# Quarkonia measurements in CMS

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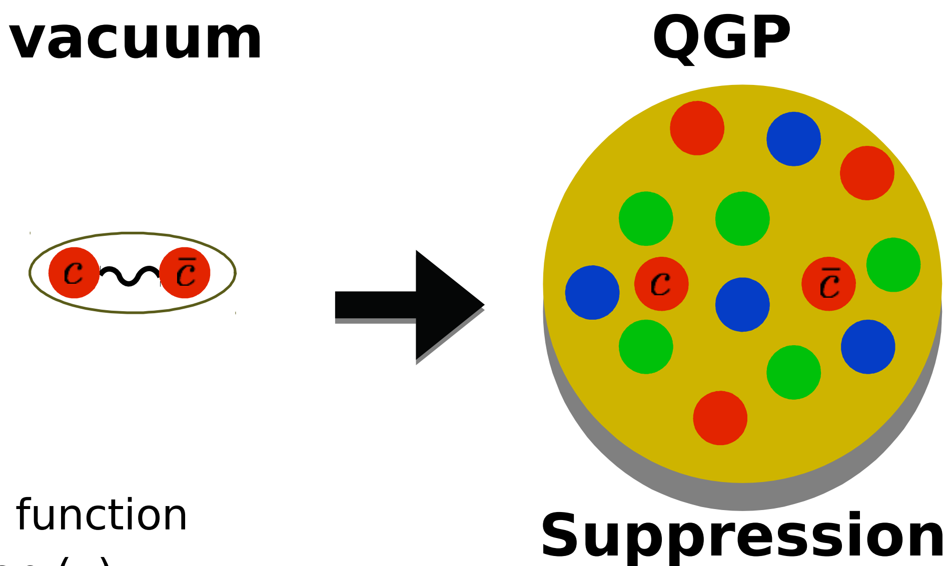
# Introduction

$$\tau^{c\bar{c}}_{\text{formation}} \lesssim \tau^{QGP}_{\text{formation}} < \tau^{QGP}_{\text{life}} < \tau^{\text{quarkonium}}_{\text{decay}}$$

- Quarkonia are expected to experience the whole QGP evolution
  - Debye screening, regeneration




- Cold nuclear matter effects should be addressed to understand effects from the QGP
  - Modification on the parton distribution function
    → shadowing at low momentum fraction (x)
  - Gluon radiation by multiple parton scattering in the nucleus
    → $p_T$ broadening, coherent energy loss

# Quarkonia measured in pp, pPb, PbPb collisions

- Cross-section
  - Provides accurate production rates
- $R_{AA}$, $R_{pA}$
  - Nuclear modification factor
  - Measurement of an absolute suppression with respect to reference system
- Forward/backward ratio
  - Compares nPDF in small and large x region in a system
- Double ratio
  - Measurement of relative modification of the excited states (nS) to the ground state (1S)
  - Cancels initial state effects (shadowing)

$$\frac{\left[\frac{\psi(2S)}{J/\psi}\right]_{PbPb}}{\left[\frac{\psi(2S)}{J/\psi}\right]_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$

# Outline

- Prompt $J/\psi$ in pPb at 5 TeV
  - arxiv:1702.01462 (EPJC accepted)
- Prompt $\psi(2S)$ in pPb at 5 TeV
  - CMS-PAS-HIN-16-015
- Relative modification of prompt $J/\psi$ and $\psi(2S)$ from pp to PbPb at 5 TeV
  - arxiv:1611.01438 (PRL accepted)
- Relative modification of Υ(nS) from pp to PbPb at 5 TeV
  - CMS-PAS-HIN-16-008
- $R_{AA}$ of Υ(nS) from pp to PbPb at 5 TeV
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**pPb system**

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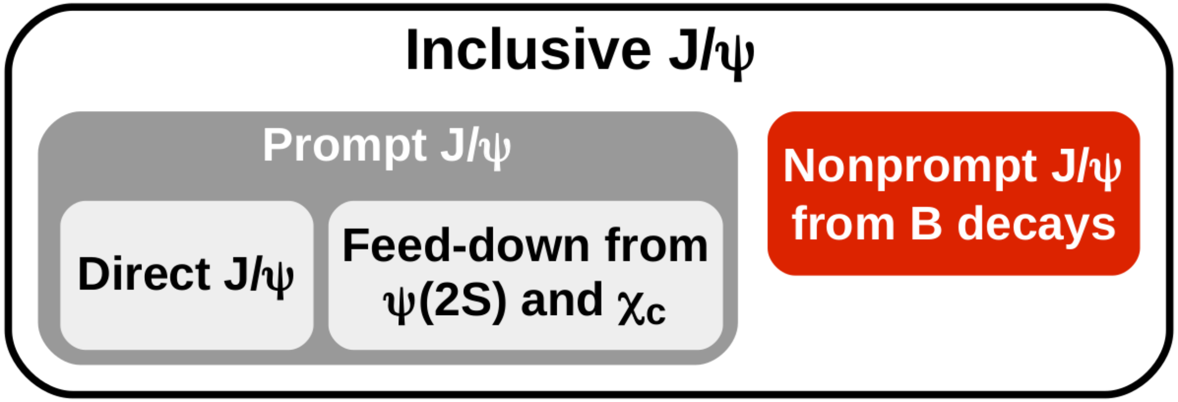
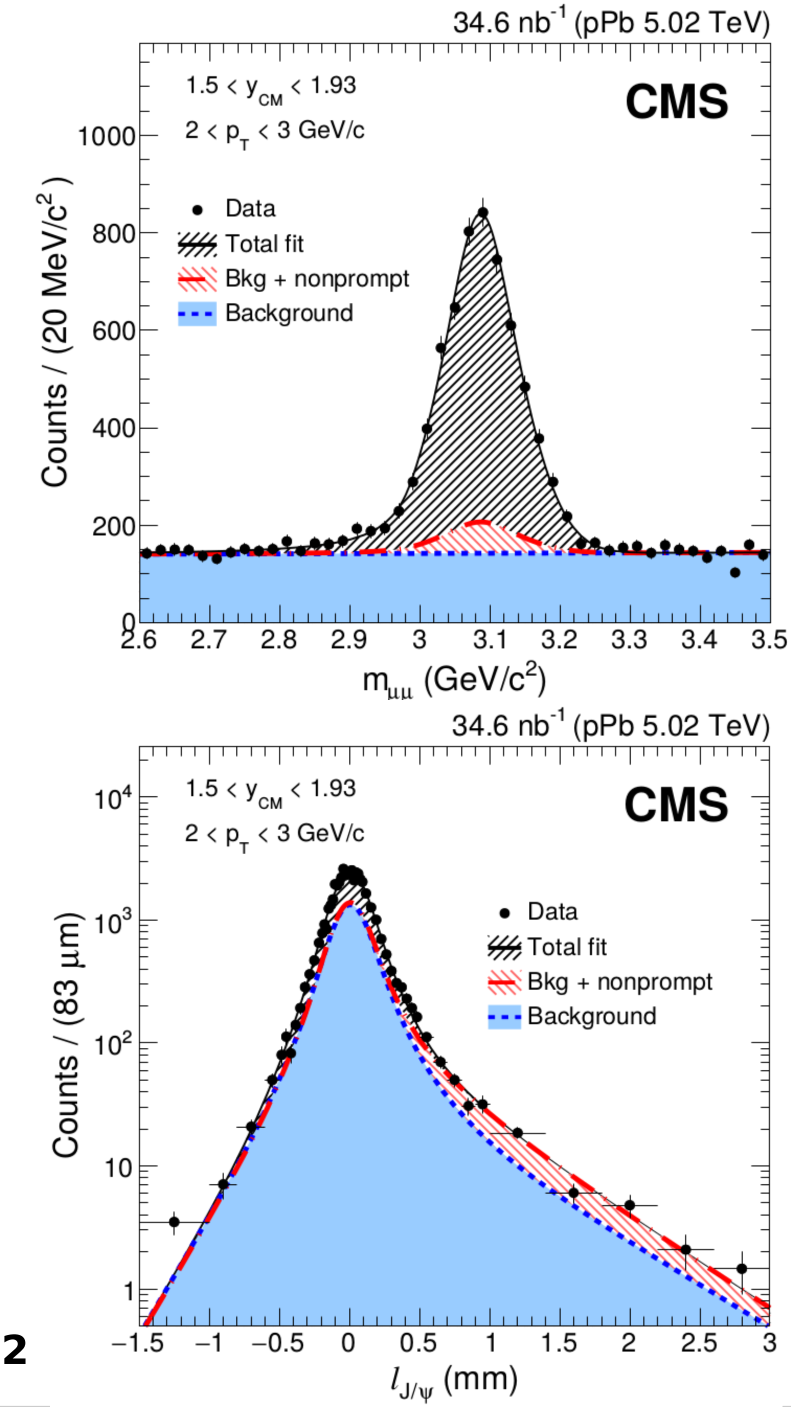
**PbPb system**

# Prompt & nonprompt charmonia




- **Prompt charmonia**
  - Debye screening, regeneration
- Nonprompt charmonia
  - b quark energy loss due to elastic collisions, gluon radiation

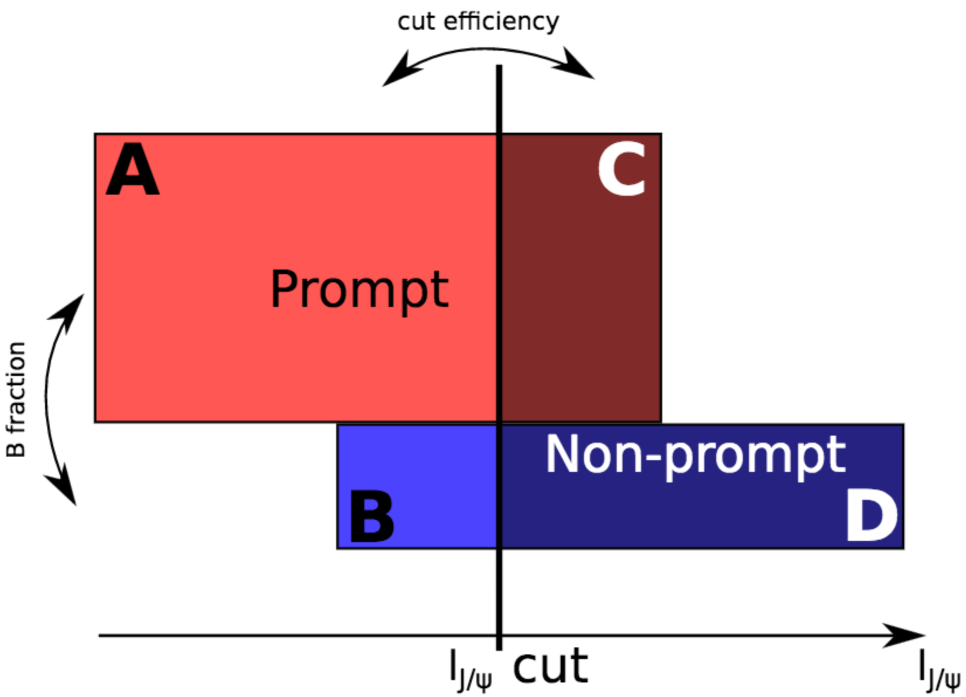
**arXiv:1702.01462**



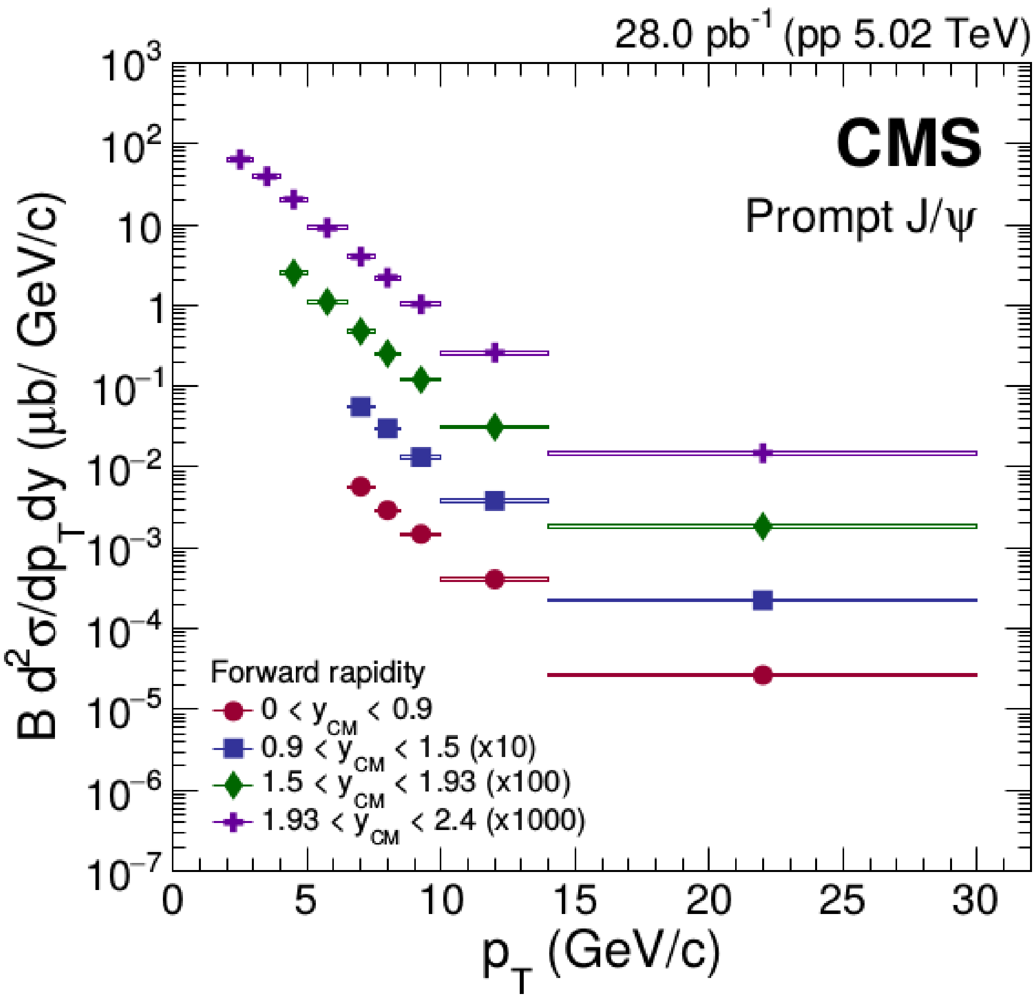
# How to separate prompt & nonprompt charmonia?

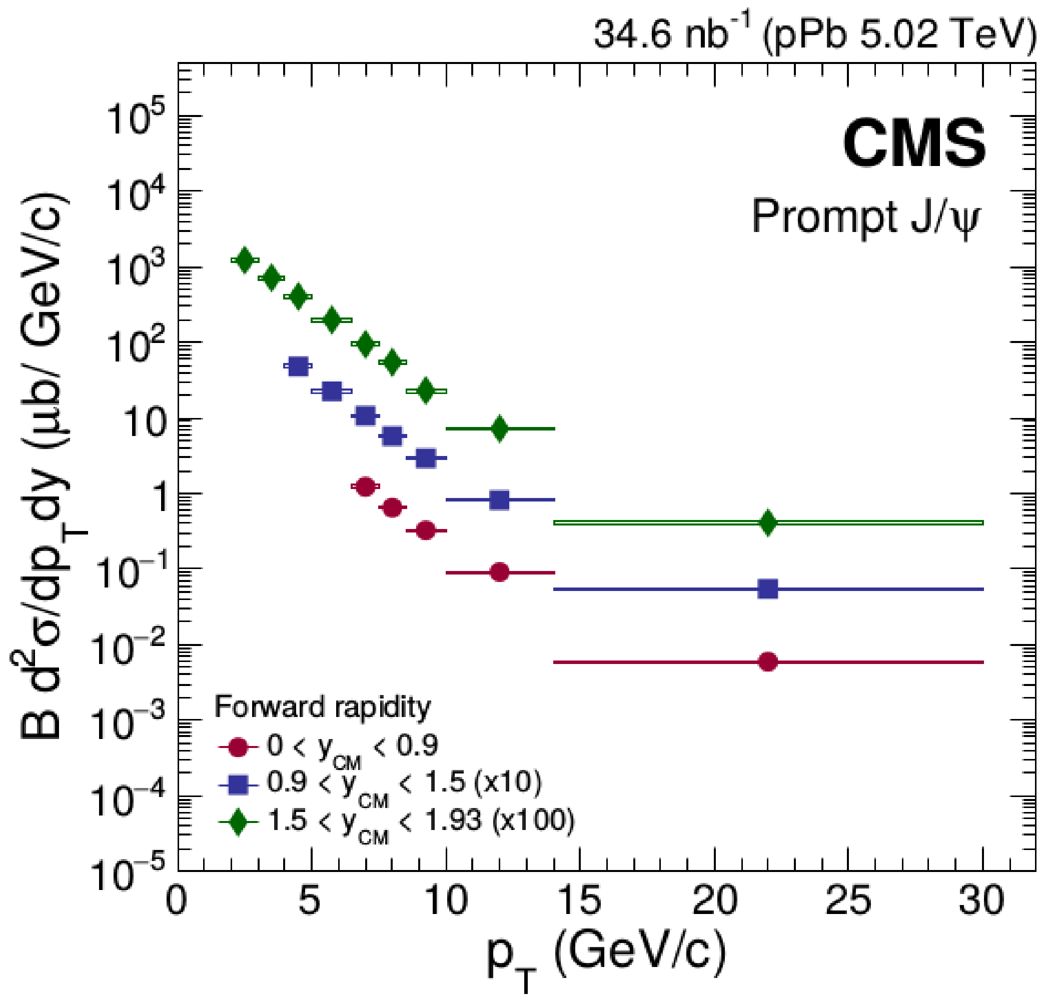
- 2D fits of dimuon mass and lifetime
  - $R_{AA}$, $R_{pPb}$, $R_{FB}$, cross-sections

- Rejecting nonprompt using a cut on lifetime
  - Double ratio
    - Used with low statistics signal: $\psi$(2S)
    - Correction to account for remaining nonprompt contamination
      - Reverted lifetime cut
      - MC efficiency of lifetime cut



# Prompt J/ψ cross-section

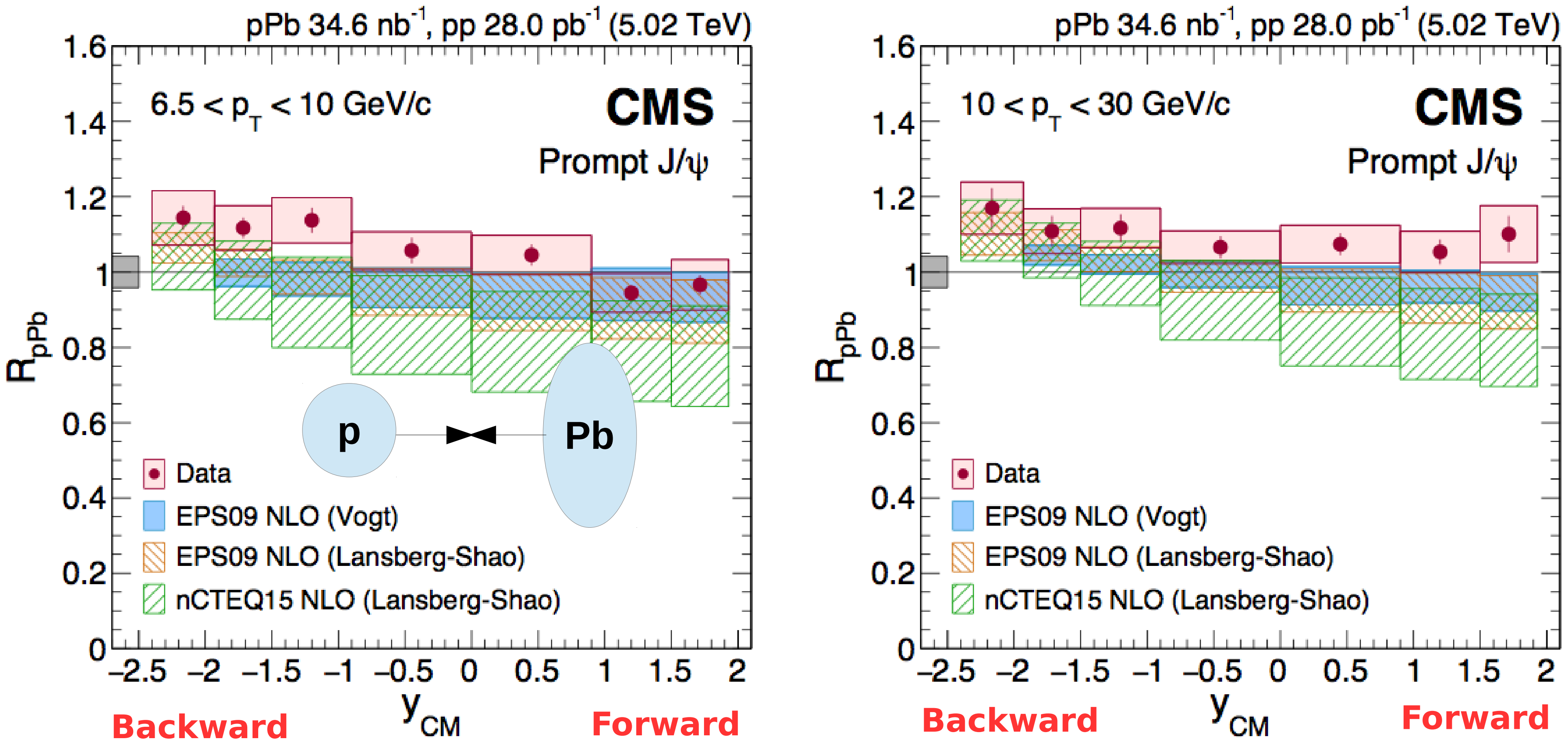



- Not only the relative measurements ($R_{AA}$, $R_{FB}$, $R_{pA}$) but also cross-sections allow us to have better understanding how quarkonia production is modified in the heavy-ion collisions

**arXiv:1702.01462**

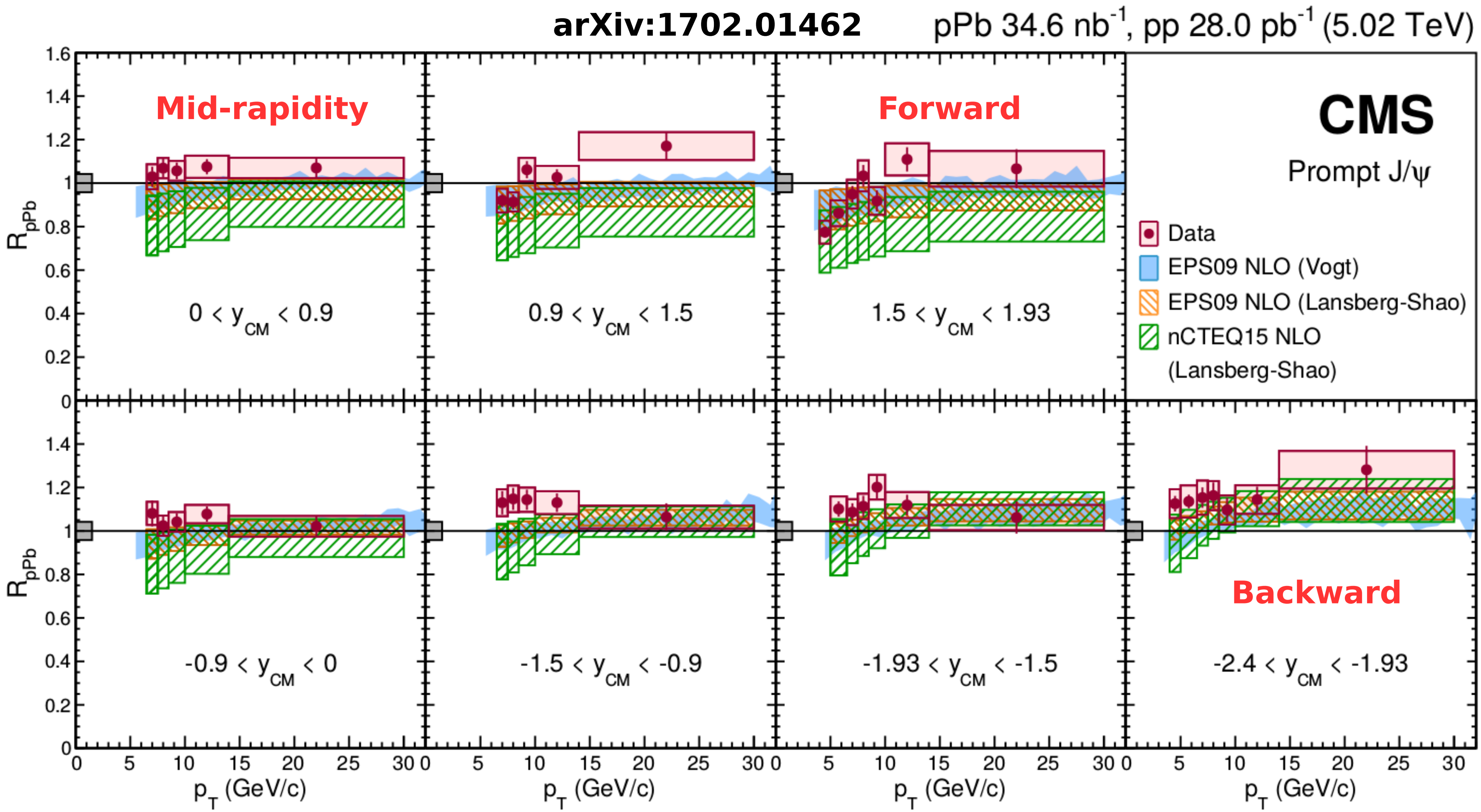
# Prompt J/ψ $R_{pPb}$ : theory comparison




- Lower $p_T$: decrease of $R_{pPb}$ with $y_{CM}$
- Higher $p_T$: $R_{pPb}$ above unity for the whole $y_{CM}$ range
- Shadowing calculations slightly lower than data but describe the $y_{CM}$ trend

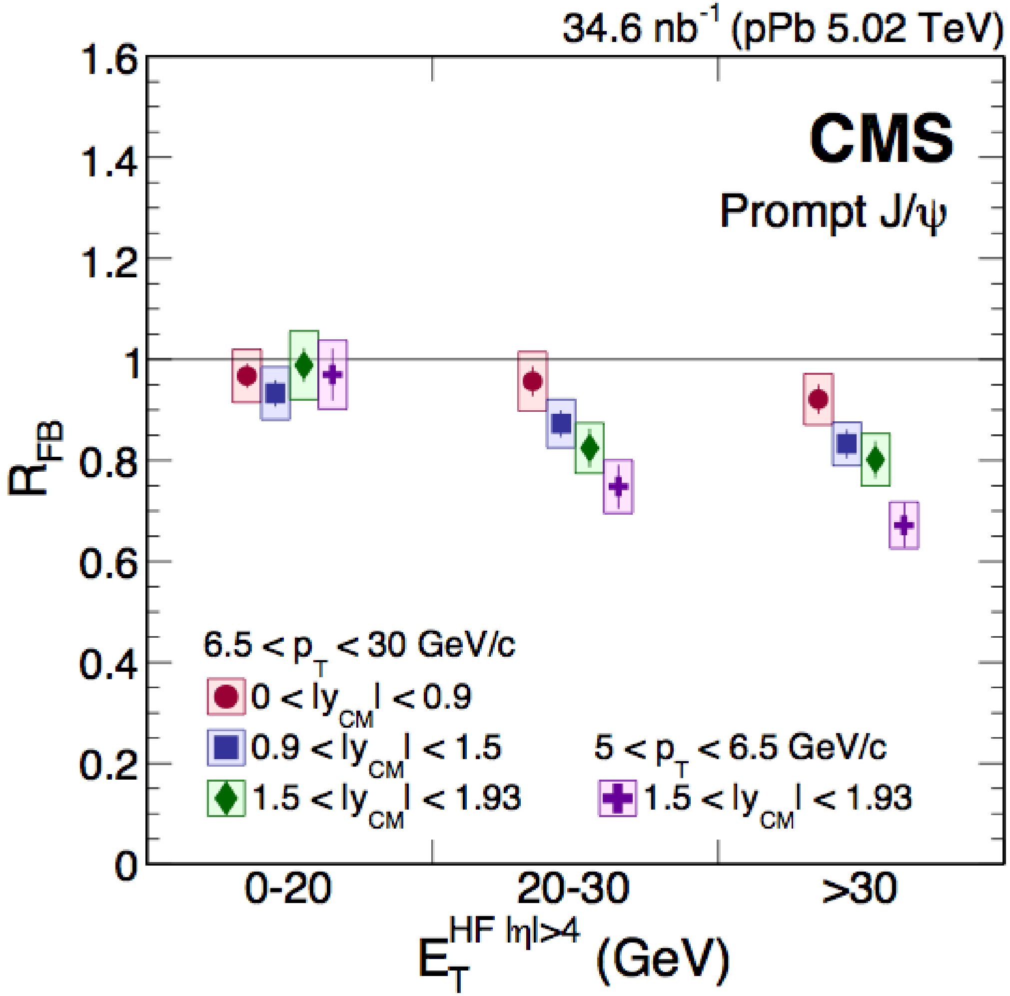
**arXiv:1702.01462**

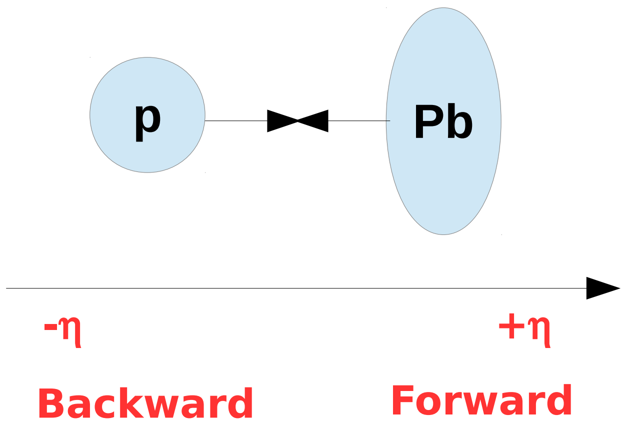
# Prompt J/ψ $R_{pPb}$ : theory comparison




- Prompt J/ψ $R_{pPb}$ above unity at mid and backward rapidity (Pb-going direction)
- Suppression in the most forward bin ($1.5 < y_{CM} < 1.93$) for $p_T \lesssim 7.5$ GeV/c
- Shadowing calculation slightly lower than data, but describe suppression at forward

# Prompt J/ψ forward/backward ratio in pPb




- Event activity characterized by the transverse energy deposited in the Hadron Forward calorimeters in 4 < |η| < 5.2
- $R_{FB}$ decreases for increasing event activity
  - Enhanced nuclear effects for increasing event activity

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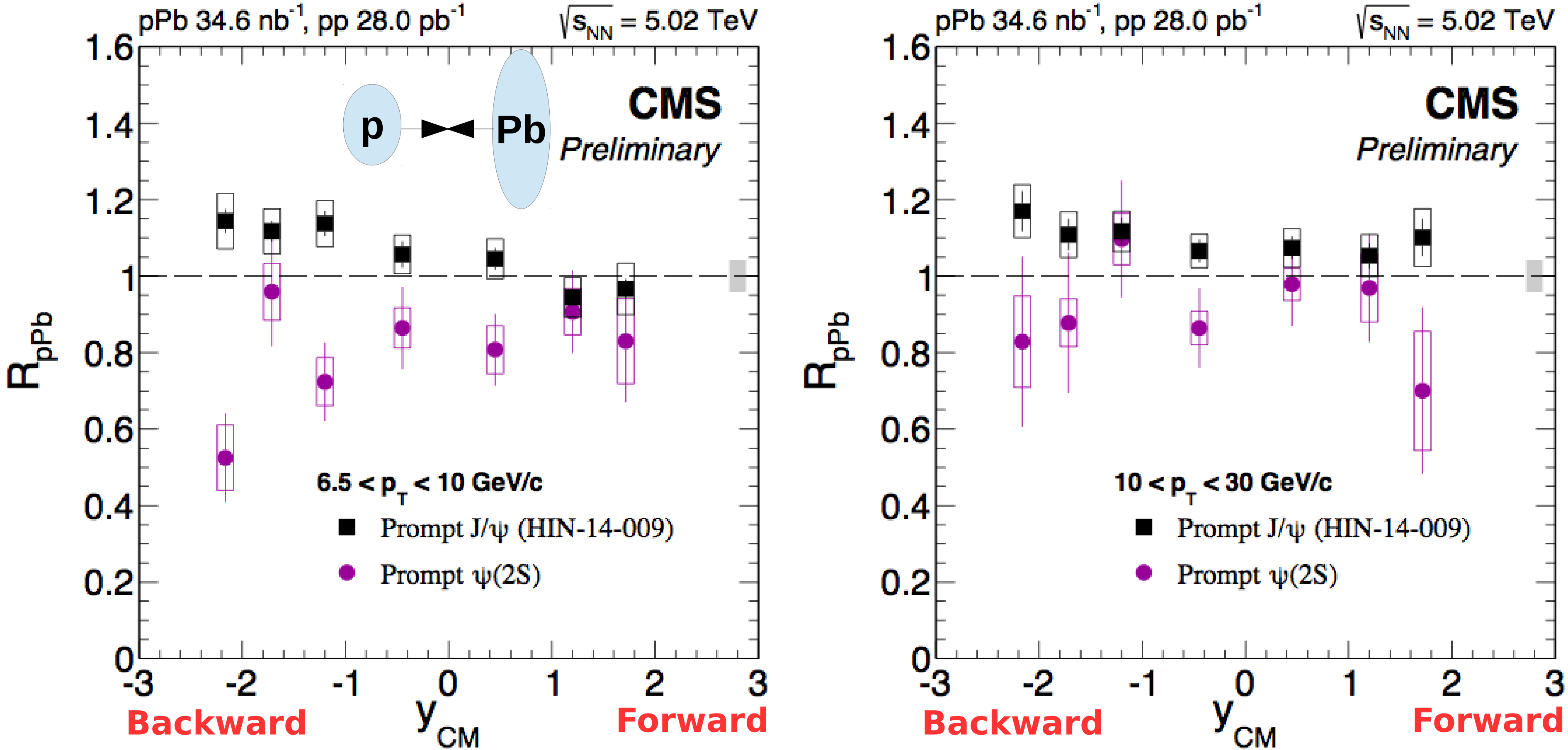
# Prompt $\psi(2S)$ $R_{pPb}$




- $R_{pPb}(\psi(2S)) < R_{pPb}(J/\psi)$
- Indication of final state effect: suppression by interactions with co-moving matter?
  - Note: multiplicity does not change much from backward to forward

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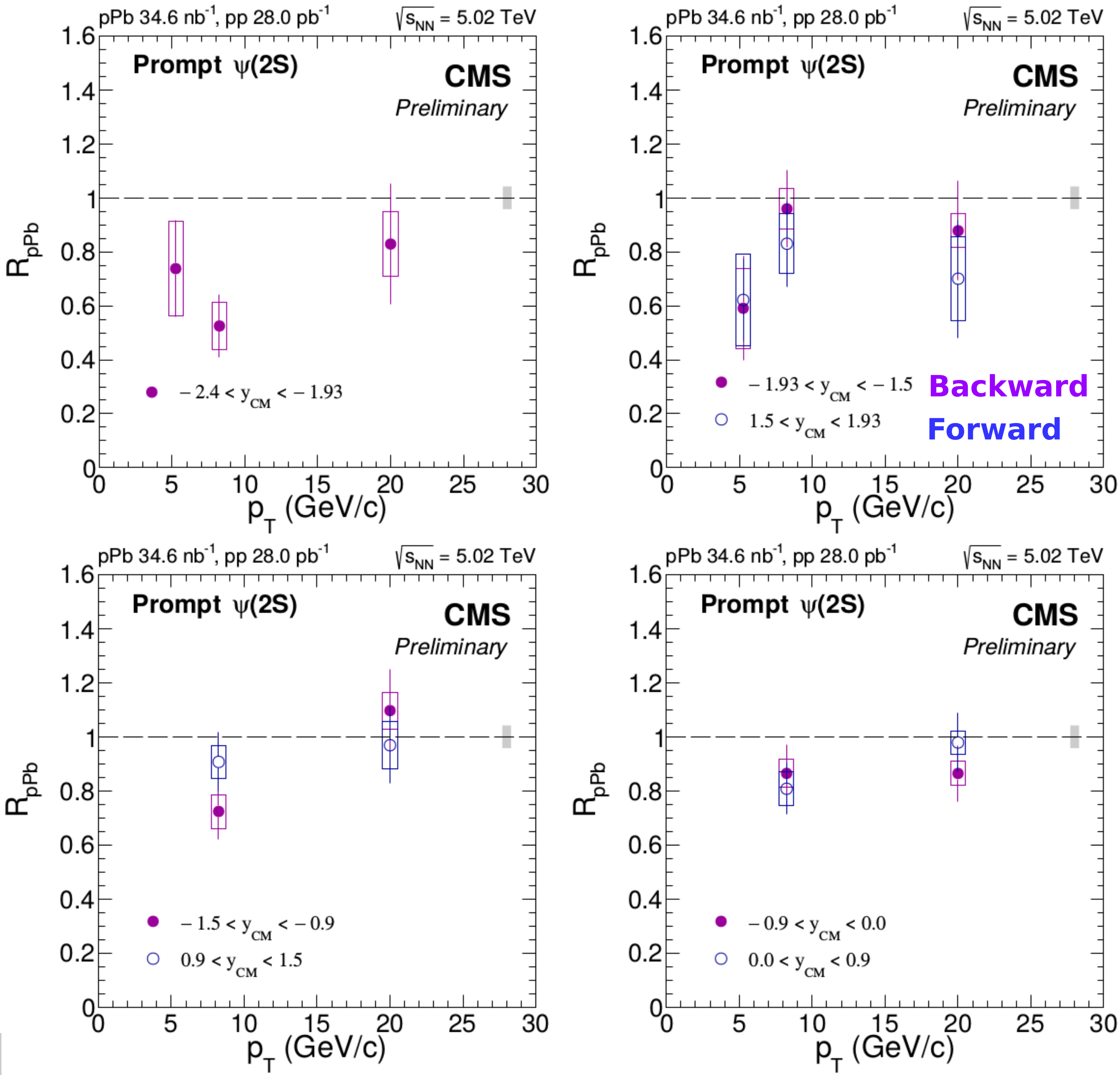
# Prompt ψ(2S) $R_{pPb}$




- $R_{pPb}(\psi(2S))$ showed forward to backward ratio close to unity
  - Even at the most forward & backward region, $R_{FB}$ is unity

CMS PAS HIN-16-015

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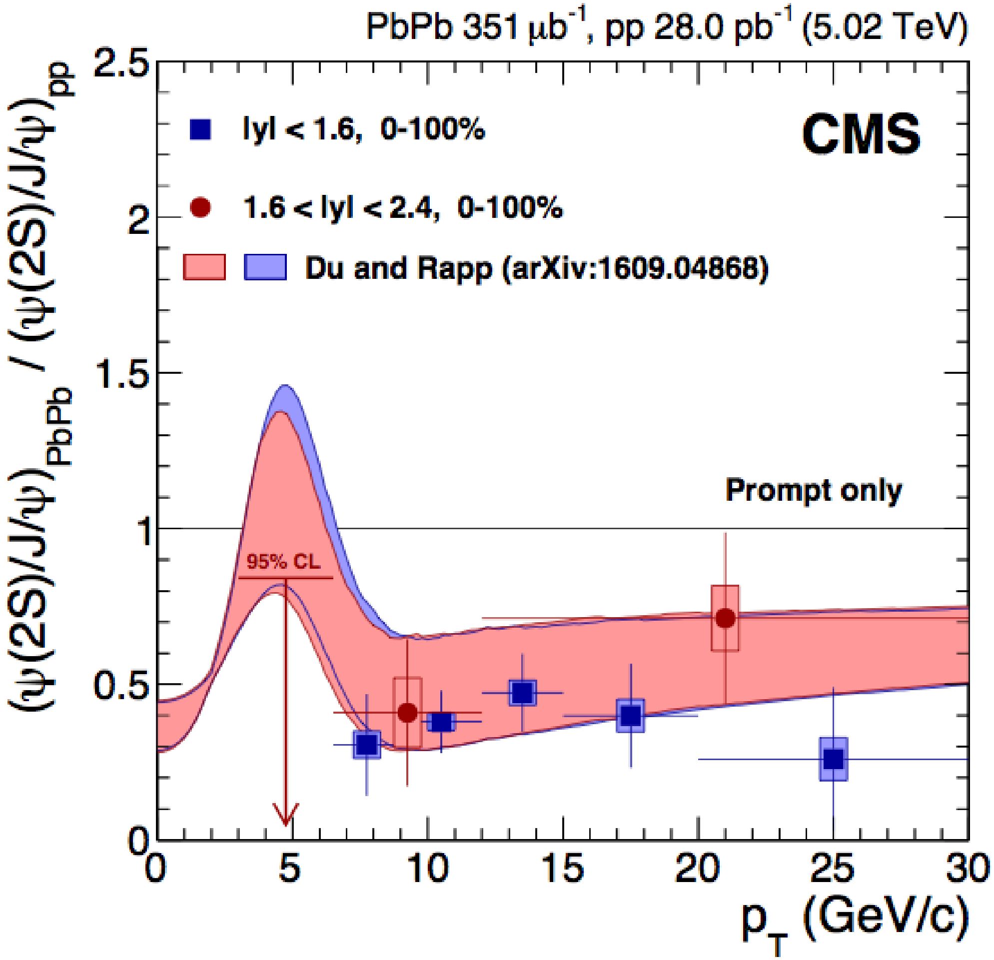
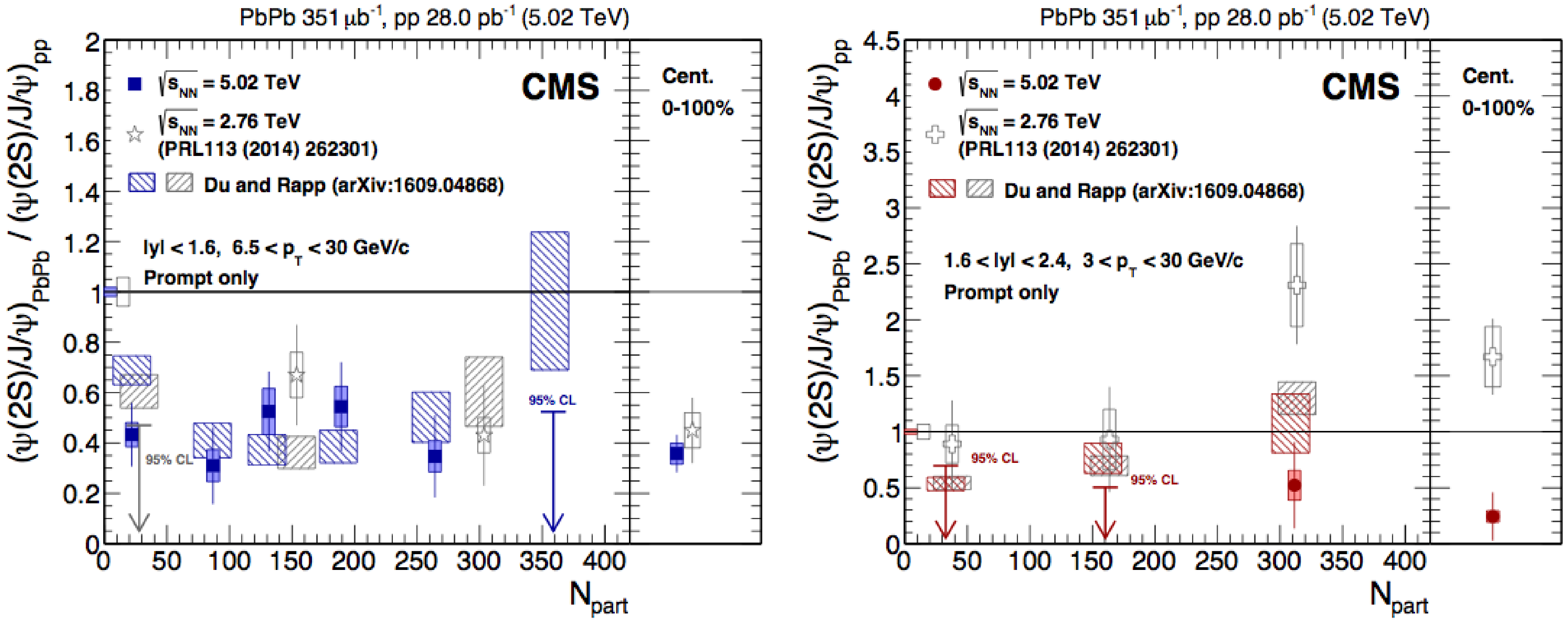
# $\psi(2S)$ / $J/\psi$ vs. $p_T$ in PbPb




**arXiv:1611.01438**

- $R_{AA}(\psi(2S))/R_{AA}(J/\psi) < 1$ in all bins → $\psi(2S)$ is more suppressed than $J/\psi$
- No $p_T$ dependence within uncertainties

# ψ(2S) / J/ψ vs. centrality in PbPb




- CMS results vs centrality, $p_T$ and rapidity can help to constrain the model:
  - Relative contribution of primordial and regenerated charmonia
  - Dissociation and regeneration rates
  - Temperatures at which J/ψ and ψ(2S) regenerate

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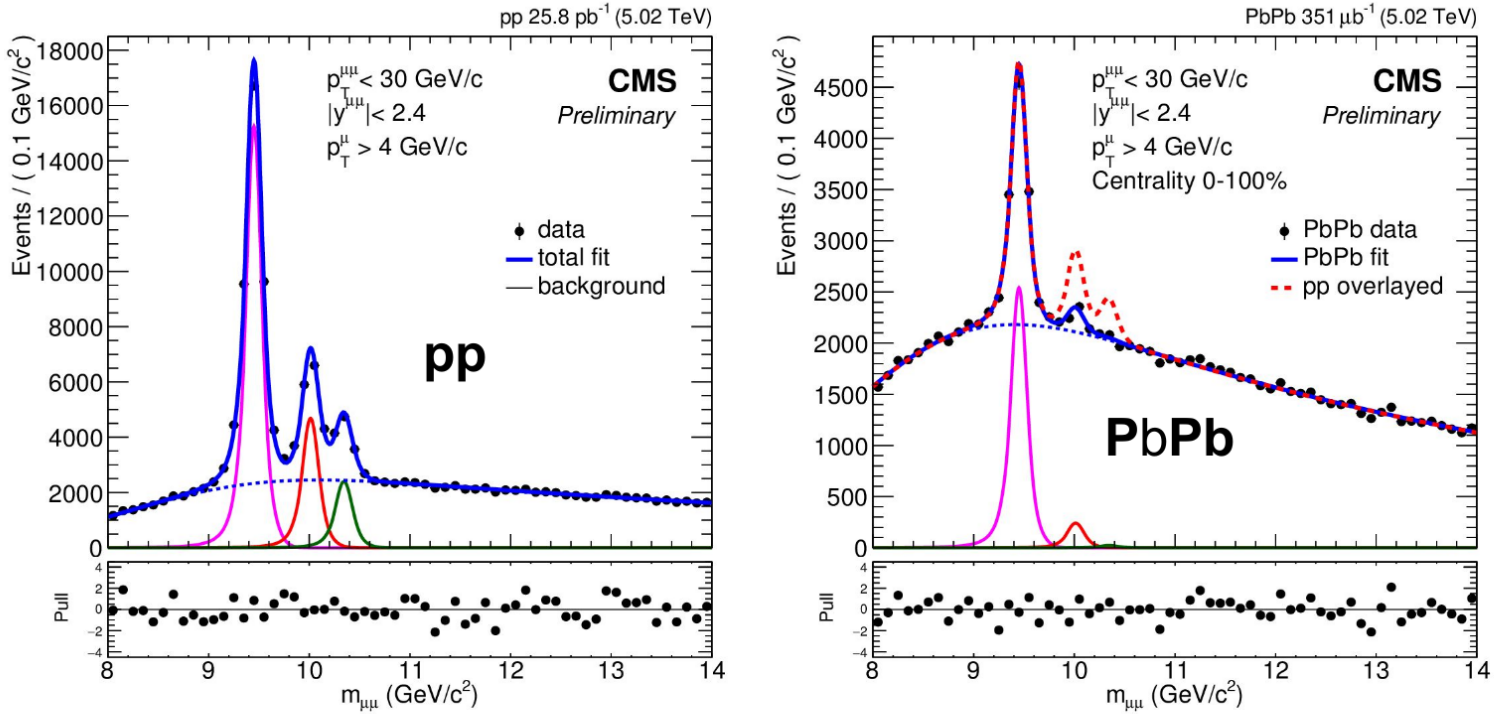
# Bottomonia

- Advantages of bottomonia over charmonia for probing the QGP
  - Negligible nonprompt fraction → Easier interpretation in theory
  - Υ(1S) has the strongest binding energy among quarkonia
  - Smaller contribution for cold-nuclear-matter effect is expected
  - Less regeneration is expected

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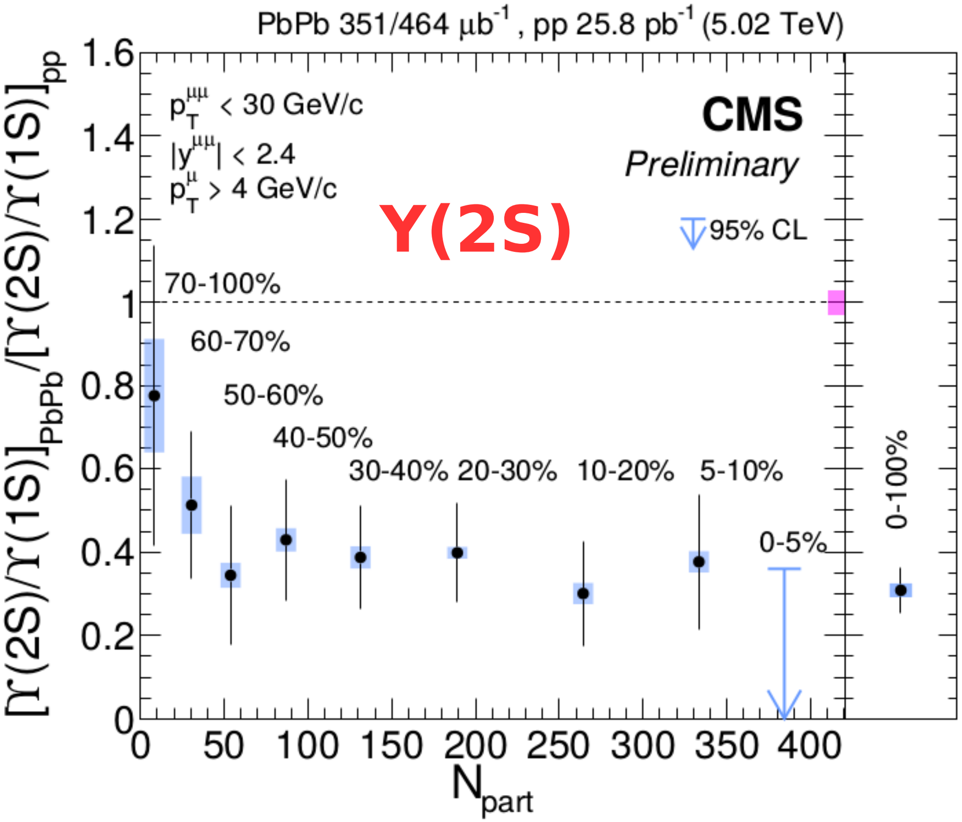
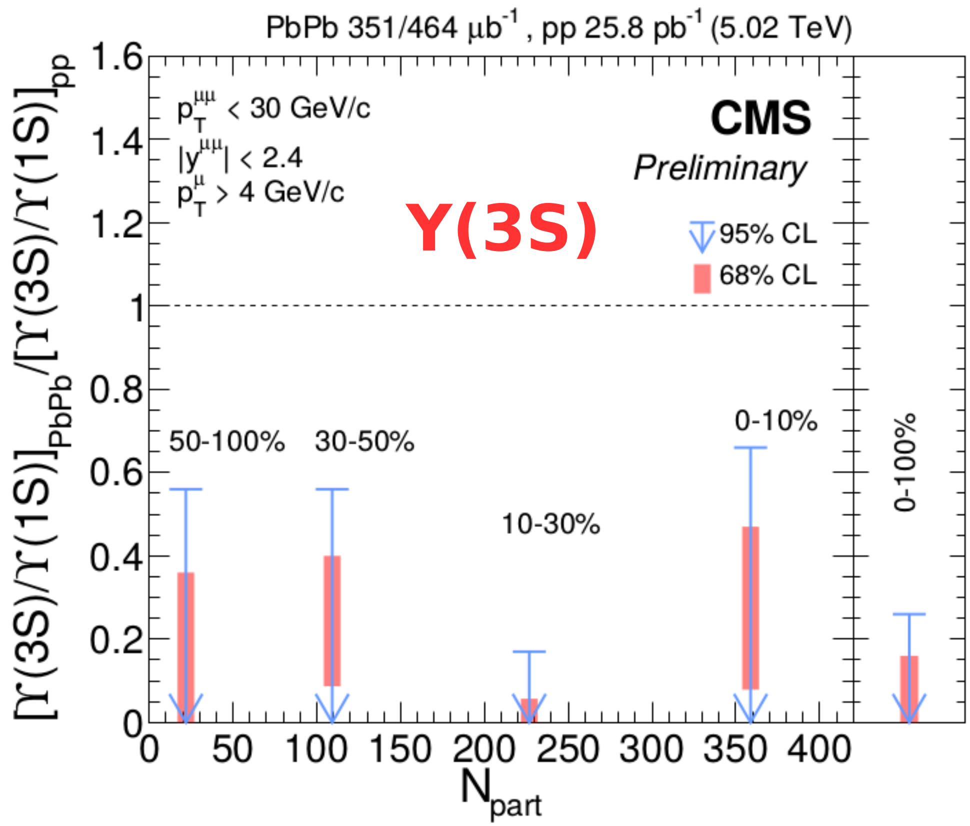
# Υ(nS) double ratios in PbPb collisions

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- Υ(2S) has relative suppression with downward trend in centrality
  - Consistent with unity at most peripheral 70-100%
- Strong relative suppression of Υ(3S) in centrality integrated bin as well as over all centralities studied

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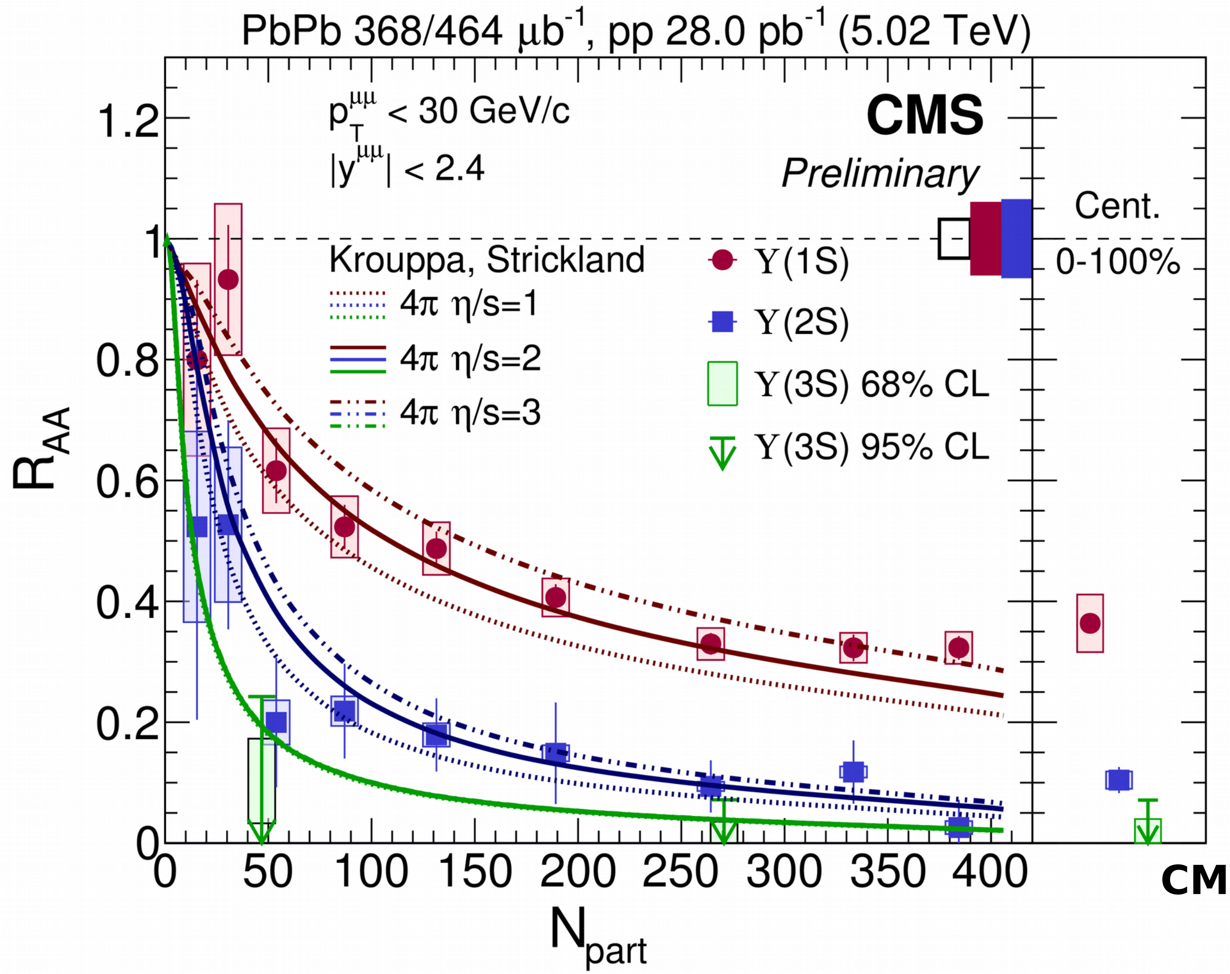
# Υ(nS) $R_{AA}$ vs. centrality : theory comparison

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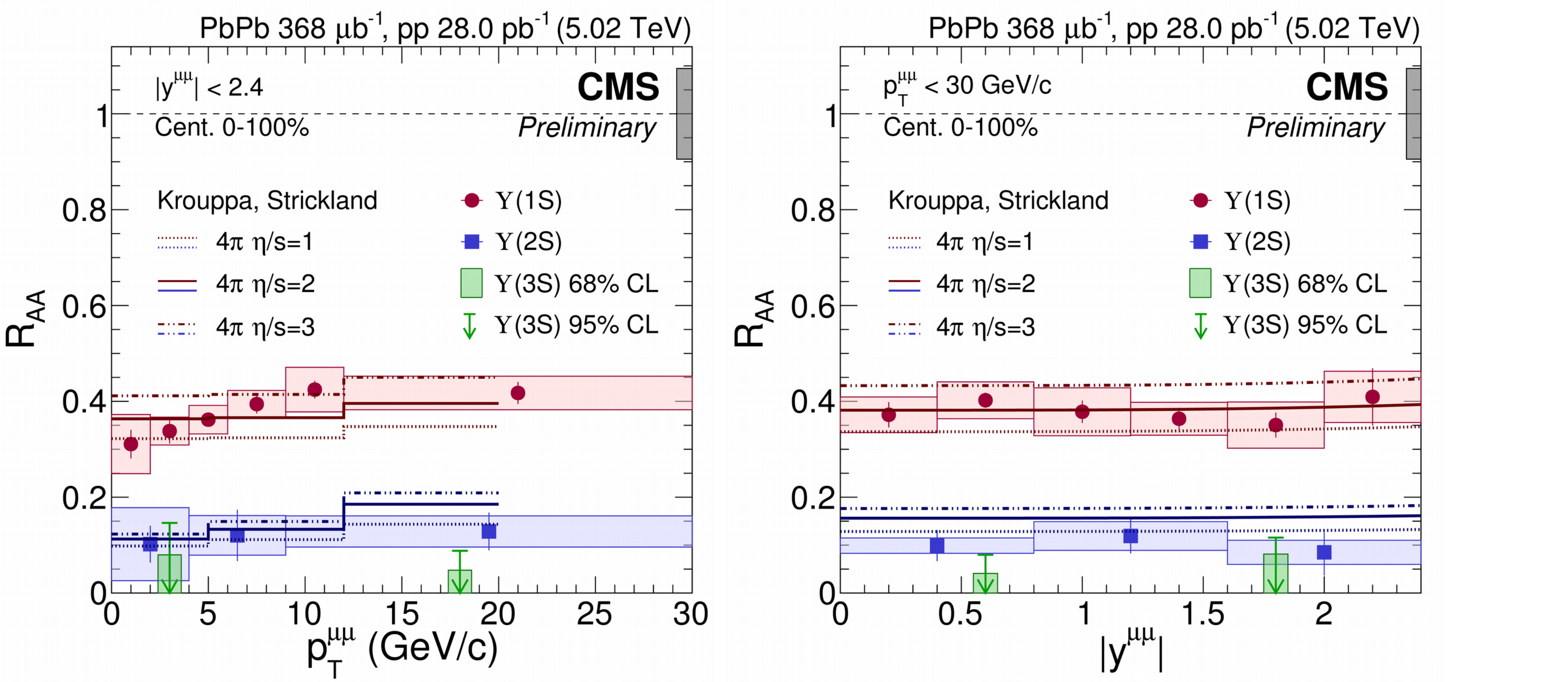
- Suppression of all three Υ(nS) states as a function of centrality
  - $R_{AA}$ of Υ(1S), Υ(2S) at the most central to the most peripheral bin increase to unity within uncertainty
  - Sequential melting
  - Hydrodynamic model from Krouppa, Strickland describes measurements

# Υ(nS) $R_{AA}$ vs. $p_T$, |y| : theory comparison

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- Constant suppressions as a function of $p_T$ and |y|
  - Υ(1S) has a slightly increasing trend in $p_T$
  - The increasing trend on Υ(1S) is also slightly stronger than hydrodynamic model prediction

# Summary

- Prompt J/ψ and ψ(2S) production in pPb and PbPb collisions
  - Prompt J/ψ $R_{pPb}$ is above unity in general,
    - EXCEPT at low $p_T$ & forward region
    - The effects which causes the asymmetry between forward and backward production found to be larger with higher hadronic activity
  - Prompt ψ(2S) is suppressed over all measured region
    - A hint of different final state effects for the excited state to the ground state

  - Prompt J/ψ $R_{pA}$ ≈ 1.15 & $R_{AA}$ ≈ 0.4
  - Prompt ψ (2S) $R_{pA}$ ≈ 0.8 & $R_{AA}$ << 0.4 (based on double ratio)

- Υ(1S) and Υ(2S) $R_{AA}$ have similar trends → $R_{AA}$ towards 1 at the most peripheral bin