

# MULTIPLICITY DEPENDENCE OF STRANGENESS AND CHARGED PARTICLE PRODUCTION IN PROTON–PROTON COLLISIONS\*

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In this contribution, the production rates and the transverse momentum distributions of strange hadrons are reported as a function of charged particle multiplicity. In this analysis, the data collected in proton–proton collisions at  $\sqrt{s} = 13$  TeV with the ALICE detector at the LHC are used. It is found that the production rate of  $K_S^0$ ,  $\Lambda$ ,  $\Xi^\pm$ , and  $\Omega$  increases with multiplicity faster than that for charged particles. The higher the strangeness content of the hadron, the more pronounced is the increase. Moreover, the energy and multiplicity dependence of charged particle production in  $pp$  collisions are presented and the results are compared to predictions from Monte Carlo (MC) event generators. It turns out that the average multiplicity density increases steeply with center-of-mass energy for high-multiplicity classes.

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## 1. Introduction

A recent multiplicity-dependent study of the strange and multi-strange hadron production in  $pp$  collisions has provided quite interesting results hinting at a Quark–Gluon Plasma (QGP) like properties in  $pp$  collisions [1]. The enhancement of strangeness production in high-energy nucleus–nucleus collisions has historically been proposed as one of the first signatures of QGP formation [2]. This work provides a comprehensive study of energy and multiplicity dependence of charged-particle production measured with forward and central multiplicity estimators, which serve as an important reference for

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multiplicity-dependent measurements in  $pp$  collisions. In this work, the multiplicity dependence of strange hadron production rates and their transverse momentum distributions at center-of-mass energy 13 TeV are measured and compared with the previous 7 TeV results.

## 2. Charged particle production

The description of the ALICE detector setup can be found in [3, 4]. This measurement relies on track segments called Silicon Pixel Detector (SPD) tracklets covering the kinematic region of  $|\eta| < 1.8$ .

Results are presented for inelastic collisions with at least one charged particle in the central region  $|\eta| < 1.0$  (called the “INEL > 0” event class). Figure 1 shows the charged-particle pseudorapidity-density distribution measured using a forward multiplicity estimator (total charge deposited in V0A and V0C scintillators) and a central multiplicity estimator (tracklets in the central SPD detector) for different multiplicity classes. These multiplicity classes are made by dividing the event samples based on the total charge deposited in V0A and V0C scintillators (for forward multiplicity estimator) and a number of SPD tracklets (for central multiplicity estimator) which is proportional to the charged particle production. The observed asymmetry for the forward estimator reflects the asymmetric acceptances of our scintillator detectors V0A (which covers the pseudo-rapidity range of  $2.8 < \eta < 5.1$ ) and V0C (which covers the pseudo-rapidity range of  $-3.7 < \eta < 1.7$ ), which can also be seen in simulated data at the particle level. An advantage of using a forward multiplicity estimator is that it provides an unbiased measurement of  $\langle dN_{ch}/d\eta \rangle$  at mid-rapidity due to auto-correlation.

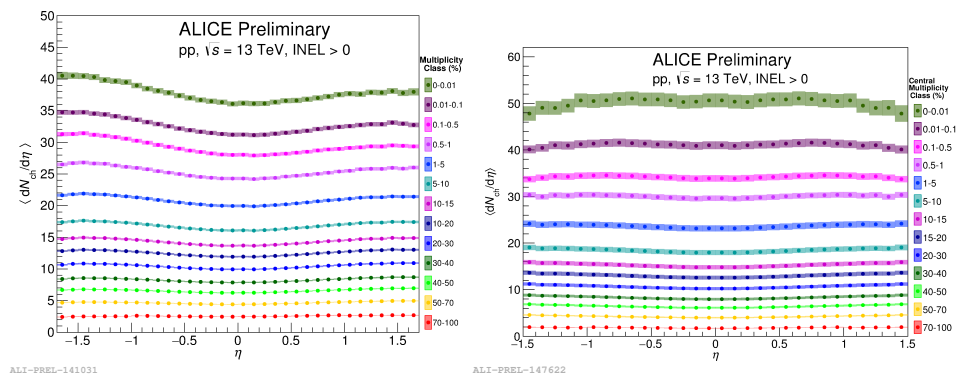


Fig. 1. Multiplicity dependence of the pseudorapidity density distributions measured with forward (left) and central (right) multiplicity estimators.

Normalized pseudorapidity-density distributions are presented in Fig. 2 for both forward and central multiplicity estimators. We used the inclusive pseudorapidity density distribution of charged particles to normalize the distributions. Using the normalized distribution, we reduced most of the correlated systematic uncertainties. The normalized results in Fig. 2 show up to  $\sim 7$  and  $\sim 5$  times more charged particle production in the highest multiplicity class (0–0.01%) with the central and forward estimators, respectively.

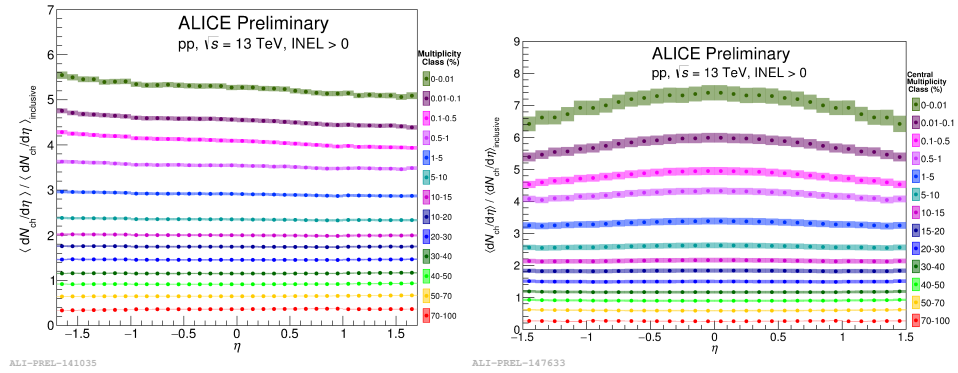


Fig. 2. Normalized multiplicity dependence of the pseudorapidity density distributions measured with forward (left) and central (right) multiplicity estimators.

PYTHIA 8 predictions implemented with color reconnection (CR) in the string fragmentation process is compared with the multiplicity class (0.01–0.1%) as shown in Fig. 3. This model describes the data within 15%, how-

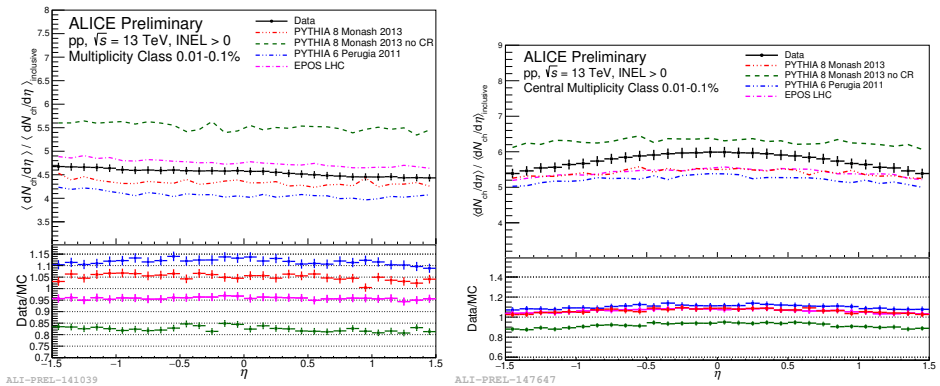


Fig. 3. Normalized pseudorapidity density distribution of charged particles is compared with different MC models for multiplicity bin 0.01–0.1% for forward (left) and central (right) multiplicity estimators.

ever, PYTHIA 8 with no color reconnection overestimates the data by up to 20%. We have also compared the PYTHIA 6 Perugia tune and EPOS-LHC models, which incorporate collective flow like effects in the simulation to the (0.01–0.1%) multiplicity class and they follow the same trend as PYTHIA 8 with CR. Figure 4 shows the energy dependence of the pseudo-rapidity density distribution. The evolution of the average pseudo-rapidity density with the center-of-mass energy for different multiplicity classes from low multiplicity to high multiplicity is parametrized by a power law function. The rise in the average pseudo-rapidity density as a function of center-of-mass energy becomes steeper for high multiplicity classes, which could be due to multiple parton interactions [5, 6].

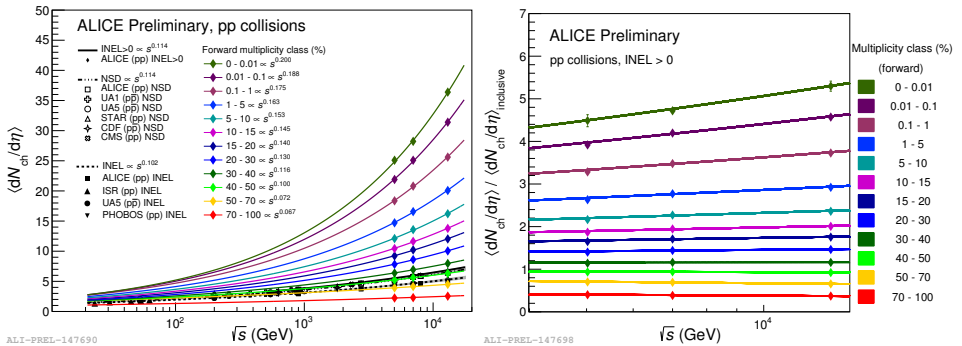


Fig. 4. Energy dependence of the pseudorapidity density distributions in  $pp$  collisions at  $\sqrt{s} = 5.02, 7$  and  $13$  TeV for forward and central multiplicity estimators.

### 3. Strange hadron production

New measurements of strangeness production in  $pp$  collisions at  $\sqrt{s} = 13$  TeV and in Xe–Xe collisions at  $\sqrt{s_{NN}} = 5.44$  TeV using new data samples will be discussed here. Figure 5 shows the energy dependence of the  $\langle p_T \rangle$  of strange hadrons *versus* the charged multiplicity at mid-rapidity, where results are compared to the previous  $pp$  measurements at  $\sqrt{s} = 7$  TeV. The  $\langle p_T \rangle$  of  $K_S^0$  as shown in Fig. 5 is marginally greater for 13 TeV center-of-mass energy, where as for  $\Lambda$  and  $\Omega$ , it scales with 13 TeV center-of-mass energy. The evolution of the ratio of the total yield of strange particles to the yield of pions (in order to quantify the strangeness enhancement) as a function of charged particle multiplicity at mid-rapidity is shown in Fig. 6. This ratio is measured for strange and non-strange hadrons including  $p$ ,  $K_S^0$ ,  $\Lambda$ ,  $\phi$ ,  $\Xi$  and  $\Omega$  and for all the available colliding systems. We observe a smooth evolution with multiplicity across all colliding systems including the Xe–Xe system, from low multiplicity  $pp$  to central A–A collisions.

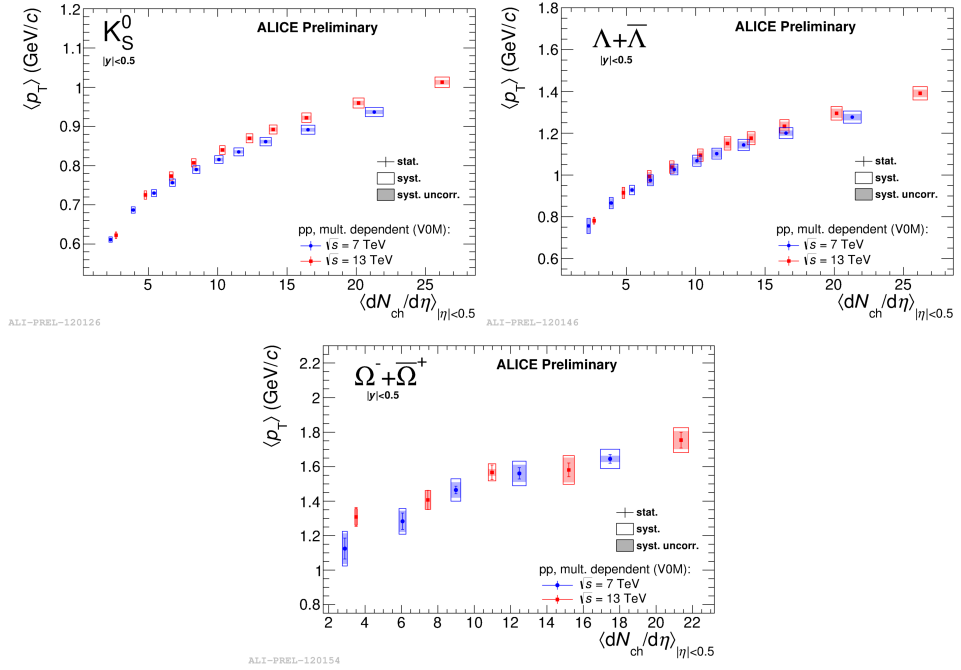


Fig. 5.  $\langle p_T \rangle$  of  $K_S^0$ ,  $\Lambda$ , and  $\Omega$  as a function of multiplicity in forward multiplicity event classes at  $\sqrt{s} = 7$  and 13 TeV.

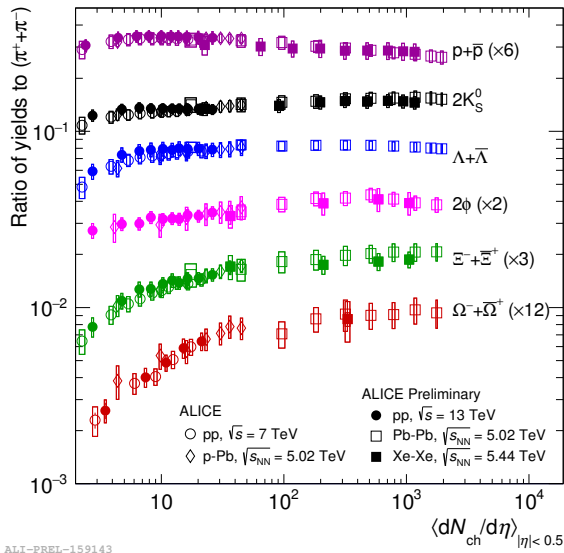


Fig. 6. Hadron-to-pion yield ratios as a function of the charged particle multiplicity in  $pp$ ,  $p$ -Pb, Pb-Pb, and Xe-Xe collisions at the LHC.

#### 4. Conclusion

To improve our understanding of various aspects of multiplicity-dependent final-state observable properties, in particular at high multiplicity, an unbiased measurement of  $\langle dN_{\text{ch}}/d\eta \rangle$  at mid-rapidity is very crucial.

In this contribution, we measured for the first time the pseudo-rapidity distributions of charged particles in proton–proton collisions at  $\sqrt{s} = 13$  TeV for different multiplicity classes and estimators. The average charged particle multiplicity density ( $\langle dN_{\text{ch}}/d\eta \rangle$ ) increases steeply with center-of-mass energies for high-multiplicity classes. Similar results and conclusions can be drawn for 5.02 and 7 TeV center-of-mass energies. We also report the first observation of multiplicity dependence of strangeness production in  $pp$  collisions at 13 TeV. These measurements show that strangeness yields scale well with the center-of-mass energy, while the average momentum does not.

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#### REFERENCES

- [1] J. Adam *et al.* [ALICE Collaboration], *Nature Phys.* **13**, 535 (2017).
- [2] J. Rafelski, B. Müller, *Phys. Rev. Lett.* **48**, 1066 (1982).
- [3] K. Aamodt *et al.* [ALICE Collaboration], *JINST* **3**, S08002 (2008).
- [4] J. Adam *et al.* [ALICE Collaboration], *Phys. Lett. B* **753**, 319 (2016).
- [5] P. Bartalini, J. Gaunt (Eds.), *Advanced Series on Directions in High Energy Physics: Multiple Parton Interactions at the LHC*, Volume 29, World Scientific, 2018, DOI: 10.1142/10646.
- [6] T. Sjöstrand, M. van Zijl, *Phys. Rev. D* **36**, 2019 (1987).