

Probing the Nuclear Equation of State by Azimuthal Distribution of Collective Expansion in Mid-Central Heavy Ion Collisions

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One of the main motivations to study heavy ion collisions at high energy is to obtain information on the equation of state (EoS) for nuclear matter under extreme conditions of pressure and temperature. The search for hot and dense nuclear matter created in such collisions is confronted with dynamical consequences of the high incident energy necessary to reach the high temperature and pressure and with the question whether thermal equilibrium is reached in finite systems. Dynamical aspects related to the initial phase of the collision and to the evolution stage of the fireball play an important role. Therefore, detailed experimental information on the expansion dynamics is required.

The present work is based on ¹⁹⁷Au + ¹⁹⁷Au and ¹³⁰Xe + ¹³³Cs¹²⁷I data from FOPI - Phase II experiments at SIS/GSI-Darmstadt. In order to extract model-free experimental information, we concentrated on the mean kinetic energy in the c.m. system, $\langle E_{kin}^{cm} \rangle$, and on the flow energy, E_{coll}^{cm} , extracted from its dependence as a function of the mass corresponding to the reaction products ($Z=1,2$ and 3) within a polar angular range of $80^\circ \leq \theta_{cm} \leq 100^\circ$. Both, E_{kin}^{cm} and E_{coll}^{cm} , show an azimuthal distribution which can be nicely fit with the following expression: $(E_{coll}, E_{kin}^{cm}) = (E_{coll}^0, E_{kin}^0) - (\Delta E_{coll}, \Delta E_{kin}) \cdot \cos 2\Phi$. Figure 1 provides

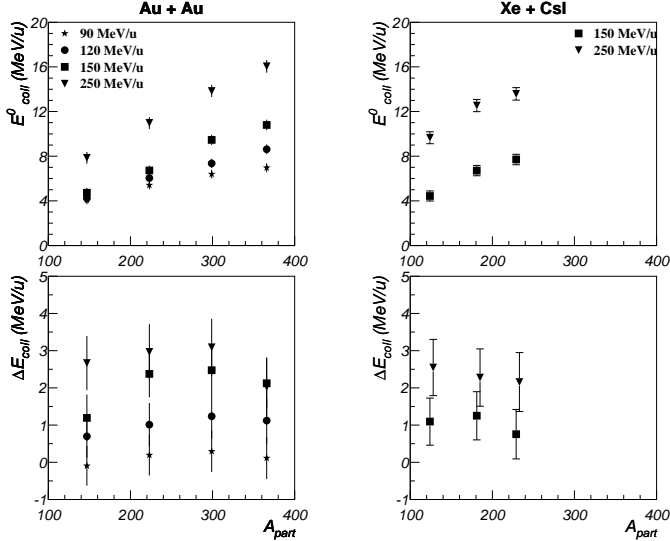


Figure 1: E_{coll}^0 (top panels) and ΔE_{coll} (bottom) as a function of A_{part} at different incident energies in the Au+Au (left) and Xe+CsI (right) systems. a global representation of the results, displaying E_{coll}^0 and ΔE_{coll} as functions of A_{part} for both measured systems. At 90 A·MeV, the in-plane and out-of-plane flow values are very similar ($\Delta E_{coll} \sim 0$) at all centralities in Au+Au, as may be characteristic for the E_{tran} region, the incident energy where a transition from in-plane to out-of-plane enhancement in the azimuthal yield distributions was observed. At all energies, the energy E_{coll}^0 increases with the

centrality corresponding to an increasing baryonic number A_{part} of the fireball. The difference between the out-of-plane and in-plane energy ΔE_{coll} develops a maximum in mid-central Au+Au collisions.

To get insight on the main mechanism behind the observed experimental trends, we calculated the expansion dynamics within a semi-analytical hybrid model [1] for a 200-nucleon fireball, which roughly corresponds to the A_{part} at $b=4-6$ fm in Au + Au collisions. Within this quite simplistic approach the variation of the flow energy with the azimuthal angle is caused by the different times the system can expand undisturbed by the presence of spectator material. It is obvious, though, that

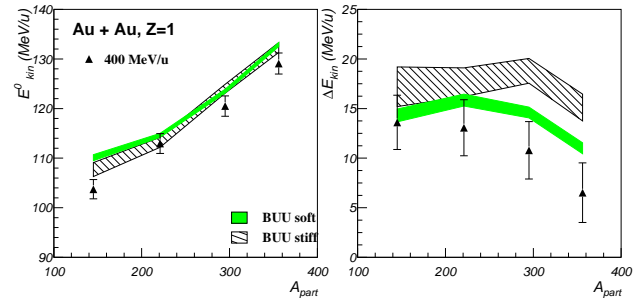


Figure 2: E_{kin}^0 and ΔE_{kin} as a function of A_{part} for $Z=1$ ($A=1,2,3$) fragments, Au+Au at 400 A·MeV. The experimental results are represented by triangles, the BUU results are represented by gray zones for soft EoS and dashed zones for stiff EoS, respectively.

pre-equilibrium processes can be important and that dynamic long-term anisotropies can be produced in the collective expansion, with either effect absent in the simple scenario above. Thus, a comparison with the *ab initio* microscopic transport model becomes important. Correspondingly, for the 400 A·MeV Au+Au collisions we present in Fig. 2 the results of the Boltzmann-Uehling-Uhlenbeck (BUU) transport code [2] using momentum dependent mean fields ($m^*/m=0.79$), in-medium elastic cross sections ($\sigma = \sigma_0 \tanh(\sigma^{free}/\sigma_0)$ with $\sigma_0 = \rho^{-2/3}$) and soft ($K=210$ MeV, gray zone) or stiff ($K=380$ MeV, dashed zone) EoS. The two EoS parametrizations do not show any sensitivity in E_{kin}^0 , both being in a quite good agreement with the data. As far as the values of ΔE_{kin} are concerned, the calculations with the soft EoS reproduces the overall trend of the experiment while the calculations with the stiff EoS overestimate significantly especially at higher centralities (lower impact parameter) the measured values.

References

- [1] M. Petrovici et al., Phys. Rev. Lett. 74 (1995) 5001
- [2] P. Danielewicz and Q. Pan, Phys. Rev. C 46 (1992) 2002, P. Danielewicz, Nucl. Phys. A 673 (2000) 375