Elliptic and triangular flow of (multi-)strange hadrons and ϕ mesons in BES-II energies at STAR

Li-Ke Liu[1,*] (for the STAR Collaboration)

[1]Key Laboratory of Quark & Lepton Physics (MOE) and Institute of Particle Physics, Central China Normal University, Wuhan 430079, China

Abstract. In these proceedings, we present the measurements of elliptic (v_2) and triangular (v_3) flow of (multi-)strange hadrons and ϕ mesons in 19.6 and 14.6 GeV Au+Au collisions from STAR. The number of constituent quark (NCQ) scaling of v_2 and v_3 holds well at $\sqrt{s_{\rm NN}}$ = 19.6 GeV, which indicates the collective flow is built up in the partonic stage. At these energies, the anti-particles show better NCQ scaling than the particles for both v_2 and v_3, which may be caused by the different contributions from the produced and transported quarks.

1 Introduction

At sufficiently high temperature and/or high density, quantum chromodynamics (QCD) predicts a transition from hadronic matter to deconfined partonic matter [1, 2]. Results from top-RHIC and LHC energies indicate a new form of matter with small viscosity and high temperature, created in high-energy heavy ion collisions [3, 4]. Lattice QCD calculations predict that, the phase transition from hadronic matter to the QGP phase is a smooth crossover at vanishing baryon chemical potential (μ_B) region. A first-order phase transition is expected at a finite baryon chemical potential region. Locating the first-order phase boundary with a critical point is essential in establishing the QCD phase diagram. It motivates the Beam Energy Scan (BES) program at RHIC, which covers energy $\sqrt{s_{\rm NN}}$ = 3.0 - 62.4 GeV and corresponding baryon chemical potential 750 - 73 MeV. It can help us explore the QCD phase structure in the high baryon density region.

Anisotropies in particle momentum distributions relative to the reaction plane are referred to as anisotropic collective flow. Elliptic flow coefficient, v_2, is sensitive to the dynamics at the early stages of the system evolution in heavy-ion collisions and equation of state of the medium [5]. Triangular flow v_3 is particularly sensitive to the initial geometry fluctuations [6]. The hadronic interaction cross sections of multi-strange hadrons and ϕ mesons are expected to be small [7–9]. Hence, the anisotropic flow of these hadrons provides information on the early stages of the high-energy collisions. A hint of smaller v_2 for ϕ mesons compared to charged particles is observed for BES-I Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 7.7 and 11.5 GeV [10].

In these proceedings, with the enhanced statistics datasets, we report the measurements of v_2 and v_3 of (multi-)strange hadrons ($K^{\pm}$, K^0_S, Λ, $\bar{\Lambda}$, Ξ, $\bar{\Xi}^+$, Ω, $\bar{\Omega}^+$) and ϕ mesons from BES-II Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 14.6 and 19.6 GeV.

*e-mail: likeliu@mails.ccnu.edu.cn

2 Data sets and Analysis strategy

Data samples for Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 14.6 and 19.6 GeV taken in 2019 are used in the analysis. The number of good events analyzed are 270$\times10^6$ and 440$\times10^6$ for 14.6 and 19.6 GeV, respectively. The primary vertex position of each event along the beam direction, V_z, is selected to be within $\pm$ 70 cm from the center of the Time Projection Chamber (TPC). To eliminate possible beam interactions with the vacuum pipe, the vertex along the radial direction, V_r, is selected to be smaller than 2 cm. To select good quality tracks, $p_T > 0.2$ GeV/c, and a distance of closest approach (DCA) from vertex, DCA $\leq$ 3 cm, and at least 15 space points in the TPC acceptance are required. The particle identification at low transverse momentum is performed via their specific energy loss measured by the TPC. At intermediate and high transverse momenta, the particle identification is performed using the Time of Flight (TOF) detector. The strange hadrons such as K^0_S, Λ, $\bar{\Lambda}$, Ξ^-, Ξ^+, Ω^-, and Ω^+ are reconstructed using KF-Particle package [11]. The ϕ mesons are reconstructed via K^+K^- channel. The systematic uncertainties on the measurements are obtained by varying the above analysis cuts. The dominant sources of systematic uncertainties are the particle identification cuts and quality track selection cuts.

3 Results and Discussions

v_2 and v_3 of Identified Particles

Figure 1 shows the p_T differential elliptic flow of the identified particles for mid-central (10-40%) Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6 GeV. The black markers show baryon v_2 results, and the red markers show meson v_2 results. There is a clear mass ordering when $p_T < 1.5$ GeV/c. It could be due to the interplay of radial expansion and anisotropic flow, which is consistent with hydrodynamics predictions [12]. When $p_T > 1.5$ GeV/c, the v_2 of particles is grouped according to the hadron type, called baryon-meson splitting, which indicates that the coalescence could be dominant process of hadronization in this p_T-region.

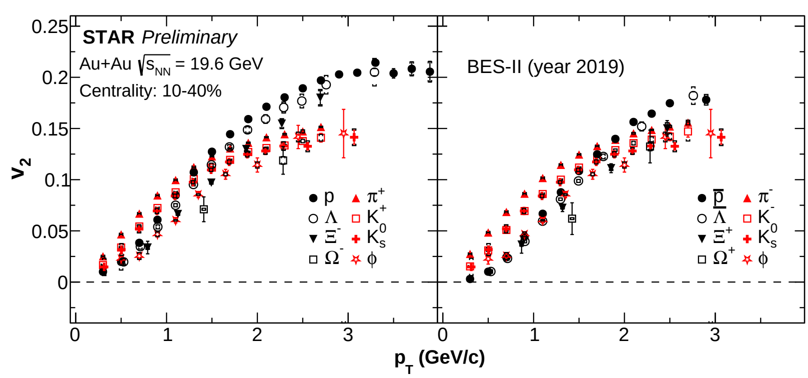

Figure 1. p_T differential elliptic flow of the identified particles in 10-40% Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6 GeV.

The p_T differential triangular flow of the identified particles in 0-30% and 30-70% Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6 GeV are shown in Fig. 2. While the v_2 strongly relies on the centrality, the v_3 shows a weak dependence on centrality. These results indicate that the event-by-event fluctuations are the dominant source for triangular flow.

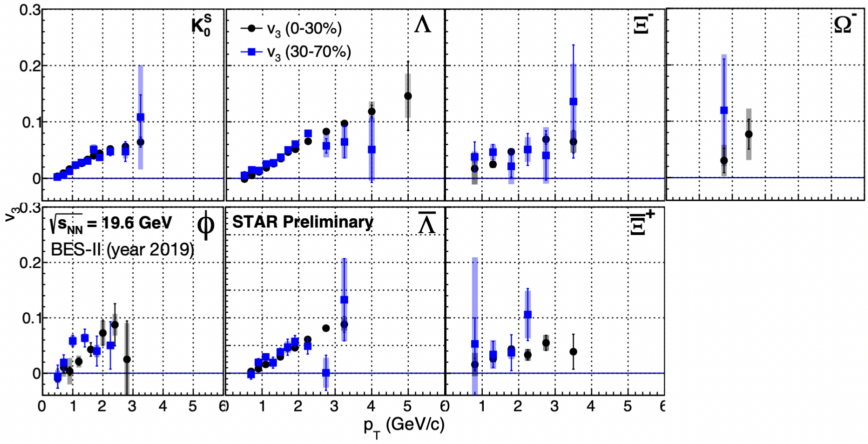

Figure 2. p_T differential triangular flow of the identified particles in 0-30% and 30-70% Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV. The vertical bars and shaded bands are the statistical and systematic uncertainties, respectively.

Test of NCQ Scaling of v_2 and v_3

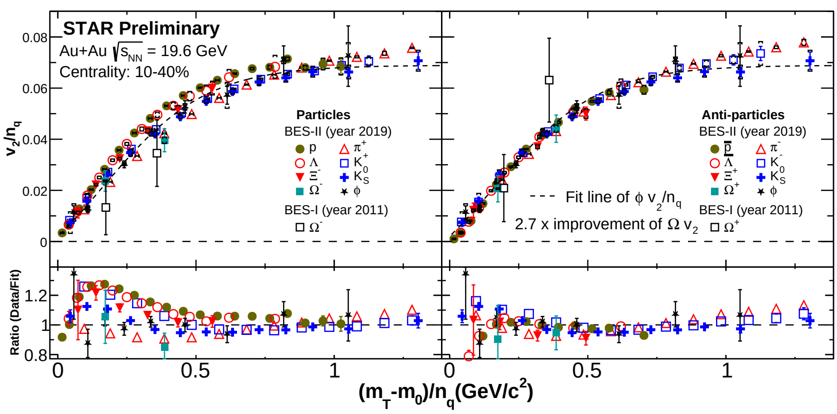

Figure 3. The number-of-constituent quark (NCQ) scaled elliptic flow, v_2/n_q versus $(m_T - m_0)/n_q$, for 10-40% central Au+Au collisions for identified particles (left pad) and corresponding anti-particles (right pad) at $\sqrt{s_{NN}}$ = 19.6 GeV where dash lines show the fit of ϕ mesons v_2.

Figure 3 shows the test of NCQ scaling of v_2 in centrality 10-40% at $\sqrt{s_{NN}}$ = 19.6 GeV. The NCQ scaling of v_2 holds within 10% for anti-particles, and 20% for particles. A similar scaling behavior is observed for v_3 and holds within 15% for anti-particles, and 30% for particles.

The NCQ scaling reflects that the quarks are the most effective degrees of freedom in determining hadron flow at intermediate p_T, which means that the collective flow has been built up in the partonic stage at this collision energy. Meanwhile, the NCQ scaling of anti-particles works better than that of particles both for v_2 and v_3, which may be caused by the different contributions from the produced and transported quarks. The strange hardons and ϕ meson v_2 are measured in Au+Au collisions at BES-II 14.6 GeV, the NCQ scaling of v_2 holds at 20% level and measurements in finer centrality bins are underway.

4 Summary

In summary, we report the elliptic and triangular flow of strange hadrons $K^{\pm}$, K^0_S, Λ, $\bar{\Lambda}$, Ξ^-, $\bar{\Xi}^+$, Ω^-, $\bar{\Omega}^+$, and ϕ mesons at 14.6 and 19.6 GeV from BES-II. At $\sqrt{s_{\mathrm{NN}}}$ = 19.6 GeV, the NCQ scaling of v_2 (v_3) holds within 10 (15)% for anti-particles, and within 20 (30)% for particles. It indicates that the partonic collectivity could build up at this energy. Meanwhile, the NCQ scaling of anti-particles holds better than particles, which indicates the contribution of transported quarks in particles. At $\sqrt{s_{\mathrm{NN}}}$ = 14.6 GeV, the NCQ scaling of v_2 holds at 20% level in 0-80% central Au+Au collisions. The data taking for BES-II program (3-19.6 GeV) has completed during the year 2019 to 2021 with high statistics and detector upgrades. Such datasets will help scan the QCD phase diagram over a wide range of baryon chemical potential. It is expected to provide more precise differential measurements of v_2 and v_3 especially for less abundant particles: multi-strange hadrons and ϕ mesons. It will offer additional information to constrain the equation of state (EoS) and phase boundary of the produced QCD matter in the high baryon density region.

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