**Proceedings of the Eleventh EGS4 Users' Meeting in Japan, KEK Proceedings 2003-15, p.37-44**

# THE RESPONSE OF THE HIGH-RESOLUTION HIGH-ENERGY PHOTON SPECTROMETER II

**K. Osaka[a], H. Utsunomiya[a], H. Akimune[a], T. Osaki[b], M. Igashira[b], K. Furutaka[c], and H. Harada[c]**

[a]*Department of Physics, Konan University*

*8-9-1 Okamoto, Higashinada, Kobe 658-8501, Japan*

[b]*Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology,*

*O-Okayama, Meguro-ku, Tokyo 152-8550, Japan*

[c]*Tokai Works, Japan Nuclear Cycle Development Institute,*

*Tokai-mura, Naka-gun, Ibaraki 319-1194, Japan*

**Abstract**

We report the response of the high-resolution high-energy photon spectrometer to 10.7 MeV γ rays produced in the $^{27}$Al(p,γ)$^{28}$Si reaction with and without the Compton suppression mode. A tail of the full-energy peak and an enhancement of the low-energy component were investigated in detail with a $^{137}$Cs standard source. EGS4 simulations of these phenomena were made assuming imperfect charge collection due to the effect of trapping/detrapping charge carriers by defects or trapping centers of a coaxial HPGe detector. A preliminary result is presented.

## 1. Introduction

The High-resolution High-energy photon Spectrometer (HHS) was manufactured for the purpose of high-energy γ-ray spectroscopy associated with transmutation of nuclear waste. The HHS consists of a large-volume twin HPGe detector surrounded by segmented BGO detectors that play a role of Compton suppression (Fig. 1). Previously, peak efficiencies and response functions of the twin Ge detector were fully reported along with a preliminary result of the response of the HHS to 10.7 MeV γ rays produced in the $^{27}$Al(p,γ)$^{28}$Si reaction.[1] Tailing phenomena appeared in the full-energy peak were also pointed out.

In this report, the response of the HHS to the 10.7 MeV γ rays with and without the Compton suppression mode is presented with sufficient statistics. The response to the high-energy γ rays is satisfactorily reproduced by EGS4 simulations except for the "tail region" immediately below the full-energy peak and the "low-energy region" below the Compton edge. A tail of the full-energy peak and its associated phenomenon were investigated with a collimated $^{137}$Cs γ-ray source. A preliminary result of EGS4 simulations of these phenomena is presented. .

## 2. Response of the HHS to 10.7 MeV γ rays

Monochromatic 10.7 MeV γ rays were produced by irradiating an aluminum foil mounted on a stainless-steel plate by a beam of 1 MeV protons accelerated by the pelletron of the Research Laboratory for Nuclear Reactions at Tokyo Institute of Technology. The front of a 150 mm-thick lead collimator and the entrance of the HHS were positioned at 50 mm and 373 mm from the reaction point, respectively. The collimator had a 6-mm diameter hole up to 50-mm depth followed by a tapered hole whose diameter is 12 mm at the back of the collimator. The high-energy γ rays passed through the collimator and impinged on the twin Ge detector of the HHS. Pulse-height distributions of 10.7 MeV γ rays measured with anti-Compton gates off and on are shown by the upper and lower panels of Fig. 2, respectively. Data were also taken at an off-resonance energy of the proton beam. These (dashed lines in Fig. 2) served as background to the measured energy distributions.

EGS4 simulations were performed for the response functions of the HHS. The BGO layout was defined to be axial-symmetric in EGS4 with the section corresponding to the cooling rod (Fig. 1) being irrelevant to energy deposit. The simulation includes forward scattering of 10.7 MeV γ rays when passing through the lead collimator. Results of the simulation are shown by the thin lines in Fig. 3 after being normalized to the full-energy peaks of the data. The overall agreement between the simulations and the data is satisfactory except for the region immediately below the full-energy, single-escape, and double-escape peaks (upper panel). In addition, the low-energy part below the Compton edge is slightly underestimated by the simulation.

## 3. Tailing and Related Phenomena

### 3.1 Experimental investigation of the tailing and related phenomena

The tailing phenomenon was investigated in detail for the twin Ge detector (Fig. 1) with a $^{137}$Cs standard γ-ray source. γ rays from the $^{137}$Cs source were collimated by a 50-mm thick lead block with a hole of 6 mm diameter and impinged on the twin Ge detector in parallel to the cylindrical axis with an offset $x$ [mm] from the axis. The data with $x$ = 0, 10, 20, 30, and 40 are shown in Fig. 4. Note that the radii of the inner electrode and the Ge crystal is 5 mm and about 40 mm, respectively (Fig. 1).

### 3.2 Ordinary EGS4 simulations

The EGS4 code does not take the effect of trapping/detrapping charge carriers into account. Results of the ordinary EGS4 simulation are shown by the dashed lines in Fig. 4. One can see that there are apparent discrepancies between data and simulations not only between the full-energy peak and the Compton edge (tail region) but also below the Compton edge (low-energy region). It is remarkable that the discrepancies become more prominent in the middle part of the Ge detector at $x$ = 10, 20, and 30 than in the center at $x$ = 0 and near the end of the active volume at $x$ = 40.

### 3.3 EGS4 simulations of the tailing and related phenomena

Trapping and detrapping charge carriers produce pulses with slow rise times and reduced amplitudes.[2] If defects or trapping centers would be highly concentrated in some part of the HPGe crystal where the electric field is weaker than normal, they could have the largest effect on imperfect charge collection and thus the tailing phenomenon. The literature reported that these defective pulses are related to events that take place near the electrodes ($n^+$ - i and $p^+$ - i junctions)[3] and in the region where the electric field is locally weak[4]. The present data (Fig. 4) however indicate that the imperfect charge collection corresponds to events in the middle region of the HPGe crystal. The electric field is normally smaller in the middle part than near the electrodes when bias is fully applied to a coaxial HPGe detector.[2] The tailing phenomenon cannot be attributed to this small but normal electric field of the middle part of the HPGe crystal unless defects or trapping centers are highly concentrated there. It may not be however unreasonable to assume that defects can be created near the electrodes and the edge of the HPGe crystal during cutting and polishing procedures.

We simply assumed that the trapping/detrapping occurs in the middle part not throughout the whole volume but near the edge of the HPGe crystal. The upper panel is the cross sectional view of the quarter section of the twin Ge detector which is surrounded by the dotted line in the lower panel of Fig. 5. A linear form of the charge-collection efficiency ($\varepsilon$) was assumed in the edge part of the crystal: $\varepsilon(r) = 6\,r$ [%] at $r < 50/3$ and $\varepsilon(r) = 100\%$ at $r \geq 50/3$, where $r$ is the distance from the middle point of the edge shown by the symbol O in the upper panel. Note that the thickness of the inner electrode (700 μm $n^+$ contact) and that of the outer electrode (0.3 μm $p^+$ contact) were treated as dead layers. The efficiency is illustrated by the gradation in Fig. 5. Results of the EGS4 simulation with the imperfect charge collection are shown by the dotted lines in Fig. 4. The agreement with the data is greatly improved in the middle region ($x$ = 10, 20, and 30).

## 4. Conclusions

The response functions of the HHS to 10.7 MeV $\gamma$ rays produced in the $^{27}Al(p,\gamma)^{28}Si$ reaction with and without the Compton suppression mode are satisfactorily reproduced by EGS4 simulations. There remain some discrepancies between the data and the simulation. The discrepancy is prominent in the region immediately below the full-energy peak (tail region) and less prominent below the Compton edge (low-energy region). These are related to imperfect charge collection (ICC) due to trapping/detrapping of charge carriers by defects or trapping centers of the coaxial HPGe detector. A preliminary EGS4 simulation was performed assuming that the ICC takes place near the edge of the HPGe crystal. The simulation improved the agreement between data and simulations to large extent.

The tailing of the full-energy peak and the enhancement of the low-energy component have not been studied well in the past. They must be understood to reproduce the response function of the HHS. Currently, EGS4 simulations including the ICC near the electrodes ($p^+$ and $n^+$ contacts) are in progress.


## Acknowledgment

This work was supported in part by the Japan Private School Promotion Foundation and by the JNC Cooperative Research Scheme on the Nuclear Fuel Cycle.


## References


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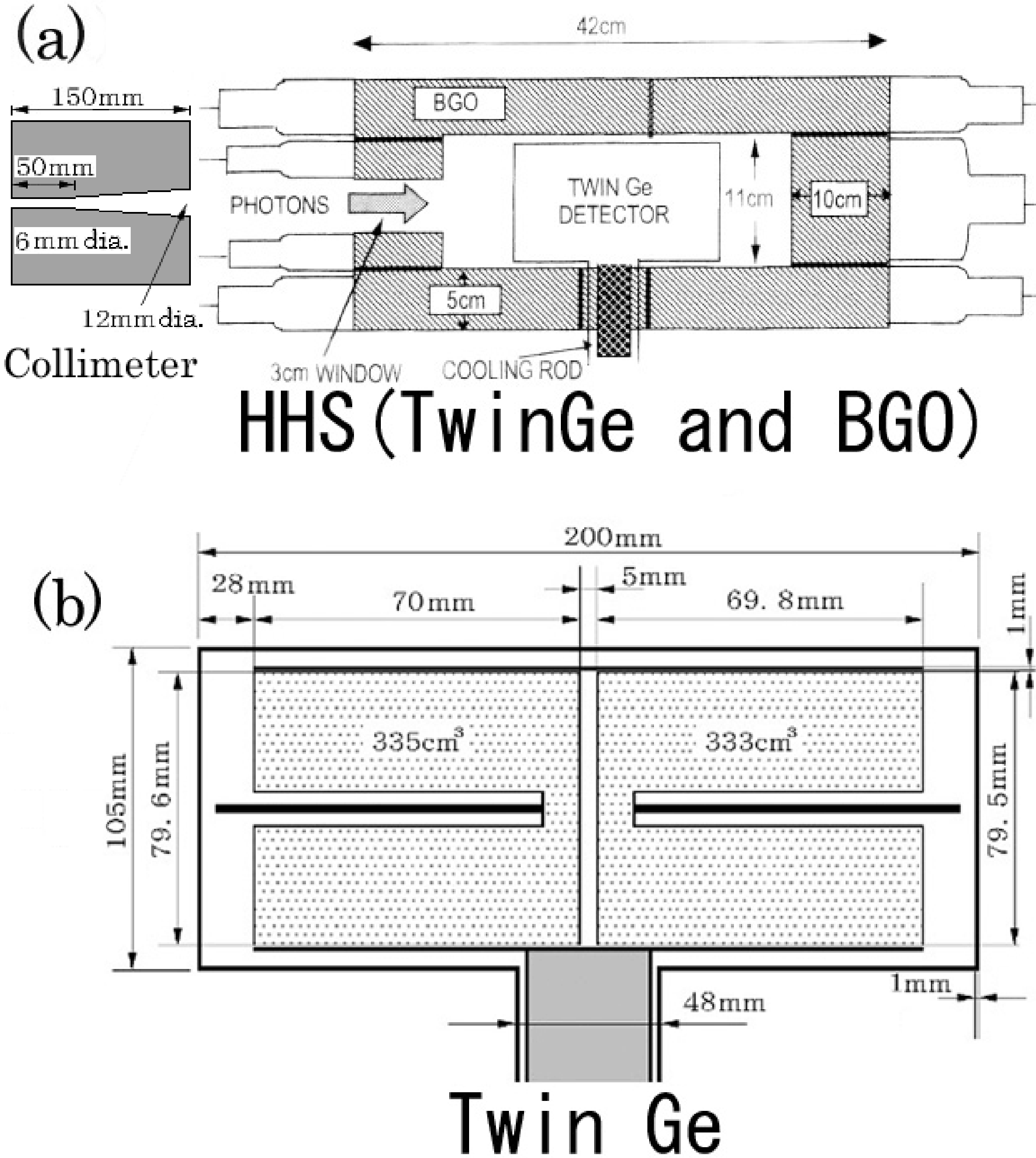


Fig. 1 The High-resolution High-energy photon Spectrometer (HHS) (top) and the Twin Ge detector (bottom). All figures are given in units of mm unless indicated.

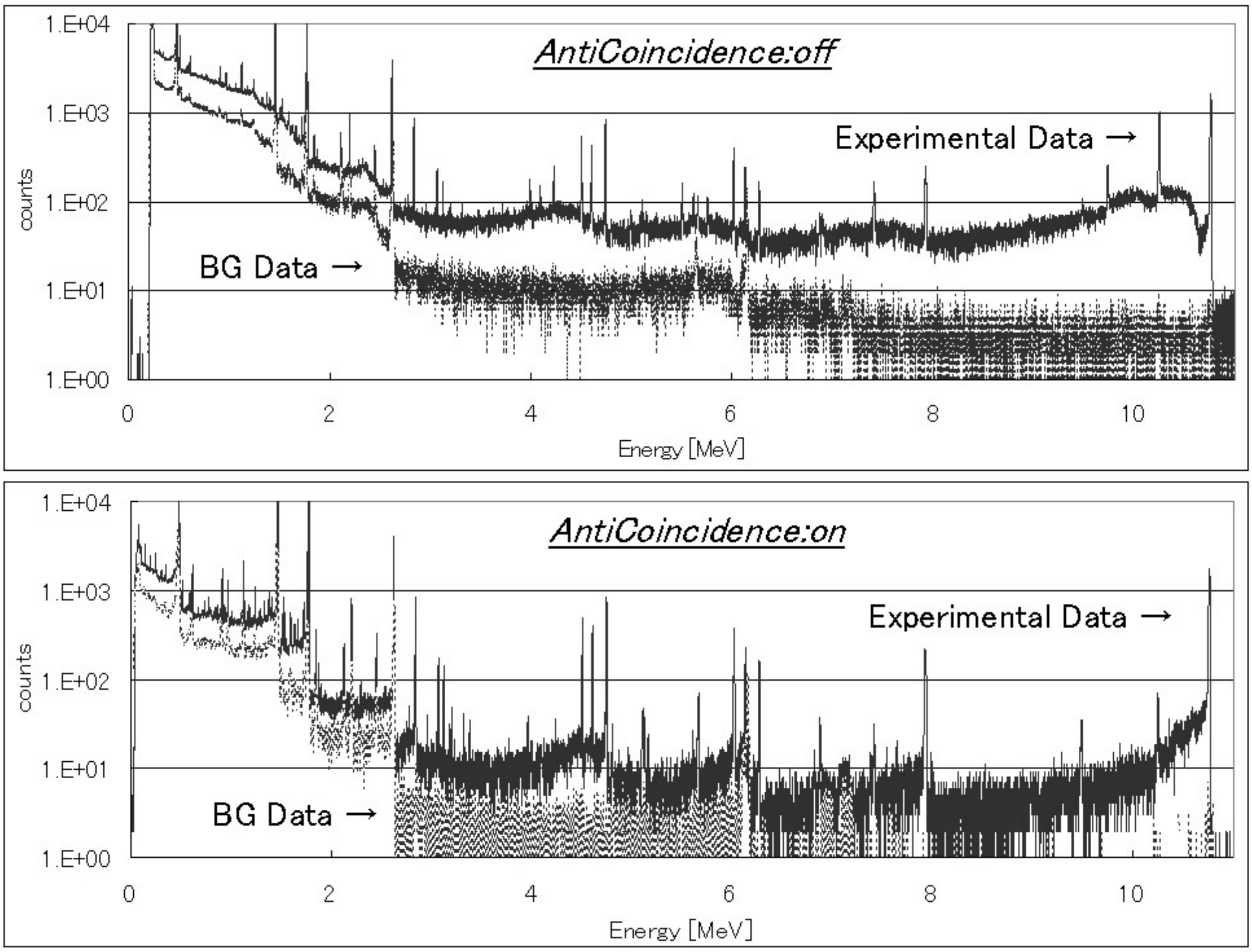


Fig. 2 Response functions of the HSS to 10.7 MeV $\gamma$ rays produced in the $^{27}Al(p,\gamma)^{28}Si$ reaction with (bottom) and without (top) the Compton suppression mode. Data were also taken at an off-resonance energy of the beam for background measurements.

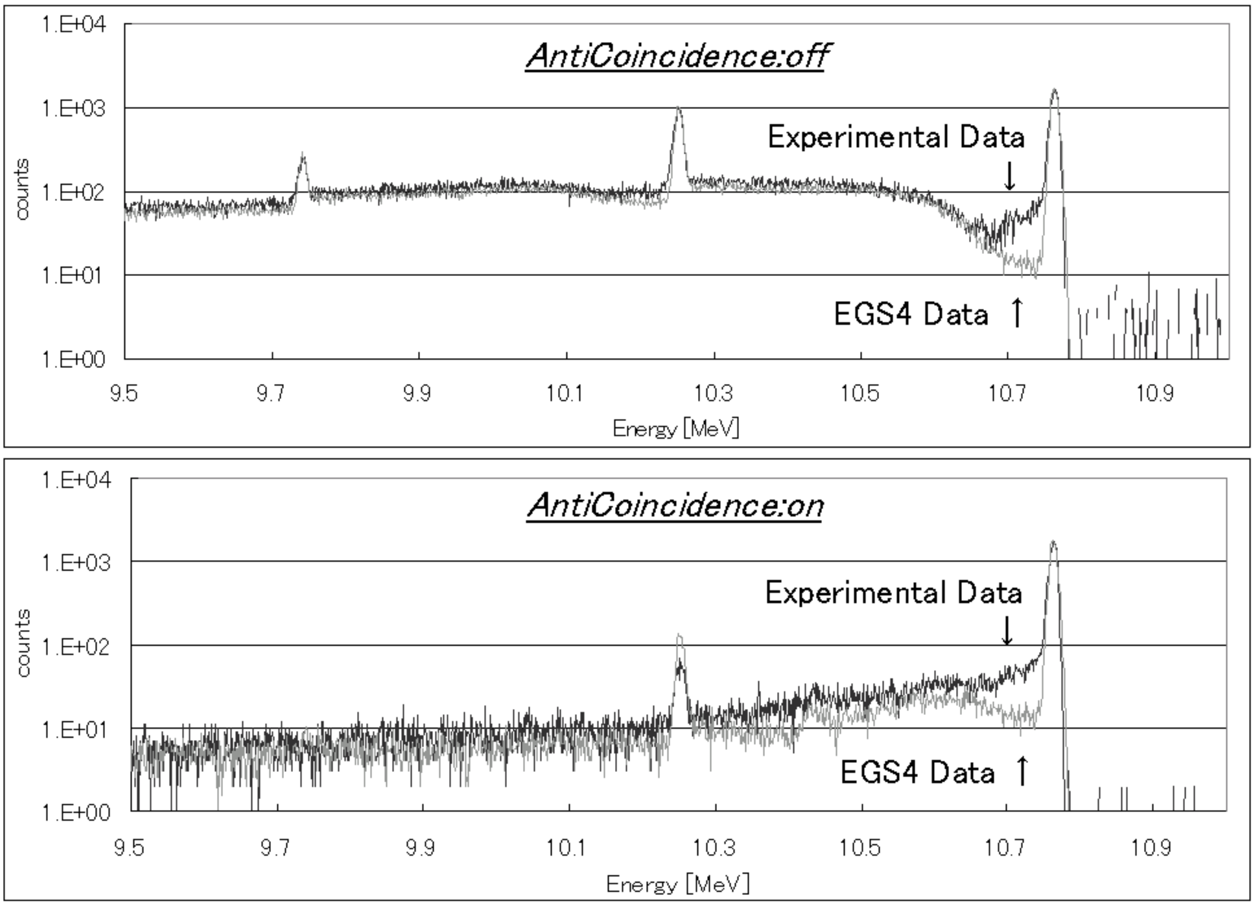


Fig. 3 Comparison of response functions of the HHS to 10.7 MeV γ rays with EGS4 simulations. Discrepancies between the data and the simulation are seen in the regions between the full-energy peak and the Compton edge (tail region) and below the Compton edge (low-energy region). The single-escape peak appeared in the energy spectrum taken with anti-coincidence gates on because the escape can occur through the entrance of the HHS.

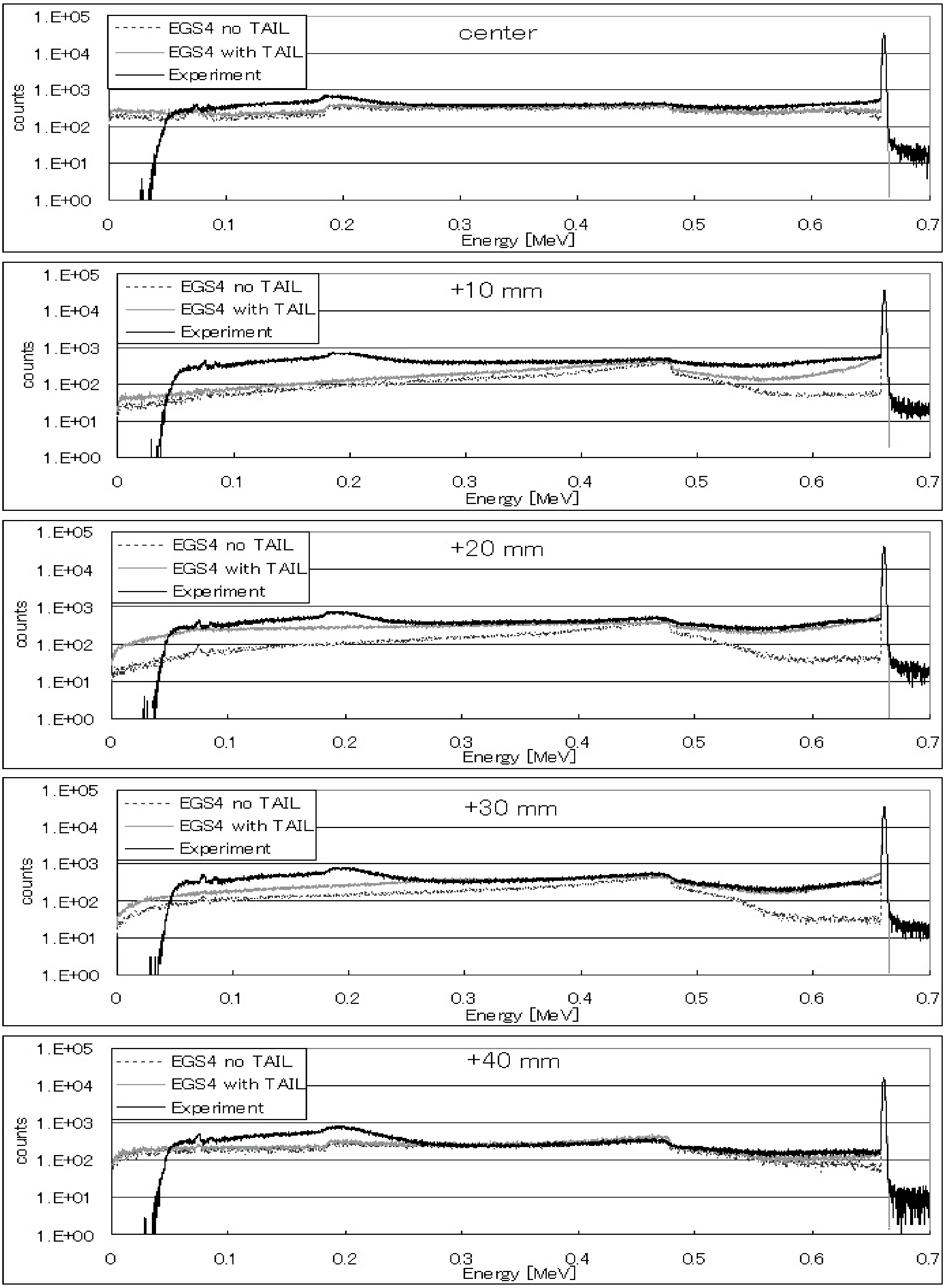


Fig. 4 Pulse-height distributions of γ rays from a collimated $^{137}Cs$ standard source measured with the twin Ge detector (Fig. 1). γ rays impinged on the HPGe detector in parallel to the cylindrical axis with an offset *x* [mm] from the axis.

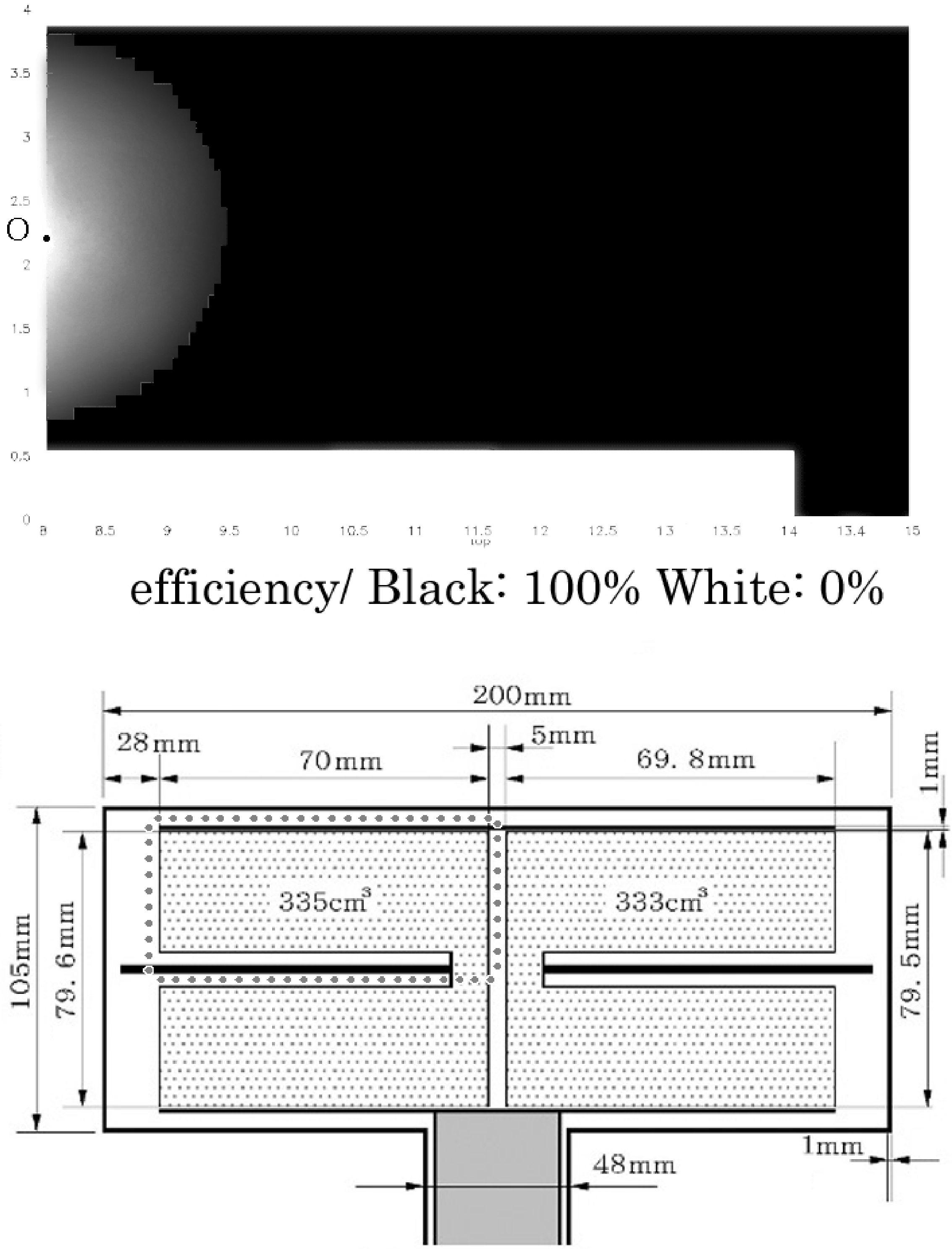


Fig. 5 The efficiency of charge collection near the edge of the HPGe crystal (upper panel) which is the cross sectional view of the quarter section of the twin Ge detector which is surrounded by the dotted line (lower panel). All figures are given in units of *mm* unless indicated.