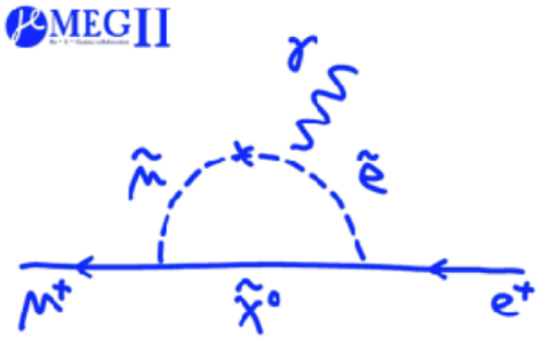
東京大学
素粒子物理国際研究センター
International Center for Elementary Particle Physics
The University of Tokyo

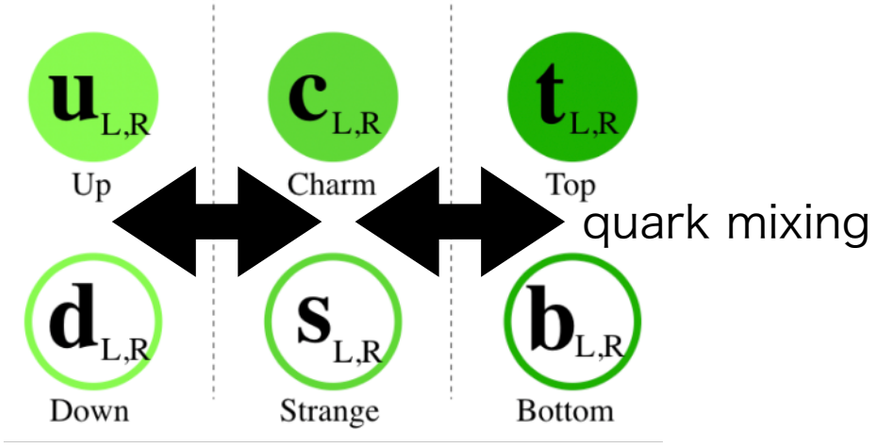


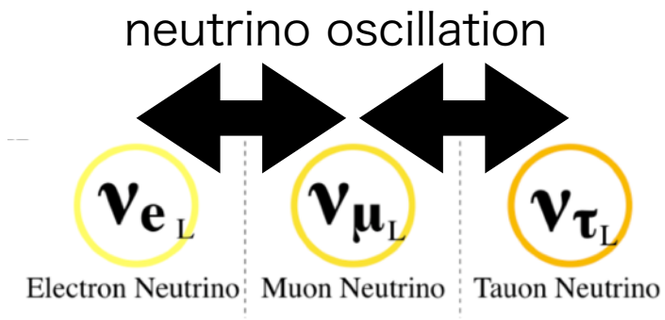
MEG II実験液体キセノン検出器のMPPCのアニーリングによる光子検出効率回復について

Sei Ban (ICEPP), for the MEG II collaboration
17th Mar. 2022, JPS 第77回年次大会(2022) @online, 17aA572-8

Charged Lepton Flavor Violation

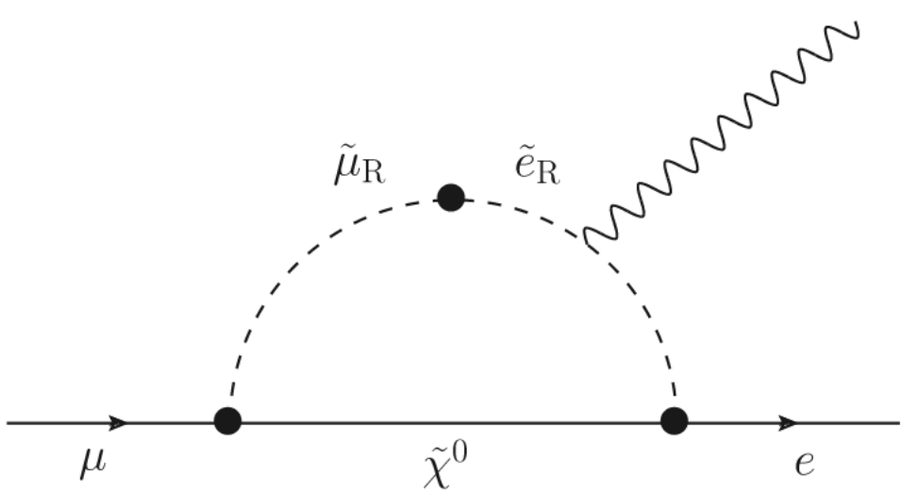
- In quark and neutrino (neutral lepton) sector, the flavor violates in SM



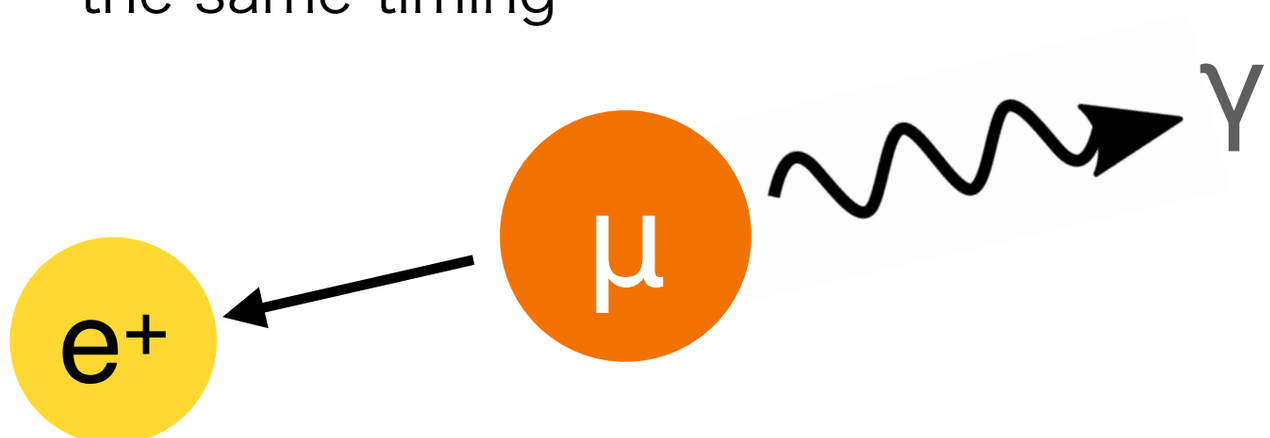


- Some theories BSM predict flavor violation in the charged lepton sector
  - In the Standard Model, it is practically prohibited : $Br(\mu \rightarrow e\gamma) = 10^{-54}$
  - In BSM, $Br(\mu \rightarrow e\gamma) \sim O(10^{-14})$ is predicted : large enough to search

- Signal : Gamma-ray and positron with 52.8 MeV ($=m_\mu/2$)
  back-to-back
  the same timing

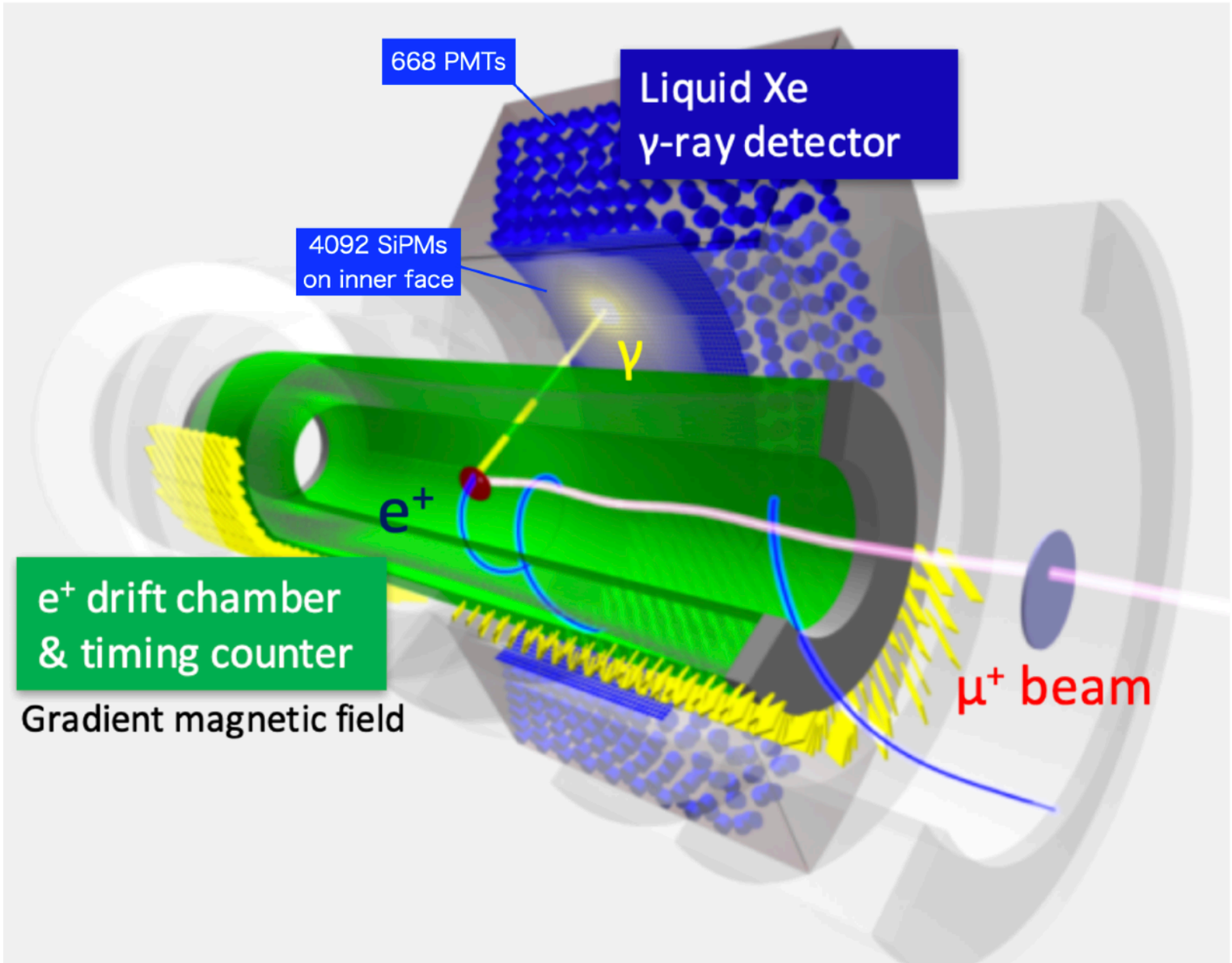


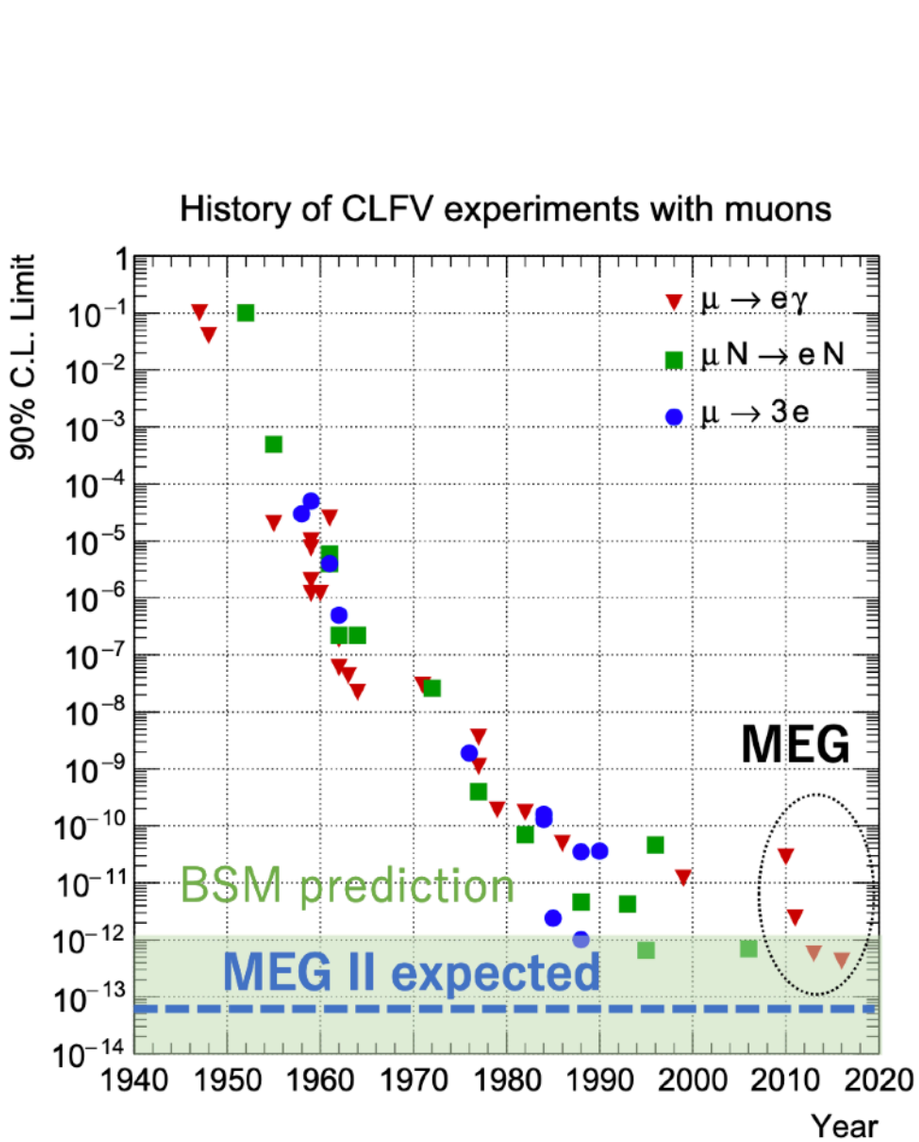
Possible diagram in SUSY-GUT senario



MEG II experiment

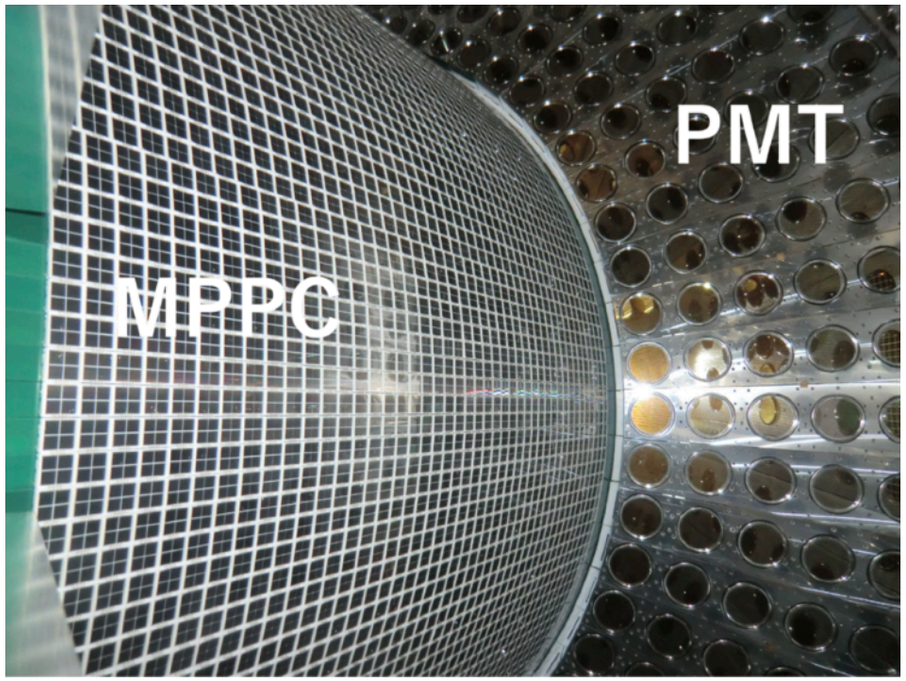
- MEG II experiment aims to search for charged lepton flavor violation : $\mu^+ \rightarrow e^+\gamma$
  - with higher sensitivity by one order of magnitude compared to the MEG
- Consists of LXe detector for γ-ray, drift chamber & timing counter for e^+
- Engineering run and physics run with full number of readout channels were conducted in 2021

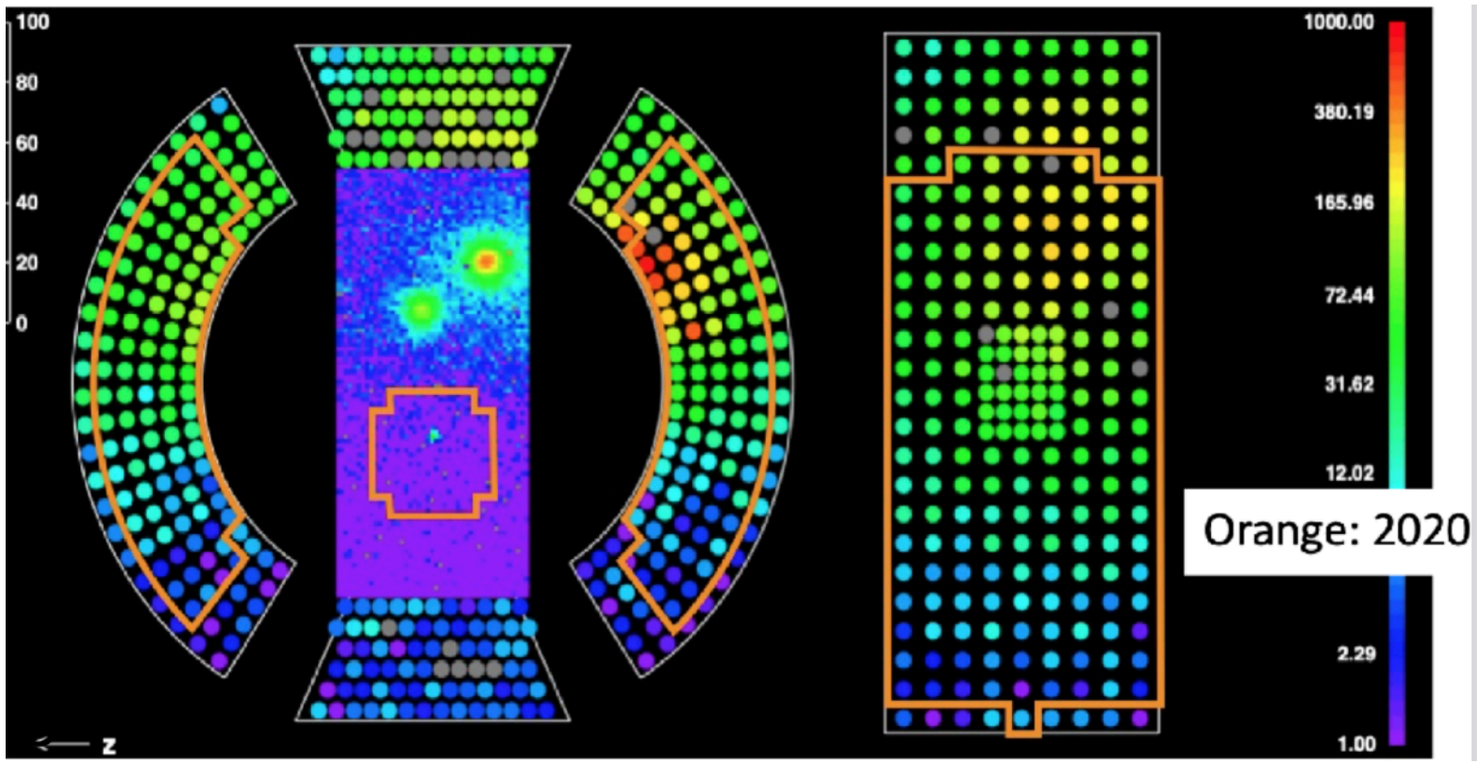




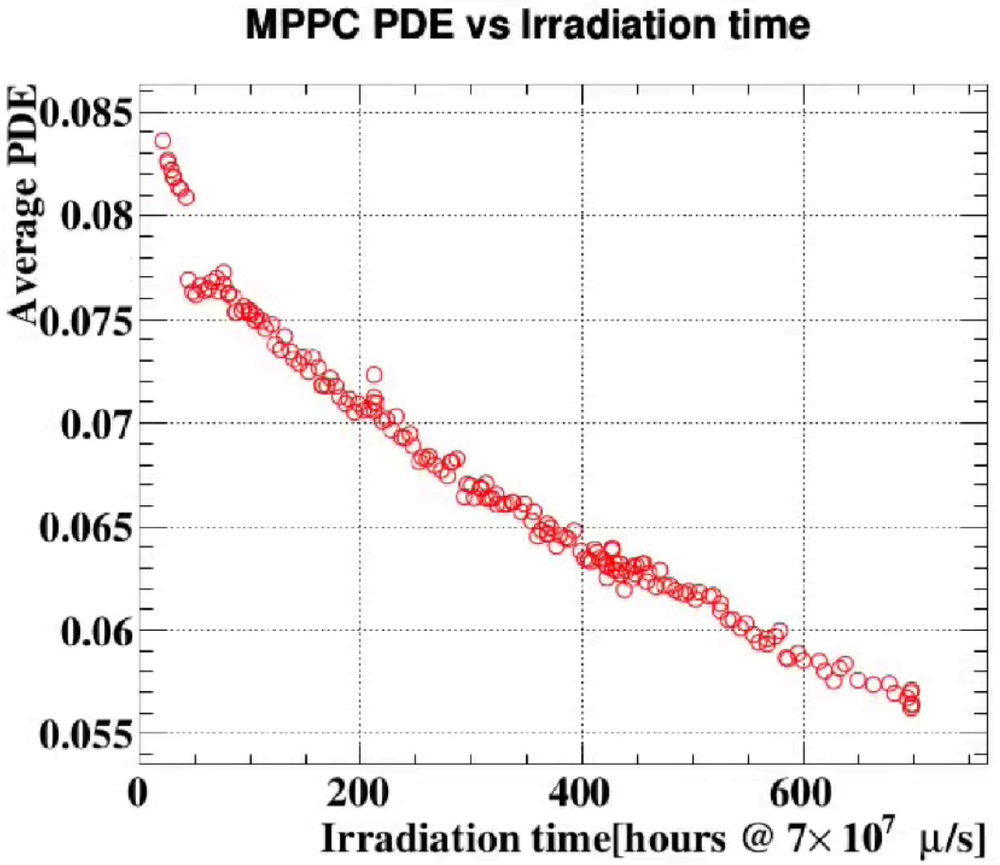
Liquid xenon detector / PDE decrease

- Liquid xenon detector consists of 4092 VUV-sensitive MPPCs on the inner face and 668 VUV-PMTs on the other faces
  - Measuring the energy, position and timing of incoming gamma-rays
- Photon Detection Efficiency (PDE) decrease was observed in 2021 run (known problem since 2017)
  - Averaged PDE : 8.4% → 5.6%
  - The cause of PDE decrease is under investigate (radiation damages?)





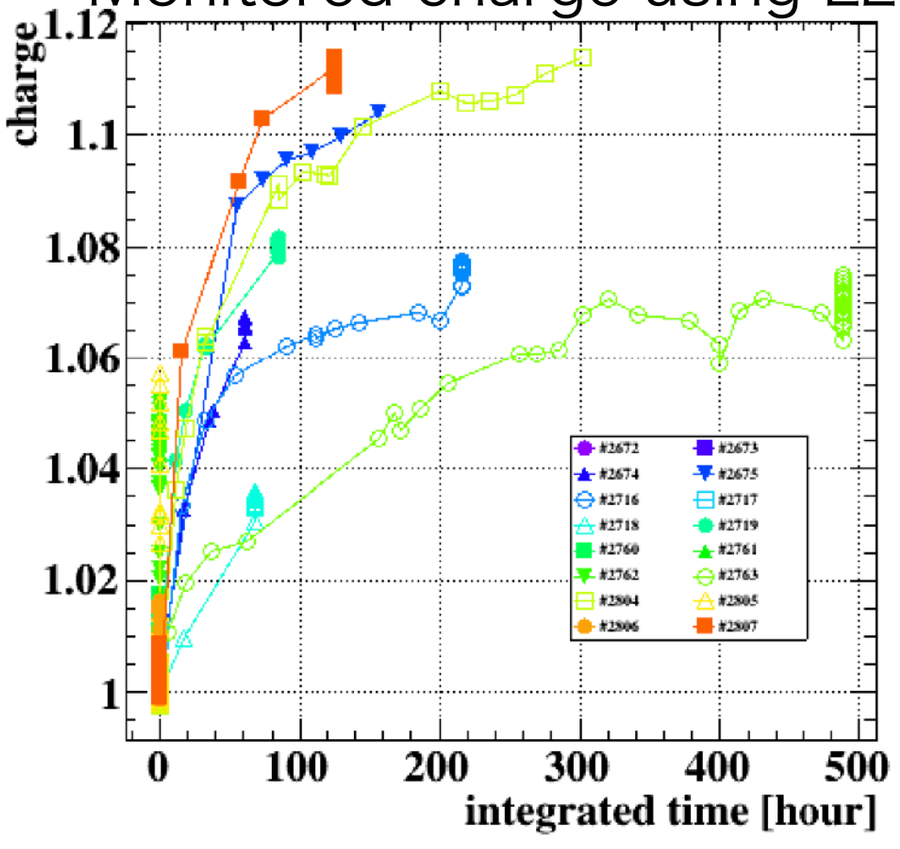
Example event display of liquid xenon detector (pile up event)



Previous works / Annealing by Joule heating

- Annealing (heating) of MPPCs will recover the PDE
- Annealing was conducted using Joule heating by passing currents to MPPCs
- Confirmed the recovery of PDE for annealed channel (8 MPPCs were annealed)
- It is difficult to anneal whole MPPCs because re-cabling of ~4000 channels to power supply (with high current) is required

Monitored charge using LED



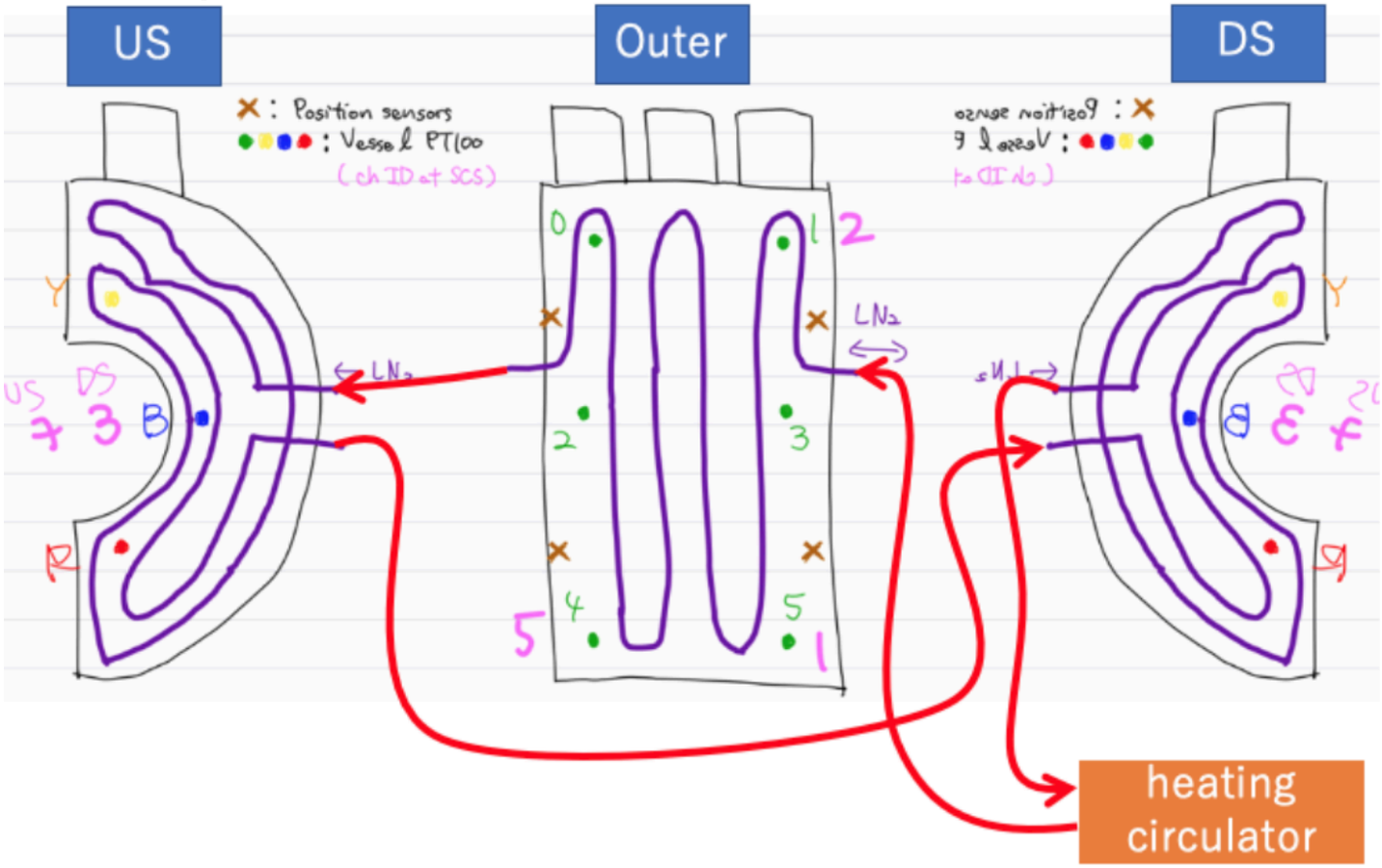
Apply HVs with LED lighting to enhance current

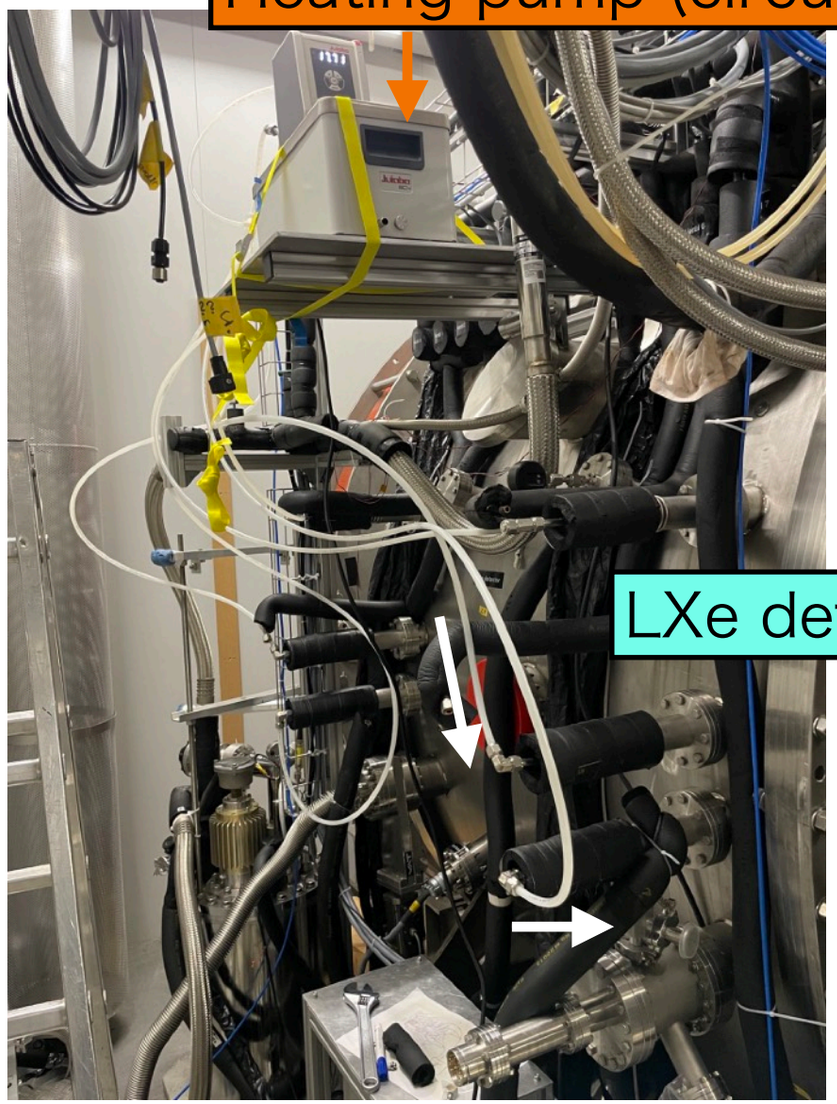
Keithley 6450 x2
HV supply
(can provide high current : ~20mA)

67V
68V → heated at ~70℃
69V

Annealing with hot water circulation

- Circulating hot water through the cooling pile that surrounds the detector
  - Be able to heat up entire of the detector easily
  - The temperature of hot water is limited up to 45℃ because of the temp. limitation of detector components



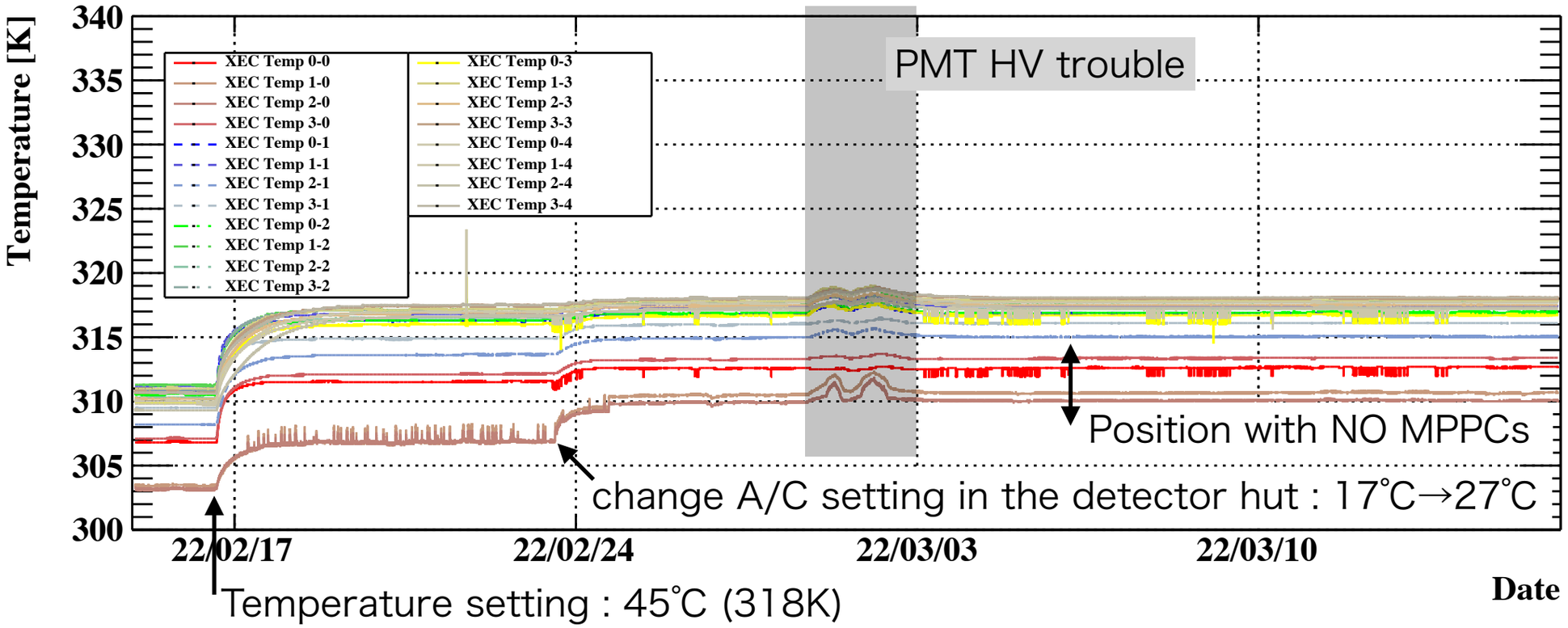


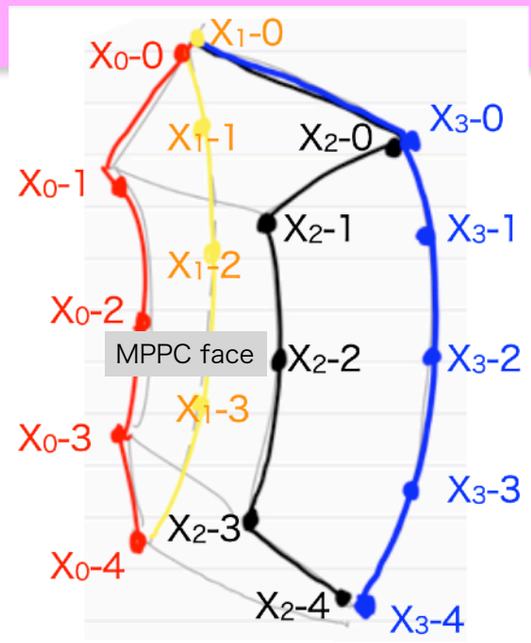
(by previous work)

- PDE recovery can be estimated from the PDE for blue LED (installed in the detector)
  - Correlation exists between PDE_{VUV} and PDE_{LED} : $PDE_{LED} \sim 0.1 \times PDE_{VUV}$
- The expected value of charge increase is 1~5% for one month annealing at 45℃

Annealing with hot water circulation

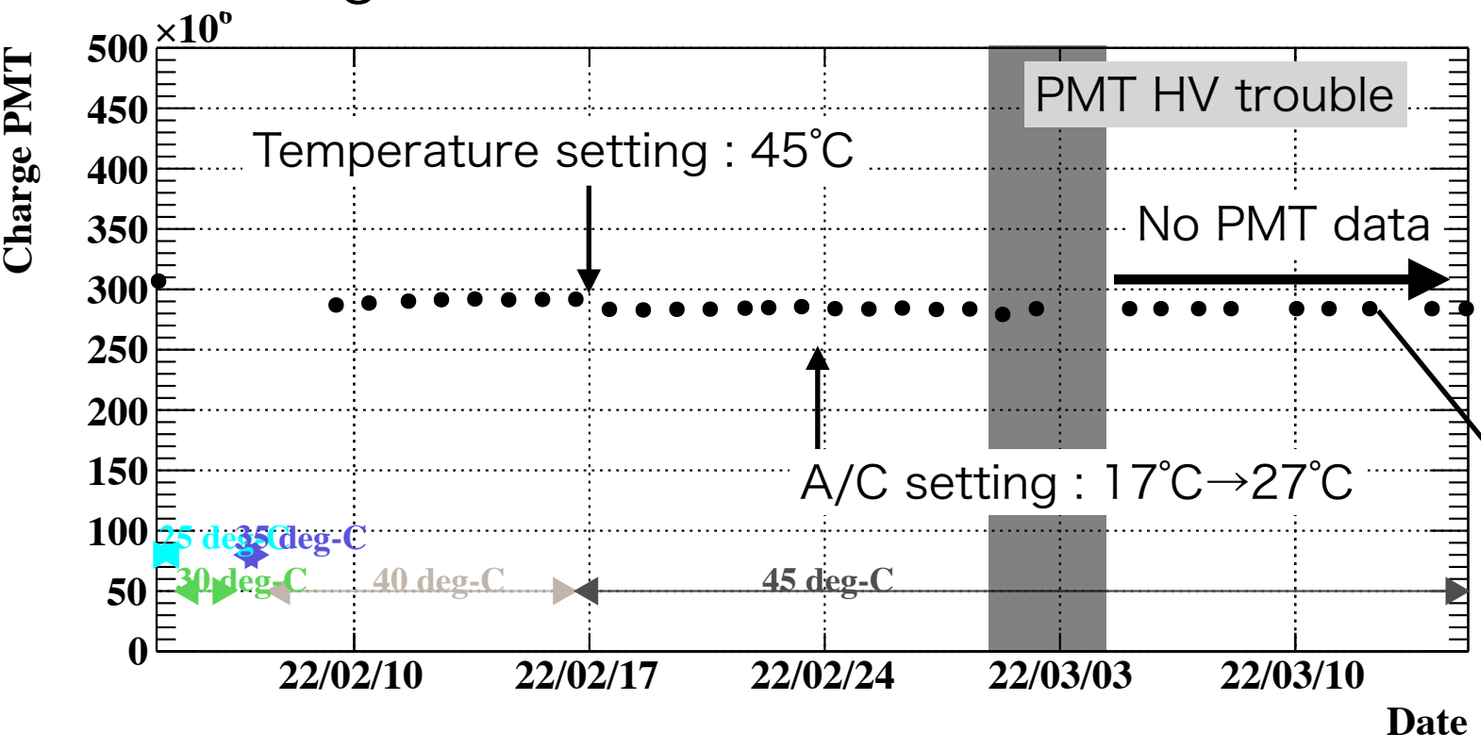
Temperature is monitored by sensors inside the detector





Temp. are within
3℃ range
Stable within 0.1℃

PMT charge is also monitored to monitor the LED intensity

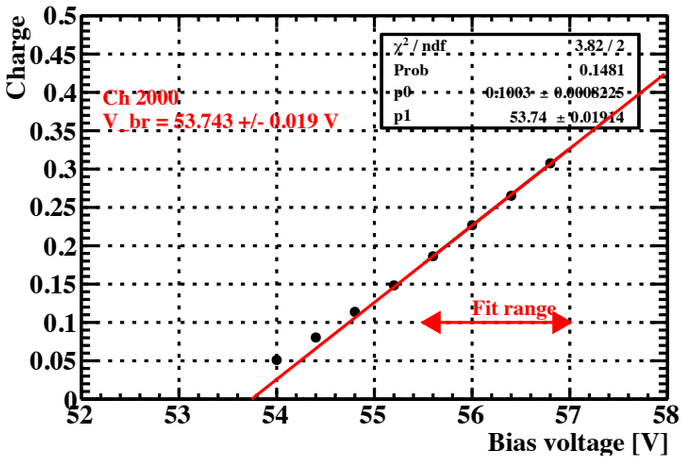


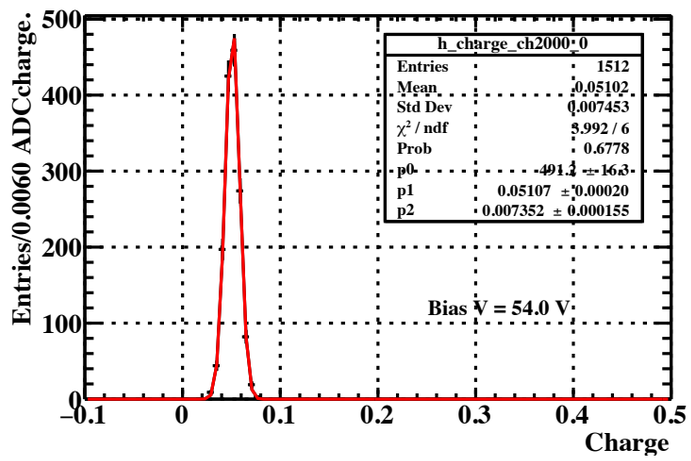
HV modules for PMTs had some troubles on 1st Mar.
→ No PMT signal are available anymore

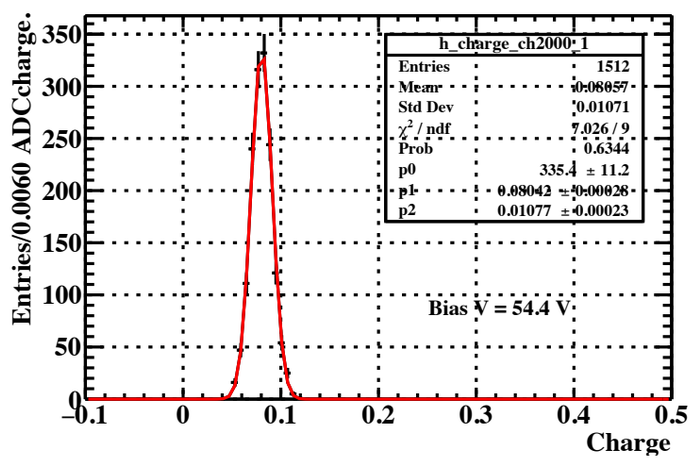
Average between 2/17 and 2/28
- PMT charge is almost constant in this period
  - fluctuation : 0.08%

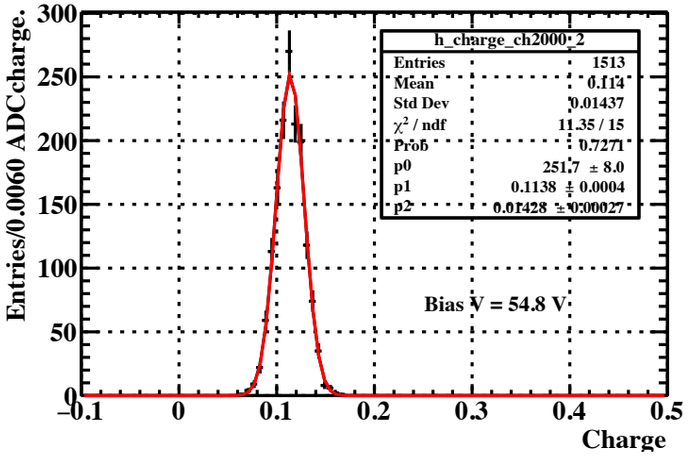
Annealing with hot water circulation / MPPC charge

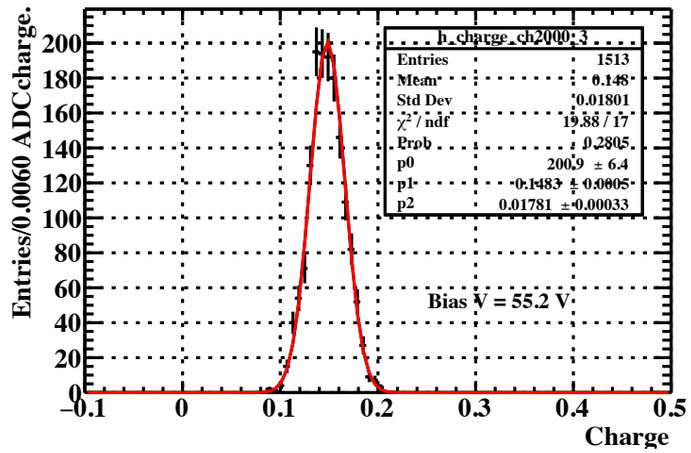
- LED data with various bias voltages are taken for monitoring the PDE_{LED}
- Breakdown voltages are estimated by extrapolating the gain curve with linear fit
- Example charge distributions and gain curve of an MPPC at the central region

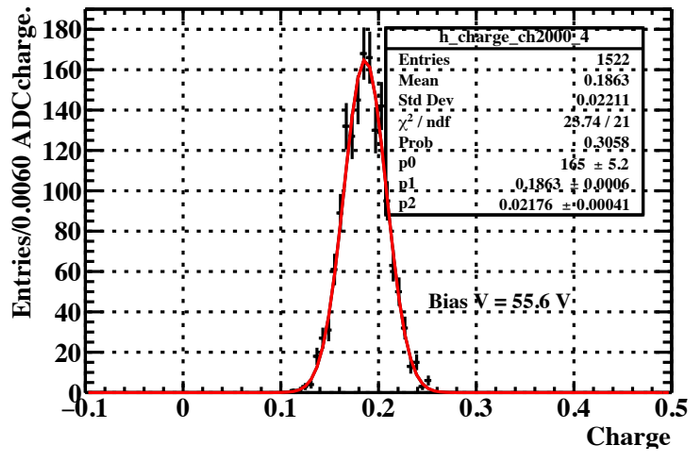


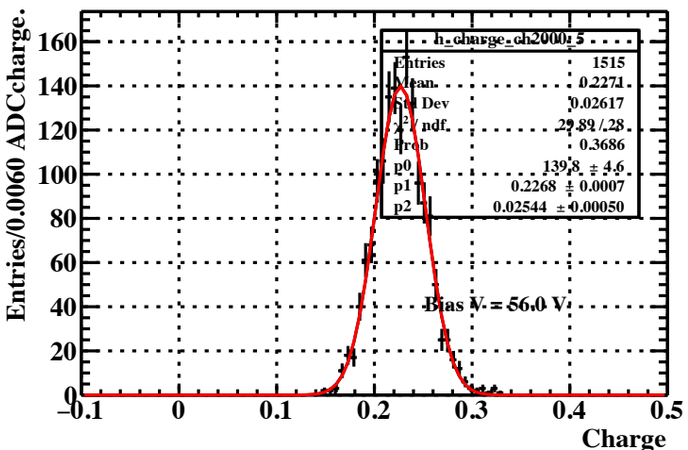


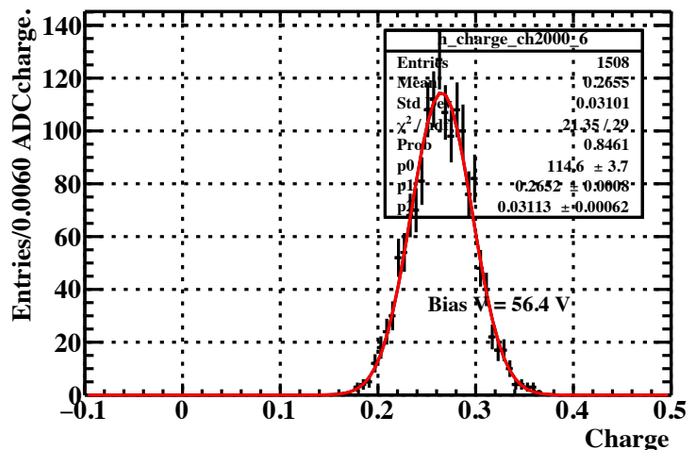


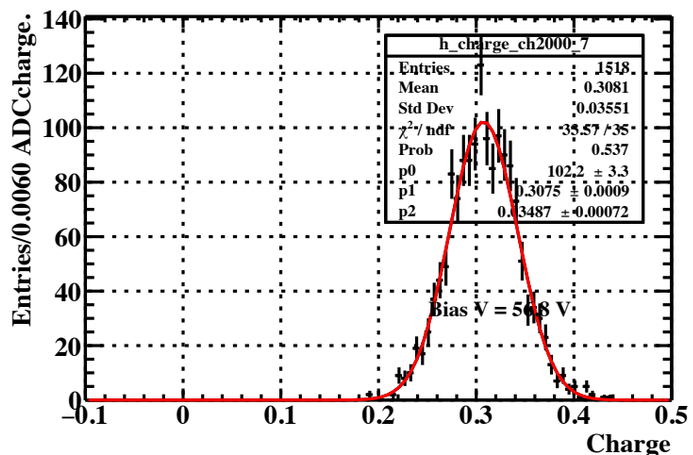










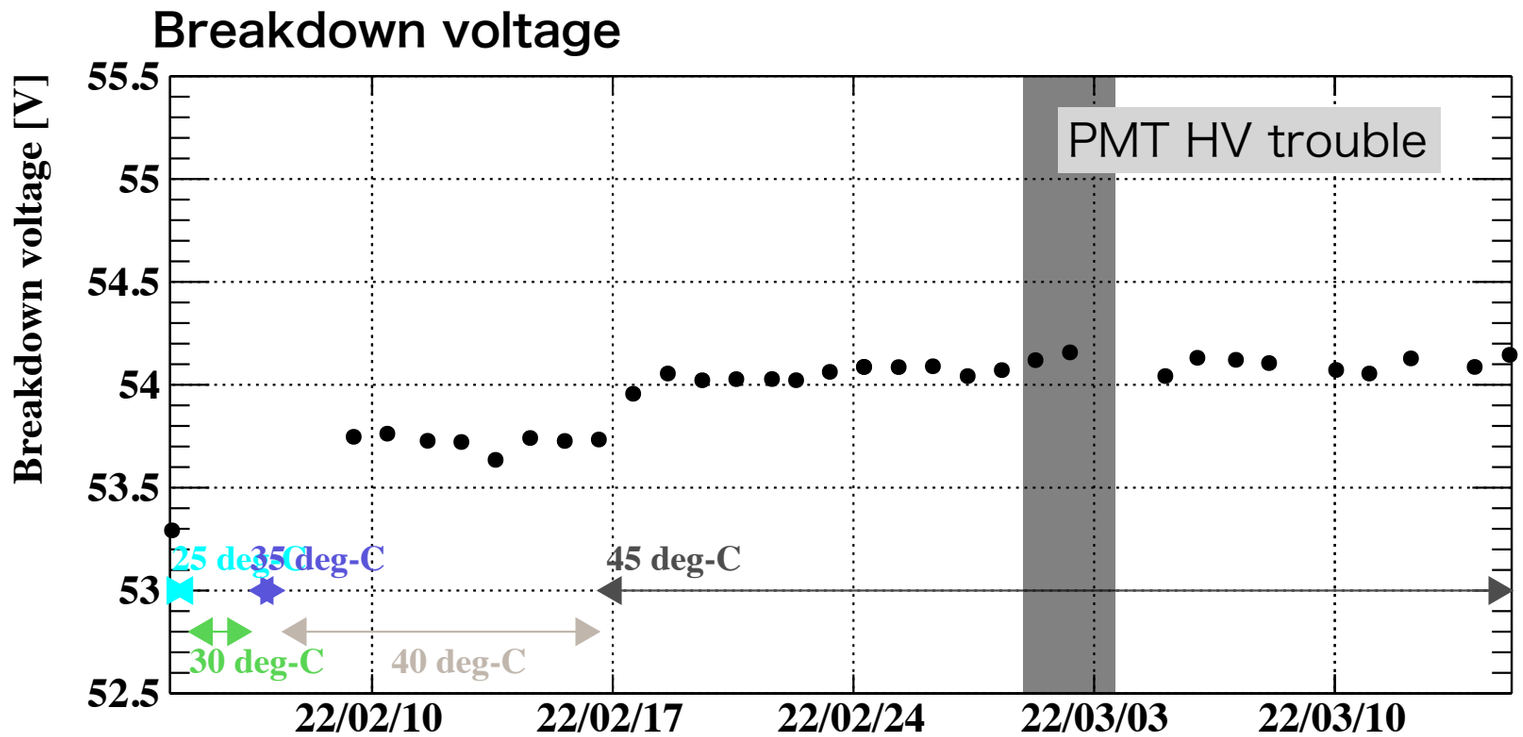


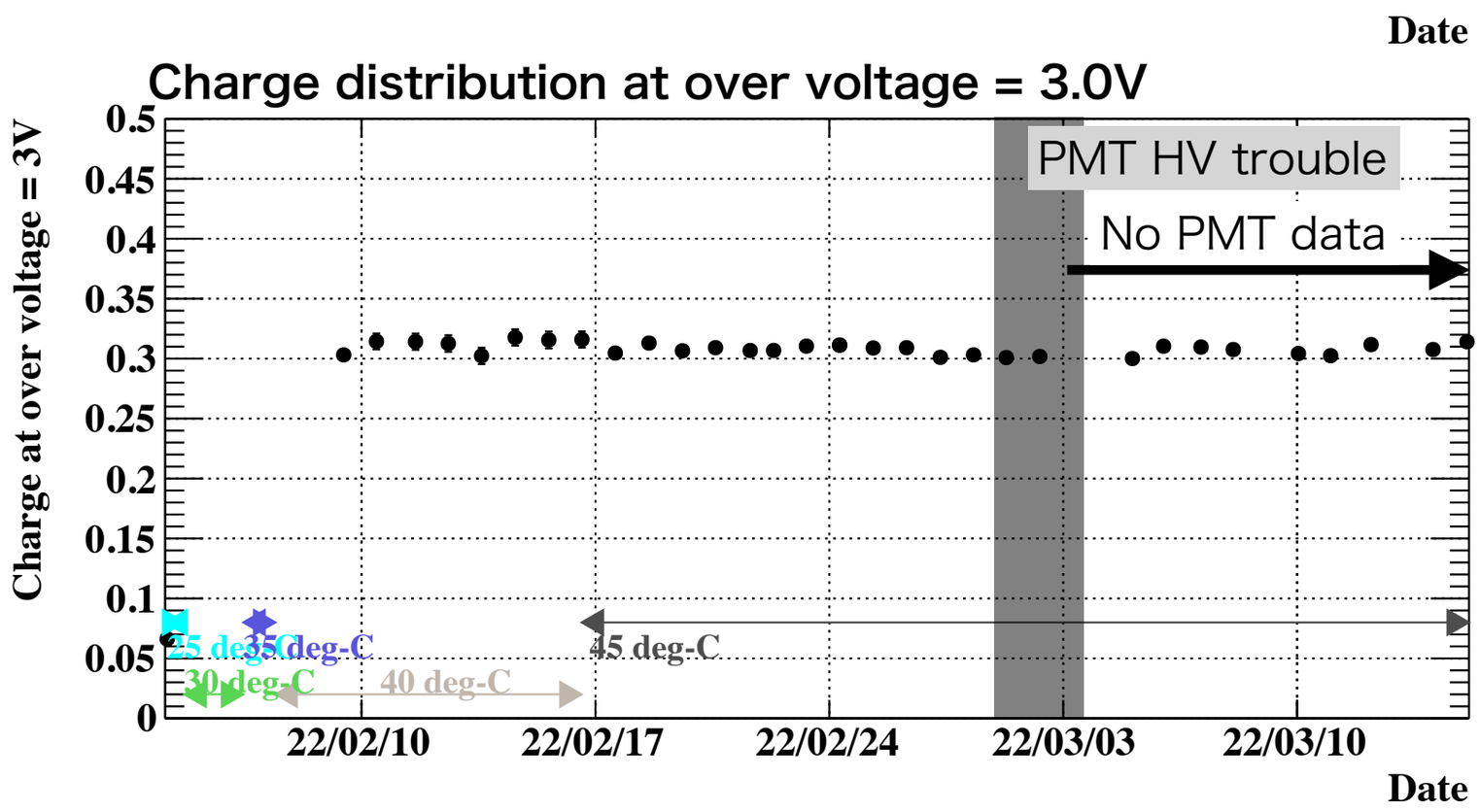
Annealing with hot water circulation / MPPC charge

Charge of single channel
- An MPPC at the central region
- Charge at over voltage: 3.0 V
- Normalized by PMT charge

Charge (∝ PDE_{LED}) increase cannot be seen
- Breakdown voltage fluctuates with ~0.3 V (corresponds to 6K fluctuation with 0.05 V/K)
- The algorithm to calculate V_{br} may have some problem
- Charge has correlation to the breakdown voltage

→ Estimation of charge by this algorithm may also have problem

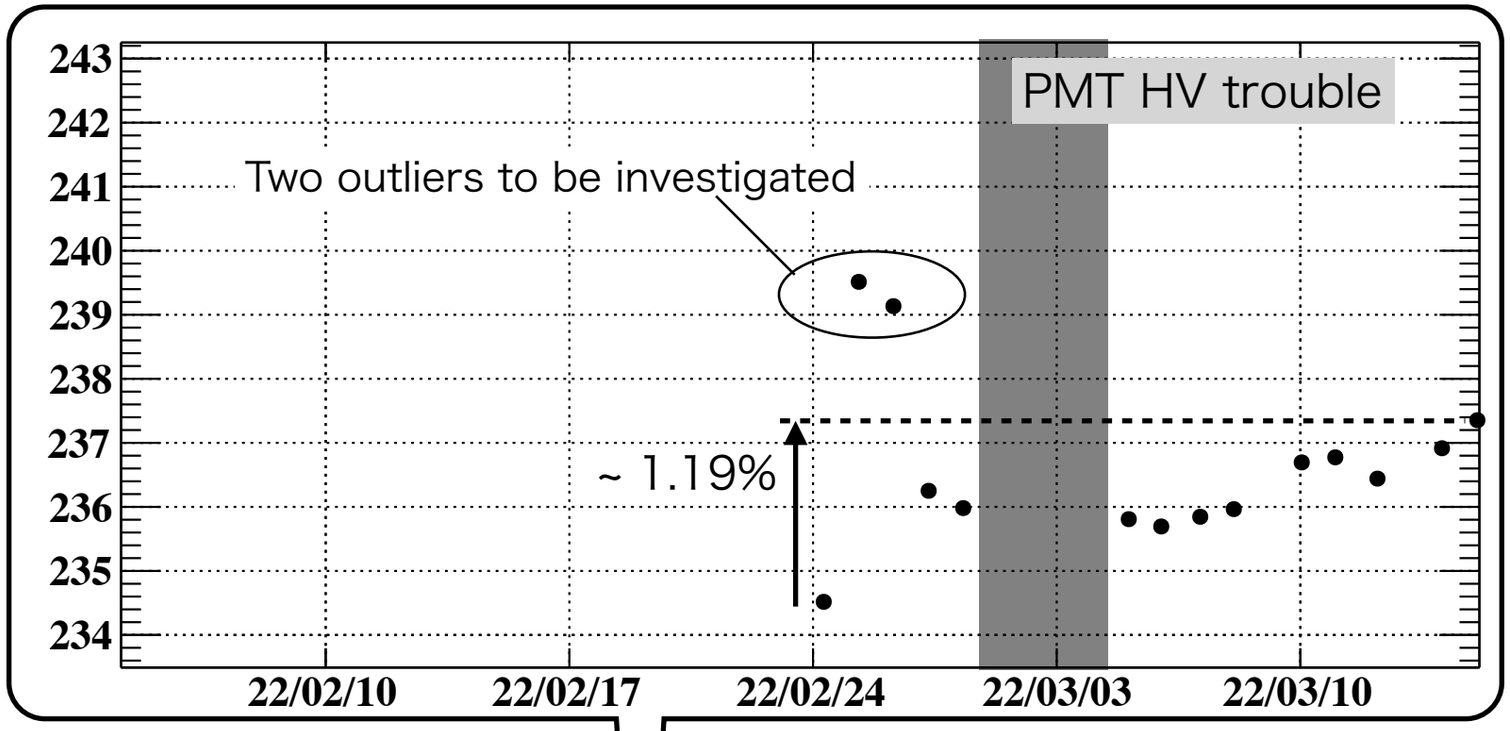


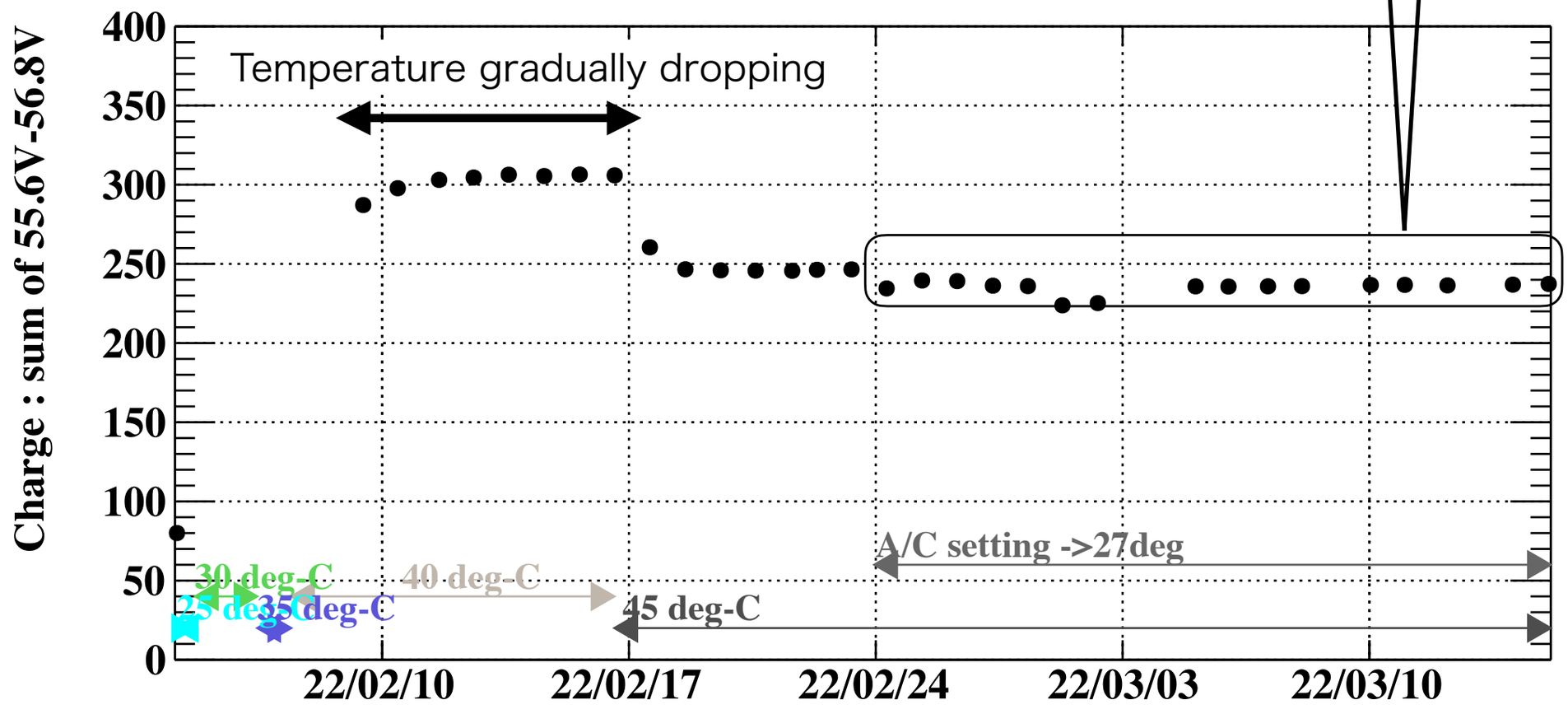


Annealing with hot water circulation / MPPC charge

Charge at constant bias voltage
(sum of 55.6, 56.0, 56.4, 56.8 V)
- sum charge of ~400 MPPCs
- NOT normalized by PMT charge

Slight charge increase can be seen
- ~1.2% after the temperature becomes constant
- Should be monitored carefully more





Summary

MEG II experiment searches for charged lepton flavor violation : $\mu+\rightarrow e+\gamma$

Full channel operation was conducted in 2021

PDE decrease of MPPCs (LXe detector) is an issue

Annealing with hot water circulation is ongoing to recover the PDE
- Temperature is well controlled in whole detector region
- LED data are taken (everyday) to monitor the MPPC charge
  - PDE recovery can be estimated from charge increase for visible LED
- Charge at constant **over** voltage does not increase
  - Algorithm to estimate the breakdown voltage seems to have some problem
- Charge at constant **bias** voltage increases slightly
  - ~1.2% with 20 days annealing at 45℃
  - will keep monitoring carefully to evaluate the PDE recovery

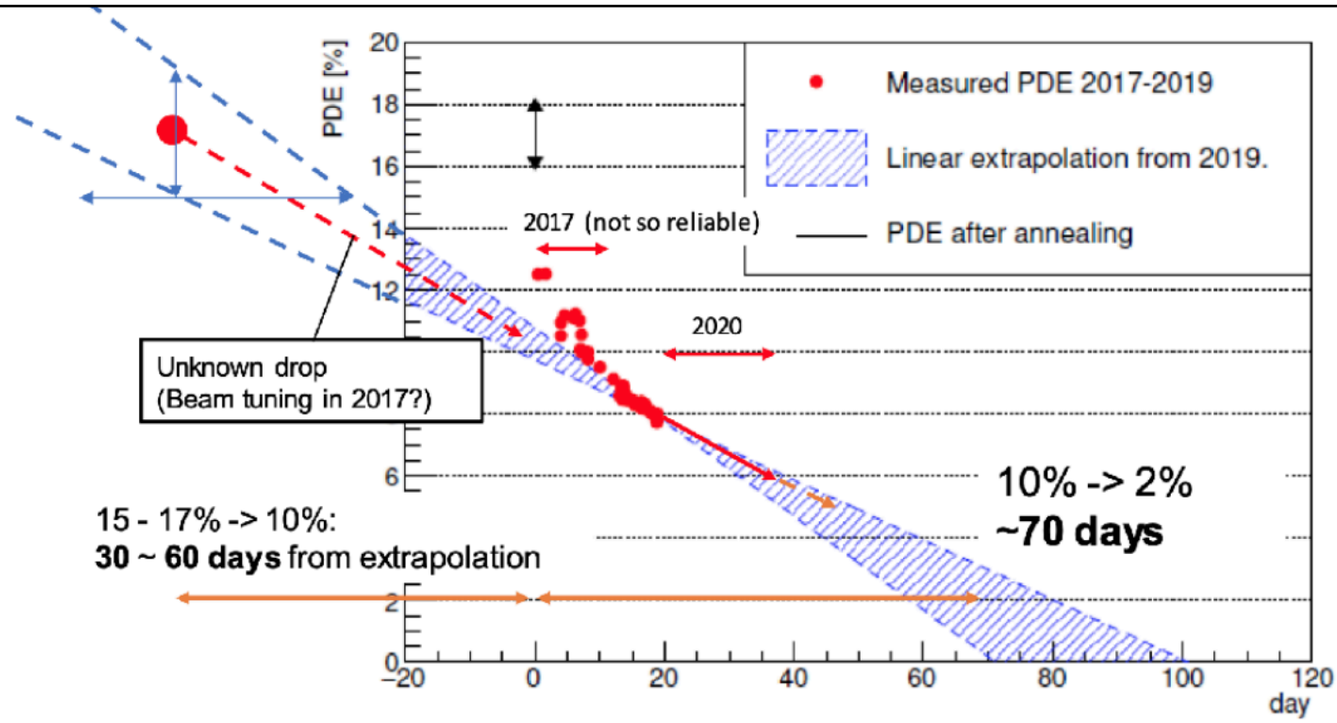
Back up

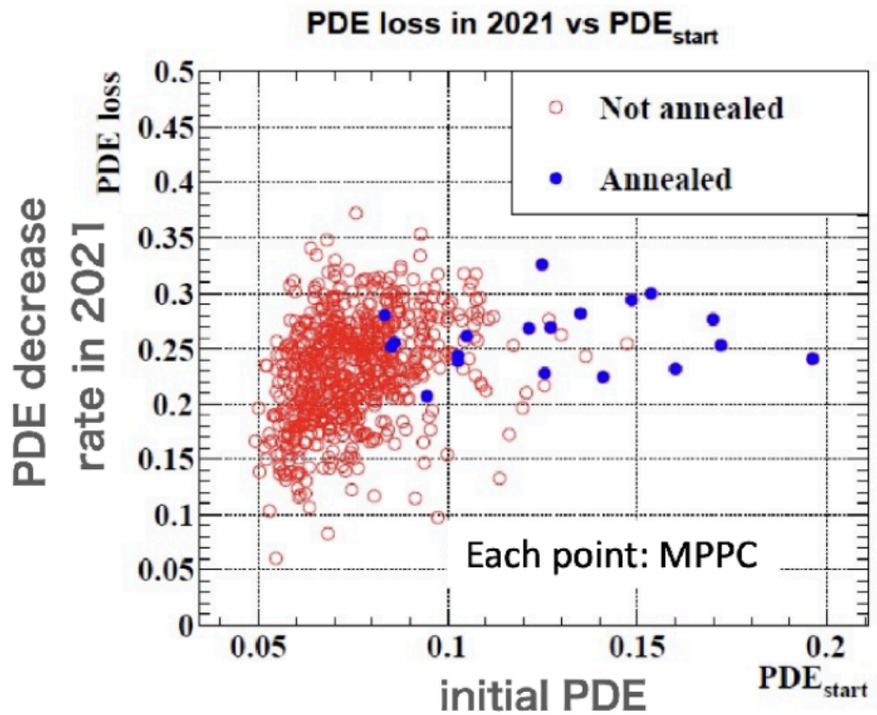
PDE decrease

Slide from T. Iwamoto (15aA562-4)

γ detector (LXe) Issue

- MPPC PDE decrease
  - observed in 2017 under muon beam
  - The cause to be investigated
  - Based on 2021 operation, PDE will change from 16% to 2% in ~100 days MEG II intensity
  - Annealing recovers PDE fully
- Strategy for run 2022
  - LXe MPPC can sustain ~ 120 days with 5×10^7 μ/s
    - Beam intensity optimization necessary
  - Annealing for all MPPCs during accelerator winter shutdown period

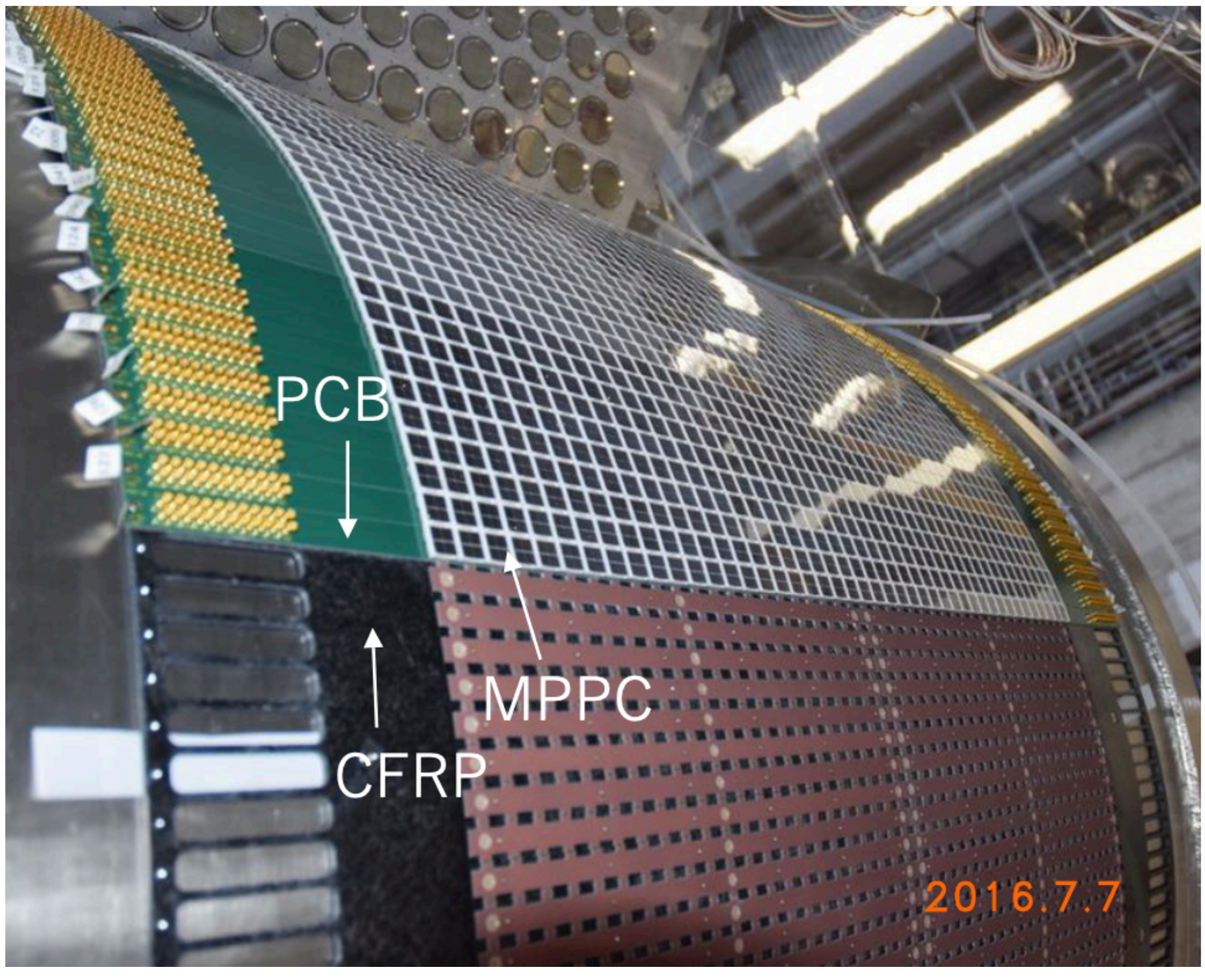




Temperature limitation

CFRP should not exceed 45℃

→ the maximum temperature setting in hot water annealing must be 45℃

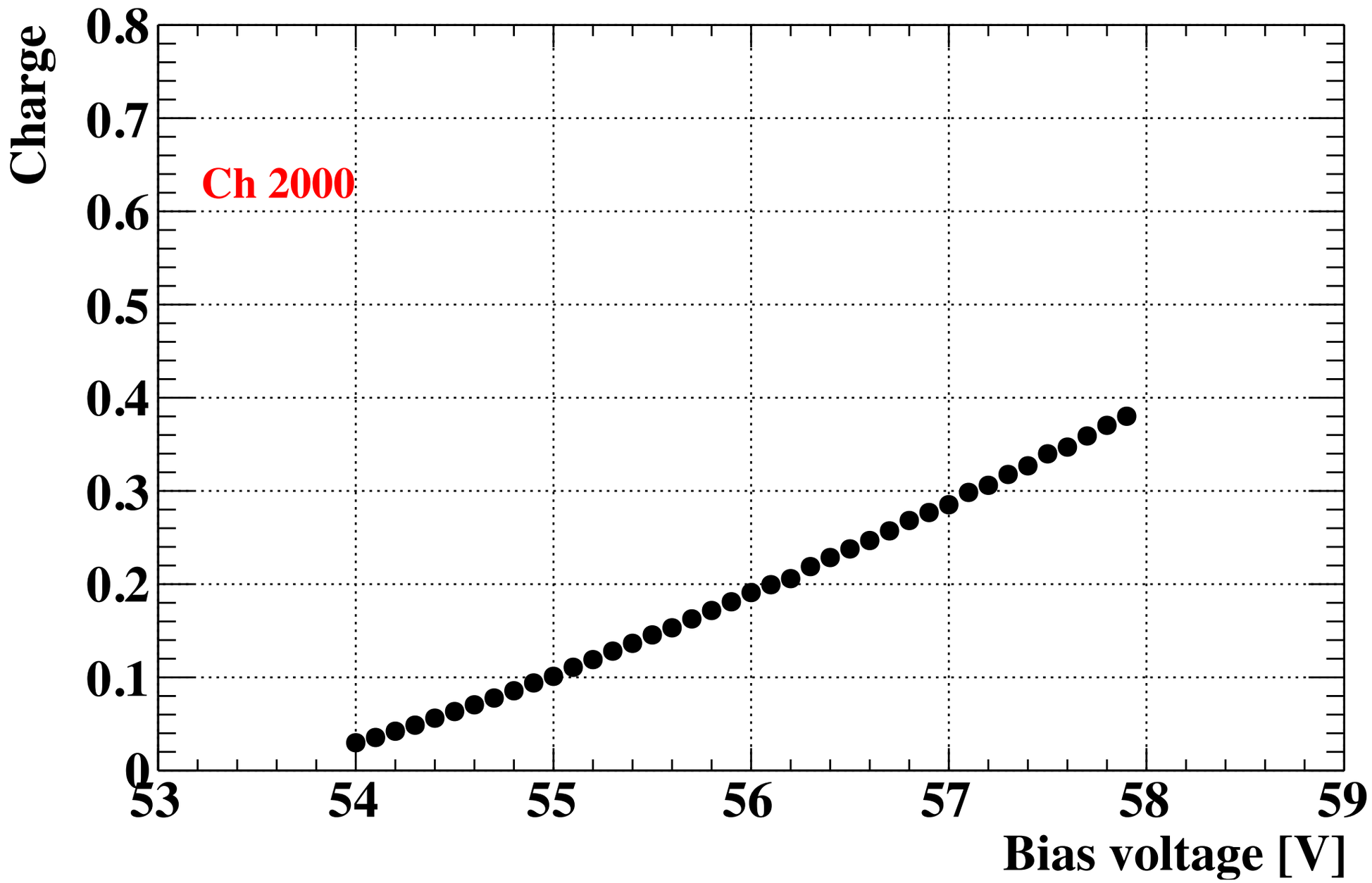


- Temperature limit
  - MPPC: 100°C
  - PCB: 120°C
  - **CFRP: 45°C**
  - Glue: 65°C

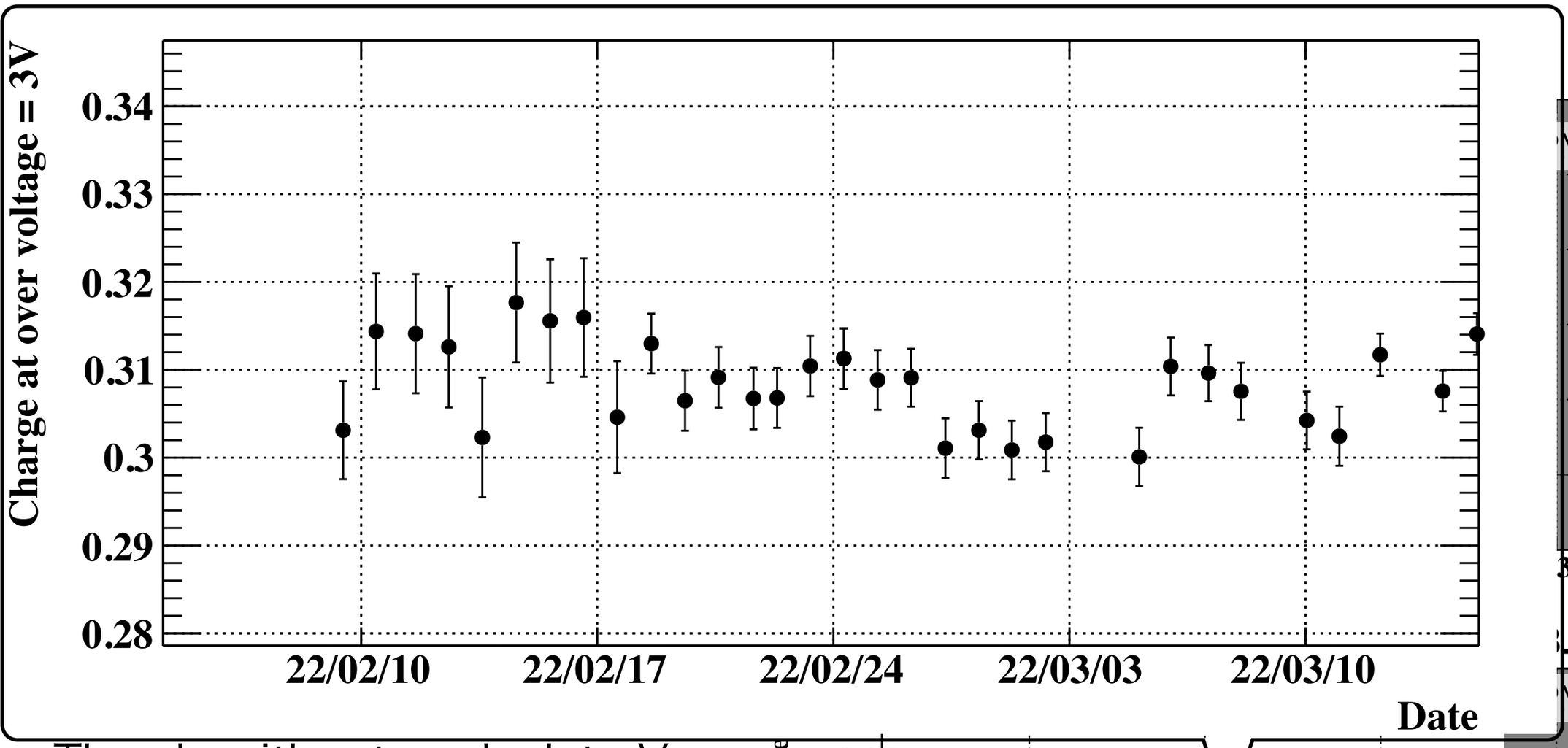
Gain (charge) dependence on bias voltage

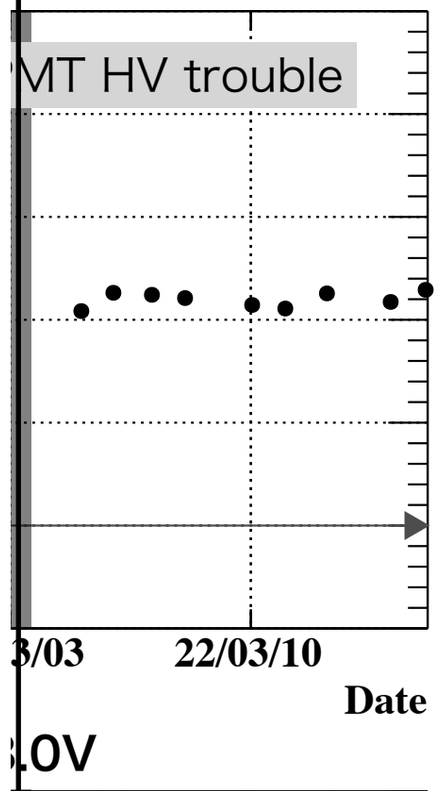
- ch2000, at 45℃ (pump setting)
- MPPC charge as a function of bias voltage : 54.0～57.9 V with 0.1 V stepping
- PMTs are off due to the HV problem

- Charge vs Bias voltage [V]



Annealing with hot water circulation / MPPC charge





- The algorithm to calculate V_{br} may have some problem
- Charge has correlation to the breakdown voltage

→ Estimation of charge by this algorithm may also have problem