AXEL: High pressure xenon gas Time Projection Chamber for neutrinoless double beta decay search

2016 J. Phys.: Conf. Ser. 718 062047

(http://iopscience.iop.org/1742-6596/718/6/062047)

Journal of Physics: Conference Series **718** (2016) 062047 doi:10.1088/1742-6596/718/6/062047

AXEL: High pressure xenon gas Time Projection Chamber for neutrinoless double beta decay search

Sheng Pan

Kyoto University, Oiwake-cho Sakyo-ku Kyoto-shi Kyoto-fu, Japan.

E-mail: bansei0526@scphys.kyoto-u.ac.jp

Abstract. AXEL is a high pressure xenon gas TPC detector being developed for neutrinoless double-beta decay search. We use proportional scintillation mode with a new electroluminescence light detection scheme to achieve very high energy resolution with a large detector. The detector has a capability of tracking which can be used reduce background. The project is in a R&D phase, and we report current status of our prototype chamber with 10 L and 8 bar Xe gas. We also present the results of the photon detection efficiency measurement and the linearity test of silicon photomultiplier(SiPM).

1. Introduction

AXEL is a high pressure xenon gas time projection chamber (TPC), currently under development, for the search for neutrinoless double beta decay ($0\nu\beta\beta$ decay). This detector has three excellent features : extendable to large mass (1 ton enriched high pressure ^{136}Xe gas), good energy resolution (aiming 0.5 % FWHM at 2.48 MeV , i.e. Q value of the $0\nu\beta\beta$ of ^{136}Xe) and strong background rejection power using event topology. With these features, we are aiming to explore all the region of inverted hierarchy of neutrino masses.

Schematic view of the AXEL detector is illustrated in Fig. 1. Primary scintillation lights are detected by PMTs and used as the start timing of the event. Ionized electrons drift toward so called Electroluminescence Light Collection Cell (ELCC) plane and are converted to light signal by electroluminescence (EL) process. The concept of ELCC is shown in Fig. 2. It consists of an anode plate, supporting PTFE plate, mesh and silicon photon multiplier (SiPM), we will use Multi-Pixel Photon Counters (MPPC's) produced by Hamamatsu photonics. The anode plate and PTFE have holes corresponding to MPPC's and make cell structure. By applying high voltage between the anode plate and mesh, ionized electrons are collected into cells along the lines of electric field, and generate EL photons, which are detected by VUV-sensitive MPPCs cell by cell. Because the EL region is contained in the each cell, this detector has less dependence on event position. Furthermore, It is easy to extend to large area due to the solid structure.

2. R&D status

2.1. Measurement of the basic properties of MPPC

2.1.1. VUV photon detection efficiency (PDE) The wavelength of the electroluminescence photon from Xe gas is peaked at VUV region (178nm). HAMAMATSU photonics recently developed MPPCs sensitive to VUV photons from liquid xenon[2]. We constructed a setup to measure the MPPC's photon detection efficiency (PDE) for VUV photons in 8 bar high pressure

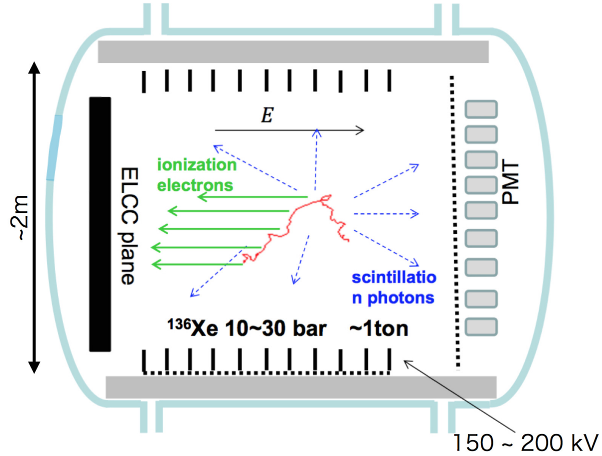

Figure 1. Schematic view of the AXEL detector

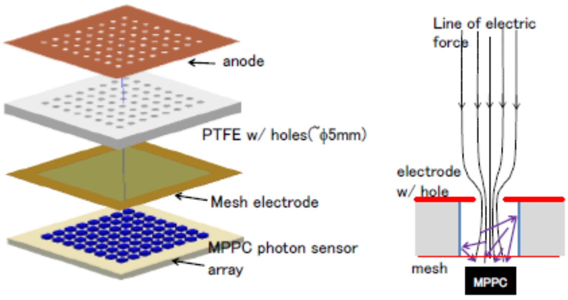

Figure 2. Concept of ELCC

gaseous xenon. A VUV sensitive Photomultiplier tube (PMT) is used as a reference. Figure 3 shows the schematic view and picture of the setup. The coincidence signal of PMT and two MPPCs placed on top of the setup are used for the data acquisition trigger in order to remove PMT's dark current event. As a constant light source, vapor deposited ^{241}Am alpha source (5.4 MeV) is mounted on top of the setup and generate scintillation light. Due to high pressure gas, the range of the alpha-ray from ^{241}Am is less than 2 mm, so it can be regarded as a point-like light source. Photon spectrum of alpha source detected by PMT is shown in Figure 4. Peak structure corresponding to the monochromatic alpha energy is clearly seen. The PDE of VUV MPPC is calculated by comparing the numbers of photons detected by the MPPC and PMT by taking into account the acceptance difference, crosstalk and afterpulse of MPPC and the PMT's quantum efficiency. Figure 5 shows the obtained PDE as a function of applied over-voltage.

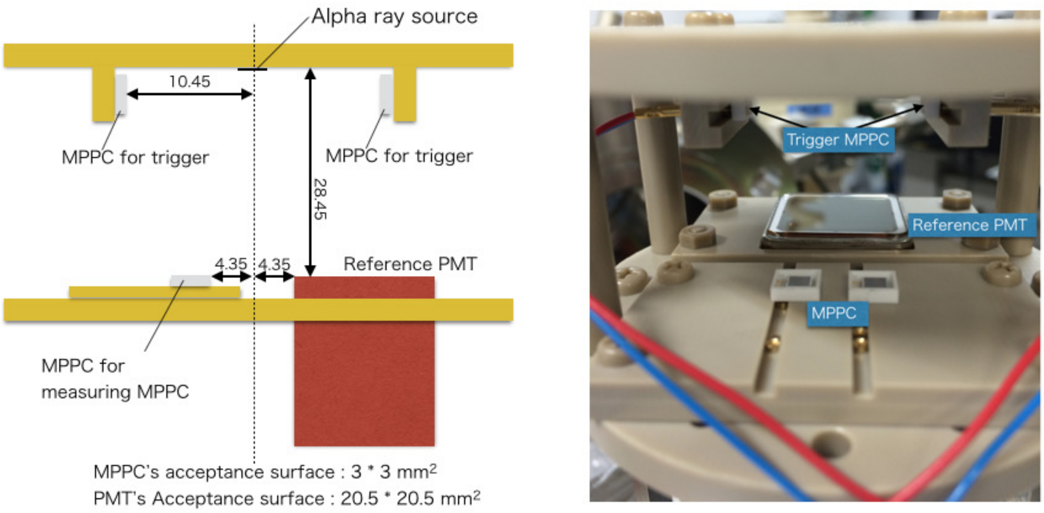

Figure 3. Left : Schematic view of the setup to measure MPPC's PDE. Right : Picture of the setup.

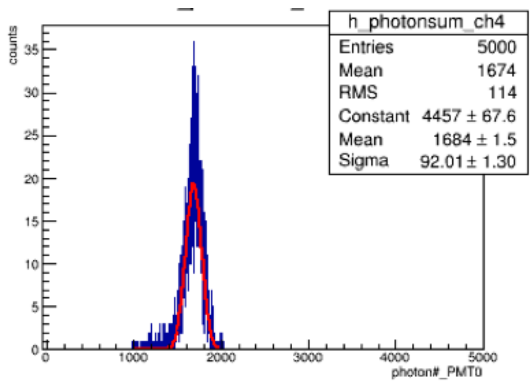

Figure 4. Photon spectrum detected by PMT.

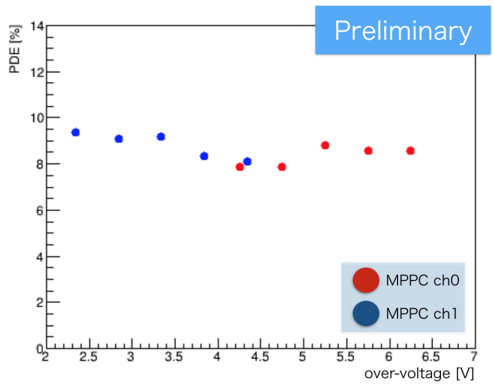

Figure 5. PDE of the VUV MPPC as a function of applied over-voltage.

2.1.2. Liniarity The linearity of MPPC is very important to realize high energy resolution. In our experiment, many photons ($\sim 10^5$) would be detected in relatively long time ($\sim 5\mu$sec). The linearity of MPPC for such a long pulse was measured by comparing MPPC and PMT with controlled LED light. The picture of setup is shown in Figure 6.Typical waveform sample of MPPC and PMT are shown in Figure 7. Figure 8 shows the results of the linearity measurement of two types of MPPC : 50 μm pixel-pitch and 25 μm pixel-pitch. Saturation is observed for light stronger than 4×10^4photons /5μs (50μm-pitch, 3,600 pixels), 5×10^4 photons /5μs (25μm-pitch, 14,400 pixels), respectively. Correction is necessary for such a high light yield. Fluctuation remaining after the correction is evaluated to be about 0.0033% at $\sim 10^5$ photons and is negligibly small compared to other factors.
The recovery time of the MPPC τ is also evaluated by fitting the saturation curve with the function :

$$y = \frac{1}{1/ax + \frac{\tau}{\mathrm{N}_{\mathrm{pixels}} \times 5\mu\mathrm{s}}}. \tag{1}$$

The result is 49.5 ns for 50μm-pitch device and 89.3 ns for 25μm-pitch device, respectively.

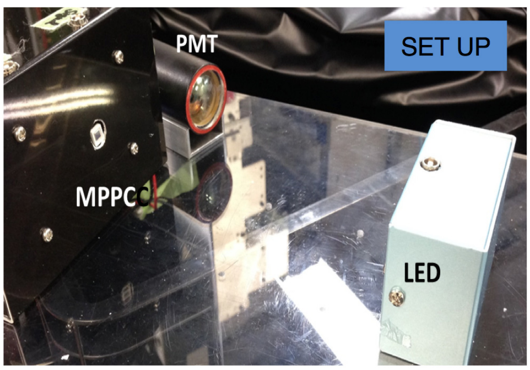

Figure 6. Setup to measure MPPC's linearity.

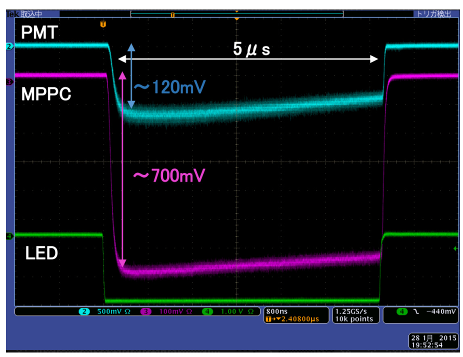

Figure 7. Typical waveform of MPPC and PMT. Square wave supplied to LED is also shown.

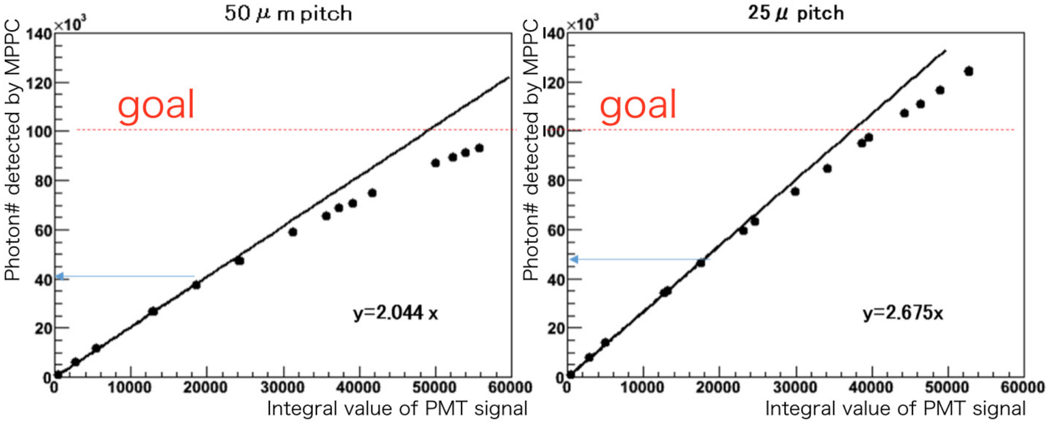

Figure 8. The response of the MPPC to the large light. The horizontal axis is the light yield (a.u.) measured by the PMT. The vertical axis is the number of photons measured by the MPPC'S

2.2. Demonstration with prototype chamber

We have developed a small prototype detector with a 6 cm-long and 10 cm-diameter sensitive volume as shown in Fig.9,10. The ELCC plane has 64(8 × 8) MPPC's placed in 7.7 mm pitch. Two PMT's, which are sensitive to VUV photons and tolerable to a 10 bar pressure are installed at the drift plane. Performance at 4 bar Xe gas was evaluated using gamma ray from a ^{57}Co source. Since the VUV-sensitive MPPC was not available at this time, MPPC's sensitive to visible photons were used together with a sheet coated with tetra-phenyl-butadien as the wavelength shifter.

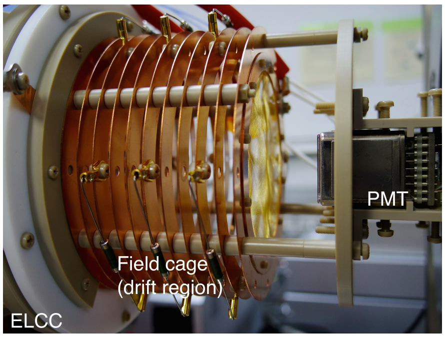

Figure 9. Picture of the prototype detector. Sensitive region, ELCC and PMT can be seen.

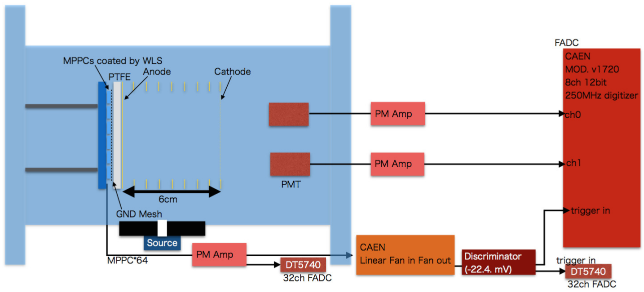

Figure 10. Schematic view of the prototype detector and signal readout.

2.3. Energy Resolution

We measured energy resolution with 122keV gamma-rays from ^{57}Co source. Events contained in the center 6×6 cells were selected. Figure 11 shows the distribution of the total number of photons which corresponds to the deposited energy. Four peaks corresponding to the K_α and K_β X-ray from Xenon (29.8keV, 33.00keV), escape peak of gamma-ray from ^{57}Co (92keV) and full peak of ^{57}Co (122keV) are clearly seen. The energy resolution was evaluated by fitting these peaks with Gaussian. The obtained energy resolution are shown in table 1. The energy resolution at the $0\nu\beta\beta$ Q value was evaluated by fitting measured energy resolutions with a function : $A\sqrt{E} + BE$, where E is deposit energy [keV] and A, B are fitting parameter, and extrapolating it to Q-value, 2.48MeV. The result is 4.96%(FWHM) at Q-value and this value is bad compared with our final goal of 0.5%. Contribution from the linear term is large, so some factors other than statistics may be dominant. Most probable source is considered to be the optical crosstalk at the WLS sheet. We expect that the usage of the VUV-sensitive MPPCs will solve this problem and improve energy resolution.

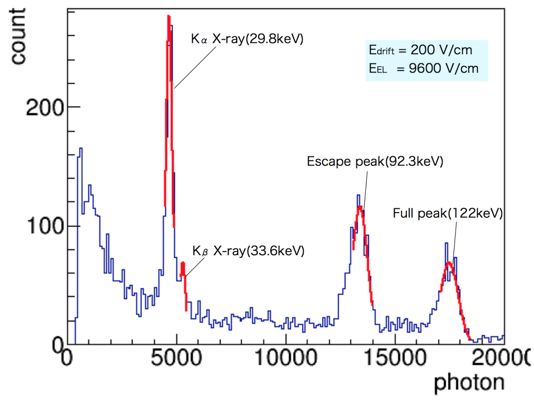

Figure 11. Number of detected photons when irradiated with 122keV gamma-rays from ^{57}Co source.

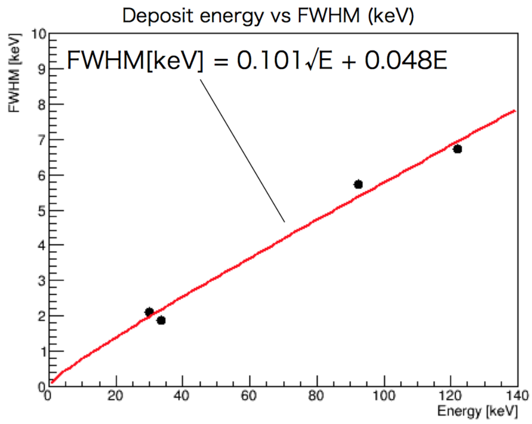

Figure 12. Deposit energy vs energy resolution (FWHM) [keV].

Table 1. Energy resolution of each peak

Energy [keV]	29.78	33.62	92.28	122.06
Number of detected photon	4692.2	5323.6	13418.2	17501.9
Energy resolution (FWHM)	7.1%	5.6%	6.2%	5.5%

3. Summary

AXEL is a $0\nu\beta\beta$ search experiment with high pressure Xe gas TPC and has three excellent features : high energy resolution, large mass and background rejection ability. We demonstrated the concept of AXEL detector with a prototype detector and achieved the energy resolution of 4.96%(FWHM) at Q-value, which is estimated by extrapolating the measurement using a ^{57}Co gamma-ray source. This value is not sufficient to our final goal, 0.5%, but we have some solutions to improve energy resolution : replacing MPPCs with VUV sensitive MPPCs, applying fiducial cut in the drift direction using the information of PMT's signal, etc. Basic properties of MPPCs are also studied. The result of MPPC's PDE is about 8 - 9.5 %. This value satisfies our requirement. The linearity of MPPC is not sufficient for expected maximum number of photons, 10^5 photons/5μs, but we can apply correction.

References

[1] Aprile E, Bolotnikov A, Bolozdynya A and Doke T *Noble Gas Detector*, ISBN:978-3-527-40597-8
[2] Kaneko D, *Performance of UV-sensitive MPPC for liquid xenon detector in MEG experiment*, DOI:10.1109/NSSMIC.2013.6829484