Recent CMS results on Quarkonium in pPb and PbPb

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on behalf of the CMS Collaboration

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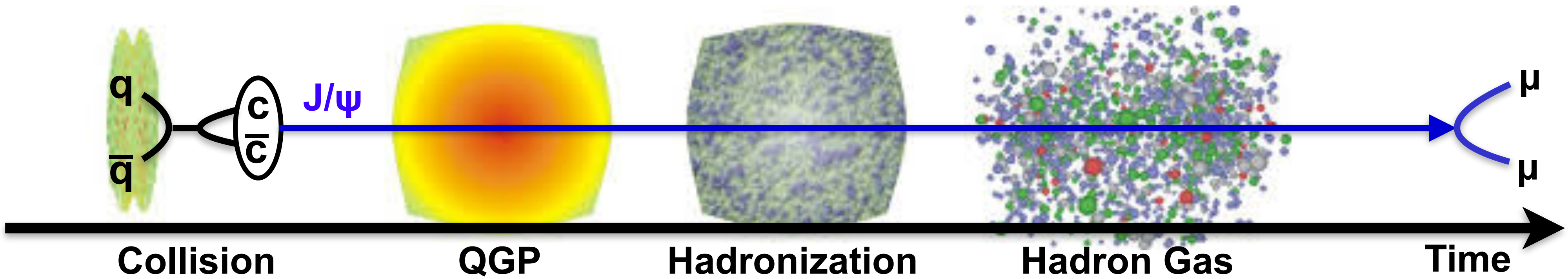
13th International Workshop on Heavy Quarkonium

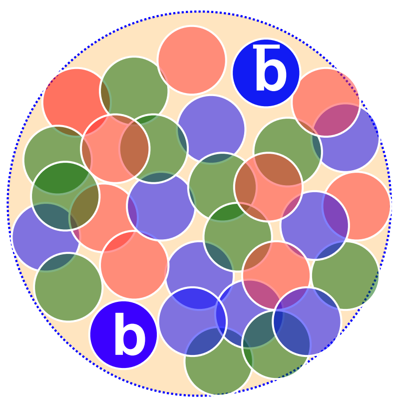
Quarkonia in Pb-Pb Collisions

Quarkonia are produced in the early stages of the collision



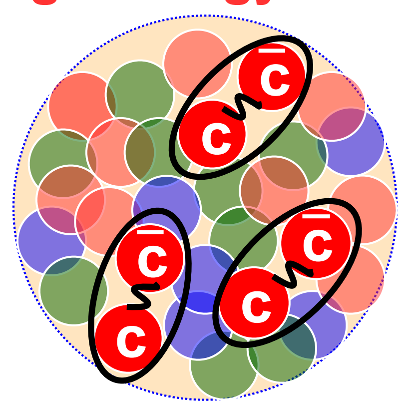
The Quark-Gluon Plasma is expected to modify the quarkonium production

QGP



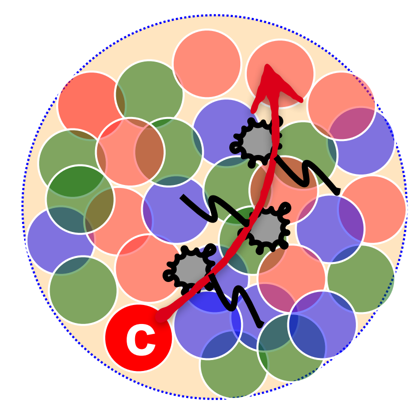
Suppresion
Debye screening

QGP
@ high energy density



+Enhancement
Regeneration

QGP

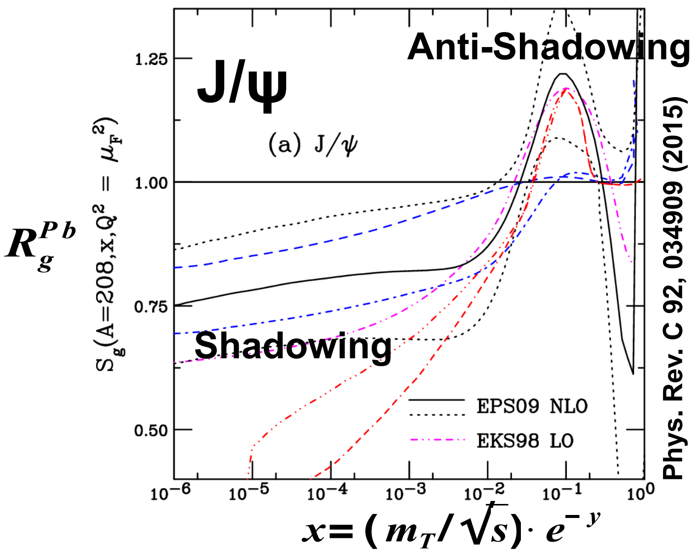


+Energy loss
at high p_T

Quarkonia are good probes of the medium evolution

Quarkonia in pPb Collisions

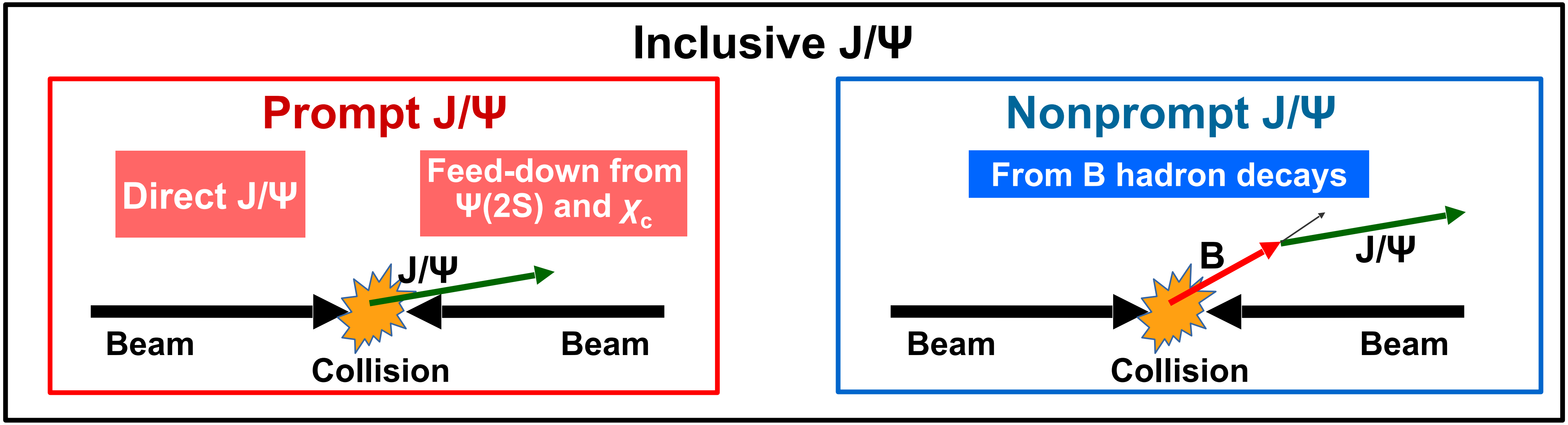
- Study of quarkonia in pPb allows to probe Cold Nuclear Matter effects:
  - ➢ Initial state energy loss
  - ➢ Nuclear PDF modifications
  - ➢ Nuclear absorption



Excited States in Heavy-Ion Collisions

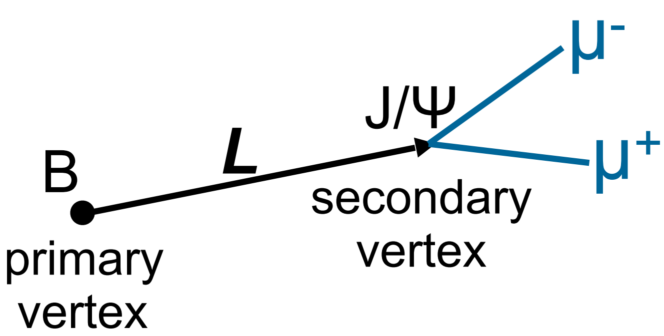
- The study of ψ(2S), Υ(2S) and Υ(3S) brings additional information:
  - ➢ Excited states are **less tightly bounded** than the 1S states
    - More suppressed in the QGP compared to J/ψ or Υ(1S)
  - ➢ Models including nPDF and energy loss effects **predict similar suppression** for ψ(2S) as for J/ψ

Prompt and Nonprompt Charmonia

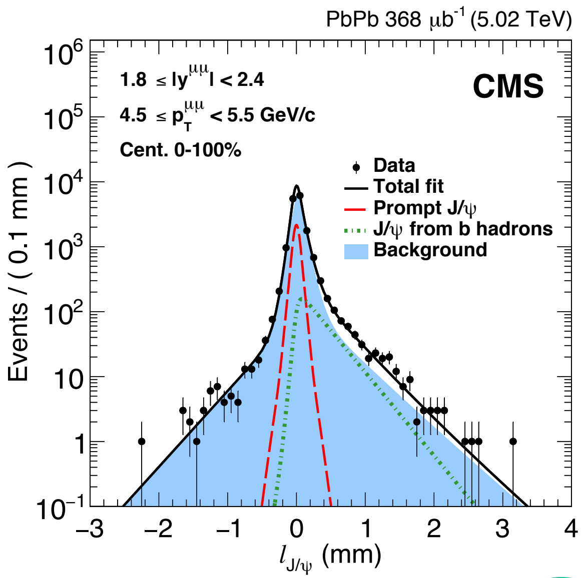


- **Prompt Charmonia:**
  Directly affected by the QGP
- **Non-Prompt Charmonia:**
  Reflects energy loss of b quarks in the QGP

Separation based on **pseudo-proper decay length** ($l_{J/\Psi}$)



$$\ell_{J/\psi} = \frac{m_{J/\psi}}{p^{\mu\mu}} L$$



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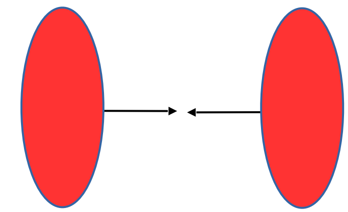
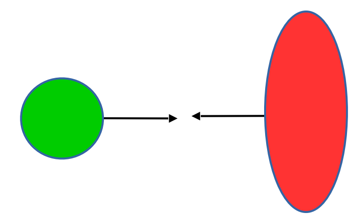
Outline

- **Υ(nS) in PbPb at 5.02 TeV**
  - ➢ Phys. Lett. B 790 (2019) 270



- **J/ψ in PbPb at 5.02 TeV**
  - ➢ Eur. Phys. J. C 78 (2018) 509

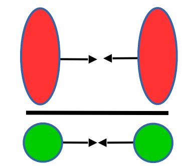
- **Prompt ψ(2S) in pPb at 5.02 TeV**
  - ➢ Phys. Lett. B 790 (2019) 509



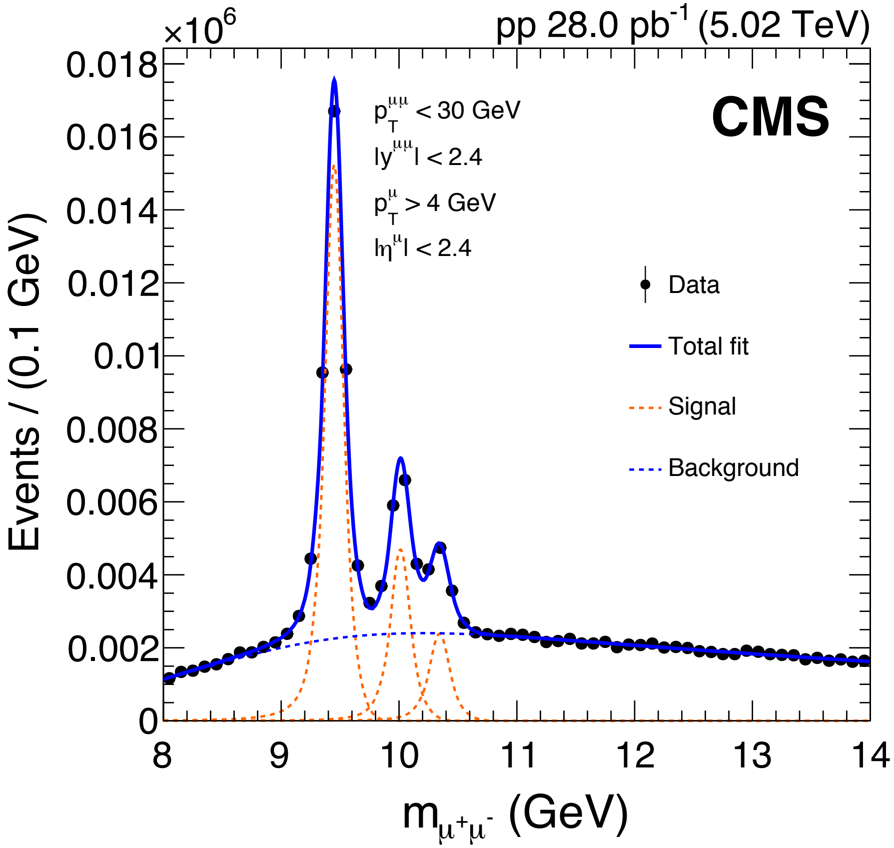
- **Prompt J/ψ in high-multiplicity pPb at 8.16 TeV**
  - ➢ Phys. Lett. B 791 (2019) 172

Υ(nS) in PbPb at 5 TeV

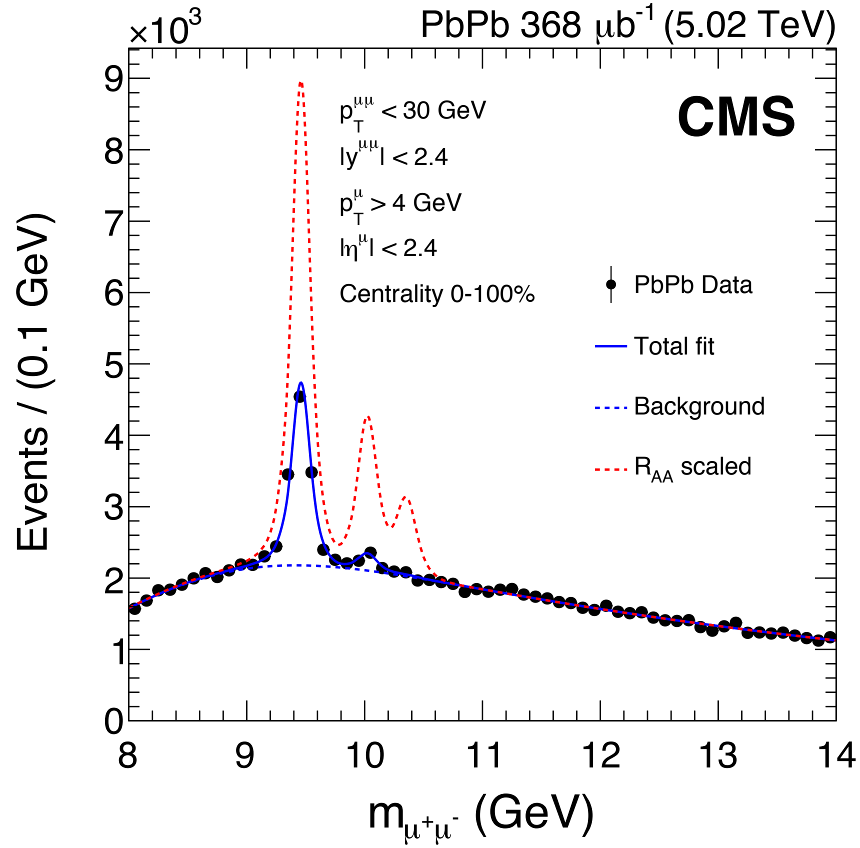
Y(nS) modification in PbPb



pp



PbPb



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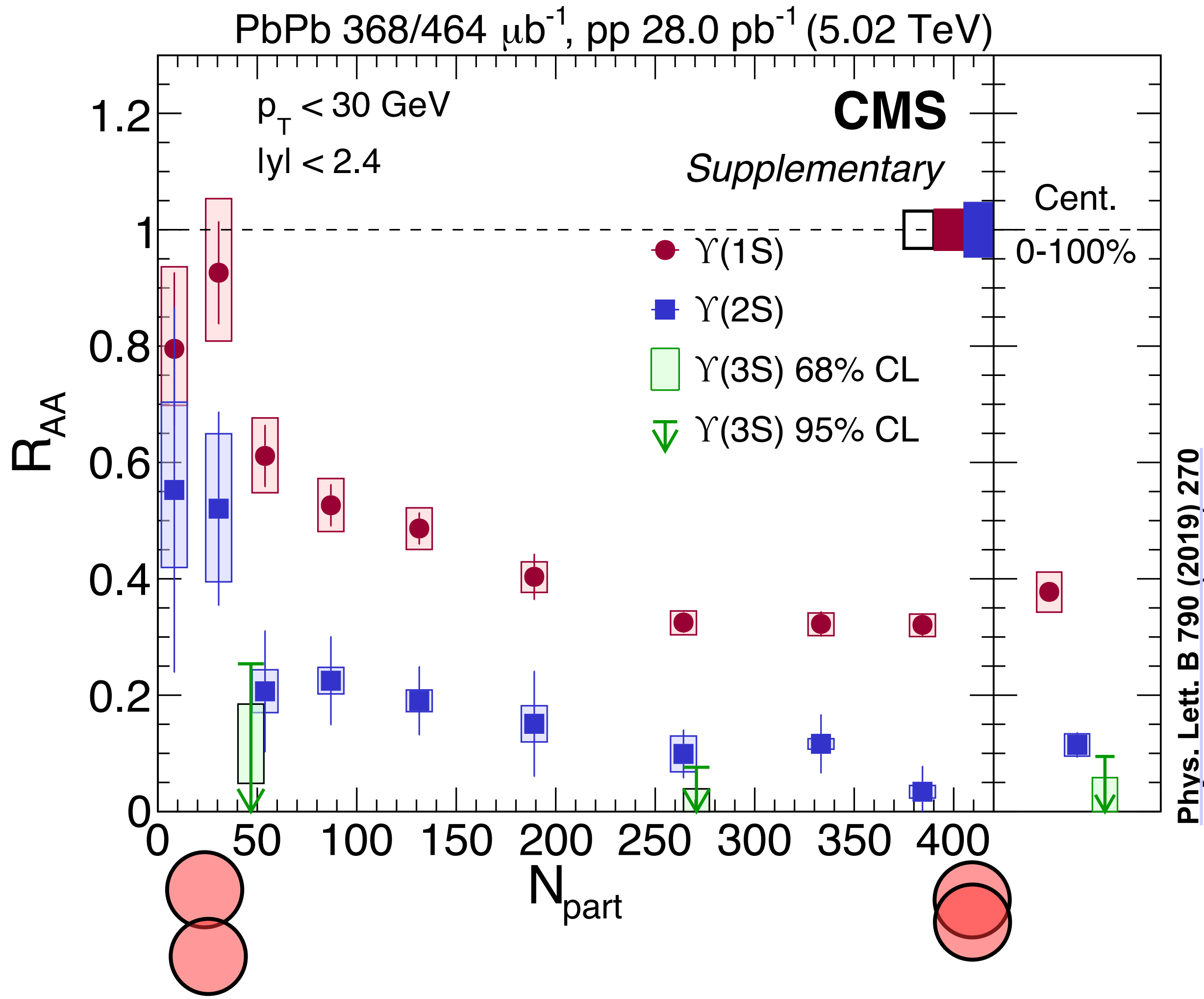
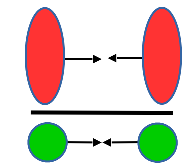
- Clear suppression of bottomonium states in PbPb collisions compared to pp

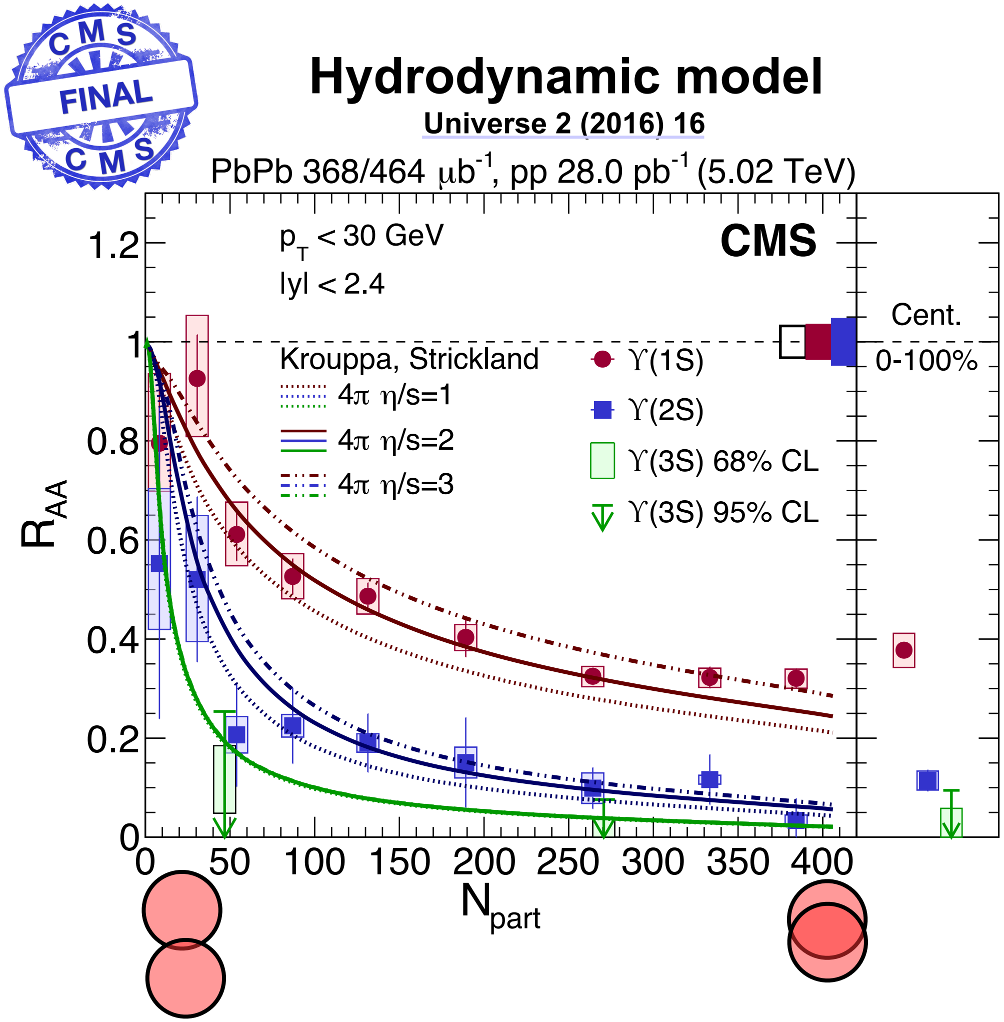
Y(nS) modification in PbPb

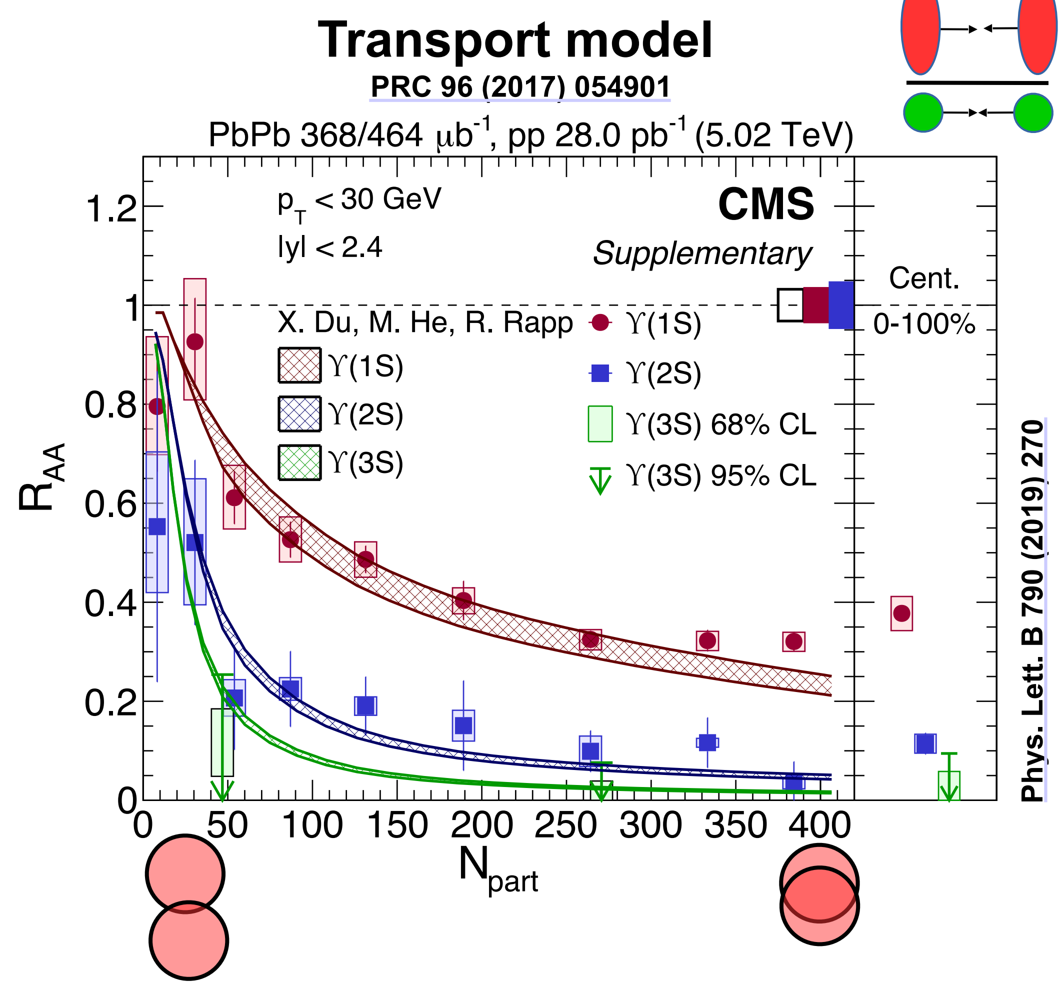




- Y(nS) suppression increases with collision centrality
- Weakly bound states more suppressed -> R_{AA}(Y(3S)) < R_{AA}(Y(2S)) < R_{AA}(Y(1S))
- Still no observation of Y(3S) mesons in PbPb collisions

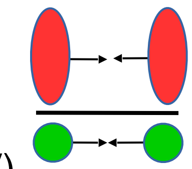
Υ(nS) modification in PbPb

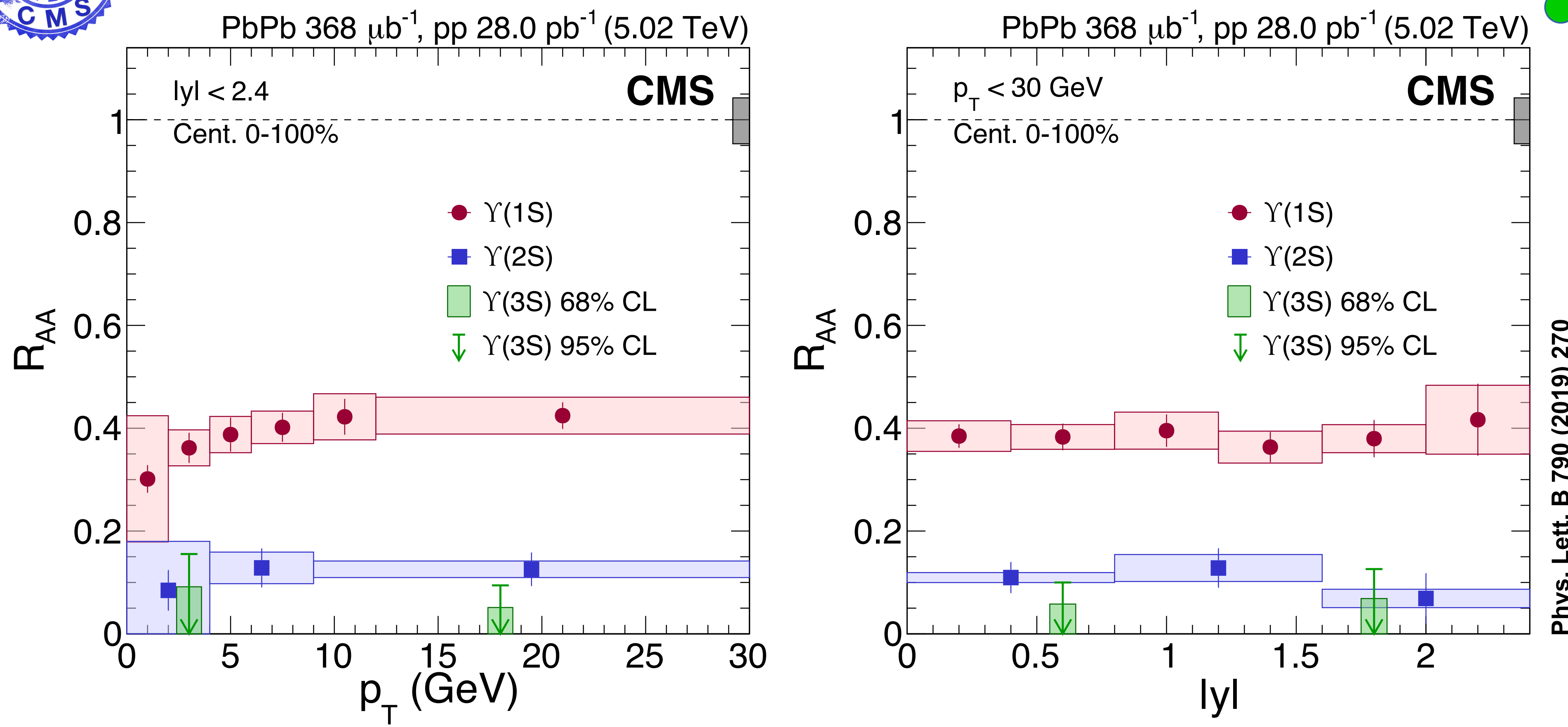




- Comparisons with an hydrodynamic model (Krouppa et al) and a transport model (Du et al), show good agreement with the measurements

Υ(nS) modification in PbPb

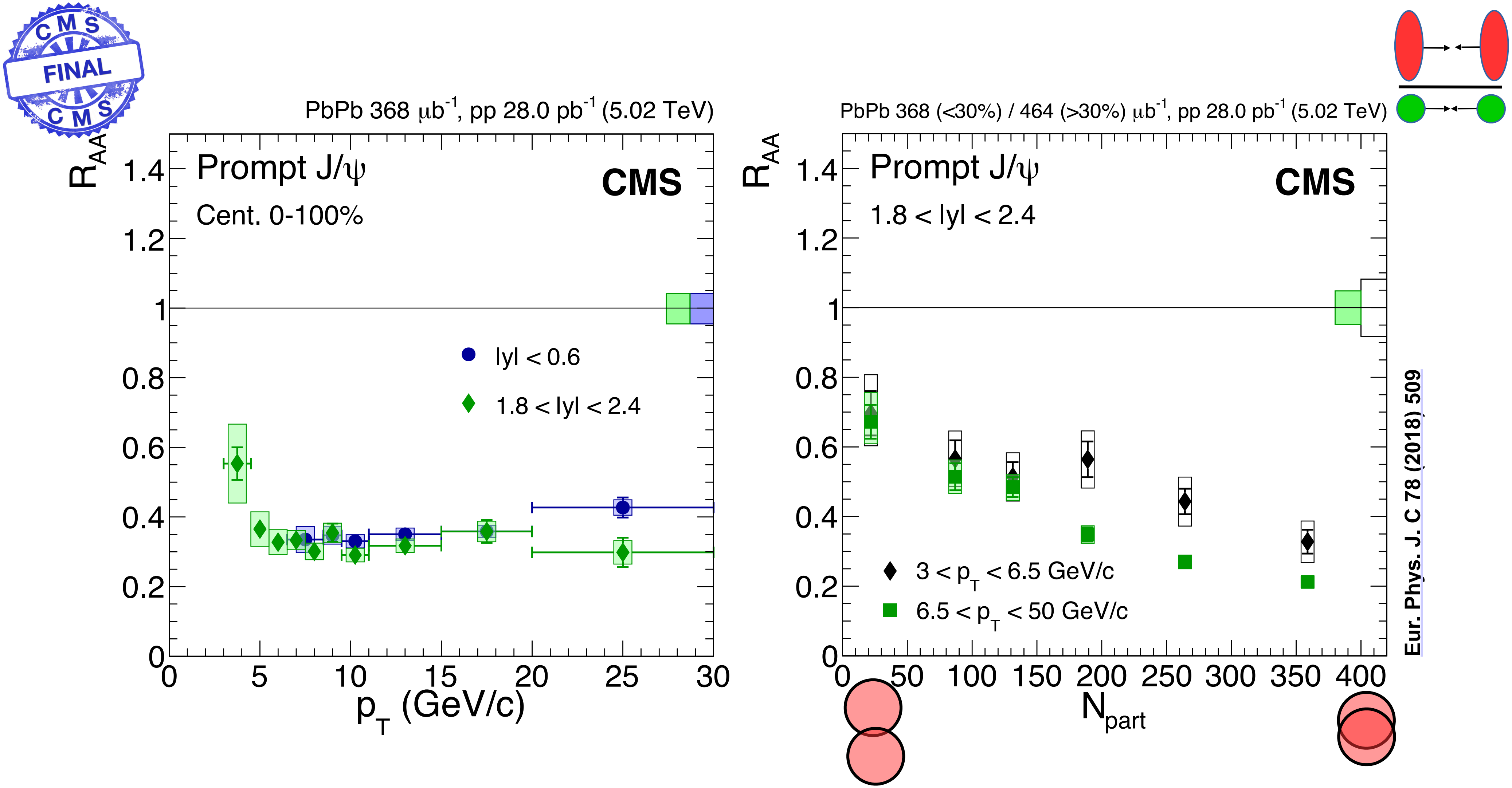




- Hint of less suppression of Υ(1S) at high p_T
- No significant dependence of Υ(nS) R_{AA} on rapidity

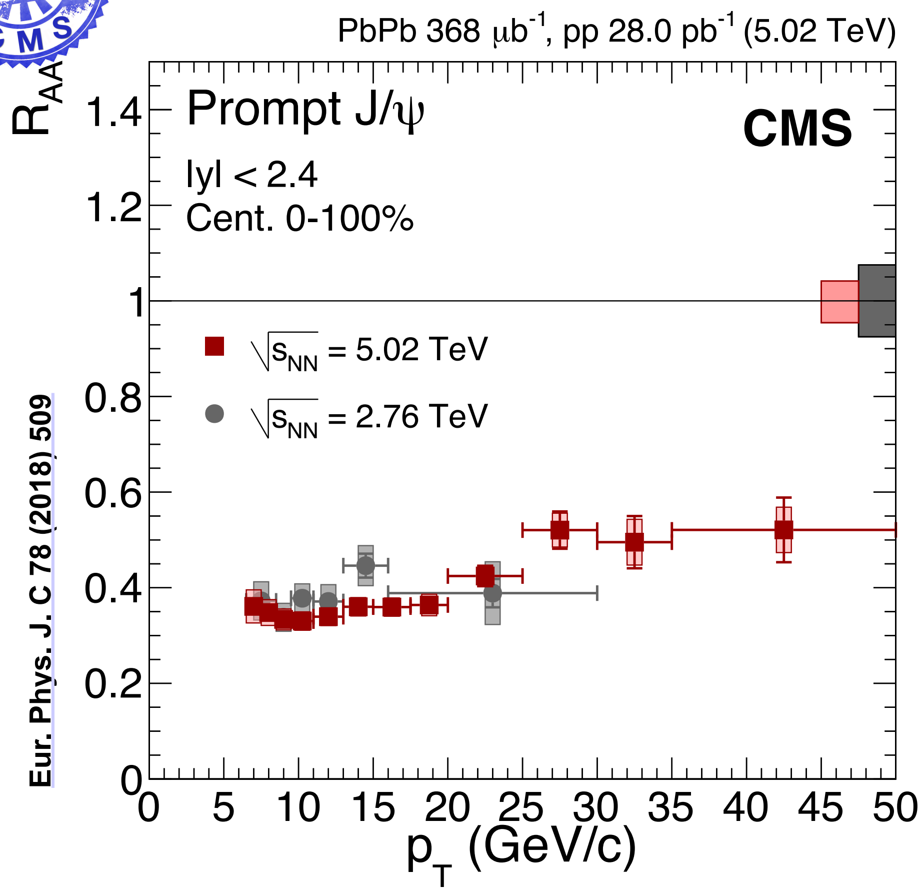
J/ψ in PbPb at 5 TeV

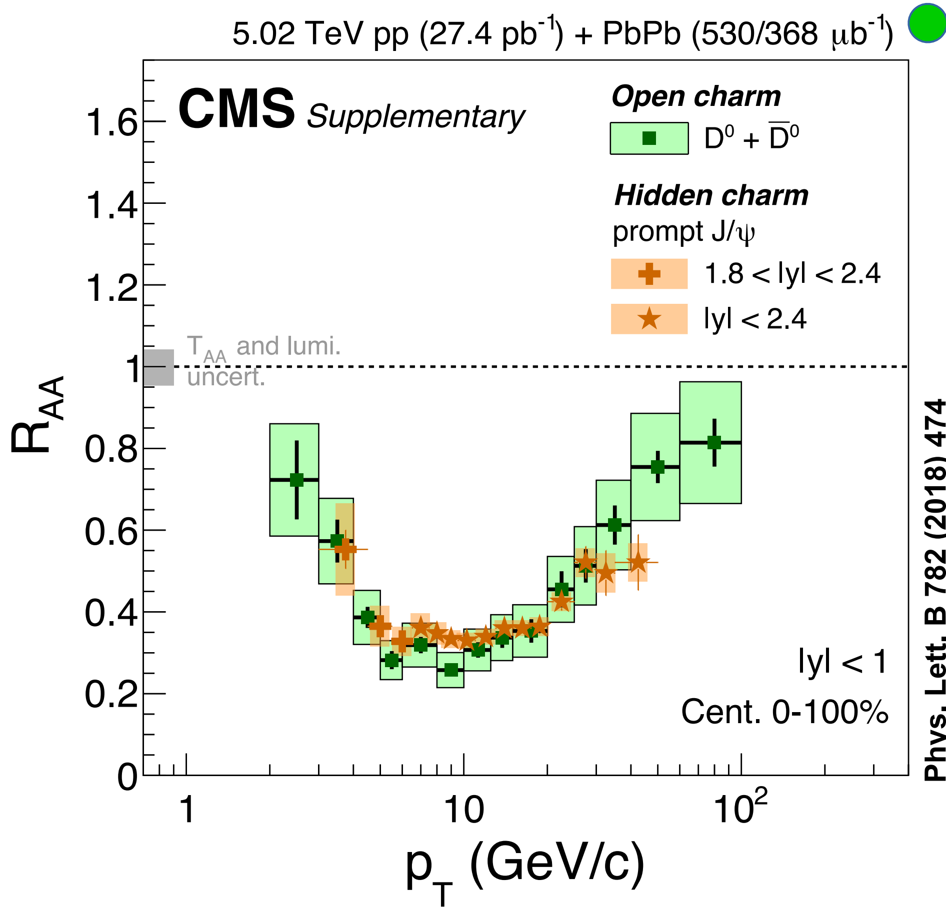
Prompt J/ψ modification in PbPb



- Similar p_T trend between different rapidities bins
- Less suppression at low p_T in central events (cent < 30%)
    - Regeneration of J/ψ at p_T > 3 GeV/c ?

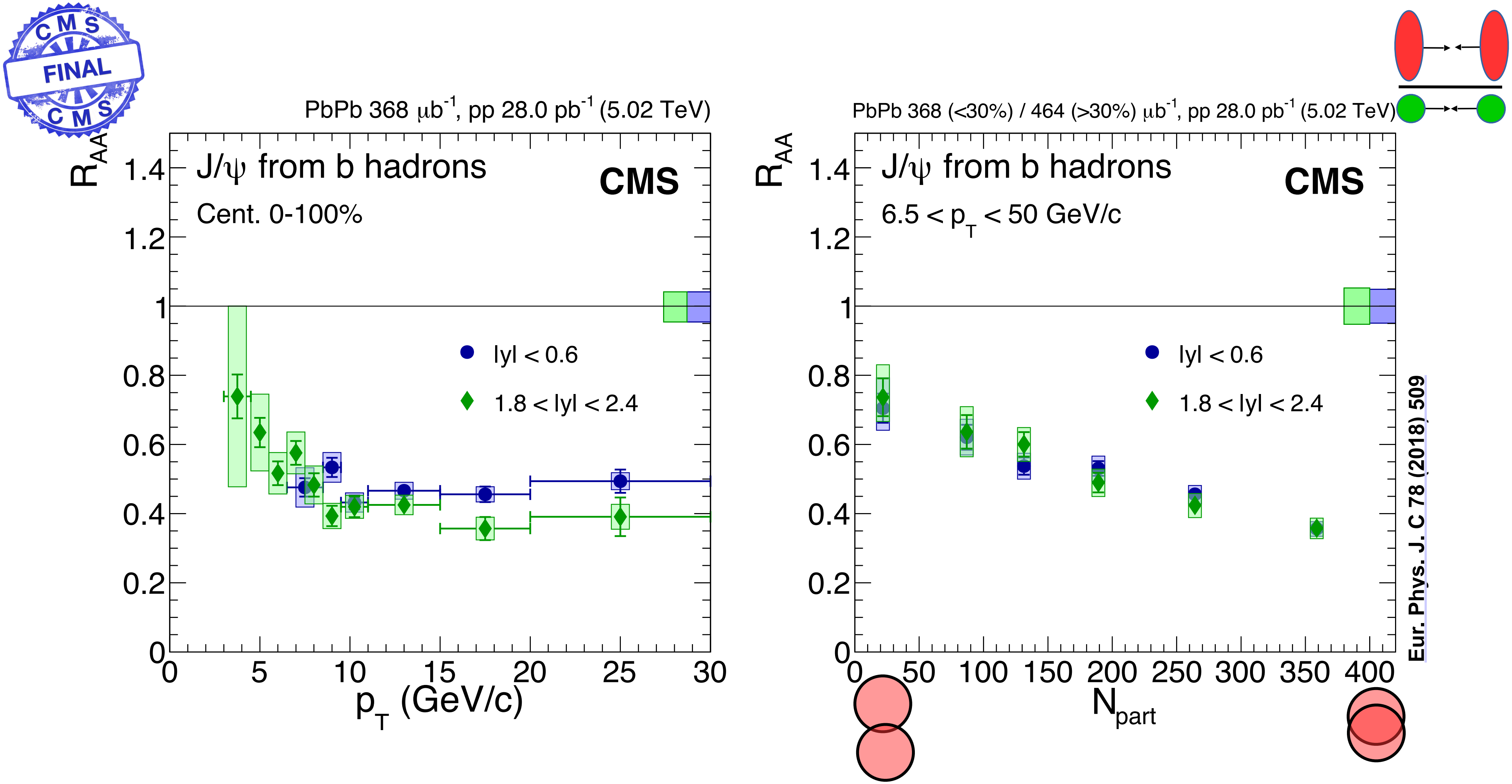
Prompt J/ψ modification in PbPb





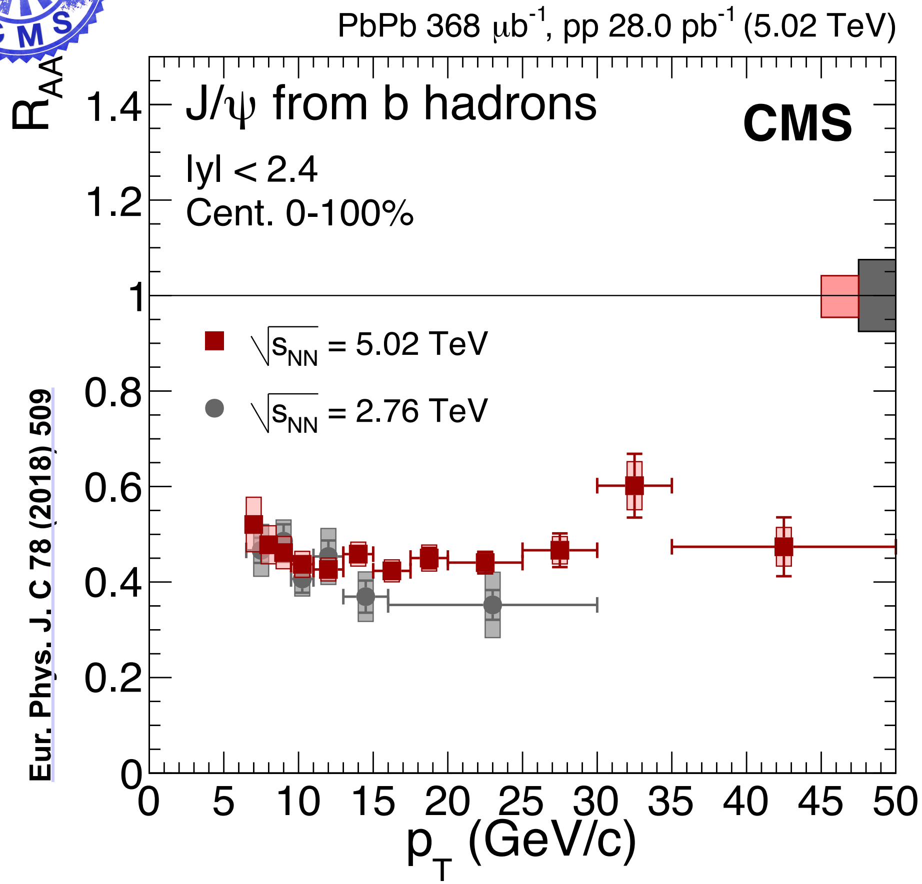
- Hints of increasing J/ψ R_{AA} towards high p_T
- Similar level of suppression between prompt J/ψ and D^0 mesons
  - Contribution from energy loss on J/ψ?

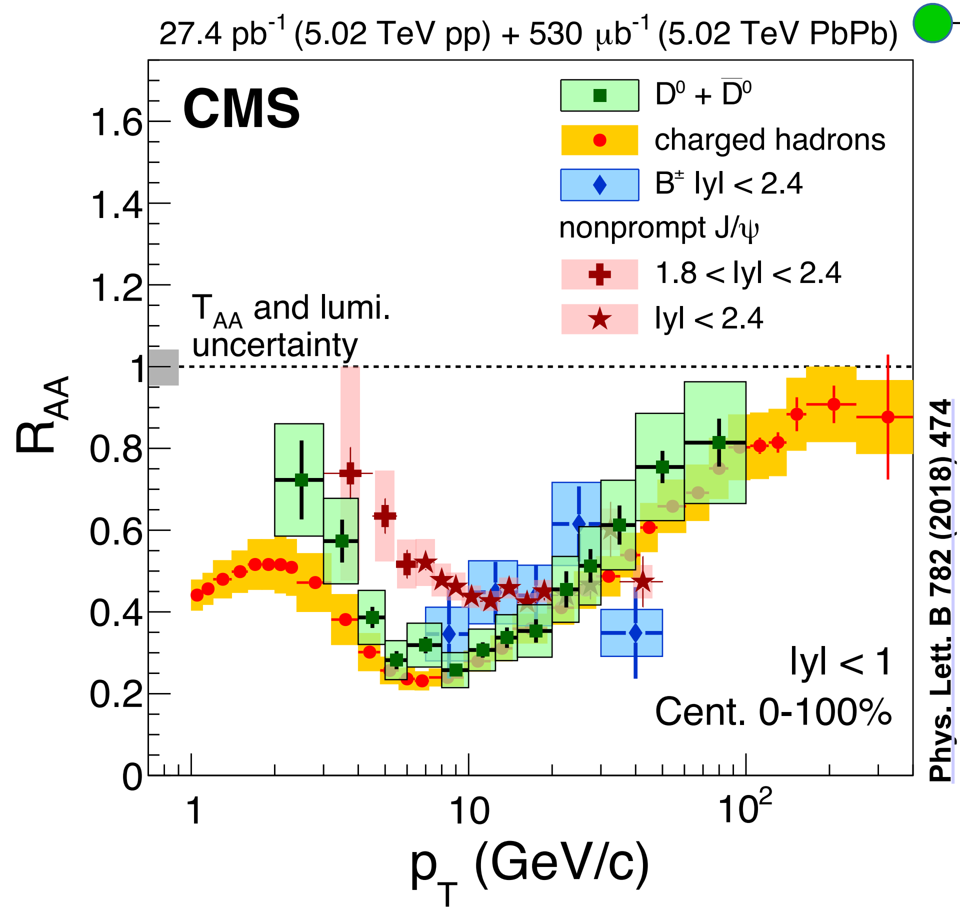
Nonprompt J/ψ modification in PbPb



- Less suppression of nonprompt J/ψ at high p_T and more central collisions
- No significant dependence on rapidity

Nonprompt J/ψ modification in PbPb

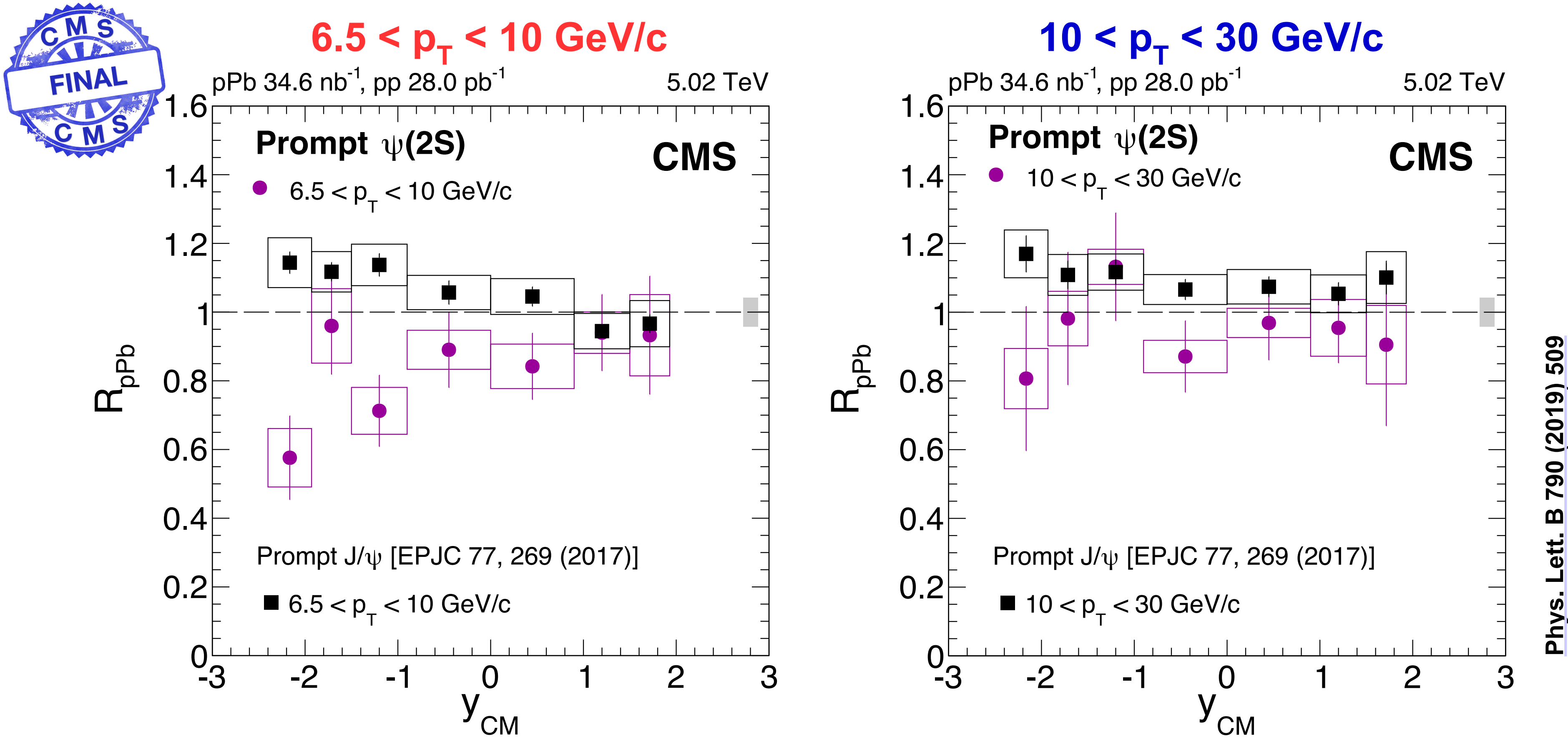


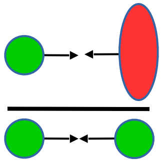


- Less suppression of nonprompt J/ψ at lower p_T
- Similar suppression at high p_T between open beauty, open charm and light hadrons -> Universal flavour dependence of $\mathbf{E}_{\mathbf{loss}}$ at high p_T ?

Prompt ψ(2S) in pPb at 5 TeV

Prompt ψ(2S) in pPb





- **Ratio: R_{pPb} (ψ(2S)) < R_{pPb} (J/ψ) especially at backward** (Pb-going direction)
- Different suppression between J/ψ and ψ(2S) could be consistent with FS inelastic interactions of ψ(2S) with comoving particles in the medium

Prompt J/ψ in high-multiplicity pPb at 8 TeV

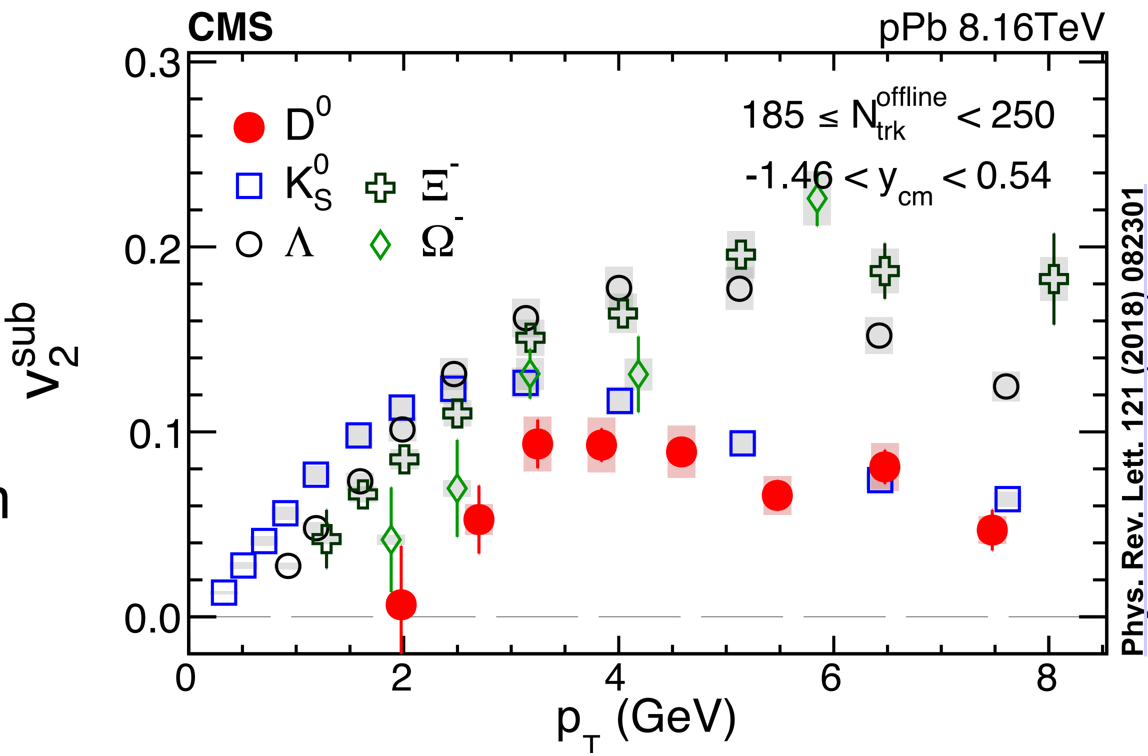
Charm quark dynamics in pPb

Heavy quark collectivity in PbPb reflects the presence of QGP medium and its response to the initial collision geometry.

Observation of charm flow at high-multiplicity pPb

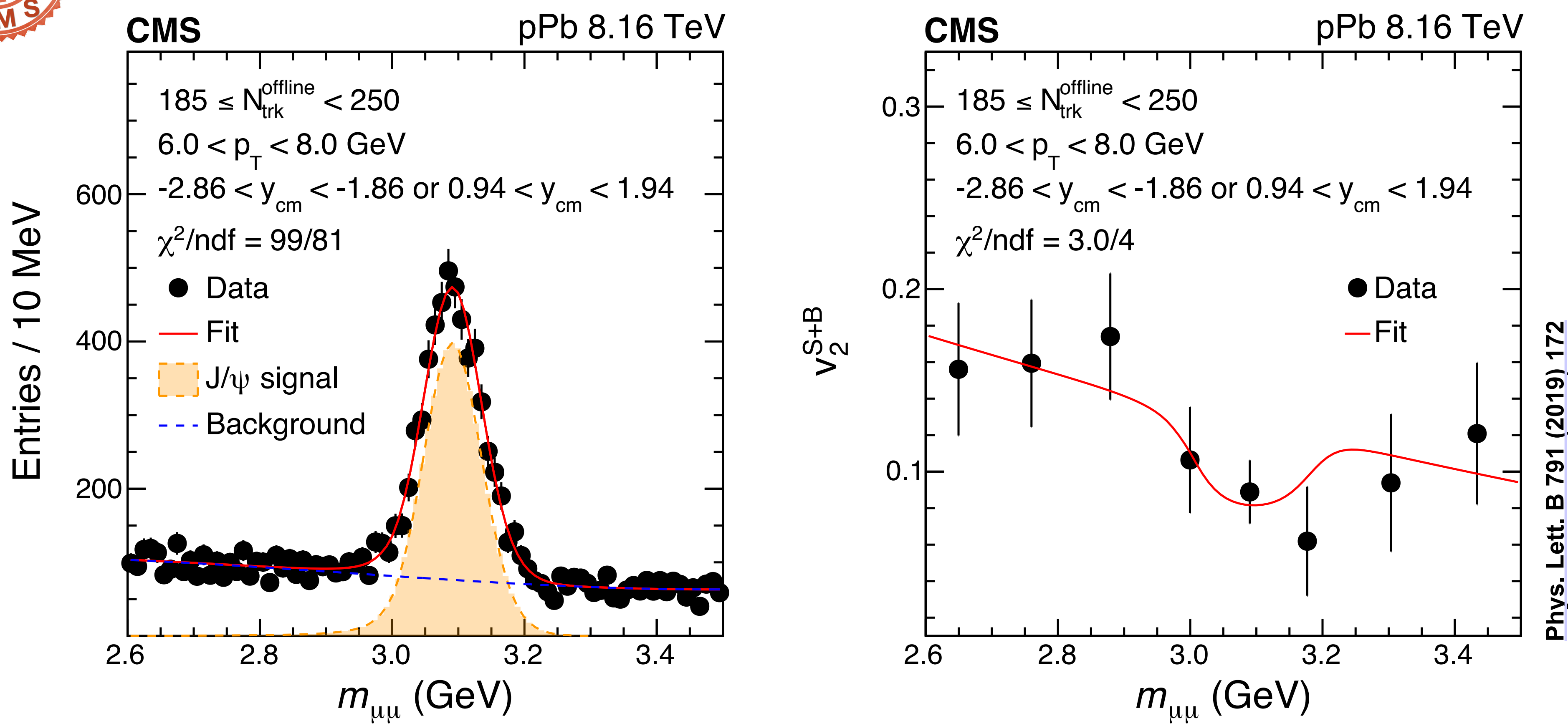
$$0 < v_2(D^0) < v_2(K_s)$$

Collectivity in small systems from charm or light quarks?



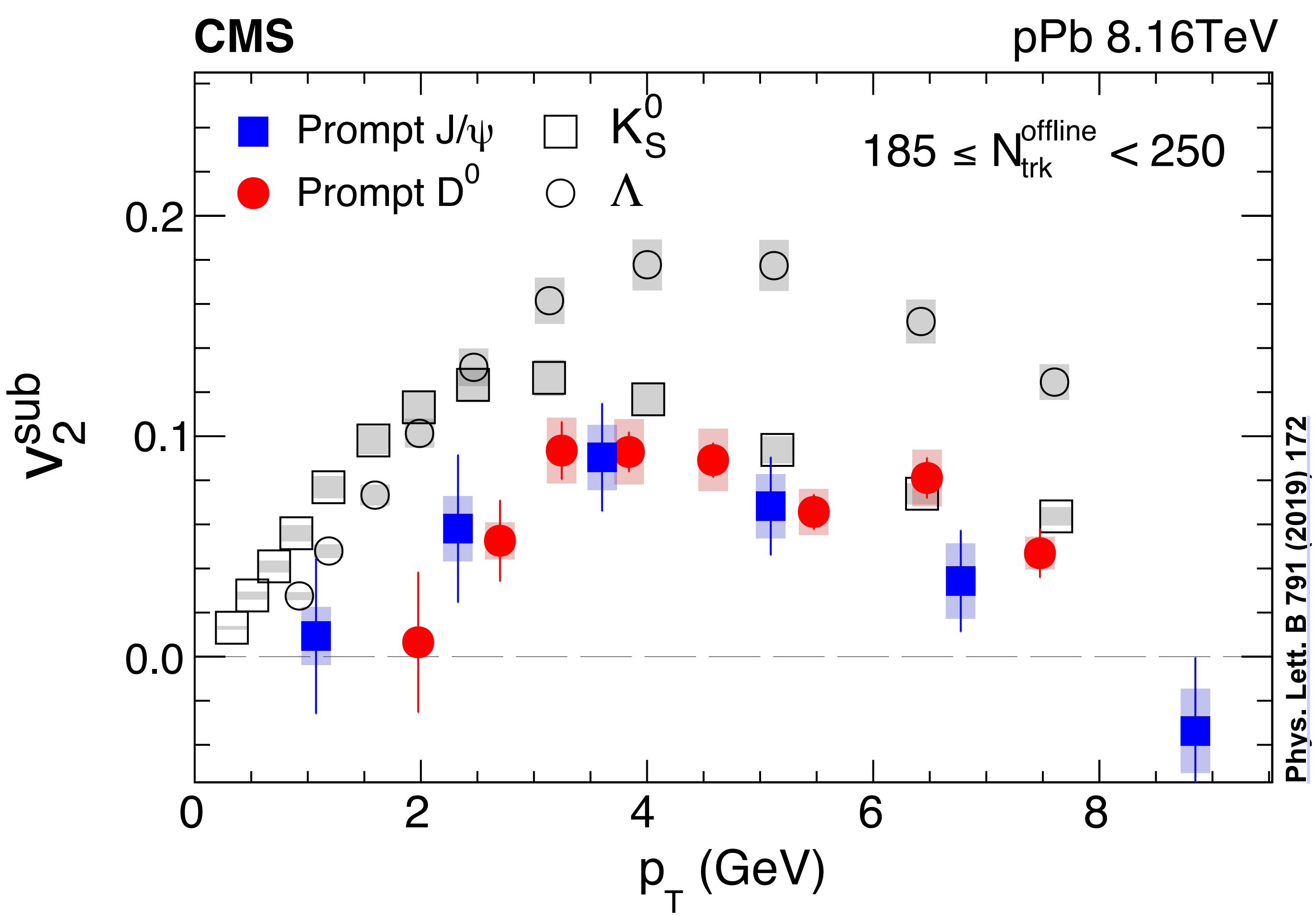
Measurements of J/ψ flow needed to complete the picture of charm dynamics

Prompt J/ψ v_2 in high-multiplicity pPb



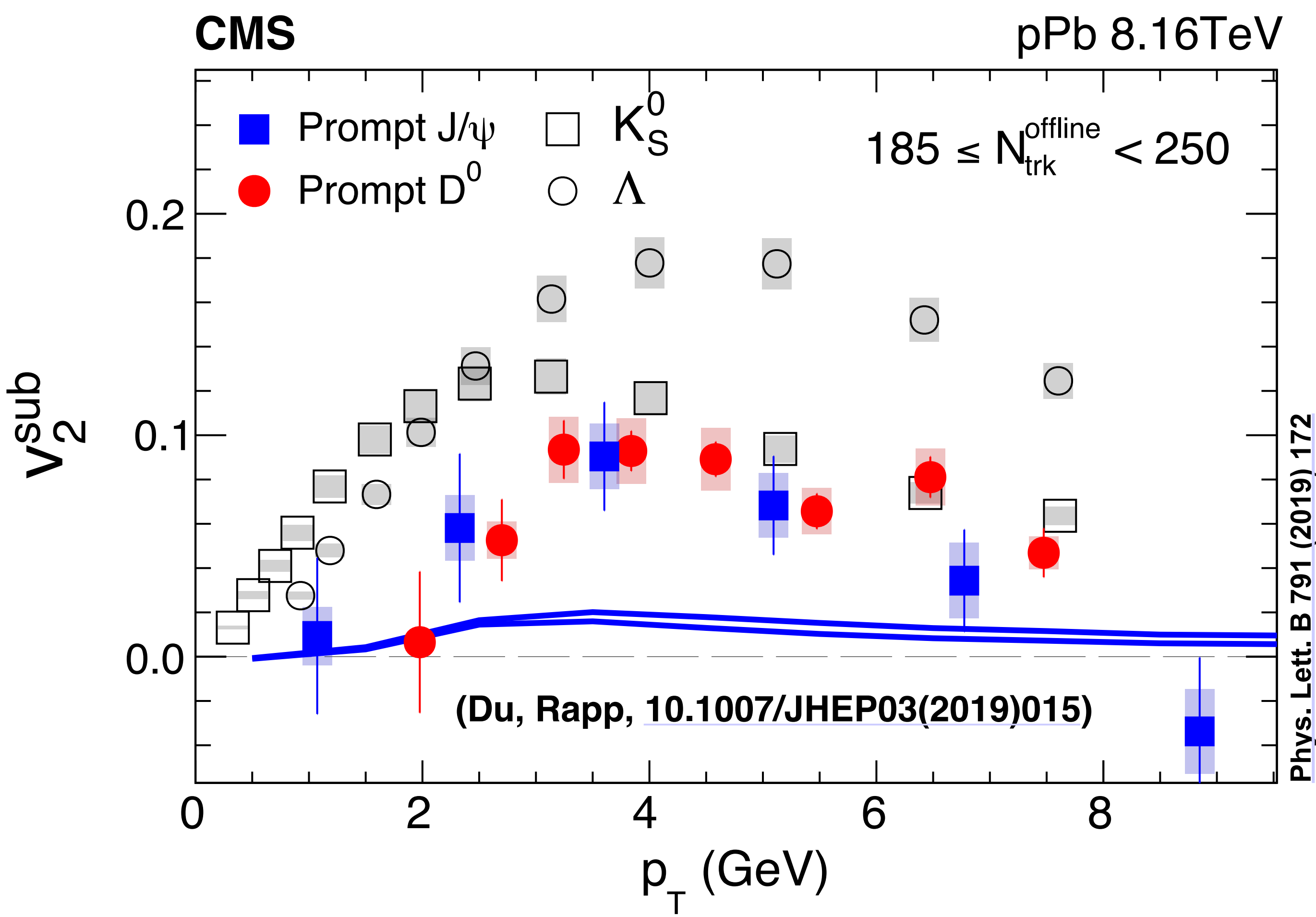
- Measure J/ψ elliptic flow by fitting the dimuon invariant mass and v_2 spectra
- Prompt J/ψ extracted by selecting candidates with low decay lengths ($l_{J/\psi}$)

Prompt J/ψ v_2 in high-multiplicity pPb



- Observation of prompt J/ψ flow in high-multiplicity pPb -> charm collectivity
- Smaller v_2 of charm quarks compared to light quarks

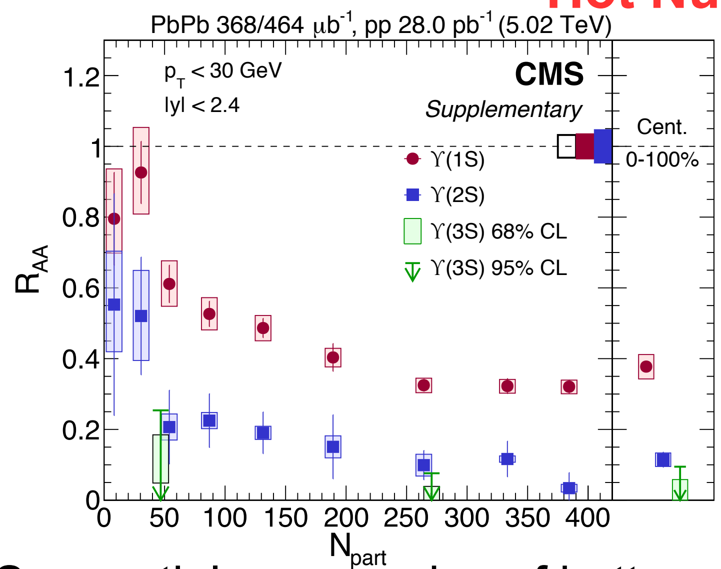
Prompt J/ψ v_2 in high-multiplicity pPb



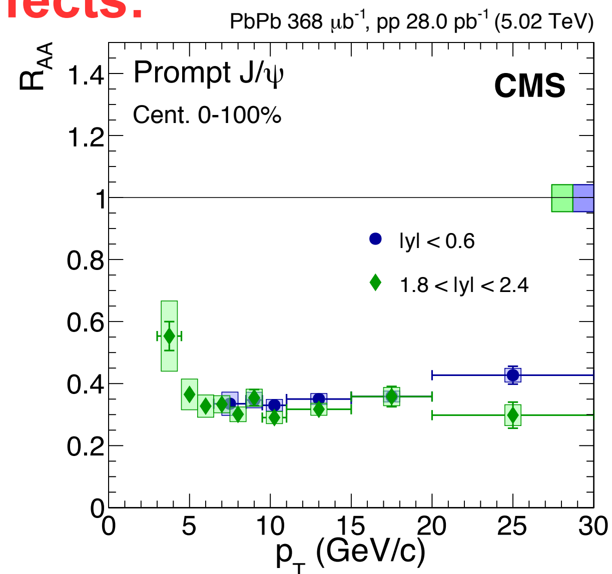
- Non-zero J/ψ v_2 in model calculations (Du, Rapp) arise from FS interactions in the elliptic fireball, but significantly underpredicts the CMS results.
- Initial-state (or pre-equilibrium) effects beyond QGP?

SUMMARY

Hot Nuclear Matter Effects:

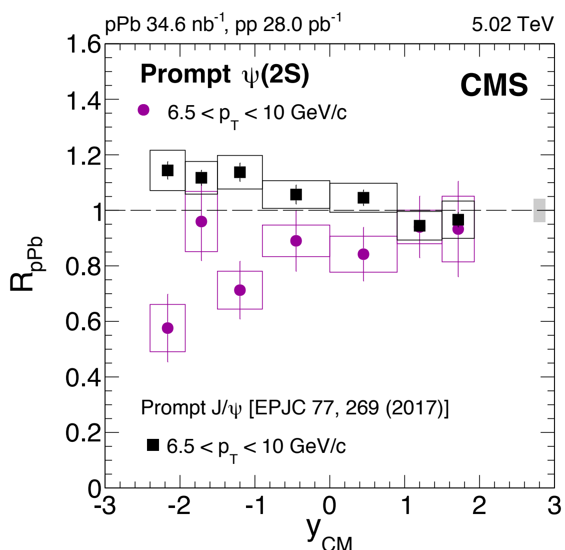


Sequential suppression of bottomonia



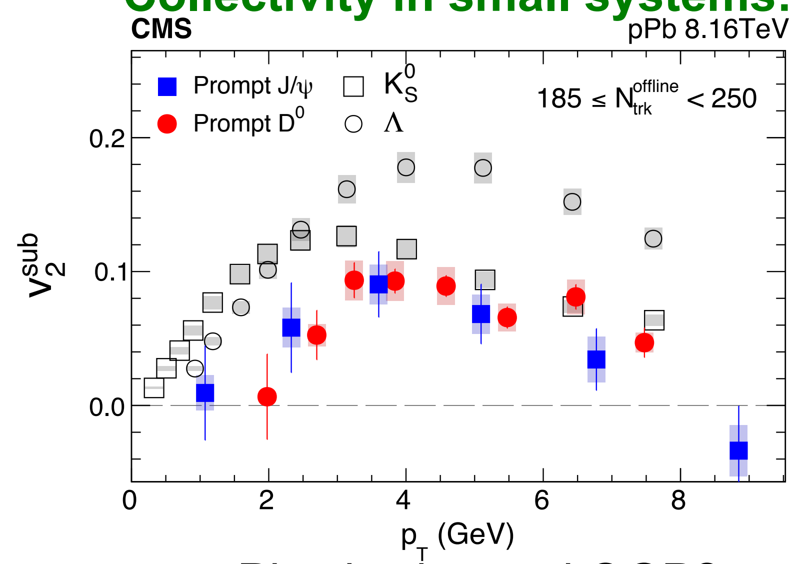
Energy loss and regeneration of J/ψ

Cold Nuclear Matter Effects:



ψ(2S) interactions with comovers?

Collectivity in small systems:



Physics beyond QGP?

Thank you for your attention!

Acknowledgement

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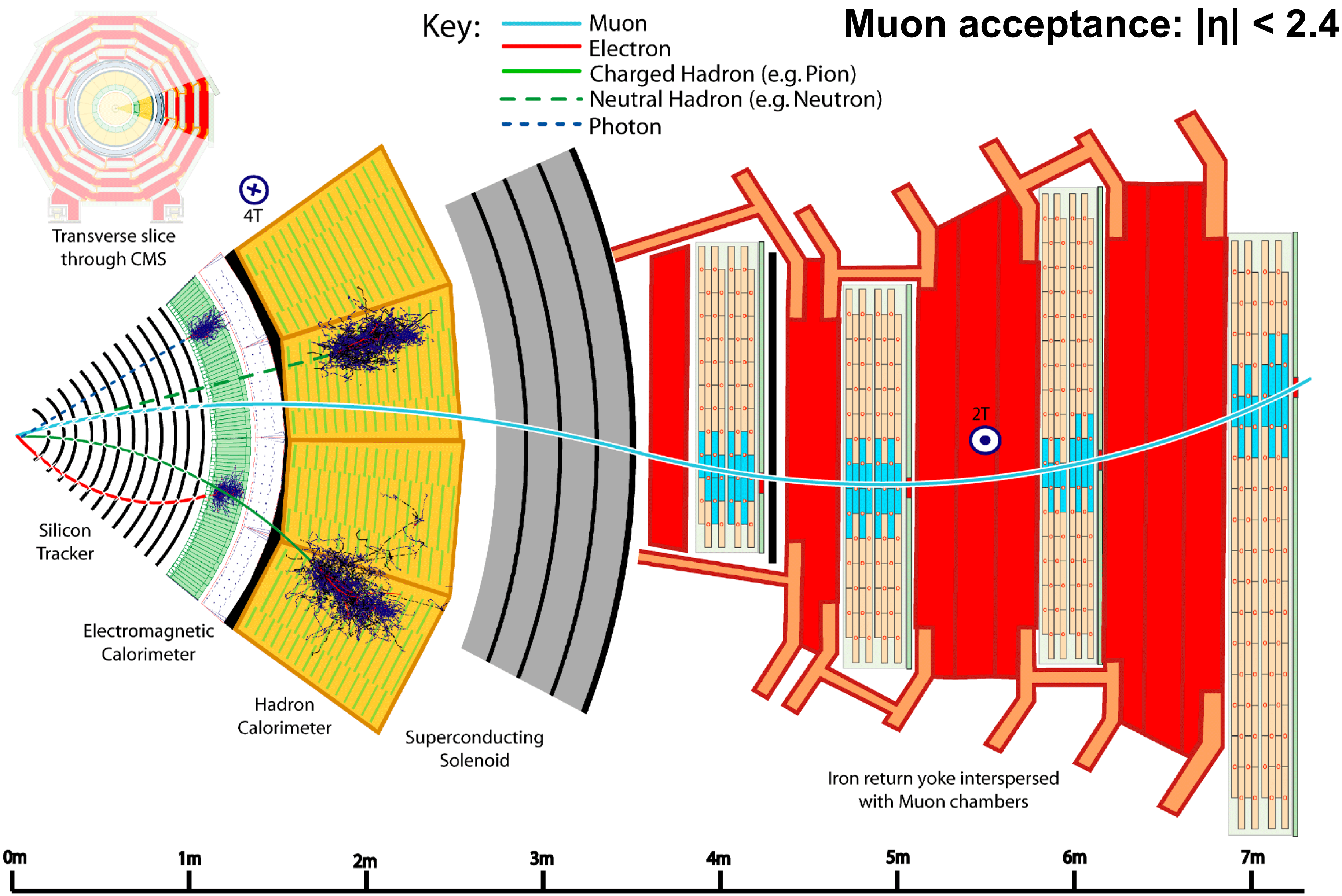
BACKUP

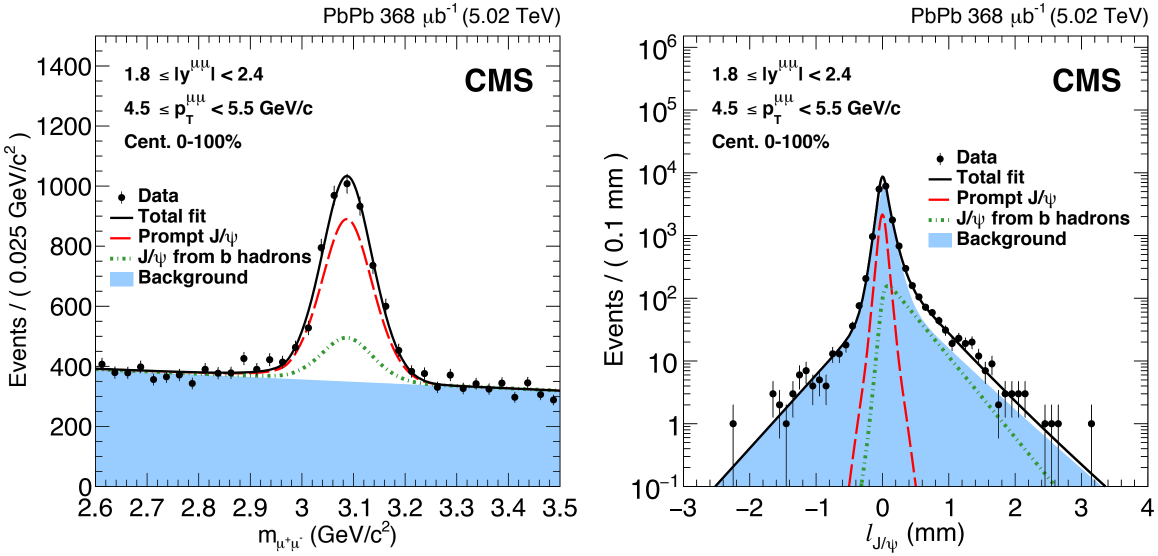
CMS Detector



Prompt and Non-Prompt Charmonia

Two techniques to separate components:

1. **2D fits of dimuon mass and pseudo-proper decay length**



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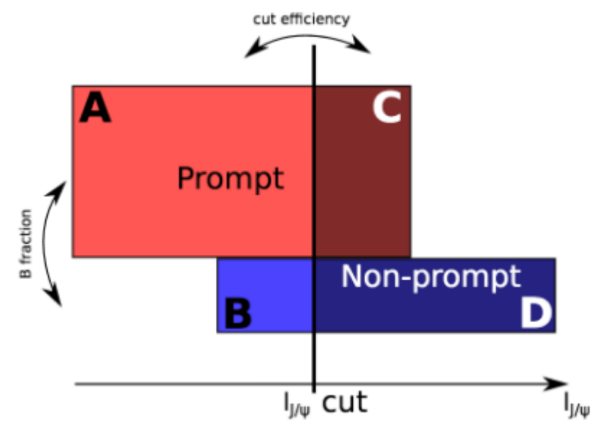
2. **Rejecting non-prompt applying a cut on pseudo-proper decay length**

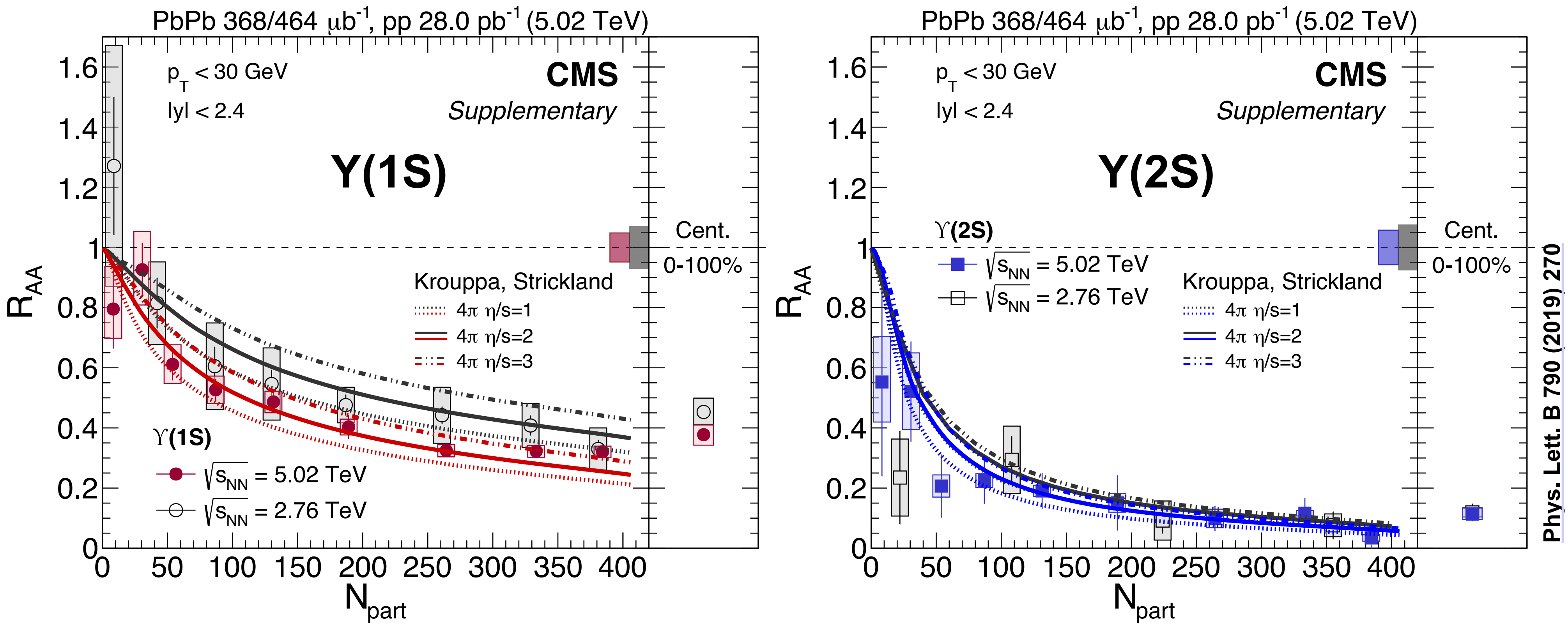
Data-based corrections applied to remove non-prompt contamination

- Using reverted $l_{J/\psi}$ cut
- MC efficiency of $l_{J/\psi}$ cut



Υ(nS) modification in PbPb

2.76 vs. 5.02 TeV



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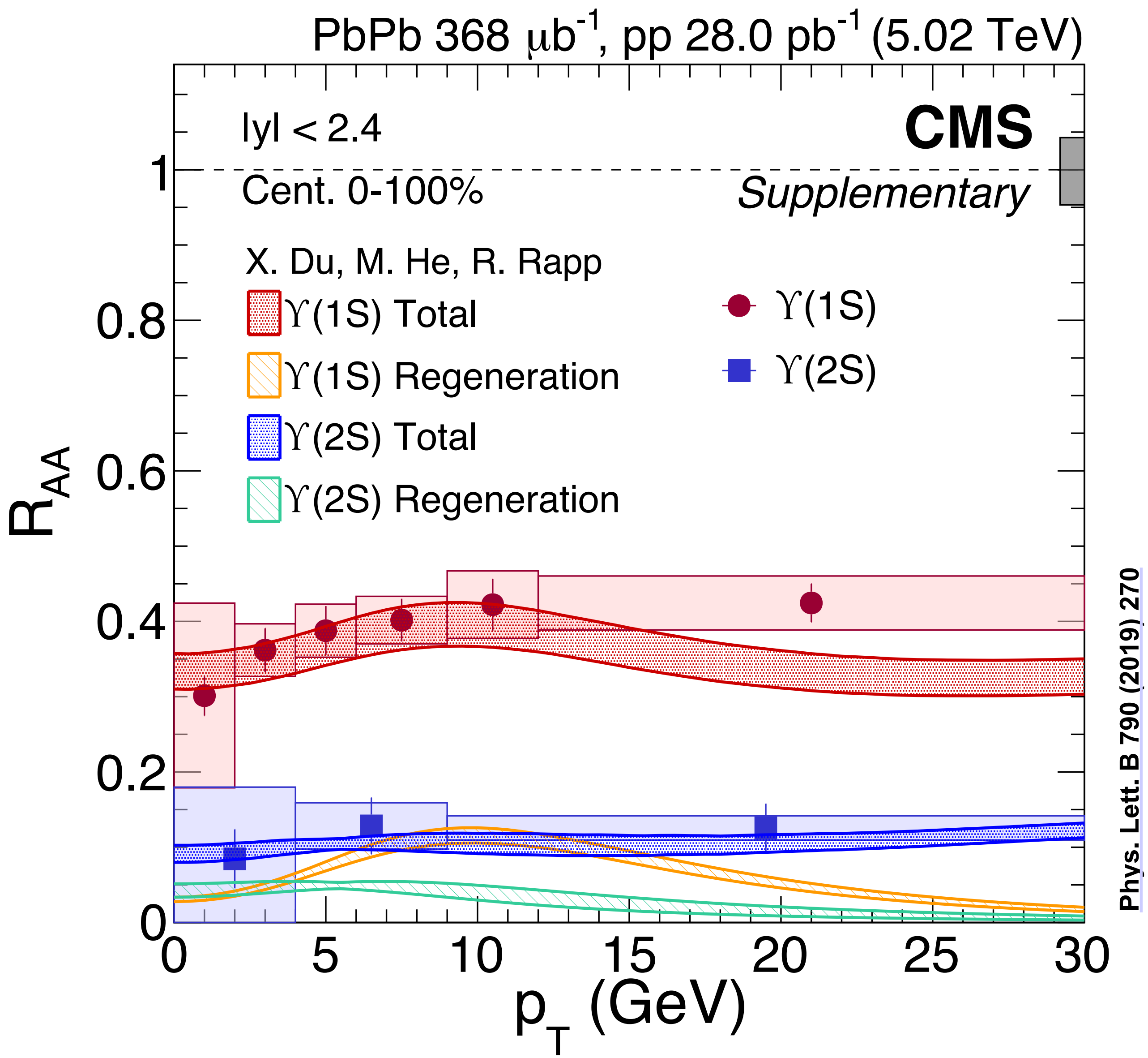
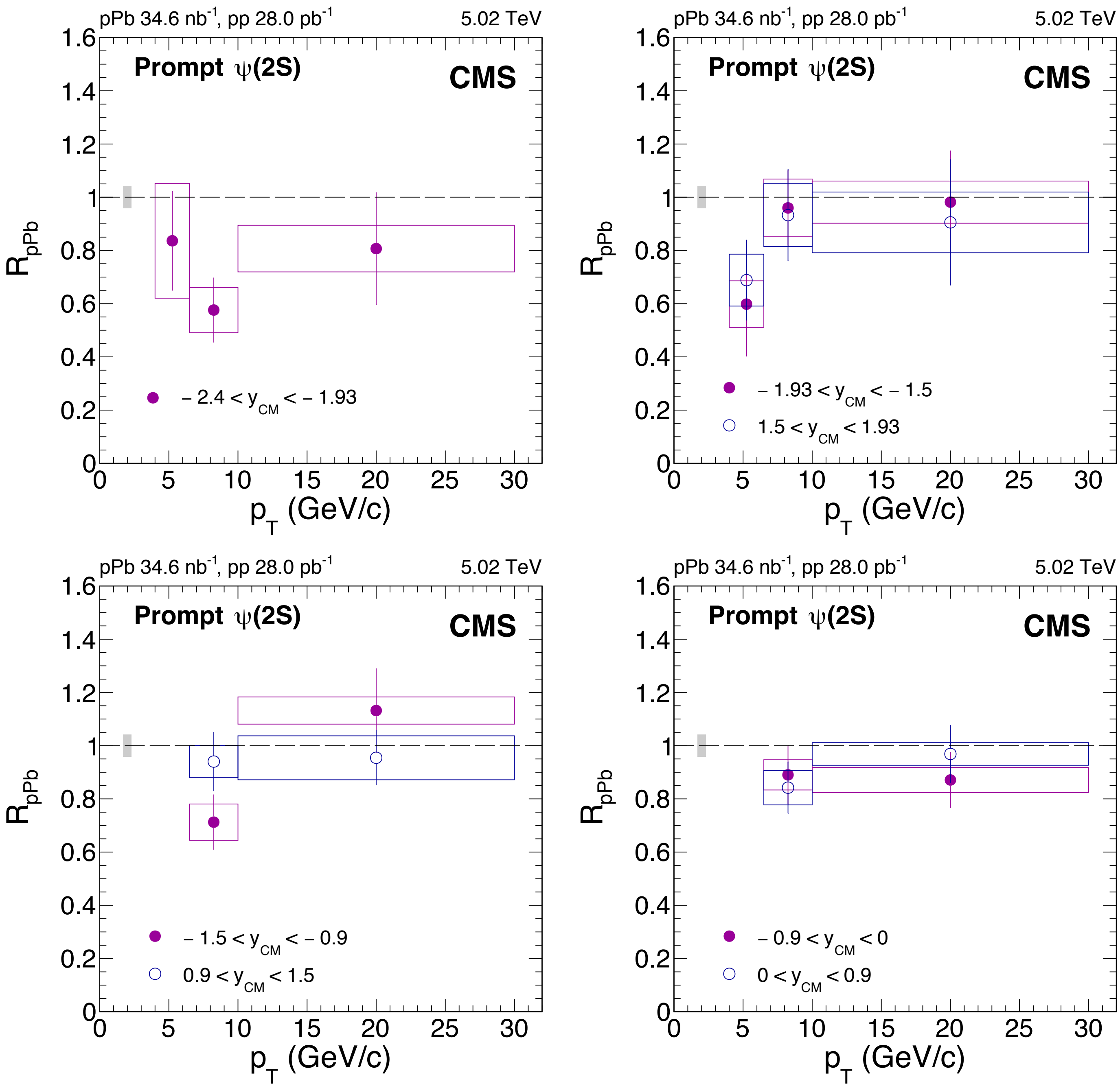


ψ(2S) modification in pPb



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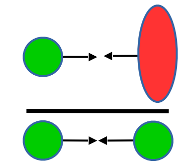
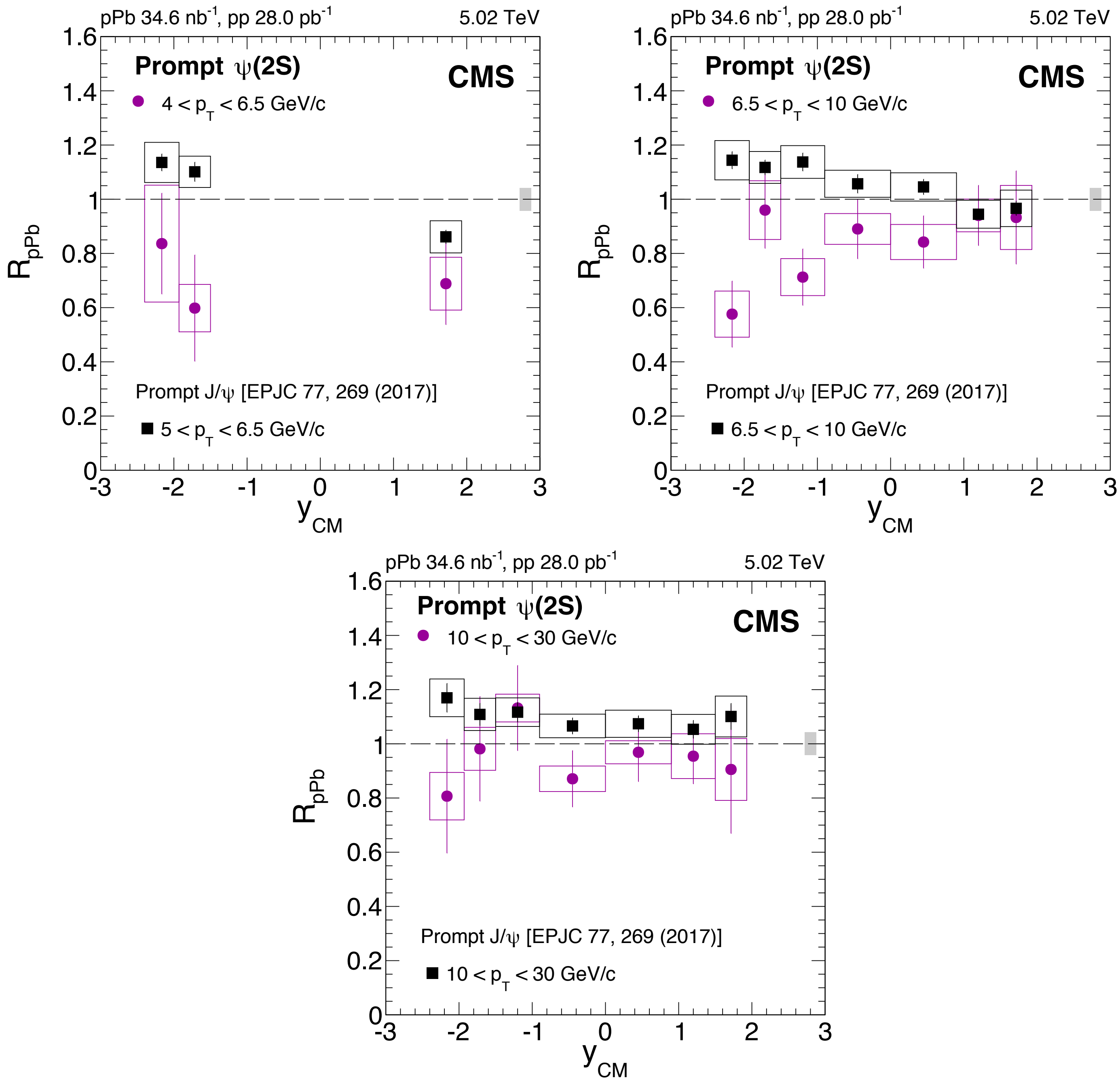


ψ(2S) modification in pPb



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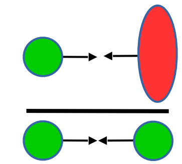
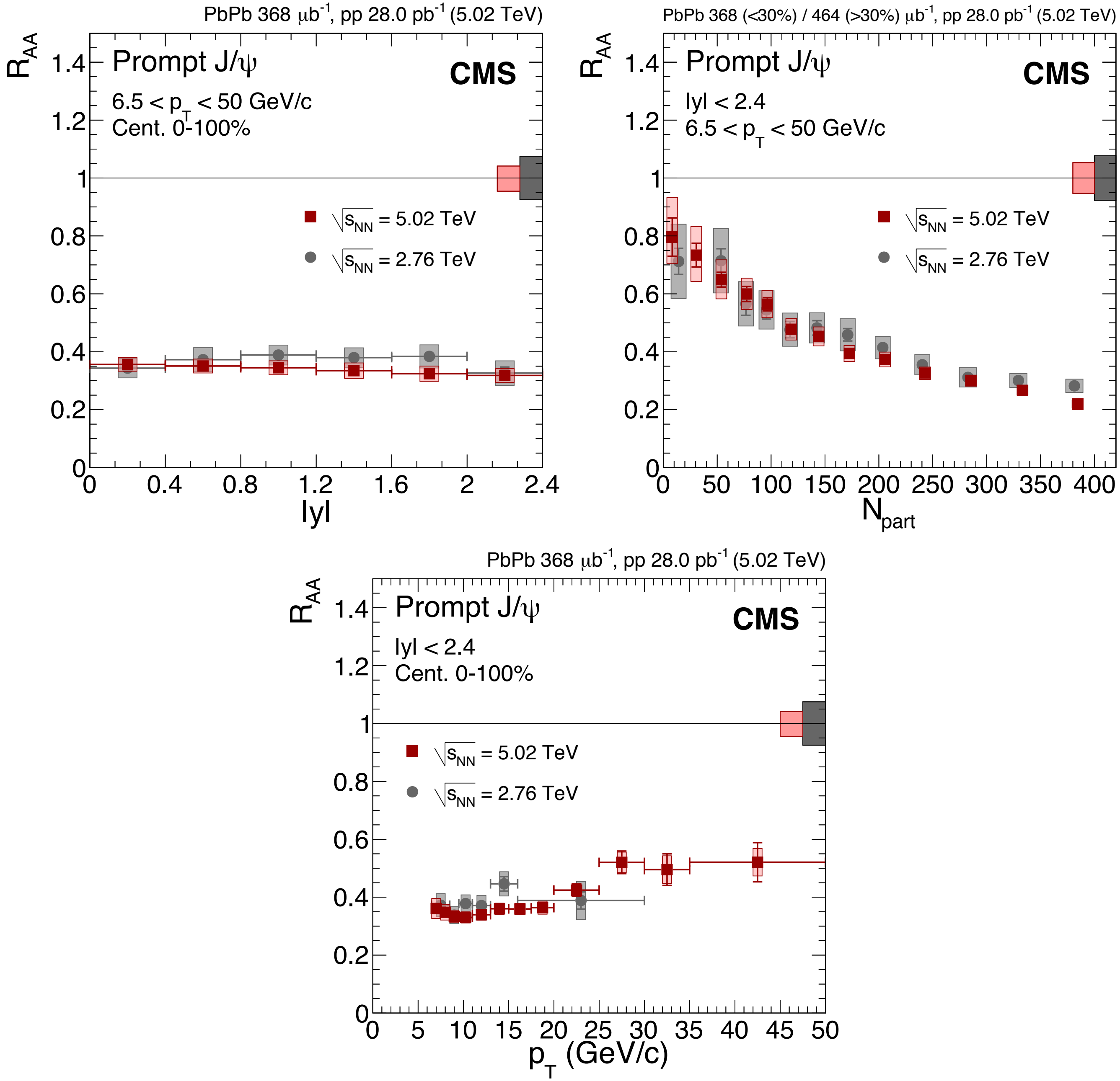


J/ψ modification in PbPb

2.76 vs. 5.02 TeV



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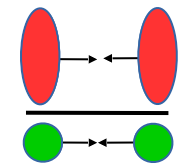
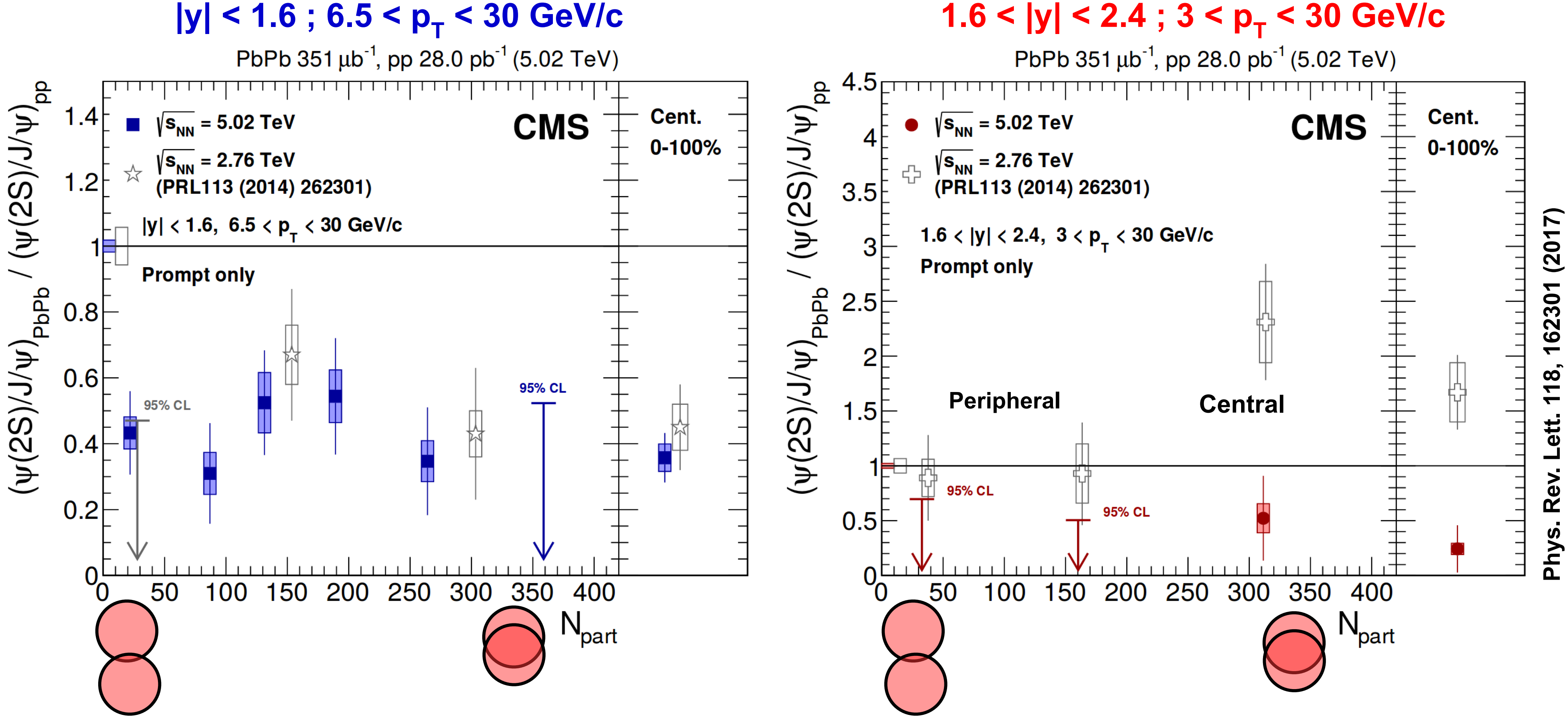


ψ(2S) / J/ψ vs Centrality

2.76 vs. 5.02 TeV

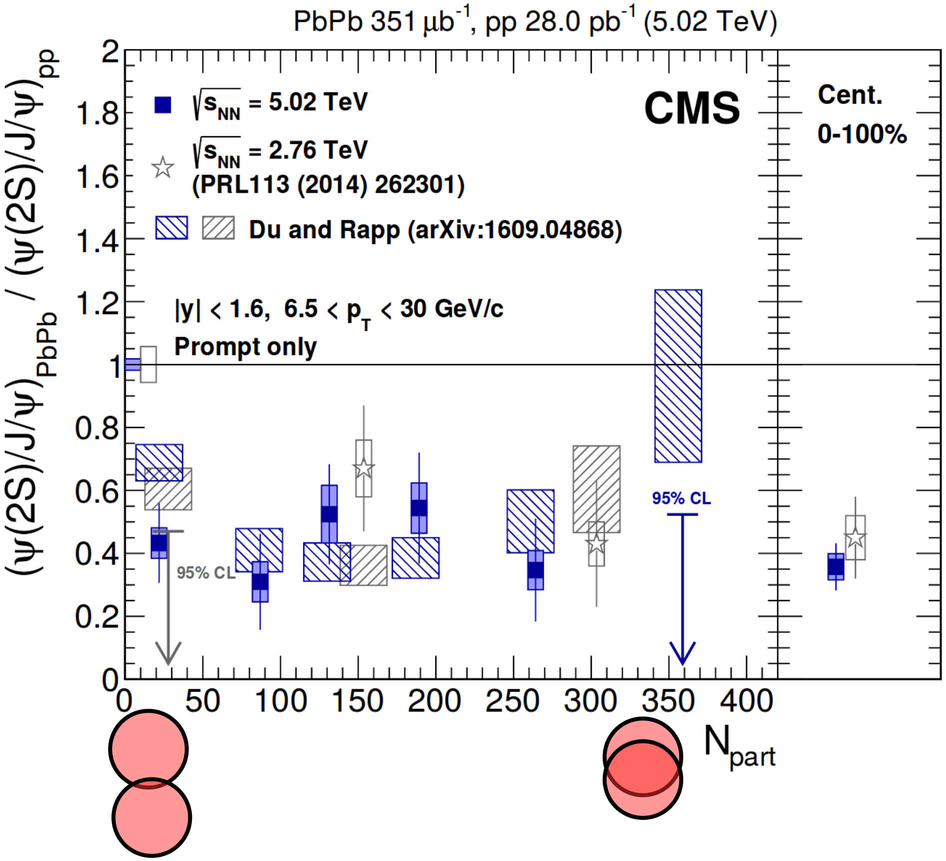


- **ψ(2S) is more suppressed than J/ψ** at 5.02 TeV
- No strong N_{part} dependence at 5.02 TeV
- Double ratio at 5.02 TeV consistently lower than at 2.76 TeV in 1.6 < y < 2.4, 3 < p_T < 30 GeV/c, especially for most central collisions (~3 s.d. in 0-100%)

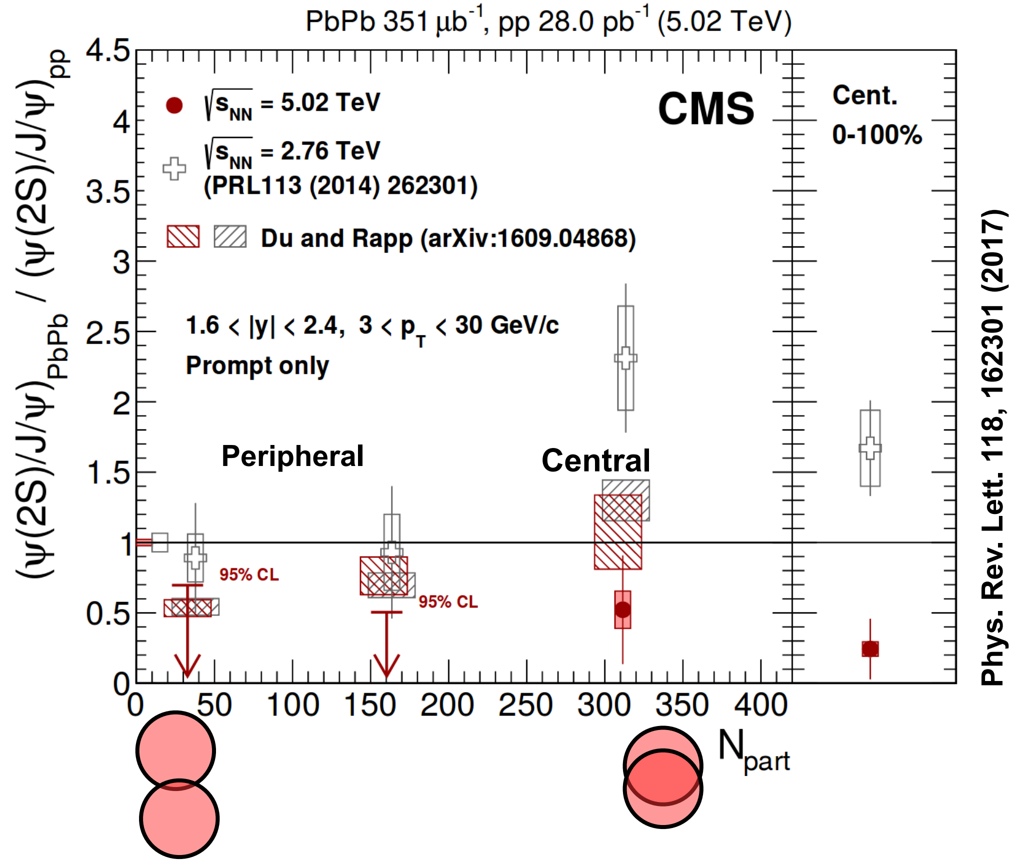
ψ(2S) / J/ψ vs Centrality

2.76 vs. 5.02 TeV

$|y| < 1.6$; $6.5 < p_T < 30$ GeV/c



$1.6 < |y| < 2.4$; $3 < p_T < 30$ GeV/c



- A sequential regeneration model of charmonia states in the fireball evolution might explain the smaller suppression of ψ(2S) compared to J/ψ observed by CMS in PbPb at 2.76 TeV
- Due to the increase in transverse flow from 2.76 TeV to 5.02 TeV, the model predicts that more regenerated J/ψ are produced at $p_T > 3$ GeV/c, thus suppressing the double ratio at $3 < p_T < 30$ GeV/c, in agreement with the CMS measurements