Mapping the Symmetry Energy Using Reconstructed Quasiprojectile Sources

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To fully understand the symmetry energy term in the nuclear binding energy equation, a detailed mapping of the variation of the symmetry energy as a function of temperature and density is needed. The current study uses projectile-like sources, called quasiprojectiles, that were reconstructed from isotopically identified fragments formed from the reactions 32 and 45 MeV/nucleon ^{40}Ar, ^{40}Ca and ^{48}Ca on ^{112}Sn and ^{124}Sn. The technique of isoscaling was used on the isotopically resolved yields from these
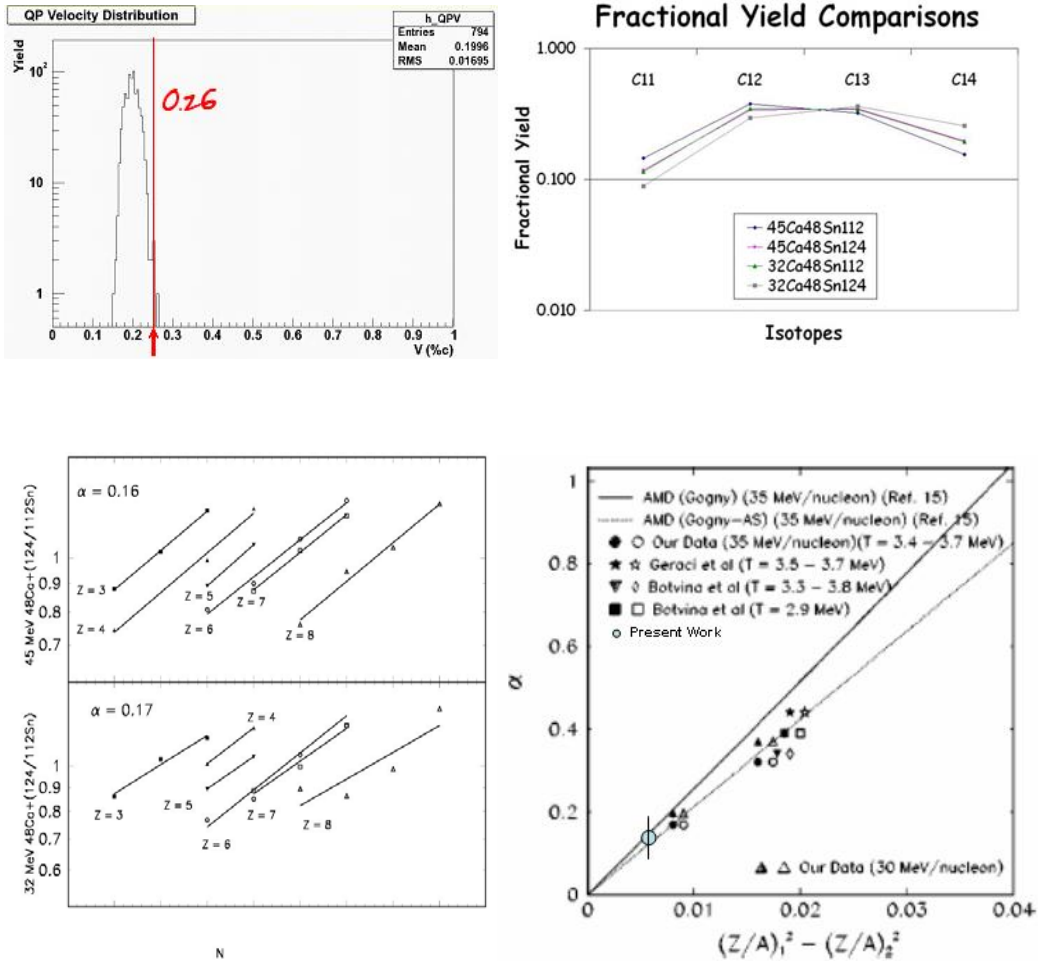

Figure 1. Top Left -Velocity spectrum of reconstructed sources from the reaction 32MeV/nucleon ^{48}Ca + ^{124}Sn. These sources have $Z_{source} = Z_{beam}$ and multiplicity greater than 3. The red arrow shows the beam velocity at 0.26c. Top Right -The fractional yields of Carbon, for four systems. Bottom Left - Isoscaling of the fragment yields from Lithium to Oxygen for two sets of systems. Bottom Right - Comparison of experimental a (32 MeV/nucleon) with literature values (35 MeV/nucleon) is consistent with the observed trend (Figure from Ref.[3]).

sources to determine the isoscaling parameter α. α will also be determined from the isotopic yields from a

hybrid model, using DIT, the Deep Inelastic Transfer code of Tassan-Got [1], to simulate the interaction stage and form the quasiprojectiles, and SMM, the Statistical Multifragmentation Model of Botvina [2], to simulate the breakup stage of the quasiprojectile sources.

Quasiprojectiles are forward focused, so a forward array with good forward angle coverage and granularity is needed, and is provided by, FAUST, the Forward Array Using Silicon Technology [2]. FAUST has 68 detector telescopes arranged in 5 rings covering 2° to 33° with 90% angular coverage. The experimental details and analysis can be found in [4-7]. To reconstruct an event the quasiprojectile charge, Z_{qp}, and apparent quasiprojectile mass number, A_{qp}, are calculated using $Z_{qp} = \sum Z_f$ and $A_{qp_{Apparent}} = \sum A_f$, where the summations are over the charge of the fragment, Z_f, and the mass number of the fragment, A_f. FAUST does not detect neutrons, so future analysis using the technique of Rowland will be used to correct for missing neutrons [8]. The apparent quasiprojectile excitation energy is calculated using the balance of energy: $E^*_{qp_{Apparent}} = \sum (m_f + E_{f_{cms}}) - m_{qp}$, where the masses can be calculated from the mass number and the mass excesses, which are know from the mass tables of Audi *et al*. [9], and the energy of the fragment in the center of mass frame is given by, $E_{f_{cms}} = \frac{1}{2} m_f v^2_{f_{cms}}$.

Since we want quasiprojectiles that have undergone multifragmentation a multiplicity requirement of greater than 3 is used, which discards lower multiplicity events that can be from other sources, such as scattered beam and other sources. An additional cut of $Z = Z_{beam}$, which is opened to $Z = Z_{beam} \pm 5$ to increase statistics, also helps select quasiprojectile sources. To verify that the reconstructed sources are projectile-like, the velocity spectrum should be sharply peaked near beam velocity. As shown in top left of the figure the peak is sharply peaked near the beam velocity at 0.26c.

The isotopic yields from the quasiprojectiles formed from the reactions ^{48}Ca on ^{112,124}Sn at 32 and 45MeV/nucleon were calculated. The isotopic yields were then used to find the fractional yields using, $FY = \dfrac{Y(^A X_Z)}{\sum Y(^A X_Z)}$, where the yield of a given isotope is divided by the yields of all the isotopes of that element, which is independent of the number of events and the systems can be compared to one another. The fractional yields of Carbon for these four systems are shown in the top right of the figure. The more neutron-rich system at each energy has larger fractional yields for the neutron rich isotopes than the proton-rich system. Comparing the energy effect the higher energy pair of systems have a reduced difference between the neutron-rich and proton-rich systems. The other elements, H, He, Li, Be, B, N and O exhibit the same trends.

The technique of isoscaling was then used on the isotopically resolved yields from these sources [10]. The reactions ^{48}Ca on ^{112,124}Sn at 32 and 45MeV/nucleon are shown at the bottom left of the figure. The 45 MeV/nucleon systems have a mean excitation energy around 146 MeV and an a of 0.16, while the 32 MeV/nucleon systems have a mean excitation energy around 108 MeV and an a of 0.17. The 32 MeV/nucleon α is compared to literature values (35MeV/nucleon data) in the bottom right of the figure and follows the trend.

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