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

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Abstract

The data for isobar collisions ($^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr+$^{96}_{40}$Zr) at $\sqrt{s_{\rm NN}}$ = 200 GeV has been taken at RHIC in the year 2018. The elliptic flow (v_2) for charged hadrons differs in the two isobar collision systems, which indicates a difference in the nuclear structure between the two nuclei. We report the transverse momentum (p_T) and centrality dependence of v_2 of K^0_s, Λ, $\bar{\Lambda}$, ϕ, Ξ^-, and $\overline{\Xi}^+$ particles at mid-rapidity for Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. We also compare the results to those in Cu+Cu, Au+Au, and U+U collisions to understand the system size dependence.

1 Introduction

Heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) indicates the presence of a strongly interacting medium called Quark Gluon Plasma (QGP). Elliptic flow studies of the produced particles in this medium provide an understanding the early time anisotropy in the medium. In 2018, a dedicated isobar collision run of Ru+Ru and Zr+Zr $\sqrt{s_{\rm NN}}$ = 200 GeV was successfully

carried out at RHIC. Despite the same nucleon number, the anisotropic flow coefficients were observed to be different in the two collision systems [1]. This indicates that the difference in nuclear structure may also leave imprints on the elliptic flow of particles. Recent studies also discuss probing of nuclear structures via v_2 ratios as well as the v_2-$[p_T]$ correlations in isobar collisions [2, 3]. Strange and multi-strange hadrons have a smaller hadronic cross-section compared to light hadrons, making their elliptic flow an excellent probe for understanding the initial state anisotropies of these isobar collisions.

2 Analysis details

In these proceedings, 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 $\sqrt{s_{\rm NN}}$ = 200 GeV using the data collected by the STAR experiment. A total of nearly 650M events have been analysed for each of the isobar collisions. The Time Projection Chamber (TPC) and Time-Of-Flight (TOF) have been used to identify the decay daughters of these shortly lived particles and their reconstruction. The weakly decaying neutral strange particles K^0_s and $\Lambda(\bar{\Lambda})$ are reconstructed using invariant mass technique and their weak-decay (V0) topology through the decay channel: $K^0_s \rightarrow \pi^+ + \pi^-$ and $\Lambda \rightarrow p + \pi^-$, respectively [4]. ϕ-mesons have been reconstructed using the invariant mass technique through its hadronic decay channel: $\phi \rightarrow K^+K^-$. Event mixing technique is used for combinatorial background estimation for ϕ meson. The reconstruction of multi-strange particle $\Xi^-(\overline{\Xi}^+)$ involves finding two secondary vertices and the various topological selections. The combinatorial background for the weakly decaying particles is constructed using rotational background method [5]. The η-sub event plane method has been used to calculate v_2 of these (multi-)strange hadrons [4]. The maximum resolution achieved 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 $\sqrt{s_{\rm NN}}$ = 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 dominance of quark coalescence mechanism for hadronization at intermediate p_T region. A clear centrality dependence of v_2 has been observed for K^0_s, Λ and Ξ^- as shown in

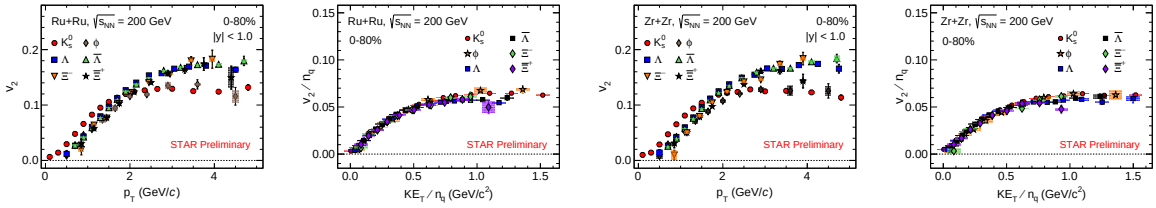

Figure 1: v_2 as a function of p_T of (multi-)strange hadrons and NCQ-scaled v_2 as a function of transverse kinetic energy for Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The vertical lines and shaded boxes denote statistical and systematic uncertainties, respectively.

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

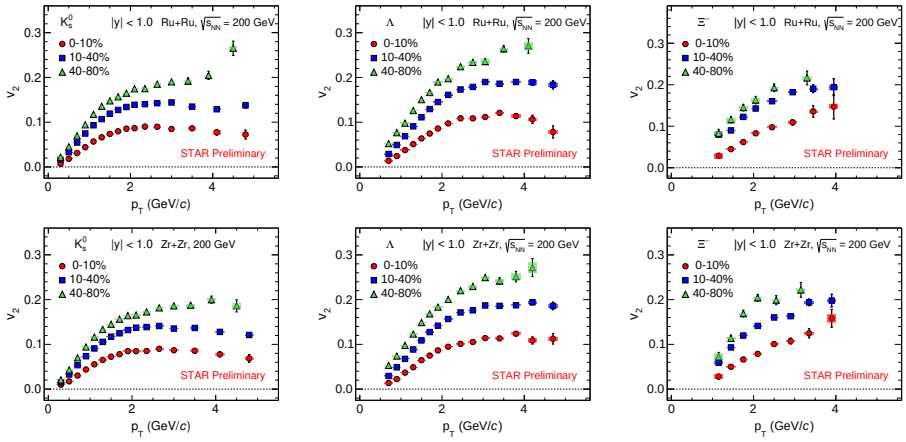

Figure 2: Top panel: Centrality dependence of v_2 of K^0_s, Λ and Ξ^- as a function of p_T in Ru+Ru collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV; Bottom Panel: Same for Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The vertical lines and shaded boxes denote statistical and systematic uncertainties,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

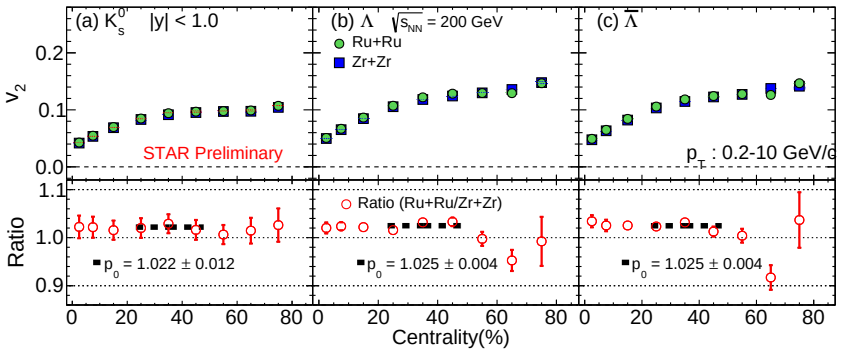

Figure 3: p_T-integrated v_2 as a function of centrality for K^0_s, Λ, and $\bar{\Lambda}$ in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The vertical lines on the ratio includes statistical and systematic uncertainties. The dotted lines denotes the fitting with a constant.

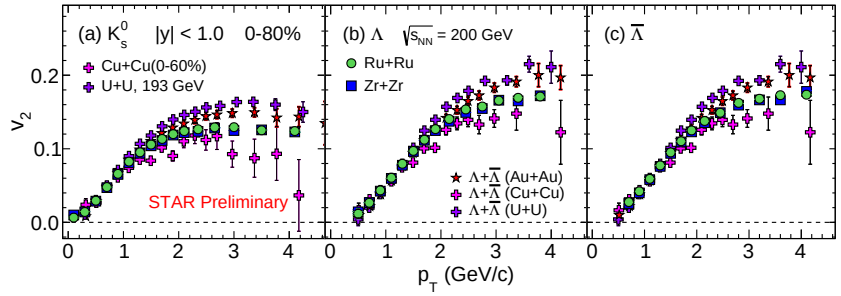

Figure 4: v_2 of K^0_s, Λ and $\bar{\Lambda}$ in minimum bias Cu+Cu, Ru+Ru, Zr+Zr, Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{\rm NN}}$ = 193 GeV [6–8].

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

In conclusion, we presented the elliptic flow of K^0_s, Λ, $\bar{\Lambda}$, ϕ, Ξ^-, and $\bar{\Xi}^+$ particles in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. In both isobar species, we noticed a mass ordering at low p_T and a baryon-meson splitting at intermediate p_T. The NCQ scaling, which is representative of the partonic degrees of freedom and coalescence hadronization, is followed by all strange particles and anti-particles. The hadron v_2 ratio exhibits a deviation from unity of around 2% when integrated over p_T. This indicates the differences in nuclear density and deformation between the two isobar nuclei. On comparing several collision systems with comparable beam energies, we also observed the v_2 to be higher for larger colliding systems.

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