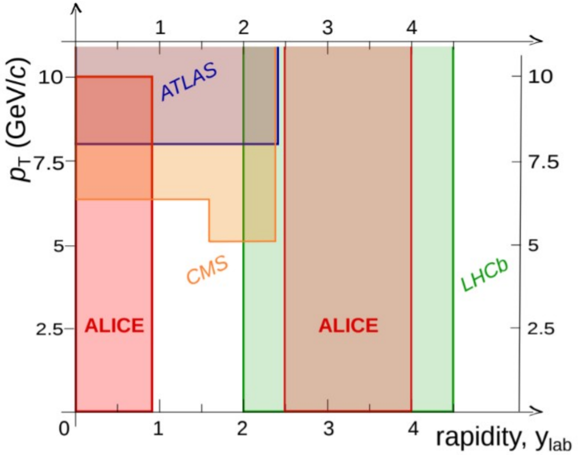
Heavy flavor production in proton-nucleus collisions at the LHC.

Theraa Tork

Quarkonia as Tools 2022

Outline

- Introduction and motivation:
  - ➔ Cold nuclear matter effects.
  - ➔ The nuclear modification factor.
  - ➔ Why to study yields vs multiplicity.
- Results of proton-nucleus collisions, the production of :
  - ➔ Charmonia : J/Ψ and Ψ(2S).
  - ➔ Open charm : D-mesons.
  - ➔ Bottomonia : Υ(nS).
- Summary



Cold nuclear matter effects

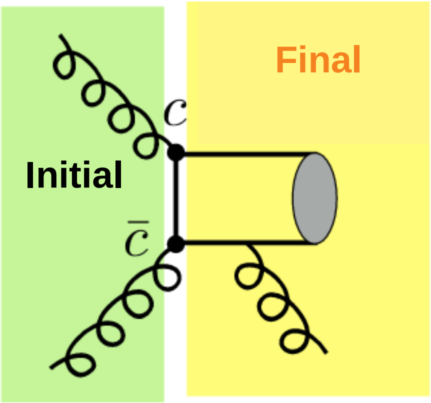
pA Collisions are important to study cold nuclear matter effects (CNM).

➔ **Initial state effect** :

- Parton shadowing due to modification of nuclear PDFs.
- Color Glass Condensate CGC i.e medium with high density of small x gluons.

➔ **Intial-Final** state effect :

- Energy loss energy lost by partons via gluon emission.



➔ **Final state effects** :

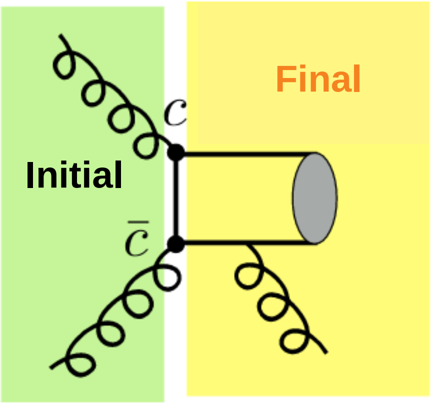
- Interaction with comoving particles.
- Nuclear absorption due to the interaction with the nucleons of the colliding nuclei.

Cold nuclear matter effects

pA Collisions are important to study cold nuclear matter effects (CNM).

➔ **Initial state effect** :
- ✔ Parton shadowing due to modification of nuclear PDFs.
- ✔ Color Glass Condensate CGC i.e medium with high density of small x, self interacting gluons.

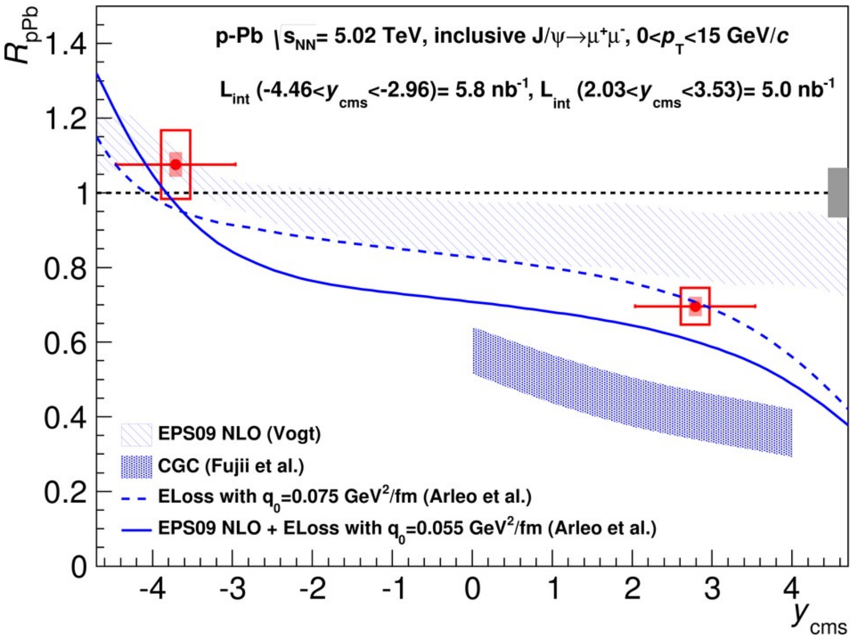
➔ **Intial-Final** state effect :
- ✔ Energy loss energy lost by partons via gluon emission.



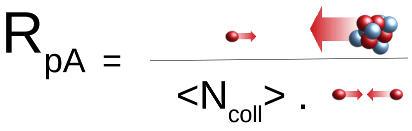
➔ **Final state effects** :
- ✔ Interaction with comving particles.
- ✗ ~~Nuclear absorption due to the interaction with the nucleons of the colliding nuclei~~ (**neglected at LHC energies**).

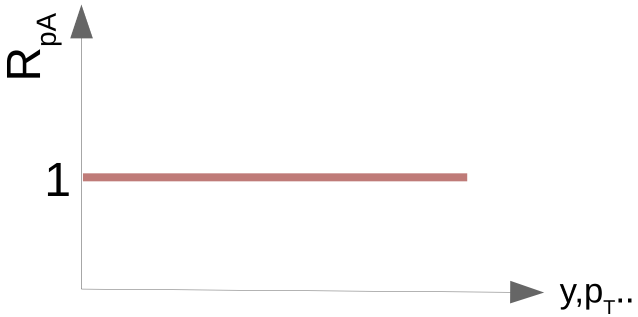
Nuclear modification factor

Goal : to understand the CNM effect on the particles production by comparing cross section in pA collisions to pp collisions



ALICE **JHEP 02 (2014) 073**



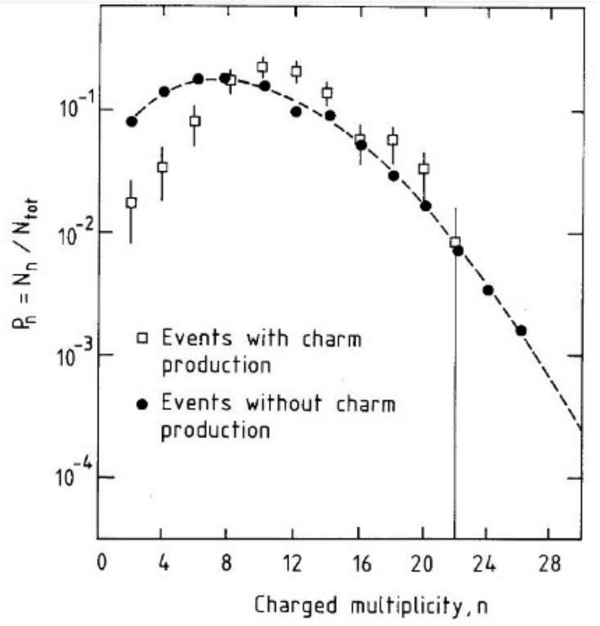


if $R_{pA} \neq 1 \rightarrow$ nuclear effect

Charged-particle multiplicity

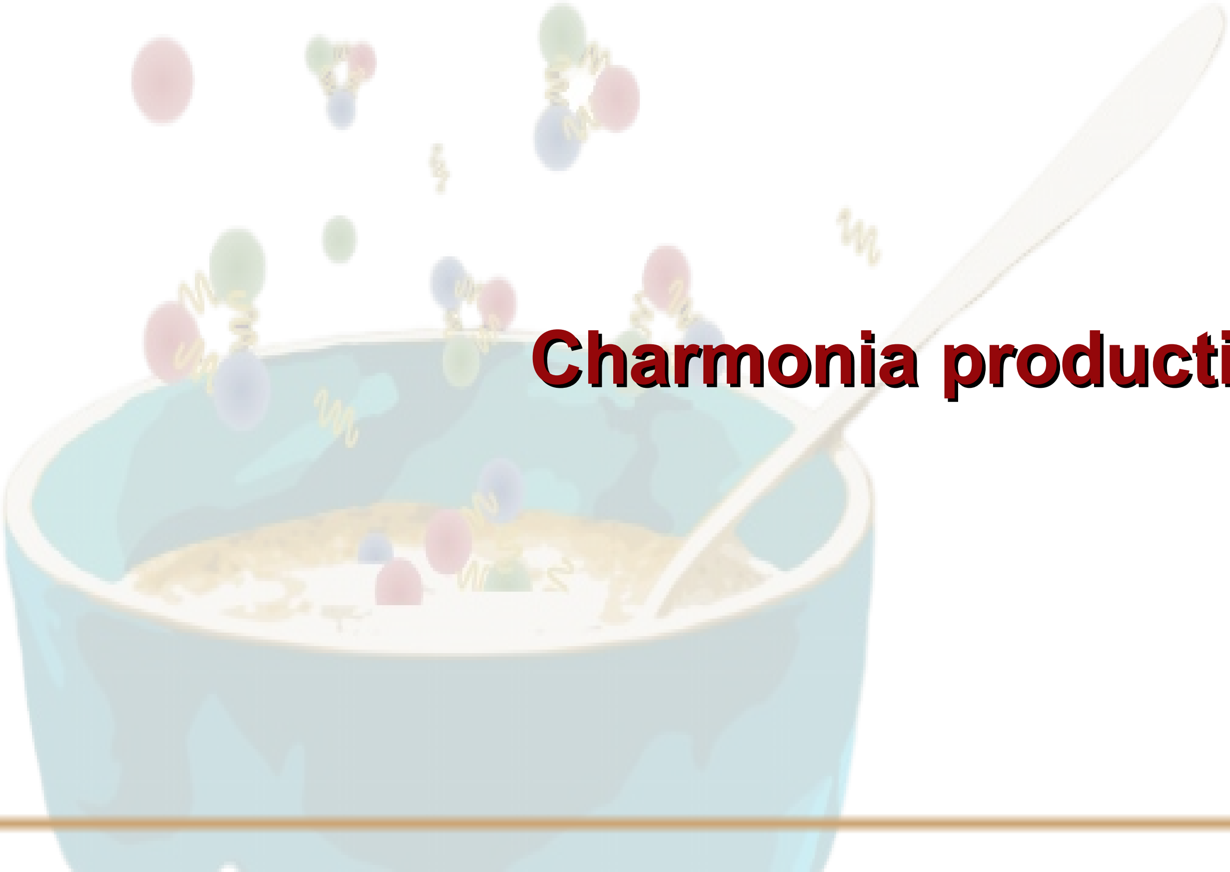
Goal : gain some insight into the processes occurring in the collision and the interplay between the hard and soft mechanisms in particle production.

- Charm and beauty are produced in hard processes.
- A larger multiplicity in events with charm production with respect to those without charm was observed in 1988 by the NA27 Collaboration.
- At LHC energies, a correlation between the heavy flavor production and charged-particle multiplicity was found.



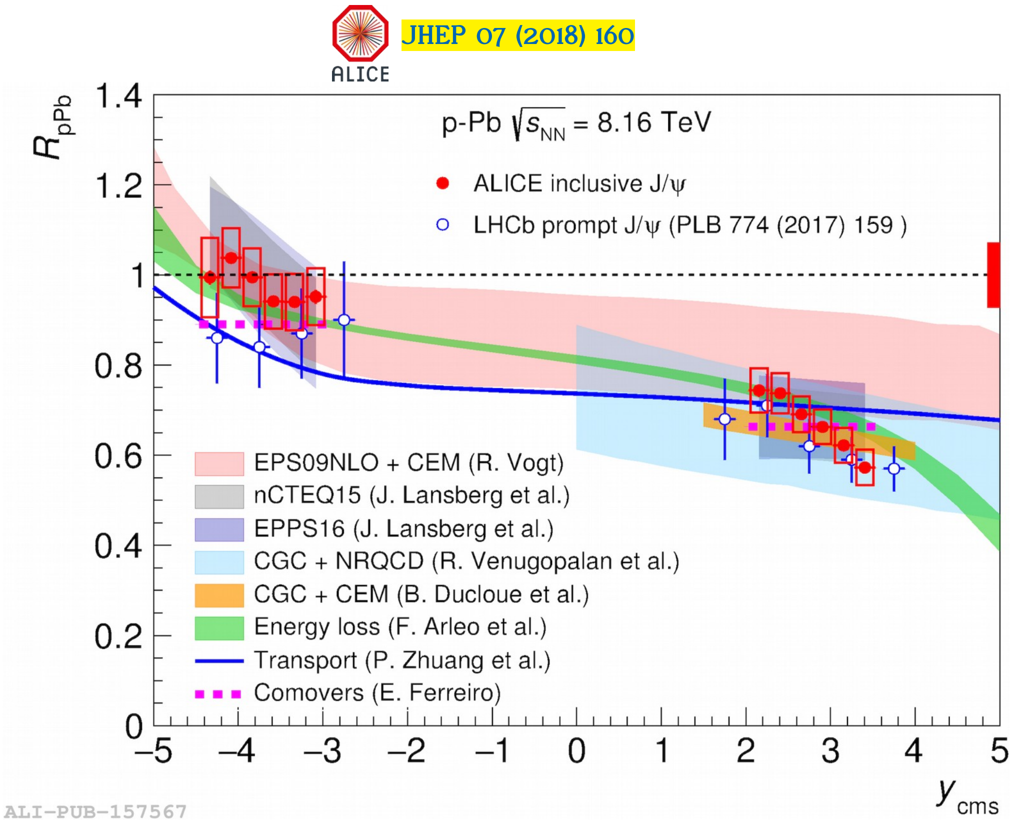
NA27 Z.Phys.C41:191,1988

Charmonia production



The ground state "J/Ψ"

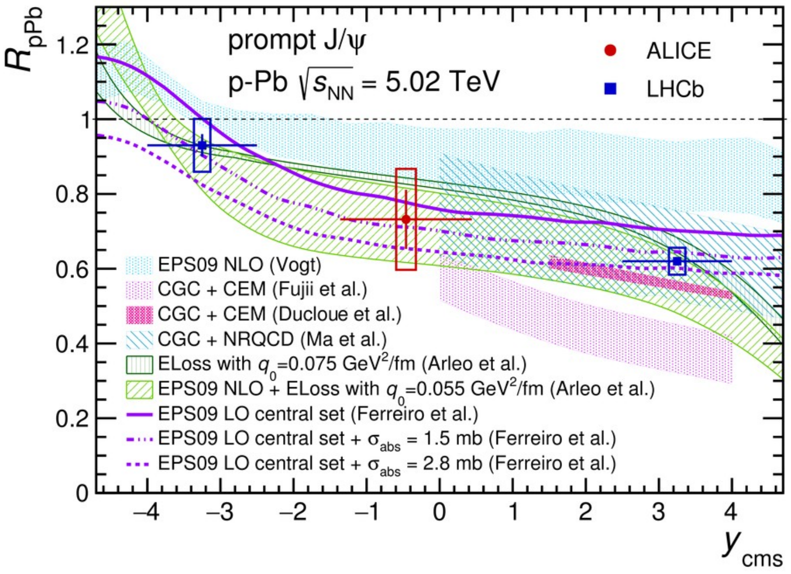
JHEP 07 (2018) 160



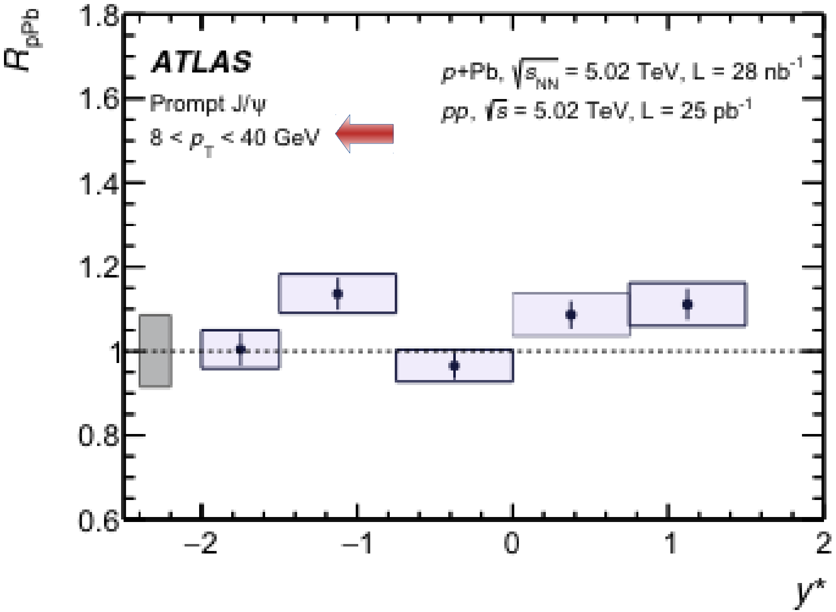
- Agreement between **ALICE** and **LHCb** results.
- Results is described by different models:
  - Shadowing.
  - nPDF.
  - CGC.
  - Energy loss.
  - Transport.
  - Comovers.

J/Ψ at midrapidity

ALICE Eur. Phys. J. C 78 (2018) 466



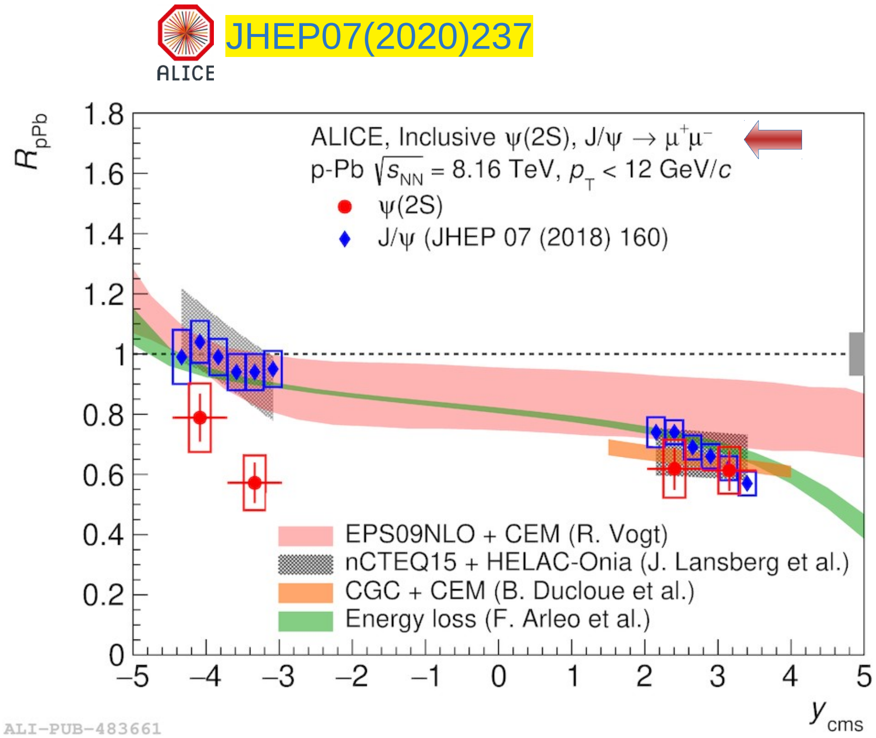
Eur. Phys. J. C (2018) 78:171



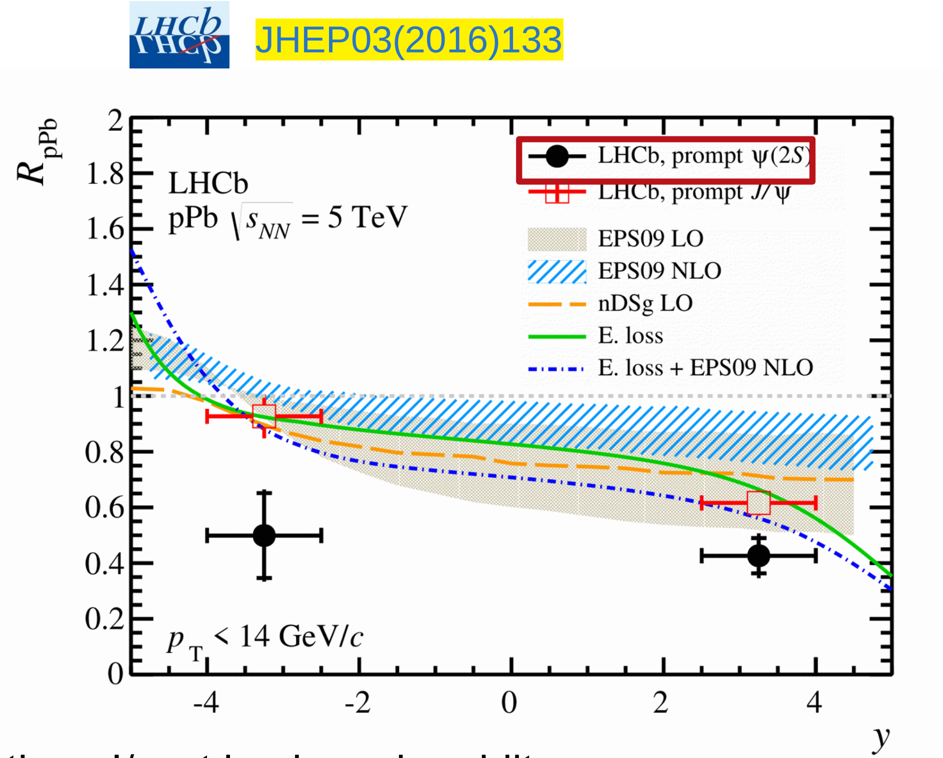
- $R_{pPb}^{J/\Psi}$ at midrapidity
- Described by CNM models which contain shadowing, CGC and energy loss.

The excited state "Ψ(2S)"

JHEP07(2020)237

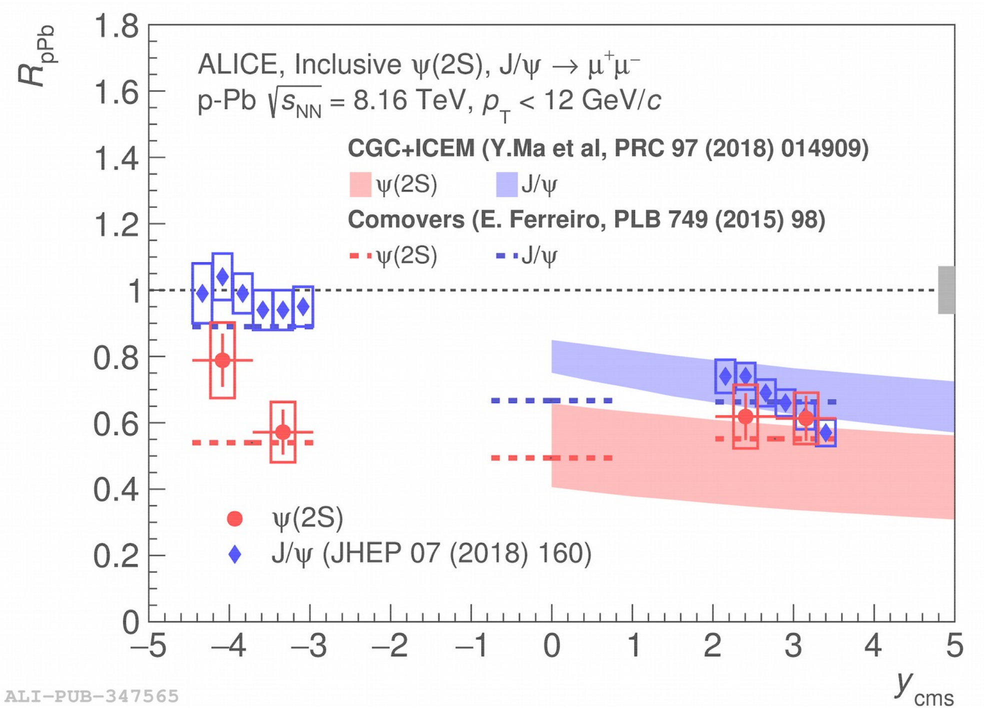


JHEP03(2016)133



- ψ(2S) experience a stronger suppression than J/ψ at backward rapidity.
- Initial state CNM effects did not reproduce the Ψ(2S) results at backward rapidity.

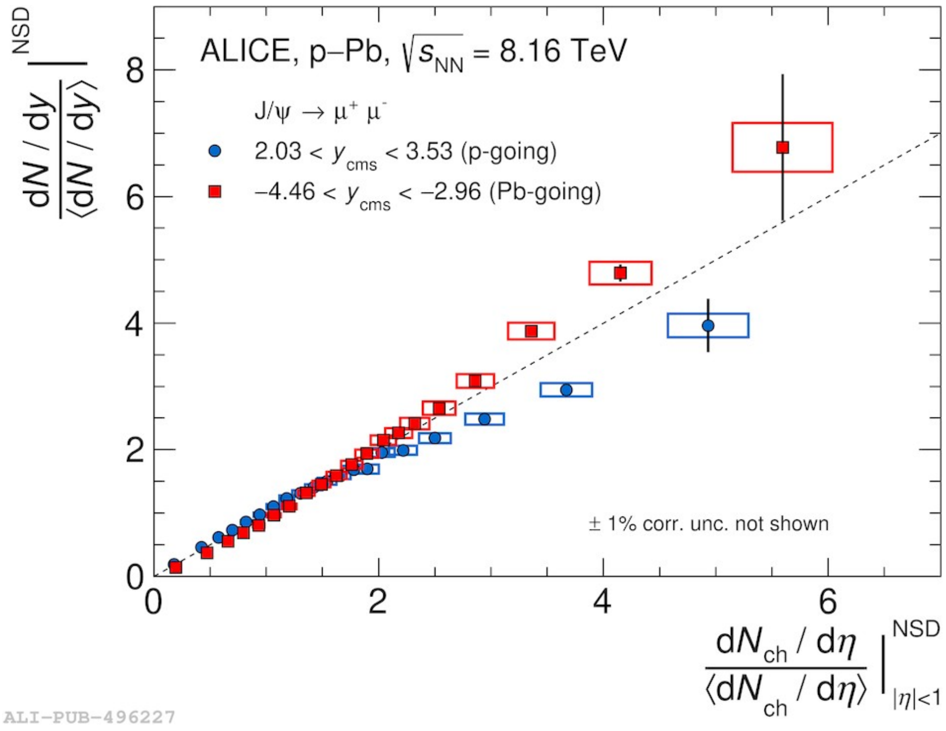
Ψ(2S) With final state effect calculations



JHEP07 (2020) 237

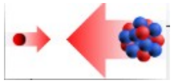
Ψ(2S) is better described with final state models "Comovers" i.e interaction of the **J/Ψ** or **Ψ(2S)** with the co-moving final-state hadrons.

J/Ψ yields Vs charged-particle multiplicity

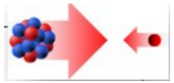


ALICE JHEP09(2020)162

- J/Ψ normalized yields Vs normalized charged-particle multiplicity.
- Increase with increasing multiplicity.
- Different behavior at forward and backward rapidity (different bjorken x regions.)

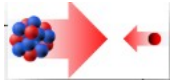


p-Pb (p-going direction)



Pb-p (Pb-going direction)

J/Ψ Vs multiplicity and model calculations



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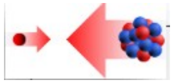
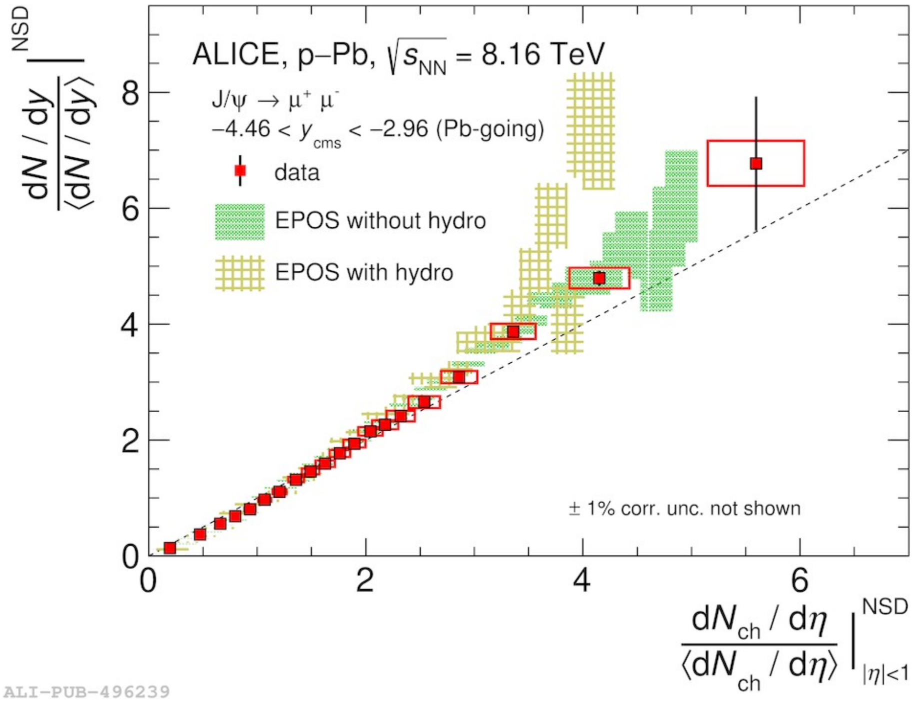
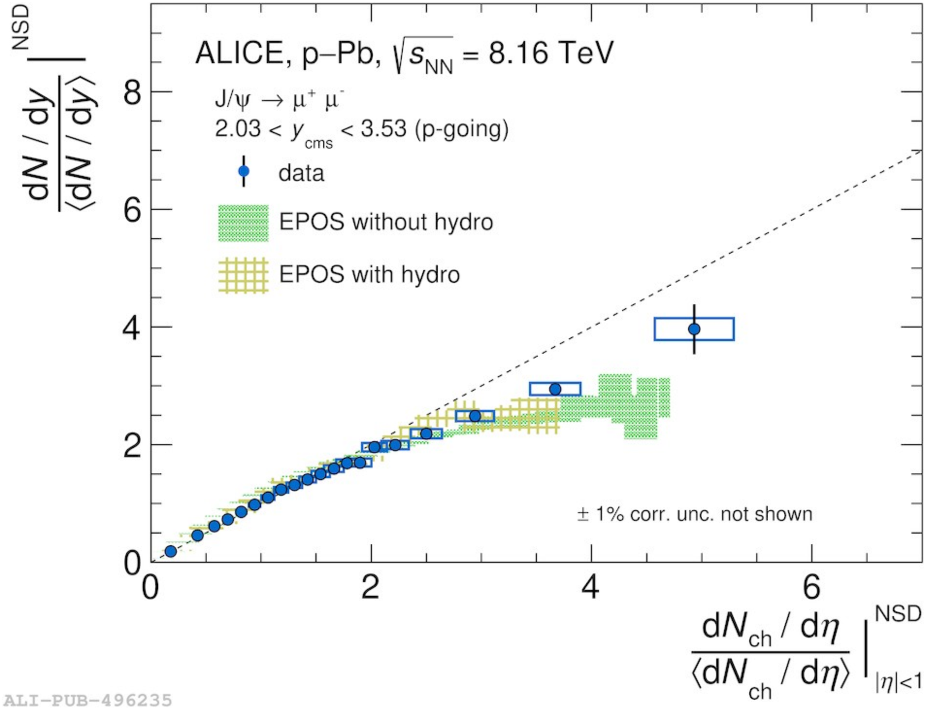
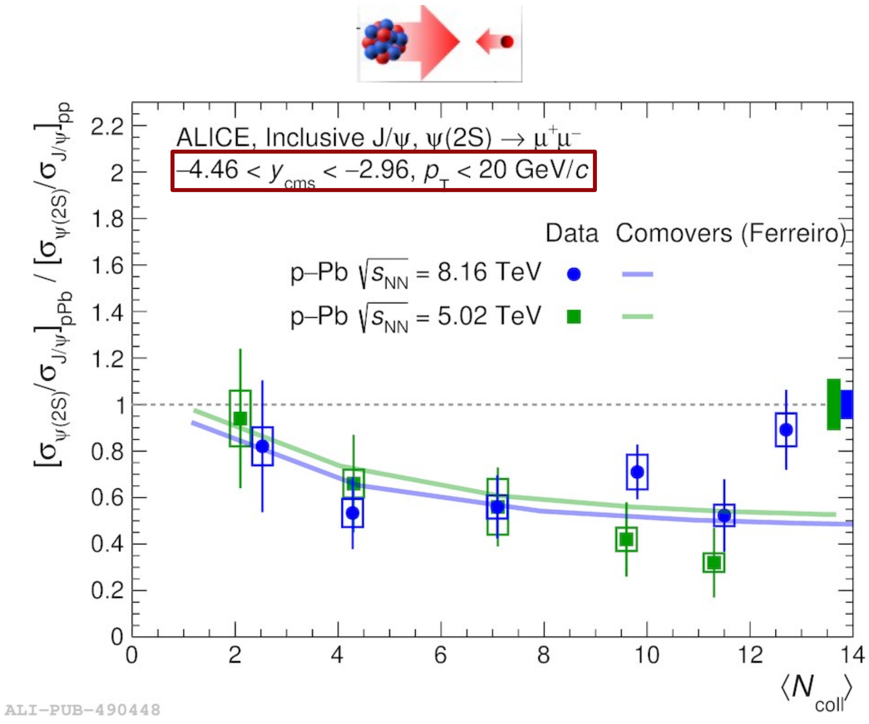


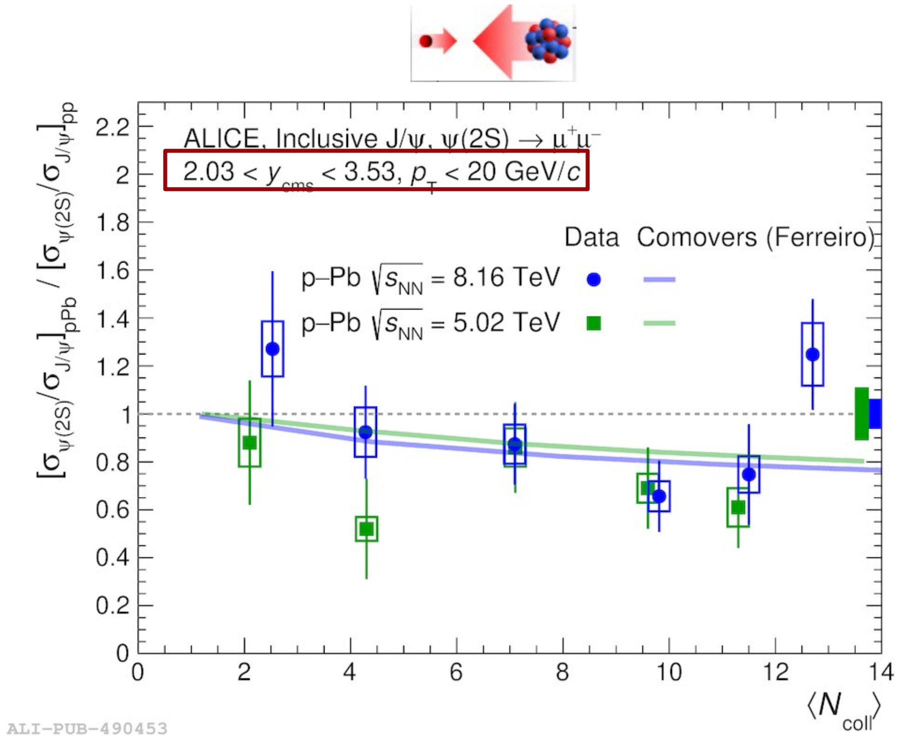




☞ See Johannes presentation about EPOS.

Ψ(2S)-over-J/Ψ double ratio





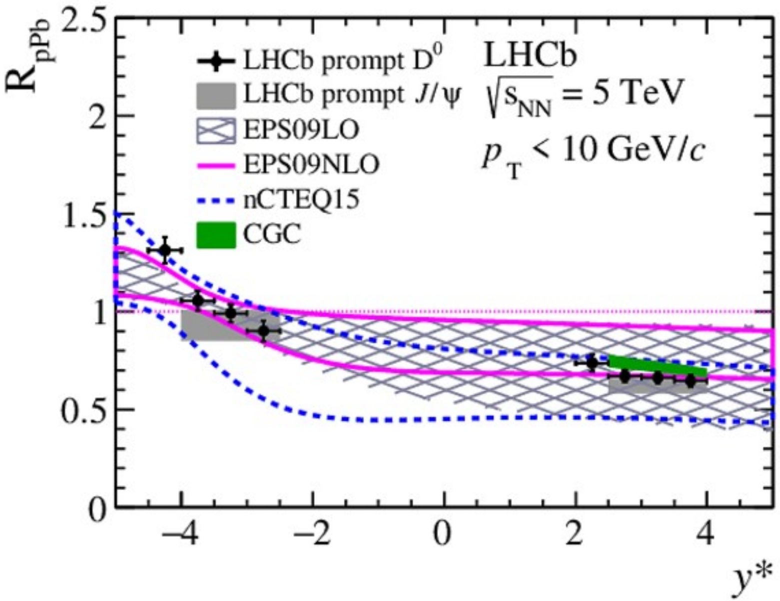
- <N_{coll}> is proportional to the charged-particle mutlpilicity.
- Comovers model described the double ratio Vs <N_{coll}>

JHEP 02 (2021) 002

Open charm

R_{pPb} of Prompt D^0 at forward rapidity

JHEP 10 (2017) 090

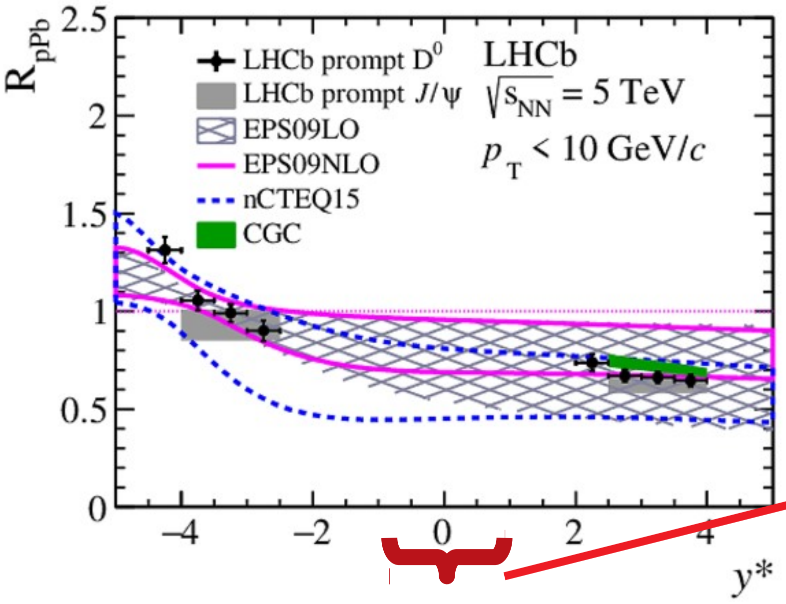


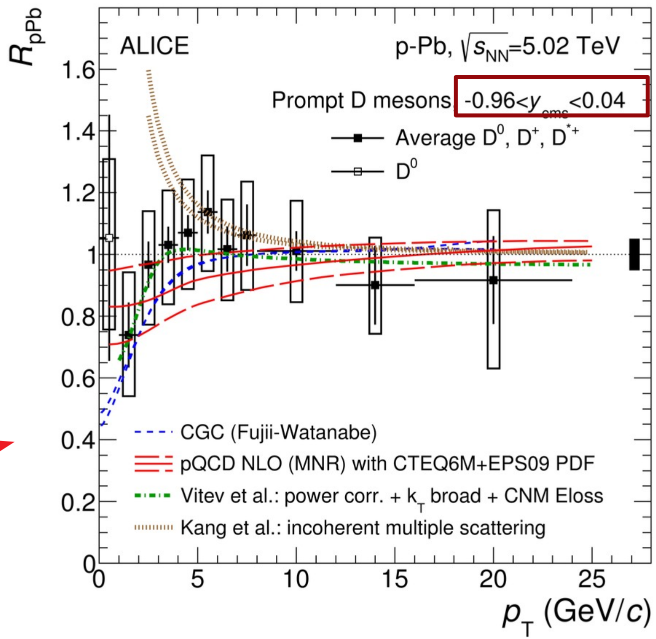
- Prompt D^0 meson Vs rapidity.
- Stronger suppression at forward rapidity than backward rapidity.
- CNM effects reproduced the behavior of R Vs y of D^0 meson.

R_{pPb} of Prompt D^0 at midrapidity

JHEP 10 (2017) 090

PRC 94, 054908 (2016)

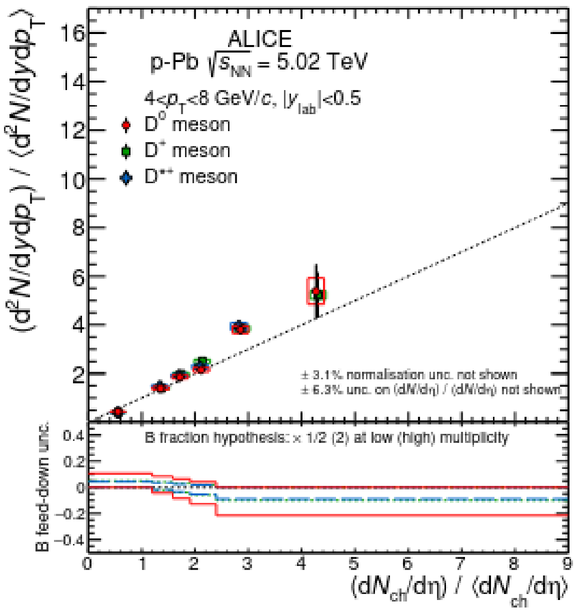


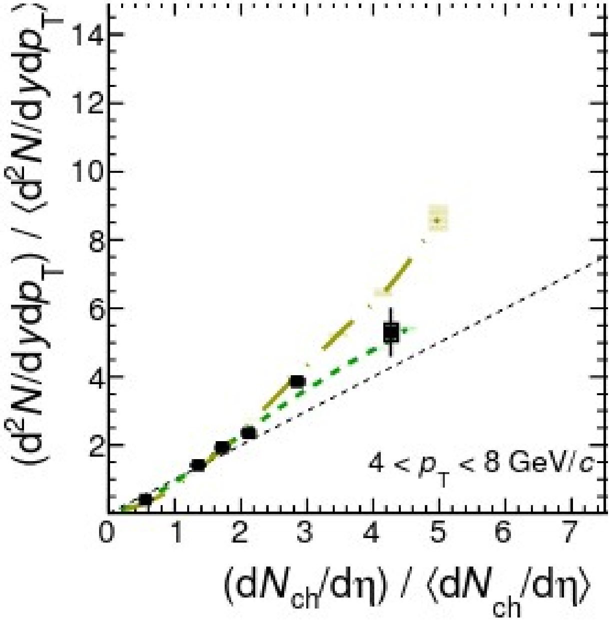


The overall R_{pPb} is compatible with unity at midrapidity .

Prompt D-meson Vs multiplicity

JHEP08(2016)078

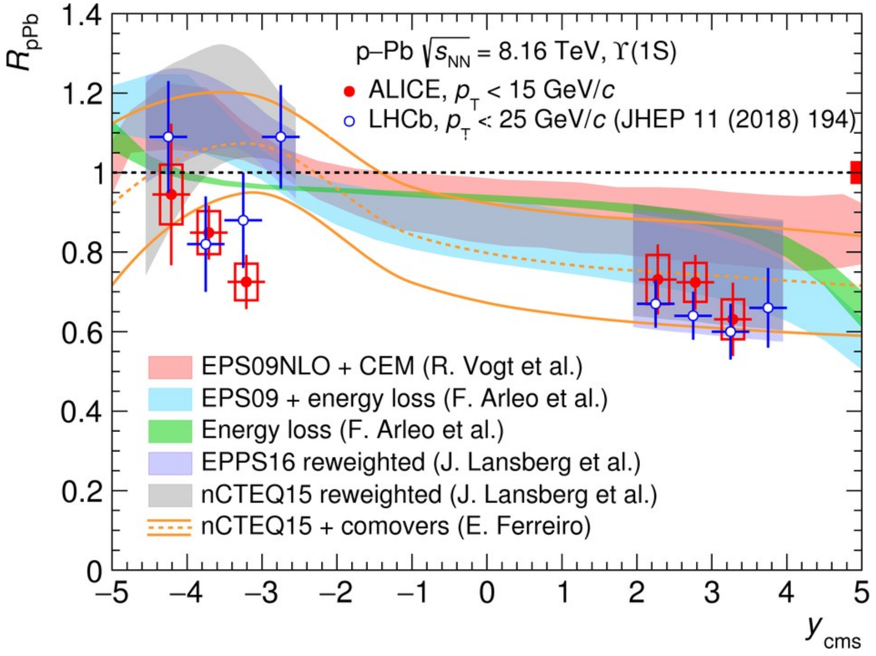




- Increase of normalized yields of D-meson as a function of charged particle multiplicity .
- The trend of the results was reproduced with EPOS event generator.

Bottomonia production

$R_{pPb}^{\Upsilon(1s)}$ Vs y

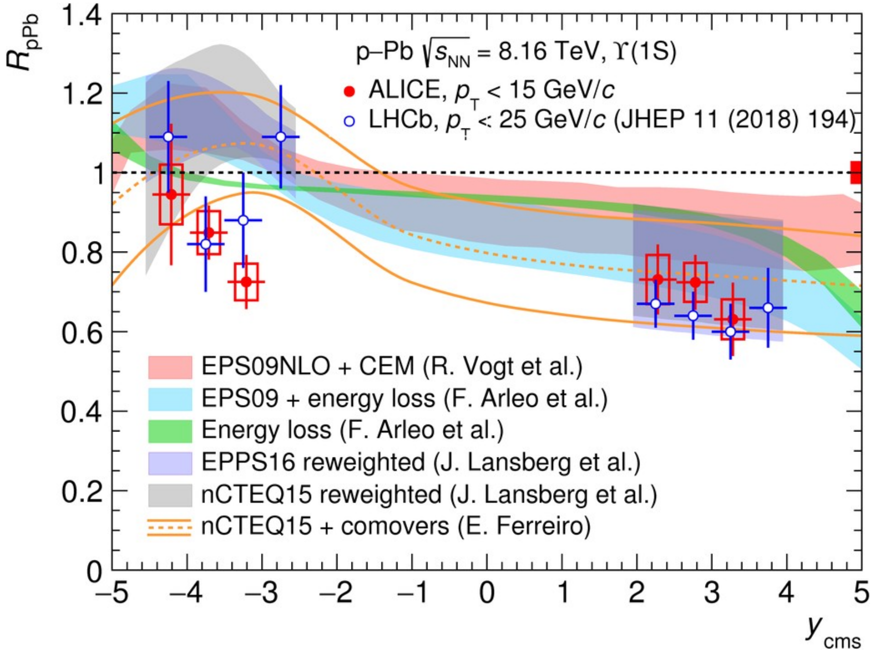


PLB 806 (2020) 135486

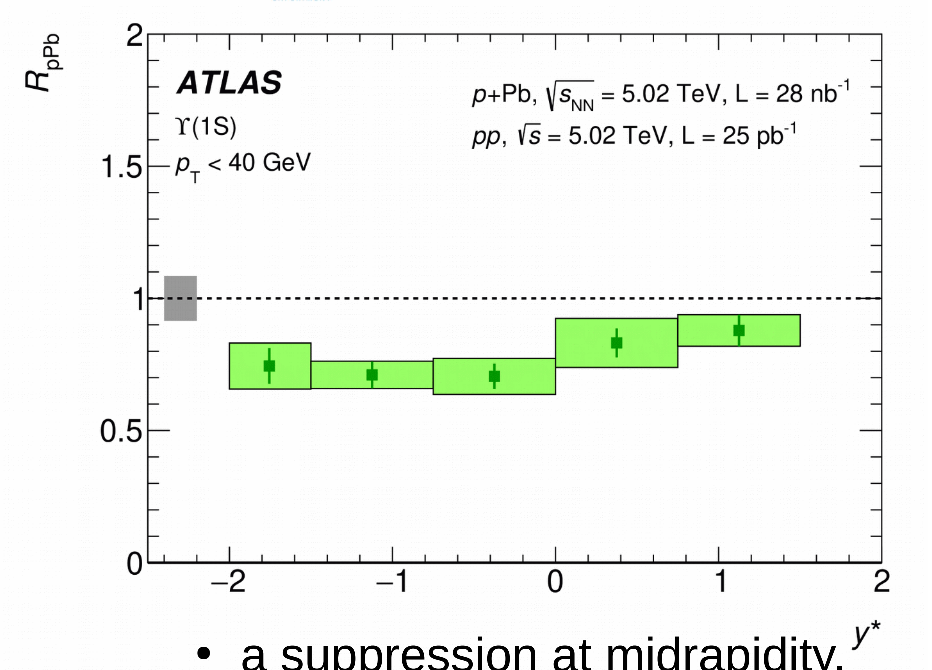
- Hint of stronger suppression at forward rapidity than backward.
- Agreement between **ALICE** and **LHCb** results.
- Described by models include CNM effects.

$R_{pPb}^{\Upsilon(1s)}$ Vs y

PLB 806 (2020) 135486

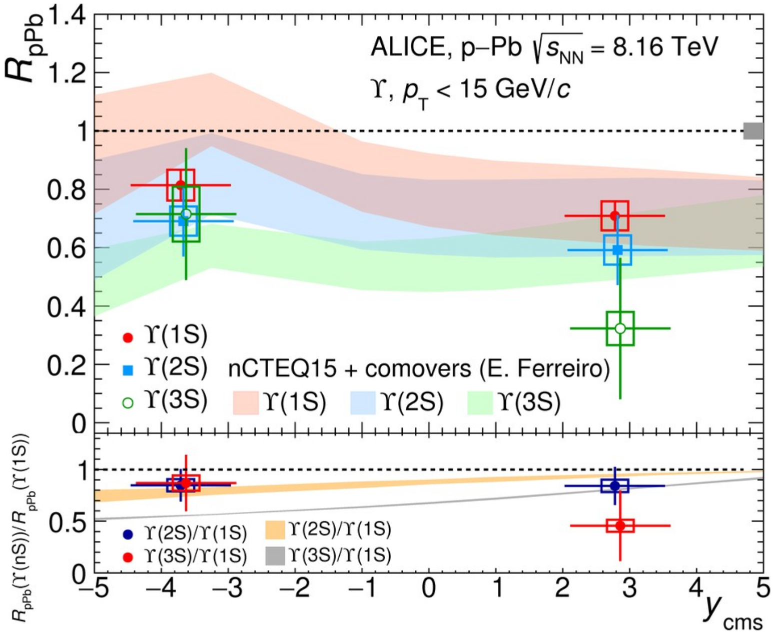


Eur. Phys. J. C 78 (2018) 171



- a suppression at midrapidity.
- No rapidity dependence at midrapidity observed.

$R_{pPb}^{\Upsilon(nS)}$ Vs y

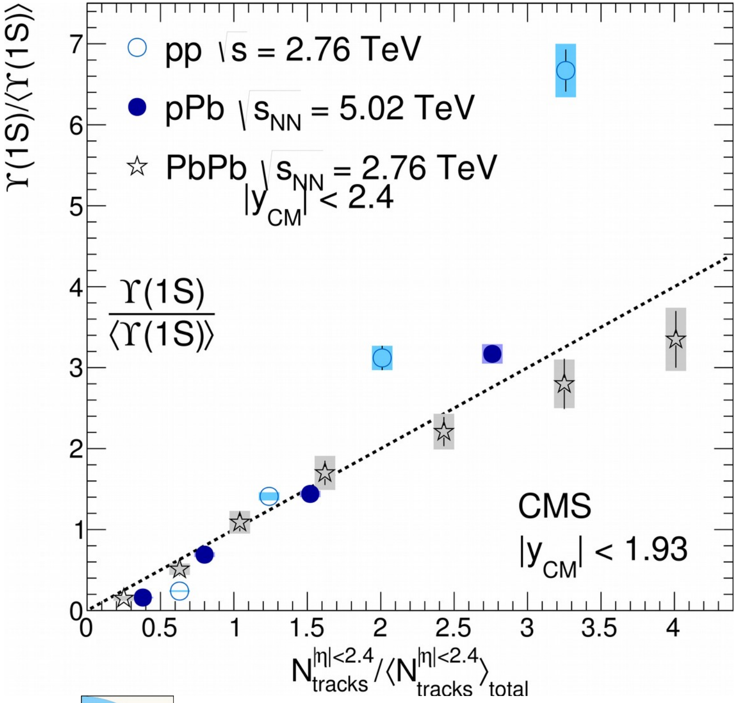


ALICE

PLB 806 (2020) 135486

A hint of stronger suppression for excited states compared to the ground state at forward rapidity.

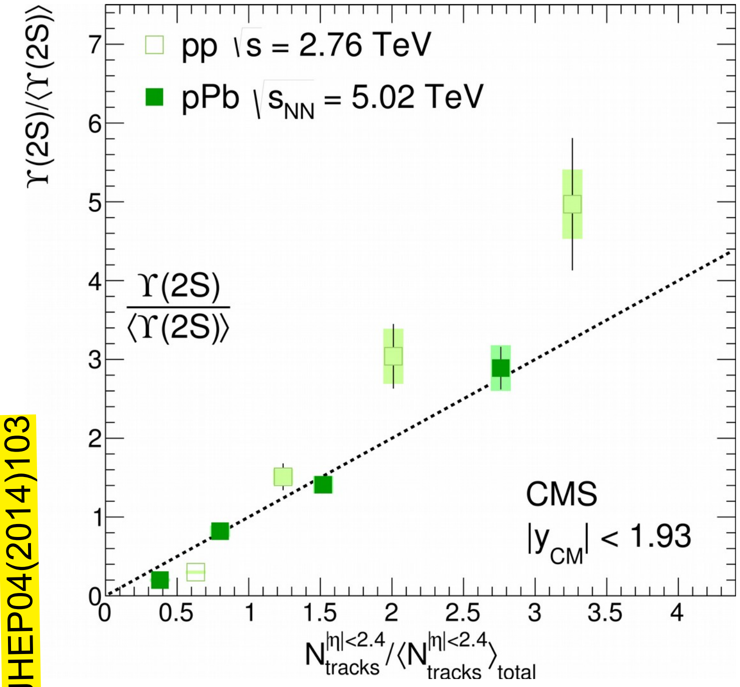
ϒ(1S) Vs mulltiplicity at midrapidity

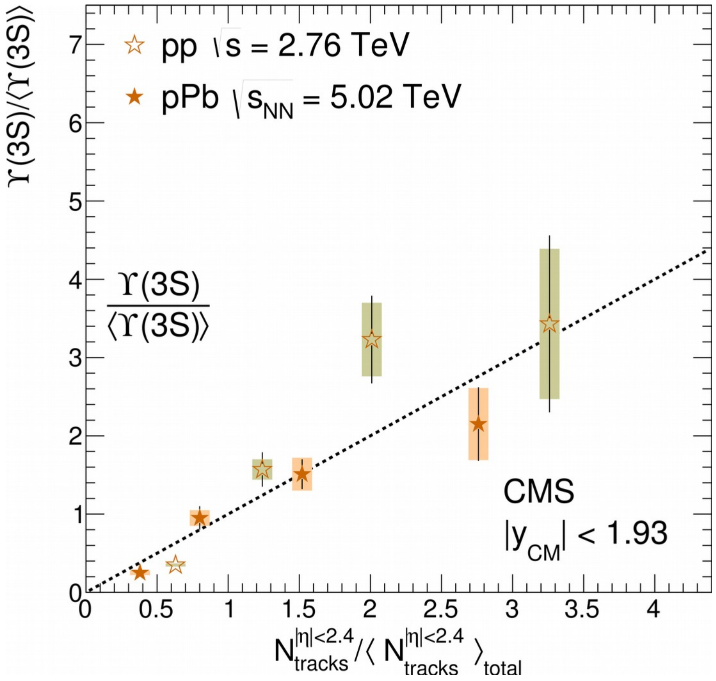


JHEP04(2014)103

- Increase of the Y(1S) as a function of multiplicity.
- Similar to the behavior of J/ψ and open heavy flavor.

ϒ(nS) Vs multiplicity at midrapidity





JHEP04(2014)103

- ϒ(nS) increases with increase multiplicity.
- Stronger increase for the results in pp than p-Pb.

Summary

- **Charmonia production at 8.16 TeV :**
  - J/Ψ stronger suppression at forward rapidity.
  - Ψ(2S) experience a stronger suppression than J/Ψ at backward rapidity.
  - Final state effects described the Ψ(2S) production better than CNM effects.
  - Increasing of J/Ψ normalized yields as a function of charged-particle multiplicity.
- **Open heavy flavor production at 5 TeV :**
  - Stronger suppression at forward rapidity than backward region of D meson.
  - At midrapidity, R_{pPb} is compatible with unity.
  - Increase of the normalized yields as a function of multiplicity.
- **Bottomonia production at 8 and 5 TeV :**
  - Hint of stronger suppression at forward rapidity.
  - Excited state suppression experience stronger suppression at forward rapidity.
  - Normalised Yields are increasing as multiplicity increases.

Thank you !

High multiplicity events in small systems

⚠ **Small systems = pp or p-Pb collisions**

Unexpected observations in small systems at high multiplicity :

- Elliptic Flow : long-range angular correlation.
  10.1007/JHEP09(2010)091.

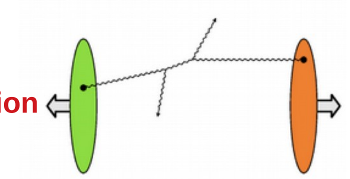
- Enhanced production of strange hadrons similar to Pb-Pb collisions.
  Nature Phys **13,** 535–539 (2017).

How to interpret this behavior ?

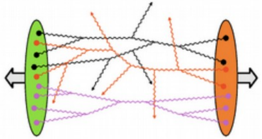
→ QGP droplets in high multiplicity events.

→ Multi parton interactions : several interaction at parton level in a single collision.

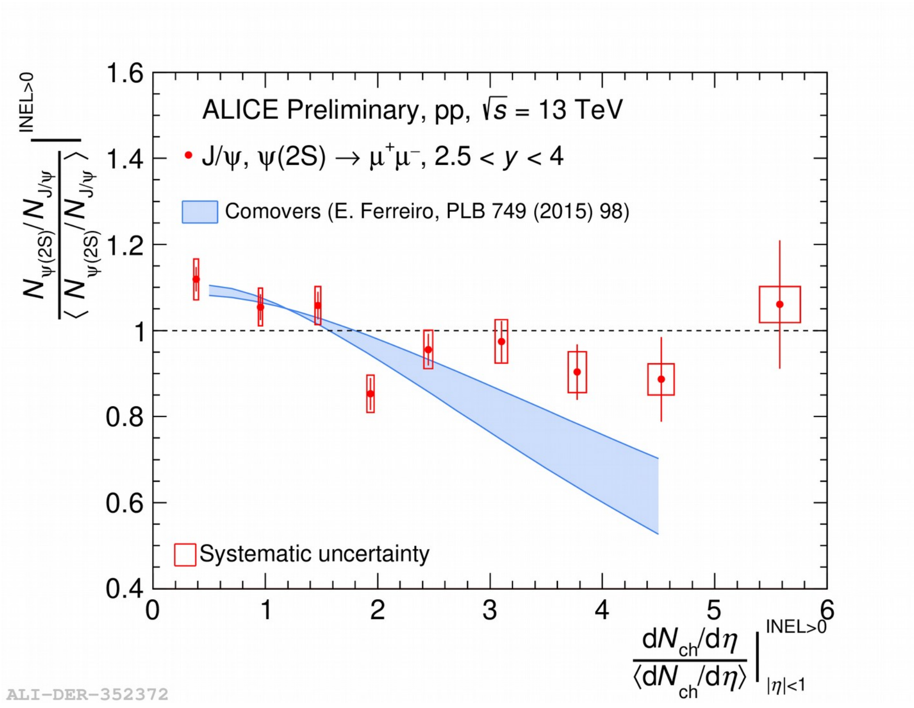
Single parton interaction



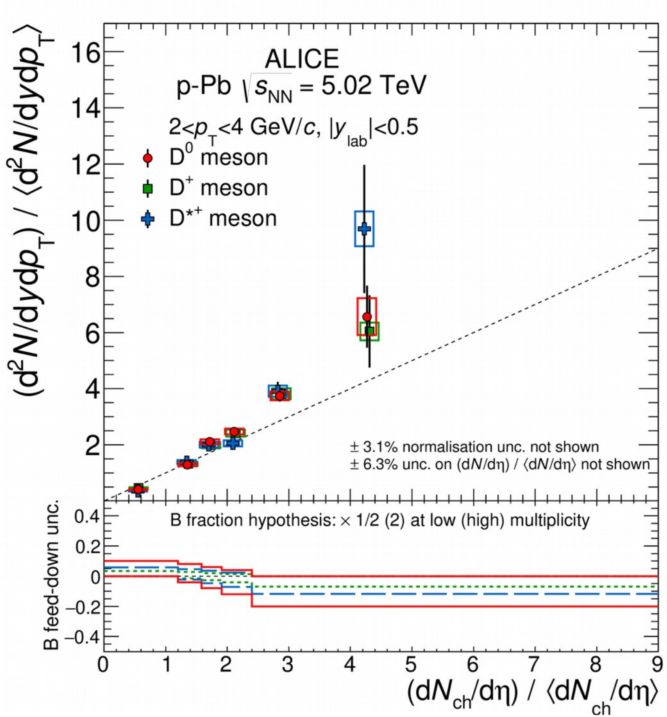
Multi parton interaction

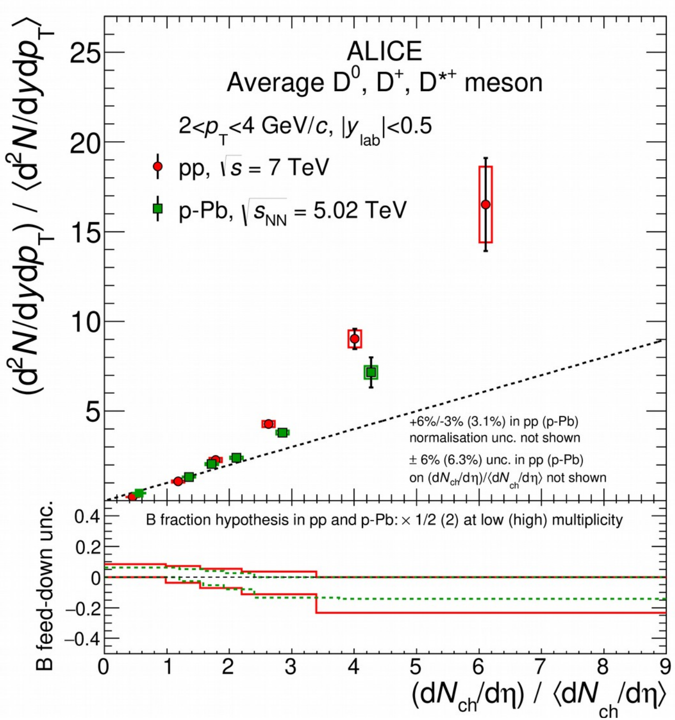


Ψ(2S)-over-J/Ψ double ratio



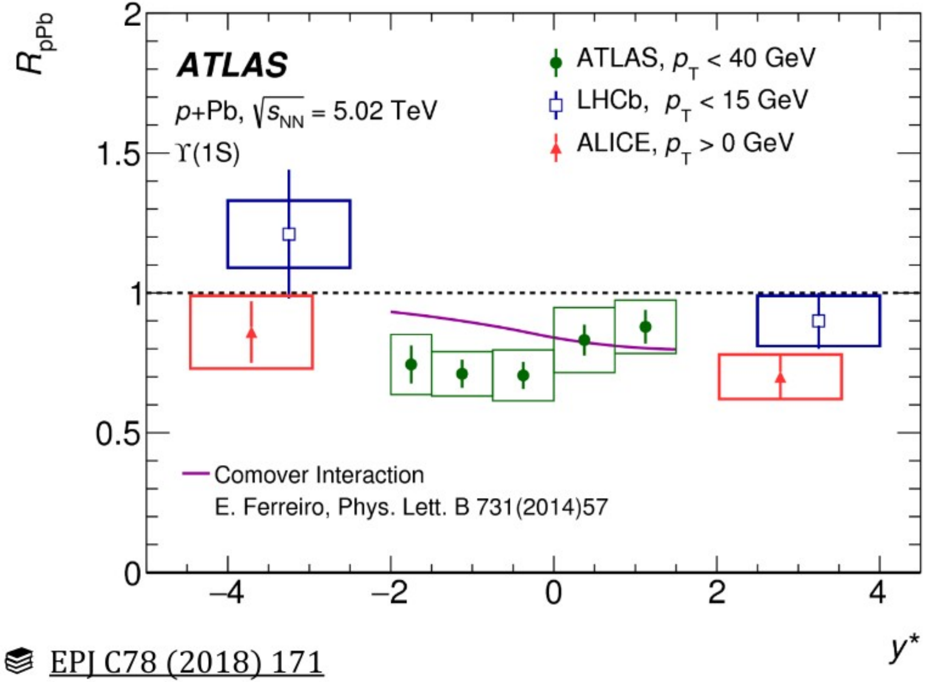
Prompt D Vs multiplicity





- Increase of prompt D Vs multiplicity.
- Stronger increase in pp than p-Pb.

ALICE, ATLAS and LHCb: $R_{pPb}^{\Upsilon(1s)}$



EPJ C78 (2018) 171

- Suppression at midrapidity !
- No rapidity dependence at midrapidity.