Centrality dependence of elliptic flow of multi-strange hadrons in Au+Au collisions at $\sqrt{s}NN$ = 200 GeV

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Centrality dependence of elliptic flow of multi-strange hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract. We present recent results of the mid-rapidity elliptic flow (v_2) for multi-strange hadrons and the ϕ meson as a function of centrality in Au + Au collisions at the center of mass energy $\sqrt{s_{NN}} = 200$ GeV. The transverse momentum dependence of ϕ and Ω v_2 is similar to that of pion and proton, indicating that the heavier strange (s) quark flows as strongly as the lighter up (u) and down (d) quarks. These observations constitute a clear piece of evidence for the development of partonic collectivity in heavy-ion collisions at the top RHIC energy. In addition, the mass ordering of v_2 breaks between the ϕ and proton at low transverse momenta in the 0-30% centrality bin, possibly due to the effect of late hadronic interactions on the proton v_2.

1. Introduction

In high energy nucleus nucleus collisions, the produced particles are anisotropic in momentum space. The elliptic flow, v_2, which is the second Fourier coefficient of the azimuthal distribution of produced particles with respect to the reaction plane, is defined as $v_2 = \langle \cos 2(\varphi - \Psi) \rangle$, where φ is the azimuthal angle of produced particle and Ψ is the azimuthal angle of the reaction plane. It has been shown that elliptic flow is sensitive to the early stage of heavy-ion collisions and equation of state of the formed system [1]. However, early dynamic information might be obscured by later hadronic rescatterings [2]. Multi-strange hadrons and the ϕ meson are believed to be less sensitive to hadronic rescatterings in the late stage of collisions, as their freeze-out temperatures are close to the phase transition temperature and their hadronic interaction cross sections are expected to be small [3, 4, 5]. Previous measurements of ϕ and Ω v_2 from STAR were limited by statistics [6, 7], thus the p_T and centrality dependence of ϕ and Ω v_2 are not clear. Furthermore, with high precision measurements of ϕ meson v_2, one can compare it with proton v_2 in the low p_T region. It may provide information on the effect of hadronic rescatterings in the late stage of the collision.

2. Results and Discussions

In these proceedings, v_2 measurements of multi-strange hadrons from the STAR experiment at $\sqrt{s_{NN}} = 200$ GeV Au + Au collisions are presented. About 730 million minimum bias events recorded by STAR in 2010 and 2011 were used in the analysis. The Time Projection Chamber (TPC) was used for centrality definition and event plane determination. The centrality was determined by the number of tracks from the pseudorapidity region $|\eta| \leq 0.5$. The particle

identification (PID) was achieved via energy loss in TPC and flight time in the Time of Flight (TOF). The multi-strange hadrons and the ϕ meson were reconstructed though the following decay channels: $\phi \to K^+ + K^-$, $\Xi^- \to \Lambda + \pi^-$ ($\overline{\Xi}^+ \to \overline{\Lambda} + \pi^+$) and $\Omega^- \to \Lambda + K^-$ ($\overline{\Omega}^+ \to \overline{\Lambda} + K^+$). The η sub-event plane method is used for the v_2 measurement [8] . In this method, one defines the event flow vector for each particle based on particles measured in the opposite hemisphere in pseudorapidity. An η gap of $|\Delta\eta| > 0.1$ between positive and negative pseudorapidity sub-events is introduced to suppress non-flow effects.
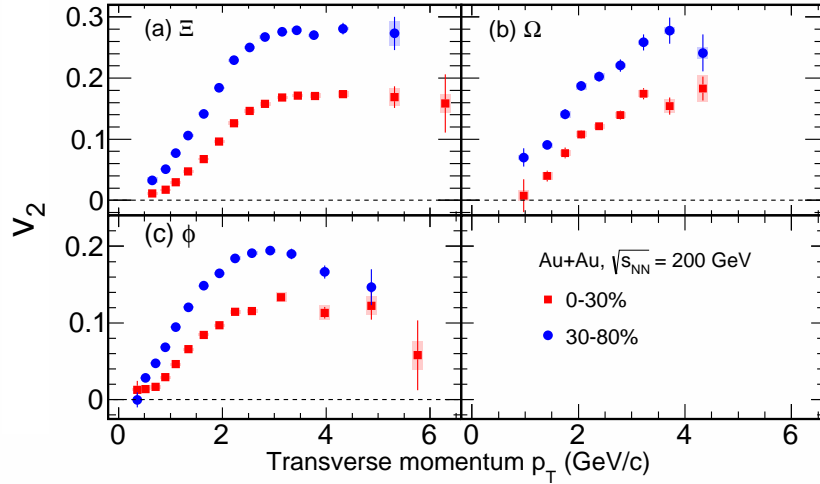

Figure 1. The v_2 as a function of p_T at midrapidity ($|y| < 1.0$) for (a) $\Xi^- + \overline{\Xi}^+$ (b) $\Omega^- + \overline{\Omega}^+$ and (c) ϕ in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV for 0-30% and 30-80% centrality. The systematic uncertainties are shown by shaded boxes and the statistical uncertainties by vertical lines.

Figure 1 [9] shows the elliptic flow v_2 as a function of transverse momentum p_T at midrapidity ($|y| < 1.0$) for (a) $\Xi^- + \overline{\Xi}^+$, (b) $\Omega^- + \overline{\Omega}^+$ and (c) ϕ in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV for 0-30% and 30-80% centrality. A clear centrality dependence of $v_2(p_T)$ is observed for multi-strange hadrons and ϕ meson, which is similar to that of light and strange hadrons previously measured by the RHIC experiments [10, 11]. The v_2 values are larger in peripheral collisions (30-80% centrality) than those in central collisions (0-30% centrality). This is consistent with an interpretation in which the anisotropy in final momentum space is driven by the anisotropy in initial position space.

Figure 2 [9] shows the v_2 as a function of p_T for π, p (panel (a)) and ϕ, Ω (panel (b)) in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV for 0-80% centrality. A comparison between v_2 of π and p, consisting of up (u) and down (d) light constituent quarks is shown in panel (a). Correspondingly, panel (b) shows a comparison of v_2 of ϕ and Ω containing s constituent quarks. This is the first measurement of Ω baryon v_2 up to 4.5 GeV/c with high precision. In the low p_T region ($p_T<2.0$ GeV/c), the v_2 of ϕ and Ω follows mass ordering. At intermediate p_T ($2.0<p_T<5.0$ GeV/c), a baryon-meson separation is observed. It is evident that the $v_2(p_T)$ of hadrons consisting only of strange constituent quarks (ϕ and Ω) is similar to that of light hadrons, π and p. However the ϕ and Ω do not participate strongly in the hadronic interactions, because of the smaller hadronic cross sections compared to π and p. It suggests that most of the collectivity is developed during the partonic phase in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV.
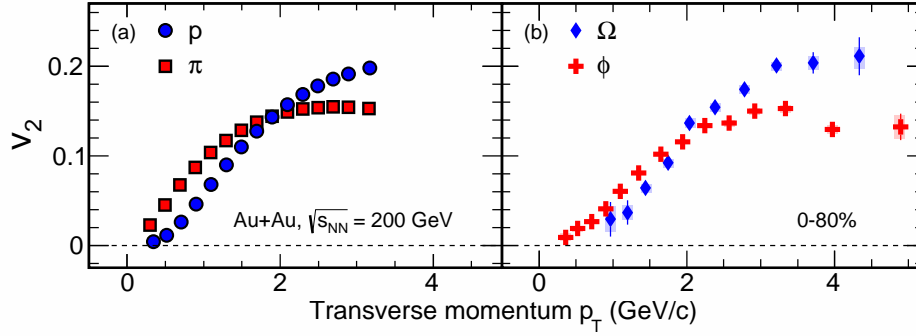
Figure 2. The v_2 as function of p_T for π, p (a) and ϕ, Ω (b) in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV for 0-80% centrality. The systematic uncertainties are shown by the shaded boxes while vertical lines represent the statistical uncertainties.
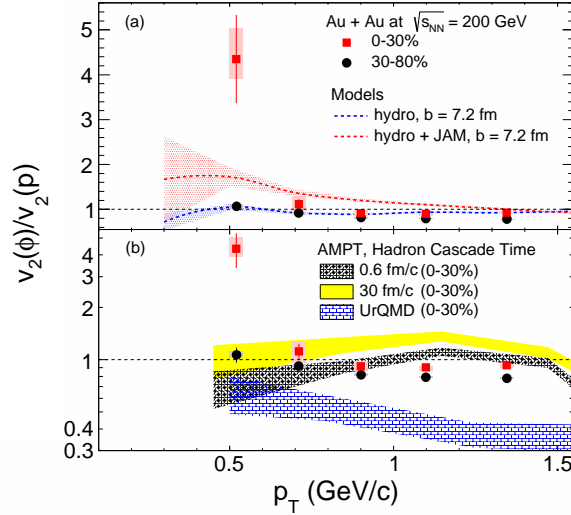
Figure 3. The ratio of $v_2(\phi)$ to $v_2(p)$ as function of p_T in Au + Au collisions at $\sqrt{s_{NN}} =$ 200 GeV for 0-30% and 30-80% centrality. Shaded bands are the systematic uncertainties and vertical lines are the statistical uncertainties. The bands in panel (a) and (b) represent the hydro and transport model calculations for $v_2(\phi)/v_2(p)$, respectively.

Hydrodynamical model calculations predict that v_2 as a function of p_T for different particle species follows mass ordering, where the v_2 of heavier hadrons is lower than that of lighter hadrons [12]. The identified hadron v_2 measured in experiment indeed proves the mass ordering in the low p_T region (p_T<1.5 GeV/c) [10]. Recently, Hirano et $al.$ predict the mass ordering of v_2 could be broken between ϕ mesons and protons at low p_T (p_T<1.5 GeV/c) based on a model with ideal hydrodynamics plus hadron cascade process [2]. As the model calculations assign a smaller hadronic cross section for ϕ mesons compared to protons, the broken mass ordering is regarded as the different hadronic rescattering contributions on the ϕ meson and proton v_2. Figure 3 [9] shows the ratios of ϕ v_2 to proton v_2 from model calculations and experimental data. This ratio is larger than unity at $p_T \sim 0.5$ GeV/c for 0-30% centrality. It indicates breakdown of the expected mass ordering in that momentum range. This could be due to a large effect of

hadronic rescattering on the proton v_2, which qualitatively agrees with hydro + hadron cascade calculations indicated by the shaded red band in panel (a) of Fig. 3. A centrality dependence of $v_2(\phi)$ to $v_2(p)$ ratio is observed in the experimental data. Namely, the breakdown of mass ordering of v_2 is more pronounced in 0-30% central collisions than in 30-80% peripheral collisions. In the central events, both hadronic and partonic interactions are stronger than in peripheral events. Therefore, the larger effect of late stage hadronic interactions relative to the partonic collectivity produces a greater breakdown of mass ordering in the 0-30% centrality data than in the 30-80%. This observation indirectly supports the idea that the ϕ meson has a smaller hadronic interaction cross section. The ratio of ϕ v_2 to proton v_2 was also studied by using the transport models AMPT [13] and UrQMD [14]. The panel (b) of Fig. 3 shows the $v_2(\phi)$ to $v_2(p)$ ratio for 0-30% centrality from AMPT and UrQMD models. The black shaded band is from AMPT with a hadronic cascade time of 0.6 fm/c while the yellow band is for a hadronic cascade time of 30 fm/c. Larger hadronic cascade time is equivalent to stronger hadronic interactions. It is clear that the $v_2(\phi)/v_2(p)$ ratio increases with increasing hadronic cascade time. This is attributed to a decrease in the proton v_2 due to an increase in hadronic re-scattering while the ϕ meson v_2 is less affected. The ratios from the UrQMD model are much smaller than unity (shown as a blue shaded band in the panel (b) of Fig. 3). The UrQMD model lacks partonic collectivity, thus the ϕ meson v_2 is not fully developed.

3. Summary
In summary, high-statistics elliptic flow measurements for multi-strange hadrons (Ξ and Ω) and ϕ meson as a function of centrality and p_T were reported in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The p_T dependence of ϕ and Ω v_2 is observed to be similar to that of light hadrons, π and p, indicating that most of the collectivity is developed in the initial partonic phase for light and strange hadrons. The comparison between the ϕ and p v_2 at low p_T shows that there is a possible violation of hydro-inspired mass ordering between ϕ and p. Model calculations suggest that the p_T dependence of $v_2(\phi)$ to $v_2(p)$ ratios can be qualitatively explained by the different effects of late-stage hadronic interactions on the ϕ and proton v_2.

4. Acknowledgments

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