

# Collectivity of (non-)strange hadrons in high-multiplicity pp with CMS

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**Abstract.** Observation of an enhanced long-range, near-side, two-particle correlation (known as the “Ridge”) in high-multiplicity pp and pPb collisions opened up new opportunities of exploring QCD dynamics in small collision systems. The CMS detector at the LHC has excellent capabilities of reconstructing weakly decaying strange hadrons such as  $K_S^0$ ,  $\Lambda$  and  $\Xi$ . Studies of strange hadron production and correlations in small colliding systems provide additional insights into the physical origin of the observed collective phenomena. New results for  $p_T$  spectra and long-range two-particle correlations for charged particles and identified strange hadrons in high-multiplicity pp and pPb collisions are presented. The data at various collision energies for pp and pPb collisions are compared to those obtained for PbPb at similar multiplicities. Multi-particle cumulants for pp and pPb events are studied in order to more fully explore the collective nature of the long-range correlations.

## 1. Introduction

As all of the material presented in this talk has been submitted for publication, this proceeding will only briefly summarize the results and refer the reader to the final submitted papers. Full information about all heavy ion physics results from CMS, including figures, data tables, and links to the relevant submitted and/or published work, can be found at:

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSHIN>.

## 2. Strange hadron production in pp, pPb, and PbPb: HIN-15-006

These results are presented in Ref. [1] and are summarized here.

Measurements of strange hadron ( $K_S^0$ ,  $\Lambda$ , and  $\Xi$ ) transverse momentum spectra in pp, pPb, and PbPb collisions are presented over a wide range of event charged-particle multiplicity and particle rapidity. The study is based on samples of pp collisions at  $\sqrt{s} = 7$  TeV, pPb collisions at  $\sqrt{s} = 5.02$  TeV, and PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV, collected with the CMS detector at the LHC. In the context of hydrodynamic models, the measured particle spectra are fitted to a blast wave function, which describes an expanding fluid-like system. When comparing at a similar multiplicity, the extracted radial-flow velocity parameters are found to be larger in pp and pPb collisions than that in PbPb collisions. The average transverse kinetic energy  $\langle KE_T \rangle$  of strange hadrons is observed to increase with multiplicity, with a stronger increase for heavier particles. At similar multiplicities, the difference in  $\langle KE_T \rangle$  between the strange-particle species is larger in the smaller pp and pPb systems than in the PbPb system. For pPb

collisions,  $\langle KE_T \rangle$  in the Pb-going direction for  $K_S^0$  ( $\Lambda$ ) is 6% (12%) larger than in the p-going direction for events with the highest particle multiplicities.

### 3. Correlations of changed and strange hadrons in pp: HIN-16-010

These results are presented in Ref. [2] and are summarized here.

The CMS detector has been used to measure two- and multi-particle azimuthal correlations with  $K_S^0$ ,  $\Lambda$ , and inclusive charged particles over a broad pseudorapidity and transverse momentum range in pp collisions at  $\sqrt{s} = 5, 7, \text{ and } 13$  TeV. With the implementation of high-multiplicity triggers during the LHC 2010 and 2015 pp runs, the correlation data are explored over a broad particle multiplicity range. The observed long-range ( $|\Delta\eta| > 2$ ) correlations are quantified in terms of azimuthal anisotropy Fourier harmonics ( $v_n$ ). The elliptic ( $v_2$ ) and triangular ( $v_3$ ) flow Fourier harmonics are extracted from long-range two-particle correlations. After subtracting contributions from back-to-back jet correlations estimated using low-multiplicity data, the  $v_2$  and  $v_3$  values are found to increase with multiplicity for  $N_{\text{trk}}^{\text{offline}} \lesssim 100$ , and reach a relatively constant value at higher values of  $N_{\text{trk}}^{\text{offline}}$ . The  $p_T$  dependence of the  $v_2$  harmonics in high-multiplicity pp events is found to have no or very weak dependence on the collision energy. In low-multiplicity events, similar  $v_2$  values as a function of  $p_T$  are observed for inclusive charged particles,  $K_S^0$ , and  $\Lambda$ , possibly reflecting a common back-to-back jet origin of the correlations for all particle species. Moving to the higher-multiplicity region, a particle species dependence of  $v_2$  is observed with and without correcting for jet correlations. For  $p_T \lesssim 2$  GeV/c, the  $v_2$  of  $K_S^0$  is found to be larger than that of  $\Lambda$ . This behavior, which is consistent with predictions of hydrodynamic models, is similar to what was previously observed for identified particles produced in pPb and AA collisions at RHIC and the LHC. This mass ordering is reversed at higher  $p_T$  values. Finally,  $v_2$  signals based on four- and six-particle correlations are observed for the first time in pp collisions. The  $v_2$  values obtained with two-, four-, and six-particle correlations at  $\sqrt{s} = 13$  TeV are found to be comparable within uncertainties. These observations provide strong evidence supporting the interpretation of a collective origin for the observed long-range correlations in high-multiplicity pp collisions.

### References

- [1] Khachatryan V, et al. (CMS Collaboration) 2016 Multiplicity and rapidity dependence of strange hadron production in pp, pPb, and PbPb collisions at the LHC *Preprint* nucl-ex/1605.06699
- [2] Khachatryan V, et al. (CMS Collaboration) 2016 Evidence for collectivity in pp collisions at the LHC *Preprint* nucl-ex/1606.06198