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COMPTON SUPPRESSION TESTS ON Ge AND BGO PROTOTYPE DETECTORS FOR GAMMASPHERE

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During the last decade the application of arrays of 10–30 Compton Suppressed germanium (CSG) detectors in the field of γ-ray spectroscopy has led to a number of significant advances in studies of nuclear structure. Despite the success of these instruments, most of them are limited to detecting two-fold (and in a few cases three-fold) coincidences from high-multiplicity cascades. To increase the detection sensitivity for weak cascades, proposals have recently emerged for construction of much larger arrays. In the U.S.A., the proposed array, called GAMMASPHERE [1], is to have 110 large CSG detectors which will subtend a solid angle of almost 2π steradians, sufficient to permit routine acquisition of up to 5-fold coincidences from high-multiplicity cascades. This together with other improvements, will yield a resolving power [1] several orders of magnitude greater than currents arrays. In Europe, an array of similar size and power, called EUROGAM [2], is currently being constructed. In this paper, we report on measurements of the Compton suppression and overall P/T ratio of two Ge detectors in a BGO shield of the honeycomb pattern illustrated in fig. 1. These were the first prototype CSG detector assemblies for GAMMASPHERE. A more detailed description of these results can be found in ref. 3.

INDIVIDUAL BGO AND GE DETECTOR PERFORMANCE

The BGO shield was manufactured by Solon Technologies and represents the original honeycomb design. As can be inferred from fig. 1, this shield consists of six BGO elements which surround a Ge detector (in the honeycomb implementation, close-neighbor Ge detectors share a common BGO detector). There is also a backplug of BGO behind each Ge detector to suppress forward-scattered photons. This backplug is cylindrical except for a slot to accommodate an off-axis tube containing the cold finger and electrical cable connecting the Ge crystal to its remote liquid nitrogen dewar and preamplifier.

For efficient suppression of events in which a photon undergoes multiple scattering, it is desirable that the BGO discriminator threshold be set as low as possible. The low-energy response of the shield was measured using 59.5 keV γ rays from a ^{241}Am source. Peak/noise ratios of 20/1 – 36/1 were measured for the different BGO sectors, where lower energy γ rays and L-x rays from ^{237}Np were absorbed by a 0.25 mm copper disc and the aluminum cladding of the BGO. This excellent low energy response allowed us to easily place the discriminator

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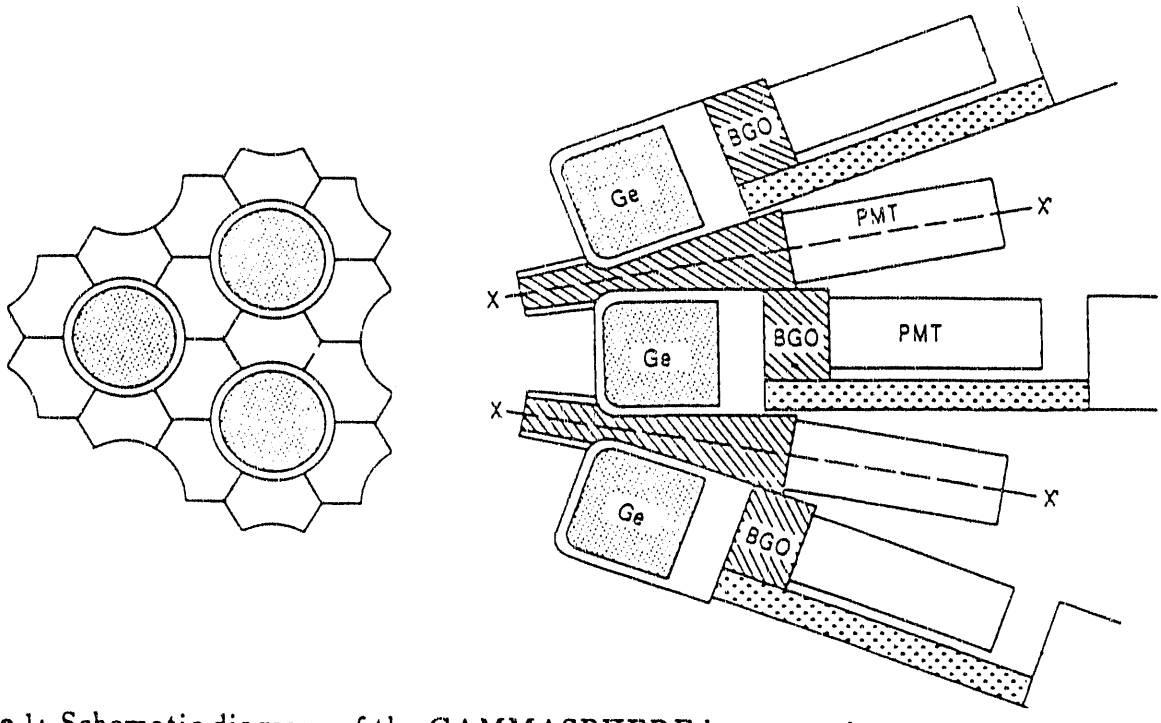

Figure 1: Schematic diagram of the GAMMASPHERE honeycomb arrangement of Ge detectors and their BGO Compton-suppression shields. One diagram shows a section through one Ge crystal, its neighbors on opposite sides and their shared BGO shields. The other shows a view, from the center of the array, of three neighboring Ge detectors and their shields.

thresholds at 10 keV for the suppression tests. The energy resolution of the individual BGO detectors at 662 keV (^{137}Cs) was typically 18%, while the time resolution (with a leading edge discriminator set near the single-electron noise) averaged 2.5 ns FWHM for full-energy ^{60}Co γ-ray interactions.

Suppression tests were carried with on two high-purity n-type Ge detectors which have very similar characteristics, e.g. they have full-energy peak efficiencies at 1.33 MeV of 75% and 76% for detector I and II, respectively. These detectors had time resolutions of $\sim$ 8.5 ns FWHM using a ^{60}Co source and an energy resolution of 2.23 and 2.25 keV at 1.33 keV using an amplifier shaping time of 6 μsec.

COMPTON-SUPPRESSION TESTS

The Compton-suppression measurements were performed by recording, for each event, the pulse height from the Ge detector and a logic bit which indicated whether or not there was a coincidence, within a time window of approximately 400 ns, between the Ge detector and the BGO shield. It was therefore possible to acquire suppressed and unsuppressed spectra simultaneously. The radioactive sources were suspended from a string well away ($\geq$ 1 m) from walls, the floor or other substantial matter in order to minimize the background caused by scattered photons from such material. The source was on the Ge detector axis at 25.9 cm (the original design distance for GAMMASPHERE) from the front face of the detector.

The effectiveness of the BGO Compton-suppression shield in suppressing the Compton background is demonstrated in fig. 2. In the bottom panel, the spectrum from a ^{60}Co source

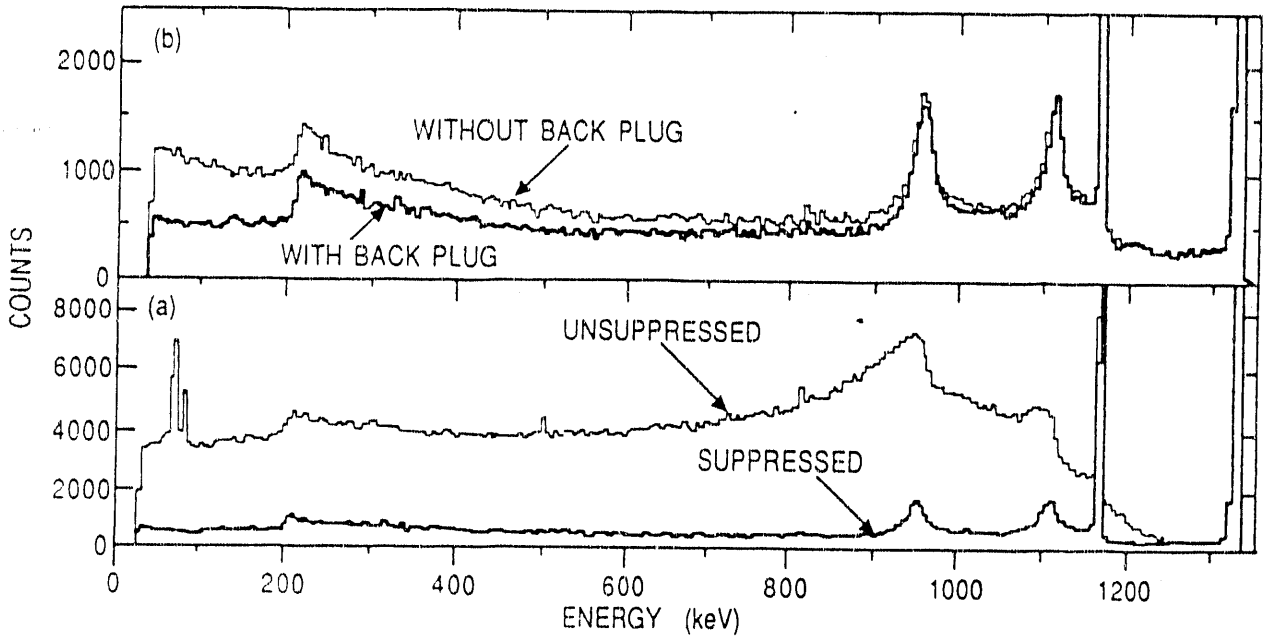

Figure 2: Plots showing the effect of Compton suppression on Ge detector spectra of a ^{60}Co source. (a) Suppressed and unsuppressed versions of the same spectrum are compared. (b) Properly normalized suppressed spectra are shown, with and without the backplug contributing to the suppression.

is shown with and without suppression. The performance of the shield is usually summarized in terms of a single parameter, the peak-to-total (P/T) ratio, which is defined here as the ratio of the area of the full-energy peaks to the total number of counts in the spectrum at energies greater than 100 keV. For the unsuppressed spectrum shown in fig. 2a, a P/T of 0.246 was measured while the suppressed spectrum (active backplug) gives P/T of 0.678.

Without the backplug, the P/T ratio is reduced to 0.622. The 10% difference that the backplug makes to the P/T is significant; it would improve the resolving power when detecting triple and quadrupole coincidences by about 30% and 40%, respectively. For comparison, fig. 2b shows two suppressed spectra of ^{60}Co, one with the backplug contributing and the other with the backplug in place but electronically disconnected. Clearly, the backplug contributes significantly to the suppression, not only in the low energy portion of the spectrum, as one would expect from a single scattering, but also up to the highest energies, indicating that multiple scattering in the Ge crystal is significant.

MONTE CARLO SIMULATIONS

Ge detector spectra, calculated using Monte Carlo simulations based on the GEANT library [4], were used to develop and optimize the GAMMASPHERE design. To simplify the calculations, the experimental geometry under which measurements were made was not reproduced in complete detail. The most important idealization used was to consider the radiation source to be a massless, monochromatic (or dichromatic for ^{60}Co) source which emitted γ rays only into the part of space occupied by the suppression shield and the Ge detector. Thus, the effect of γ rays scattered off materials other than the suppressor was not

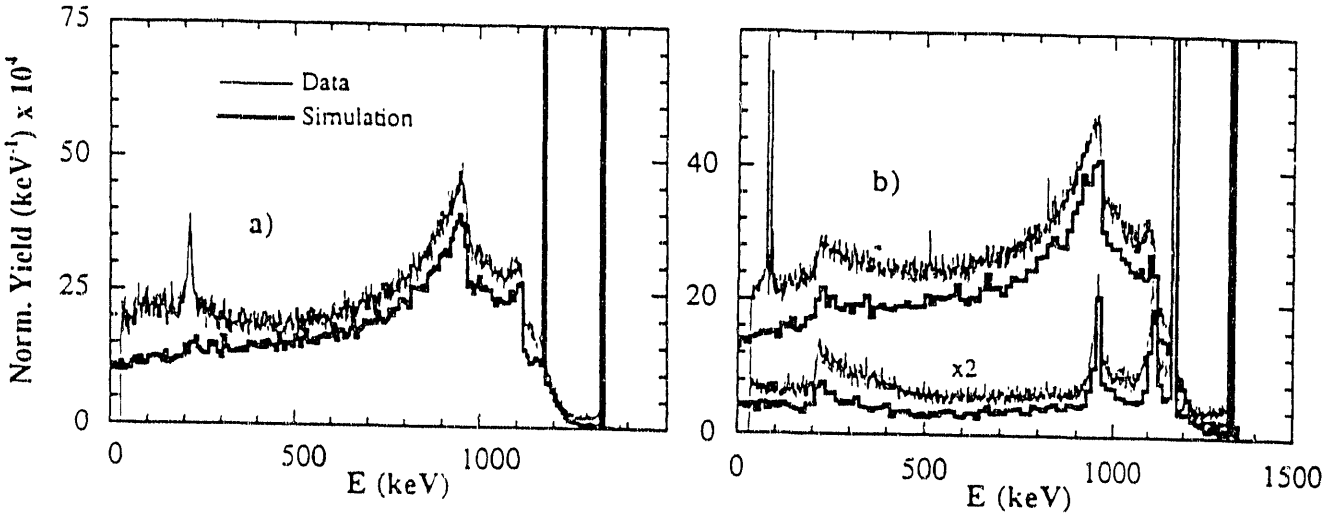

Figure 3: (a) Comparison of calculated and measured spectra of a bare Ge detector which is located away from scattering material to the maximum extent possible. (b) Comparison of calculated and measured unsuppressed and suppressed spectra. Suppressed spectra are multiplied by a factor of 2.

taken into account.

Simulated ^{60}Co spectra for the bare Ge detector and for the Ge detector in its shield are compared with experiment in fig. 3. Though qualitative similarities are obvious, there are large disagreements between the simulations and experiments. An immediate concern is whether the poorer results obtained experimentally reflect some problem with the implementation of the design or result primarily from idealizations in the simulations. To access these two possible explanations, it is instructive to compare the simulations to specific aspects of the data which should not be affected by a continuum arising from scattering. One such feature is the two peaks near the Compton edges for the ^{60}Co lines. The size, width and mean position of these peaks depends strongly on the design and performance of the "backscatter lip" region of the suppressor which extends out beyond the front face of the Ge detector. We find excellent absolute agreement between the simulated and experimental Compton-edge peaks. In fact, we can conclude that the experimental trigger efficiency in this lip region for $\sim$220 keV γ rays is 94$\pm$7% of that of the idealized simulations. This is important since there was concern about light collection from the lip region due to the complex light path. Other aspects which can be isolated for comparison are: (i) the performance of the backplug behind the Ge, and (ii) the percentage of γ rays which are transparent to the BGO shield. In both cases, excellent absolute agreement is obtained when the experimental data are compared to the simulations.

The quantitative agreement on these three aspects gives us confidence that there are no serious problems with the performance of the prototype suppressor resulting from the combination of the comparatively low light output of BGO and the complex geometry of the suppression shield. It also shows that simulations, based on widely used codes like the

GEANT package are sufficiently accurate to guide the design of Compton suppressor arrays.

It is also important to understand the origin of the discrepancies between the simulated and observed spectra. Since the calculations appear to simulate the performance of the suppressor, the differences between the simulated and measured spectra must result from an incorrect description of the spectrum of radiation incident on the detector system in the simulations. Further investigations of scattering makes it clear that the bulk of the scattering contribution to the continuum background would have to originate from material very near the source or the Ge detector. For example, the ^{60}Co source used in the measurements was encapsulated in a 24 mm $\times$ 10 mm $\times$ 2 mm plastic container. Simulations predict that scattering from this material produces a continuum amounting to 13% of the photopeak yield. This accounts for 40% (13 of 33%) of the scattered background, without a detailed treatment of the experimental environment.

We conclude that Monte Carlo simulations can accurately describe the performance of these prototype Compton-suppressed spectrometers. However, to obtain agreement with the measured spectra, it is necessary to include a background contribution from scattering materials near the source and detector. This emphasizes that the design of experimental apparatus (target chambers, ladders, frames etc.) requires great care to fully realize the high P/T values possible with Compton-suppressed arrays such as GAMMASPHERE.

CONCLUSIONS

Compton suppression tests have been carried out on two large n-type Ge detectors and a BGO shield which are prototypes for GAMMASPHERE. With a ^{60}Co radiation source, a peak-to-total ratio of 0.678 is obtained for a 75% Ge detector when operated with the shield. It is also found that a cylindrical BGO backplug behind the Ge crystal makes an important contribution to the effectiveness of the shield. The performance of the Ge detector and its shield can be well reproduced in Monte Carlo simulations if account is taken of γ rays which scatter from material near the source and Ge detector. The peak-to-total ratio, energy resolution and timing characteristics of these prototypes confirm that GAMMASPHERE will be capable of dramatic improvements in resolving power over that of the current generation arrays.

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