Constraining the symmetry energy with isotopic yield distributions

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In the past few years the importance of the symmetry energy term in the nuclear equation of state has stimulated a growing interest in isospin effects in nuclear reactions. Understanding the properties of asymmetric nuclear matter both at normal densities and at densities away from the saturation density has an important impact on the study of the nuclear structure close to the drip lines [1] and of astrophysical processes [2].

The study of the multifragmentation process in violent heavy ion collisions at Fermi energies is important for the investigation of the symmetry energy. Indeed the isotopic distribution of fragments produced in such collisions is governed by the free energy at the density and temperature of the fragmenting source. Thus, information on the free symmetry energy can be extracted from the isotopic yield distributions.

The production of fragments up to *Z=7*, detected in FAUST, from a range of isotopically identified quasi-projectiles obtained in the $^{32}S+^{112}Sn$ has been studied by S. Soisson [3]. By looking at the fragment isotopic distributions it has been shown that, within the adopted Statistical Multifragmentation Model picture, the symmetry energy of the primary hot fragments produced from the decay of neutron-rich sources appears to be considerably lower than the symmetry energy of the same fragments produced from neutron-poor sources.

We have extended the analysis to heavier fragments produced in $^{78,86}Kr+^{58,64}Ni$ at 35MeV/nucleon reactions and detected with NIMROD+ISiS apparatuses, located in the Neutron Ball. A stringent selection of the events has allowed the reconstruction of the quasi-projectile, obtaining events, on average, spherical, with a total detected charge $30 \le Z \le 34$. Moreover, particles not produced from projectile-like sources have been removed from the analysis [4,5].

The quasi-projectile (QP) mass distributions sorted by excitation energy show the same trend observed in $^{32}S+^{112}Sn$: increasing the QP excitation energy, the QP mass distribution broadens, as shown in fig. 1. We should notice that in our analysis free neutrons have been included in the QP mass and excitation energy determination, while they were not included in the previous analysis.

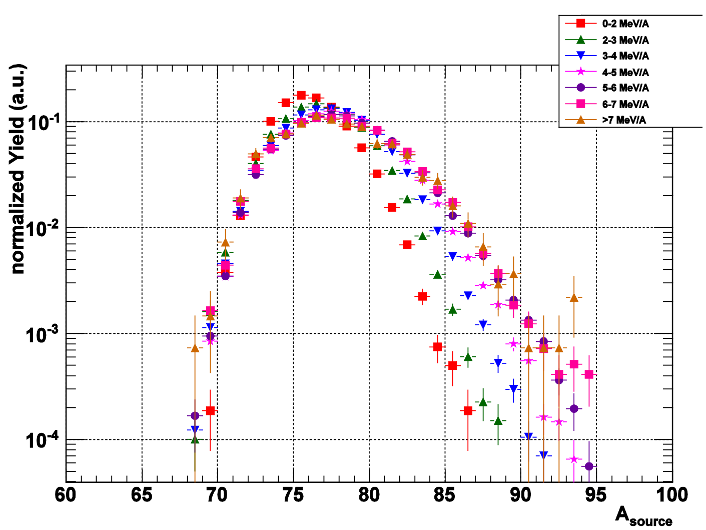

FIG. 1. Mass distribution of *Z*=36 quasi-projectile sources in seven excitation energy ranges.

The fragment charge distribution of the reconstructed sources ^{71}Kr to ^{89}Kr

($\frac{N-Z}{A}$ = -0.014 - 0.19) do not show the odd-even behavior observed for the lighter neutron poor QP source ^{27}S ($\frac{N-Z}{A}$ =-0.185), as shown in fig. 2. A possible reason could be the higher mass of the Kr source or the smaller $\frac{N-Z}{A}$ asymmetry of the most n-poor Kr source.

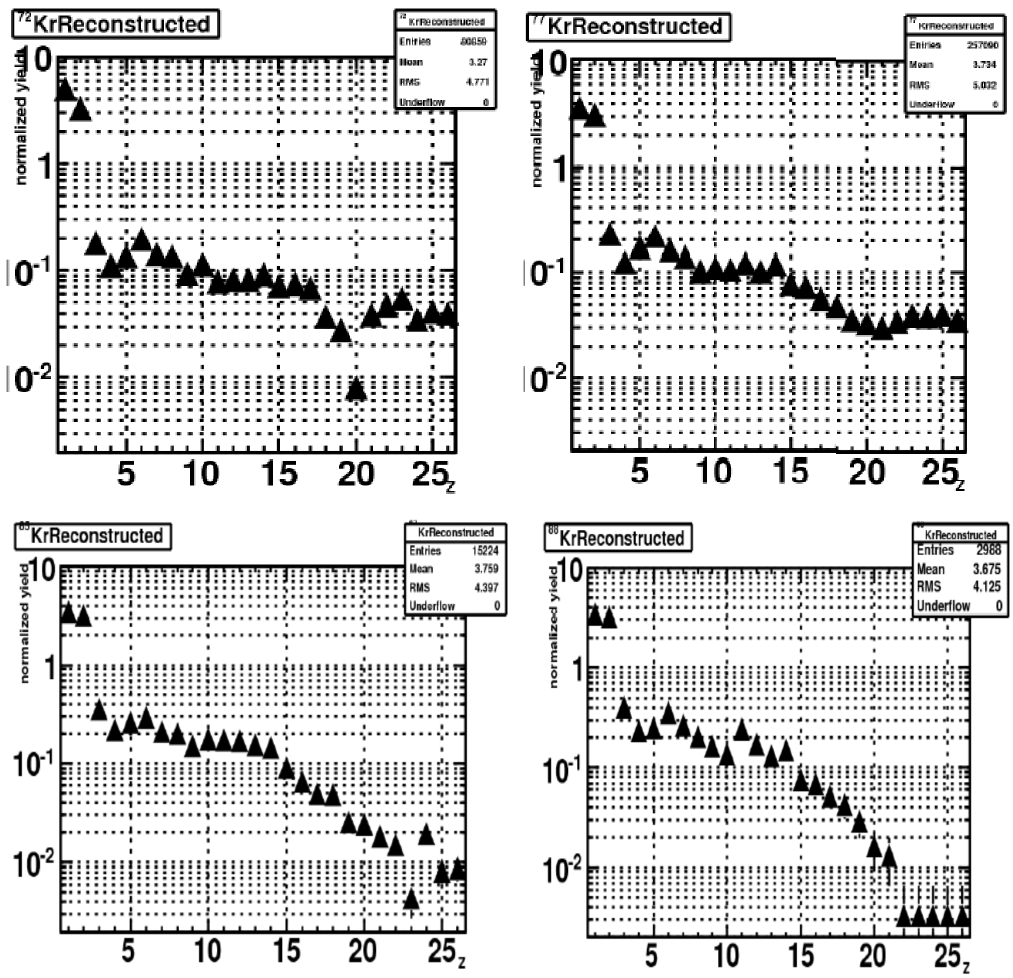

FIG. 2. Normalized fragment charge distribution for the multifragmentation of the ^{72}Kr (top left), ^{77}Kr (top-right), ^{85}Kr (bottom-left) and ^{88}Kr (bottom-right). The yields are normalized to the total number of sources of the corresponding mass.

In agreement with previous studies and the S case, the fragment charge distributions change shape with the increase of the source excitation energy, moving from a U-shape to an exponential-like distribution. No odd-even effect is observed in the Kr case for the neutron-poor sources at low excitation energy, as show in fig. 3. The average neutron-proton ratio of the produced fragments is found to be correlated to the neutron richness of the source, as shown in [3].

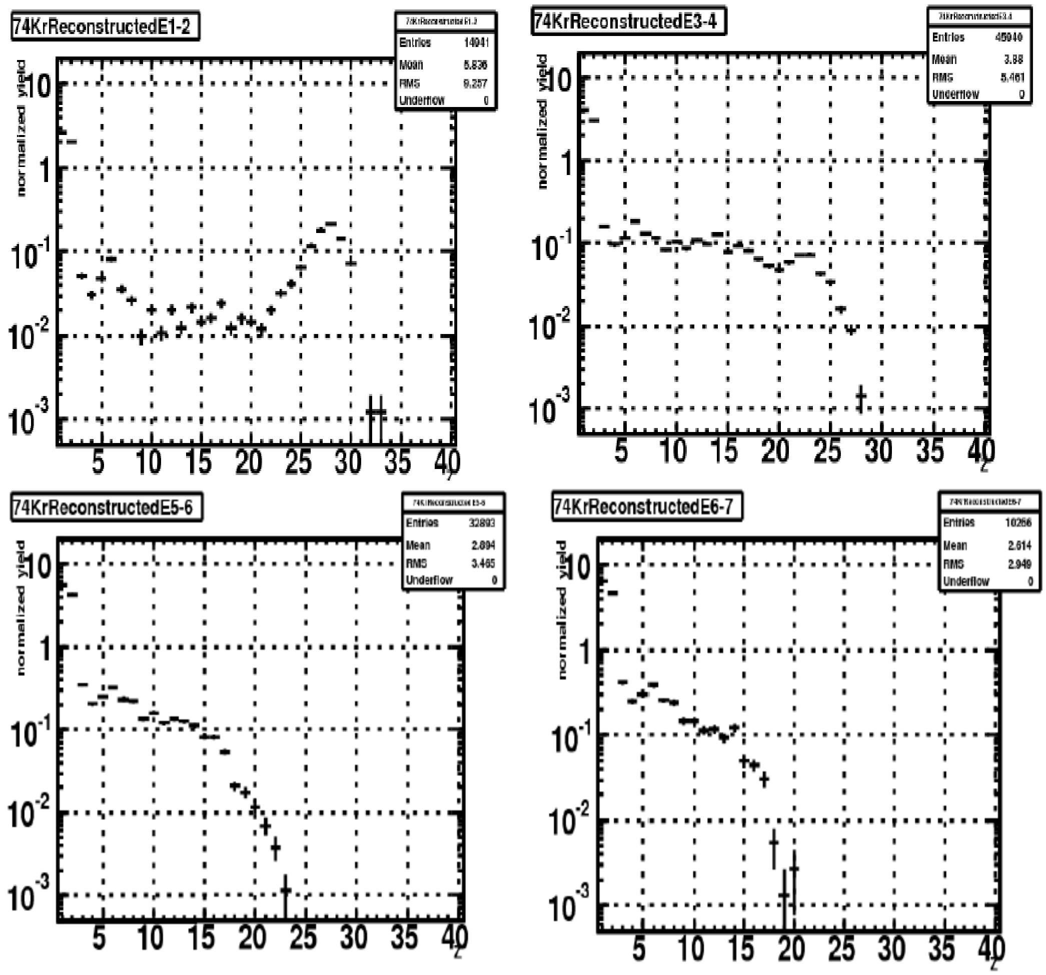

FIG. 3. Fragment charge distribution for the reconstructed source ^{74}Kr for 4 excitation energy bins: 1-2 (top left), 3-4 (top-right), 5-6 (bottom-left) and 6-7 (bottom-right). The yields are normalized to the total number of sources of the corresponding mass in the given excitation energy bin.

A comparison of these results and of the isotopic yield of heavy fragments ($Z > 8$) with the Statistical Multifragmentation Model is in progress. In particular, it will be interesting to verify if for sources larger that S produced in reactions involving a higher mass projectile (such as the Kr+Ni reactions that we are analysing) lower symmetry energy coefficients are needed to reproduce the distributions of fragments produced in n-rich sources.

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