Investigating the Fragmentation of Excited Nuclear Systems

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Motivation

To better constrain the symmetry energy term of the nuclear equation of state using experimental fragment yield ratios.

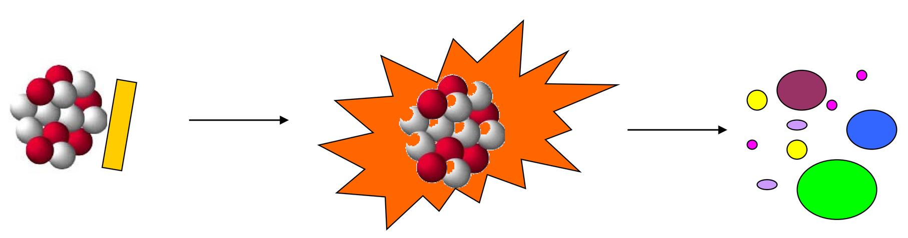
To optimize the source definition in order to improve precision of the calculation of the symmetry energy.

Background

Current Equation of State of nuclear matter is shown below. The first term is the energy for symmetric nuclear matter (N=Z). The second term is the term is the bulk symmetry energy for nuclear matter, E_{sym}, multiplied by the square of the asymmetry of nuclear matter (N≠Z), δ. The E_{sym} is the term we will be looking to constrain.

$$E(\rho, \delta) = E(\rho, \delta = 0)+E_{sym}(\rho)\delta^2$$

Nuclear collision reactions lead to fragments, most of which can be detected by the Neutron and Ion Multidetector for Reaction Oriented Dynamics (NIMROD).



If yields of the fragments ($Y_1(N,Z)$, $Y_2(N,Z)$), identified by Z and A, can be determined for two sources, these yields can be compared (neutron-rich to neutron-poor). The ratio of these yields is exponentially related to N, Z, α, and β.

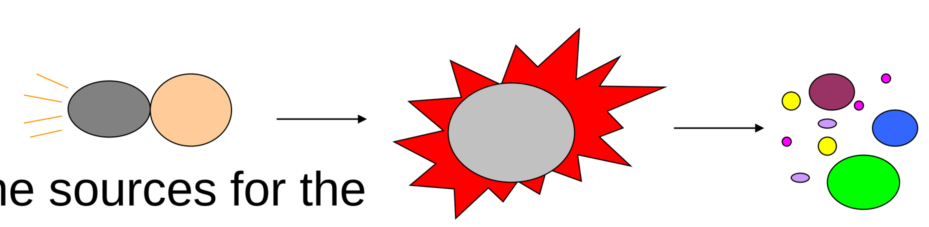
$$R_{21}(N,Z) = Y_2(N,Z)/Y_1(N,Z) = C\exp(N\alpha + Z\beta)$$

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

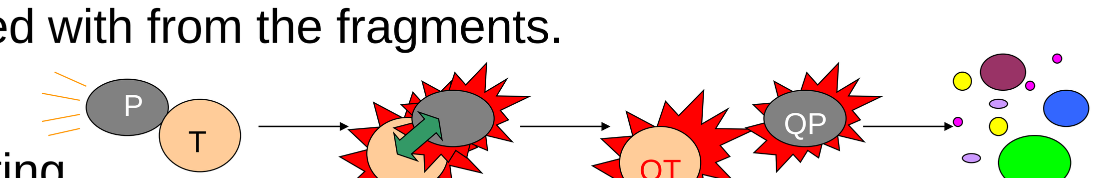
The α is related to the symmetry energy coefficient, C_{sym} (also E_{sym}), along with another parameter Δ. If we can constrain α and Δ, we can better constrain C_{sym}.

Source Definition

In our collision systems, the projectile and target have different neutron-to-proton (N/Z) ratios.

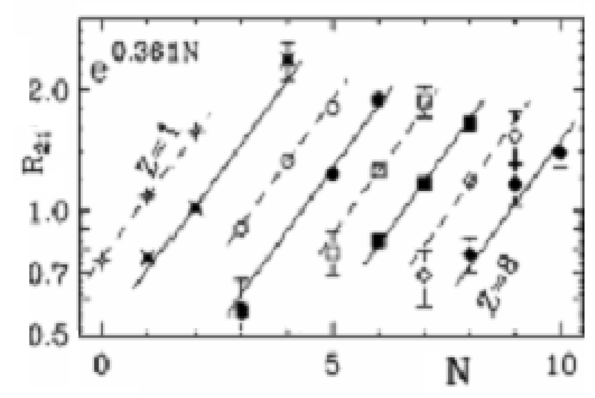


System-to-system isoscaling defines the neutron-poor and neutron-rich compound nuclei as the sources for the isoscaling. These compound nuclei do not provide the best definition of the source. The fragmenting source would be better defined as an excited "quasi-projectile" (QP), reconstructed with from the fragments.



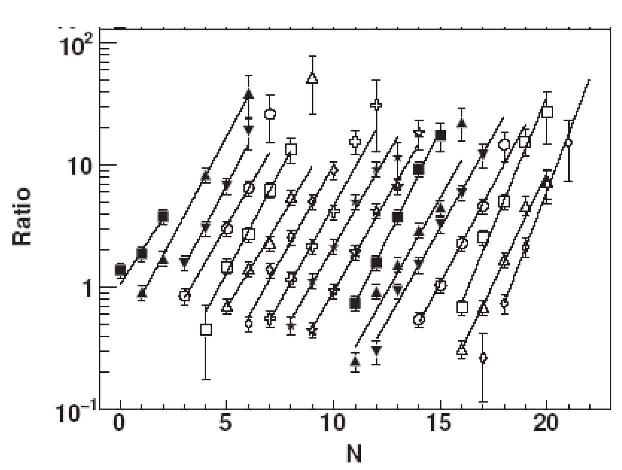
Taking a QP as the fragmenting source, there are many QPs that result from the reaction. Each QP will have a specific N/Z, resulting in a distribution of the QPs in N/Z from the reaction and the yield of each.

Evolution of Isoscaling

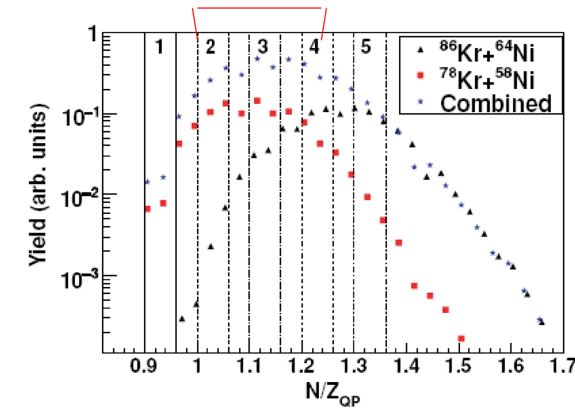


Tsang. Phys. Rev. C 64, 041603(R) (2001)

The first isotopic scaling (isoscaling) was done by Tsang at MSU (shown at left), and used the compound nuclei of the reaction systems as the neutron-poor and neutron-rich sources of the fragment yields. This system-to-system isoscaling uses a global α and β (averages over the isotopes) to fit the lines, which are then parallel and evenly spaced.



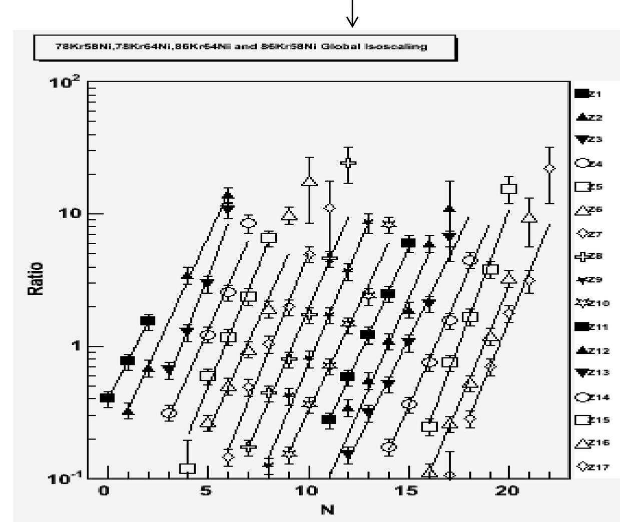
Wuenschel, Phys. Rev. C 79, 061602(R) (2009)



Wuenschel, Phys. Rev. C 79, 061602(R) (2009)

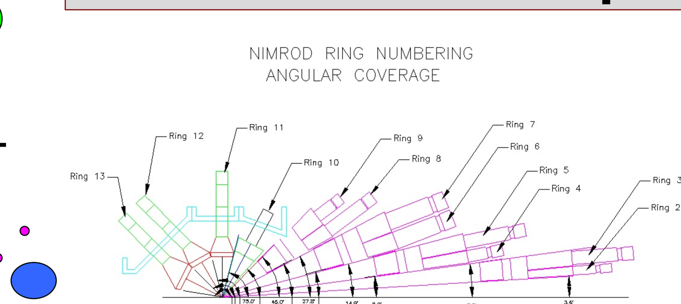
Wuenschel *et. al.* began using a reconstructed QP as the source, and was then able to divide the QP into neutron-poor and neutron-rich bins from the distribution in N/Z (shown on right) and could be compared through isoscaling instead of the two systems.

With this bin-to-bin comparison method (shown above left), the slope of the isoscaling lines (α) and the distance between them (β) can be fitted individually for each Z. Better fits in isoscaling mean better C_{sym} estimations.



Wuenschel selected her sources as QPs in bins of a width of 0.06 in N/Z, and compared the neutron-rich QPs of bin 4 (N/Z=1.20-1.26) with the neutron-poor QPs of bin 2 (N/Z=1.00-1.06). We decided to try and find the optimal selection of QPs (by N/Z bin width) and trying all of the different comparisons between the bins to determine the optimal selections for isoscaling, an example of which is shown at left.

Experimental Details



Data was taken from an experiment done by S. Wuenschel using ^{86,78}Kr on ^{64,58}Ni at 35 MeV/Z at the TAMU Cyclotron Institute with the NIMROD-ISiS array.

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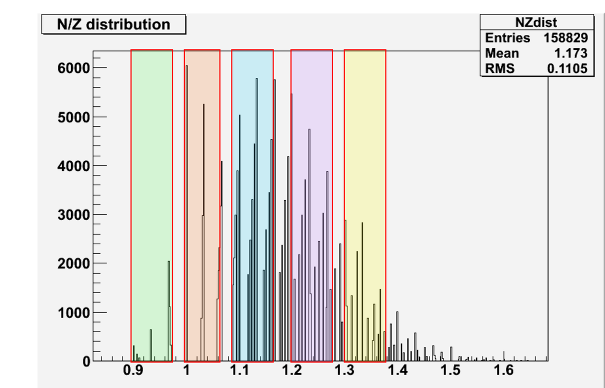
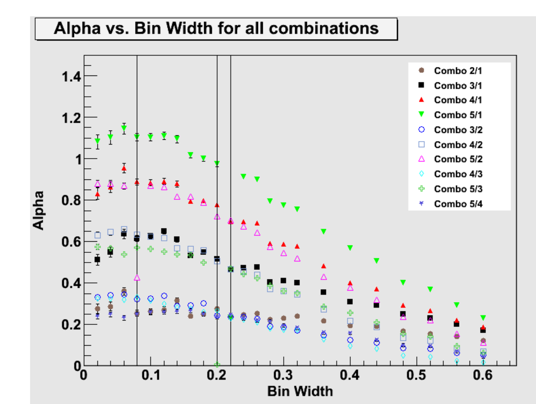
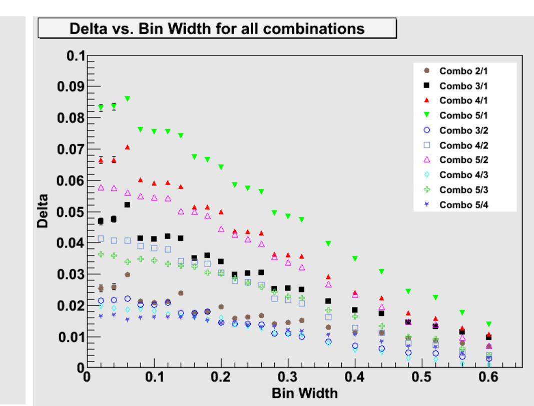
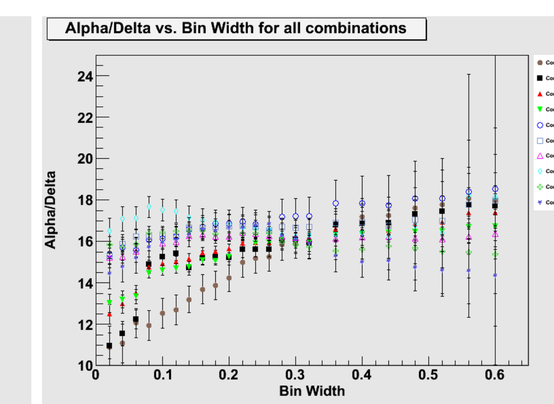
Current Research

The distribution of QP N/Z was divided into 5 bins. From these 5 bins, there are 10 possible neutron-rich to neutron-poor comparisons. We looked to find the best bins for comparison and the best selection of QPs by changing the width of the N/Z bins.







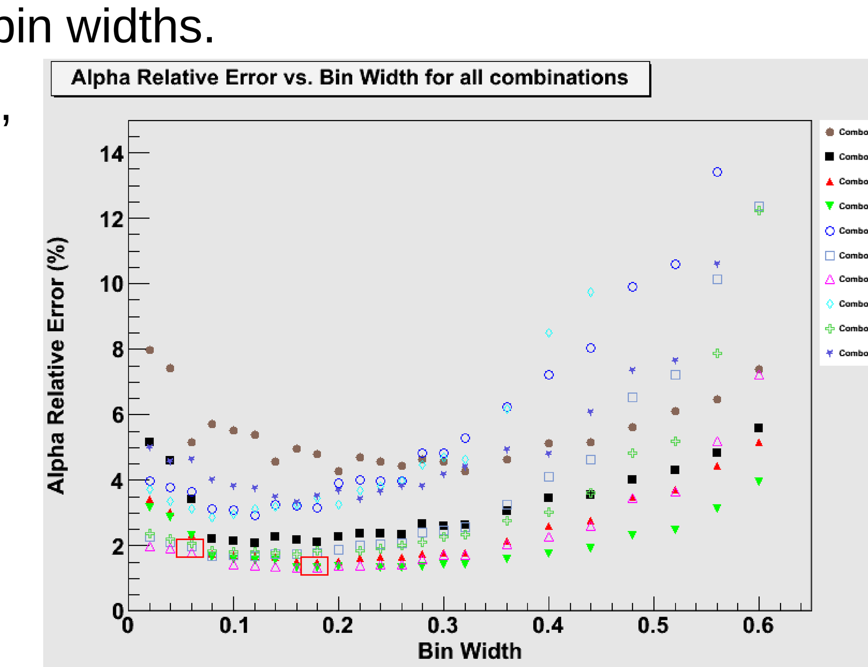


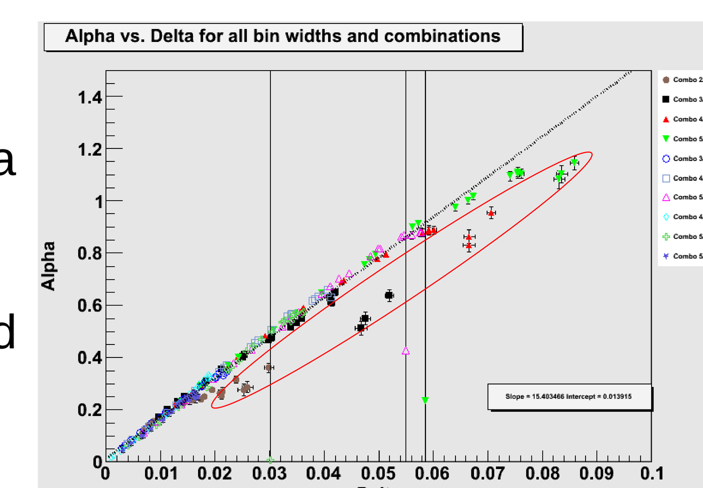
The bin comparisons trend by bin separation.
We see a collapse of α and Δ for large bin widths.

$$\frac{\alpha}{\Delta} = \frac{4}{T}C_{sym}$$

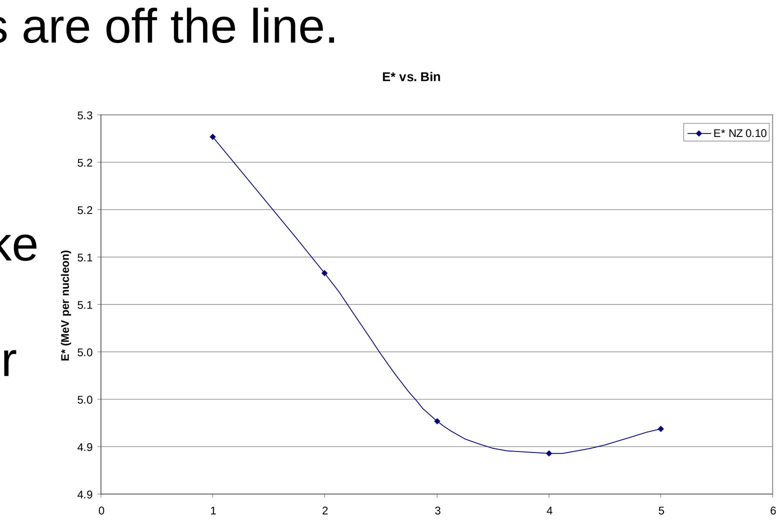
From these parameters, we can get a good estimate of the C_{sym}.

From looking at the relative error on α, a bin width of 0.18 and comparing bins 5 and 2 would give the best fit.





Examining α and Δ, we see that the comparisons involving bin 1 for the smallest 3 bin widths are off the line.



The excitation energy of the QP's that make up bin 1 is higher from those of the other bins. This could be a partial explanation for the lower α for a given Δ.

Acknowledgements

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