Development of New Muon Monitors for J-PARC neutrino beam line

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NUFACT
August 29th , 2019

Contents

- What is MUMON, Why is MUMON important?
- New detector candidates for MUMON
  1. Diamond detector
  2. PMT
  3. EMT - Type I
  4. EMT - Type II

(EMT : Electron Multiplier Tube)

- Discussion
- Proposals and preparation of EMT beam test
- Summary

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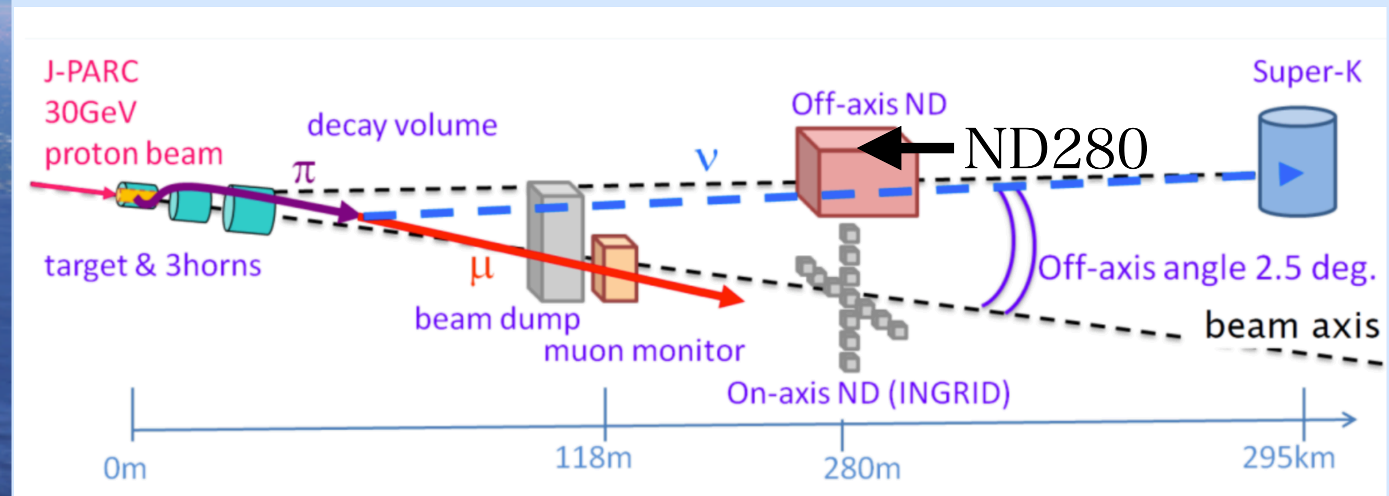
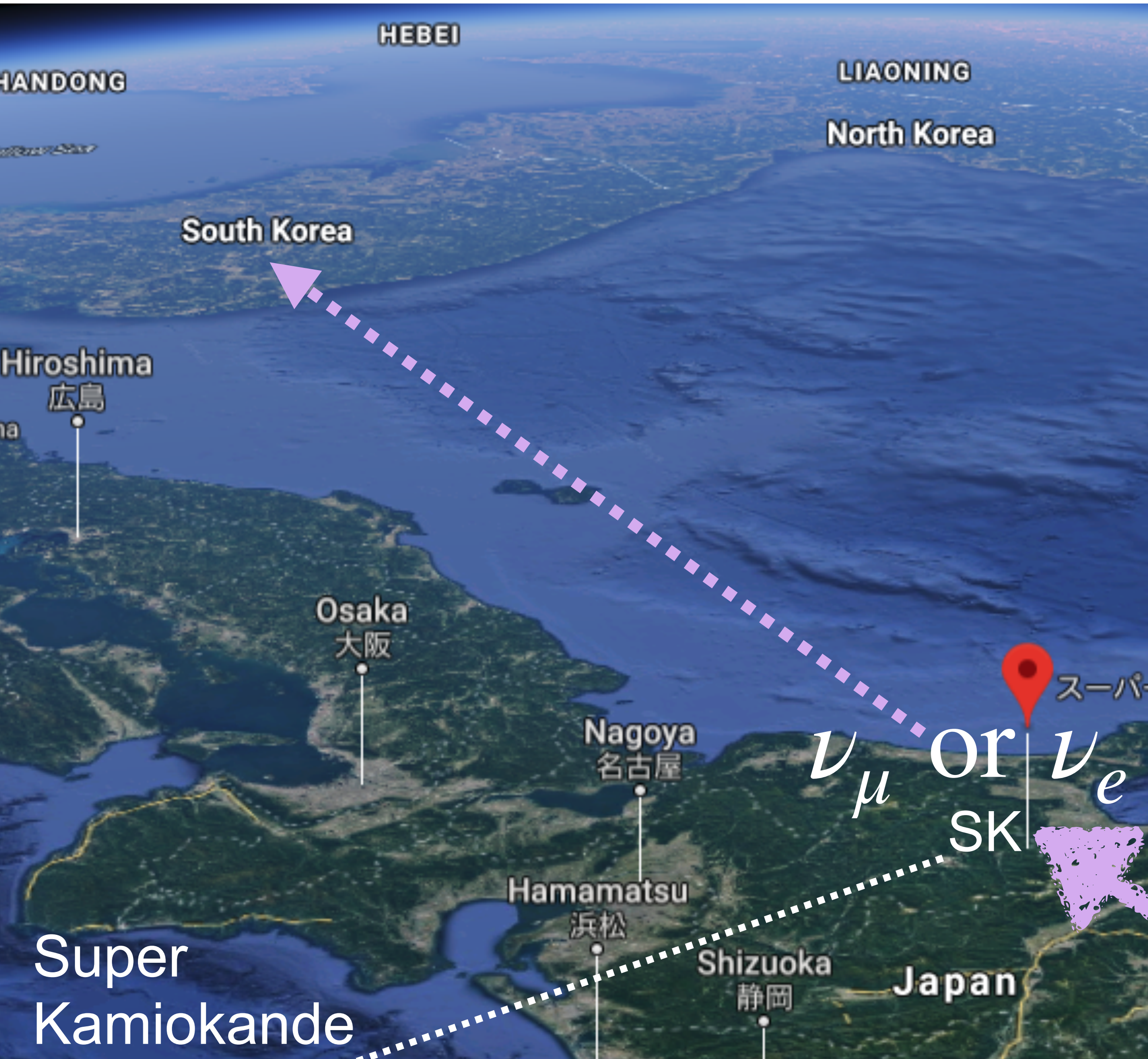
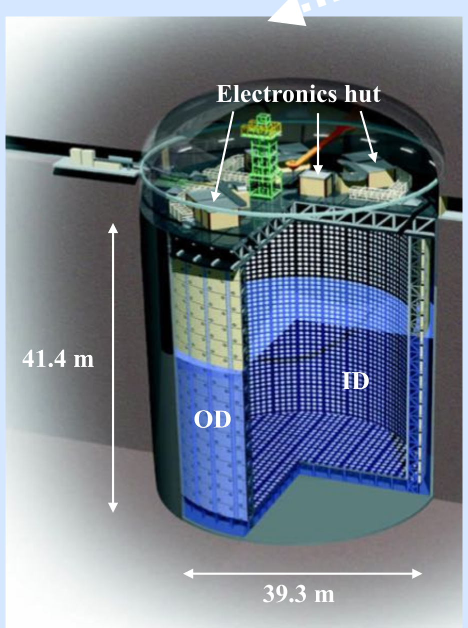
What is J-PARC neutrino experiment?

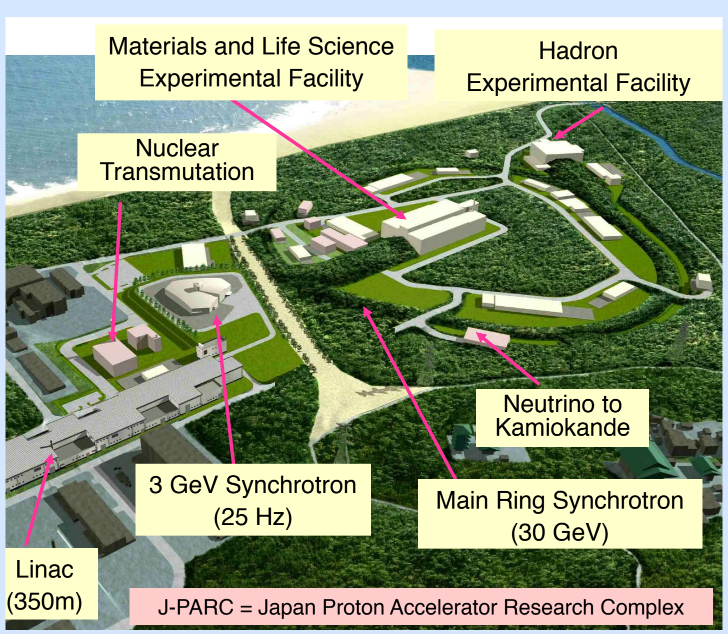


T2K beam line

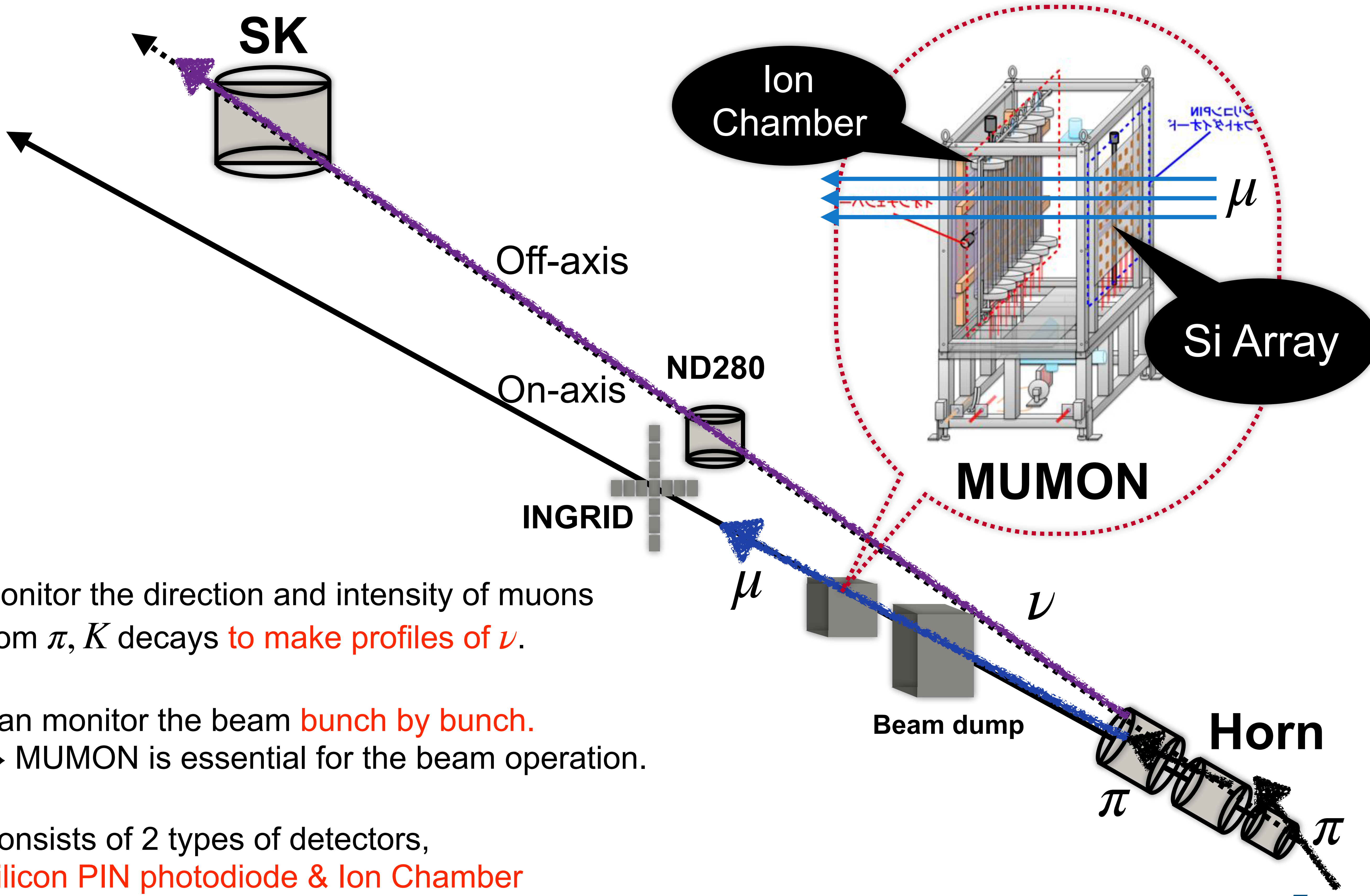
- Tokai to Kamiokande (T2K) experiment aims to discover the CP violation in the lepton sector with neutrino oscillation (2σ significance now).
- Statistics and systematic error reduction are necessary to achieve a higher significance level.







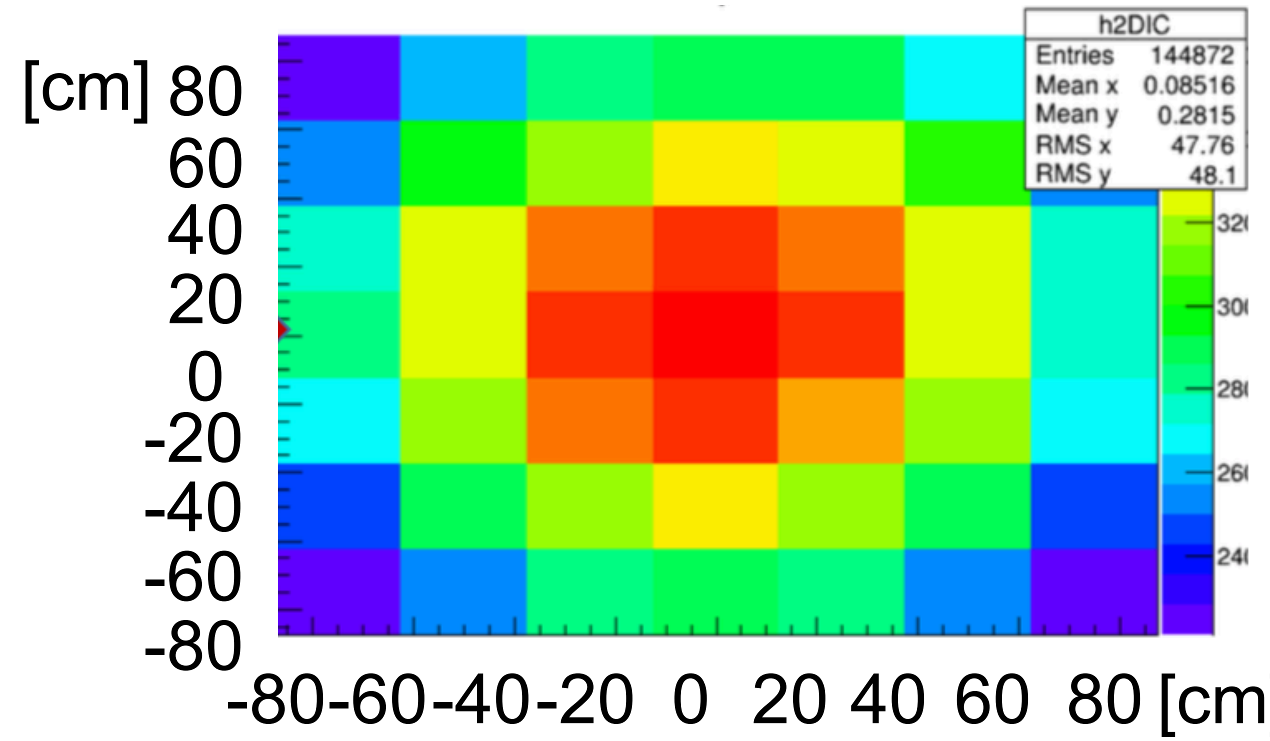
What is a muon monitor (MUMON)?



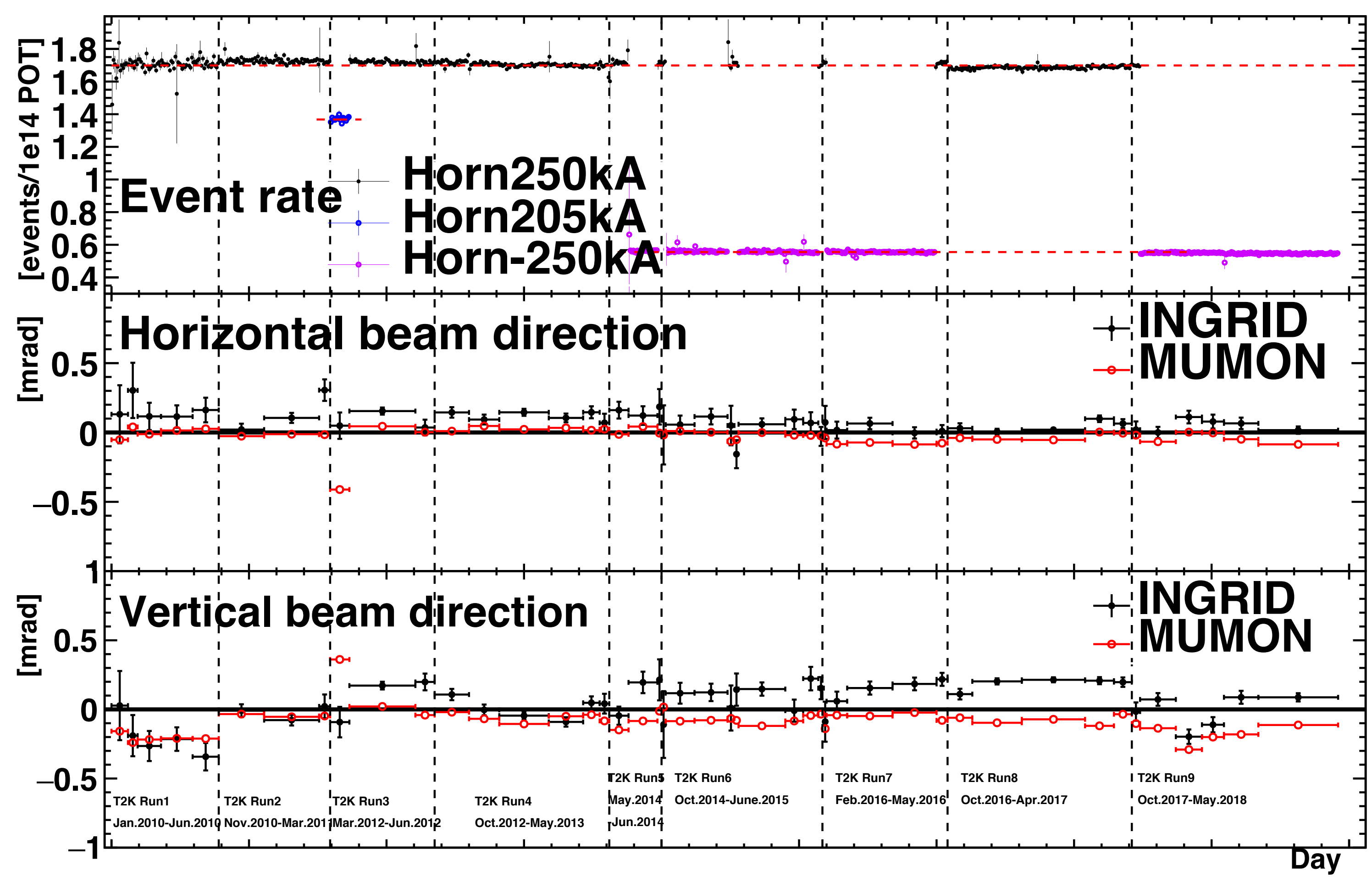
- Monitor the direction and intensity of muons from π, K decays to make profiles of ν.
- Can monitor the beam bunch by bunch.
  → MUMON is essential for the beam operation.
- Consists of 2 types of detectors,
  Silicon PIN photodiode & Ion Chamber
  (Ar or He).

Current (Si, IC) detectors

- Each array has 7×7 channels and covers 150 cm^2
- Get beam intensity and center position by fitting collected charge 2D distribution
- The detector intrinsic resolution (RMS)
  - Beam center < 0.3 mm
  - Beam intensity < 0.1%



Example of 2D profile

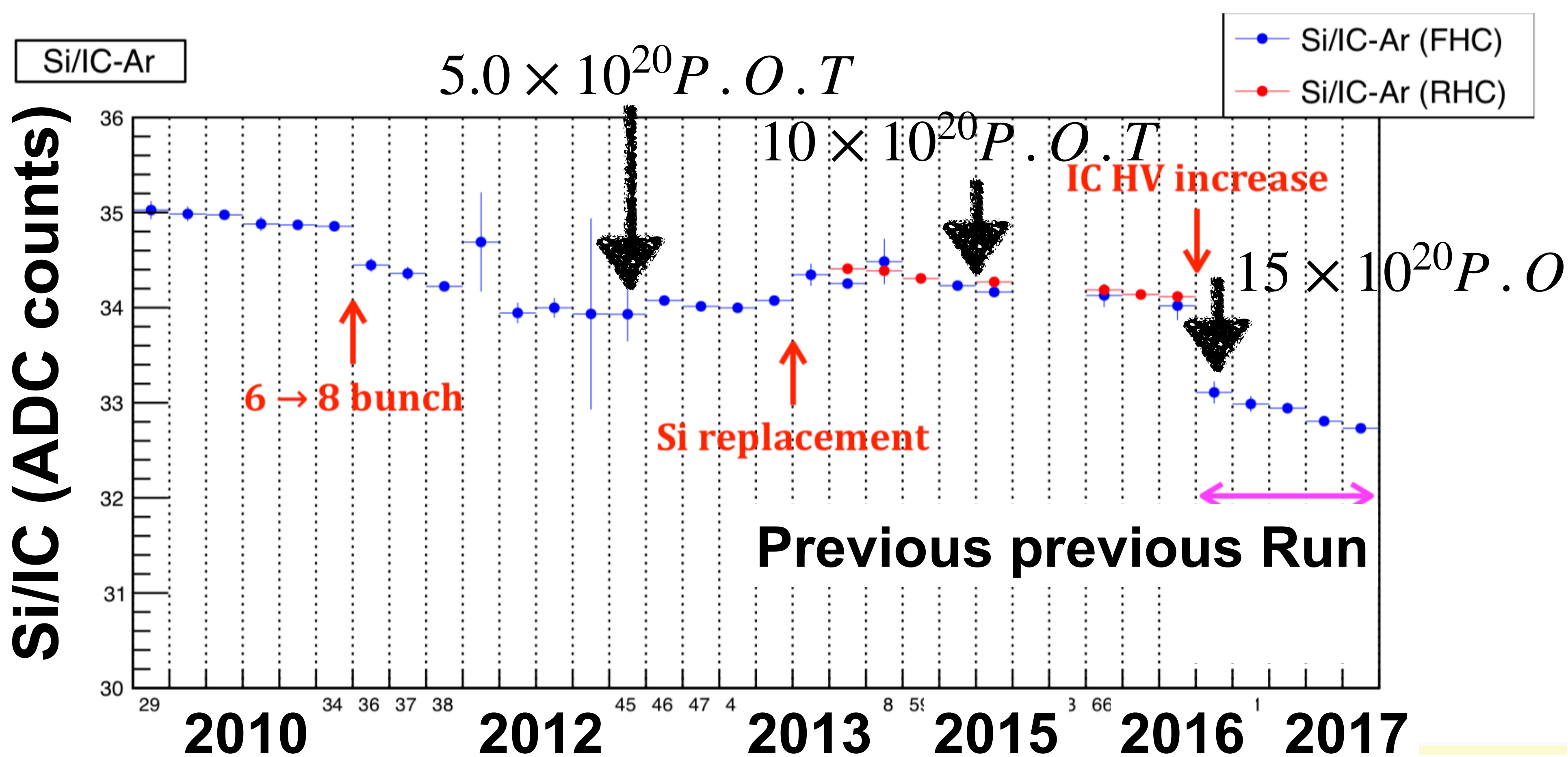


Monitoring T2K beam

Some issues of Current detectors

Si & IC has shown excellent performance since the T2K started. However, we are concerning some issues as beam power is getting increasing.

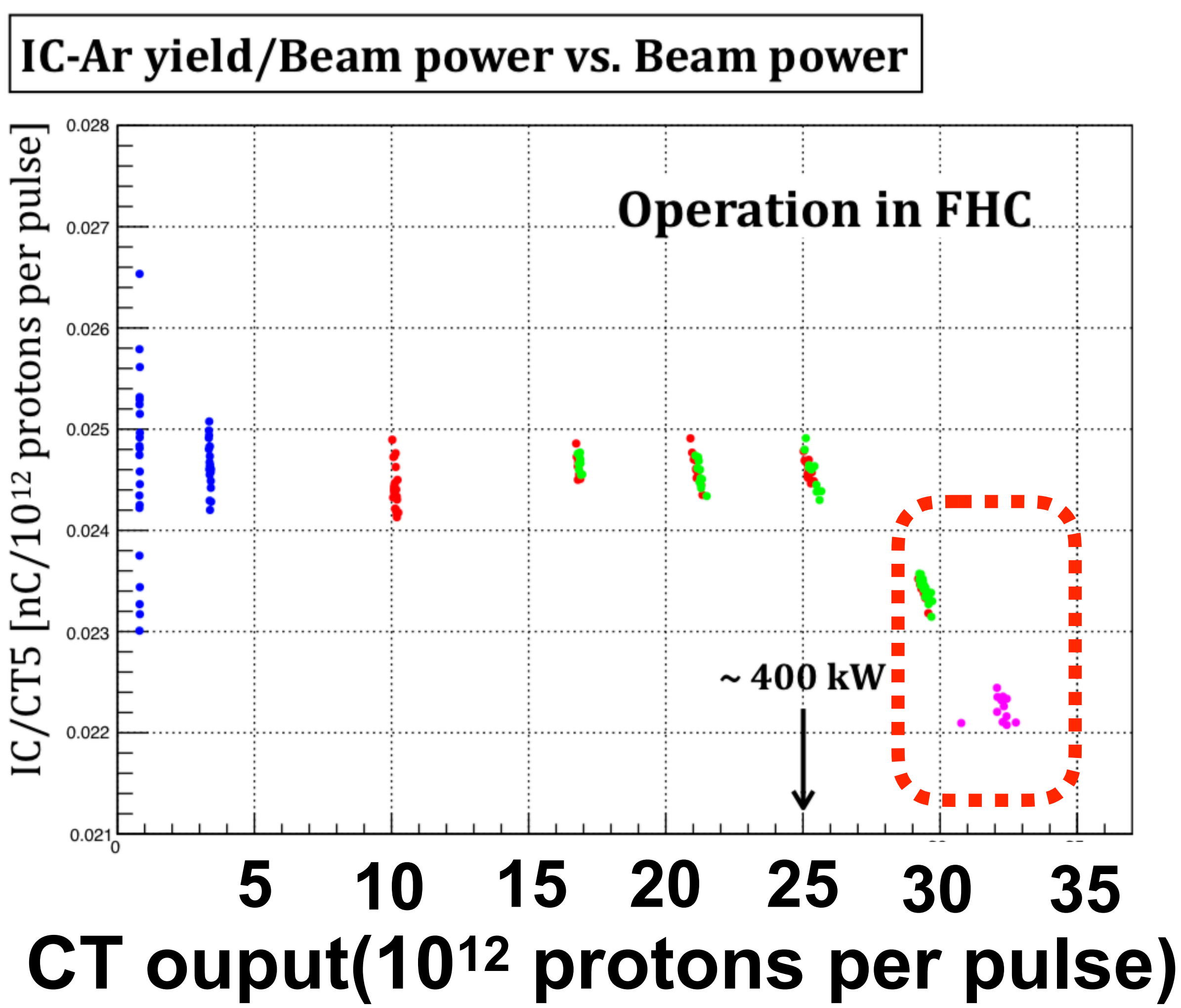
1st issues : Degradation for Silicon Detectors

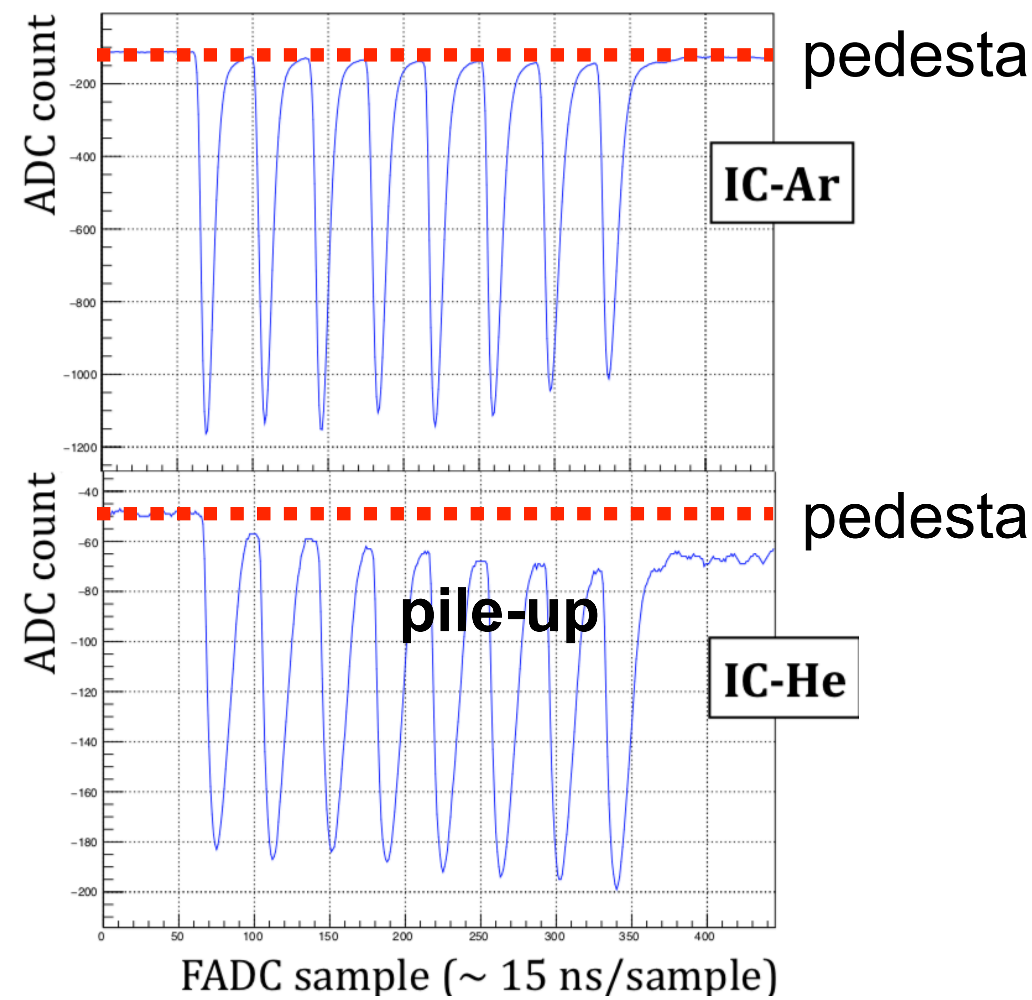


Signal decrease (~1%/5×10^{20} P.O.T) is seen that may be due to damage. We will have to replace Si detectors frequently (1/half a year) for future more high intensity T2K beam.

Some issues of Current detectors

2nd issues : Signal response for IC chambers





At high intensity , more electron-ion pairs are created and distort the electric field inside the detector, which worsen yield collection.

[solution 1] : Higher voltage application → Breakdown is a big concern

[solution 2] : Use of He gas instead of “Ar” → Pileup is seen due to faster ion drift speed

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Why new detectors?

- We are planning to increase the T2K beam power in the near future.

	Now (485 kW)	Future plan (1.3 MW)
# of protons / pulse	2.4×10^{14}	3.2×10^{14}
Operation cycle	2.48 s	1.16 s

<u>Our concerning issues could be problematic!</u>

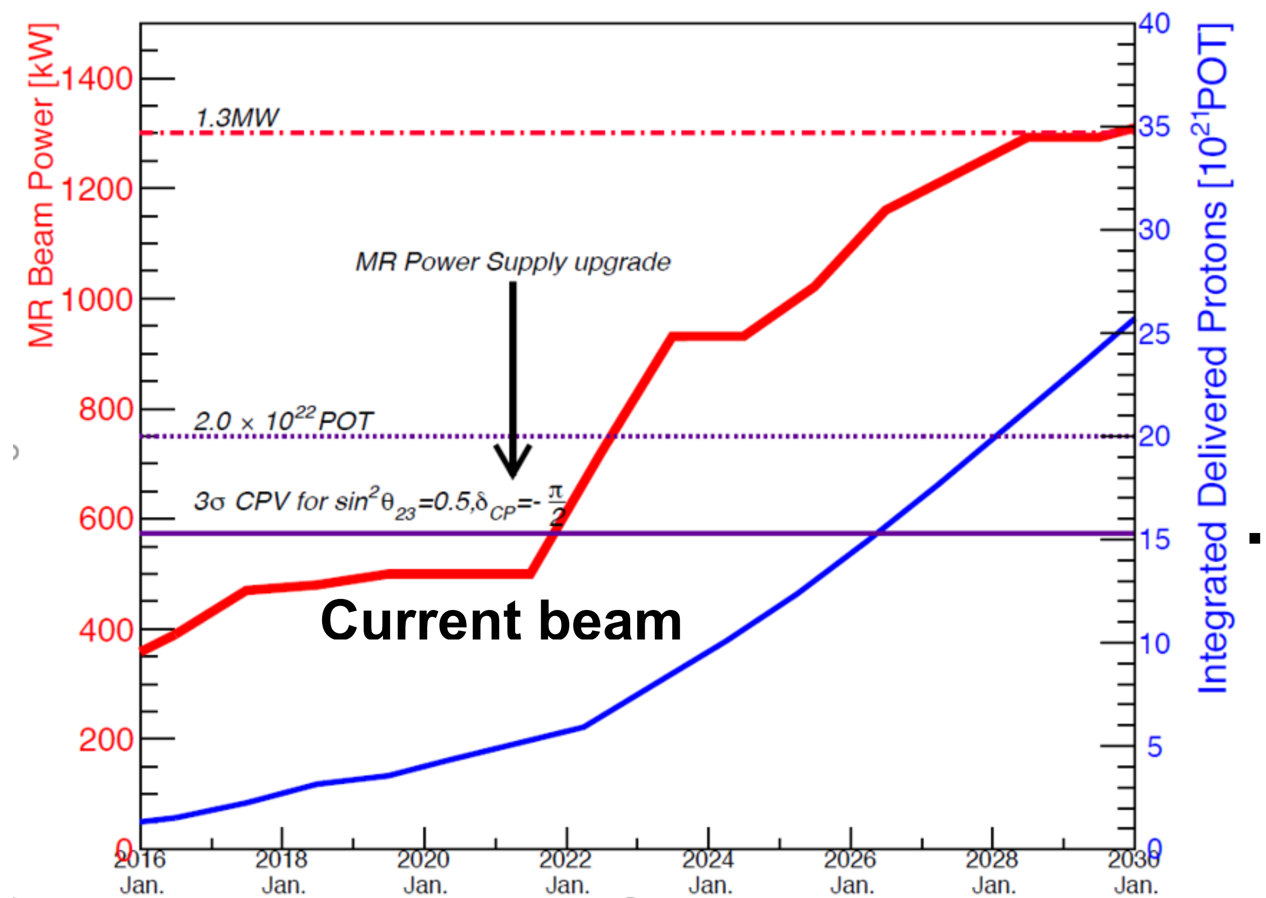
Candidates for new detectors

Diamond

Diamond detectors are expected have higher radiation resistance thanks to higher displacement energy.

PMT or EMT

EMT is like “PMT” using a aluminum instead of photocathode (detail later).
→ may have higher radiation resistance.



Upgrade plan for J-PARC ν beam

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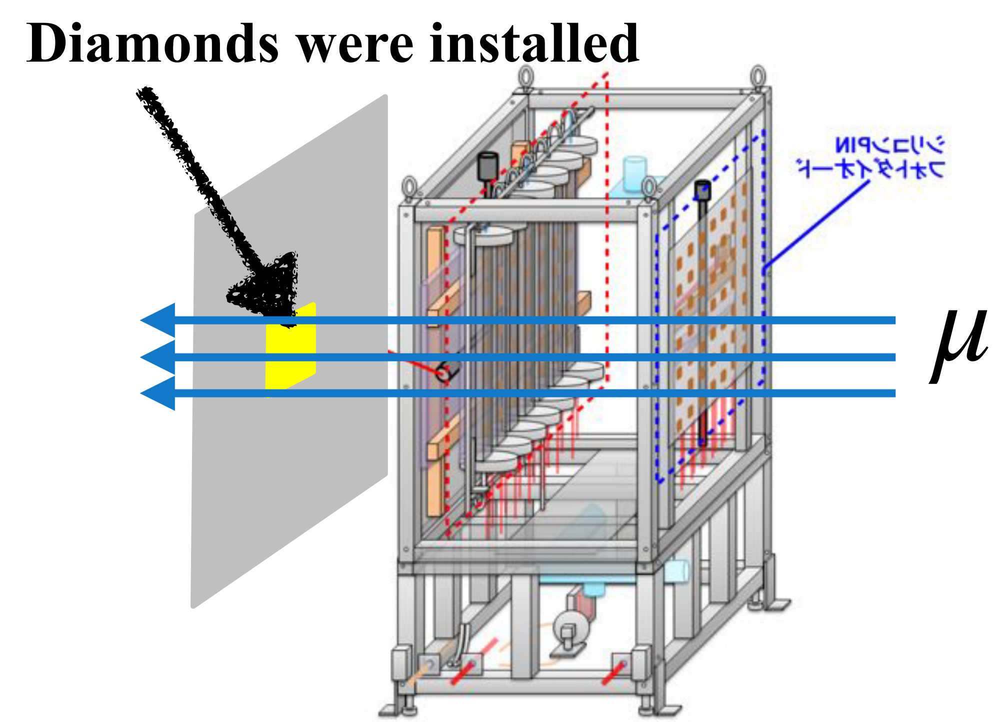
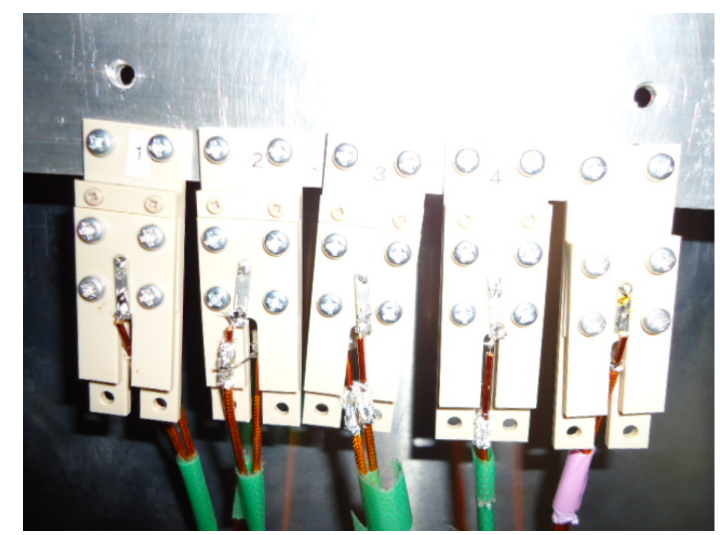
1st candidate : Diamond

	A1, A2	B1, B2	C1, C2
Edge	metaled	Not metaled	metaled
Dim.	3.8 × 3.8 × 0.5 (mm³)	4.0 × 4.0 × 0.5 (mm³)	4.5 × 4.5 × 0.5 (mm³)
Crystal	Element 6	Element 6	Element 6
Electrode	Element 6	Element 6	CIVIDEC





Diamonds detectors have been installed from 2012 - 2017
C1 and C2 are relatively new ones.

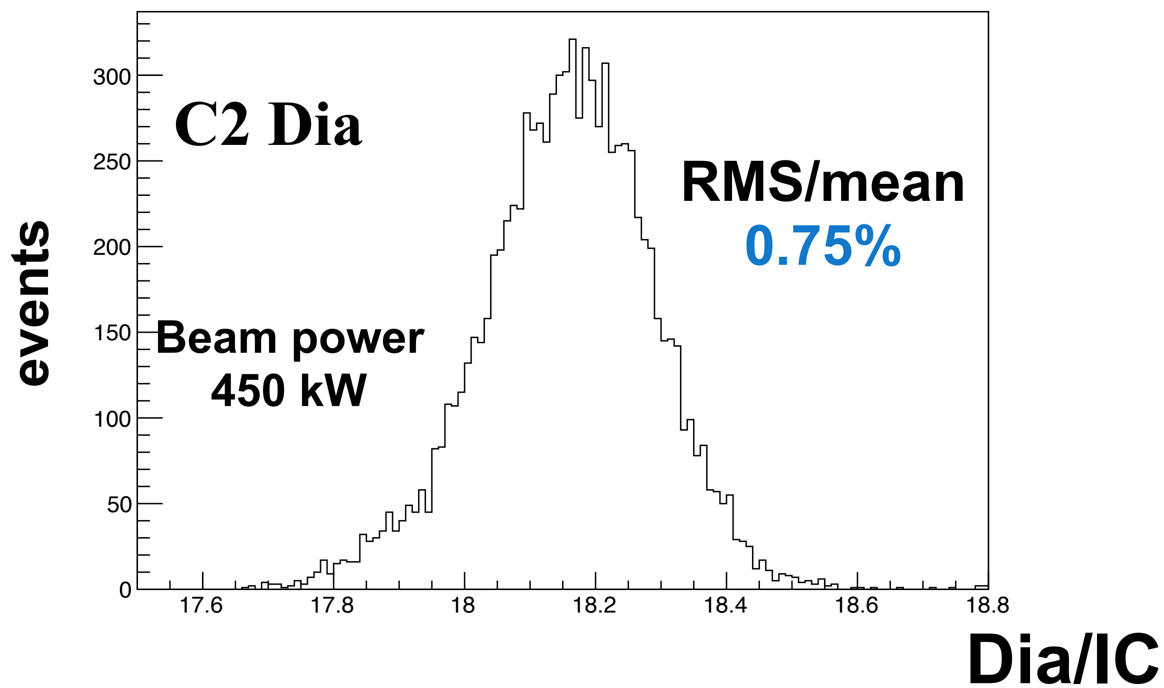
Intensity resolution and Linearity

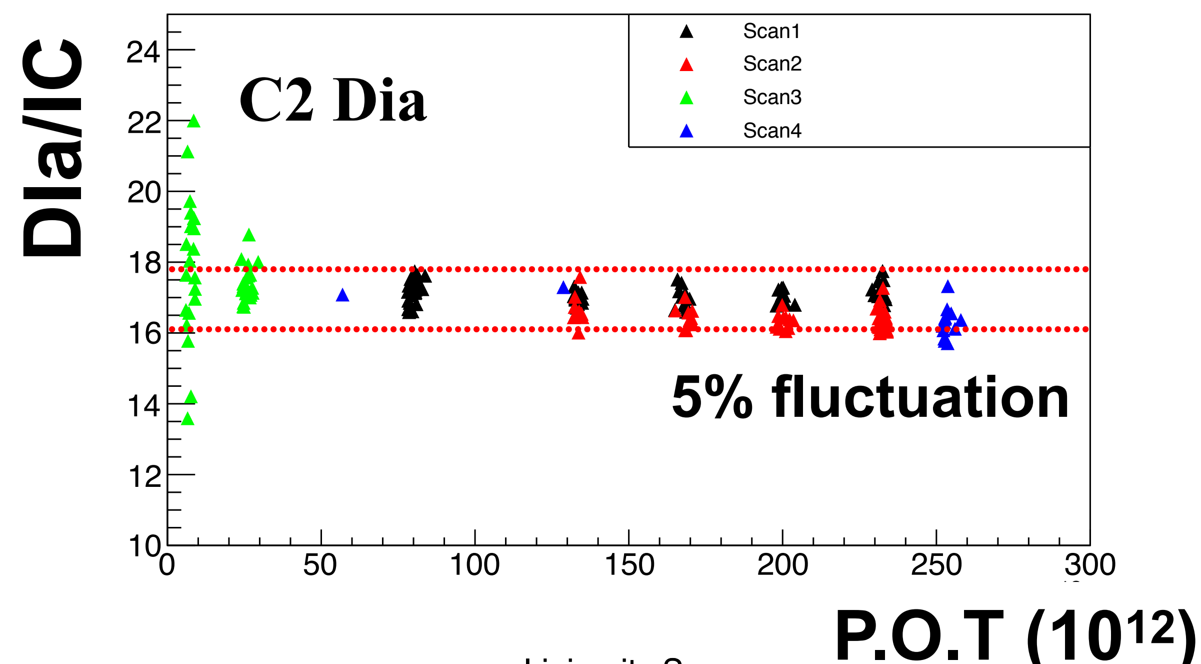
Comparison with current detectors

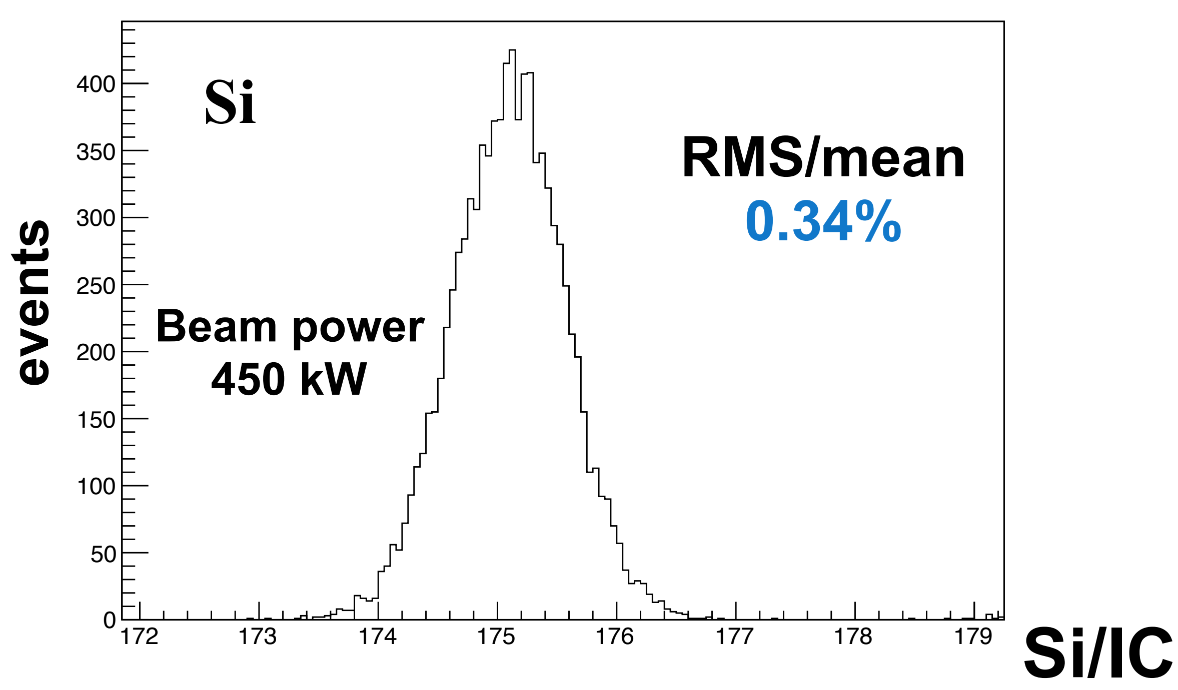
- Intensity resolution : less than 1% for both (requirement is 1%)
- Linearity : 5% fluctuation (less than 5% for Si, IC) (requirement is 5%)

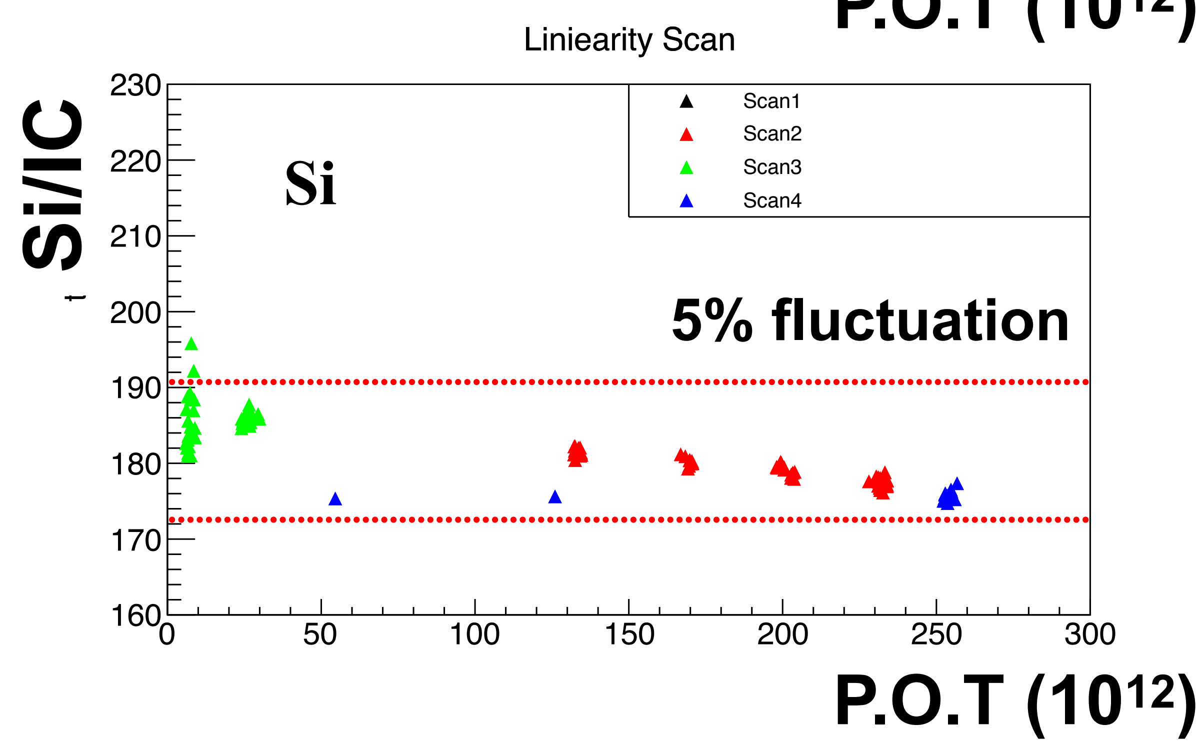
intensity resolution

Linearity

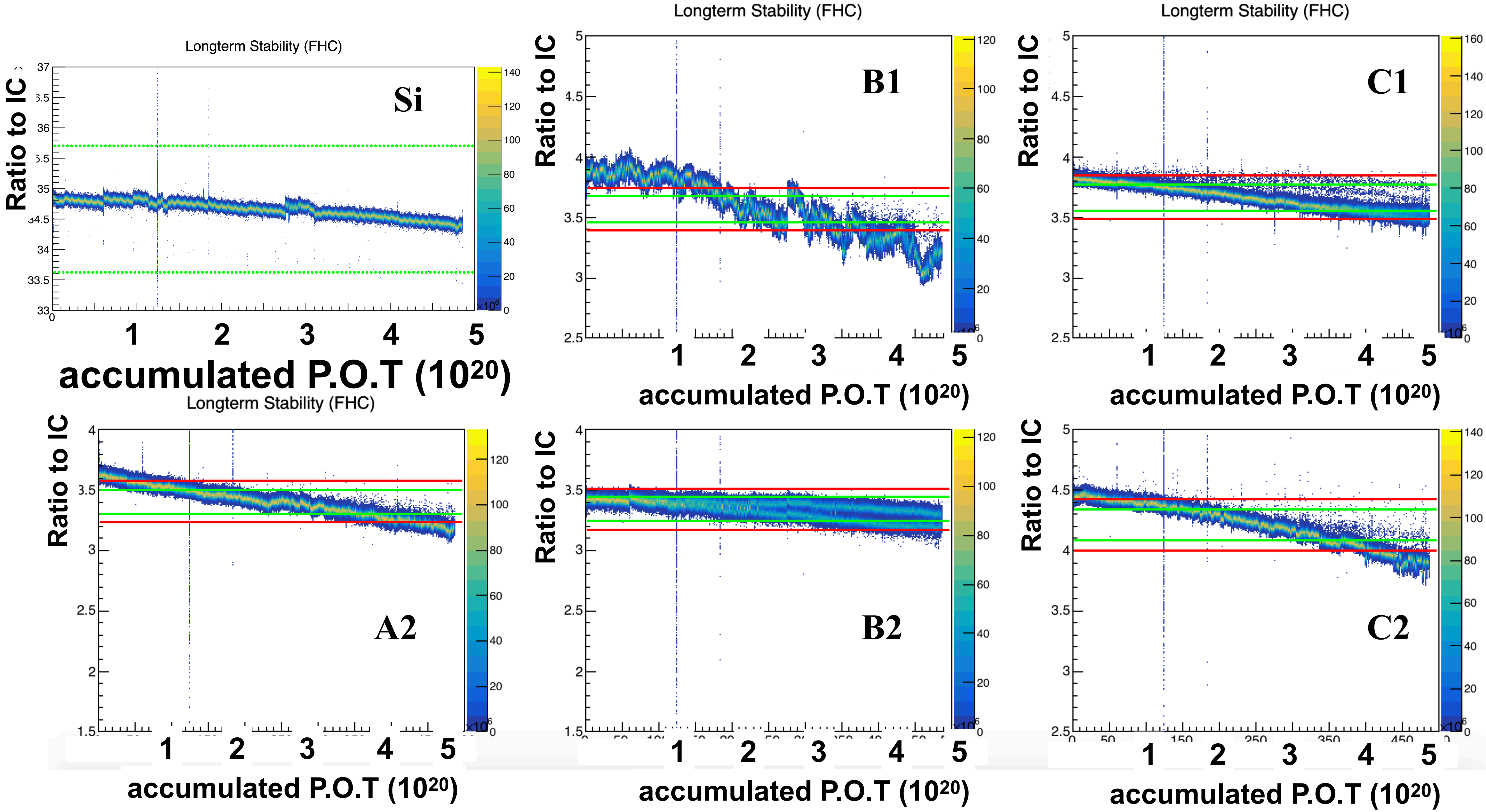








Stability



Stability (Green : 3%, Red : 5% degradation)

More than 5% degradation are seen for all diamond detectors until 5.0×10^{20} protons on target (P.O.T.) is accumulated, while less than 3% for Si.

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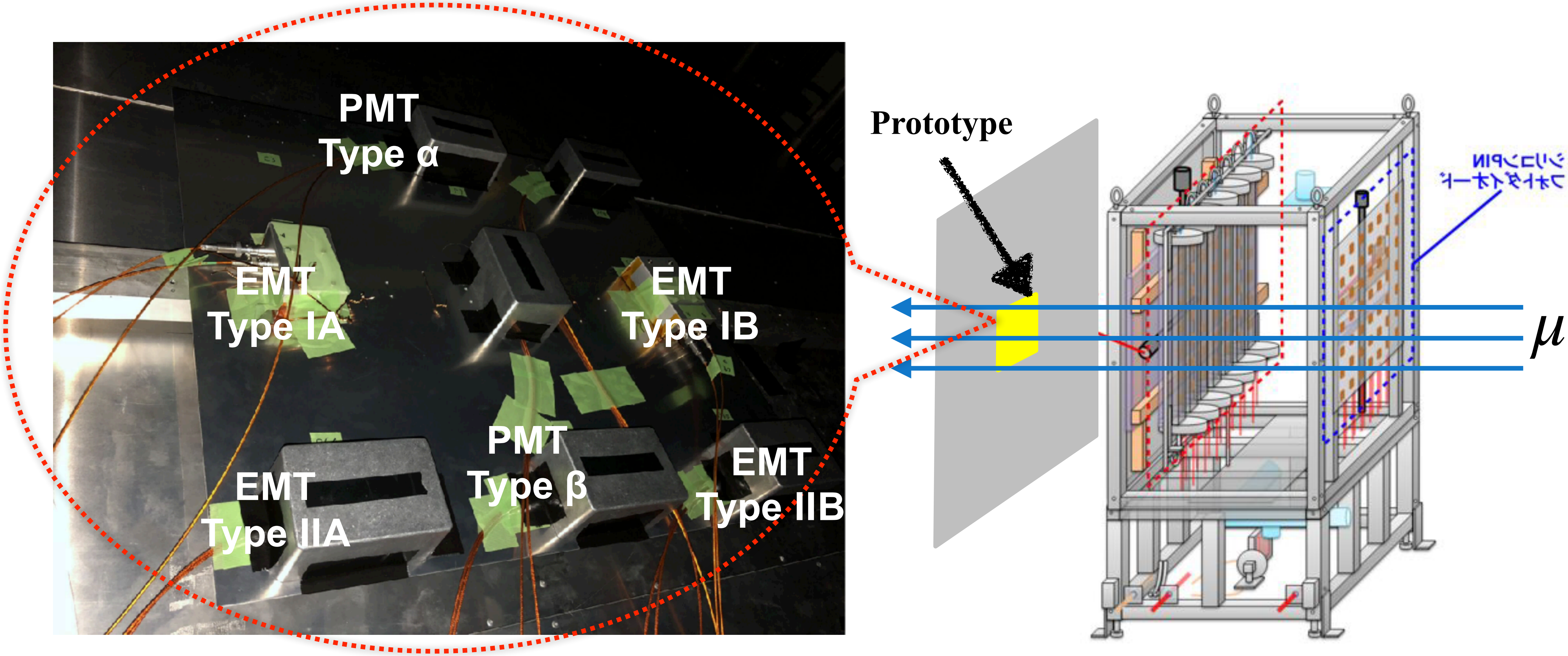
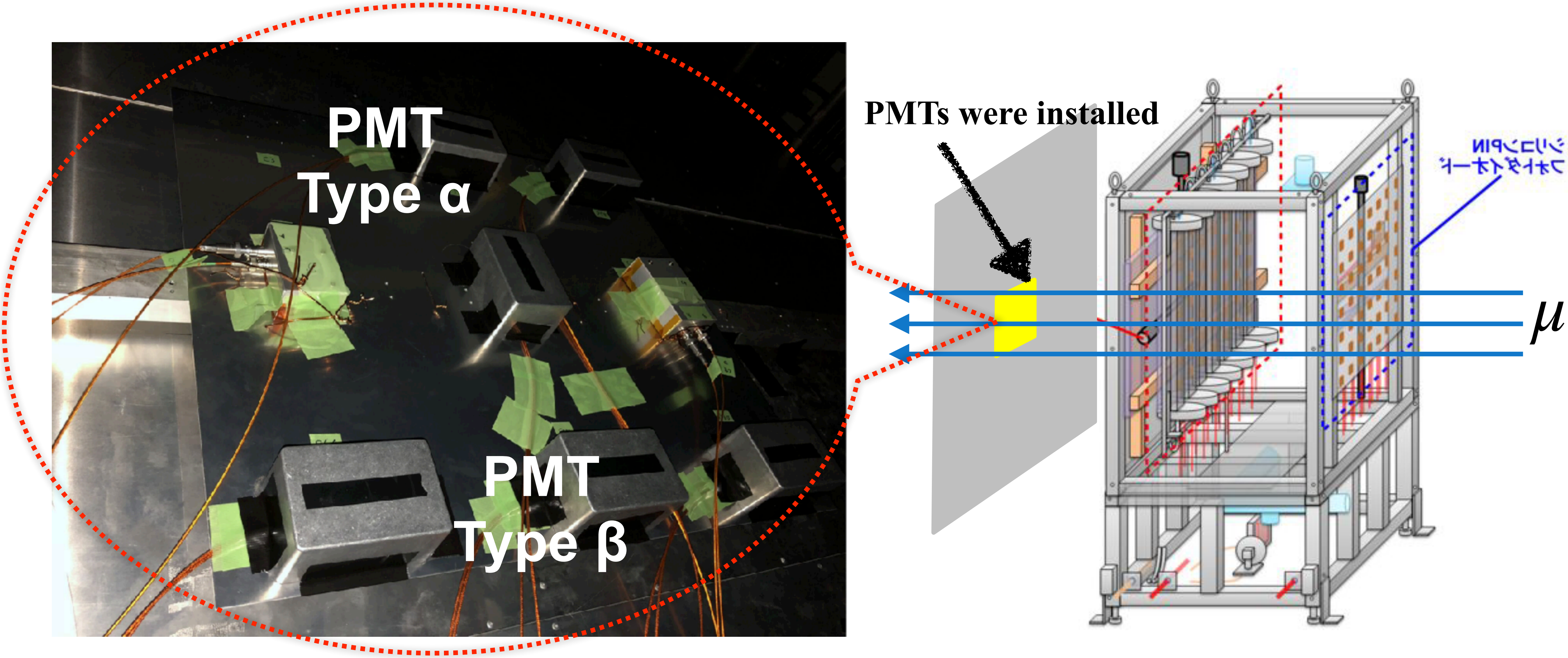
The development of prototype detectors
- PMT & EMT -



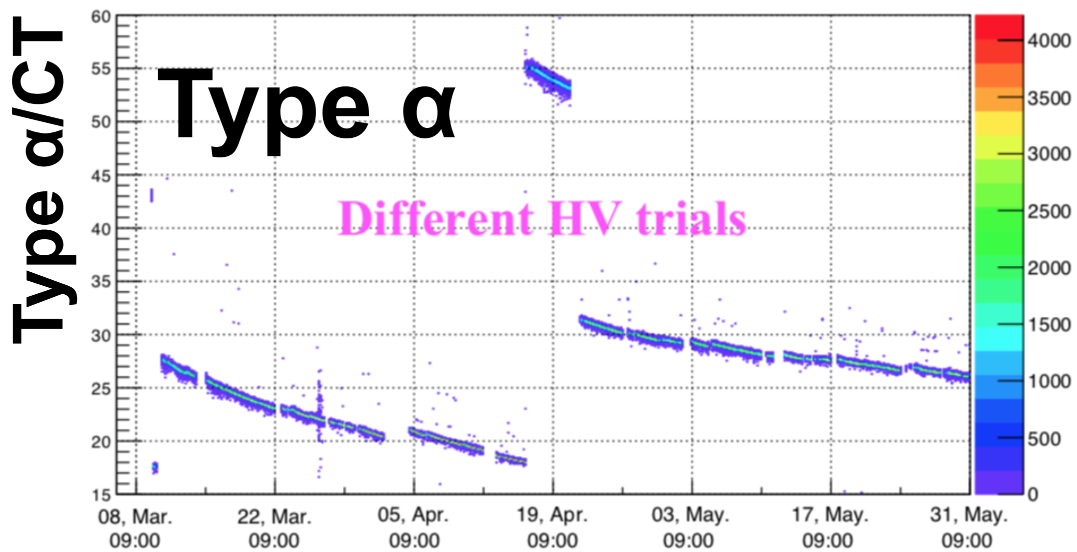
- Tested the 2 types of PMTs and 4 types of EMTs in the same places as the diamond detectors.
- Results of this commissioning run are shown in the paper, "*Y. Ashida et al., Prog. Theor. Exp. Phys., 103H01, 2018*".

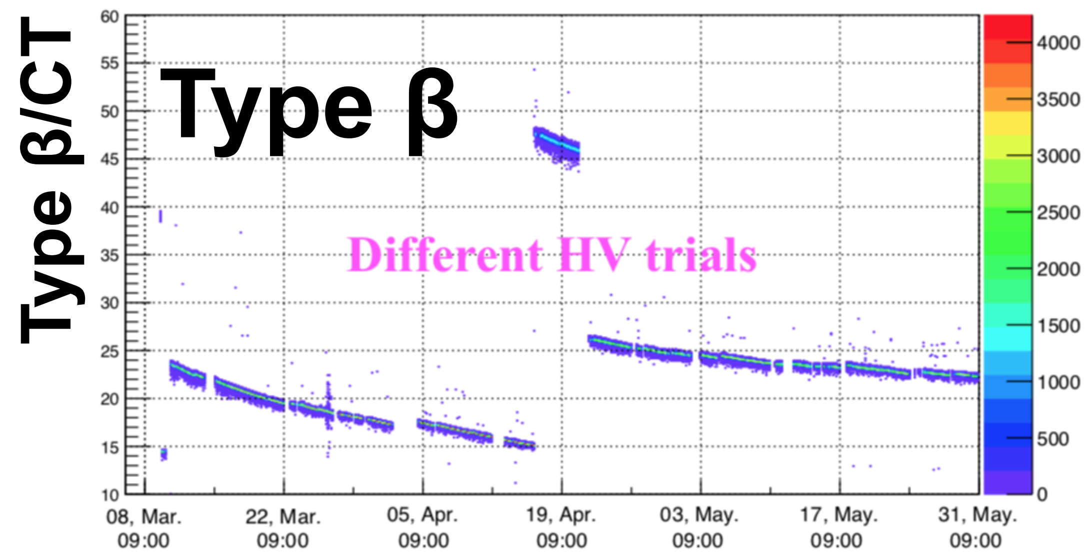
2nd candidate : PMT



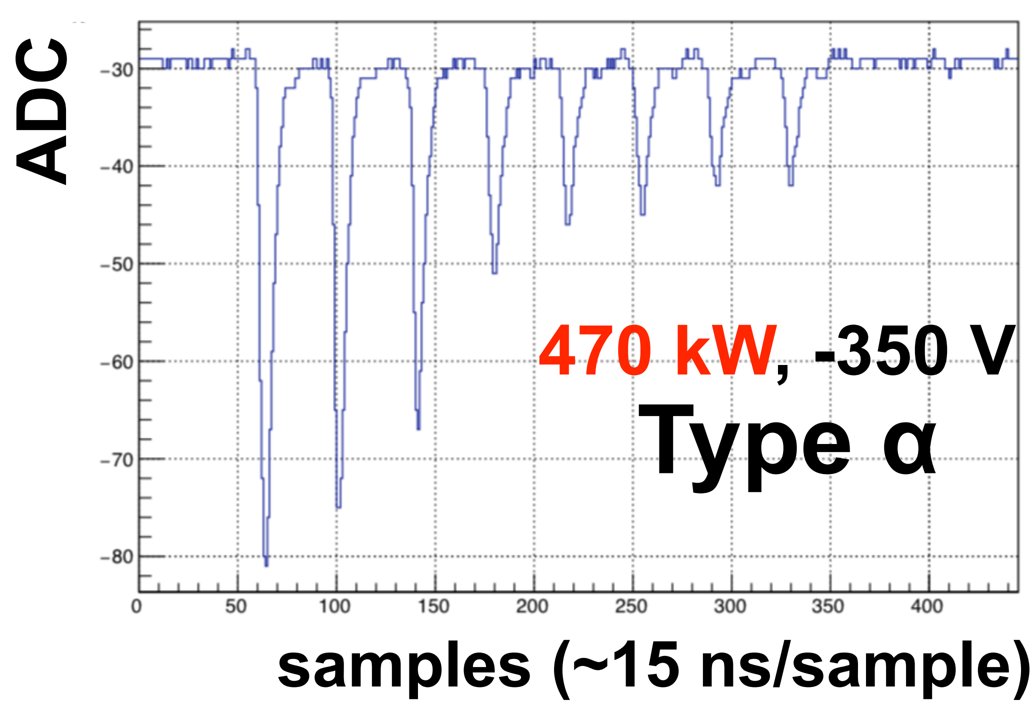
- Two nominal PMTs (Hamamatsu R9880) were installed.
- A BNC connector was used for the PMT-Type near the detector, not for PMT-Type β (radiation damages were expected to be different).
- Linearity and stability were checked.

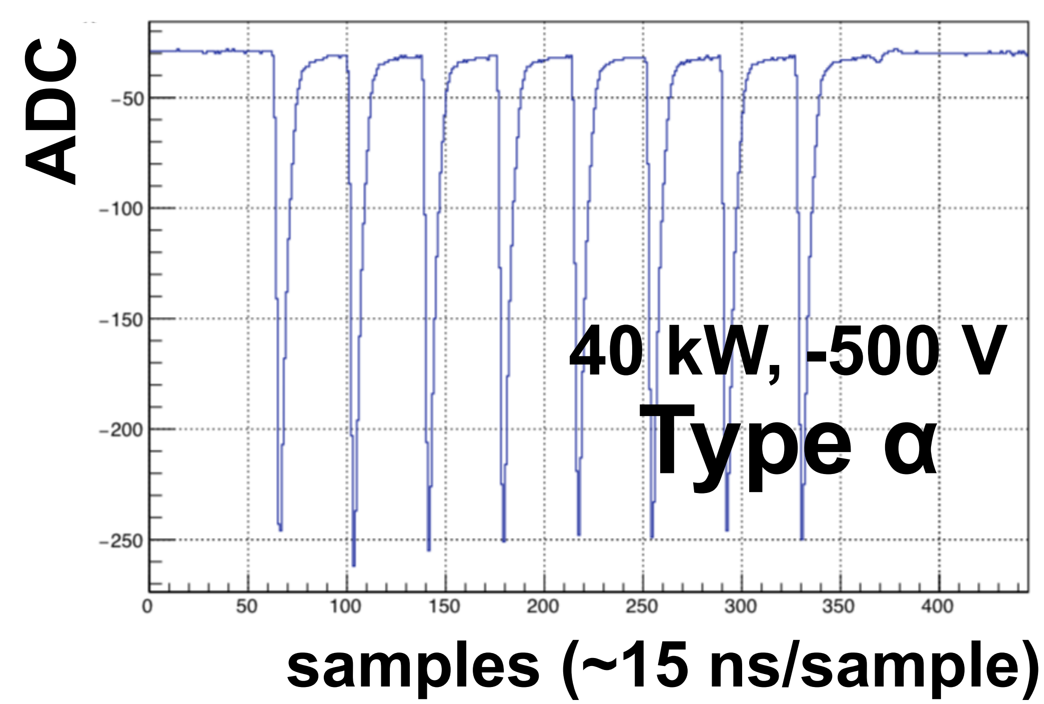
2nd candidate : PMT





Unstable events were found if the different HV were applied.
Stability is worse compared with current detectors.





Saturated in the case of current T2K beam power

PMT doesn't seem a good candidate for MUMON

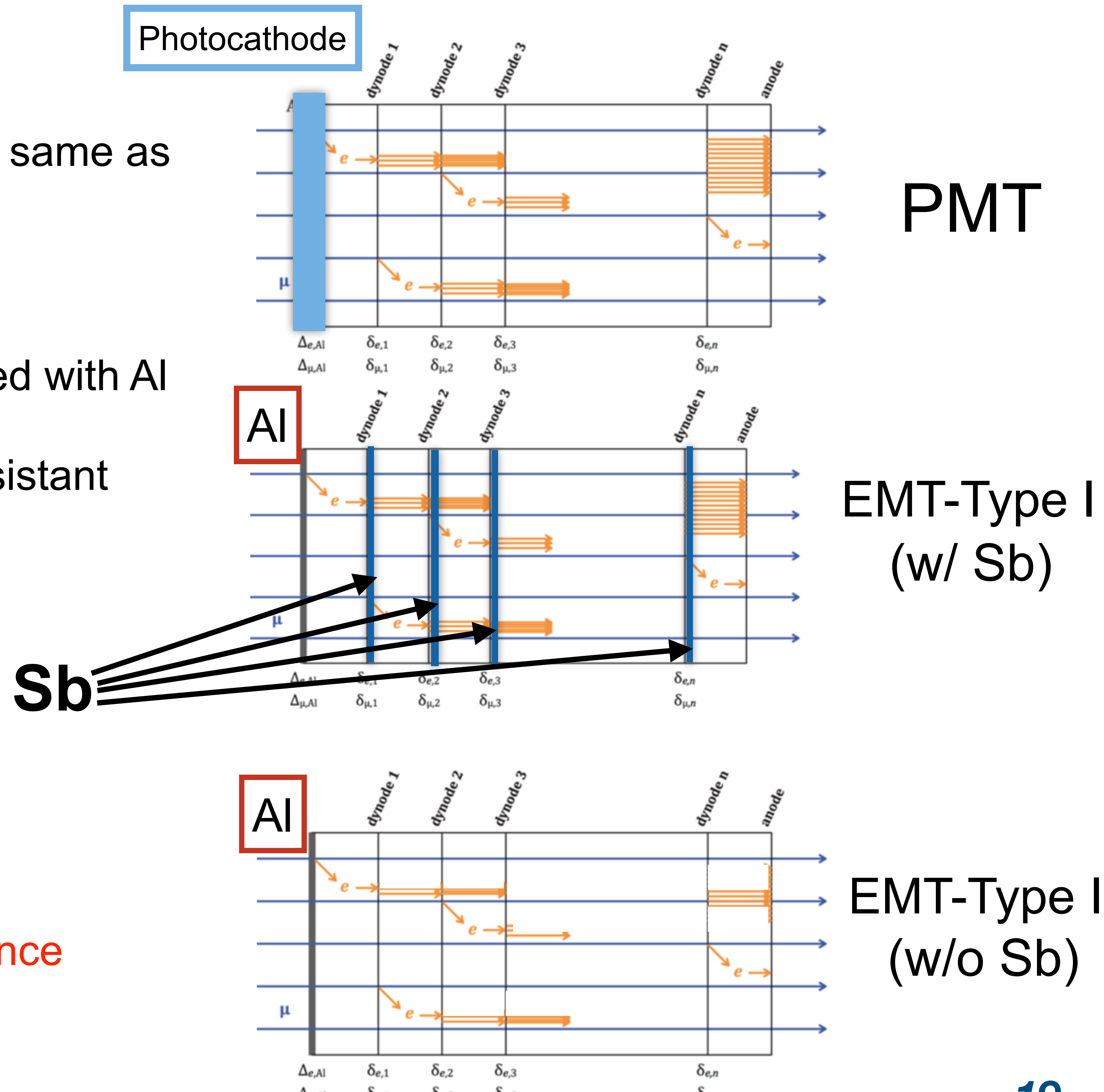
Introduction of EMT structure

- The components of EMT are the same as the standard PMT except for the photocathode.

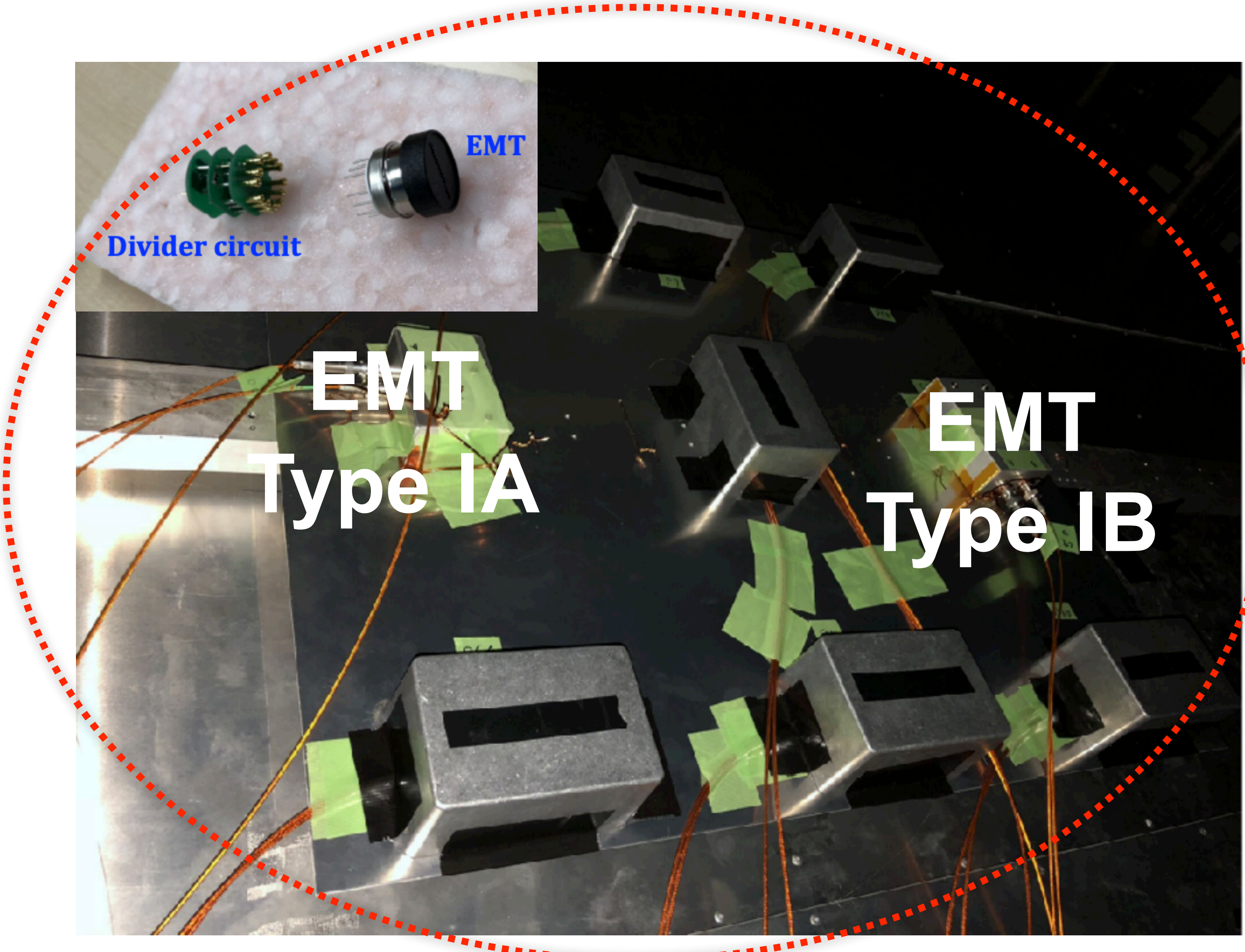
- Photocathode material is replaced with Al for EMT.
  → expect the higher radiation-resistant accepting the low signal.

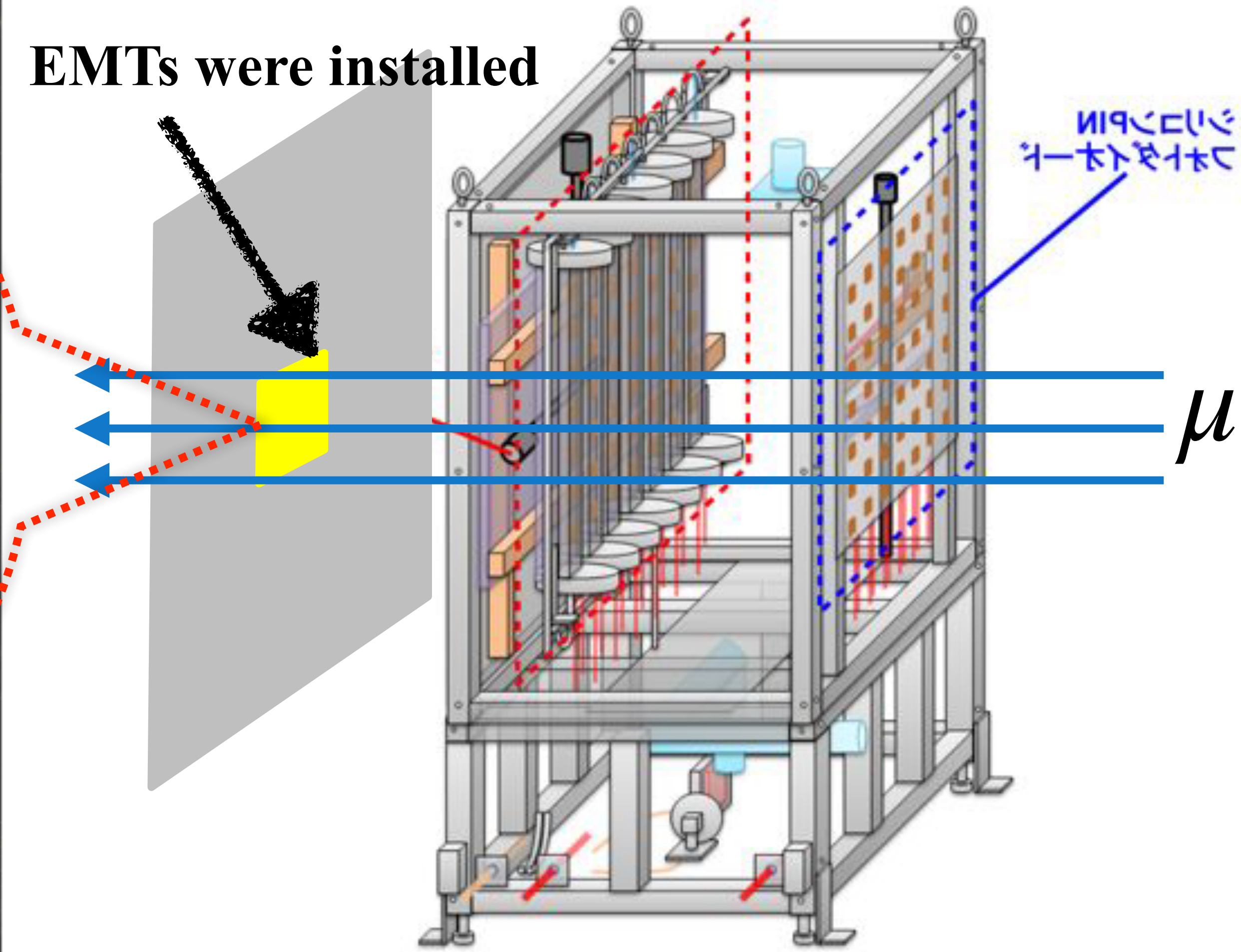
- Current options
  1. Type I (Dynodes with Sb)
  → higher for the signal amplitude
  → expected gain : ~10^6

  2. Type II (Dynodes without Sb)
  → higher for the radiation resistance
  → expected gain : 10~10^3



3rd candidate : EMT-Type I





- 2 prototype detectors (Type IA & Type IB) are custom-mades using Hamamatsu R9880. Capacitances on dynodes are different.

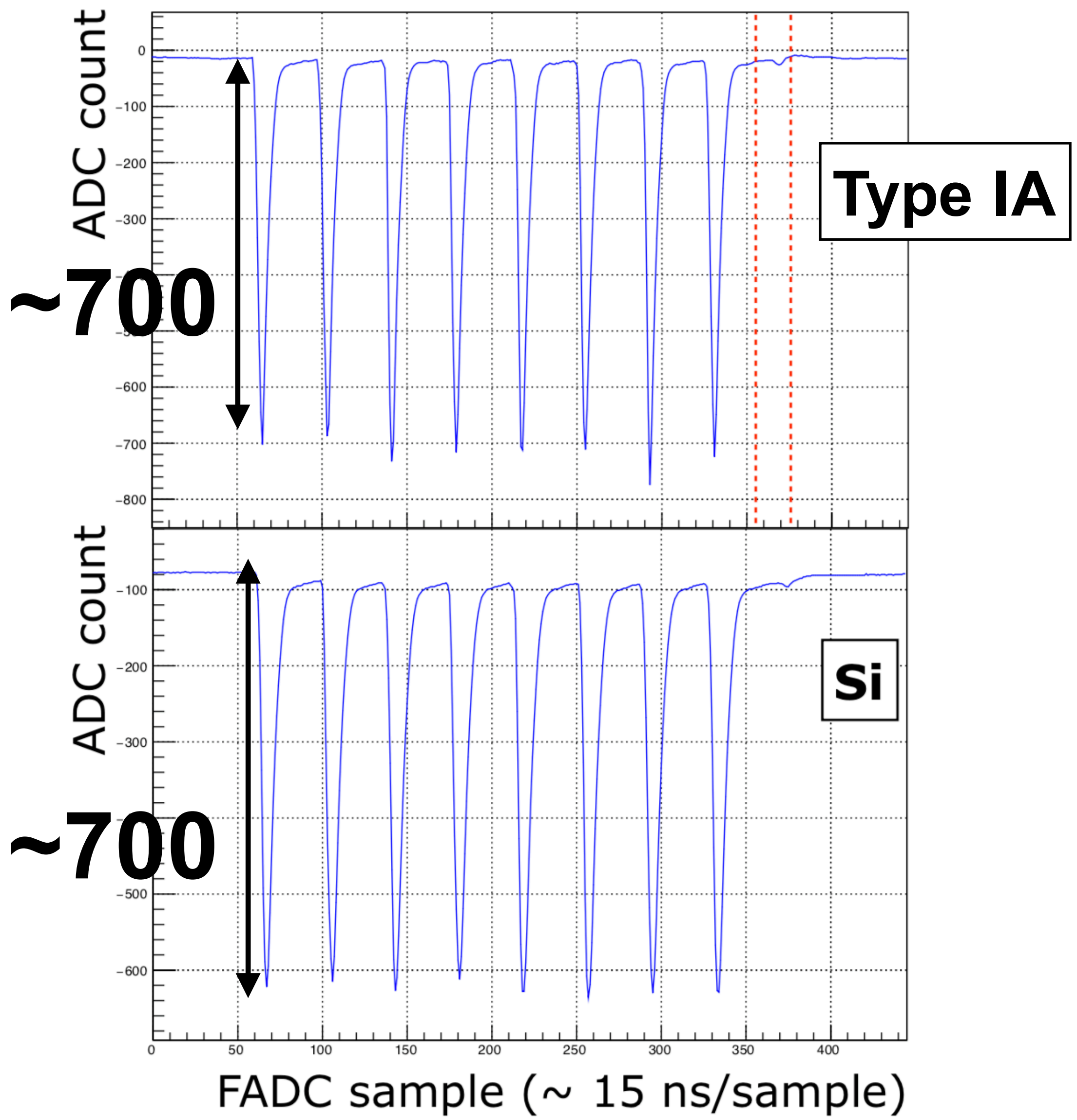
- Readout : 65 MHz Flash-ADC same as Si and IC.

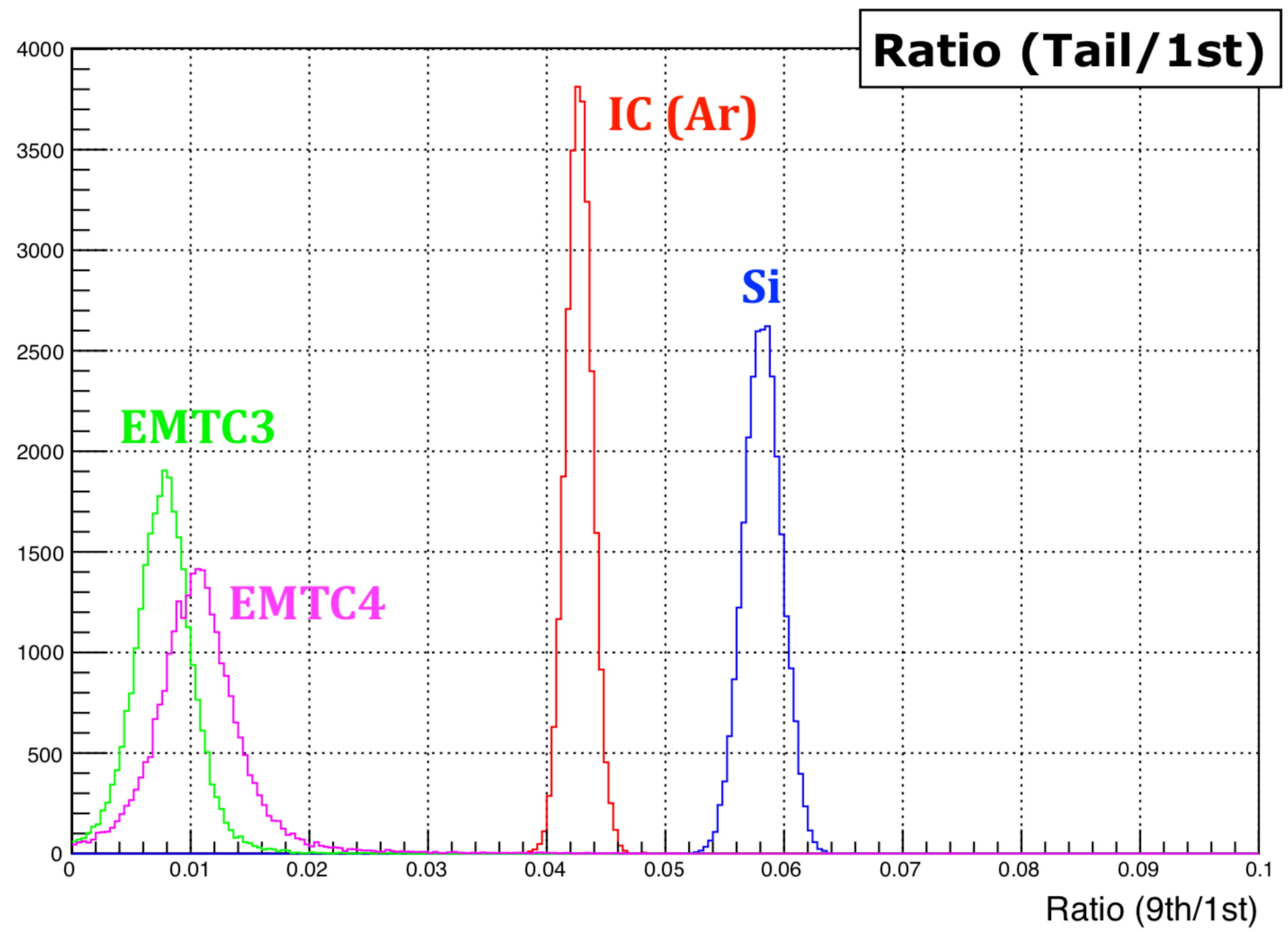
	Capacitance (IA)	Capacitance (IB)
Dynode 5	-	100 nF
Dynode 6	-	100 nF
Dynode 7	10 nF	100 nF
Dynode 8	10 nF	330 nF
Dynode 9	10 nF	330 nF
Dynode 10	10 nF	330 nF

Y. Ashida et al., Prog. Theor. Exp. Phys., 103H01, 2018

Time Response

- Smaller tail contribution is better because tail contribution affects bunch-by-bunch monitoring for T2K.
- In this analysis, tail contribution is estimated by calculating the ratio of 1st bunch and the tail of final bunch.





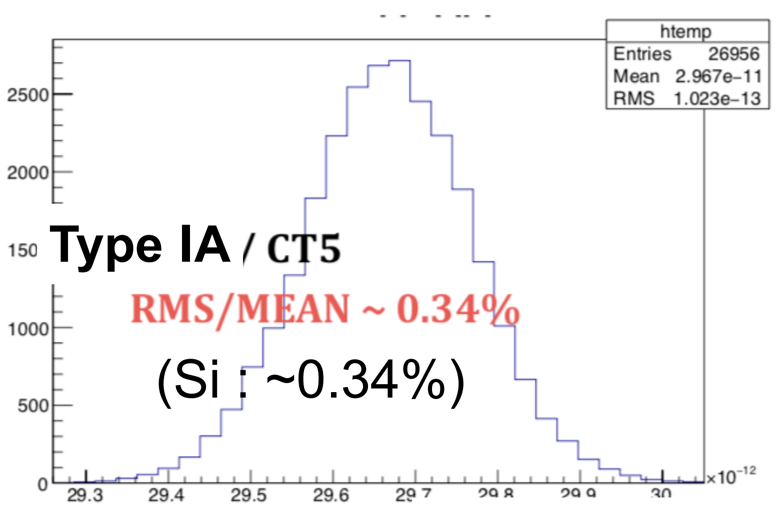
Ratio of tail contribution to 1st bunch

Y. Ashida et al., Prog. Theor. Exp. Phys., 103H01, 2018

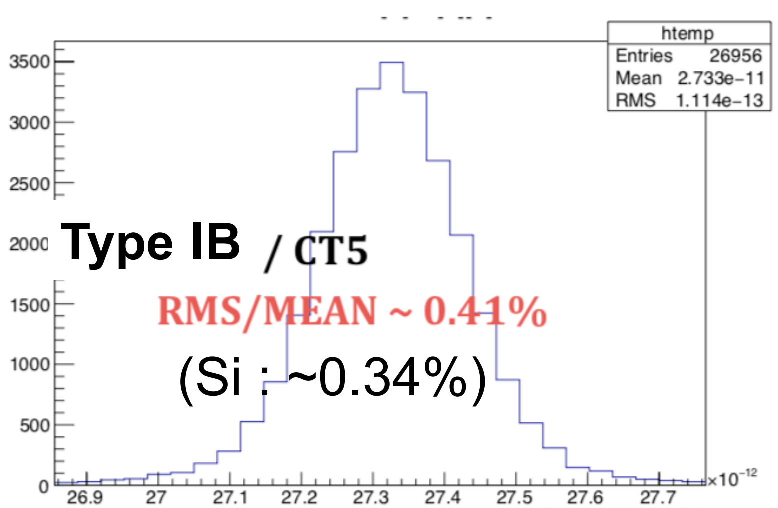
Intensity resolution and Linearity

- Intensity resolution and Linearity are checked.
- Type IB shows better linearity than Type IA thanks to the improvement of capacitance.
- Higher voltage worse the linearity due to the electric field distortion.

intensity resolution

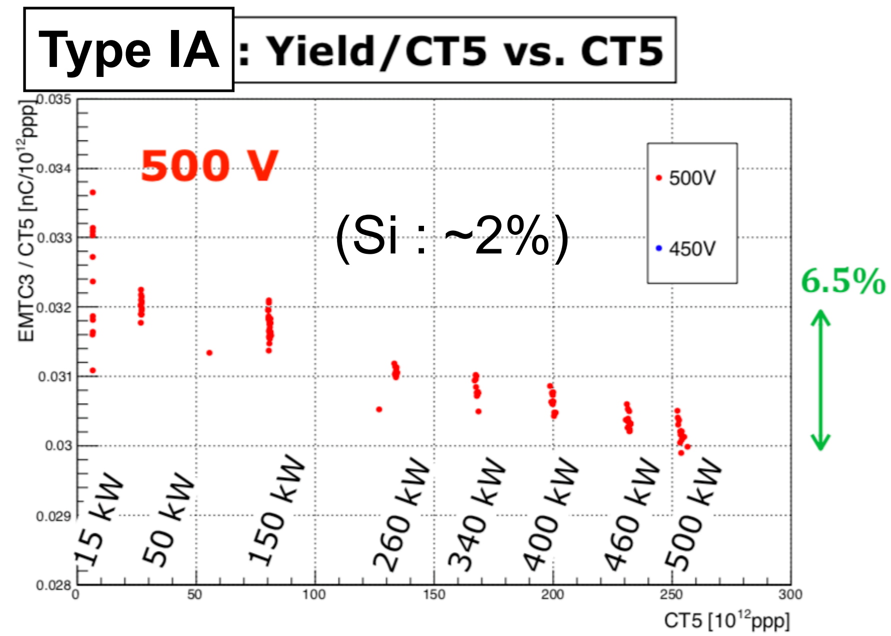


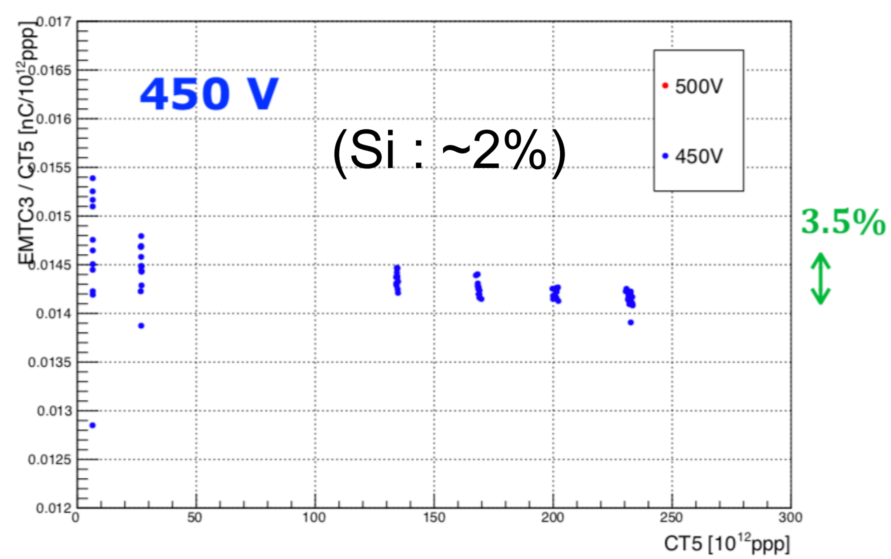
Type IA/CT

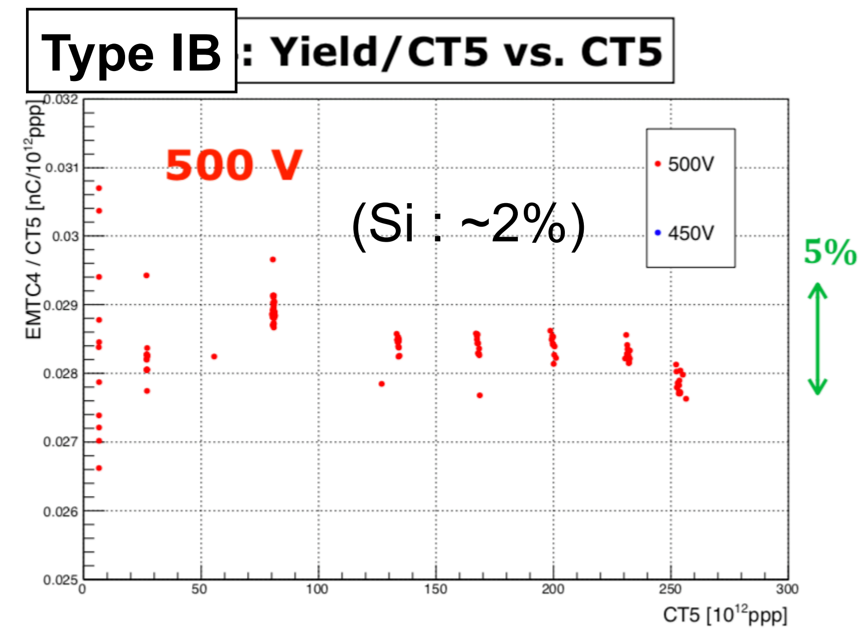


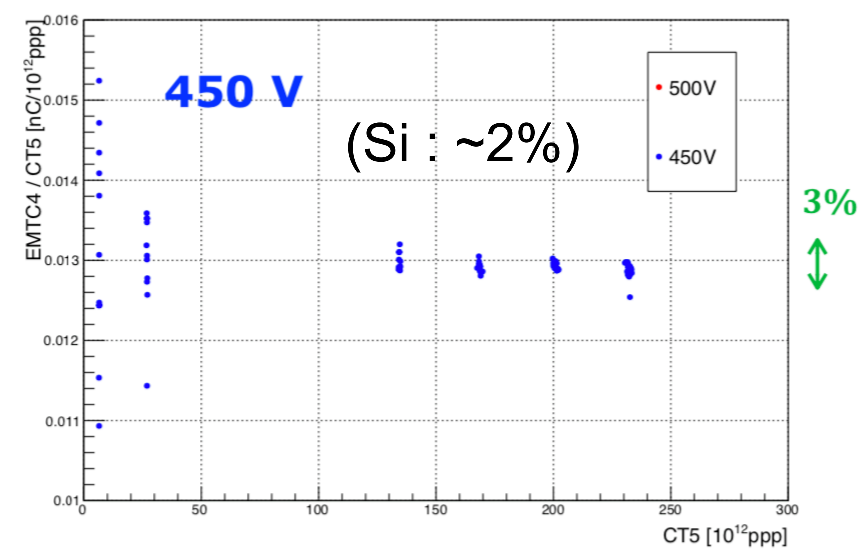
Type IB/CT

linearity







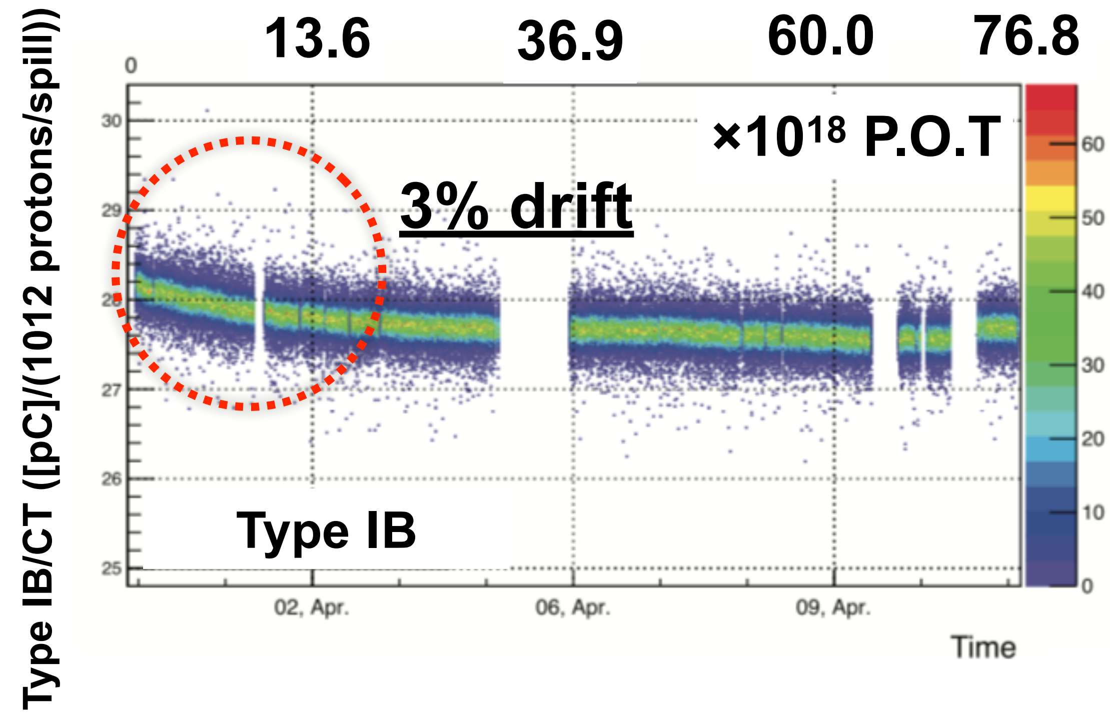


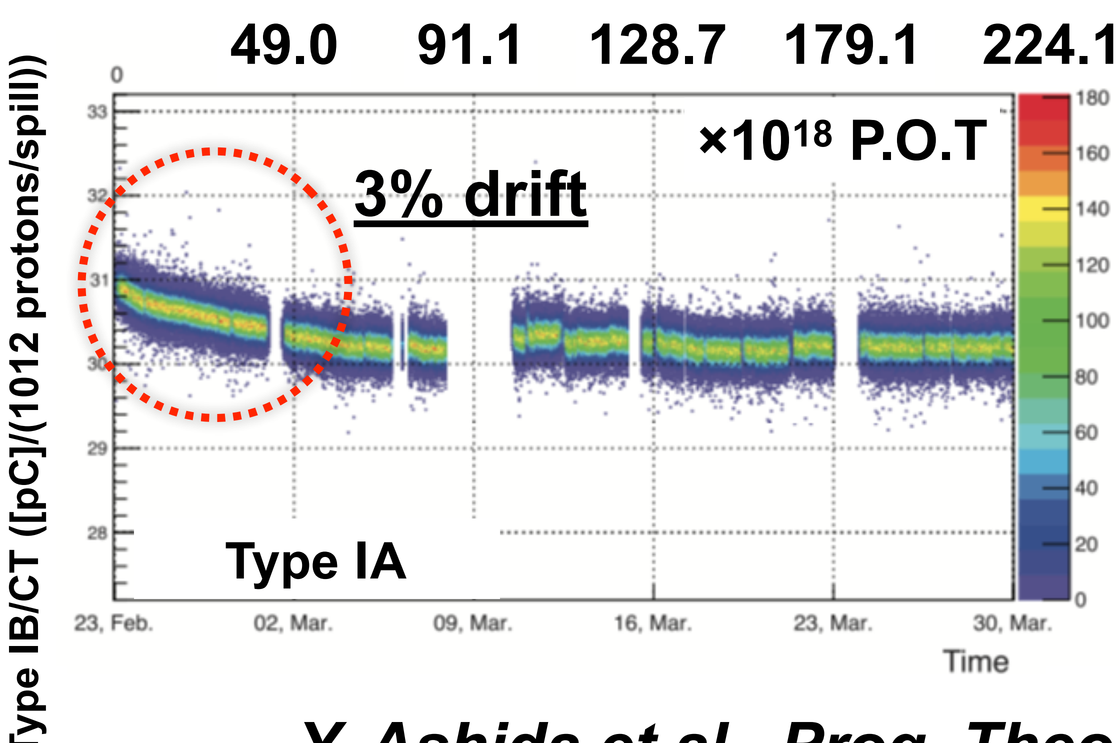
Y. Ashida et al., Prog. Theor. Exp. Phys., 103H01, 2018

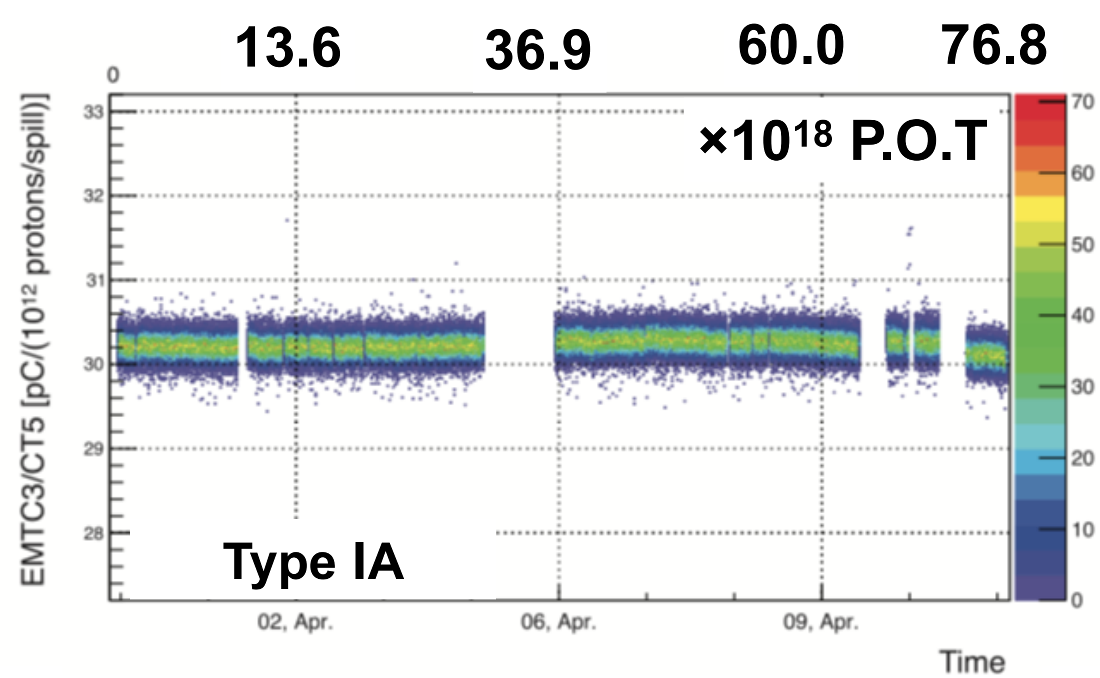
Stability

- We can see ~3% drift for first 10 days since installation.
(~2.2 mC)
→ Hamamatsu recommended that we should stabilize the alkali-metal condition on dynodes for "warming-up" before use. (1~5 mC)
→ This kind of effect will be studied in the next beam test (detail later).

- After the drift, both EMT shows the nice performance as for stability.

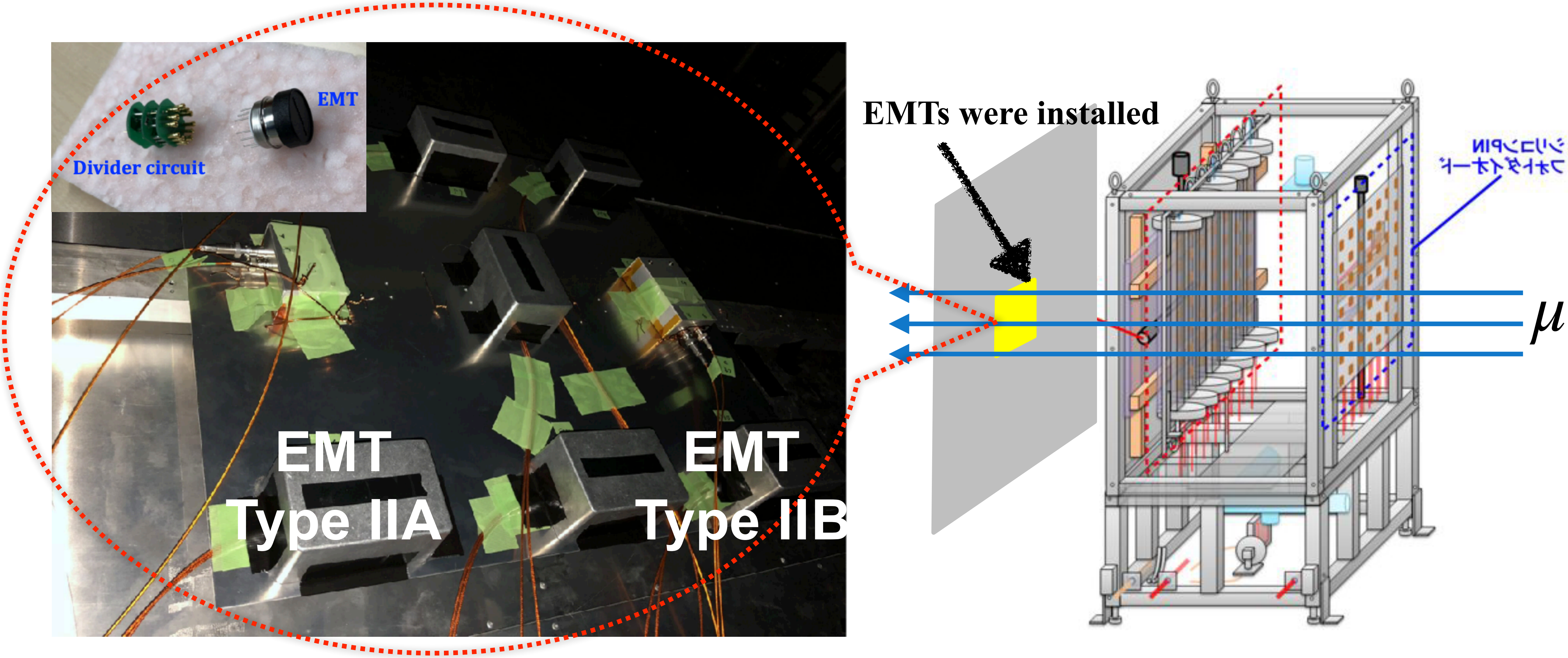






Y. Ashida et al., Prog. Theor. Exp. Phys., 103H01, 2018

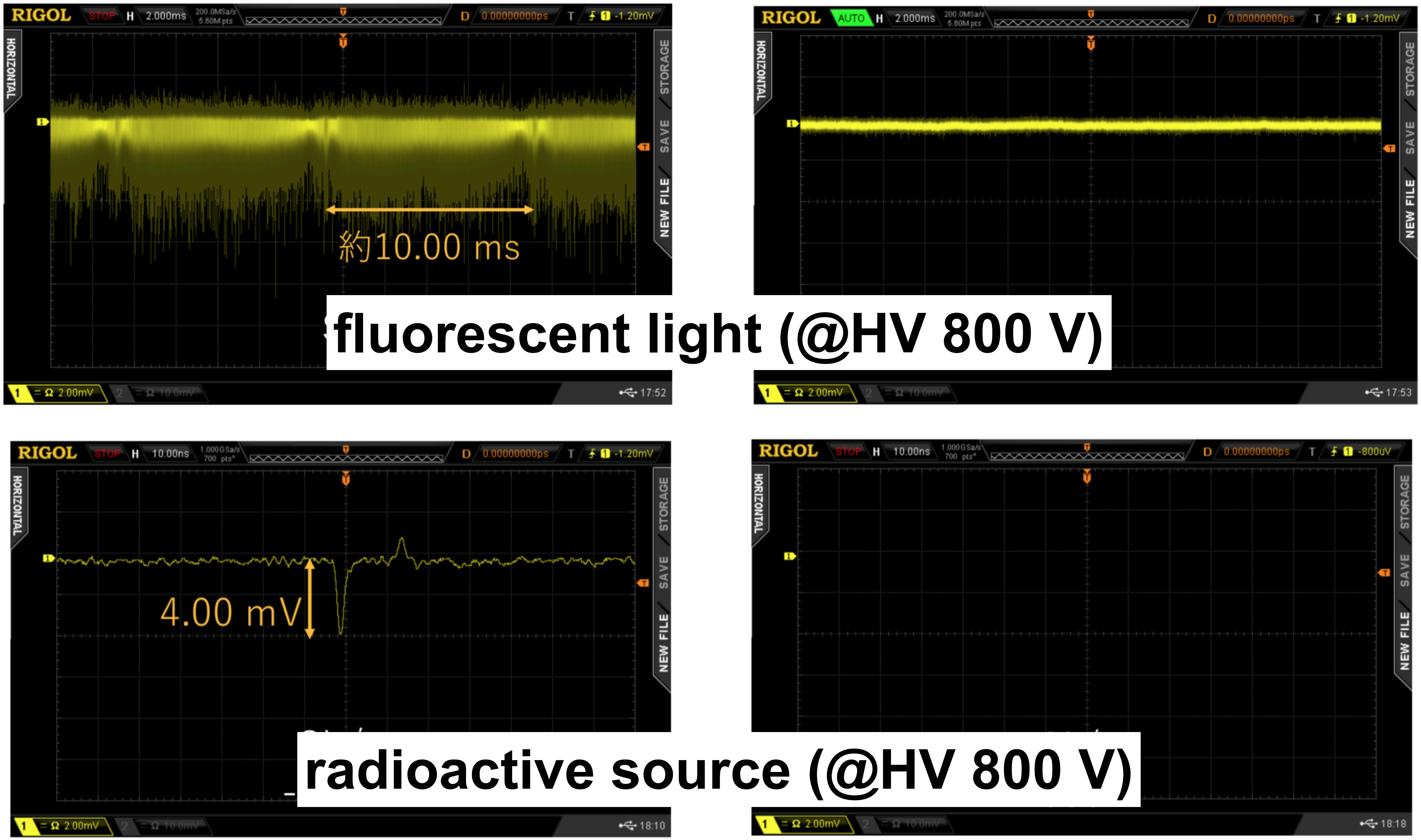
4th candidate : EMT-Type II



- EMT - Type II has no Sb on dynodes (expected gain is 10~10^3).
  → We are expecting the higher radiation resistance than Type I.
- Unfortunately we cannot see any signal on this commissioning at 450 V.
- We tried other sources such as “fluorescent light”, “radioactive source (^{152}Eu)”.

Signal check with other conditions

Type I (w/ Sb) | **Type II (w/o Sb)**



We are looking forward to seeing the signal with Type II in the beam test.

Sumary and Discussion from the commissioning run

Diamond

- Tail contribution, intensity resolution and linearity are good, however, stability, which is most important parts for monitors, is worse.

PMT

- Intensity resolution and linearity are worse than ones of current detectors.

EMT Type I

- All properties (Intensity resolution, linearity, and stability) are comparable or better than current detectors.

EMT Type II

- No signal

We concluded that EMT - Type* I *was the best candidate. We would like to investigate EMT - Type* II *for higher intensity beam.

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Proposals of EMT beam test

EMT is expected to have better performance for T2K beam.
→ We proposed the beam test for EMT to investigate more.
→ Accepted by Research Center For Electron Photon Science (ELPH) at Tohoku university in Japan.
→ Electron beam. The Conversion factor on radiation damages ($\mu/e \fallingdotseq 1.12$)

We are planning to measure the followings…

1. Linearity
From current intensity (1.7×10^{7} μ/cm²/3 μs) to future intensity (3.9×10^{7} μ/cm²/3 μs)

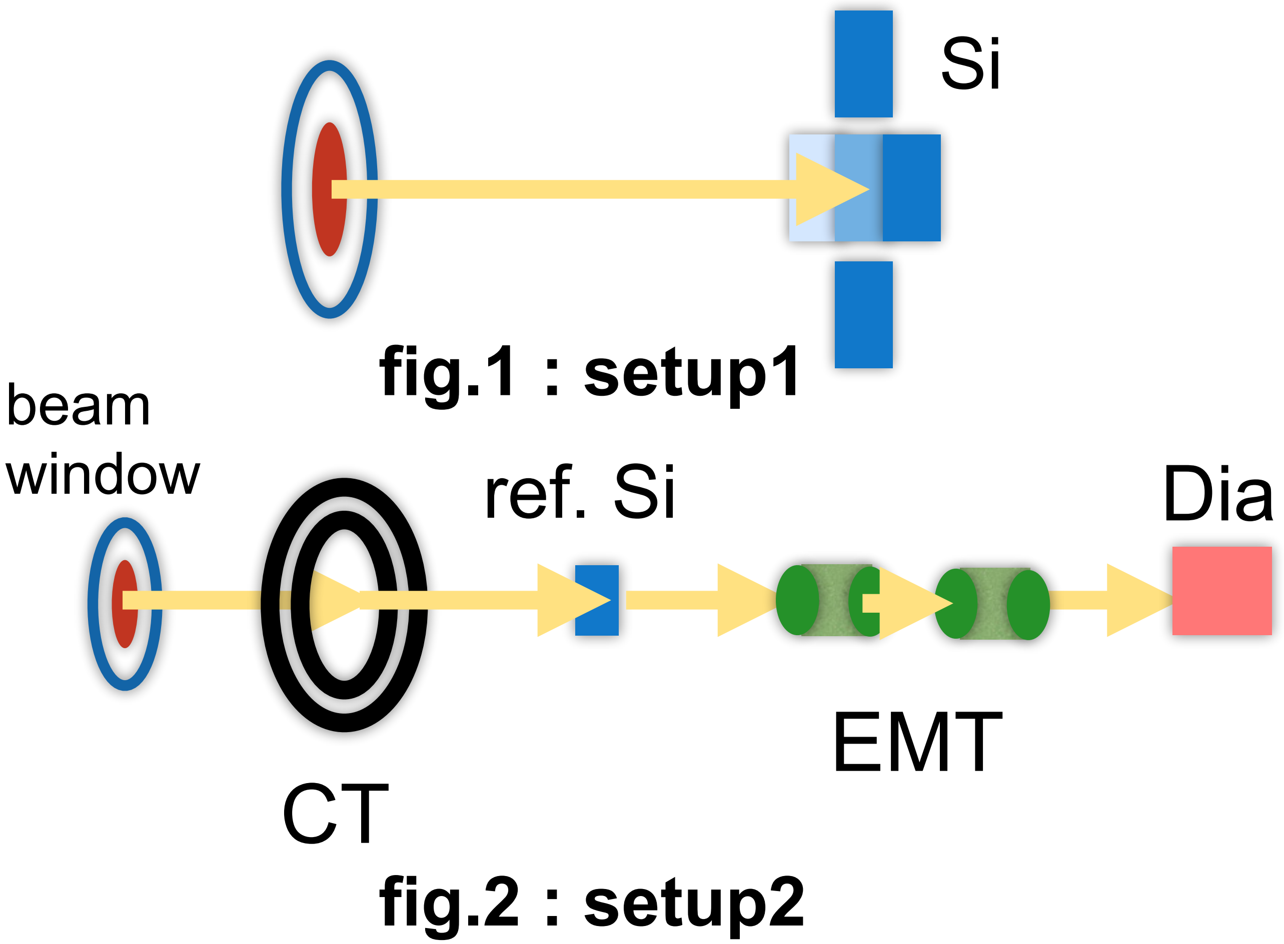
2. Stability
corresponding to 10-years beam exposure with future intensity (2.9×10^{15} μ/cm²)

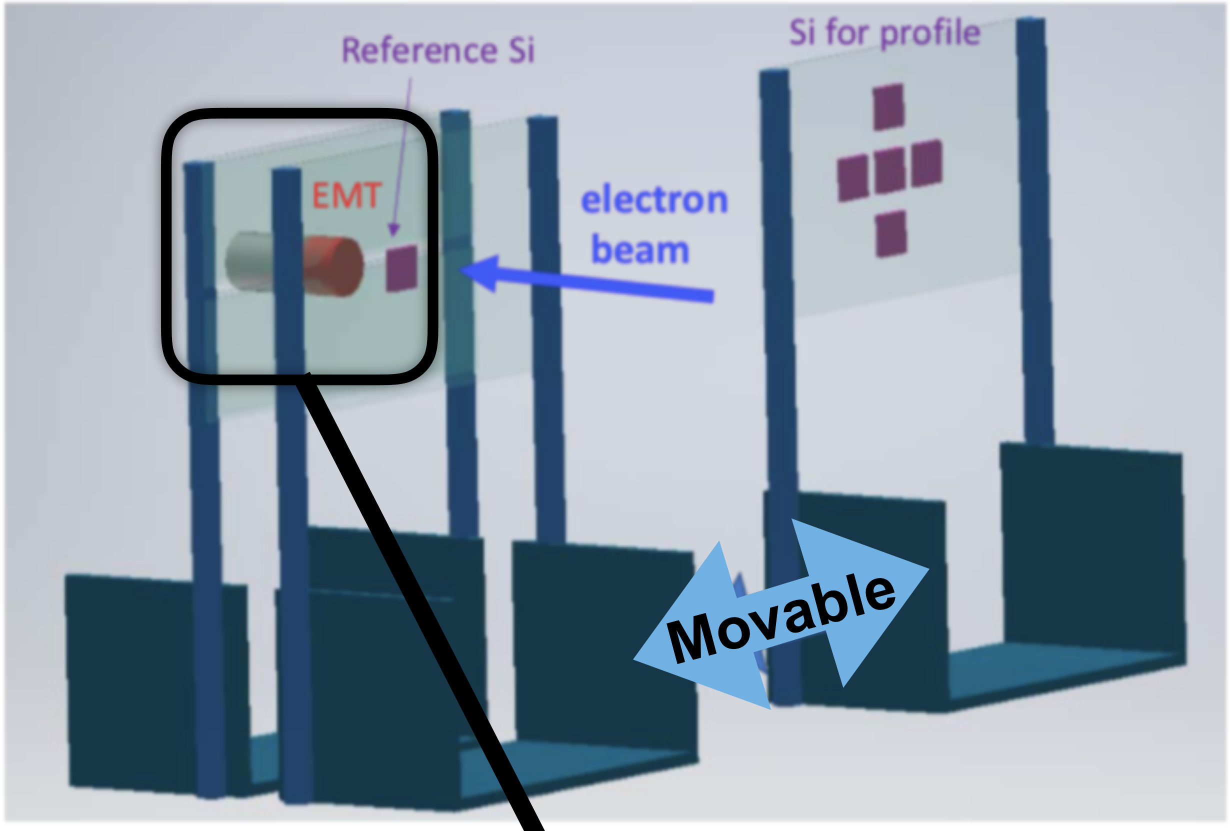
3. Stability of diamond detectors

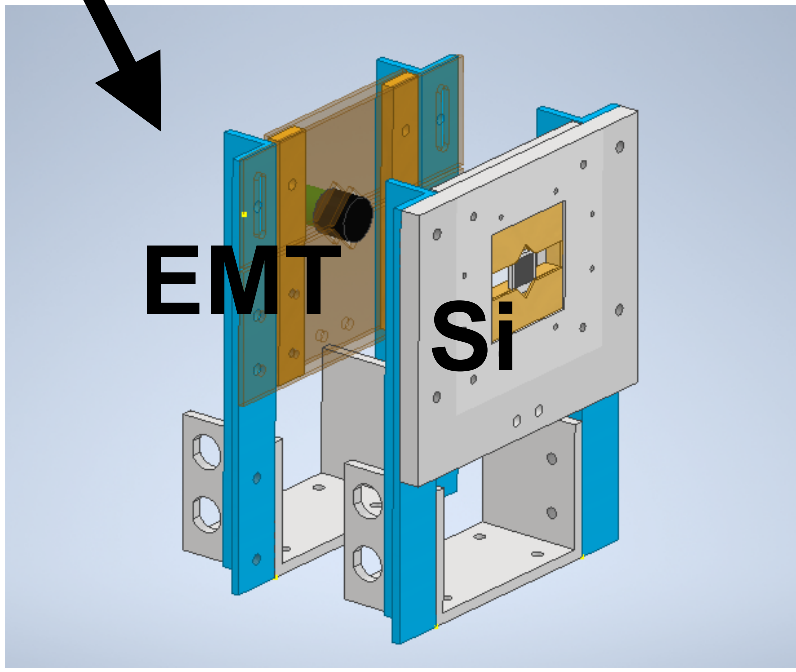
4. Others
・the effect of warming-up effect of EMT
・etc…

Timeline	Augu	September	October
General	Decision of Run plan		Expected beam time
Design	Decision	Manufacture	Check
Hardware (CT &	signal check of	Confirmation of DAQ performance	
DAQ	Development of DAQ		

Preparation of EMT beam test







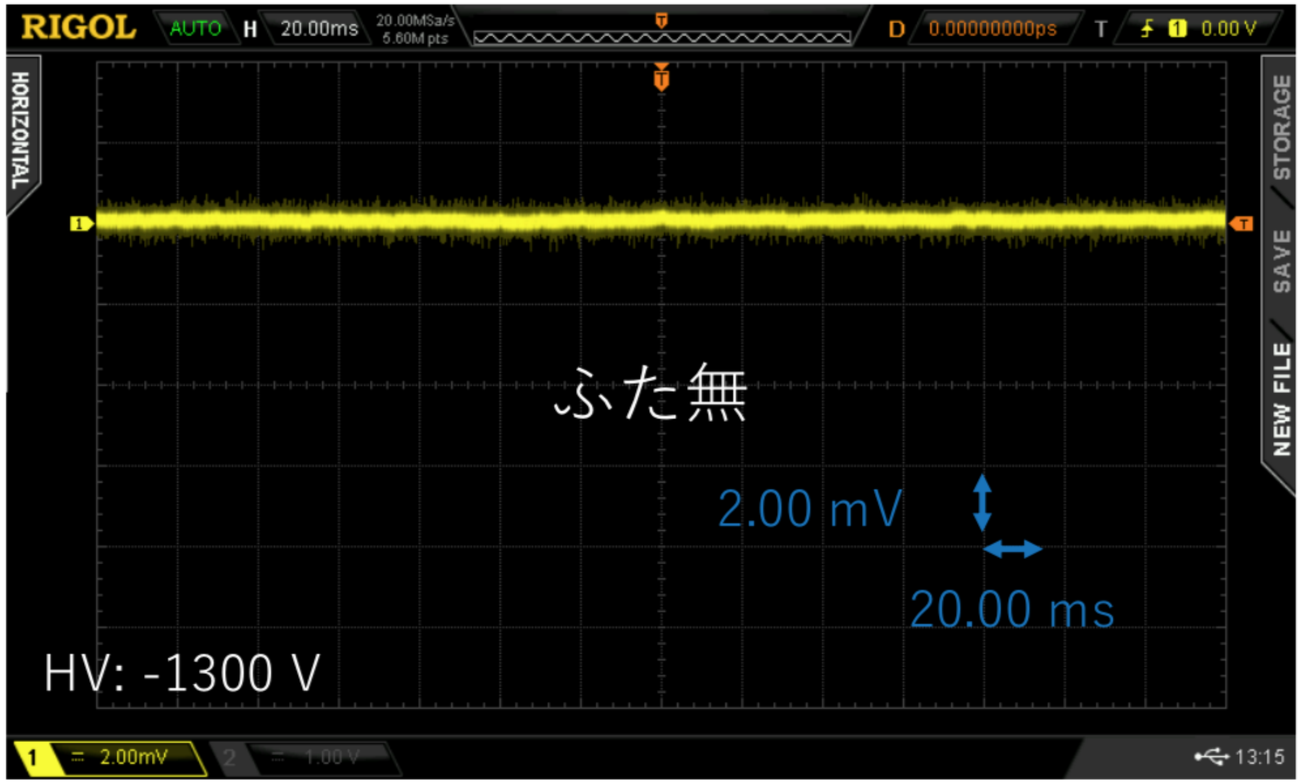
- Setup1 is used for making the profile of electron beam.
- CT is put in the upstream to calibrate the beam intensity.
- 1 silicon detector will be put in front of EMTs to be compared with EMTs' performance.

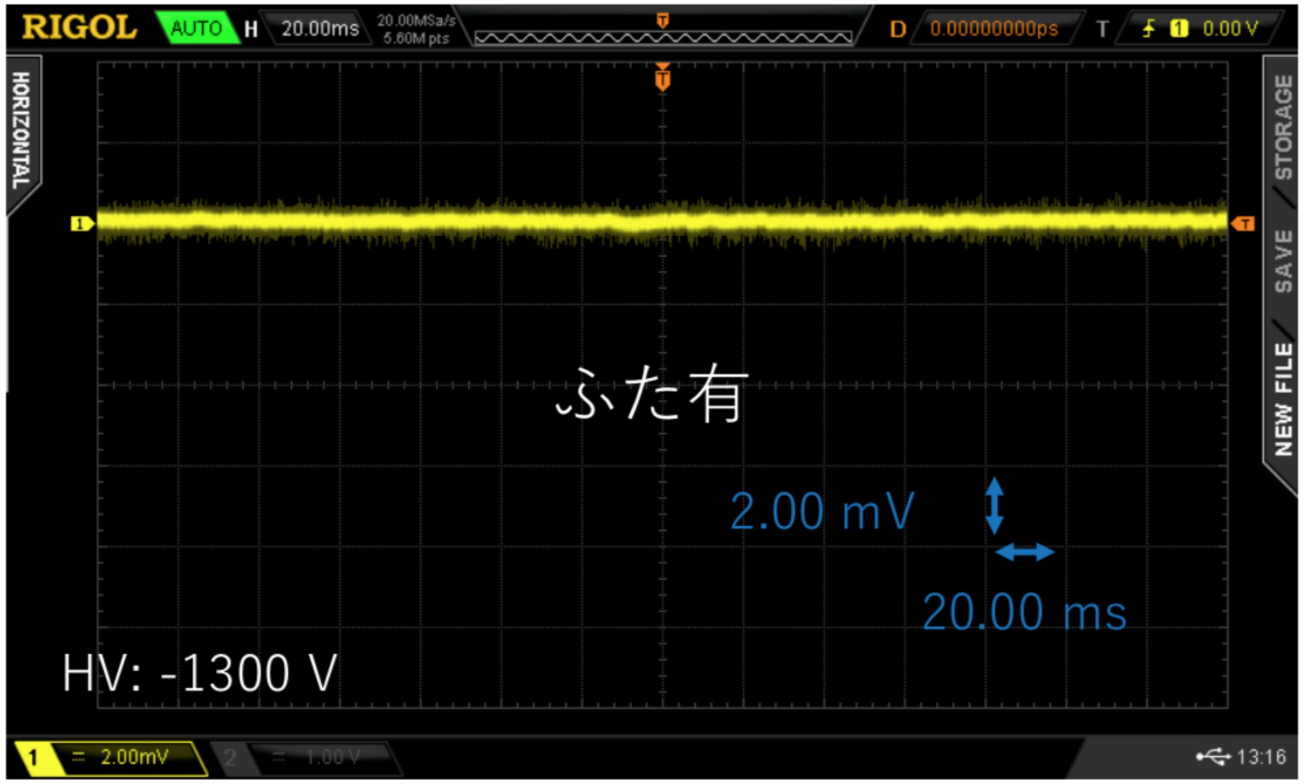
Summary

- J-PARC neutrino experiment is aiming to discovering the CP violation (currently 2 σ).
- MUMON is essential for the T2K experiment in order to generate a well oriented neutrino beam.
- Current MUMON detectors have some concerns, which will be problematic for higher intensity beam of T2K.
- We are planning to develop new detectors (Diamond, EMT) for MUMON which has more radiation resistance.
- EMT seems to have a better performance according to the commissioning. So the beam test is planned.
- Currently we are preparing the beam test which will be conducted in the end of October 2019.

Backup

Signal check for Type II





HV : -1300 V, fluorescent light