Nuclear
Instruments and
Methods in
Physics Research

Beta counting system for fast fragmentation beams*

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Elsevier use only: Received date here; revised date here; accepted date here

Abstract

A new beta counting system has been developed at the National Superconducting Cyclotron Laboratory to study the beta decay of exotic nuclei produced by fast fragmentation. This system uses a double-sided silicon strip detector to detect both fragment implants and their subsequent beta decays; these events are correlated on a pixel-by-pixel basis, providing a direct measurement of the decay time with specific particle identification information regarding the parent nucleus. The experimental capabilities of this system are described, and future plans discussed.

1. Introduction

Beta decay properties of nuclei with extreme neutron-to-proton ratios serve as sensitive tests for nuclear structure models in regions far from the valley of stability; in addition, beta decay half-lives and endpoint energies are important nuclear physics input parameters for astrophysical network calculations. Significant progress has been made in the measurement of beta decay half-lives of exotic

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* This work has been supported in part by National Science Foundation grants PHY-95-28844 and PHY-01-10253.

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nuclei. This can be directly attributed to particle-detection techniques employed with fast fragmentation beams. These are defined as beams of radioactive species produced by fragmentation of primary particles with energies greater than 10 MeV/nucleon.

As the beta energy spectrum is continuous, it is necessary to have unique identification of the beta-particle-emitting source to assign the properties of the decay correctly. For fast beams, energy loss, time of flight, and magnetic rigidity can be used to determine the atomic number and mass of each fragment on an event-by-event basis. By correlating particle implants with their subsequent beta decays, such particle identification can then be applied to the beta-particle-emitting nucleus. At the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University, we have developed a new beta counting system to accomplish this. Fast fragments are implanted in a double-sided silicon strip detector (DSSD); implantation and decay events are directly correlated within each pixel of the detector, providing not only identification of the parent nucleus but also a direct measurement of the decay time.

2. Technical aspects

The system employs a Micron Semiconductor Ltd. Type BB1 DSSD. The DSSD is a single 4 cm x 4 cm silicon wafer segmented in 40 1-mm wide strips in both the x and y dimensions. A 985 μm thick DSSD is used to ensure sufficient silicon for detection of the high-energy beta particles expected from the decay of nuclei far removed from the line of beta stability. The DSSD is placed between two 5 cm x 5 cm x 500 μm Si PIN detectors. An additional 5 cm x 5 cm x 300 μm PIN diode is located downstream of these. The PIN detectors and the DSSD are mounted on an ISO-160 flange for easy coupling to the beam-line vacuum. Two 50-pin feedthroughs on this flange are used to bring the DSSD signals to a grounding board placed immediately outside the vacuum chamber. The grounding board provides a common ground for each of the 80 output channels. Additional detectors, including a parallel-plate avalanche counter and a 5 cm x 5 cm x 500 μm PIN detector, are located upstream of this array to provide beam diagnostics and energy loss information necessary for particle identification. The detector arrangement is shown in Figure 1.

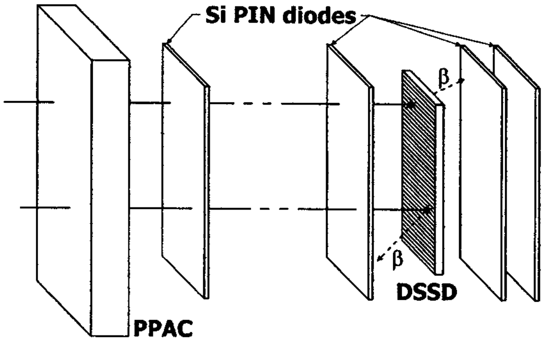

Fig. 1. Schematic representation of the beta counting system. Distances and dimensions are not to scale.

One of the challenges in designing electronics for the beta counting system is the range of charged particle energies that must be measured. A fast fragment implant will deposit more than 1 GeV total energy in the DSSD, while an emitted beta particle will deposit less than 1 MeV. Early implementation of the beta counting system at NSCL used single-output preamplifiers coupled with high gain shaping amplifiers. Fragment implantations resulted in ADC overflows in the channels corresponding to the strip in which the fragment was stopped and several neighboring strips. Implantation events had an average multiplicity of six in both the front and back sides of the detector, making it difficult to determine the location of a given fragment. With the current system, reliable energy information can be obtained for both implants and decays. For fragment implants, a multiplicity of one is observed for the majority of events in both front and back strips.

To accommodate the broad range of energies observed for implants and decays, the grounded DSSD signals are first processed by six 16-channel preamplifier modules supplied by MultiChannel Systems. These modules contain precision pre- and shaping amplifier electronics and provide both high gain (2 V/pC) and low gain (0.1 V/pC) analog outputs. Three of these modules were specified to have inverted output signals, and the other three non-inverted, so that the processed outputs from both the front and back sides of the DSSD share the same polarity. The outputs are designed to drive 50 Ω inputs with amplitudes of ±2 V. The signal rise time from both the low and high gain outputs is 320 ns. As a result, the low gain signals, which provide the fast fragment implantation energy information, can be sent directly to analog-to-digital converters (ADCs) with no further shaping. For this purpose we have used both Phillips 7164H CAMAC ADCs and CAEN V785 VME ADCs. As the high gain signals carry information from low-energy beta decay events, they require further processing. This is accomplished using Pico Systems 16-channel shaper/discriminator modules in CAMAC. The shaper gains and discriminator threshold levels can be set via computer control over the CAMAC bus. The shaper output of the Pico Systems module is sent directly to an ADC (either CAMAC or VME as before) while each discriminator output is combined in a logical OR gate to provide the master trigger. Individual discriminator signals are also sent to coincidence registers for zero suppressed readout of both sets of energy ADCs and to scalers for rate monitoring. A simplified electronics diagram is shown in Figure 2.

The energy resolution of the system was measured using alpha particles from a ^{228}Th source. Individual strip resolutions were observed to be better than 80 keV full width at half maximum at 8.78 MeV.

Events are time stamped with a resolution of 30.5 μs using two EG&G RC014 realtime clocks in CAMAC. At the beginning of an experimental run, these clocks are reset to zero and started using the CAMAC control bus. The first clock reaches its 16-bit full scale in two seconds while the second operates as a slave to the first, incrementing only as the first reaches full scale and automatically resets itself. The clocks are read with every master trigger so that each event carries a time stamp relative to the start of the current run. Decay times are obtained by subtracting the time of a fragment implant from that of its associated beta decay.

For events to be properly correlated it is necessary that a given implanted fragment beta decays before a subsequent fragment implantation in the same DSSD pixel. For this reason, the fragment beam is defocused to illuminate as much of the DSSD as possible. This lengthens the average time between implants within a given pixel by distributing implants over as many pixels as possible. Since the profile of the incoming beam is roughly Gaussian in both the horizontal and vertical directions the beam spot is observed to be round while the detector itself is square. As a result, fragments are distributed over ~1000-1200 of the 1600 DSSD pixels. To measure half-lives of range ≤ 1 s, the average time between implants should be greater than 10 s. This can be achieved by maintaining an average implant rate of ~100 Hz.

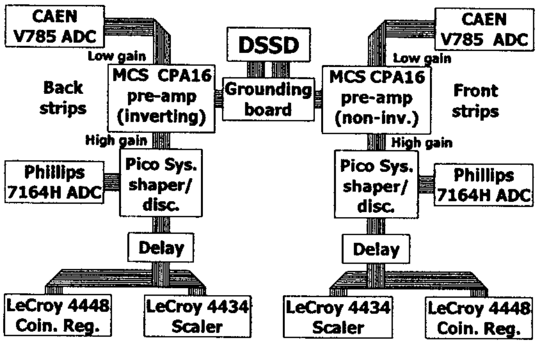

Fig. 2. Schematic of the DSSD electronics.

3. Experimental use

The beta counting system has been used to characterize the decay of short-lived radionuclides produced using the NSCL's Coupled Cyclotron Facility. A 140 MeV/nucleon ^{86}Kr beam was made incident on a 376 mg/cm^2 Be target to produce neutron-rich species in the A ~ 60 region. These nuclides of interest were separated from other fragmentation products by the new A1900 fragment separator, which was equipped at its intermediate image plane with a 1% momentum slit and a 330 mg/cm^2 Al wedge degrader. The separated fast fragment beam was directed to the beta counting station in the S1 experimental vault. Event-by-event particle identification of the fast fragment beam was determined from energy-loss and time-of-flight data from the upstream PIN detector. Implant events were identified as those events with low-gain signals above threshold in both front and rear strips and a signal above threshold in the upstream PIN diode. Decay events were identified as those with high-gain signals above threshold in both front and rear strips and no signal above threshold in the upstream PIN.

One of the nuclides implanted within the DSSD during the experiment was ^{57}V. ^{57}V fast fragment implants in a given pixel were correlated with subsequent beta decay in the same pixel with 30% efficiency. Decay curves can be generated by histogramming the differences in absolute time between implant events and their correlated beta decay events. The decay curve for ^{57}V is depicted in Figure 3. A half-life of 350±10 ms has been deduced, consistent with the previously measured values of 323±30 ms [1] and 340±80 ms [2].

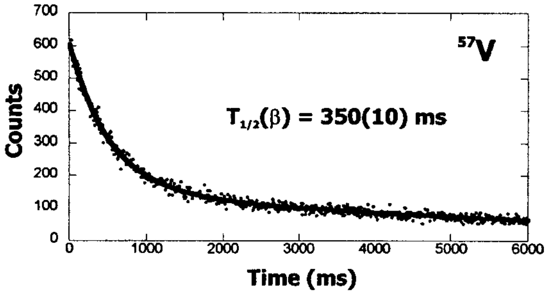

Fig. 3. Decay curve for the beta decay of ^{57}V.

4. Conclusions and further development

Fast fragmentation beams provide an opportunity to study the beta decay of exotic nuclei. At the NSCL, we have developed a new beta counting system to take advantage of this; by correlating fast fragment implants with their subsequent beta decays within a double-sided silicon detector, we are able to measure decay times directly. The beta counting station can be augmented with other detector systems to learn details of the low-energy quantum structure of the daughter nucleus. We have recently used 6 detectors from the new MSU segmented germanium array [3] to measure beta-delayed gamma rays for neutron-rich nuclides near N = 32. A high-efficiency neutron detector array (NERO) is under development at the NSCL and will be used in concert with the beta counting station to measure half-lives and delayed neutron probabilities for nuclei along the rapid neutron capture pathway. Finally, plans have been made to augment the beta counting array with additional silicon detectors in order to perform true beta calorimetry. This system will be used initially to study the decay of doubly-magic ^{100}Sn in the hopes of determining the Gamow-Teller decay strength to the ground state of ^{100}In.

References

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