Experimental Indications for the Response of the Spectators to the Participant Blast

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The equation of state (EOS) of nuclear matter, responsible for its response to temperature and density, belongs to the key topics of nuclear physics. Intensive effort has been invested to extract information on the equation of state and on in-medium nucleon-nucleon interactions by observing light particles emerging from central collisions in full-acceptance experiments. The most important observables in these experiments are the collective flow of particles and the kaon production emerging from the expanding fireball. However the analysis of these experimental data using transport calculations has not yet reached a conclusion on the stiffness of the EOS, because both the nuclear compressibility and the momentum dependent interactions (MDI) influence the flow patter. Further progress requires observables that depend exclusively either on the EOS or on MDI. Recently, it has been brought into the discussion that the kinematical properties of the spectators in mid-peripheral collisions carry important complementary information to the results of the above-mentioned experiments. According to these model calculations [1], the transversal and the longitudinal momentum distributions of the spectators are influenced by the participant blast, occurring after the compression phase in the colliding zone, and thus the momentum distributions are sensitive to the nuclear force. More specifically for some favourable systems the expanding fireball would cause an acceleration of the spectator fragments. This acceleration is an observable that is sensitive mainly to the MDI. However, the momentum distributions have to be measured with high precision in order to yield conclusive results.

To this purpose, we made use of a high-resolution magnetic spectrometer, the FRS at GSI. A 1 *A* GeV ^{238}U beam impinged on two different targets, a 36 mg/cm^2 titanium target and a 50.5 mg/cm^2 lead target. The magnetic rigidity of each projectile-residue could be measured with high precision by determining the deflection in a magnetic dipole field. This gave a measure of the longitudinal momentum, and hence on the velocity, with a statistical relative uncertainty of $\pm 5\cdot 10^{-4}$, once the product is identified in mass and atomic number. Details of the experimental set-up and the detector equipment, as well as a description of the analysis method can be found in ref. [2]. Fission and fragmentation residues could be disentangled thanks to their longitudinal momentum distributions inside the limited angular acceptance of the spectrometer. The isotopic and kinetic features of the products, generated in the two reactions and differently transmitted through the FRS, formed a characteristic pattern in velocity and neutron excess, which allowed the separation between fragmentation and fission residues, as described in ref. [2]. For safety, we only considered the mean velocity values of fragmentation-evaporation residues for nuclei with $Z \geq 20$, where fission and fragmentation are clearly separated in velocity. The mean values of the velocity distributions of fragmentation residues are shown in Figure 1 as a function of the mass number. Statistical uncertainties are not shown in order not to overload the figure. They correspond to the fluctuations of the points. The absolute uncertainty amounts to less than 0.05 cm/ns for each system, ^{238}U + Pb and ^{238}U + Ti, independently.

With increasing mass loss, the velocities first decrease as expected from previously established systematics [3], then level off, and finally increase again. Light fragments are on the average even faster than the projectiles. This finding is in contrast to the expectation that lighter products, which are assumed to be produced in more violent collisions, are slowed down in the reactions, since they experience more friction in the nucleus-nucleus collision [3]. The re-acceleration of spectator fragments is interpreted as the response of the spectators to the participant blast postulated by Shi, Danielewicz and Lacey [1]. In the frame of this theoretical work, the precise measurement of the kinematical properties of the spectators represents a new tool to determine the in-medium nucleon-nucleon interactions. The present experiment supports the feasibility of this method. As stated in ref. [1], this kind of data will give new information on the EOS of nuclear matter. In particular, the acceleration found for relatively small impact parameters, presumably leading to the production of light reaction residues, is selectively sensitive to the momentum-dependence of the nuclear mean field [1].

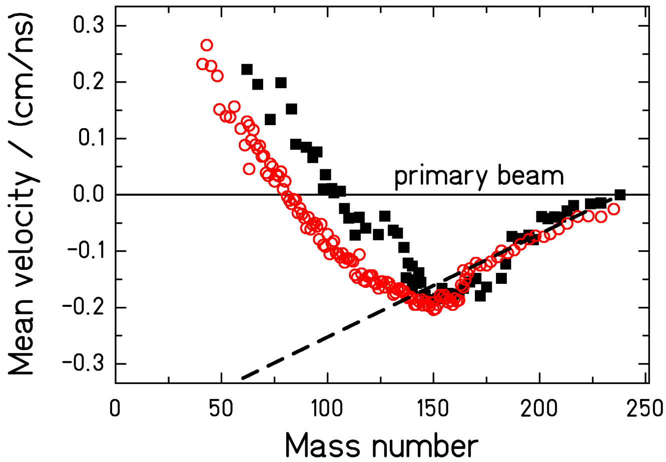

Figure 1: Mean longitudinal velocities of fragmentation residues produced in ^{238}U + Pb (■) [2] and ^{238}U + Ti (○) [this work] at 1 *A* GeV in the frame of the projectile. The dashed line marks the Morrissey systematics [3].

[1] L. Shi, P. Danielewicz and R. Lacey, PRC **64** (2001) 034601.

[2] T. Enqvist et al., Nucl. Phys. **A 658** (1999) 47.

[3] D. J. Morrissey, PRC **39** (1989) 460.