ANISOTROPIC FLOW MEASUREMENTS WITH MULTI-PURPOSE DETECTOR AT NICA*

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The anisotropic transverse flow is one of the key observables to study the properties of dense matter created in heavy-ion collisions. The performance of Multi-Purpose Detector for directed and elliptic flow measurements is studied with Monte Carlo simulations of heavy-ion collisions at NICA energies $\sqrt{s_{NN}} = 4$–11 GeV.

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1. Introduction

The Multi-Purpose Detector (MPD) at NICA collider has a substantial discovery potential concerning the exploration of the QCD phase diagram in the region of high net-baryon densities and moderate temperatures [1]. The anisotropic collective flow, as manifested by the anisotropic emission of particles in the plane transverse to the beam direction, is one of the important observables sensitive to the transport properties of the strongly interacting matter: the equation of state (EOS), the specific shear and bulk viscosity [2]. The azimuthal anisotropy of produced particles can be quantified by the Fourier coefficients v_n in the expansion of the particles azimuthal distribution as: $\mathrm{d}N/\mathrm{d}\phi \propto 1 + \sum_{n=1} 2v_n \cos(n(\phi - \Psi_n))$, where n is the order of the harmonic, ϕ is the azimuthal angle of particles of a given type, and Ψ_n is the azimuthal angle of the n^{th}-order event plane. In this work, we briefly review the available experimental results for the collision energy dependence of directed (v_1) and elliptic (v_2) flow and discuss the anticipated performance of MPD detector for flow measurements at NICA energies.

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2. Collision energy dependence of directed and elliptic flow

The slope of the rapidity dependence dv_1/dy near mid-rapidity ($y \sim 0$) is a convenient way to characterize the overall magnitude of directed flow signal [3]. A minimum in dv_1/dy for baryons could be related to the softening of equation of state due to the first order phase transition between hadronic matter and sQGP [3]. The recent results from the STAR experiment at RHIC ($\sqrt{s_{NN}} = 7.7$–200 GeV) seem to support this prediction, both protons and Λ hyperons dv_1/dy show a minimum around $\sqrt{s_{NN}} = 10$–20 GeV [4], see left panel of Fig. 1. The gray/green curves show the approximate upper and lower bounds for centrality dependence of dv_1/dy for protons.

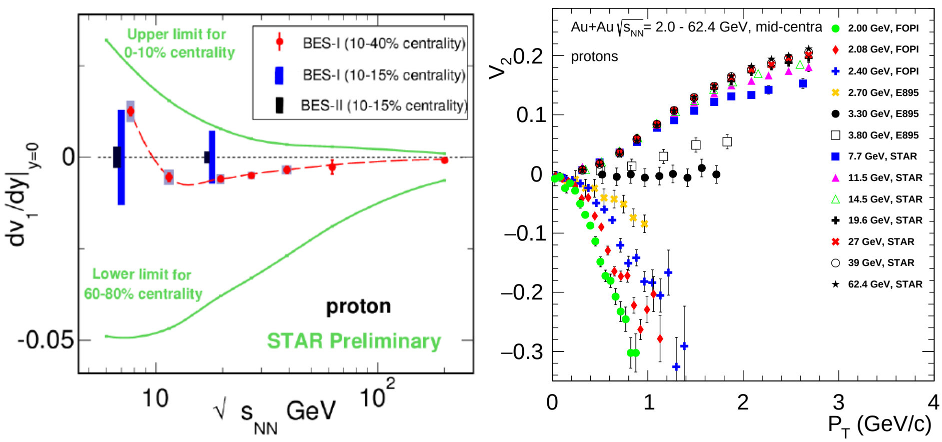

Fig. 1. (Color online) Left: Excitation function of dv_1/dy for protons from Au+Au collisions based on results from STAR [4]. Excitation function of $v_2(p_{\rm T})$ of protons from mid-central Au+Au collisions at energies from $\sqrt{s_{NN}} = 2$ to 62.4 GeV [2].

In general, the assumption of purely hadronic physics is disfavored by the comparison with predictions from current state-of-the-art models [3]. However, all current models are not able to reproduce the $\sqrt{s_{NN}}$ dependence of baryon dv_1/dy-slope reported by STAR. Thus, further progress in the area of model calculations and high-statistics differential measurements of v_1 is needed.

The right panel of Fig. 1 shows the excitation function for differential elliptic flow $v_2(p_{\rm T})$ of protons from mid-central Au+Au collisions at $\sqrt{s_{NN}} = 2$ to 62.4 GeV [2]. The figure shows that the $v_2(p_{\rm T})$ for protons changes relatively little as a function of beam energy in the range of $\sqrt{s_{NN}} = 11.5$–62.4 GeV [5] and this may result from the interplay of the hydrodynamic and hadronic transport phase [6]. In the energy range of $\sqrt{s_{NN}} = 11$–2 GeV, the passage time $t_{\rm pass}$ increases from 2 fm/c to 16 fm/c, and the shadowing effects by the spectator matter start to play an important role in the generation of elliptic flow [7].

3. Performance for flow measurements with MPD detector

The anticipated performance of MPD detector for the directed flow measurements of charged pions, kaons and protons is demonstrated in figure 2. A sample of 5 M minimum-bias Au+Au collisions at $\sqrt{s_{NN}} = 5$ (left panel) and 11 GeV (right panel) simulated with the UrQMD event generator [6] was used for the analysis. The MPD detector response was simulated using the Geant4 toolkit and the resulting signals from the detector subsystems were used as input information for the full reconstruction procedure, which includes the realistic particle identification in TOF and TPC detectors ($|\eta| < 1.5$) of MPD. The first-order event plane was reconstructed using the energy deposition of particles detected in the forward hadronic calorimeters (FHCal), located at ($2 < |\eta| < 5$).

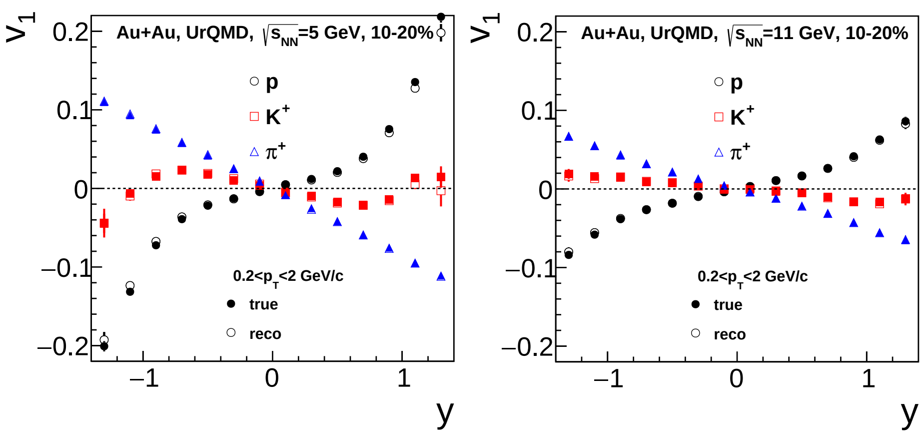

Fig. 2. Directed flow v_1 for charged pions, kaons and protons as a function of rapidity y for Au+Au collisions at $\sqrt{s_{NN}} = 5$ (left) and 11 GeV (right). The results from the UrQMD model are marked as true, and the ones from the full MPD reconstruction procedure are marked as reco.

Figure 3 shows the elliptic flow signal v_2 of protons from 10–40% mid-central Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV obtained using the event plane analysis of 5M events from the current state-of-the-art transport models: UrQMD [8], JAM [7], PHSD [9], AMPT [10], and hybrid vHLLE+UrQMD model [6]. A second-order event plane angle (Ψ_2) is reconstructed from the charged particles reconstructed in TPC at mid-rapidity ($|\eta| < 1.0$). For comparison, we plotted the published results from the STAR experiment [5] obtained by the same method of analysis. The pure hadronic transport system (as described by the UrQMD or JAM models) does not appear to explain the relatively large flow of the particles at NICA energies [6]. The hybrid models: vHLLE+UrQMD [6] and string melting version of AMPT [10] provide a much better description of the data.

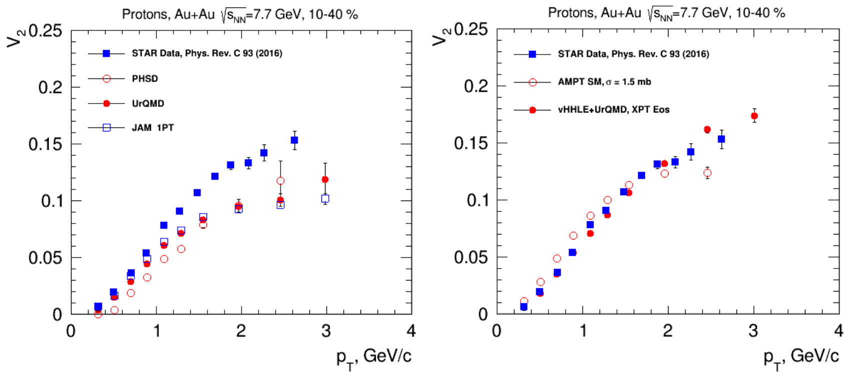

Fig. 3. The comparison of $v_2(p_T)$ of protons from 10–40% mid-central Au+Au collisions from event plane analysis using events UrQMD, PHSD, JAM, AMPT and hybrid vHLLE+UrQMD models with published results from STAR [5].

In summary, the high-statistics differential measurements of v_n anticipated from the MPD experiment expected to provide valuable information about the properties of strongly interacting matter at NICA energies.

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