Development of Large-Area Charged Particle Detector with Inorganic Scintillator Plates and Wavelength Shifting Fibers

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***Abstract*– A Large-area charged particle detector for high energy physics experiments has been developed. This detector includes inorganic scintillator plates with thicknesses of 0.5 mm and wavelength-shifting fibers (WLSF) of 0.2 mm in diameters. The size of effective area is 1 m by 1 m. The WLSF are connected to both plate surfaces optically, and on the top and the bottom, fibers are attached along to x- and y-axis direction, respectively. The best WLSF to obtain large number of photoelectrons is determined, which enables us to detect charged particles with thinner scintillation crystals. This means an improvement of position resolution of this detector. The number of photoelectrons obtained from a new type scintillation crystal, which is more reasonable than the conventional ones are also measured. This detector enables us to detect charged particles with higher position resolution and lower cost than conventional scintillation detectors and gas chambers.**

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.

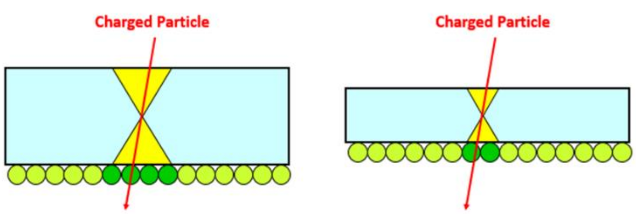

Fig. 1. Using a high density and thin inorganic crystal enables us to detect charged particles with high position resolution. When the crystal is thin, the distance to the boundary surface is short, and the spread of the light is smaller.

As a scintillation crystal, La-GPS(Ce) scintillator is used. It has chemical composition of $(La_{0.75}Ga_{0.24}Ce_{0.01})_2Si_2O_7$. It emits 30,000 to 40,000 photons/MeV. The emission wavelength is 390 to 410 nm. Its density is 5.3 g/cm^3[1]. 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 4 layers of WLSF on the crystal; 2 layers for the longitudinal direction and other 2 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.

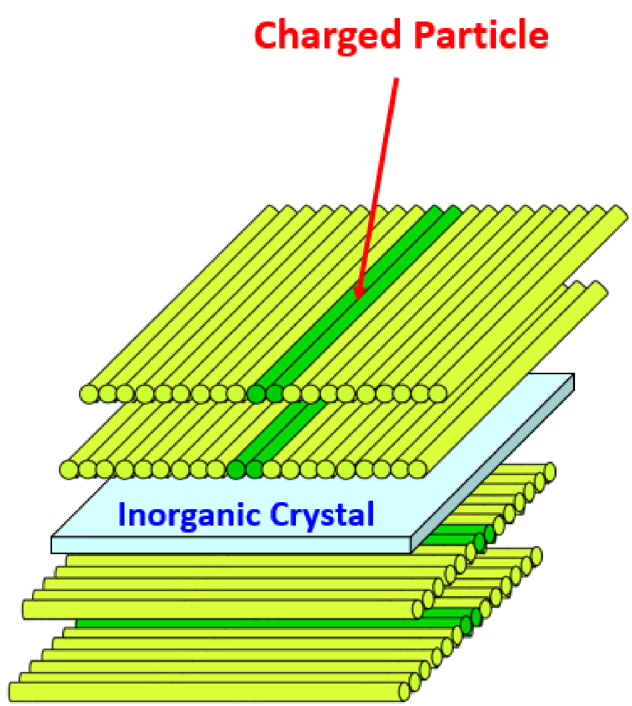

Fig. 2. The detection part is composed of two layers of WLSF on the inorganic scintillation crystal. 1 layers are for the longitudinal direction and another two layers are for the lateral direction.

We measured the number of photoelectrons with two kinds of fibers B-3 (300) MJ and Y-11 (300) MJ, which are manufactured by Kuraray Co. Ltd. to determine which kind of WLSF is the best to read out the light. We also measured the number of photoelectrons with high-growth-rate La-GPS crystal. High-growth-rate scintillation crystal is a scintillator which is crystalized at the higher rate than the conventional one. It is much more reasonable than the conventional one while it contains micro bubble and is not transparent completely.

II. Experimental

The number of photoelectrons was measured by using the La-GPS scintillation crystals. As a WLSF, B-3 (300) MJ and Y-11 (300) MJ are used. Fig. 3. shows the La-GPS crystal and the WLSF used in this experiment.

Fig. 3. The La-GPS crystal (left) used as a scintillator. The Y-11 (300) MJ WLSF (center) and the B-3 (300) MJ WLSF (right) are 0.2 mm in diameter. They are arranged in sheet-like.

La-GPS crystal is manufactured by C&A Co., Ltd., which has the thickness of 0.5 mm. and yield 30000 to 40000 photons/MeV light output. Peak wavelength of emission light is 390 to 410 nm and [1]. B-3 (300) MJ and Y-11 (300) MJ WLSF are made by Kuraray Co. Ltd., which are 0.2 mm in diameters. B-3 (300) MJ Fiber has emission peak of 450 nm and absorption peak of 351 nm[2]. Y-11 (300) MJ 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].

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 90Sr radiation source was detected by the 0.5-mm La-GPS crystal. The crystal was covered with the WLSF sheet. WLSF sheets with 1 to 6 layers of B-3(300) MJ, WLSF sheets with 1 to 6 layers of Y-11 (300) MJ, and a WLSF sheet with 1 layer of Y-11 (300) MJ and 1 layer of B-3 (300) MJ are prepared. A PMT was attached to the end of the sheet. The detection was triggered by three PMTs. Two bundles of 5 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.

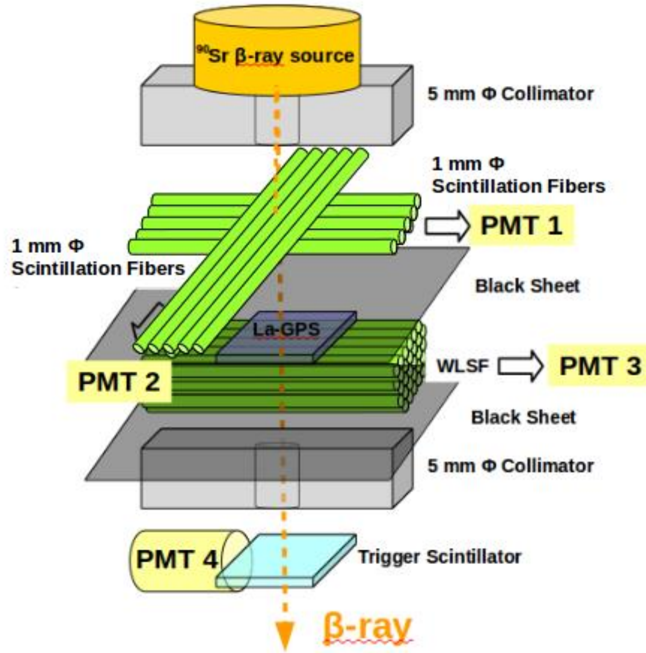

Fig. 4. Setup of the experiment is shown above. The detection is triggered by three PMTs.

The number of photoelectrons using high-growth-rate La-GPS with the thickness of 0.5 mm was measured in the same set-up. Taking the results of former experiment into consideration, we experimented using WLSF sheets with 1 to 6 layers of B-3 (300) MJ. Fig. 5. shows the high-growth-rate La-GPS crystal used in this experiment.

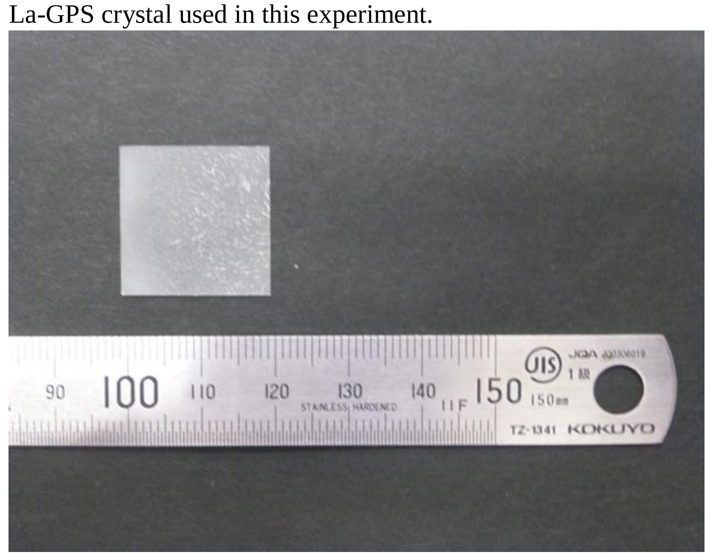

Fig. 5. The high-growth-rate La-GPS crystal with the thickness of 0.5 mm used in the experiment is shown above. It contains micro bubble and is not transparent completely. However, it is more reasonable than conventional ones.

III. RESULTS

The results for Y-11 (300) MJ WLSF are shown in Fig. 6. and Fig. 7. The number of photoelectrons is a value on one side reading.

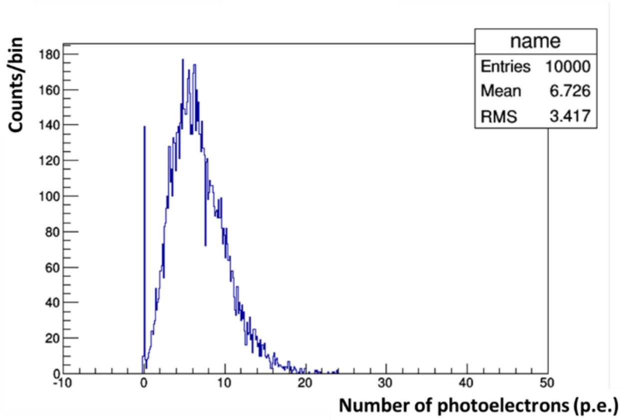

Fig. 6. The distribution of number of photoelectrons detected with 0.5 mm La-GPS crystal, 6 layers Y-11 (300) MJ WLSF on one-side reading is shown above. 6.7 photoelectrons are detected in average.

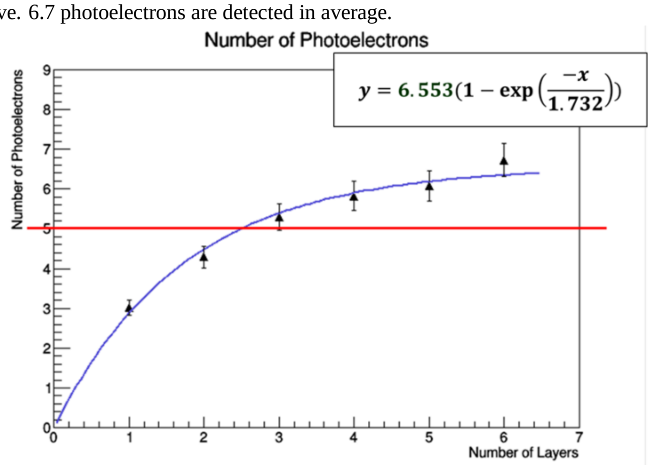

Fig. 7. Averaged number of photoelectrons detected on one-side reading for 0.5 mm La-GPS crystal by changing the number of Y-11 (300) MJ WLSF layers is shown above.

According to Fig. 7., the number of photoelectrons are gradually approaching a specific value. The experimental data could be approximated to a function y=6.553(1-e-x/1.732), and this means the number of photoelectrons are saturated to 6.553 as increasing the number of layers. Energy deposit in 1.0 mm crystal is approximately 1 MeV, thus approximately 13 photoelectrons per 1 MeV can be collected. Considering the number of photoelectrons are doubled with both sides reading, 3 WLSF layers are enough for detecting 10 photoelectrons, which corresponds to of 99% or more detection efficiency.

The results for B-3 (300) MJ WLSF are shown in Fig. 8. and Fig. 9. The number of photoelectrons is a value on one side reading.

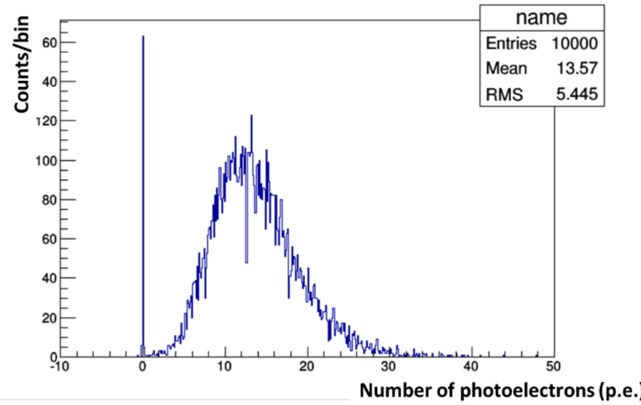

Fig. 8. The distribution of number of photoelectrons detected with 0.5 mm La-GPS crystal, 6 layers B-3 (300) MJ WLSF on one-side reading is shown above. 13.6 photoelectrons are detected in average.

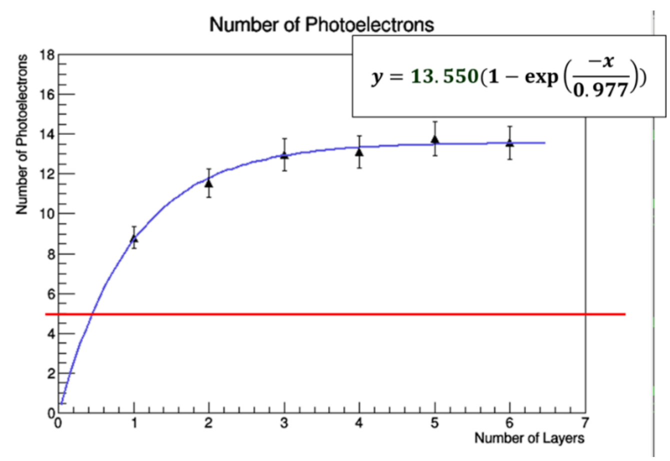

Fig. 9. Averaged number of photoelectrons detected on one-side reading for 0.5 mm La-GPS crystal by changing the number of B-3 (300) MJ WLSF layers is shown above.

According to Fig. 9., the number of photoelectrons are gradually approaching a specific value. The experimental data could be approximated to a function y=13.550(1-e-x/0.977), and this means the number of photoelectrons are saturated to 13.550 as increasing the number of layers. Energy deposit in 1.0 mm crystal is approximately 1 MeV, thus approximately 27 photoelectrons per 1 MeV can be collected. Considering the number of photoelectrons are doubled with both sides reading, 1 WLSF layer is enough for detecting 10 photoelectrons, which corresponds to of 99% or more detection efficiency.

The result for B-3 (300) MJ WLSF and high-growth-rate La-GPS is shown in Fig. 10. The number of photoelectrons is a value on one side reading.

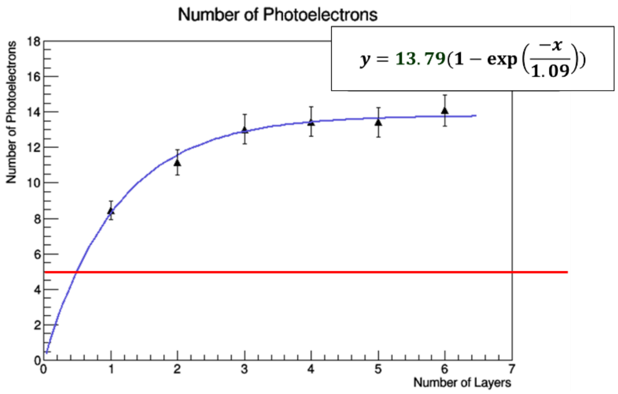

Fig. 10. Averaged number of photoelectrons detected on one-side reading for 0.5 mm high-growth-rate La-GPS crystal by changing the number of B-3 (300) MJ WLSF layers is shown above.

According to Fig. 10., the number of photoelectrons are gradually approaching a specific value. The experimental data could be approximated to a function y=13.79(1-e-x/1.09), and this means the number of photoelectrons are saturated to 13.79 as increasing the number of layers. Energy deposit in 1.0 mm crystal is approximately 1 MeV, thus approximately 28 photoelectrons per 1 MeV can be collected. Considering the number of photoelectrons are doubled with both sides reading, 1 WLSF layer is enough for detecting 10 photoelectrons, which corresponds to of 99% or more detection efficiency. The number of photoelectrons when using high-growth-rate La-GPS is approximately equal to the value when using conventional one.

IV. Discussion

We propose the large-area charged particle detector with inorganic scintillator plates and wavelength shifting fibers including inorganic scintillation crystals. It is confirmed that photons from La-GPS can be read out with WLSF B-3 (300) MJ and Y-11 (300) MJ. When using B-3 (300) MJ, the more photoelectrons can be obtained and 1 WLSF layer is enough for detecting 10 photoelectrons with both sides reading. The same result is obtained when using high-growth-rate La-GPS. Taking the crad of WLSF cannot absorb photons, 2 layers of WLSF is enough for charged particle detection. By using these inorganic crystals, “high position resolution” and “lower cost” detector can be made.

Acknowledgment

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