Measurement of excited **ϒ** suppression with observation of **ϒ**(3S) in PbPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV in CMS

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on behalf of the CMS Collaboration

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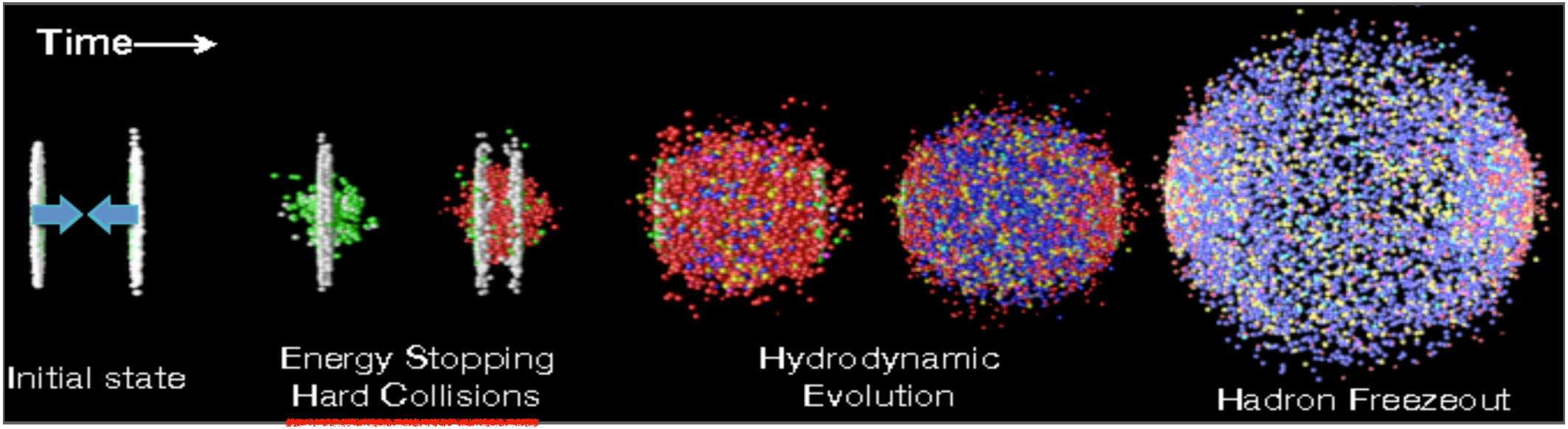
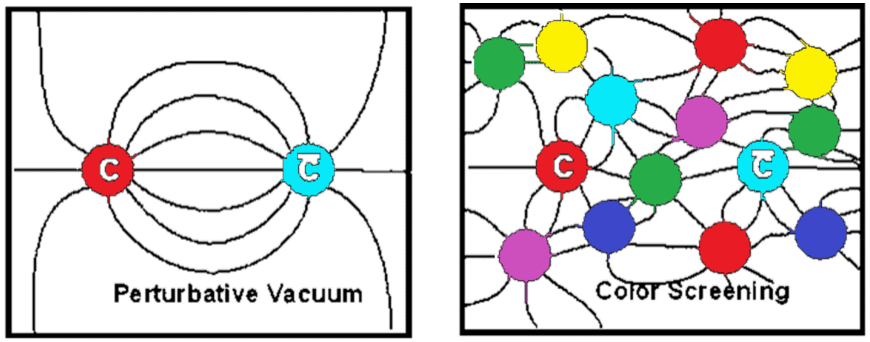
Introduction

- Probing QCD matter with quarkonia is effective way to understand both hot and cold effects in heavy-ion collisions
  - Produced in initial hard scattering (~1 fm), able to encode information of evolution of QGP via interaction
- Heavy mass $Q\bar{Q}$ in low $p_T \rightarrow$ good candidate to test NRQCD

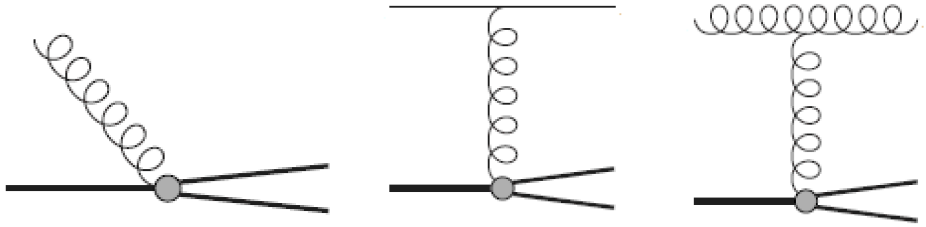


Quarkonia to probe the QGP

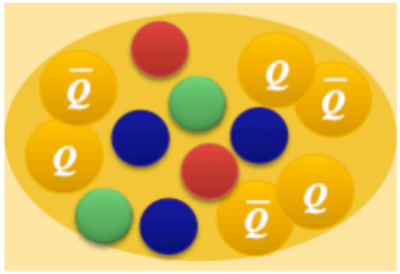
- Hot and cold effects in action in heavy-ion collisions
  - Cold nuclear matter effects → nPDF, nuclear absorption, Cronin effect
  - Hot medium interactions → color screening, Landau damping, dissociation, regeneration



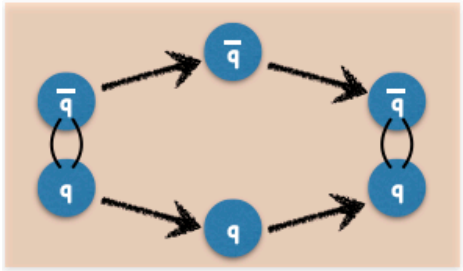
Phys. Rev. C 99, 034905 (2019)



Gluo-dissociation Inelastic parton scatter at NLO



Statistical/Uncorrelated



Correlated

Statistical effect strong for charmonia
Recent findings[1,2] favor (correlated) recombination also for $b\bar{b}$

[1] Singh, Ganesh, Mishra
[2] N. Brambilla et al.

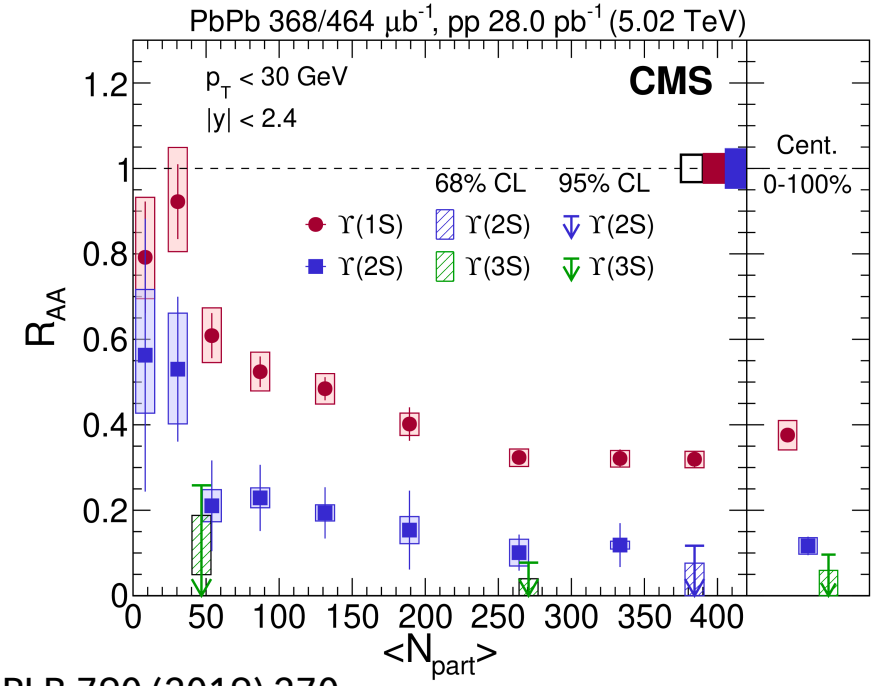
Nuclear modification factor (R_{AA})

- Suppression of quarkonia measured via R_{AA}
- Excited states **Υ** measurement is challenging
  - Small S/B ratio in AA → ↑statistical uncertainty

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

$\langle T_{AA}\rangle$: average of nuclear overlap function

➡ **Υ**(3S) ambiguous in previous measurement (limit of 2015 PbPb data)



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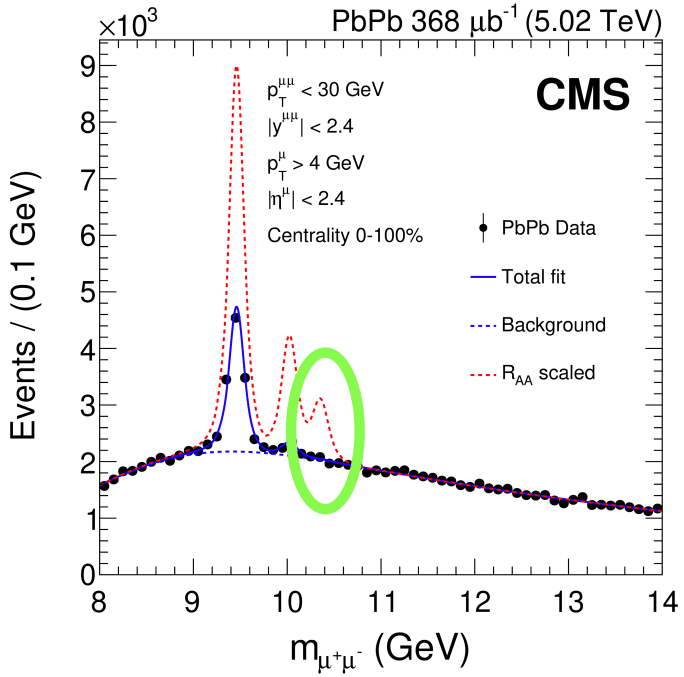
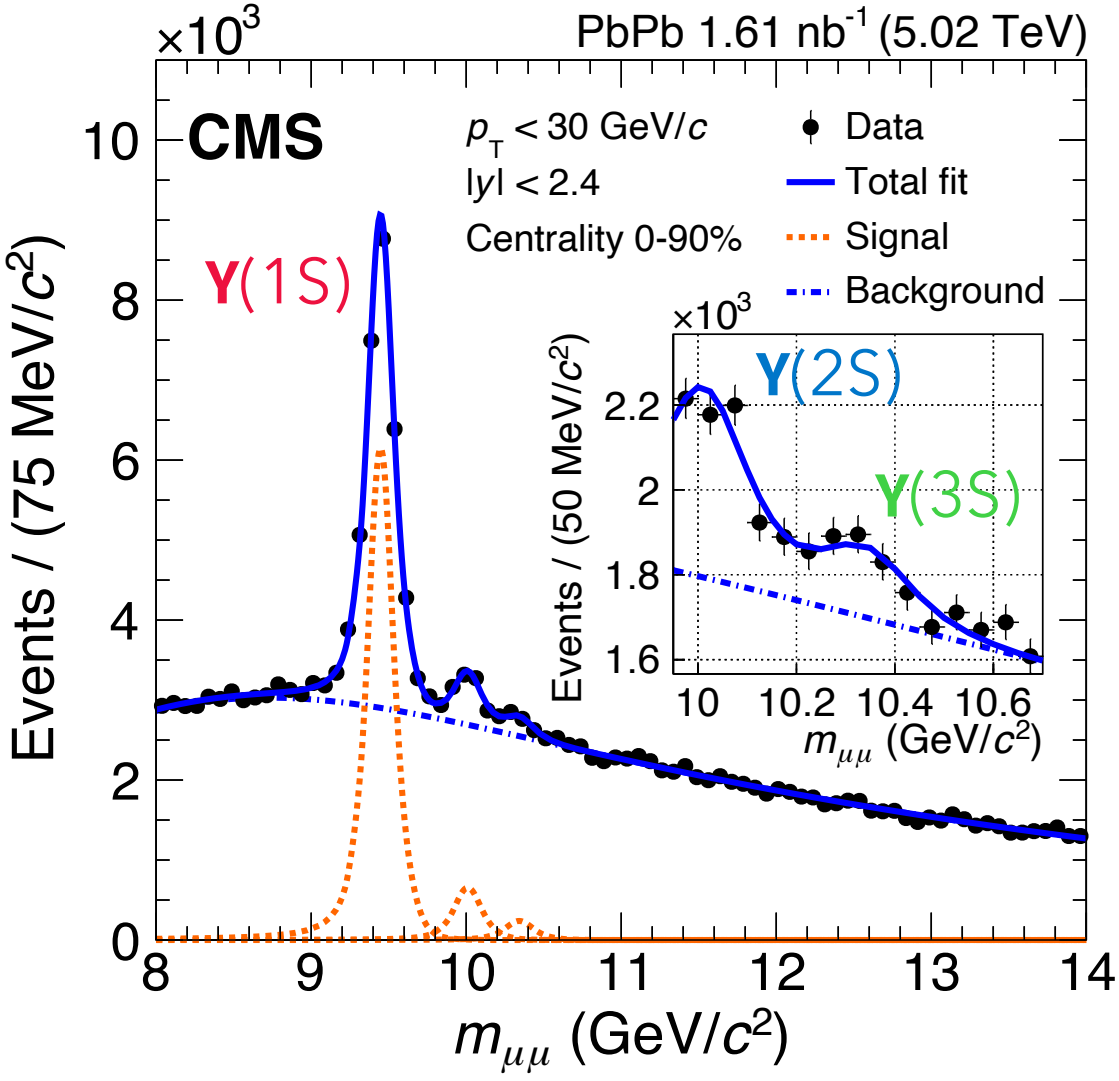


First observation of Υ(3S) in AA

- Using CMS 2018 PbPb data
- Signal extracted with unbinned extended likelihood fit
- Υ(3S) observed in PbPb collisions with $> 5\sigma$!
  - Signal clearly visible thanks to data control with BDT

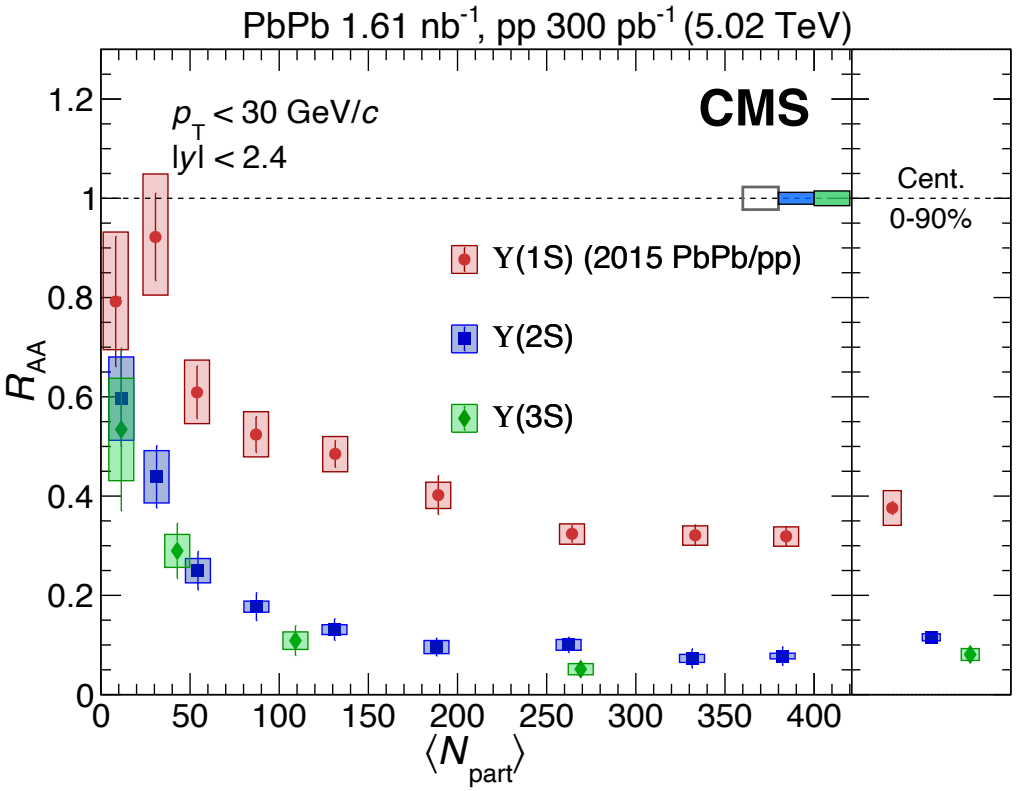


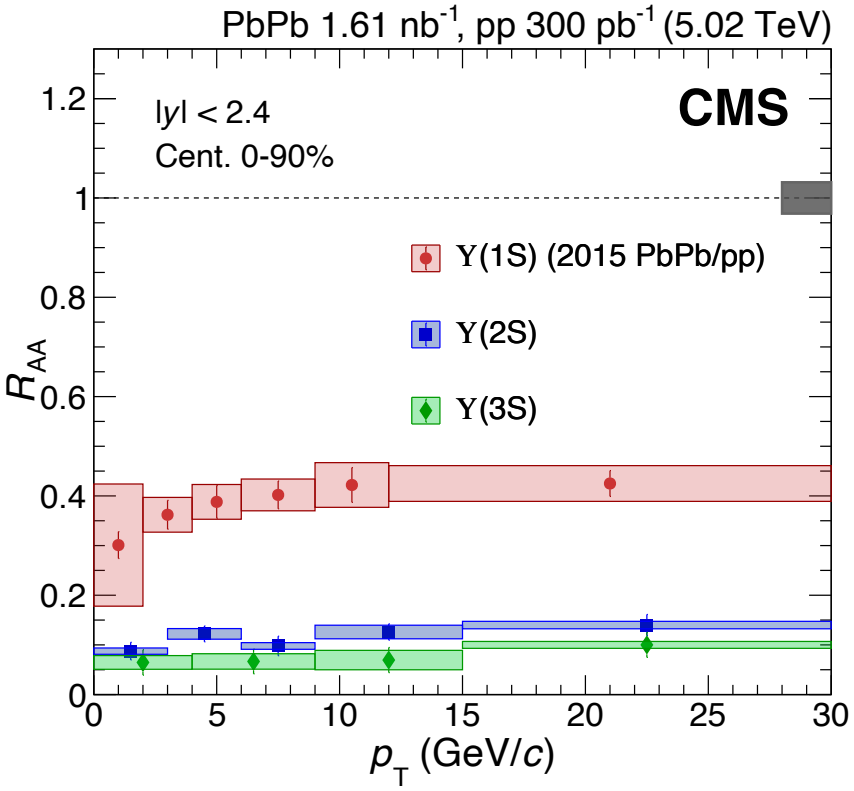
arXiv:2303.17026

Result - R_{AA}

arXiv:2303.17026

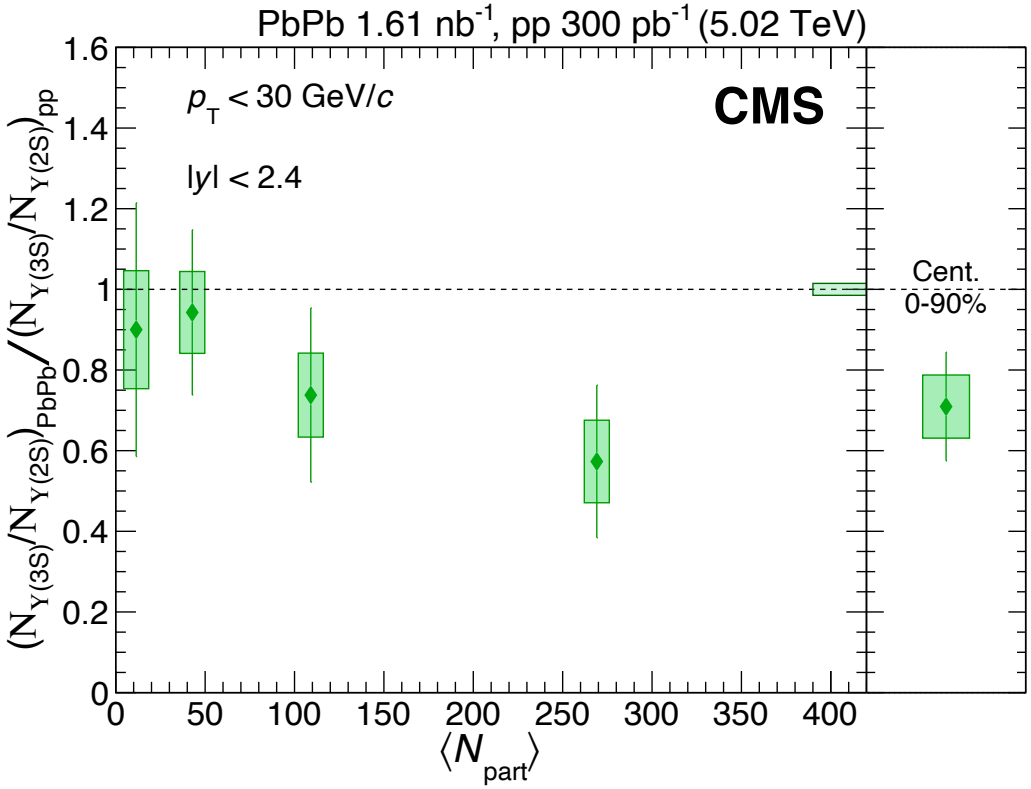
- Sequential suppression apparent RAA: **Υ**(1S) > **Υ**(2S) > **Υ**(3S) in scanned p_T and $\langle N_{part} \rangle$ spectra
- No clear dependence on transverse momentum

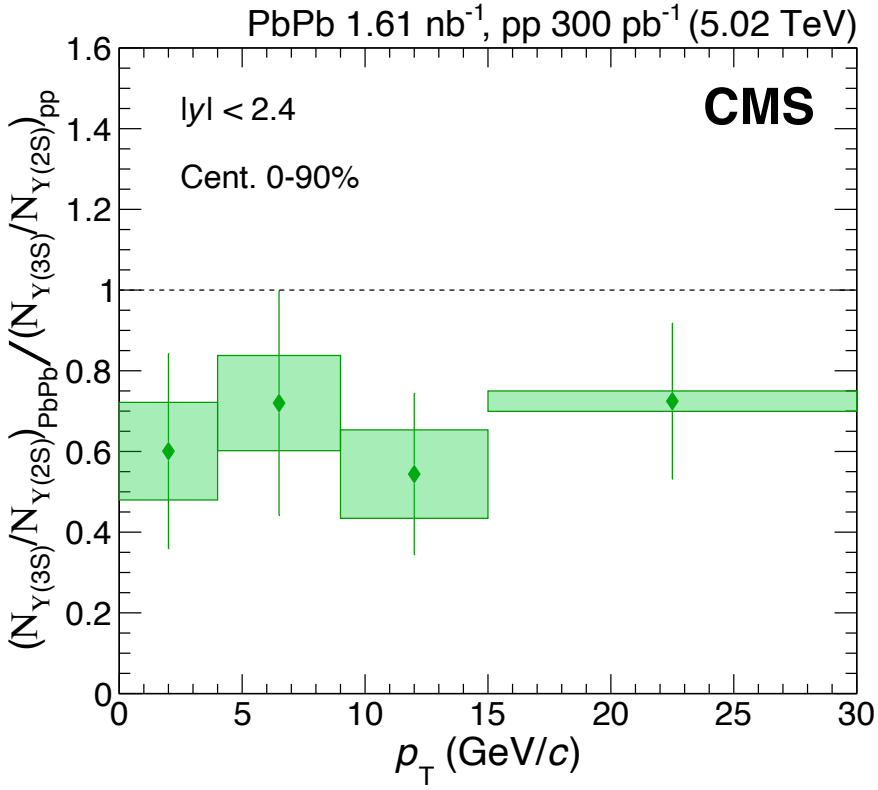




Result - Double ratio **Υ**(3S)/**Υ**(2S) arXiv:2303.17026

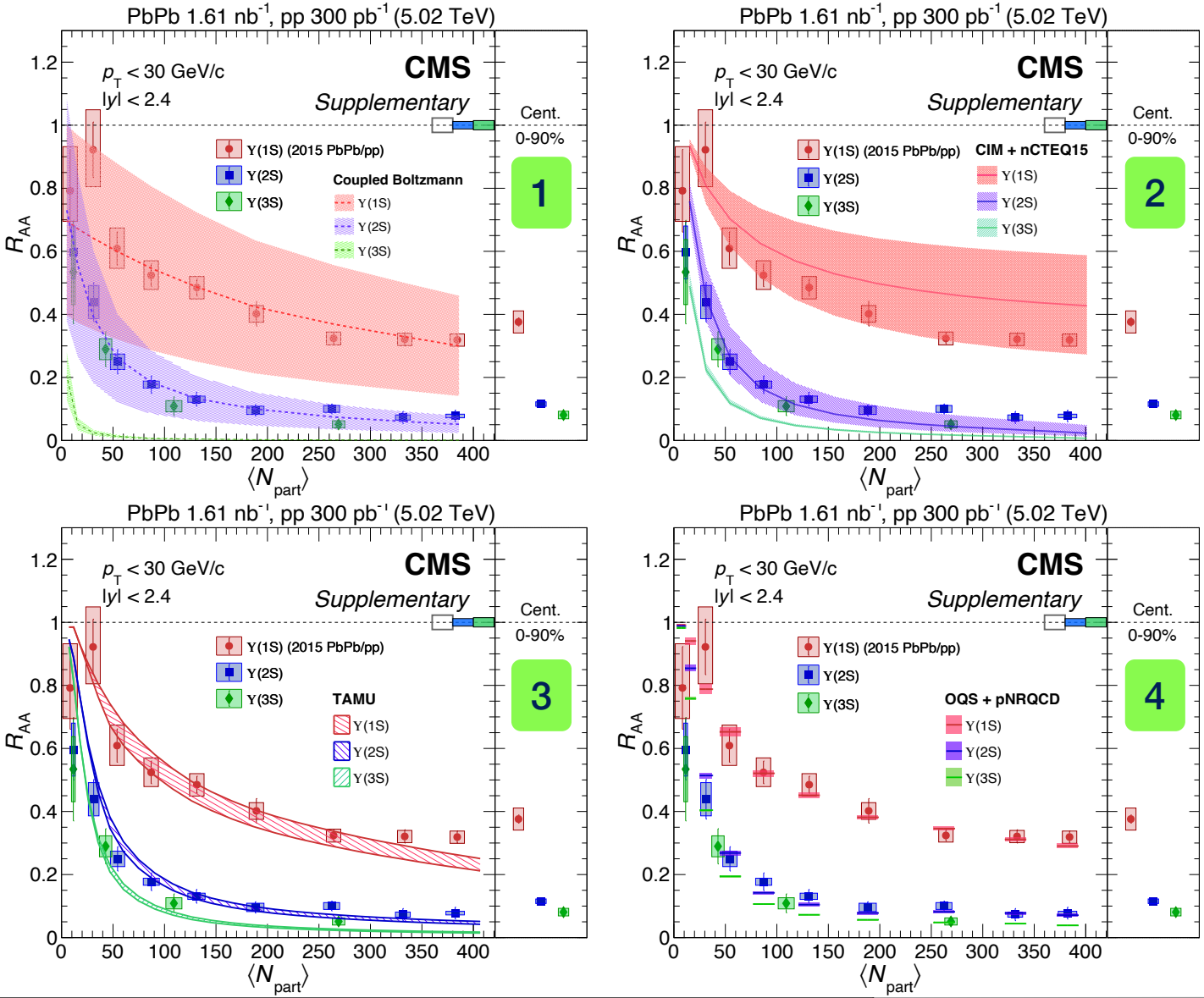
- Double ratio < 1 → heavier suppression for **Υ**(3S) than **Υ**(2S)
- Cancel out nPDF effects advantageous for theory calculation





Theory ↔ Experiment

- Many models to predict the sequential suppression pattern



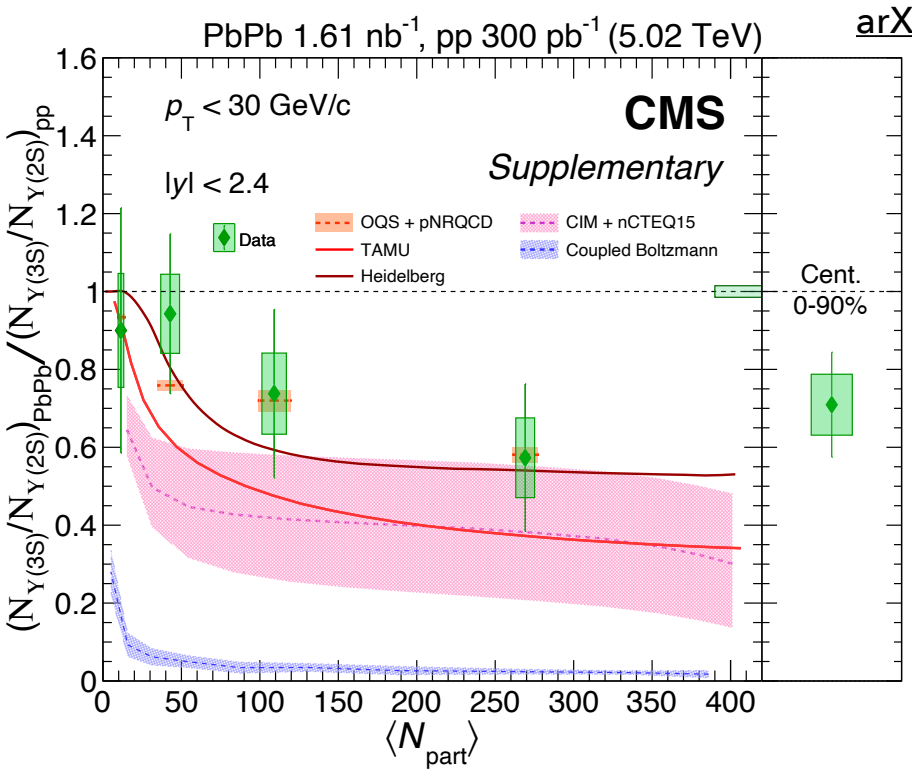
- Precise experiment data to improve model parameterization

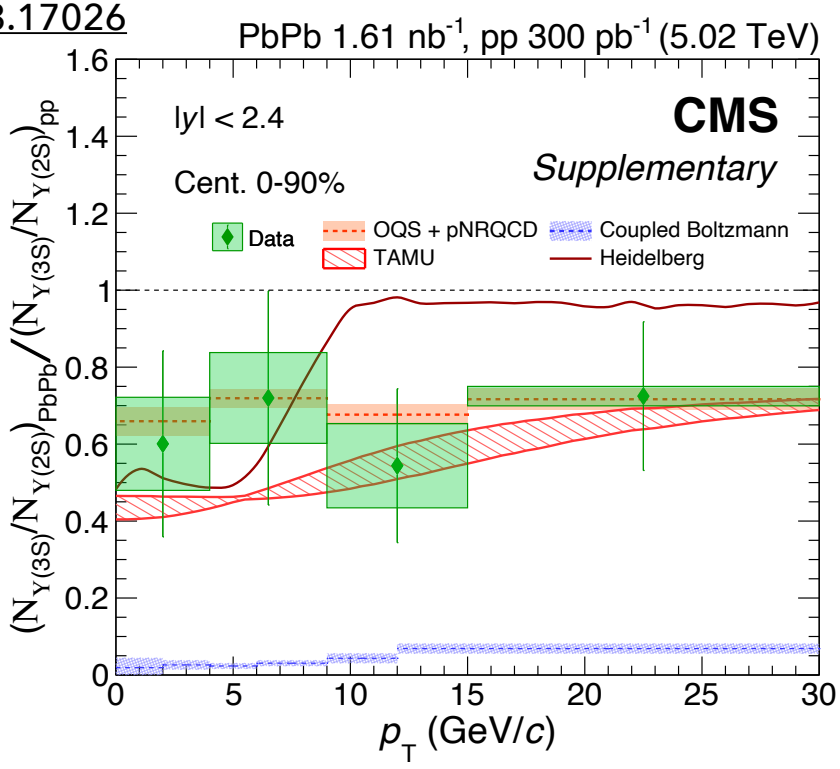
1. Couple Boltzmann transport model
2. Comover interaction model
3. Transport, kinetic rate eq. (TAMU)
4. pNRQCD in open quantum system

Theory ↔ Experiment

- Level of suppression for excited states sensitive for model
  - Tension between model predictions

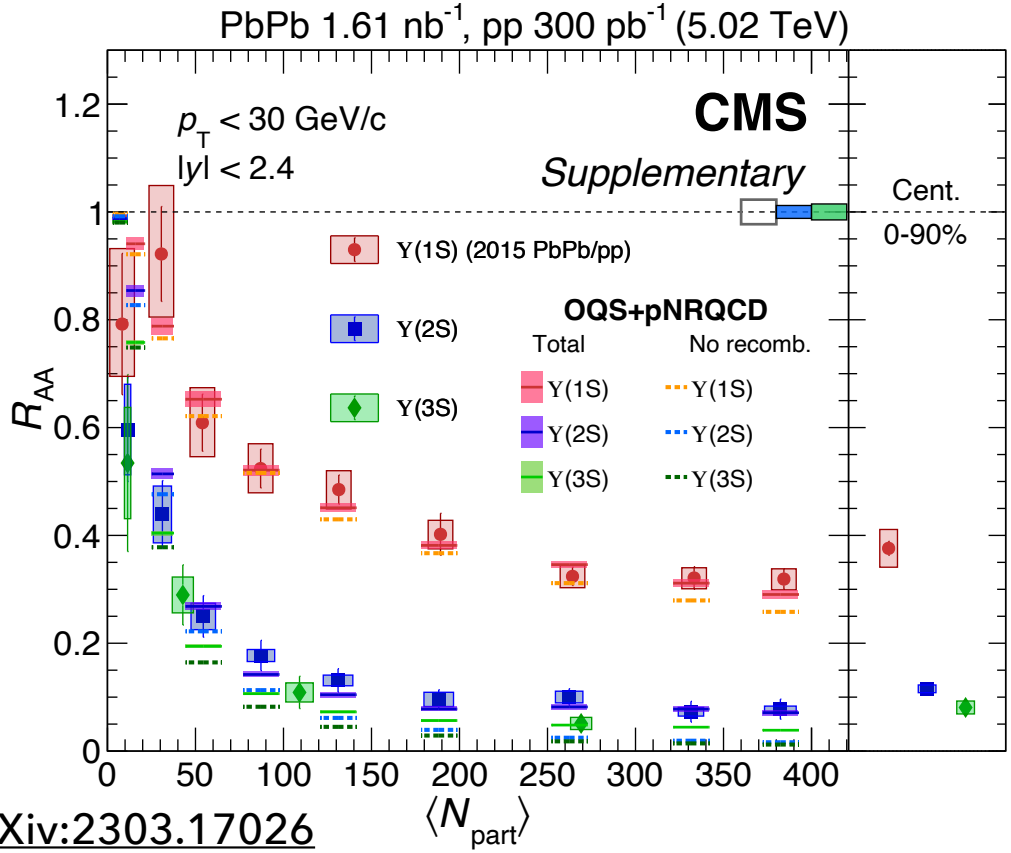
arXiv:2303.17026

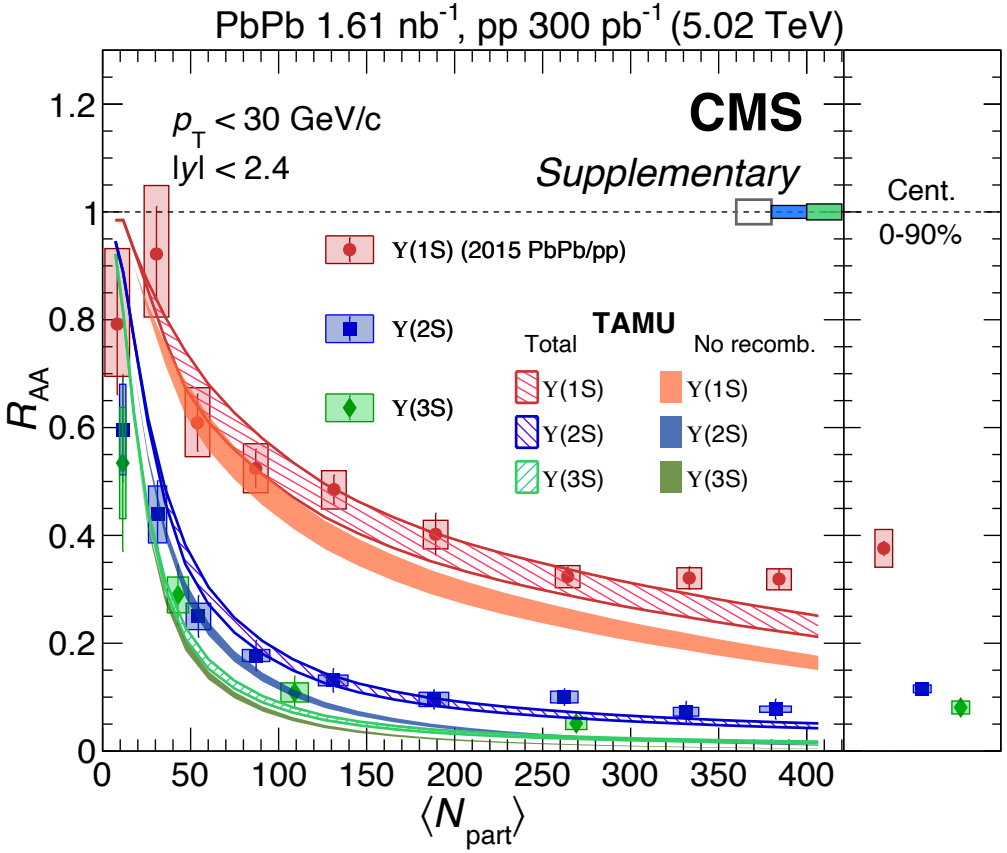




More about recombination

- Role of recombination in bottomonia non negligible
  - Continuous contribution through centrality
  - Substantial for excited states





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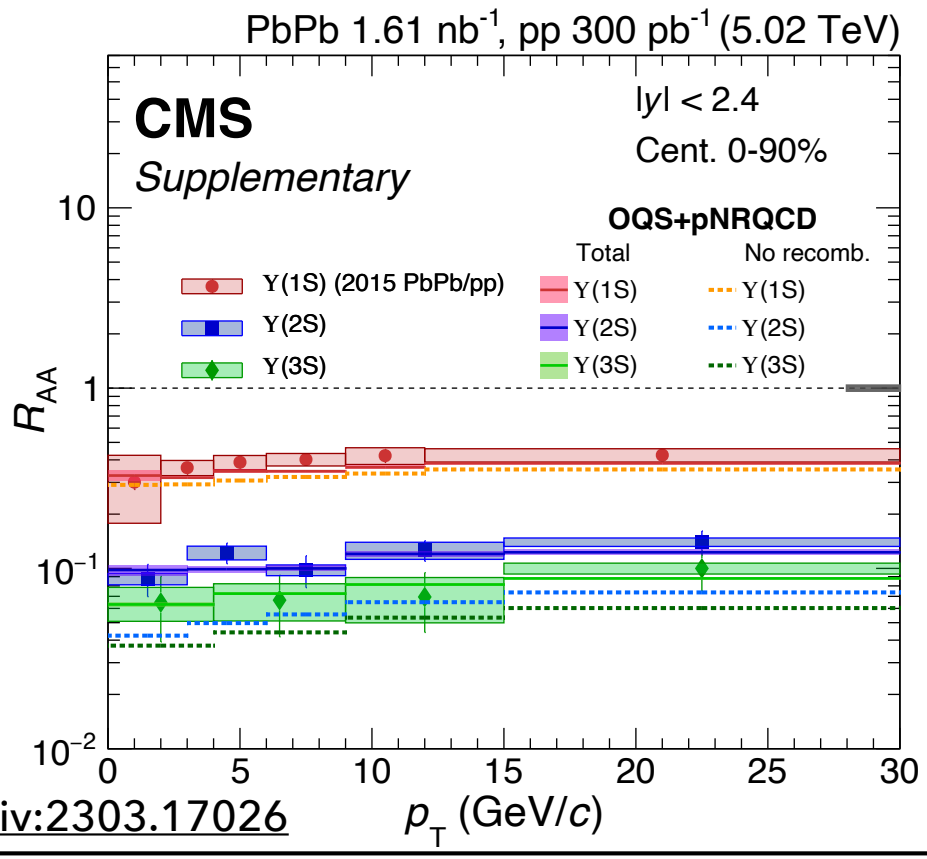
More about recombination

- Recombination at work over a large p_T range
  - Significant portion in low p_T excited states → correlated (diagonal) recombination



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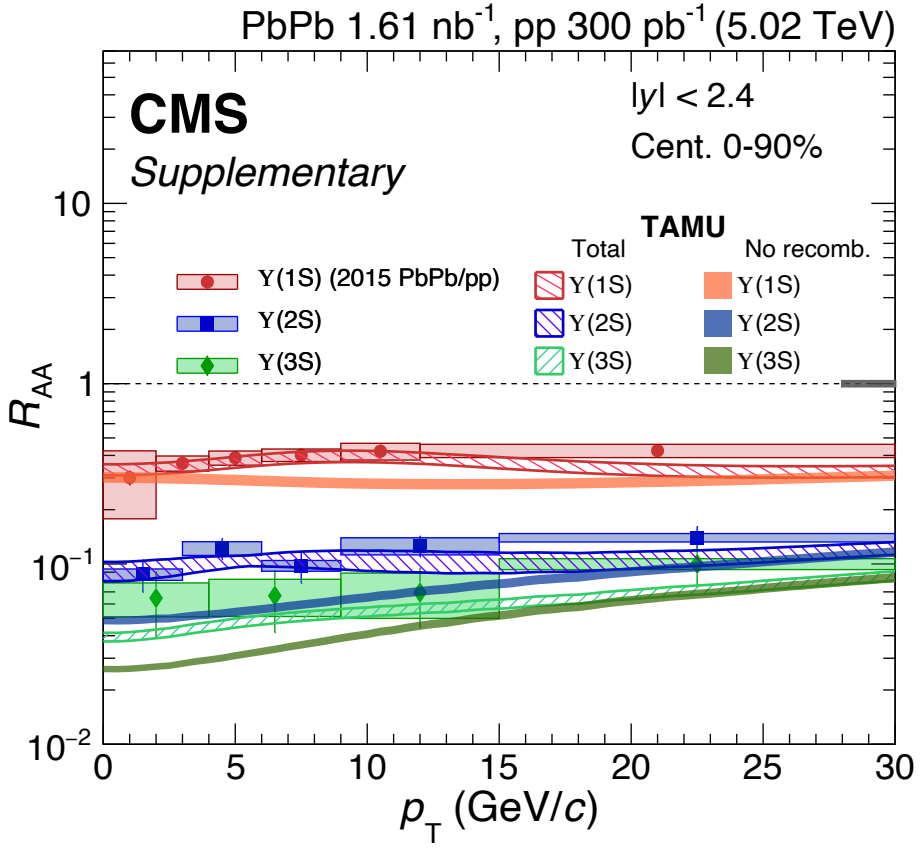
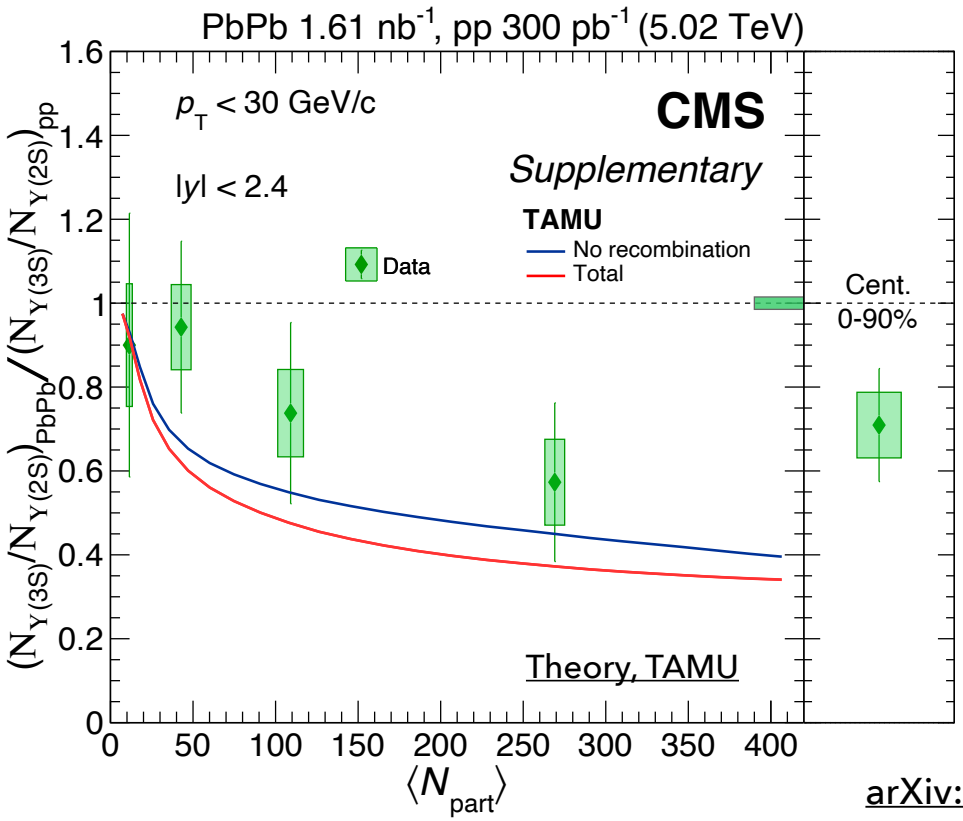
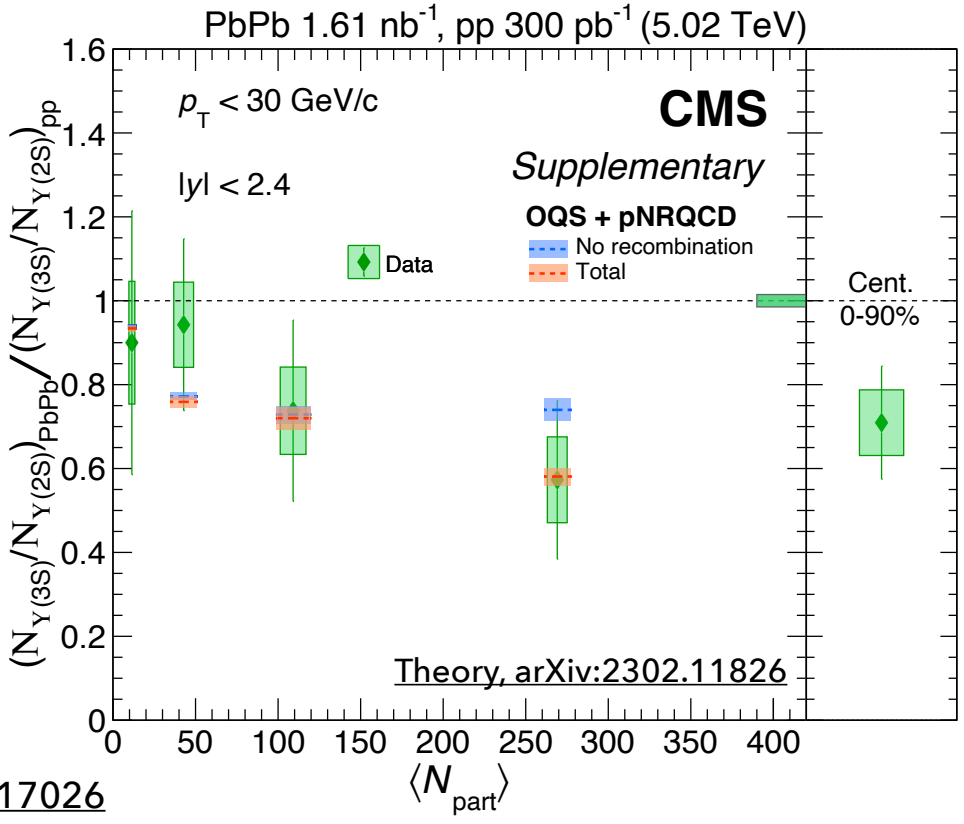


Theory ↔ Experiment

- No recombination increase double ratio
  - absolute regeneration component ratio larger than double ratio





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R_{AA} PbPb vs. pPb

- Bottomonium suppression heavier for all three S-wave states
  - Sequential also in pPb → QGP droplet? comover?
  - Important to constrain both system!

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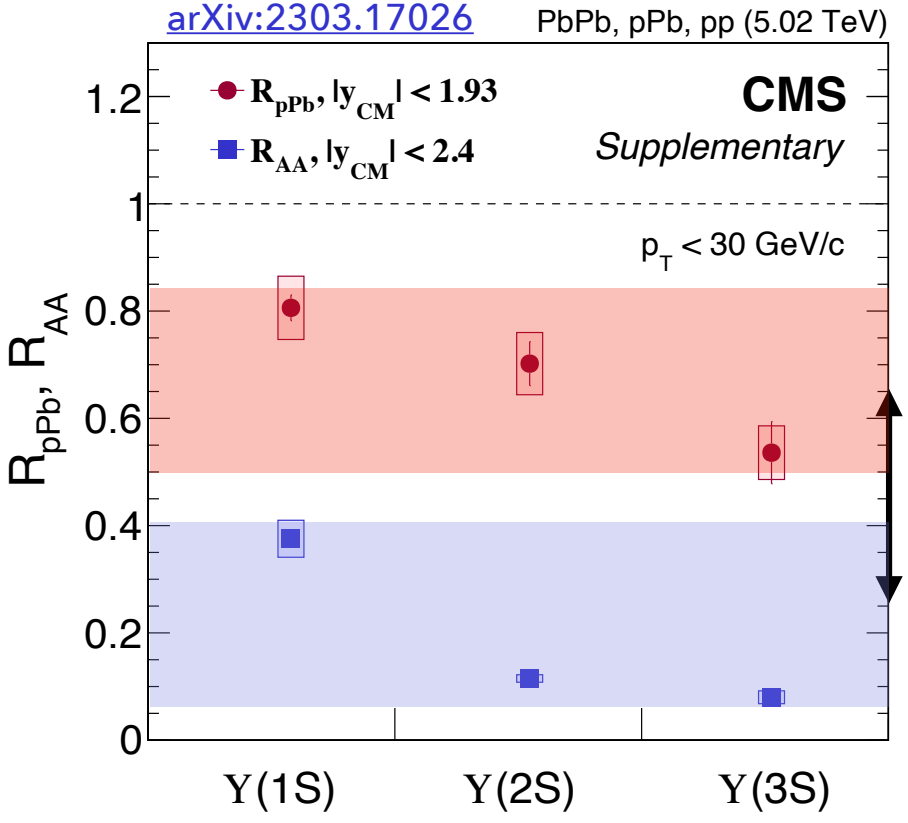
arXiv:2303.17026



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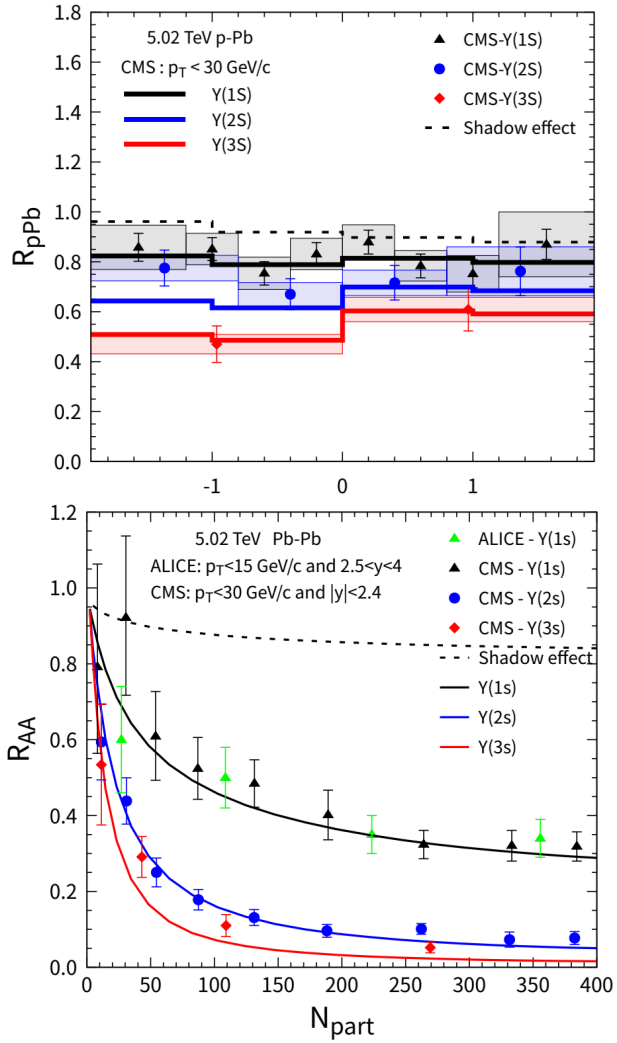
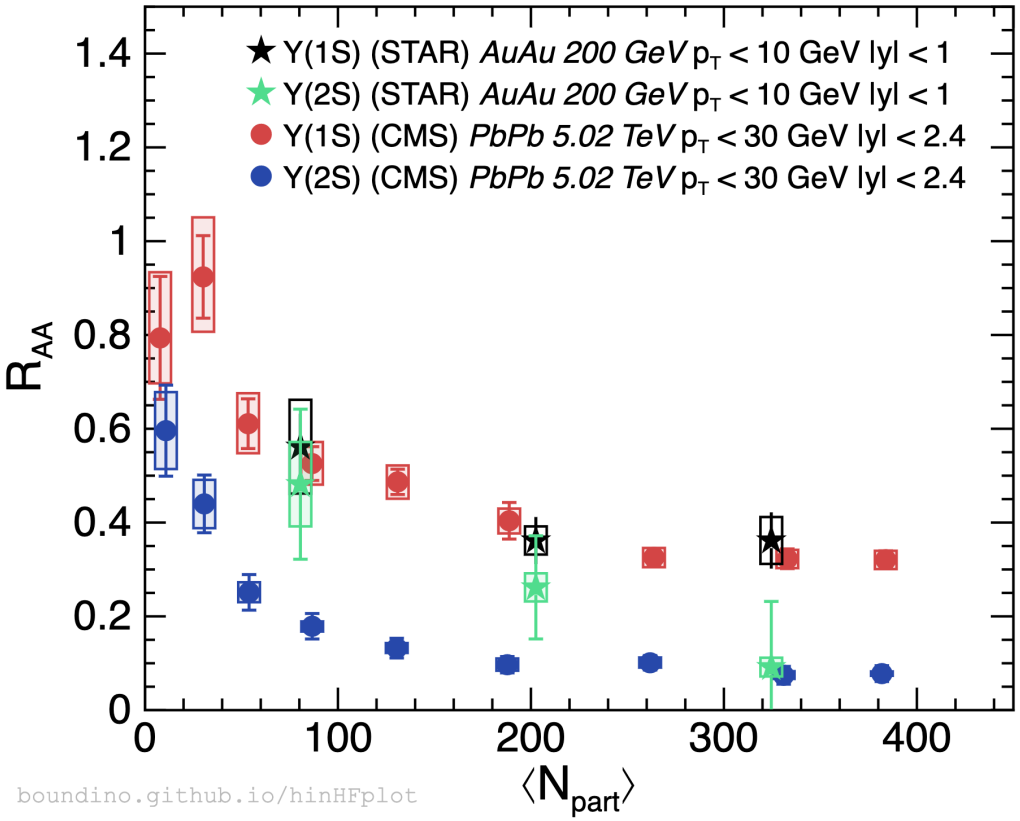
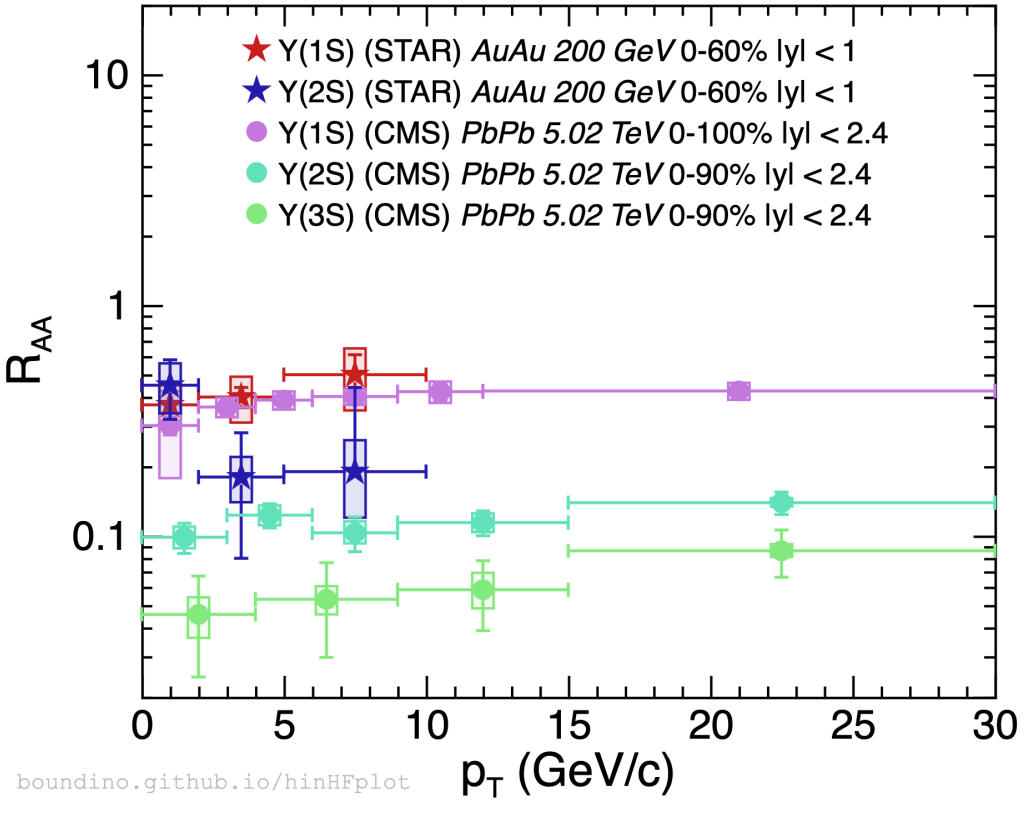


Comparison with RHIC

- Similar suppression for **Υ**(1S) →suppression already saturated at RHIC?
  - More data to be conclusive!
- **Υ**(2S) vs. ⟨N_{part}⟩ different shape → system size/temperature effect?





CMS, arXiv:2303.17026 STAR, PRL 130 112301

S-wave $Q\bar{Q}$ in PbPb

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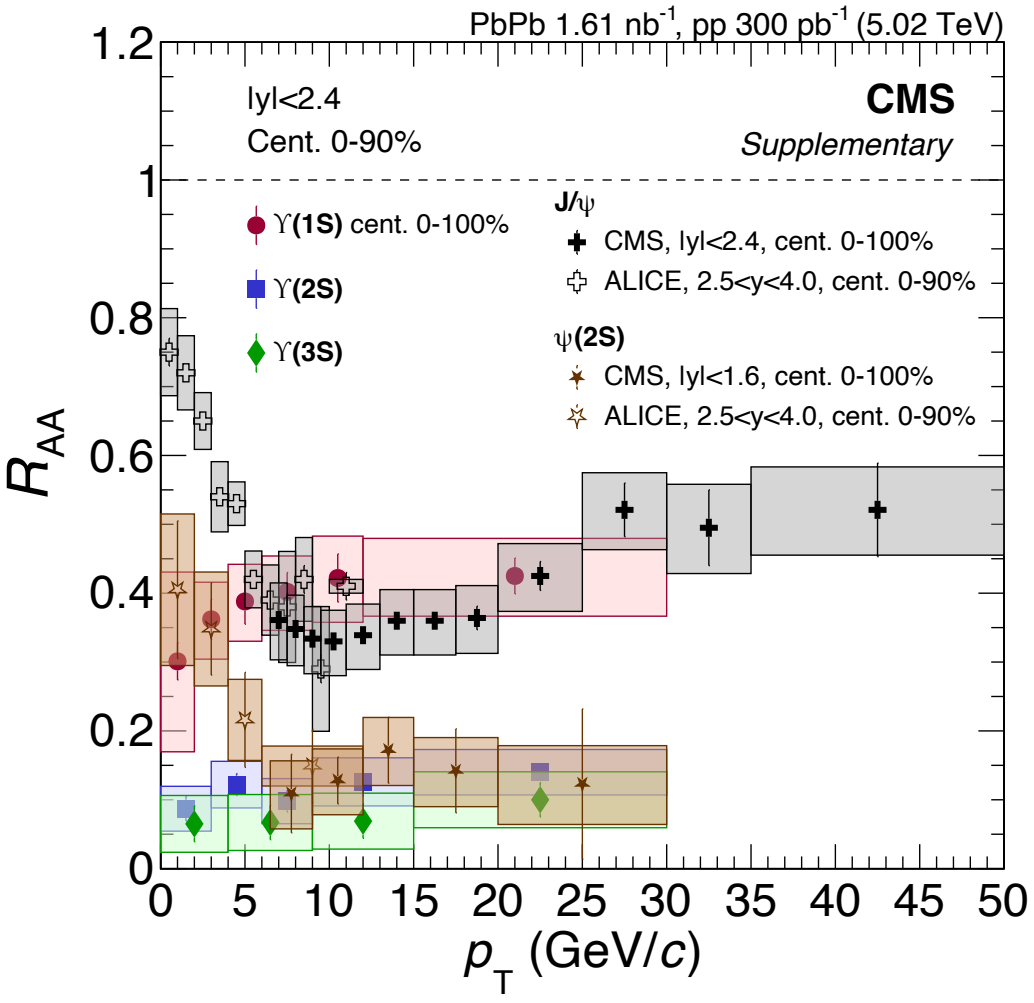
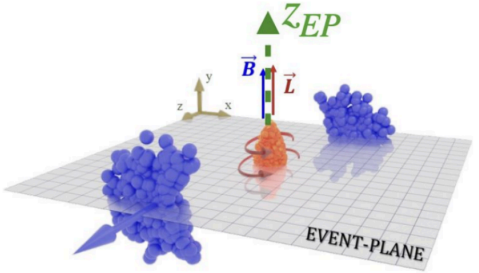


- Clear difference in low p_T between charm and beauty sector
  - $\propto$ Binding energy
  - Different recombination source

Questions to ask

- Are we correctly describing the heavy qq̄ production?
- What is the polarization of quarkonia in QGP?
- Final stage effects and feed-down contribution



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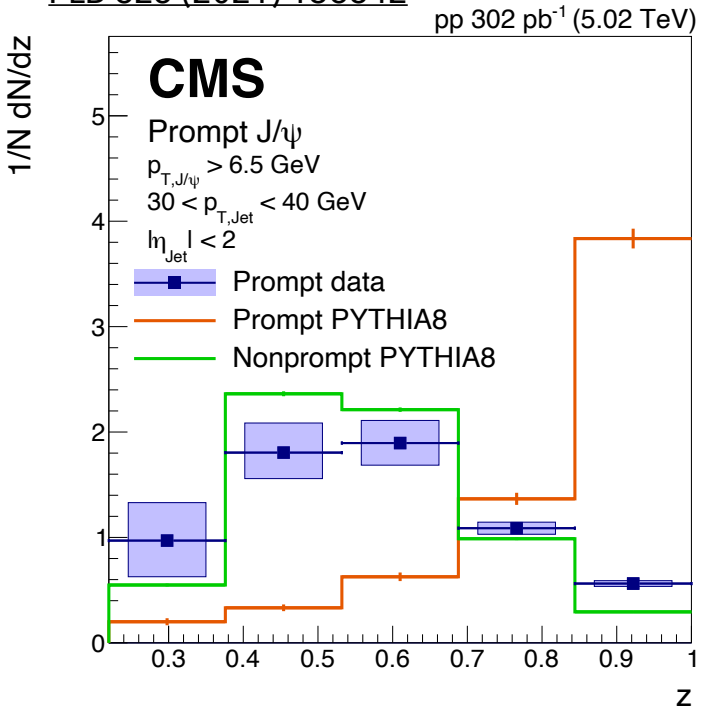
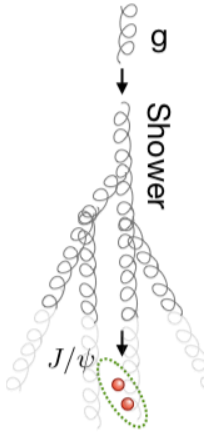
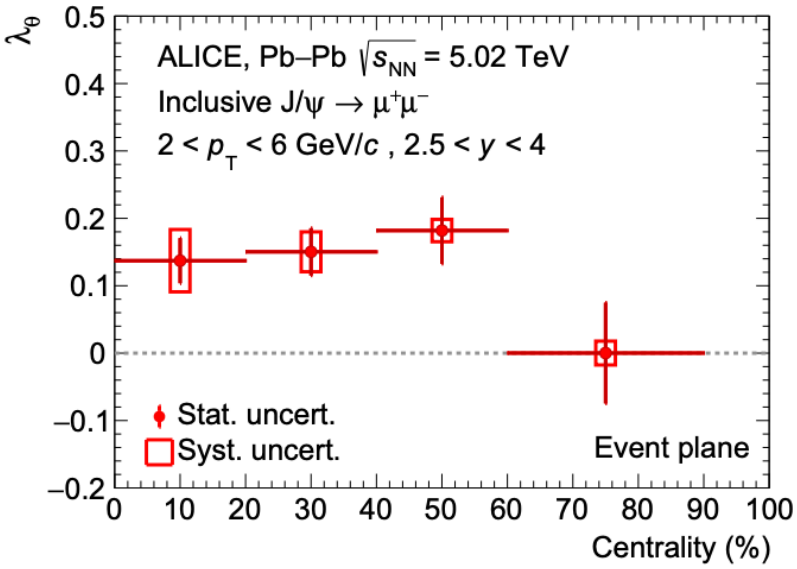


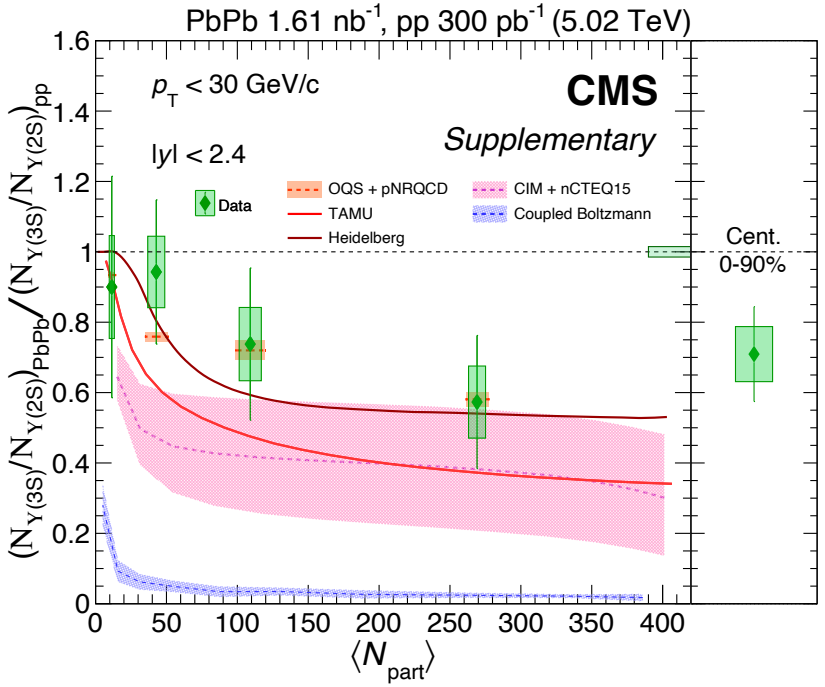


arXiv:2204.10171



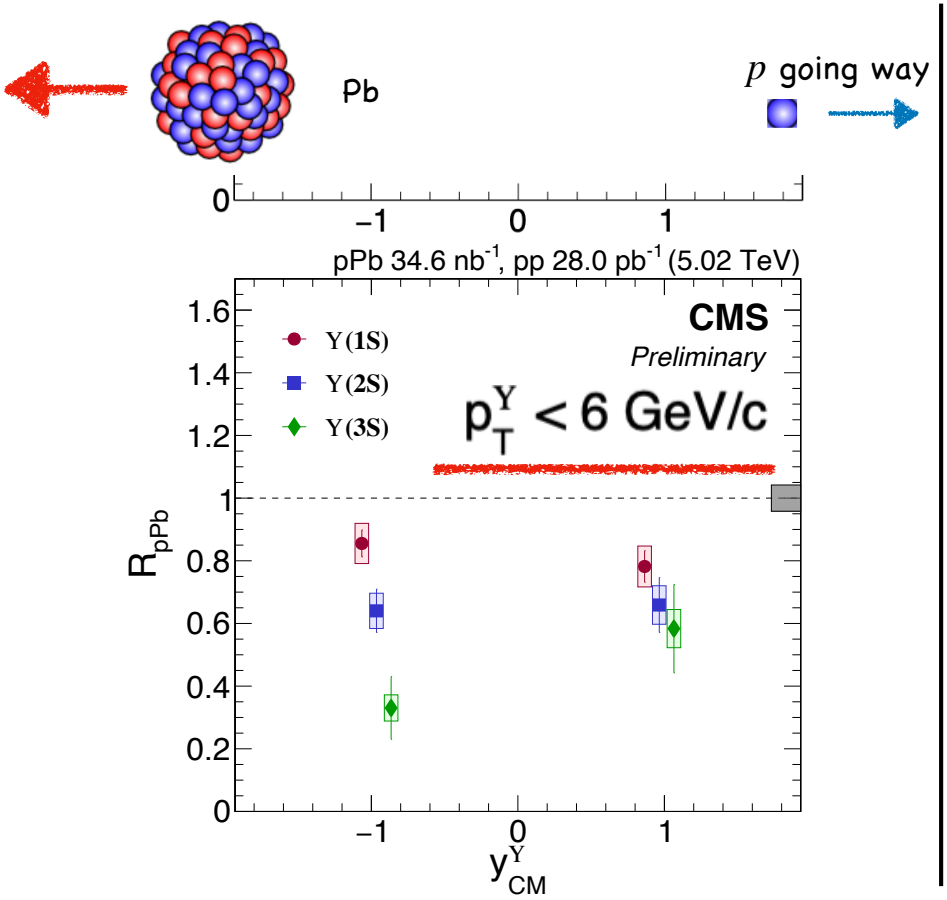
Summary

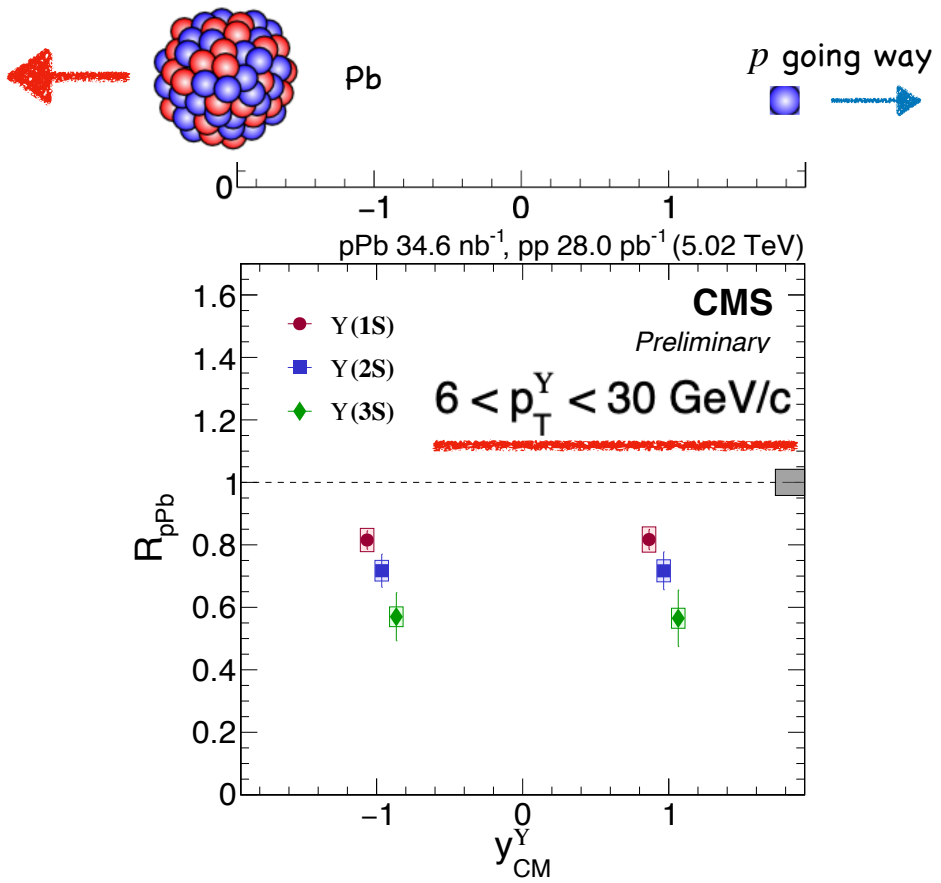
- First observation of **ϒ**(3S) meson in AA
- Measured R_{AA} of both excited **ϒ** states strengthening sequential suppression picture
- Better constraint on theoretical models with new data & observables



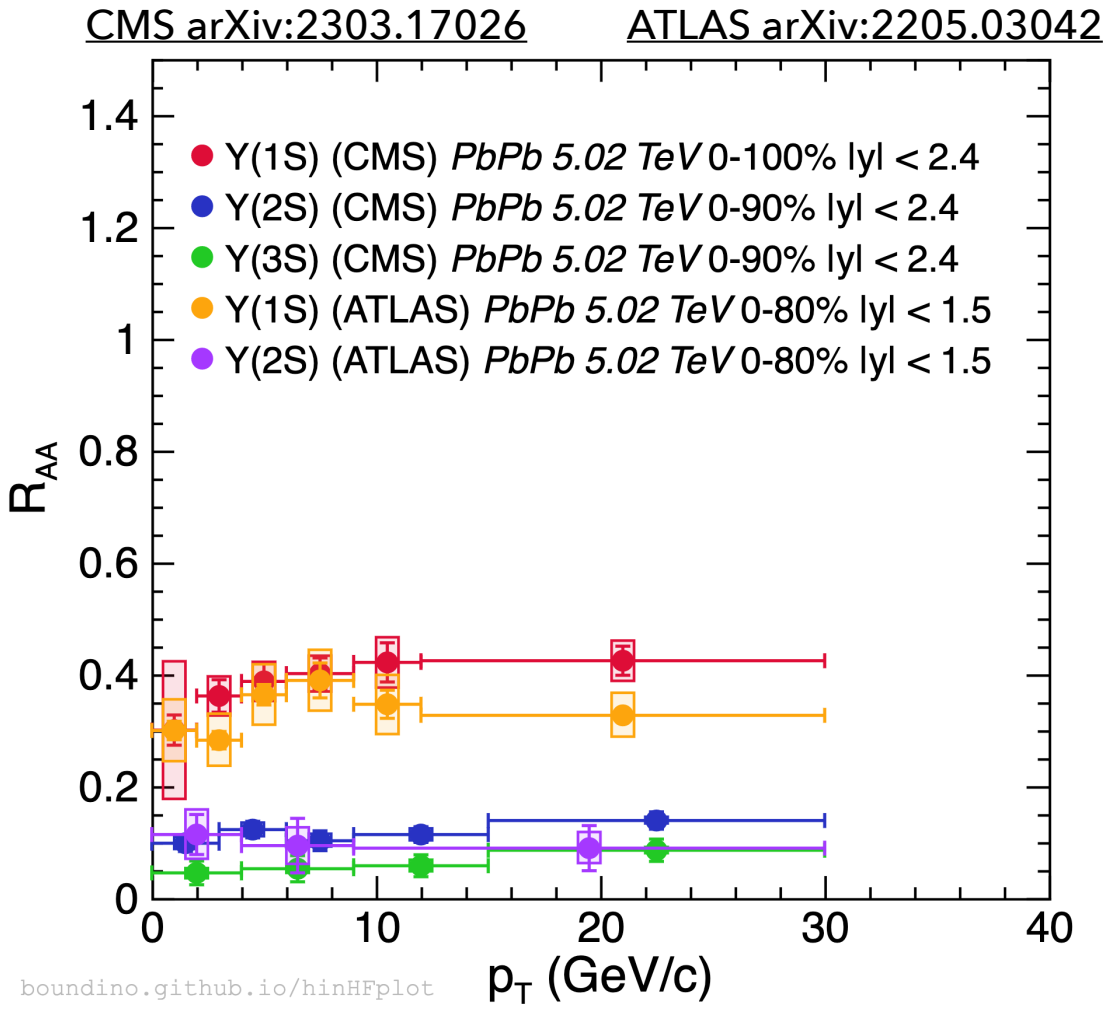
Thank you

Comover effect fwd vs. bwd?

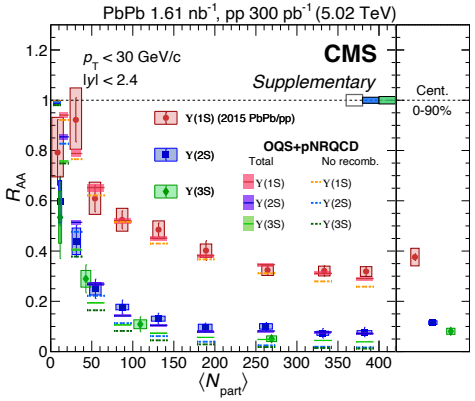


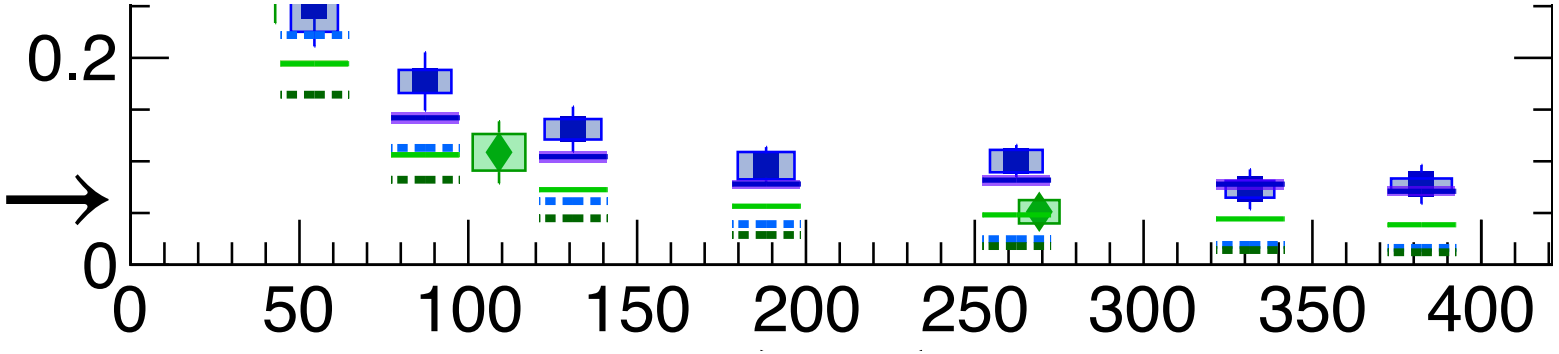


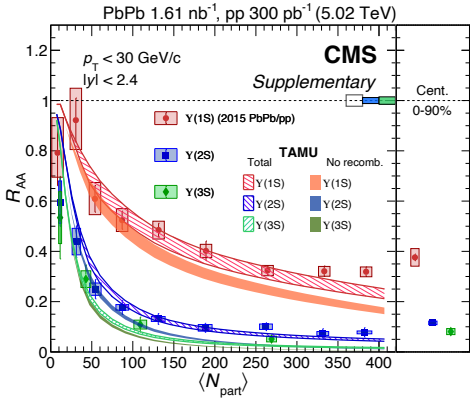
CMS and ALTAS **Υ** in 5.02 TeV PbPb results

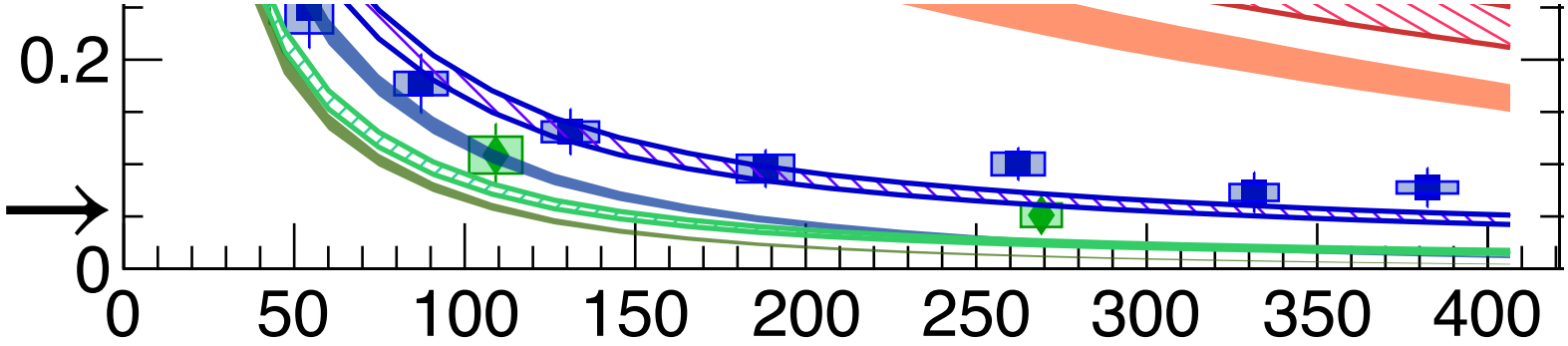


More about recombination









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