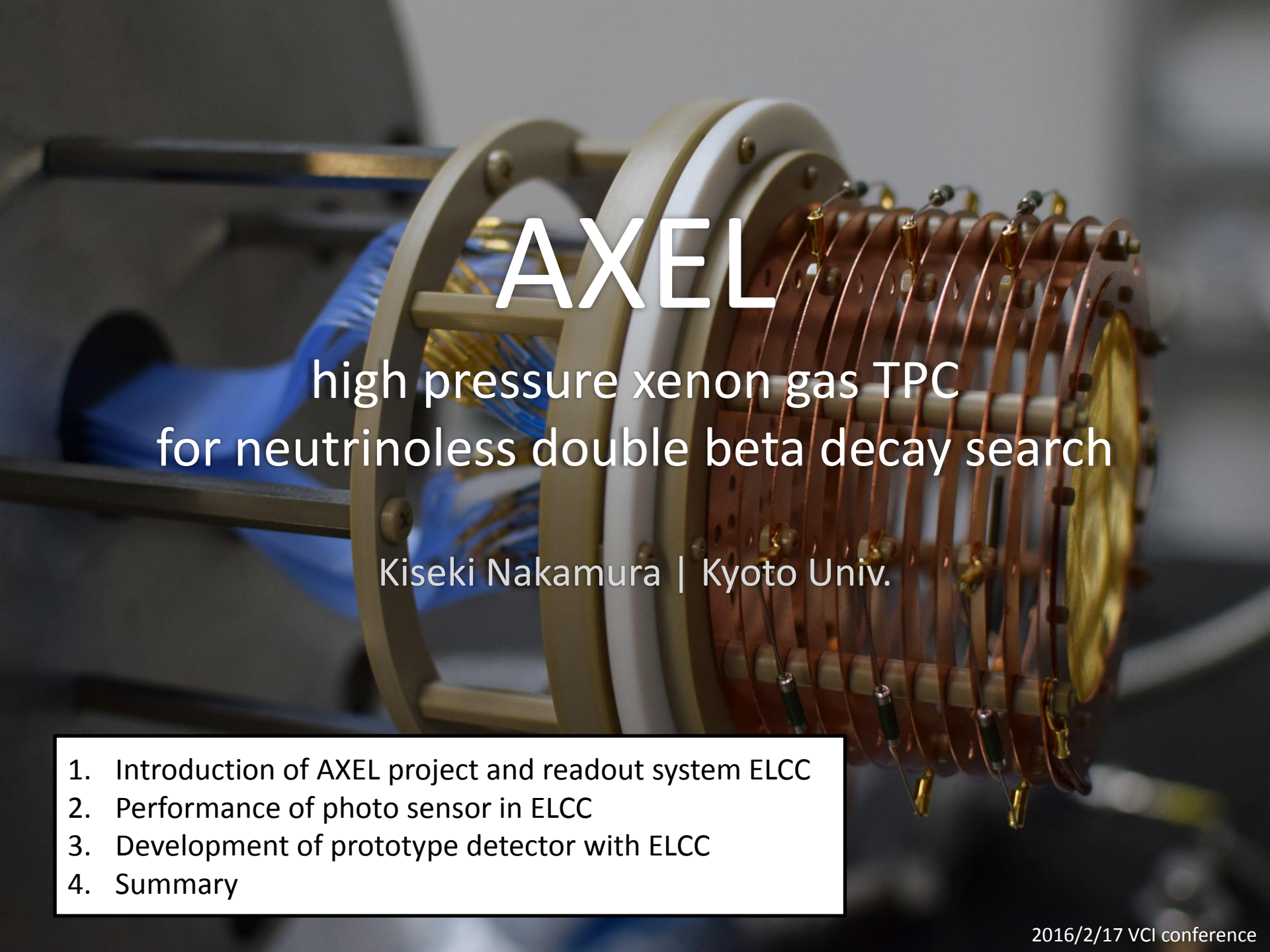
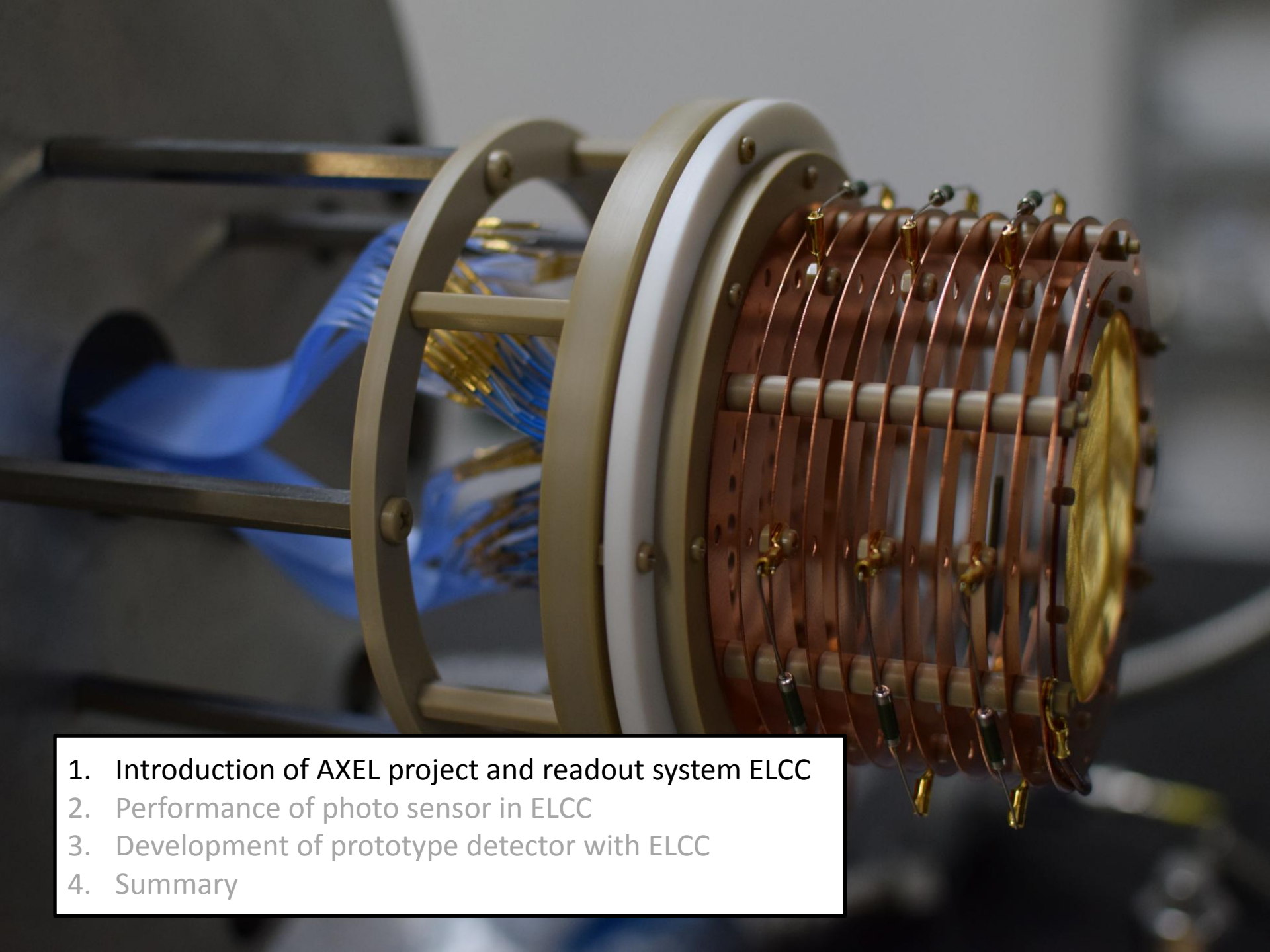


AXEL

high pressure xenon gas TPC for neutrinoless double beta decay search

Kiseki Nakamura | Kyoto Univ.

1. Introduction of AXEL project and readout system ELCC
2. Performance of photo sensor in ELCC
3. Development of prototype detector with ELCC
4. Summary



1. Introduction of AXEL project and readout system ELCC
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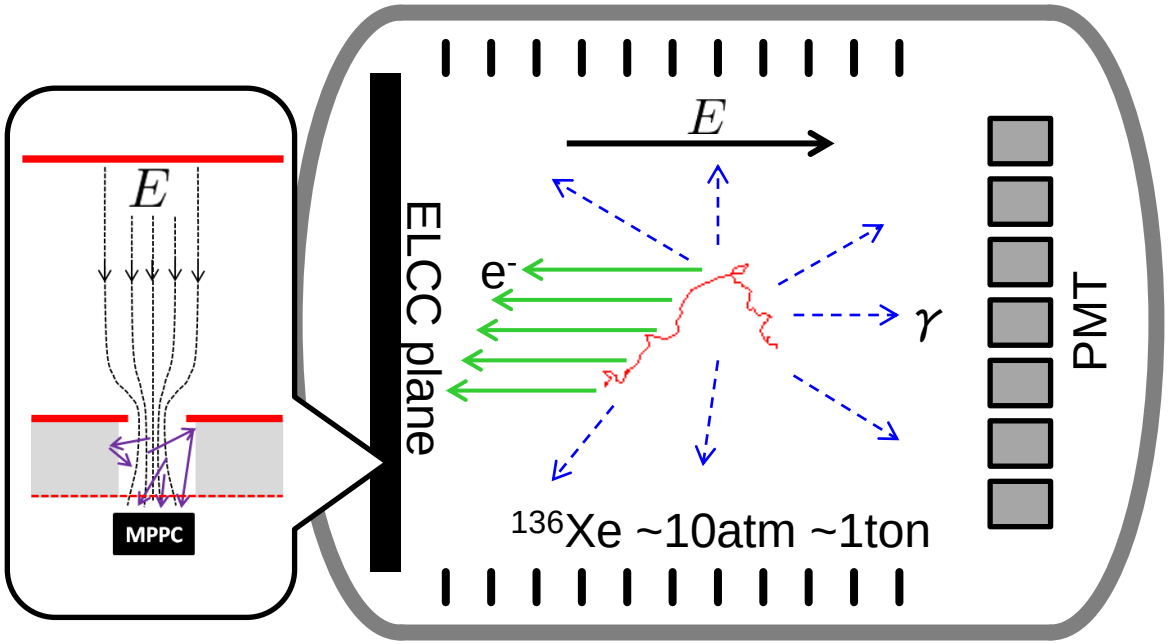
AXEL experiment

High pressure Xe gas TPC for 0νββ search

Targets

- High energy resolution : **0.5%** (FWHM) @2.5MeV
- Large mass : **1ton** (ϕ2×1.7m, high pressure)
- BG discrimination : **pixel readout** (7.5mm pitch)

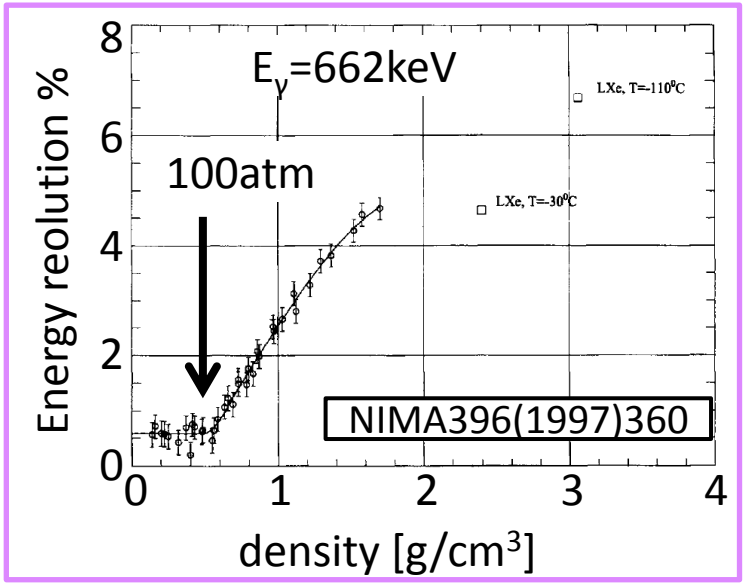
- Similar idea as NEXT experiment
- We introduce a new idea for signal readout (ELCC)



High energy resolution

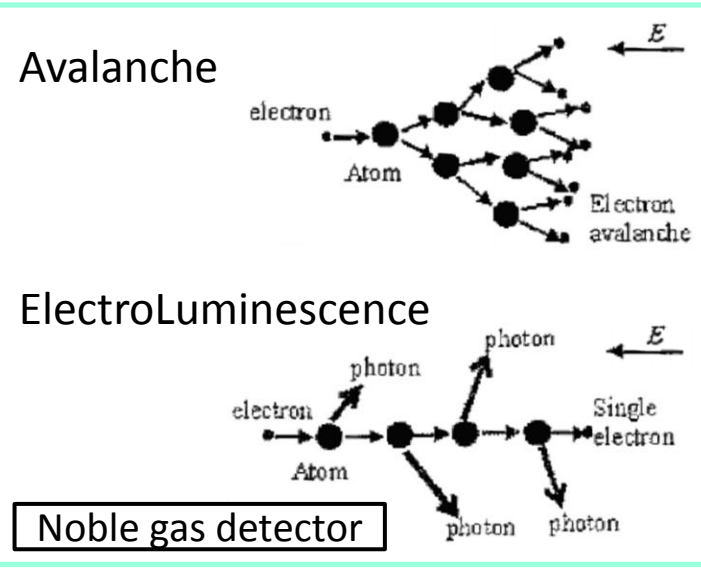
Ionization process

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



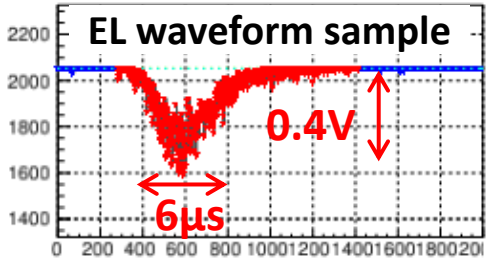
Signal multiplication

- Use ElectroLuminescence (EL)
- light yield/length is proportional to the electric field
- amplification fluctuation is small



EL readout idea: ELCC

Electro Luminescence Collection Cell

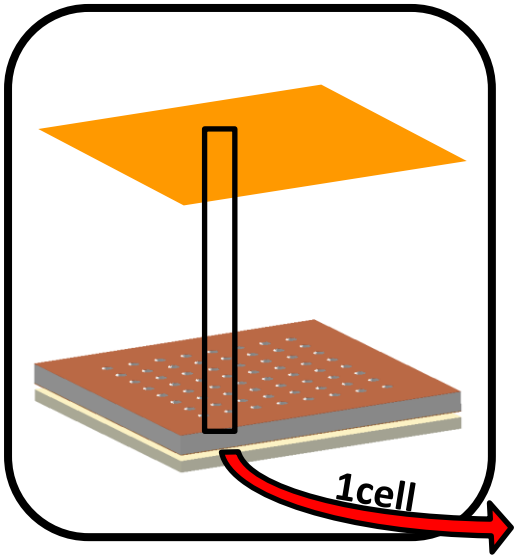


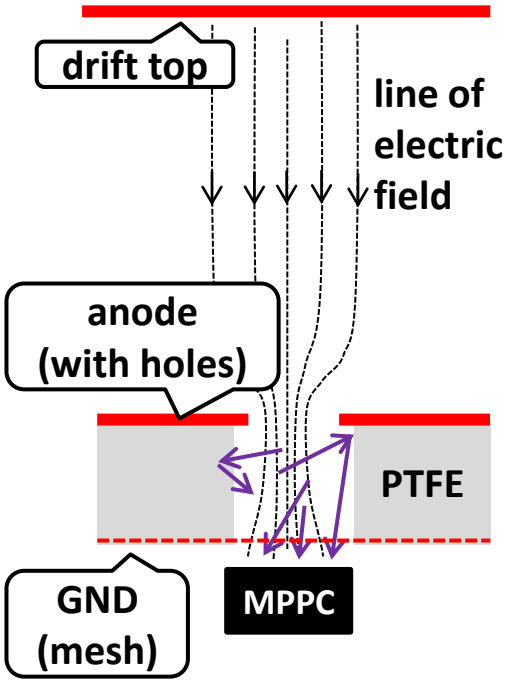
ELCC system

1. Readout is pixelized
2. Each cell collect electrons along the line of electric field
3. Electroluminescence photons are generated in each cell
4. photons are detected by MPPC(SiPM) in each cell

Merit of ELCC

- uniform response in wide area
- no deflection of mesh
- rigid structure

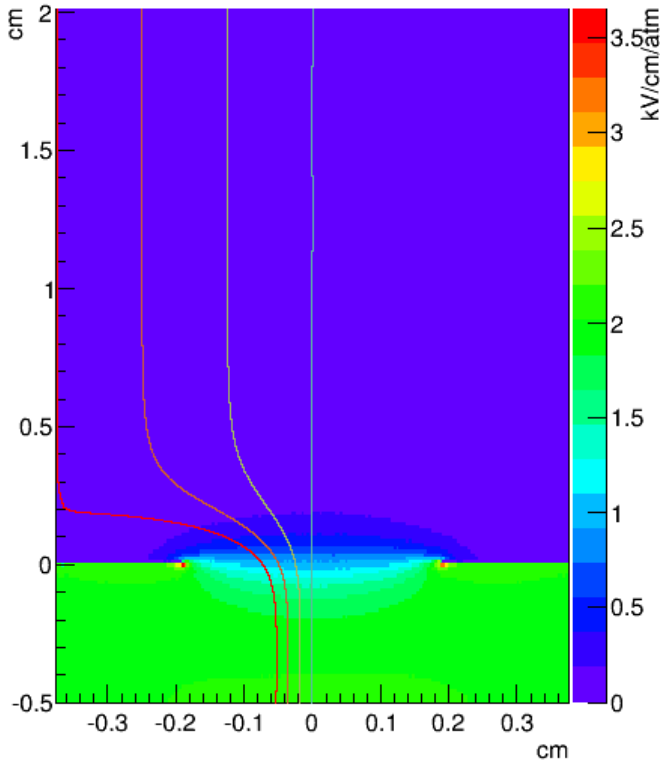


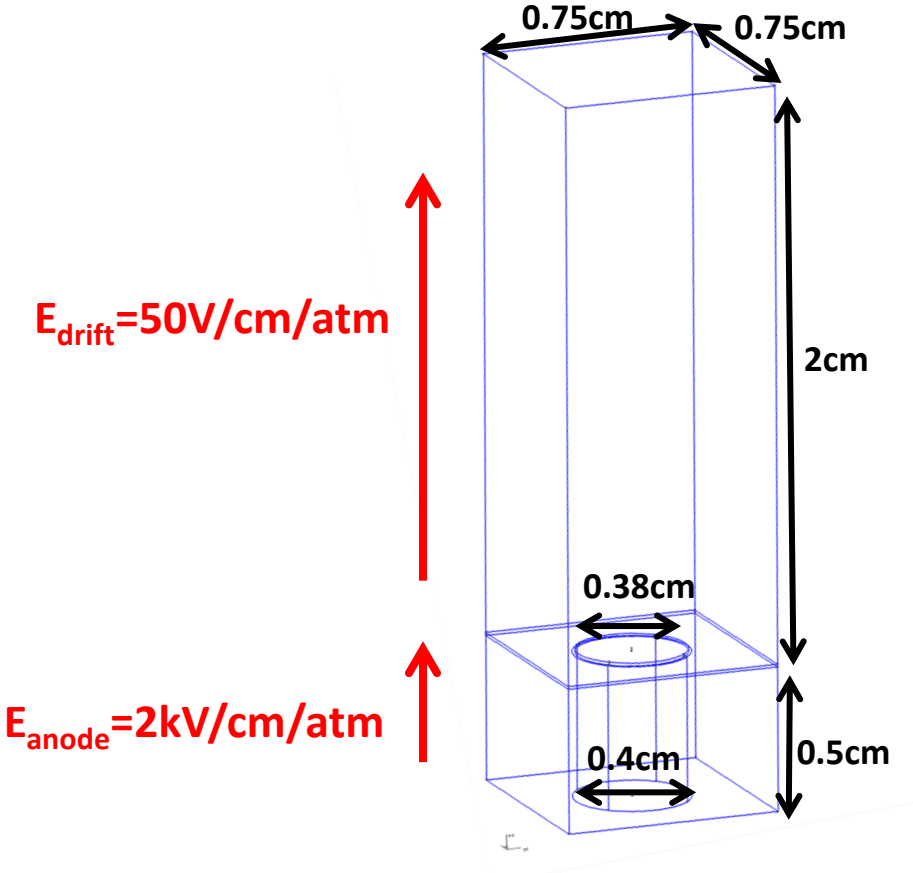


Electric field simulation

Electric field simulation using FEMM (gmsh + elmer)

- By applying higher electric field in the EL region, lines of the electric field are pulled into the cell





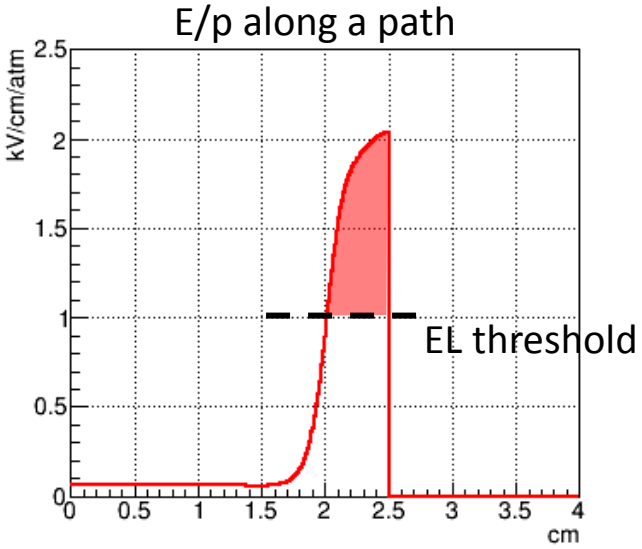
Position dependence of $Yield_{EL}$

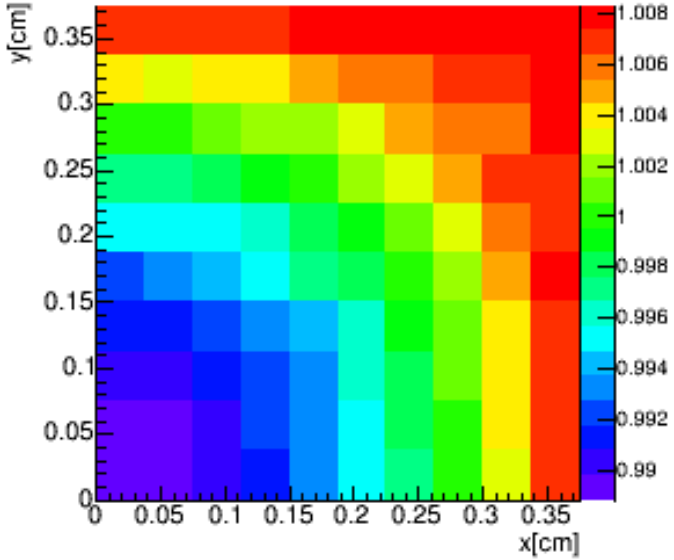
Estimation of position dependence of $Yield_{EL}$ in a cell

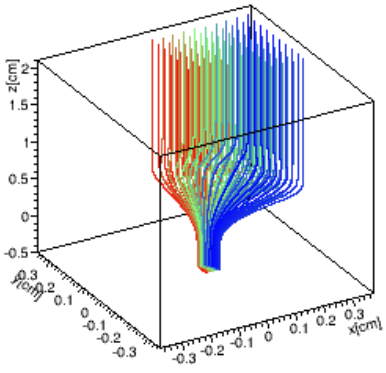
- $Yield_{EL}$ formula

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

- calculate integrated N_{ph} along line of electric field (x 100)
- fluctuation of $Yield_{EL}$ is 0.47% (rms)



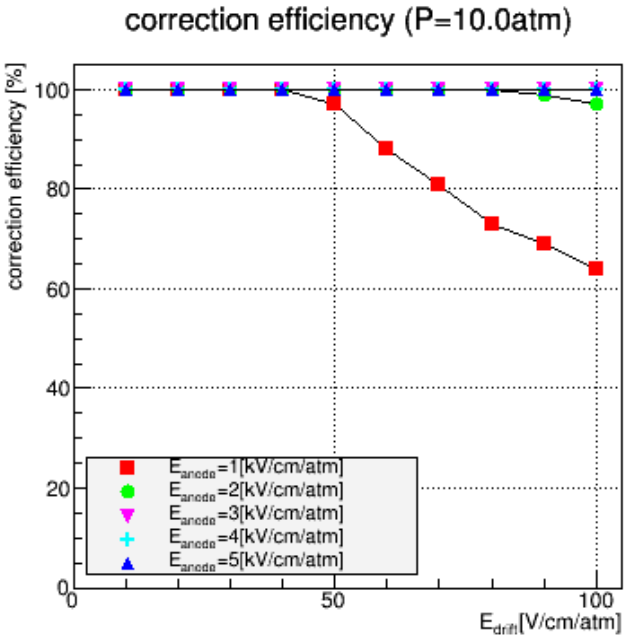


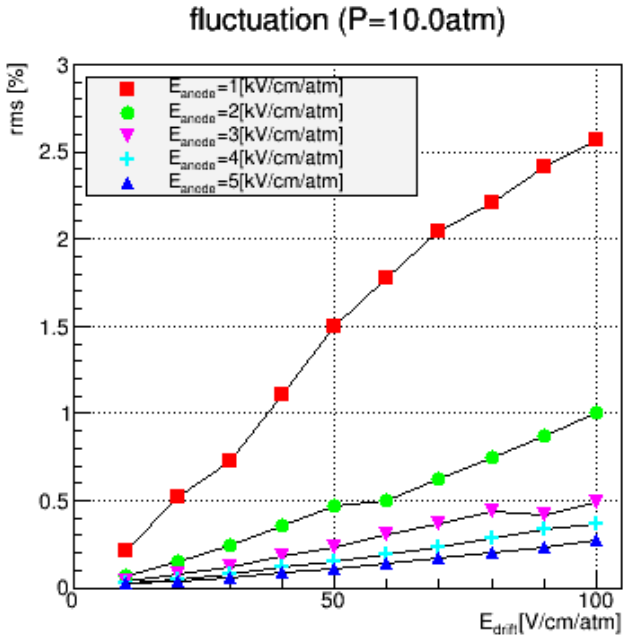


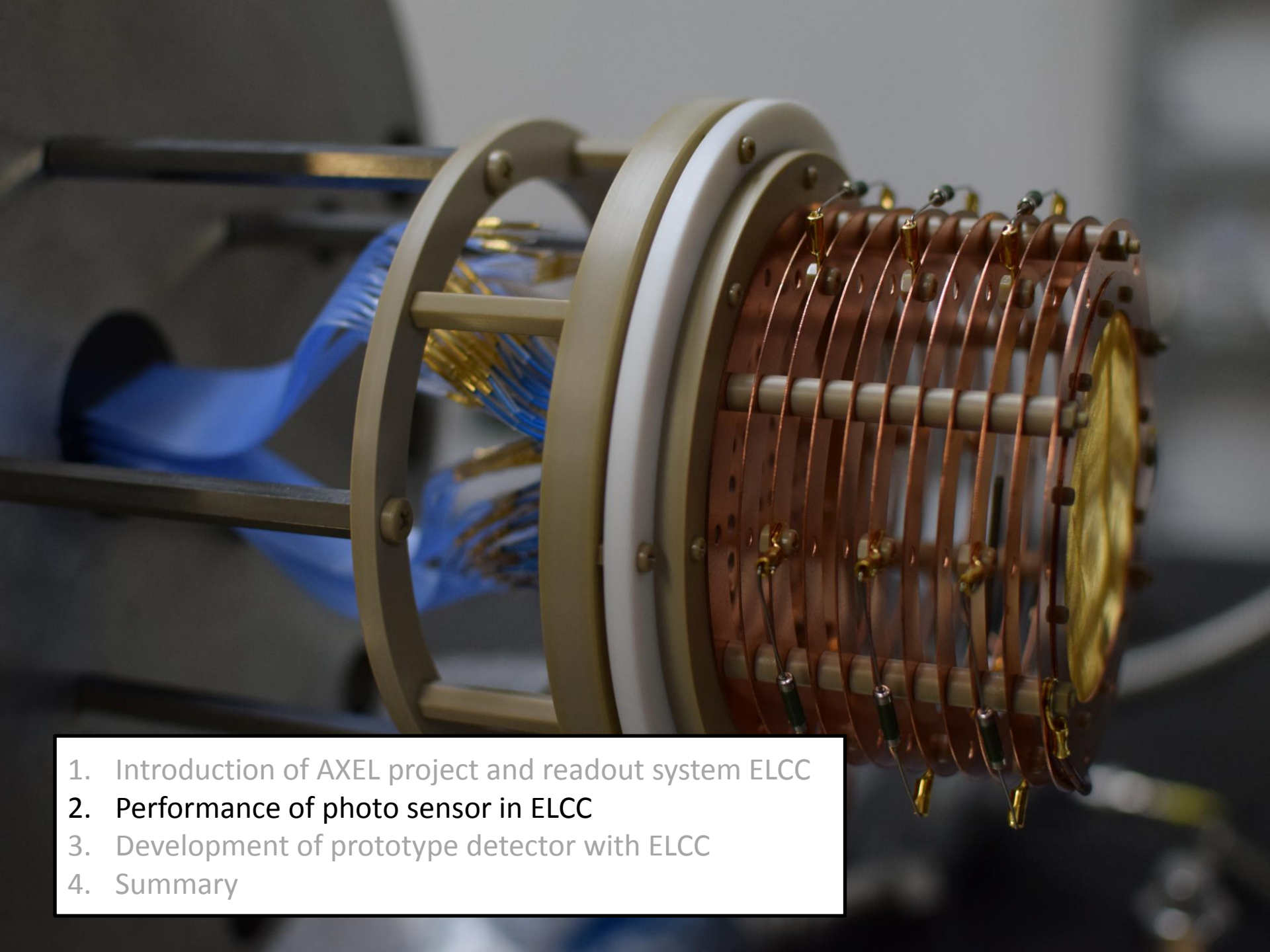
Electric field optimization

Collection efficiency depends on electric field

- Higher E_{anode} and lower E_{drift} give better collection
  - because E_{anode} is less disturbed by E_{drift}
- Another issues
  - Attachment would be significant for low E_{drift}
  - Concern of discharge for high E_{anode}







1. Introduction of AXEL project and readout system ELCC
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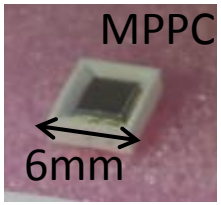
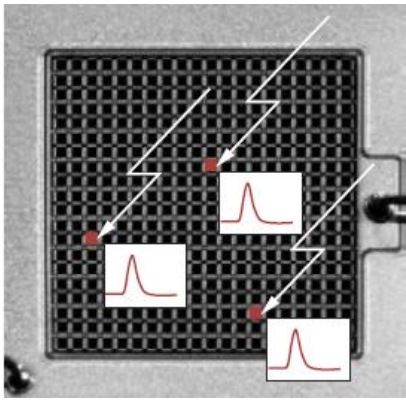
Requirement for photo sensor

Small size (<7.5mm) for putting in the cell

- MPPC is small and comparatively cheap





Sensitivity for VUV photons

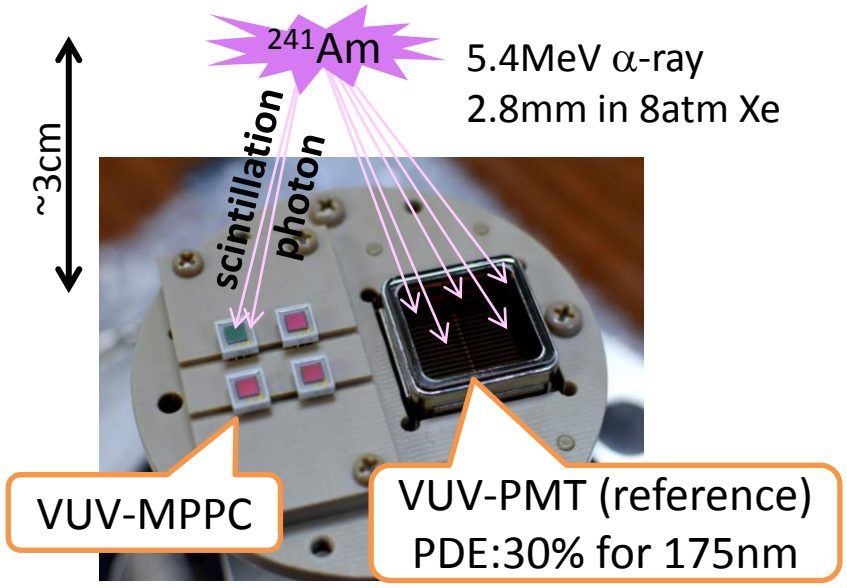
- MEG group developed it with HAMAMATSU for liquid Xe
- We measured PDE for VUV photons in high pressure Xe gas

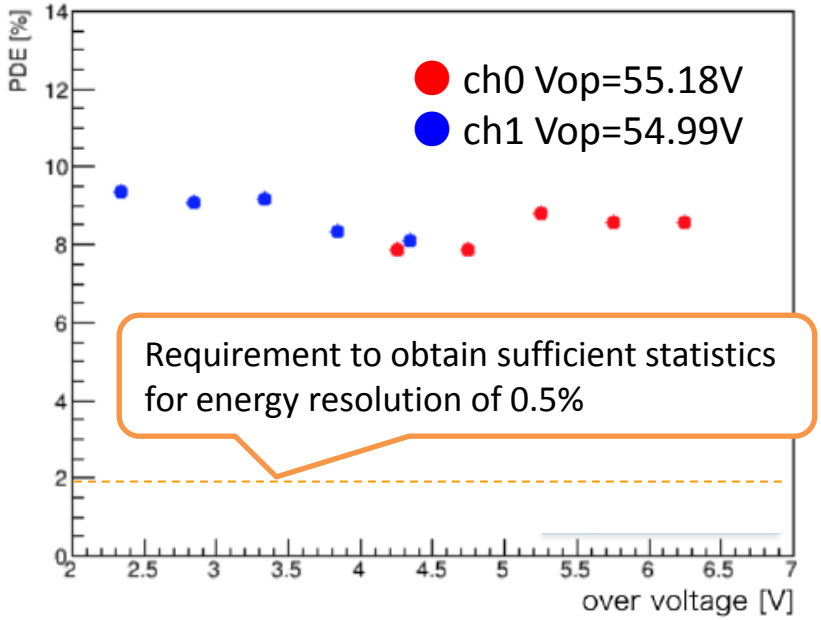
Good linearity to keep high energy resolution

- Number of pixel limits linearity of MPPC
- $0\nu\beta\beta$ event could generate ~10^5 photons in ~5μs for 1 MPPC
- MPPC pixel is not so much(1600), but recovery time is fast(50ns)
- We measured linearity for large amount of photons (~10^5/5μs)

PDE measurement for VUV

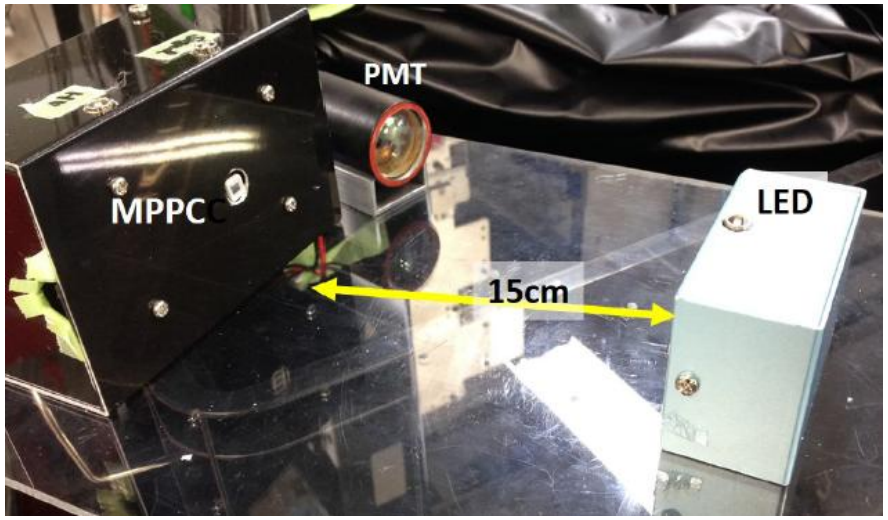
- We measured MPPC's PDE by using PMT as a reference
  - Measured PDE : ~8% (>2%, sufficient for our ELCC)
  - Over voltage dependence is under investigation
    - Over voltage (ΔV) : $\Delta V = V_{bias} - V_{breakdown}$
    - In case of visible type, PDE increase when over voltage increase
    - VUV may be enough strong to create e-/hole pair certainly

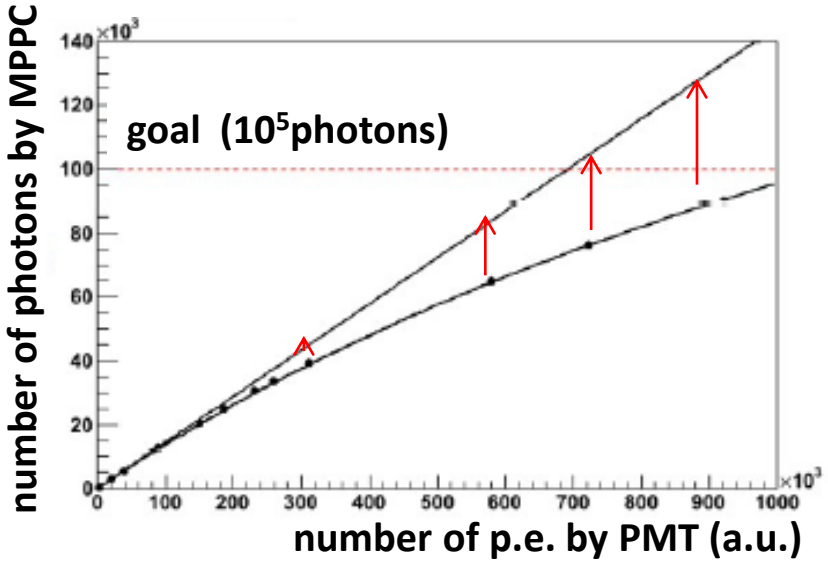


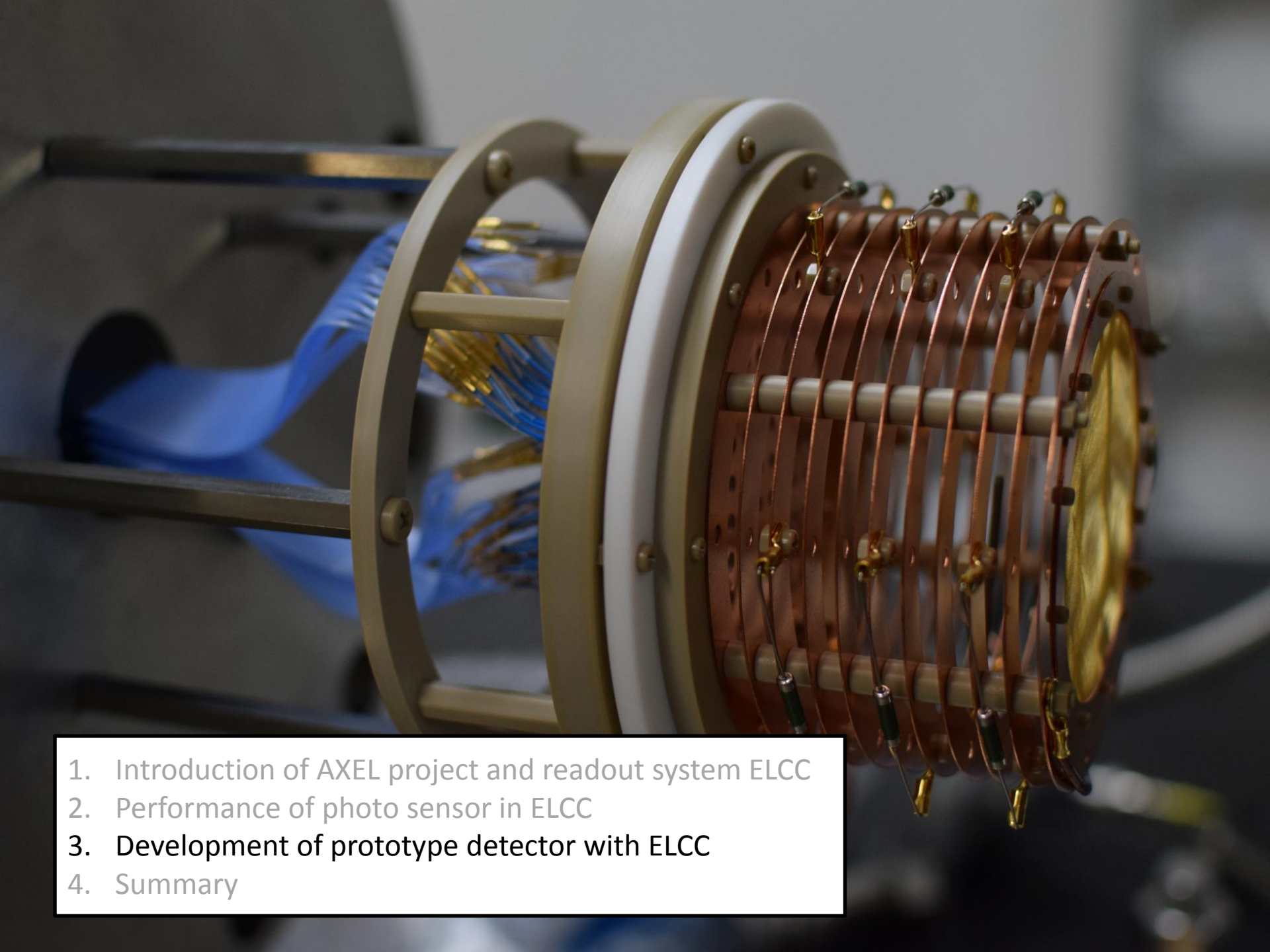


Linearity measurement

- We measured MPPC's linearity by using PMT as a reference
  - Irradiated LED light up to ~10^5/5μs
  - Observed saturation is slightly larger than expected from the number of pixels and recovery time. Under investigation
  - After correction, expected residual fluctuation is 0.12% (< 0.5% : target energy resolution)







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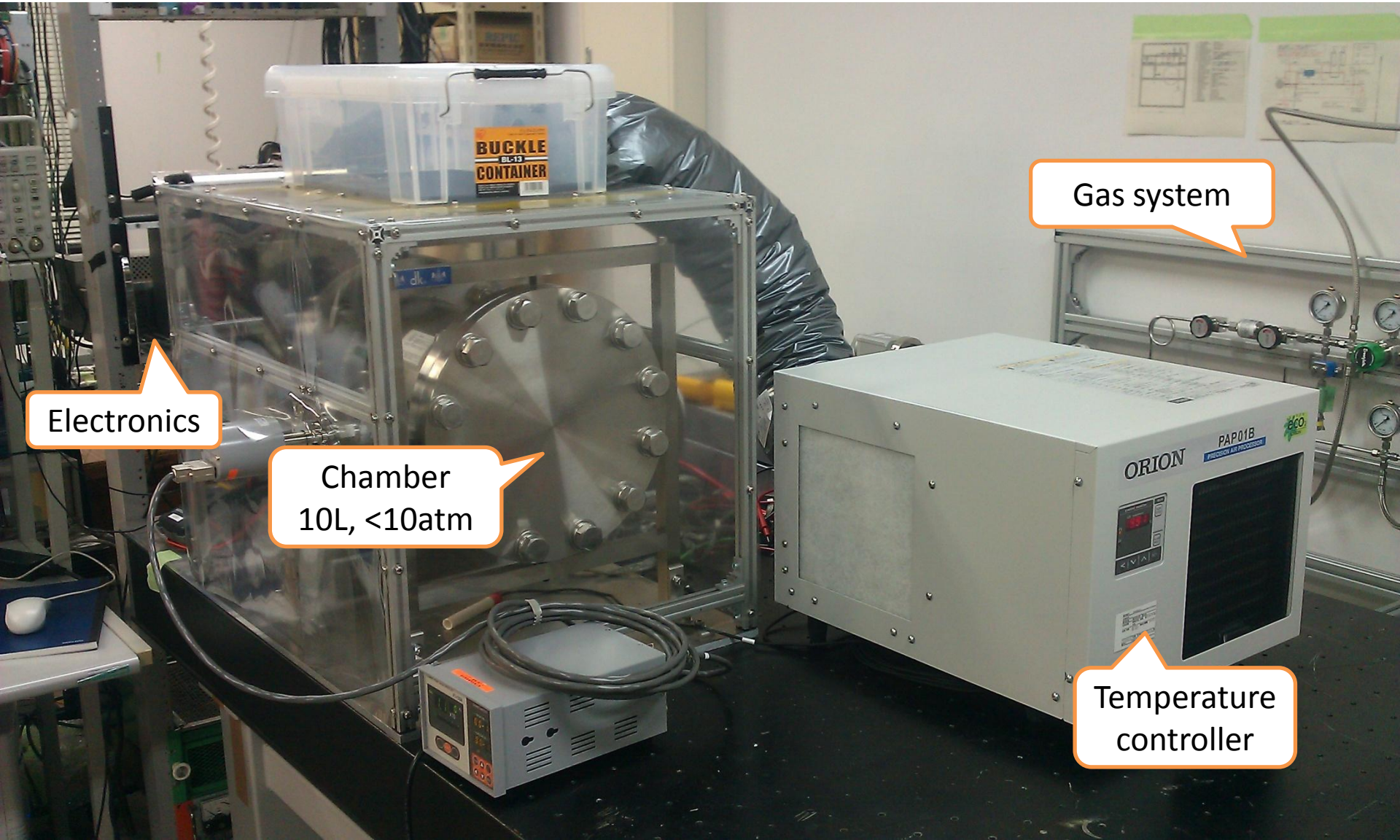
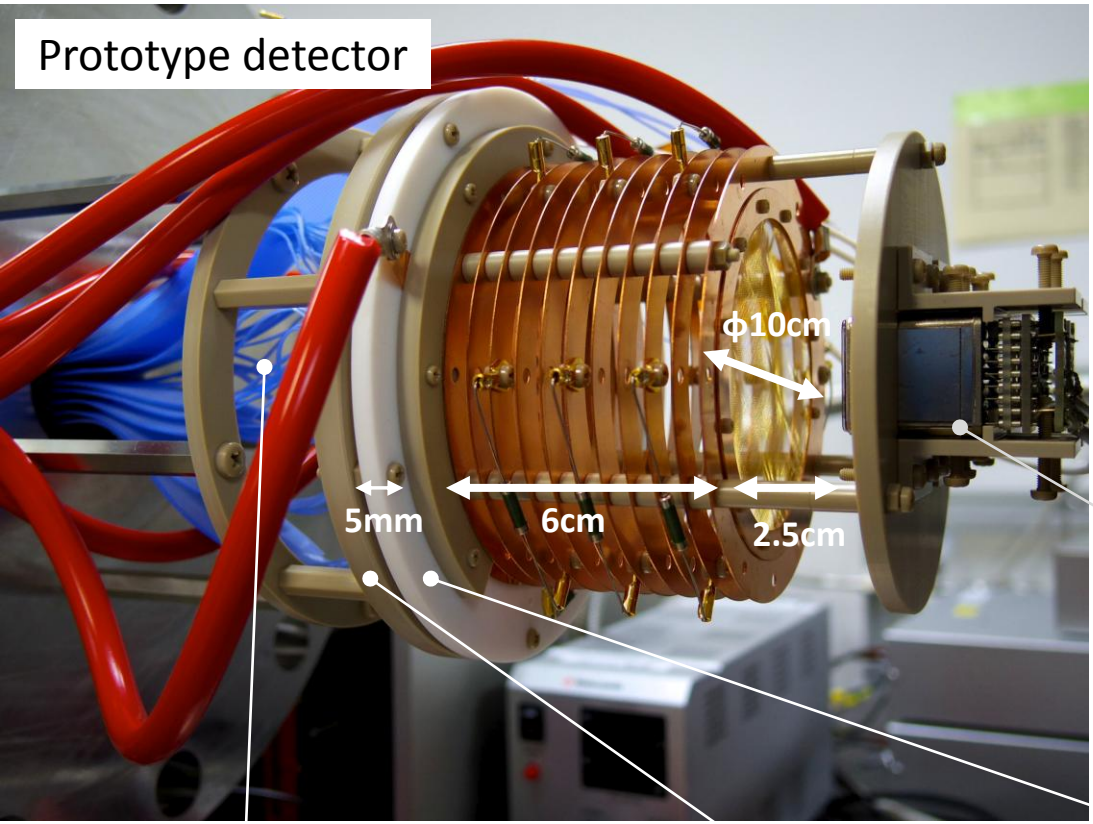
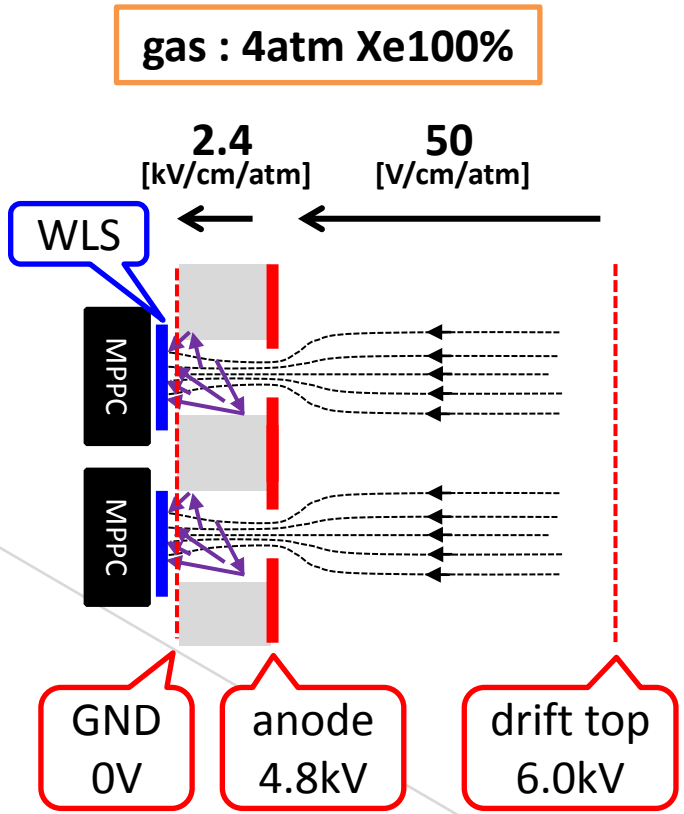
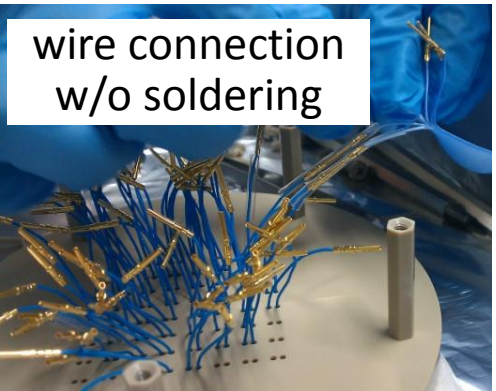
Prototype detector : outside

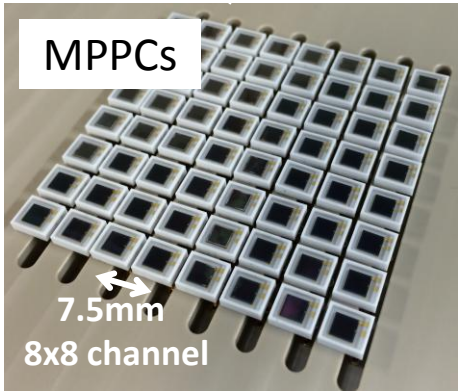


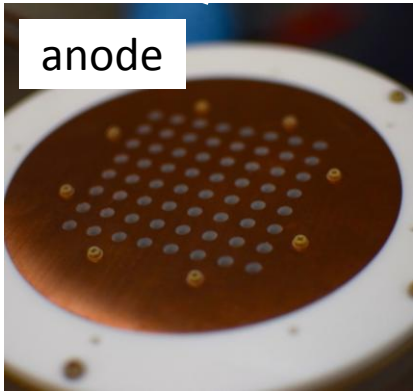
Prototype detector : inside

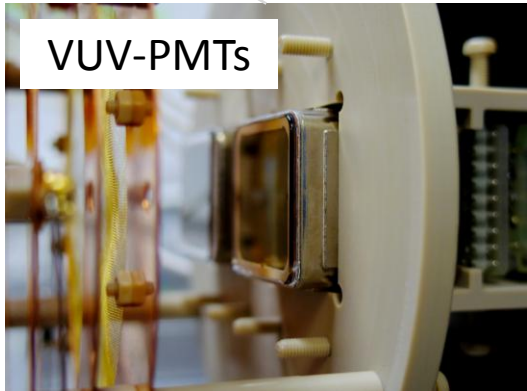








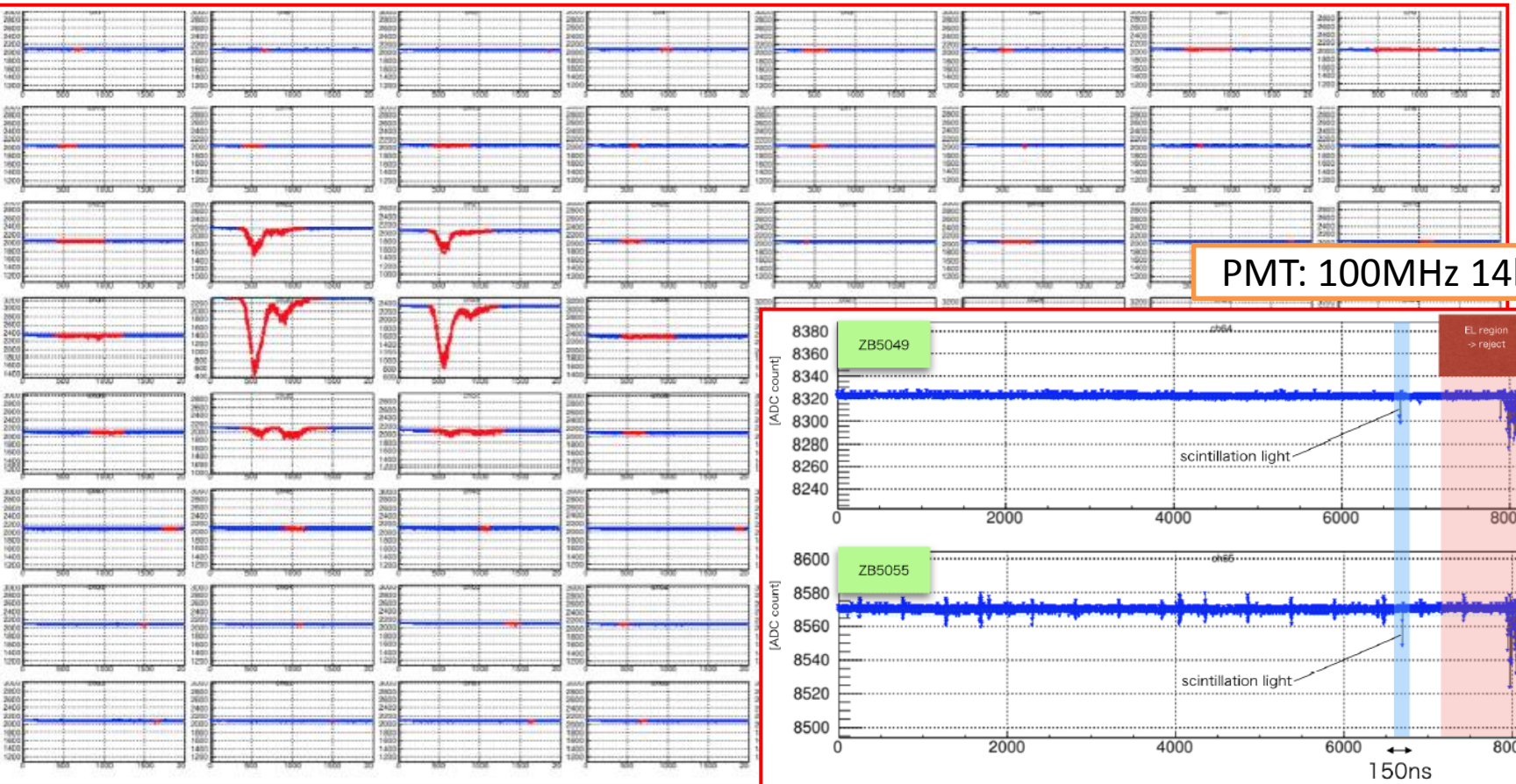




event sample

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

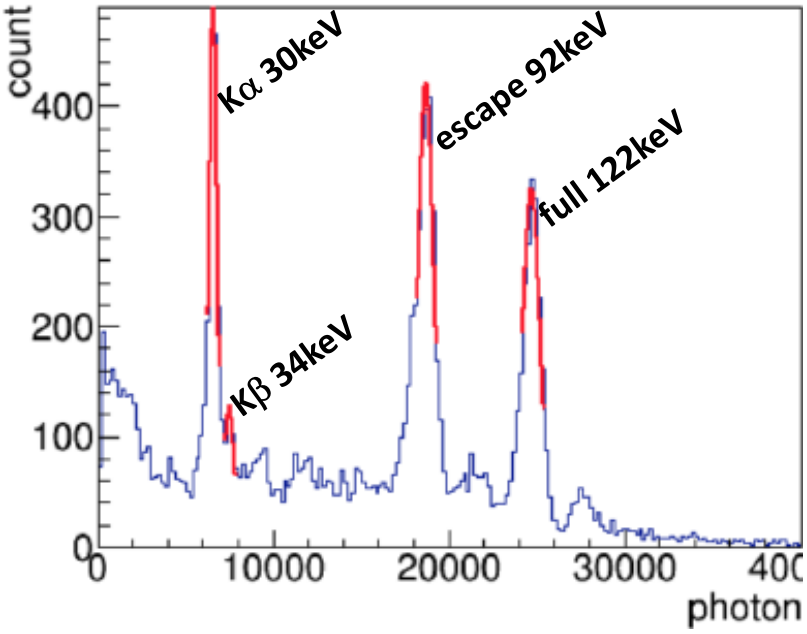
MPPC: 65MHz 12bit 2Vpp



PMT: 100MHz 14bit 2Vpp

Energy resolution

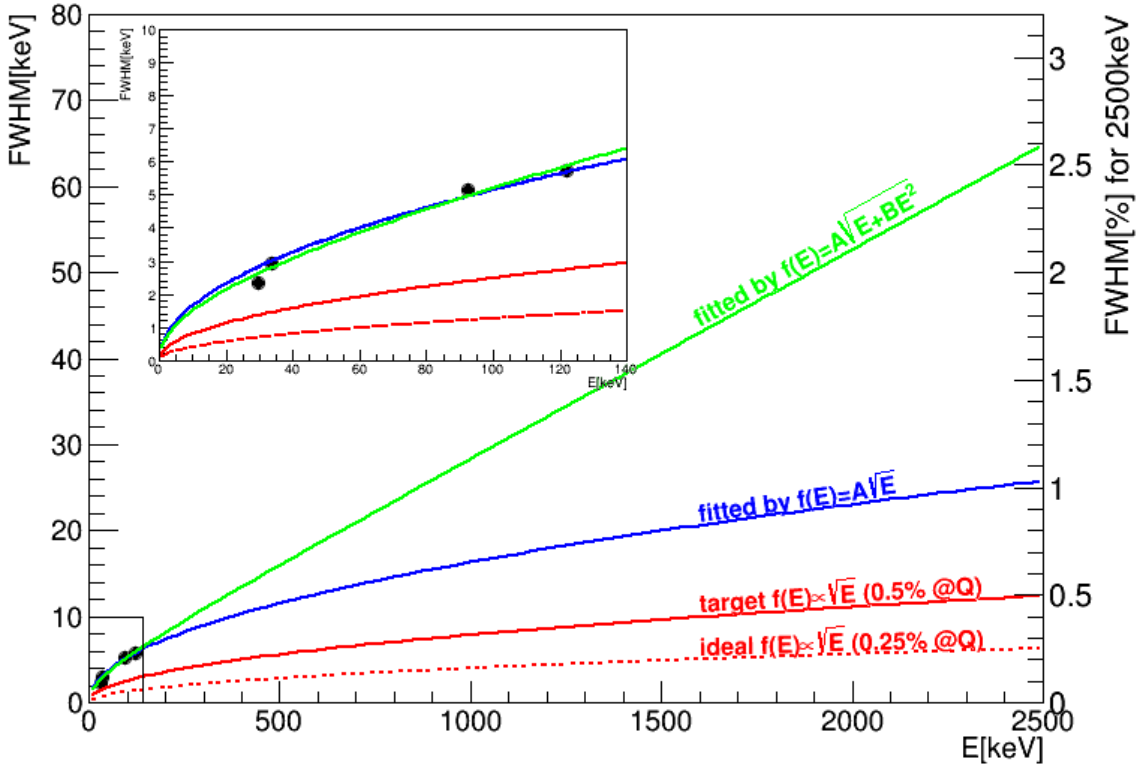
- γ-ray measurement from ^{57}Co (122keV)
  - Four peaks are observed
  - FWHMs are evaluated by fitting Gaussian



	Kα	Kβ	escape	full
energy	29.8keV	33.6keV	92.3keV	112keV
photon #	6605	7516	18711	24710
FWHM	7.9%	8.7%	5.6%	4.7%

Energy resolution estimation at Q

- Estimated resolution is ~2.5%(FWHM)
  - Several factor for the target
- We plan to improve energy resolution by
  - VUV-MPPC
  - gas circulation
  - crosstalk suppress
  - etc...
- We also plan to make larger detector



Summary

AXEL project

- $0\nu\beta\beta$ search with high pressure xenon gas TPC with high energy resolution, large mass and tracking ability
- New readout idea : ELCC (electric field simulation is OK)

MPPC performance studies

- PDE for VUV photon : 8% (OK)
- Linearity for 1e5/5μs : correction fluctuation is 0.12% (OK)

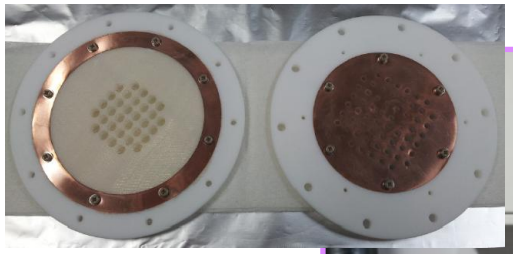
Prototype detector

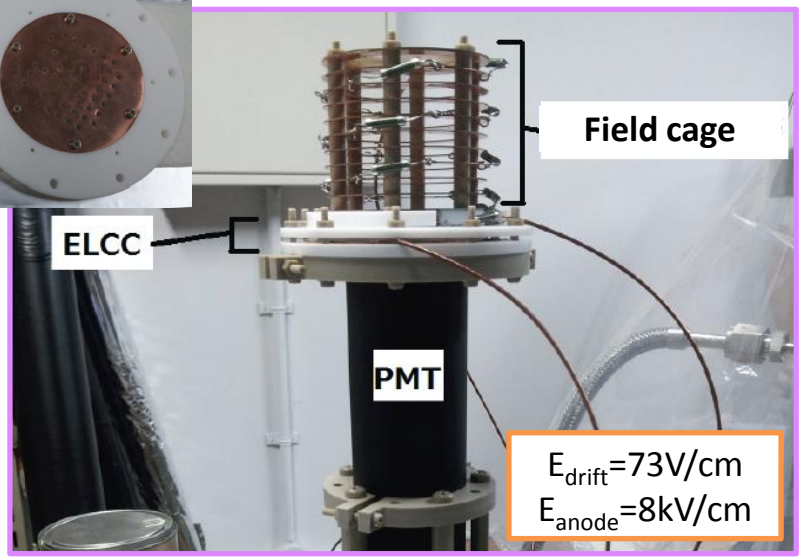
- Energy resolution : ~1%(FWHM) at Q (not so bad)
- There are many rooms for improvement

ELCC demonstration by UV-PMT

Setup

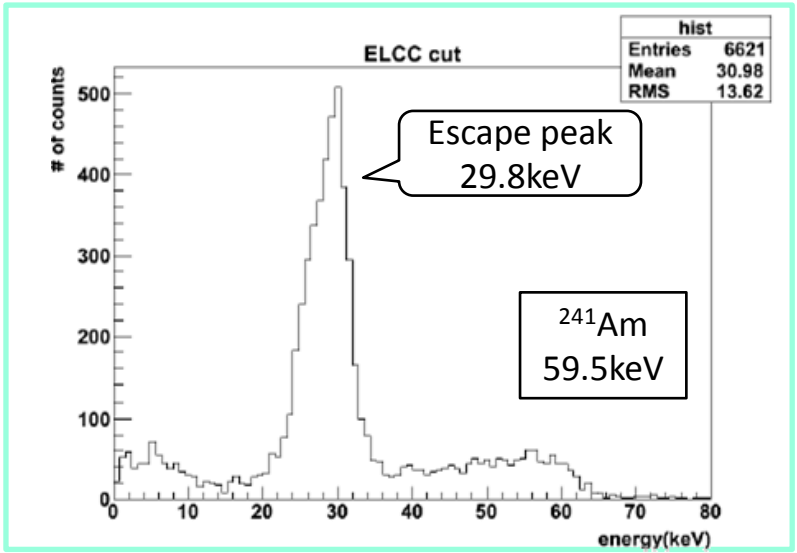
- 1atm Xe
- UV-PMT (H3178-51Q)
- all cells are merged
- detection size: 28x28x55mm





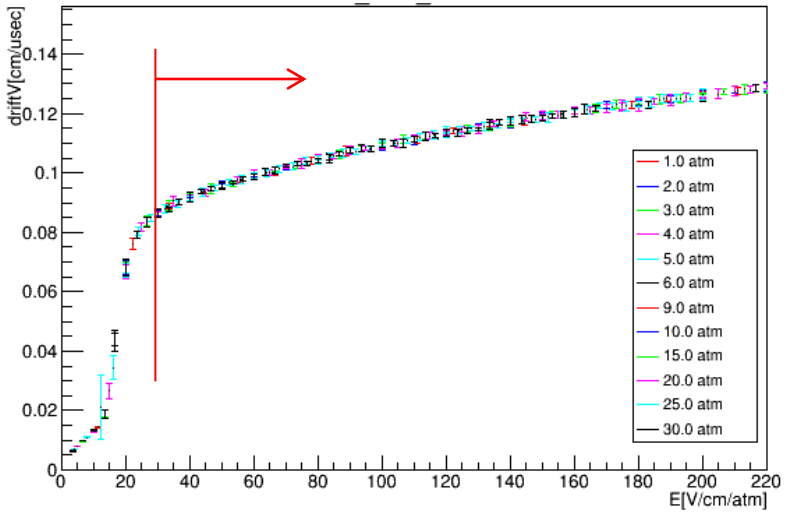
energy resolution (FWHM)

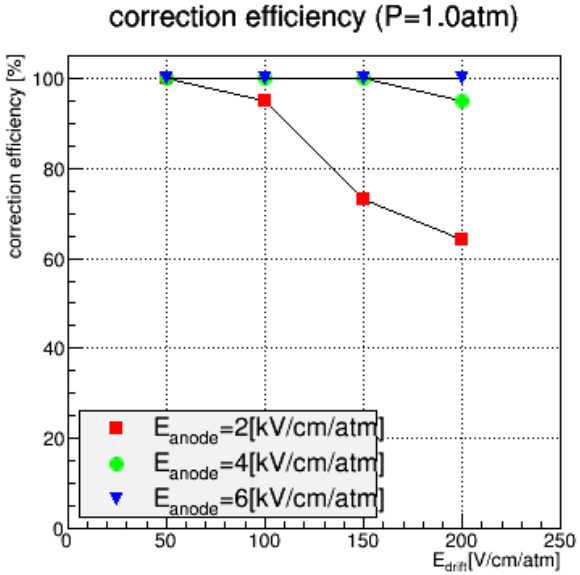
- 13.8% @30keV (fit right edge)
- 1.5% @2.5MeV (converted)

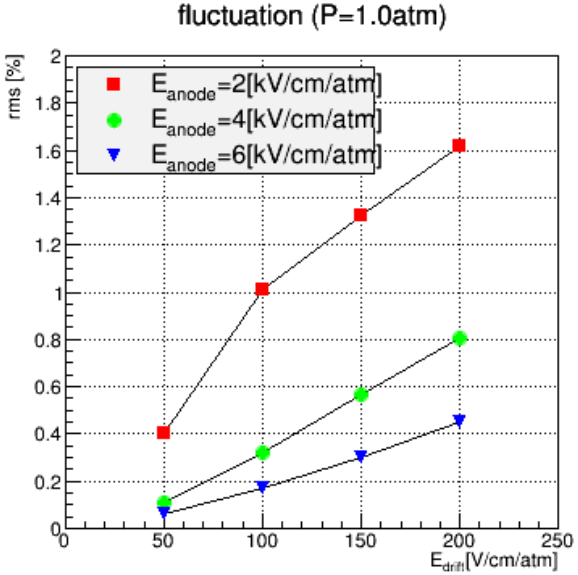


Voltage for 1atm

- Drift
  - 73V/cm is enough
  - driftV change small at > 30V/cm
- Anode
  - 8kV is enough



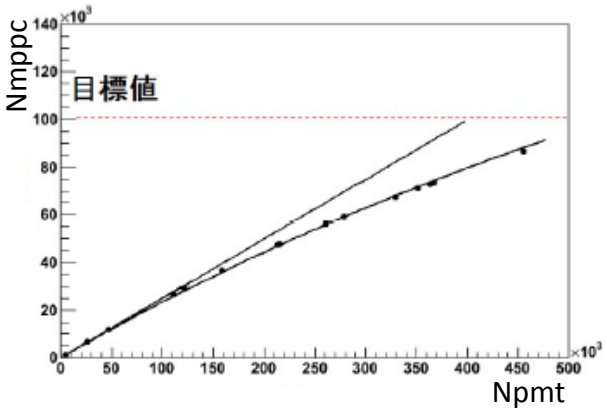


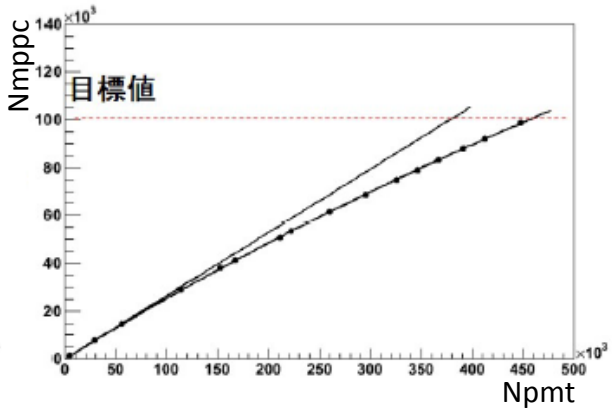


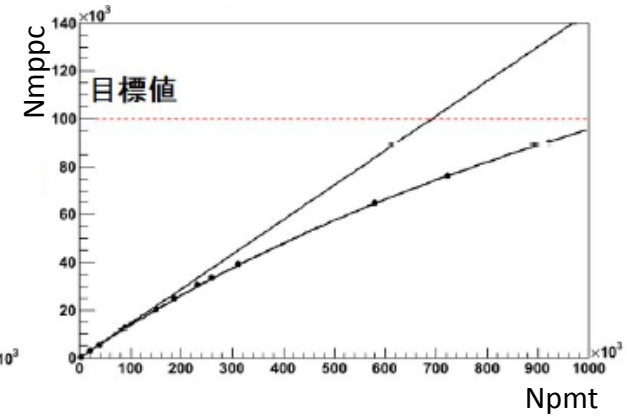
Linearity measurement

Result

- Slowly saturated (25mm pitch is better)







MPPC pixel pitch	50μm	25μm	VUV 50μm
photon# to keep linearity	1.5 x 10^4	2.5 x 10^4	1.5 x 10^4
N_{pixel}	3600	14400	3600

- After correction, fluctuation is 0.12% (< 0.5% : aim of Eres)

Linearity measurement

- photon rate per pixel : $k[1/(\mathrm{pixel}\cdot\mathrm{s})] = \dfrac{N_{\mathrm{true}}}{N_{\mathrm{pixel}}\cdot\Delta t}$
- average gain : $g = \displaystyle\int_0^\infty \underbrace{ke^{kt}}\underbrace{g_0(1-e^{-t/\tau})}dt = \frac{g_0}{1+k\tau}$

probability to hit after t sec

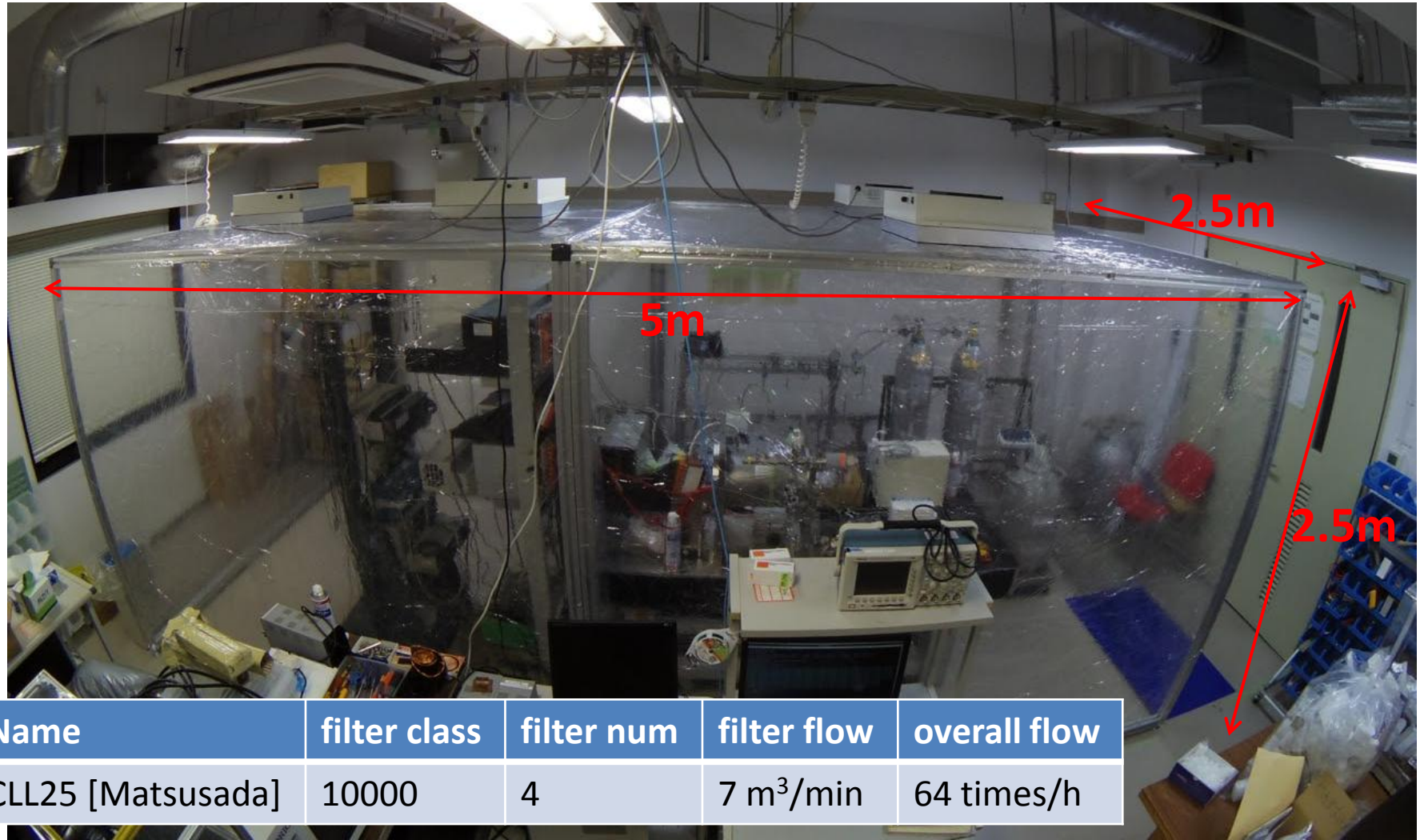
gain after t sec
τ : recovery time

- Observed photon# : $N_{\mathrm{obs}} = \dfrac{N_{\mathrm{true}}}{1+k\tau}$
- Fluctuation of correction

$$\frac{\Delta N}{N} = \frac{N_{\mathrm{true}} - N_{\mathrm{obs}}}{N_{\mathrm{true}}} = \sqrt{\frac{\tau}{N_{\mathrm{pixel}}\cdot\Delta t}} = \sqrt{\frac{25\mathrm{ns}}{3600\cdot 5\mu\mathrm{s}}} = 0.0012$$

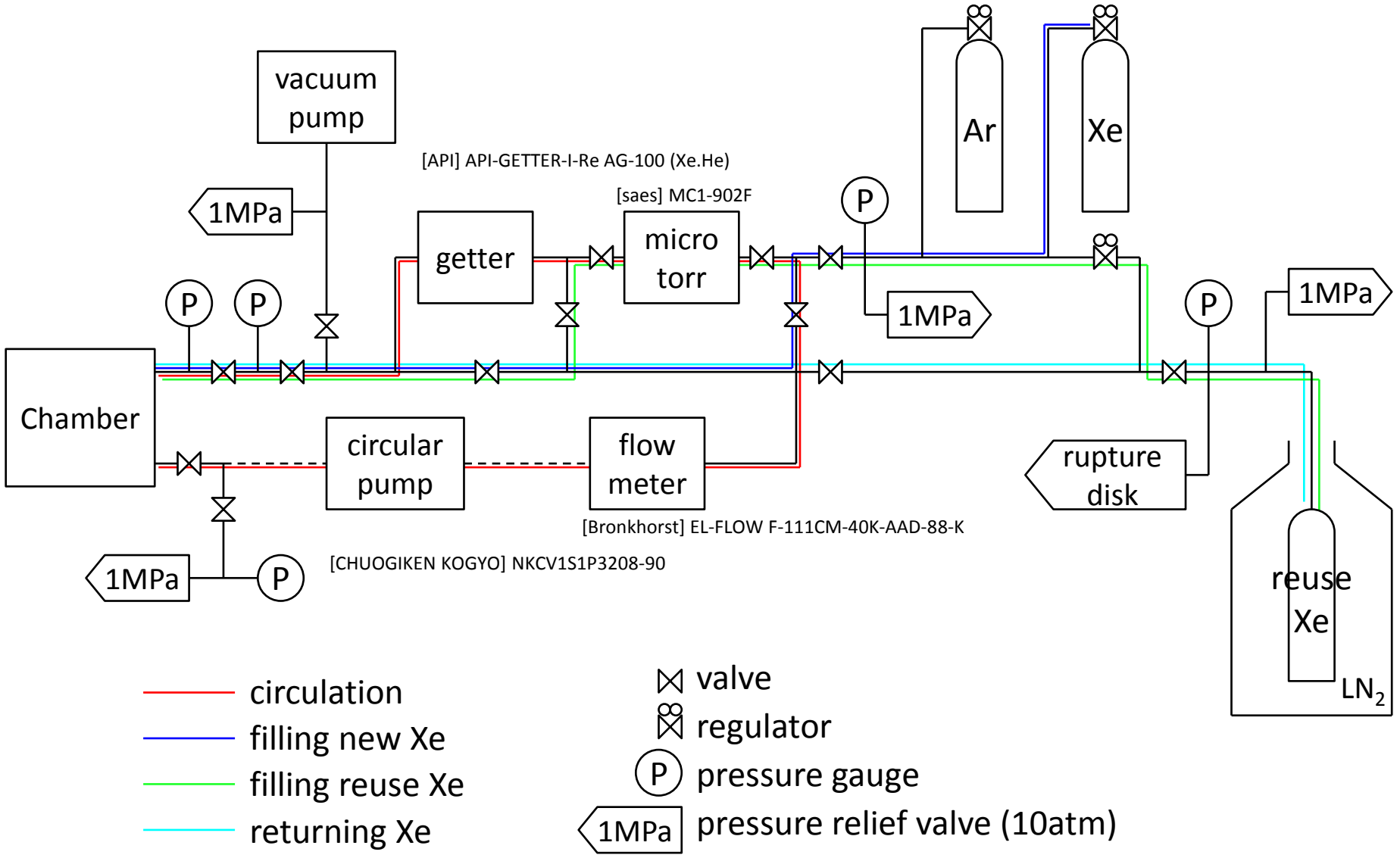
Prototype detector : clean room

- For installation of VUV-MPPC (bare)



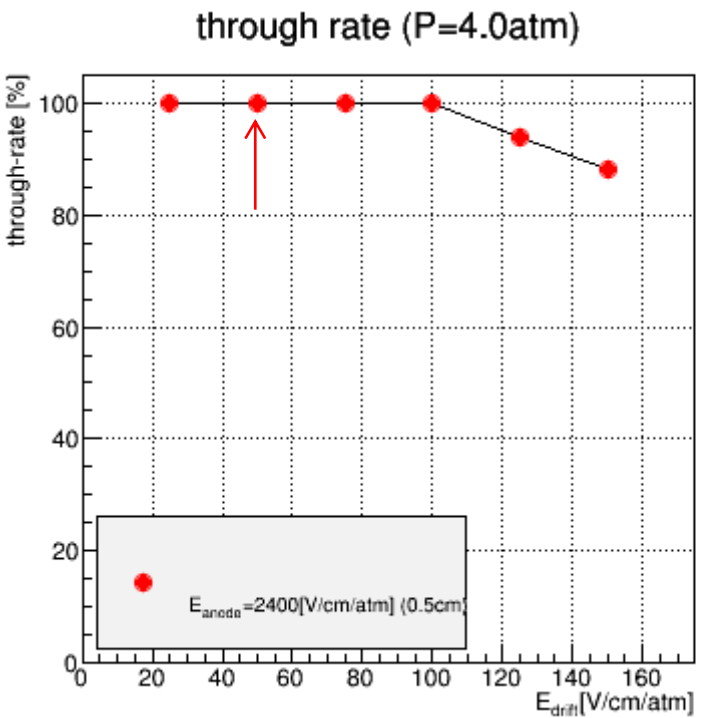
Name	filter class	filter num	filter flow	overall flow
CLL25 [Matsusada]	10000	4	7 m^3/min	64 times/h

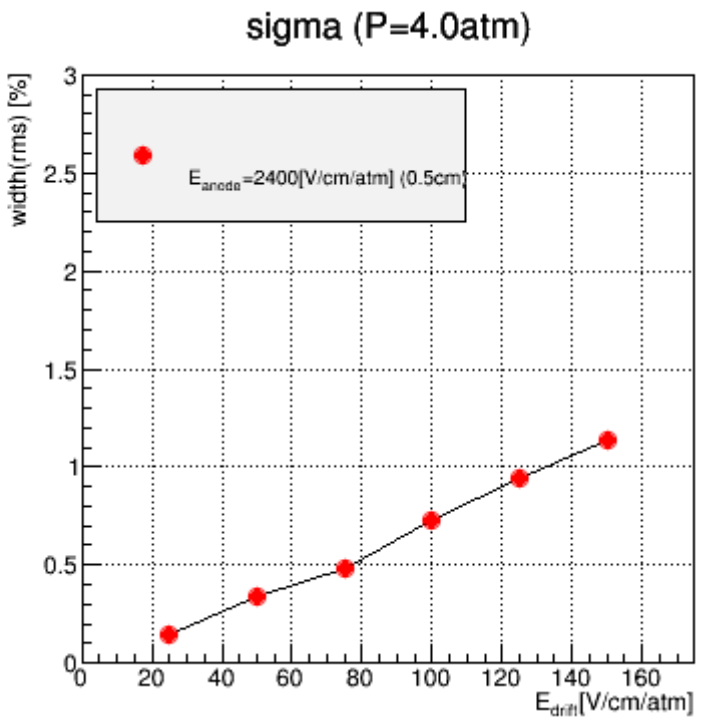
Prototype detector : gas system



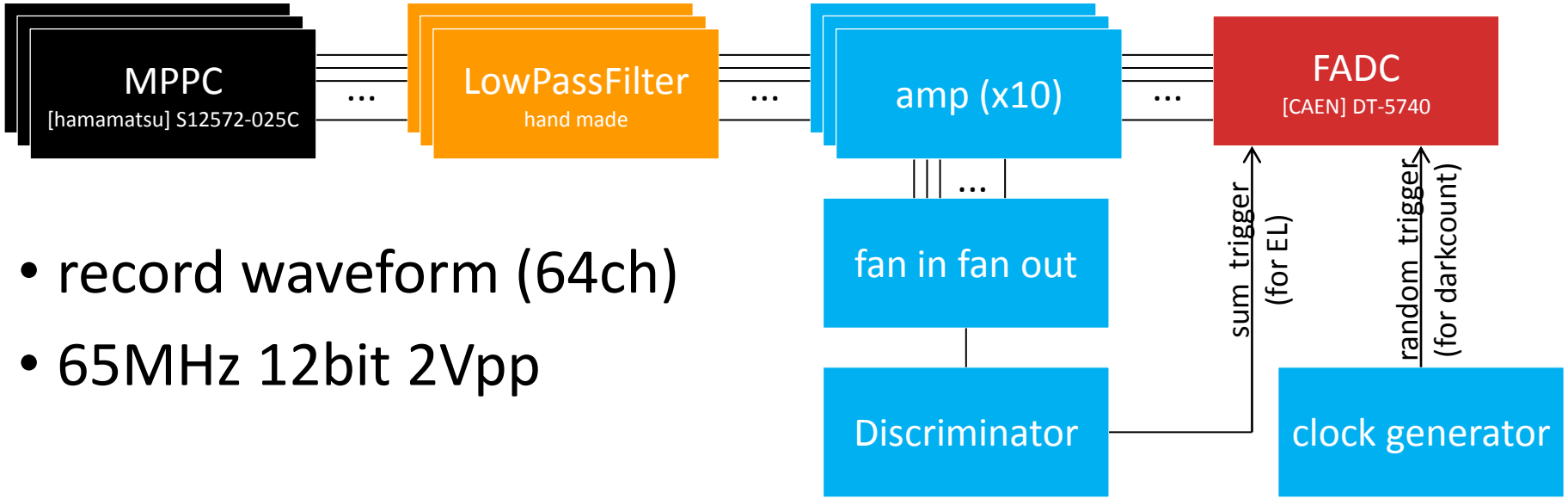
High voltage optimization

- Electric field
  - E_{anode} = 2.4kV/cm/atm
  - E_{drift} = 50V/cm/atm
- correction efficiency (by FEMM) is 100%

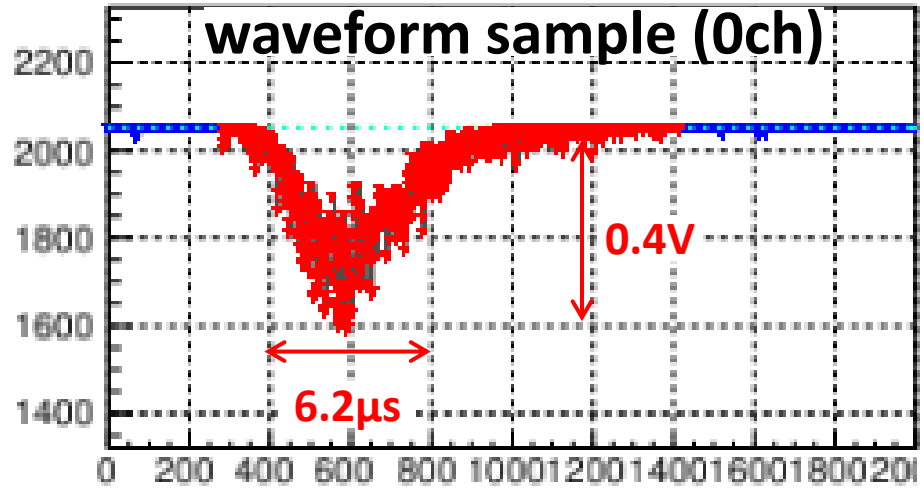


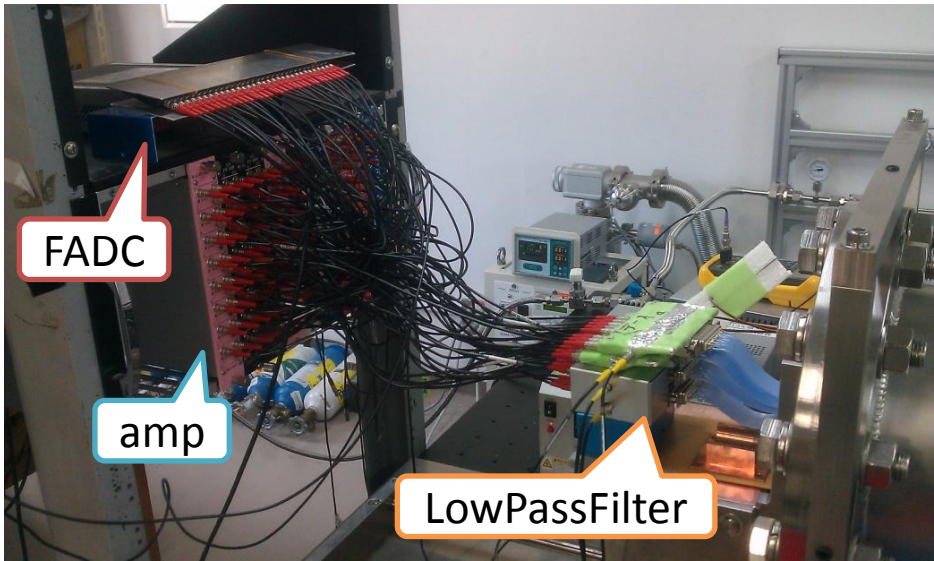


Data acquisition



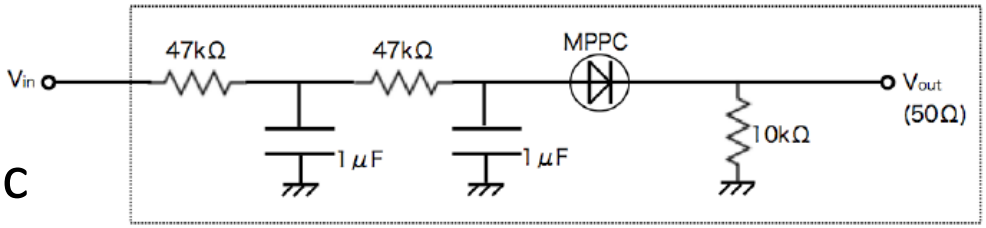
- record waveform (64ch)
- 65MHz 12bit 2Vpp

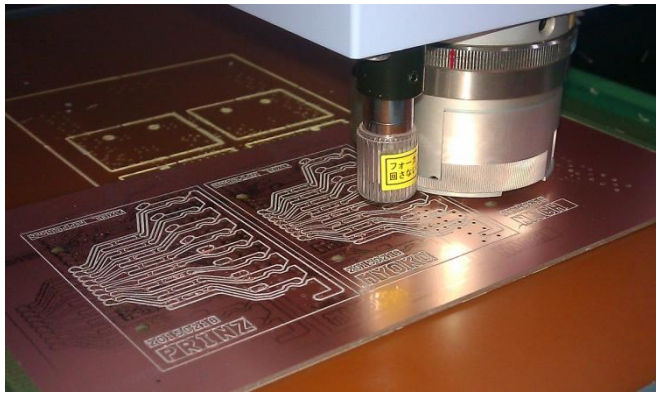


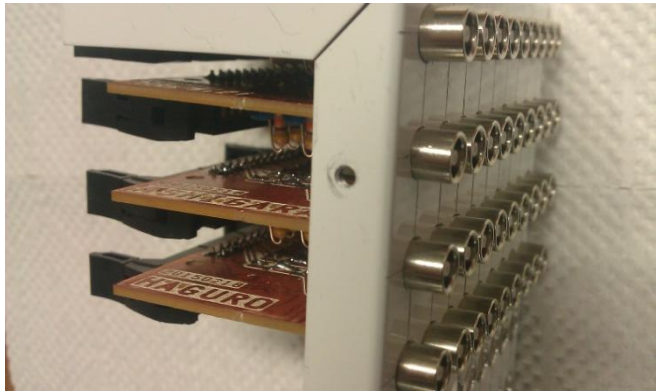


electronics

- low pass filter (64ch)
  - large time constant : 50msec
  - large capacitance : 1uF
  - for large and long pulse



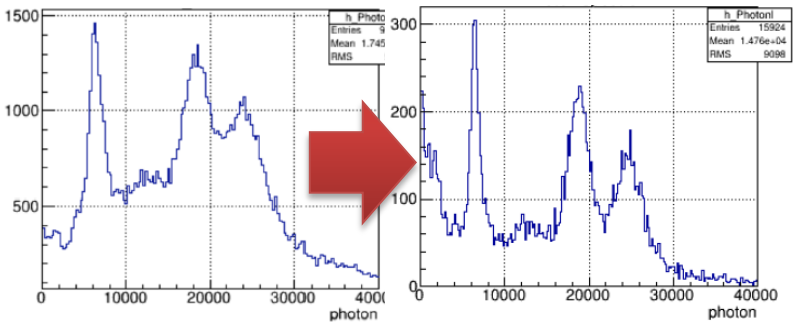




gamma ray measurement

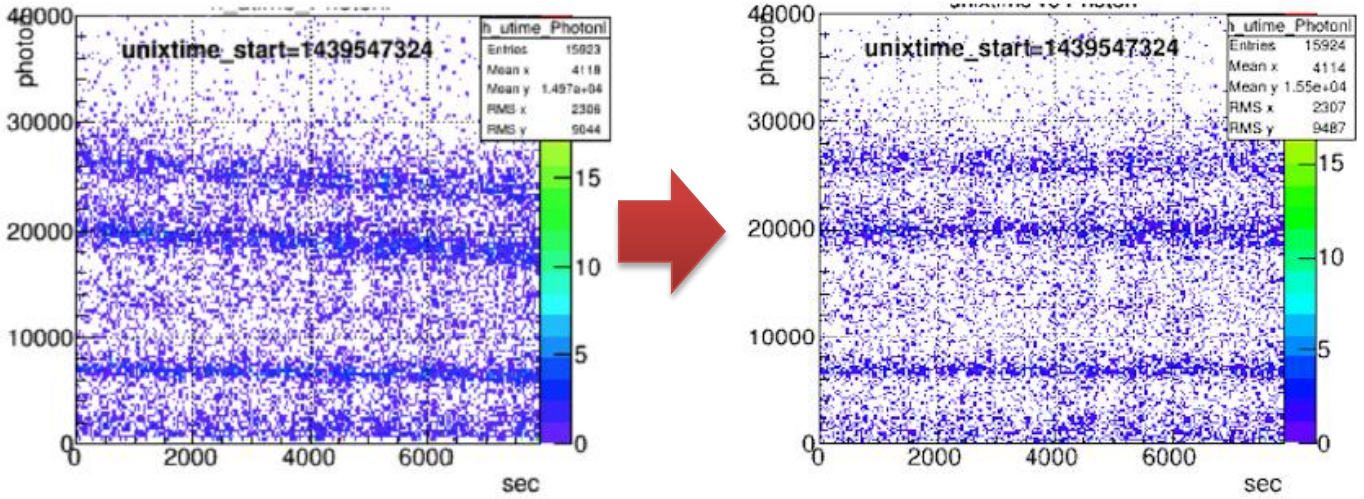
- We measured γ-ray from ^{57}Co (122keV)
  - fiducial cut

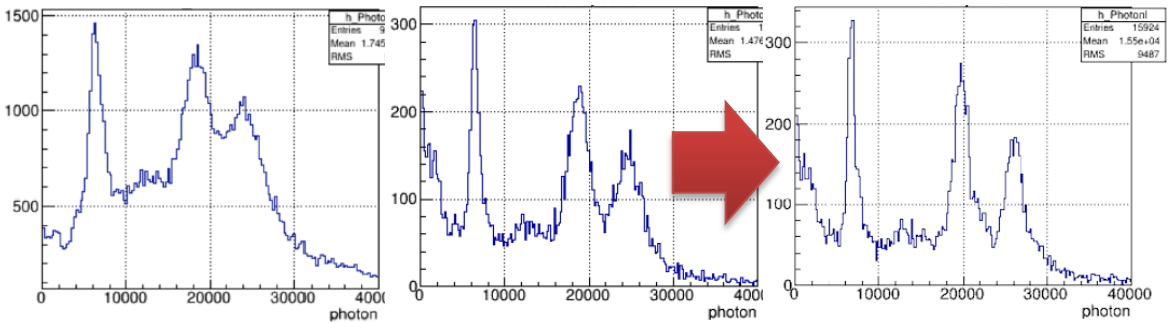
red: veto



gamma ray measurement

- We measured γ-ray from ^{57}Co (122keV)
  - time dependence correction

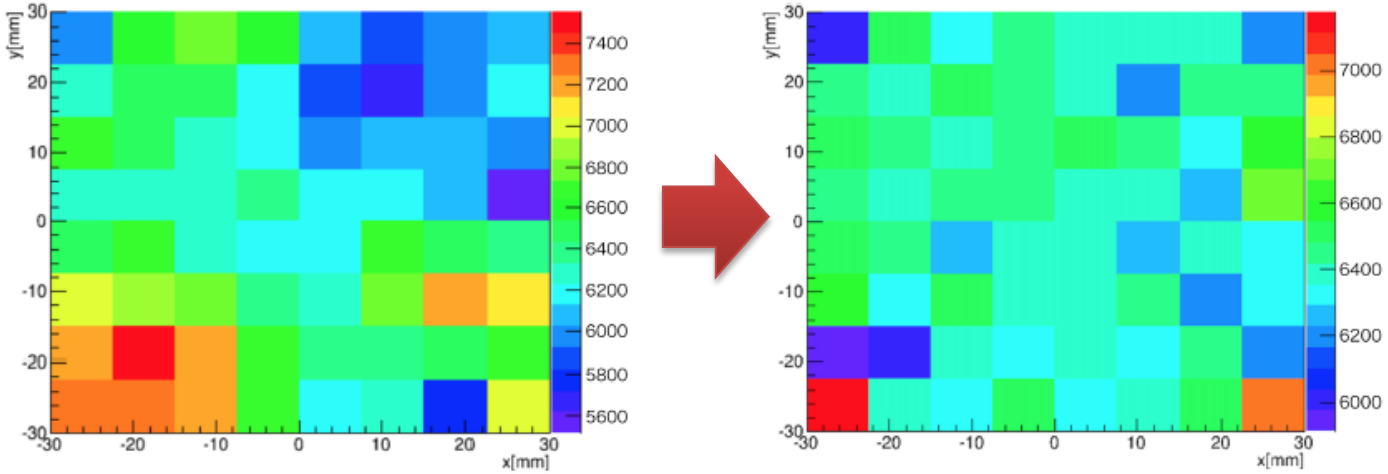


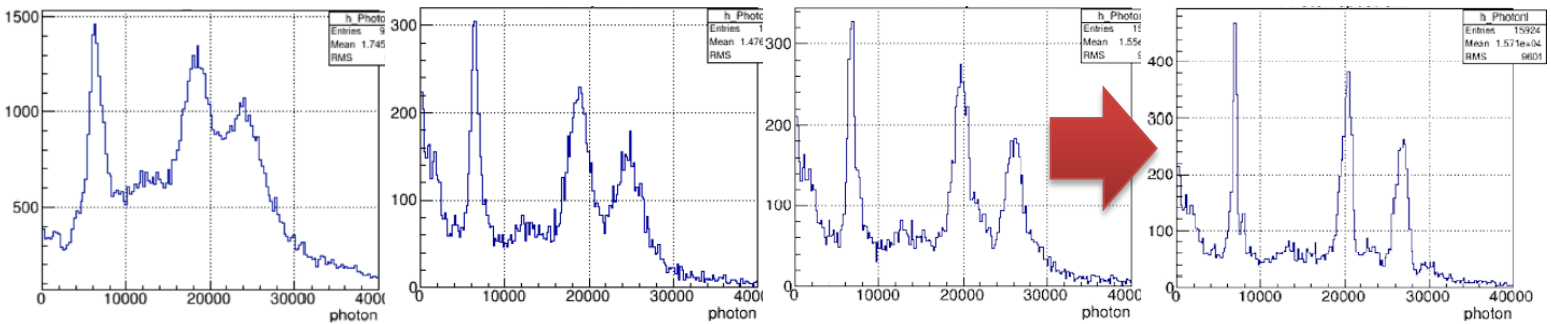


gamma ray measurement

- We measured γ-ray from ^{57}Co (122keV)
  - EL gain correction

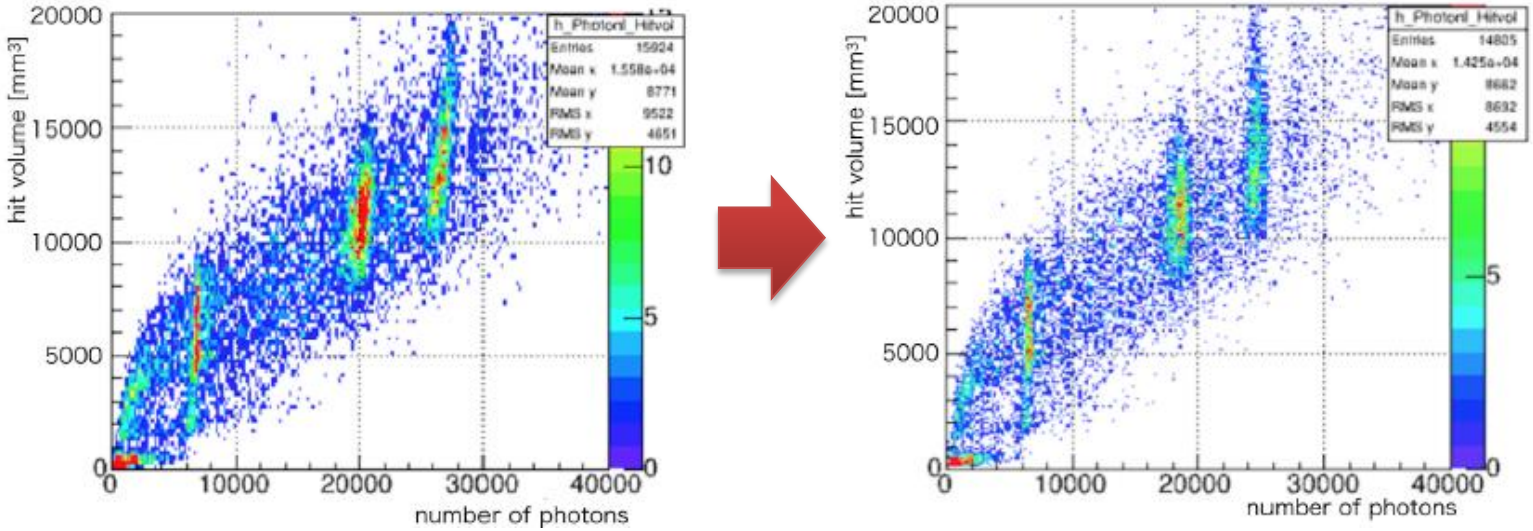
photon# of 30keV gamma for each cell

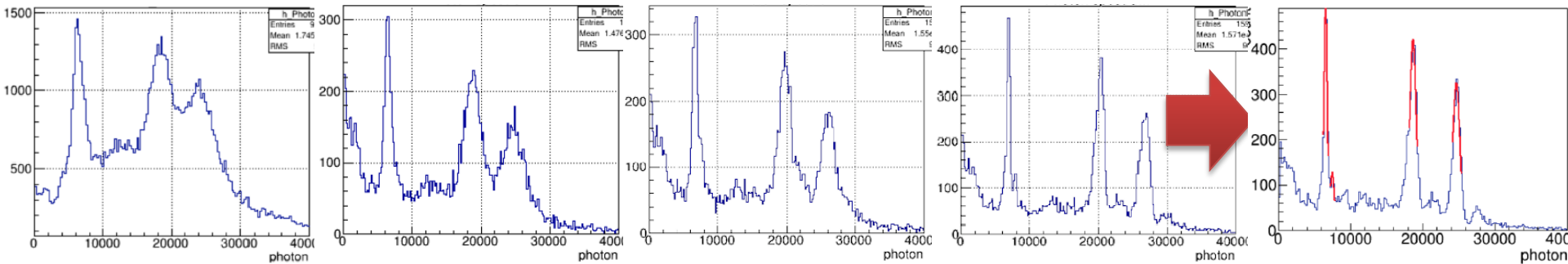




gamma ray measurement

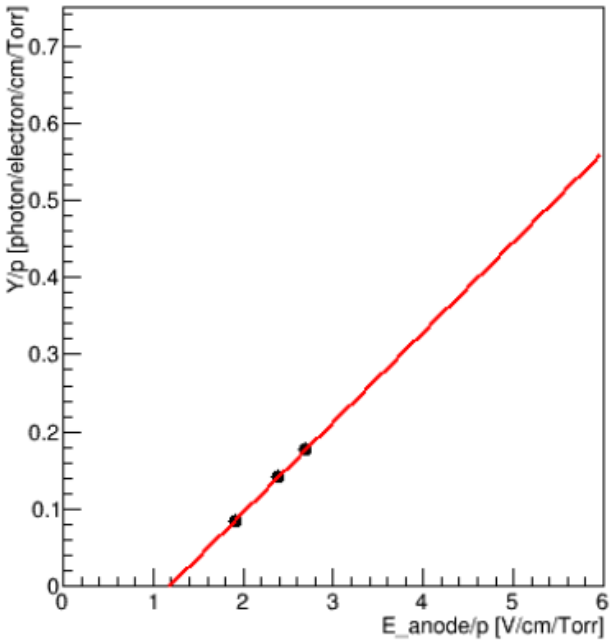
- We measured γ-ray from ^{57}Co (122keV)
  - hit volume correction
    - (recombination is seen ?)

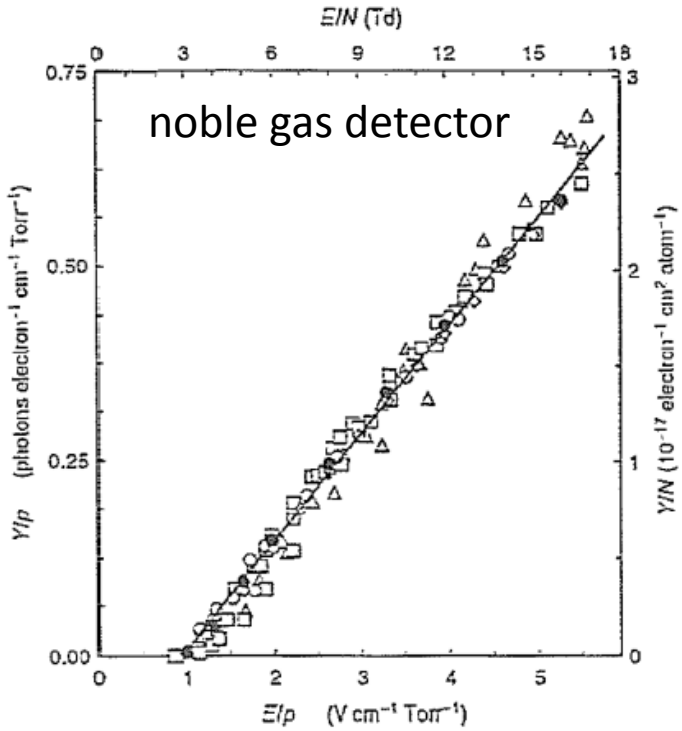




E_{anode} dependence

- Linear dependence --> OK
- We can supply higher E_{anode}





Yield calculation

$$\alpha = P_{\mathrm{coll}} \times Y \times \Omega \times P_{\mathrm{trans}} \times \frac{1}{2} \times \mathrm{PDE}$$

measured

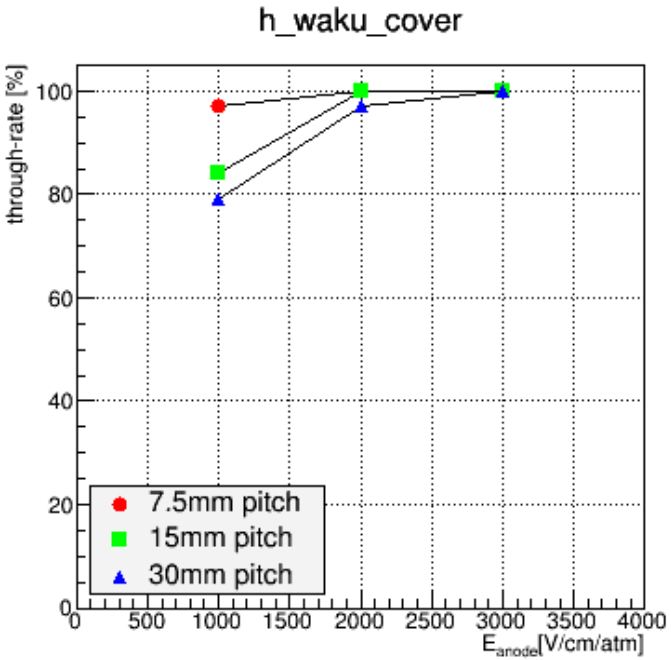
calculated

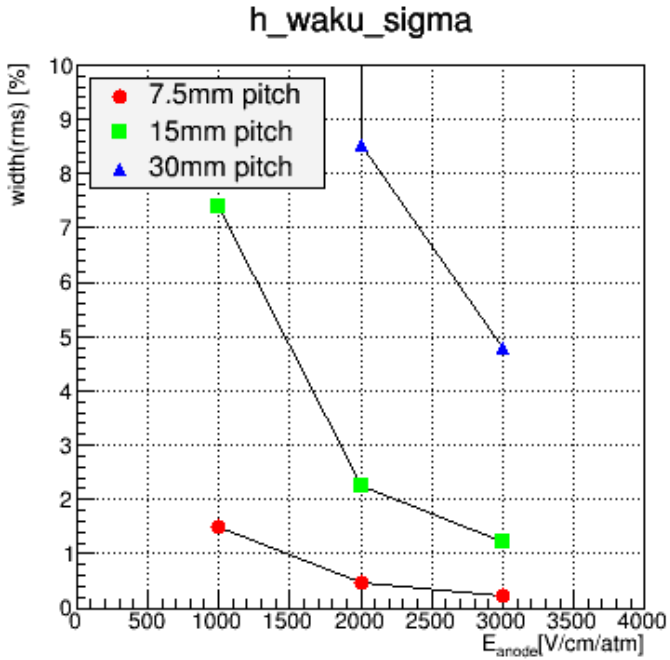
- α : detected EL photon# per electron (measured)
- P_{coll} : collection efficiency of electric field line (100%)
- Y : Yield of EL (calcutated)
- Ω : solid angle of EL photon to MPPC (12.9%)
- P_{trans} : WLS translation efficiency 50%
- 1/2 : translated photon direction (up/down)
- PDE : PDE of MPPC (35%)

cell pitch

Garfield++

- finer pitch is better (but ch# increase)



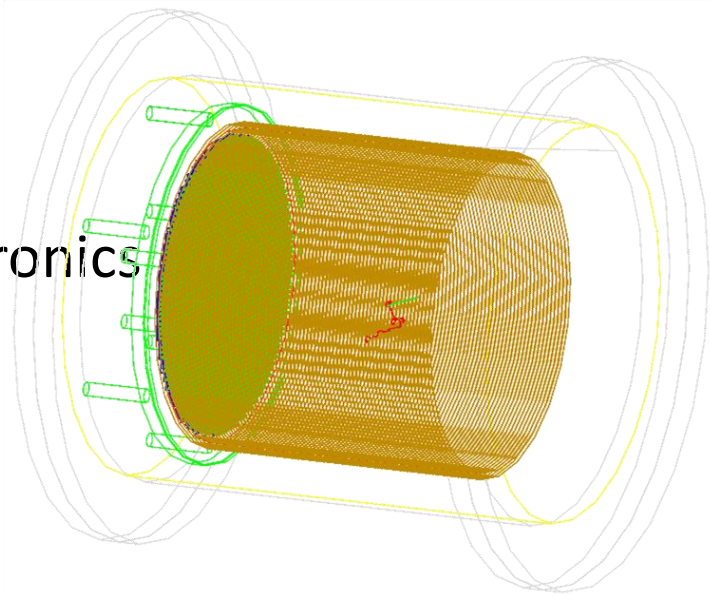


Future Prospects

- Properties

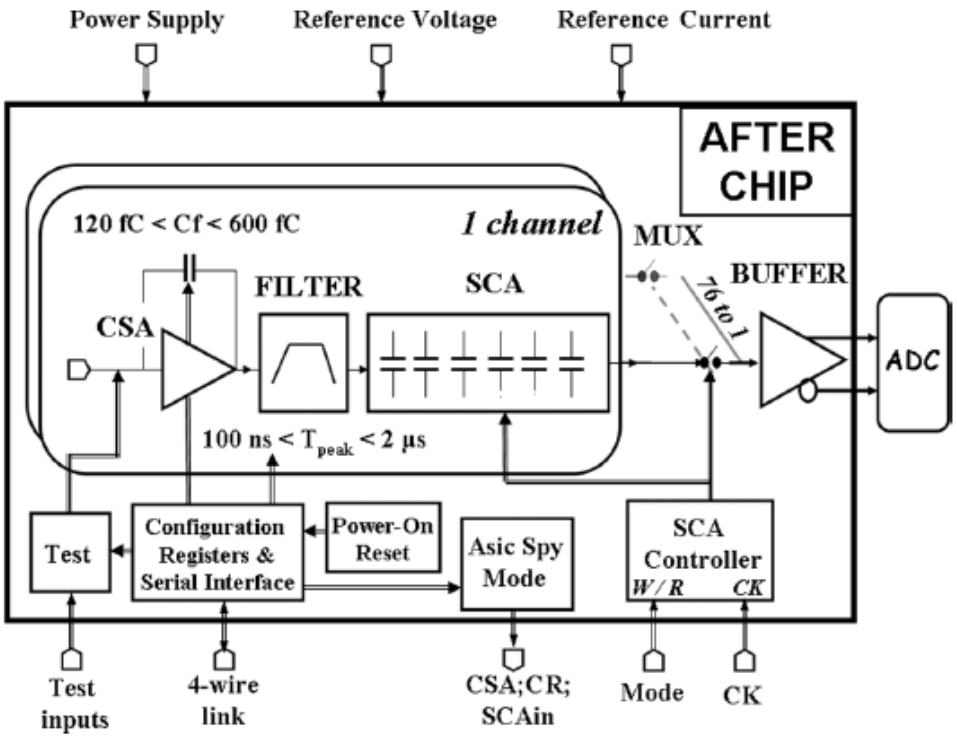
	volume	mass	channel#	purpose
current	0.216L	5g	64	ELCC test
next	~150L	~10kg	~3000	2.5MeV demonstration
future	~5000L	~1ton	~50000	0nbb search

- Status
  - started Geant4 simulation
  - started development of readout electronics



Readout electronics

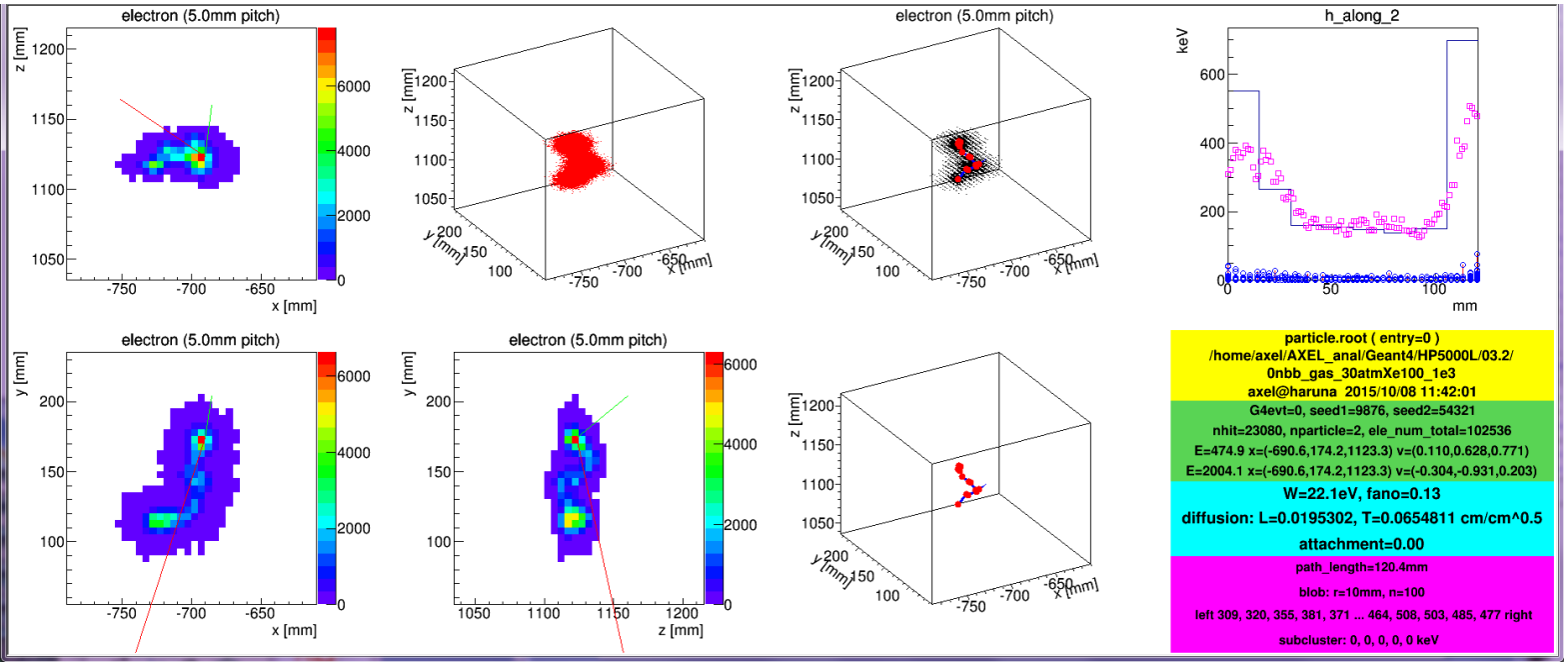
- For 1ton detector, MPPC # will be 50000
- AFTER chip (ASIC) 72ch 511sampling
- developing board for AFTER



Parameter	Value
Number of channels	72
Samples per channel	511
Dynamic Range	2 V / 10 MIPs on 12 bits
MIP charge	12 fC to 60 fC
MIP/Noise ratio	100
Gain	4 values from 4 mV / fC to 18 mV / fC
"Detector" capacitor range	20 pF -30 pF
Peaking Time	100 ns to 2 µs (16 values)
INL	1% 0-3 MIPs ; 5% 3-10MIPs
Sampling frequency	1 MHz to 50 MHz
Readout frequency	20 MHz to 25 MHz
Polarity of detector signal	Negative (T2K) or Positive
Test	1 among 72 channels or all

IEEE Transactions on Nuclear Science 55 3 (2008) 1744

Tracking simulation



- Geant4 simulation
  - with diffusion

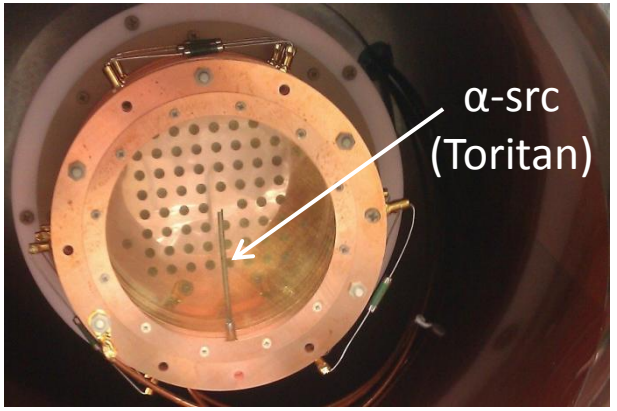
signal efficiency

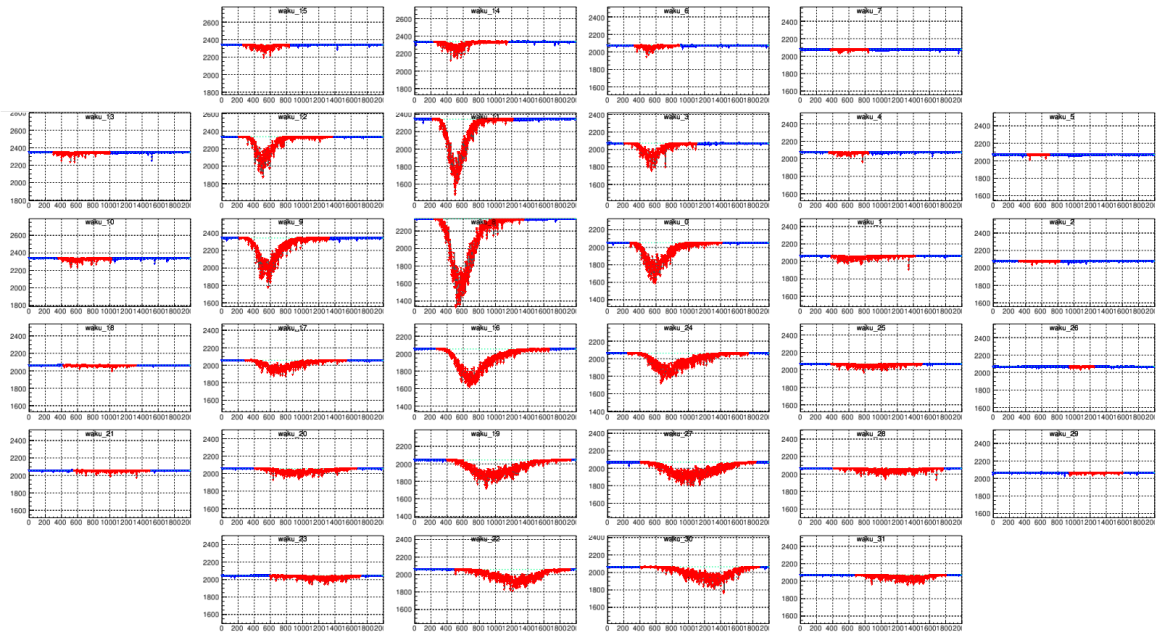
	2.5	5	7.5	10 [mm]
Xe25%+He75%	84.6	75.8	73.0	71.0
Xe50%+He50%	80.5	77.4	73.9	67.1
Xe75%+He25%	77.6	73.2	69.2	59.5
Xe100%	64.7	60.5	51.4	36.7

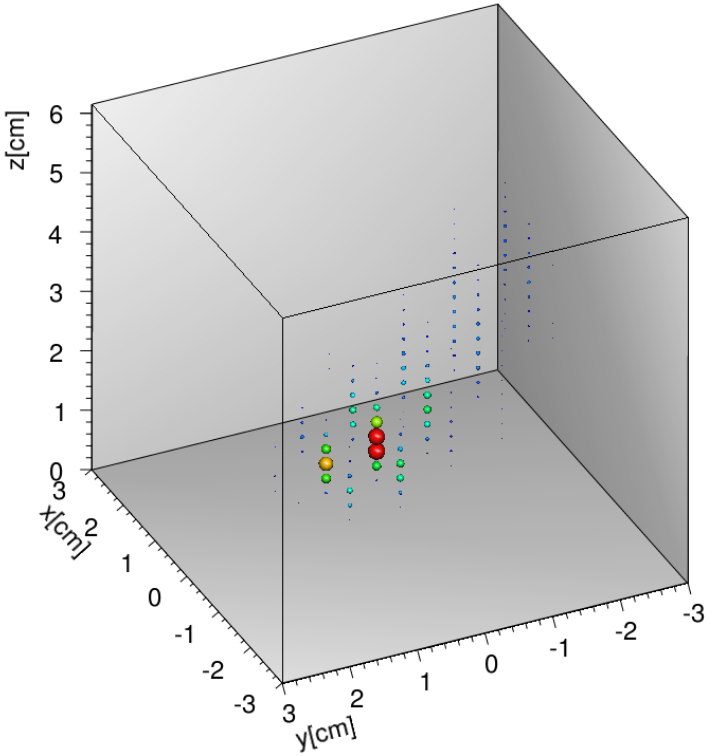
Tracking demonstration (α-ray)

- Detect EL light
  - OK !
- Track width is too large ?
  - large $Diff_{tra}$ --> High Pressure
  - blurred at WLS --> UV-MPPC

gas : Xe 1atm
E_{anode}=1.6kV/0.5cm
E_{drift}=0.4kV/6cm
$Diff_{tra}$=0.34cm/√cm

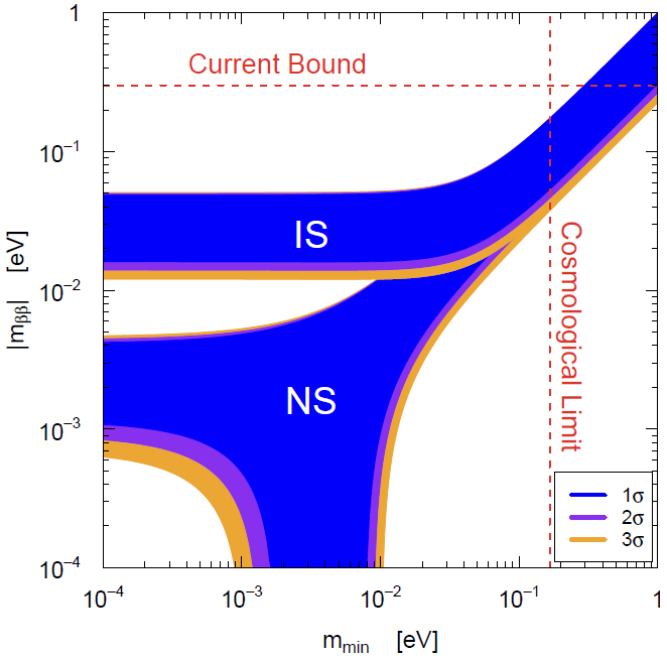






Signal estimation

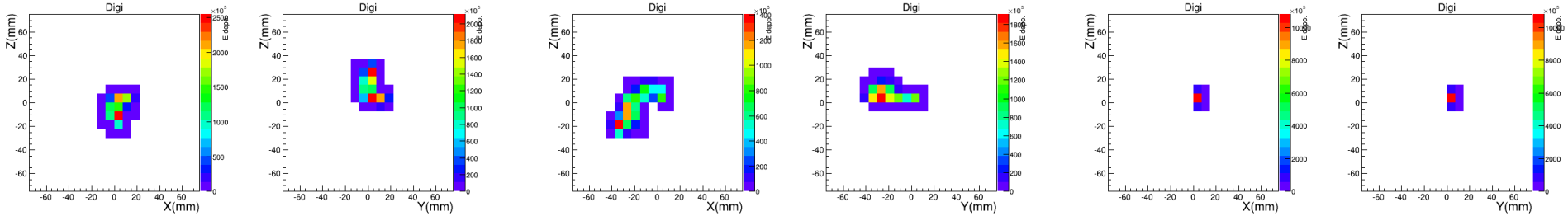
- Physics goal
  - 0νββ discovery !
  - or exclude inverted hierarchy



- Expected event rate
  - 0.5 count/year/ton ($m_{\beta\beta}$=10meV)
  - We need several tons of ^{136}Xe....
  - BG rate requirement in ROI < ~1 count/year

Comparison of 0νββ, e and α

- Event topology by tracking
  - α BG is well rejected
  - γ BG with 2.5MeV photoelectric absorption is difficult to reject perfectly.
  - (multi site events such as Compton scattering can be rejected)



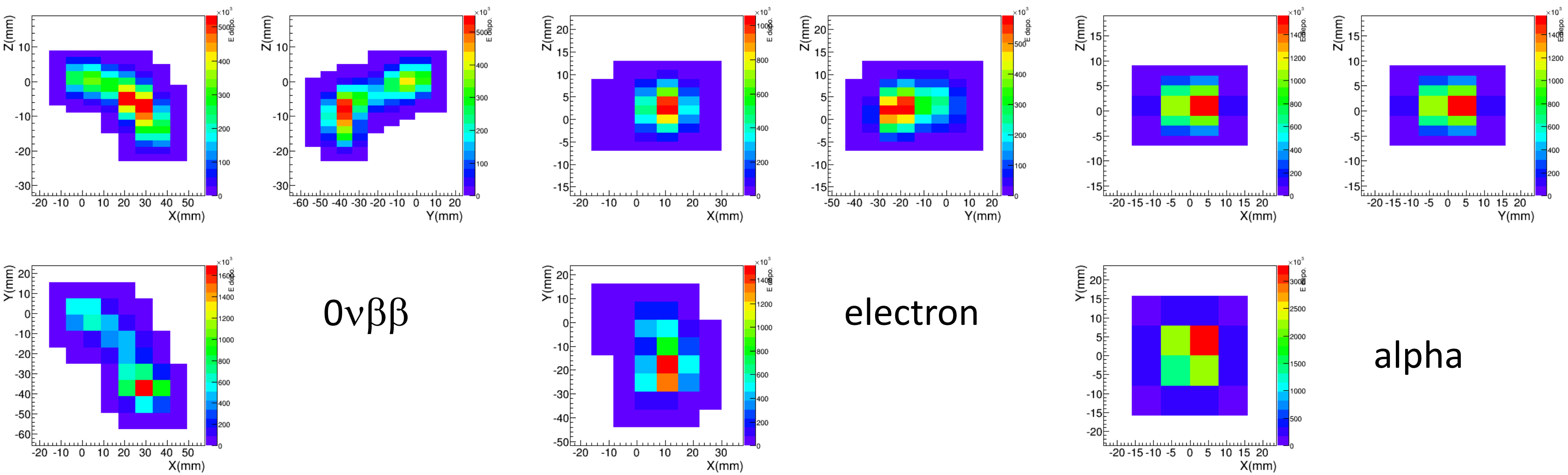
0νββ

electron

alpha

Comparison of 0νββ, e and α

- Event topology by tracking
  - α BG is well rejected
  - γ BG with 2.5MeV photoelectric absorption is difficult to reject perfectly.
  - (multi site events such as Compton scattering can be rejected)

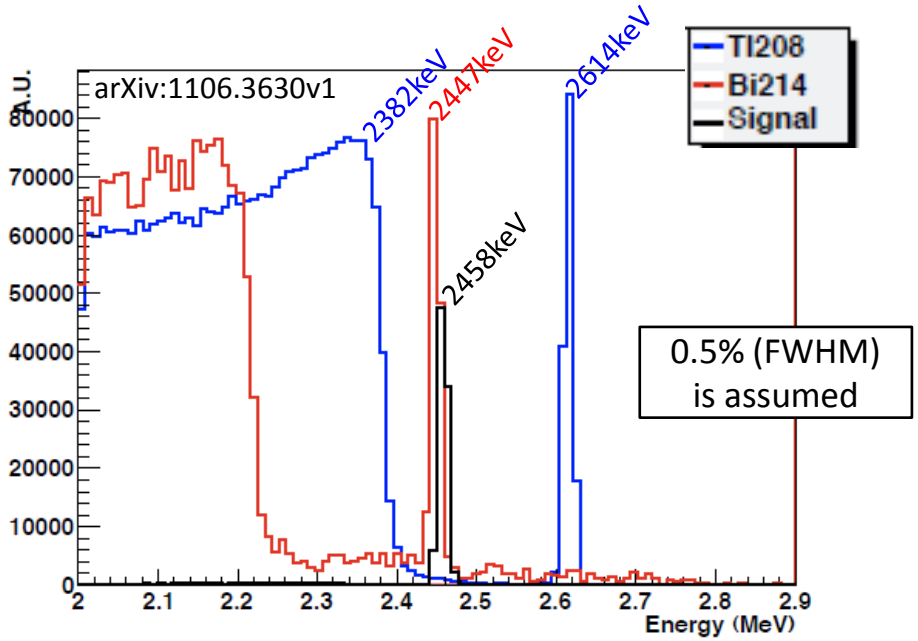


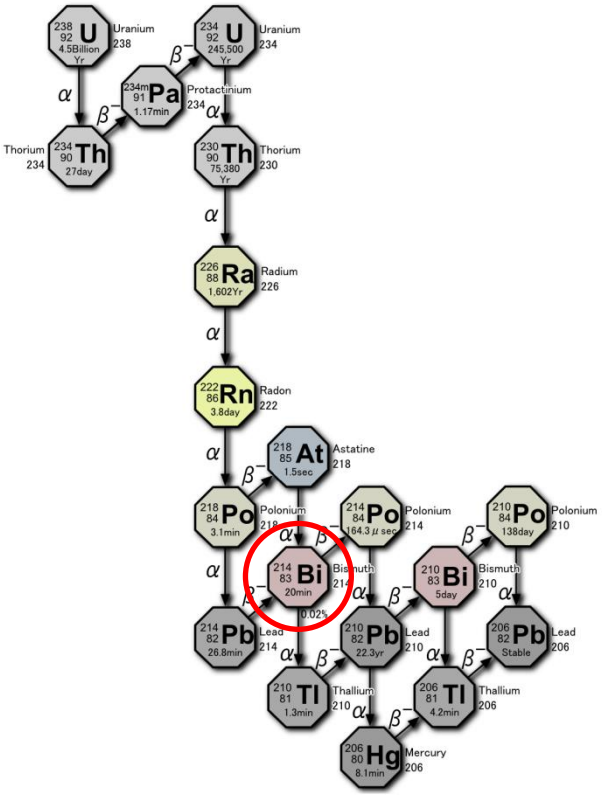
View scales are different. Cell size is same.

γ-ray BG around the ROI

- Energy resolution of 0.5%
  - γ-ray from **^{208}Tl** can be rejected
  - γ-ray from **^{214}Bi** interacting photoelectric absorption can be serious BG

From NEXT presentation (arXiv:1106.3630v1)





Rate of ^{214}Bi γ-ray

- Attenuation length of 2.5MeV γ-ray
  - 140cm in 30atm Xe -> self shielding is not effective
  - 20cm in water -> external BG stop by water shield
- Materials of detector must be checked
  - Vessel is the most heavy component (10ton : copper)
  - EXO uses clean copper for vessel : U < 5ppt 95% U.L.

Mass ~10*10^6 g

Contamination 5*10^{-12} g/g

Avogadro # 6.02*10^{23}

solid angle ~0.1

branching ratio 0.0157

photoab. ratio 0.02

$$R_{BG} = M \times C \times \frac{N_A}{M_{^{238}\mathrm{U}}} \times \frac{\ln 2}{T^{^{238}\mathrm{U}}_{1/2}} \times \Omega \times B \times R = 643 \text{ counts/year}$$

atomic weight 228

half life 4.468*10^9

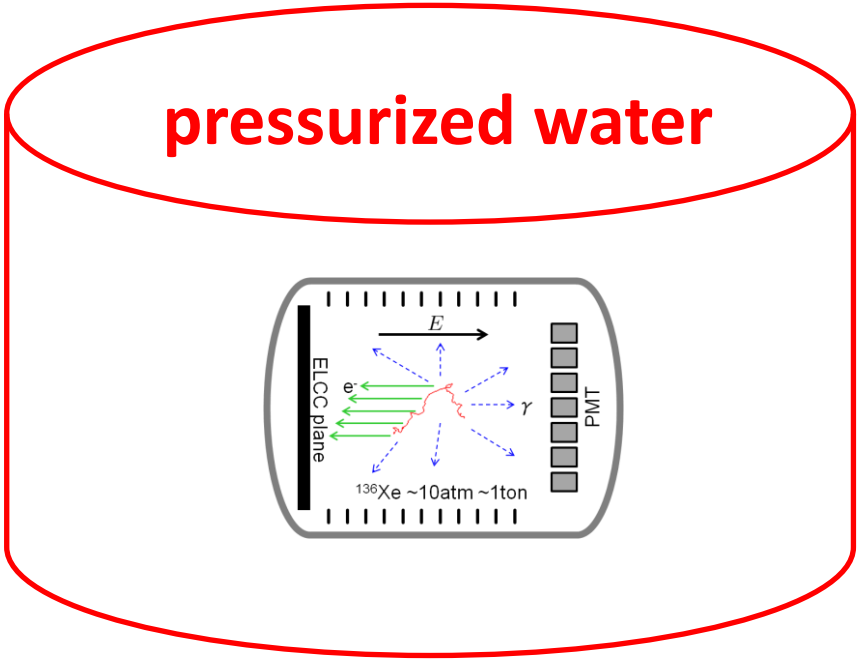
How to deal with ^{214}Bi ?

- Improve energy resolution
  - Energy difference between 0νββ and γ from ^{214}Bi is 0.44%
  - Intrinsic energy resolution is 0.25%
- Put some shield “in” the vessel
  - pressure vessel become huge
- Make clean vessel
  - purifying copper
- Make light vessel
  - titanium is strong and light (NEXT group’s approach)
  - need 2 ton --> still need purification

- --> we noticed rejection of high energy γ is not so easy

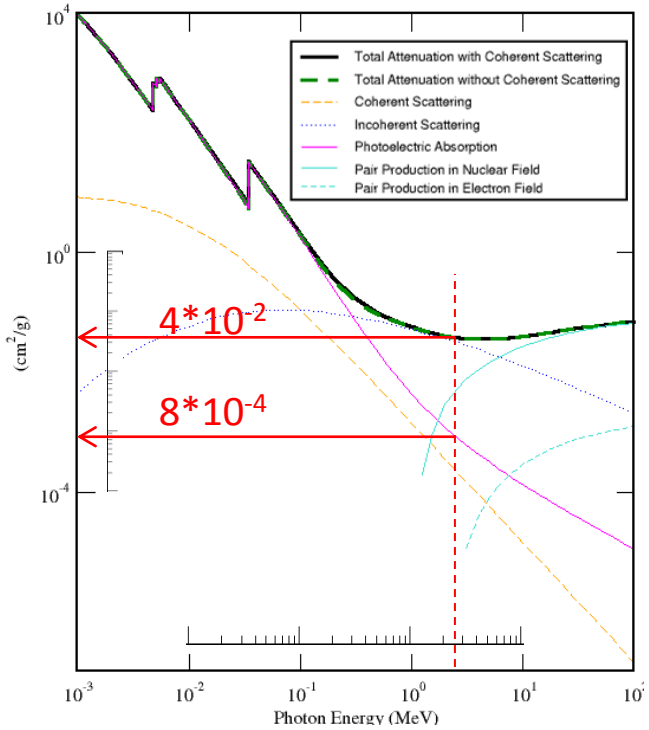
Pressurized water shield

- Merit
  - Greatly reduce the mass inside the water shield (~30kg)
  - Clean (<0.1ppt U, ILIAS UKDM)
  - Work as active veto (need PMT for high pressure)
  - Liquid is easy high pressure (in addition, it's safe)
  - Cheap
- Next to do
  - check MPPC (10^5 ~100kg) BG
  - Geant4 simulation

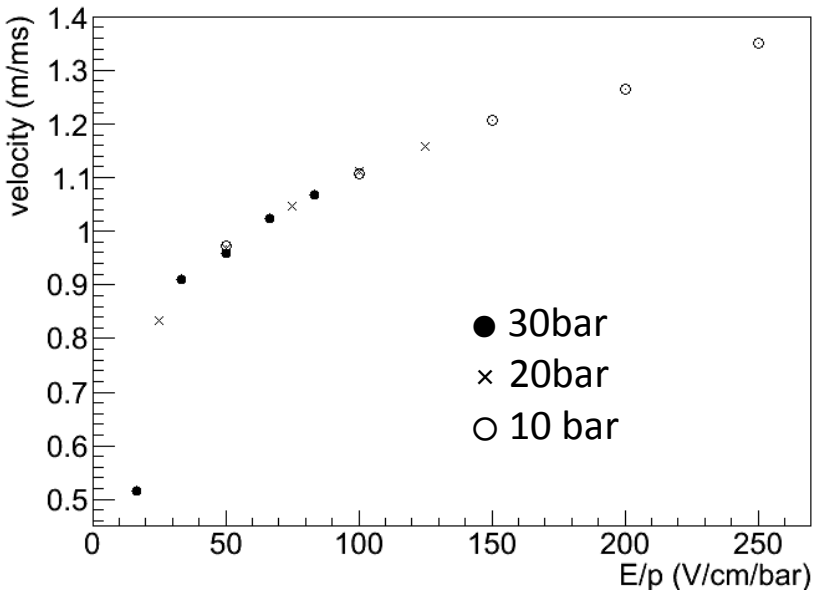


Stopping power

- Attenuation length of 2.5MeV γ-ray
  - 140cm in 30atm Xe
  - 20cm in water
- Shielding
  - Xe self shielding is not effective



Electric Field and electron drift



@ E=1.5kV/cm, p=30 bar

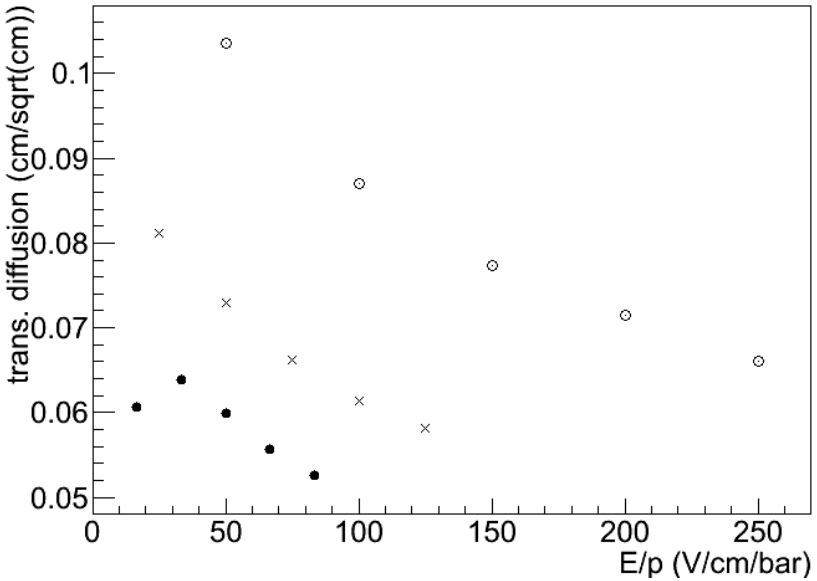
Drift velocity 0.96m/ms

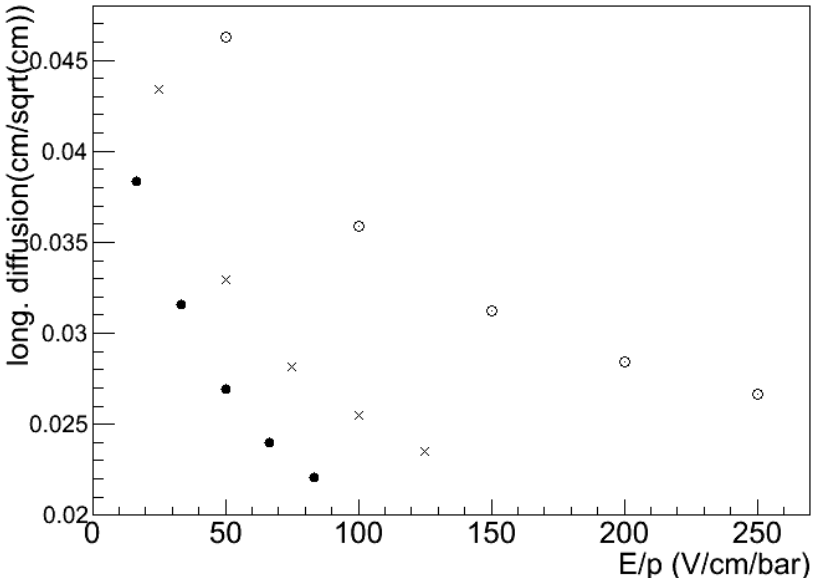
- Possibly add H_2, N_2 or He to increase the drift velocity.
  - It will also reduce diffusion.
  - It will also reduce light yield

diffusion after 1m drift

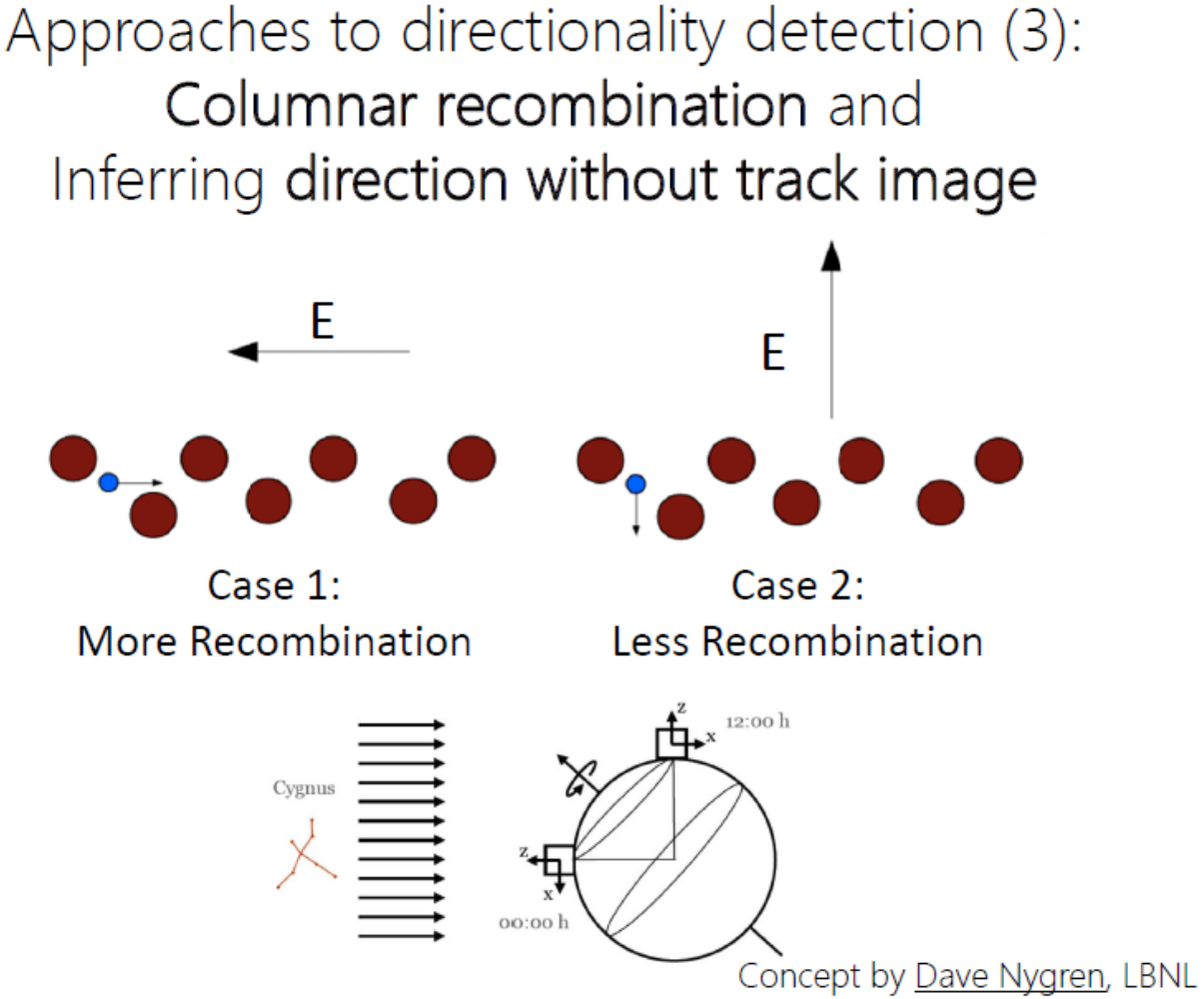
- transverse : 6mm
- longitudinal : 2.7mm

MAGBOLTZ calculation





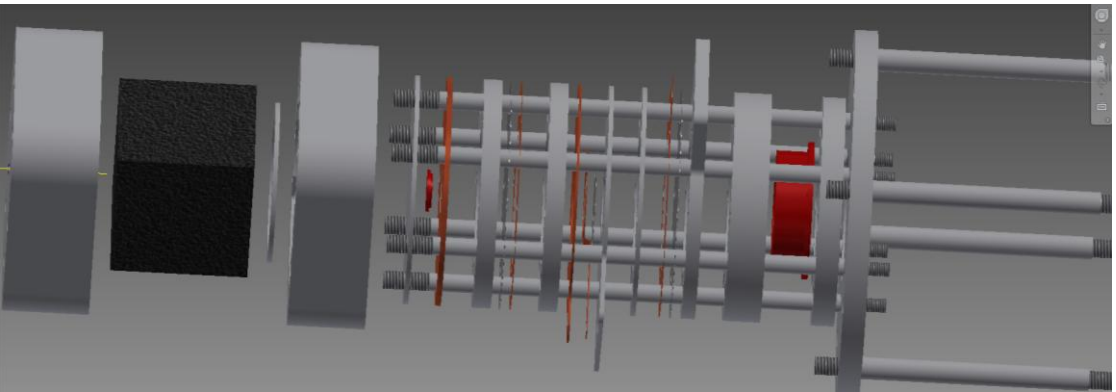
Directional dark matter Search

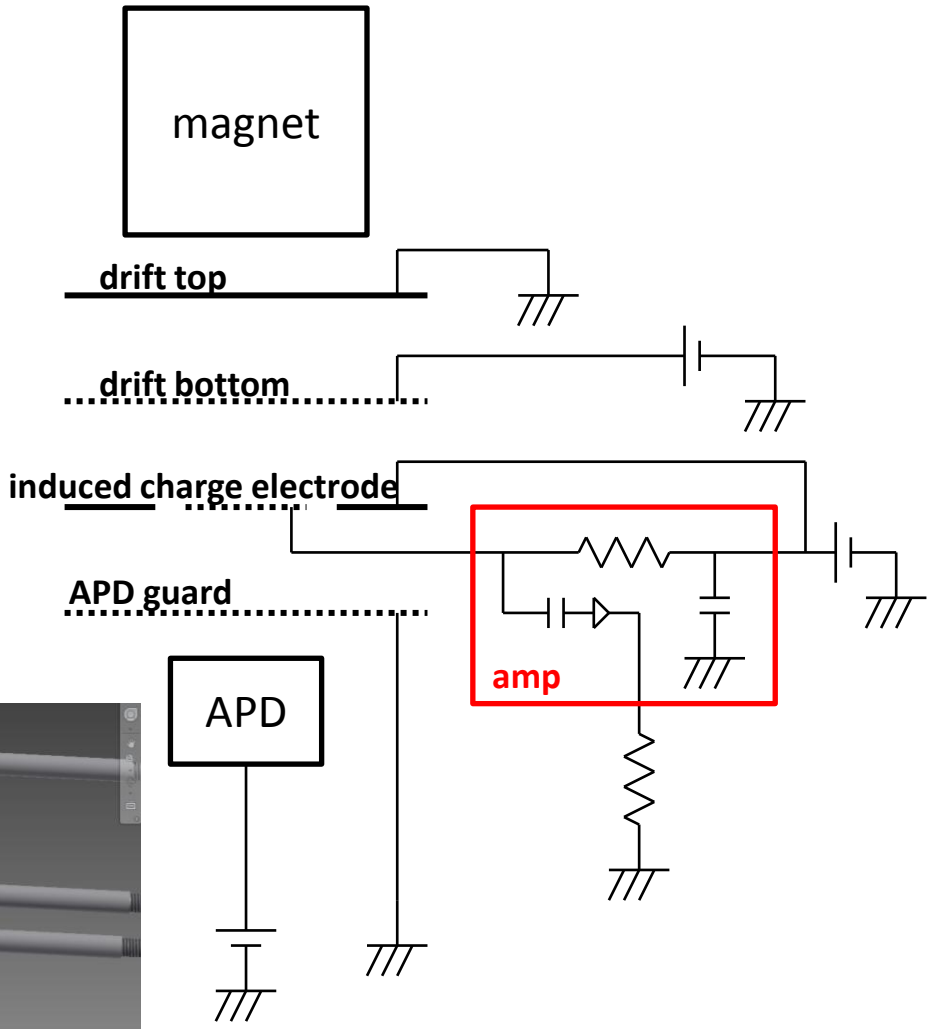


- Measure recombination rate from scintillation yield and ionization yield
- We are planning to apply magnetic field to enhance the recombination yield for one direction

Recombination measurement

- Purpose
  - measure recombination and ionized signal (5.4MeV α)
  - test putting magnetic field





Recombination measurement

- Status
  - construction just started