MEG II 実験液体キセノン検出器用 VUV-MPPCの放射線耐性に関する研究

(Study on Radiation Damage of VUV-MPPC for the Liquid Xenon Detector in the MEG II Experiment)

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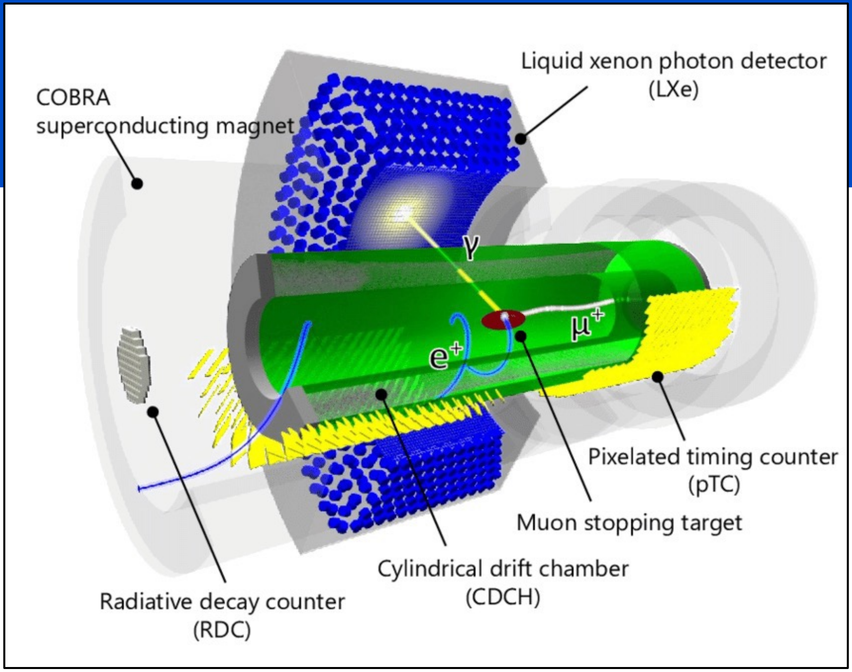
Core-to-Core Program

ICEPP
The University of Tokyo

MEG II
Mu - E - Gamma collaboration

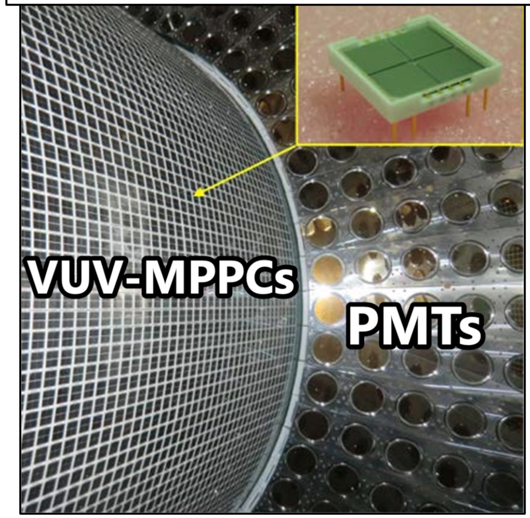
Introduction

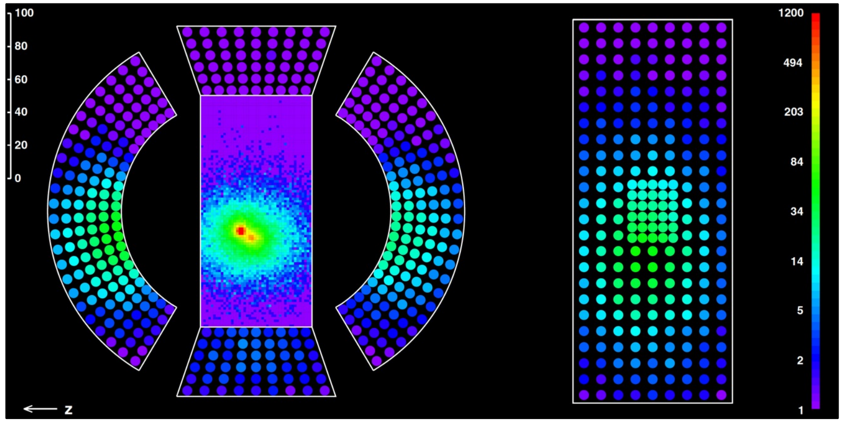


- MEG II experiment
  - Searching for $\mu^+ \rightarrow e^+\gamma$ as a probe for new physics
    - with the world's highest intensity muon beam ($3\text{-}5\times10^7$ μ/s)
- For gamma-ray measurement
  - Liquid Xenon (LXe) detector
    - Measure the position, energy, timing of gamma-ray
    - Using VUV-MPPCs

Vacuum UltraViolet (VUV) light sensitive MPPCs (Today's topic)

inside of LXe detector

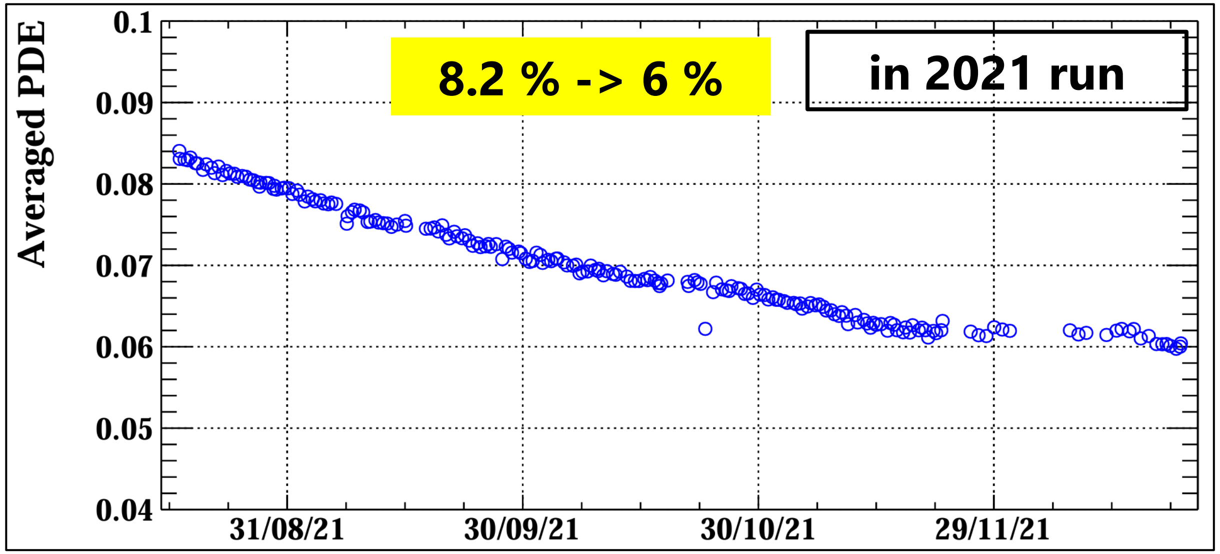




Background of this study

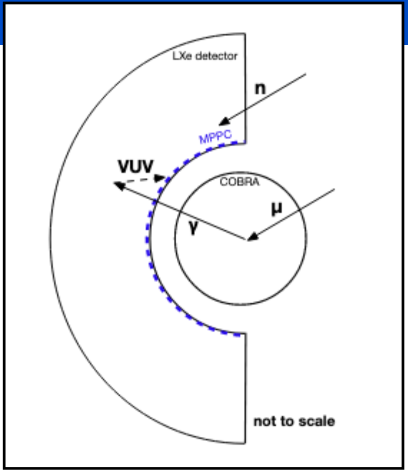
- Photon detection efficiency (PDE) for VUV light rapidly decreases during physics run.
  - Found that PDE can recover by annealing (70 °C, 28h)
    - Annealing was performed in MEG II every shutdown period after 2021 run ->not crucial for experiment
  - But we still want to understand cause

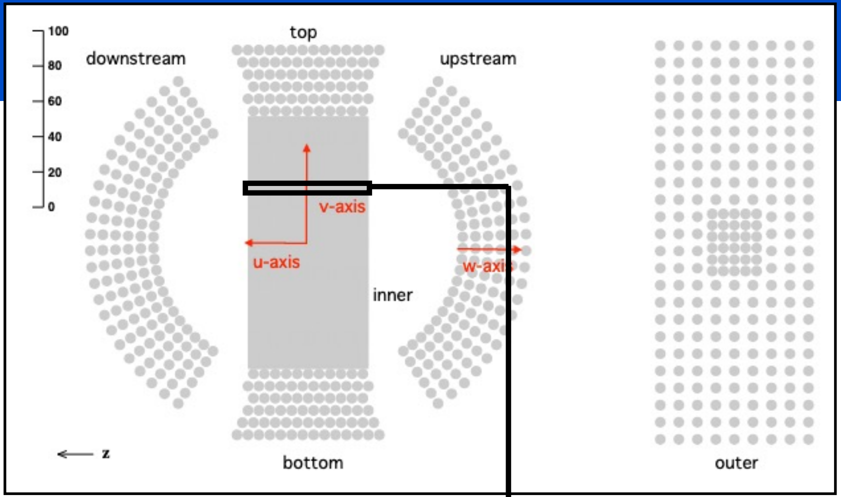
$N_{\mathrm{photon}} = 1.1\times10^{11}\ \mathrm{photon/mm^2}$



K. Afanaciev, et al., Eur. Phys. J. C 84 (2024), 190

Background of this study

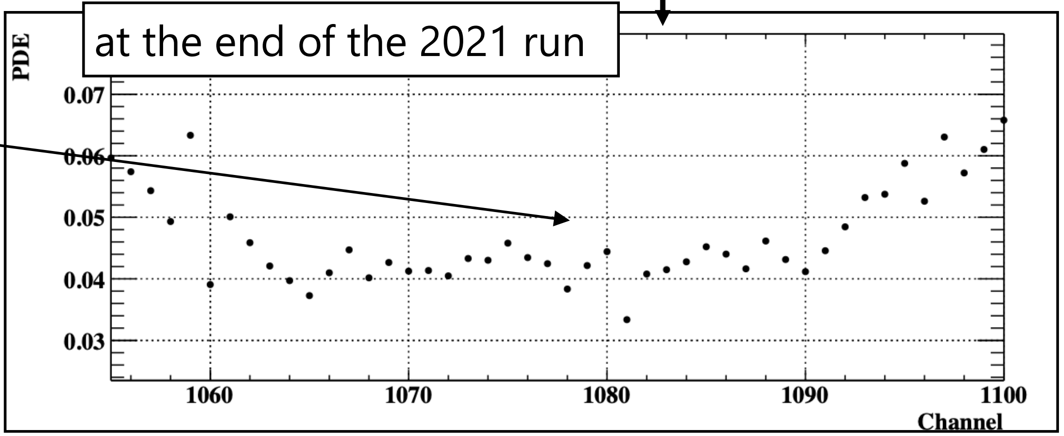




- Radiation environment
  - Radiation from the muon stopping target: Gamma-ray
  - Radiation from LXe: VUV light (scintillation light from gamma-ray)
  - Radiation from the accelerator: Neutron
- PDE decrease at the center is larger
- Muon stopping target is centred with reference to LXe detector

Most likely to be caused by radiation from muon stopping target and LXe

Radiation candidates: gamma-ray, ***VUV light***


at the end of the 2021 run

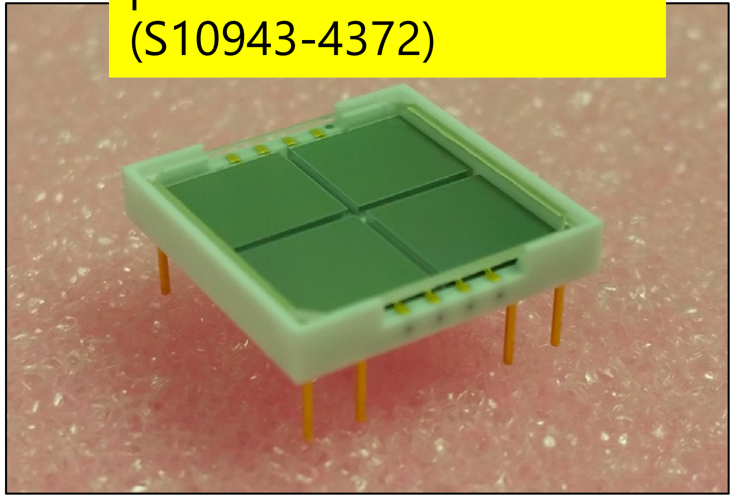
upstream ← center → downstream

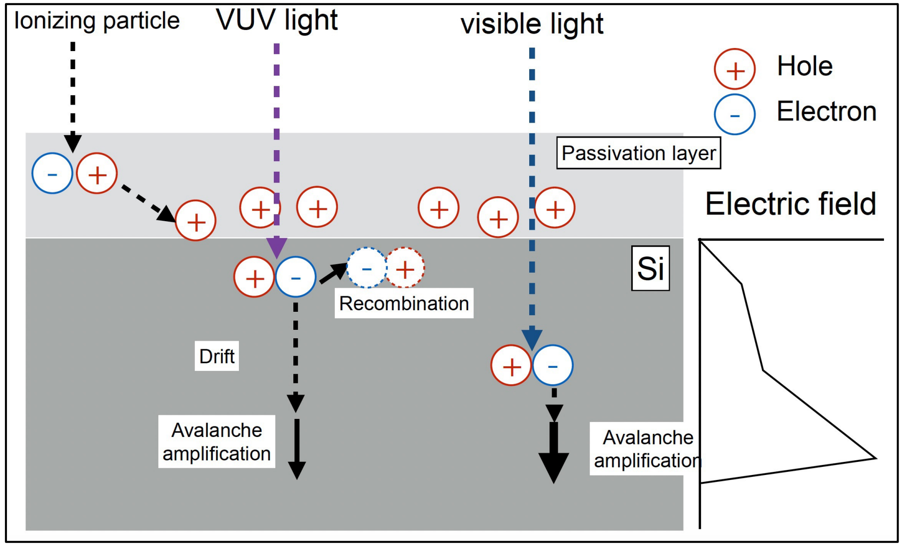
Radiation damage of VUV-MPPCs

- Candidate for radiation damage:
  Surface damage
  - Caused by ionizing radiation (gamma-ray or VUV light)
- Previous lab tests
  - VUV-MPPCs were irradiated with VUV light at room temperature, low temperature (~165 K), in liquid xenon
    - Humidified VUV-MPPC was irradiated with VUV light in room temperature
  - VUV-MPPCs were irradiated with gamma-ray at room temperature, low temperature (~165 K)
- PDE degradation was not reproduced in laboratory

(PDE degradation was actually observed by VUV irradiation, but 10^4 *slower)*

picture of VUV-MPPC (S10943-4372)





K. Ieki, et al., Nucl. Inst. and Meth. A 1053 (2023), 168365

Motivation of this study

1. It's known that VUV sensitivity of VUV-MPPC is worsened by absorbing moisture
   - Coming from VUV-MPPC has no moisture resistance layer on the surface
2. VUV-MPPCs in MEG II were exposed at ambient humidity during storage and installation

→ Combine the above two results

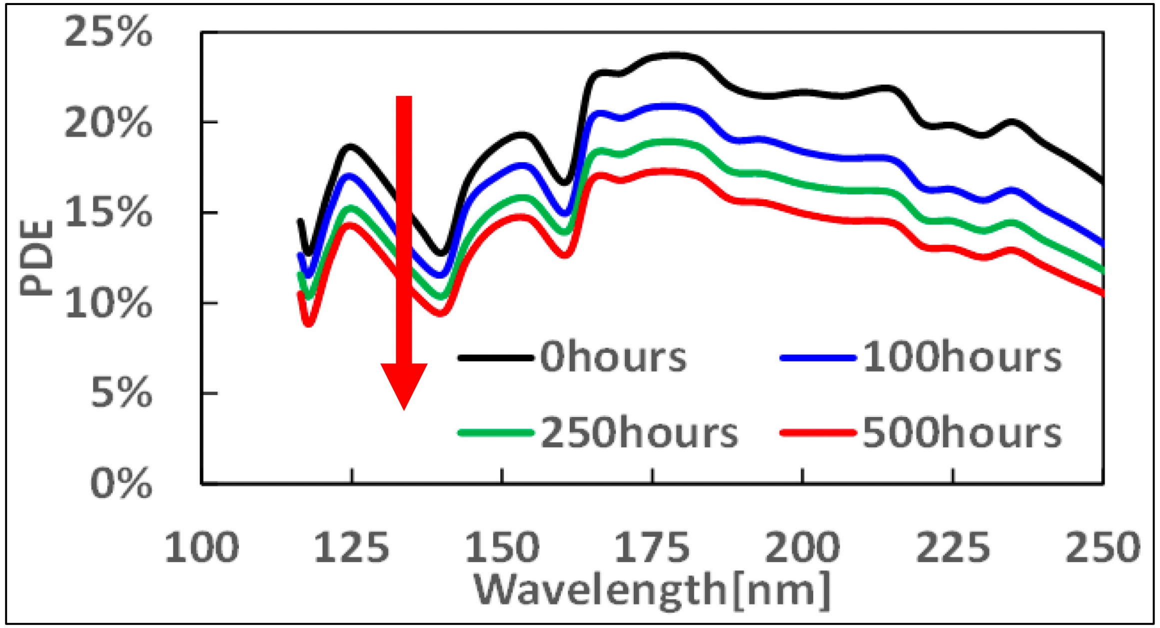
Hypothesis

→ Humidity duffused into the MPPCs might accelerate the radiation damage

→ Measure PDE of humidified VUV-MPPC during VUV irradiation

Condition: 60°C, 90% r.h.
(89 times faster than 25°C, 60% r.h.)

Measured by HPK



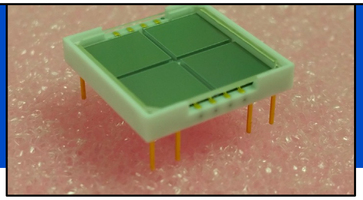
R. Yamada, et al., "Development of MPPC with high sensitivity in NUV or VUV," 2022 IEEE NSS/MIC/RTSD

Method

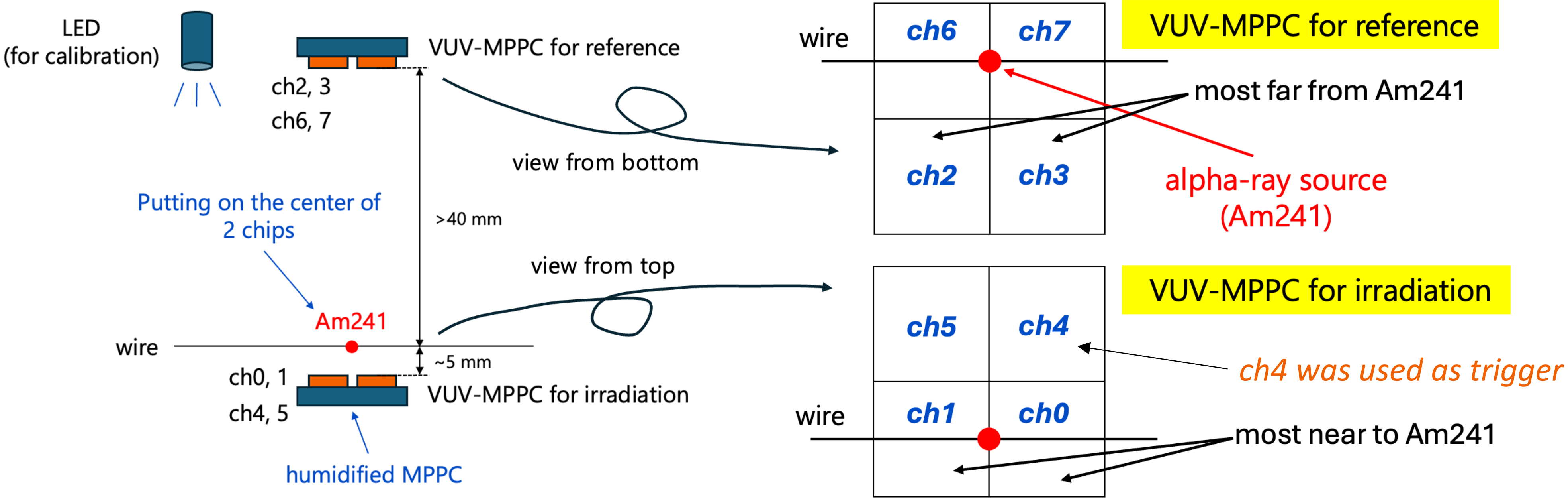
- Irradiate VUV-MPPC with scintillation light (VUV light, $\lambda = 175\ \mathrm{nm}$) from LXe
  - To test the humidified VUV-MPPC is damaged by VUV light or not
  - Irradiate enough to reproduce the speed of PDE decrease of the LXe detector
    - Continuous irradiation for 300 hours
- Install the VUV-MPPC, alpha-ray source (Am241) and LED in LXe
  - Alpha-ray is used for exciting LXe
  - LED is for the measurement of the gain
  - Sustain the temperature in LXe (168 K) during data taking

Setup

4 chips in one VUV-MPPC



	ch0,1,4,5 (VUV-MPPC's chips for irradiation)	ch2,3,6,7 (VUV-MPPC's chips for reference)
Annealing (done before humidification)	150 °C x 16 hours baked (Assume humidity inside VUV-MPPC were removed)	not annealed
Humidity	60 °C x 250 hours, 90 % r.h. (89 times faster than 25°C, 60% r.h.)	not humidified
Note	for test of radiation damege	for reference of LXe stability



LED
(for calibration)

VUV-MPPC for reference

ch2, 3
ch6, 7

view from bottom

Putting on the center of 2 chips

>40 mm

view from top

Am241

wire

~5 mm

ch0, 1
ch4, 5

VUV-MPPC for irradiation

humidified MPPC

wire

ch6 ch7
ch2 ch3

VUV-MPPC for reference

most far from Am241

alpha-ray source
(Am241)

ch5 ch4
ch1 ch0

VUV-MPPC for irradiation

ch4 was used as trigger

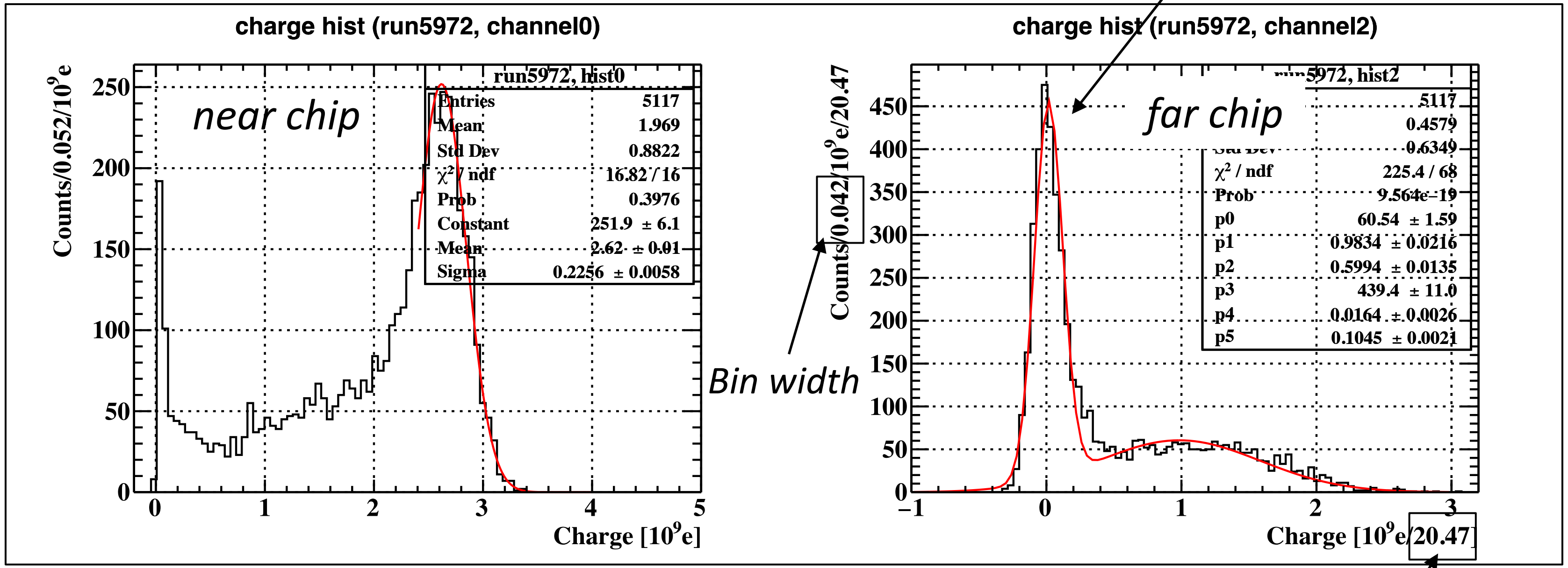
wire

most near to Am241

Result – Charge of alpha-ray and MPPC gain

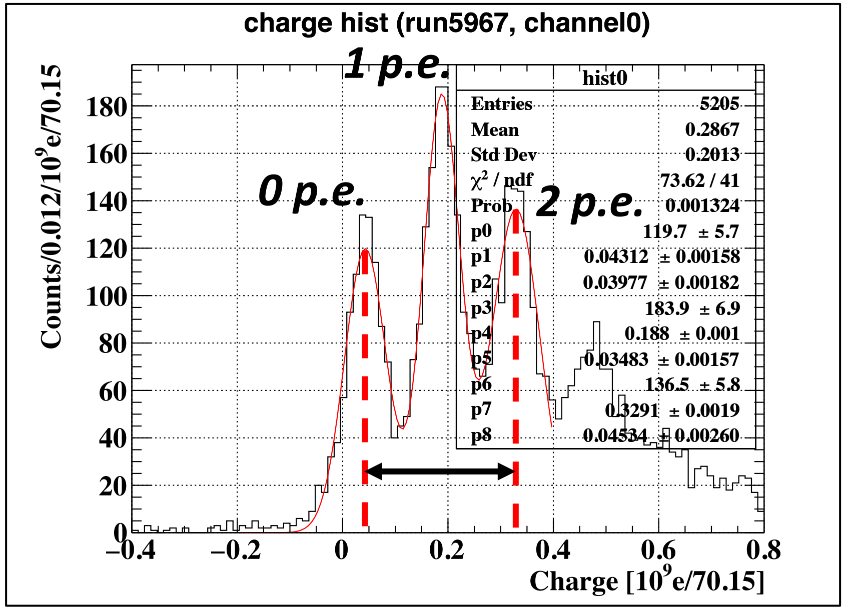
alpha-ray

alpha-ray emitted from the shadow of wire



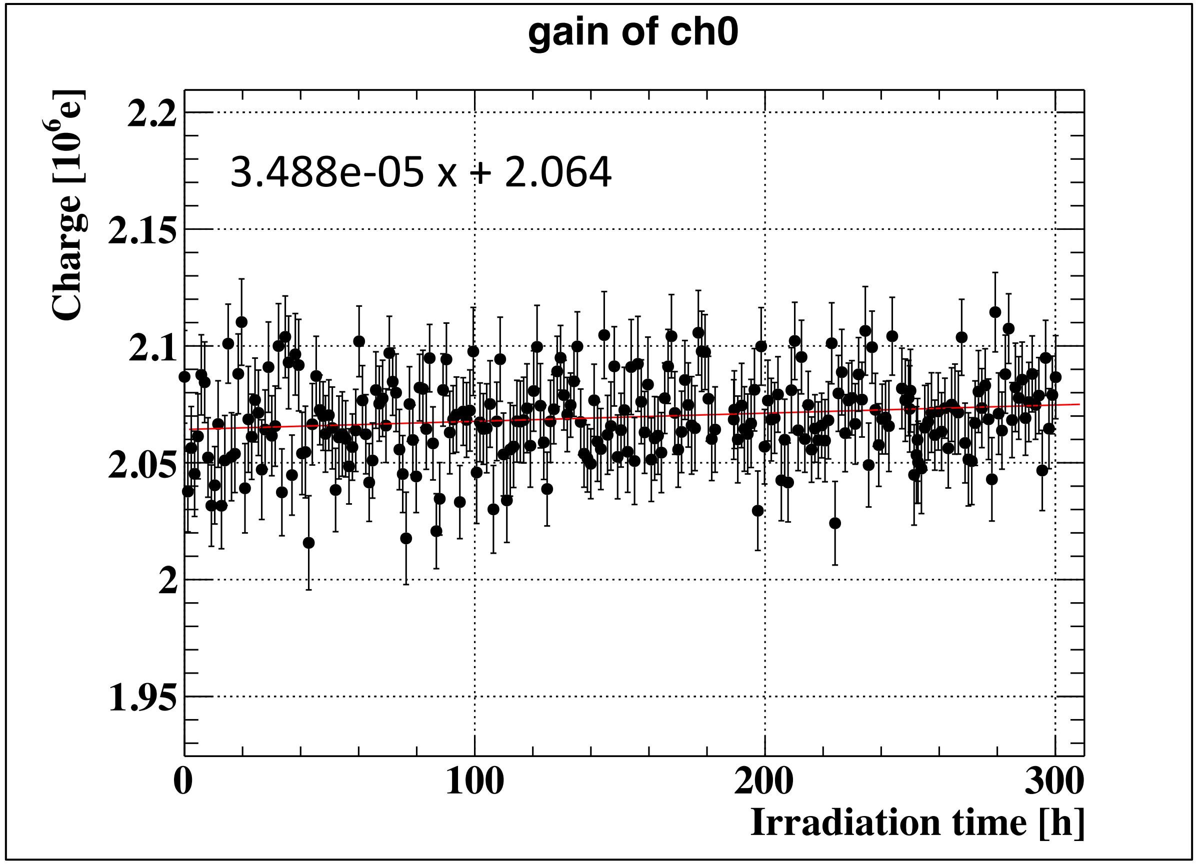
FEGain

LED



- Charge peak of alpha-ray
  - Calculated by gaussian peak
- MPPC gain
  - Calculated from dividing the difference between 0 p.e. and 2 p.e. peak by 2

Result – Stability of the gain



Temp: 168 ± 0.5 K

- Gain is stable during VUV light irradiation

Result – Calculation of radiation dose

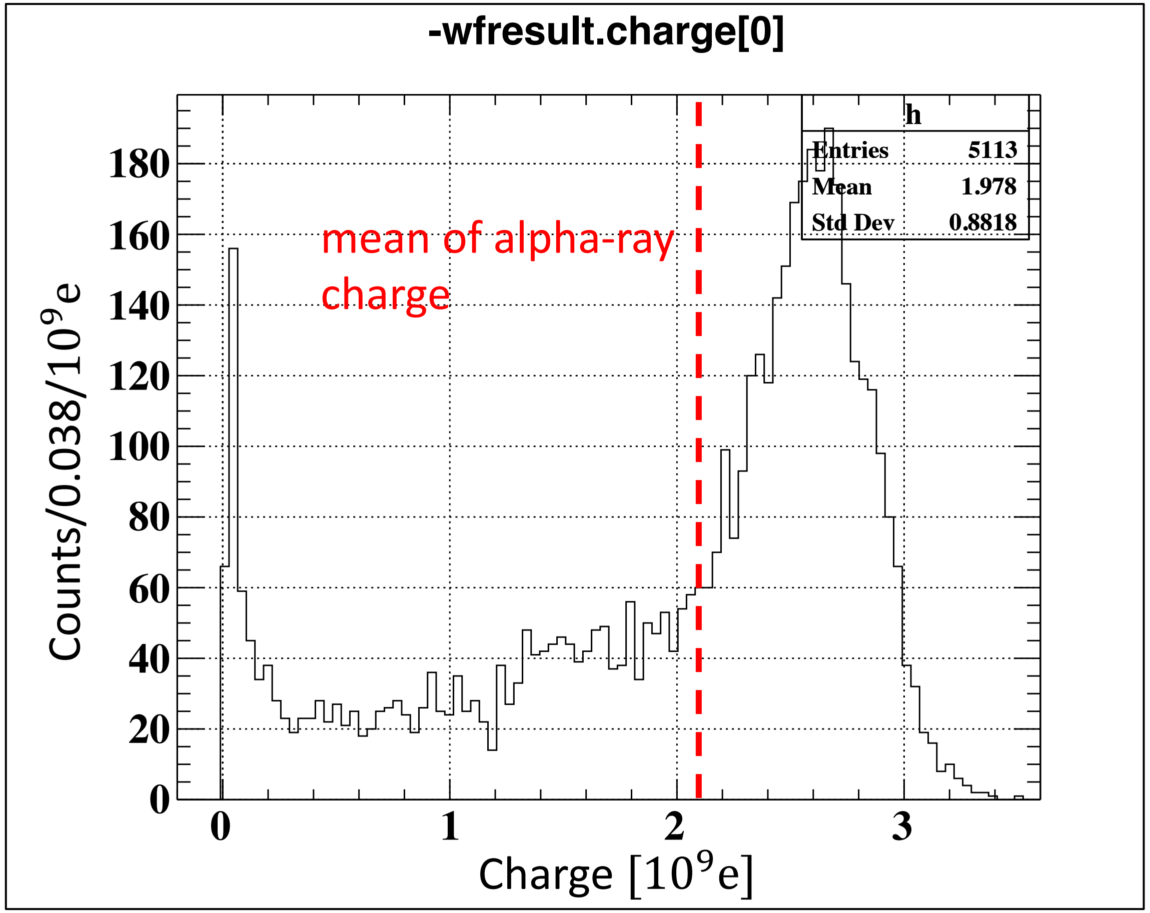
- The number of irradiated VUV light is calculated below

$$\mathrm{VUV\ light\ irradiation\ dose} = \underbrace{\frac{\mathrm{Charge\ of\ alpha-ray}}{\mathrm{Gain}} \cdot \frac{1}{\mathrm{PDE}} \cdot \frac{1}{\mathrm{ECF}}}_{\text{Impinging photon per event}} \cdot \mathrm{trigger\ rate\ [Hz]} \cdot \mathrm{irradiation\ time\ [sec]} \cdot \frac{1}{\mathrm{Surface\ area\ of\ 1\ chip\ [mm^2]}}$$

Trigger rate and charge of alpha-ray signal

- Trigger rate
  - Calculated by the mean of the first 10 data takings
    - Because the trigger rate was expected to decrease by VUV photon irradiation
- Average charge of alpha-ray
  - Calculated by the mean of first 10 data takings
    - Because the charge of alpha-ray was expected to decrease by VUV photon irradiation

alpha-ray

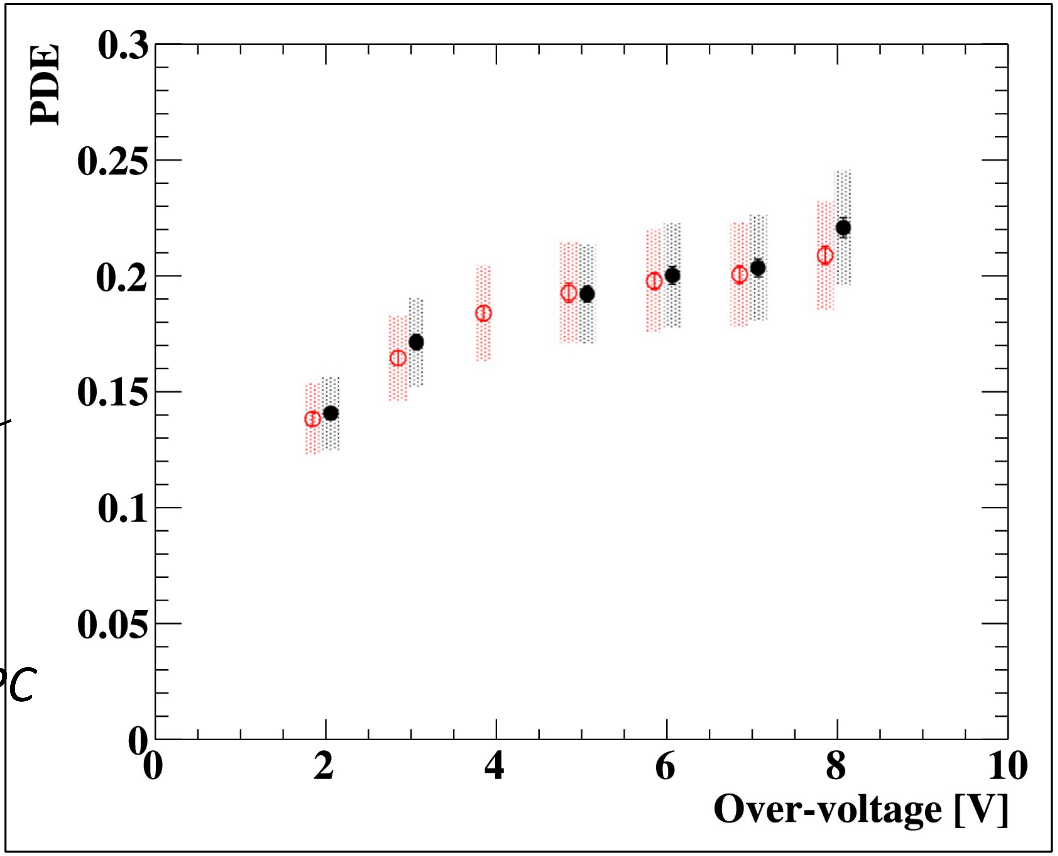


Result – Estimation of initial PDE

	Over voltage [V]
ch0	3.51
ch1	3.53
ch2	3.66
ch3	3.57

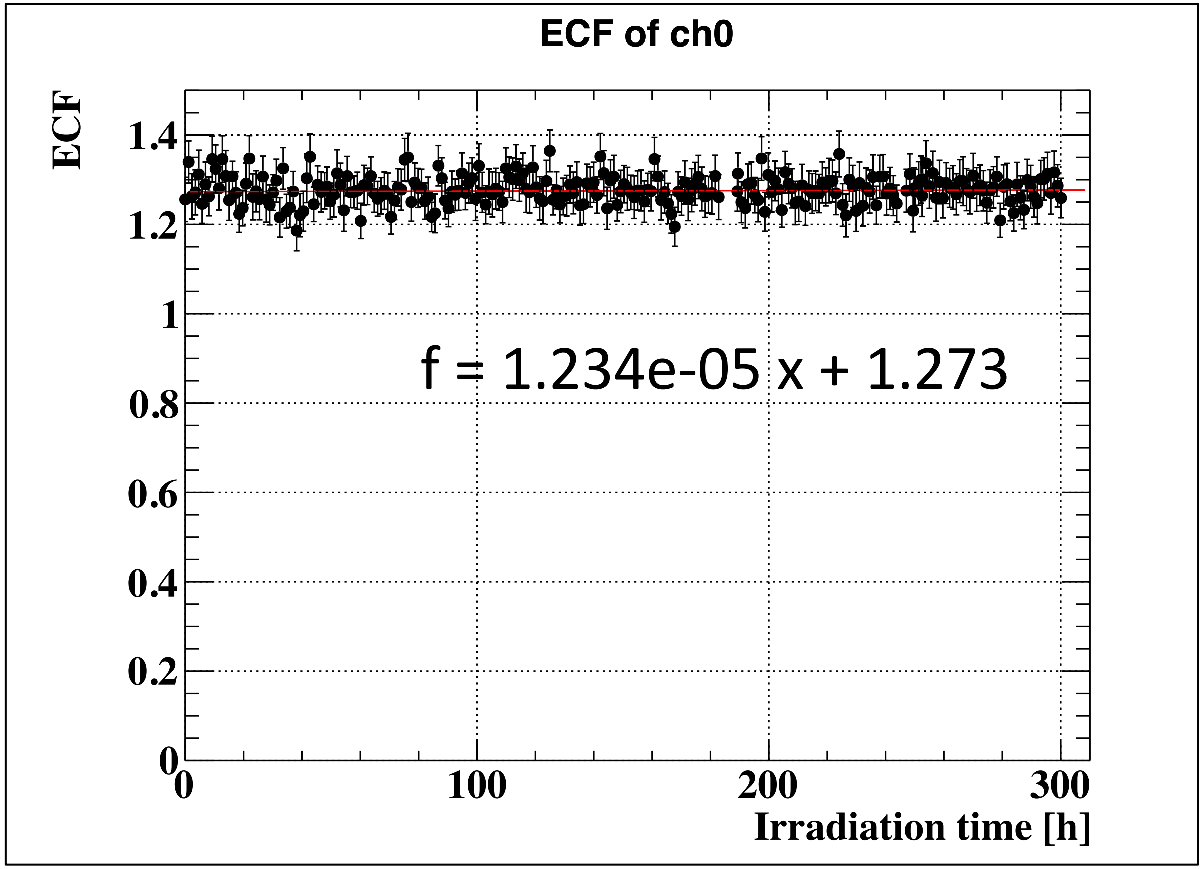
- *Expected PDE: ~15 ± 2 %*

Humidity inside VUV-MPPC decrease PDE



K. Ieki, et al., Nucl. Inst. and Meth. A 925 (2019), 148-155

Result – ECF Transition



- Irradiation dose was calibrated by ECF (Excess Charge Factor)

Expected PDE decrease

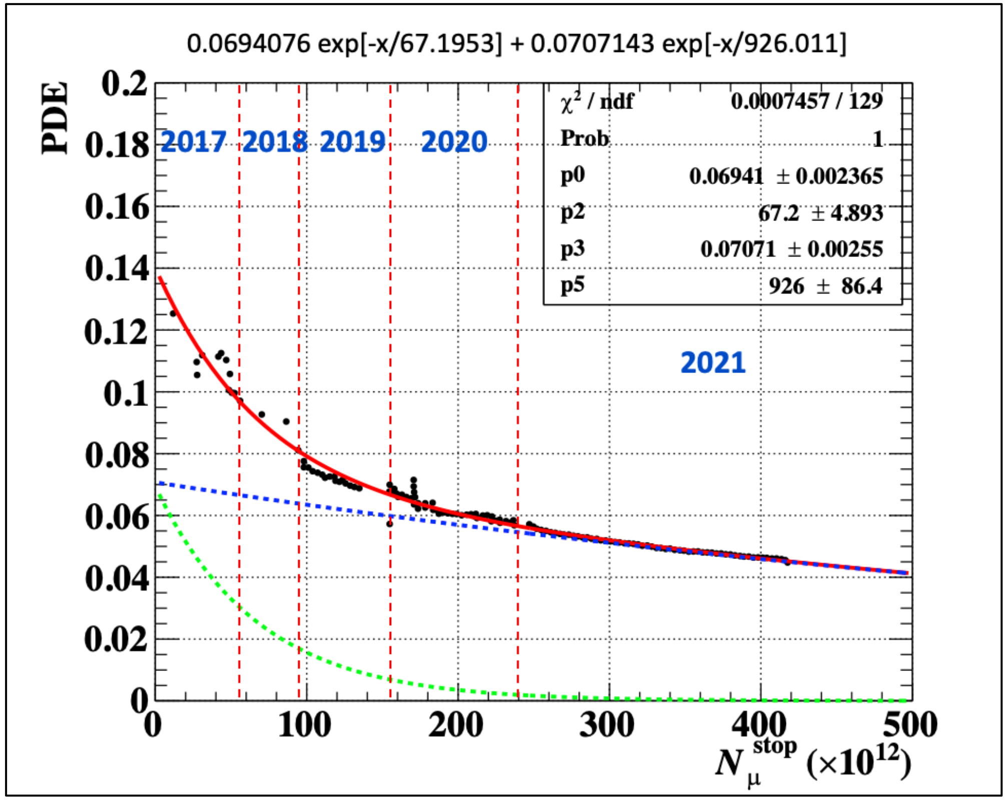
The PDEs in 2017-2021 are measured from the VUV-MPPCs at the center of the LXe

Stopped muons in 2017-2021: 410×10^{12}

ch	0	1
ratio of radiation dose of this experiment to that of 2017-2021	0.015	0.017
Expected Initial PDE	~15 %	~15 %
Expected PDE Decrease (in relative)	~ 1.4-5.0 %	~ 1.6-5.6 %

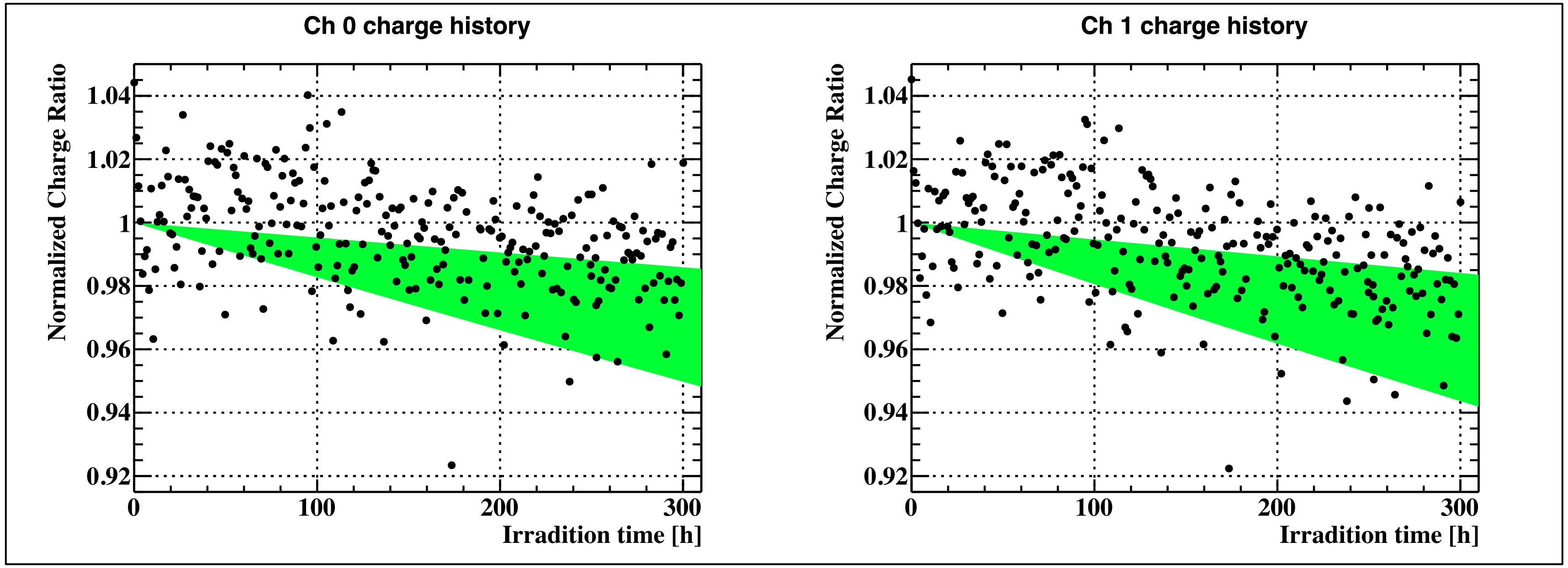
Estimated from the blue function

Estimated from the red function



Partially modified from S. Kobayashi, PhD thesis (2022) (https://www.icepp.s.u-tokyo.ac.jp/download/doctor/phD2022_kobayashi.pdf)

Result – PDE decrease in this study



- The PDE decrease expected within the green region
- The normalized charge ratio seems decreased by irradiation as a whole
  - But the fluctuation of each point is too large comparing with the expected band
- Currently, we cannot conclude if the VUV light is the cause of the PDE decrease or not
- Systematic error can be reduced by further detailed analysis

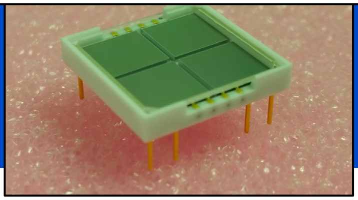
Sammary & Outlook

- Summary
  - Rapid PDE decrease for VUV light was observed in the MEG II LXe detector
  - Studied effect of absorption of moisture inside the VUV-MPPC with VUV light irradiation
  - The charge signal of far chips makes large systematic error for the normalized charge ratio
- Next step
  - Analysis
    - to reduce the systematic error of PDE transition
    - to estimate PDE decrease speed in this test with smaller uncertainty
  - Experiment
    - Using a PMT for reference to reduce the systematic error
  - Irradiate VUV-MPPC with gamma-ray
    - in LXe
    - to test the effect of moisture inside the VUV-MPPC

Backup

Setup

4 chips in one VUV-MPPC



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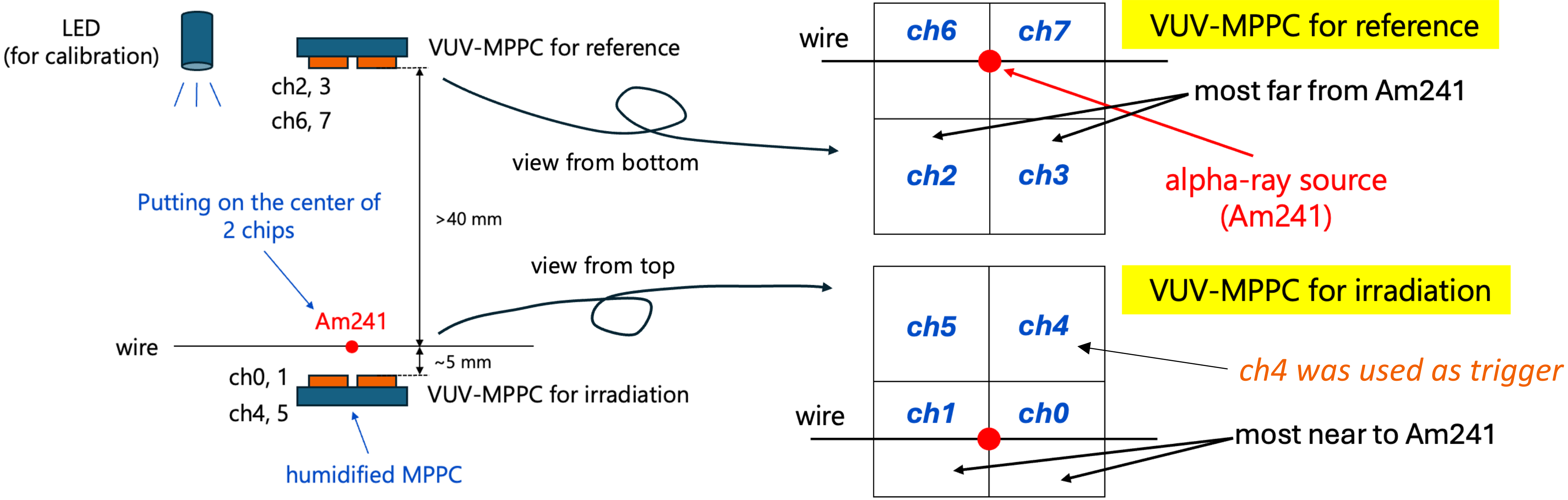
Annealing (done before humidification)	150 ℃ x 16 hours baked before accelerated test (Assume humidity inside VUV-MPPC were removed)	not annealed
Humidity	89 times accelarated (60 ℃ x 250 hours, humidity 90 ％)	not accelerated
Note	for test of radiation damege	for reference of LXe stability

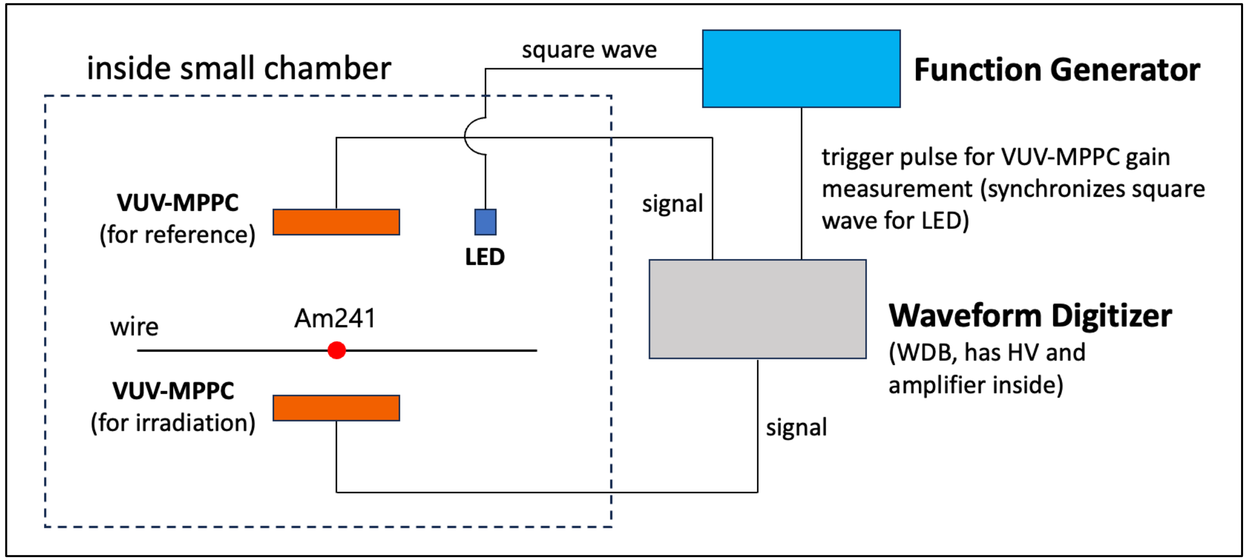


Control of cooling system and DAQ

- Cooling System
  - SCS2000 was used for control of the pressure and temperature inside the small chamber "*automatically*"
    - Control LN2 flow by setting upper and lower limit of the pressure
  - Took the data of pressure and temperature inside small chamber
- DAQ
  - Used WaveDREAM Board (WDB) as a waveform digitizer
  - Has HV and amplifier inside
    - Gain for alpha-ray run: 1 (ch0,1), 5 (ch4,5), 25 (ch2,3,6,7)
    - Gain for LED run: 70.15 (ch0,1,2,3)
  - Took the data of VUV-MPPC signal from alpha-ray and LED light every 1 hour


SCS2000


WaveDream Board


inside small chamber

square wave

Function Generator

trigger pulse for VUV-MPPC gain measurement (synchronizes square wave for LED)

VUV-MPPC
(for reference)

LED

signal

wire

Am241

Waveform Digitizer
(WDB, has HV and amplifier inside)

VUV-MPPC
(for irradiation)

signal

Result – Number of photon entering near chips

ch	0	1
trigger rate	37.7 event/sec	37.7 event/sec
mean charge	$1.98\ 10^{9}\mathrm{e}$	$2.19\ 10^{9}\mathrm{e}$
gain	$2.064\ 10^{6}\mathrm{e}$	$2.064\ 10^{6}\mathrm{e}$
expected PDE	~15%	~15%
ECF	1.273	1.263
Surface area of 1 chip	$5.95\times5.85\ \mathrm{mm}^2$	$5.95\times5.85\ \mathrm{mm}^2$
Irradiation time	300 hours	300 hours

VUV light irradiation dose in 2017-2021:
$4\times10^{11}\ \mathrm{photon}\cdot\mathrm{mm}^{-2}$

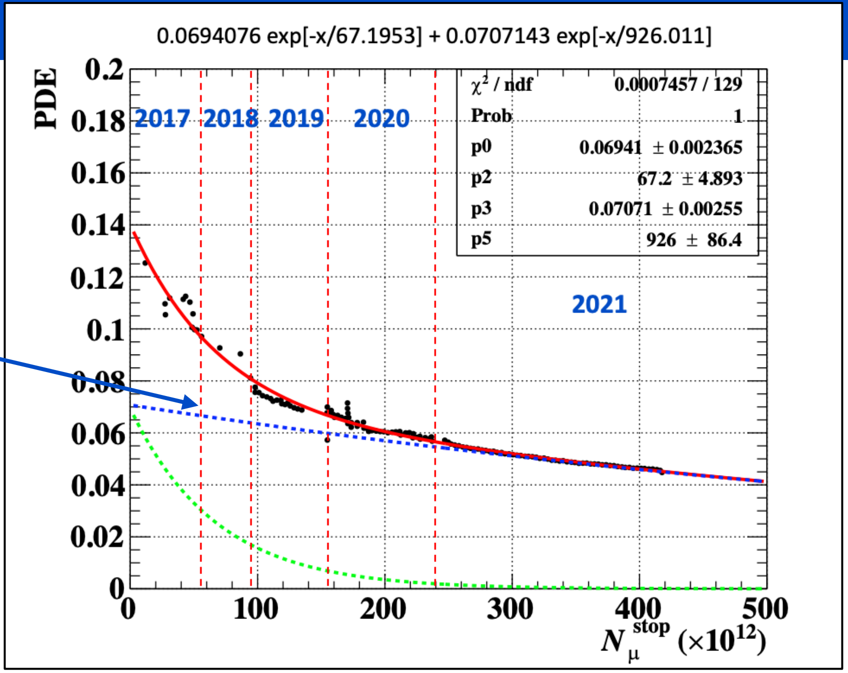
ch	0	1
VUV light irradiation in this experiment	$5.9\times10^{9}\ \mathrm{photon}\cdot\mathrm{mm}^{-2}$	$6.6\times10^{9}\ \mathrm{photon}\cdot\mathrm{mm}^{-2}$
ratio of radiation dose of this experiment to that of 2017-2021	$\mathbf{0.015}$	$\mathbf{0.017}$

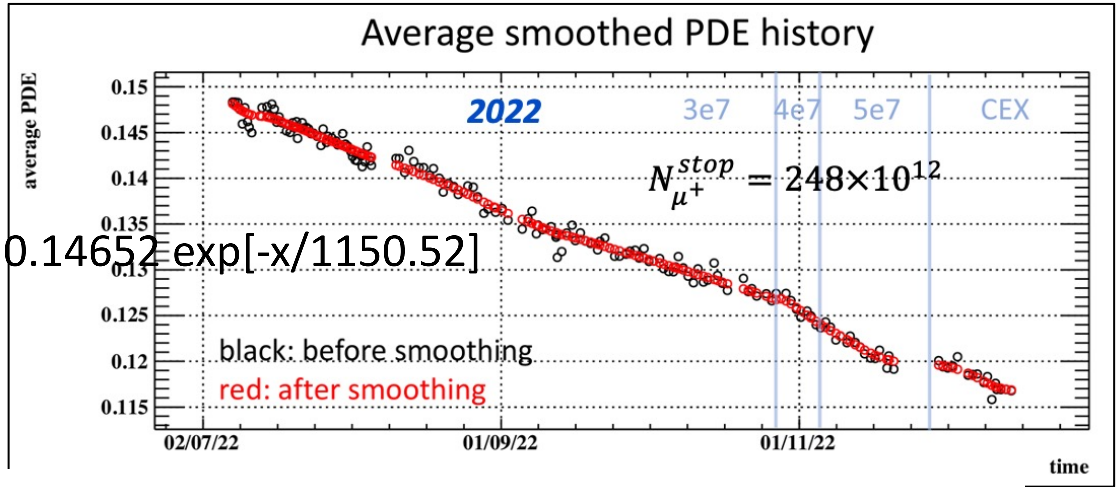
Normalized Charge Ratio

$$\text{Normalized Charge Ratio (at point i for ch m} = 0 \text{ or } 1) = \underbrace{\left(\frac{Q_i^{m=0\text{ or }1}}{\frac{1}{4}\sum_{m=2,3,6,7} Q_i^m}\right)}_{\text{Relative Charge}} \underbrace{\left(\frac{1}{10}\sum_{i=1}^{10}\frac{Q_i^{m=0\text{ or }1}}{\frac{1}{4}\sum_{m=2,3,6,7} Q_i^m}\right)^{-1}}_{\text{Normalization Factor}}$$

Result – Expected PDE decrease

- The one component (blue) of fitting function has similar time constant to that of 2022 physics run
- But the PDE decrease in 2022 physics run is measured from the average PDE of all VUV-MPPCs.
  - The VUV photon irradiation dose has position dependence to each VUV-MPPC (see page 4)
- In 2022 run, the VUV-MPPCs were annealed.
  - This is similar to the VUV-MPPC in this study
- It is better using the PDE history calculated from the VUV-MPPCs at the center of the LXe detector in 2021 physiscs run
  - To compaire with the PDE transition in this study
  - Now analysing. It will be done soon
  - In this presentation, including the effects of annealing and position dependence as expected PDE decrease

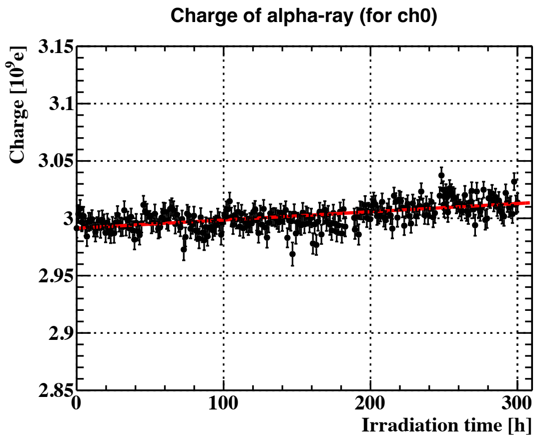


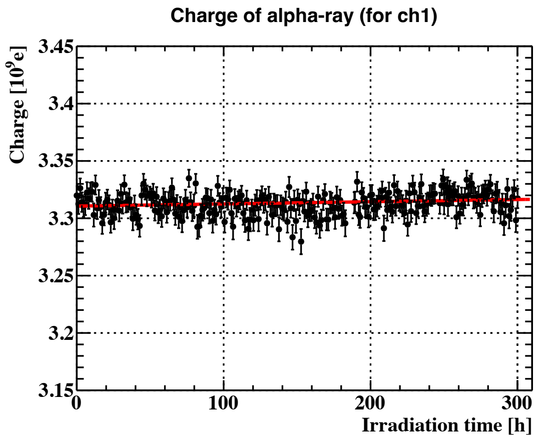


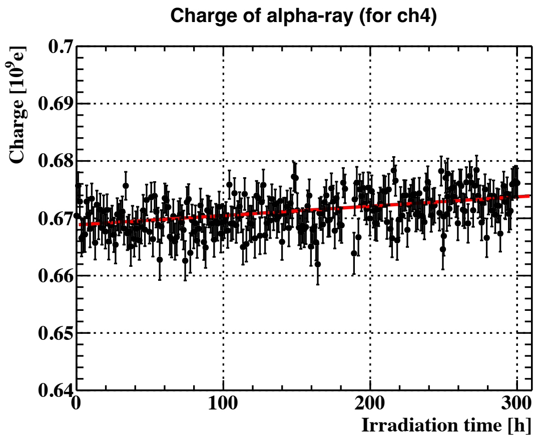
0.14652 exp[-x/1150.52]

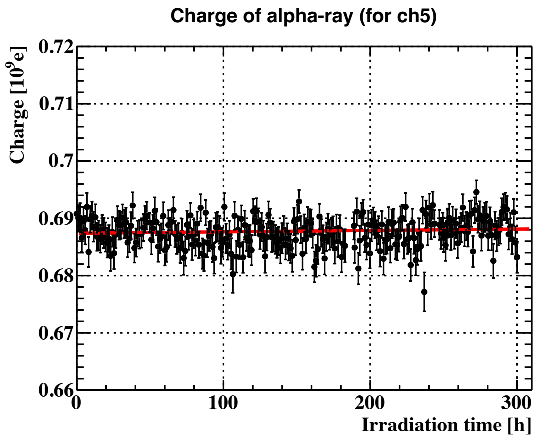
https://indico.psi.ch/event/15204/contributions/47074/attachments/26518/49397/matsushita20231123.pdf

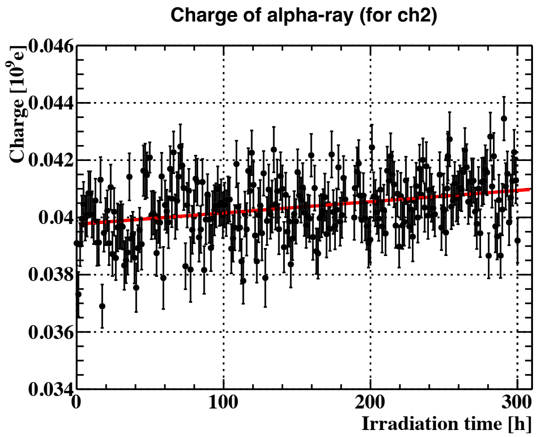
Alpha-ray charge history

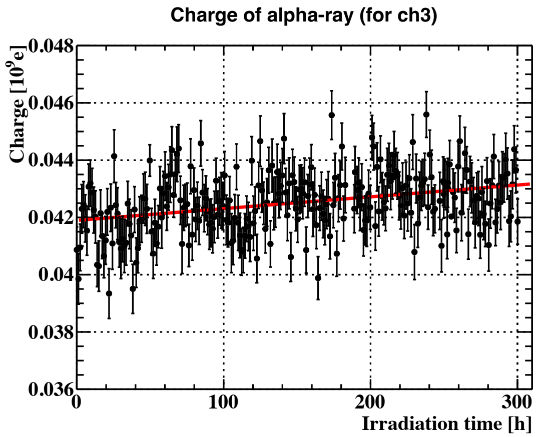


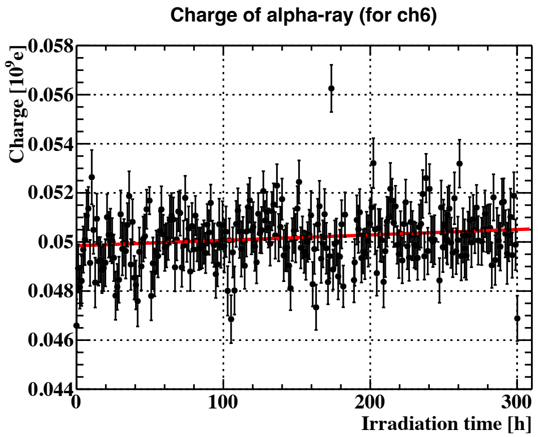


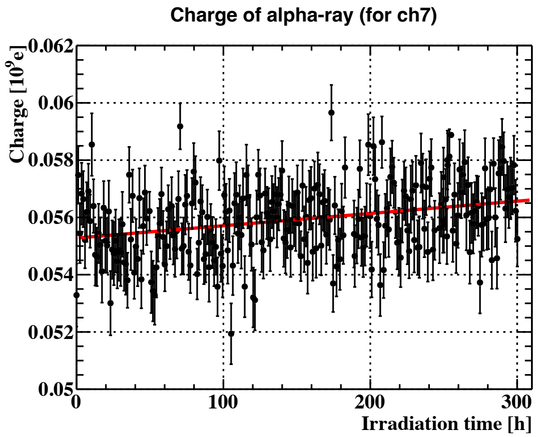




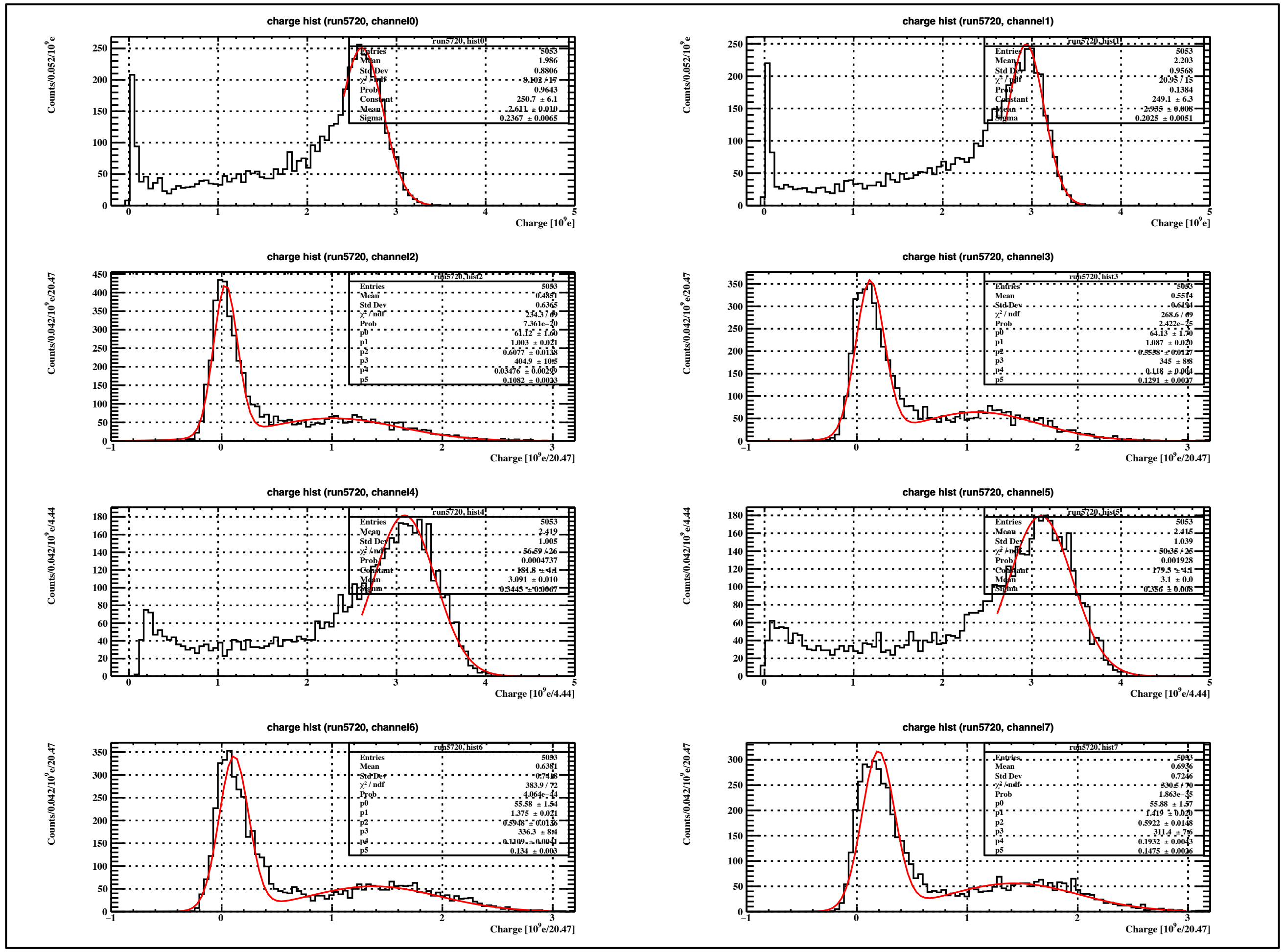


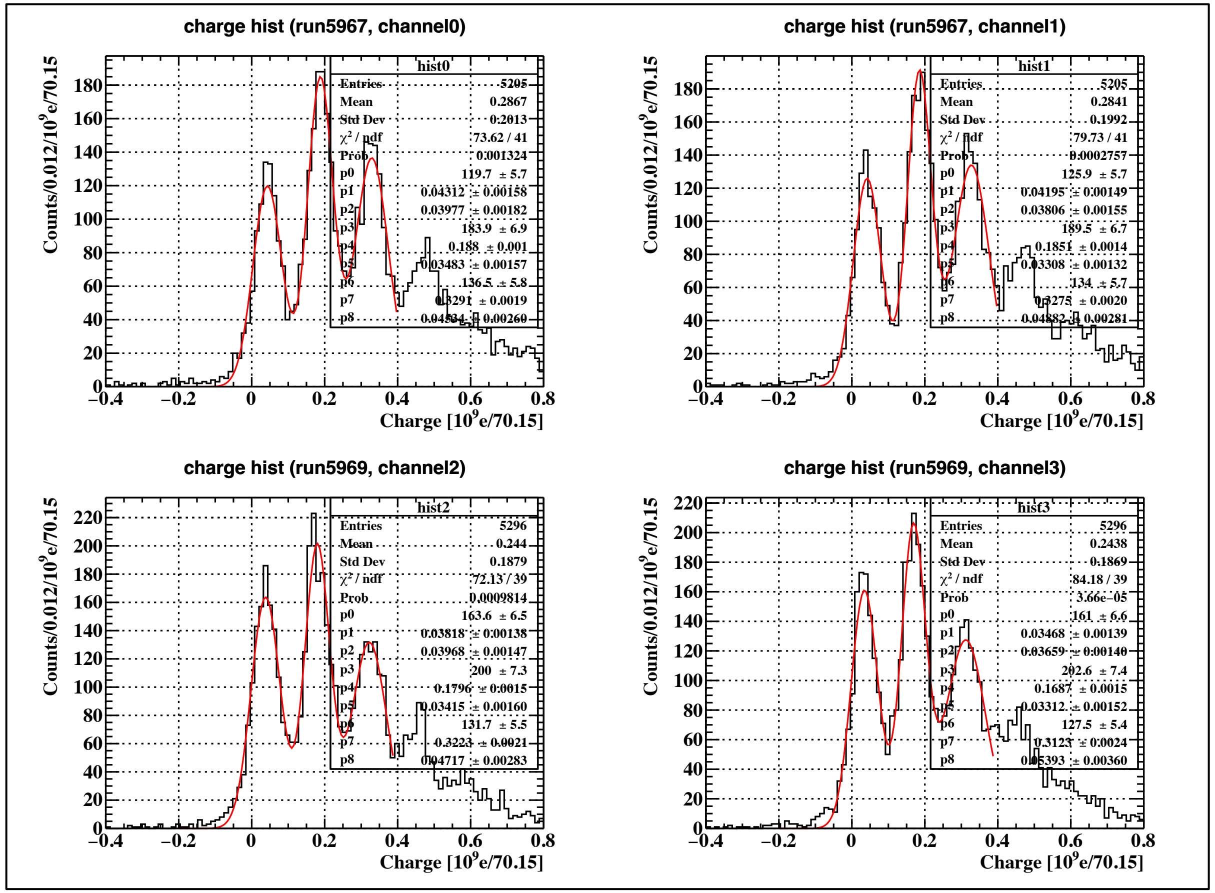






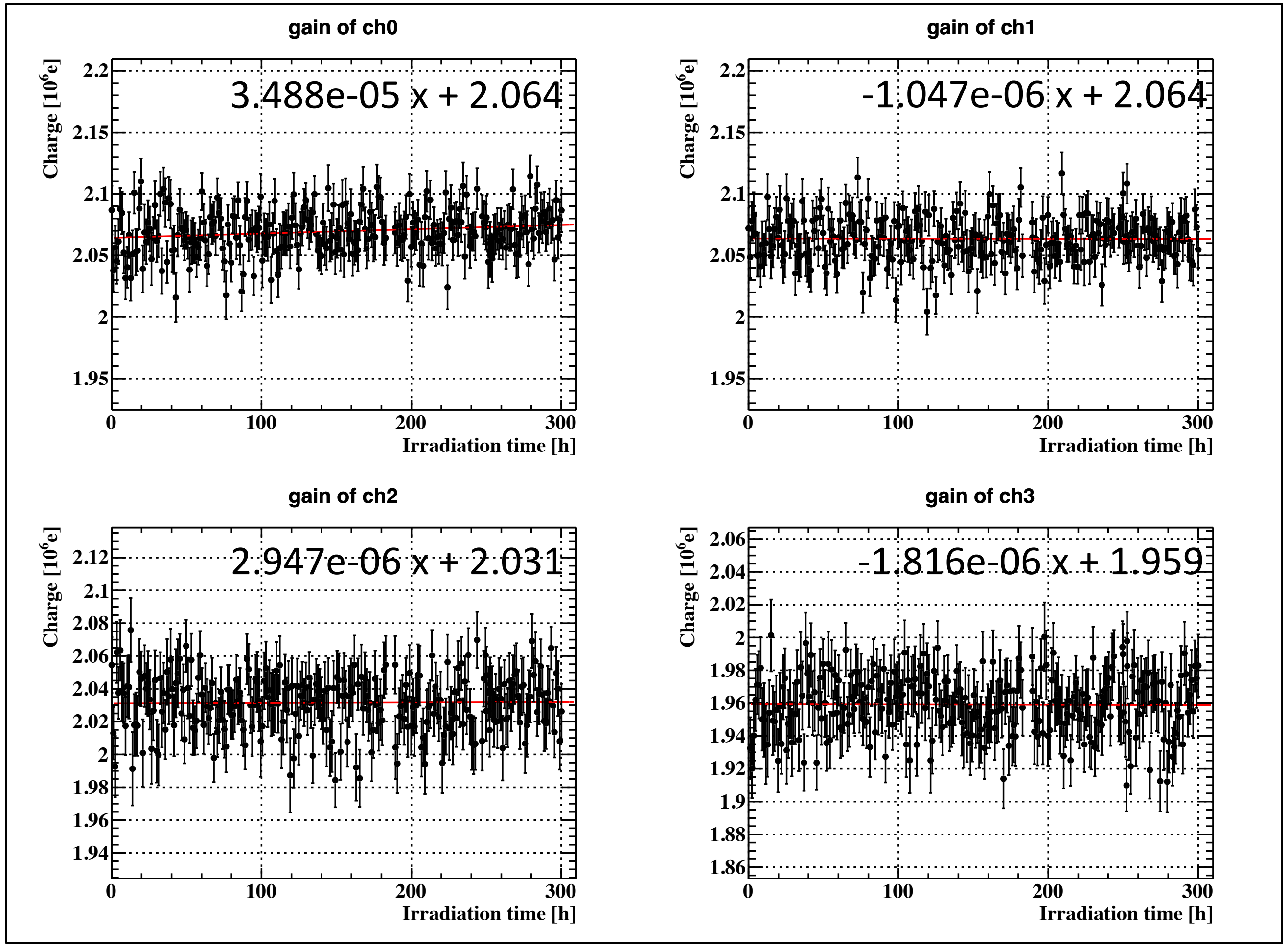
Signal of DAQ





Result – Stability of LXe

Vover ~ 3.5 V

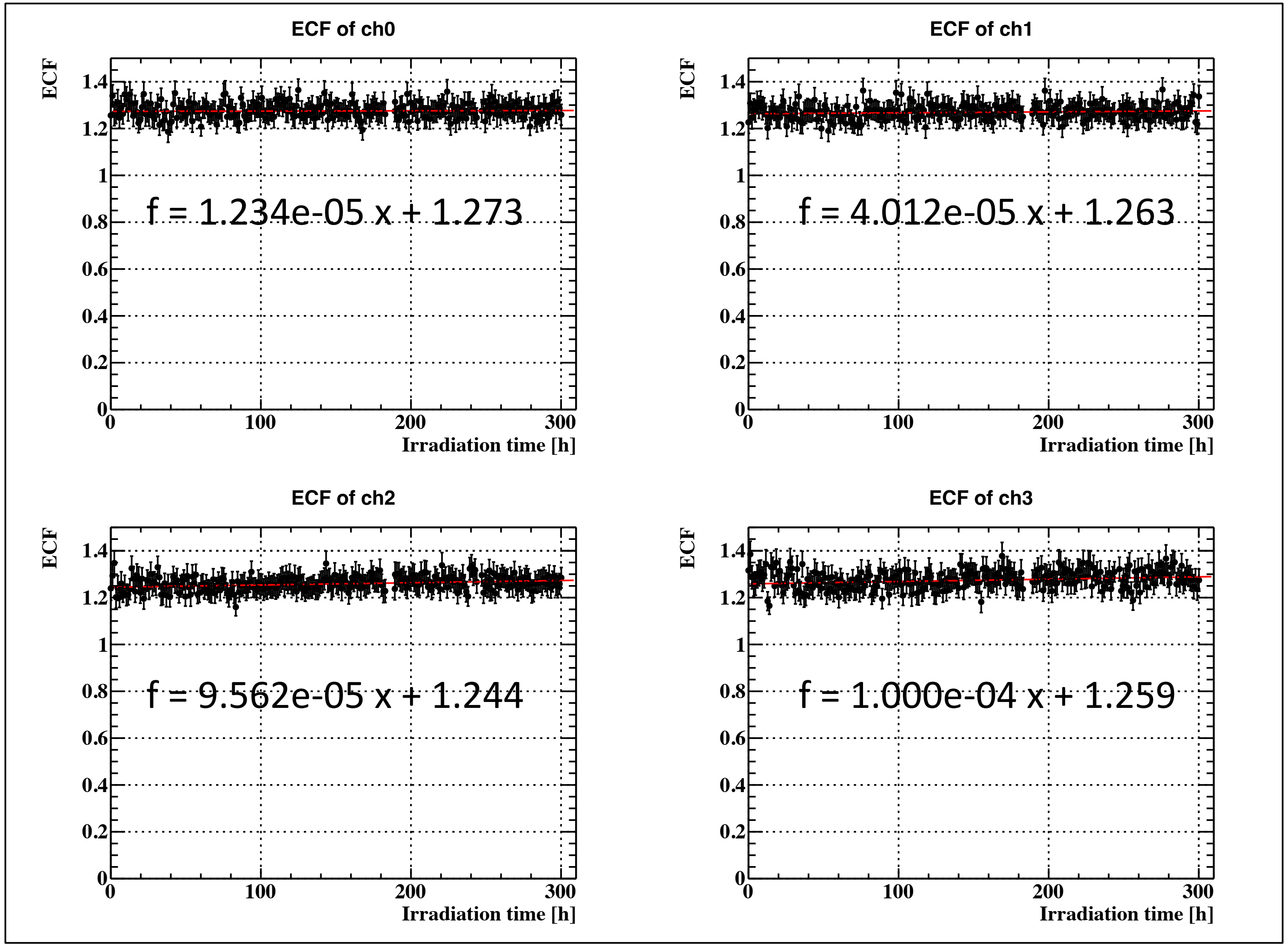


Temp: 168 ± 0.5 K

- Gain is stable during VUV light irradiation

Result – ECF (Excess Charge Factor) Transition

Vover ~ 3.5 V



Expected PDE decrease

Stopped muons in 2017-2021: 410×10^{12}

ch	0	1
ratio of radiation dose of this experiment to that of 2017-2021	0.015	0.017
Stopped Muons $\left(N_{\mu}^{\mathrm{stop}}\right)$ corresponding to this experiment	6.2×10^{12}	7.0×10^{12}
Expected Initial PDE	~15 %	~15 %
Expected PDE Decrease	~0.21-0.75 %pt	~0.24-0.85 %pt
Expected PDE Decrease (in relative)	~ 1.4-5.0 %	~ 1.6-5.6 %

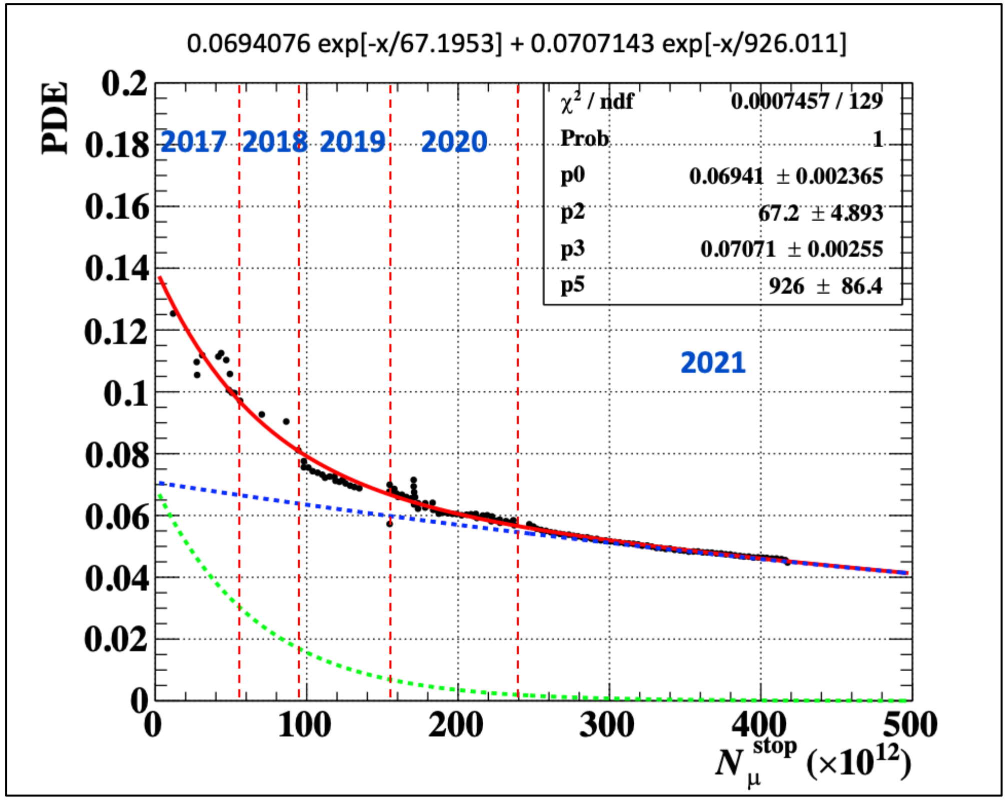
Expected PDE Decrease in relative (Lower Limit)

$$= 1 - \frac{0.074\exp(-N_{\mu}^{\mathrm{stop}}\cdot(15/14)/67) \ + \ 0.076\exp(-N_{\mu}^{\mathrm{stop}}\cdot(15/14)/926)}{0.15}$$

Expected PDE Decrease in relative (Upper Limit)

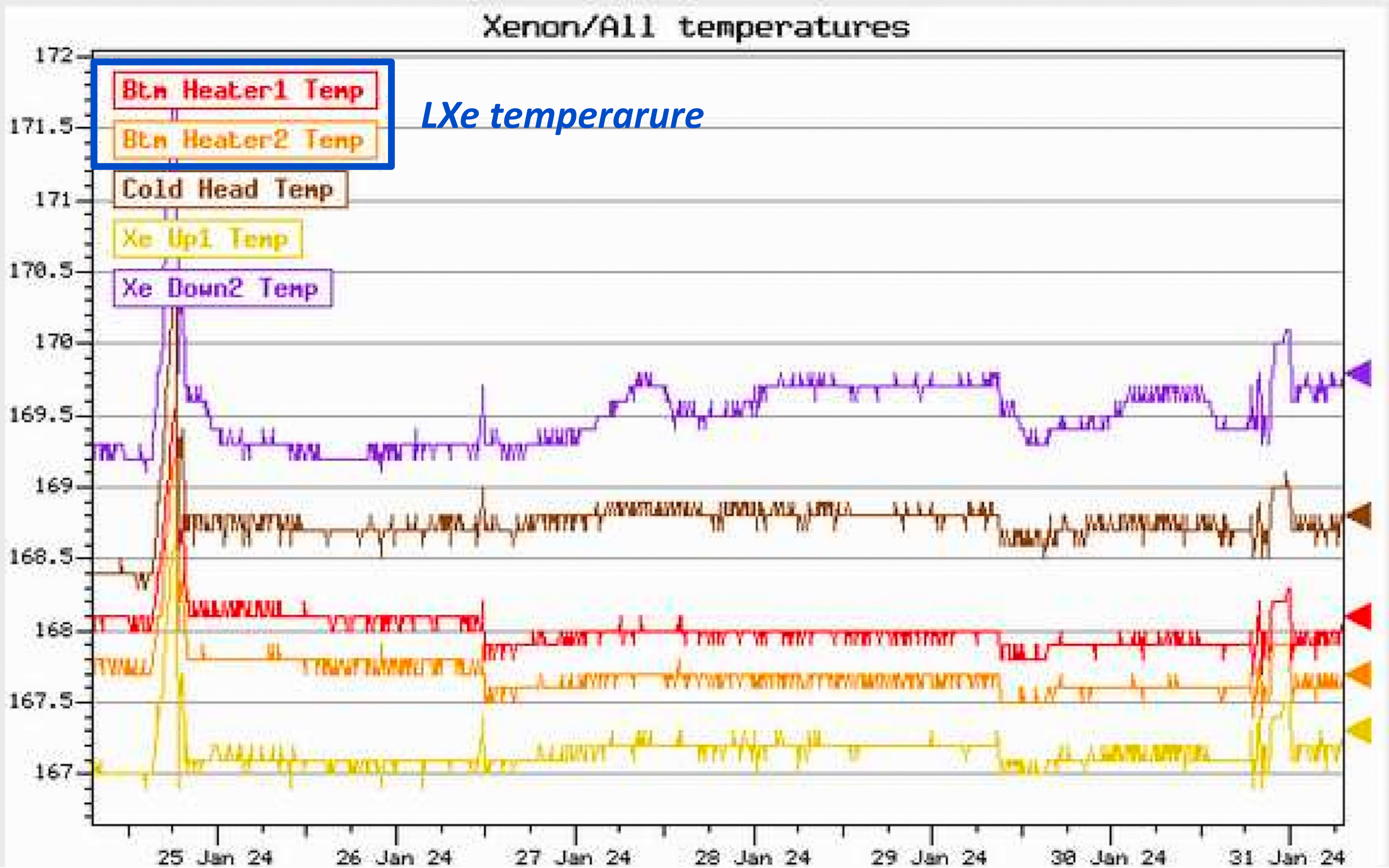
$$= 1 - \exp(-N_{\mu}^{\mathrm{stop}}\cdot(15/7.1)/926.011)$$

The PDEs in 2017-2021 are measured from the VUV-MPPCs at the center of the LXe



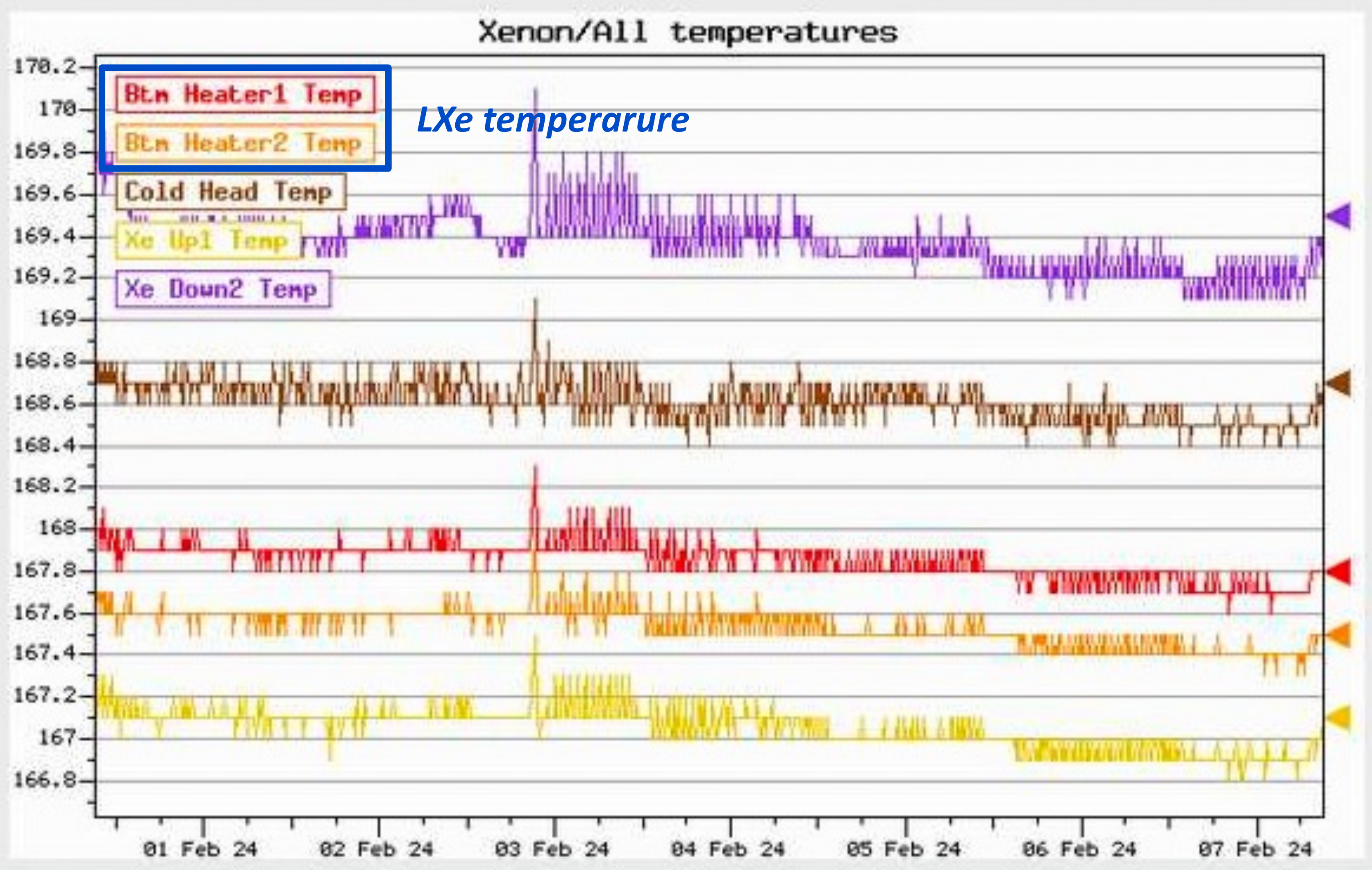
Partially modified from S. Kobayashi, PhD thesis (2022) (https://www.icepp.s.u-tokyo.ac.jp/download/doctor/phD2022_kobayashi.pdf)

Temperature history



LXe temperarure

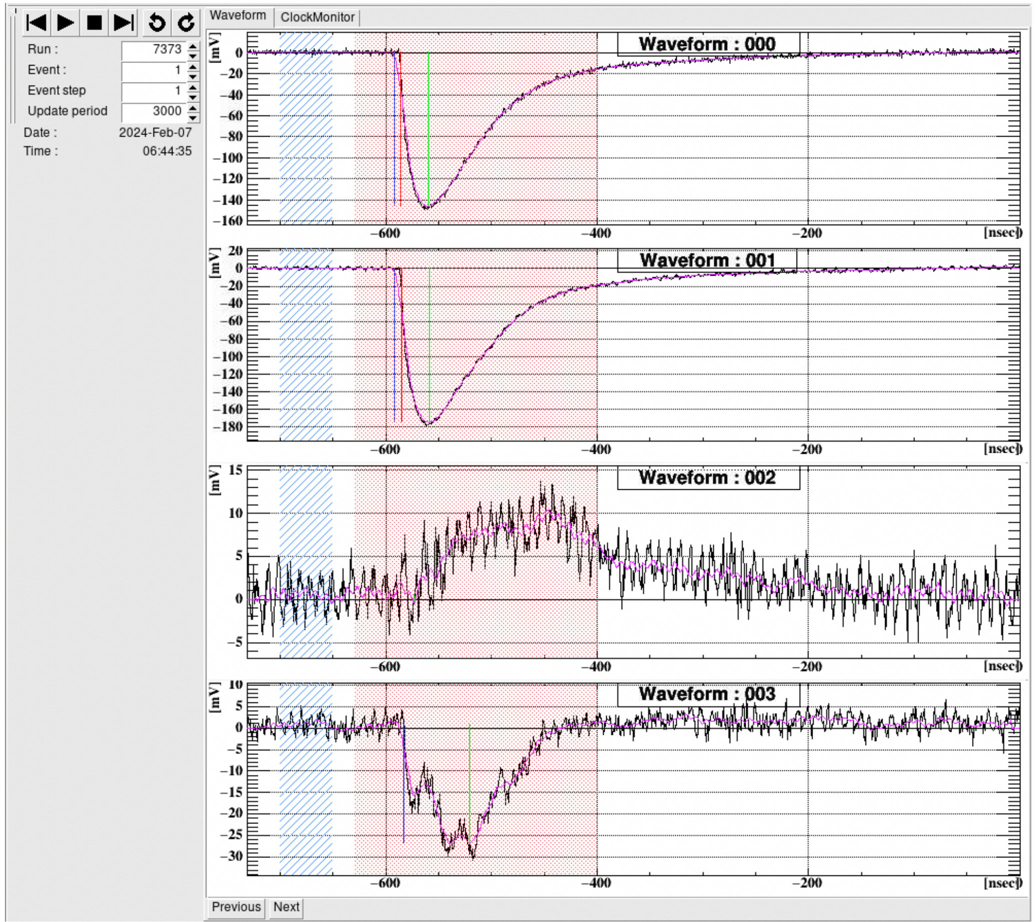
Temperature history



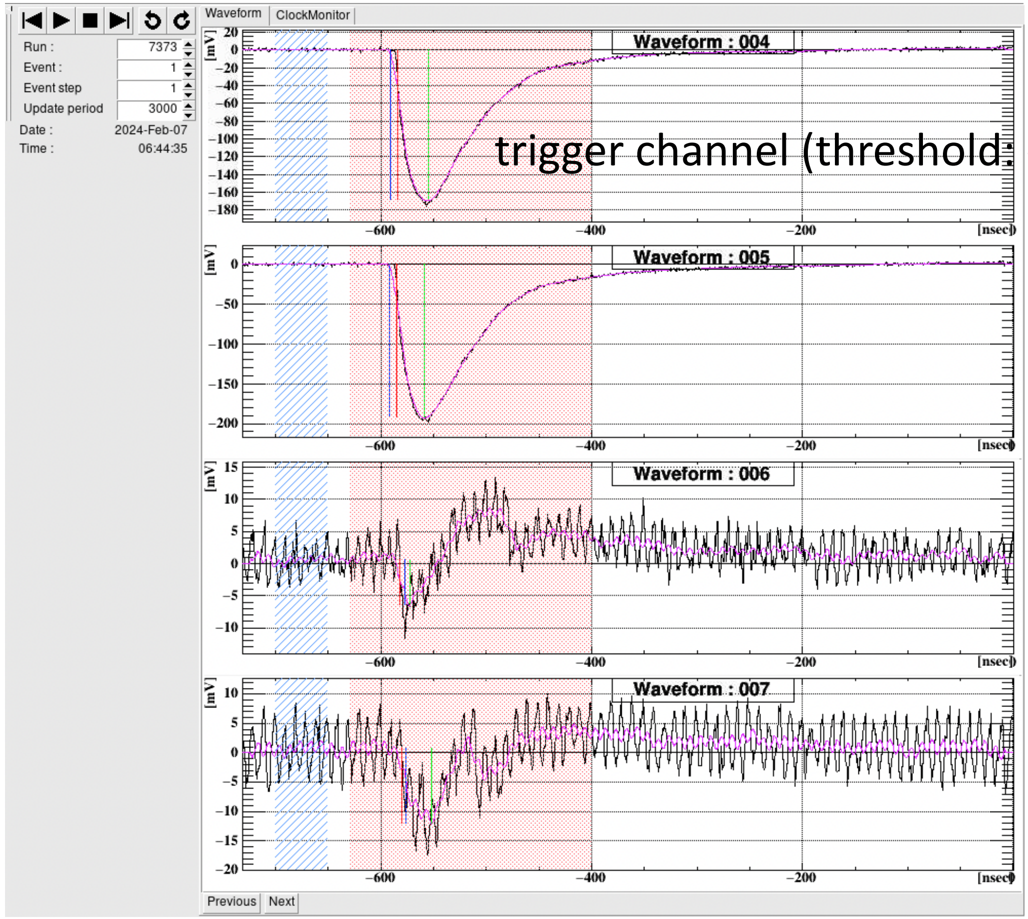
LXe temperarure

Result - Waveform of alpha-ray

- Mostly, the waveform of ch0, 1 were got as data.



Run : 7373
Event : 1
Event step 1
Update period 3000
Date : 2024-Feb-07
Time : 06:44:35

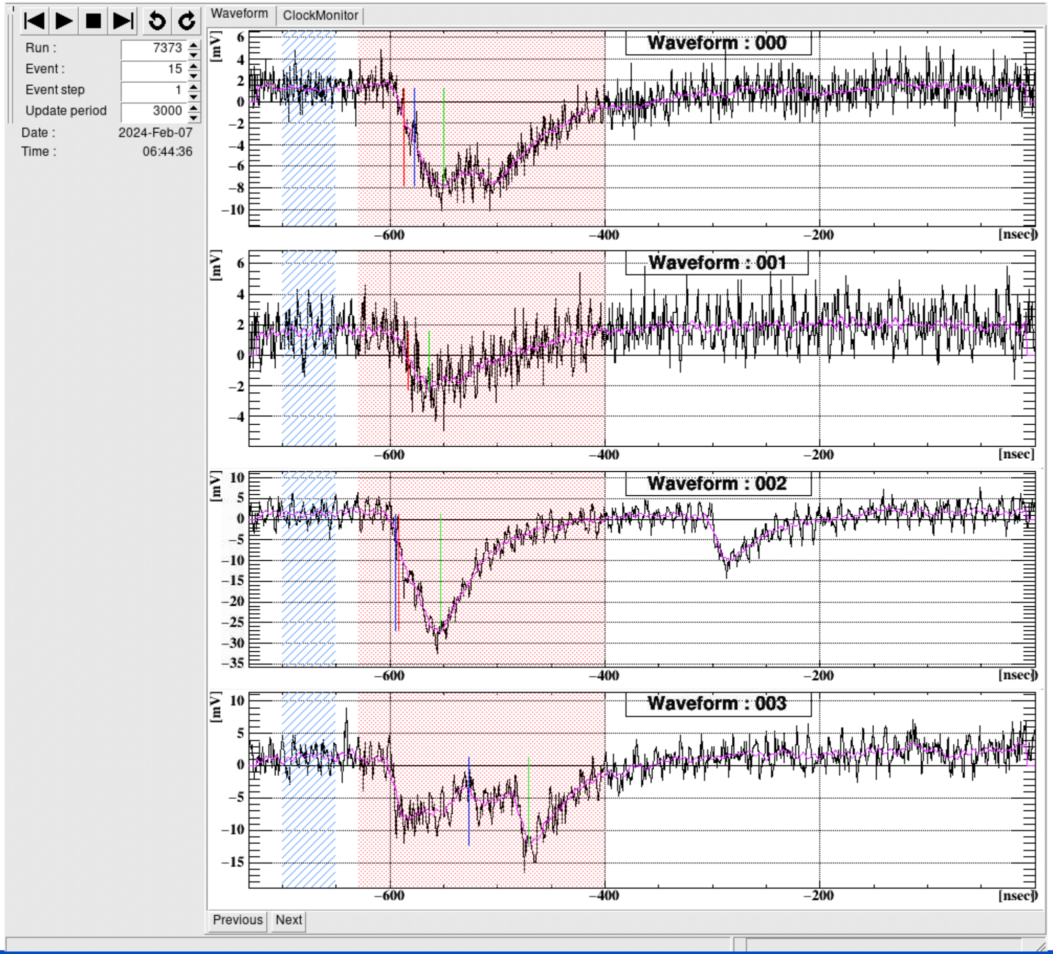


Run : 7373
Event : 1
Event step 1
Update period 3000
Date : 2024-Feb-07
Time : 06:44:35

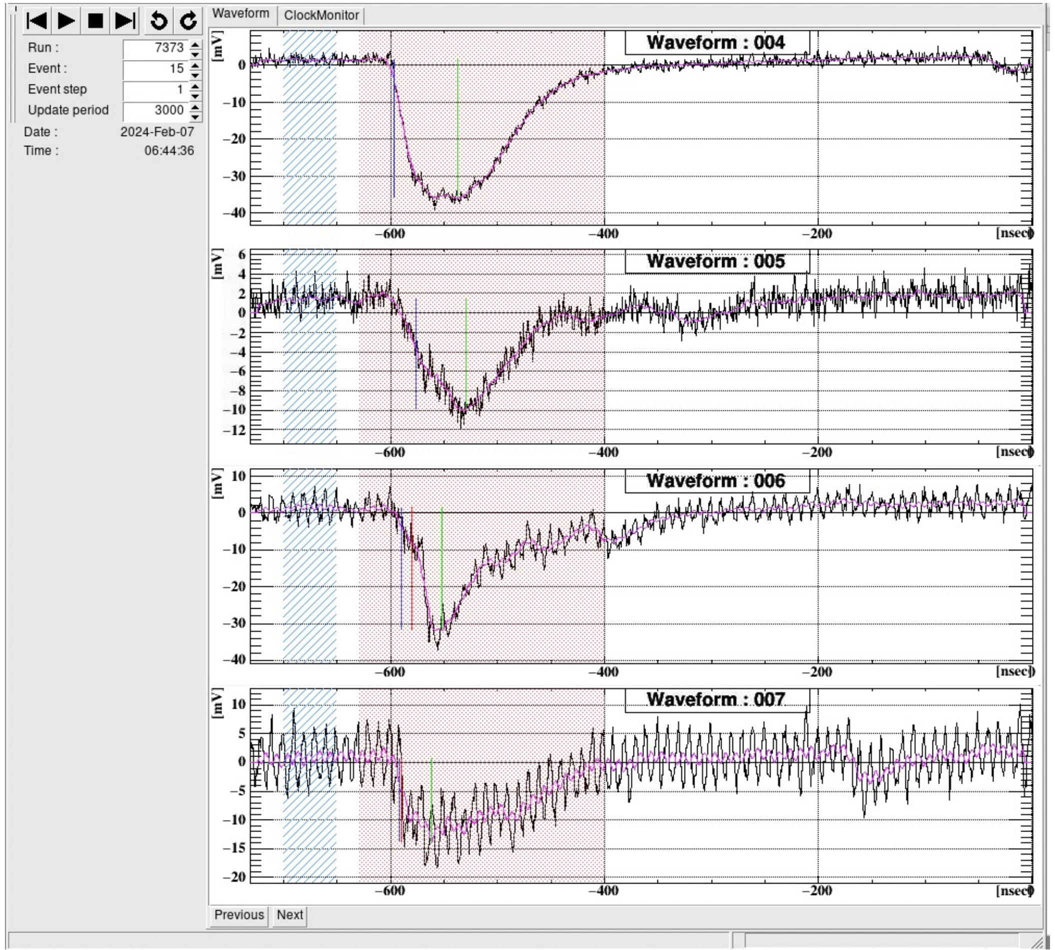
trigger channel (threshold: -20mV)

Result - Waveform of alpha-ray

- Sometimes small pulse came in ch0,1

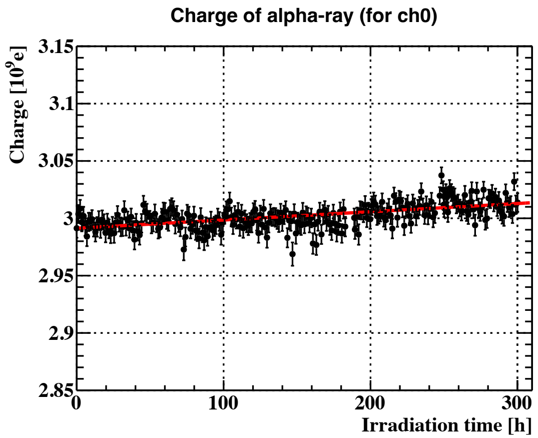


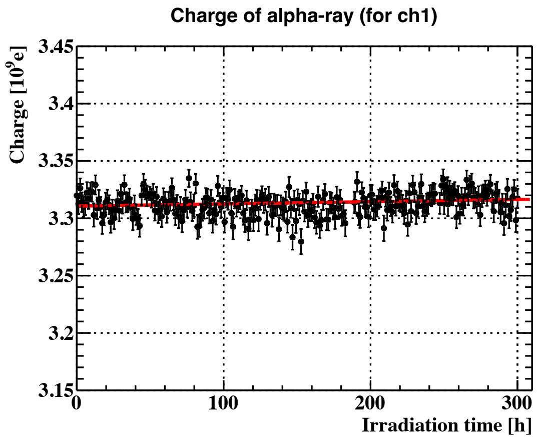
Run : 7373
Event : 15
Event step 1
Update period 3000
Date : 2024-Feb-07
Time : 06:44:36

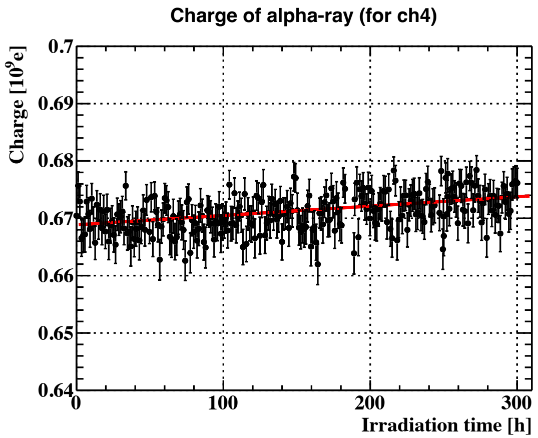


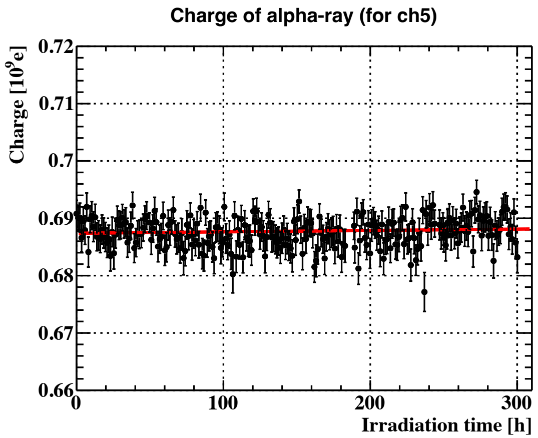
Run : 7373
Event : 15
Event step 1
Update period 3000
Date : 2024-Feb-07
Time : 06:44:36

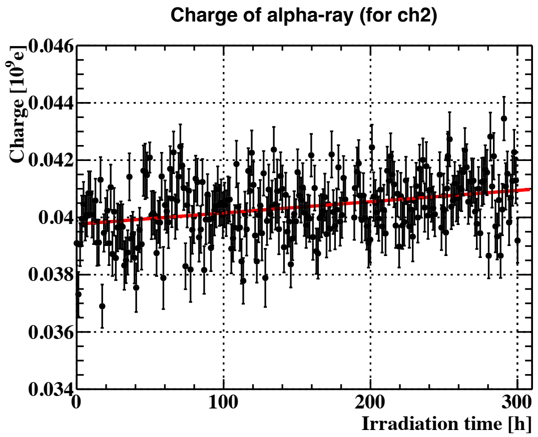
Alpha-ray charge history

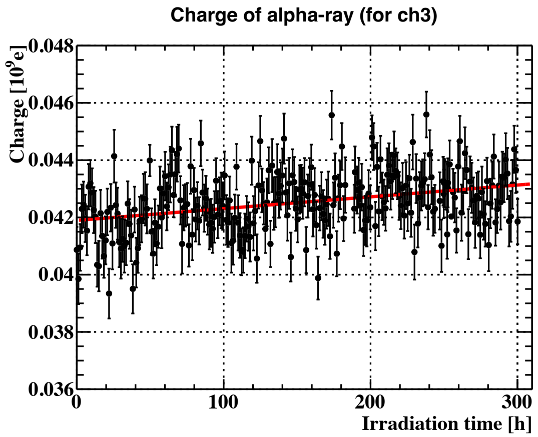

Charge of alpha-ray (for ch0)

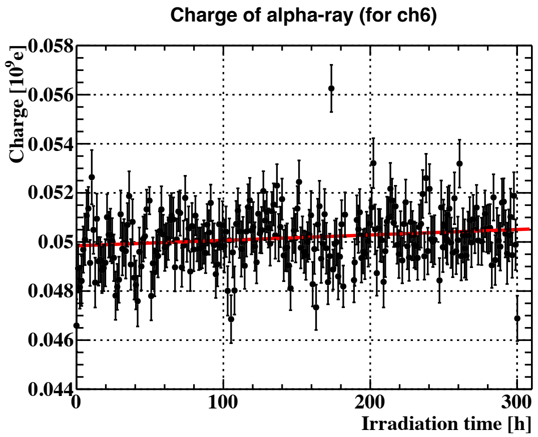

Charge of alpha-ray (for ch1)

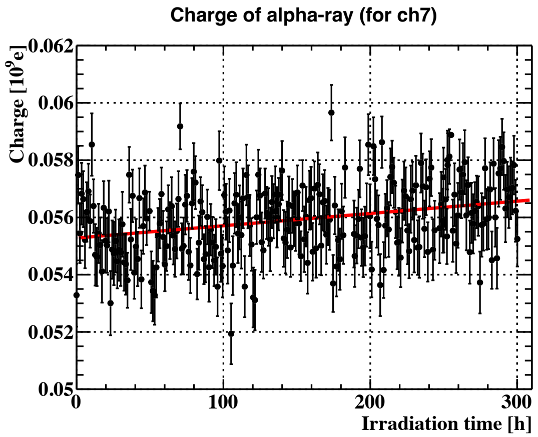

Charge of alpha-ray (for ch4)


Charge of alpha-ray (for ch5)

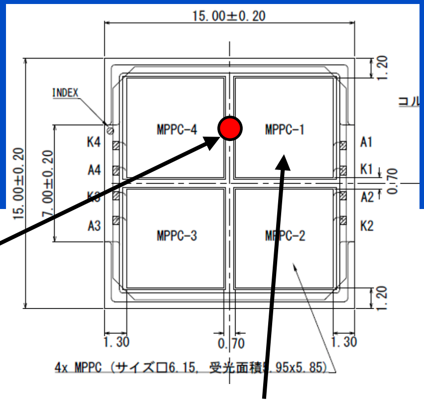

Charge of alpha-ray (for ch2)


Charge of alpha-ray (for ch3)


Charge of alpha-ray (for ch6)

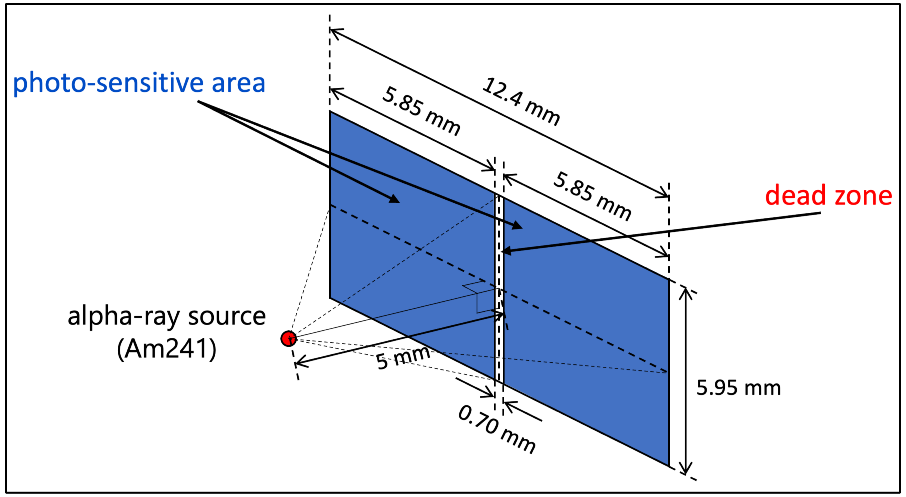

Charge of alpha-ray (for ch7)

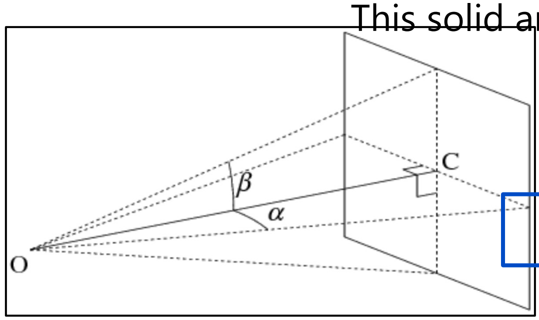
Calculation of the probability of photon entering a chip in VUV-MPPC



alpha-ray source
(Am241)

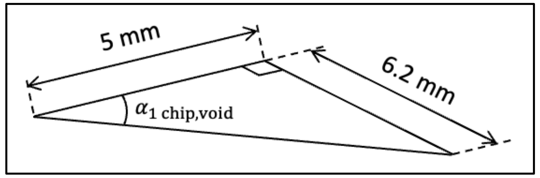
sensor chip
(5.95×5.85 mm²)

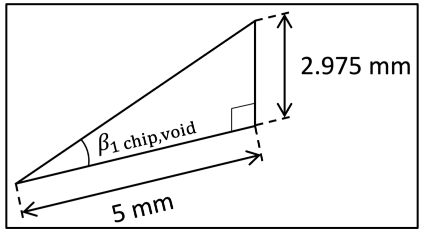


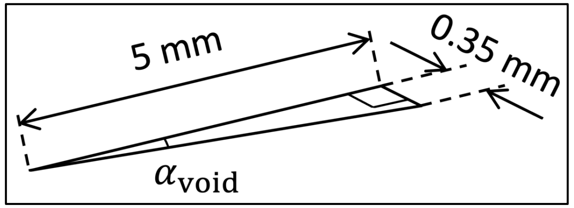


This solid angle is given by

$$\boxed{\Omega = 4 \arcsin(\sin \alpha \sin \beta)}$$







- The probability of photon entering a chip with including the dead zone: $P_{1\ \mathrm{chip,void}}$
  - $\alpha_{1\ \mathrm{chip,void}} = 0.892\ \mathrm{rad}$
  - $\beta_{1\ \mathrm{chip,void}} = 0.537\ \mathrm{rad}$

  -> $\Omega_{1\ \mathrm{chip,void}} = 2 \arcsin\left(\sin \alpha_{1\ \mathrm{chip,void}} \sin \beta_{1\ \mathrm{chip,void}}\right) = 0.819$
- $P_{1\ \mathrm{chip,void}} = \Omega_{1\ \mathrm{chip,void}}/4\pi = 0.0652$

- The probability of photon entering the dead zone: P_{void}
  - $\alpha_{\mathrm{void}} = 0.0699\ \mathrm{rad}$
  - $\beta_{\mathrm{void}} = \beta_{1\ \mathrm{chip,void}} = 0.537\ \mathrm{rad}$

  ->$\Omega_{\mathrm{void}} = 2 \arcsin(\sin \alpha_{\mathrm{void}} \sin \beta_{\mathrm{void}}) = 0.0714$
- $P_{\mathrm{void}} = \Omega_{\mathrm{void}}/4\pi = 0.00568$

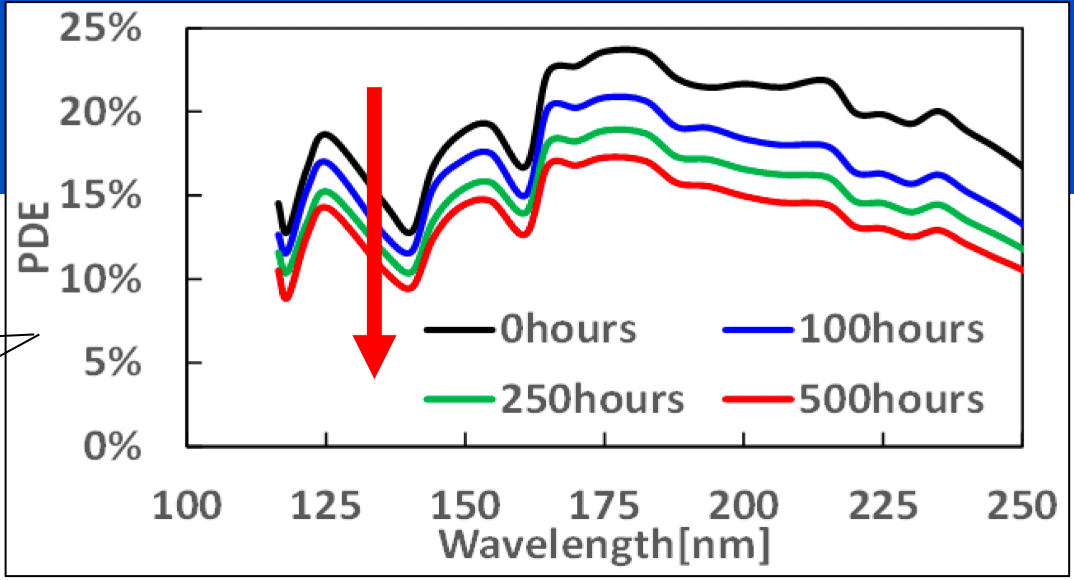
The probability of photon entering a chip without the dead zone:

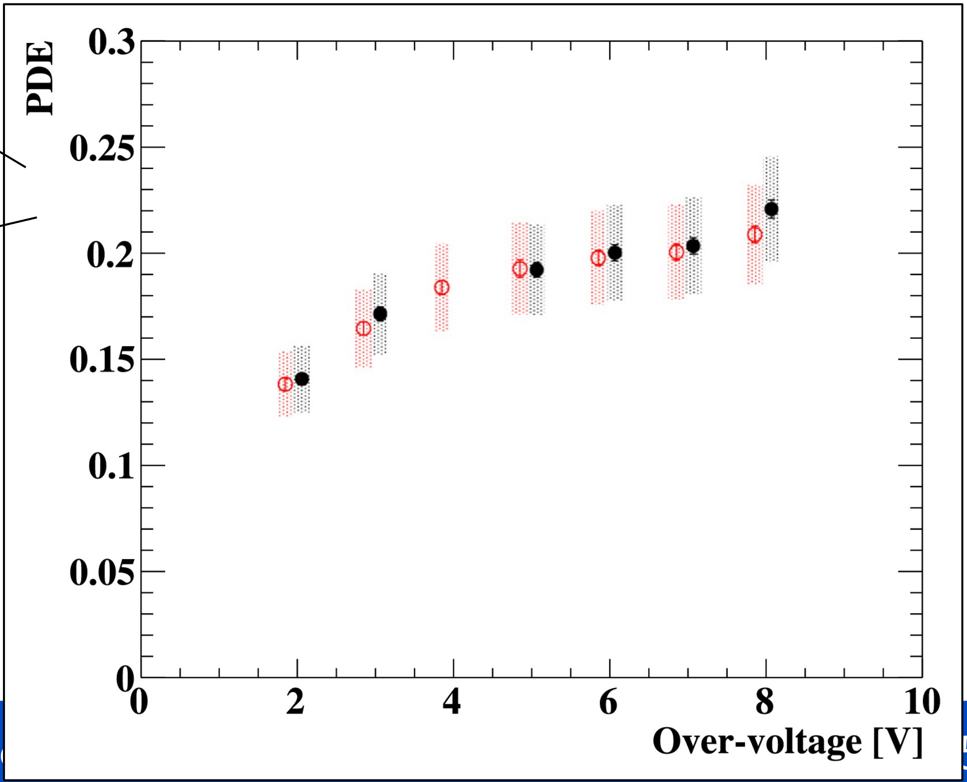
$$P_{1\ \mathrm{chip}} = P_{1\ \mathrm{chip,void}} - P_{\mathrm{void}} = 0.0652 - 0.00568 = \boxed{0.0595}$$

Estimation of PDE

Over voltage		
∼5 V	PDE to 175 nm (0 hour humifidification)	∼24 %
	PDE to 175 nm (250 hour humifidification)	∼19 %
∼3.5 V	PDE to 175 nm (0 hour humifidification)	∼18 %
	Estimated PDE to 175 nm (250 hour humifidification)	**∼15 %**
	Uncertainty of PDE to 175 nm	**∼ ±2%**

$$18\ \% - \frac{3.5\ \mathrm{V}}{5\ \mathrm{V}} \cdot (24 - 19)\ \% = 14.5\ \% {\sim} 15\ \%$$





Number of photon entering a chip in VUV-MPPC

- $N_{pho} = \frac{E\alpha}{W} \times P_{1\ \mathrm{chip}} = \frac{4.78\ \mathrm{MeV}}{18.75\ \mathrm{eV}} \times 0.0595 = (1.52 \pm 0.7) \times 10^4$ photon
  - $E_\alpha = 4.78\ \mathrm{MeV}$
  - W = 17.9 eV or 19.6 eV −> (18.75 ± 0.85) eV
  - $P_{1\ \mathrm{chip}}$ = 0.0595
- Becquerel of Am241: 100 Bq??
  ->Irradiation dose:
  1.52×10^4 photon $\times 100\ \mathrm{Hz} \cdot (5.95 \cdot 5.85\ \mathrm{mm}^2)^{-1}$
  $= 4.4 \times 10^4\ \mathrm{photon} \cdot \mathrm{Hz} \cdot \mathrm{mm}^{-2}$
  $= 5.5 \times 10^8\ \mathrm{photon} \cdot \mathrm{h}^{-1} \cdot \mathrm{mm}^{-2}$
- The reasons of mismatch of expected and measured radiation rate
  - Reflection of the surface of VUV-MPPC
  - The alpha-ray emitted from the shadow of wire
  - The real solid angle is larger than expected one

ch	0	1
expected impinging photon per alpha-ray	$(1.52 \pm 0.7) \times 10^4$ photon	$(1.52 \pm 0.7) \times 10^4$ photon
expected radiation rate	$5.5 \times 10^8\ \mathrm{photon} \cdot \mathrm{h}^{-1} \cdot \mathrm{mm}^{-2}$	$5.5 \times 10^8\ \mathrm{photon} \cdot \mathrm{h}^{-1} \cdot \mathrm{mm}^{-2}$
measured radiation rate	$2.0 \times 10^7\ \mathrm{photon} \cdot \mathrm{h}^{-1} \cdot \mathrm{mm}^{-2}$	$2.2 \times 10^7\ \mathrm{photon} \cdot \mathrm{h}^{-1} \cdot \mathrm{mm}^{-2}$
Ratio of measured radiation rate to expected radiation rate	**0.036**	**0.04**

Shimada’s measured radiation rate (including ECF):
$9.7 \times 10^7\ \mathrm{photon} \cdot \mathrm{h}^{-1} \cdot \mathrm{mm}^{-2}$

Number of photon entering ch0

$$\frac{1.98}{2.064\cdot10^{-3}\cdot0.15}\,\mathrm{photon}\cdot\frac{1}{1.273}$$
$$\cdot\,37.7\ \mathrm{Hz}\cdot300\cdot3600\ \mathrm{sec}$$
$$\cdot\,(5.95\cdot5.85\ \mathrm{mm}^2)^{-1}$$
$$=5.9\times10^{9}\ \mathrm{photon}\cdot\mathrm{mm}^{-2}$$

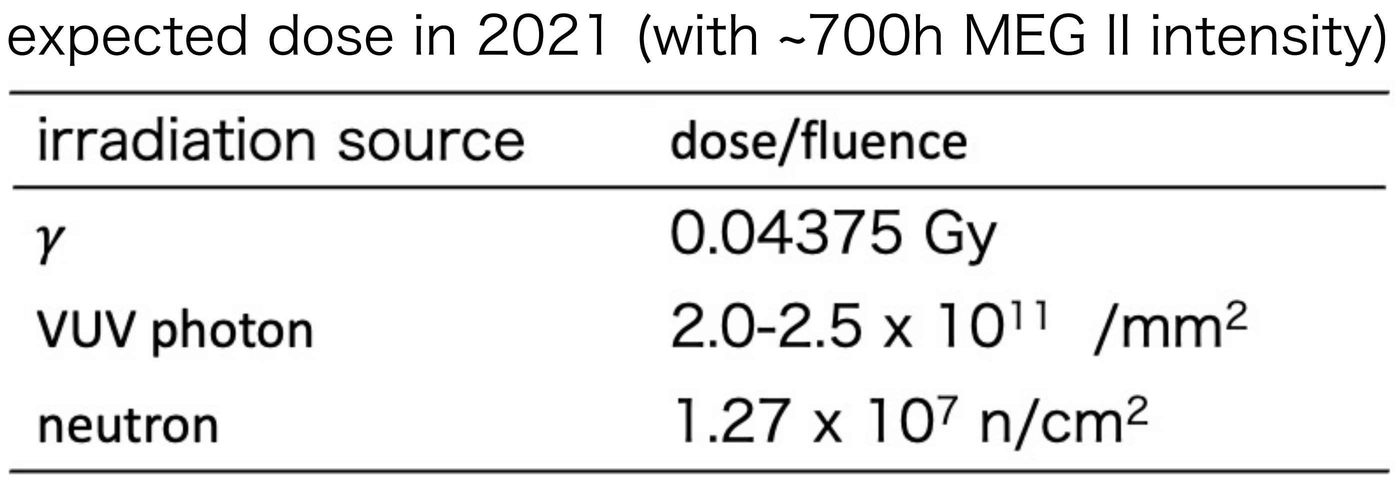
trigger rate	37.7 event/sec
mean charge	1.98 10^9*e
gain	2.064 10^6*e
expected PDE	~15%
ECF	1.273
Surface area of 1 chip	$5.95\times5.85\ \mathrm{mm}^2$
Irradiation time	300 hours

ratio of radiation dose to 2017-2021 run: *0.053*

Radiation dose in Shimada’s thesis (including ECF (〜30 %), maybe overestimated)	9.7×10^7 photon/h/mm2 https://www.icepp.s.u-tokyo.ac.jp/download/master/m2020_shimada.pdf
Radiation dose in this experiment	2.0×10^7 photon/h/mm2

VUV light irradiation in this experiment	*5.9*10^9 photon*mm^-2*
VUV light irradiation in 2021 run	*4.0*10^11 photon*mm^-2*
ratio of radiation dose to 2021 run	*0.015*

Expected irradiation dose in 2021 MEG II

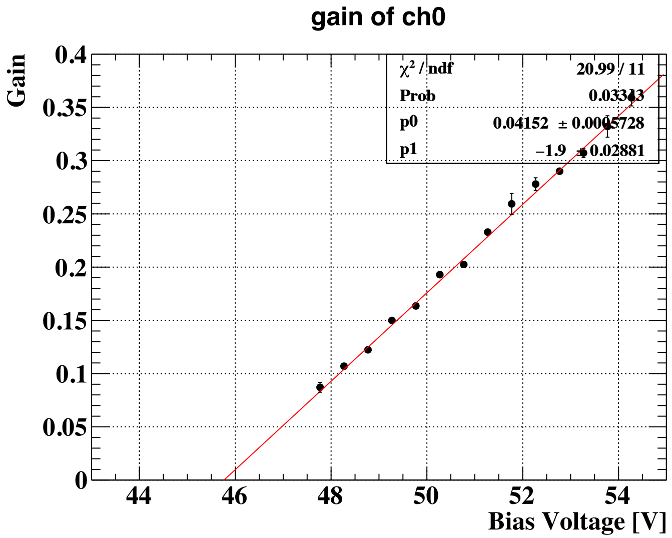


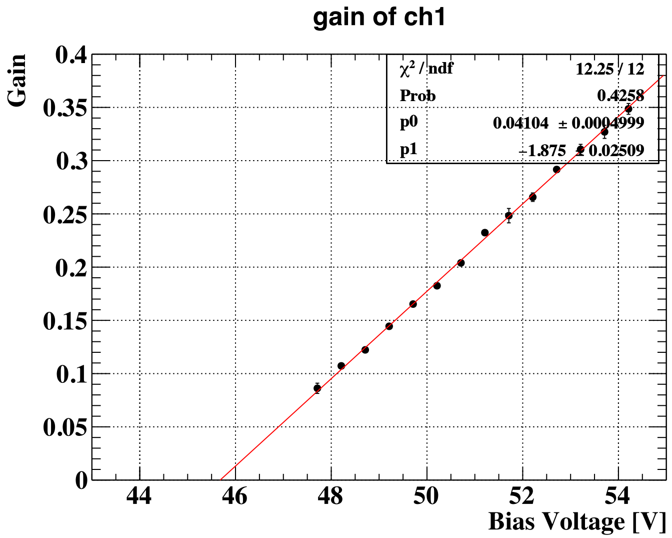
expected dose in 2021 (with ~700h MEG II intensity)

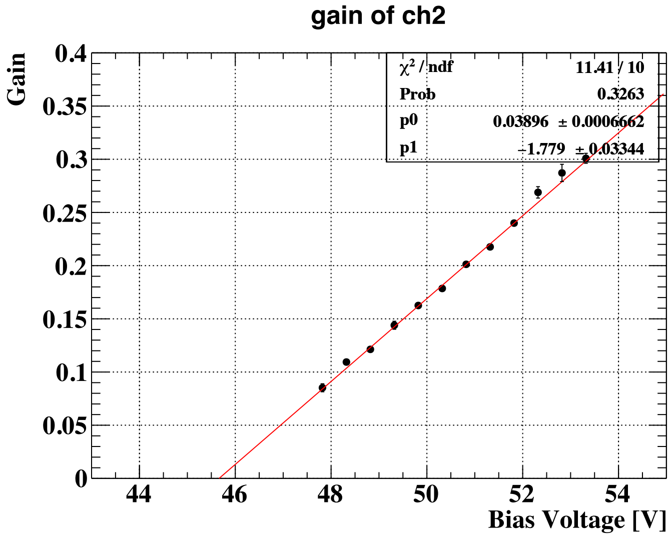
irradiation source	dose/fluence
γ	0.04375 Gy
VUV photon	2.0-2.5 x 10^{11} /mm^2
neutron	1.27 x 10^7 n/cm^2

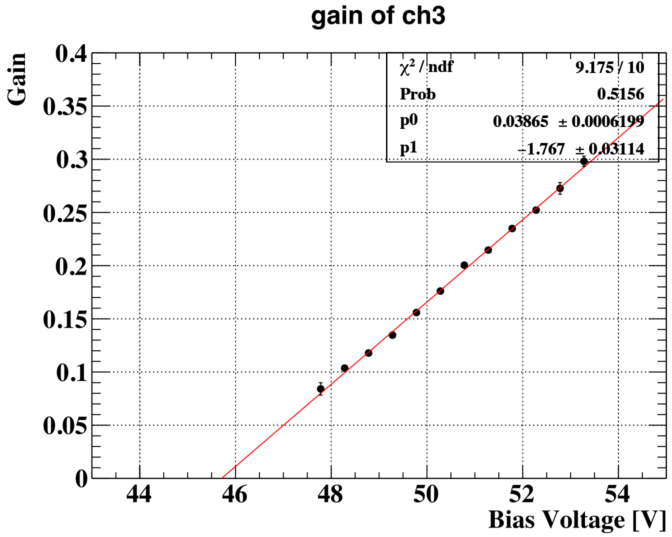
Result – Breakdown Voltage

	Breakdown voltage [V]
ch0	45.76
ch1	45.68
ch2	45.66
ch3	45.71

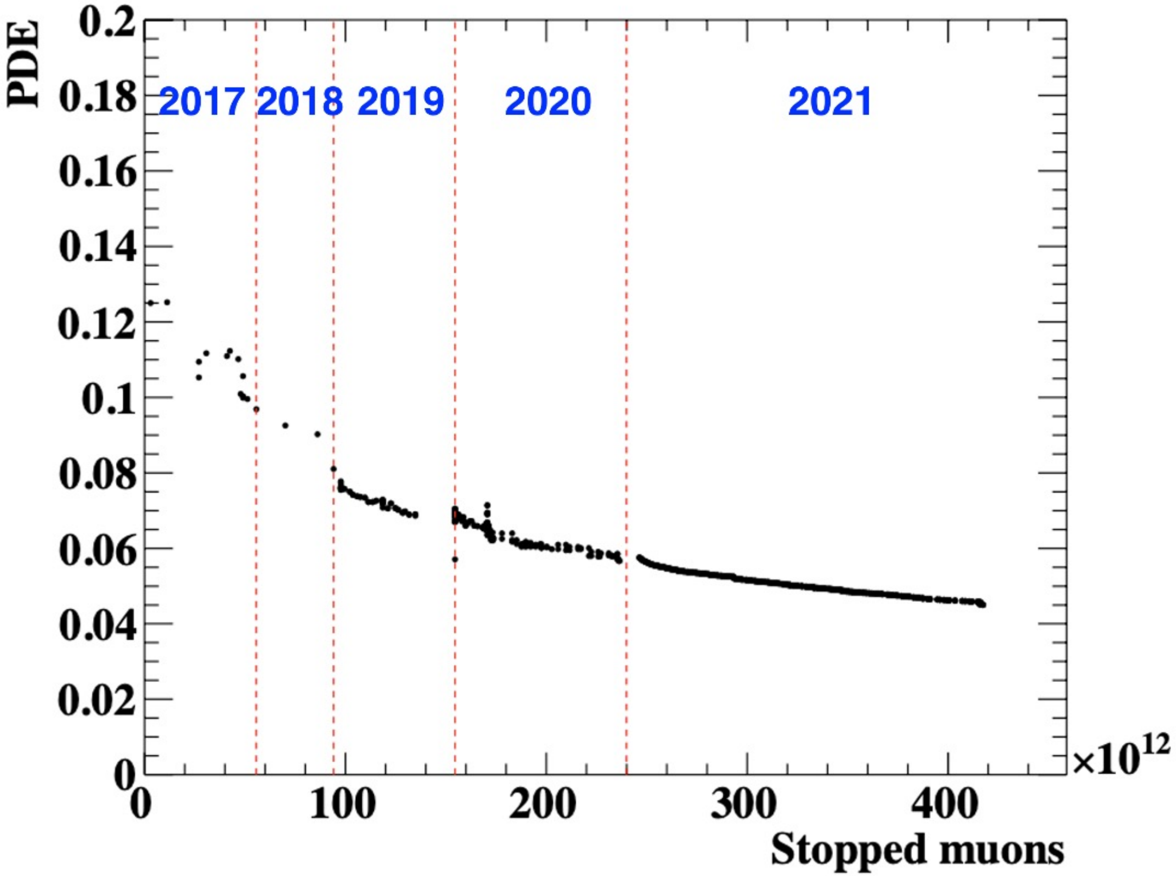

gain of ch0


gain of ch1

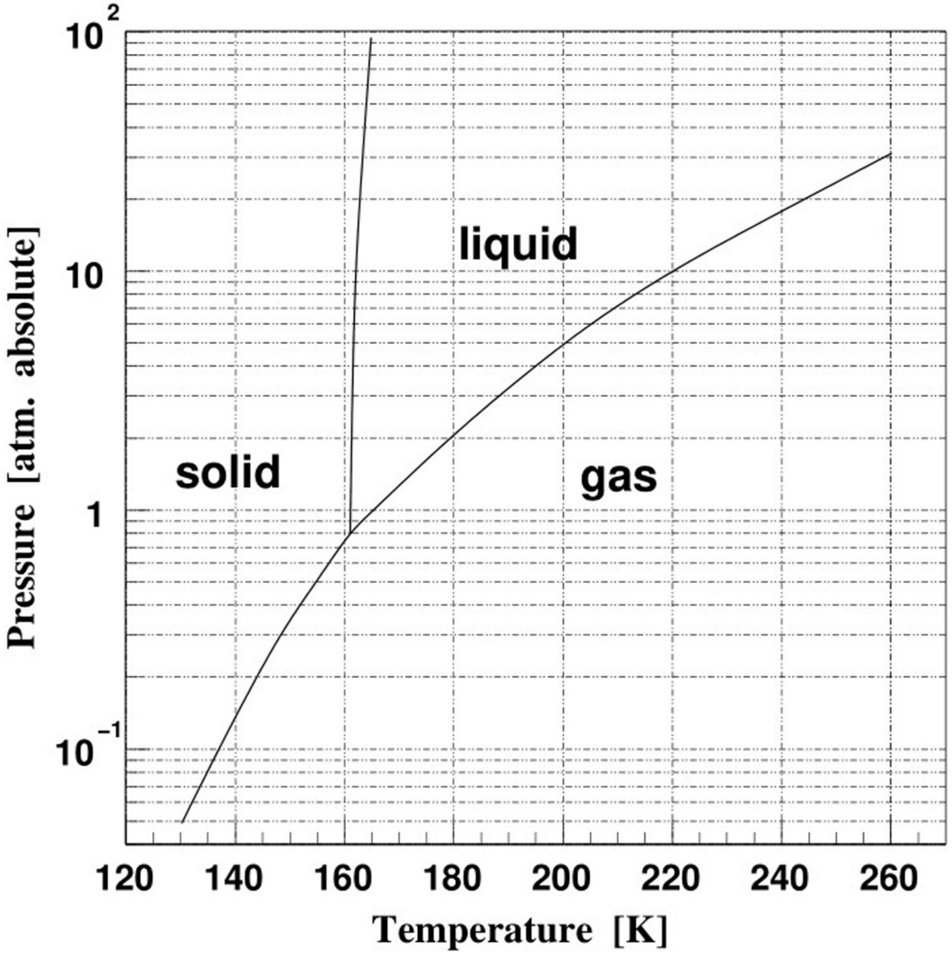

gain of ch2


gain of ch3

PDE degrease in 2017-2021

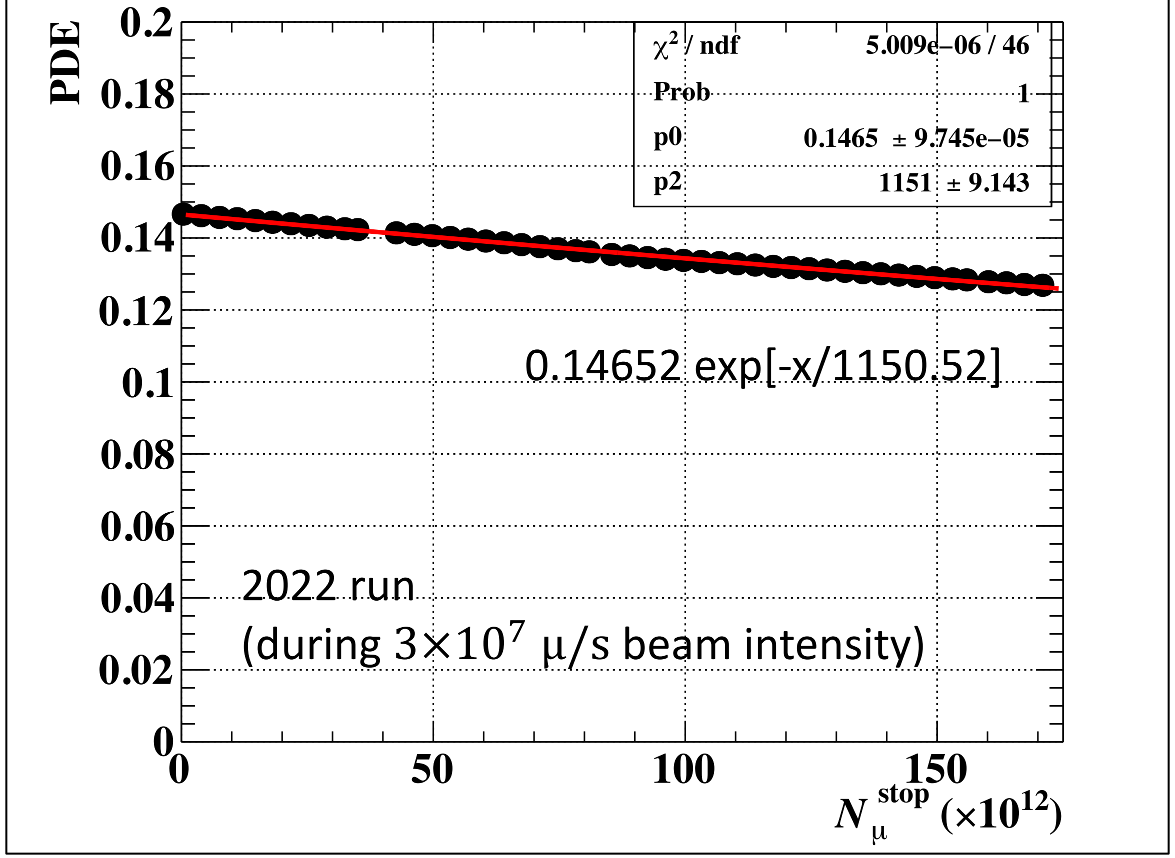


Phase diagram of xenon

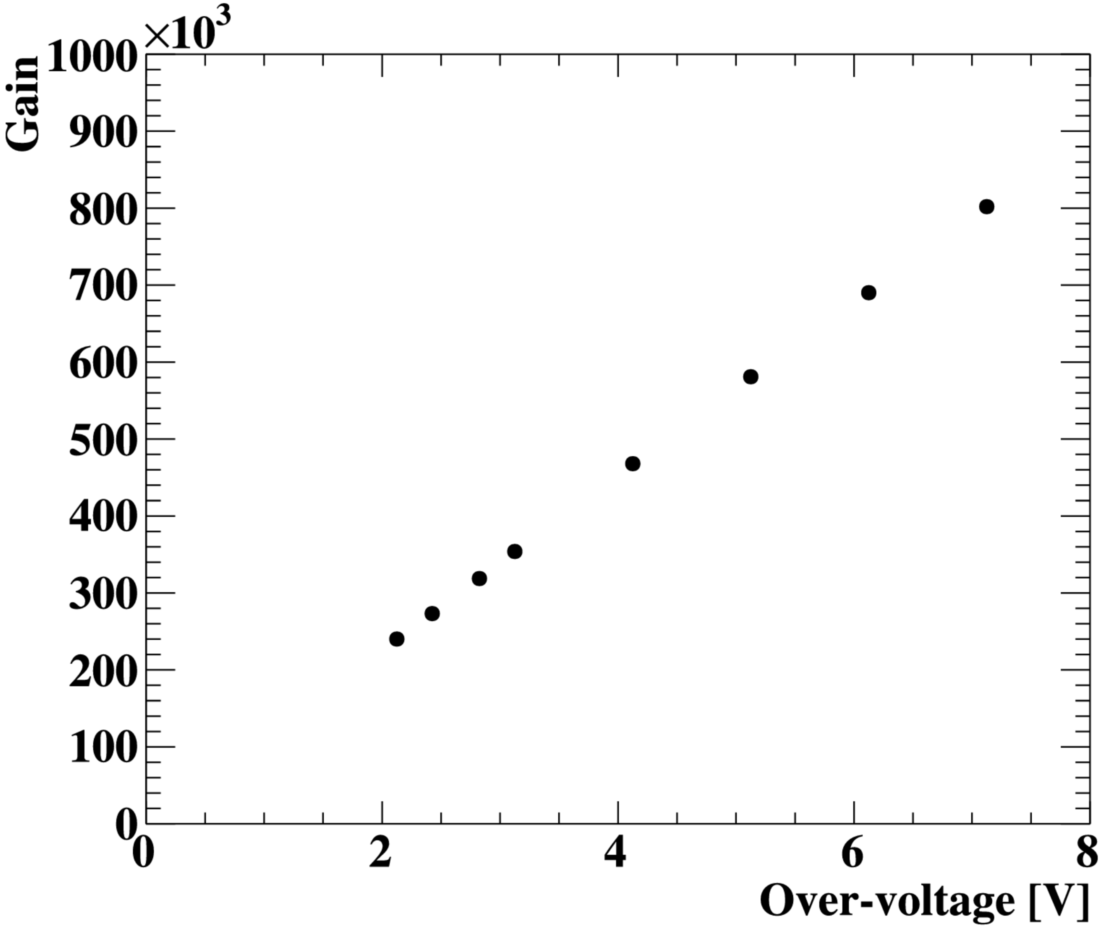


Result – Expected PDE decrease

stopped muons in 2022 run (during 3×10^7 μ/s beam intensity): 170×10^{12}

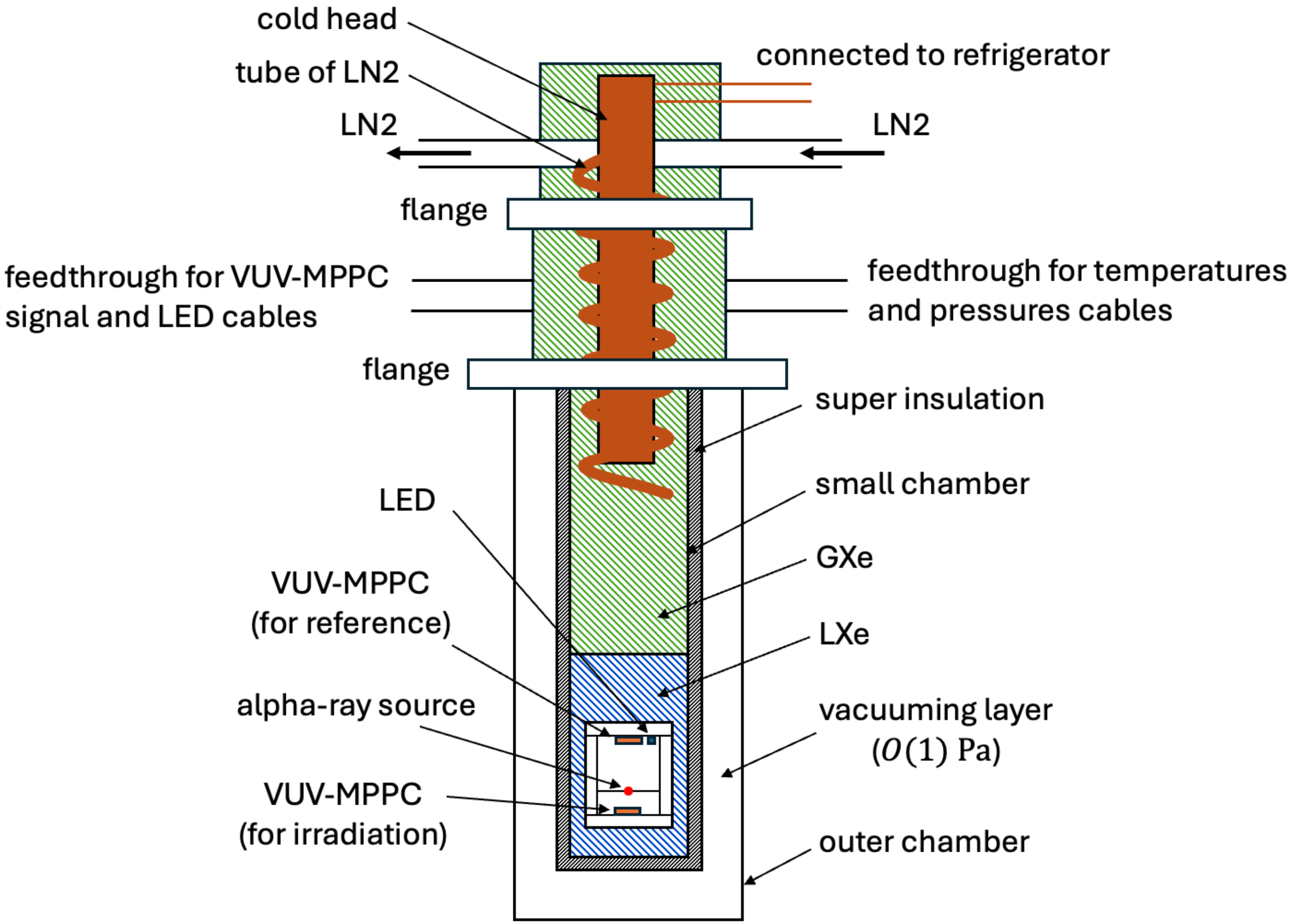


Gain vs Over voltage



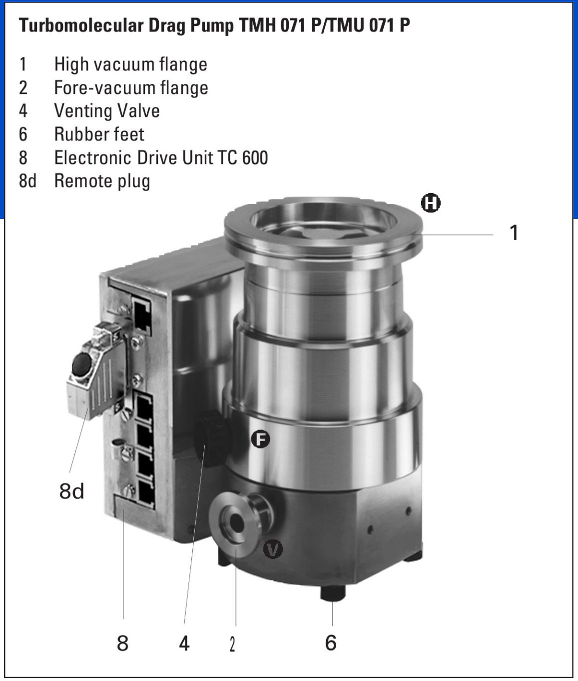
Small chamber construction

- Inside small chamber, separeted into GXe and LXe
  - By cooling, LXe accumulated in the bottom of small chamber
- Small chamber is covered by a outer chamber
  - Between the small and outer chamber is vacuumd
  - This works like "magic bottle"



Vacuuming and leak check

- Turbo pump (Pfeiffer Vacuum, TMH 071P)
  - Used for vacuuming inside the small chamber
  - Reach $O(10^{-4})\ \mathrm{Pa}$ in this experiment
- Scroll pump
  - Used for vacuuming of the outer chamber
  - Reach $O(1)\ \mathrm{Pa}$ in this experiment
- Helium leak detector (Alcatel, ASM 122 D)
  - Detects the leak of a flange using helium
  - There were no leak even high-sensitivity ($O(10^{-10})\ \mathrm{mbar \cdot l/s}$)



Pulification of GXe and cooling of small chamber

- After vacuuming, entering GXe inside the small chamber
  - Purify GXe throught the getter (impurity < 1 ppb)
- Cooling of inside the small chamber
  - Refrigerator (Iwatani, PDC08)
    - Cooling cold head inside small chamber
  - LN2
    - Helped cooling of the small chamber
    - Emergency Used (because the refrigerator didn't work

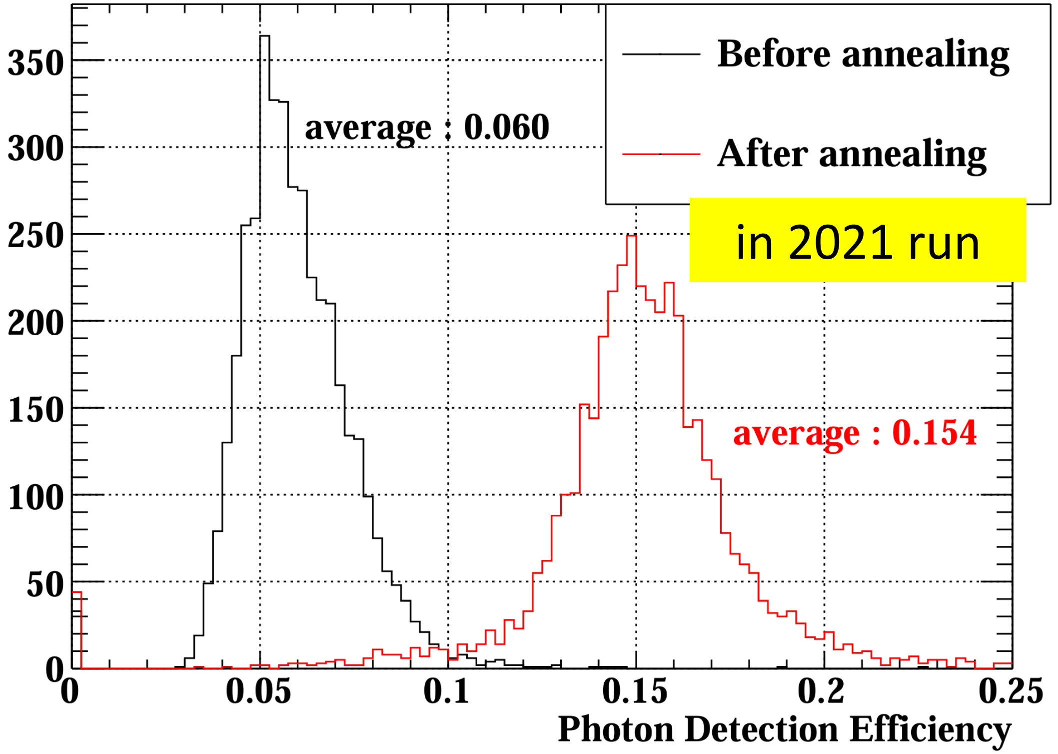
Tips

- Superinsulation
    - Multiple layer film made from alminum
- LN temperature: 77 K (196 ˚C)

Annealing

- Heating the VUV-MPPCs (at 70 ˚C)
  - to remove the accumulated positive charges
- PDE can be returned to original value by annealing.
- Sample
  - Baking condition: 150 ℃ x 16 hours

Annealing each MPPC for 28 hours (at 70 °C)



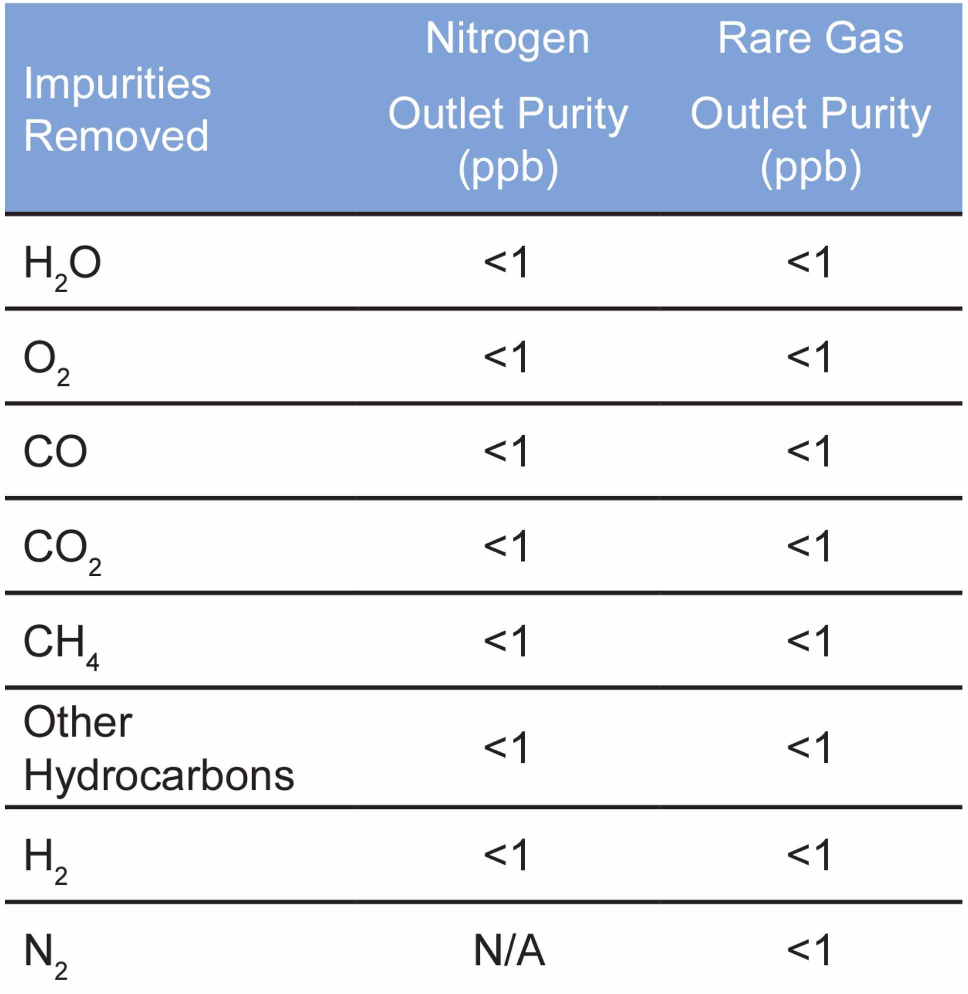
in 2021 run

Calculation of LXe height filling inside small chamber

- small chamberの容器の内径（直径）: 101 mm
  ->面積: 8008 mm^2 = 80.1 cm^2
  ->容器の底から~~20.6~~ 36 cmまで、液体キセノンに浸る
  1.65L = 1650 cm^3
  1 L = 1000 cm^3

- GXe inside high pressure tank: 750 L, 0.23 MPa
  - when the pressure is 0.12 MPa, the volume is 750×0.23/0.12 = 1438 L
- LXe volume is 500 times smaller than GXe volume
  - 1438 L in GXe -> 1438/500 = 2.88 L in LXe
- Inner diameter of small chamber: 101 mm
  - Bottom area of small chamber: $8.01\times10^3\ \mathrm{mm}^2$
- the height of LXe inside small chamber is $2.88\times10^6 / 8.01\times10^3$ = 360 mm = 36 cm
  - 1 litre = $1\times10^6\ \mathrm{mm}^2$

Getter (PS3-MT3-R-2)



Impurities Removed	Nitrogen Outlet Purity (ppb)	Rare Gas Outlet Purity (ppb)
H_2O	<1	<1
O_2	<1	<1
CO	<1	<1
CO_2	<1	<1
CH_4	<1	<1
Other Hydrocarbons	<1	<1
H_2	<1	<1
N_2	N/A	<1