Virtual Quarkonia As Tools 2021

Quarkonium production in proton-nucleus collisions at the LHC

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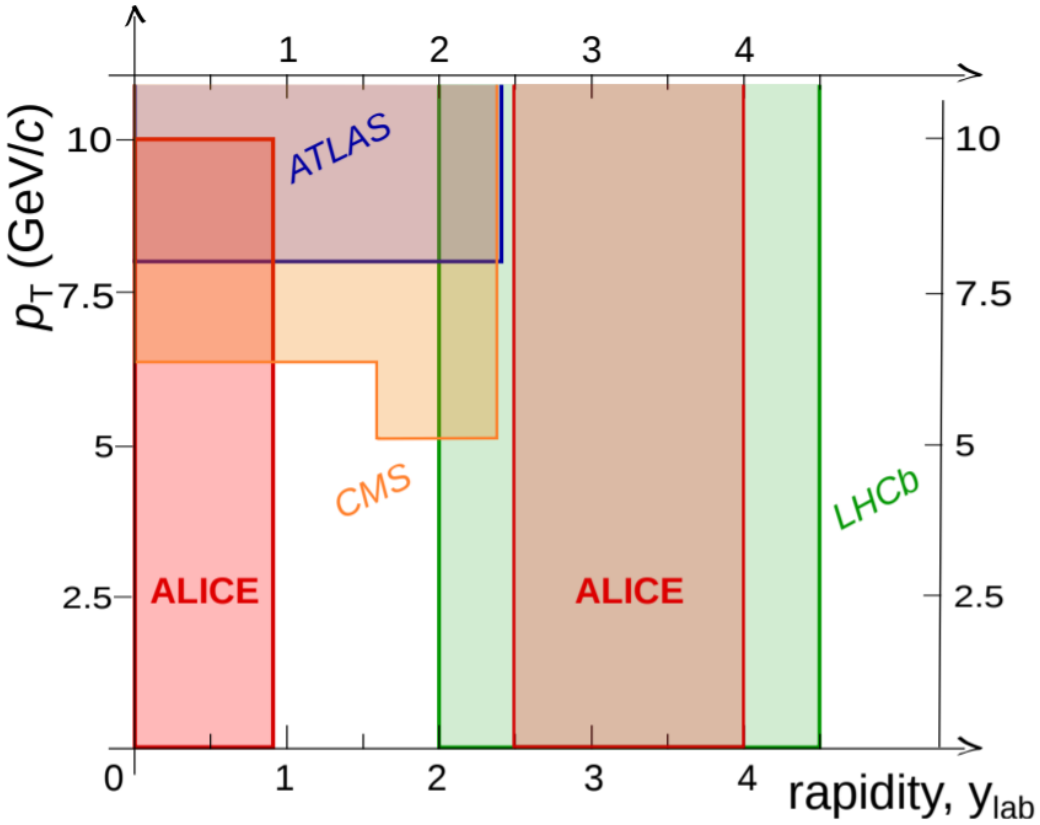
SEZIONE DI TORINO

Quarkonium production at the LHC



- Complementarity of all the experiments

- LHC offers a unique opportunity to explore quarkonium production in a very wide kinematic range

ALICE
- **Forward** & **mid rapidity** coverage
- Charmonia **down to zero p_T**
- Bottomonia **down to zero p_T**

CMS
- **Mid-rapidity** coverage
- Charmonia at **high p_T**
- Bottomonia **down to zero p_T**

LHCb
- Wide **forward rapidity** coverage
- Charmonia **down to zero p_T**
- Bottomonia **down to zero p_T**

ATLAS
- **Mid-rapidity** coverage
- Charmonia at **high p_T**
- Bottomonia **down to zero p_T**

Overview

In this presentation a selection of the latest LHC results in p–Pb collisions

Charmonia in p–Pb collisions ($\sqrt{s_{NN}} = 5.02, 8.16$ TeV)

- J/ψ production as a function of p_T, y and centrality

ALICE JHEP 07 (2018) 160 — CMS EPJC 77 (2017) 269

LHCb PLB 774 (2017) — ALICE JHEP 2009 (2020) 162

- ψ(2S) production as a function of p_T, y and centrality

LHCb JHEP 1603 (2016) 133 — ALICE JHEP 02 (2021) 002

ALICE JHEP 07 (2020) 237 — ATLAS EPJC 78 (2018) 171

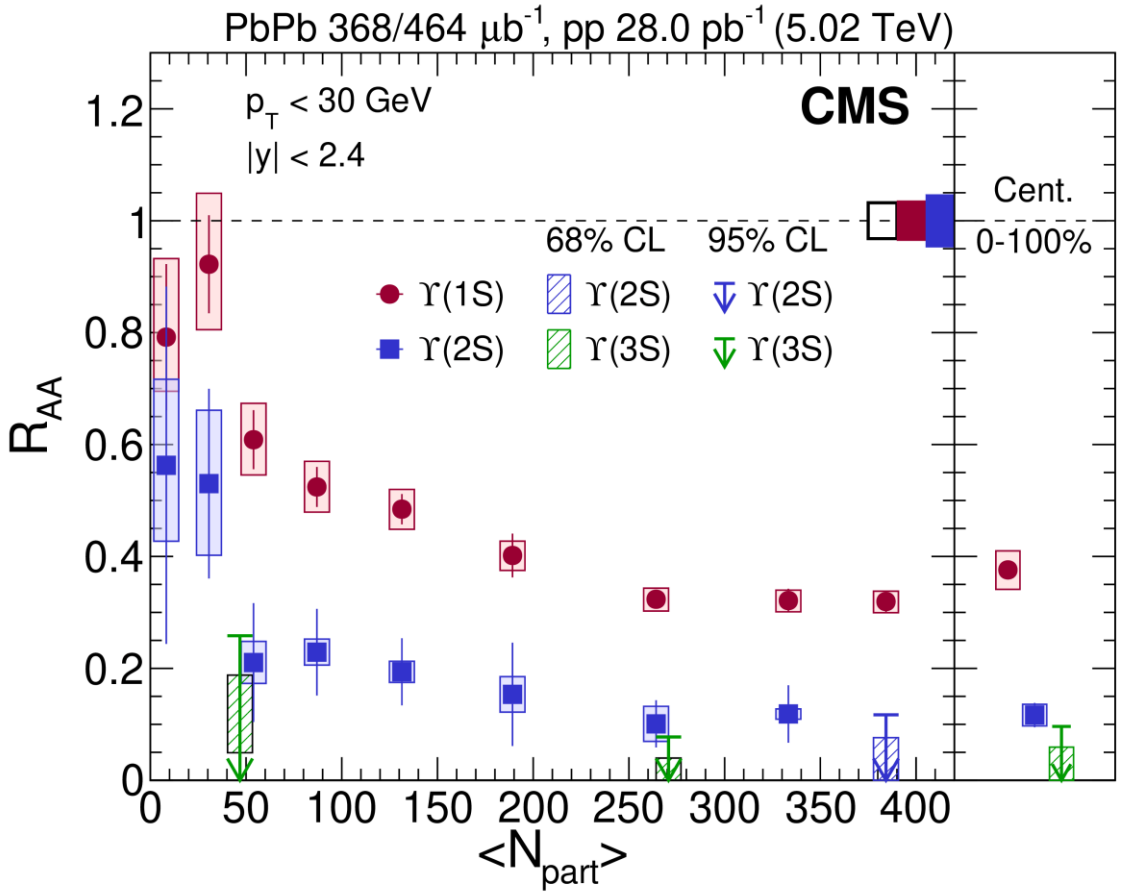
Bottomonia in p–Pb collisions ($\sqrt{s_{NN}} = 5.02, 8.16$ TeV)

- ϒ(nS) production as a function of p_T, y and centrality

ALICE PLB 806 (2020) 135486 — LHCb JHEP 11(2018)194

ATLAS EPJC 78 (2018) 171 — CMS JHEP 04 (2014) 103

Nuclear modification factor



❑ Sequential suppression of **ϒ(nS)** states

arxiv:1805.09215

Nuclear modification factor (R_{AA}): quantifies the modification induced by a medium on the quarkonium production

$$R_{AA} = \frac{\sigma_{AA}}{N_{coll} \cdot \sigma_{pp}}$$

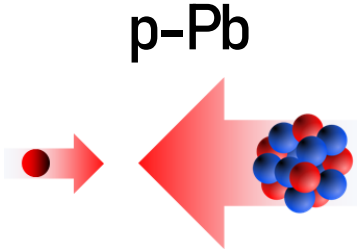
- σ_{AA} = cross section in AA collisions
- σ_{pp} = "reference" cross section in pp
- N_{coll} = number of collisions

In an ideal world…

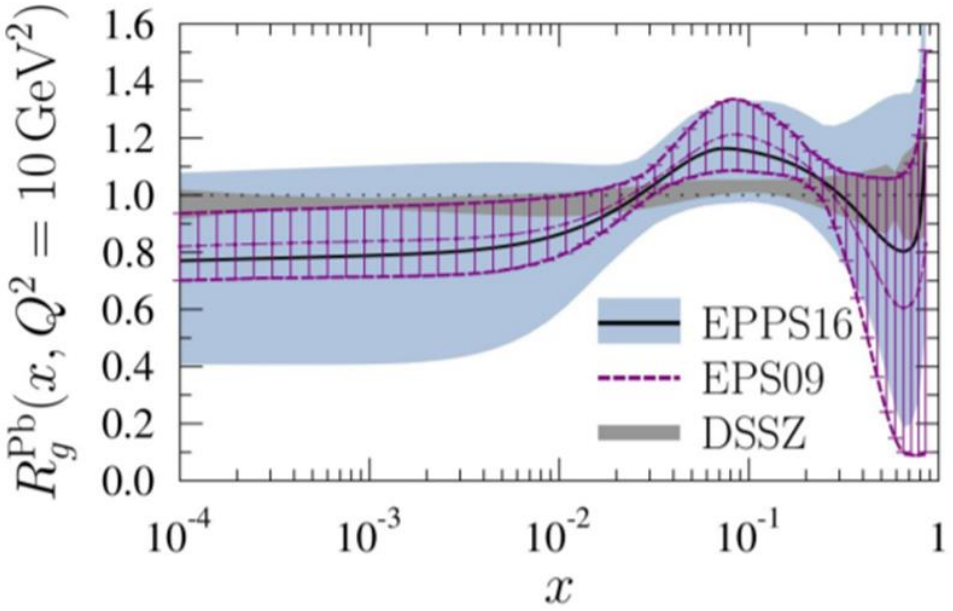
$$R_{AA} \begin{cases} = 1 & \rightarrow \textbf{no medium} \text{ effect} \\ \neq 1 & \rightarrow \textbf{medium} \text{ effect} \end{cases}$$

… but quarkonium production may be modified without QGP formation ⟹ **cold nuclear matter effects**

Quarkonia in pA collisions



Important for the study of
Cold Nuclear Matter effects (CNM)



Nuclear absorption

$q\bar{q}$ pair dissociation induced by the interaction with the nucleons of the colliding nuclei

$\Longrightarrow$ negligible at LHC energies!

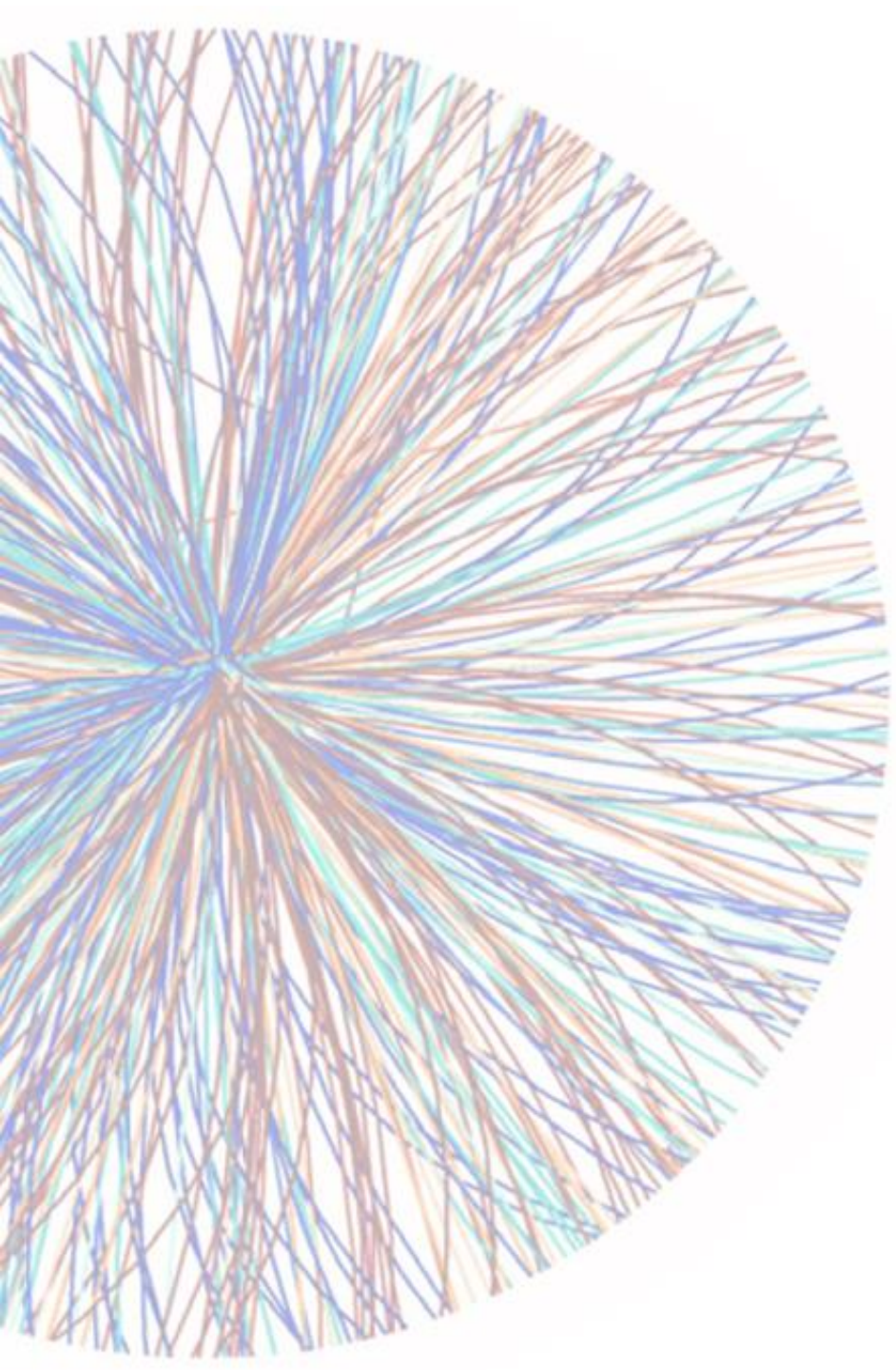
Energy loss in a cold nuclear matter

The energy lost by partons via small-angle gluon emission determines the modification of the charmonium p_{T} spectrum in pA collisions

Parton shadowing

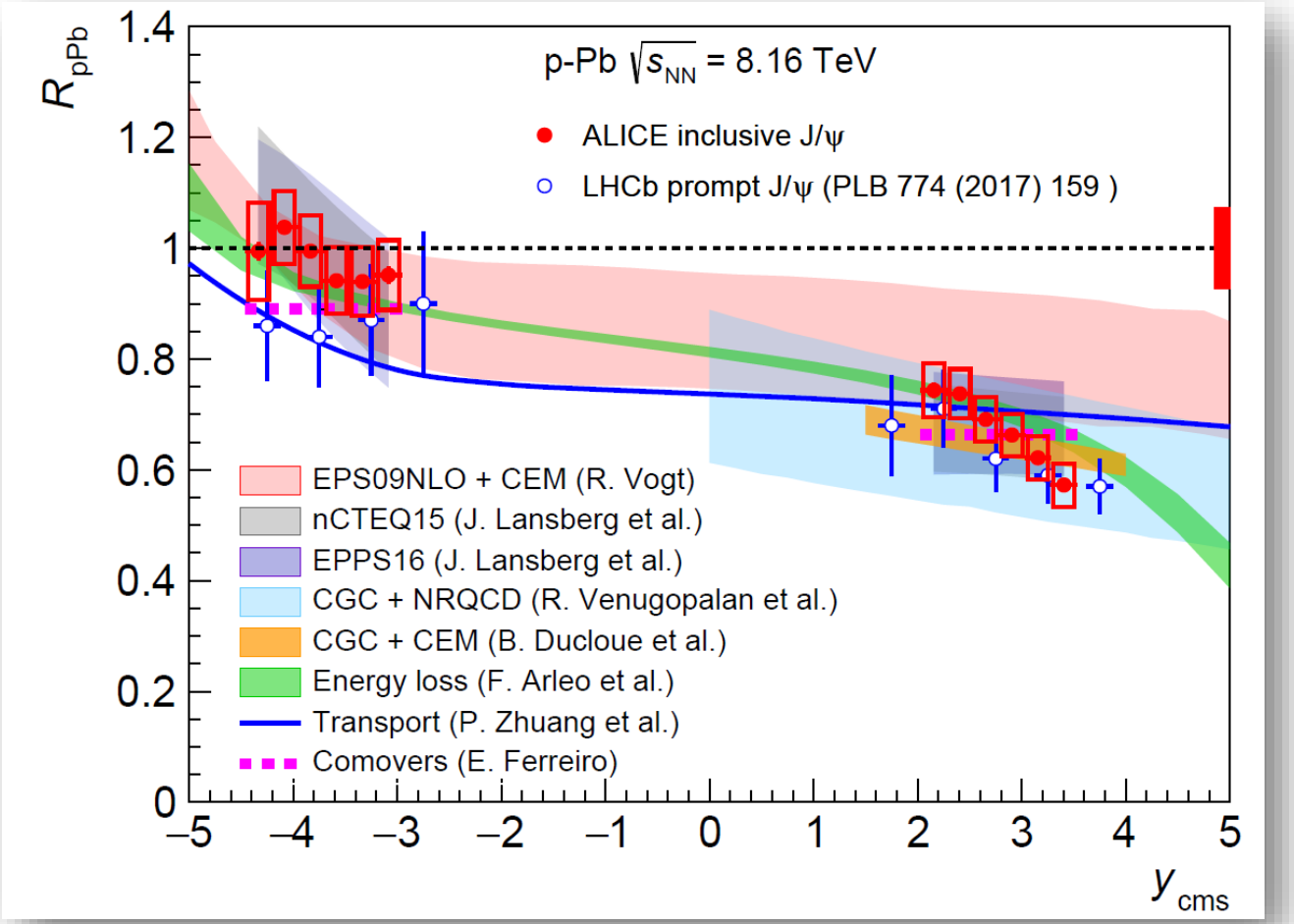
The nuclear environment determines the PDF modification of nucleons inside nuclei w.r.t. free nucleons

$$R_g^{\mathrm{Pb}} = \frac{\text{PDF in bound Pb nucleus}}{\text{PDF in free nucleon}}$$



Charmonia in p-Pb collisions

J/ψ in p-Pb collisions



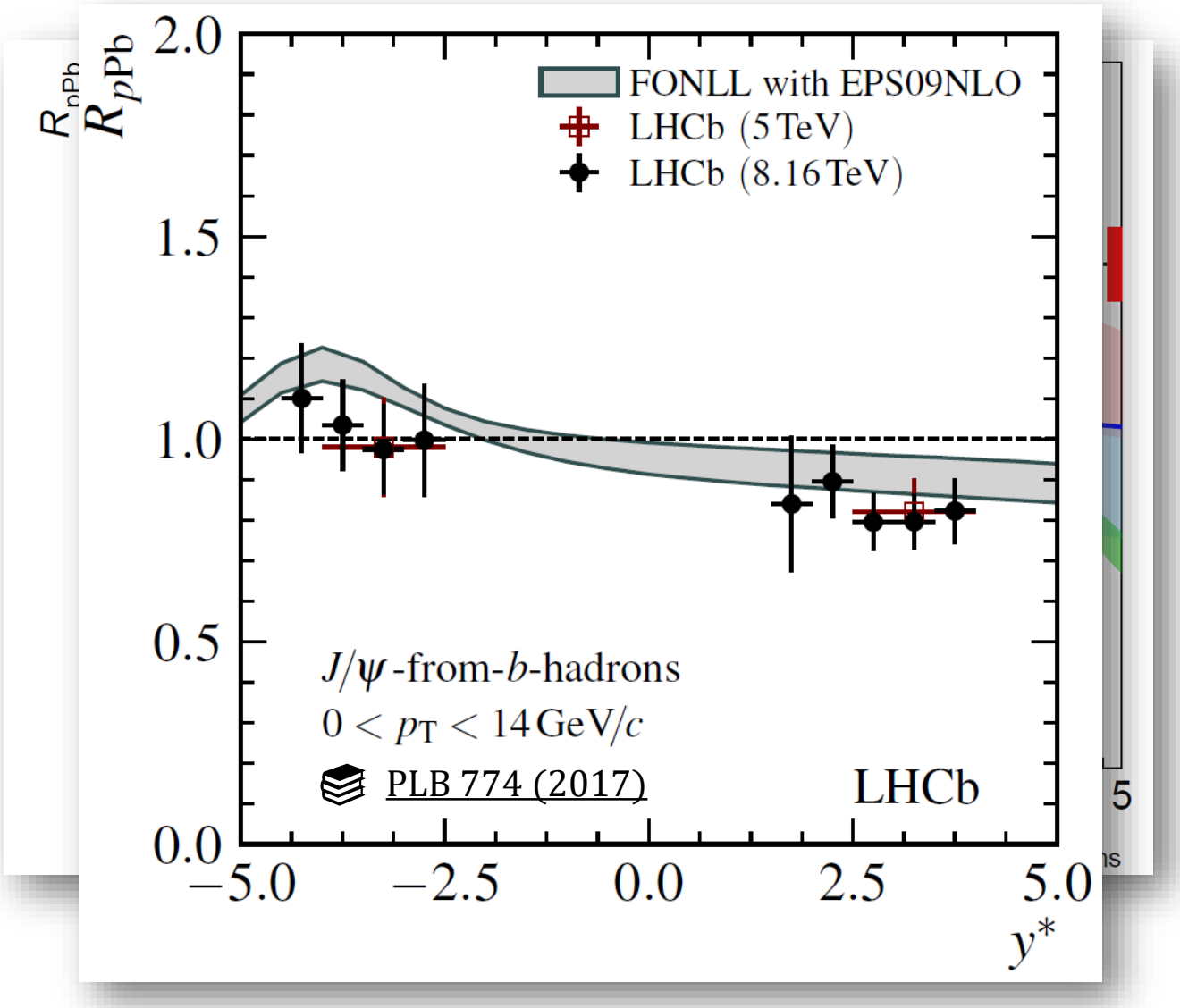
JHEP 07 (2018) 160 PLB 774 (2017)

R_{pPb} vs y

- Stronger J/ψ suppression at forward rapidity
- R_{pPb} compatible with unity at backward rapidity
- **ALICE** (**inclusive**) and **LHCb** (**prompt**) results are in fair agreement within a similar kinematic domain
- Good agreement with models including **shadowing**[1,2,3], **CGC**[4,5], **energy loss**[6], **transport models**[7] and interaction with **comovers**[8]

[1] arxiv:1707.09973
[2] arxiv:1712.07024
[3] arxiv:1712.07024
[4] arxiv:1707.07266
[5] arxiv:1605.05680
[6] arxiv:1407.5054
[7] arxiv:1607.07927
[8] arxiv:1411.0549

J/ψ in p-Pb collisions



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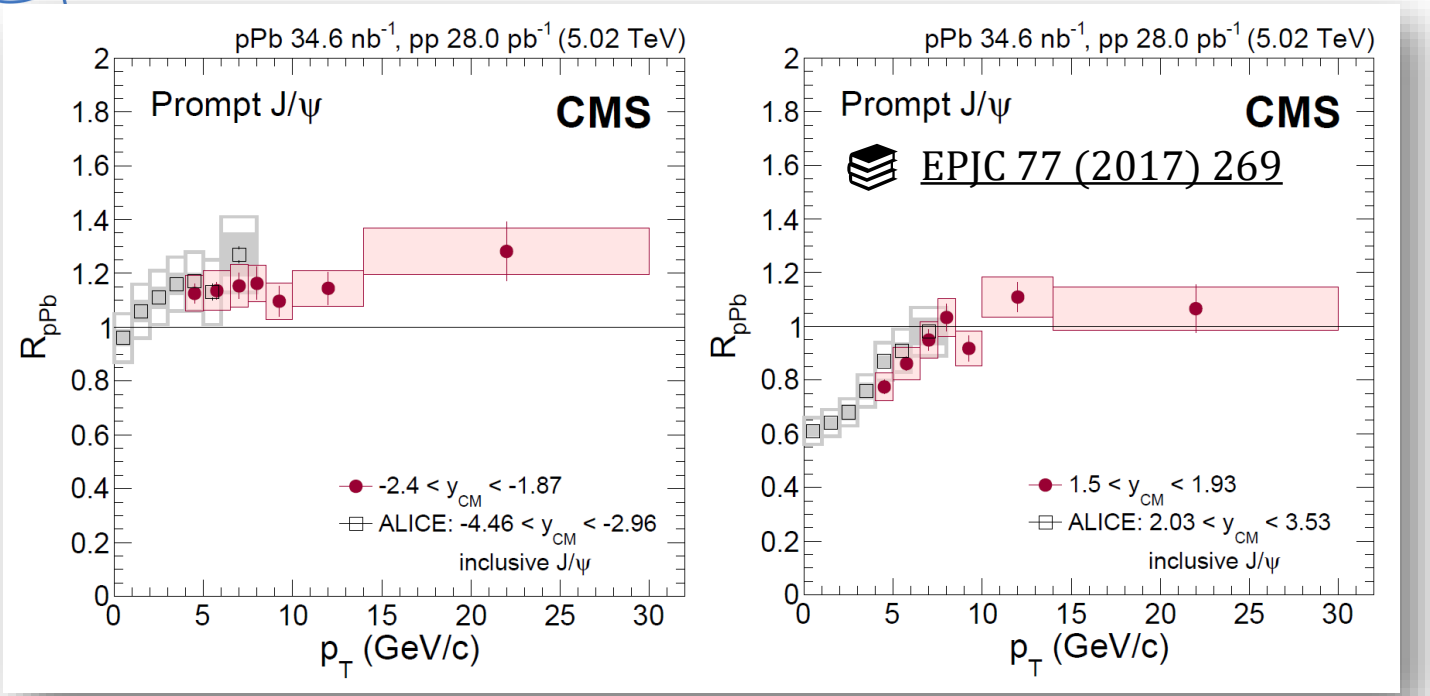
J/ψ from *b* hadrons

- No strong dependence of R_{pPb} vs rapidity
- well described by **FONLL + EPS09NLO**

JHEP 9805:007,1998

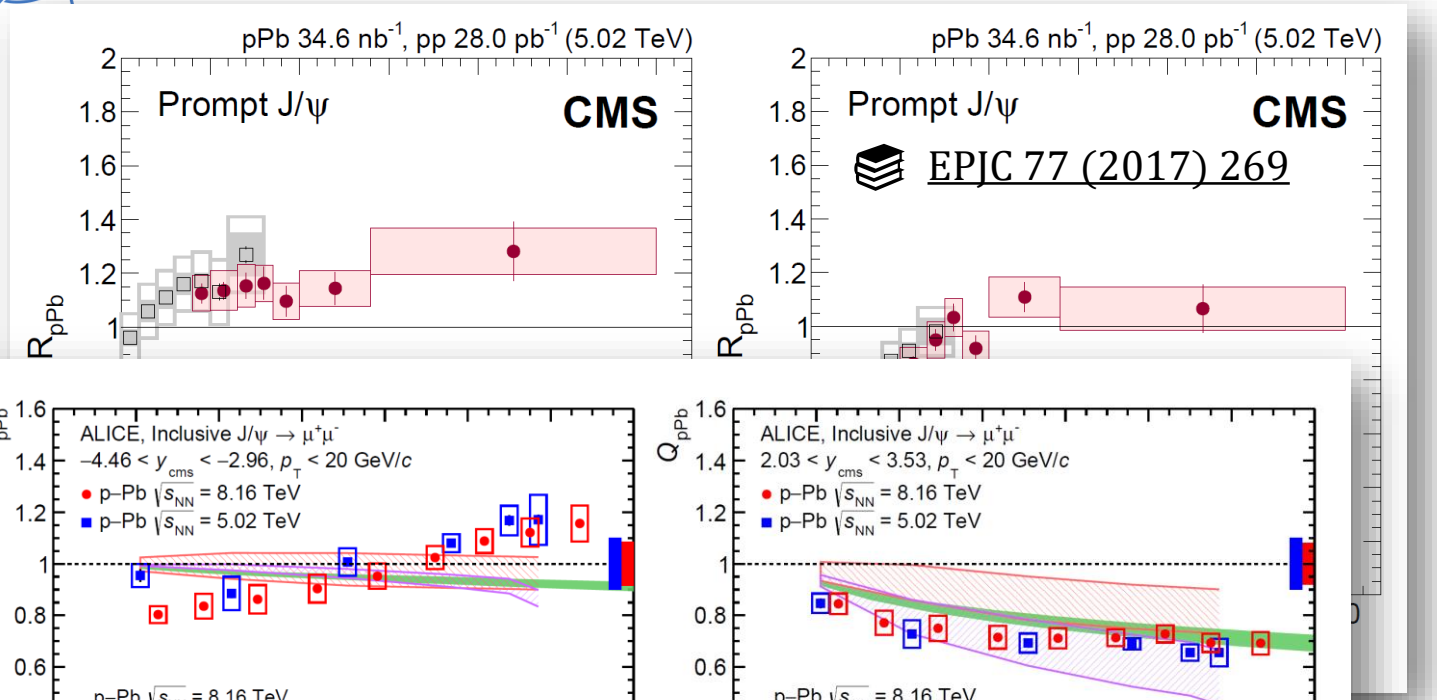
J/ψ in p-Pb collisions



R_{pPb} vs p_T

- Low p_T (**ALICE**): clear evolution with p_T at forward and backward rapidity
- High p_T (**CMS**): R_{pPb} does not show a strong dependence on the p_T

J/ψ in p-Pb collisions



EPJC 77 (2017) 269

JHEP 2009 (2020) 162

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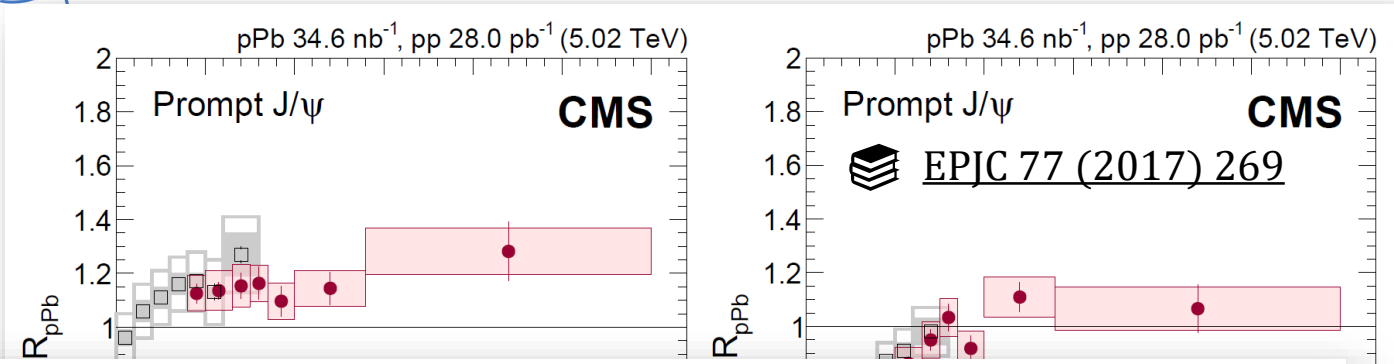
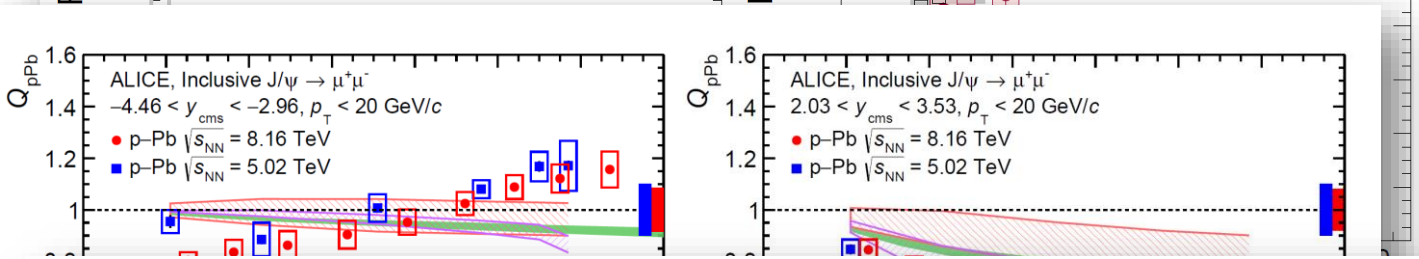
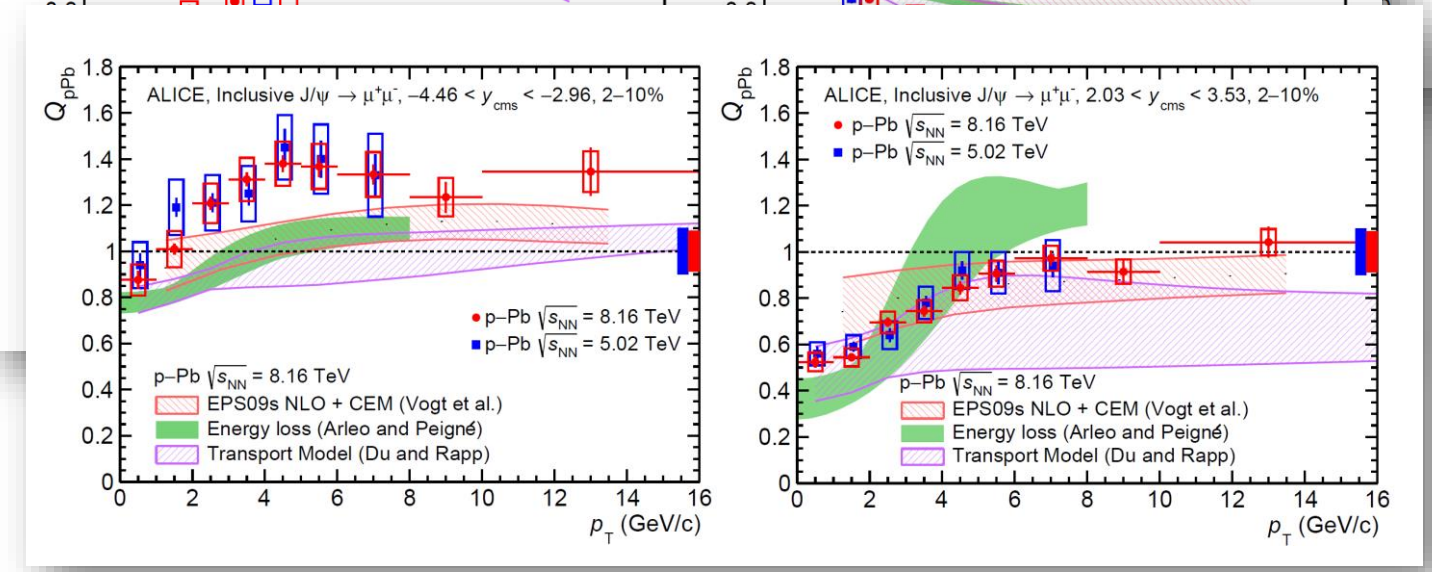
R_{pPb} vs centrality

- Opposite trend at backward (increase) and forward rapidity(decrease)
- Backward rapidity: some tension with data and theoretical models

J/ψ in p-Pb collisions







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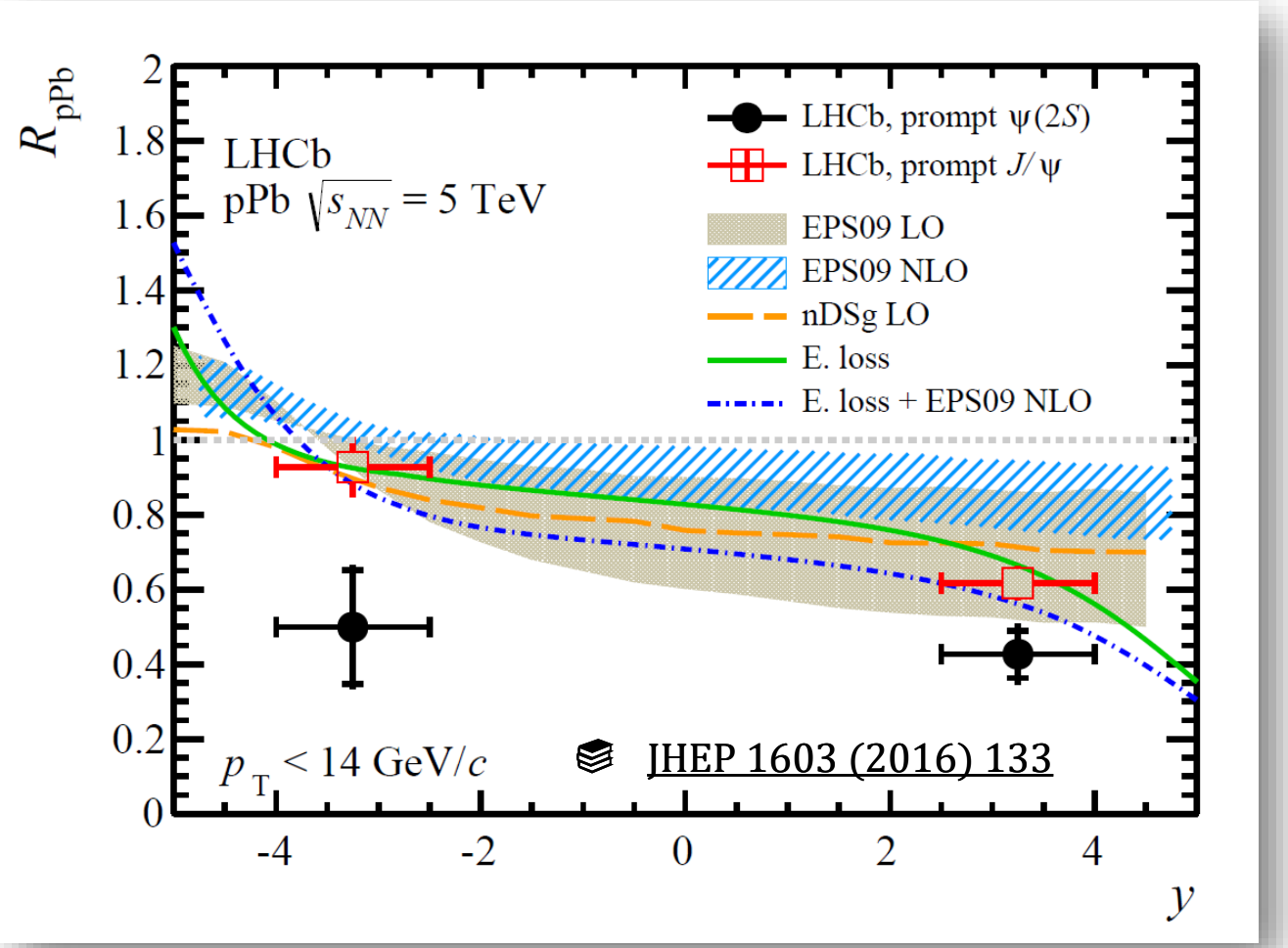
- Backward rapidity: some tension with data and theoretical models

➢ R_{pPb} p_T shape for different centrality classes not really described by models

Comprehensive description of p_T and centrality is for the moment missing

ψ(2S) in p-Pb collisions



R_{pPb} vs y

- Prompt ψ(2S) shows a similar suppression at forward and backward rapidity
- Prompt ψ(2S) more suppressed at **backward rapidity** with respect to J/ψ
- Models including **shadowing**[1,2,3], **energy loss**[4,5] does not describe this larger ψ(2S) suppression at backward rapidity

[1] arxiv:1305.4569
[2] arxiv:1402.1747
[3] arxiv:1301.3395
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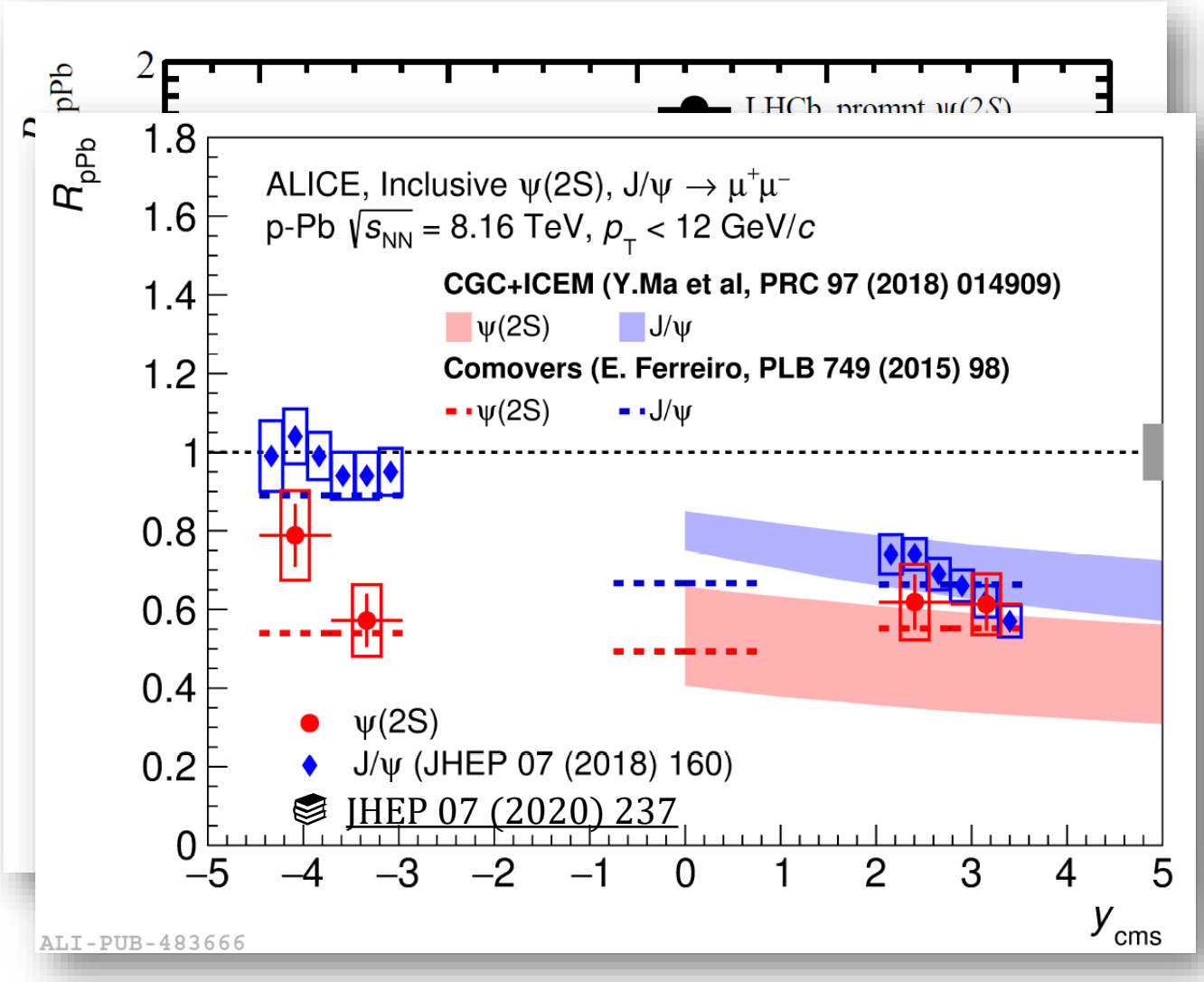

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- ψ(2S) is better described by models including **final state effect** as **Comovers**[1] and **CGC+ICEM**[2]

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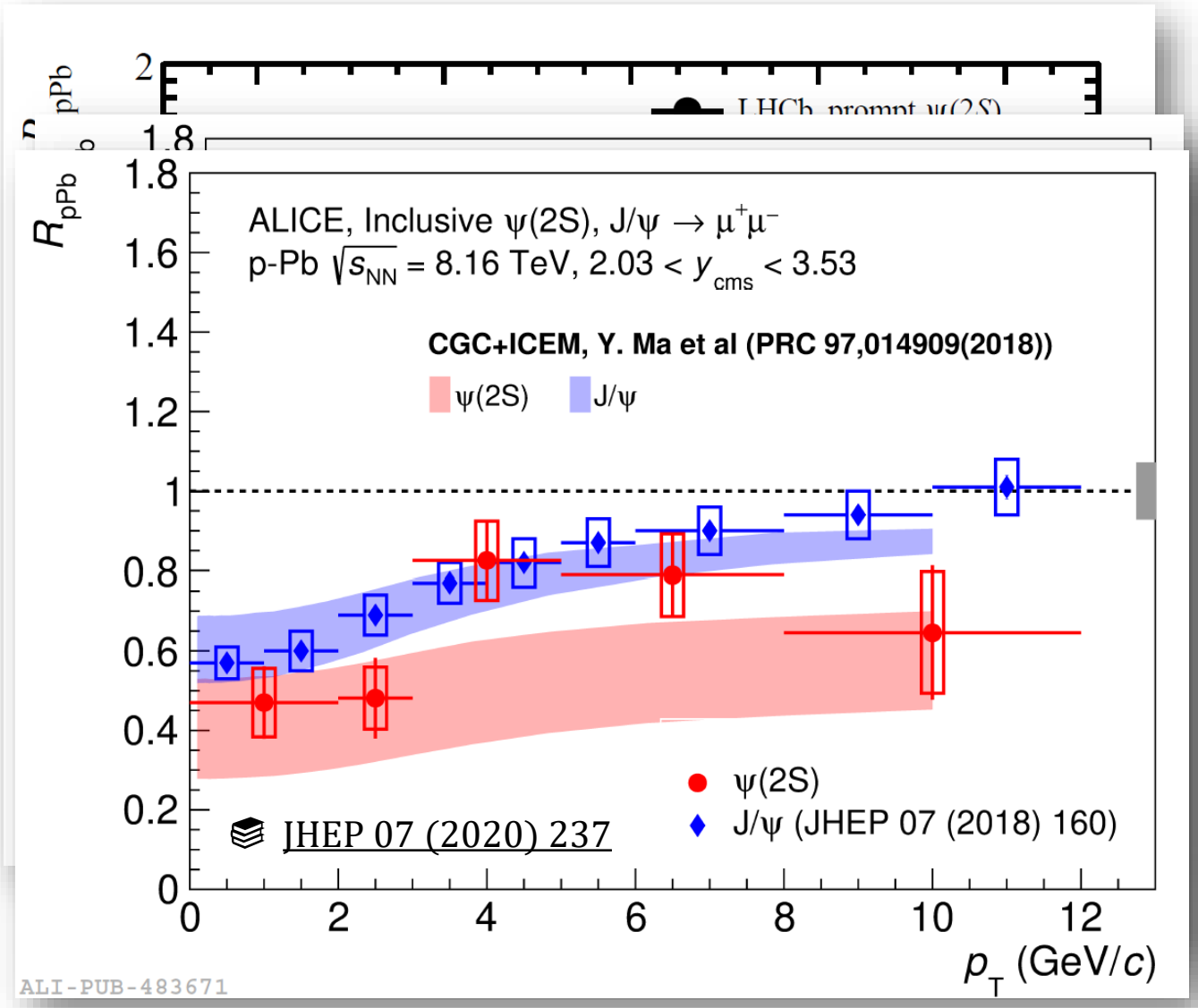
ψ(2S) in p-Pb collisions



R_{pPb} vs y and p_T

- Prompt ψ(2S) shows a similar suppression at forward and backward rapidity
- Prompt ψ(2S) more suppressed at **backward rapidity** with respect to J/ψ
- Models including **shadowing**[1,2,3], **energy loss**[4,5] does not describe this larger ψ(2S) suppression at backward rapidity

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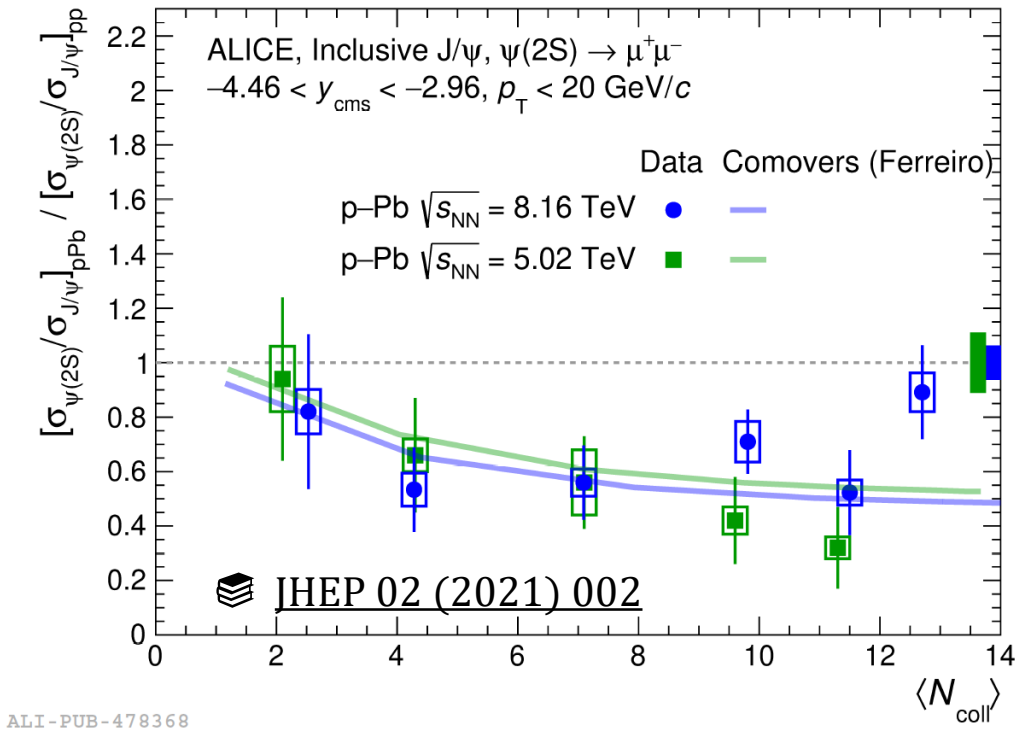
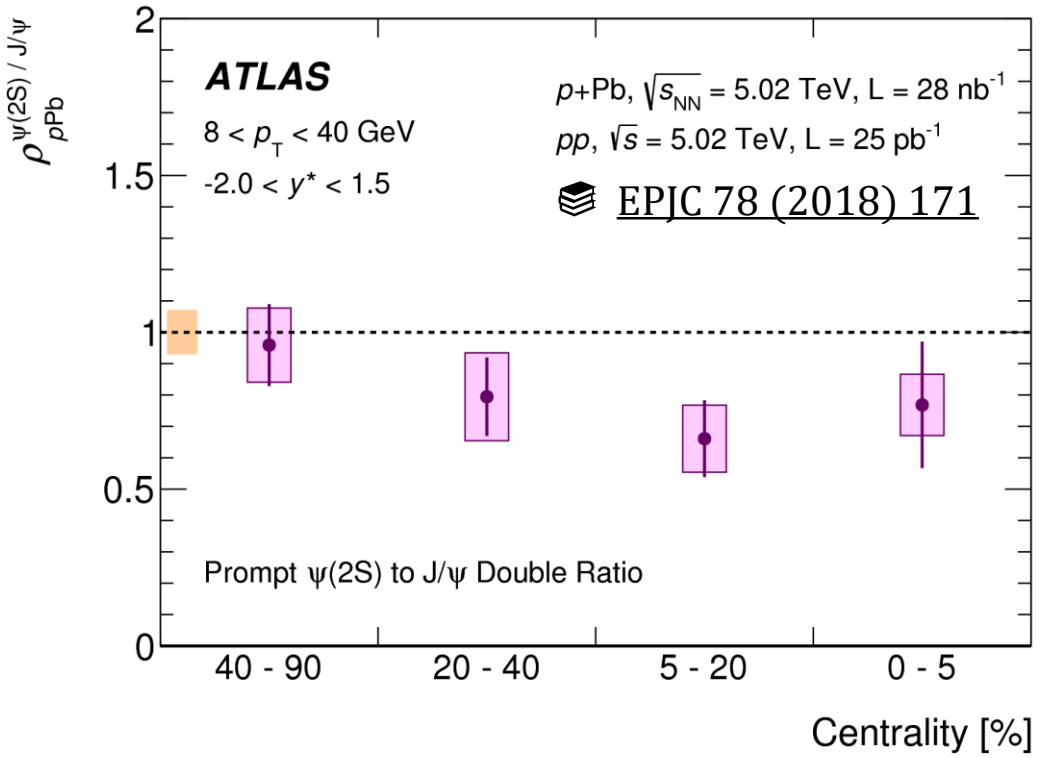
ψ(2S) in p-Pb collisions

Double ratio vs centrality



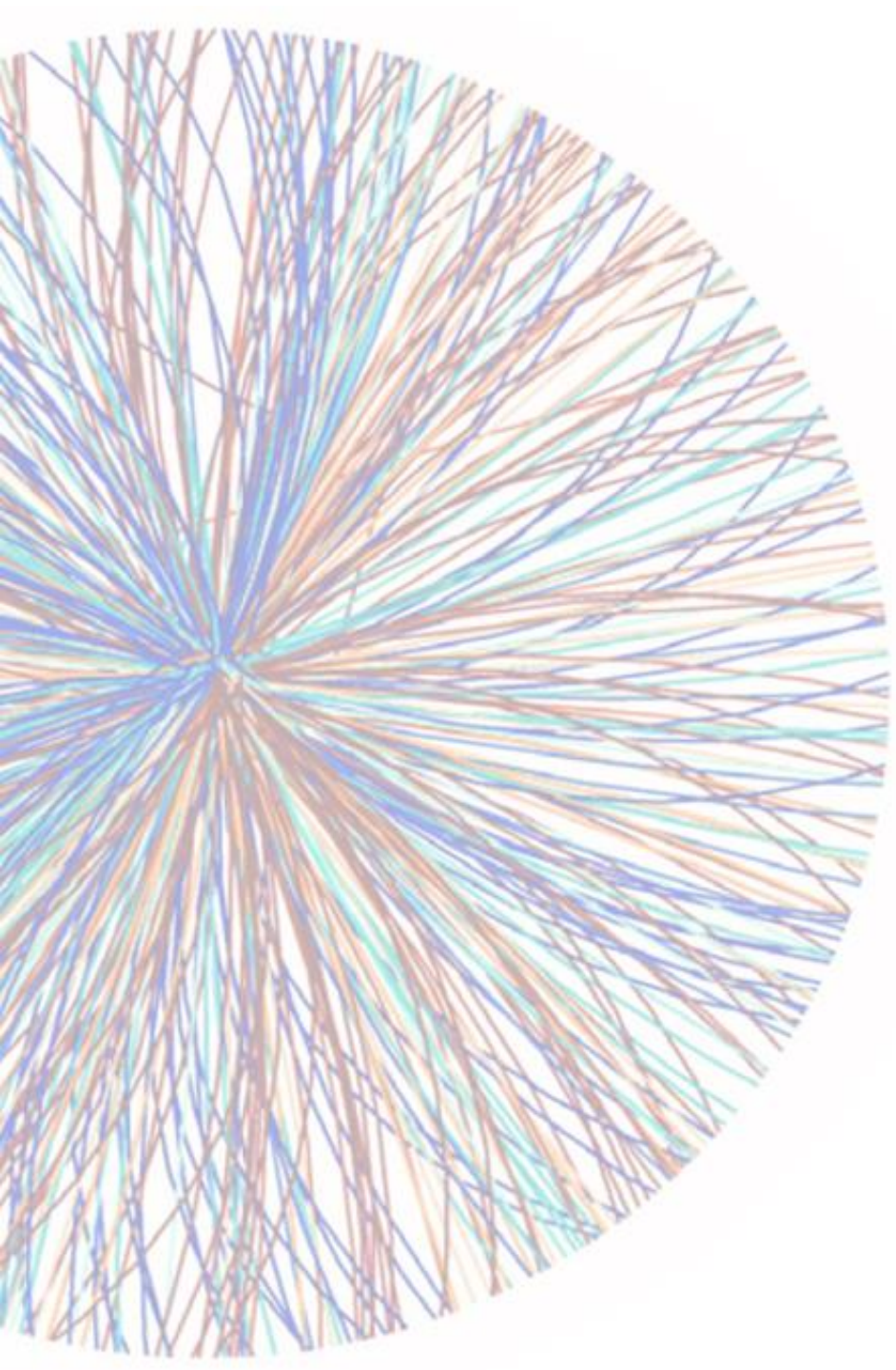


$p_T < 20$ GeV/c (inclusive)

- No evident energy dependence
- Results in agreement with the **Comovers** model

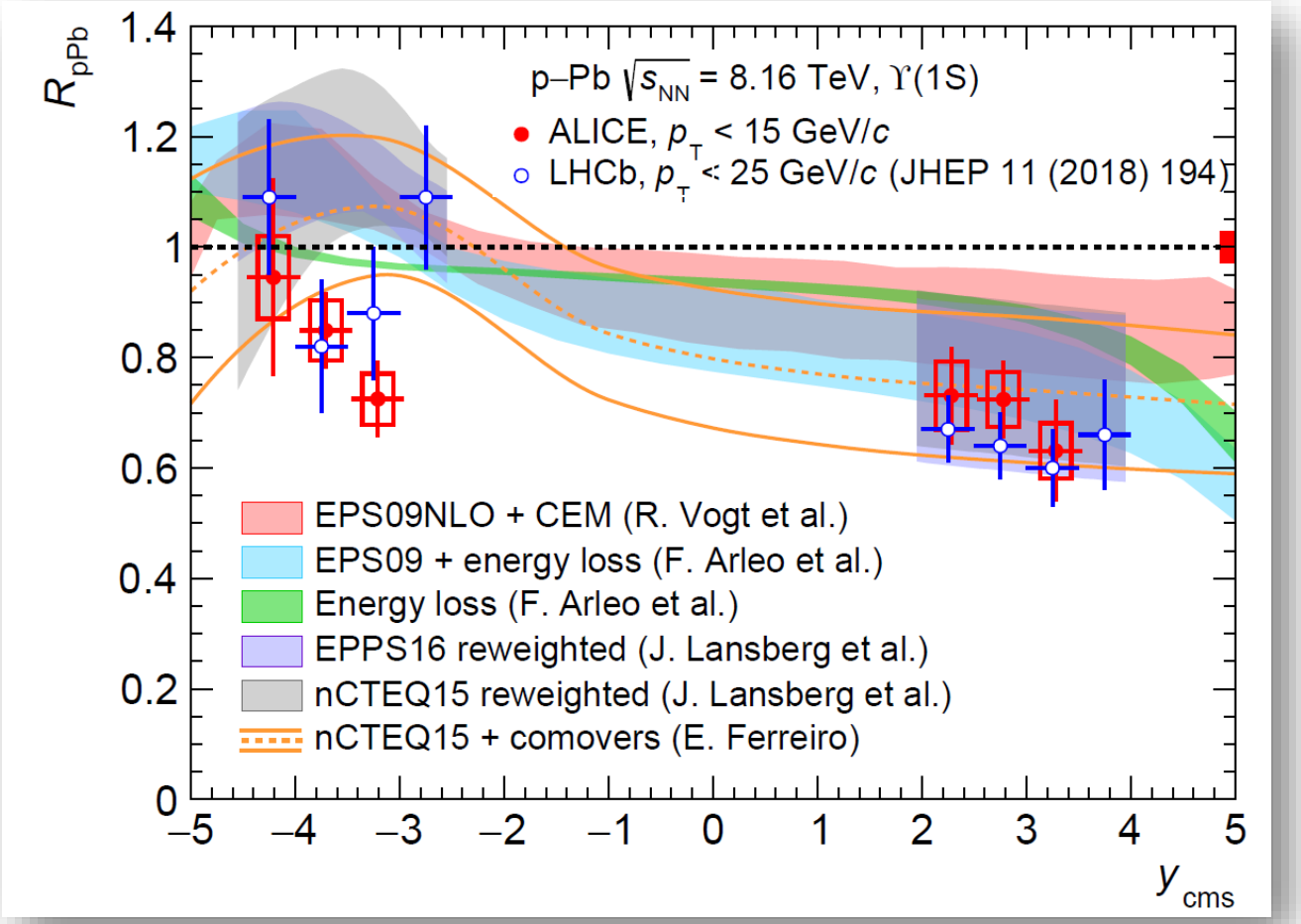
$8 < p_T < 40$ GeV/c (prompt)

- Slight decrease with increasing centrality
- Similar trend between low p_T (backward rapidity) and high p_T (mid-rapidity)



Bottomonia in p-Pb collisions

Υ(1S) in p-Pb collisions



PLB 806 (2020) 135486 JHEP 11(2018)194

R_{pPb} vs y

- Hint for smaller Υ(1S) suppression at backward rapidity
- **ALICE** and **LHCb** results are in fair agreement within a similar kinematic domain
- Good agreement with models including **shadowing**[1,4,5], **energy loss**[2,3] and interaction with **comovers**[6]

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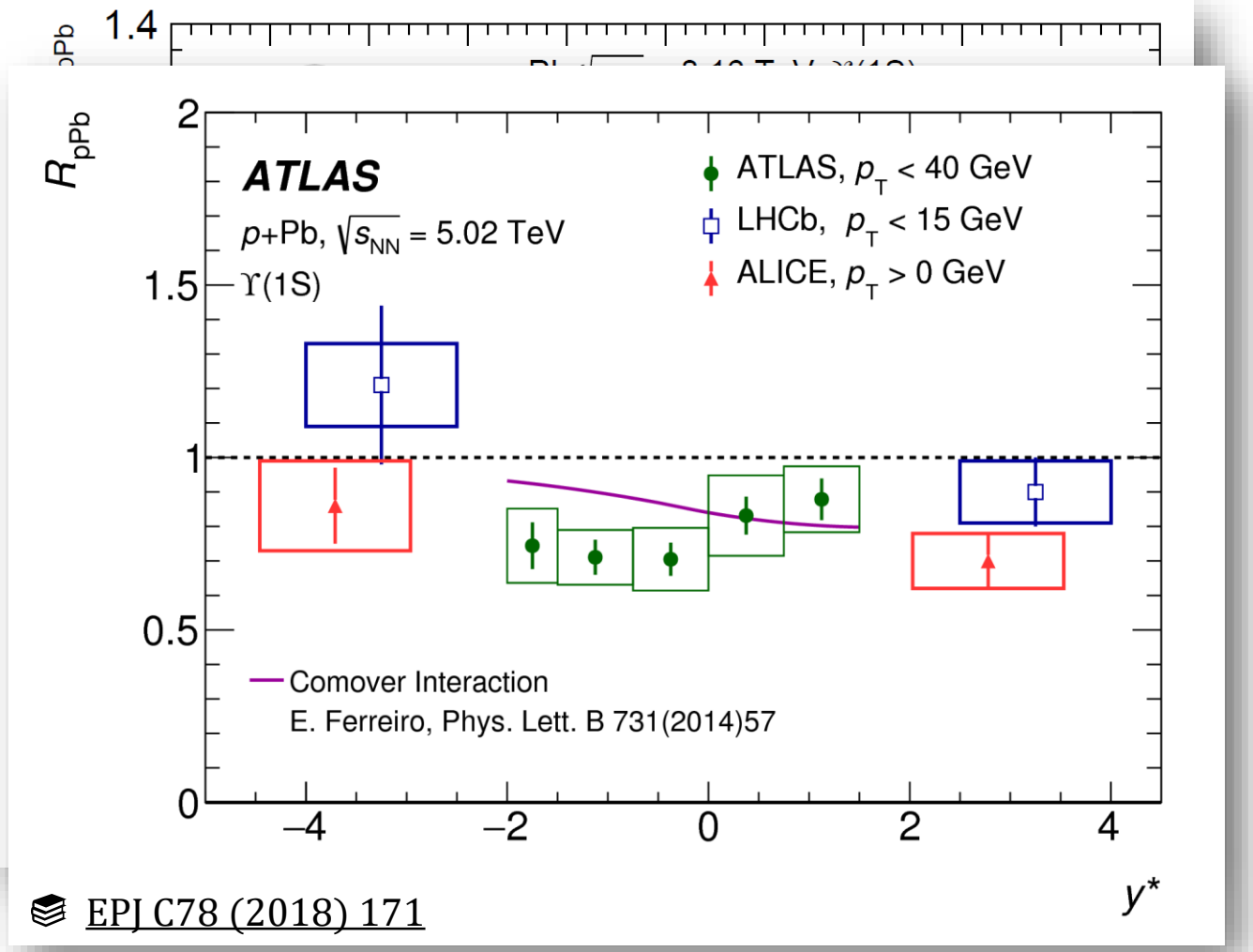

EPJ C78 (2018) 171

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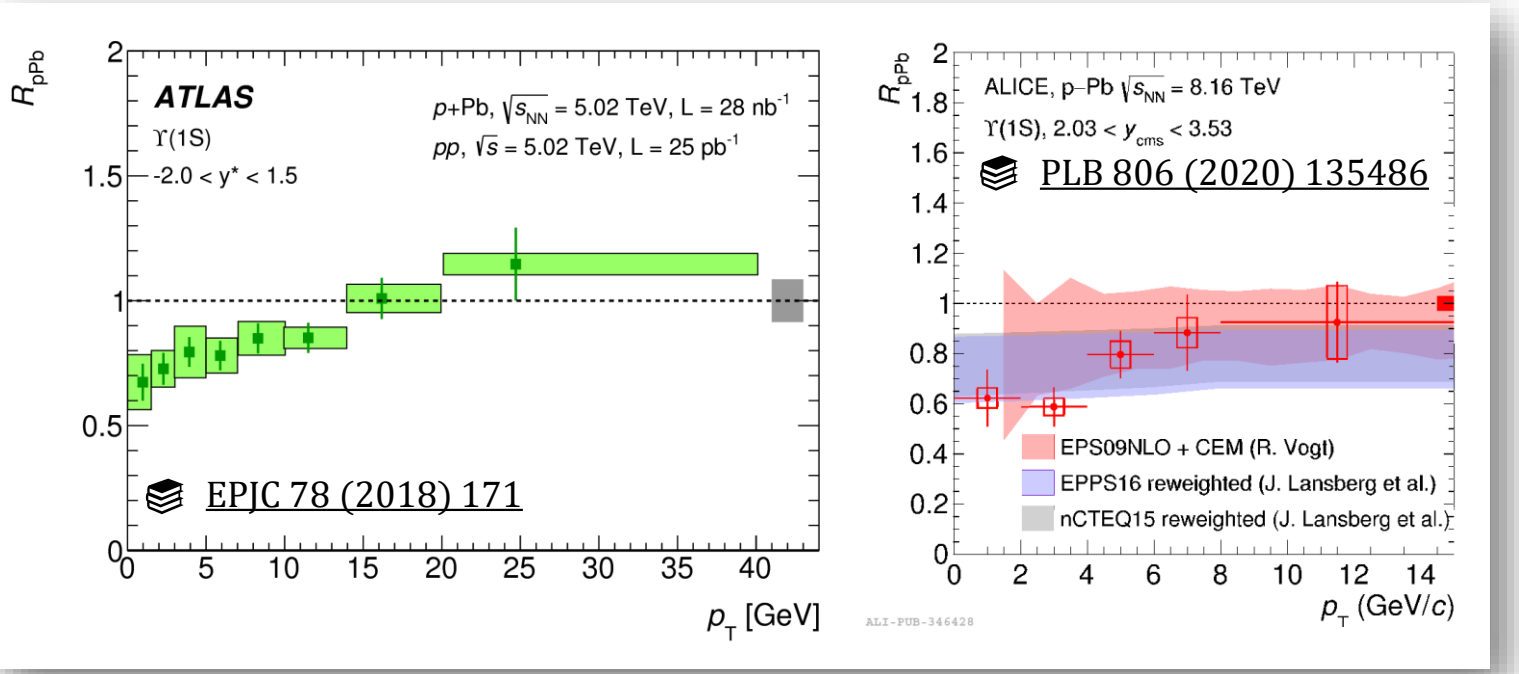
- No strong rapidity dependence observed by **ATLAS** ($p_T < 40$ GeV/c)

Υ(1S) in p-Pb collisions



R_{pPb} vs p_T

- Similar behavior at forward (**ALICE**) and at mid-rapidity (**ATLAS**)
- Larger suppression at low p_T
- The trend as a function of p_T is in qualitative agreement with models including **shadowing**[1,2,3]

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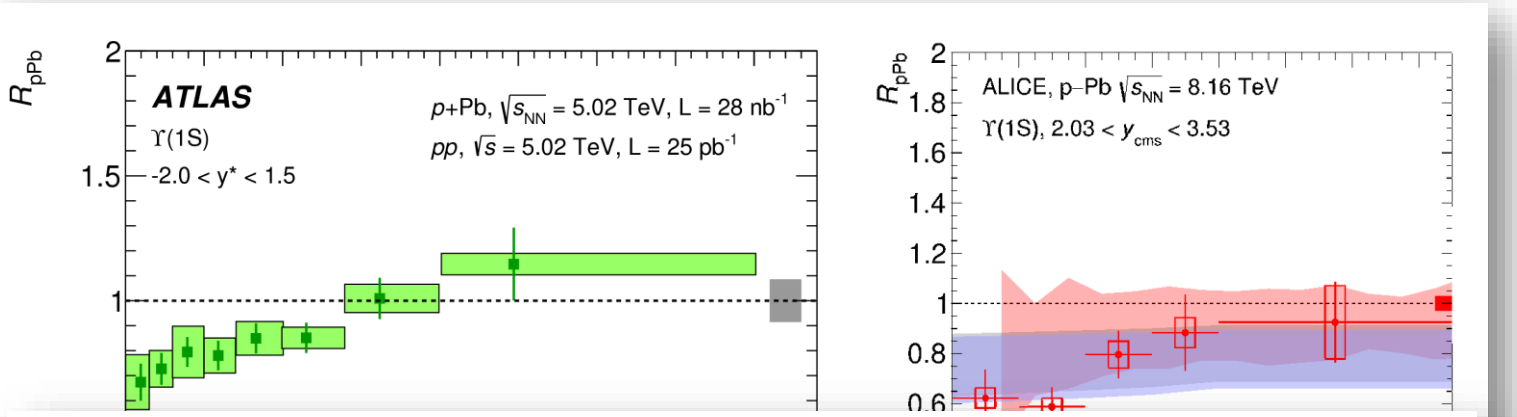
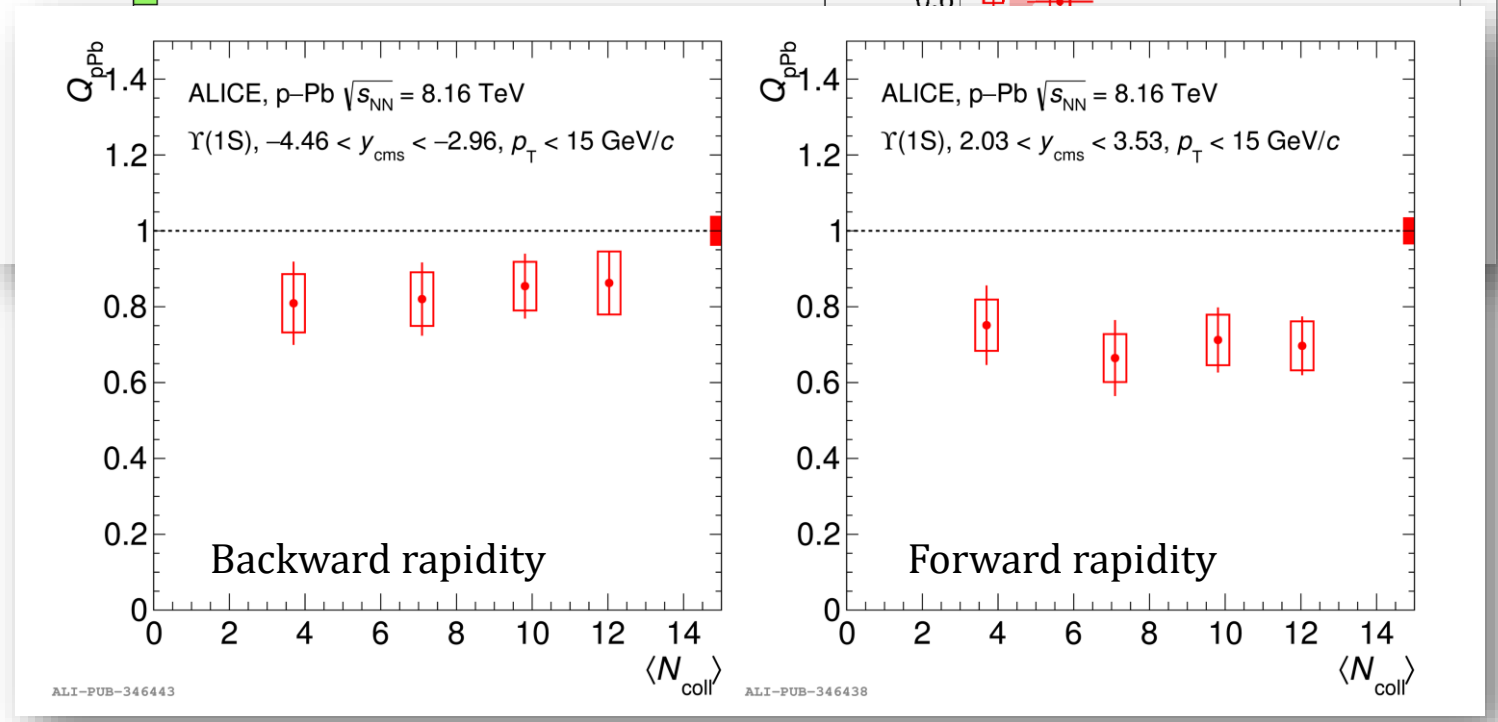
Υ(1S) in p-Pb collisions





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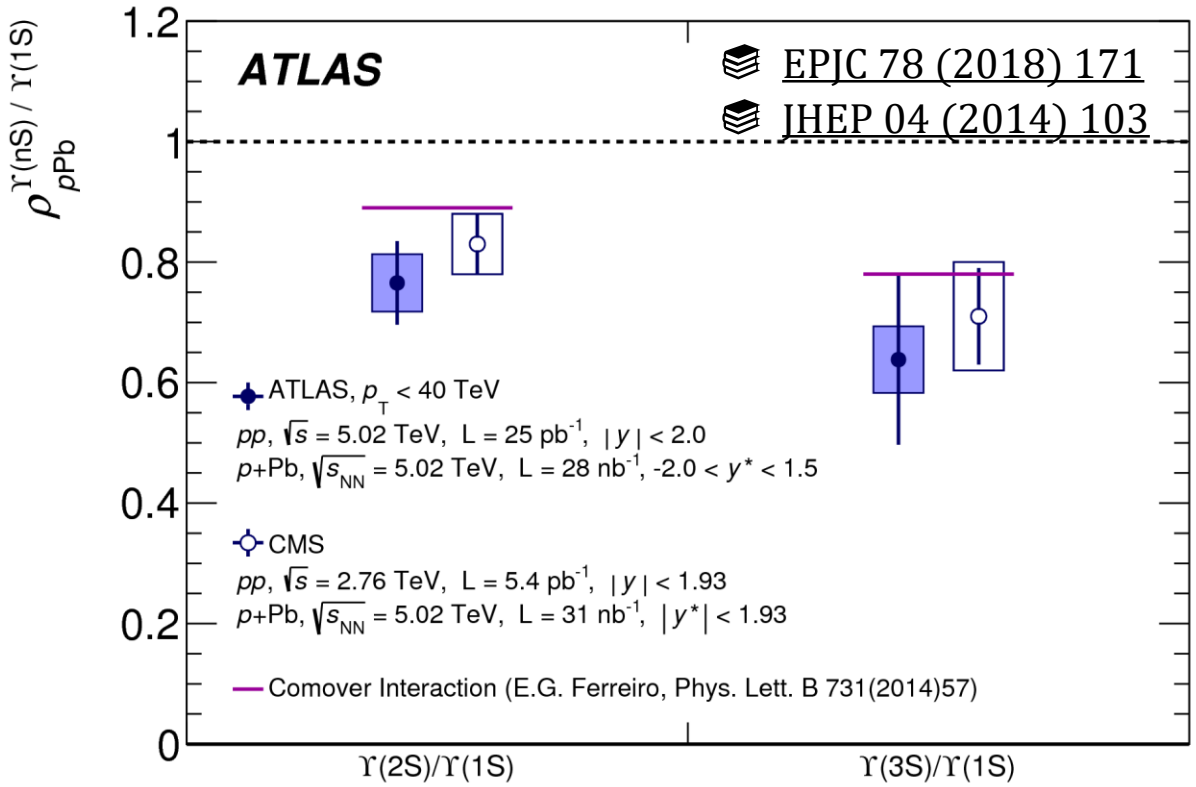
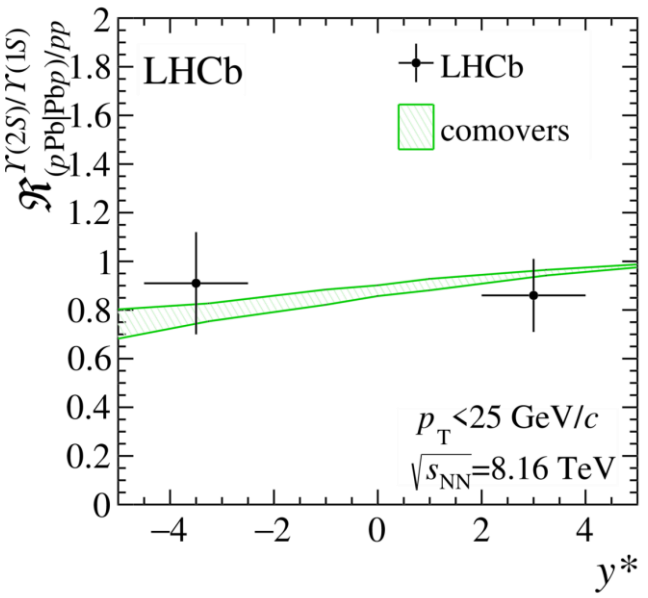
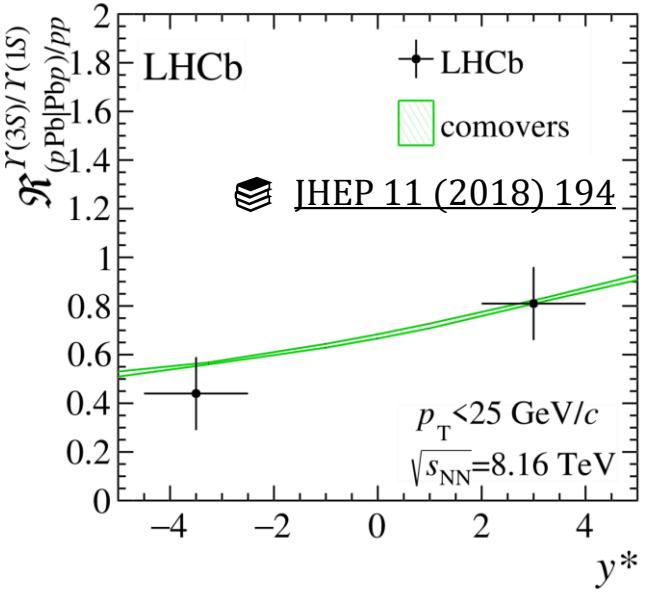
R_{pPb} vs centrality

- No visible centrality dependence at backward and forward rapidity

Υ(nS) in p-Pb collisions







Double ratio

- Indication of larger of Υ(2S) and Υ(3S) suppression w.r.t. Υ(1S)
- Results are in agreement with the **Comover model** at forward (**LHCb**) and at mid (**CMS, ATLAS**) rapidity

Summary

- **J/ψ and ψ(2S) production as a function of p_T, y and centrality**
  - Larger J/ψ suppression at backward rapidity in agreement with models including **shadowing**, **energy loss**, **transport models** and **comovers** interaction
  - Some tension between data and models for the results as a function of centrality and p_T
  - **Final state effects** necessary to explain the larger ψ(2S) suppression w.r.t. J/ψ
- **ϒ(nS) production as a function of p_T, y and centrality**
  - Hint for smaller ϒ(1S) suppression at backward rapidity in agreement with **shadowing**, **energy loss** and interaction with **comovers**
  - Similar behavior as a function of p_T at forward and mid rapidity
  - No visible centrality dependence at backward and forward rapidity
  - Hint of larger of ϒ(2S) and ϒ(3S) suppression w.r.t. ϒ(1S)