Using break-up mechanisms in heavy ion collisions at low energies to constrain the asymmetry energy at Low Nuclear Density

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Nuclear reactions just below the Fermi energy present a unique opportunity for probing the dynamics of nuclear matter below normal nuclear density using shape fluctuations, spin and relative multiplicities of the produced fragments. The results of these interactions are theorized to be dependent upon and sensitive to the asymmetry energy. Composite systems resulting from semi-peripheral collisions may exhibit prolate (elongated) shapes with a large associated angular momentum. More neutron-rich nuclear reactions are expected to have a greater sensitivity to the density dependence of the asymmetry energy through observing ternary or quaternary events from the breaking of the Projectile-Like-Fragment (PLF) and/or Target-Like-Fragement (TLF) [1]. Some of these effects have been recently observed in ^{124}Sn + ^{64}Ni and ^{112}Sn+^{58}Ni at 35 MeV/nucleon [2,3] and by Wilczyński *et al.* using ^{197}Au+^{197}Au at 15 MeV/nucleon [4-6] . However, using multiple systems at the same beam energy to correct for systematic effects and drawing comparisons to theoretical simulations is of high value in attempting to use the experimental results to determine additional constraints to the density dependence of the asymmetry energy at low nuclear density.

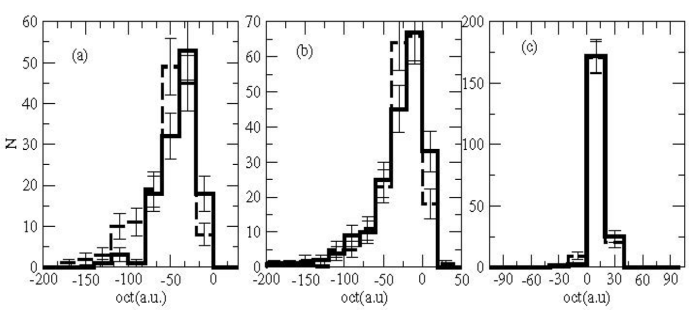

FIG. 1a. Octupole fluctuations of the primary fragments (in position space) for ^{132}Sn+^{64}Ni at 10A MeV. Figures (a) through (c) represent impact parameters 6 - 8 fm at freeze out, repsctively. Dashed lines represent asy-stiff and solid lines the asy-soft density dependance of the asymmetry energy respectively.

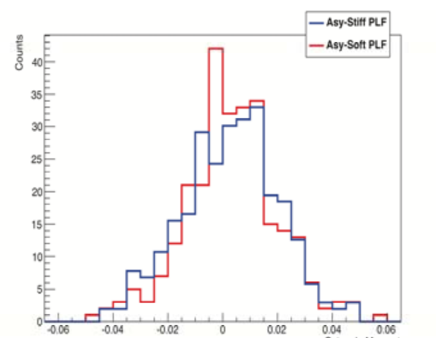

FIG. 1b. Octupole fluctuations of the Projectile-Like-Fragments (PLFs) from reactions of ^{124}Sn + ^{64}Ni at 15AMeV via TWINGO code for b= 6fm and t = 450fm/c (freeze out).

Results from DiToro *et al.* [1] (Fig.1a) and simulations using TWINGO code [7-12] (a Boltzmann-Nordheim-Vlasov stochastic mean field approach) have been used to calculate the fluctuations in quadrupole and octupole moments to facilitate the prediction of the relative expected ternary (quaternary) breaking of the PLF (and TLF) resulting from semi-peripheral interactions of heavy nuclei below the Fermi energy. In the case of ^{124}Sn+^{64}Ni at 15 MeV/nucleon, Fig. 1b shows the octupole fluctuations of the PLF extracted from the BNV mean field interaction. In this way we can see that there are noticeable differences in the quadrupole and octupole fluctuations with respect to the asymmetry energy. It is expected that reactions using $^{124,136}Xe$, in addition to ^{124}Sn, projectiles at 15 MeV/nucleon should exhibit the same signatures. Additionally, to gain insight into the observables pertinent to the experiment on long time scales, CoMD (Constrained Molecular Dynamics [13,14]) code has been used to show a noticeable difference in the multiplicity of the Z≥3 fragments as well as a number of additional observables.

The results from over 1 million events from $^{136}Xe+^{64}Ni$, $^{124}Xe+^{58}Ni$ and $^{124}Sn+^{64}Ni$ reactions at 15 MeV/nucleon simulated through CoMD have been used to help design and build an experimental apparatus consisting of a combined recommissioning of the FAUST array [15] and the TAMU Quadrupole Triplet Spectrometer. The FAUST-Triplet Spectrometer (Fig. 2) will allow for Time-of-Flight (ToF) measurement of the PLFs produced from 0.5º to 45º off beam axis. Furthermore, the intermediate mass fragments (IMFs) produced in the ternary (quaternary) breaking of the PLF (and TLF) resultant from semi-peripheral reactions will be detected by both the ΔE-E technique for Z-identification

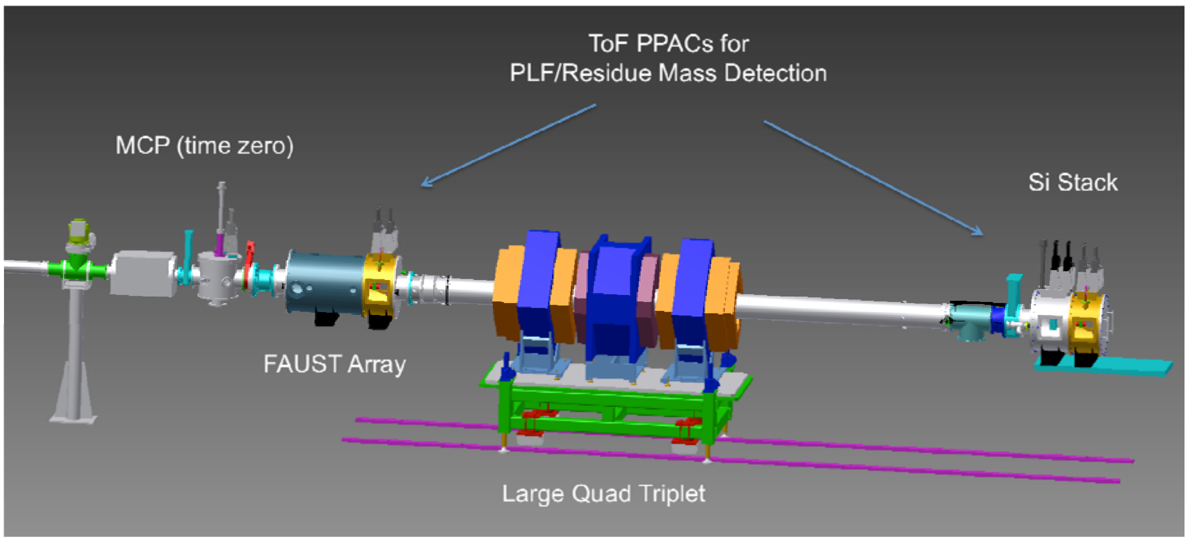

FIG. 2. Faust-Triplet Line in its current configuration.

and/or the ToF technique for mass identification. To achieve this, FAUST (68 Si-CsI telescopes arranged in 5 rings, covering 1.6 º to 45º in theta) has been upgraded with new charge sensitive preamplifiers that have an integrated fast-timing pickoff circuit with excellent timing resolution (100's of pico-seconds FWHM) resulting in a mass resolution of ~1-3 mass units for the PLFs and greater resolution for the IMFs. Furthermore, a micro-channel plate detector [16] has been installed upstream of the FAUST array to generate the start time to coincide with the timing from each of the Si detectors in FAUST allowing for 68 individual fast timing measurements per event.

The remainder of the coverage (from 0.5º to 1.6 º) will be in the Triplet (large triple quadrupole magnet) spectrometer using Parallel Plate Avalanche Counters (PPACs) [17] before and after the triplet (for ToF and position sensitivity) in conjunction with a 1000µm Si detector for total energy measurements to be able to mass-identify the particles transported through the spectrometer. The beam will be stopped before the PPACs in a small diameter beam block (covering 0-0.5º) allowing for maximum transmission of PLFs and/or IMFs that would have normally been lost down the throat of the FAUST array. Spectrometer settings have been determined via the TRANSPORT [18] code in conjunction with historical calibrations of the spectrometer to optimize the transport of the most probable particles. The experiment is planned for the Fall of 2013.

Based on the expected experimental and current theoretical results, probing the fragmentation mechanism competition of the primary nuclei and neck fragmentation at low-intermediate energies in heavy, asymmetric systems should provide additional constraints on the asymmetry energy at low nuclear density. We have nearly completed the first round of initial simulations using CoMD and TWINGO to predict the prevalence of the reaction observables and for eventual comparison to collected experimental data. A large portion of these calculations were performed on several supercomputing facilities at Texas A&M University (Medusa/Orion at the Laboratory for Molecular Simulations, Chemistry Department and Hydra/Eos at theTexas A&M University Super-Computing Facility) as well as on the Lonestar cluster at the University of Texas at Austin.

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