PROMPT ψ(2S) AND J/ψ MODIFICATION IN pPb AND PbPb COLLISIONS AT 5.02 TeV WITH CMS

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Quark Matter 2017

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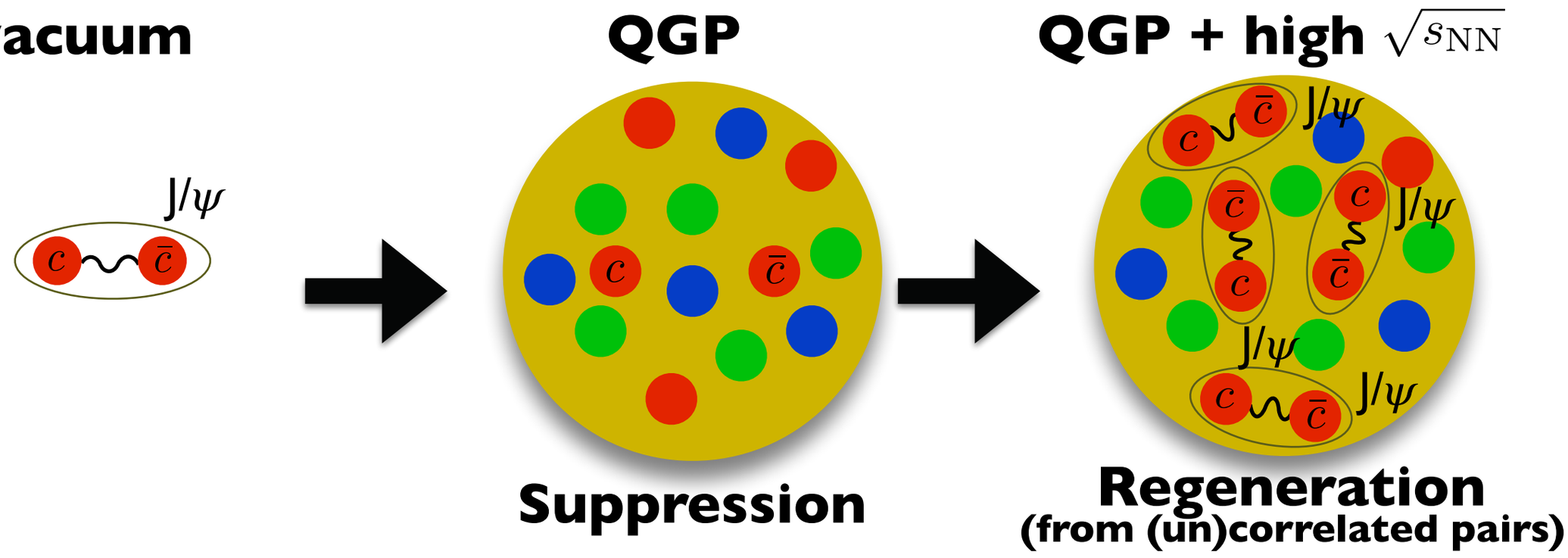
CHARMONIA IN HEAVY ION COLLISIONS

Charmonia are bound states of $c\bar{c}$

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

⟶ expected to **experience the whole QGP evolution**

The presence of QGP should affect charmonia production (yield and kinematics)

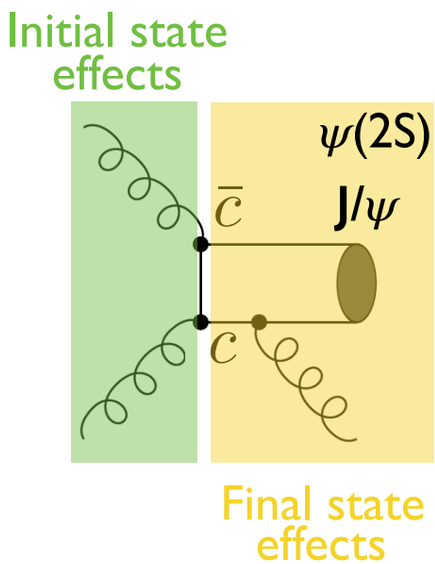


Charmonia are excellent probes for the QGP

Need also to address effects due to Cold Nuclear Matter

CHARMONIA IN pPb COLLISIONS

- Study of J/ψ in pPb allows to probe **Cold Nuclear Matter effects**:
  - ✦ Initial state: Modification of nuclear PDFs
  - ✦ Initial-Final: Coherent energy loss
  - ✦ Final state: Nuclear absorption (negligible @ LHC)

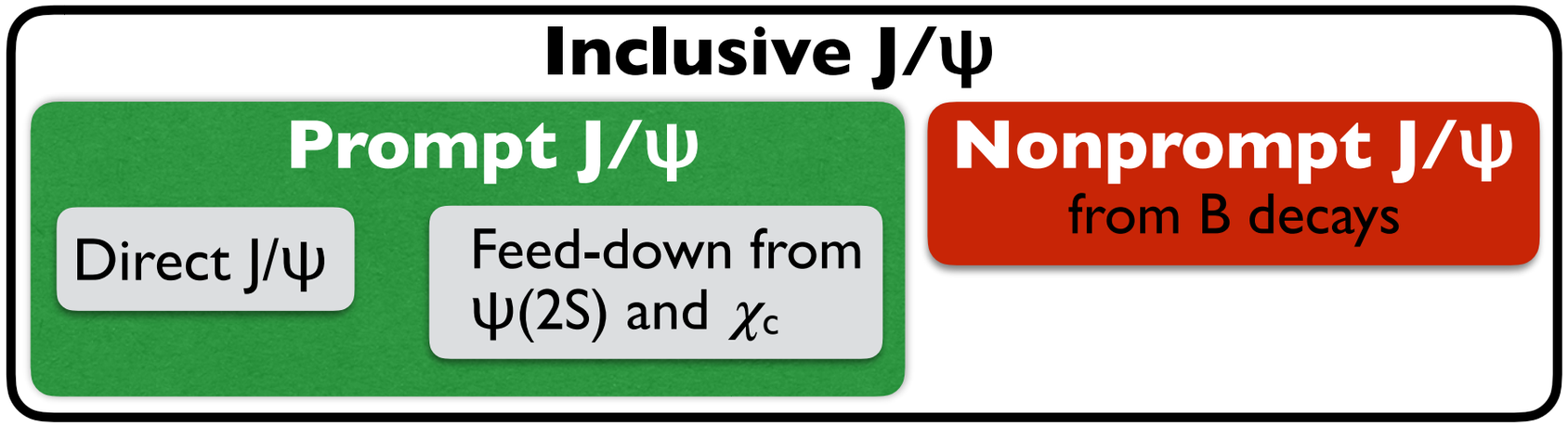


- Study of ψ(2S) in pPb brings additional information:
  - ✦ Excited states are less tightly bound than the 1S state (J/ψ)
  - ✦ Models including Cold Nuclear Matter effects predict similar suppression as for J/ψ

- **Other final state effects** can be important in pPb: *e.g.* interaction with comovers

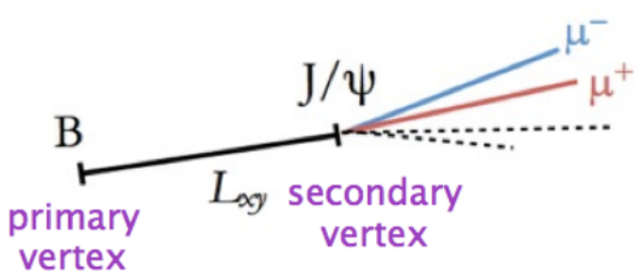
- Reference from **pp data** (28.0 pb^{-1})

PROMPT AND NONPROMPT CHARMONIA



- **Prompt component:**
  affected by color screening and regeneration in the QGP
- **Nonprompt component:**
  reflects E_{loss} of b quarks in the medium

Separation of components based on **pseudo-proper decay length** ($\ell_{J/\psi}$):



$$\ell^{3D}_{J/\psi} = L_{xyz} \cdot \frac{m_{J/\psi}}{p_{\mu\mu}}$$

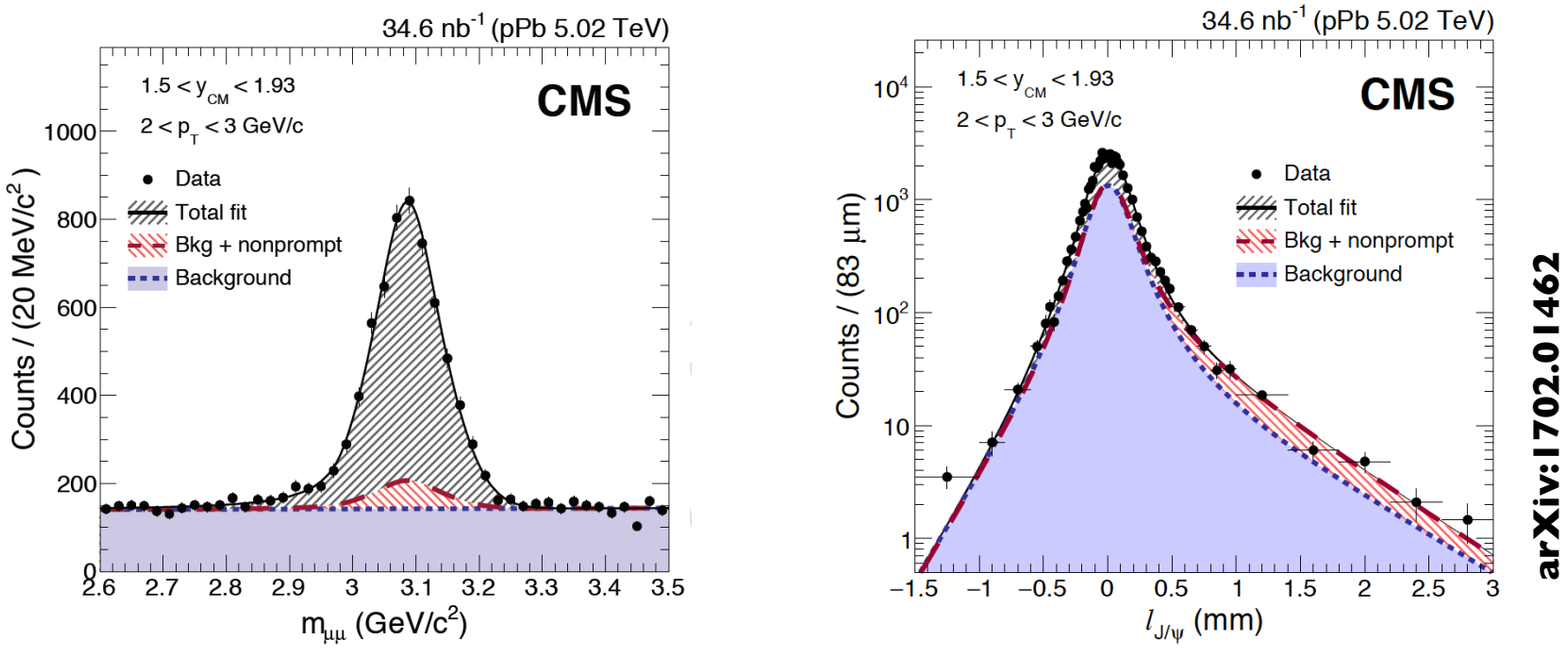
This talk:
prompt charmonia

Ta-Wei Wang's talk (8th):
nonprompt charmonia
& full B reconstruction

PROMPT AND NONPROMPT CHARMONIA

Two techniques to separate components:

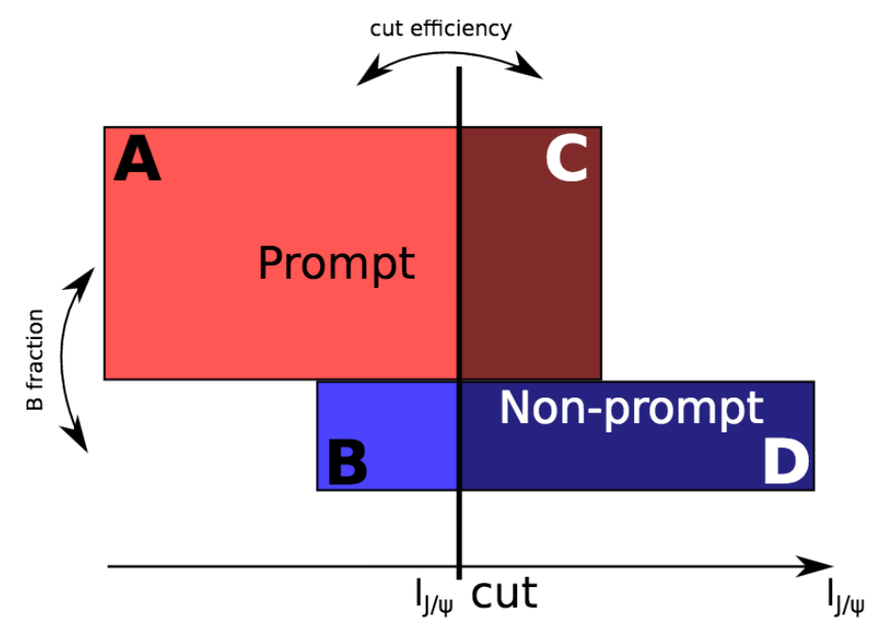
1. **2D fits of dimuon mass and pseudo-proper decay length**



2. **Rejecting nonprompt using a cut on $\ell_{J/\psi}$**
   (can be used with low stats: ψ(2S) analyses)

Correction (from data) to account for remaining nonprompt contamination:

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



OUTLINE

- **Prompt J/ψ in pPb at 5 TeV**
  - HIN-14-009, arXiv:1702.01462

Songkyo Lee's poster: L03

- **Prompt ψ(2S) in pPb at 5 TeV**
  - HIN-16-015

- **Relative modification of prompt J/ψ and ψ(2S) from pp to PbPb at 5 TeV**
  - HIN-16-004, arXiv:1611.01438

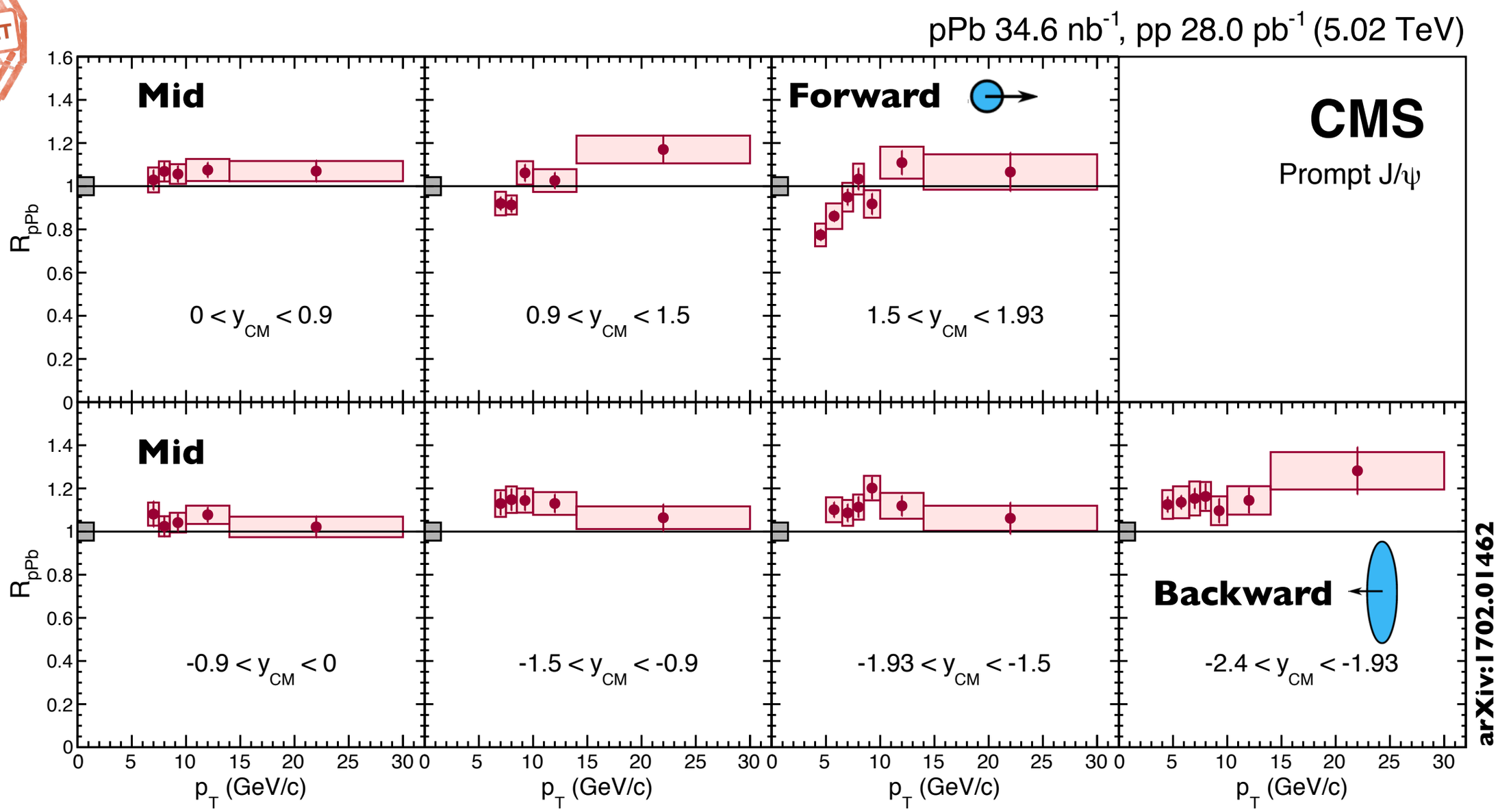
OUTLINE

- **Prompt J/ψ in pPb at 5 TeV**

- **Prompt ψ(2S) in pPb at 5 TeV**

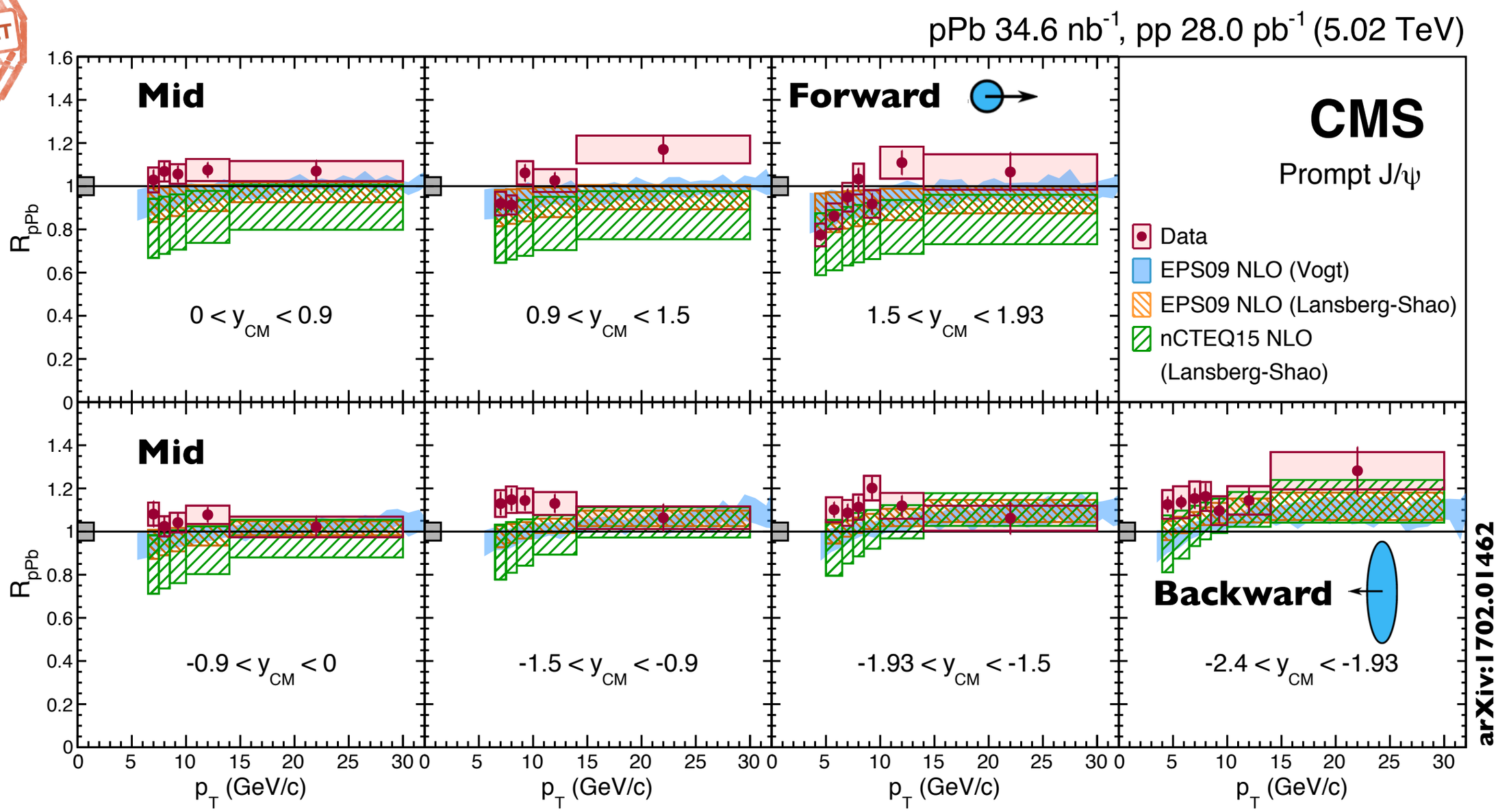
- **Relative modification of prompt J/ψ and ψ(2S) from pp to PbPb at 5 TeV**

PROMPT J/ψ R_{pPb}



- Prompt J/ψ R_{pPb} above unity at mid and backward (Pb-going direction) rapidity
- Suppression in the most forward bin ($1.5 < y_{CM} < 1.93$) for $p_T \lesssim 7.5$ GeV/*c*

PROMPT J/ψ R_{pPb}



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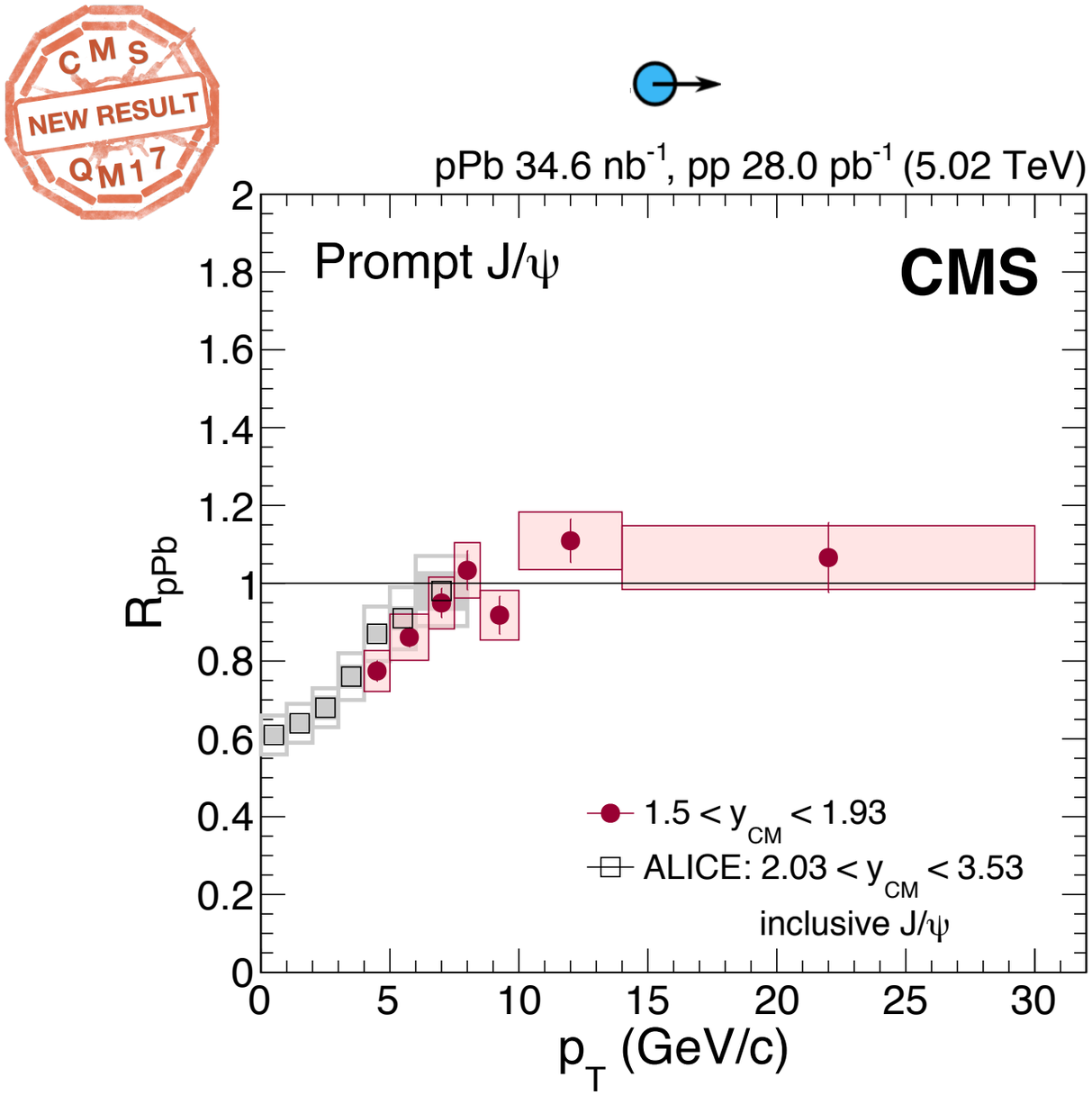
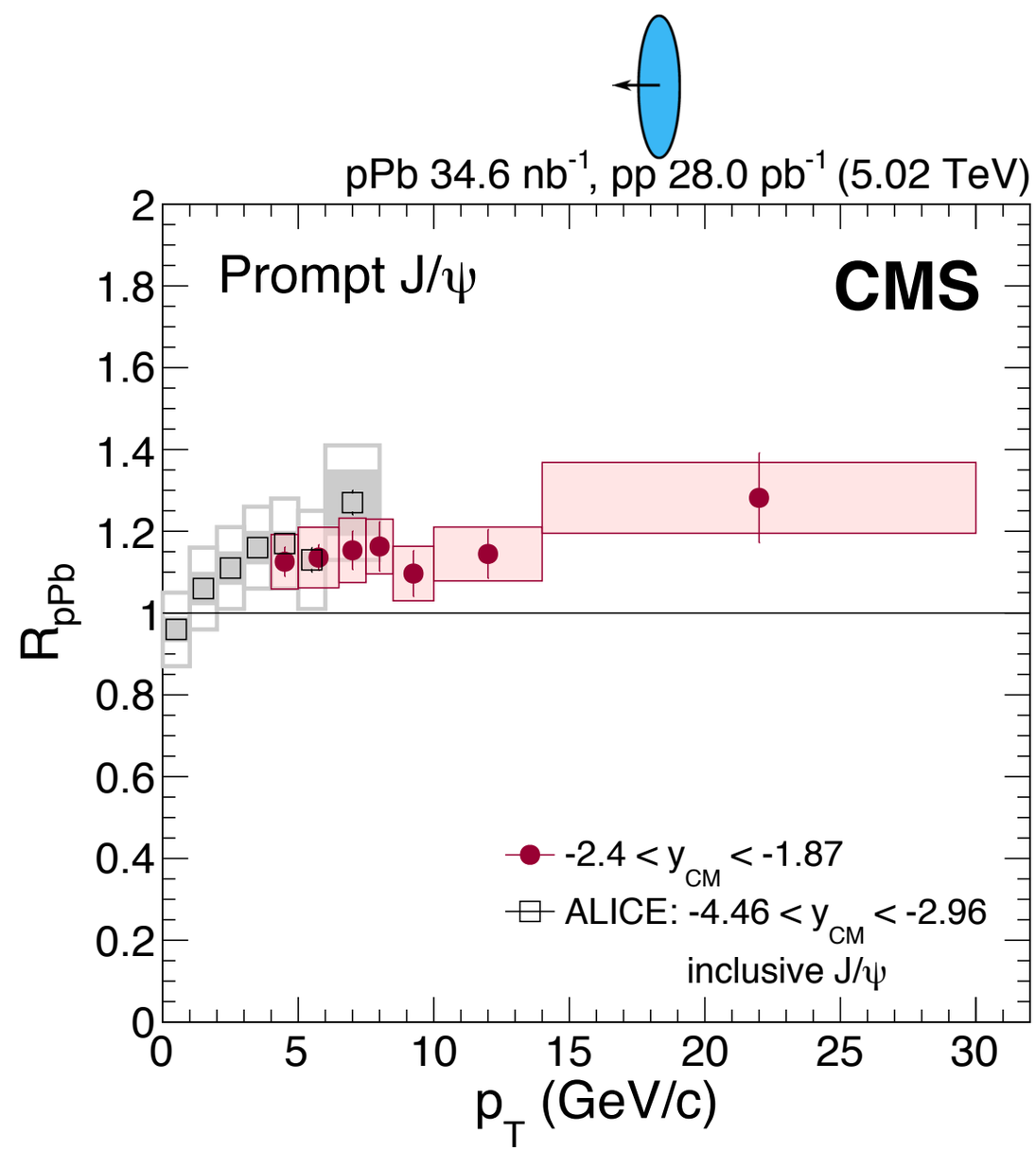
- Shadowing calculations slightly lower than data, but describe suppression at forward

PROMPT J/ψ R_{pPb}

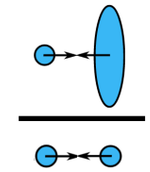


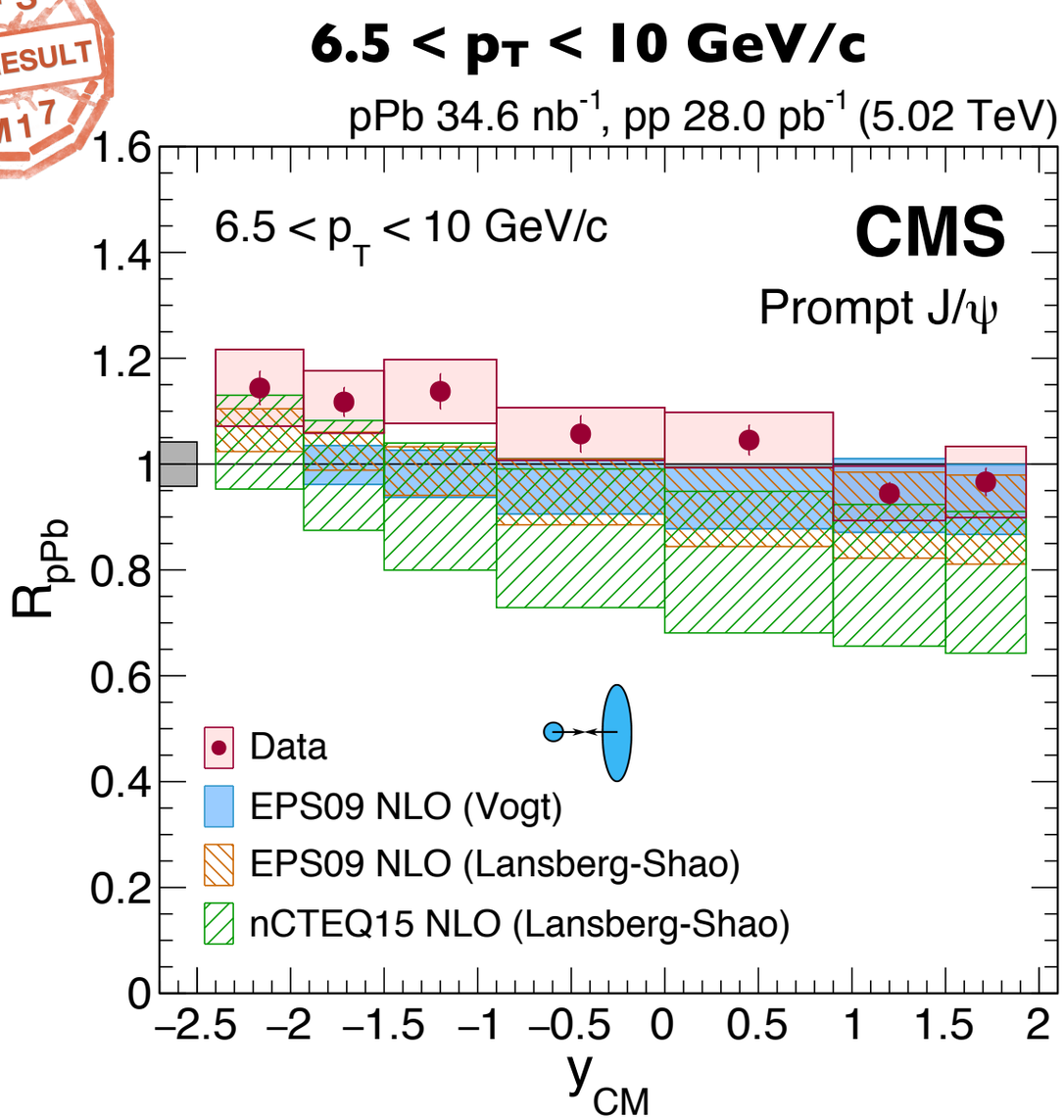


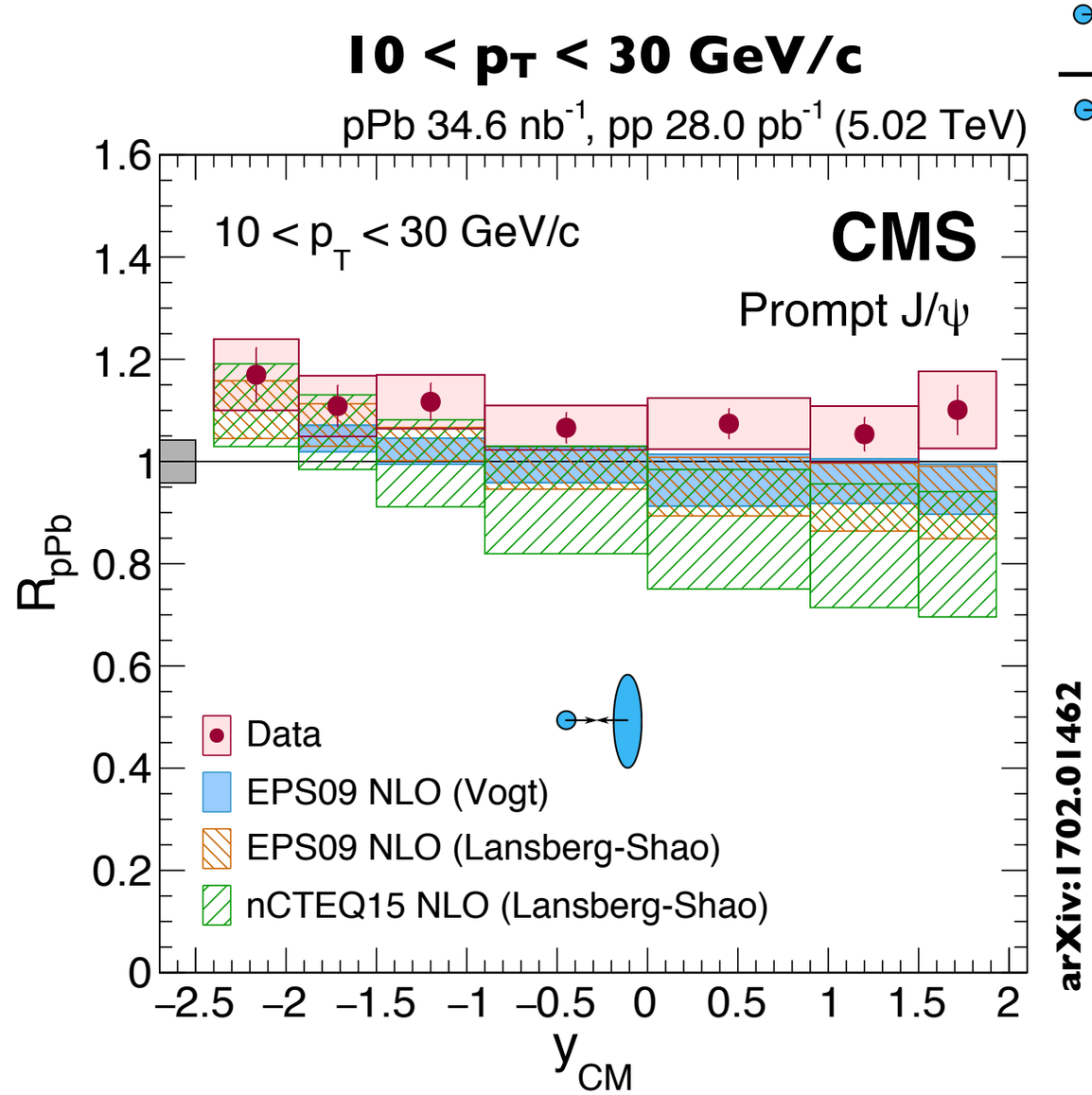
CMS: arXiv:1702.01462
ALICE: JHEP 1506 (2015) 055

- CMS measurement extends ALICE one to higher p_T
- Different rapidity ranges, so effects could be different
- Results in the most forward and backward bins ($4 < p_T < 8$ GeV/*c*) consistent with ALICE

PROMPT J/ψ R_{pPb}

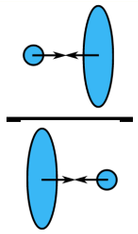


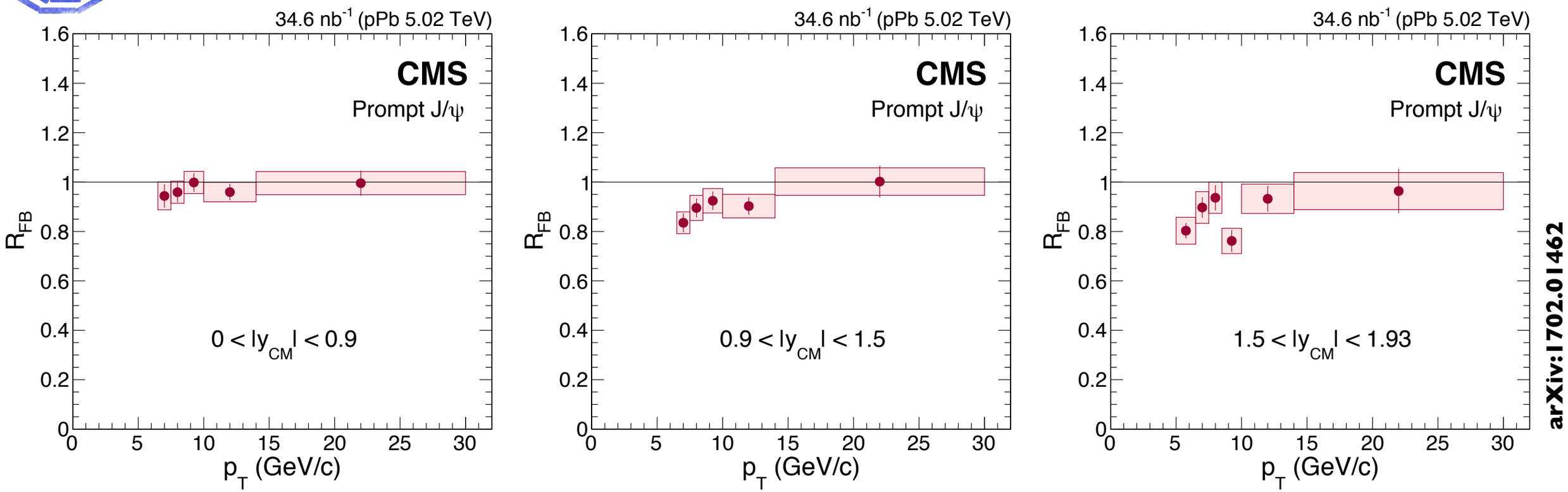




- Lower p_T: decrease of R_{pPb} with y_{CM}
- Higher p_T: R_{pPb} above unity for the whole y_{CM} range
- Shadowing calculations slightly lower than data but describe the y_{CM} trend

FORWARD/BACKWARD J/ψ IN pPb

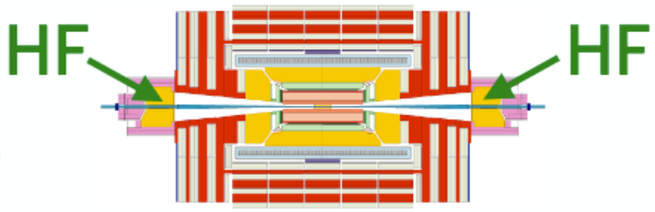




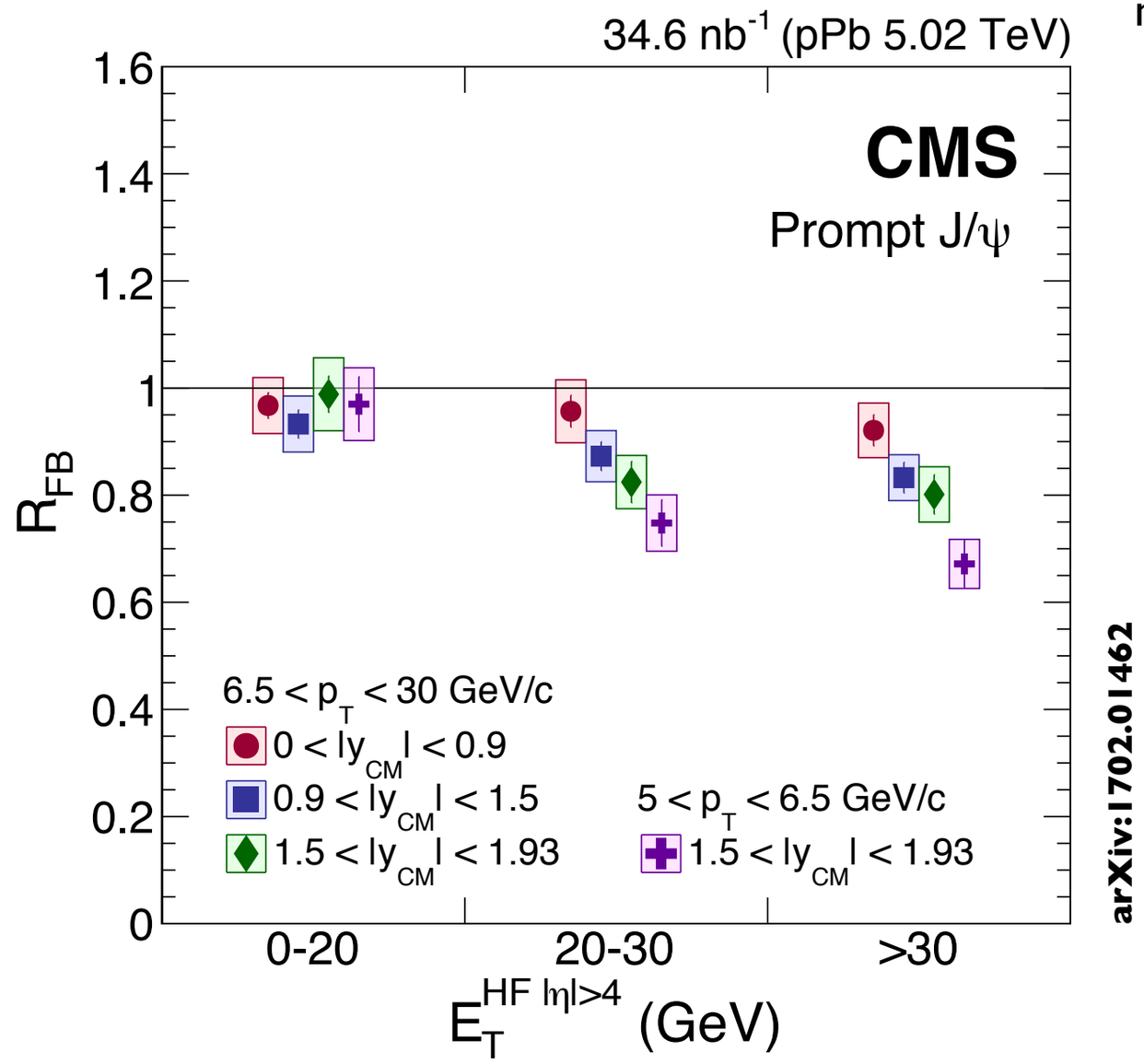
- Prompt J/ψ R_{FB} below with unity for $p_T \lesssim 7.5$ GeV/*c* and $|y_{CM}| > 0.9$.
- y_{CM} dependence in $6.5 < p_T < 10$ GeV/*c*

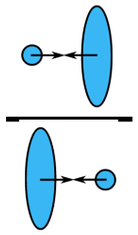
FORWARD/BACKWARD J/ψ IN pPb

Event activity characterised by the **transverse energy deposited in the Hadron Forward calorimeters** in $4 < |\eta| < 5.2$ ($E_T^{HF|\eta|<4}$)



muons measured in $|\eta| < 2.4$





- **R_{FB} decreases for increasing event activity**
- Enhanced nuclear effects for increasing event activity

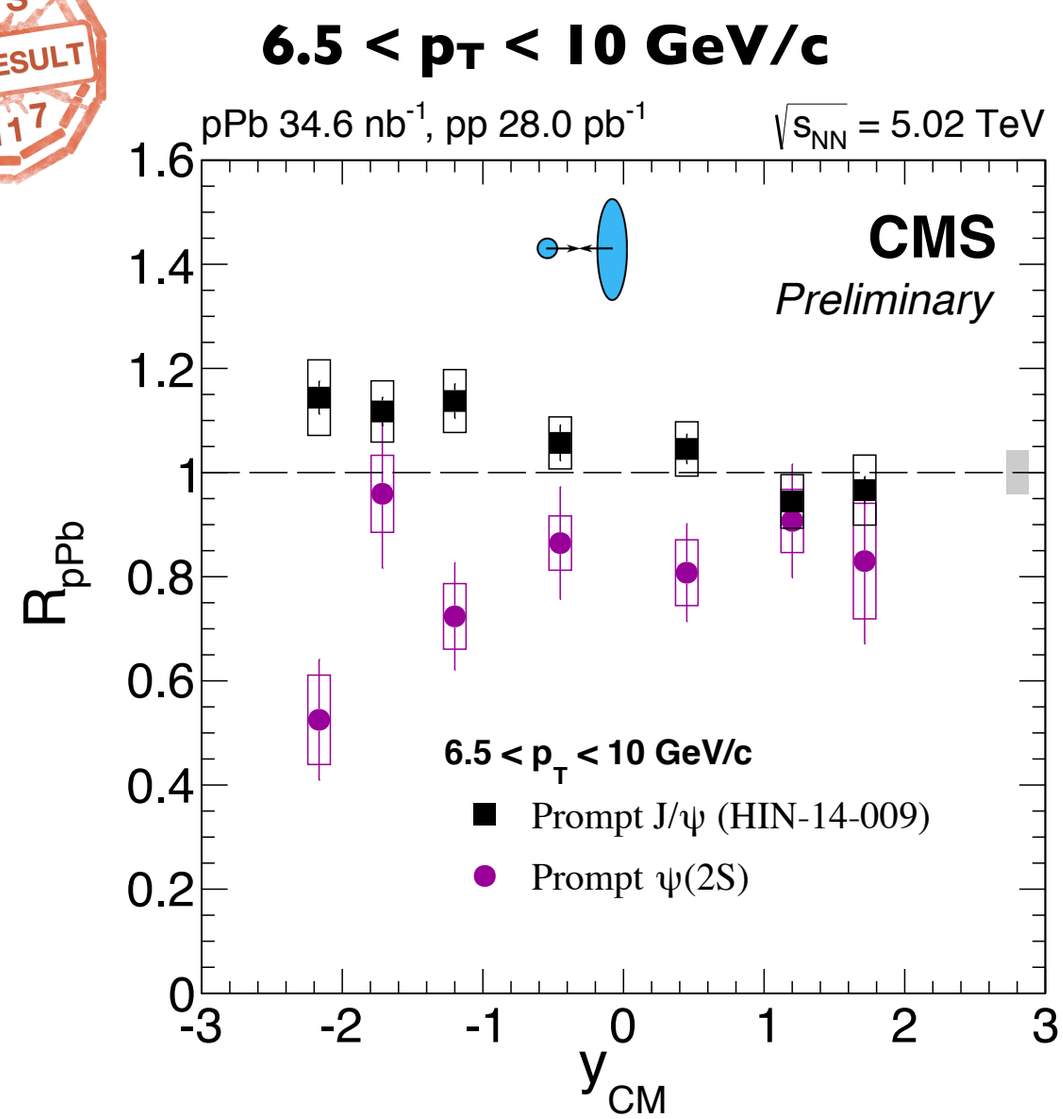
OUTLINE

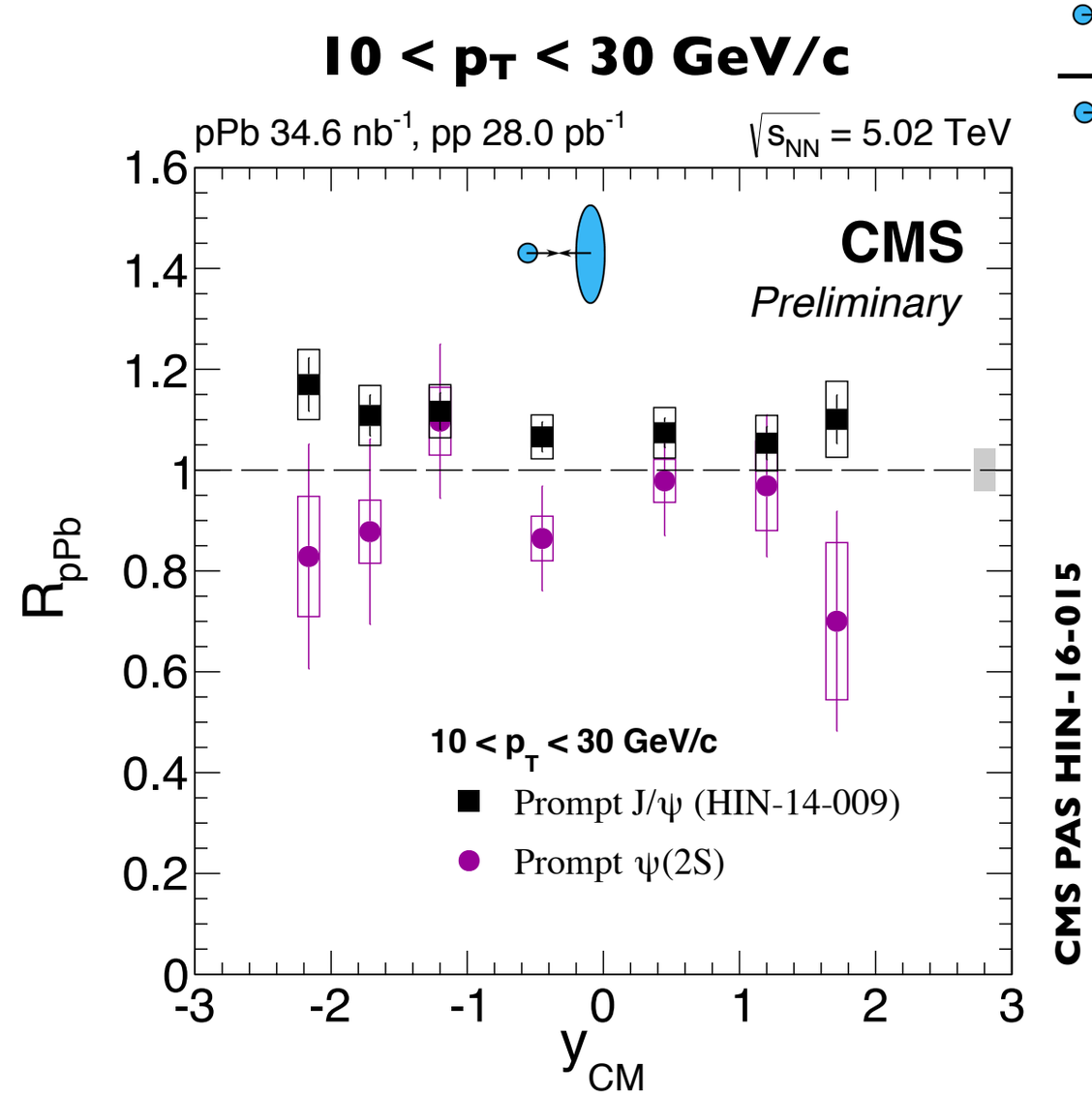
- Prompt J/ψ in pPb at 5 TeV

- **Prompt ψ(2S) in pPb at 5 TeV**

- Relative modification of prompt J/ψ and ψ(2S) from pp to PbPb at 5 TeV

PROMPT ψ(2S) IN pPb





- **Ratio: $R_{pPb}(\psi(2S))/R_{pPb}(J/\psi) < 1$ at backward** (Pb-going direction)
- ψ(2S) suppression stronger at most backward rapidity and lowest p_T
- Indication of final state effect: suppression by interactions with co-moving matter?
  Note: multiplicity does not change much from backward to forward

OUTLINE

- Prompt J/ψ in pPb at 5 TeV

- Prompt ψ(2S) in pPb at 5 TeV

- **Relative modification of prompt J/ψ and ψ(2S) from pp to PbPb at 5 TeV**

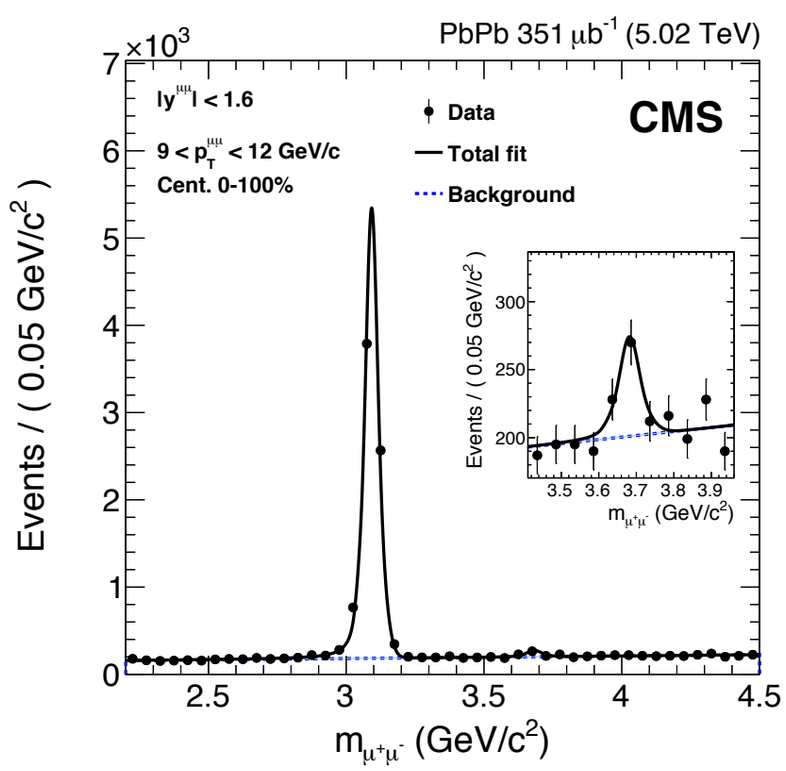
J/ψ AND ψ(2S) MODIFICATION IN PbPb

Double ratio of charmonia in PbPb and pp at 5 TeV:

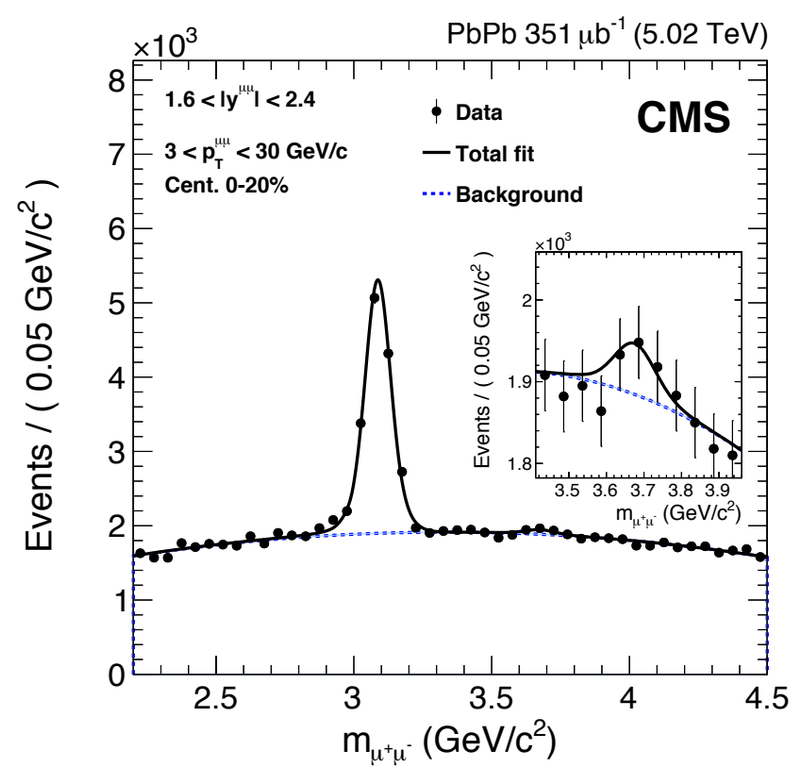
$$\frac{\left[\frac{\psi(2S)}{J/\psi}\right]_{PbPb}}{\left[\frac{\psi(2S)}{J/\psi}\right]_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$

- Many corrections and uncertainties cancel (experimental and theoretical)
- Relative modification of ψ(2S) and J/ψ in PbPb

|y| < 0.9 ; 9 < p_T < 12 GeV/c
Cent: 0-100%

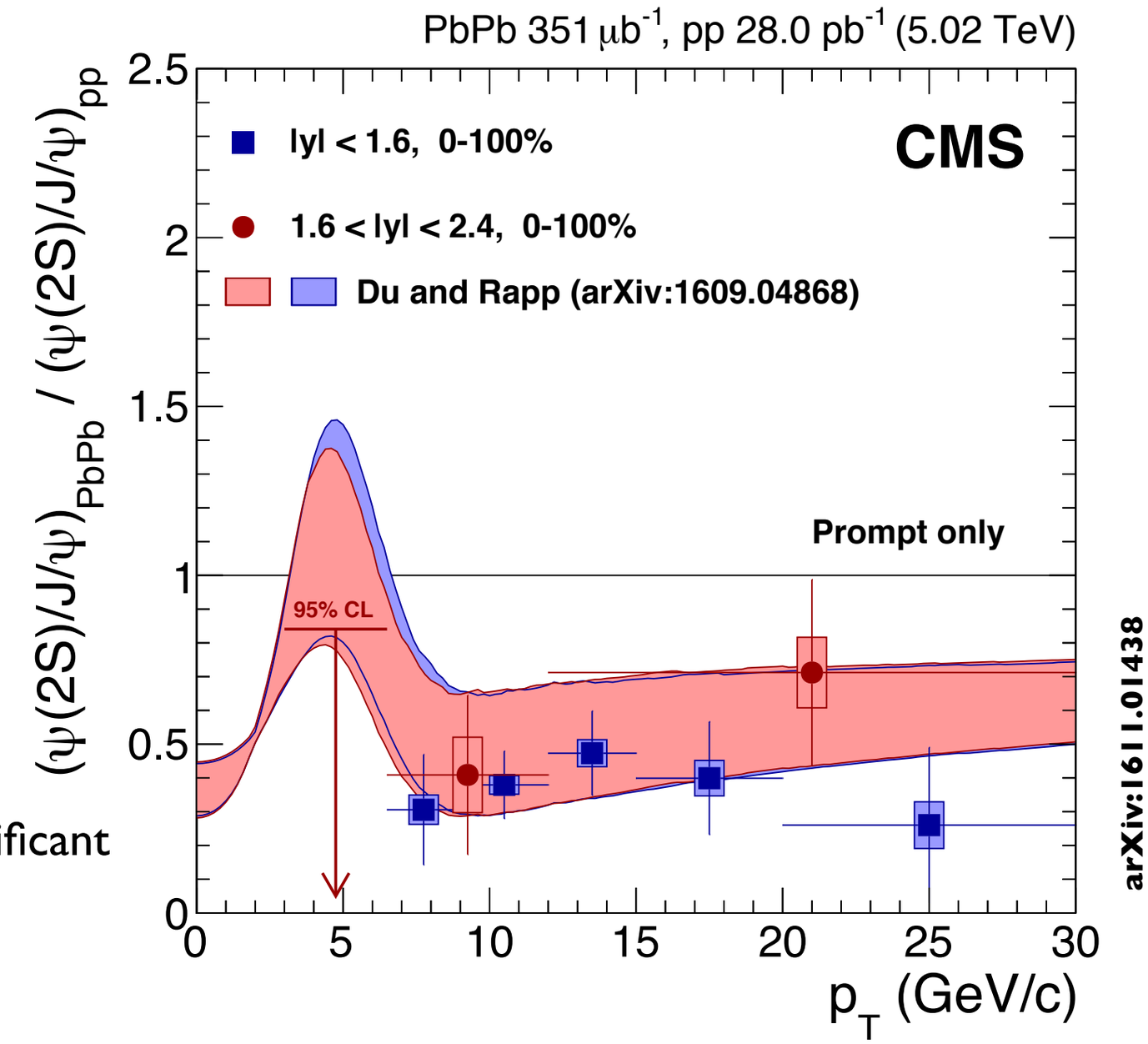


1.6 < |y| < 2.4 ; 3 < p_T < 30 GeV/c
Cent: 0-20%



arXiv:1611.01438

ψ(2S) /J/ψ vs p_T



95% CL where no significant ψ(2S) signal in PbPb

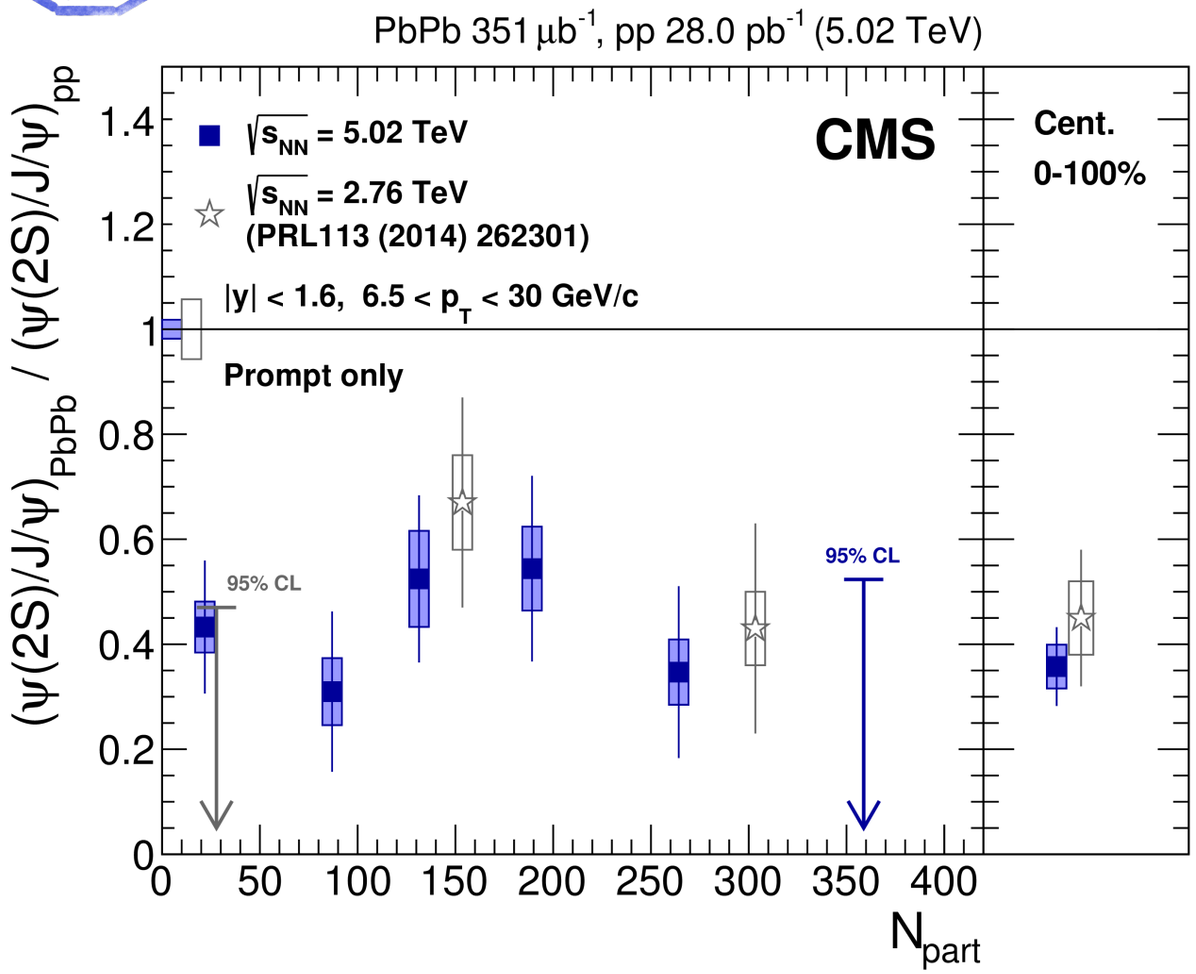
- $R_{AA}(\psi(2S))/R_{AA}(J/\psi) < 1$ in all bins → **ψ(2S) is more suppressed than J/ψ**
- No p_T dependence within uncertainties
- X. Du and R. Rapp: transport model with temperature dependent reaction rates

  → ψ(2S) regenerated later than J/ψ in the fireball evolution?

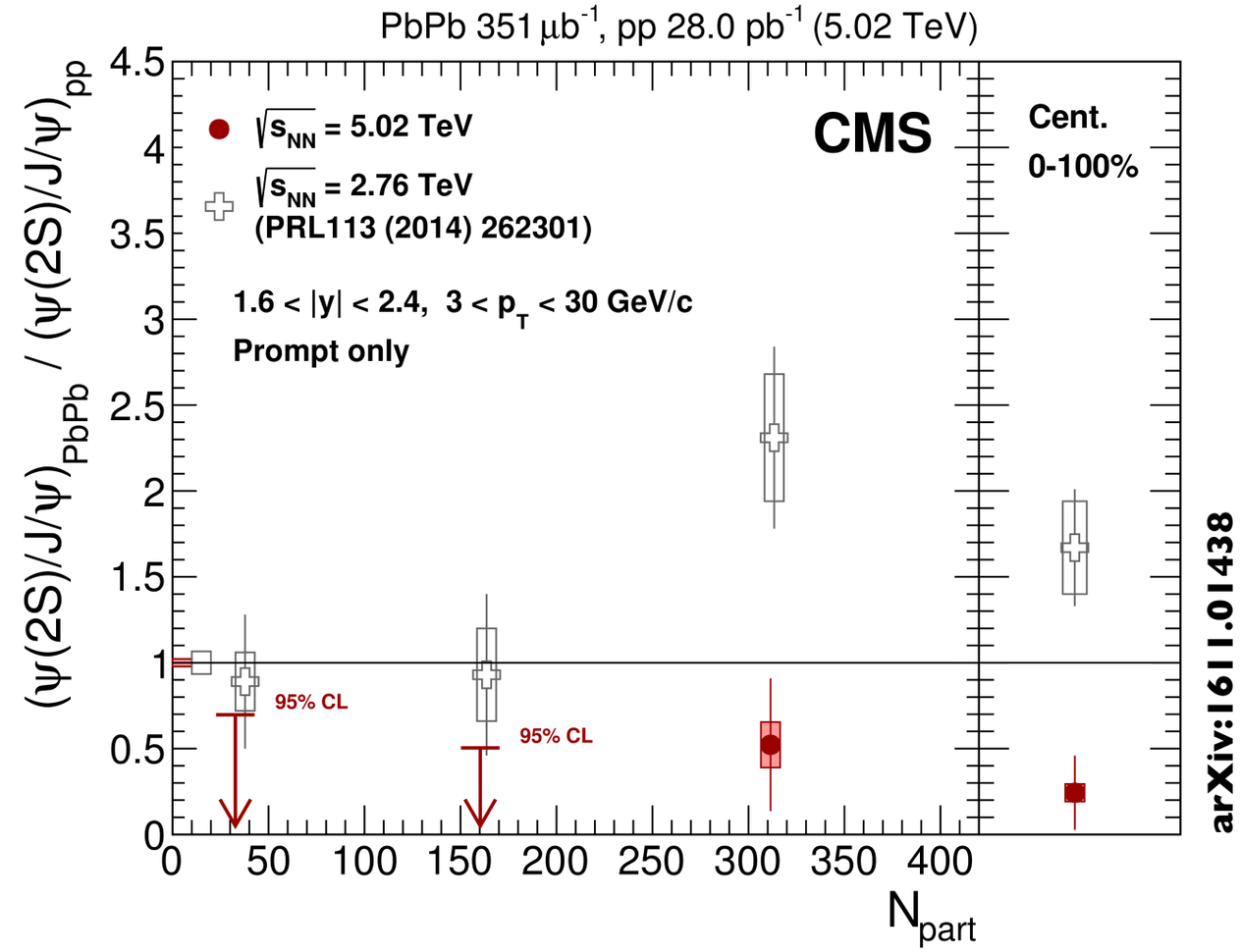
ψ(2S) /J/ψ vs CENTRALITY

2.76 vs. 5.02 TeV

|y| < 1.6 ; 6.5 < p_T < 10 GeV/c



1.2 < |y| < 2.4 ;3 < p_T < 30 GeV/c



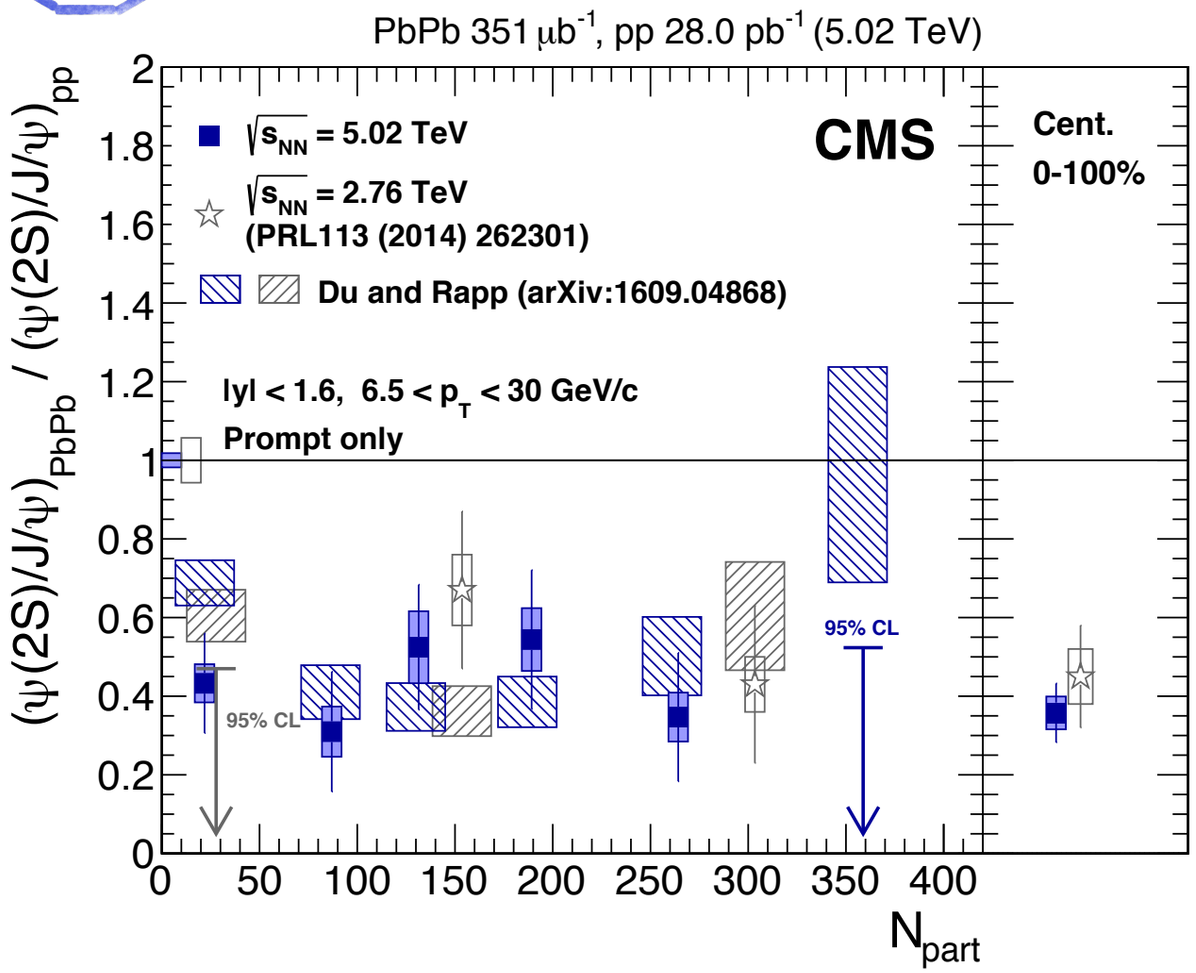
arXiv:1611.01438

- **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 < 10 GeV/c



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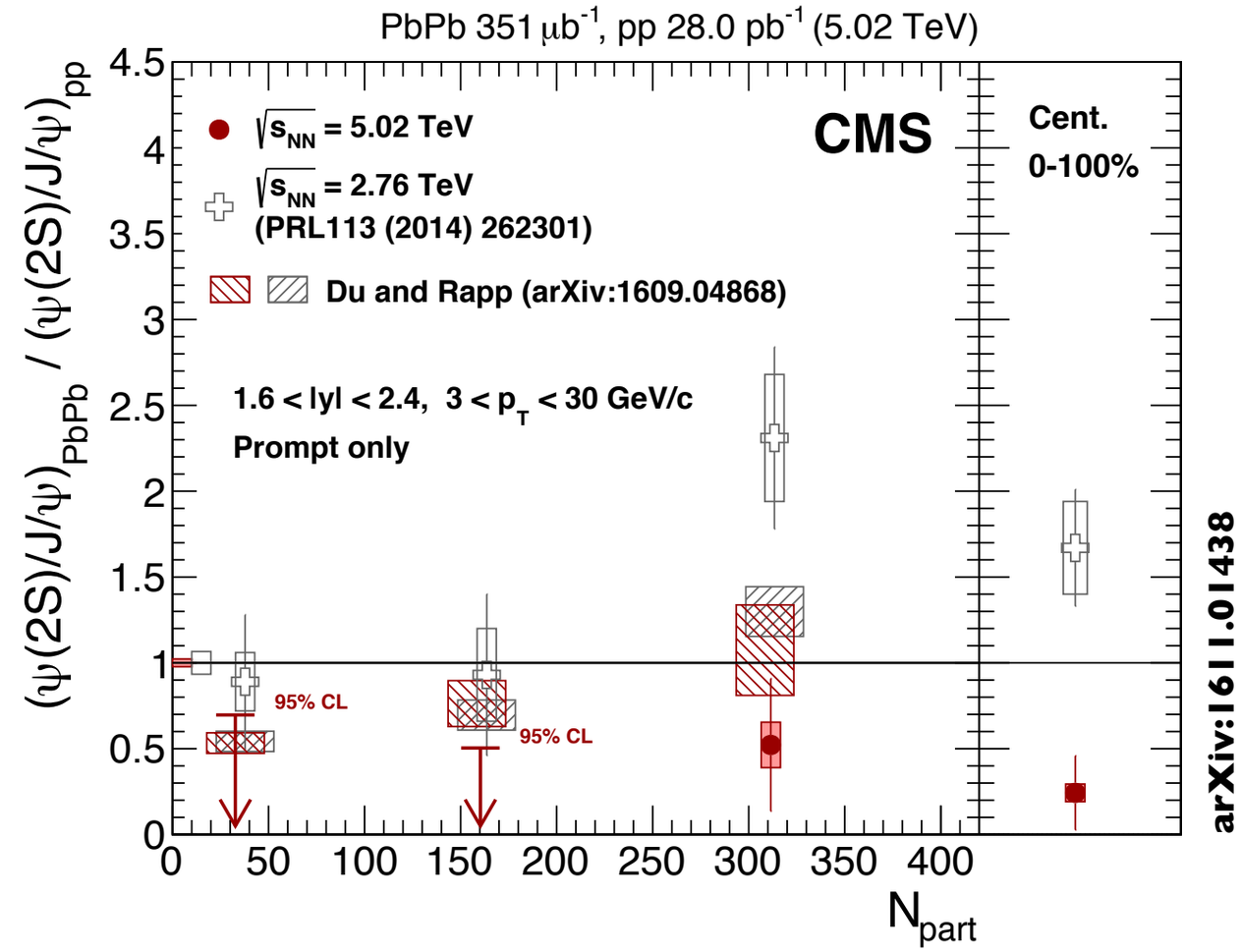


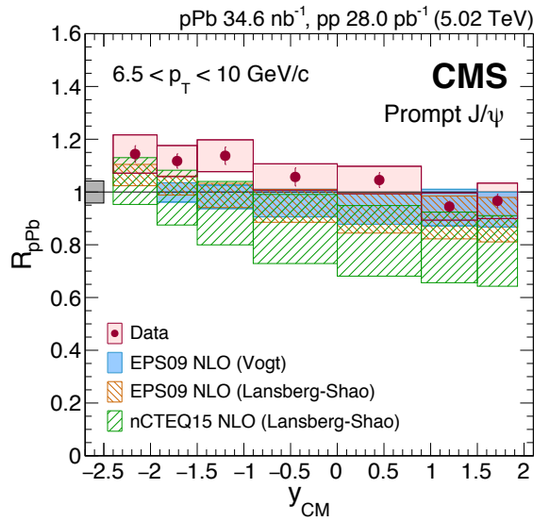
CMS results vs centrality, p_T and rapidity can help to constrain the model:

- Relative contribution of primordial and regenerated charmonia
- Dissociation and regeneration rates
- Temperatures at which J/ψ and ψ(2S) regenerate
- …

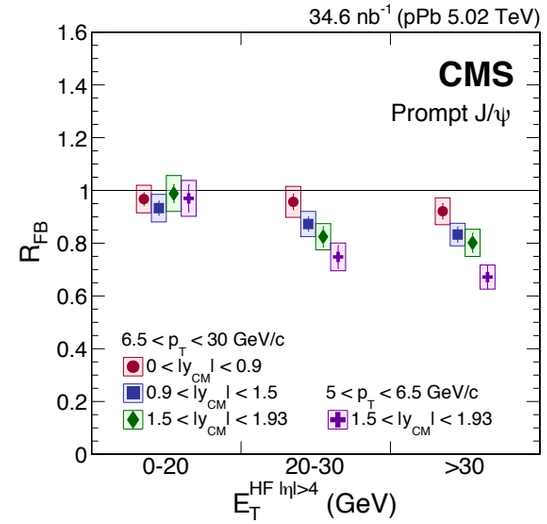
SUMMARY

Probing Cold Nuclear Matter effects:

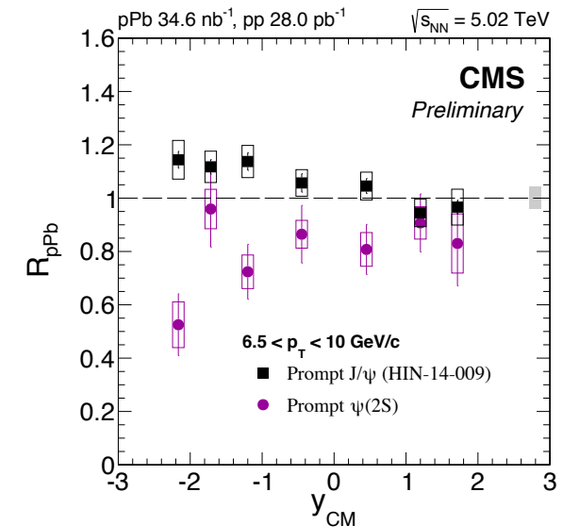
Less strong effects than in PbPb in the kinematical ranges studied by CMS



No strong p_T or y_{CM} dependence



Nuclear effects increase with event activity



Effects beyond CNM (final state) affecting ψ(2S)?

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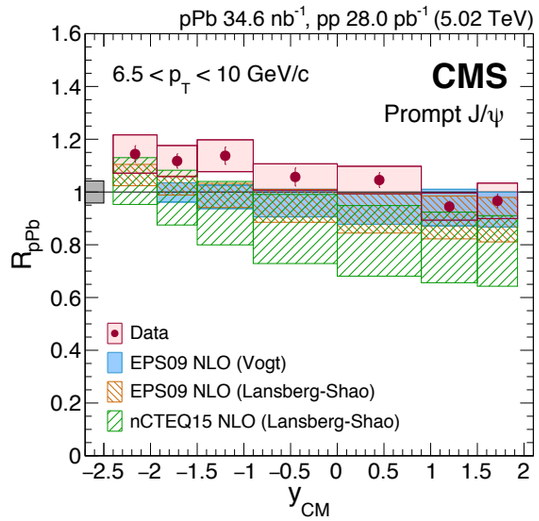

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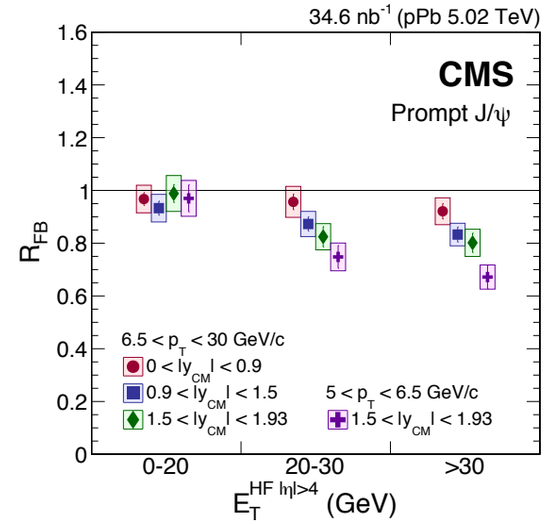

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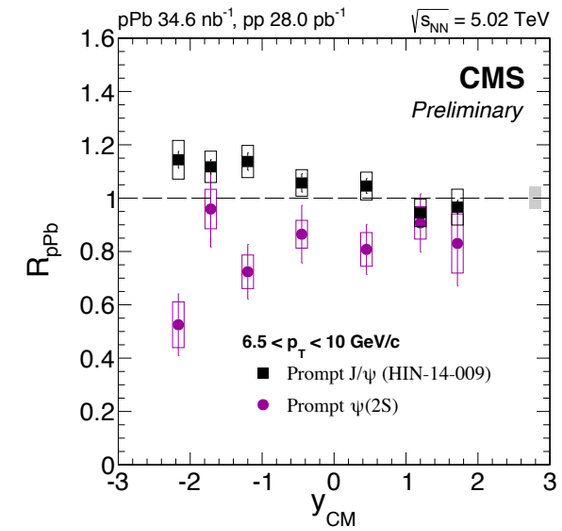
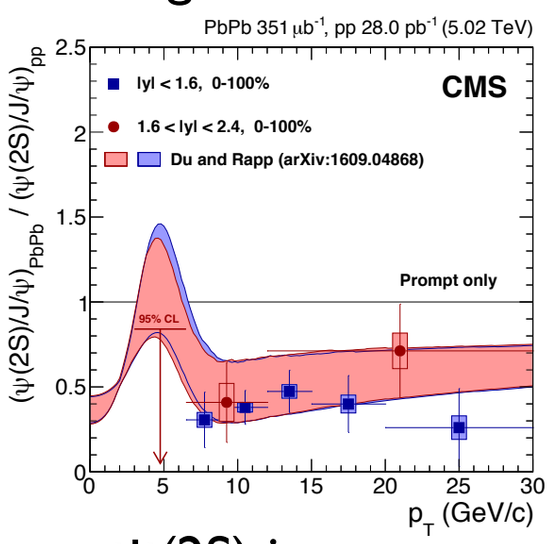


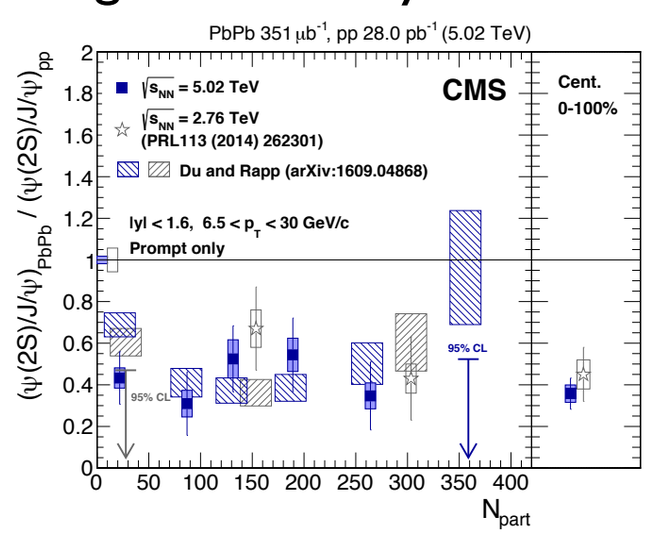
Effects beyond CNM (final state) affecting ψ(2S)?

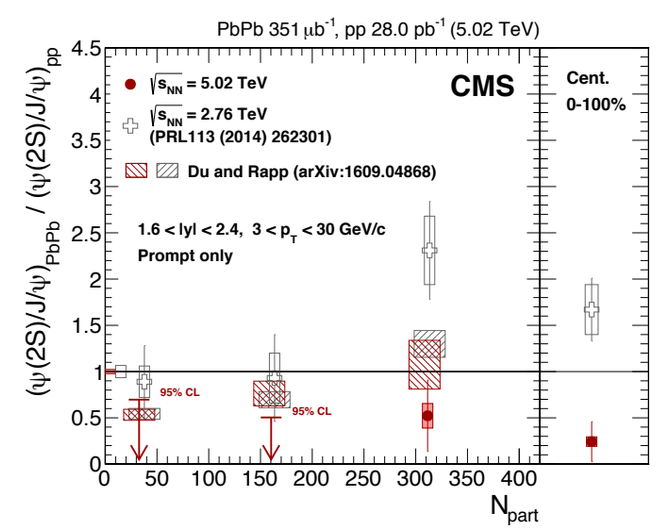
Probing QGP effects:

Strong effects in the kinematical ranges studied by CMS



ψ(2S) is more suppressed than J/ψ



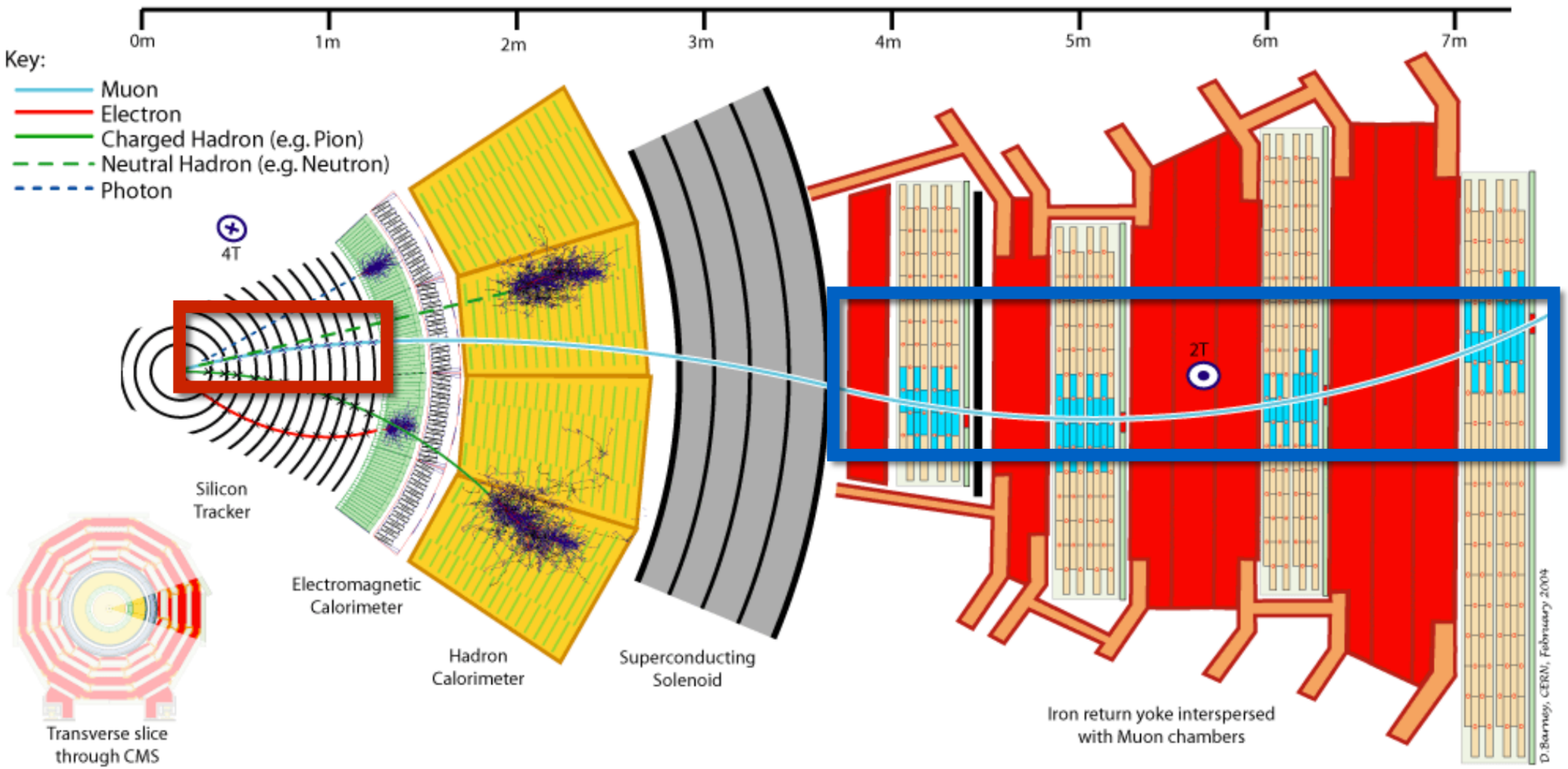


ψ(2S) regenerated later than J/ψ in the fireball evolution?
Results help to constrain model ingredients

THANK YOU FOR YOUR ATTENTION

BACKUP

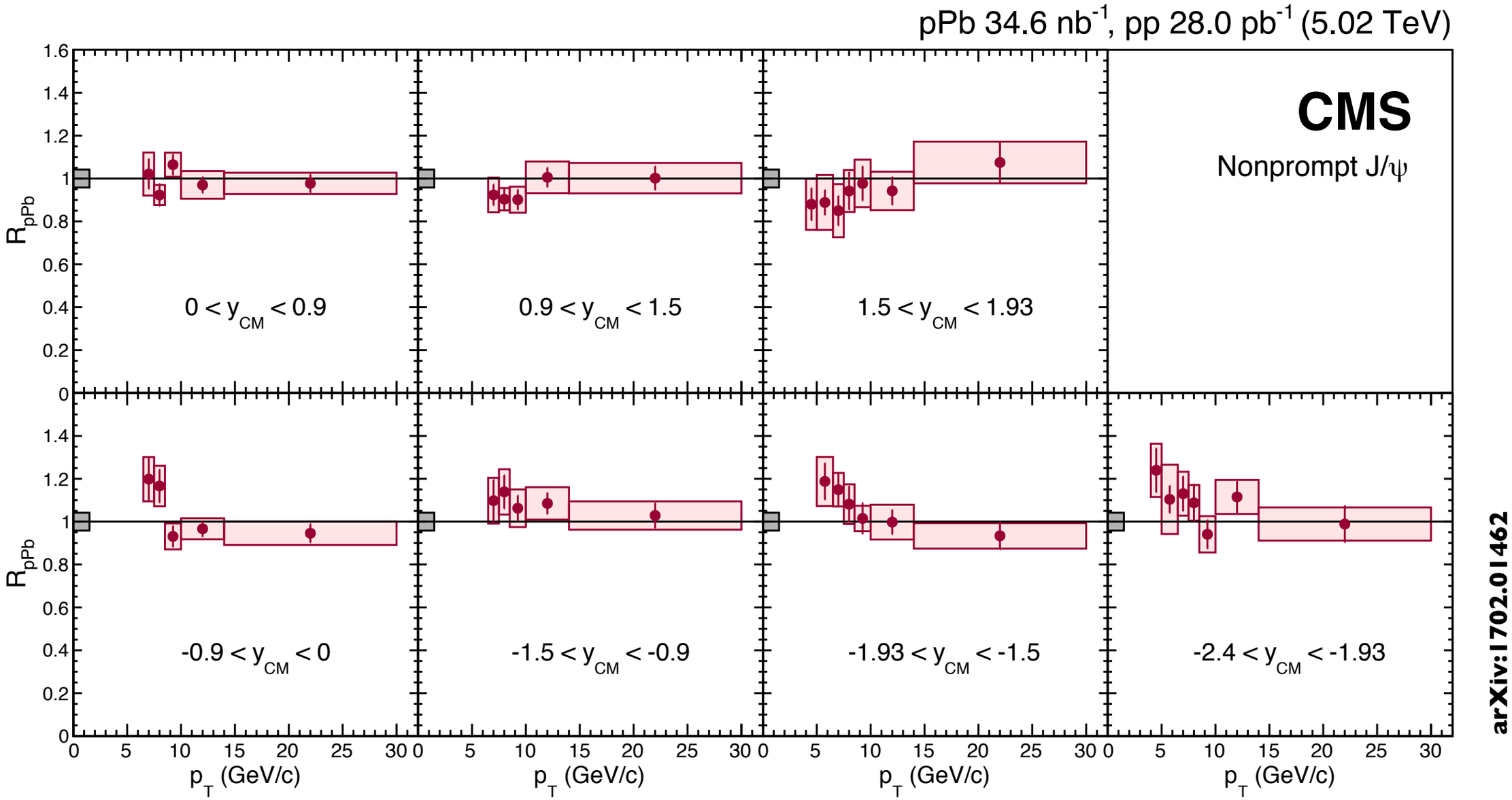
CMS DETECTOR



Muon acceptance: $|\eta| < 2.4$

J/ψ IN pPb

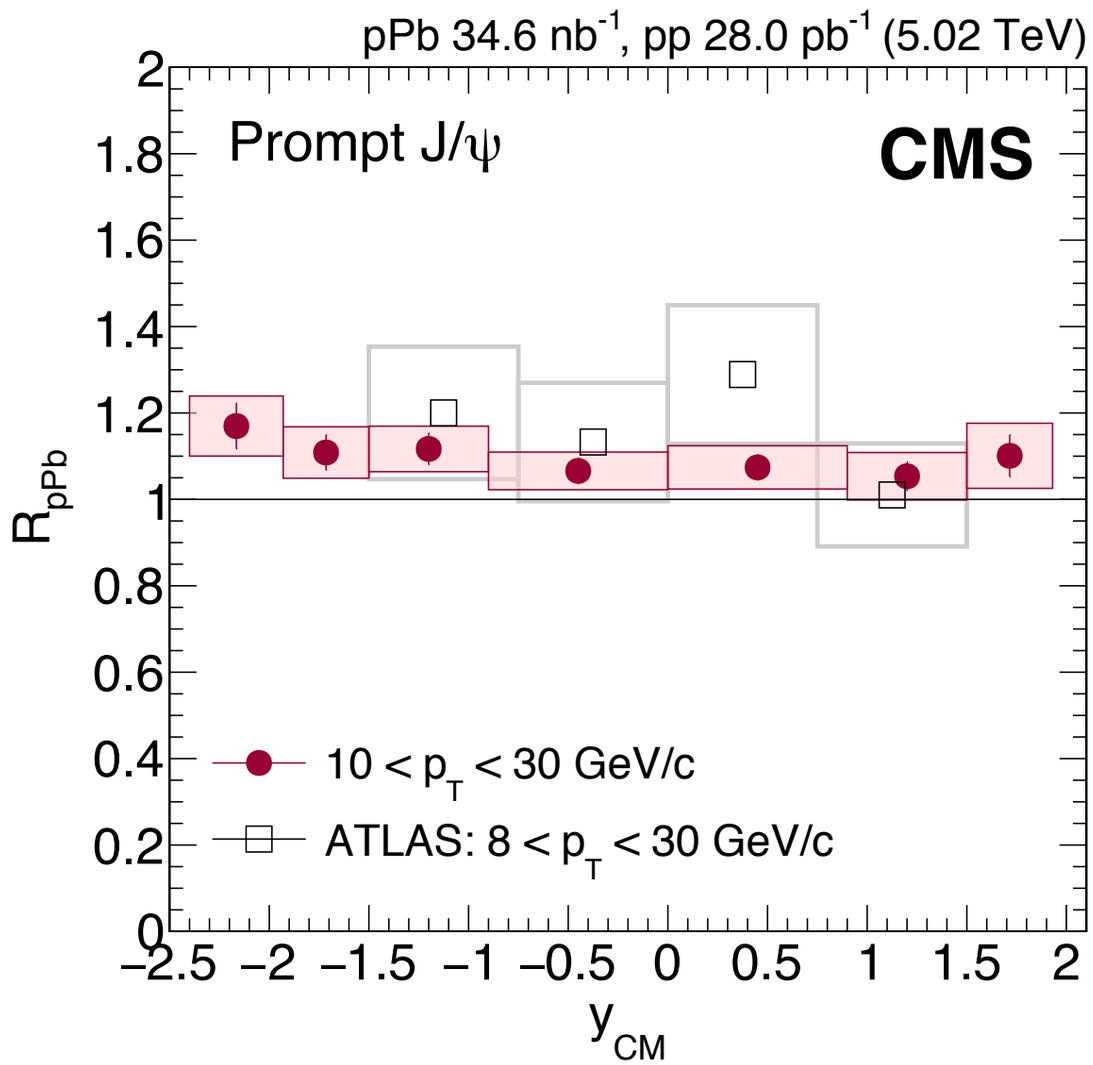
Nonprompt

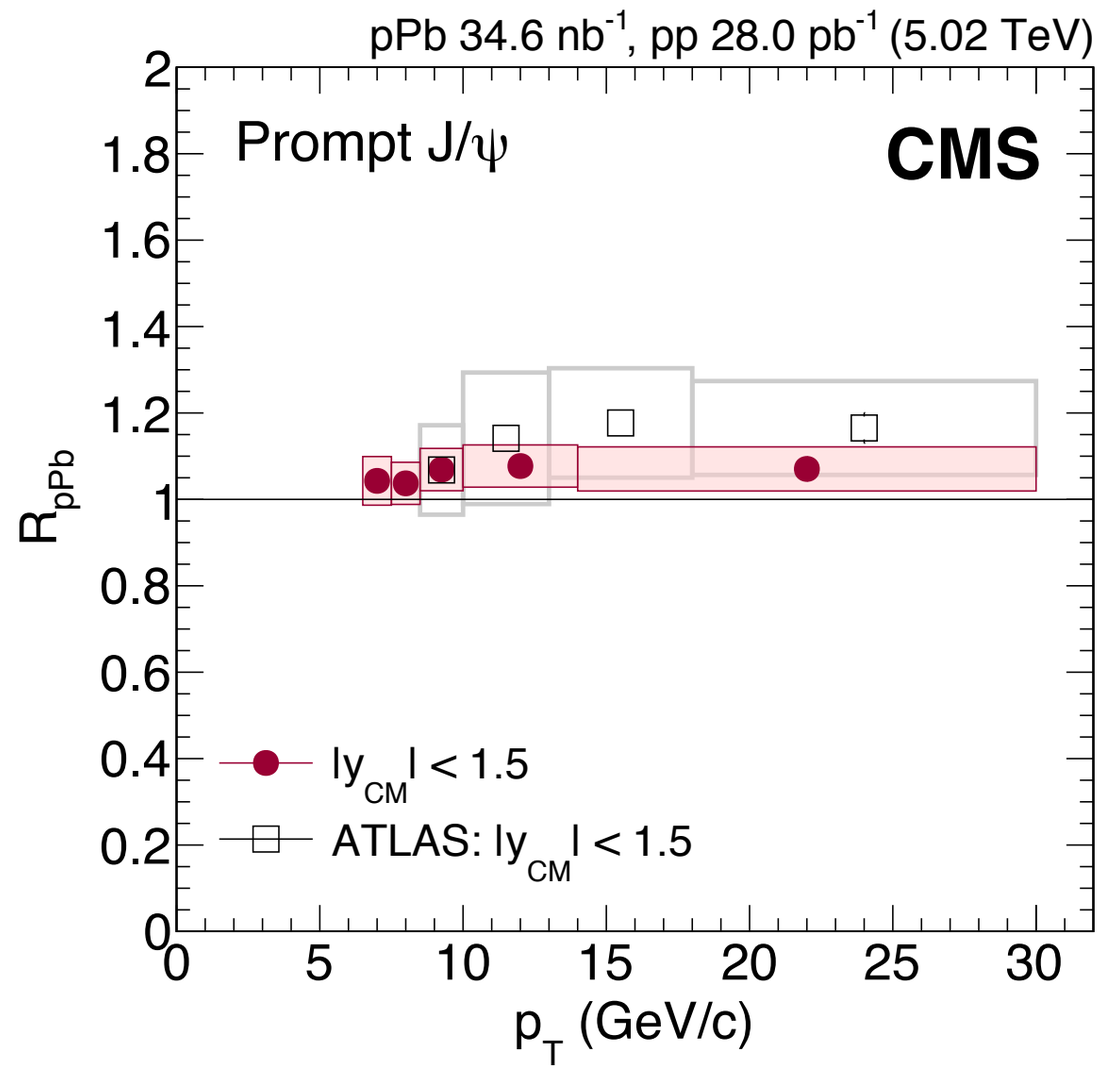


arXiv:1702.01462

J/ψ IN pPb

Prompt





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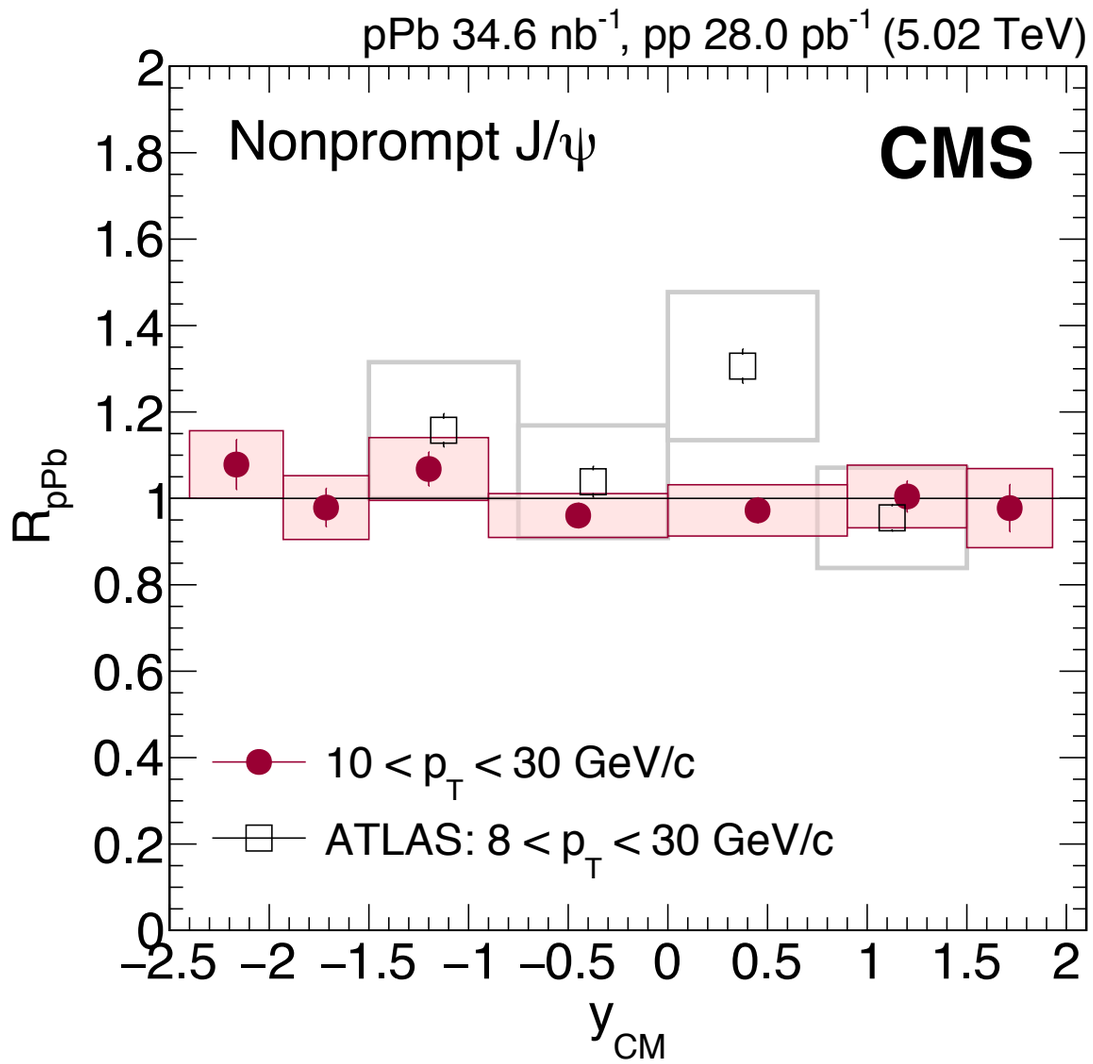
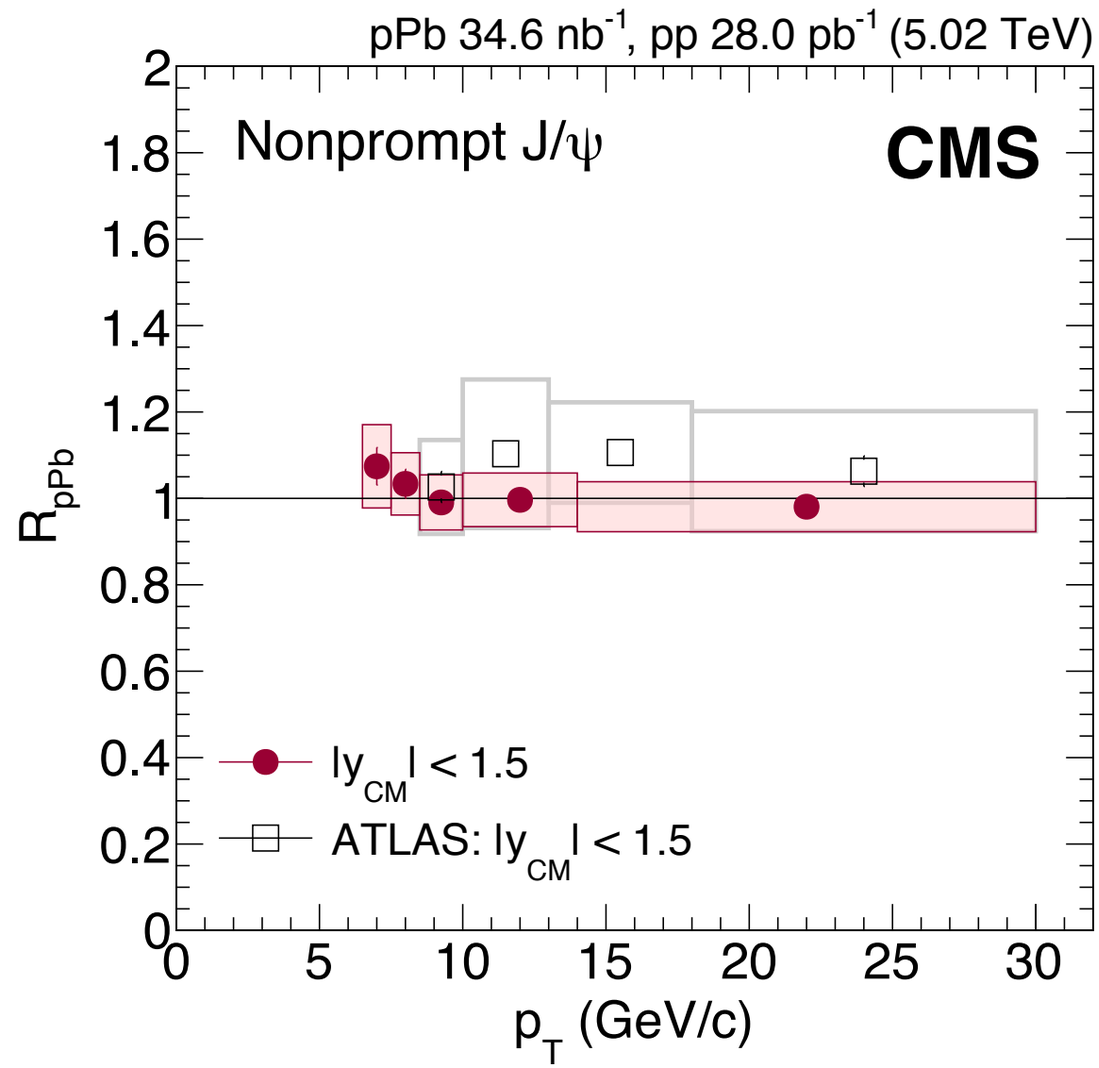
J/ψ IN pPb

Nonprompt





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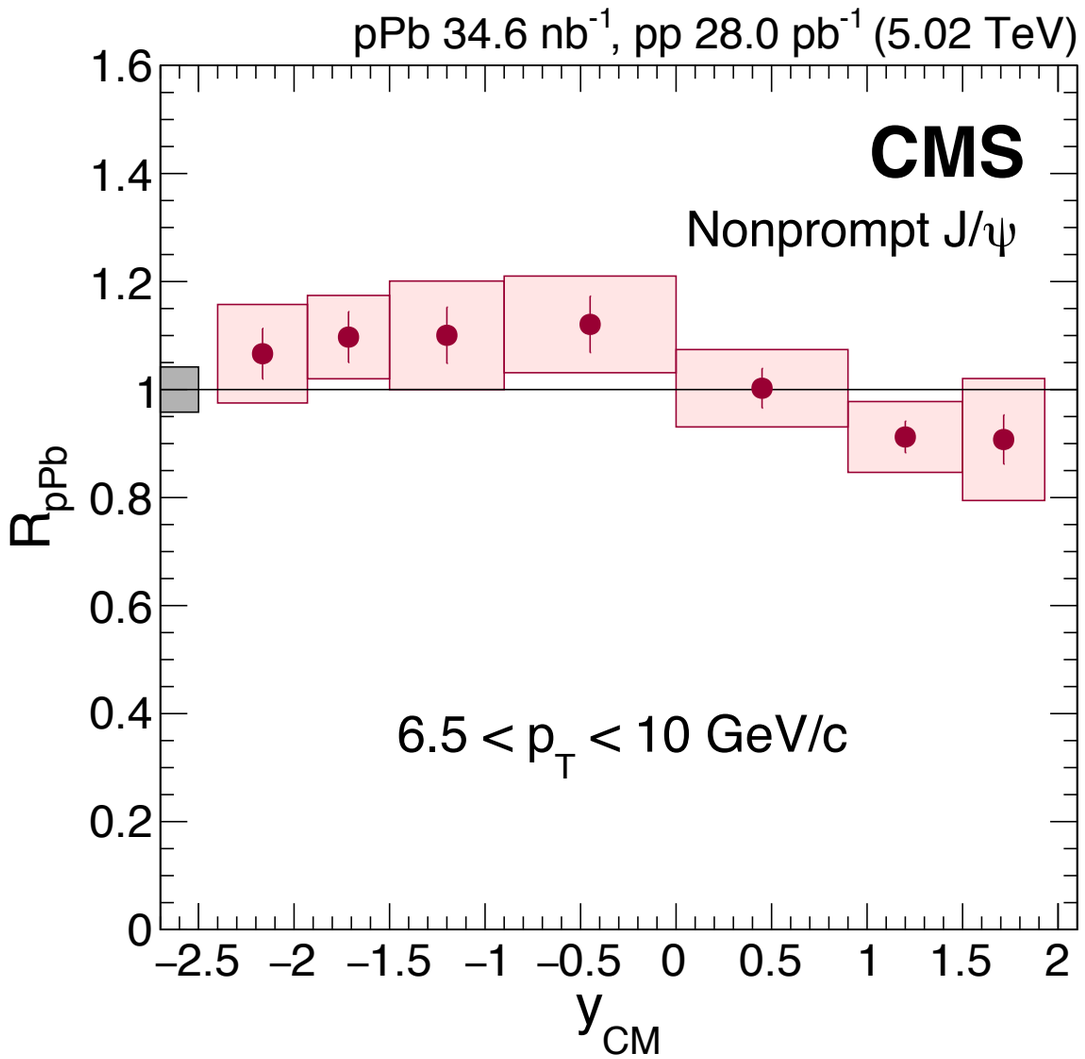
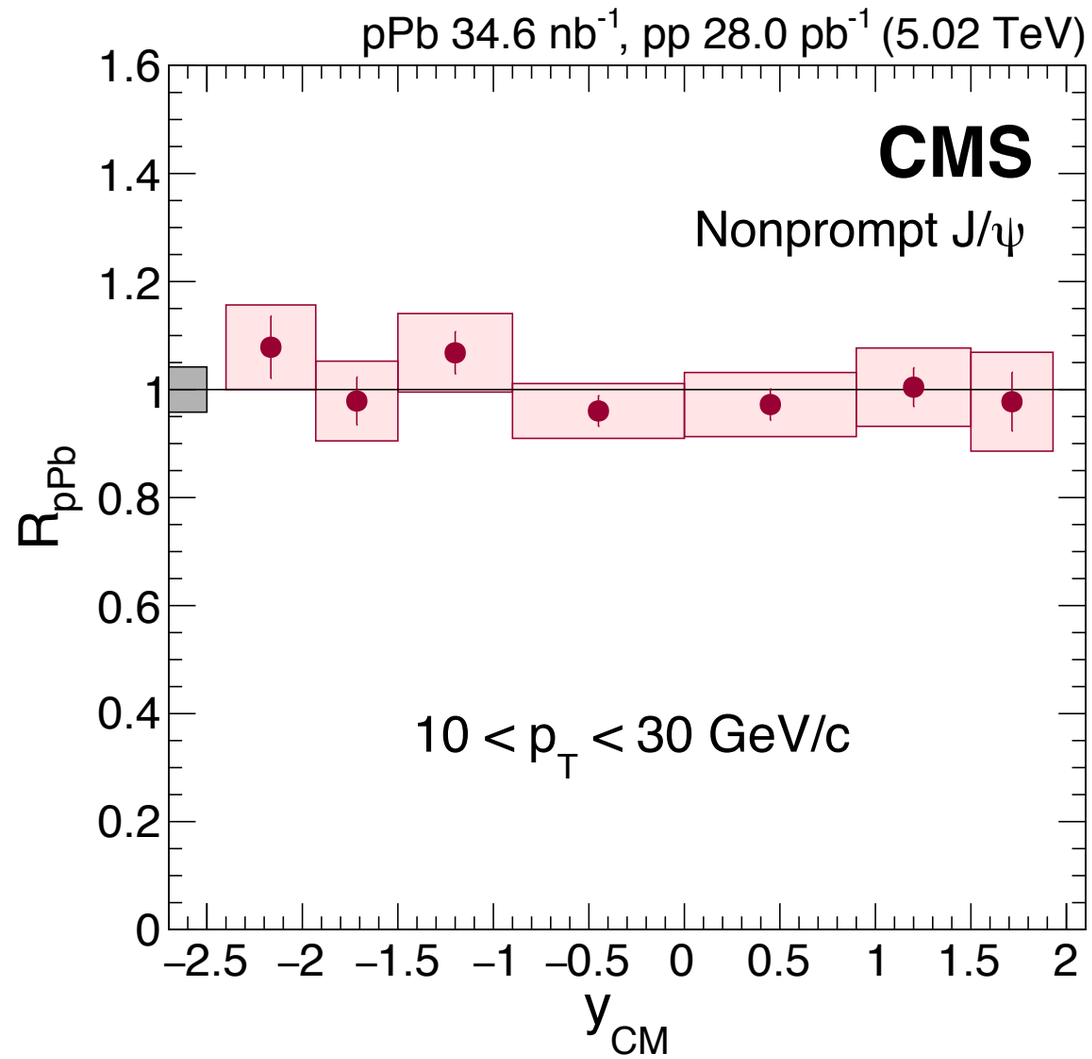
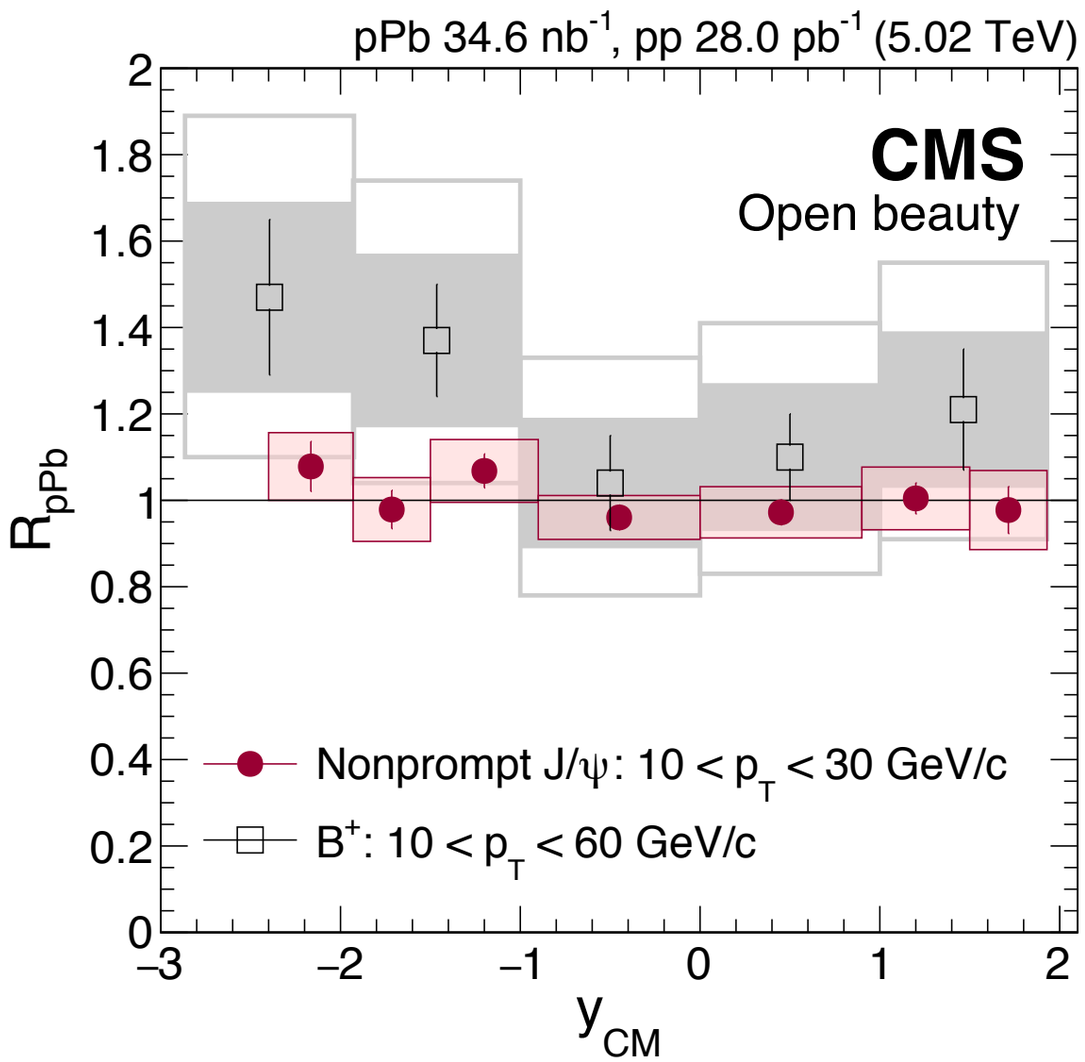
Nonprompt

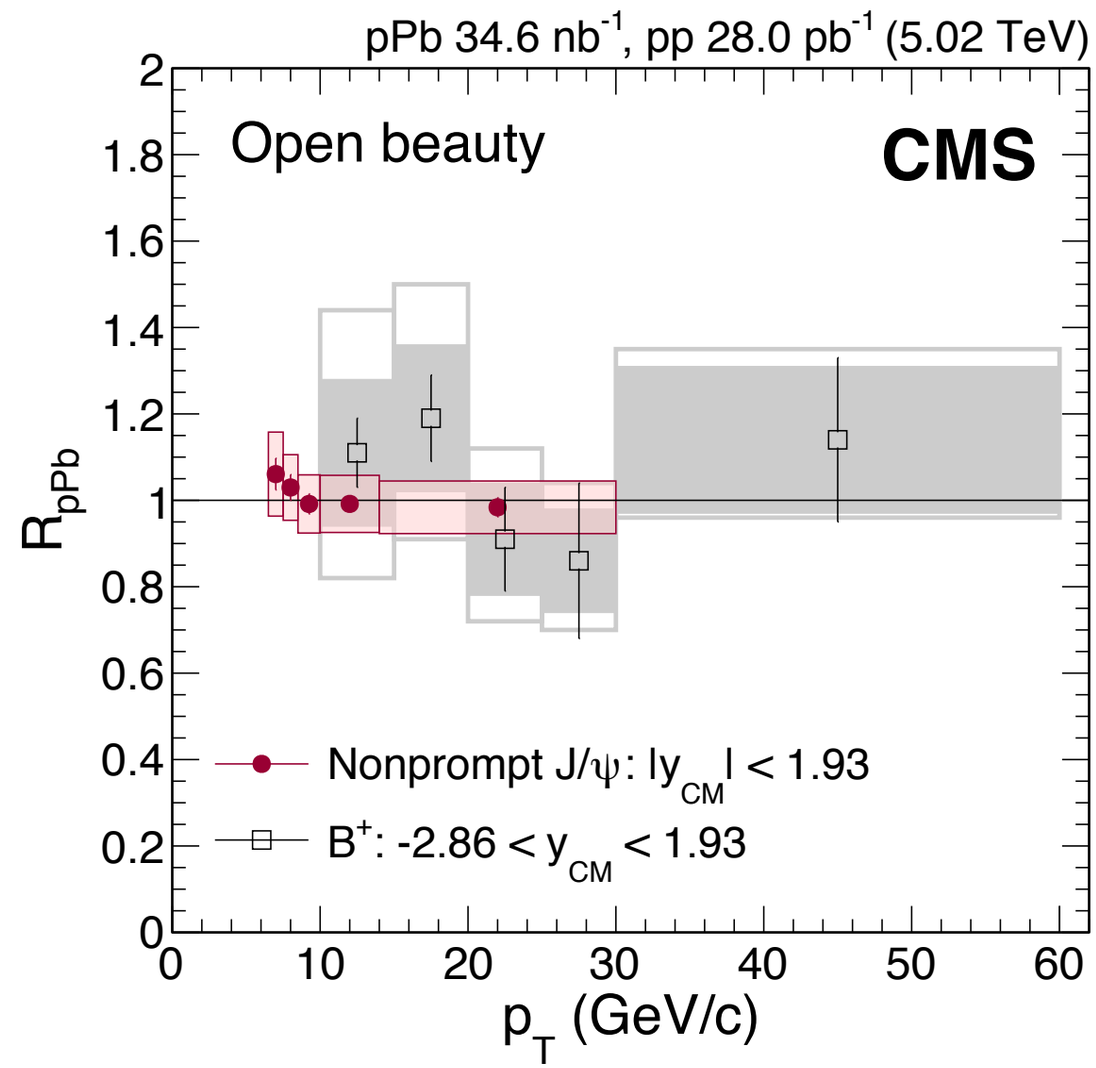




arXiv:1702.01462

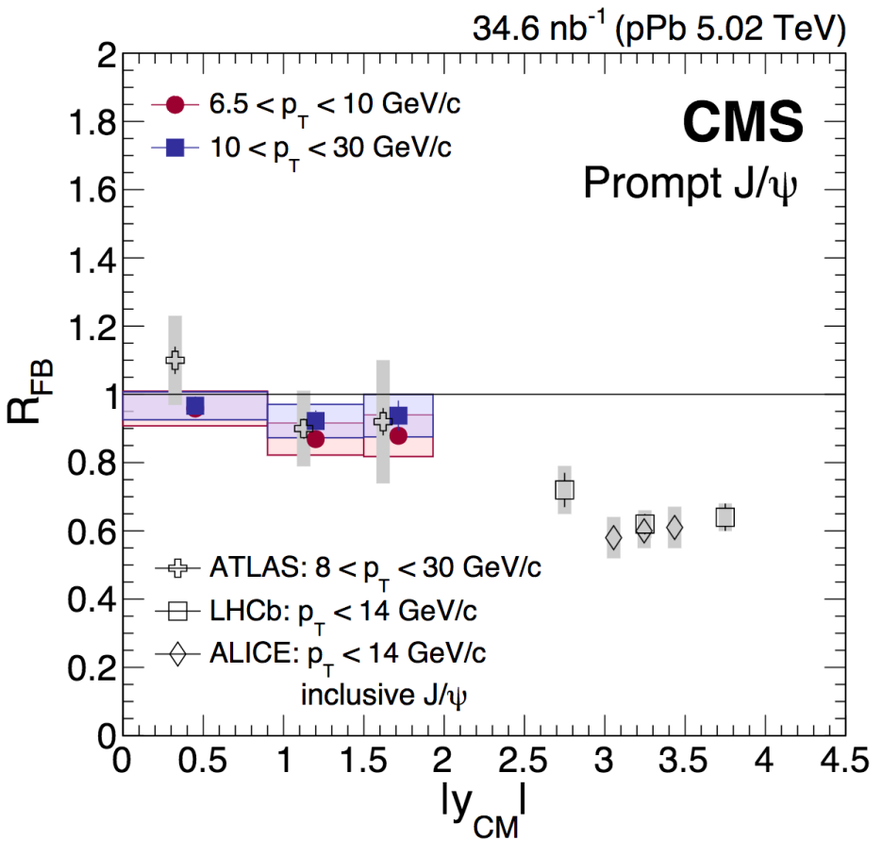
J/ψ IN pPb

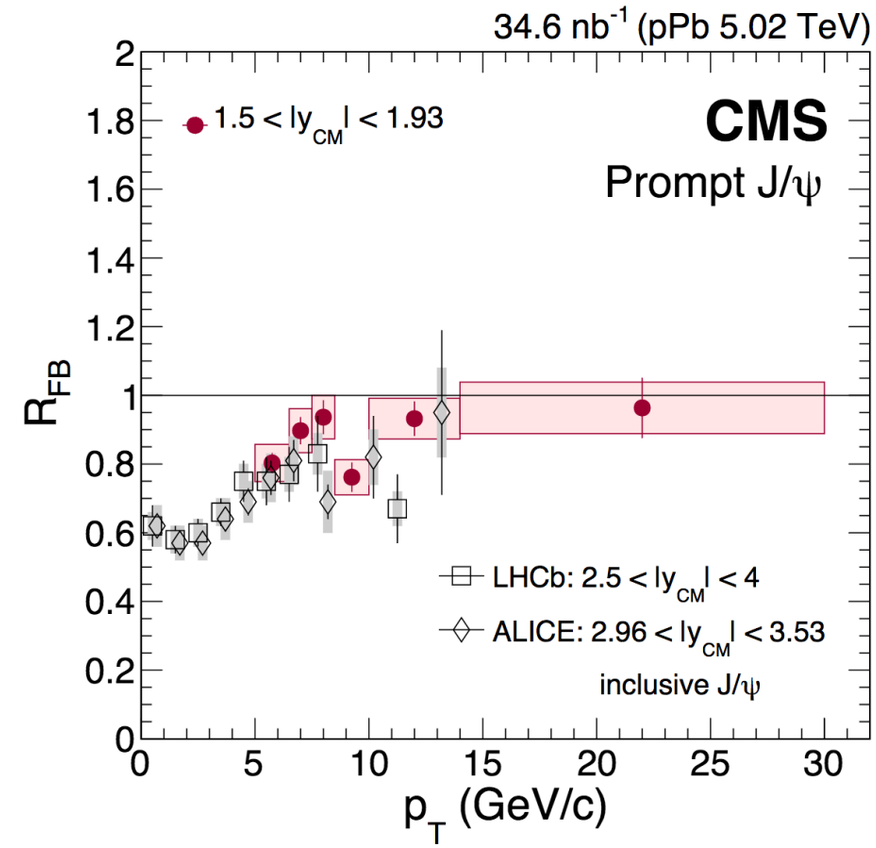




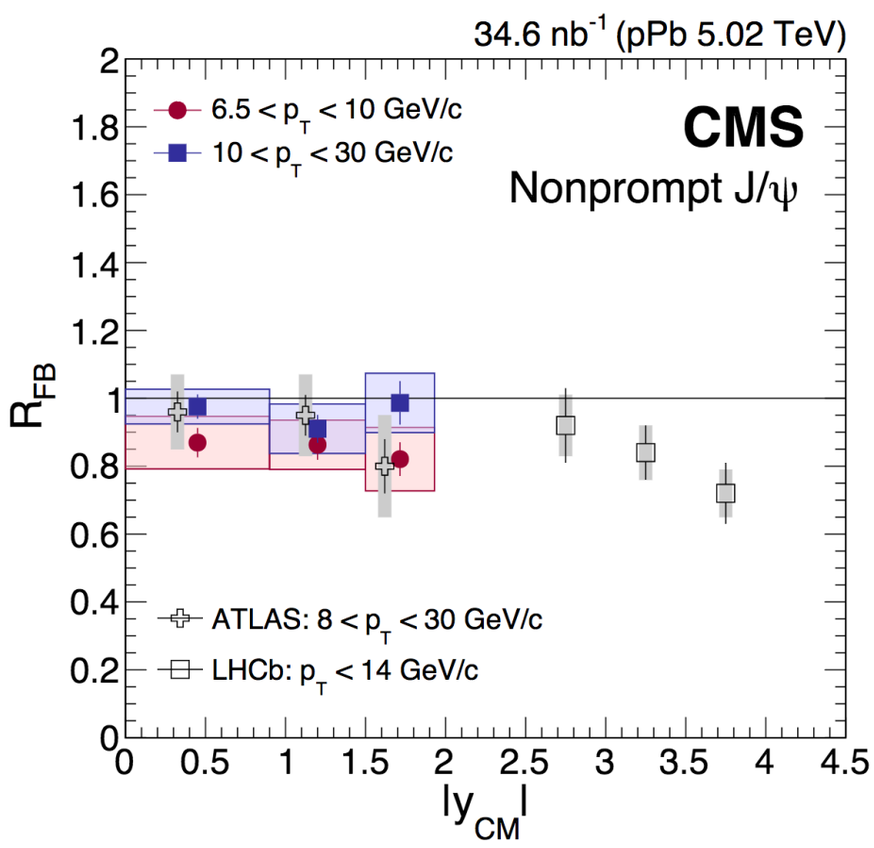
arXiv:1702.01462

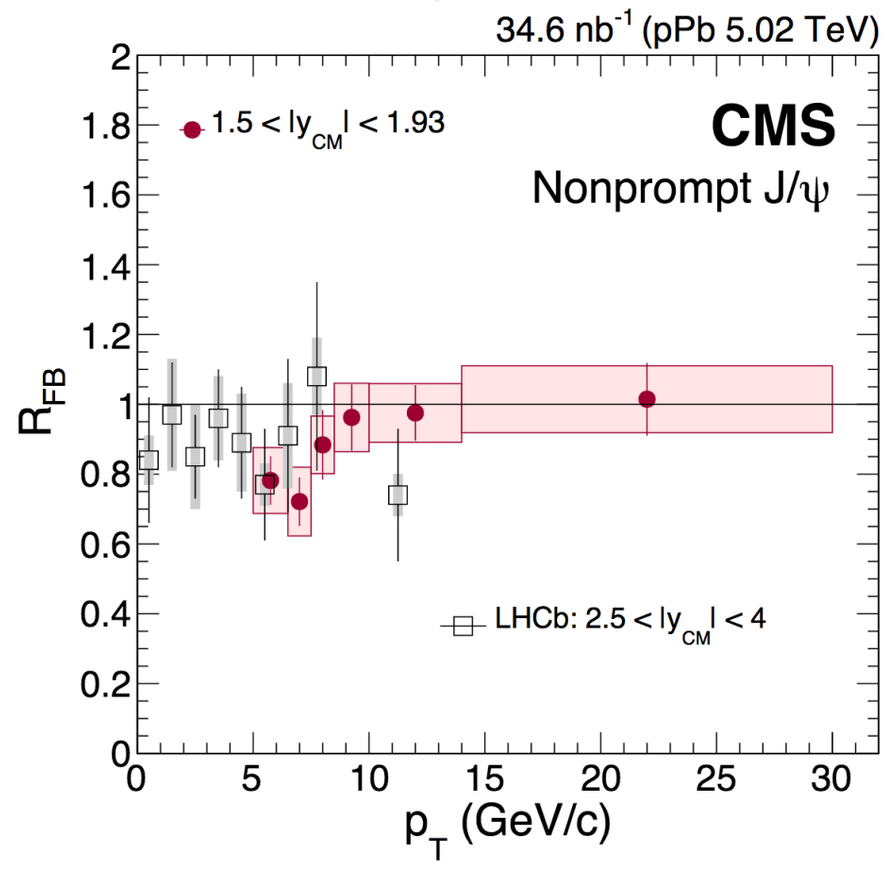
J/ψ IN pPb





Prompt

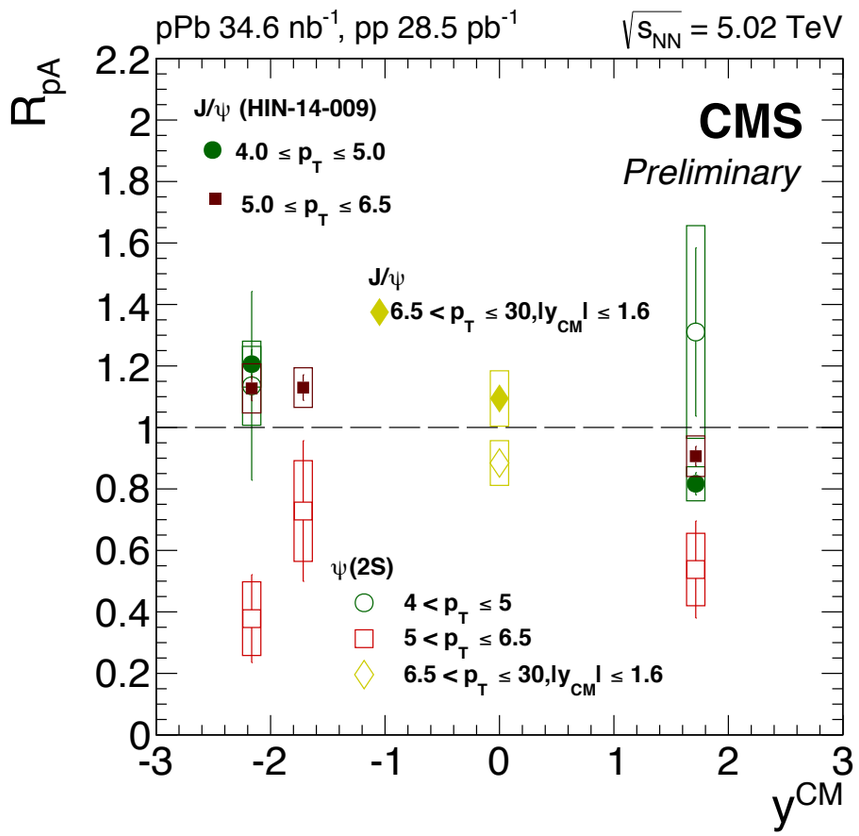


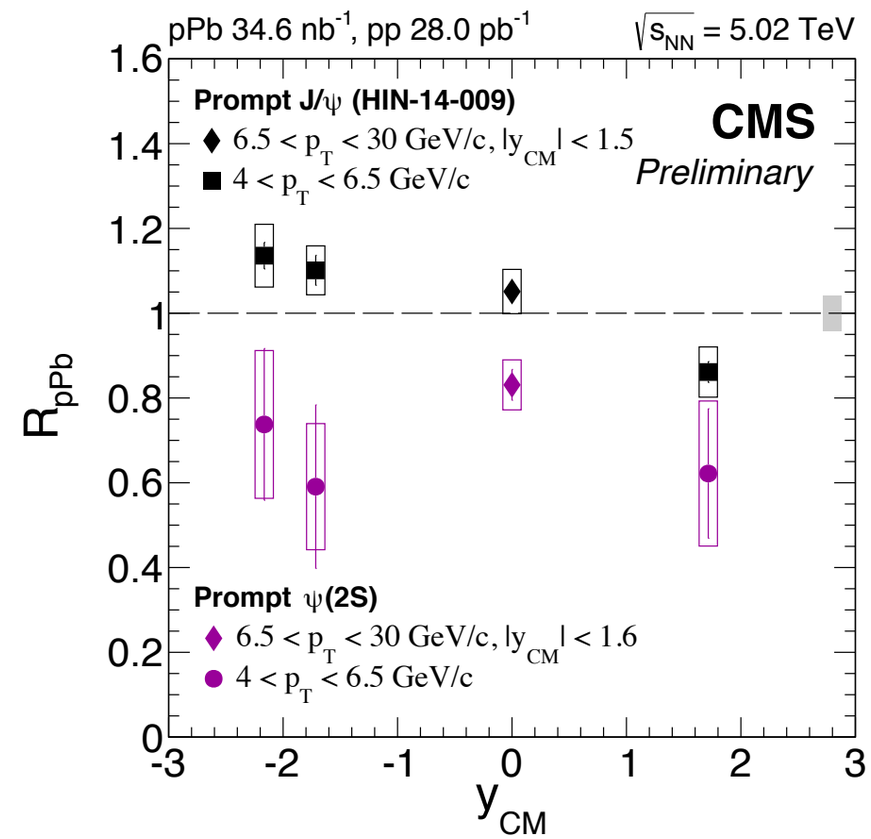


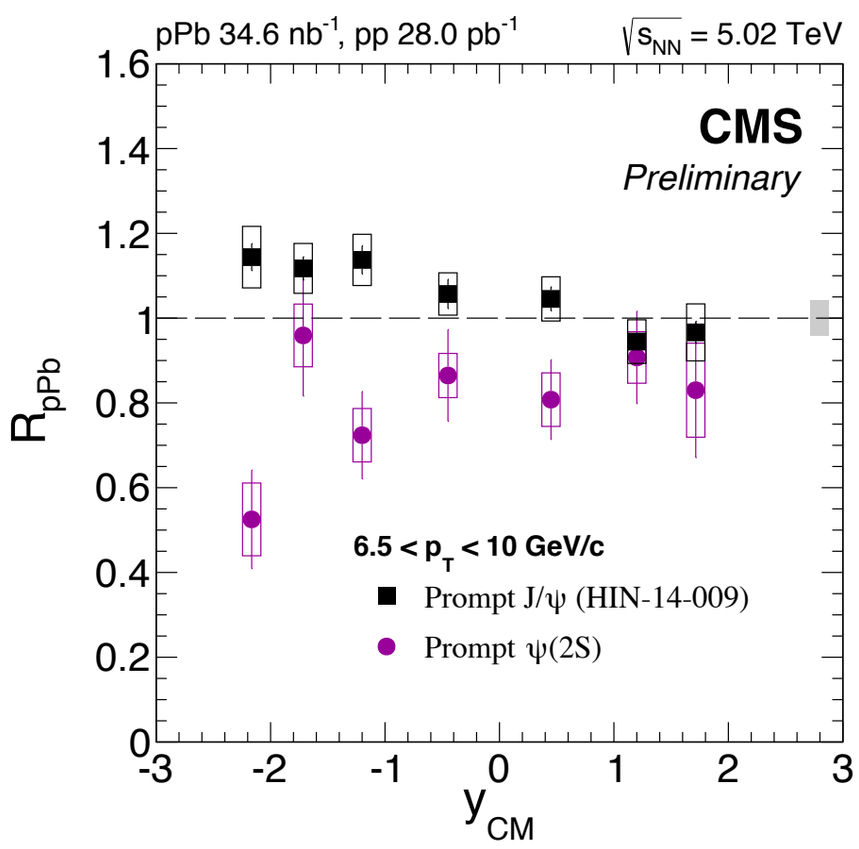
Nonprompt

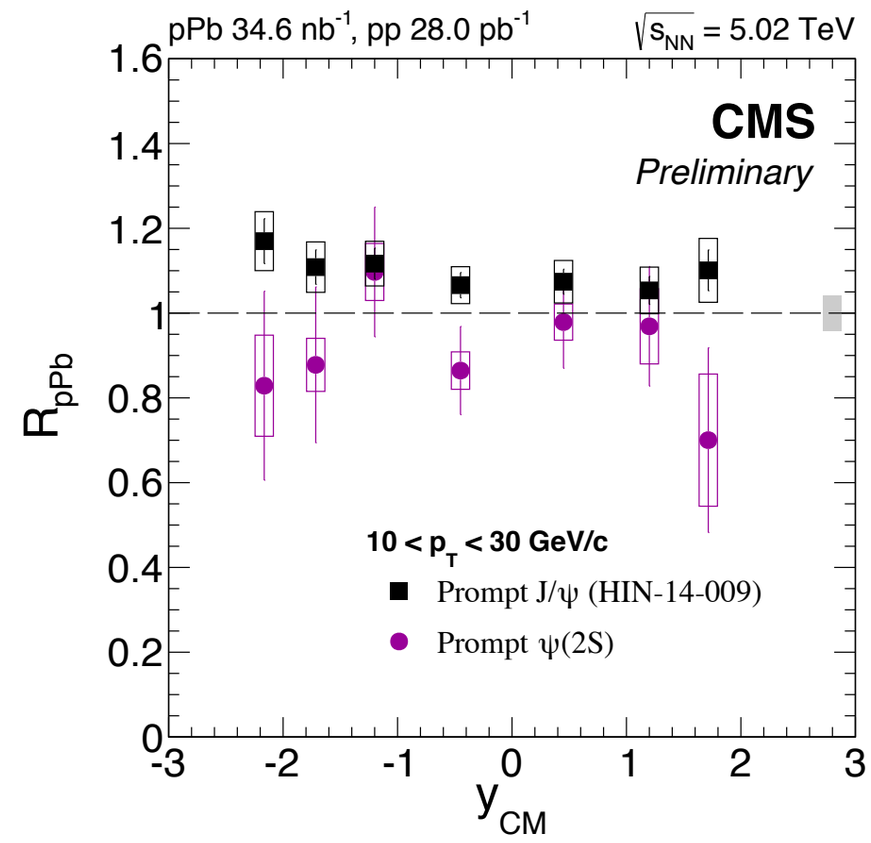
arXiv:1702.01462

ψ(2S) IN pPb



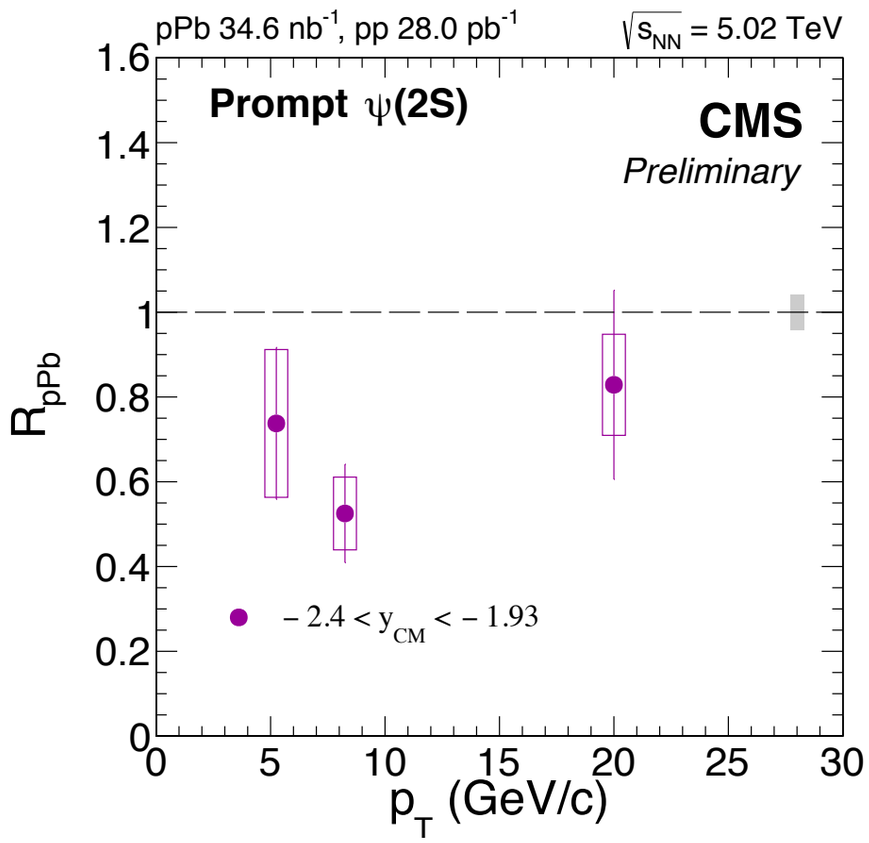


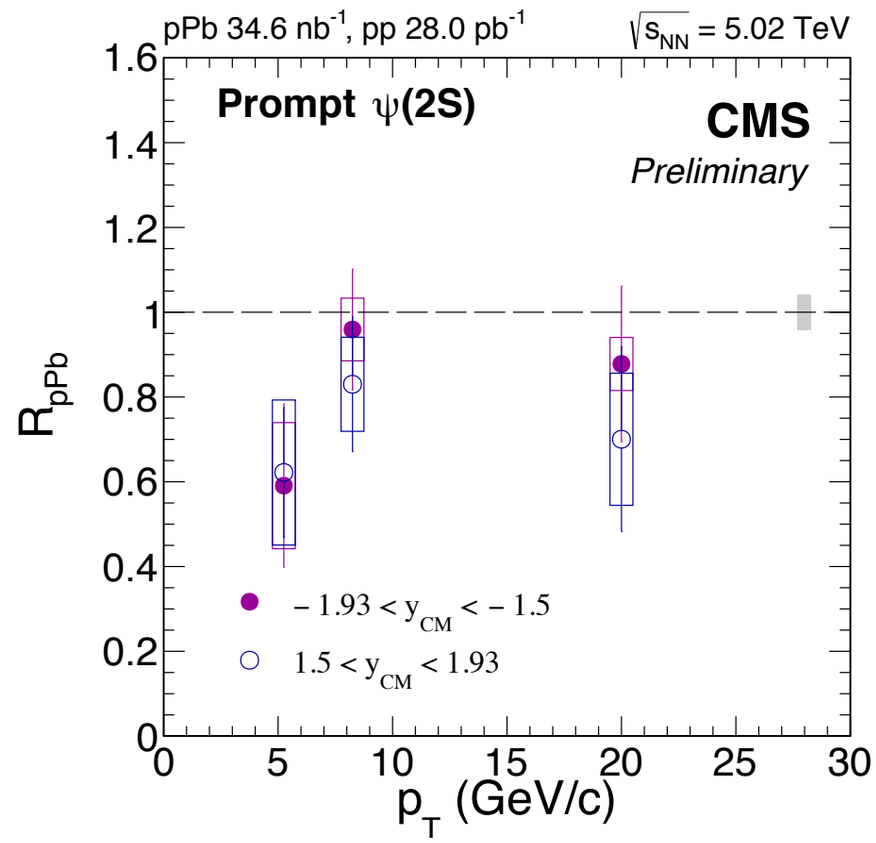


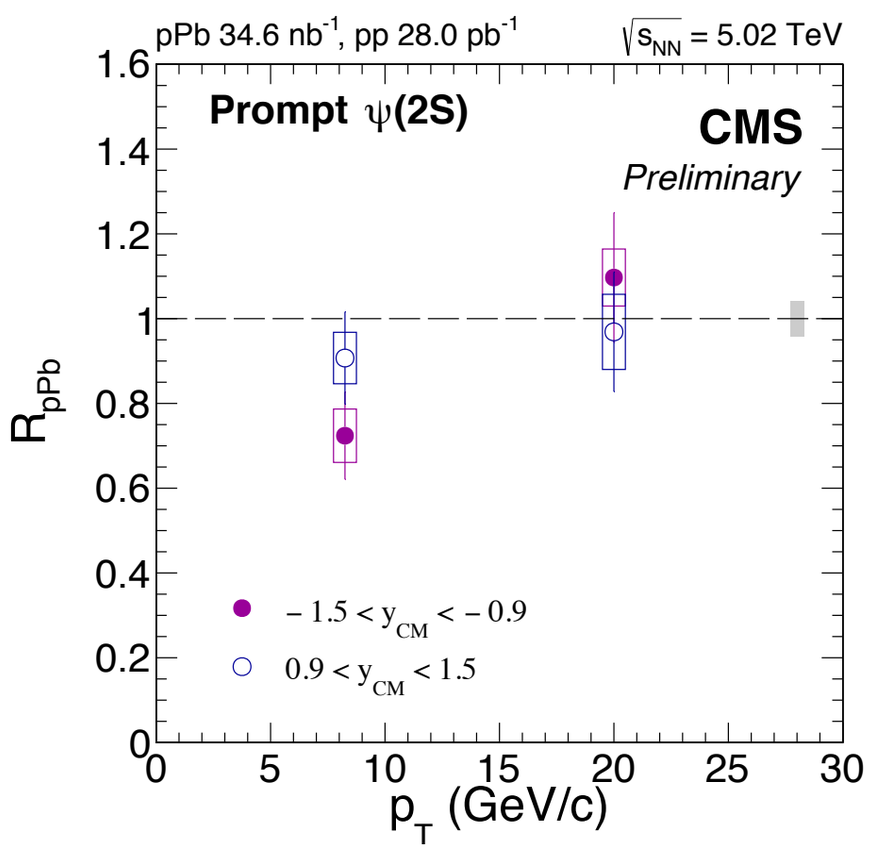


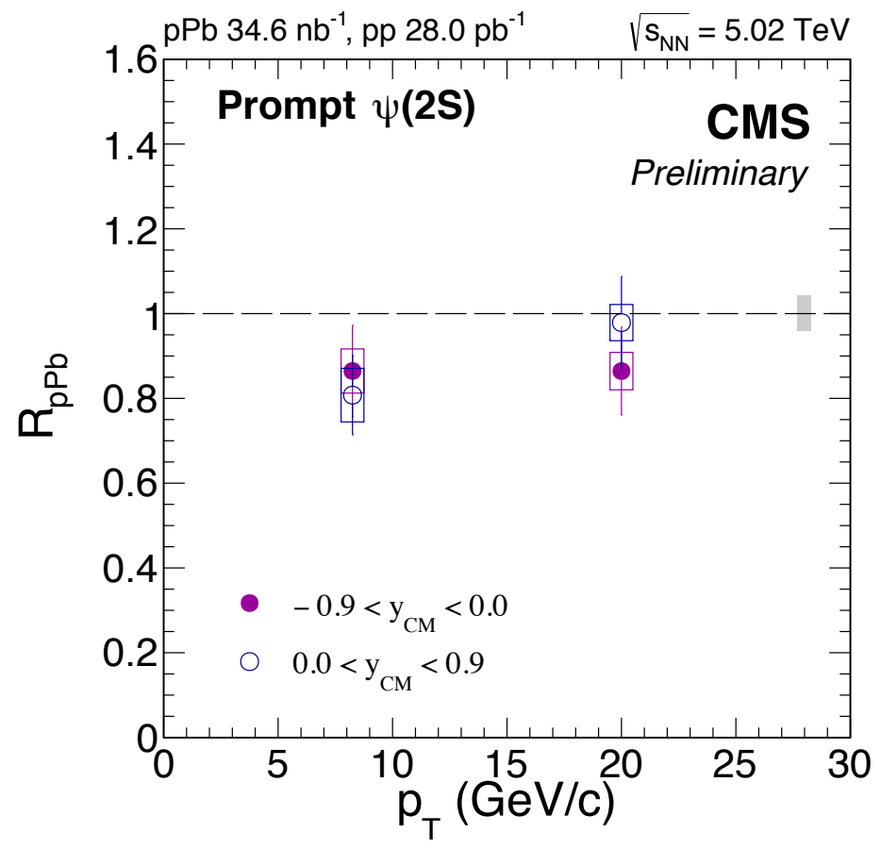
CMS PAS HIN-16-015

ψ(2S) IN pPb



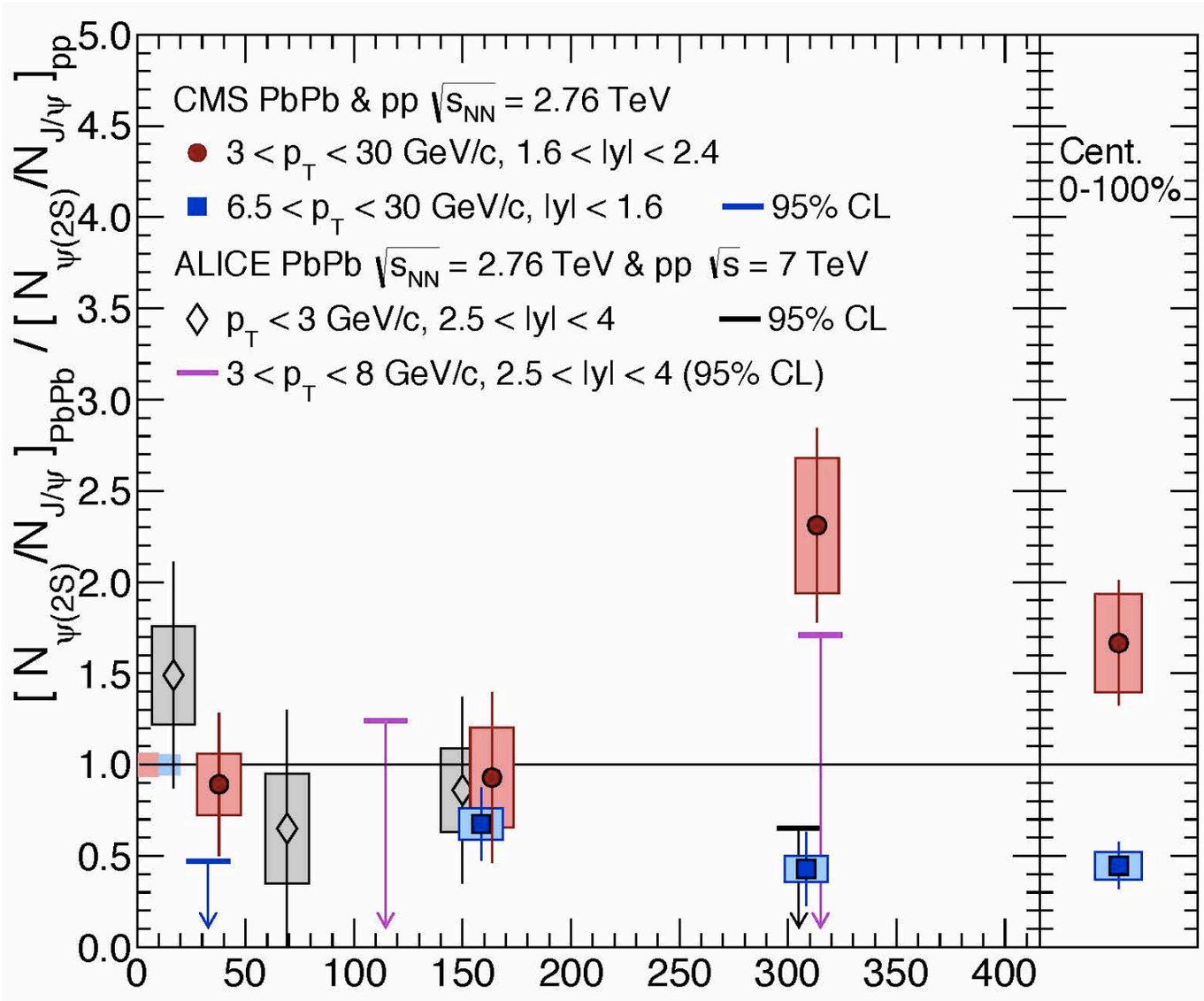






CMS PAS HIN-16-015

ψ(2S) /J/ψ DOUBLE RATIO: CMS VS ALICE



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SEQUENTIAL REGENERATION

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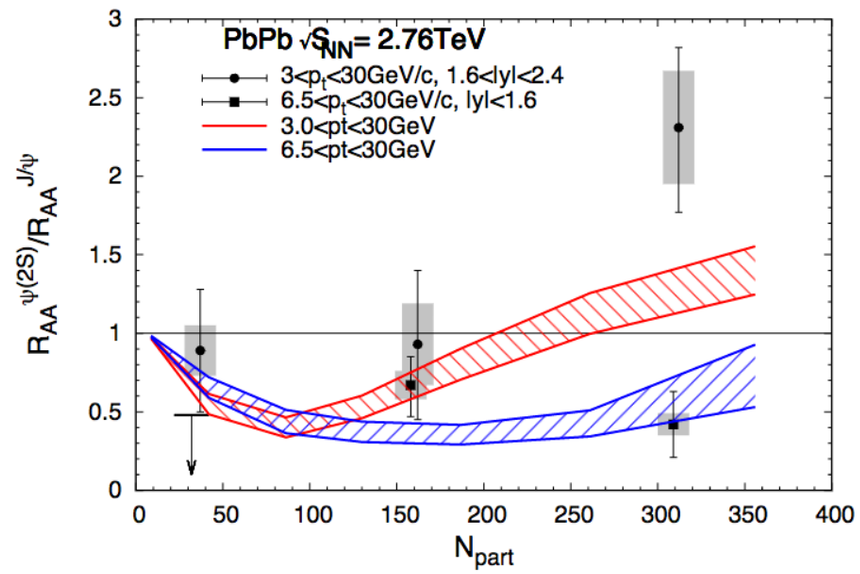
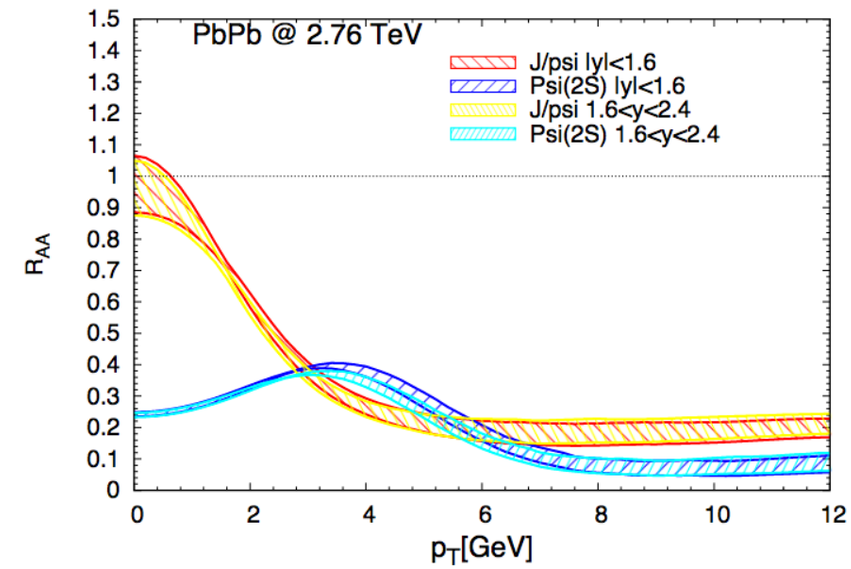
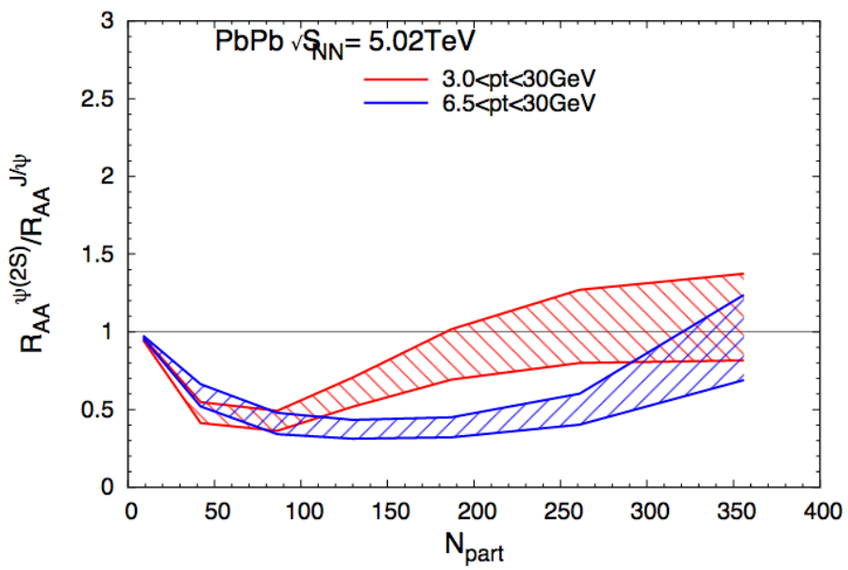
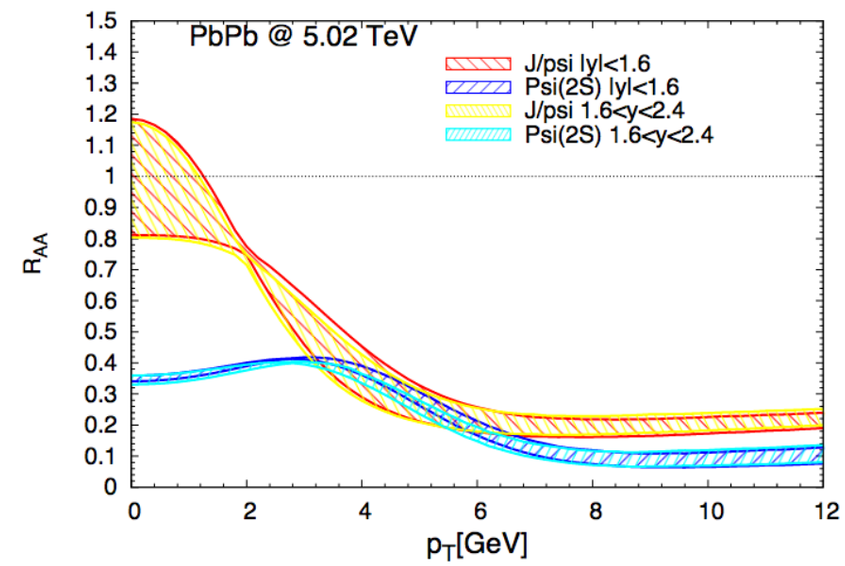




$T_0 \sim 600$ MeV





$T_0 \sim 640$ MeV

2.76 TeV ⟶ 5 TeV

7% increase of initial temperature
10% more shadowing
40% increase charm cross section

c

R_{AA} VS. BINDING ENERGY