Investigation of particle antiparticle elliptic flow difference at STAR experiment*

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The azimuthal anisotropy in particle emission in the transverse plane, known as anisotropic flow, is used to study the properties of strongly interacting hot and dense medium created in heavy-ion collisions. Anisotropic flow coefficients are the key observables which reflect the viscous hydrodynamic response to the initial spatial anisotropy, produced in the early stages of the collision. In previous studies performed by the Solenoidal Tracker At RHIC (STAR) collaboration at the Relativistic Heavy Ion Collider (RHIC) the increase of the elliptic flow (v_2) difference between particles and antiparticles at the lower collision energies has been observed. In these proceedings we present the measurement of the two-particle elliptic and triangular flow correlations for identified particles performed by the STAR experiment. Our measurements are compared with the EPOS model simulations as well.

1. Introduction

Studying the properties of the strongly interacting matter is one of the major milestones for current heavy ion research. Various experimental facilities have been designed to investigate the Quantum Chromo-Dynamical (QCD) phase diagram such as Beam Energy Scan (BES) [1] at Relativistic Heavy Ion Collider (RHIC) [2]. This program is at the forefront of experimental efforts designed to map the thermodynamical and transport properties of strongly interacting QCD matter. Flow is an observable characterizing the shape of the expanding matter [4, 5]. It is very sensitive to the properties of the system at very early time of its evolution. In the previous studies performed by STAR collaboration [3, 8, 9] the increase of the difference in elliptic flow of particles and antiparticles with the decrease of the collision energy has been observed. However, the sources of these phenomena were not well understood.

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2. Measurements

The two-particle correlations (2PCs) are obtained by averaging over all unique combinations in single event, and then over all events [6]. All particles from one collision are divided into two groups - subevents a and b considering their pseudorapidity (η). The 2PCs are calculated with the following formula:

$$c_n\{2\} = \langle\langle 2\rangle\rangle_{a|b} = \langle\langle e^{in(\phi_1^a - \phi_2^b}\rangle\rangle = \langle\frac{\langle Q_{n,a}Q^*_{n,b}\rangle}{\langle M_a M_b\rangle\rangle} \quad (1)$$

where: n - flow harmonic, ϕ - particle's azimuthal angle, $M_{a/b}$ - multiplicity of particles in subevents a and b, and $Q_{n,a/b} \equiv \sum_i e^{in\phi_i^{a/b}}$ - flow vector. This leads to the following cumulant-based definition of harmonic flow v_n:

$$v_n\{2\} = \sqrt{c_n\{2\}} \quad (2)$$

The flow dependence on the transverse momentum of particles is given by:

$$v_n(p_T) \ = \ v_n^2(p_T, p_T^{ref})/\sqrt{v_n^2(p_T^{ref}, p_T^{ref})}, \quad (3)$$

where p_T^{ref} is the transverse momentum of the reference particle. The 2PCs carry flow and non-flow (NF) contribution: short-range (HBT, decays of resonances, etc.) and long-range (momentum-conservation, di-jets, etc.) [6, 7]. In order to suppress NF impact on the measurements, the $\Delta\eta$ between subevents is introduced. In the Figure 1 $v_n\{2\}$ measurements with different gap in the pseudorapidity are presented. The bigger $\Delta\eta$ is used the more NF contribution is suppressed. It is more pronounced for peripheral events.

Calculated flow measurements are scaled with the number of constituent quarks of given hadron (NCQ-scaling) in function of transverse kinetic energy (KE_T) [12].

For identification of particles the Time Projection Chamber (TPC) and Time-Of-Flight (TOF) information were used in the momentum range p (GeV/c) ≤ 4.0 and rapidity $|y| < 1.0$.

3. Results and discussion

The p_T-differential two-particle correlations for various flow harmonics were measured for the data collected by STAR at two collision energies: $\sqrt{s_{NN}}$ = 200 GeV and 39 GeV. For all flow measurements only statistical errors are taken into account. The p_T-differential two-particle correlations $v_2\{2\}$, $v_3\{2\}$ and $v_4\{2\}$ for identified hadron in centrality range $10\% - 40\%$,

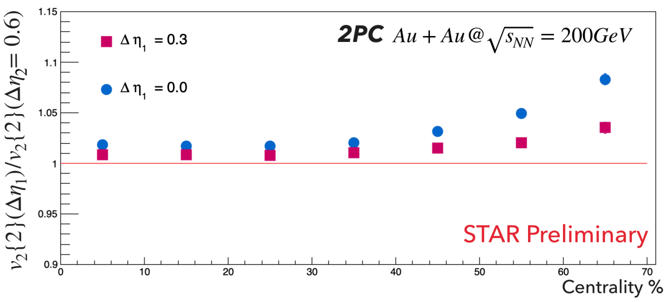

Fig. 1: Ratio of the centrality dependent $v_2\{2\}$ with $\Delta\eta_1 = 0.0$ and 0.3 to $v_2\{2\}$ with $\Delta\eta_2 = 0.6$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The transverse momentum range: $0.2 < p_T$ (GeV/c)< 4.0.

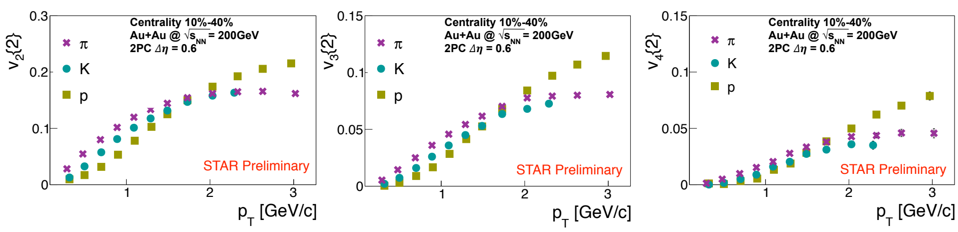

Fig. 2: $v_2\{2\}$, $v_3\{2\}$ and $v_4\{2\}$ in function of p_T for $\Delta\eta = 0.6$, centrality $10\% - 40\%$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

measured for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are shown in Fig. 2. The mass dependence is visible for all studied harmonics. The NCQ(KE$_T$)-scalings are presented in Fig.3. All studied harmonics $v_n\{2\}/n_q^{n/2}$ scales with KE$_T$/nq.

The elliptic and triangular flow for identified hadrons measured in Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV are presented in Fig.4 and 5. Both v_n show similar trends.

The ratios of particles to antiparticles elliptic and triangular flow are shown in Fig.6 and 7. The differences between protons' and antiprotons'

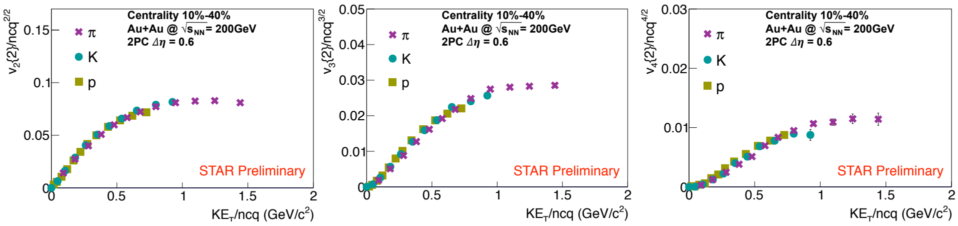

Fig. 3: Scaling with number of constituent quarks ($ncq^{n/2}$, where n is the flow harmonic) of $v_2\{2\}$, $v_3\{2\}$ and $v_4\{2\}$ in function of KE_T/ncq with $\Delta\eta = 0.6$, centrality $10\% - 40\%$ for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

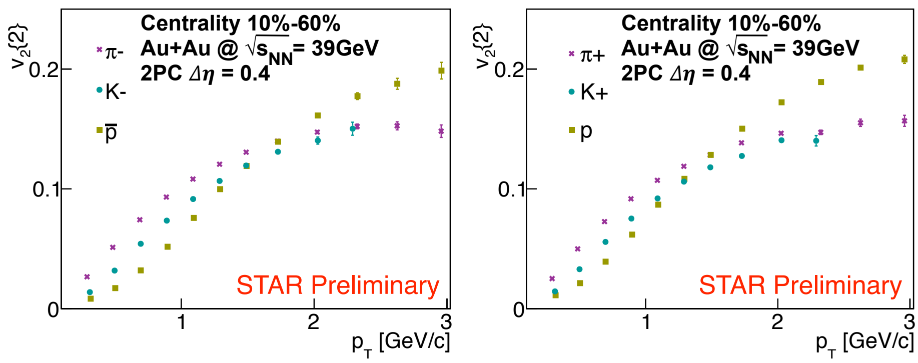

Fig. 4: Particles (left panel) and antiparticles (right panel) $v_2\{2\}$ in function of p_T for $\Delta\eta$ gap equals 0.4, centrality $10\% - 60\%$ for Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV.

elliptic flow, especially for lower p_T, are significant. On the other hand, the available statistic for introduced cuts and $\Delta\eta$ does not allow for such clear conclusion in case of triangular flow.

The performed experimental studies of elliptic flow are compared with results obtained using simulated EPOS model data [10, 11]. Hydrodynamical evolution included in the model is based on the Equation of State corresponding to the baryonic chemical potential (μ_B) equals to zero. The research was done for two collision energies $\sqrt{s_{NN}} = 39$ GeV and 200 GeV,

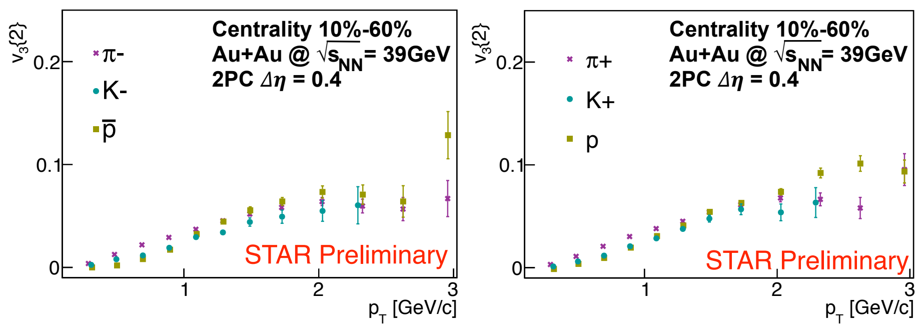

Fig. 5: Particles (left panel) and antiparticles (right panel) $v_3\{2\}$ in function of p_T for $\Delta\eta = 0.4$, centrality 10%−60% for Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV.

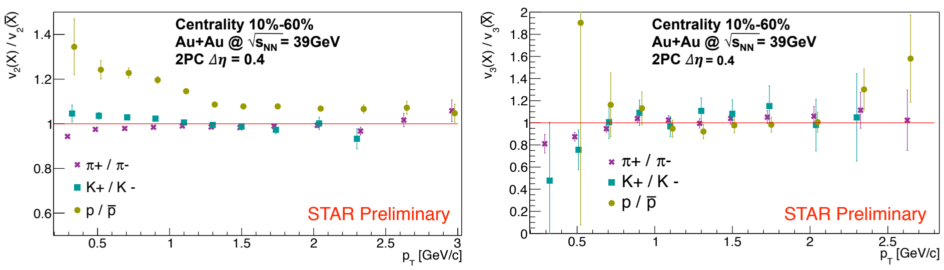

Fig. 6: Ratio of $v_2\{2\}$ (left panel) and $v_3\{2\}$ (right panel) of particles to antiparticles, $\Delta\eta$ gap equals 0.4, centrality $10\% - 60\%$ for Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV.

is presented in Fig. 7.

The EPOS model does not reproduce pions' elliptic flow for $p_T > 2$ GeV/c at $\sqrt{s_{NN}} = 200$ GeV, while at $\sqrt{s_{NN}} = 39$ GeV the model fails in describing v_2 of π's in the whole p_T range. Comparisons with the experimental flow measurements can be a useful constrain for the future model development.

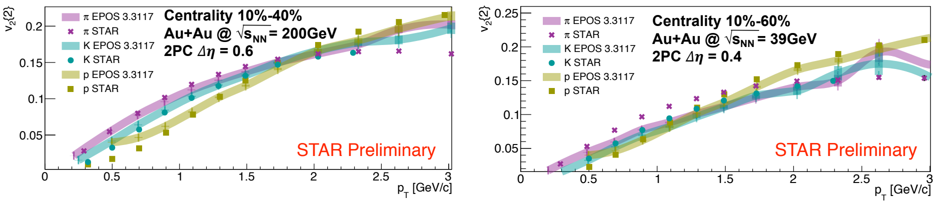

Fig. 7: $v_2\{2\}$ of identified particles at $\sqrt{s_{NN}} = 200$ GeV (left panel) and $\sqrt{s_{NN}} = 39$ GeV (right panel). STAR experimental data are compared with EPOS 3.3117 simulated data.

4. Conclusion

In summary, we have presented a comprehensive set of STAR v_n measurements for Au+Au collision energies $\sqrt{s_{NN}} = 39$ GeV and 200 GeV. The mass dependence of all studied harmonics is visible. The NCQ(KE$_T$)-scaling works for gold ion collisions at $\sqrt{s_{NN}} = 200$ GeV, while it seems to be broken at $\sqrt{s_{NN}} = 39$ GeV by protons. This could indicate the various origins of these baryons. Elliptic flow of protons is larger than for antiprotons at $\sqrt{s_{NN}} = 39$ GeV. In the case of triangular flow, which is a fluctuation-driven quantity, the differences are not that relevant.

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