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Characterization and performance of the DTAS detector

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A B S T R A C T

DTAS is a segmented total absorption γ-ray spectrometer developed for the DESPEC experiment at FAIR. It is composed of up to eighteen NaI(Tl) crystals. In this work we study the performance of this detector with laboratory sources and also under real experimental conditions. We present a procedure to reconstruct offline the sum of the energy deposited in all the crystals of the spectrometer, which is complicated by the effect of NaI(Tl) light-yield non-proportionality. The use of a system to correct for time variations of the gain in individual detector modules, based on a light pulse generator, is demonstrated. We describe also an event-based method to evaluate the summing-pileup electronic distortion in segmented spectrometers. All of this allows a careful characterization of the detector with Monte Carlo simulations that is needed to calculate the response function for the analysis of total absorption γ-ray spectroscopy data. Special attention was paid to the interaction of neutrons with the spectrometer, since they are a source of contamination in studies of β-delayed neutron emitting nuclei.

1. Introduction

Decay studies of exotic nuclear species at the focal plane of the FAIR-NUSTAR Super Fragment Separator in the DESPEC experiment [1] will provide information on the nuclear structure and the astrophysics impact of exotic nuclei. Far from stability, the Q_β values are very large, and the corresponding increase in level density implies, on the one hand, the fragmentation of the β feeding into many levels populated in the decay and, on the other hand, the fragmentation of the γ intensity between many possible cascades. Total Absorption γ-Ray Spectroscopy (TAGS) has been shown to be an accurate tool to determine β-decay intensity distributions for such nuclei far from the valley of β stability. This technique avoids the so-called *Pandemonium* effect [2], related to the relatively poor efficiency of HPGe detectors. Instead of detecting individual γ rays as in high-resolution experiments with HPGe detectors, TAGS aims to detect the full β-delayed electromagnetic cascade. This is achieved with spectrometers made of large scintillator crystals covering a solid angle of $\sim 4\pi$. To extract the β-intensity distributions a deconvolution procedure is applied to the measured energy spectrum using the detector response, as will be explained later.

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For this reason, a new spectrometer has been designed and constructed for the DESPEC experiment [3]. The Decay Total Absorption γ-ray Spectrometer (DTAS) is a segmented detector that consists of a maximum of eighteen NaI(Tl) crystals with dimensions 150 mm × 150 mm × 250 mm [3]. The choice of the material, as well as the geometry, comes from a careful study where several goals and constraints were taken into account: the efficiency, the amount of dead material, the energy and time resolution, the neutron sensitivity, the sensitivity limit for high-lying β-intensity, the coupling to ancillary detectors, and the cost [3]. The advantage of the segmentation in this case is threefold: the possibility to extract information from the module-multiplicity spectra, as will be explained later, the possibility of using the individual modules as single γ detectors, and the mechanical flexibility of the set-up. In fact, we consider two main configurations for DTAS: a sixteen-module configuration designed for experiments at fragmentation facilities, as proposed in [3], and an eighteen-module configuration for experiments at ISOL-type facilities. Both configurations without shielding can be seen in Fig. 1. In the eighteen-module configuration side holes can be made by moving away the modules of the horizontal central plane, thus allowing access from both sides of the detector, as shown in Fig. 1 bottom. In this way DTAS can be combined with ancillary detectors and it is possible to position a beam pipe in the centre of the spectrometer. This configuration has recently been commissioned at IGISOL [4], with holes of 10 cm used to place a HPGe detector from one side and the beam pipe with a β detector from the other side. The two central modules were separated by 16 cm instead of 10 cm in order to lower their counting rate, so that it was comparable to the external modules. The configuration foreseen for FAIR [3], with sixteen modules, will be coupled to the Advanced Implantation Detector Array (AIDA) [5]. In order to place AIDA in the centre of DTAS, the two central modules in the eighteen-module configuration are removed and the two modules above the central hole are supported by a specially designed aluminium frame with external dimensions identical to a module, as shown in Fig. 1 upper panel.

The shielding surrounding DTAS is composed of stainless steel sheets, lead bricks and aluminium, and it served to reduce the background counting rate by one order-of-magnitude in the measurements of this work. The allocation of individual modules to positions in the arrangement was done according to their resolutions, ranging from 7% to 9% at 661.7 keV, so that the positions associated with the lowest counting rates (the eight corners of the assembly shown in Fig. 1) were occupied by the modules with the poorest resolution.

The outline of the article is the following: in Section 2 we will describe the procedure to reconstruct the full energy deposited in the detector from the signals of the individual modules. In Section 3 a method to evaluate the summing-pileup contamination will be explained, and its validation with calibration sources will be discussed. Finally, the Monte Carlo (MC) response function of the detector will be described in Section 4, and the reproduction of several calibration sources and the neutron contamination coming from β-delayed neutron emitters will be discussed.

2. Total energy reconstruction: hardware sum and software sum

In this section we will describe the electronic chain employed to process the signals from the individual modules of DTAS, and the procedure to reconstruct the total energy deposited in the detector. In particular, two methods to calculate the total energy sum will be discussed: the hardware sum and the software sum.

2.1. Signal processing

In order to analyse data from DTAS we have to reconstruct accurately, for each event, the energy deposited in the full spectrometer and its module-multiplicity, M_m (number of modules that fire above the threshold, often known as fold). The full energy released in the spectrometer is obtained by summing the energy deposited in the individual modules, either electronically or via software. The electronic chain to process the signals from the modules was designed with this idea in mind, and it is represented in Fig. 2.

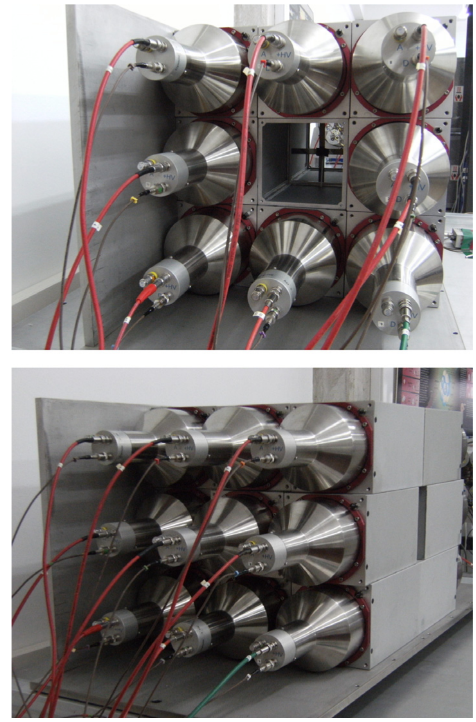

Fig. 1. DTAS detector in the sixteen-module configuration (top) and in the eighteen-module configuration (bottom) without radiation shielding

We use Mesytec MSI-8p preamplifiers [6] for both anode and dynode signals from the photomultiplier tubes (PMTs). MSI-8p are custom adapted units with fixed gain, preamplifier constants optimized for these PMTs and without timing filter amplifier. After the preamplifier, dynode signals are split into two branches; one branch is sent to a CAEN N625 Quad Linear FAN-in FAN-out [7], and the other to Mesytec MSCF-16 shapers. The N625 module acts as an analog signal adder and one of the outgoing signals is processed in an ORTEC 671 amplifier [8] to produce the sum energy signal (hardware sum) sent to the analog to digital converter (ADC), a CAEN V785 module, of the data acquisition system (DACQ). Another output from the N625 module is used to construct a common stop signal sent to a time to digital converter (TDC), CAEN V775, using an ORTEC 474 Timing Filter Amplifier and an ORTEC 584 Constant Fraction Discriminator. The MSCF-16 shapers provide individual energy and timing output signals that are sent to the individual channels of the ADC and TDC modules respectively. The anode signals after the preamplifier are sent to sampling digitizers of a second digital DACQ, running in self-triggered mode, which is not discussed in this publication.

In order to carry out the hardware sum properly we need to match the gains of the different PMTs by adjusting the high voltage (HV) applied to them, so that the signals of individual modules are aligned. Note that aligned here means having the same amplitude for the same energy deposited.

The software sum is reconstructed offline from the individual signals processed with the MSCF-16 shapers. In the following subsections we will show a method of correcting possible changes in the gain of the modules, as well as the way to perform properly the alignment and determine the software sum of these signals.