連続講演：16pG22-10,11,12,13

Study on gain decrease of PMTs in MEG II gamma ray detector

MEG II実験ガンマ線検出器のPMTゲイン減少に関する研究

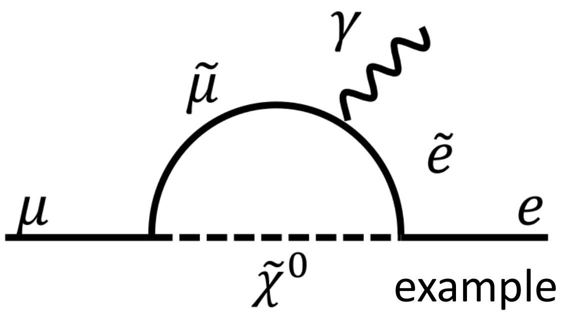
Kazuki Toyoda on behalf of MEG II Collaboration

16pG22-10

JPS annual meeting @Nagoya Univ.

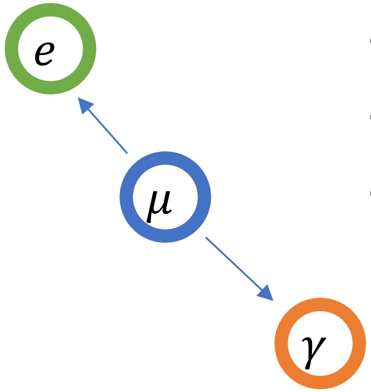
$\mu \to e\gamma$

- charged lepton flavor violation
  - practically **forbidden** in Standard Model by tiny neutrino mass
  - but many predictions by **new physics** are **within experimental reach**
    - eg. SUSY with GUT/Seesaw



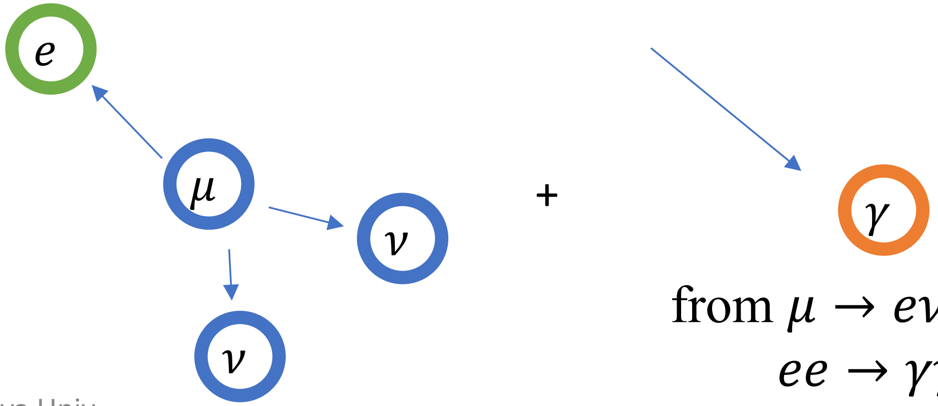
example of $\mu \to e\gamma$ decay

- $\mu \to e\gamma$ search
  - signal



- both 52.8 MeV/c
- back to back
- same timing

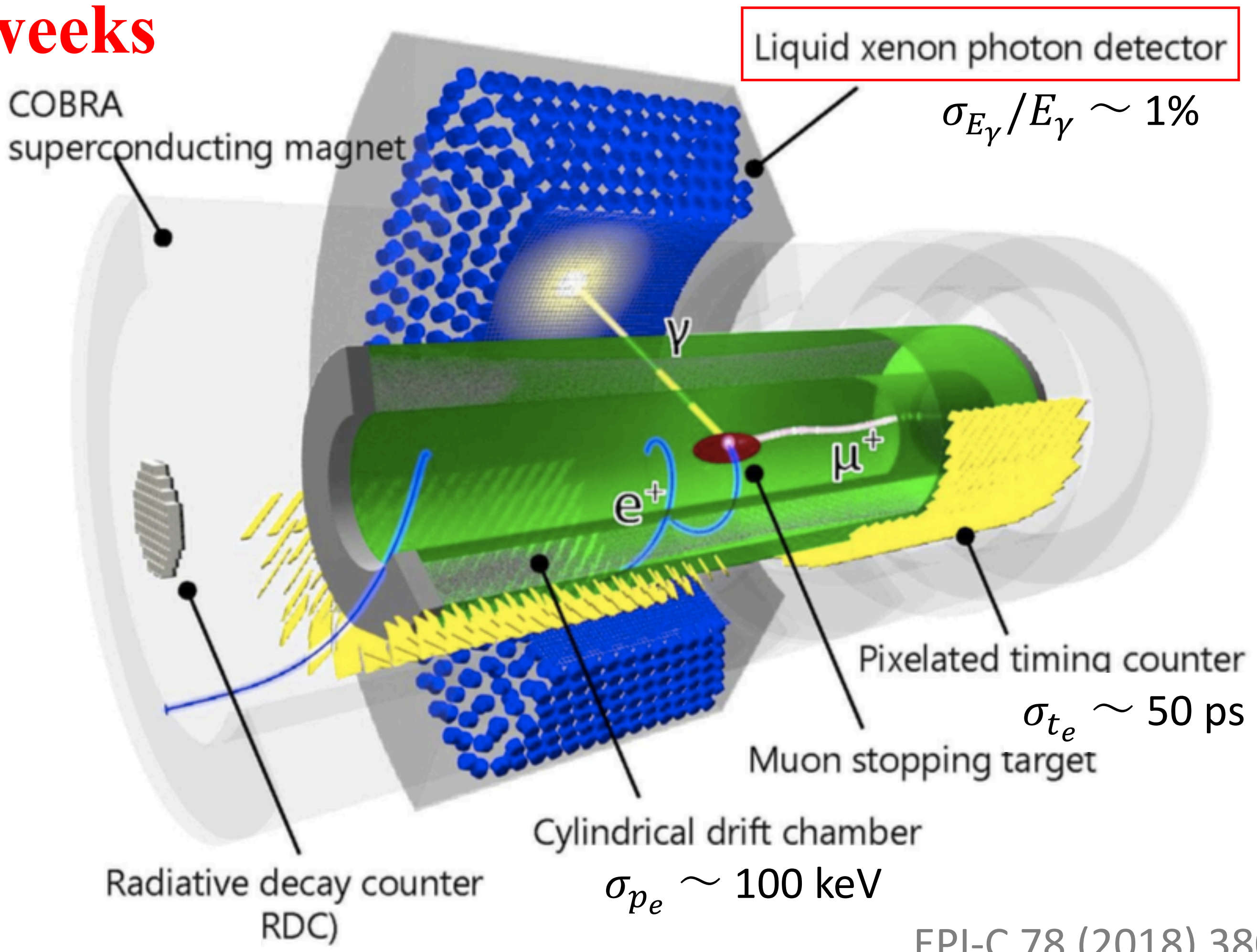
  - dominant background: accidental



from $\mu \to e\nu\nu\gamma$
$ee \to \gamma\gamma$

MEG II Experiment

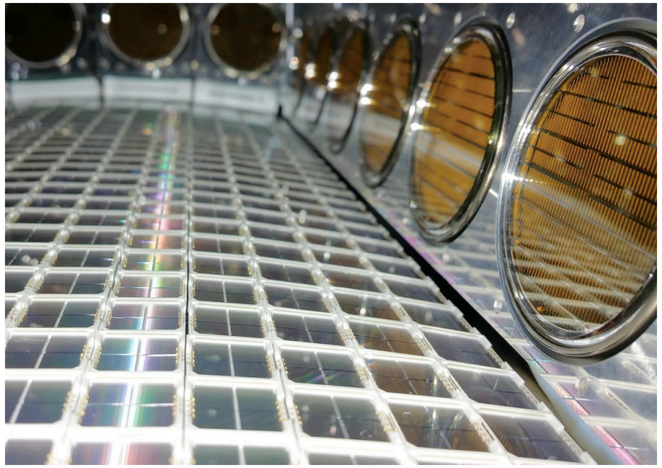
- MEG II is experiment to search for $\mu \rightarrow e\gamma$
- goal sensitivity: **6.0×10^{-14} in 60 weeks**
  - MEG I result:
    $Br(\mu \rightarrow e\gamma) < 4.2\times10^{-13}$ (90% C.L.)
    (sensitivity: 5.3×10^{-13})
- key concept:
  - high μ intensity: $7\times10^{7}\mu/s$ @PSI
  - high resolution detectors
- this talk is on γ detector



EPJ-C 78 (2018) 380

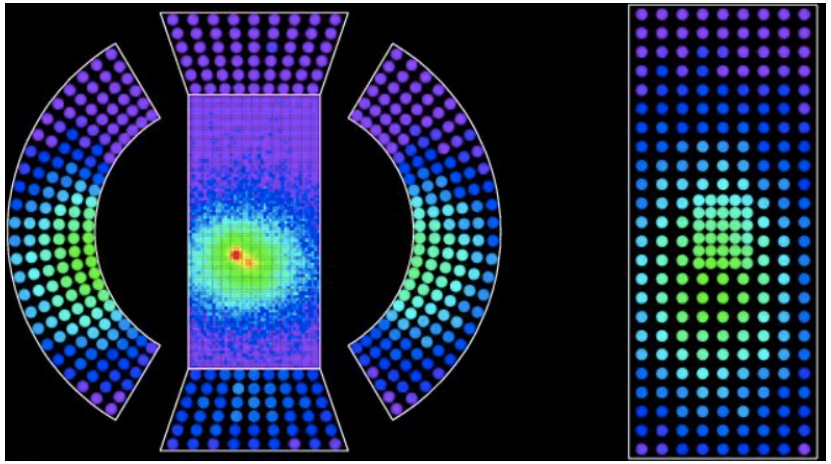
LXe Detector

- LXe scintillator (VUV light ~175 nm)
- PMTs on γ incident surface are replaced with MPPCs



2 inch PMT × 700 ch

12 mm×12 mm MPPC × 4000 ch



MC event display
example of pile up

→ improve uniformity and granularity

- energy resolution : **2%** @MEG I → **1%** @MEG II (expected)
- position resolution: **5 mm** @MEG I → **2.5 mm** @MEG II (expected)

- need precise calibration of ~ 5000 photosensors

Photosensor Monitoring

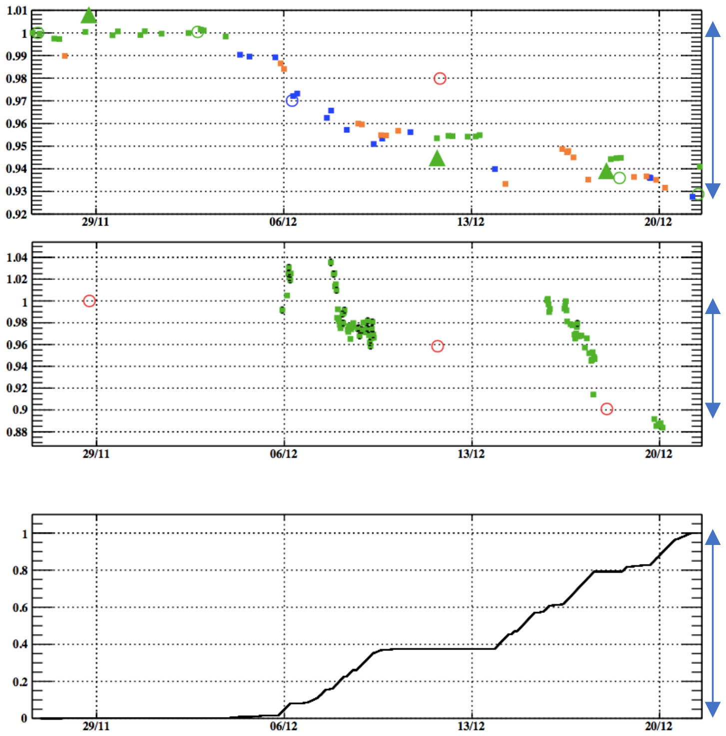
- calibration sources
  - ^{241}Am α ray source → absolute response for LXe scintillation light
  - blue LED → gain calculation by Poisson statistics, monitor relative variation by large photon statistics

- monitor during pilot run in 2018
  (ref: JPS2019a19pT14-6)
  - **response decreased** with muon beam
    → investigate in detail
    - PMT : this talk
    - MPPC: next 3 talks & 17aG22-7,8

PMT response

MPPC response

# of incident VUV photon



7%

10%

5×10^{10} /mm^2

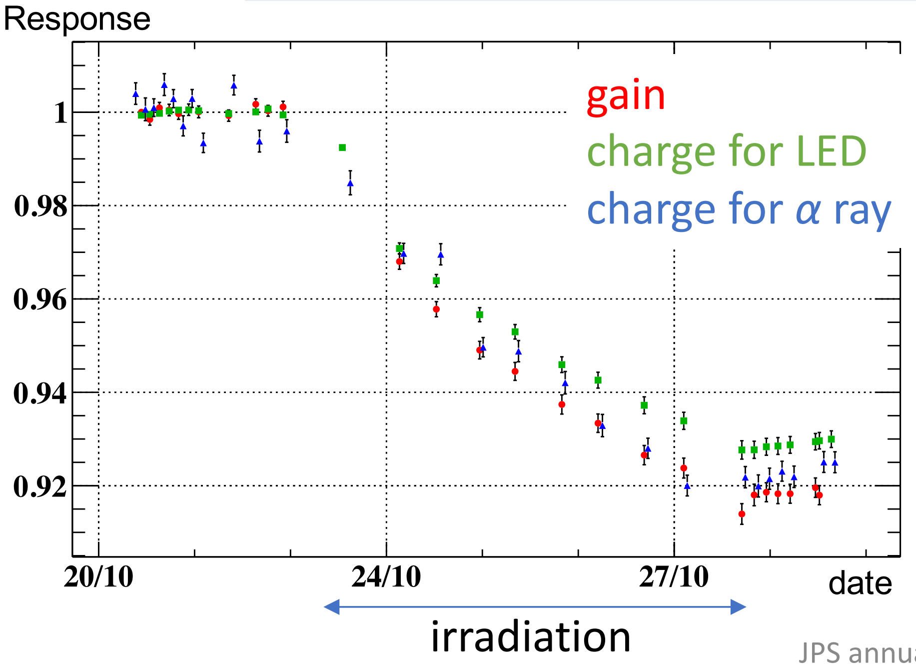
date (1 month)

Fast Gain Decrease

Calibration by Various Method

- $charge = LY \times QE \times CE \times G$

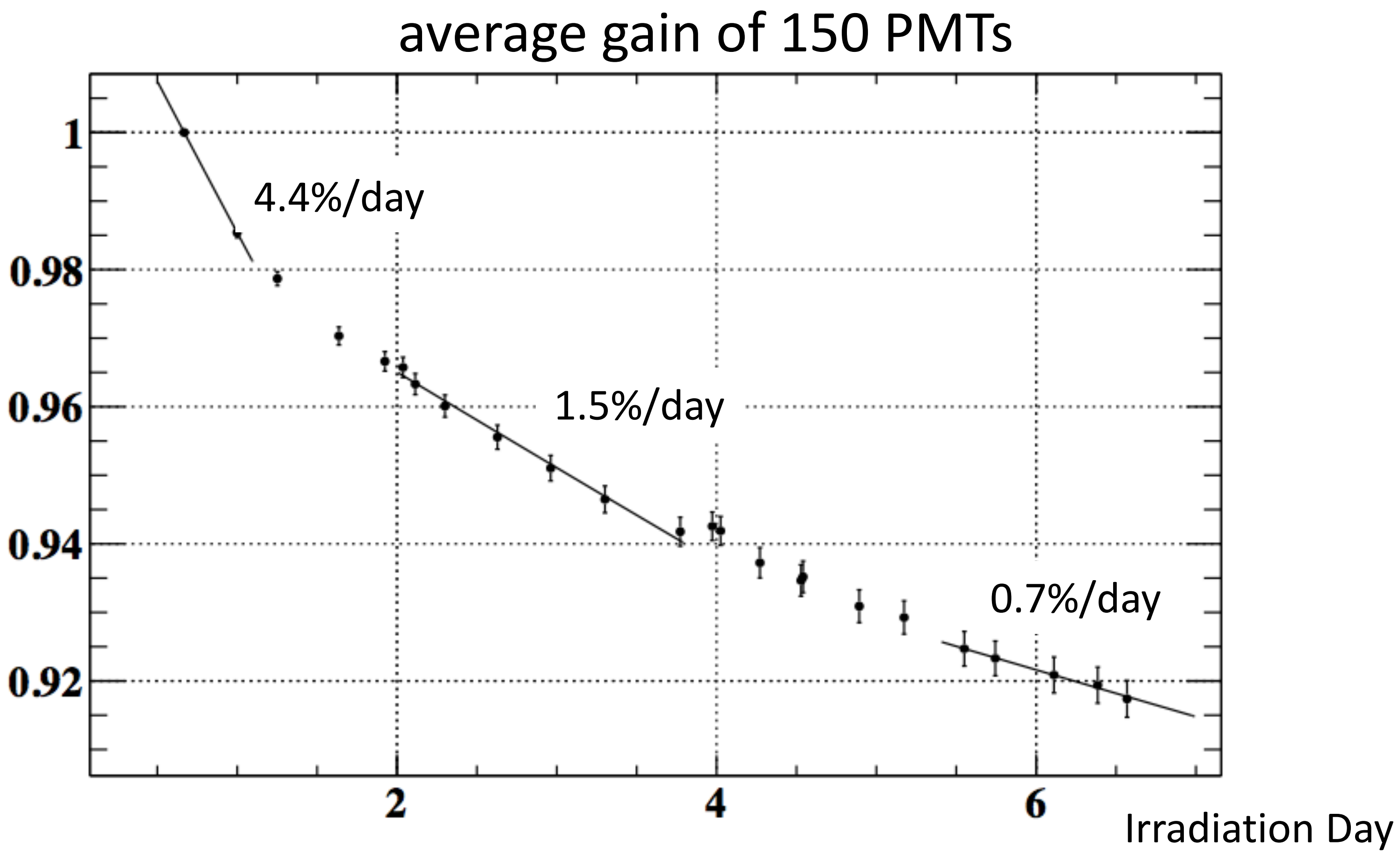
	comment
LY : Light Yield	no effect on LED light
QE: Quantum Efficiency	dependent on wavelength
CE: Collection Efficiency	
G : Gain	calculated by LED Poisson statistics



- average of 200 PMTs in LXe detector
- decrease (~8%) is consistent with each other within 1%
  → **gain is main cause** of decrease
- possible cause:
  degradation of dynode material

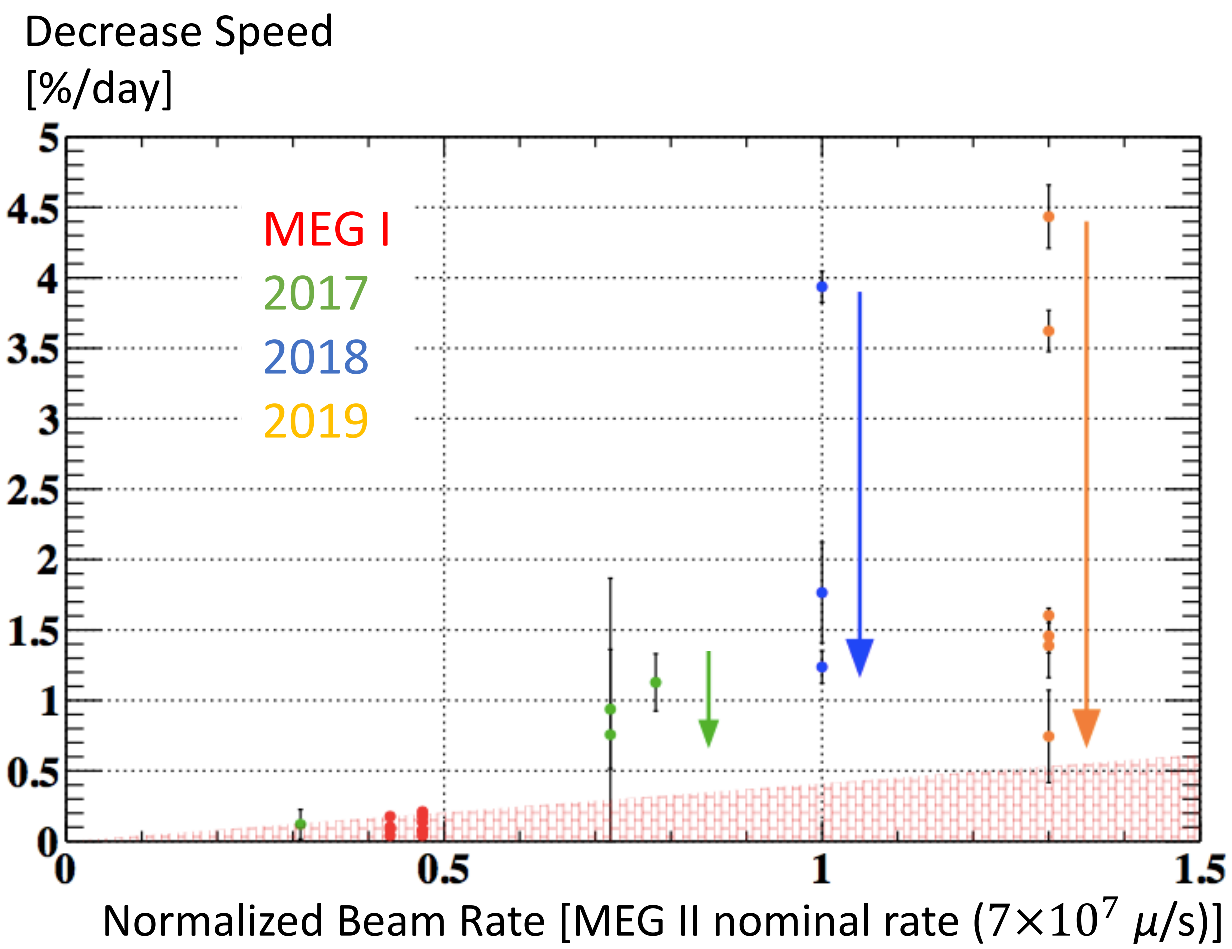
Decrease Speed

- decrease speed gradually decreases
  - slower than exponential



Beam Rate Dependence of Decrease Speed

➢ compare decrease speed at different muon beam rate

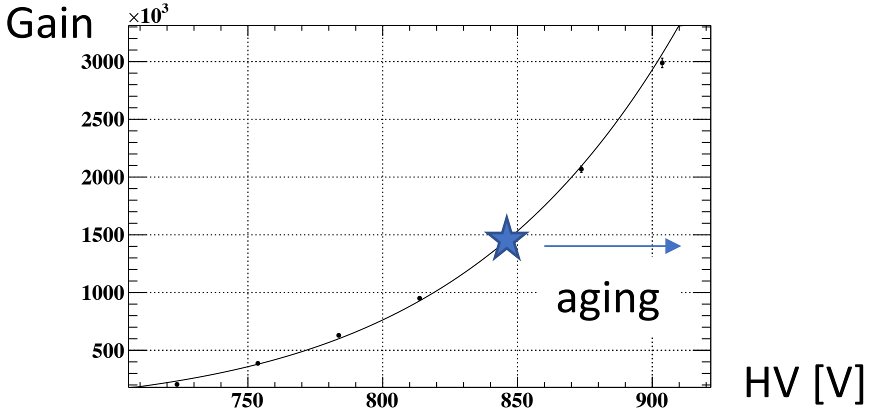


- strong dependence on beam rate
- **much faster decrease** at MEG II nominal rate than expected from MEG I observation

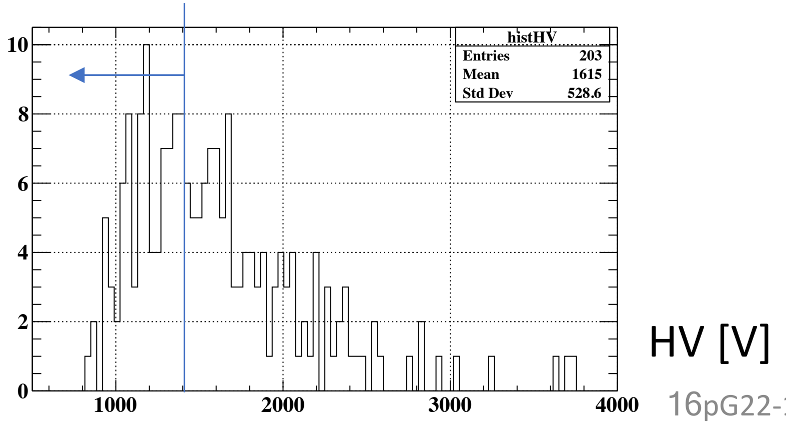
- larger gain is available by applying large HV
- can operate at safe HV?

HV Estimation

- estimate HV necessary after 3 years operation
- assumptions:
  - constant decrease rate: $G = G_0 e^{-\alpha t}$ (faster than observation)
  - HV dependence : $G = a(HV - HV_0)^k$
    - assume only a becomes smaller



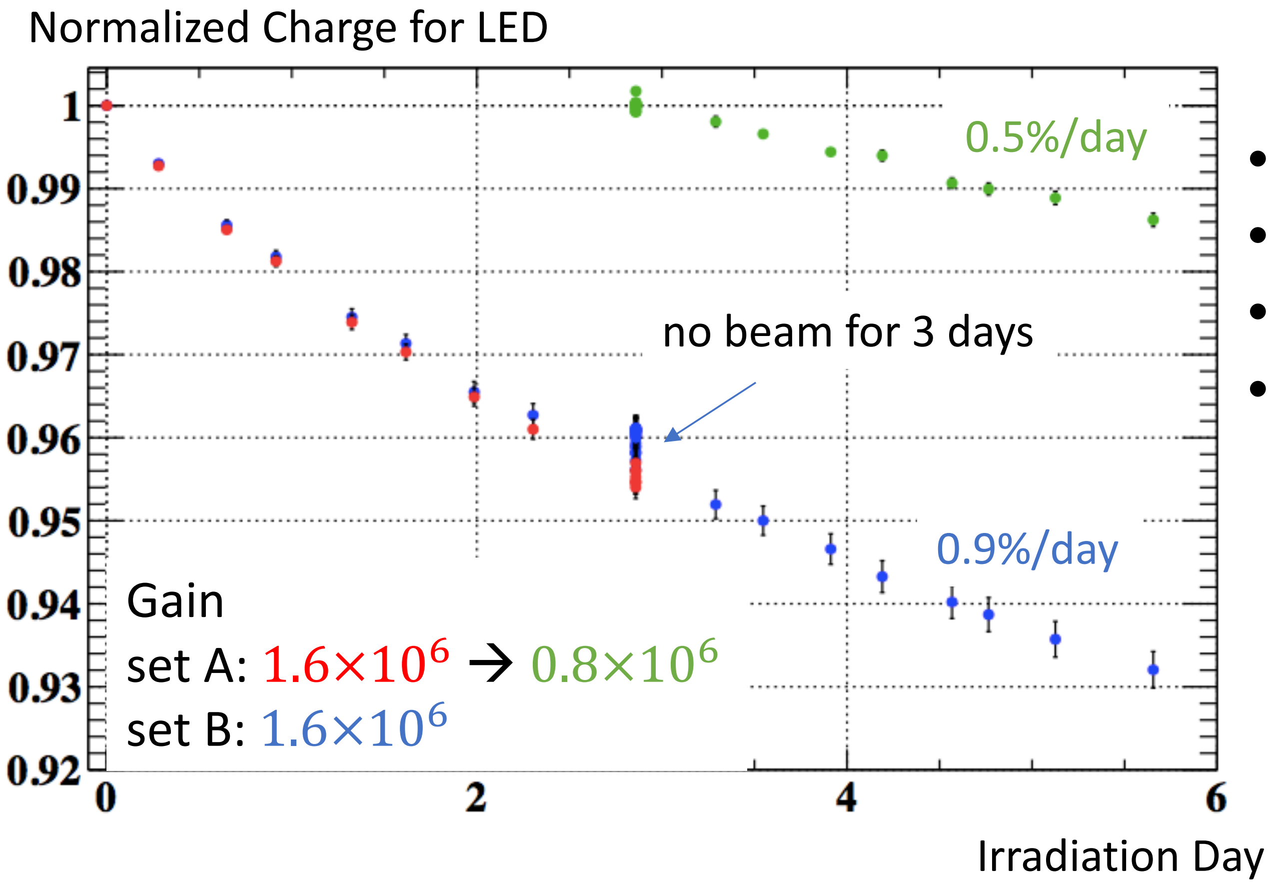
- result:
  - HV for most PMTs exceeds safety limit (1400 V)
    → need a way of making decrease slower



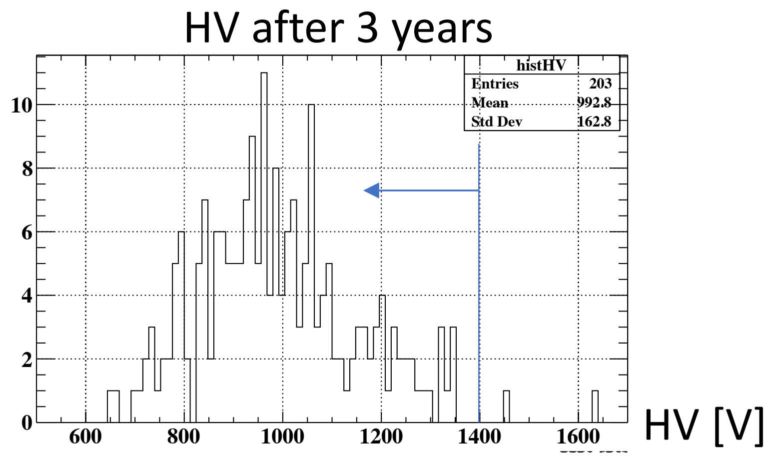
Half Gain Solution

Gain Dependence of Decrease Speed

➢ operation with half gain by lowering HV



- separate PMTs into 2 sets
- lowered HV of set A just after 3-day-operation
- **slower decrease** @lower gain
- most PMTs will be operated at safe HV with low-gain-operation



Effect of Half Gain Operation

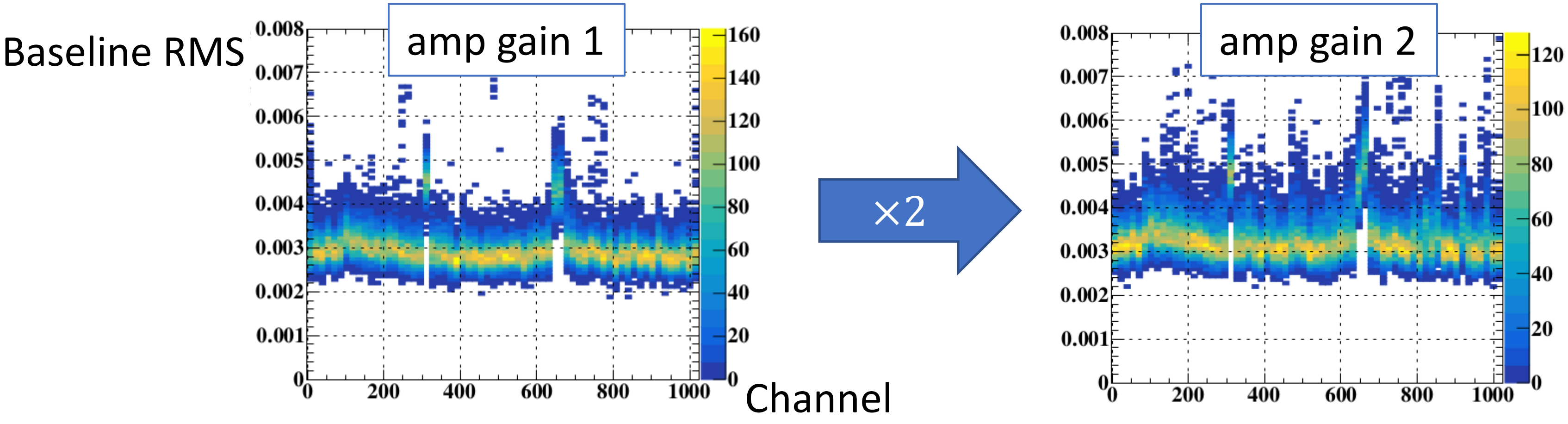
- smaller number of detected photons?
  - decrease of CE is only 5%
  - photon statistics does not largely contribute to resolutions (cf. 16pG22-13)

affected by HV

$$charge = \boxed{LY \times QE \times \mathbf{CE}} \times G$$

determine statsitics

- worse S/N?
  - signal decrease can be compensated by doubling gain of readout electronics
  - no increase of noise observed → S/N does not change!
    (dominant noise seems to generate after amp of electronics)



Summary

- PMTs are used in γ ray detector of MEG/MEG II experiment
- gain decrease correlated with muon beam
  - strong dependence on beam rate
  - **so rapid** that **too large HV** is necessary to compensate for decrease
- solution: half gain operation
  - **smaller decrease at smaller gain** → safe HV even after 3 years run
  - little effect on detector performance
    → to be checked by monochromatic 55 MeV γ this year

Backup

PMT Principle

- $G = \prod a_i V_i^{k_i}$ (i: dynode)

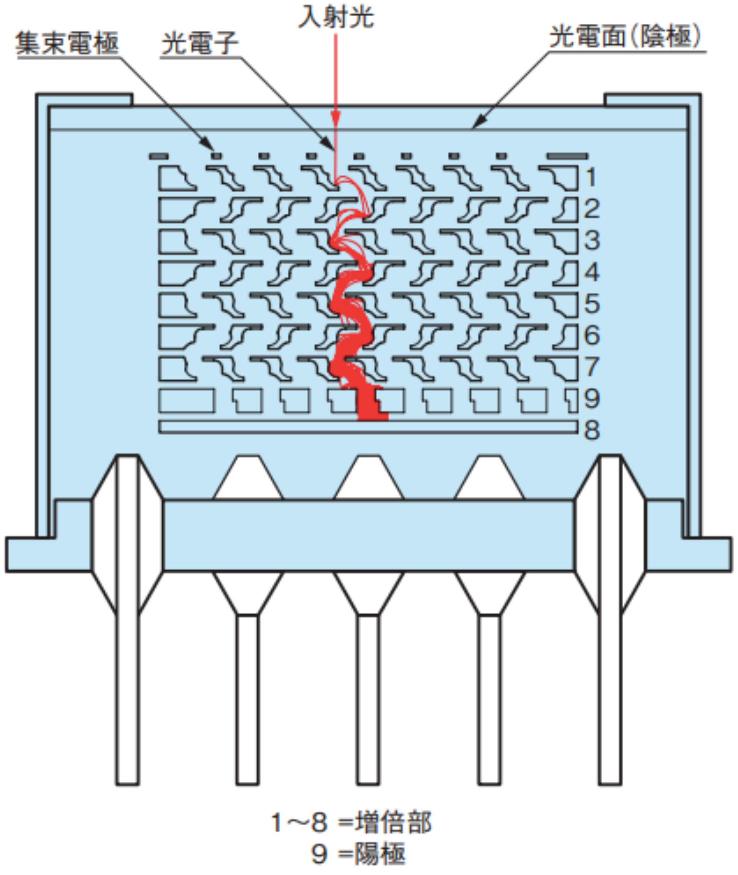


図 2-5 メタルチャンネル型

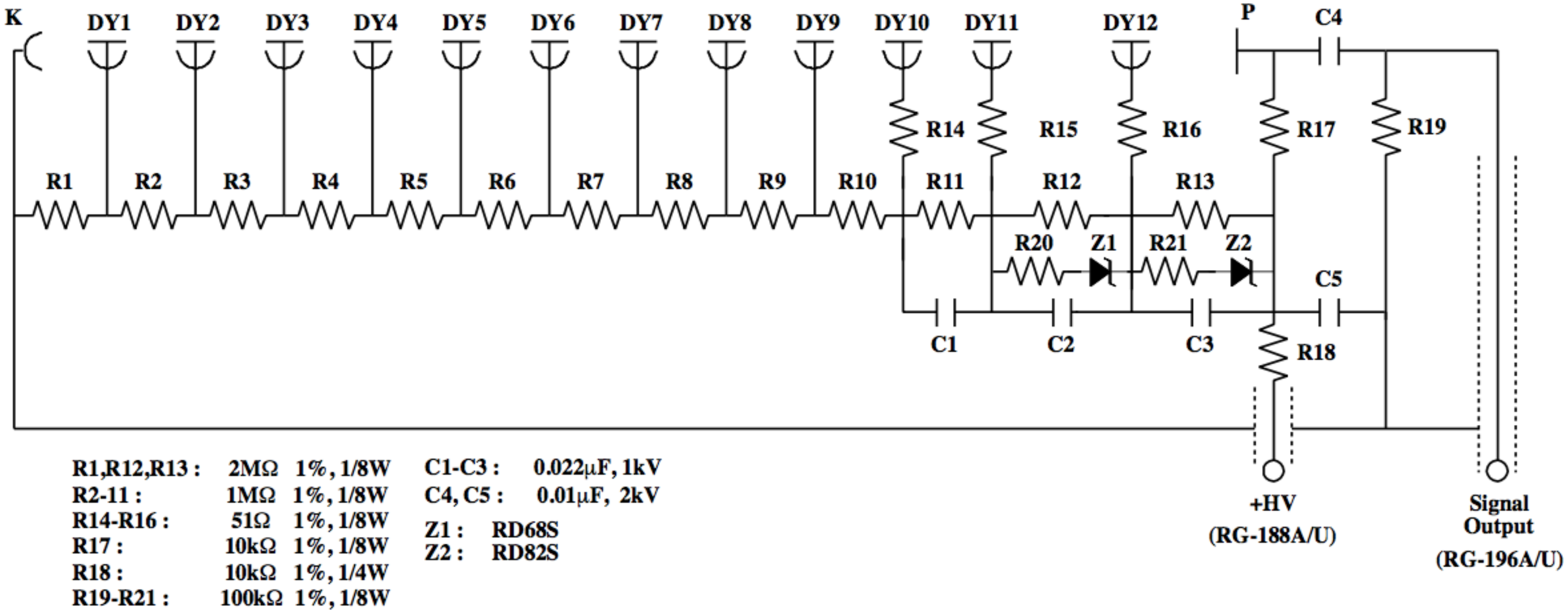
Hamamatsu

PMT Information

➢ R9288 & R9869

Size	57 mm ϕ
Active area size	45 mm ϕ
PMT length	32 mm
Photo-cathode material	K-Cs-Sb
Dynode type	Metal channel → fast, small, robust for B-field

Aluminum strip → low temp.
Zener Diodes → large signal

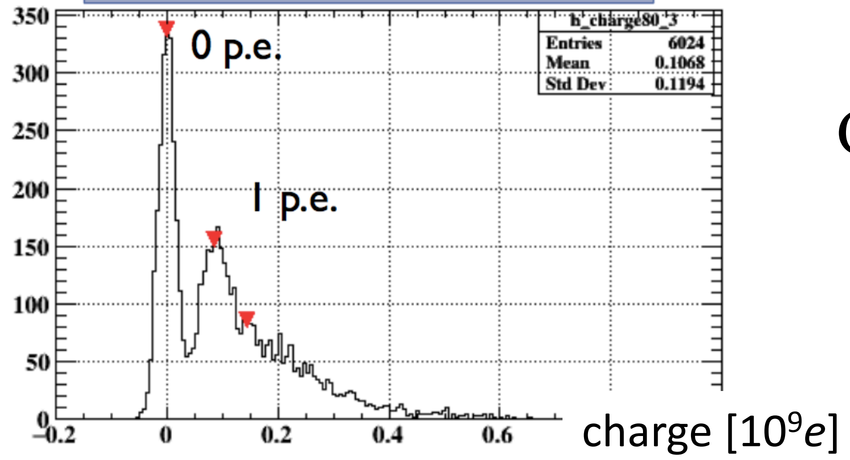


MPPC Monitoring

- $charge = N_{photon} \cdot PDE_{\lambda} \cdot gain \cdot ECF$
  - weak LED

PDE : Photon Detection Efficiency (depend on wavelength)
gain : charge from 1 pixel
ECF : Excess Charge Factor (= crosstalk + afterpulsing)

Example of charge distribution



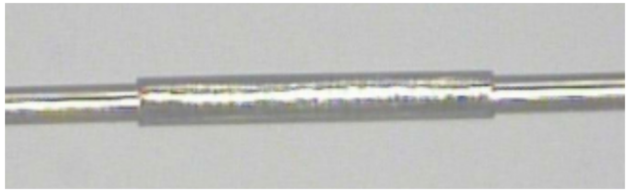
Charge follows "Poisson + correlated noise" distribution

$$gain \cdot ECF = \frac{mean}{\mu\ (expected\ \#\ of\ primary\ discharge)}$$

estimated from pedestal fraction: $P(0\ pe) = e^{-\mu}$

- Strong LED: response for visible light
- charge from scintillation by α from ^{241}Am
- current from scintillation by γ from μ

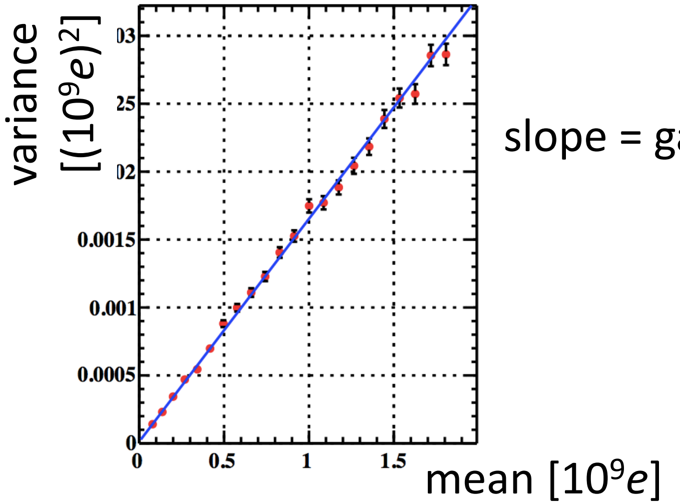
LED



^{241}Am α source

PMT Monitorin

- $charge = N_{photon} \cdot QE \cdot CE \cdot gain$
  - LED of different intensity



slope = gain

QE : Quantum Efficiency
CE : Collection Efficiency
gain : charge from 1 photoelectron

depend on B-field

Charge follows Poisson distribution

$$gain = \frac{variance}{mean}$$

  - Strong LED: response for visible light
  - charge from scintillation by α from ^{241}Am
  - current cannot be read out

$charge = N_{photon} \cdot QE \cdot CE \cdot gain$
LED of different intensity
Strong LED: response for visible light
charge from scintillation by α from ^{241}Am
current cannot be read out

LED

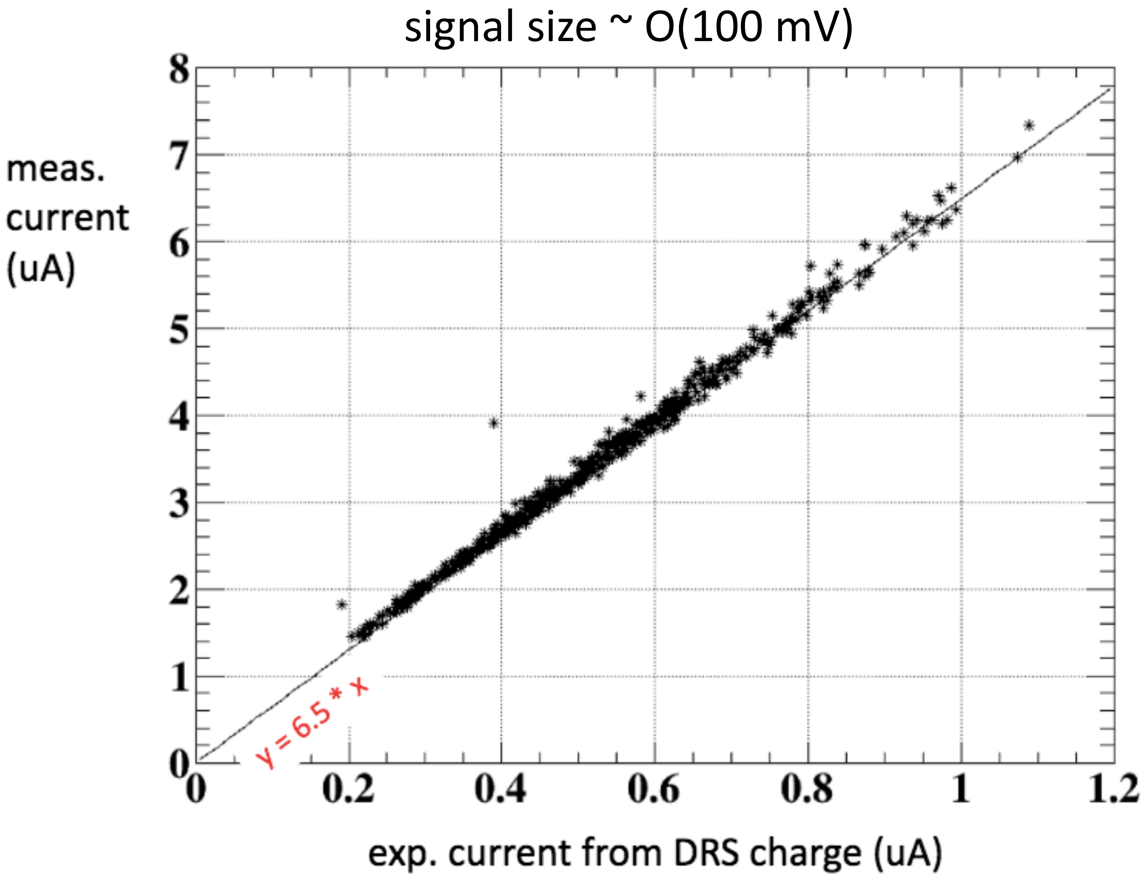
Charge follows Poisson distribution

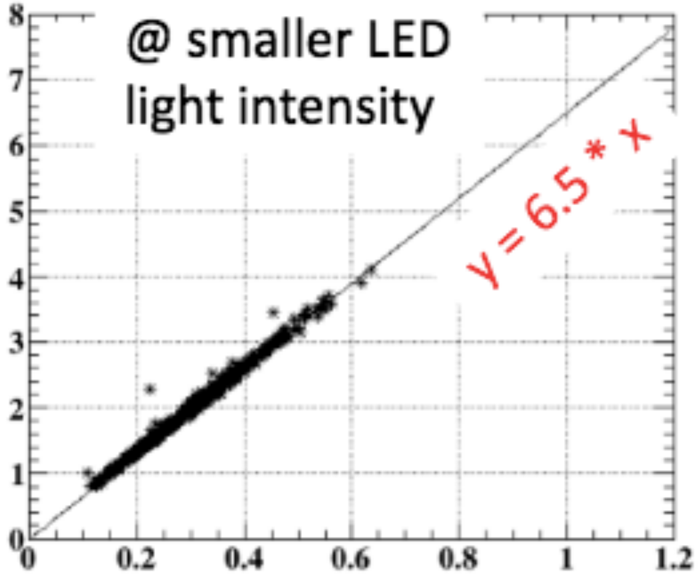
$$gain = \frac{variance}{mean}$$

^{241}Am α source

Dose Estimation

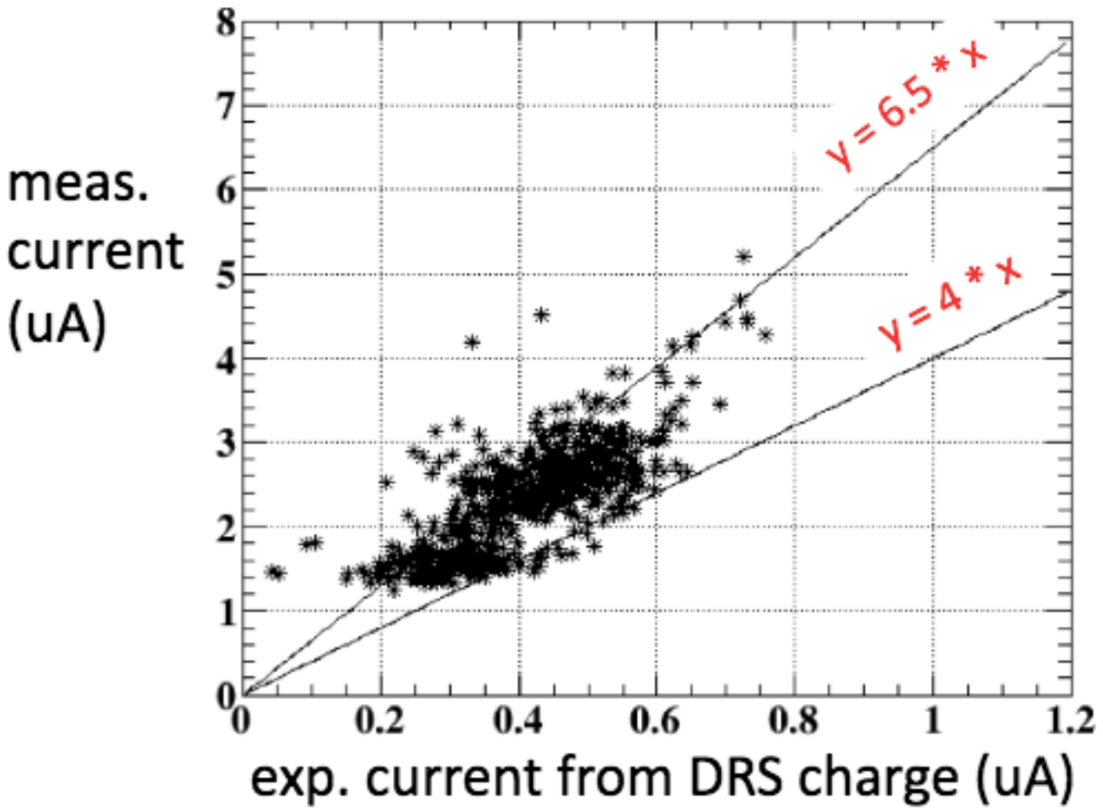
➢ MPPC current for pulsed LED light (20 kHz)





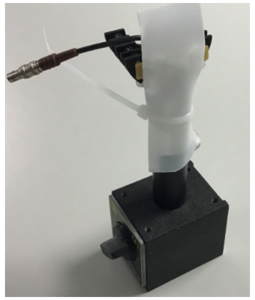
Dose Estimation

- MPPC current for signals from muon beam



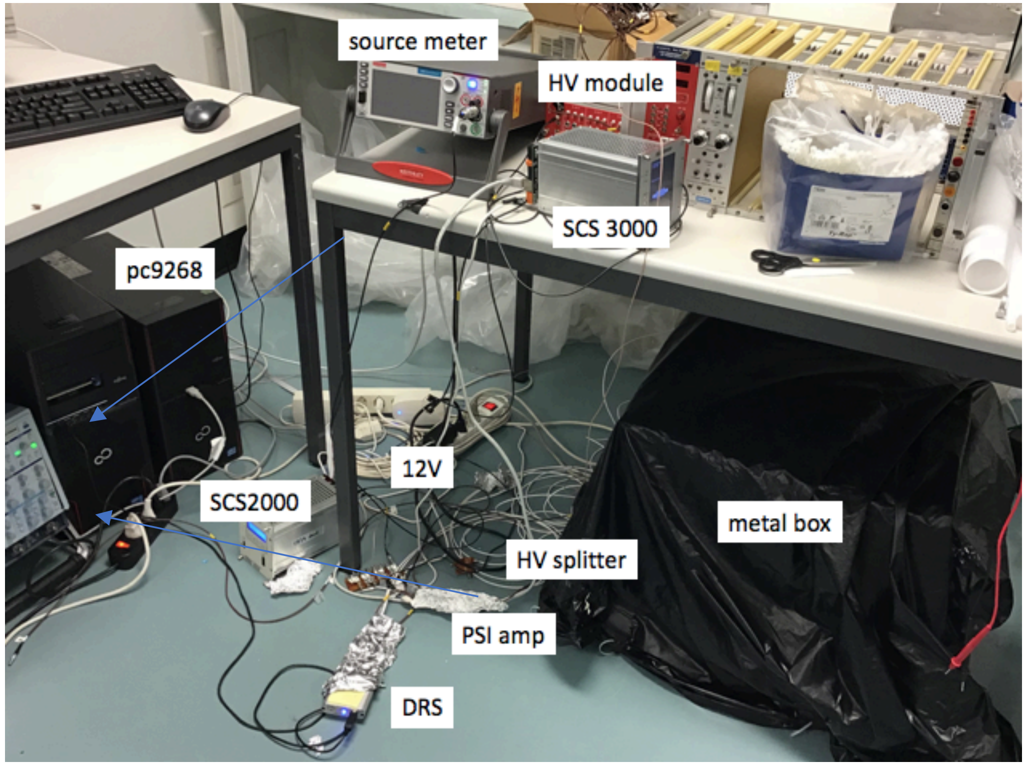
Irradiation of LED Light

- motivation: confirm that cause is dynode damage should be independent of wavelength
- setup
  - LED with pulse operation (1 MHz)
  - PMT with large gain (5×10^6)
  - MPPC for light monitor



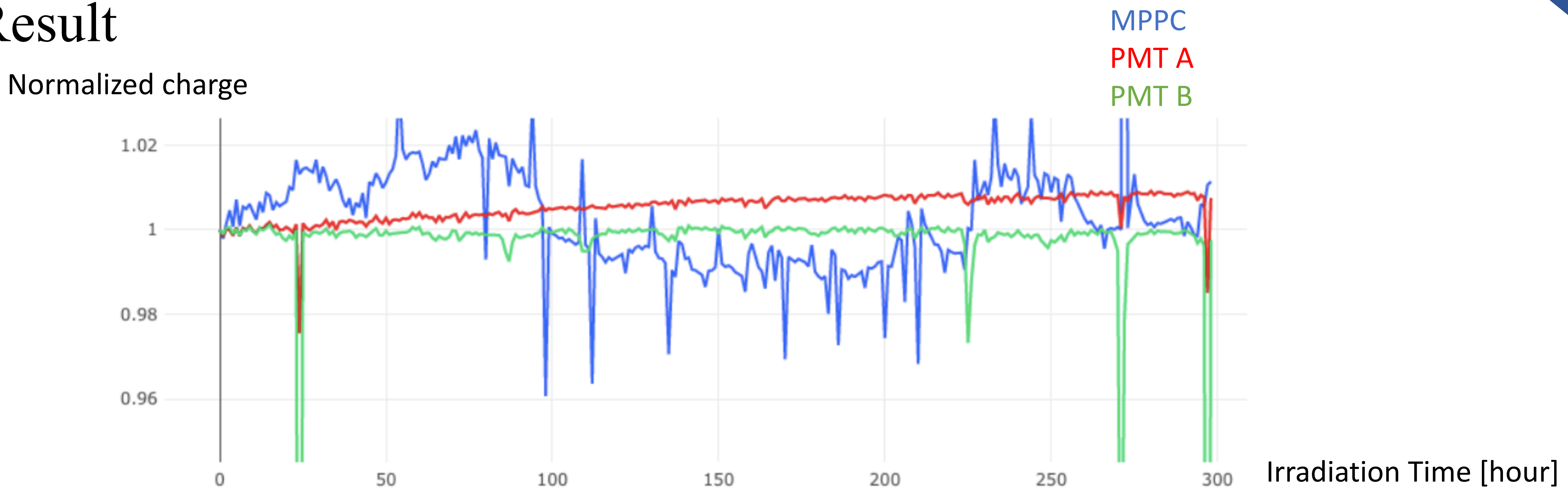
LED

PMT & MPPC



Irradiation of LED Light

➢ Result



- no decrease observed except for only a few % fluctuation
  - > 5×10^{16} photon/PMT/day for >10 days
  - (2×10^{13} photon/PMT/day for 6 days @LXe detector)
- possibly different in LXe temperature (165 K)