Status and prospects of the AXEL experiment

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for the AXEL Collaboration

27 Oct 2023, Workshop on Xenon Detector 0νββ Searches, SLAC

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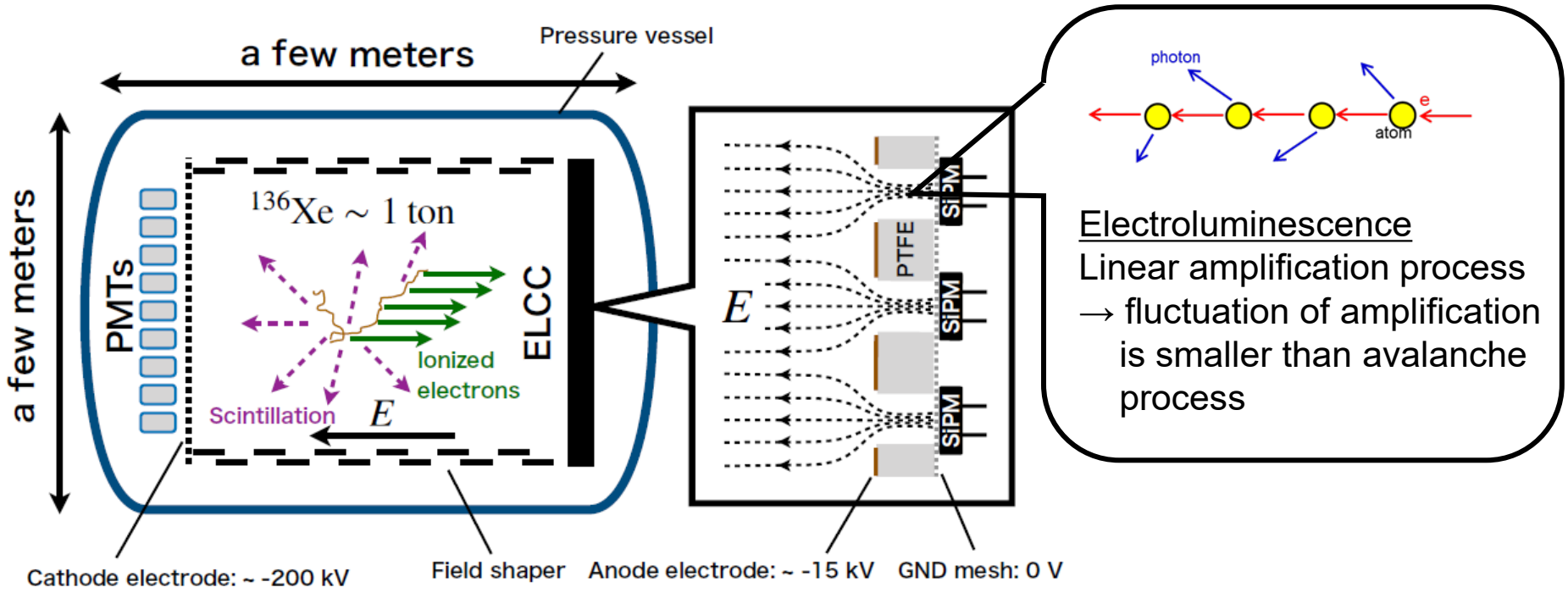
AXEL experiment

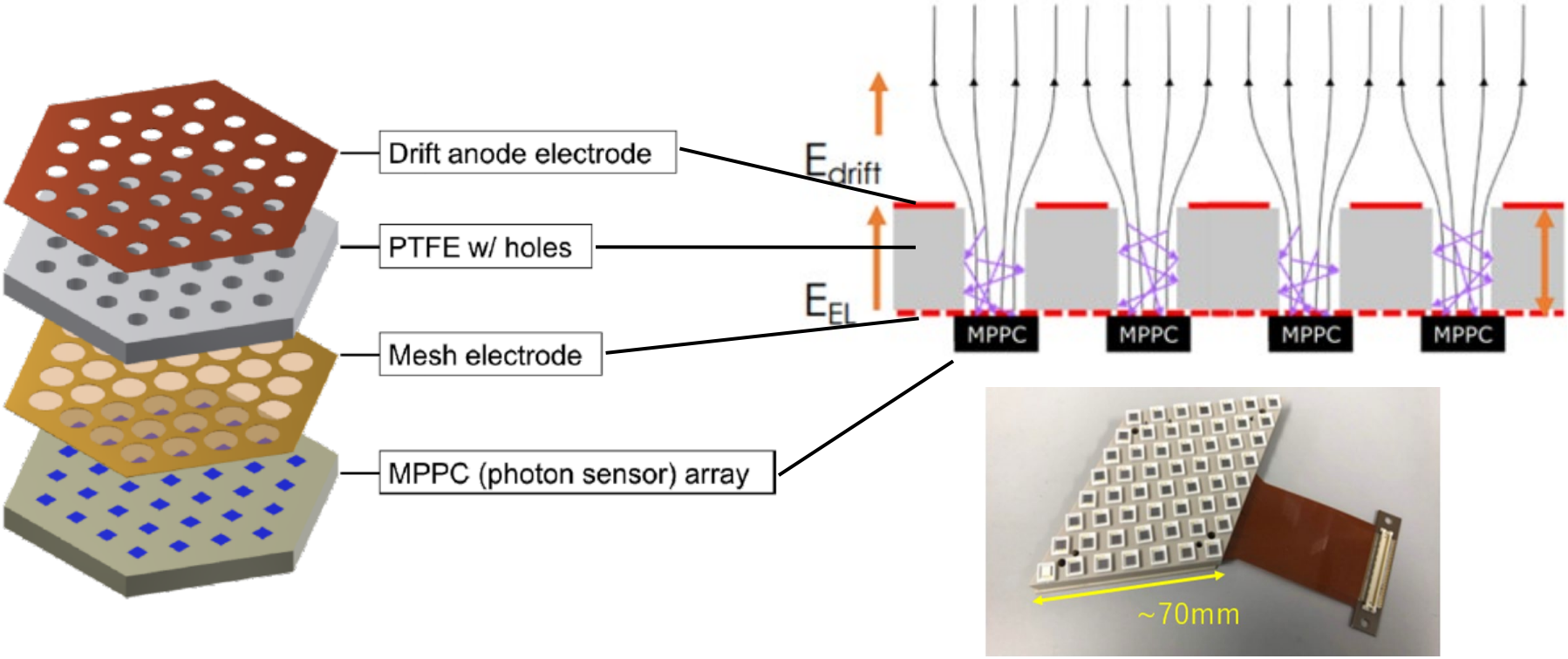
A Xenon ElectroLuminescence detector

- High pressure xenon gas TPC
- Advantages for 0νββ search
  - Energy resolution : EL process for energy measuring
  - Large mass : technology exists for ton scale ^{136}Xe
  - BG rejection : 3D track is obtained with cell readout structure(ELCC)



ELCC : Electroluminescence Light Collection Cell

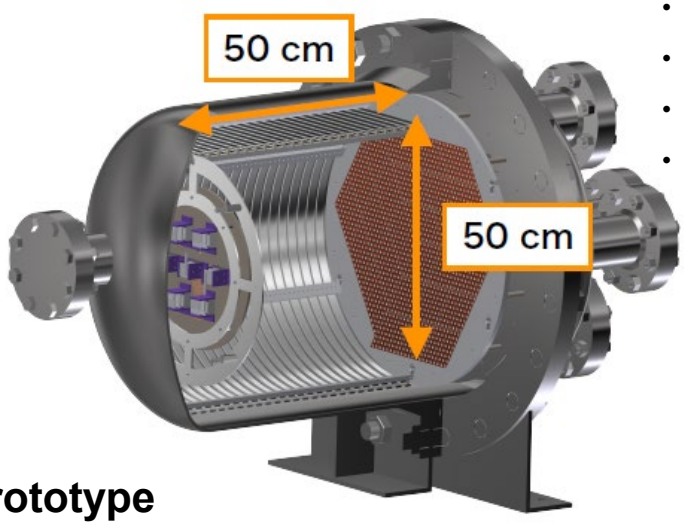
- Detect EL lights with VUV-sensitive MPPC
- EL process → Good energy resolution
- Amplification in cells → Uniform detection, Tracking
- Rigid unit structure → Mechanically easy to extend



a unit of MPPC array

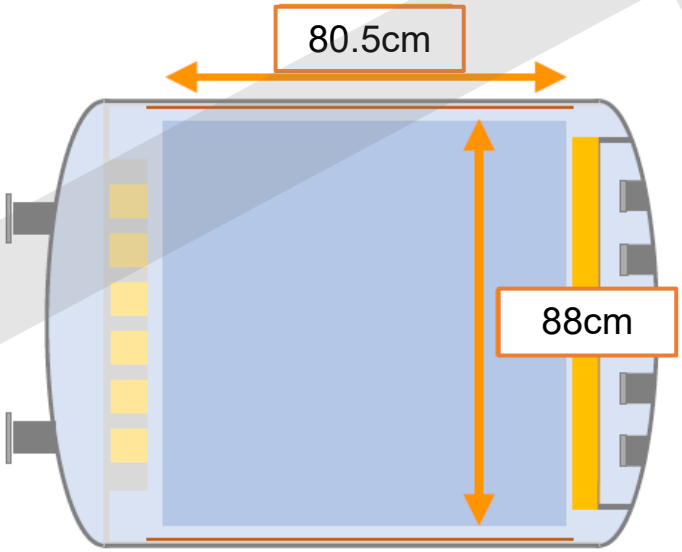
Roadmap of experiment

180-L prototype
2018 -
- ～4.5kg @ 8bar
- phase-1 : 168ch
- phase-2 : 672ch
- know-how of enlargement

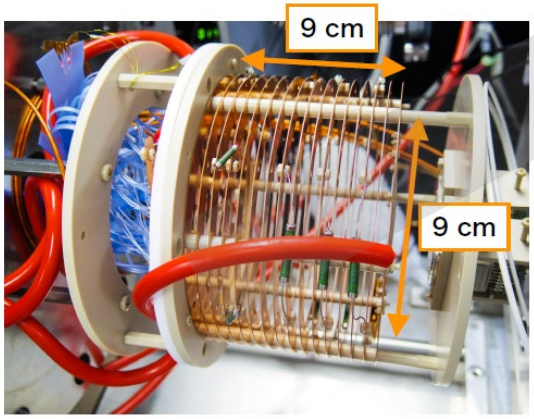


1t scale

200kg scale



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

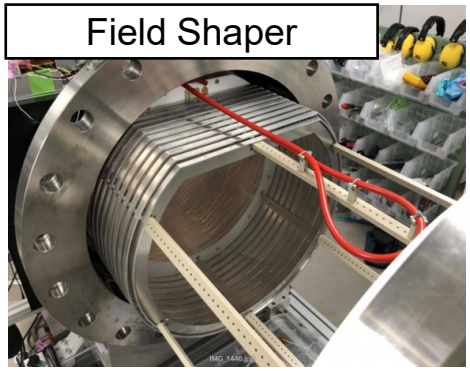


1,000-L detector
2022 –
- ~20kg @ 8bar
- Physics run
- Underground

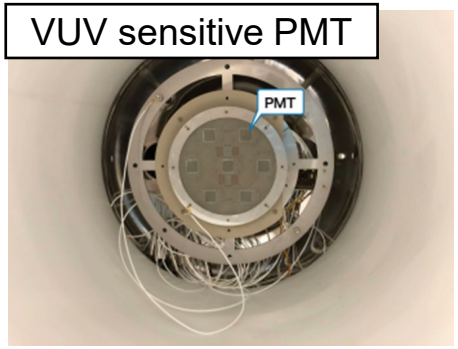
Contents

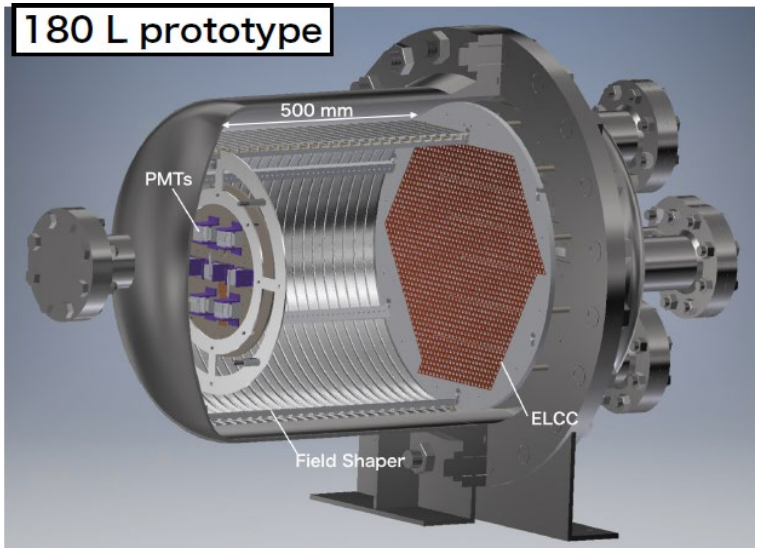
180L prototype detector

Field Shaper

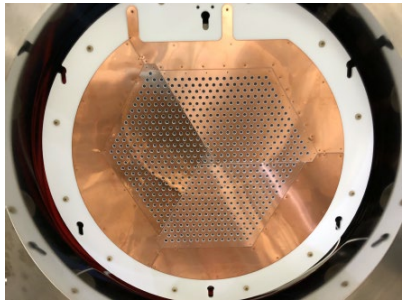


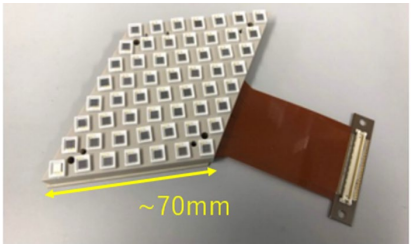
VUV sensitive PMT



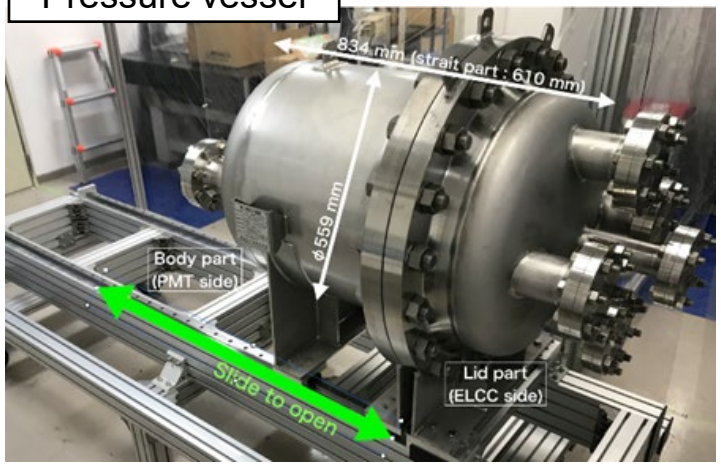


ELCC anode(12units)

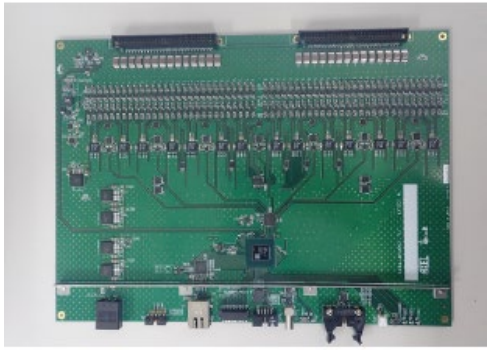


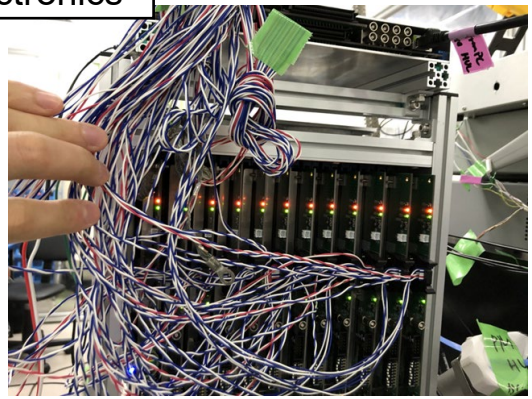


Pressure vessel



Front end electronics

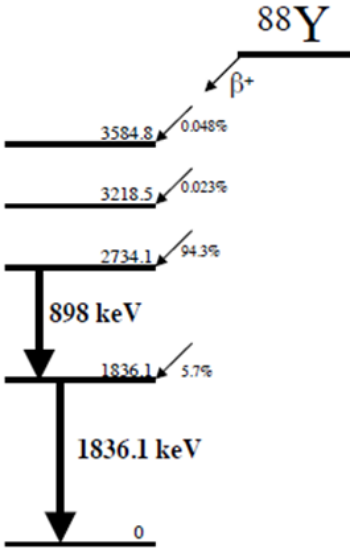




Energy measurement

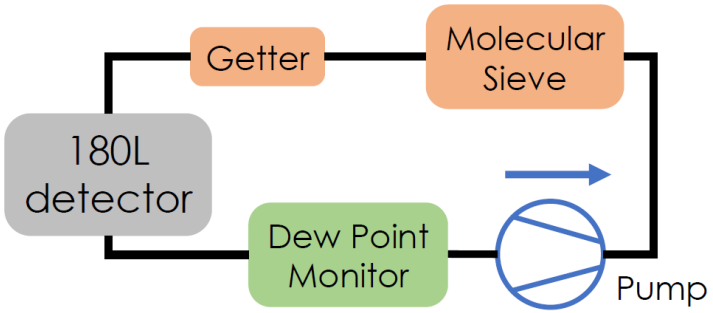
Two kinds of source were used for measurement

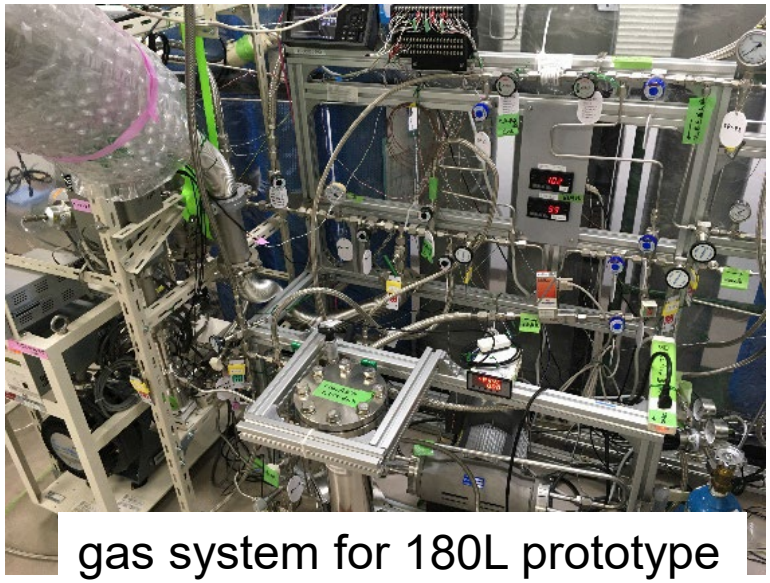
- ^{88}Y : 898keV γ, 1836keV γ
- Thoriated tungsten rod : Thorium series



Xenon circulation and purification

- Purification
  - Molecular Sieve : H_2O, O_2, CO_2, etc
  - Getter : N_2
- Pressure, temperature, and dew point are monitored.

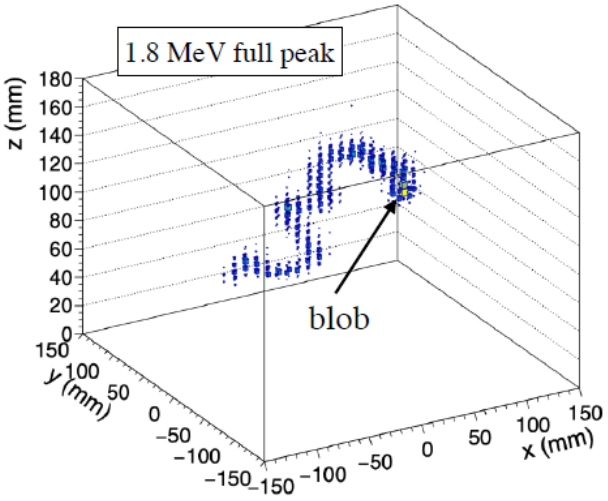


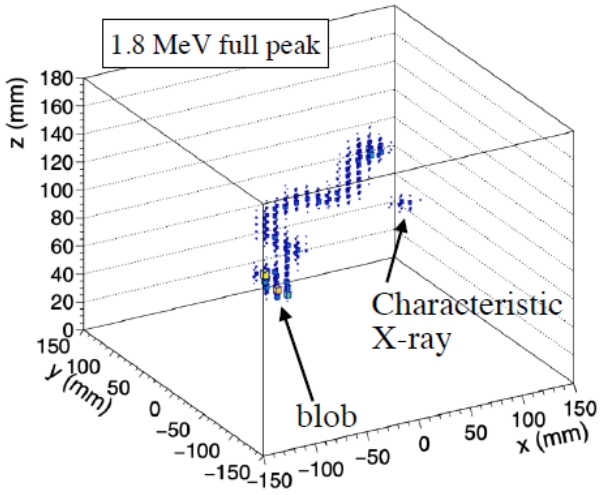


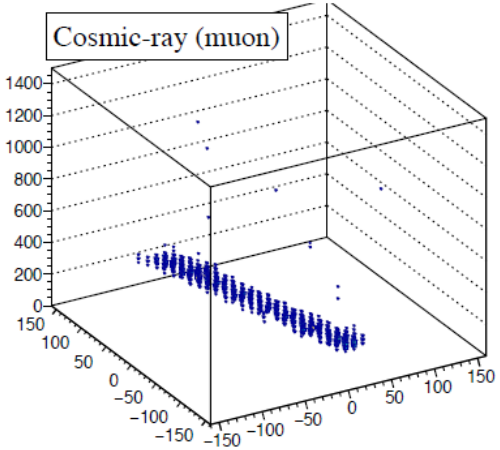
gas system for 180L prototype

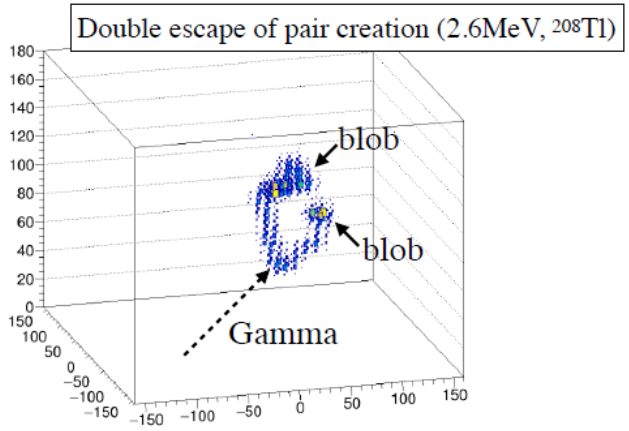
Event topology

- Bragg peak appears as “blob” in the endpoint of track
- Characteristic x-ray cluster is separated with main photo electron cluster → Can be used to reject gamma ray BG



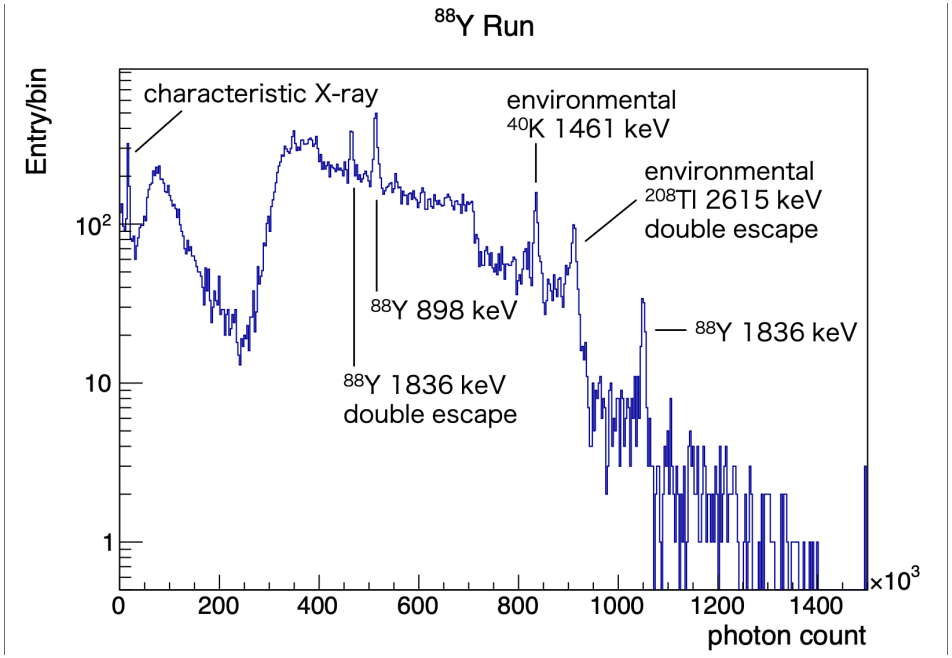


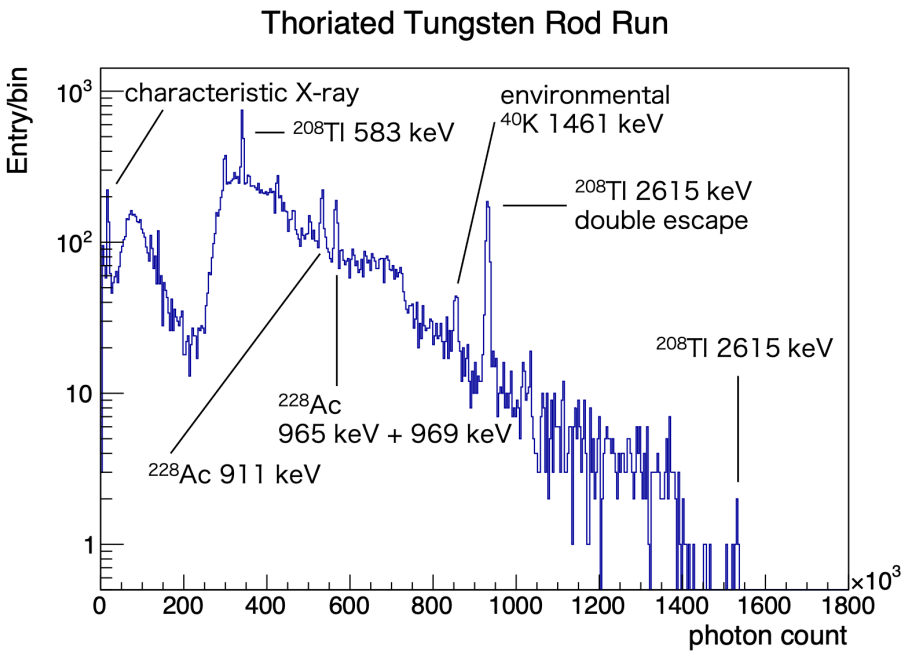




Energy spectrum

- ^{88}Y Run
  - ^{88}Y : 898 keV, 1836keV, double escape of 1836keV
- Thoriated Tungsten Rod Run
  - ^{208}Tl : 583keV, 2615keV, double escape of 2615keV
  - ^{228}Ac : 911keV, 965keV and 969keV
- Environmental ^{40}K, ^{208}Tl are also observed





Breakdown of energy resolution

- The contributions from various sources to the energy resolution for the peak of ^{88}Y 1836keV gamma ray
- Resolution of data and estimation are in agreement within the margin of error
- If all improvement successfully done, expect **0.31%** @ Q-value

	FWHM
Error in the time variation correction	0.32 %
Fluctuation of the number of initial ionization electrons	0.29 %
Fluctuation of the EL conversion	0.24 %
Error in the EL gain correction	0.23 %
Recombination	0.22 %
Fluctuation of the MPPC non-linearity	0.18 %
z mis-reconstruction	0.16 %
Variation in time bin of time variation correction	$\lesssim$ 0.16 %
Accuracy of the MPPC recovery times	$\lesssim$ 0.11 %
Error in the z-dependence correction	$\lesssim$ 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	0.64 % to 0.68 %
Data total	(0.73 ± 0.11) %

MPPC upgrade
0.24% → 0.14%

achieve target drift electric field (100V/cm/bar)
0.22% → 0%

improve scintillation photon detection efficiency
0.16% → 0%

can be improved with longer and more stable data taking

(0.60 ± 0.03)% @ Q-value

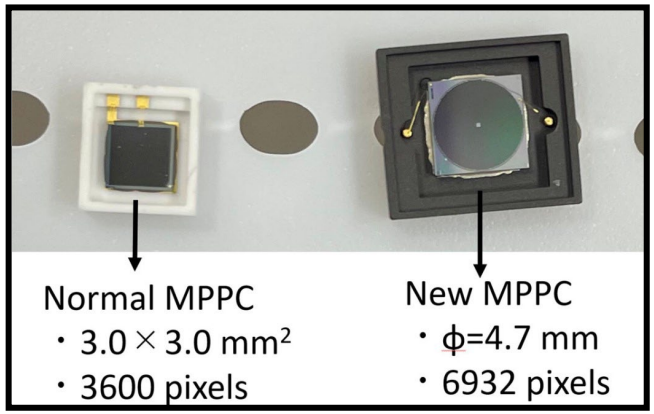
Contents

New MPPC

Large-area MPPC

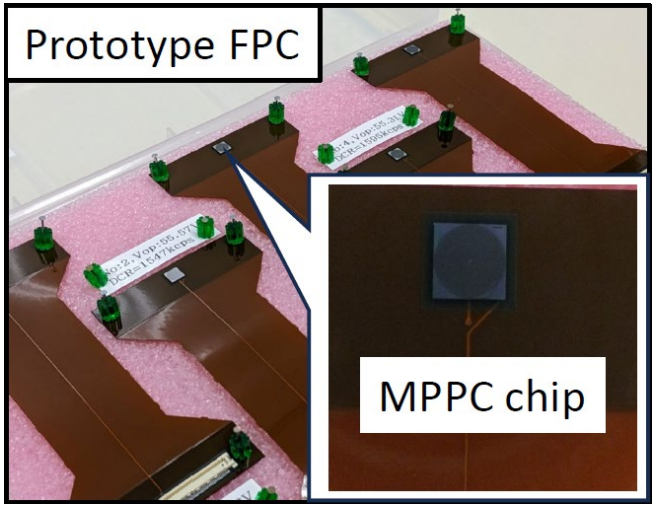
- ~ twice larger area than before
- Reduce statistical fluctuation of EL photon

→Improve fluctuation of EL conversion



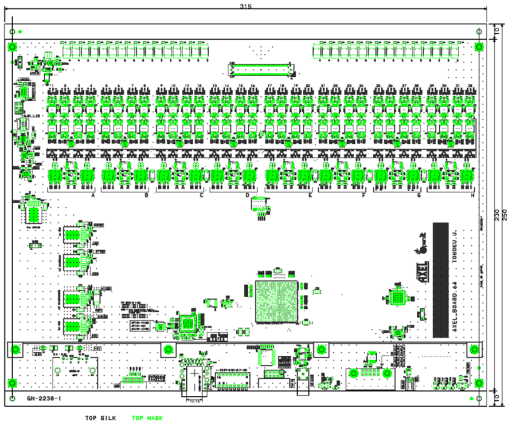
MPPC without package

- Remove ceramic package because of its RI contamination
- Place the MPPC chip directly on flexible printed circuit (FPC)
- Finish the evaluation of prototype FPC with 1 channel



Readout electronics board

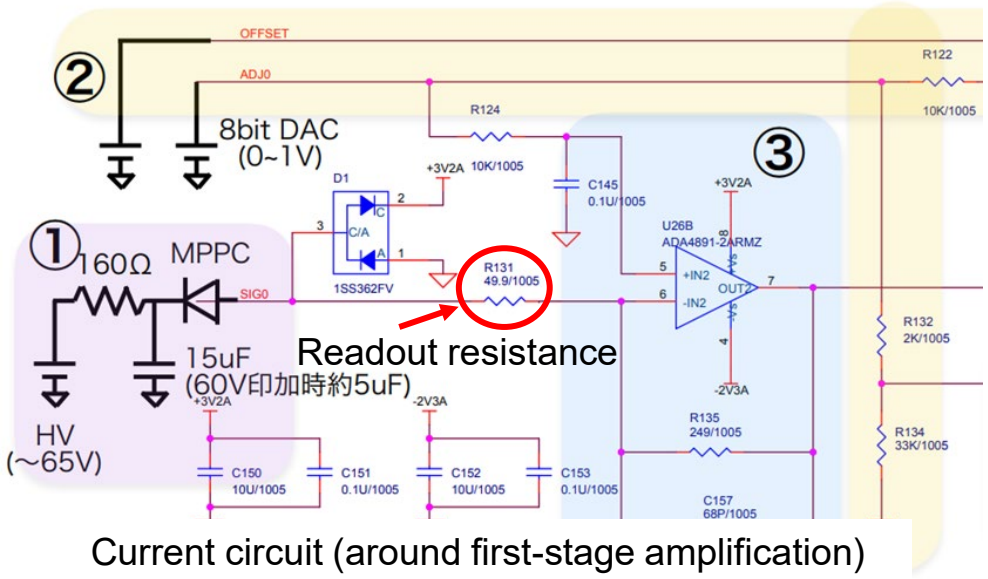
Higher density for space saving



- 56 → 64 ch/board
- Low head connector

Optimization

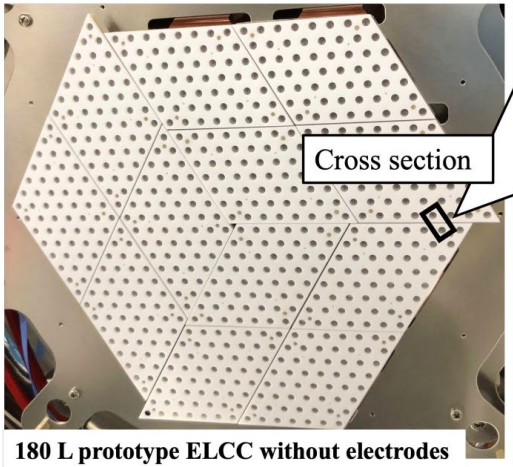
- Gain optimization for new MPPC signal size
- Readout resistance 50Ω → 10Ω to suppress MPPC nonlinearity by bias voltage drop



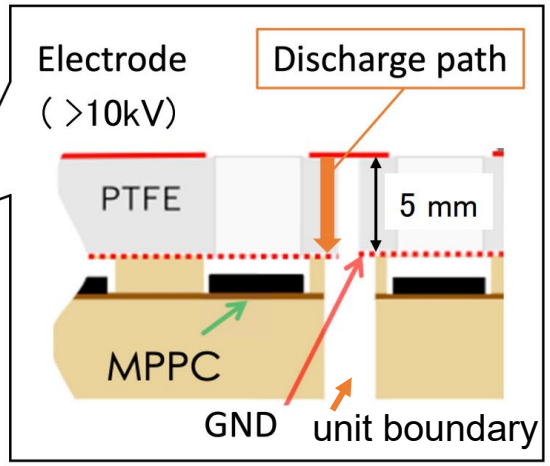
Current circuit (around first-stage amplification)

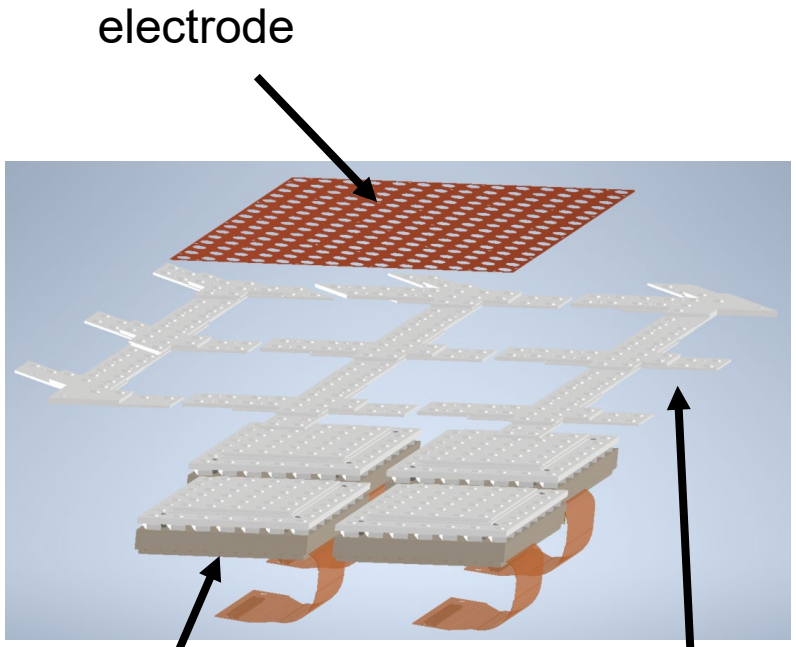
Suppression of discharge at ELCC

- High resistive Diamond-like carbon (DLC) as electrode
- Add alternate layer that cover the edges of ELCC unit to extend discharge path

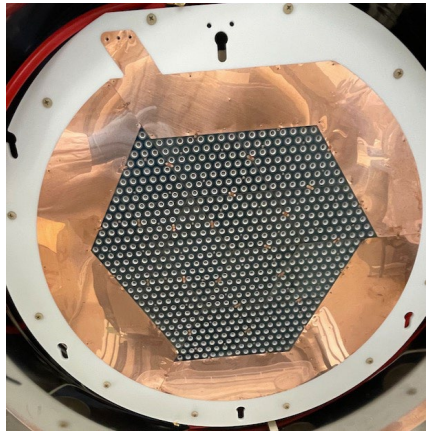


180 L prototype ELCC without electrodes





DLC coating electrode
(150MΩ/mm^2)

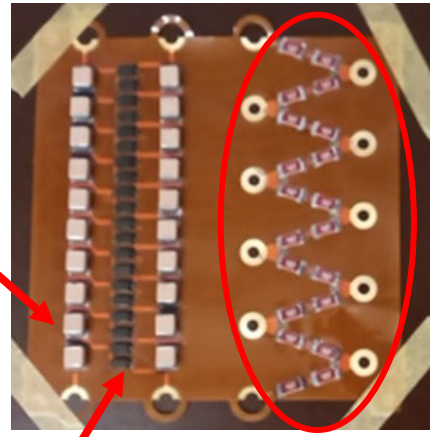


ELCC plane with DLC electrode

High voltage supply

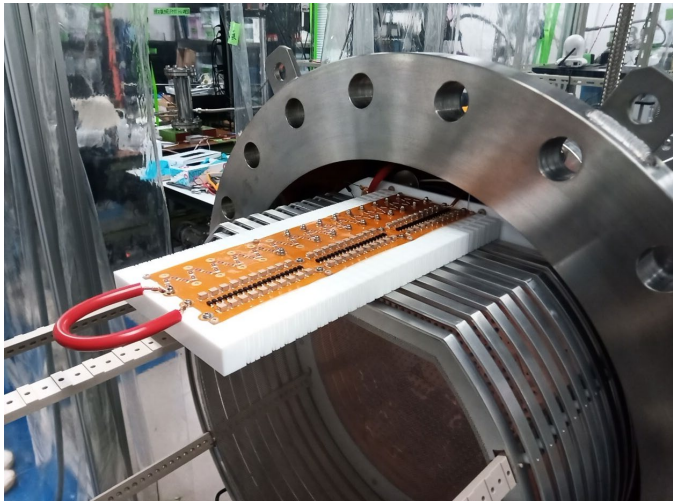
Cockcroft-Walton(CW) multiplier

- Low AC input to High DC output inside the chamber
  → Avoid high voltage feedthroughs
- Implemented on FPC
- Varnish coating to prevent surface discharge



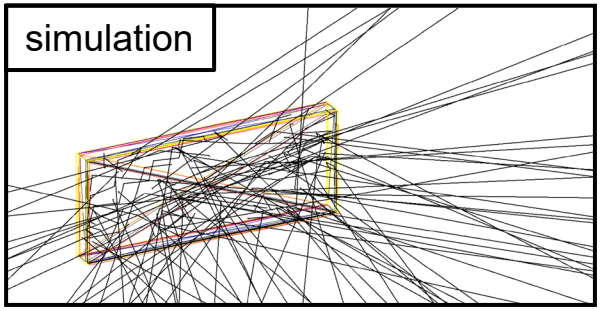
Performance evaluation with 180L prototype

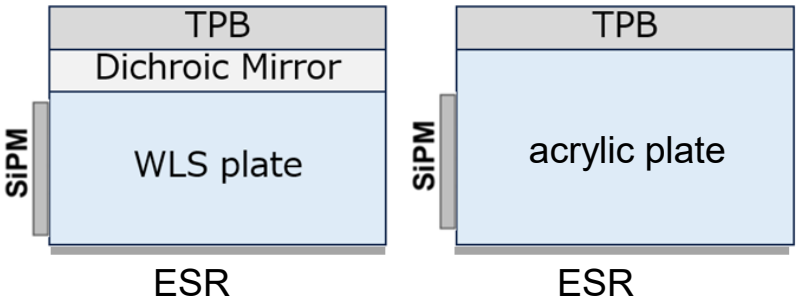
- **44.6kV** with 30 steps in atmosphere is achieved
- Instability of AC amplifiers due to capacitive loading
  - Shorten the cable
  - Consider using LC resonance
  - Higher power AC supply
- Target voltage for 1000L : 76kV (@8bar)
  - Countermeasure for instability
  - More steps



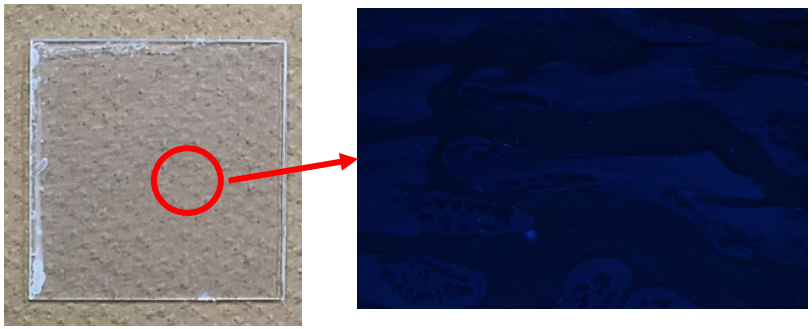
Scintillation photon detection

- For now, 7 VUV-sensitive PMTs are used
  - Signal of each PMT is 1p.e. level
    → dark pulse causes mistake of z-position reconstruction
  - Increasing the light intensity allows us to select the scintillation pulse that corresponds to the signal
- New detection configuration
  - Wavelength shifted photon is detected at the side
    → large detection area
  - Simulation with 2 types of configuration
  - R&D to establish uniform coating is ongoing





2 types of configuration



TPB dip coating makes uneven fluorescence

Status of 1000L detector

1000L-size pressure vessel

- Installed at Kamioka observatory (~1000m underground) on May 17, 2023
- Size: 1mΦ × 1.5m, Weight: 1.4 ton
- Inner-fixed feedthrough for saving space for electronics

Gas circulation system

- Under construction in Tohoku univ.

installation of pressure vessel

inside

Gas circulation system

Contents

Summary

AXEL experiment

- High pressure xenon gas TPC with unique readout structure ELCC
- Evaluation for 180L prototype and R&Ds for 1000L detector are ongoing

180L prototype

- FWHM Energy resolution @1836keV : 0.73% → 0.60% @ Q-value
- Resolution of data and estimation are consistent
- If all improvement successfully done, expect 0.31% @ Q-value

1000L detector

- New MPPC : twice larger area, removed ceramic package
- High Voltage
  - prevent discharge at ELCC : DLC electrode, additional cover layer
  - Cockcroft-Walton multiplier : 44.6kV in atmosphere, countermeasure for instability
- Scintillation photon detection : R&D is ongoing
- Pressure vessel was installed at Kamioka. Gas system is under construction in Tohoku.