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Accessing the nuclear symmetry energy in Ca+Ca collisions

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Abstract

The status of the analysis of the INDRA-VAMOS experiement performed at GANIL, using the reactions ^{40,48}Ca+^{40,48}Ca reactions at 35AMeV, are presented. Isotopic distributions of fragments produced in multifragmentation events provide information on the importance of the surface term contribution in the symmetry energy by comparison to AMD predictions.

1 Motivations

1.1 Equation of state of asymmetric nuclear matter

The understanding of the structure and evolution of astrophysical compact objects, as well as the structure of nuclei far from the valley of stability requires the knowledge of the equation of state of nuclear matter under extreme conditions of temperature, densities ans isospin. Heavy ion collisions are one of the most powerful way to reproduce such conditions in laboratories.

The equation of state for asymmetric nuclear matter is usually expressed as a term related to symmetric matter and a term which takes into account the isospin asymmetry of the system. This term is usually refered to as the symmetry energy. Despite the recent experimental and theoritical efforts [1], relatively weak constraints exist on the density dependence of the symmetry energy. A variety of observables have been proposed to access the symmetry energy in heavy ion collisions [2]. The isotopic distributions of fragments produced in multifragmentation events seem rather promising to investigate properties of low density nuclear matter.

Indeed these reactions are believed to proceed through a low density stage at finite temperature during which fragments are expected to be formed [3]. However, surface effects could be important, as at saturation density, leading to differences between the symmetry energy extracted from multifragmentation systems and the infinite nuclear matter symmetry energy.

Recently, A. Ono *et al.* addressed this question [4]. By means of AMD simulations of ^{40}Ca+^{40}Ca, ^{48}Ca+^{48}Ca, ^{60}Ca+^{60}Ca and ^{46}Fe+^{46}Fe collisions at 35 AMeV, the authors shown that the symmetry energy at finite temperature and subsaturation density extracted from primary fragment isotopic distributions corresponds to the symmetry energy of nuclear matter, *i.e.* surface effects are negligible in multifragmentation events.

Indeed, a global fit of the yield distributions with a quadratic function :

$$K(N,Z) = \eta(Z) + \xi(Z)N + \zeta(Z)\frac{(N-Z)^2}{N+Z},$$

allows to determine the $\zeta(Z)$ parameter. Within a statistical treatment, the authors show that $\zeta(Z)$ can be related to the ratio of the surface to volume term of the symmetry energy :

$$\zeta(Z) \propto 1 - \frac{c_S}{c_V}(2Z)^{-1/3}.$$

AMD predictions indicate such term to be independent of Z, suggesting that properties of infinite nuclear matter can be directly obtained from the information of fragmentation. Since secondary decay effects are expected to distort the signature of the symmetry energy encountered in primary fragment isotopic distributions [5], secondary deexcitation has to be taken into account for a meaningful comparison of experimental data to theoritical calculations. The experimental verifications of such predictions is one of the main goal of the experiment performed by the INDRA collaboration coupling

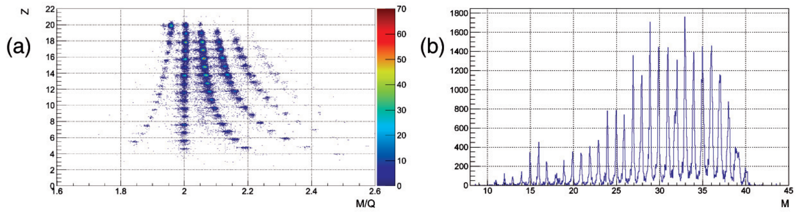

Figure 1: (a) Z vs. M/Q spectrum of the ^{40}Ca+^{48}Ca reaction.
(b) Isotopic distribution for the ^{40}Ca+^{48}Ca reaction.

the 4π detector INDRA and the VAMOS spectrometer. The experiement was performed at GANIL where ^{40,48}Ca+^{40,48}Ca reactions at 35AMeV were measured.

2 Status of the analysis

The INDRA multidetector [6, 7] has a structure in rings centered on the beam axis and covers around 90% of the 4π solid angle. Telescope detectors, constituted by an ionisation chamber, a silicon detector and a CsI provide detection and identification of the reaction products with low thresholds.

The mass spectrometer VAMOS [8] is designed to select and identify (Z, A, E) heavy reactions products. Its focal plane detection system consists of two drift chambers, an ionisation chamber, a silicon wall and a CsI wall which provide ΔE, E, Z, position and time of flight measurements. The scattering angles at the angles, Bρ parameters of each fragment are obtained by a software trajectory reconstruction. The coupling of these two detectors allow us to have an event by event complete characterisation.

The time of flight (ToF) measurement has been obtained by a TAC calibration, to determone the channel to ns conversion factor, combined to the analysis of elastic events to dertermine the time offset. The flight path length, combined with the ToF measurement allows us to determine the particle velocity at the target position. We then determine the mass and M/Q ratio, given by the equations [9, 10] :

$$\frac{M}{Q} = \frac{B\rho}{3.105 \times \beta} \qquad M = \frac{2E_{tot}}{931.5016 \times \beta^2}$$

The charge Z is obtained from the standard ΔE-E procedure in silion and CsI detectors. Figure 1a shows a typical Z vs M/Q spectrum for the ^{40}Ca+^{48}Ca system. The fragments with M/Q=2 lies on a straight line. Masses from Z=5 to Z=20 are identified. Indeed, the ^{8}Be absence in the spectrum allows us to undoubtely identify the charges. The isotopic distributions for each system are obtained by the M/Q and M measurements, and the Q evaluation. An example of isotopic distribution is presented in fig. 1b. A very good isotopic separation is obtained for all the isotopes, up to the heaviest detected mass.

3 Conclusion

A very good mass identification is obtained by the analysis of VAMOS data, up to the highest detected masses. A combinaition of this information to the event characterization that can be obtained by the INDRA analysis will allow us to have an insight on the density dependance of the symmetry energy and the importance of the surface term in multifragmentation events.

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