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The GREAT spectrometer

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Abstract

The GREAT spectrometer is designed to measure the decay properties of reaction products transported to the focal plane of a recoil separator. GREAT comprises a system of silicon, germanium and gas detectors optimised for detecting the arrival of the reaction products and correlating with any subsequent radioactive decay involving the emission of protons, α particles, β particles, γ rays, X-rays or conversion electrons. GREAT can either be employed as a sensitive stand-alone device for decay measurements at the focal plane, or used to provide a selective tag for prompt conversion electrons or γ rays measured with arrays of detectors deployed at the target position. A new concept of triggerless data acquisition (total data readout) has also been developed as part of the GREAT project, which circumvents the problems and limitations of common dead time in conventional data acquisition systems.

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1. Introduction

Implantation detection systems coupled with in-flight recoil separators have been one of the most powerful tools available for the study of nuclei far from stability. They offer the benefits of efficient microsecond separation, independent of the chemistry of the reaction products, combined with sensitive detection of the reaction products and

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measurement of their subsequent radioactive decays. With such instruments, the frontiers of knowledge of the decay properties of extremely proton-rich and heavy nuclei have been pushed back at a remarkable rate. More recently, spectroscopic studies of their excited states have burgeoned through the exploitation of recoil-decay tagging (RDT) [1,2] and related techniques.

The Gamma Recoil Electron Alpha Tagging (GREAT) Spectrometer heralds a new generation of implantation detection systems, holistically designed to measure the protons, α particles, β particles, γ rays, X-rays and conversion electrons emitted by reaction products transported to the focal planes of recoil separators. GREAT comprises a combination of gas, silicon and germanium detectors optimised for the study of nuclei produced with very low cross-sections down to the level of pb. GREAT can either be used on its own for focal plane decay studies, or in conjunction with prompt radiation detector arrays deployed at the target position, as a tagging spectrometer for RDT experiments. One of the limitations of this delayed coincidence technique is the severe dead time losses in the data acquisition system. A novel triggerless data acquisition method, total data readout (TDR), has therefore been developed for GREAT to circumvent this problem [3].

2. Detection system

The GREAT spectrometer is initially to be deployed on the gas-filled recoil separator RITU at Jyväskylä [4]. The detection elements that make up GREAT are shown schematically in Fig. 1. These detectors are described in more detail in the following sections.

2.1. Multiwire proportional counter

A transmission multiwire proportional counter (MWPC) is positioned at the entrance of GREAT. The MWPC has an aperture of 131 mm (horizontal) × 50 mm (vertical), with a central vertical 1 mm wide strut to support the thin Mylar foil entrance and exit windows. The entrance window separates the isobutane of the MWPC from the low-pressure helium gas of RITU, while the exit window separates the isobutane from the vacuum in which other GREAT detectors are operated.

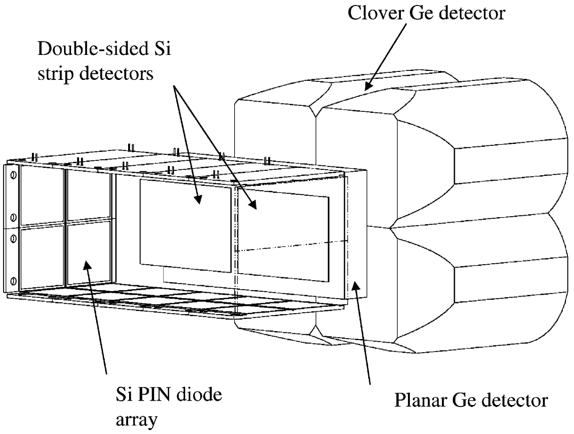

Fig. 1. Schematic drawing of GREAT showing the arrangement of the silicon and germanium detectors. The separated recoils pass through the multiwire proportional counter (not shown) and enter the detector system from the left.

The principal function of the MWPC is to distinguish between recoiling reaction products passing through it and their radioactive decays. Ions propagating through the detector generate energy loss, timing and position signals, which are shaped using commercial NIM electronics. The energy loss and timing measurements can be combined with the energy measured in the implantation detector, described in the next section, to make a clean distinction between fusion reaction products and scattered beam particles. This is important for maximising the efficiency for correlating radioactive decays with the correct ion implantation.

2.2. Implantation detector

The transmitted recoils can be slowed down using a system of adjustable degrader foils, before being implanted into a pair of adjacent double-sided silicon strip detectors (DSSSDs). The DSSSDs are used to measure the energies of ions that are implanted and of the protons, α particles and β particles they subsequently emit. Each DSSSD has an active area of 60 mm × 40 mm and a thickness of 300 μm. The strip pitch is 1 mm in both directions, matching the position resolution of the MWPC and giving a total of 4800 pixels. After allowing for the non-uniform distribution of ions across the focal plane, this is at least an order of magnitude increase compared with the position sensitive strip detector (PSSD) used previously and provides a significant improvement in correlation performance.

The DSSSDs are mounted side by side on a hollow block through which coolant is circulated, to reduce their temperature to −20 °C. The active areas of the two DSSSDs are separated by a gap of 4 mm, giving an estimated typical recoil collection efficiency of ~85%. This compares with ~70% for the single 80 mm × 35 mm PSSD.

The strips are individually instrumented using thick-film hybrid charge sensitive preamplifiers [5]. The preamplifier cards are mounted on 10 motherboards that can each accommodate up to 20 modules of either polarity. The motherboards are mounted inside the vacuum chamber on the outside surface of the cooling block and plug directly into connectors on the PCBs housing the DSSSD wafers. This minimises both the distance and the number of connections between the DSSSDs and the input stage of the preamplifiers, thereby maximising the energy resolution.

2.3. Conversion electron detector array

Reaction products are typically implanted into the DSSSDs at depths of ~1–10 μm, depending on the target-projectile combination. Conversion electrons that are emitted during a subsequent radioactive decay process therefore have a significant probability of emerging from the DSSSD in the backward hemisphere relative to implantation. An array of 28 silicon PIN diodes is mounted in a box arrangement around the perimeter of the DSSSDs to measure the energies of the conversion electrons.

Each PIN diode has an active area of 28 mm× 28 mm and has a thickness of 500 μm. The PIN diodes are mounted in pairs on a motherboard. The front-end components of the commercial high-resolution charge sensitive preamplifiers are mounted on custom PCBs that plug directly on the back of the motherboards, so as to be as close as possible to the PIN diodes. The 14 motherboards form two rings around the inside surface of the cooling block, so the PIN diodes and the front-end components are all cooled. With these arrangements, an energy resolution of ~5 keV can be achieved, which is a marked improvement on the quadrant detectors previously used [6]. The geometrical efficiency of the array is ~30%. This compares with GEANT Monte Carlo simulations that predict that the efficiency for the full energy electron detection in a single PIN diode has a maximum value of ~23% for 300 keV electrons, dropping to ~13% for 600 keV electrons. However, the probability of electrons scattering between PIN diodes means that the efficiency for registering any signal is significantly higher at ~40% for electron energies above ~200 keV. Combined with the lower thresholds that can be achieved with the PIN diode array, this marks another significant improvement in performance.

2.4. Planar germanium strip detector

A planar double-sided germanium strip detector has been designed for GREAT to measure the energies of X-rays and low-energy γ rays. The rectangular crystal has an active area of 120 mm × 60 mm and a thickness of 15 mm. The strip pitch on both faces is 5 mm, providing position information that can be correlated with other GREAT detectors. The detector is housed in its own cryostat and mounted directly behind the DSSSDs, with the front surface of the Ge crystal approximately 10 mm downstream of the DSSSD. It has a thin beryllium entrance window and is mounted inside the vacuum chamber, to minimise the attenuation of the photons. It can also be used to detect high-energy β particles ($\geqslant 2$ MeV) that penetrate through the DSSSD.

2.5. Clover germanium detector

The energies of higher energy γ rays are measured using a clover Ge detector mounted outside the vacuum chamber. Each of the four crystals has a diameter of 70 mm before shaping and is 105 mm long. The first 30 mm of their length is tapered at

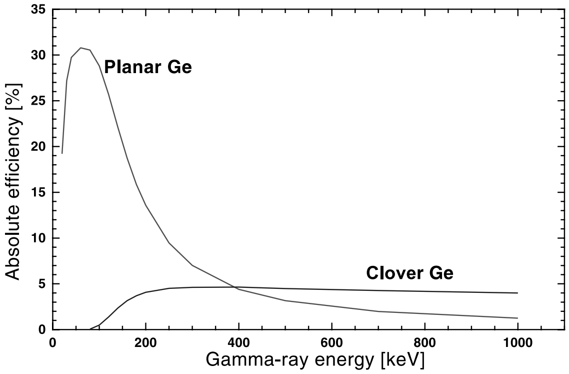

Fig. 2. Absolute efficiency of the planar Ge strip detector and the clover Ge detector as a function of γ-ray energy, simulated using the Monte Carlo code GEANT. The simulations assume a realistic source distribution in the DSSSD and take into account the attenuation of γ rays in the intervening materials.

an angle of 15° on the outside surfaces. The crystals have fourfold segmentation. The efficiency of the Ge detectors has been simulated using GEANT and is plotted as a function of γ-ray energy in Fig. 2. A suppression shield with bismuth germanate crystals, 185 mm long, surrounds the clover detector to improve its peak-to-total ratio.

3. Total data readout

In the past, experiments using implantation detection systems have normally used a common dead-time data acquisition system, where a typical trigger condition might be that a signal is recorded in the implantation detector. The signals from all other detectors are then delayed and read out as part of that event. In many experiments it is desirable to have wide trigger gates, for example when investigating short-lived γ-decaying isomers. However, this leads to a high dead time, particularly when running at high rates to compensate for the low cross-sections of the channels of interest. The TDR concept has been developed for GREAT, in order to overcome this limitation [3].

The front-end electronics (shaping amplifiers and constant fraction discriminators (CFDs)) are commercial NIM and CAMAC modules. The energy signals are sent to the inputs of VXI cards having 32 independent 14-bit ADC channels. A gate is generated individually for each input, either by the associated external CFD or by a software controlled trigger. Each ADC conversion is time-stamped within the ADC card and passed on to the Event Collator, which then assembles the fragments using spatial and temporal associations required by the experiment. A VME module known as the Metronome facilitates the time-stamping, controlling the distribution and synchronization of a 100 MHz clock for all ADCs.

4. Summary and outlook

The GREAT spectrometer and its associated TDR system are scheduled for full commissioning during 2002. The significant improvements in the detector system will take full advantage of the recent upgrade of the RITU separator and the ongoing ion source developments at Jyväskylä. The TDR method will open up new opportunities for studying the most exotic nuclei by allowing the collection of very rare events without crippling dead time losses.

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