# N/Z transport within a deformed nuclear system

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Neutron-proton equilibration is sensitive to the asymmetry energy in the nuclear equation of state. The process is governed by the contact time between the colliding nuclei and the gradient of the potential driving the equilibration. Recently, N/Z equilibration within a single dynamically produced and deformed nuclear system has been observed [1-3]. The decaying excited projectile-like fragment (PLF*) has an angular distribution indicative of decay on a timescale shorter than its rotational period. The N/Z composition was observed to depend on the decay angle and thus on the lifetime, consistent with equilibration between regions of the decaying PLF*[4-8]. We present observations that the composition of the heavy fragment changes with decay angle in a consistent manner.

Data from a $^{70}$Zn-$^{70}$Zn reaction at 35 MeV/nucleon using the NIMROD-ISIS array was analyzed [3]. To focus on N/Z in binary decays, events were selected where two mass identified fragments were detected. The events were sorted based on atomic number followed by mass number, with the heaviest (second heaviest) designated as $Z_H$ ($Z_L$). In order to ensure the PLF* fragments corresponded to a large fraction of the initial projectile, events were required to have $Z \geq 7$ for $Z_H$ and $Z \geq 3$ for $Z_L$. A total Z cut of minimum Z=21 (70% of beam) and maximum Z=32 for all fragments was also included. Fig. 1 shows the Z distribution for the heaviest vs. the second heaviest fragment. The distribution is strongly weighted toward lighter fragments, but extends with significant yield to $Z_H$ and $Z_L$ at near the Z of the beam.

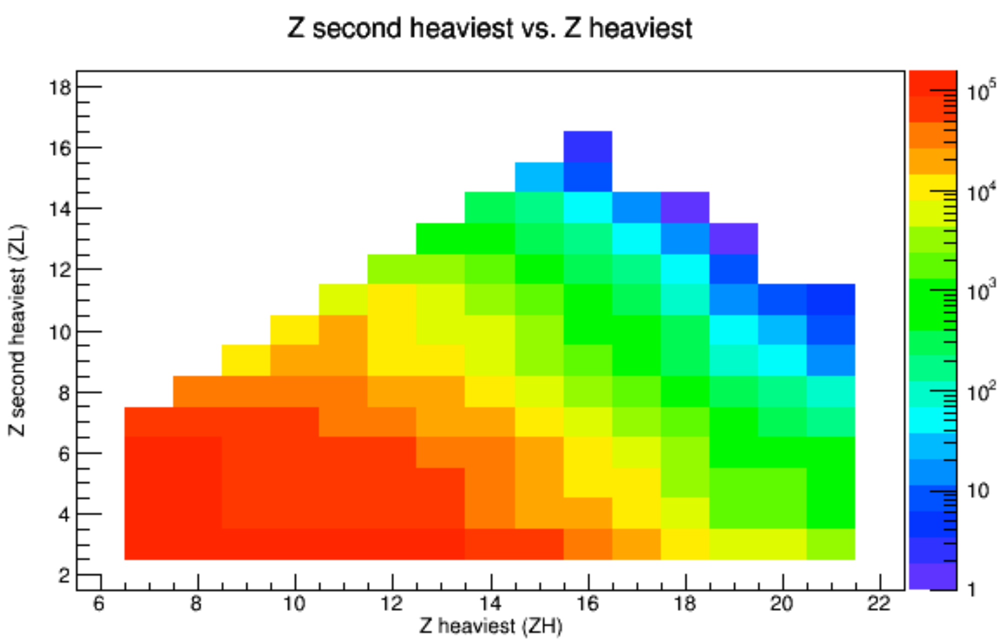


**FIG. 1.** Z second heaviest vs. Z heaviest distribution.

The decay angle ($\alpha$) is the angle between the relative velocity ($v_{REL}$) defined as $v_H$-$v_L$ and the center-of-mass velocity ($v_{CM}$) of the two fragments. The angle $\alpha$ was calculated using the formula

$$\alpha = 180 - \cos^{-1}(\vec{v}_{REL} \cdot \vec{v}_{CM}/(\|v_{REL}\|\|v_{CM}\|)).$$

Aligned emission of the $Z_L$ in the backward direction (towards the target) corresponds to $\alpha$=180°.

The angular distributions for select pairing of $Z_H$ and $Z_L$ are shown in Fig. 2. A large peak between 160-180°, seen most clearly in asymmetric pairings, is consistent with previous findings, indicating a timescale of dynamical binary splitting of the PLF* much shorter than its rotational period. For more symmetric splits of the PLF* (i.e. similarly sized $Z_H$ and $Z_L$), the peak at 180° becomes less pronounced and the peak at 0° becomes more prominent. The width of the peak also

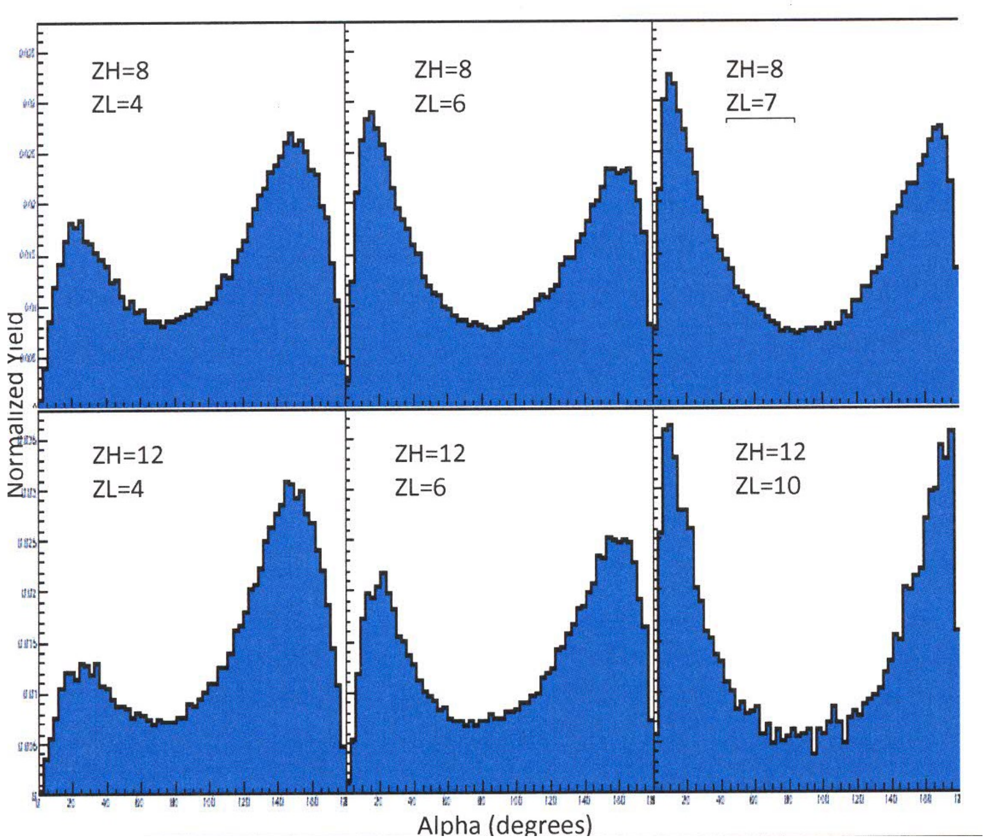


**FIG. 2**. Angular distributions for select ZH and ZL pairing.

narrows indicating stronger alignment, both forward and backward.

Next, the composition of $Z_H$ and $Z_L$ were examined as a function of angle. Fig. 3 depicts a maximum (minimum) <(N-Z)/A> at 180° for $Z_H$ ($Z_L$). As the angle decreases from 180°, indicating a greater contact time, the <(N-Z)/A> decreases (increases) for $Z_H$ ($Z_L$) reaching an equilibrium value between 20-40°. As the two fragments become more symmetric for constant $Z_L$, the <(N-Z)/A> for $Z_H$ decreases for α=160-180°.

Results indicate that when the smaller fragment is emitted in the backward direction (i.e. towards the target, α=180°), there is less N/Z equilibration, corresponding to a shorter equilibration time. As α decreases, the N/Z converges towards equilibrium. This effect is strongly dependent on the composition of the second heaviest fragment, although this may be due to greater changes in <(N-Z)/A> coming from smaller isotopic range and smaller values for A.

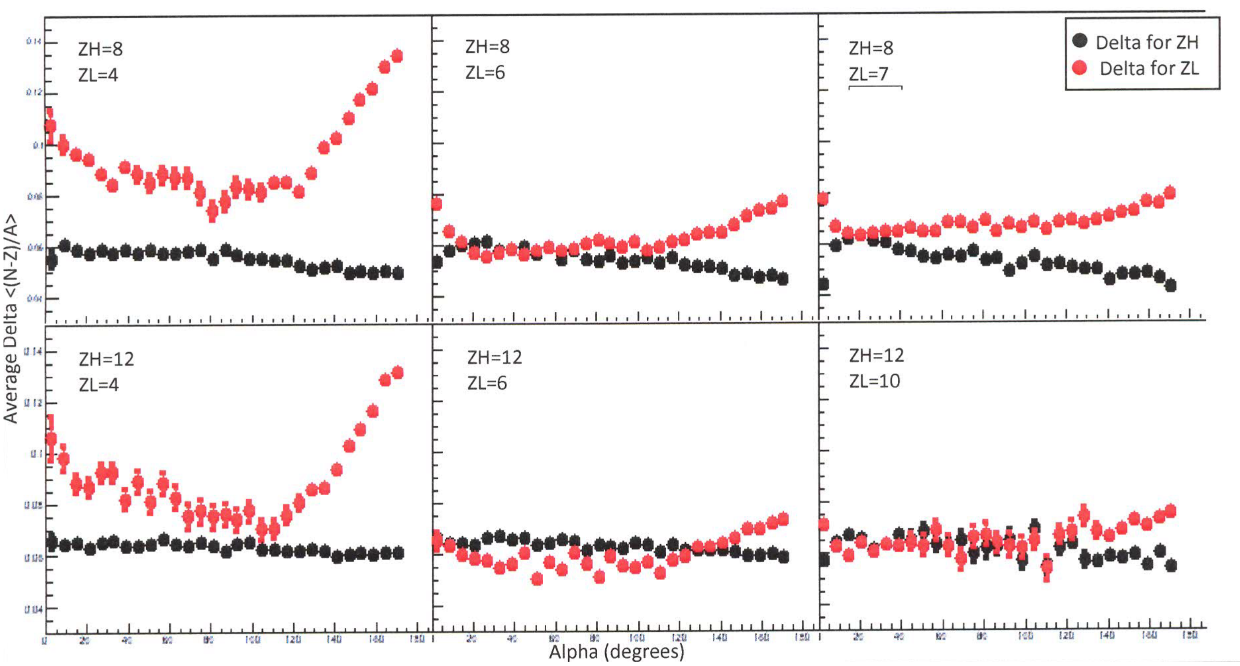


**FIG. 3.** Average Delta (<(N-Z)/A>) vs. Alpha. Red points correspond to Delta calculated for the second heaviest fragment (ZL). Red points correspond to Delta calculated for the heaviest fragment (ZH).

Future work will focus on quantifying the effect observed here and determining timescales. The analysis will also be performed on the $^{64}Zn$-$^{64}Zn$ data. Given the good mass resolution and coverage of NIMROD-ISIS, the study of this process using reconstructed PLFs* is an unique opportunity.

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