# Elliptic Flow from the Parton-Hadron-String-Dynamics


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The discovery of large azimuthal anisotropy at the Relativistic Heavy Ion Collider (RHIC) is a conclusive evidence for the creation of dense partonic matter in ultra relativistic nucleus-nucleus collisions. With sufficiently strong interactions, the medium in the collision zone can be expected to locally equilibrate and exhibit hydrodynamically driven flow. The momentum anisotropy is generated due to pressure gradients in a collective expansion of an initial geometry of the “almond-shaped” collision zone produced in noncentral collisions. The pressure gradients need to be large enough to translate an early stage coordinate space asymmetry to a final state momentum space anisotropy. A large number of elliptic flow measurements have been performed by many experimental groups at SIS, AGS, SPS and RHIC energies over the last twenty years. Very recently azimuthal asymmetries have been measured also at LHC. Studying the energy dependence of anisotropic flow allows to search for the onset of the transition to a phase with partonic degrees of freedom at an early stage of the collision as well as possibly to identify the location of the critical end-point that terminates the first order phase transition.

The dynamics of partons, hadrons and strings in relativistic nucleus-nucleus collisions is analyzed within the novel Parton-Hadron-String Dynamics (PHSD) transport approach [1], which is based on a Dynamical Quasi-Particle model for partons (DQPM) matched to reproduce recent lattice-QCD results - including the partonic equation of state - in thermo-dynamic equilibrium. It was demonstrated that the PHSD model gives a reasonable reproduction of hadron rapidity distributions and transverse mass spectra for SPS and also for RHIC energies. Here we present results of the PHSD model for the elliptic flow.

The elliptic flow parameter is defined as the 2-nd Fourier coefficient $v_2$ of the particle distributions in emission azimuthal angle $\phi$ with respect to the reaction plane angle $\Phi$, and for a given rapidity window can be written as

$$v_2 = \langle \cos(2(\phi - \Phi)) \rangle = \langle \frac{p_X^2 - p_Y^2}{p_X^2 + p_Y^2} \rangle$$

where $p_x$ and $p_y$ are the $x$ and $y$ component of the particle momenta. This coefficient can be considered as a function of centrality, rapidity, transverse momentum, etc.

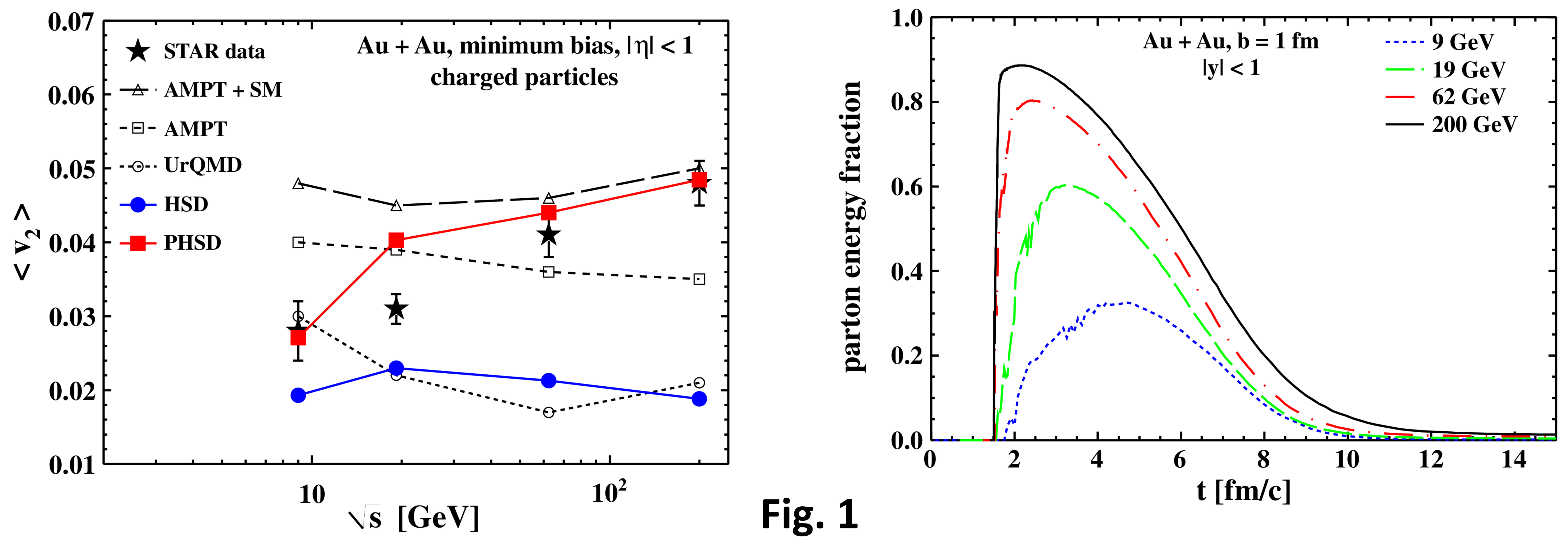


Fig. 1

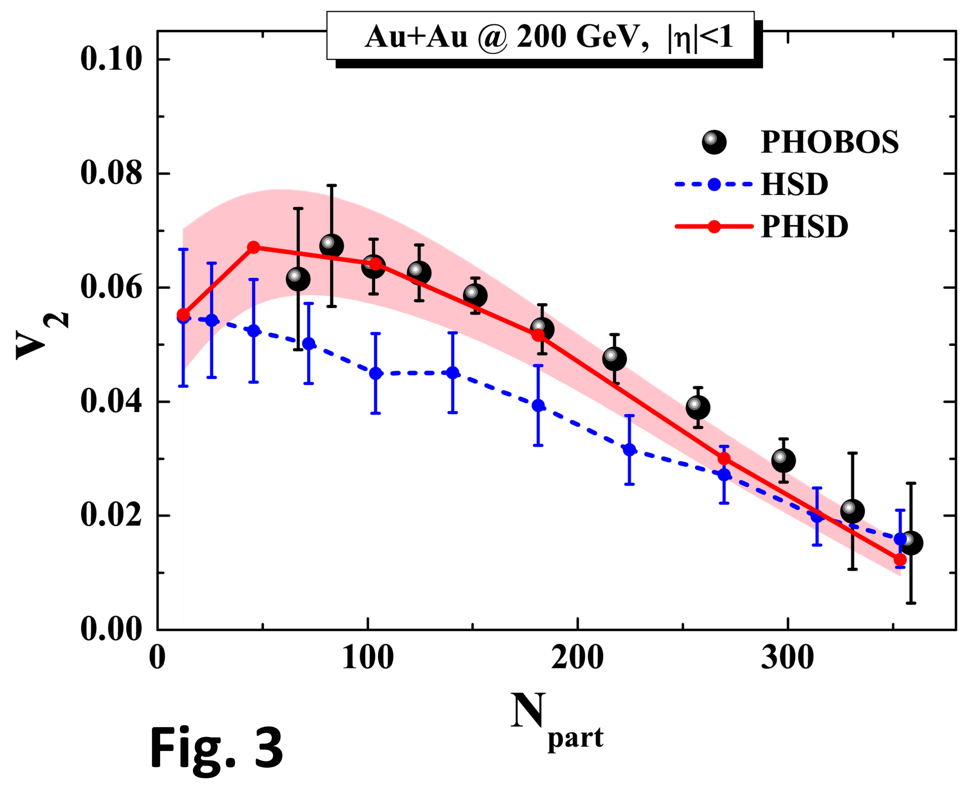


Fig. 3

The experimental data together with available model results [2] are presented for the transient energy range. The HSD and UrQMD models are based on microscopic transport approaches which incorporate hadron interactions, color string formation and resonance decay. Despite different reali-zations both models do not reproduce a rise of < $v_2$ > with the collision energy. The AMPT (A Multi Phase Transport model) uses initial conditions of a perturbative QCD inspired model which produces multiple minijet partons. The later scatter before they are allowed to fragment into hadrons which increases the elliptic flow by about 30%. The string melting version of the AMPT model (AMPT-SM) gives rise to extra 20% of < $v_2$ > and agrees with the data at the top RHIC energy. As follows from Fig.1 (l.h.s.), PHSD is the only model that describes roughly the < $v_2$ > increase with the collision energy. The PHSD model is based on Kadanov-Baym equations for partons and includes many re-alistic properties of dynamical quasiparticles for the quark-gluon transport; it naturally goes over to the HSD model at lower energies. An explanation of the growth of < $v_2$ > with energy is presented in Fig.1 (r.h.s). The main contribution to the elliptic flow is coming from an initial quark-gluon stage. The parton energy fraction and the time that the system spends in the partonic phase go down with decreasing collision energy.

The elliptic flow $v_2$ for Au+Au collisions at the top RHIC energy as a function of the centrality (participants number $N_{part}$) from HSD and PHSD is compared in Fig.3 to the data measured by the PHOBOS Collaboration [5]. The relative enhance-ment of elliptic flow for PHSD with respect to the HSD result [6] can be traced back to the high interaction rate in the partonic phase and to the repulsive mean field for partons. We note in passing that PHSD calculations without mean fields only give a tiny enhancement for the elliptic flow relative to the HSD result.

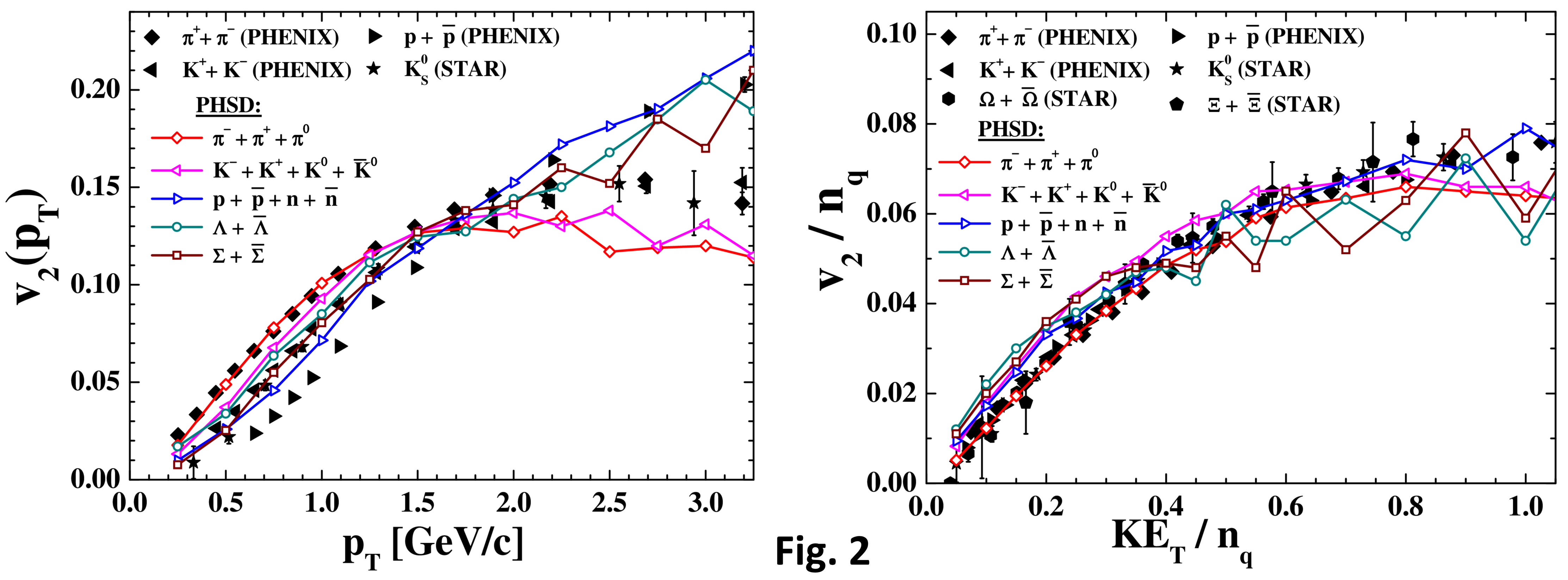


Fig. 2

In Fig.2 (l.h.s.) we plot the elliptic flow $v_2$ versus the transverse momentum $p_T$ for different particle species for Au+Au collision at $\sqrt{s}$ = 200 GeV. A test of the PHSD hadronization approach is provided by the ‘constituent quark number scaling’ of the elliptic flow $v_2$ which has been observed experimentally in central Au + Au collisions at RHIC [3, 4]. In this respect we plot $v_2 / n_q$ versus the transverse kinetic energy ($KE_T$) per constituent parton. The results for the scaled elliptic flow are shown in Fig.2 (r.h.s.) in comparison to the data from the STAR and PHENIX Collaborations for different hadrons and suggest an approximate scaling, roughly in line with the data.

**Conclusions**. The PHSD transport model presently is the only approach that roughly describes the increase of the elliptic flow with beam energy (Fig.1). This increase of < $v_2$ > can be traced back to a gradual increase of the space-time four-volume for partons with energy since the partonic transport properties drive the system to a larger amount of collectivity in the early reaction phase.

## References


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