MARS - A NOVEL $\gamma$-RAY DETECTOR ARRAY

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The status of the MARS project to build a $\gamma$-ray tracking array is presented. It comprises the development of tracking algorithms, the simulation of $4\pi$ arrays and the calculation and analysis of pulse shapes from highly segmented detectors.

1 Introduction

MARS - Mini ARray of Segmented detectors - is the Italian effort to explore the feasibility of building a high performance $4\pi$ array for $\gamma$-ray spectroscopy based on $\gamma$-ray tracking.

The most advanced present arrays, EUROBALL and GAMMASPHERE, are built of Compton suppressed HPGe spectrometers arranged in tightly packed spherical configurations. Despite the fact that these arrays are already composed of more than 100 detectors, their performance is limited to an efficiency of only about 10% and a response function (P/T-ratio) with about 60% of the total intensity in the full energy peak at 1 MeV. The good P/T-ratio is achieved rejecting the signal from the detector when the surrounding BGO shield detects $\gamma$-rays Compton scattered out of the Ge crystal. However, the use of the suppression shields prevents to cover more than one half of the solid angle with Ge detectors limiting the achievable efficiency considerably to the present values. It is an established fact that an array with better performance cannot be obtained by simply increasing the number of detectors.
A possible solution of this problem may come from recent advances in crystal segmentation technology and digital signal processing which opened the possibility to operate the detectors in a position sensitive mode. This enables to build a compact array solely out of Ge detectors omitting the BGO shields. As it is expected from simulations, an array consisting of a limited number (≈ 50 - 100) of such detectors can have unprecedented features: an efficiency of up to ≈ 50% while maintaining a P/T-ratio of ≈ 70%.

The unique capability of a γ-ray tracking array allows the search for extremely weak reaction channels and experiments with weak beam intensities (e.g. radioactive beams) addressing open questions and new kinds of physics in nuclear structure, astrophysics and fundamental interactions.

2 Results

2.1 Tracking algorithms and simulation of 4π array performances

The task of a γ-ray tracking algorithm is to identify 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 of a γ-ray. In order to value the different sequences, we defined a “figure of merit” which is derived from the angle-energy-correlation for Compton scattering; the cross sections for photoelectric effect, Compton scattering, and pair production; and the feature for pair production with two 511 keV γ-rays emitted back-to-back. If the value for a certain sequence of interaction points is below a threshold, it is accepted as a reconstructed γ-ray.

We tested our tracking algorithm for both an ideal 4π Ge shell and realistic configurations consisting of real detectors (Fig. 1). The performances are
Table 1. Photopoint efficiencies and P/T-ratios (in %) for different $4\pi$ configurations after tracking simulated for 1 or 25 incident $\gamma$-rays, respectively, at an energy of 1332 keV. For comparison the values for the non-tracking array EUROBALL are given.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$\epsilon_{\text{Photo}}$ ($M_2 = 1$)</th>
<th>$\epsilon_{\text{Photo}}$ ($M_2 = 25$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ideal Ge shell</td>
<td>53 [87]</td>
<td>32 [70]</td>
</tr>
<tr>
<td>Ball (120 detectors)</td>
<td>26 [68]</td>
<td>15 [45]</td>
</tr>
<tr>
<td>Barrel (54 cyl. detectors)</td>
<td>25 [68]</td>
<td>15 [45]</td>
</tr>
<tr>
<td>Barrel (54 hex. detectors)</td>
<td>25 [71]</td>
<td>15 [47]</td>
</tr>
<tr>
<td>Barrel (36 cyl. detectors)</td>
<td>19 [69]</td>
<td>12 [45]</td>
</tr>
<tr>
<td>Barrel (36 hex. detectors)</td>
<td>20 [67]</td>
<td>12 [48]</td>
</tr>
<tr>
<td>EUROBALL</td>
<td>$\approx$ 9 [56]</td>
<td>$\approx$ 6 [47]</td>
</tr>
</tbody>
</table>

listed in Table 1. The remarkable drop between the ideal shell and a realistic configuration is mainly due to the gaps between the real detectors. It has to be noted that even the barrel with only 36 detectors performs considerably better than EUROBALL with 239 detectors.

2.2 MARS prototype detector

For the MARS project we ordered a cylindrical 25-fold segmented detector with 6 angular sectors, 4 transversal slices and a segment on the front face (see Fig. 2). This prototype has been delivered recently and is under test. The energy resolution was specified to be 2.3 keV FWHM at 1332 keV for the segments which is fulfilled for all segments except those in the front slice.

2.3 Position determination using pulse shape analysis

Necessary input for the tracking algorithm are, for each point of interaction, the three-dimensional position and the energy deposit. This information is obtained from the analysis of the shapes of the signals from the segments.

In Fig. 2, the dependence of the signals on the position of the interaction is demonstrated. The shown signals are calculated applying computer programs we developed $^2$. 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. Their amplitudes increase with decreasing distance between the interaction point and the border to the neighbouring segment.

In order to test the algorithms for pulse shape analysis, we treated a simplified problem considering one or two interactions randomly distributed within only one segment. The resulting composite signals from the segments are then analysed to extract the number, position, and energy of the original
point(s). A program using a genetic algorithm (GA) is able to determine the number of interactions correctly for 89% of the events. The average variance between reconstructed and true position is about 2 mm. The average variance of the energies is 0.04 (the sum of the energies is normalised to 1). The approaches applying artificial neural networks (ANN) yield for this set of data the correct number of interactions for up to 94% of the events and variances of about 5.5 mm and 0.08 for the distance and the energy respectively.

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References