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

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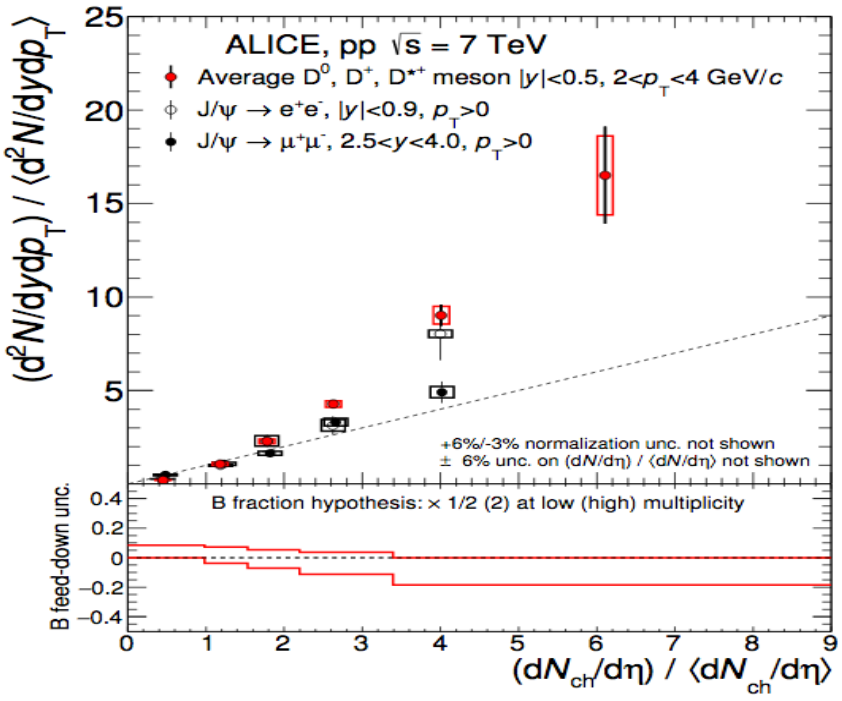
Heavy flavor Vs. multiplicity

- **Good observable related to the underlying event accompanying heavy-flavor production in pp collisions.**
  - Connection to Multiple Partonic Interaction (MPI)
  - Connection to final-state effect (color reconnection etc.)
- **Helps to understand the strong hadronic activity associated with heavy-flavor production.**
  e.g g->ccbar, qqbar ->ccbar etc.
- **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)

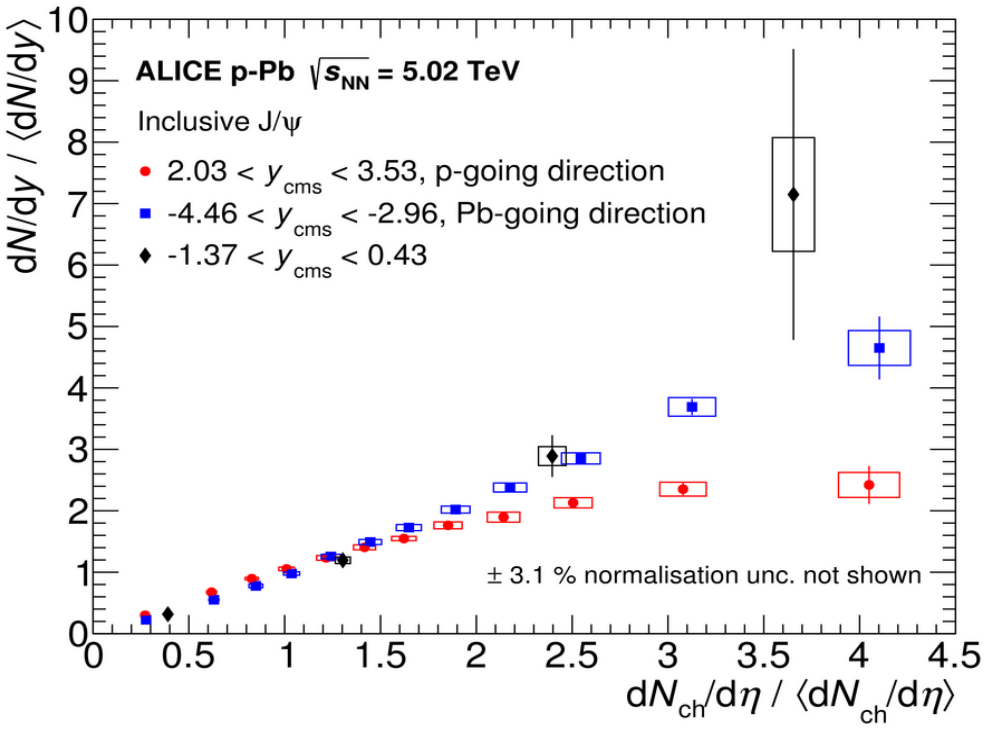
- ALICE has measured D mesons and J/ψ as a function of multiplicity.
  - Mid rapidity J/ψ(D) yield (|η|<0.9) Vs. mid rapidity charged particles (|η|<1.0)

  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)

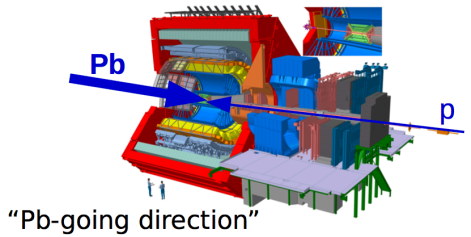
  Observation:
  - Nearly linear increase

- The increase of J/ψ and D yield with multiplicity reveals that MPIs are relevant for J/ψ and D production.
- Different trend of the behavior w.r.t rapidity gap hinting for different phenomena.
- The higher multiplicity reach for pp collisions at √*s* = 13 TeV may be able to provide further insight.

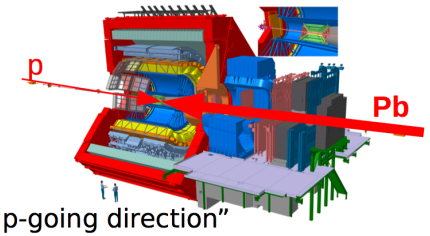
When going from pp to p-Pb……..



Physics LettersB776(2018)



"Pb-going direction"



"p-going direction"

- **Stronger increase of relative J/ψ yields at forward and backward rapidity with relative multiplicity.**
  - **p going direction: Trend shows saturation at high multiplicity**
  - **Pb going direction: Similar trend as that of pp collisions**

These studies have been extended to pp@ 5.02 and 13 TeV, and p-Pb@8.16 TeV.

New exciting results!!

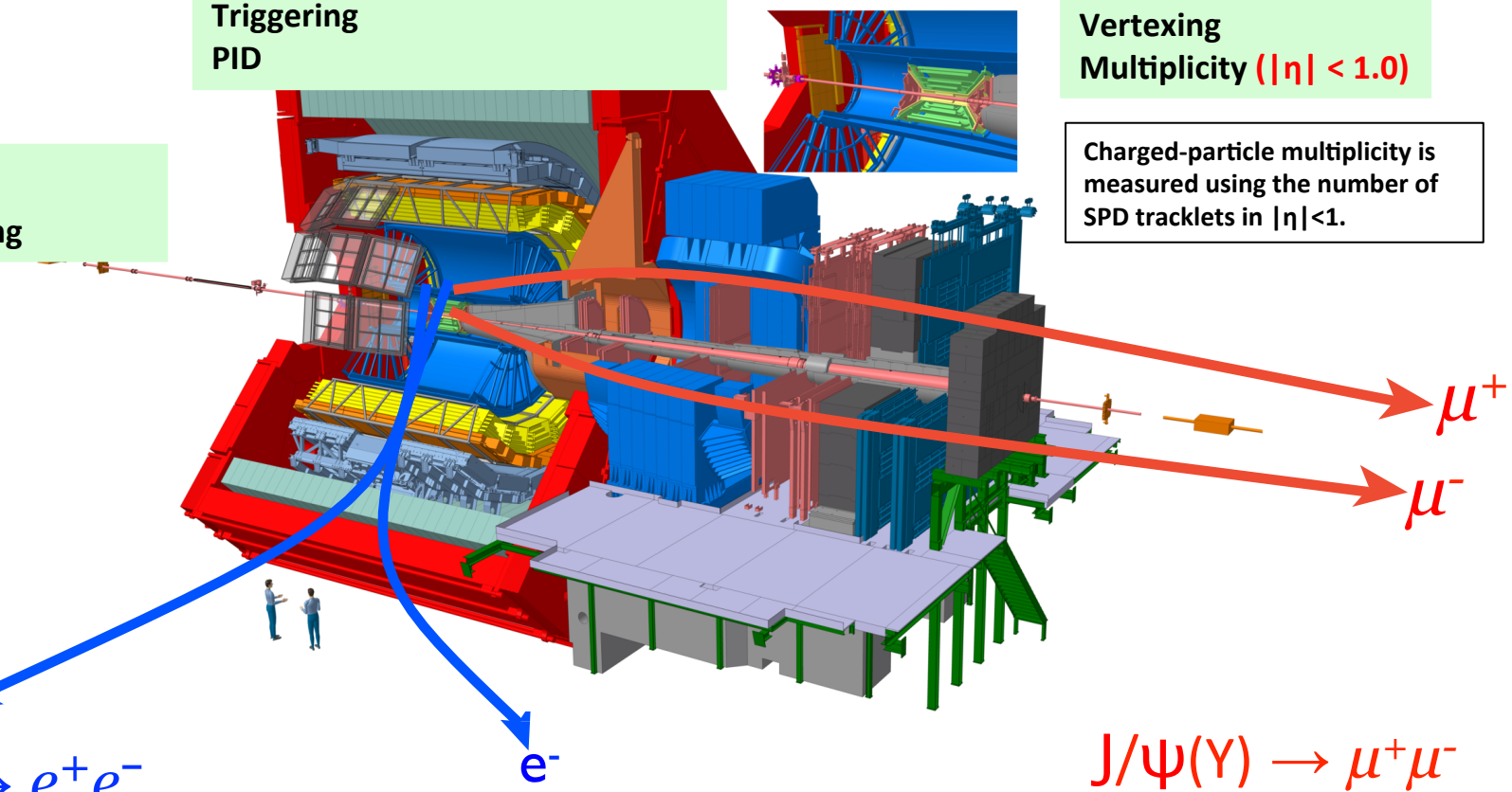
The ALICE Detector

EMCAL
High momentum electron
Triggering
PID

ITS
Tracking
Vertexing
Multiplicity ($|\eta| < 1.0$)

V0
Triggering

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



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

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

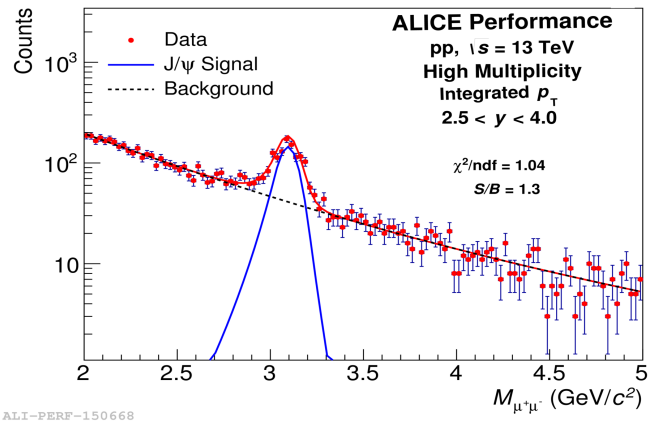
TPC
$-0.9 < \eta < 0.9$
Di-e: $p_T > 0$ GeV/c
Single-e: $p_T > 0.2$ GeV/c

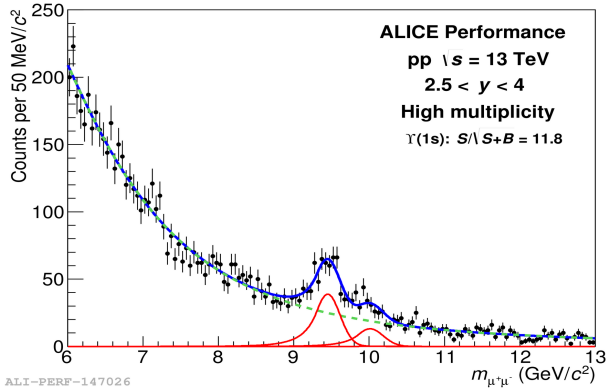
ALICE Central barrel
$|\eta| < 0.9$

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

Signal Extraction

Dimuon pp@13 TeV

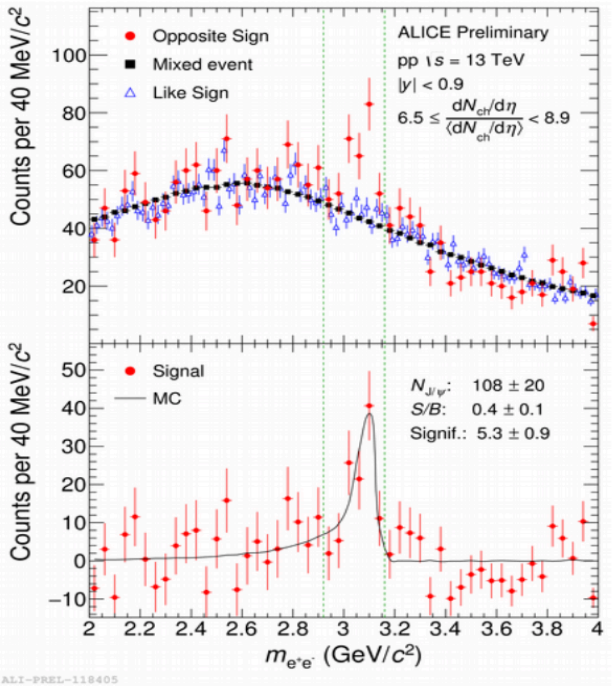




Fitting procedure based on

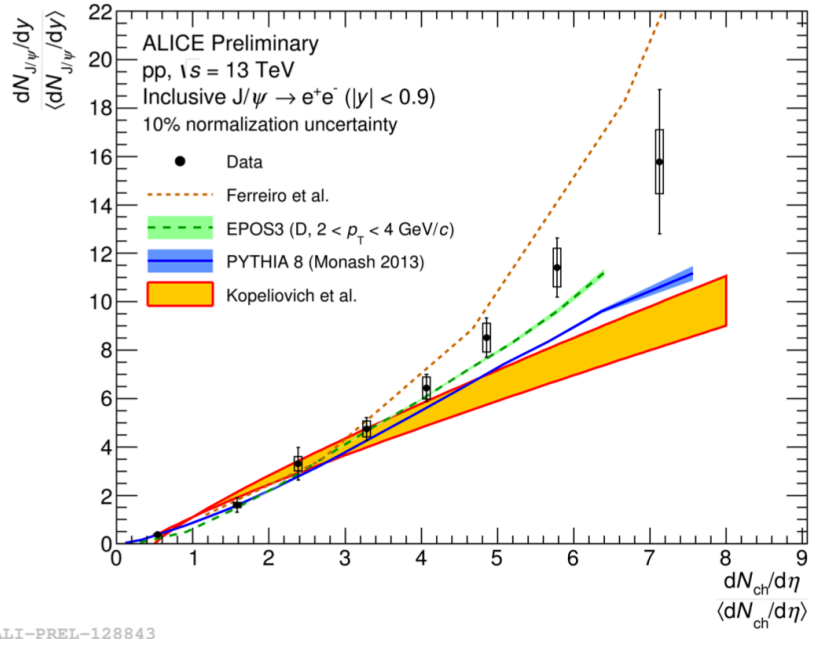
- **Signal:**
  Extended Crystal Ball function
- **Background:**
  variable-width Gaussian function

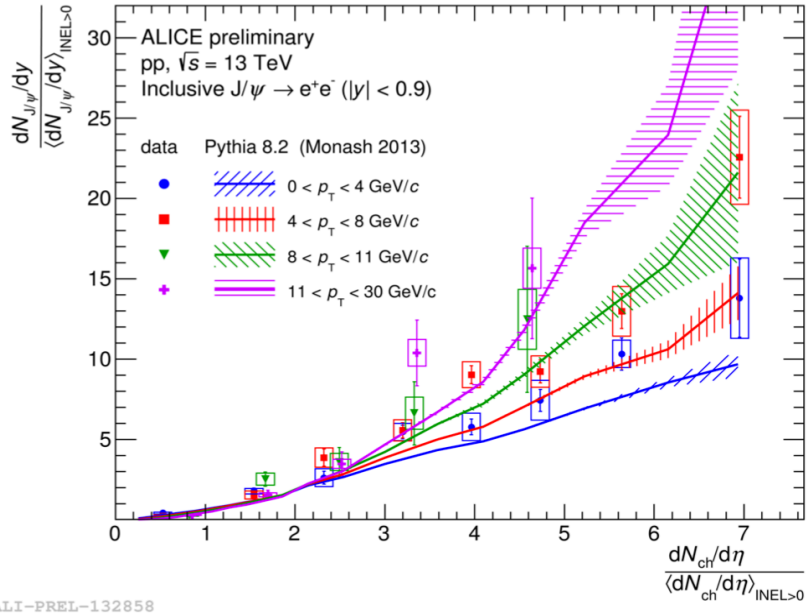
Dielectron pp@13 TeV



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

Mid-rapidity J/ψ yield vs. multiplicity in pp@13 TeV





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

Theoretical models

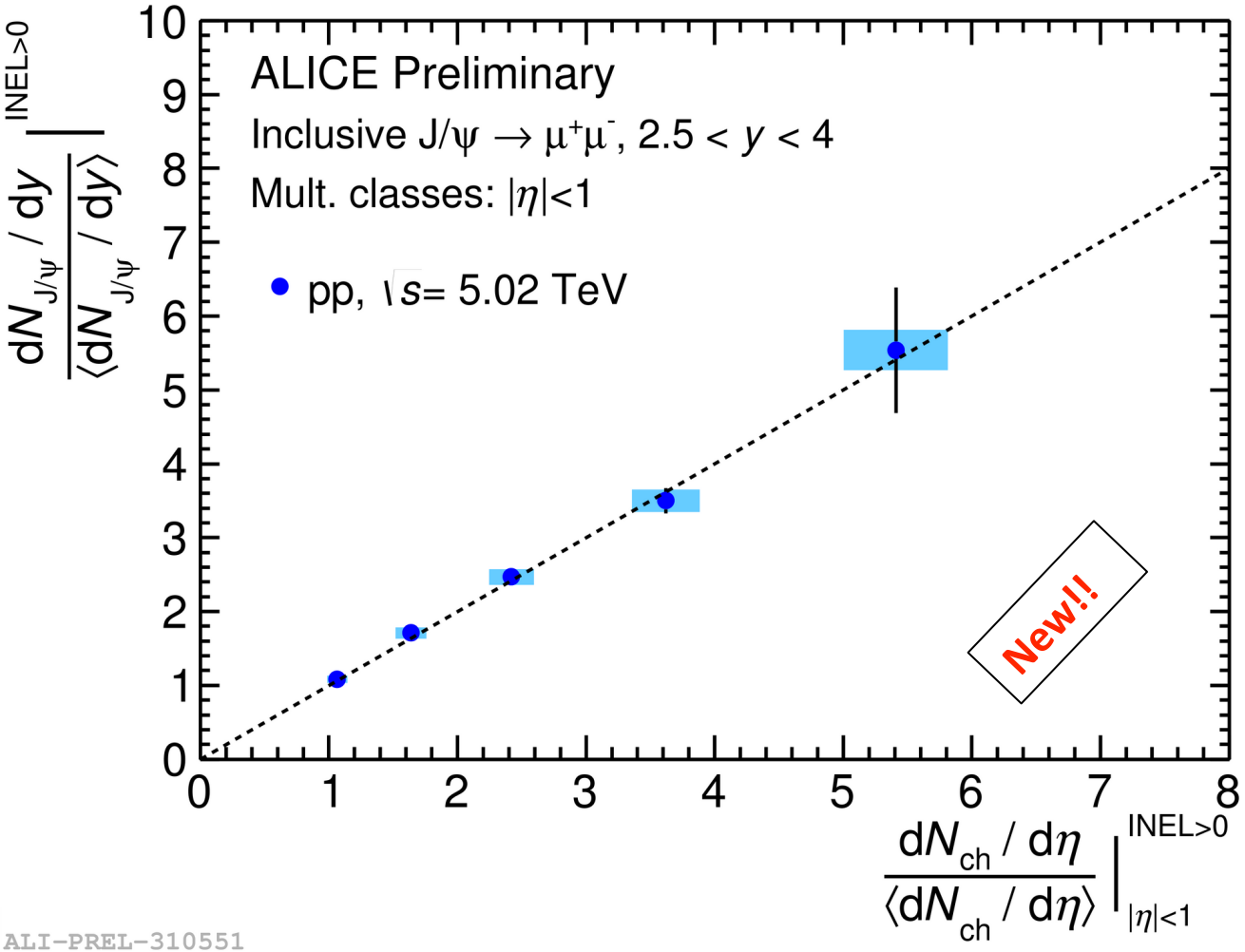
- String percolation
- Hydro dynamical evolution (EPOS3)
- Multiple parton interaction (PYTHIA8)
- Contributions of higher Fock states

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

Ferreiro	PRC86 (2012) 034903
EPOS3	Phys. Rept.350 (2001) 93
PYTHIA8	Comput. Phys.Commun.178(2008)852
Kopeliovich	PRD88 (2013) 116002

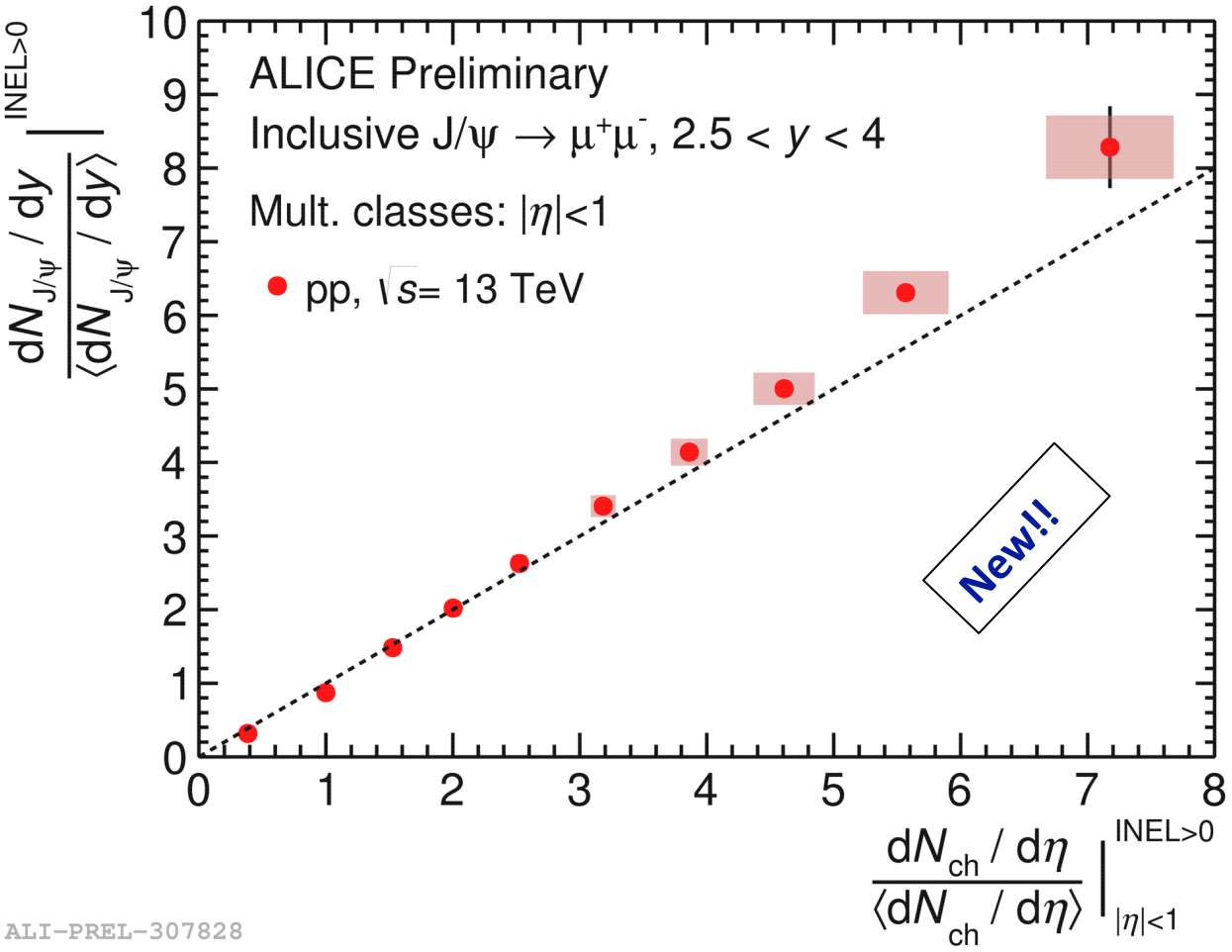
Forward-rapidity J/ψ yield vs. multiplicity in pp@5.02 TeV

- **J/ψ at forward rapidity (2.5 < *y* < 4.0) versus charged-particle at mid-rapidty (|η|<1.0) has been measured by ALICE.**
  - **Linear increase w.r.t charged-particle multiplicity.**



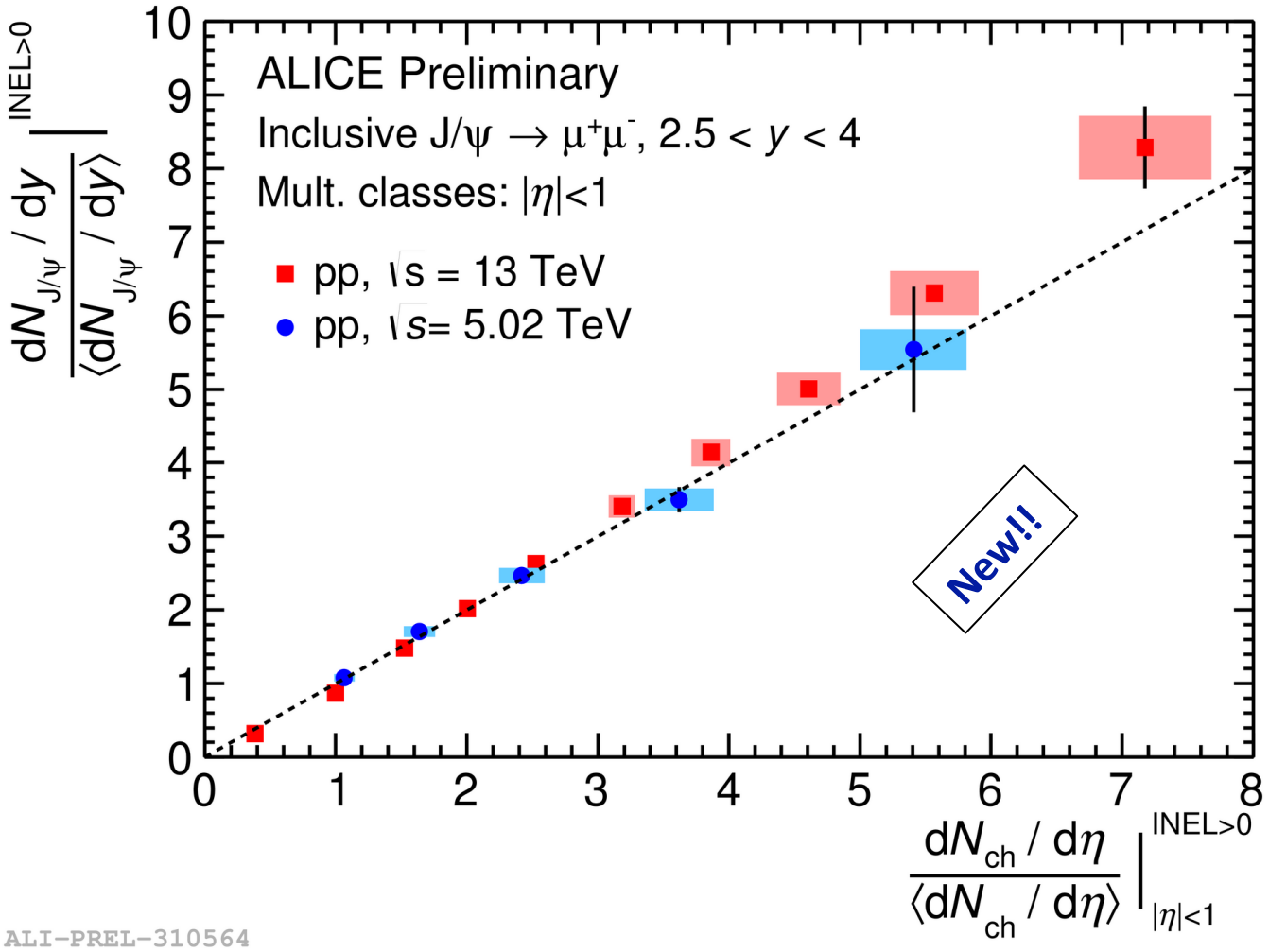
Forward-rapidity J/ψ yield vs. multiplicity in pp@13 TeV

❖ **The multiplicity reach is extended w.r.t pp@5.02 TeV**



❖ **Also, showing linear increase**

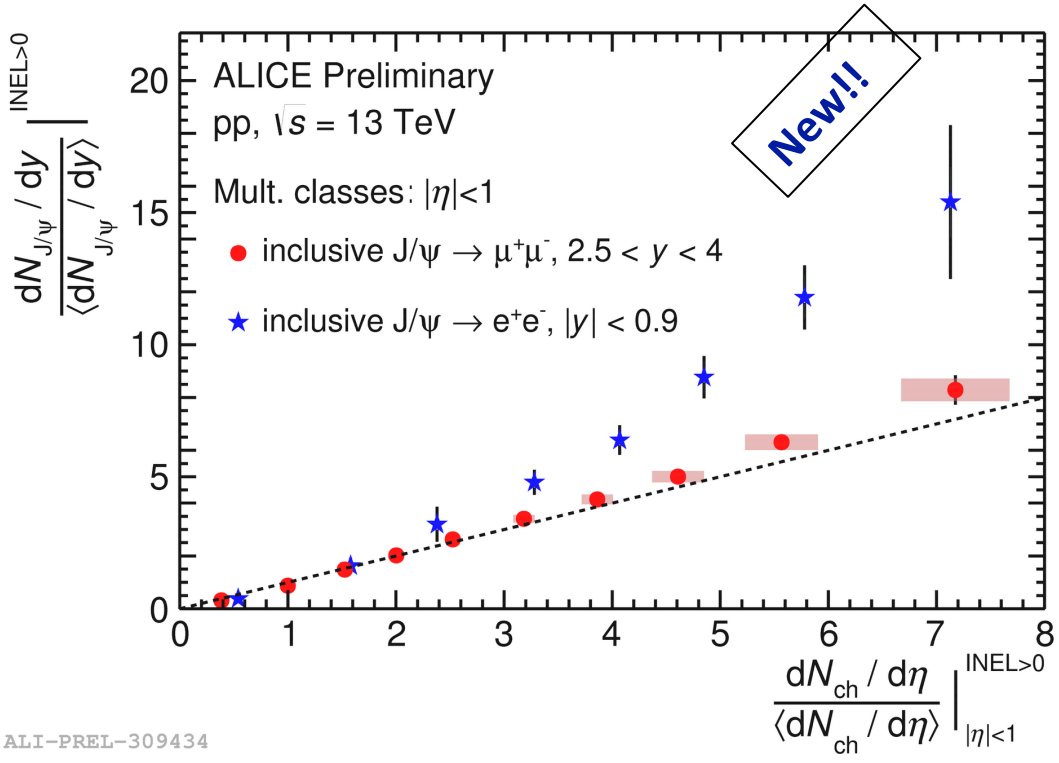
Forward-rapidity J/ψ yield vs. multiplicity in pp@5 and 13 TeV



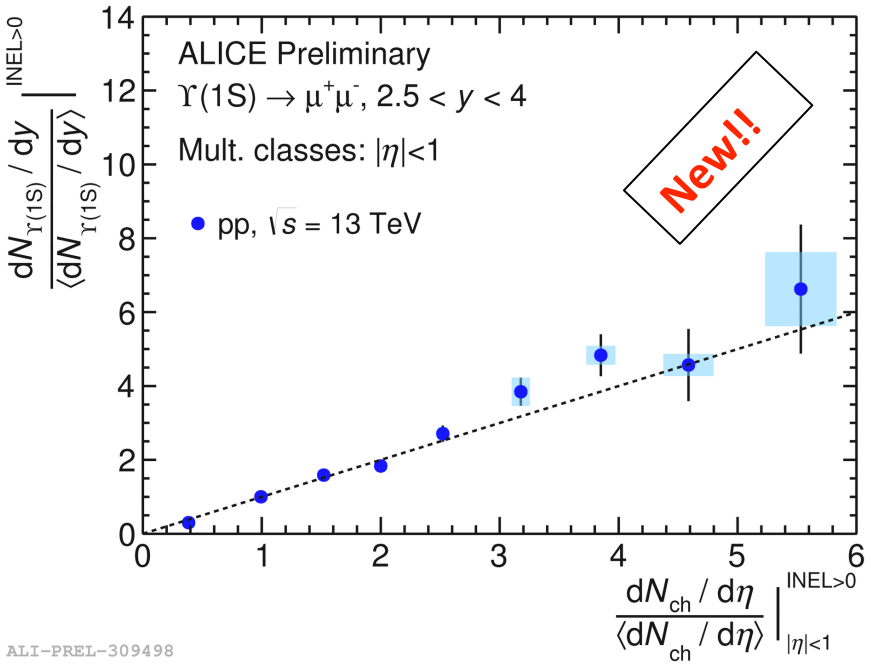
❖ **Trend is independent of colliding energy.**

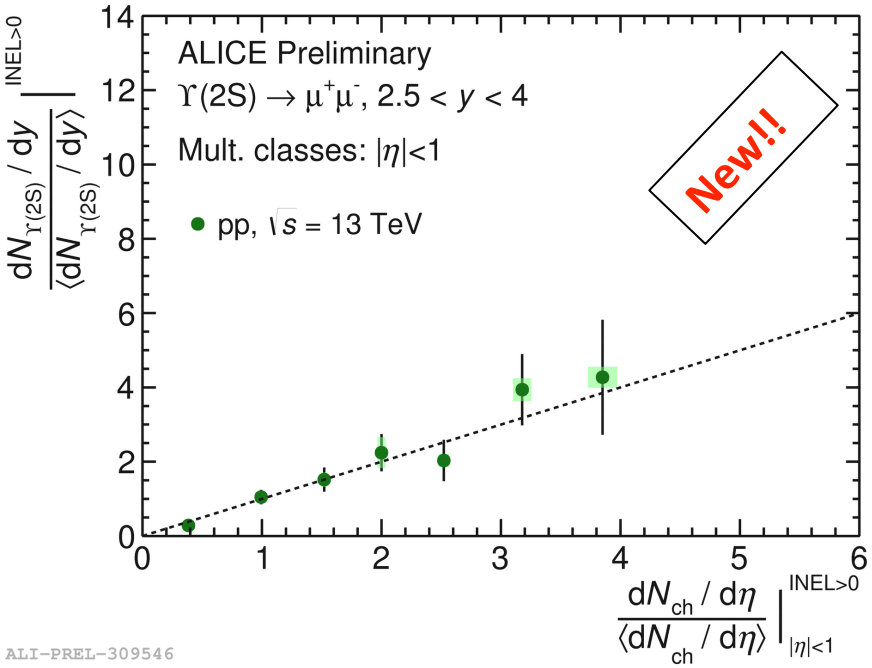
Forward-y and mid-y J/ψ yield vs. multiplicity in pp@13 TeV

- **J/ψ Vs. multiplicity at forward-rapidity is compared with mid-rapidity (|η|<1.0) measurement**
  - **Different J/ψ vs. multiplicity trend has been observed at mid and forward rapidity.**
  - **Increase is faster than linear at mid-y, while it is almost linear at forward-y**
  - **Hinting possible bias of auto-correlations and jets in mid rapidity J/ψ Vs. multiplicity result**



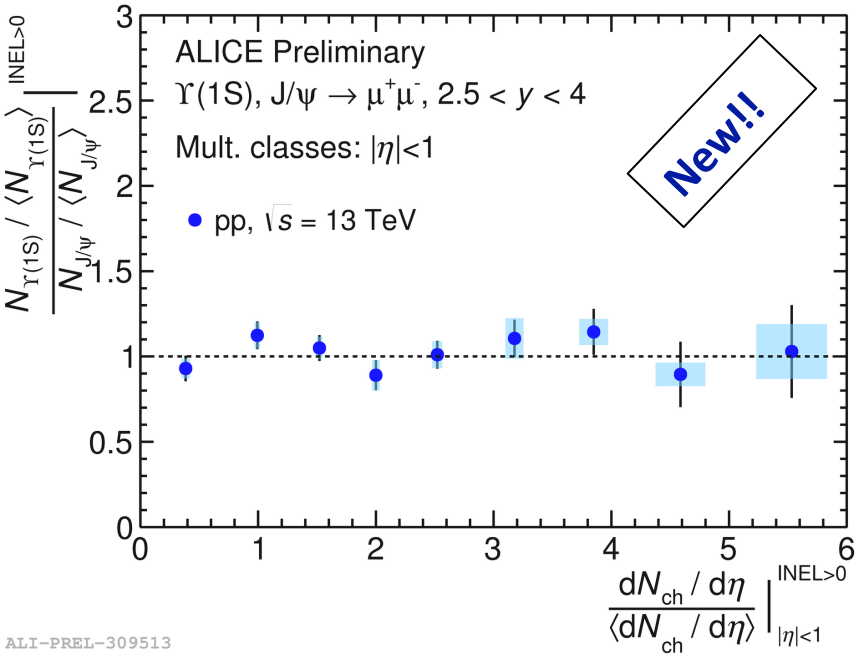
Forward-rapidity ϒ yield vs. multiplicity in pp@13 TeV

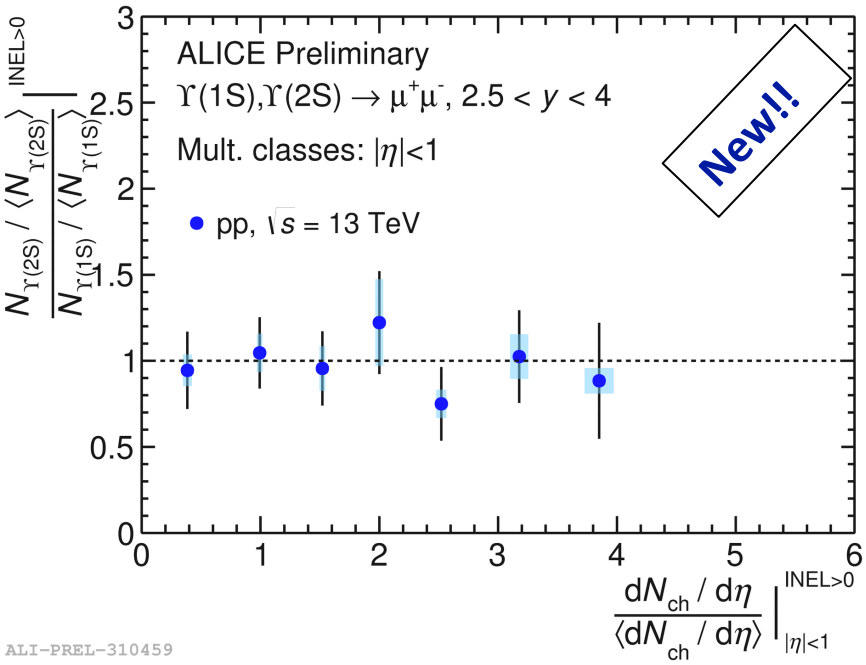




- **For the first time, ϒ(1S) and ϒ(2S) at forward rapidity (2.5 < *y* < 4.0) versus charged-particle at mid-rapidity (|η|<1.0) have been measured by ALICE.**
  - **A linear increase of relative ϒ(1S) and ϒ(2S) yield as a function of relative charged-particle multiplicity is observed.**

Double ratio

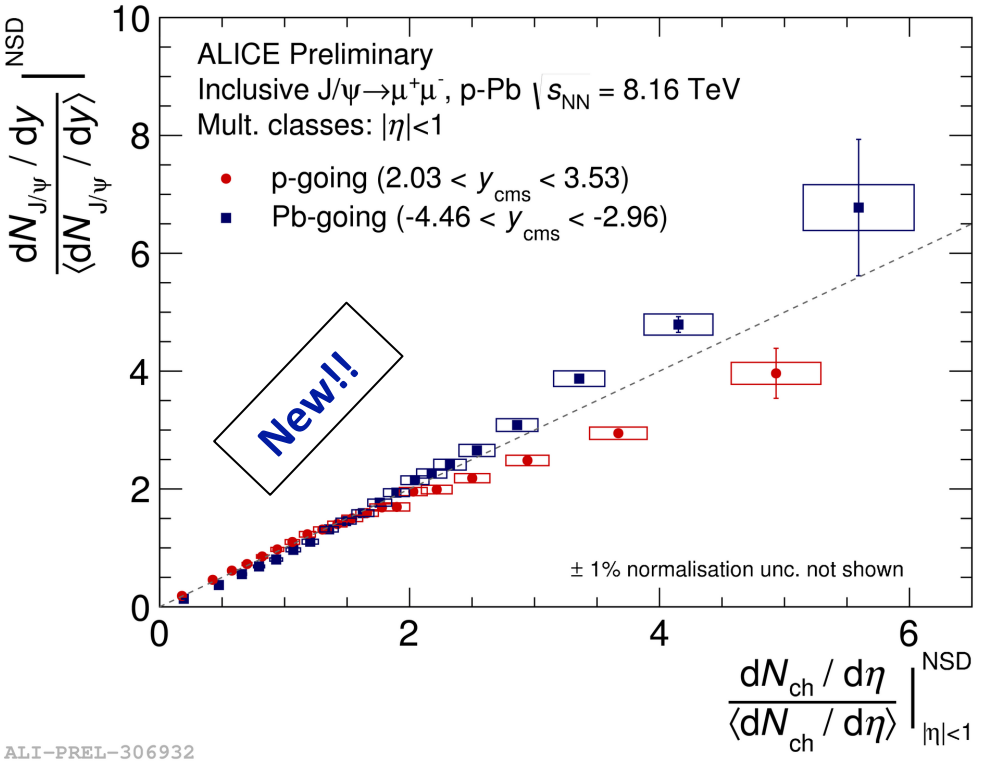




- **The double ratio ϒ(1S)/J/ψ and ϒ(2S)/ϒ(1S) has been studied for pp@ 13 TeV**
  - **The ratio is found to be unity irrespective of charged-particle multiplicity.**
  - **The multiplicity dependence production is same for J/ψ, ϒ(1S) and ϒ (2S).**
  - **ϒ(nS)/ϒ (1S), are found to decrease with increasing charged-particle multiplicity, when ϒ and charged particles are measured in mid-rapidity. (CMS Collaboration, JHEP04(2014)103)**

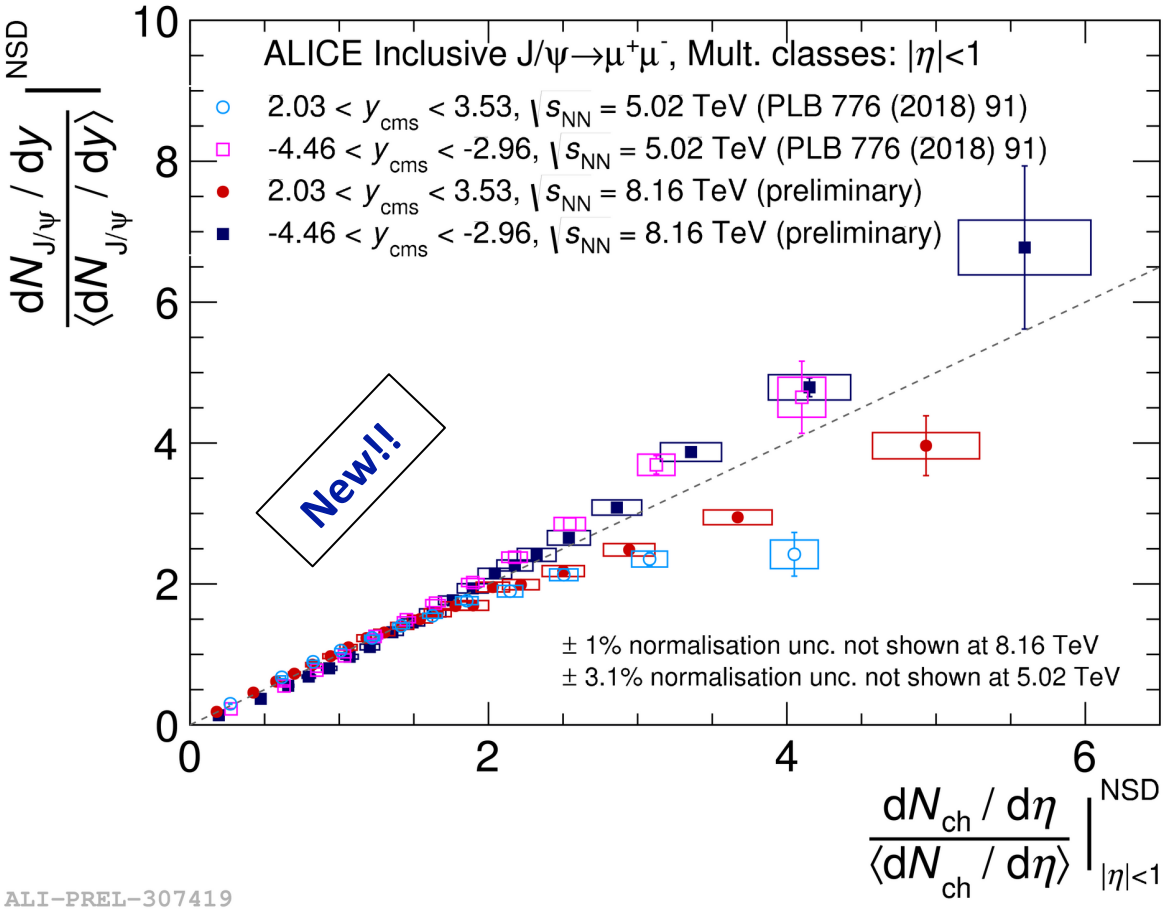
Forward-rapidity J/ψ yield vs. multiplicity in p-Pb@8.16 TeV

- **Recently, ALICE has also measured forward rapidity J/ψ versus charged-particle multiplicity at mid-rapidity for p-Pb@8.16 TeV .**
  - **At low multiplicity, both p-Pb and Pb-p show a linear increase with charged-particle multiplicity.**
  - **Beyond $dN_{ch}/d\eta/\langle dN_{ch}/d\eta\rangle \approx 2$, J/ψ yield in p-Pb collisions show slower than linear increase, whereas J/ψ yield in Pb-p continue to increase linearly.**



Forward-rapidity J/ψ yield vs. multiplicity in p-Pb@8.16 TeV

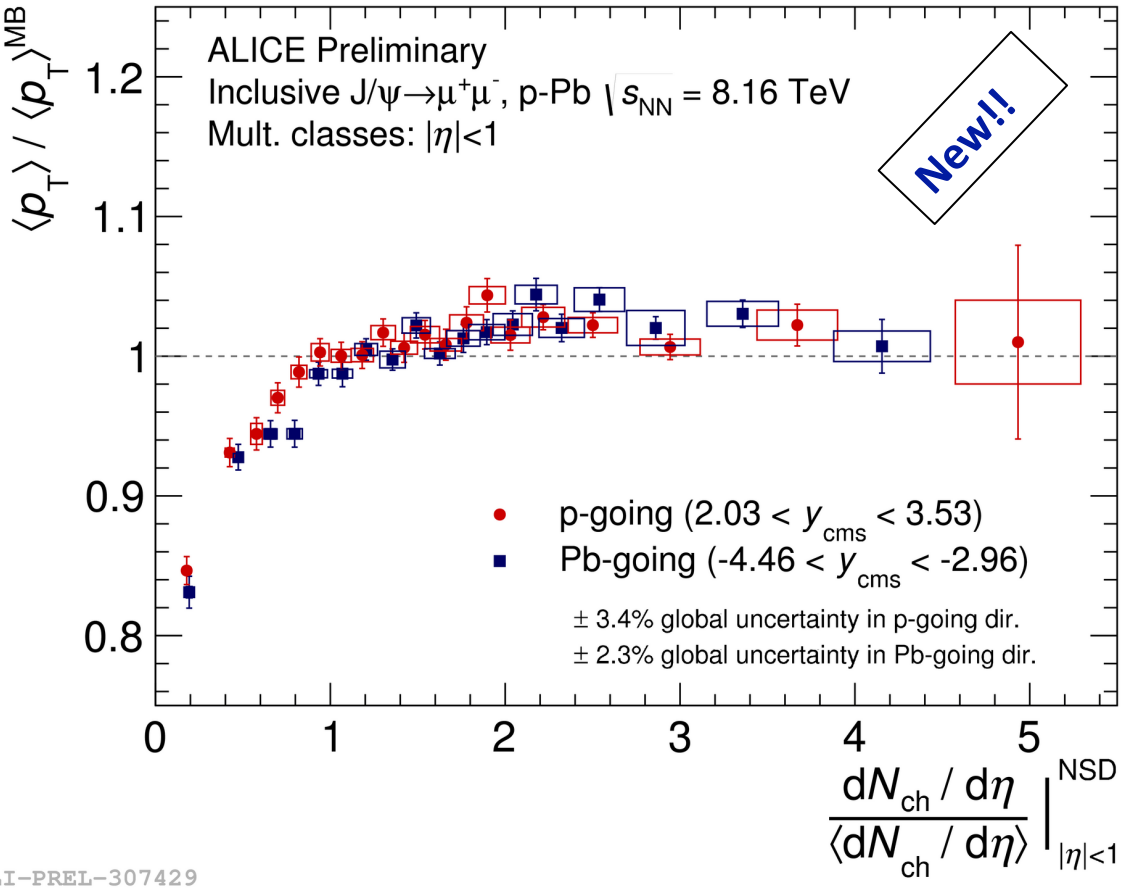
- **When we compare with similar measurement at p-Pb@5.02 TeV …..**
  - **Colliding energy independent but a rapidity dependence behavior is seen.**



Forward-rapidity J/ψ <p_T> vs. multiplicity in p-Pb@8.16 TeV

❖ **Recently, <p_T> of J/ψ as a function of charged-particle multiplicity has been studied by ALICE**

- **Both rapidity regions show a similar trend for <p_T> of J/ψ which saturates around relative multiplicity ≈ 1.5.**
- **The relative <p_T> is independent of rapidity.**

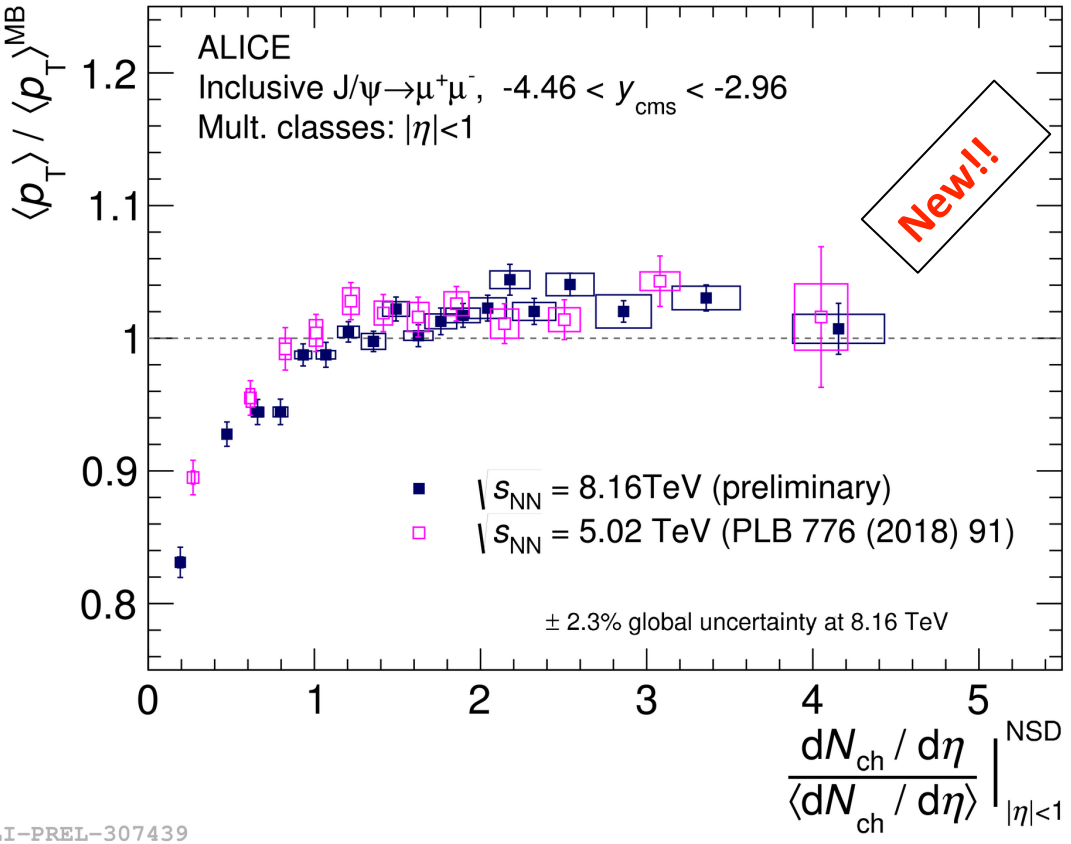


ALI-PREL-307429

Forward-rapidity J/ψ <p_T> vs. multiplicity in p-Pb@8.16 TeV

❖ **Recently, <p_T> of J/ψ as a function of charged-particle multiplicity has been studied by ALICE**

- **Both rapidity regions show a similar trend for <p_T> of J/ψ which saturates around relative multiplicity ≈ 1.5.**
- **The relative <p_T> is independent of rapidity.**
- **When comparing with results of p-Pb@5.02TeV : Relative <p_T> is independent of center-of-mass energy.**



ALI-PREL-307439

Summary

ALICE has extended the study of quarkonium production versus charged-particle multiplicity in pp collisions at 5.02 and 13 TeV, and p-Pb collisions at 8.16 TeV at forward and backward rapidities.

- 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.
- Double differential ratios of ϒ(1S) to J/ψ and ϒ(2S) to ϒ(1S) are found to be close to unity and independent on multiplicity.
- New results hinting for auto-correlation and jet-bias for mid rapidity J/ψ vs. mid rapidity charged-particle multiplicity study.
- The J/ψ vs. multiplicity study extended to p-Pb collisions to understand J/ψ production from pp to Pb-Pb collisions. The J/ψ vs. multiplicity results for p-Pb collisions is also center-of-mass independent as like pp collisions.

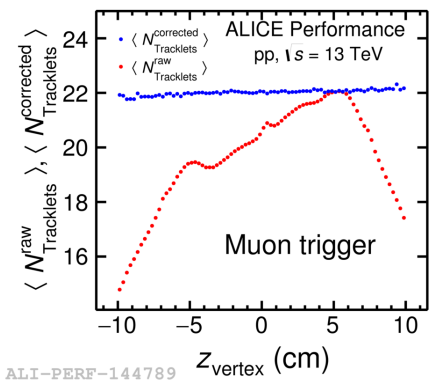
Thank you!!

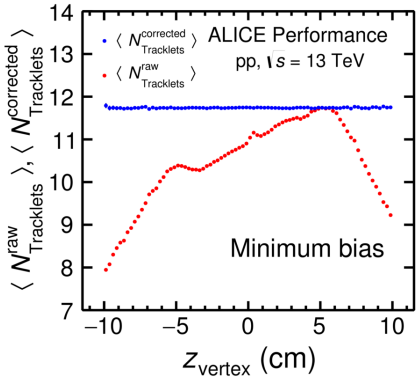
Multiplicity determination

- **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.**

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

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



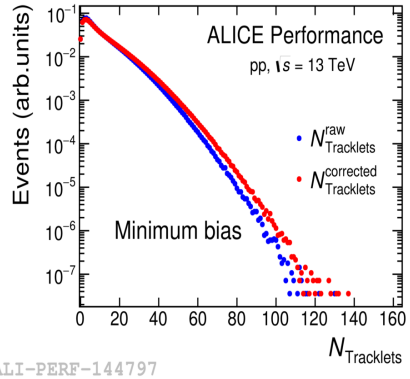


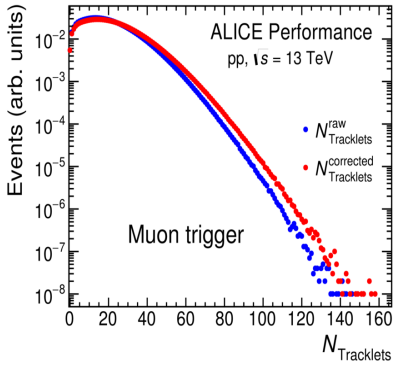
- **Here, ΔN_{rand} follows a Poissonian distribution centered around ΔN.**

- **z_v^0 corresponds to z_{vertex} position where $\langle N_{trk}\rangle$ is maximum.**

- **The efficiency loss at z_0 and other track-to-particle-corrections need to be taken into account to evaluate the actual charged-particle value.**

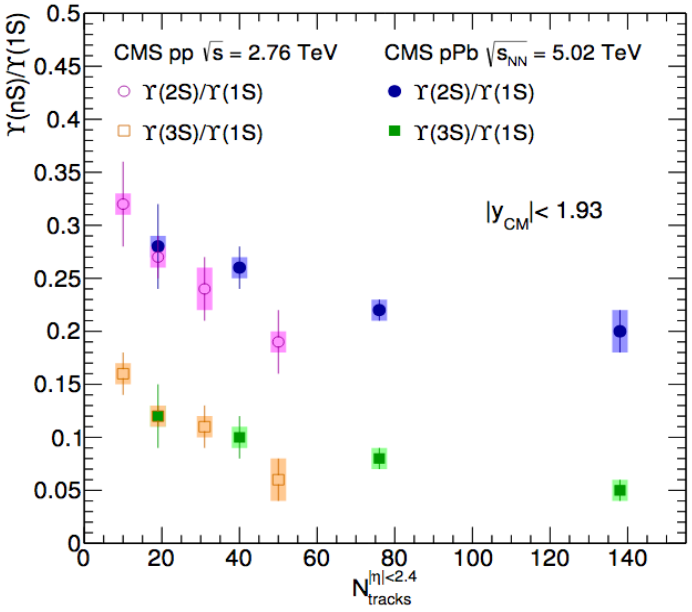
$$\frac{\langle dN_{ch}/d\eta\rangle_i}{\langle dN_{ch}/d\eta\rangle} = \frac{f(\langle N_{trk}^{corr}\rangle_i)}{\langle dN_{ch}/d\eta\rangle_{INEL>0}}$$





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

ϒ Vs. multiplicity



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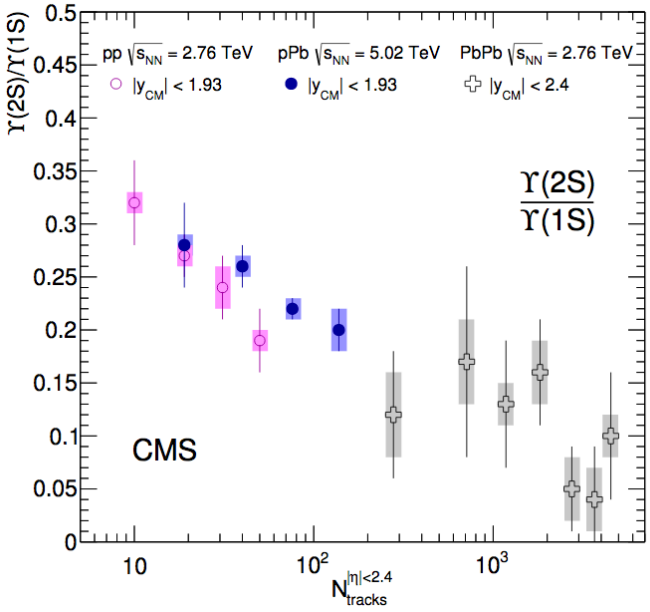


- **The excited-to-ground-states ratios, Y(nS)/*Y*(1S), are found to decrease with increasing charged-particle multiplicity.**
- **The tightest bound state, Y(1S), was observed to be less suppressed than the more loosely bound excited states, Y(2S) and Y(3S).**
- **Global behavior of double ratio has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

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

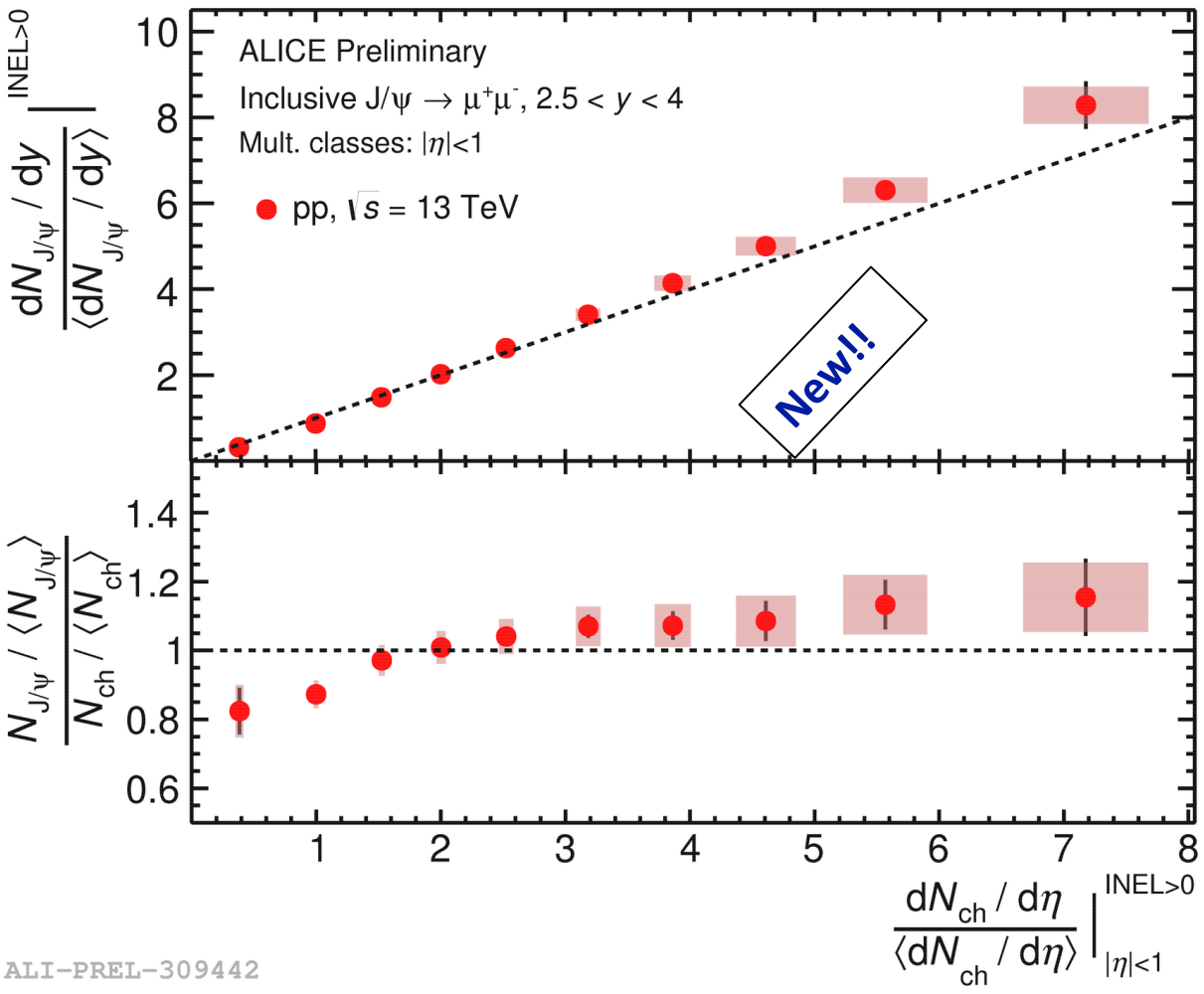
- **MB trigger**
- **$-0.9 < \eta < 0.9$**
- **Track quality cuts**
- **Rejection of tracks from photon conversion**
- **TPC electron identification**

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

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

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

Forward-rapidity J/ψ yield vs. multiplicity in pp@13 TeV



- Low multiplicity region is below linear:: Would be more interesting to investigate