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Azimuthal anisotropy of φ meson in U+U and Au+Au collisions at RHIC

Vipul Bairathi (for the STAR Collaboration)

National Institute of Science Education and Research (NISER), Jatni-752050, India.

E-mail: vipul@rcf.rhic.bnl.gov/vipul.bairathi@gmail.com

Abstract. The measurements of the azimuthal anisotropy of φ meson in the U+U and Au+Au collisions at the Relativistic Heavy-Ion Collider (RHIC) are reported. The centrality dependence of the Fourier coefficients v_2, v_3, v_4 and v_5 is presented for φ meson at midrapidity ($|\eta| \leq 1.0$), in U+U and Au+Au collisions at $\sqrt{s_{NN}}$ = 193 and 200 GeV, respectively. The η-sub event plane method is used with a η gap of 0.1 to suppress the non-flow effects. A strong centrality dependence is observed for the φ meson elliptic flow (v_2), whereas no clear centrality dependence is observed for v_3, v_4 and v_5. Ratios of the Fourier coefficients, v_3/v_2 and v_4/v_2^2 as a function of transverse momentum (p_T) are also presented. A systematic comparison of the Fourier coefficients for the two systems U+U and Au+Au is discussed.

1. Introduction

Azimuthal anisotropy is an important tool for studying the properties of the hot and dense matter created in high energy heavy-ion collsions at the Relativistic Heavy Ion Collider (RHIC) [1]. It describes the momentum space anisotropy of produced particles in non-central heavy-ion collisions, which is expected to be caused by the pressure gradient developed in the early stages of collisions. The azimuthal distribution of the produced particles can be expanded as a Fourier series [2],

$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n(\phi - \psi_{RP})\right] \tag{1}$$

where ϕ is the azimuthal angle and ψ_{RP} is the reaction plane angle. The reaction plane is defined by the beam direction and impact parameter vector between the two colliding nuclei. The reaction plane angle ψ_{RP} is not measurable directly, so the Fourier coefficients are determined with respect to the estimated event plane angle (ψ_n) as $v_n = \langle \cos n\,(\phi - \psi_n)\rangle$. The observed v_n coefficients are then corrected for event plane resolution.

The φ meson is the lightest bound state of a strange (s) and an anti-strange ($\bar{s}$) quark, and is considered as a clean probe for the study of the properties of the matter created in heavy-ion collisions. The φ meson has a life time of $\sim$ 42 fm/c [3]. φ meson generally decays outside the fireball therefore its decay daughters do not undergo significant re-scattering in the hadronic phase. In addition, the hadronic interaction cross-section of the φ meson is expected to be small compared to the other hadrons [4]. Although the generation of the azimuthal anisotropy is an early time phenomenon, its magnitude might still be affected by the late stage hadronic interactions. Due to the above properties of the φ meson, its v_n coefficients are relatively


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unaffected by late stage interactions [5, 6]. Therefore φ meson v_n could reflect the collective motion of the partonic phase. This makes the φ meson a clean probe for the study of the properties of the matter created in heavy-ion collisions [7].

2. Data Analysis

The data analyzed were recorded with the STAR experiment at RHIC during 2011 and 2012 for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV, respectively. The minimum bias triggered events with a primary collision vertex position along the longitudinal beam direction (V_z) within 30 cm from the center of the detector are selected for this analysis. An additional cut on the transverse position of the primary vertex radius ($V_r < 2.0$ cm) from the center of the beam pipe has also been used to minimize effects of beam pipe interactions. The total number of events analyzed are ∼562 million and ∼293 million for Au+Au and U+U collisions, respectively. The STAR's Time Projection Chamber (TPC) [8] and Time Of Flight (TOF) [9] detectors were used for particle identification. The TPC is capable of tracking charged particles within $|\eta| < 1.0$ and has full azimuthal coverage. The TPC detector measures the momentum of the charged tracks as well as the specific ionization energy loss. This energy loss information is then used to identify the individual tracks by comparing them with the theoretical predictions using Bichsel functions [10]. The TOF detector measures the time taken by a track to traverse the distance from the primary vertex to the TOF detector. The TOF also has full azimuthal coverage and works within $|\eta| < 0.9$. φ mesons are identified using the invariant mass technique from their decay to K^+ and K^- with branching ratio of 48.9%. The mixed event technique has been used for combinatorial background estimation [11]. The η-sub event plane method 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. An η gap of 0.1 between positive and negative pseudo-rapidity sub-events has been introduced to suppress non-flow effects [1]. Invariant mass method has been used to extract the flow coefficients of the φ meson [12].

3. Results

3.1. Flow Harmonics (v_n)

The differential flow harmonics v_n (n = 2-5) for φ meson as a function of the transverse momentum (p_T) at mid-rapidity ($|y| < 1.0$) in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV for minimum bias events are presented. Figure 1 shows the

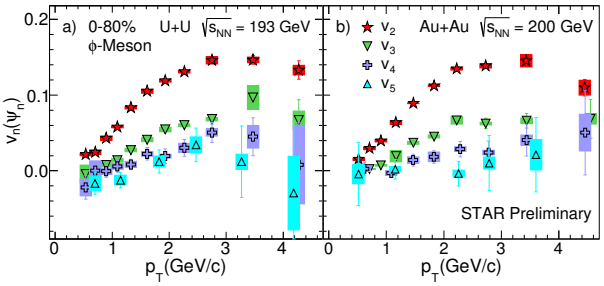


Figure 1. (Color online) φ meson v_n as function of p_T in U+U collisions (a) and Au+Au collisions (b) for minimum bias (0 − 80% centrality). The different colored bands are the systematic uncertainties and vertical lines are the statistical uncertainties.

φ meson flow coefficients v_n for Au+Au and U+U. It is observed that the values are comparable between the two collision systems and $v_2 > v_3 > v_4 > v_5$. The v_n coefficients as a function of

p_T first increase for $p_T < 2.0$ GeV/c, saturate for intermediate p_T and then decrease for higher $p_T > 3.5$ GeV/c. A similar type of p_T dependence is observed for both systems.

3.2. Centrality Dependence

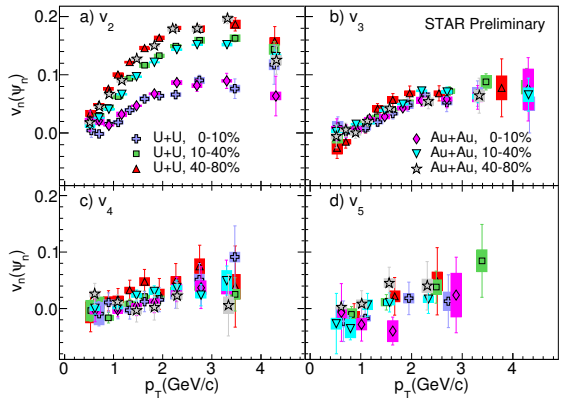


Figure 2. (Color online) φ meson v_2, v_3, v_4 and v_5 as function of p_T in U+U collisions and Au+Au collisions for three different centrality bins($0-10\%$, $10-40\%$ and $40-80\%$). The different colored bands are the systematic uncertainties and vertical lines are the statistical uncertainties.

Figure 2 shows the centrality dependence of φ meson flow coefficients v_n for Au+Au at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV. Strong centrality dependence is observed for the elliptic flow (v_2) in both Au+Au and U+U collisions. We found v_2 values higher in peripheral collisions ($40-80\%$ centrality) compare to central collisions ($0-10\%$ centrality). No clear centrality dependence is observed for other flow harmonics. This can be explained as the higher flow coefficients v_3, v_4 and v_5 are generated due to fluctuations corresponding to the initial states of the colliding nuclei.

3.3. Ratio (v_3/v_2)

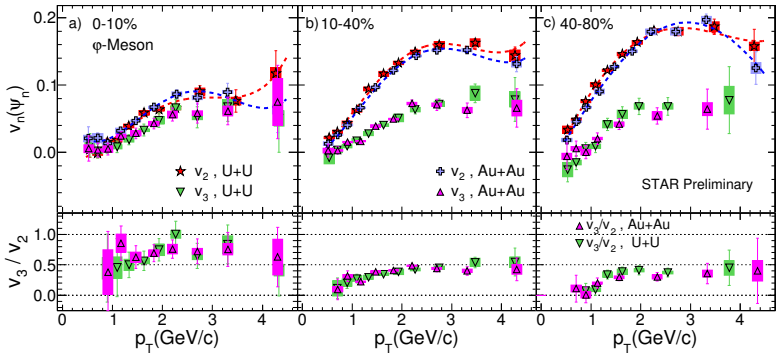


Figure 3. (Color online) v_3/v_2 ratio as a function of p_T in U+U collisions and Au+Au collisions for three different centrality bins($0-10\%$, $10-40\%$ and $40-80\%$). Different colored bands are the systematic uncertainties and vertical lines are the statistical uncertainties. The dashed lines are the 4th order polynomial fit to the v_2 to get v_2 at the p_T corresponding to v_3.

Figure 3 shows the ratio of v_3 to v_2 as a function of p_T for Au+Au and U+U collisions at $\sqrt{s_{NN}} = 200$ GeV and 193 GeV, respectively. We observe the v_3/v_2 ratio for $p_T > 1.5$ GeV/c

is constant for both U+U and Au+Au collisions and this is qualitatively consistent with the prediction from hydrodynamic calculations [13].

3.4. Ratio (v_4/v_2^2)

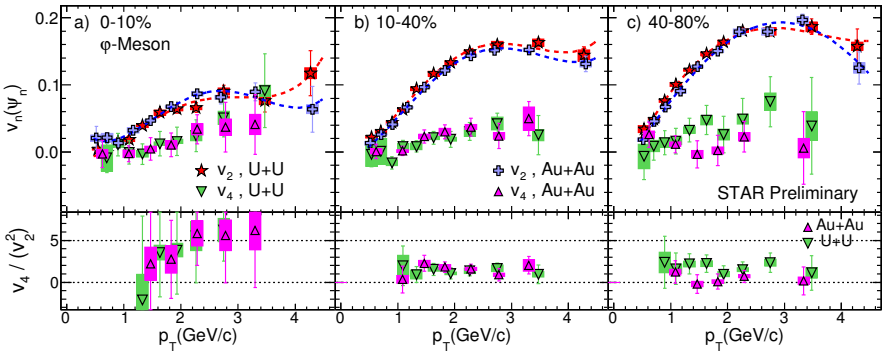


Figure 4. (Color online) v_4/v_2^2 ratio as a function of p_T in U+U collisions and Au+Au collisions for three different centrality bins($0-10\%$, $10-40\%$ and $40-80\%$). The different colored bands are the systematic uncertainties and vertical lines are the statistical uncertainties.The dashed lines are the 4th order polynomial fit to the v_2 to get v_2 at the p_T corresponding to v_4.

Figure 4 shows the ratio of v_4 to v_2^2 as a function of p_T for Au+Au and U+U collisions at $\sqrt{s_{NN}}$ = 200 and 193 GeV, respectively. We observe the ratio v_4/v_2^2 of φ meson is constant for U+U and Au+Au collisions. We found that the ratio has higher values for central collisions compared to peripheral collisions in both U+U and Au+Au collisions. We also found that the ratio v_4/v_2^2 has higher values than expected from a hydrodynamic model [13].

4. Summary

φ meson azimuthal anisotropy coefficients v_n (n = 2-5) has been measured in U+U and Au+Au collisions at $\sqrt{s_{NN}}$ = 193 GeV and 200 GeV, respectively. The v_n results were compared as a function of the transverse momentum for minimum bias (0-80%) events and in the centrality ranges 0-10%, 10-40% and 40-80%. A strong centrality dependence is observed for elliptic flow (v_2), but no clear centrality dependence is observed for v_3, v_4 and v_5 for both the Au+Au and U+U systems. The ratios of flow coefficients has been measured as function of the transverse momentum. The ratio v_3/v_2 for $p_T > 1.5$ GeV/c is found to be constant for both the U+U and Au+Au systems, and is consistent with the expectations from a hydrodynamic model [13]. The ratio v_4/v_2^2 is found to be higher than expected from the hydrodynamic model [13].

References

[1] A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C **58**, 1671 (1998).
[2] S. A. Voloshin and Y. Zhang, Z. Phys. C **70**, 665-672 (1996).
[3] K. A. Olive *et al.* (Particle Data Group), Chin. Phys. C **38**, 090001 (2014).
[4] J. Adams *et al.* (STAR Collaboration), Nucl. Phys. A **757**, 102 (2005).
[5] A. Sibirtsev *et al.*, Eur. Phys. J. A **29**, 209-220 (2006).
[6] B. Mohanty and N. Xu, J. Phys. G **36**, 064022 (2009).
[7] M. M. Aggarwal *et al.* (STAR Collaboration), *Preprint*: nucl-ex/1007.2613
[8] M. Anderson *et al.*, Nucl. Instrum. Meth. A **499**, 659 (2003).
[9] W. J. Llope *et al.*, Nucl. Instrum. Meth. A **522**, 252-273 (2004).
[10] H. Bichsel, Nucl. Instrum. Meth. A **562**, 154 (2006).
[11] B. I. Abelev *et al.*, (STAR Collaboration), Phys. Lett. B **673**, 183 (2009).
[12] N. Borghini and J. Y. Ollitrault, Phys. Rev. C **70**, 064905 (2004).
[13] C. Lang and N. Borghini, Eur. Phys. J. C **74**, 2955 (2014).