AXEL : Neutrinoless double beta decay search with a high pressure xenon gas Time Projection Chamber

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Abstract. AXEL is a high pressure xenon gas TPC detector being developed for neutrinoless double-beta decay search. It is operated at the proportional scintillation mode. We have developed 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 to reduce background. The project is in a R&D phase, and we report the current status of our prototype chamber with 10 L and 4 bar Xe gas.

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) of $^{136}$Xe. This detector has three excellent features: extendable to large mass (ton scale), good energy resolution (aiming 0.5 % FWHM at 2.46 MeV, i.e. Q value of $0\nu\beta\beta$ of $^{136}$Xe) and strong background rejection power using event topology. With these features, we are aiming to explore all the regions of inverted hierarchy of neutrino masses.

Schematic view of the AXEL detector is illustrated in Figure 1. Primary scintillation lights are detected by PMTs and used as the start timing of the event. Ionized electrons drift toward so-called the Electroluminescence Light Collection Cell (ELCC) plane and are converted to light signals by the electroluminescence (EL) process. The concept of ELCC is shown in Figure 2. It consists of an anode plate, supporting PTFE plate, mesh and silicon photon multiplier (SiPM). The anode and PTFE plates have holes to each of which a SiPM is attached. One set of holes and a SiPM make up a 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 SiPM’s cell by cell. Because the EL region is contained in each cell, this detector has less dependence on event position. The structure is rigid and is easy to extend to a large area.

2. Demonstration with a prototype detector

We have developed a small prototype detector with a 9 cm-long and 10 cm-diameter sensitive volume as shown in Figure 3. The ELCC plane has 64(8 × 8) VUV-sensitive MPPC’s as the SiPM (Type No:S13370-4870 by Hamamatsu photonics) placed in 7.5 mm pitch. Two PMT’s, which are sensitive to VUV photons and tolerable to a 10 bar pressure are installed. Performance
with 4 bar Xe gas was evaluated using gamma ray from a $^{57}$Co source. The applied electric field strengths are 100 V/cm/bar for drift region and 2700 V/cm/bar for EL region.

2.1. Energy Resolution

We evaluated the energy resolution with 122 keV gamma-rays from $^{57}$Co source. Events contained in the center 33 cells were selected (see Figure 4). Figure 5 shows the distribution of the total number of photons which corresponds to the number of ionization electrons and hence the deposited energy. Four peaks corresponding to the K$_{\alpha}$ and K$_{\beta}$ X-ray from Xenon (29.8keV, 33.0keV), the 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 the first three peaks (29.8keV, 33.0keV, 92keV) with Gaussians and the last peak (122keV) with “Gaussian $+ax+b$” considering continuous components from background. The obtained energy resolutions are shown in table 1. The energy resolution at the 0$\nu\beta\beta$ Q-value is evaluated by extrapolating measured energy resolutions. We tried two extrapolations: $A\sqrt{E}$ assuming statistical dependence only and $A\sqrt{E} + BE^2$ assuming statistical dependence plus linear dependence on energy, where $E$ is the
deposited energy [keV] and A, B are fitting parameter. The fitting results are $(0.42 \pm 0.019)\sqrt{E}$ and $(0.39 \pm 0.036)\sqrt{E} + (0.0023 \pm 0.0028)E^2$ respectively and shown in Figure 6. Extrapolated energy resolution at 2458 keV (Q-value) is 0.85% with the function $A\sqrt{E}$ and 2.03% with the function $A\sqrt{E} + BE^2$. Source of the linear term is now under investigation.

![Figure 5](image)

**Figure 5.** Number of detected photons when irradiated with 122keV gamma-rays from $^{57}$Co source.

![Figure 6](image)

**Figure 6.** Deposit energy vs energy resolution (FWHM) [keV].

| Energy [keV] | Number of detected photon | Energy resolution (FWHM) |
|--------------|---------------------------|--------------------------|
| 29.78        | 4517.3                    | 7.3±0.47%                |
| 33.62        | 5169.5                    | 7.0±1.7%                 |
| 92.28        | 13900.2                   | 4.6±0.69%                |
| 122.06       | 18445.0                   | 4.0±0.30%                |

3. Future plan

As the next step, we plan to evaluate our prototype detector with higher energy gamma ray, 511 keV. In 2017, we will construct a larger prototype detector, φ40 cm-diameter and 40 cm-long to measure the performance at the $0\nu\beta\beta$ decay Q-value.

4. Summary

AXEL is a $0\nu\beta\beta$ search experiment with a high pressure Xe gas TPC and has three excellent features: high energy resolution, large mass and background rejection ability. We demonstrated the concept of the AXEL detector with a prototype detector and achieved an energy resolution of 0.85%(FWHM) - 2.03%(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: optimizing electric field strengths of drift region and EL region, installing gas purification system, etc. We also plan to construct a larger prototype detector to measure responses to the $0\nu\beta\beta$ Q-value.

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