

Azimuthal Anisotropy of ϕ meson in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in STAR at RHIC

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ABSTRACT

We present the measurements of ϕ -meson triangular flow (v_3) and quadrangular flow (v_4) at mid-rapidity ($|y| < 1.0$) in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Transverse momentum (p_T) and centrality dependence of $v_3(p_T)$ and $v_4(p_T)$ are shown and compared with corresponding elliptic flow (v_2) values. We also present the various higher harmonic ratios and their possible implications.

INTRODUCTION

The main aim of STAR experiment at the Relativistic Heavy Ion Collider (RHIC) is to study the properties of hot and dense matter created in the collision of two heavy nuclei. In the 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. The flow is a measure of the anisotropy in momentum space. In a picture of the hydrodynamic expansion of the system formed in the collisions, the flow is an early time phenomenon and sensitive to the equation of state of the system formed in the heavy ion collisions [1]. The higher harmonics of ϕ -meson which is the bound state of s and \bar{s} quarks are one of the cleanest probes for the early collision dynamics since the ϕ -meson has a small hadronic interaction cross section with other hadrons [2] and freezes out relatively earlier compared with other light flavor hadrons. Therefore, the higher harmonics of the ϕ -meson can be used as a clean probe to measure early time collectivity of the system created in heavy-ion collisions.

EXPERIMENTAL SETUP AND METHOD USED

The data for the present analysis has been carried out by the STAR experiment during RHIC run 2011 with a minimum bias trigger. In this analysis we have used the Time Projection Chamber (TPC) and Time of Flight (ToF) detectors. The TPC is capable of tracking charged particles within the pseudo-rapidity interval $|\eta| < 1.0$ and has full azimuthal coverage [3]. The TPC detector measures the momentum of the charged tracks as well as the specific ionisation energy loss. This energy loss information is then used to identify the individual tracks by comparing them with the theoretical predictions using Bichsel functions.



The TOF PID capabilities overlap with TPC dE/dx PID capabilities at low momenta and reach

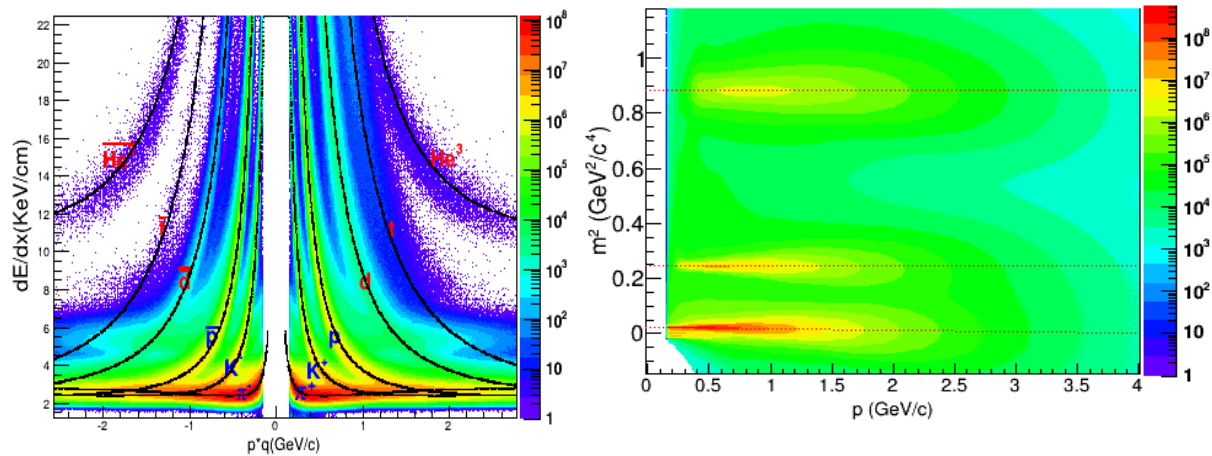


Figure -1. Left Figure: dE/dx as a function of momentum*charge. Right Figure: The mass squared (m^2) as a function of momentum for minimum bias (0-80%) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

to momenta of ~ 1.7 GeV/c for pions and kaons and ~ 3 GeV for protons. A representative plot of dE/dx as a function of (momentum*charge) (Left Figure) and m^2 as a function of particle momentum (Right Figure) is shown in Figure 1, respectively, for a minimum bias (0-80%) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Theoretical curves are shown by solid black lines.

Azimuthal anisotropy can be quantified by studying the Fourier expansion of the azimuthal angle (ϕ) distribution of produced particles with respect to the reaction plane angle (ψ_R) and can be written as

$$E \frac{d^3N}{d^3P} = \frac{1}{2\rho} \frac{d^2N}{pTdpTdy} \left(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \psi_R)) \right)$$

where y is rapidity, ϕ is the azimuthal angle of each particle and ψ_R is the event plane. The sine terms in the Fourier expansion vanish due to the reflection symmetry with respect to the reaction plane. The reaction plane ψ_R is not measurable directly so the Fourier coefficients are determined with respect to the estimated event planes

$$v_n^{\text{obs.}} = \langle \cos(n(\phi - \psi_n)) \rangle$$

where v_n represent n^{th} order harmonics with $n = 2, 3, 4$ corresponding to elliptic, triangular and quadrangular flow respectively and ψ_n are the n^{th} order event planes. The v_n measured with respect to the event plane are corrected for the event plane resolution. The total number of events analyzed is 562 million.

The η -sub event plane method [4] 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 0.15 between positive and negative pseudo-rapidity sub-events has been introduced to suppress non-flow effects. The invariant mass method [5] has been used to extract the v_n of ϕ -meson.

RESULTS AND DISCUSSIONS

The ϕ -meson v_n as a function of transverse momentum (p_T) for a minimum bias (0 – 80%), 0 – 30% and 30 – 80% centralities in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is presented in Figure 2.

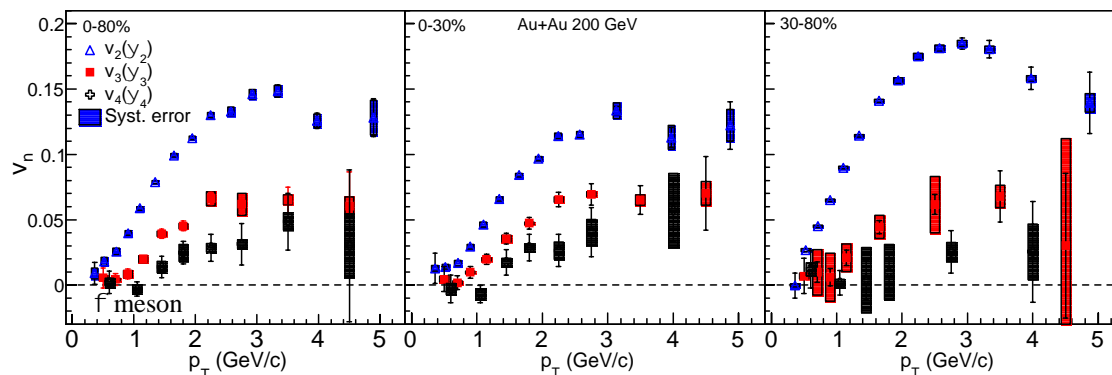


Figure -2. v_n of ϕ -meson as a function of transverse momentum (p_T) in Au+Au at $\sqrt{s_{NN}} = 200$ GeV. The line is a 4th order polynomial fit to the measured ϕ -meson V_2 . The vertical bars in each point correspond to the statistical error and shaded bands correspond to the systematic error.

The vertical bars in each data point correspond to the statistical error and shaded bands correspond to the systematic error. From the Figure 2, we conclude that all v_n measurement of the ϕ -meson show an increasing trend with increasing p_T i.e. $v_n(p_T)$ at 200 GeV increases with transverse momentum and reaches its maximum at intermediate p_T (~ 3 GeV/c) after which it decreases again.

Further the magnitude of v_2 is greater than v_3 and v_4 ($v_2 > v_3 > v_4$). In this figure, we also observe that v_2 shows strong centrality dependence i.e. the ϕ -meson v_2 values for 30 – 80% is larger than that of 0 – 30%. This is expected because eccentricity of the initial nuclear overlap area which reflects the initial spatial anisotropy is larger for 30 – 80% (mid central to peripheral) than that for 0 – 30% (central to mid peripheral) collisions. The flow coefficient v_3 exhibits no centrality dependence which suggests that its origin is entirely from fluctuations of the initial geometry of the system. Similarly the v_4 measured with respect to ψ_4 does not depend strongly on the collision centrality which indicates strong contribution from the flow fluctuations.



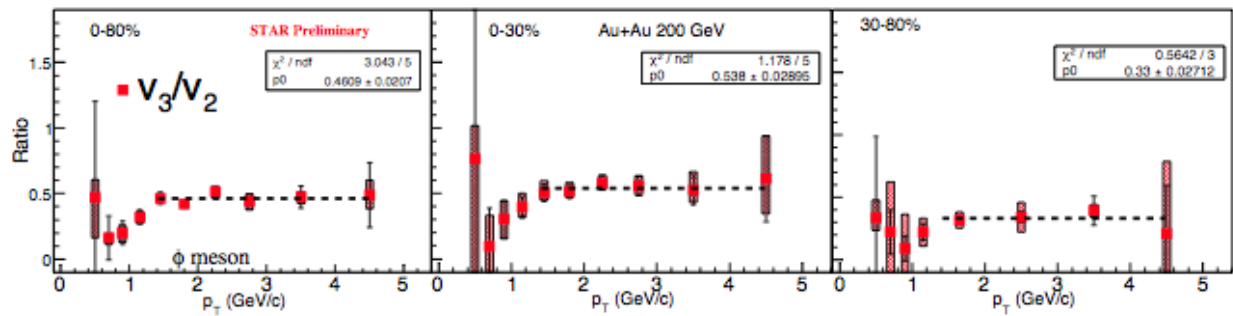


Figure -3. The v_3/v_2 as a function of transverse momentum (p_T) in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The vertical bars in each point correspond to the statistical error and shaded bands correspond to the systematic error.

Figure 3 shows ϕ -meson v_3/v_2 as a function of p_T for a minimum bias (0 - 80%), 0 - 30% and 30 - 80% centralities in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. From the figure, we can say that the ratio (v_3/v_2) is constant for $p_T > 1.5$ GeV/c and shows a centrality dependence.

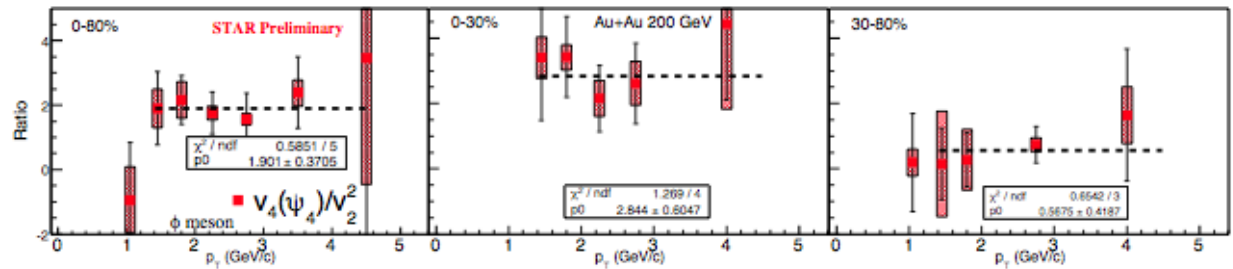


Figure -4. The $v_4(\psi_4)/v_2$ ratio as a function of transverse momentum (p_T) in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The vertical bars in each point correspond to the statistical error and shaded bands correspond to the systematic error.

Figure 4 presents ϕ -meson $v_4(\psi_4)/v_2$ as a function of p_T for a minimum bias (0 - 80%), 0 - 30% and 30 - 80% centralities in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The ratio $v_4(\psi_4)/v_2$ is expected to reach 0.5 [6] in ideal hydrodynamics. From the figure, we can see that the ratio is near or larger than one for all the centralities. One explanation is that the interactions among the produced particles are not strong enough to produce local thermal equilibrium, so that the hydrodynamic description breaks down and the resulting value is higher. It is also argued that elliptic flow fluctuations may enhance the value of $v_4(\psi_4)/v_2$. As per the calculations of coalescence model, the value of the ratio ($v_4(\psi_4)/v_2$) is ≈ 0.75 [7], which is also lower than what we have observed in our measurement.



Summary

We report the measurement of ϕ -meson azimuthal anisotropy v_n for $n = 2, 3$ and 4 as a function of transverse momentum (p_T) in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. We observe that v_n increases with p_T and has a maximum value at 2-3 GeV/c. We also observe a strong centrality dependence of $v_2(\psi_2)$ but no centrality dependence for the harmonics $v_3(\psi_3)$ and $v_4(\psi_4)$. We also observe that the ratio v_3/v_2 is constant for $p_T > 1.5$ GeV and $v_4(\psi_4)/v_2$ ratio is higher for central collisions compare to peripheral collisions. The values of the ratio $v_4(\psi_4)/v_2$ were found to be greater than 1, well in excess of the value of 0.5 expected from ideal hydrodynamics or the value of ~ 0.75 expected from coalescence arguments.

REFERENCES

- [1] J. Adams et al., "Multi-strange baryon elliptic flow in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV", Physics Review Letter, Volume No. 95, 122301 (2005).
- [2] Md. Nasim, Bedangadas Mohanty and Nu Xu., "Elliptic flow of ϕ -mesons as a sensitive probe for the onset of the deconfinement transition in high energy heavy-ion collisions", Physics Review C, Volume No. 87, 014903 (2013) and B. Mohanty and N.Xu., "Probe of the QCD phase diagram with ϕ -mesons in high-energy nuclear collisions", Journal of Physics G, Volume No. 36, 060422 (2009).
- [3] M. Anderson et al., "The STAR Time Projection Chamber: A Unique Tool for Studying High Multiplicity Events at RHIC", Nucl. Instrum. Meth. A, Volume No. 499, 659 (2003).
- [4] A. M. Poskanzer and S. A. Voloshin "Methods for analyzing anisotropic flow in relativistic nuclear collisions", Physics Review C, Volume No. 58, 1671 (1998).
- [5] N. Borghini and J. Ollitrault, "Azimuthally sensitive correlations in nucleus-nucleus collisions" Physics Review C, Volume No. 70, 064905 (2004).
- [6] C. Lang et al., "Dissipative corrections to particle spectra and anisotropic flow from a saddle-point approximation to kinetic freeze out", Eur. Phys. J. Volume No. C 74 (2014) 2955.
- [7] L. W. Chen et al., " ϕ and Ω production in relativistic heavy-ion collisions in a dynamical quark coalescence model", Physics. Review. C, Volume No. 73, 044903 (2006).

