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Gamma-ray tracking with the MARS detector

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Abstract. The feasibility of the entire process of γ-ray tracking is demonstrated experimentally for the first time. The accuracy of the results is tested by the capability for Doppler correction of γ-rays emitted in flight. The resolution of the 847.8 keV ($2^+ \rightarrow 0^+$) transition detected with the MARS detector after Coulomb excitation of a ^{56}Fe beam could be improved from 15 keV to below 5 keV (FWHM).

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1 Introduction

The next generation of detector arrays for nuclear-structure studies with γ-ray spectroscopy will be based on the concept of γ-ray tracking [1]. The major goal of such an array is the combination of both high photopeak efficiency ($\epsilon_{\mathrm{Ph}} > 40\%$) and peak-to-total ratio ($P/T > 60\%$).

MARS is the Italian effort to explore the feasibility of this concept [2,3]. In this contribution, we present the results of an in-beam experiment aiming at the first-time demonstration of the entire process of γ-ray tracking with experimental data.

2 Ingredients for γ-tracking

The MARS prototype detector is a cylindrical crystal with 90 mm length and 72 mm diameter. It has a closed-end geometry with an inner hole of 10 mm diameter and 75 mm length. The outer contact of the detector is divided electrically in 25 segments (fig. 1): 6 angular "sectors" (1–6) and 4 transversal "slices" (A–D) plus a segment of 10 mm diameter in the centre of the front face (F).

For a tracking detector, the processing of the signals from the segments is done in digital electronics. In our test DAQ system, the preamplifier outputs are sampled by an array of 7 digital oscilloscopes (4 channels, 200 MSamples/s, 8 bit). The energy deposited in the segments is reconstructed from these digitised pulses. Applying the MWD-algorithm [4], we obtain an intrinsic resolution of 2.2 keV at 847.8 keV.

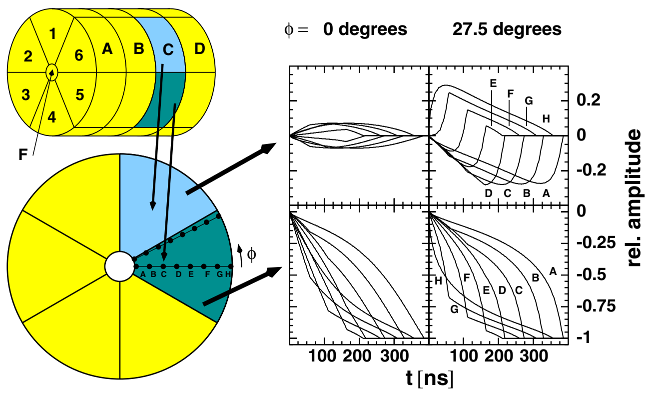

Fig. 1. Signals for single interactions within a segment of the quasi true-coaxial part of the detector. Net charge (right, bottom) and transient signals (right, top) are shown.

The points of interaction of the γ-rays are determined by the analysis of the shapes of the signals from the segments. In fig. 1, the dependence of the signals on the position of the interaction is demonstrated. The shown signals are calculated applying computer programs we

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developed [5]. An important feature of segmented detectors is the fact that not only the segment which collects the net charge released by the interaction has a signal. Also the neighbouring segments have transient signals with no net charge at the end.

Usually, there is more than one interaction in the detector or even in one segment and the measurable signals are the sum of the signals originating from the individual interactions. The decomposition algorithm has to identify the number of interaction points and to characterise each of them determining the three-dimensional position and the energy deposit. Our approach for this task is based on a genetic algorithm (GA). In order to test the algorithm, we simulated the interaction points of γ-rays and calculated the corresponding signals. Analysing these signals, the algorithm was able to localise the interaction points within an average error $\langle d \rangle = 5.4$ mm.

Eventually, the tracking algorithm identifies the individual γ-rays by reconstructing their scattering paths from the points of interaction. Every permutation of a sub-set of points is considered as a possible scattering sequence. In order to value the plausibility of different sequences, we defined a "figure of merit" derived from the properties of the main interaction processes: photoelectric effect, Compton scattering, and pair production. If its value is below a threshold a sequence is accepted as a reconstructed γ-ray.

3 In-beam experiment

Goal of the in-beam experiment presented in the following is to evidence the properness of the results of our approach for γ-ray tracking by the capability for Doppler correction of γ-rays emitted in flight. The knowledge of the emission angle of a γ-ray, in fact, is identical with the determination of its first point of interaction in the detector. Therefore, an improved Doppler correction measures directly the accuracy of the position of this first point.

In order to generate γ-rays emitted at large velocities, we employed Coulomb excitation of a 240 MeV ^{56}Fe beam obtained from the XTU Tandem Accelerator at Legnaro impinging on a 3.7 mg/cm^2 lead target. At a scattering angle of $\vartheta_{\mathrm{Lab}} \approx 60°$ velocities of $\beta \approx 0.08$ are attainable ($\sigma_{\mathrm{CLX}} = 250$ mb/sr).

The complete kinematics was defined experimentally by detecting the scattered projectiles with PHOBOS, an array of 8 PIN diodes and 7 Si detectors, in coincidence with the emitted γ-rays. In order to obtain a maximum Doppler broadening by keeping the relative angle between the PHOBOS detectors and the MARS detector at $\approx 90°$, the latter had to be placed at $\vartheta_{\mathrm{Lab}} \approx 135°$ taking into account the respective ϕ-angles. For each event, all 26 sampled pulses, the ID of the PHOBOS detector, and the time between MARS and PHOBOS were recorded. The counting rate was about 2 Hz.

The set-up of this experiment was simulated including effects which cannot be corrected afterwards like the finite opening angle of the individual PHOBOS detectors (2.6°), the blur of the velocity distribution due to the energy loss of the projectiles in the target before and after the scattering, and the finite size of the beam spot (≈ 4 mm diameter). If the positions of the simulated points are folded with an error distribution like that obtained from the analysis of simulated signals as mentioned above, an energy resolution of about 4.2 keV (FWHM) is achieved.

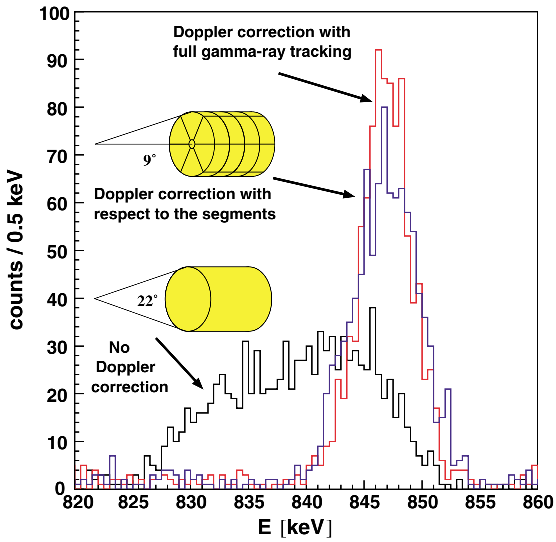

Fig. 2. Analysis of the 847.8 keV transition: no Doppler correction, Doppler correction with respect to the barycentres of the segments, and after full tracking.

In fig. 2, all three spectra contain the same events. Taking the MARS detector as one single detector, the 847.8 keV transition is a broad peak with 14.8 keV resolution (FWHM). This improves to 6-6.5 keV considering every segment as an individual detector. Currently, only for a small fraction of the data, *i.e.* one PHOBOS counter, the entire analysis with full pulse shape analysis and subsequent γ-ray tracking has been performed. Clearly, the resolution improves considerably to 4.5-5 keV (FWHM) comparable to the value expected from simulations.

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