High pressure xenon gas detector with segmented electroluminescence readout for $0\nu\beta\beta$ search

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for the AXEL collaboration

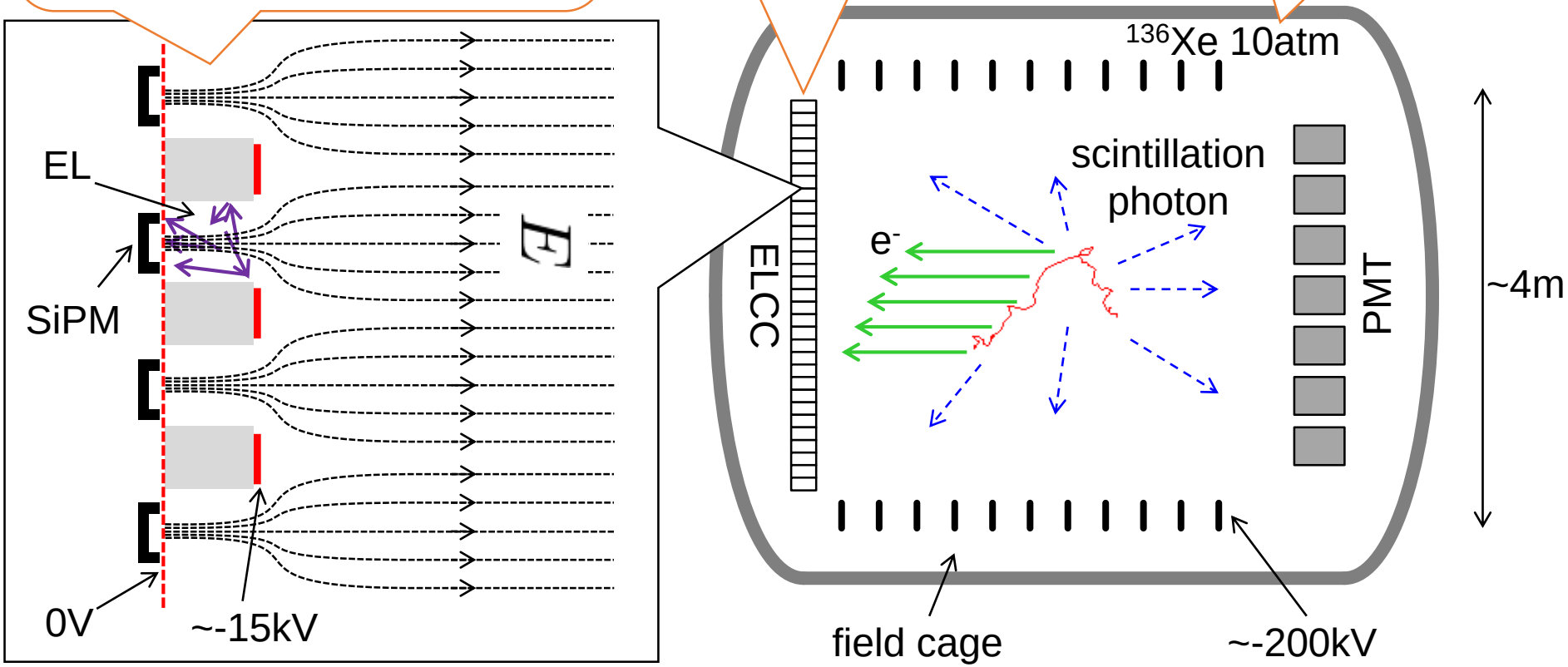
AXEL experiment

- High pressure xenon gas TPC for $0\nu\beta\beta$ search

Energy resolution: gaseous xenon + electroluminescence (EL) readout
target: 0.5%FWHM

Background rejection: tracking by segmented EL readout

Large mass: high pressure ~ ton scale



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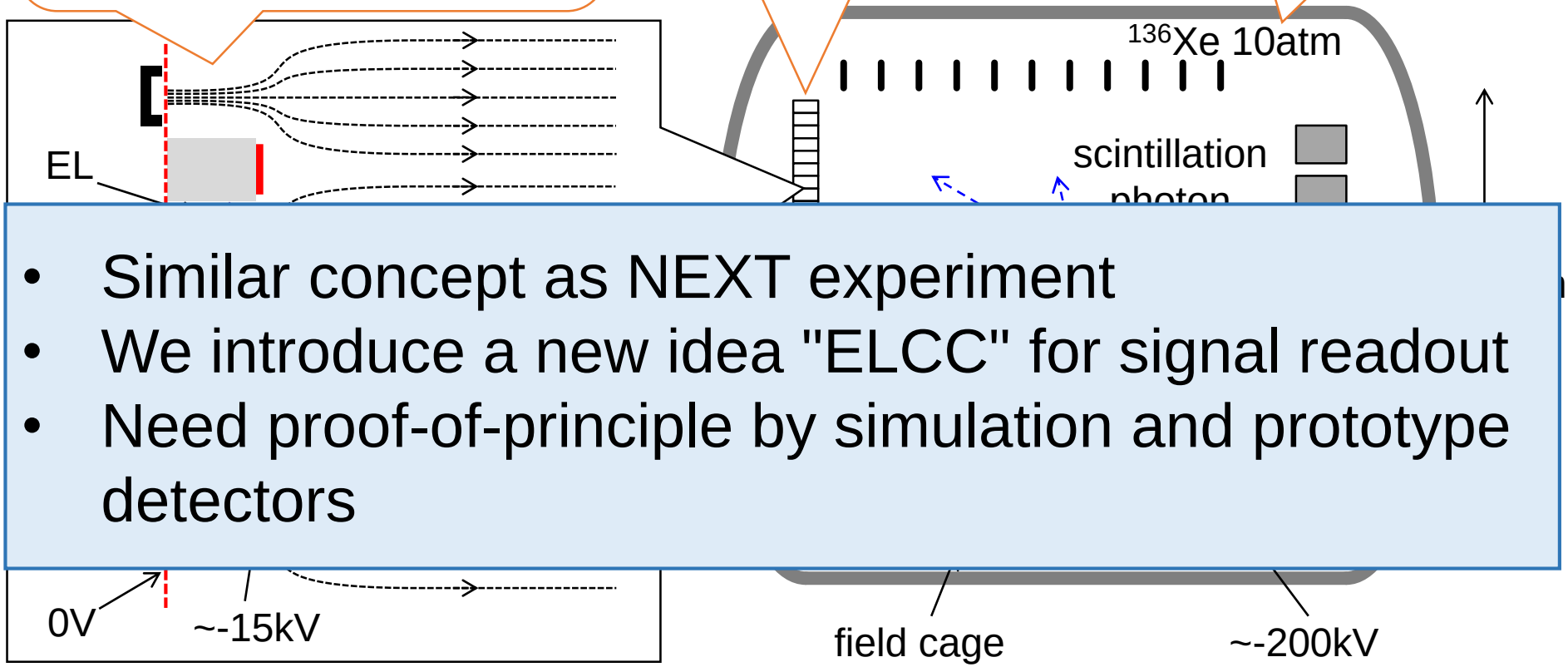
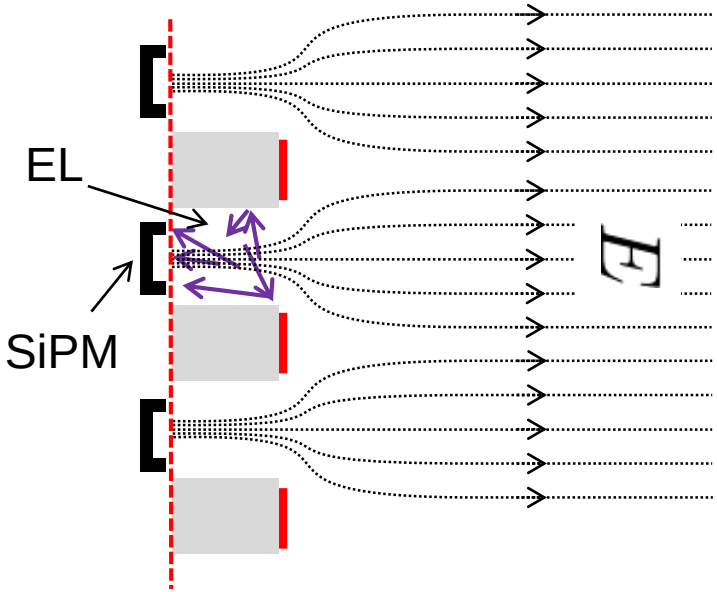
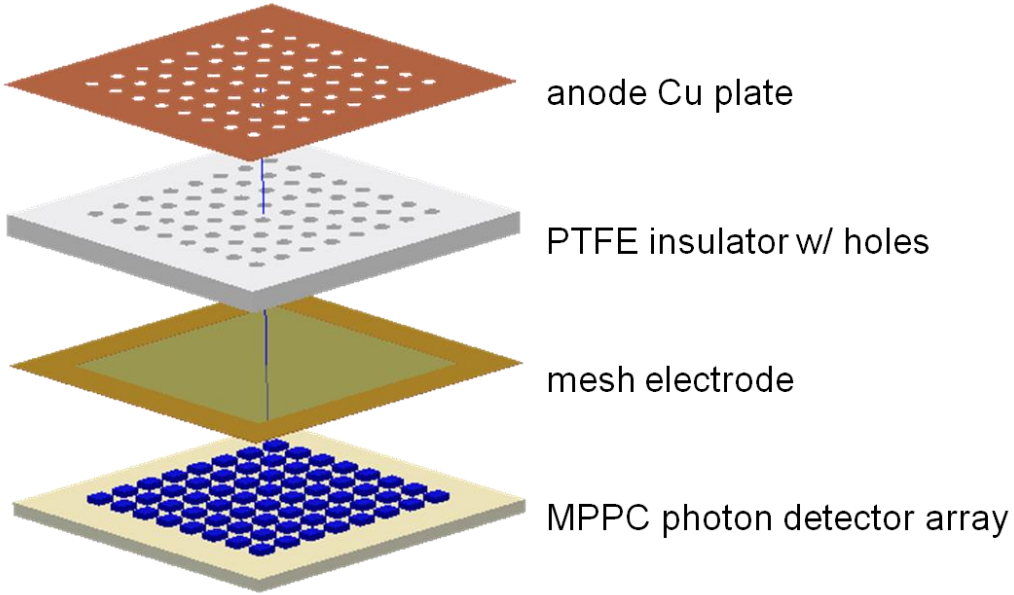


- Similar concept as NEXT experiment
- We introduce a new idea "ELCC" for signal readout
- Need proof-of-principle by simulation and prototype detectors

Segmented EL readout: ELCC

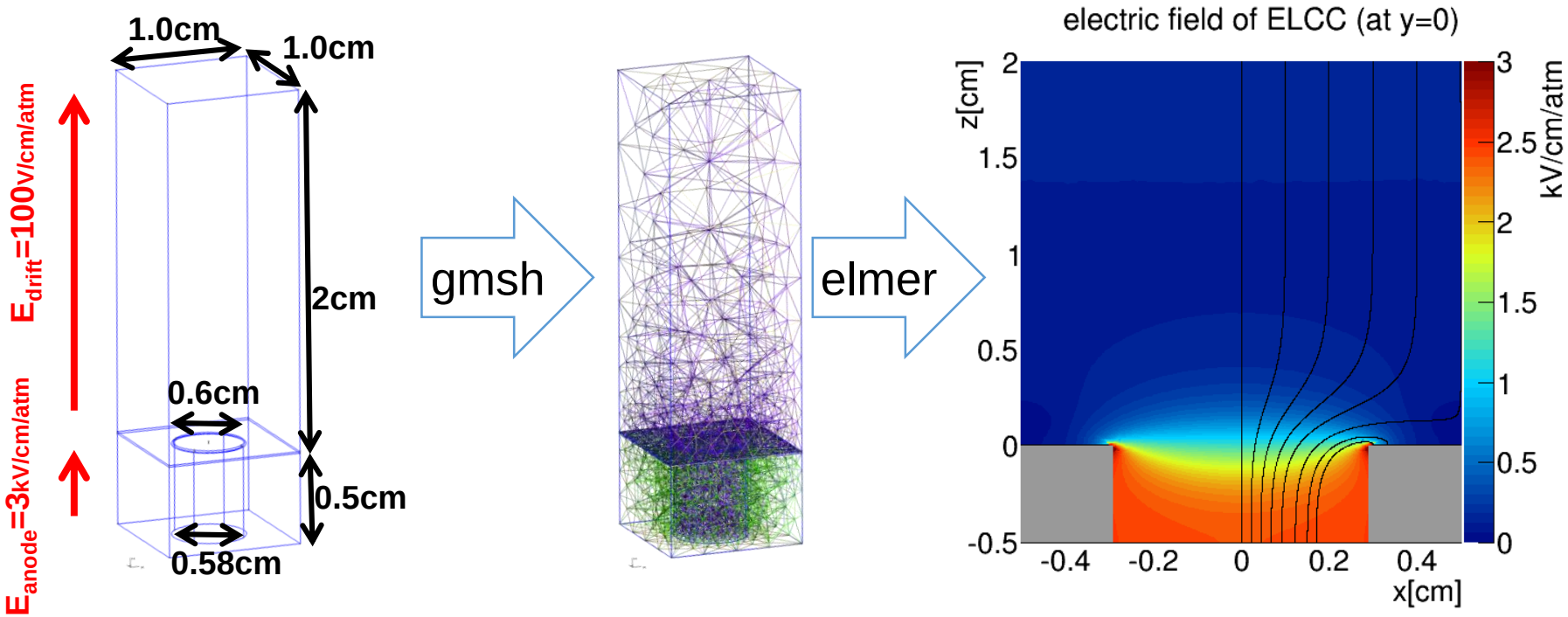
- Detect EL photons for cell by cell
- Energy measurement and tracking
- Good uniformity in wide area
- Rigid structure --> large size





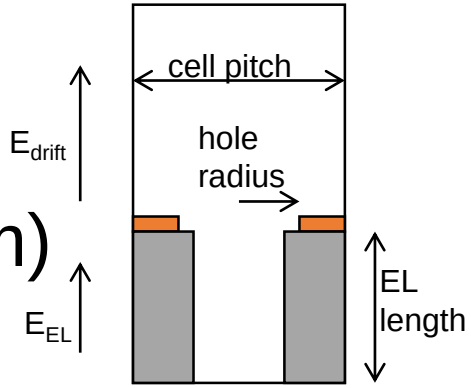
ELCC simulation

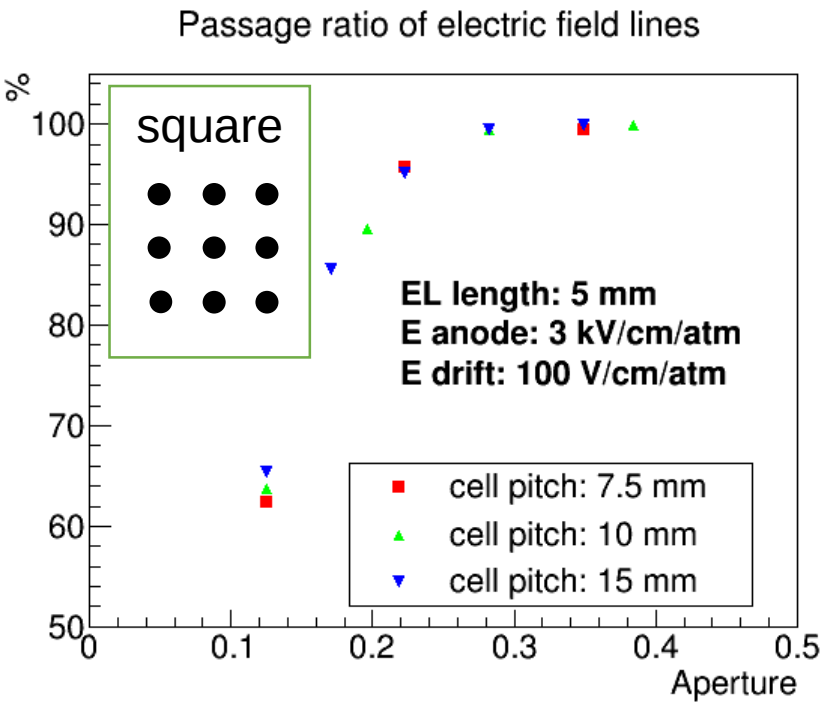
- Electric field simulation (gmsh + elmer)
- By applying high electric field in the EL region, electric field lines are pulled into the cell hole

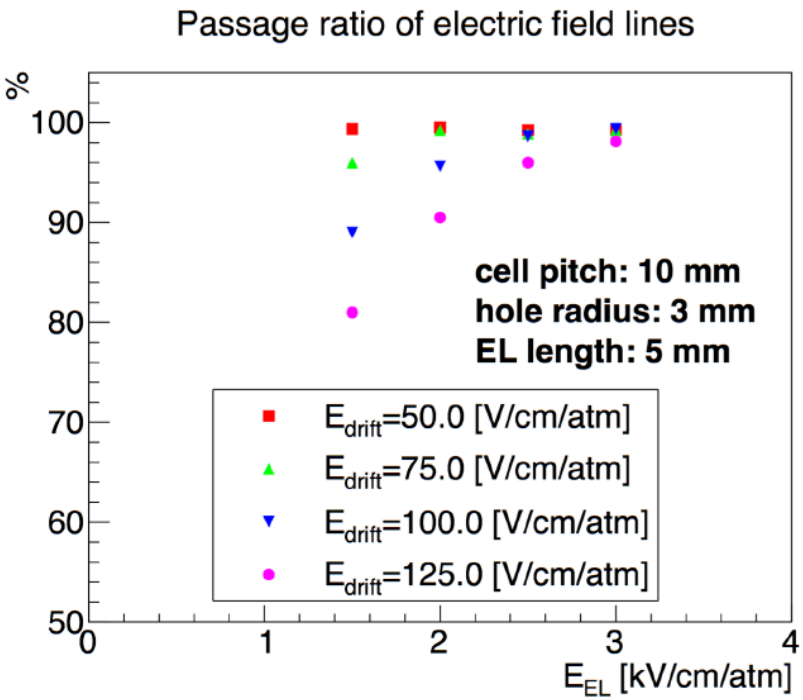


Collection of line of electric field

- Larger aperture is better
- Taking some E_{drift}, large E_{EL} is better (E_{drift}=100V/cm/atm, E_{EL}>2.5kV/cm/atm)

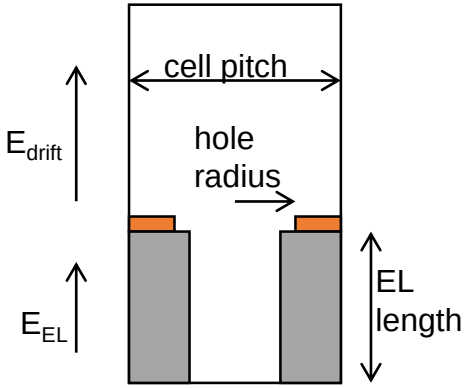


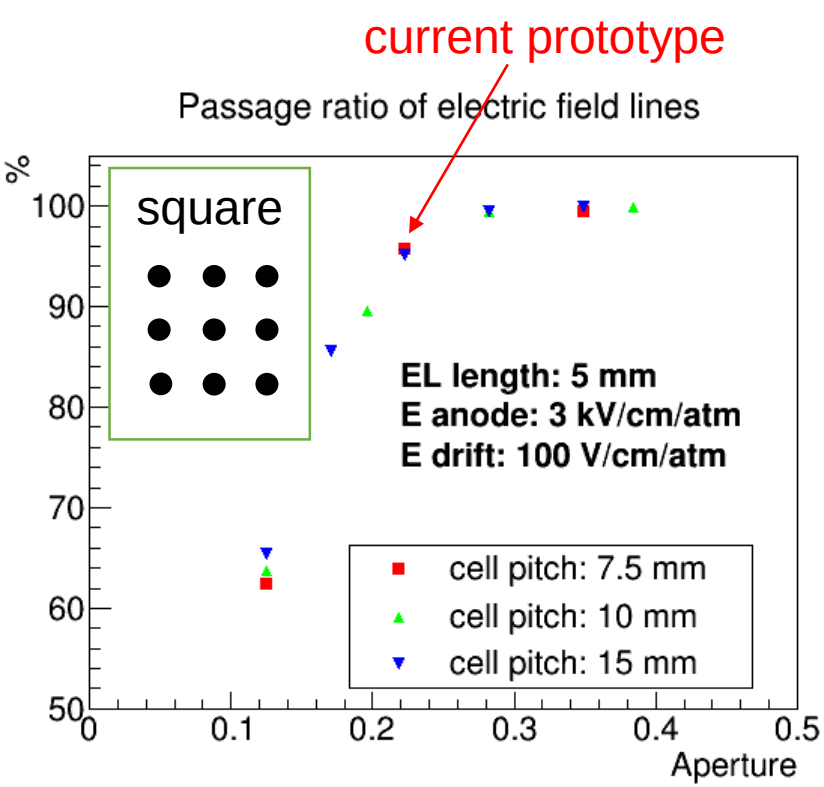


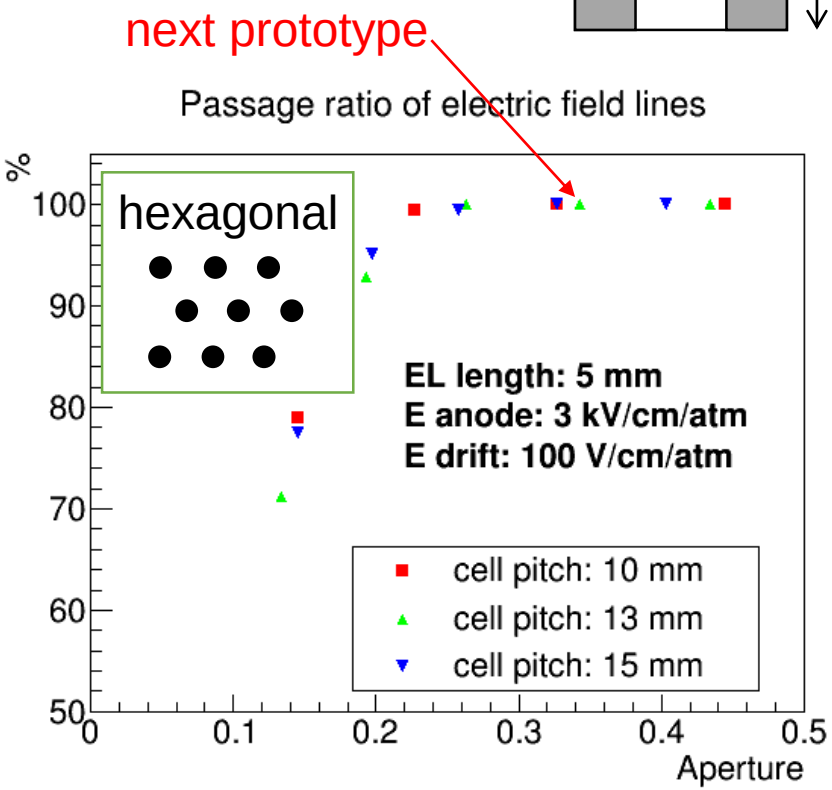


Collection of line of electric field

- Hexagonal placement is better
- Next prototype will be OK







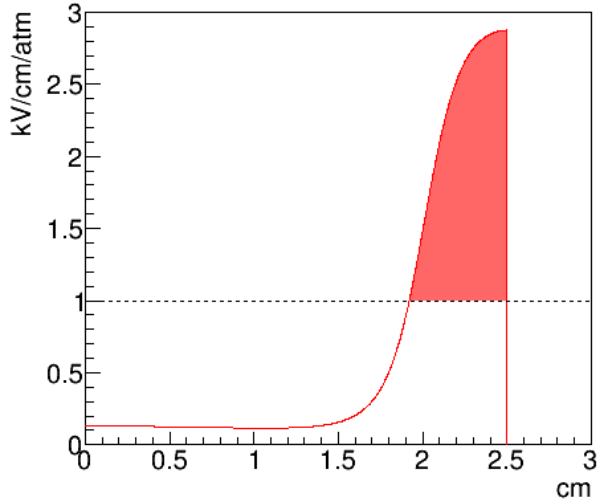
Uniformity of EL generation

- EL Yield is proportional to [electric field strength] x [path length]

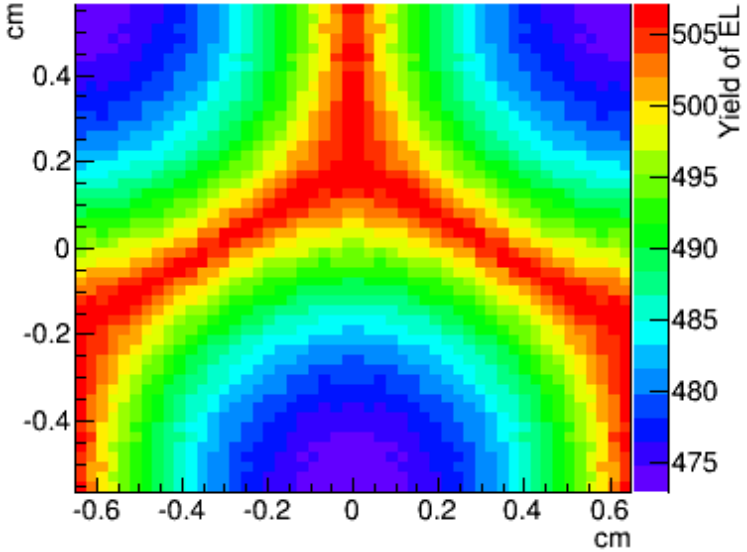
$$dN_{ph}/dx = 70(E/p - 1.0)p$$

- Uniformity : 1.4%
- Since initial electron number is 1e5, effect on energy resolution will be 1.4%/√1e5 = 0.005%

Electric field along the path

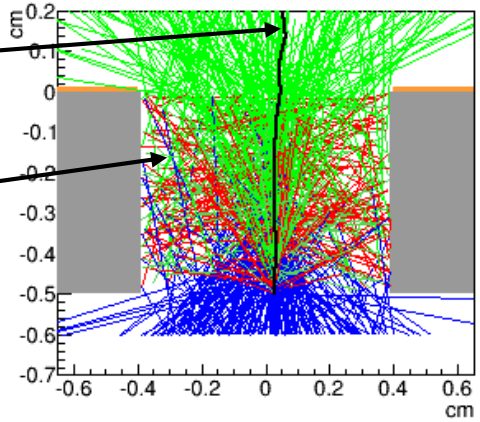


Initial position dependence of EL yield

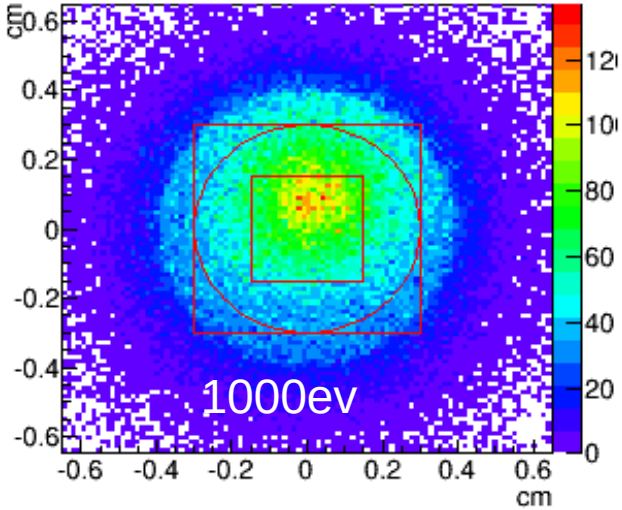


Electron and photon propagation simulation

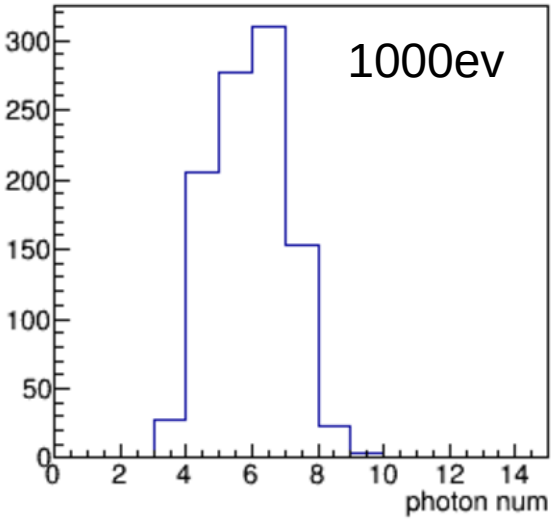
- Electron track by Garfield++
- EL photons by Monte Carlo method
- 6photon/e- @SiPM(3mm square)



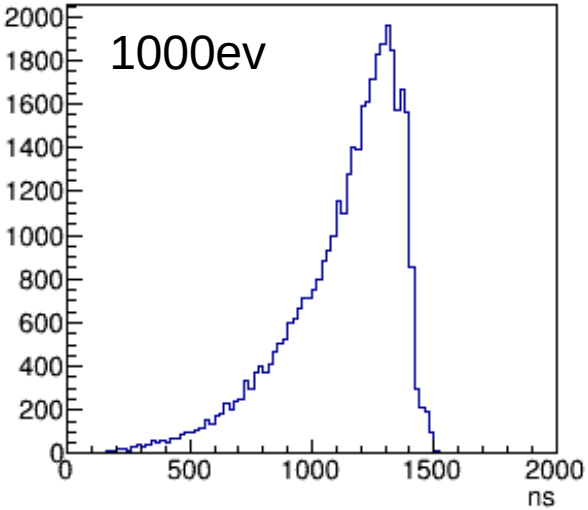
hit position at SiPM



detected photon num

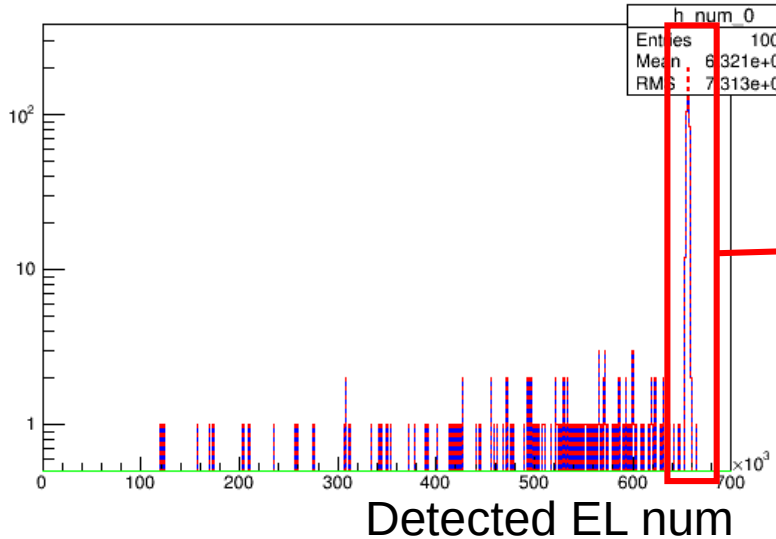


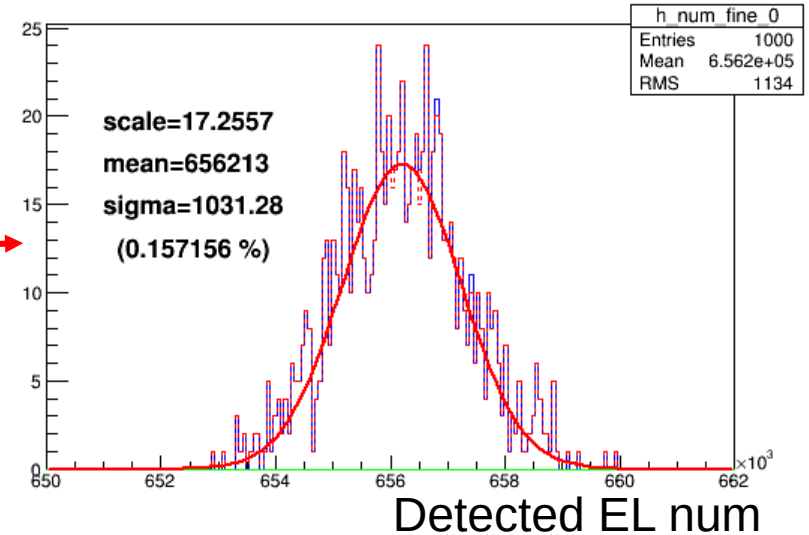
hit timing



Estimation of energy resolution

- Simulation process
  - $0\nu\beta\beta$ event by Geant4
  - statistical fluctuation with fano factor
  - drift to the ELCC plane with diffusion
  - EL generation (6photon/e^-)
- Simulated energy resolution: 0.37%(FWHM)
  - ionizing process: 0.27%
  - EL process: 0.25%



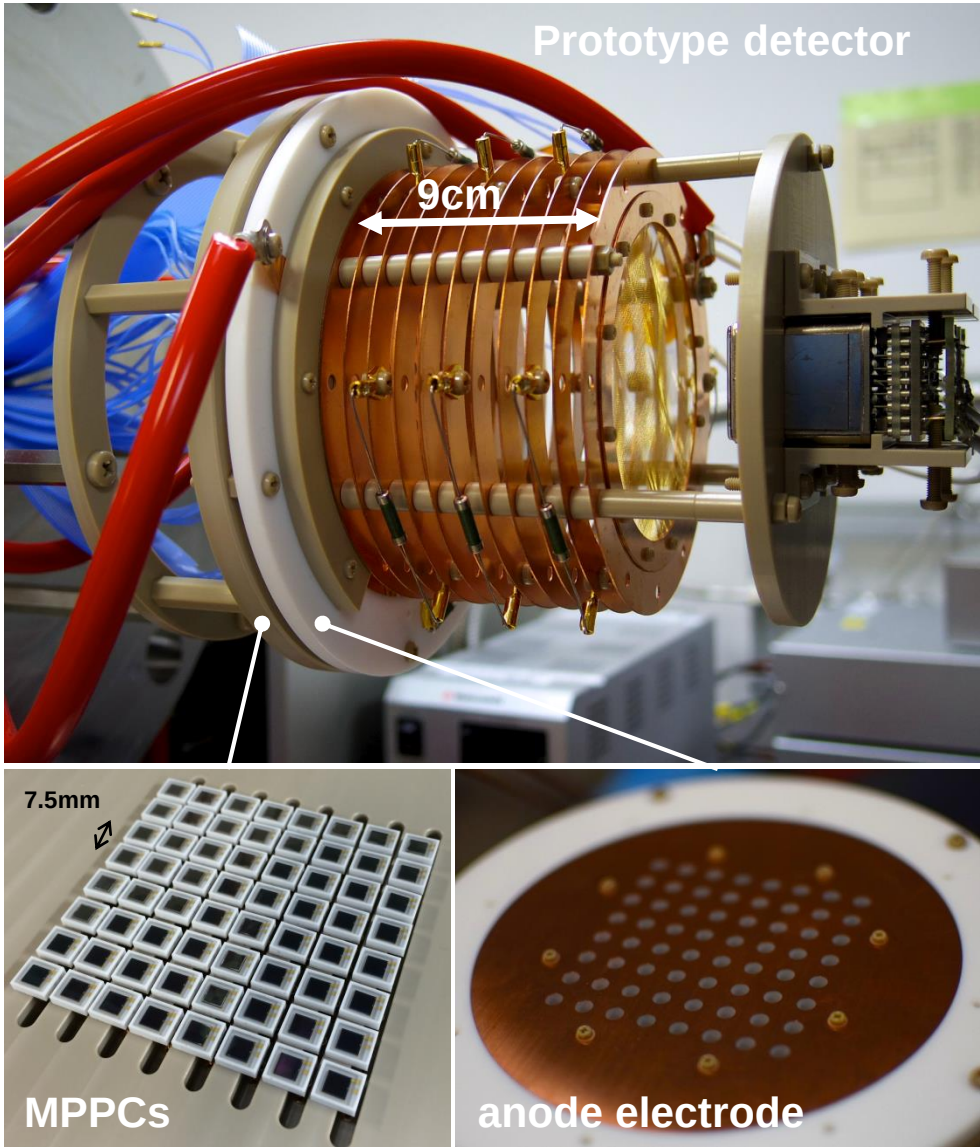


arxiv: 1701.03931

Prototype detector

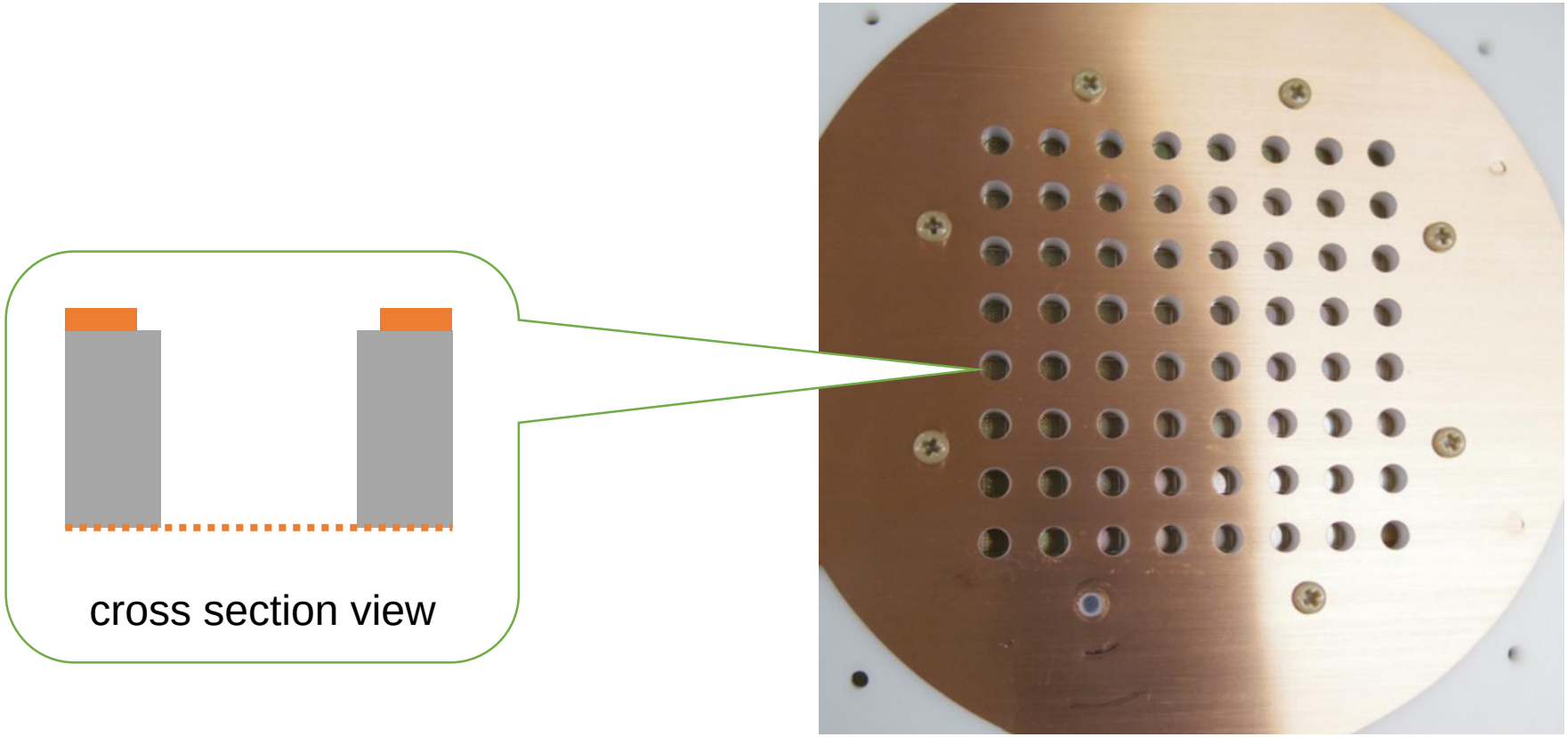
- Parameters
  - Sensitive region: 6 x 6 x 9 cm
  - Cell num: 64
  - Gas pressure: 4 bar
  - E_{drift}: 100 V/cm/atm
  - E_{EL}: 2.7kV/cm/atm

- MPPC-VUV3
  - PDE: 23%
  - Size: 3 x 3 mm^2



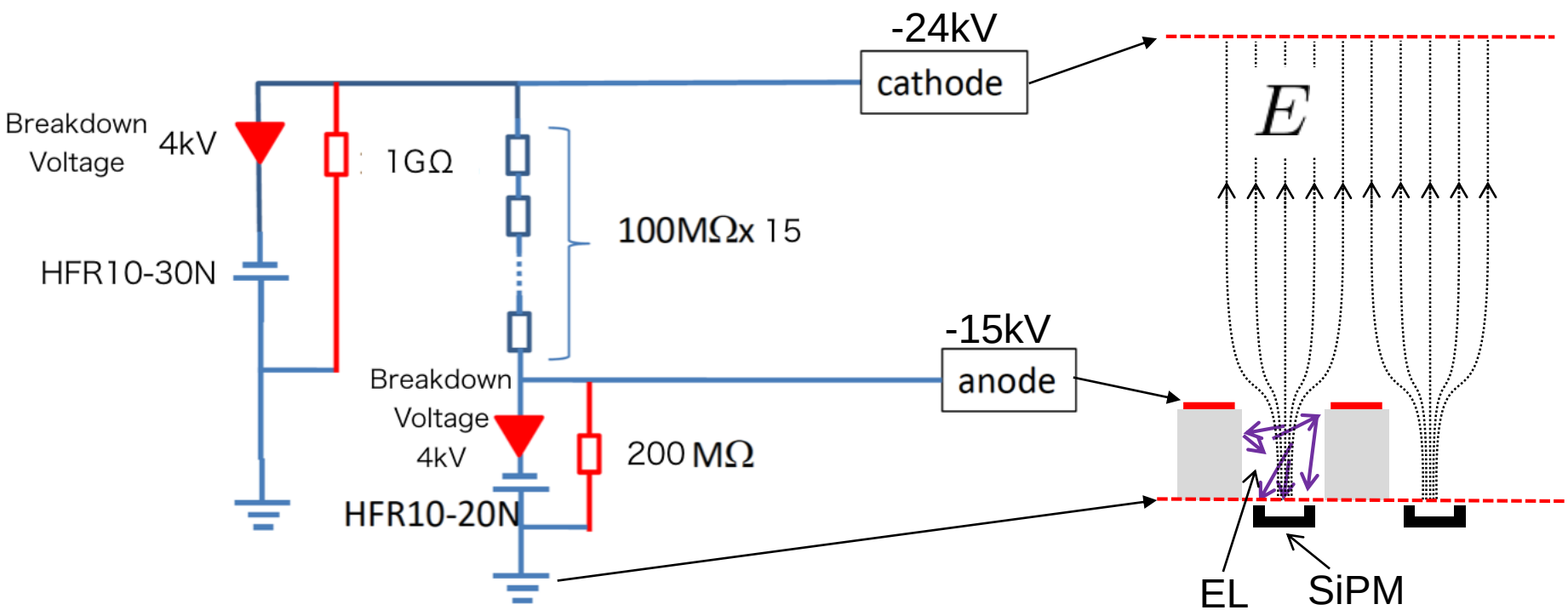
ELCC design

- To prevent discharge, PTFE holes is slightly smaller than anode(Cu) holes



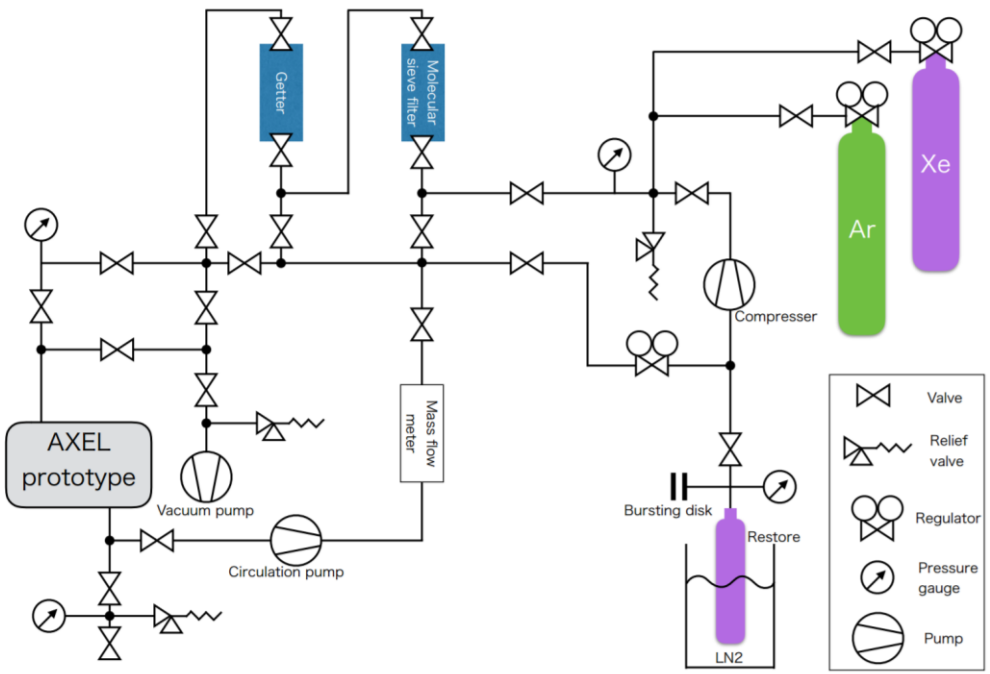
High voltage applying

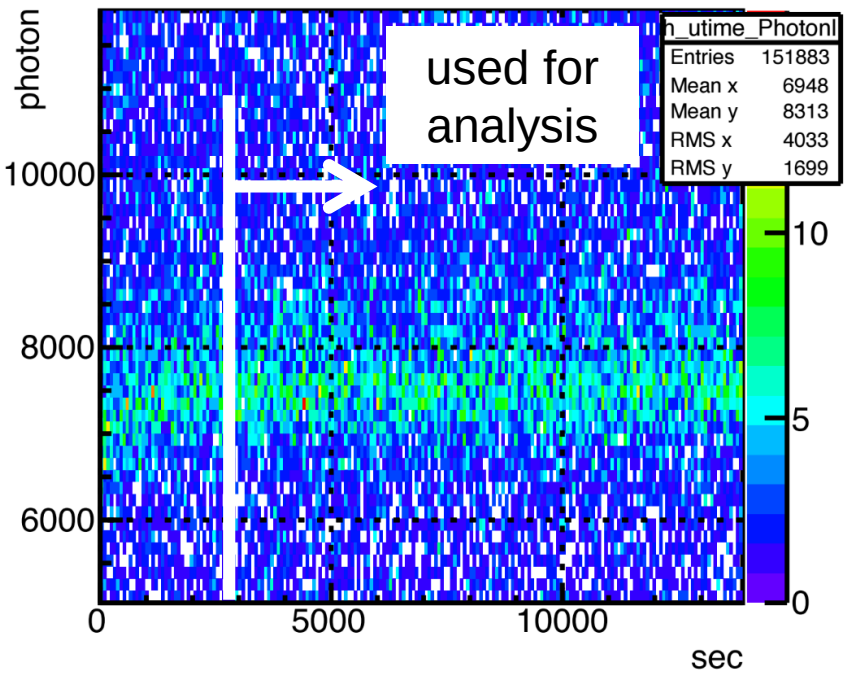
- Two HV modules to control both EL field and drift field
  - HFR10-30N, HFR10-20N [Matsusada-precision]
- Diode and resistance for circuit protection



Gas circulation system

- Circulate high pressure xenon gas
  - pump: PumpWorks PW2070
  - SAES micro torr MC1-902FV
  - API-GETTER-I -Re
  - Number of photons slightly increase at first

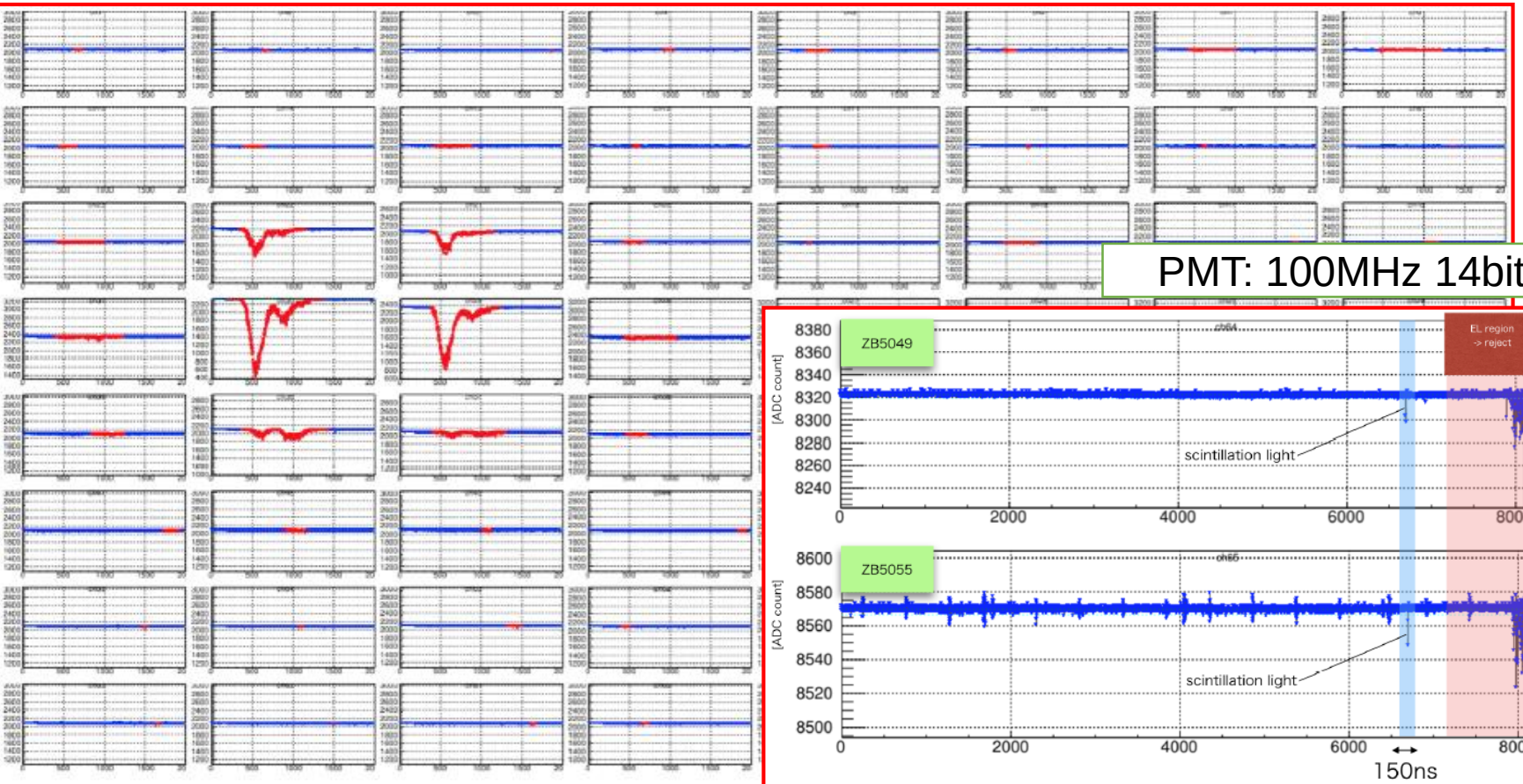




Event sample

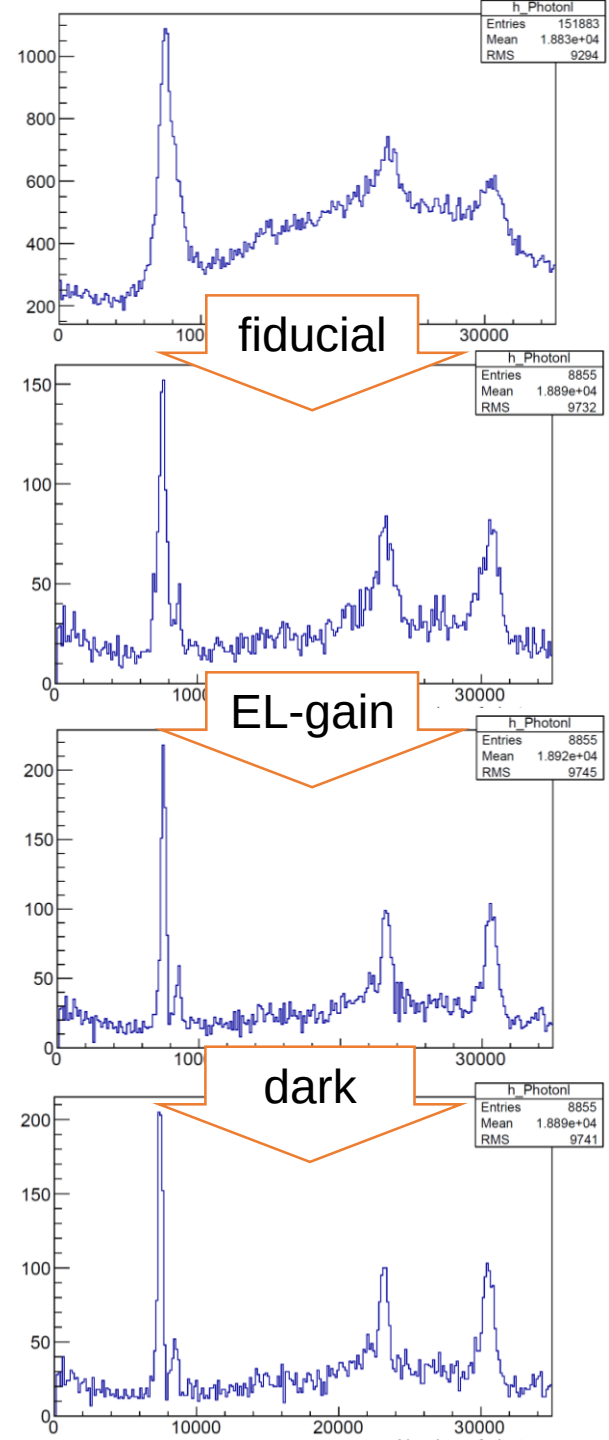
- Waveforms of MPPC and PMT
- EL light & scintillation light are observed

MPPC: 65MHz 12bit 2Vpp



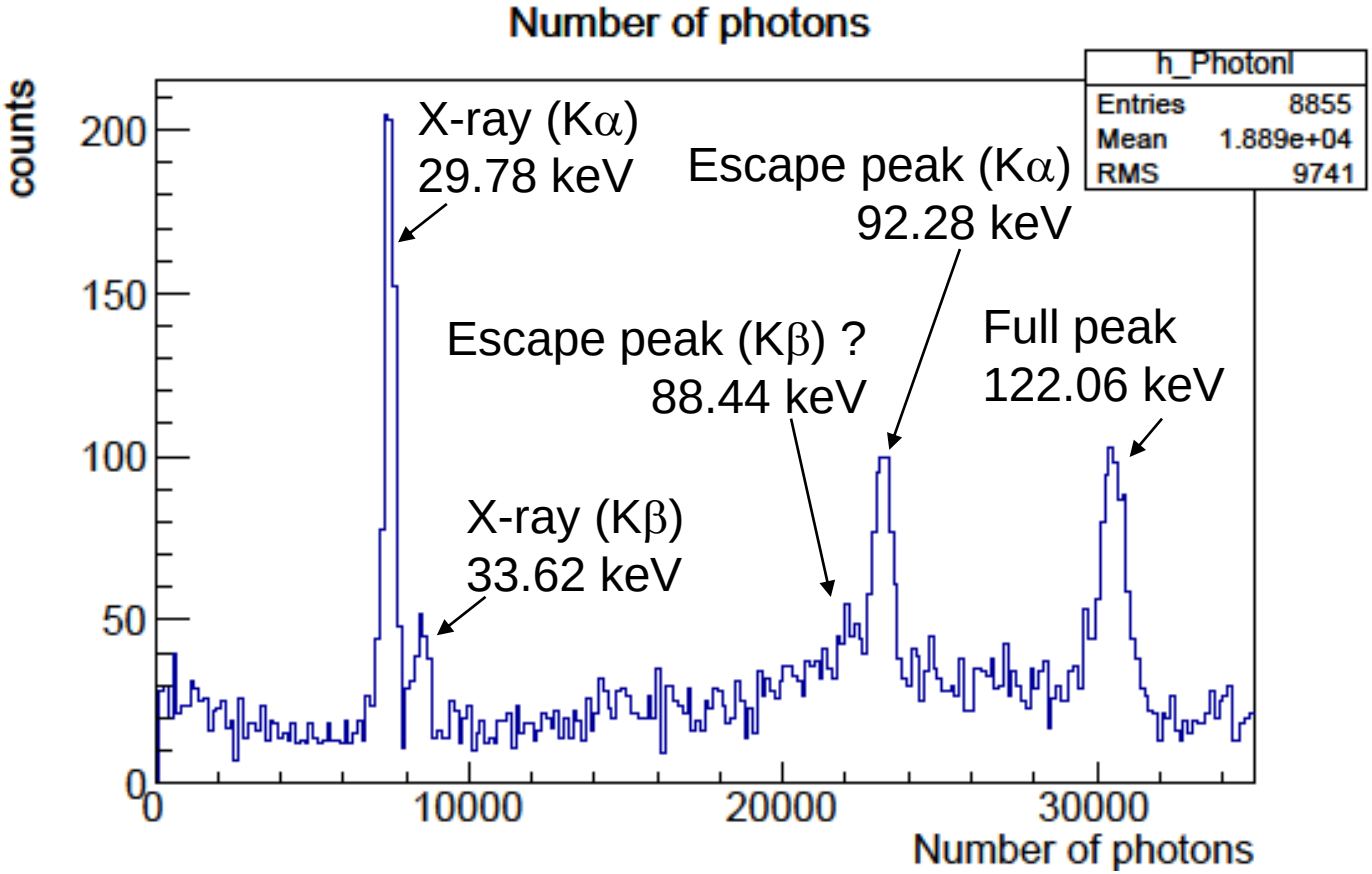
Analysis flow

- Fiducial cut
  - XY by hit channel, Z by PMT timing
- EL gain correction
  - Measure each cell gain by 30keV peak
- Dark count correction
  - Depend on time duration of EL photon



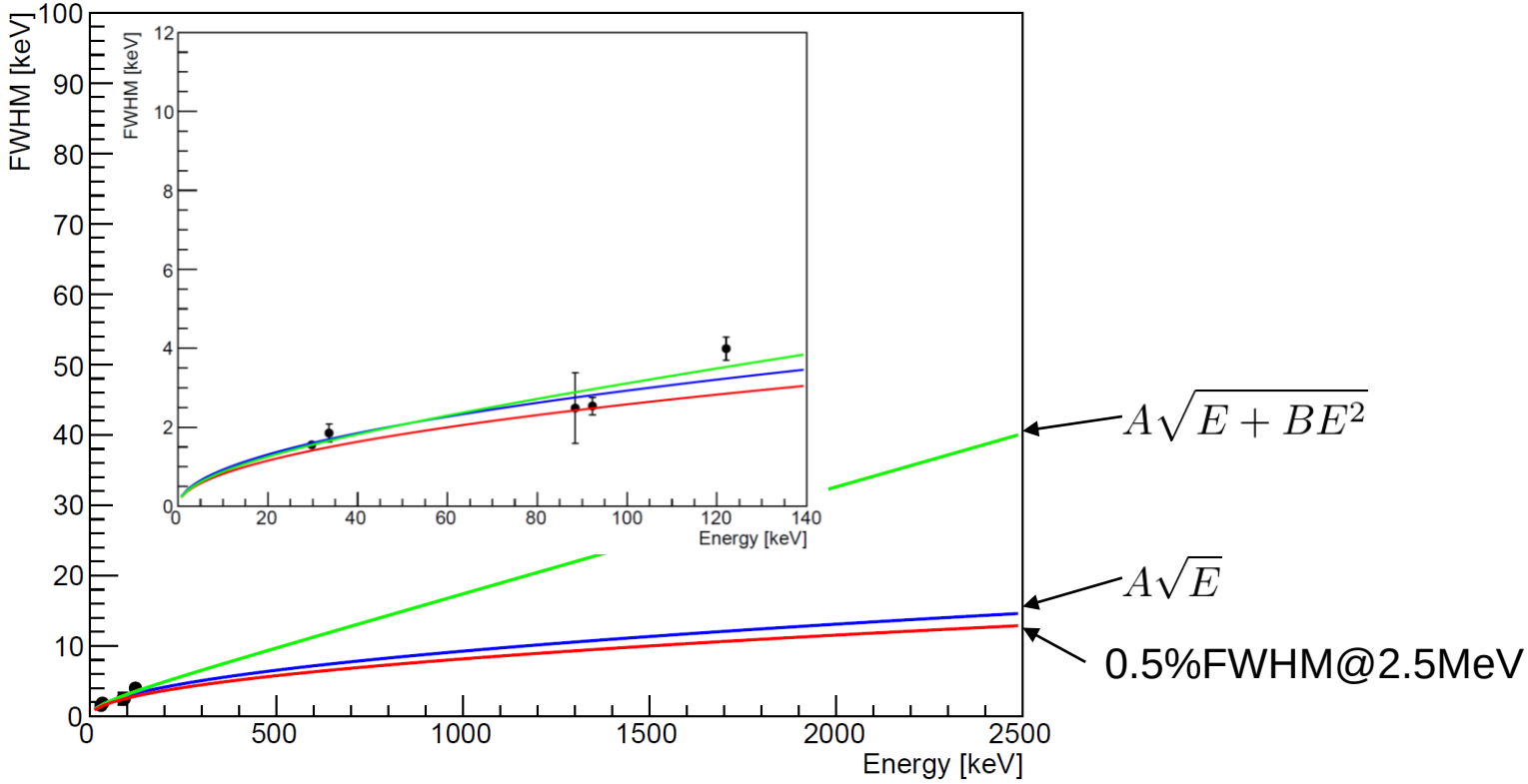
Measured energy spectrum

- Four (five?) peaks are observed using ^{57}Co source



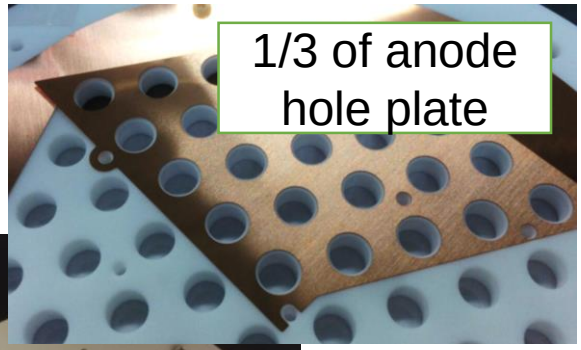
Measured energy resolution

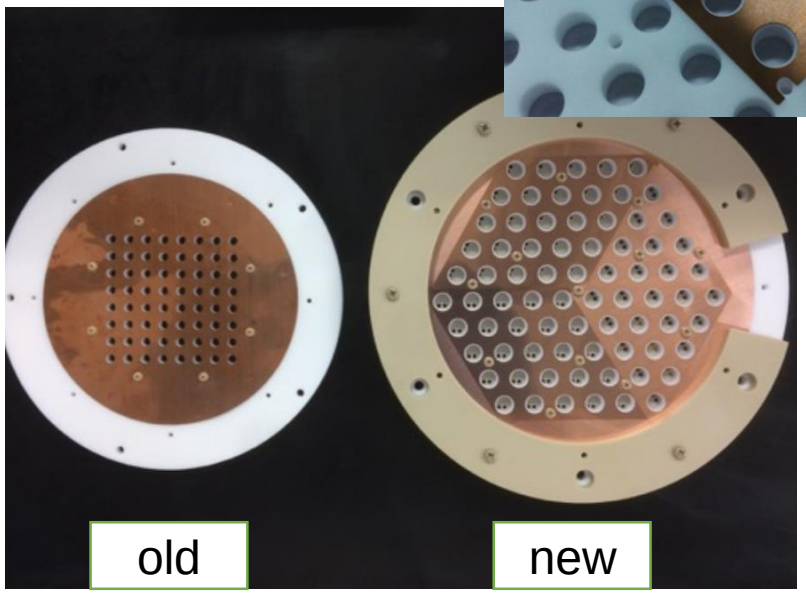
- Measured energy: 30,34,88,92,122 keV
- Extrapolating 2.5MeV by assuming
  - $A\sqrt{E+BE^2}$: 1.61%FWHM
  - $A\sqrt{E}$: 0.59%FWHM

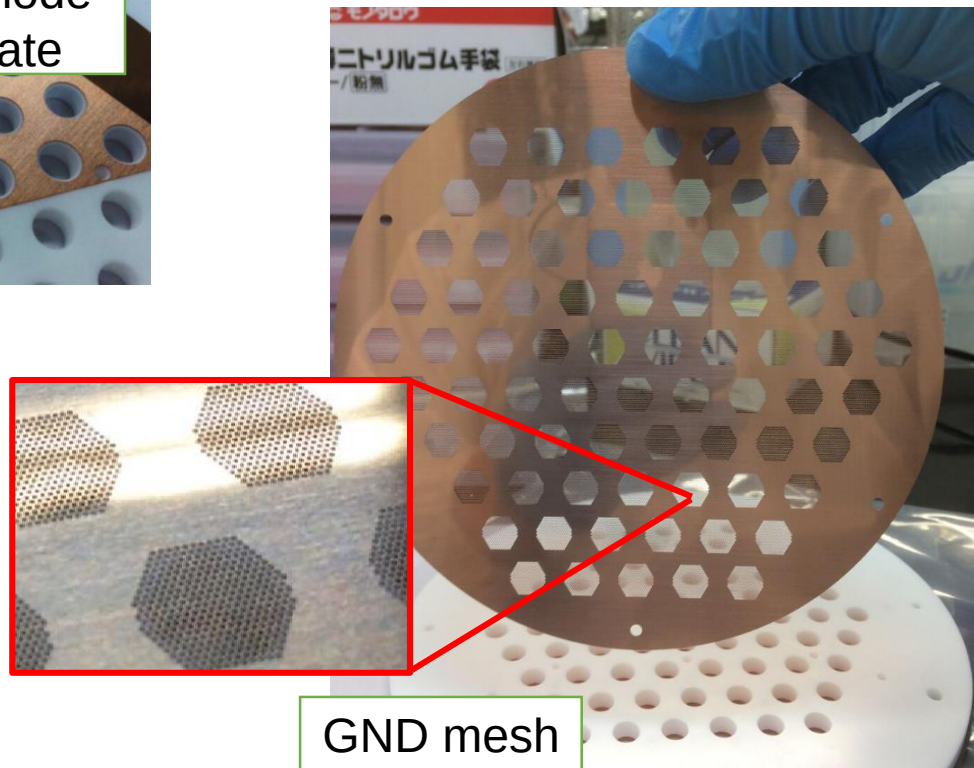


Upgrade of ELCC structure

- New ELCC will come soon for testing...
  - Higher energy measurement (511keV gamma-ray)
  - Multi electrode (scale up study)
  - Hexagonal placement (better than square one)





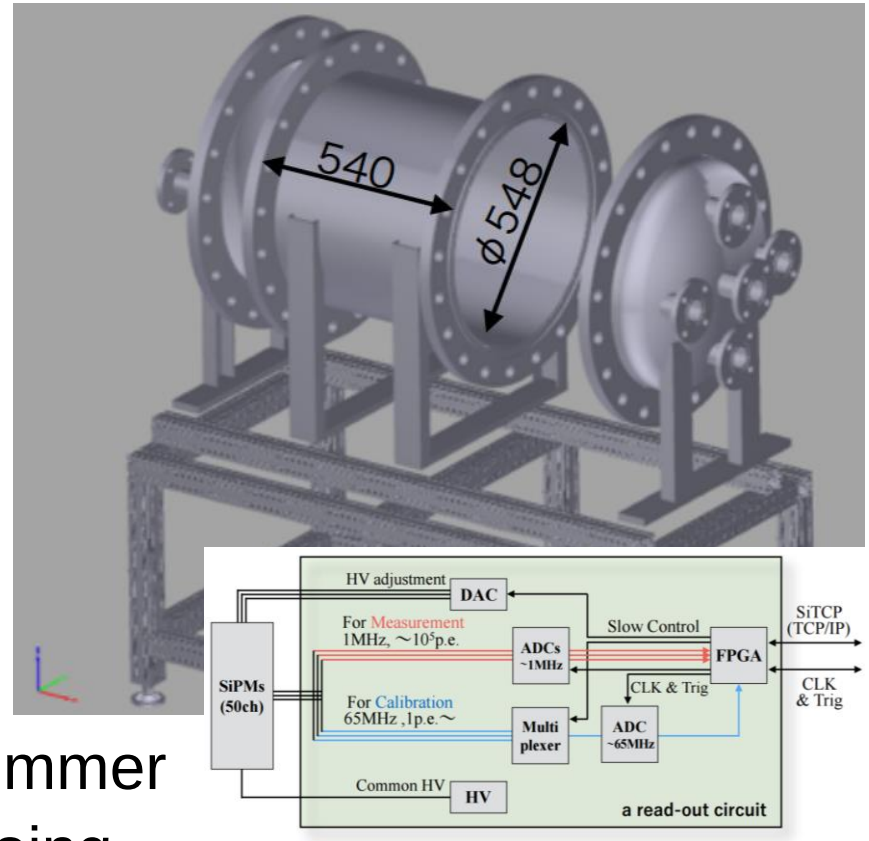


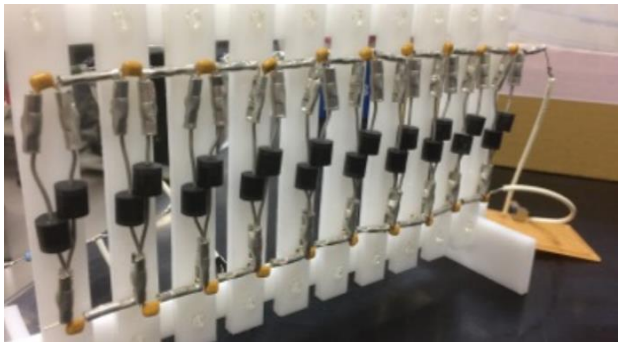
Large prototype project

- 100L scale detector

- Purpose
  - test at 2.5MeV
  - test tracking
  - get large size technique

- Status
  - Chamber will come by this summer
  - Electronics development ongoing
  - Developing Cockcroft-Walton high voltage generation
  - Cabling test

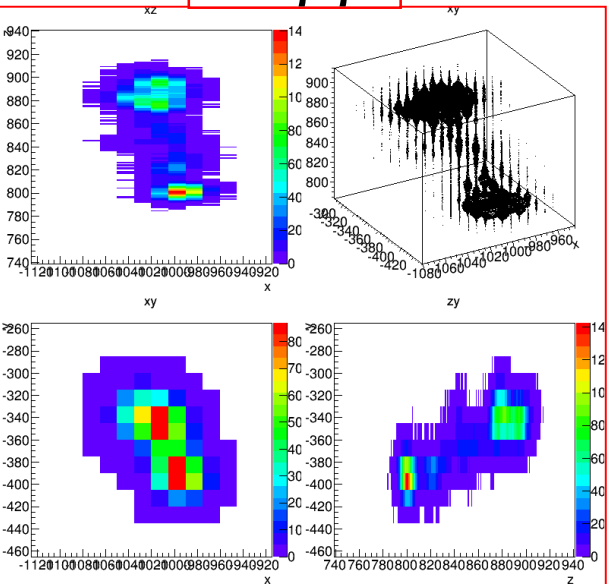




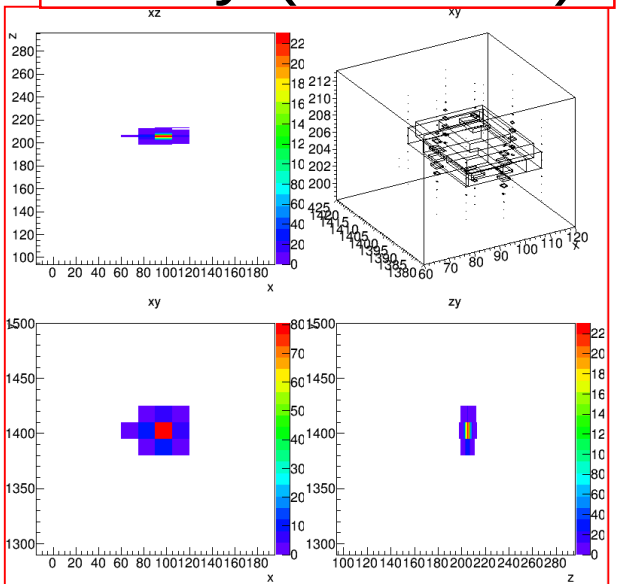
Simulation study for BG rejection

- Track topology (by Geant4)
  - 2-blobs : $0\nu\beta\beta$
  - small : α-ray BG
  - multi-site : γ-ray BG with Compton scattering (~98%)
- Basically, 2.5MeV γ-ray with photo absorption (~2%) is the serious background

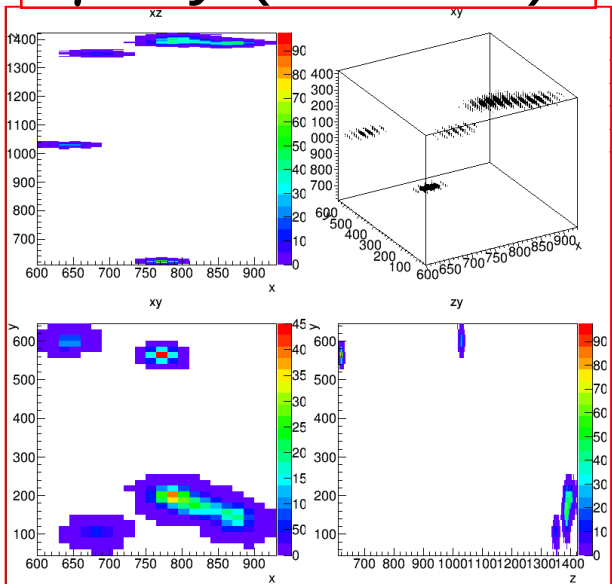
$0\nu\beta\beta$



α-ray (2.5MeV)



γ-ray (2.5MeV)



BG simulation with Geant4

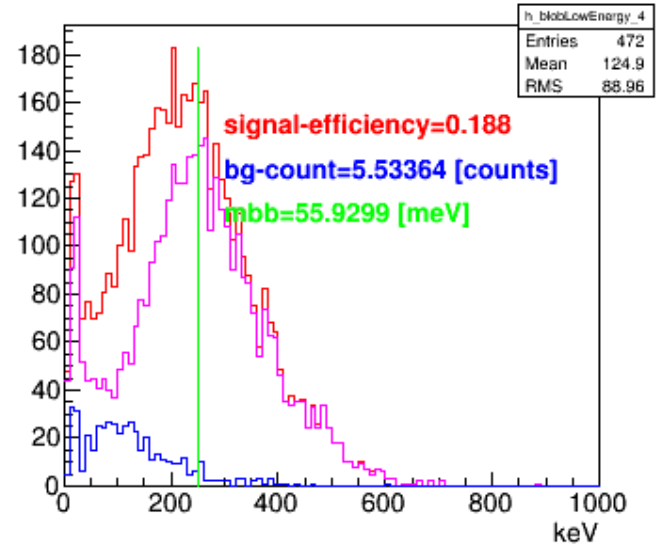
- Assumption
  - 1 ton ^{136}Xe
  - 2.9ppt ^{214}Bi in chamber

Upper limit of EXO's copper

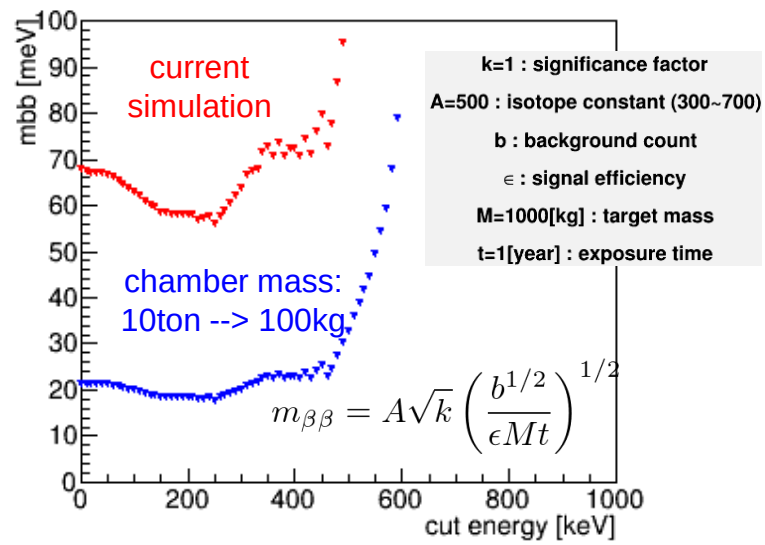
Heaviest component

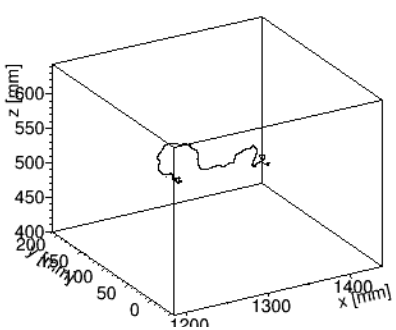
- Sensitivity
  - $m_{\beta\beta}$=60meV (current)
  - $m_{\beta\beta}$=20meV (reduce chamber mass: 10ton --> 100kg)

energy of lower blob

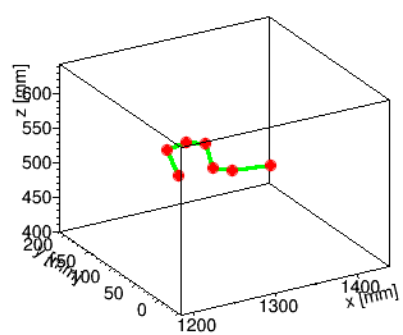


lower limit of mbb for each cut energy [4]





original electron track



reconstructed track

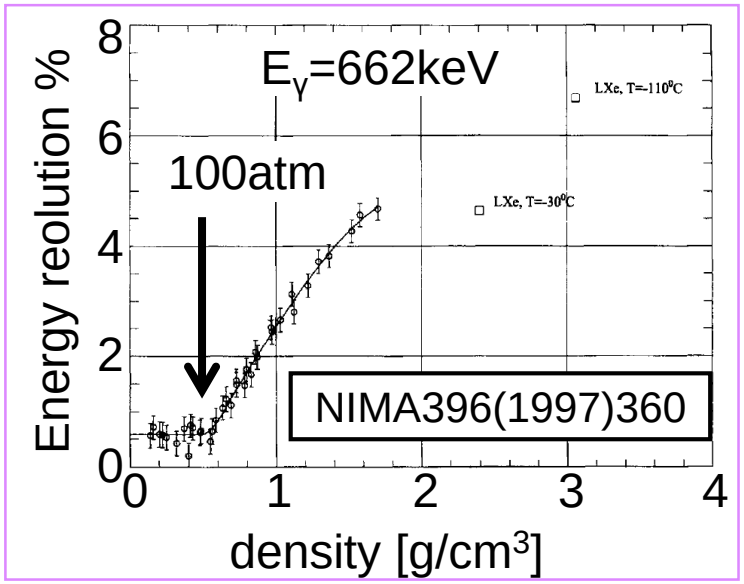
Summary

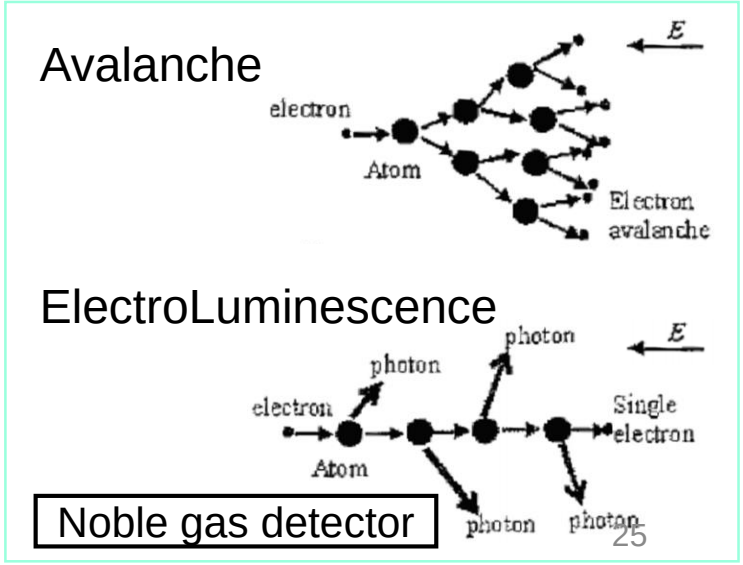
- AXEL project developing high pressure xenon gas TPC for 0nbb search.
- Segmented electroluminescence readout (ELCC) is key component.
- Simulated performance of ELCC is good.
- Energy resolution measured by current prototype detector: 0.6-1.6%FWHM @ 2.5MeV
- Large prototype construction started.
- 1ton detector sensitivity will reach ~20meV

High energy resolution

- <u>Ionization process</u>
  - Use gaseous xenon
  - W-value = 22.1eV
  - Fano-factor = 0.13
  - => 0.25%(FWHM) @2.5MeV

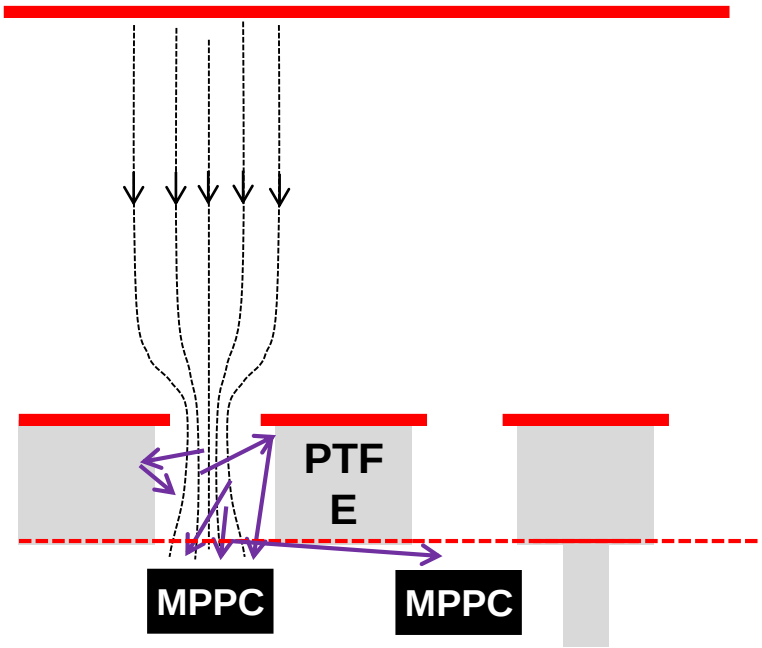
- <u>Signal multiplication</u>
  - Use ElectroLuminescence (EL)
  - light yield/length is proportional to the electric field
  - amplification fluctuation is small

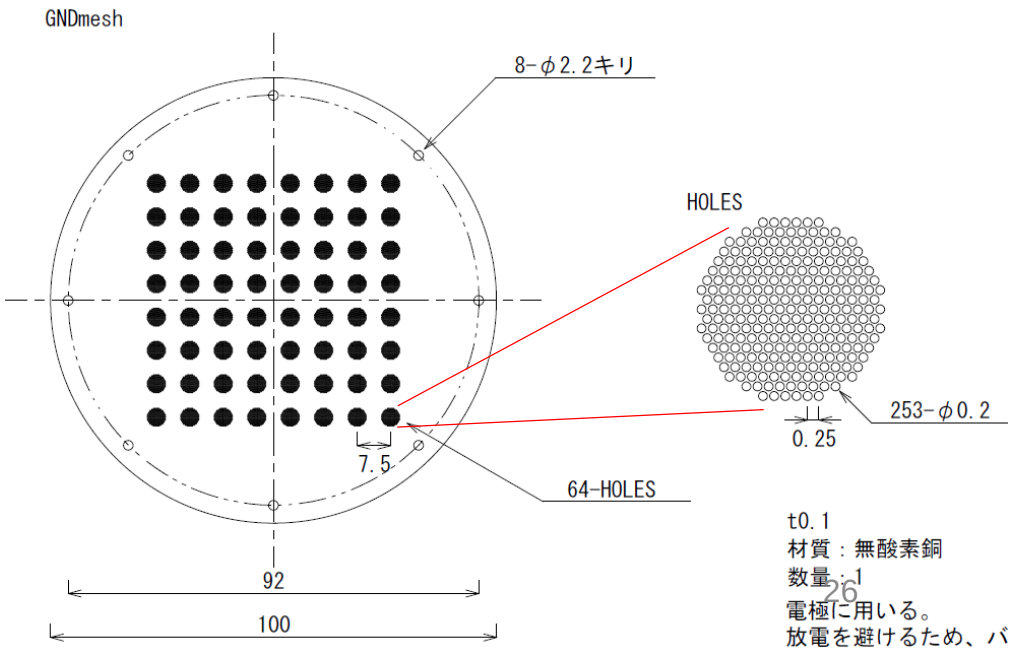




New GND mesh idea

- Fine etched electrode
  - Isolate cell from EL photon
  - Strong for stretching and deflection





Tracking

rate of γ-ray from ^{214}Bi (2448keV)

Avogadro number 6.02×10^{23}[/mol]

branching ratio 0.0157

$$R_\gamma = M \times C \times \frac{N_A}{M_{^{238}\mathrm{U}}} \times \frac{\ln 2}{T_{\frac{1}{2}}^{^{238}\mathrm{U}}} \times B = 180000 \text{ [cts/year]}$$

chamber mass 10^7[g](=10ton)

contamination 2.9×10^{-12}(=2.9ppt)

atomic weight of ^{238}U 238 [g/mol]

half life of ^{238}U 4.468×10^9[year]

process	0νββ efficiency	γ (2448keV) rate
initial condition	100%	180000 cts/year
fiducial-cut	79%	12000 cts/year
multi-cluster-cut	49%	75 cts/year
2-blob-selection	19%	5.5 cts/year

solid angle (chamber --> gas)

98% is Compton

Simulated signal-efficiency and BG-rate for each analysis steps