AXEL
High pressure xenon gas TPC

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for the AXEL collaboration

Nagoya Workshop on Technology and Instrumentation
in Future Liquid Noble Gas Detectors, 2024/02/15

Introduction

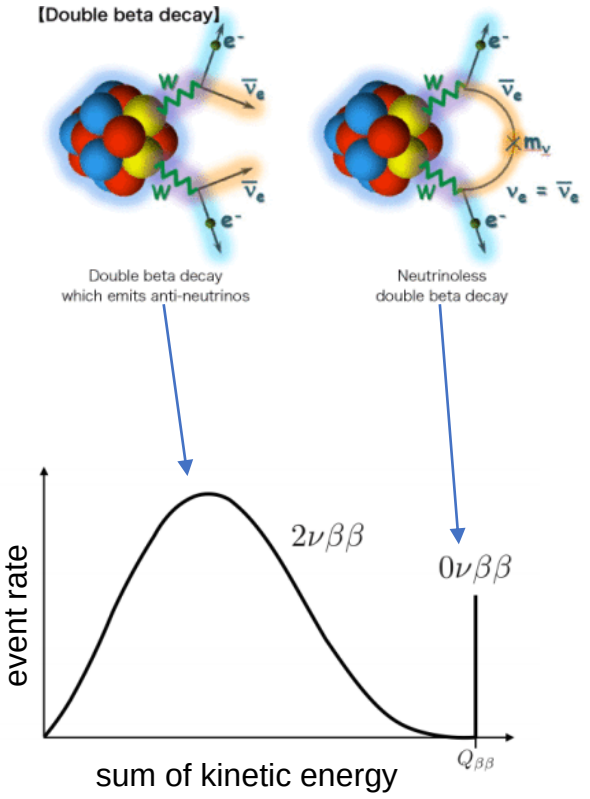
Neutrinoless double beta decay: $0\nu\beta\beta$

- Motivation: Proof of Majorana neutrino (if it happen)
  - Origin of the light neutrino mass: See-Saw mechanism
  - Matter-antimatter asymmetry: Leptogenesis

$$\nu \overset{?}{=} \bar{\nu}$$

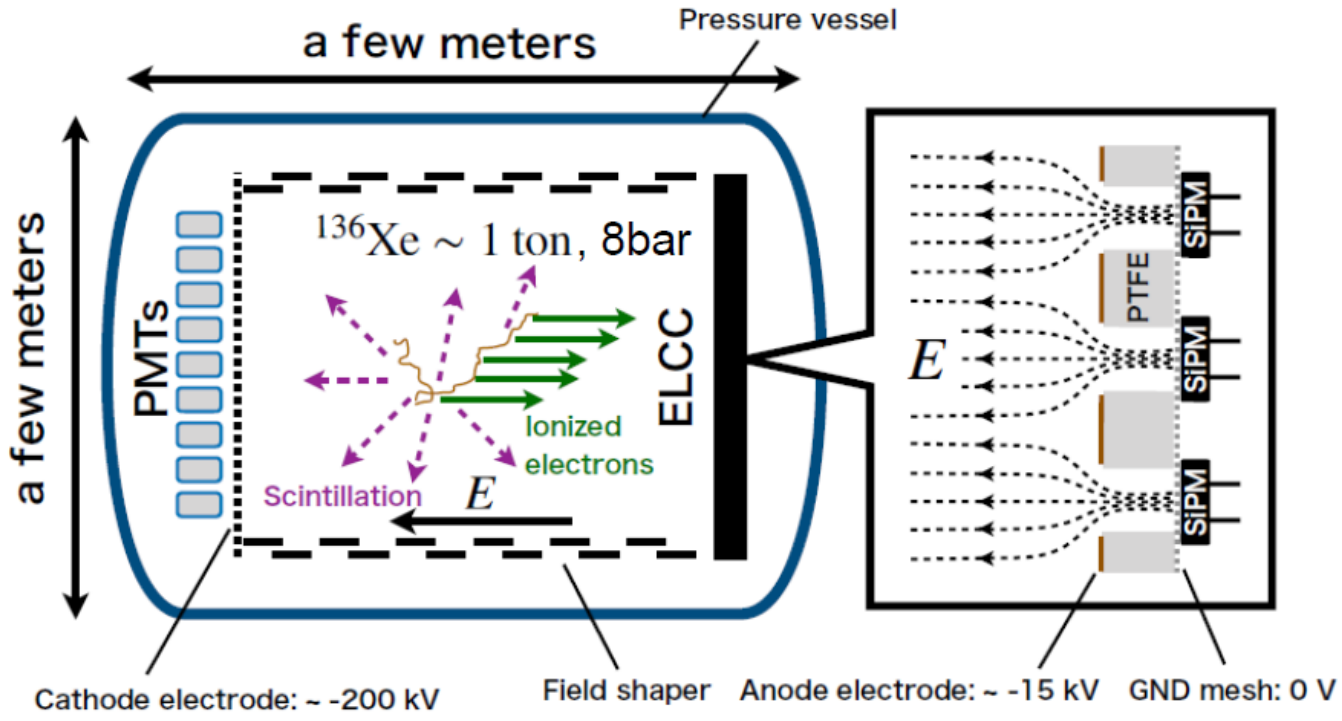
- Feature of $0\nu\beta\beta$
  - Rare event: >1e26 year (^{136}Xe)
  - Mono energy: 2.5MeV (^{136}Xe)

- Requirements for the detector
  - Large mass
  - Low background
  - Good energy resolution



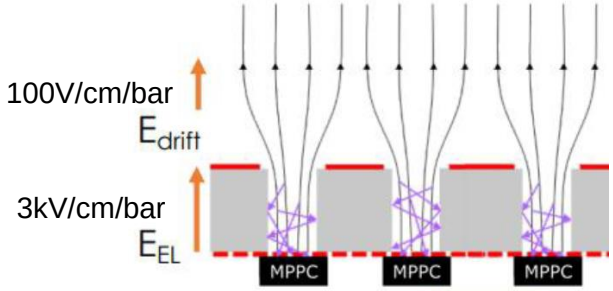
AXEL experiment

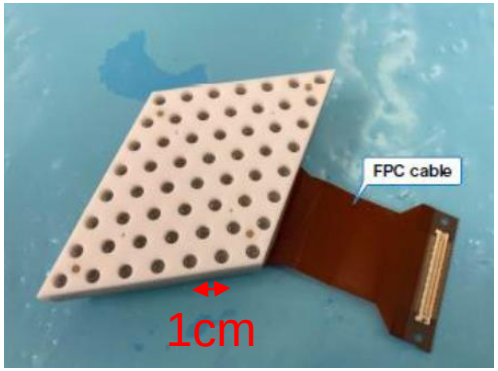
- High pressure xenon gas TPC (Time Projection Chamber)
  - Large mass by high pressure
  - background reduction by tracking
  - high energy resolution by using electroluminescence

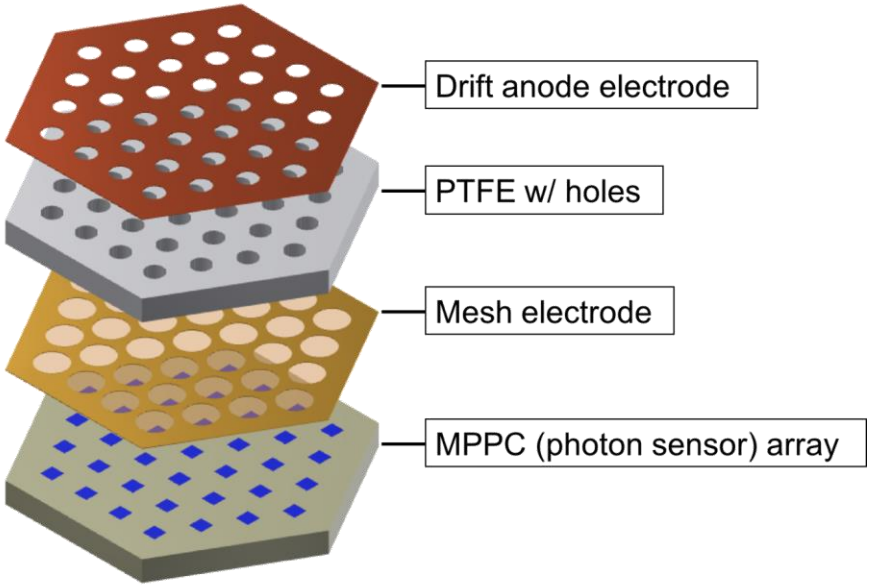


ELCC Electroluminescence Light Collection Cell

- AXEL's original readout structure
- Ionization electrons are detected via electroluminescence (EL) cell by cell
- Features
  - EL process is linear amplification --> high energy resolution
  - Pixelized hit pattern for 3D track reconstruction --> BG rejection
  - Scalability thanks to its rigid structure --> large mass





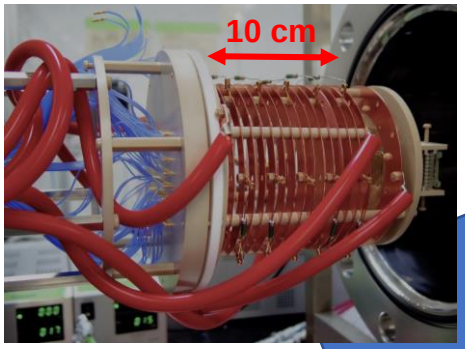


Roadmap

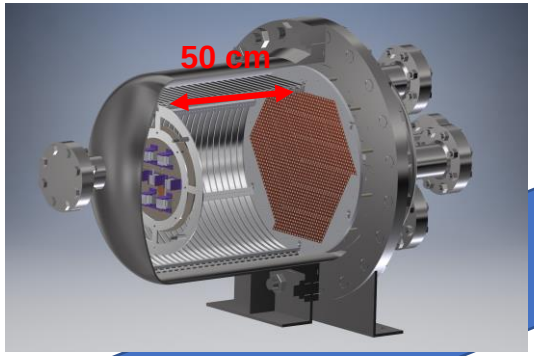
- Constructed 10-L, 180-L prototype
- New 1000-L detector development is ongoing
- Goal: ton scale detector

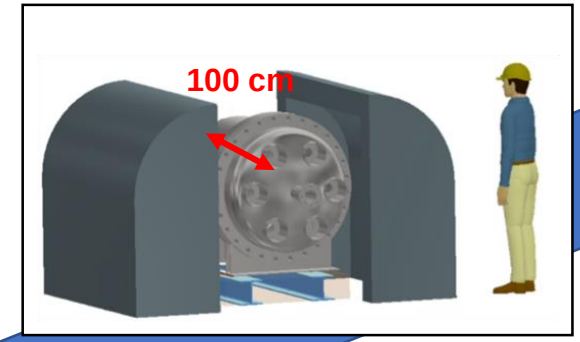
ton scale

10-L prototype
- 2014-2018
- 0.05kg@8bar 64ch
- ELCC proof of concept



180-L prototype
- 2018-
- 4.5kg@8bar 672ch
- performance test at Q





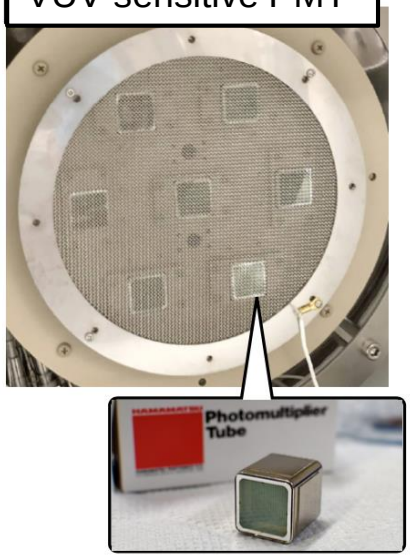
1000-L detector
- 2024-
- 30kg@8bar 6000ch
- physics run at underground

Performance of 180 L prototype

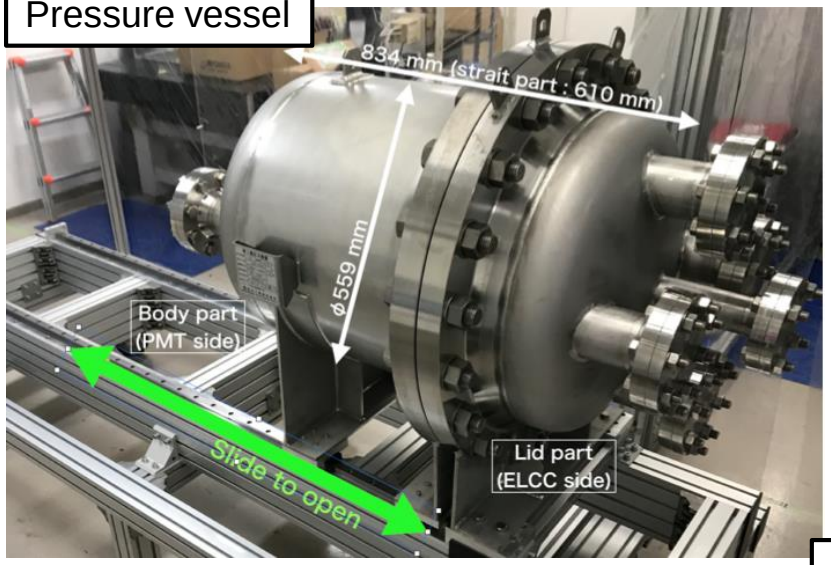
PTEP 2024 013H01

180L prototype

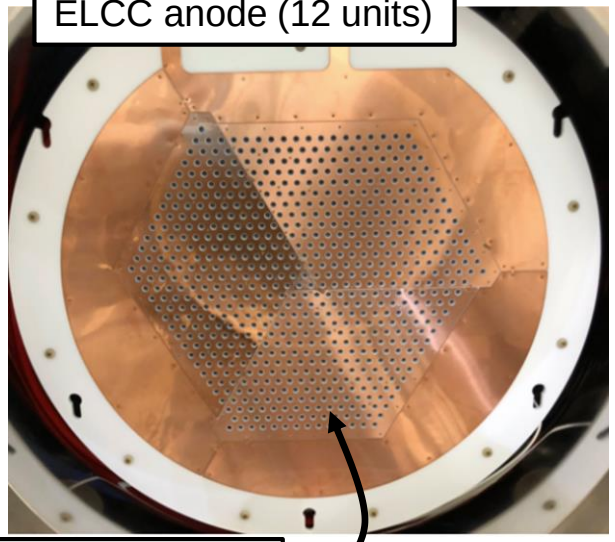
VUV-sensitive PMT



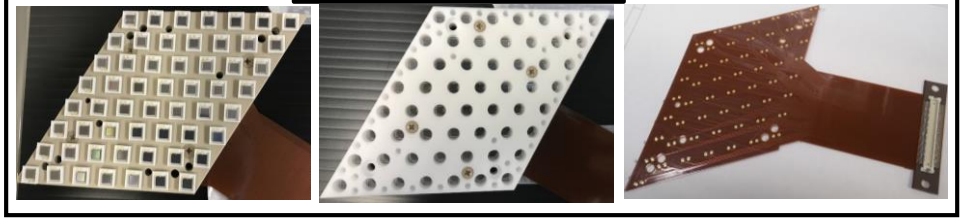
Pressure vessel



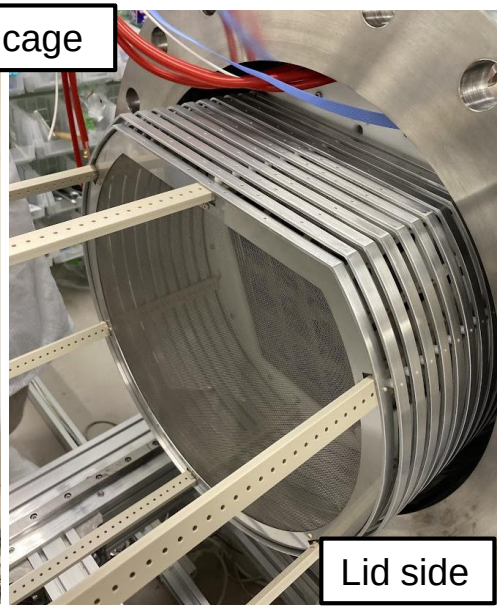
ELCC anode (12 units)



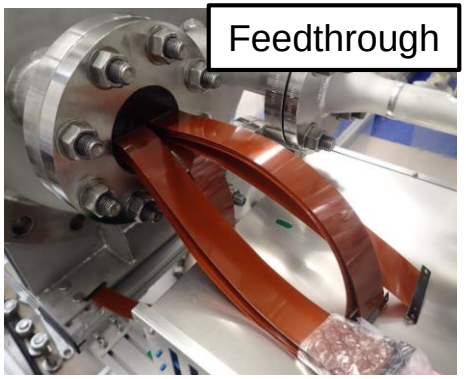
Single ELCC unit



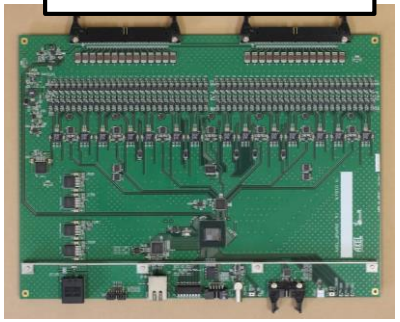
Field cage



Feedthrough



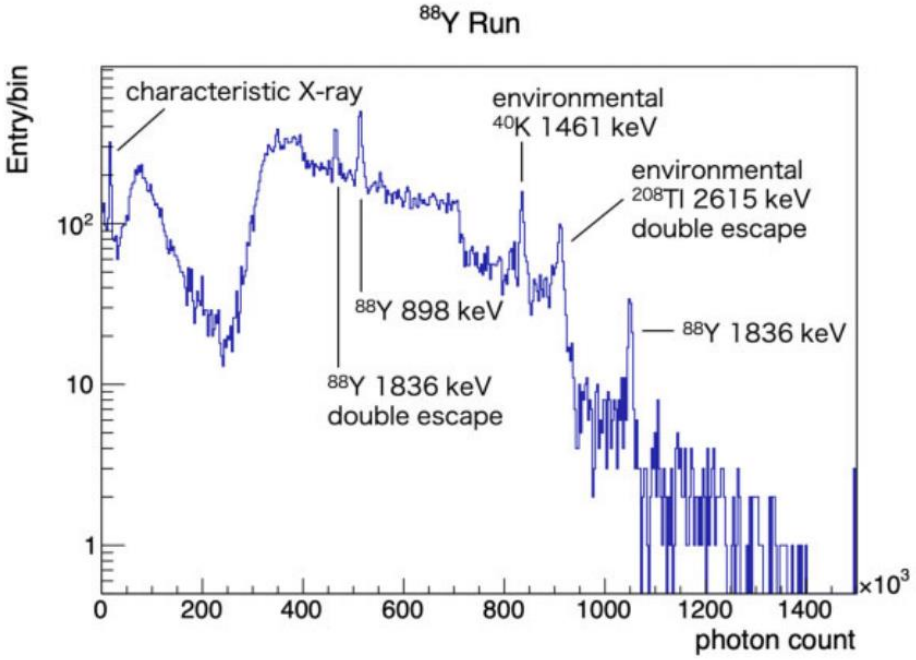
Electronics board

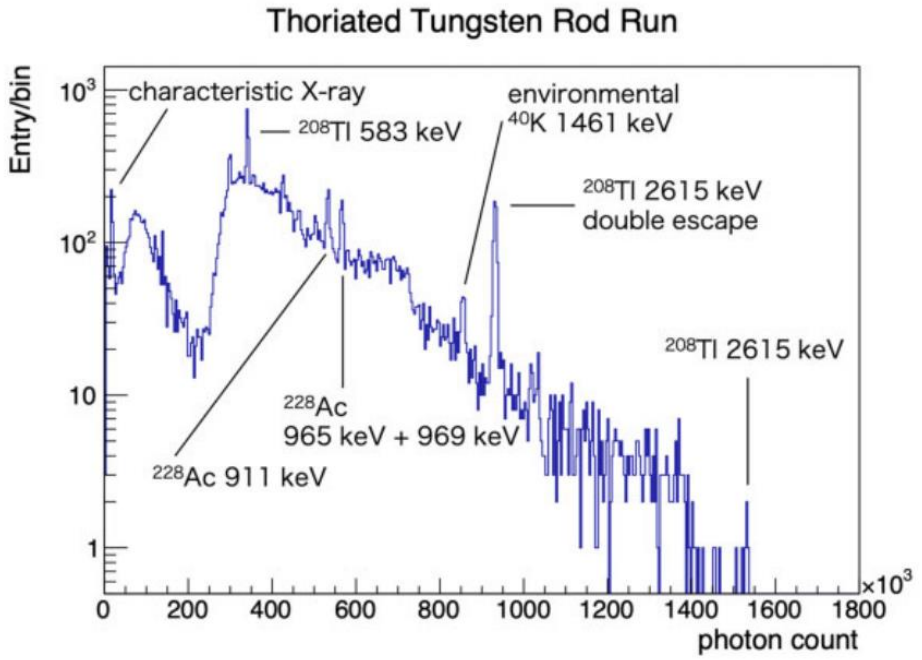


Energy measurement

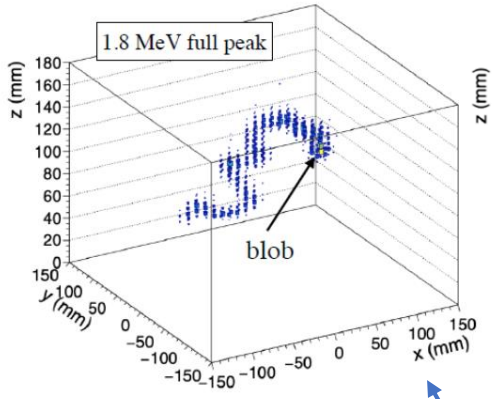
PTEP 2024 013H01

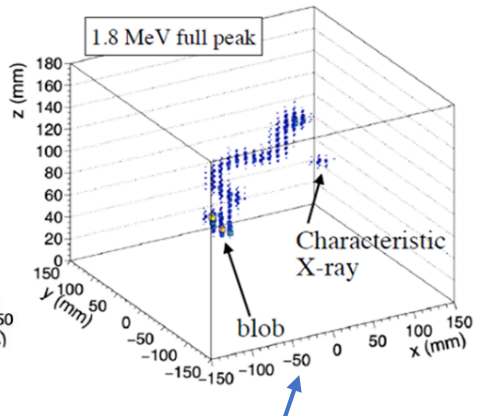
- Two kind of the measurement were done
  - ^{88}Y source: 1.8MeV
  - Thoriated tungsten rod: 2.6MeV
  - c.f. ^{136}Xe 0nbb Q-value: 2.5MeV

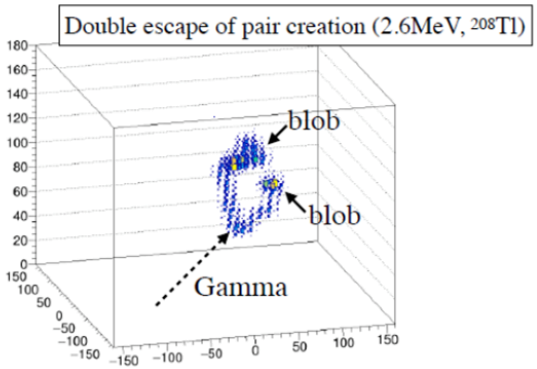


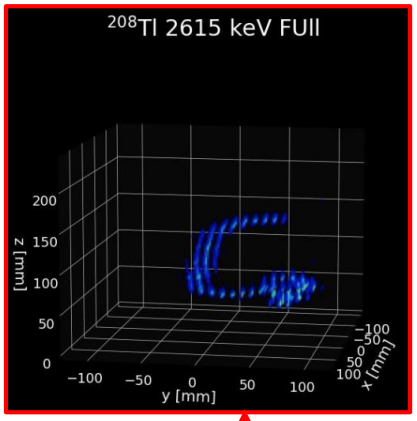


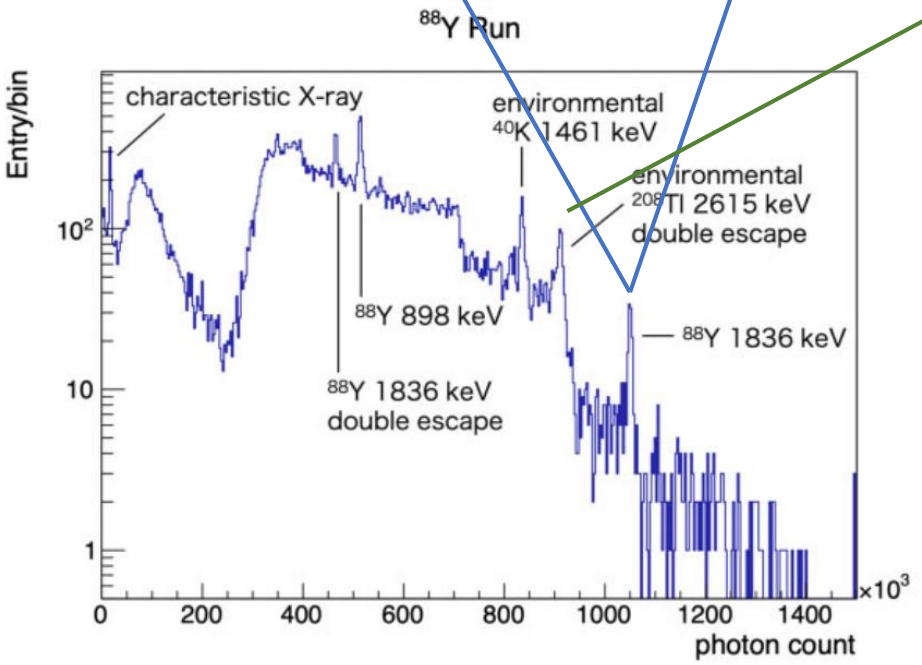
Event topology

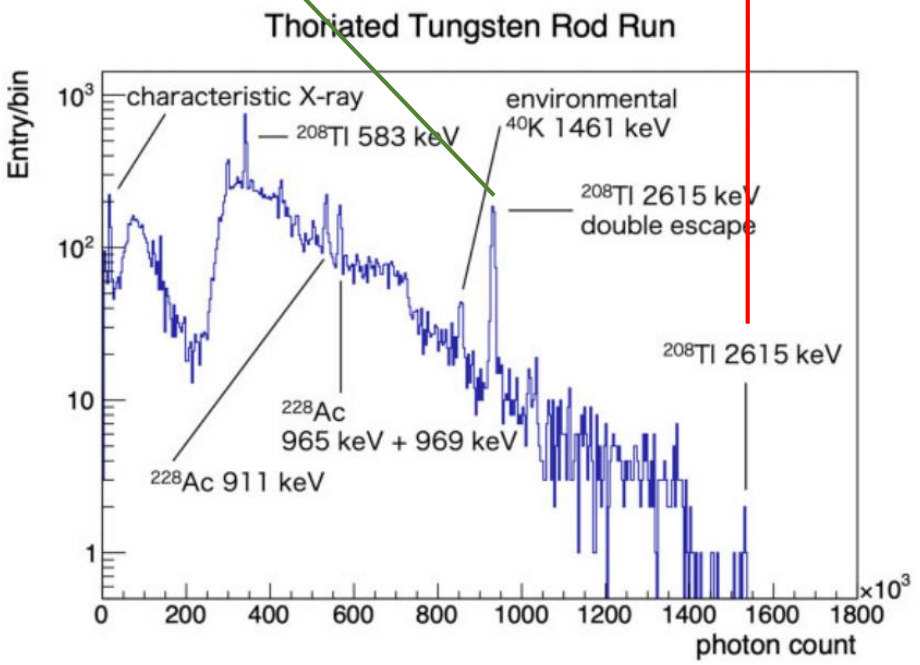






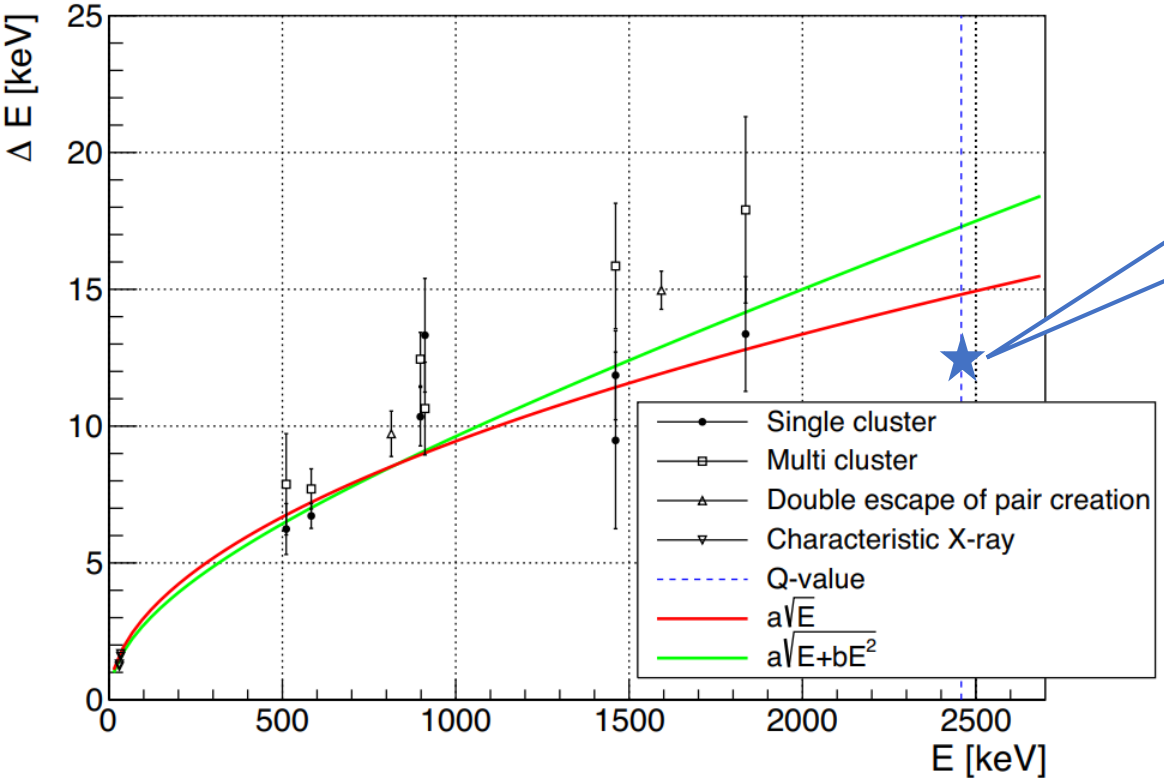






Evaluation of energy resolution

- Extrapolation of energy resolution (FWHM) to Q-value
  - $a\sqrt{E}$: 0.662 ± 0.029 %
  - $a\sqrt{E+bE^2}$: 0.717 ± 0.209 %



Target: 0.5 % (FWHM)

Only single cluster is used for the evaluation

Breakdown of energy resolution

- Breakdown of energy resolution in FWHM

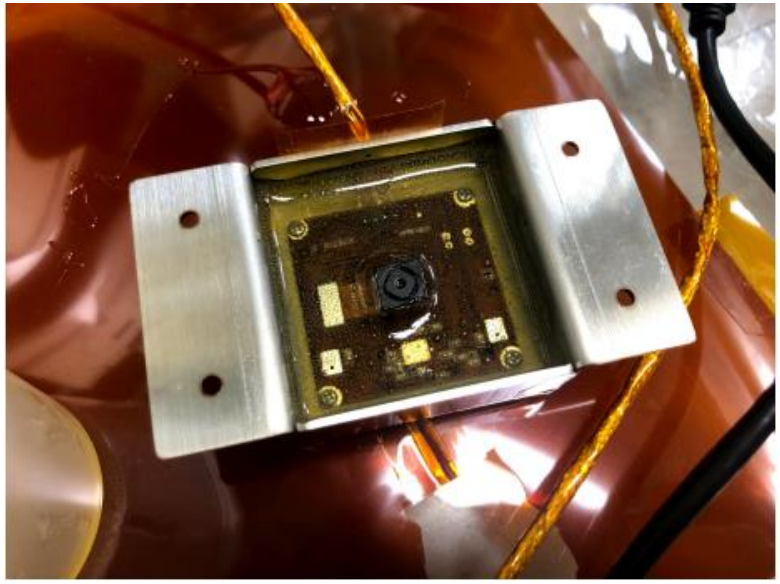
Error in the time variation correction	0.32%
Fluctuation of the number of initial ionization electrons	0.29%
Fluctuation of the EL generation and detection	0.24%
Error in the EL gain correction	0.23%
Recombination	0.22%
Fluctuation of the MPPC non-linearity	0.18%
z mis-reconstruction	0.13%
Variation in time bin of time variation correction	$\lesssim 0.16\%$
Error in the z-dependence correction	$\lesssim 0.11\%$
Accuracy of the MPPC recovery times	$\lesssim 0.11\%$
Offset of the baseline	$\lesssim 0.09\%$
Fluctuation of the attachment	$\lesssim 0.02\%$
Position dependence of the EL gain	0%
Waveform processing in the FEB	0%
Estimation total	0.63% to 0.67%
Data total	$0.73 \pm 0.11\%$

Discharge and countermeasure

Discharge monitoring method

details are written in K.Z.Nakamura-Dth

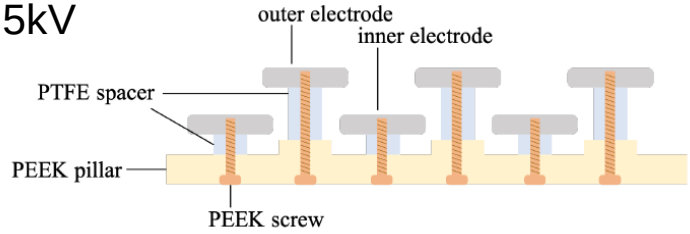
- USB camera potted with epoxy resin in SUS case is installed in the chamber
- Take a photo using motion detection software "motion"
- We can know where discharge is happening

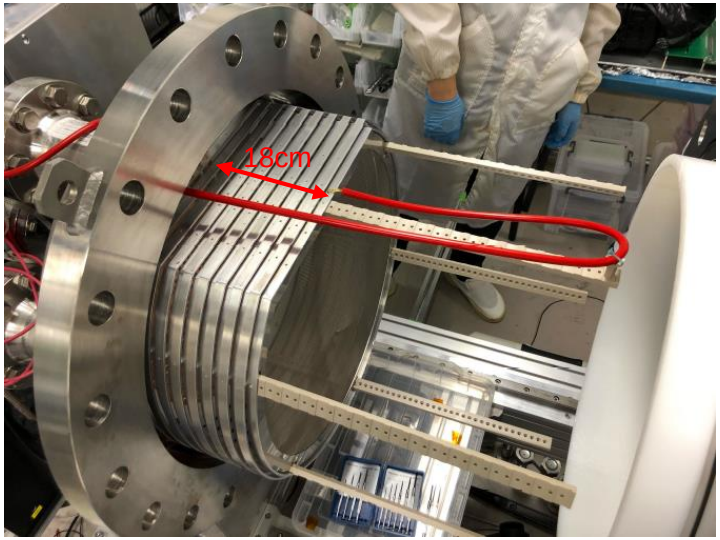


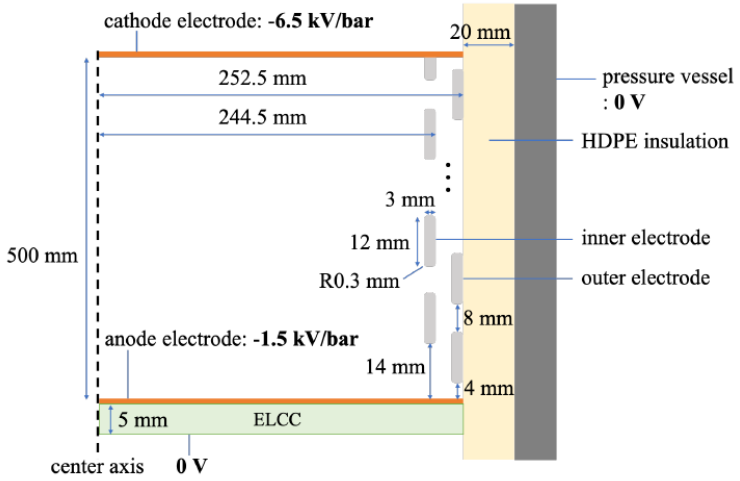
Field cage for HP180L

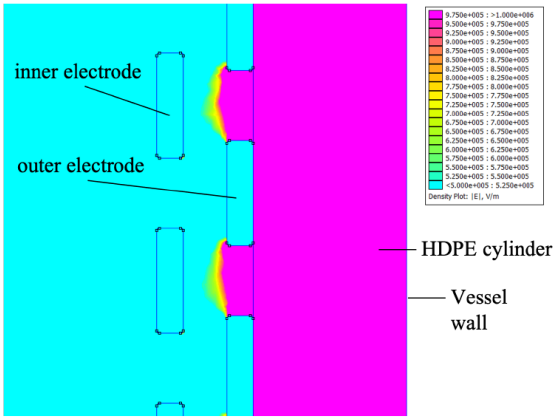
details are written in Yoshida-Dth

- Design
  - two size electrodes are overwrapping --> shield chamber GND
  - rounded electrode --> avoid field concentration
  - drift length: 18cm (to be updated to 50cm)
  - Voltage
    - cathode: -20.9kV
    - anode: -9.5kV





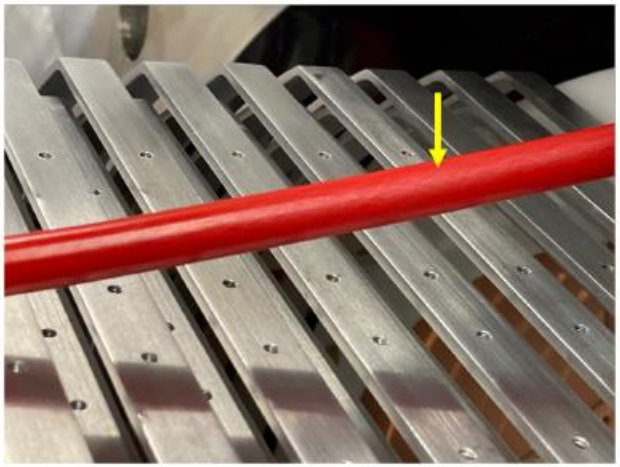


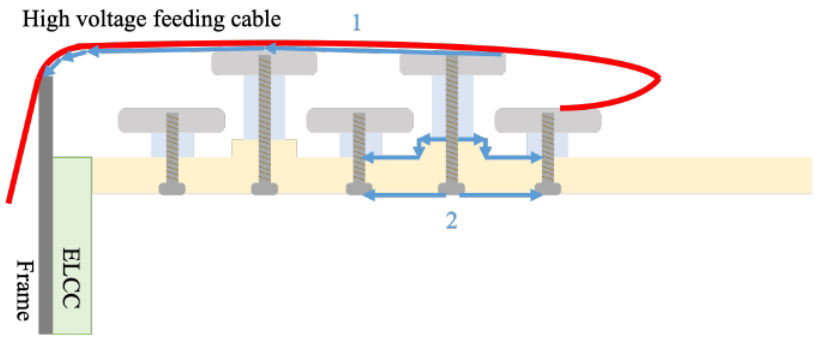


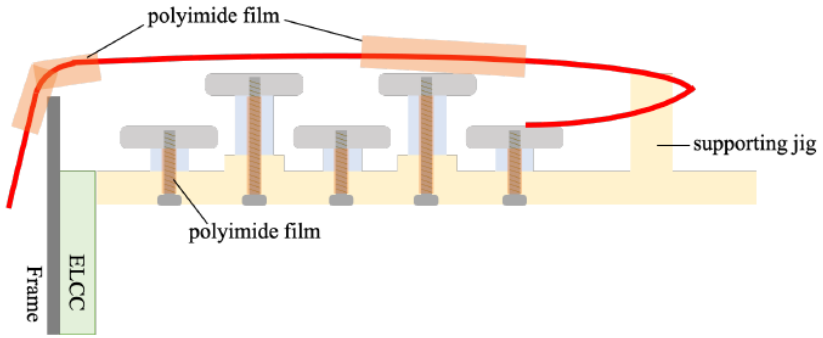
Field cage for HP180L

details are written in Yoshida-Dth

- Discharge
  - 1. HV cable surface
  - 2. from screw axis thorough the gap between jig and spacer
  - --> polyimide cover works well

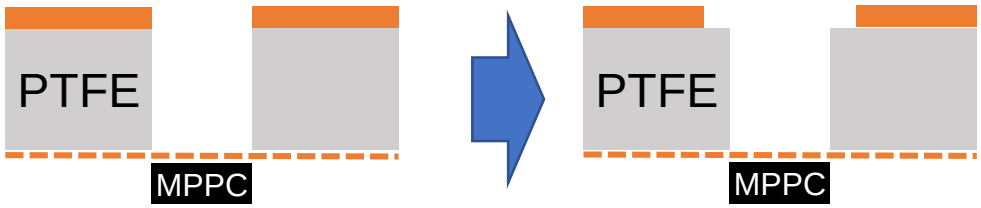






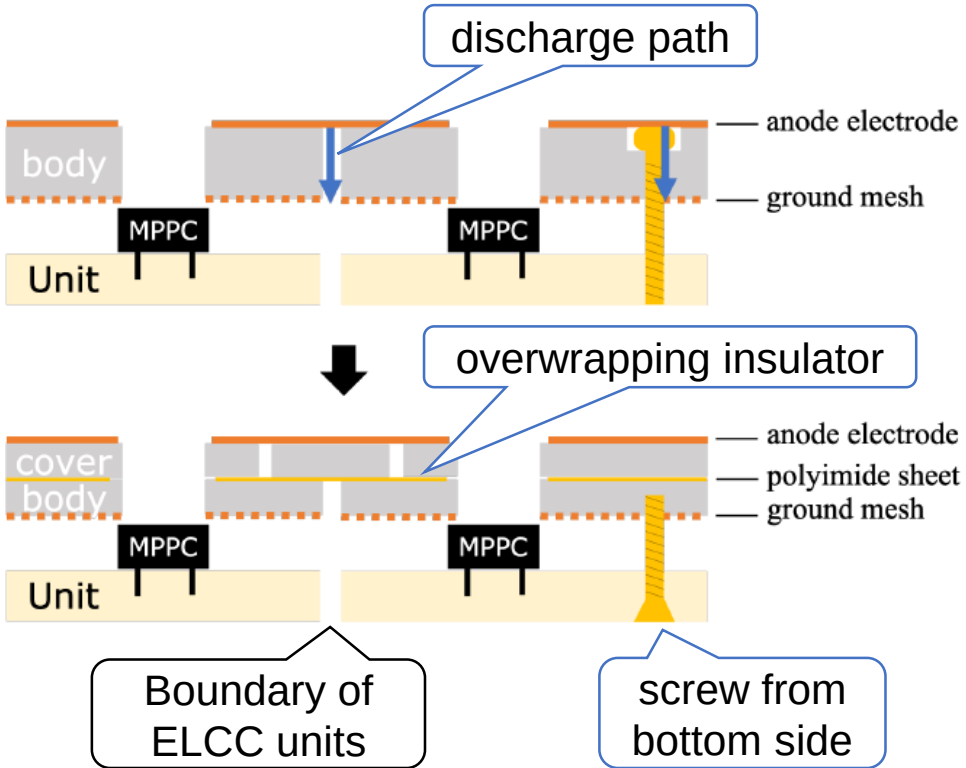
ELCC design history

- 1. Initial trial (proof of principle)
  - a lot of small discharge event were detected
  - discharge rate was suppressed by using electrode with a bit larger hole



- 2. Unit structure (extendable)
  - discharge happened at the edge of the ELCC unit

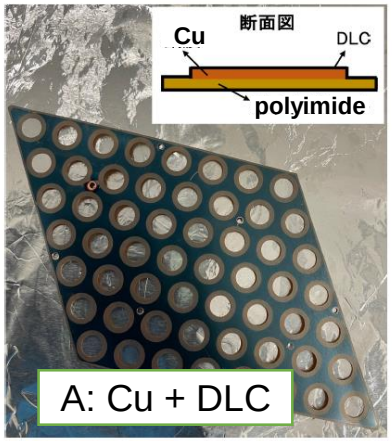
- 3. Overwrapping insulator
  - improved but did not reach target value
  - very difficult to take out 1 unit (for maintenance and so on)

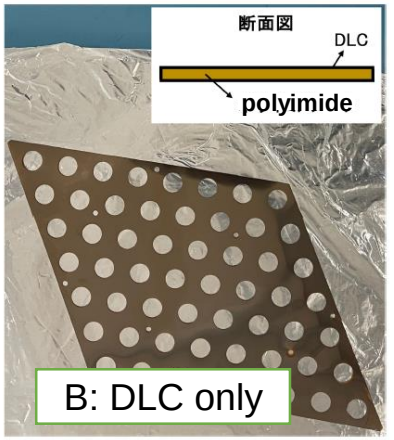


ELCC design story

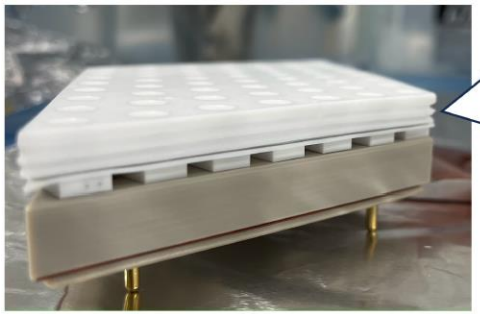
details are written in Hikida-Mth

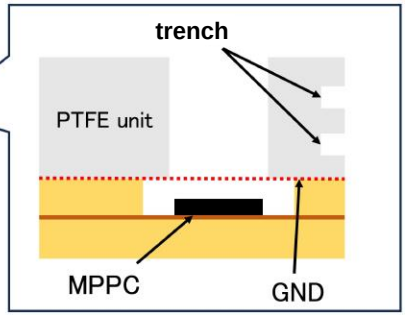
- 4. High resistance electrode (DLC)
  - DLC spattered electrode
  - still discharge happened
  - 150 Mohm/square DLC is not sufficient
  - --> DLC sputtering tends to create microscopic structure at the edge of the electrode, triggering the discharge.

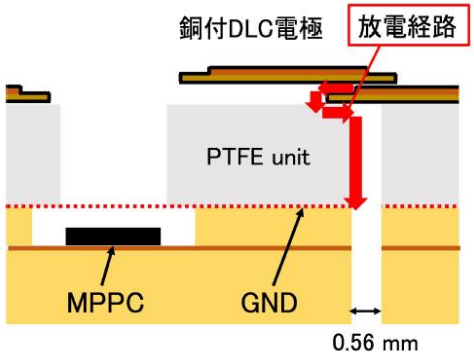


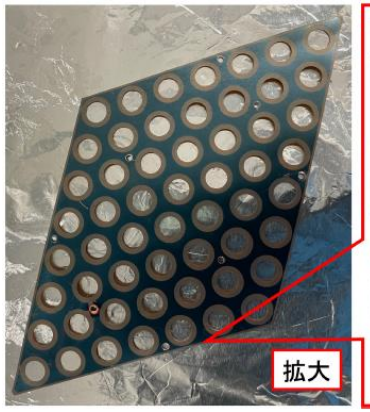


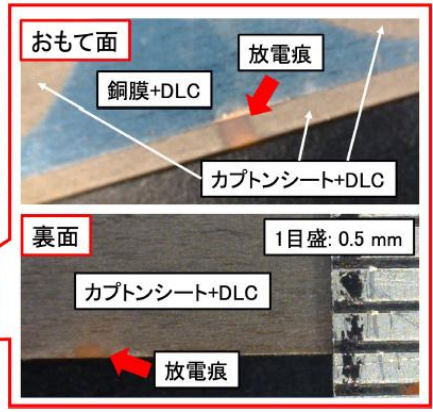
- 5. Side trenched insulator
  - discharge frequency has surpressed significantly
  - after several discharge, continuous discharge started (maybe due to the peeled off DLC carbon)







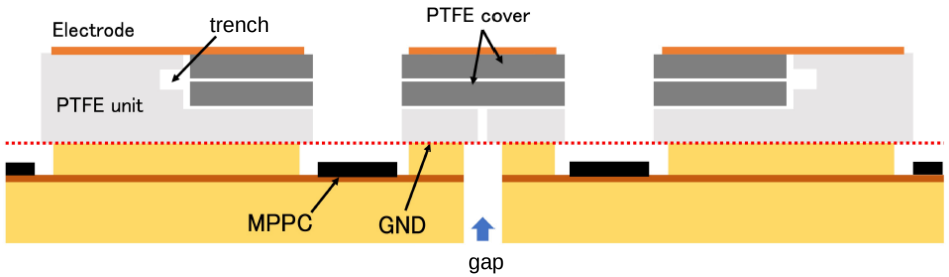


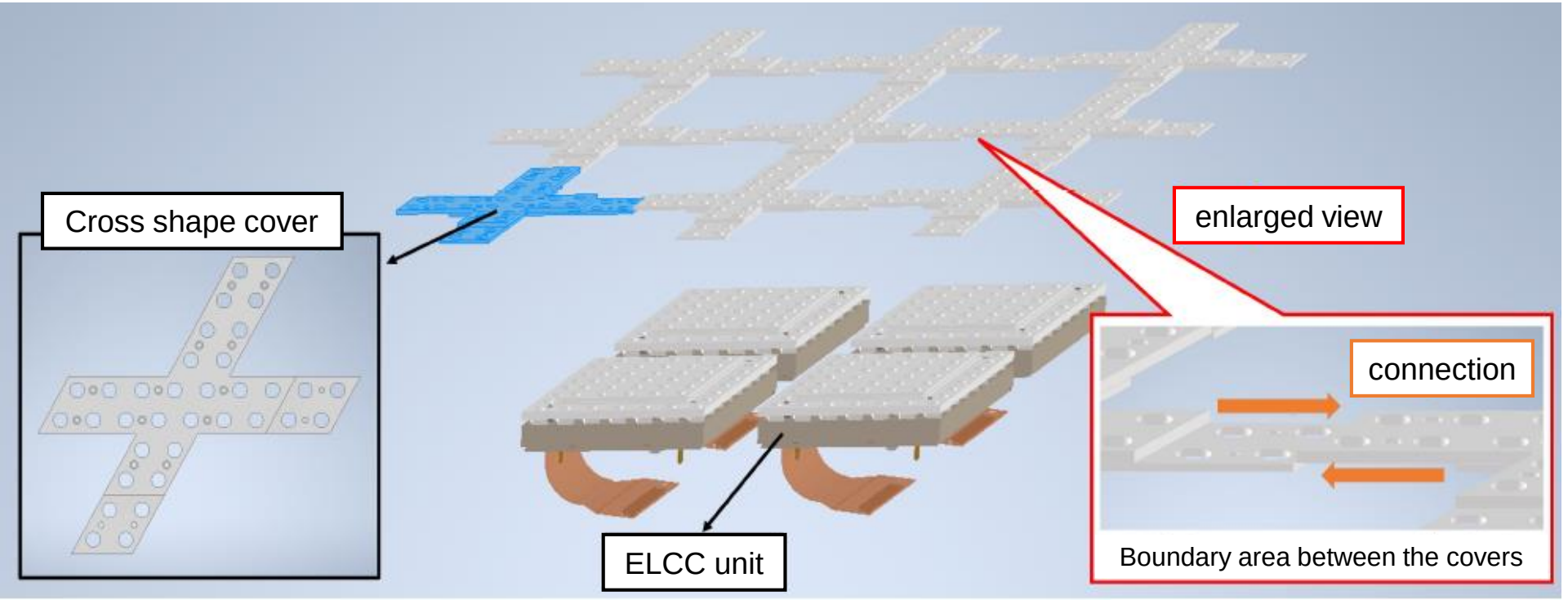


ELCC design history (3)

details are written in Hikida-Mth

- 6. Cross shape insulator cover
  - updated overwrapping insulator
  - easier to maintain 1 unit
  - --> Test is ongoing!



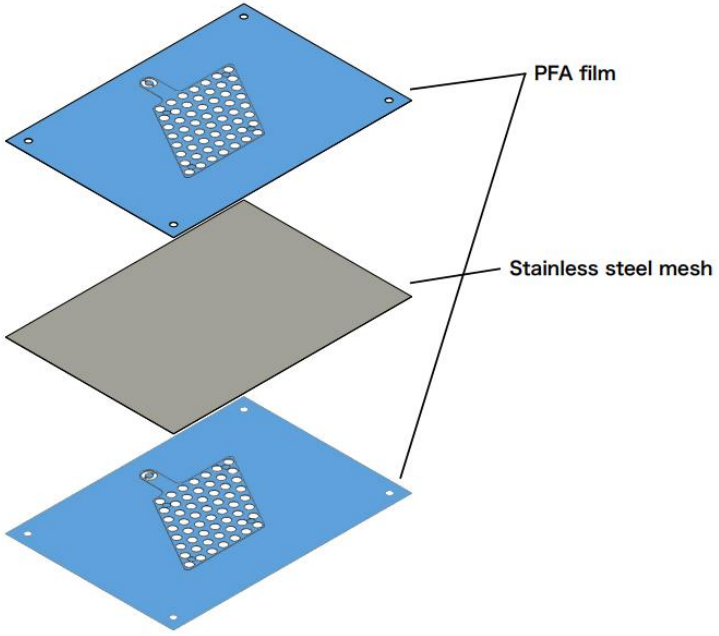


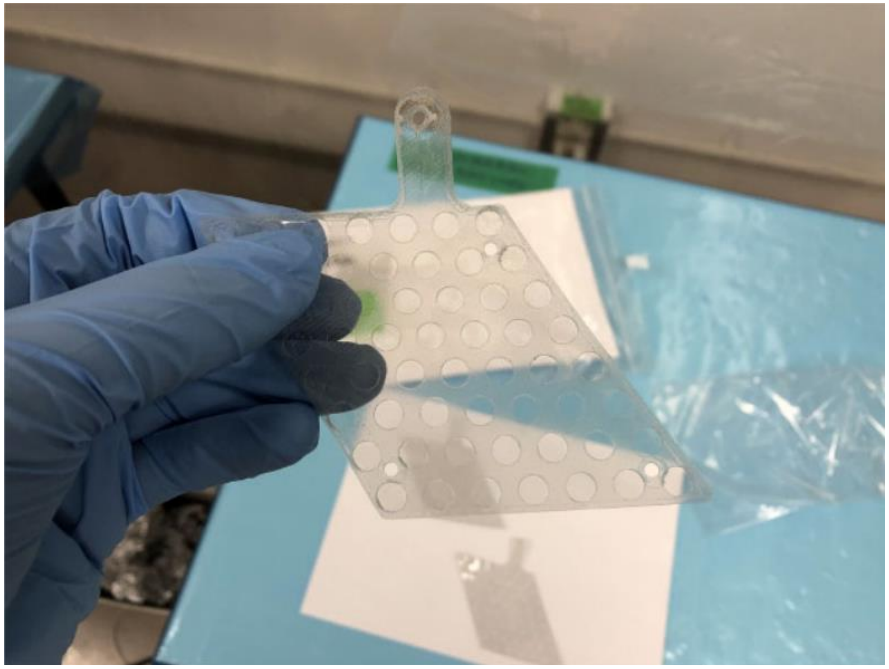
GND mesh development

details are written in K.Z.Nakamura-Dth

- Problem
  - Mesh edge sometimes fray --> enter the ELCC hole --> trigger discharge

- Mesh making method
  - 1. SUS mesh is head welding by PFA films
  - 2. Welded mesh is cut with a Tomson mold

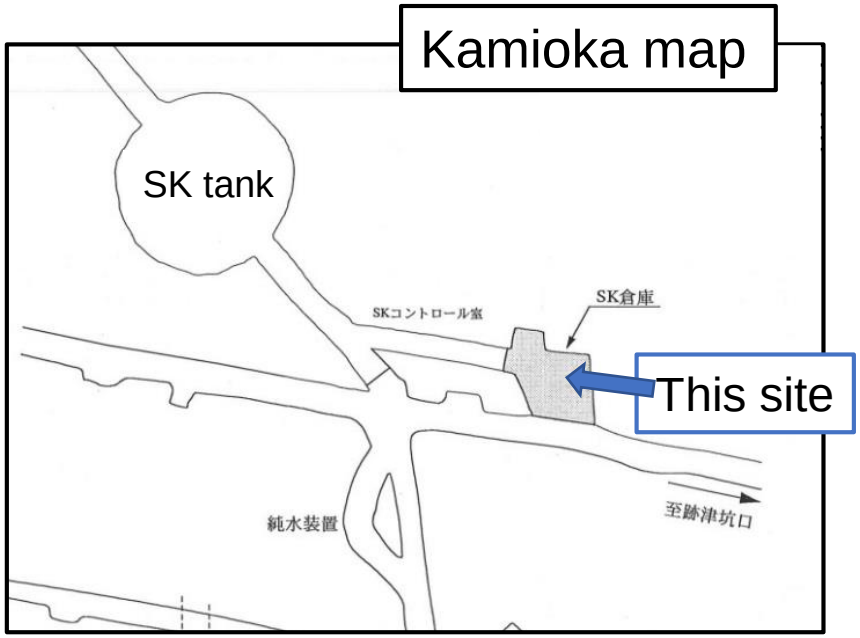


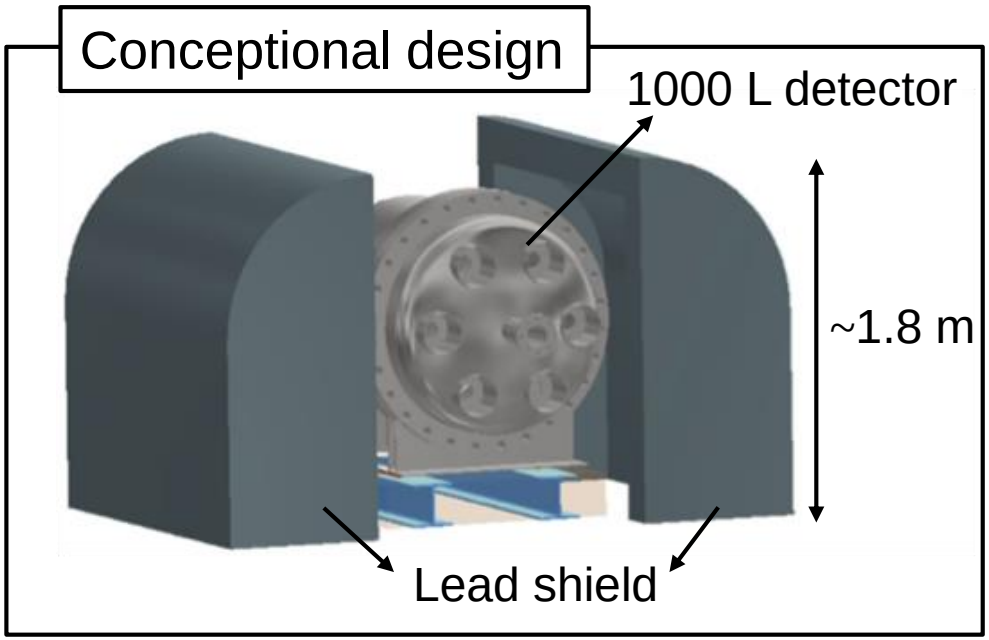


R&Ds for 1000 L detector

1000 L detector experiment

- Site: Kamioka observatory of ICRR
  - ~1000m underground
- Estimated performance
  - 0nbb event rate: 0.25 events/year ($T_{1/2}$=2.3 x 10^{26} year)
  - Background rate: <0.1 events/year (assuming ^{214}Bi)





Pressure vessel

- Specification
  - Size: 1.0 mΦ x 1.5 m
  - Weight: 1.4 ton
  - Pressure: up to 10atm

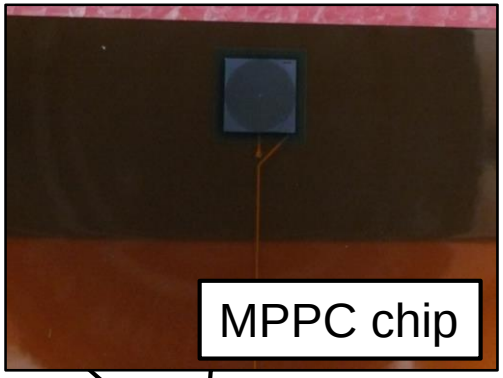
Arrive at Kamioka (30.Mar.2023)

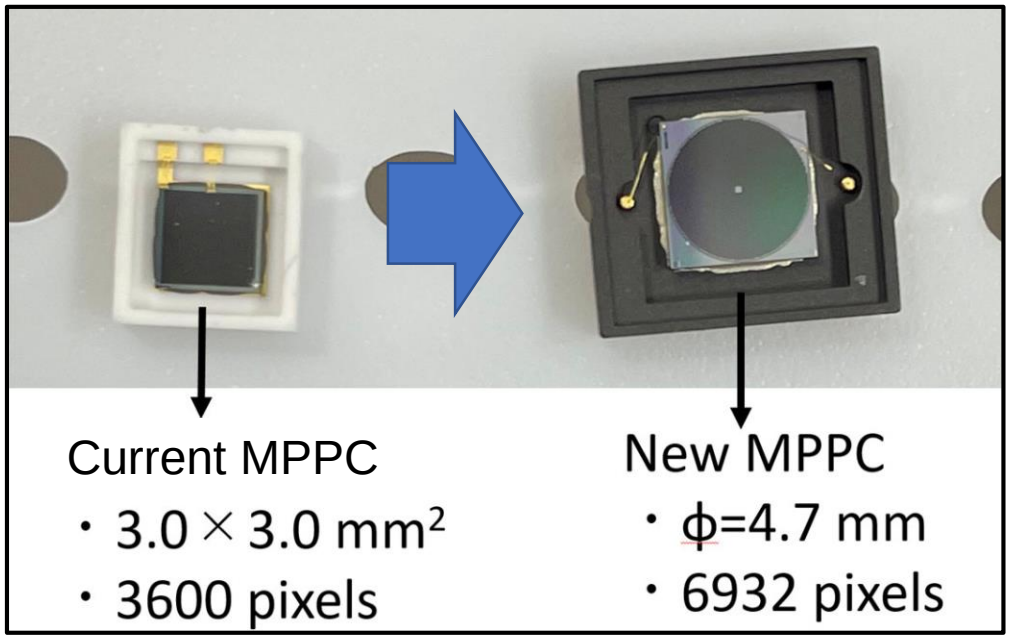
Complete installation (17.May.2023)

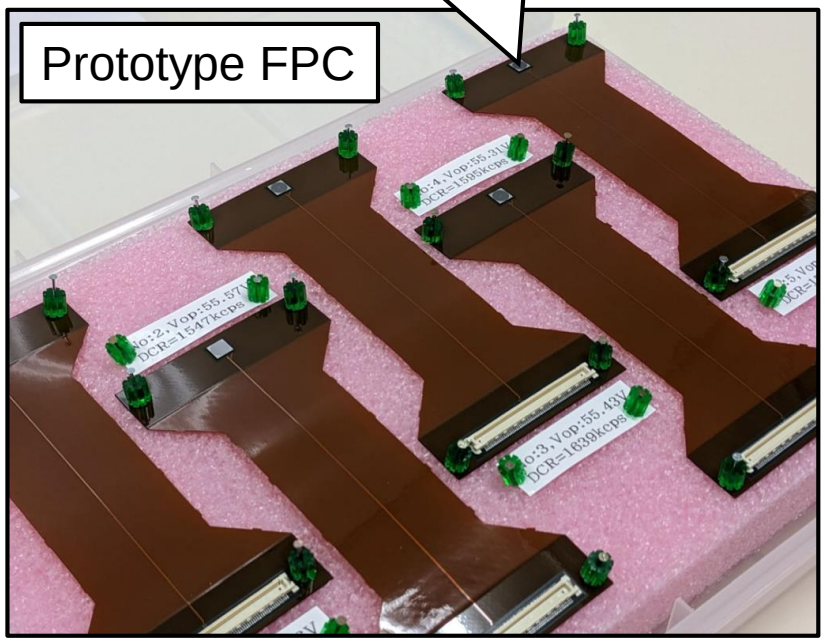
New MPPC

- Large-area MPPC
  - ~ twice larger area than before
  - circle shape --> reduce dark count from unnecessary area
  - --> increase EL photon statistics

- MPPC on FPC
  - Remove ceramic package to reduce RI contamination
  - Evaluation of prototype FPC with 1 channel



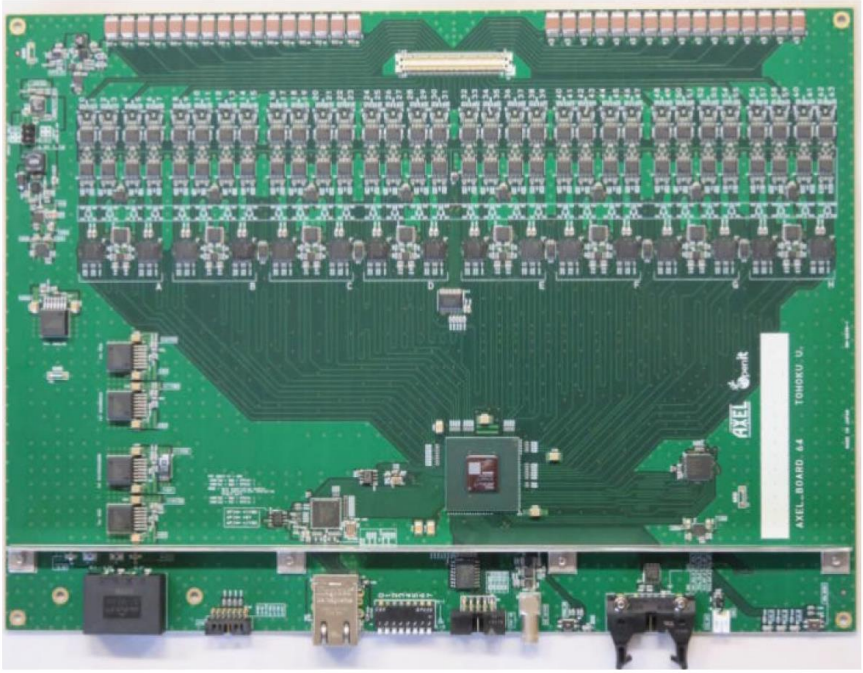




New electronics

- Spec
  - 64ch MPPC waveform readout board with DC coupling
  - 65V bias apply (individual bias adjustment)
  - Two types of gain
    - Low gain: EL photons
    - High gain: 1p.e. calibration

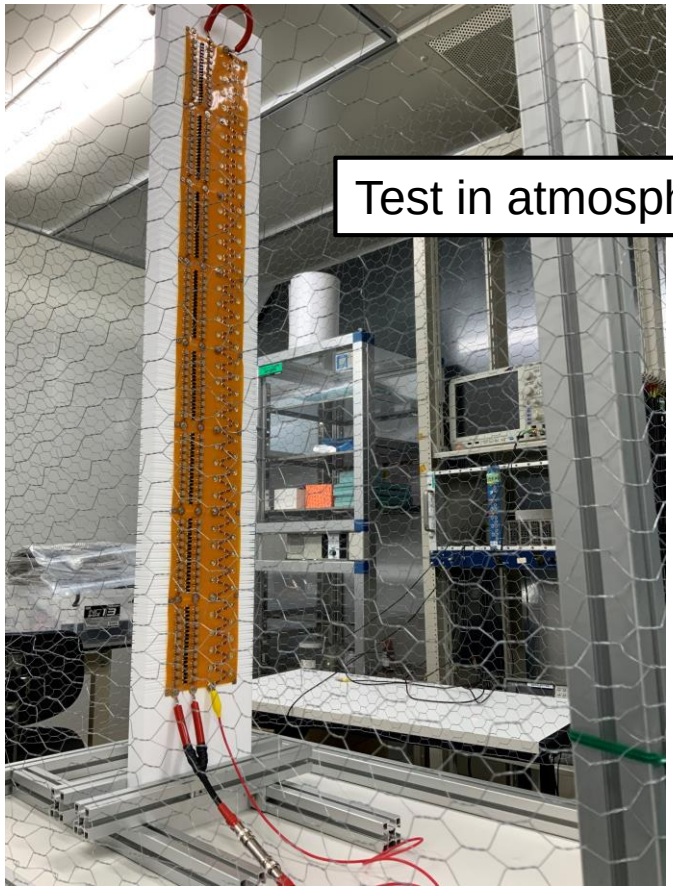
- Status
  - 1st product just arrived (2024/2/5)



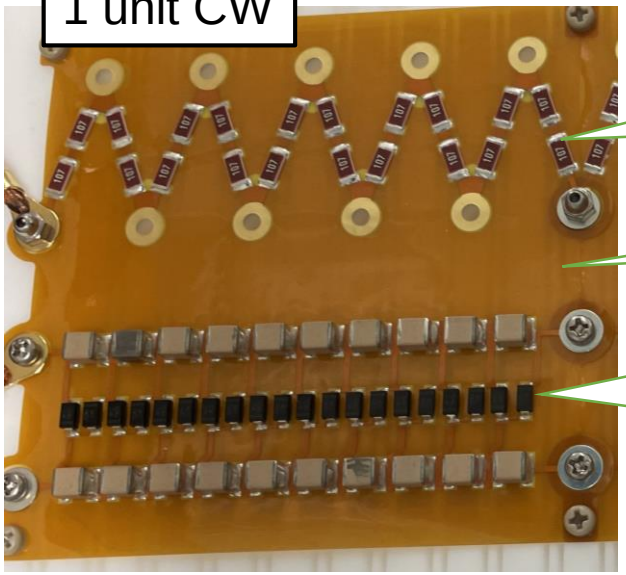
High voltage supply

- Cockcroft-Walton (CW) circuit
  - Make high voltage in the chamber
  - 10step unit structure

- Performance check
  - 71.86kV in atmosphere (80step)
  - 30kV in xenon gas (30step)
  - target: 76kV in xenon gas



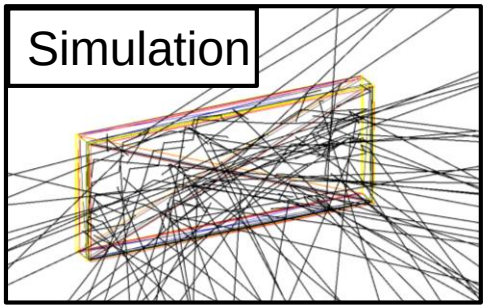
1 unit CW

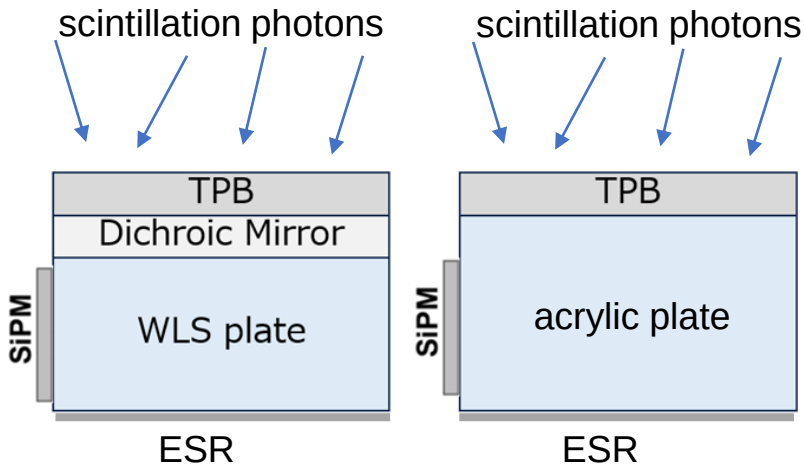


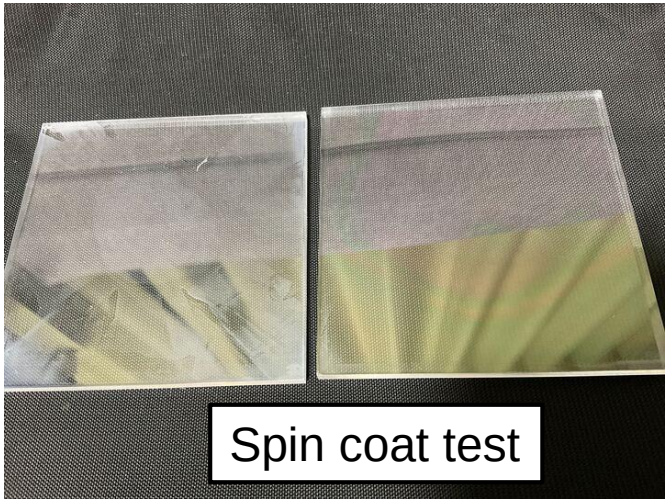
Scintillation light detection

- VUV-PMT
  - detect scintillation photon --> determine absolute z position
  - accidental coincidence is problem
    (current scintillation detection yield is not so good)

- New detection method
  - Wavelength shifted photon is detected at the side by SiPM
  - Large detection area
  - Simulation study with 2 types of configuration
  - R&D of WLS coating method is ongoing







Summary

- AXEL: high pressure xenon gas TPC
  - EL readout --> energy resolution
  - pixel readout --> event topology

- 180 L prototype: large size prototype detector
  - energy resolution: ~0.7% FWHM @2.5MeV extrapolated
    - breakdown investigation
    - further improvements to achieve 0.5% FWHM (target)
  - event topology:
    - clear tracks are obtained up to 2.5MeV gamma-ray

- Technical R&Ds
  - Field cage, ELCC, mesh developments to prevent discharge
  - Development of Cockcroft-Walton in xenon gas
  - Effective scintillation detection method
  - and so on