

Energy Spectrum of Cosmic-Ray Photons Observed at the Ground Level in Japan

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INTRODUCTION

The public was exposed to terrestrial gamma-rays, secondary cosmic-rays, and to radiations from the radon in the atmosphere and from the radioactivities in foods. Since cosmic-rays account for 16 percent of the exposure dose, it is important to investigate for estimation of the exposure dose to the public. The pulse-height spectrum of cosmic-ray photons was obtained for estimation of the energy spectrum of cosmic-ray photons at the ground level in Japan.

METHODS

MEASUREMENT

Measurement of cosmic-rays were carried out by using a spherical NaI(Tl) scintillation detector with a 7.6cm diameter whose density is $3.6\text{g}\cdot\text{cm}^{-3}$. The measuring system using the spherical detector is illustrated in the higher part of Fig.1. The measurements of cosmic-ray muons were carried out by using a plastic scintillation detector with a 7.6cm diameter whose density is $1.03\text{g}\cdot\text{cm}^{-3}$. The pulse-height spectra by cosmic-ray muons were measured by placing the spherical detector in a lead shield of 10cm in thickness, because it is commonly accepted that the soft component of cosmic-rays could be successfully separated from the hard one by using a 10cm thick lead shield. Difference of the pulse-height spectrum caused by difference between a density of NaI(Tl) scintillation detector and a density of a plastic scintillation detector was revised. The energy divisions were converted so that the peak energy observed by a spherical plastic scintillation detector was equalize to the peak energy observed by a spherical NaI(Tl) scintillation detector.

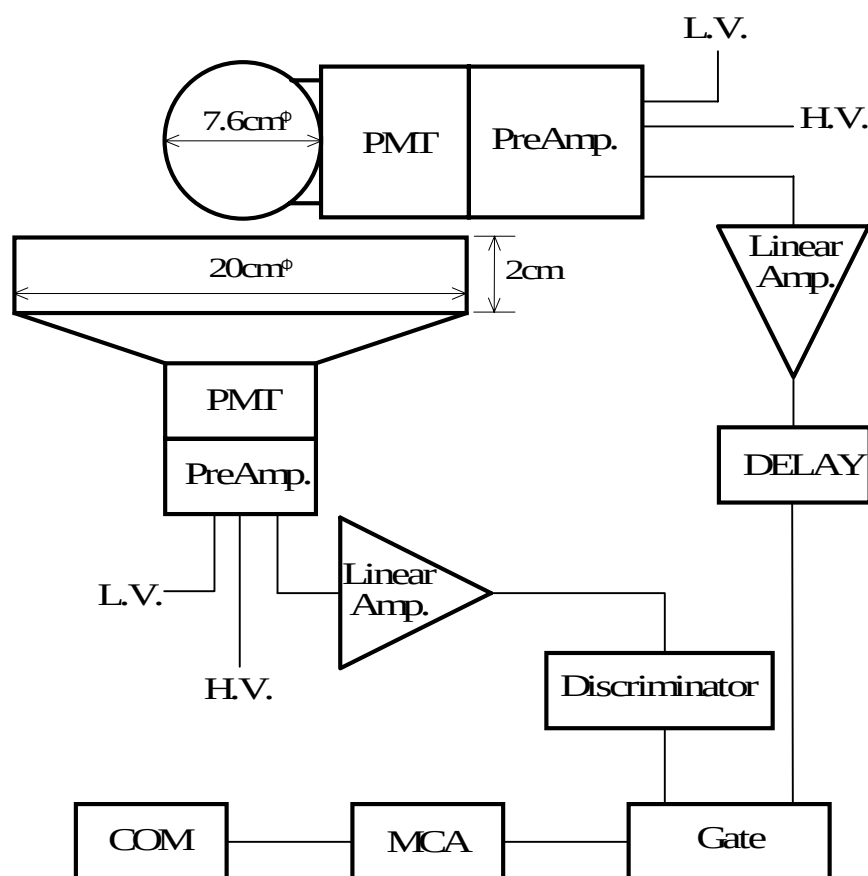


Fig.1 Measuring system used for the observation of the pulse-height spectra of cosmic-rays. A coincidence counting system using circular plane detector shown in Fig.1 was used in order to clarify

the pulse-height spectra of cosmic-ray muons and cosmic-ray electrons excluding the influence of the environmental gamma-rays. A circular plane detector of 20cm in diameter and 2cm in thickness was used for getting gate pulse of about 5μ sec in width which were generated after passing through the pulse-height discriminator set at the level beyond the largest signal by natural gamma-rays. These measurements were carried out on the top of the No.3 building in Fukuyama University.

SIMULATION

The absorptions of cosmic-ray electrons absorbed in the spherical NaI(Tl) scintillation detector by the single detector counting and the coincidence counting were simulated by using the EGS4 Monte Carlo Code(Nelson et al 1985). A longitudinal section of the organic detectors is schematically illustrated in Fig.2. The detector are composed of the circular plane plastic scintillator and the spherical NaI(Tl) scintillator. The spherical NaI(Tl) scintillator of 7.6cm in diameter was covered with an aluminum cover of 0.05cm in thickness. A circular plane block shows the plastic scintillator of 20cm in diameter and 2cm in thickness. This scintillator was used for getting the gate signal while the coincidence counting was performed. The composition and the physical quantities of the plastic scintillator were assumed to be those of the polystyrene resin ($\text{CH}(\text{C}_6\text{H}_5)\text{CH}_2$)_n. The distance between the aluminum case and the circular plane plastic block is 0.5cm.

The NaI(Tl) scintillator was irradiated by the electrons whose directions were determined by generating random number so that the electron scalar flux was proportional to $\cos^3 \theta$, where θ is the zenith angle. 10^5 histories were calculated for the determination of the probability distributions of the absorbed energy caused by electrons below 10GeV. The energy spectrum of the cosmic-ray electrons reported by O.C.Allkofer(Allkofer 1975) was used for calculation of the pulse-height spectrum of cosmic-ray electrons in the natural environment.

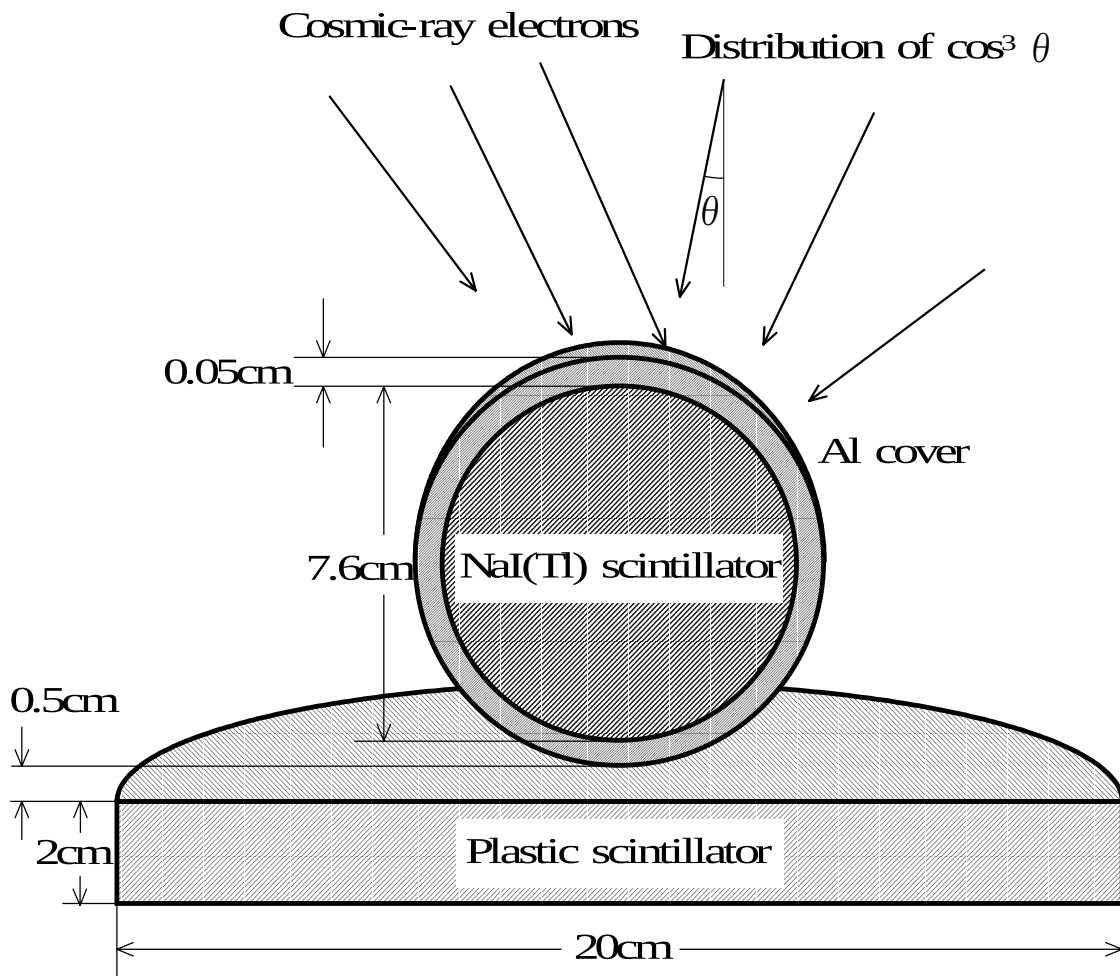


Fig.2 The model used for the calculation of the energy deposition spectra of cosmic-ray electrons incident on the spherical plastic scintillation detector.

Conceptual illustration of the simulation by the single detector and the coincidence counting was shown in Fig.3. A: Since the electron was stopped in the spherical NaI(Tl) scintillator, the circular plane plastic scintillator was not deposited absorbed energy. Absorbed energy in the spherical NaI(Tl) scintillator was counted in the case of the single detector. But absorbed energy was not counted in the case of the coincidence counting. B: The electron was through both the spherical NaI(Tl) scintillator and the circular plane plastic scintillator. Since absorbed energy in the circular plane plastic scintillator was 4MeV, absorbed energy in the spherical NaI(Tl) scintillator was counted in the case of both the single detector and the coincidence method. C: The electron was through both the spherical NaI(Tl) scintillator and the circular plane plastic scintillator. But absorbed energy by the coincidence counting was not counted. Because absorbed energy in the circular plane plastic scintillator was 2MeV, was smaller than 3.5MeV. D: The electron was through only the spherical NaI(Tl) scintillator. Thus the absorbed energy by the coincidence counting was not counted.

The pulse-height spectra were determined by the absorbed energy in the spherical NaI(Tl) scintillator. The pulse-height spectrum by the single detector doesn't concern with the energy deposition in circular plane scintillator. The pulse-height spectrum by the coincidence counting was counted when the absorbed energy in the circular plane plastic scintillator was higher than 3.5MeV.

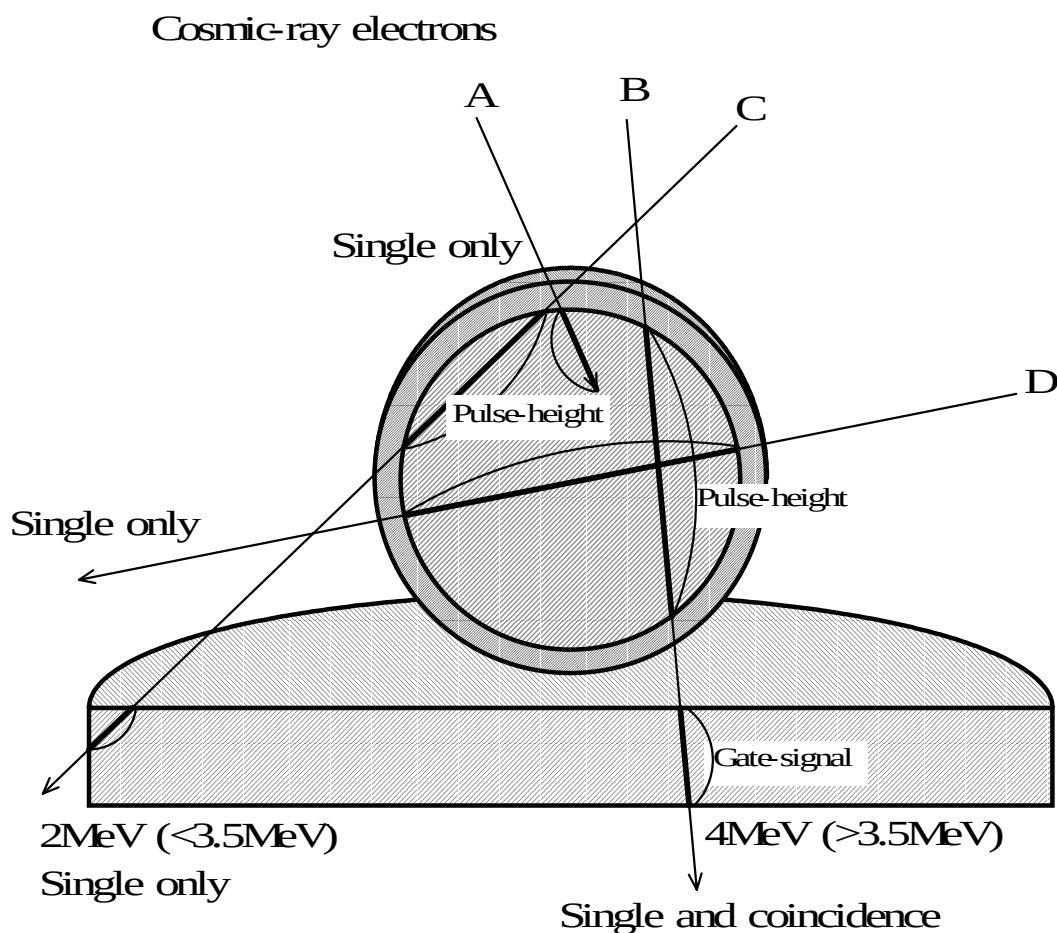


Fig. 3 Conceptual illustration of the simulation by the single detector counting and the coincidence counting.

RESULTS and DISCUSSION

PULSE-HEIGHT SPECTRA by COSMIC-RAYS

The pulse-height spectra of cosmic-rays observed by using the single detector, by the coincidence counting and by the plastic scintillator covered with the lead were shown in Fig.4. The energy calibration was performed by using peak channels of ^{40}K and ^{208}Tl gamma-rays observed in the NaI(Tl) scintillator and the correspondence energies of 1460keV and 2610keV. The energy calibration of the pulse-height spectrum obtained by the coincidence counting was carried out by using the results determined in the case of the single detector. The pulse-height spectrum by the single detector was not observed at the lower energy than 1.5MeV. The pulse-height spectrum by the coincidence counting was not observed at the lower energy than 2.5MeV. The energy calibration of the pulse-height distribution by the spherical plastic scintillator covered with the lead shield was performed by using the compton edges of ^{40}K and ^{208}Tl gamma-rays and the correspondence energies of 1243keV and 2381keV. The peak energy of pulse-height spectrum observed by the spherical plastic detector covered with the lead shield was 14.5MeV, that by the spherical NaI(Tl) detector was 32.5MeV. As the difference of the each peak energies was caused by the difference of the density between the plastic and the NaI(Tl), the pulse-height spectrum observed by the plastic scintillator was revised so that the pulse-height spectrum by the plastic scintillator could be compared with the pulse-height spectra by the NaI(Tl) scintillator.

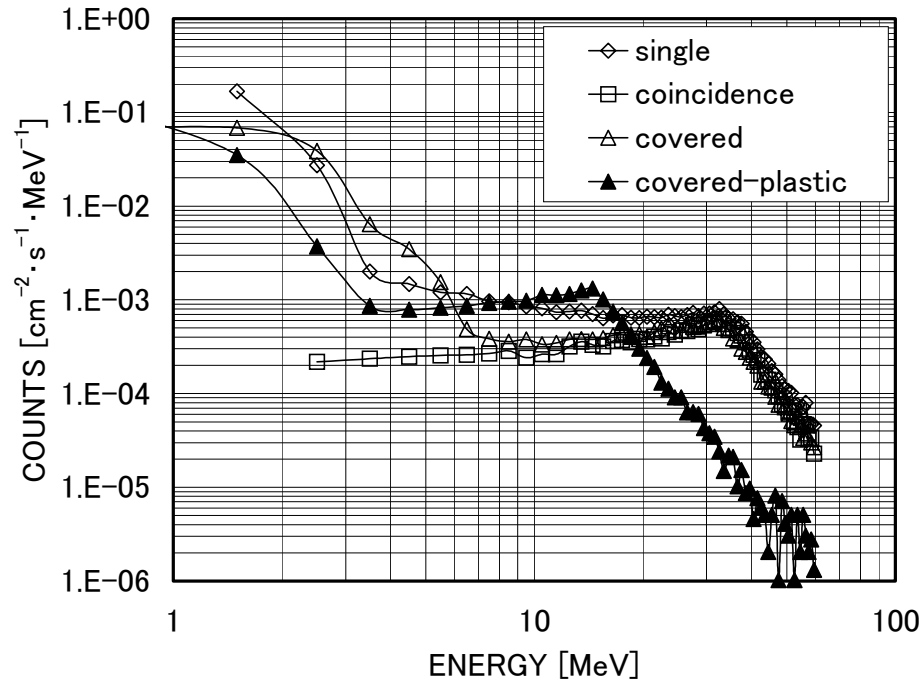


Fig.4 The pulse-height spectra of cosmic-ray s by the single detector, by the coincidence counting and by the plastic covered with the lead shield.

The simulated pulse-height spectra of cosmic-ray electrons by the single detector and the coincidence counting were shown in Fig.5. The pulse-height spectrum of cosmic-ray electrons by the single detector was labeled "electron", and the pulse-height spectrum by the coincidence counting was labeled "electron_". As the pulse-height spectra were included the statistics error, were revised by the smoothing method.

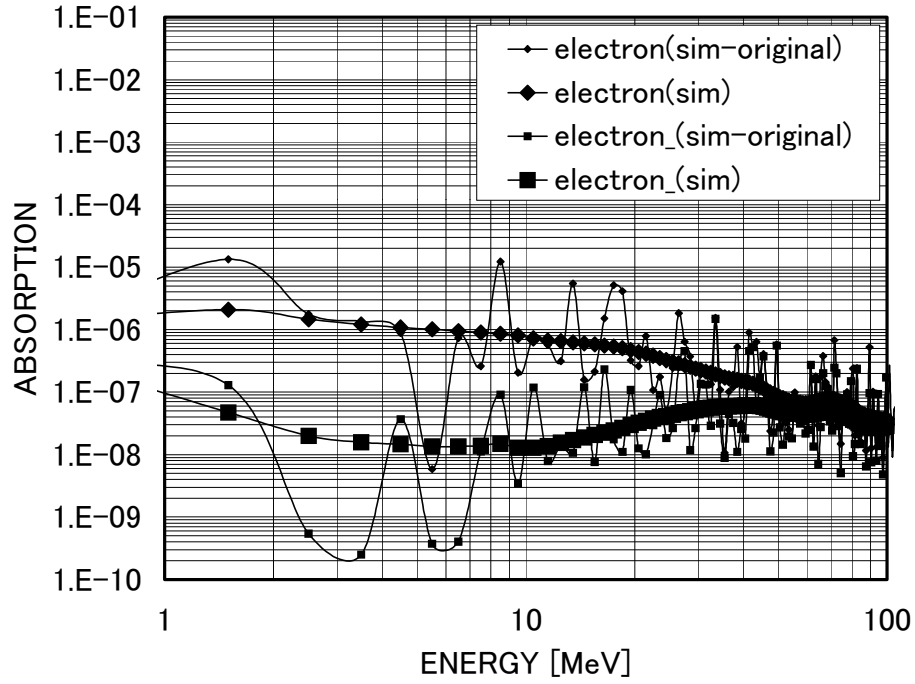


Fig.5 The energy deposition spectra of cosmic-ray electrons.

DETERMINATION of COSMIC-RAY ELECTRON COMPONENT

The pulse-height spectra observed by the coincidence counting and by the plastic covered with lead shield were shown in Fig.6. The pulse-height spectrum by the coincidence counting was composed by cosmic-ray muons and cosmic-ray electrons. The pulse-height spectrum by the plastic covered with the lead shield was composed by the cosmic-ray muons and the environmental gamma-rays at the lower energy.

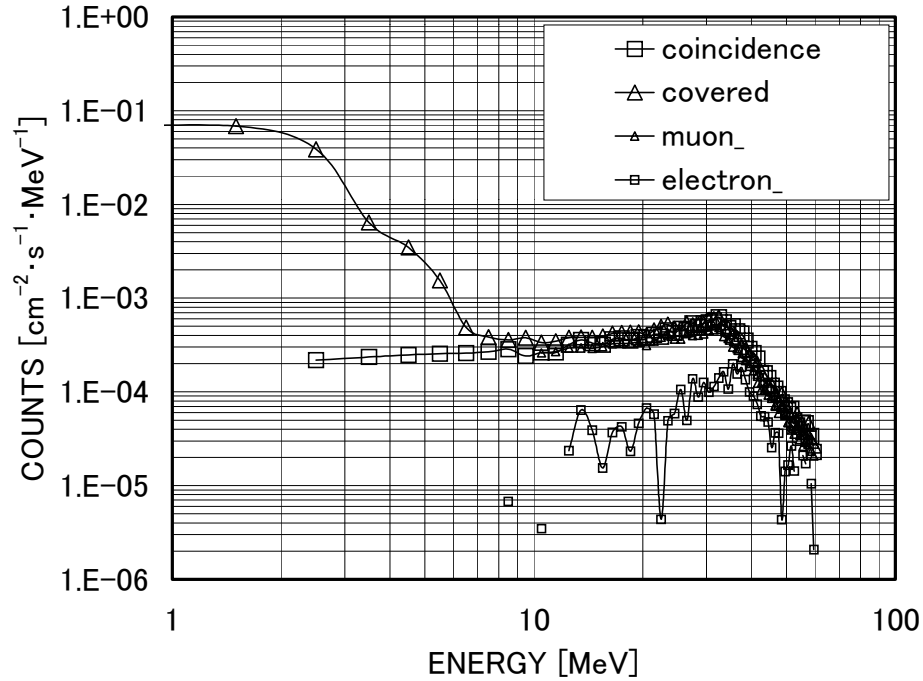


Fig.6 The pulse-height spectra observed by the coincidence counting and by the plastic covered with the lead shield used for the determination of the pulse-height spectrum of cosmic-ray electrons.

The counts by the coincidence counting were limited by the solid angle formed by the spherical scintillator and the circular plane scintillator. The muon scalar flux is proportional to $\cos^2 \theta$, where θ is the zenith angle. Thus the pulse-height spectrum of the cosmic-ray muons by the plastic covered with the lead shield could be revised that by the coincidence counting. The conversion factor was 1.29. The pulse-height spectrum by the plastic covered with lead shield divided by 1.29 were the pulse-height spectrum of cosmic-ray muons by the coincidence counting at higher energy region. The intensity of the pulse-height spectrum of cosmic-ray electrons by the coincidence counting at higher energy was obtained by the difference between the pulse-height spectrum by the coincidence counting and that of cosmic-ray muons. The intensities of the pulse-height spectra of cosmic-ray electrons simulated were determined by using the counts obtained above.

DETERMINATION OF COSMIC-RAY MUONS COMPONENT

The pulse-height spectrum by the coincidence counting and the simulated pulse-height spectrum of cosmic-ray electrons by coincidence counting were shown in Fig.7. The pulse-height spectrum of cosmic-ray muons by coincidence counting was obtained the difference of the each pulse-height spectra.

As the pulse-height spectrum of cosmic-ray electrons was very small, the pulse-height spectrum of cosmic-ray muons resembles the pulse-height spectrum by the coincidence counting. The pulse-height spectrum of cosmic-ray muons by the single detector was seemed to be the corrected pulse-height spectrum of cosmic-ray muons by the coincidence counting. This is 1.29 times as large as pulse-height spectrum by the coincidence method. The pulse-height spectrum of cosmic-ray muons by the single detector was labeled "muon", and the pulse-height spectrum by the coincidence counting was labeled "muon_".

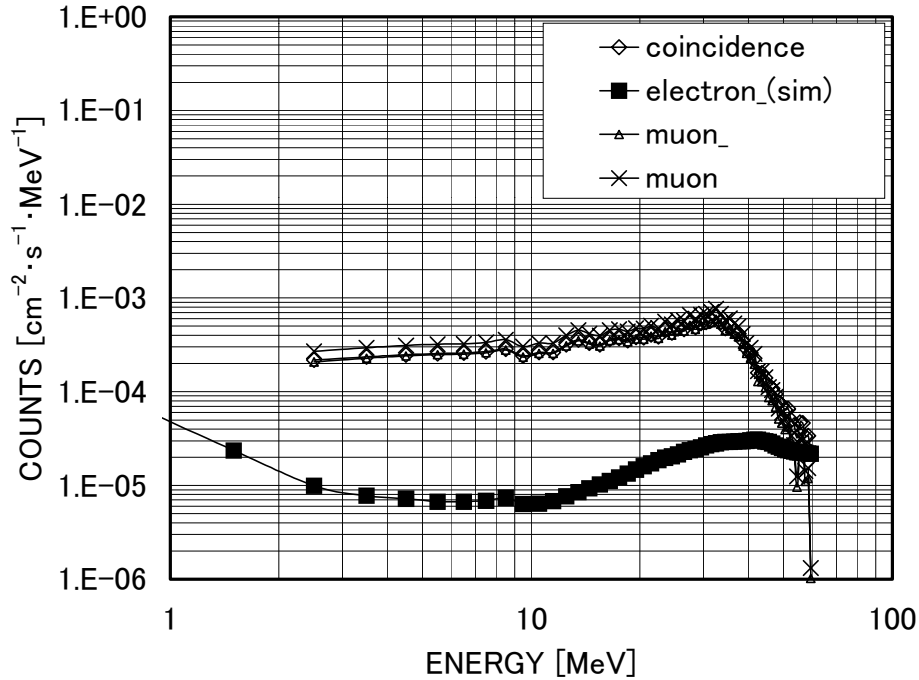


Fig.7 The pulse-height spectra of the cosmic-ray charged particles and the cosmic-ray electrons used for the determination of the pulse-height spectrum of cosmic-ray muons.

DETERMINATION of COSMIC-RAY PHOTONS COMPONENT

The simulated pulse-height spectrum of cosmic-ray electrons by the single detector and the pulse-height spectrum of cosmic-ray muons obtained following the way above stated above were shown in Fig.8. Cosmic-ray electrons were main component at the lower energy region. Since the pulse-height spectrum observed by the single detector was composed cosmic-ray muons, electrons and photons, the pulse-height spectrum of cosmic-ray electrons and muons subtracted from the pulse-height spectrum by the single detector was the pulse-height spectrum of cosmic-ray photons.

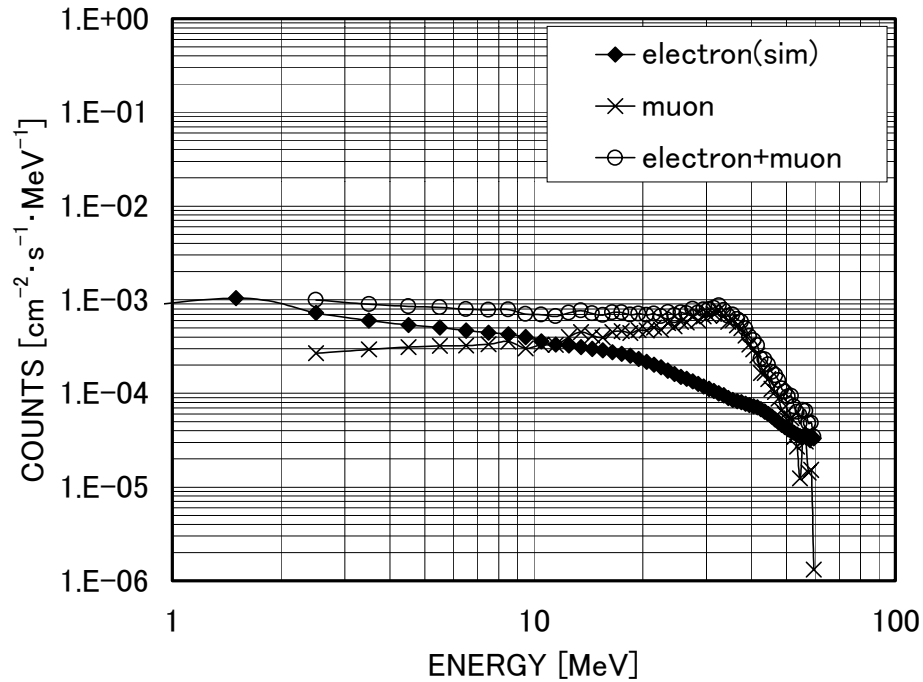


Fig.8 The pulse-height spectra of cosmic-ray electrons and cosmic-muons.

The pulse-height spectrum by the single detector and the pulse-height spectrum of cosmic-ray electrons and muons were shown in Fig.9. The pulse-height spectrum of photons was intensive at the lower energy region. The cosmic-ray photons could not be separated from the environmental gamma rays below 3.5MeV. The pulse-height spectrum of cosmic-ray electrons and muons was observed at the higher energy region above 14MeV. Thus the pulse-height spectrum of cosmic-ray photons was observed in the energy region below 14MeV. The pulse-height spectrum of cosmic-ray photons does not observed above 14MeV. This may indicate that there are a few photons above 14MeV in the natural environment. But, at the same time, the pulse-height spectrum by cosmic-ray electrons might be overestimated because it may include the pulse-height spectrum by cosmic-ray photons, although the pulse-height spectrum by the coincidence counting was not assumed to include the pulse-height spectrum of cosmic-ray photons.

The investigation of this possibility must be the subject of future research. The pulse-height spectrum of cosmic-ray photons by the coincidence counting will be investigated by the simulation. The pulse-height spectrum of cosmic-ray photons above 14MeV will be successfully separated by using the calculated results.

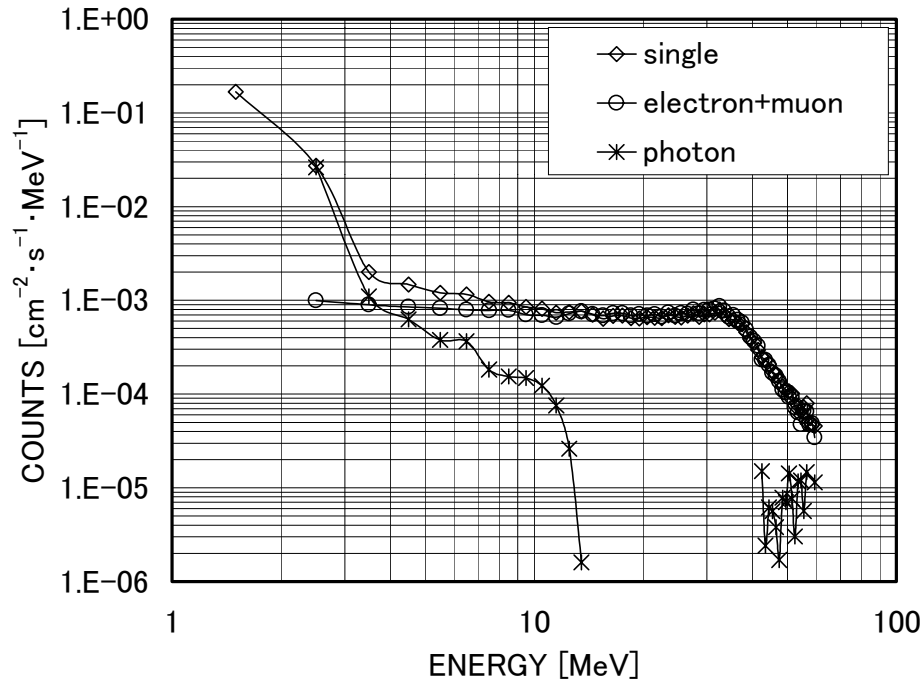


Fig.9 The pulse-height spectra of cosmic-rays by the single detector and cosmic-ray electrons and muons used for the determination of the pulse-height spectrum of cosmic-ray photons.

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