

Observation of the  $Y(3S)$  meson and sequential suppression of  $Y$  states in PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV

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on behalf of the CMS collaboration,  
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# Introduction

- Bottomonia are good probes to study the QGP

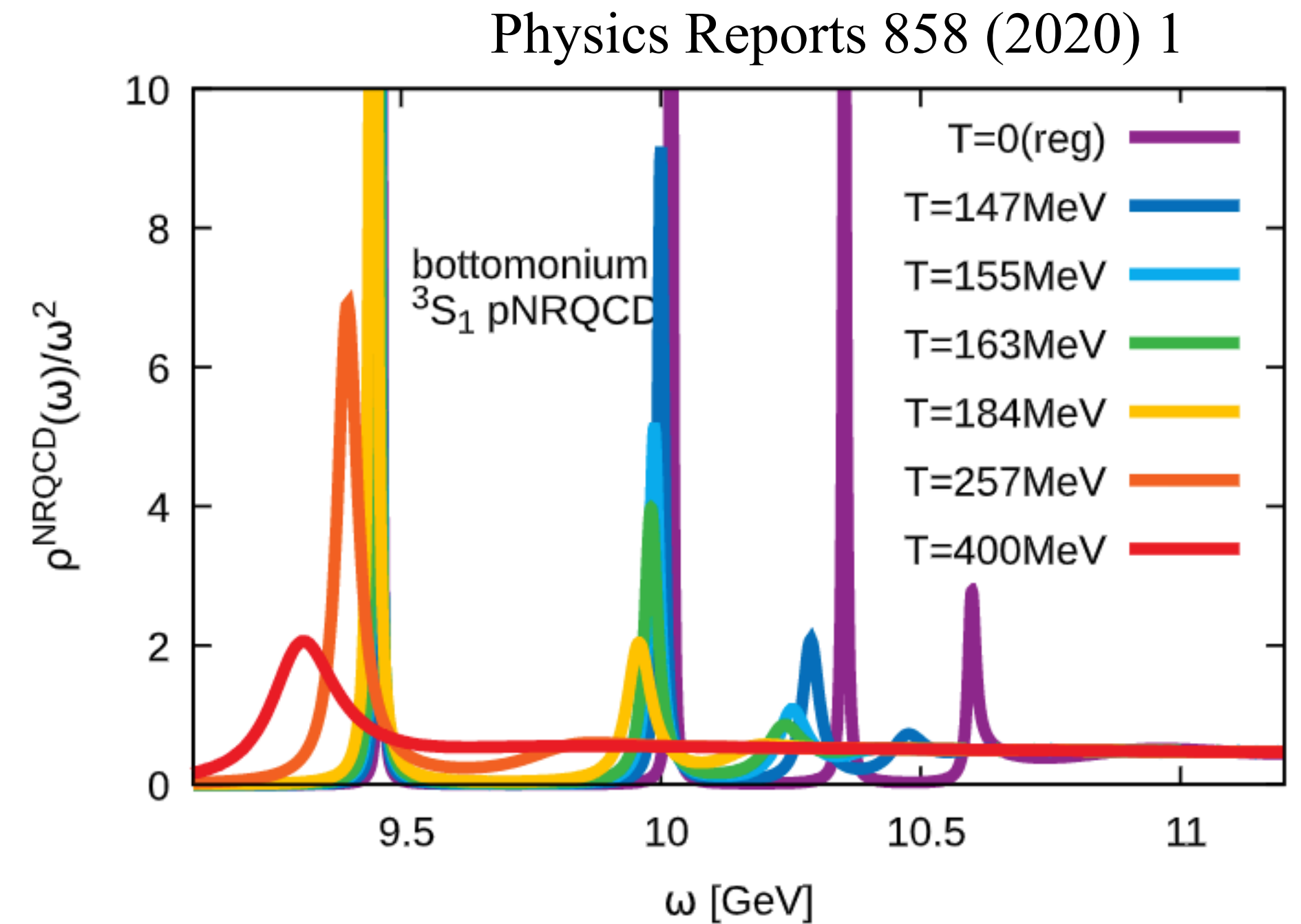
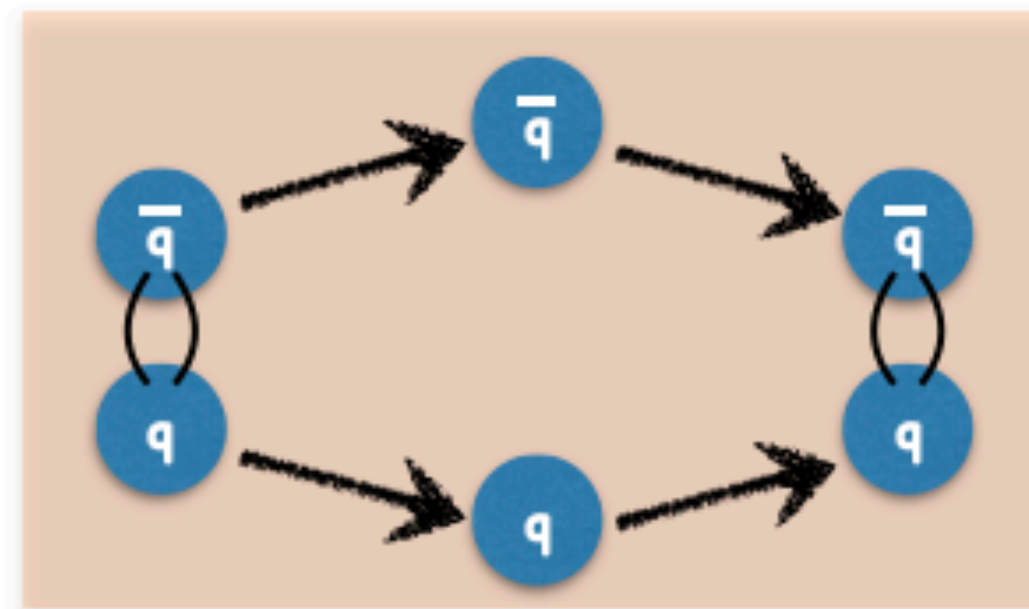
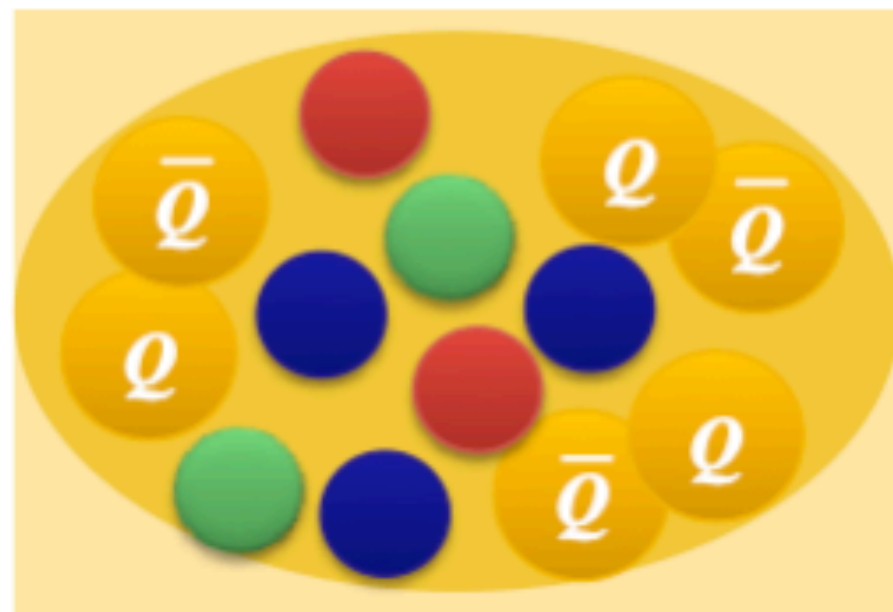
☑ Produced mostly from initial hard scattering

☑ Sensitive to in medium effects

(color screening, gluo-dissociation, recombination)

❖ Uncorrelated

❖ Correlated



# History of $Y$ measurement in HI with CMS

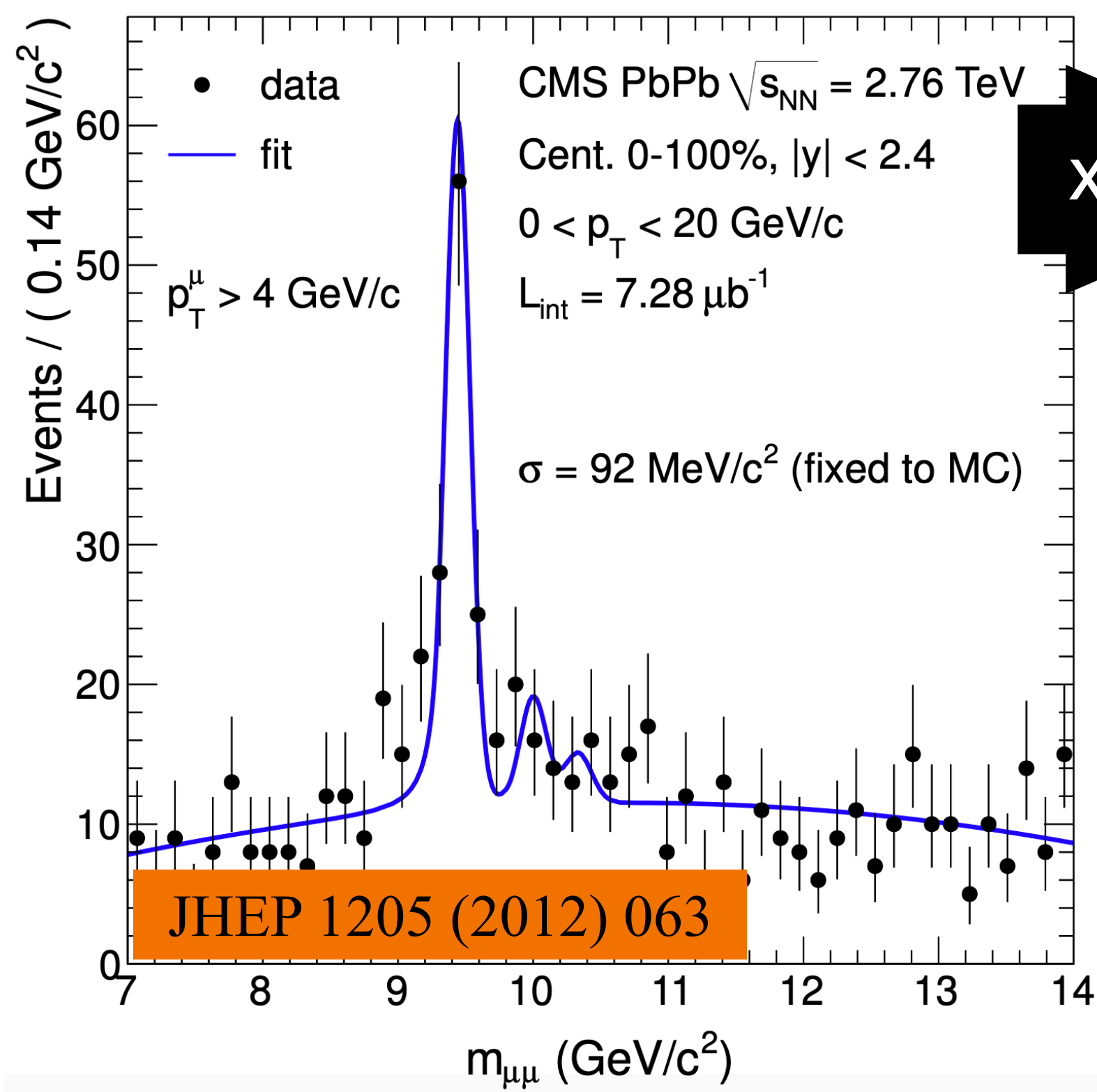
- Limited statistics in previous measurements

$7.28 \mu\text{b}^{-1}$

$166 \mu\text{b}^{-1}$

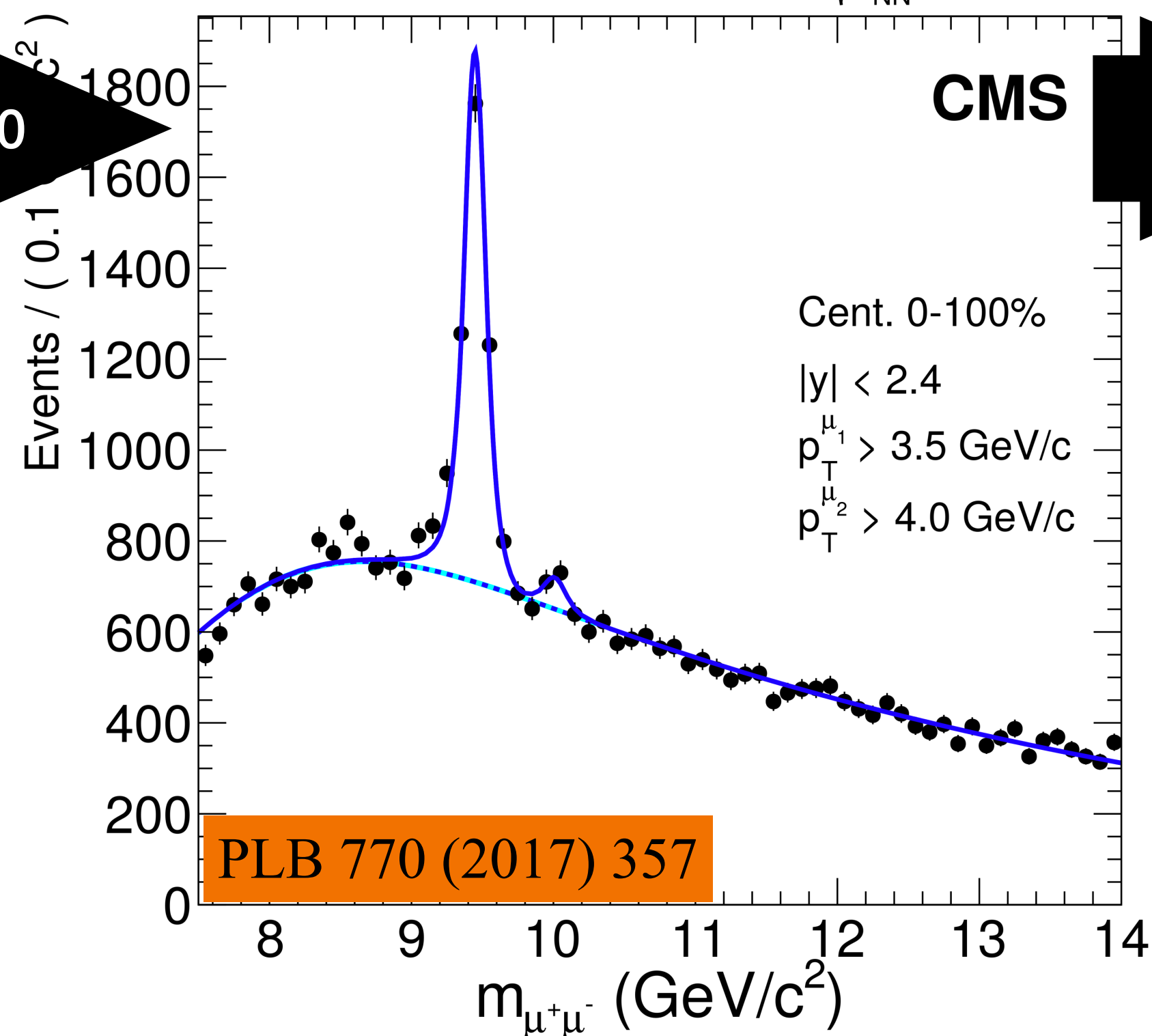
$368 \mu\text{b}^{-1}$

2.76 TeV



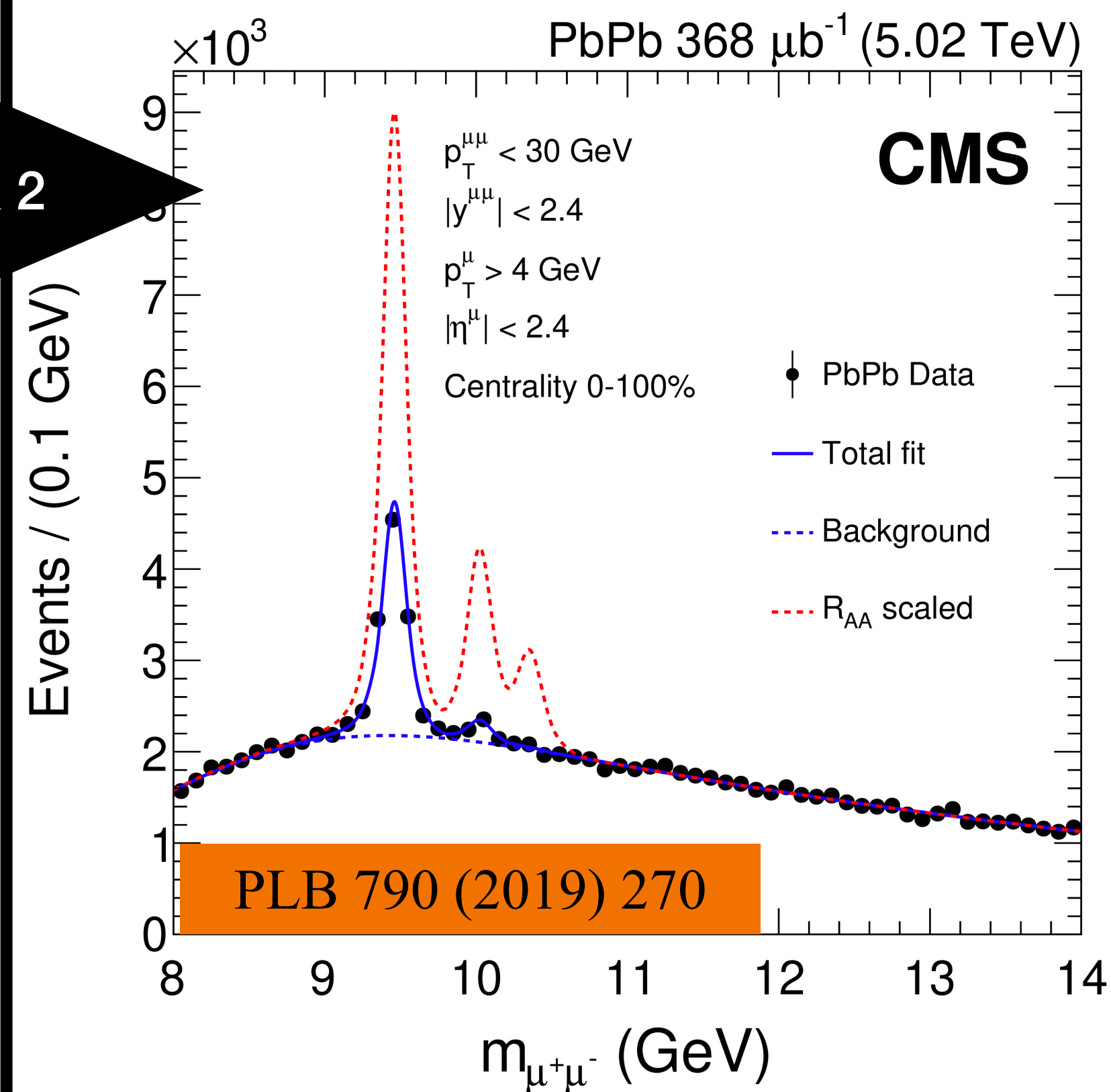
X 20

PbPb  $\sqrt{s_{\text{NN}}} = 2.76 \text{ TeV}$



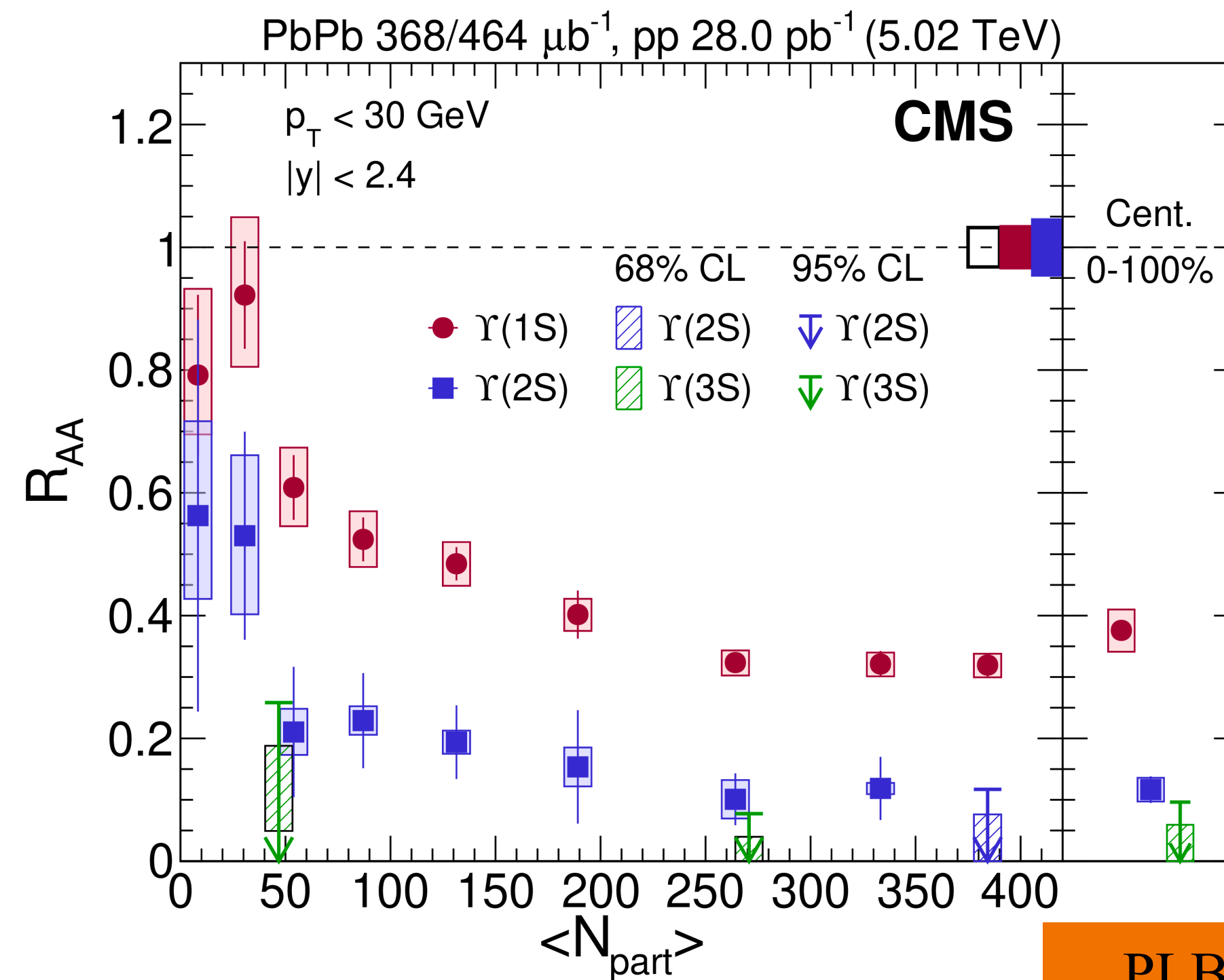
X 2

5.02 TeV

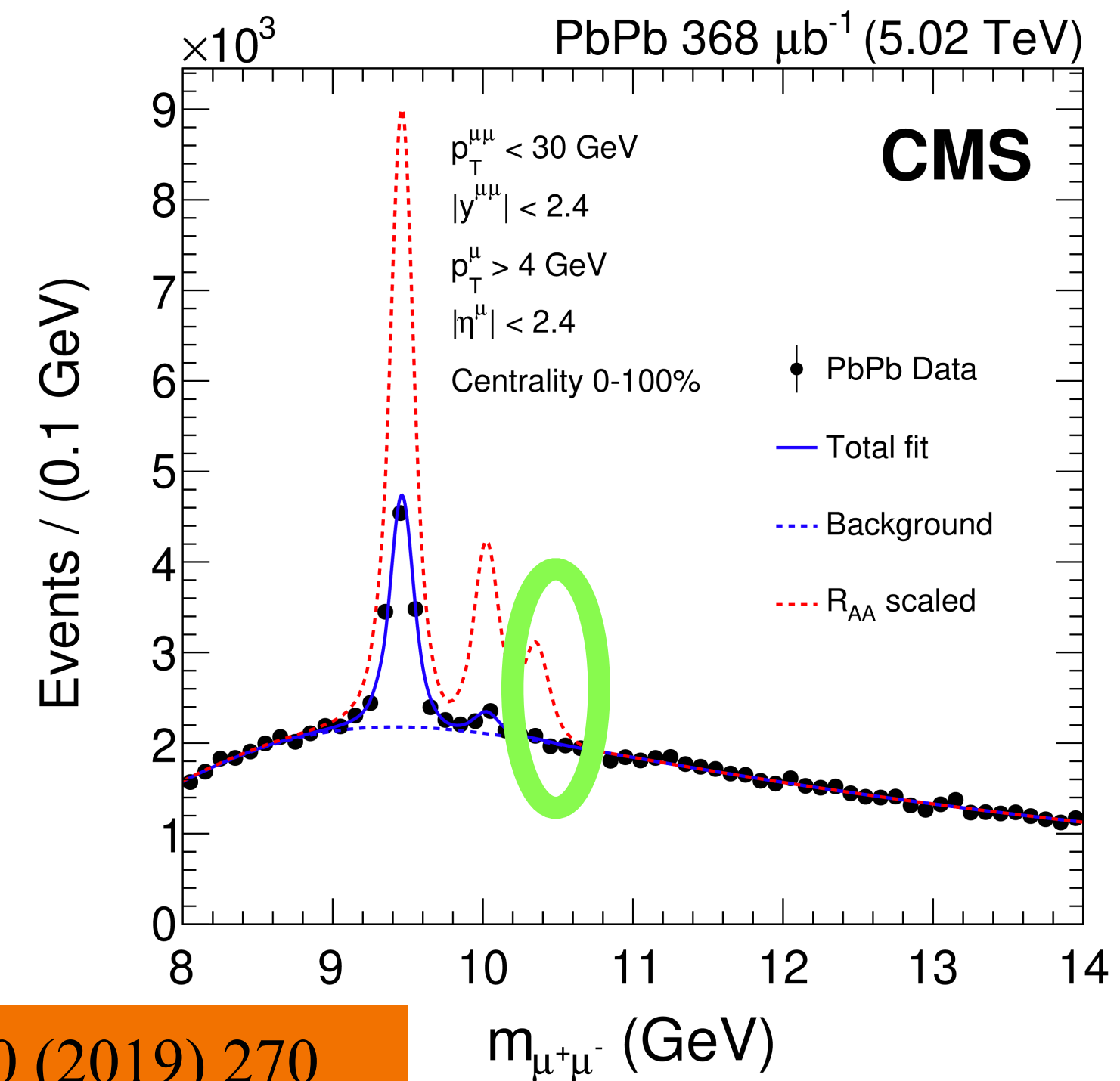


# Motivation

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

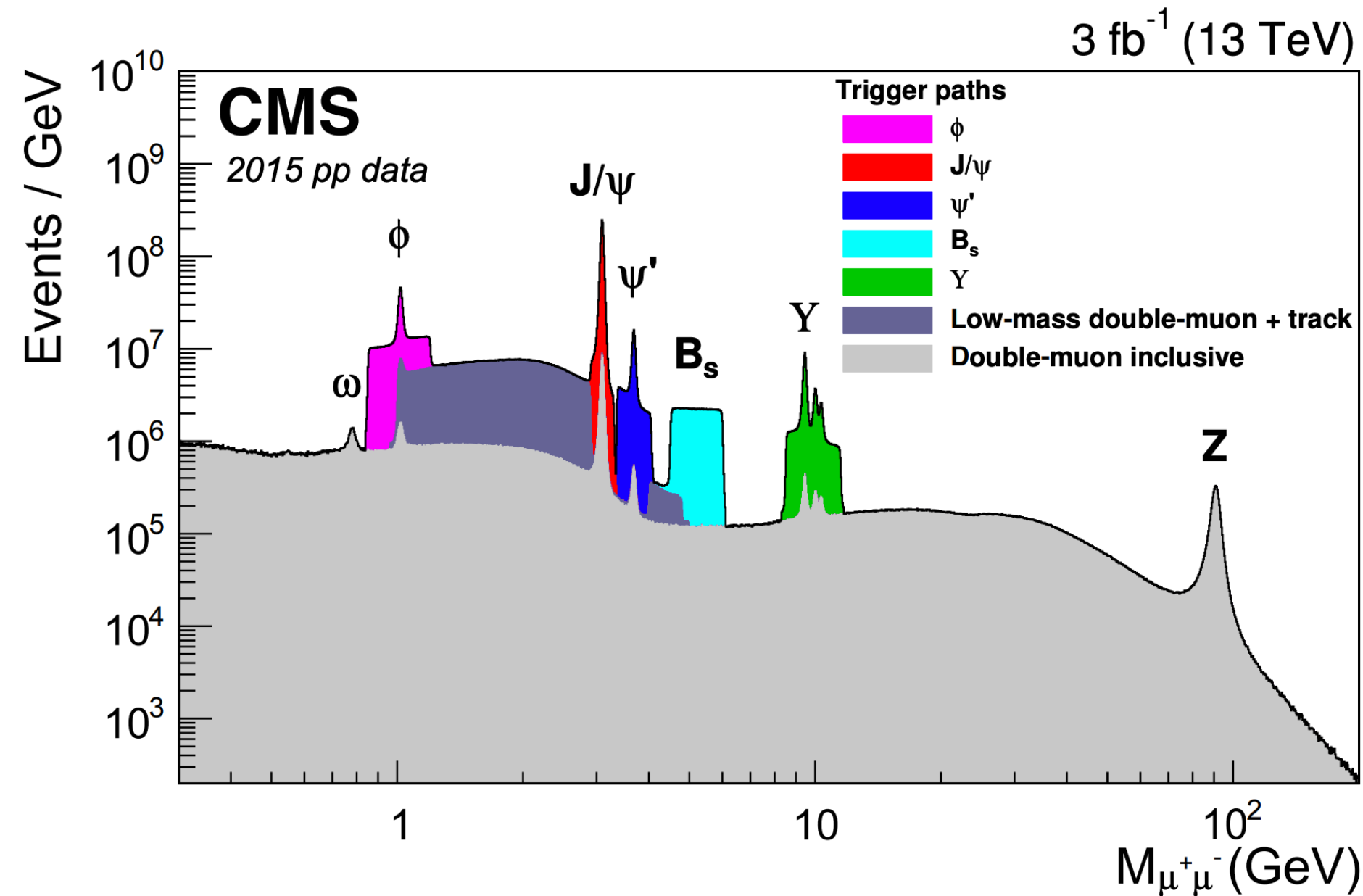


PLB 790 (2019) 270





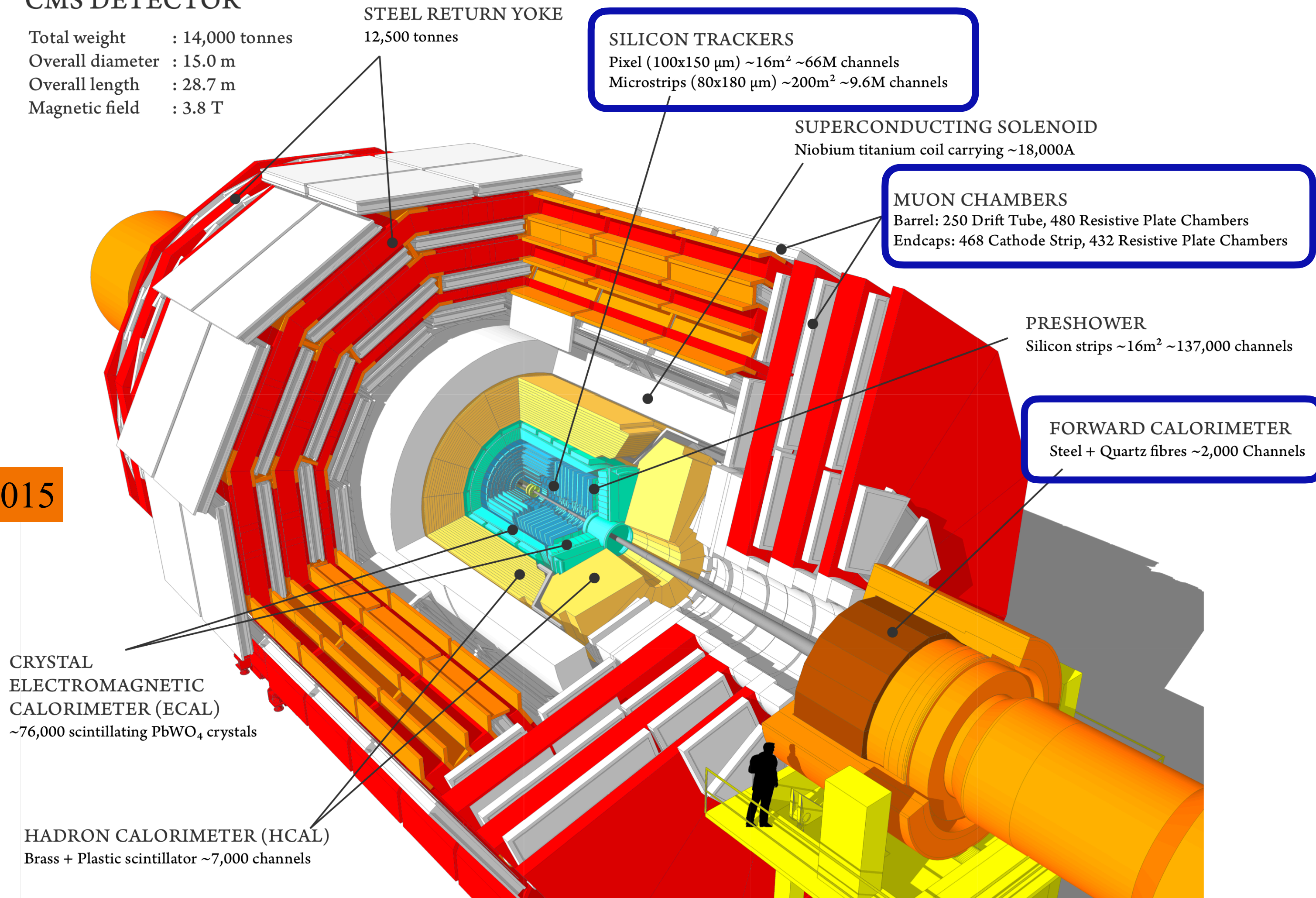
# The CMS detector



JINST 13 (2018) P06015

## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T



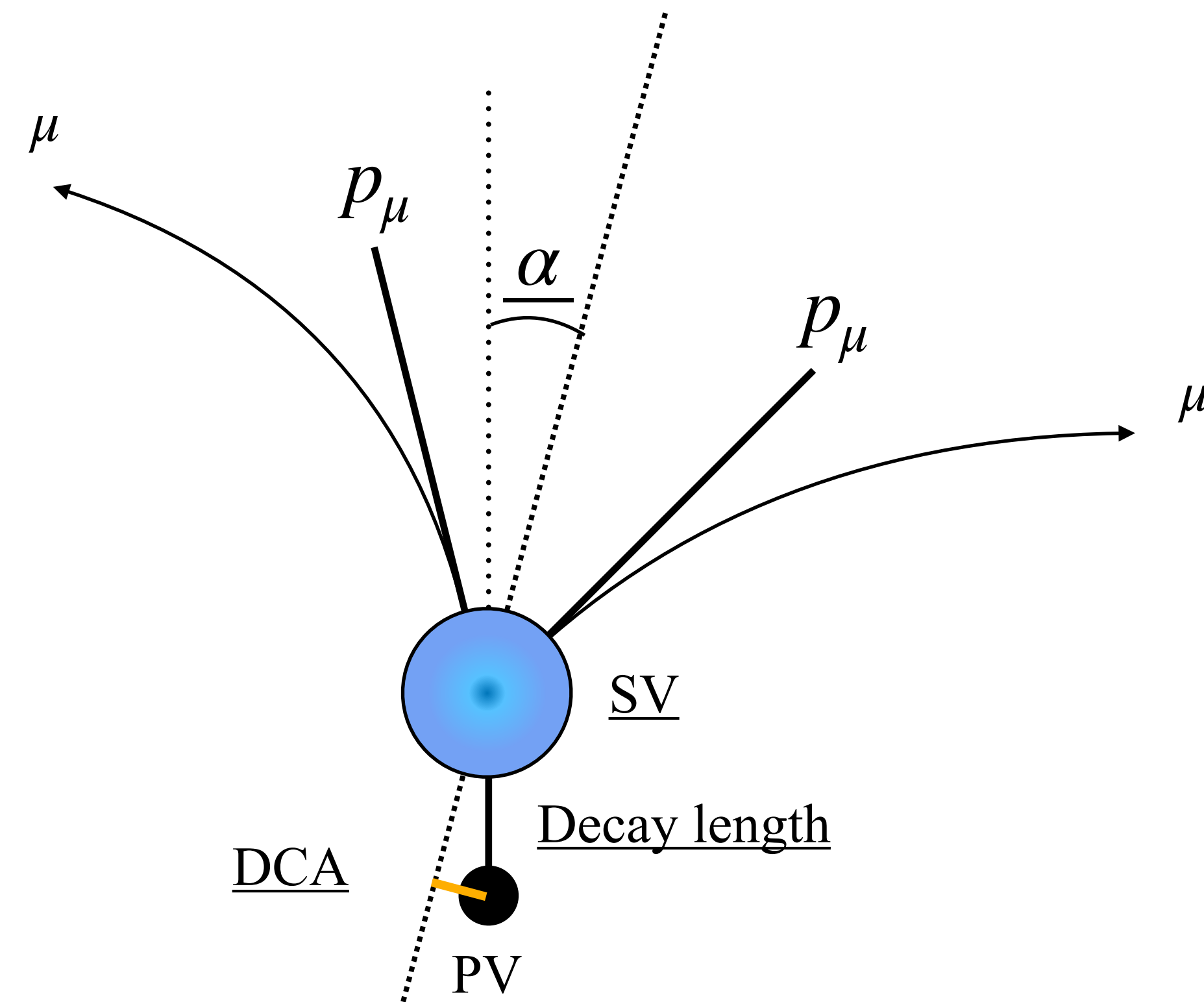
The CMS is the perfect detector for bottomonium measurement in HI collisions.

- ❖ Wide  $p_T$  range of muon ( $> \mathcal{O}(100)$  GeV)
- ❖ Good momentum resolution
- ❖ Large cover of muon reconstruction

# Analysis Method - Sample selection

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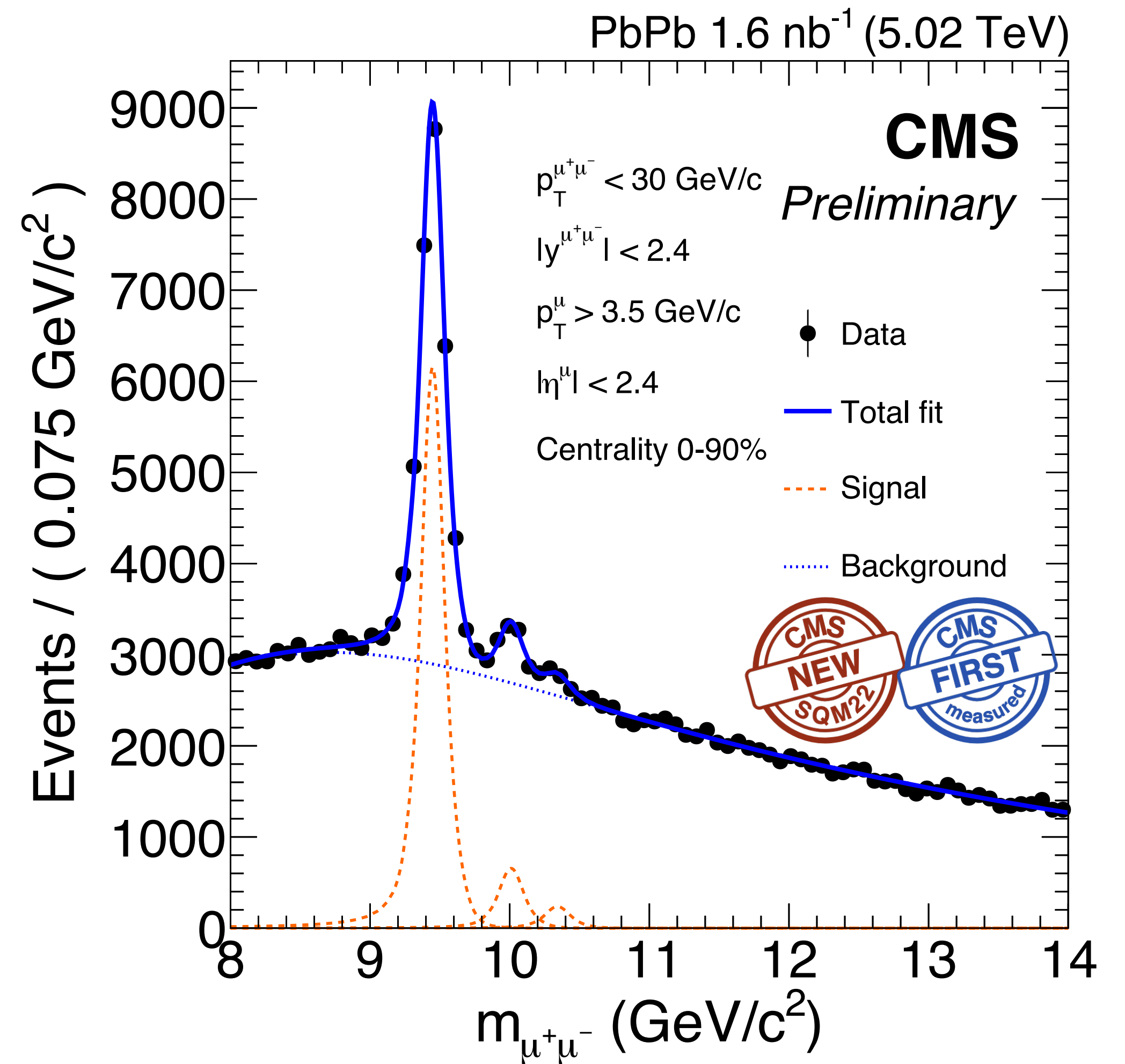
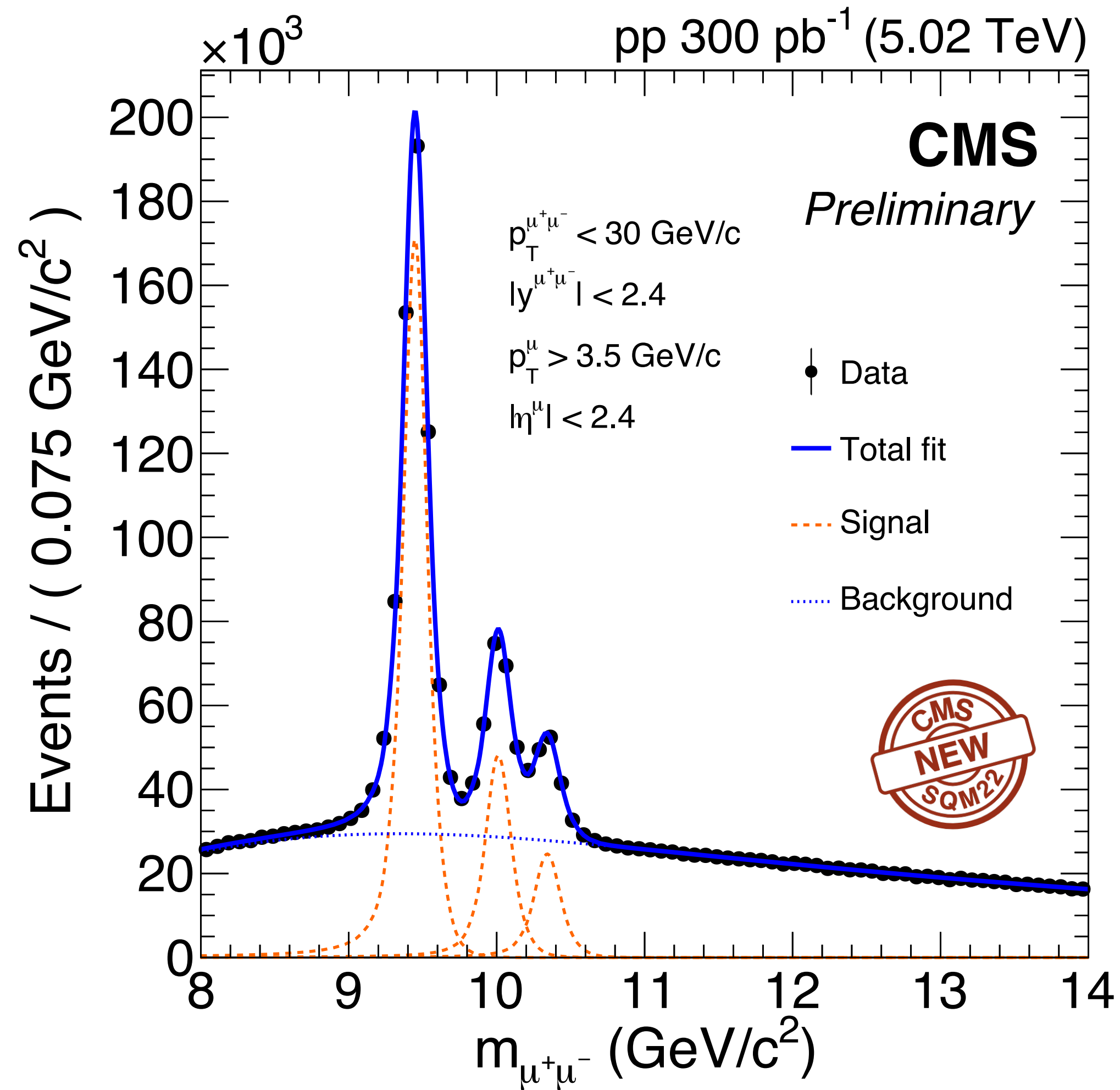
- Signal enhancement with MVA selection(BDT) for PbPb data
  - ▶ Signal(MC) and background (side band data) classification
    - Pointing angle  $\alpha$ ,
    - Distance to closest approach (DCA),
    - Vertex related information





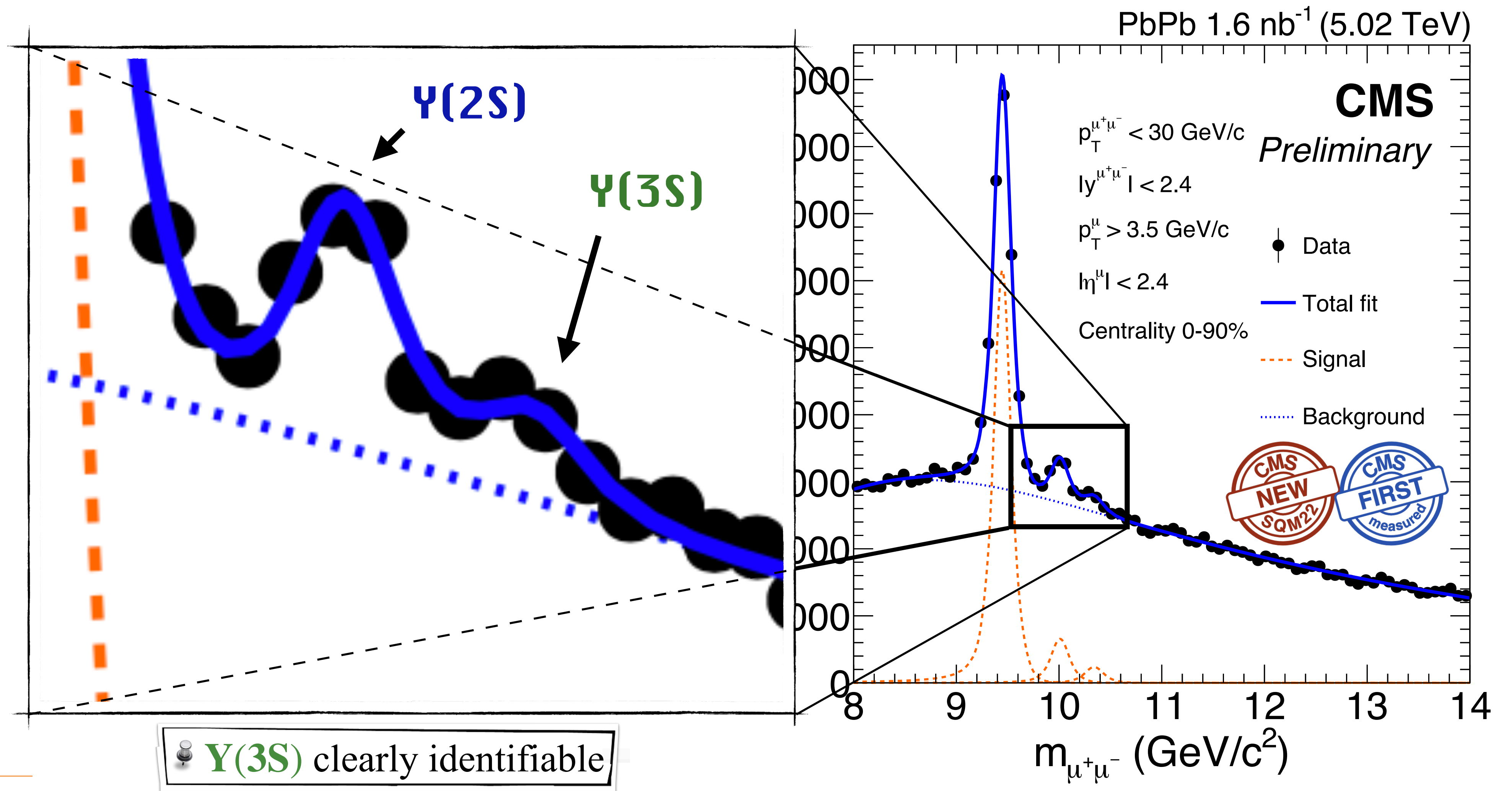
# Y(nS) signal extraction

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📍 First Observation of **Y(3S)** in AA collision ( $> 5\sigma$ )!

# $\Upsilon(nS)$ signal extraction



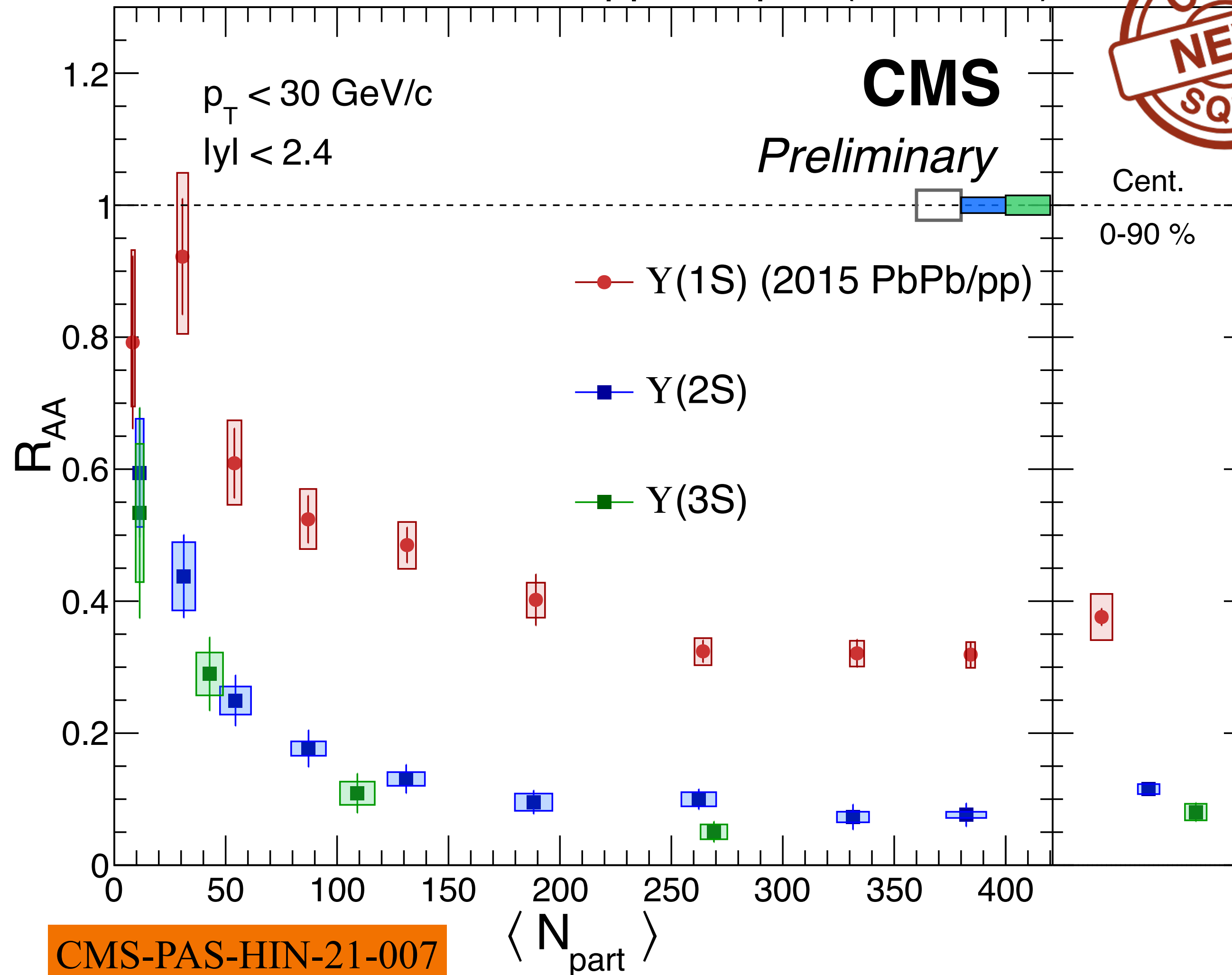


# New result! Nuclear modification factor ( $R_{AA}$ )

PbPb 1.6 nb<sup>-1</sup>, pp 300 pb<sup>-1</sup> (5.02 TeV)



**CMS**  
*Preliminary*



◆ Y(3S) measured in all centrality region

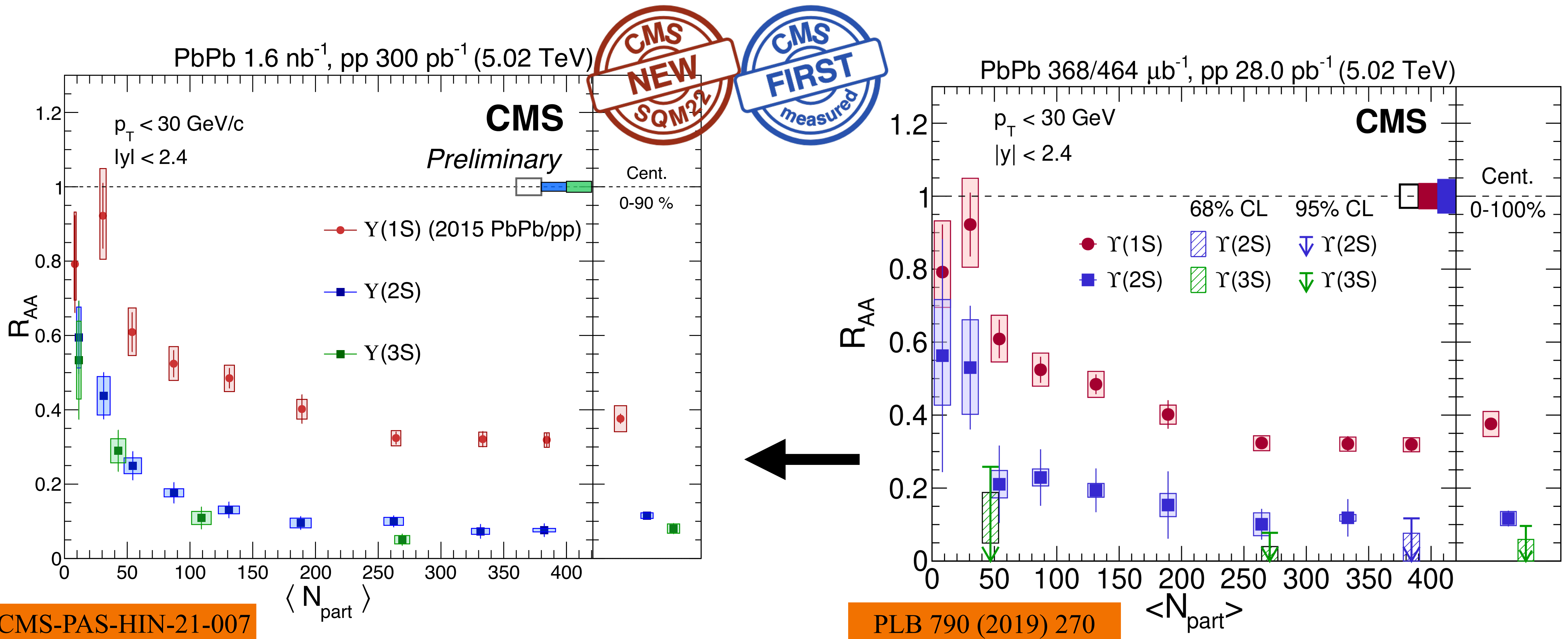
◆ Improved Y(2S)!

◆ Clear suppression

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

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# New result! Nuclear modification factor ( $R_{AA}$ )



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PLB 790 (2019) 270

❖ Improved **Y(2S)**!

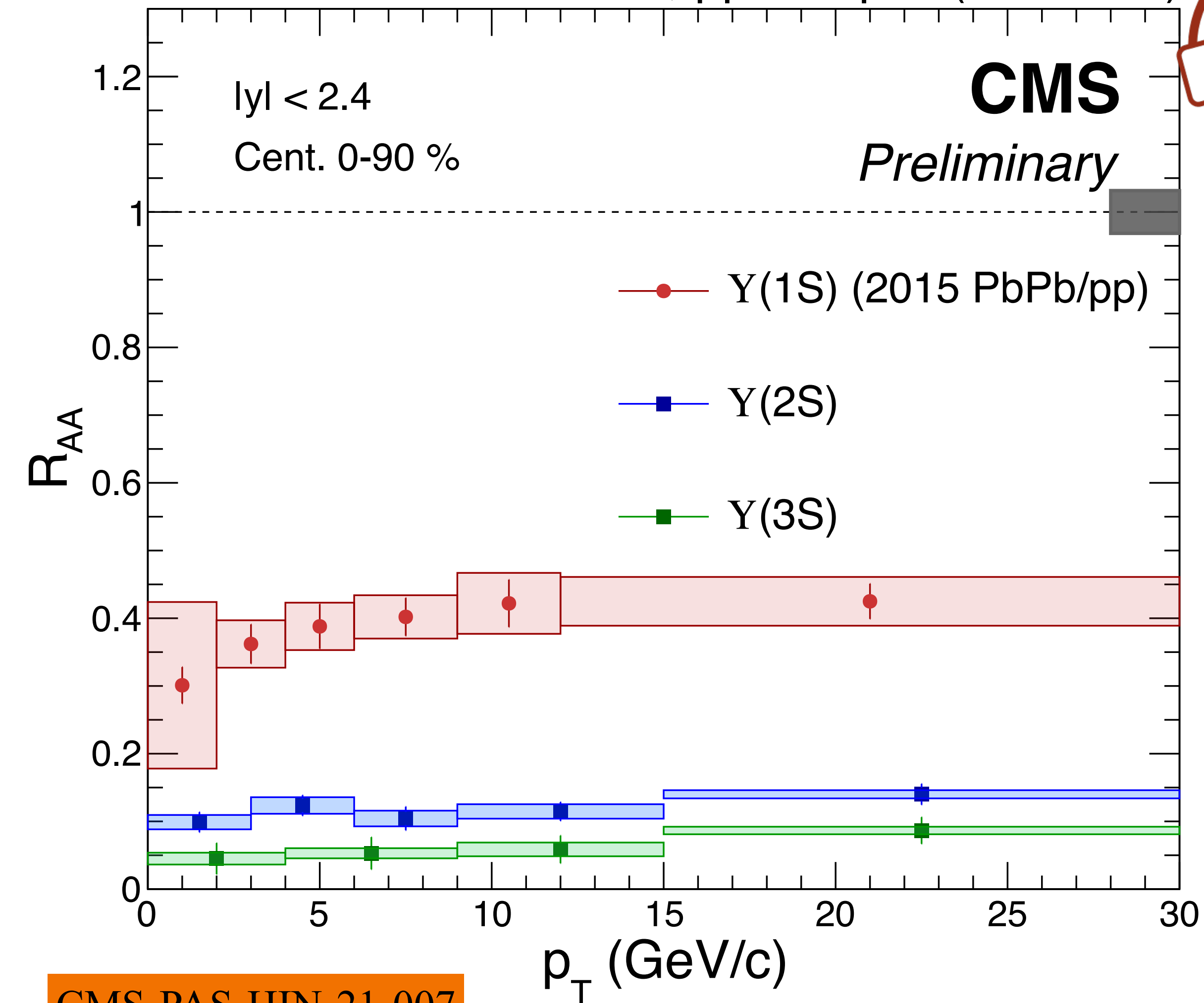
# New result! Nuclear modification factor ( $R_{AA}$ )

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**CMS**  
*Preliminary*

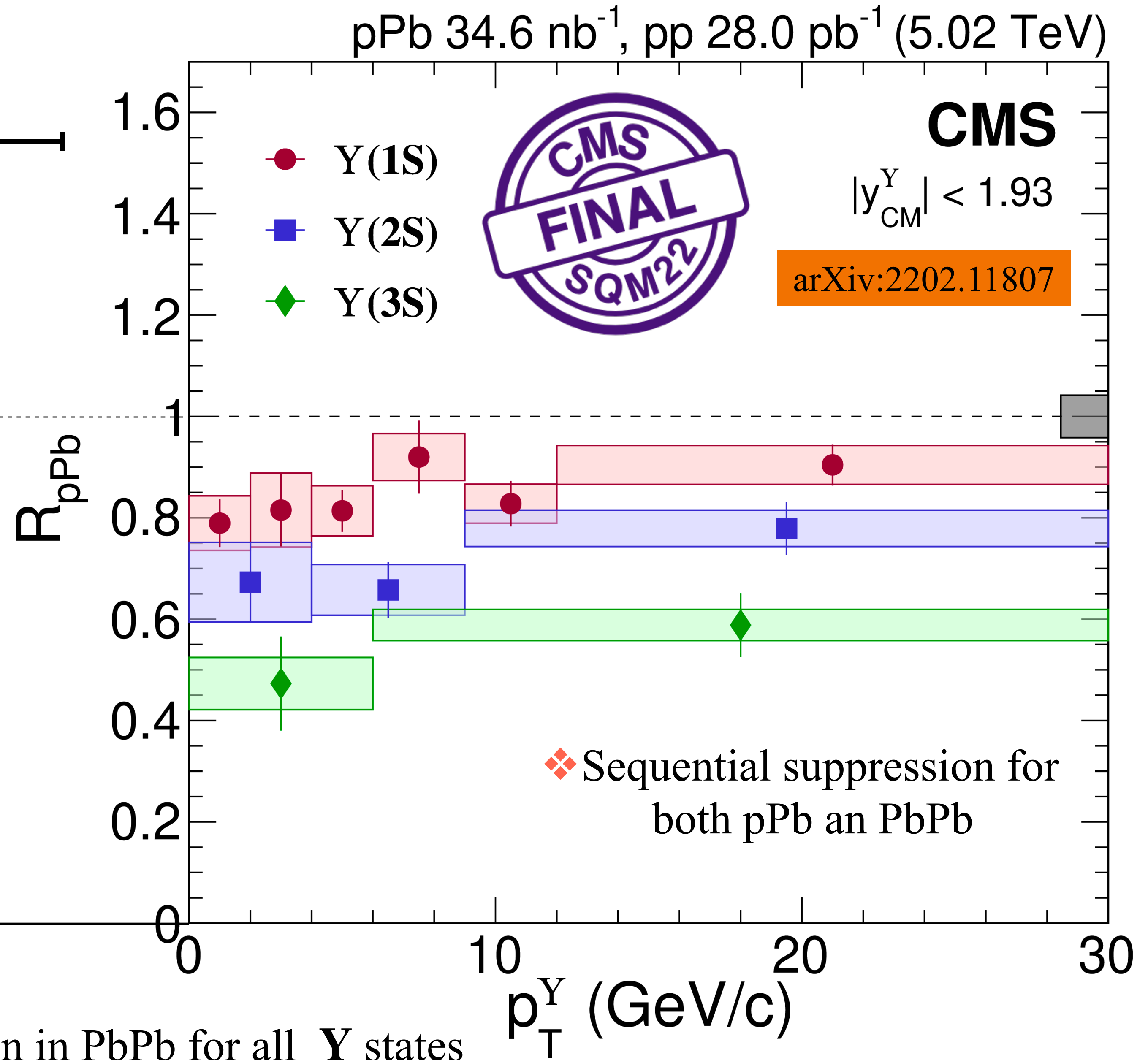
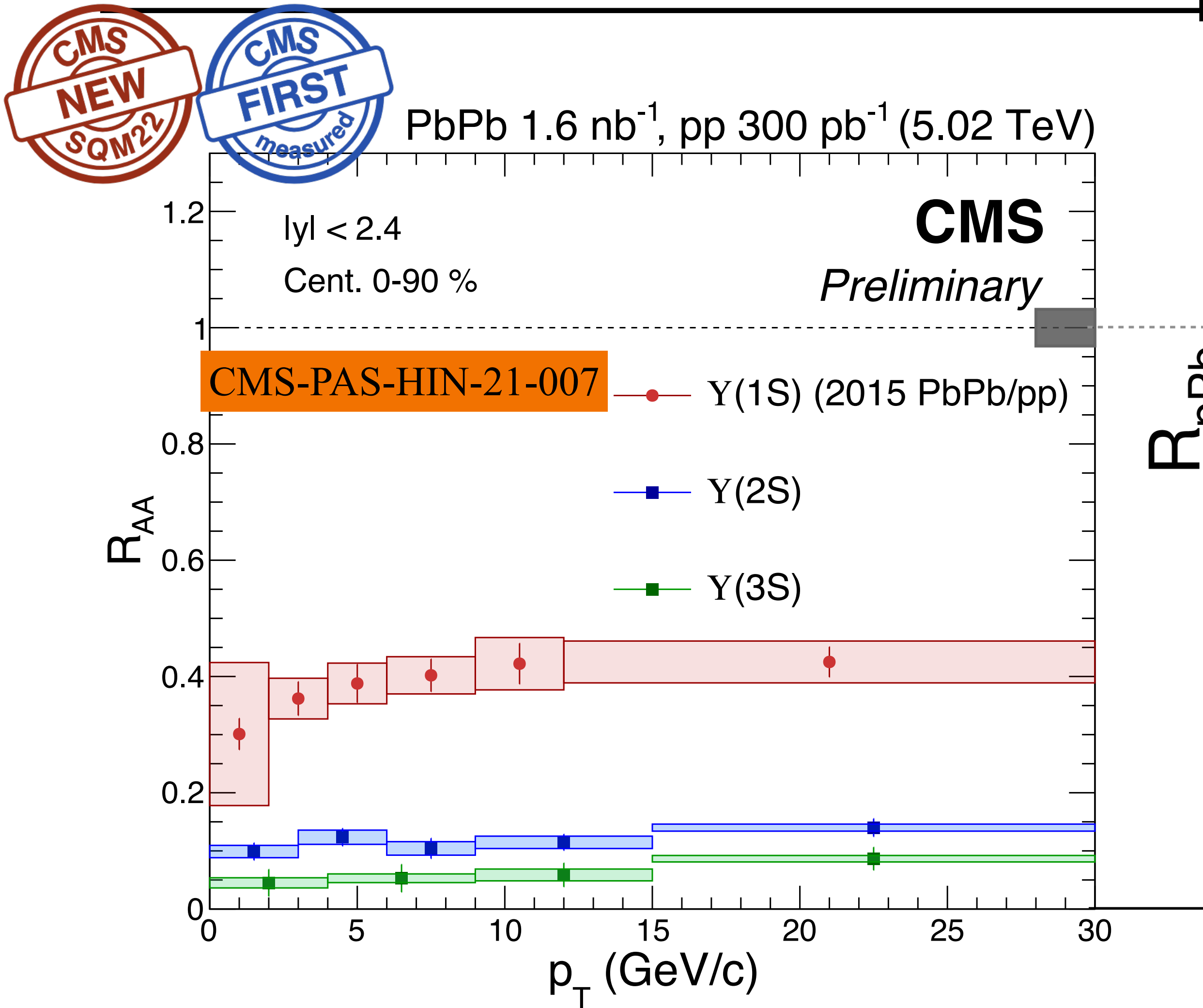
$|y| < 2.4$   
Cent. 0-90 %



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

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# Comparison with pPb

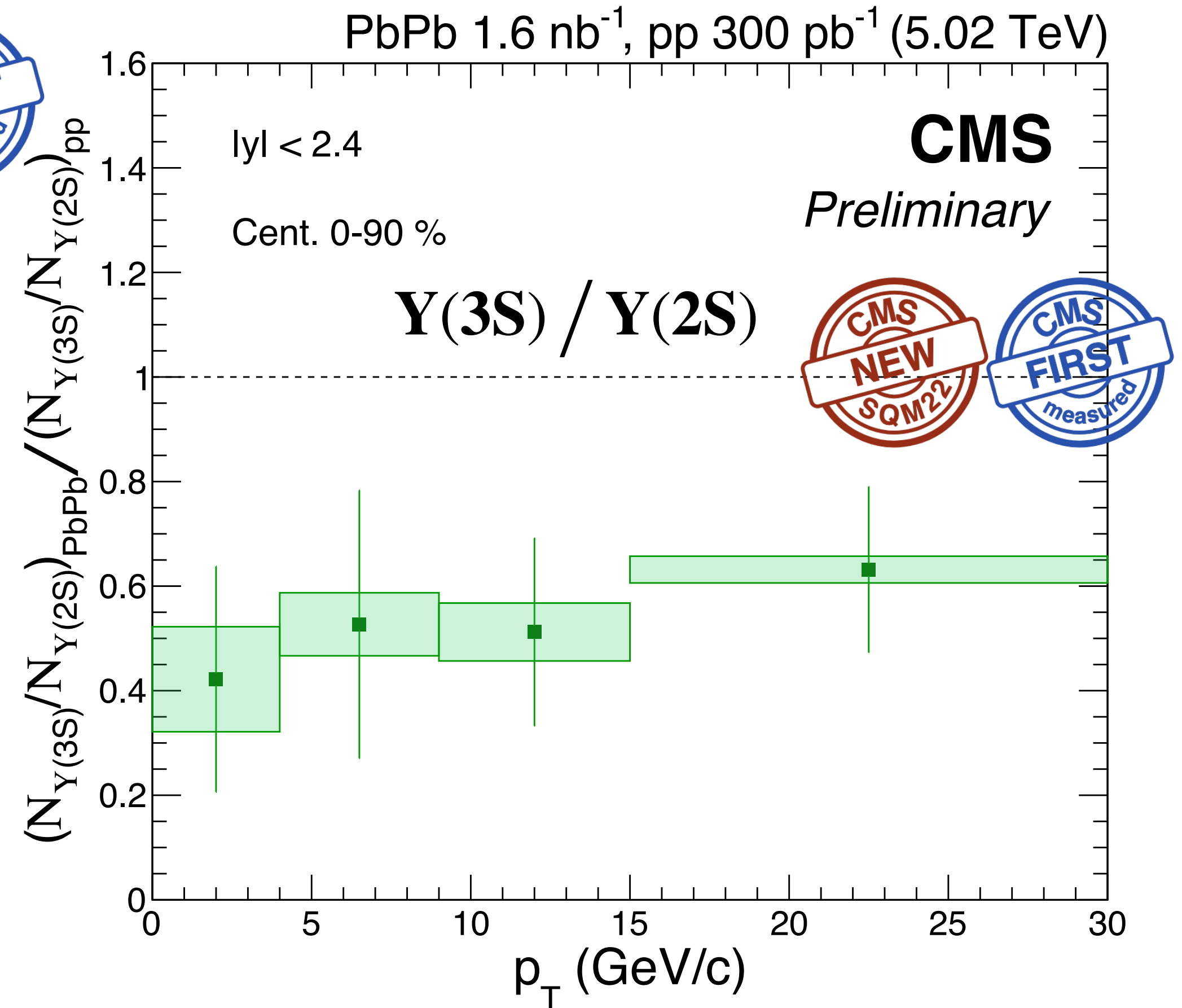
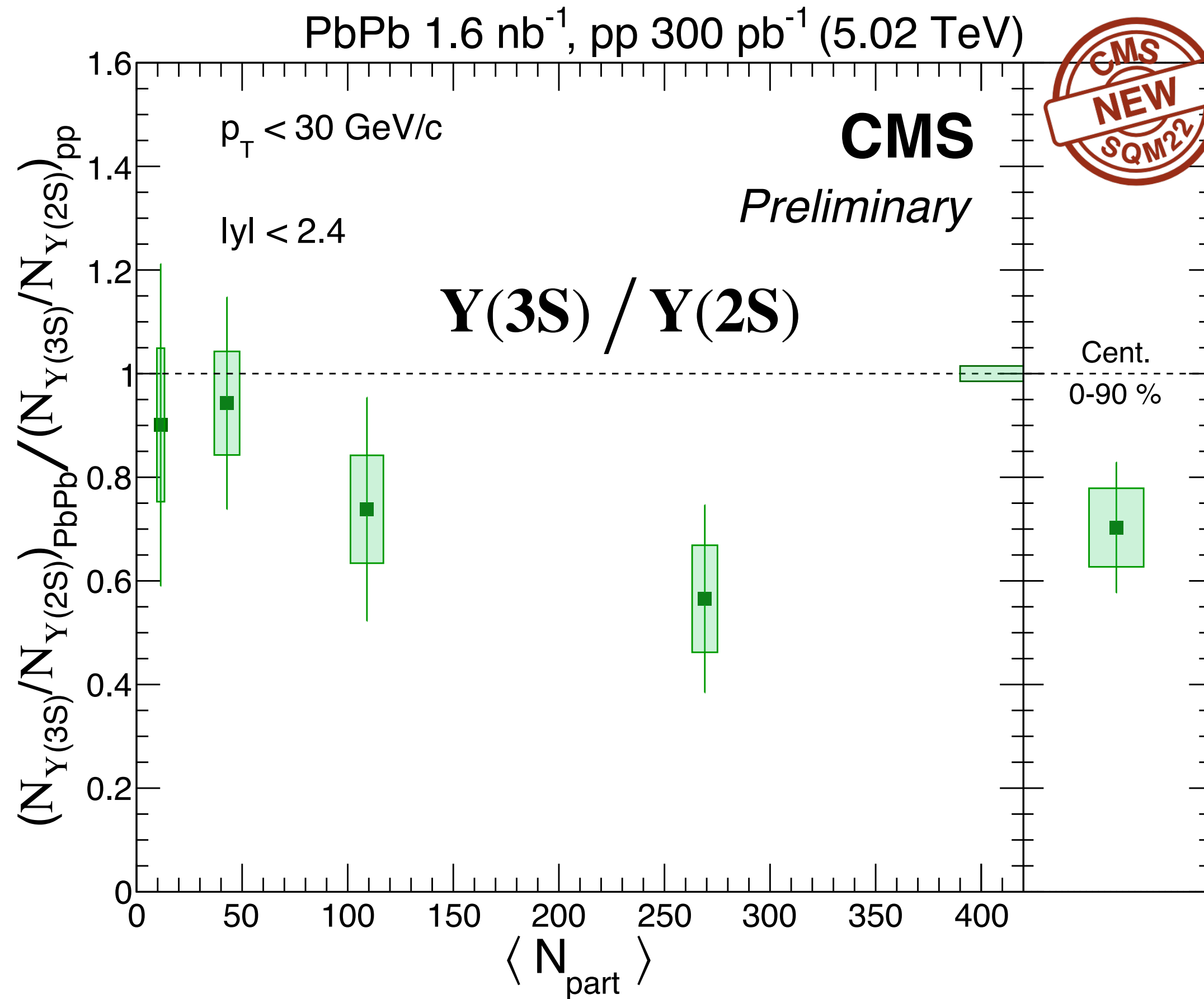


◆ Stronger suppression in PbPb for all **Y** states



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

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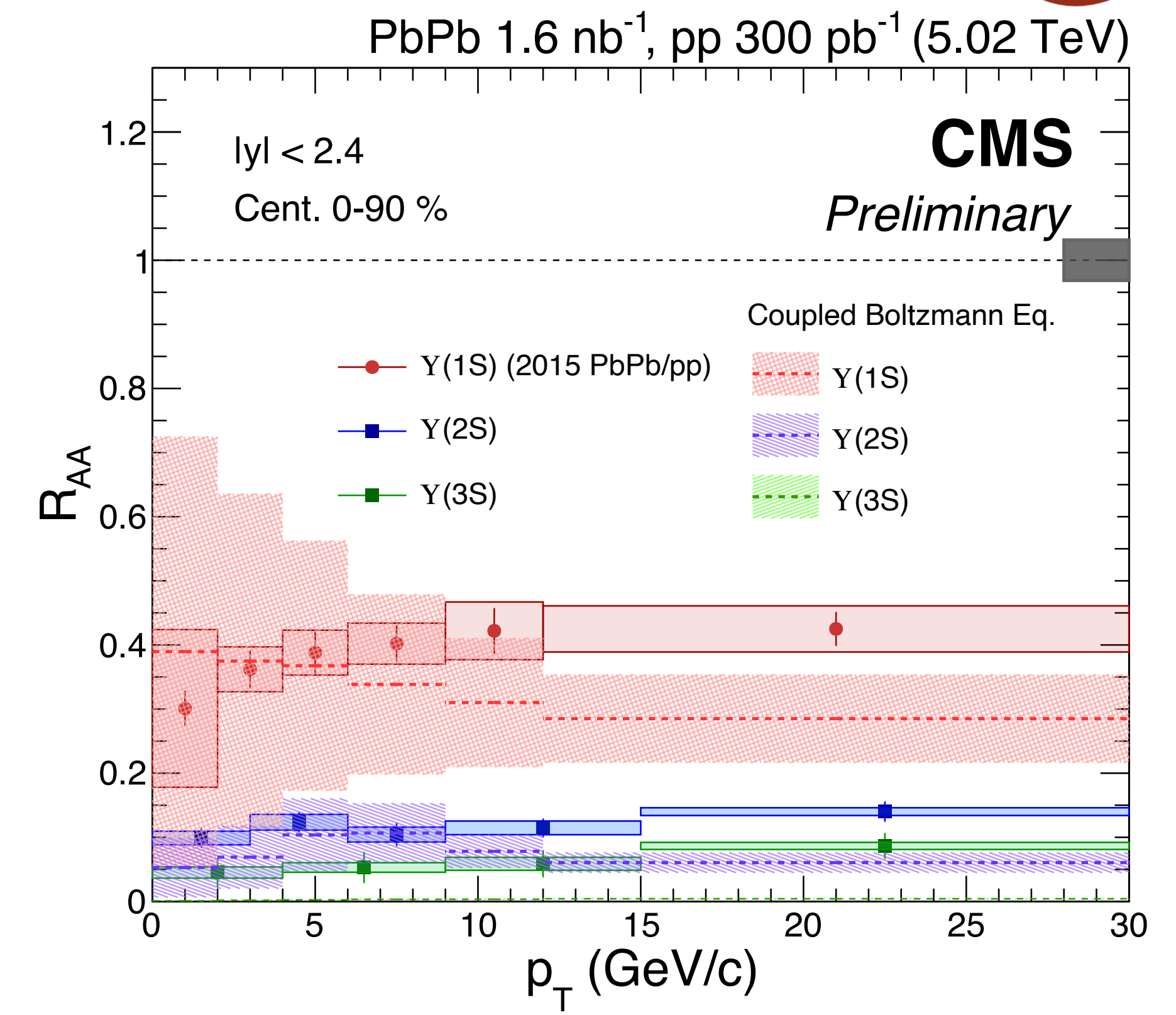
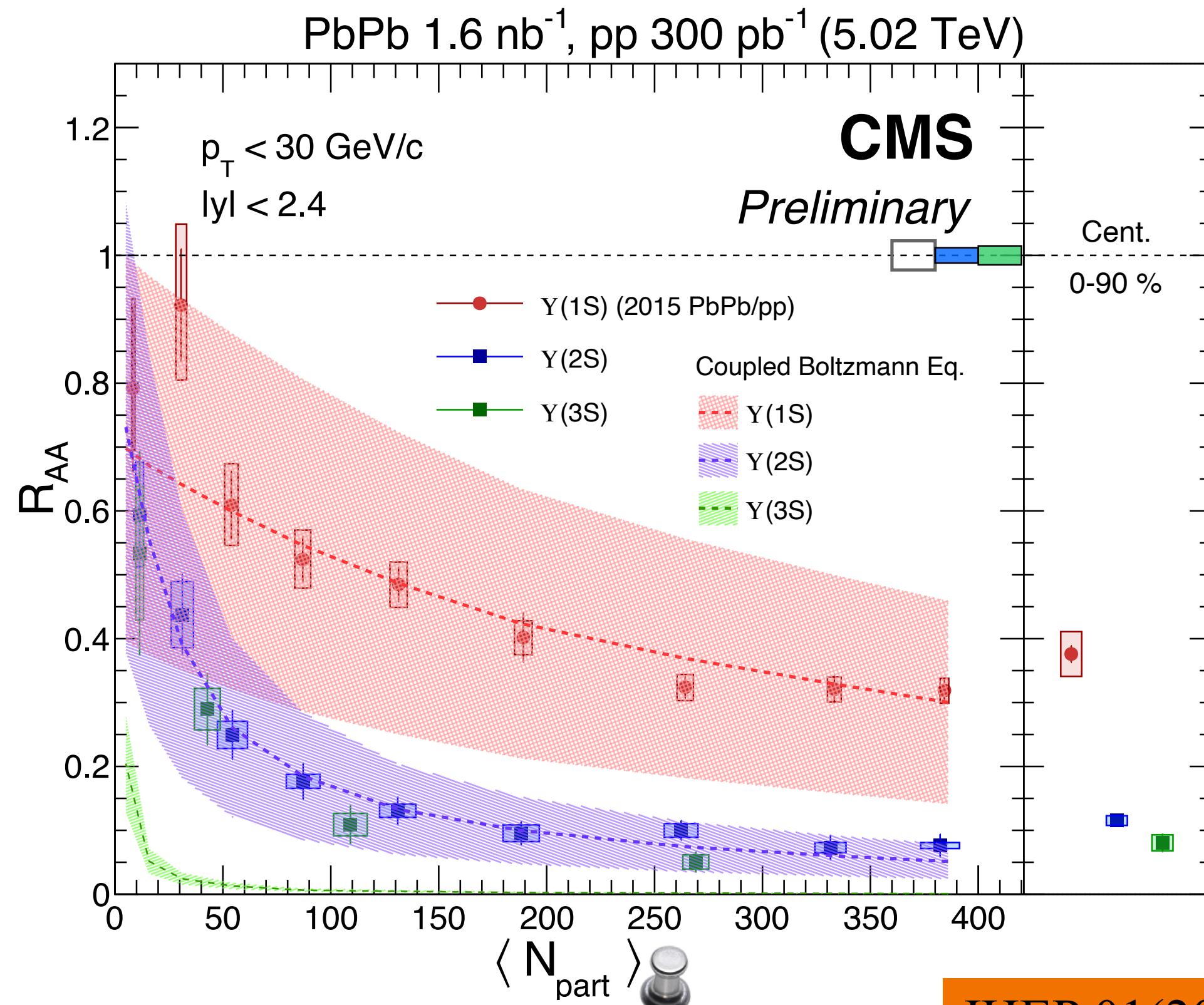


❖ Stronger suppression of **Y(3S)** in central region

❖ **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 (1)



JHEP 01(2021) 046

## Coupled Boltzmann Equation

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

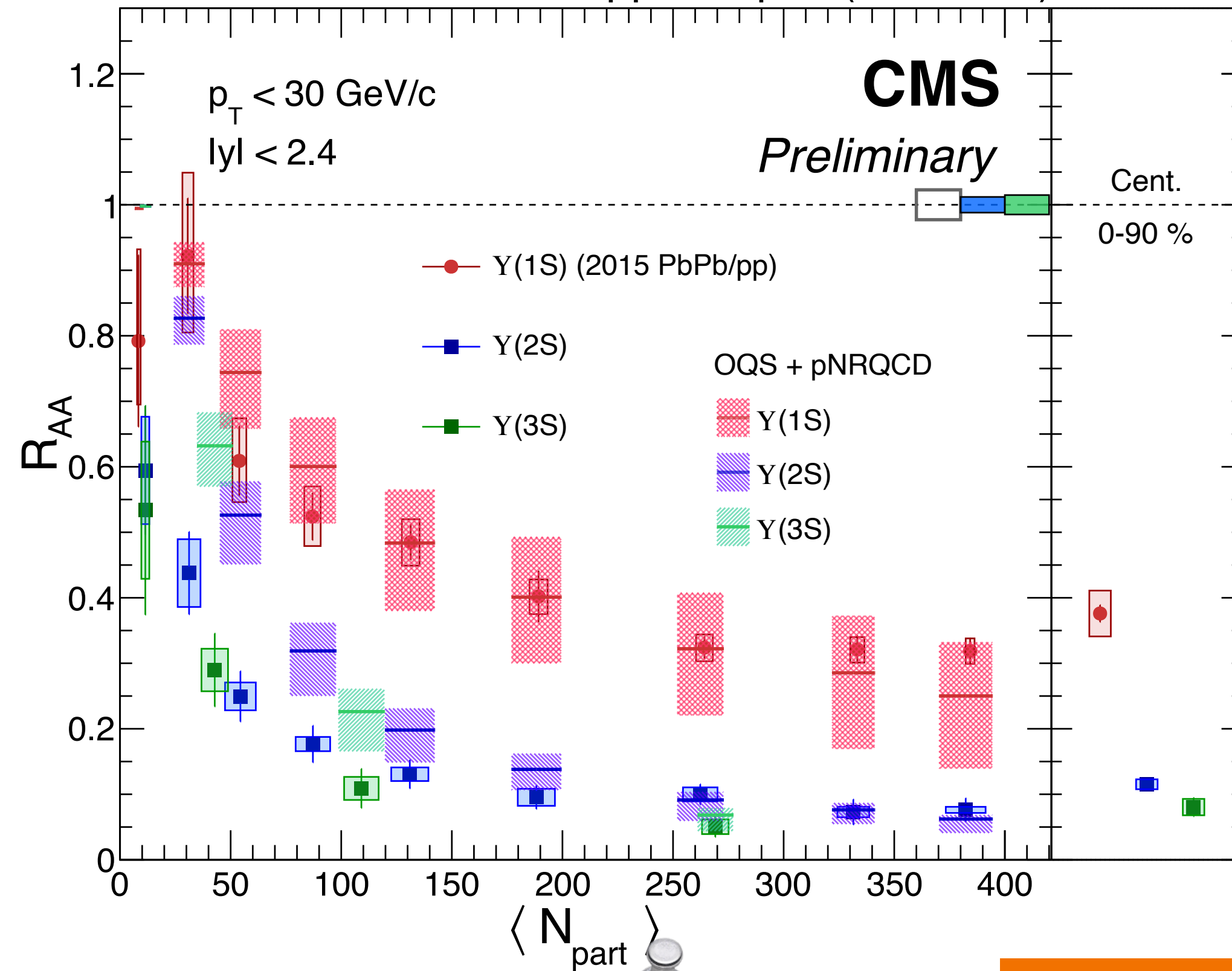
- ❖ Predicts larger **Y(3S)** suppression than data
- ❖ Discrepancy at high  $p_T$



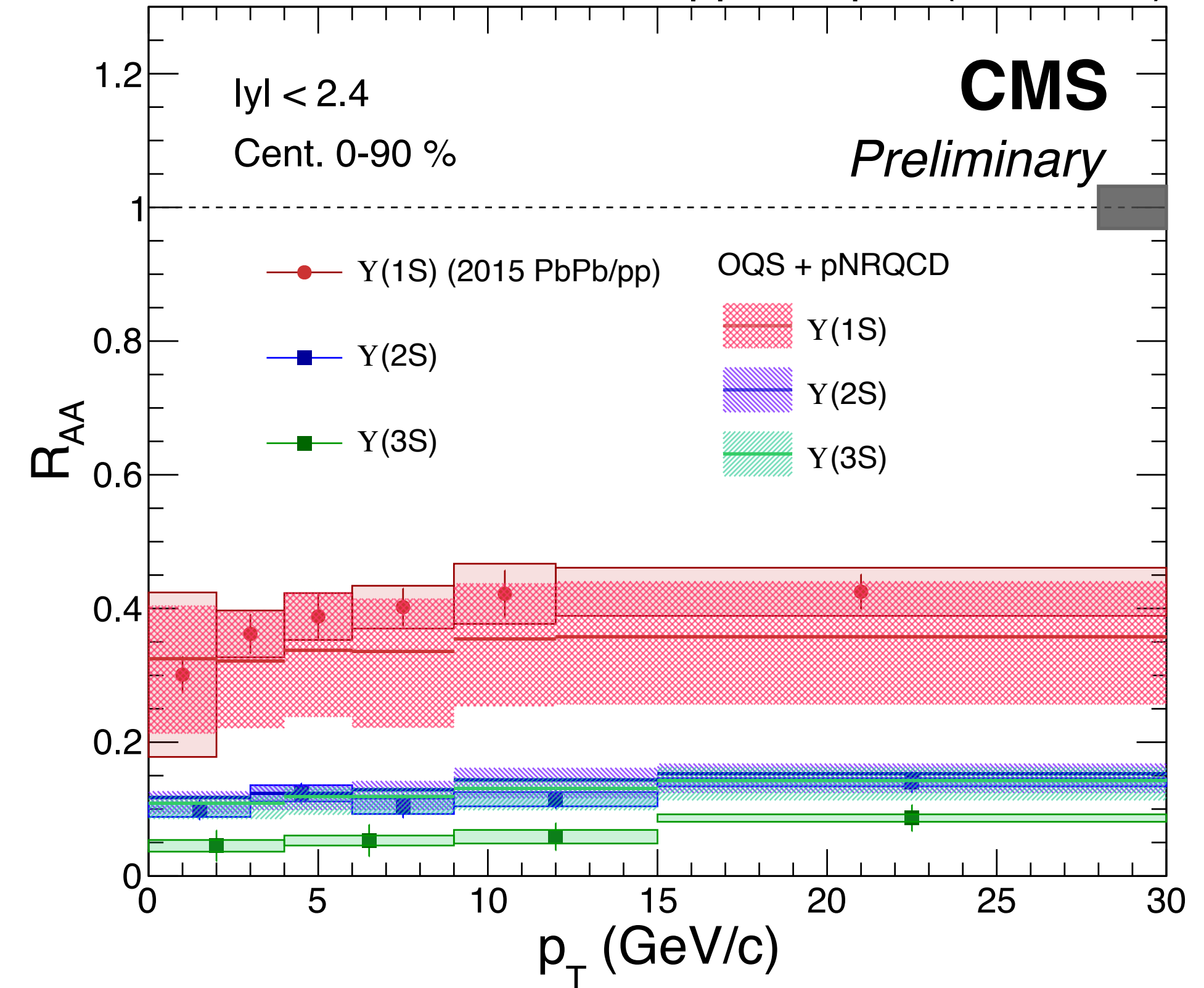
# $R_{AA}$ Comparison with theory (2)



PbPb 1.6 nb<sup>-1</sup>, pp 300 pb<sup>-1</sup> (5.02 TeV)



PbPb 1.6 nb<sup>-1</sup>, pp 300 pb<sup>-1</sup> (5.02 TeV)

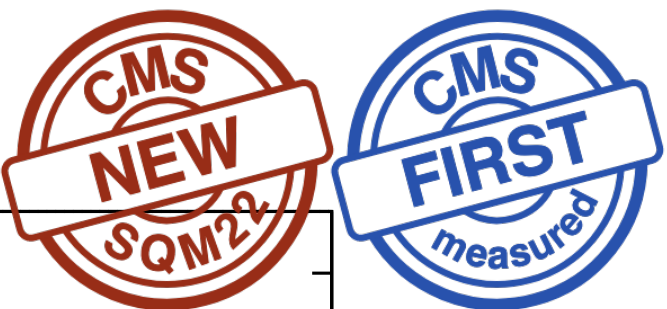
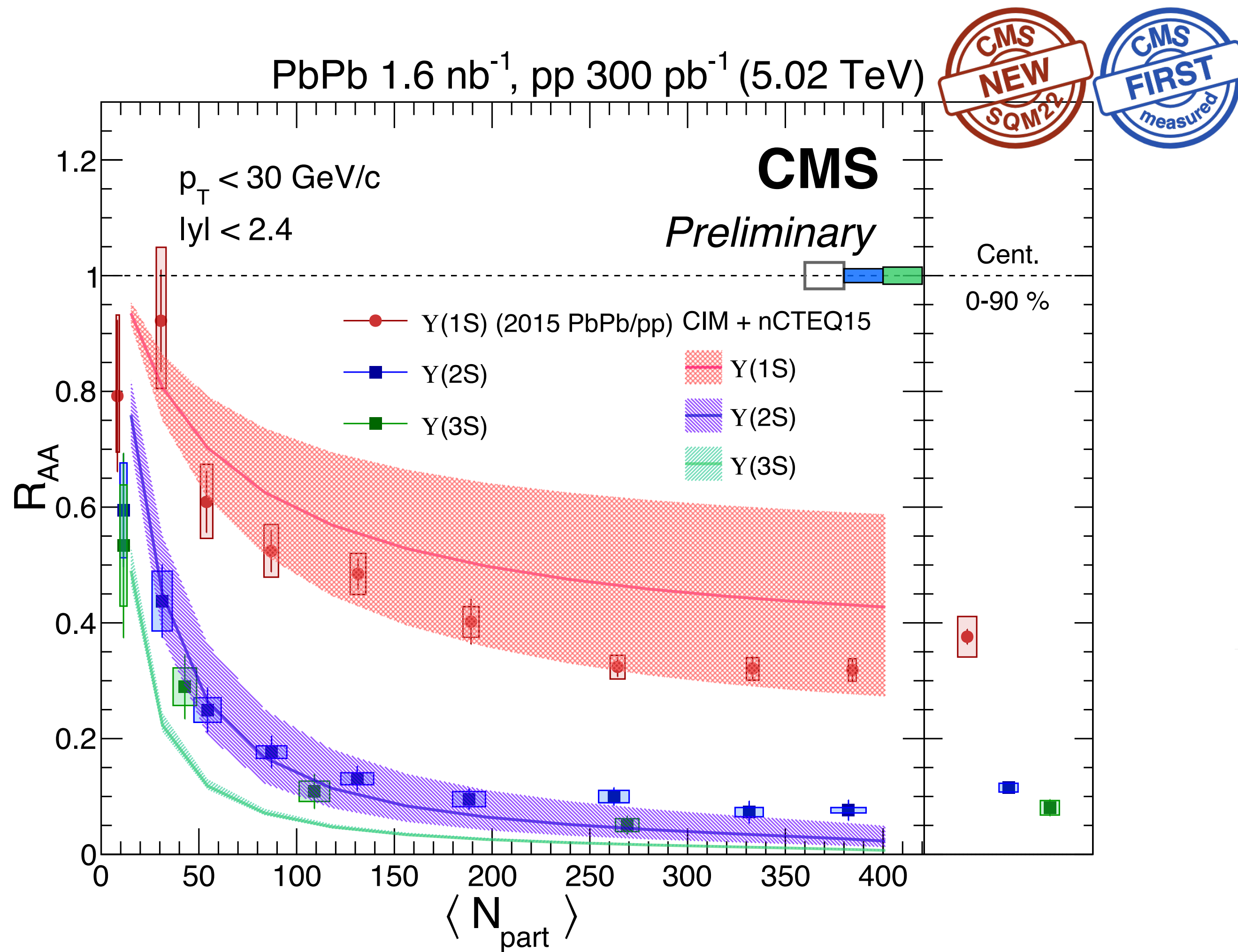


PRD 104 094049

- 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  $R_{AA}(3S)$  vs  $p_T$

# $R_{AA}$ Comparison with theory (3)



## Comover interaction model + nCTEQ15

JHEP 10(2018) 094

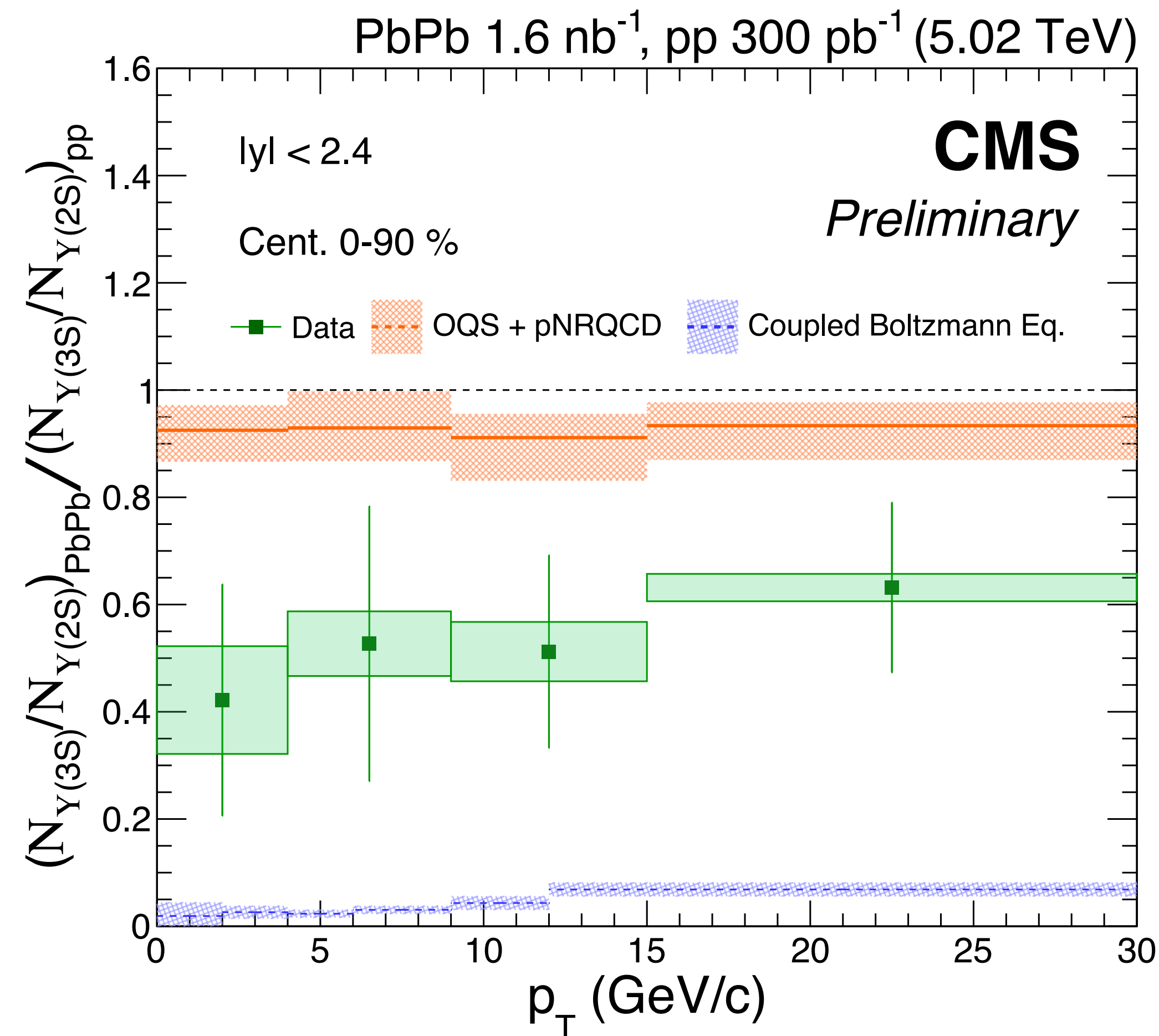
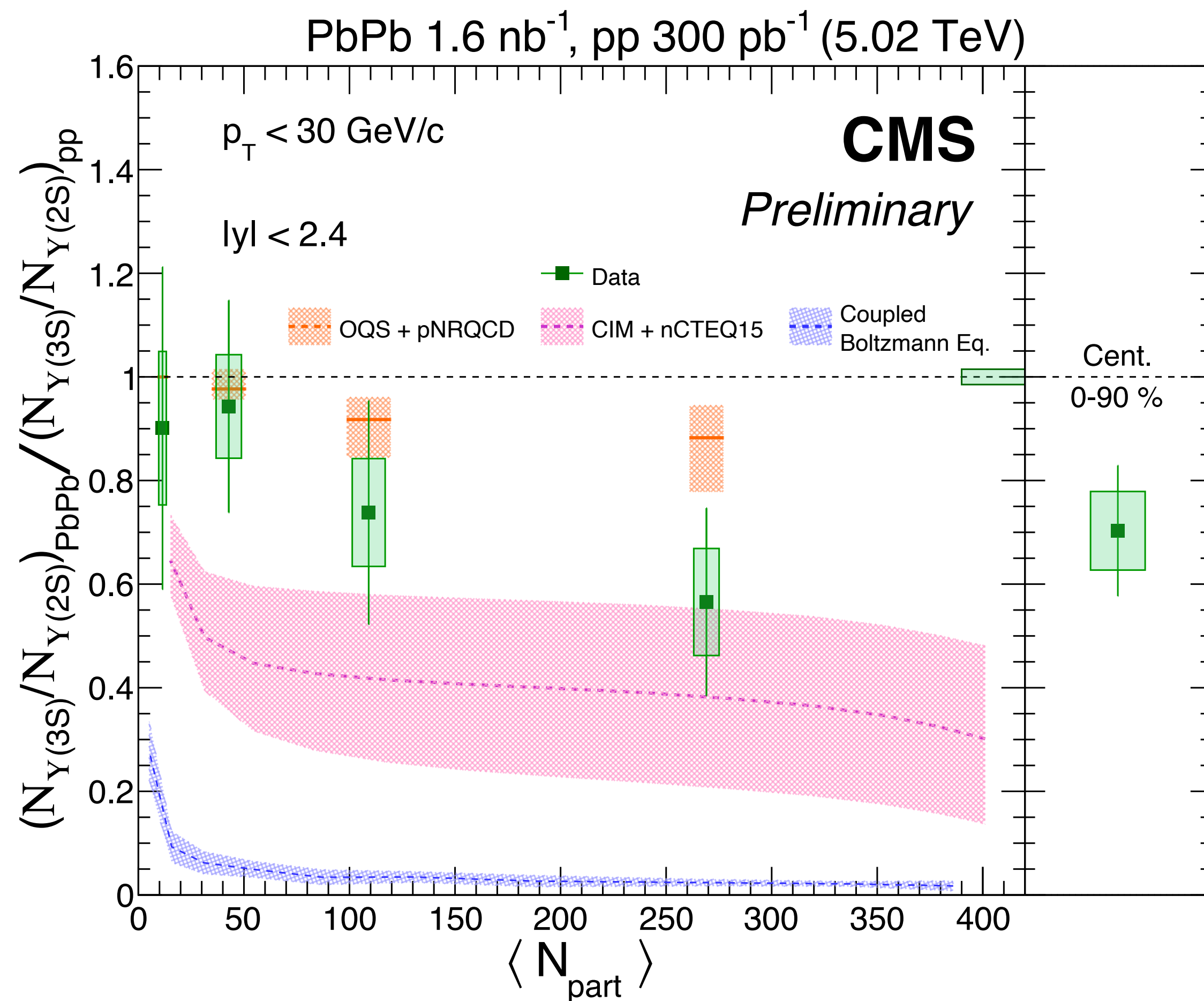
- Gluon acting as proxy of pion in comover breakup
- No regeneration calculation
- nPDF + CIM cross-section uncertainties combined
- Feed down contributions included

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

Some mismatches between data and theories



# Double ratio comparison with theories



**Models over/under-estimate the excited states' suppression ratio**

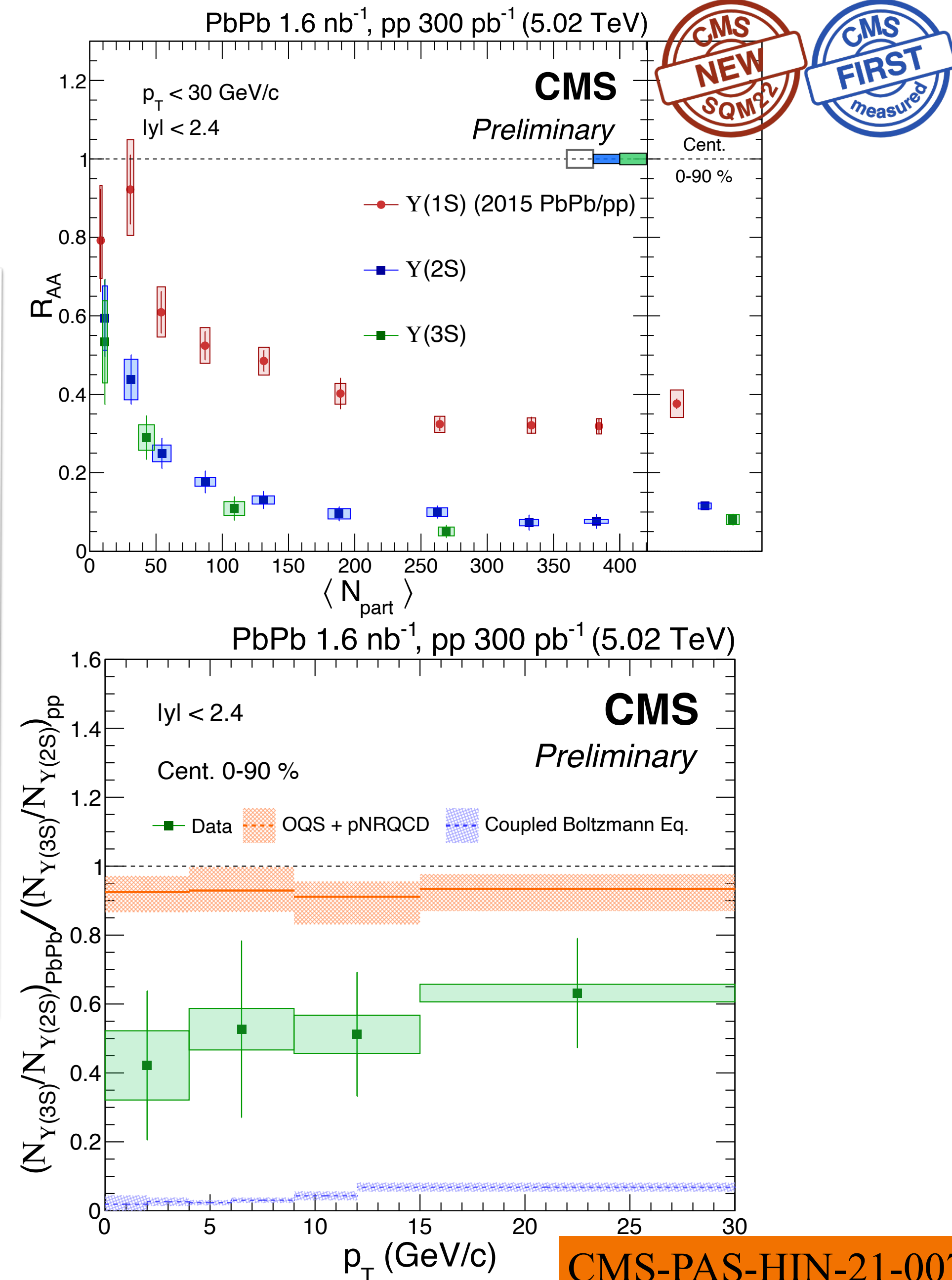
# Conclusion & Take home Message

First observation of **Y(3S)** in PbPb collisions!

Sequential suppression of Y(nS)

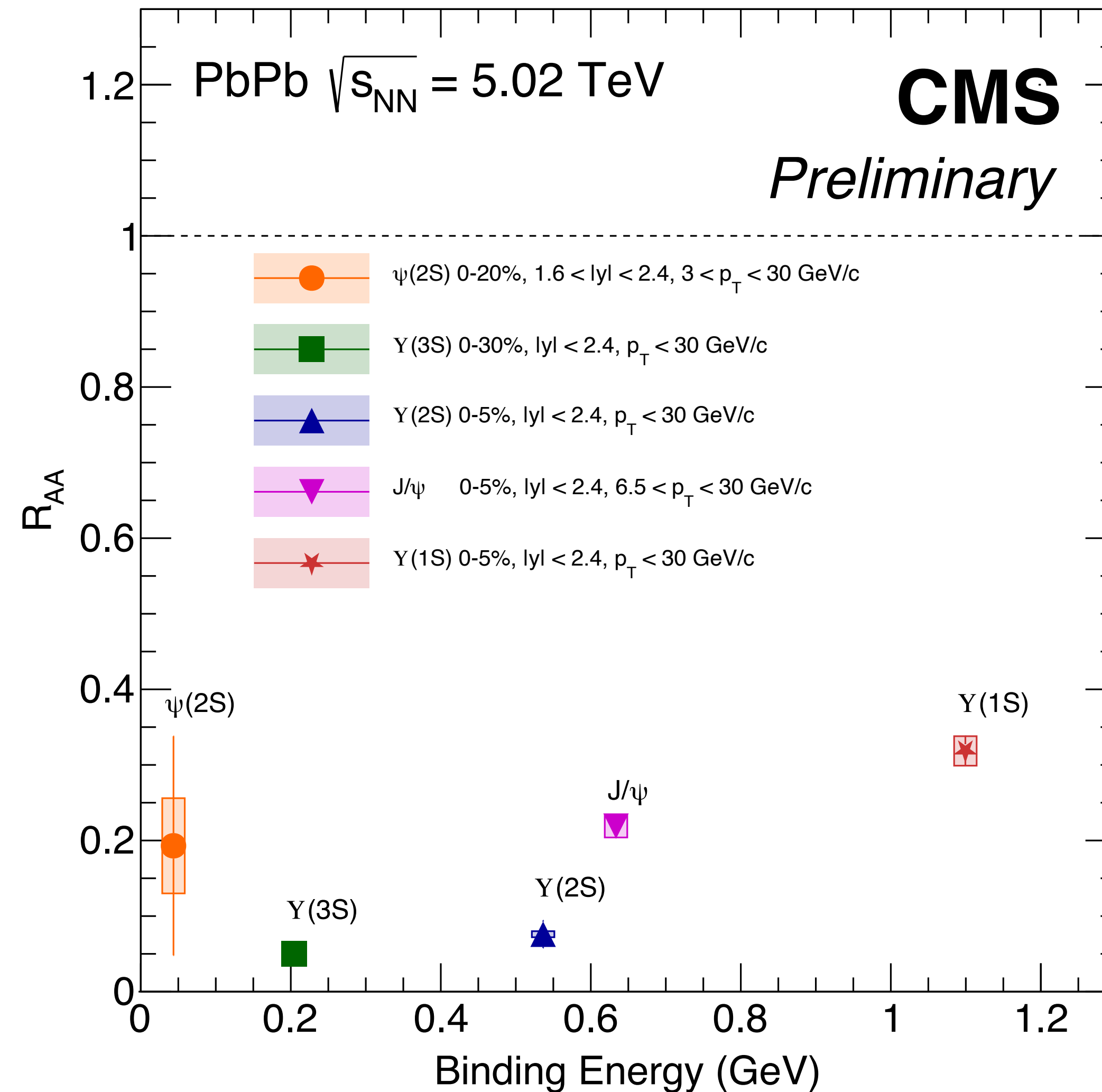
Strong constraints on theoretical models

Need to carefully treat the theoretical ingredients



# Back Up

# Binding energy relation of suppression of quarkonia

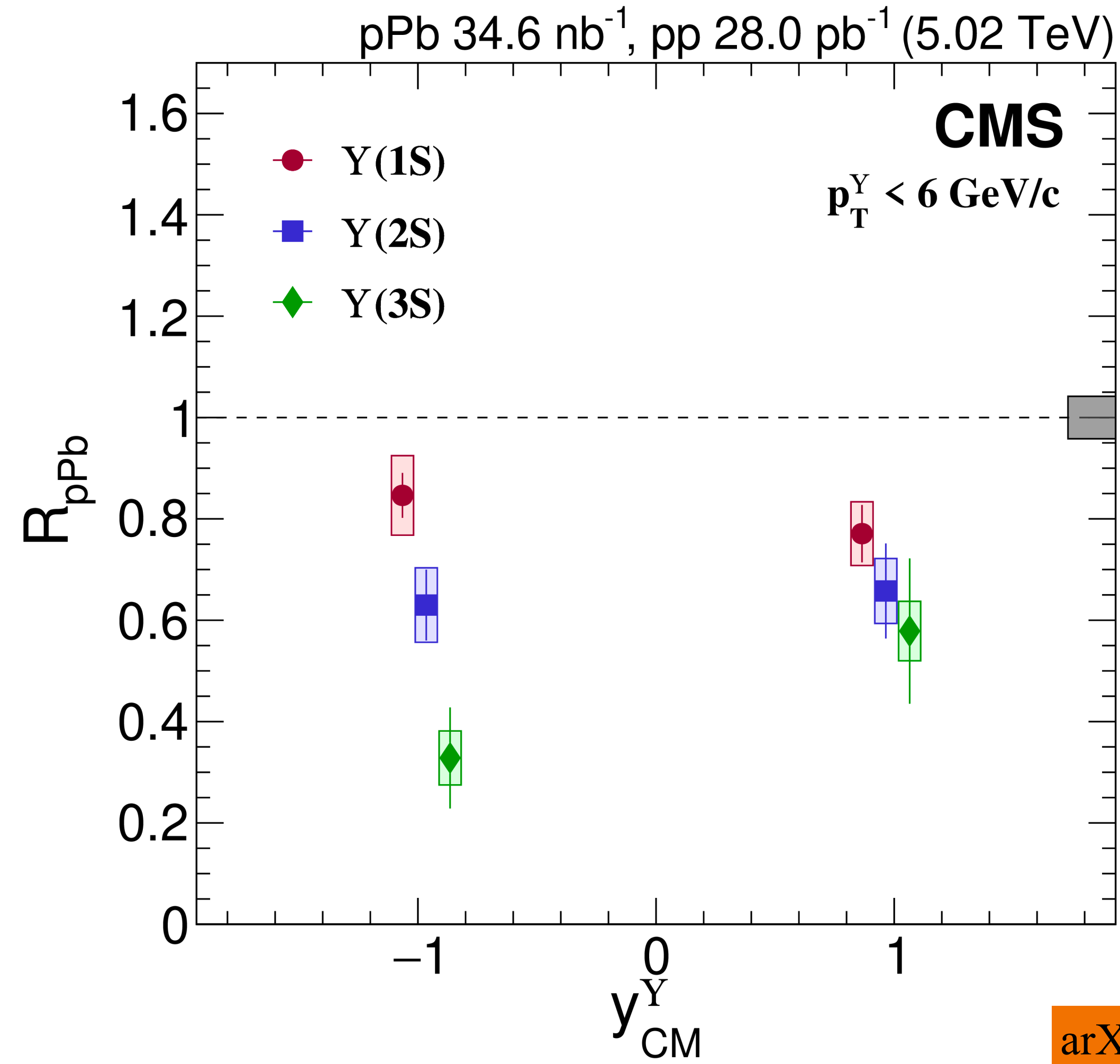


EPJC 78 (2018) 509

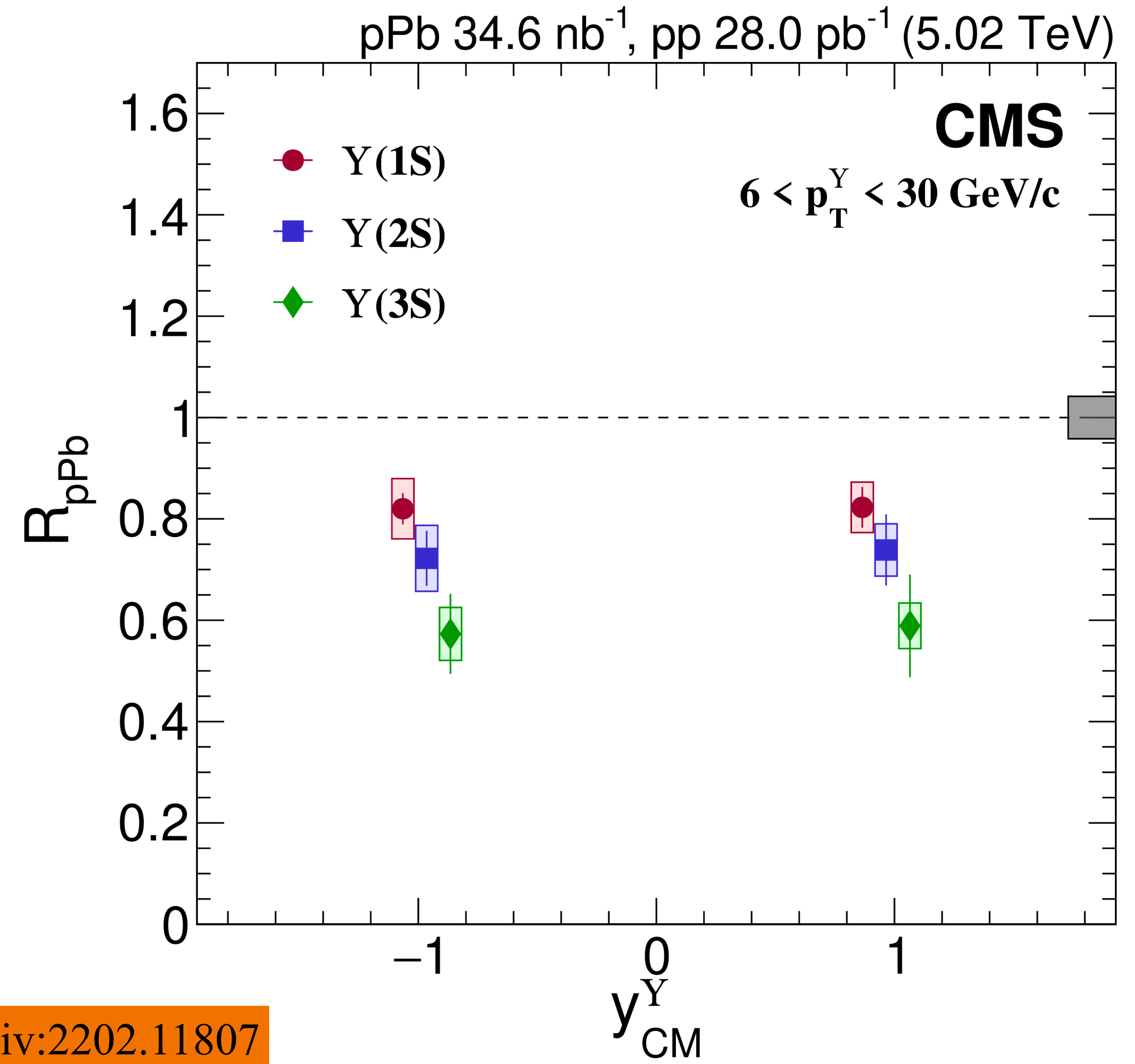
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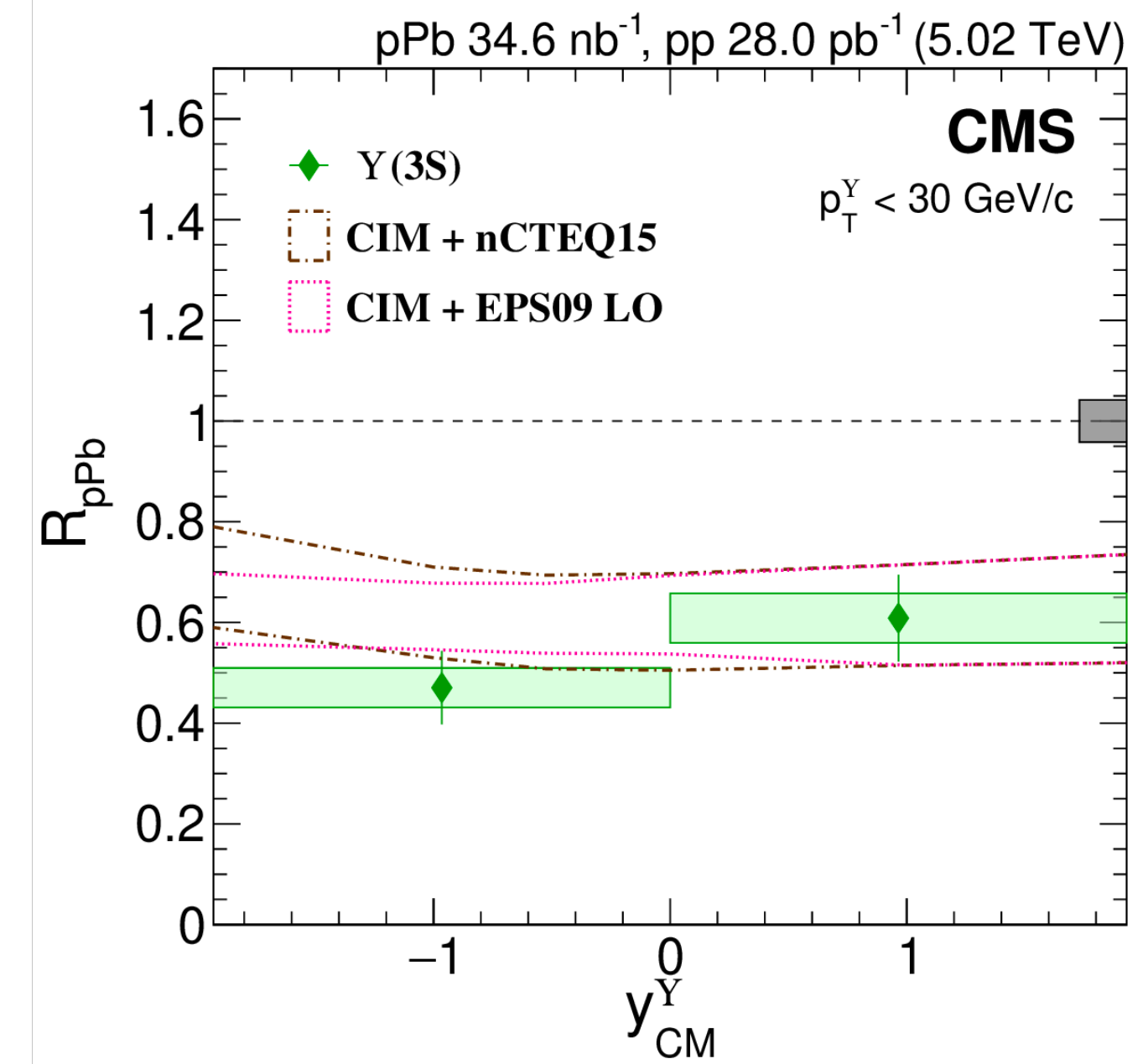
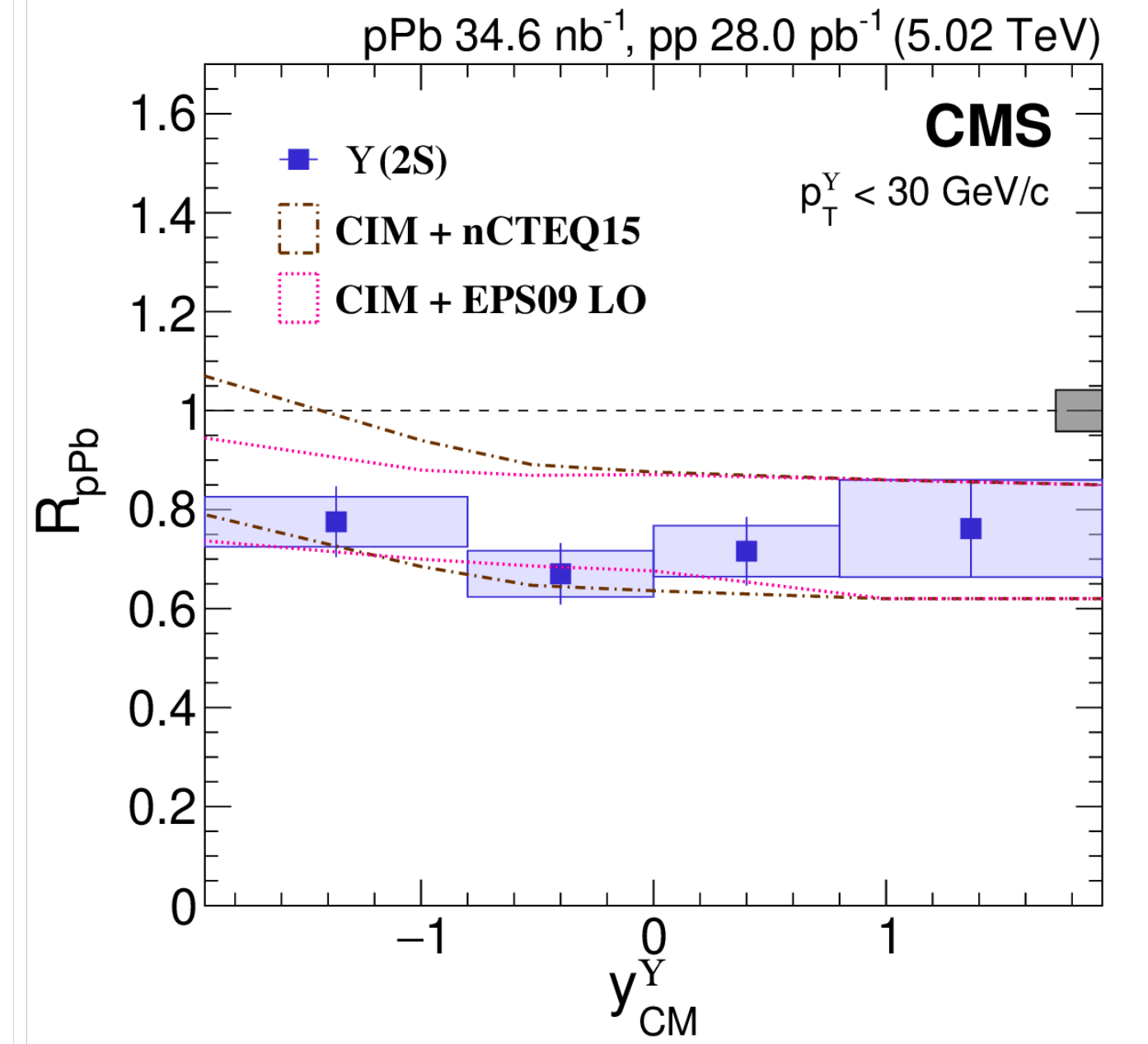
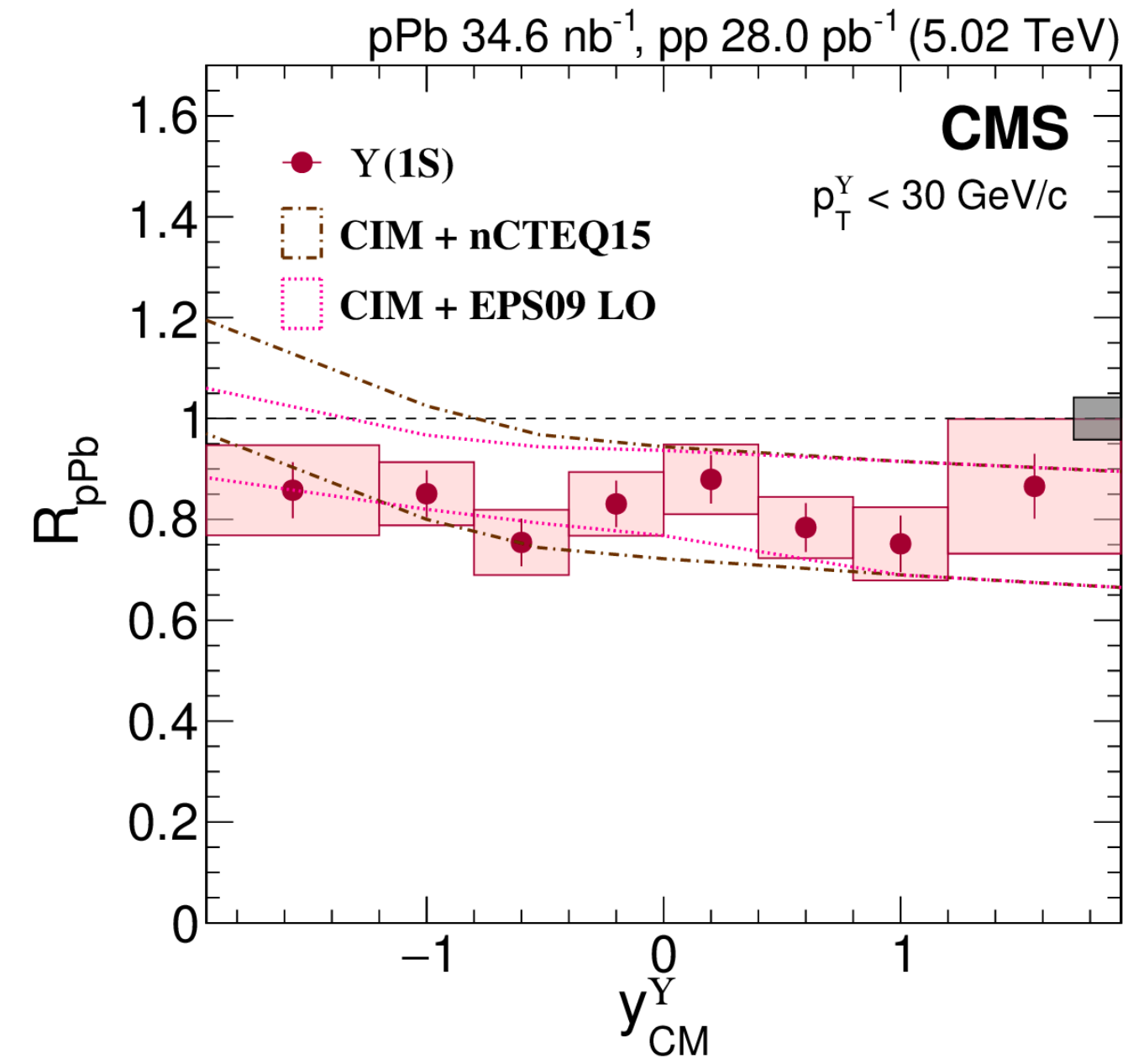
# $R_{pPb}$ forward and backward



arXiv:2202.11807



# $R_{pPb}$ theory comparison



arXiv:2202.11807