DETECTING HIGH ENERGY γ–RAYS WITH HPGe DETECTORS*

F. CAMERA, A. BRACCO, P. BOSETTI, M. MATTIUZZI

G. LO BIANCO AND M. PIGNANELLI

Universitá di Milano, Dipartimento di Fisica
and
INFN sez. Milano
via Celoria, 16 20133 Milano, Italy

J.J. GAARDHØJE, Z. ŻELAZNY AND I.G. BEARDEN

The Niels Bohr Institute, Blegdamsvej 15-17, 2100 Copenhagen, Denmark

AND A. MAJ

H. Niewodniczański Institute of Nuclear Physics
Radzikowskiego 152, 31-342 Kraków, Poland
and
The Niels Bohr Institute, Blegdamsvej 15-17, 2100, Copenhagen, Denmark

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The "Adding Mode" technique has been applied to measure the response of a HPGe (82%) detector with a BGO anti-Compton shield for the 15.1 MeV γ-rays produced by the reaction $D(^{11}B,n\gamma)^{12}C$. The measured energy resolution for the 15.1 MeV γ-rays emitted by ^{12}C is 209 keV and the efficiency relative to a measurement in a "Suppressed Mode" increased of an order of magnitude. Due to the recoil velocity ($\beta \simeq 0.05$) of $^{12}C^*$, the Doppler broadening contribution to the measured FWHM is 140 keV. The experimental results has been compared to simulated spectra calculated with the GEANT libraries. The effects that a segmentation of an HPGe crystal would have on energy resolution is also discussed.

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1. Introduction

The possible use of HPGe detectors with BGO anti-Compton shield to measure high energy γ rays ($10< E_\gamma < 20$ MeV) has became recently particularly attractive since arrays of such detectors are now in operation and even larger arrays are under construction [1, 2, 3]

The only existing measurement of high energy γ-rays with a composite detector consisting of a BGO plus a HPGe with efficiency $\varepsilon \simeq 30\%$ was made in connection to a Giant Dipole Resonance study in hot nuclei [4]. In this measurement the energy deposited in the HPGe and in the BGO were summed together to enhance the full energy peak efficiency. In addition, the performance of a composite detector consisting of a 20% efficient HPGe detector surrounded by 6 BaF_2 crystals has been recently studied [5].

These measurements show that unprecedented good energy resolutions and efficiency are obtained applying the "Adding Mode" technique, namely summing together the energy deposited in the HPGe and in the BGO crystals. Consequently, it is important to study and understand in detail the response of composite detectors built with the largest HPGe crystals now commonly available (80–90%).

In this paper the results of a test-experiment that we have performed to measure the response function of a HPGe detector with its anti-Compton shield to 15.1 MeV gamma rays are reported [6]. Monte-Carlo calculations has also been performed to reproduce the experimental data and to study how a segmentation of the HPGe Crystal would affect the energy resolution of the suppressed and summed spectra.

2. The measurement

In the test-experiment we have used a 82% efficient HPGe cylindrical crystal with the first 1.5 cm tapered by an angle of 10 degrees. The anti-Compton shield had the same geometry as the GA.SP array [2]. The front face of the BGO crystal was shielded with a 5 cm thick lead collimator to prevent the direct detection in the BGO of γ-rays from the source or from the target. The central hole of the lead collimator had a diameter of 4.5 cm. The HPGe detector was at a distance of about 27 cm from the target centre and at an angle of 110 degrees relative to the beam direction.

The 15.1 MeV γ-rays were emitted by $^{12}C^*$ produced in the reaction $D(^{11}B,n\gamma)^{12}C$ at the Tandem Accelerator Laboratory of the Niels Bohr Institute in Denmark. The deuteron target had an aluminium backing of sufficient thickness to stop both the 19 MeV Boron beam and the recoiling particles. Due to the inverse kinematics of the reaction used, the fused carbon compound had a high initial velocity ($\beta \simeq 0.05$).

The energy resolution for the 1.332 MeV ^{60}Co line was measured to be 2.5 keV. The BGO anti-Compton shield consists of 8 scintillators, each equipped with a PM. The gain matching of each BGO scintillator was obtained acting on the focus grid of the tube and the overall measured energy resolution at the 661 keV line of ^{137}Cs was approximately 20%. The energy signals of the BGO and HPGe were the inputs of two NIM ADC Silena and the digitalized pulse heights were written on an exabyte tape.

In the left panel of Fig. 1 the measured spectrum obtained with the "Adding Mode" technique is displayed. The 15.1 MeV peak (shifted to 14.84 MeV because of the Doppler-shift) is clearly visible, as indicated by the arrow. From the spectra it is evident that the response function in the summed spectrum is very well concentrated in the full energy peak (FWHM=209 keV). The escape peaks and the Compton shoulder which dominate the "single" spectrum are no more clearly visible.

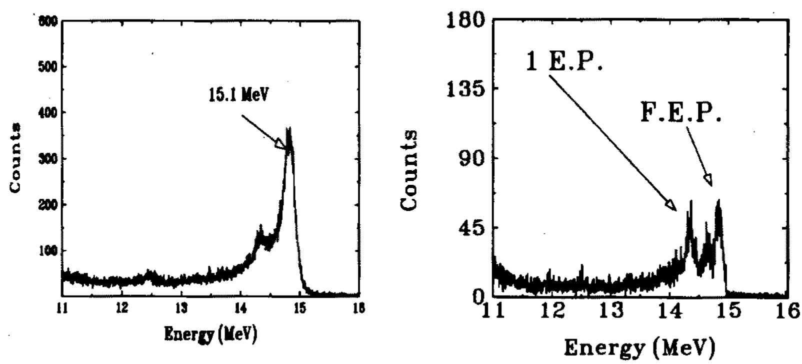

Fig. 1. In the left panel the measured γ-ray spectrum obtained in "Adding Mode" is shown. The 15.1 MeV peak is visible. The FWHM of the 15.1 MeV peak is 209 keV. In the right panel the "Compton Suppressed" spectrum is displayed. F.E.P. and 1 E.P. denote the full energy and the first escape peak, respectively.

In the right panel of Fig. 1 the energy spectra measured with the HPGe in anticoincidence with the BGO is also shown. The measured width of the full energy peak measured in anticoincidence with the BGO was found to be 140 keV. Such a value is totally induced by the Doppler broadening Γ_{DB} due to the finite opening angle of the HPGe crystal.

In an "ideal" experiment in which the recoil velocity is zero or for measurements at 0 or 180 degrees the intrinsic energy resolution (Γ_{HPGe}) of the composite HPGe+BGO detector can be estimated to be $\Gamma_{HPGe} \simeq 150$ keV. A second point which is interesting to notice is that the number of the full energy peak events in the suppressed spectrum is 10 time smaller than the one measured in the summed spectra, showing that the "Adding Mode" technique increases the full energy peak efficiency of an order of magnitude.

The reason for the small measured FWHM in the summed spectra can be understood with the help of Fig. 2 where the measured spectra of the energy deposited in the HPGe and BGO detectors, in the case of full energy peak events, are shown. One can see that less than the 15% of total gamma energy is deposited in the BGO while the majority of the energy is lost in the HPGe crystal.

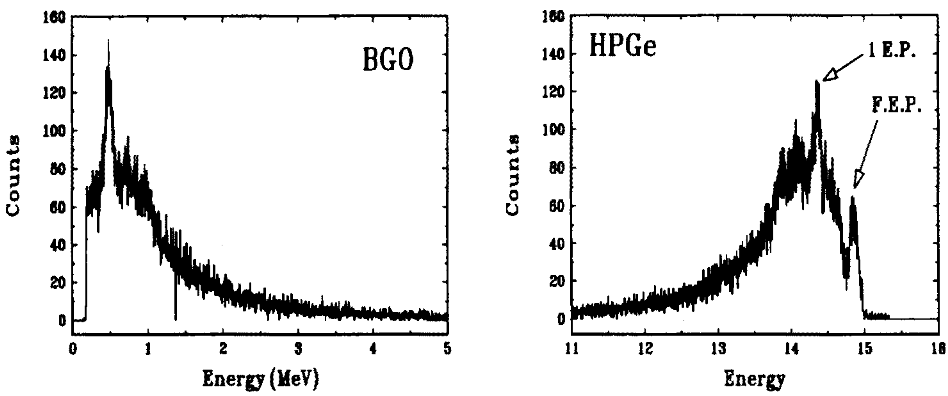

Fig. 2. Energy spectra measured with the BGO detector (left panel) and with the HPGe detector (right panel) when the entire energy of the 15.1 MeV γ-ray is collected in the combined HPGe+BGO detector.

3. Monte-Carlo simulations

The experimental conditions of the present measurement were simulated with a Monte-Carlo code using the GEANT libraries from CERN [7] The simulated system is a Germanium crystal 75 mm long and with a diameter of 70 mm. The first 16 mm of the crystal had a conical geometry. The Ge has, along its axis, a hole with a diameter of 11 mm and a length of 62 mm. The simulated BGO shield was divided into 5 different conical volumes to describe the geometry of the used shield. To account for the non sensitive materials which surround the detectors the simulations were made for a HPGe crystal in an Aluminium housing 2 mm thick with, behind, a coaxial copper cylinder 20 mm in diameter and 80 mm long.

The qualitative and quantitative agreement between simulations and measurements is good as Figs 3 and 4 show. The ratio between the full energy peak areas of the suppressed and of the summed spectrum was calculated to be 11.3 ± 1.1 in agreement with the measured value of 10.3 ± 1.1.

Recently, "Segmented" HPGe detector prototypes were developed. Such detectors have the external collecting electrode divided into two symmetric

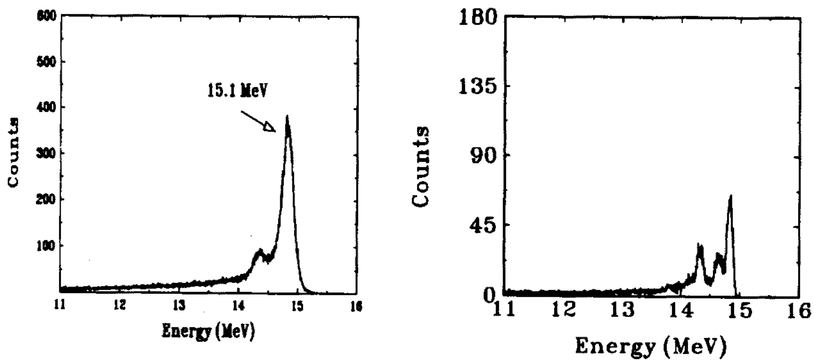

Fig. 3. Calculated response of the HPGe+BGO detector for 15.1 MeV γ-rays. In the left plot the calculated energy spectrum obtained summing event by event the energy deposited in both the HPGe and in the BGO is shown while in the right plot the spectra of the events in anticoincidence with the BGO are displayed. The Doppler shift of the used reaction has been taken into account.

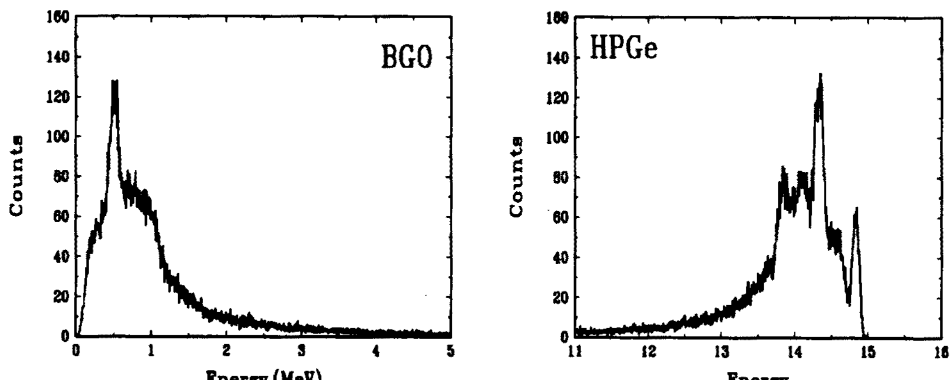

Fig. 4. Calculated energy spectra for the BGO detector (left panel) and the HPGe detector (Right panel) when the entire energy of the 15.1 MeV γ rays is deposited in the HPGe+BGO detector.

sections. Such a geometry allows to strongly reduce the Doppler broadening induced by the opening angle of the HPGe crystal by recognizing in which part the gamma ray interacts first. The basic idea is to Doppler-correct the energy of the events which triggers the two sections of the crystal by θ_0 (the angle between the detector and the beam direction) and by $\theta_0 \pm 0.25\Delta\theta$ if only one section was triggered. In the formula $\pm\Delta\theta$ represents the angle subtended by the germanium and the positive-negative signum represents the right-left section of the crystal.

Fig. 5 shows, for θ_0 = 110 degrees and β =0.05, the calculated full energy peak FWHM for different γ-energy when this technique is applied to suppressed or summed spectra.

Fig. 5 clearly shows that, in the simulated case, the FWHM of the full energy peak is sensitively reduced by Doppler-correcting the events.

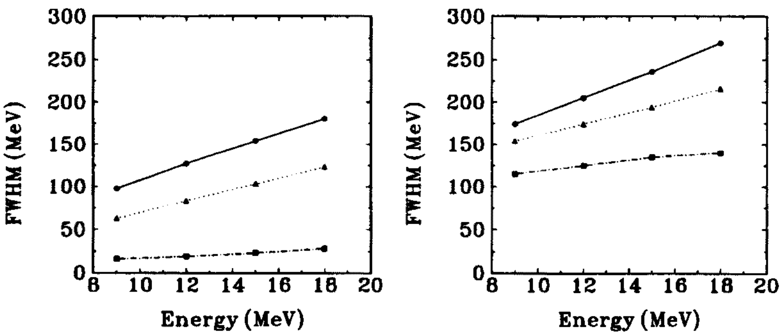

Fig. 5. The calculated behaviour of the FWHM as a function of γ energy calculated in "Compton Suppressed Mode" (left panel) and "Adding Mode" (right panel). The solid lines show the width of the Full Energy Peak, calculated for the case discussed in the text, not using the Doppler correction algorithm. The dotted lines show the FWHM after the application of the Doppler correction algorithm while the dot-dashed lines are the results in the case when no Doppler-broadening is present.

4. Conclusion

The response of a composite detector HPGe ($\varepsilon \simeq 80\%$) plus a BGO shield to high energy γ-rays was studied. The main result is a very good energy resolution of this composite detector. Monte–Carlo simulations, performed using GEANT libraries, reproduce nicely quantitatively and qualitatively the measured spectra.

Monte-Carlo simulations on the behaviour of a "Segmented" detector show that it is possible, using a simple algorithm, to sensibly reduce the Doppler-broadening of the full energy peak. More sophisticated algorithms might provide even better results.

Unfortunately, in spite of the advantage of the very good energy resolution and full energy peak efficiency, the time resolution of the HPGe+BGO systems is much worse than that of scintillator detectors. Consequently, for in-beam measurements in which neutron discrimination by time of flight is required, these HPGe+BGO detectors should be used far away from the target, thus limiting the solid angle.

REFERENCES

[1] R. Lieder, Contribution to this conference.
[2] C. Rossi Alvarez, Contribution to this conference, INFN Internal Report, BE-90/11 28 November 1990; D.Bazzacco *et al.*, Proceedings of the International Conference on Nuclear Structure at High Angular Momentum, Ottawa, May 1992 AECL 10613.
[3] F. Stephens, Contribution to this conference.
[4] A. Bruce, J.J. Gaardhøje, B. Herskind, R. Chapman, J.C. Lisle, F. Khazaie, P.J. Twin, J.N. Mo *Phys. Lett.* **B215**, 237 (1988).
[5] A. Krasznahorkay, J. Bacelar, A. Bałanda, A. Buda, *Nucl. Instrum. Methods Phys. Res.* **A316**, 306 (1992).
[6] F. Camera, A. Bracco, M. Mattiuzzi, G. Lo Bianco, M. Pignanelli, J.J. Gaardhøje, I.G. Bearden, Z. Żelazny, A. Maj, *Nucl. Instrum. Methods Phys. Res.* in print.
[7] Geant Reference manual CERN/DD/ee/84-1 1986.