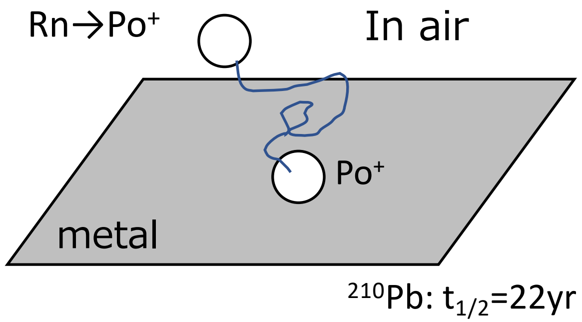
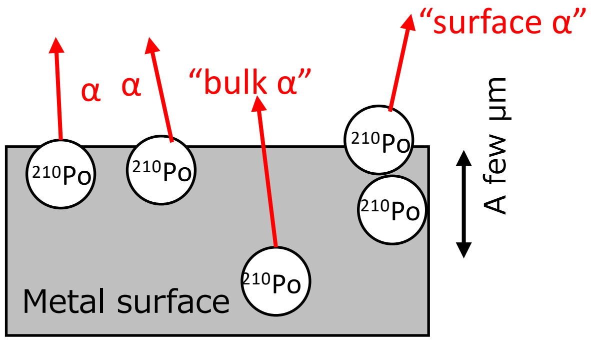
Alpha particle Imaging Chamber (*AICHAM*) for screening LowBG surface RI contamination

Hiroshi Ito (Tokyo Univ. of Sci.)

1. Introduction

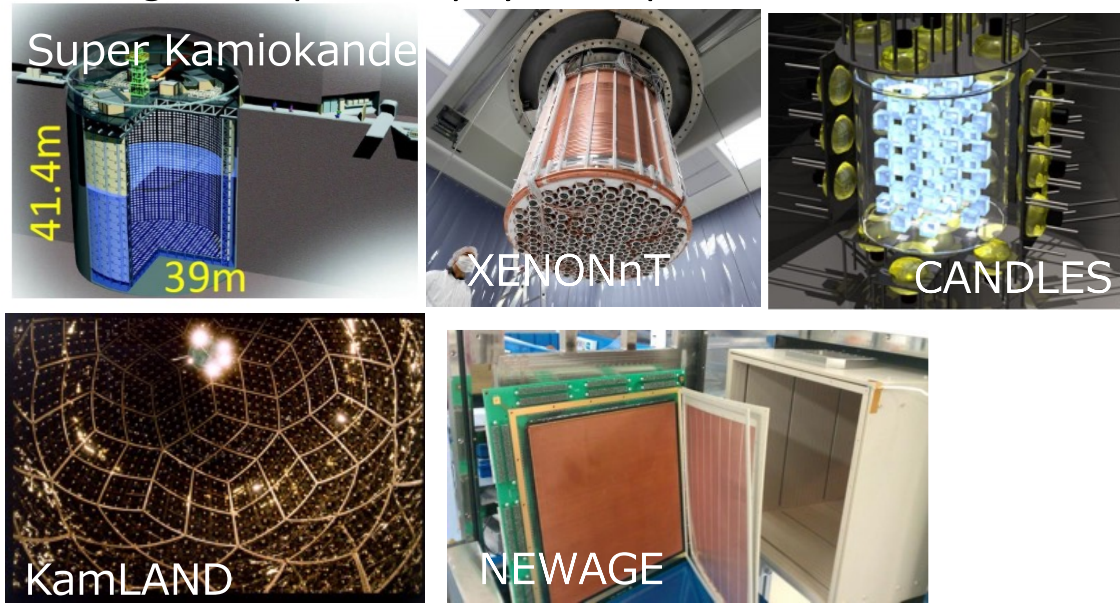
- In underground experiments, it is required the detector with "ultra-low radioactive impurities" and "massive target". Then, a production of clean materials had been established by many groups for a long time.
- Low BG α imaging from the detector surface would be one of next important keys for rare event searches, such as DM/0vββ.



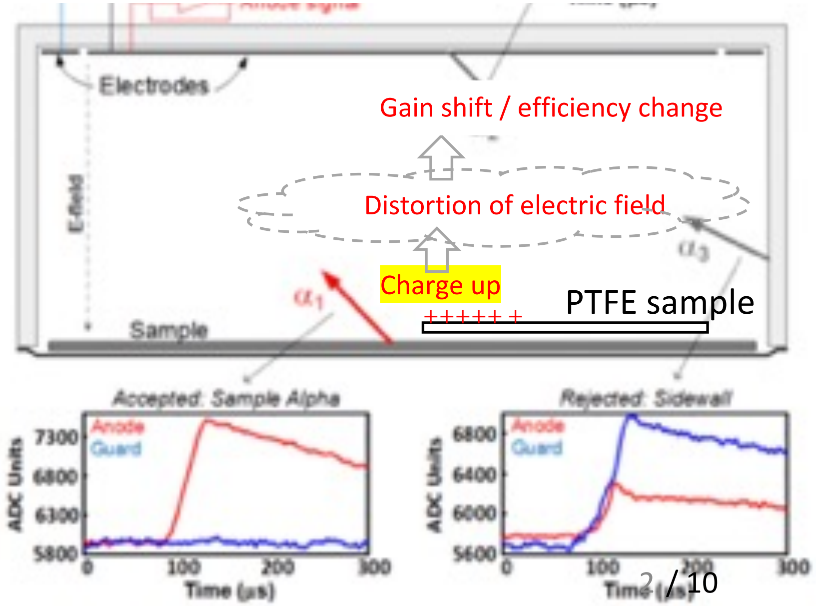


- We have used ultra-low α spectrometers (XIA, UltraLo1800). It has a good sensitivity and good energy resolution for metal sample. Alpha imaging cannot be obtained.
- Non-metals such as PTFE (used as a detector wall) has a tend to charge up on the surface. Electric field would be distortion, then **gain shift and efficiency change** can be occurred. It has an issue not to measure correctly for non-metal sample.
- Imaging α helps to us background study of DM/0vββ searches. It will be found "uniform" or "cluster distribution" on the surface of detector configuration.

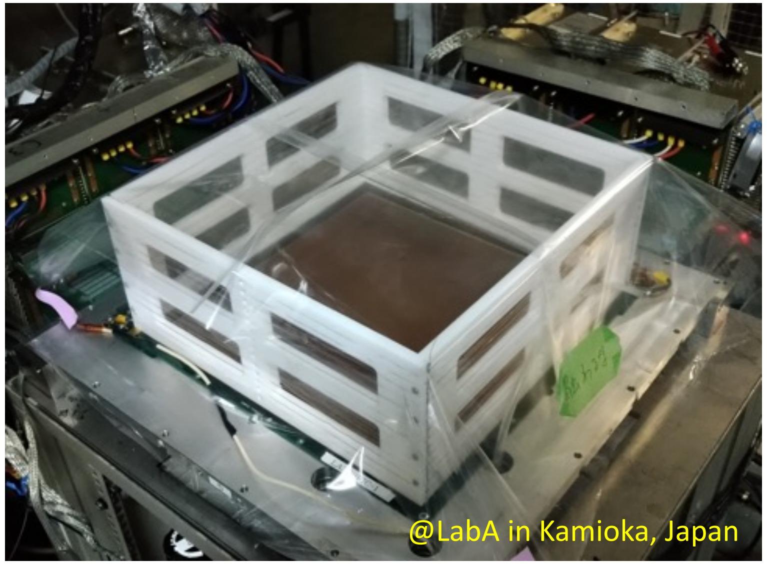
Underground particle physics experiments



Conventional ultra-low α spectrometer



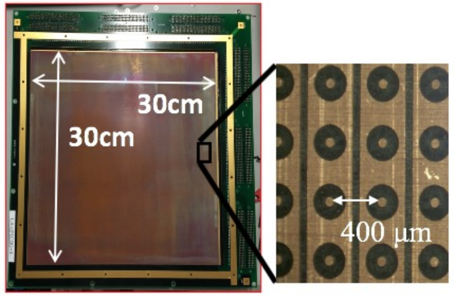
2. Alpha-particle Imaging Chamber (AICHAM)

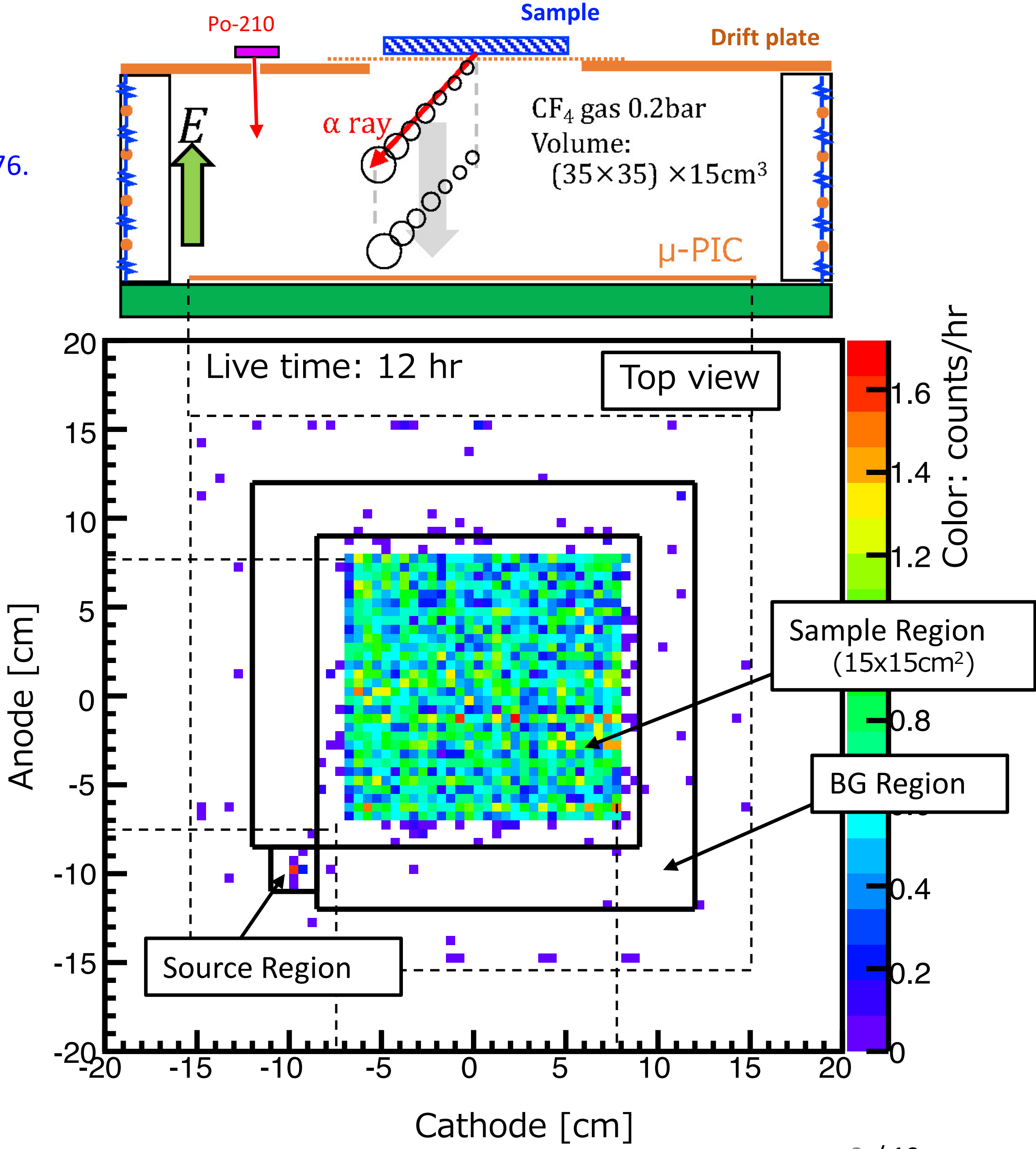


NIM A 953 (2020) 163050.
J. Phys.: Conf. Ser. 2156 (2021) 012176.

Low-alpha μ-PIC

NIMA 977 (2020) 164285.





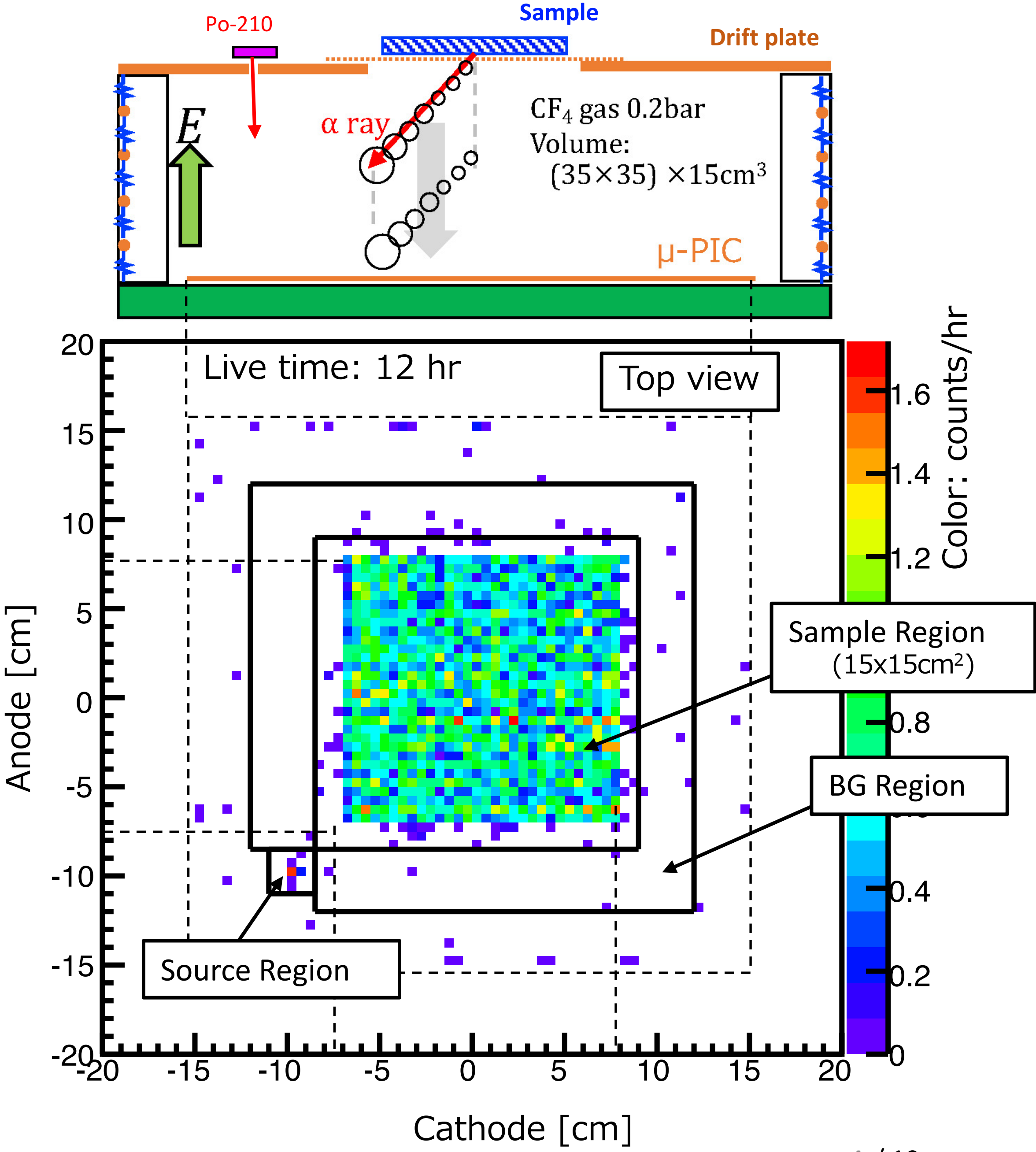
- Based on a gaseous Time projection Chamber (TPC)
  - Conversion from t to z : 3D track of α can be reconstructed.
  - Refurbished from NEWAGE-0.3a detector.

  Phys. Lett. B 686 (2010) 11.
- Using μ-PIC: maicro-pixel chamber
  - Upgraded to low-alpha μ-PIC
  - used of low α material: improved sensitivity to be O(10^{-3}) α /cm^2/hr, suppressing self radio isotopes.
- Characterization: imaging alpha emission point
  - Enable to discriminate sample region, BG region, and source region.
  - Net α rate from the sample can be obtained in a same time measuring.

2. Alpha-particle Imaging Chamber (AICHAM)

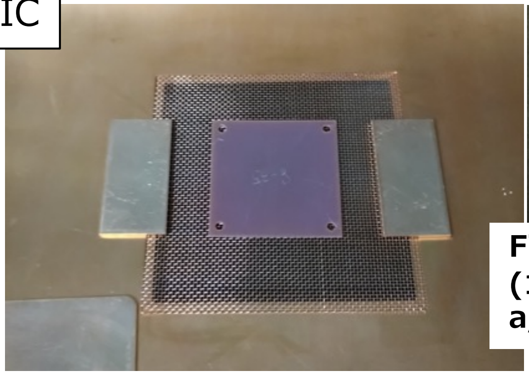
In order to screen sample with ultra-low BG level, it must be taken into account also systematic uncertainties, but not only statistical error.

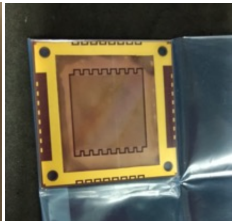
- Advantages of Imaging
  - Canceled out uncertainty of **measuring condition for sample and BG** when net alpha rate calculation, because of a same data taking.
  - Reduced uncertainty of **gas gain** and **efficiency** status for a long measuring time by monitoring with the source set in the edge region.
  - Taken into account **acceptance** of alpha tracks. Especially, acceptance is basically small at near the wall. Can be select fiducial area with good acceptance.
- Higher freedom of sample measurement
  - Enable to measure several samples in a same time.
  - Enable sample with charged up on the surface.
  - Thick sample is ok.
- That is "chamber"
  - No liquid sample can be measured.
- 2021-2022 work to upgrade
  - Be short drift length (30 cm ⇨ 15 cm)
  - Extend effective area (10×10 cm^2 ⇨ 15×15 cm^2)



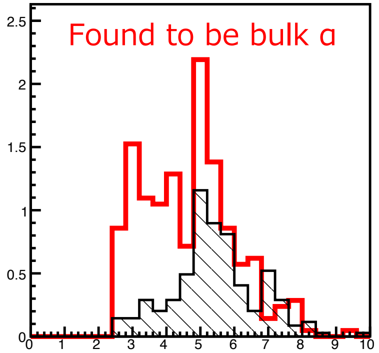
3. Screening sample using AICHAM

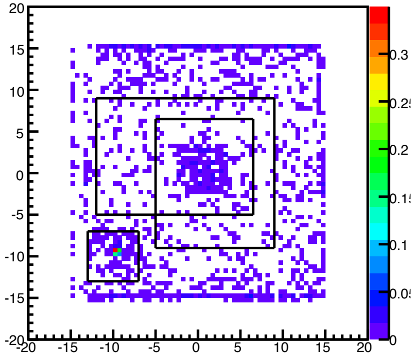
μ-PIC





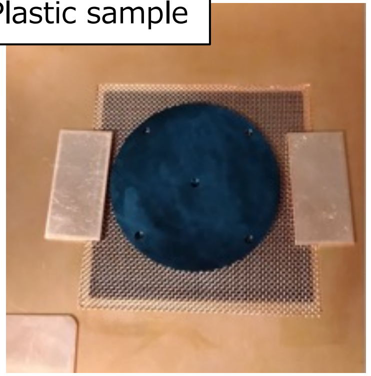
Finite net alpha was found.
(1.09±0.14) x10^{-1} a/hr/cm2 @E>2.5MeV



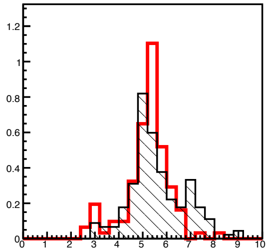


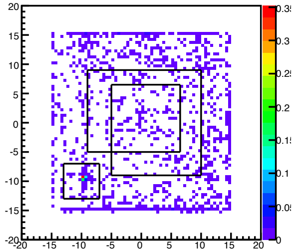
Clear image was obtained

Plastic sample



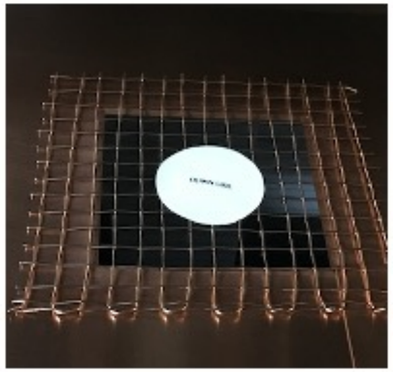
No significant finite alpha was found.
< 3.3x10^{-3} (90%CL) a/hr/cm2 @E>2.5MeV





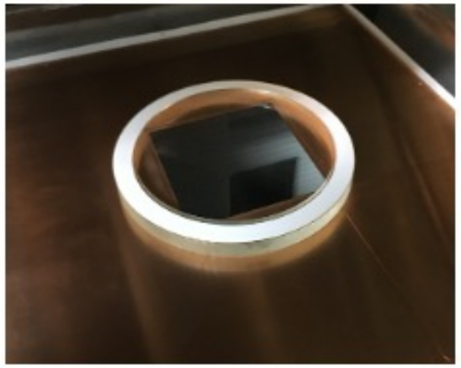
- Sample screening have been conducted for several underground experiment groups. AICHAM provides following data:
  - Energy spectra (sample and BG) with **σ_E~10% for 5.3 MeV**
  - Alpha emission images with **σ_x~5mm**

Ra disk for SK-Gd



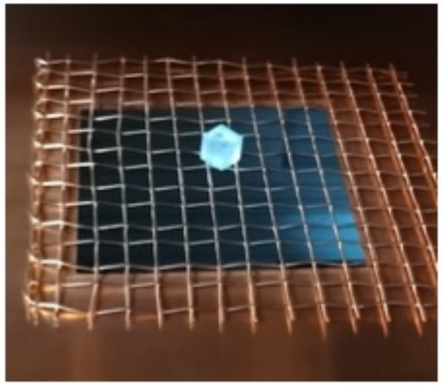
PMT glass sample for Hyper-K

Flange glass for neutron consortium group

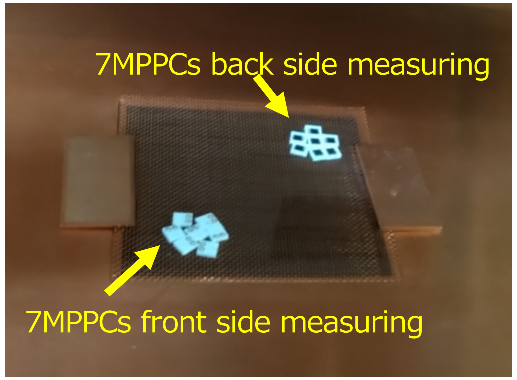


PTFE sheet of PICOLON group

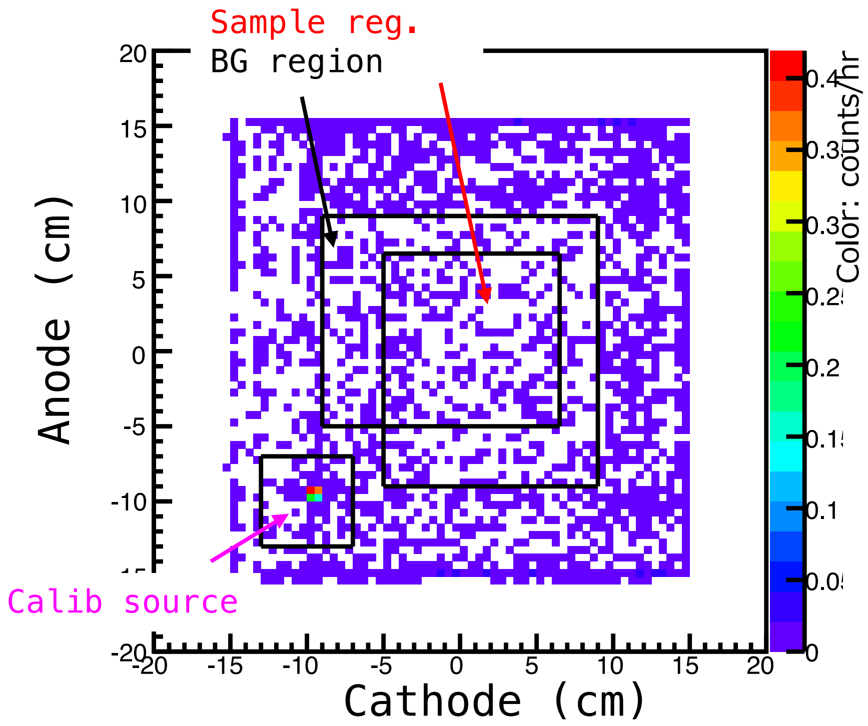
La-GPS scintillator

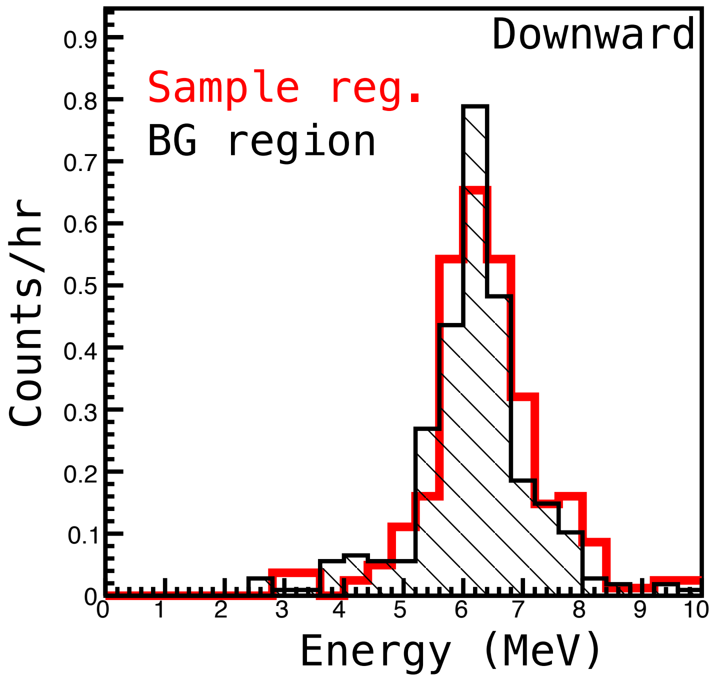


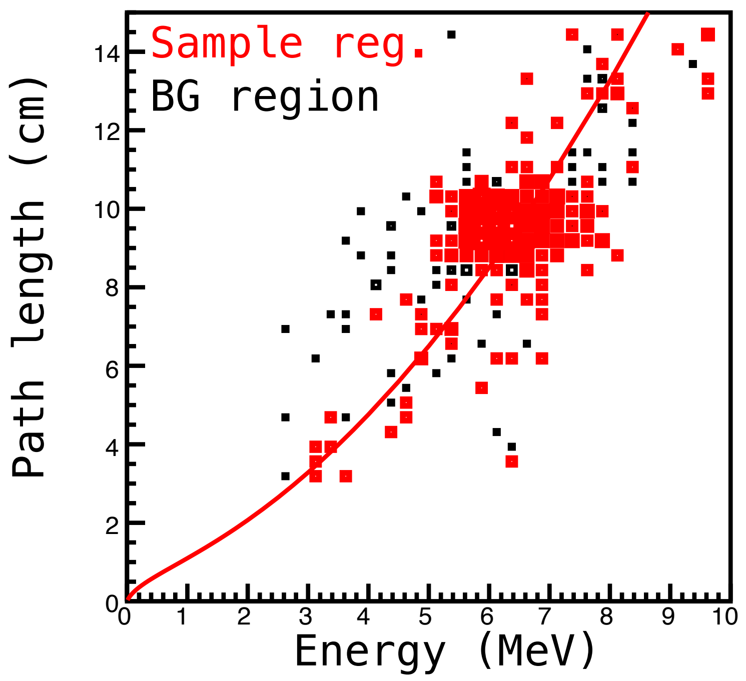
MPPC for AXEL group



4. Background study





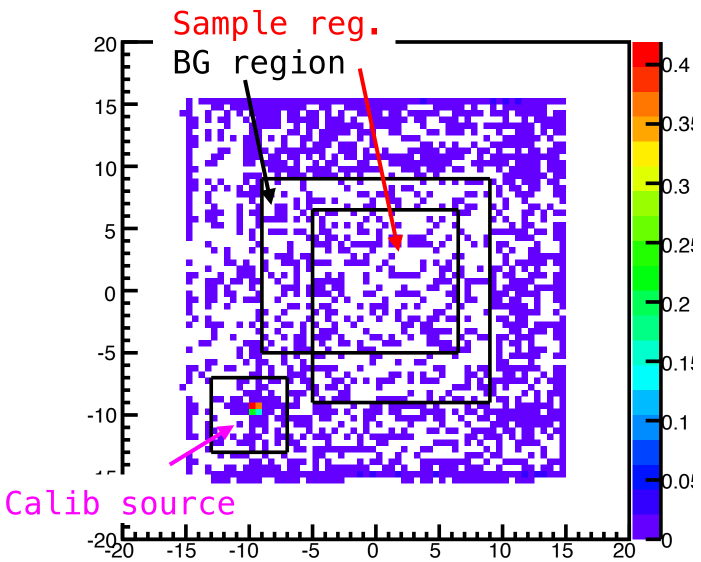


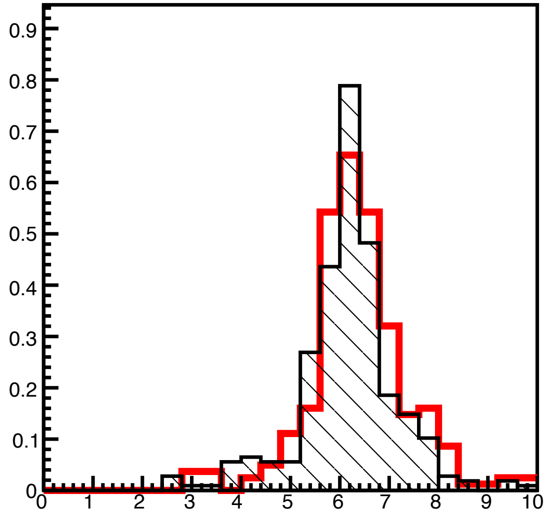
- efficiency 0.365 ± 0.023
- Live time = 558.7 hr (~1 month)
- Effective area 9.5 x 9.5 cm^2
- Sensitivity < 2.4 $x10^{-3}$ (90%CL) a/cm^2 /hr @E>2.5MeV
- BG radon alpha = (8.2 ± 0.3)$x10^{-3}$ a/cm^2 /hr

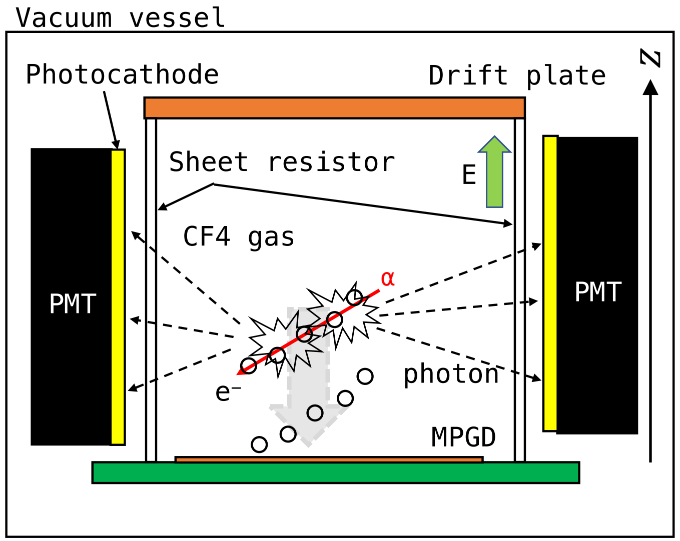
5. Next plan to install PMTs in AICHAM

Suppresses radon-alpha events that could not be removed by activated charcoal.

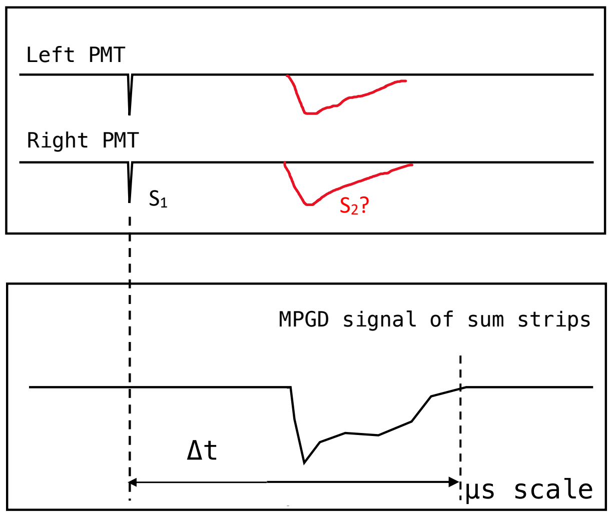
- Current AICHAM is self-trigger type TPC. alpha emission position z cannot be determined.
- Detecting CF4 gas scintillation photon simultaneously, we can obtain the z position by timing Δt.
- Z position of alpha emitted from sample is a constant. The radon alpha is distributed uniformly in the TPC.
- Therefore, radon α-rays can be suppressed by the timing cut.

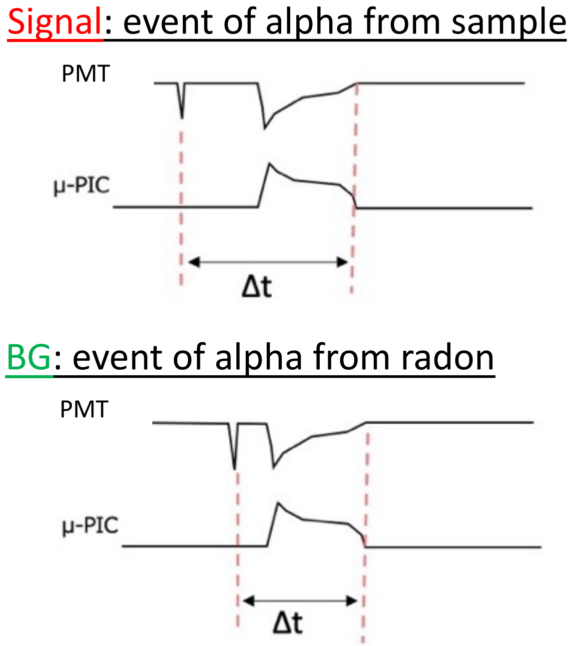




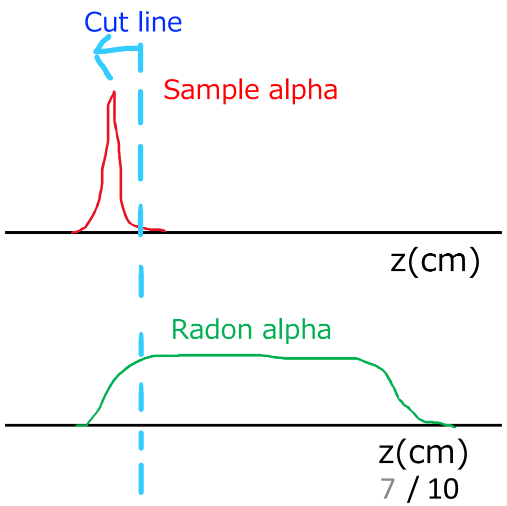


Prediction of event signal





Storing data,
Predicted z distribution

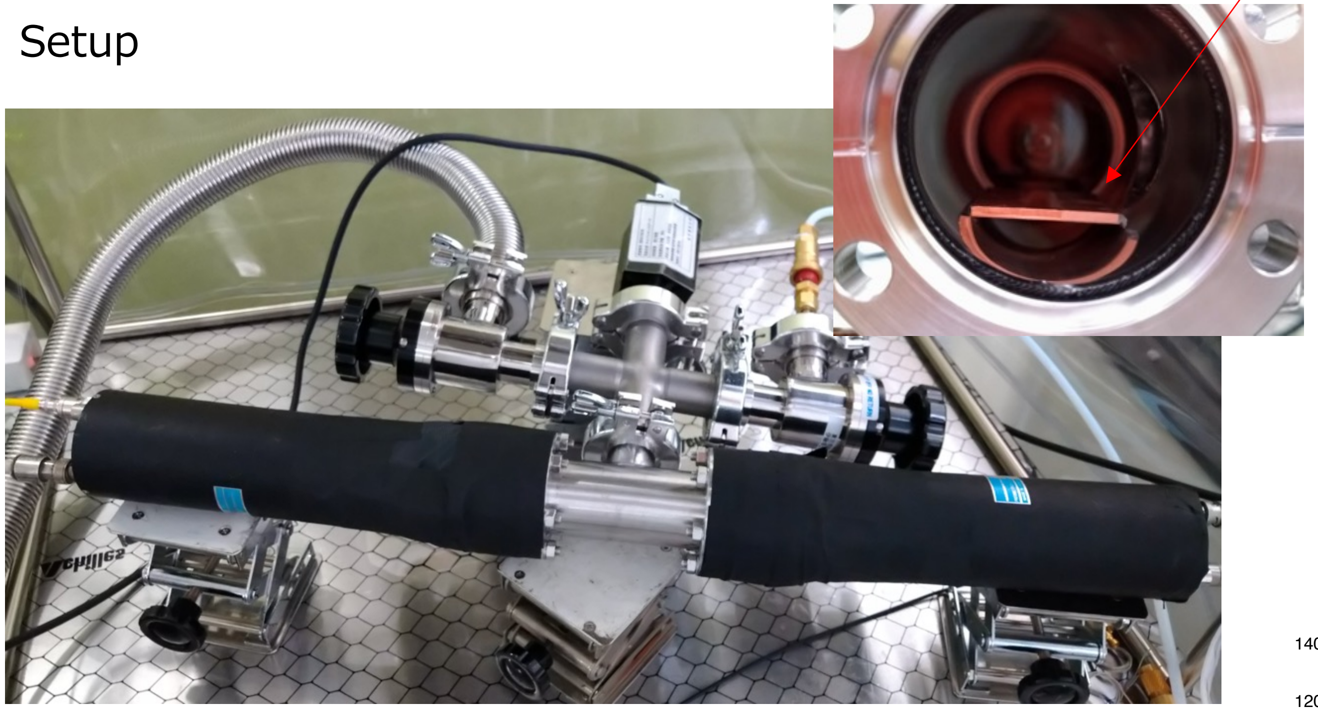


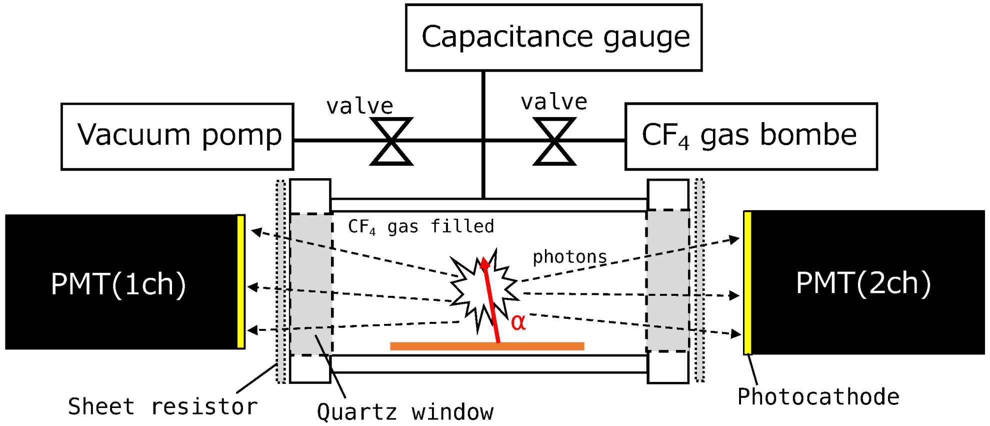
5. Next plan to install PMTs in AICHAM

5.1. test of CF_4 scintillation photon detection

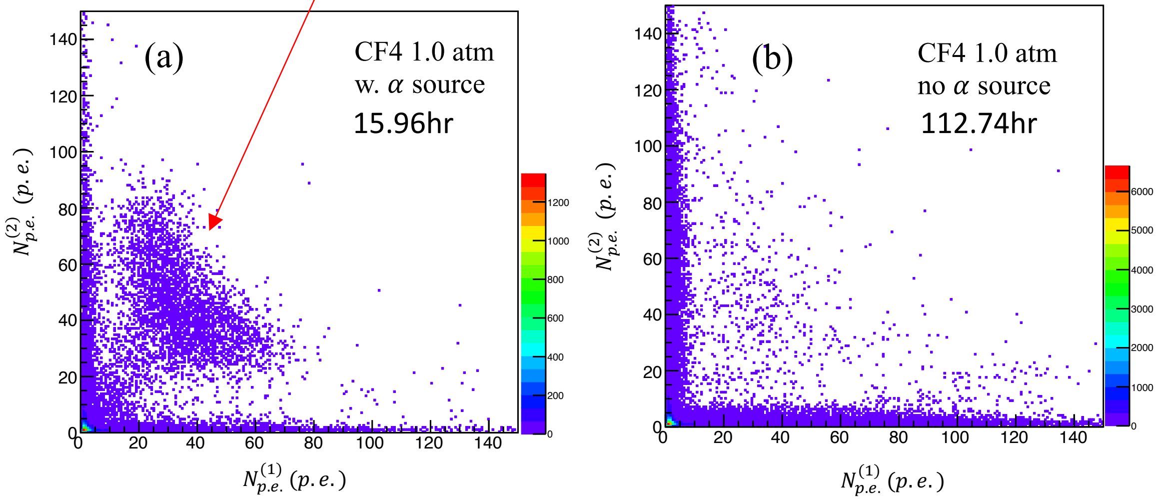
Alpha source
5.3 MeV mono-energy (^{210}Po)

Setup





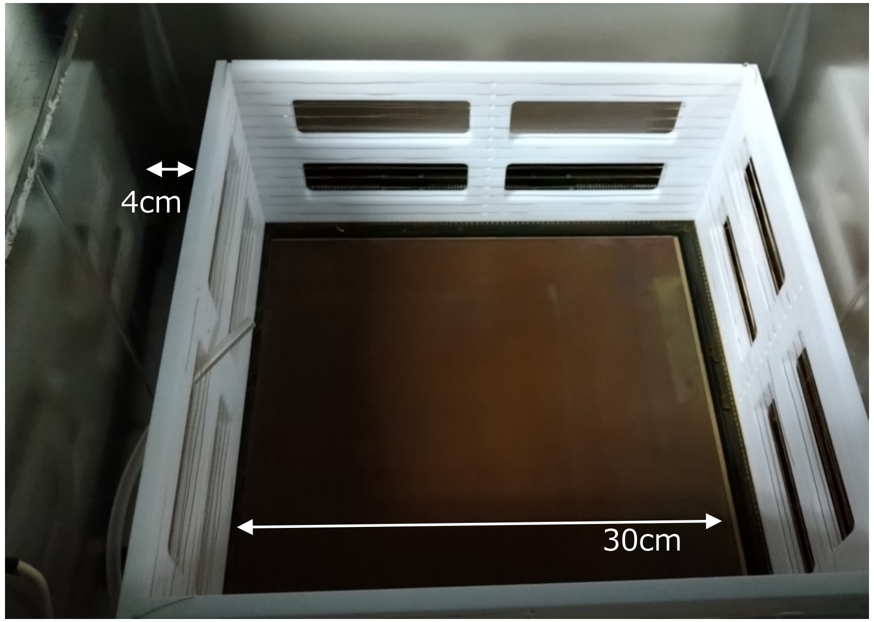
total 80 p.e. was observed.



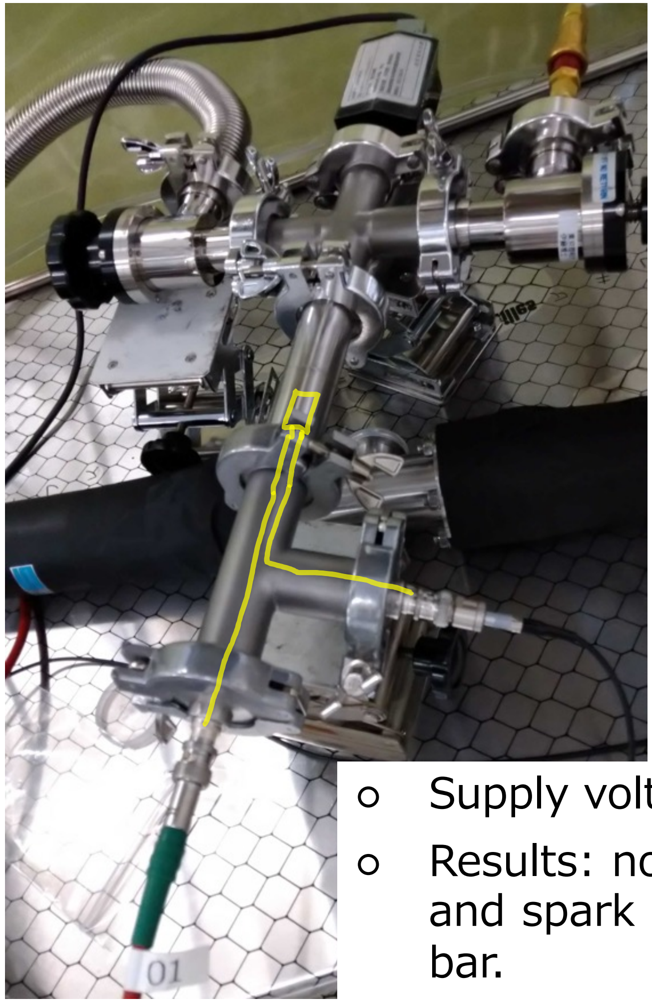
- The simple setup with usual two PMTs (2” size).
- Comparing p.e. distribution w. and w.o. alpha source.
- Total 80 p.e. was observed for CF_4 scintillation emission by 5.3 MeV alpha particles.
- Enough to see CF_4 scintillation light in AICHAM.

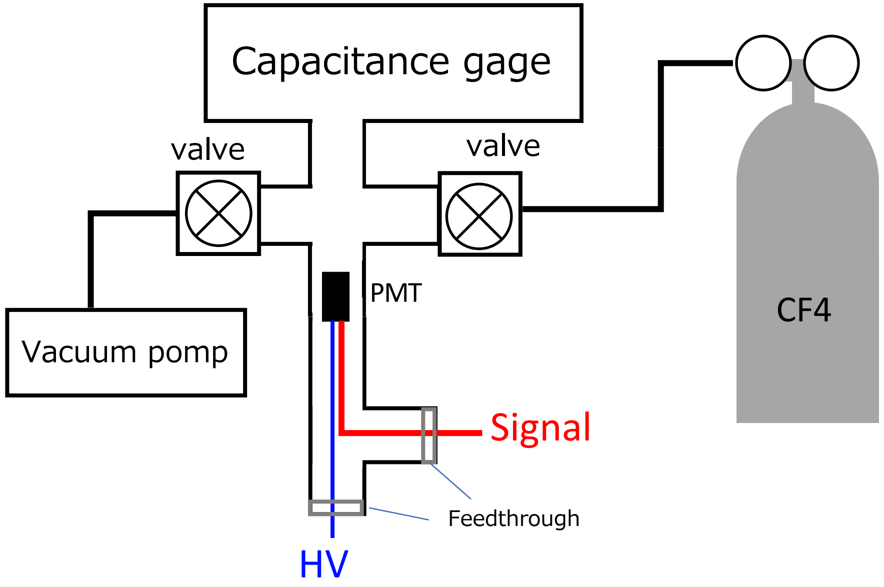
5. Next plan to install PMTs in AICHAM

5.2. test of PMT performing in low pressure CF_4 gas



- We want to install PMT in AICHAM, however usual PMT is larger for side space.
- We prepared ϕ8mm PMTs





- Supply voltage: 1200 V (gain $\sim 10^7$).
- Results: no spark and workable was found at 0.2 bar and spark and HV down at 1000V was found at 0.05 bar.
- The PMT can be used in AICHAM.
- We will measure RI impurities contamination in the φ8mm PMTs, next step.

Summary

- We have been developing Alpha-particle Imaging Chamber (*AICHAM*) to screen radioactive impurities for sample surface based on gaseous μ-TPC in low BG.

  Advantages of "imaging"

  - Canceled out uncertainty of **measuring condition for sample and BG.**
  - Reduce uncertainty for **Monitor gas gain** and **efficiency** for a long measuring time.
  - Taken into account **acceptance** of alpha tracks at near the wall.
- AICHAM has demonstrated to measure alpha from sample surface with sensitivity of $\mathbf{2.4\times10^{-3}\ \alpha/cm^2/hr\ (90\%\mathit{CL})}$ for $E > 2.5\ \mathrm{MeV}$, $9.5\times9.5\ \mathrm{cm}^2$.
- If you'd like to measure your sample by AICHAM, please contact us.
- Next plan <u>is an installing PMTs in AICHAM</u> to suppress radon alpha events (to improve the sensitivity). The preparation has been started.

Backup

MPPC screening results

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Two clusters are clearly visible in the α-ray emission image shown in the center panel of Fig. 1. This measurement demonstrated that the detector can measure more than one samples at one time. Since the background data are also taken simultaneously, systematic uncertainty for the gas condition change can be cancelled out. In addition, the data of a calibration source (^{210}Po) placed outside of the sample area allow us to monitor the gas gain as a function of the measuring period. Measured energy spectra of the sample (front and back side) and background region are shown in the right panel of Fig. 1. Alpha rays from the both sides of MPPCs were detected significantly over the background. As a result, 0.58 ± 0.04 α/hr per a side of one MPPC in average was obtained, and it was found the α-ray emission rate of front and back side are similar.

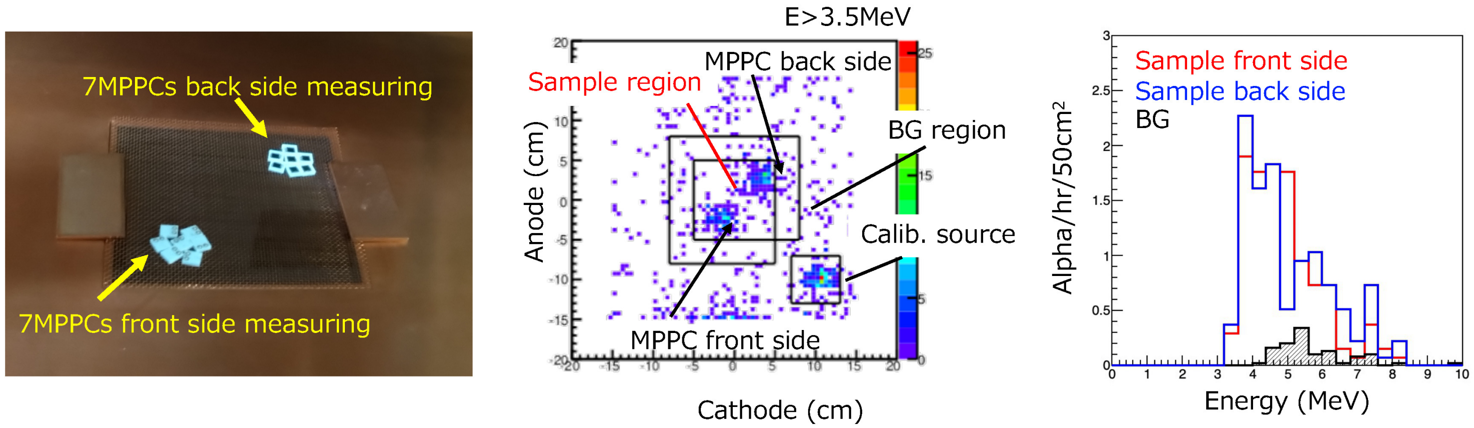
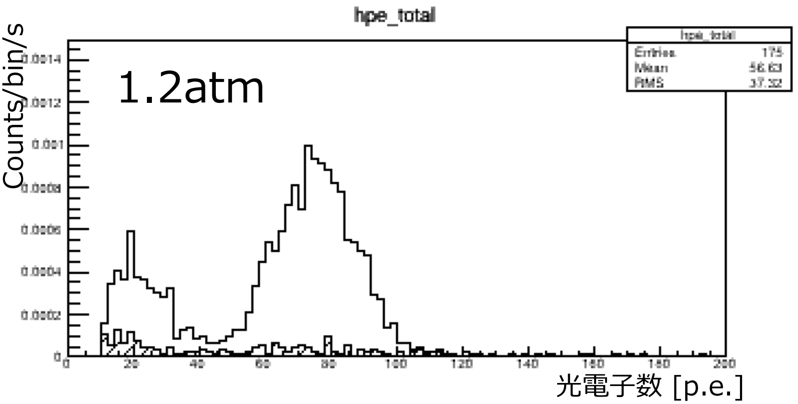
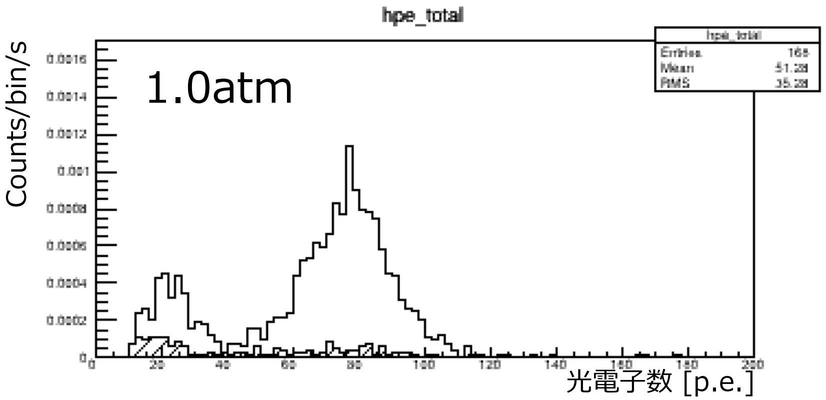
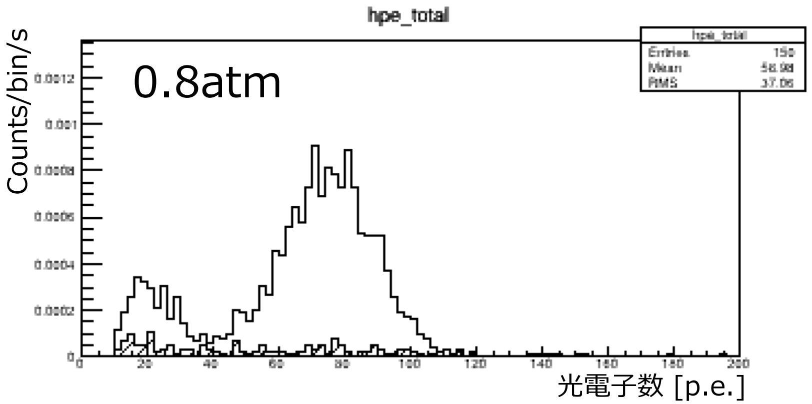


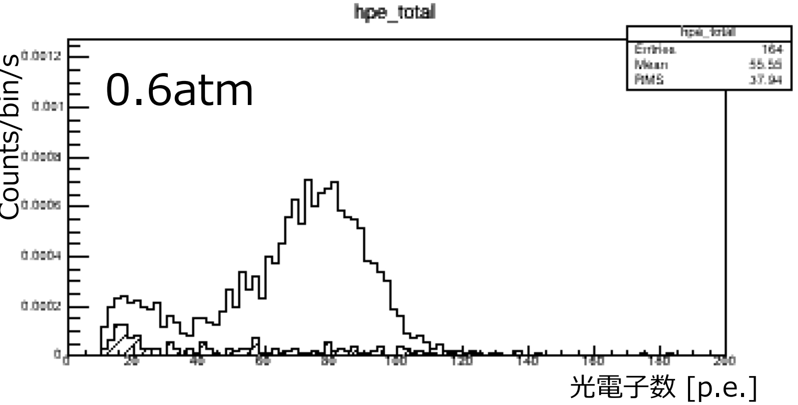
Figure 1. Sample screening of MPPCs. Left panel is a picture of the setup. Center panel is an obtained image of the α-ray emission. Right panel is energy spectra of the front and back side of the sample and the background (red, blue and black).

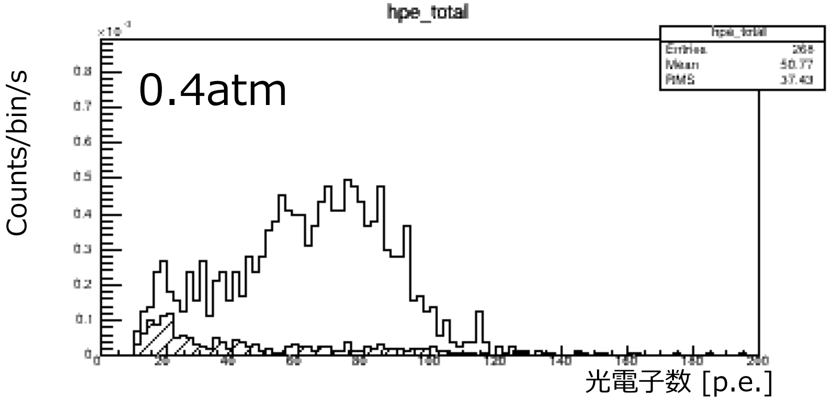
CF4 emission light yiled of 5.3 MeV of alpha in CF_4 gas pressure

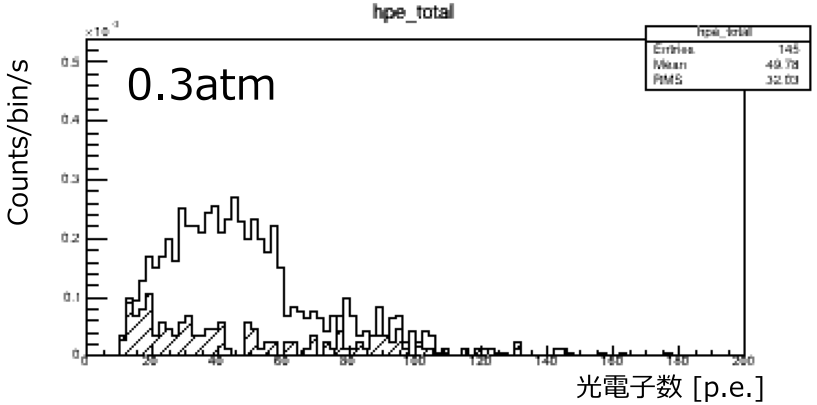


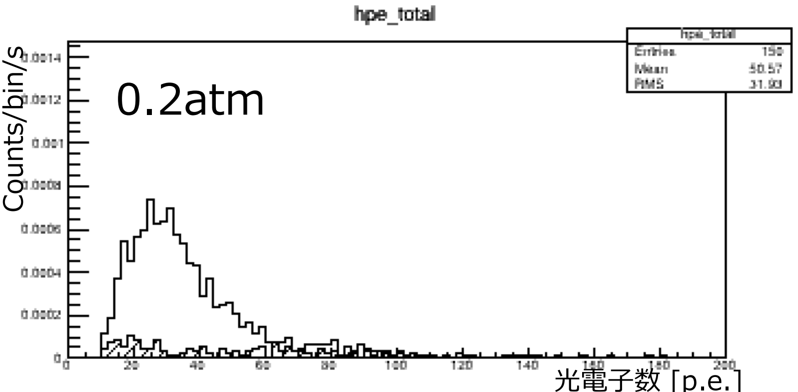


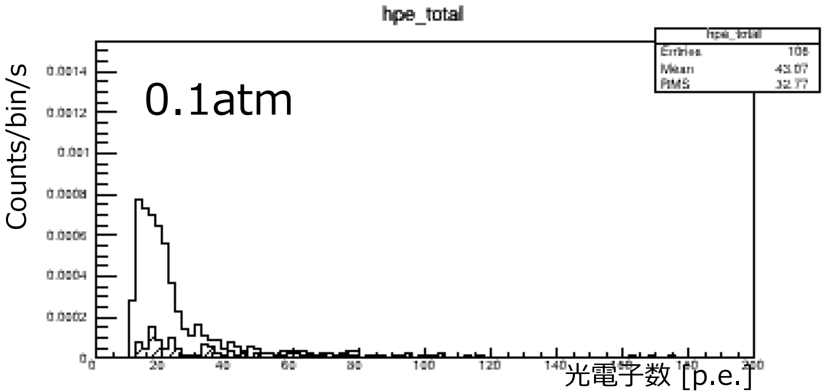


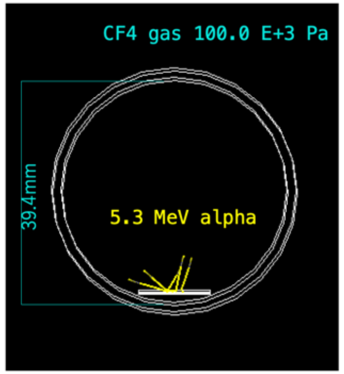


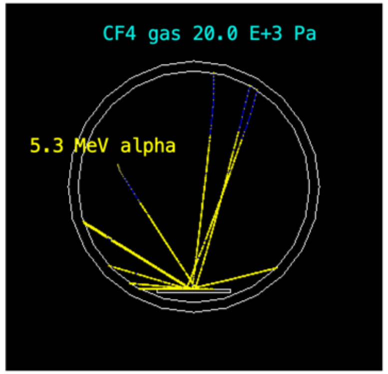








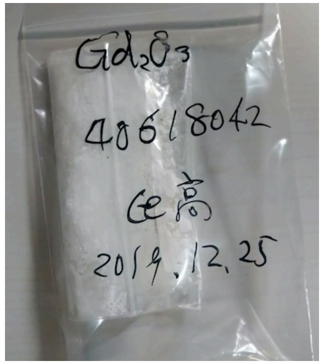


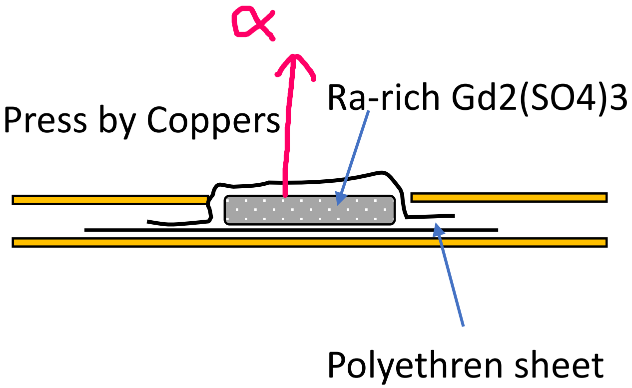


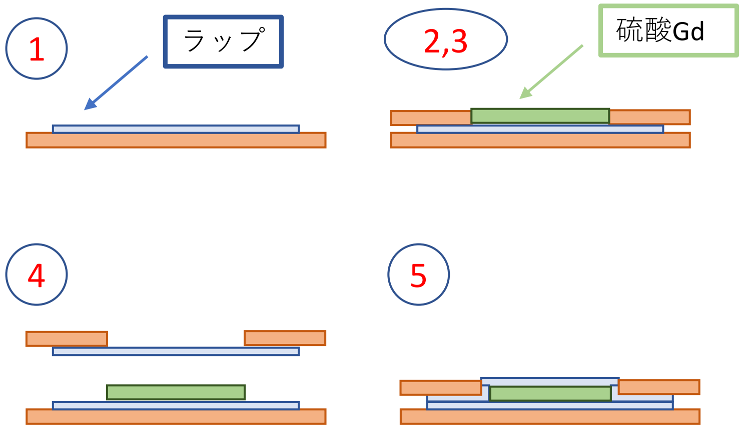
Powder sample can be measured.

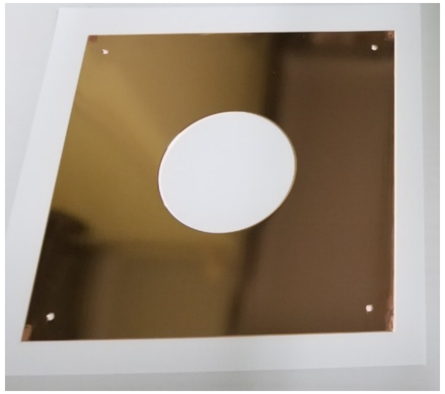
When the powder sample is covered by the thin sheet, its alpha emission rate can be measured.

Note: alpha energy deposition in the sheet passing the sheet, it should be corrected energy shift.

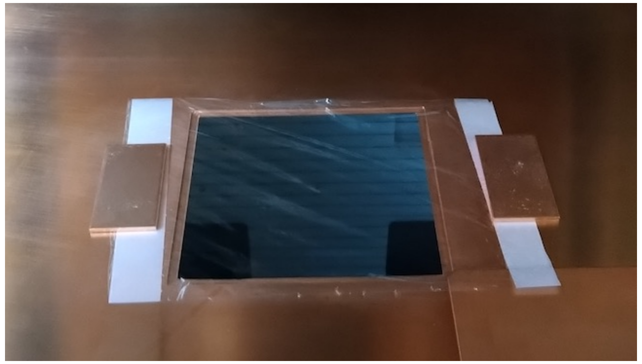


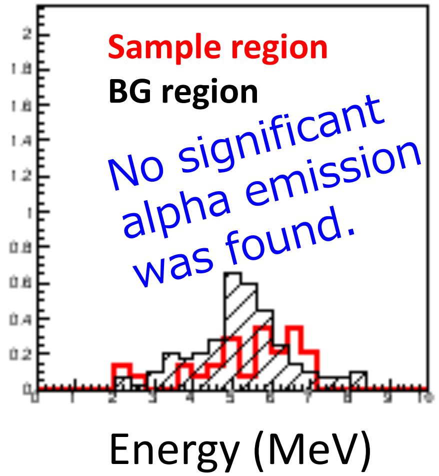




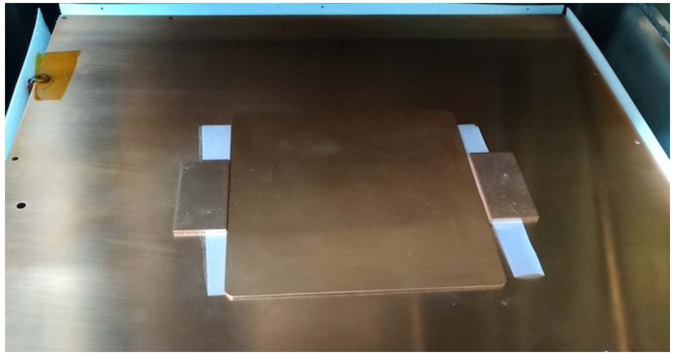


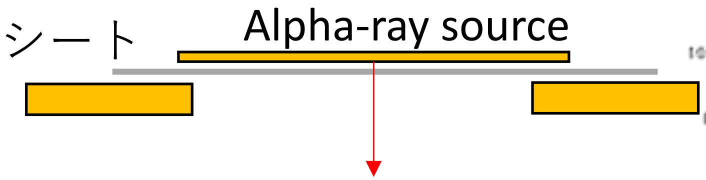
(1) Is it clean the sheet ?

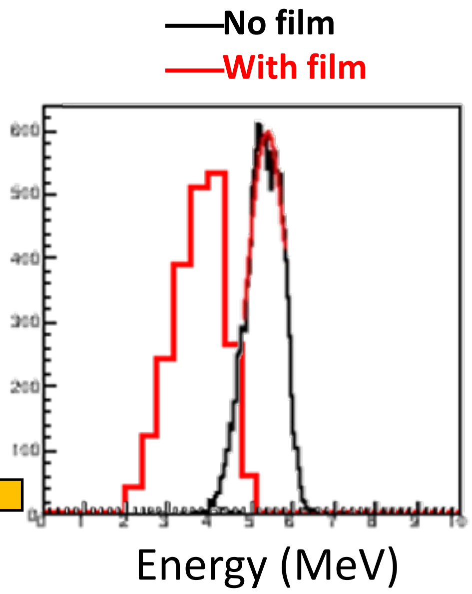




(2) How deposits energy passing through the sheet



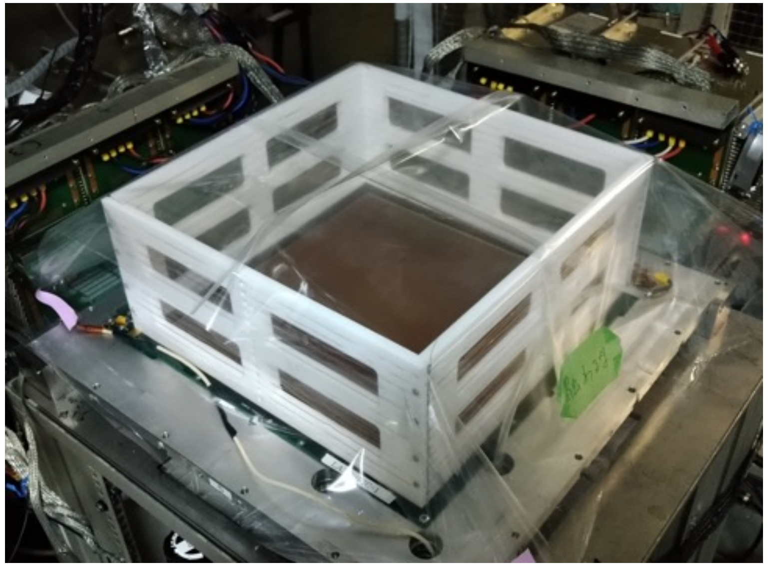




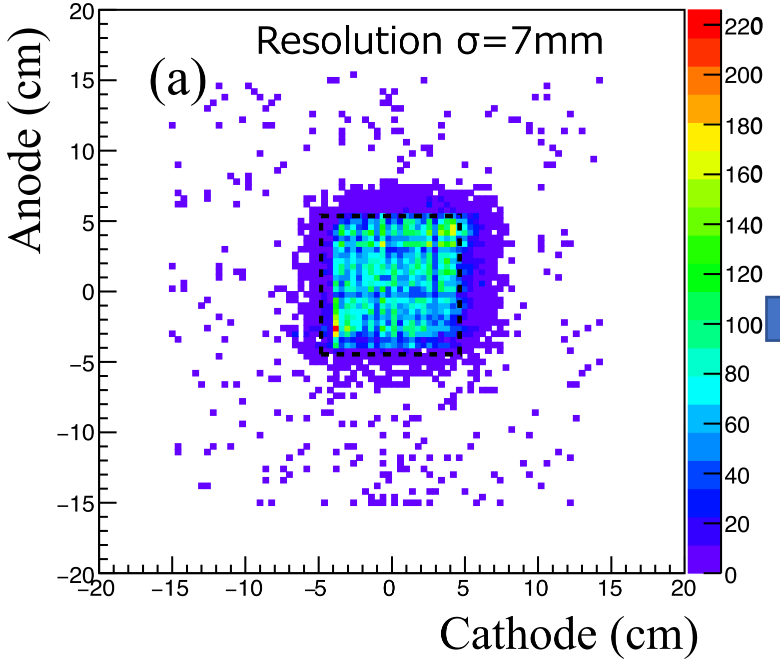
Appendix

To be short drift length 30cm -> 15cm

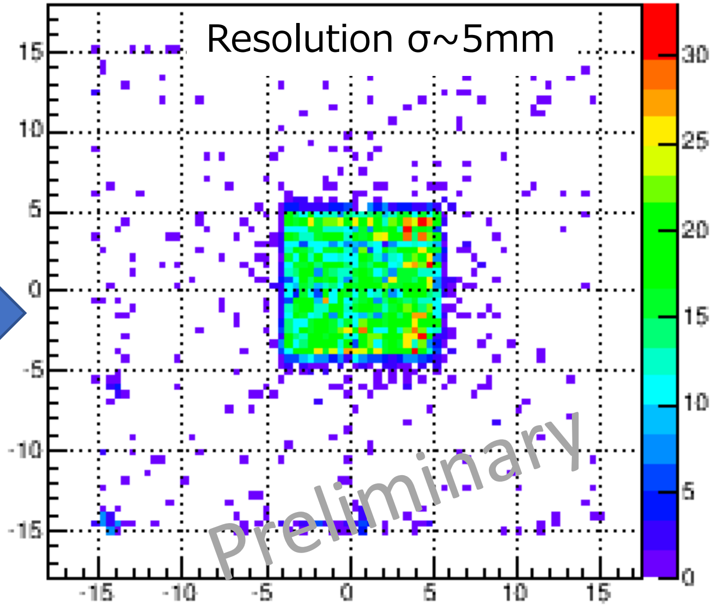
2020 ⇨ 2021

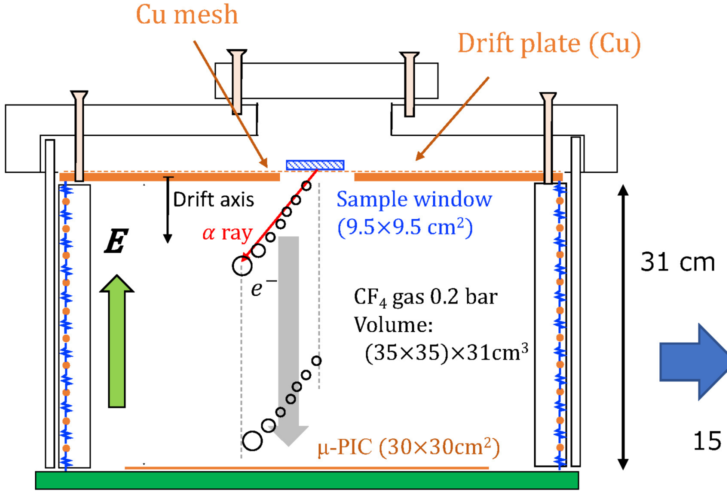


Before

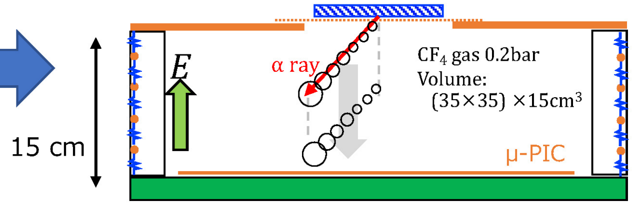


After





Before



After

Drift length was shorted in order to
- improve position resolution,
- reduce radon background.

We obtained