Probing nuclear structure using elliptic flow of strange and multi-strange hadrons in isobar collisions

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Abstract

Isobar collisions, $^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr+$^{96}_{40}$Zr, at $\sqrt{s_{\rm NN}}$ = 200 GeV have been performed at RHIC in order to study the charge separation along the magnetic field, called the Chiral Magnetic Effect (CME). The difference in nuclear deformation and structure between the two isobar nuclei may result in a difference in the flow magnitudes. Hence, elliptic flow measurements for these collisions give direct information about the initial state anisotropies. Strange and multi-strange hadrons have a small hadronic cross-section compared to light hadrons, making them an excellent probe for understanding the initial state anisotropies of the medium produced in these isobar collisions. The collected datasets include approximately two billion events for each of the isobar species and provide a unique opportunity for statistics hungry measurements. In this proceeding, we will report the elliptic flow (v_2) measurement of K^0_s, Λ, $\overline{\Lambda}$, ϕ, Ξ^-, $\overline{\Xi}^+$, Ω^-, and $\overline{\Omega}^+$ at mid-rapidity for Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The centrality and transverse momentum (p_T) dependence of v_2 of (multi-)strange hadrons will be shown. System size dependence of v_2 will be shown by comparing the v_2 results obtained from Cu+Cu, Au+Au, and U+U collisions. The number of constituent quark (NCQ) scaling for these strange

hadrons will also be tested. We will also compare the p_T-integrated v_2 for these two isobar collisions. Transport model calculations will be compared to data to provide further quantitative constraints on the nuclear structure.

1 Introduction

Relativistic heavy-ion collisions indicate the presence of a strongly interacting medium called Quark Gluon Plasma (QGP). Studies of the elliptic flow of produced particles in this medium provide insight into the early anisotropy in the medium. Despite having the same number of nucleons, the anisotropic flow coefficients of Ru+Ru and Zr+Zr were observed to be distinct in the isobar collision run at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV at the Relativistic Heavy Ion Collider (RHIC) [1]. This suggests that the difference in nuclear structure may also leave imprints on the elliptic flow of particles. Recent studies also discuss the use of v_2 ratios and v_2-$[p_T]$ correlations in isobar collisions to probe nuclear structures. [2, 3]. Compared to light hadrons, (multi-)strange hadrons have a smaller hadronic cross-section, making their v_2 an excellent probe of the initial state anisotropies in these isobar collisions.

2 Analysis details

We report strange and multi-strange hadron v_2 in $^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr+$^{96}_{40}$Zr collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV using the data collected by the STAR experiment. Each isobar collision had roughly 650M events analysed. The Time Projection Chamber (TPC) and Time-Of-Flight (TOF) have been used to identify the decay daughters of these short-lived particles and reconstruct them using invariant mass technique. Using their weak-decay topology, strange particles K^0_s, $\Lambda(\bar{\Lambda})$, and $\Xi^-(\overline{\Xi^+})$ are reconstructed. The combinatorial background for these hadrons is constructed using rotational background method [4]. ϕ-mesons are reconstructed using hadronic decay channel and event mixing technique is used for combinatorial background estimate. The v_2 is calculated using η-sub event plane method [5]. The maximum resolution for the second order event plane is nearly 48% for both collision systems.

3 Results

Figure 1 shows the v_2 of strange and multi-strange hadrons as a function of p_T for minimum bias Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. An approximate mass ordering at low p_T and a baryon-meson splitting at intermediate p_T is observed. All particles and anti-particles tend to follow the number of constituent quark (NCQ) scaling within 10% as shown in Fig. 1, indicating partonic collectivity as well as domination of quark coalescence mechanism for hadronization at intermediate p_T region. A clear centrality dependence of v_2 has been observed for K_s^0, Λ and Ξ^- as shown in

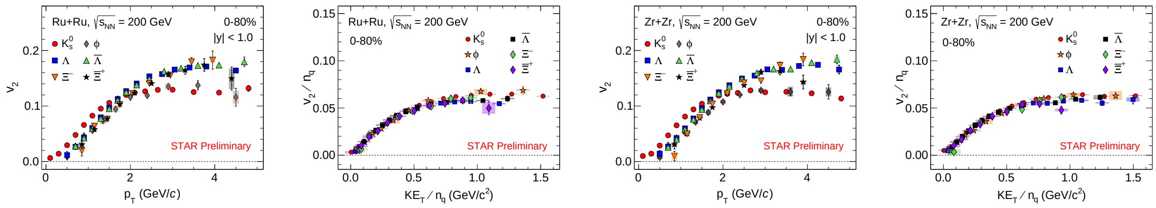

Figure 1: v_2 as a function of p_T of (multi-)strange hadrons and NCQ-scaled v_2 as a function of transverse kinetic energy for Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV. The vertical lines and shaded boxes denote statistical and systematic uncertainties, respectively.

Fig. 2 and for other hadrons for the isobar collision systems. The p_T-integrated v_2 for

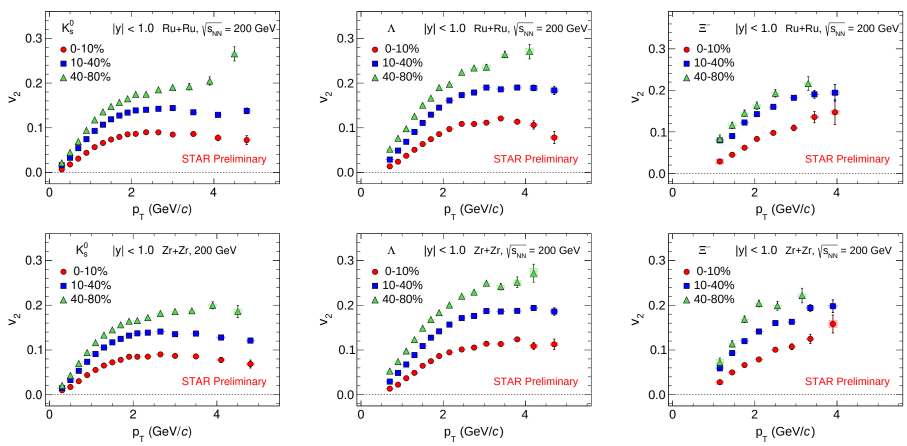

Figure 2: Top panel: Centrality dependence of v_2 of K_s^0, Λ and Ξ^- as a function of p_T in Ru+Ru collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV; Bottom Panel: Same for Zr+Zr collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV. The vertical lines and shaded boxes denote statistical and systematic uncertainties, respectively.

strange hadrons was also studied as a function of the collision centrality as shown in Fig. 3. The ratios of v_2 between the two isobar collisions for K_s^0, Λ, and $\bar{\Lambda}$ show clear deviation of nearly 2% from unity in mid-central collisions, indicating a difference in nuclear structure and shape [1].

We investigated the system size evolution of v_2 by comparing the ${}^{63}_{29}$Cu+${}^{63}_{29}$Cu, ${}^{96}_{44}$Ru+${}^{96}_{44}$Ru, ${}^{96}_{40}$Zr+${}^{96}_{40}$Zr, ${}^{197}_{79}$Au+${}^{197}_{79}$Au collisions in 0-80% centrality at $\sqrt{s_{\mathrm{NN}}}$ = 200

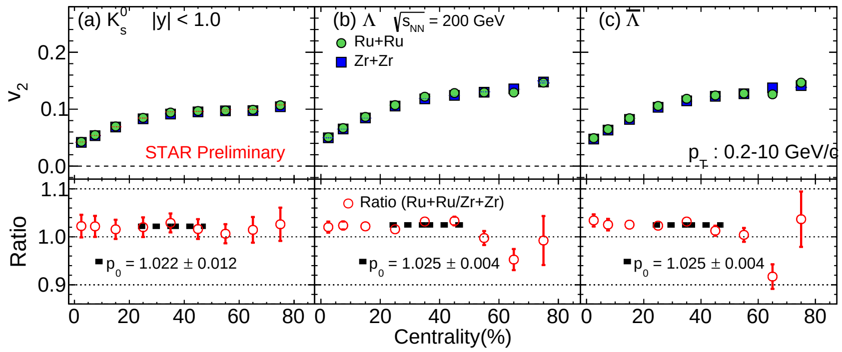

Figure 3: p_T-integrated v_2 as a function of centrality for K_s^0, Λ, and $\bar{\Lambda}$ in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The vertical lines on the ratio includes statistical and systematic uncertainties. The dotted lines denotes the fitting with a constant.

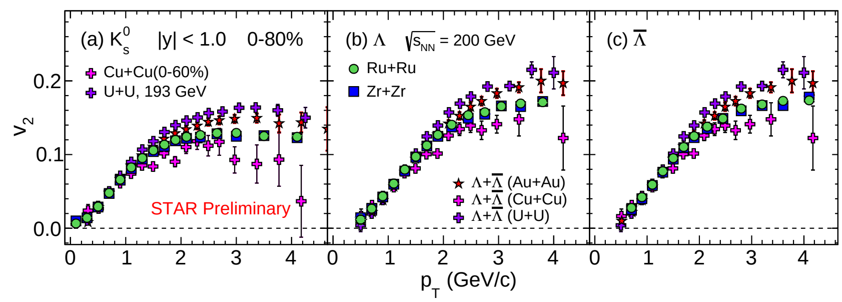

Figure 4: v_2 of K_s^0, Λ and $\bar{\Lambda}$ in minimum bias Cu+Cu, Ru+Ru, Zr+Zr, Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{\rm NN}}$ = 193 GeV [6–8].

GeV, and $^{238}_{92}$U+$^{238}_{92}$U collisions at $\sqrt{s_{\rm NN}}$ = 193 GeV [6–8]. Figure 4 shows an approximate system size dependence of v_2 for $p_T > 1.8$ GeV/c, based on the nuclear size. The v_2 in U+U and Au+Au is observed to be higher, whereas in Cu+Cu is slightly lower than those in isobar collisions.

4 Conclusion

We presented the elliptic flow of K_s^0, Λ, $\bar{\Lambda}$, ϕ, Ξ^-, and $\overline{\Xi}^+$ particles in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. In these isobar collisions, we noticed a mass ordering at low p_T and a baryon-meson splitting at intermediate p_T. The NCQ scaling representing the partonic degrees of freedom and coalescence hadronization, is followed by all strange hadrons. The hadron v_2 ratio exhibits a deviation from unity of around 2% when integrated over p_T indicative of different nuclear density and deformation between the two isobar nuclei. The v_2 is observed to be higher for larger colliding systems. These results when compared to model calculations may shed light on structures of these nuclei.

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