Isoscaling, SMM and the symmetry energy: connecting the dots

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Knowledge of the nuclear symmetry energy (E_{sym}) is essential for understanding not only the structure of radioactive nuclei [1], but also many important issues in astrophysics [2] and significant theoretical and experimental works [3-5] have been devoted to its study. While the value of symmetry energy has been well constrained at normal nuclear density and zero temperature, heavy ion collisions remain the most powerful way to study the nuclear matter behaviour in extreme conditions of temperature and density, that can otherwise be encountered only in astrophysical environments, like supernova explosions and neutrons stars. Several observables in heavy ion collisions are known to be affected by the symmetry energy (E_{sym}), but quantitative information is difficult to extract, due to secondary decay of excited primary fragments, which can distort signatures contained in primary fragment observables. Among those observables, isoscaling [6] applies for a variety of reaction mechanisms that are dominated by phase space, including evaporation, multifragmentation, and deep inelastic scattering under the condition of statistical emission. Isoscaling has been observed for the secondary fragments from ^{78,86}Kr+ ^{58,64}Ni at 35AMeV reactions, taken on the NIMROD-ISiS array. The details of the experiment can be found in Ref. [7]. A comparison to models is now needed to constrain E_{sym}. The Statistical Multifragmentation Model (SMM) [8] has been widely used for interpreting experimental data on multiple fragment production in different nuclear reactions and to extract information on the symmetry energy starting from secondary fragments.

In the present work we are analysing SMM, paying special attention to the effects of the secondary de-excitation on the value of observables which can be extracted from experimental data and their correlation with input symmetry energy value in the model. Among the observables we focus on is the isoscaling parameter α_1 to figure out how the symmetry energy values, which can be extracted from it for both hot and cold fragments, are related. Starting from SMM, the isotopic yield of each fragment (N,Z) emitted in the multifragmentation of the quasi-projectile has been determined for both the quasi-projectile sources (^{78}Kr and ^{86}Kr), in order to compute the isoscaling parameter α. For hot fragments (i.e. before the secondary de-excitation) the behaviour of α as a

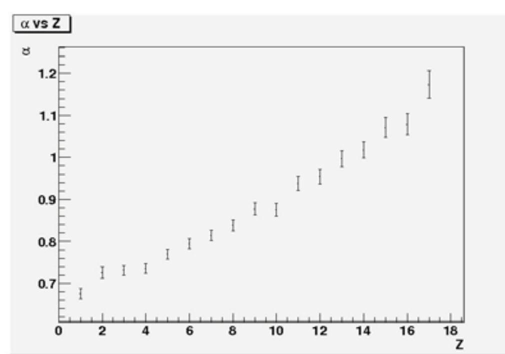

FIG. 1. Isoscaling parameter α from the fitting of the yield ratios of each Z for hot SMM fragments.

function of the fragment charge Z for a chosen source excitation energy (5 MeV/nucleon) and input symmetry energy coefficient (25 MeV) is shown in Fig. 1. The α parameter shows the same behaviour as function Z, even for other values of source excitation energy (3, 4 and 7 MeV/nucleon) and input symmetry energy values C_{sym} (4, 8 and 14 MeV). Attempts to physically interpret this trend have been done by varying the source size, to eventually figure out finite size effects, by isolating the Coulomb contribution (C_{sym} = 0) and by selecting a narrow hot fragment excitation energy window. A selection based on the source temperature seems to be the most promising, but work is still in progress.

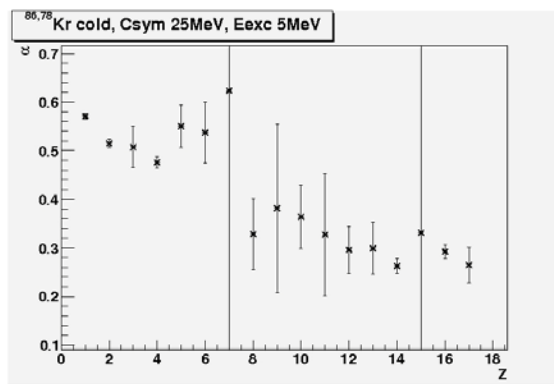

FIG. 2. Isoscaling parameter α from the fitting of the yield ratios of each Z for cold SMM fragments.

Experimentally only cold fragments can be detected and, unless we rely on models to reconstruct primary quantities, information has to be extracted from secondary fragments (i.e. after de-excitation). The behaviour of the α parameter as a function of the fragment charge is plotted in Fig. 2. The same trend has been observed varying the source excitation energy and the symmetry energy input parameter. The physical interpretation of gap in the α value between Z=7 and Z=8 is still under analysis.

The isoscaling parameter α can be linked theoretically [6,9-11] to nuclear symmetry energy by the relation:

$$\alpha = \frac{4C_{sym}}{T}\left[\left(\frac{Z}{A}\right)_1^2 - \left(\frac{Z}{A}\right)_2^2\right] \tag{1}$$

where C_{sym} is the symmetry energy coefficient, T is the temperature and the Z/A values correspond to the neutron richness of the neutron-rich and neutron-poor sources, respectively. An analysis of α, such as the one performed on experimental data, will allow us to reconstruct the C_{sym} value ($C_{sym}out$) and to study its correlation with the input C_{sym} value ($C_{sym}in$). The correlations for both hot and cold fragments are plotted in Figs.3(a) and Figs.3(b), respectively. The $C_{sym}out$ values extracted from hot fragments are in good agreement with the input values $C_{sym}in$, suggesting that information on C_{sym} can be extracted from primary fragments. The correlation is significantly damped for excitation energy above 3 AMeV by the secondary de-excitation, which distorts the signatures of the symmetry energy.

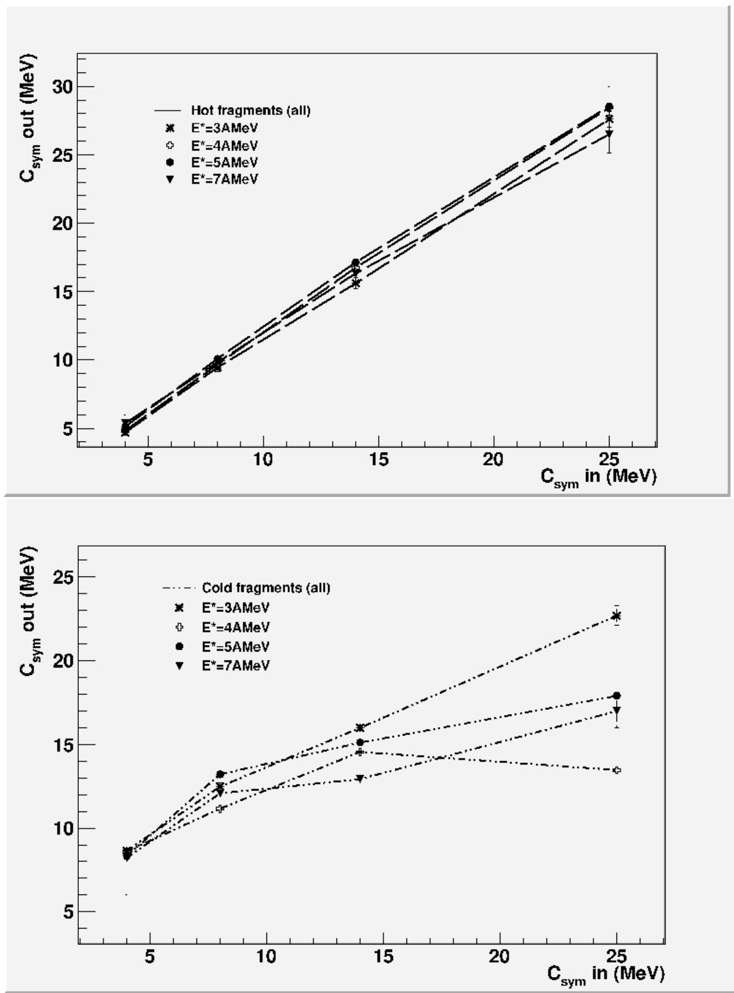

FIG. 3. Correlation between the SMM input symmetry energy coefficient value ($C_{sym}in$) and the symmetry energy coefficient value determined by the isoscaling parameter α obtained by the analysis of hot (upper part) and cold (lower part) fragments.

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