COMMISSIONING OF THE DARESBURY RECOIL SEPARATOR

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Captures of protons and alpha particles by proton-rich radioactive nuclei are important in the energy generation and nucleosynthesis of explosive astrophysical events, such as novae and X-ray bursts. However, most of these reaction rates are uncertain owing to the incomplete spectroscopic information available from stable beam experiments. Direct measurement of capture reaction cross sections using radioactive ion beams will significantly improve our understanding of explosive astophysical phenomena. The Daresbury Recoil Separator (DRS) has been installed at the HRIBF for the measurement of such capture reactions by recoil detection. Because capture reactions are weak (cross sections on the order of microbarns) and the full beam enters the recoil separator, it is important that the separator and its detector systems have a very high ($10^{-10} - 10^{-12}$) selectivity. We are currently commissioning the DRS with a variety of stable beam experiments that have been designed to test and optimize the performance of the separator and its detector systems.

The DRS uses two crossed-field velocity filters and a 50° dipole magnet to spatially separate nuclear reaction products by mass and charge. At the focal plane of the separator, a carbon-foil microchannel plate detector determines the position in the dispersive plane and time of arrival of the particle, and a gas ionization counter gives 3 energy signals ($\Delta E - \Delta E - E$) that determine the total energy and atomic number of the particle. The focal plane detectors were tested offline at ORNL using α-emitting radioactive sources. The position resolution of the carbon-foil microchannel plate detector is 1 mm. The total energy resolution of the ion counter is about 200 keV for 5.8 MeV alpha particles.

Initially the calibration and alignment of the velocity filters and quadrupoles of the DRS were tested by injecting highly-collimated stable beams into the DRS without a target. The position and shape of the beams were observed at the final and two intermediate foci of the DRS using phosphors. The positions of some quadrupole magnets were slightly (movements of less than 1 mm) adjusted to remove "walk" that the magnets introduced to the beam. The electric field of each velocity filter was calibrated relative to the magnetic field to about 1 part in 1000 using beams with different electric rigidity.

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The performance of the DRS has been studied using reactions with high cross sections such as elastic scattering and fusion-evaporation reactions. Elastic scattering reactions fill the angular acceptance of the separator. We measured nearly symmetric reactions, e. g. ^{12}C(^{14}N,^{12}C)^{14}N, which are also useful for testing the primarily beam rejection since the recoiling nuclei have about the same energy and mass as the incident beam. A control system for the DRS has been implemented that allows for smart tuning of multiple DRS magnets in unison using predefined tuning "knobs." The optimum transmission through the DRS for elastic scattering corresponds to an acceptance of 3 msr, consistent with measurements made using a ^{244}Cm alpha source. This should be sufficient for measurements of capture reactions which are very forward focused, $\theta \leq 0.5^{\circ}$. The rejection of the primary beam in our measurements of elastic scattering was typically 10^{-11} to 10^{-12}. Those scattered beam particles which do make it to the focal plane detectors are cleanly separated from the primary beam by the ΔE signals from the ion counter.

Fusion evaporation reactions fill both the energy and angle acceptance of the DRS, so they are a good choice for testing the dispersion matching of the separator as well as optimizing the acceptance. We studied the ^{27}Al(^{16}O,^{41}Ca) reaction and found the position of the ^{41}Ca recoils to be dispersed at the focal plane and correlated with their energy. Substantial adjustment of the DRS elements using the tuning knobs was required to remove this undesirable dispersion. Further measurements of fusion-evaporation reactions are required to develop a universal optical solution which will not be energy-dispersive for a broad range of electric and magnetic rigidities. We will increase the acceptance of the focal plane detectors by enlarging the entrance window to the ionization counter and by building a larger carbon-foil microchannel plate detector.

We have also performed an initial measurement of the ^{1}H(^{12}C,^{13}N) capture reaction cross section, which closely simulates the capture reactions that will be studied with radioactive ion beams. A ^{12}C beam at 8 MeV bombarded a CH_2 target, and the recoiling ^{13}N ions were detected at the focal plane of the DRS. A plot of the $\Delta E - E$ paricle-identification spectrum from the ionization counter taken during this run is shown in Fig. 1. The beam rejection was measured to be 2×10^{-11}, consistent with the typical rejection measured with the elastic scattering reactions. The recoiling ^{13}N ions are cleanly separated by the ionization counter from the small amount of ^{12}C that does reach the focal plane. The acceptance of the separator during this run was measured to be 15% of that expected from the charge-state distribution. The recoiling ^{13}N ions were also dispersed at the focal plane by their energy which is symptomatic of the improper dispersion matching of the separator. We are currently working to improve the optics of separator in order to achieve a high and reliable transmission of the recoil group to the focal plane. Since the yield from the ^{1}H(^{12}C,^{13}N) reaction is only 50% of that expected from the ^{1}H(^{17}F,^{18}Ne) reaction, and the ^{13}N group is cleanly identified with only 15% transmission through the separator, the ^{1}H(^{12}C,^{13}N) measurement does demonstrate that the DRS has sufficient sensitivity to measure capture reaction cross sections with radioactive beams in inverse kinematics.

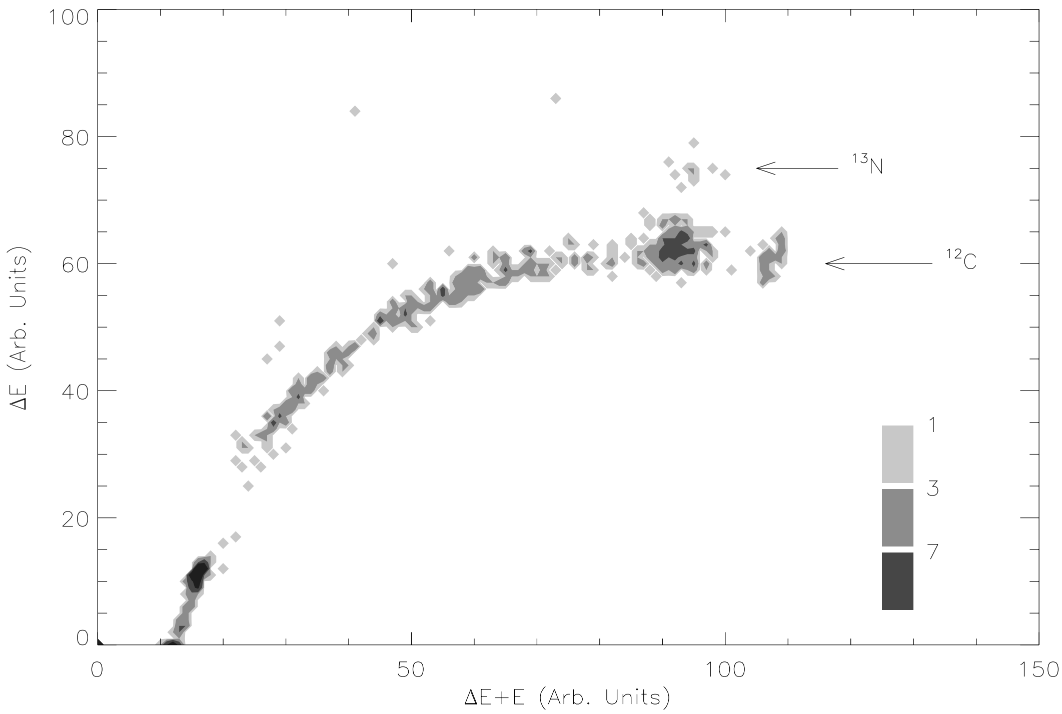

Figure 1: Particle-ID spectrum from the DRS gas ionization counter for a measurement of the $^{1}H(^{12}C,^{13}N)$ reaction.