Systematic investigation of partonic collectivity through centrality dependence of elliptic flow of multi-strange hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV in STAR

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Abstract

We present the measurement of centrality dependence of multi-strange hadrons (Ω, Ξ and ϕ) elliptic flow (v_2) at mid-rapidity in Au+Au collision at $\sqrt{s_{NN}}$ = 200 GeV. We investigate number-of-constituent quark (NCQ) scaling of identified hadrons v_2 for different collision centralities. Maximum deviation from ideal NCQ scaling is observed at the level of 10% for centrality 30-80% at $(m_T - m_0)/n_q > 0.6$ GeV/c^2. This may indicate smaller contribution to the collectivity from the partonic phase in the peripheral collisions. We also observe that the mass ordering of v_2 break down between proton and ϕ-meson for p_T <1 GeV/c . This could be due to the effect of later stage hadronic interactions on v_2.

1. Introduction

In non-central nucleus nucleus collisions, the overlapping area is not spatially isotropic. This initial spatial anisotropy is then transformed into momentum anisotropy because of pressure gradients developed due to the subsequent interactions among the constituents [1]. The elliptic flow (v_2) is a measure of the anisotropy in momentum space. The elliptic flow parameter is defined as the second Fourier coefficient of the particles distribution in emission azimuthal angle (ϕ) with respect to the reaction plane angle (Ψ) and can be defined as

$$v_2 = \langle \cos(2(\phi - \Psi)) \rangle. \tag{1}$$

One of the main goals of the STAR experiment at Relativistic Heavy Ion Collider (RHIC) is to study the properties of the QCD (Quantum Chromodynamics) matter at extremely high energy and parton densities, created in the heavy-ion collisions. In such a case, measurement of v_2 plays a crucial role. Within a hydrodynamical framework, v_2 is an early time phenomenon and sensitive to the equation of state of the system formed in the collisions [1]. Thus v_2 can be used as probe for early system although its magnitude may change due to later stage hadronic interactions. The hadronic interaction cross sections of multi-strange hadrons (Ω, Ξ and ϕ) is small and also they freeze-out close to the quark-hadron transition temperature predicted by lattice QCD [2, 3]. Hence, the multi-strange hadrons are expected to provide information from the partonic stage of the evolution in the heavy-ion collisions. Furthermore, the multi-strange hadron anisotropic flow in heavy-ion collisions when compared to those from K_S^0 and Λ, hadrons having single strange valence quark, will be useful for understanding the collective dynamics of the strange quarks. Previous results show when v_2 of hadrons are scaled by the number-of-constituent quarks (n_q)

and measure as a function of $(m_T - m_0)/n_q$, where m_T is the transverse mass and m_0 is the mass of the hadron, the v_2 values follow a universal scaling for all the measured hadrons and nuclei [4]. This observation, referred to as the number-of-constituent quark scaling, is considered as signature of partonic collectivity in heavy-ion collisions [5, 6].

2. Data Sets and Methods

The results presented here are based on an analysis of 240 million minimum bias events taken during the 2010 Au+Au run at $\sqrt{s_{NN}}$= 200 GeV [7]. The Time Projection Chamber (TPC) and Time of Flight (TOF) detectors with full 2π coverage were used for particle identification in the central rapidity (y) region ($|y| < 1.0$). Particles are identified using information of the specific energy loss as a function of momentum (using TPC) and square of the particle mass as a function of momentum (using TOF). We reconstruct $\Omega^{\pm}$, $\Xi^{\pm}$ and ϕ through their decay channel : $\Omega^- \longrightarrow \Lambda + K^-$ ($\overline{\Omega}^+ \longrightarrow \overline{\Lambda} + K^+$) , $\Xi^- \longrightarrow \Lambda + \pi^-$ ($\overline{\Xi}^+ \longrightarrow \overline{\Lambda} + \pi^+$) and $\phi \longrightarrow K^+ + K^-$. Topological and kinematic cuts were applied to reduce the combinatorial background for Ω and Ξ.
The η-sub event plane method [8] has been used for the flow analysis. In this method, one defines the event flow vector for each particle based on particles measured in the opposite hemisphere in pseudo-rapidity (η). An η gap of $|\eta| < 0.05$ between positive and negative pseudo-rapidity sub-events has been introduced to suppress non-flow effects. v_2 vs. invariant mass method has been used to extract v_2 of multi-strange hadrons. Details of this method can be found in the reference [9].

3. Results

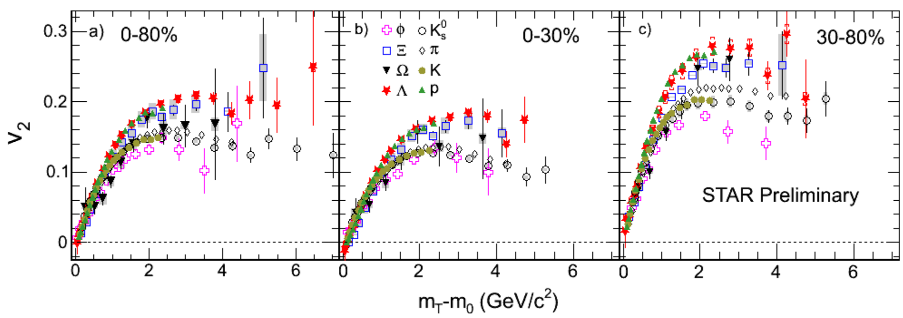

Figure 1: (Color online) v_2 vs. $m_T - m_0$ of identified hadrons for Au + Au collisions at $\sqrt{s_{NN}}$= 200 GeV with $|y| < 1.0$ for centralities a) 0-80%, b) 0-30% and c) 30-80%. Systematic errors on K^0_S, Ξ, and Ω are shown by shaded band and for Λ by cap symbol. The vertical lines are the statistical errors.

The v_2 of identified hadrons (π, K, p, K^0_S, Λ, Ξ, Ω and ϕ) as a function of transverse kinetic energy $m_T - m_0$ at $\sqrt{s_{NN}}$= 200 GeV for various centralities are shown in Fig. 1. We observed a splitting between baryon and meson v_2 at intermediate $m_T - m_0$ for centrality 0-30%. However for 30-80% centrality, we observed no such distinct grouping among the baryons and among the mesons. For mesons and baryons, multi-strange hadrons show smaller v_2 than other identified hadrons ($v_2(\phi) < v_2(K^0_S)$, $v_2(\Xi) < v_2(\Lambda)$) at intermediate $m_T - m_0$. As the multi-strange hadrons v_2 mostly reflect collectivity from the partonic phase, therefore our observation may indicate smaller contribution to the collectivity from the partonic phase in the peripheral collisions.

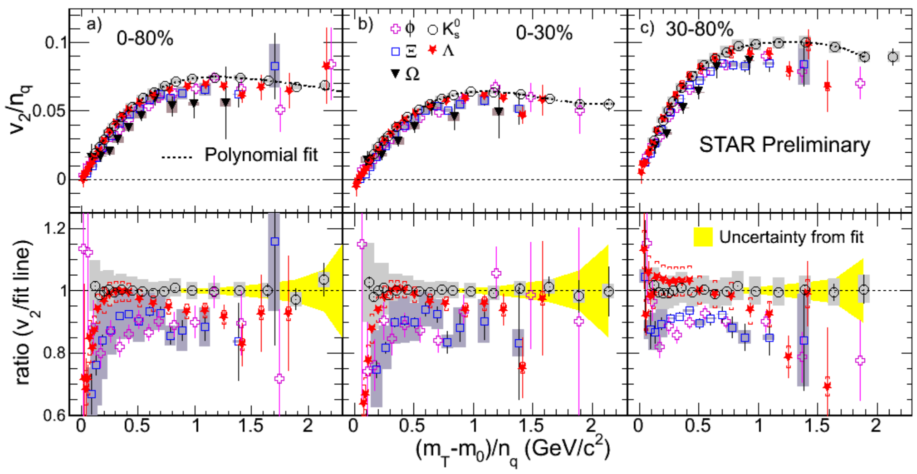

Figure 2: (Color online) v_2/n_q vs. $(m_T - m_0)/n_q$ in Au + Au collisions at $\sqrt{s_{NN}}$= 200 GeV $|y| < 1.0$ for centralities a) 0-80 %, b) 0-30 % and c) 30-80 %. Systematic errors on K^0_S, Ξ, and Ω are shown by shaded band and for Λ by cap symbol. The vertical lines are the statistical errors. Dotted black curve in the upper panels is polynomial fit to K^0_s v_2 and yellow band represent uncertainty due to fit.

The observed NCQ scaling for 0-80% collision centrality at RHIC was considered as a good signature of partonic collectivity [4, 10]. It will be interesting to investigate NCQ scaling for different centralities as it could help us to understand partonic collectivity for different system size. Figure 2 shows v_2 scaled by number-of-constituent quarks (n_q) as a function of $(m_T - m_0)/n_q$ in Au + Au collisions at $\sqrt{s_{NN}}$= 200 GeV for different collision centralities. The ratio of v_2 of other hadrons to the K^0_s v_2 fit curve is shown in the corresponding lower panels. Because of large statistical error, ratio for Ω is not shown. From the results in the panel (b) of Fig. 2 we find that scaling holds for all identified strange hadrons for 0-30% centrality. This indicates that the major part of flow could be developed at the partonic phase for 0-30% centrality. On the other hand, for 30-80% centrality shown in panel (c) of Fig. 2 we observe that ϕ-meson shows a deviation of the order of 10% from the fit line for the range $(m_T - m_0)/n_q > 0.6$ GeV/c^2. This could be interpreted as due to small contribution from the partonic phase to the collectivity.

According to ideal hydrodynamics, $v_2(p_{\rm T})$ follows a mass ordering for $p_T < 2$ GeV/c, such that v_2 of heavier particles is small and vice-versa. In data, mass ordering was observed in the low p_T region [10] . Recent phenomenological calculation based on ideal hydrodynamical model together with the hadron cascade shows that the mass ordering of v_2 could be broken between that of ϕ-meson and proton at low p_T ($p_T < 1.5$ GeV/c) [11]. This is because of late stage hadronic re-scattering effects. High statistics data, collected in the year of 2010, allows for such an investigation. Figure 3 shows the comparison between π, K, p and ϕ-meson v_2 for centralities 0-80%, 0-30% and 30-80%. v_2 of K^0_S, Λ, Ξ and Ω are not shown in Fig. 3 for clarity. We observed mass ordering in v_2 for all identified particles like π, K, K^0_S, p, Λ, Ξ and Ω except ϕ-meson. One can see from Fig. 3 that for 0-30% centrality at low p_T ($p_T < 1$ GeV/c) ϕ-meson

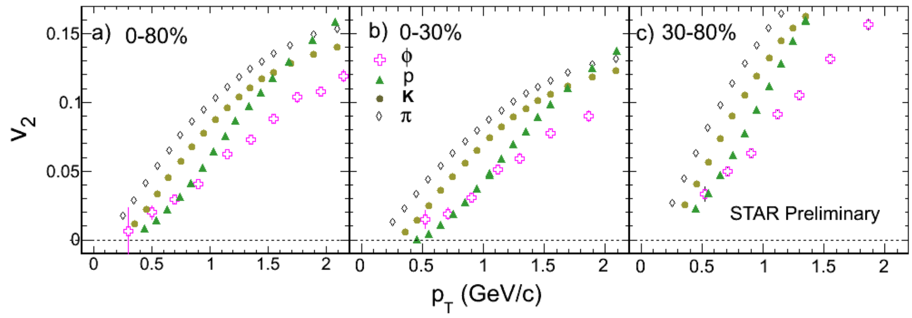

Figure 3: (Color online) v_2 vs. p_T of π, K, p and ϕ-meson for Au + Au collision at $\sqrt{s_{NN}}$= 200 GeV with $|y| < 1.0$ for centralities a) 0-80 %, b) 0-30 % and c) 30-80 %.

v_2 is either higher or similar to that of proton v_2 although mass of the ϕ-meson (1.019 GeV/c^2) is greater than mass of the proton (0.938 GeV/c^2). This observation is consistent with the scenario of hadronic re-scattering effect as predicted in the theoretical model [11].

4. Summary

In summary, we present a systematic measurement of centrality dependence of multi-strange hadrons v_2 at mid-rapidity using a high statistics data in Au + Au collisions at $\sqrt{s_{NN}}$= 200 GeV collected in the year 2010. We have observed a clear baryon-meson splitting at intermediate $m_T - m_0$ for centrality 0-30% and NCQ scaling holds for this centrality. This is consistent with the idea of partonic collectivity. The grouping among baryons and among mesons is observed to be broken for 30-80% centrality. Multi-strange baryon (meson) shows smaller v_2 compared to other identified baryons (mesons) for 30-80% centrality. We observe that ϕ-meson v_2 shows a larger deviation in quark-number scaling in 30-80% centrality than that in 0-30%. It may indicate smaller contribution from the partonic phase to the collectivity. In order to investigate effect of hadronic re-scattering effect on v_2, we have studied a comparison between ϕ-meson and proton v_2 in the low p_T region. We observe $v_2(\phi) \geqslant v_2(p)$ for $p_T < 1.0$ GeV/c for 0-30% centrality. This observation is consistent with later stage hadronic re-scattering effect as predicted in the theoretical model [11].

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