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# Performance of a Test Calorimeter of Lead Scintillating Fiber Modules

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A new electro-magnetic (EM) calorimeter complex FOREST comprises three independent calorimeters, covering a solid angle of about  $4\pi$  sr in total. The Backward Gamma detector brought from SPring-8/LEPS is employed to cover the central part of FOREST. Backward Gamma consists of lead scintillating fiber (Lead/SciFi) detector modules. The performance of a test calorimeter made up with 9 Lead/SciFi detector modules of Backward Gamma has been studied by using a positron beam with energies up to 800 MeV.

## §1. Experimental Setup

The performance study of a test calorimeter was made at the electron/positron beamline dedicated to testing detectors at LNS. The test calorimeter is made up with Lead/SciFi detector modules stacked in a  $3 \times 3$  array, which is a small portion corresponding to a polar angle from  $60^\circ$  to  $90^\circ$  of the Backward Gamma detector. Momentum-analyzed positrons were used as an incident beam with the energy ranging from 200 to 800 MeV. A beam profile monitor (BPM) was used to specify the position of the incident positrons. BPM consists of two layers of scintillating fiber (SciFi) hodoscopes. Each hodoscope is composed of 16 SciFi modules with a cross section of  $3 \times 3$  mm<sup>2</sup>. The upstream and downstream layers determine the  $x$  and  $y$  positions of the incident positron, respectively. Figure 1 shows the experimental setup for the performance study of the calorimeter.

The trigger condition for the data acquisition system is described as

$$[x \text{ fiber OR}] \otimes [y \text{ fiber OR}], \quad (1)$$

where  $\otimes$  means coincidence of signals. The maximum trigger rate was 2 kHz and a fraction of accidental coincidence events was negligibly small. The energy calibration for the Lead/SciFi detector modules was made by using 300, 460, 590, and 800 MeV positrons injected on to the central region ( $6 \times 6$  mm<sup>2</sup>) of each module one by one. The detector module has the shape of a truncated pyramid. Therefore the position and the tilted angle of the calorimeter were set so that the beam axis was perpendicular to the front face of the module of interest. Then the gain of each detector module was adjusted.

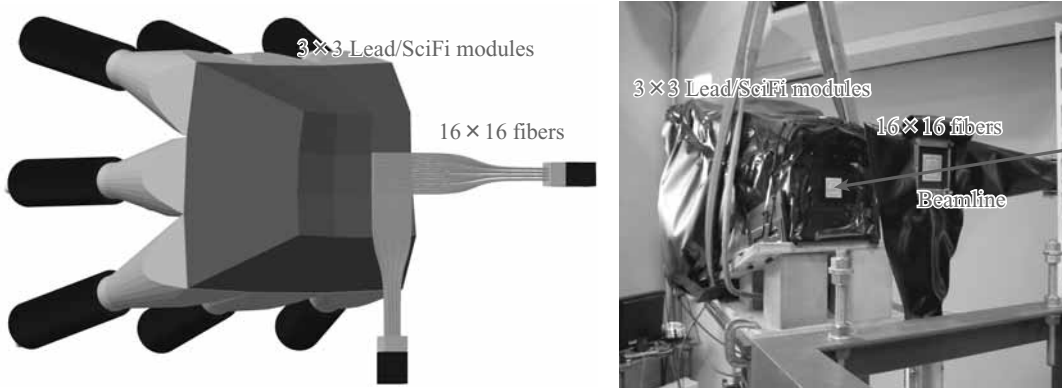


Fig.1. Experimental setup for the performance study of a test calorimeter comprised of 9 Lead/SciFi detector modules. The  $16 \times 16$  scintillating fiber hodoscopes are placed in front of the calorimeter to determine the position of incident positions.

## §2. Energy Response

The deposited energy in the calorimeter is obtained by summing up the measured energies with 9 detector modules as

$$E = \sum_{j=1}^9 E_j. \quad (2)$$

The positrons injected on to the central region ( $6 \times 6 \text{ mm}^2$ ) were selected in the energy measurement to suppress the energy leakage out of the detector modules in the lateral direction. The linearity of the energy response was checked with the ratio of the reconstructed energy to the incident positron energy. Figure 2a) shows the ratio as a function of the incident energy. The normalization of the reconstructed energy is arbitrary. A linear function  $r_\mu(E_i)$  of the incident energy  $E_i$  was fitted to the measured ratio  $r_\mu$ . The fitted result is expressed as

$$r_\mu(E_i) = (1.1307 \pm 0.0022) - (5.0769 \pm 0.3433) \times 10^{-5} E_i, \quad (3)$$

where  $E_i$  is in MeV. The non-linearity of the energy response was found to be less than 6% for the incident beam energies from 200 to 800 MeV.

The energy resolution  $\sigma_E/E$  can be evaluated with a Gaussian mean  $\mu$  and a width  $\sigma$  of the reconstructed energy distribution as

$$\frac{\sigma_E}{E} = \left\{ \left( \frac{\sigma}{\mu} \right)^2 - \left( \frac{\sigma_b}{\mu_b} \right)^2 \right\}^{1/2}, \quad (4)$$

where the effect of beam energy spread  $\sigma_b/\mu_b$  [3] is subtracted. Figure 2 b) shows the measured energy resolution as a function of the incident energy. The energy resolution  $\sigma_E/E$  may be expressed as

$$\frac{\sigma_E}{E} = \left\{ \left( \frac{a_2}{E} \right)^2 + \left( \frac{a_1}{\sqrt{E}} \right)^2 + a_0^2 \right\}^{1/2}. \quad (5)$$

The function (5) is fitted to the data to give the result,

$$\frac{\sigma_E}{E}(E_i) = \left\{ \left( \frac{1.93 \pm 0.11}{E_i} \right)^2 + \left( \frac{6.91 \pm 0.08}{\sqrt{E_i}} \right)^2 + (0.00 \pm 0.92)^2 \right\}^{1/2}, \quad (6)$$

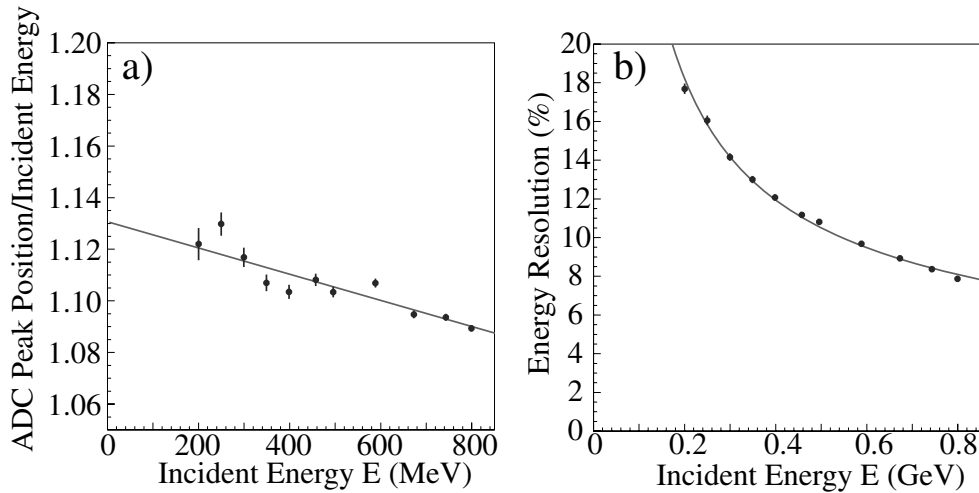


Fig.2. The energy response as a function of the incident positron energy. a) The ratio of the reconstructed energy to the incident energy. The normalization factor is arbitrary. The data are fitted with a linear parametrization  $1.1307 - 5.0769 \times 10^{-5} E_i$ . b) The measured energy resolution. The data are well expressed with the parametrization  $\sqrt{(1.93/E_i)^2 + (6.91/\sqrt{E_i})^2 + (0.00)^2}$ .

where the parameters  $a_0$ ,  $a_1$ , and  $a_2$  are given in % and  $E_i$  in GeV, respectively. The energy resolution for 1 GeV positrons corresponds to 7.2%. The details of the analysis for the energy resolution are described elsewhere [4].

### §3. Position Resolution

The incident position of positrons on the calorimeter was reconstructed by the energy weighted average of the position vectors  $\vec{x}_i$  of 9 modules as

$$\vec{x}_r \propto \sum_{j=1}^9 C_j E_j \vec{x}_j, \quad (7)$$

where the origin of the position vectors was the common center of a circumscribed sphere for front faces of the modules. The normalization was made in such a way that the length of the reconstructed position vector should be the radius of the sphere (300 mm). Since the energy deposit to the central module was much larger than that to the peripheral modules, the weight for the signal from the central module was set to be smaller by using an extra factor  $C_i$ :

$$C_j = \begin{cases} C_0 & \text{for the central module} \\ 1 & \text{for the peripheral modules} \end{cases} \quad (8)$$

The factor  $C_0$  was determined for each incident energy so that the mean of the difference between the reconstructed position and the incident position determined by BPM would be 0. The determined values of  $C_0$  are  $0.01765 \pm 0.00002$ ,  $0.02684 \pm 0.00001$ ,  $0.02484 \pm 0.00001$ ,  $0.02123 \pm 0.00001$ ,  $0.02562 \pm 0.00001$ , and  $0.02473 \pm 0.00001$  for the incident energies of 300, 400, 500, 590, 670, and 800 MeV, respectively. The difference distribution has a Gaussian shape whose mean is 0 by using the determined  $C_0$ . The  $x$  ( $y$ ) position resolution is estimated with the width  $\sigma_x$  ( $\sigma_y$ ) which is obtained by fitting a Gaussian function

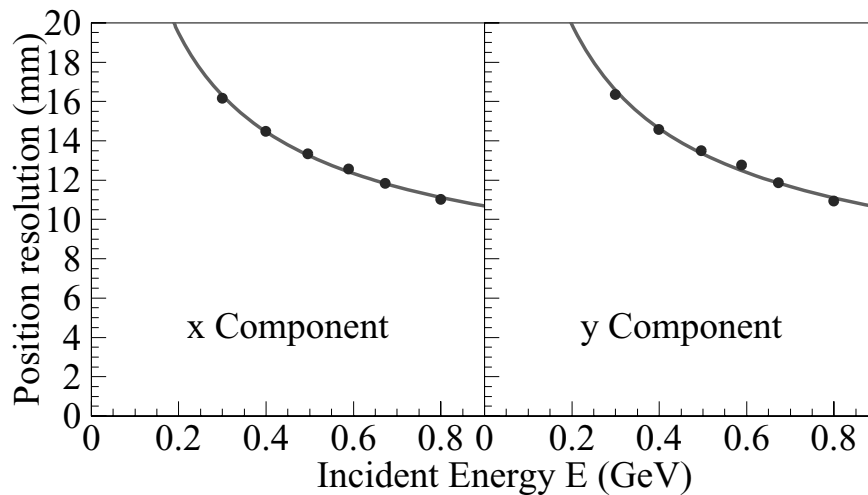


Fig.3. The position resolution as a function of the incident energy. The left and right panels show  $x$  and  $y$  components, respectively. The data are fitted with the form  $\sqrt{(a_2/E_i)^2 + (a_1/\sqrt{E_i})^2 + (a_0)^2}$ .

to the difference distribution in  $x$  ( $y$ ) direction. Figure 3 shows the position resolution as a function of the incident energy. The position resolution  $\sigma_x$  and  $\sigma_y$  may also be represented with a similar function to Eq. (5). The fitted result are

$$\left\{ \begin{array}{l} \sigma_x(E_i) = \left\{ \left( \frac{0.00 \pm 0.00}{E_i} \right)^2 + \left( \frac{8.27 \pm 0.03}{\sqrt{E_i}} \right)^2 + (6.18 \pm 0.07)^2 \right\}^{1/2} \text{ and} \\ \sigma_y(E_i) = \left\{ \left( \frac{0.00 \pm 0.00}{E_i} \right)^2 + \left( \frac{8.53 \pm 0.03}{\sqrt{E_i}} \right)^2 + (5.68 \pm 0.07)^2 \right\}^{1/2}, \end{array} \right. \quad (9)$$

where the position resolution  $\sigma_x$  ( $\sigma_y$ ) and  $E_i$  are given in mm and GeV, respectively. The  $x$  and  $y$  position resolutions for 1 GeV positrons correspond to 10.3 mm and 10.2 mm, respectively. The details of the analysis for the position resolution are described elsewhere [5].

## Acknowledgment

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## References

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