Quarkonium production as a function of charged-particle multiplicity in pp and p–Pb collisions with ALICE at the LHC

Theraa TORK,
On behalf of the ALICE collaboration.
IJCLab, Paris-Saclay university.

DIS2022, 2-6 May 2022
Santiago de Compostela, Spain.

High multiplicity events and MPI

Features known as a signature of QGP were observed in pp and p-Pb collisions:

- Elliptic flow of charged particles: long-range angular correlation.
  JHEP 10.1007/09(2010).

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

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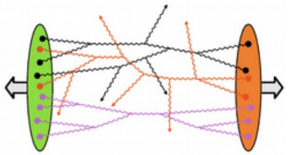
  Nature Phys 13, 535–539 (2017).

How to interpret this behavior ? **possible scenarios:**

- **Final state effects**: e.g. interaction with co-moving particles. Comovers effects are expected to be stronger for loosely bound states. Phys. Lett. B 749 (2015) 98–103

- **QGP droplets** in high multiplicity events.

- **Multiparton interactions (MPIs)**: several parton–parton interactions in a single hadron-hadron collision.



Increase number of parton-parton interactions → increase charged-particle multiplicity.

Outline

How does multiparton interactions (MPIs) influence quarkonium production ?

To answer this question we will go through :

The reference system, pp collisions at $\sqrt{s}$ = 13 TeV:

- Double J/ψ production cross section.
- Multiplicity dependence of :
  - J/ψ and ψ(2S) production.
  - bottomonia ϒ(nS) production .

The p–Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV:

- Cold nuclear matter effects.
- Multiplicity dependence of:
  - J/ψ and ψ(2S) production.

Where to look for MPI

It is directly connected with event multiplicity

- Quarkonium pairs production (ideally):
  - Direct probe for MPIs.
  - In addition, provide information on single quarkonium production mechanism.

  But it needs large statistics to measure (p_T and / or y differential) cross section.

- (or) Quarkonium production vs multiplicity:
  - Indirect probe for MPI.
  - Gain insight on the correlation between soft and hard process in the interaction.

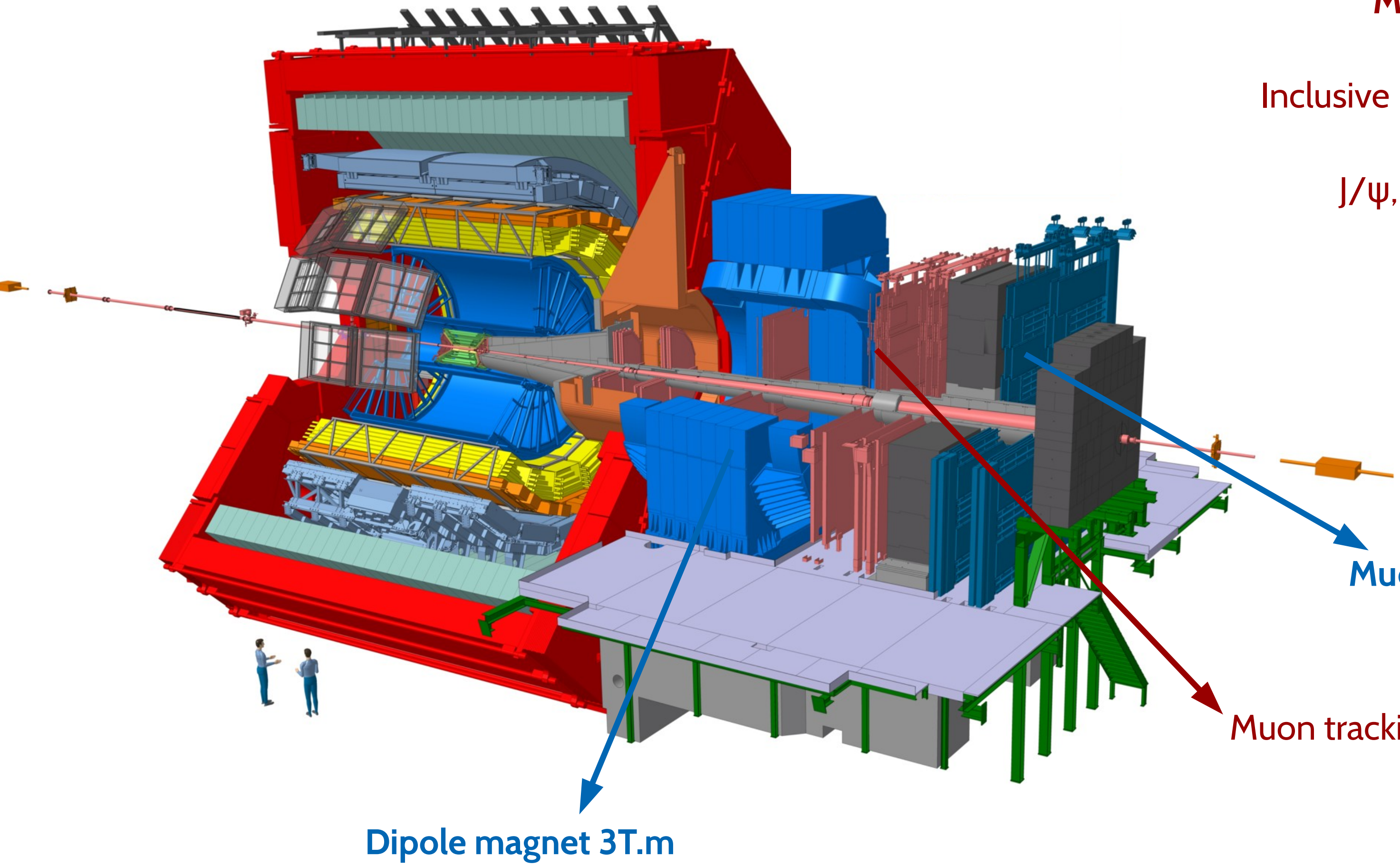
The ALICE Experiment

Muon spectrometer

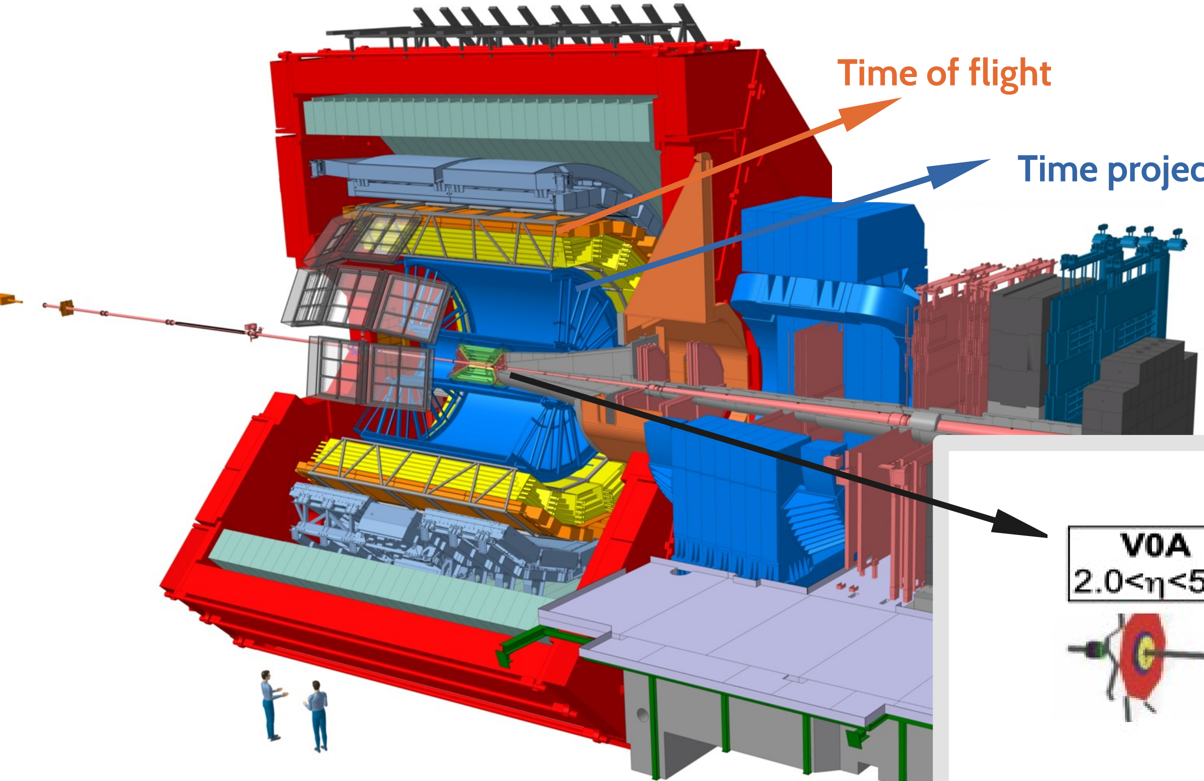
$-4.0 < \eta_{lab} < -2.5$

Inclusive production, down to $p_T = 0$ of

J/ψ, $\psi(2S)$, $\Upsilon(nS) \rightarrow \mu^-\mu^+$.



The ALICE Experiment



Central barrel

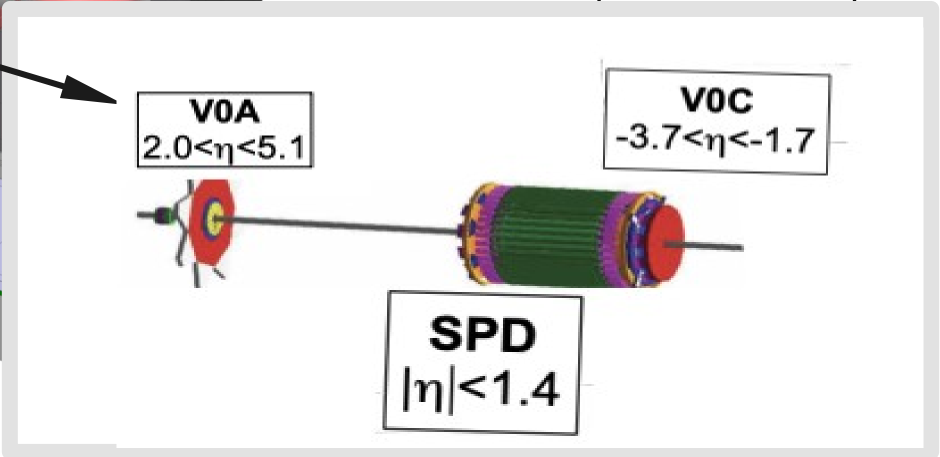
$|\eta_{lab}| < 0.9$

Inclusive, prompt and non prompt $J/\psi \rightarrow e^{-}e^{+}$ analysis at midrapidity down to $p_T = 0$.

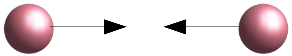
Multiplicity is measured

- with SPD in the restricted range $|\eta| < 1$.
- Or with V0 detector

($-3.7 < \eta < -1.7$ and $2.0 < \eta < 5.1$).



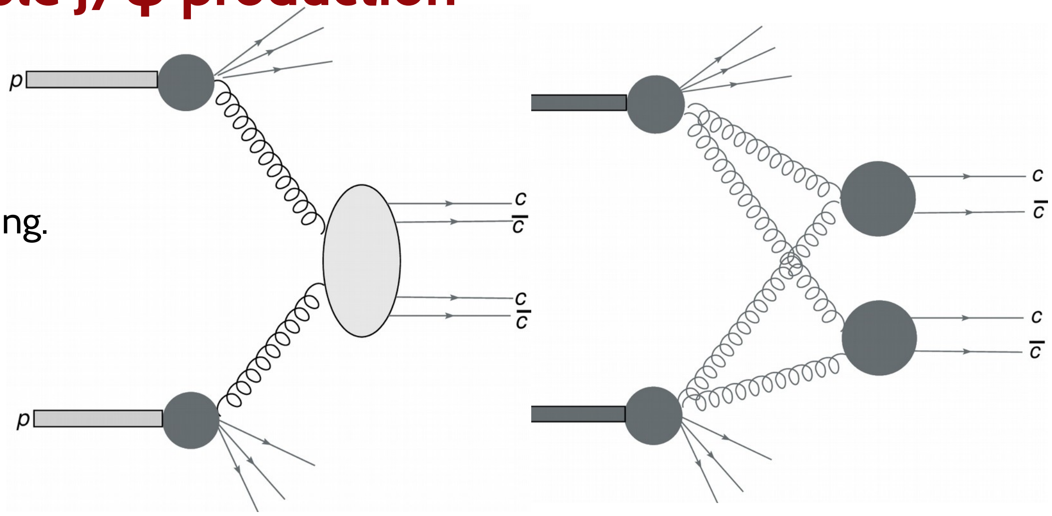
The reference system: pp collisions at $\sqrt{s}$ = 13 TeV



Double J/ψ production

Important to gain an insight on :

- Single J/ψ production.
- MPI: single and double parton scattering.



AIP Conf. Proc. 1523 (2013) 1, 255-259

Double J/ψ production

Important to gain an insight on :
- Single J/ψ production.
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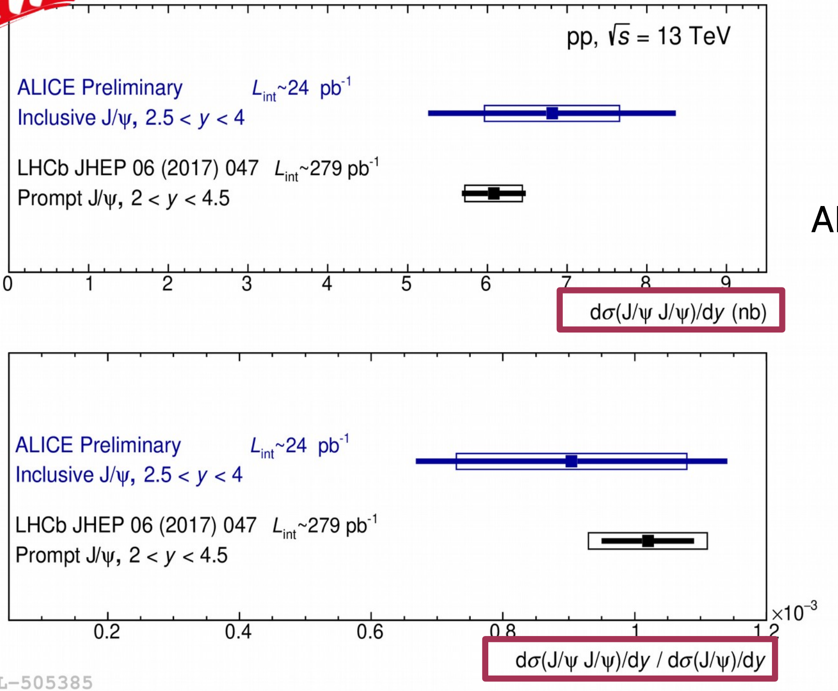
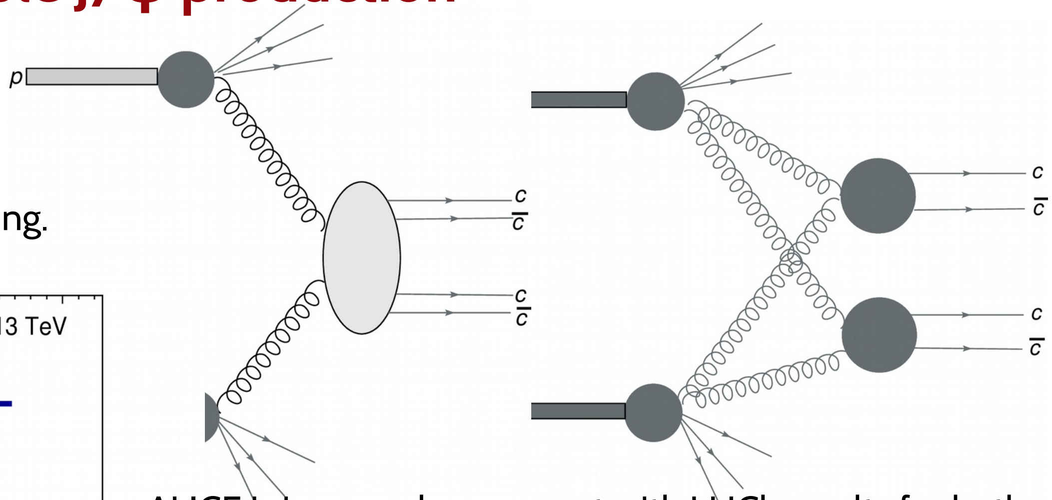
NEW





AIP Conf. Proc. 1523 (2013) 1, 255-259

ALICE is in a good agreement with LHCb results for both:

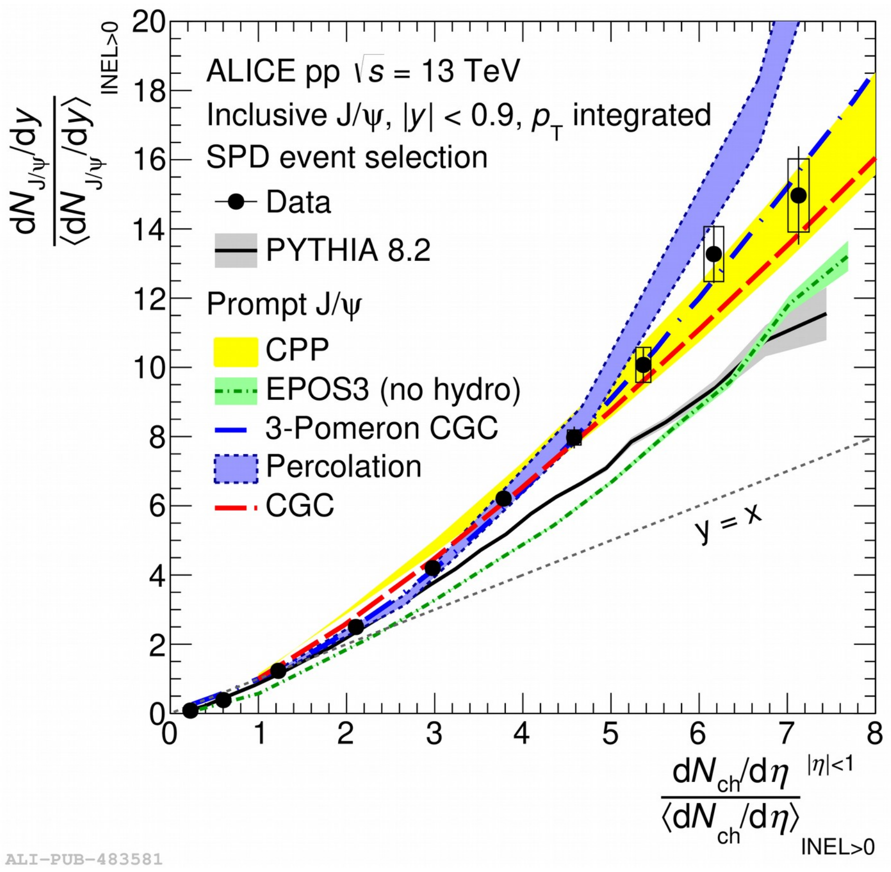
- Double J/ψ cross section.
- Double-to-single J/ψ cross section ratio.

Caveats:
- LHCb measured prompt double J/ψ production.
- Slight difference in the rapidity window between ALICE and LHCb.

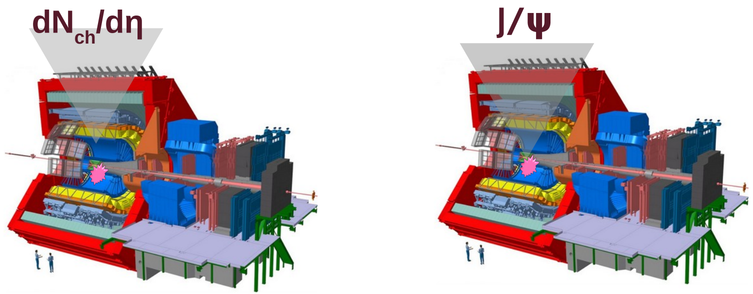
Multiplicity dependence of J/ψ production

measured at midrapidity

PLB 810 (2020) 135758



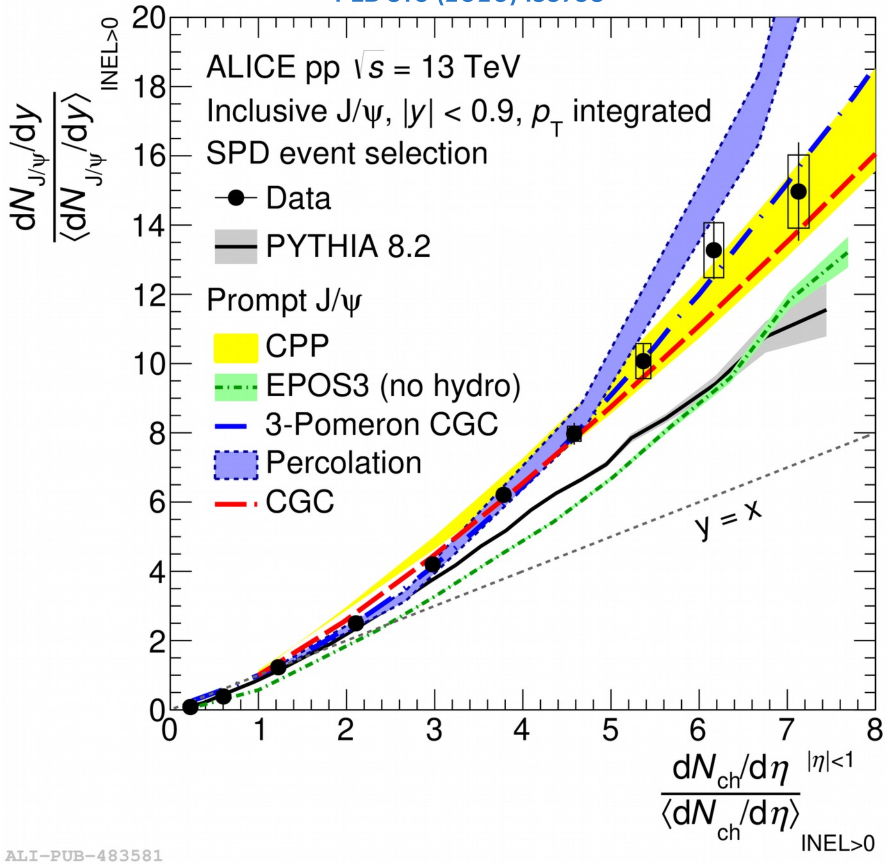
- Self normalized J/ψ yields vs multiplicity at midrapidity.
- Faster than linear increase of J/ψ yields vs multiplicity .
- The trend is described by models that include either initial and/or final state effects.
- EPOS 3 and PYTHIA 8.2 event generators do not reproduce the behavior of the data.



Multiplicity dependence of J/ψ production

measured at midrapidity

PLB 810 (2020) 135758



- Self normalized J/ψ yields at midrapidity vs multiplicity at midrapidity.
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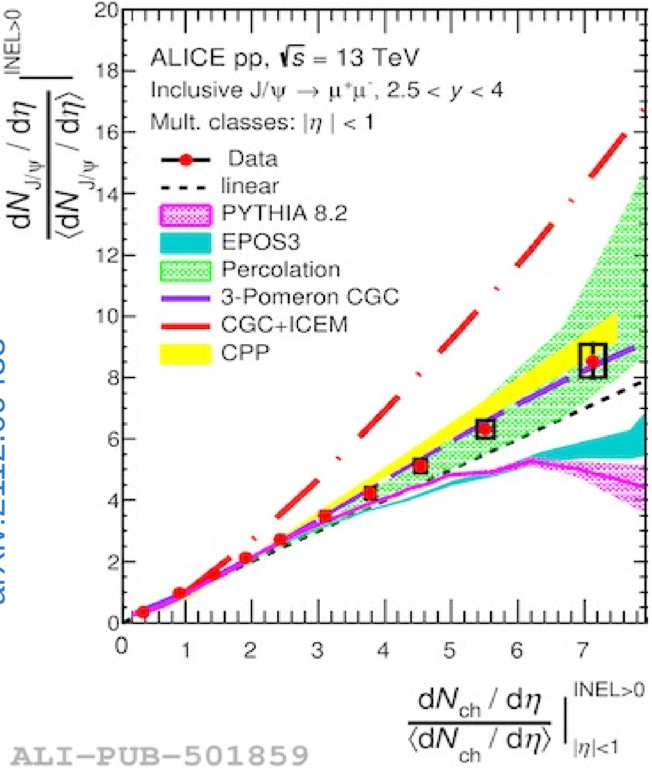
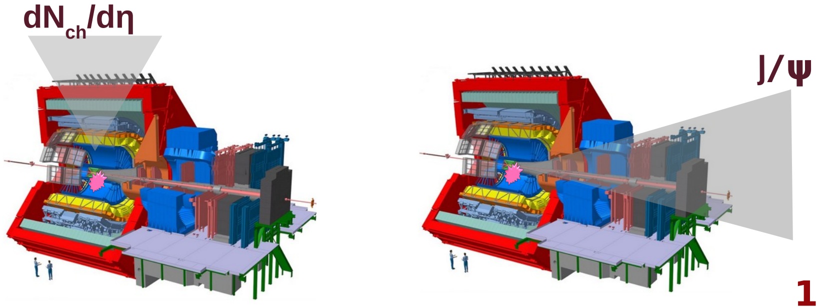
Multiplicity dependence of J/ψ production

measured at forward rapidity



arXiv:2112.09433

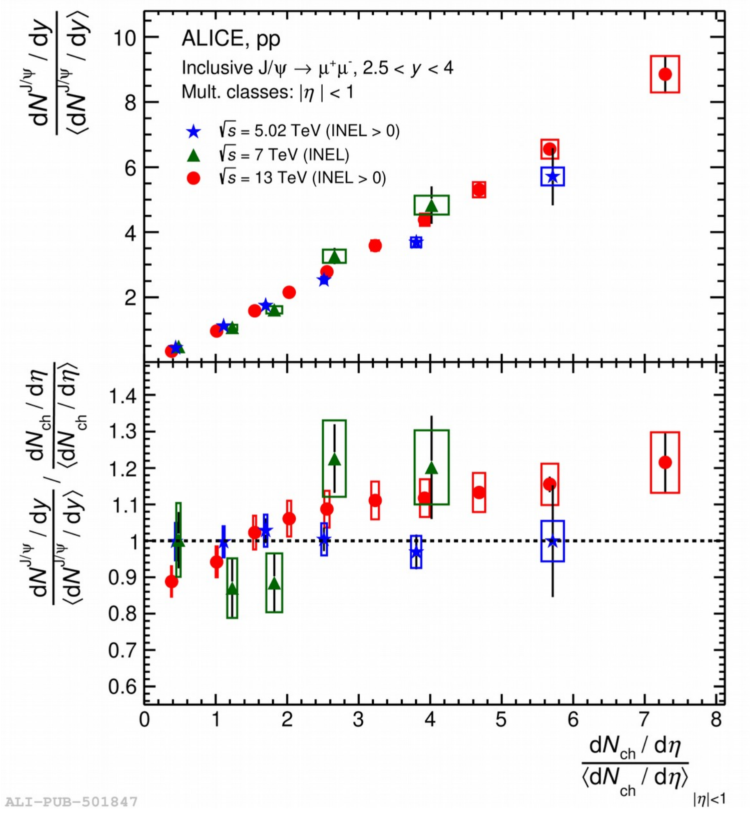
- J/ψ yields at forward rapidity vs multiplicity measured at midrapidity:
  - Compatible with a linear increase within uncertainty.
  - Models includes initial and/or final state effects reproduce the measurements
- EPOS 3 and PYTHIA 8.2 event generators do not reproduce the behavior of the data.



ALICE

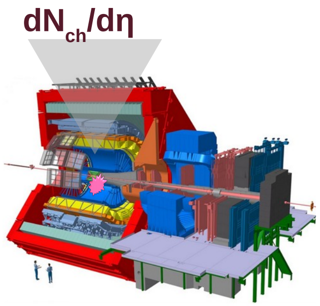
Multiplicity dependence of J/ψ production at different c.m.s energies

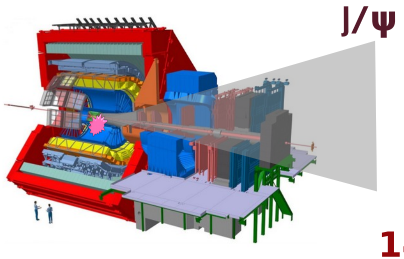
Higher energies, more MPIs ?



arXiv:2112.09433

- J/ψ yields at forward rapidity vs multiplicity measured at midrapidity at √s = 5.02 TeV, 7 TeV, and 13 TeV:
  - Compatible with a linear increase within uncertainty.
  - The data points at the three collision energies are compatible with each other.

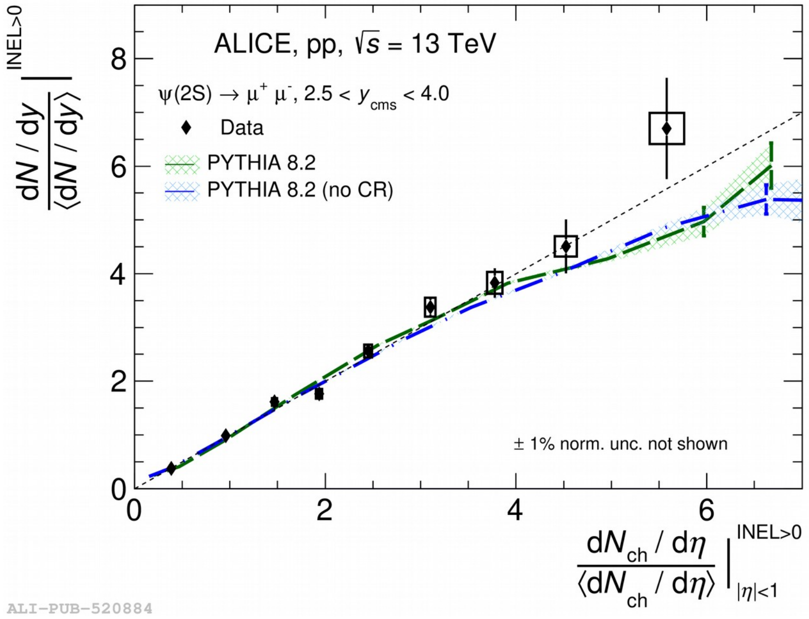


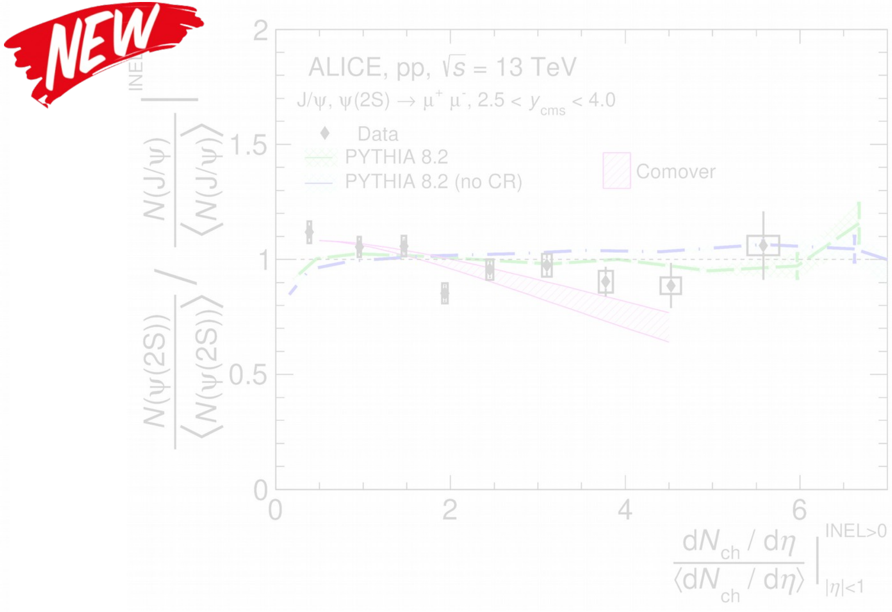


Multiplicity dependence of ψ(2S) production

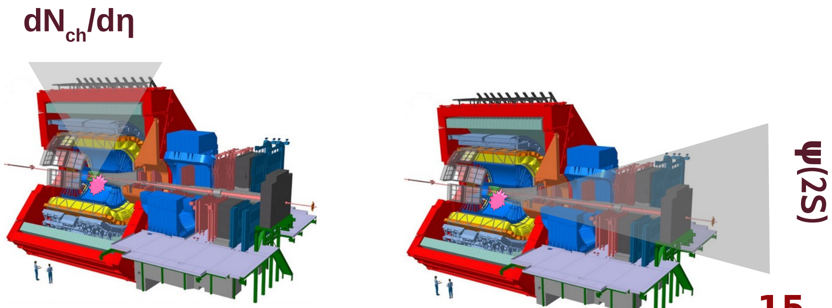
ψ(2S) is the radial excited state of J/ψ

arXiv:2204.10253



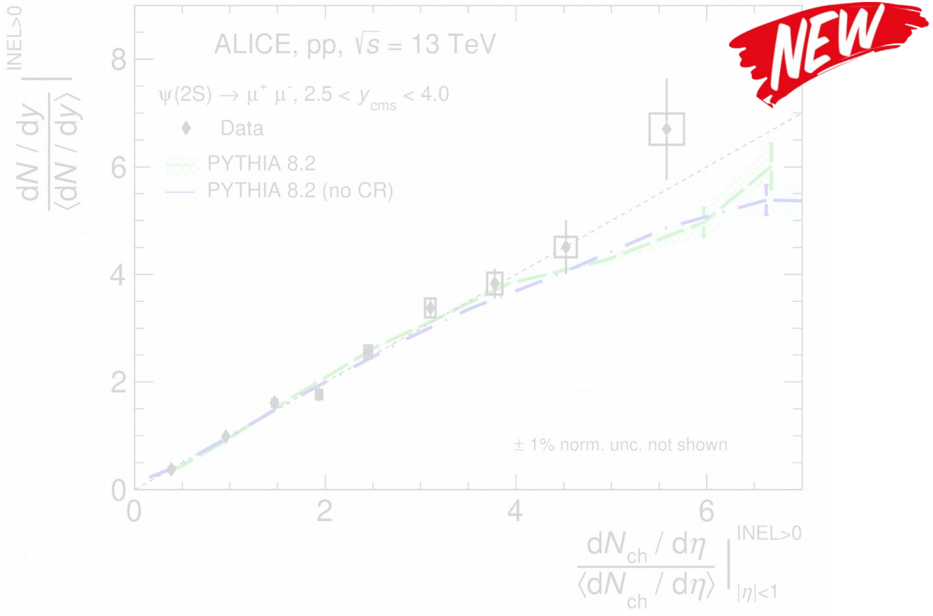


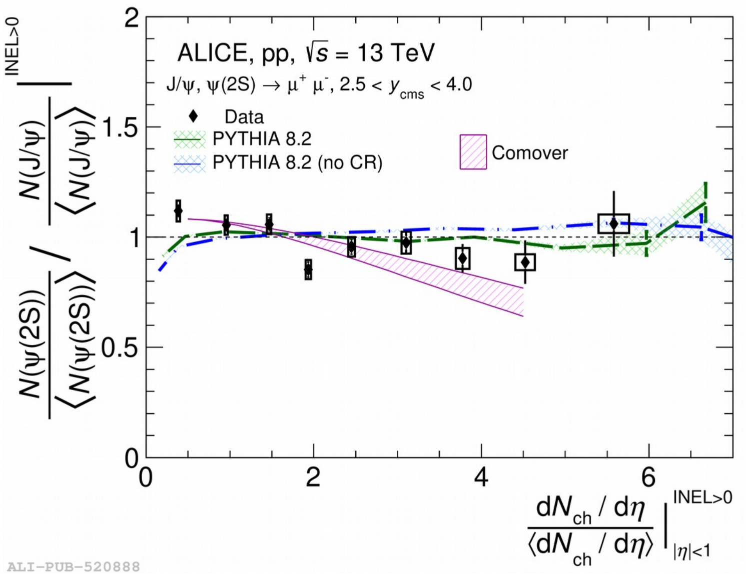
- ψ(2S) yields increase linearly with $dN_{ch}/d\eta$.
- PYTHIA 8.2 predicts the trend of the measurements at the probed multiplicities.



Multiplicity dependence of ψ(2S) production

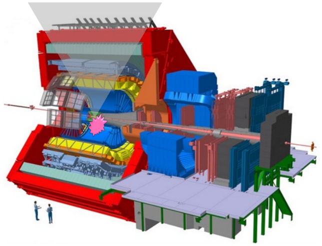
ψ(2S) is the radial excited state of J/ψ

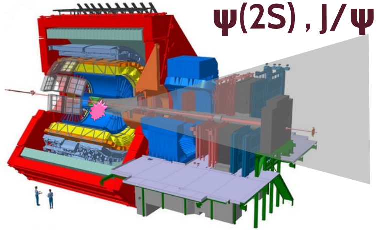




arXiv:2204.10253

$dN_{ch}/d\eta$

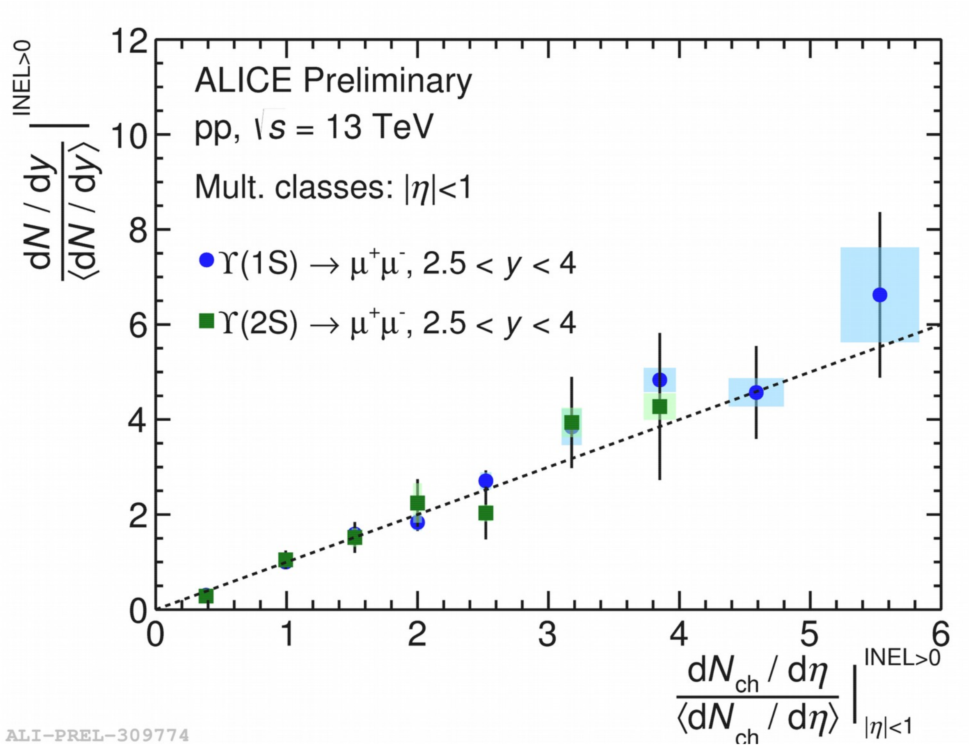




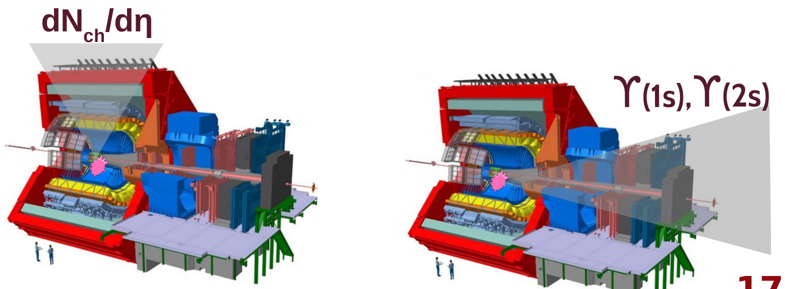
- Similar behavior for J/ψ and ψ(2S) vs multiplicity.
- Measurements are compatible with available models within uncertainties:
  - Comovers: predicts a stronger suppression of ψ(2S) at high multiplicity.
  - PYTHIA 8.2 : suggests a flat ψ(2S)-to- J/ψ ratio.

Multiplicity dependence of Υ(nS) production

Made of bottom and anti-bottom quarks

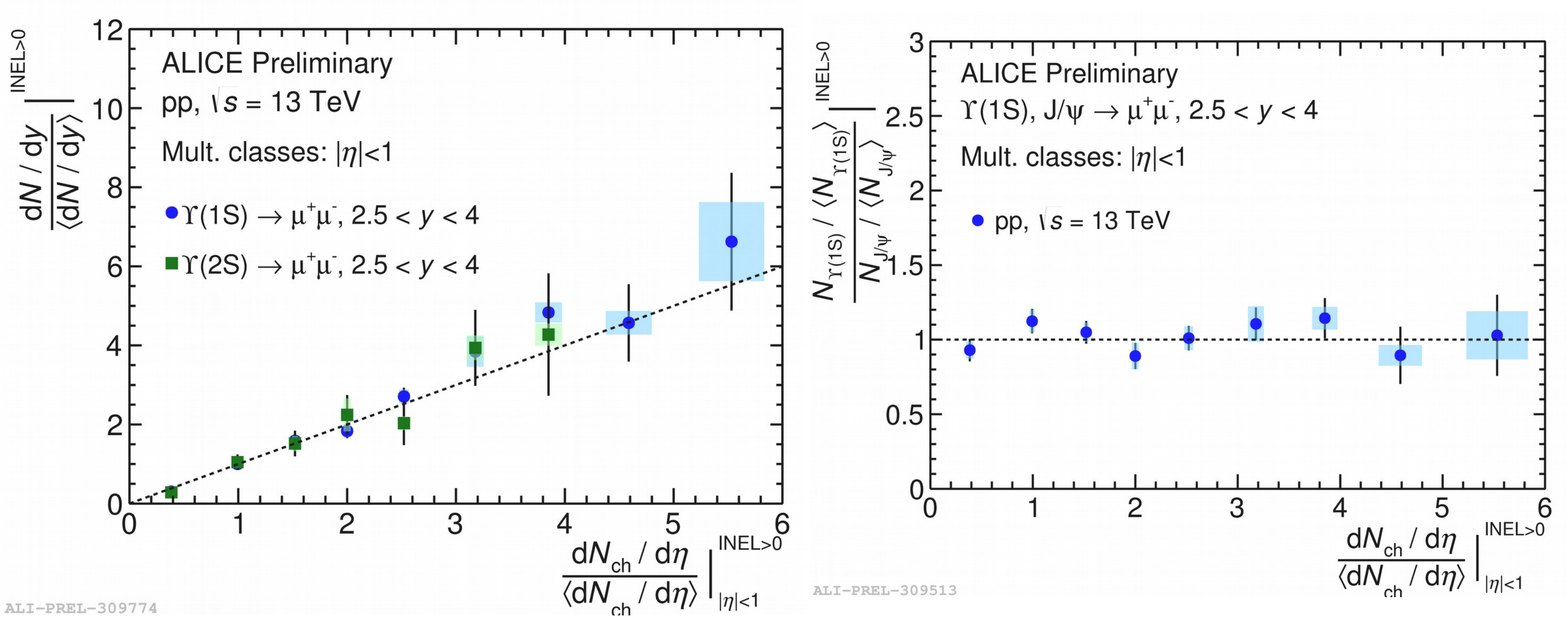


- Υ (1S) and Υ (2S) yields increase with $dN_{ch}/d\eta$.
- The trend is compatible with a linear increase (y = x).



Multiplicity dependence of ϒ(nS) production

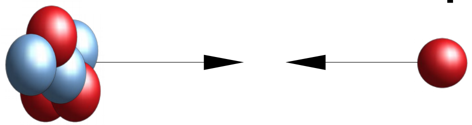
Made of bottom and anti-bottom quarks



- Compared to J/ψ, similar behavior of ϒ (1S) vs multiplicity.
- Current precision on the measurements can not confirm nor rule out final-state effects

p–Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

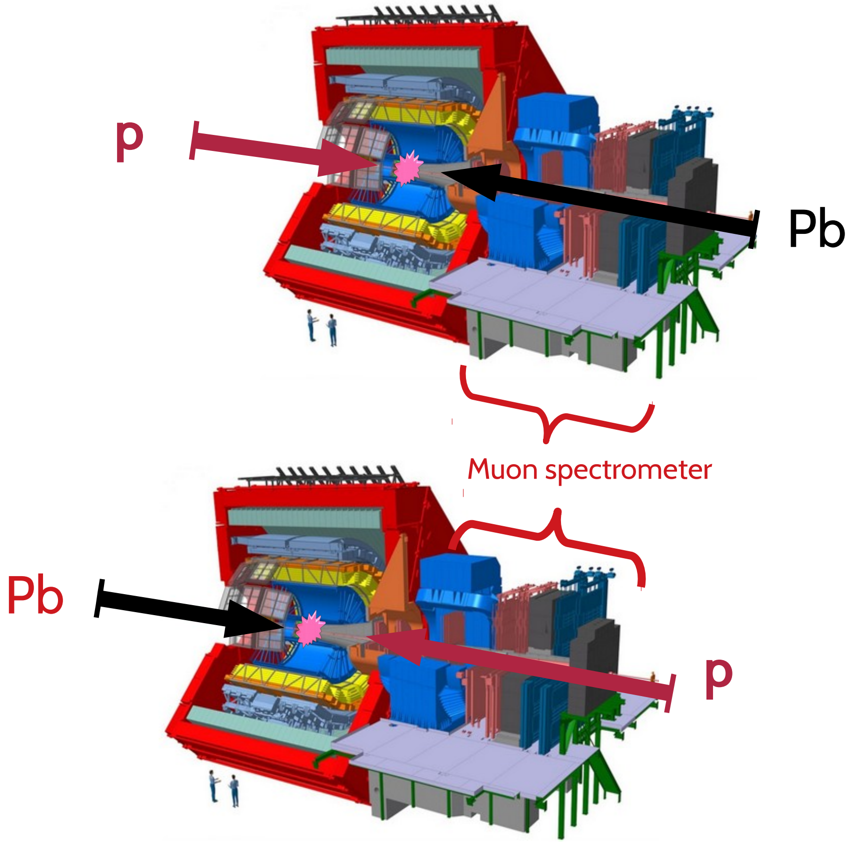
How does the nuclear environment affect quarkonium production vs multiplicity ?



p–Pb configurations

Definition of forward and backward rapidity regions in p-Pb collisions

Muon reconstructed at forward rapidity.
p-going direction.
$2.03 < y_{cms} < 3.53$



Muon reconstructed at backward rapidity.
Pb-going direction.
$-4.46 < y_{cms} < -2.96$

Cold nuclear matter effects

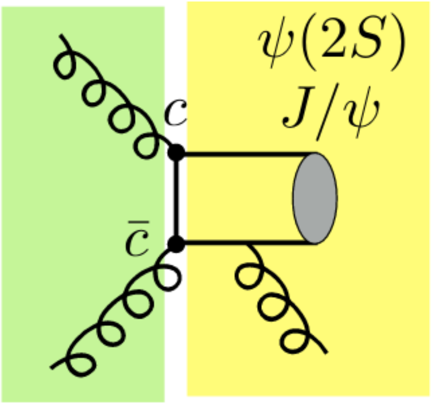
➔ **Initial state effects** :

- Parton shadowing due to modification of PDFs in nuclei. R. Vogt, Phys. Rev. C 71, 054902, JHEP10(2014)073
- Color Glass Condensate (CGC), i.e medium with high density of small Bjorken-*x* gluons.

  F. Gelis, arXiv:1002.0333

➔ Initial-Final state effects :

- Fully coherent energy loss:by partons via gluon emission.
  F.Arleo et.al,JHEP 01 (2022) 164



©b.Diab

➔ **Final state effects** :

- Interaction with comoving particles. E.G.Ferreiro, Phys. Lett. B 749 (2015) 98-103
- Nuclear absorption due to the interaction with the nucleons of the colliding nuclei.

  L. Kluberg et.al, arXiv:0901.3831

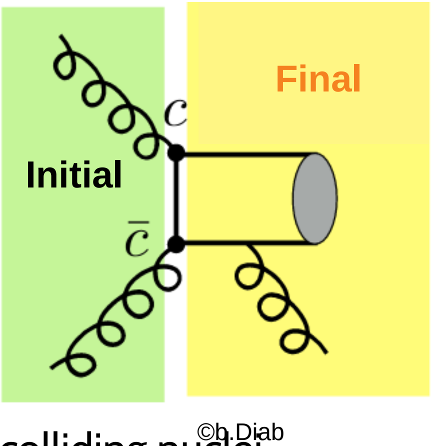
Cold nuclear matter effects

➔ Initial state effects :

- ✔ Parton shadowing due to modification of PDFs in nuclei.
- ✔ Color Glass Condensate CGC i.e medium with high density of small Bjorken-*x* gluons.

➔ Initial-Final state effects :

- ✔ Fully coherent energy loss: by partons via gluon emission.



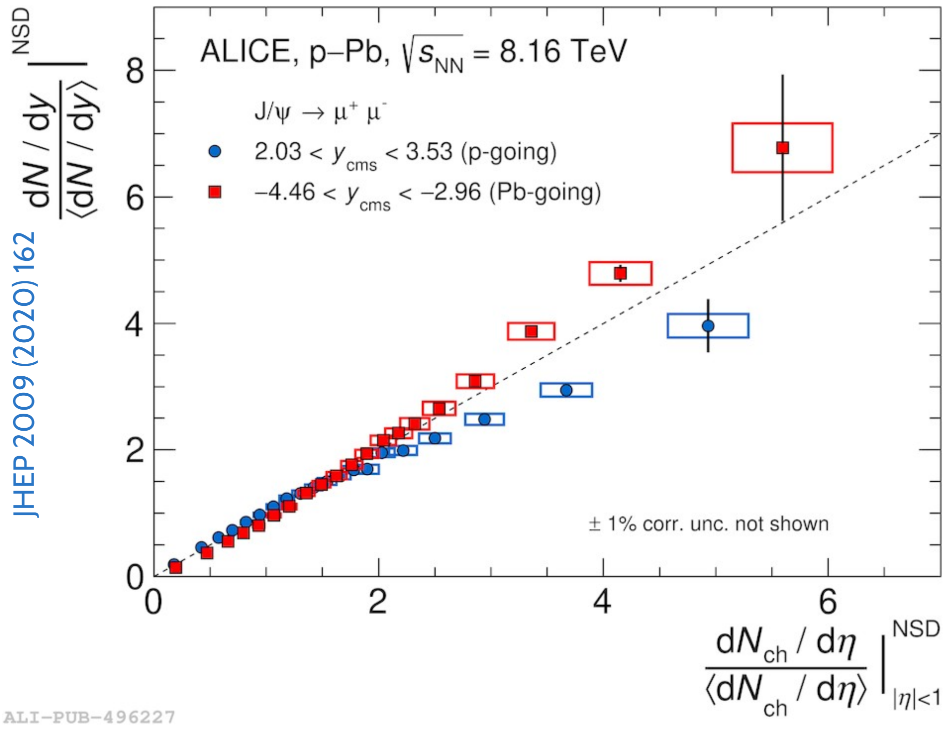
➔ Final state effects :

- ✔ Interaction with comoving particles.
- ✗ ~~Nuclear absorption due to the interaction with the nucleons of the colliding nuclei~~ (negligible at LHC energies).

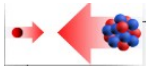
Multiplicity dependence of J/ψ production

measured at forward-backward rapidity

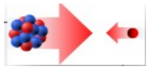
JHEP 2009 (2020) 162



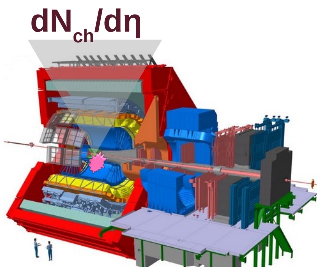
- J/ψ yields increase with dN_{ch} / dη in both rapidity regions.
- Faster (Slower) than linear increase observed at backward (forward) rapidity.
- The different behavior likely due to different Bjorken-*x* regions probed.

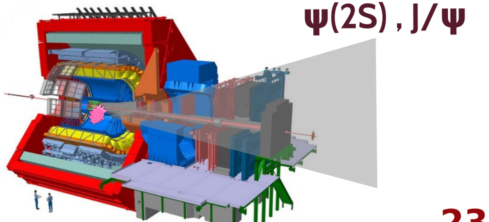


p-Pb (p-going direction)



Pb-p (Pb-going direction)

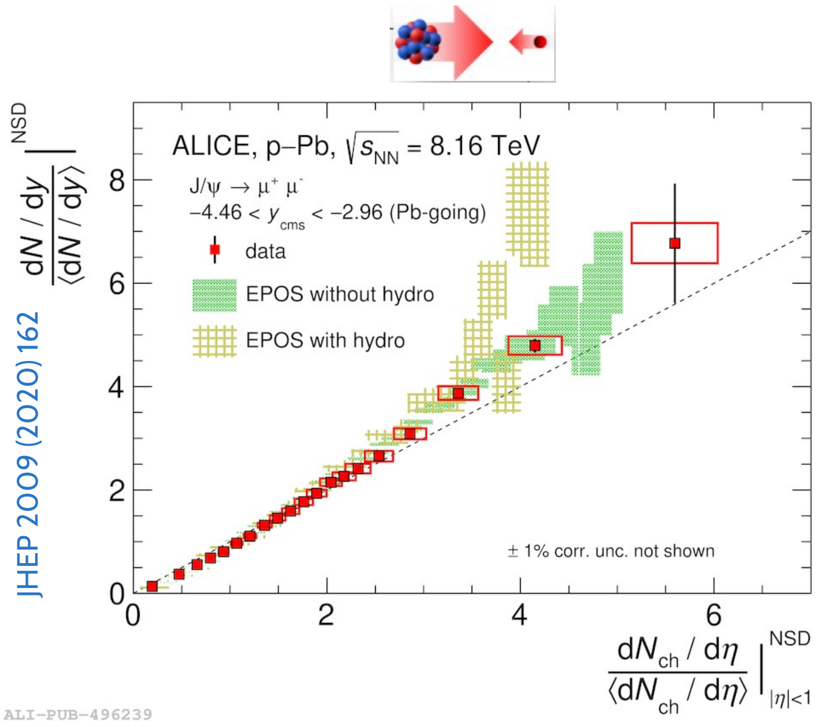


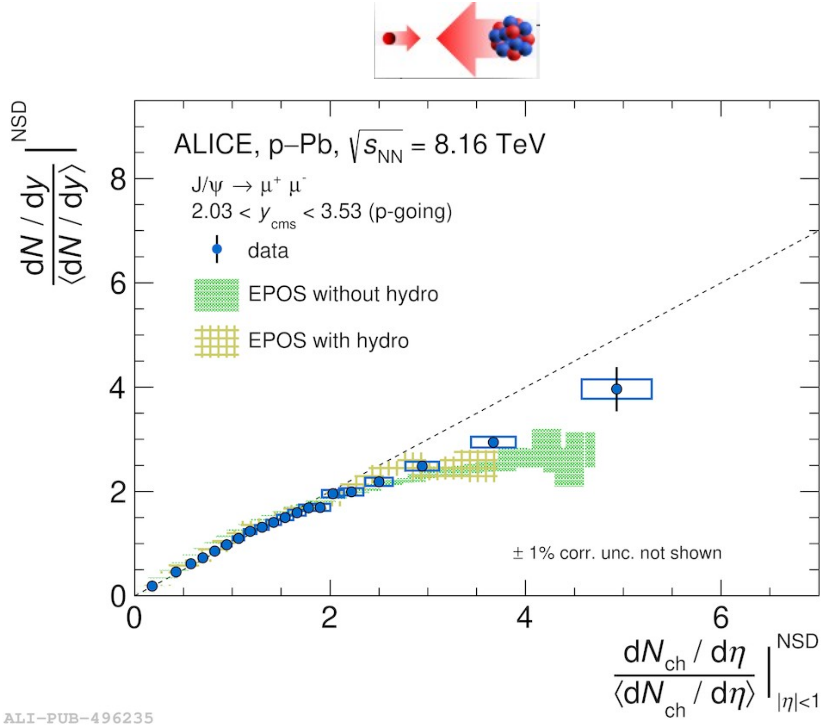


Multiplicity dependence of J/ψ production

measured at forward-backward rapidity

JHEP 2009 (2020) 162





JHEP 2009 (2020) 162

EPOS describes the behavior of J/ψ vs multiplicity in both rapidity regions.

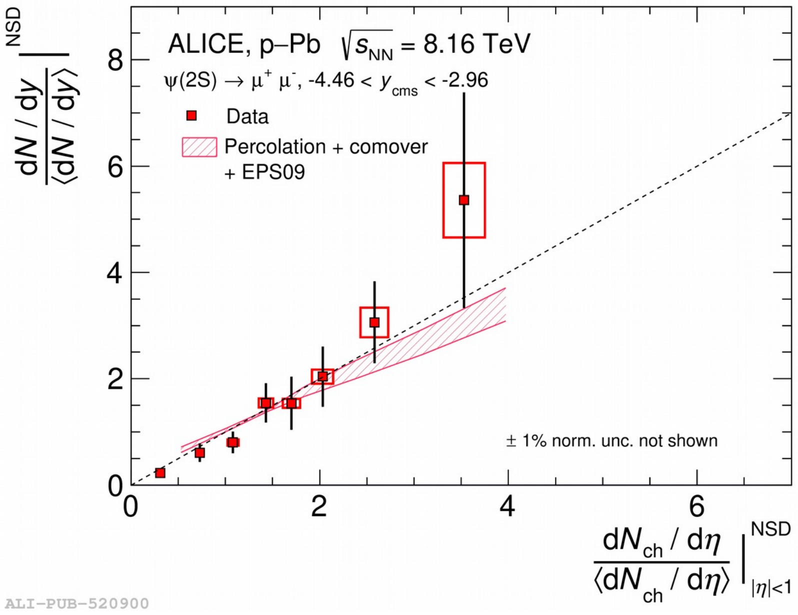
Multiplicity dependence of ψ(2S) production

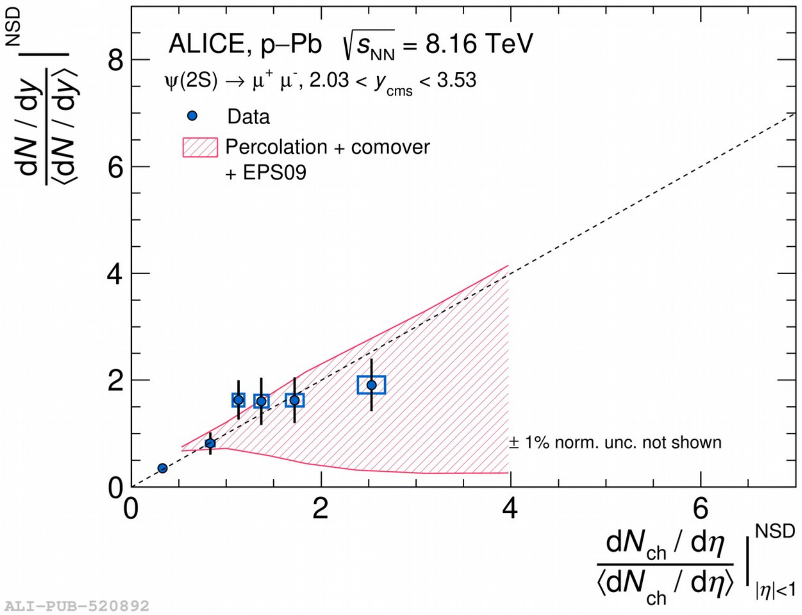
ALICE

NEW

measured at forward-backward rapidity

arXiv:2204.10253





arXiv:2204.10253

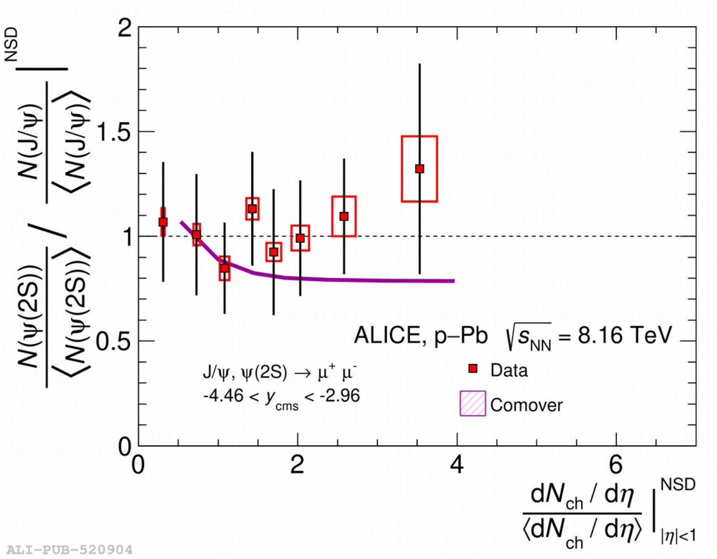
- The ψ(2S) yield increases with increasing $dN_{ch}/d\eta$ in p–Pb collisions.
- Percolation+ comovers+EPS09 calculation predicts the trend of the measurements
  - Large uncertainty at forward rapidity due to EPS09 nPDF uncertainty.

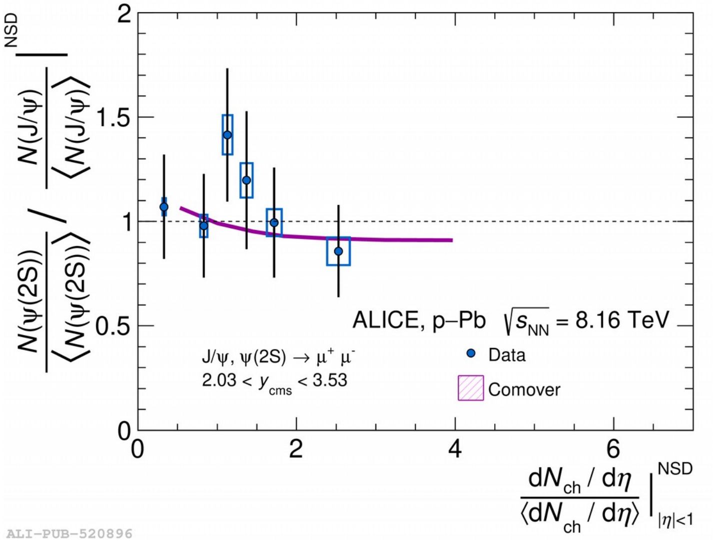
Multiplicity dependence of ψ(2S) production

measured at forward-backward rapidity

NEW

arXiv:2204.10253





arXiv:2204.10253

- Similar behavior of J/ψ and ψ(2S) vs $dN_{ch}/d\eta$ in p-Pb.
- Similar trend of the ψ(2S)-to-J/ψ ratio vs multiplicity in both rapidity regions.
- The comovers calculation describes the data within statistical and systematic uncertainties.

Conclusions

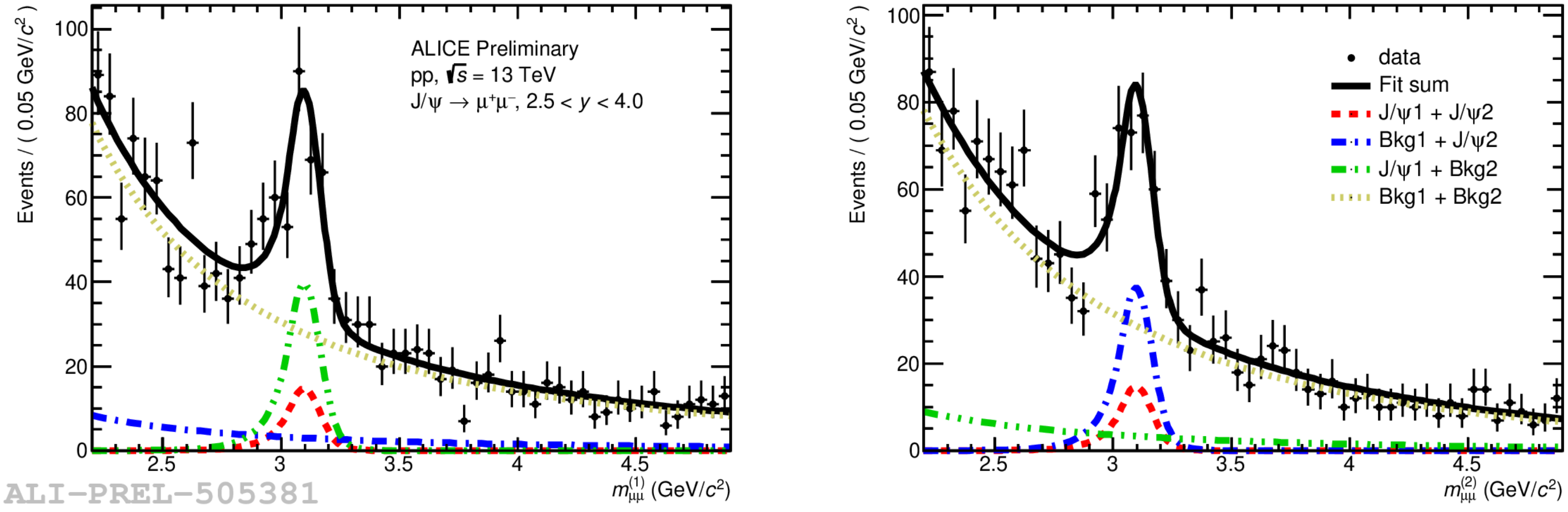
- In pp collisions at $\sqrt{s}$ = 13 TeV:
  - First measurement of double-J/ψ production in ALICE.
  - The behaviour of J/ψ yield at midrapidity and forward rapidity with respect to charged-particle multiplicity at midrapidity is described by models that include either initial and/or final state effects. All these models include the influences of MPI on particle production.
  - ψ(2S) and ϒ (1S) results as a function of charged-particle multiplicity can not confirm nor rule out a possible influence of final-state effects.
- In p–Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV:
  - J/ψ yield at forward and backward rapidity as a function of charged-particle multiplicity is described by EPOS calculation, that includes both initial and final state effects.
  - ψ(2S) measurements at large rapidities are not conclusive due to limited statistics.
  - More stringent tests of the models are needed to disentangle initial and final-state effects.

LHC RUN 3 will bring constraints to MPI modeling thanks to higher statistics expected for data.

Thank you

Double J/ψ production

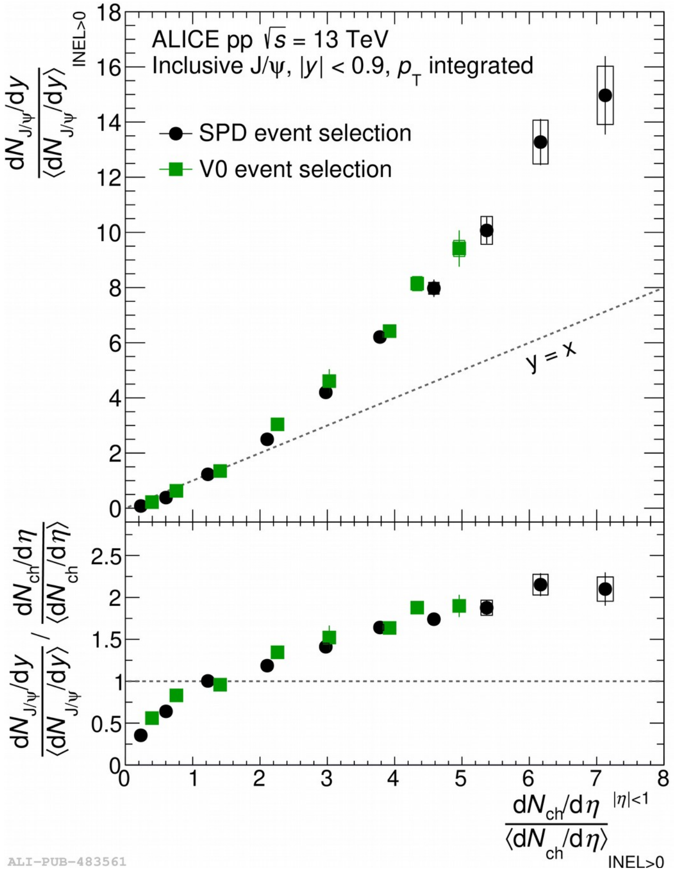
One-dimensional projections of the two-dimensional fit of reconstructed di-Jpsi.



Multiplicity dependence of J/ψ production

measured at midrapidity

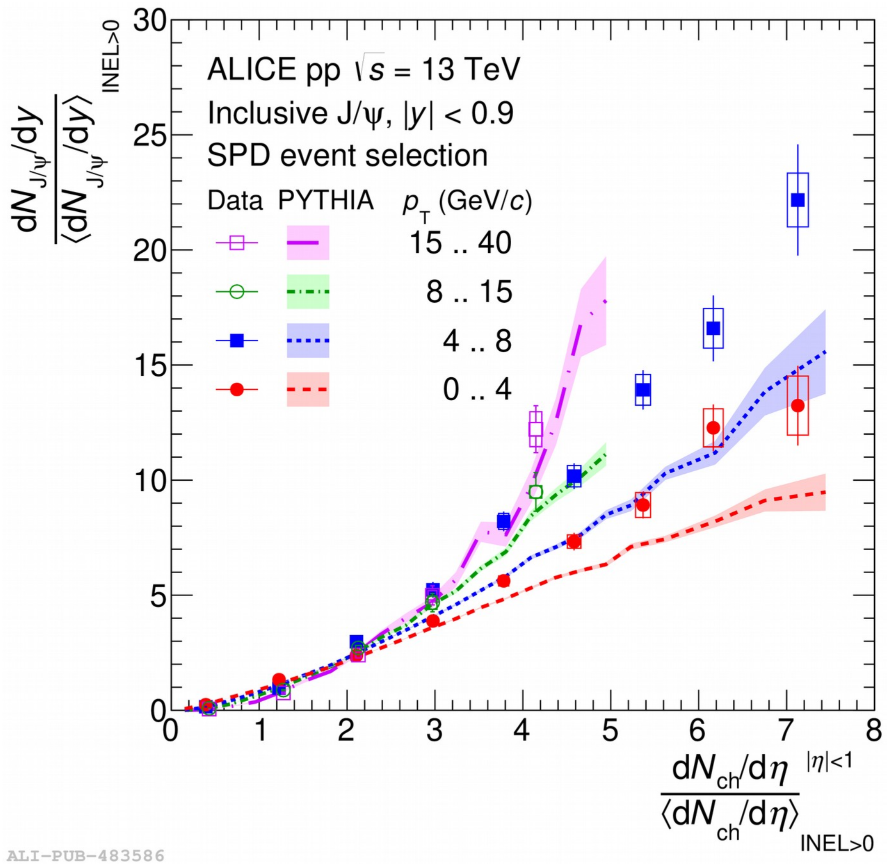
arXiv:2005.11123



Normalized inclusive J/ψ yield at midrapidity as a function of normalized charged-particle pseudorapidity density at midrapidity (|η|<1) with the event selection based on SPD tracklets at midrapidity and on V0 amplitude at forward rapidity in pp collisions at TeV.

Multiplicity dependence of J/ψ production

measured at midrapidity
p_T dependence ?



arXiv:2112.09433

Normalized inclusive J/ψ yield at midrapidity as a function of normalized charged-particle pseudorapidity density at midrapidity (|η|<1), for different p_T ranges.

PYTHIA 8.2 reproduce the data in the $p_T > 8$ GeV/c.