MEG II実験陽電子タイミングカウンターの放射線損傷による影響の評価
Evaluation of radiation damage effect on positron timing counter for MEG II experiment

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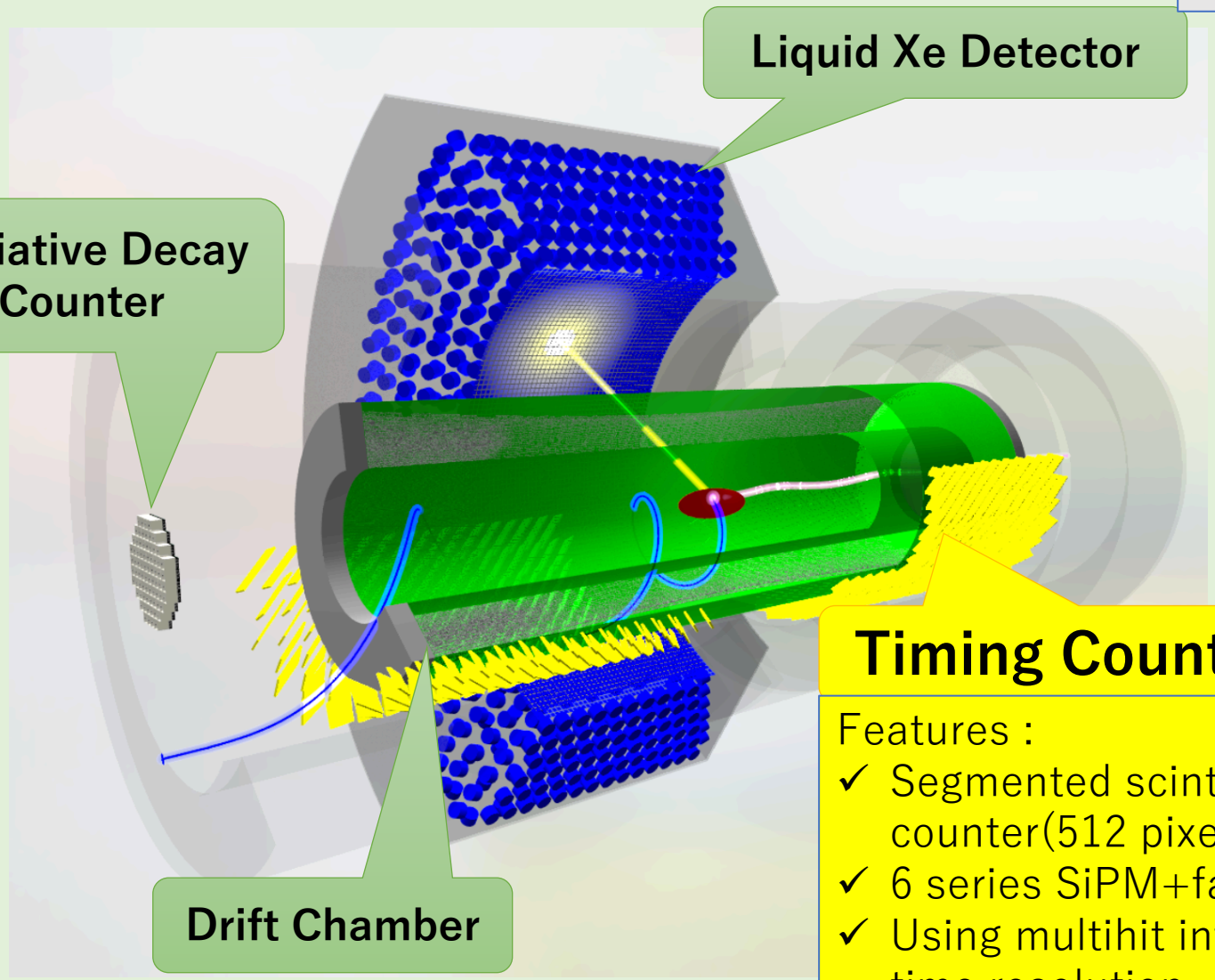
宇都宮大学峰キャンパス

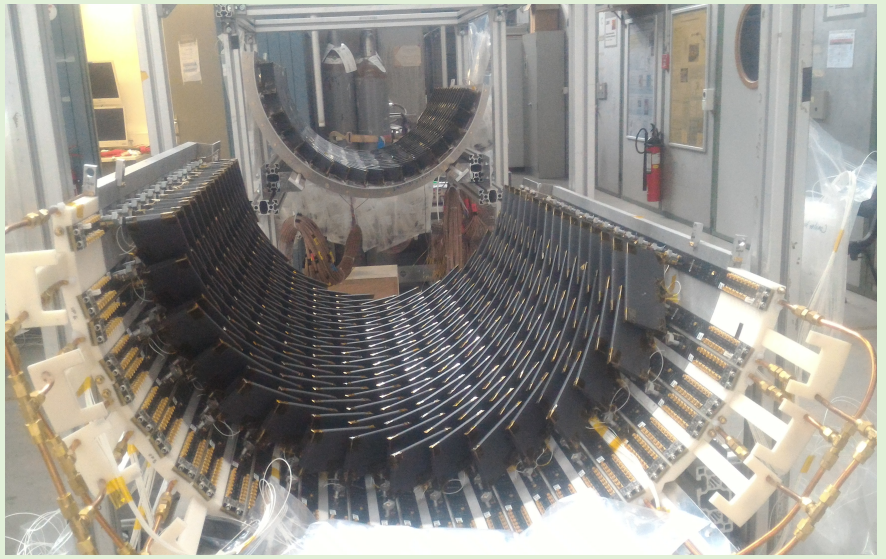
Outline

- **Introduction**
  - **MEG II Experiment**
  - **Motivation : Radiation Damage Problem**
  - **SiPMs information**
- Measurement for Main SiPM
- Measurement for New SiPM
- Summary

MEG II experiment

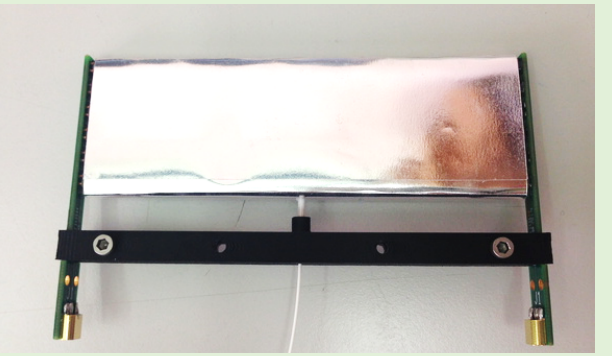
The most sensitive $\mu^+ \to e^+ \gamma$ search :
Sensitivity : $\sim 4\times10^{-14}$
(×10 better than MEG experiment !)





Timing Counter(TC)

Features :
- ✓ Segmented scintillation counter(512 pixels)
- ✓ 6 series SiPM+fast scinti.
- ✓ Using multihit information, time resolution ~ 30ps



1 pixel counterとPCBの写真は
https://meg.web.psi.ch/docs/talks/JPS/2015a/yoshida_jps2015a.pptxより引用

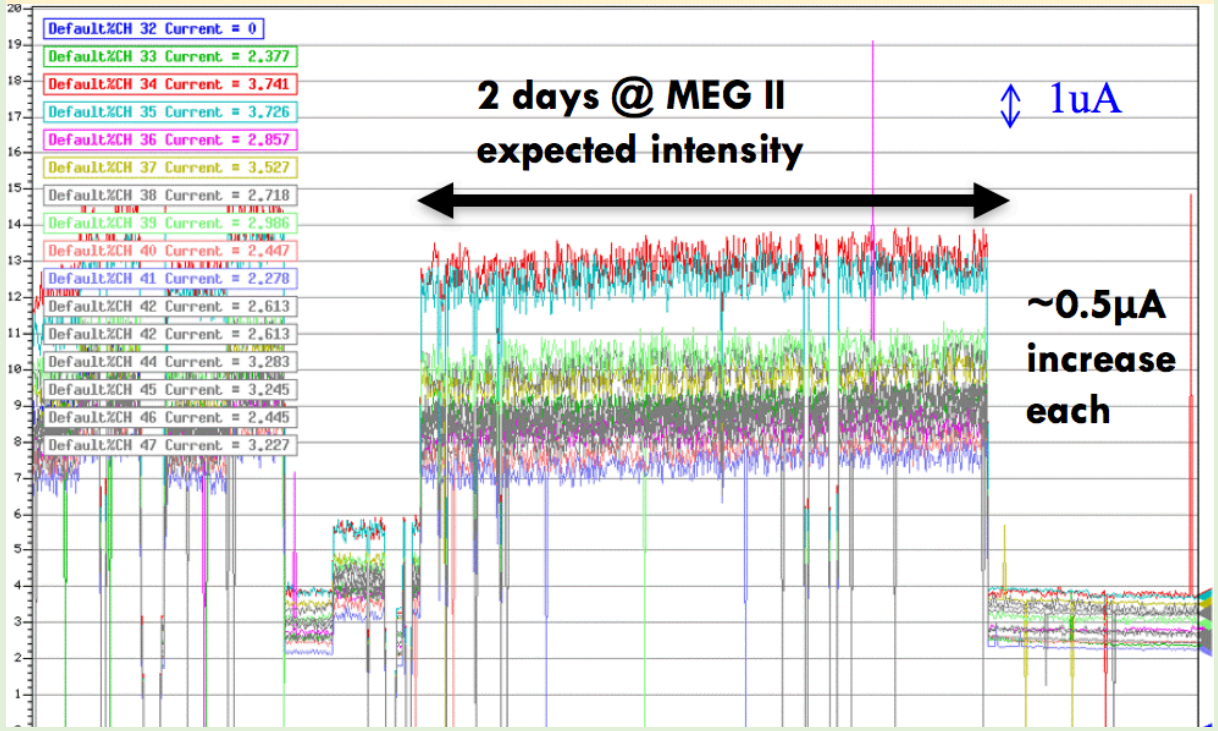
Radiation Damage Problem of SiPMs

Motivation

- ✓ Obvious increase of sensor current in previous pilot runs due to radiation damage
- ✓ Estimated effect of radiation damage in MEG II
  - ➢ Maximum fluence : ~ 1.4×10^{11} $[e^+/cm^2]$
  - ➢ Extrapolated from current increase measured in the last pilot run : **~ 100 μA**
- ✓ We must understand radiation damage effect on counter performance
  - ➢ How the radiation damage affects 6 series SiPMs performance?
  - ➢ Can we achieve our **operation requirement**?

✓ **TC Operation Requirement :**
achieve ~30ps during 3 years physics run

Observed current increase at the past pilot run



Irradiation test of SiPMs

Main : ASD-NUV3S-P High-Gain (MEG)

- Used in most of counters
- 3mm x 3mm (50 μ m pitch),surface mount
- Operation range : **Vbd + 2~3.5**
- Current increase was estimated ~ 100 μ A(6 series) during MEG II physics run
- Production line closed
- **Irradiated with Sr90(37MBq)**

New version : ASD-NUV-SiPM3S-P

- To be used for spare counters
- 3mm x 3mm (40 μ m), surface mount
- Wider operation range(Vbd + 2~6) and higher gain
- Developed by AdvanSiD after the first TC pixel production
- **Beam test was done at Beam Test Facility(BTF) in Italy**

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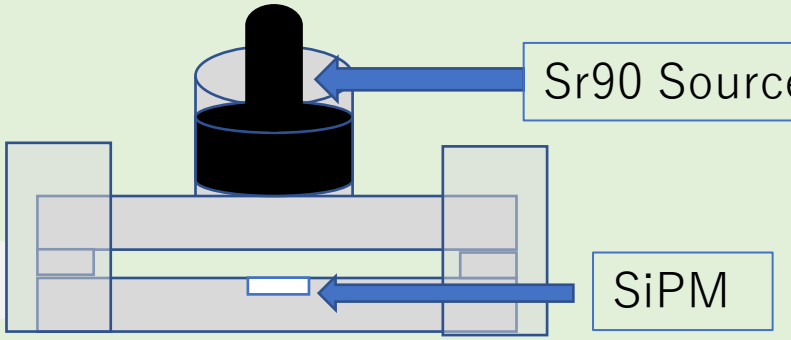
- **Measurement for Main SiPM**
  - **Irradiation & experimental setup with Sr90**
  - **Result of waveform analysis**
  - **Solution for current increase**
- Measurement for New SiPM
  - Beam test setup
  - Time resolution measurement
- Summary

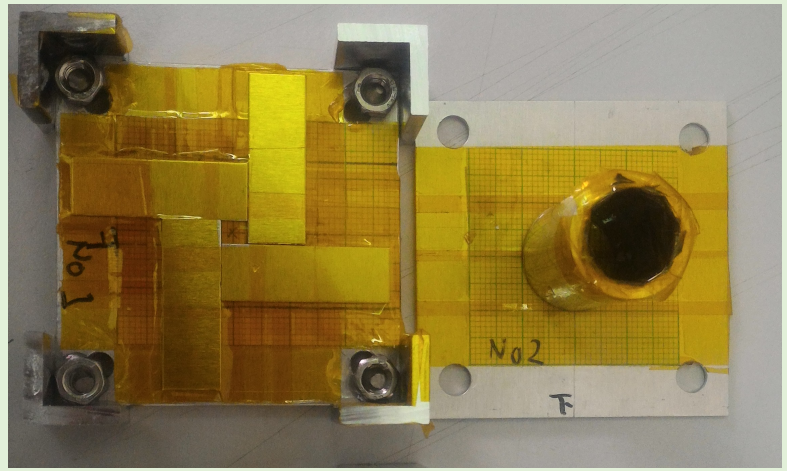
Irradiation & IV characteristics

Irradiation & measurement

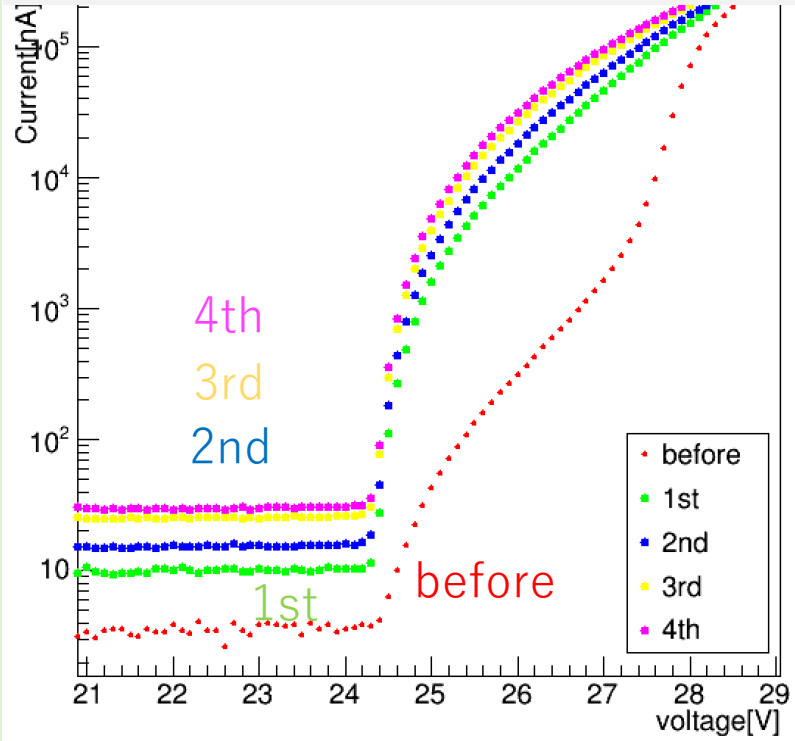
- ✓ 6 SiPMs were Irradiated by e^- from Sr90(37MBq)
  - ➢ Roughly 70 hour each × 4 times irradiation
    - ➢ Roughly 280hour in total
- ✓ Measure time resolution & IV characteristics

Irradiation set up

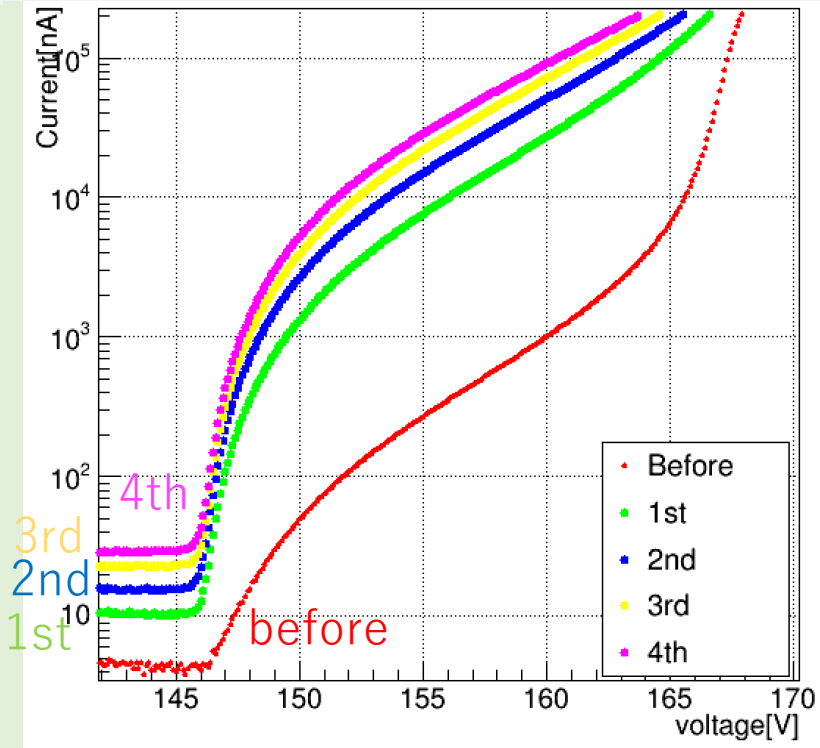




Example of **1** SiPM IV characteristics



Example of **6** SiPMs IV characteristics

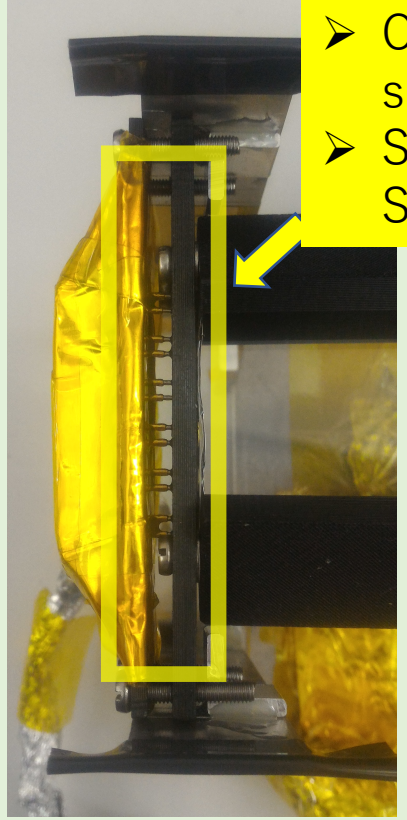


Counter Assembly

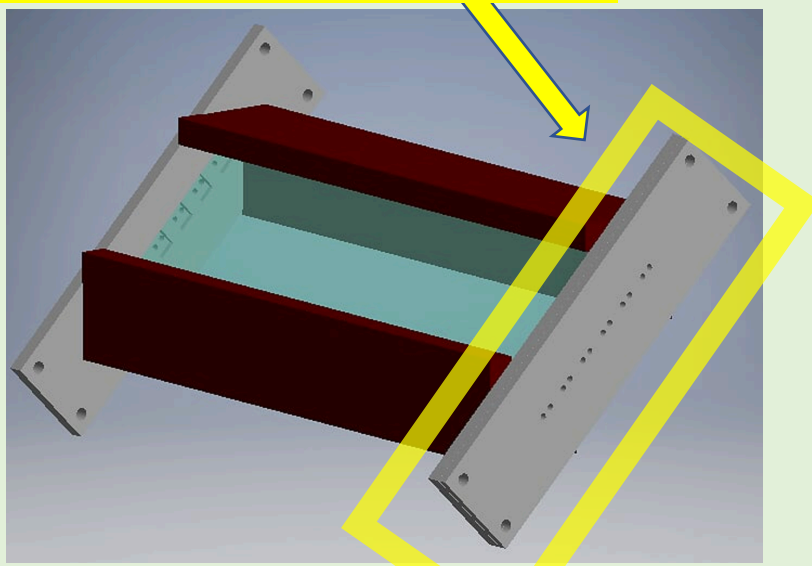
For this test, we made set up for time resolution measurement of single counter

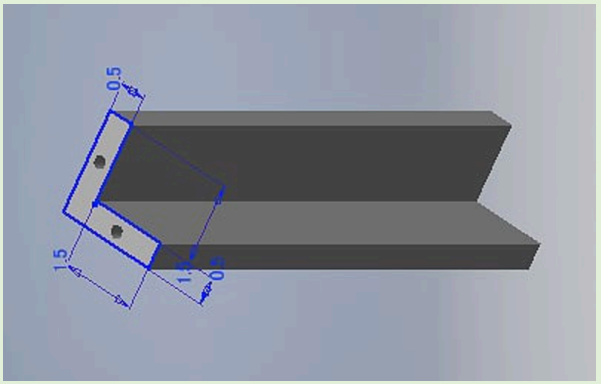
Requirement

- ✓ **Set & remove SiPMs frequently**
- ✓ **6 series circuit at each side**
- ✓ **Precise & stable alignment b/w scintillator and SiPMs**
- ✓ **Simple structure & not so many parts**



- Optical grease is put on scintillator
- Spring test probe pin push the SiPMs onto the scintillator





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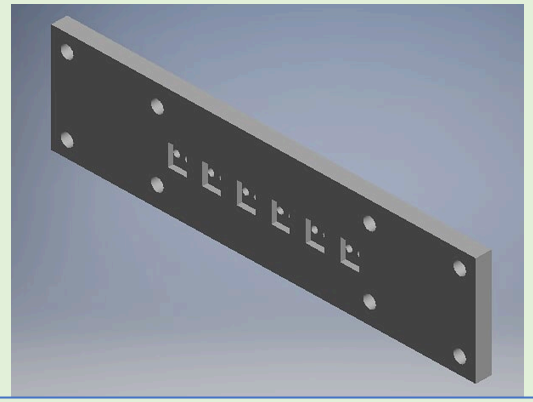

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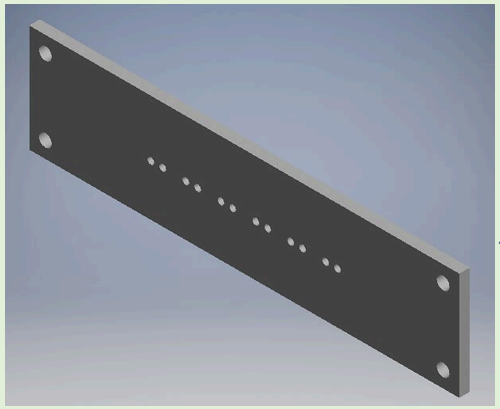


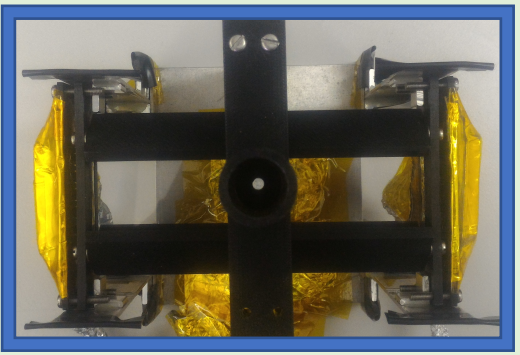
Assemble

Parts 1.
Fix the scintillator

Parts 2.
Square hole for 6 SiPMs, and small circle hole for spring test probe pin

Parts 3.
Fix spring test probe pin on this board
Make 6 series circuit with parts 2.

Time resolution Measurement Setup



- ✓ 6 irradiated SiPMs were set at one side
- ✓ On the other side, reference SiPMs were set to check the measurement system

time resolution (one side)

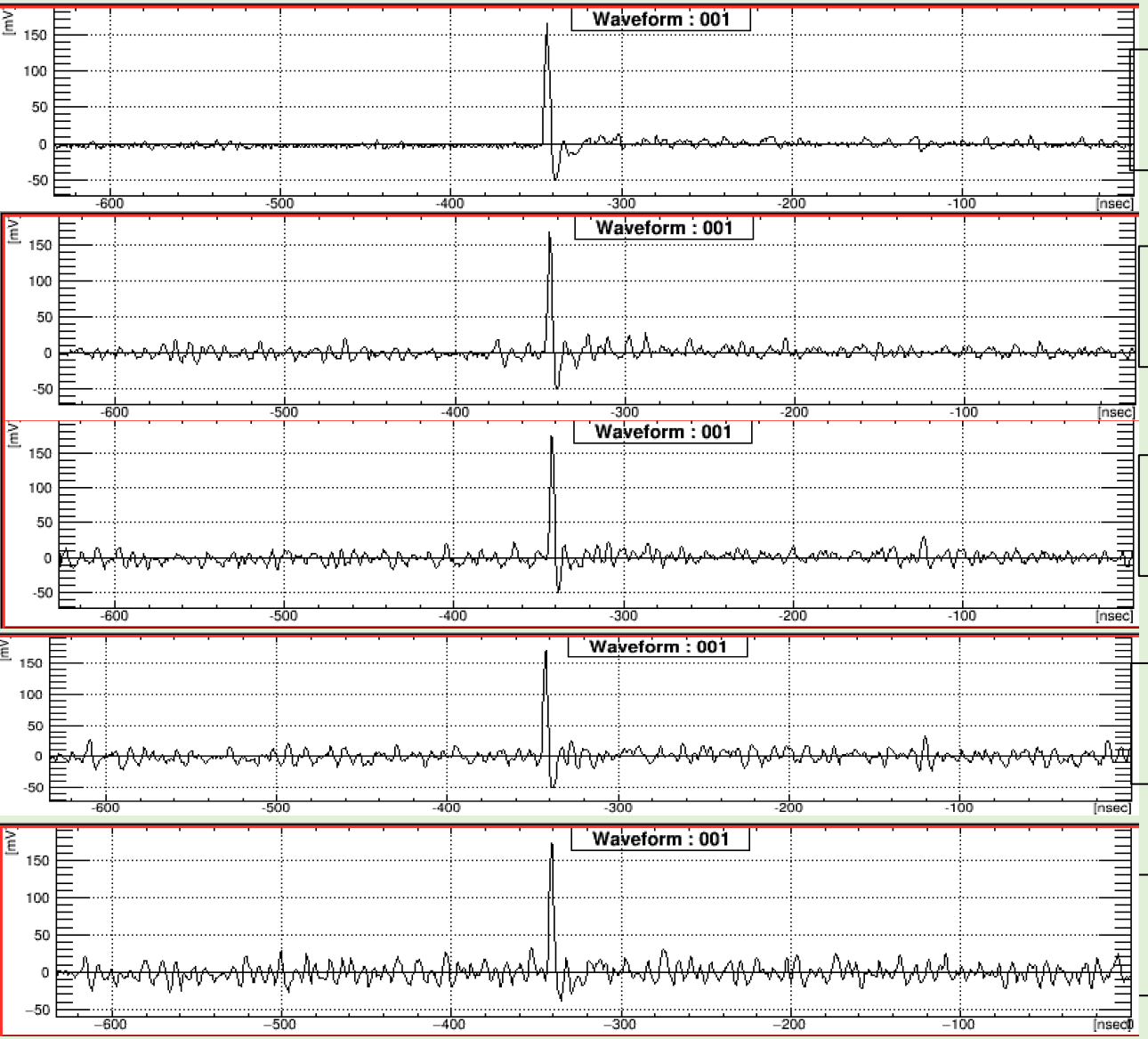
$\sigma(t_{signal} - t_{ref}) \sim \sigma(t_{signal})$

t : picked up time of the channel

Domino **R**ing **S**ampling chip : **DRS**

Waveform digitizer used in MEG

Typical Waveform around optimal voltage



Before irradiation
current : ~ 2 μ A

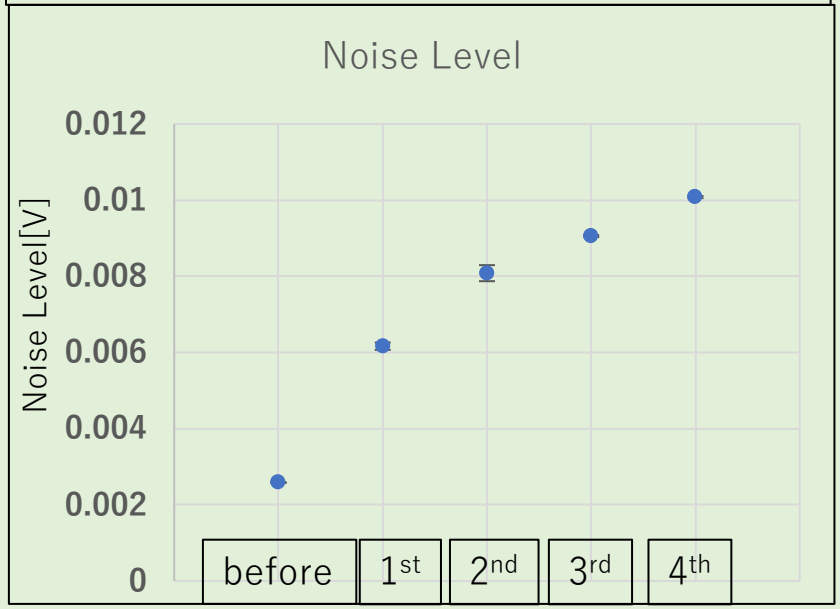
1st irradiation
current : ~53 μ A

2nd irradiation
current : ~94 μ A

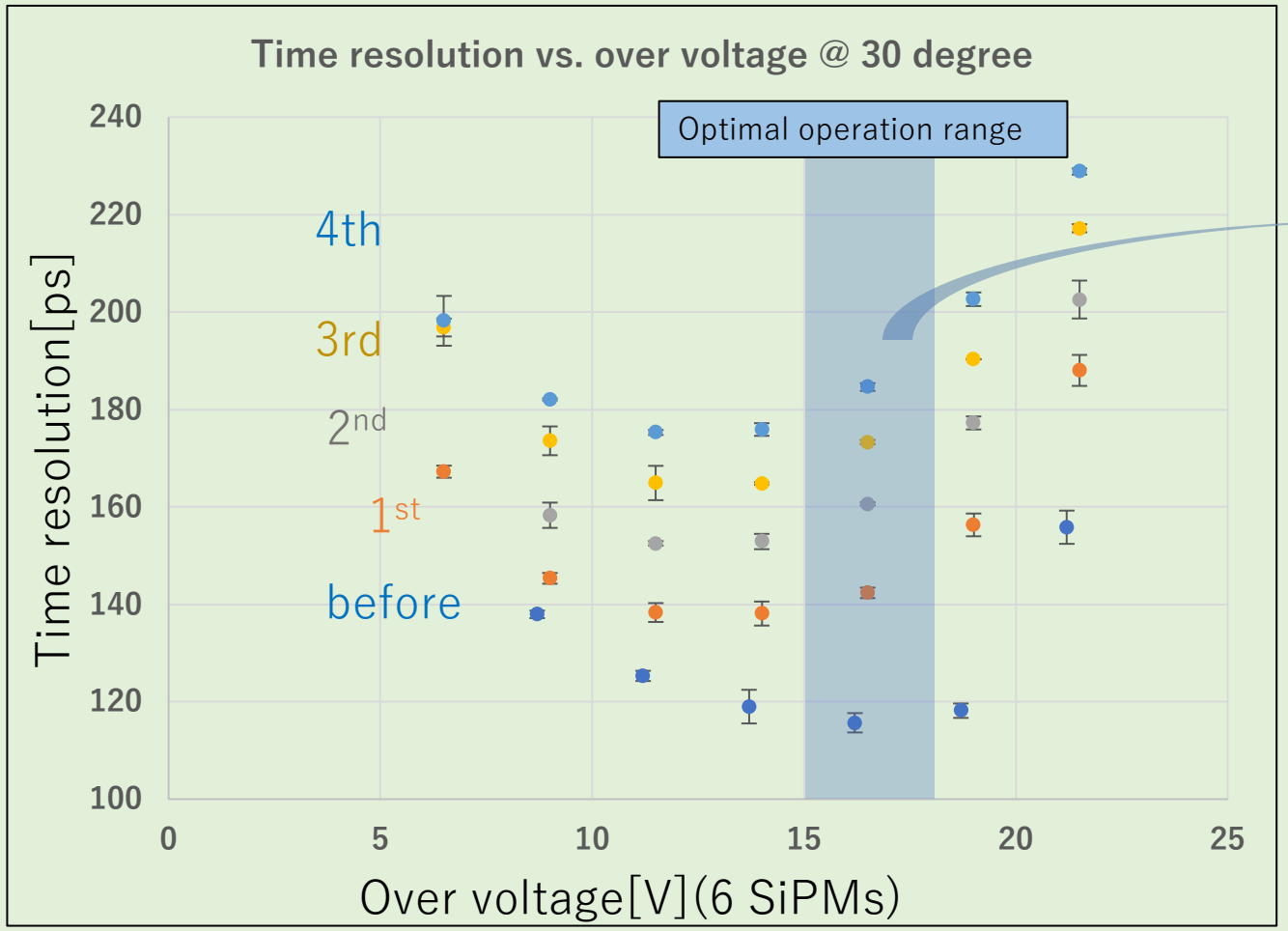
3rd irradiation
current : ~126 μ A

4th irradiation
current : ~155 μ A

1. Dark noise increase
2. Precision of baseline calculation and timing pick up becomes worse
3. Time resolution becomes worse



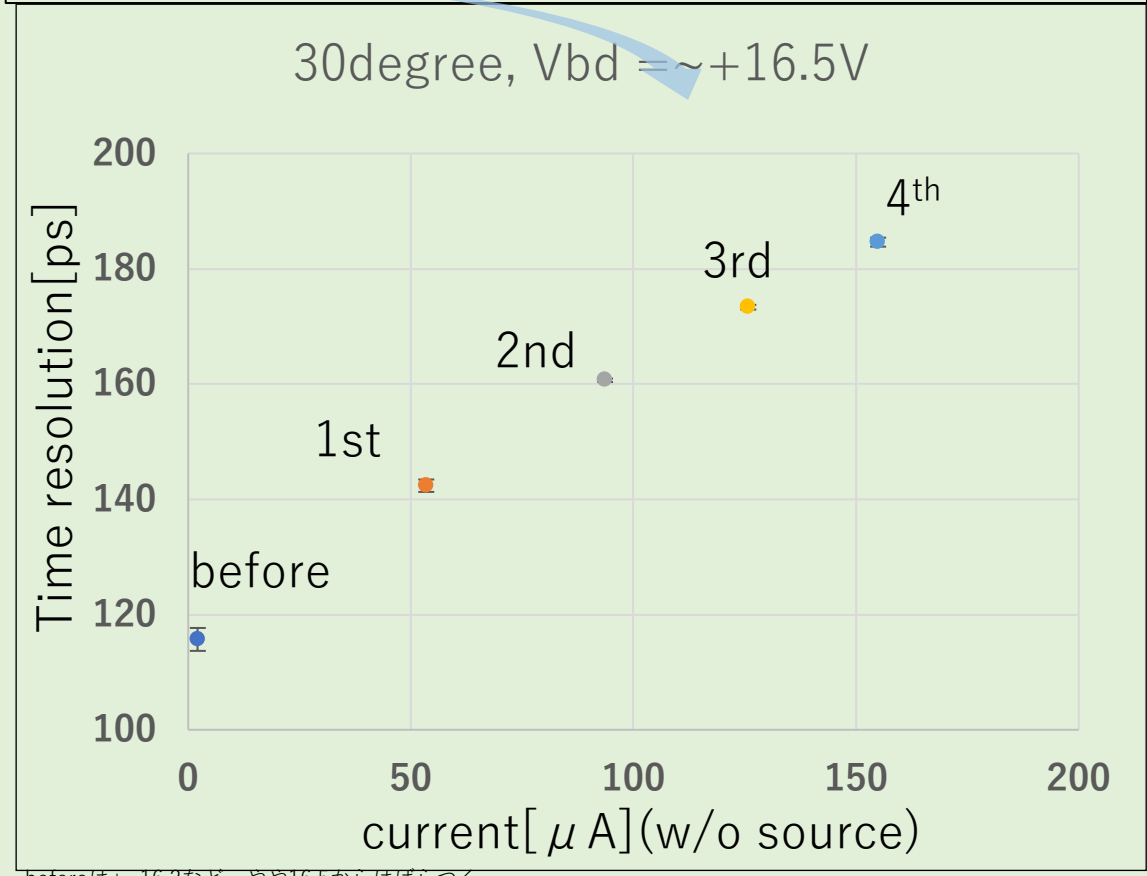
Time resolution after irradiation



※2nd とbeforeの152.5V(~+6V)の点は今回無し

Data taking was done 2 times or 3 times(only 1st)
Error shows the √(Σ(x-x_mean)^2/(n-1))of each measurement

- Current increase worsens time resolution
- ~39% deterioration after 2nd (~140 hours) irradiation (I ~ 94 μA) at first optimal voltage(best point)



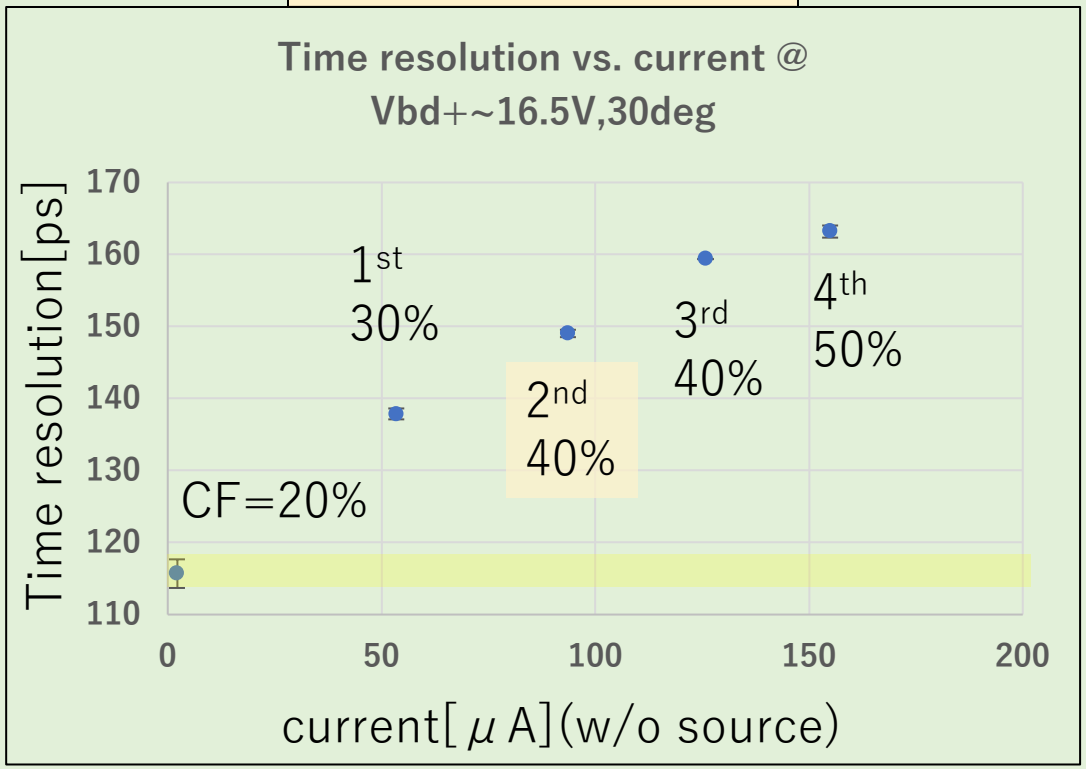
beforeは+~16.2など、やや16.5からはばらつく

Time pick up parameter optimization

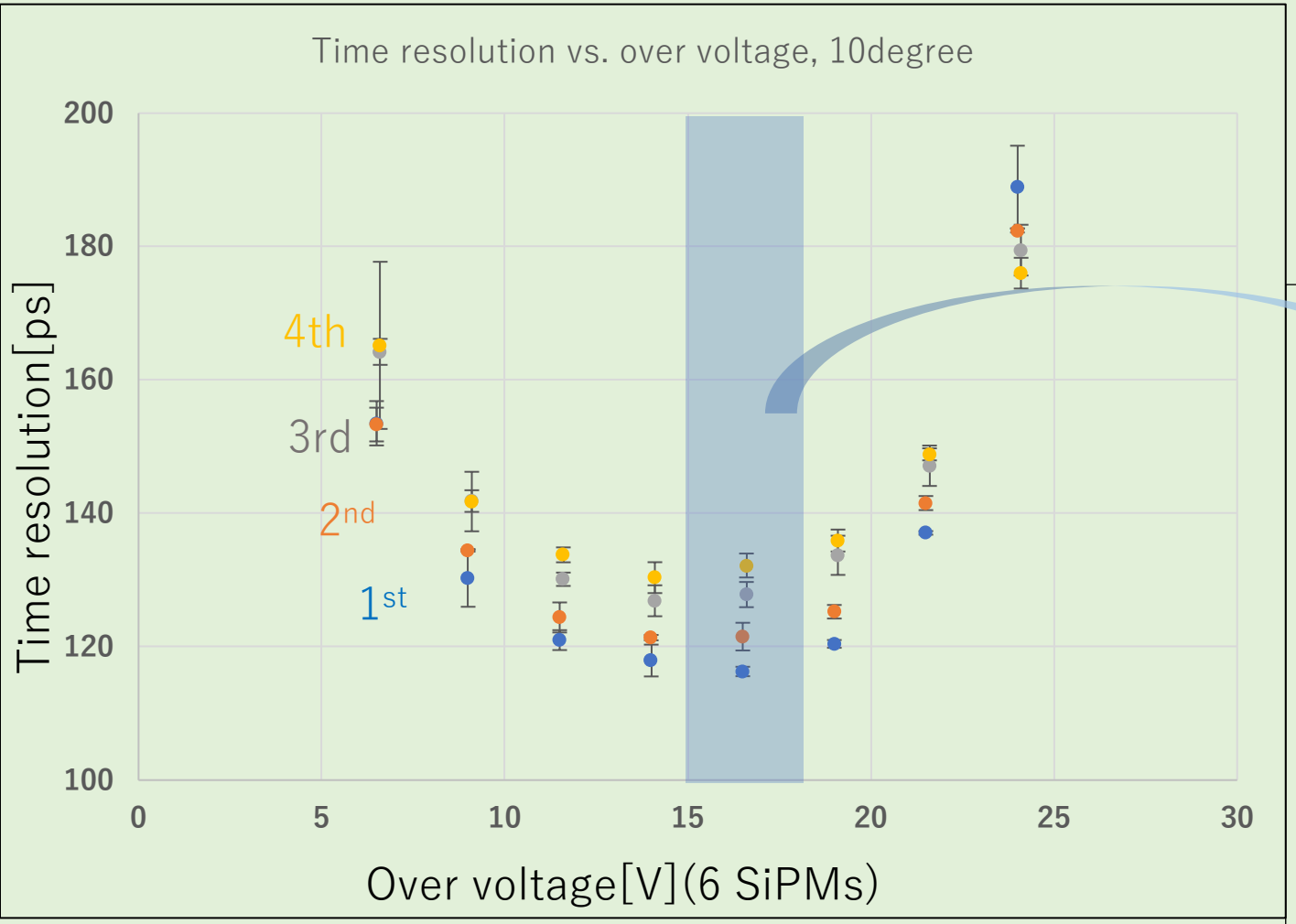
✓Constant Fraction(CF):pick up at **XX%** of peak height

➢After irradiation, we checked and optimized CF value(XX = 20,30,40 or 50%)

~ 29% deterioration around 100 μA(2nd)



Cooling : 30degree -> 10 degree

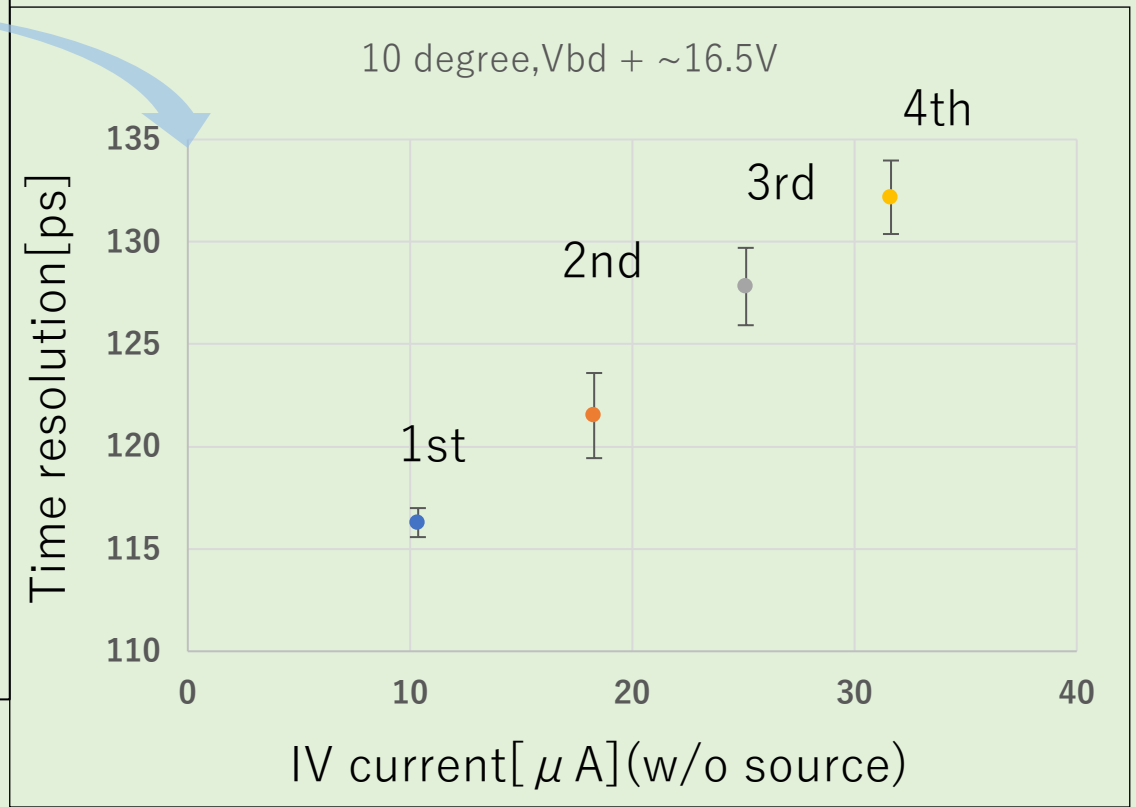


□ Possible solution for increased current

Lowing temperature of SiPMs and suppressing the dark noise

Deterioration : ~ 5%

Current level : ~94 μA -> ~18 μA



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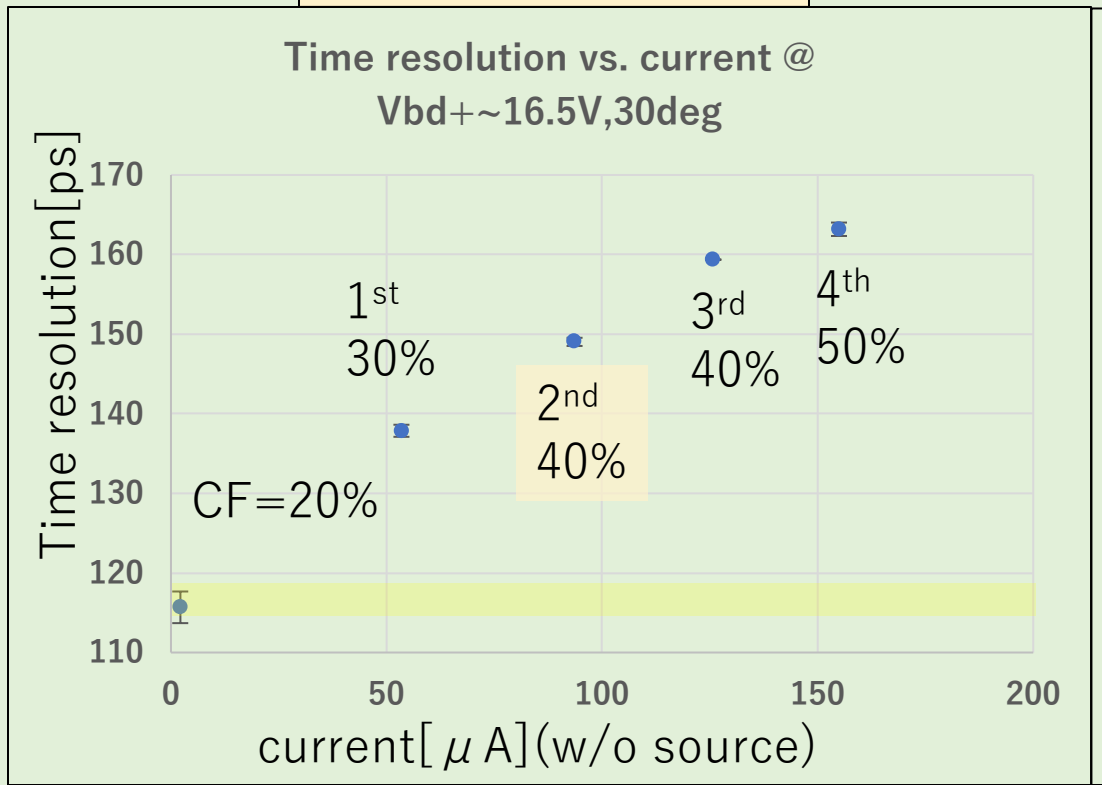
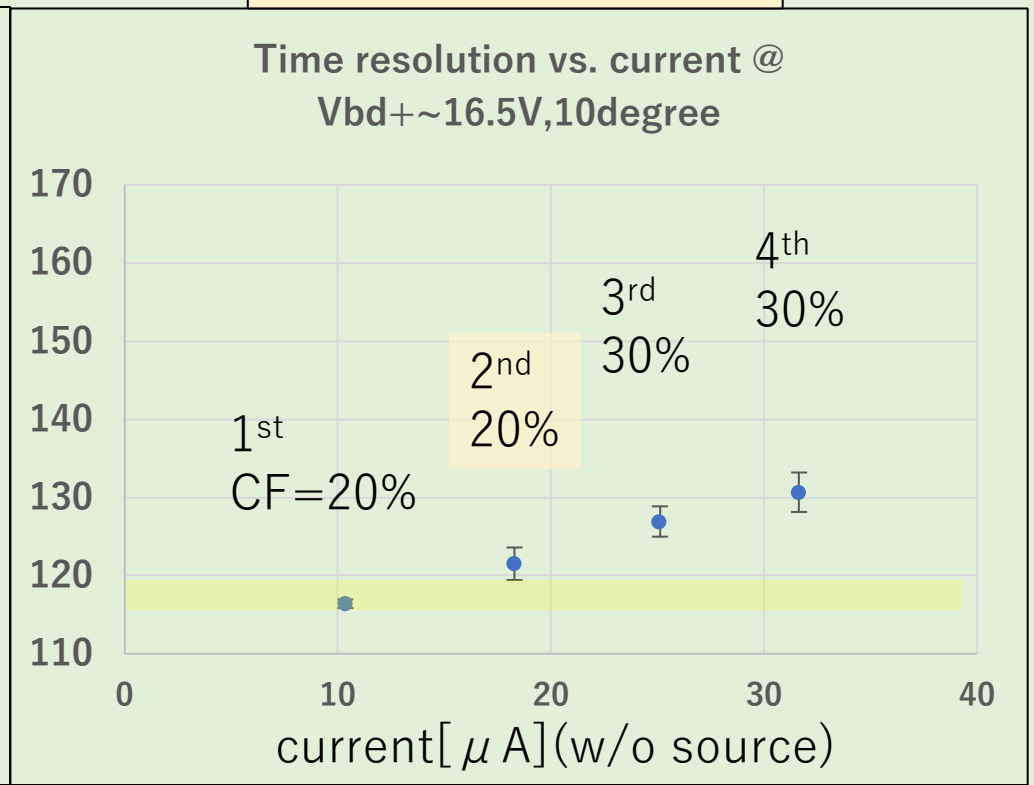


~ 5% deterioration at 2nd measurement



Summary of Irradiation test for Main SiPM

- We investigated radiation damage effect on 6 series SiPMs
- Time resolution worsened by ~29% around current increase level expected for 3-years operation in MEG II(~100 μ A)
- By cooling down to 10deg and parameter optimization for time-pickup analysis, deterioration is suppressed to ~5%
- **If we can operate TC at 10 degree, the radiation damage effect is almost negligible!**

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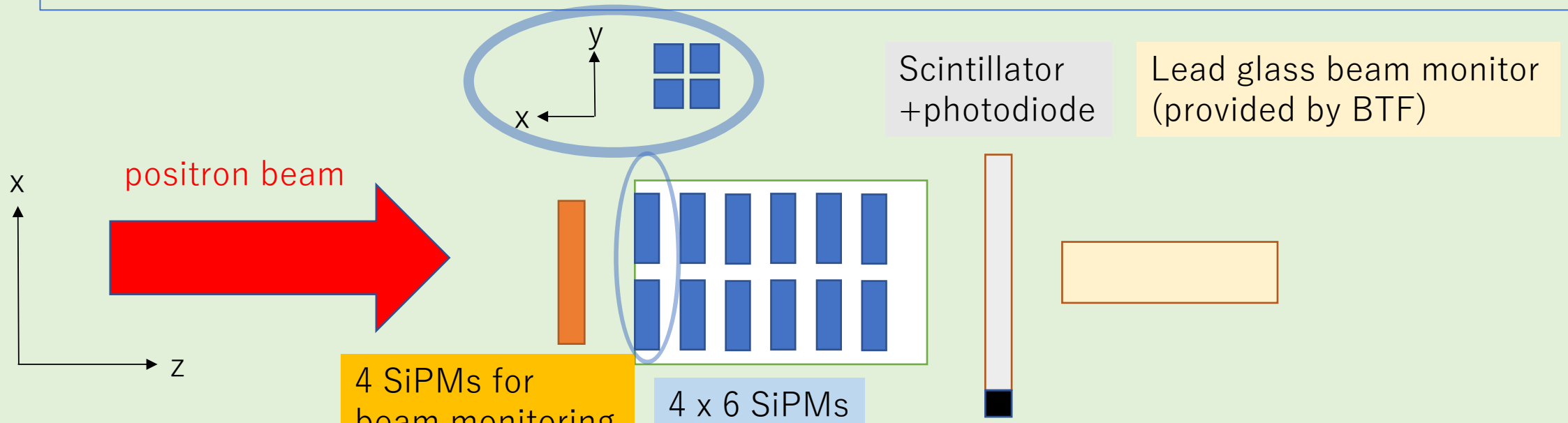
- Measurement for Main SiPM
  - Irradiation & Experimental Setup with Sr90
  - Result of waveform analysis
  - Solution for current increase
- **Measurement for New SiPM**
  - **Beam test setup**
  - **Time resolution measurement**
- Summary

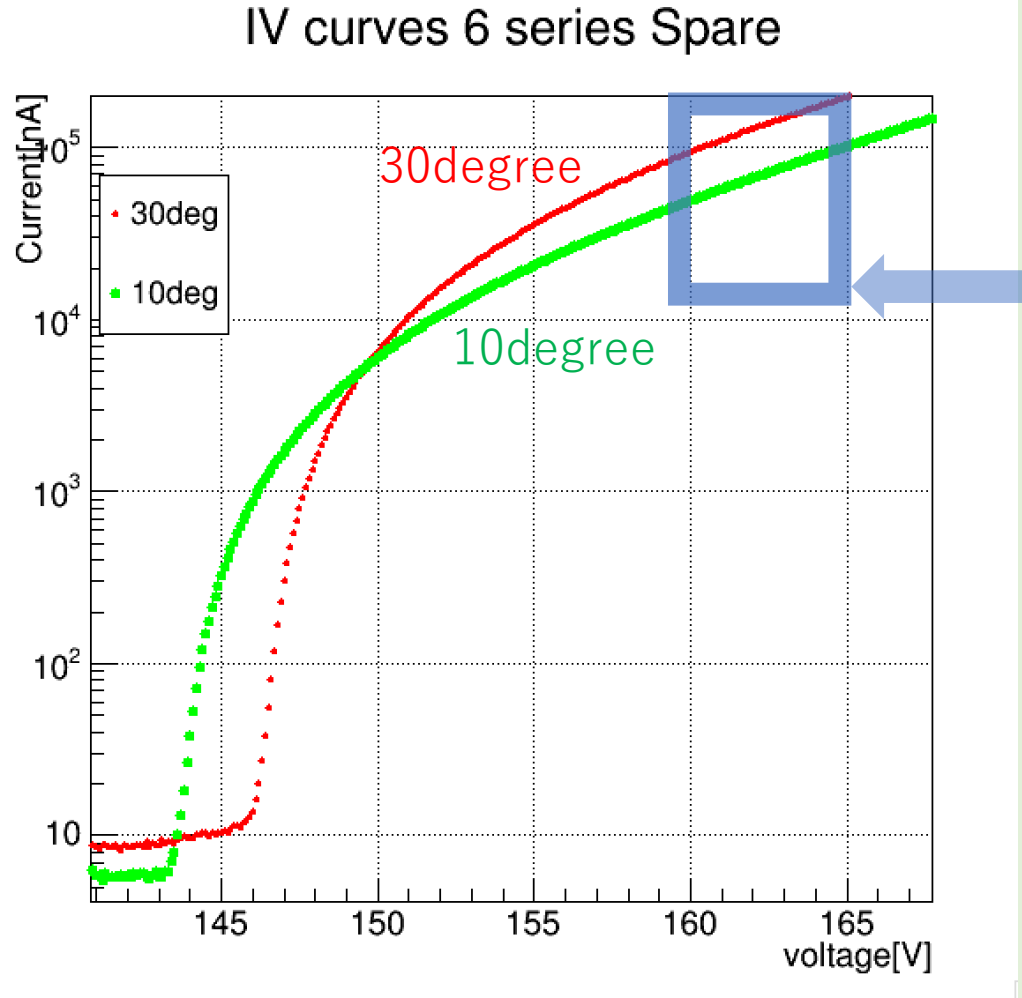
Irradiation Test of New SiPMs at BTF

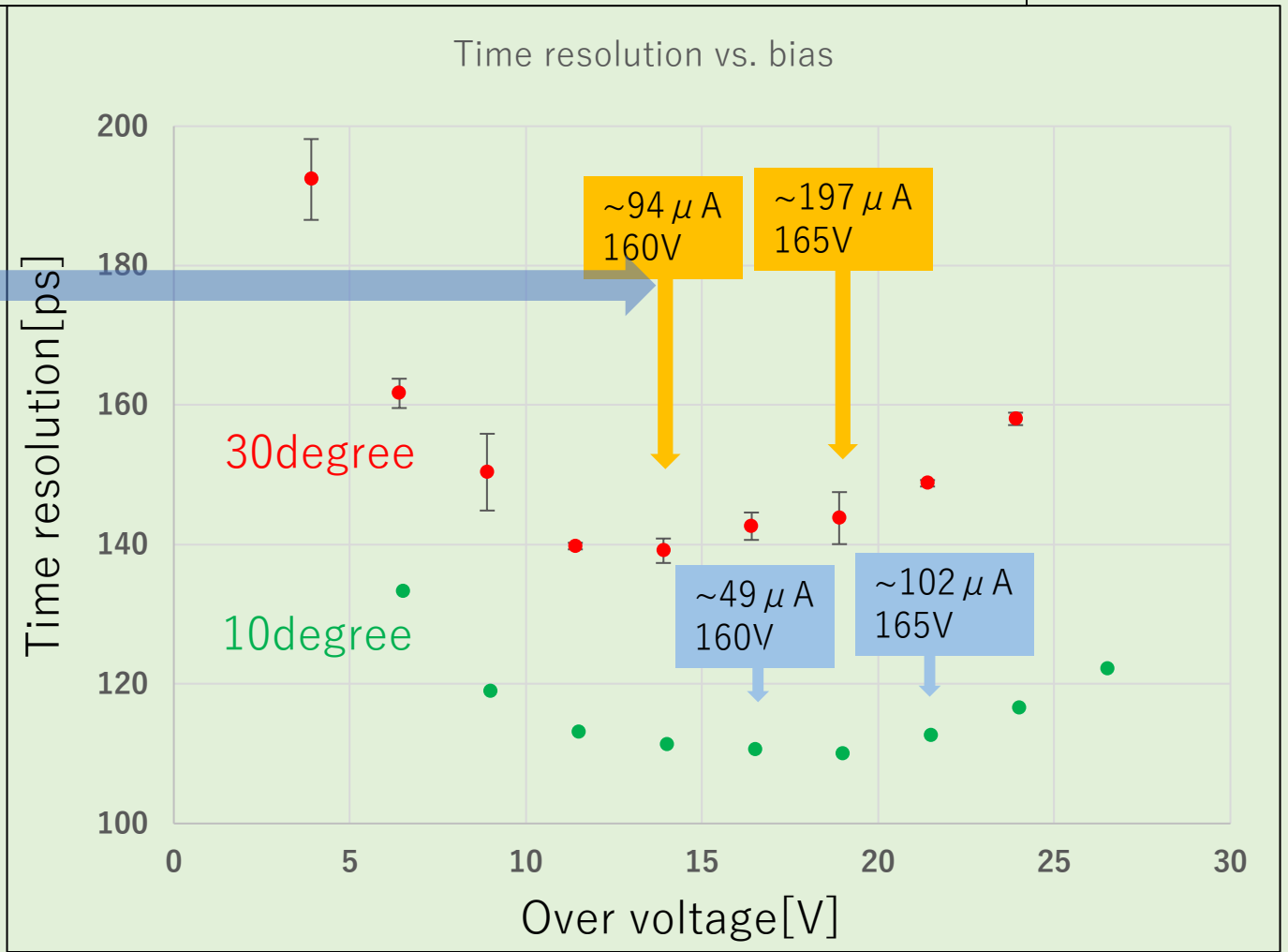
- ✓Positron irradiation was done @BTF, Frascati
- ✓Expected total dose during physics run $< \sim 1.3 \times 10^{10}\ [e^+/SiPM]$
- ✓Actual total dose at BTF : $\sim 1 \times 10^{11}\ [e^+/SiPM]$
  - ➢8 times larger irradiation



Result

- Deterioration of time resolution seems to be smaller
- Even better time resolution(~110ps) for much higher dose at 10 degree





Summary

- Current increase due to radiation damage was observed, we checked the effect on time resolution with dedicated set up.
- **Main** : Using Sr90, we checked radiation damage effect
  - **Around ~ 100 μA @ 30deg, there was ~29% deterioration**
  - **By operation at low temperature, deterioration can be suppressed to ~ 5%**
- **New** : At BTF irradiation test, we checked radiation damage effect
  - **Radiation tolerance is sufficient for MEG II experiment**
- **System for operation at lower temperature is being developed, and will be tested.**

Back up

MEG II experiment

The most sensitive $\mu^+ \to e^+\gamma$ **search experiment** in the world with the most intense DC muon beam at PSI

✓**In Standard Model**

strongly suppressed and cannot be found by experiment

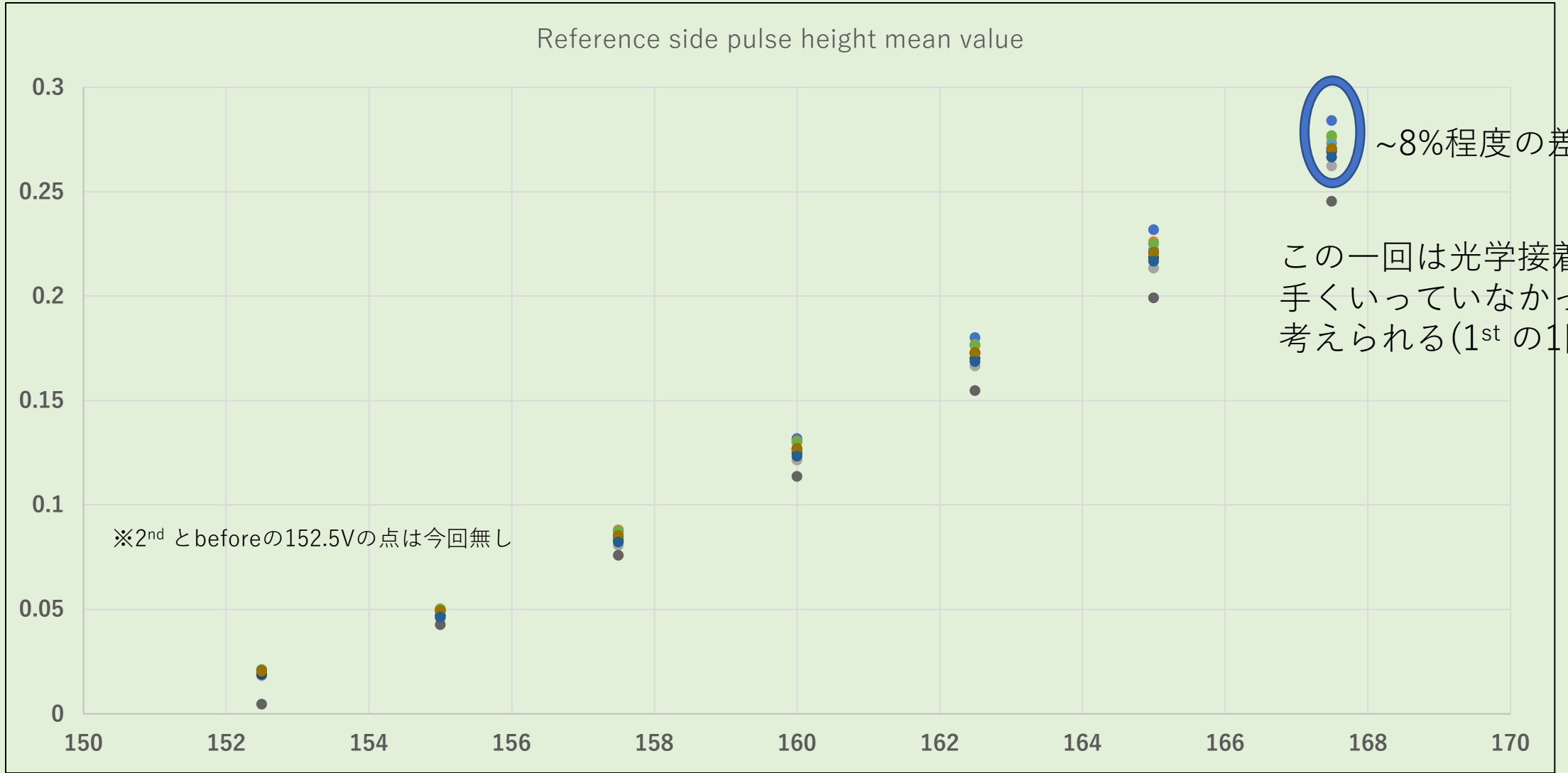
✓**In Beyond Standard Model with SUSY-GUT, SUSY-seesaw model …**

Br$(\mu^+ \to e^+ \gamma)$ becomes larger and we can find by experiment !

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

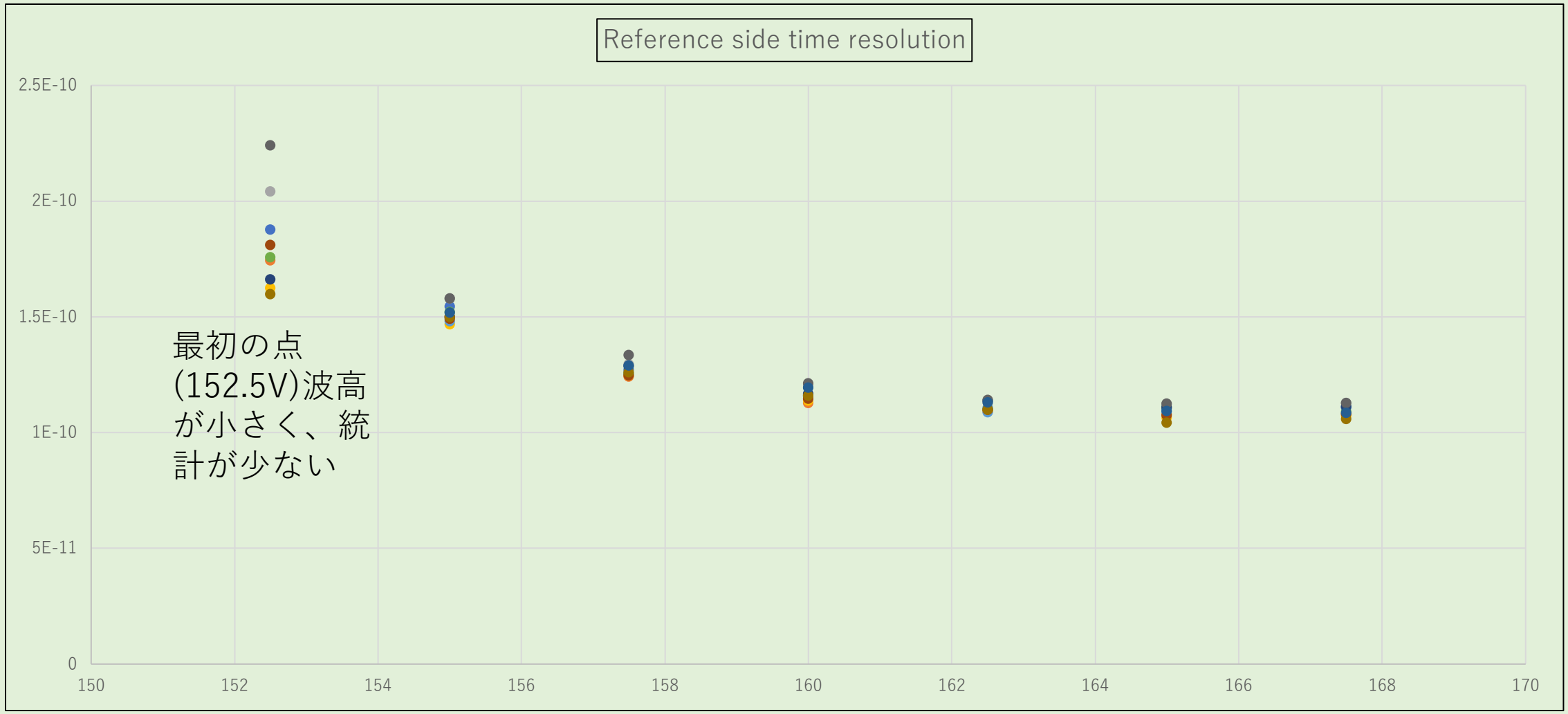
Reference side pulse height

Preliminary!



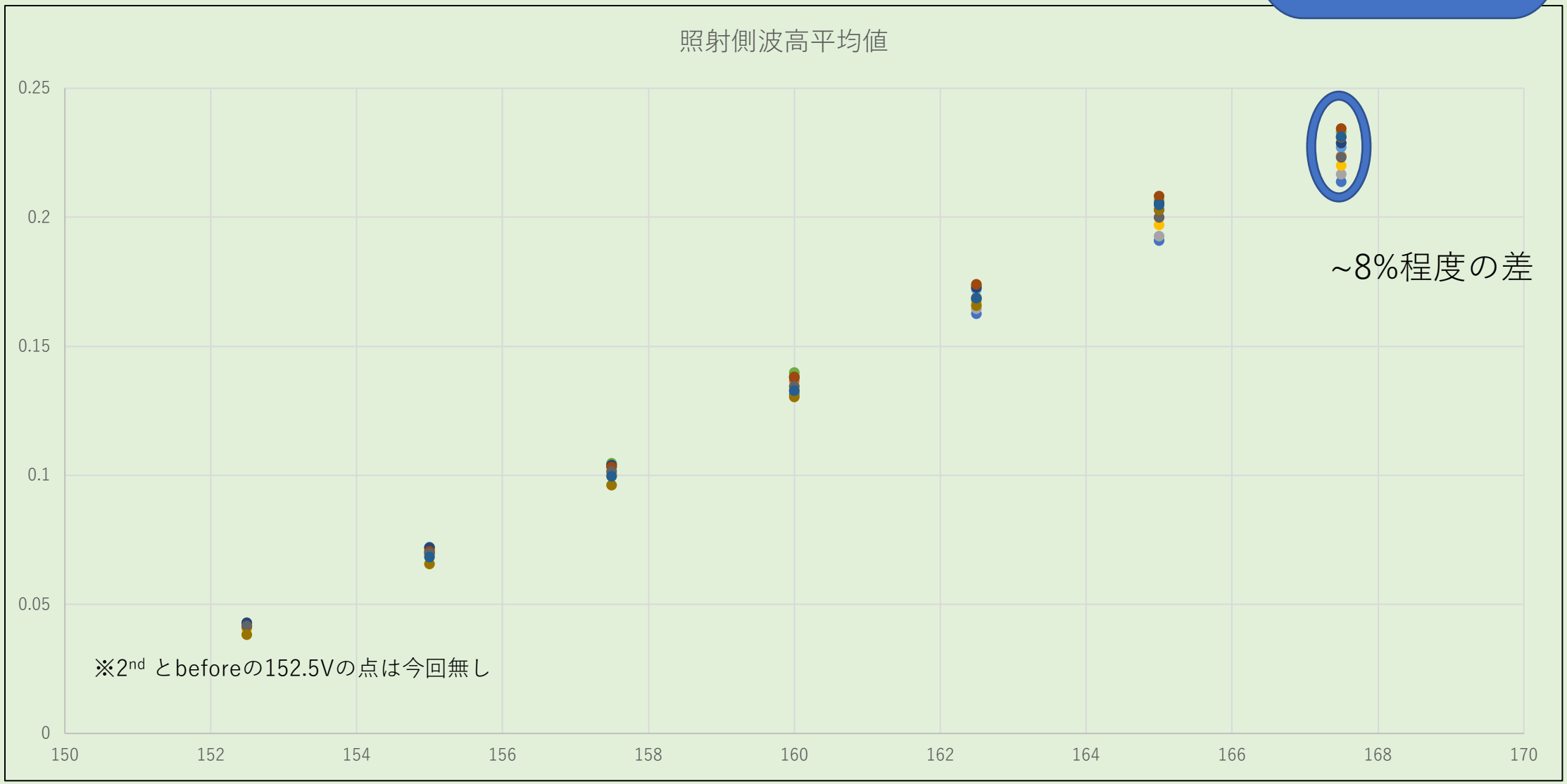
Reference side time resolution

Preliminary!



Irradiation side pulse height

Preliminary!



SiPMs current monitor at 27V

Preliminary!

SiPM/irradiation	0	1	2	3	4
1	1657.8667	45633.8667	63280.5	84428.3667	95042.8667
2	1565.7333	34364.4	62130.6	76460.5667	95245.3333
3	2658.4667	52697.5	71533.5667	92707.7667	105351.9
4	1390.7667	28652.7333	56494.3	70718	88781.4333
5	2784.9	40051.4667	70129.8667	92391.6667	104784.9667
6	2305.1667	52769.4	72692.5	87207.9333	105961.1333
average	2.06048335	42.36156112	66.04355557	83.98571668	99.19460555
STDEV	0.59960515	9.829402921	6.405944149	8.831454687	7.158465668