J/ψ production as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 5.02 TeV with ALICE

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DAEHEP2018
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Outline

- Motivation
- Multiplicity Dependence
- Theoretical Approaches
- Experimental Method
- Results
- Conclusions and Outlook

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].

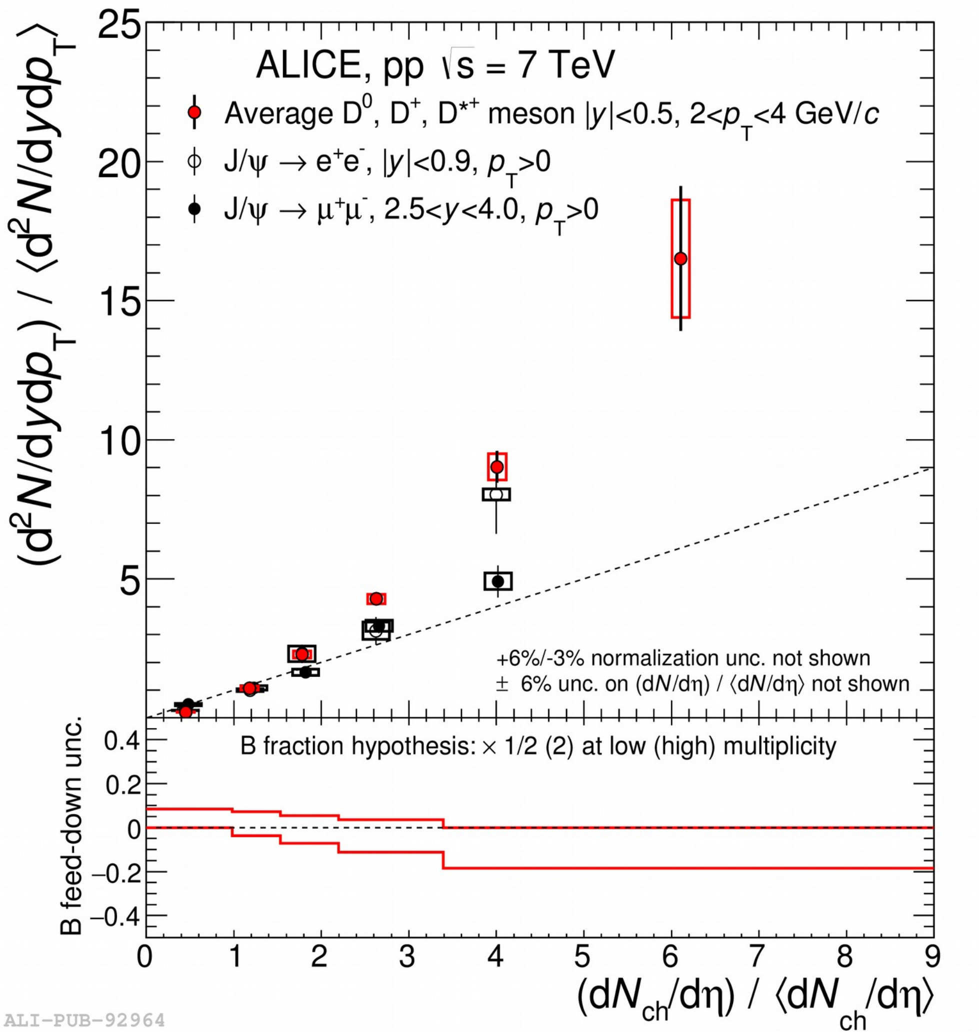
J/ψ production in small systems, particularly in pp collisions:

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

Multiplicity dependence of J/ψ 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.
- Independent from hadronisation.
- Mid-rapidity and forward rapidity J/ψ don't show the same trend at higher multiplicity bins.
- In this present work the evolution of relative J/ψ yield as a function of charged-particle multiplicity is studied in pp collisions at $\sqrt{s}$ = 5.02 TeV at forward rapidity.
- To see the effect of multiplicity dependence of hadron production at lower energies.

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:

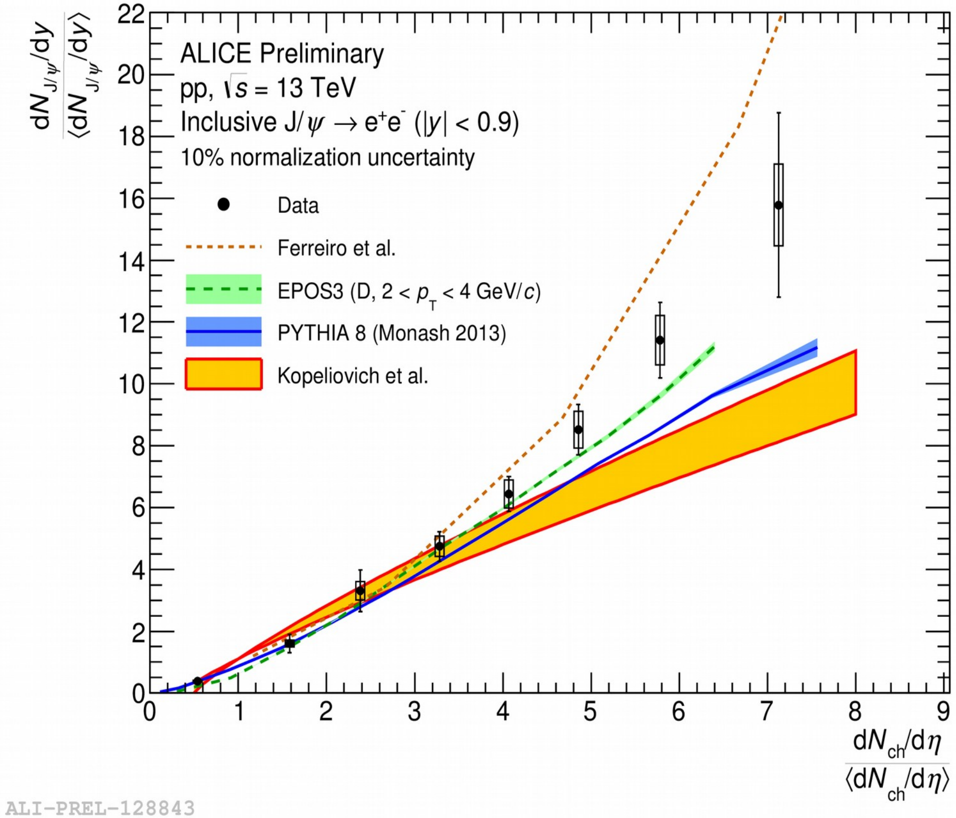
[PRC86 (2012)034903]

- 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 $\sqrt{s}$ = 13 TeV.
- Multiplicity reached in pp collisions at $\sqrt{s}$ = 13 TeV is twice that at $\sqrt{s}$ = 7 TeV.

J/ψ measurement with ALICE

$J/\psi \rightarrow e^+ + e^-$ (Central Barrel: **$|\eta|$< 0.9**)
$\rightarrow \mu^+ + \mu^-$ (Muon Spectrometer: **$-4.0 < \eta < -2.5$**)

SPD : Multiplicity measurement

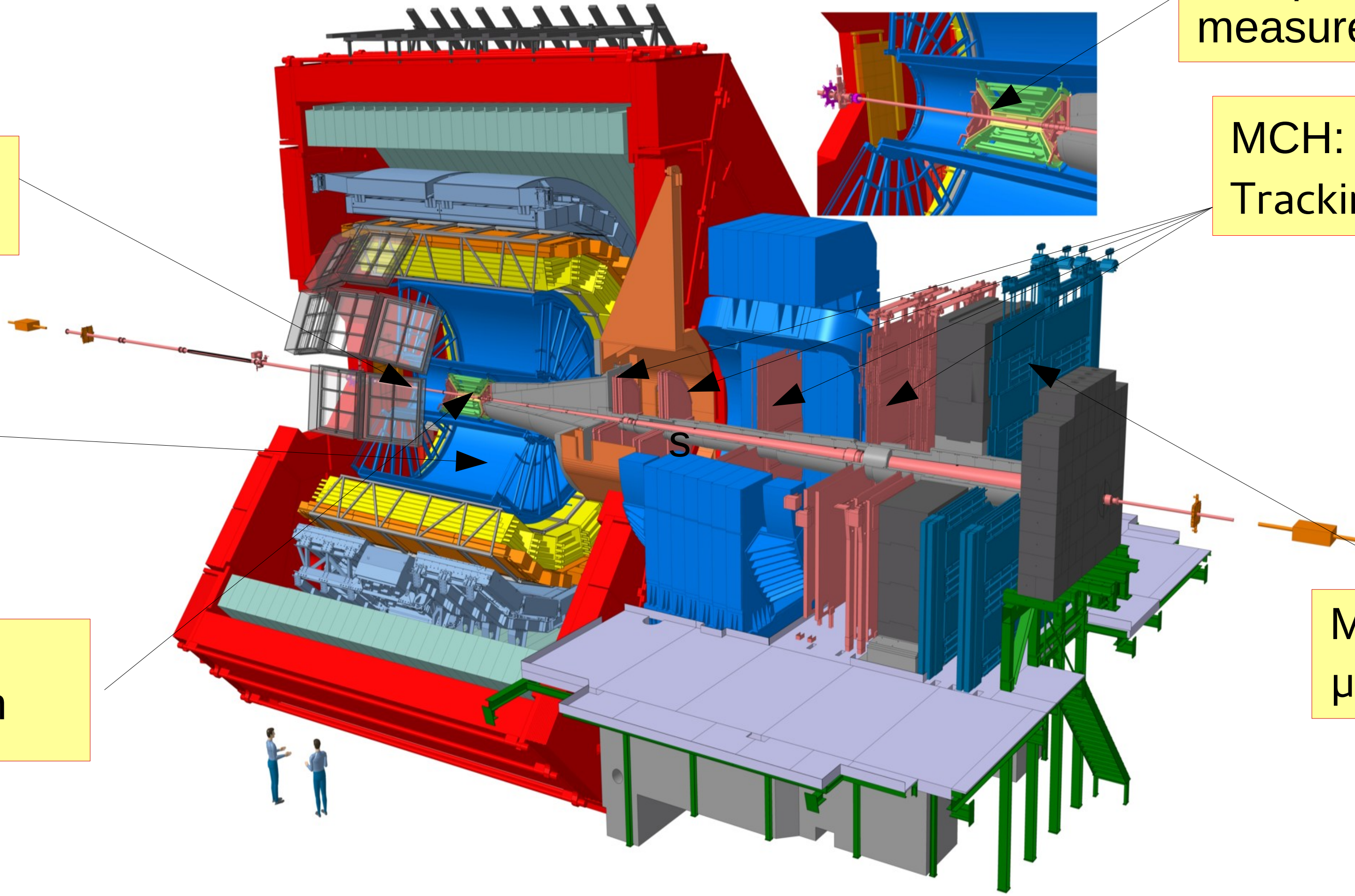
T0,V0 : Triggering

MCH: μ Tracking

TPC : Tracking & PID

MTR: μ Trigger

ITS : Vertex reconstruction



Analysis ingredients

- Data taken in 2015
- Minimum bias events, MB (106M)
- Low p_T muon triggered events (~1.2M)
- Pile-up events are rejected
- PYTHIA6 and PYTHIA8 Monte-Carlo are used to determine $dN_{ch}/d\eta$ from SPD tracklets
- One particle selected within $|\eta| < 1$ i.e. INEL > 0 event class selected

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

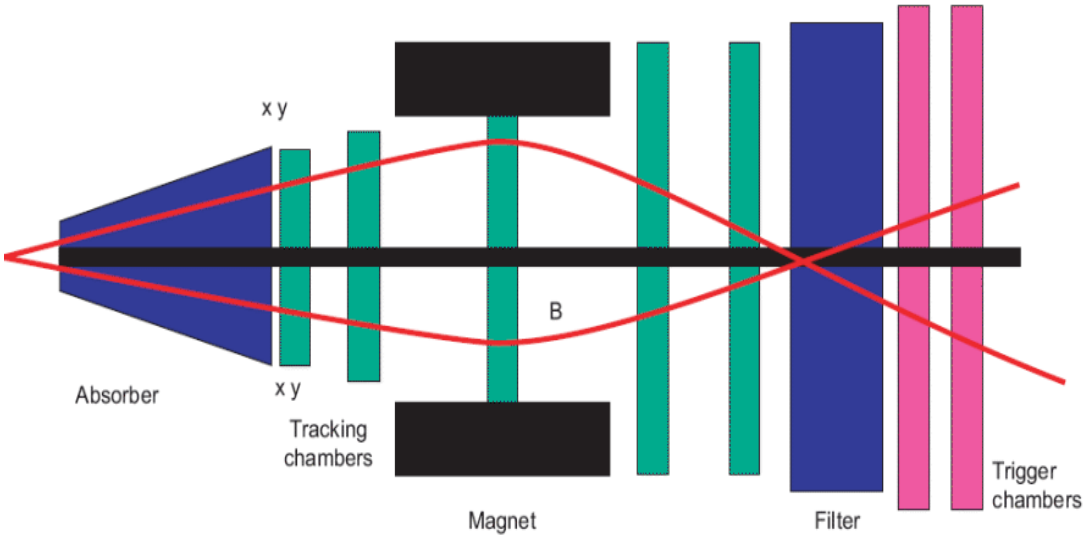
MC particle selection:

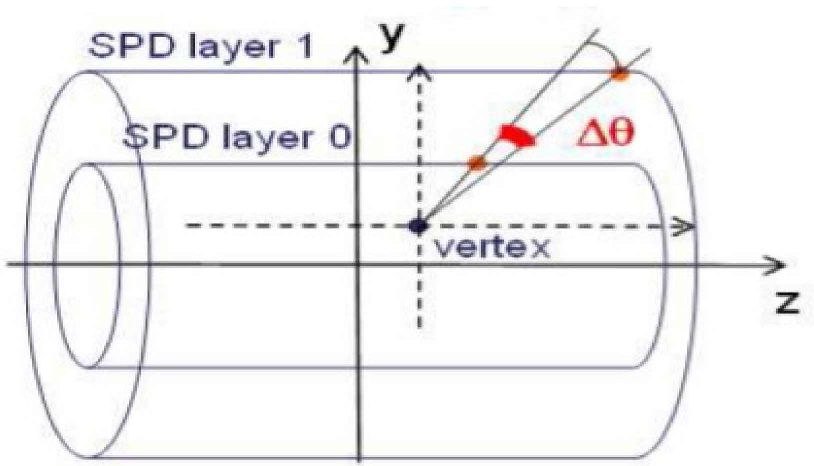
- Charge ≠ 0
- Physical primary
- $|\eta| < 1$
- z-Vertex within 10 cm

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

Relative yield
i = Multiplicity bin

Track and tracklet selection





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

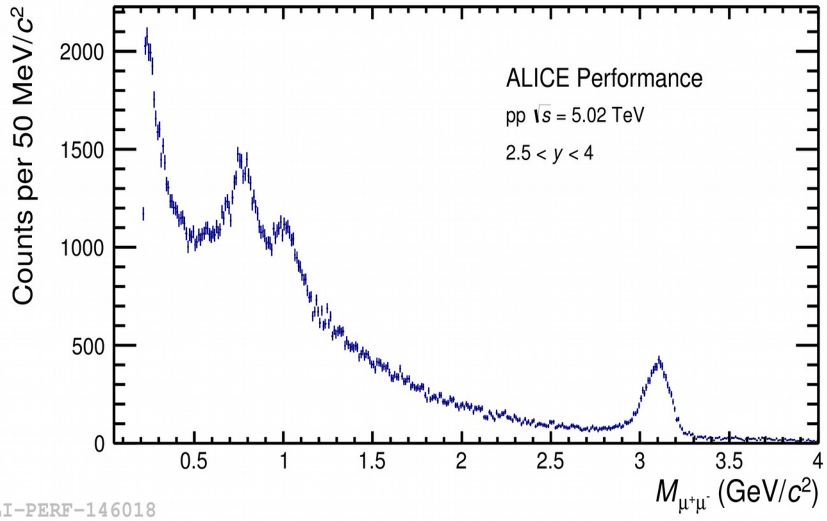
Muon channel

- Unlike sign dimuon pair.
- $-4.0 < \eta < -2.5$ (for each muons), 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.

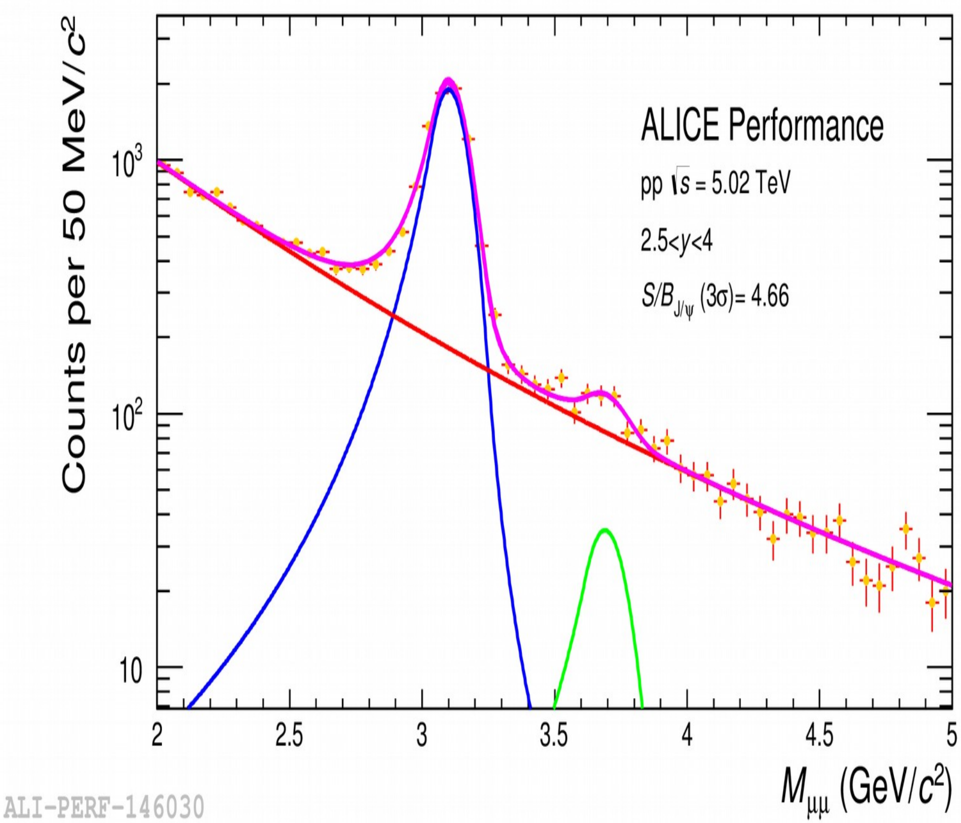
ITS

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

Signal extraction

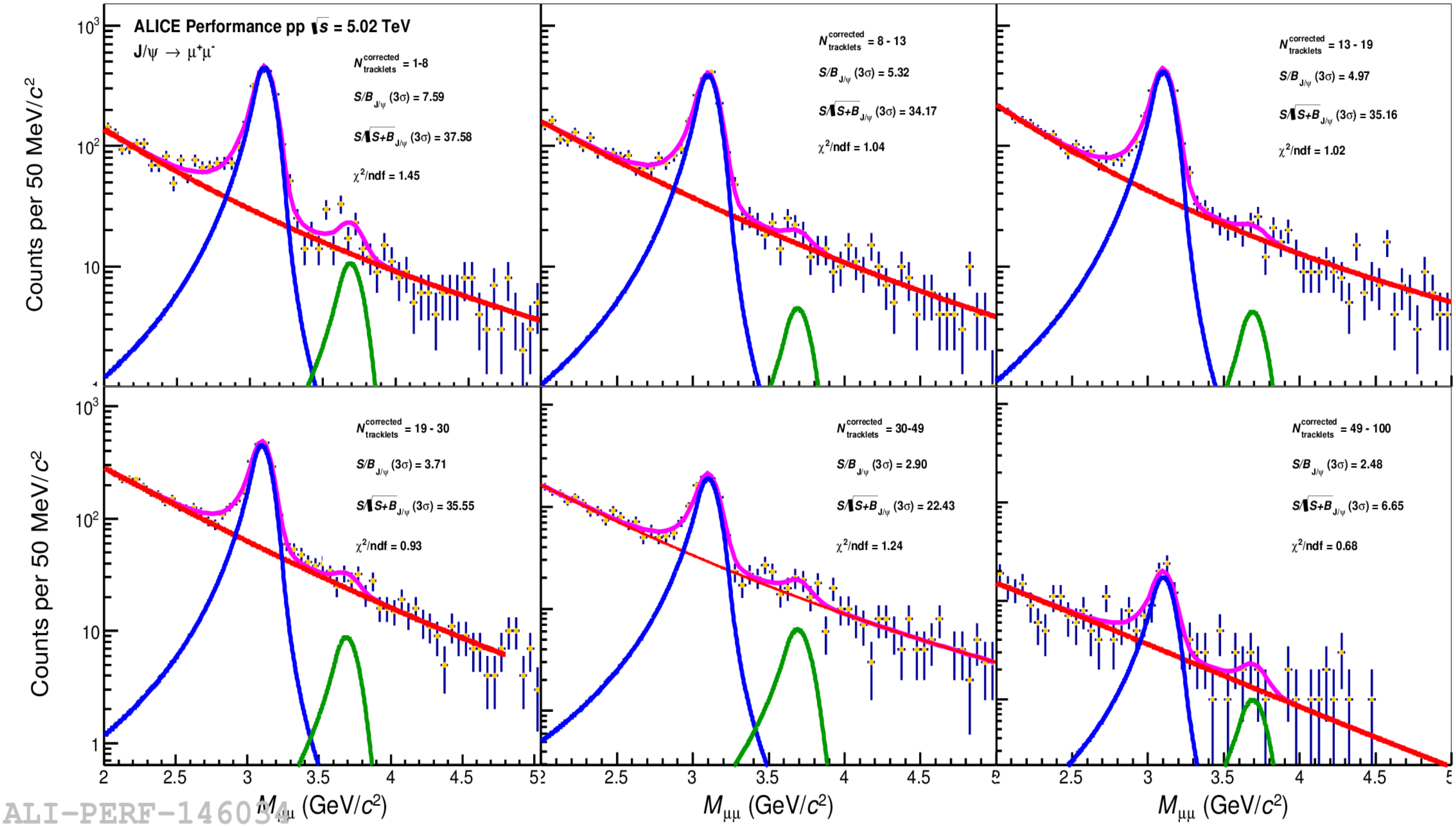


- 2 Set of signal function CB2 & NA60.
- 2 Set of background function VWG & pol1/pol2.
- 2 set of range used (2-5, 1.7-4.8) for background and signal extractions.
- Mass and width of Ψ(2S) are fixed to those of the J/Ψ.
- All the parameters are kept free except the tail parameters.



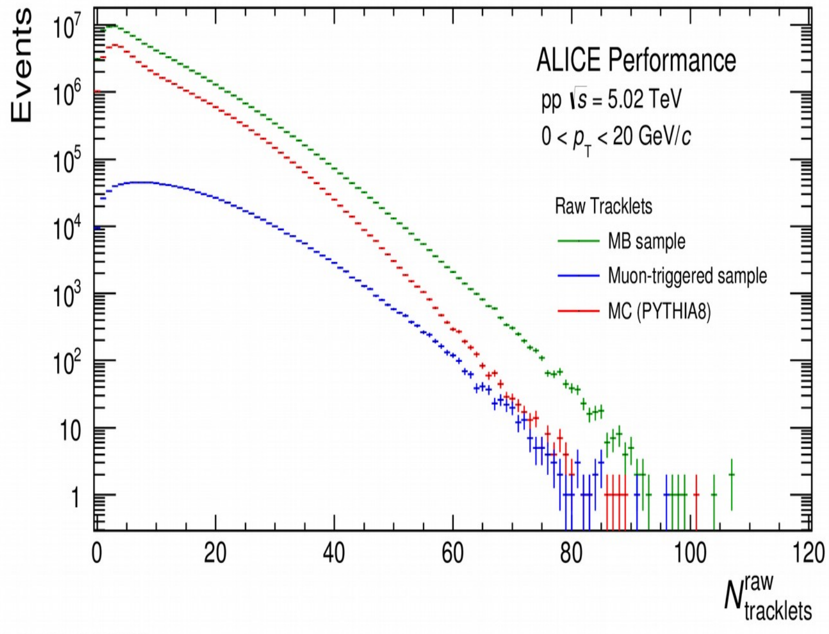
$N_{J/\Psi}$ = 7461 ± 112 (stat) ± 236 (syst.)

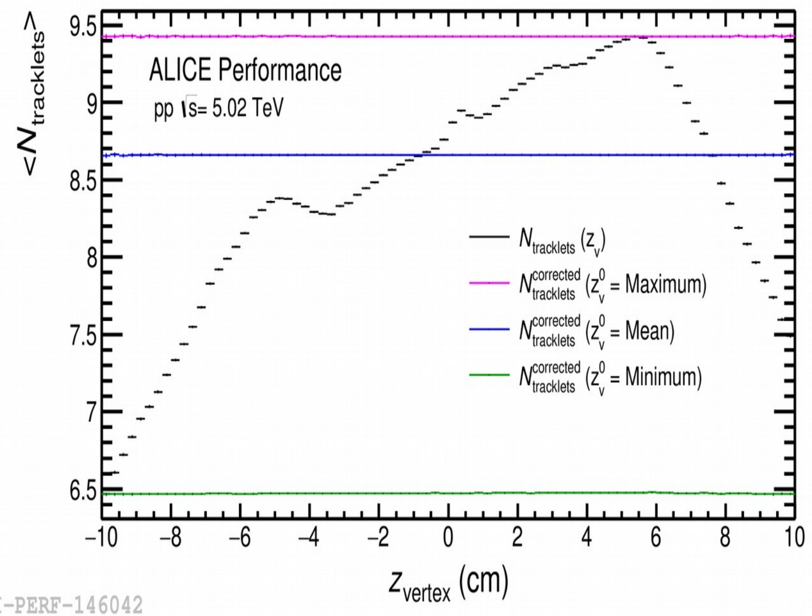
J/Ψ in multiplicity bins (CB2+VWG)



Example

Tracklet correction





- The number of SPD tracklets are corrected for acceptance and efficiency using a data driven method.
- Reference value $\langle N_{tr}\rangle(z_0)$ is either the maximum, minimum or mean value.
- Randomized corrections are done using Poisson distribution for 3 reference values.
- In this present analysis the reference value is chosen as maximum.

$$N_{tr}^{corr}(z) = N_{tr}(z) + \Delta N_{rand} \qquad \Delta N = N_{tr} \frac{\langle N_{tr}\rangle(z_0) - \langle N_{tr}\rangle(z)}{\langle N_{tr}\rangle(z)}$$

Charged-particles measurements

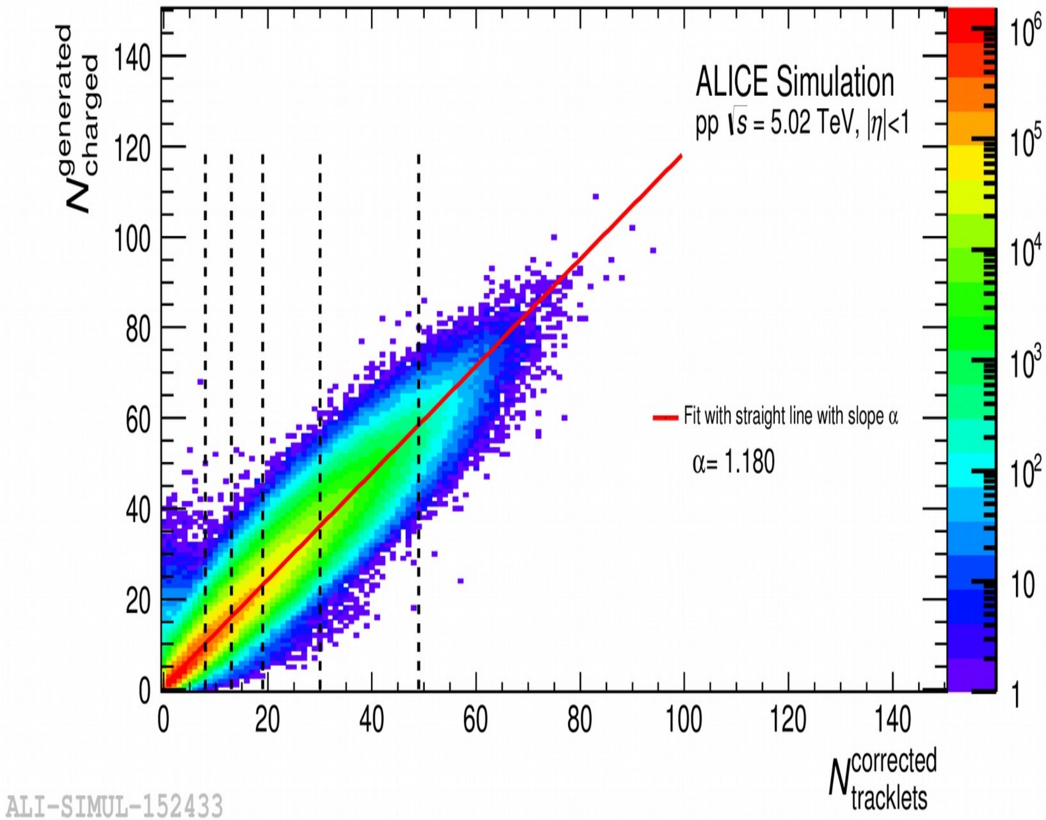
The charged-particle density is calculated by

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

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

$\langle N^{corr}_{trk} \rangle$ is the corrected mean tracklet.

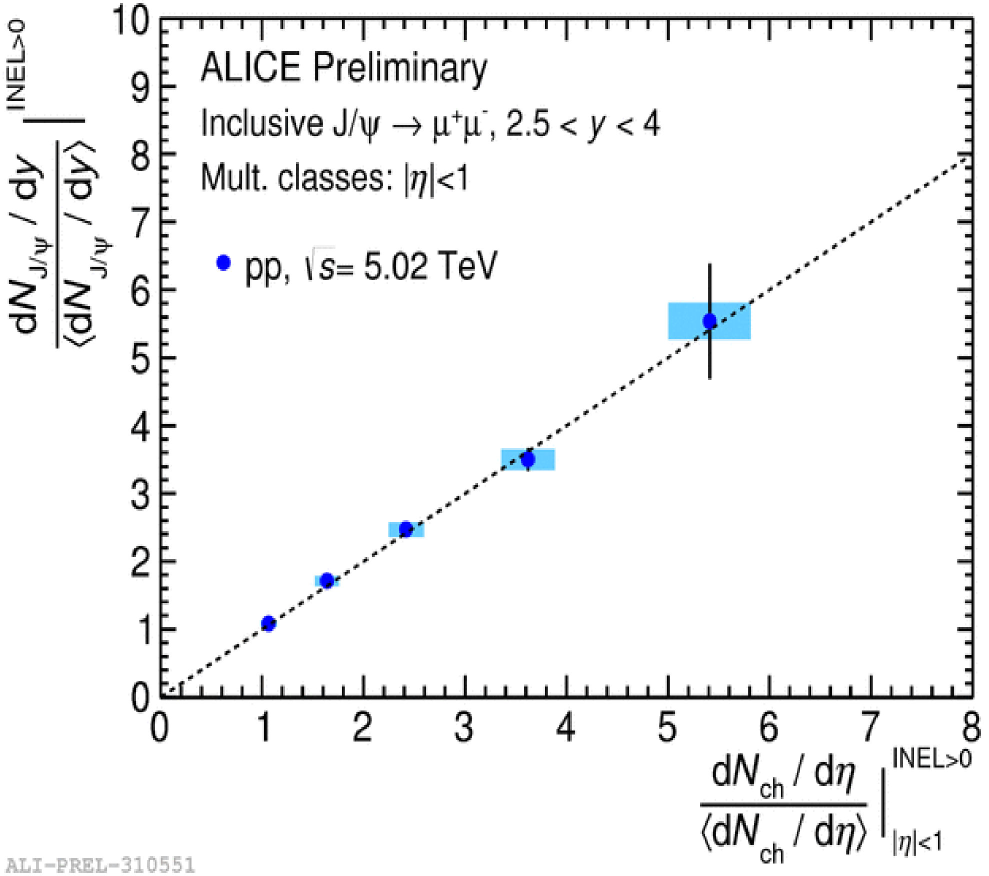
Here the pseudo-rapidity range is $-1 < \eta < 1$.



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.



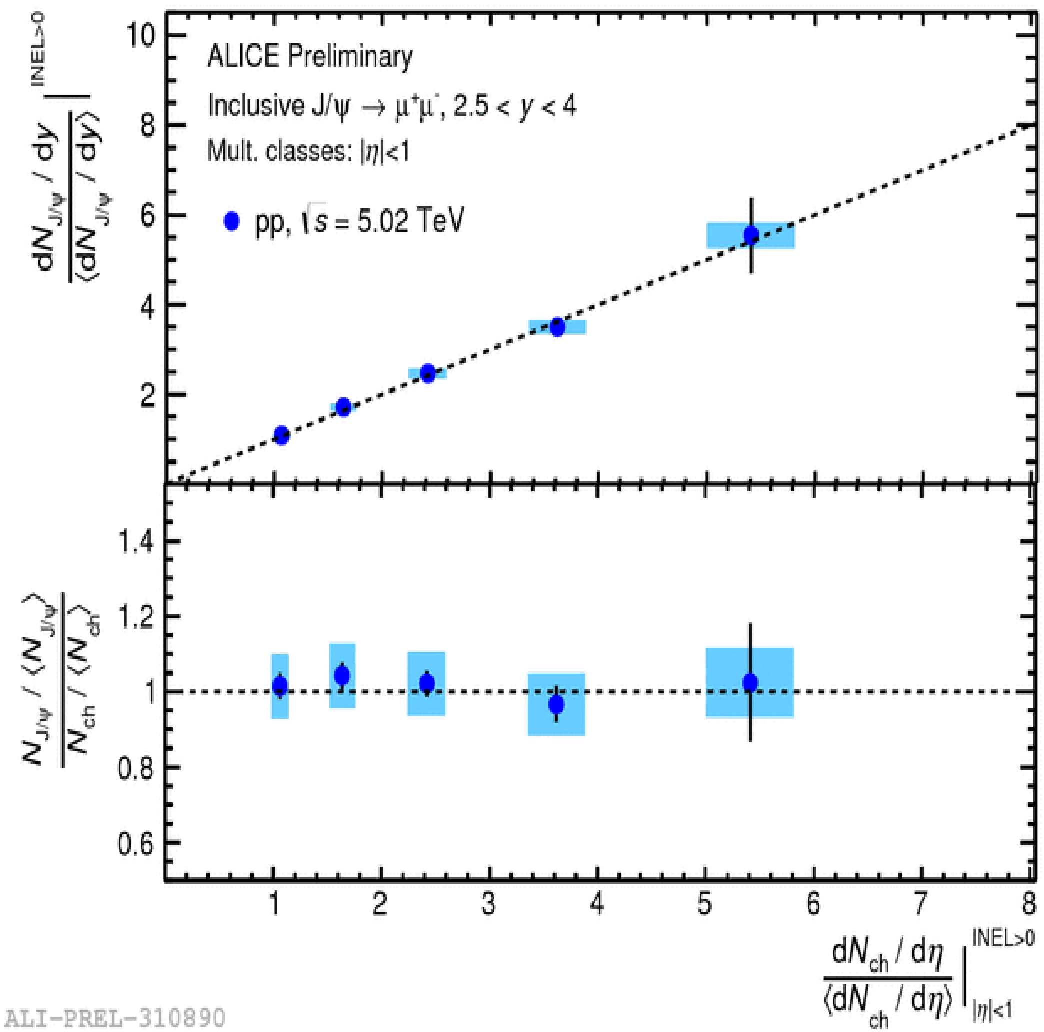
*±1.4% normalisation unc. On $<dN_{ch}/d\eta>$

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

- The ratio of self-normalised J/ψ yield to the self-normalised charged-particle is shown in the bottom panel.

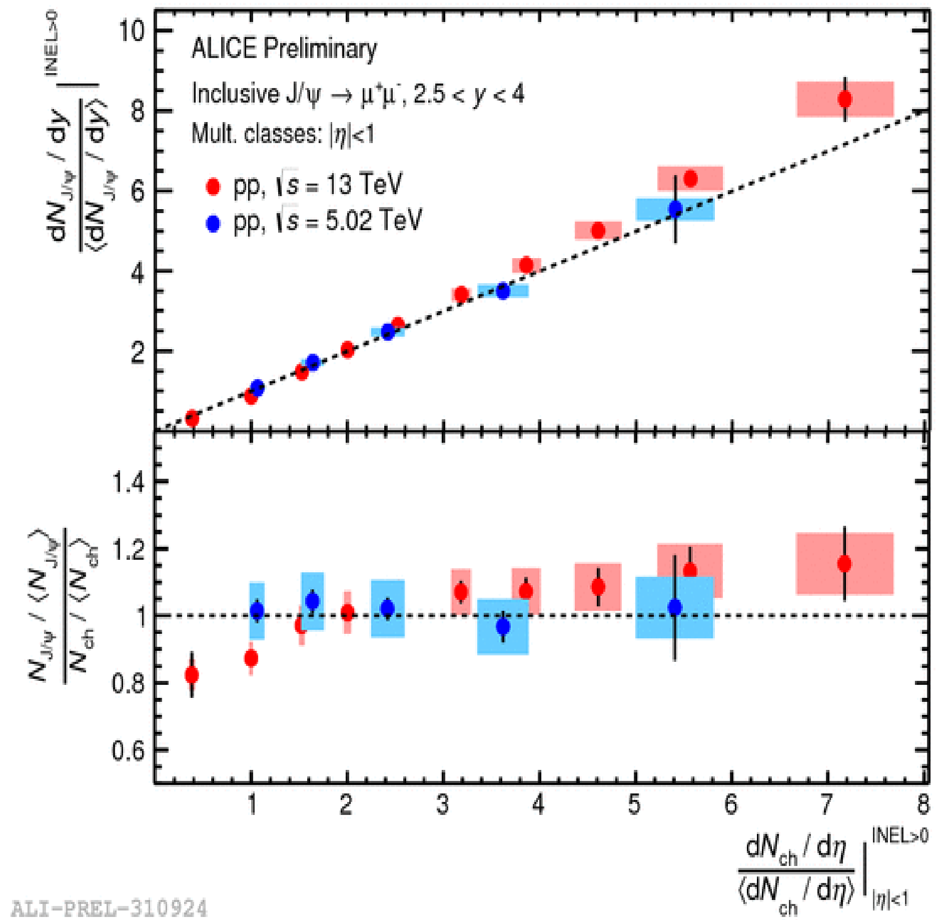
- No deviation from unity at forward rapidity.

*±1.4% normalisation unc. on <dN_{ch}/dη>



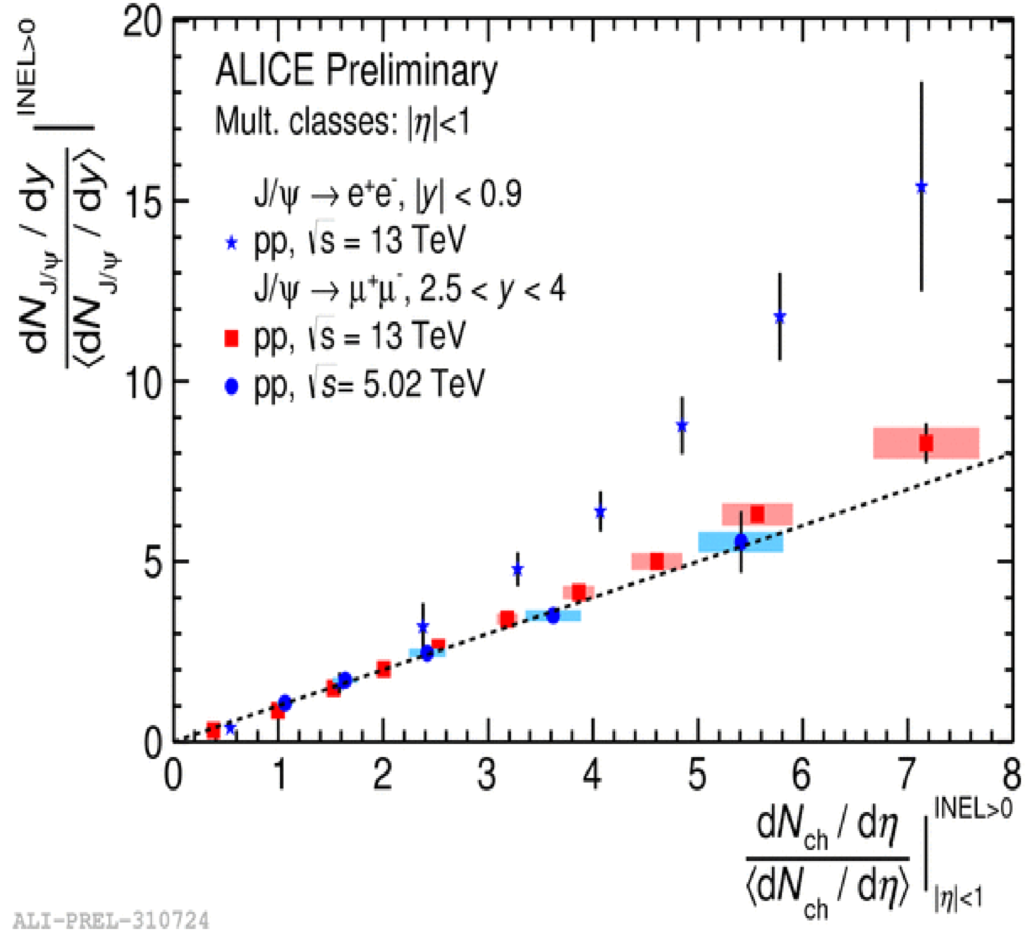
Energy dependence in pp collisions

- The results are compared to forward rapidity measurement in pp collisions at √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 √s is observed so far at forward rapidity.



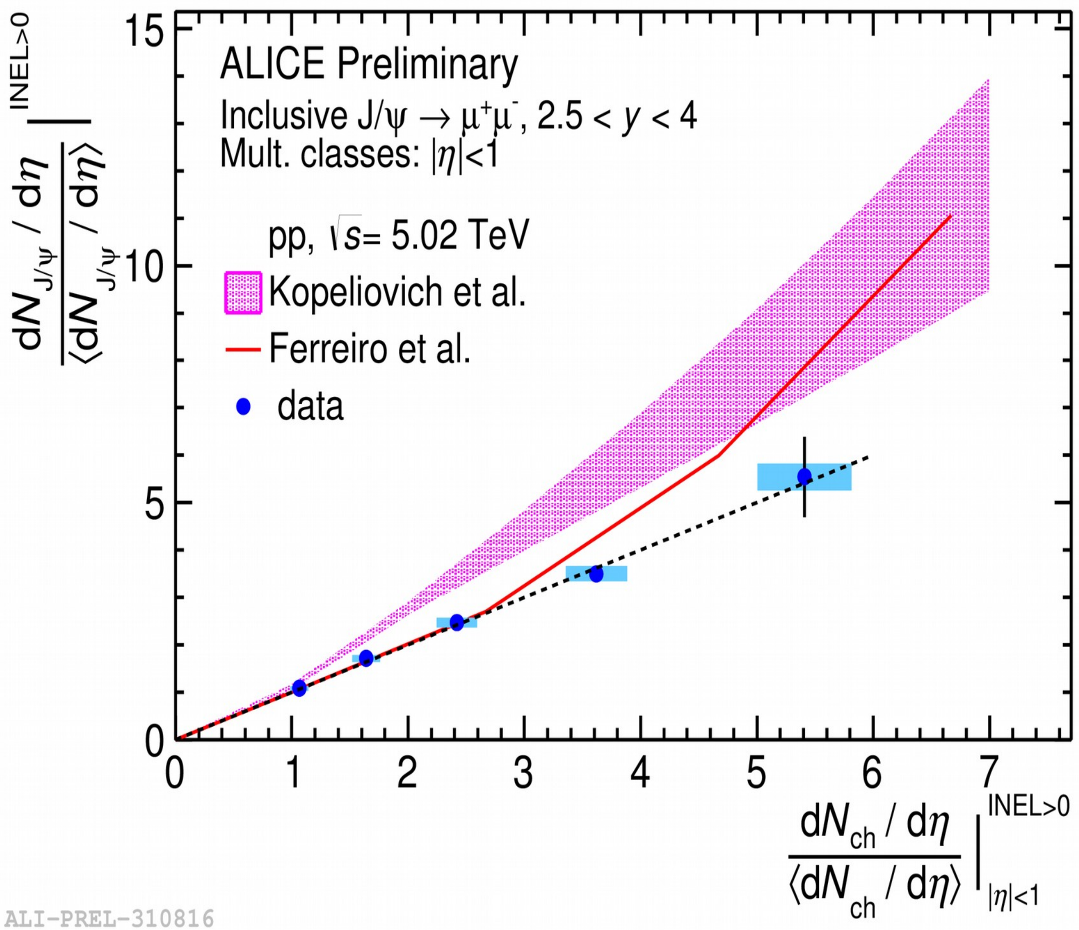
Rapidity dependence

- The results are compared to forward and mid-rapidity measurements in pp collisions $\sqrt{s}$ = 13 TeV.
- Both multiplicity and J/ψ are measured in mid rapidity → No *y*-gap. At forward rapidity measurement → *y*-gap.
- No strong change of multiplicity dependence with $\sqrt{s}$ is observed so far at forward rapidity.
- Steeper increase at mid-rapidity compared to forward rapidity ← possibly due to an auto-correlation bias.



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 (slide 5).
- 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.



Conclusion & outlook

- The multiplicity dependence of J/ψ has been studied in pp collisions at $\sqrt{s}$ = 5.02 TeV.
- Relative J/ψ yield increases linearly with multiplicity in pp collisions at $\sqrt{s}$ = 5.02 TeV.
- The increase is similar to that of forward rapidity J/ψ observed by ALICE in pp collisions at $\sqrt{s}$ =13 TeV.
- Data are qualitatively described by theoretical models.
- The increase seems to depend on the rapidity gap between the J/ψ and the multiplicity measurement.
- The absence of energy dependence of the increase will be further studied by looking at the $\sqrt{s}$ = 2.76 TeV data.

Thank You :)

Extras

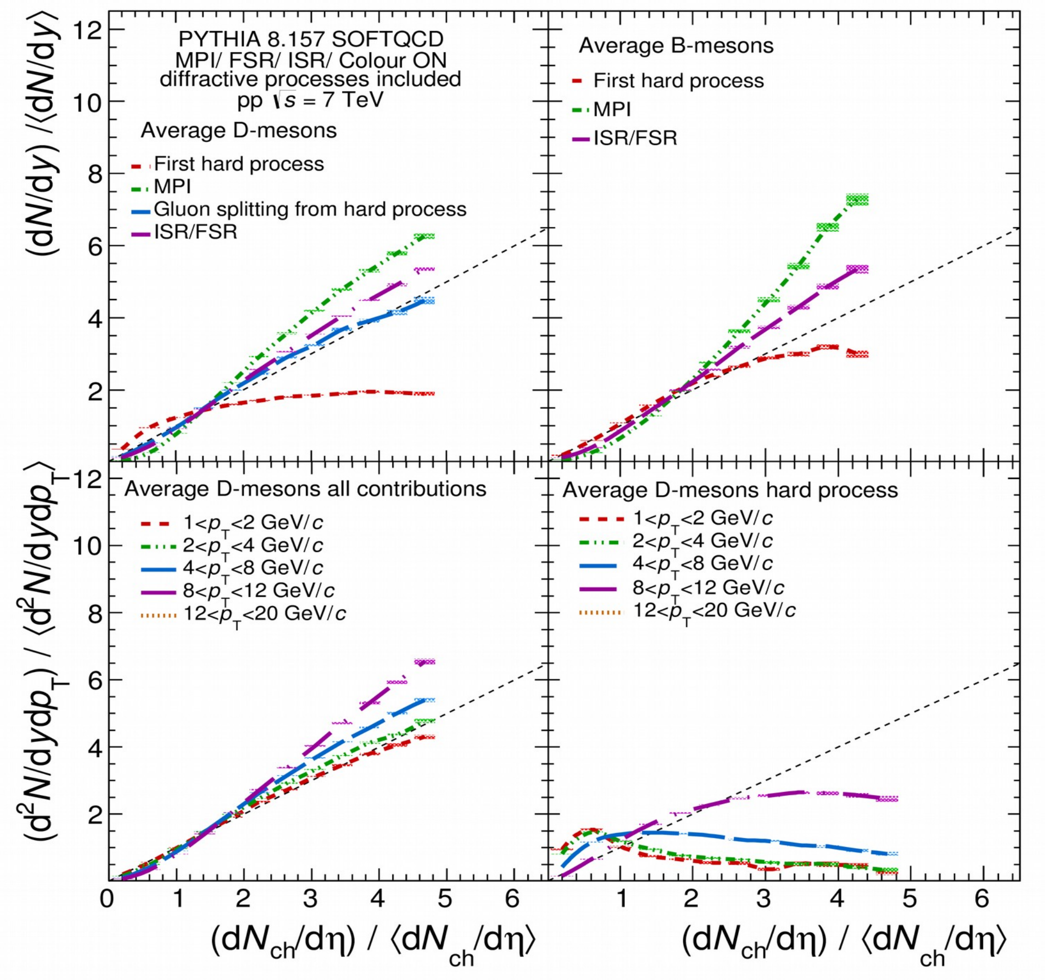
Theoretical Interpretation

PYTHIA8 simulation

[T. Sjostrand, S. Mrenna, P. Z. Skands:Comput.Phys.Commun. 178 (2008) 852–867]

- Heavy flavour production via four mechanism :
  1. First hard process.
  2. Hard processes in MPI.
  3. Gluon splitting.
  4. Initial/final state radiation.

- Small number of MPI contribute to the low multiplicity intervals.
- High multiplicity events are dominated by a large number of MPI.



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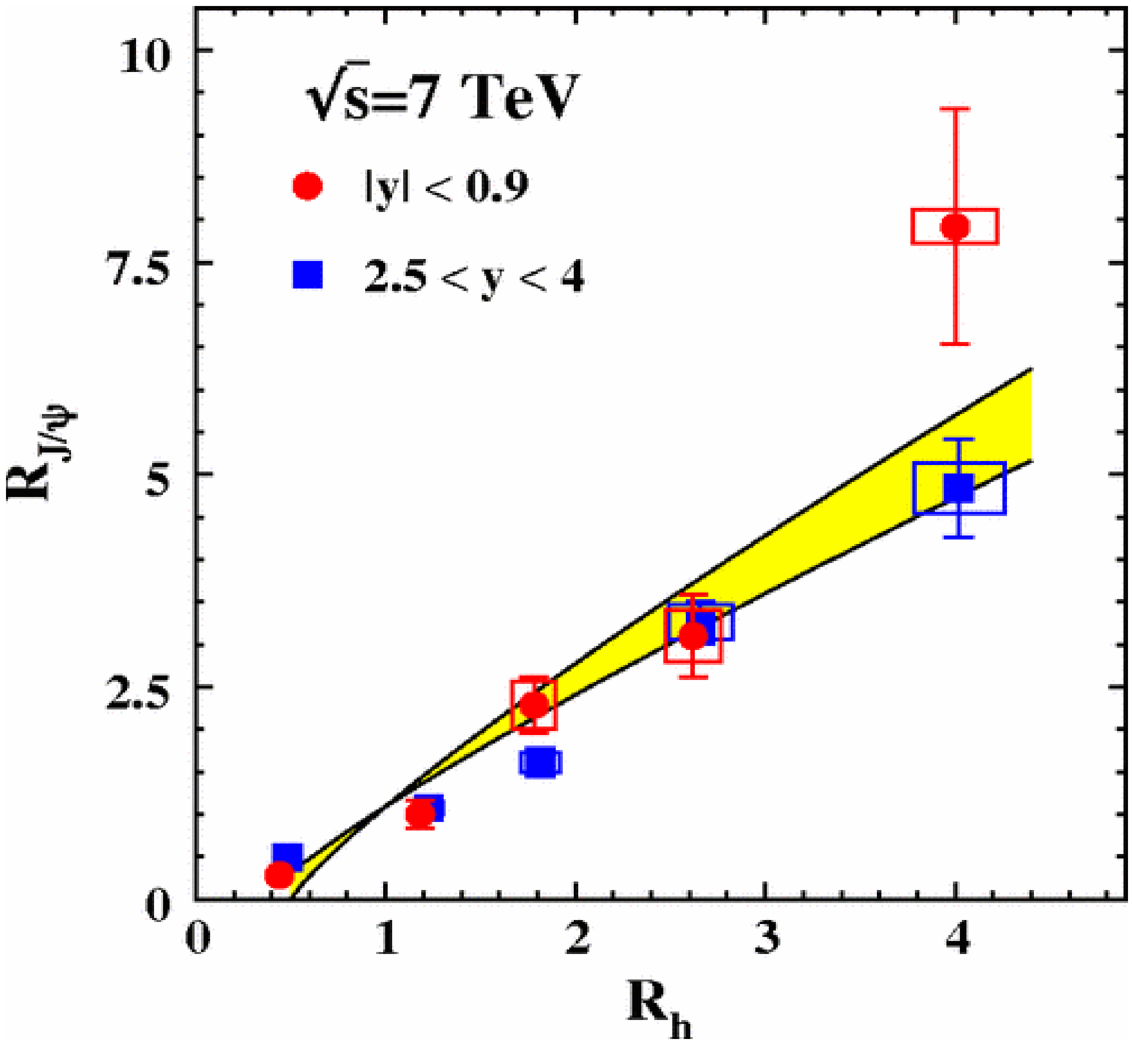
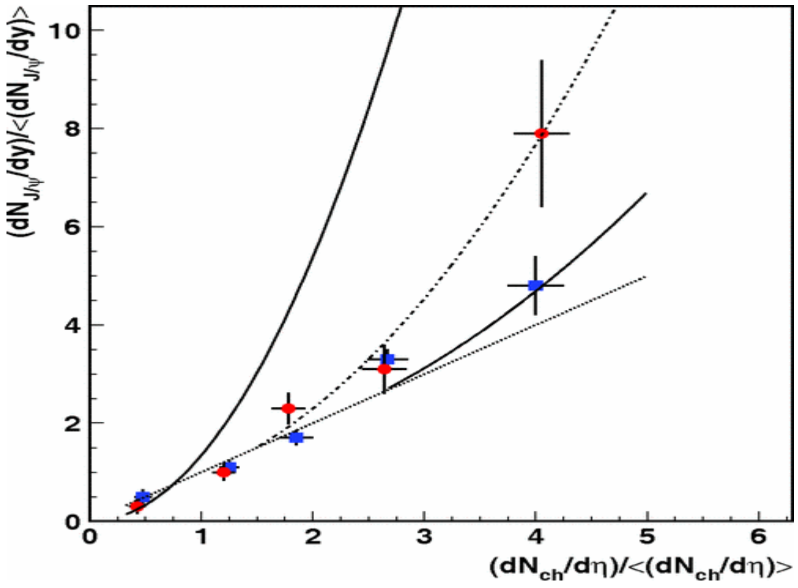
Theoretical Interpretation

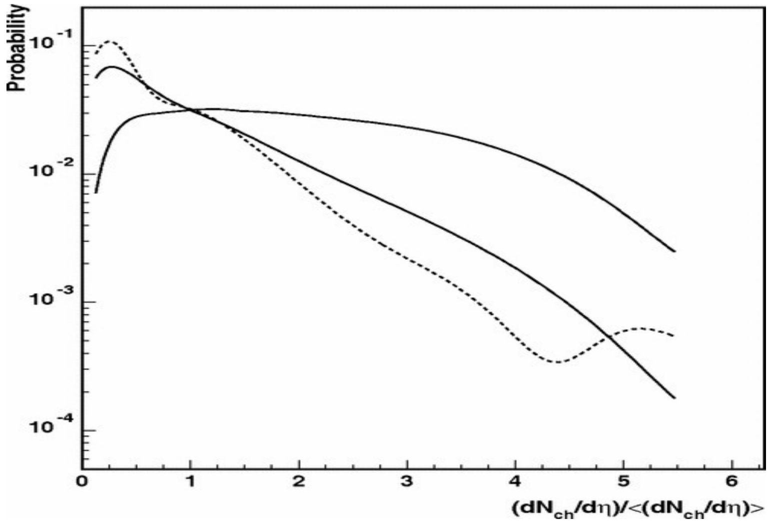
- Larger Hadron multiplicities than the mean value in collisions can be reached due to an increased number of gluons in p-Pb .
- Nucleus act as single source of gluon.
- J/ψ production rate also enhanced.
- Analogy between high-multiplicity pp collisions and p-A collisions.



B.Z. Kopeliovich et al.
PRD 88, 116002 (2013)

Theoretical Interpretation





(E. G. Ferreiro, C. Pajares: Phys.Rev. C86 (2012)034903)

Parton saturation & String Interaction Model :

- Central (|y|<0.9 dashed line) & forward (2.5<y<4, dotted line) rapidity ranges from ALICE.
- Linear increase at low density,
- Quadratic increase at higher density.
- The departure from linearity, consequence of the parton saturation or the strong interaction among colour ropes that take place at LHC energies.

Theoretical Interpretations

PRD 97,094002 (2018)

PYTHIA8 simulation:

- First hard process.
- Hard processes in MPI.
- Gluon splitting.
- Initial/final state radiation.
- With and without colour reconnection.
- Study performed at LHC energies at forward rapidity.
- Increase in J/ψ as a function of multiplicity in all energies.
- The enhancement with multiplicity is higher in higher energies.
- These predictions are not fully comparable to data.