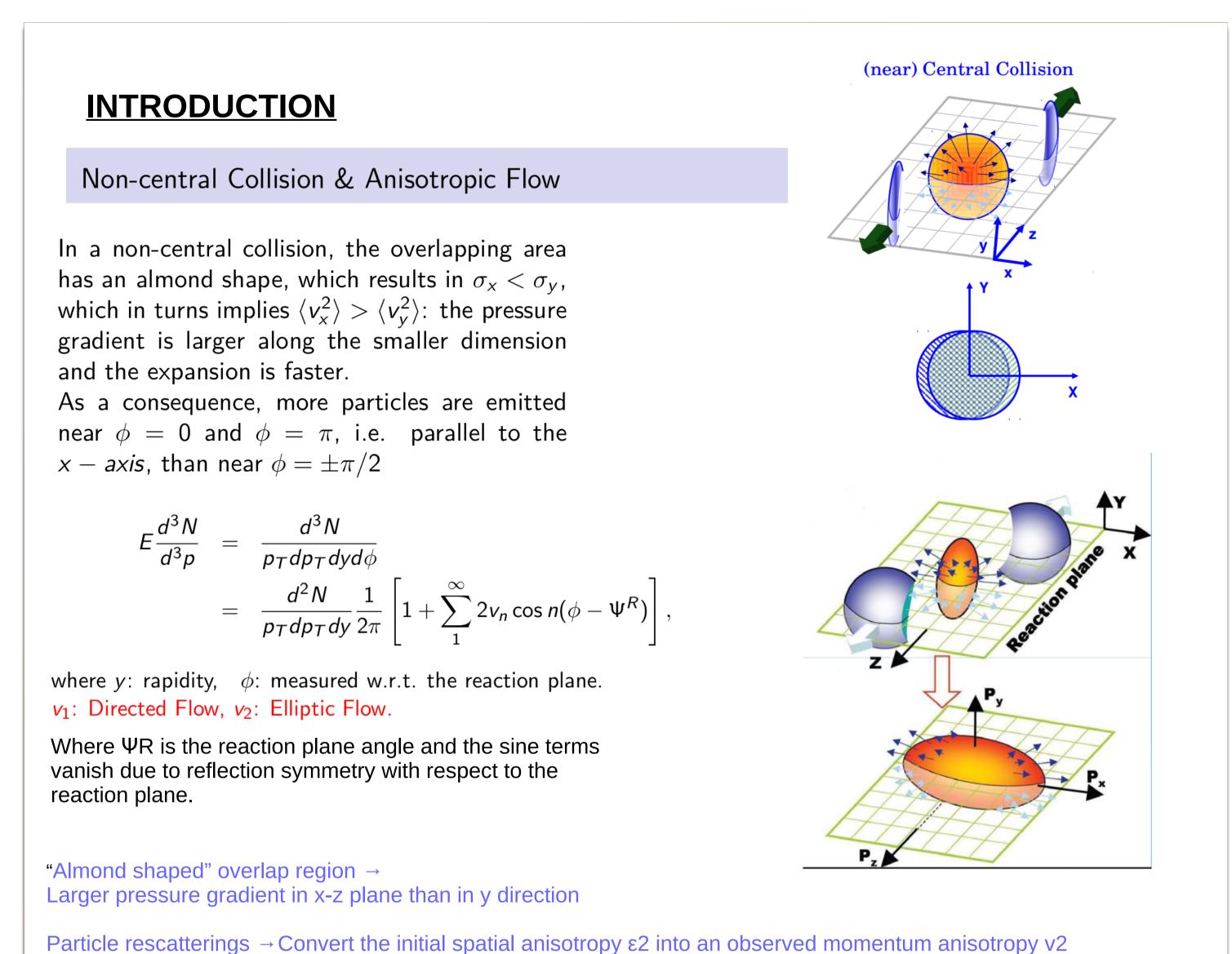# Anisotropic flow studies in heavy ion collisions at relativistic energies
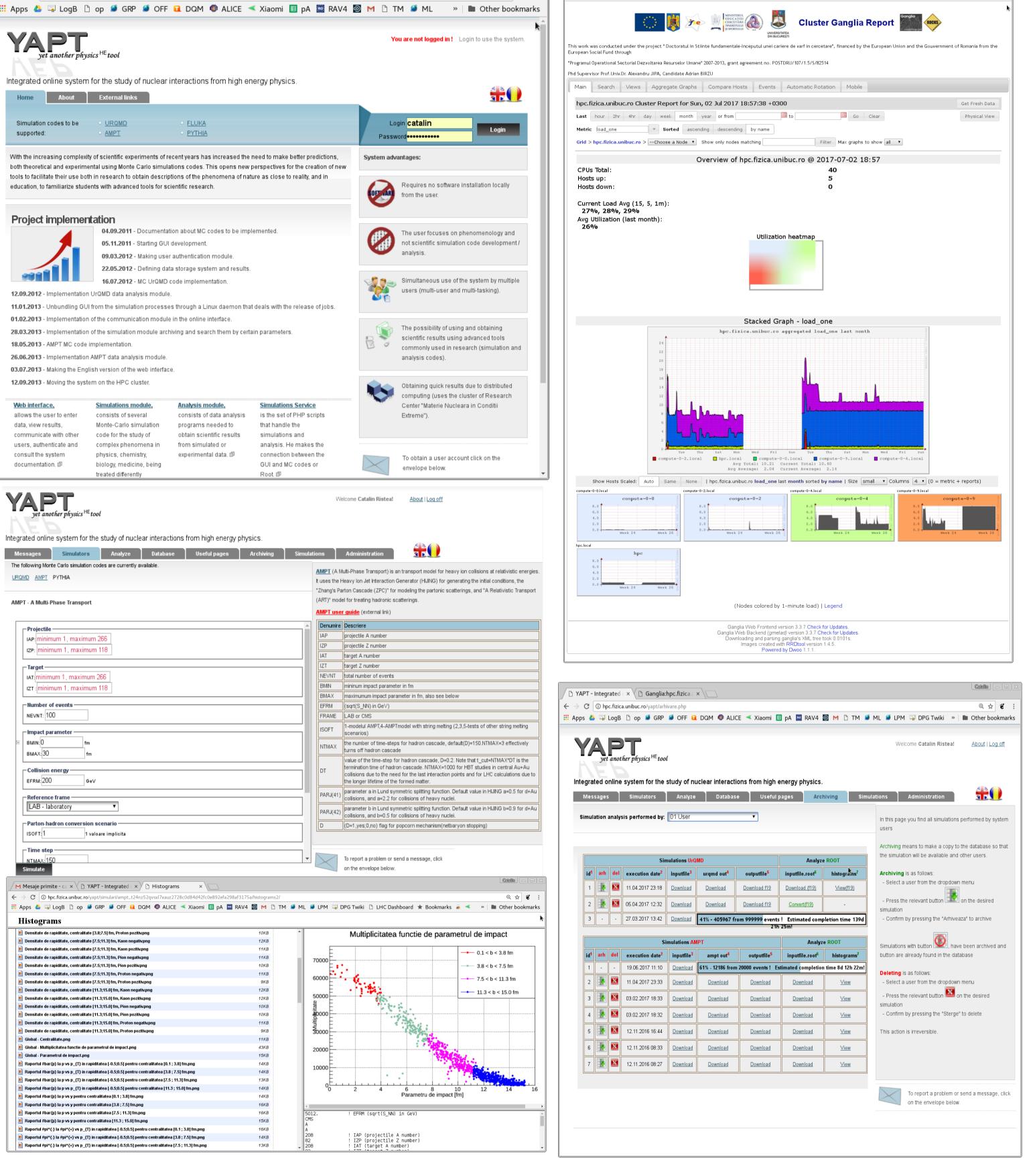
C. Ristea*,**, A. Jipa*, O. Ristea*, T. Petruse*, I. Lazanu*, M. Calin*, T. Esanu***

*University of Bucharest, Faculty of Physics, **Institute of Space Science, Magurele, ***IFIN-HH, Magurele

INTRODUCTION

Non-central Collision & Anisotropic Flow

In a non-central collision, the overlapping area has an almond shape, which results in $\sigma_x < \sigma_y$, which in turns implies $\langle v_x^2 \rangle > \langle v_y^2 \rangle$: the pressure gradient is larger along the smaller dimension and the expansion is faster.

As a consequence, more particles are emitted near $\phi = 0$ and $\phi = \pi$, i.e. parallel to the $x - axis$, than near $\phi = \pm \pi/2$.

$$E\frac{d^3N}{d^3p} = \frac{d^3N}{p_T\,dp_T\,dy\,d\phi}$$
$$= \frac{d^2N}{p_T\,dp_T\,dy}\frac{1}{2\pi}\left[1 + \sum_1^\infty 2v_n\cos n(\phi - \Psi^R)\right],$$

where y: rapidity, ϕ: measured w.r.t. the reaction plane.
v_1: Directed Flow, v_2: Elliptic Flow.

Where ΨR is the reaction plane angle and the sine terms vanish due to reflection symmetry with respect to the reaction plane.

"Almond shaped" overlap region →
Larger pressure gradient in x-z plane than in y direction

Particle rescatterings →Convert the initial spatial anisotropy ε2 into an observed momentum anisotropy v2

Asymmetry disappears with time →Sensitive to the early stages of collision [1].

(near) Central Collision

WEB INTERFACE FOR MONTE CARLO GENERATION

YaPT system has three major parts: the **Web interface** which allows the user to enter data, view results, communicate with other users, authenticate and consult the system documentation, the **Simulations module**, which consists of several Monte-Carlo simulation codes for the study of relativistic heavy ion collisions, being treated differently depending on their specific needs and **Analysis module** which consists of data analysis programs needed to obtain scientific results from simulated or experimental data [2].

BIBLIOGRAPHY:

[1] A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671 (1998); S. Voloshin and Y. Zhang, Z. Phys. C 70, 665 (1996)
[2] S. Cioranu, A. Jipa, P. M. Potlog, Romanian Reports in Physics, Vol. 67, No. 3, P. 819–830, 2015
[3] T. Z. Yan et al, arXiv: 0711.0127 [nucl-th]
[4] STAR Collaboration, Phys. Rev. C 93, 014907 (2016)
[5]. UrQMD code - S.A.Bass et al., Prog.Part.Nucl.Phys. 41 (1998) 225; M.Bleicher et al., J.Phys. G25 (1999) 1859
[6]. AMPT code - Z. W. Lin, C. M. Ko, B. A. Li, B. Zhang and S. Pal, Phys. Rev. C 72, 064901 (2005).
[7]. NA49, Phys. Rev. C 68, 034903 (2003)

FOURIER COEFFICIENTS

Anisotropic flows generally depend on both particle transverse momentum and rapidity, and for a given rapidity, the anisotropic flows at transverse momentum pT can be evaluated according to:
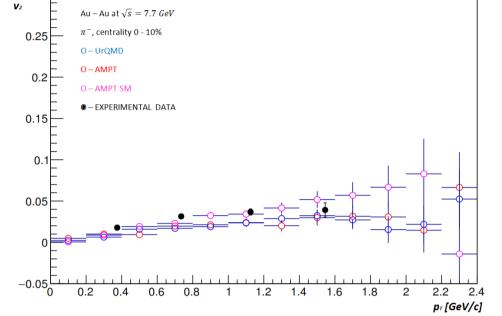
$$v_n(p_t) = \langle \cos(n\phi) \rangle, \qquad (2)$$
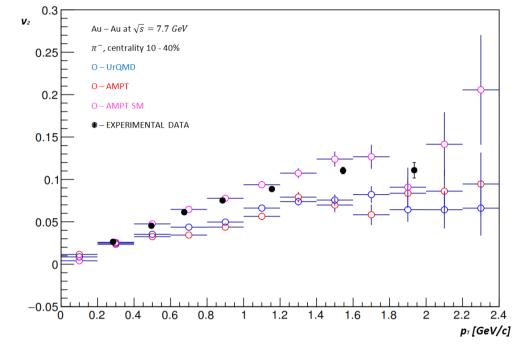
Where <...> denotes average over the azimuthal distribution of particles with transverse momentum pT. The elliptic flow v_2 can further be expressed in term of single-particle averages:

$$v_2 = \langle \cos(2\phi) \rangle = \langle \frac{p_x^2 - p_y^2}{p_t^2} \rangle,$$

where where px and py are, respectively, projections of particle transverse momentum in and perpendicular to the reaction plane [3].
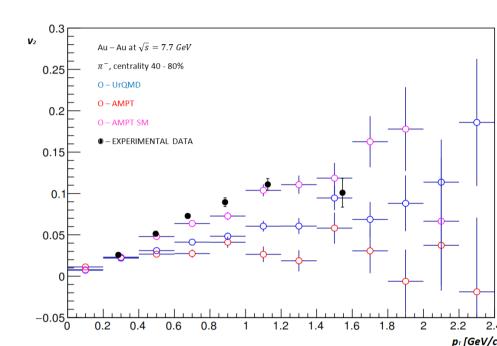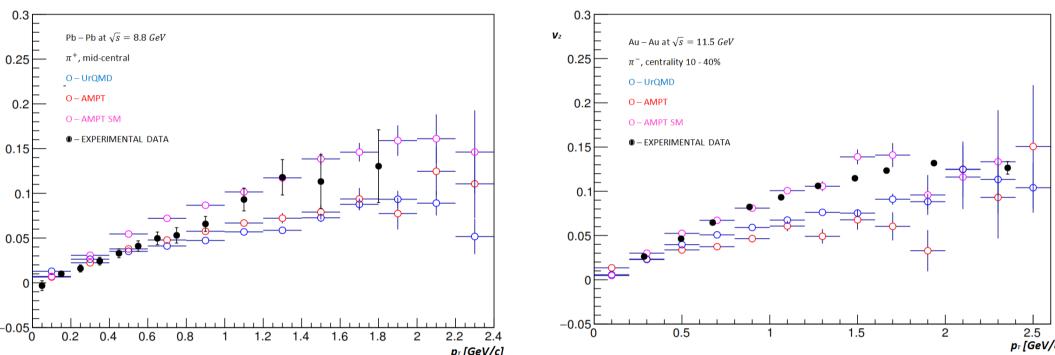
SIMULATIONS

Figure 1: Elliptic flow v2 of negatively charged pions as a function of transverse momentum for 0-10% (left), 10-40% (middle), 40-80% (right) centrality classes in Au+Au collisions at sqrt(sNN)=7.7 GeV.

Experimental data from the STAR experiment [4] are shown with black closed symbols and the simulated data with colored open symbols (blue-UrQMD [5], red-default AMPT [6], magenta-AMPT with string melting, considering a parton-parton interaction cross sections of 3 mb). UrQMD simulated data under predicts the experimental data suggesting that a purely hadronic system (as described by the UrQMD model) does not appear to explain the relatively large flow of the particles at these energies. The best description of the data is provided by the the AMPT-SM model. The elliptic flow from default AMPT is lower than the corresponding results from STAR experiment.

The elliptic flow coefficient obtained in Pb+Pb collisions at 8.8 GeV [7] and Au+Au at 11.5 GeV [4].
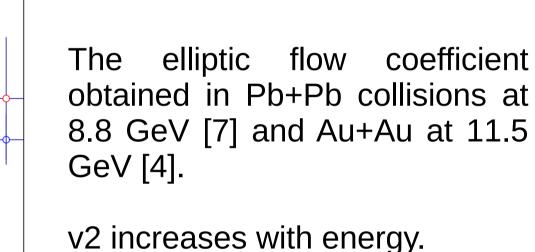
v2 increases with energy.

Figure 2: Elliptic flow v2 of charged pions as a function of transverse momentum produced in semi-central Pb+Pb [7] and Au+Au [4] collisions.
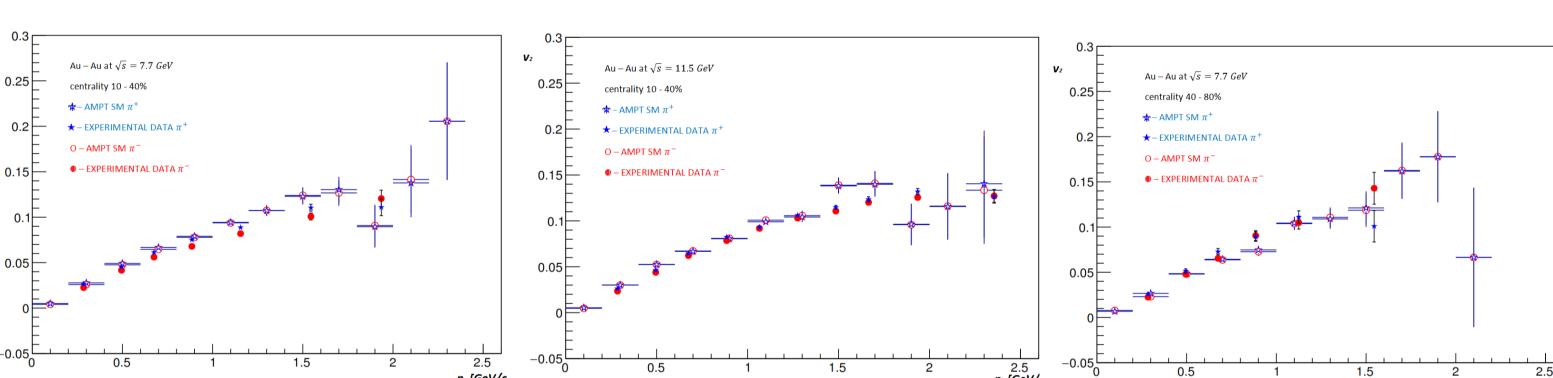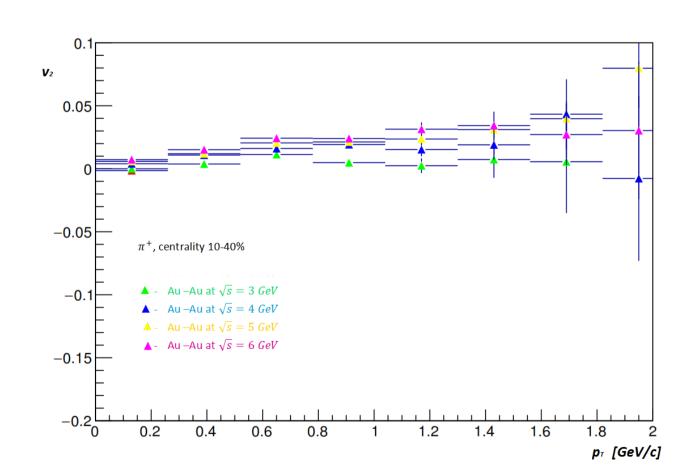

Figure 3: Elliptic flow v2 of charged pions as a function of transverse momentum for 10-40% (left) Au+Au collisions at 7.7 GeV, 10-40% (middle) centrality in Au+Au collisions at 11.5 GeV and for 40-80% Au+Au collisions at 7.7 GeV. Experimental data are from [4].

In Au+Au collisions at 7.7 GeV (center of mass energy) there are differences between v2 values for pi+ and pi-, and this difference could be explained by the coulomb interaction between the charged pions with the fireball net-charge of protons. At low energies, as is the case for 7.7 GeV, the Coulomb interaction is important, but when the energy increases, the interaction decreases in intensity (at 11.5 GeV, middle panel, the pi+ pi- differences disappear). This coulomb interaction depends on the fireball size, therefore in peripheral collisions at 7.7 GeV the asymmetry is not observed anymore (right panel). The simulated results with UrQMD, AMPT-default and AMPT-SM do not present this asymmetry.
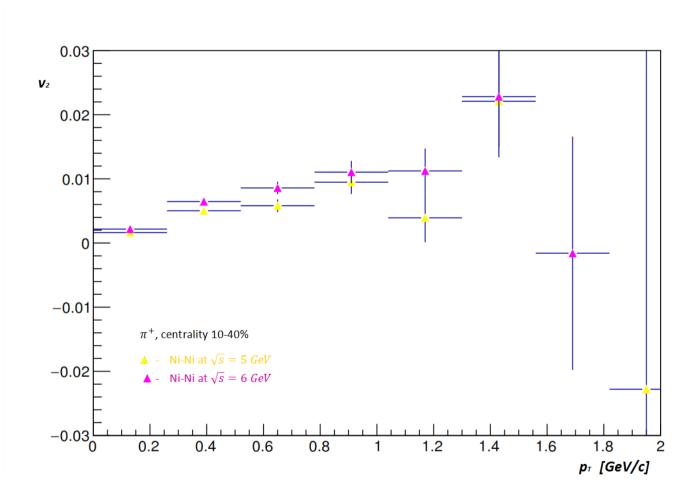

Figure 4: Elliptic flow v2 of positive pions as a function of transverse momentum for 10-40% centrality in Au+Au collisions (left) and Ni+Ni collisions, simulated with AMPT code, at different energies (indicated in figure legend).

Elliptic flow increases with the energy and also with the system syze (in Au+Au collisions is larger than in Ni+Ni collisions).

CONCLUSIONS

The elliptic flow coefficients obtained in heavy ion collisions (Au+Au and Pb+Pb) collisions at moderate energies simulated with UrQMD and AMPT (default version and string melting version) codes are presented. These results are compared with existent experimental data from STAR experiment and NA49 experiment. For charged pion v2, the best description of the experimental data is provided by the the AMPT-SM model and may imply that initially hot and dense matter produced around mid-rapidity consists of partons. The elliptic flow increases with energy and system syze.