AXEL
High pressure Xenon gas TPC for neutrino-less double beta decay search

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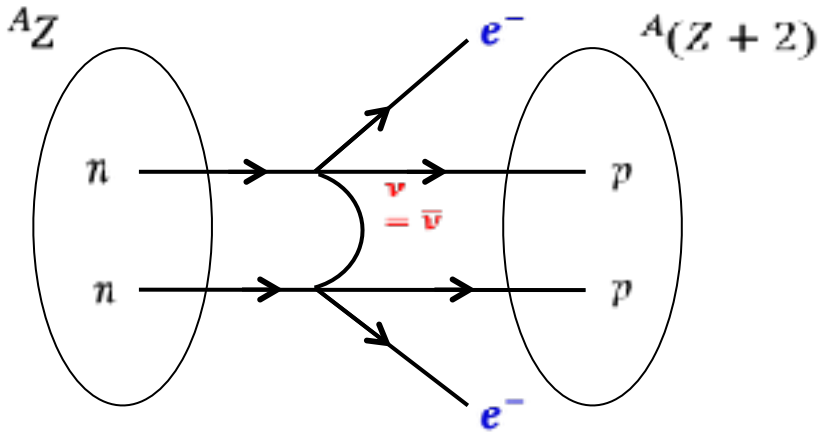
neutrino-less double-beta ($0\nu\beta\beta$) decay



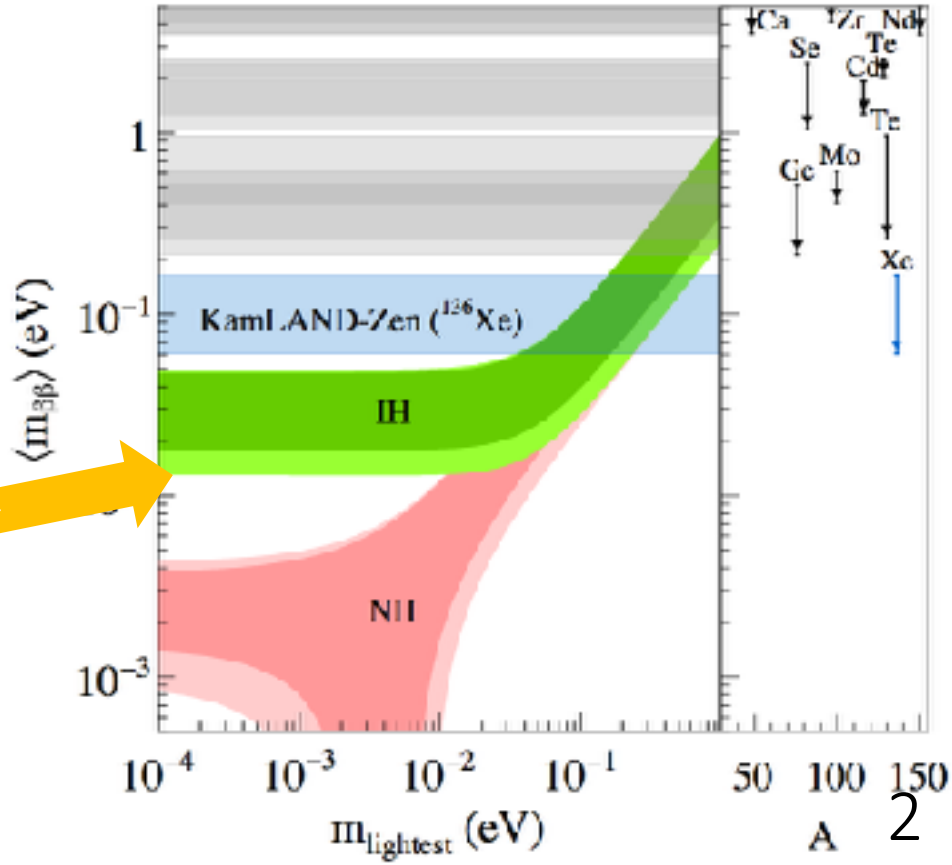
happens if neutrino is its own anti-particle (Majorana type) and has Mojorana mass components.

Next generation experiments are aiming to cover here, but...

Life time $\propto m_{\beta\beta}^{-2}$

Need > 1 ton double-beta nuclei

J.Shirai, Neutrino2016

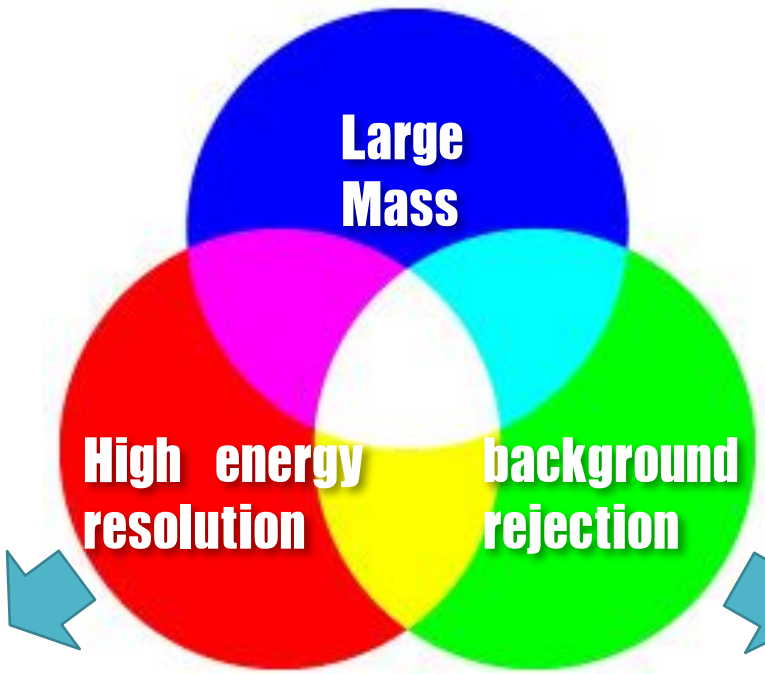


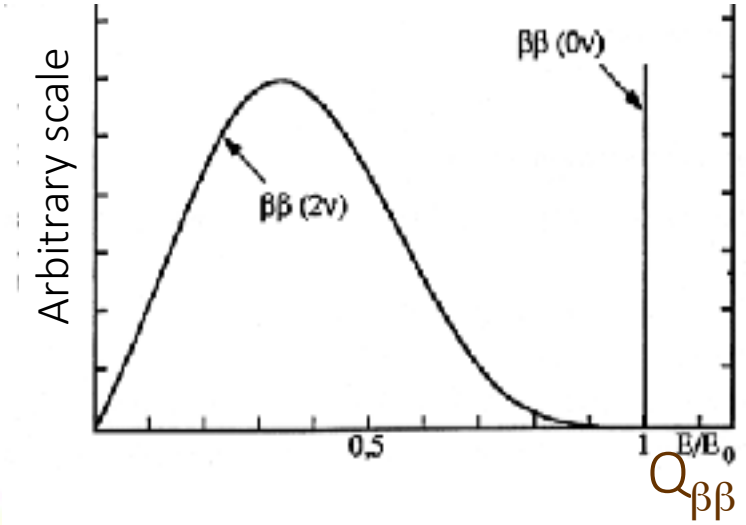
Keys for $0\nu\beta\beta$ decay search and our approach

^{136}Xe

abundance : 8.9%

$Q_{\beta\beta} = 2.48$ MeV





Semiconductors, bolometers and

Ionization of noble gas!

tracking detectors

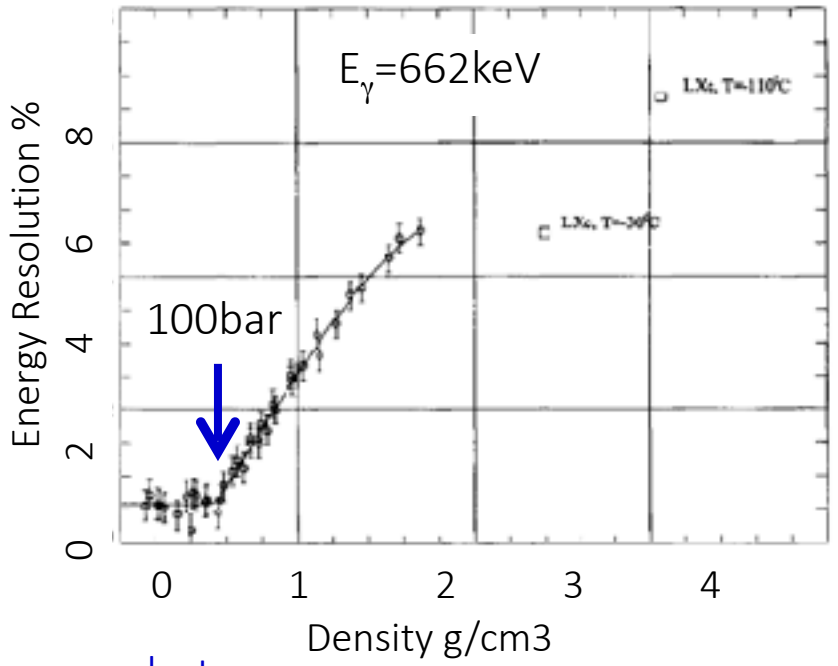
High Energy resolution by Xenon proportional scintillation mode (Electroluminescence from ionization electrons)

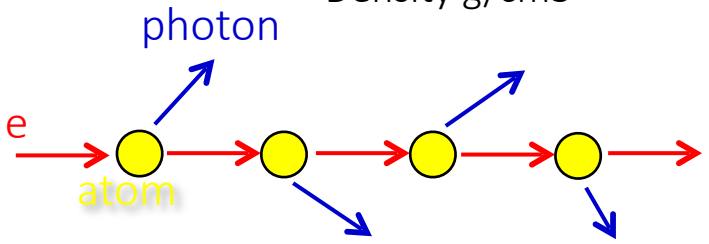
- W-value 21.5 eV, Fano factor<0.17
  - → 0.29%(FWHM)@2.48MeV
  - → comparable to semi-conductors!
  - c.f. Ge 0.2%, EXO ~3%, KamLand-Zen ~9%
- At higher density, energy resolution becomes worse.

→ reject liquid option.

- Proportional Scintillation mode using electroluminescence lights
  - linear process →Good linearity and stability
  - #photons ∝ voltage drop rather than the field strength.
- There is already pioneering work by the NEXT collaboration

A. Bolotnikov, B. Ramsey Nucl. Instr. And Meth. A396(1997) 360

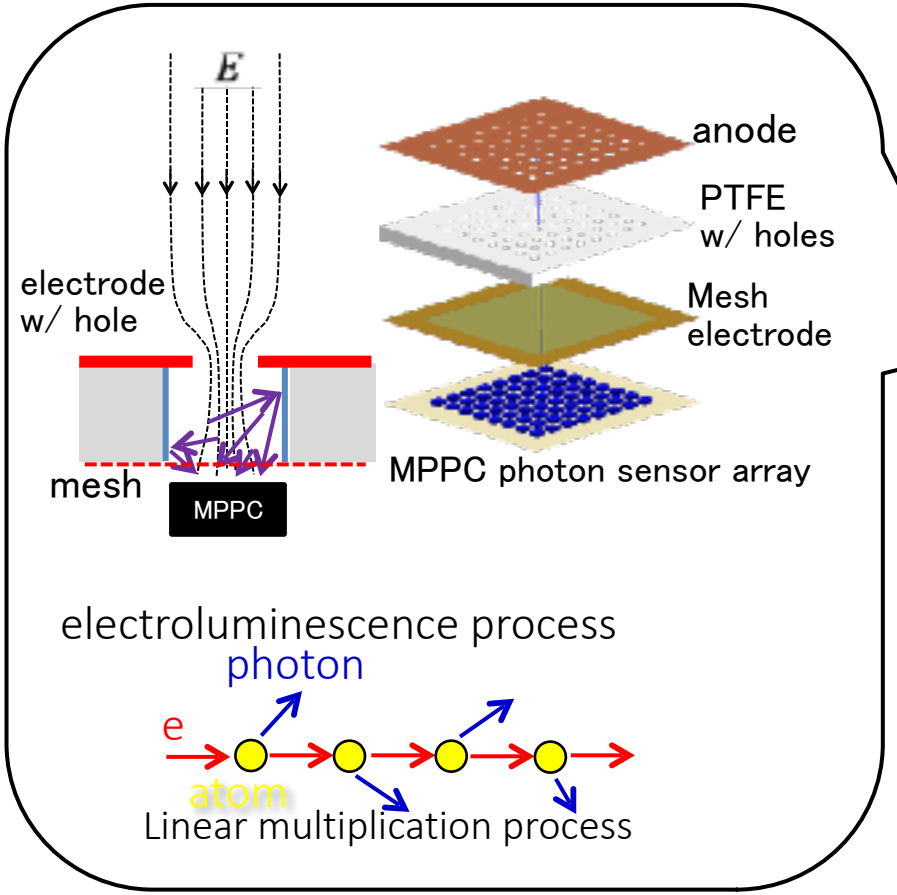




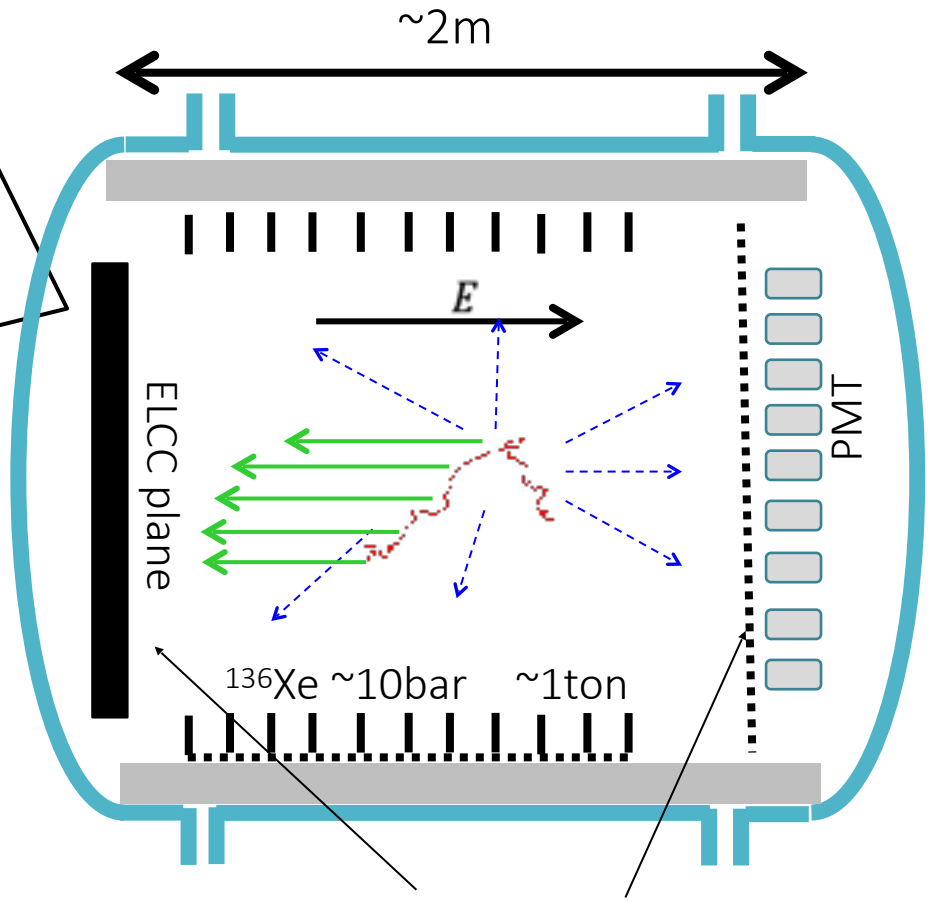
electroluminescence

What we propose in the AXEL project

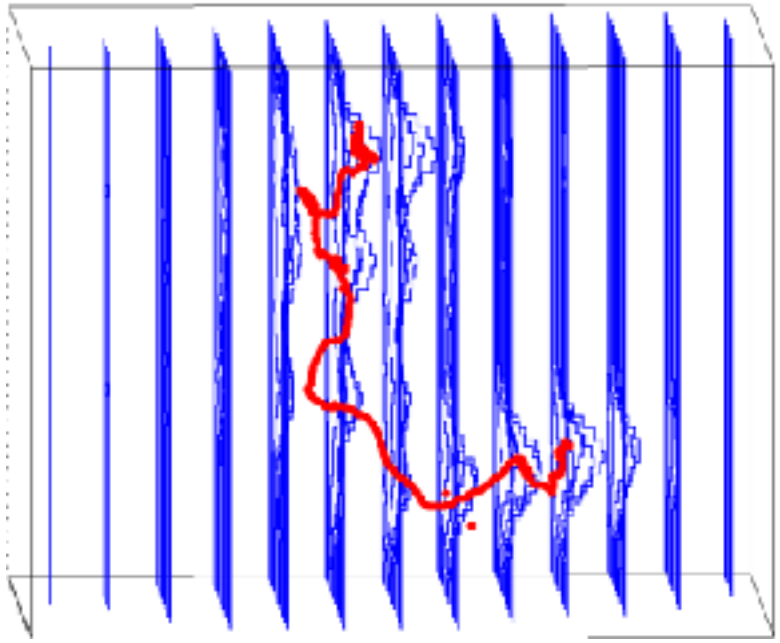
Electro luminescence light collection cell (ELCC)



High energy resolution
(goal: <0.5%(FWHM))



Background rejection by event topology



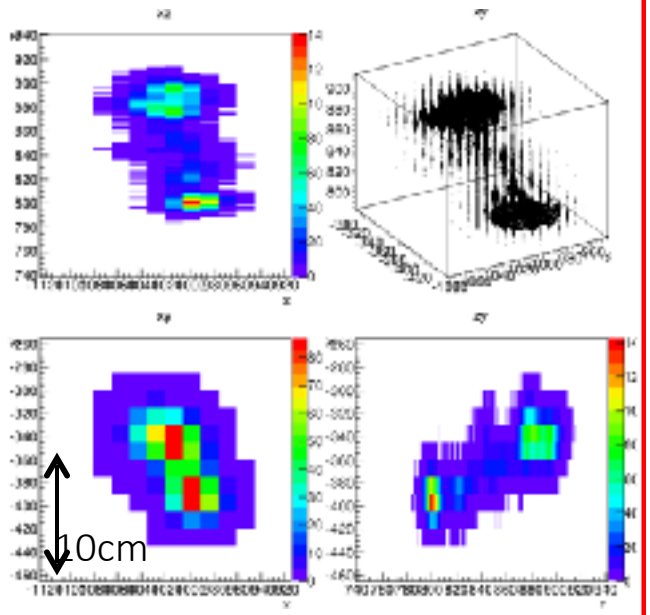
AXEL

-Expected event topologies-

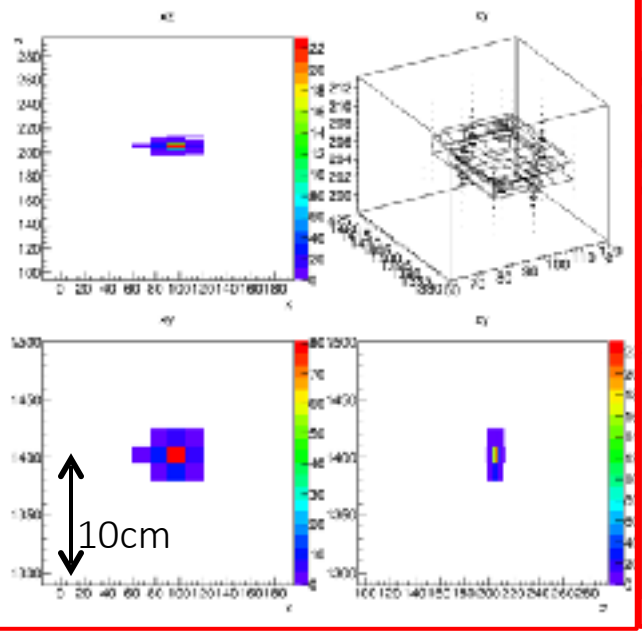
simulation

10atm, 15mm pitch, 1μs sampling (~1mm)

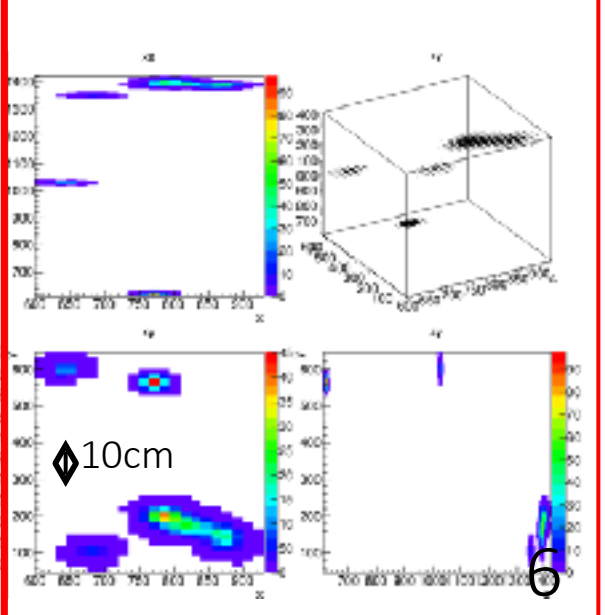
0νββ



α

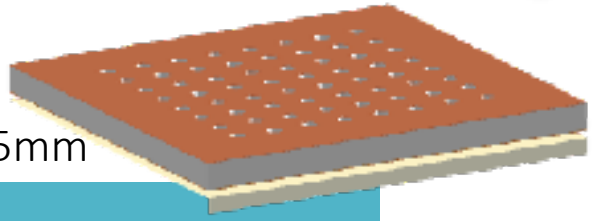


Compton γ

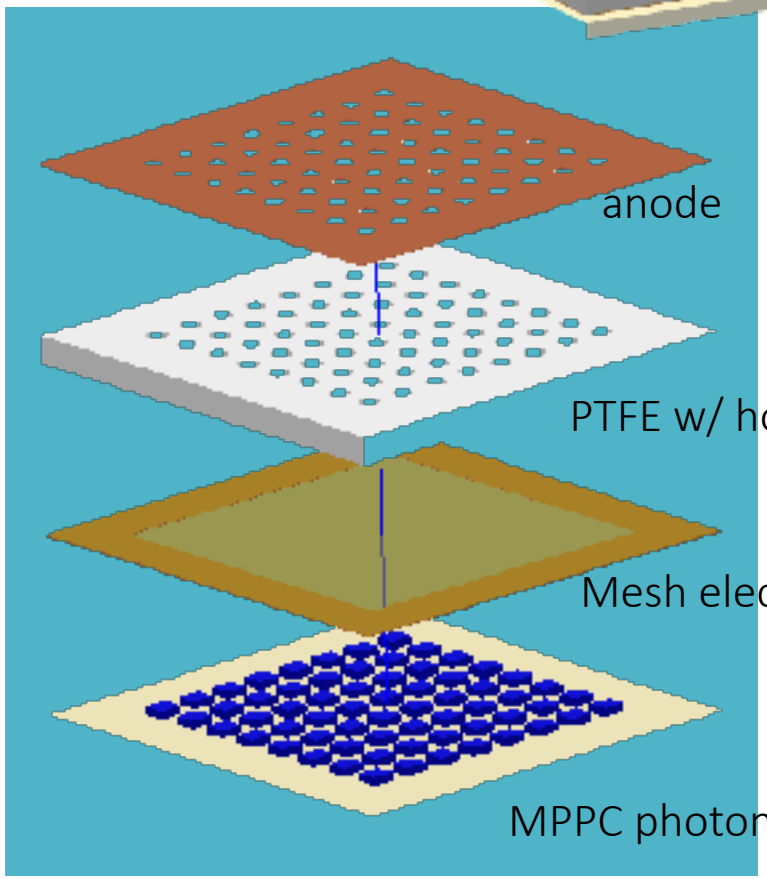


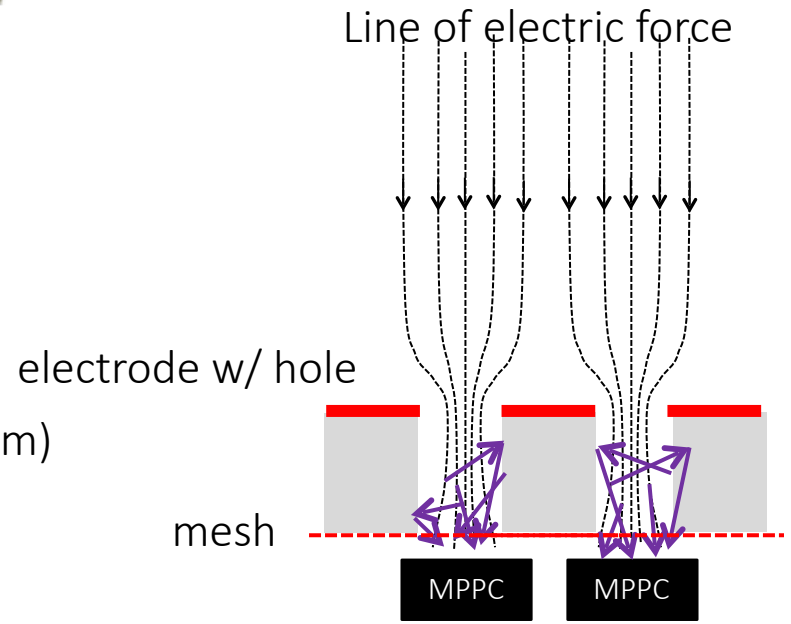
ELCC

-ElectroLuminescence Light Collection Cell -



CELL pitch 7.5mm~15mm

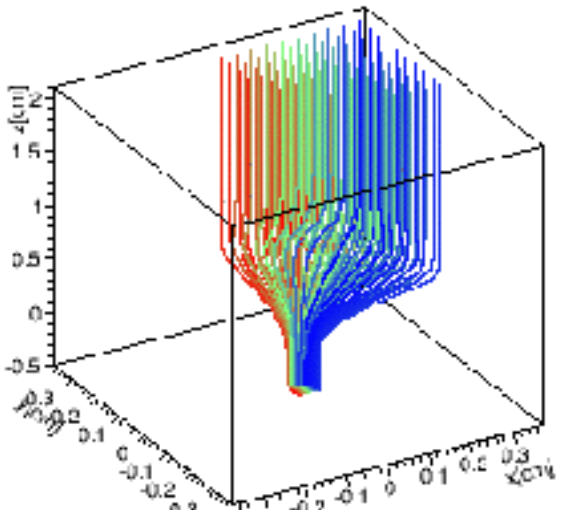




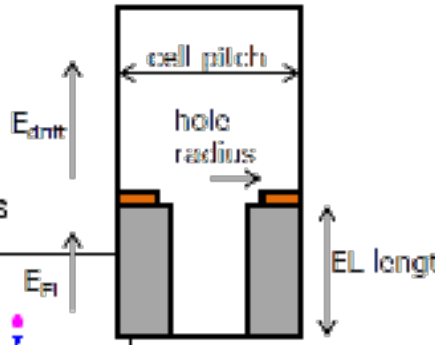
- Uniform response in wide area
- extendable to large size with the rigid structure

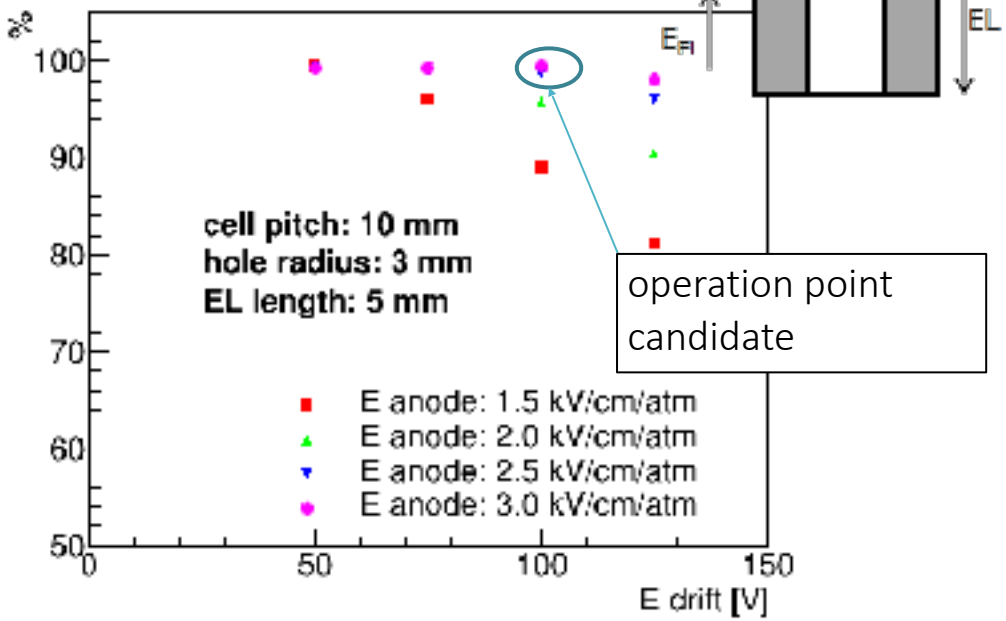
ELCC -Electric field calculation-

- ✓ by Finite Element Method(Elmer)
- ✓ Electric field lines are collected into cell when E_{EL}/E_{drift} and hole size is sufficiently large.
- ✓ Non-uniformity of field inside cell : < 1.7%



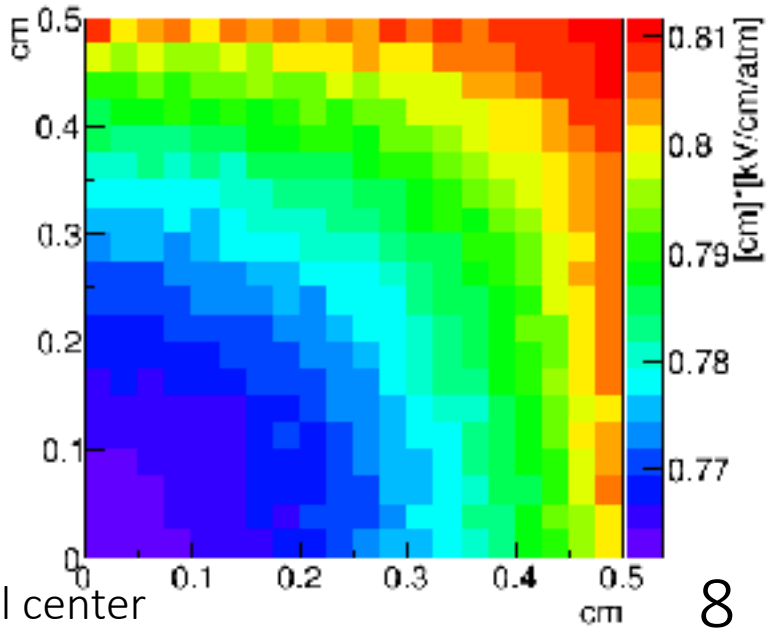
pass ratio of electric field lines





operation point candidate

Integral of field over EL threshold



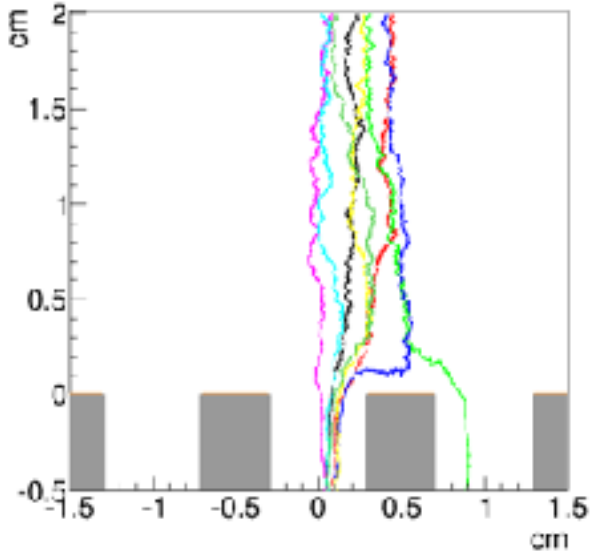
cell center

ELCC - electron track simulation-

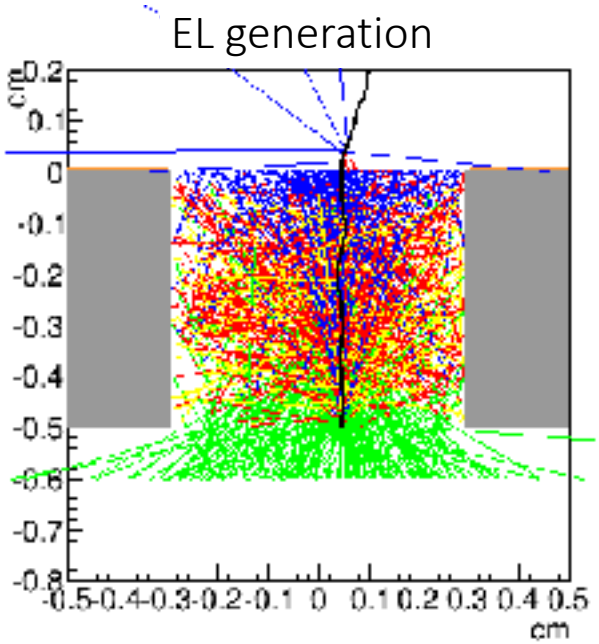
- by Garfield++
  w/ hand-made EL generation code
- ~15% of tracks go next cells, still collection efficiency is ~100%
- 60photons x PDE/1e- w/ 3mm□ MPPC)

E_{drift}=100V/cm/atm
E_{EL}=3kV/cm/atm

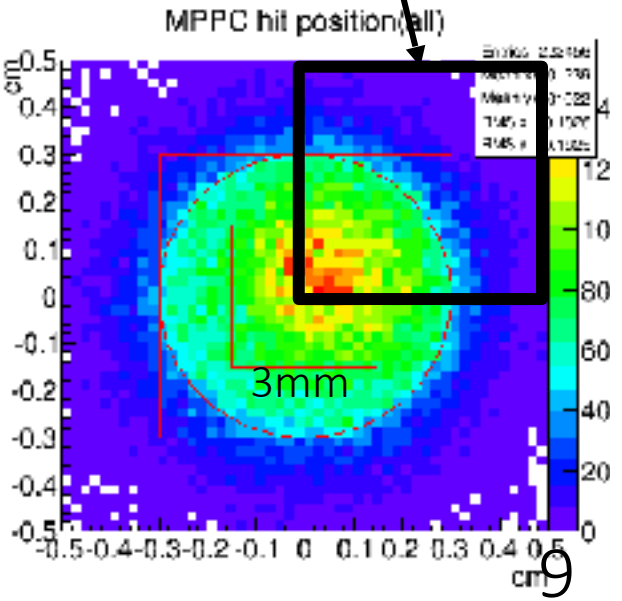
electron tracks



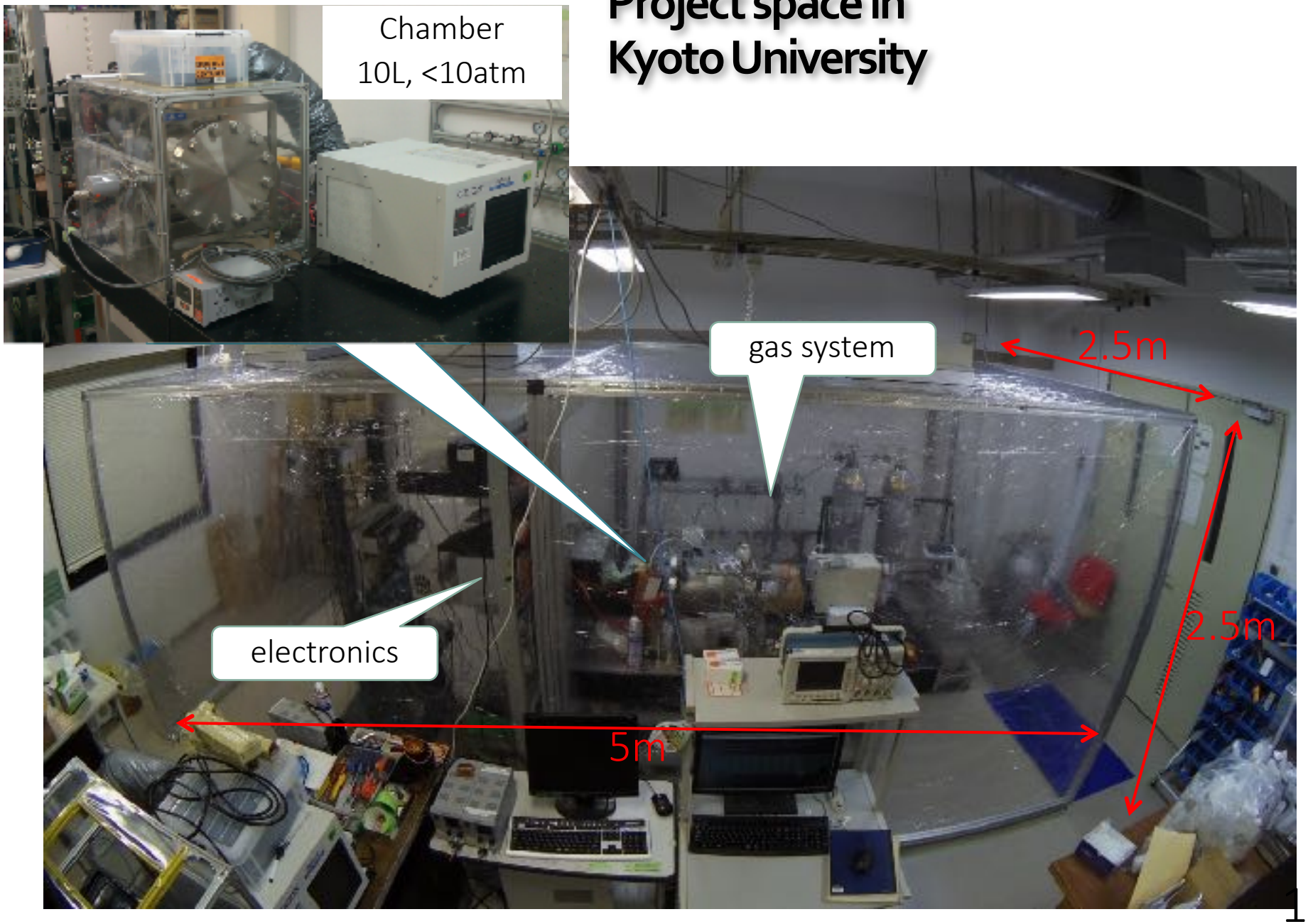
EL generation



Initial electron generation region



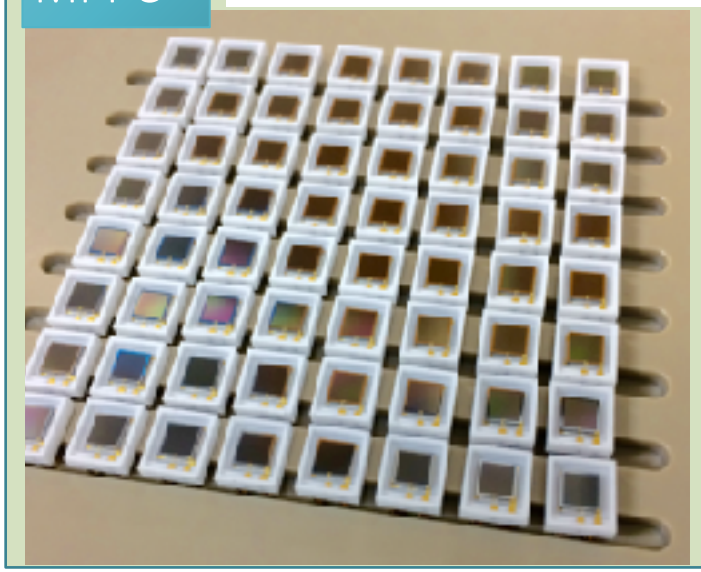
Project space in Kyoto University



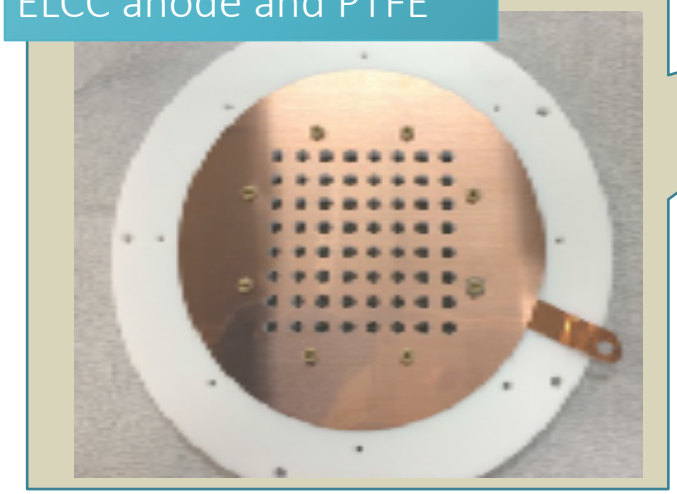
Prototype detector for ELCC demonstration

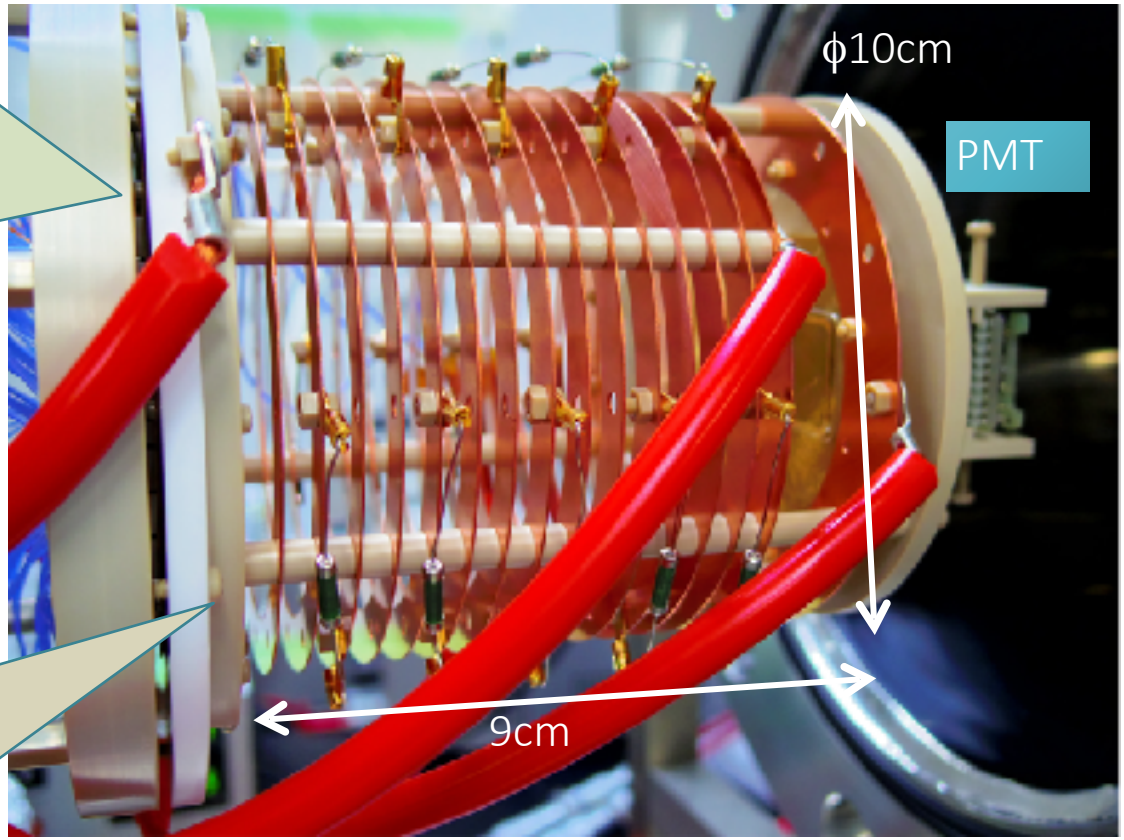
8x8 sensors
sensitive to VUV(175nm) photons

MPPC



ELCC anode and PTFE





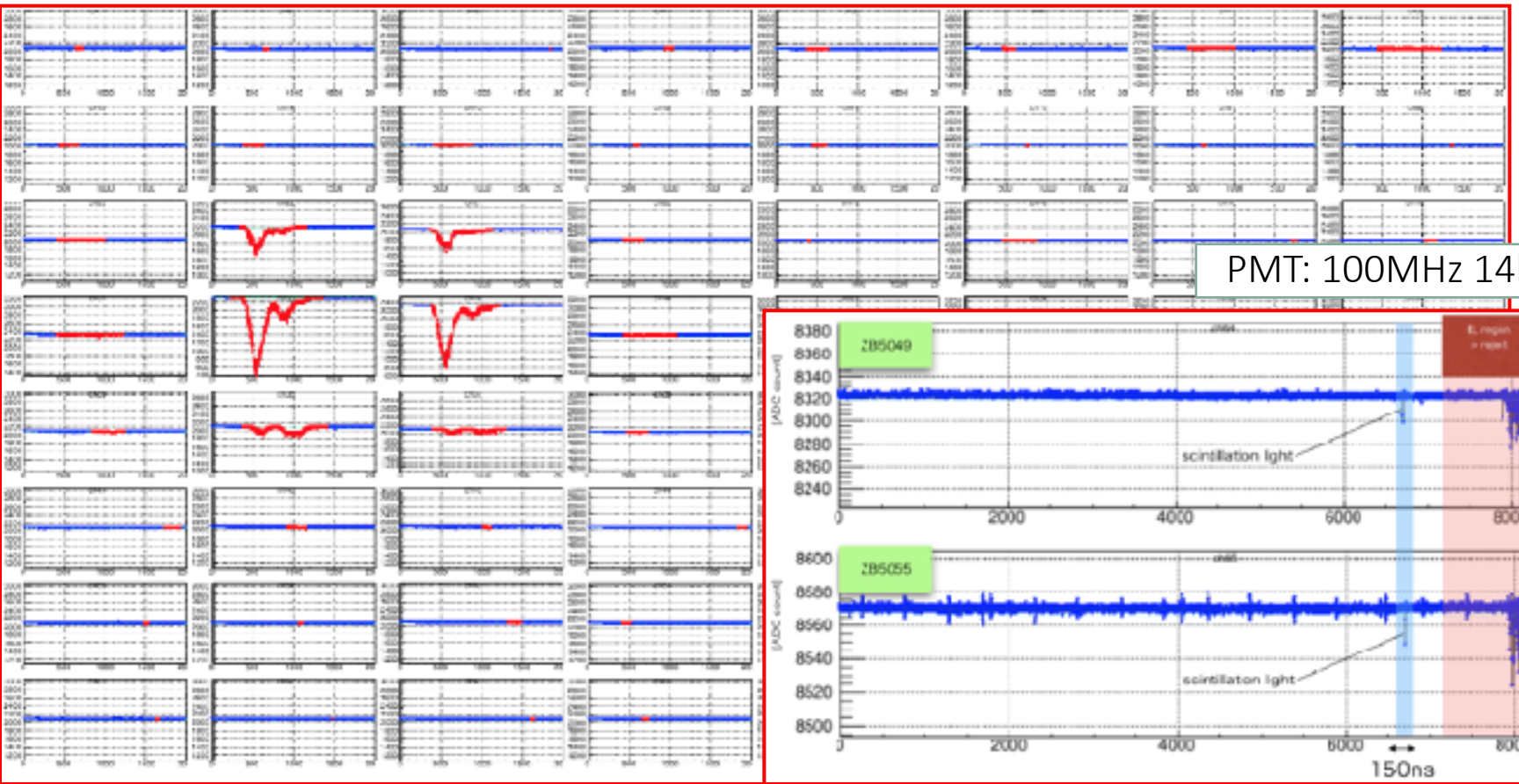
Purpose: demonstrate high energy resolution at 511 keV, 10bar.
However, only 122 keV, 4 bar result today…

Event sample

waveforms of MPPC and PMT

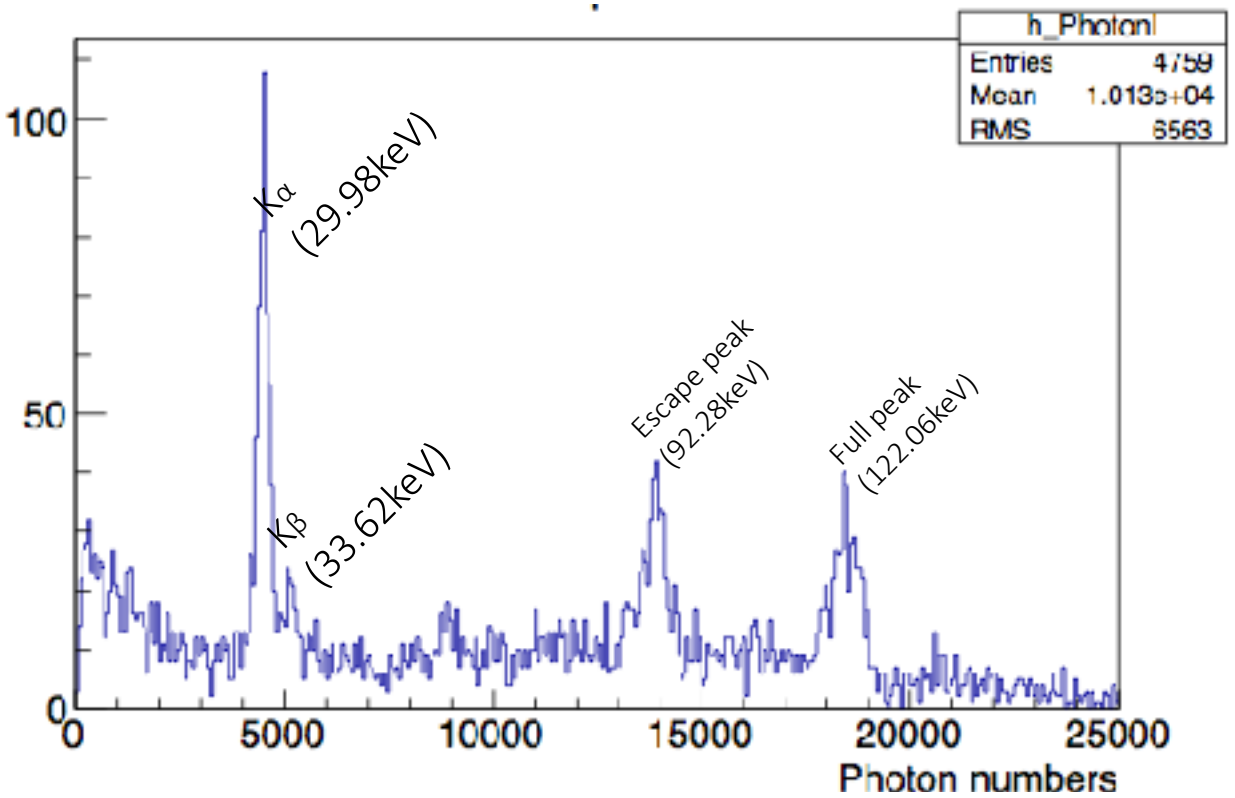
EL light & scintillation light are observed

MPPC: 65MHz 12bit 2Vpp



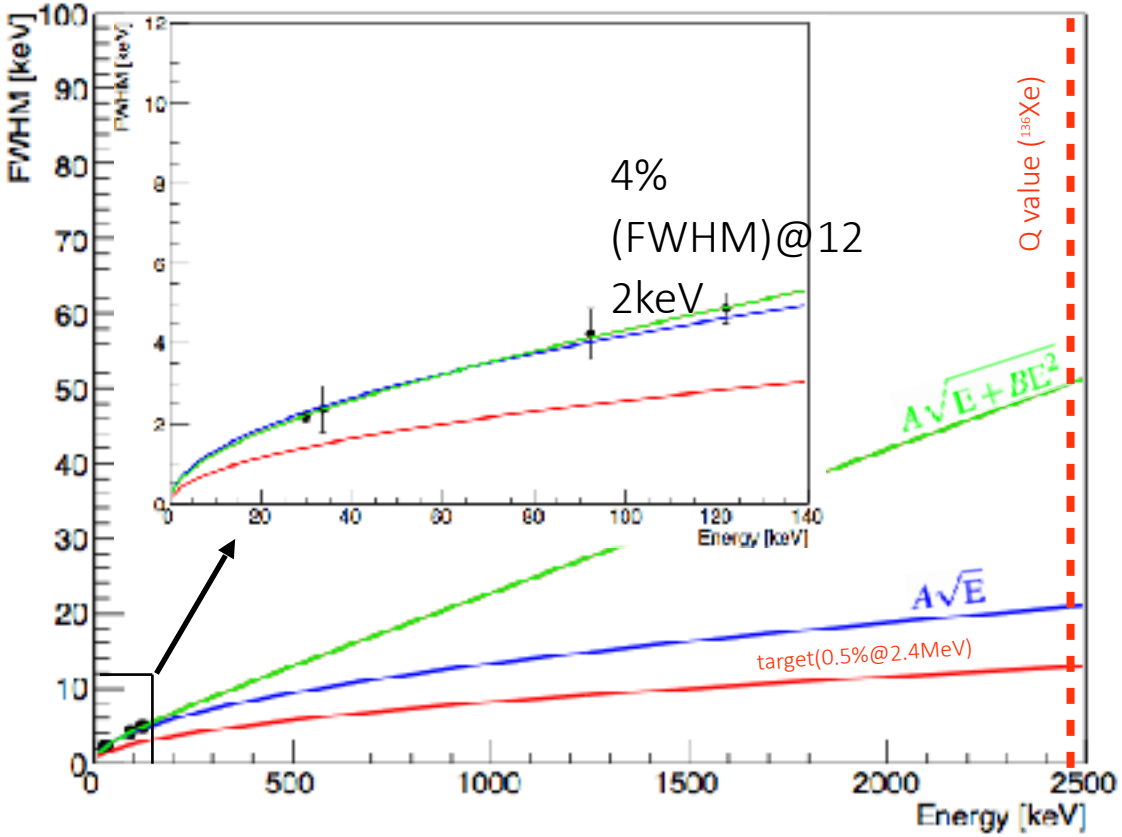
PMT: 100MHz 14bit 2Vpp

Spectrum for ^{57}Co (122keV) source



@ 4bar

Energy resolution at 4 bar

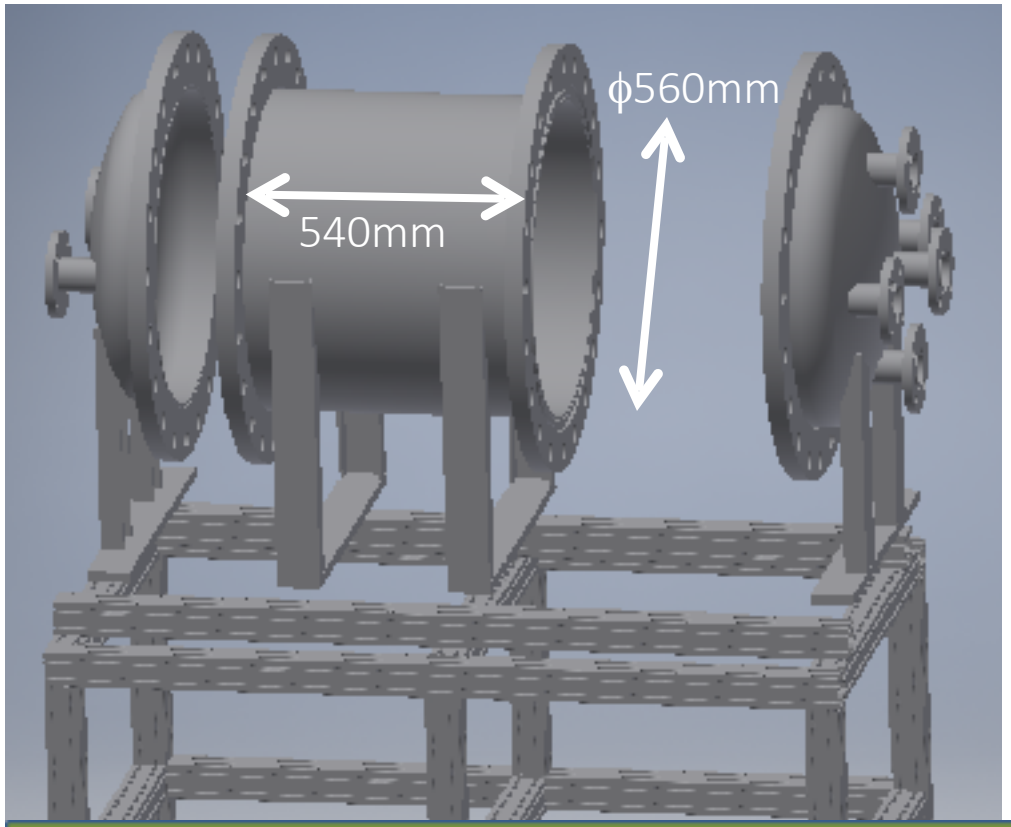


Extrapolated FWHM energy resolution at Q value(2458keV)

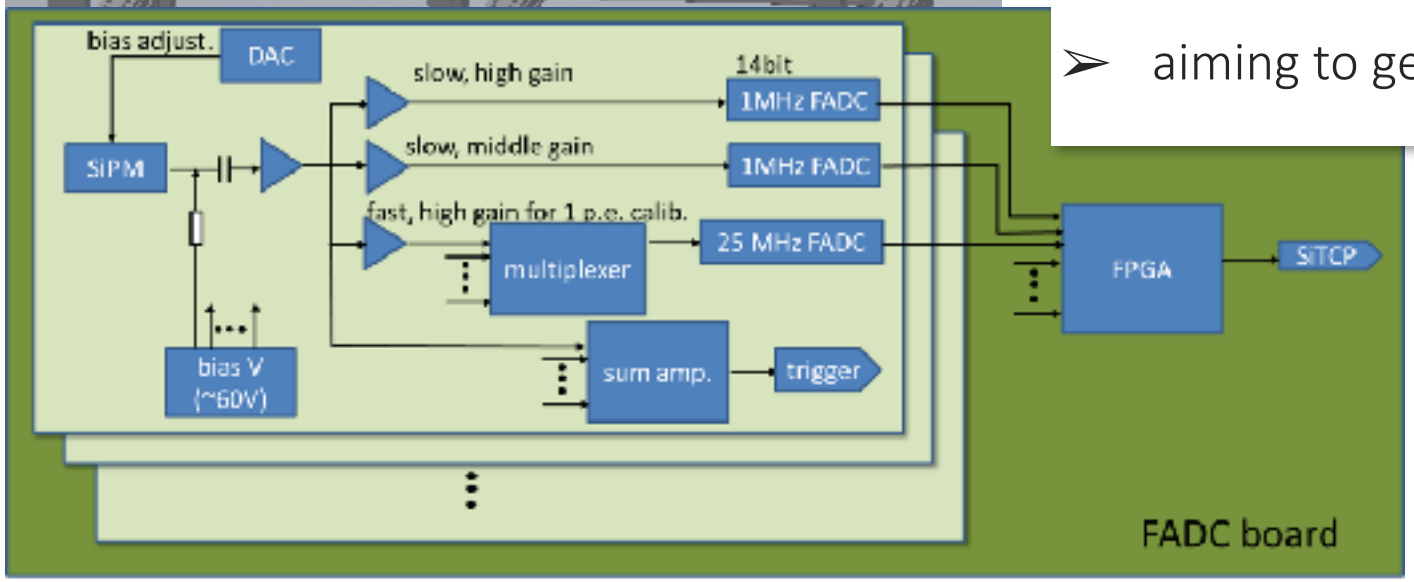
- ✓ 0.85% when extrapolated by $A\sqrt{E}$
- ✓ 2.03% when extrapolated by $A\sqrt{E+BE^2}$

Next step : measurement of 511 keV@10 bar w/ improved discharge protection and gas circulation

Next prototype

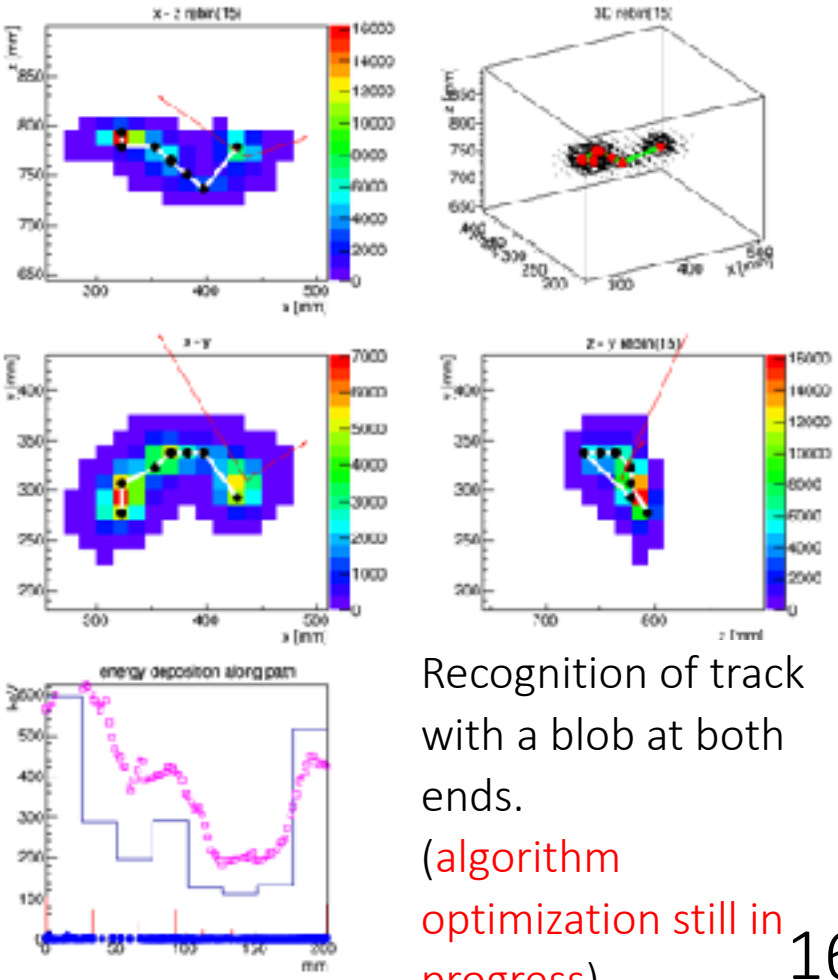


- ➢ demonstrate energy resolution at around Q-value
- ➢ ~1,000 channel
  - ✓ Hamamatsu photonics VUV-4 MPPC
  - ✓ developing custom FADC board
- ✓ Cathode voltage ~70kV
  - ✓ developing Cockcroft-Walton power supply
- ➢ aiming to get result by 2017 Fall



(very) rough sensitivity estimation for 1-ton detector

- 10bar 1ton enriched ^{136}Xe
- Signal
  - ✓ a few events/year @ $m_{\beta\beta}$=20meV
    - 79% contained in fiducial volume
    - 49% after clustering
    - 22% after blob-recognition
- Background
  - ✓ Only ^{214}Bi considered now. (cannot be separated by *E*)
  - ✓ 10 ton low background(3ppb) material
    - 12k evts/yr in fiducial
    - 75 evts/yr after clustering
    - 7 evts/yr w/ blob-recognition
  - ✓ considering thin vessel in pressurized wator
    - 0.1 evts/yr



Recognition of track with a blob at both ends.
(algorithm optimization still in progress)

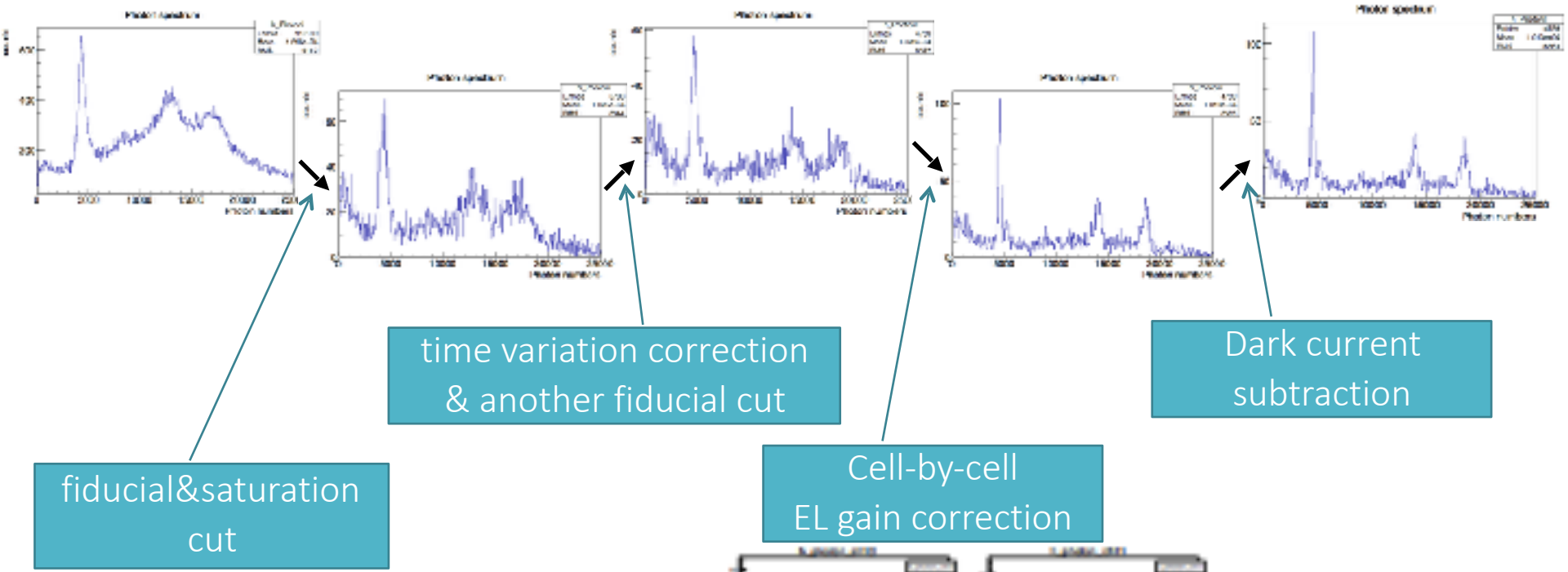
Summary

- AXEL is a high pressure Xe-gas TPC to search for $0\nu\beta\beta$
- We have developed a new electroluminescensce read out method, ELCC.
  - high energy resolution
  - extendable to large size
- Performance demonstrated at 122 keV, and to be demonstrated at 511 keV in this year and 2 MeV in the next year
- It is for pure Xenon → very slow drift → not applicable to T2K ND…

Data at 4bar w/ ^{57}Co(122keV)

Photon spectrum at various stage of correction/cut

E_{EL}=2.7kV/cm/atm
E_{drift}=100V/cm/atm

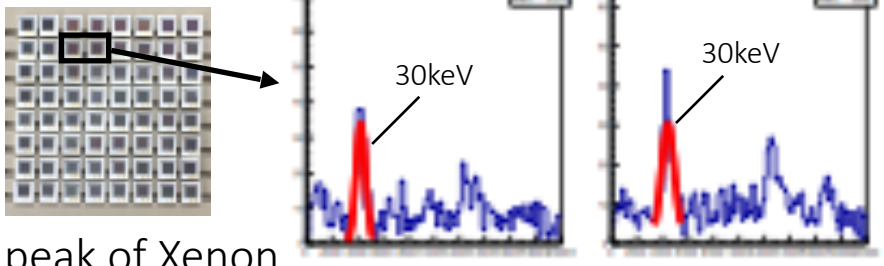


fiducial&saturation cut

time variation correction & another fiducial cut

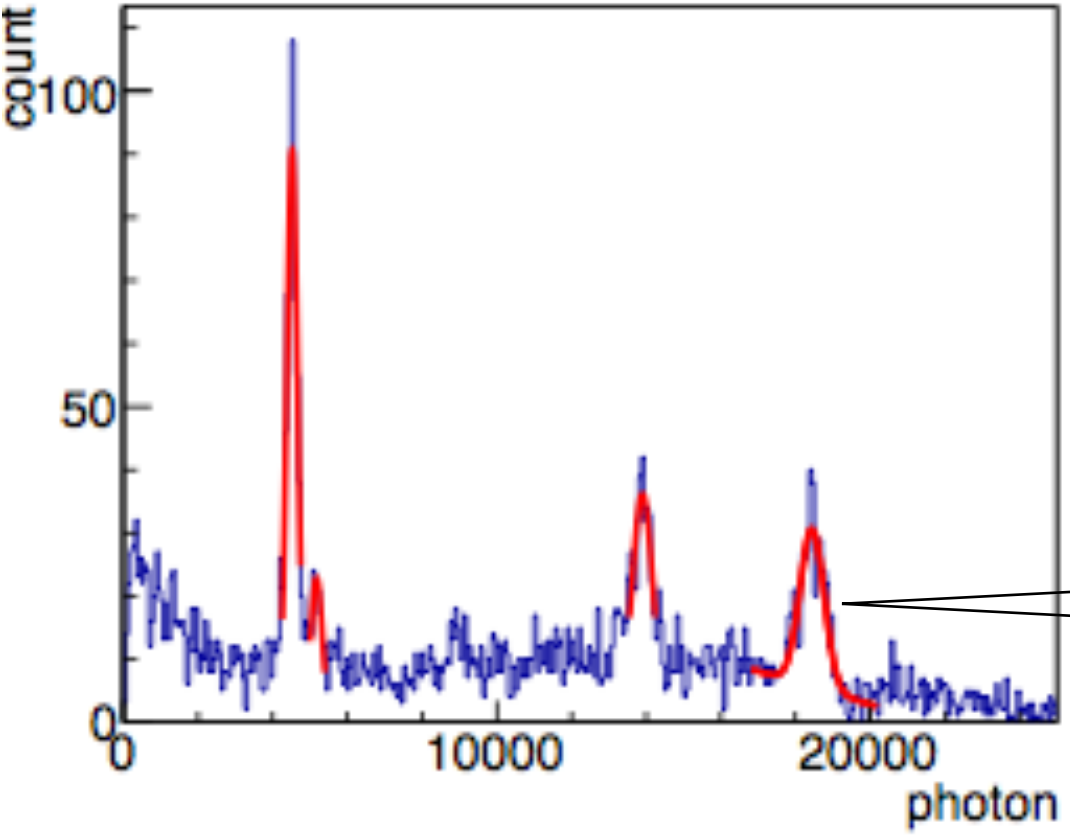
Cell-by-cell EL gain correction

Dark current subtraction

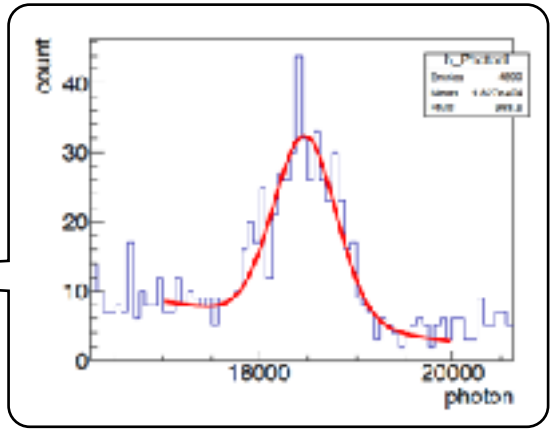


30keV escape peak of Xenon

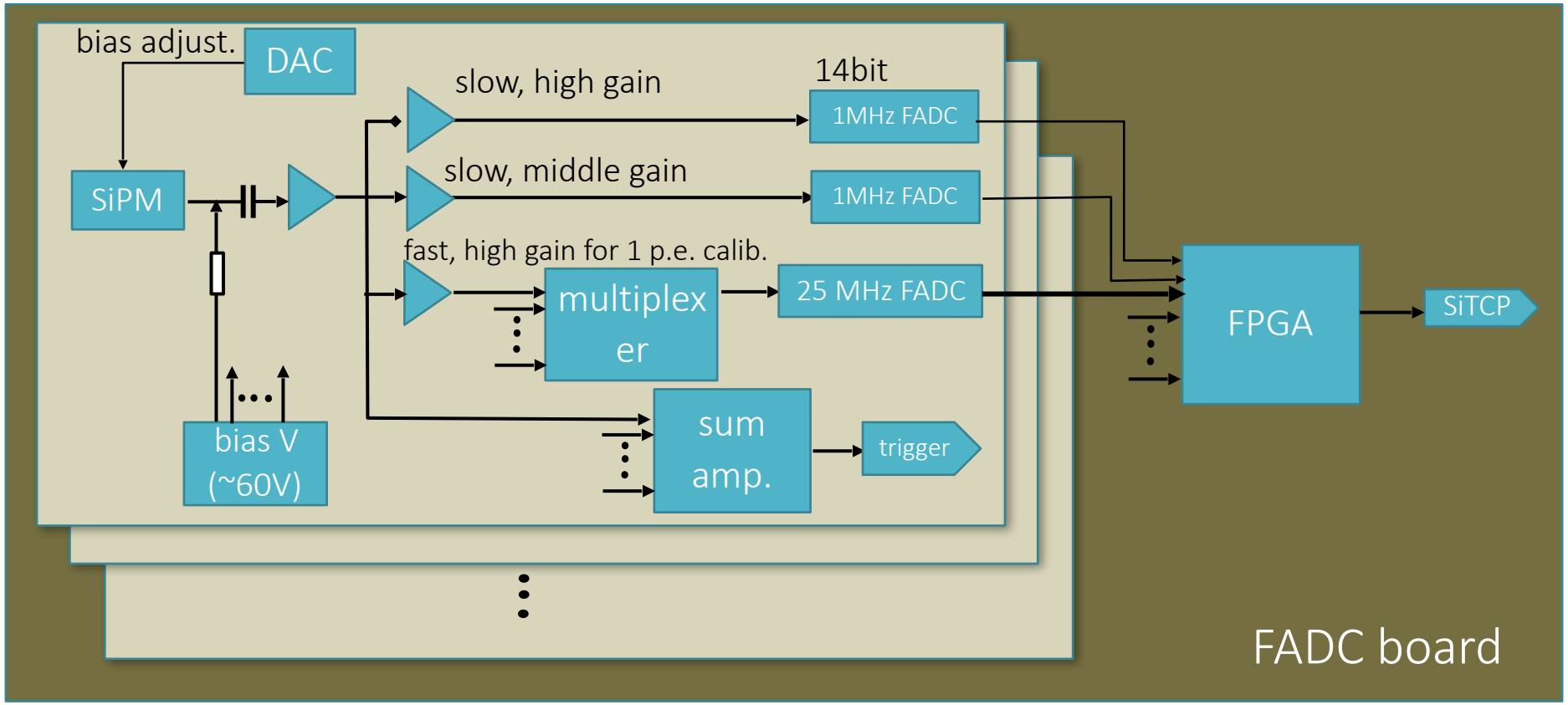
Energy resolution



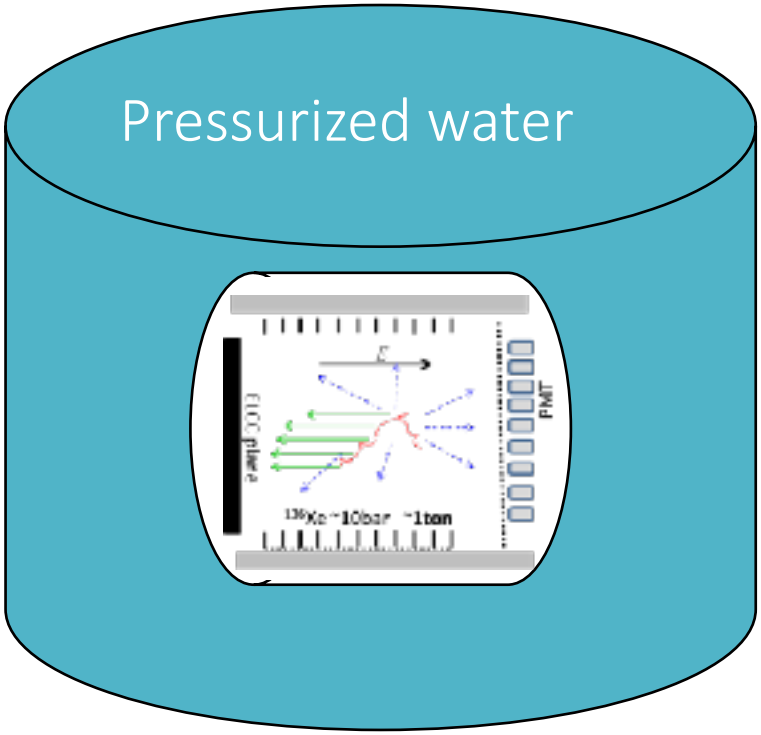
ガウシアンでフィット
122keVだけはバックグラウンドの影響を考慮するため、
“ガウシアン + ax + b”でフィット



Energy [keV]	29.78	33.62	92.28	122.06
# of photon	4517.3	5169.5	13900.2	18445.0
FWHM	7.3%	7.0%	4.6%	4.0%


bias adjust.
DAC
SiPM
slow, high gain
14bit
1MHz FADC
slow, middle gain
1MHz FADC
fast, high gain for 1 p.e. calib.
multiplex
er
25 MHz FADC
FPGA
SiTCP
bias V
(~60V)
sum
amp.
trigger
FADC board

Finally,
(very) rough sensitivity estimation



- Thin vessel in low-bkg. pressurized water

  bkg 7evts/yr → 0.1 evts/yr

  → sensitivity to ~20 meV

- detection of positive Ion
  - Could give good spacial resolution
  - an idea, but very premature