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Azimuthal anisotropy of strange hadrons in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV at RHIC

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Abstract. We present the measurement of the azimuthal anisotropy of strange hadrons (K_s^0, ϕ and Λ) at mid-rapidity ($|y| < 1.0$) in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV using the STAR detector at RHIC. We present the centrality and transverse momentum dependence of flow coefficients v_n for $n = 2, 3, 4$. A strong centrality dependence of v_2 is observed for the particles K_s^0, ϕ and Λ in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV similar to Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. We studied the number of constituent quark scaling (NCQ) of the flow coefficients. The NCQ scaling of the flow coefficients holds within uncertainties for the particles studied in the U+U collisions. We also present the comparison of the results to the AMPT transport model.

1 Introduction

A strongly interacting, hot and dense medium named Quark Gluon Plasma (QGP) is believed to be created in high-energy relativistic heavy-ion collisions at Relativistic Heavy Ion Collider (RHIC) [1]. Experimentally, the dynamics and the collective behavior of such strongly interacting medium have been studied by measuring the azimuthal anisotropy of the produced particles relative to the reaction plane [2]. The initial spatial anisotropy is converted into momentum space anisotropy through rescatterings among the constituents in the medium. The initial coordinate space anisotropy diminishes as the system expands. Due to this self-quenching effect, the azimuthal anisotropy is thought to be sensitive to the earliest stages of heavy-ion collisions [3]. The study of azimuthal anisotropy is based on Fourier expansion of the azimuthal angle, ϕ, of the momentum space distribution, $dN/d\phi \propto 1 + \sum_n 2v_n \cos n(\phi - \Psi_n)$. In experiments, the flow harmonics, v_n, can be measured using the equation $v_n = \langle \cos n\,(\phi - \psi_n) \rangle$, where the v_n and ψ_n are the magnitude and phase of the nth-order of flow harmonics, respectively. The published results for second harmonic (elliptic flow, v_2) from Au+Au collisions at RHIC have demonstrated the collective expansion feature, the mass ordering of elliptic flow among various hadron species [4, 5]. Strange hadrons, especially multistrange hadrons, and the ϕ meson because of their of small hadronic interaction cross section and freeze-out temperature close to the phase transition temperature, are believed to be less sensitive to hadronic rescatterings in the late stage of collisions and thus serve as a good probe for the partonic stage in heavy-ion collision [6]. Recent developments suggest that measurements of higher order flow harmonics can yield information about initial state fluctuations [7], which help to constrain the initial conditions of hydrodynamic simulation for a precise extraction of the QGP transport properties [8].

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2 Analysis Method

In this work, we have used minimum bias dataset from $\sqrt{s_{NN}}$ = 193 GeV U+U collisions collected by the STAR experiment during year 2012. The main detectors used in the analysis are Time Projection Chamber (TPC) and Time Of Flight (TOF) detector for the identification of charged particles at mid-rapidity ($|\eta| < 1.0$). The charged particles with a transverse momentum (p_T) range of $0.2 < p_T < 2.0$ GeV/c are selected for the event plane reconstruction. The event plane angle is calculated in two separated pseudorapidity windows, with a gap of 0.1 units between them to reduce non-flow effects. We reconstruct K_s^0, ϕ and $\Lambda(\bar{\Lambda})$ using invariant mass method through their decay channels: $K_s^0 \rightarrow \pi^+ + \pi^-$, $\phi \rightarrow K^+ + K^-$ and $\Lambda(\bar{\Lambda}) \rightarrow p + \pi^-(\bar{p} + \pi^+)$. Topological and kinematic cuts are applied to reduce the combinatorial background for K_s^0 and $\Lambda(\bar{\Lambda})$. The detailed description of the procedures can be found in the Ref. [9]. We have used standard Event-Plane method for the calculation of flow coefficients v_n relative to the event plane angle ψ_n [2].

3 Results and Discussions

3.1 Flow harmonics (v_n)

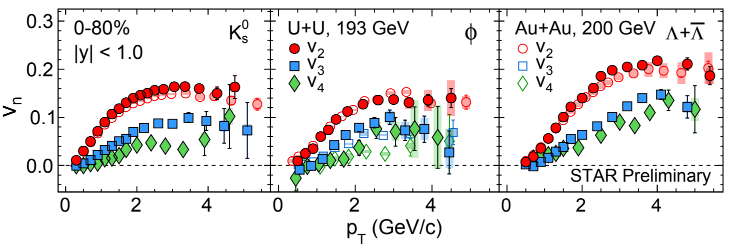

Figure 1. Flow harmonics $v_n(p_T)$ for K_s^0, ϕ and $\Lambda + \bar{\Lambda}$ in 0-80% centrality U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV (solid symbols) compared with those from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV (open symbols) from Ref. [5]. The systematic uncertainties are shown with shaded boxes and the statistical uncertainties by vertical lines.

Figure 1 shows 0-80% centrality $v_n(p_T)$ of K_s^0, ϕ and $\Lambda + \bar{\Lambda}$ at mid-rapidity in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV. The v_n values increases with p_T for the measured range. The magnitude of flow harmonics $v_2 > v_3 > v_4$. The v_2 values shows similar p_T dependence in U+U and Au+Au collisions.

3.2 Centrality dependence

Figure 2 shows $v_n(p_T)$ of K_s^0, ϕ and $\Lambda+\bar{\Lambda}$ at mid-rapidity for 0-10%, 10-40% and 40-80% most central U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV. A clear centrality dependence of $v_2(p_T)$ is observed for K_s^0, ϕ and $\Lambda + \bar{\Lambda}$ similar to that in Au+Au collisions measured by the STAR experiment [5]. The v_2 values are found to be larger in peripheral collisions (40-80%) compared to the central collisions (0-10%). Higher order flow harmonics v_3 and v_4 shows a much weaker centrality dependence, if any.

3.3 NCQ scaling

Figure 3 shows the v_2, v_3 and v_4 scaled by the power of number of constituent quarks ($n_q^{n/2}$) as a function of $(m_T - m_0)/n_q^{n/2}$ for 0-80% and 10-40% in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV, where m_T and m_0 are the transverse mass and the rest mass of the particles, respectively. Flow harmonics v_n scaled by the $n_q^{n/2}$ vs. $(m_T - m_0)/n_q^{n/2}$ lie on a single curve for the particles studied within uncertainties in U+U collisions, similar to that is observed for identified hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV by the PHENIX collaboration in the Ref. [10].

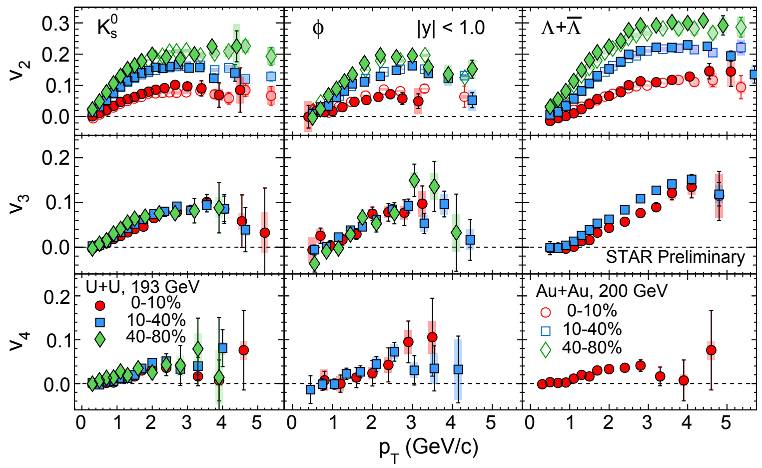

Figure 2. v_2(top panels), v_3(middle panels) and v_4(bottom panels) vs. p_T of K_s^0, ϕ and $\Lambda + \bar{\Lambda}$ for 0-10%, 10-40% and 40-80% centrality in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV (solid symbols) compared with those from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV (open symbols) from Ref. [5]. The systematic uncertainties are shown with shaded boxes and the statistical uncertainties by vertical lines.

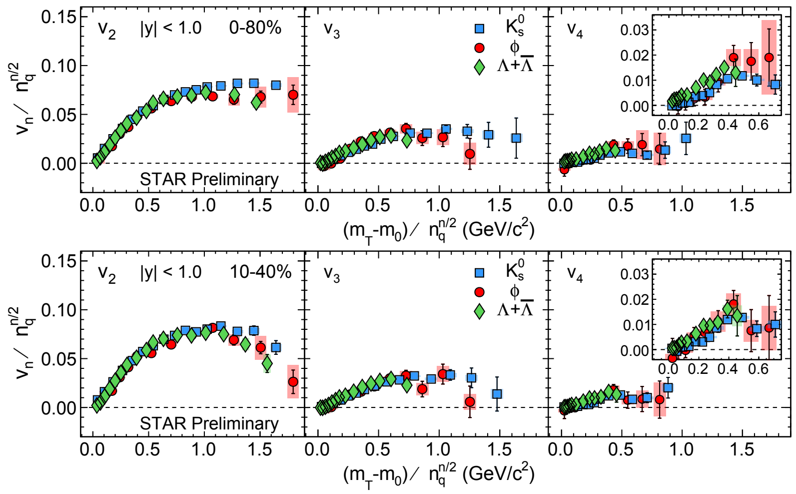

Figure 3. v_n scaled by the power of number of constituent quarks ($n_q^{n/2}$) as function of $(m_T - m_0)/n_q^{n/2}$ for 0-80% (top panels) and 10-40% (bottom panels) in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV.

3.4 Model comparisons

Figure 4 shows the v_n coefficients of K_s^0, ϕ and $\Lambda + \bar{\Lambda}$ for 0-80%(left panels) and 10-40%(right panels) centrality in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV. The same v_n analysis method is used for the model study. The AMPT (with the string melting) model [11] with a 3 mb parton cross-section, describes the data at low p_T < 2.0 GeV/c.

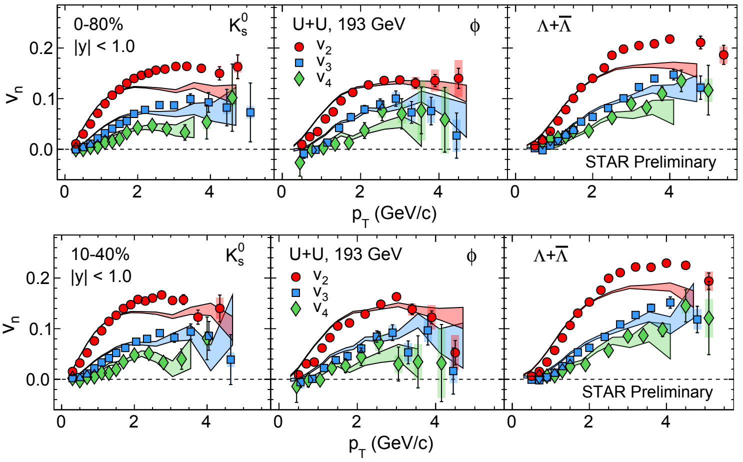

Figure 4. Comparison of the v_n coefficients of K_s^0, ϕ and $\Lambda + \bar{\Lambda}$ for 0-80% (top panels) and 10-40% (bottom panels) centrality in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV (solid symbols) with AMPT (shaded bands).

4 Summary

We present results on flow coefficients v_n (n = 2,3,4) for strange hadrons in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV and compared with the corresponding results from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The centrality dependence of $v_n(p_T)$ is presented. A clear centrality dependence is observed for elliptic flow v_2 in U+U collisions similar to Au+Au collisions. Higher order flow coefficients (v_3, v_4) are found to be less sensitive to the collision centrality. The constituent quark number scaling $v_n/n_q^{n/2}$ vs. $(m_T - m_0)/n_q^{n/2}$ for different particles scale to a single curve within uncertainties for each harmonic. The results were compared with the transport model AMPT. The AMPT model explains the data at low $p_T < 2$ GeV/c. This work is supported by the DAE and DST, of the Government of India.

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