T2K Muon Monitor

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for the T2K Collaboration

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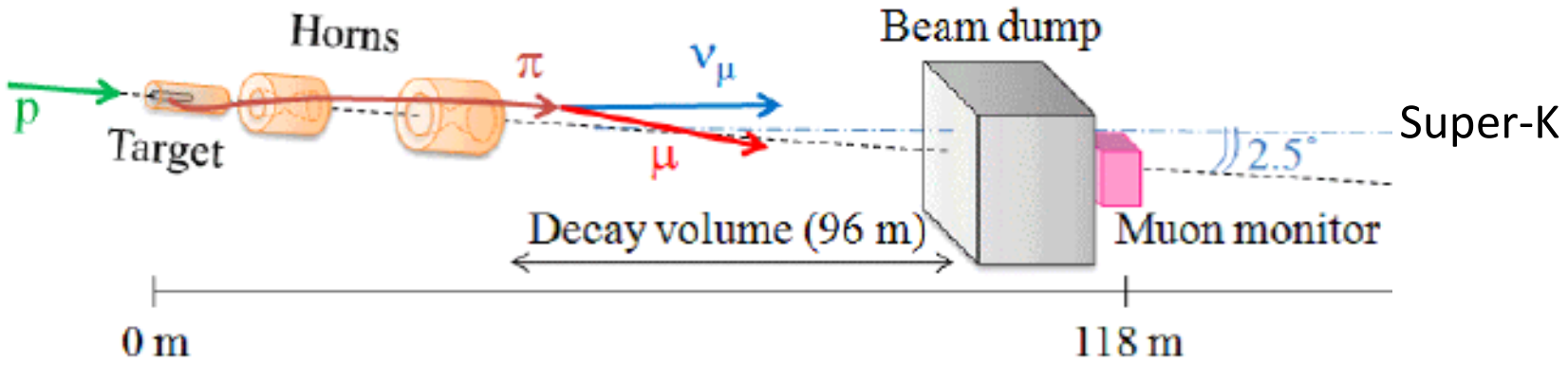
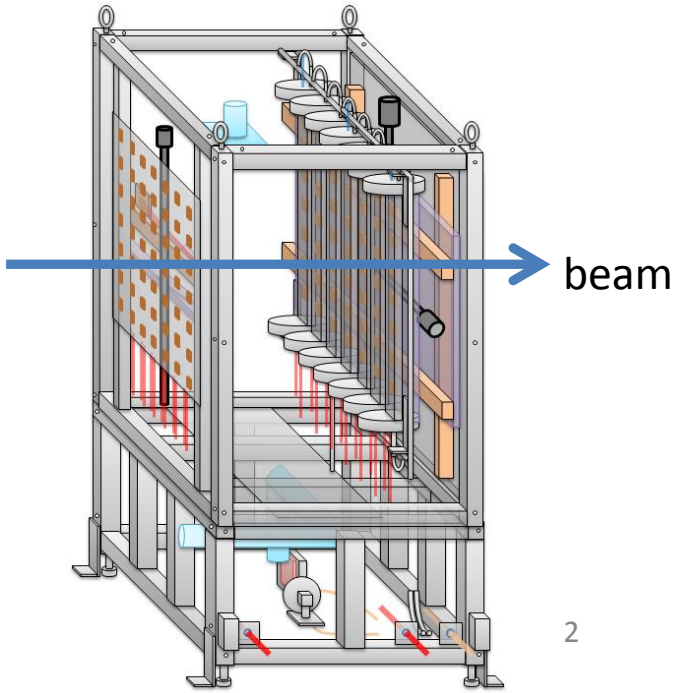
Purpose of muon monitor (MUMON)



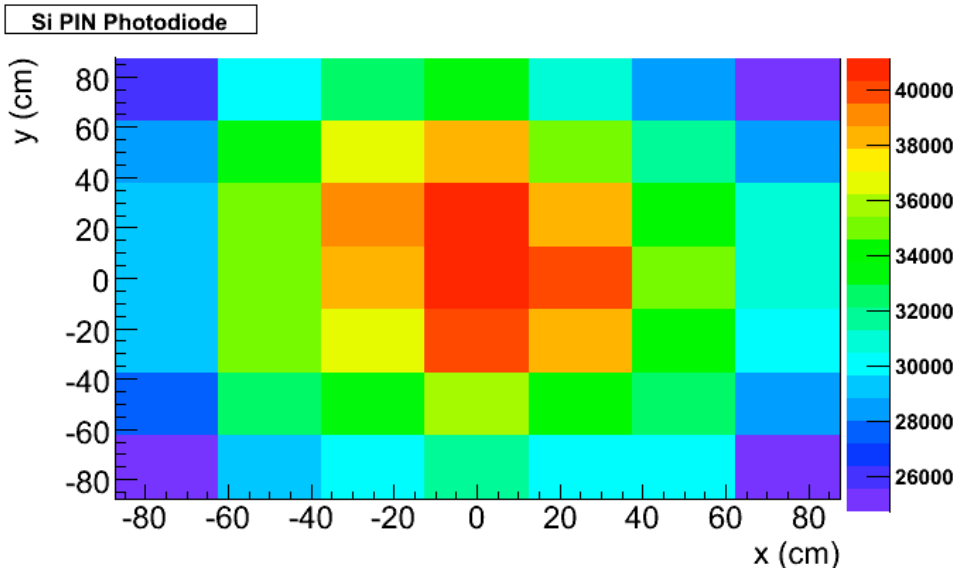
- Monitor neutrino beam direction and intensity by measuring muon profile

- Composed of two independent detector for redundancy
  - ✓ Si PIN Photodiode
  - ✓ Ionization Chamber
- Each detector has 49 (=7 × 7) sensors

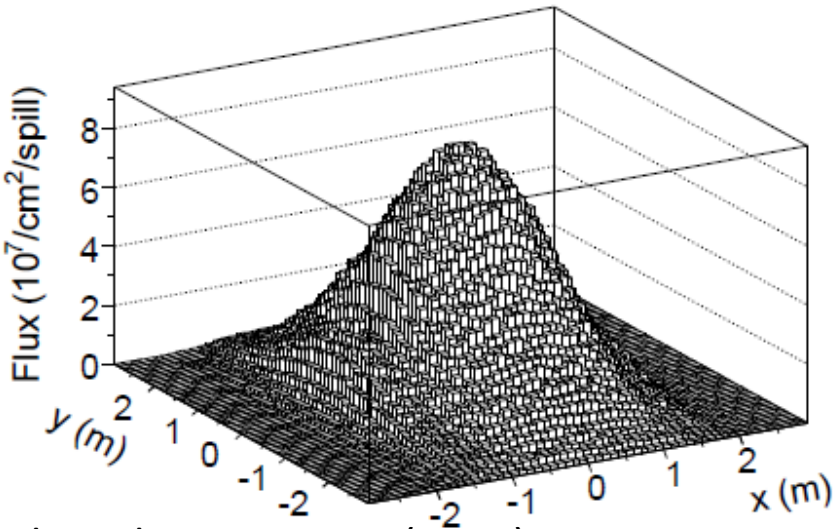


method to obtain beam profile

- take data of collected charge in each channel
- make 2D histogram by filling each collected charge
- Fit histogram by 2D gaussian function
- get profile center(RMS<1cm) and muon intensity(RMS/Mean <1%)



Two-dimensional profile at MUMON (MC)



Reference: K. Matsuoka et al., Nucl. Instr. and Meth. A 624, 591 (2010)
http://arxiv.org/abs/1008.4077

earthquake damage

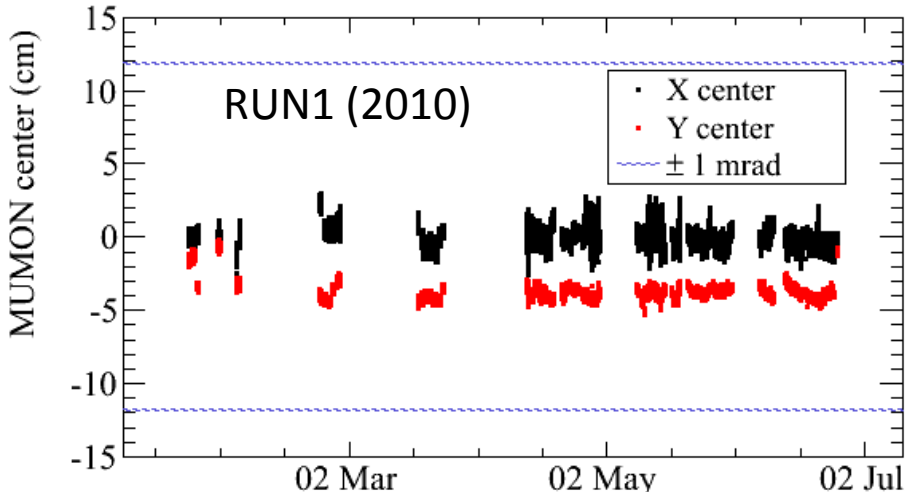
- Fortunately, all detectors and most of cables and gas pipes were not damaged.

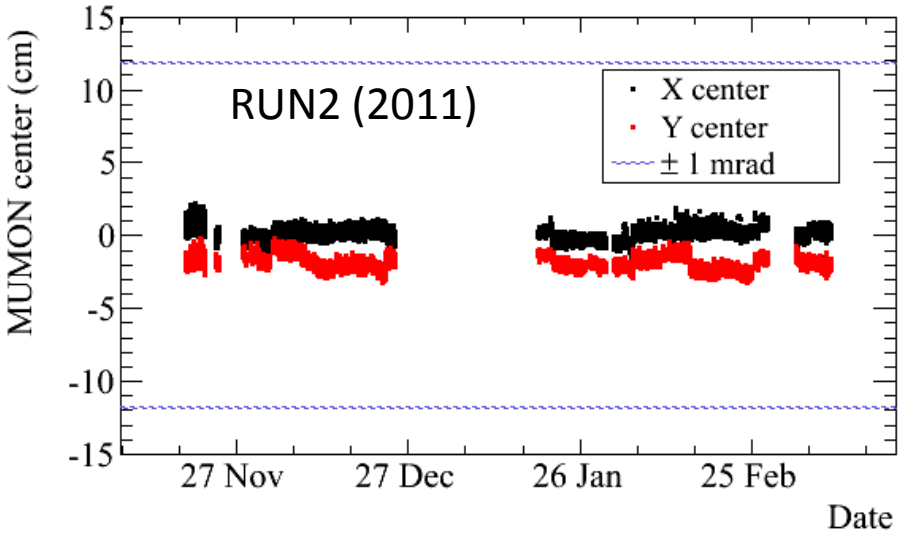
- MUMON survey has been done.

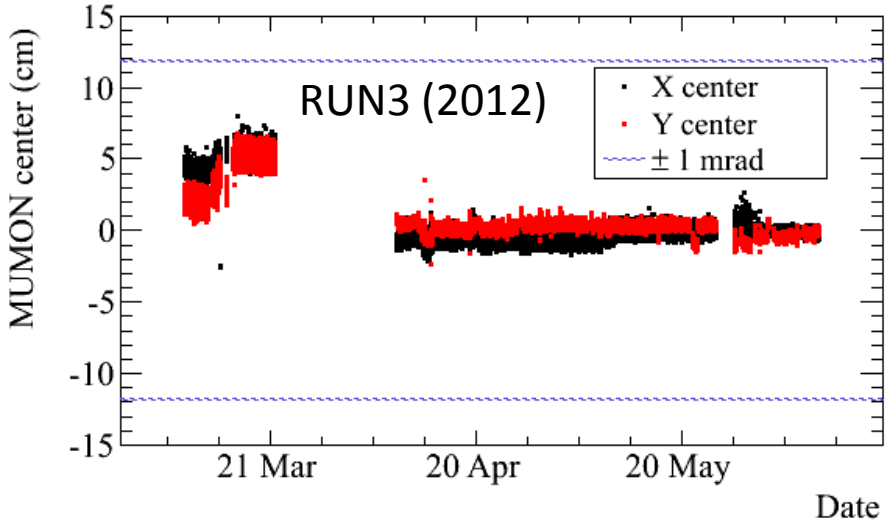
  →Please see Ishii-san's slide.
- Data after the earthquake has been taken same as before the earthquake.
- Beam profiles are consistent with past data.

beam center stability

obtained by fitting the profile of Si detectors





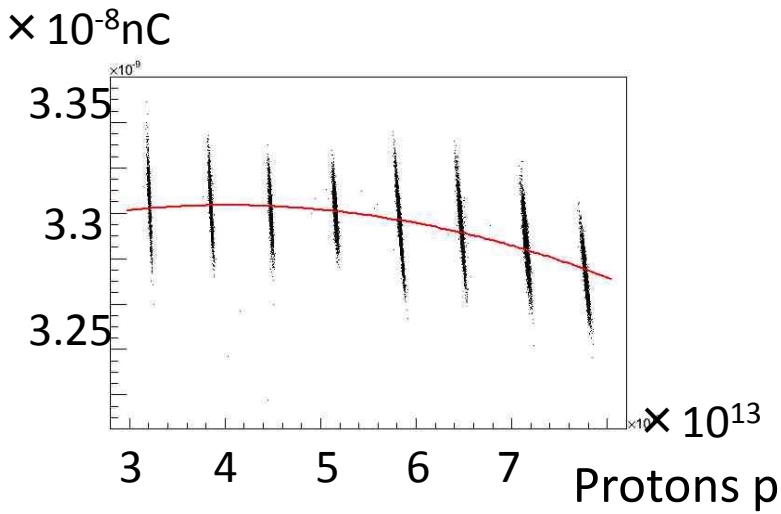


Beam direction has been well-controlled so far.

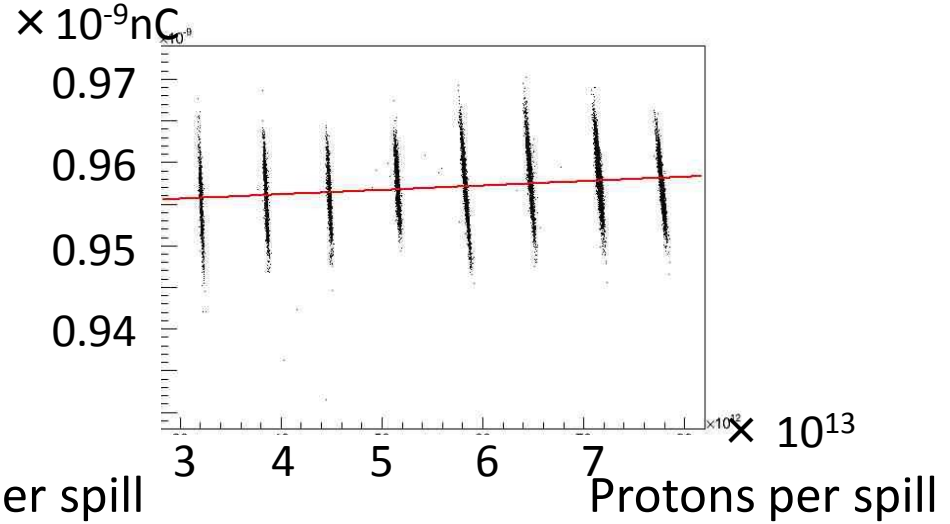
(We want to control |beam center|<1mrad(11.8cm at MUMON))

Si detectors' linearity

Si total charge/Protons per spill



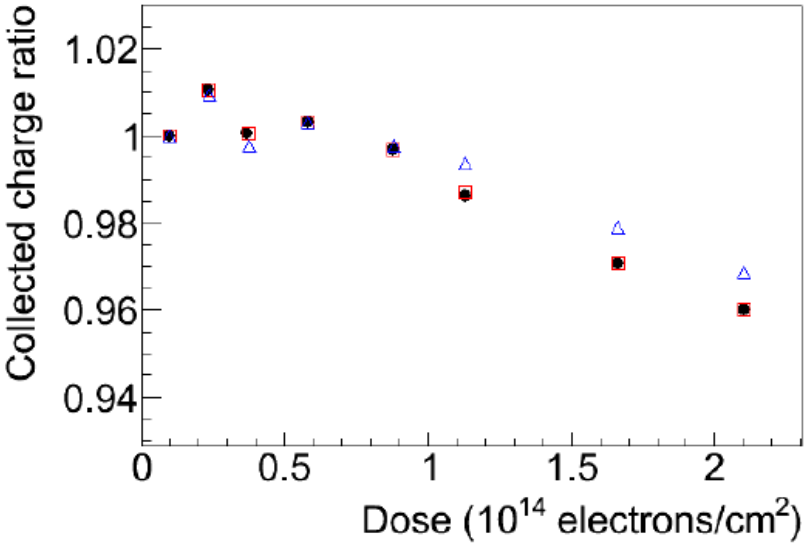
IC total charge/Protons per spill



- Non-linearity has been observed for Si detectors at high beam intensity.
- This may be bacause the charges induced by muon (8.1nC @ ~160kW, ~10^{13}Protons per bunch) beam excced the charges originally induced by HV (3.2nC).

Si detectors' radiation tolerance

- Radiation resistivity of Si detectors is not so good.
- From past beam test, we estimated lifetime of Si to be 8.1 x 10^{20} POT (when horn current is 250kA).
- After the lifetime collected charge decreases more than 1% compare to the beginning of usage.
- Delivered POT until this summer is 3.0 x 10^{20} POT.
- We need to replace them in the future.
  (We plan to replace in December).



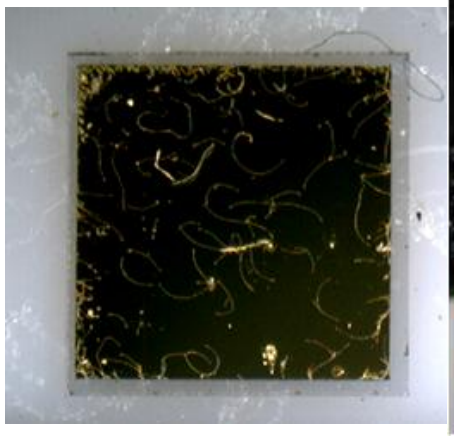
past beam test using e^- beam

diamond as a candidate of alternate detector

- When intensity of T2K beam reach 750kW, lifetime of Si detectors is about 1 month.
- So, we are studying diamond detector as a candidate of alternate detector in future.

- Some samples of diamond detector (by Diamond Detectors Ltd.) are installed at MUMON.

gold coated
CVD diamond



4mm
×4mm
×0.5mm(t)

package

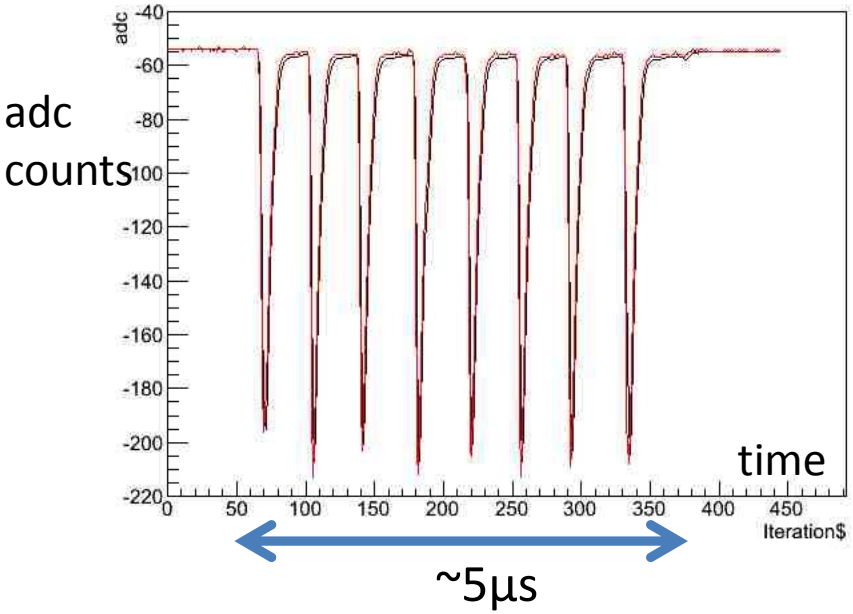
HV:200V

status of diamond detector –pile up-

waveform

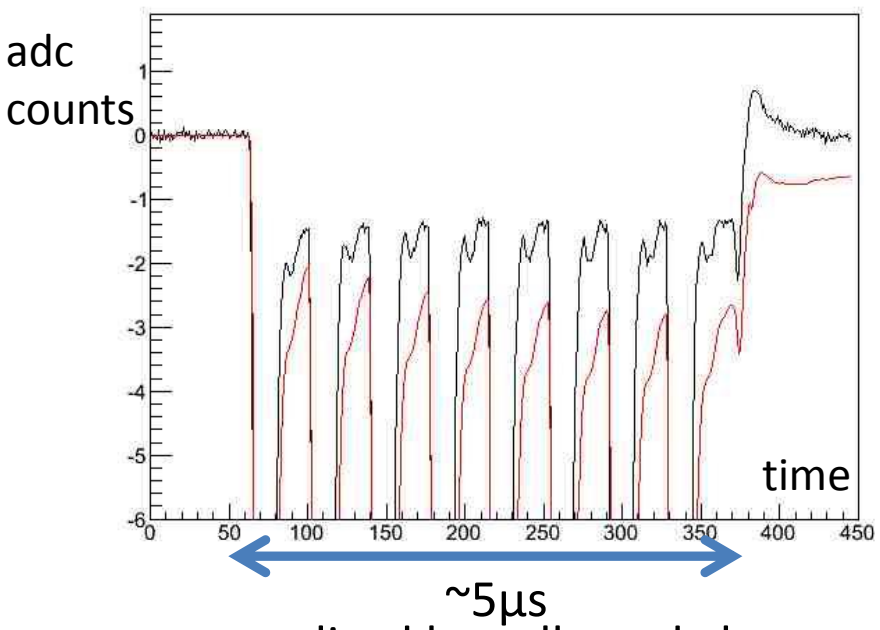
black:diamond

red:Si



normalized by collected charge

closeup

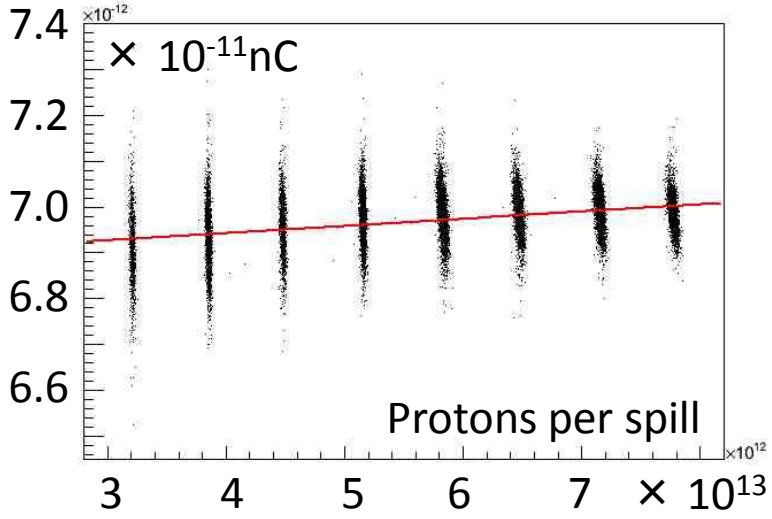


normalized by collected charge

- Incomplete drift of careers causes pile-up effect.
- Pile-up effect in diamond is smaller than in Si due to fast drift mobility.

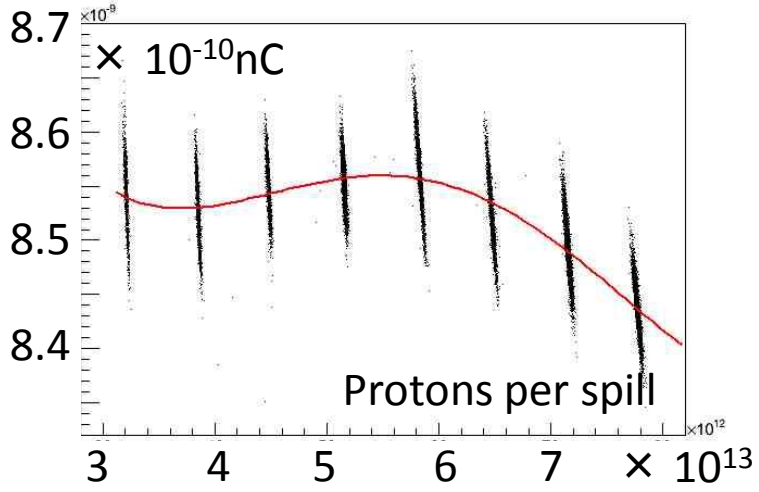
status of diamond detector

Charge/Protons per spill



Diamond

Charge/Protons per spill



Si (center)

- Better linearity than Si

- Diamond Detectors Ltd. ceased to produce diamond detectors.
- So, we plan to purchase new diamond detectors.
- We also look for companies which can attach electrodes to diamond detectors.
- Your information is welcome.

Summary

- MUMON has two independent detectors, Si PIN photodiode and Ionization chamber.
- Damage by the earthquake was not critical.
- MUMON has been stable and had good data taking.
- Linearity and radiation resistivity of Si become issue at high intensity.
- We are studying diamond detector as a candidate of alternate detector in future.

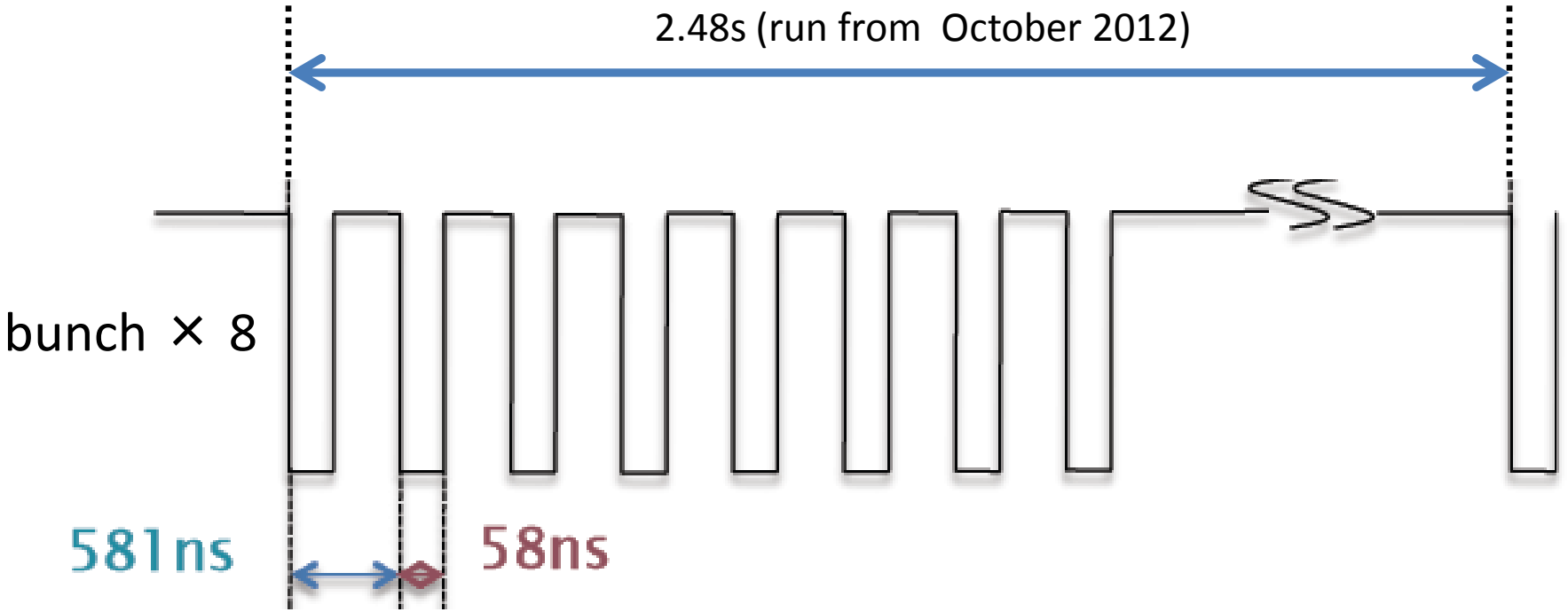
Back up

picture

Ionization Chamber

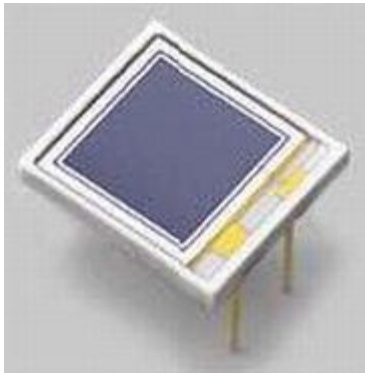
SI PIN photodiode

beam structure

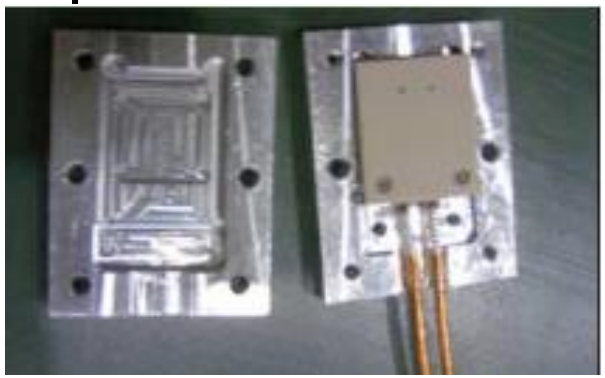


Silicon PIN photodiode

- HAMAMATSU S3590-08
- Active area:10mm × 10mm
- thickness: 0.3mm
- HV: 80V

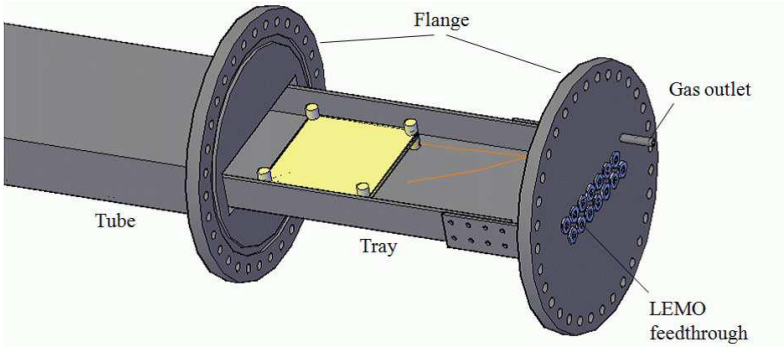


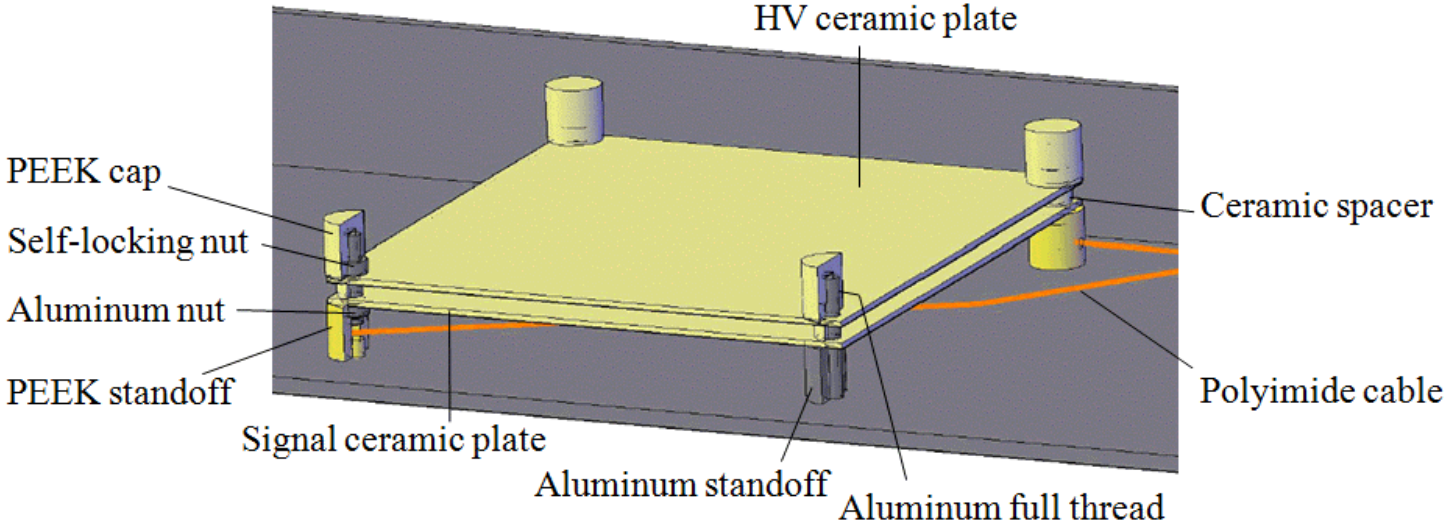
- not tolerant of the severe radiation
- lifetime: ~1month with the 0.75MW proton beam
- Packages were designed so that replacement can be quickly done



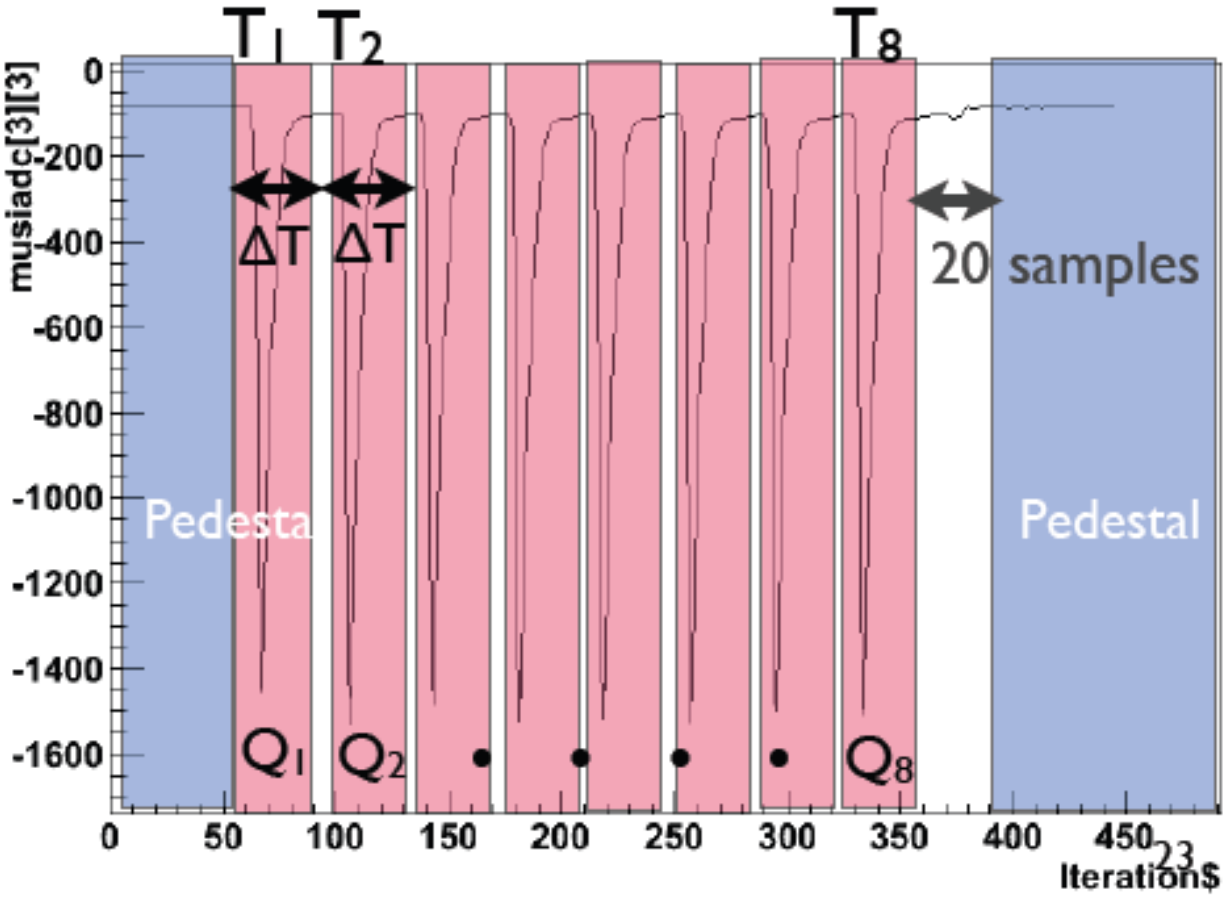
Ionization chamber

- Active area: 75mm × 75mm
- thickness : 3mm
- Gas : Ar+N_2 (2%)(<~300kW)
  : He+N_2 (1%)(>~300kW)
- N_2 gas : mixed for faster and stable response
- HV:200V



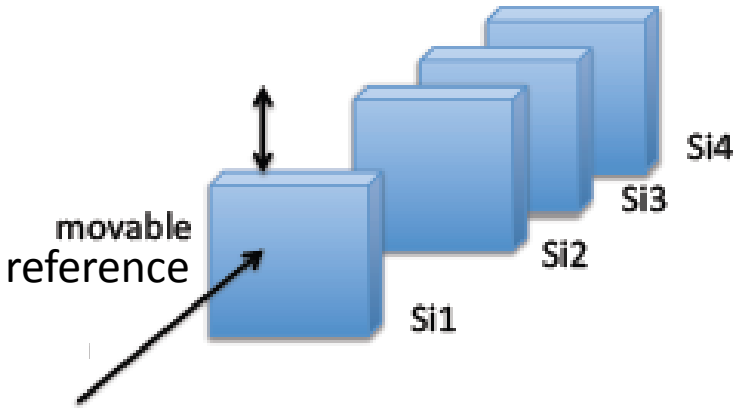


charge integration

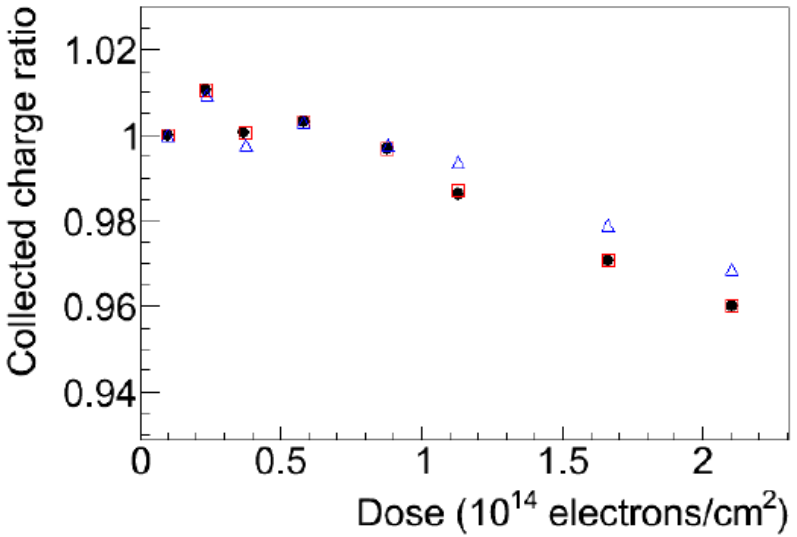


Estimation of Lifetime of Si

- Radiation damage test was conducted using 100 MeV electron linac at Uji (Kyoto) in 2009.
- From the result of the test, we set 1.0×10^{14} electrons/cm^2 as the limit.



100 MeV electron beam



Estimation of Lifetime of Si

- In the T2K experiment, main component of radiation at MUMON is muon.
- So, we estimated limit for T2K beam using NIEL scaling (the dose of some particles can be replaced with that of 1 MeV neutrons).

  →**8.1 x 10^{20}** POT (250kA)
- Delivered POT so far is 3.0 x 10^{20} POT (Good Spill).
- Our target for next run is 8.0 x 10^{20} POT.

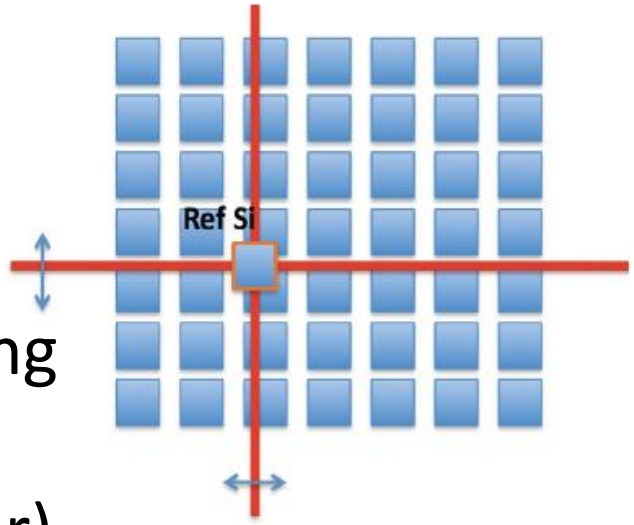
→ **Better to replace current Si detectors.**

Replacement of Si

- Calibration for all channels has been done by comparing with the reference movable Si.

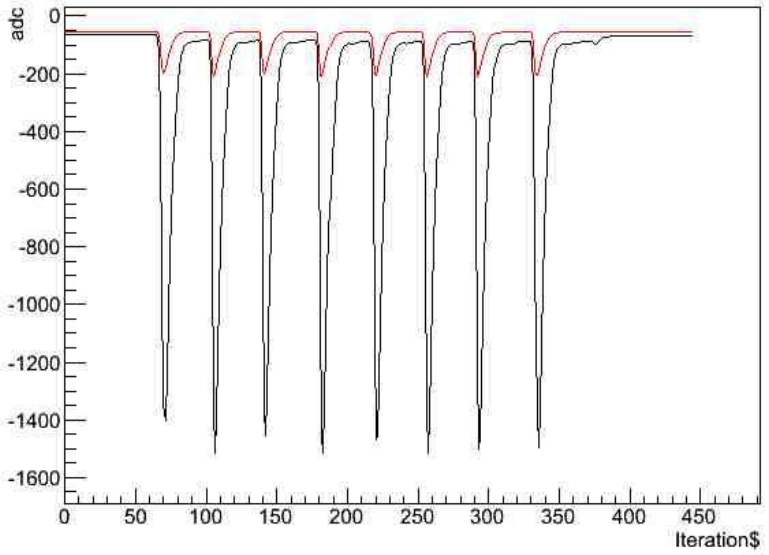
- So, this reference Si sensor will be left for reproducibility check.

- Radiation damage of reference Si detector will not exceed the limit until next summary because It is always evacuated to the bottom position during data taking.
(~70% intensity compared to the center)



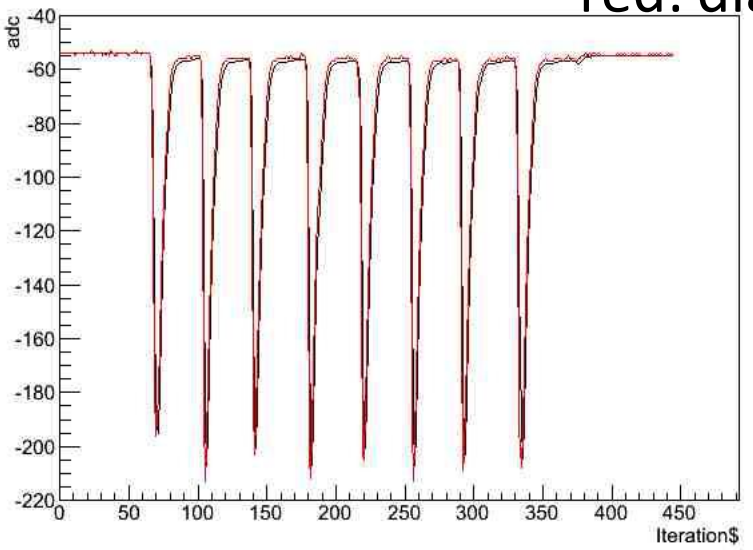
waveform comparison

raw waveform
(overwriting for removing noise)



1bin:~15ns

black: Si
red: diamond



normalized by pulse height

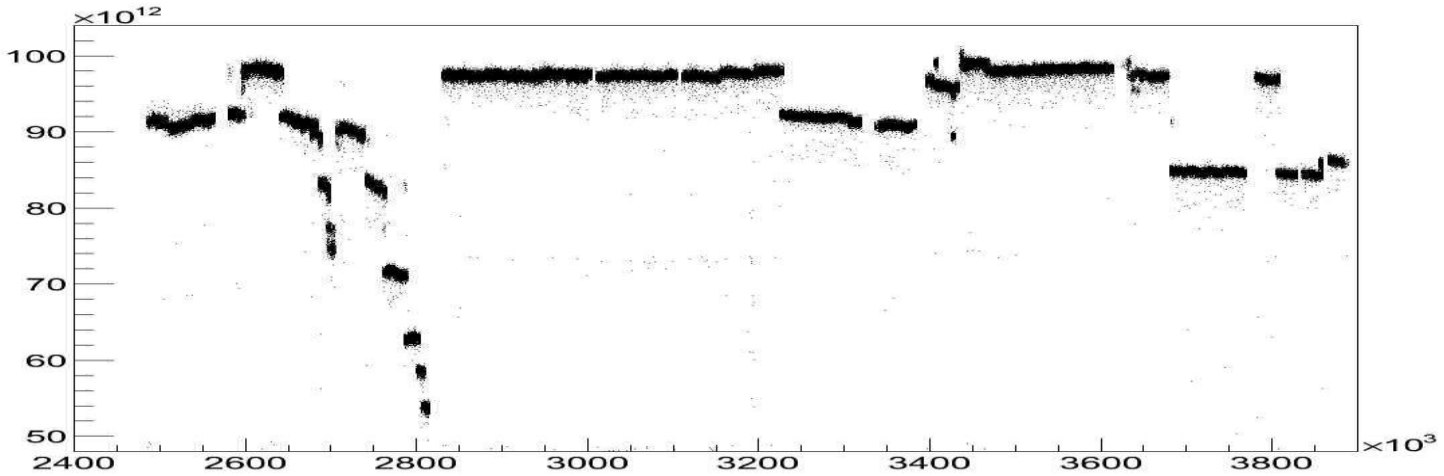
Diamond detector's signal is about 10 times smaller
than that of SI installed same place.
This is because surface area and band gap are different.

property of diamond

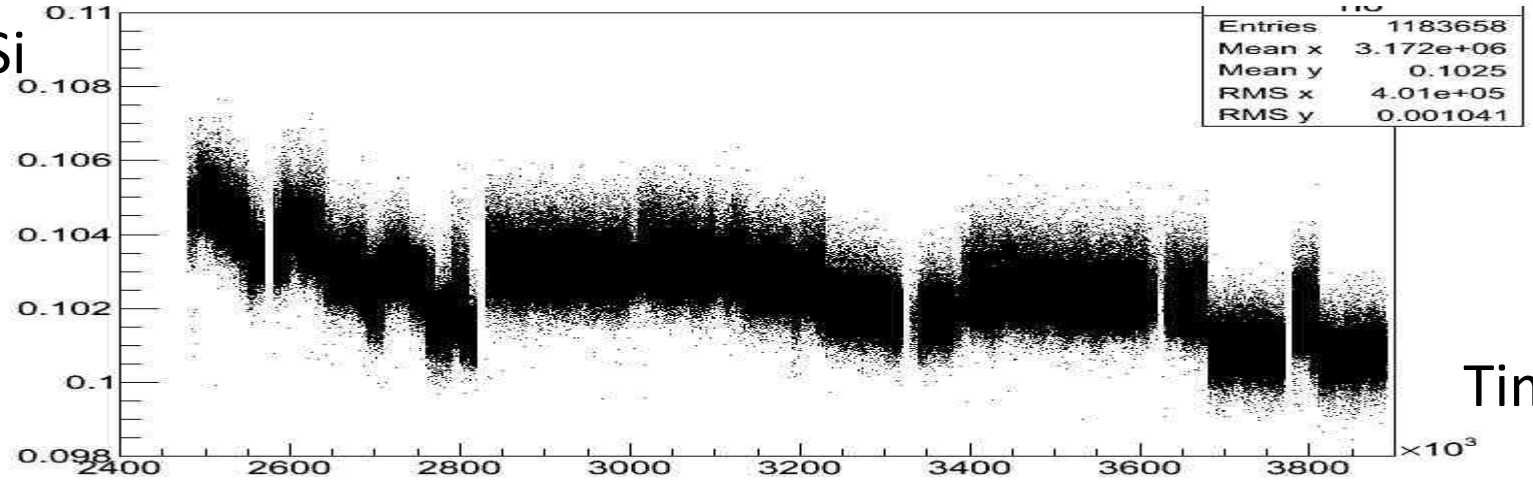
	Si	Diamond
Atomic number	14	6
density (g/cm^3)	2.33	3.52
band gap (eV)	1.12	5.47
electron mobility (cm^2/Vs)	1350	1800
hole mobility (cm^2/Vs)	480	1200

Dia / Si time dependence

CT5

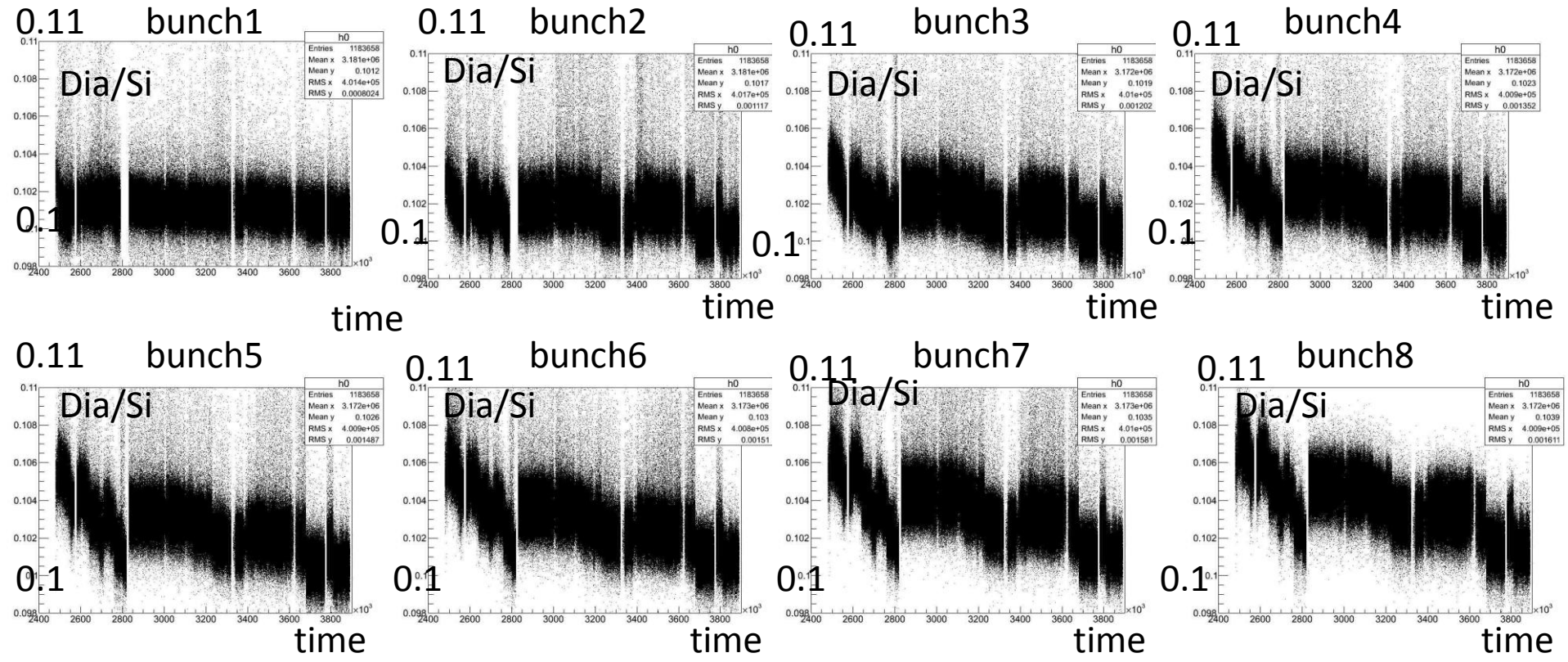


Dia / Si



Time

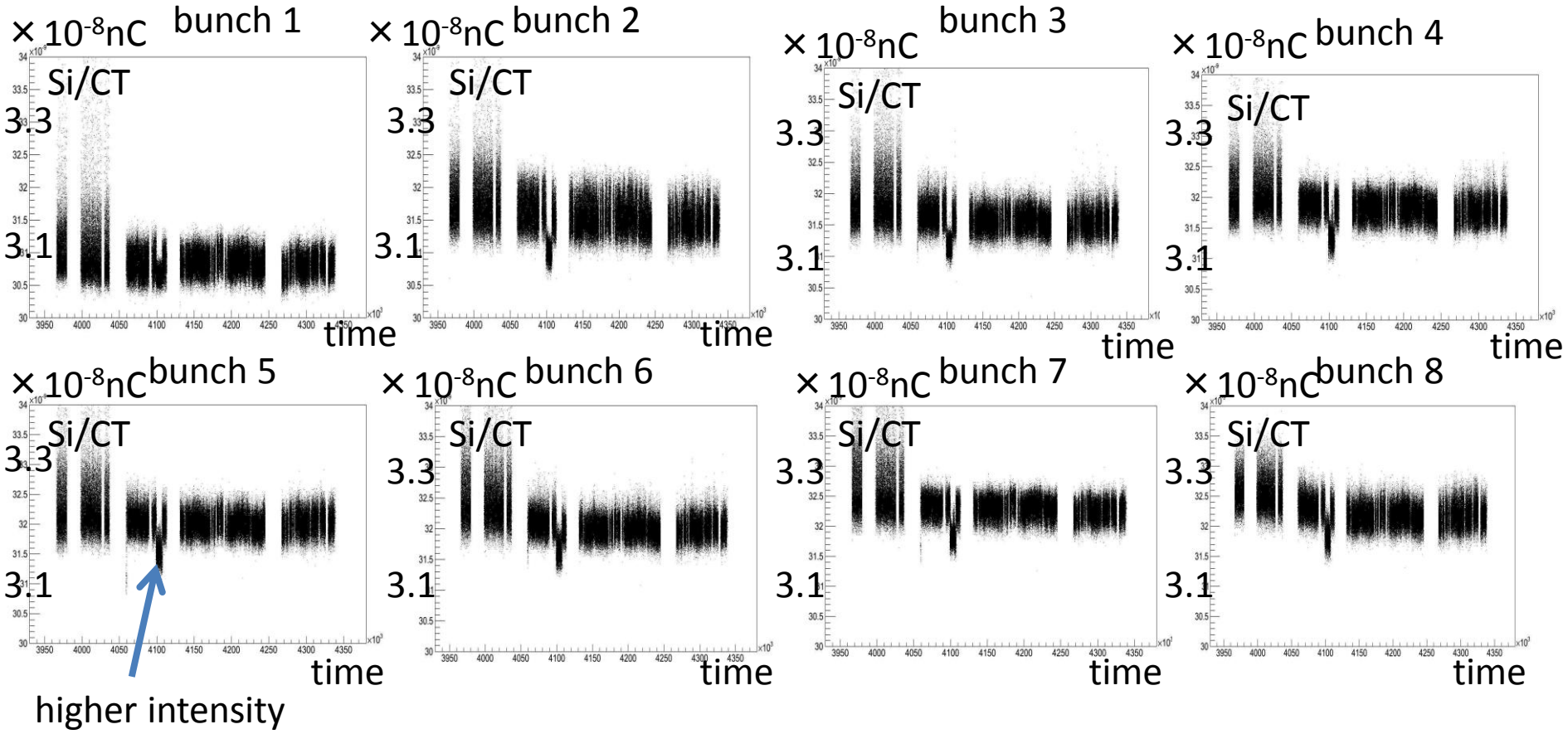
Dia /Si ratio time dependence



Dia charge/Si charge is stable at 1st bunch

Protons per spill dependence becomes larger In latter bunches

Si total charge/Protons per spill

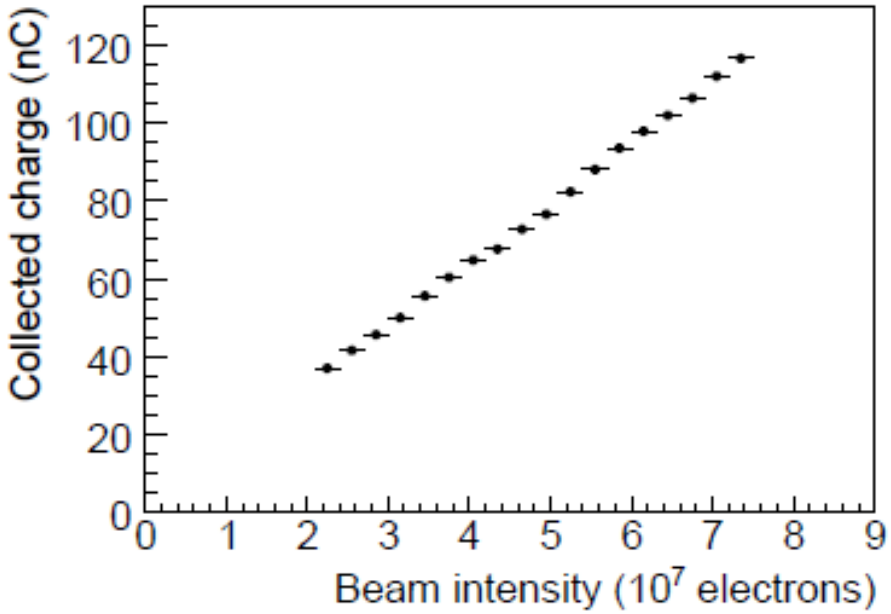


higher intensity

Charge collection decrease is seen from 2nd bunch.

past beam test

- Non-linearity has not observed in past beam test using electron beam in which electrons per time was not so strong.



past beam test using e^- beam