J/ψ production as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE at the LHC

Dhananjaya Thakur
(For the ALICE Collaboration)
Indian Institute of Technology Indore, India

3rd Heavy Flavor Meet

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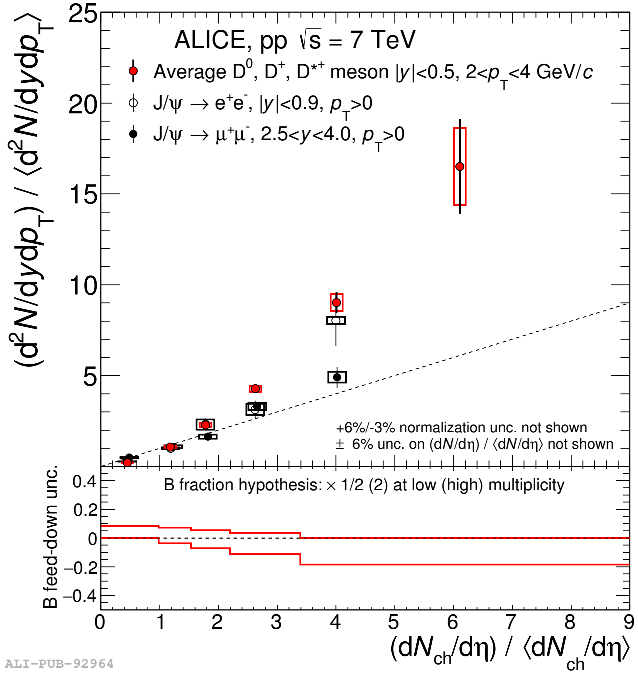
- In particular, these measurements help in understanding the interplay between the soft and hard mechanisms.

J/ψ(D) meson vs. multiplicity in pp collisions



JHEP09(2015)148 (ALICE Collaboration)

❖ **ALICE has measured D mesons and J/ψ as a function of multiplicity.**

❖ **Mid rapidity J/ψ(D) yield (|η|<0.9) vs. mid rapidity charged particles (|η|<1.0)**

Observation:

➢ **A stronger than linear increase towards higher multiplicity**

❖ **Forward rapidity (2.5 < y < 4.0) J/ψ yield vs. mid rapidity charged particles (|η|<1.0)**

Observation:

➢ **Nearly linear increase**

❖ **The increase of J/ψ and D meson yield with multiplicity reveals that MPIs are relevant for J/ψ and D meson production.**

❖ **The higher multiplicity reach for pp collisions at √s = 13 TeV might help to provide further insight.**

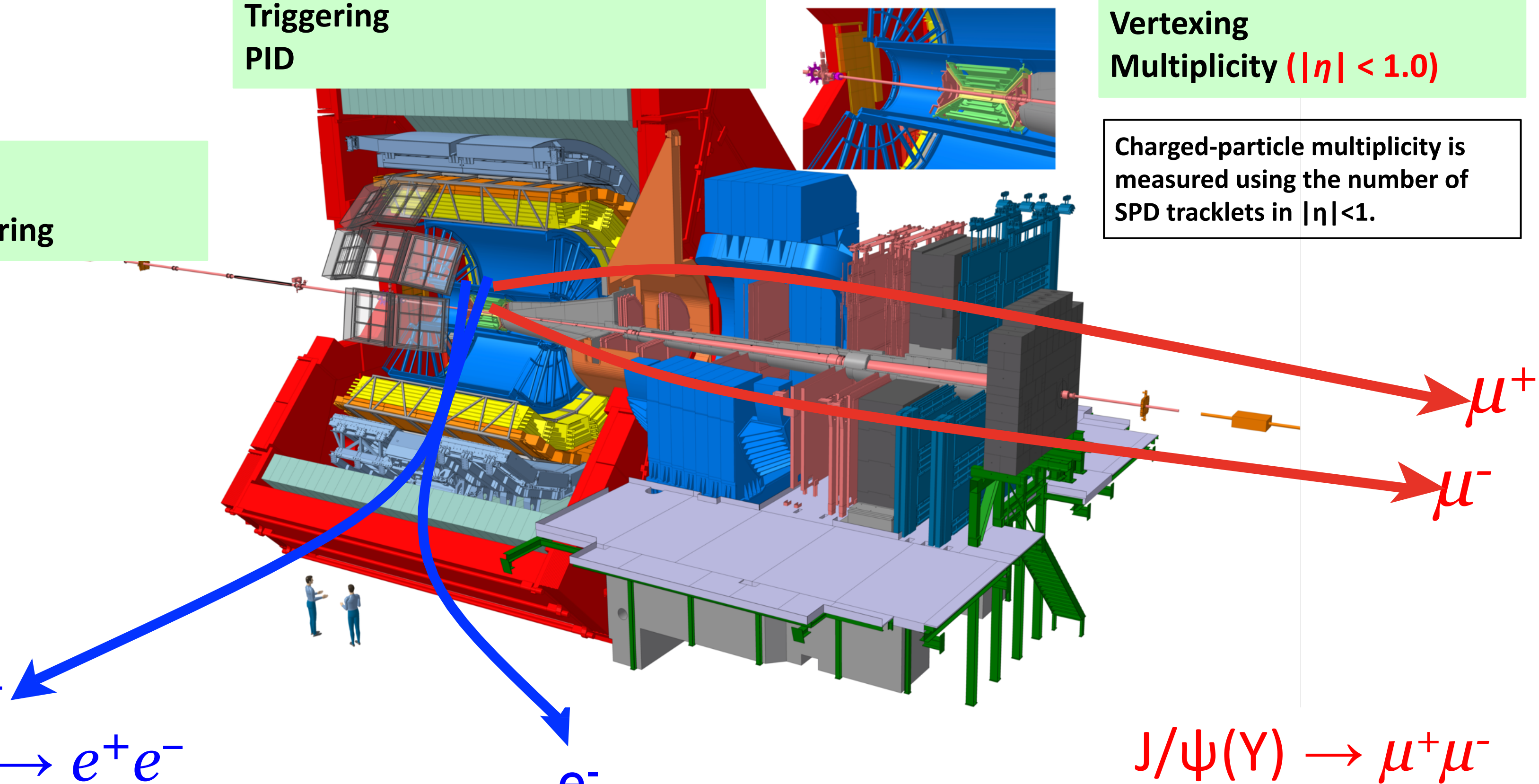
The ALICE Detector

EMCAL
High momentum electron
Triggering
PID

ITS (SPD+SDD+SSD)
Tracking
Vertexing
Multiplicity ($|\eta| < 1.0$)

Charged-particle multiplicity is measured using the number of SPD tracklets in $|\eta|<1$.

V0
Triggering



$J/\psi \rightarrow e^+e^-$

$J/\psi(\Upsilon) \rightarrow \mu^+\mu^-$

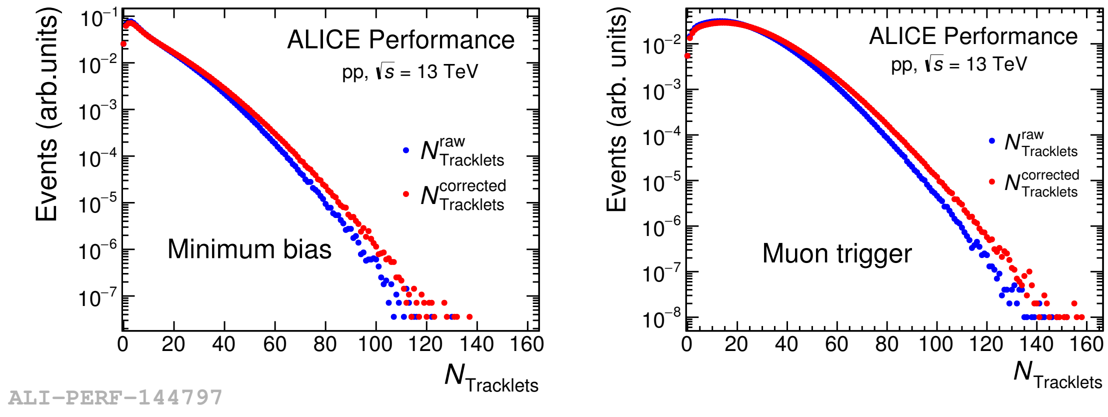
TPC
$-0.9 < \eta < 0.9$
Di-*e*: $p_T > 0$ GeV/c
Single-e: $p_T > 0.2$ GeV/c

ALICE Central barrel
$|\eta| < 0.9$

MUON
$-4.0 < \eta < -2.5$
Di-μ: $p_T > 0$ GeV/c
Single-μ: $p_T > 0.5$ GeV/c

Charged-particle measurements

❖ **Charged-particle multiplicity is measured using the number of SPD tracklets in |η|<1. Acceptance and efficiency effects for the SPD have been corrected using a data-driven method.**



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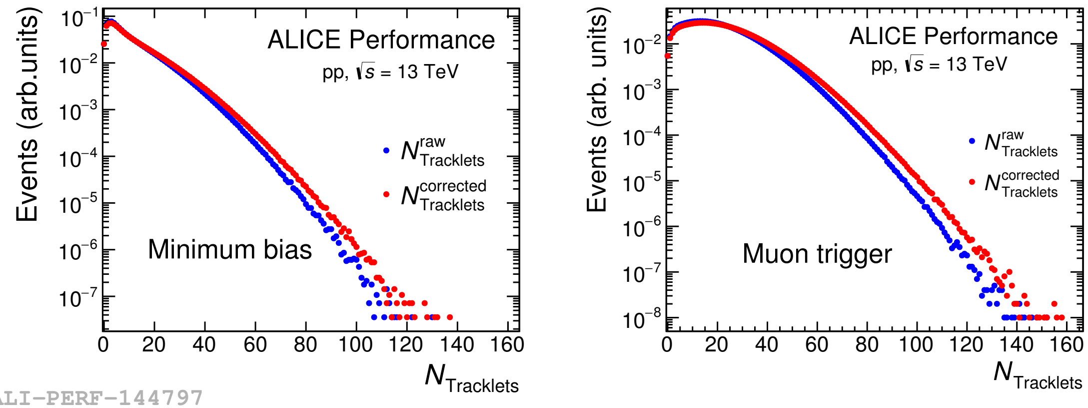
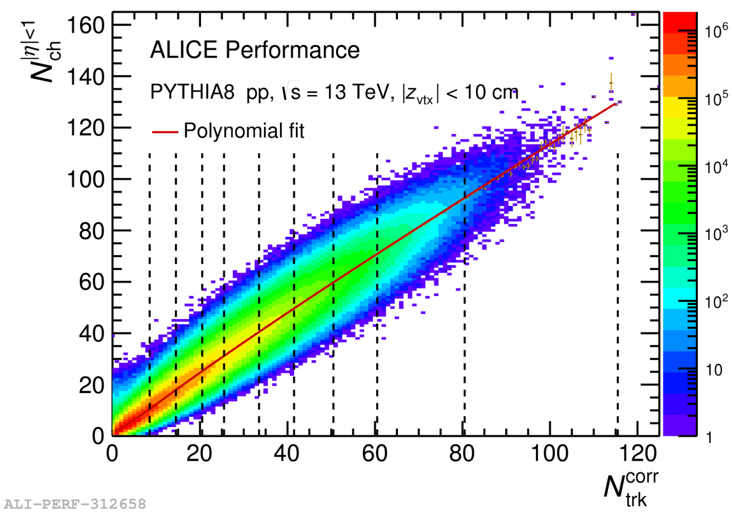


ALI-PERF-144797

- The conversion function from corrected-N_{trk} to $dN_{ch}/d\eta$, " *f* ", is estimated using Monte-Carlo simulations.



ALI-PERF-312658

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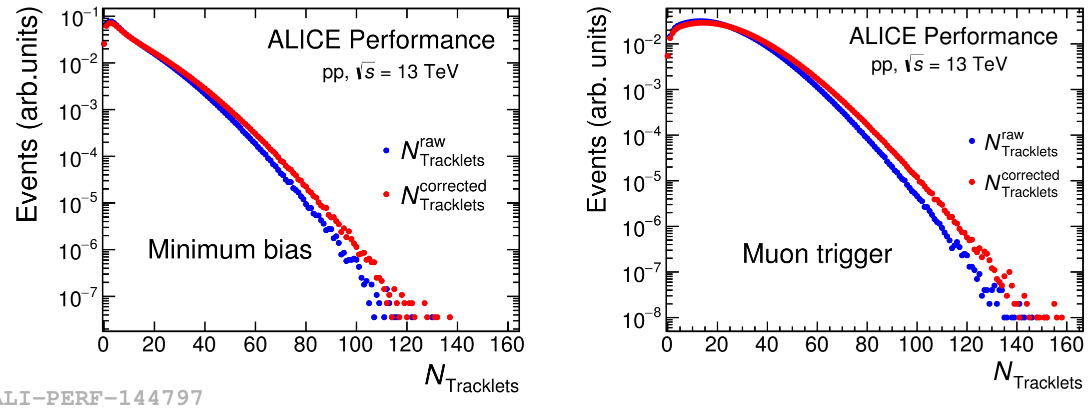

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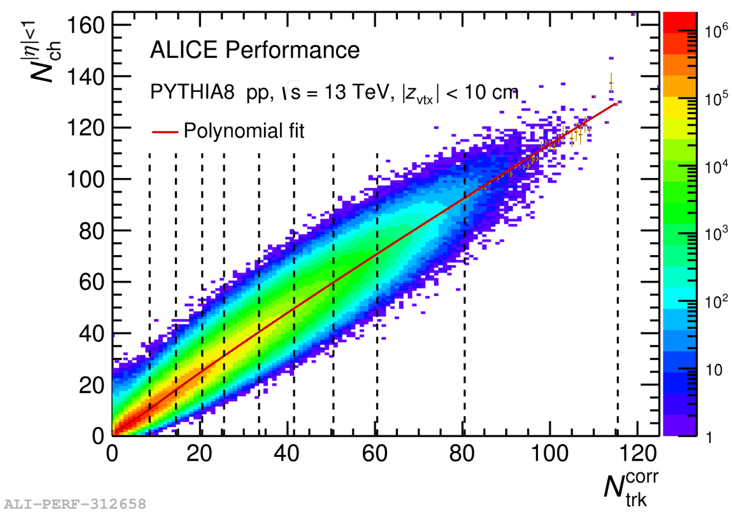
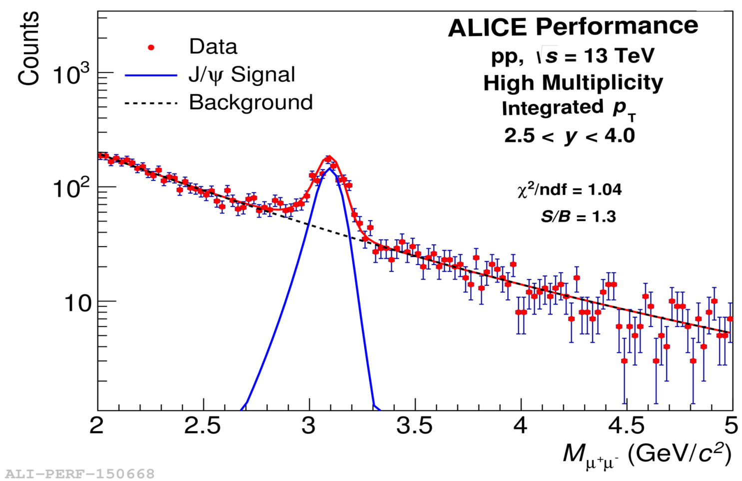


$$\frac{<dN_{ch}/d\eta>_i}{<dN_{ch}/d\eta>} = \frac{f(<N^{corr}_{trk}>_i)}{<dN_{ch}/d\eta>_{INEL>0}}$$

Signal Extraction

Dimuon, pp at √s =13 TeV



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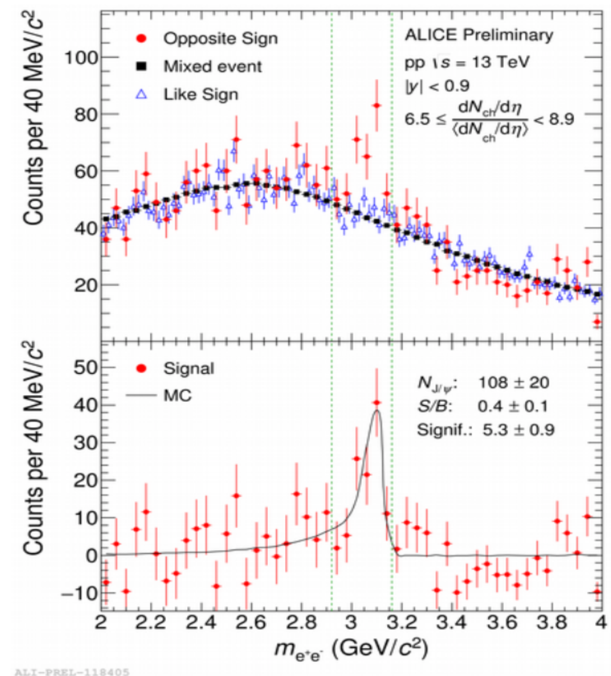


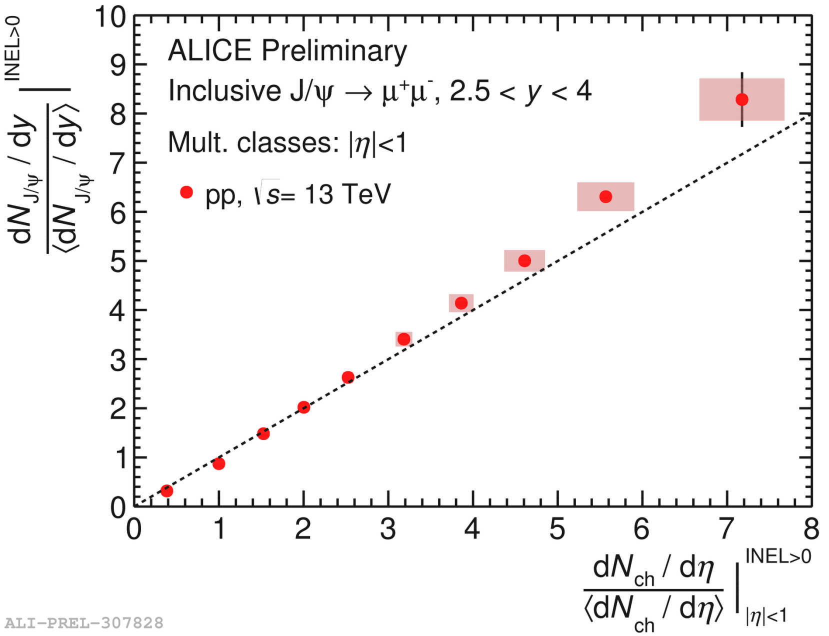
Fitting procedure based on

- ➢ **Signal:**
  Extended Crystal Ball function
- ➢ **Background:**
  variable-width Gaussian function

- ➢ **Signal:**
  bin by bin counting in 2.92 - 3.16 GeV/c^2
- ➢ **Background:**
  Subtracted using normalized like-sign pair distribution

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

❖ **Highest ever multiplicity reached by ALICE in pp collisions**



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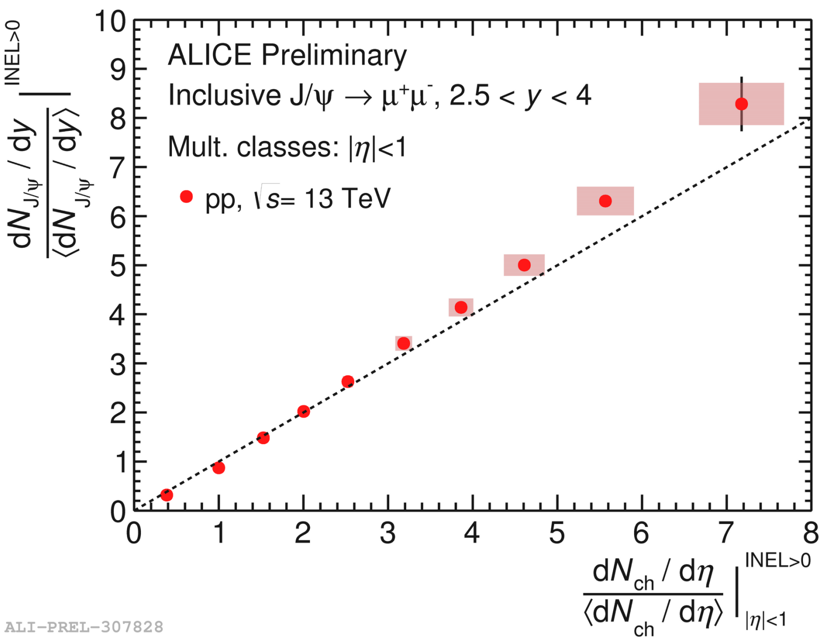

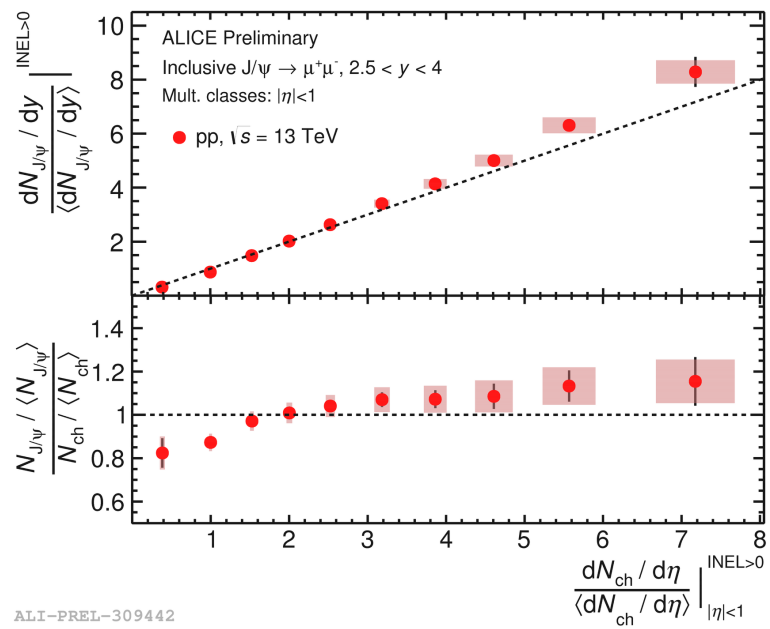

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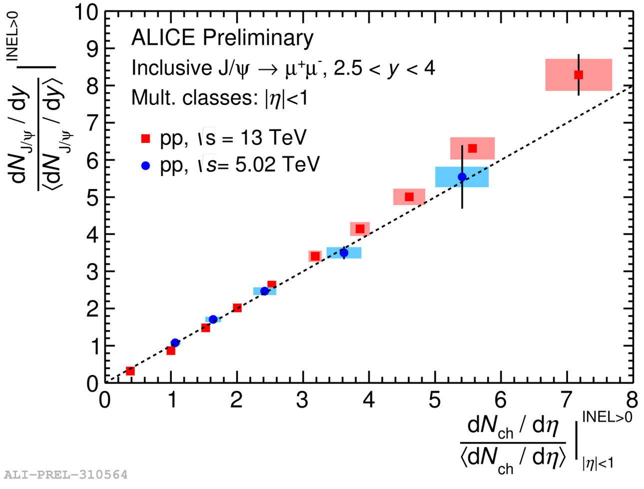
√s and rapidity dependence of J/ψ vs. multiplicity



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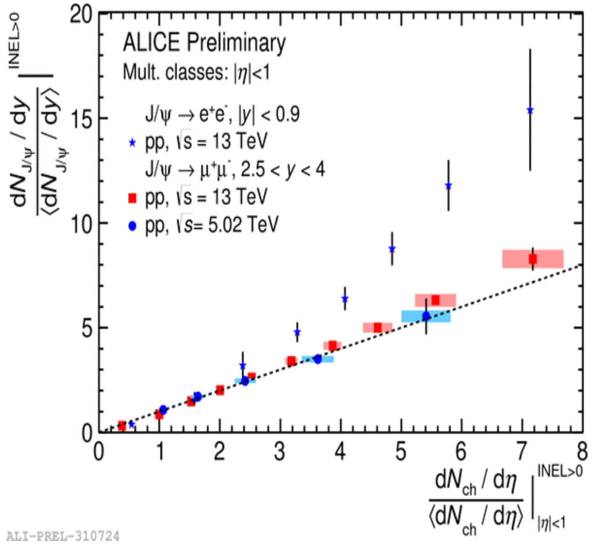

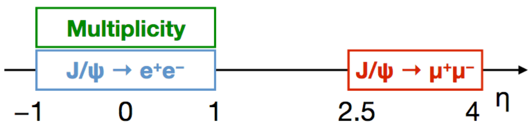

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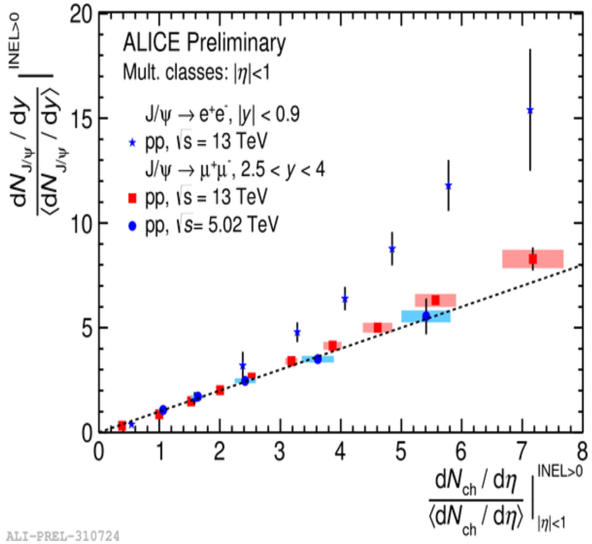

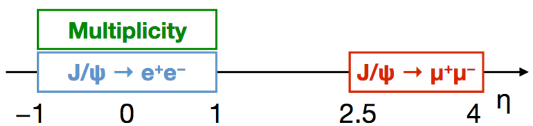

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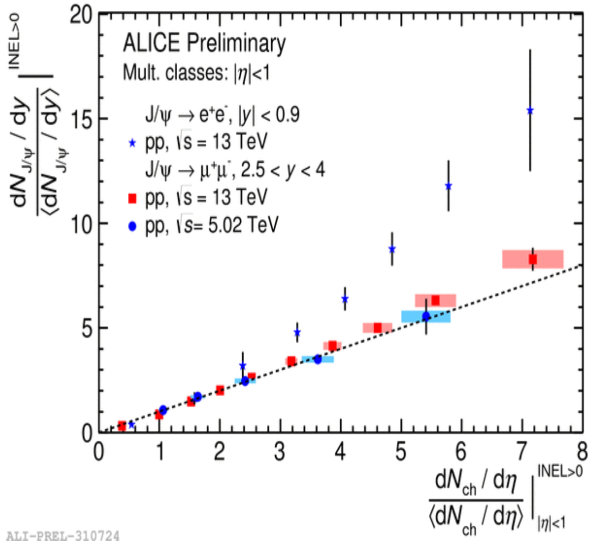

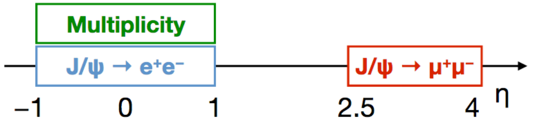

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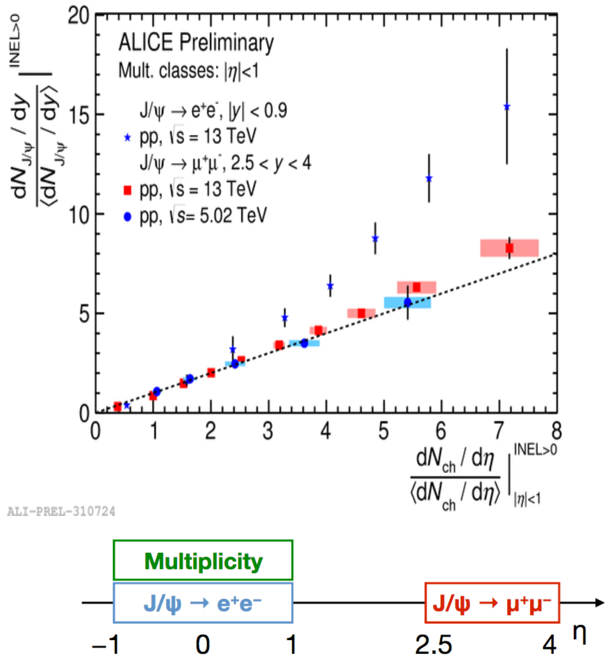

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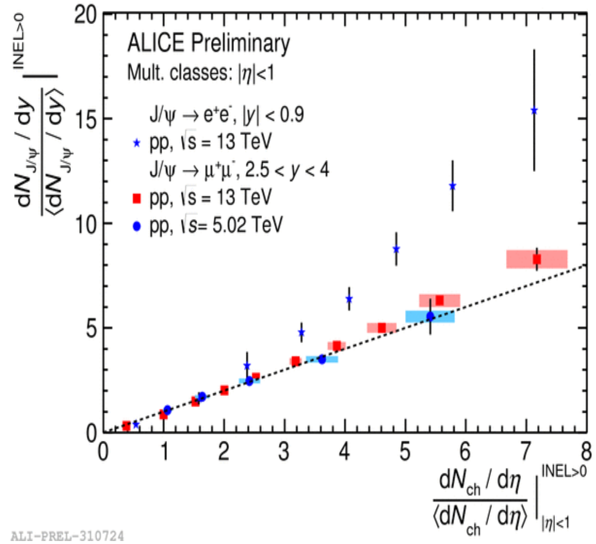

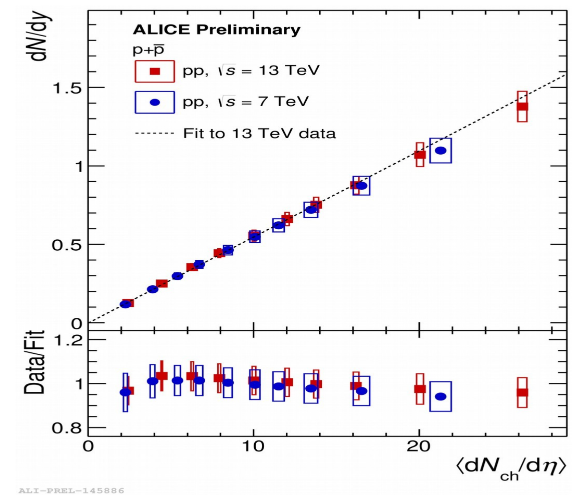

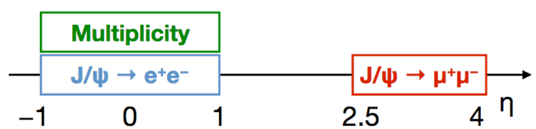

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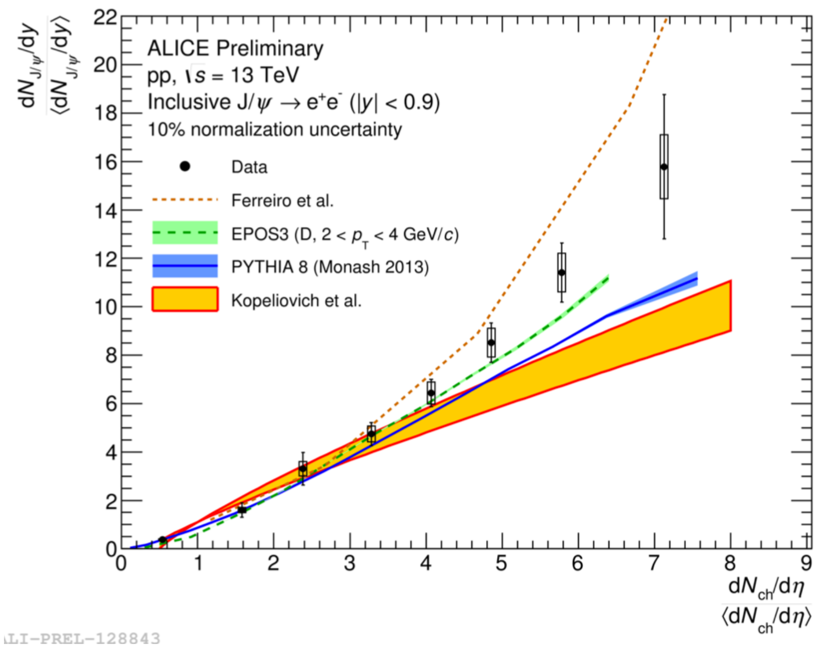
- **Physics scenario such as saturation would influence differently HF production at mid or forward rapidity**
- **Linear trend is also observed for light flavors, where there is rapidity gap in the measurement of multiplicity (by forward rapidity detector V0M) and signal (by mid-rapidity detector).**
  - **Event activity associated with production of light flavor and heavy flavor is nearly same.**

Model Study: Mid-rapidity J/ψ yield vs. multiplicity in pp at √s = 13 TeV



❖ **Stronger than linear increase of J/ψ yield is observed towards higher multiplicity**

Theoretical models

- **String percolation**
- **Hydro dynamical evolution (EPOS3)**
- **Multiple parton interaction (PYTHIA8)**
- **Contributions of higher Fock states**

Ferreiro	PRC86 (2012) 034903
EPOS3	Phys. Rept.350 (2001) 93
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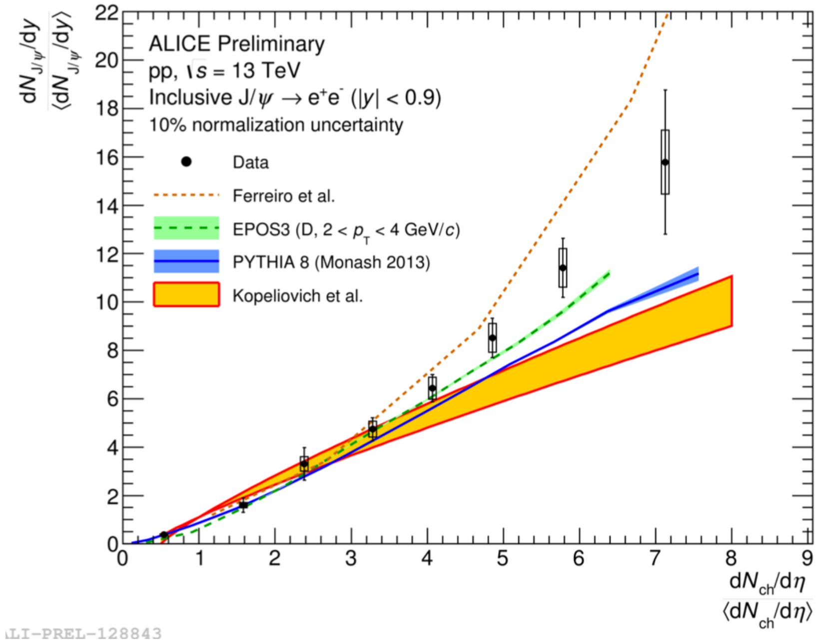

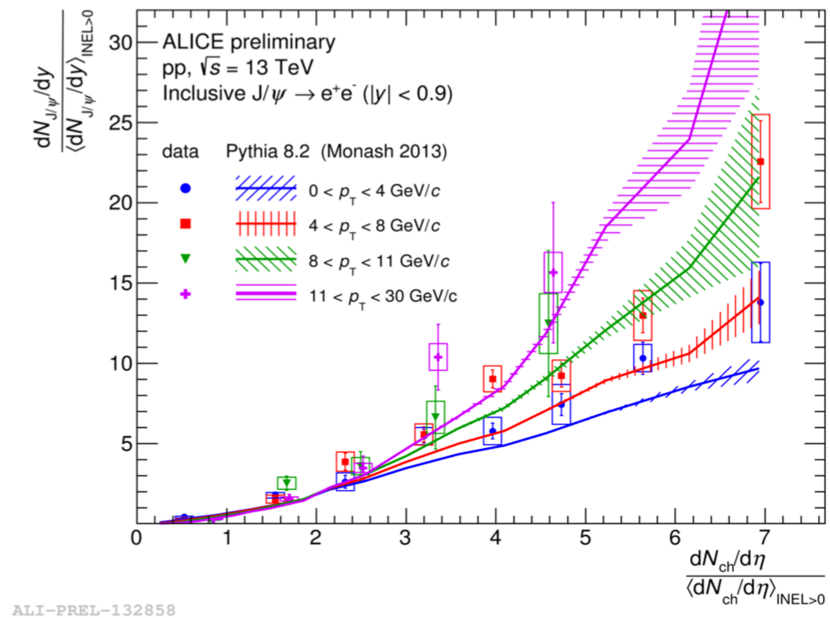

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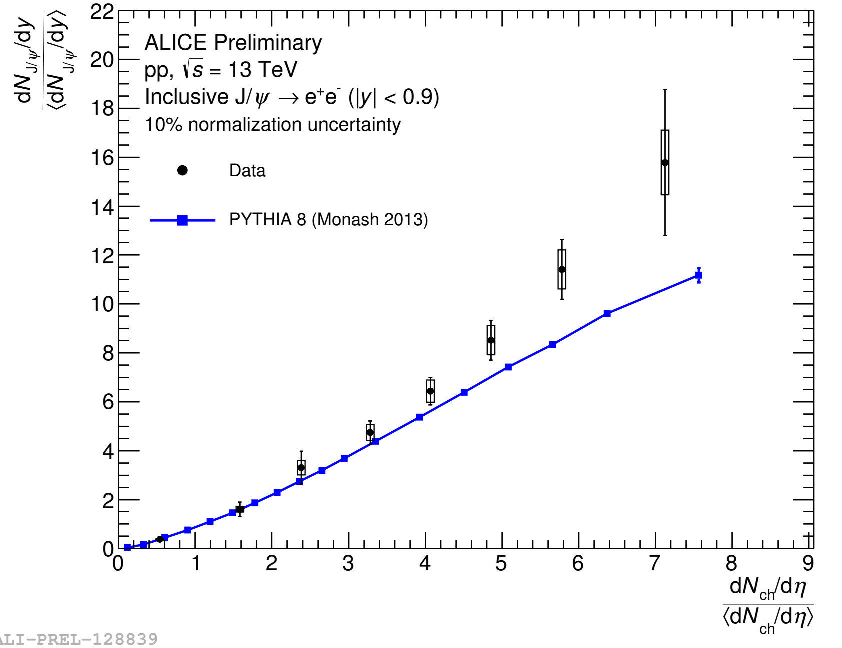
- **The high p_T analysis is based on EMCAL triggered data**
- **The increase of J/ψ production as a function of multiplicity seems steeper at higher transverse momenta**
- **The p_T dependence behavior is explained at least qualitatively by PYTHIA8, which includes MPI processes.**

What does PYTHIA8 tell us ?

- J/ψ production has contributions from dedicated processes in PYTHIA8:
  - ✓ Initial *c* or *b* quarks originate via first hardest 2->2 partonic interactions
  - ✓ Has finite production probability from the subsequent hard processes in MPI
  - ✓ Heavy quarks from gluon splitting
  - ✓ Gluons from initial/final state radiations
  - ✓ Color reconnection (at the hadronization stage)



- The events with a small number of MPI contribute to the low multiplicity interval, while high multiplicity events are dominated by a large number of MPI

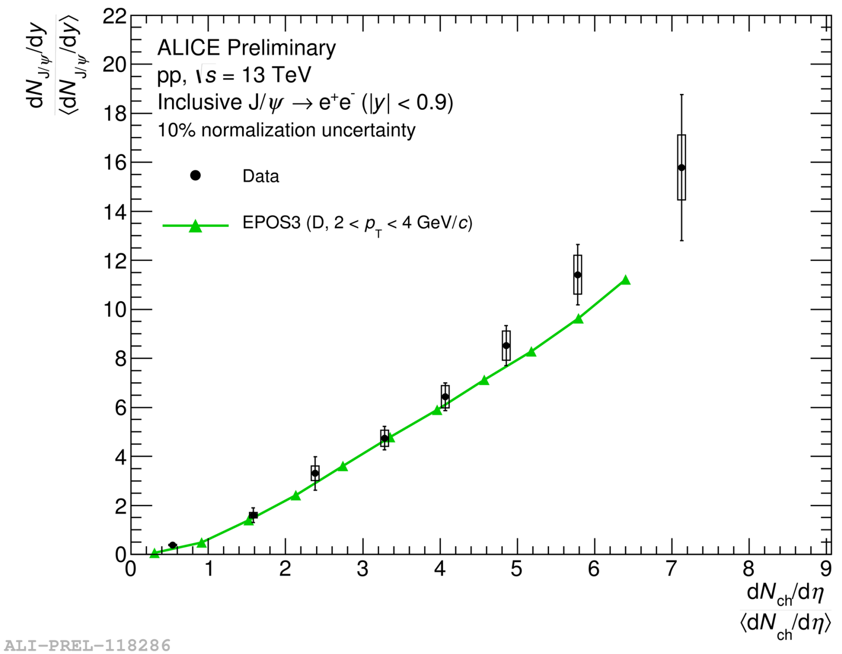
- Monash 2013 tuned PYTHIA8 describes well the data in the low multiplicity region

What does EPOS3 tell us ?

❖ **EPOS3 imposes the same theoretical scheme in pp, pA and AA systems**

✓ **Initial conditions followed by a hydrodynamical evolution**

✓ **Initial conditions based on "Gribov-Regge" formalism. Multiple interaction occurs in parallel**



❖ **The EPOS calculation is for D meson, which should be a very good proxy for J/ψ.**

❖ **The good description of the data with EPOS3 model shows that the energy density reached in pp collisions at the LHC is high enough to apply hydrodynamical evolution**

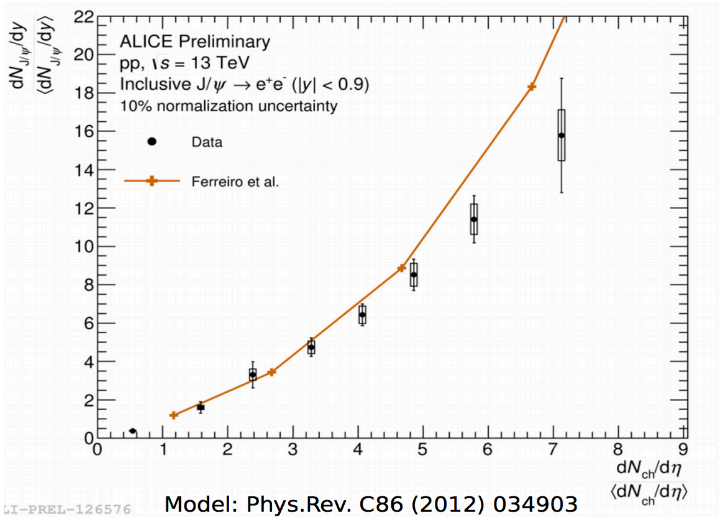
❖ **Result of EPOS version 3.1 and 3.2 differ significantly**

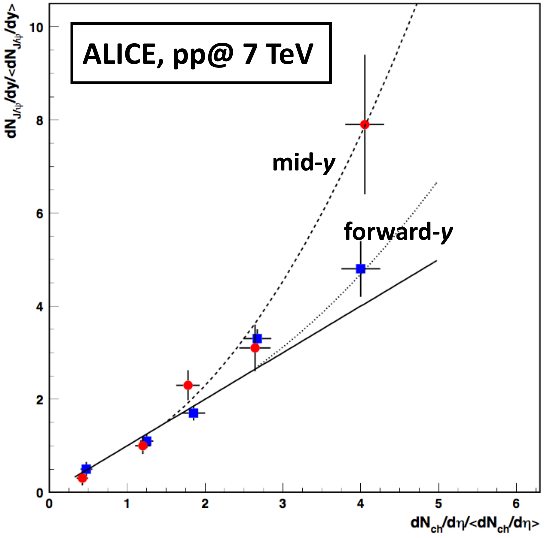
What does Percolation tell us ?

- ❖ **High-energy hadronic collisions are driven by the exchange of color sources (strings) between the projectile and the target**

- ❖ **The number of parton-parton collisions is reflected as the number of produced strings (N_s)**

  - ✓ **J/ψ multiplicity α N_s**
  - ✓ **Charged particle multiplicity α $\sqrt{N_s}$**





Ferreiro et al. Phys. Rev. C86 (2012) 034903

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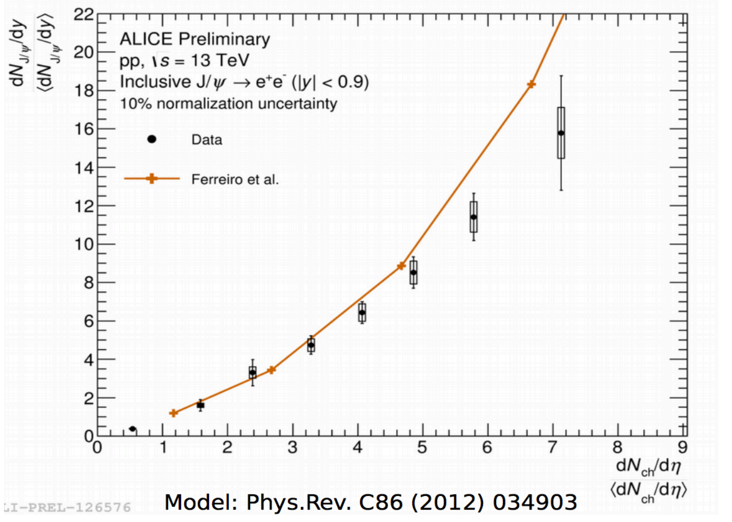
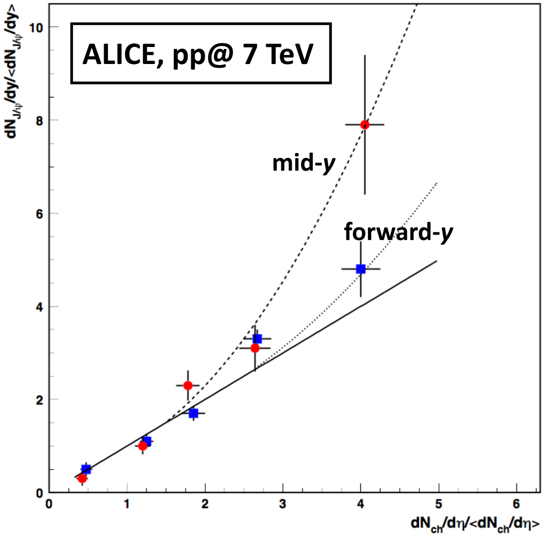


Model: Phys.Rev. C86 (2012) 034903

At Low multiplicity

$$\frac{n_{J/\psi}}{\langle n_{J/\psi}\rangle} = \frac{\frac{dN}{d\eta}}{\left\langle \frac{dN}{d\eta}\right\rangle}$$



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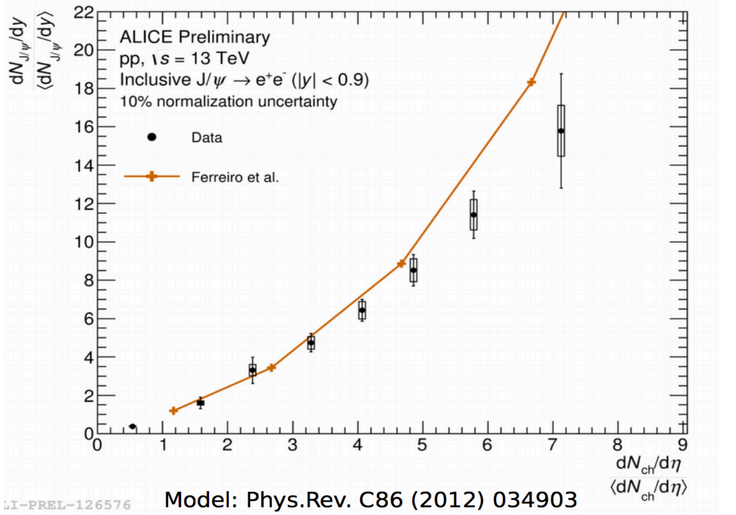

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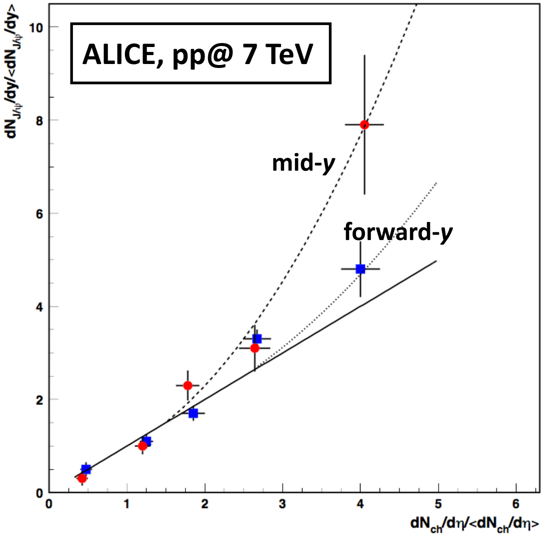
At High multiplicity

$$\frac{n_{J/\psi}}{\langle n_{J/\psi}\rangle} = \langle\rho\rangle\left(\frac{\frac{dN}{d\eta}}{\langle\frac{dN}{d\eta}\rangle}\right)^2$$



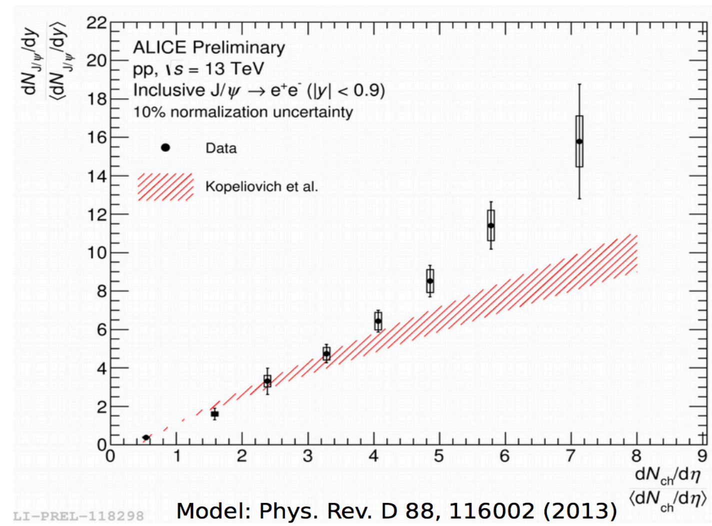
Ferreiro et al. Phys. Rev. C86 (2012) 034903

What does "higher Fock states" model tell us ?

- **Higher Fock component:** **In high energy nuclei, gluons at small-*x* overlap longitudinally, act as a single source of gluons**

- **The inelastic collisions of the Fock components lead to high hadron multiplicity**

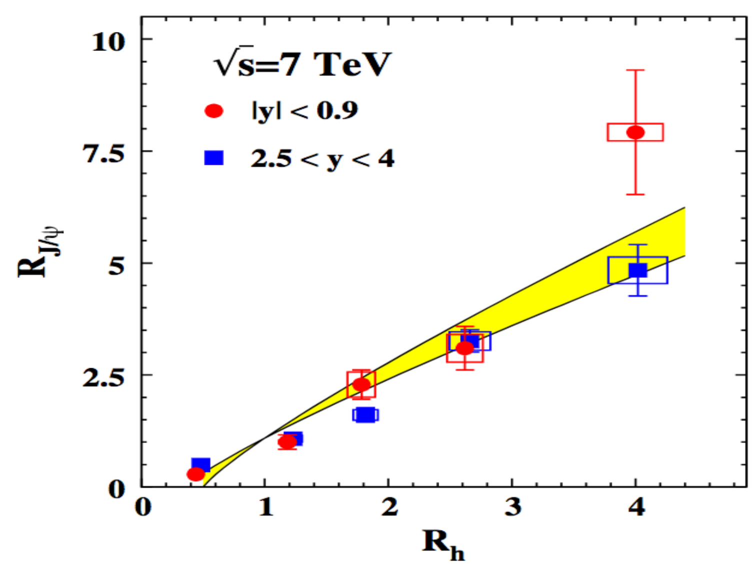
- **The relative production of J/ψ is enhanced in such gluon-rich collisions**



Model: Phys. Rev. D 88, 116002 (2013)

$$R_h^{pp} \equiv \frac{dN_h^{pp}/dy}{\langle dN_h^{pp}/dy\rangle},$$

$$R_{J/\Psi}^{pp} \equiv \frac{dN_{J/\Psi}^{pp}/dy}{\langle dN_{J/\Psi}^{pp}/dy\rangle},$$



- **More gluons participating in collisions with $R_h^{pp} > 1$, explains why $R_{pp}^{J/\Psi}$ rises with increasing R_h**

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- ***Another possible explanation:* Physics scenario such as saturation would influence differently HF production at mid or forward rapidity.**

- **Event generators including MPI reproduce well the data, thus revealing the importance of MPI in hadronic collisions.**

Summary

ALICE has performed the study of J/ψ as a function of multiplicity for pp collisions at √*s* =13 TeV, where the highest multiplicity measured by ALICE in pp collisions has been reached

- **Forward rapidity quarkonia vs. mid rapidity charged-particle multiplicity is showing almost a linear increase, irrespective of collision energy.**

- **J/ψ production at forward rapidity is approximately linear as a function of mid-rapidity multiplicity, while a faster than linear trend is observed for J/ψ without rapidity gap.**

- **New results hinting for auto-correlation and jet-bias for mid rapidity J/ψ vs. mid rapidity charged-particle multiplicity study.**

- ***Another possible explanation:* Physics scenario such as saturation would influence differently HF production at mid or forward rapidity.**

- **Event generators including MPI reproduce well the data, thus revealing the importance of MPI in hadronic collisions.**

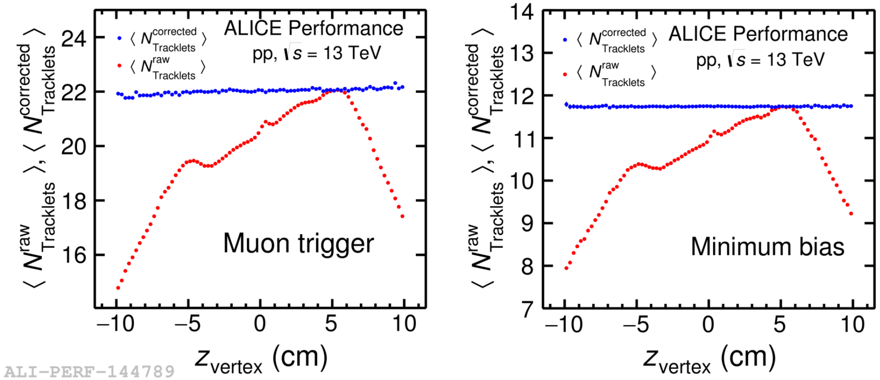
Thank you!!

Multiplicity determination

❖ **Charged-particle multiplicity is measured using the number of SPD tracklets in $|\eta|<1$. The variation of the SPD efficiency with the *z* position of the primary vertex (z_{vertex}) is corrected using a data-driven method.**

$$\Delta N = \frac{<N_{trk}>(z_v^0) - <N_{trk}>(z_v)}{<N_{trk}>(z_v)}$$

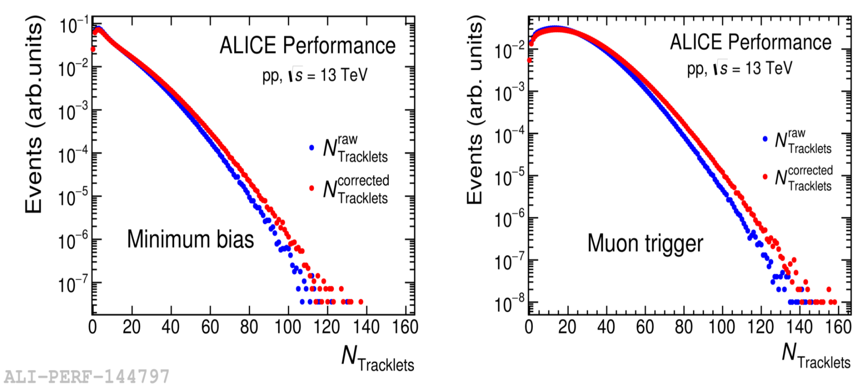
$$N_{trk}^{corr}(z_v) = N_{trk}(z_v) + \Delta N_{rand}$$



❖ **Here, ΔN_{rand} follows a Poissonian distribution centered around ΔN.**

❖ **z_v^o corresponds to z_{vertex} position where $<N_{trk}>$ is maximum.**

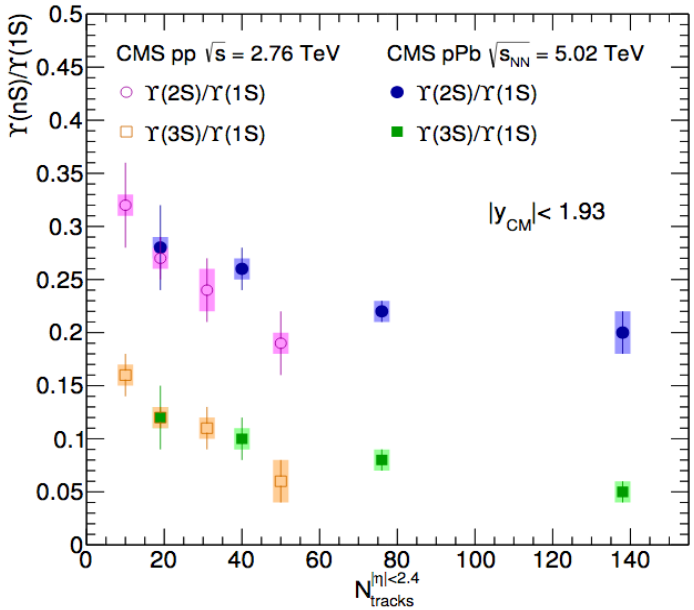
❖ **The efficiency loss at z_o and other track-to-particle-corrections need to be taken into account to evaluate the actual charged-particle value.**



$$\frac{<dN_{ch}/d\eta>_i}{<dN_{ch}/d\eta>} = \frac{f(<N_{trk}^{corr}>_i)}{<dN_{ch}/d\eta>_{\text{INEL}>0}}$$

❖ **The conversion function " f " is estimated using Monte Carlo simulations.**

Υ Vs. multiplicity



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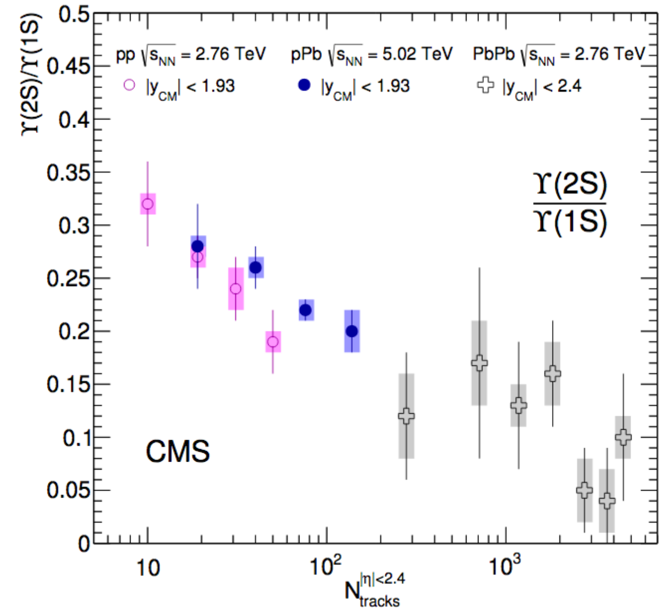


- **The excited-to-ground-states ratios, Υ(nS)/*Υ*(1S), are found to decrease with increasing charged-particle multiplicity.**
- **The tightest bound state, Υ(1S), was observed to be less suppressed than the more loosely bound excited states, Υ(2S) and Υ(3S).**
- **Global behavior of double ratio has been observed irrespective of the collisions system; pp, p-Pb, and Pb-Pb.**

Analysis strategy

- **Silicon Pixel Detector (SPD) is used for charged particle and vertex determination**

$J/\psi \rightarrow e^{+}e^{-}$

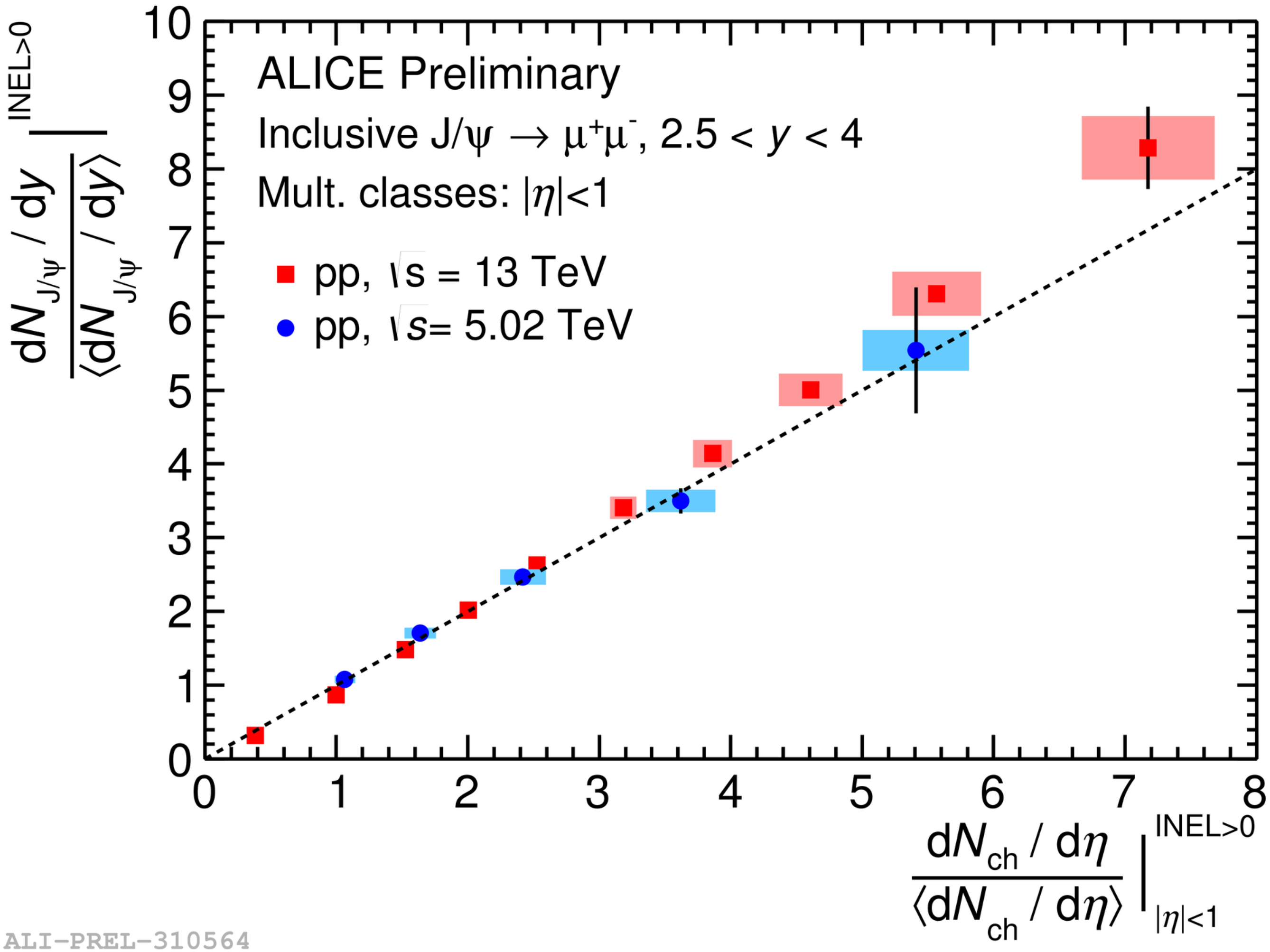
- **MB trigger**
- **$-0.9 < \eta < 0.9$**
- **Track quality cuts**
- **Rejection of tracks from photon conversion**
- **TPC electron identification**

$J/\psi \rightarrow \mu^{+}\mu^{-}$

- **Dimuon trigger: MB and two opposite sign muon tracks**
- **$-4.0 < \eta < -2.5$**
- **17.6 cm < R_{abs} < 89.5 cm**

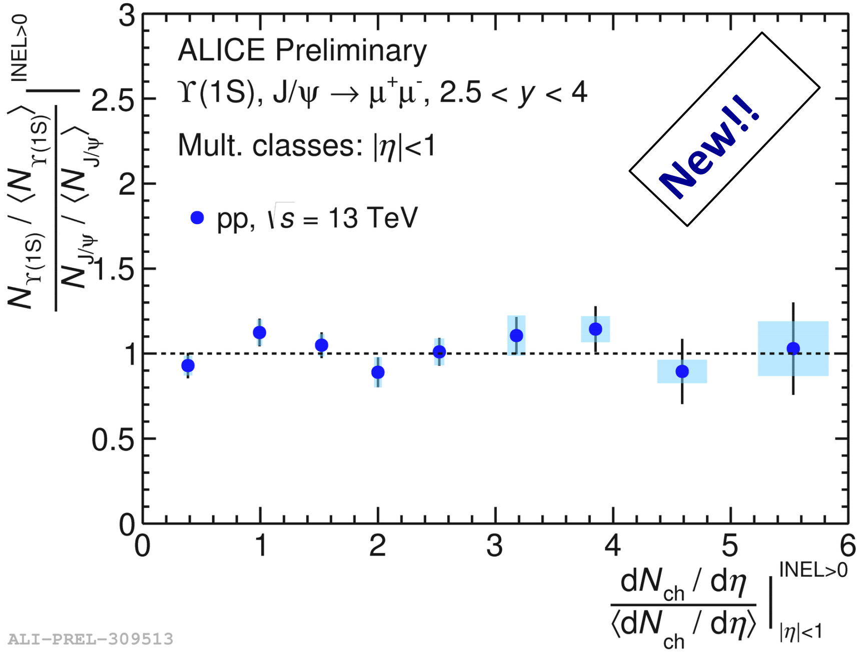
(R_{abs} = Radial position of the track at the end of the absorber)

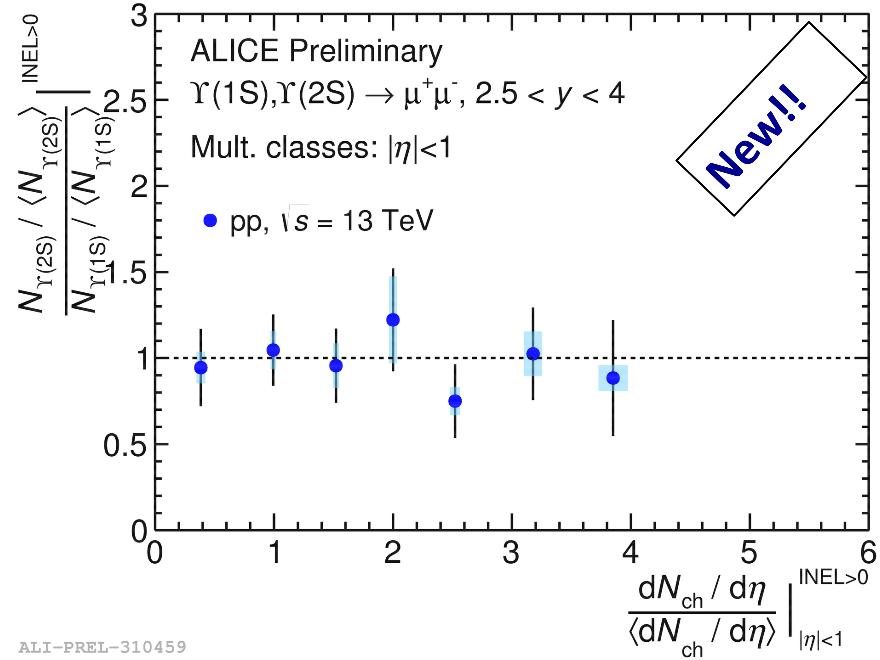
Energy dependence of J/ψ yield vs. multiplicity



❖ Trend is independent of colliding energy.

Double ratio





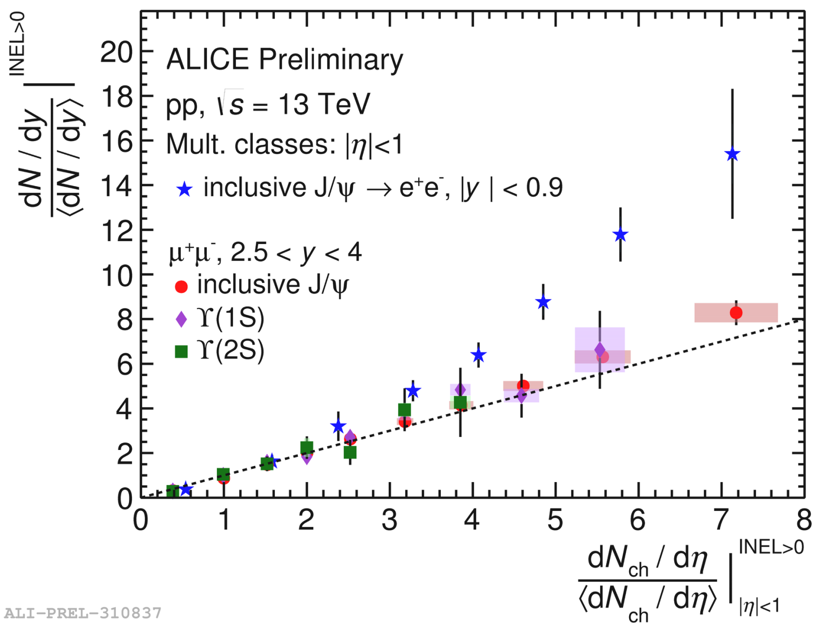
❖ **The double ratio ϒ(1S)/J/ψ and ϒ(2S)/ϒ(1S) has been studied for pp@ 13 TeV**

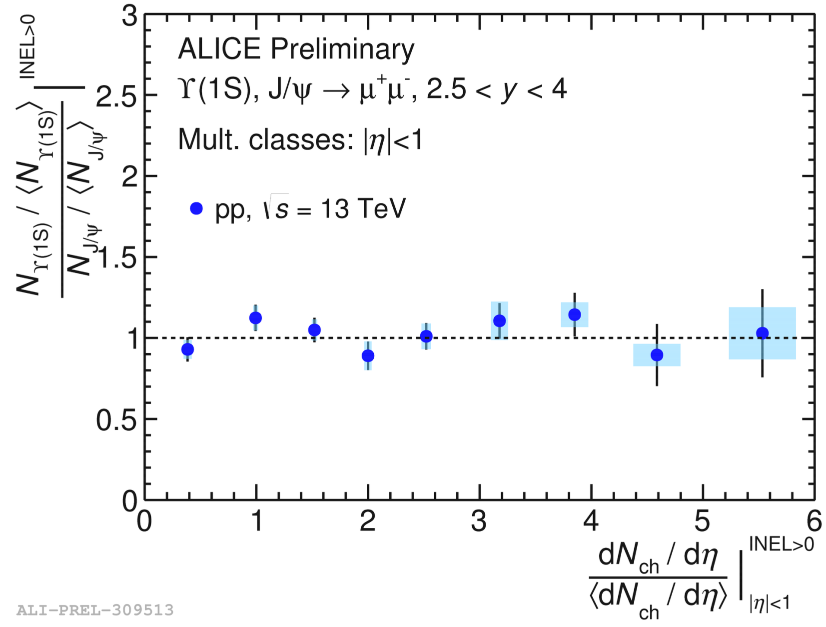
➢ **The ratio is found to be unity irrespective of charged-particle multiplicity.**

➢ **The multiplicity dependence production is same for J/ψ, ϒ(1S) and ϒ (2S).**

➢ **ϒ(nS)/ϒ (1S), are found to decrease with increasing charged-particle multiplicity, when ϒ and charged particles are measured in mid-rapidity. (CMS Collaboration, JHEP04(2014)103)**

Quarkonium vs. multiplicity





- **The multiplicity dependence production is same for J/ψ, ϒ(1S) and ϒ (2S).**
  - **The event activity associated with the production of heavy-flavor is also independent of quark content of the particle**