First Compton imaging tests with i-TED

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***Abstract*— The objective of this work is to demonstrate the Compton imaging capabilities of a novel gamma-ray Total-Energy Detector called i-TED. The latter is intended for neutron-capture cross-sections measurements of astrophysical interest, thereby enhancing detection sensitivity by means of the simultaneous combination of neutron Time-of-Flight with gamma-ray Compton-imaging techniques. The developed Compton demonstrator comprises five position-sensitive radiation detection modules of high energy resolution, which feature an overall position-sensitive field-of-view of 125 cm². Each detector module is based on 50x50mm² large $LaCl_3$(Ce) monolithic crystals optically coupled to 8x8 pixels silicon photomultipliers. In previous works we have determined the energy resolution (3.92(3)% at 662 keV) and spatial resolution (1-3 mm FWHM) for the detectors used in i-TED. In this work we investigate the impact of different experimental effects in the reconstructed Compton image by means of distant point-like gamma-ray source measurements. Apart from the Compton image algorithm itself, we investigate experimentally the impact of the scatter-absorber distance in the efficiency and resolution of the reconstructed Compton image. Other experimental effects play an important role, in particular the intrinsic position-reconstruction algorithm chosen for both the transversal xy-coordinates and the depth-of-interaction. These results will be presented together with a discussion focused on the technique and scope of the project. This work is of interest for other applications requiring high gamma-ray imaging efficiency, such as nuclear medicine and homeland security.**

***Index Terms*— Energy resolution, Gamma-ray detectors, Nuclear imaging, Position sensitive particle detectors, Spatial resolution.**

I. Introduction

With the aim of demonstrating the Compton imaging technique in combination with Time of Flight (TOF) neutron-capture measurements [1], a novel radiation detector with high efficiency and imaging capabilities, so-called i-TED, is being developed in the framework of the HYMNS project [2]. According to MC-simulations [1] the electronic collimation provided by the Compton technique, at variance with mechanical collimation [3], is expected to provide a significant advantage for discriminating spatially-localized gamma-ray background sources. The most common source of background in this kind of exeperiments are thermalized neutrons, which are eventually captured in the walls of the experimental hall or surrounding set-up materials.

Each i-TED detector is composed of two detection stages, scatter and absorber, both of them operated in time-coincidence mode. Since Compton images are obtained from the deposited energy and the interaction position of the incoming gamma-ray in each detection stage, a high resolution on both the energy and the reconstructed position are required. The energy resolution has been studied in detail in a previous work [4]. First results for the spatial resolution yield excellent values between 1 and 3 mm FWHM depending on the crystal thickness and algorithm used [5]. In this work we focus on the next steps after the energy and spatial characterization of the individual PSDs, hereby aiming at the best compromise between detection efficiency and gamma-ray image resolution. Sec. II presents a concise description of the main hardware used to develop the i-TED demonstrator. Sec. III shows examples of some preliminary results obtained for Compton imaging with the demonstrator. Additionally, some i-TED features are discussed, such as the possibility to adjust the scatter-absorber distance, and thus define the most convenient efficiency-resolution balance for the needs of each particular experiment or application.

II. Materials and Methods

For the two detection stages of i-TED monolithic crystals of $LaCl_3$(Ce) with thicknesses of 10 mm and 30 mm are used for scatter- and absorber-PSDs, respectively. To enhance detection efficiency, one and four PSDs are used respectively for the scatter and absorber stages, as shown below in Fig.1. All crystals have a base surface of 50x50 mm², and five of their six faces are covered with reflector and encapsulated in a thin aluminum housing. The base of the crystal has a 2 mm thick fused-silica optical window. The latter is optically coupled to an 8x8 pixels SiPM (SensL ArrayJ 60035-65P-PCB), where every pixel consists of more than 20000 avalanche photodiodes (APD). These APDs lack a spectrometric response by themselves, but the response of the sum of all of them does depend on the energy deposited in the crystal by the incident

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radiation. See [4] for details.

Fig 1. Photograph of one i-TED Compton module composed of one scatter PSD and four absorber PSDs. The system is mounted on a linear positioning stage to remotely control the separation scatter-absorber. See text for details.

In order to read the large number of acquisition channels in i-TED (320 pixels) customized electronics by PETSYS [6] are used. The scalability of the latter is an important aspect towards the construction of the final i-TED detector [1], which will feature 1280 pixels and a corresponding number of acquisition channels.

III. PRELIMINARY RESULTS AND OUTLOOK

A distinctive feature of time-of-flight neutron capture cross-section measurements is the large dependency of the capture yield with the neutron energy (see e.g. [3]). To cope with this experimental effect, i-TED features the possibility to enhance efficiency at the cost of image-resolution, and vice-versa. This is illustrated in Fig.2, which shows the Compton angular resolution dependency as a function of the scatter-absorber distance (focal distance).

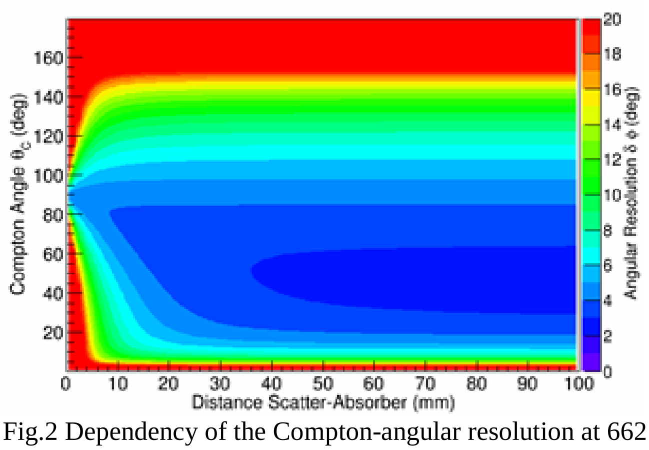

Fig.2 Dependency of the Compton-angular resolution at 662 keV as a function of the scatter-absorber distance. Calculation made for intrinsic position- and energy-resolutions of 1 mm FWHM and 3.5% at 662 keV, respectively.

Short scatter-absorber distances lead to a high detection efficiency (not shown in the figure) and poor average angular resolution, whereas large distances (20-30 mm) lead to a higher contribution of events with high angular resolution, at the cost of efficiency. In order to explore and exploit this feature we have made a series of systematic measurements. The Compton image resolution and efficiency have been analyzed as a function of the focal distance. An example for 20 mm focal distance is shown below in Fig.2 using a ^{137}Cs source placed at 20 cm distance in front of the detector and a simple Back-projection algorithm.

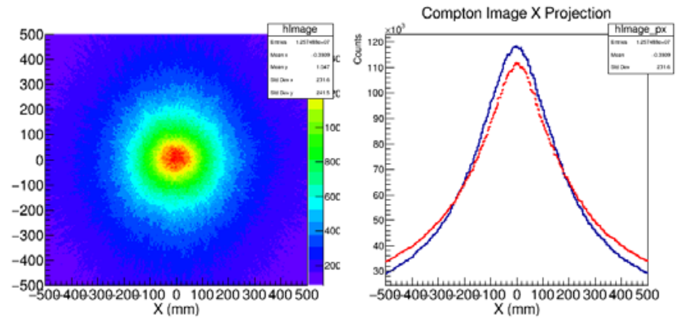

Fig 2. Example of a Compton image in 2D (left) and its projection over the horizontal- and vertical-axis (right). A point-like ^{137}Cs source was placed centered at 20 cm distance from i-TED.

Apart from the Back-projection algorithm, a ML-EM reconstruction method has been implemented as well, which allows one to depict more clearly the contributions of the different experimental features, such as e.g. the position reconstruction resolution (algorithm) and energy-calibration accuracy.

Next steps in the framework of this project include the implementation of a customized vertical xy-table of 1500x1500mm^2 size, which is synchronized with our acquisition system and allows for a very large number of systematic measurements in order to accurately characterize the spatial performance of i-TED and to benchmark the goodness of the implemented Compton imaging algorithms.

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