Measurement of quarkonium production as a function of multiplicity in pp collisions with ALICE

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3rd Heavy Flavour Meet 2019

IITI, Indore, India

Outline

- Motivation
- Multiplicity Dependence
- Theoretical Approaches
- Experimental Method
- Results
- Summary

Motivation

J/ψ production in Pb-Pb collisions:

An important tool to probe the formation of QGP.

- J/ψ suppression [T.Matsui and H.Satz,PLB178 (1986) pp.416-422].
- (re)generation of charmonium [R. Thews et al., PRC63 (2001) 054905] & [P. Braun-Munzinger et al., PLB490 (2000) 196-202].

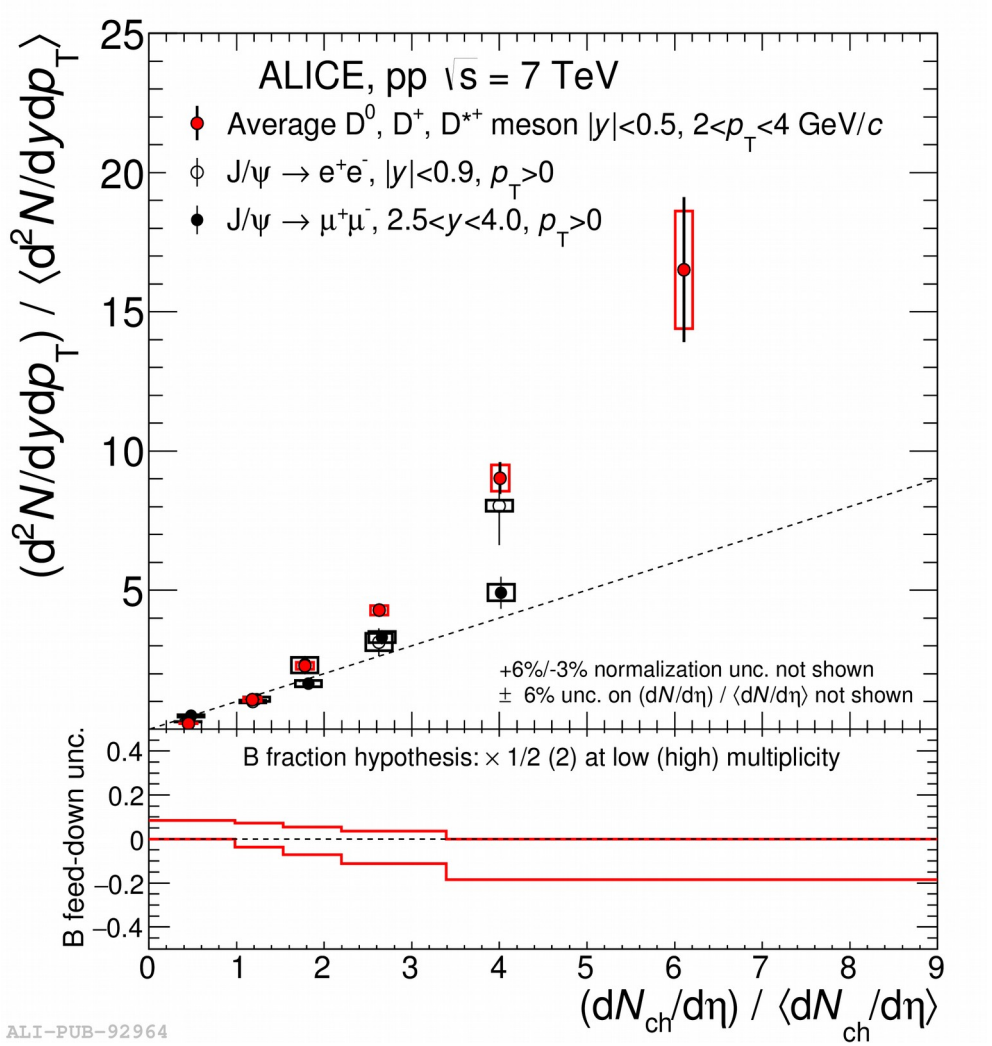
Quarkonium production in small systems, particularly in pp collisions:

- Provides a crucial test for hadronisation models and QCD.
- Baseline for p-Pb and Pb-Pb measurements.

Multiplicity dependence of quarkonium production in pp collisions:

- Correlation between soft and hard processes.
- To understand the effect of Multiple Parton Interactions (MPI).
- MPI contribution to hard processes [Sjöstrand & van Zijl, PRD36 (1987) 2019].
- To look for possible collective behaviour in small systems.

ALICE observations in pp collisions



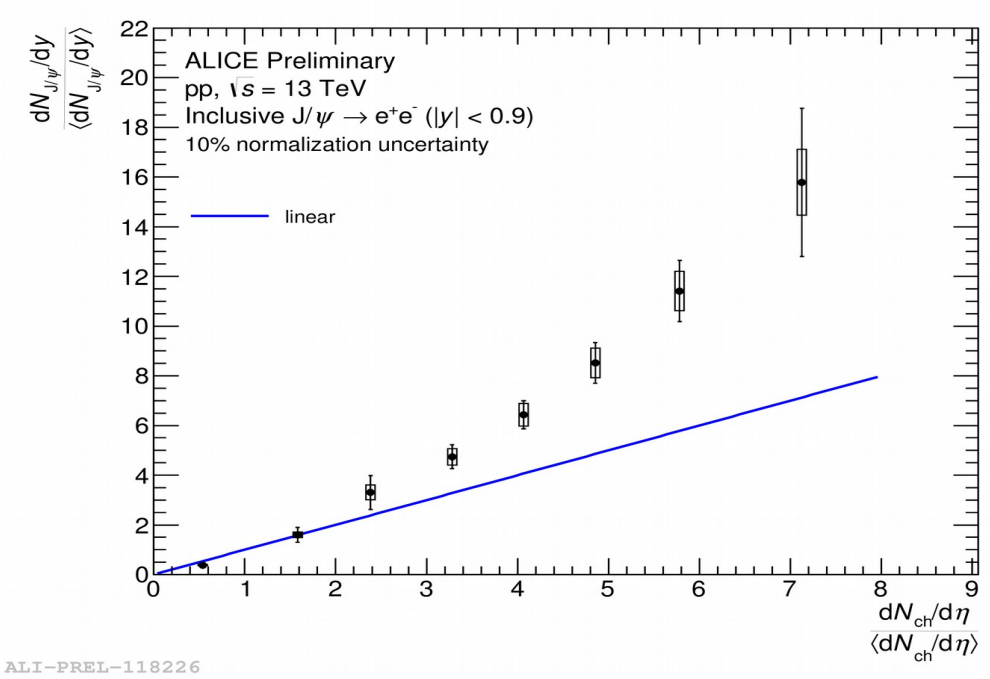
[ALICE, JHEP 09 (2015) 148].

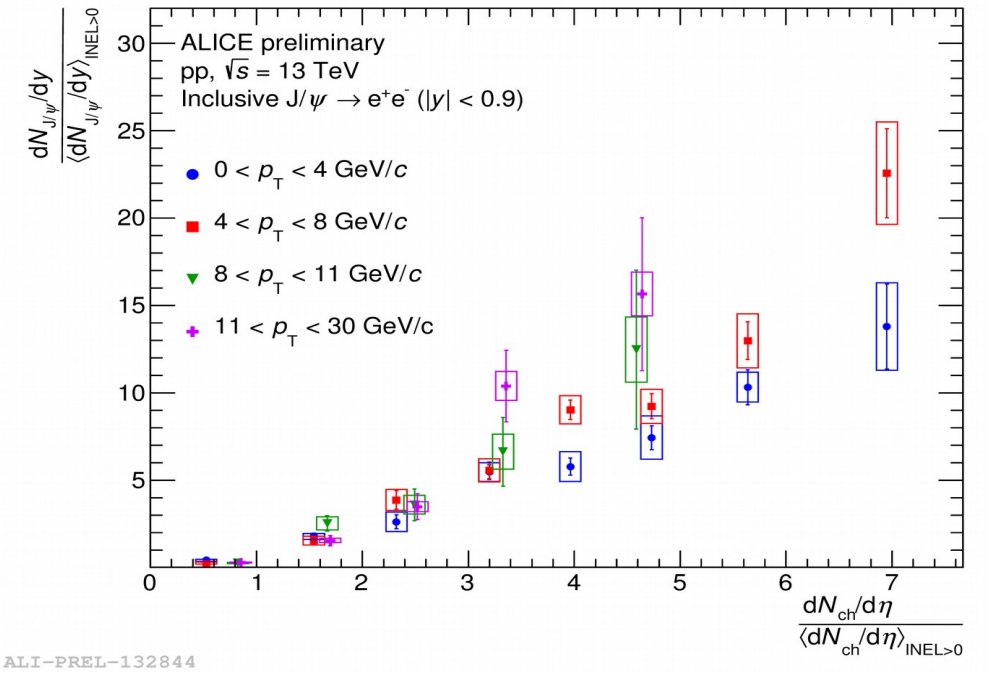
- Increase of the relative yield with multiplicity observed for D mesons and J/ψ in pp collisions at $\sqrt{s}$ = 7 TeV.

  ALICE, JHEP 09 (2015) 148
- Independent from hadronisation.
- Mid-rapidity and forward rapidity J/ψ don't show the same trend for the highest multiplicity bin.

ALICE observations in pp collisions

Mid-rapidity pp $\sqrt{s}$ = 13 TeV





- Multiplicity reached in pp collisions at $\sqrt{s}$ = 13 TeV is twice that at $\sqrt{s}$ = 7 TeV.
- EMCAL triggered data extend J/ψ p_T reach.
- High-p_T J/ψ indicate even stronger increase with multiplicity.

Theoretical interpretations

PYTHIA8 simulation:

[Comput.Phys.Commun.178 (2008) 852–867]

- Hard processes in MPI.
- Gluon splitting.
- Initial/final state radiation.

EPOS3:

[Phys.Rept. 350 (2001) 93–289]

- Gribov-Regge formalism (MPI) included.
- Hydro evolution of the system.

Percolation model:

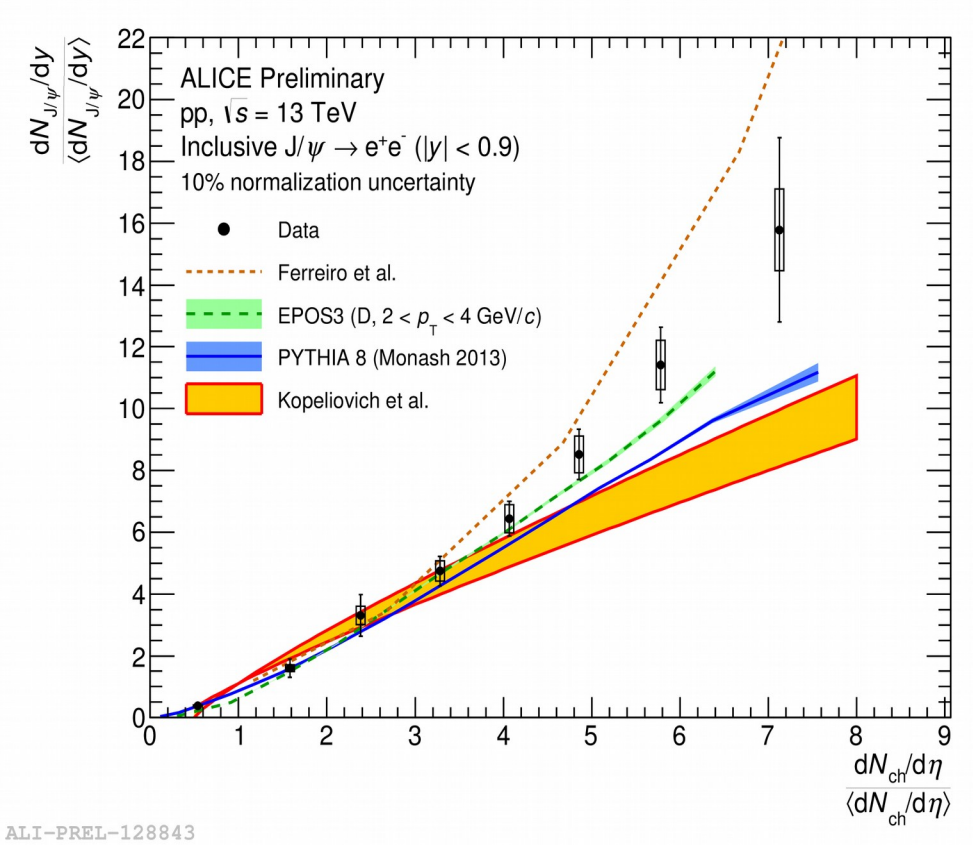
[PRC86 (2012)034903]

- Linear increase at low density.
- Quadratic increase at higher density.

Kopeliovich et al:

[PRD 88, 116002 (2013)]

- Contributions of higher Fock states to reach high multiplicity in pp.
- Higher number of gluons → J/ψ rate also enhanced.



Theoretical model predictions also give similar multiplicity dependence in pp collisions at √s = 13 TeV at mid-rapidity.

Quarkonium measurements with ALICE

$J/\psi \rightarrow e^+ + e^-$ (Central Barrel: $|\eta| < 0.9$)

$\Upsilon \rightarrow \mu^+ + \mu^-$ (Muon Spectrometer: $-4.0 < \eta < -2.5$)

EMCAL: trigger, electron ID

T0,V0: Triggering

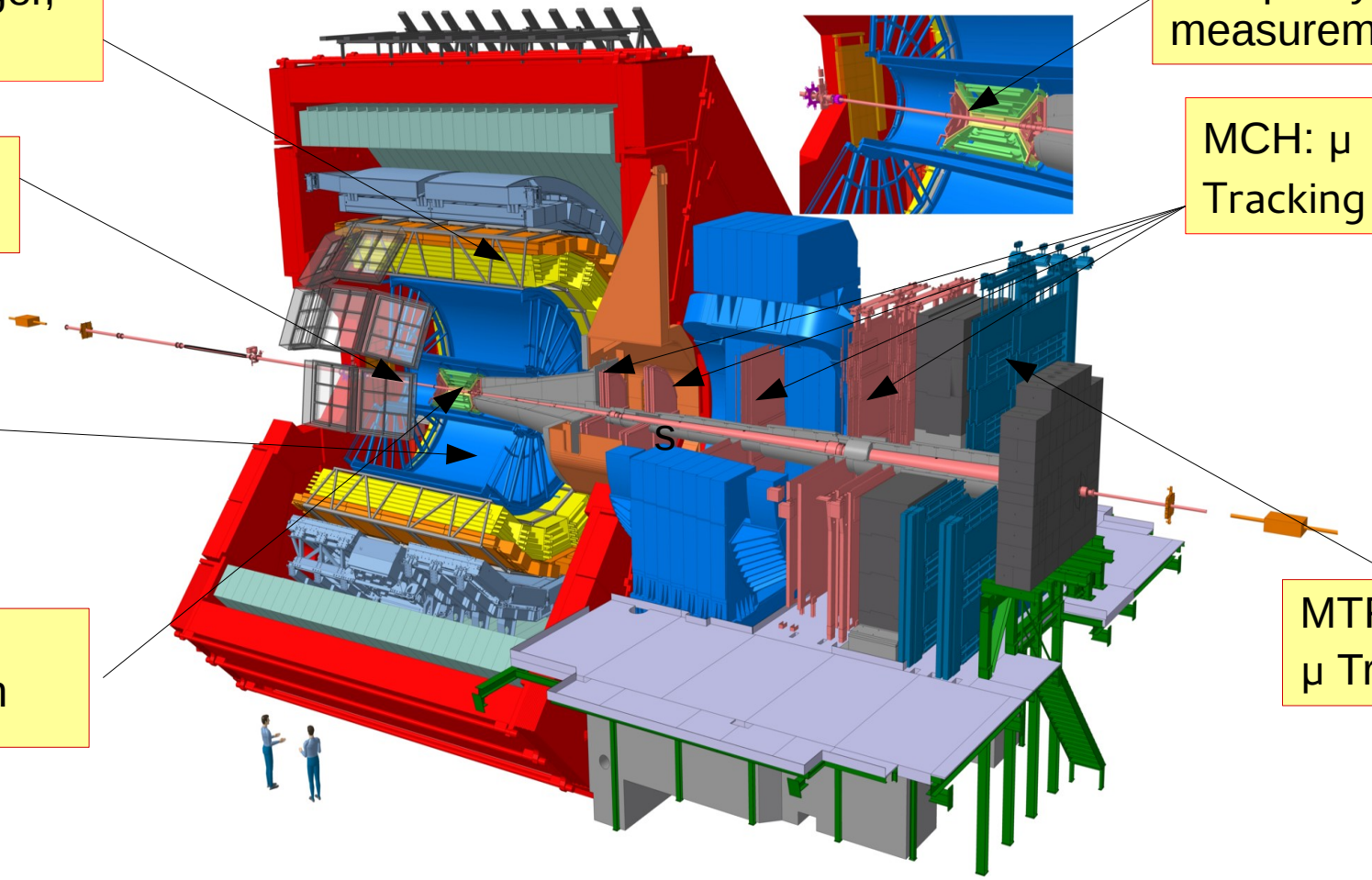
TPC: Tracking & PID

ITS: Vertex reconstruction

SPD: Multiplicity measurement

MCH: μ Tracking

MTR: μ Trigger



Analysis ingredients

- Data taken at 5.02 and 13 TeV.
- Minimum bias events, MB.
- Di-muon events, CMUL.
- Pile-up events are rejected.
- Monte-Carlo are used to determine $dN_{ch}/d\eta$ from measured number of SPD tracklets.
- One charged-particle required within $|\eta|<1$ i.e. INEL>0 event class selected.
- ϵ, efficiency factor that includes corrections due to event class, trigger selection and pile-up rejection.

Event Selection Cuts:

- Events with a reconstructed SPD vertex
- $N_{contributor}>0$
- $\sigma^{SPD}>0.25$ cm
- $|z^{SPD}_{v}|<10$ cm
- $|\eta|<1$ on SPD tracklets

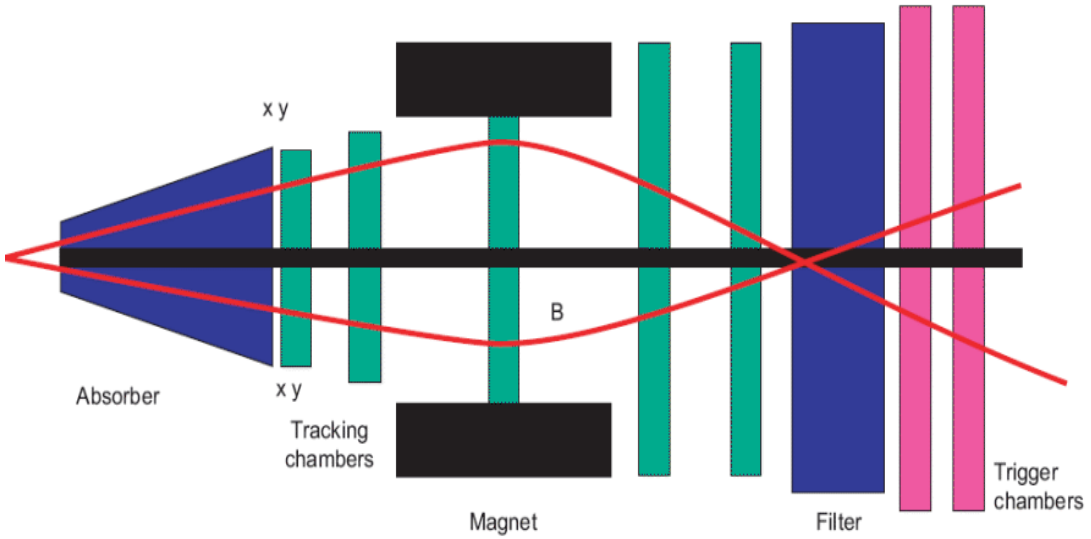
MC particle selection:

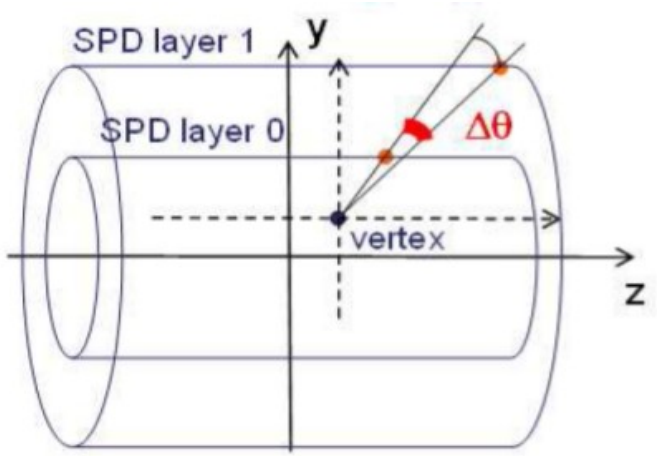
- Charge ≠ 0
- Physical primary
- $|\eta|<1$
- z-Vertex within 10 cm

$$\frac{dN_{J/\psi}/dy}{\langle dN_{J/\psi}/dy \rangle} = \frac{N^{i}_{J/\psi}}{N^{tot}_{J/\psi}} \times \frac{N^{tot}_{MB}}{N^{i}_{MB}} \times \epsilon$$

→ Relative yield
i = Multiplicity bin

Track and tracklet selection





$$\Delta\theta_{MAX} = \theta_0 - \theta_1 (25\ \text{mrad})$$

Muon channel

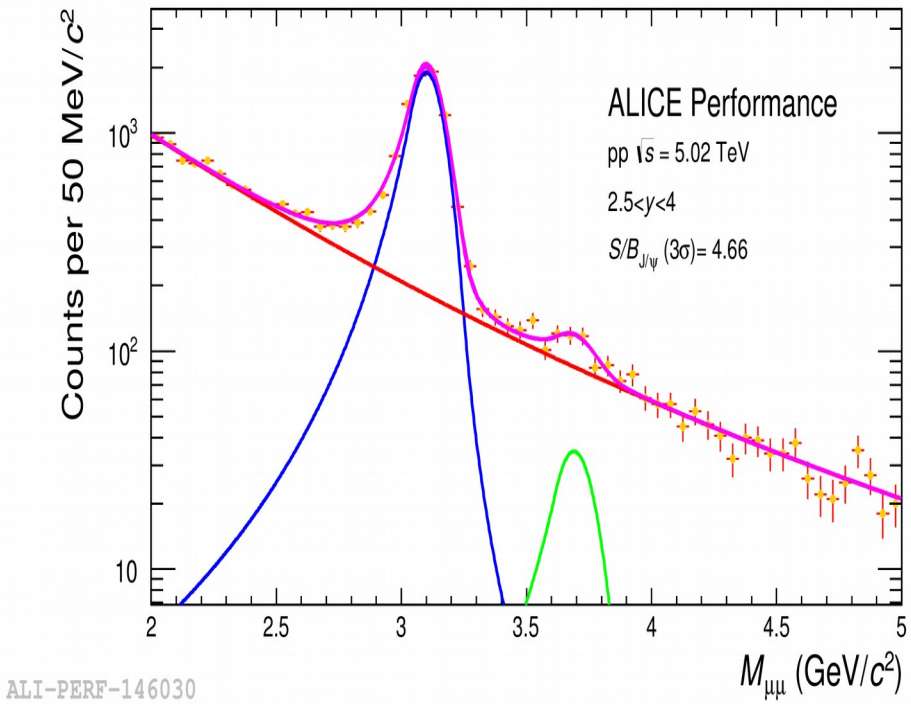
- Unlike-sign dimuon pair.
- $-4.0 < \eta < -2.5$ (for each muon), to reject tracks at the edge of the acceptance.
- $17.6 < R_{abs} < 89.5$ (cm) (for each muon), removes tracks crossing the thicker part of the absorber.
- $2.5 < y < 4.0$ (on dimuon pair), to match with the spectrometer acceptance.
- Both μ^+ & μ^- matching the trigger.
- *p X DCA* (Distance of closest approach) only for Y.

ITS

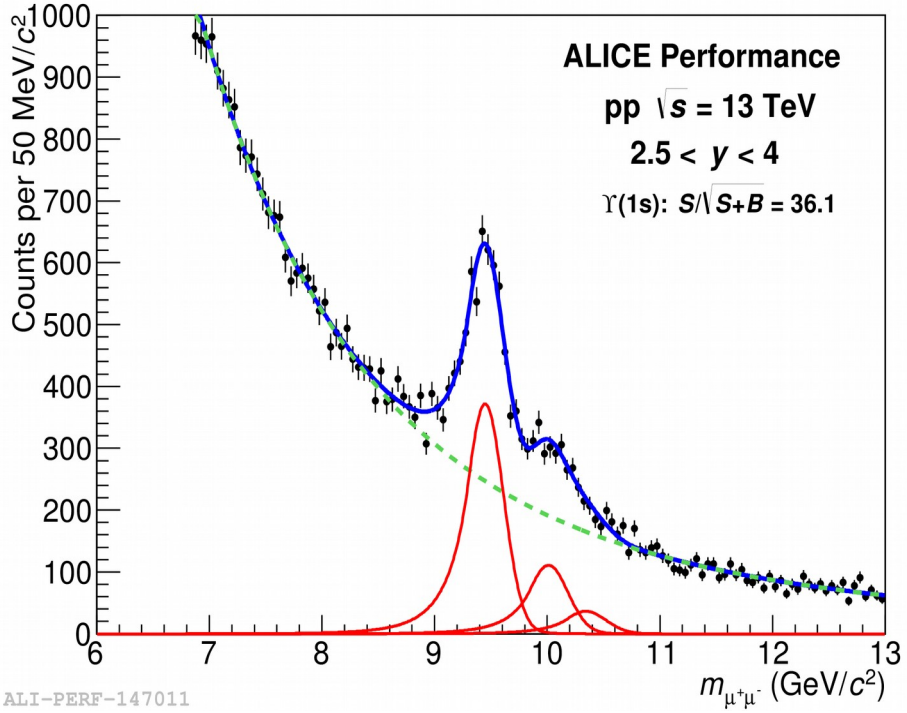
Tracklets are defined by pairs of hits in the two SPD layers.

Quarkonium signal

J/ψ family



Υ family



- Signal extraction is done by fitting invariant mass of opposite sign di-muons.
- Extended Crystal Ball function (signal).
- Variable Width Gaussian (background).

Charged-particle measurements

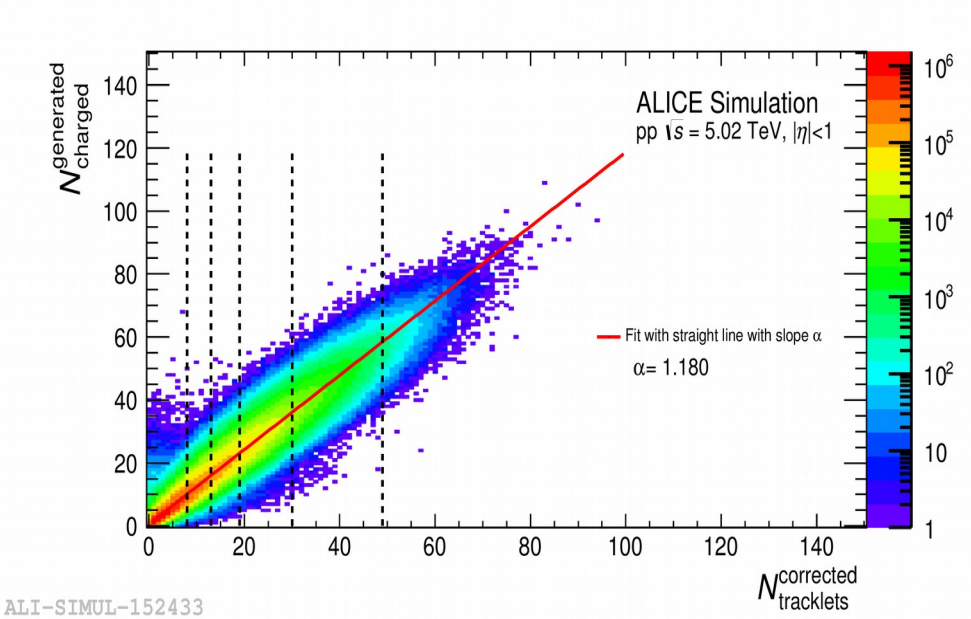
The charged-particle density is calculated by

$$\left\langle \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}\eta} \right\rangle^{\mathrm{i}} = \frac{f\left\langle N_{trk}^{Corr} \right\rangle^{\mathrm{i}}}{\Delta\eta}$$

where, *f* is a polynomial function, used to take into account possible non-linearities.

$\langle N^{corr}_{trk} \rangle$ is the mean number of tracklets corrected by SPD acceptance and efficiency.

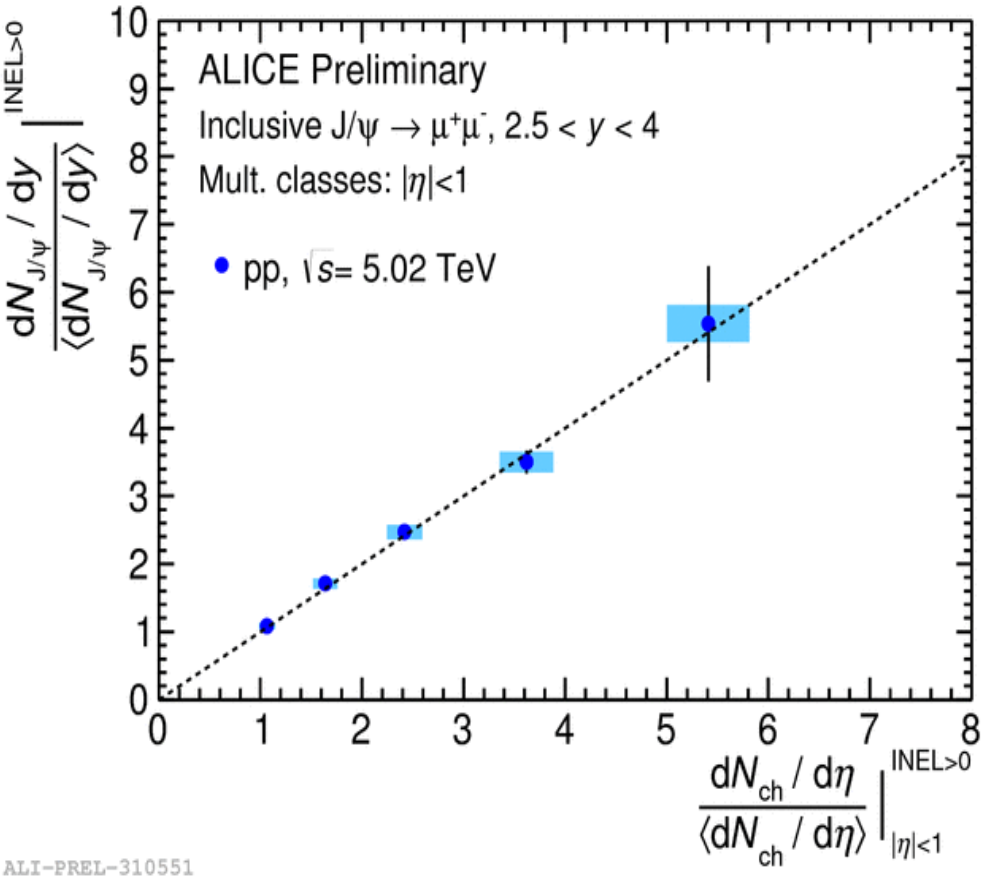
Here the pseudo-rapidity range is $|\eta|<1$.



Results

J/ψ vs multiplicity in pp at $\sqrt{s}=5.02$ TeV

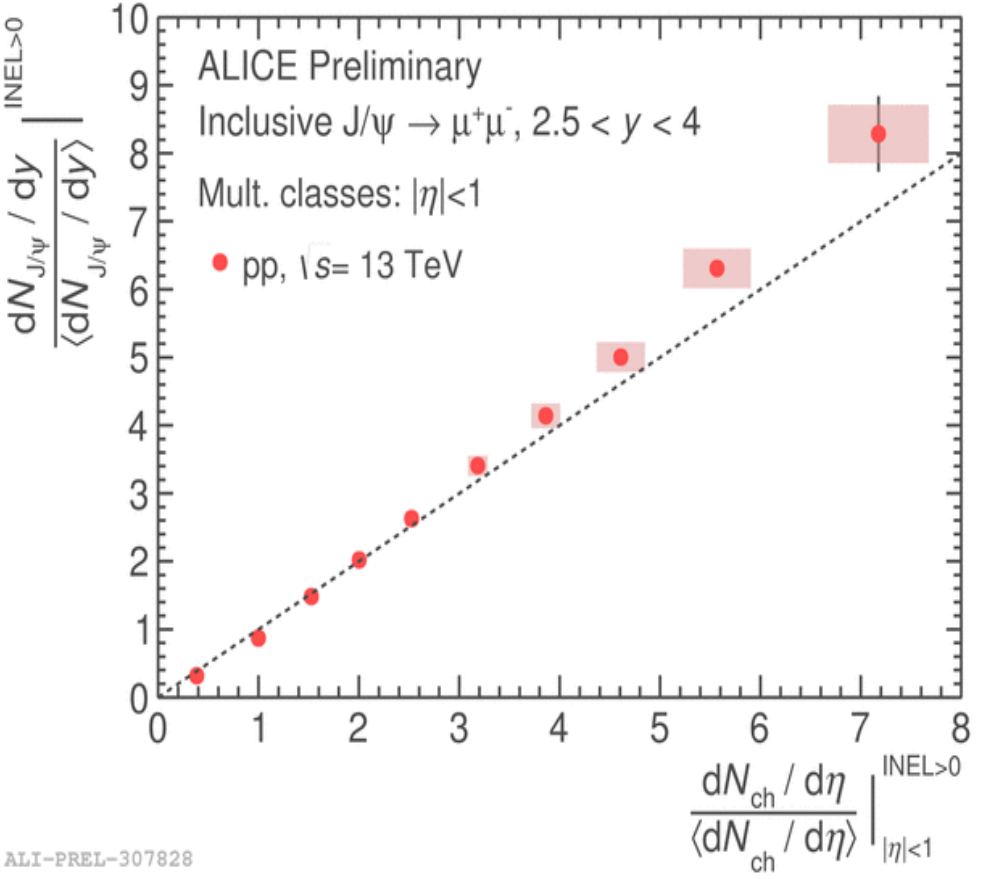
- Multiplicity dependence of J/ψ production is shown in pp at $\sqrt{s}$ = 5.02 TeV.
- Relative J/ψ and relative charged-particle density are measured for INEL>0 event class.
- Results are compared to diagonal correlation (y=x).
- Linear increase of relative J/ψ yield with the charged-particle multiplicity at forward rapidity.



*±1.4% normalisation unc. On $\langle dN_{ch}/d\eta \rangle$

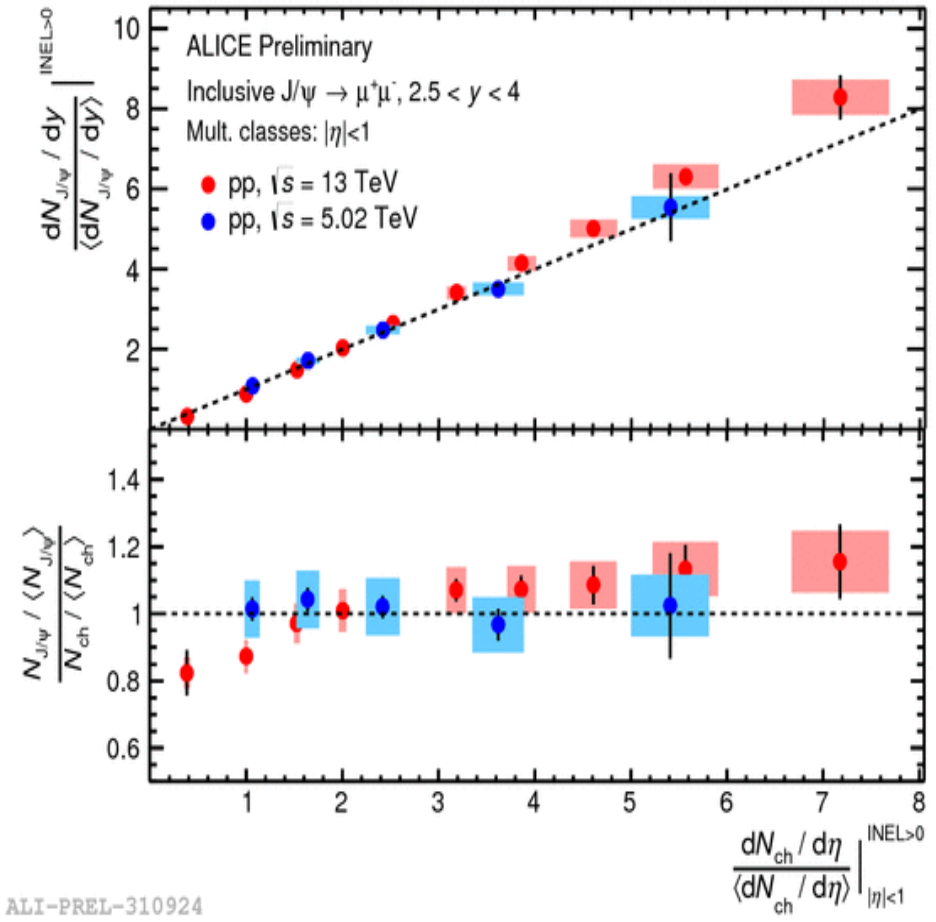
J/ψ yield vs multiplicity in pp at $\sqrt{s}=13$ TeV

- J/ψ yield as a function of multiplicity at high multiplicity pp 13 TeV.
- Relative multiplicity extended up to 8.
- Almost linear increment of relative yield with increase of multiplicity.



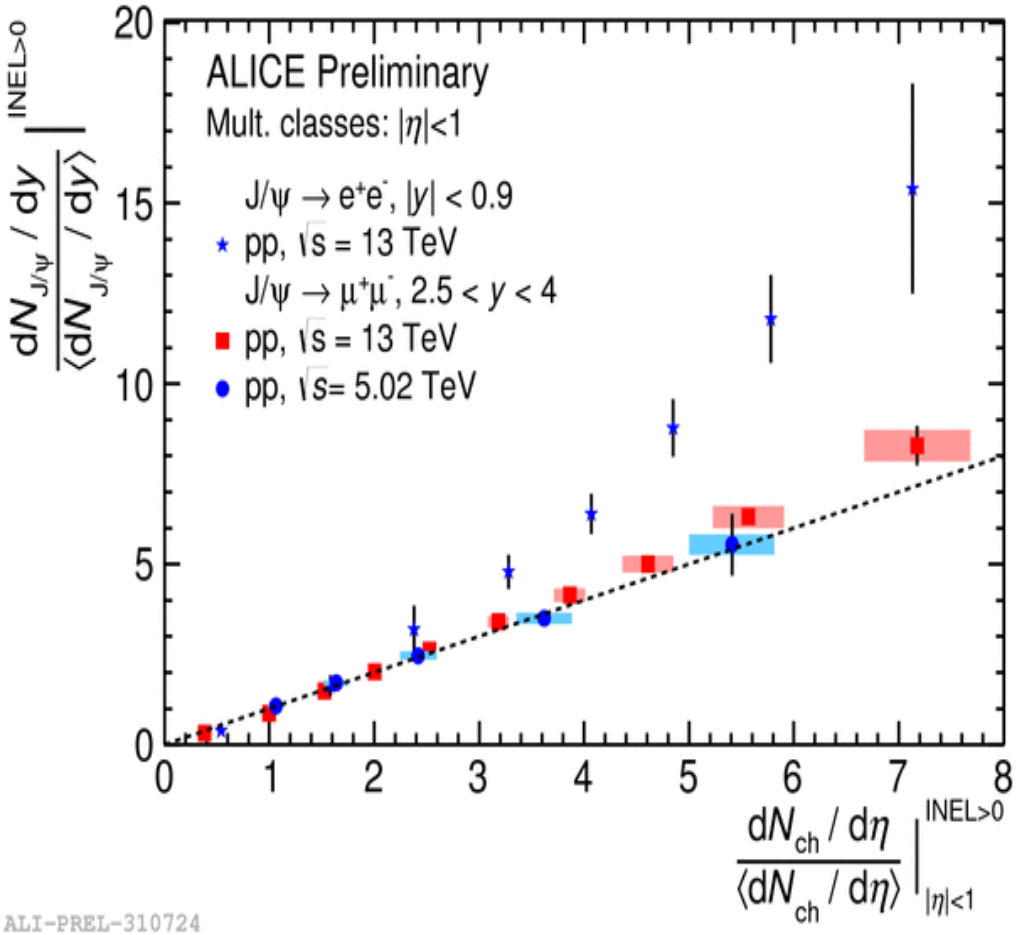
Energy dependence in pp collisions

- The results are compared to forward rapidity measurement in pp collisions at $\sqrt{s}$ = 13 TeV.
- We observe a similar multiplicity dependence at forward rapidity.
- Linear increase of J/ψ yield as function of multiplicity.
- No strong change of multiplicity dependence with $\sqrt{s}$ is observed at forward rapidity.



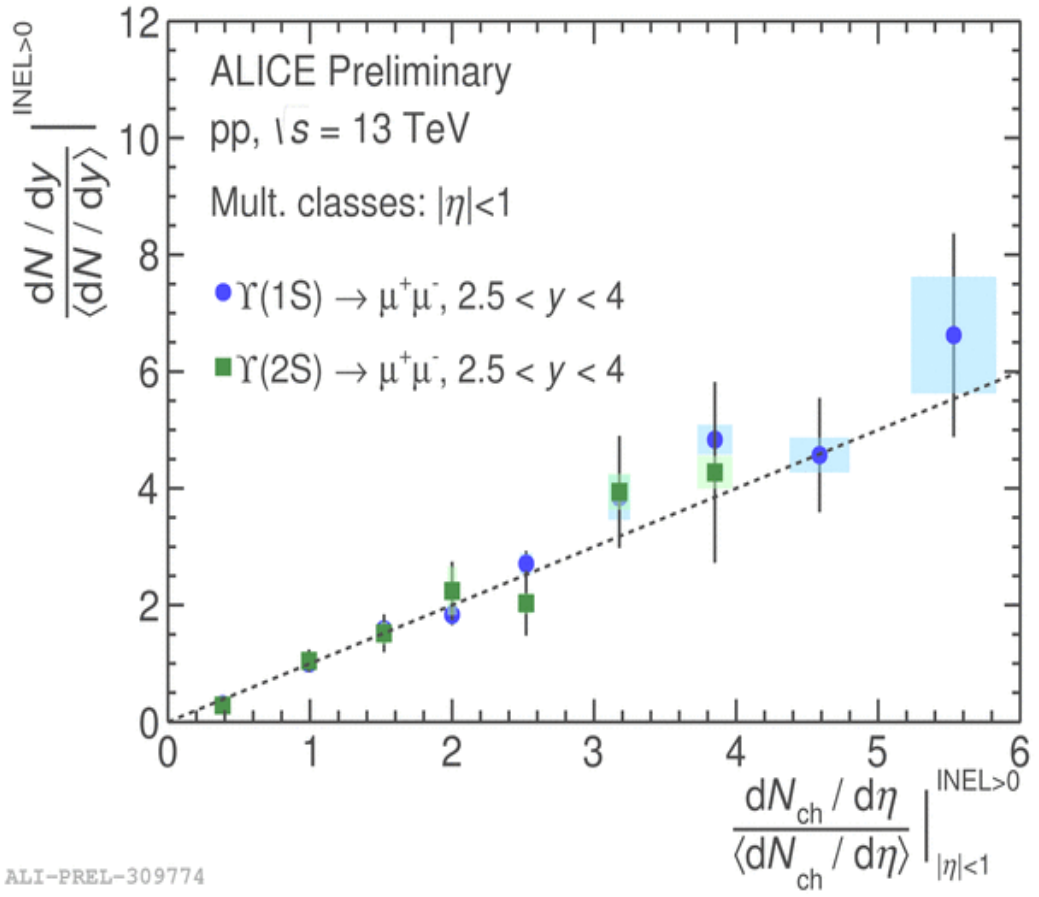
Rapidity dependence

- The results are compared to mid-rapidity measurements in pp collisions at √s = 13 TeV.
- Steeper increase at mid-rapidity compared to forward rapidity ← possibly due to an auto-correlation bias.



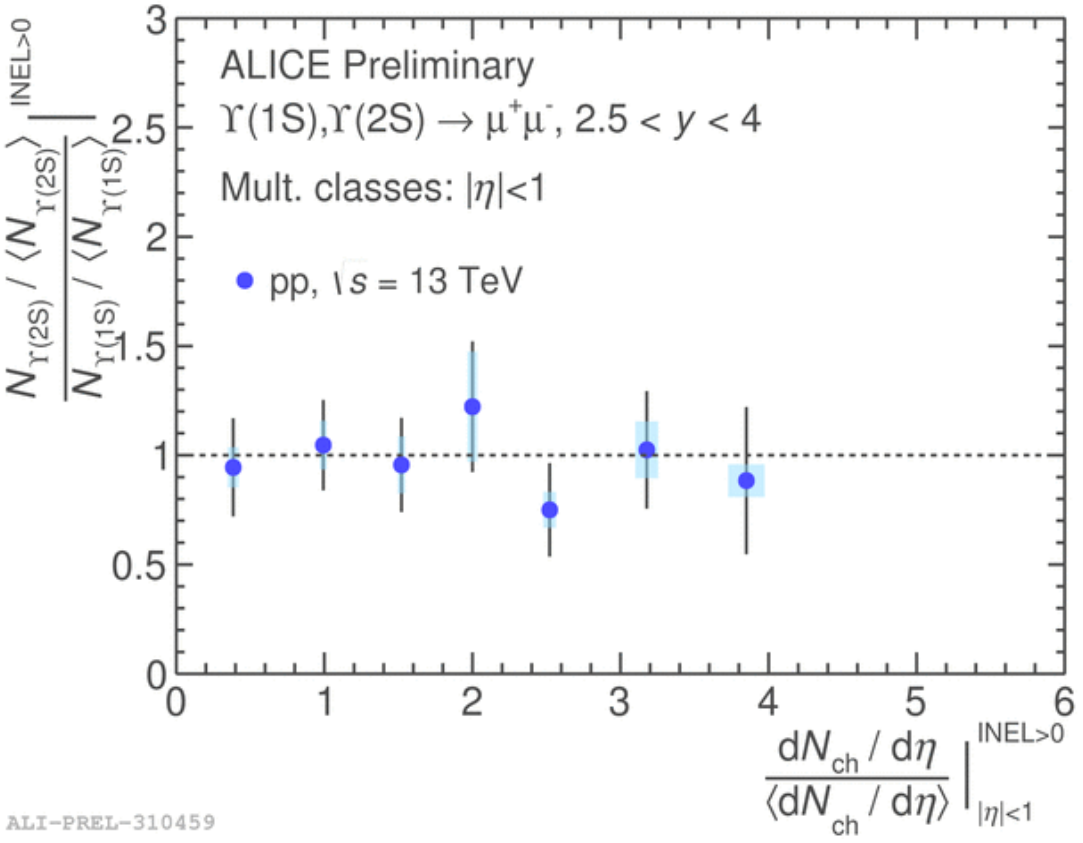
Υ yield vs multiplicity in pp at $\sqrt{s} = 13$ TeV

- First ALICE measurement of Υ production as a function of multiplicity in pp collisions at √s = 13 TeV.
- Multiplicity is measured at mid-rapidity and Υ is measured at forward rapidity – same as J/ψ.
- Υ(1S) and Υ(2S) yields increase linearly with multiplicity.



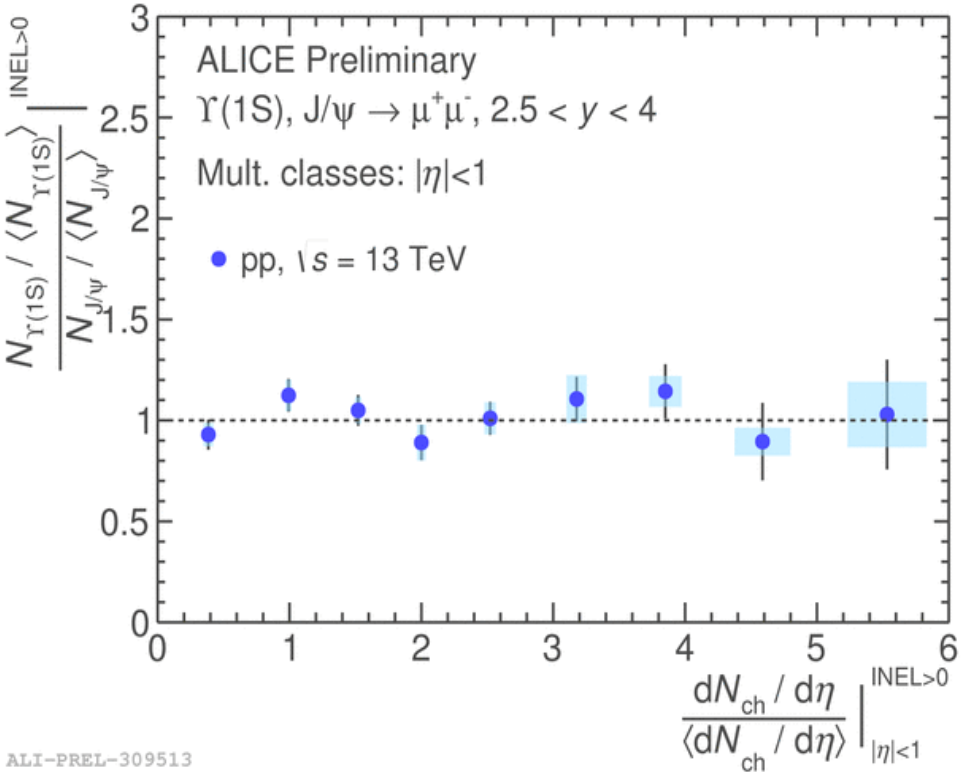
Comparison of Y(1S) to Y(2S)

- Ratio of excited state to ground state yield of Y.
- Y(1S)/Y(2S) is independent of multiplicity.
- The double ratio follows unity.
- Within uncertainty also consistent with the dropping multiplicity dependence observed by CMS (JHEP 04 (2014) 103).
- The increase is independent of the bottomonium resonance.



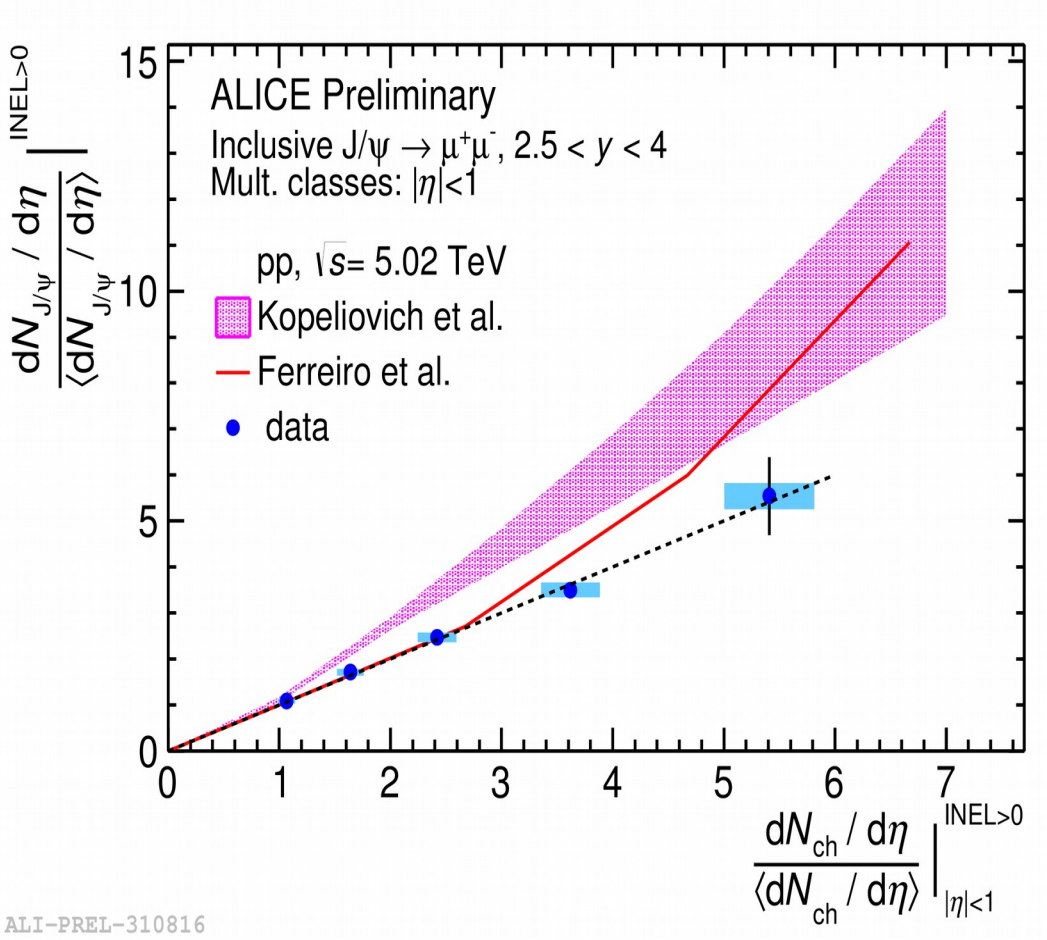
Quarkonium state dependence

- The ratio of Y to J/ψ shows almost no deviation from unity.
- Both J/ψ and Y have similar multiplicity dependence at forward rapidity.
- Multiplicity dependence is independent of invariant mass and quark content of quarkonium states.



Comparison with model calculations

- Two model predictions are provided: from Kopeliovich et al. [PRD 88, 116002 (2013)] and from Ferreiro et al. (percolation model) [PRC86(2012)034903] at forward rapidity.
- The approach is similar to that discussed in the introduction.
- Both models show a similar trend at $\sqrt{s}$ = 5.02 TeV.
- Stronger than linear increase with multiplicity is observed.
- The percolation model reproduces the data better.



Summary

- The multiplicity dependence of J/ψ, Y has been studied in pp collisions at different energies and rapidity region at ALICE.
- Relative yield of quarkonia increase linearly with multiplicity in pp collisions only at forward rapidity.
- Independently of energy and quark content.
- The increase seems to strongly depend on the rapidity gap between the J/ψ and the multiplicity measurement.
- Data are qualitatively described by theoretical models at $\sqrt{s}$ = 5.02 TeV.
- It will be interesting to explore multiplicity dependence of quarkonia in more detail (i.e. ψ(2s), $\langle p_T \rangle$-J/ψ measurements) in small systems.

Thank You.