Nuclear Instruments and Methods in Physics Research A 622 (2010) 614–618

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Experimental test of the background rejection, through imaging capability, of a highly segmented AGATA germanium detector

M. Doncel [a,*], F. Recchia [b], B. Quintana [a], A. Gadea [c,d], E. Farnea [b]

[a] Laboratorio de Radiaciones Ionizantes, Universidad de Salamanca, Spain
[b] INFN sezione di Padova, Padova, Italy
[c] IFIC Valencia, Valencia, Spain
[d] INFN Laboratori Nazionali di Legnaro, Legnaro, Italy

The AGATA Collaboration

ARTICLE INFO

Article history:
Received 15 July 2010
Accepted 22 July 2010
Available online 4 August 2010

Keywords:
Gamma spectroscopy
Gamma tracking
Imaging
Position-sensitive germanium detectors

ABSTRACT

The development of highly segmented germanium detectors as well as the algorithms to identify the position of the interaction within the crystal opens the possibility to locate the $\gamma-$ray source using Compton imaging algorithms. While the Compton-suppression shield, coupled to the germanium detector in conventional arrays, works also as an active filter against the γ rays originated outside the target, the new generation of position sensitive $\gamma-$ray detector arrays has to fully rely on tracking capabilities for this purpose. In specific experimental conditions, as the ones foreseen at radioactive beam facilities, the ability to discriminate background radiation improves the sensitivity of the gamma spectrometer. In this work we present the results of a measurement performed at the Laboratori Nazionali di Legnaro (LNL) aiming the evaluation of the AGATA detector capabilities to discriminate the origin of the γ rays on an event-by-event basis. It will be shown that, exploiting the Compton scattering formula, it is possible to track back γ rays coming from different positions, assigning them to specific emitting locations. These imaging capabilities are quantified for a single crystal AGATA detector.

1. Introduction

Over the last decade the Nuclear Structure community has undertaken the development of position sensitive $\gamma-$ray detectors based on highly electrically segmented germanium diodes. This has opened a new era for gamma-spectroscopy techniques with the construction of large detector arrays based on the concept of $\gamma-$ray tracking [1–3]. Gamma tracking arrays will be fundamental instruments for the nuclear structure studies using the next generation of radioactive-ion and high-intensity stable beam facilities. In particular, the experimental conditions foreseen at the radioactive ion beam (RIB) facilities will impose quite stringent requirements to the detection devices. In RIB facilities, the beam intensities will be orders of magnitude lower than the intensities at the existing stable beam facilities. Furthermore, the nuclei of interest might have to be detected in a high-background environment as a result of both, the cocktail of nuclear species reaching the secondary target and the partial decay of the secondary beam. In these conditions, maximum reachable detection sensitivity and selectivity will be essential for the success of experiments. The situation is worse in the case of RIB facilities with in-flight production, where very high velocities (v/c up to 50%) and lower beam intensities (a few pps in the case of the most exotic species) are expected. These secondary beams are obtained following projectile fragmentation or fission. Here, $\gamma-$ray tracking has to provide also a reasonable detection efficiency and energy resolution.

It is foreseen that $\gamma-$ray tracking arrays will operate together with complementary detectors using background suppression techniques as well as tagging techniques in order to reduce the high background induced by the harsher environment of RIB facilities with respect to that of the stable beam ones. An example is offered by the RISING instrument, installed at the focal plane of the Fragment Separator (FRS) in GSI [4]. A detailed study [5] of the radiation components in the target area showed that background sources are the beam dump or the implantation detector, but also the decays occurring at a distance of 1–4 m upstream from the target which are likely originated in the FRS tracking detectors and degraders.

A possible way to reduce the background is the use of very narrow time gates [5]. But to have a sizeable effect, a FWHM time resolution of the order of 1 ns would be required for the detectors.

* Corresponding author. Tel.: +34 923294434; fax: +34 923294584.
E-mail address: doncel@usal.es (M. Doncel).

0168-9002/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2010.07.069

Unfortunately this resolution is far exceeding what is currently achievable with a conventional large-volume germanium detector. However, the use of segmented-contact germanium detectors could lead to a significant background reduction. Currently efforts are ongoing in order to: improve the timing properties of germanium detectors with the use of pulse shape analysis [6]; discriminate gammas from neutrons, which constitute another important contribution to the background [7,8]; and use optimized electronics, as the fast-reset preamplifiers, to avoid long dead times due to signal saturation produced by the high energy charged particle background [9]. In this context, an additional technique to improve the response function relies on the possibilities opened by the γ−ray tracking to provide partial information on the incoming direction of the γ rays, thus allowing a reduction of the γ−ray background coming from sources with different origin than the target.

In this work, for the first time, the background reduction capability has been investigated experimentally in a test using an AGATA 36-fold segmented symmetric prototype germanium detector. It is important to notice that the functionality of a single segmented AGATA detector cannot be scaled directly to the full tracking array. Fundamental parameters for the imaging analysis, as the average distance between interactions, bear severe differences in their values when evaluated for a cluster of several AGATA capsules. However, in the present work it has been decided to perform the imaging analysis in the conditions expected for a real full tracking array, by means of requesting an average distance corresponding to the most probable distance between interactions in the full array. Distances larger than 2 cm correspond to about 70% of the total events for 1 MeV γ rays in the full AGATA, or larger than 1 cm that correspond to about 90% of the events in the above-mentioned conditions. Concerning the multiplicity of the interactions, while it does not represent a problem in a real tracking array, in the present work, to simplify the signal decomposition within the single detector in the Pulse Shape Analysis process, the analysis has been limited to data with only two interactions. Monte Carlo simulations for the full AGATA show that 95% of photopeak events have more than two interactions and reduce to 82% if all events are included, therefore, the procedures described in this work have a wide applicability for AGATA detectors.

2. The experiment

As mentioned above, in setups as RISING, the three main sources of background are the Fragment Separator detectors and degraders (upstream), the target in the center of the setup and the beam dump or implantation/tracking detector for the reaction products after the target (downstream).

In order to emulate in simplified conditions the experimental setup, the measurement has been performed placing three sources around an AGATA prototype detector. The positions of the sources have been chosen to roughly reproduce the incoming direction of the radiation from target, beam dump and beam line in an in-beam experiment. The data analysis has been performed with the goal to demonstrate that γ rays coming from different sources can be separated according to their incoming direction.

3. Experimental measurements

The measurements have been made with one of the single symmetric AGATA prototype crystals (S#001) equipped with charge-sensitive fast preamplifiers. The signals (36 segments+-central contact) were acquired using digitizer cards with 14 bits resolution and 100 MHz sampling rate (CAEN Model Number N1728A). These NIM-standard digitizer modules calculate directly the amplitude (energy) of the input signal, through a moving window deconvolution algorithm [10] running on the on-board FPGA. They provide also the data corresponding to the sampled pulses. Proper synchronization of the 37 channels is fundamental considering the subsequent analysis performed. A common clock was distributed in daisy chain to all of the modules, while the trigger signal, which was generated by a leading edge discriminator sensing the central contact of the AGATA detector, was distributed through a star connection. Each module was read out independently, the full event being reconstructed off-line by exploiting the time stamp information. In order to limit the rate of data transferred only the first 200 samples were read out for each channel together with the energy value calculated internally, as explained above.

Sources of ^{60}Co (E_1=1173 keV and E_2=1332 keV), ^{137}Cs (E=661 keV) and ^{152}Eu (E_1=122 keV, E_2=244 keV, E_3=344 keV and E_4=1408 keV) have been used for the measurement. Considering a Cartesian coordinate system in the center of the frontal face of the crystal, with the Z-axis pointing to the center of the detector, the position coordinates in mm, for the three different sources are the following: ^{60}Co (807, 586, 68); ^{137}Cs (−147, 147, −978) and ^{152}Eu (−816, −567, −104).

In order to obtain the positions of the interactions the analysis of pulse shapes was performed using the grid search PSA algorithm [11] which uses a signal basis calculated using MGS code [12].

4. Algorithm implementation

Our algorithm performs a comparison between the scattering angle of the γ ray in the first interaction as it is obtained from the kinematics of the Compton scattering (θ_C) and the angle estimated from geometrical considerations (θ_G) for the three positions of the sources. The former is calculated using a simple probabilistic tracking, i.e. assuming that the first interaction recorded is a Compton scattering and that the γ ray is fully absorbed in the detector. The scattering angle can be calculated with the Compton scattering formula as follows:

$$\cos\theta_C = 1 - \frac{(E_\gamma - E'_\gamma)mc^2}{E'_\gamma E_\gamma} \quad (1)$$

where E_γ, the initial energy of the γ ray, and E'_γ, the energy after the scattering, are known.

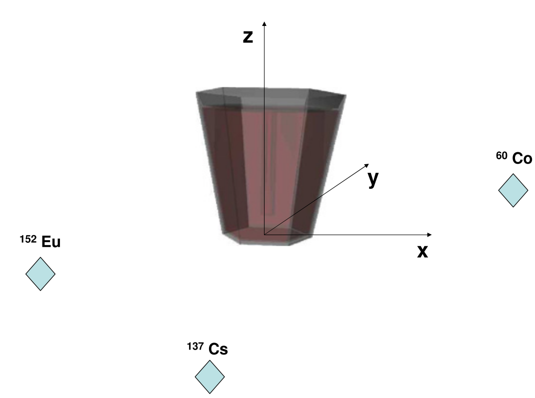

Fig. 1. Geometrical description of the position of the sources with respect to the detector. The crystal is 80 mm diameter and 90 mm length. The sources are placed around the detector at approximately 1 m distance. For pictorial needs the scale is not respected.