Understanding the Isotopic Fragmentation from a Nuclear Collision

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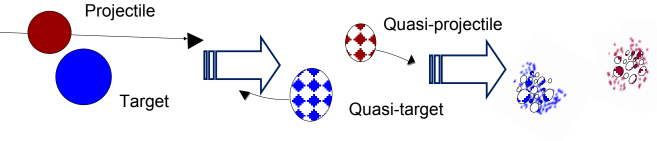
Motivation

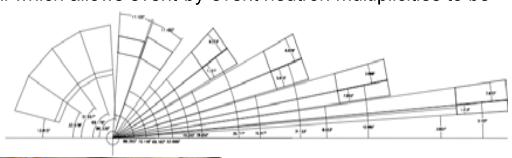
Constraining the symmetry energy can help us to better understand the nuclear equation of state and the behavior of nuclear matter. Isoscaling is one experimental observable that can help add information on the symmetry energy coefficient by looking at the isotopic scaling differences present in nuclear sources of differing neutron to proton ratio (N/Z) and therefore different nuclear asymmetries. Isoscaling analysis on experimental data was compared to a set of theoretical simulations of quasi-projectiles performed using the Deep Inelastic Transfer and Statistical Multifragmentation Model codes. Comparisons of unfiltered theoretical data with that of detector threshold filtered theoretical data can examine the existence of possible detector bias on the results of the experimental data.

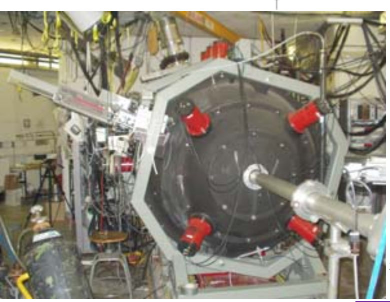


Experimental Setup

Experimental data[1] for ^{86,78}Kr projectiles on ^{64,58}Ni targets at 35 MeV/u was taken on the NIMROD-ISiS array, a neutron and ion multi-detector at Texas A&M University (TAMU)[2]. NIMROD-ISIS is a detector array that houses 228 detector modules arranged into 14 rings. The detector possess Si-CsI telescopes that provide excellent isotopic resolution. It is housed within the TAMU Neutron Ball which allows event-by-event neutron multiplicities to be measured.

NIMROD-ISiS





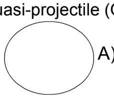
To left: A photograph of the NIMROD-ISiS array housed inside the TAMU Neutron ball.
Above: A schematic cross-section of the ring structure of the NIMROD-ISiS array. The detector is cylindrically symmetric about the x-axis.

1) S. Wuenschel, Thesis, Texas A&M University, 2009.
2) S. Wuenschel *et al.*, Nucl. Instrum. Methods Phys. Res. A **604**, 578 (2009).

Theoretical Simulations

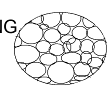
The Deep Inelastic Transfer code was coupled to the Statistical Multifragmentation Model to simulate the collision of ^{78}Kr + ^{58}Ni and ^{86}Kr + ^{64}Ni at 35 MeV/u.

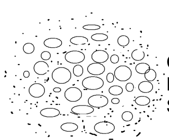
Quasi-projectile (QP)



A) PRIMARY STAGE

B) PARTITIONING STAGE





C) BREAK-UP or EVAPORATION STAGE

Deep Inelastic Transfer (DIT): Theoretical code to simulate nuclear collisions in which nucleons are exchanged between the projectile and target after interaction occurs. In peripheral collisions, quasi-projectile and quasi-target nuclei are formed in a highly excited state (E* between ~1-7 MeV/u). This excited quasi-projectile is then de-excited using the SMM code.

Statistical Multifragmentation Model (SMM): Attempts to describe the breakup pattern of any excited nuclei. As an excited nucleus expands, the density of the nuclear matter decreases, and a fragmentation process occurs. This is modeled in SMM by exploring all of the possible fragment distributions, or partitions. The simulation is carried out at a reduced density of ~1/6 ρ_0, in order to account for the expansion of the nucleus. The first stage of the SMM model provides a primary fragment distribution. Some of these primary fragments still have some excitation energy and can undergo a secondary decay. After SMM completes the secondary decay, one is provided with a final fragment distribution in which each fragment is characterized by its charge, mass, energy and angle of emission.

J. Bondorf *et al.*, Phys. Rep. **257**, 133 (1995)

Isoscaling Analysis

Isoscaling is performed by comparing the isotopic yields of fragments from two different systems, which differ in their source N/Z. In this experiment, rather than comparing systems, N/Z bins are compared so that the delta N/Z between the compared sources can be determined exactly. The equation for the yield ratio, $R_{2,1}(N,Z)$, is:

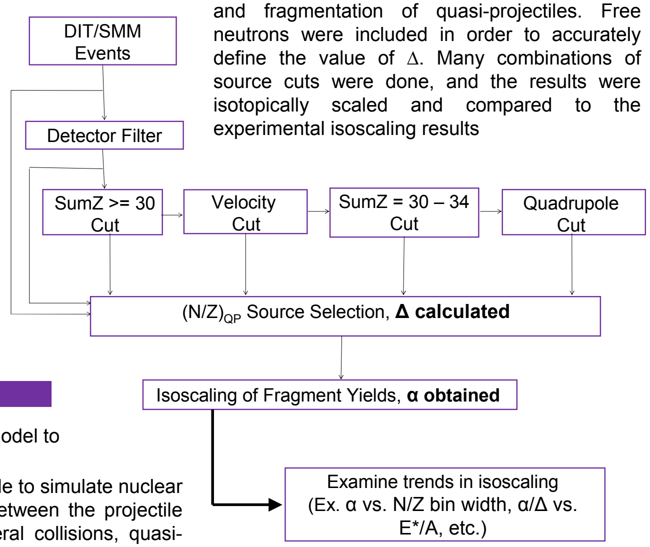
$$R_{2,1}(N,Z) = \frac{Y_2(N,Z)}{Y_1(N,Z)} = C\, e^{(\alpha N + \beta Z)}$$

$Y_2(N,Z)$ and $Y_1(N,Z)$ are the yields of a specific isotope for the most neutron-rich source and the most neutron-poor source, respectively. The yield ratios exhibit an exponential dependence on the neutron and proton number of the chosen fragments. The isoscaling parameter, α is associated with the symmetry energy coefficient by the formula:

$$\alpha = \frac{4C}{T}\left(\frac{Z^1}{A_1} - \frac{Z^2}{A_2}\right) = \frac{4C}{T}\Delta$$

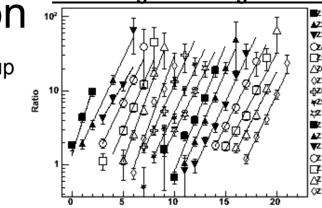
1) S. Galanopoulos et al., AIP Conf. Proc. 1099 (2009) 786.
2) S. Wuenschel et al., Phys. Rev. C 79 (2009) 061602.

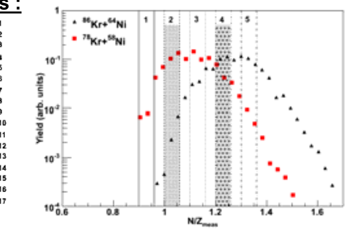
DIT/SMM was used to simulate the production and fragmentation of quasi-projectiles. Free neutrons were included in order to accurately define the value of Δ. Many combinations of source cuts were done, and the results were isotopically scaled and compared to the experimental isoscaling results



Discussion

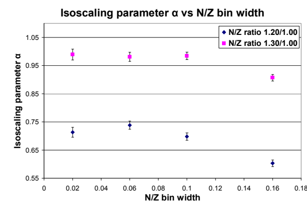
Isoscaling Plot using N/Z Bins :





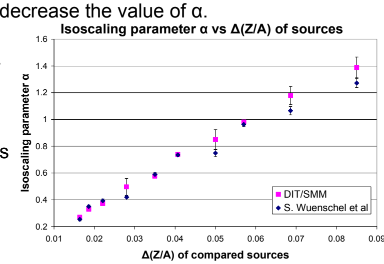
Isoscaling was performed using sources both from different systems and from different $(N/Z)_{QP}$ bins within a given system. The yields of isotopes from two sources were compared based on N/Z bins of defined width from the reconstructed quasiprojectiles. This gave well-defined Δ values for use in comparisons of α/Δ with excitation energy (E*/A). The various bin widths used were 0.02, 0.06, 0.1 and 0.16 intervals in N/Z.

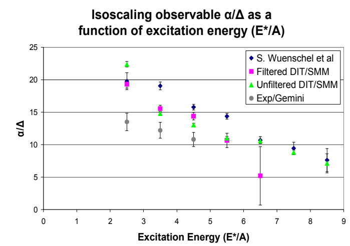
The simulated data was filtered according to the same source cuts that were applied to the experimental data. Due to poor statistics, the source selection cuts on quadrupole and SumZ = 30-34 were removed from the filter. process.



The isoscaling parameter α was plotted as a function of increasing N/Z bin width. It can be seen (from figure at left) that there is a general trend of lowering alpha with increasing bin width. This result would make sense in that while the relative bin positions stay fixed, the broadening bin width will have an effect of decreasing the Δ(Z/A) and so decrease the value of α.

The isoscaling parameter α, is shown versus the Δ. The term α/Δ is related to the symmetry energy coefficient via a known temperature. Good agreement is seen in the comparison of α versus Δ for the experimental data of S. Wuenschel and DIT/SMM model run for this project.





The evolution of α/Δ versus excitation energy (E*/A) is shown for experimental data, filtered and unfiltered DIT/SMM simulations and an experimentally reconstructed QP de-excited via the Gemini code. All four data sets show a drop in α/Δ with increasing E*, which can be associated with a decrease in the density of the emitting source. Also, the agreement of both the unfiltered and filtered DIT/SMM data with the experimental results shows that the experimental analysis is largely free of detector bias. The DIT/SMM data correlates better with the experimental data than does the sequential de-excitation code Gemini.

S. Wuenschel et al., Phys. Rev. C 79 (2009) 061602.

Acknowledgements

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