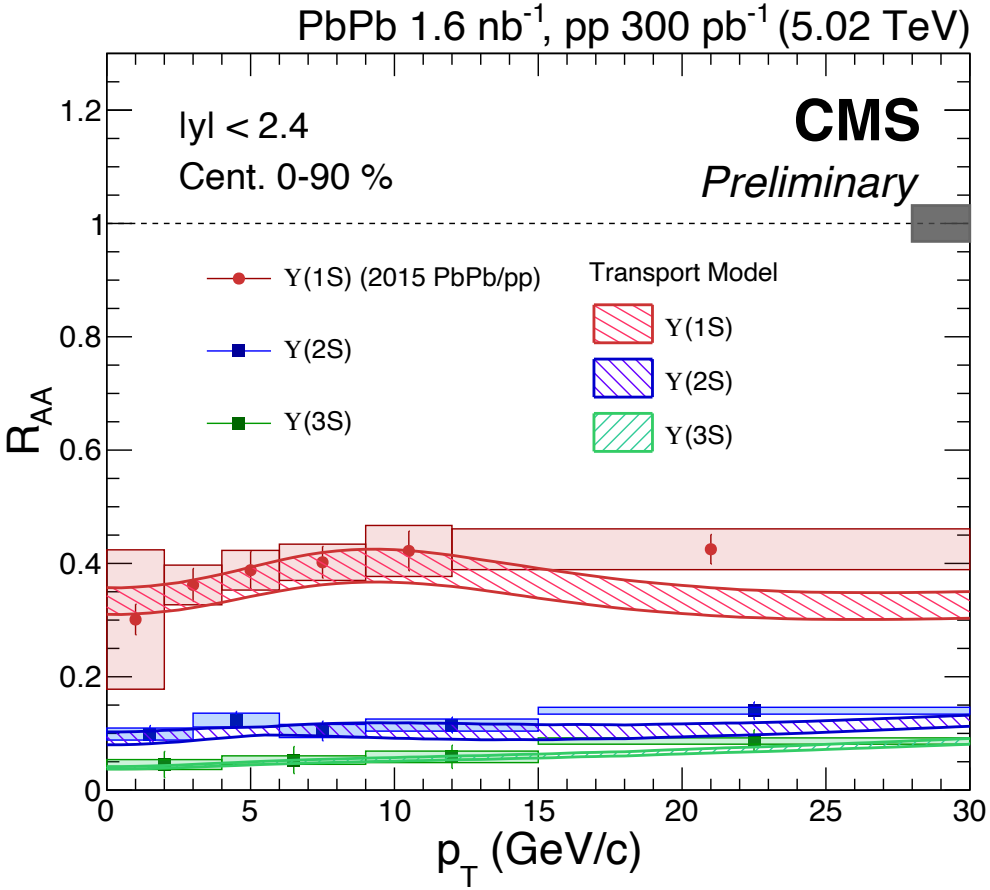
- Coupled Boltzmann Equation

- Incl. dissociation & regeneration
- Large uncertainty from nPDF
- No regeneration in Υ(3S)
- Feed down included

Comparison with Transport theory



PRC 96 (2017) 054901



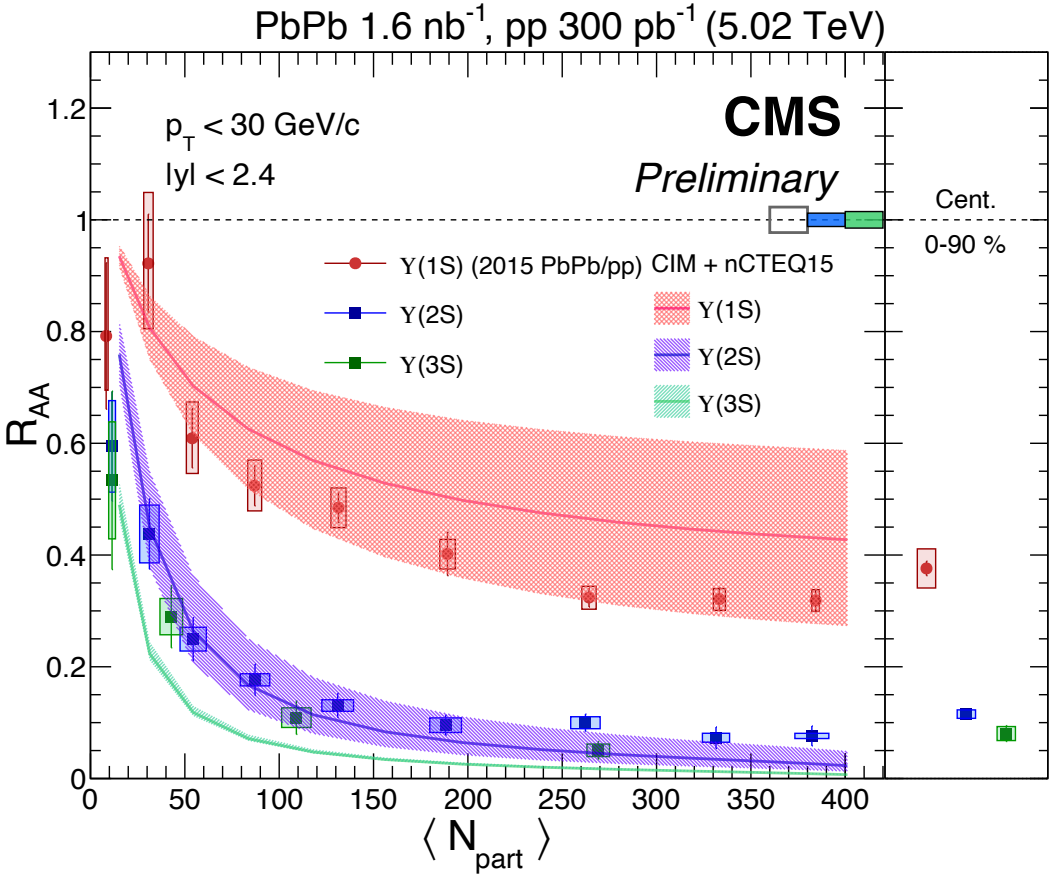
CMS-PAS-HIN-21-007

- Transport model with kinetic rate

- Solution of kinetic rate eq.
- Feed down included
- Uncertainty depend on formation time or regeneration *T*

Comparison with CIM

CMS-PAS-HIN-21-007

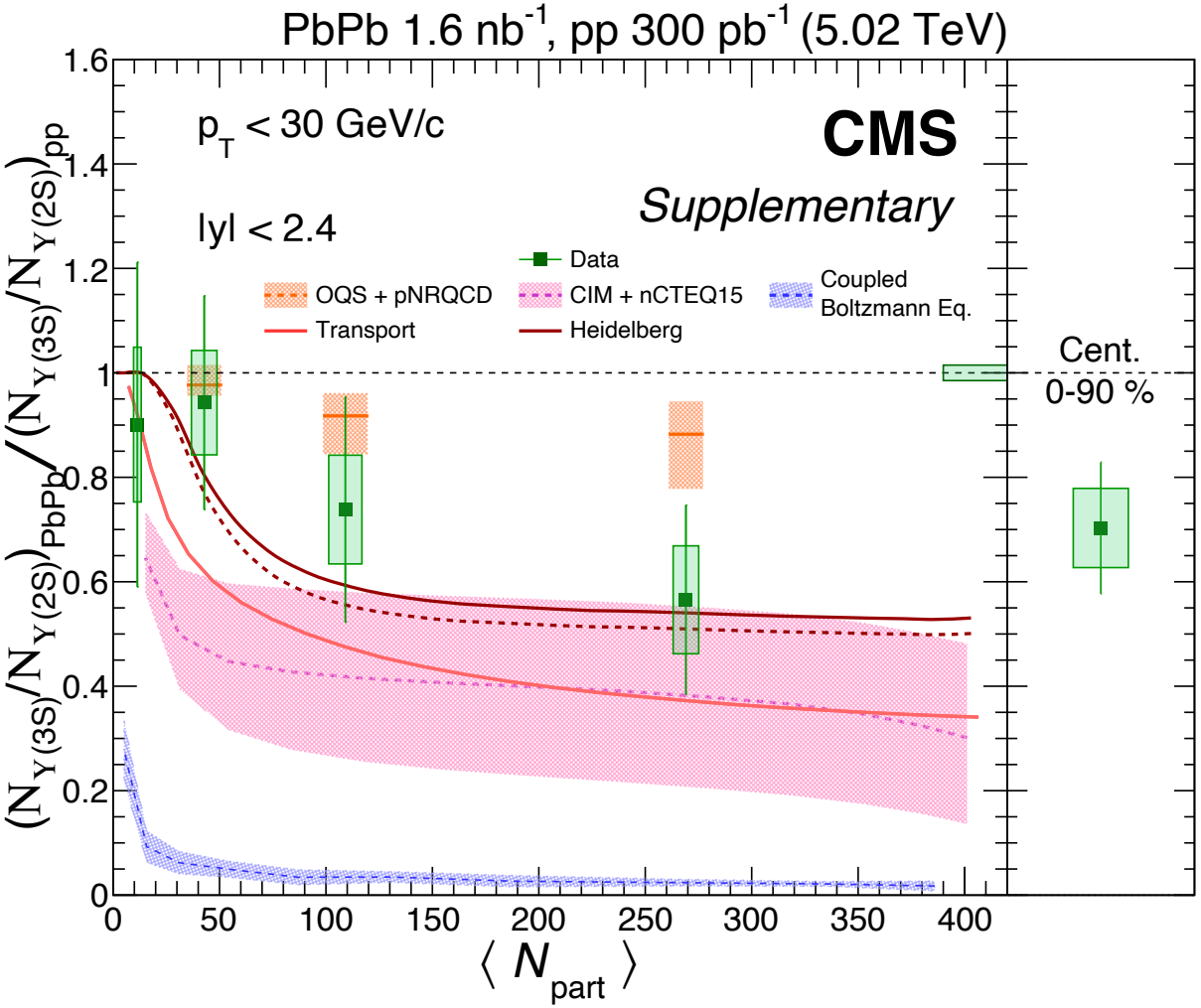


JHEP 10(2018) 094

- Gluon acting as proxy of pion in comover breakup
  - No regeneration calculation
- nPDF + CIM cross-section uncertainties combined
- Feed down contributions included

Summary of data/theory comparison

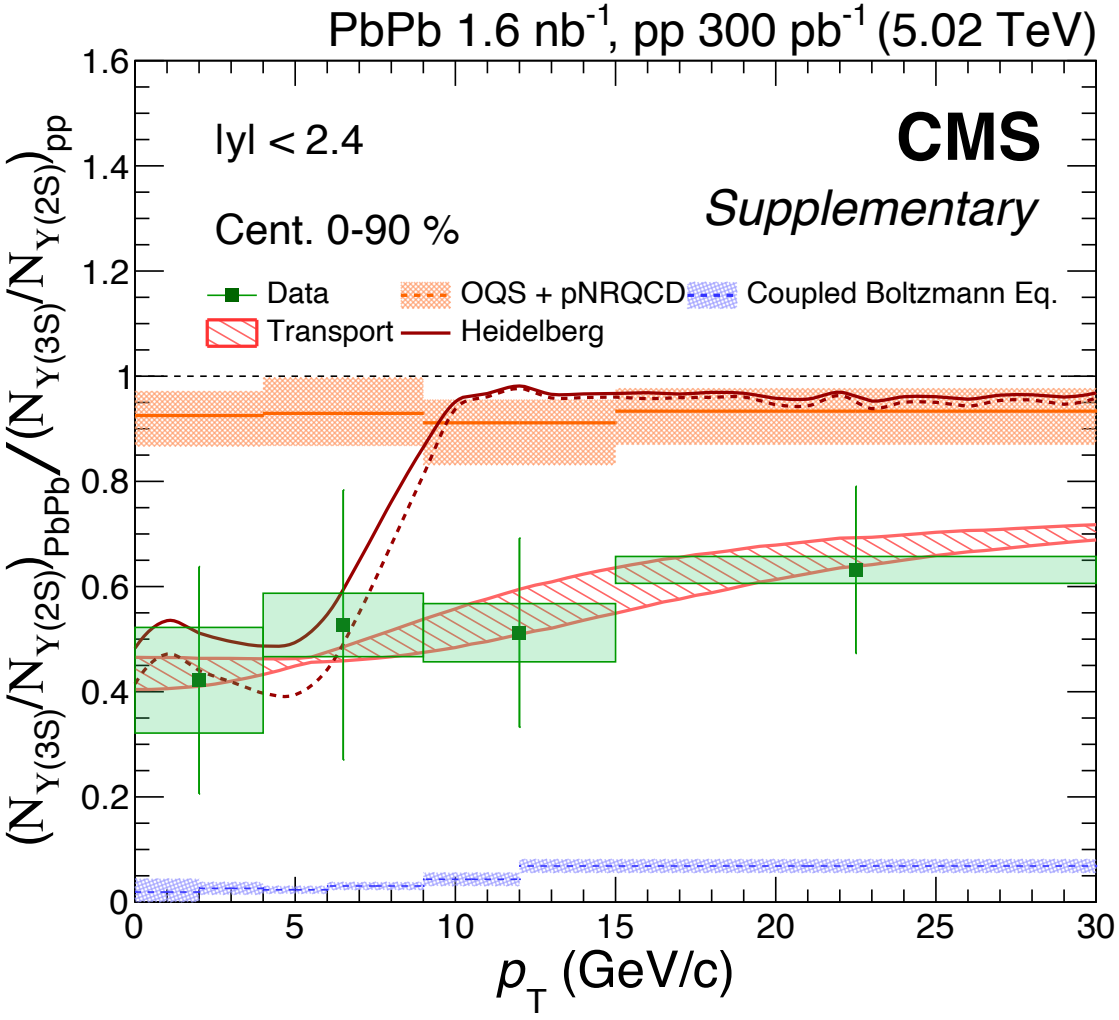
CMS-PAS-HIN-21-007



- All model tend to describe heavier suppression for Y(3S) towards central collisions
  - The amount of relative suppression though varies by different assumptions and calculations
  - Regeneration of the excited states should be treated with care

Summary of data/theory comparison

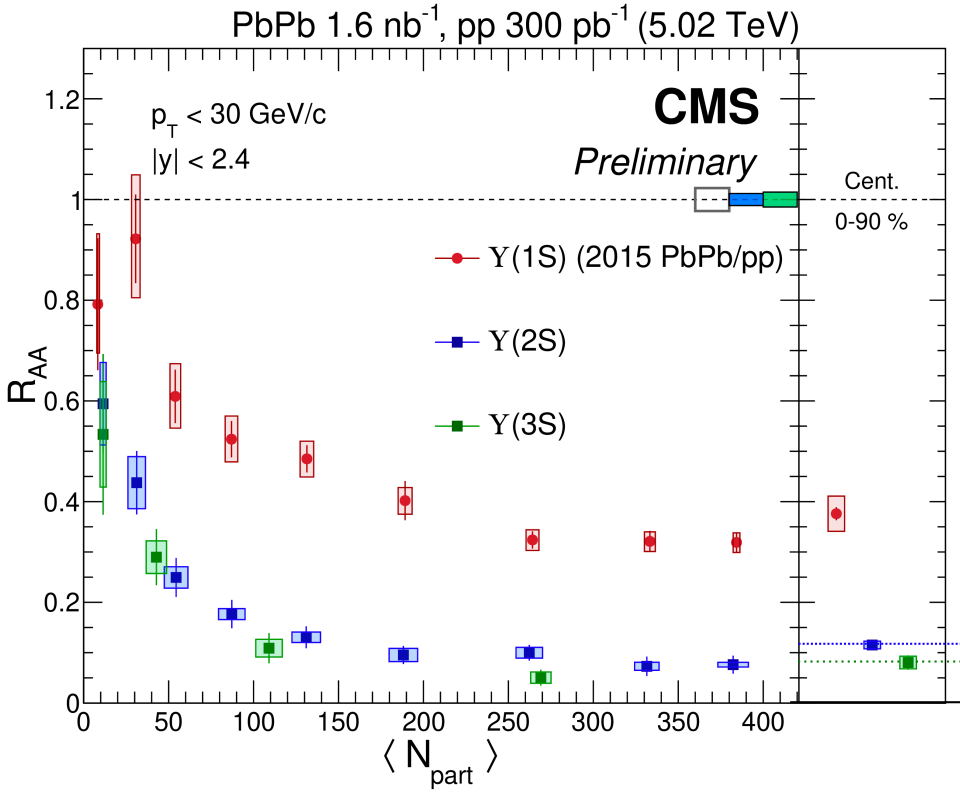
CMS-PAS-HIN-21-007



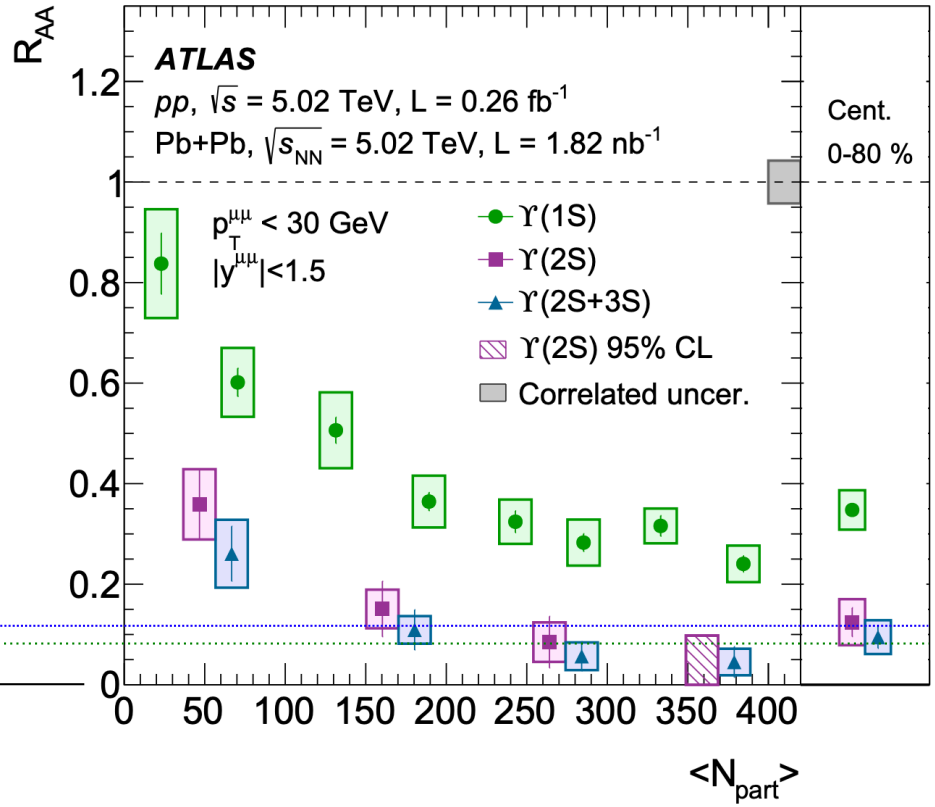
- Some model fail to describe the pT spectra
  - Data emphasis Y(3S) points to be important constraint to modeling bottomonia production and suppression!

Comparison with other experiment

CMS-PAS-HIN-21-007



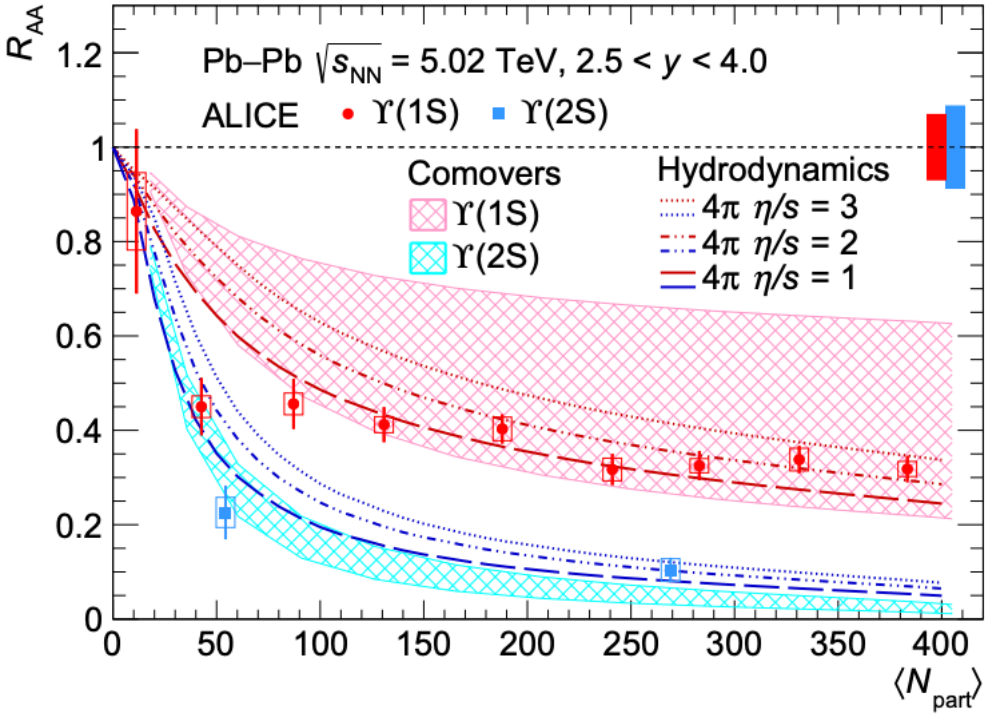
arXiv:2205.03042v1

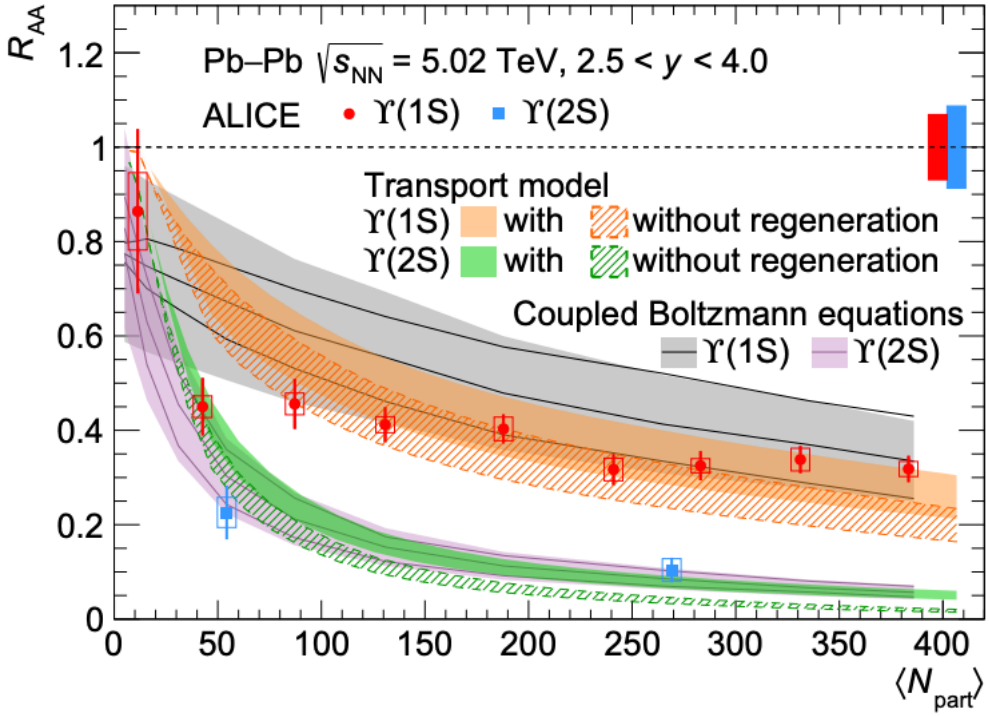


- Our data matches very will with data from ATLAS

Upsilon suppression in forward

Phys. Lett. B 822 (2021) 136579



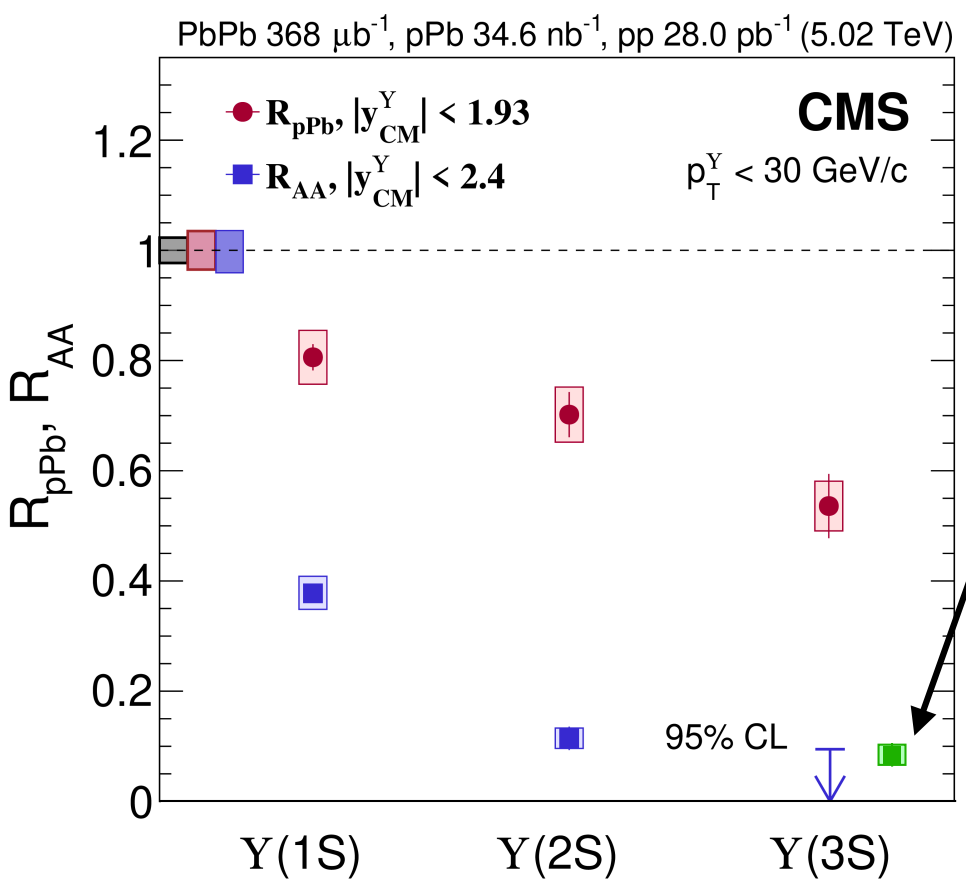


- Forward data from ALICE very similar to CMS measurement in rapidity < 2.4

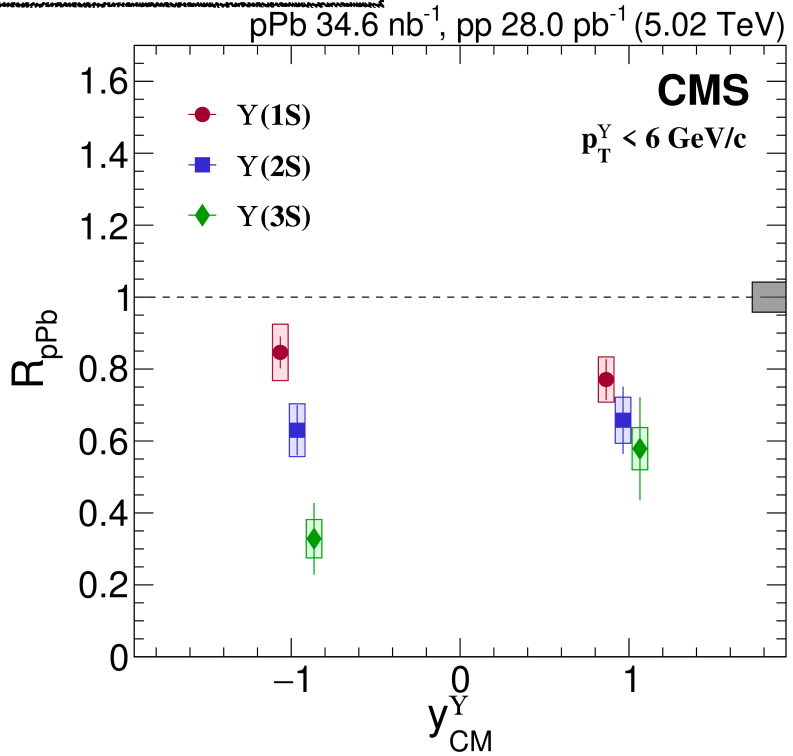
Impact of the system size

- Sequential suppression for pPb and PbPb
- Heavier suppression in backward
  - Comover effect?

arXiv:2202.11807, CMS-PAS-HIN-21-007

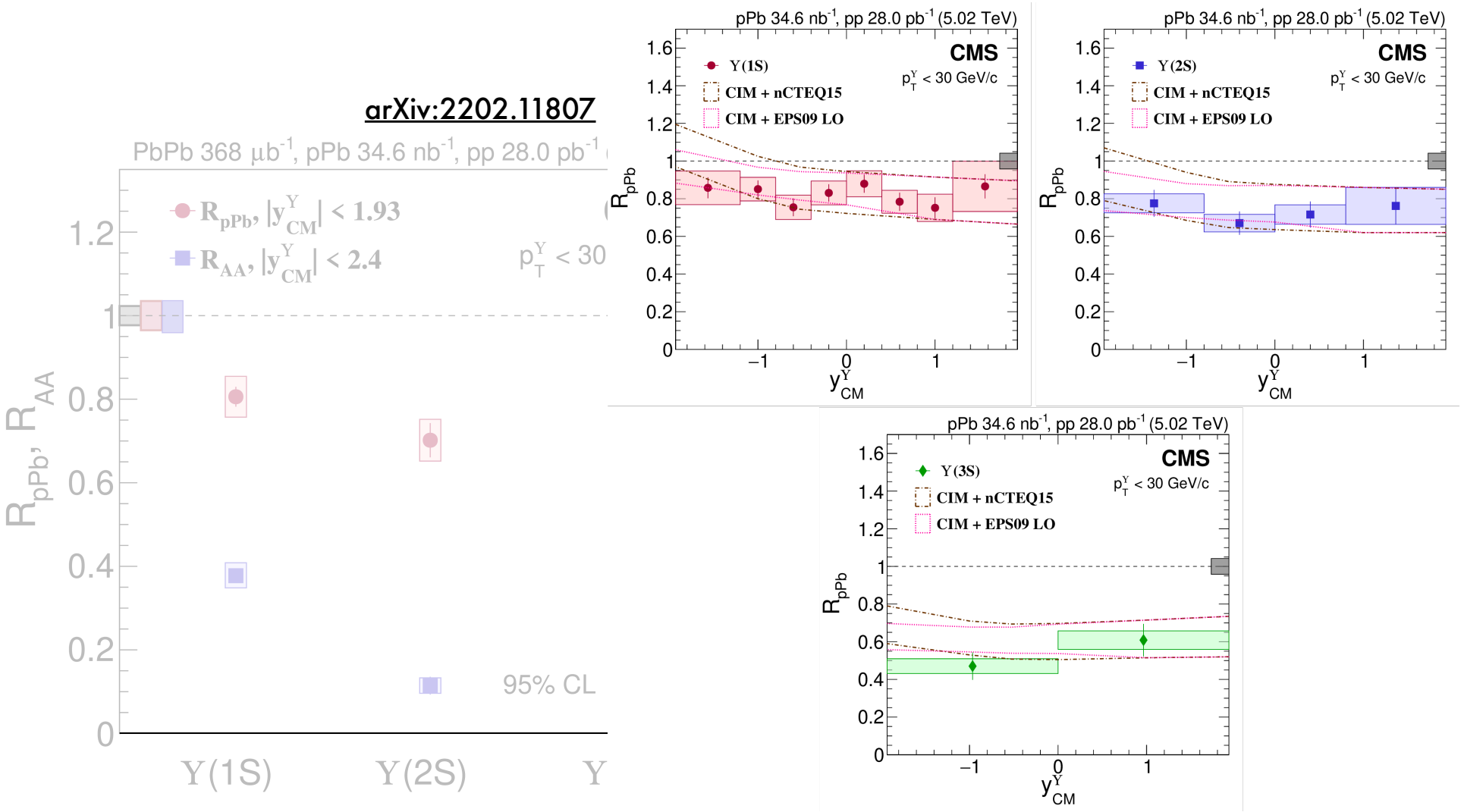


Our Υ(3S) result



- Stronger suppression in PbPb for all Υ states compared to that of pPb

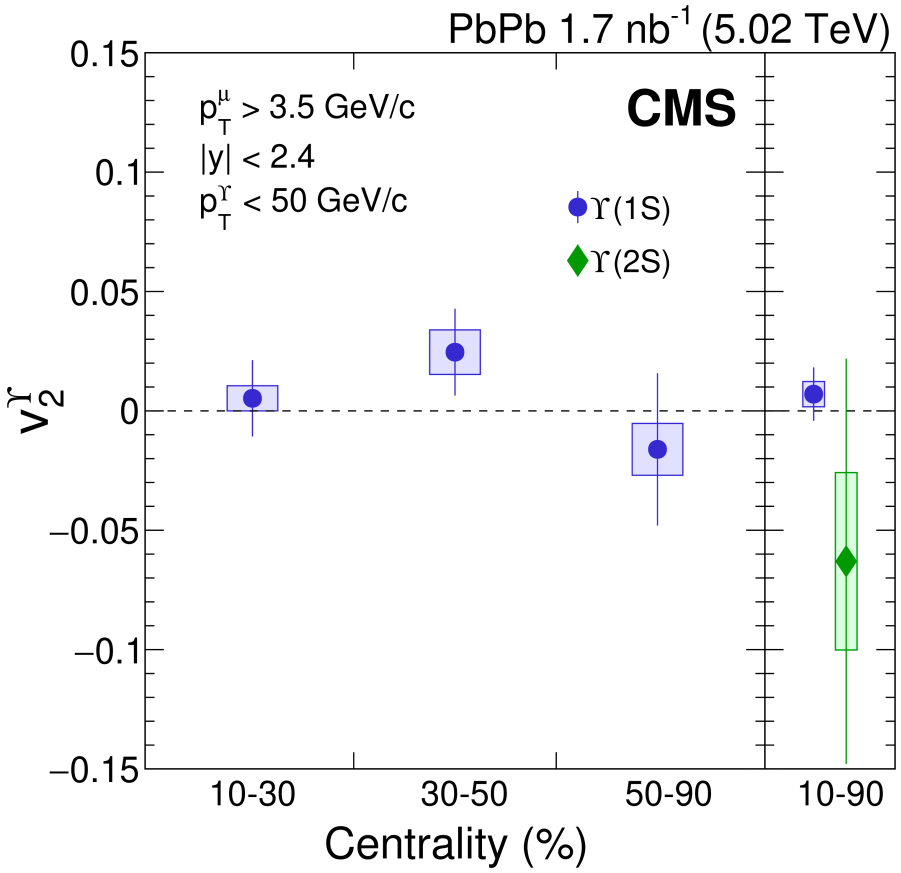
Impact of the system size

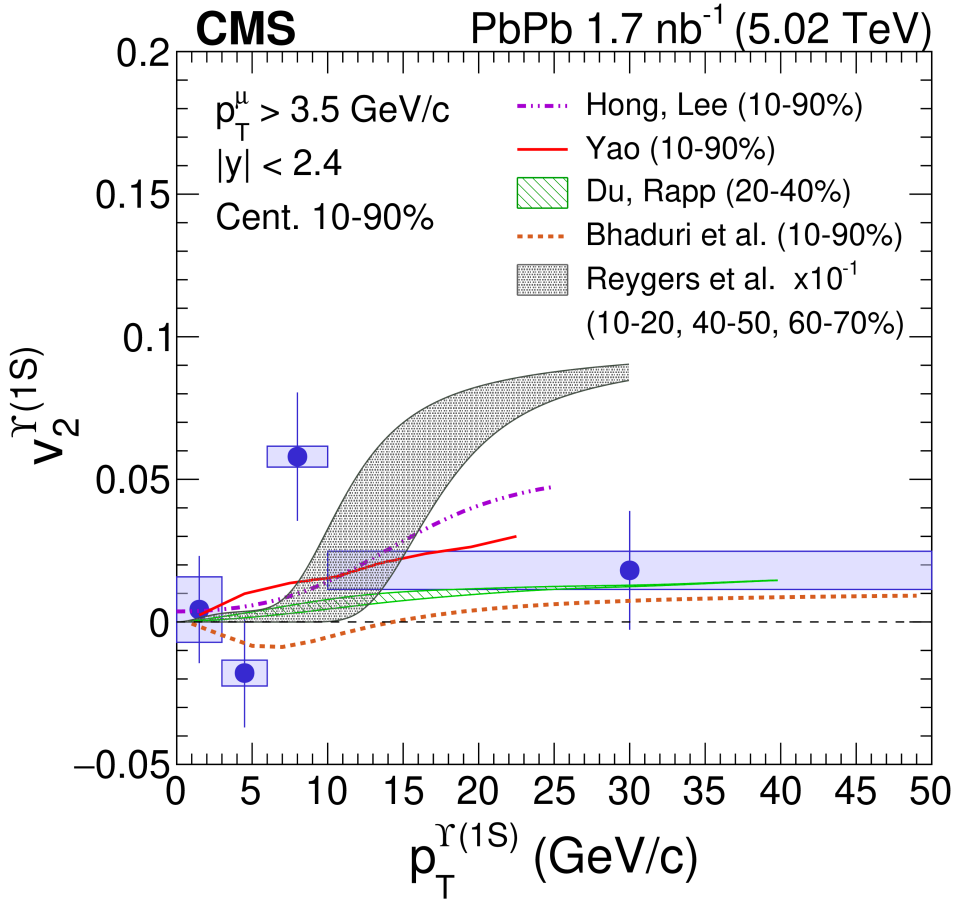


- Stronger suppression in PbPb for all Υ states compared to that of pPb
- Compatible with the comover description

Elliptic flow of Υ in AA

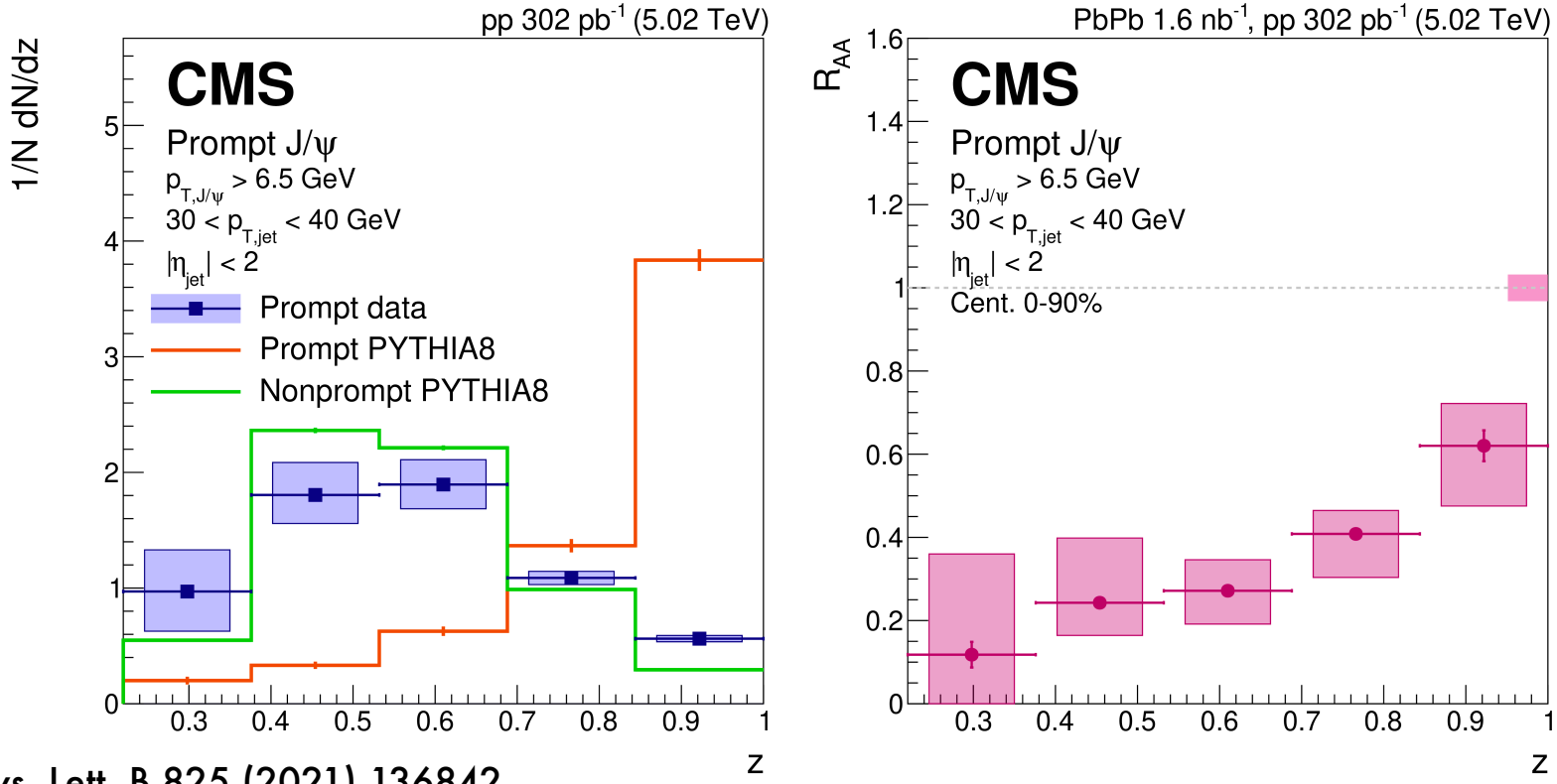
Phys. Lett. B 819 (2021) 136385





- Elliptic flow coefficient compatible to zero →different collectivity for bottomonium in HIC
- Compatible with most of the data in error range
  - Calls for another magnitude of precision in data measurement!

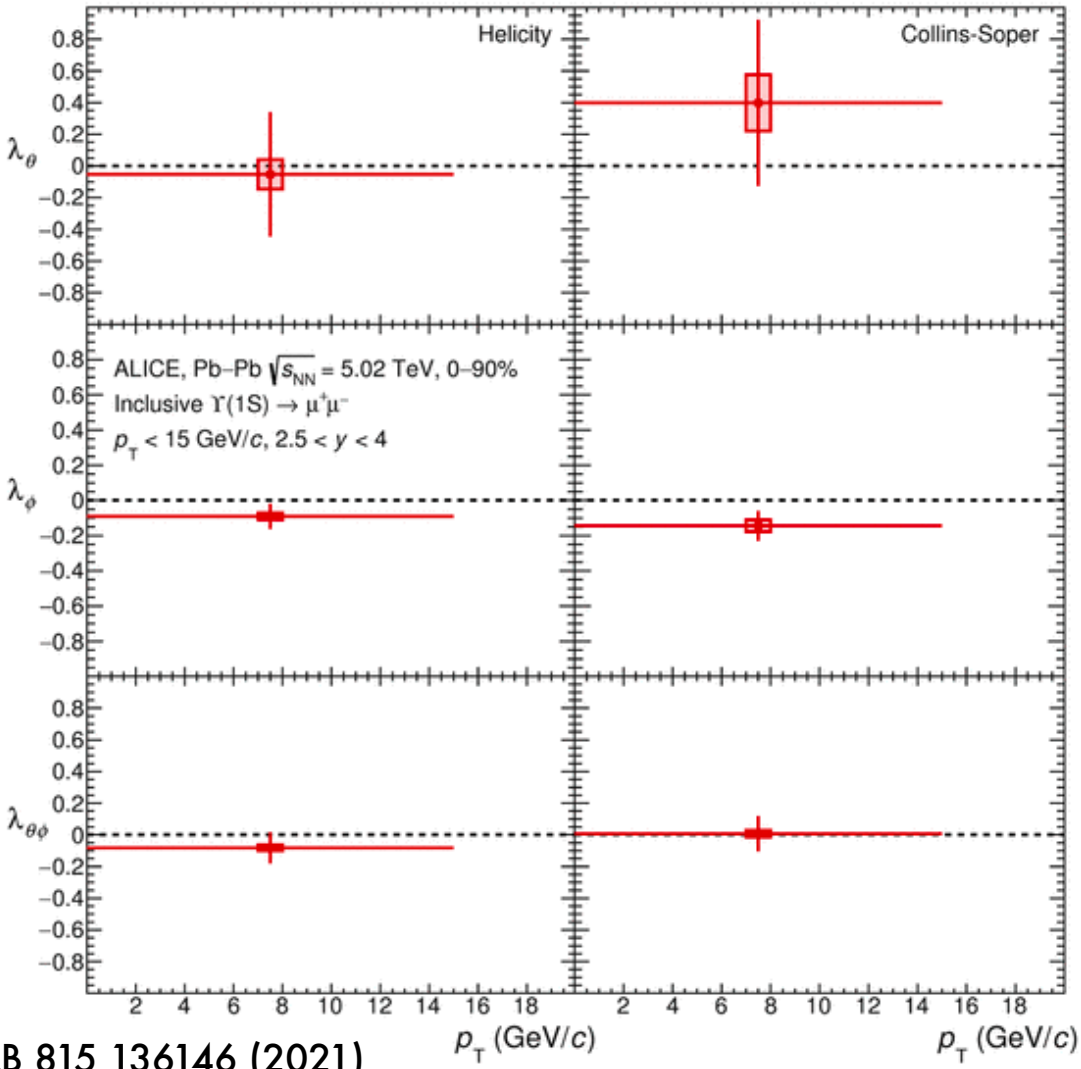
Will gluon fragmentation matter for bottomonia?



Phys. Lett. B 825 (2021) 136842

- J/ψ z measurement gave strength to production of prompt charmonia from gluon fragmentation
- Will this be also true for "even more early produced Υs?"

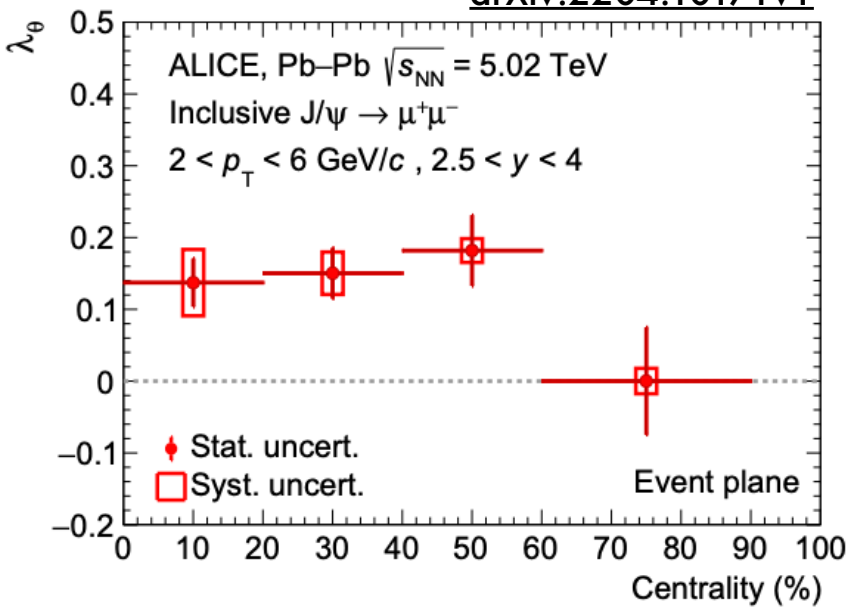
Polarization of Υ(1S)



PLB 815 136146 (2021)

	Helicity	Collins-Soper
λ_θ	$-0.090 \pm 0.395 \pm 0.101$	$0.418 \pm 0.526 \pm 0.178$
λ_ϕ	$-0.094 \pm 0.072 \pm 0.020$	$-0.141 \pm 0.087 \pm 0.033$
$\lambda_{\theta\phi}$	$-0.074 \pm 0.099 \pm 0.020$	$0.017 \pm 0.113 \pm 0.024$

arXiv:2204.10171v1



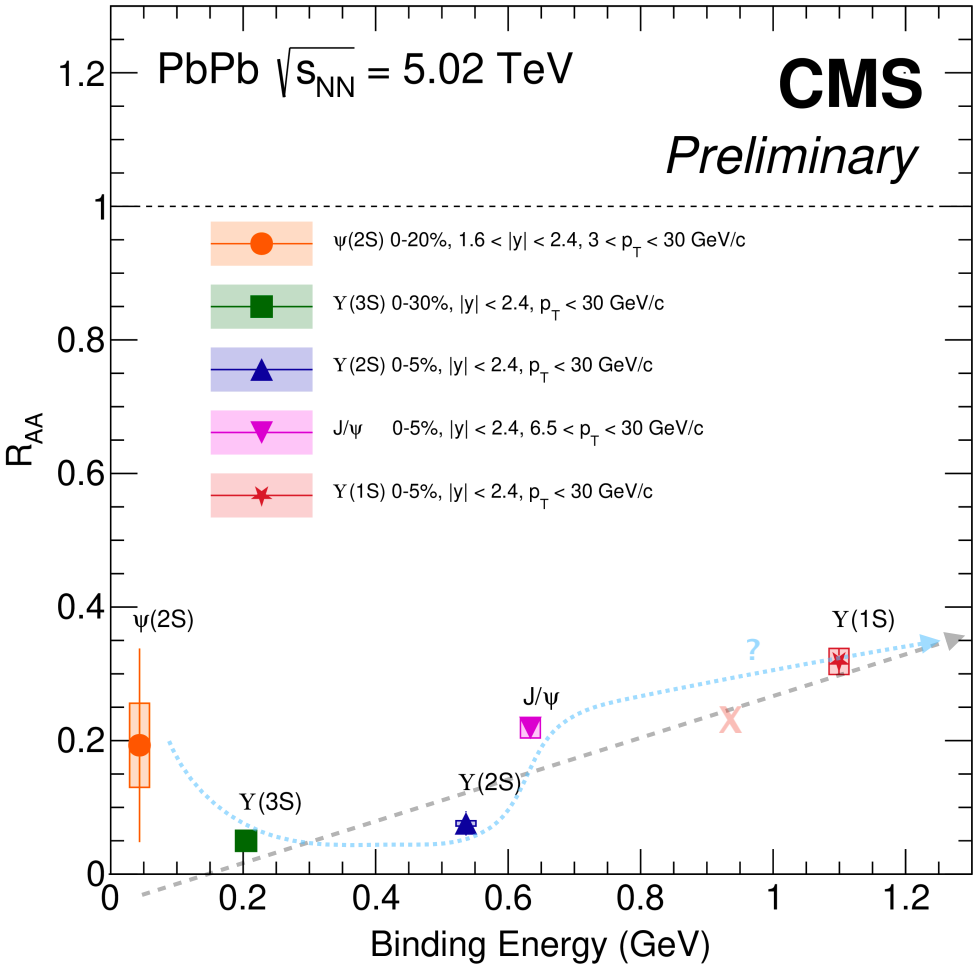
- Unlike J/ψ in PbPb, data suggest unpolarized Υ
  - Partly due to lack of statistical recombination (abundant for J/ψ in central collision low p_T)

Conclusion

- Recent observation of $\Upsilon(3S)$ completes the final missing piece of the sequential suppression picture of the S-wave bottomonia states
- Data and model for Υ in PbPb collisions in LHC still inconclusive due to low statistics/large parameter uncertainty
  - Clarifying yet uncertain effects (feed down/polarization) would help better analyze/understand data

Conclusion

CMS-PAS-HIN-21-007

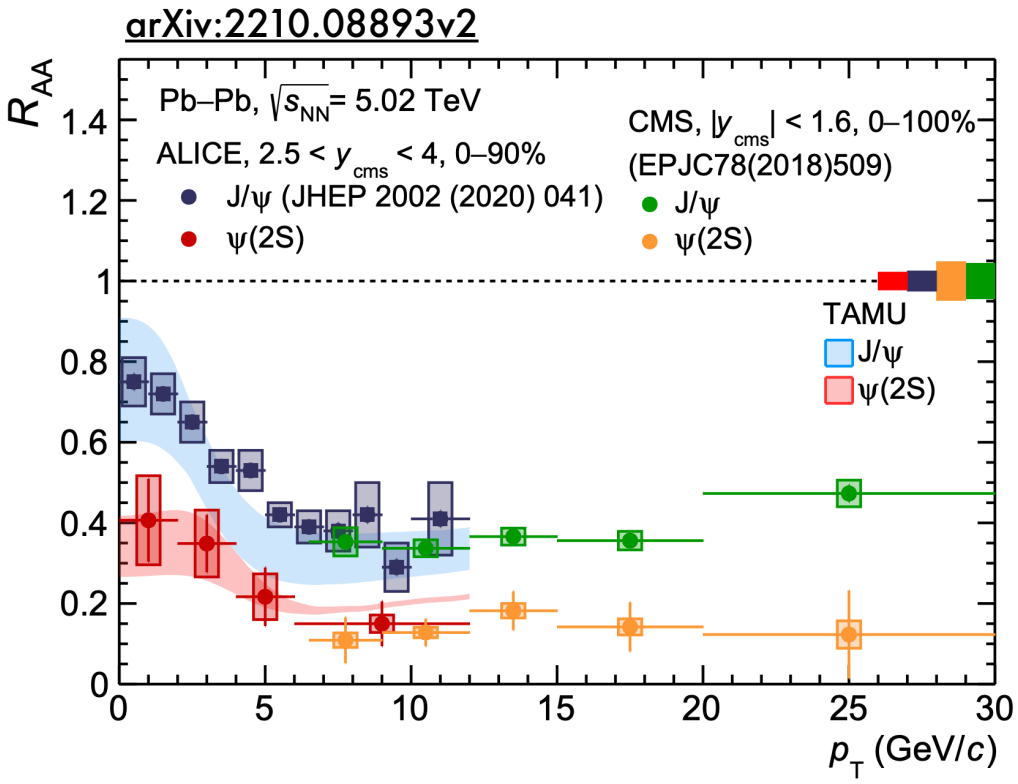


- Questions regarding pinpointing the QGP temperature with quarkonia perspective
  - Not trivial only with the suppression data
  - Stringent test to our experimental capability & knowledge for understanding QCD

Back up

Korea Univ. mascot, Hoi and Daro

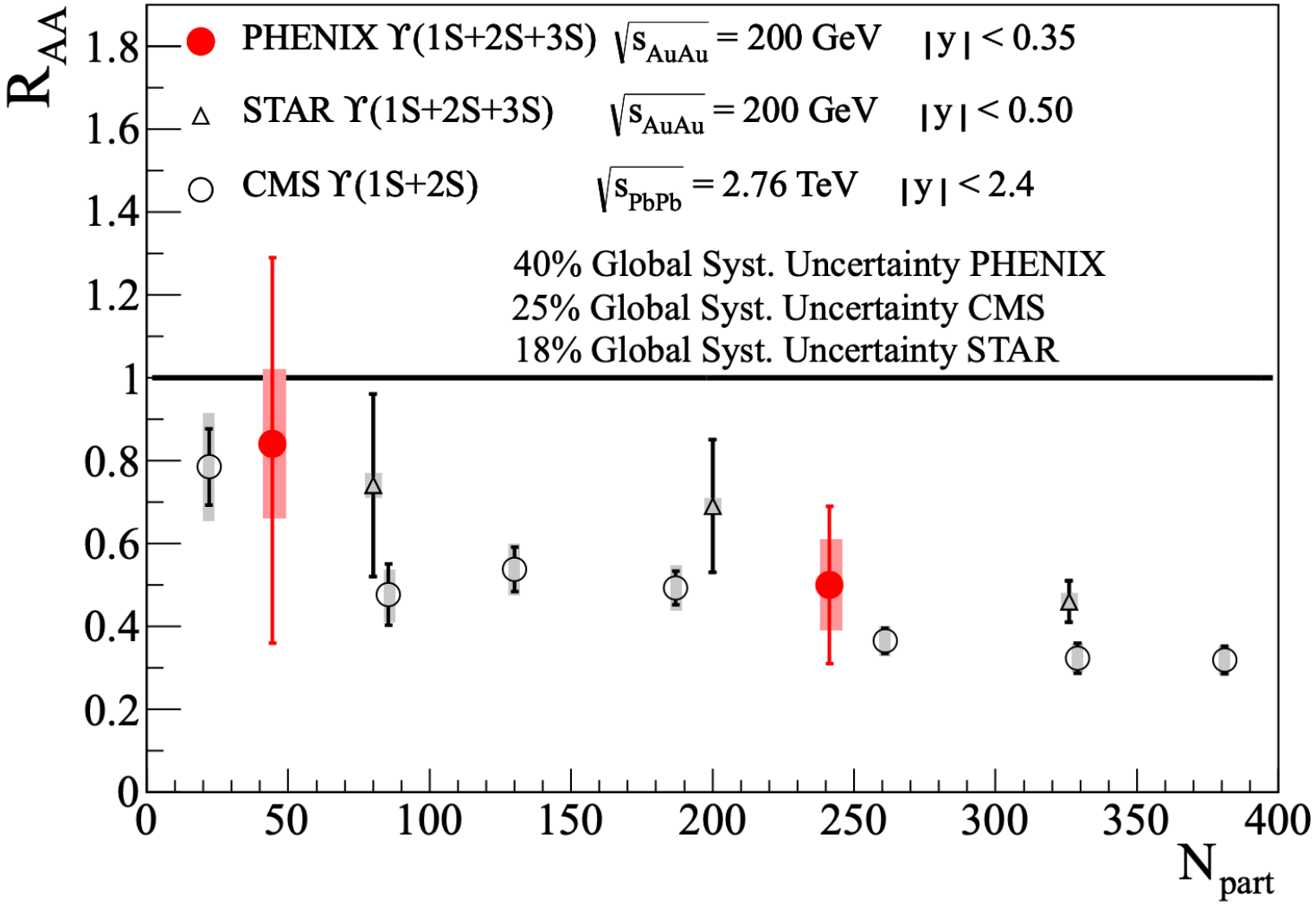
Excited states of charmonia



- (Statistical) recombination boost R_{AA} for charmonia case

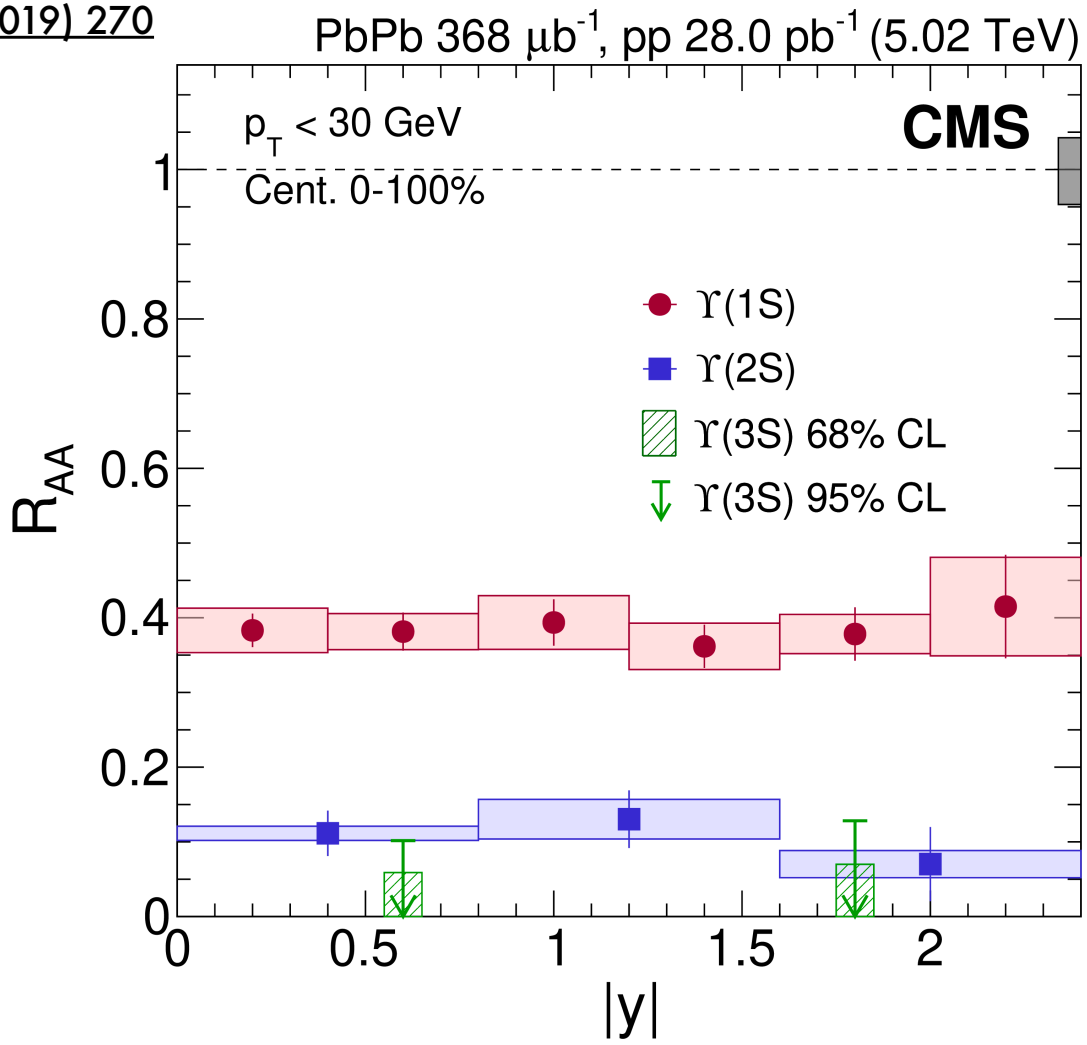
Star & Phenix measurement @ 200 GeV Au+Au, CMS 2.76 TeV

Phys. Rev. C 91, 024913



Rapidity dependence of upsilon modification

Phys. Lett. B 790 (2019) 270



- No sign of rapidity dependence for the ϒ states