

Recent elliptic flow results from Beam Energy Scan at STAR

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Abstract. We present measurement of elliptic flow, v_2 , for charged and identified particles at midrapidity in Au+Au collisions at $\sqrt{s_{NN}} = 7.7 - 39$ GeV. We compare the inclusive charged hadron v_2 to those from high energies at RHIC ($\sqrt{s_{NN}} = 62.4$ and 200 GeV), at LHC ($\sqrt{s_{NN}} = 2.76$ TeV). The energy dependence of the difference in v_2 between particles and anti-particles is discussed.

1. Introduction

Searching for the region of a possible phase transition between the Quark Gluon Plasma (QGP) and the hadron gas phase in the QCD phase diagram is one of the main goals of the Beam Energy Scan (BES) at RHIC. Due to the sensitivity to the underlying dynamics in the early stage of the collisions, the elliptic flow (v_2) could be used as a powerful tool [1]. In the top energy ($\sqrt{s_{NN}} = 200$ GeV) for Au+Au and Cu+Cu collisions at RHIC, the number of constituent quark (NCQ) scaling in v_2 reflects that the collectivity has been built up at the partonic stage [2, 3, 4]. Especially, the NCQ scaling of multi-strange hadrons, ϕ and Ω , provides the clear evidence of partonic collectivity because they are less sensitive to the late hadronic interactions [5, 6]. Further, a study based on a multi-phase transport model (AMPT) indicates the NCQ scaling is related to the degrees of freedom in the system [7]. The holding of the NCQ scaling reflects the partonic degree of freedom, whereas the breaking of the scaling reflects the hadronic degree of freedom. In reference [8], the importance of ϕ meson has been emphasized. Without partonic phase, the ϕ meson v_2 could be small or zero. Thus, the measurements of elliptic flow with the BES data offer us the opportunity to investigate the phase boundary in the QCD phase diagram.

In this proceedings, we present the v_2 results of charged and identified hadrons from the STAR experiment in Au+Au collisions at $\sqrt{s_{NN}} = 7.7 - 39$ GeV. The Time Projection Chamber (TPC) [9] is used as the main detector for event plane determination. The centrality is determined by the number of tracks from the pseudorapidity region $|\eta| \leq 0.5$. The particle identification for π^\pm , K^\pm and p (\bar{p}) is achieved via the energy loss in the TPC and the time of flight information from the multi-gap resistive plate chamber detector [10]. Strange hadrons are reconstructed from their decay channels: $K_S^0 \rightarrow \pi^+ + \pi^-$, $\phi \rightarrow K^+ + K^-$, $\Lambda \rightarrow p + \pi^-$ ($\bar{\Lambda} \rightarrow \bar{p} + \pi^+$), and $\Xi^- \rightarrow \Lambda + \pi^-$ ($\Xi^+ \rightarrow \bar{\Lambda} + \pi^+$). The detailed description of

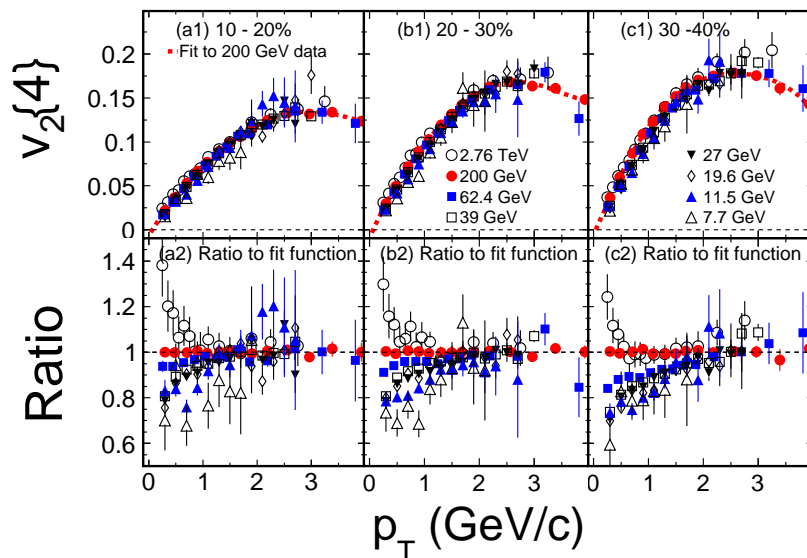


Figure 1. The top panels show $v_2\{4\}$ vs. p_T at midrapidity for various collision energies ($\sqrt{s_{NN}} = 7.7$ GeV to 2.76 TeV). The results for $\sqrt{s_{NN}} = 7.7$ to 200 GeV are for Au+Au collisions [15] and those for 2.76 TeV are for Pb + Pb collisions [16]. The dashed red curves show the fifth order polynomial fits to the results from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The bottom panels show the ratio of $v_2\{4\}$ vs. p_T for all $\sqrt{s_{NN}}$ with respect to the fit curve. The results are shown for three collision centrality classes: 10 – 20% (a1), 20 – 30% (b1) and 30 – 40% (c1) [17].

the reconstruction procedure can be found in Refs. [2, 3, 11]. The event plane method [12] and cumulant method [13, 14] are used for the v_2 measurement.

2. Results and Discussions

Figure 1 [17] shows the p_T dependence of $v_2\{4\}$ from $\sqrt{s_{NN}} = 7.7$ GeV to 2.76 TeV in 10 – 20% (a1), 20 – 30% (b1) and 30 – 40% (c1) centrality bins, where the ALICE results in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are taken from Ref. [16]. The 200 GeV data is empirically fit by a fifth order polynomial function. For comparison, the v_2 from other energies are divided by the fit and shown in the lower panels of Fig. 1. We chose 200 GeV data as the reference, because the statistical errors are smallest. For p_T below 2 GeV/c, the v_2 values increase with collision energy. Beyond $p_T = 2$ GeV/c the v_2 results are comparable within statistical errors. The increase of $v_2(p_T)$ at low p_T as a function of energy could be due to the change of chemical composition from low to high energies and/or larger collectivity at higher collision energy.

Figure 2 [18, 19] shows the excitation function for the relative difference of v_2 between particles and anti-particles. In order to reduce the non-flow effect, the η -sub event plane method is used for the measurement. The η -sub event plane method is similar to the event plane method, except one defines the flow vector for each particle based on particles measured in the opposite hemisphere in pseudorapidity. An η gap of $|\eta| < 0.05$ is used between negative/positive η subevent to guarantee that non-flow effects are reduced by enlarging the separation between the correlated particles. The difference between the v_2 values of the baryon and the corresponding anti-baryon is within 10% at $\sqrt{s_{NN}} = 39$ and 62.4 GeV, while the difference increases as the beam energy decreases to below 39 GeV. At $\sqrt{s_{NN}} = 7.7$ GeV, the difference in the v_2 values of the protons versus anti-protons is around 60%. The difference between v_2 values for the π^+

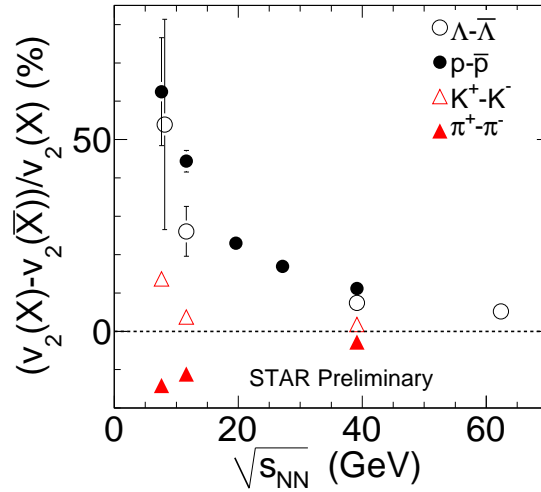


Figure 2. (Color online) The difference of v_2 for particles and anti-particles ($v_2(X) - v_2(\bar{X})$) divided by particle v_2 ($v_2(X)$) as a function of beam energy in Au+Au collisions (0-80%) [18, 19].

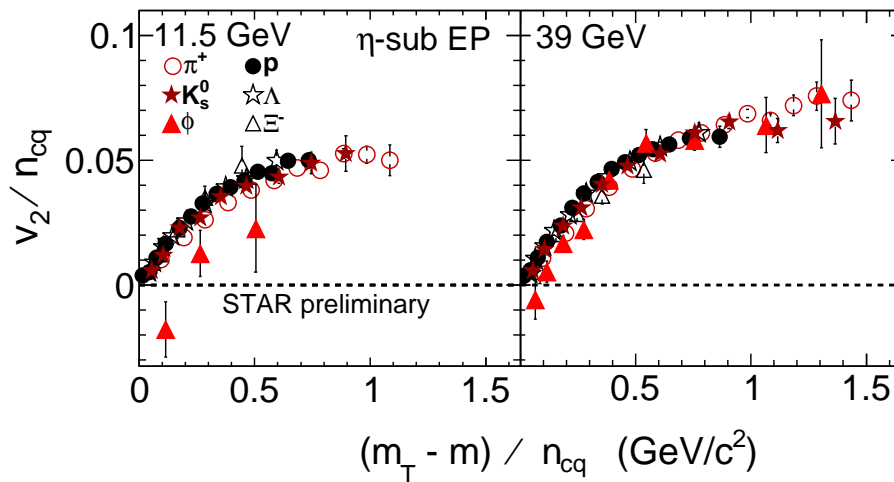


Figure 3. (Color online) The number of constituent quark (n_{cq}) scaled v_2 as a function of transverse kinetic energy over n_{cq} ($(m_T - m)/n_{cq}$) for various identified particles in Au+Au collisions (0-80%) at $\sqrt{s_{NN}} = 11.5$ and 39 GeV [22, 23].

versus π^- is within 3% and those for the K^+ versus K^- is within 2% at $\sqrt{s_{NN}} = 39$ GeV. With the decrease of beam energy, the v_2 values of π^+ versus π^- and K^+ versus K^- start to show the difference. The v_2 of π^- is larger than that of π^+ and the v_2 of K^+ is larger than that of K^- . This difference between particles and anti-particles could be qualitatively reproduced by considering the baryon transport effects [20] or by introducing hadronic potential effect in model

calculations [21]. These results indicate that the hadronic interaction become more dominant at the lower beam energy. The immediate consequence of the significant difference between baryon and anti-baryon v_2 is that the NCQ scaling is broken between particles and anti-particles when $\sqrt{s_{NN}} < 39$ GeV. Figure 3 [22, 23] shows the $m_T - m$ differential v_2 for the selected identified particles. The v_2 and $m_T - m$ ($m_T = \sqrt{p_T^2 + m^2}$) are divided by number of constituent quark in each hadron. The m represents the invariant mass for the corresponding particle. The similar scaling behavior at $\sqrt{s_{NN}} = 39$ GeV is observed as was found in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Especially, the v_2 of the ϕ mesons which are less sensitive to the later hadronic interactions follow the same trend of v_2 as for the other particles. It suggests that the partonic degree of freedom and collectivity has been built up at $\sqrt{s_{NN}} = 39$ GeV. Whereas, at $\sqrt{s_{NN}} = 11.5$ GeV, the v_2 for ϕ mesons falls off from other particles. The mean deviation from the v_2 values of π^+ is 2.6σ . More events at 11.5 GeV are needed for a clear conclusion.

3. Summary

In summary, we present the v_2 measurements for charged hadrons and identified hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 7.7 - 39$ GeV. The comparison with Au+Au collisions at higher energies at RHIC ($\sqrt{s_{NN}} = 62.4$ and 200 GeV) and at LHC (Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV) shows the $v_2\{4\}$ values at low p_T ($p_T < 2.0$ GeV/ c) increase with increase in the collision energy. The difference between the v_2 of particles and anti-particles is observed. The baryon and anti-baryon v_2 show significant difference for $\sqrt{s_{NN}} < 39$ GeV. The difference of v_2 between difference particles and anti-particles (pions, kaons, protons and Λ s) increases with decreasing of the beam energy. Experimental data indicates that the hadronic interactions become more important at the lower beam energy.

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