ESF Exploratory Workshop on How to Constrain the High Density Symmetry Energy

(To be held in Zagreb, Croatia from 2nd to 4th of October 2009)

The case

MOTIVATION

The behaviour of the nuclear medium as a function of density is of fundamental importance to both nuclear physics and astrophysics, in particular for the supernova explosion dynamics and the neutron star properties [1-4]. It is usually referred to as a (nuclear) equation of state (EOS). Despite of decades of theoretical and experimental efforts concentrated on resolving the EOS of (isospin) symmetric nuclear matter, the question of hardness of the nuclear medium to the compression is unsolved. It was propounded that a longstanding problem of the EOS determination cannot be solved without constraining the term coming from the isospin contribution [5], the so-called asymmetric term related to the symmetry energy of the Bethe-Weizsäcker mass formula. Indeed, our understanding of the EOS is limited, largely due to our poor knowledge of the density dependence of the nuclear symmetry energy. Heavy-ion reactions induced by neutron-rich nuclei, especially radioactive beams, have a crucial role to play in this field. While considerable progress has been made recently in determining the symmetry energy around and below normal nuclear matter density ($\rho/\rho_0 \sim 0.3$-0.6, for recent references see, e.g., [6-14]) much more work is still needed to probe its high-density behaviour.

METHOD AND PROCEDURE

To this aim, it is urgent to propose a comprehensive measurement which can be undertaken under controlled condition in the laboratory. Collisions between energetic atomic nuclei create for a short laps of time a piece of compressed nuclear matter, a procedure already used to determine properties of isospin symmetric EOS at supernormal densities (see e.g. [15,16]). By colliding nuclei of energy from about 200 A MeV or higher and with large difference in their neutron-to-proton (N/Z) contents, i.e. isospin, one may expect to reach condition which will provide an experimental insight into properties of the symmetry-energy term of EOS at high densities. Such energies are currently available only at Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany and its SIS synchrotron. Several potentially useful experimental observables have been identified among which the most promising is the neutron-proton differential transverse and elliptic flow in reactions within the energy range of SIS [14,17,18]. As pointed out by the authors, these nucleon-multiplicity weighted observables minimize the influence of the isoscalar part in the EOS while maximizing that of the symmetry term. Effects of other dynamical ingredients in the intermediate range of collision energies are also reduced. The expected effects are, nevertheless, small and require measurements of high precision.

The original predictions of [17] have been revised by more recent calculations [19] (Fig. 1, see also [20] for a review) which demonstrated the sensitivity of the predictions to the specific ingredients of the transport model used. It is, therefore, mandatory to experimentally identify mean-field effects related to the neutron richness of the system with a double-differential flow measurement for two systems with different N/Z contents [19]. An example with stable beams presently available from SIS is represented by the pair of mass-symmetric ^{112}Sn+^{112}Sn and ^{124}Sn+^{124}Sn reactions. Measurements at several bombarding energies will also be useful for confirming the trends predicted for these asymmetry-dependent observables (Fig. 1).

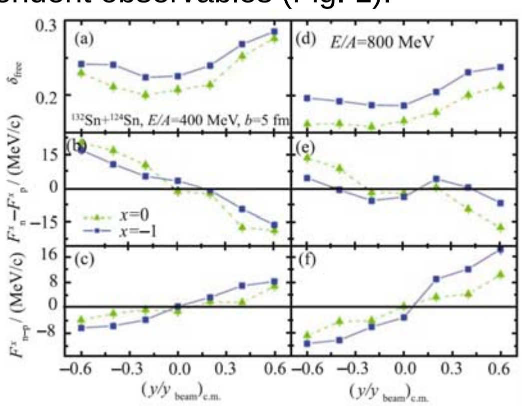

Figure 1: Rapidity distributions of the isospin asymmetry of free nucleons (top panels), the difference of the average nucleon transverse flows (middle), and of the neutron-proton differential transverse flow (bottom) for ^{132}Sn + ^{124}Sn reactions at E/A = 400 MeV (left) and 800 MeV (right) and b = 5 fm and for asy-stiff (x = -1, squares) and asy-soft (x = 0, triangles) parameterizations of the nuclear symmetry energy. The lines are meant to guide the eye (from ref. [19]).

An important argument, besides the theoretically motivated advantages of the differential flow observables, has come from the high precision that can be reached in measurements of collective flows. The agreement of directed and elliptic flow values for ^{197}Au + ^{197}Au reactions in the energy range near 100 A MeV, measured at GSI with both, the FOPI and INDRA detectors, has shown that an accuracy of the order of 5% can be reached on an absolute level. This includes the corrections necessary to account for the dispersion of the experimentally reconstructed reaction plane [15,16]. Considerably smaller uncertainties, on the level of percent, can be expected for differential observables provided that data with sufficiently high statistics are collected. The use of mass-symmetric systems permits the application of additional methods for reducing systematic errors.

GOAL AND FOLLOW-UP

Beside an adequate beam of ions one needs an appropriate detection device able to provide the required quality of physical information. Although only components of such an apparatus are currently available at GSI (Large Area Neutron Detector – LAND and a time-of-flight wall) all needed equipment does exist in European laboratories (e.g. CHIMERA Si-CsI telescopes of INFN-LNS, Catania and a telescope array of Krakow) and may be moved to GSI, if a consensus is reached. Besides an obvious need that representatives of these European laboratories sit together to find the most adequate solution in building the necessary detection apparatus from existing components one of main goals of the proposed Exploratory Workshop is to discuss and converge towards the best choice of experimental details including an ample discussion of the best choice of reaction system(s), energies as well as observables in order to fix all experimental parameters. The participation of the most renowned theoreticians in the field is mandatory to achieve the most appropriate choice.

To summarize, the eventual goal of the proposed Workshop is threefold:

- **(i) to firmly pave an experimental proposal to be submitted to the Proposal Advisory Committee of GSI,**
- **(ii) to form a formal international collaboration with a possible intention**
- **(iii) to apply for an ESF grant in the framework of the Research Networking Programme.**

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