Constraining the nuclear matter equation of state around twice saturation density *

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Heavy ion collisions at intermediate energies as a tool to constrain the properties of the nuclear equation of state EOS is object of intense experimental and theoretical efforts since several decades [3]. During a heavy ion reaction the colliding system reaches densities larger than the nuclear saturation density. The nuclear EOS determines the densities reached during the collisions as well as the forces which are driving the colliding matter apart.

The FOPI Collaboration has measured the excitation function of 'elliptic flow' between 0.09 to 1.5 A.GeV [1]. Elliptic flow, denoted by $v_2(p_t, y) =< cos(2\Phi)) >$, where Φ is the azimuthal angle with respect to the reaction plane, is shown in the left panel of Fig. 1. The data is compared to predictions of the IQMD transport model [2] using various phenomenological EOS's: HM ('stiff momentum dependent'), SM ('soft momentum dependent'), with compression moduli at ground state density $K_0 = 380$ MeV and $K_0 = 200$ MeV. The data is best described by using a 'soft' EOS. In order, to account for the complete shape of $v_2(y_0)$ a new observable is introduced $v_{2n} = |v_{20}| + |v_{22}|$, v_{20} and v_{22} result from a fit to $v_2(y_0)$ using the function $v_2(y_0) = v_{20} + v_{22}y_0^2$. Model predictions for the quantity $v_{2n}(E_{beam})$ for different EOS are shown together with FOPI data in the right panel of Fig. 1. The predictions vary by a factor ≈1.6 which is far above the measured uncertainty (≈1.1), the comparison clearly favors a 'soft' EOS. This is valid not only for protons but for all light charged particles (A $\leq$ 4).

In order to characterize which 'typical' densities where probed during the collisions we have determined within the same transport model at which times in the course of the collision and which conditions influence the most the development of the proton elliptic flow. The model predicts elliptic flow develops its final shape quite early, just after projectile and target have passed, and that its strength and shape – i.e. v_2 as function of the rapidity – are mostly influenced by the force of the mean field. Therefore, in this scope, the 'typical' density of the 'measured' EOS can be built from the mean value weighted by this force up to the passing time. It is depicted in Fig. 2 as a function of the bombarding energy in the Au+Au system at b=3 fm. It shows that the density range, relevant to the EOS evidenced by the FOPI Collaboration, spans in the range $\rho = (1.25 - 2.0)\rho_0$.

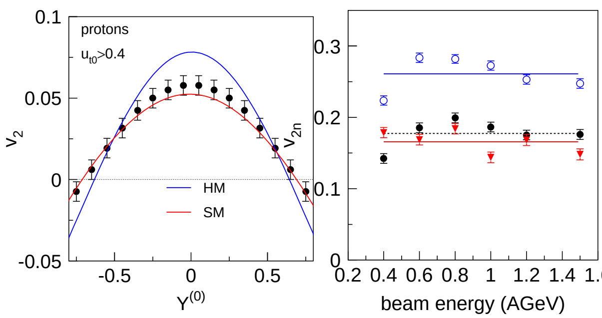

Figure 1: Left: Proton elliptic flow data for Au+Au collisions at 1.2A GeV as a function of the rapidity $-v_2(y_0)$, and IQMD-SM/HM simulations. See [1] for further explanations. Right: Experimental data of the shape parameter v_{2n} for protons as a function of beam energy for semi-central Au+Au collisions.

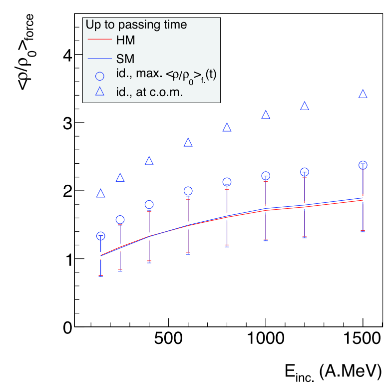

Figure 2: Mean value of the reduced density, computed up to the passing time, weighted by the force of the mean field seen by the participant protons, as a function of the incident energy as predicted by IQMD in Au+Au collisions at b=3 fm, for various EOS's. The error bars are the standard deviations. The blue symbols refer to the SM EOS: the circles depict the instantaneous maximum value of the force-weighted density reached over all times. The triangle is the same, restricted to the central compression zone.

References

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