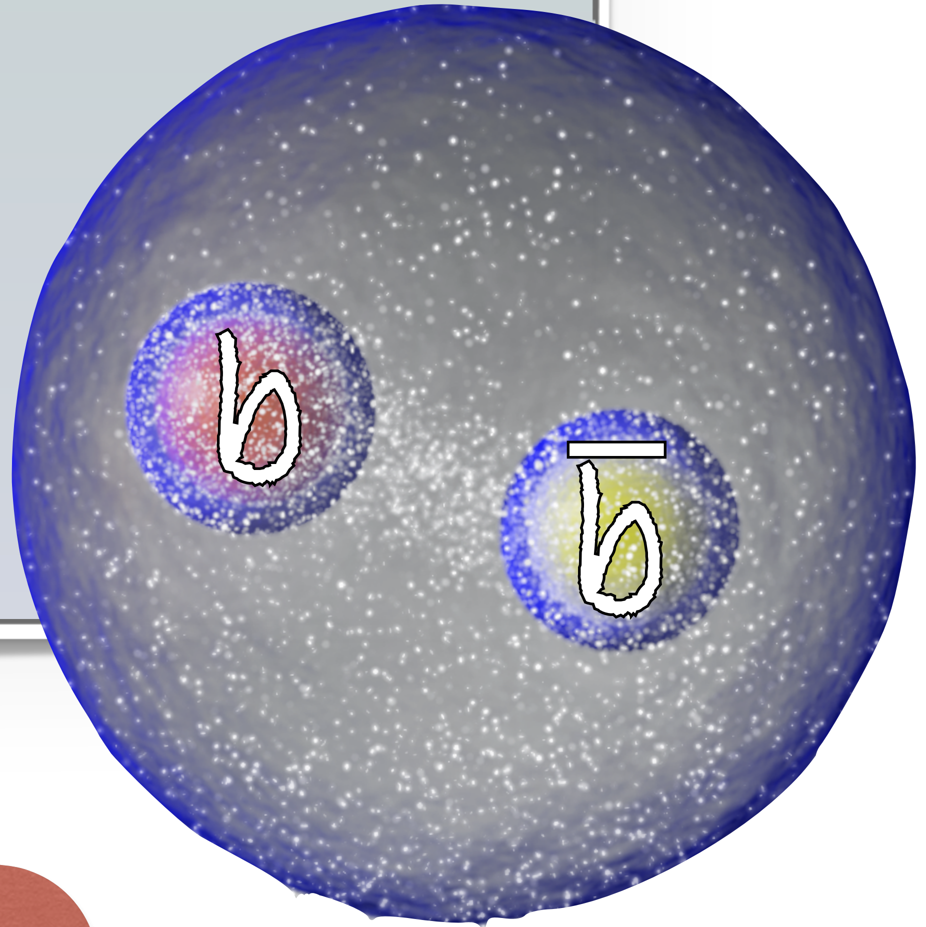
Observation of $\Upsilon(3S)$ in PbPb with the CMS detector



[HIN-21-007]

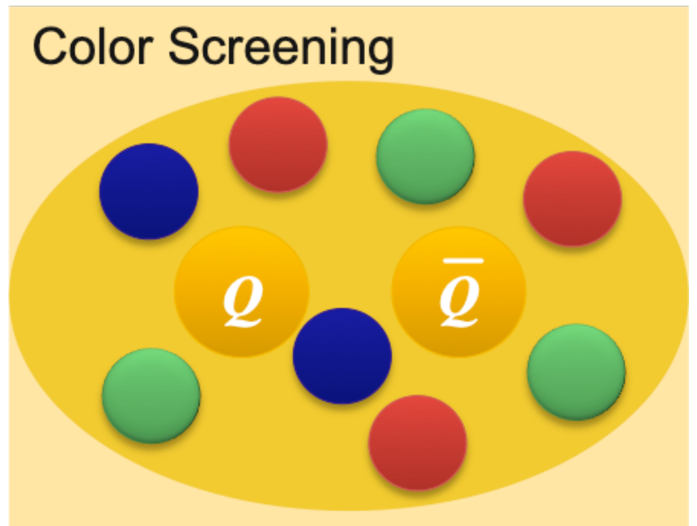
JaeBeom Park (CU Boulder / KU)
- on behalf of the CMS Collaboration

Hard Probes 2023 @ Aschaffenburg (Germany)

Motivation

Quarkonia in heavy ion collisions

- Quarkonium suppression —> QGP formation
- Binding energy ordering of suppression —> Sequential melting



Experimental aspect

- Nuclear modification factor using quarkonium yields in heavy ion and baseline (pp) collisions
- Sequential suppression still not fully resolved over 36 years…

[PLB 178 (1986) 416]

Volume 178, number 4 PHYSICS LETTERS B 9 October 1986

J/ψ SUPPRESSION BY QUARK–GLUON PLASMA FORMATION ☆

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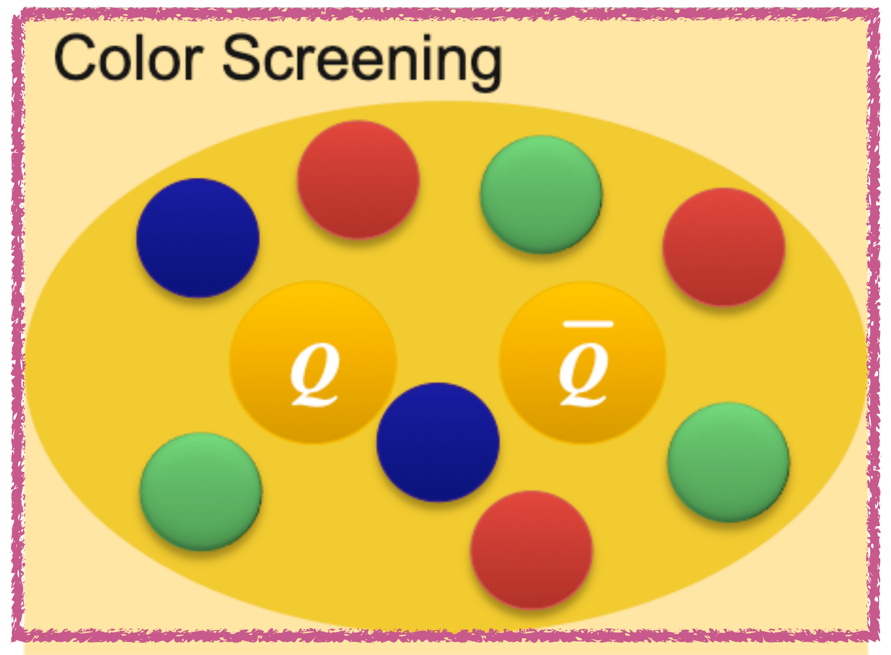
Received 17 July 1986

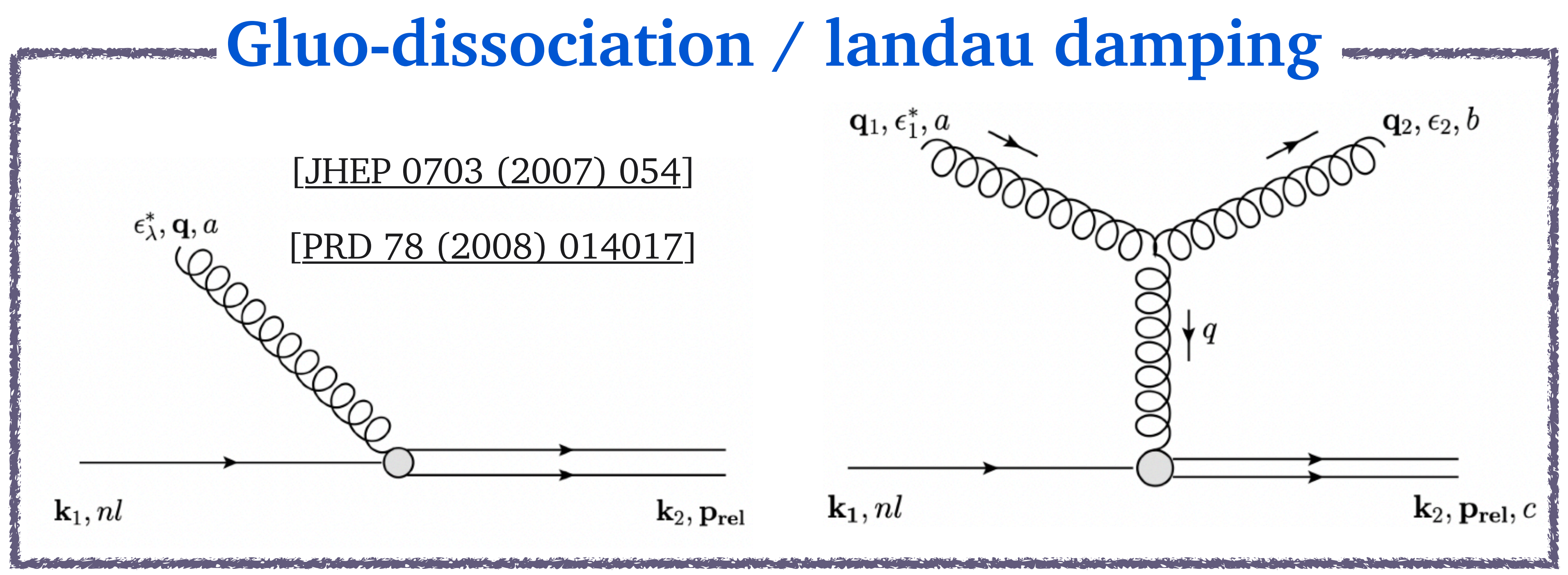
If high energy heavy ion collisions lead to the formation of a hot quark–gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, the temperature dependence of the screening radius, as obtained from lattice QCD, is compared with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. It is concluded that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark–gluon plasma formation.

Motivation

Suppression

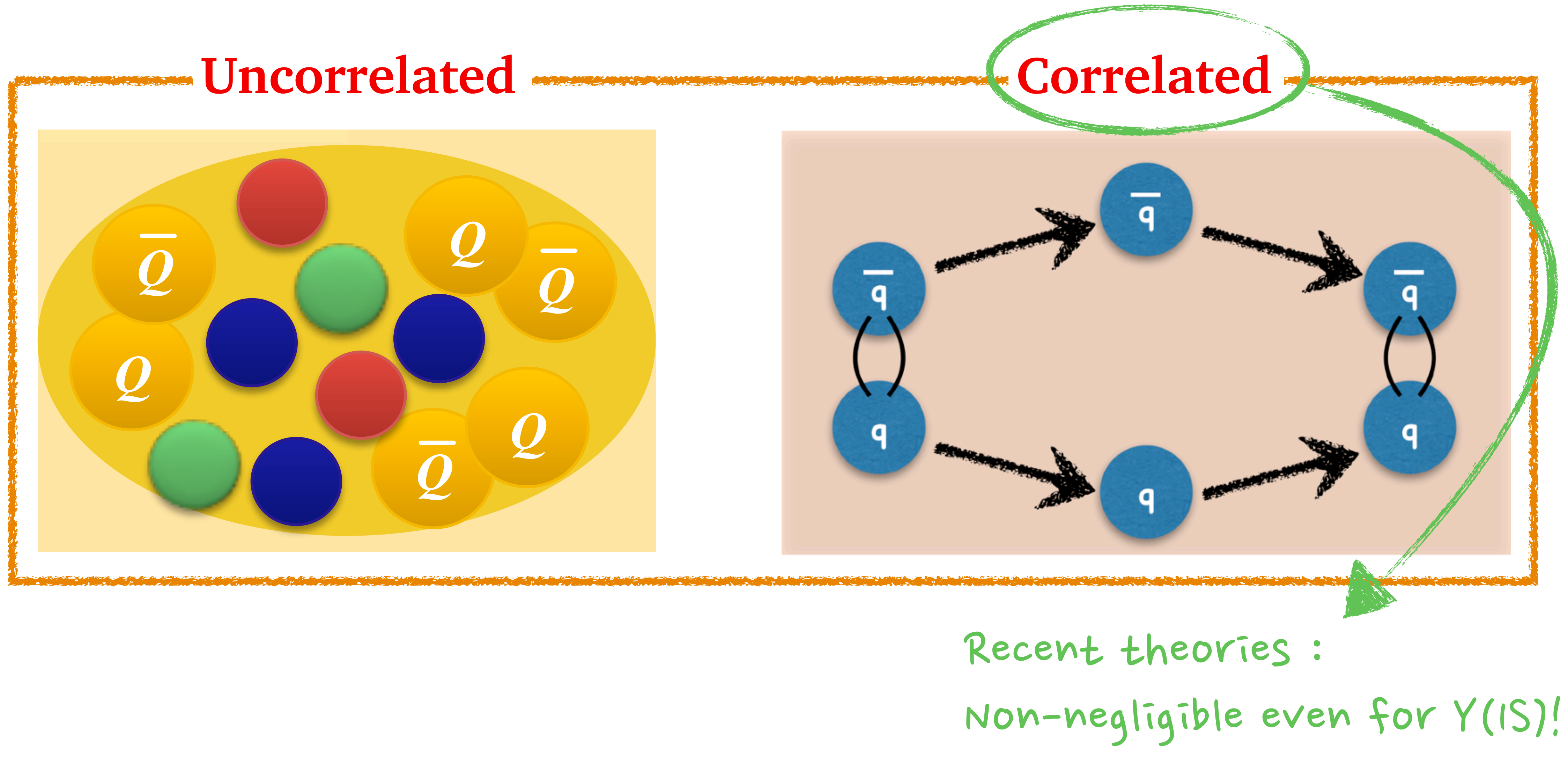
- Debye screening
  - — static color screening : $ReV_s(r,T)$
- Gluo-dissociation / Landau-damping
  - — dynamical screening : $ImV_s(r,T)$





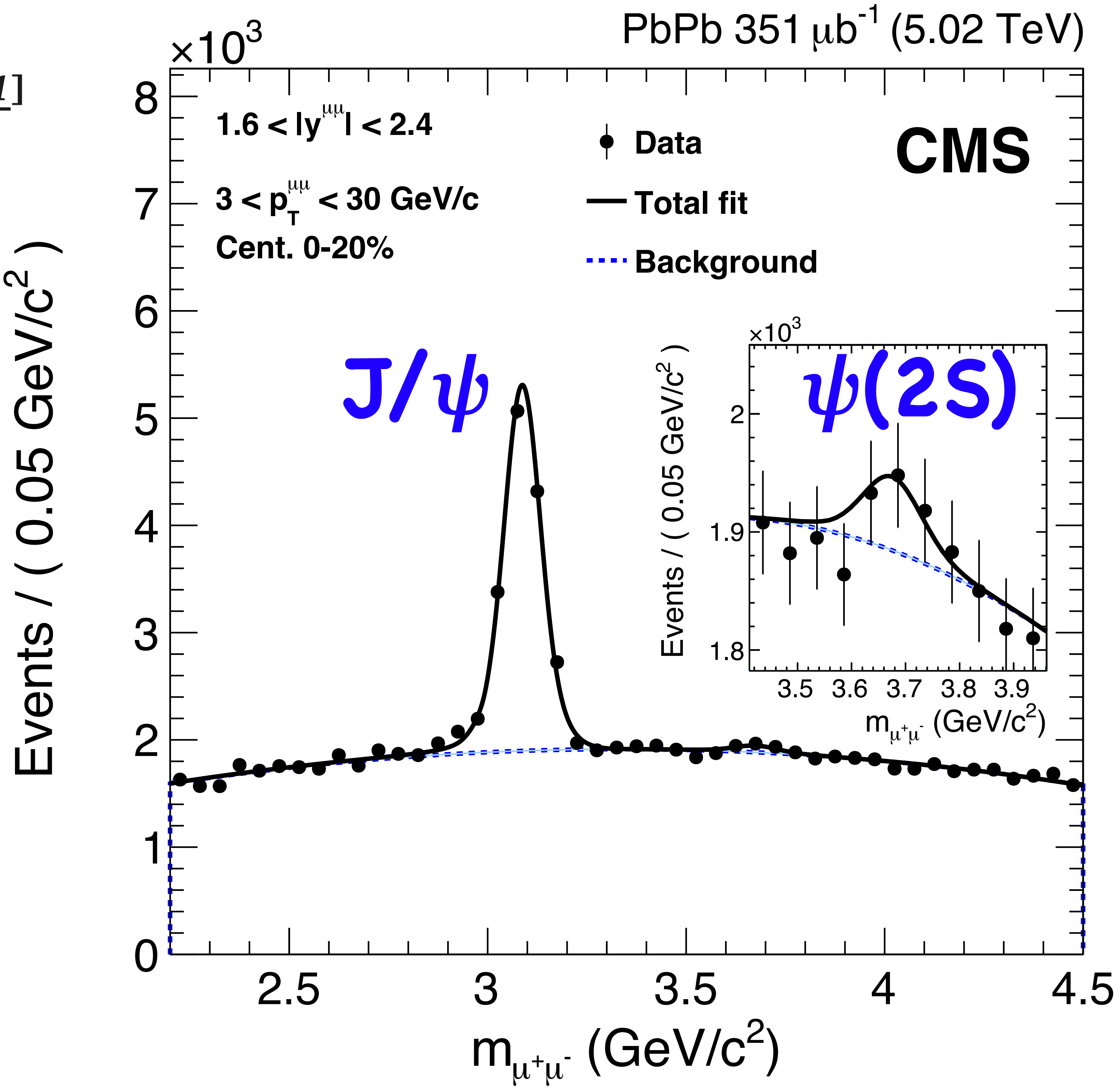
Recombination (Regeneration)

- Uncorrelated recombination (off-diagonal)
- Correlated recombination (diagonal)

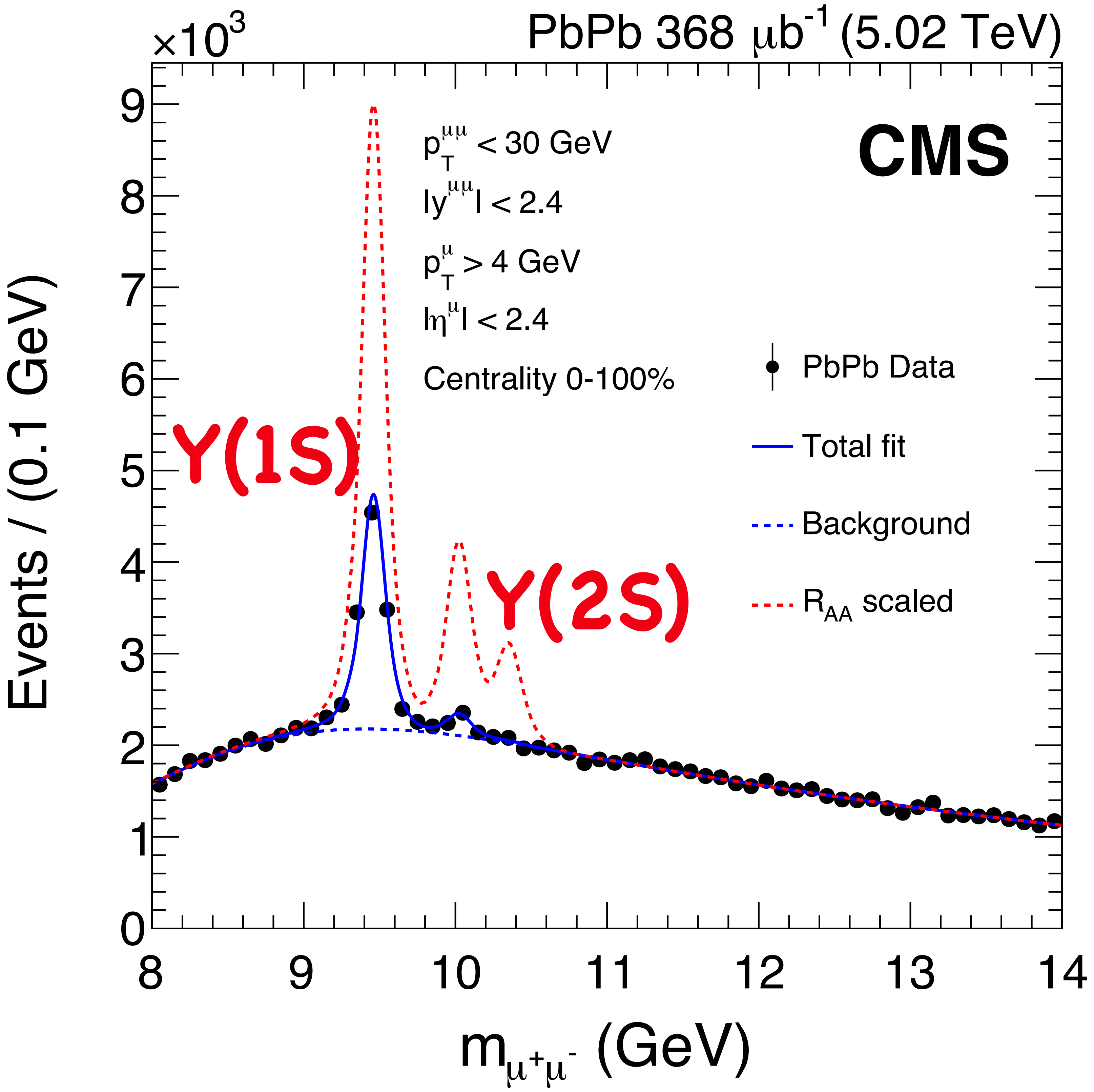


Quarkonia in AA with CMS

[PRL 118 (2017) 162301]

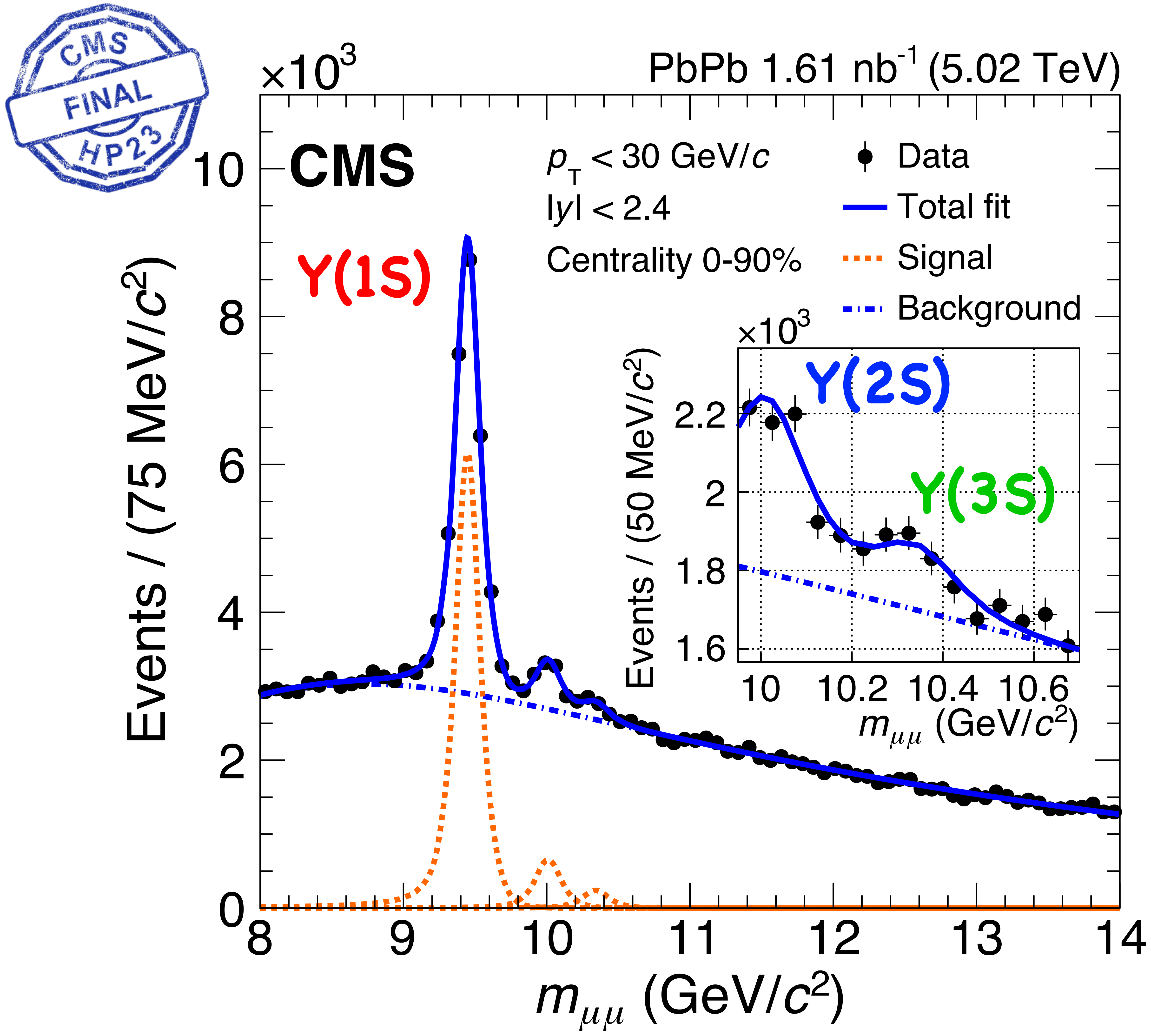


[PLB 790 (2019) 270]



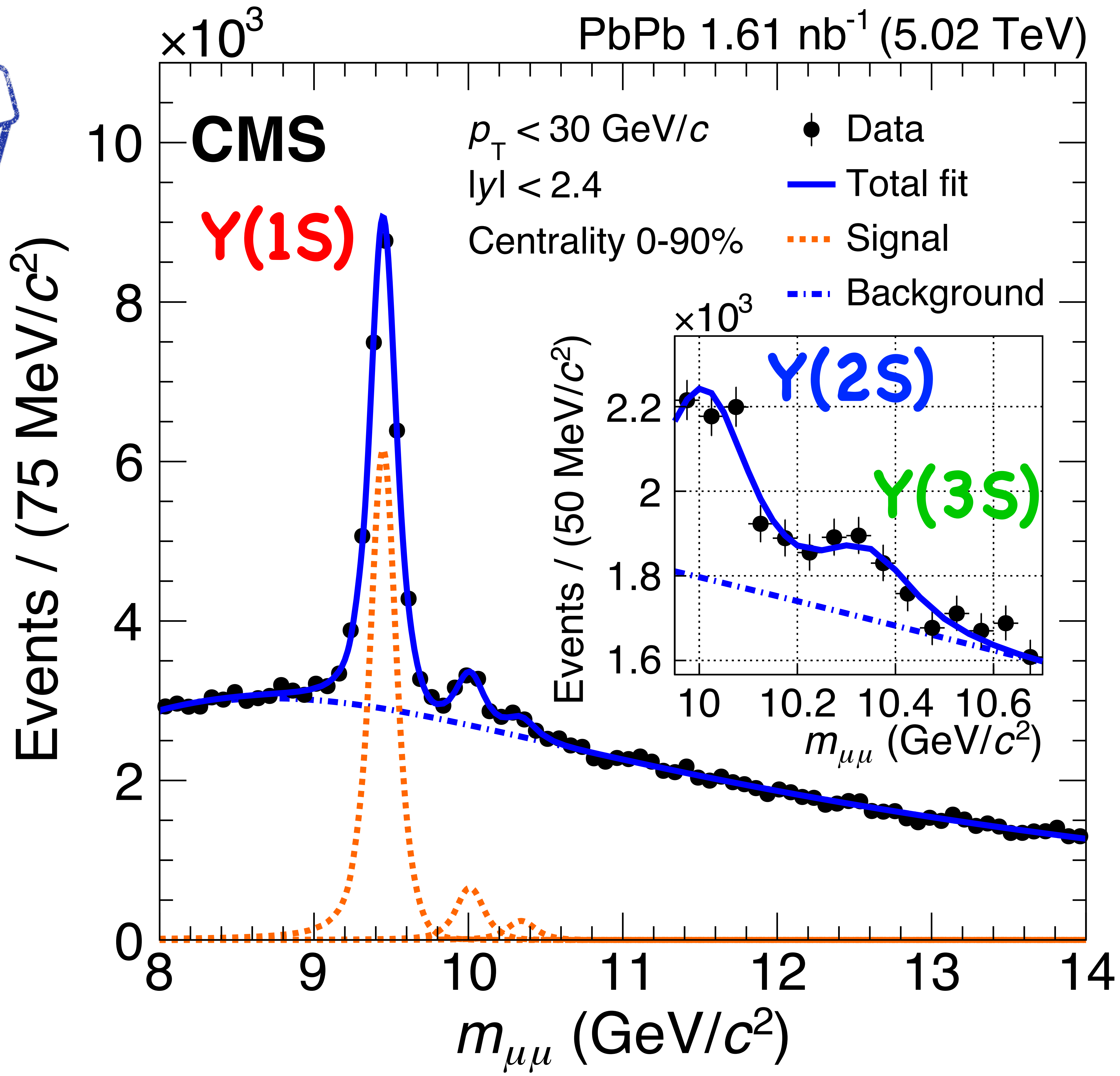
- Previous charmonium and bottomonium measurements in PbPb through dimuon decay channel
- Hunt of the Υ(3S) meson in PbPb collisions with CMS!
  - a) Larger statistics : 2015 ($0.37nb^{-1}$) —> 2018 ($1.6nb^{-1}$)
  - b) Improved analysis technique : MVA application for background reduction

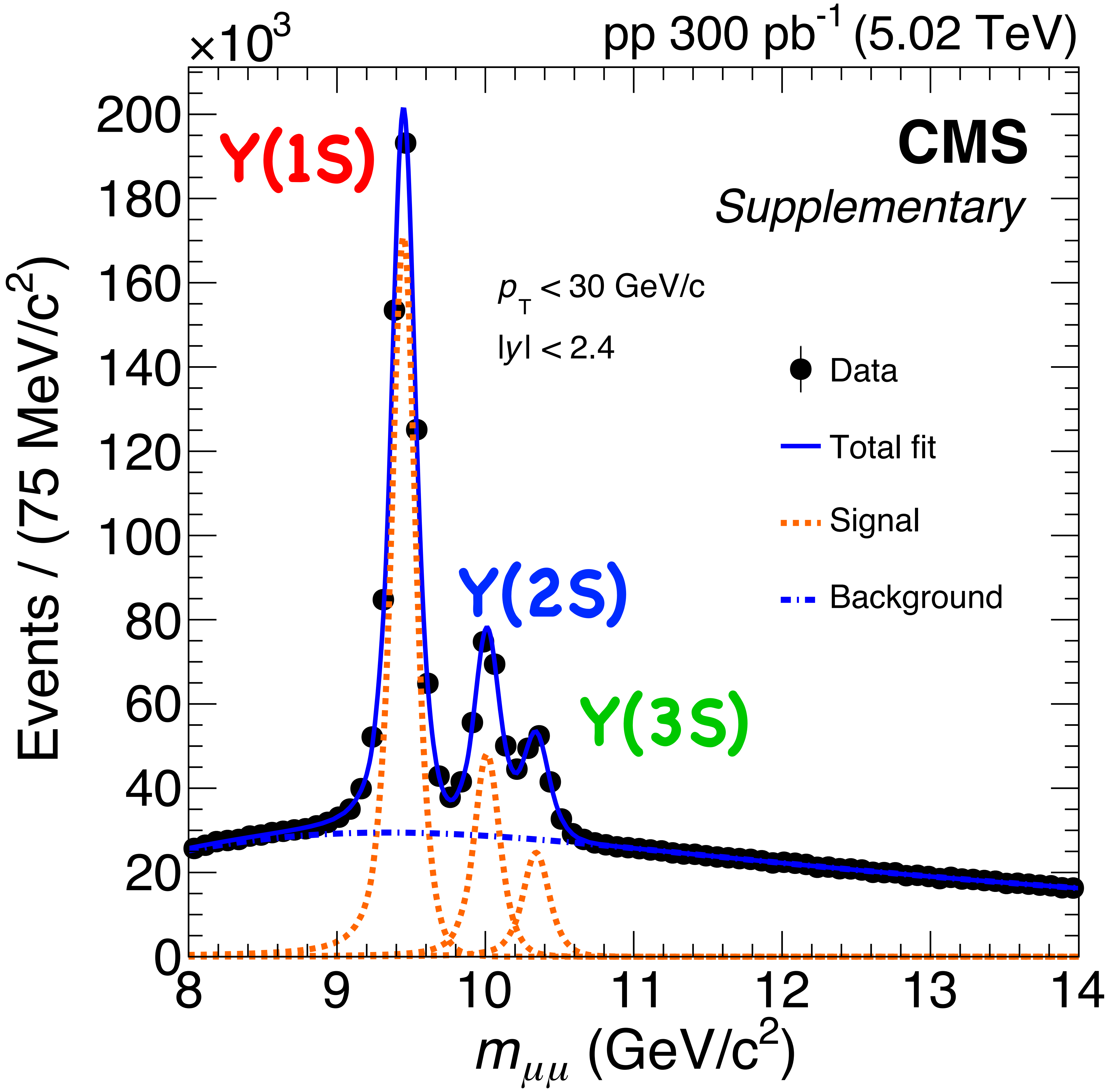
Observation of Υ(3S) in PbPb



- **Observation of the Υ(3S) meson in PbPb!**
  - First clear identification of Υ(3S) peak in AA!
  - Significance > 5σ using fit likelihood ratio
  - MVA application to maximize signal significance
  - Finally reached to measure five S-wave quarkonium states : J/ψ, ψ(2S), Υ(1S), Υ(2S), **and Υ(3S)**

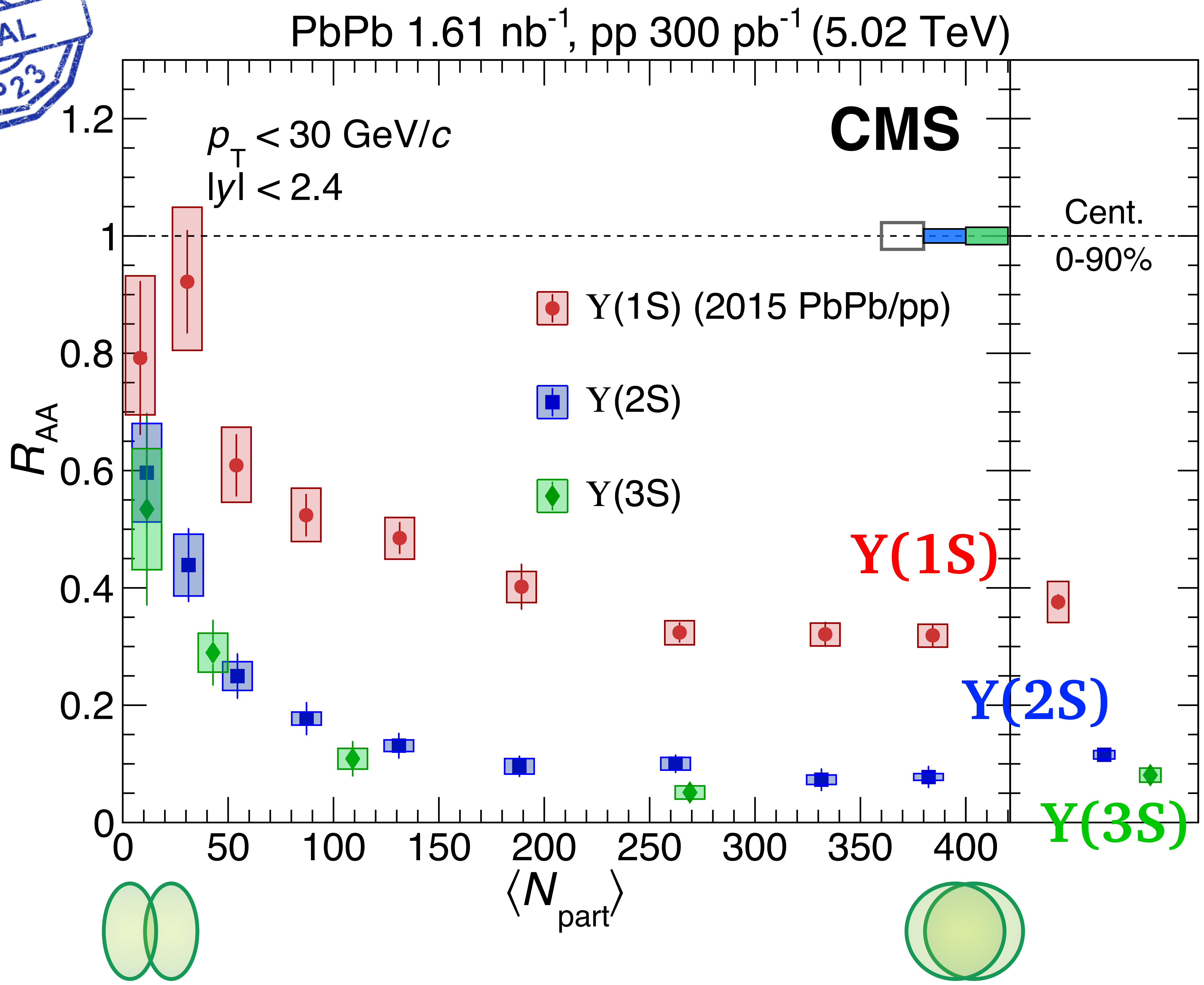
Υ peaks in PbPb and pp





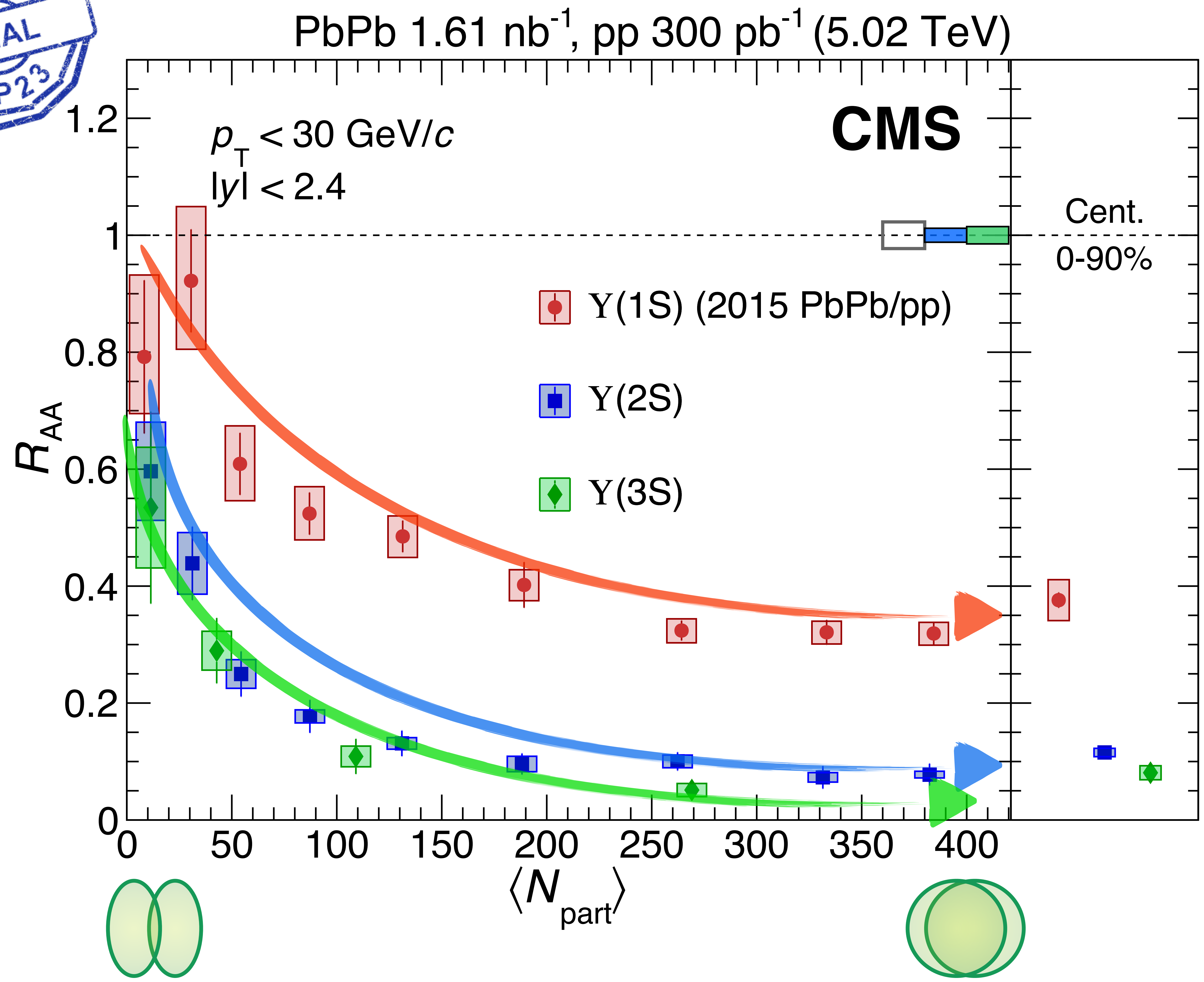
- Excellent signal extraction both in PbPb and pp

Υ(nS) R_{AA} in PbPb



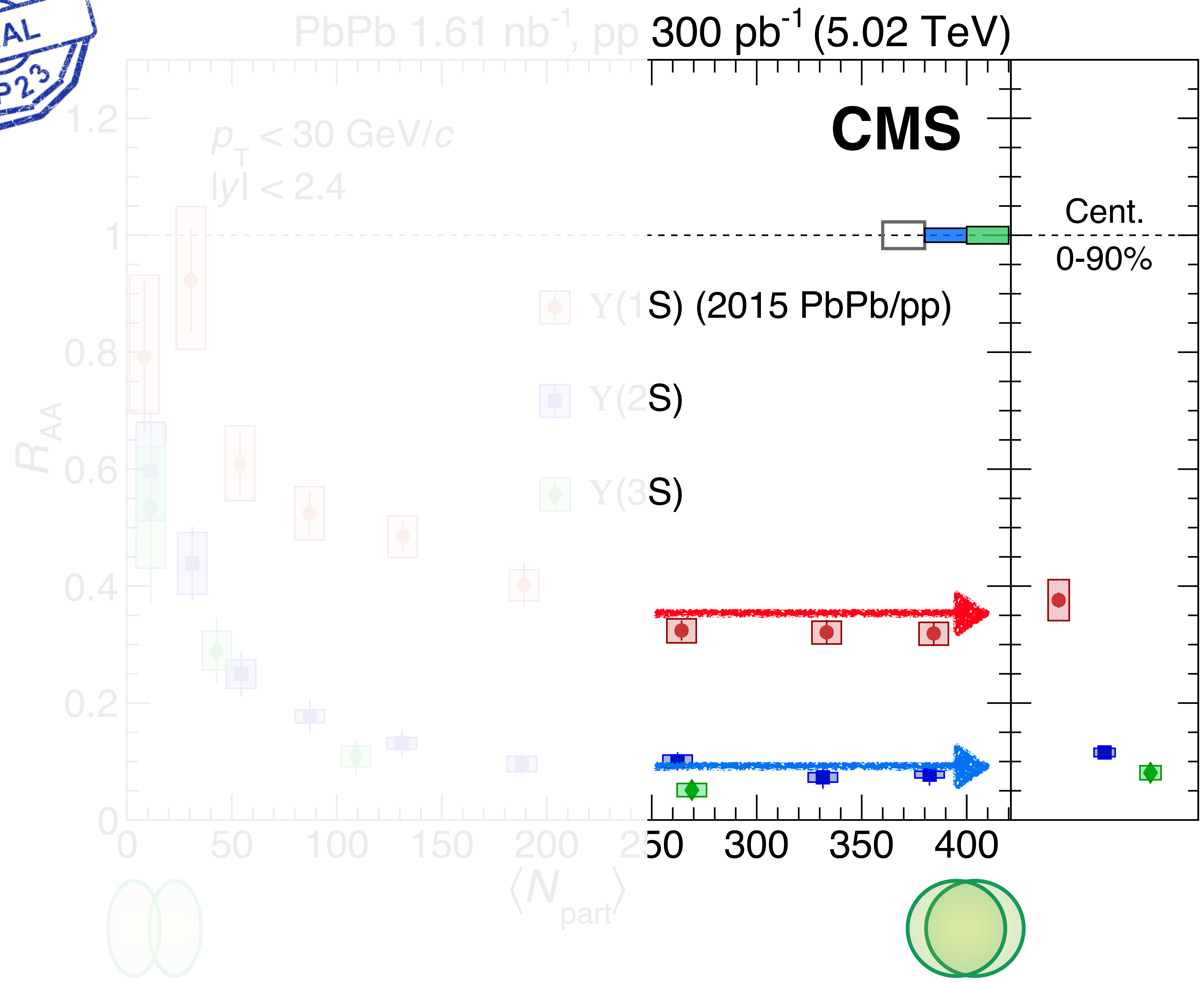
- Ordering of Υ suppression
  - R_{AA}(Υ(1S)) > R_{AA}(Υ(2S)) > R_{AA}(Υ(3S))

Υ(nS) R_{AA} in PbPb



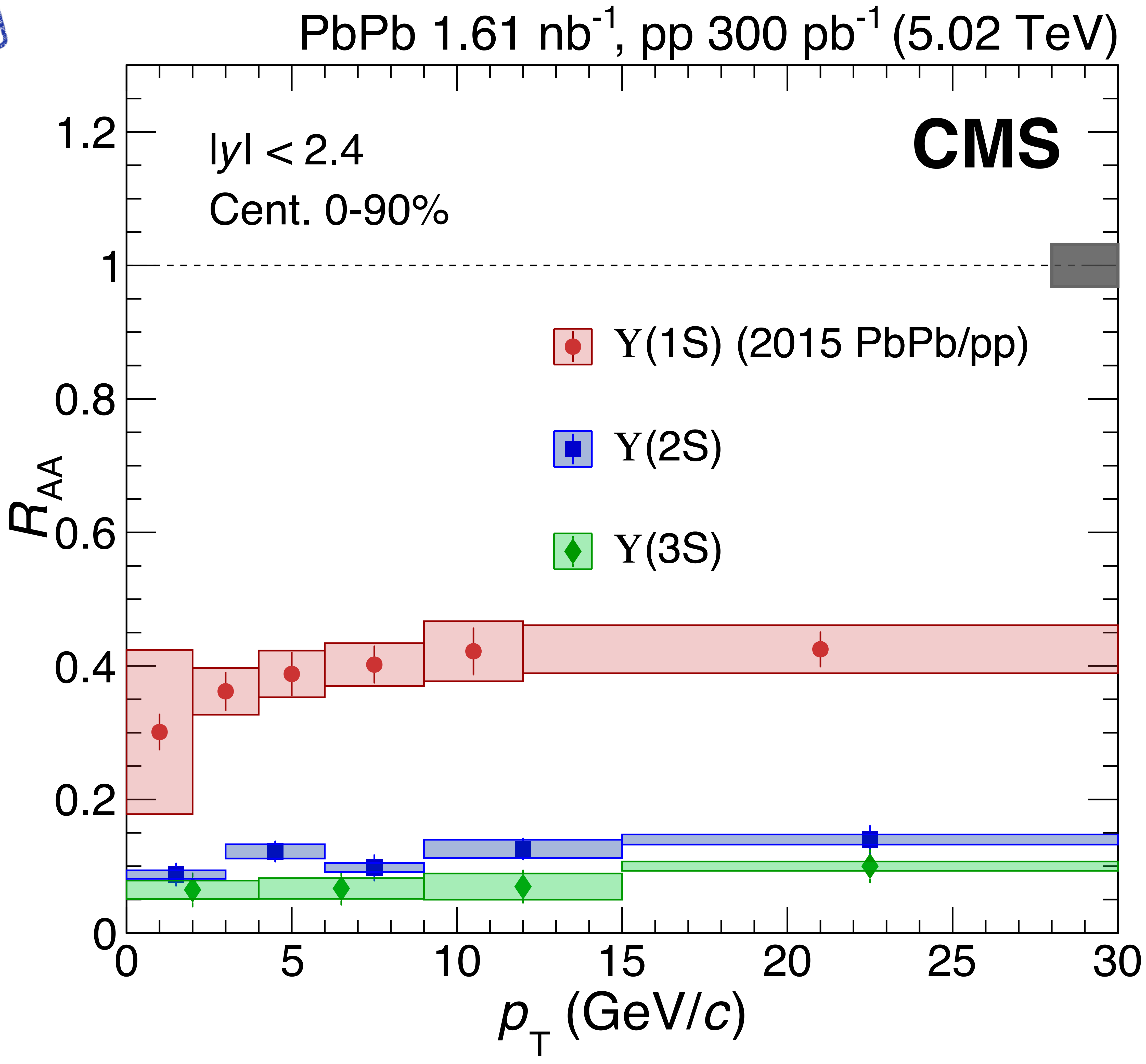
- Ordering of Υ suppression
  - R_{AA}(Υ(1S)) > R_{AA}(Υ(2S)) > R_{AA}(Υ(3S))
- Gradual decrease towards central collisions

Υ(nS) R_{AA} in PbPb



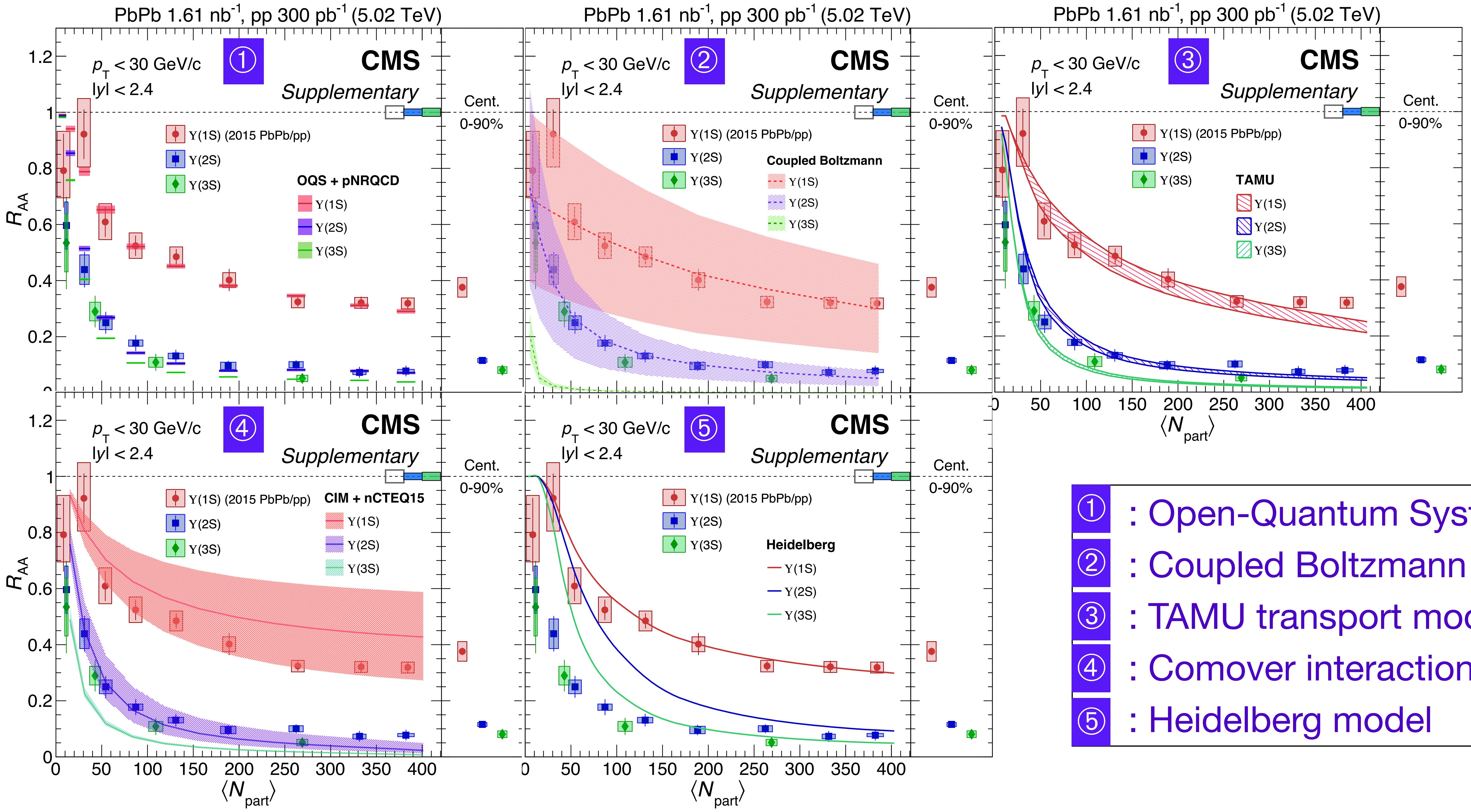
- Ordering of Υ suppression
  - R_{AA}(Υ(1S)) > R_{AA}(Υ(2S)) > R_{AA}(Υ(3S))
- Gradual decrease towards central collisions
- Possible saturation in central collisions?
  - Dissociation ≈ Recombination?
  - Need more precision data

Υ(nS) R_{AA} in PbPb



- Sequential suppression in all p_T region
  - R_{AA}(Υ(1S)) > R_{AA}(Υ(2S)) > R_{AA}(Υ(3S))
- No significant dependence on p_T
  - Coincidence of multiple effects?
    - Everything depends on p_T
      - Dissociation
      - Recombination
      - Feed down fraction
      - Formation time

Model comparison R_{AA}



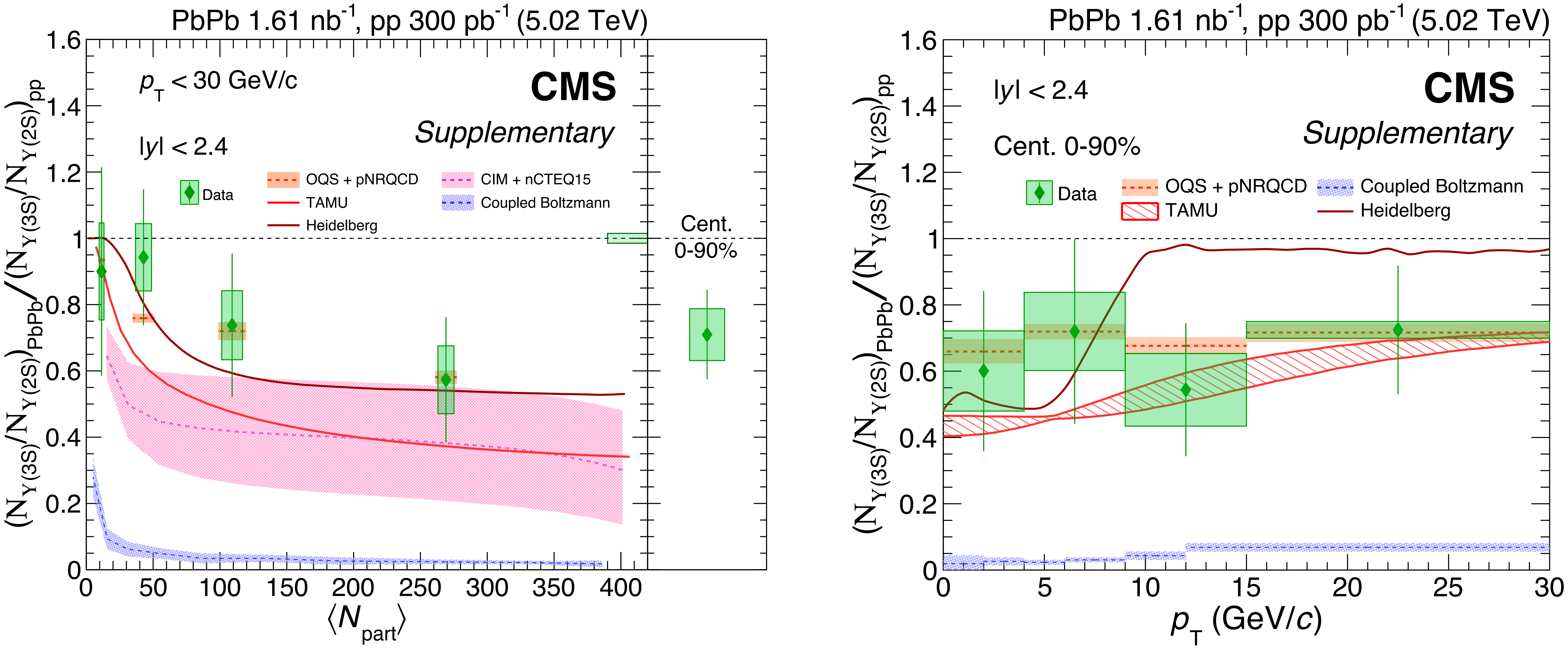
①,②,③ : w/ recombination
④,⑤ : w/o recombinaton

②,③,④ : w/ CNM effects
①,⑤ : w/o CNM effects

① : Open-Quantum System + pNRQCD
② : Coupled Boltzmann transport equation
③ : TAMU transport model
④ : Comover interaction model
⑤ : Heidelberg model

- Different ingredients, different assumptions… All in agreement with Υ(1S) R_{AA}
- Deviations appear for excited states —> Focus on excited states constraints

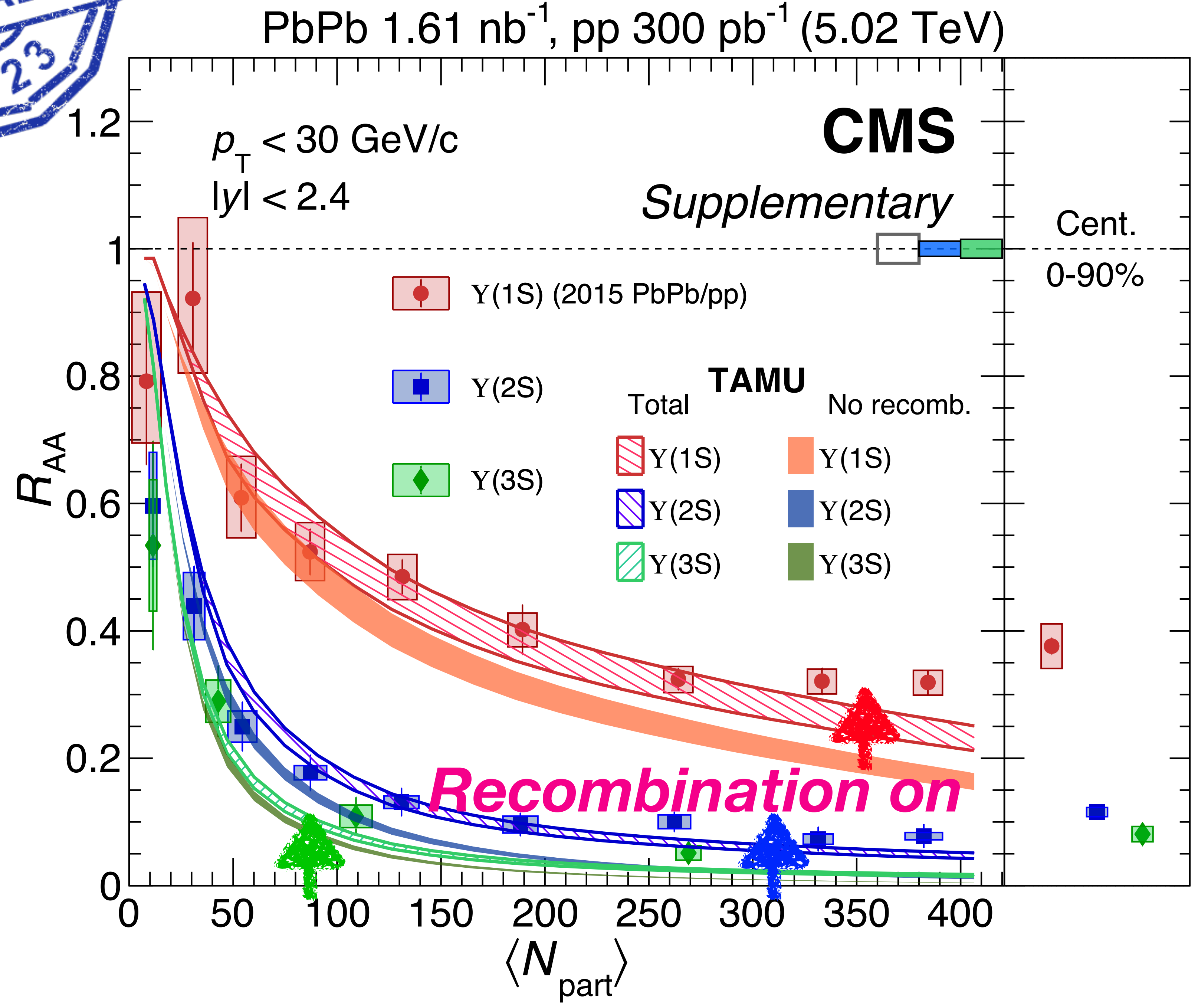
Double ratio of Υ(3S)/Υ(2S)



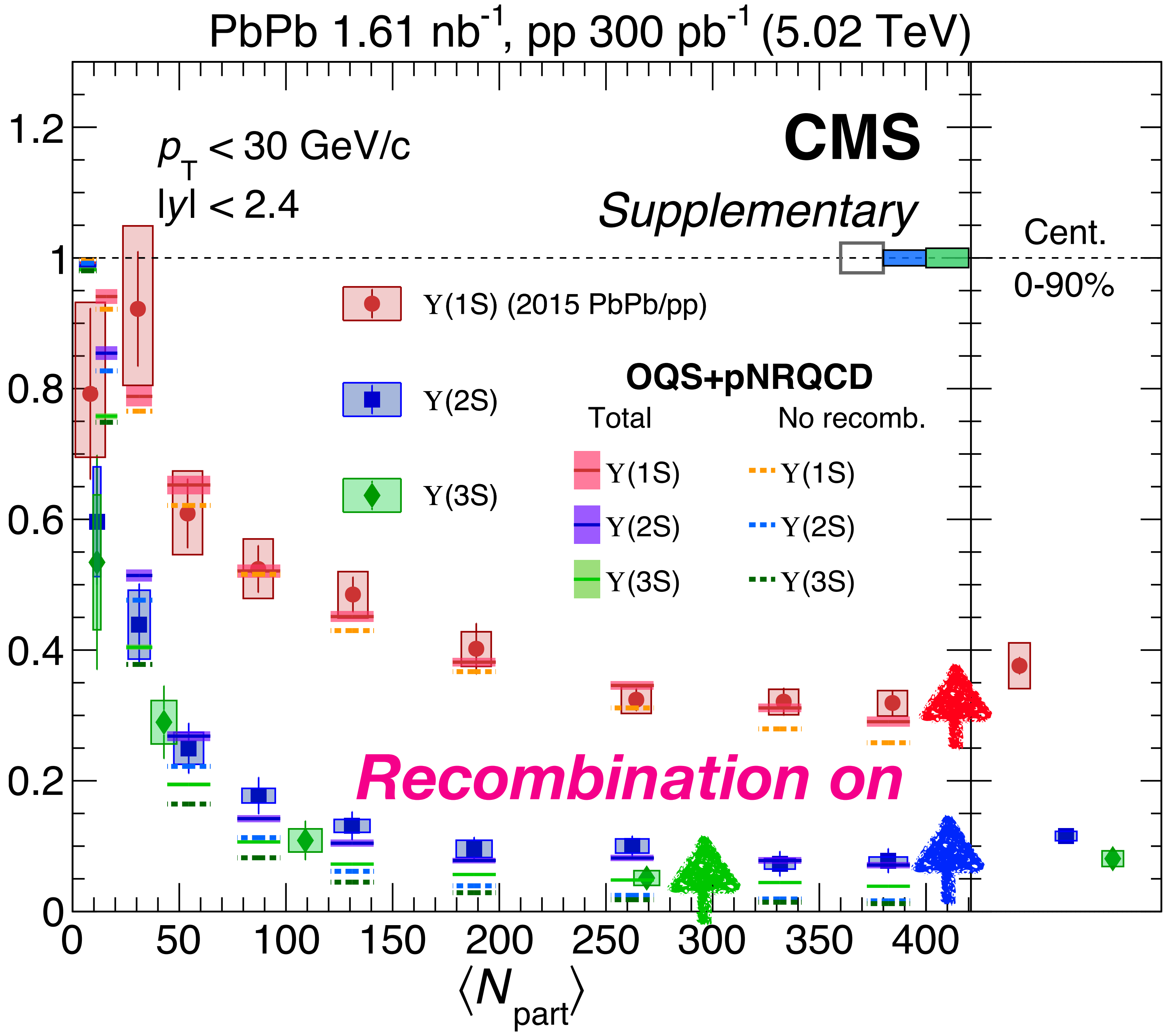
- Υ(3S)/Υ(2S) double ratio — indicating stronger suppression for Υ(3S)
- Significant differences among models
  - Strong constraints on models to describe both centrality and p_T dependence

Recombination effect

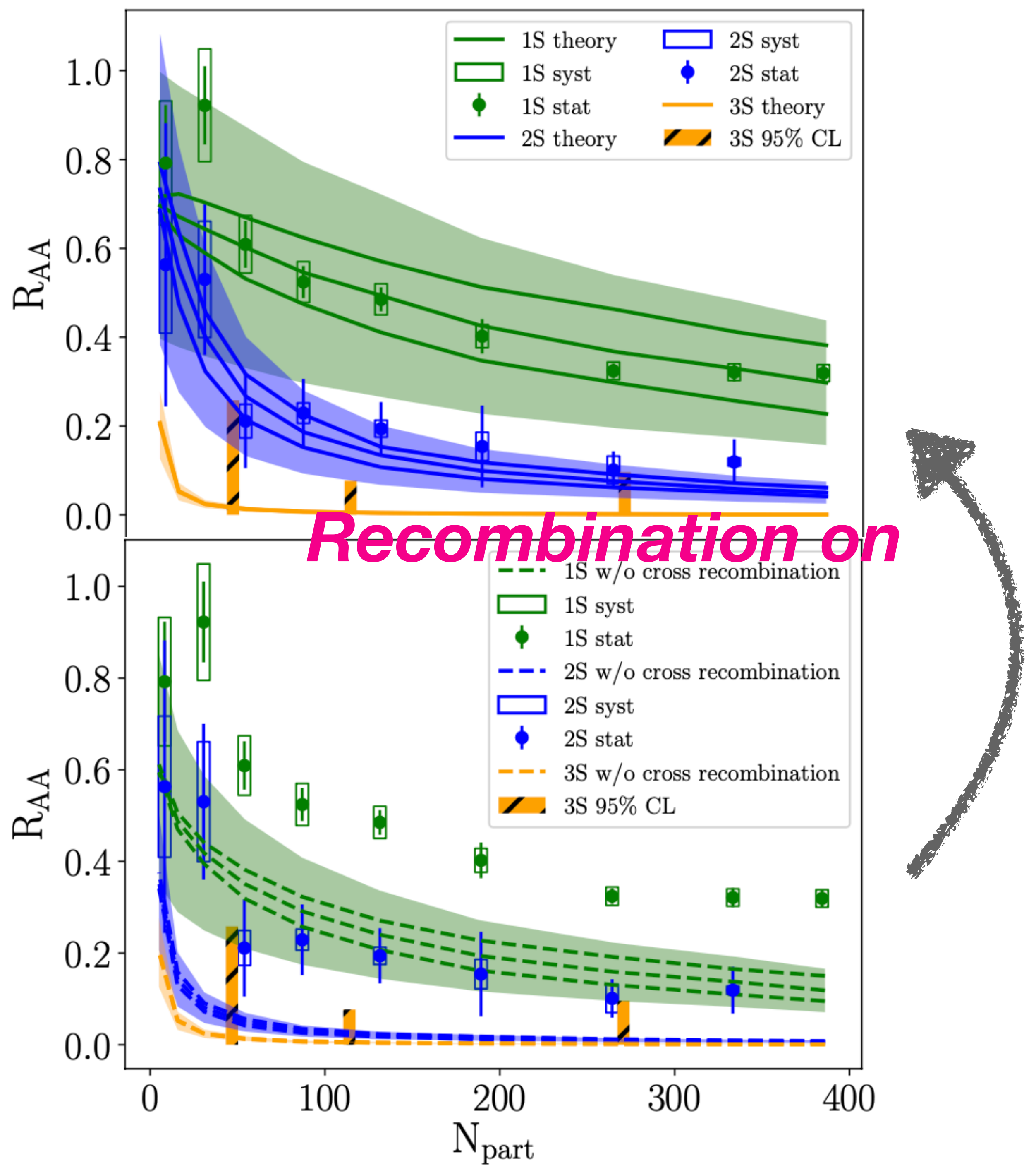
[PRC 96 (2017) 054901]



[arXiv:2302.11826]



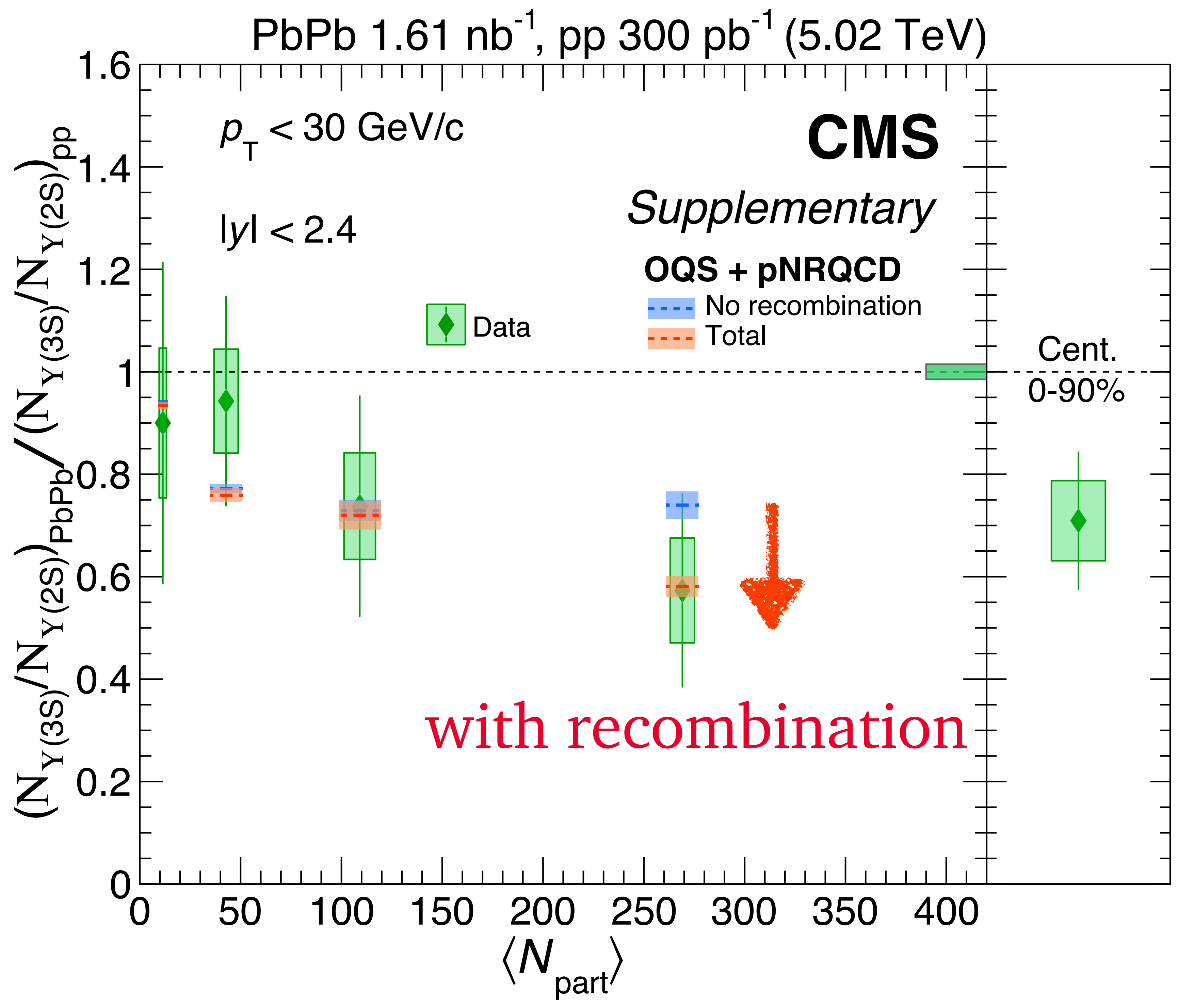
[JHEP 01 (2021) 046]



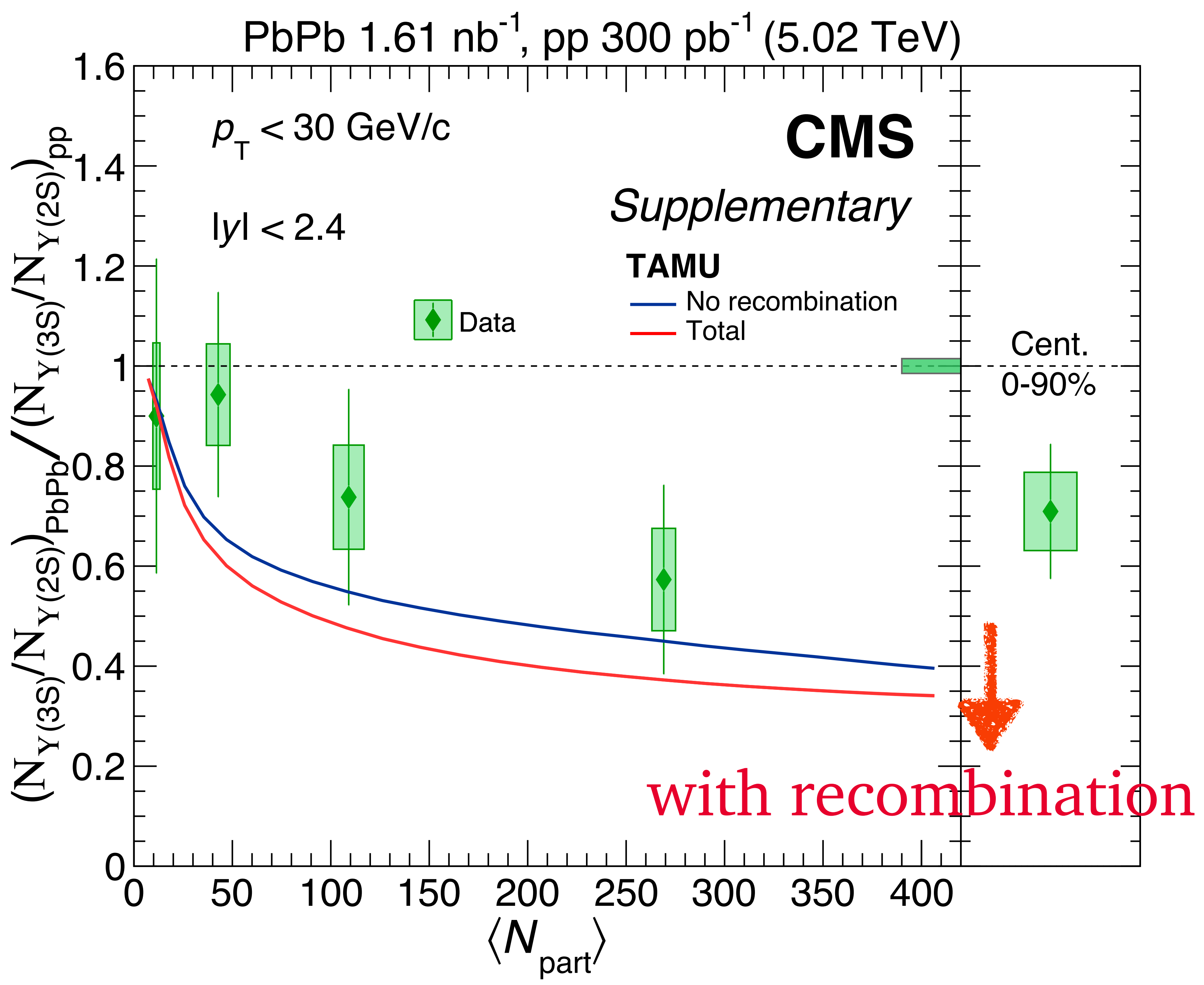
- Recent theory calculations : Importance of recombination for Upsilons!
  - Correlated (diagonal) term become the dominant component
  - Larger effect for excited states

Recombination effect

OQS + pNRQCD



TAMU

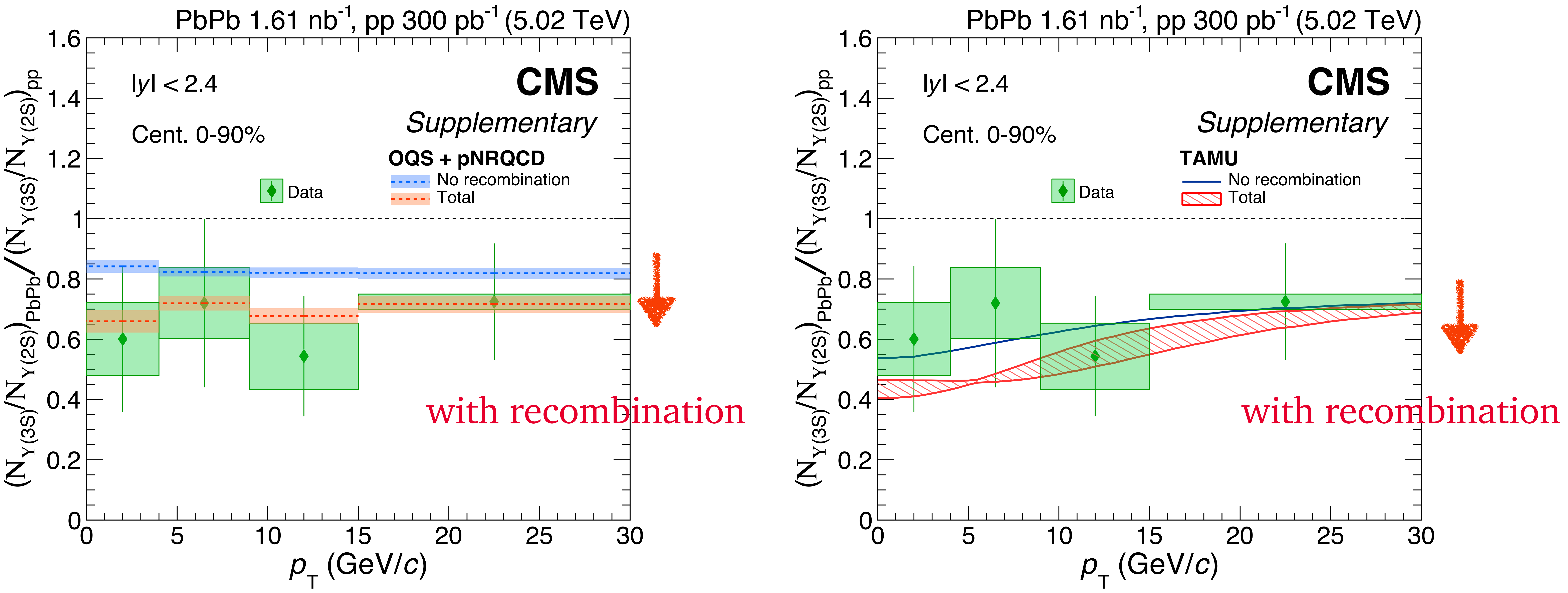


- Decrease of Υ(3S)/Υ(2S) double ratio w/ recomb. —> more recomb. for Υ(2S)!
- Suppression : Υ(3S) > Υ(2S) > Υ(1S) <—> Recombination : Υ(2S) > Υ(3S) > Υ(1S)

Recombination effect

OQS + pNRQCD

TAMU



- Similar finding seen vs p_T : Larger recombination for Y(2S) than Y(3S)
- Important for sophisticated treatment of recombination for excited states

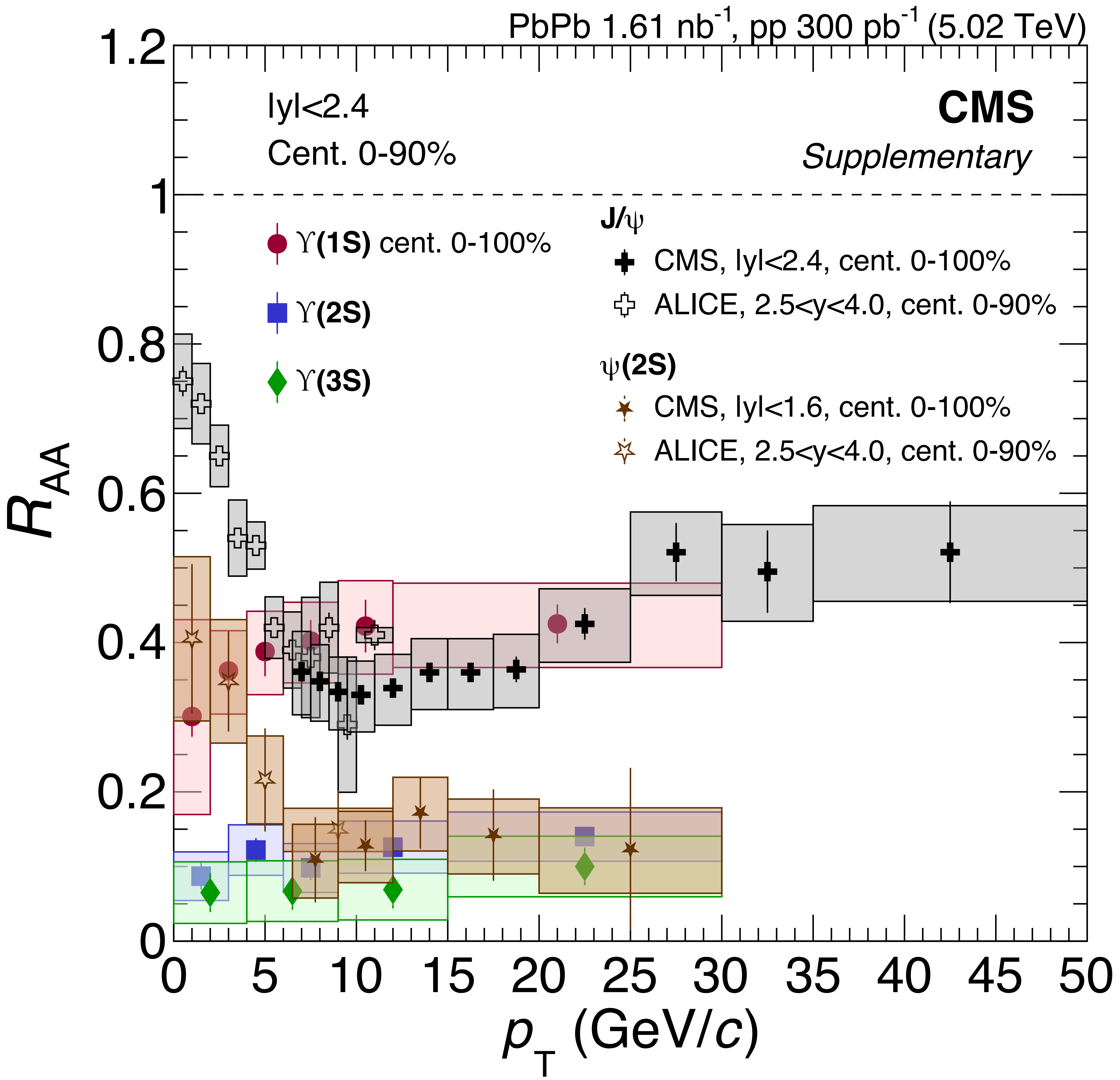
Quarkonia R_{AA}

[PLB 790 (2019) 270]

[EPJC 78 (2018) 509]

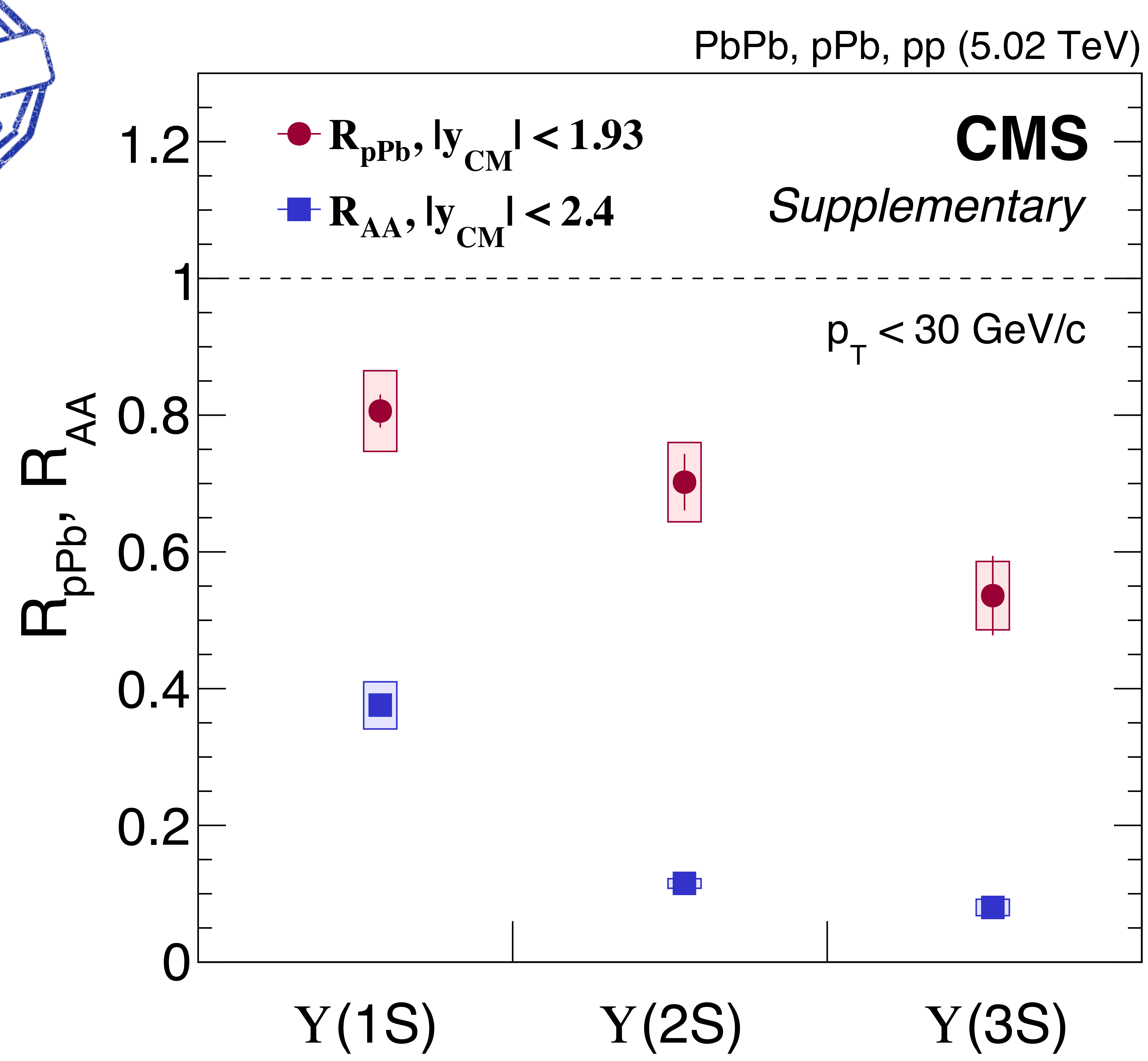
[JHEP 02 (2020) 041]

[arXiv:2210.08893]



- R_{AA} of five S-wave quarkonium states vs p_T
- Enhancement of R_{AA} for charmonia at low-p_T
  - Abundant charm production
- Towards high-p_T
  - When (if any) start to see increase vs p_T?
  - Interesting to see how much coming from jet-fragmentation

Modification in pA / AA

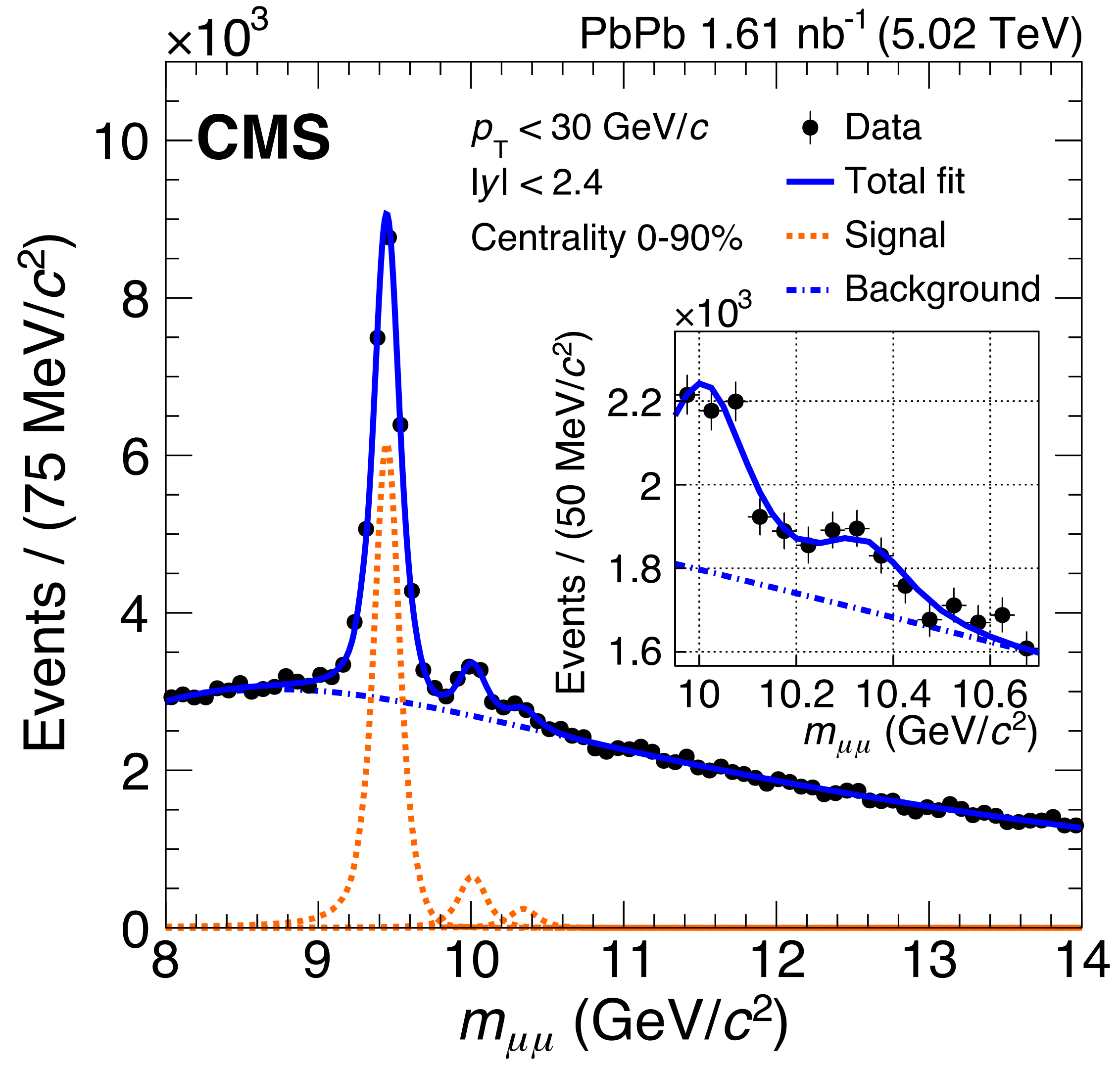


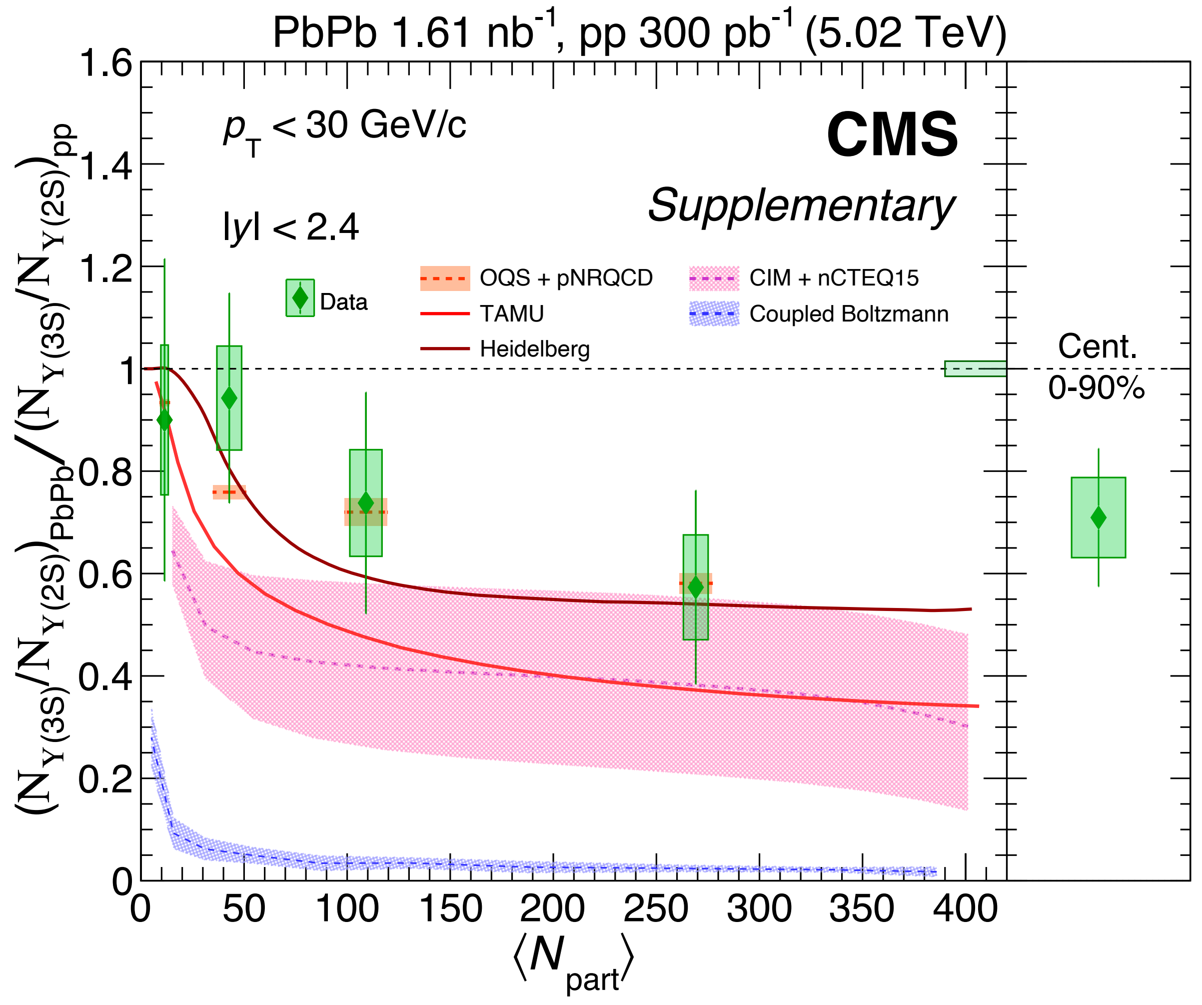
- Ordering of suppression in both pPb and PbPb!
- Crucial information to study cold/hot nuclear matter effects + initial/final state effects
- Current models have difficulties in describing both collision systems

Summary

[HIN-21-007]

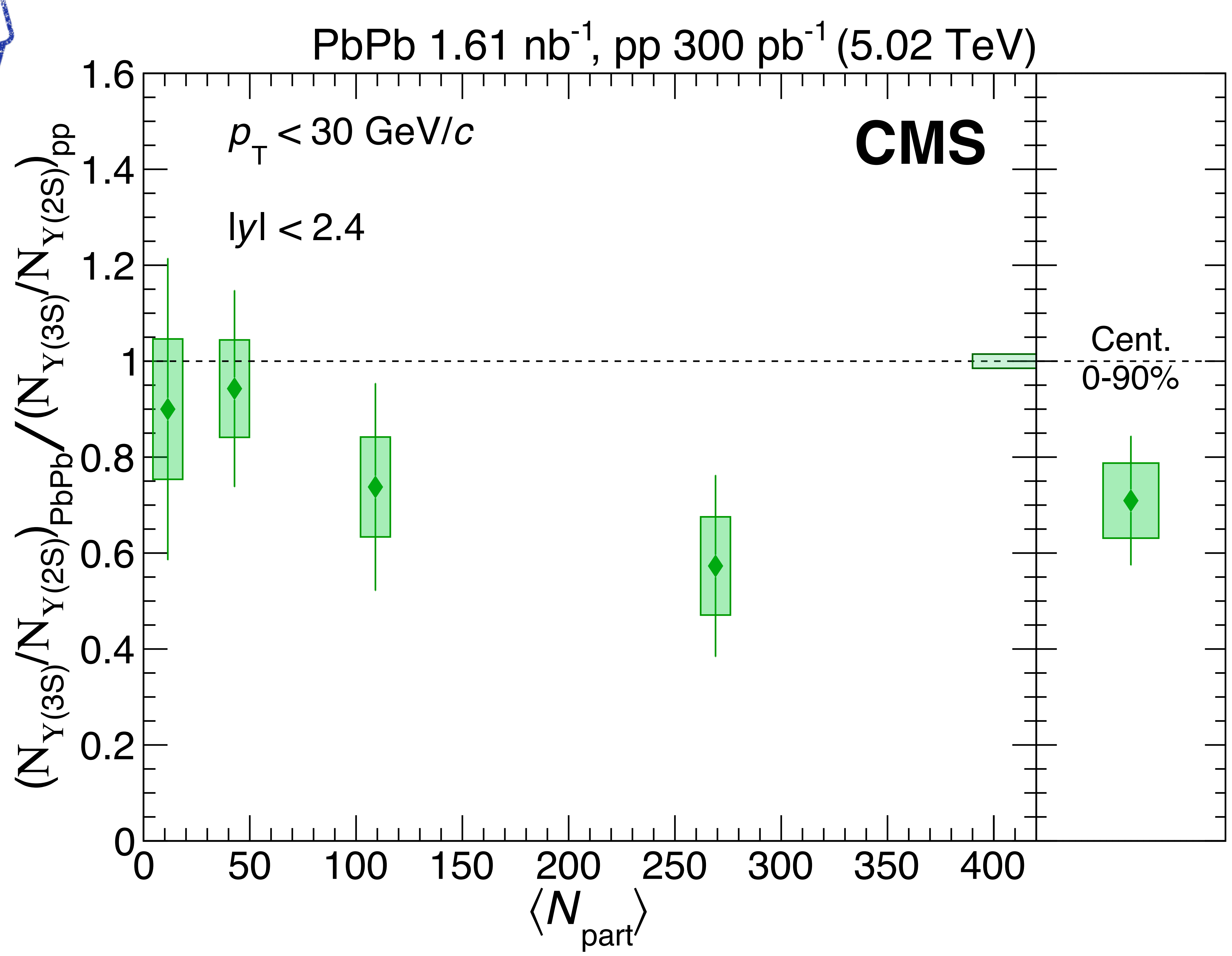
- First observation of the Υ(3S) meson in PbPb collisions with CMS
- Highest precision of Υ sequential suppression in heavy ion collisions
- Excited states Υ(3S)/Υ(2S) giving strong constraints to models
- Sequential suppression in both pPb and PbPb!

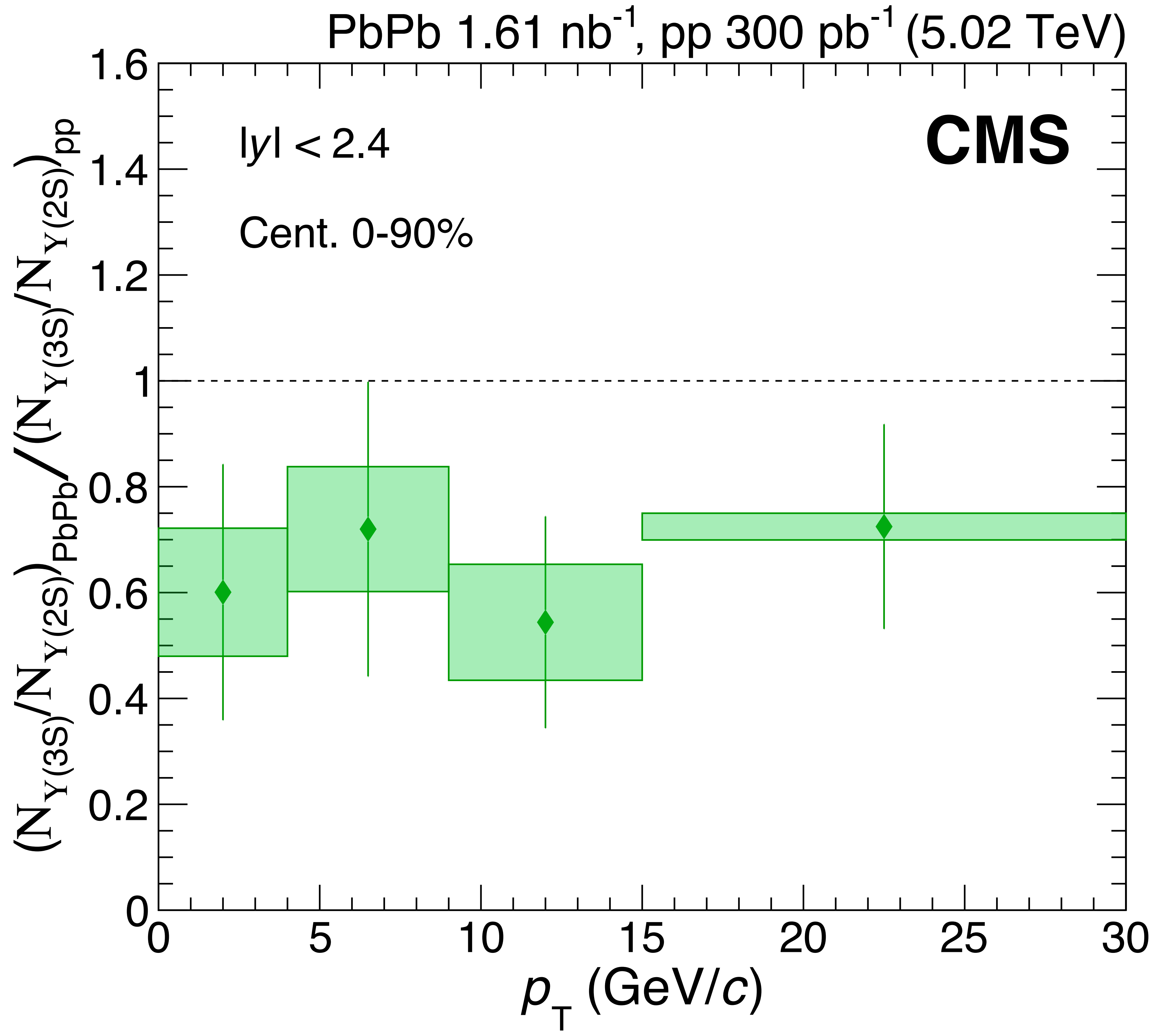




Back-up

Double ratio Υ(3S)/Υ(2S)



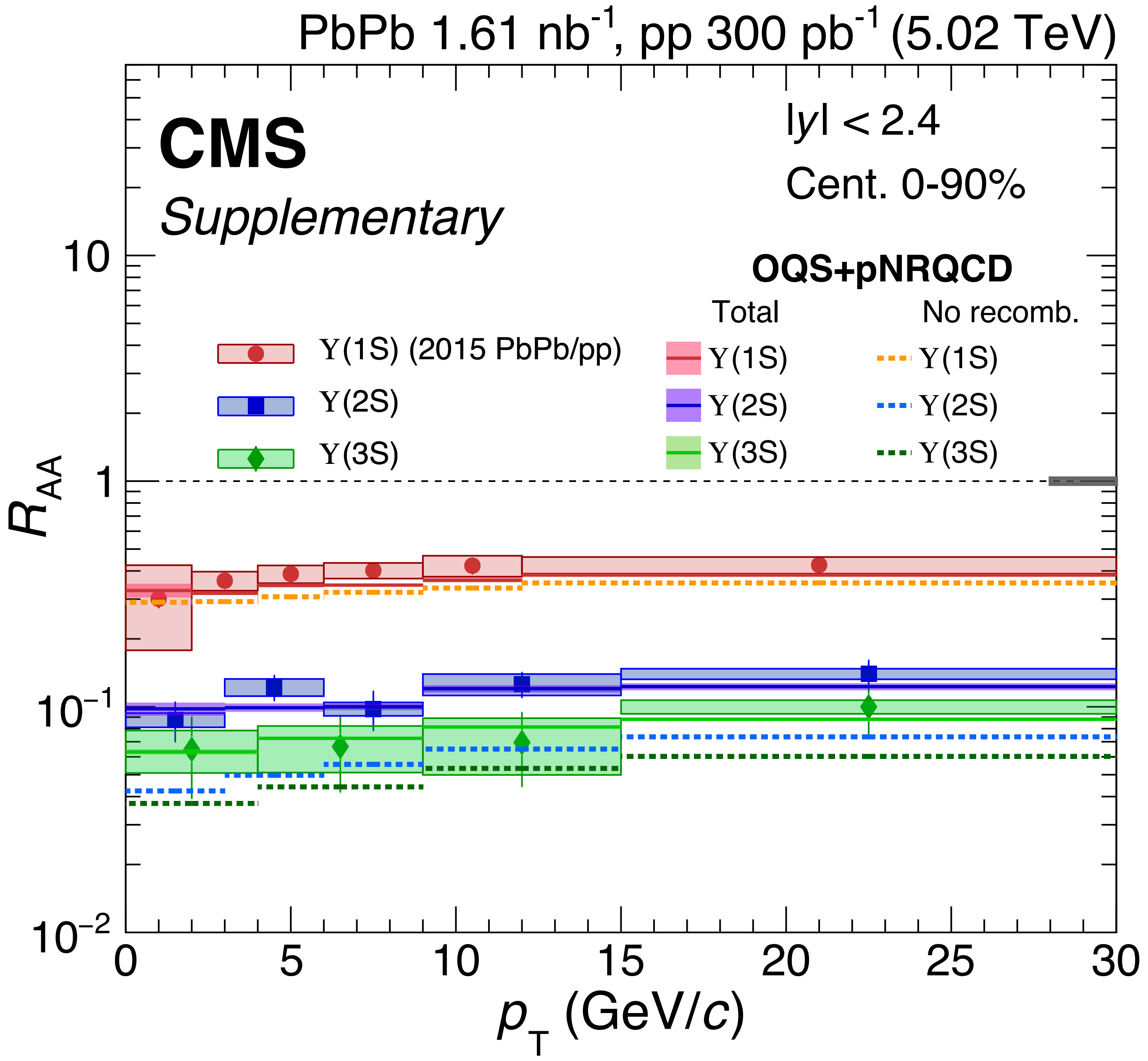


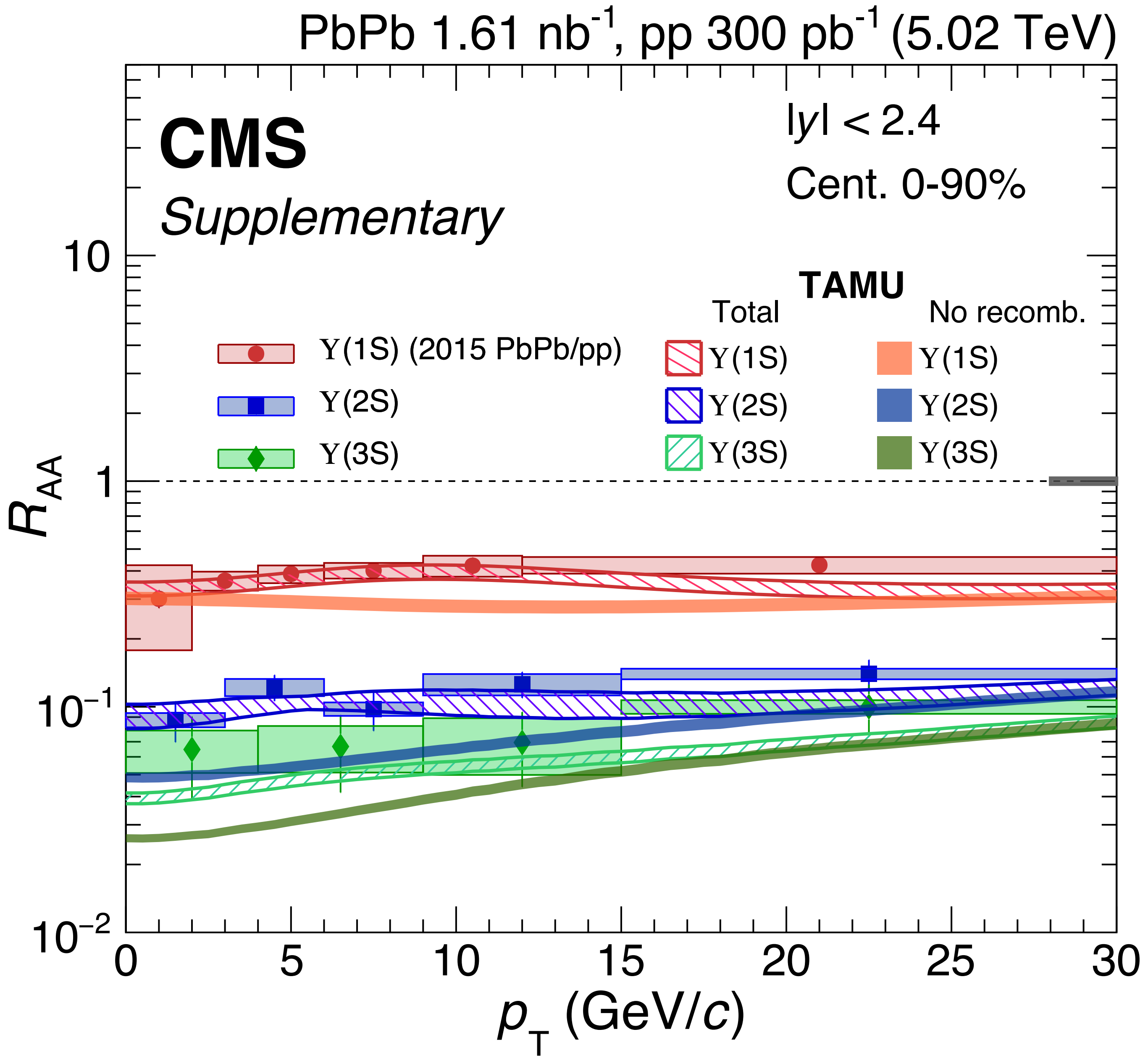
- Stronger suppression for Υ(3S) than Υ(2S) in central collisions & overall studied p_T region
- Υ(3S)/Υ(2S) double ratio as an important probe to study different in-medium effects

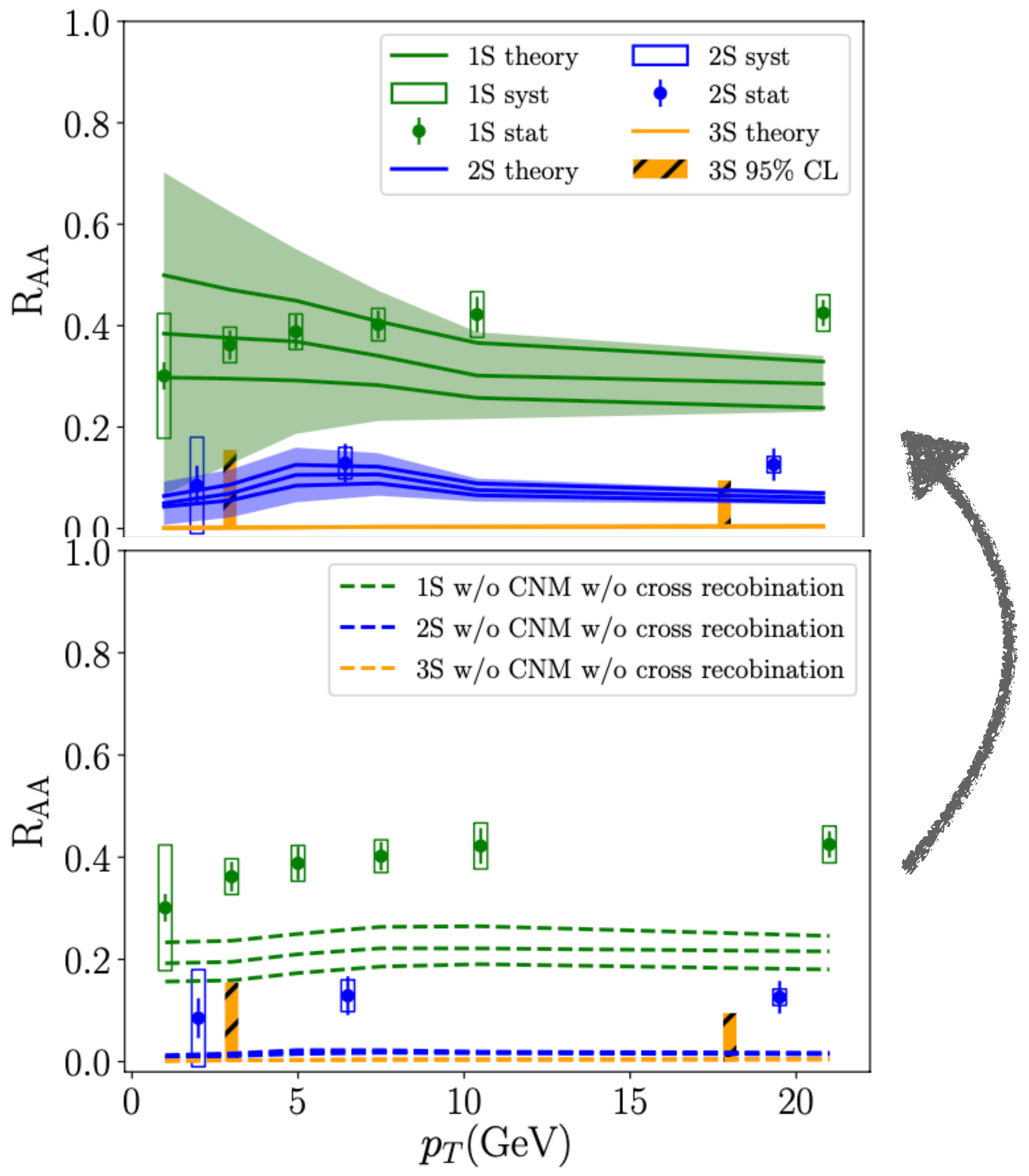
Recombination effect

CMS FINAL HP23

[PRC 96 (2017) 054901] [arXiv:2302.11826] [JHEP 01 (2021) 046]



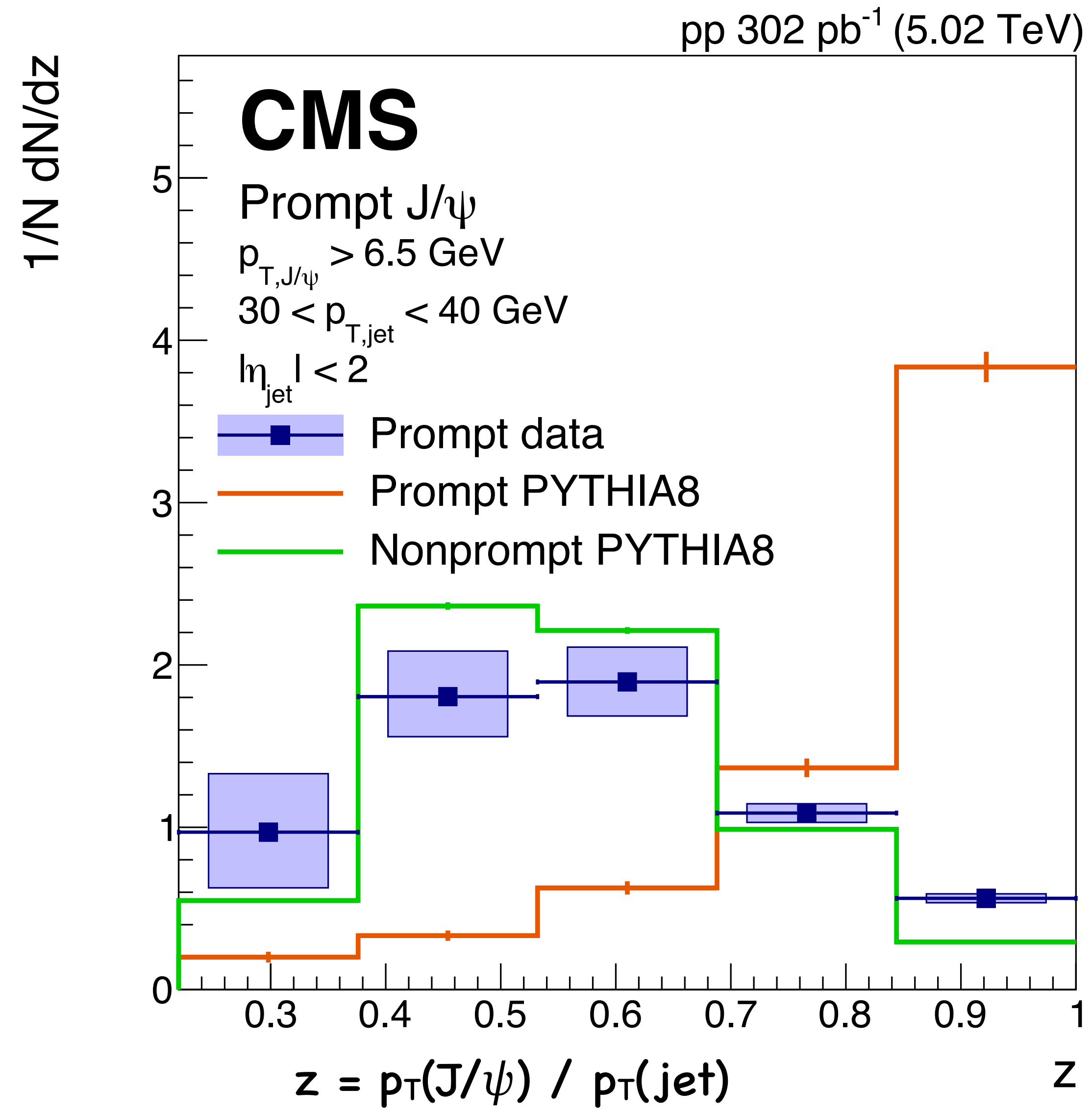


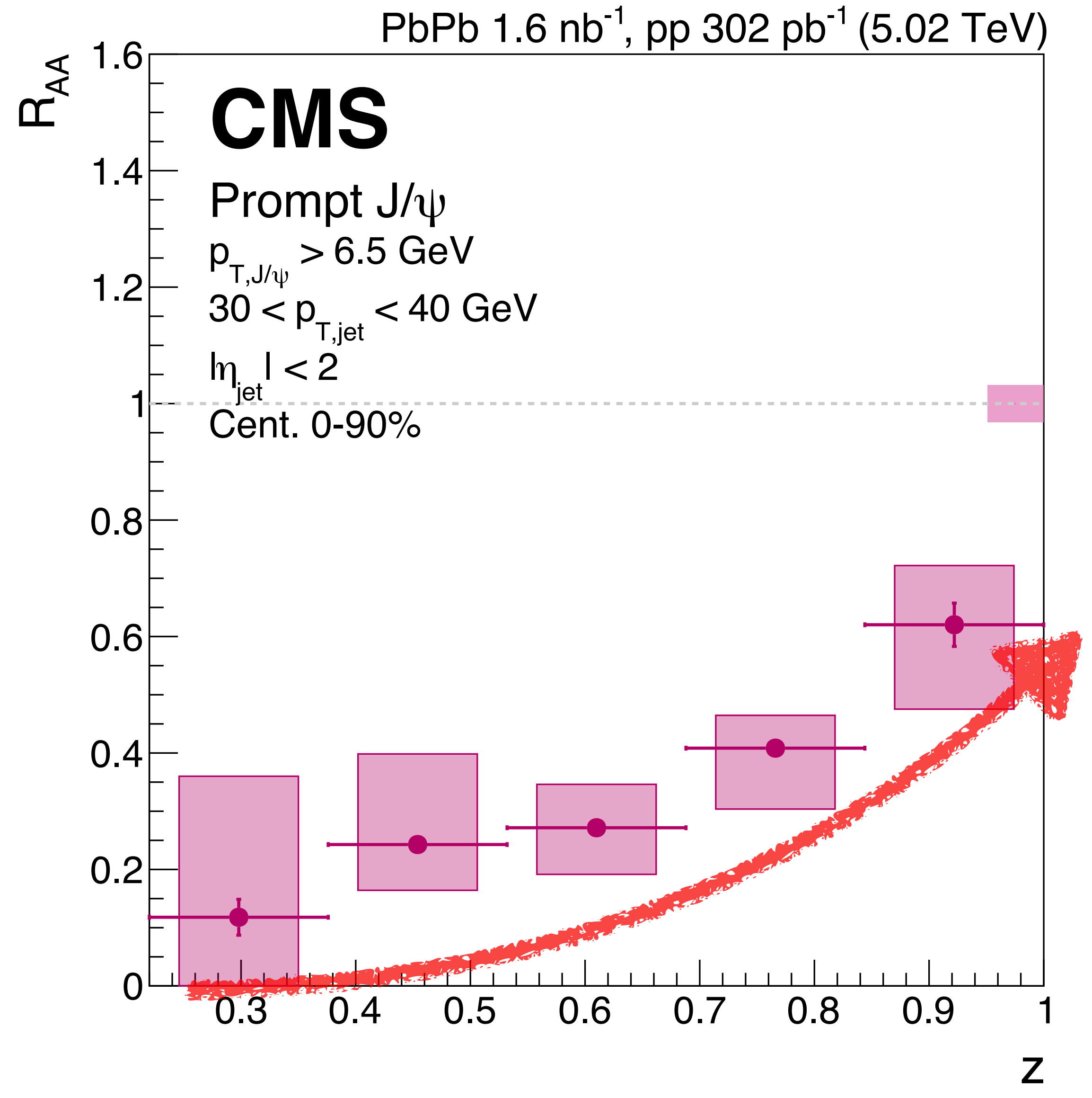


- Recombination effect on Υ R_{AA} — Huge contribution for excited states

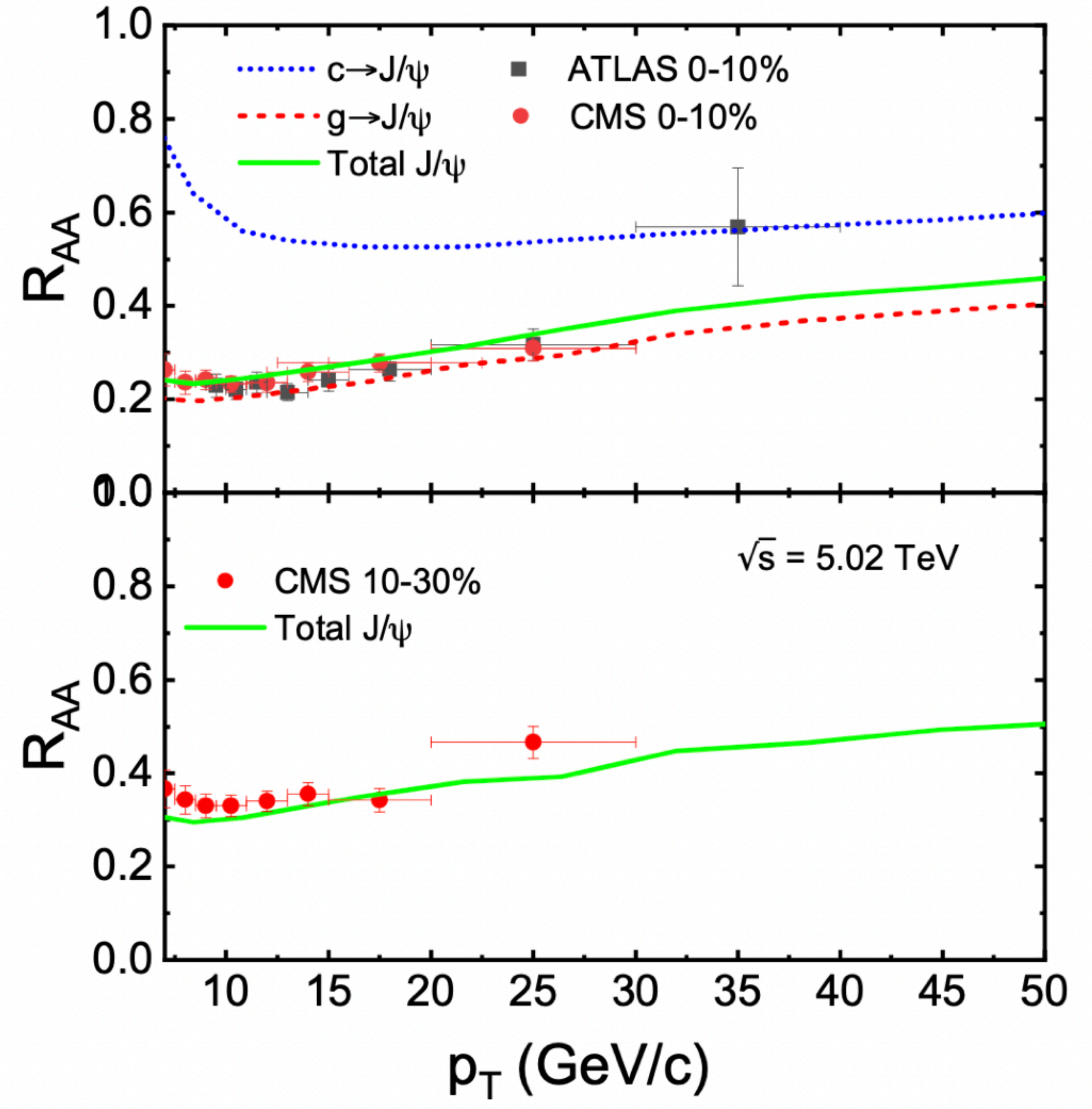
J/ψ in jets

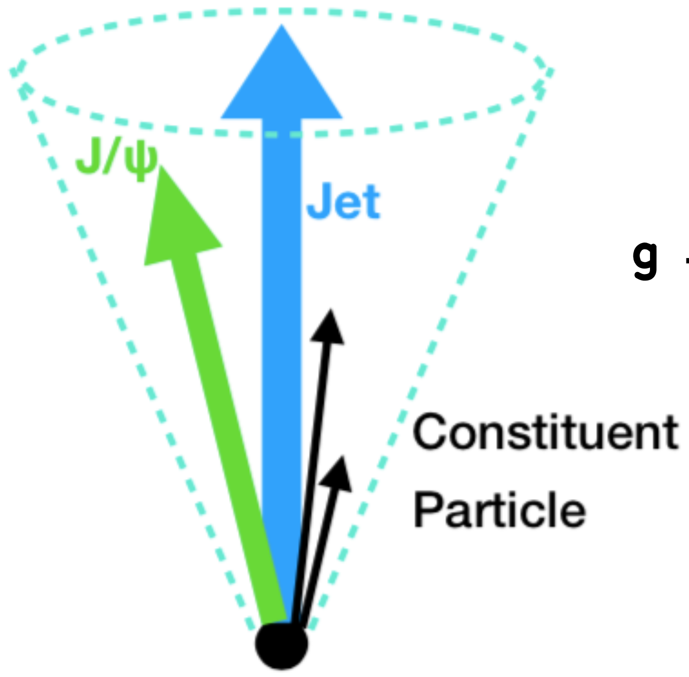
[PLB 805 (2020) 135434]

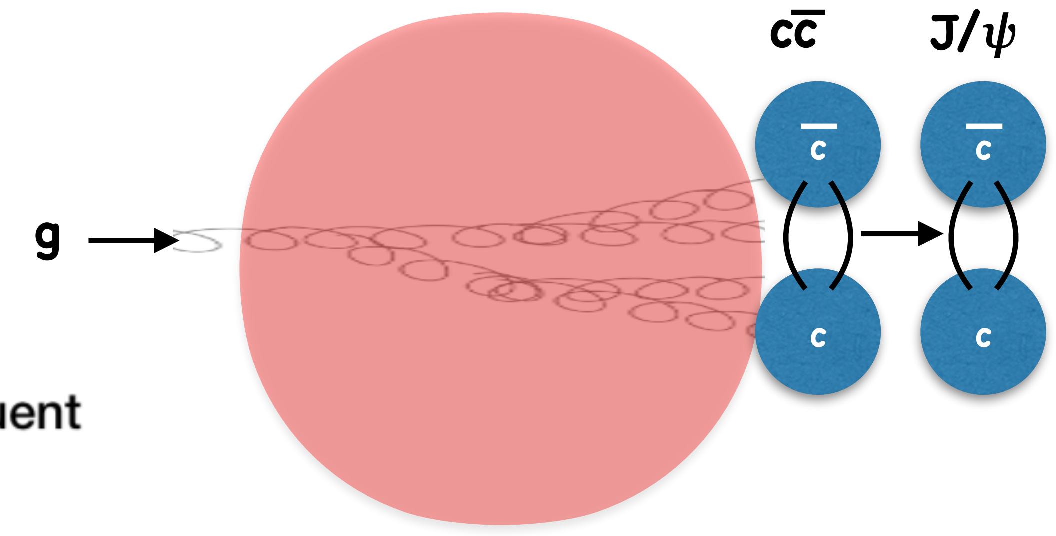




[arXiv:2208.08323]



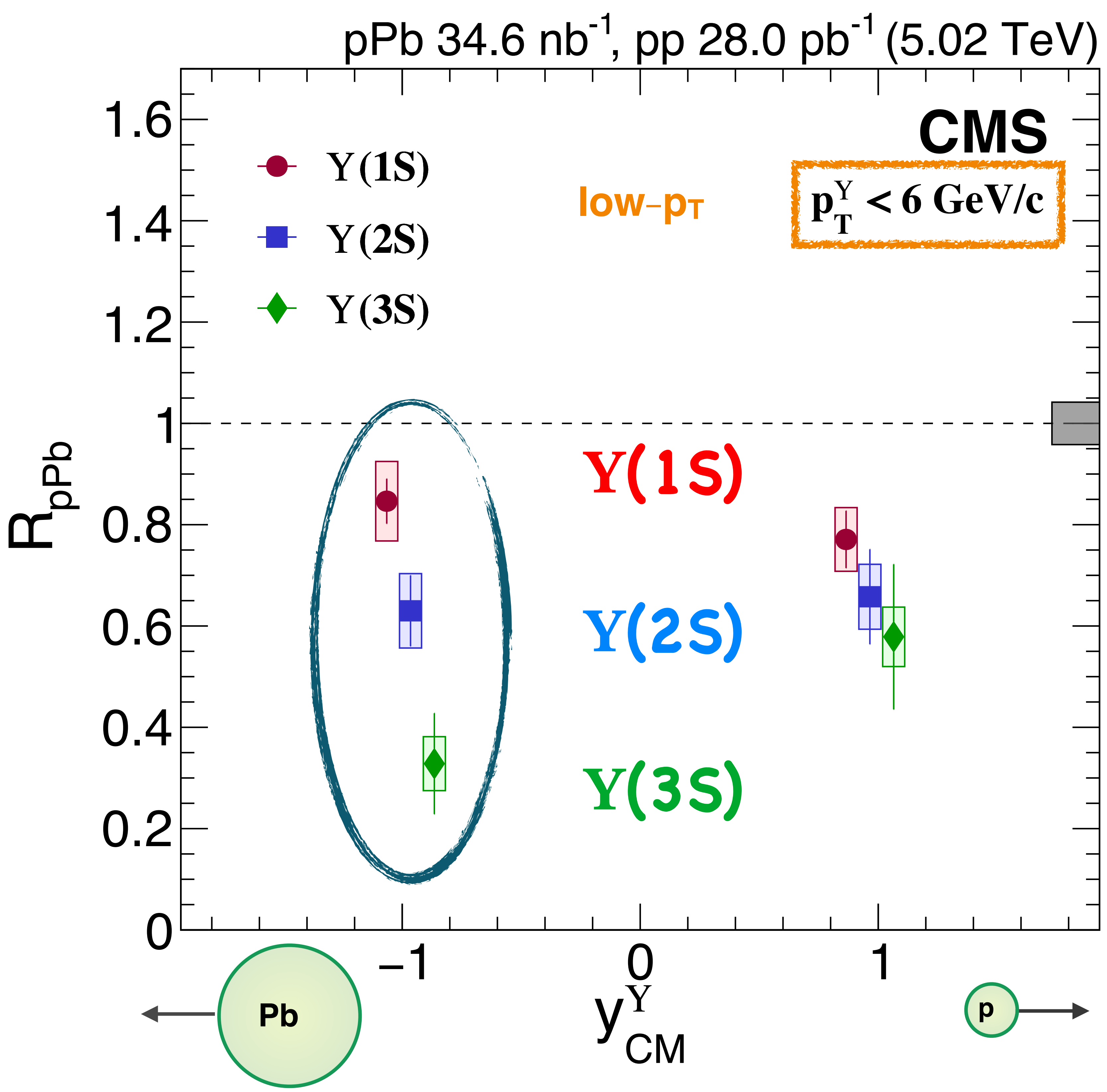


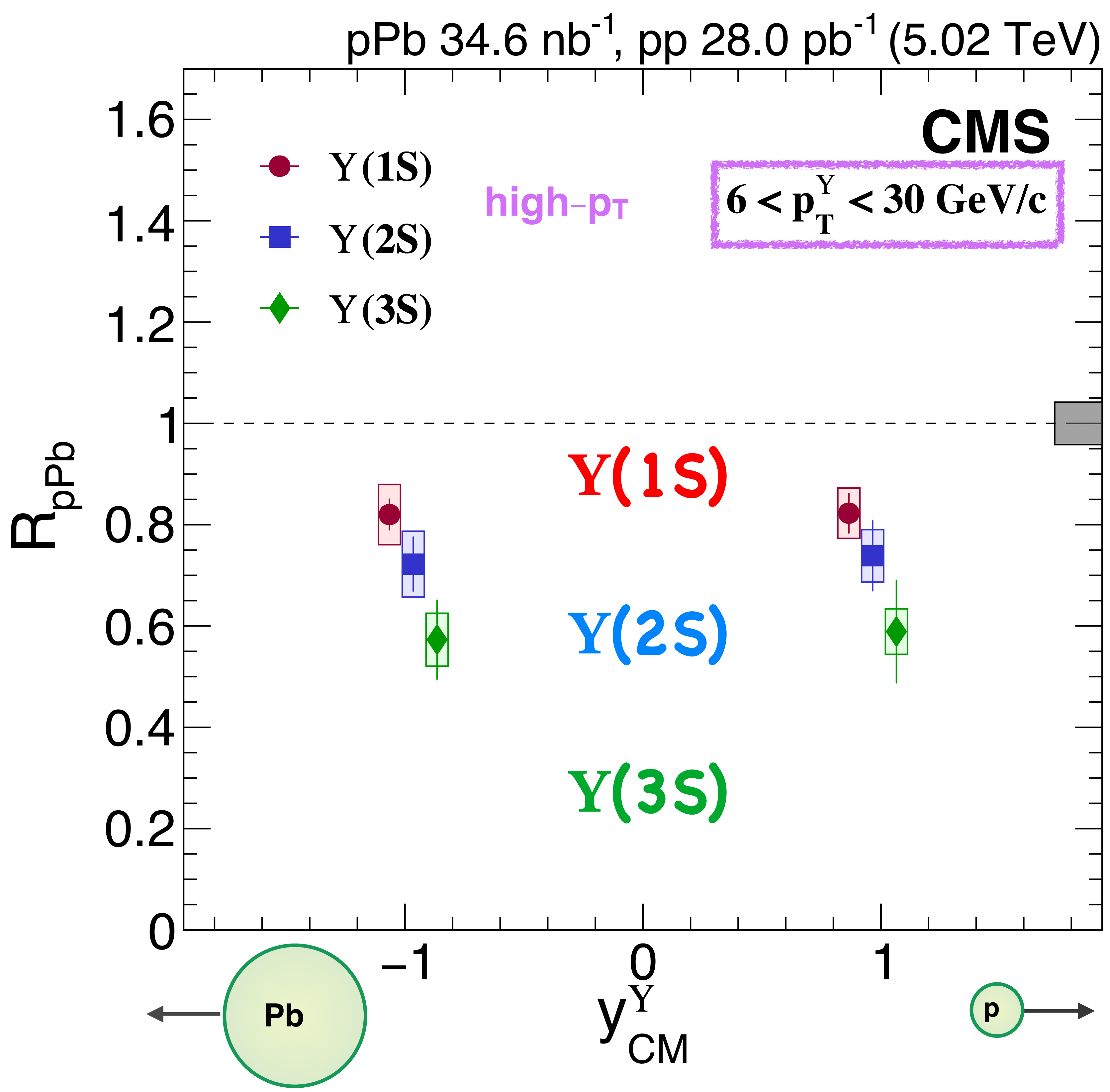


- Mandatory to include jet quenching for J/ψ suppression : Already ongoing studies e.g. LBT
- What about bottomonia?
  —> Measurement : Υ in or associated with jets!

Υ modification in pPb

[PLB 835 (2022) 137397]





- Stronger suppression for excited states at *backward rapidity* & *low-p_T*

Feed down correction

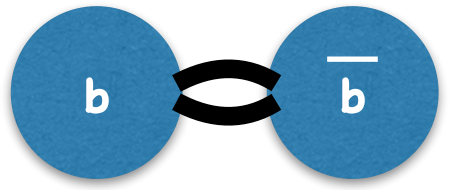
$$\mathscr{F}_{nS}^{mS} = \mathscr{B}(mS \to nS)\frac{\sigma_{mS}}{\sigma_{nS}}$$

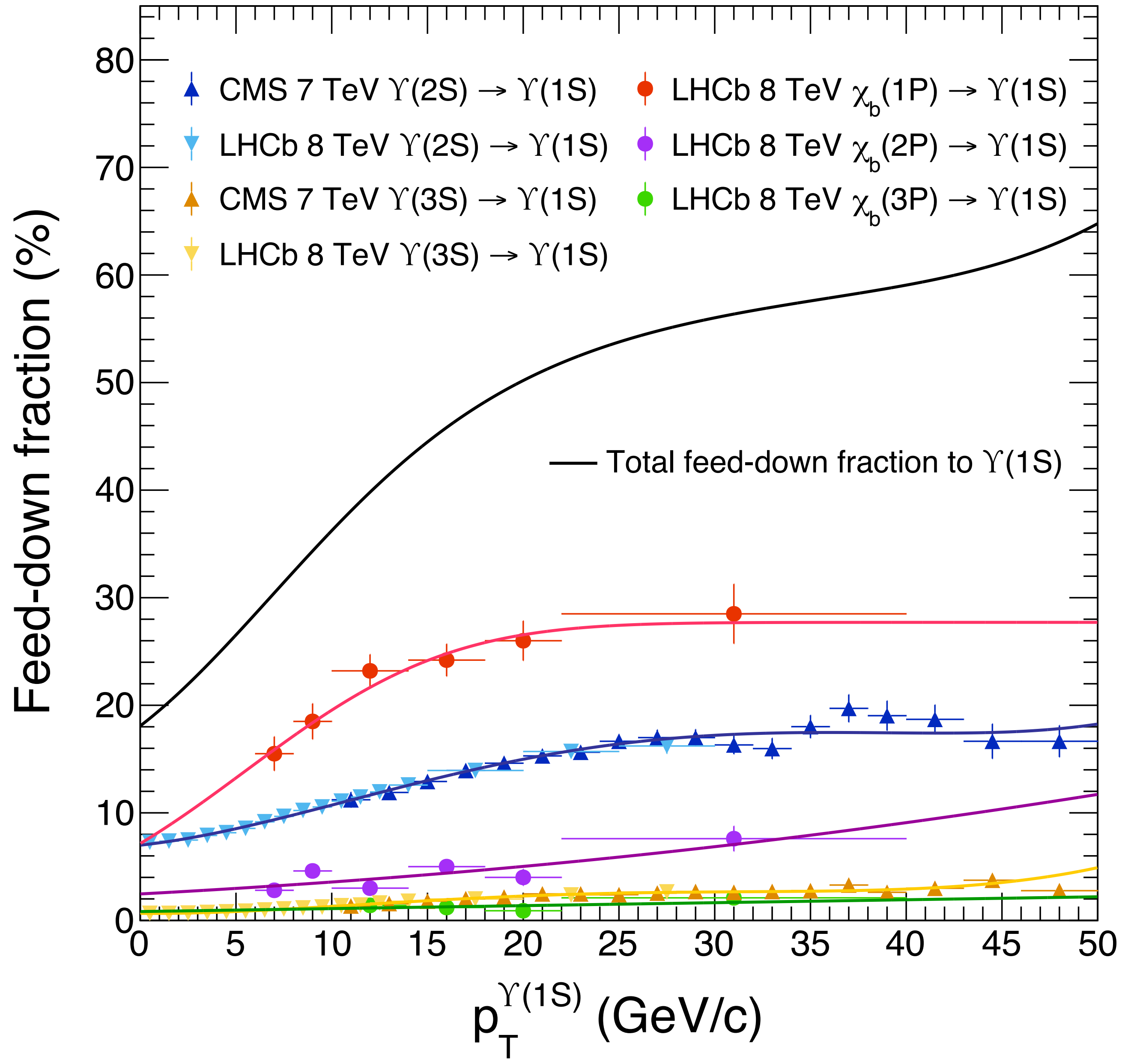
[JHEP 11 (2015) 103]

[PLB 749 (2015) 14]

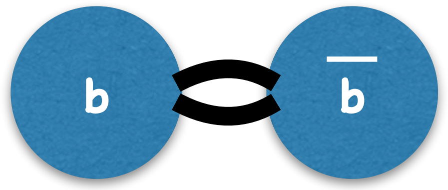
[EPJC 74 (2014) 3092]

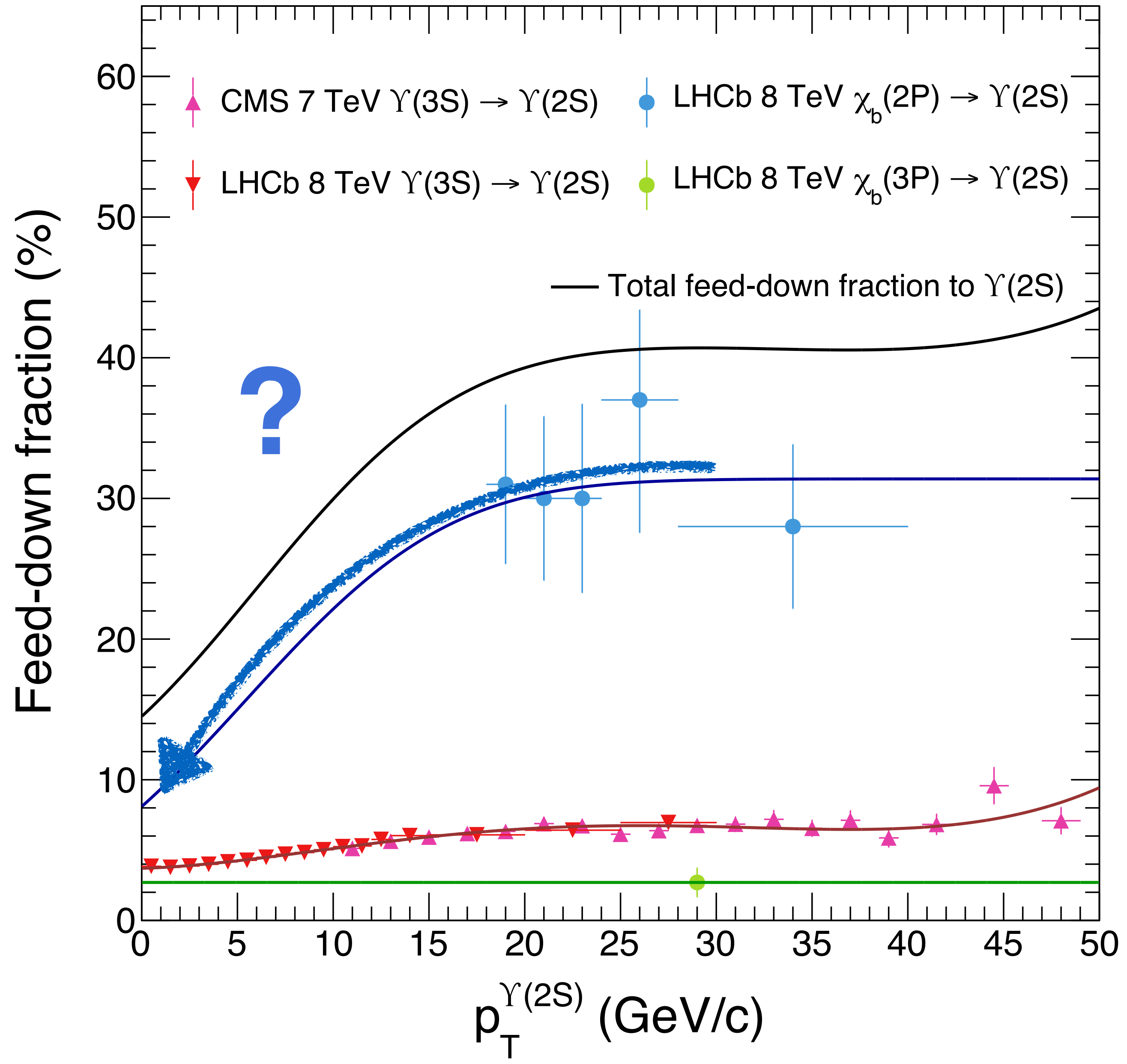
Υ(1S)





Υ(2S)





Υ(3S)