At LHC energies, the charged-particle multiplicity dependence of particle production is a topic of considerable interest in $pp$ collisions. It has been argued that multiple partonic interactions play an important role in particle production mechanisms, not only affecting the soft processes but also the hard processes. Recently, ALICE has measured $J/\psi$ production as a function of charged-particle multiplicity to study the correlation between soft and hard processes. In this contribution, we present the $J/\psi$ production versus multiplicity for $pp$ and $p-Pb$ collisions measured by ALICE. We compare the results with different theoretical models.

PACS numbers: 25.75.Dw, 25.75.Nq, 12.38.Mh
I. INTRODUCTION

Understanding the mechanism of charmonium production is one of the major challenges in pp collisions. There are many theoretical models that try to explain heavy-flavor production in hard scattering processes. Examples are the Color Singlet Model [1], non-relativistic QCD (NRQCD) [2] and the Color Evaporation Model [3]. The production of charm and anti-charm quark pairs are described by perturbative Quantum Chromodynamics (pQCD) and their binding into charmonium states by non-perturbative QCD. Charmonium suppression is a universally accepted probe for the de-confined medium in heavy-ion collisions. To understand the suppression, it is necessary to understand $J/\psi$ production in pp collisions and also potential cold nuclear matter effects in $p$–$Pb$ collisions. Recently, ALICE has measured $J/\psi$ as a function of charged-particle multiplicity in $J/\psi \rightarrow \mu^+\mu^-$ and $J/\psi \rightarrow e^+e^-$ at $\sqrt{s} = 7$ TeV, and observed an increasing trend with respect to charged-particle multiplicity [5]. A similar result has been found for D-meson production. This reveals that the multiple partonic interaction (MPI) which was thought to affect only soft processes can also affect the hard processes and hence $J/\psi$ production. With the help of new data at $\sqrt{s} = 13$ TeV, we can measure the trend with multiplicity more precisely than what was previously possible at $\sqrt{s} = 7$ TeV. Therefore, to have a clear view of the observed picture, ALICE has extended this analysis to pp collisions at $\sqrt{s} = 13$ TeV and $p$–$Pb$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV. We present the results of this analysis and compare them to available theoretical models.

II. EXPERIMENTAL SETUP AND ANALYSIS PROCEDURE

ALICE is one of the four major experiments at the LHC. Details about ALICE can be found in Ref. [6]. For the present work, two different spectrometers have been used for $J/\psi$ reconstruction. The central barrel detector covers the rapidity range $|y| < 0.9$ and includes the Inner Tracking System (ITS) and Time Projection Chamber (TPC). It is used for the reconstruction of $J/\psi$ via the di-electron decay channel. The forward muon spectrometer is used for the reconstruction of $J/\psi$ via the di-muon decay channel in the rapidity range -4.0 < $y$ < -2.5. Two V0 scintillator arrays used for triggering and are located at -3.7 < $\eta$ < -1.7 and at 2.8 < $\eta$ < 5.1. The V0 detectors are also used as a high-multiplicity trigger.

The charged-particle pseudo-rapidity density ($dN_{ch}/d\eta$) is measured at mid-rapidity ($|\eta| < 1.0$) from the information of track segments (tracklets) in the Silicon Pixel Detector (SPD). Several cuts are applied to determine the accurate position of the $z$-coordinate of the vertex ($z_{vtx}$). Tracklets are measured within $|\eta| < 1.0$ and $|z_{vtx}| < 10.0$ cm. This account for the SPD inefficiency and acceptance. The correction factor is randomized on an event-by-event basis using data driven method [7]. This also take into account the SPD inefficiency and acceptance. The correction factor is randomized on an event-by-event basis using a Poisson distribution, for the matching of true charged-particle multiplicity and the tracklet multiplicities.

The self-normalized $J/\psi$ yield in bins of charged-particle multiplicity is calculated as:

$$\frac{dN_{J/\psi}}{dy} = \frac{N_{J/\psi}^{corr, i}}{N_{J/\psi}^{corr, integrated}} \times \frac{N_{MB}^{integrated}}{N_{MB}^{corr, integrated}},$$

where ($N_{J/\psi}^{corr, i}$, $N_{J/\psi}^{corr, integrated}$) and ($N_{MB}^{corr}$, $N_{MB}^{integrated}$) are the corrected number of $J/\psi$ and number of minimum bias events in $i^{th}$ multiplicity bin and integrated over all multiplicity bins, respectively. In $p$–$Pb$ collisions, the mean $p_T$ of $J/\psi$, $\langle p_T^{J/\psi} \rangle$, is found by fitting the mean $p_T$ of unlike-sign pairs of muons as a function of the dimuon invariant mass.

III. RESULTS

Figure 1 shows the relative yield of inclusive $J/\psi$ at mid-rapidity as a function of charged-particle multiplicity for integrated $p_T$ and in $p_T$ slices. It can be see from the figure that a stronger than linear increase of yield is observed as compared to the charged-particle multiplicity. These data are more precise and extend the multiplicity reach with respect to the results at $\sqrt{s} = 7$ TeV. The result is compared to four models: Ferreiro et al. [11], EPOS3 [10], PYTHIA 8 [12] and Kopeliovich et al. [12].

- The model of Ferreiro et al., which is able to well-explain pp result at $\sqrt{s} = 7$ TeV [11], overestimates the $J/\psi$ yield at high multiplicities in pp at $\sqrt{s} = 13$ TeV. This model assumes that in high energy hadronic collisions all the interacting partons have finite spatial extension and thus collide at finite impact parameter by means of parton-parton collisions. It considers color strings as the fundamental degrees of freedom. According
to this model, $J/\psi$ multiplicity is proportional to number of strings produced ($N_s$), whereas charged-particle multiplicity behaves roughly as $\sqrt{N_s}$, due to the interaction among the strings.

- **EPOS3** includes MPI and hydrodynamical expansion of the system, describes well the azimuthal correlation of D-meson with charged-particle[13], is also describes the multiplicity dependence of $J/\psi$ production. The good agreement of the EPOS3 model with data shows that the energy density reached in $pp$ collisions at the LHC might be high enough to be described by a hydrodynamical evolution.

- **PYTHIA 8** has MPI and color reconnection in the final state underestimates the data towards the higher multiplicity bins.

- The model of Kopeliovich et al. assumes higher Fock states in protons, which contain increased number of gluons. Inelastic collisions of the Fock components lead to high hadron multiplicity and the relative production of $J/\psi$ is enhanced in such gluon-rich collisions.

All the models containing MPI, qualitatively reproduce the multiplicity dependence of $J/\psi$ production, which reveals the importance of MPI in $pp$ collisions and in particular for heavy-flavor production. Among all, EPOS is describing the data best. The self normalized $J/\psi$ yield as a function of charged-particle multiplicity studied in four $p_T$ intervals is shown in the right panel of Fig[1]. The results are compared with PYTHIA8. It reproduces the multiplicity and $p_T$ dependence well, further highlighting the importance of MPI. The enhancement is strongest at high $p_T$, indicating that the effect of MPI is more important at higher $p_T$ in the production of $J/\psi$.

The multiplicity dependence of $J/\psi$ production as a function of charged-particle multiplicity has also been studied in $p$-$Pb$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV [14]. ALICE has performed the study in different rapidity ranges by inverting the directions of the lead and proton beams. The measurement has been performed in three rapidity regions, forward ($2.03 < y_{cms} < 3.53$), backward ($-4.46 < y_{cms} < -2.96$) and mid-rapidity ($-1.37 < y_{cms} < 0.43$), as shown in the left panel of Fig[2]. The mid-rapidity and backward-rapidity data show a linear increase of self-normalized $J/\psi$ yield with multiplicity. At forward rapidity a saturation towards higher multiplicity is observed. In this kinematic region, the proton probes the small Bjorken-x region of the Pb-nucleus, where cold nuclear effect, gluon shadowing and saturation effects are expected.

ALICE has also measured $\langle p_T^{J/\psi} \rangle$ as a function of multiplicity at forward and backward rapidities, which is shown in the right panel of the Fig[2]. It can be seen from the figure that both rapidity regions show a similar trend. The $\langle p_T \rangle$ is the same within uncertainty. The $\langle p_T \rangle$ of charged hadrons is represented by a dashed band. The $\langle p_T^{J/\psi} \rangle$ shows a similar trend as that observed in $Pb$-$Pb$ collisions for charged particles [15], possibly hinting at collective effects in $p$-$Pb$ collisions.

### IV. SUMMARY

In this contribution, the multiplicity dependence of $J/\psi$ production has been presented for $pp$ collisions at $\sqrt{s} = 13$ TeV and $p$-$Pb$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Also, $\langle p_T^{J/\psi} \rangle$ as function of multiplicity for $p$ – $Pb$ collisions at
FIG. 2. Self-normalized yield and mean transverse momentum of $J/\psi$ as a function of self-normalized charged-particle multiplicity for $p$–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The result for self-normalized yield of inclusive $J/\psi$ production at forward ($2.03 < y_{cm} < 3.53$), backward ($-4.46 < y_{cm} < -2.96$) and mid-rapidity ($-1.37 < y_{cm} < 0.43$) are shown in left pannel. The result for self-normalized mean transverse momentum of $J/\psi$ at forward ($2.03 < y_{cm} < 3.53$) and backward rapidity ($-4.46 < y_{cm} < -2.96$) are shown in right panel.

$\sqrt{s_{NN}} = 5.02$ TeV has been presented at forward and backward rapidities. Preliminary results of $J/\psi$ production as a function of charged-particle multiplicity for $J/\psi \rightarrow e^+e^-$ are presented. Similar work at forward rapidity looking at the decay channel $J/\psi \rightarrow \mu^+\mu^-$ is ongoing. The $J/\psi$ yield versus charged-multiplicity study for $p$–Pb results will help to understand differences in the production mechanisms between $pp$ and $p$–$Pb$ collisions.

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