RESPONSE OF THE COMPOSITE CLUSTER HPGe DETECTORS OF THE EUROBALL ARRAY TO HIGH ENERGY γ-RAYS*

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The performances of the composite Cluster detectors of the EUROBALL array have been investigated with γ-rays of 15.1 MeV produced in the reaction $^{11}\mathrm{B} + \mathrm{D} \rightarrow^{12} \mathrm{C} + \gamma + n$ at 19.1 MeV. The Cluster detector is made of 7 encapsulated germanium crystals mounted in a single cryostat. The pulse height to energy conversion of the individual crystals is found to be very linear. The coincidence fold distribution is given for various energies and compared to simulation calculations of the Cluster response. A simple add-back procedure improves consistently the full energy peak efficiency. The efficiency of the composite detector is compared to that of large volume BaF_2 scintillator.

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1. Introduction

High energy γ-ray spectroscopy brings important information both for nuclear structure and reaction mechanism studies. Although most of the works are based on measurement of γ-rays at $E_\gamma \leq 2$ MeV, a lot can be also learned by studying γ-rays in the 5–20 MeV interval. In this case dedicated instruments with high efficiency are needed. Until few years ago, the standard germanium detectors had commonly about 30% relative efficiency at 1.332 keV and an order of magnitude less at 10 MeV [1]. This is why high energy γ-ray array have been made with inorganic scintillator detectors like NaI(Tl), BGO or BaF_2 which can be built in large volume giving a high efficiency at high γ-ray energy. In particular, the BaF_2 scintillator time response gives the possibility to reject neutrons by time of flight technique if necessary. The drawback of these scintillator detectors is that the energy resolution cannot be better than 5–6% at 15 MeV. On the other hand, in the last years large germanium crystals have been available and were largely used in detection arrays for low energy spectroscopy. More recently, a new composite detector has been developed for the EUROBALL array, namely the cluster germanium detector. It is characterized by a very good energy resolution of about 2 per mil for γ-rays of 1.332 keV. Its response function up to 10 MeV has been studied with an Al source and standard electronics. We present here the results of the response function of these detectors studied at 15 MeV when mounted in the EUROBALL array and connected to the VXI electronics. They concern mainly the linearity of the pulse-height to energy conversion, the features of single and "add-back" spectra, the resolution and the efficiency of the cluster detectors and the comparison to large volume BaF_2 detectors.

2. The cluster germanium detectors in the EUROBALL array

Each cluster detector is made of seven encapsulated germanium crystals of about 60% relative efficiency each, for a total volume of 2000 cm^3, placed in a single cryostat and surrounded by a BGO anti-compton shield. A complete description of the geometry can be found in [1] and [2]. The EUROBALL array has 15 of these composite cluster detectors in its backward hemisphere. The pre-amplifier output of each crystal is fed in a VXI electronic card which contains both energy and time channels. For the energy part, there are two ADC's corresponding one to a full range of 4 MeV and the other to 20 MeV.

3. The measurement

The reaction ^{11}B + D $\rightarrow$ ^{12}C + γ + n at $E_{\rm lab}$ = 19.1 MeV was used to populate the resonant state at 15.11 MeV in ^{12}C nucleus. The target was made of $C_{32}D_{66}$ material and was 490μg/cm^2 thick. Both the recoiling nucleus and the beam were stopped in the tantalum backing of the target. The beam intensity was kept to 1–2 nA.

The experimental setup consisted in both EUROBALL (Clovers and Clusters) at 90° and in the backward hemisphere, and the eight large volume BaF_2 detectors of the HECTOR array in the forward hemisphere. The EUROBALL clusters were used in the standard anti-coincidence mode with their corresponding BGO anti-compton shield. The EUROBALL VXI electronics and acquisition system were used. Energy spectra were measured as singles to avoid rejecting events that deposited the whole energy in one individual capsule. No time information was available as we are dealing with a reaction emitting only one γ-ray and no time reference from the accelerator was used.

Energy spectra measured with the germanium clusters are shown in figure 1. Figure 1(a) shows the full spectra in a logarithmic scale. The inset shows the region around 15.11 MeV on a linear scale. The "single" spectrum was obtained by summing the 105 individual energy spectra from all individual capsules while the "add-back" spectrum results from the sum of the 15 cluster detectors spectra. The cluster spectra are obtained through the "add-back" procedure: as the reaction emits only one γ-ray, there is not a sizable chance of detecting two different γ-rays in the cluster and the signals from the seven capsules were simply added.

Figure 1(b) shows the spectrum measured in a single capsule for events that deposited the full 15 MeV in one cluster, when 1 (fold = 1) or more (fold $\geq$ 2) capsules were hit. Most of the γ-ray energy is deposited in one capsule, which corresponds to the first hit capsule as can be verified with simulation calculations. The remaining 1 MeV is essentially deposited in one or two other capsules (see figure 2). From this spectrum it is clear that to get the best energy resolution in the add-back technique it is very important to have a good energy calibration both at high and at low γ-ray energy. This was done for each crystal detector by using several radioactive sources (^{152}Eu, ^{137}Cs, ^{133}Ba, ^{60}Co, ^{88}Y and ^{56}Co) emitting known γ-ray lines ranging from 122 keV to 3.56 MeV.

Due to the high velocity ($\beta = v/c \approx 5\%$), the Doppler correction was applied with two different procedures for the single data and the add-back data. In the first case, each capsule polar angle was considered. In the second case, the first hit capsule could be identified with that having the highest deposited energy in the cluster and consequently the corresponding polar angle was used for the cluster spectrum Doppler correction.

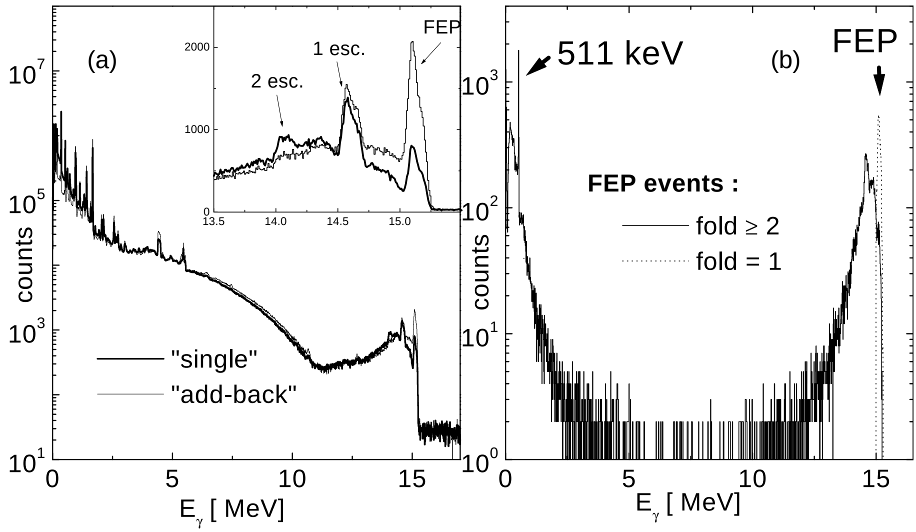

Fig. 1. (a) Energy spectrum measured with the single capsule ("single", thick line) and with the add-back technique ("add-back", thin line). Inset: Blow up of the 15 MeV region in a linear scale, (b) Energy spectrum measured in individual capsules for the class of events that deposited the full 15 MeV in one cluster.

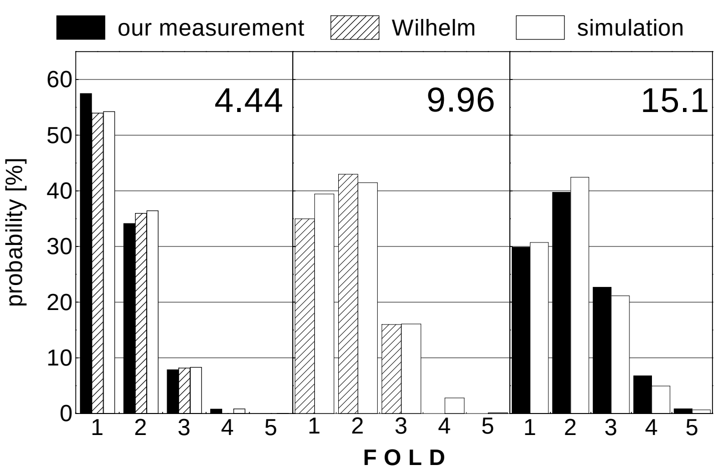

Fig. 2. Coincidence fold distribution within the cluster detector at three γ-ray energies. Our measurements (black column) are compared to that of reference [1] (hatched columns) and to GEANT simulations (empty columns).

The energy gain was found to be stable with time to about 0.5 per mil on average. A good linearity was found for the cluster detectors. In particular the measured energy was underestimated by about 0.2% (40 keV) for the 15

MeV line when the calibration with the radioactive sources was used. This results is clearly specific to the cluster used in the EUROBALL standard setup.

The hit distribution is shown in figure 2 as a function of the γ-ray energy. The three cases considered here correspond to one step decays to the ground state of the measured nuclei (4.44 MeV and 15.11 MeV from the ^{12}C and 9.96 MeV from the ^{24}Al [1]). Our result for the 4.44 MeV line is comparable to that of [1]. Simulation calculations based on the GEANT libraries [3] including the cluster geometry have been made and the results show an overall agreement for the three different energies.

4. Energy spectra and efficiency

Figure 1(a) shows the cluster energy spectrum in the 15 MeV region. The ratio of the area of the Full Energy Peak (FEP) to that of the first escape peak (1 esc.) increases by a factor of $\approx$ 3 when applying the add-back procedure.

The energy resolution of the stopped 4.44 MeV line is found to be about 10 keV. In the case of the 15.11 MeV line the width of 70 keV measured at 157° includes 37 keV of Doppler broadening, contribution from the X-ray pile-up due to scattering on the collimators and the calibration uncertainties discussed earlier.

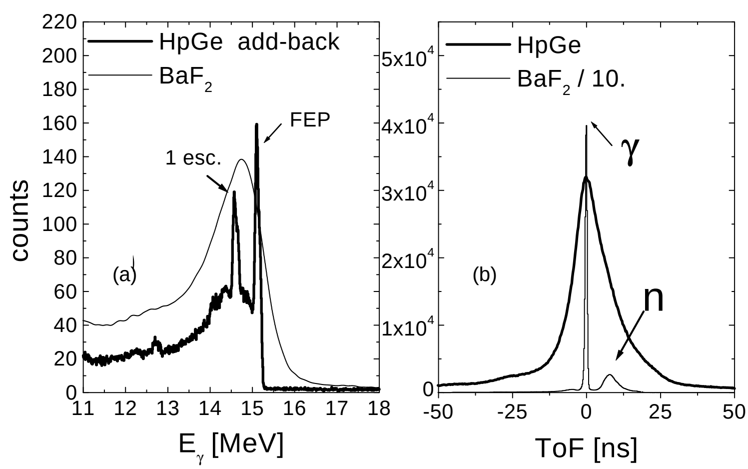

Fig. 3. Comparison of the energy spectra (a) and of the time spectra (b) measured in the same experiment with one cluster detector ("add-back", thick line) and with a large volume BaF_2 scintillator (thin line).

Finally the data measured in one cluster are compared with those measured simultaneously with one of the HECTOR large volume BaF_2 detectors, see figure 3. Clearly the germanium cluster detector gives a much better energy resolution. On the other hand, the corresponding time resolution is much worse than in the scintillator case (as no time information was available for the ^{11}B reaction, the spectrum measured with the reaction ^{37}Cl + ^{110}Pd is shown). This last point will make it more difficult to reject neutrons by time of flight technique. Consequently the use of cluster detectors in nuclear reactions like fusion where many neutrons are produced requires a very careful treatment of the neutron rejection.

Considering the geometry of the present setup in which the cluster detectors with about 130 mm in diameter and 78 mm length were positioned at 440 mm from the target and the BaF_2 with 145 mm in diameter and 175 mm length were positioned at 300 mm from the target, the full energy peak efficiency for one cluster is approximately 40% of that of a BaF_2 scintillator after subtraction of the background and the escape peaks. This number can become smaller if a longer flight distance is needed to make a good neutron rejection by time of flight technique.

5. Conclusion

The response of the germanium cluster detectors to 15.1 MeVγ-rays has been studied using the reaction D(^{11}B,$n\gamma$)^{12}C at $E_{\rm beam} = 19.1$ MeV and the EUROBALL setup. The conversion between pulse height to γ-ray energy has been found to be very linear. As a consequence energy calibration based on standard radioactive sources can be used and shows deviations lower than 40 keV at 15 MeV. The add-back procedure used on an event by event basis improves the photo-peak efficiency by a factor of about 3. The detection efficiency of a cluster is found to be about 40% of one BaF_2 scintillator of the HECTOR array.

Altogether one can say that experiments requiring the detection of γ-rays in the 10–20 MeV interval with good energy resolution, can benefit from the use of the cluster detectors although some caution has in general to be taken if one needs to reject neutrons by time of flight.

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