Development of High Position Resolution Gamma-ray Detector Using Wavelength Shifting Fibers

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Introduction

Electromagnetic calorimeters are often used in particle physics experiment. Typical position resolution is 1 cm because it observes center of electromagnetic showers. Almost all high energy gamma-rays create electron positron pair first. If the reaction point is measured, the gamma-ray detector with the position resolution of 0.1mm is realized.

Recently we developed new gamma-ray detectors for 511 keV PET gamma-rays. This detector is consisted of scintillator plates, WaveLength Sifting Fibers.[1][2] six month ago we founded that the reaction point can be measured in this detector. GEANT4 simulation shows that this detector has excellent performance for 1GeV gamma-rays. [3] This research is supported by KAKENHI of Japan Society for the Promotion of Science, 16H03969. We are constructing the prototype detectors and we will perform the test beam experiment in this autumn.

Structure of detector

Our detector consisted of 30 layers. Each layer consisted of 10 times 10 scintillator plates. The size of each scintillator plate is 30 mm times 30 mm times 1 mm. 144 WLSFs cover each 30 mm times 30 mm surface of each palate(Fig.1(a)). For one side of the ends of 144 WLSFs, the 1-12th fibers are connected to 1st PPD, 13-24th fibers are connected to 2nd PPD and so on. For the other side of the ends, the (12 k + i)th fibers are connected to the ith PPD. Thus, 48 PPDs are used in each layer to measure the position of an electron-positron pair.

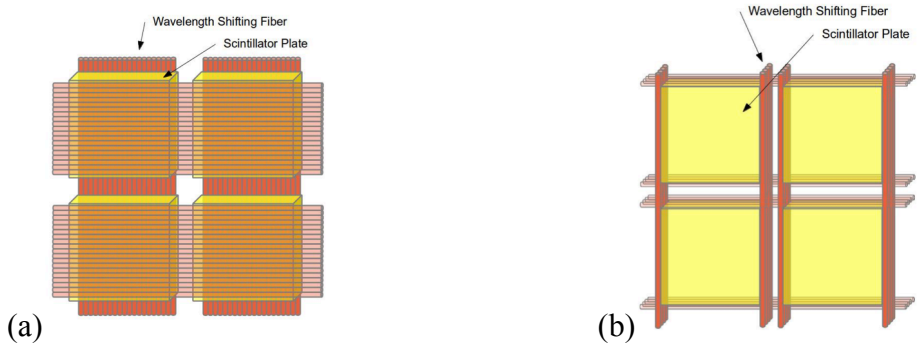

Fig. 1. These figures are small Layer samples which consist of 4 scintillators. (a) WLSFs attached to the surface. (b) WLSFs attached to the side. Bending Fibers solves a problem that fibers intersect.

15 plus 14 WLSFs are attached on each side surface(Fig1.(b)). Thus there are 2 X-sheet + 2 Y-sheets attached to each scintillator plates. One ends are connected to the up-down direction, second ends are connected to the left-up right-down direction, third ends are connected to the left-down right-up direction and last ends are gathered to one big bundle and connected to a photomultiplier tube (PMT). (30 + 39

+ 39) × 2 = 216 PPDs are used to identify the fired plate and to measure the assumed energy, and 2 PMTs are used to create the trigger signal.

GEANT4 simulations

Fig.2 shows the typical event of GEANT4 simulations.

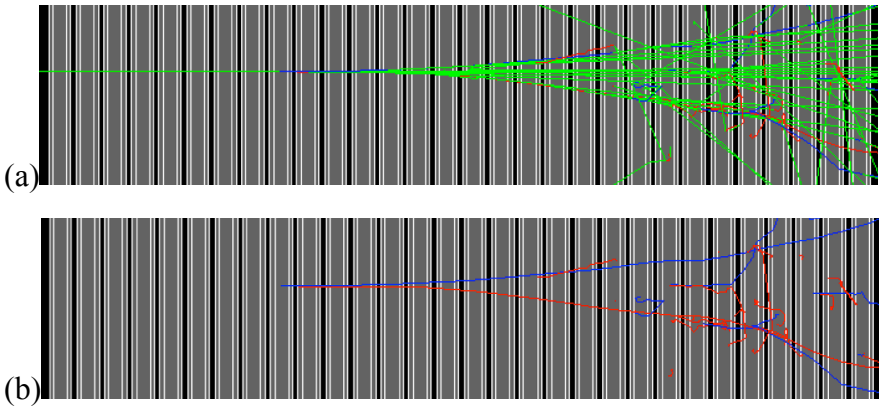

Fig. 2. These figures are typical distribution of electromagnetic shower. Gamma-ray which has kinetic energy of 1GeV incident from left side. Yellow, red and blue lines show gamma-rays, electrons and positrons, respectably. (a) is shows gamma-rays and charged particles. (b) is shows the charged particles only.

An electron-positron pair production is occurred in a 9th layer. The electron and positron penetrate 3 or 4 layers almost the same direction, and spread in rear part of detector. When an electron-positron pair production is occurred in a scintillator plate, the light yield depends on the longitudinal position of the pair creation. The light yield of the next plate corresponds to the energy loss of two minimum ionizing particles. In the case that the Gadolinium Aluminum Germanium Garnet (GAGG) scintillator plate of 1 mm thickness, the energy loss of nest plate is about 2 MeV. The energy loss of third plate is almost same as that of second plate. Since electro-magnetic shower grow at downstream, the energy loss at downstream is often greater than 2 MeV. Sometime small energy loss is appeared due to 511keV gamma-ray from annihilated positron. The reaction plate is regarded as the first plate when 2 or more continuous plates have energy loss as 1.5 to 2.5 MeV.

About 100,000 photons are emitted in the second plate. 15 photo-electrons are detected at each end of the 144 WLSFs bundle. This value is enough to determine the position of the electron-positron pair with the 0.1 mm of resolution. About 150 photo-electrons are detected at all ends of the side WLSFs bundle. The energy resolution of reaction plate is about 160 keV. This value is enough to select the reaction plate.

GEANT4 simulations shows 87 % of gamma-rays are detected with a position resolution of 0.1mm, 9% of gamma-rays pass through and 4% of gamma-rays occur multi-scattering in first or second plate.

We are constructing the prototype detectors and we will perform the test beam experiment in this Autumn. The result will be shown in this conference.

Reference

[1] H.ITO, et al., IEEE Medical Imaging Conference 2014, 8-15 Nov. 2014, Seattle, Washington, USA

[2] N.NAOMI, et al., Advancements in Nuclear Instrumentation Measurement Methods and their Applications, 220, Apr. 20-24 2015, Lisbon Convention Center, Portugal

[3] A.KOBAYASHI, et al., International Symposium on Radiation Detectors and Their Uses, 206, Jan. 18-21 2016, KEK, Japan