# Quarkonium states as probes of multiparton interactions in small systems with ALICE

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IJCLab, Université Paris-Saclay
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8 July 2022

# Introduction

Features known as a signature of QGP were observed in high multiplicity events in pp and p—Pb collisions, such as:

- Elliptic flow of charged particles: long-range angular correlation.

  ALICE collaboration, PLB 719 (2013). CMS collaboration, JHEP 10.1007/09(2010).
- Enhanced production of strange hadrons similar to Pb—Pb collisions.

  ALICE collaboration, Nature Phys 13, 535-539 (2017).

# Introduction

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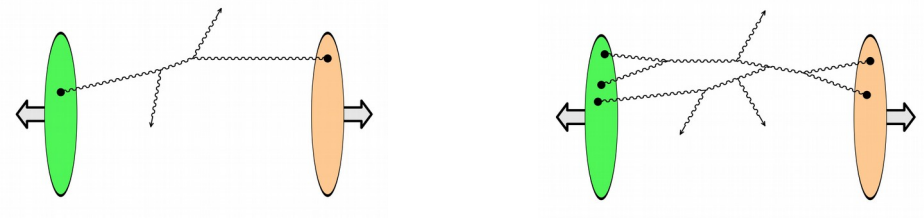
How to interpret these behaviors ? **possible scenarios:**

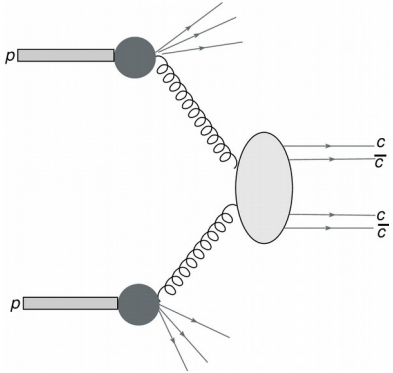
- QGP droplets in high multiplicity events.
- Non linearities originating from multiparton interactions (MPIs).



# Where to look for MPIs with quarkonia ?

- Quarkonium pair production (ideal tool):
  - Direct probe for MPIs.
  - Provide information on single quarkonium production mechanism.

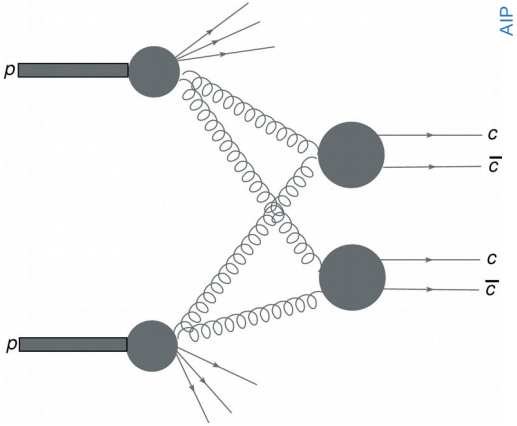
    ⚠ Large luminosity is required.



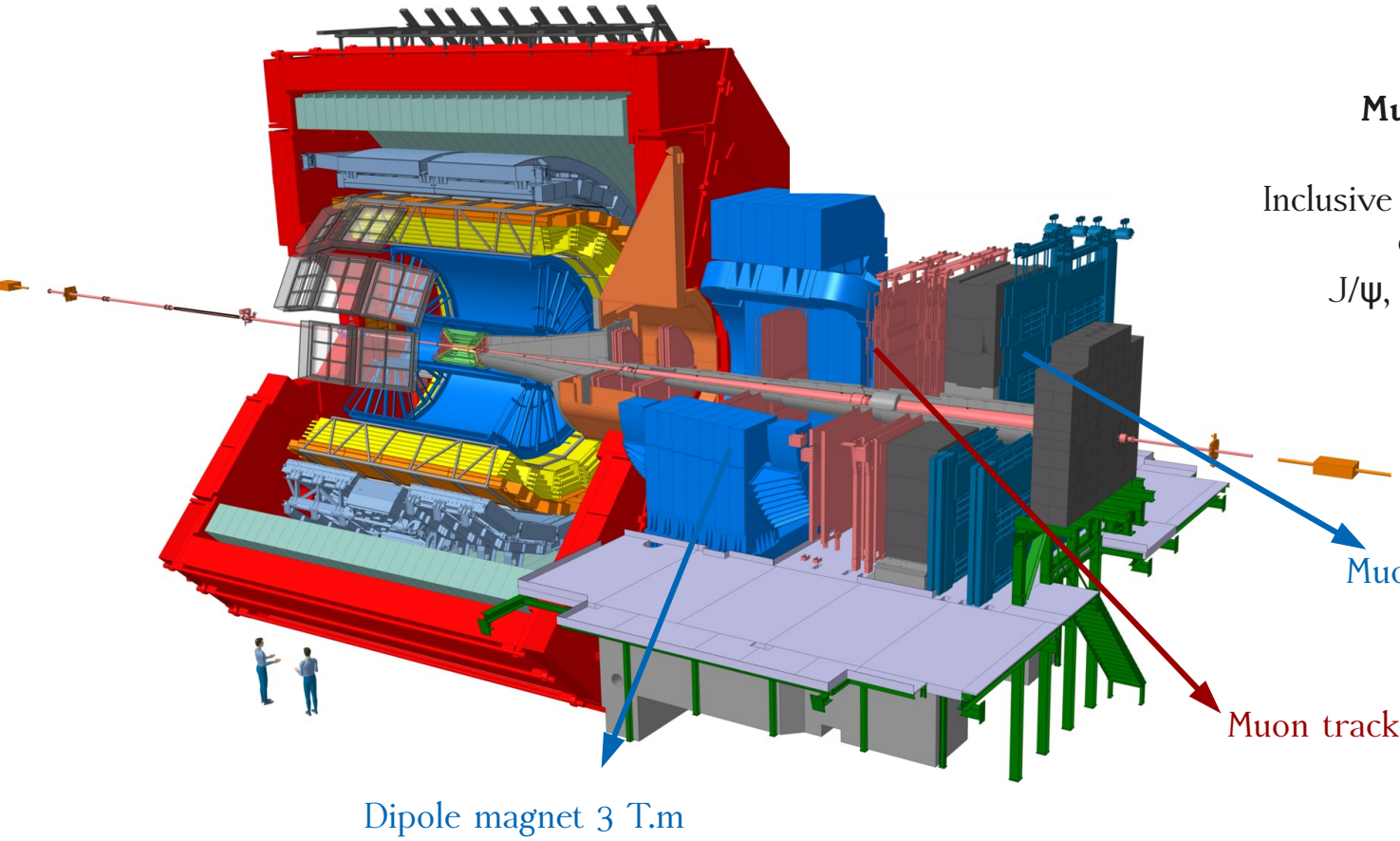

AIP Conf. Proc. 1523 (2013) 1, 255-259

- Quarkonium production vs charged-particle multiplicity:
  - Indirect probe for MPIs.

    Multiplicity is correlated with the number of MPIs.
  - Gain insight on the correlation between soft and hard processes occurring in the same event.



# The ALICE Experiment



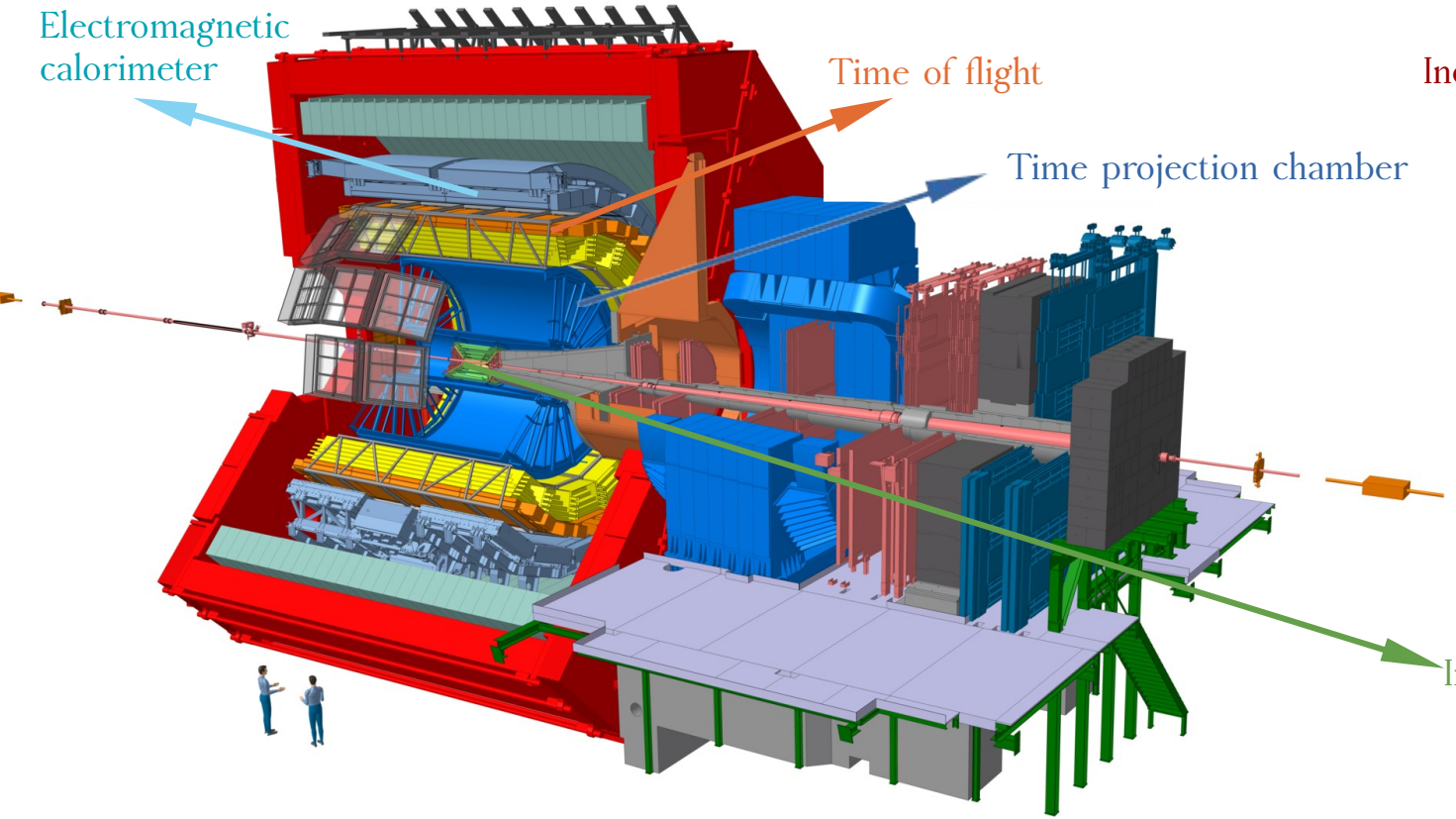

**Muon spectrometer**

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

Inclusive quarkonium production, down to $p_T = 0$

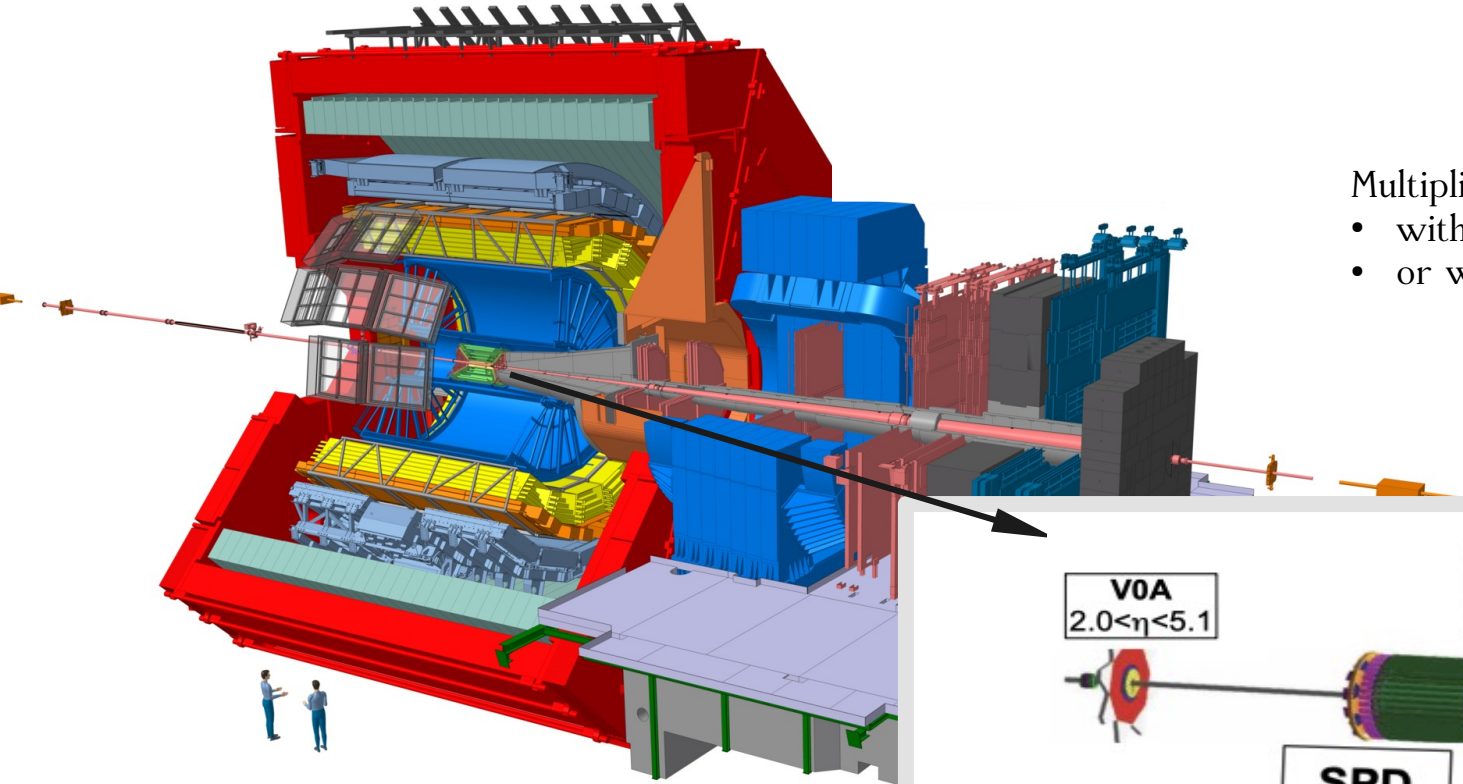
$J/\psi$, $\psi(2S)$, $\Upsilon$ (nS) $\rightarrow \mu^-\mu^+$.

# The ALICE Experiment

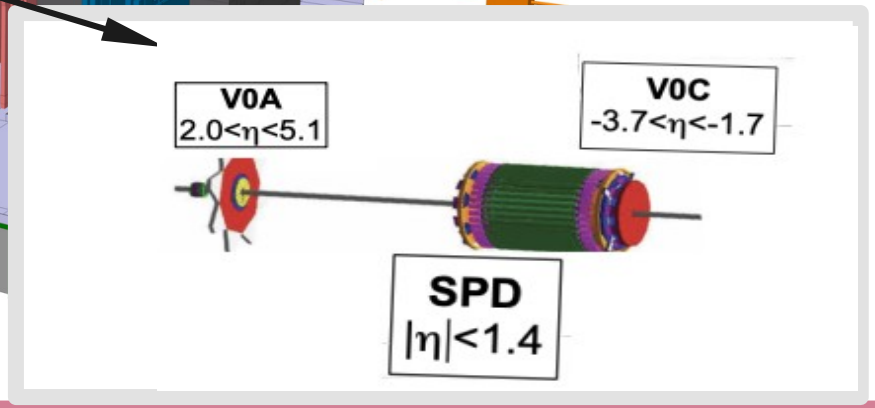



Central barrel
$|\eta_{lab}| < 0.9$
Inclusive, prompt and non prompt
$J/\psi \rightarrow e^{-}e^{+}$ analysis at midrapidity
down to $p_T = 0$.

# The ALICE Experiment



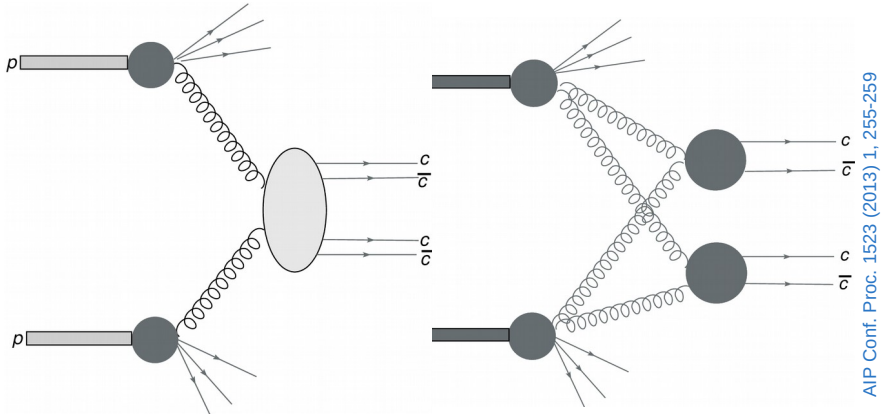
Multiplicity is measured
- with SPD within $|\eta| < 1$.
- or with V0 detector.



# J/ψ pair production

Important to gain an insight on :

- J/ψ production mechanism.
- Single and double parton scattering.



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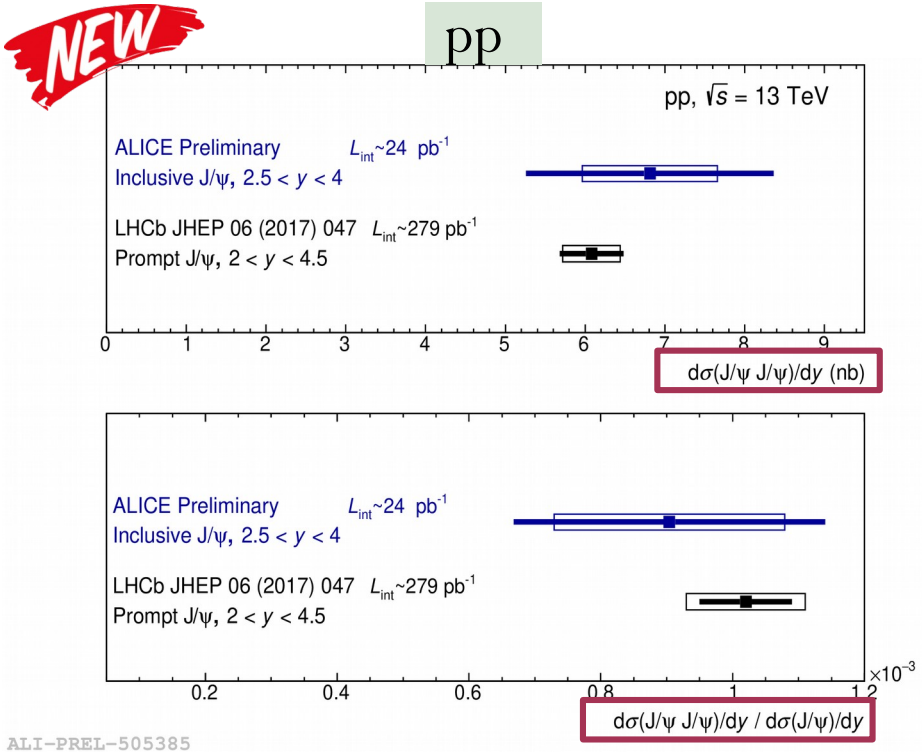
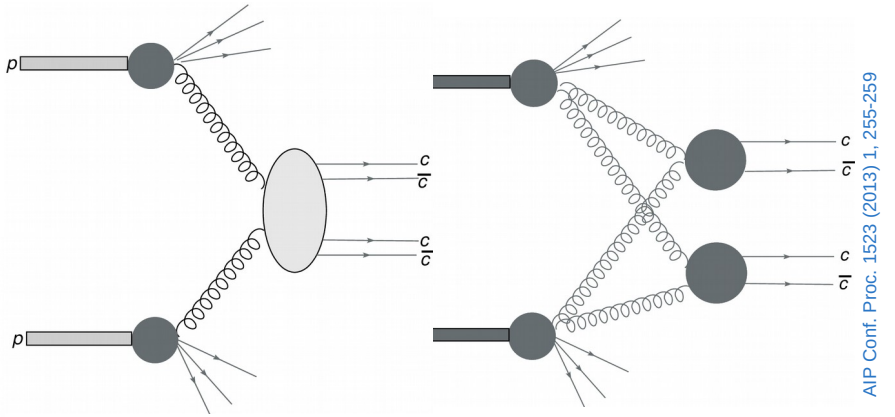


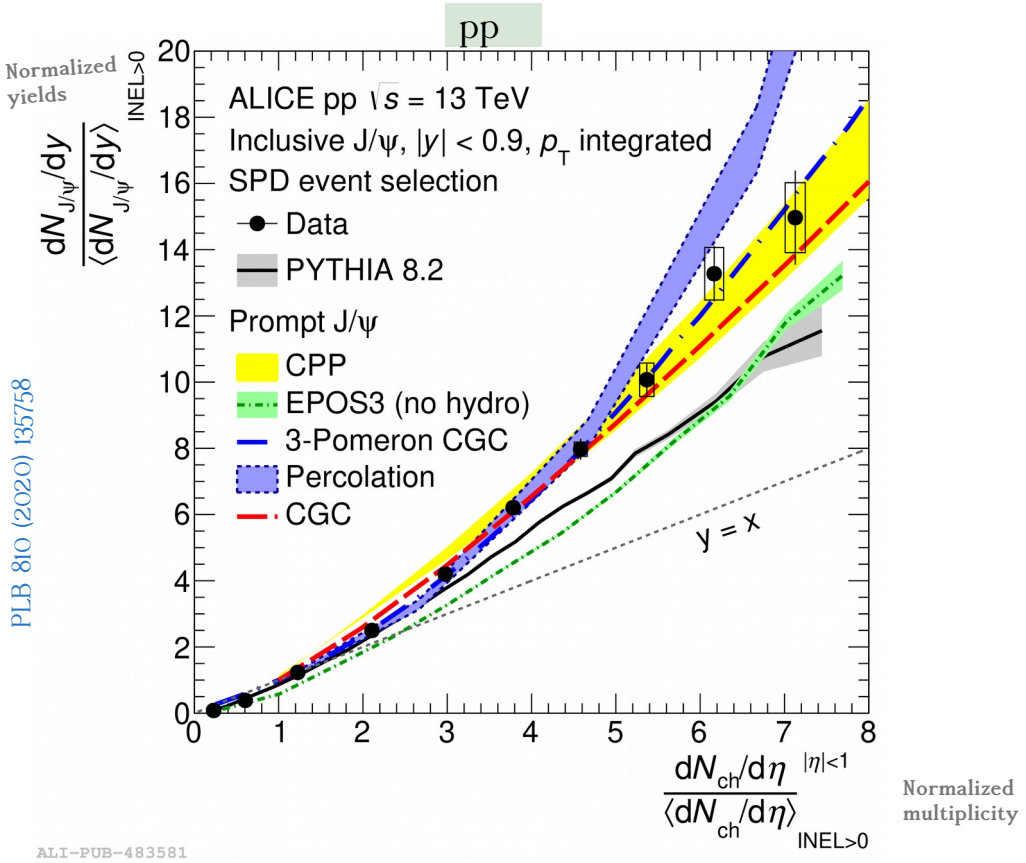

**Good agreement between ALICE and LHCb results :**

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

Caveats:

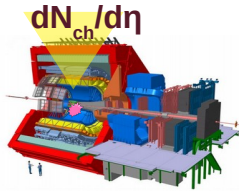
- LHCb measured double prompt J/ψ production.
- Slightly different rapidity window for ALICE and LHCb.

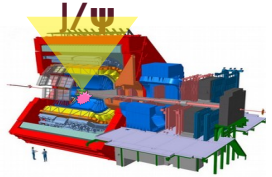
# Multiplicity dependence of J/ψ production




PLB 810 (2020) 135758

- J/ψ self-normalized yields present a **faster than linear increase** as a function of self-normalized charged-particle multiplicity, both measured at midrapidity.
- Models including initial state effects (CGC and 3pomeron CGC), or initial and final state effects (percolation, CPP, EPOS3 and PYTHIA8) **describe qualitatively the measurements.**




Percolation: E.G. Ferreiro et al, Phys. Rev. C 86, 034903.
CGC: Y.-Q. Ma, et al, Phys. Rev. D 98 (7) (2018) 074025.

CPP: B. Z. Kopeliovich etal, Phys. Rev. D 88, 116002
3 pomeron: E. Levin, Eur. Phys. J. C 80 no. 6, (2020) 560.

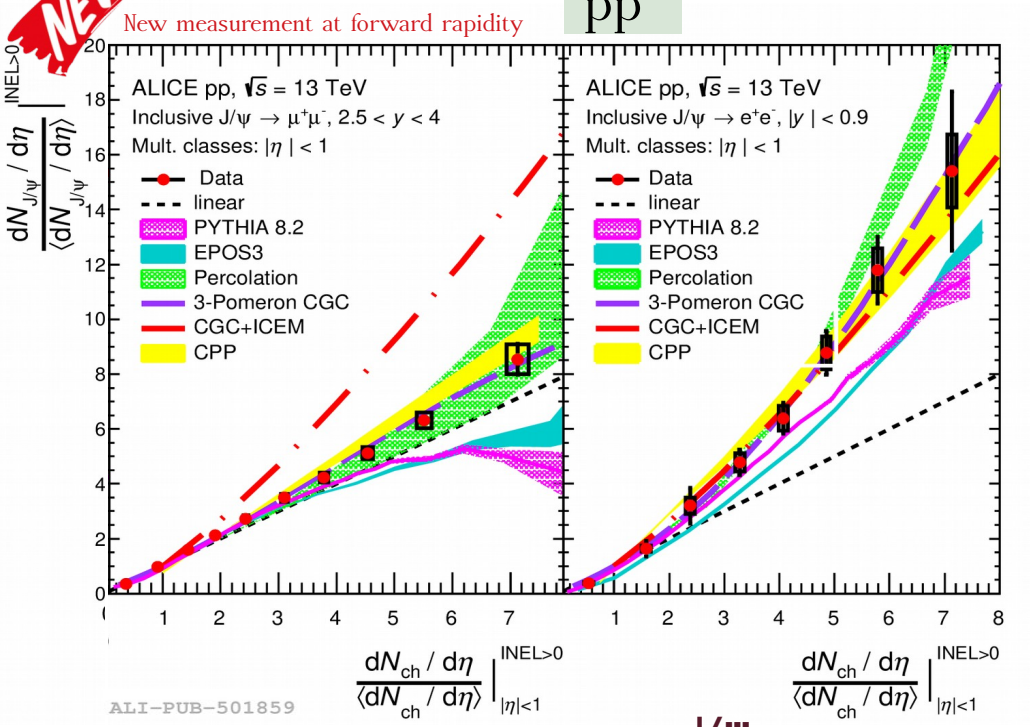
EPOS 3: K. Werner, B. et al, Phys. Rev. C 89, 064903.
PYHTIA 8.2: T.Sjöstrand et al, arXiv:1410.3012v1.

# Multiplicity dependence of J/ψ production

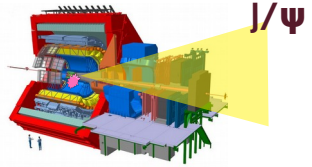
NEW

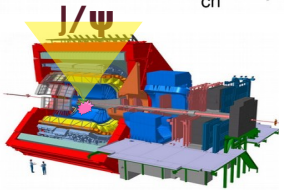
New measurement at forward rapidity

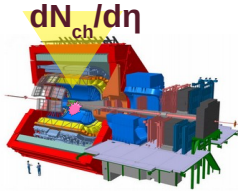
pp




- J/ψ self normalized **yields at forward rapidity show a less rapid increase than midrapidity results** (no strong deviation from linearity within uncertainties).
- Models including initial state effects (CGC+ICEM and 3pomeron CGC ), or initial and final state effects (percolation, CPP, EPOS3 and PYTHIA8) **describe qualitatively the measurements.**

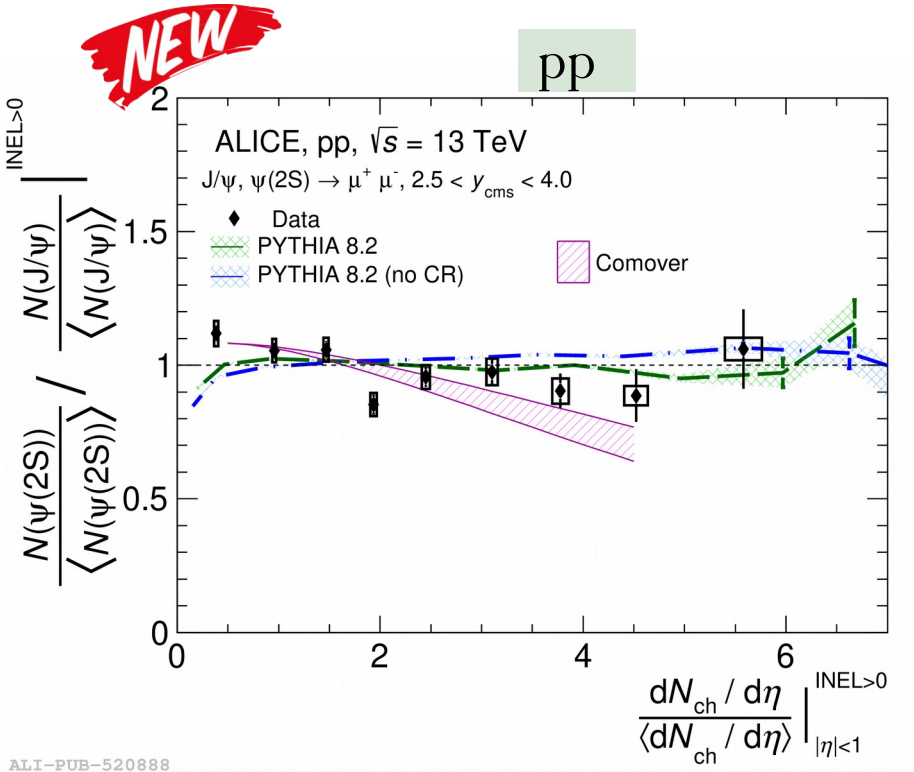



JHEP 06 (2022) 015

# Multiplicity dependence of ψ(2S) production




arXiv:2204.10253

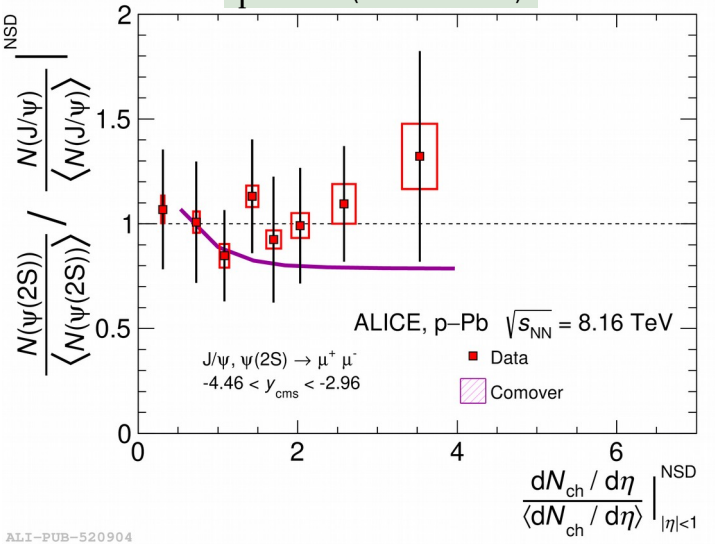
Comovers: E.G.Ferreiro, Phys. Lett. B 749 (2015) 98–103

- **Similar behavior for J/ψ and ψ(2S) vs multiplicity.**
- Measurements are compatible with available models within uncertainties:
  - Comovers:
    - Interaction of quarkonia with final state particles that are co-moving with them.
    - Predicts a stronger suppression of ψ(2S) at high multiplicity with respect to J/ψ.
  - PYTHIA 8.2 : suggests a flat self normalized ψ(2S)-to-J/ψ ratio.
- **The statistics do not allow to disentangle any possible final state effects.**

# Multiplicity dependence of ψ(2S) production

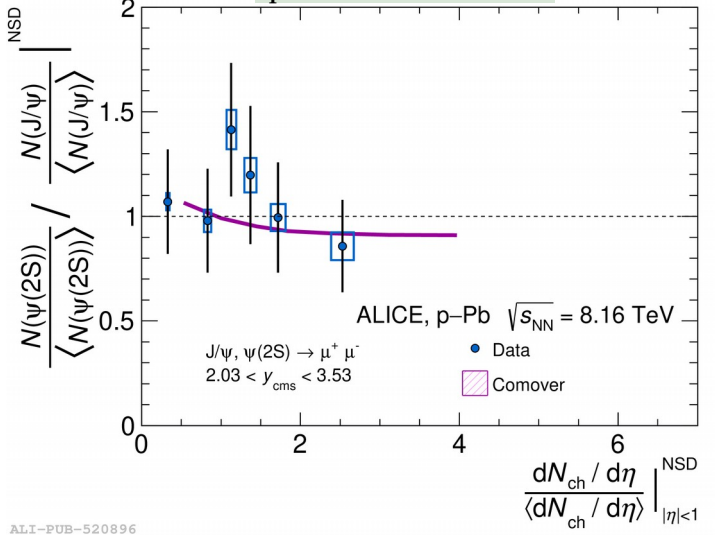
arXiv:2204.10253

p—Pb (backward)




NEW

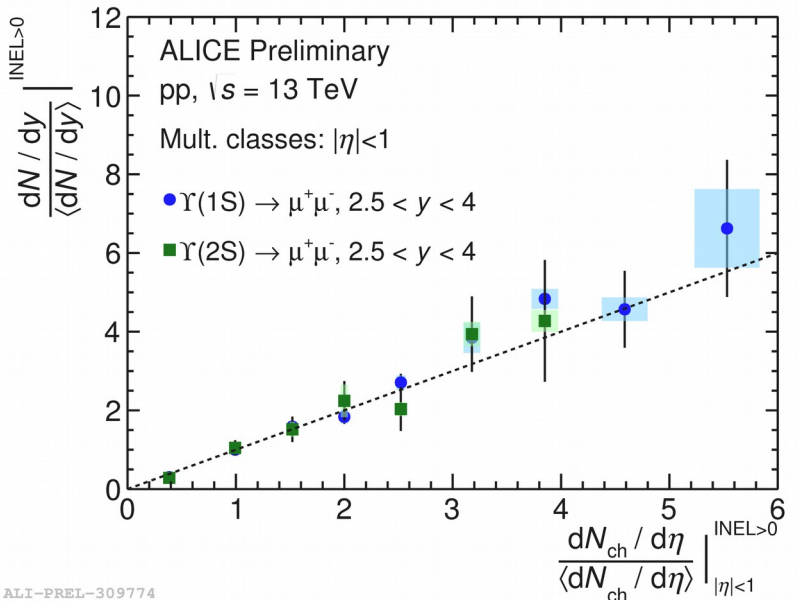
p—Pb (forward)

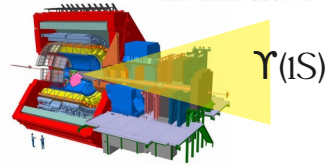


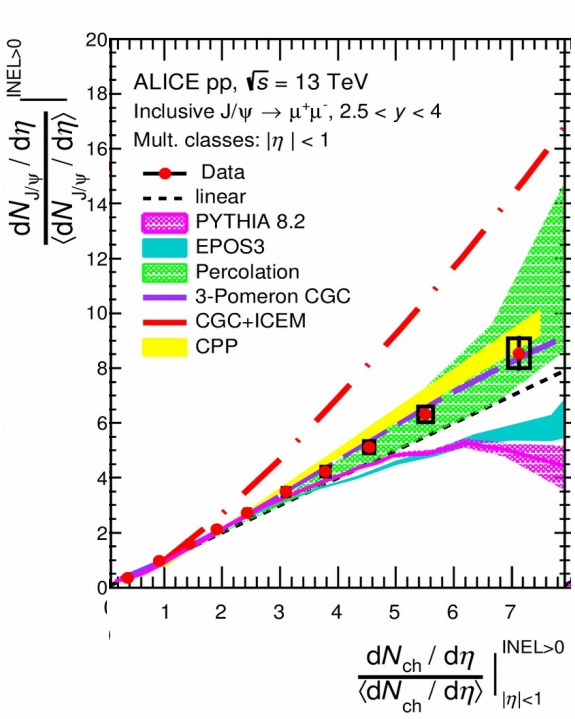

arXiv:2204.10253

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

# Multiplicity dependence of Υ(nS) production




**Rising trend observed for Υ(1S) and Υ(2S)** self-normalized yields measured at forward rapidity **vs multiplicity** at mid rapidity (similar behavior as observed for J/psi)

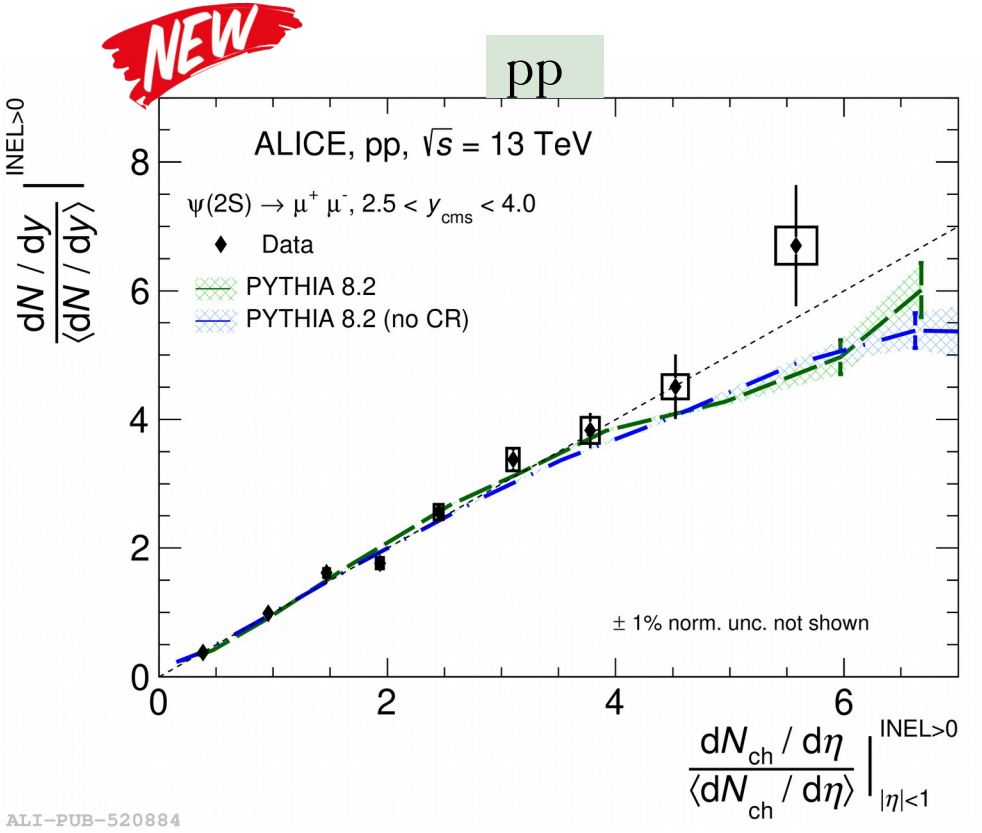
# Summary

- J/ψ pair production measured in ALICE for the first time; results are compatible with LHCb ones.
- Quarkonium self-normalized yields increase as a function of charged-particle multiplicity both in pp and p—Pb collisions.
- Results are described by models which include MPIs in the calculation.
- Data on ψ(2S)/ J/ψ ratio do not show evidence for strong final state effects in high multiplicity pp collisions

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

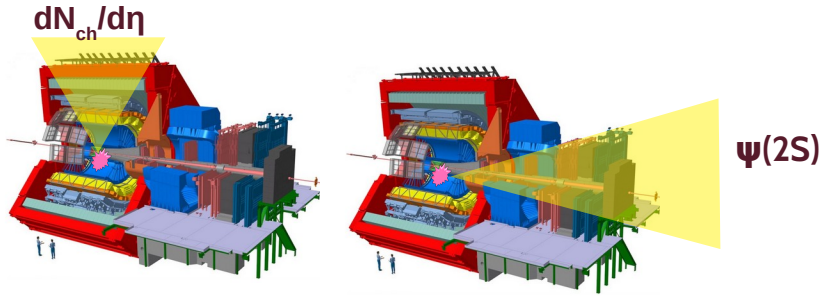
# Thank you

# Multiplicity dependence of ψ(2S) production



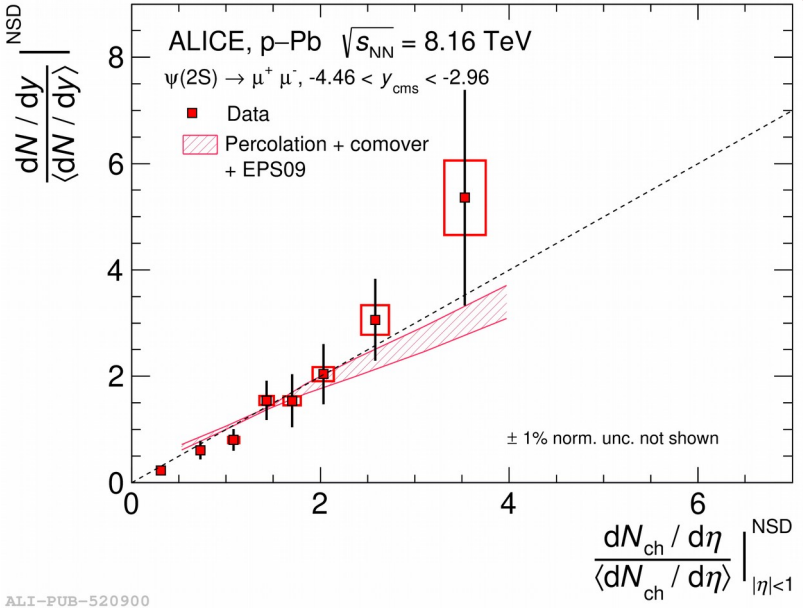

arXiv:2204.10253

- ψ(2S) self-normalized **yields increase linearly with $dN_{ch}/d\eta$**.
- **PYTHIA 8.2 predicts the trend** of the measurements up to 5 times the average multiplicities.



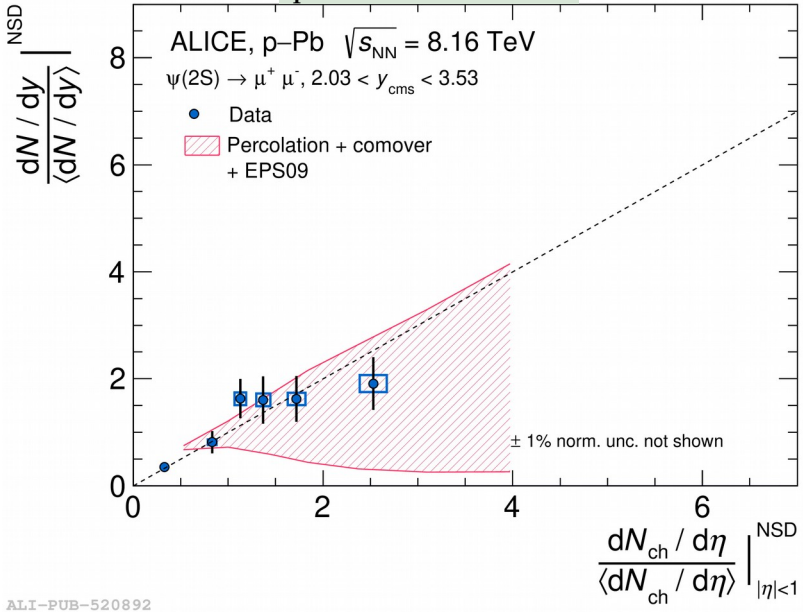
# Multiplicity dependence of ψ(2S) production

p—Pb (backward)




NEW

p—Pb (forward)




arXiv:2204.10253

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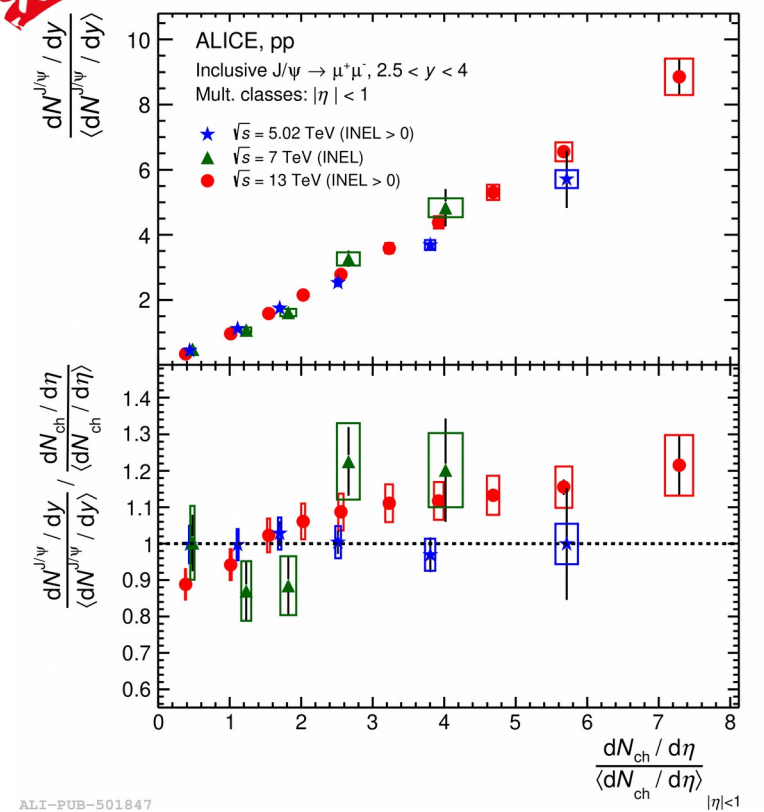
- The ψ(2S) **yield increases with increasing** $\mathbf{dN_{ch}/d\eta}$ in p-Pb collisions.
- Percolation+ comovers+EPS09 calculation predicts the trend of the measurements
  - Large uncertainty at forward rapidity due to EPS09 nPDF uncertainty.

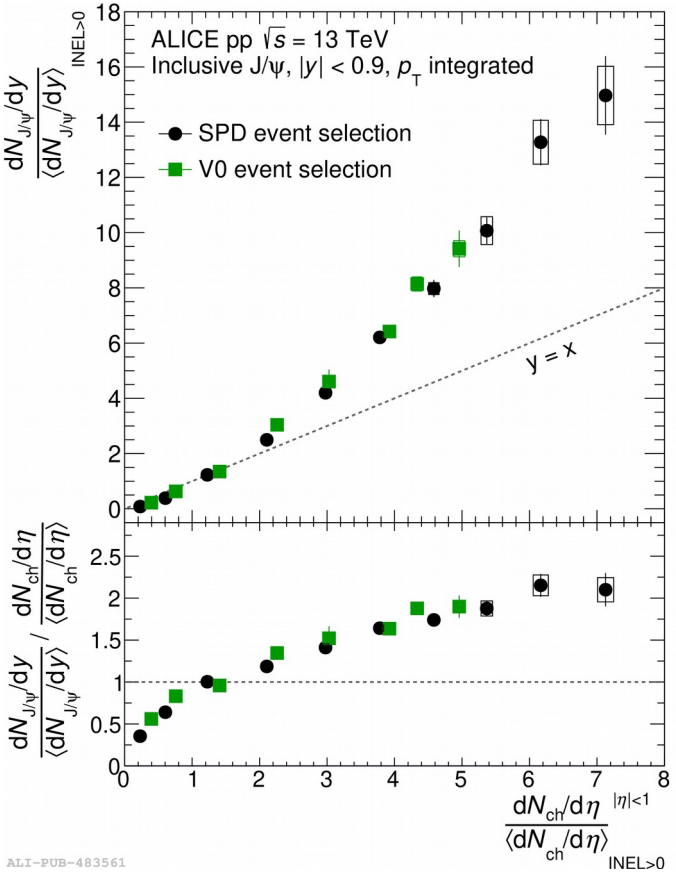
# J/ψ production vs multiplicity




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 J/ψ production




arXiv:2005.11123

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