Study of collective flow effect at the NICA energies with 3FD model approach.

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JINR Summer Student Program
August 2015

Abstract

Collisions of relativistic heavy-ions produce matter at very high energy density and temperature. The dynamical evolution of this hot and dense medium reflects its state and the degrees of freedom that govern the different stages it undergoes. In this work we used the Three-Fluid Hydro Model (3FD) as an event generator for simulating collisions of the heavy ions (Au) at the NICA energy range: $\sqrt{s_{NN}} = 4$ to 11 GeV. The directed flow (v_1) and elliptic flow (v_2) signals for charged pions and protons from Au+Au collisions at $\sqrt{s_{NN}} = 7$ and 11.5 GeV were calculated and compared to the published data from the STAR collaboration. Also we get familiar with basic elements of Mpd-Root framework used for simulations and analysis for the NICA/MPD experiment.

1 Introduction

1.1 NICA Project

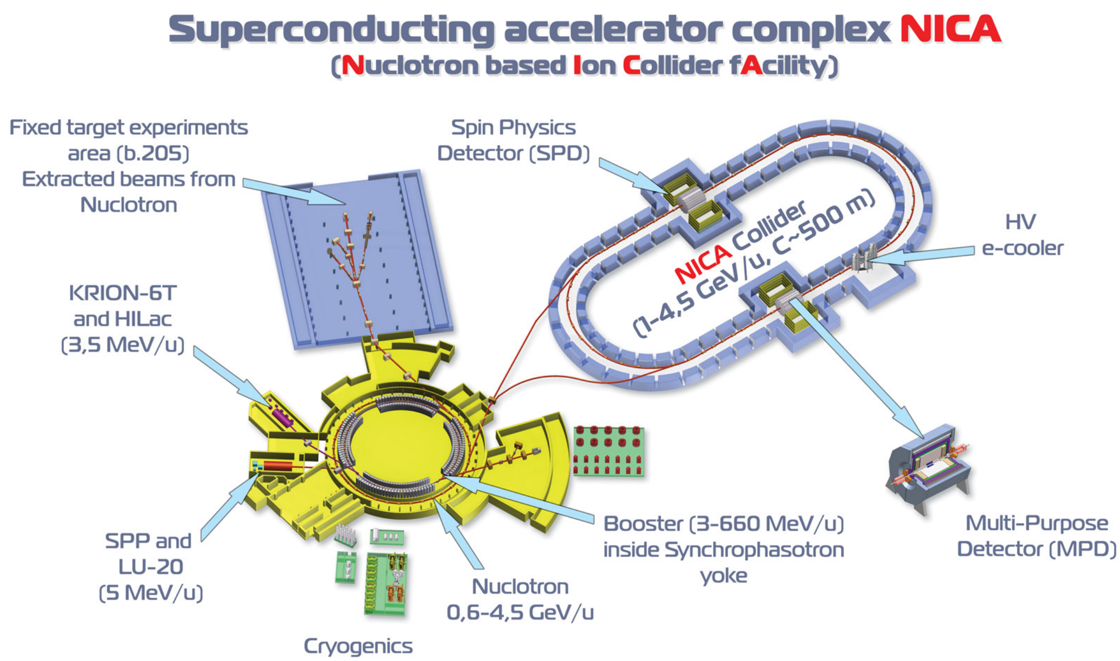

Figure 1: The view of the NICA facility at JINR, Dubna

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A new project of Nuclotron-based Ion Collider fAcility (NICA) is proposed at JINR (Dubna) Fig.1. The main goal of the NICA facility is a search for the mixed phase of quark matter and baryon rich hadronic matter as a consequence of a first order phase transition. The NICA collider will cover the energy range from $\sqrt{s_{NN}} = 4 \div 11$ GeV for heavy ion collisions, which is considered recently to be the most interesting area of the QCD phase diagram. The most remarkable experimental results were observed in study the collective flow phenomena occurring in the early stage of nuclear collisions at RHIC and LHC. Investigation of collective flow provides important information about the EoS and transport properties of the new state of the matter - quark gluon plasma (QGP). Event-by-event fluctuations and correlations are expected to give us signals of the critical behavior of the system [1].

The **M**ulti**P**urpose **D**etector (MPD) is designed to fully exploit the NICA physics potential. MPD will be a spectrometer with a large uniform acceptance, capable of detecting and identifying hadrons, electrons and gammas at a very high event rate achieved at the NICA.

1.2 Flow analysis

Flow analysis is an important tool to probe the hot, dense matter created in heavy-ion collisions. Collective flow effects are typically characterized by the Fourier coefficients v_n:

$$E\frac{d^3N}{d^3\mathbf{p}} = \frac{dN}{p_T dp_T d\phi dy} = \frac{1}{2\pi}\frac{dN}{p_T dp_T dy}\left(1 + 2\sum_{n=1}^{\infty} \nu_n \cos(n(\phi - \Psi_{RP}))\right)$$

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

where ϕ represents the azimuthal emission angle of a charged hadron and Ψ_R 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 is characterized by the first-order harmonic, v_1, of the Fourier expansion of the particle azimuthal angular distribution with respect to the reaction plane. It describes a sideward motion of nuclear fragments and newly produced particles. It probes the onset of bulk collective dynamics during thermalization, thus providing valuable information on the pre-equilibrium stage [2].

Elliptic flow, v_2, describes the azimuthal momentum space anisotropy of particle emission from non-central collisions in the plane transverse to the beam direction, and is defined as the second harmonic coefficient of the Fourier decomposition. This is a fundamental observable since it directly reflects the initial spatial anisotropy of the nuclear overlap region in the transverse plane, directly translated into to the observed momentum distribution of identified particles. Since the spatial anisotropy is the largest at the beginning of the evolution, elliptic flow is especially sensitive to the early stages of system evolution. A measurement of elliptic flow provides access to the fundamental thermalization time scale and many other things.

In this work we used the Three-Fluid Hydro Model (3FD) as an event generator for simulating collisions of the heavy ions (Au) at the NICA energy range: $\sqrt{s_{NN}} = 4$ to 11 GeV. The directed flow (v_1) and elliptic flow (v_2) signals for charged pions and protons from Au+Au collisions at $\sqrt{s_{NN}} = 7$ and 11.5 GeV were calculated as a function of rapidity y, pseudorapidity η and transverse momentum P_t for different bins in collision centrality.

1.3 MPD detector

The NICA collider is going to have two interaction points, allowing the two detectors to operate simultaneously. The MultiPurpose Detector (MPD) Fig.2. is one of these detectors. In the first stage of the NICA/MPD project are considered analysis on multiplicity and spectral characteristics of identified hadrons including strange particles, multi-strange baryons and anti-baryons, characterizing entropy production and system temperature at freeze-out.

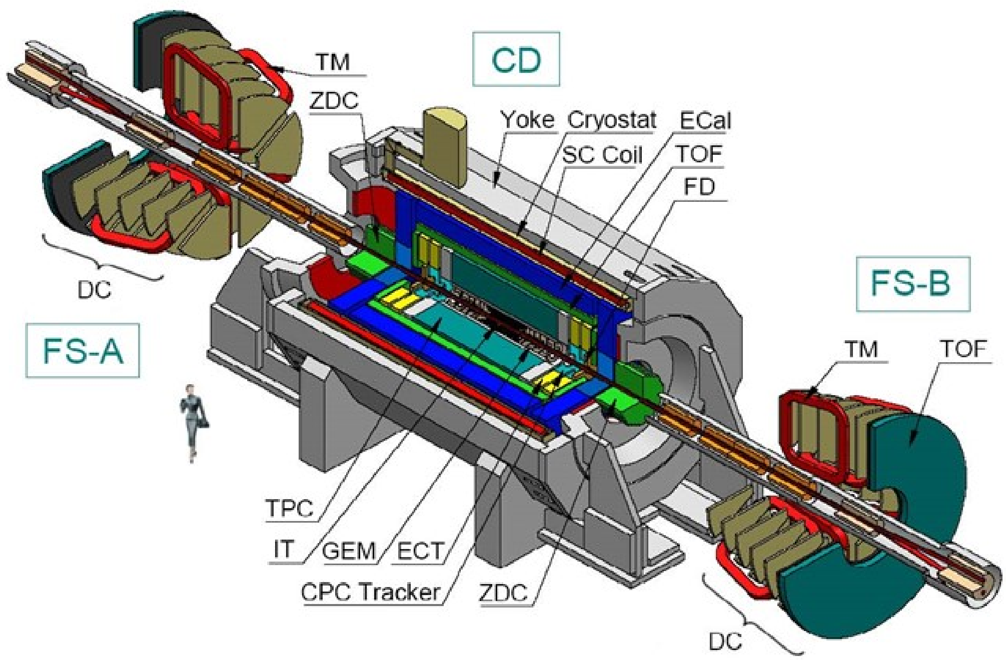

Figure 2: The view of the MPD (Multi Purpose Detector)

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1.4 Three-Fluid Hydro Model

For the description of hadron-hadron collisions of nuclear interactions the following theoretical models are used: hydrodynamic and transport. There are two kinds of hydrodynamic models: single-fluid or multi-fluid. These models have been extended to treat the baryon-free fluid on an equal footing with the baryon-rich ones.

The 3FD model treats a nuclear collisions from the very beginning: from the stage of the incident cold nuclei to the final freeze-out stage. The basic idea of a 3FD approximation to heavy-ion collision is that each space-time point of a generally non-equilibrium distribution of baryon-rich matter can be represented as a sum of two distinct contributions initially associated with constituent nucleons of the projectile and target nuclei. This model reasonably reproduces a large volume of experimental data in a wide energy range from AGS to SPS accelerators and predicts collective phenomena such as directed and elliptic flows. In this work we used 3FD generator which was designed for simulations of nuclear collisions in the energy range from few up to 200 GeV/nucleon.

2 Results

2.1 Comparison of the 3FD model with data from STAR

As result of the beam energy scan (BES) program at RHIC, the data for $\sqrt{S_{NN}}$ =7.7, 11.5, 19.6, 27, 39 and 62.4 GeV were collected, analyzed and published by STAR collaboration. $\sqrt{S_{NN}} = 7.7$ and 11.5 GeV are within the range of NICA facility. The STAR data represent the main source of experimental information for future MPD project at NICA.

We generated a large volume of statistics for gold-gold collisions at the energy range in the laboratory frame for 7.7 and 11.5 GeV/nucleon, by 3FD generator with a 1st-order-transition EoS (tph) and calculated v_1 and v_2 as a function of rapidity y, pseudorapidity η and transverse momentum P_t for protons, π^{-+}-mesons for several bins in collision centrality. To compare the results obtained we took data from the STAR collaboration [3].

2.2 The directed and elliptic flow: comparison with STAR data.

The comparison of the rapidity dependence of directed flow, $v_1(y)$, for protons and negative charged pions from 3FD model generated events and STAR data for 10-40% central Au+Au collisions at $\sqrt{S_{NN}} = 7.7$ GeV and $\sqrt{S_{NN}} = 11.5$ GeV are shown in Figs. 3 and 4. They show that 3FD model describes the STAR data for directed flow of pions and protons rather well.

Figures 5 and 6 show the transverse momentum dependence of elliptic flow signal v_2 for charged pions and protons from 0-80% central Au+Au collisions at $\sqrt{S_{NN}} = 7.7$ GeV and $\sqrt{S_{NN}} = 11.5$ GeV. In contrast to the directed flow the 3FD model in 1-st order phase transition mode is not able to reproduce STAR data for elliptic flow. This is more visible for case of protons where the model can reproduce only 50% of the measured elliptic flow signal.

As the next plan we plan to run 3FD model with crossover phase transition and make comparison with STAR data again. We also plan to continue on this project this semester and finish the reconstruction and analysis of generated events using MpdRoot framework.

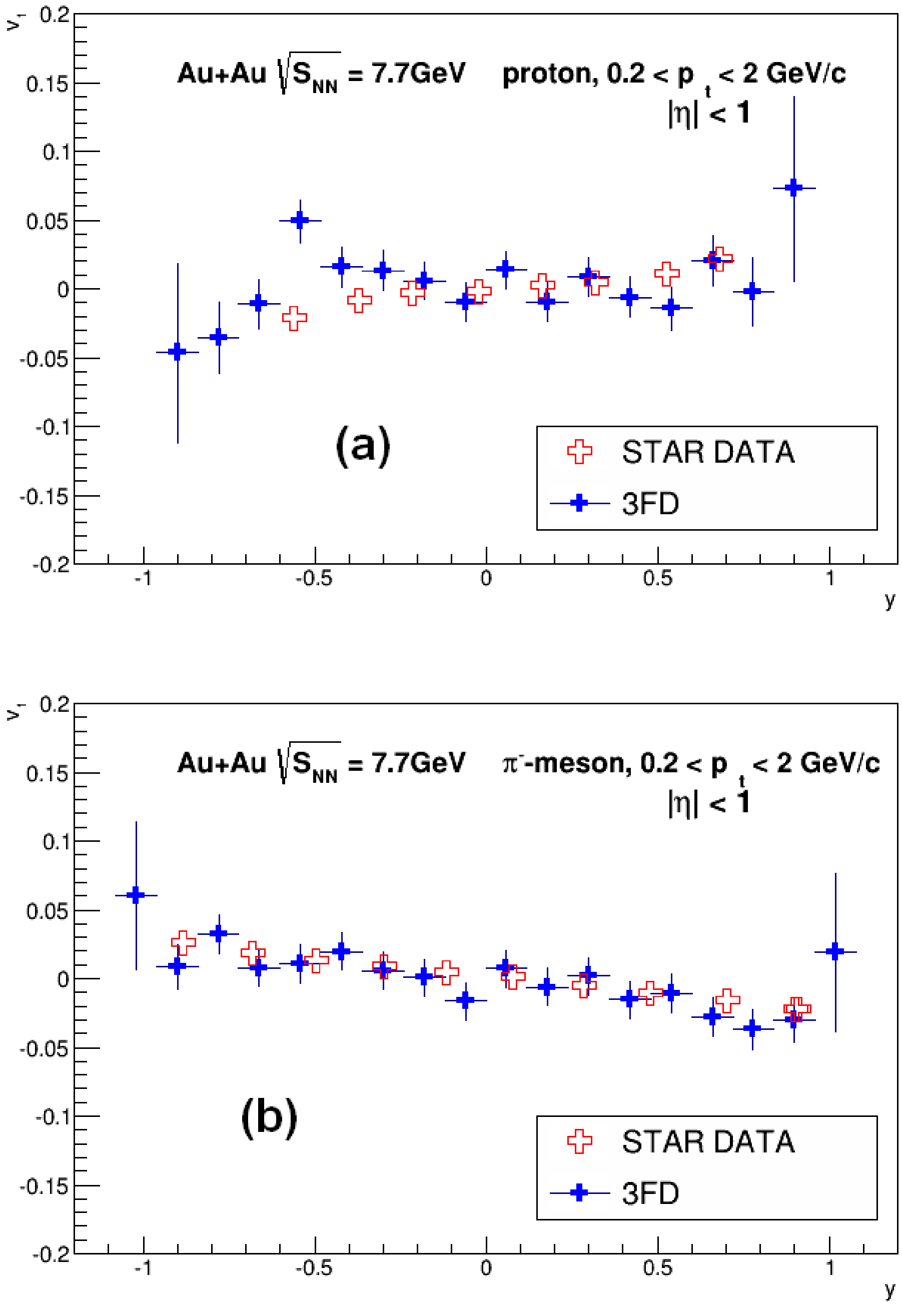

Figure 3: Directed flow $v1$ for protons (a) and negative π-mesons (b) from 10-40% central Au+Au collision at collision energies $\sqrt{S_{NN}} = 7.7$ GeV derived from 3FD. The experimental data are from the STAR collaboration.

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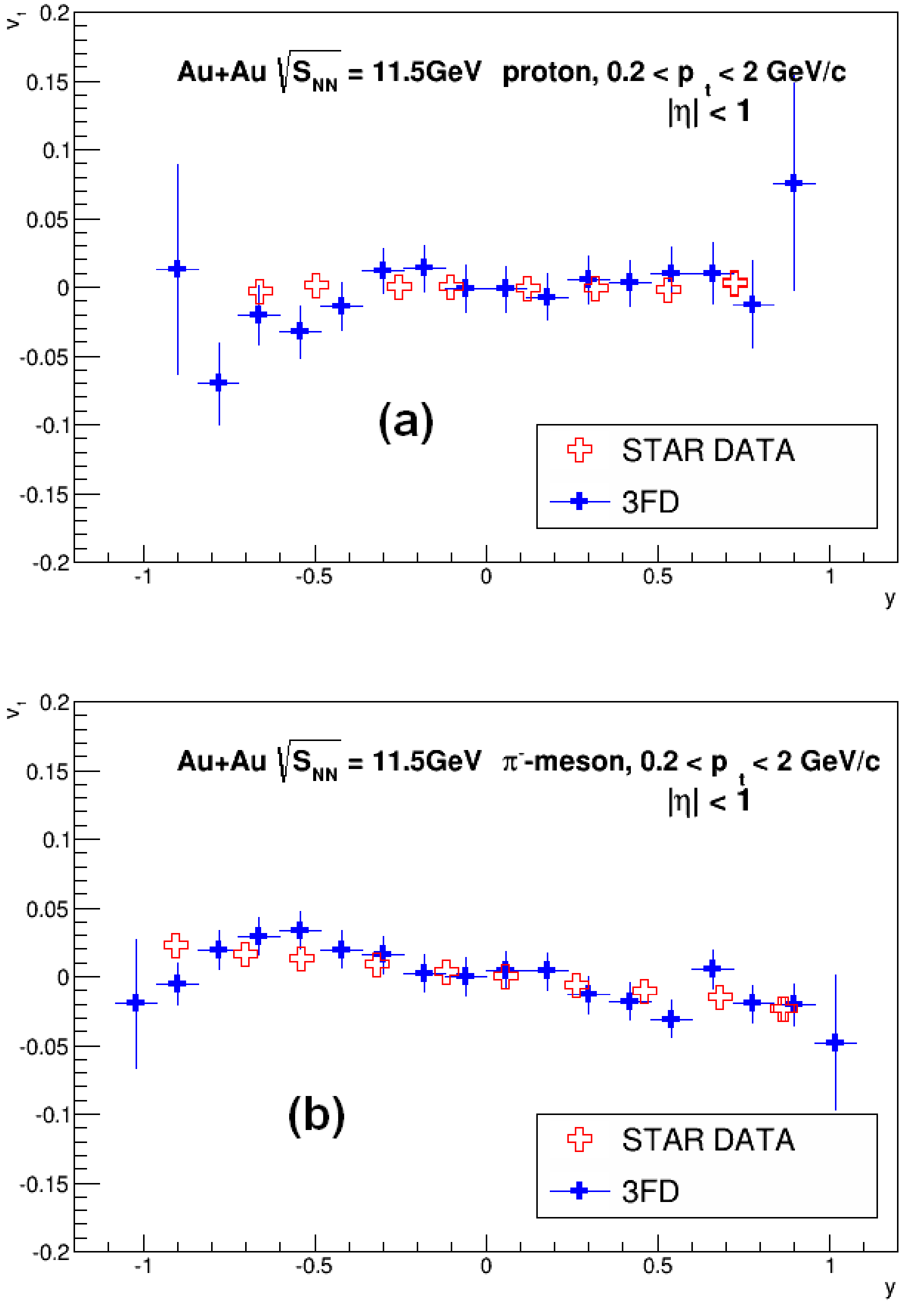

Figure 4: Directed flow $v1$ for protons (a) and negative π-mesons(b) from 10-40% central Au+Au collision at collision energies $\sqrt{S_{NN}} = 11.5 GeV$ derived from 3FD. The experimental data are from the STAR collaboration.

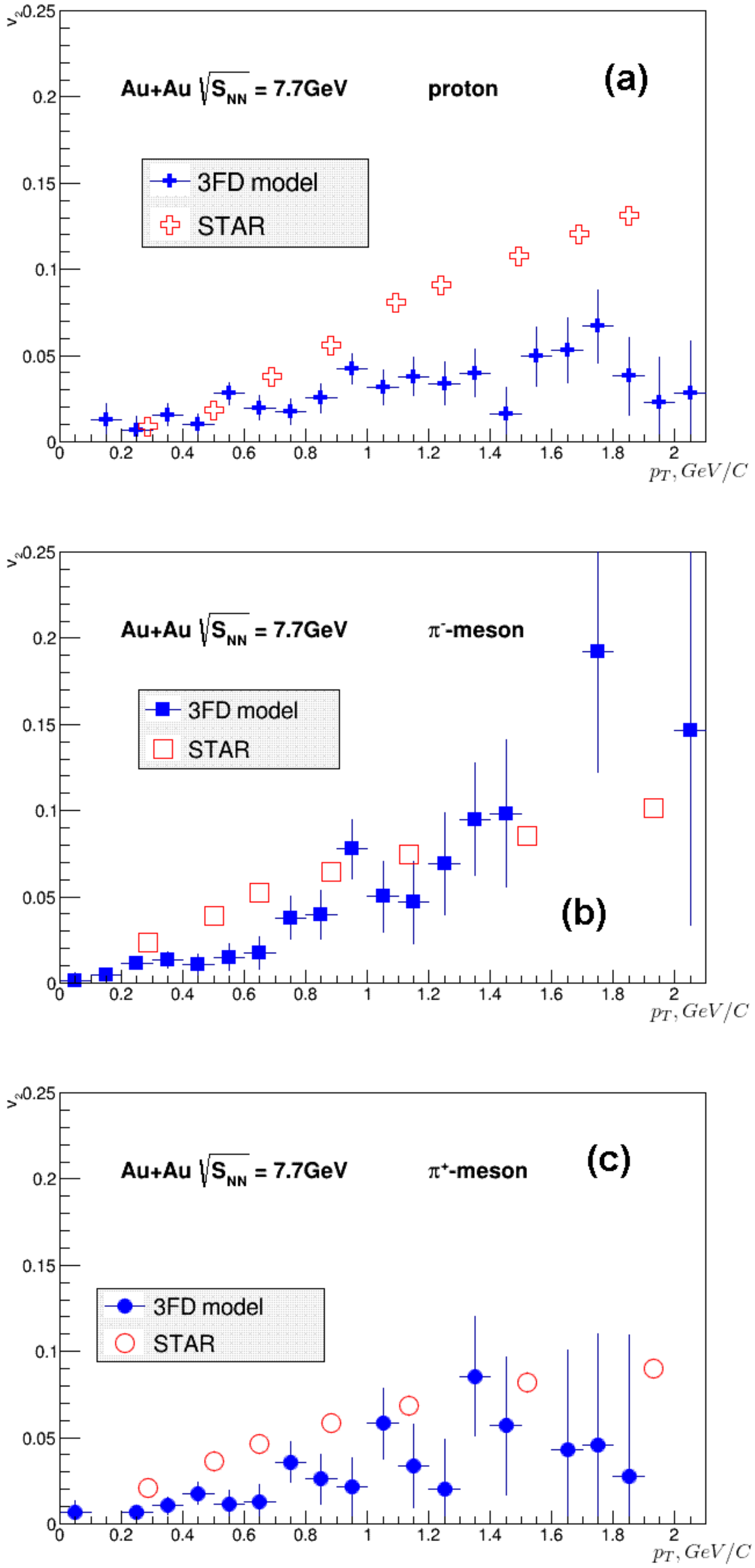

Figure 5: Elliptic flow $v2$ for protons (a) and negative (b), positive(c) π-mesons.

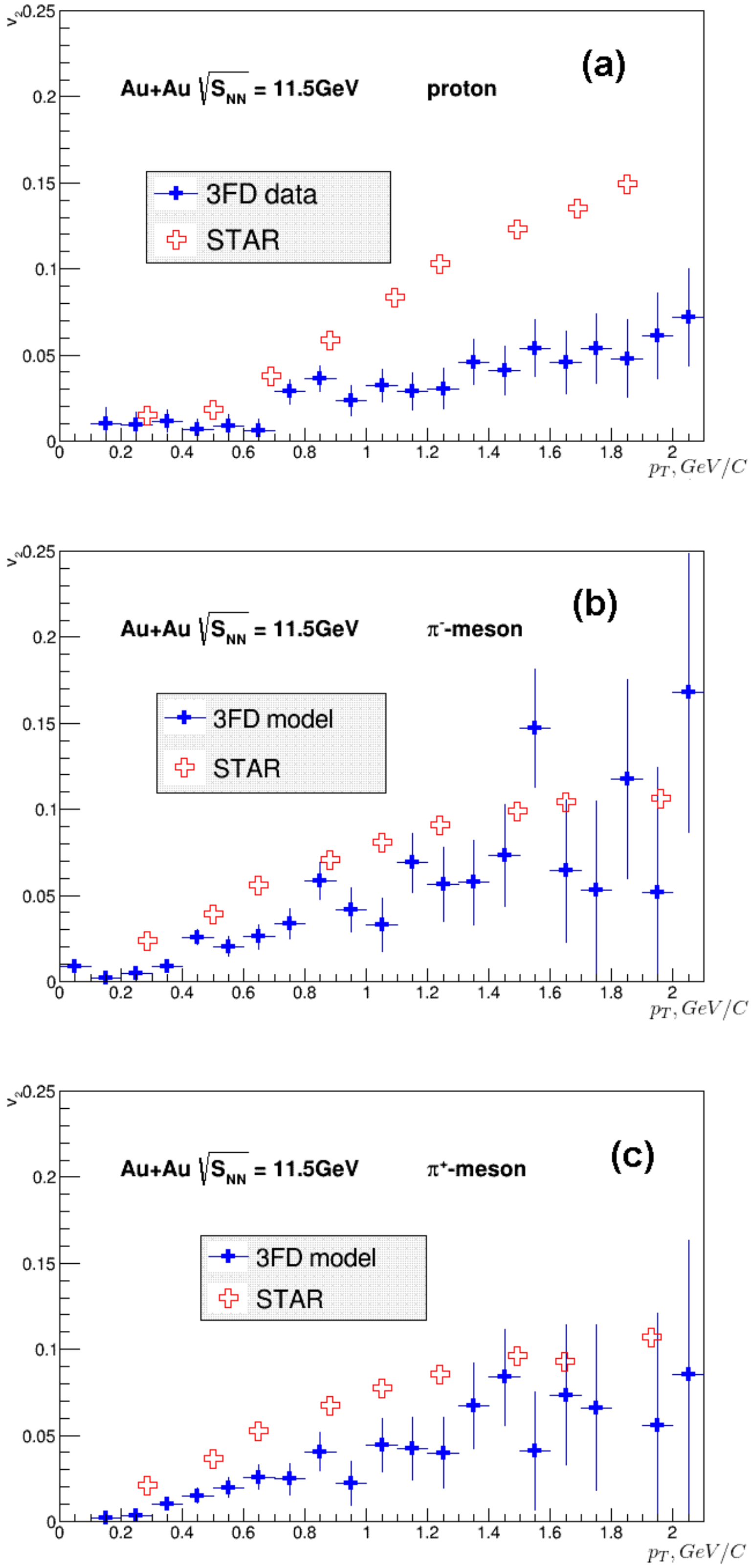

Figure 6: Elliptic flow $v2$ for protons (a) and negative π-mesons (b), positive π-mesons (c)

References

[1] N. S. Geraksiev for the MPD collaboration *Feasibility of Anisotropic Flow measurements at NICA/MPD* PoS (Baldin ISHEPP XXII)131

[2] V P Konchakovski, W Cassing, Y B Ivanov, Toneev V D *Directed flow in relativistic heavy-ion collisions within the PHSD transport approach and 3FD hydrodynamical model* 2015.Journal of Physics: Conference Series 612(2015) 012055

[3] V. P. Konchakovski, W. Cassing, Yu. B. Ivanov, V. D. Toneev *Examination of the directed flow puzzle in heavy-ion collisions* arXiv:1404.2765