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Evidence for collective phenomena in pp collisions

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Abstract

Measurements of two- and multi-particle angular correlations in pp collisions at $\sqrt{s}$ = 5, 7, and 13 TeV are presented. The data, corresponding to integrated luminosities of 1.0 pb^{-1} (5 TeV), 6.2 pb^{-1} (7 TeV), and 0.7 pb^{-1} (13 TeV), were collected using the CMS detector at the LHC. The second-order (v_2) and third-order (v_3) azimuthal anisotropy harmonics of unidentified charged particles, as well as v_2 of K^0_S and $\Lambda/\overline{\Lambda}$ particles, are extracted from long-range two-particle correlations as functions of particle multiplicity and transverse momentum. For high-multiplicity pp events, a mass ordering is observed for the v_2 values of charged hadrons (mostly pions), K^0_S, and $\Lambda/\overline{\Lambda}$ at $p_T \lesssim 2$ GeV/c. The v_2 signals are also extracted from four- and six-particle correlations for 13 TeV pp collisions, with comparable magnitude to those from two-particle correlations. These observations strongly support the interpretation of a collective origin for the observed long-range correlations in high-multiplicity pp collisions.

Keywords: CMS, heavy ion, ridge, correlation, pp, collectivity

1. Introduction

Observation of long-range two-particle azimuthal correlations at large relative pseudorapidity in high-multiplicity proton-proton [1, 2] and proton-lead [3] collisions at CMS [4] has opened up new opportunities for studying novel dynamics of particle production in small, high-density quantum chromodynamic (QCD) systems. Such correlations have been extensively studied over the past decades in nucleus-nucleus collisions and have been suggested to result from the hydrodynamic collective flow of a strongly interacting and expanding medium.

In systems such as pp and pPb, where the transverse size of the overlap region is comparable to that of a single proton, the formation of a hot and dense fluid-like medium was not expected. Various theoretical models have been proposed to interpret the origin of the observed long-range correlations in small collision systems [5], including initial-state gluon correlations without final-state interactions and hydrodynamic flow that develops in a conjectured high-density medium. Owing to the magnitude of the correlation signal, significant progress has been made in unraveling the nature of the ridge correlations in high-multiplicity pPb collisions. CMS measured anisotropy Fourier harmonics (v_n) using identified particles [6] and multi-particle correlation techniques [7, 8], which reveal features that support a collective origin of the observed correlations.

In high-multiplicity pp collisions, the nature of the observed long-range correlation still remains poorly understood. To provide insights on such correlations, a detailed study of two- and multi-particle azimuthal

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correlations with unidentified charged particles, as well as correlations of reconstructed K^0_S and $\Lambda/\overline{\Lambda}$ particles at various LHC collision energies has been carried out. The results of v_2 and v_3 harmonics, extracted from two-particle correlations, are studied as functions of particle p_T and event multiplicity. The residual contribution to long-range correlations of back-to-back jet correlations is estimated and removed by subtracting correlations obtained from very low multiplicity pp events. The v_2 harmonics are also extracted using the multi-particle cumulant method to shed light on the possible collective nature of the correlations. The results are directly compared to those found for pPb and PbPb systems over a broad range of similar multiplicities.

2. Result

Results presented in this proceeding have been published in Ref. [9], where $v_n^{\rm sub}\{2\}$ denotes the v_n results, extracted from long-range ($|\Delta\eta| > 2$) two-particle correlations, after subtracting the jet contribution. By assuming the jet-induced correlations are invariant with event multiplicity, a procedure of removing jet-like correlations developed for pPb collisions [8] is employed. The method consists of subtracting the results for low-multiplicity events, where the ridge signal is not present, from those for high-multiplicity events.

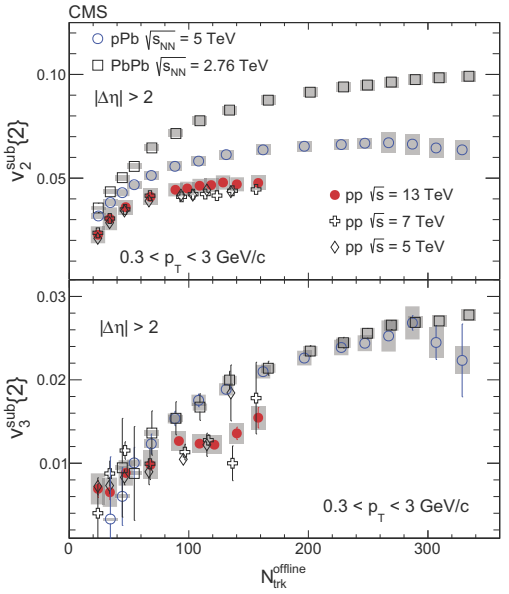

Fig. 1. The $v_2^{\rm sub}\{2\}$ (top) and $v_3^{\rm sub}\{2\}$ (bottom) results of charged particles as a function of $N_{\rm trk}^{\rm offline}$, averaged over $0.3 < p_T < 3.0$ GeV/c, in pp collisions at $\sqrt{s}$ = 5, 7, and 13 TeV, pPb collisions at $\sqrt{s_{NN}}$ = 5 TeV, and PbPb collisions $\sqrt{s_{NN}}$ = 2.76 TeV, after correcting for back-to-back jet correlations estimated from low-multiplicity data. The error bars correspond to the statistical uncertainties, while the shaded areas denote the systematic uncertainties. Systematic uncertainties are found to have no dependence on $\sqrt{s}$ for pp results and therefore are only shown for 13 TeV. Taken from Ref. [9].

The $v_2^{\rm sub}\{2\}$ and $v_3^{\rm sub}\{2\}$ flow harmonics for charged particles with $0.3 < p_T < 3.0$ GeV/c, after applying the jet correction procedure, are shown in Fig. 1 for pp collisions at $\sqrt{s}$ = 5, 7, and 13 TeV as function of $N_{\rm trk}^{\rm offline}$. Here, $N_{\rm trk}^{\rm offline}$ denotes the number of tracks with $|\eta| < 2.4$ and $p_T > 0.4$ GeV/c. The previously published pPb data at $\sqrt{s_{NN}}$ = 5 TeV and PbPb data at $\sqrt{s_{NN}}$ = 2.76 TeV are also shown for comparison among different collision systems.

Within experimental uncertainties, there is no or only a very weak energy dependence for the $v_2^{\rm sub}\{2\}$ values for pp collisions at all three energies,. The $v_2^{\rm sub}\{2\}$ results for pp collisions become relatively constant as $N_{\rm trk}^{\rm offline}$ increases, which is similar to pPb results, while the PbPb results show a moderate increase over