STAR measurements on azimuthal anisotropy of ϕ mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 27 and 54.4 GeV

Prabhupada Dixit (for the STAR collaboration)

Indian Institute of Science Education and Research, Berhampur, India
prabhupadad@iiserbpr.ac.in

Abstract. The elliptic flow coefficient (v_2) of ϕ mesons at mid-rapidity as a function of transverse momentum (p_T) is measured for Au+Au collisions at centre of mass energies ($\sqrt{s_{NN}}$) 27 and 54.4 GeV. The v_2 measurement is done using event plane from Time Projection Chamber (TPC, $|\eta|$ <1.0) and Event Plane Detectors (EPD, 2.1<$|\eta|$<5.1) for 54.4 and 27 GeV, respectively. A high precision test of the number of constituent quark scaling of ϕ meson v_2 (by including measurements for other hadrons) has been shown.

1 Introduction

In extremely hot and dense medium, the matter exists in a new state where quarks and gluons are no longer bound inside the hadrons. This state is called Quark-Gluon Plasma (QGP). To study the various macro-state properties of QGP, azimuthal anisotropy in its expansion is used as one of the well-known observables [1]. Due to the difference in pressure gradient along different axes of the collision system, the expansion of medium is not isotropic and this initial spatial anisotropy gives rise to the anisotropy in momentum space. To study different order of azimuthal anisotropy, Fourier expansion of the azimuthal distribution of particles in momentum space is used [2], which is given by

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left[1 + \sum_n 2v_n \cos n(\phi - \psi_R)\right]. \quad (1)$$

The coefficient v_n is called n^{th}-order flow coefficient which is given by

$$v_n = \langle \cos n(\phi - \psi_R) \rangle. \quad (2)$$

The angled bracket indicates the average over all the particles and all the events. ψ_R is the reaction plane (plane spanned by the impact parameter vector and collision axis) of the collision system. In this proceedings, we have studied the second-order flow coefficient v_2, known as elliptic flow coefficient. The elliptic flow of ϕ mesons is considered as a good probe for the initial stage of the medium

produced in heavy-ion collisions. Due to its small hadronic interaction cross-section and early freeze-out, ϕ-meson v_2 is less affected by the late-stage hadronic interactions. In this proceedings, elliptic flow of ϕ mesons at mid-rapidity as a function of transverse momentum in Au+Au collision at $\sqrt{s_{NN}}$ = 27 and 54.4 GeV is presented. We have used high statistics 27 GeV data from year 2018 and 54.4 GeV data from year 2017.

2 Data Sets and Methods

The main STAR detectors that we have used in our analysis are the Time Projection Chamber (TPC), the Time Of Flight (TOF) detector and the Event Plane Detectors (EPDs). The TPC and TOF have full azimuthal coverage and have pseudorapidity coverage of $|\eta|<1.0$. The TPC is used to detect charged particles by measuring their ionization energy loss (dE/dx) and TOF is used to identify charged particles with high p_T. The EPDs have pseudorapidity coverage of $2.1<|\eta|<5.1$. These EPDs are used to construct the event plane of the collision.

We first reconstruct ϕ mesons by calculating the invariant mass ($M_{inv} = \sqrt{E_i^2 - p_i^2}$) of its daughter particles K^+ and K^- from the same events. The combinatorial background is calculated by using the event-mixing method. The normalized background distribution is subtracted from the signal+background distribution from the same events to get the signal of ϕ mesons. The signal distribution is then fitted with the Breit-Wigner function to calculate the yield of ϕ mesons.

We have used the second-order event plane from TPC using η sub-event method for 54.4 GeV and EPD full event plane for 27 GeV to calculate v_2. The observed v_2 has been corrected by the event plane resolution. The event plane resolution as a function of centrality is shown in Fig. 1. More details can be found in [3].

v_2 of ϕ mesons has been calculated by using the invariant mass method [4], in which, v_2 is calculated as a function of the invariant mass of K^+ and K^- as shown in the lower panel of Fig. 1 (right) and the distribution is fitted with Eq. (5).

$$v_2^{S+B}(M_{inv}) = v_2^S \frac{S}{S+B}(M_{inv}) + v_2^B \frac{B}{S+B}(M_{inv}) \tag{3}$$

where v_2^S is v_2 of signal and v_2^B is v_2 of background. S is the yield of the ϕ meson and B accounts for the total background counts. v_2^B can be approximated as a first-order polynomial function of invariant mass and v_2^S can be obtained as a free parameter of the fit.

3 Results

The p_T dependence of ϕ meson v_2 has been studied at $\sqrt{s_{NN}}$ = 27 GeV using EPD event plane and compared to v_2 using TPC event plane [5] for 0-80% centrality events. TPC and EPDs have different η coverage and have different

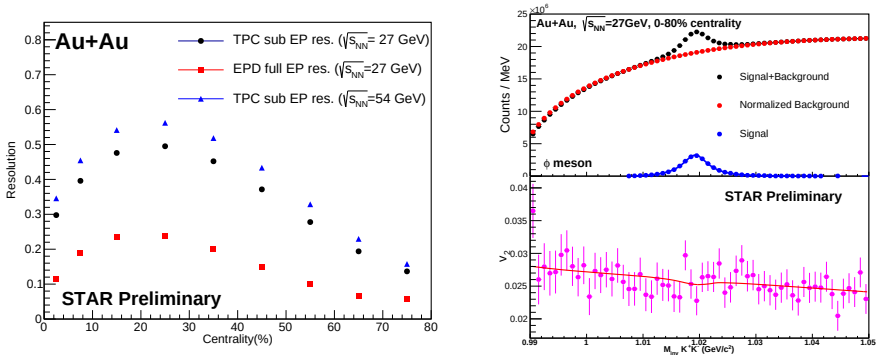

Fig. 1. Left panel shows TPC sub-event plane resolutions for $\sqrt{s_{NN}} = 27$ and 54.4 GeV as a function of centrality. EPD full-event plane resolution for $\sqrt{s_{NN}} = 27$ GeV is also shown. In the upper right panel, invariant mass distribution of K^+ and K^- from the same events (signal + background), from the mixed events (normalized background) and the background subtracted signal is shown. In the lower right panel, v_2 using EPD event plane is plotted as a function of the invariant mass of K^+ and K^-. The distribution is fitted with Eq. (5).

minimum η gap between reconstructed ϕ mesons and the event plane (0.05 for TPC and 1.1 for EPD) but as shown in Fig. 2 (left panel) the v_2 for both the event planes are compatible with each other within statistical uncertainties which indicates that the effect of non-flow is negligible. In the right panel, we have compared the high precision measurement of ϕ meson v_2 at $\sqrt{s_{NN}} = 54.4$ with that at 62.4 GeV [5] and found that they are compatible with each other.

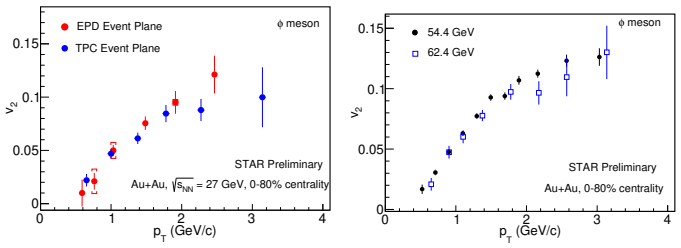

Fig. 2. Left panel shows the comparison of v_2 using TPC event plane and EPD event plane at $\sqrt{s_{NN}}$ =27 GeV for centrality 0-80% and the right panel shows the comparison between v_2 at $\sqrt{s_{NN}}$ =54.4 GeV and 64.4 GeV for centrality 0-80%. Vertical lines represent statistical uncertainties and cap-symbols represent systematic uncertainties. The systematic errors are shown for only v_2 using EPD event plane.

One of the main goals of the STAR experiment is to search for turn-off signal of QGP which can be studied by the number of constituent quark (NCQ) scaling

in v_2 for all hadrons as a function of energy. The number of constituent quark scaling has been studied at $\sqrt{s_{NN}} = 27$ and 54.4 GeV using v_2 of ϕ as well as other identified hadrons [5]. The results are shown in Fig. 3.

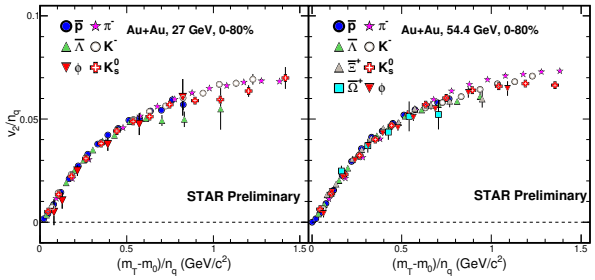

Fig. 3. v_2 scaled by the number of constituent quarks as a function of transverse kinetic energy per number of constituent quarks for various charged hadrons are shown at $\sqrt{s_{NN}} = 27$ and 54.4 GeV for 0-80% centrality. Only statistical error bars are shown in Fig.3.

The NCQ scaled v_2 is found to be similar for all the particles under study. This observation can be interpreted as the collectivity being developed at the partonic stage of the evolution of the system in Au+Au collisions at $\sqrt{s_{NN}} =$ 27 and 54.4 GeV.

4 Summary

The elliptic flow coefficient v_2 of ϕ mesons has been studied for Au+Au collisions at $\sqrt{s_{NN}} = 27$ and 54.4 GeV. v_2 of ϕ meson at $\sqrt{s_{NN}} = 27$ GeV using EPD event plane is found to be in good agreement with v_2 using TPC event plane. The NCQ scaling is observed for all the hadrons at both these energies which indicates the partonic collectivity developed inside the medium during the earlier stage of its evolution.

References

1. H. Sorge. Elliptical flow: A signature for early pressure in ultrarelativistic nucleus-nucleus collisions. *Phys. Rev. Lett.*, 78:2309–2312, Mar 1997.
2. S. Voloshin and Y. Zhang. Flow study in relativistic nuclear collisions by Fourier expansion of Azimuthal particle distributions. *Z. Phys. C*, 70:665–672, 1996.
3. A. M. Poskanzer and S. A. Voloshin. Methods for analyzing anisotropic flow in relativistic nuclear collisions. *Phys. Rev. C*, 58:1671–1678, Sep 1998.
4. N. Borghini and J.-Y. Ollitrault. Azimuthally sensitive correlations in nucleus-nucleus collisions. *Phys. Rev. C*, 70:064905, Dec 2004.
5. L. Adamczyk and et al. Elliptic flow of identified hadrons in au+au collisions at $\sqrt{s_{NN}} = 7.7$–62.4 gev. *Phys. Rev. C*, 88:014902, Jul 2013.