The CARDS array for Neutron-Rich Decay Spectroscopy at HRIBF

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An array for decay studies of neutron rich nuclei has been commissioned for use at the UNISOR separator at HRIBF. This array consists of three segmented clover Ge detectors, plastic scintillators, and a high resolution (~ 1 keV) Si conversion electron spectrometer. These detectors are mounted on a support that surrounds a moving tape collector. This system has been named CARDS (Clover Array for Radioactive Decay Studies). The detectors have been outfitted with digital flash ADCs (XIA DGFs) that fit the preamp signals, with built-in pileup rejection.

Of the several thousand nuclei that are predicted to be particle stable, only about 2200 have been observed. Of those about which little or nothing is known experimentally, the overwhelming majority lie on the neutron-rich side of the valley of beta stability. Understanding the properties of these nuclei, such as half-lives, decay energies, masses, is crucial to understanding the astrophysical r-process and element formation. Additional detailed structure data provides information about shell structure, particle configurations and interactions. Furthermore, one can expect that new structures and excitation modes will be observed as the nuclear potential diffuses nearing the neutron-drip line. Interesting structure questions remain even in the regions nearer to stability, (one example of this is the level structure of even-even Cd isotopes [1,2]) which will require detailed level-structure measurements to answer.

The difficulty in studying these isotopes through the usual method of fusion-evaporation reactions is limited by the possible stable target/beam combinations. A major step in overcoming this obstacle is through the fission of very heavy (and neutron-rich) nuclei. The operational development of the UC target/ion-source at ORNL, although intended for Radioactive Ion Beams, offers the possibility of performing detailed nuclear-decay spectroscopy experiments on neutron-rich nuclei.

The two major factors (other than production) to consider when attempting to study nuclei formed in this way is the efficiency of extracting the desired species from the source, (which mainly deals with the time it takes for the species to get out of the target), and how to deal with the background caused by other species formed in the fission of Uranium Carbide (UC). The first issue is the subject of intense development effort at the Holifield Radioactive Ion Beam Facility (HRIBF). Details on beam

development at HRIBF can be found in Refs 3 and 4. To address the second problem, we have constructed and commissioned an array named CARDS (Clover Array for Radioactive Decay Spectroscopy) for decay studies of neutron-rich nuclei at the UNISOR separator (and RMS [5]) at HRIBF, shown in Fig 1. The current version of this array consists of three segmented clover Ge detectors, plastic scintillators, and a high resolution (~ 1 keV) Si conversion electron spectrometer. The detectors are mounted on a support that surrounds a moving tape collector. The tape drive can be operated in two modes, dependent upon the half-life of interest: observing the decays of the products as they are implanted at the collection spot (the detectors are located at the point of deposit) for short-lived species; or observing the decays after the material is collected and then moved away from the collection point to the detectors for measuring longer-lived species. This facility has been designed so that in the future it can be installed and expanded on the beam line directly off the RIB Injector high-voltage platform. At the UNISOR location, the beam intensity is limited to 25 nA. Off the platform, production beam intensities should be in the tens of microamps with a proportional increase in yields.

The CARDS array can hold 4 or 8 detectors in the ring, allowing angular correlations to be made between coincident gammas. Plastic Scintillators located directly in front of these Ge detectors allow one to reject background events (from longer lived species left on the tape, room background, etc.) by requiring a coincidence between plastic and Ge. In the current version of CARDS, one of these detector stations contains a high-resolution conversion electron spectrometer.

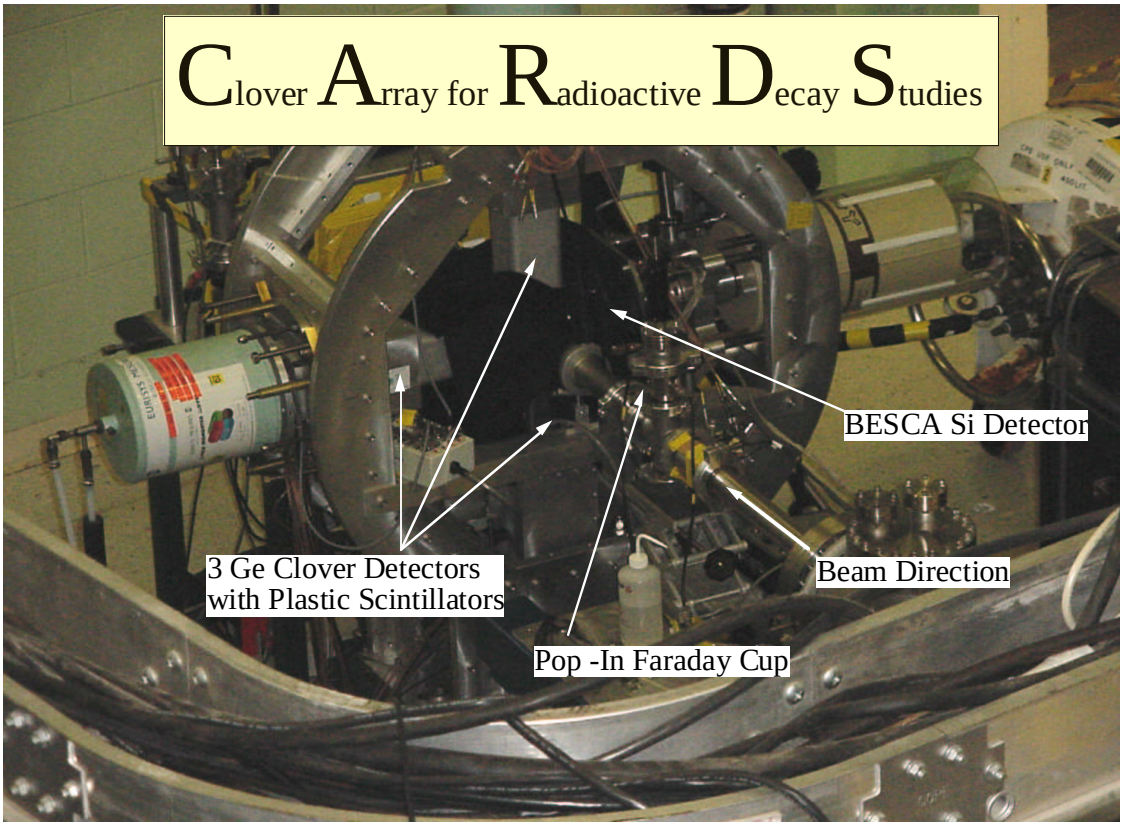

Fig 2. The CARDS array for neutron-rich decay studies.

The decays of many of the nuclei we have or plan to study have a significant percentage of their decays proceed via electric monopole (E0) transitions. The study of these E0 transitions via observation of conversion electrons will aid in our understanding of shape coexistence in very neutron-rich systems. In addition, the study of conversion coefficients can establish the nature of the transitions. The conversion electron spectrometer BESCA (Bellows Electron Spectrometer for the CARDS Array) consists of a 5 mm thick liquid nitrogen cooled SiLi detector. The detector is mounted on a moveable cold finger, and the entire Si detector assembly can be pulled back and valved off as needed, providing BESCA with an independent vacuum system. An example which shows the excellent energy resolution and low threshold of this system is shown in Fig. 2.

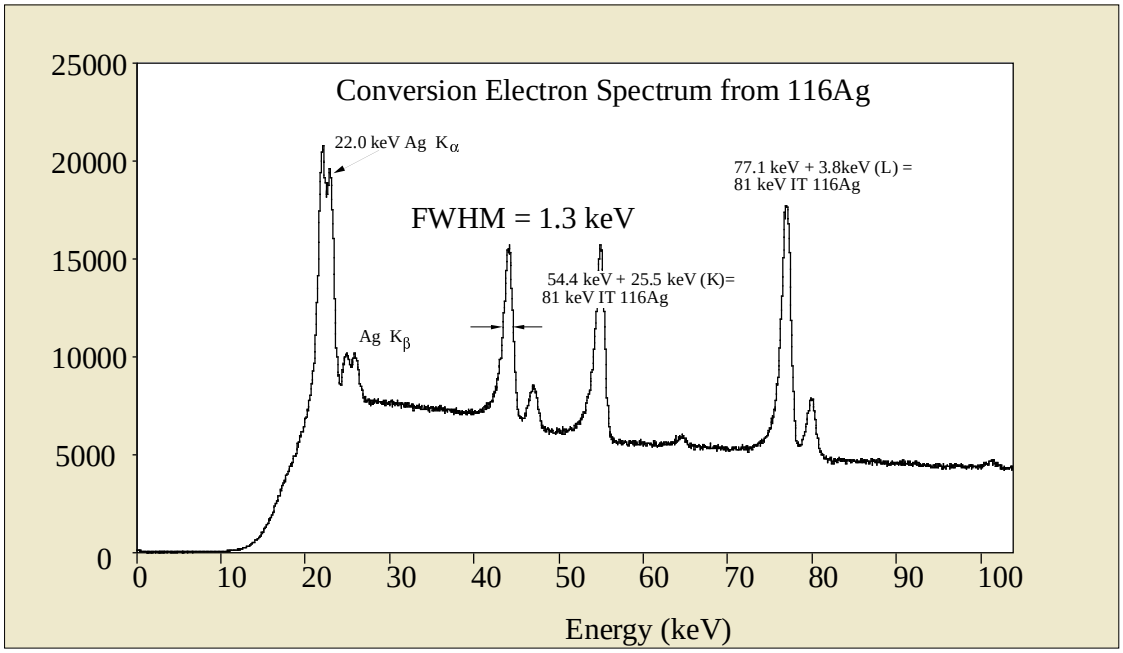

Figure 2. Conversion electron spectrum taken with BESCA.

Our data acquisition system uses a digital spectroscopy system based on DGF-4C modules (produced by X-ray Instrumentation Associates) [6,7]. These modules incorporate 40 MHz flash ADC's, and serve as a replacement for amplifiers, discriminators, conventional ADC's and TDC's. Signals from the preamps are input directly into the DGFs. The module then analyzes the preamp signals via the on-board processors. Each preamp signal is analyzed to determine its amplitude by fitting the waveform and is time-stamped with a continuously running clock. The information is then stored in the onboard buffers until readout. The deadtime of this system is determined by the readout time of the modules. The processors can also be programmed to reject pileup events, thus allowing a higher count rate to be used.

Events that arrive within a short period of time (i.e. before the signal returns to baseline) can be fit independently rather than summed or rejected as pileup. For example (see Fig. 3), consider a second event that arrives ~5μs after the first, so that the signal is still above baseline. With analog electronics this would form a peak with an amplitude much higher than the actual event due to summing. The DGFs fit the shape of the

waveform and give correct individual energies for each event. Only events arriving too close to be fit correctly are rejected as pileup. All events receive a timestamp with a resolution of 25 ns/bin. Coincidences between the various detectors are obtained via a software TAC that compares the value of the time stamps attached to each event. Half-life measurements are performed by setting time = 0 (in software) equal to the end of the tape movement. Depending on the rate, data can be taken in either singles or gated mode (i.e. gated on a particular detector).

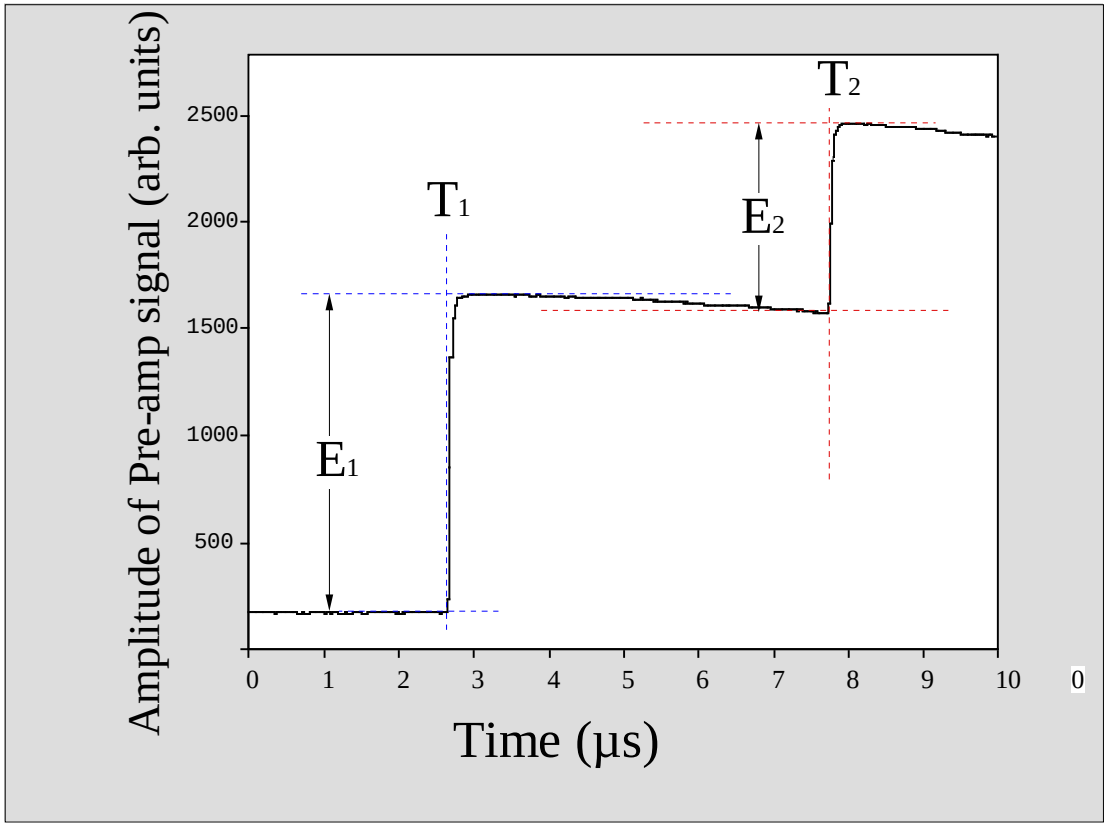

Figure 3. Illustration of how our electronics measures peak amplitude. The DGFs would correctly determine the amplitude of both events E_1 and E_2. Conventional analog electronics would give the second signal an amplitude equal to the height above baseline causing sum-peaks.

The CARDS array is currently in operation at HRIBF. Recent spectroscopy experiments that have been performed include ^{116,118}Ag, and ^{70,74}Cu, in addition to numerous rate measurements for use in beam development. In the near future, we plan to add neutron detectors to enable us to measure beta-delayed neutron emission.

References

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