

Charge asymmetry dependency of π/K anisotropic flow in U+U $\sqrt{s_{NN}} = 193$ GeV and Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions at STAR

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Abstract. In this paper we present STAR's measurements of v_2 and v_3 for charged kaons and pions at low transverse momentum range ($0.15 < p_T < 0.5$ GeV/c), as a function of event charge asymmetry (A_{ch}) in both U+U collisions at $\sqrt{s_{NN}} = 193$ GeV and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. We found that in 20% – 60% centrality, the ratio of slope parameters of $\Delta v_3(A_{ch})$ to that of $\Delta v_2(A_{ch})$, is $+3\sigma$ below the predicted value (1/3) from local charge conservation at freeze-out, indicating that it is unlikely that such effect can have a significant contribution to the splitting of elliptic flow of charged pions as a function of A_{ch} . We also observed a smaller $\Delta v_2(A_{ch})$ slope for kaons relative to pions. Our measurements serve as important consistency checks for the phenomena suggested as the consequence of the chiral magnetic wave.

1. Introduction

Theoretical study [1] indicates that, the electric quadrupole deformation, induced by chiral magnetic wave (CMW) at finite baryon density in Quark Gluon Plasma, will lead to a difference in elliptic flow of low momentum hadrons, by increasing v_2 of negatively charged hadrons and decreasing v_2 of positively charged ones. The magnitude of this difference is predicted to be proportional to the charge asymmetry parameter A_{ch} , defined as

$$A_{ch} \equiv \left\langle \frac{N_+ - N_-}{N_+ + N_-} \right\rangle,$$

here N_+ and N_- represent number of positive particles and number of negative particles in one event respectively. Such charge asymmetry dependency of π elliptic flow has been observed in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the STAR experiment at the Relativistic Heavy Ion Collider [2] [3]. The trend and the magnitude of the slope of $\Delta v_2(A_{ch})$ for π^\pm , to the first order, are consistent with the theoretical calculation. This observation has been used as an evidence for CMW [4] [5], which stems from the interplay of Chiral Magnetic Effects (CME) [6] [7] [8] and Chiral Separation Effects (CSE) [9] [10]. Nevertheless, recently it is argued that the local charge conservation at freeze-out, together with the characteristic shape of $v_2(\eta)$ and $v_2(p_t)$ at STAR, may also contribute to the elliptic flow splitting as a function of A_{ch} [11]. The effect of which has been qualitatively studied by hydrodynamic model. In particular, it is predicted [11] that with this alternative mechanism, a similar effect for higher flow harmonics v_3 may also exist, and the $\Delta v_3(A_{ch})$ slope for π^\pm should be $\sim 1/3$ of the $\Delta v_2(A_{ch})$ slope. Here the v_3 , known as triangular

flow, is the third harmonic coefficient of the Fourier expansion of the final momentum-space azimuthal anisotropy, defined in a way similar to that of elliptic flow v_2 [12].

In this paper, we present 1) experimental measurement of v_2 and v_3 difference between negatively charged and positively charged pions, at low p_T as a function of A_{ch} in Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions at STAR, in order to test the proposed mechanism due to local charge conservation at freeze-out. 2) the same measurement in U+U $\sqrt{s_{NN}} = 193$ GeV as the CMW effect is also expected to exist. 3) A_{ch} dependency of Δv_2 for kaons, as they are suggested [1] to have a weaker effect than that of pions due to hadronic effects. The latter two measurements also serve as important consistency checks for the phenomena due to CMW.

2. Data sets and analysis details

2.1. Data sets and cuts

In this analysis, ~ 328 M and ~ 555 M minimum-bias triggered events, from year 2010 and year 2011 respectively, in Au+Au $\sqrt{s_{NN}} = 200$ GeV, as well as ~ 280 M minimum-bias triggered events in U+U $\sqrt{s_{NN}} = 193$ GeV at STAR experiment [13] have been used. To reject background events, all events are required to have primary vertex along beam direction (V_z) within 30 cm from the detector center, and primary vertex radius (V_r) within 2 cm from the beam center.

All charged particles are firstly required to have pseudorapidity within unity ($|\eta| < 1$). For the calculation of charged asymmetry, charged particles within transverse momentum window, $0.15 < p_T < 12$ GeV/c, are used, with the exception of low p_T protons ($p_T < 0.4$ GeV/c) which are mostly due to beam-pipe knockout interactions. The same p_T cut was also applied on antiprotons to match that used for protons. The A_{ch} is calculated event by event and according to which the whole sample is divided into five sub-groups, in which each has almost the same number of events, for each centrality bin. Due to finite detecting efficiency, the observed A_{ch} is usually larger than real A_{ch} . To take this into account, HIJING events [14] have been used to convolute with detector acceptance and efficiency to derive the real A_{ch} from the observed A_{ch} .

For the flow analysis, the cut on Distance of the Closest Approach to primary vertex of π/K , $dca < 1$ cm, is applied to reject secondary particles, and cut on $0.15 < p_T < 0.5$ GeV/c is used to guarantee that tracks have good particle identification and almost the same mean p_T . Time projection chamber (TPC) [15] and time-of-flight (TOF) detector [16] are used to identify particles. In this analysis, only tracks satisfy both criteria, 1) within 2σ below/above theoretical dE/dx (tracks' average energy loss per unit length) curves, 2) within m^2 windows, $0 < m_\pi^2 < 0.1$ ($0.15 < m_K^2 < 0.35$) for $\pi(K)$, are selected as particles of interest.

2.2. Q-cumulants method

The Q-cumulants method [17] is used to calculate v_2 and v_3 . In this method, all multi-particle cumulants are expressed in terms of various expressions with respect to flow vectors (Q-vectors). For example, two-particle correlations for single event and all events can be obtained by

$$\langle 2' \rangle = \frac{p_n Q_n^* - m_q}{m_p M - m_q}, \quad \langle \langle 2' \rangle \rangle = \frac{\sum_{i=1}^N (w_{\langle 2' \rangle})_i \langle 2' \rangle_i}{\sum_{i=1}^N (w_{\langle 2' \rangle})_i},$$

here p_n , q_n , Q_n^* are different flow vectors, while m_p and m_q are number of particles in particles of interest group and reference particle group, respectively. Using differential second order cumulant $d_n\{2\} = \langle \langle 2' \rangle \rangle$, one can estimate differential flow by

$$v_n'\{2\} = \frac{d_n\{2\}}{\sqrt{c_n\{2\}}},$$

here c_n denotes reference flow. More calculation details are presented in [17]. In our analysis, a η -gap of 0.3 is applied to reduce non-flow correlation [18] when calculating reference flow. One significant advantage of the Q-cumulants method is that, using flow vectors, a fast and accurate calculation without exhaustly looping over all particle combinations can be provided.

3. Results

3.1. The slope of $\Delta v_3(A_{ch})$ for π^\pm versus centrality

In Figure 1, The slope parameter of $\Delta v_3(A_{ch})$ is presented as a function of centrality for π^\pm . The $\Delta v_3(A_{ch})$ slope parameter is extracted from the linear relationship between the flow difference $v_3(\pi^-) - v_3(\pi^+)$ and the charge asymmetry A_{ch} . The solid blue circles, which represent $\Delta v_2(A_{ch})$ slope, are taken from previous measurement [2] at STAR as reference. It is observed that the trend of $\Delta v_3(A_{ch})$ slope in Au+Au collisions (red triangles) is very similar to that of $\Delta v_2(A_{ch})$, however the magnitude of the former is smaller than the latter and are even negative in peripheral and central bins. Combining data points from 20% – 60% centrality, as well as data from both Au + Au and U + U collisions, the ratio of slope parameters of $\Delta v_3(A_{ch})$ to that of $\Delta v_2(A_{ch})$, is 0.026 ± 0.098 , which is consistent with zero and is $+3\sigma$ below the predicted value (1/3) from local charge conservation at freeze-out.

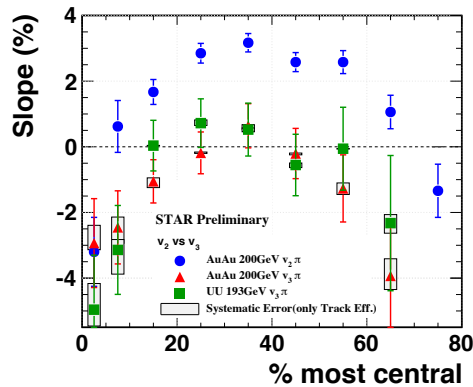


Figure 1. $\Delta v_3(A_{ch})$ slope parameters for π^\pm in both Au+Au collisions (red triangles) and U+U collisions (green squares) are shown in all centrality bins, compared with $\Delta v_2(A_{ch})$ slope (blue dots) parameters in Au+Au collisions

3.2. The slope of $\Delta v_2(A_{ch})$ for π^\pm versus centrality in U+U collisions

In figure 2 (Left) the slope parameters of $\Delta v_2(A_{ch})$ for π^\pm is presented as a function of centrality for U+U collisions. They match well with the result in Au+Au collisions. This measurement is the first step of checking such effect in U + U collisions. However, whether this effect is in any way influenced by the special geometrical set up of U+U collisions has to be answered by detailed, future studies.

3.3. The slope of $\Delta v_2(A_{ch})$ for K^\pm versus centrality

As mentioned above, the flow difference for charged kaons is supposed to have a weaker A_{ch} dependency than that of pions. In Figure 2 (Right), the same measurement for kaons is presented. Combining data points from 20% – 60% centrality, as well as data from both Au + Au and U + U collisions, the ratio of slope parameters of $\Delta v_2(A_{ch})$ for kaons and pions, is 0.57 ± 0.15 . The observation of a smaller slope for kaons than that for pions is also consistent with the expectation in Ref. [1].

4. Summary

We have presented v_2 and v_3 of low momentum charged π , as well as v_2 of low momentum charged K , as a function of event charge asymmetry (A_{ch}) in both U+U collisions at $\sqrt{s_{NN}} =$

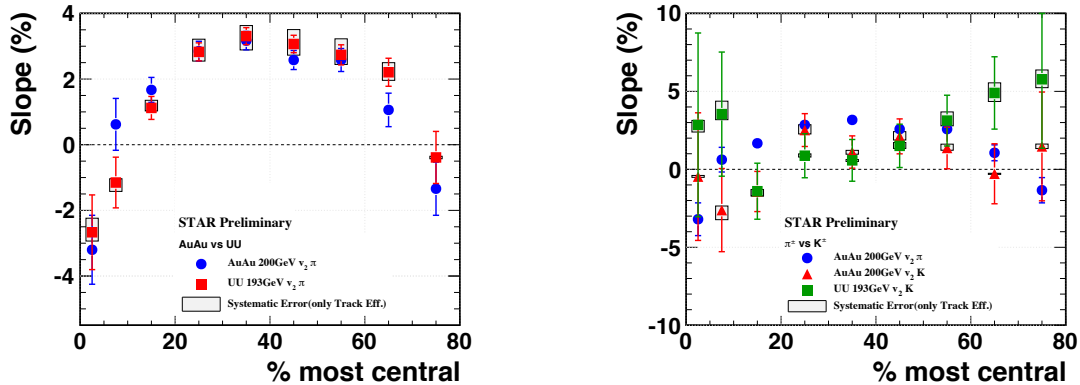


Figure 2. (Left) $\Delta v_2(A_{ch})$ slope parameters for π^\pm in U+U MinBias collisions, compared with which in Au+Au collisions. (Right) $\Delta v_2(A_{ch})$ slope parameters for K^\pm , compared with that of π^\pm

193 GeV and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. We found that in 20% – 60% centrality, for pions, the ratio of slope parameters of $\Delta v_3(A_{ch})$ to that of $\Delta v_2(A_{ch})$, is consistent with zero and is $+3\sigma$ below the predicted value (1/3) from local charge conservation at freeze-out. It is unlikely that the local charge conservation at freeze-out, when convoluted with the characteristic shape of $v_2(\eta)$ and $v_2(p_t)$ at STAR, has a significant contribution to the splitting of elliptic flow of charged pions as a function of charge asymmetry. For the same centrality range, the $\Delta v_2(A_{ch})$ slope for kaons is smaller than that for pions, with a ratio of former to latter of 0.57 ± 0.15 . This observation is also consistent with theoretical expectation. Our measurements serve as important consistency checks for the phenomena suggested as the consequence of the chiral magnetic wave.

5. Acknowledgement

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