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著者	桑島 淳宏, 玉江 忠明, 須田 利美, 石井 健一, 栗田 和好, 白井 敏之, 若杉 昌徳, 王 頌
journal or publication title	核理研研究報告
volume	41
page range	38
year	2009-03
URL	http://hdl.handle.net/10097/45486

(LNS Experiment : #2593)

Response of Electron Calorimeters for SCRIT Experiments

A. Kuwajima¹, T. Tamae¹, T. Suda², K. Ishii³, K. Kurita³, T. Shirai⁴,
M. Wakasugi², and S. Wang²

¹Laboratory of Nuclear Science, Tohoku University, Sendai, 982-0826

²RIKEN Nishina Center, Wako, Saitama 351-0198

³Department of Physics, Rikkyo University, Toshima, Tokyo 171-8501

⁴Institute of Chemical Research, Kyoto University, Uji, Kyoto 611-0011

We investigated the response of pure CsI and BaF₂ electron calorimeters for SCRIT experiments using electron beams and cosmic rays. We compared the measured results with calculations by GEANT3, and found that the inclusion of housings for crystals into GEANT3 calculations is essential in order to obtain the correct response of the detectors. Energy distribution of the cosmic rays also affects the results of the calibration very much, and the use of the accurate energy spectrum is important when the calorimeters are calibrated using cosmic rays.

§1. Introduction

The feasibility study of SCRIT (Self-Confining Radioactive Isotope ion Target) [1, 2] has been done using 121 MeV electron beams at KSR (Kaken Storage Ring) in Kyoto University. In the experiment, the energy of electrons elastically scattered from trapped Cs ions was measured using electron calorimeters of pure CsI and BaF₂. Those calorimeters were calibrated using cosmic rays and scattered electrons from a tungsten wire by comparing the measured spectra with results of GEANT3 simulations. Experiments with electron beams were performed at KSR in Kyoto University and LNS in Tohoku University. As data obtained at LNS have problems due to light leak for the CsI detectors, the results obtained from the measurements at KSR and from the cosmic rays are included in this report.

§2. Experimental Setup

Figure 1 shows a schematic view of the SCRIT experiment, which has been set up at KSR in Kyoto University. Cesium (Cs) ions injected from an ion source are trapped in the potential produced by the SCRIT electrodes and an electron beam. A tungsten wire with 50 μm diameter can be inserted onto the electron beam at 6 cm upstream from the center of SCRIT. The energy of scattered electrons is measured using CsI at 30° and BaF₂ at 40° and 60°. The distance of the front of the calorimeters from the center of SCRIT is 1750, 1180 and 790 mm for 30°, 40° and 60° detectors, respectively. Two plastic scintillation counters have been installed between the drift chamber and each calorimeter. Another plastic scintillators have been distributed around the calorimeters for measurement of the cosmic rays, which are used as veto counters during the measurements with the electron beam. The drift chamber

determines the vertex point and the angle of the scattered electrons. Each calorimeter consists of seven optically isolated crystals; each crystal has a hexagon cross section and its length is 20 cm. The cross section of the CsI and BaF₂ crystal is 41.6 cm² and 39.9 cm², respectively. Each crystal is contained in a 1.5 mm thick aluminum housing, and seven detectors are set in a cylindrical case of stainless steel. The light signal generated in the crystals is converted to the current signal by photomultipliers.

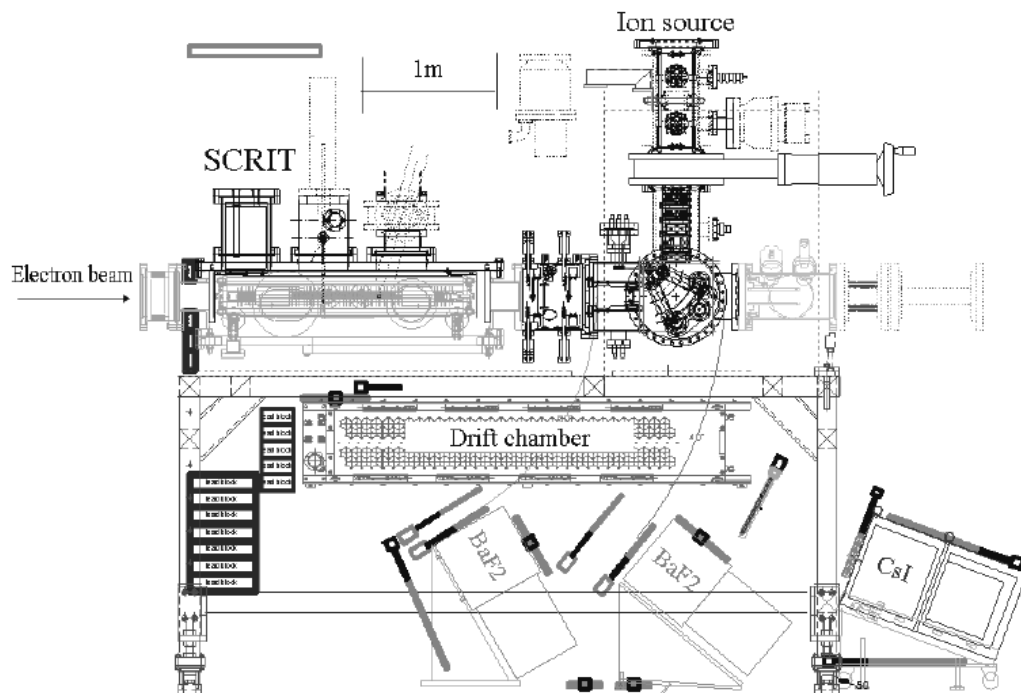


Fig.1. Prototype SCRIT and experimental setup.

§3. Calibration of Calorimeters using Cosmic Rays and a Wire Target

The calorimeters were calibrated using the cosmic rays and scattered electrons off a tungsten wire target at KSR. The calibration using cosmic rays alone was applied before the wire target was installed. The calorimeter at 60° was calibrated using only cosmic rays because the number of the scattered electrons was not enough for the calibration. Aluminum housings with a thickness of 1.5 mm for the crystals were included in the calculation; they influence the simulated spectrum very much, as shown in the following section.

The propriety of the calorimeters was evaluated using spectra of electrons scattered off the tungsten wire target. The ADC spectrum of each crystal was fitted with that calculated using GEANT3 program to determine the calibration parameter for each crystal. The simulation includes the radiative correction at the scattering point, the energy loss in materials between the target and the calorimeters, and the formation of the shower and the energy dissipation in the calorimeters. The energy spectra measured by the CsI calorimeter at 30° and BaF₂ calorimeter at 40° are compared with that calculated using GEANT3 simulation in Fig. 2; the calibration parameter for each crystal was determined by fitting

the measured spectrum to the calculation. The figure indicates that the shapes of the elastic peak of measured and calculated spectra are almost identical. A considerable background exists below 50 MeV.

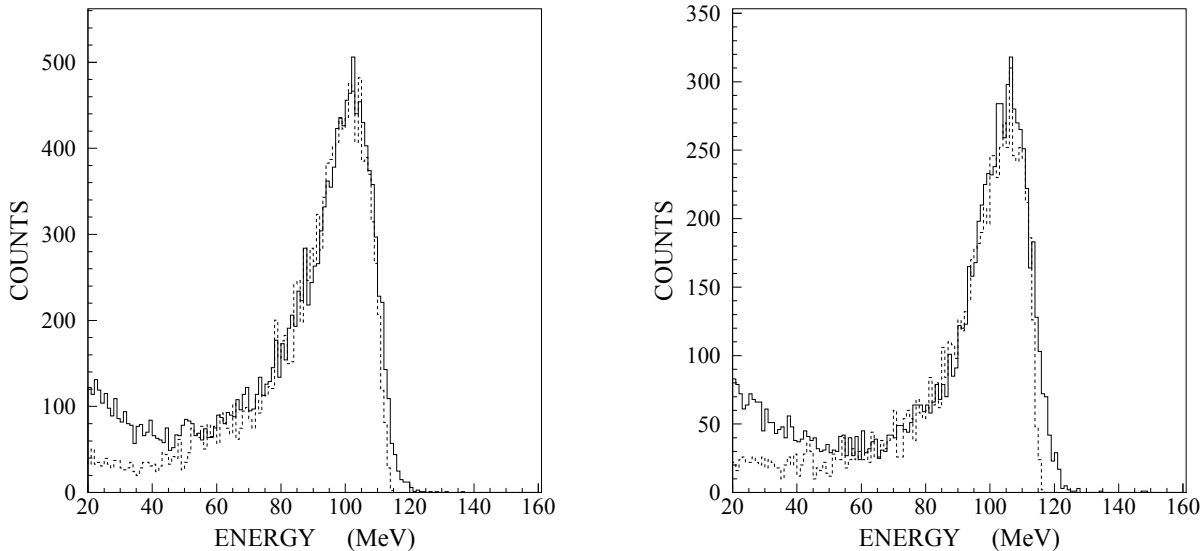


Fig.2. Total energy loss distribution in 7 crystals of the calorimeters for electrons scattered by a tungsten wire. (left: CsI calorimeter at 30° , right: BaF_2 calorimeter at 40°). (dashed line: spectrum calculated with GEANT3, solid line: measured spectrum where the calibration parameter for each crystal was obtained from fitting the data to the calculation.

The calibration of the calorimeters using cosmic rays is also useful. The high-energy cosmic rays penetrate the crystals; the main part of the cosmic rays is thought to be the muon. At the first stage, the energy distribution of muons was assumed to be constant from 0.5 to 10 GeV. The intensity of the cosmic rays was supposed to have the zenith angle dependence of $\cos^2\theta$. The fitting for each crystal and that for addition of the signals were fairly well (Fig. 3). However, the spectrum of electrons elastically scattered off the tungsten wire, which were measured by the CsI calorimeter with a 121 MeV electron beam at KSR, is 20 MeV higher than the calculation using GEANT3, as shown in Fig. 4, when we use the calibration parameter determined using cosmic rays for each crystal. The result indicates that the calibration using the parameters obtained using cosmic rays cannot reproduce the absolute value of the energies of electrons scattered off the tungsten wire.

One of the reasons is thought to be unrealistic assumption for the energy distribution of the cosmic rays. Figure 5 shows a dE/dx curve for the muon; it has a minimum around 2 GeV and increases towards lower energy. It means that the low energy component of the muons affects the energy dissipation of the cosmic rays in the calorimeters very much. Parameters for calibration were deduced by comparing the measured spectrum and calculated ones by GEANT3, where the flat spectrum of muons from 0.5 to 10 GeV (Fig.6) and a more realistic spectrum were used. The realistic muon spectrum was obtained from the BESS data [3] including the energy loss in the concrete ceiling of the experimental hall. In Fig. 7 spectra for the CsI calorimeter deduced using calibration parameters using cosmic rays are compared with the spectrum shown in Fig. 2; the solid lines in Figs. 2 and 7 are same. The energy spectrum using

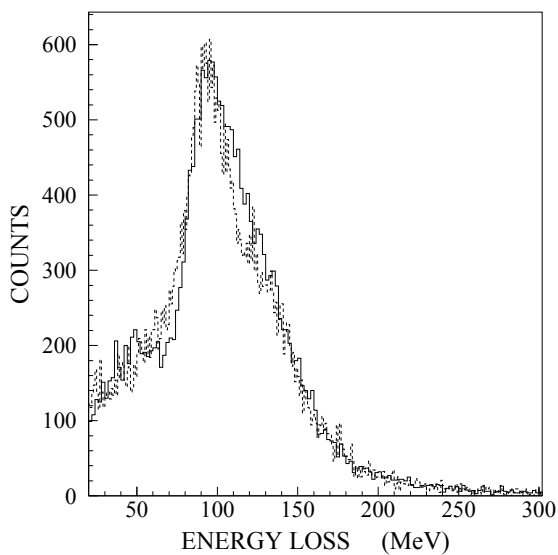


Fig.3. Total energy loss distribution of cosmic rays in 7 crystals of the CsI calorimeter. (solid line: measured spectrum, dashed line: GEANT3 calculation) Parameters for each crystal were obtained by fitting the measured spectrum with GEANT3 calculation.

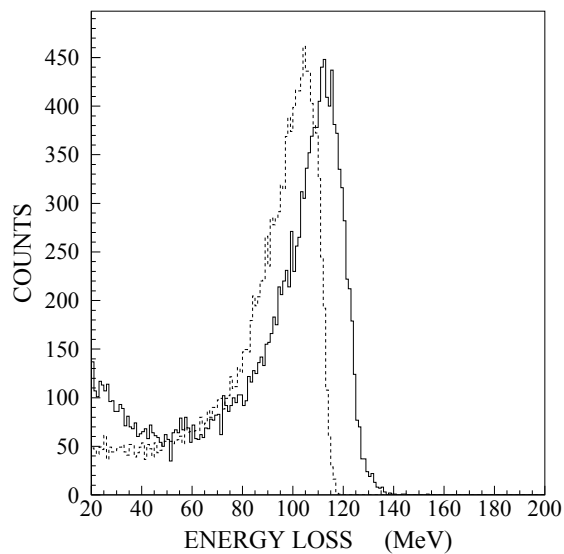


Fig.4. Total energy loss distribution in 7 crystals of the CsI calorimeter for electrons scattered by a tungsten wire. (solid line: measured spectrum, dashed line: GEANT3 calculation) Parameters for each crystal were obtained by fitting the measured spectrum of cosmic rays with GEANT3 calculation.

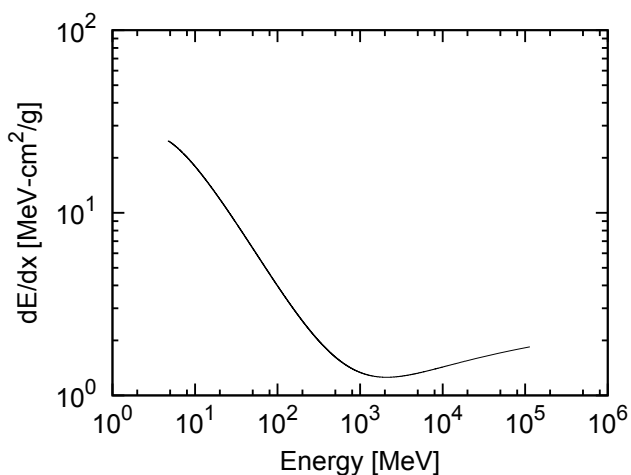


Fig.5. dE/dx curve for the muon.

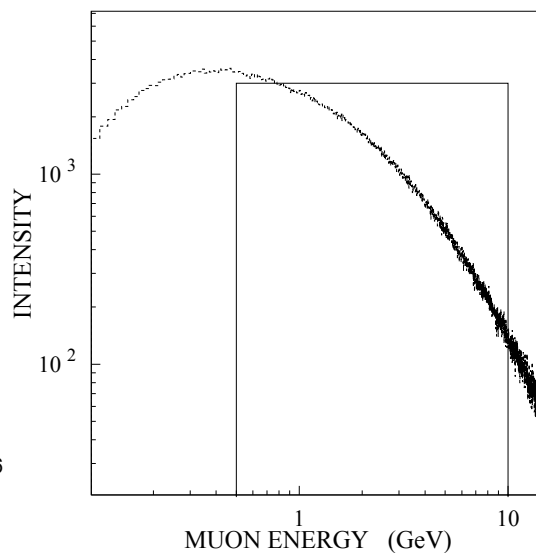


Fig.6. Muon energy spectra used for simulation. A flat distribution from 0.5 to 10 GeV and a realistic distribution were used in the calculation.

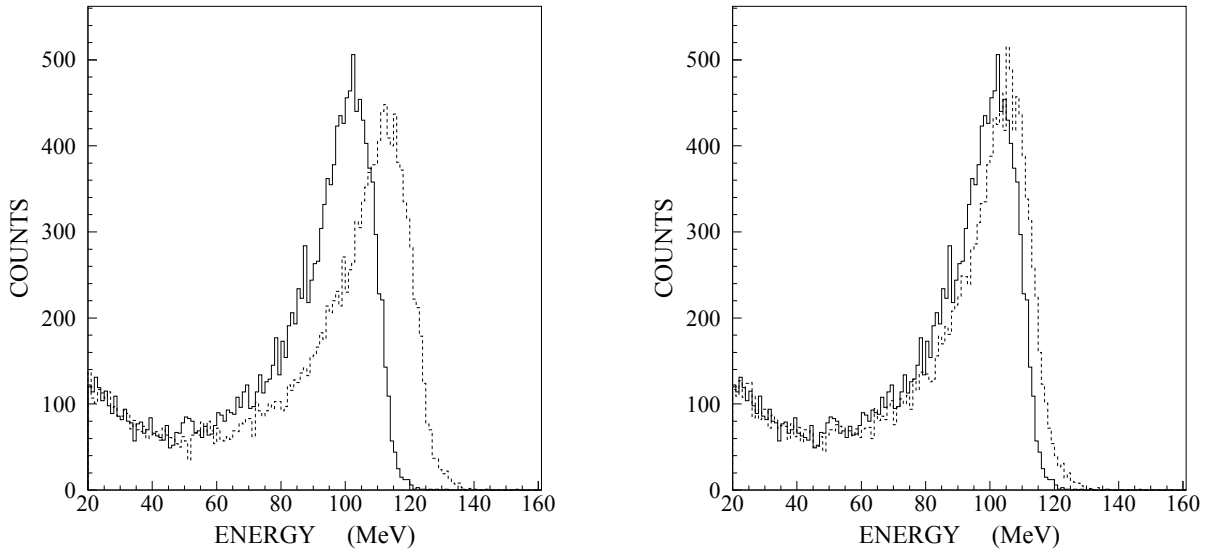


Fig.7. Total energy loss distribution in 7 crystals of the CsI calorimeter for electrons scattered by a tungsten wire. (solid line: spectrum using calibration parameters obtained from fitting with the data themselves, dashed line: spectrum using calibration parameters obtained from cosmic rays.) (left: a flat spectrum of cosmic rays is used, right: a realistic spectrum of cosmic rays is used.

parameters obtained by assuming the flat muon spectrum shifts to higher energies than the spectrum using parameters obtained from data of scattered electrons off the tungsten wire (left panel in Fig. 7). The spectrum using parameters assuming a realistic muon spectrum largely improves the reproduction although the difference of 3 MeV still remains (right panel in Fig. 7). It means that the use of the accurate spectrum is important when the calorimeters are calibrated using cosmic rays.

§4. Influence of Housing for Crystal

Each crystal of the calorimeters was contained in aluminum housings. Some parts of particles dissociate their energies in the housings, and their energies are removed from the signal. It worsens the energy resolution of the detectors. As effective thickness of the housings for the particles that move nearly parallel to the axis is much larger than the actual thickness, influence of the housings is larger for scattered electrons than for cosmic rays. The energy dissipation in the CsI crystals calculated by GEANT3 is shown for no housings (solid line) and for 1.5 mm thick aluminum housings in Fig. 8. In the calculation, electrons of 121 MeV are distributed in the area of 13 cm \times 13 cm. It indicates that the thickness of the housings should be as thinner as possible in order to improve the resolution.

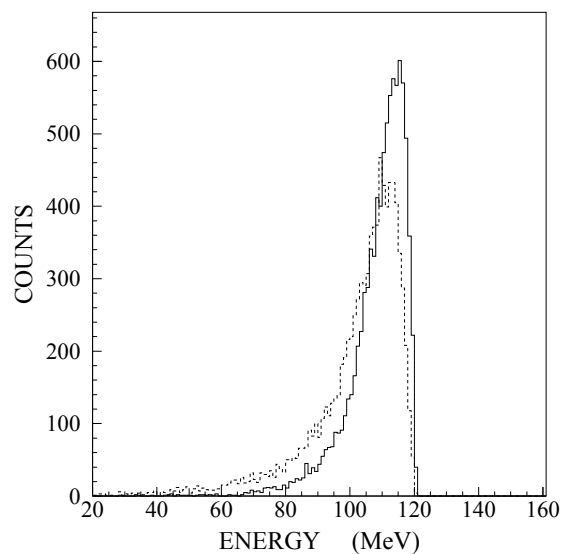


Fig.8. Influence of housings for crystals. Total energy loss distribution in 7 crystals of the CsI calorimeter was calculated for 121 MeV electrons by GEANT3. (solid line: spectrum with no housings, dashed line: spectrum with 1.5 mm thick aluminum housings.)

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