MEG II実験陽電子タイミングカウンターに用いるSiPMの荷電粒子照射による時間分解能への影響について

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Outline

- Introduction
- Measurement and Analysis
- Summary

Outline

- **Introduction**

MEG II experiment

Motivation

- Measurement and Analysis
- Summary

MEG II experiment

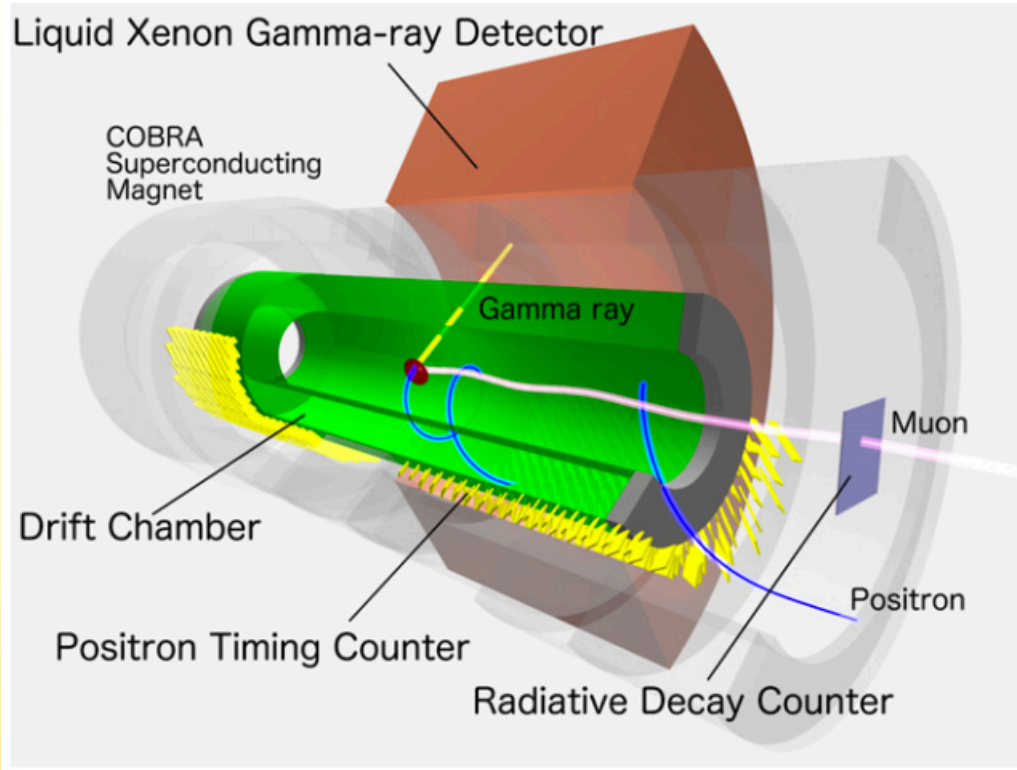
We are searching for charged Lepton Flavor Violation process

$$\mu^+ \rightarrow e^+ \gamma$$

@ Paul Scherrer Institute(PSI), with the most intense DC muon beam in the world

γ : detected by LXe detector

e^+ :detected by Drift Chamber and timing counter



引用：T.Mori and W. Ootani progress in Particle and Nuclear Physics 79 (2014) 57-94

In Standard Model

strongly suppressed and **negligeble** (cannot be found by experiment)

In Beyond Standard Model with SUSY-GUT, SUSY-seesaw model …

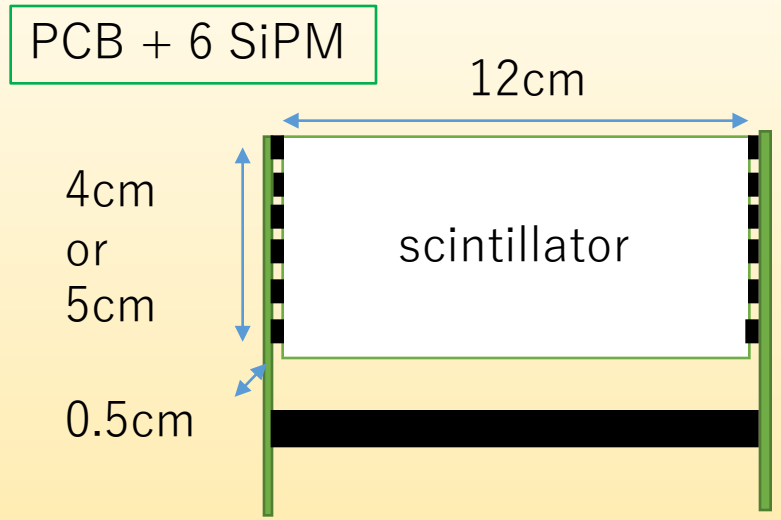
Br($\mu^+ \rightarrow e^+ \gamma$) becomes larger -> can be found by experiment !

To discover $\mu^+ \rightarrow e^+ \gamma$ means to discover new physics !

MEG II unprecedented sensitivity : Br($\mu^+ \rightarrow e^+ \gamma$)$\sim 4.0\times10^{-14}$

(×10 better than MEG experiment !)

MEG II experiment



512 pixelated positron Timing Counter (TC)

- ✓Composed of ultra-fast plastic scintillator(BC422) + 6 series **SiPM (made in AdvanSiD)** on each PCB
- ✓Small and pixelated structure -> positron hit on multiple counters
- ✓Using multi hit information, time resolution reaches **~ 30 ps**
- ✓precise tracking and event reconstruct with drift chamber

positron hit rate

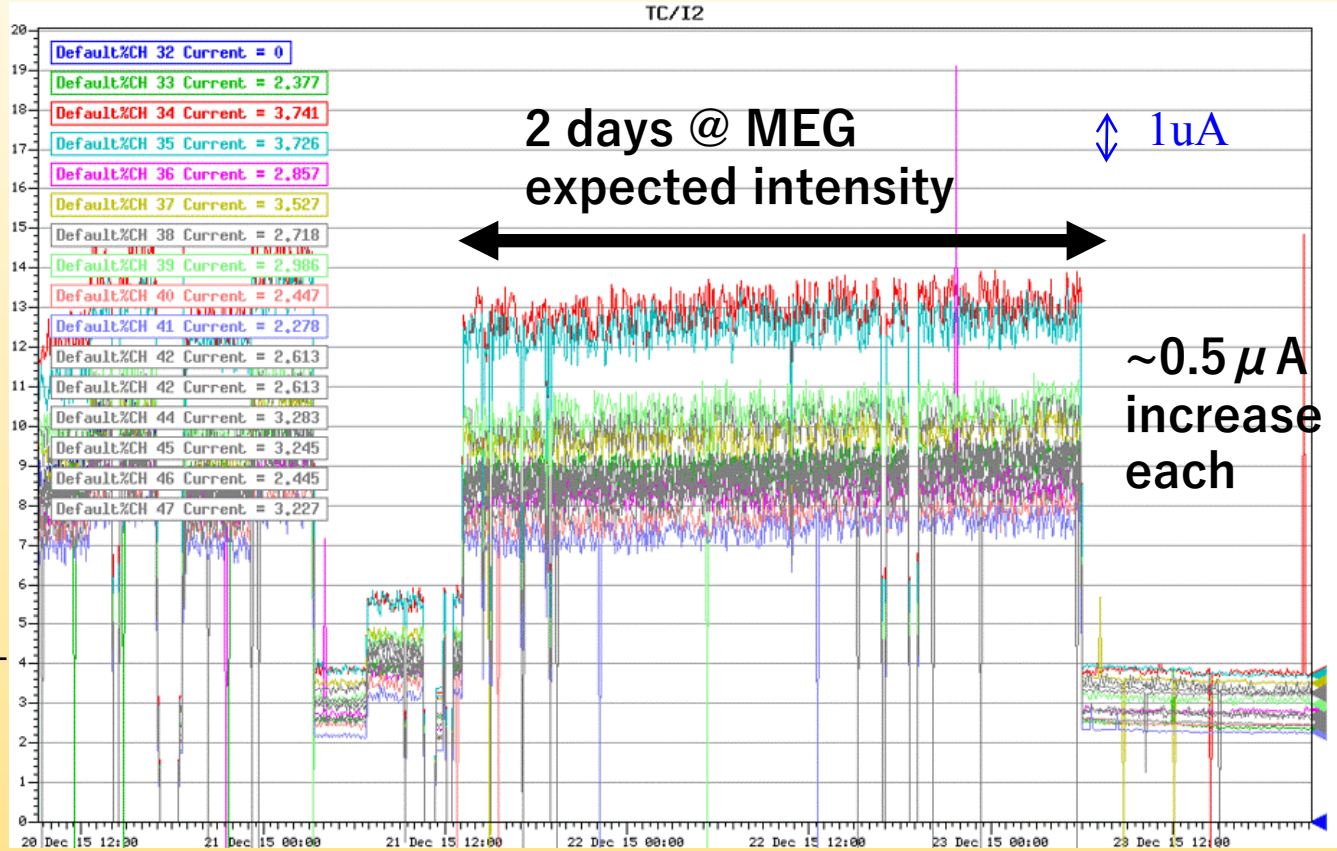
Average : 110 kHz per counter

@MEG II intensity ($\sim 10^8 \mu^+/s$ at PSI π E5)

physics data taking : 25 weeks per year * 3years

Motivation

@December pilot run with a part of full scale detector in 2015 (**pilot run 2015**)
unexpected current increase
~0.5 μA increase / 2day
may have effect on time resolution of TC



Study by using **radioactive source (Sr 90)**

- ✓ Sensor current
- ✓ IV curve
- ✓ Dark Count Rate(DCR)
- ✓ Time resolution

also check the 2016 pilot run data, and see the consistency with 2015 pilot run and radioactive source measurement

Current and time resolution

✓Current increase is mainly explained by the dark noise increase

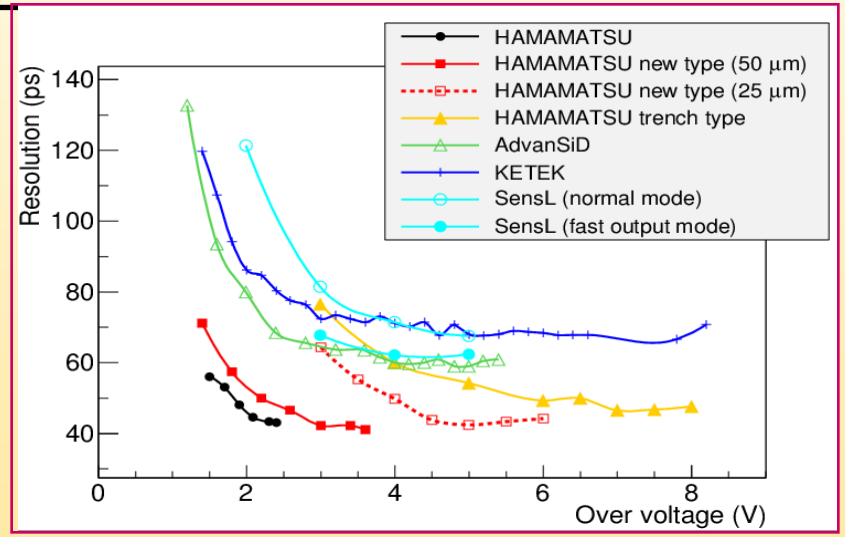
may **deteriorate the time resolution**

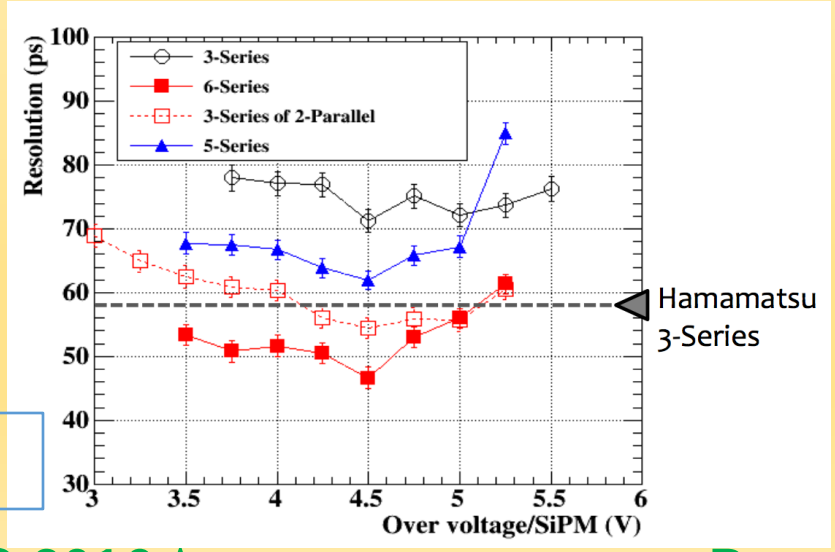
✓In addition , Current limit is determined by HV crate used in MEG II (called WD) : **100 μA each** at the expected configuration

we are using SiPM made in AdvanSiD

@ $V_{op} = V_{bd} + (2.5\sim3.0)$

so if we have to use smaller V_{op} , time resolution becomes worse





右上下引用：MEG-II 実験のための SiPM を用いた高時間分解能ポジトロンタイミングカウンターの性能最適化についての研究 JPS第69回年次大会 2014 M.Nishimura

Radiation Damage

引用: Nuclear Instruments and Methods in Physics Research A426(1999) 1-15 G. Lindström, M. Moll, E. Fretwurst
Radiation hardness of silicon detectors — a challenge from high-energy physics

✓**Bulk damage**

Damage due to Non-Ionizing Energy Loss(NIEL)

lattice defect by elastic scattering makes otiose levels - > current inc.

✓**Surface damage**

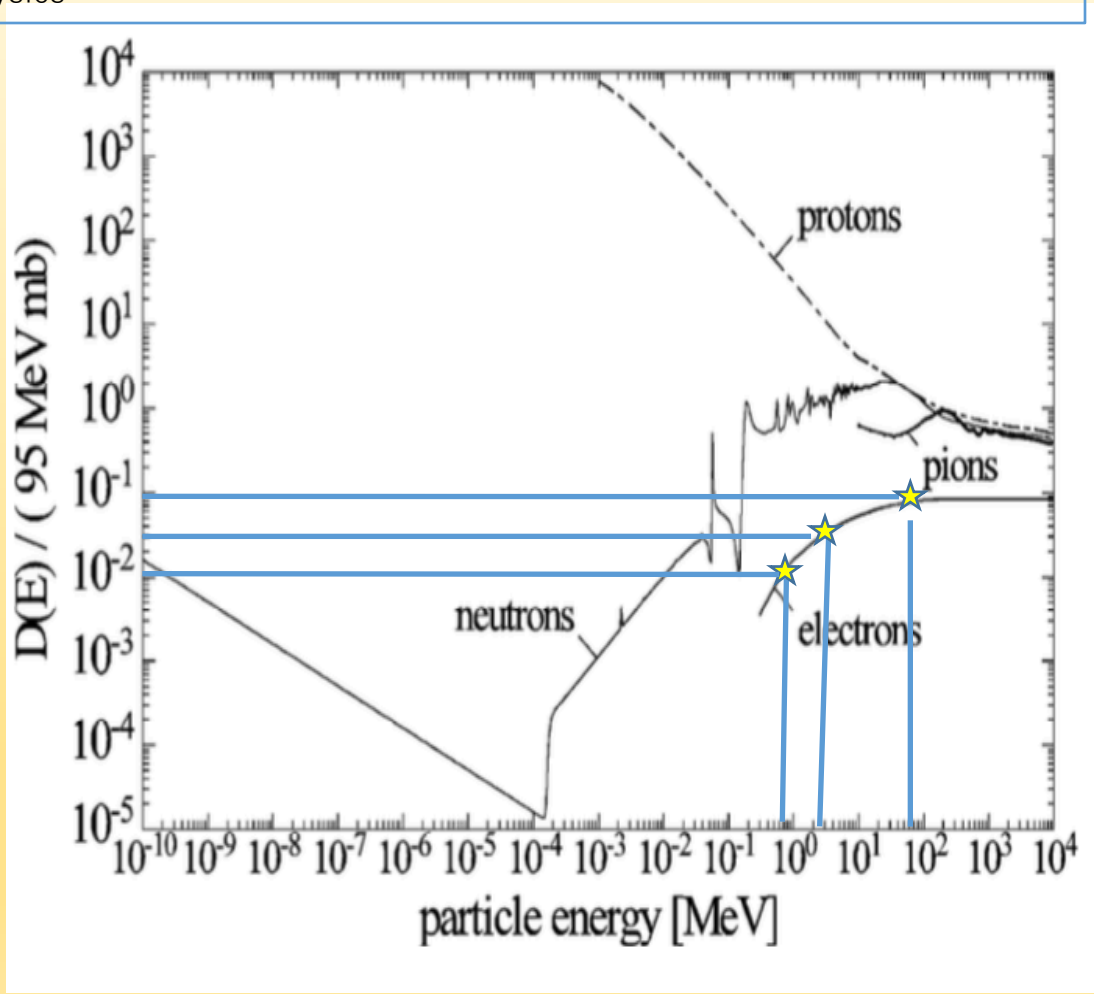
Damage due to Ionizing Energy Loss(IEL)

hole trapping and damage at insulating layer -> change the electrical property of SiPM , current inc.

Assumption

✓damage scales linearly with the number of positrons which hit on the SiPM

✓Energy difference is scaled by Si damage function



Outline

- Introduction
- **Measurement and Analysis**

Irradiation and monitoring Set up

Set up for data taking

Current Monitor

IV curve

DCR

Time Resolution

- Summary

Measurement

Bias (at each V_{op}) was applied during the irradiation and the sensor current was recorded.

Every 3 hours of irradiation, more detailed data were taken.

We analyzed

- **Current increase: to check the consistency with the pilot run**
- IV characteristics: to examine the change of the electrical properties
- Dark noise: to quantitatively measure the irradiation impact on the SiPM
- Laser signal: to measure the effect on the time resolution

Irradiation set up

✓ **Radioactive source**

$37MBq\ ^{90}Sr$ (β -ray)

✓ **Hit rate**

$\mathbf{1.3\times10^{6}}$**[electrons/s]**

measured @ plastic scinti. + SiPM + collimator

✓ **Total fluence by 15 hour irradiation**

7.0×10^{10} $[electrons]$

✓ **MEG II expected fluence(25 weeks × 3years)**

$< \mathbf{1.4\times10^{11}}$ $[\boldsymbol{e^{+}/cm^{2}}]$ (calculated from 2015 run)

Damage estimation

$$7.0 \times 10^{10} \times \frac{f_{damage}}{1.4 \times 10^{11} \times (0.3 \times 0.3)}$$

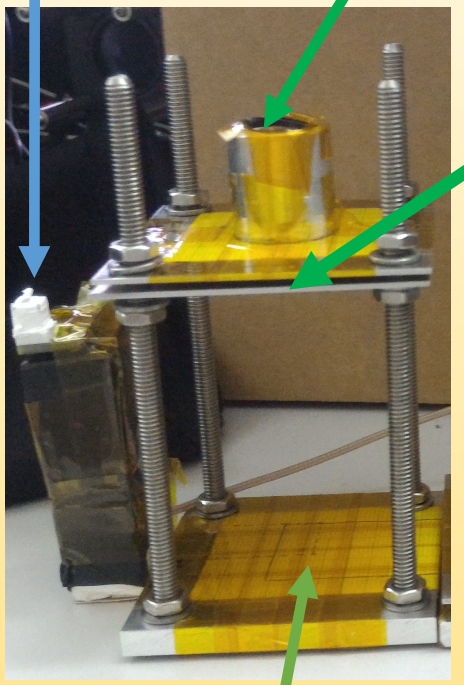
Damage factor $f_{damage} = 1/10 - 1/5$ is assumed

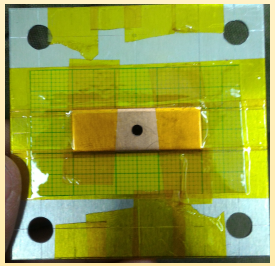
70^{+40}_{-20}% of MEG II total dose

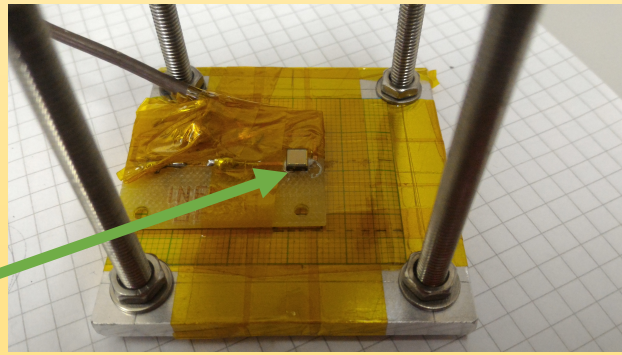
plastic scinti.(5*5*5 [mm])+SiPM(3*3[mm])
used to calculate Hit rate

Holder for Sr90

Collimator : 1.5mm
thickness Cu sheet
(hole : 2.8 mm diameter)







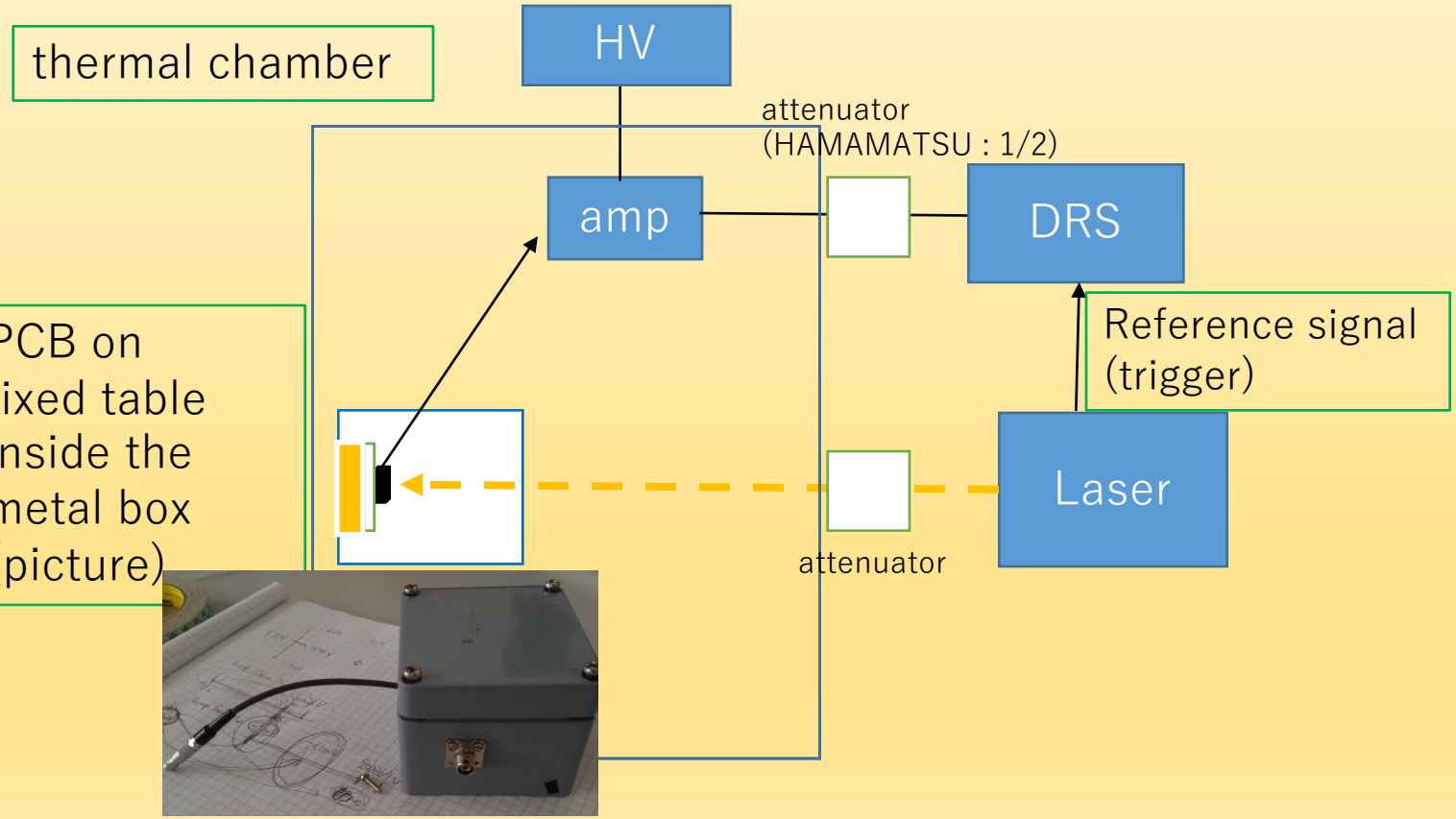
HAMAMATSU MPPC : S13360-3050PE
AdvanSiD SiPM : ASD-NUV3S-P High-Gain(MEG)
on PCB : set here

Set up for data taking

Time resolution measurement set up

Domino **R**ing **S**ampling chip : **DRS**
Waveform digitizer used in MEG

thermal chamber

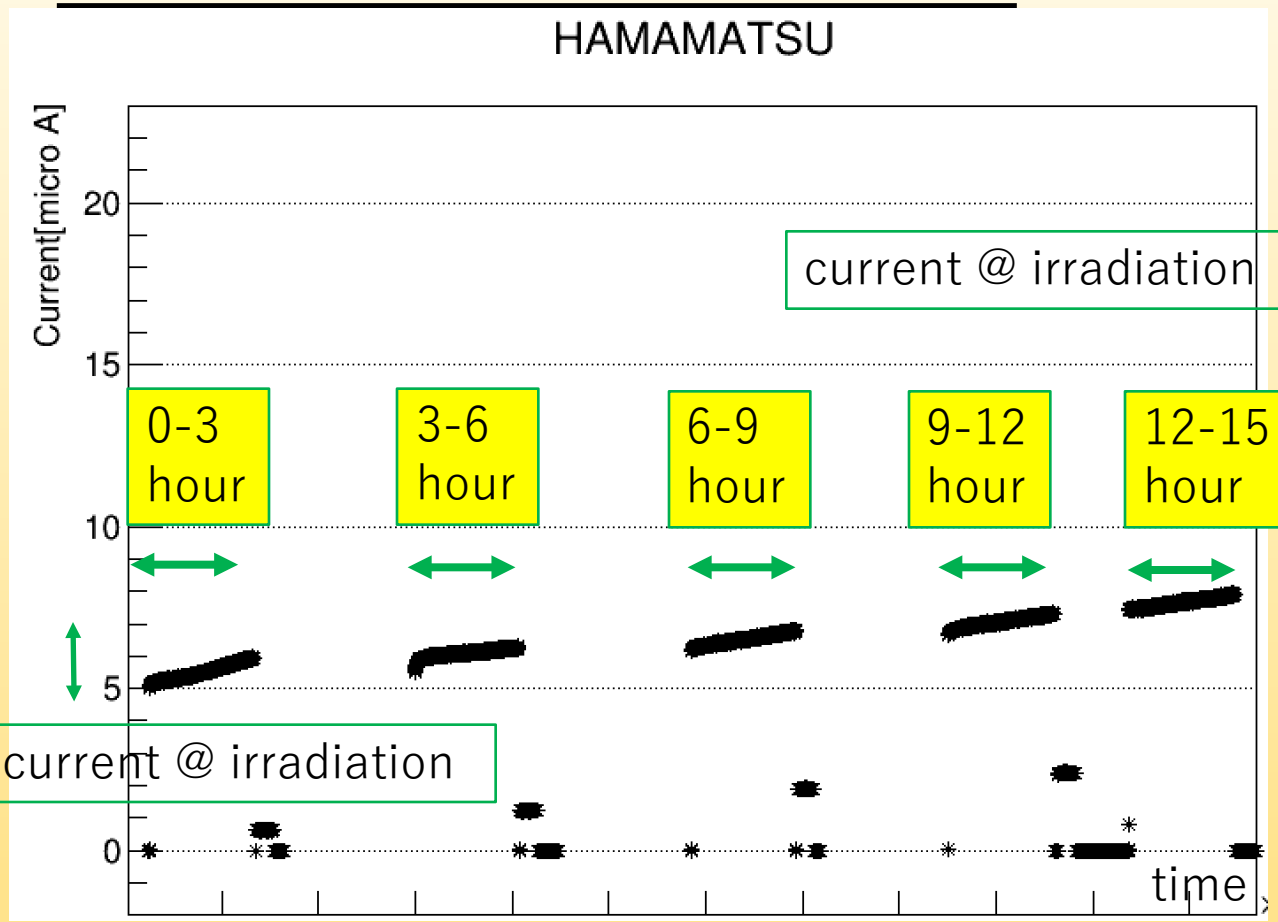


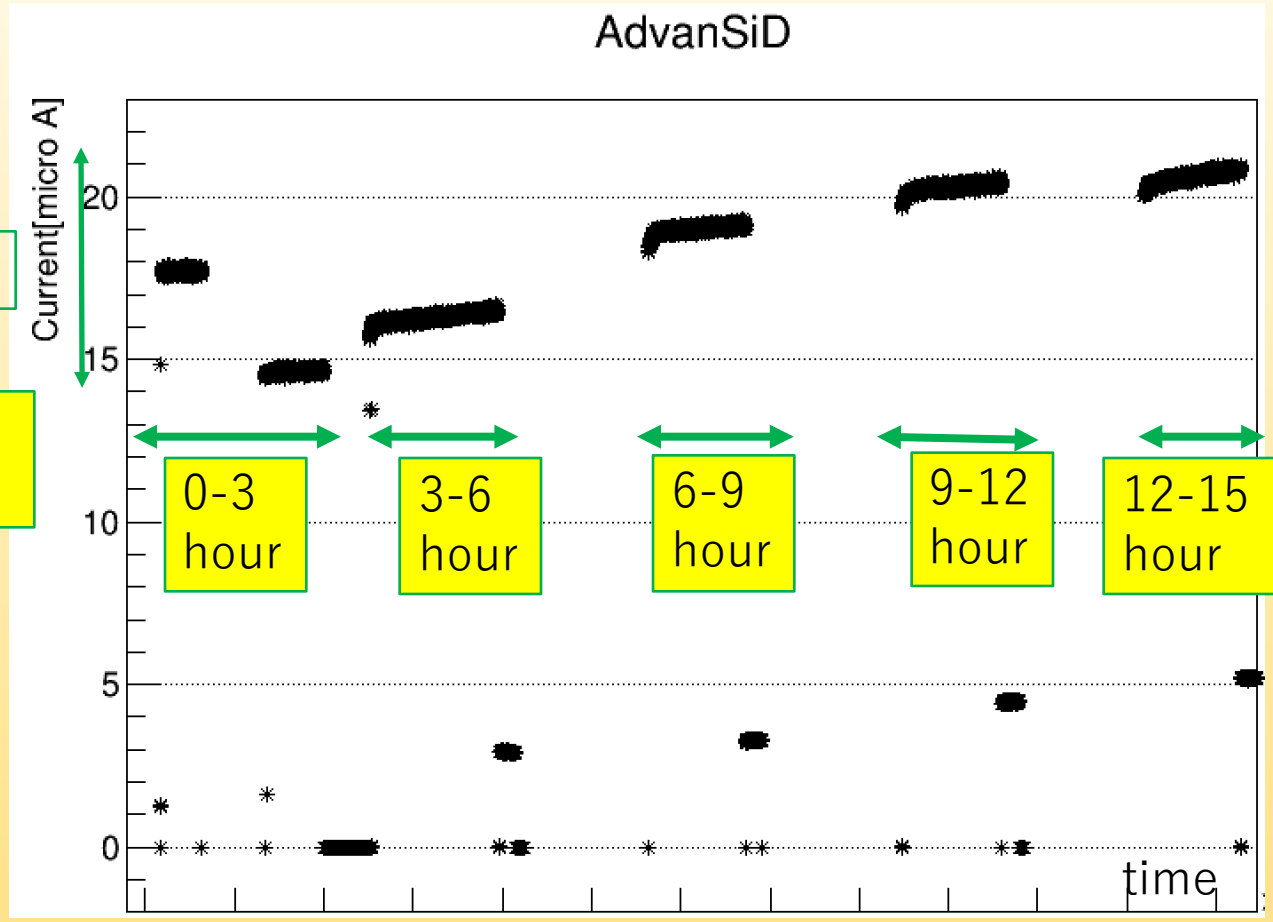
PCB on fixed table inside the metal box (picture)

data
- ✓ IV data (laser off)
- ✓ Dark noise(laser off, pocket pulser is used as trigger)
- ✓ Laser signal

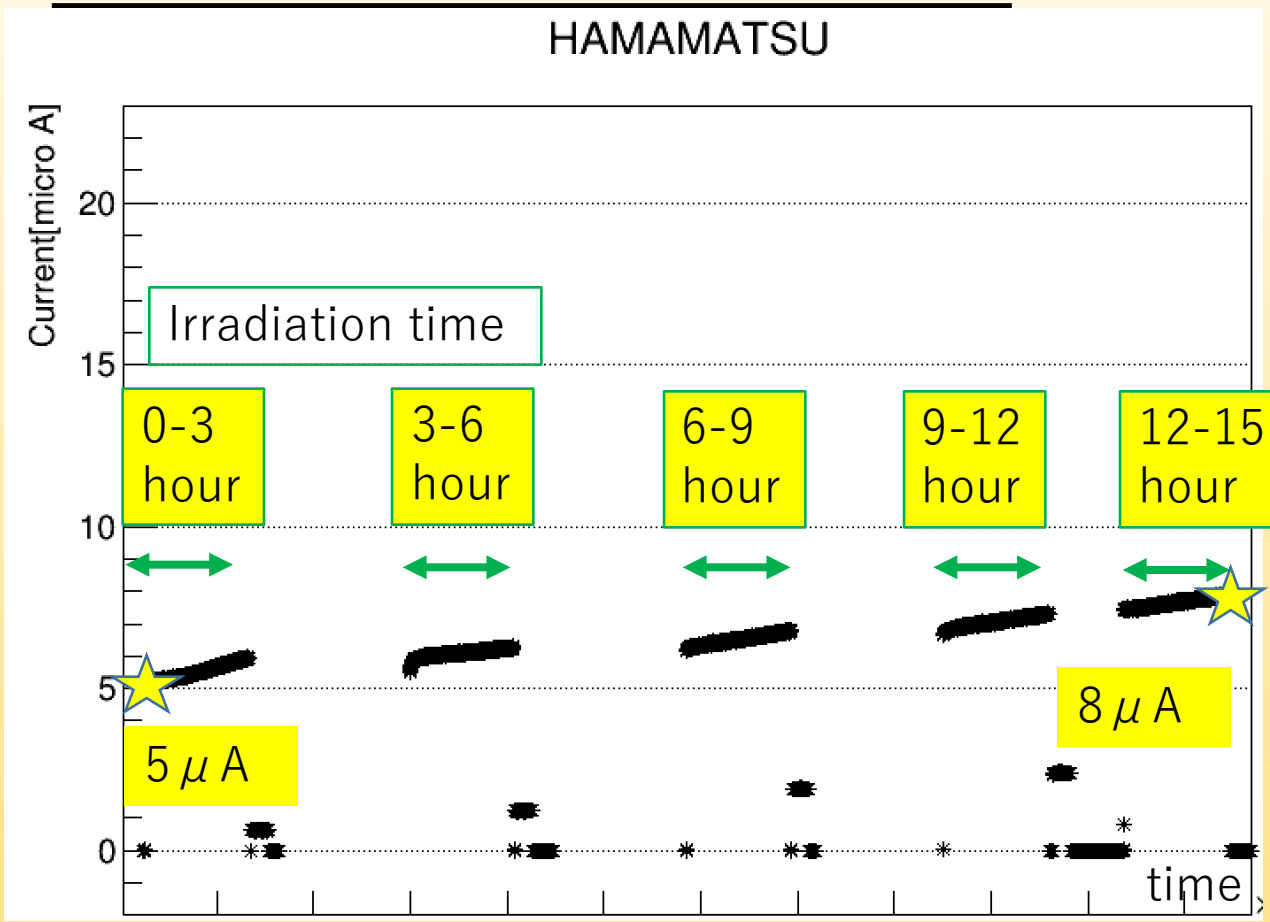
Condition
Laser frequency : 1kHz
Thermal chamber : 25 degree
Operation voltage :
HAMAMATSU:$V_{bd} + 3[V]$
AdvanSiD:$V_{bd} + 2.5[\mathrm{V}]$

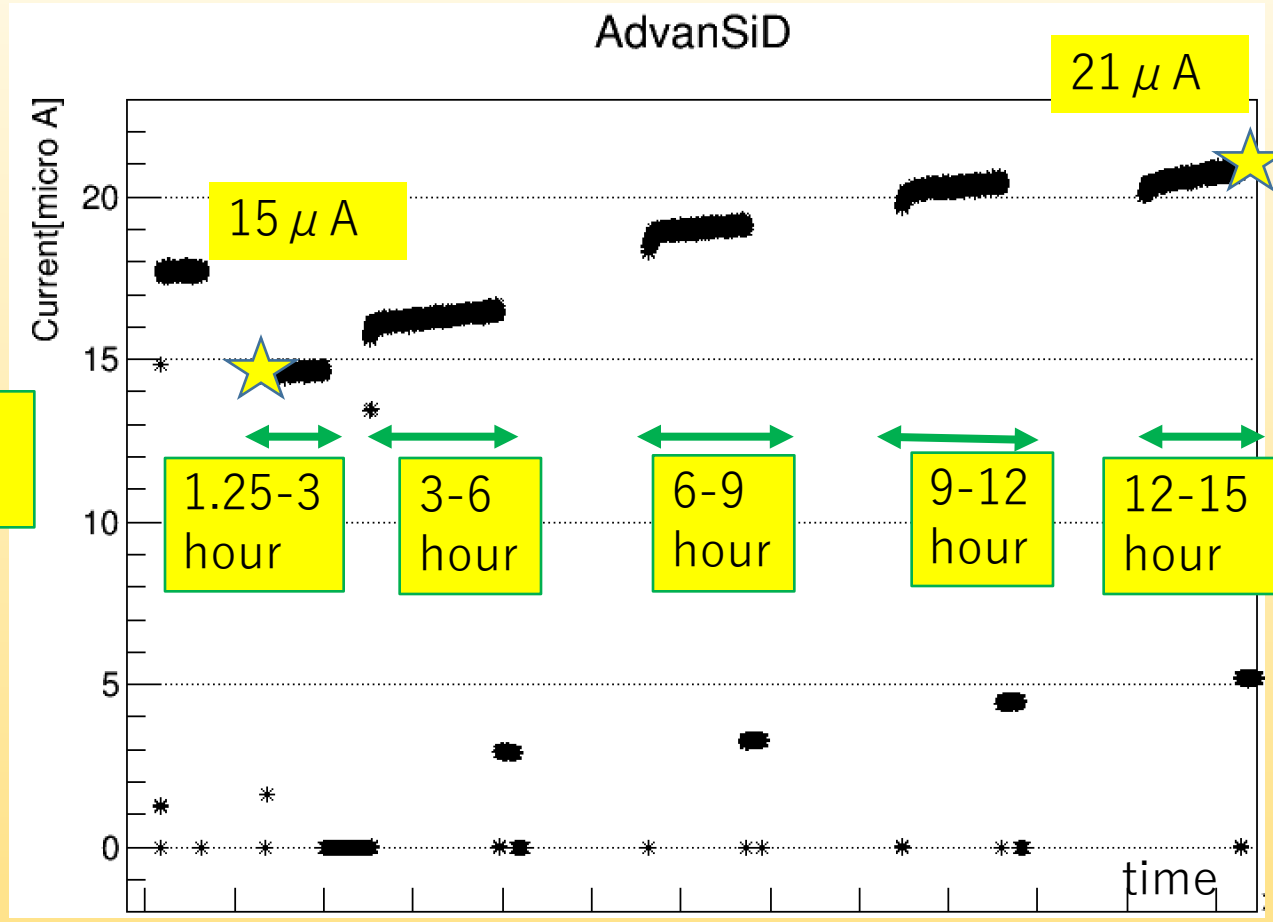
Current Increase





Current Increase





Current increase while irradiation
AdvanSiD : ~**0.44 μA per hour**
HAMAMATSU : ~**0.2 μA per hour**

Comparison with pilot run

	pilot run 2015	pilot run 2016	Sr90 SiPM
current increase	0.37 μA/6SiPM (24 hour run)	0.16 μA/6SiPM (24 hour run)	0.44 μA/SiPM (1 hour irrad)
Current increase @ expected 100% damage	123[μA/SiPM]	53[μA/SiPM]	$9.4^{+2.9}_{-3.2}$[μA/SiPM]
Expected inc. @ 6 series , 100%	196 μA/6SiPM	84 μA/6SiPM	15^{+5}_{-5} μA/6SiPM

factor ~ 1.6 to 6 series

✓ Sr90 experiment and pilot run data seems **not consistent**
Rough scaling with Si damage func.(page 9) is not sufficient, have to reconsider more precisely with similation
✓ pilot run **2015 and 2016 is also not consistent**
Linear extrapolation may not be correct(at first , current increase is fast but may becomes slow or saturate)
Have to understand current problem more detail

Possibility of extended irradiation period

	pilot run 2016	pilot run 2015	Sr90
current increase	0.16 μA/6SiPM (24 hour run)	0.37 μA/6SiPM (24 hour run)	0.7 μA/6SiPM (1 hour irrad)
% to the 1 hour Sr 90 irradiation	23 %	53 %	100 %

The conversion factor between pilot run current increase and Sr-90 current increase

- Sr-90 <-> 2015 run

1 hour <-> 1.9 days

- Sr90 <-> 2016 run

1 hour <-> 4.3 days

Radiation damage causes dark noise increase and it result in current increase

-> **Radiation damage can be scaled with current increase**

using factor : 1hour(Sr90) <-> 2 days(run) , by about 12 days irradiation we will be able to understand

- the **correct current increase** of SiPM @ 100 % physics run
- **linearity assumption** is good or not (the discrepancy of 2015 and 2016 run may come from here)

Measurement

Analysis was done on

✓**Current increase** : to see the consistency with pilot run

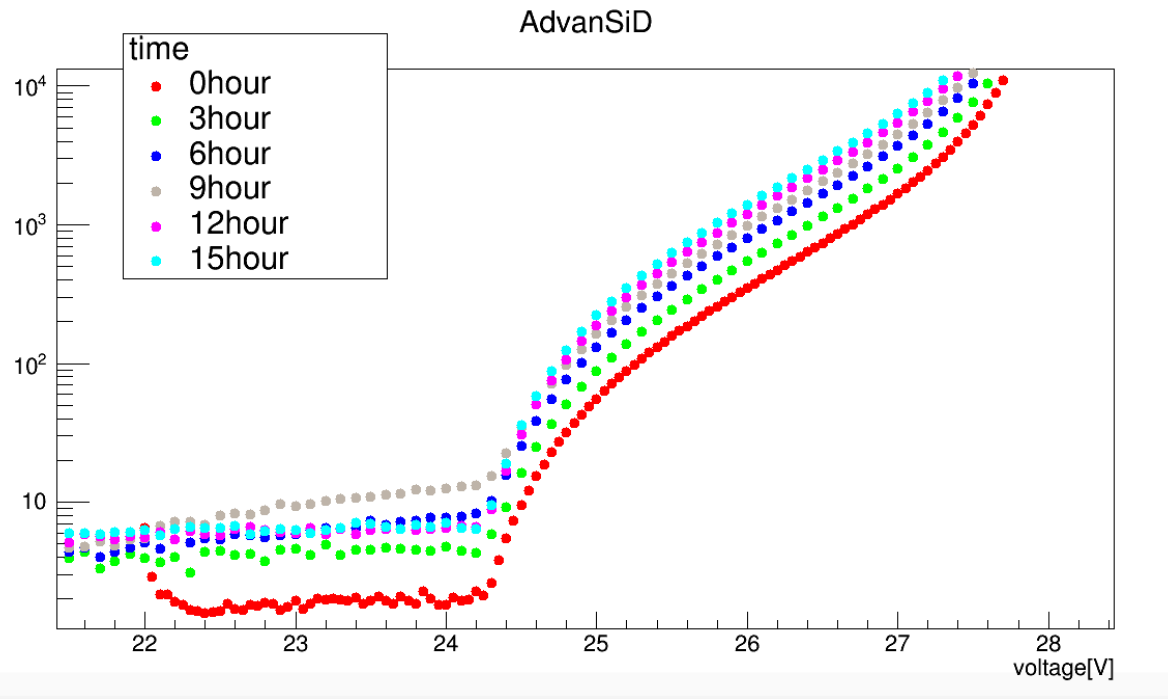
✓**IV data : to see the change of electrical property**

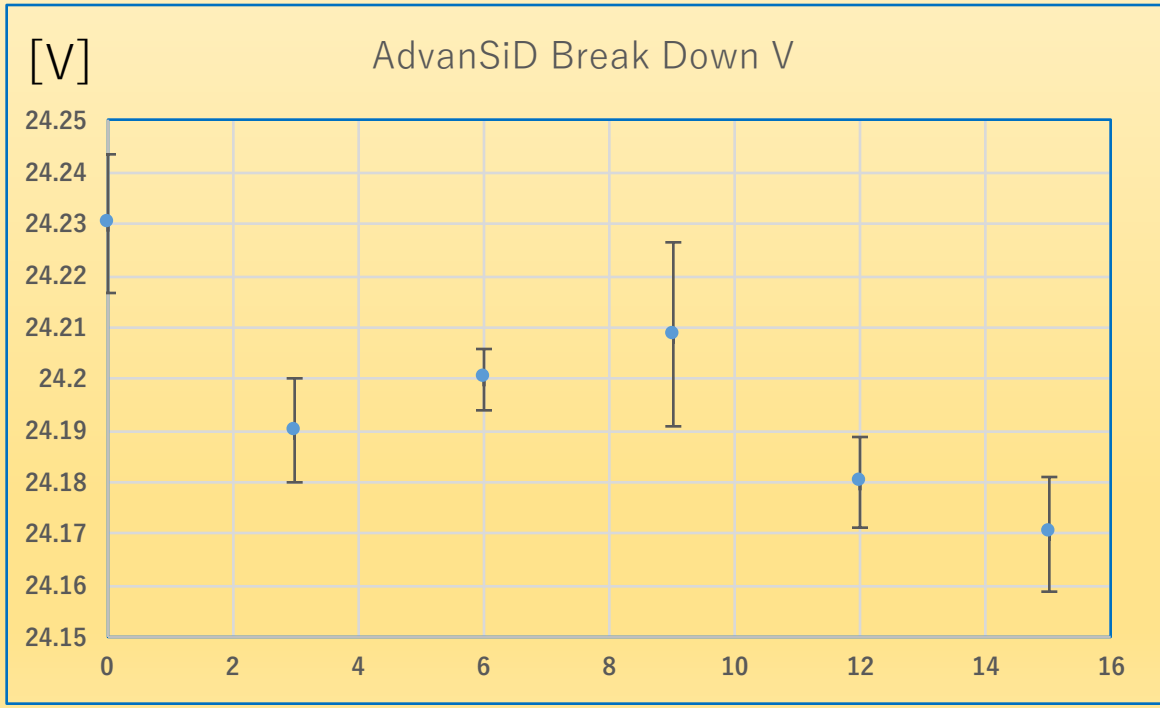
✓**dark noise : to confirm the cause of current increase**

✓**laser signal : to see the effect on time resolution**

IV curve (AdvanSiD)

By irradiation , the shape of IV curve may change and V_{bd} may change
Result : Current increase was seen but change of V_{bd} and curve shape was not seen clearly
- > the change of electrical property except dark noise seems small





only fit error is considered

IV curve (HAMAMATSU)

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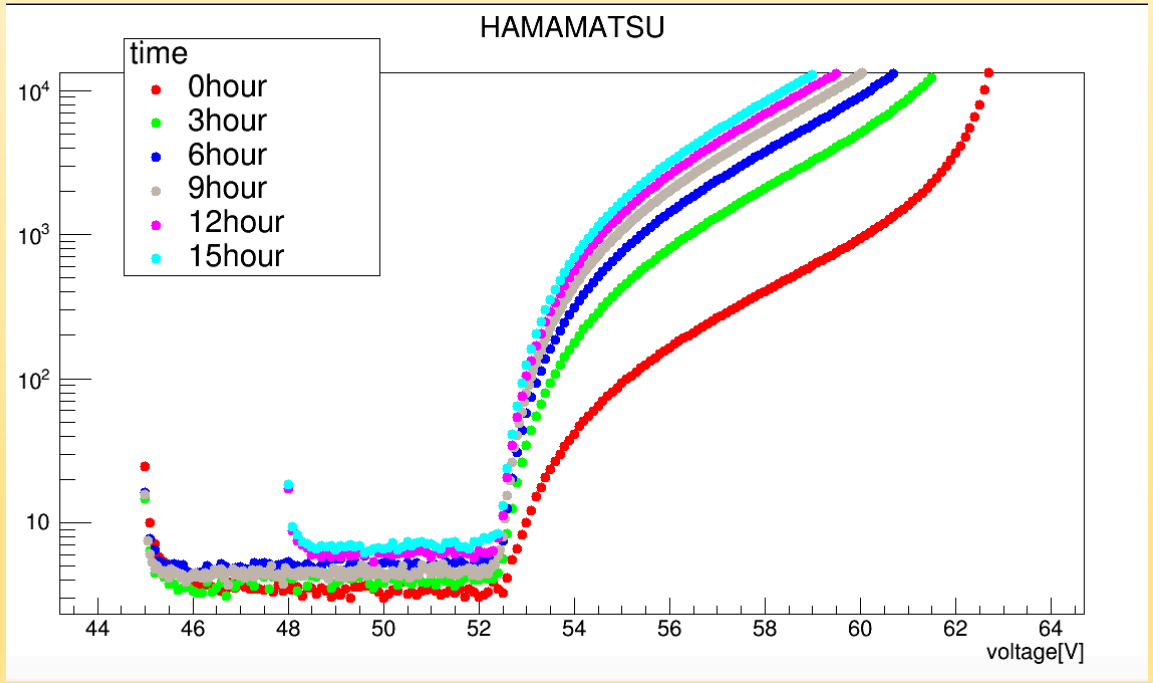
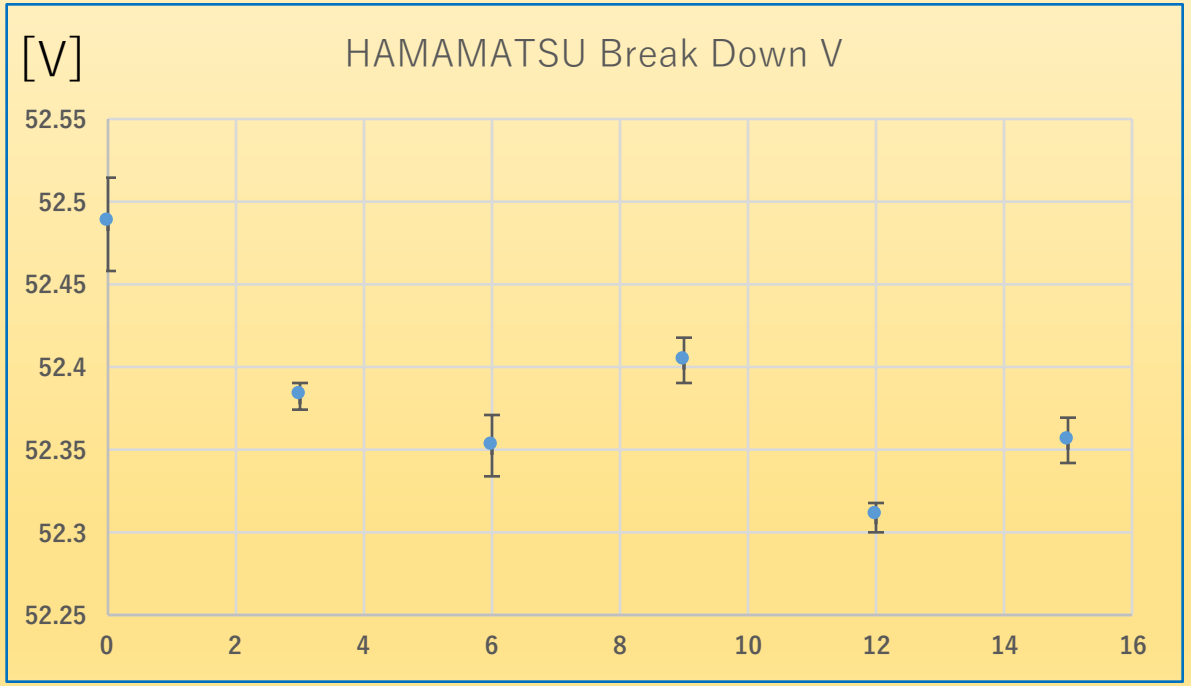
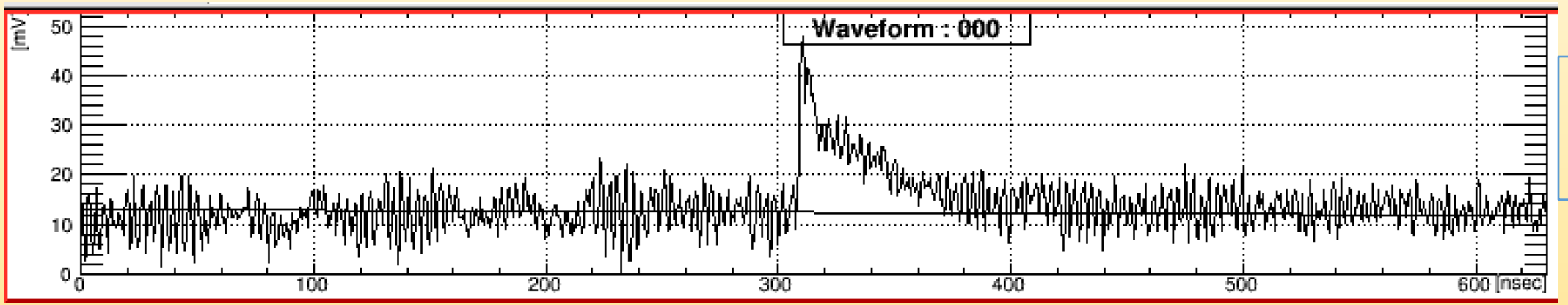


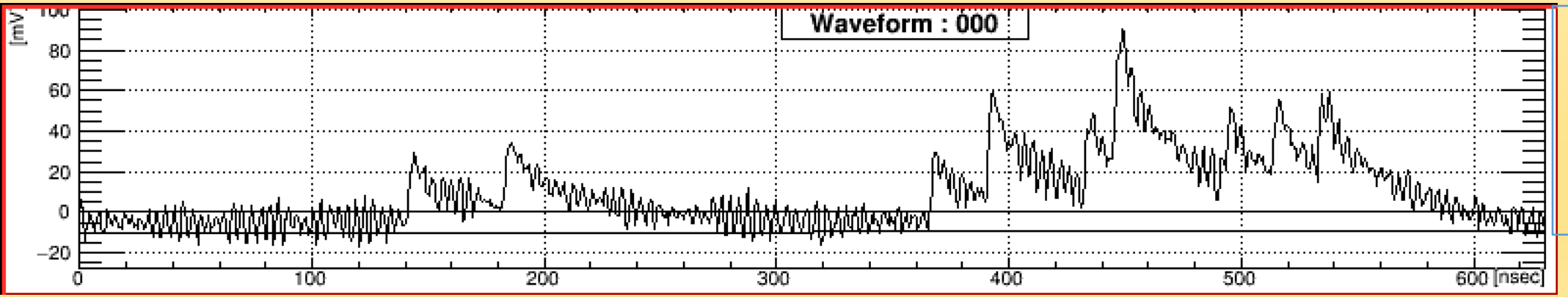


only fit error is considered

Irradiated Waveform example (HAMAMATSU)

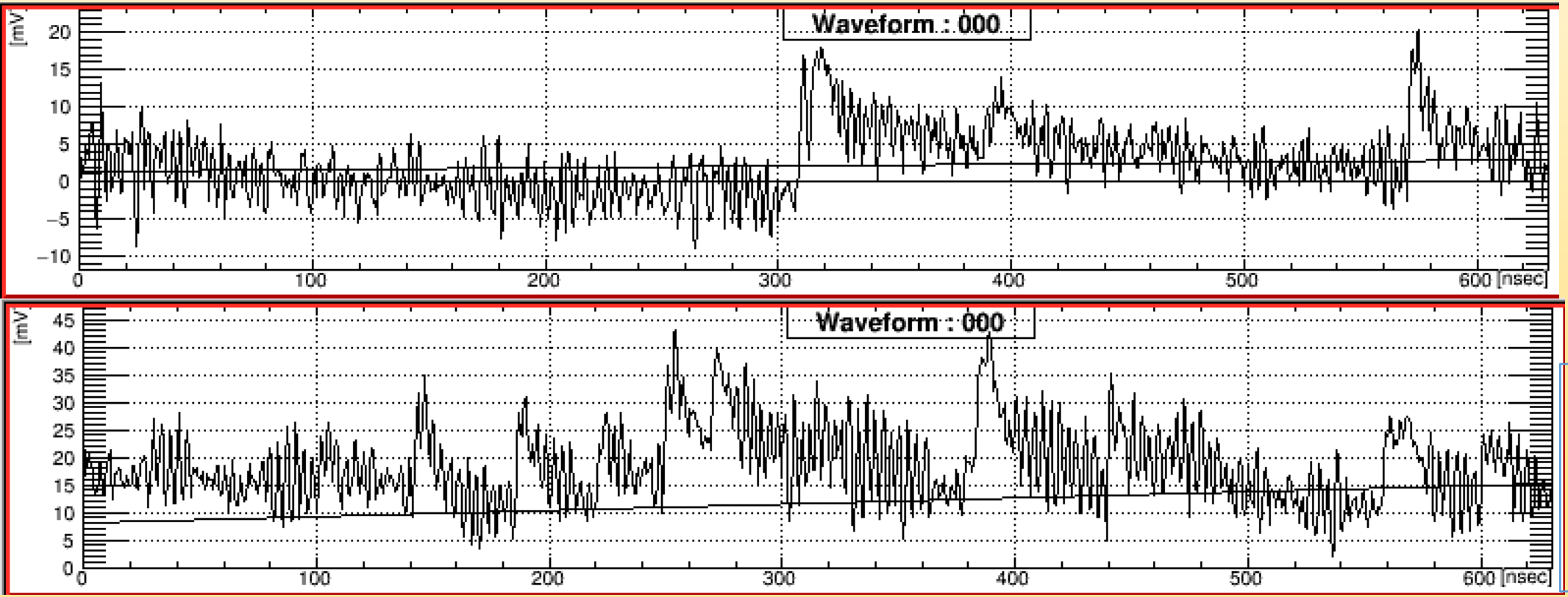


Before irradiation clear and dark noise was few



15 hour dark noise increased and sometimes become noisy

Irradiated waveform example (AdvanSiD)



3 hour

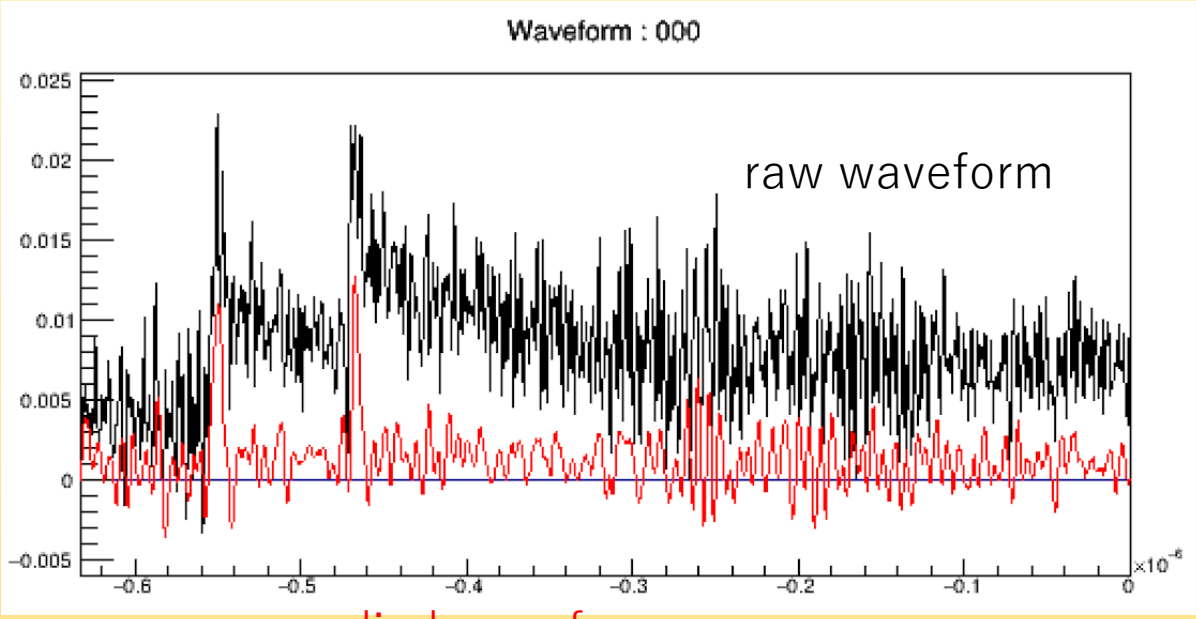
15 hour
some waveforms are difficult to analyze with raw waveform

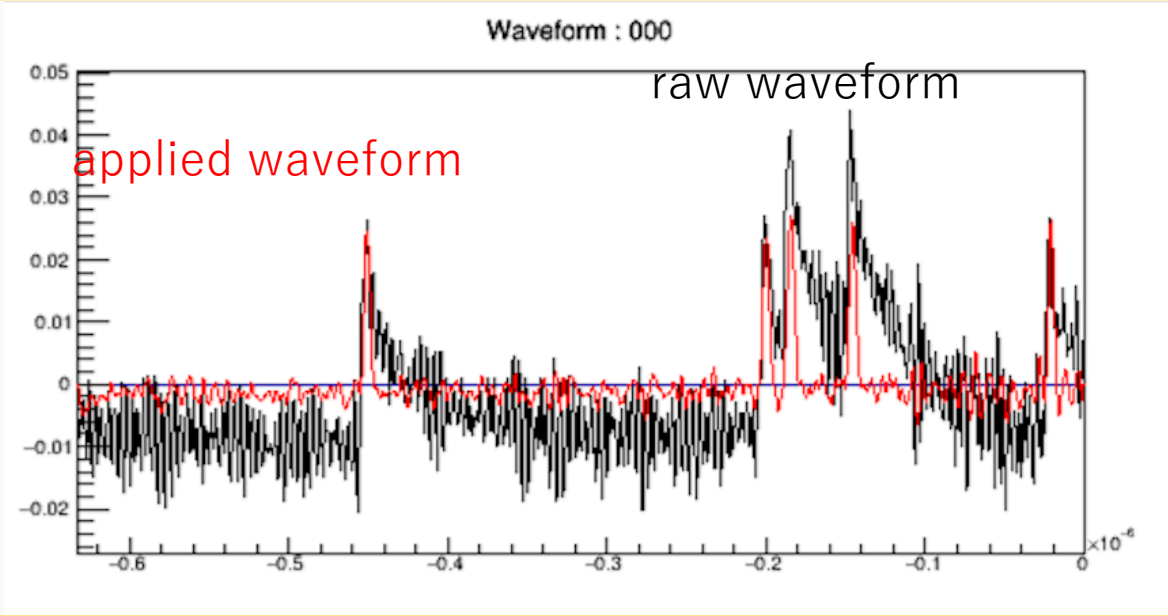
Digital Filter Applied

DCR was measured with digital filter

parameter should be optimized (now studying)

example of filtered waveforms



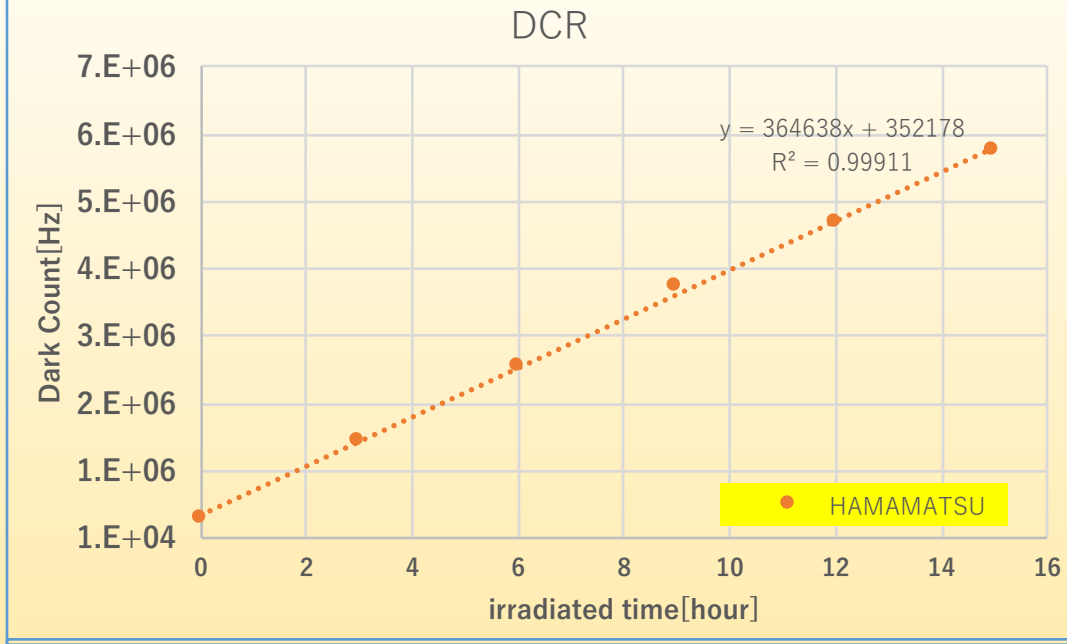


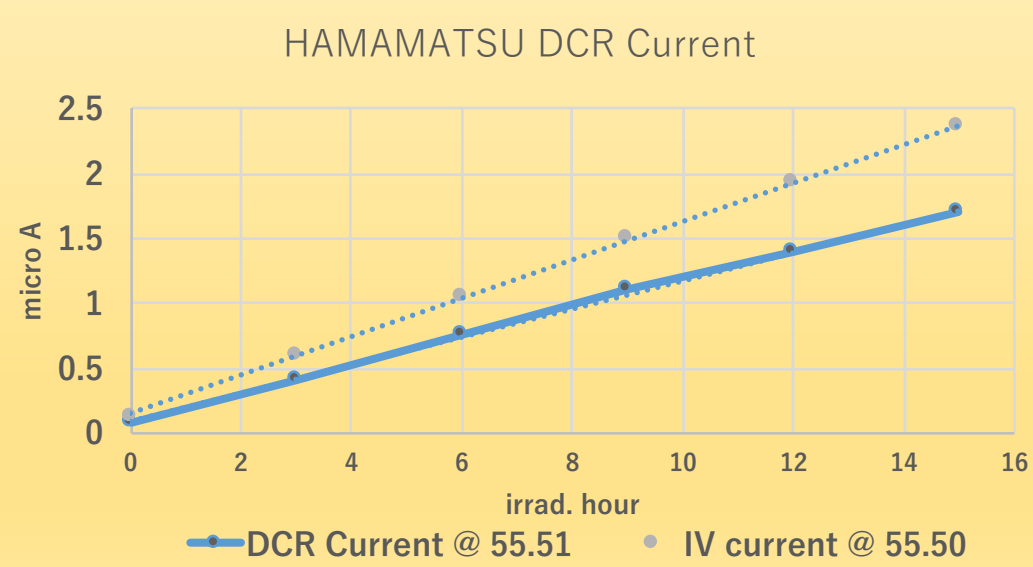
DCR(HAMAMATSU)

DCR becomes ~ **0.3Mcps** to ~**6 Mcps**

HAMAMATSU catalog spec @$V_{bd} + 3\,V$
DCR : 500 kcps

systematic uncertainty of analysis
individual difference
->future study





Current calculated from DCR
(Current $=\mathrm{DCR} * g_{\mathrm{SiPM}}(=1.7\times10^{6}\ catalog\ spec) * e$)
current increase is mainly(~70%) explained by DCR increase
Linearity is seen @ HAMAMATSU SiPM current increase

CTの効果は3 p.e まで補正

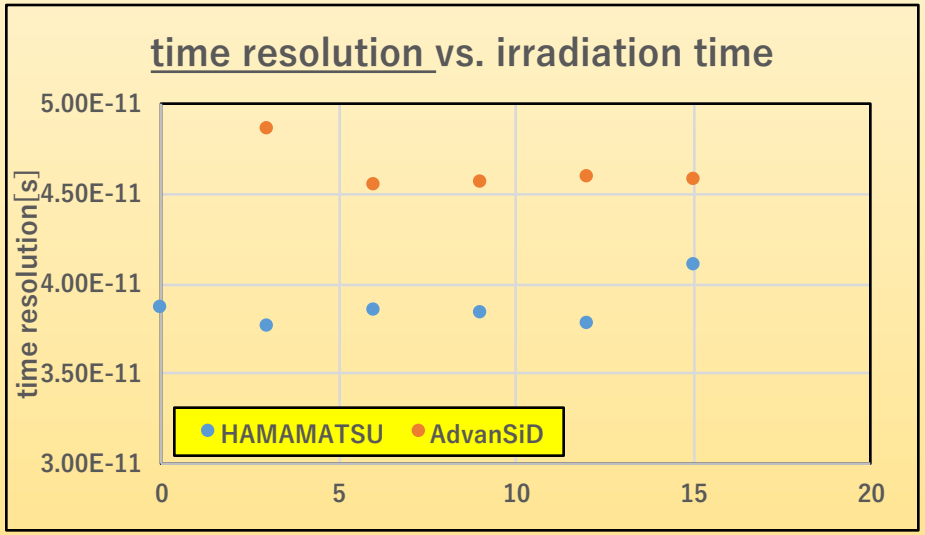
Ref) HAMAMATSU catalog page :
http://www.hamamatsu.com/jp/ja/product/category/3100/4004/4113/S13360-3050PE/index.html

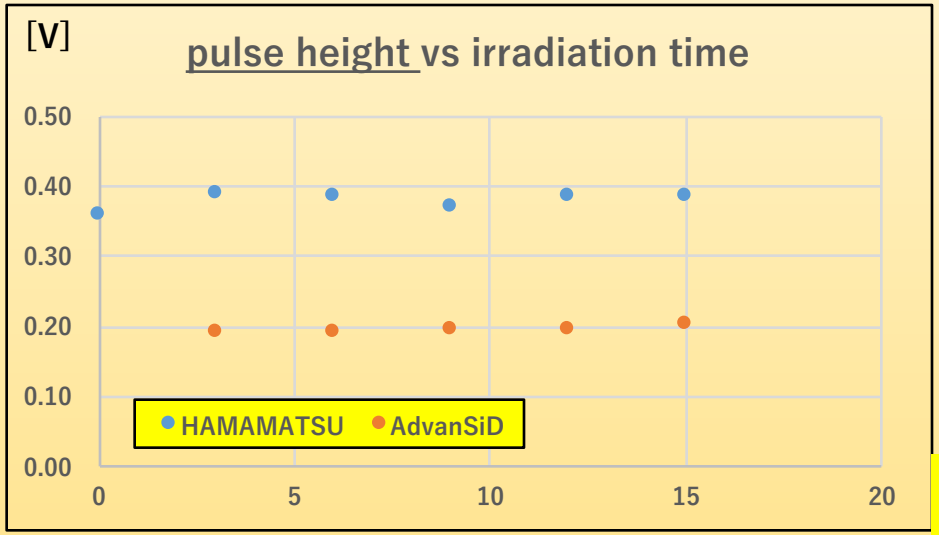
Time resolution

constant fraction time (cftime)
the time which becomes x% of the peak pulse height (this time x = 20)

- Time resolution is defined as the dispersion of the time difference between cftime of signal (t_{signal}) and cftime of reference signal ($t_{reference}$) :

$$\sigma(t_{reference} - t_{signal})$$





HAMAMATSU
: ½ attenuated

Irradiation time [hour]

-> **no significant influence on time resolution by 15 hour Irradiation**

-> **no significant decrease of pulse height**

-> deterioration of gain , time resolution was not clearly seen at this point

Summary

We carried out an irradiation test of SiPMs (AdvanSiD & HAMAMATSU) with Sr90 up to 7.0×10^{10} electrons.

From current increase

Current increase : AdvanSiD **~ 0.44 μA/hour** , HAMAMATSU **~ 0.2 μA /hour**

From IV curve

Current increase was seen but the other electrical property like V_{bd} and IV shape did not change so much

From DCR analysis

DCR became **~ 0.3 Mcps** to **6Mcps** and this was the main source of current increase

Time resolution deterioration was not seen in spite of current increase (and Dark count rate increase) at this point

Future Study

✓**Repeat experiment with current increase scale**

12 days irradiation seems enough

simulation and reconsider hit rate and irradiation period to understand the result from this time

✓**reduce uncertainty**

run data of longer period , repeat measurement , optimize analysis parameter, add SiPM sample , more study on radiation damage etc…

✓**Beam test**

we are planning the beam test @ Frascati

~50MeV positron irradiation

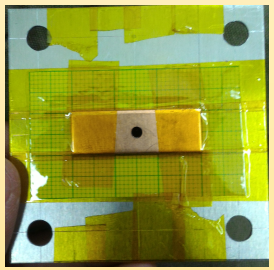
End

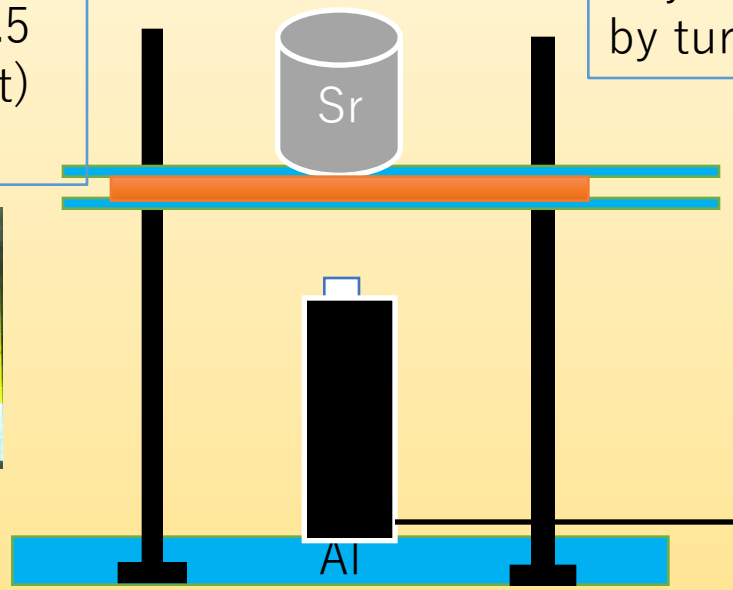
Thank you for listening !

Back up

Set up for Hit rate measurement

Collimator(1.5 mm Cu sheet)
(↓ picture)





Adjust the distance by turning the screw

PC

HV

amp

DRS

Pocket pulser (trigger)

poisson分布を仮定
Hit rate =

$$\frac{-\ln\left(\frac{\text{シグナルの無いイベント数}}{\text{全イベント数}}\right)}{window\text{幅}}$$

To get hit rate ,**randam trigger** is needed,
so we used Pocket pulser as trigger
Assuming poisonn distribution and counting no signal windows , we got **~1.3 MHz** as hit rate

Dark Count Rate(DCR) Analysis

- Waveform becomes very noisy and this time electrical noise (maybe) was also very noisy and difficult to analyze the row waveform data
- I used **deconvolution method**

Step 1

Choose the ”good shape waveform” and make the template waveform

Step 2

By setting convoluted waveform , get convolution factor

Step 3

Apply the convolution factor to the waveform data