Pionic fusion at TAMU

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Pionic fusion is the process by which two nuclei amalgamate during a collision and then cool by the exclusive emission of a pion. The resulting compound nucleus is left in or near its ground state [1]. The process requires that nearly all of the available kinetic and potential energy in the colliding system be concentrated into just a few degrees of freedom - the rest mass and kinetic energy of the emitted pion. Furthermore, the energy of the emitted pion is limited by the number of available final states of the fusion residue [2]. The combination of limited available energy and the extreme coherence required in the process ensures that the pionic fusion channel is greatly suppressed. Indeed, the measured pionic fusion cross sections range from hundreds of nanobarns for the lightest systems (He + He) to hundreds of picobarns as one moves to larger systems ($A_{tot} = 6 - 24$) [2-12].

Over this past year, forward progress has been made toward measuring cross sections of pionic fusion reactions using the Momentum Achromat Recoil Spectrometer (MARS) to measure pionic fusion residues. In August of 2013 a test experiment was conducted which aimed to identify pionic fusion reactions in the ^{12}C + ^{12}C reaction. GEANT4 simulations have been studied in an effort to identify a suitable “phoswich” (phosphor sandwich) detector construction for detecting and resolving charged pions. A phoswich is a charged particle detector made of a combination of scintillators with differing pulse shape characteristics which are optically coupled together and to a common photomultiplier tube. The parts for these phoswich detectors are fabricated and are being used in a test experiment starting May 23rd of this year.

The goal of the test run in August 2013 was to reproduce the ^{12}C + ^{12}C at 274.2 MeV measurements of Horn *et al.* [2] as a proof of concept for the detection of pionic fusion events using MARS. During the course of the experiment, MARS was tuned to look for both ^{24}Mg (π^0 emission channel) and ^{24}Na (π^+ emission channel) pionic fusion residues. Sixteen hours of data collection looking for ^{24}Na resulted in 5 counts inside the region of interest. A similar search for ^{24}Mg yielded no residues of interest. During this experiment, the beam intensity at the target location could not be measured and, as a result, it was impossible to perform a meaningful background measurement. Consequently, it cannot be determined whether the 5 counts of ^{24}Na are the result of pionic fusion reactions or background contamination. Moving forward, the decision has been made to switch to ^{4}He + ^{12}C pionic fusion reactions using a 220 MeV ^{4}He beam as these reactions have higher theoretical cross sections than those for the ^{12}C + ^{12}C system and the beam intensity from the K500 cyclotron will likely be higher for ^{4}He than for ^{12}C.

In addition to detecting the pionic fusion residues using MARS, the emitted charged pions from pionic fusion events will be detected using a phoswich detector array located in the MARS production chamber. A simulated phoswich unit has been built using GEANT4 in order to determine whether or not such a detector could be used to identify low energy charged pions. Fig. 1 shows a “fast vs. slow,” dE-E plot produced by the GEANT phoswich. In most cases the pions (red points) are sufficiently separated from the charged baryon (black points) and gamma interactions (green points). The neutron contamination (blue points), however, may pose a problem as they can be found throughout the pion response region. By requiring coincidence between the phoswich detectors and pionic fusion residues, the neutron contamination should be significantly reduced. The phoswich detector waveforms will also be recorded for pion-like events using a flash ADC. Analysis of these waveforms should also help to eliminate neutron contamination from charged pion events as the charged pions will deposit energy in both components of the phoswich while the neutrons will only deposit energy in one component, most likely the much thicker slow component. These two cases result in very different pulse shapes.

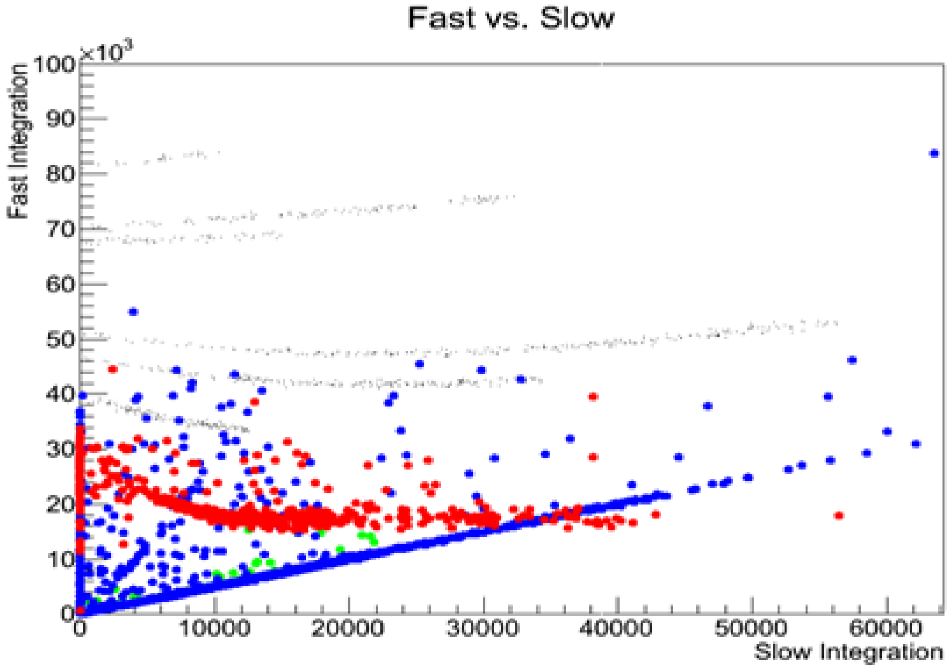

FIG. 1. A simulated "fast vs. slow" charge integration plot for different particle types interacting with a phoswich detector built using GEANT4. Pion hits (red points) are simulated along with charged baryon (black points), gamma (green points) and neutron (blue points) hits.

The MARS target chamber will be upgraded in order to accommodate the pion detector array. A cube feedthrough flange is being added in order to provide space for the many signal feedthroughs that will be necessary for the operation of the detectors. Existing flanges will also be outfitted with new feedthroughs. A test experiment will begin on May 23rd which will aim to measure the MARS transport efficiencies of the ^{16}O and ^{16}N residues of interest in the ^{4}He + ^{12}C pionic fusion reactions. Two phoswich detectors will be present in the production chamber for this test experiment in order to ensure sufficient detection efficiency of light charged particles. Construction of the phoswich array will begin after a successful test of the phoswich units in a beam experiment.

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