Measurement of excited state Υ in PbPb collision with CMS

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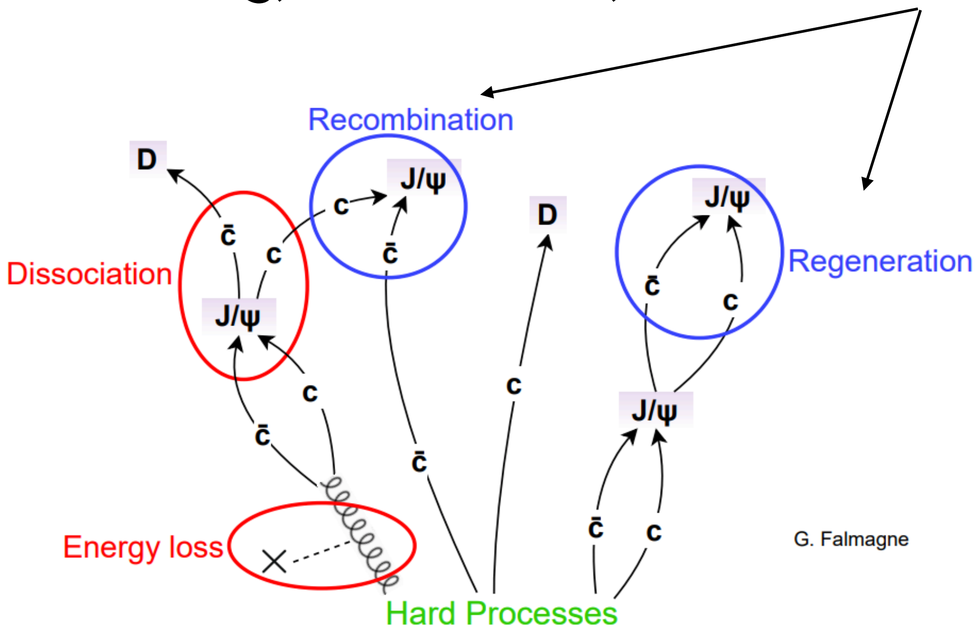
Analysis report, introduction

- Bottomonia are good probes to study the QGP

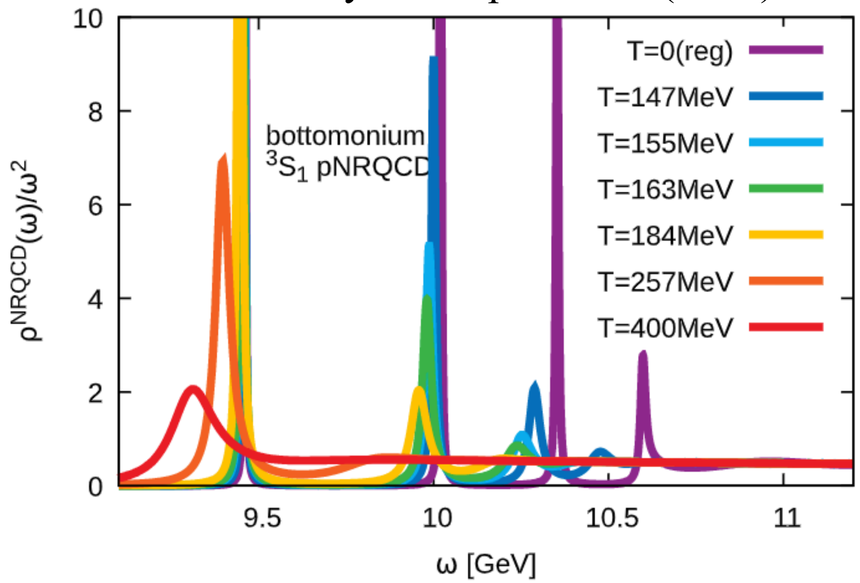
☑ Produced mostly from initial hard scattering

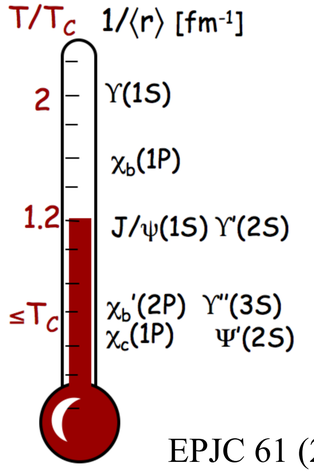
☑ Sensitive to in-medium effects

(color screening, dissociation, recombination)



Physics Reports 858 (2020) 1





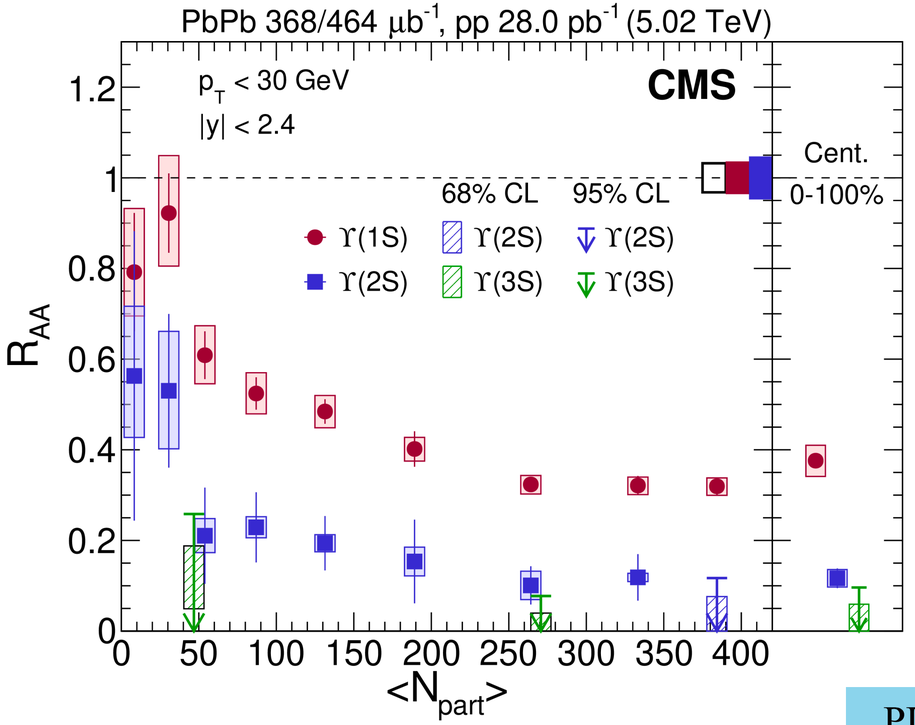
EPJC 61 (2009) 705-710

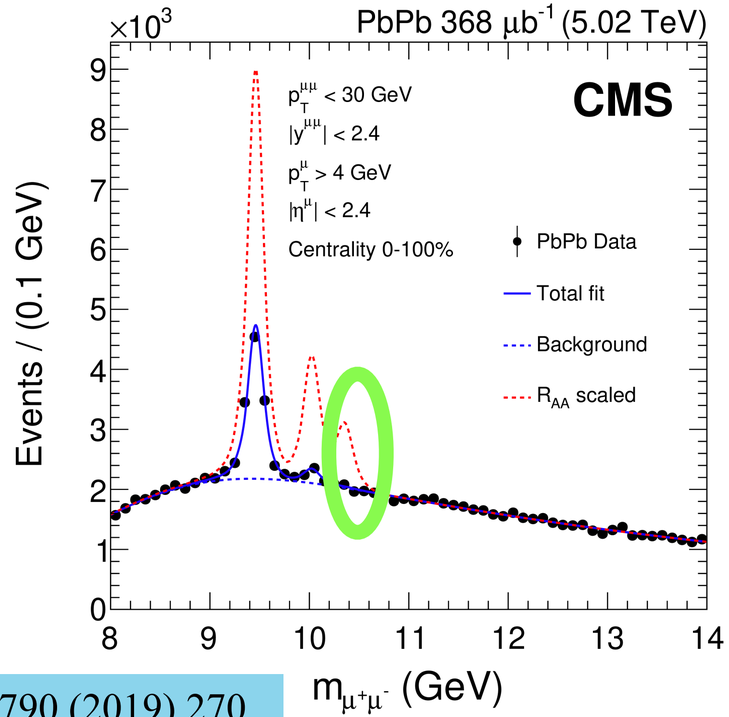
Update of sequential suppression data

- Limited statistics in previous measurements
  - No **Υ(3S)** visible in 2015 ↓
  - A nice opportunity to search for **Υ(3S)** with CMS 2018 PbPb data ($\times 4.3$ lumi.)

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

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

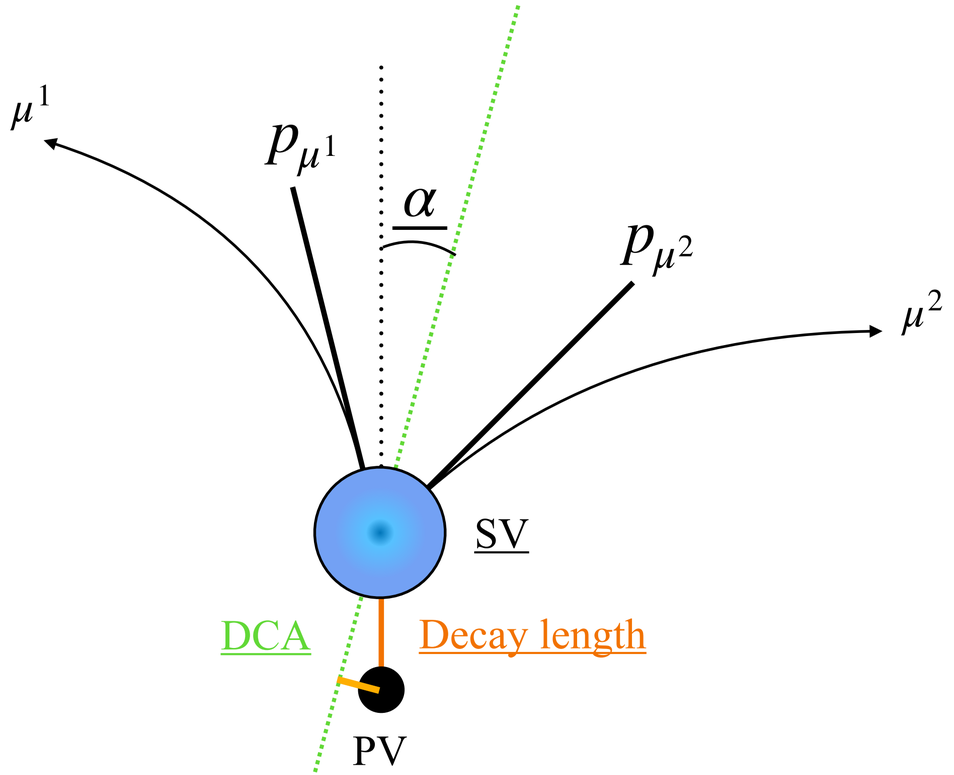




PLB 790 (2019) 270

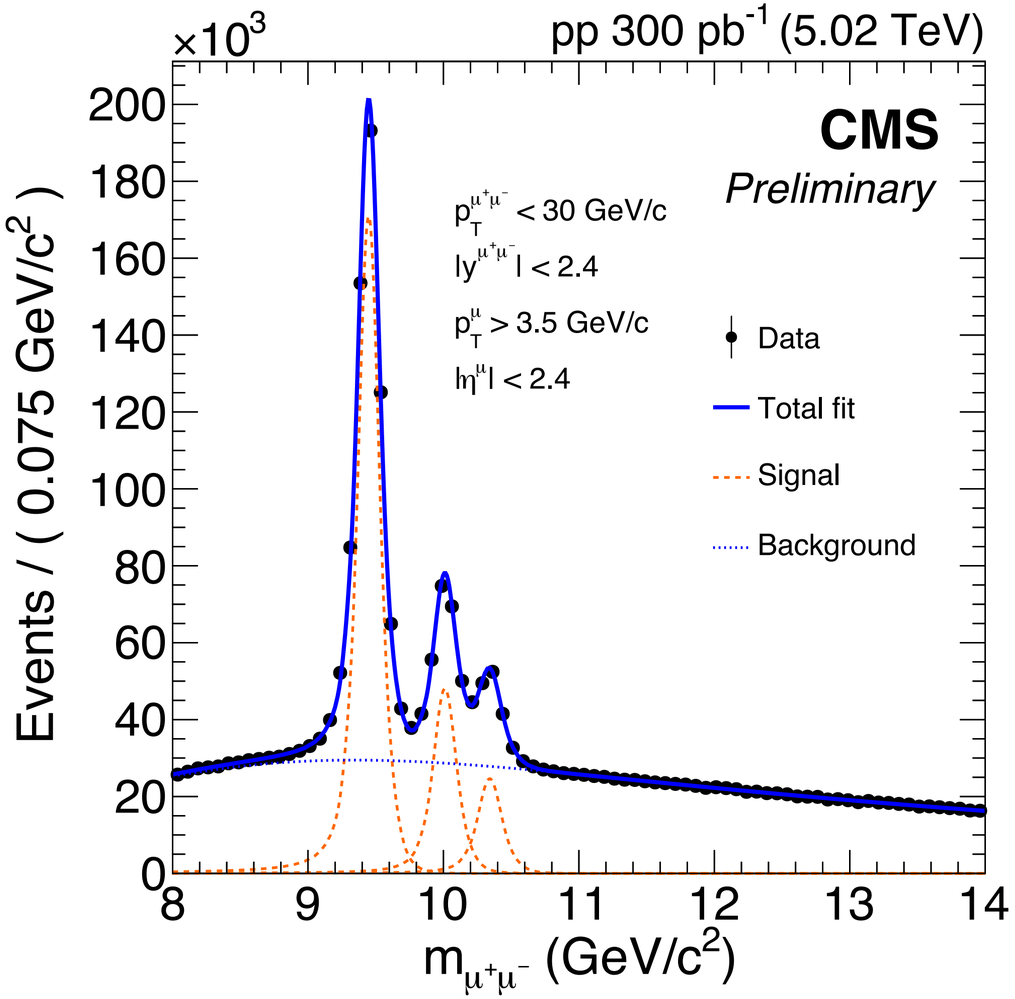
Analysis Method

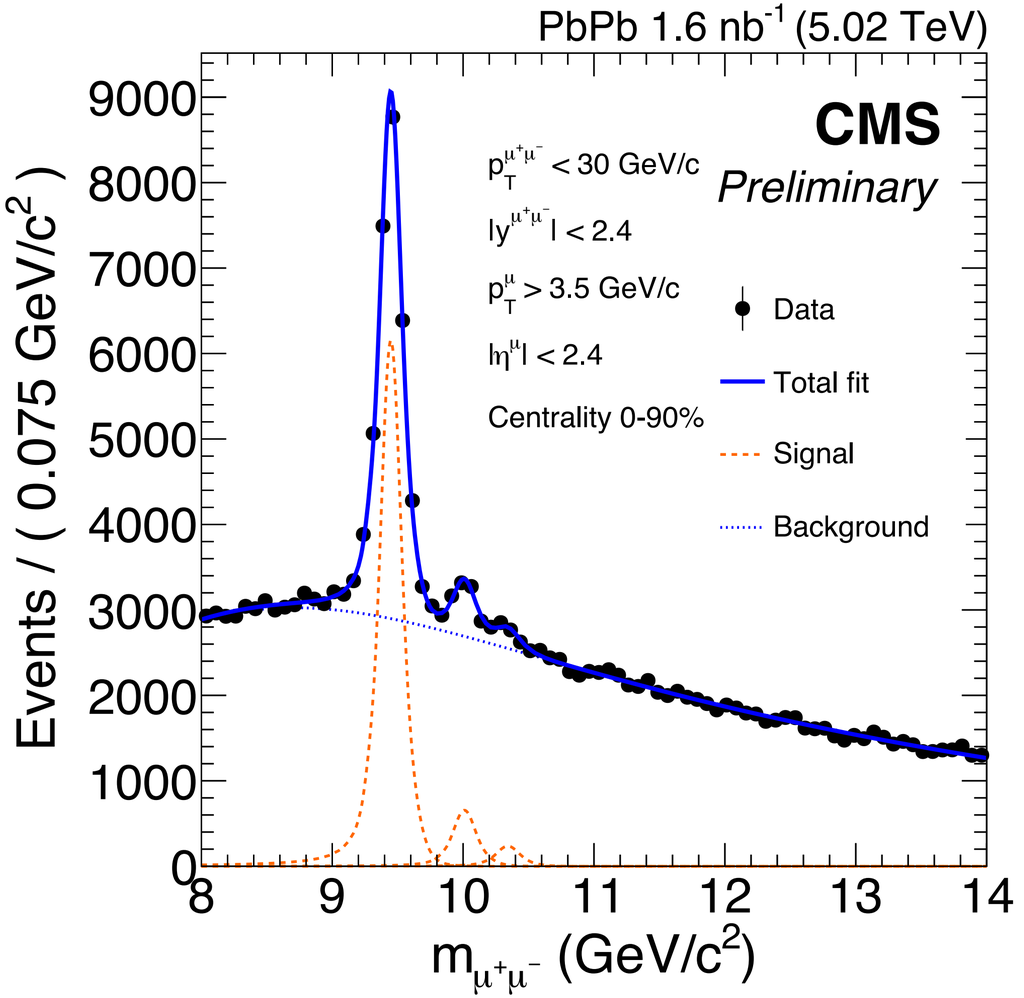
- Signal(dimuon from Y(nS)) enhancement with MVA selection(BDT) for PbPb data
  - Signal(MC) and background (side band data) classification
    - Pointing angle α
    - Distance to closest approach (DCA)
    - Vertex related information



Υ(nS) signal extraction

CMS-PAS-HIN-21-007

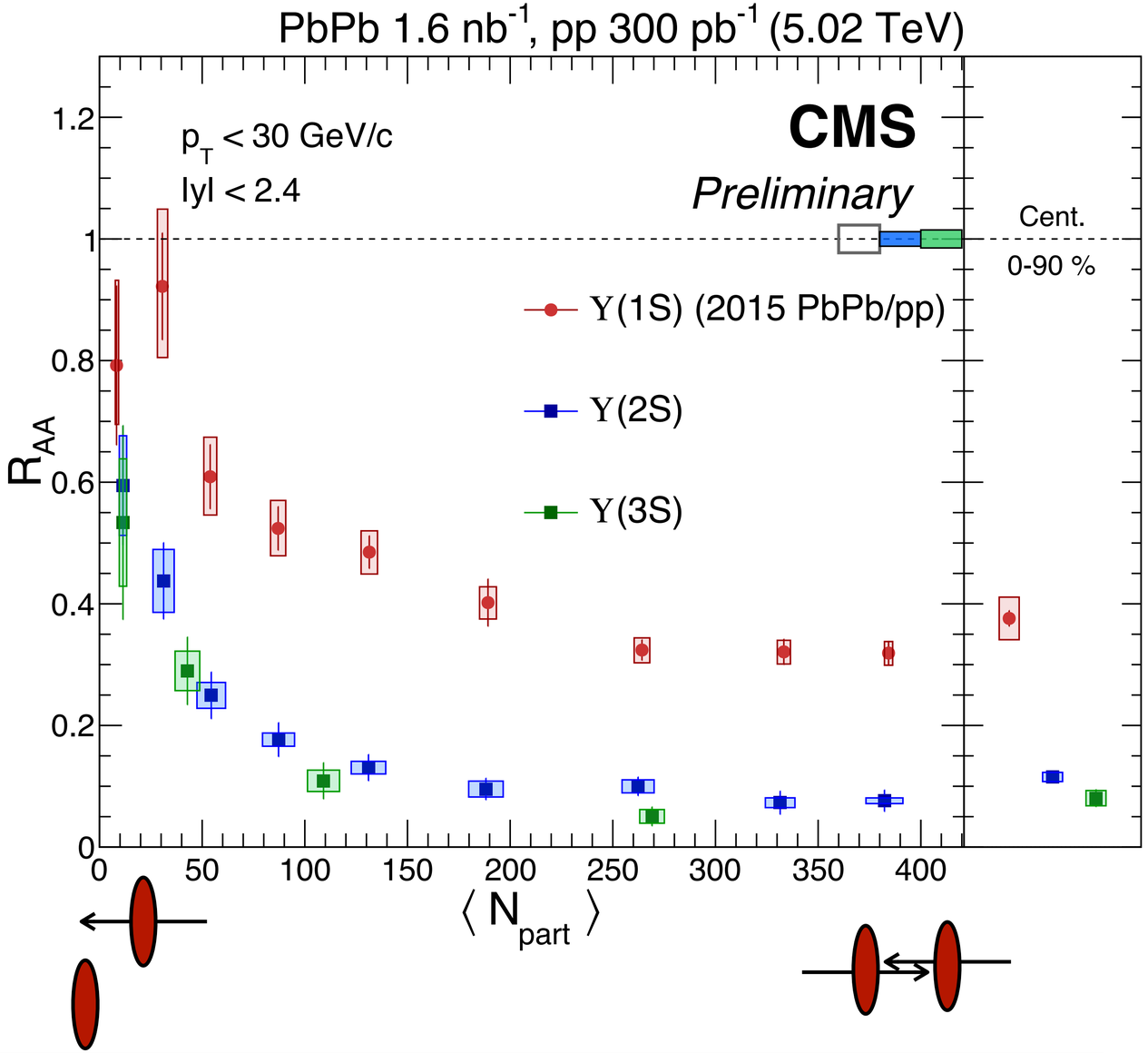




- Yield extracted with fitting on the BDT selected di-muon distribution with 3 Crystal Ball functions + background function.

First observation of **Υ(3S)** in AA collision($> 5\,\sigma$)!

Updated R_{AA} (N_{part})

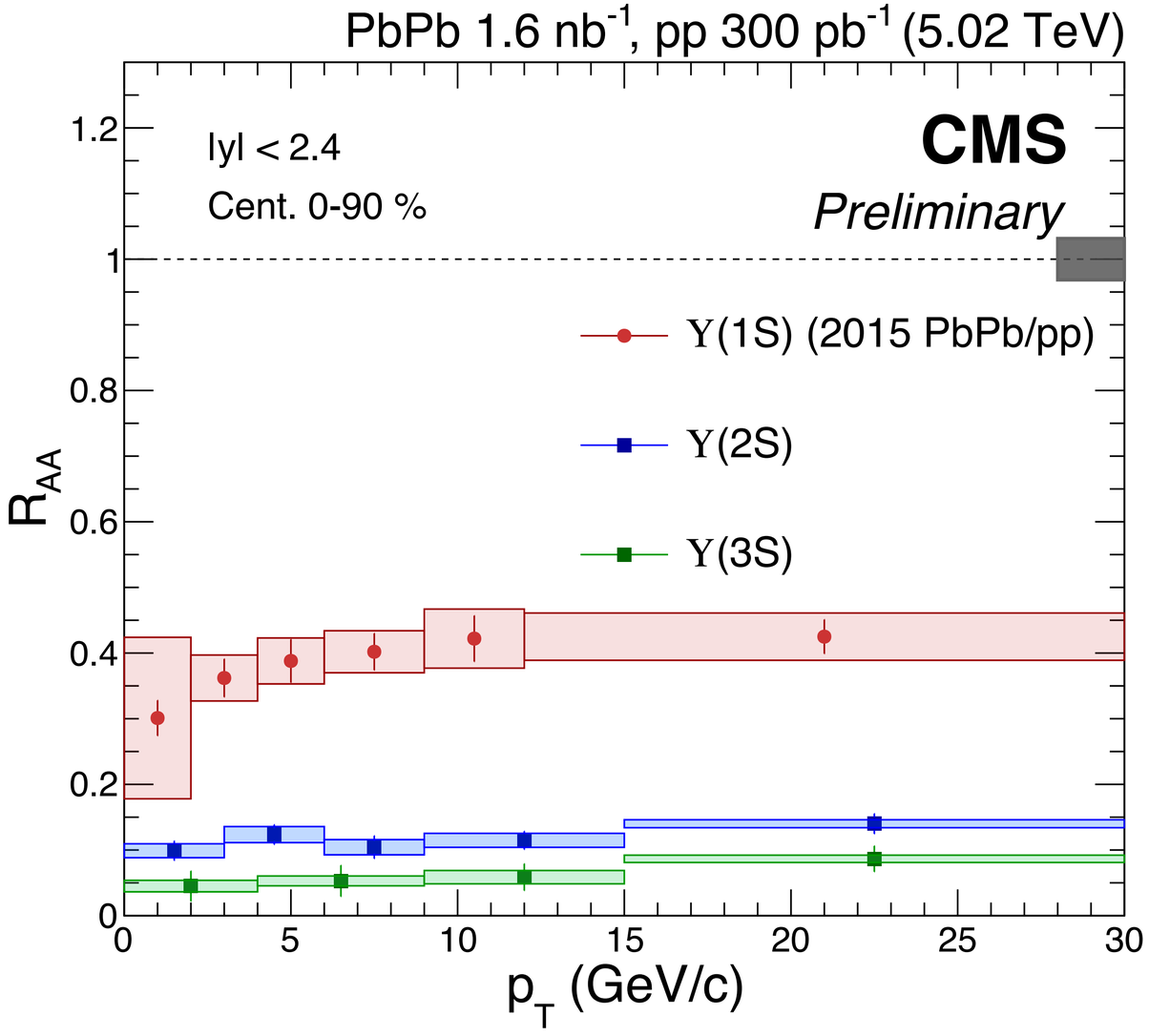


$$R_{AA}(p_T, y) = \frac{d^2N^{AA}_{\Upsilon,corr}/dp_T dy}{\langle T_{AA}\rangle d^2\sigma^{PP}_{\Upsilon}/dp_T dy}$$

- **Υ(3S)** measured in all centrality regions
- Improved **Υ(2S)** measurement!
- Clear sequential suppression

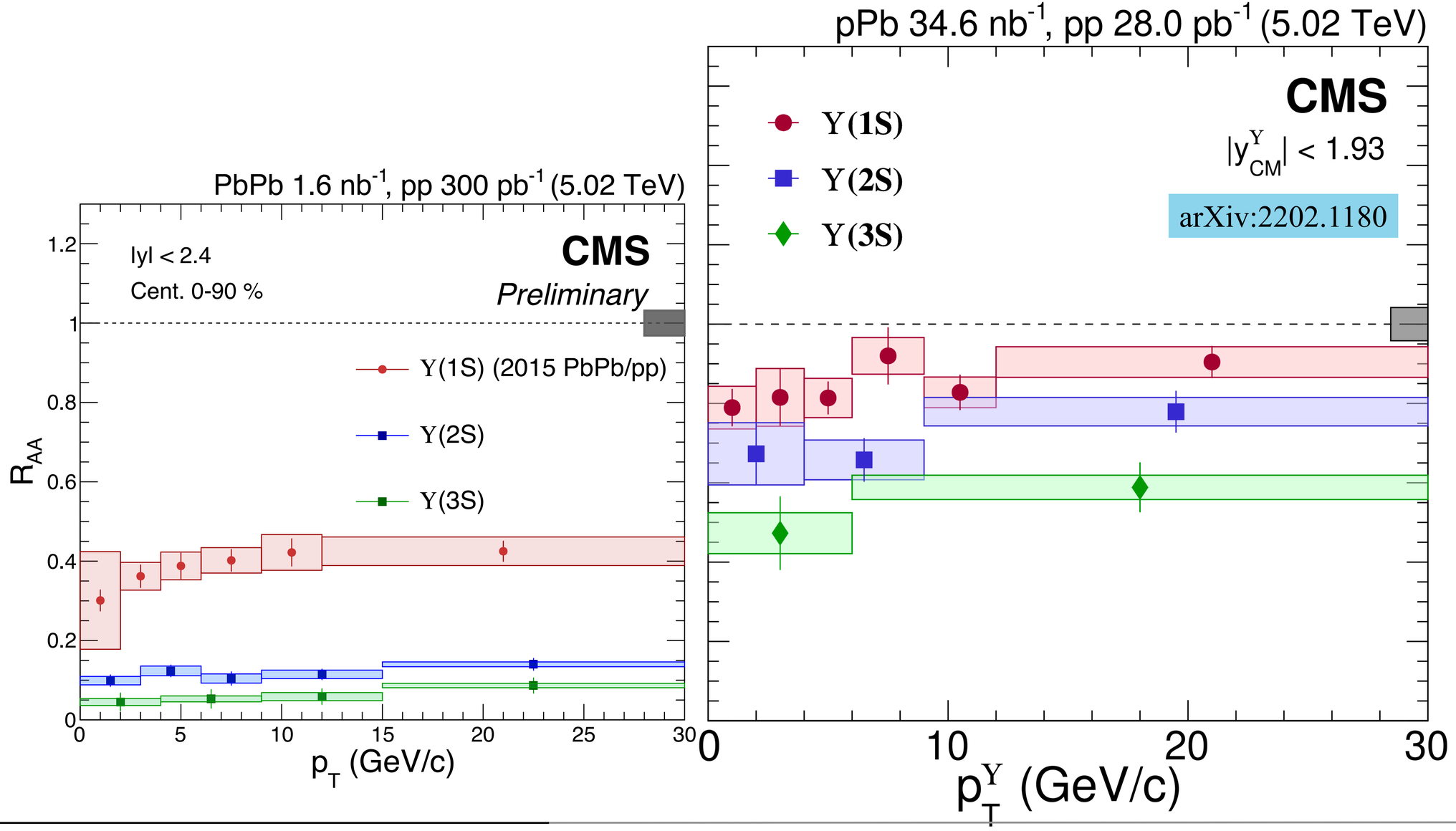
$$R_{AA}(1S) > R_{AA}(2S) > R_{AA}(3S)$$

Updated R_{AA} (p_T)



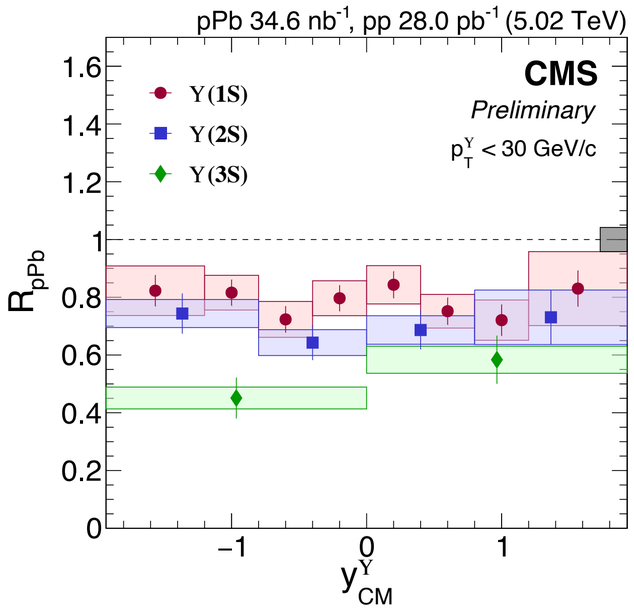
- $\Upsilon(3S)$ measured in all p_T intervals
- Sequential suppression in measured p_T range
- Slight increase of $R_{AA}(\Upsilon(3S))$ vs. p_T
- R_{AA} is lower for $\Upsilon(3S)$ than $\Upsilon(2S)$ in all intervals

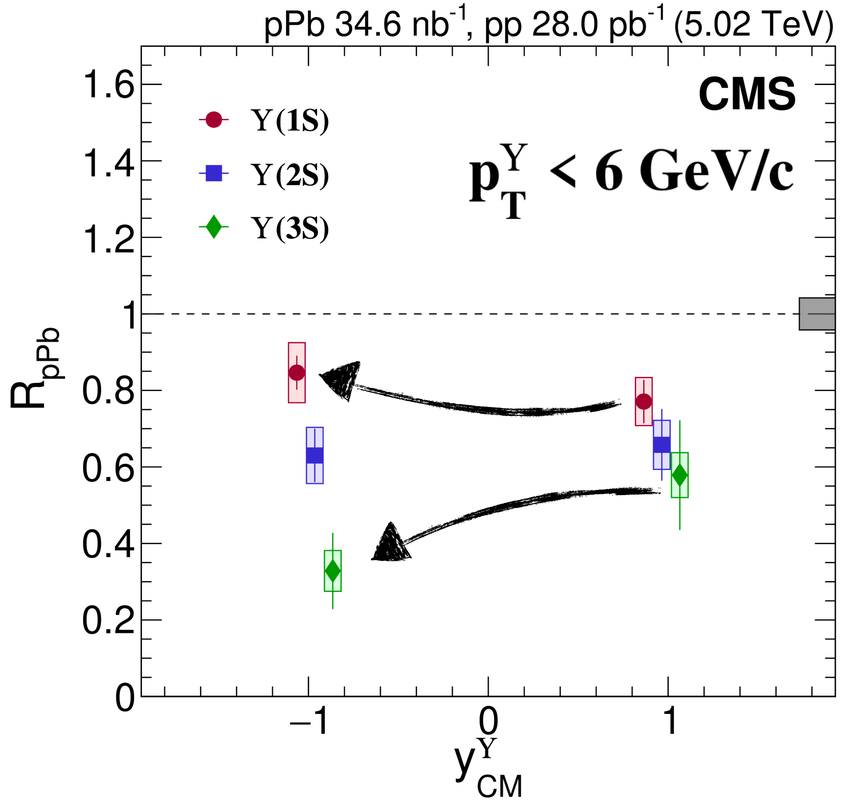
Suppression in pPb?

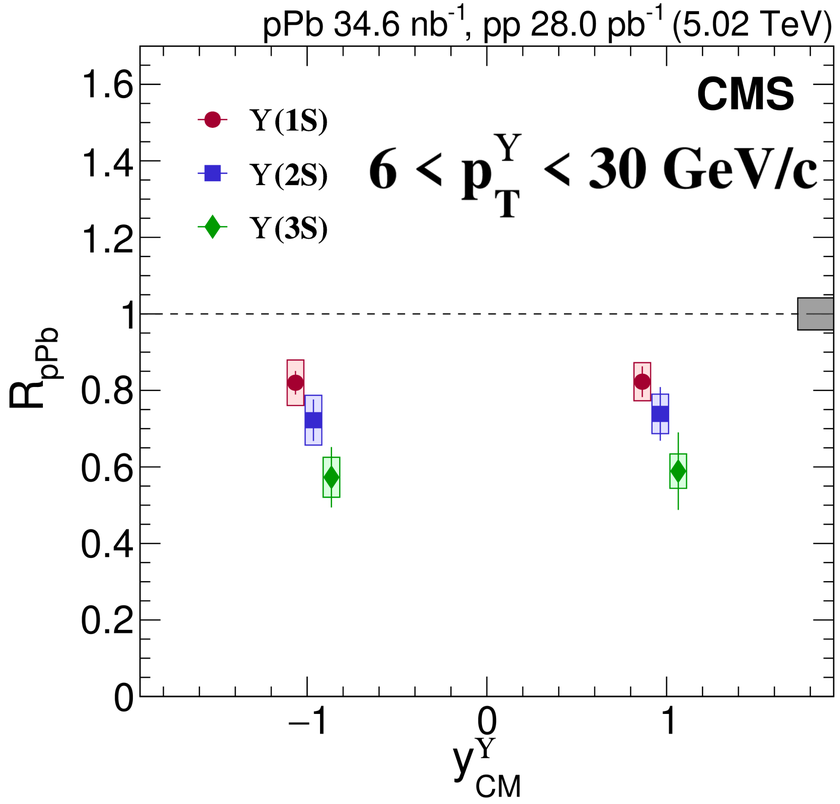


R_{pPb} forward and backward

arXiv:2202.11807

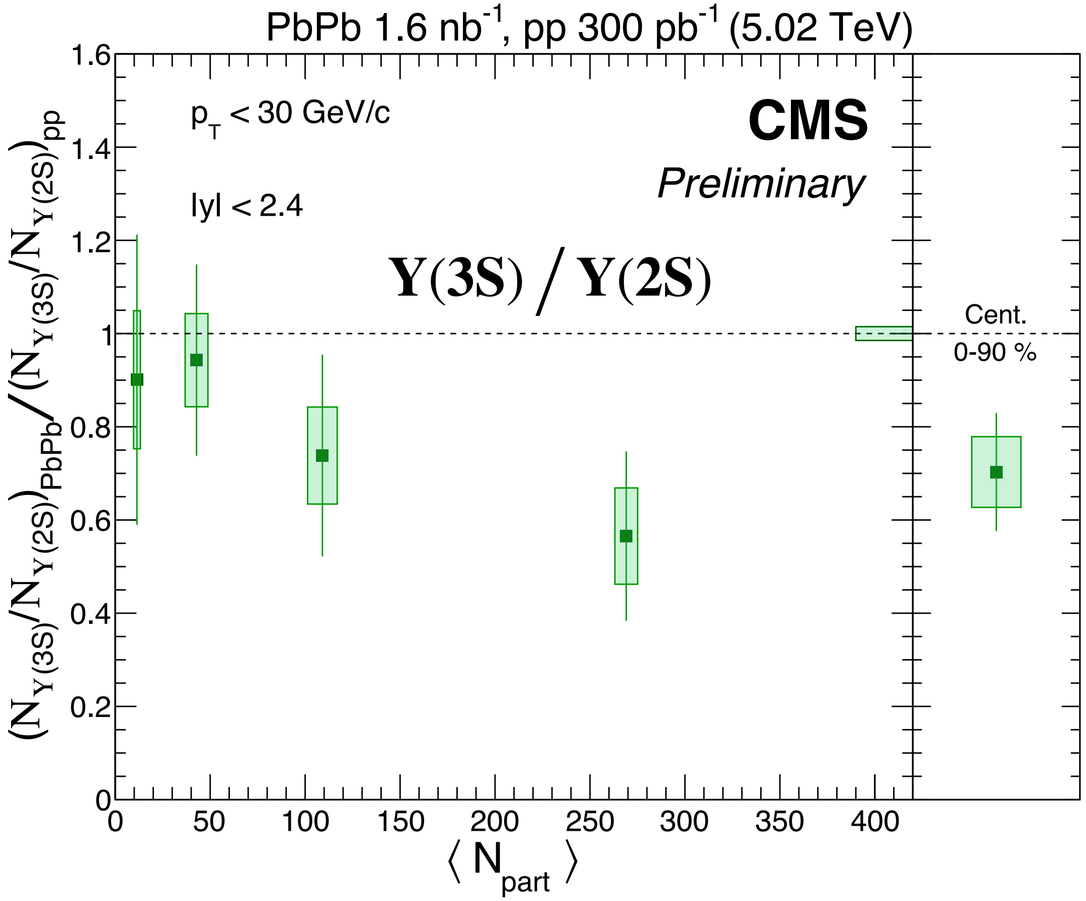


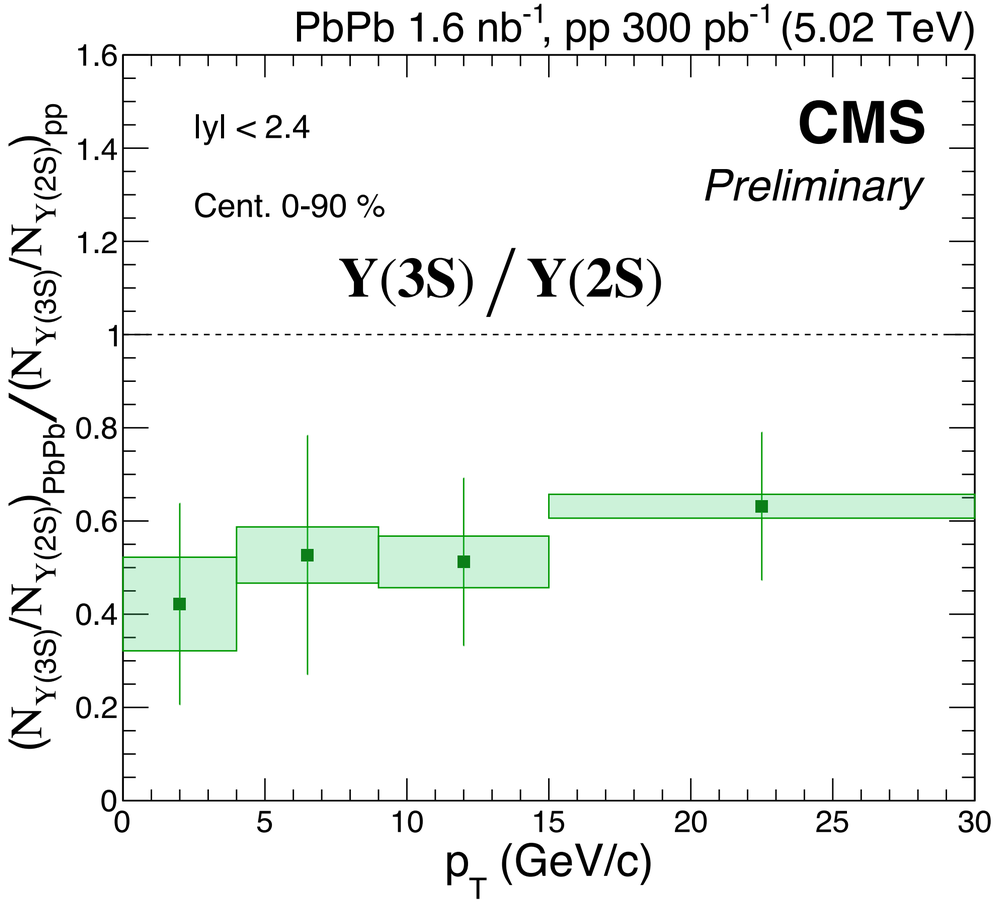




- Suppression also seen in backward rapidity (Pb going side)
- Explainable with comover interaction in low p_T?

Double ratio of Y(3S) / Y(2S)





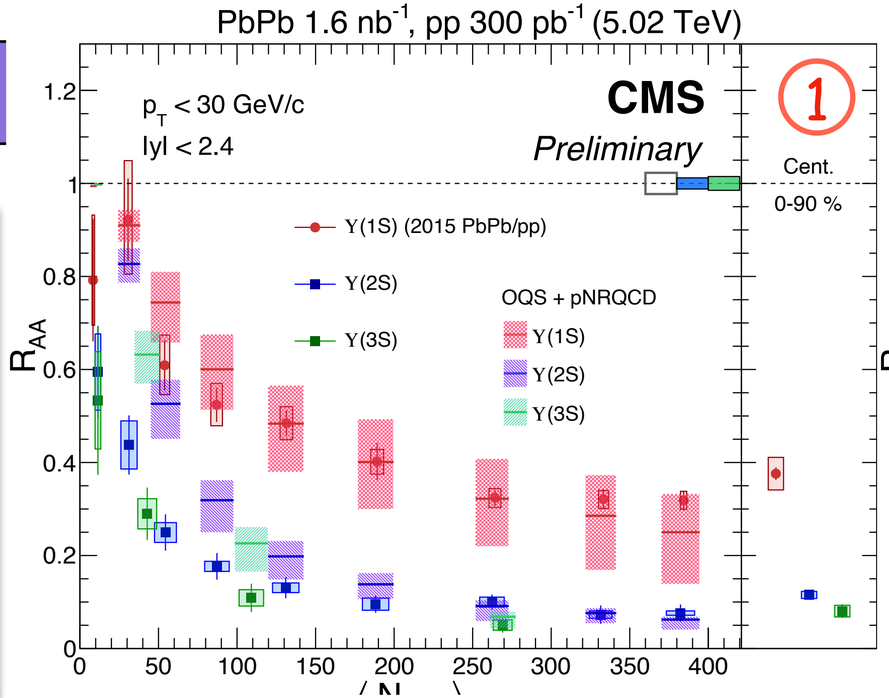
- Stronger suppression of Y(3S) in more central region

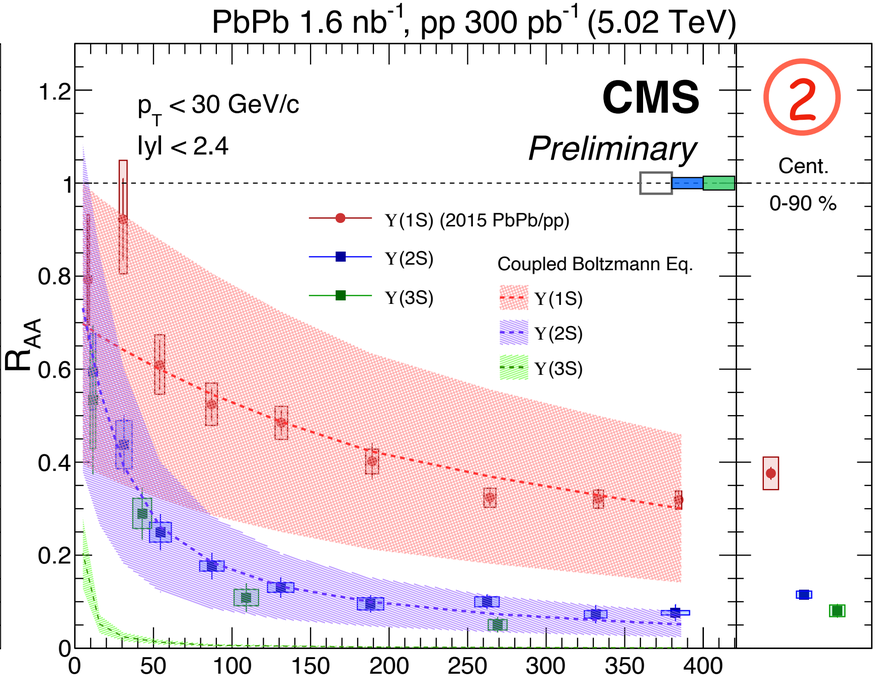
- Y(3S) more suppressed than Y(2S) in all p_T ranges
- No clear p_T dependance of double ratio Y(3S) / Y(2S)

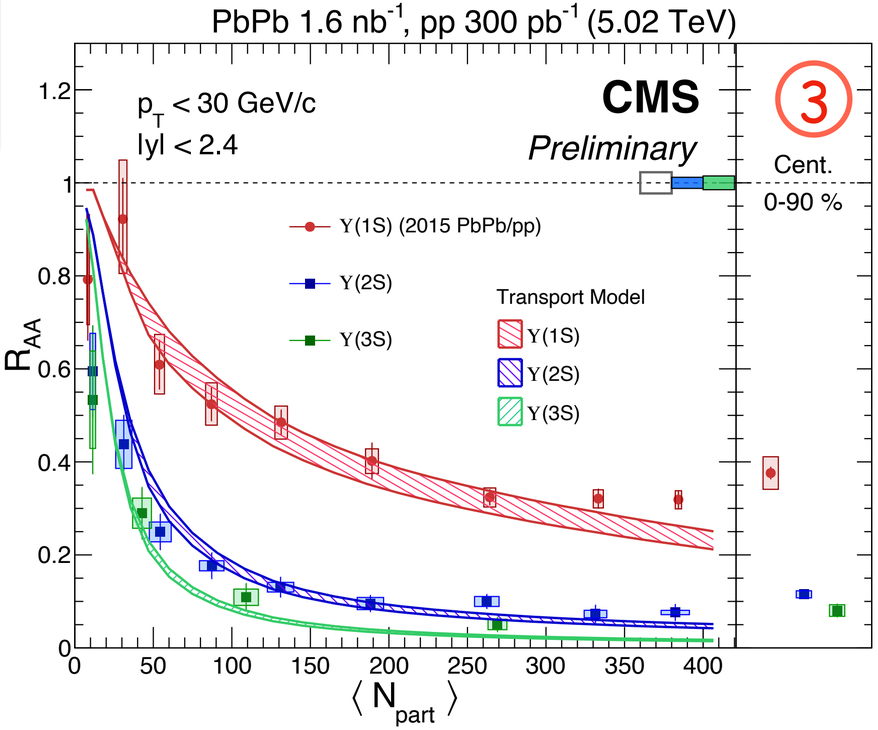
R_{AA} Comparison with theory : N_{part}

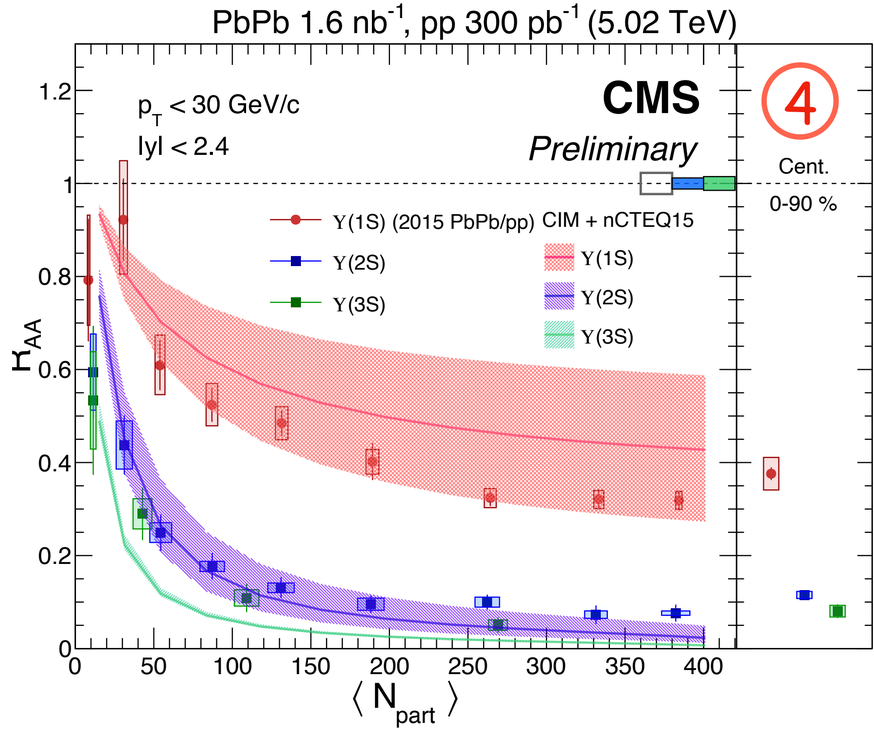
1. **Open quantum system + pNRQCD**
   PRD 104 094049
2. **Coupled Boltzmann Equation**
   JHEP 10(2018) 094
3. **Transport rate equation**
   PRC 96 054901
4. **Comover interaction model**
   JHEP 01(2021) 046

- Feed down contributions considered for all models
- Regeneration effect is different across the models(no reg. effect in (i) Y(3S) in (2) and (ii) all Y state in (4))
- Theory uncertainty such as nPDF parameters, CIM, dissociation temp., and transport coefficient

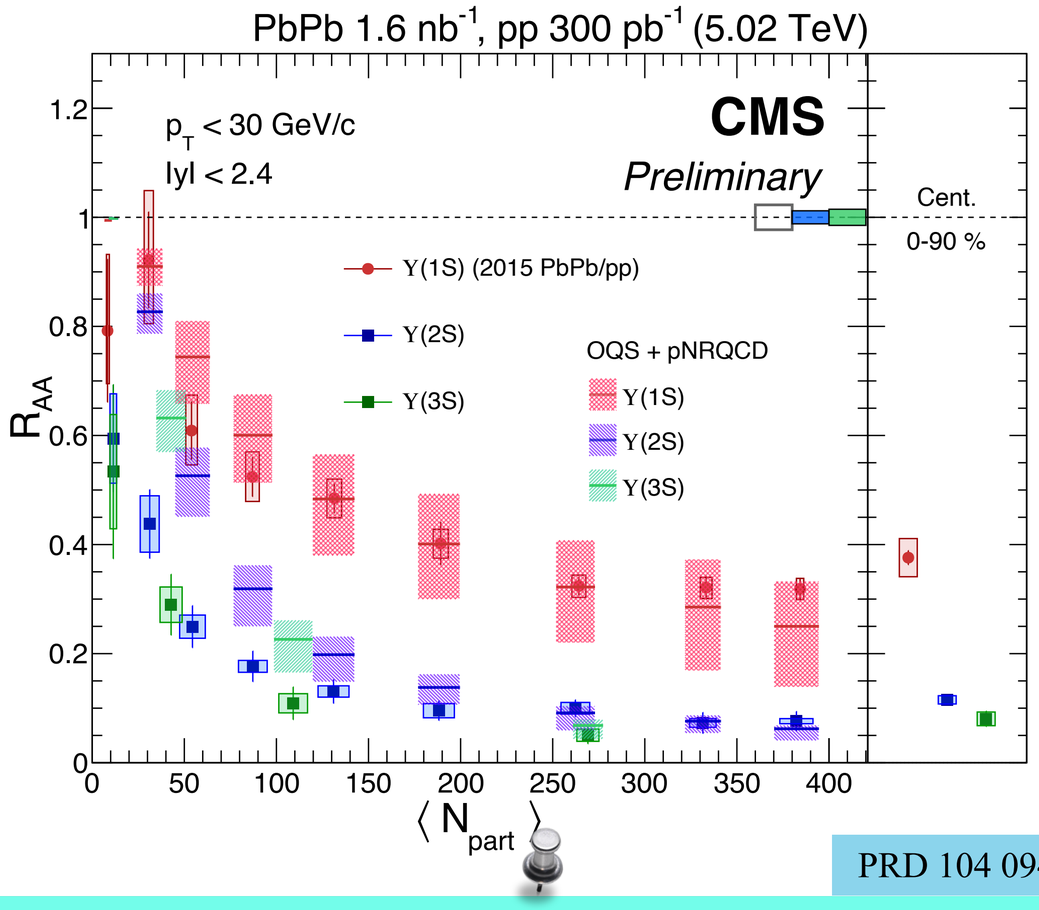








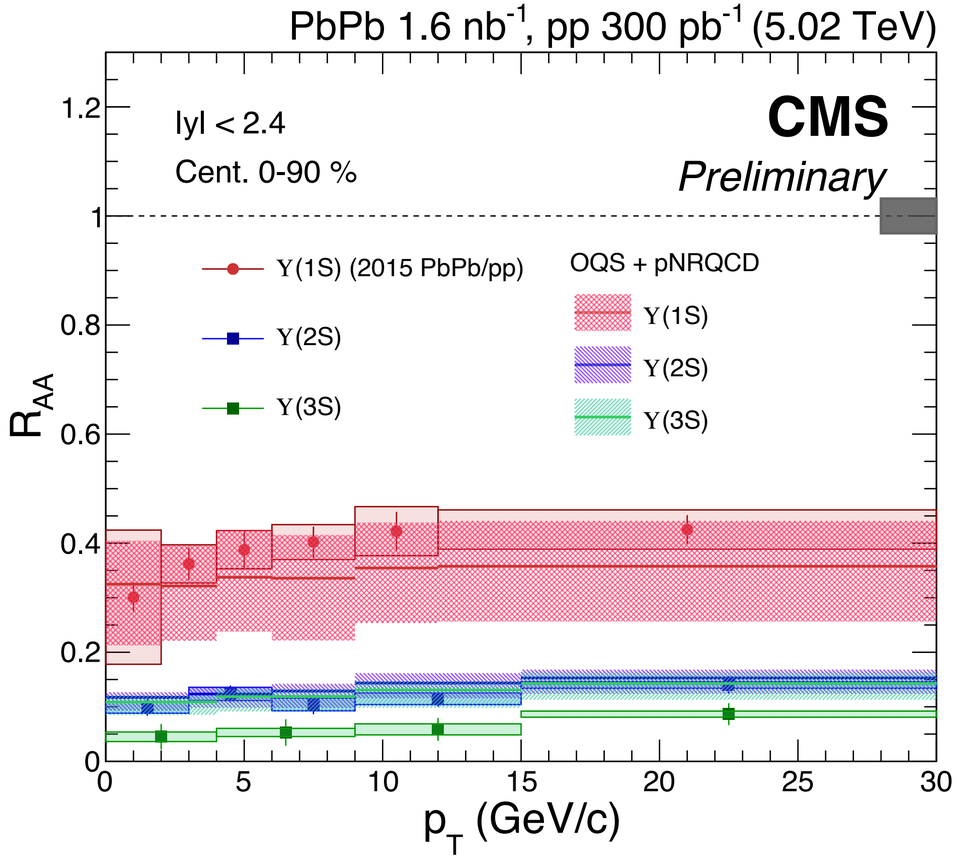
R_{AA} Comparison with theory (1)



PRD 104 094049

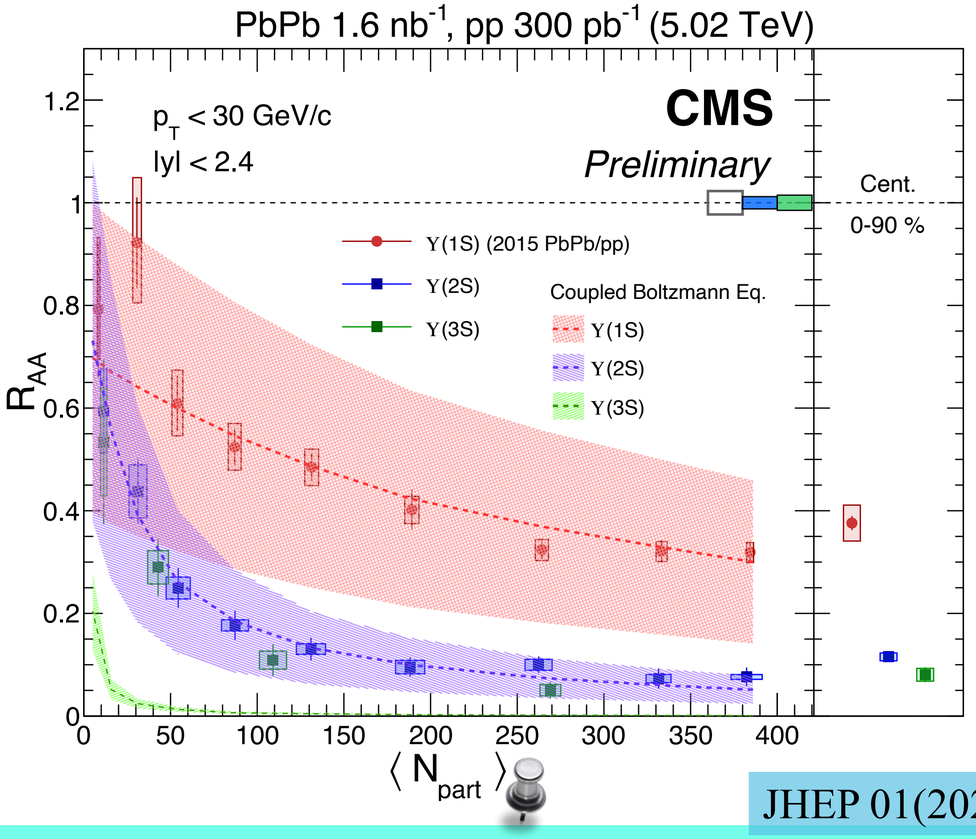
Open quantum system + potential NRQCD

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

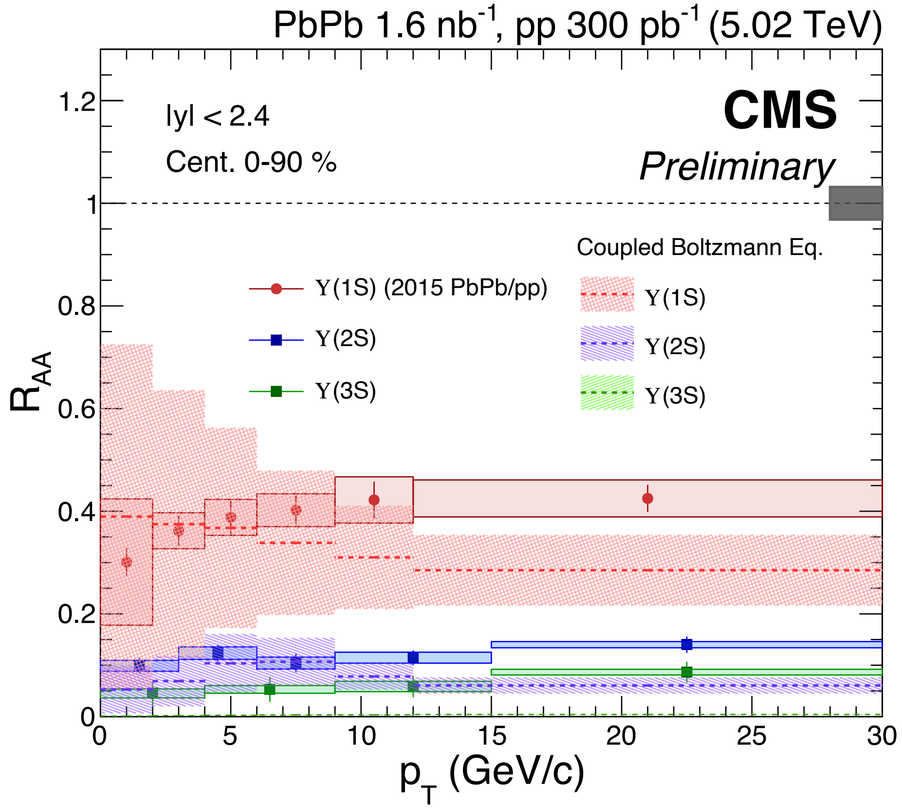


- Discrepancy of excited states in mid-peripheral collisions
- Overestimates R_{AA} $\Upsilon(3S)$ vs p_T

R_{AA} Comparison with theory (2)



JHEP 01(2021) 046

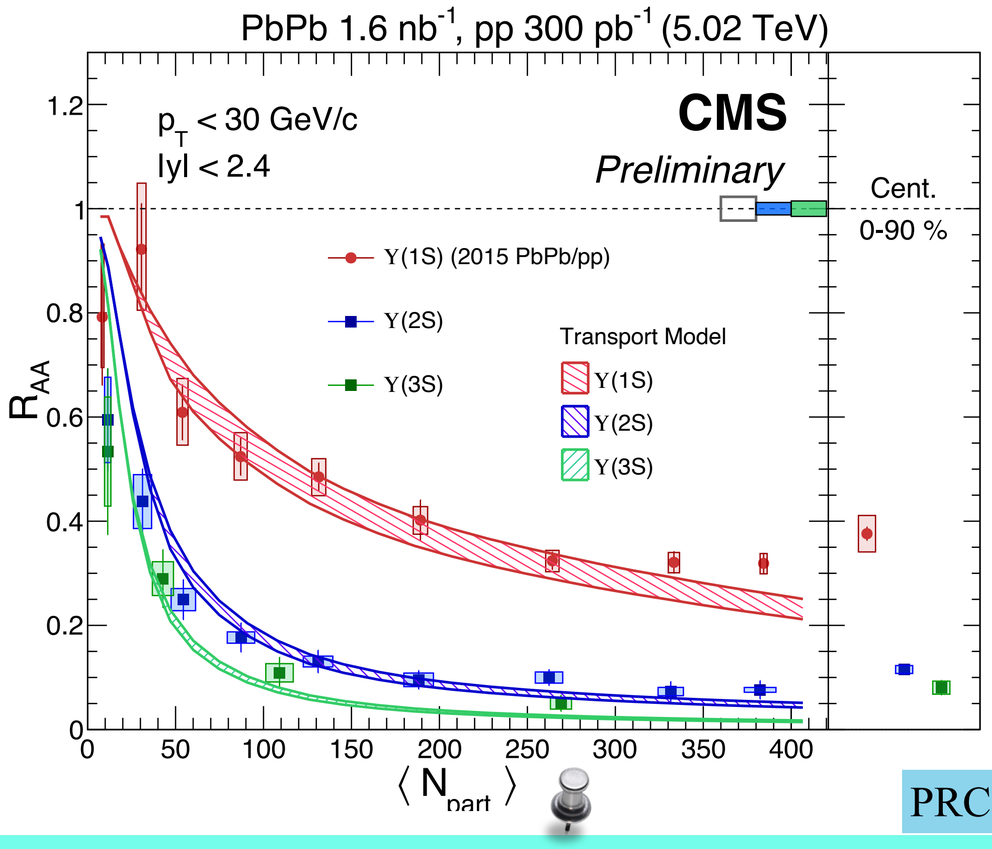


Coupled Boltzmann Equation

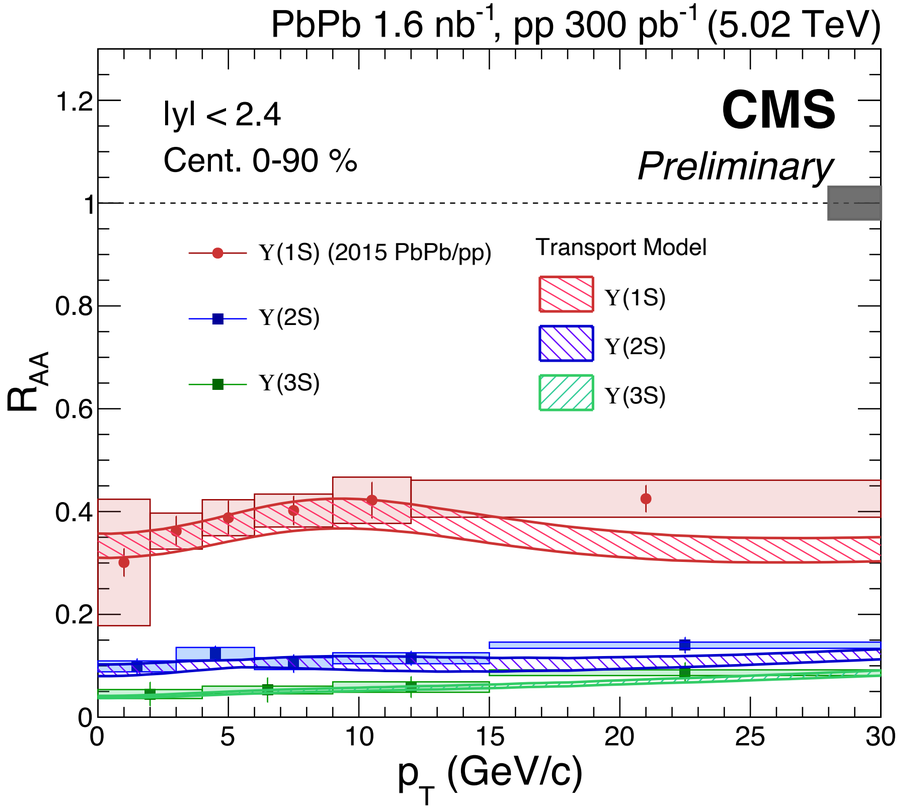
- Dissociation & regeneration
- Large uncertainty from nPDF EPPS16
  No regeneration included for **Υ(3S)**
- Feed down contributions considered

- Predicts larger **Υ(3S)** suppression than data
- Discrepancy at high p_T

R_{AA} Comparison with theory (3)



PRC 96 054901

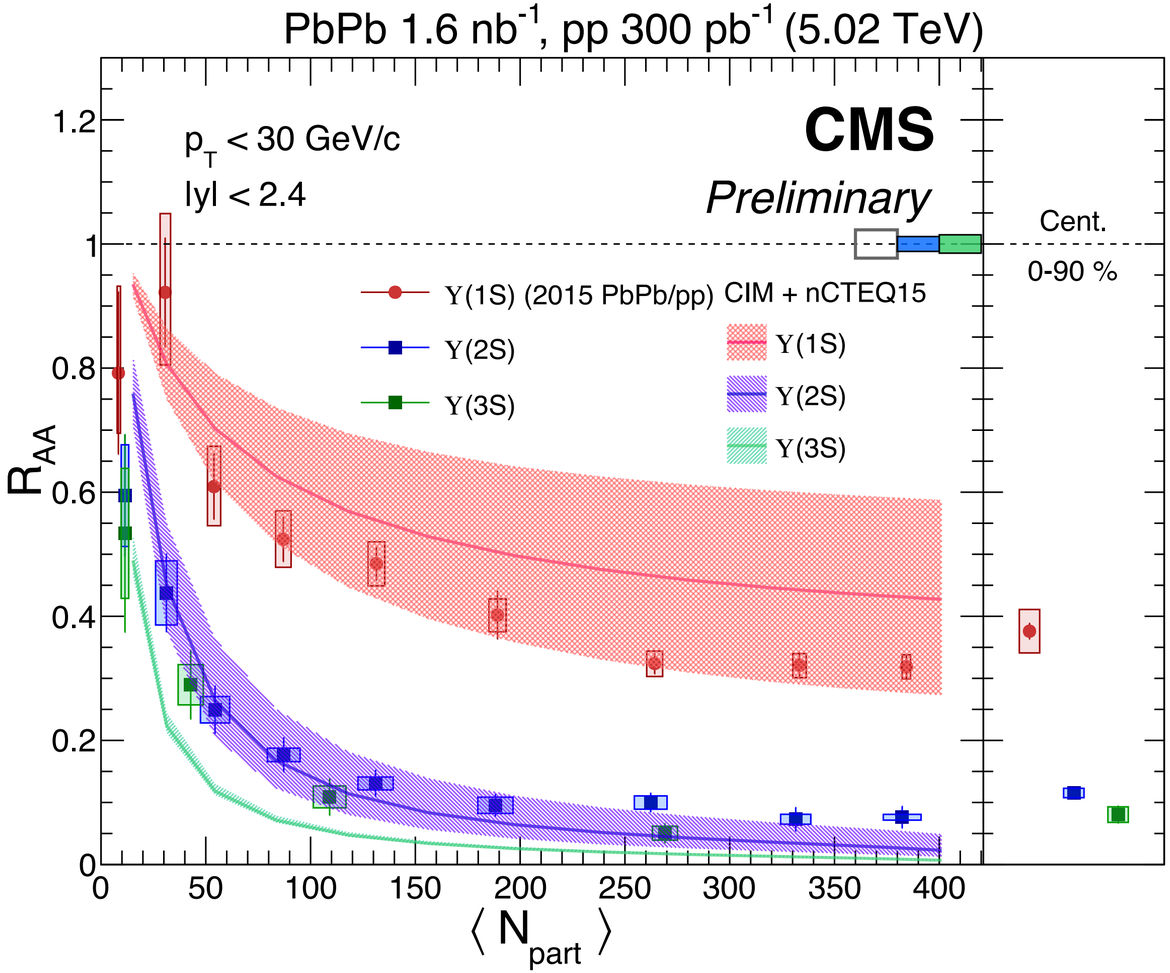


Kinetic rate equation

- In medium binding energy with T-matrix calculation
- Regeneration of excited states
- Feed down contributions considered

- R_{AA} description of the two excited states quite well in most kinematic ranges
  - Difference is seen in the most central collision & Υ(1S) high p_T
- Regeneration dominant in excited states

R_{AA} Comparison with theory (4)



Comover interaction model + nCTEQ15

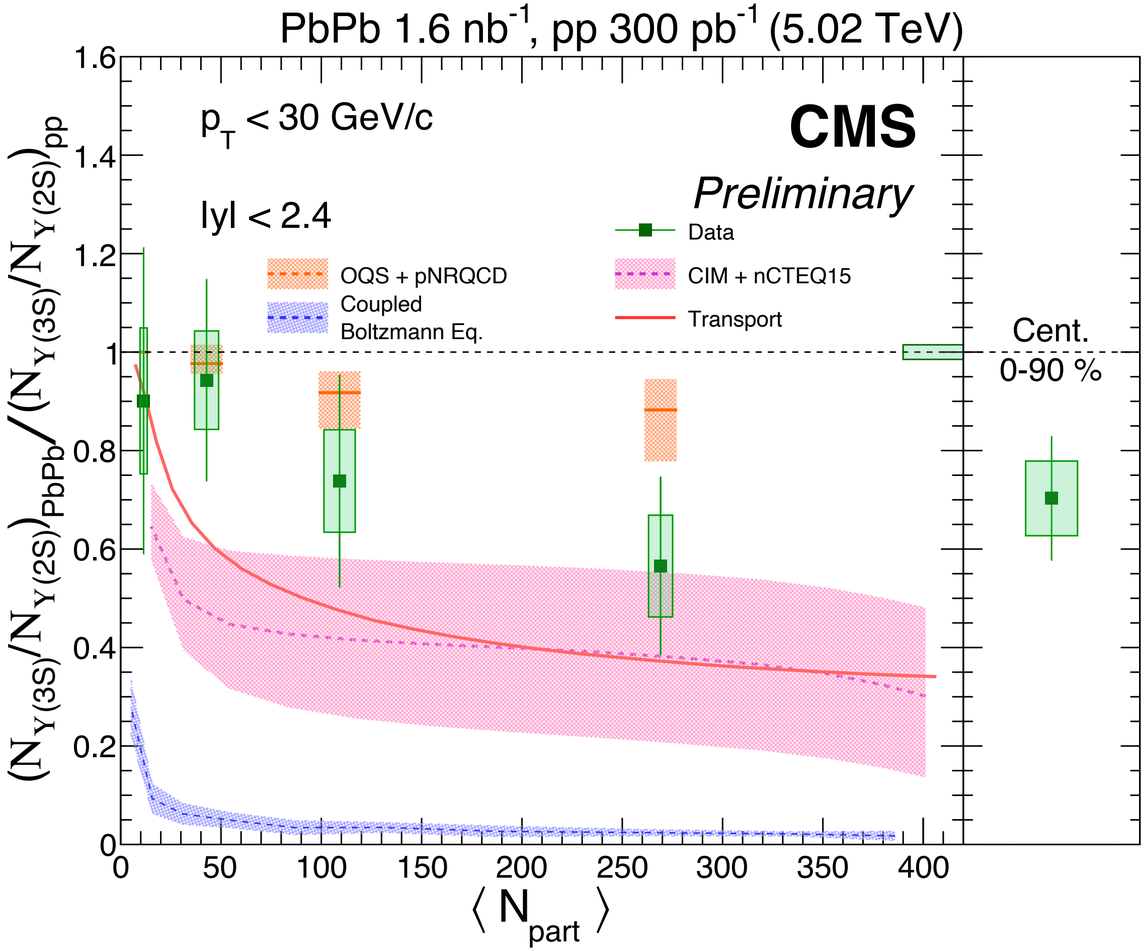
JHEP 10(2018) 094

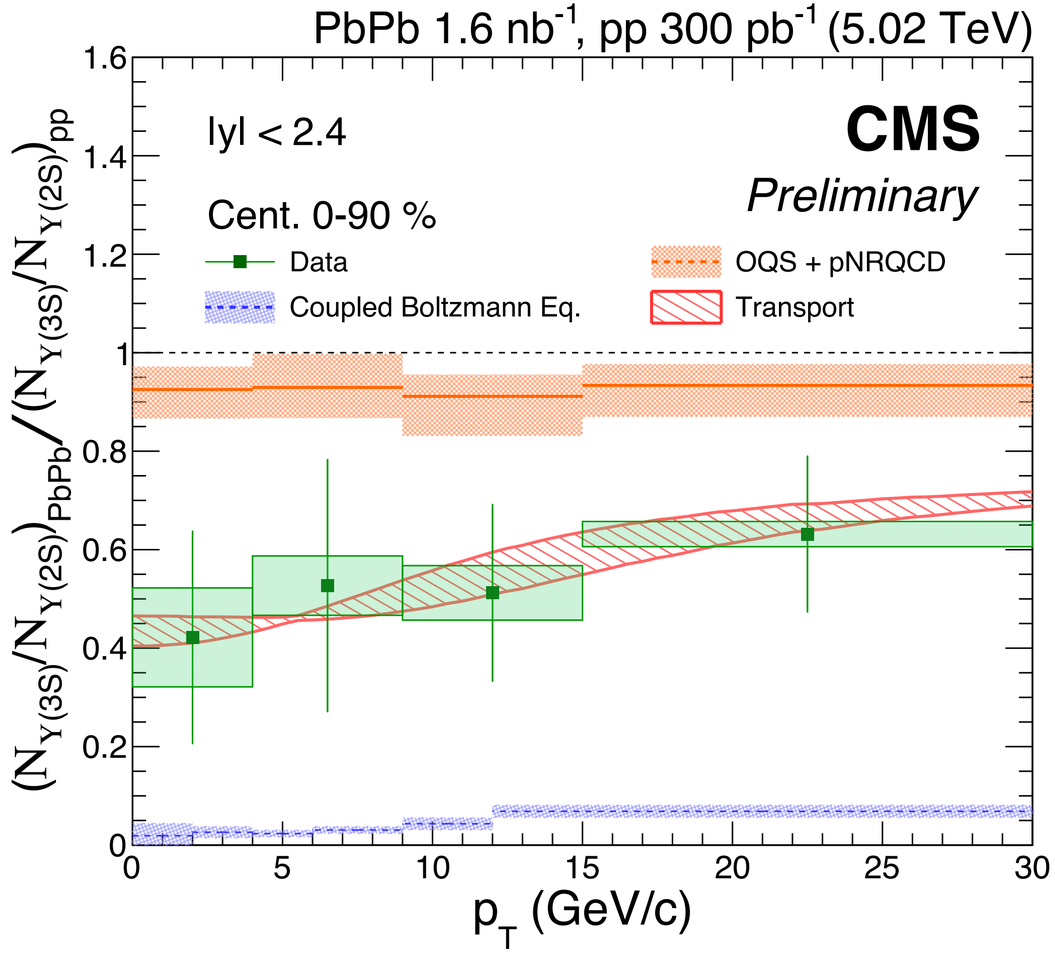
- Gluon acting as proxy of pion in comover breakup
  - No regeneration calculation
- nPDF + CIM cross-section uncertainties combined
- Feed down contributions included

❖Lower R_{AA} for Υ(3S) than data towards central collisions

Some mismatches between data and theories

Double ratio comparison with theories

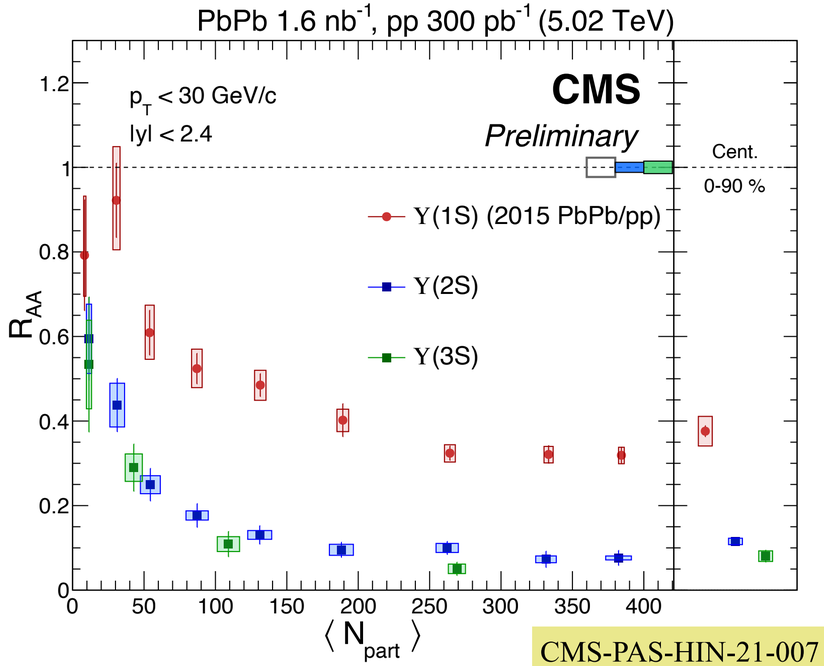




Models expect different rate of suppression between the excited states!

Conclusion & Take home Message

- First observation of **Υ(3S)** in PbPb collisions!
- Sequential suppression of **Υ**(nS)
- Strong constraints on theoretical models
  - Need to carefully treat the theoretical ingredients
- New data from Run3 around the corner!



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