Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 575 (2007) 421–432
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Compton-suppression and add-back techniques for the highly segmented TIGRESS HPGe clover detector array

M.A. Schumaker*, C.E. Svensson

Department of Physics, University of Guelph, Guelph, Ont., Canada, N1G 2W1

Received 5 January 2007; accepted 2 February 2007
Available online 2 March 2007

Abstract

Methods to optimize the performance of the TRIUMF-ISAC Gamma-Ray Escape-Suppressed Spectrometer (TIGRESS), an array of 12 large-volume, 32-fold segmented HPGe clover detectors to be used at the ISAC-II radioactive ion beam facility, have been developed based on GEANT4 Monte Carlo simulations. These methods rely on the segmentation of the outer electrical contacts of the TIGRESS HPGe clovers, and on the 20-fold segmentation of the Compton-suppression shields. The clover segmentation is utilized to make event-by-event decisions as to whether the γ-ray energy depositions in neighbouring crystals and clovers will be summed. The Compton suppressor segmentation is used to veto events selectively, and to reduce false suppression in experiments with high γ-ray multiplicity. Procedures to determine the optimal techniques and configurations of the array for a particular experiment, dependent on the expected γ-ray energies and multiplicities, and the velocity of the recoil ions, are presented.

PACS: 07.85.Nc; 29.30.Kv; 29.40.Gx; 29.40.Wk

Keywords: TIGRESS; Segmented HPGe detectors; Compton suppression

1. Introduction

Heavy ion physics has undergone a revolution with the development of Radioactive Ion Beam (RIB) facilities such as the Isotope Separator and ACcelerator (ISAC) [1] at TRIUMF. Though stable beam facilities are able to produce very high intensity beams, they are limited to the acceleration of the naturally-occurring stable isotopes and a few select long-lived radioactive species. RIB facilities, by contrast, produce a much broader range of exotic nuclei. The production yields, however, are often orders of magnitude smaller than those available with stable beams. In addition, the beams produced may contain significant isobaric impurities. These factors present enormous challenges for γ-ray spectroscopy experiments at RIB facilities; spectrometers used with radioactive beams must be highly efficient to detect the relatively small number of events of interest, and they must be highly selective to identify events amidst significant background.

Precision γ-ray spectroscopy with High-Purity Germanium (HPGe) detector arrays is an important part of the research programmes at virtually all nuclear physics accelerator laboratories [2]. Using these detectors to cover a large solid angle can provide a high detection efficiency, and their excellent energy resolution provides high sensitivity to weak γ rays. In many arrays, such as Miniball at REX-ISOLDE [3,4], Clarion at the Holifield RIB Facility [5], Exogam at SPIRAL [6,7], and TIGRESS at ISAC [8–12], very large effective HPGe detectors are achieved by close-packing multiple HPGe crystals within common cryostats. While Miniball detectors consist of clusters of hexagonal HPGe crystals, Clarion, Exogam, and the TRIUMF-ISAC Gamma-Ray Escape-Suppressed Spectrometer (TIGRESS) use clover-type detectors [13,14], in which four crystals form a square, or "four-leaf clover"

*Corresponding author. Tel.: +1 519 824 4120x53840; fax: +1 519 836 9967.
E-mail addresses: mschumak@physics.uoguelph.ca (M.A. Schumaker), sven@physics.uoguelph.ca (C.E. Svensson).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2007.02.084

configuration. Although the HPGe crystals in this arrangement are physically separate, the effective volume can be very large, since γ-ray energy depositions in multiple HPGe crystals can be summed to recover additional full-energy events. By forming an array of many such detectors, a significant fraction of the 4π solid angle around a source can be covered, providing a very high γ-ray detection efficiency.

TIGRESS will play a major role in the scientific programme planned for the ISAC-II facility at TRIUMF [2], and achieving the best possible sensitivity for TIGRESS will be essential to the success of many planned experiments. Based on tests of prototype TIGRESS HPGe detectors and Compton-suppression shields it is predicted [12] that TIGRESS will be capable of an absolute photopeak efficiency of up to 17%, and a peak-to-total ratio of up to 61%, for 1 MeV γ rays.

For experiments with accelerated beams, such as those to be performed at ISAC-II, the largest contribution to γ-ray energy resolution is, in general, Doppler broadening resulting from the angular dependence of the energies of γ rays emitted from recoiling nuclei. ISAC-II will produce accelerated ion beams of up to 6.5 MeV/A for mass $A \leqslant 150$, and as high as 15 MeV/A for light nuclei [1], resulting in typical recoil velocities of $\beta \sim 5\%$, and significant Doppler broadening effects. In order to constrain the location of the first γ-ray interaction within the large HPGe crystals and hence the angle of emission of the γ ray relative to the nuclear recoil velocity, the outer electrical contacts of the TIGRESS crystals are segmented two ways longitudinally and one laterally, resulting in 32 segments per HPGe clover. This not only allows localization of the interaction points to within the segment boundaries, but through fast waveform digitization and pulse-shape analysis, sub-segment position localization is achieved [8]. One of the most commonly used and effective methods of improving the performance of a HPGe detector array is through the use of Compton-suppression shields, composed of a high-efficiency scintillator, such as bismuth germanate (BGO). These shields significantly improve the peak-to-total ratio of the array by vetoing partial energy depositions within the HPGe volume. The disadvantage of the use of Compton-suppression shields is the decrease in solid angle covered by HPGe, which decreases the detection efficiency. Therefore, the use of Compton suppression requires a compromise between these two indicators of array performance.

For studies involving high-spin states of nuclei, numerous γ rays may be emitted by the nucleus during deexcitation. These γ rays are typically emitted in such rapid succession that they appear to be simultaneous on the scale of the HPGe time resolution (few ns). Such high-multiplicity events are accommodated in HPGe detector arrays like Gammasphere [15] due to the large number of individual detectors in the array. However, for larger HPGe detectors such as the TIGRESS clovers, it is probable that multiple γ rays may enter the same crystal, or that a γ ray may enter a part of the suppression shield at the same time as another enters the HPGe clover. In the first case, γ-ray summing can remove events from the photopeak. Therefore, as the multiplicity of γ rays is increased, and the probability of multiple hits in the same crystal increases, both the photopeak efficiency and the peak-to-total ratio decrease. In the second case, the detected interaction in the Compton-suppression shield would falsely veto the interactions in the HPGe clover. This false suppression also results in a decrease in detection efficiency.

There are many factors which may affect the performance of the TIGRESS array for a particular γ-ray cascade, and they may produce opposing effects for many sets of conditions. In order to compare the effectiveness of techniques to improve the array's performance, an appropriate figure of merit is therefore required. A detailed discussion of the resolving power of a HPGe spectrometer is given in Ref. [16]. Noting that experiments at RIB facilities will predominantly be statistics limited (due to low numbers of counts in experiments), a useful figure of merit can be obtained from the experiment-independent parameters that determine the statistical term of the resolving power. They are: the absolute photopeak efficiency, $\varepsilon_{\rm abs}$, the peak-to-total ratio, P/T, and the energy resolution of the photopeak, δE_γ, and appear in the statistical term in the combination [16]

$$\eta = \frac{(\varepsilon_{\rm abs})(P/T)}{(\delta E_\gamma)} \tag{1}$$

which we take to be our figure of merit for array performance in the current work.

2. TIGRESS array simulation

In order to compare the effectiveness of different analysis methods for a range of experimental conditions, a GEANT4 [17] simulation of the 12-detector TIGRESS HPGe detector array was created, and is shown in Fig. 1. In Ref. [12], it was demonstrated that this simulation agreed well with the measured performance of the prototype TIGRESS HPGe clover and Compton-suppression shield. Therefore, the 12-detector simulation can be used as a predictive tool for the behaviour and performance of TIGRESS.

The effects of three types of optimization methods were explored in order to optimize the performance of the TIGRESS array. The first of these depends on the ability to rapidly reconfigure both the HPGe detectors and the Compton-suppression shields to tailor the TIGRESS array's physical configuration to particular experiments. As shown in Figs. 1 and 2, the TIGRESS detectors can be arranged in two ways: *HPGe Forward*, in which the HPGe crystals are located 11.0 cm from the centre of the array, and *HPGe Back*, with a source-to-detector distance of 14.5 cm. In the HPGe Forward configuration, the front Compton-suppression shields must be pulled back in order