Development of Large-Area Charged Particle Detectors with High Position Resolution and Low Cost

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***Abstract*–A Large-area charged particle detector for high energy physics experiments has been developed. This detector includes inorganic scintillation crystals and wavelength-shifting fibers. This enables us to detect charged particles with higher position resolution and lower cost than conventional scintillation detectors and gas chambers. It has an effective area of 1 m × 1 m.**

I. Introduction

WHEN charged particles pass thorough a scintillation crystal, scintillation light is released isotropically and the light with smaller incident angle than the critical angle goes outside the crystal. The area of the light emission region on the crystal depends on the location of the light emitting point and the thickness of the crystal; as shown in Fig. 1, the emission region gets smaller as the crystal thinner. To curb this spread of the light, inorganic crystals with high densities are introduced.

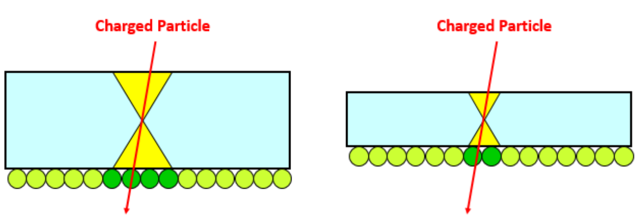

Fig. 1. Using a high density and thin inorganic crystal enables us to detect charged particles with high position resolution. When the crystal is thin, the distance to the boundary surface is short, and the spread of the light is smaller.

Wavelength-shifting fiber (WLSF) is a kind of optical fiber. It absorbs the light of the particular wavelength and emits longer wavelength light. WLSF has approximately 1 m of attenuation length.

Fibers are arranged on the crystals and lead the light to the photodetectors. As shown in Fig. 2, charged particles are detected with four layers of WLSF on the crystal; two layers for the longitudinal direction and another two layers for the lateral direction. One of the WLSF layers is composed of 5000 fibers of 0.2 mm in diameter. The position resolution is expected to be less than 0.2 mm.

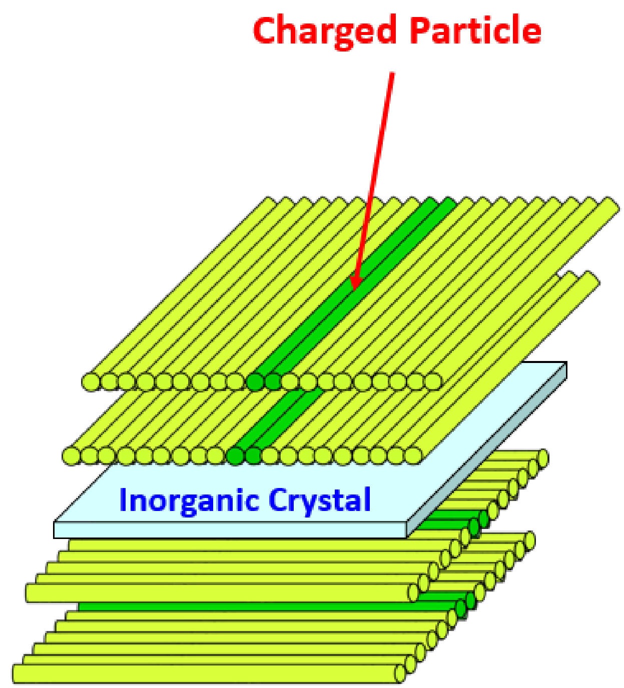

Fig. 2. The detection part is composed of four layers of WLSF on the inorganic scintillation crystal. Two layers are for the longitudinal direction and another two layers are for the lateral direction.

II. EXPERIMENTAL

The number of photoelectrons was measured by using the La-GPS scintillation crystals and the Y-11 (300) MJ WLSF sheet. Fig. 3 shows the crystals and the WLSF used in this experiment. La-GPS crystals are manufactured by C&A Co., Ltd., which have the thickness of 0.5 mm and 1.0 mm. Crystals have chemical composition of $(La,Gd)_2Si_2O_7(Ce)$ and yield 30000 to 40000 photons/MeV light output. Peak wavelength of emission light is 390 nm and density is 5.3 g/cm^3[1]. Y-11 (300) MJ WLSF is made by Kuraray Co. Ltd., which is 0.2 mm in diameter. Fiber has emission peak of 476 nm and absorption peak of 430 nm[2]. Photomultiplier tubes of R9880U-210 series manufactured by Hamamatsu Photonics K.K. are used as the photodetectors. They have ultra bialkali photocathodes of 8 mm in diameter. They have spectral response in the wavelength range of 230 nm to 700 nm and the peak wavelength of response is 400 nm[3].

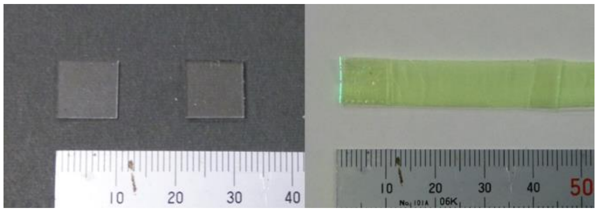

Fig. 3. The La-GPS crystals (left) have the thickness of 0.5 mm and 1.0 mm. The WLSF (right) is Y-11 (300) MJ which is 0.2 mm in diameter and arranged in sheet-like.

The number of photoelectrons was measured by changing the number of layers of WLSF. Fig. 4 shows the setup of the experiment. The β-ray from the ^{90}Sr radiation source was detected by the 0.5-mm or 1.0-mm La-GPS crystal. The crystal was covered with the WLSF sheet. The number of layers of WLSF were changed from one to six. A PMT was attached to the end of the sheet. The detection was triggered by three PMTs. Two scintillation fibers of 1.0 mm in diameters were placed orthogonally immediately above the detection part and each fiber was attached to the PMT. Another scintillation crystal was placed immediately below and attached to another PMT.

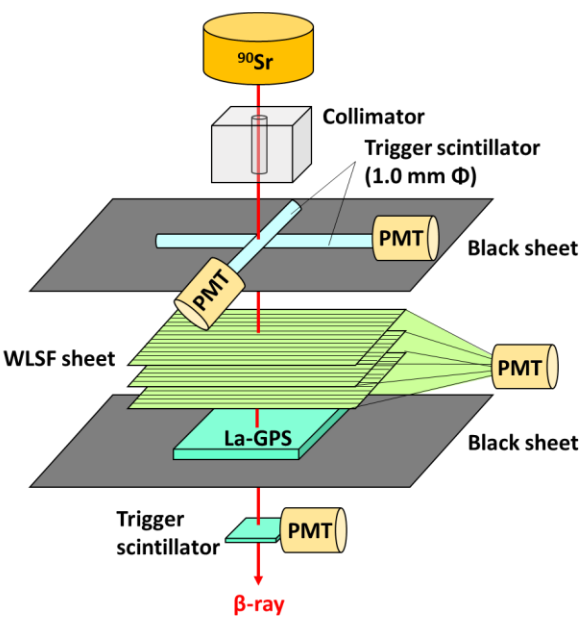

Fig. 4. Setup of the experiment is shown above. The detection is triggered by three PMTs.

III. RESULTS

The results are shown in Fig. 5 and Fig. 6. The number of photoelectrons is a value on one side reading.

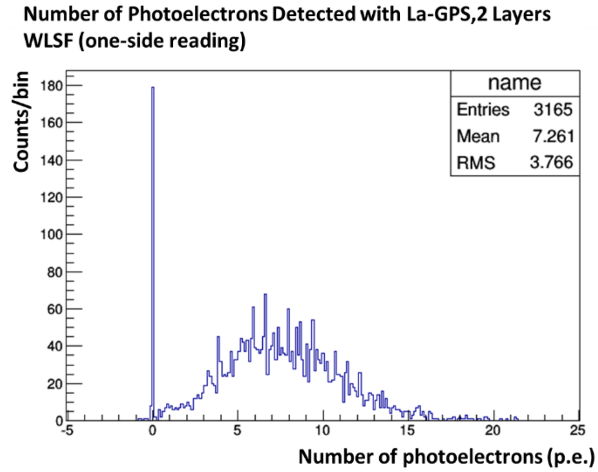

Fig. 5. The distribution of number of photoelectrons detected with 1.0 mm La-GPS crystal, 2 layers WLSF on one-side reading is shown above. 7.261 photoelectrons are detected in average.

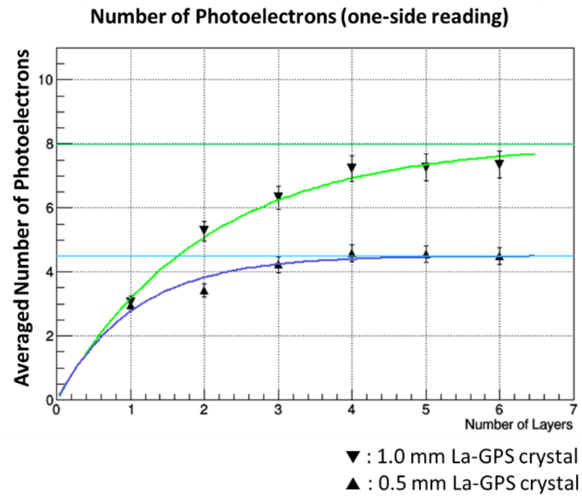

Fig. 6. Averaged number of photoelectrons detected on one-side reading for 1.0-mm La-GPS crystal and 0.5-mm La-GPS crystal by changing the number of WLSF layers is shown above. For each graph, number of photoelectrons are gradually approaching a specific value.

The experimental data could be approximated to a function $y=7.99(1-e^{-x/1.97})$ for 1.0-mm crystal, and $y=4.50(1-e^{-x/1.05})$ for 0.5-mm crystal, respectively. This means the number of photoelectrons are saturated to 7.99 for 1.0-mm crystal and 4.50 for 0.5-mm crystal as increasing the number of layers. Energy deposit in 1.0-mm crystal is approximately 1 MeV, thus approximately 7.99 photoelectrons per 1 MeV can be collected. Considering the number of photoelectrons are doubled with both sides reading, 2 WLSF layers are enough for detecting 10 photoelectrons, which corresponds to of 99% or more detection efficiency. When using 1.0-mm crystal, the number of photoelectron is increased to 1.78 times compared with 0.5-mm crystal. To obtain more than 5 photoelectrons from one side of the fiber, crystal thickness should be more than 0.56 mm.

IV. DISCUSSION

The detector requires large number of photodetectors and readout circuits, both of them cost a lot. Therefore, introducing new readout scheme is indispensable to reduce the cost.

The detection part for one direction is composed of 2 layers of WLSF. Assume one WLSF layer contains n fibers. As shown in Fig. 7, a two-digit base- ($[\sqrt{n}]$+1) number is assigned to each fiber. "[]" means rounding down to the nearest decimal. There are fiber "00" to "$[\sqrt{n}]$X". X is a value in the range from 0 to $[\sqrt{n}]$. Fibers at the same position in horizontal direction in each layers are assigned the same number. In the first layer, bundle of ($[\sqrt{n}]$+1) fibers of which the first digit are the same number are gathered, and in the second layer, bundle of ($[\sqrt{n}]$+ 1) fibers of which the second digit are the same number are gathered. Apart from it, prepare 2($[\sqrt{n}]$+1) photodetectors and divide them into two equal groups. Each number 0 to $[\sqrt{n}]$ is assigned to each photodetectors for each group. The photodetectors in the first group is for identifying the first digit number of the fired fiber; the bundle assigned to the same first digit number is attached to the photodetector of the same number. The photodetectors in the second group is for identifying the second digit number of the fired fiber; the bundle assigned to the same second digit number is attached to the photodetector of the same number. In this way, the fired fibers are identified only by 2($[\sqrt{n}]$+1) photodetectors and the cost of photodetectors and readout circuits is reduced.

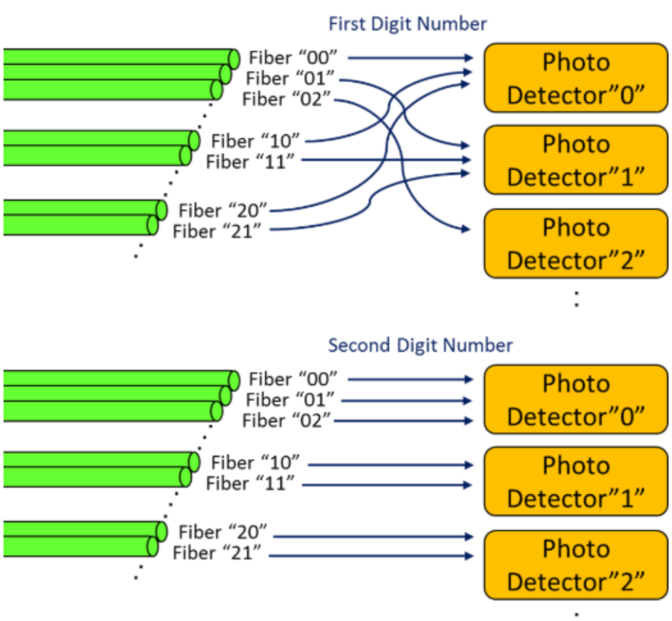

Fig. 7. Schematic diagram of detecting with smaller number of photodetectors is shown above. First digit numbers of the fired fibers are identified in the first layer. Second digit numbers are identified in the second layer.

This detector is planned to have an effective area of 1 m × 1 m by using 1 m × 1 m crystal and WLSFs. Photodetectors are suitable for measurements at high event rate. This detector may take the place of conventional scintillation detectors and gas chambers used in high energy physics experiments.

V. CONCLUSION

We propose the large-area charged particle detector with inorganic scintillation crystals. Using La-GPS crystals, 2 layers of WLSF is enough for detection of charged particles. By using these inorganic crystals and readout system with smaller number of photodetectors, "high position resolution" and "lower cost" detector can be made.

ACKNOWLEDGEMENT

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