Study of collective flow effect at the NICA beam energy with UrQMD model approach

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Abstract

The NICA (Nuclotron-based Ion Collider fAcility) Project at JINR Dubna aimed to study the properties of hot and dense baryonic matter in the wide energy range from $\sqrt{S_{NN}} = 4$ to $11\ GeV$. The main goal of this work was to perform the flow analysis of Au+Au events, generated within the UrQMD model for different energies taken from the NICA beam energy range. The UrQMD model was used in two modes: hadronic cascade and hybrid mode (with EOS corresponding to the QCD transition of the first order or crossover). The resulting flow coefficients v_1 (directred flow) and v_2 (elliptic flow) were compared with published results of STAR Collaboration. In addition the basic elements of the MpdRoot framework (simulation and analysis framework for NICA/MPD detectors) were studied. In order to read the ROOT files from UrQMD generator directly in MpdRoot the interface program was prepared.

1 Introduction

The main goal of experiments on relativistic heavy-ion collisions is to study the hadron-quark phase transition or the QCD phase structure. At top energies of the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC), the produced quark-gluon plasma (QGP) [1] is essentially baryon free and the phase transition is thus a smooth crossover according to results from the lattice QCD calculations [2]. On the other hand, studies based on various theoretical models have predicted that the hadron-quark phase transition becomes a first-order one at large baryon chemical potential [3]. A critical point is thus expected to exist between the smooth crossover and the first-order phase transition. To search for its signature, experiments under the beam-energy scan (BES) program have recently been carried out at RHIC and SPS. Future experiments will be performed at the new accelerators NICA (JINR,Dubna) and FAIR (GSI, Darmstadt). The new research facility NICA (Nuclotron-based Ion Collider fAcility) Project at JINR Dubna aimed to study the properties of hot and dense baryonic matter in the wide energy range from $\sqrt{S_{NN}} = 4$ to 11 GeV.

1.1 Collective Flow

The appearance of the transverse, azimuthally asymmetric flow is one of the key observations in the physics of relativistic heavy-ions. It proves that a collectively expanding, strongly interacting medium is formed in the course of the reaction [8]. For non-central collisions the interaction region is azimuthally asymmetric and, as a result of the collective expansion of matter, azimuthally asymmetric emission of particles takes place. The study of collective flow in relativistic nuclear collisions has potential to offer insights into the equation of state and transport properties of the produced matter. Anisotropic flow is conveniently characterized by the Fourier coefficients:

$$\nu_n(p_T, y) = \langle \cos(n(\phi - \Psi_{RP} \rangle$$

where ϕ represents the azimuthal emission angle of a particle and Ψ_{RP} is the azimuth of the reaction plane defined as containing both the direction of the impact parameter vector and the beam axis. The brackets denote statistical averaging over particles and events.

Directed flow, v_1, is the first harmonic coefficient of the Fourier expansion of the final-state momentum-space azimuthal anisotropy, and it reflects the collective sidewards motion of the particles in the final state. The shape of v_1 as a function of rapidity, y, in the midrapidity region is of interest because it has been argued that it offers sensitivity to crucial details of the expansion of the participant matter during the early stages of the collision.

Elliptic flow, v_2, is the second harmonic coefficient of the Fourier expansion and it can provide information about the pressure gradients in a hydrodynamic description, the effective degrees of freedom, the extent of thermalization, and the equation of state of the matter created at early times. The dependence of elliptic flow signal on the system size, number of constituent quarks, and transverse momentum or transverse mass, is decisive for the understanding of the properties of the produced matter [7]

1.2 UrQMD model

The Ultra-relativistic Quantum Molecular Dynamic model (UrQMD) is a microscopic model based on a phase space description of nuclear reactions, that describes the phenomenology of hadronic interactions below $\sqrt{S_{NN}} = 5$ GeV through the interaction between known hadrons and resonances. At incident energies above $\sqrt{S_{NN}} = 5$ GeV, the excitation of color strings and their fragmentation into hadrons dominates the production of particles in UrQMD. Thus, UrQMD provides an ideal tool for study the ultra-relativistic heavy ion collisions in the absence of effects from the QCD.

UrQMD version 3.4 with default parameters was used for the results presented in this paper. Then we perform the calculation within UrQMD hybrid approach with a more realistic treatment of the initial state and final stages of the reaction [5].

The hybrid mode couples the fluctuating initial state generated event-by-event by the hadron and string dynamics from UrQMD to an ideal hydrodynamic evolution. For the evolution of the hydrodynamic part different equations of state can be applied, including a hadron gas EoS and a chiral EoS with a transition to a quark-gluon plasma. At the end of the hydrodynamic evolution, defined by a transition energy density, the hydrodynamic cells are converted to particles with a Cooper-Frye prescription, and the decoupling stage is handled by the UrQMD hadronic cascade [6]. Two different scenarious for the hybrid mode were used: one where the QCD transition is of first order and one where it is a crossover.

2 Comparison with published results of STAR Collaboration

The whole set of differential directed flow $v_1(y)$ results for protons and charged pions from the UrQMD with different approaches is presented in Fig. 1 and Fig. 2 in comparison with the measured data from the STAR collaboration [11]. The average impact parameter for the selected events is $b = 7fm$. For the simulated particles we applied the STAR experimental acceptance $0.2 < p_T < 2$ GeV/c. All modes of UrQMD correctly reproduce the general trends in the differential $v_1(y)$ with bombarding energy: the $v_1(y)$ slope for protons is positive at low energies ($\sqrt{S_{NN}} < 20$ GeV) while pions have negative slope. However, the better agreement between simulations and STAR data for $v_1(y)$ for pions is achived for UrQMD hybrid mode with crossover. In contrast the $v_1(y)$ for protons from STAR measurements perefer the UrQMD results obtained in hadronic cascade mode.

v_2, as a function of the transverse momentum, p_T, for protons and charged pions from the UrQMD model is presented in Fig. 3, Fig. 4 and Fig. 5 in comparison to the measured data from the STAR collaboration[12]. The STAR data were obtained for minbias events (centrality 0-80%). Here the best agreement between STAR v_2 data for charged pions and simulated UrQMD events was observed for hybrid mode with crossover. For protons all modes of UrQMD underestimate the measured v_2 values from STAR.

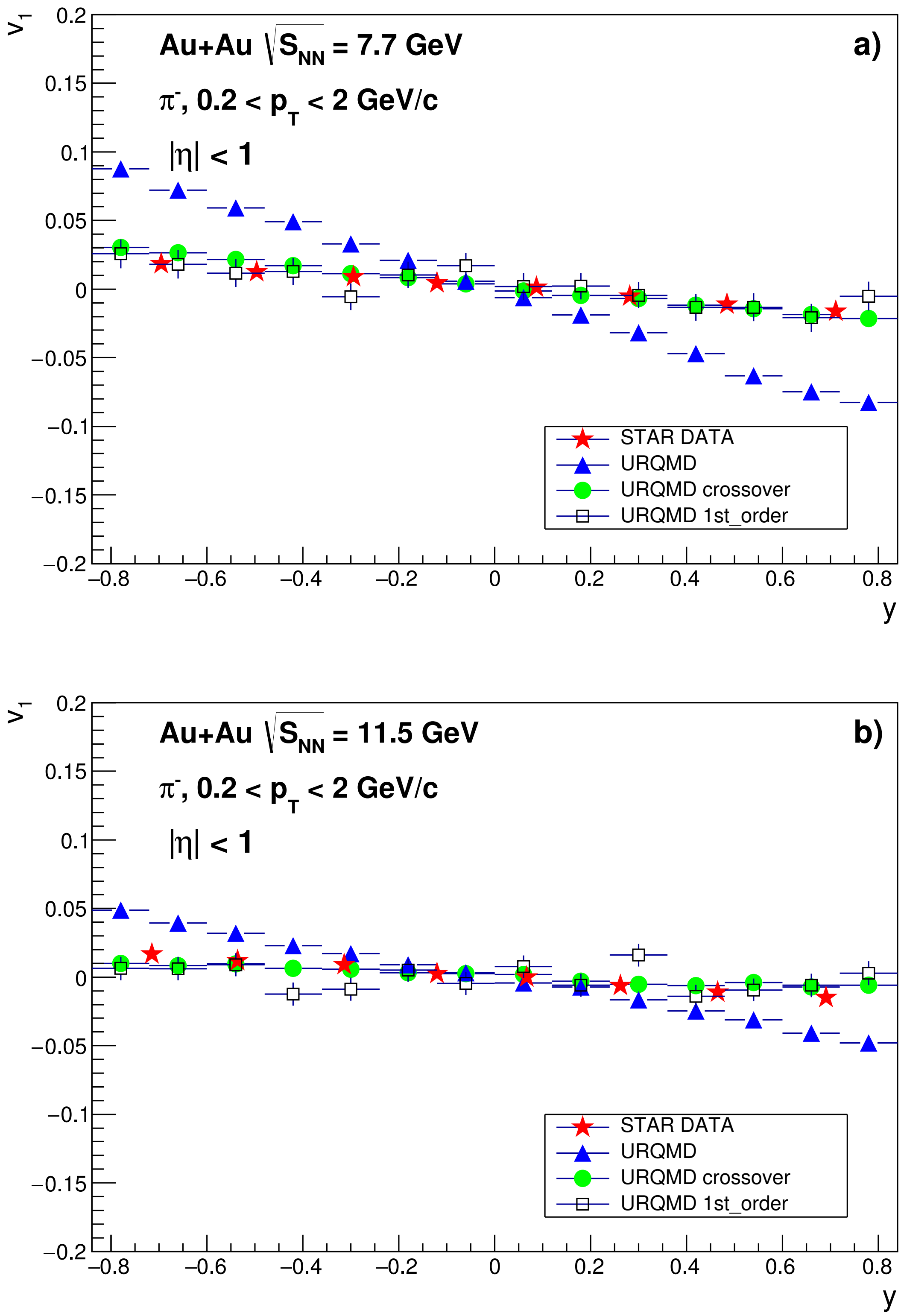

Figure 1: The directed flow v_1 for negative pions from 10-40% central Au+Au collision ar different collision energies from $\sqrt{S_{NN}}$ = 7.7 to 11.5 GeV from UrQMD and UrQMD based on different hydrodynamical approaches. Experimental data are from the STAR collaboration [11].

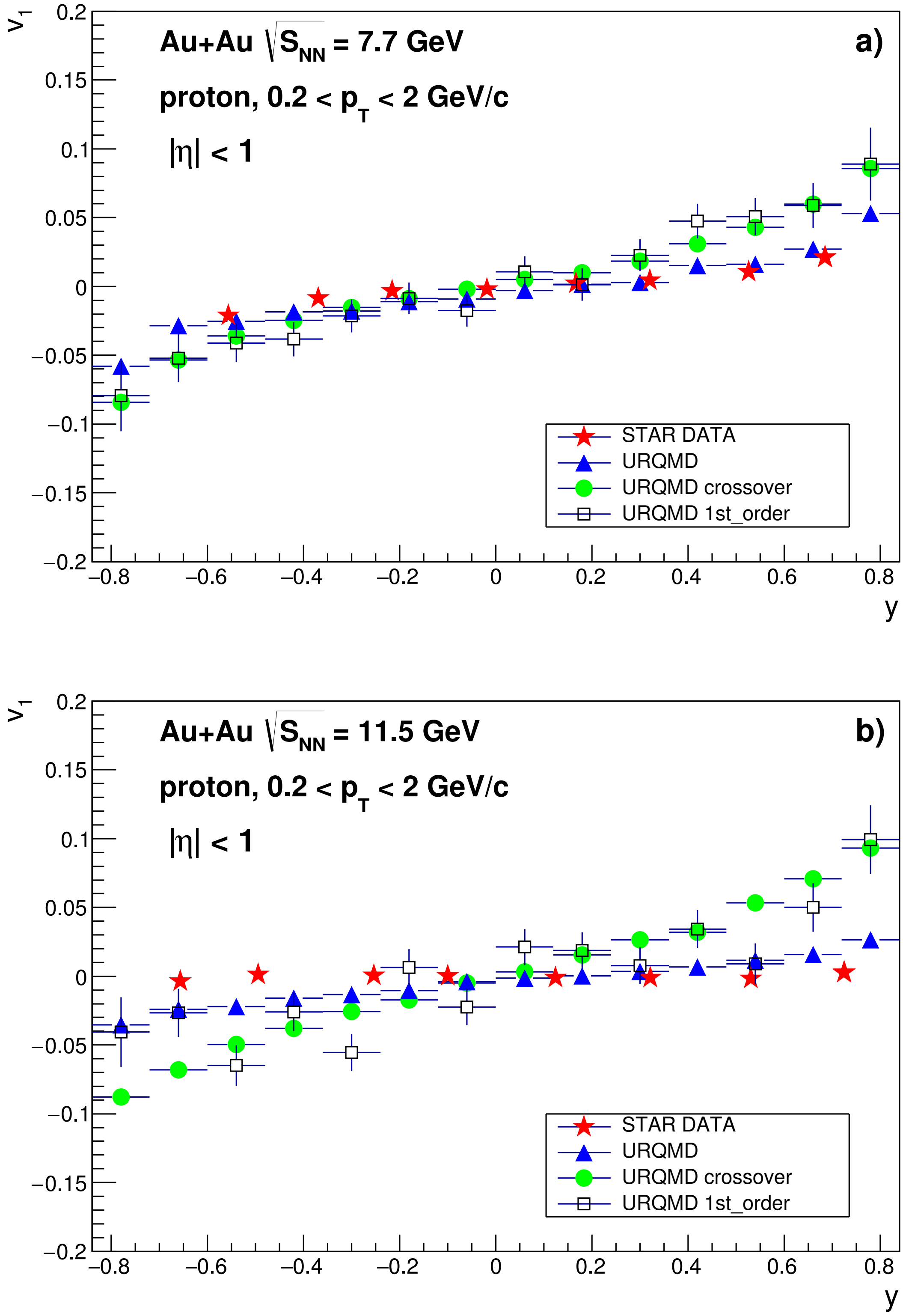

Figure 2: The directed flow v_1 for protons from 10-40% central Au+Au collision ar different collision energies from $\sqrt{S_{NN}} = 7.7$ to 11.5 GeV from UrQMD and UrQMD based on different hydrodynamical approaches. Experimental data are from the STAR collaboration [11].

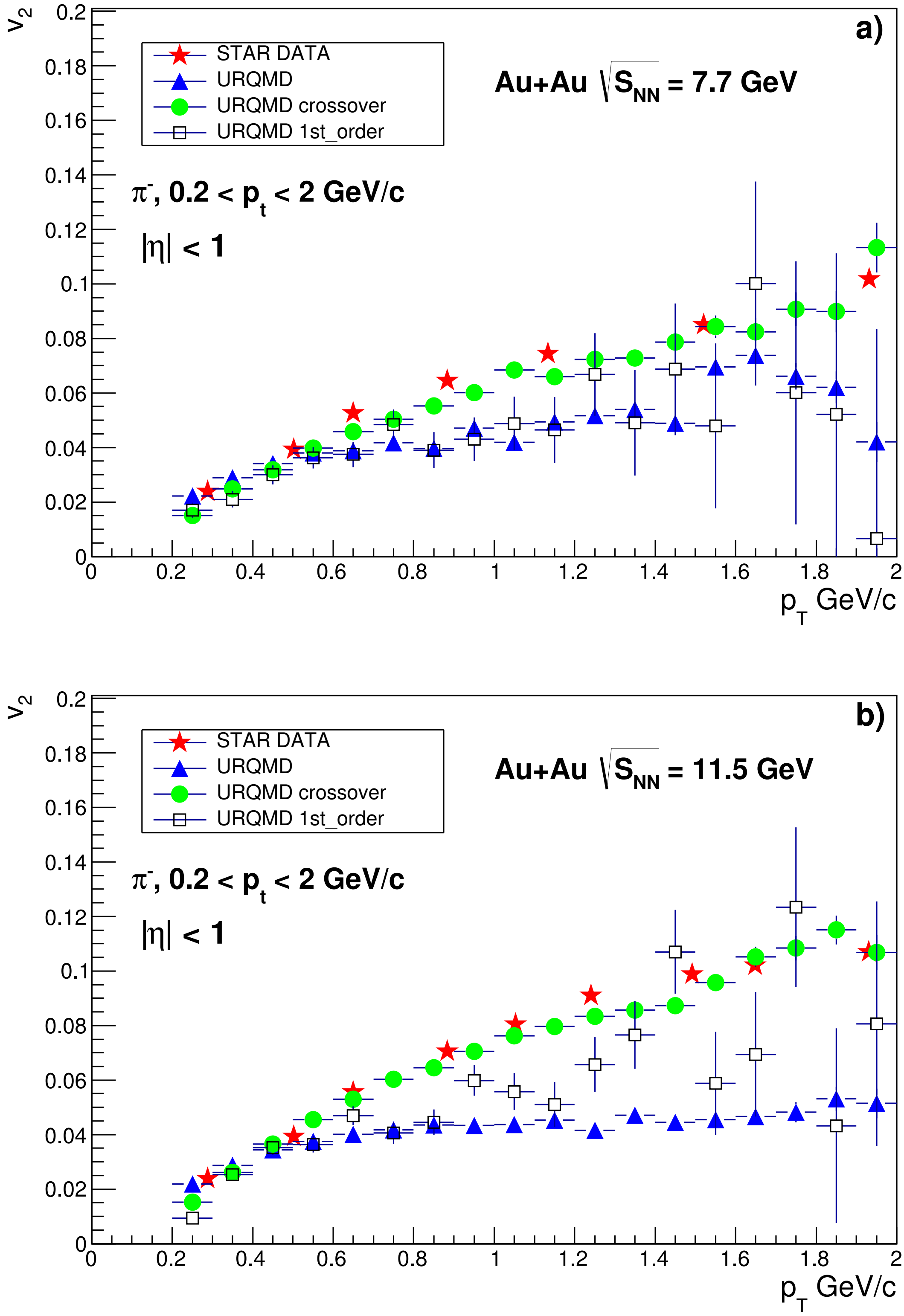

Figure 3: The elliptic flow, v_2, as a function of the transverse momentum, p_T, for negative pions from 0-80% central Au+Au collisions from $\sqrt{S_{NN}} = 7.7$ to 11.5 GeV from UrQMD and UrQMD based on different hydrodynamical approaches. Experimental data are from the STAR collaboration [12].

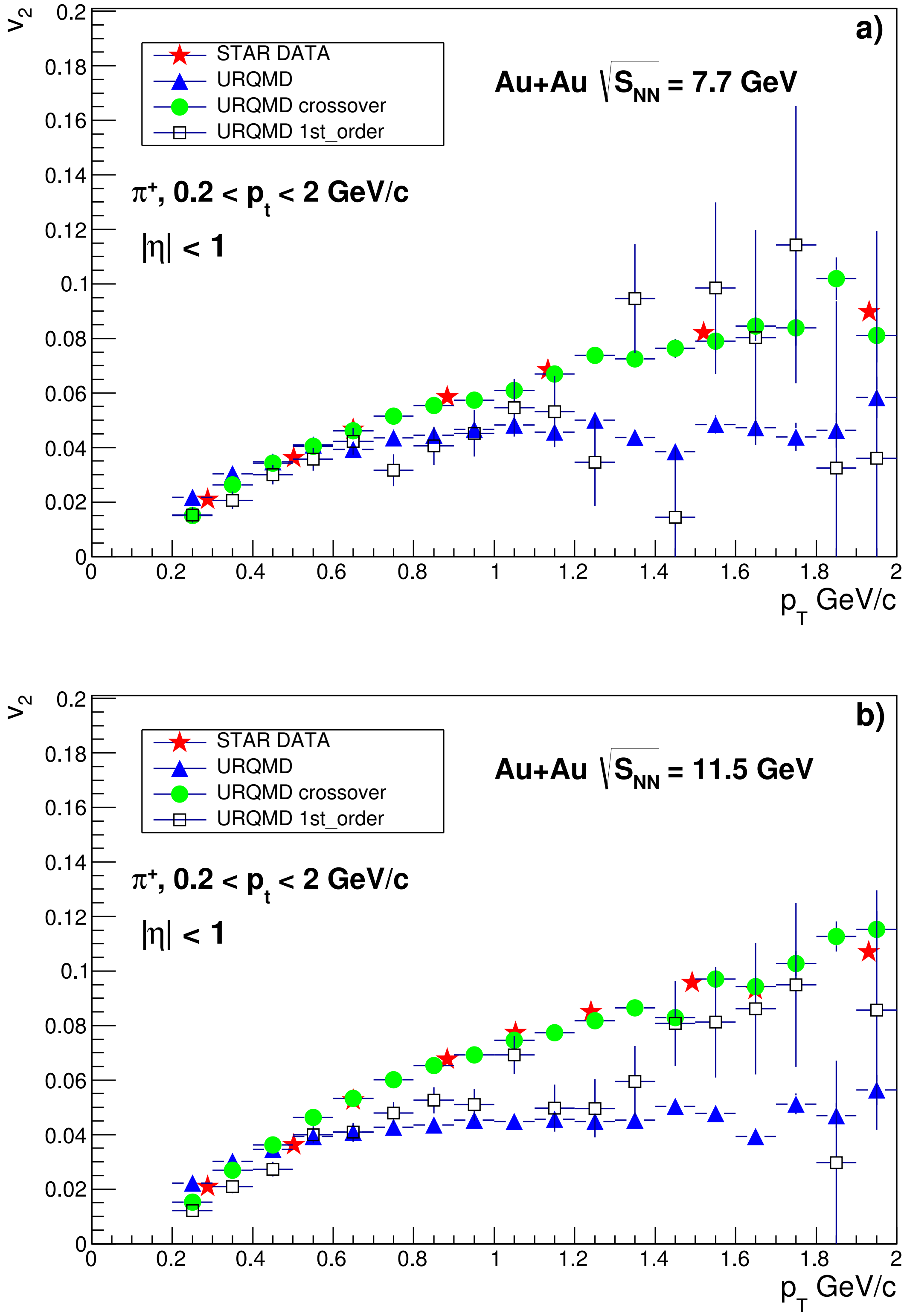

Figure 4: The elliptic flow, v_2, as a function of the transverse momentum, p_T, for positive pions from 0-80% central Au+Au collisions from $\sqrt{S_{NN}} = 7.7$ to 11.5 GeV from UrQMD and UrQMD based on different hydrodynamical approaches. Experimental data are from the STAR collaboration [12].

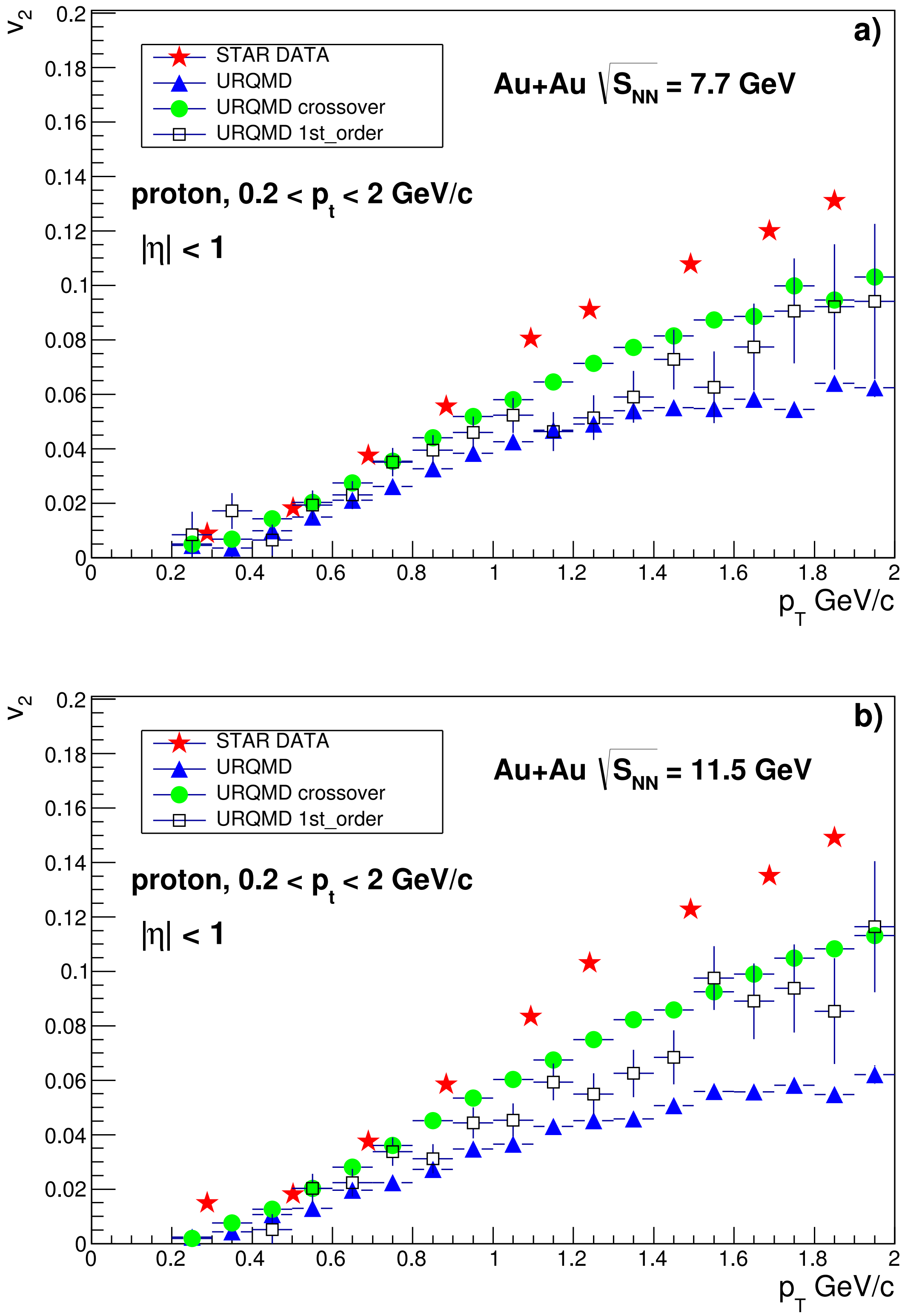

Figure 5: The elliptic flow, v_2, as a function of the transverse momentum, p_T, for protons from 0-80% central Au+Au collisions from $\sqrt{S_{NN}} = 7.7$ to 11.5 GeV from UrQMD and UrQMD based on different hydrodynamical approaches. Experimental data are from the STAR collaboration [12].

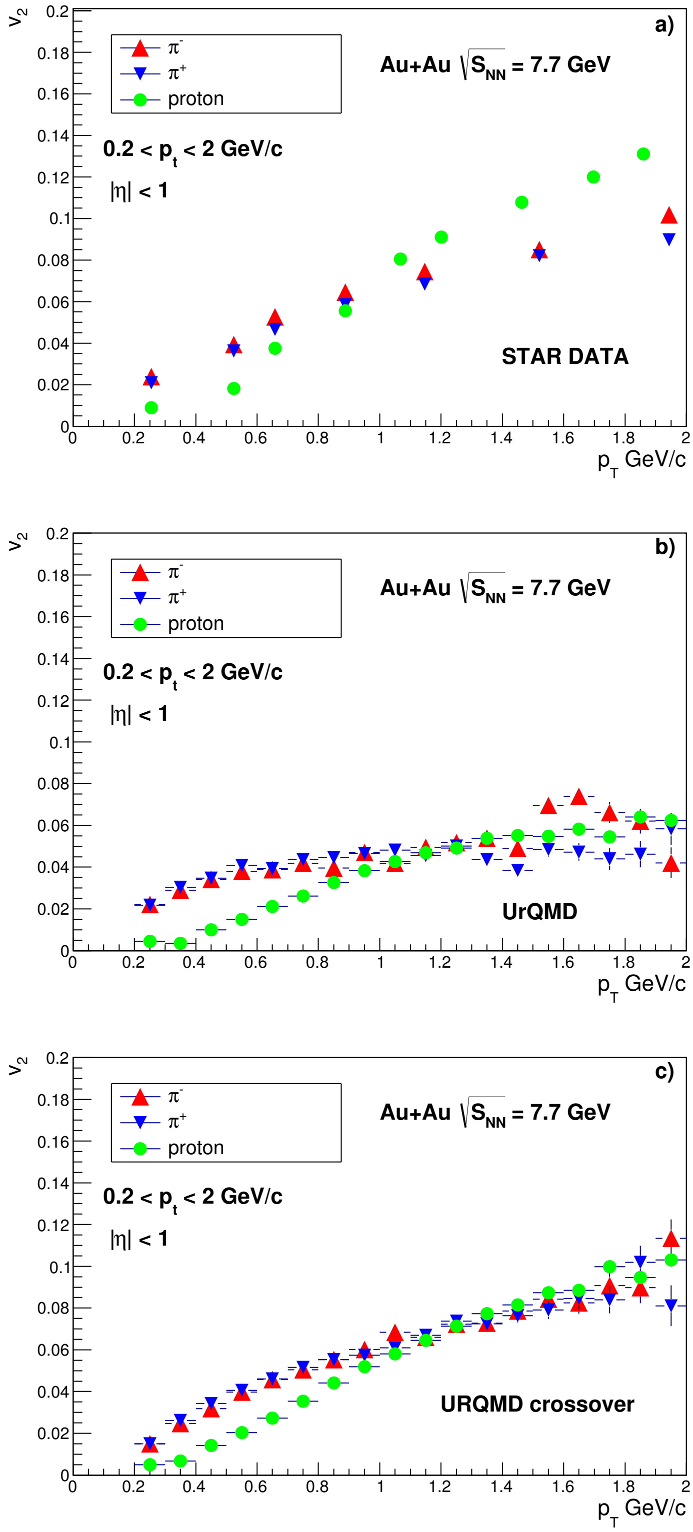

Figure 6: The elliptic flow, v_2, as a function of the transverse momentum, p_T, for protons and pions from 0-80% central Au+Au collisions $\sqrt{S_{NN}} = 7.7\ GeV$ from UrQMD and UrQMD based on different hydrodynamical approaches. Experimental data are from the STAR collaboration [12].

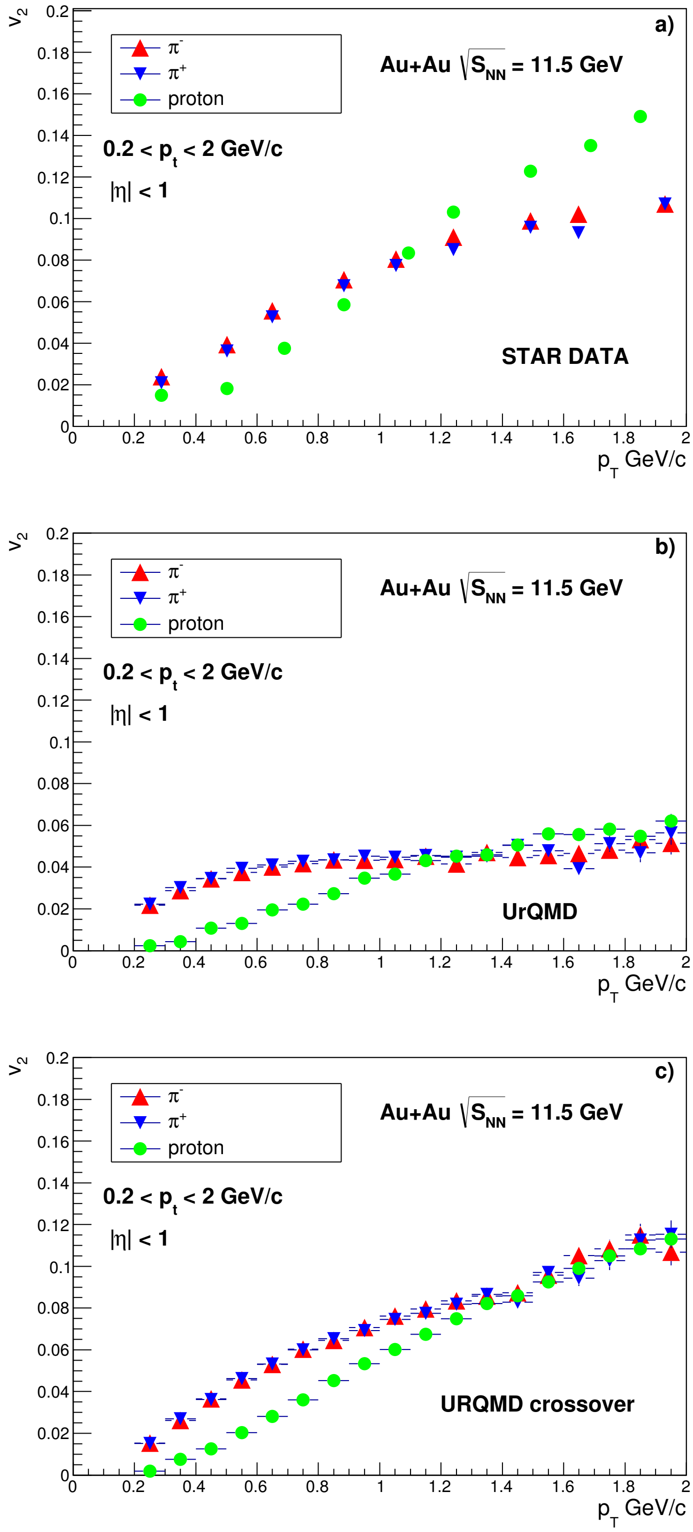

Figure 7: The elliptic flow, v_2, as a function of the transverse momentum, p_T, for protons and pions from 0-80% central Au+Au collisions $\sqrt{S_{NN}} = 7.7\ GeV$ from UrQMD and UrQMD based on different hydrodynamical approaches. Experimental data are from the STAR collaboration [12].

3 NICA / MPD detector

A conceptual design of the MultiPurpose Detector (MPD) is proposed for a study of hot and dense baryonic matter in collisions of heavy ions over the atomic mass range $A = 1197$ at a centre-of-mass energy up to $\sqrt{S_{NN}} = 11GeV$ (for Au^{79+}). The MPD experiment is foreseen to be carried out at a future JINR accelerator complex facility for heavy ions the Nuclotron-based Ion Collider fAcility (NICA) which is designed to reach the required parameters with an average luminosity of $L = 10^{27}cm^{-2}s^{-1}$ The software framework for the MPD experiment (MpdRoot) is based on the object-oriented framework FairRoot [9] and provides a powerful tool for detector performance studies, development of algorithms for reconstruction and physics analysis of the data. For a realistic simulation of various physics processes an interface to the Monte Carlo event generators for nuclear collisions (UrQMD and et) was provided.

ROOT allows to save and access terabytes of data in a highly optimized way. Because the total computing time for a given task depends both on the CPU speed and on the data access time (that includes accessing and caching information from the main memory, and accessing and caching information from the disks), the quick data access allowed by ROOT effectively improves the performance of data analysis.[10] For this reason I developed an interface for MpdRoot to write and read data generated via UrQMD in ROOT files.

4 Summary

During summer student program I get familiar with the UrQMD model and flow analysis, prepared a large sample of simulated events for Au+Au collisions at the NICA energy range from $\sqrt{S_{NN}} = 4$ to 11 GeV and then made a comparison with experimental data from the STAR collaboration
Also I wrote an interface for MpdRoot to read these events.
Next step will be to simulate and reconstruct the collisions using MpdRoot, and, then, to make flow analysis.

References

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