T2K Muon Monitor

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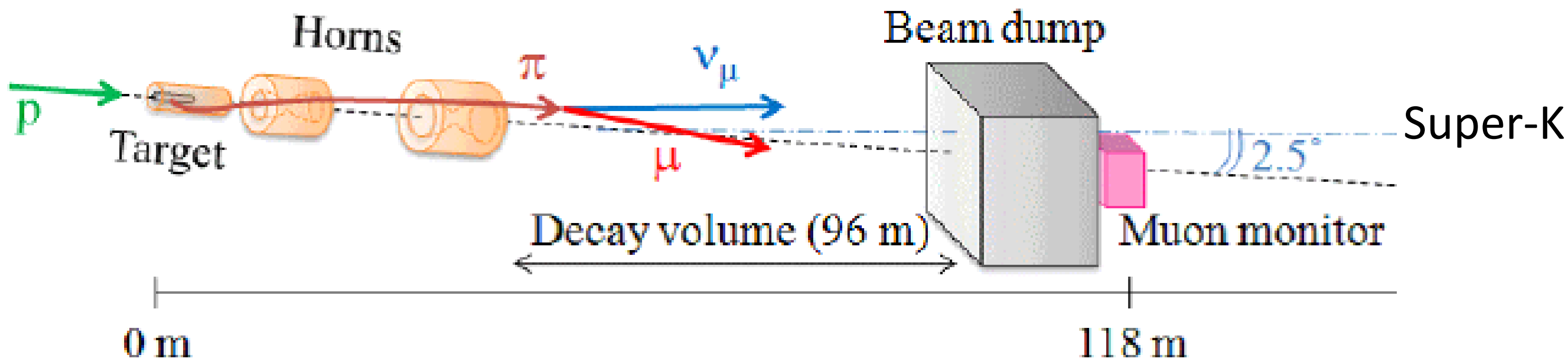
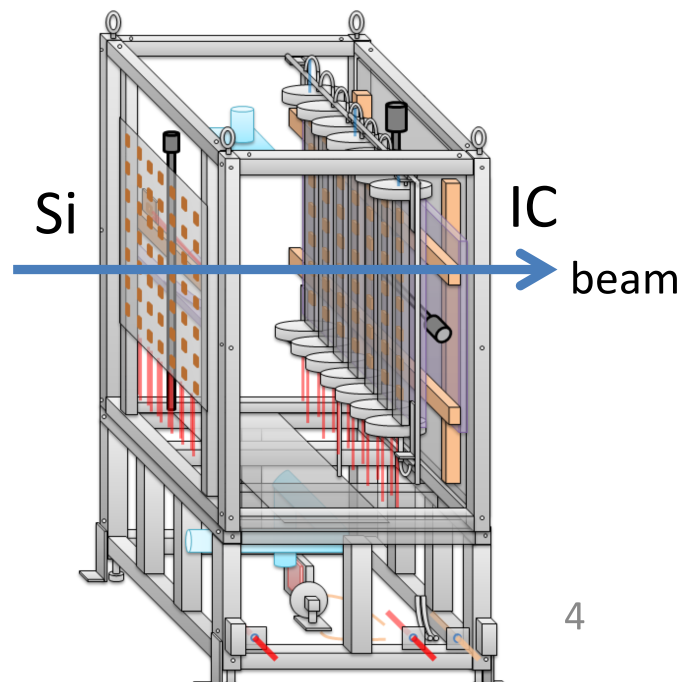
Introduction

Purpose of muon monitor (MUMON)



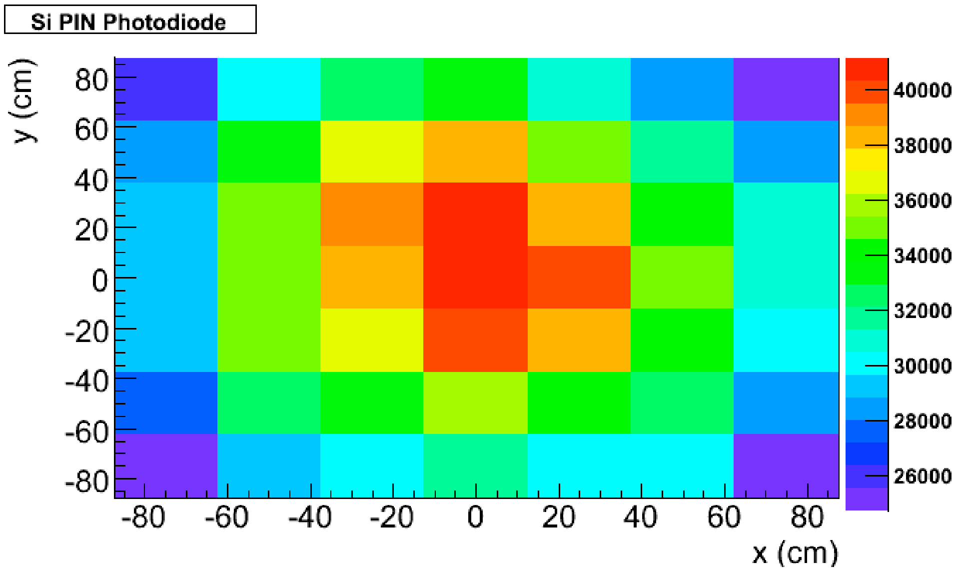
- Monitor neutrino beam direction and intensity by measuring muon profile

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

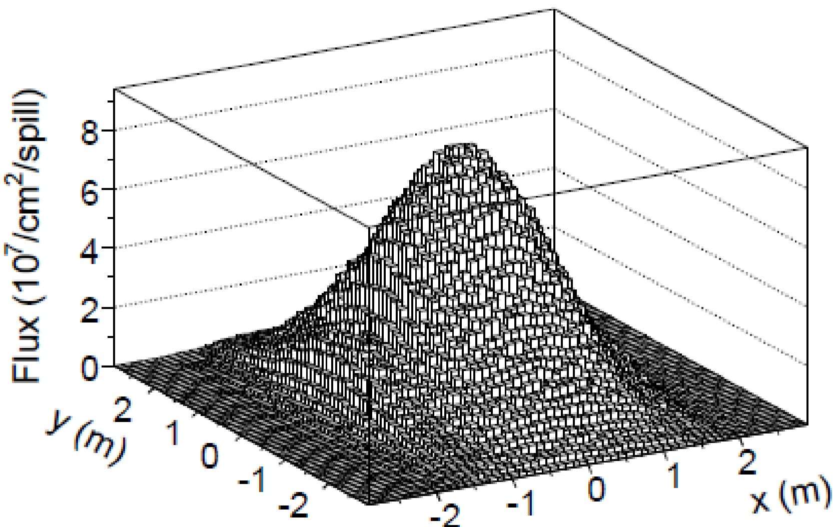


method to obtain beam profile

- get 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%)



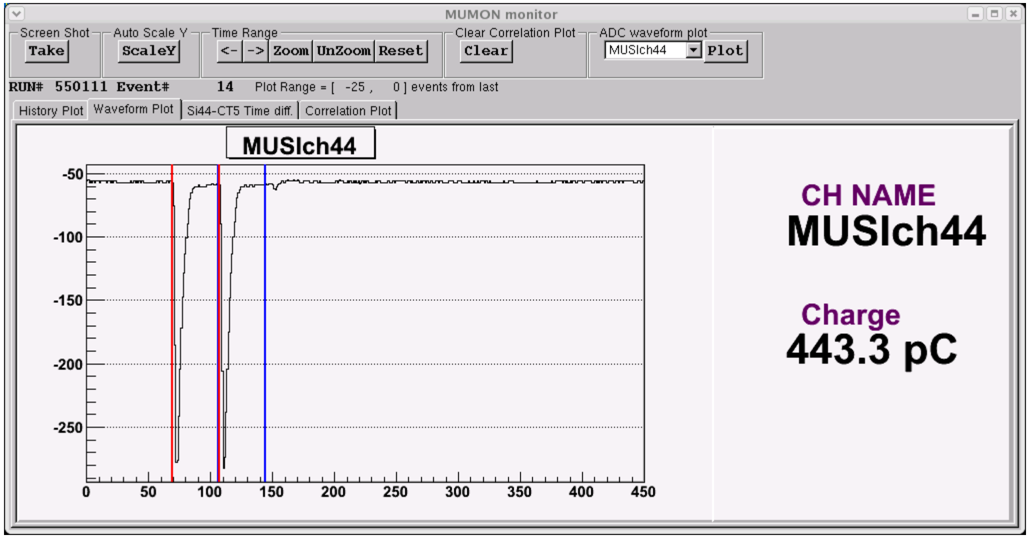
Two-dimensional profile at MUMON (MC)

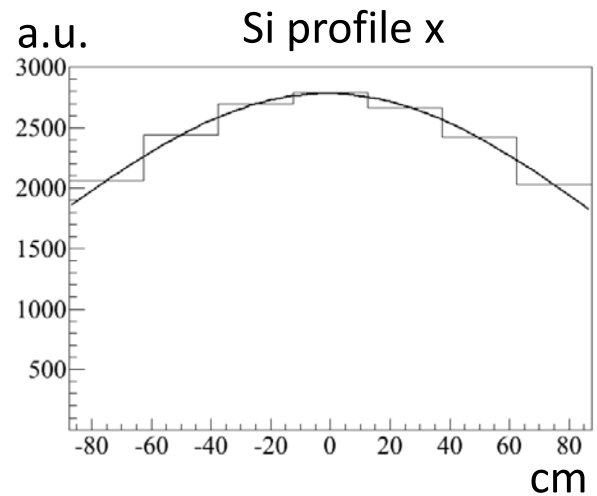


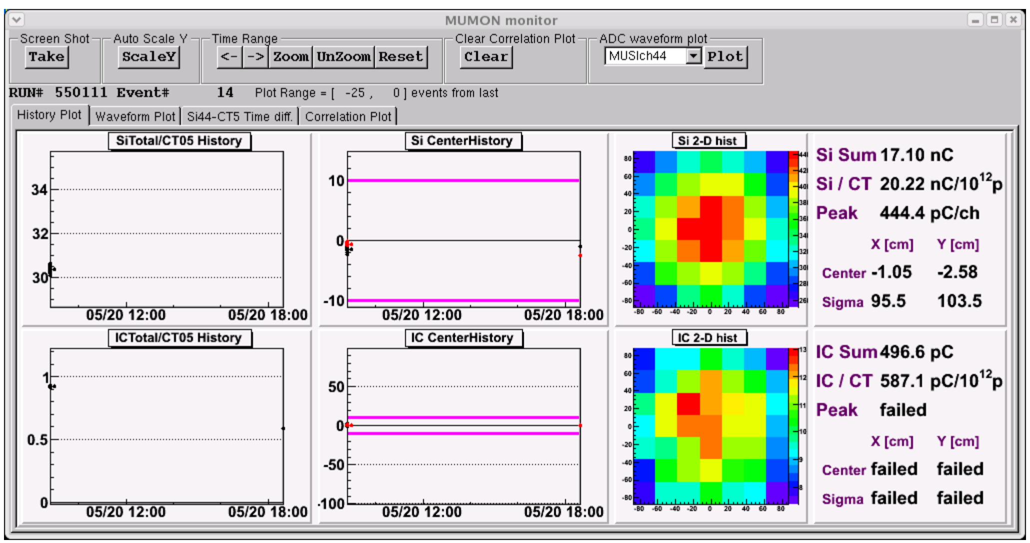
Reference: K. Matsuoka et al., Nucl. Instr. and Meth. A 624, 591 (2010)
http://arxiv.org/abs/1008.4077

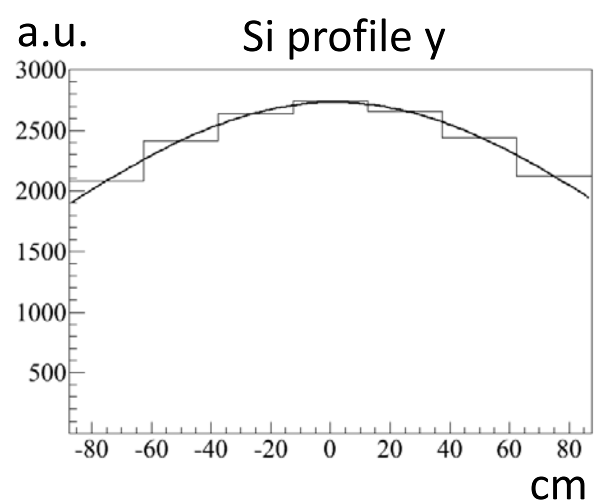
first event in anti-neutrino mode

An example of event





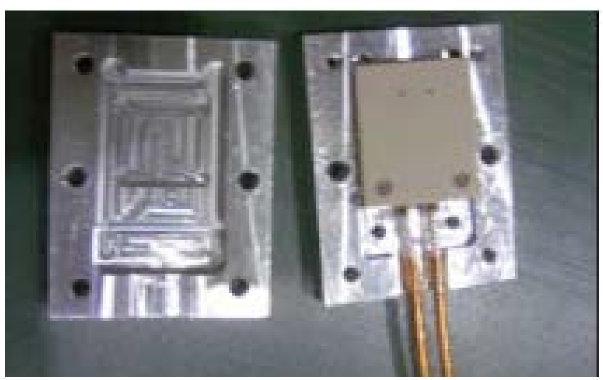




Hardware upgrade

Replacement of Si detectors

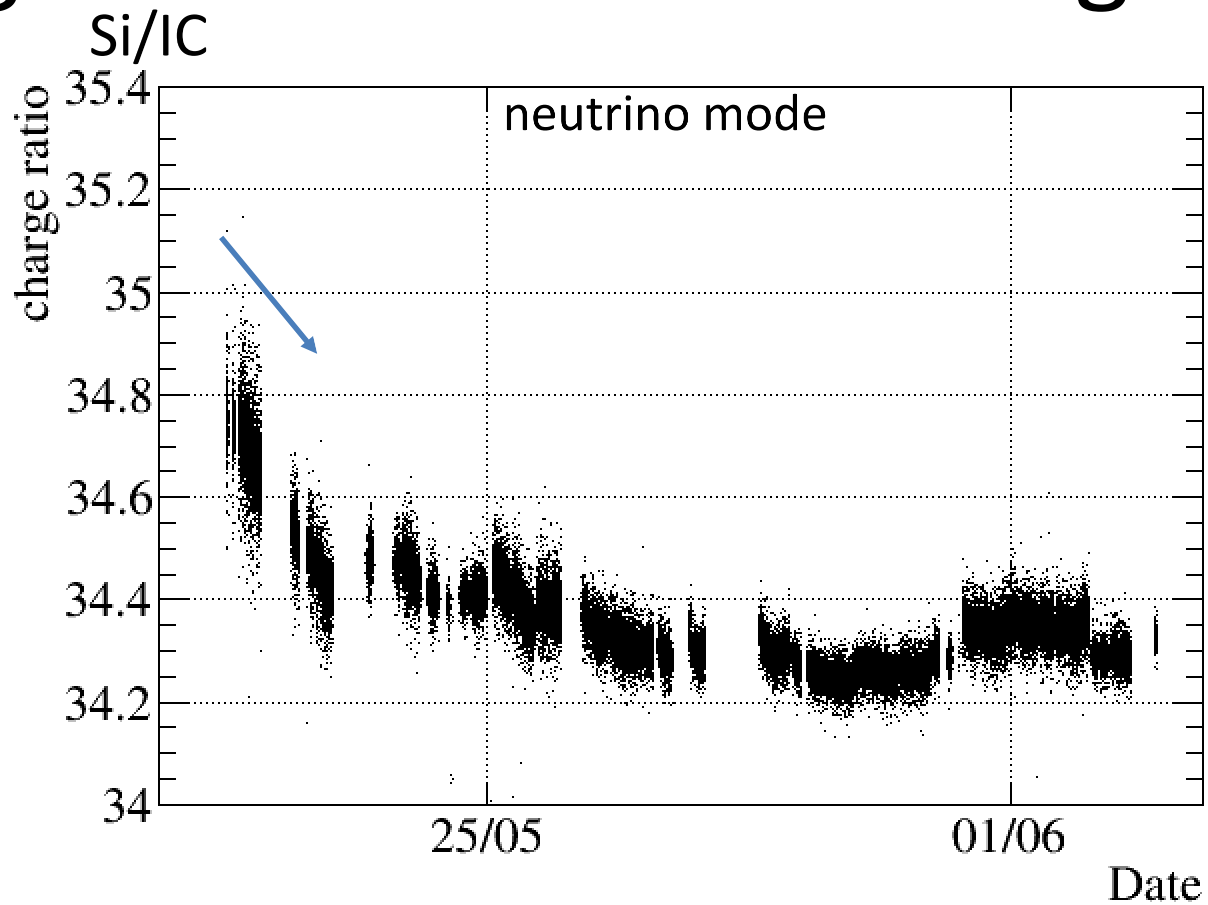
- Radiation resistivity of Si detectors is not so good.
- From past beam tests, it is expected signal from Si decreases O(1)% after 8×10^{20} POT.
- Though actual size of signal decrease was unclear, we replaced all Si detectors before 2014 RUN.
- Replacement can be very easily done.



packaging

HAMAMATSU S3590-08

Signal decrease at the beginning



- At the beginning days of RUN after replacement of Si's where POT is O(10^{18}), signal size from Sis decreased roughly 1%.
- After then, speed of signal decrease become milder and yield became stable.
- Before full replacement, partial (4) detectors were replaced tentatively. So, this phenomenon was known before full replacement.

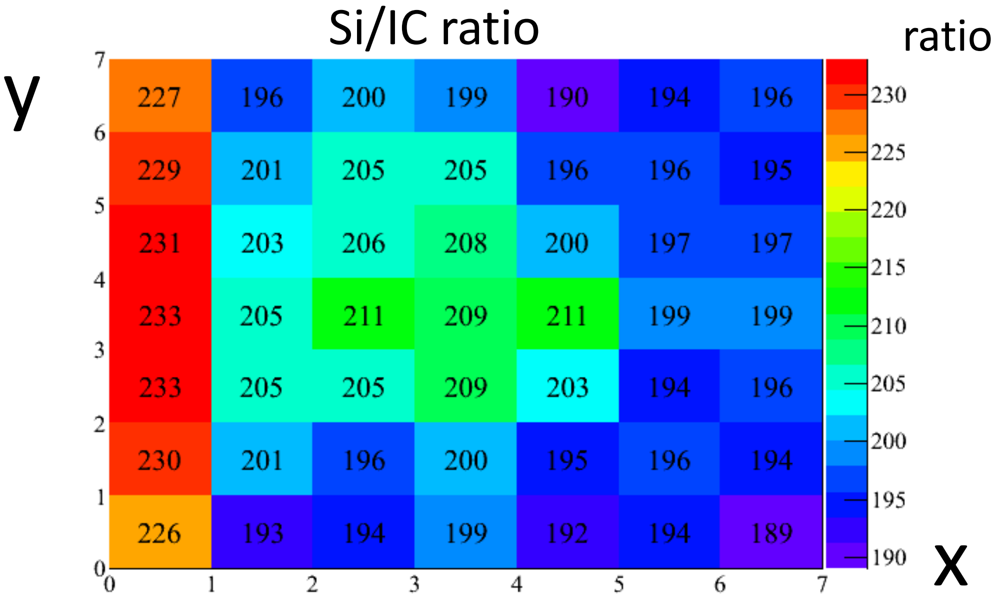
He gas trial for IC

- Now we use Ar+N_2 gas for ionization chamber.
- If POT per bunch become ~3×10^{13} (twice larger than highest POT so far), FADC value overflow (this may cause FADC trouble).
- At that period, we plan to use He+N_2 gas in which size of signal is ~0.1 compared to Ar+N_2 gas.

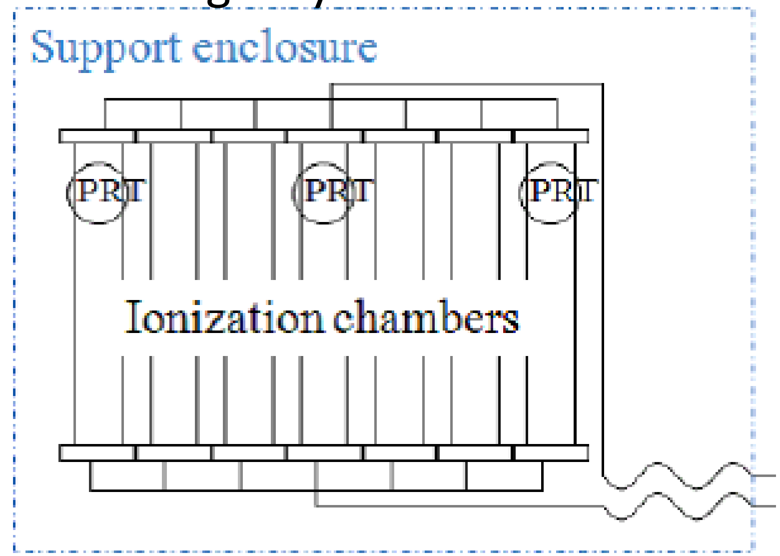
- In 2013, content of IC gas was changed to He+N_2 for the first time and took data (a few shots).
- period for replacing : 2days

beam profile measured by IC

One event from high power beam data



gas system of IC



- Ratio in the most left side was larger than that in the others.
  → Signal in the most left side was small.
- Si/He ratio was smaller than expectation (~300) for all detectors.
- Gas was not completely changed to He.
- more time needed for full replacement
- It seems gas flow is not uniform and most left chamber has smallest Ar contamination.

gas system update

- In He gas trial, fluctuation of gas flow rate and gas pressure was seen at downstream mass flow meter.
- Electromagnetic valve for stabilizing pressure was always working.

\- needle valve installed

- Check gas content while replacing

\- Added new line for gas sampling

\- distinguish 2 type of gas using density of N_2 ($Ar+2\%N_2$, $He+1\%N_2$)

Future plan

✓ Emulsion detectors downstream MUMON

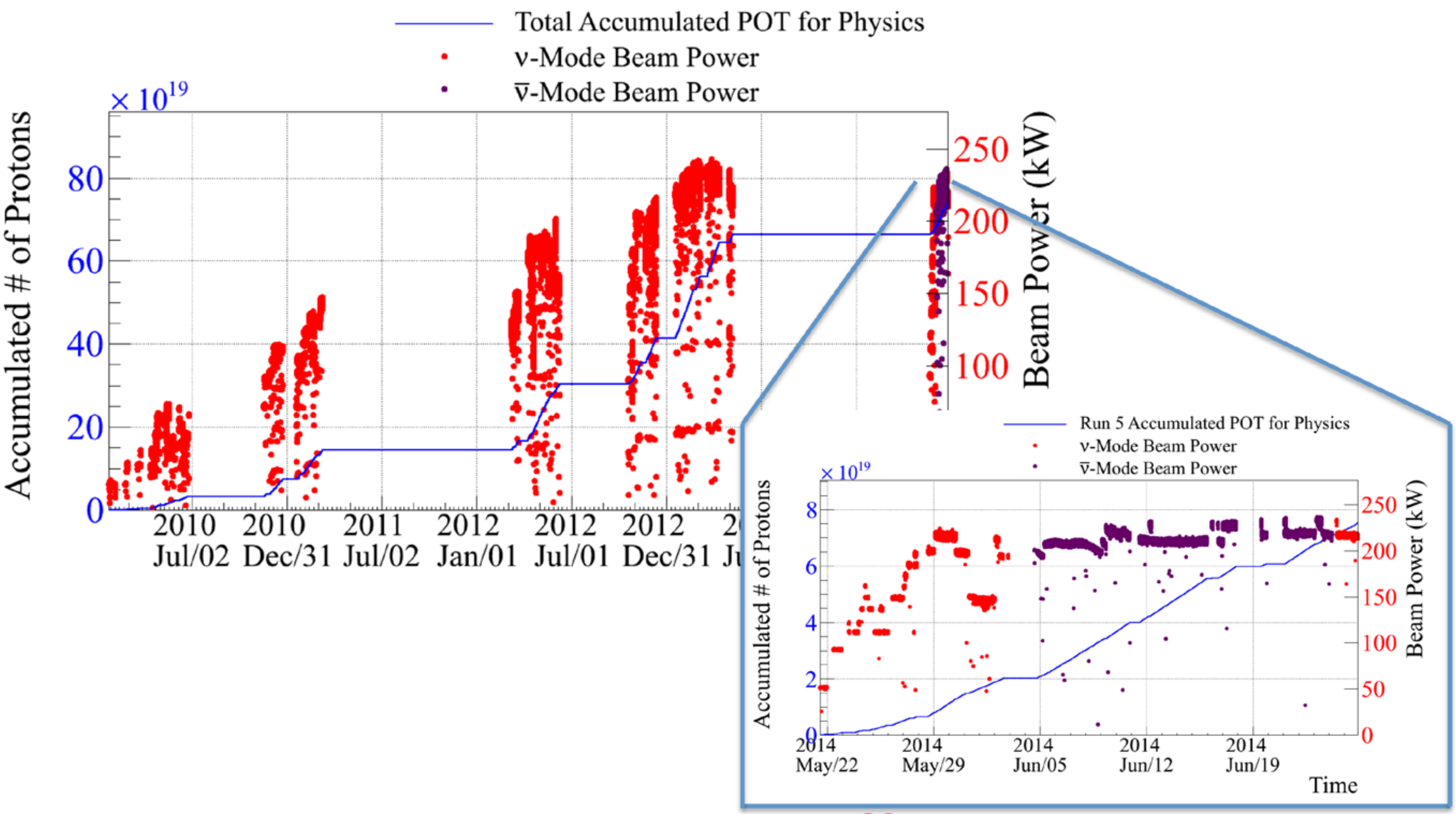
- measure precise absolute flux and momentum distribution at MUMON plane
- plan to take data in this winter

✓ a CT (Current Transformer) downstream MUMON

- signal from CT : μ^+-μ^-
- study configuration etc. (install on the beam axis is best, but difficult to fix CT)

Physics data with anti-neutrino run

Integrated POT (Full T2K Run 1–5)



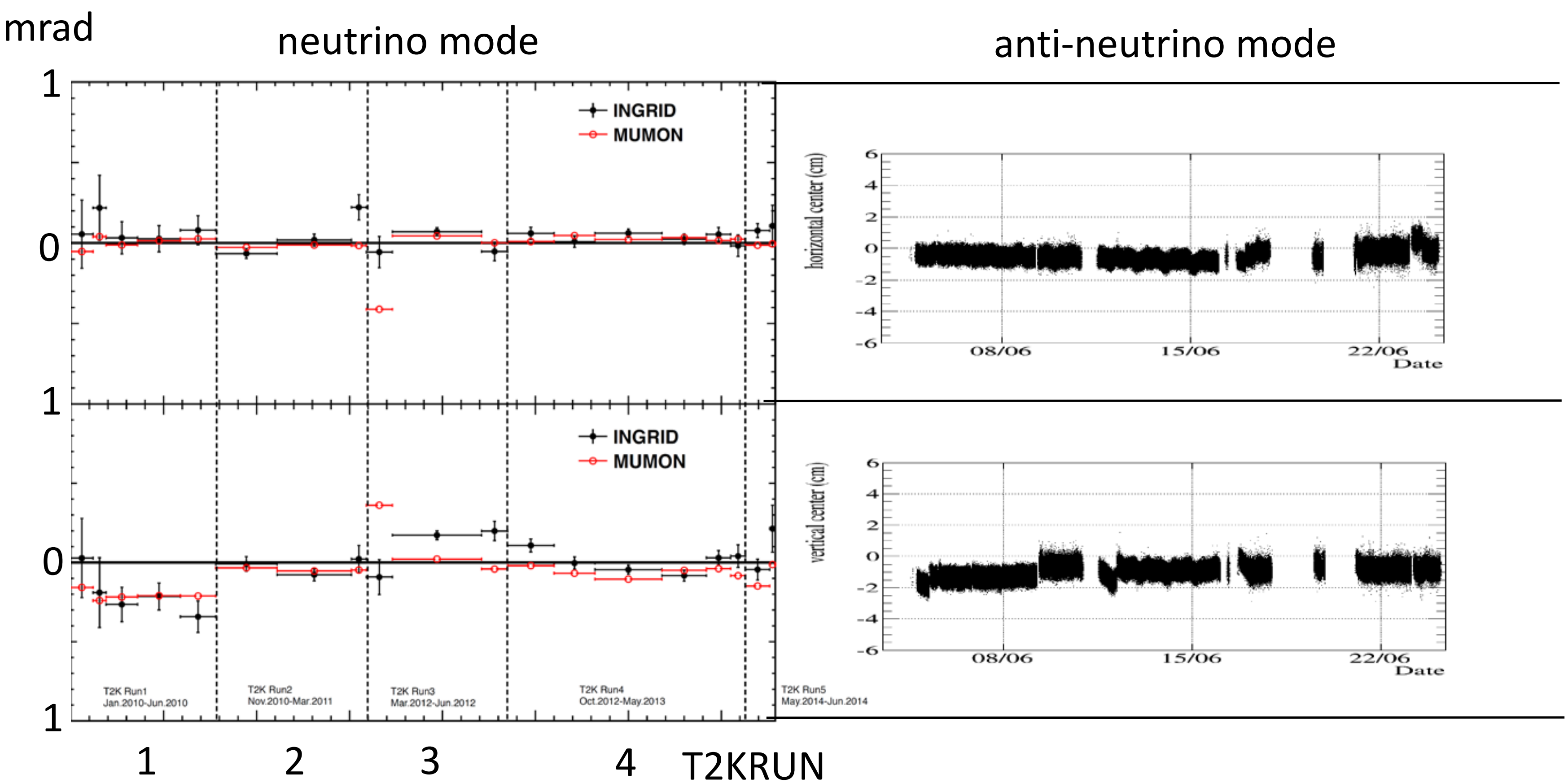
Integrated for Physics so far: 7.39×10^{20} POT

Integrated ν-Mode for Physics so far: 6.88×10^{20} POT

Integrated $\bar{\nu}$-Mode for Physics so far: 0.51×10^{20} POT

We took first anti-neutrino mode physics data in 2014 June.

Stability of beam center



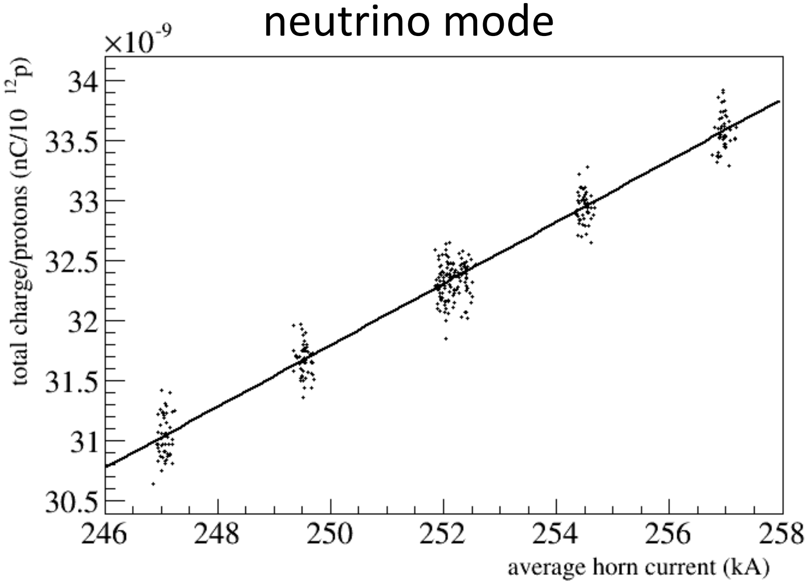
Beam center was very stable during all period.
(Requirement for analysis : center < 1mrad)

dependence of yield on horn current

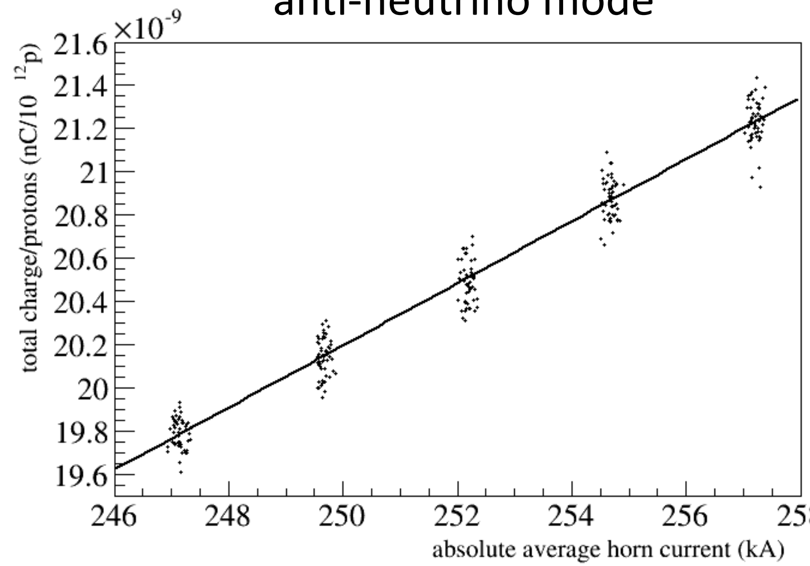
- Check the dependence of yield on the magnitude of horn current for accurate stability check
- Changing horn current ±2% from nominal value by 1% step

change of muon yield

neutrino mode



anti-neutrino mode

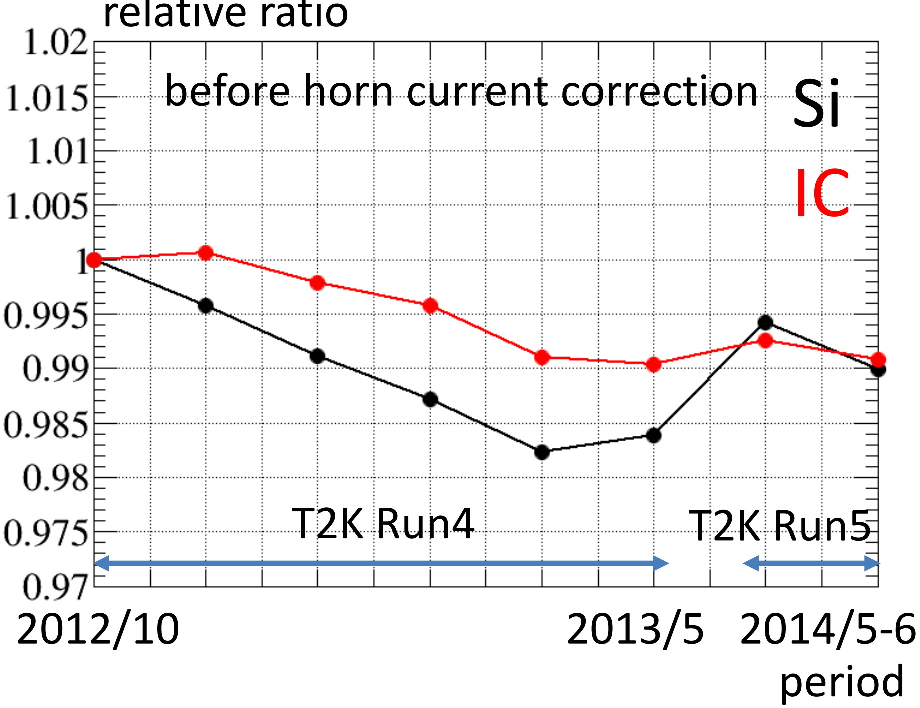


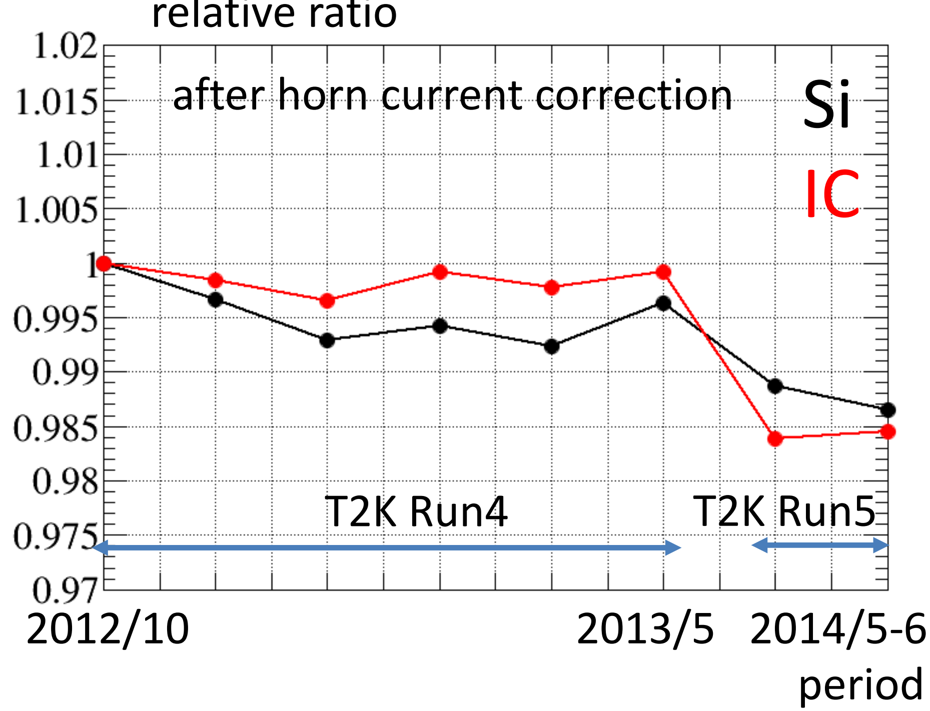
change rate (%/kA)	ν mode	$\bar{\nu}$ mode
	0.80	0.71

- Wrong sign μ are emitted from forward part of target and less sensitive to horn current.
- Thus, change rate in anti-neutrino mode is smaller than that in neutrino mode.

Stability of muon yield

neutrino mode

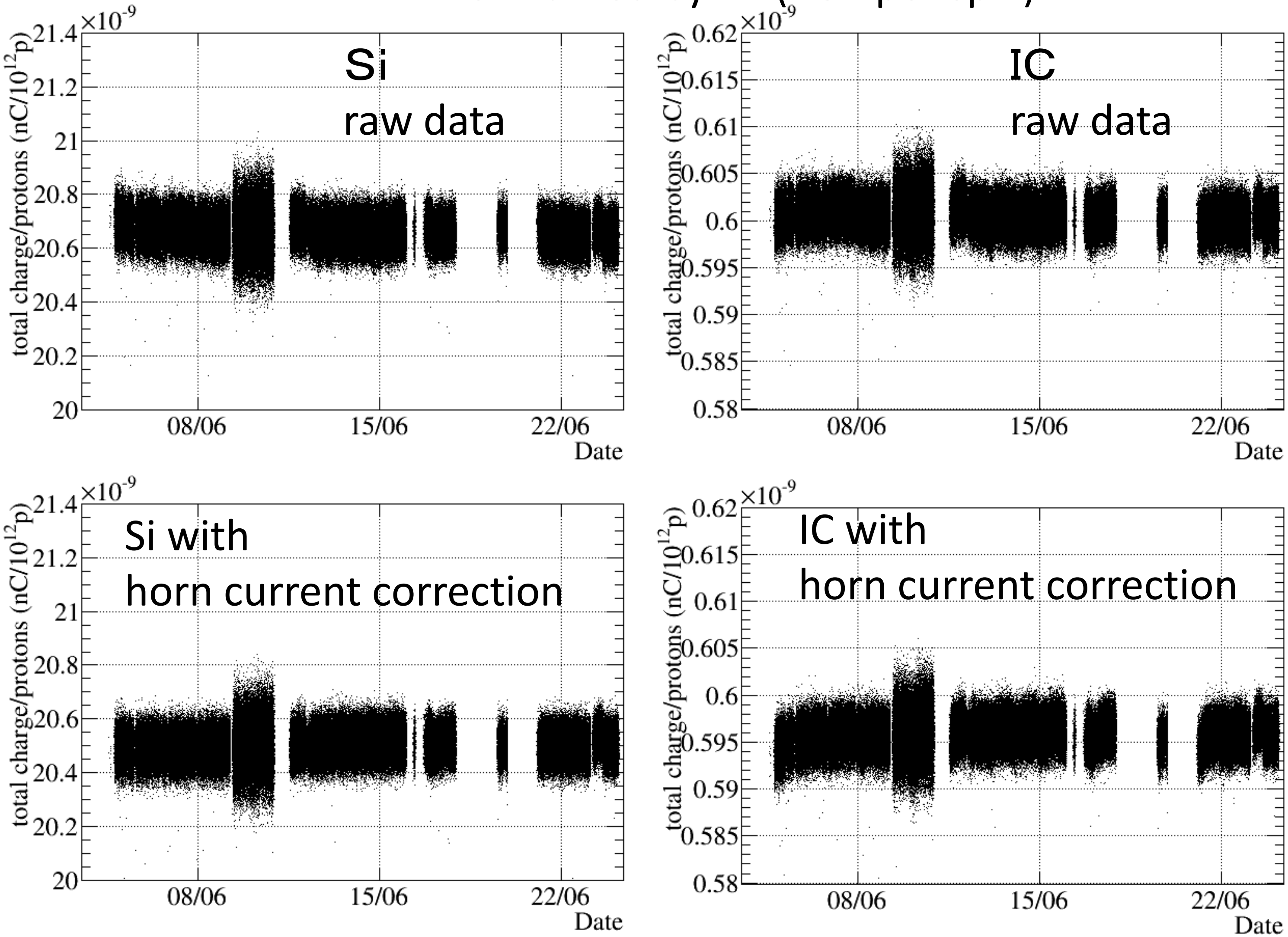




- Yield is normalized by most left period (MR RUN44 data).
- After horn current correction, yield inside T2K RUN4 and T2K RUN5 is stable within 1%.
- There is ~1% yield decrease between T2K RUN4 and T2K RUN5 probably due to replacement of target and horns.

Stability of muon yield

normalized by CT (POT per spill)

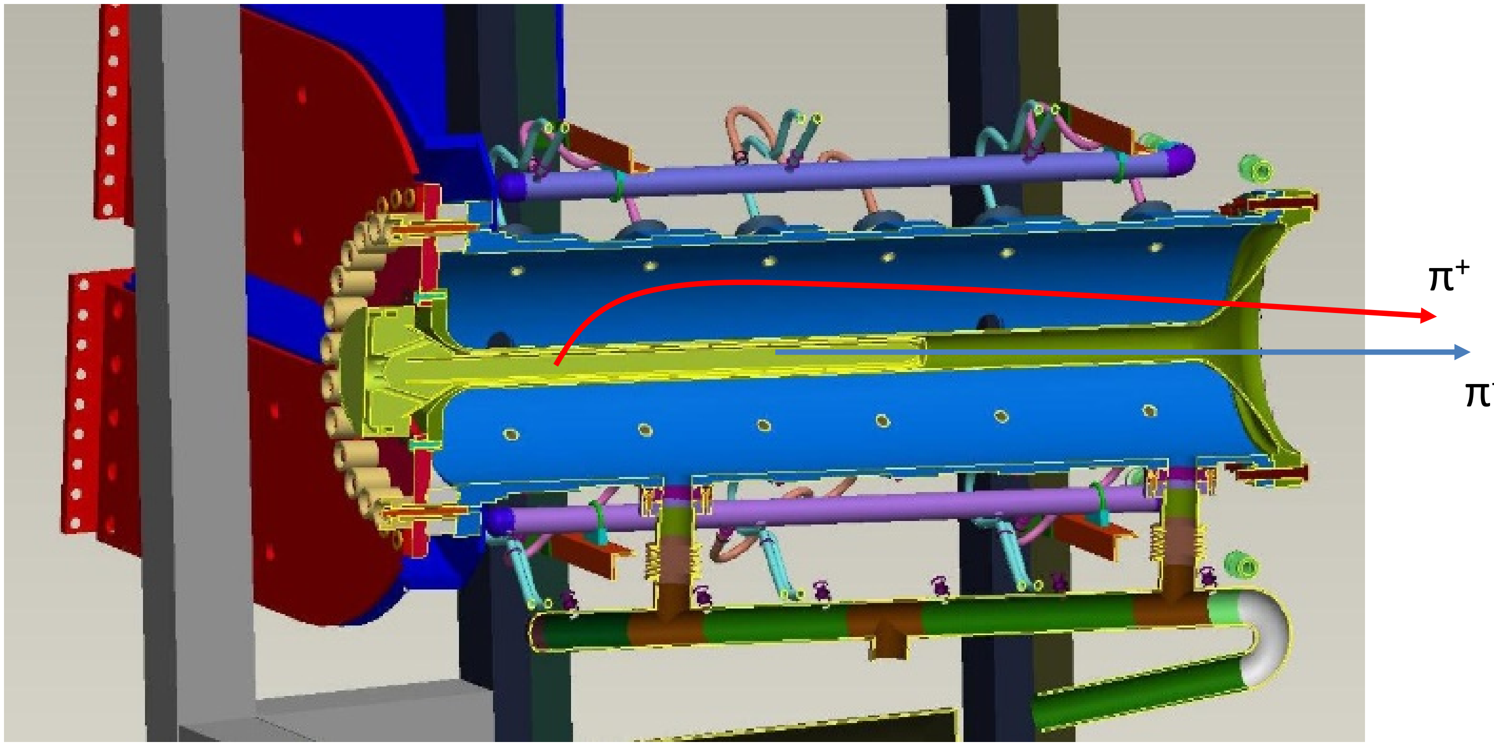


- During anti-neutrino run period, muon yield (and horn current) is stable
- larger fluctuation around Jun 10 due to change in the attenuation setting of CT

Profile Comparison with MC

horn focusing

neutrino mode (+250kA)



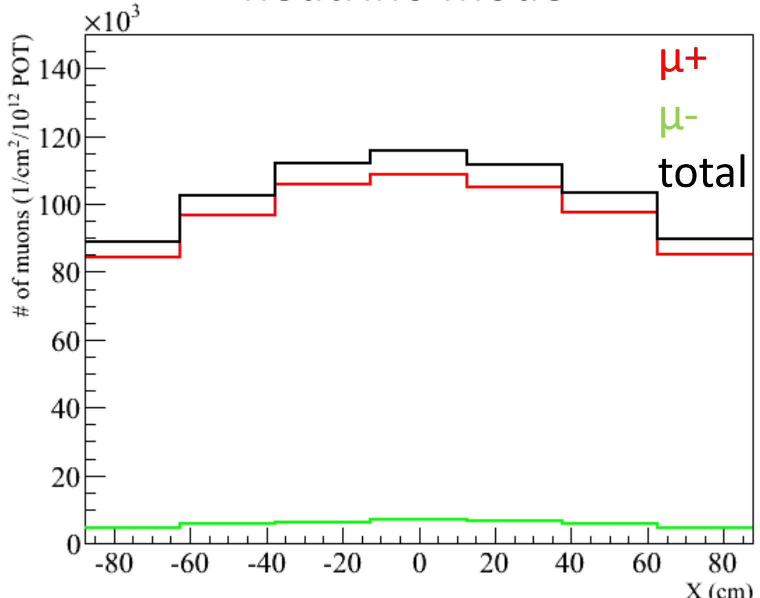
- There exists toroidal magnetic field around the target.
- No magnetic field in forward region
- In neutrino mode, π^+ are focused by horn and travel in parallel to beam axis.
- There are some π^- which are emitted very forward region

MUMON profile in MC simulation

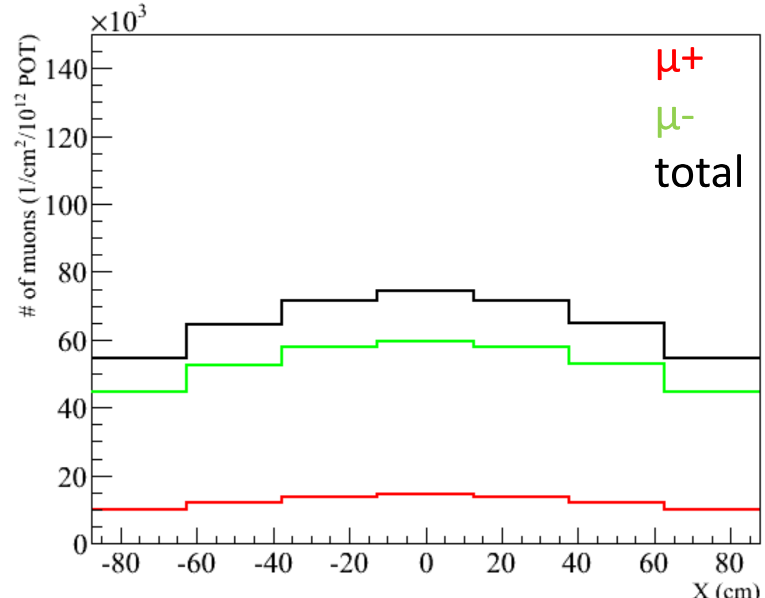
- JNUBEAM (used for SK/ND neutrino flux) is used
- FLUKA is used for target MC and gcalor (geant3) is used for the others

profile in horizontal direction

neutrino mode



anti-neutrino mode



- Signal from MUMON detector is sum of μ^+, μ^- (and δ ray)
- Yield in anti-neutrino mode is roughly 2/3 compared to that in neutrino mode.
- More π^+ are produced than π^- at the target, so ratio of wrong sign is higher in anti-neutrino mode.
- Some part of wrong sign μ are also produced from interaction in beam dump.
  (wrong sign μ: μ- in anti-neutrino mode and μ+ in neutrino mode)
- Wrong sign μ from beam dump make beam width narrower.

Profile comparison with MC simulation

Check MUMON profile using JNUBEAM (used for prediction for SK flux)

yield ratio (-250kA / 250kA)	MC	Data total
Si	0.628	0.637
IC	0.630	0.628

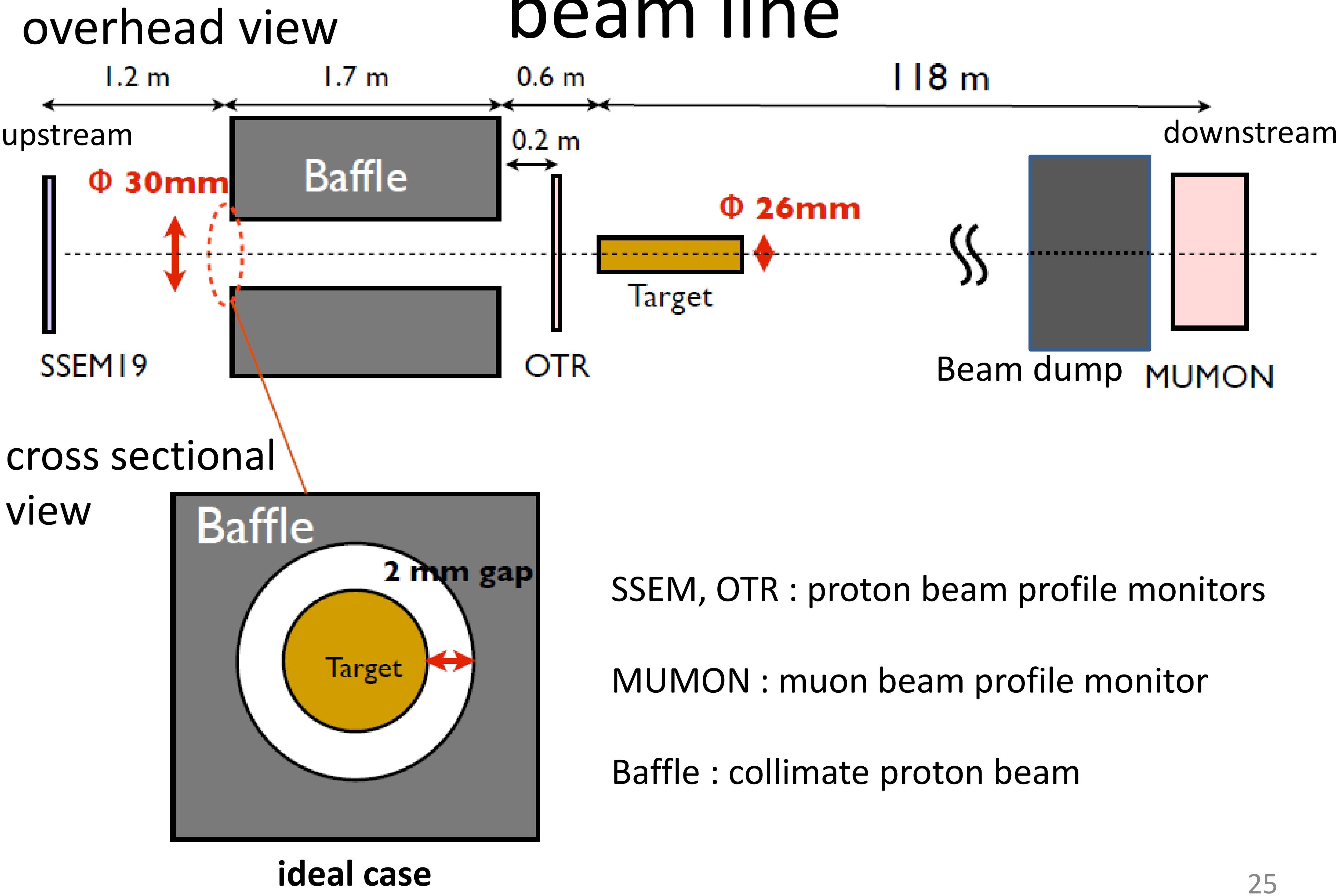
Ratio of total muon yield is consistent within 2%

width (cm)	MC X	Data X	MC Y	Data Y
Si 250kA	105.5	101.7	114.0	113.6
IC 250kA	111.7	106.4	127.0	123.8
Si -250kA	96.2	97.7	104.1	103.8
IC -250kA	104.0	103.1	115.0	113.5

- Profile width is consistent within 5% level.
- In anti-neutrino mode, beam is narrower due to larger wrong sign μ

Sensitivity to proton beam condition

beam line



SSEM, OTR : proton beam profile monitors

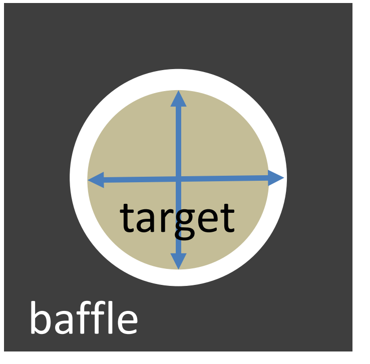
MUMON : muon beam profile monitor

Baffle : collimate proton beam

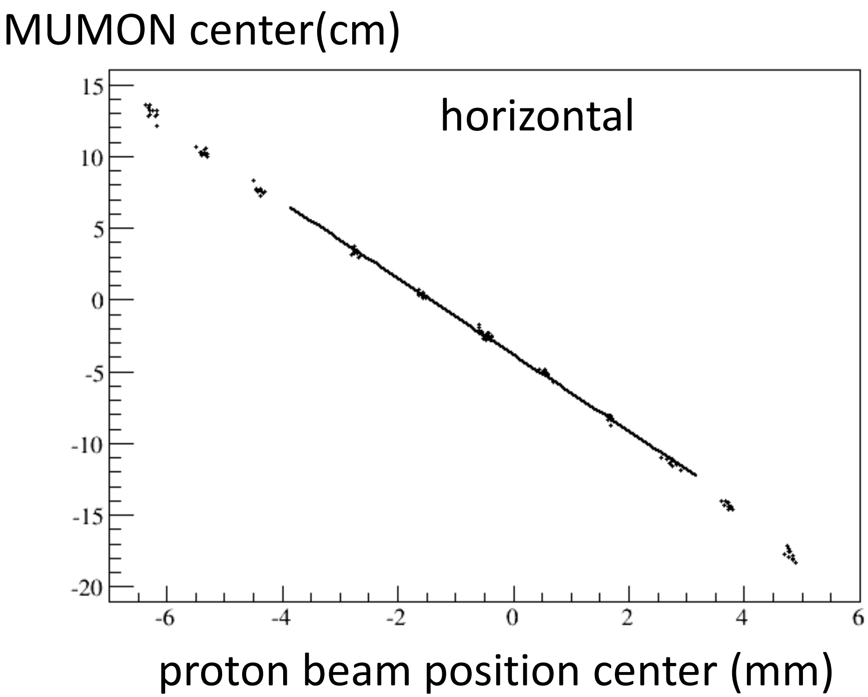
Sensitivity in MUMON to proton beam

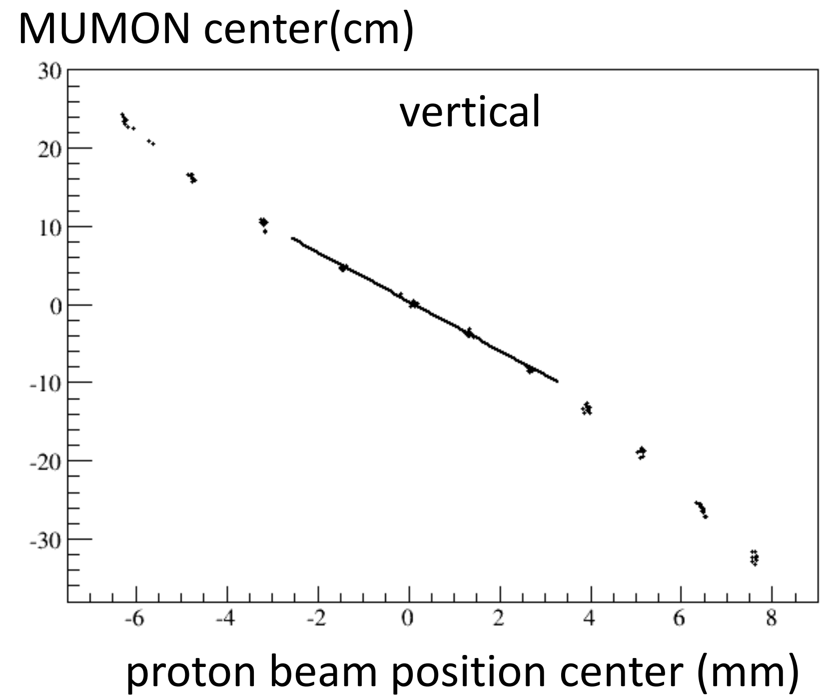
- Check the sensitivity in MUMON when proton beam position or angle is shifted in **anti-neutrino mode**.
- In fact, proton beam position is adjusted as MUMON profile center near to 0.
- Changing proton beam position by ~1mm steps or ~0.1mrad steps

Cross sectional view



Sensitivity to proton beam center



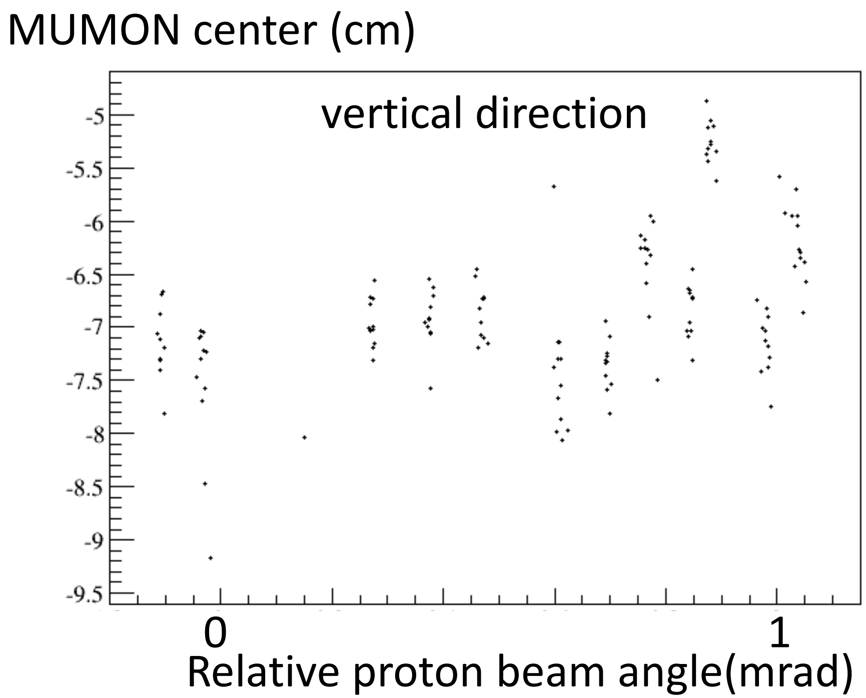


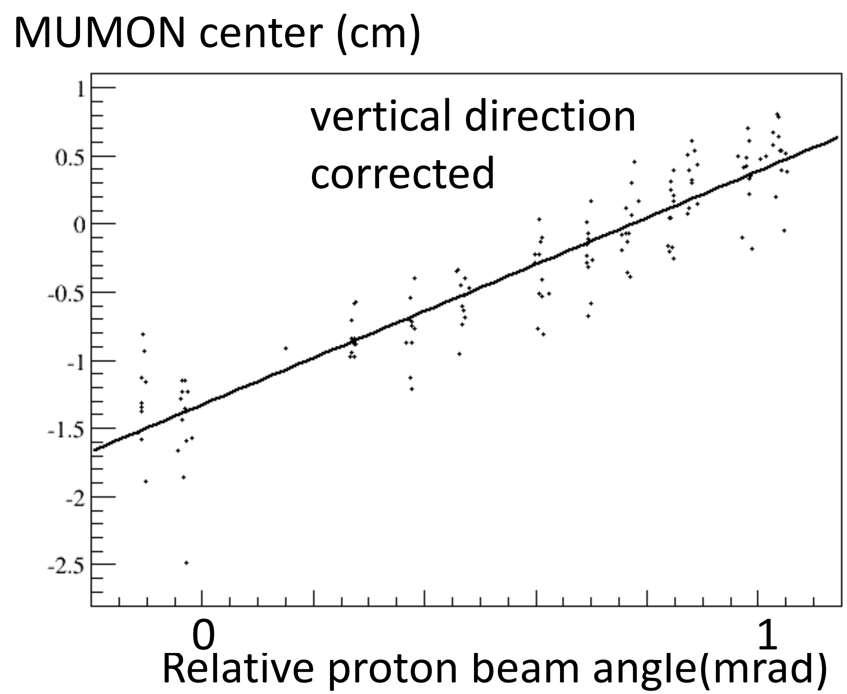
Slope (MUMON cm / beam center mm)	horizontal MC	horizontal data	vertical MC	vertical data
	-2.5	-2.7	-3.1	-3.1

- In MC, proton beam center is shifted from -2mm to 2mm.
- Data and MC is basically consistent.

Sensitivity to proton beam angle

Check MUMON profile when proton beam angle is changed





- During this study, it was difficult to stabilize proton beam center. So, raw plot has unclear correlation.
- By correcting with the relationship between MUMON center and proton beam position（-3.1 cm @MUMON/mm@p beam）shown in previous page, correlation can be seen.
- Slope is ~1.7cm (MUMON cm/mrad@ p beam). Usually, proton beam is stable within much better than 1mrad, so this effect can be neglected.

Relative alignment of target

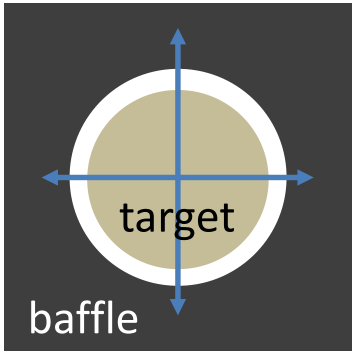
- We re-installed target and horns to new ones. At that time, baffle was also moved temporarily.
- Relative alignment of target should be checked.

- Check the MUMON profile when the proton beam position is shifted by ~1mm steps.

- narrower proton beam (2.2~2.5mm) than usual (4.2mm)
- low intensity for safety
- **horn off**

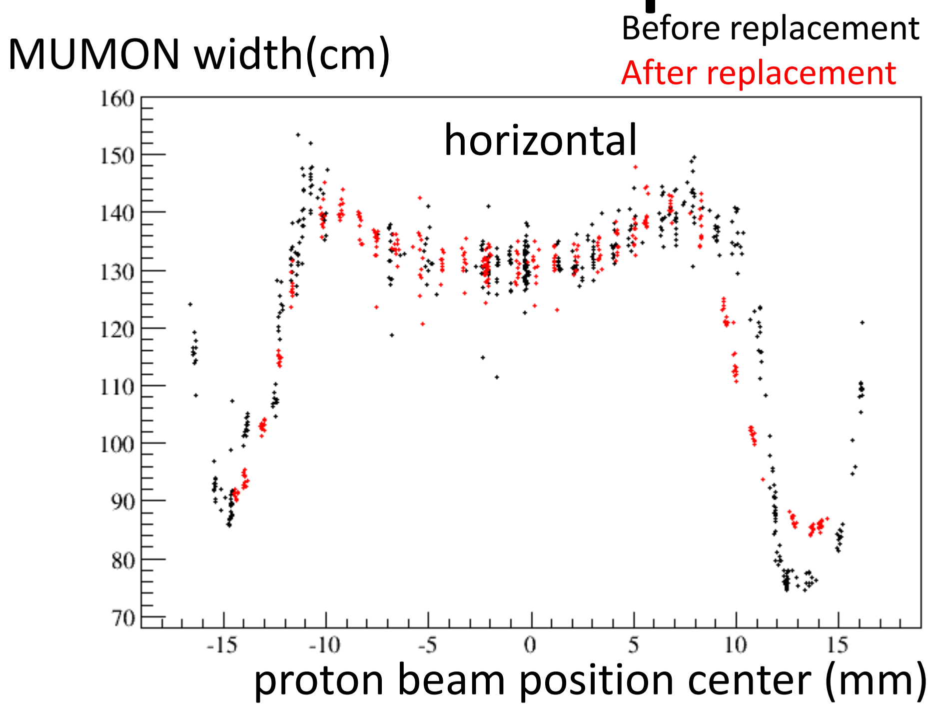
Ideal case

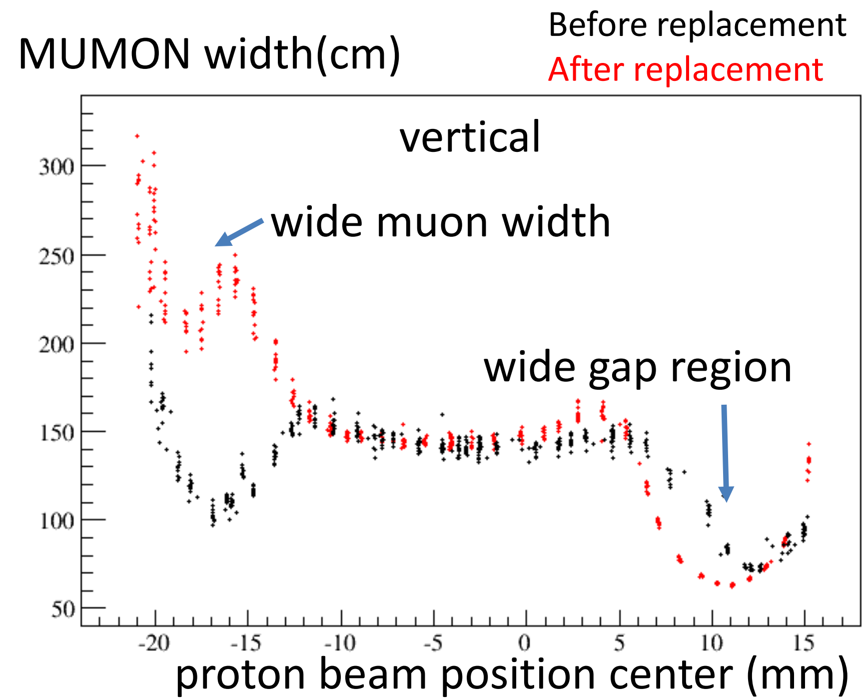
Cross sectional view



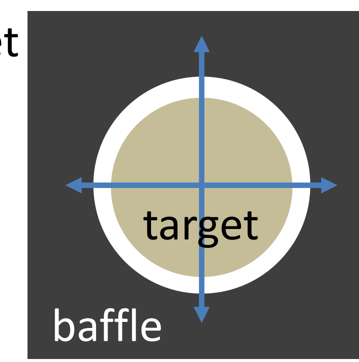
profile width

horn off





- If some part of the proton beam go through gap region between target and baffle, that hits wall or beam dump and makes narrow beam.
- Result in horizontal direction is consistent with past data.
- In vertical direction, profile width is wider in large –y region and narrow in wider large +y region.

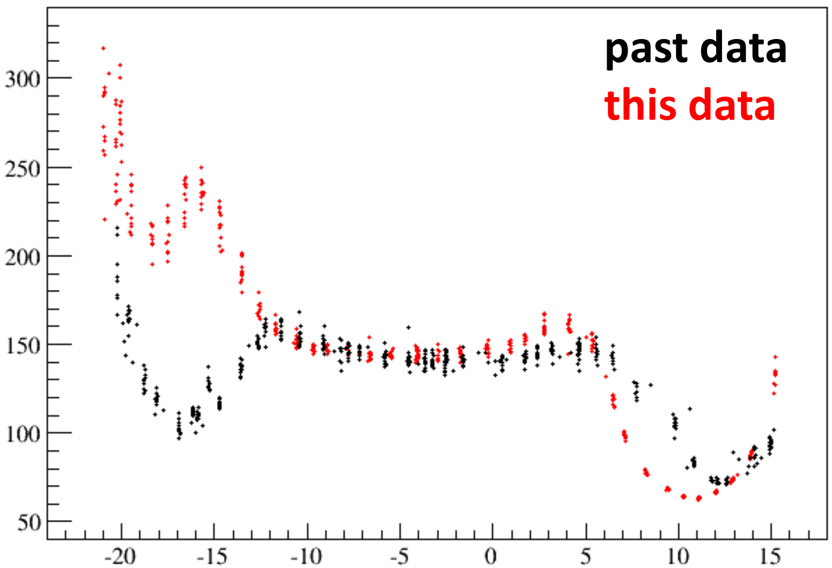


- Target position is misaligned.

Comparison : MUMON width horn off

data

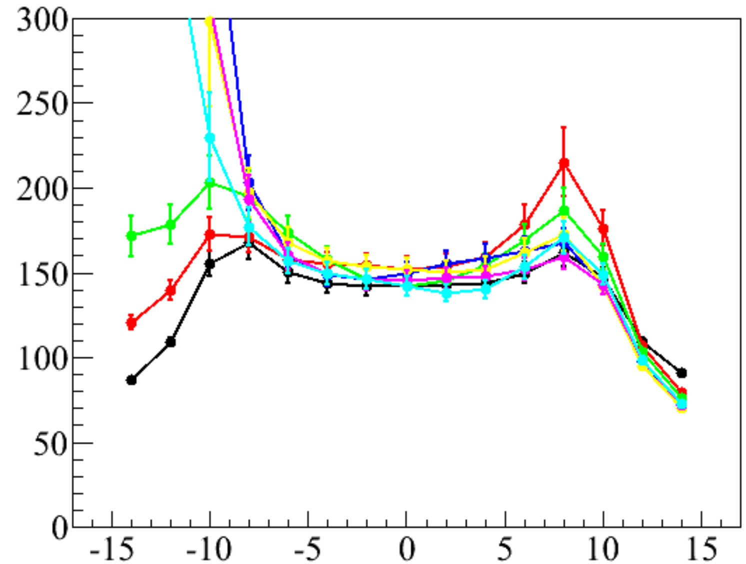
MUMON vertical width(cm)



proton beam position center (mm)

MC

MUMON vertical width (cm)



n beam position center (mm)

nominal
1mm
1.5mm
2mm
2.5mm
3mm
4mm

- Make MC profile when baffle is shifted in vertical direction.
- In MC, it is reproduced that muon width become wider when proton beam position center is in large –y position.
- The size of shift looks roughly 1.5mm.

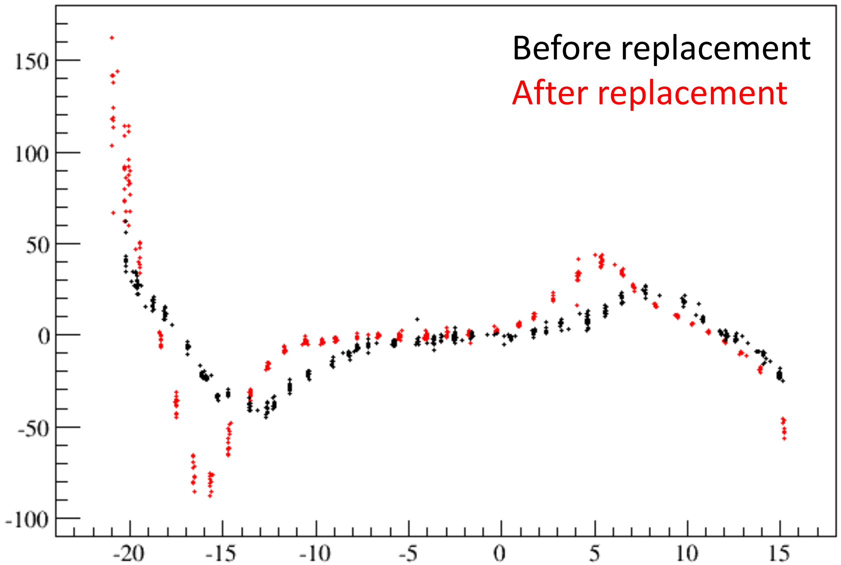
Estimation of the size of shift

horn off

size of shift
1.5mm
1.6mm
1.7mm
1.8mm
1.9mm
2mm

data

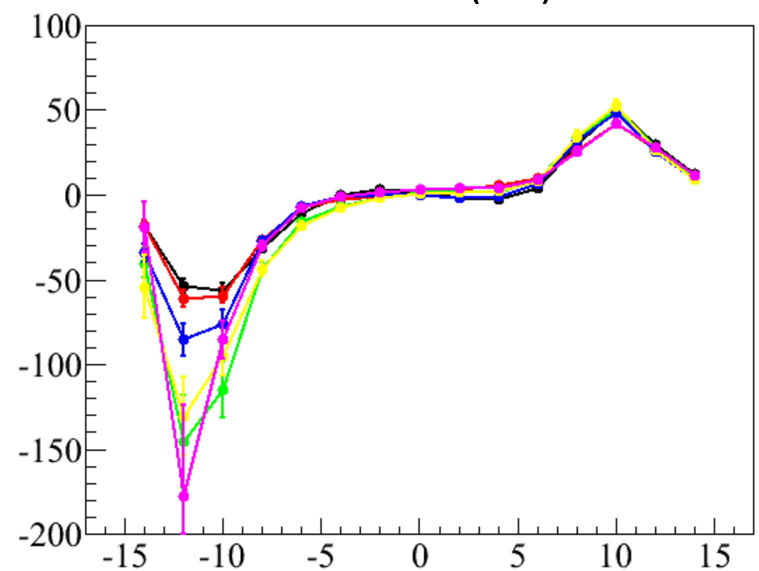
MUMON vertical center (cm)



proton beam position center (mm)

MC

MUMON vertical center (cm)



proton beam position center (mm)

- also look at muon profile center
- At the edge of the target, muon center shifts largely from 0.
- From the data V.S. MC comparison, the size of shift seems 1.6 ~ 1.9 mm in –y direction.

Summary

- In 2013 shutdown, update work (Si replacement and IC gas pipes) was done.
- T2K took first anti-neutrino beam data in 2014 June.

  In the physics run, muon yield and profile center was stable.
- Muon profile in data is consistent with that in MC simulation.
- We did commissioning study in anti-neutrino mode and confirmed change of beam condition affect muon profile as expected.
- We found alignment of new target is slightly shifted from center, but this has small effect on actual data taking.

Back up

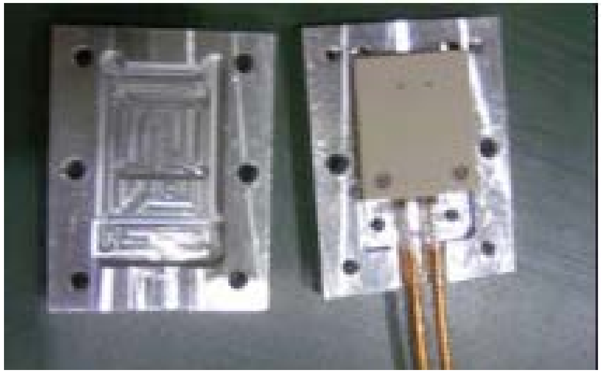
picture

Ionization Chamber SI PIN photodiode

Silicon PIN photodiode

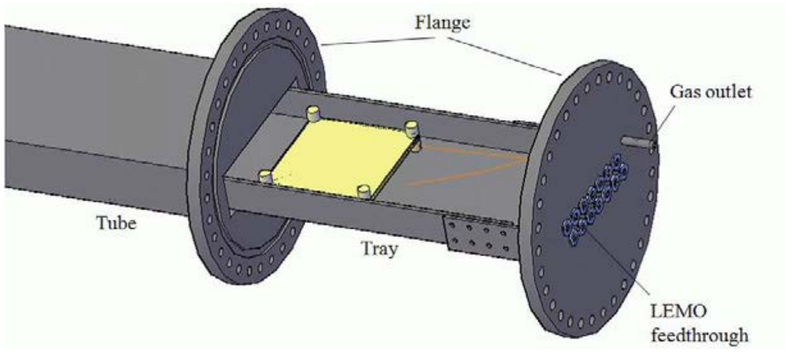
- HAMAMATSU S3590-08
- Active area:10mm × 10mm
- thickness: 0.3mm
- HV: 80V

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

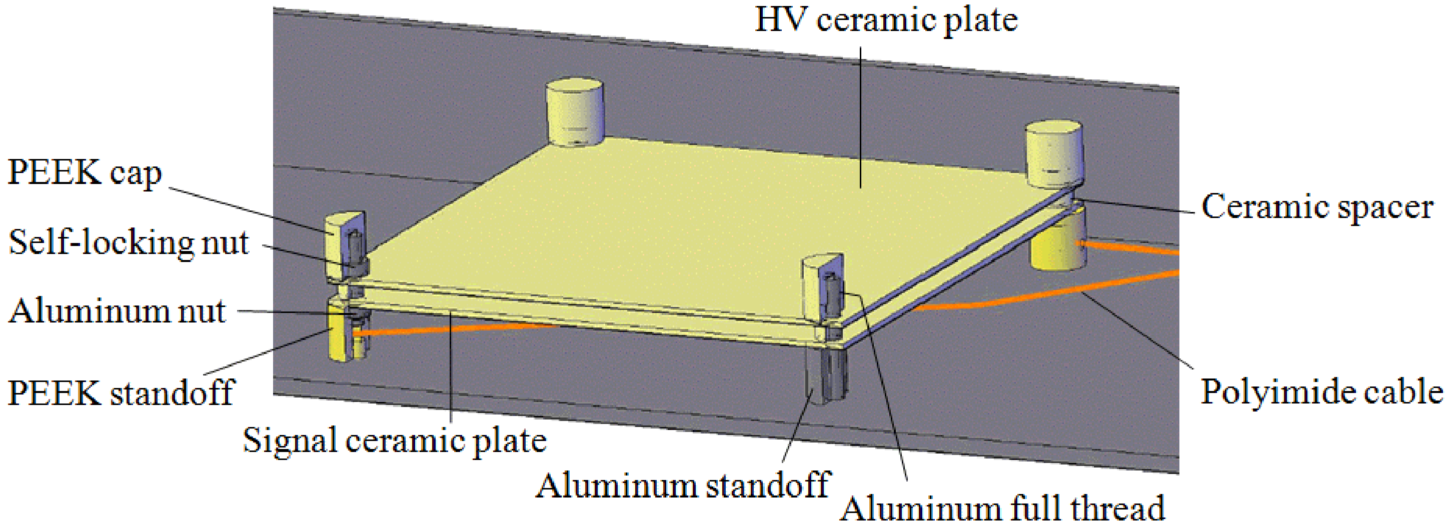


Ionization chamber

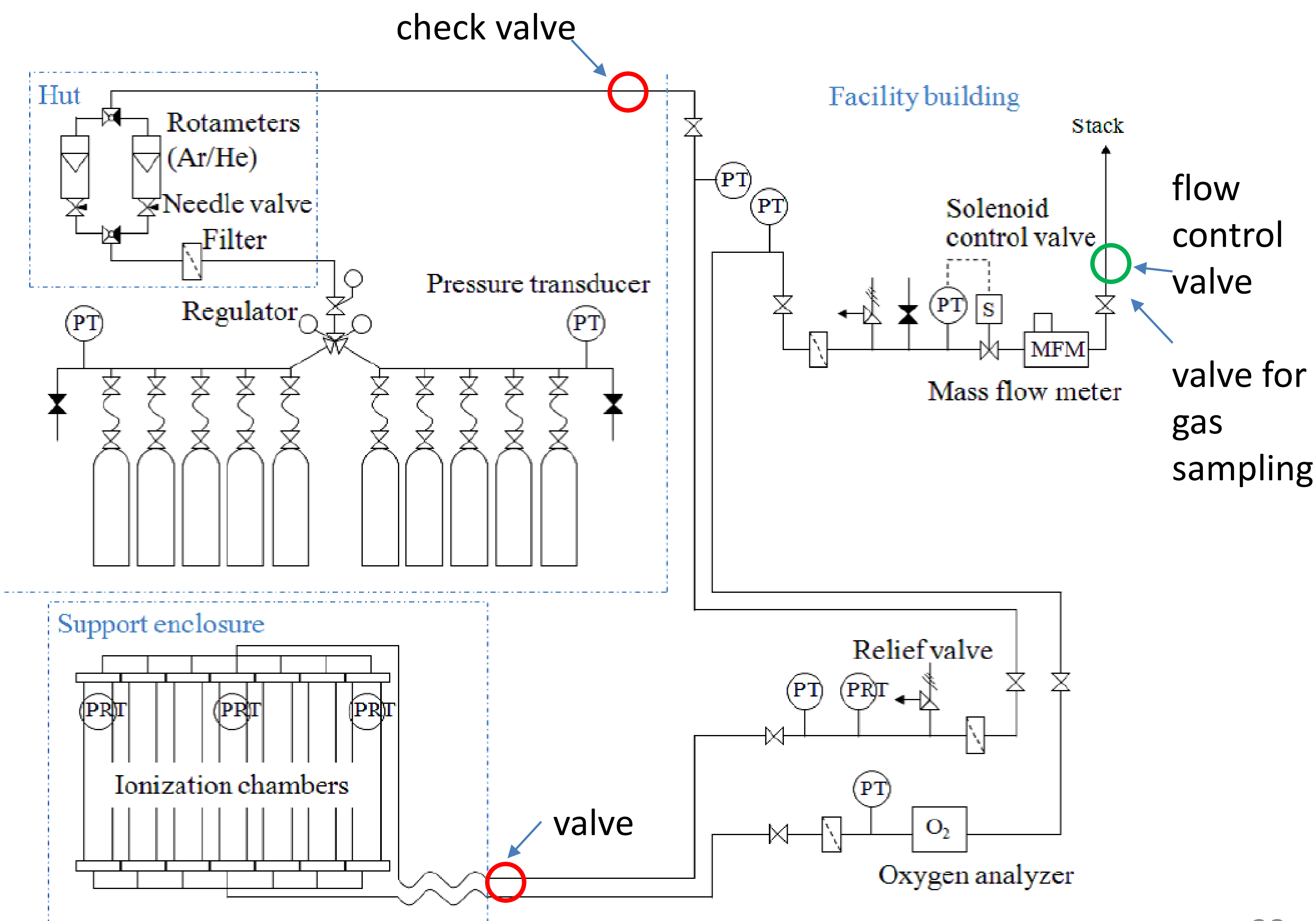
- Active area: 75mm × 75mm
- thickness : 3mm
- Gas : $Ar+N_2$ (2%)(<~300kW)
  : $He+N_2$ (1%)(>~300kW)



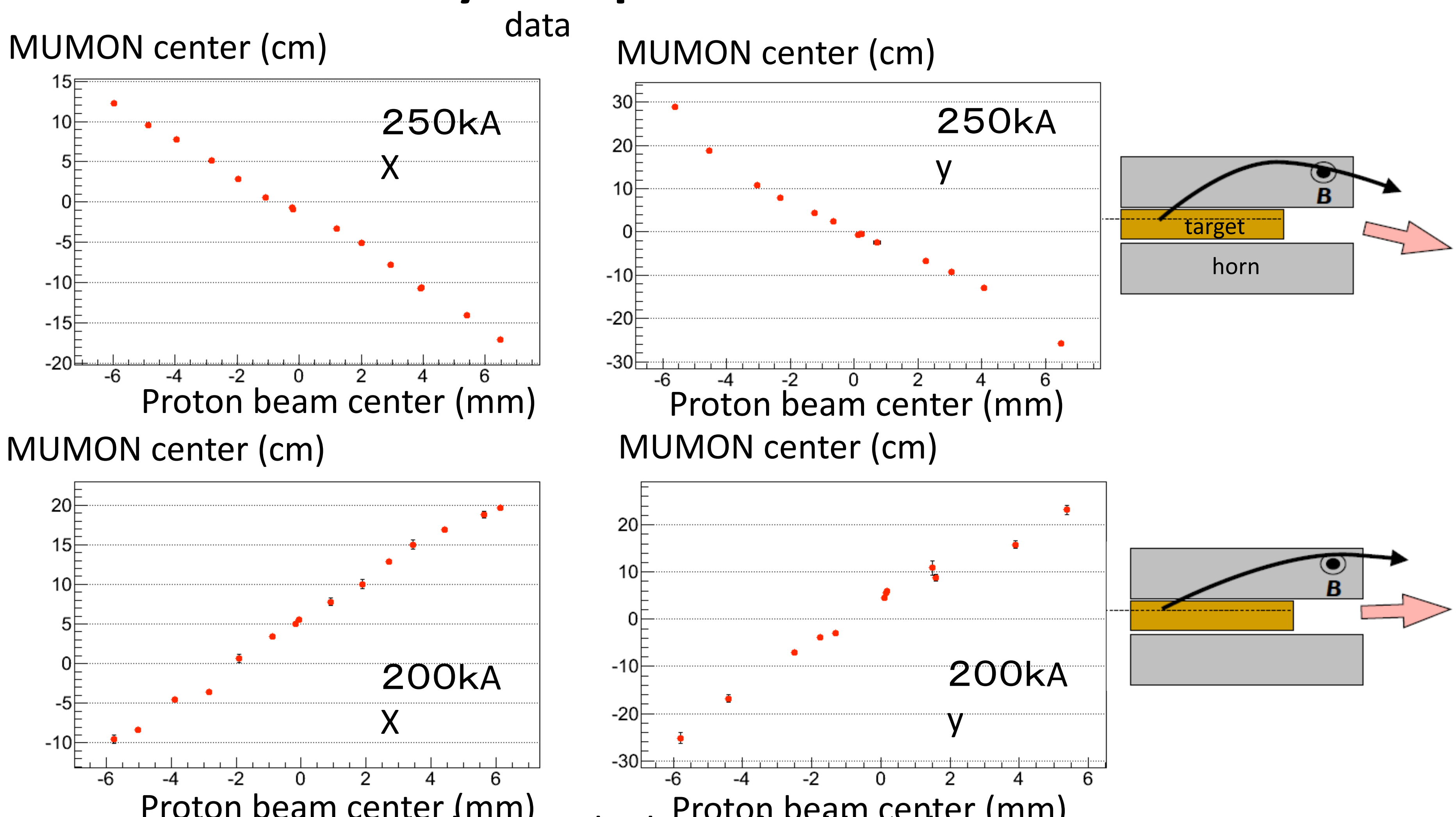
- N_2 gas : mixed for faster and stable response
- HV:200V



gas system for IC



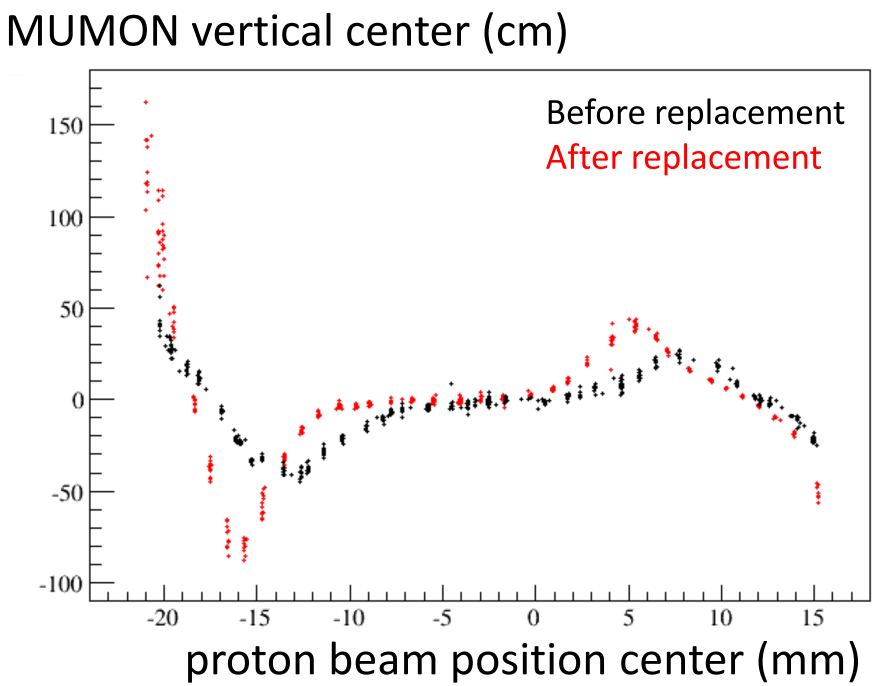
sensitivity to proton beam center



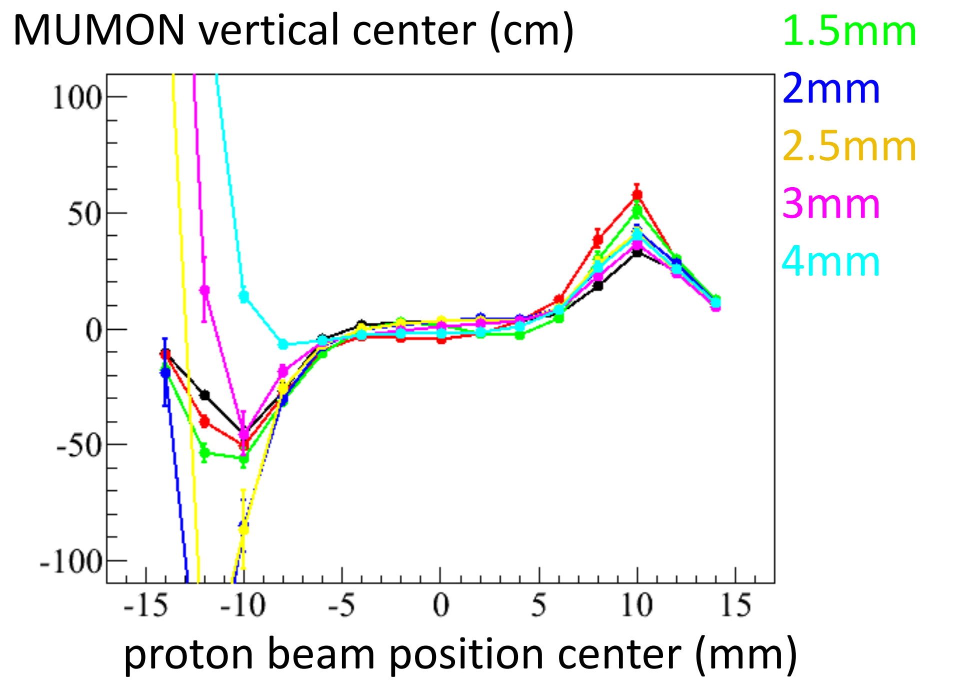
- Horn current size changes the beam focal length.
- At given horn current size, MUMON does not have sensitivity to proton beam center.

Estimation of the size of shift

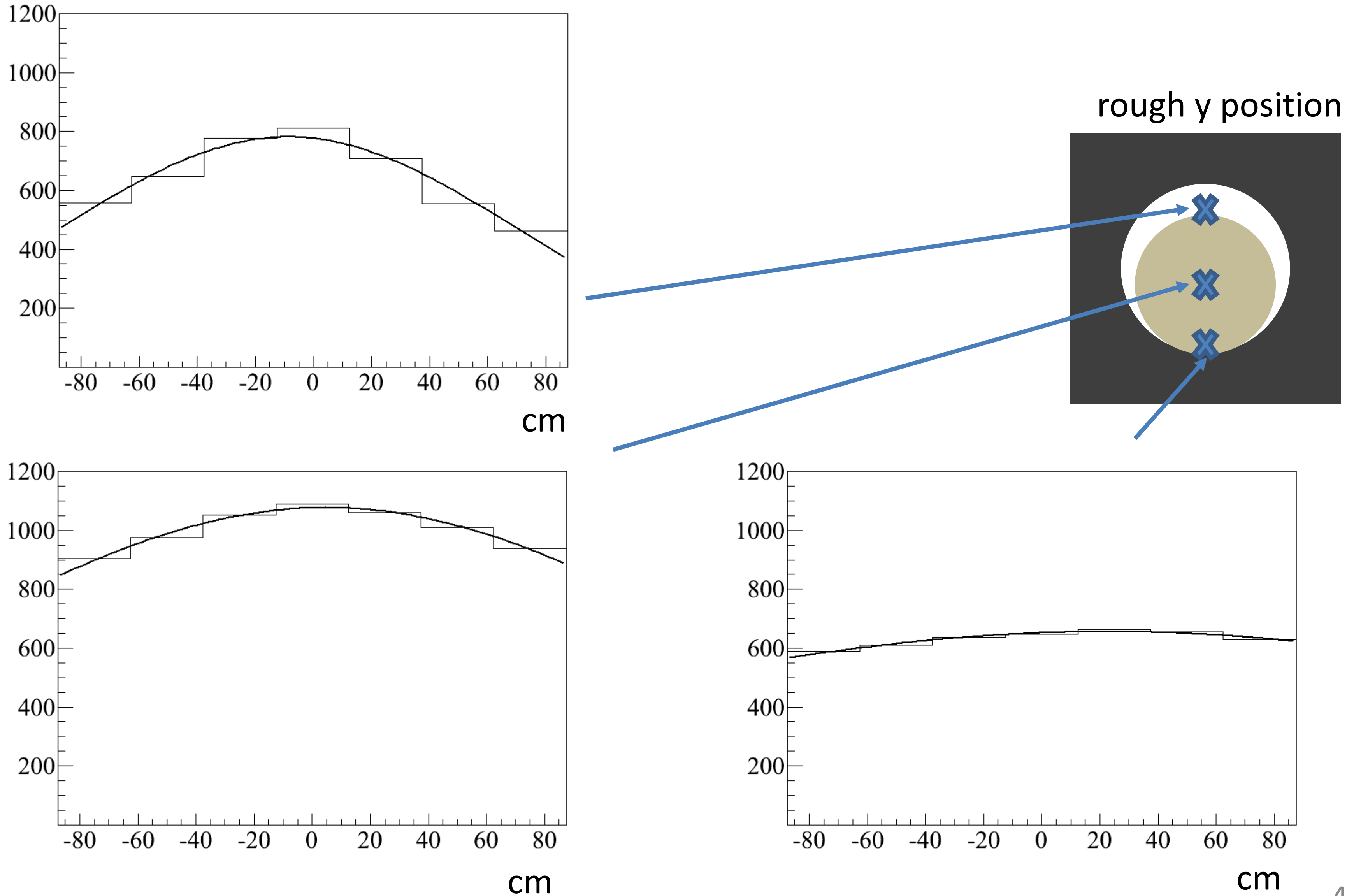
data



MC



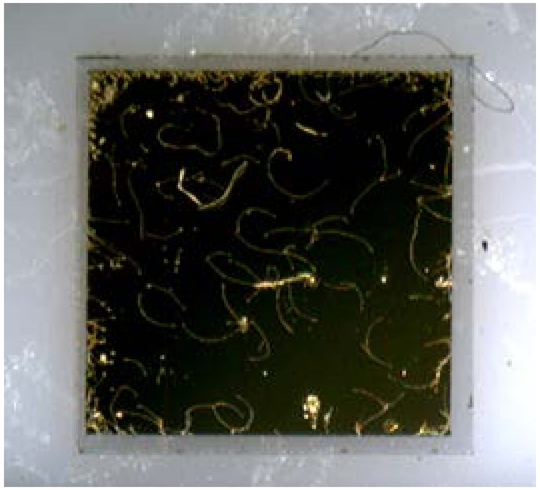
MUMON y profile



diamond detector

- When intensity of T2K beam is stronger, lifetime of Si detectors is not so long.
- So, we are studying diamond detector as a candidate of alternate detector in future.

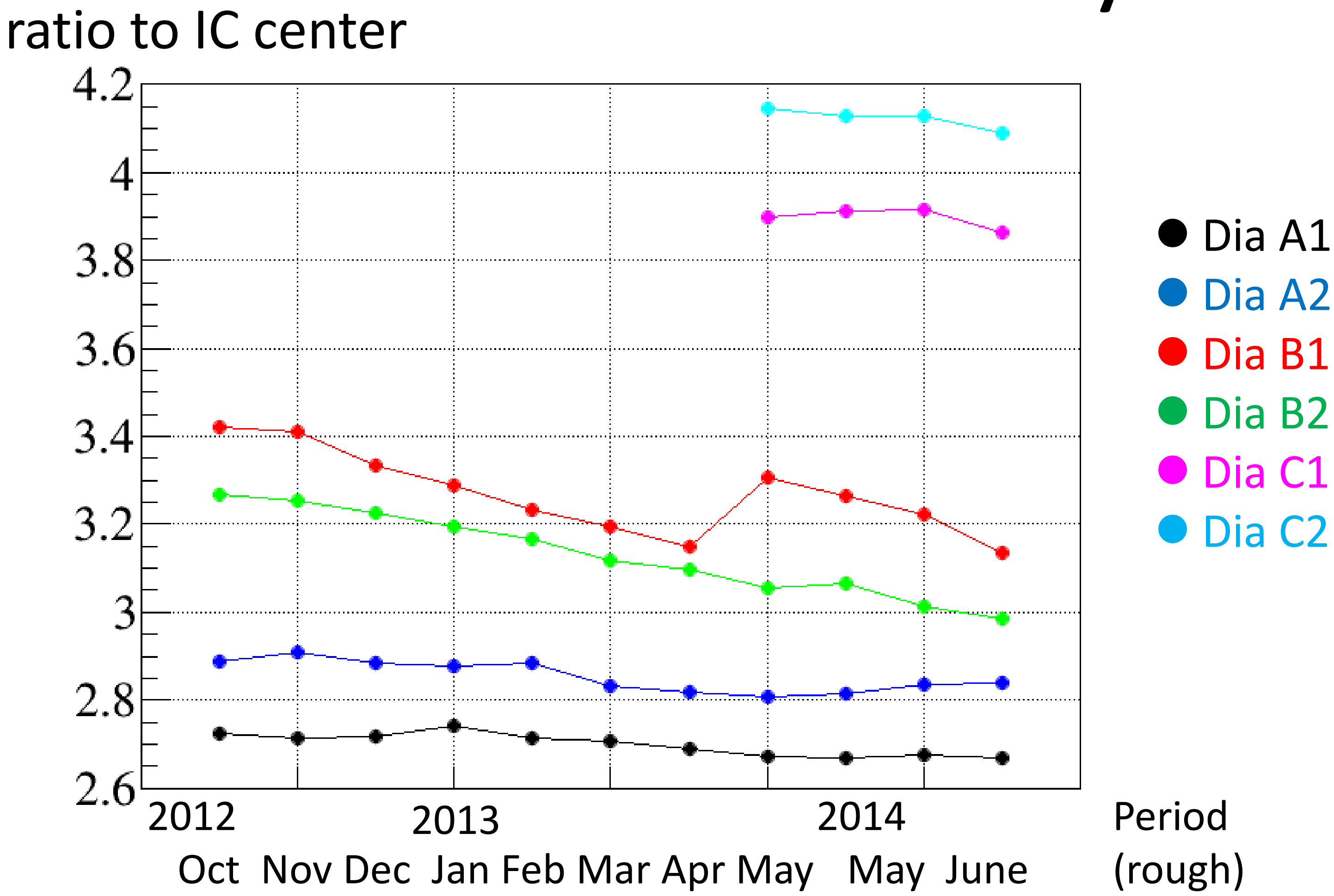
- Currently some samples of diamond detector have been installed downstream MUMON and data were taken.



~4mm × 4mm × 0.5mm(t)
surface is coated by gold

✓ diamond A : E6 detector grade
✓ diamond B : E6 electronic grade
✓ diamond C (from 2013 Apr) : purchased from cividec

Diamond Stability



Size of signal in all diamond detectors were gradually decreasing (faster than Si). Quality of crystal may not be good.

We plan to buy new diamond detectors from Japanese laboratory.

MC Profile width

MC vs data

width (cm)	MC X	Data X	MC Y	Data Y
Si 250kA	105.5	101.7	114.0	113.6
IC 250kA	111.7	106.4	127.0	123.8
Si -250kA	96.2	97.7	104.1	103.8
IC -250kA	104.0	103.1	115.0	113.5

MC μ+ vs μ-

width (cm)	X μ+	X μ-	Y μ+	Y μ-
Si 250kA	107.1	86.0	116.6	86.2
IC 250kA	113.2	93.2	130.0	96.1
Si -250kA	86.2	99.1	87.4	109.6
IC -250kA	93.0	104.7	95.6	121.7