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Strange, charm and bottom hadrons flow in pp, pPb and PbPb collisions

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We present the elliptic azimuthal anisotropy coefficient (v_2) of the identified strange hadrons, K^0_S and Λ, in pPb and PbPb collisions at 5.02 TeV at mid-rapidity ($|y| < 1$), and the heavy-flavor hadrons, D^0 and J/ψ, in pPb at 8.16 TeV and high-multiplicity pp at 13 TeV and $\Upsilon(1S)$ and $\Upsilon(2S)$, in PbPb collisions at 5.02 TeV. The data samples were collected with the CMS experiment at the LHC. The v_2 coefficients of identified strange hadrons were measured using the scalar product and multi-particle cumulant methods as a function of p_T for different centralities in PbPb collisions and event multiplicities in pPb collisions and compared with inclusive charged hadrons as well as the hydrodynamic calculations with initial conditions. The v_2 coefficients of D^0 and J/ψ mesons in pPb collisions are measured using the long-range two-particle correlation technique and compared with the results from color glass condensate (CGC) model. The positive v_2 results of D^0 and J/ψ in high multiplicity pp and pPb collisions suggest the collectivity of charm quarks in small system. For the first time, collectivity of b hadrons are studied via non-prompt D^0 using long-range two-particle correlation technique and $\Upsilon(1S)$ and $\Upsilon(2S)$ mesons using scalar product method. The v_2 results for $\Upsilon(1S)$ meson as a function of p_T is compared with theoretical predictions from five different approaches. These measurements provide insights into the origin of the collective phenomena in small and large systems.

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1. Introduction

A key feature of multiparticle correlations in ultrarelativistic nucleus–nucleus (AA) collisions is the observation of near side (relative azimuthal angle $|\Delta\varphi| \approx 0$) ridge in the measurement of two-particle angular correlation [1] that extends over a large range in relative pseudorapidity, and this feature is well explained by hydrodynamical collective flow of a strongly interacting and expanding medium [2]. But the interesting thing is that a similar ridge have been observed in high multiplicity pPb [3] and pp [4] collisions. The appearance of the ridge in smaller system (pPb and pp) triggered the heavy-ion community to investigate the cause of such behaviour in small systems and understand the dynamics of particle production mechanism in small systems. Due to the heavy mass, strange, charm and bottom quarks production and energy loss mechanisms are expected to be different from up and down quark [5, 6]. Hence studying collectivity of these quarks will give additional insight into the origin of collective behavior. This note presents the recent CMS [7] results of strange, charm and bottom hadrons collectivity using the pp data samples at $\sqrt{s}$= 13 TeV collected in 2017 and 2018 LHC run, pPb data samples at $\sqrt{s_{NN}}$= 8.16 TeV collected in 2016 run and PbPb data samples at $\sqrt{s_{NN}}$= 5.02 TeV collected in 2018 run.

2. Strange hadrons flow

The elliptic flow harmonic, v_2, measured using scalar-product $\left(v_2\{\mathrm{SP}\}\right)$ and multiparticle Q-cumulant $\left(v_2\{2\mathrm{k}\}, \mathrm{k}=1,..,4\right)$ methods [8, 9] of identified strange hadrons ($\mathrm{K^0_S}$ and $\Lambda(\bar{\Lambda})$) with $|y| < 1.0$ are shown in Fig. 1 (for $\mathrm{K^0_S}$) and in Fig. 2 (for $\Lambda\bar{\Lambda}$) for pPb collisions (top) at $\sqrt{s_{NN}}$= 8.16 TeV and PbPb collisions (bottom) at $\sqrt{s_{NN}}$= 5.02 TeV [10]. The predictions of the event-by-event viscous hydrodynamic model with AMPT initial conditions [11] for PbPb collisions are compared with data and a qualitative consistency has been found. In pPb collisions, the $v_2\{\mathrm{SP}\}$ was measured separately with respect to the Pb-going and p-going side of the event planes. The results shows that the v_2 with p-going side event plane is systematically larger than Pb-going side event plane v_2, at higher transverse momenta (p_T), which suggests that the nonflow contribution has a larger effect on the higher p_T. The results $v_2\{4\} \approx v_2\{6\}$ in Fig. 1 and Fig. 2 for pPb collisions with $185 \le N_{\mathrm{trk}}^{\mathrm{offline}} \le 250$ support the interpretation of a collective nature in high-multiplicity pPb collisions.

3. Charm hadrons flow

The left panel of Fig. 3 shows the v_2 results of charm hadrons ($\mathrm{D^0}$ at midrapidity $|y_{\mathrm{lab}}| < 1$ and J/ψ at forward rapidity $1.2 < |y_{\mathrm{lab}}| < 2.4$), obtained using the long-range two-particle correlation technique, for high-multiplicity ($185 \le N_{\mathrm{trk}}^{\mathrm{offline}} \le 250$) pPb collisions at $\sqrt{s_{NN}}$= 8.16 TeV and compared with the strange hadrons v_2 at $|y_{\mathrm{lab}}| < 1$ [12]. For both $\mathrm{D^0}$ and J/ψ, significant positive v_2 values are observed as a function of p_T, and the values are consistent with each other within their uncertainties. However, the v_2 signal values for both J/ψ and $\mathrm{D^0}$ are smaller than the strange hadrons ($\mathrm{K^0_S}$ and Λ) v_2 signals. This observation suggests that charm quarks develop a weaker collective dynamics than light quarks in small systems [13]. The observed v_2 signals for prompt $\mathrm{D^0}$ and J/ψ are compared with the results from color glass condensate (CGC) model [14]. The qualitative

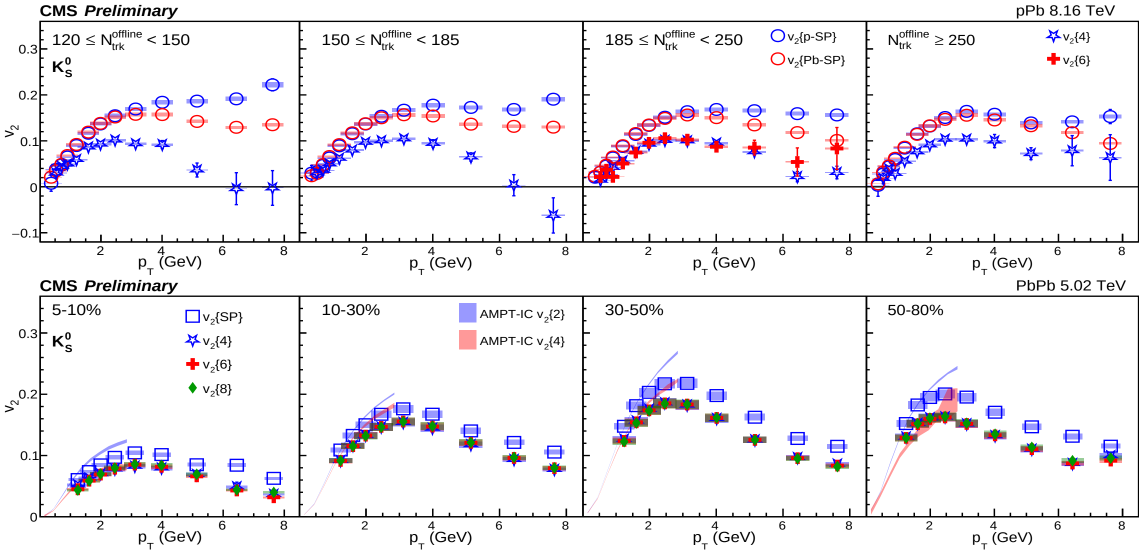

Figure 1: The v_2 results of K^0_S in pPb collisions (top panel) at $\sqrt{s_{NN}}$= 8.16 TeV and PbPb collisions (bottom panel) at $\sqrt{s_{NN}}$= 5.02 TeV [10]. In PbPb collisions (bottom panel), the shaded bands are hydrodynamic calculations of 2- and 4-particle v_2 with AMPT initial conditions. The shaded boxes are systematic uncertainties.

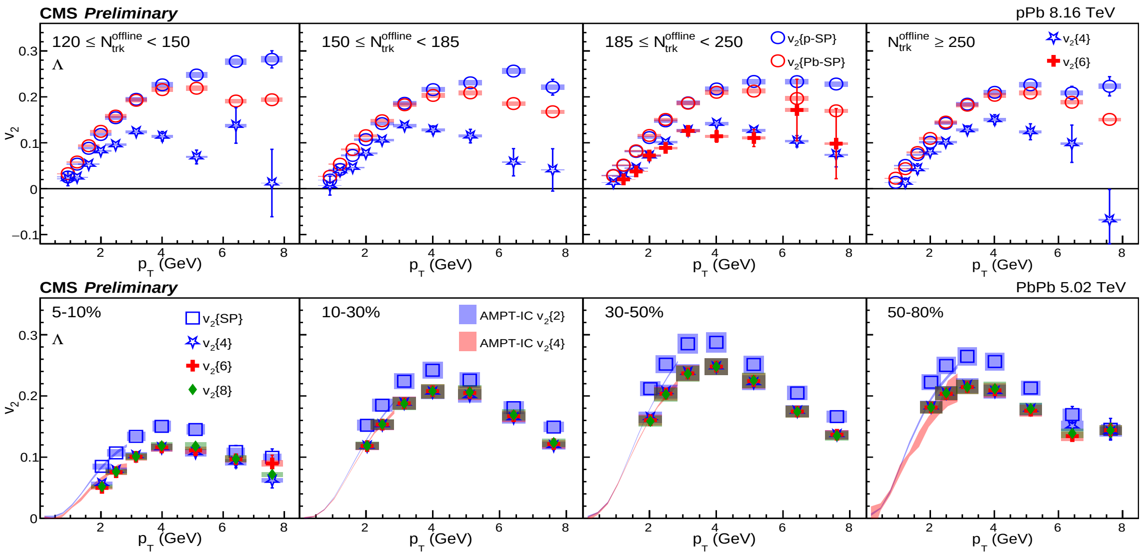

Figure 2: The v_2 results of Λ in pPb collisions (top panel) at $\sqrt{s_{NN}}$= 8.16 TeV and PbPb collisions (bottom panel) at $\sqrt{s_{NN}}$= 5.02 TeV [10]. In PbPb collisions (bottom panel), the shaded bands are hydrodynamic calculations of 2- and 4-particle v_2 with AMPT initial conditions. The shaded boxes are systematic uncertainties.

agreement between data and theory suggests that initial-state effects may play an important role in the generation of collectivity for these particles in pPb collisions [12]. To investigate further, the system size dependence of collectivity for prompt D^0 is also studied for three different p_T ranges: $2 < p_T < 4$ GeV, $4 < p_T < 6$ GeV and $6 < p_T < 8$ GeV are shown in right panel of Fig. 3 in pPb collisions at $\sqrt{s_{NN}}$= 8.16 TeV and pp collisions at $\sqrt{s}$= 13 TeV [15]. A comparable v_2 values of prompt D^0 between pp and pPb are found at multiplicities $N_{\text{trk}}^{\text{offline}} \sim 100$ within the uncertainties. For pPb system, a clear multiplicity dependence of v_2 signals are observed in all the p_T ranges, while for pp system, the multiplicity dependence is not observed clearly, because of large statistical uncertainties at low multiplicities.

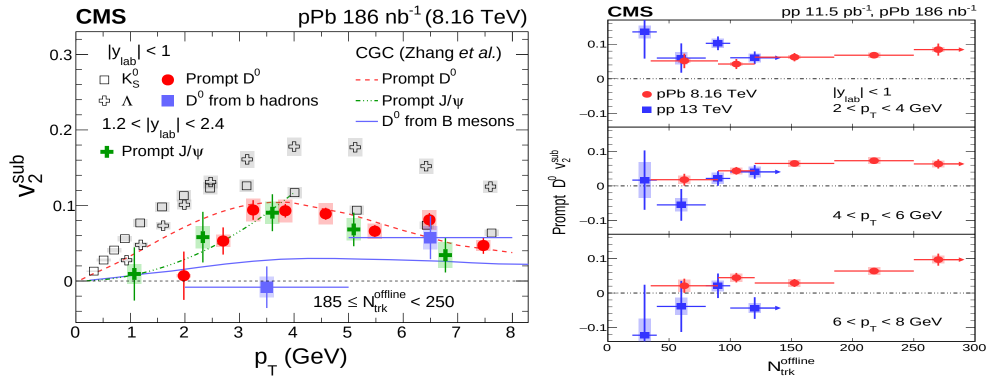

Figure 3: Left: v_2 results for prompt and nonprompt D^0, as well as K^0_S mesons and Λ baryons at midrapidity $|y_{\text{lab}}| < 1$), and prompt J/ψ mesons for $1.2 < |y_{\text{lab}}| < 2.4$), as a function of p_T with $185 \leq N_{\text{trk}}^{\text{offline}} \leq 250$ in pPb collisions at $\sqrt{s_{NN}}$= 8.16 TeV [13] [15]. The vertical bars correspond to statistical uncertainties, while the shaded areas denote the systematic uncertainties. The horizontal bars represent the width of the p_T bins. The dashed, dash-dotted, and solid lines, show the theoretical calculations of prompt D^0, J/ψ, and nonprompt D^0 mesons, respectively, within the CGC framework [14]. Right: Result of v_2 for prompt D^0 as a function of event multiplicity for three different p_T ranges with $|y_{\text{lab}}| < 1$ in pp collisions at $\sqrt{s}$= 13 TeV and pPb collisions at $\sqrt{s_{NN}}$= 8.16 TeV [15].

4. Bottom hadrons flow

The left panel of Fig. 3 shows the v_2 results for nonprompt D^0 (blue square) as a function of p_T, measured by long-range two-particle correlation technique, in pPb collisions at $\sqrt{s_{NN}}$= 8.16 TeV [12]. In low p_T bin ($2 < p_T < 5$ GeV), the nonprompt D^0 v_2 is consistent with zero while at high p_T bin ($5 < p_T < 8$ GeV), a hint of a positive v_2 value for beauty mesons is suggested but not significant within statistical and systematic uncertainties. Figure 4 (left panel) shows the p_T integrated results of $\Upsilon(1S)$ as a function of centrality, measured by scalar product method, in PbPb collisions at $\sqrt{s_{NN}}$= 5.02 TeV [16]. The rightmost plot is the average v_2 values of $\Upsilon(1S)$ and $\Upsilon(2S)$ in the 10–90% centrality interval. The observed v_2 values are consistent with zero in all the centrality intervals within the statistical uncertainties. The right panel of Fig. 4 shows the p_T dependence v_2 of $\Upsilon(1S)$ meson in 10-90% centrality and compared with various theoretical models. The v_2 values are consistently zero in all p_T bins, except for the $6 < p_T < 10$ GeV that shows 2σ deviation from zero. All the theoretical models qualitatively describe the data in lower p_T ($p_T < 10$ GeV) as shown in right panel of Fig. 4.

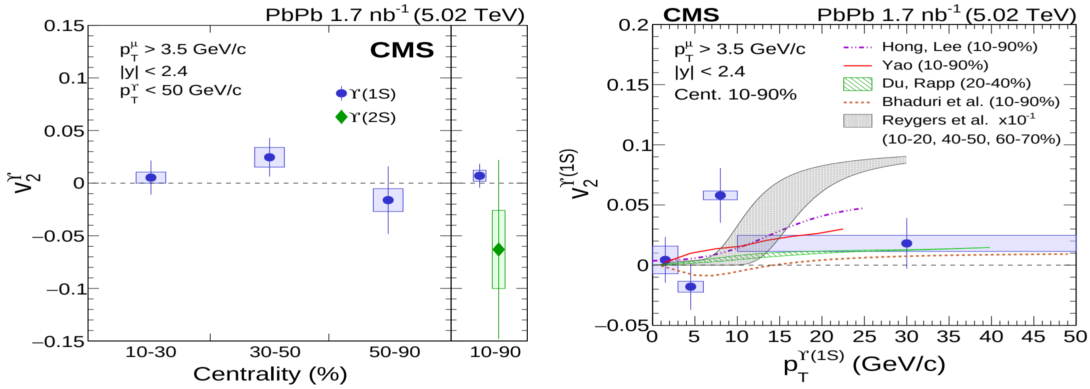

Figure 4: (Left panel) p_T integrated v_2 values for $\Upsilon(1S)$ meson measured in four centrality classes and for the $\Upsilon(2S)$ meson in the 10–90% centrality range. (Right panel) v_2 of $\Upsilon(1S)$ mesons as a function of p_T in the 10–90% centrality range compared with various model calculations [16]. The vertical bars denote statistical uncertainties, and the rectangular boxes show the total systematic uncertainties.

5. Summary

This document presents the recent CMS results on collectivity of strange, charm and bottom hadrons in pp, pPb and PbPb collisions. For the first time, the collective multiparticle correlations of identified strange hadrons have been observed in pPb collisions at $\sqrt{s_{NN}}$= 8.16 TeV. For the first time, the elliptic flow harmonic, v_2, for prompt D^0 in pp collisions at $\sqrt{s}$= 13 TeV, and for prompt J/ψ as well as nonprompt D^0 in pPb collisions at $\sqrt{s_{NN}}$= 8.16 TeV are measured and presented. Also, the v_2 coefficients for $\Upsilon(1S)$ and $\Upsilon(2S)$ are measured in PbPb collisions at $\sqrt{s_{NN}}$= 5.02 TeV and reported in this note. The presence of collective effects in small systems becomes more established by the observation of significant elliptic flow harmonic, v_2, for strange and charm hadrons in pPb and pp system. With the current statistics, the observed bottom hadrons v_2 is consistent with zero in the measured p_T and centrality intervals.

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