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Drift field generation with Cockcroft-Walton voltage multiplier in xenon gas for AXEL $0\nu\beta\beta$ search detector

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Abstract. For noble gas Time Projection Chambers (TPCs) in the field of rare event searches, operation of high voltage to generate an electric field is a key point. We designed a new structure of electrodes to shape a strong and uniform drift field without electric discharge, in which electrodes of two different radius are used. We also developed Cockcroft-Walton voltage multiplier as a high voltage generator inside a pressure vessel. We achieved −30.0 kV output and examined such kind of voltage generator is feasible as a high voltage supplier in a TPC.

1. Introduction

Time projection chambers (TPCs) using noble gas are widely developed and used for rare event searches such as neutrinoless double beta decay ($0\nu\beta\beta$) searches and direct dark matter searches. In these TPCs, a strong drift field and a large drift region are required in order to achieve high performance like good energy resolution and large target mass. Thus it is necessary to generate and operate high voltage without electric discharge, which is technically challenging.

We report on the way to form the strong drift field and to generate DC high voltage in AXEL TPC, which is a high-pressure xenon gas TPC for $0\nu\beta\beta$ search.

2. Overview of the AXEL experiment

The target of **A** **X**enon **E**lectro**L**uminescence (AXEL) experiment is the search for $0\nu\beta\beta$ of ^{136}Xe, whose Q-value is 2458 keV and the most stringent limit for the half-life is $T^{0\nu}_{1/2} > 1.07 \times 10^{26}$ yr[1].

Since $0\nu\beta\beta$ are extremely rare, the following three points are important for the search: large target mass, high energy resolution, and background rejection.

To achieve the above three points, we use a high-pressure xenon gas TPC. In AXEL TPC, VUV-sensitive PMTs detect scintillation of xenon and determine the time of an event. An applied uniform electric field, the drift field, makes the ionization electrons drift toward a tracking plane named ELCC, and then the 3D track is reconstructed via the X-Y projected track image and the drift time of ionization electrons. The deposited energy is also measured with high resolution in ELCC. Thus we can remove the background events with energy and topology information.

We have two prototype detector. We are now developing the 180-L prototype to realize 0.5% (FWHM) energy resolution at Q-value. The 10-L prototype was used for the proof of principle of ELCC[2], and it is now used for testing newly developed components.

3. Drift field cage

The energy resolution of AXEL TPC gets worse because of recombination of the ionization electrons and xenon ions. The rate of recombination depends on the intensity of the drift field; a stronger field makes recombination rate less. Position dependence of the field intensity also leads to worse energy resolution. We set the target as 100 V/cm/bar±5% for the drift field.

The drift field is defined by the anode electrode on the top of ELCC, the cathode mesh electrode on the PMT side, and the shaping electrodes aligned between the anode and the cathode. We call these electrodes and supporting structure the field cage.

The electrodes reach −15 kV for the anode and −65 kV for the cathode in the 180-L prototype. The field cage has to withstand such a high voltage without any electric discharge. To improve the efficiency of detecting initial scintillation photons, VUV reflectivity is also important.

To satisfy the above requirement, we adopt the design in Fig.1. The strip electrodes have certain voltages which degrade from the cathode voltage to the anode voltage. The cause of the field nonuniformity is the 0 V potential of the pressure vessel. Hence electric shielding, by strip electrodes of two different radius with a little overlap, is effective to realize the target uniformity.

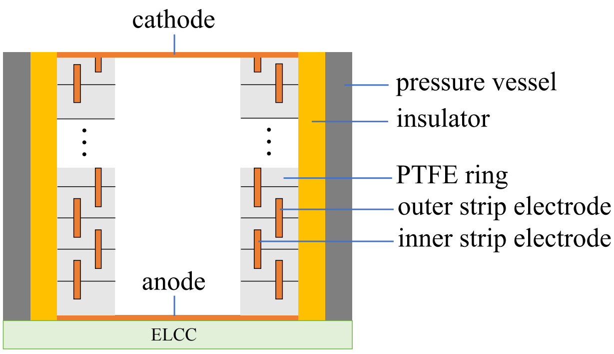

Figure 1. Schematic crosssectional view of the field cage

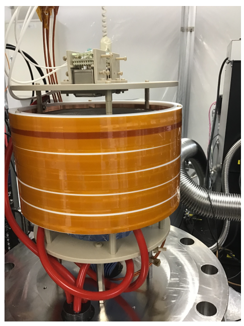

Figure 2. The field cage for the 10-L prototype

Fig.2 is the field cage by the described design for the 10-L prototype. The drift length is 10 cm, and the radius of the PTFE rings is 10 cm. Cupper strip electrodes in the PTFE rings have 0.3 mm of thickness and 12 mm of width, and their radii are 9 cm for inner and 9.3 cm for outer. The strip electrodes are placed with 10 mm spacing, thus an overlap between an outer strip and an inner strip is 2 mm. Insulation between the pressure vessel is done by 125-μm-thick polyimide sheet. According to a finite element method simulation, the condition of 100 V/cm/bar±5% is satisfied through the entire interior volume of this field cage. It was installed in the 10-L prototype, and then −6.5 kV for anode and −11 kV for cathode were successfully applied under 6 bar of xenon gas. They correspond to 75 V/cm/bar of the drift field. There was, however, discharge in case of higher voltage. It is because triple junctions on the strip electrodes and the gap between PTFE rings. They are temporarily covered with polyimide tape and can be fixed by removing PTFE between electrodes and the pressure vessel.

4. Cockcroft-Walton voltage multiplier

The cathode voltage in the 180-L prototype is −65 kV, and it reaches a few hundred kV for future ton-scale detector. Applying such a high voltage into a pressure vessel directly through a feedthrough has a severe risk of surface discharge on the feedthrough. We, therefore, take the approach of applying relatively low AC voltage and converting it to DC high voltage in the pressure vessel with Cockcroft-Walton (CW) voltage multiplier.

CW multiplier is a cascaded circuit. A stage of CW multiplier consists of two capacitors and two rectifiers. The potential of one capacitor, charging capacitor, oscillates because of AC input, and it charges another capacitor, storing capacitor. Thanks to the rectifiers, the potential of the storing capacitor is stable. Thus DC high voltage is obtained at the storing capacitor in a higher stage. The output voltage is ideally N times peak-to-peak of input AC for N-stage CW multiplier. It, however, deteriorates because of load resistors and shunt capacitance of rectifiers.

For use in xenon, we made a CW multiplier with polyimide-based FPC, which is low-outgassing (Fig.3). We used silicon diodes for rectifiers and 0.1-μF ceramic capacitors for both charging and storing capacitors. The loads are 200-MΩ for each stages. One unit consists of 10 stages, and the number of stages is extendable by connecting each other.

We measured the output of 20-stage FPC CW multiplier with several input frequencies. The voltage deterioration by load resistor was recovered with sufficiently fast AC input compared to the RC time constant. We achieved the output of −30.0 kV with 1.6 kVpp and 5 kHz input.

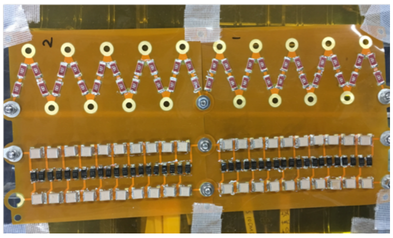

Figure 3. 20-stage FPC CW multiplier. Two units are connected.

FPC CW multiplier is placed on the field cage and thus near ELCC. Oscillating potentials of charging capacitors can cause noise. The noise effect on signals of SiPMs in ELCC was examined by oscilloscope. As a result, there was no apparent noise compared to 1 p.e. signals of SiPMs.

5. Summary

AXEL is a $0\nu\beta\beta$ search experiment with a high-pressure xenon gas TPC. Since a strong and uniform drift field is the key to achieve high energy resolution, we developed a dedicated field cage, which has strip electrodes of two different radius. As a high voltage source in the pressure vessel, we developed polyimide-base FPC Cockcroft-Walton voltage multiplier. We achieved the output of −30 kV and examined that noise caused by CW multiplier is not a problem.

Acknowledgments

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References

[1] Gando A *et al.* 2016 *Phys. Rev. Lett.* **117** 082503
[2] Ban S *et al.* 2017 *Nucl. Instrum. and Meth.* A **875** 185–192