T2K Muon Monitor

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for MUMON group

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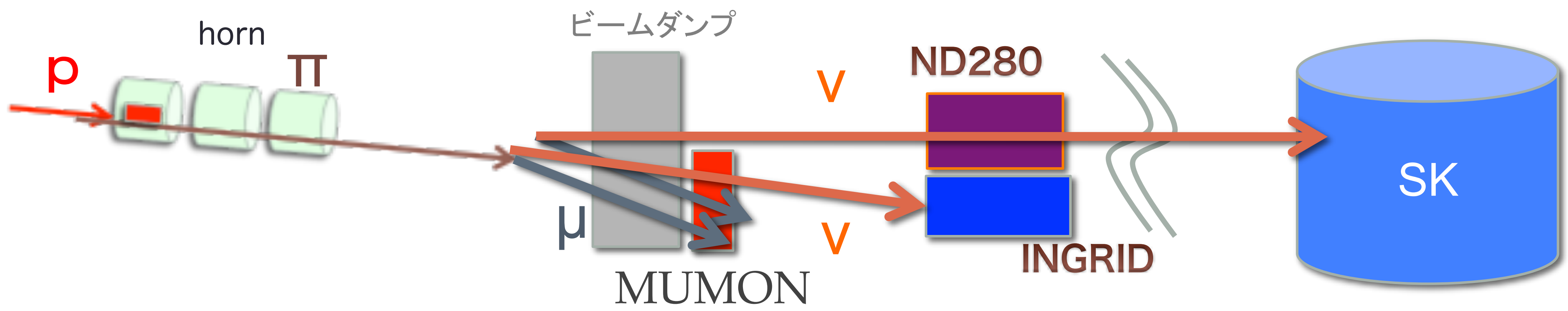
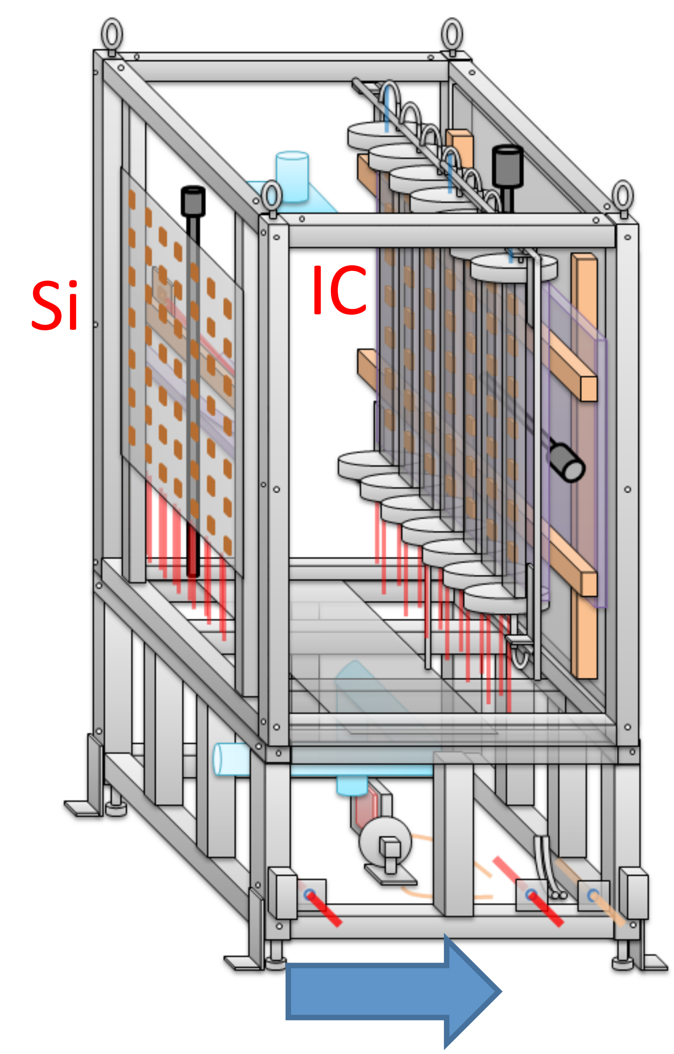
- operation status
- R&D for Ionization Chamber
- Other R&D detectors and measurement

T2K Muon Monitor

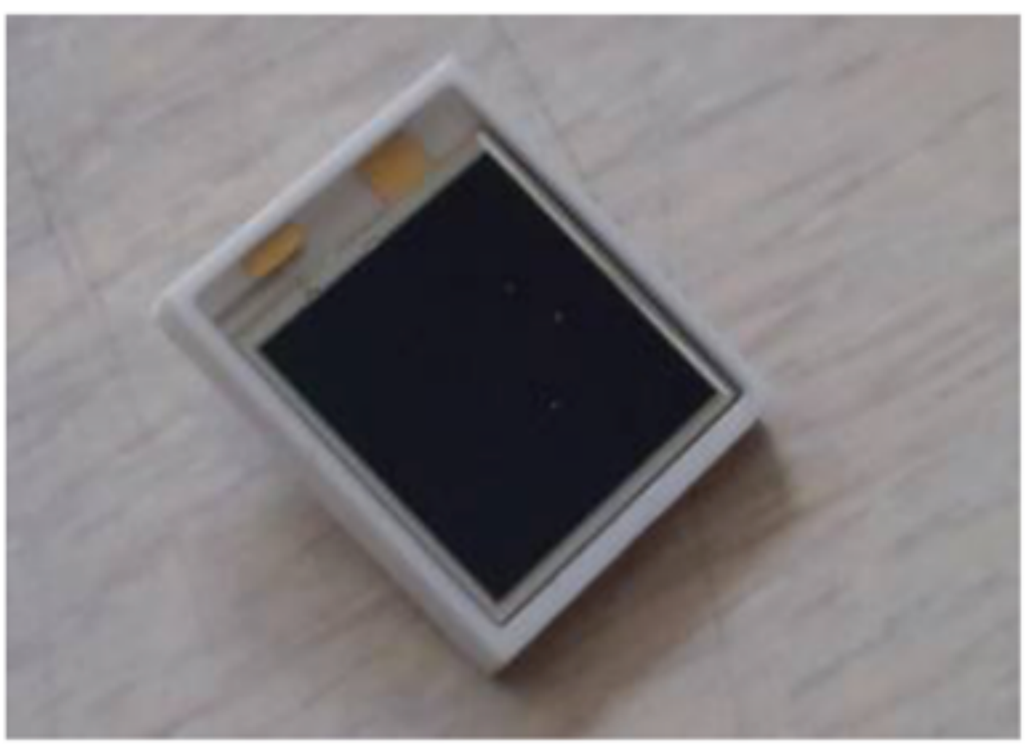


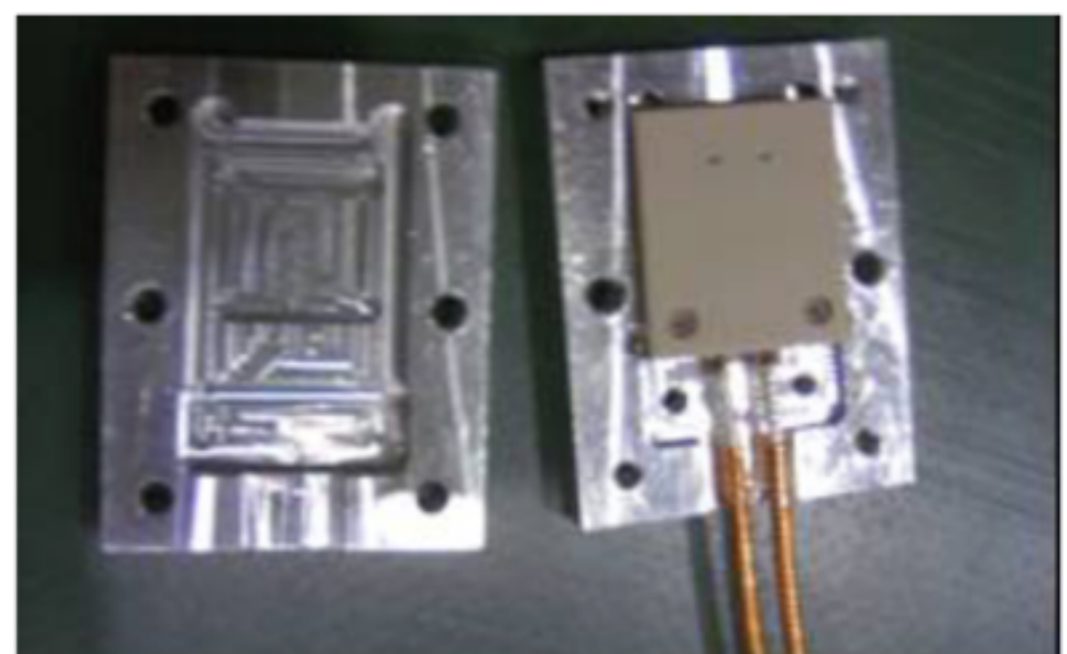
- Placed behind beam dump.
- measure muon beam >5GeV
- Two independent monitor for redundancy
  - 7x7 Si PIN photodiode array
  - 7x7 Ionization Chamber array
- muon flux ~ 10^5 /cm^2



Si PIN photodiode

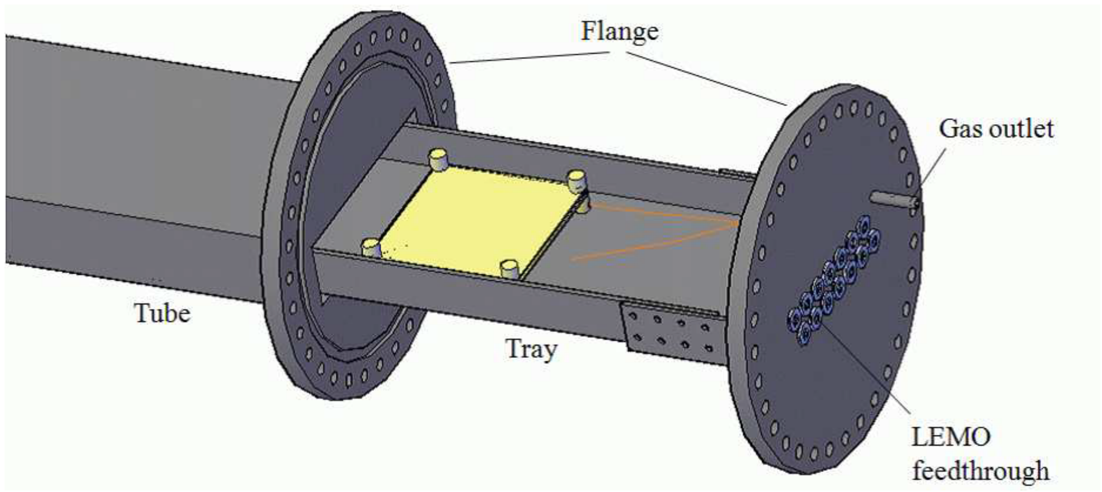
- Made by Hamamatsu photonics.
- active area of 10 × 10 mm^2,depletion layer thickness of 300 μm.
- bias voltage 80V.
- mounted on the Ceramic base to replace it easily.

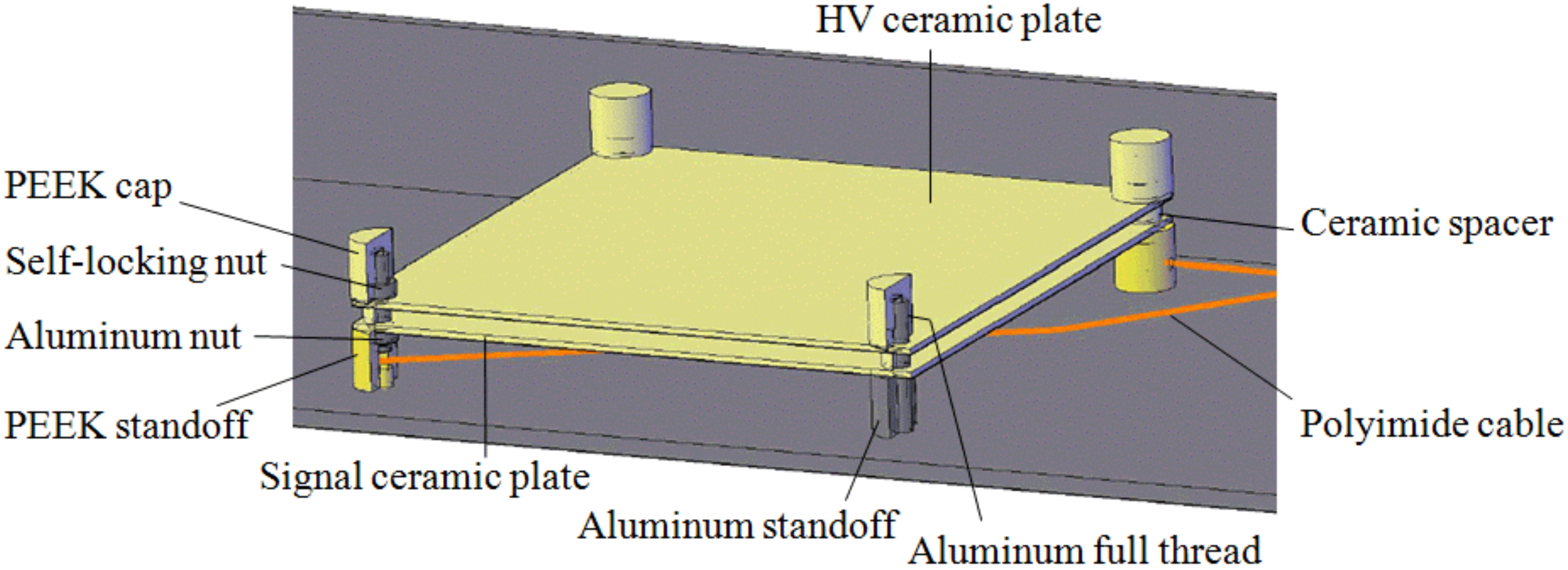




Ionization chamber

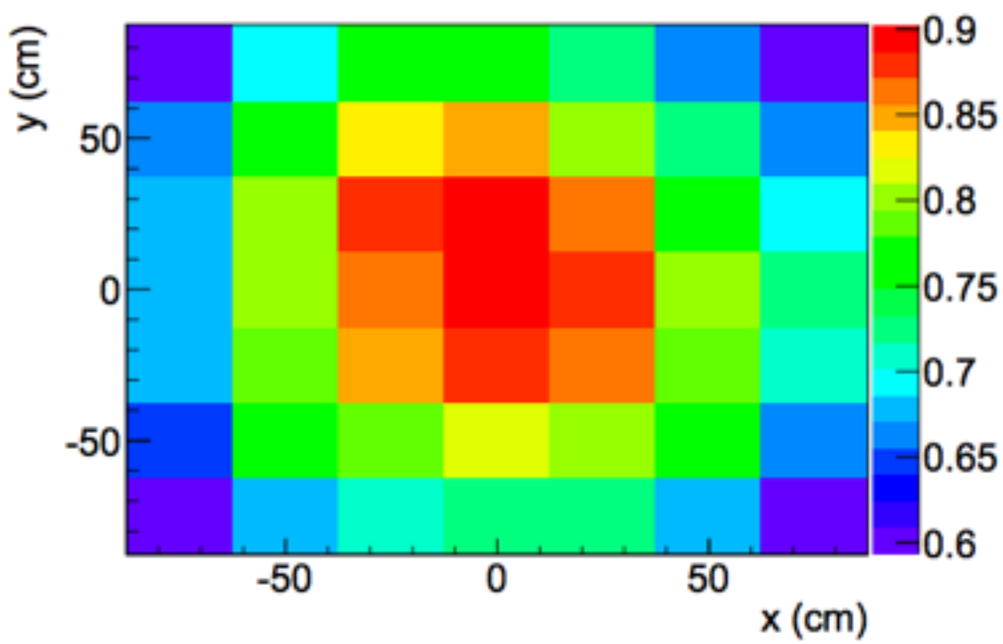
- Active area: 75mm×75mm
- thickness : 3mm
- Gas : Ar+N_2 (2%)(<~300kW)
  : He+N_2 (1%)(>~300kW)
- N_2 gas : mixed for faster and stable response
- HV:200V



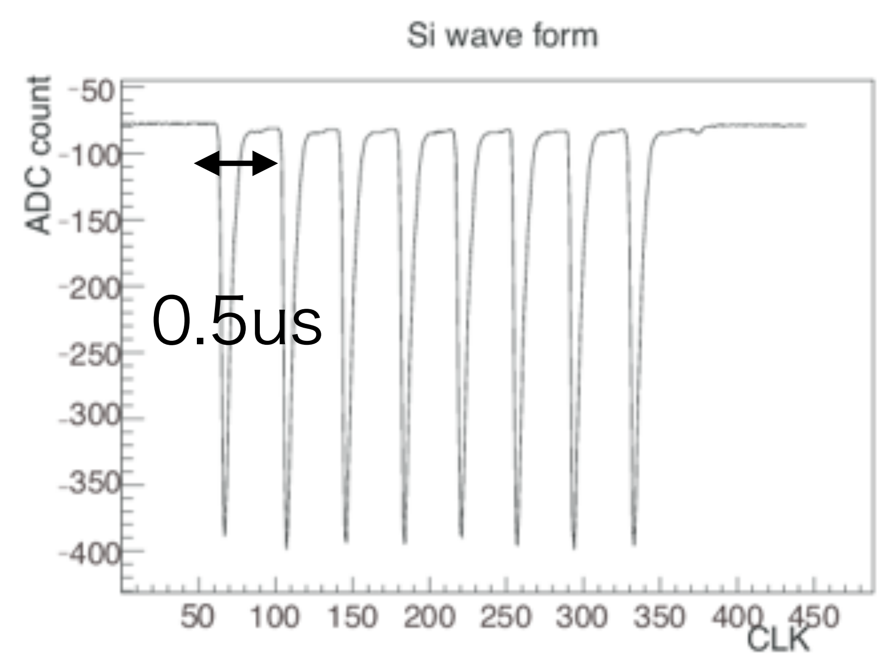


Signal and Profile

- taking data with 50MHz sampling FDAC
- integrates the signal and calculates its charge bunch by bunch for each channels.
- make 2D histogram of the charge and fit with 2D gaussian.



Si profile



Si signal

Operation status

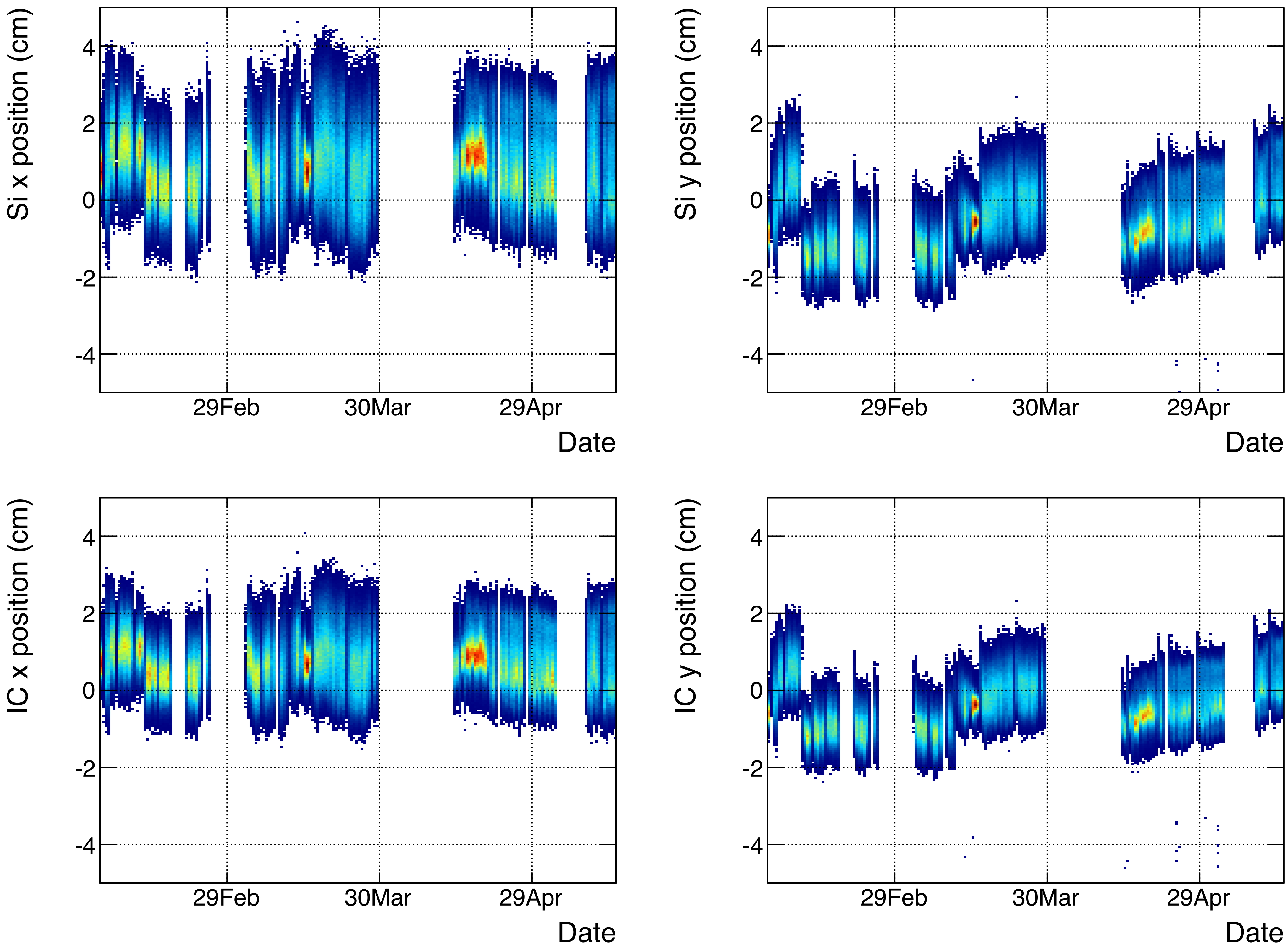
MUMON Expert

- Muon Monitor in T2K is maintained mainly by Kyoto U student.
- Designed by M.Yokoyama, Matsuoka, Kubo
- Combiner: M.Yokoyama (Kyoto.U->U. Tokyo) -> A.K. Ichikawa (Kyoto U)
- 1st expert: Matsuoka,Kubo(~2010)
- 2nd expert: Suzuki,Murakami (2009-2013)
- 3rd expert: Hiraki (2012-2015)
- 4th expert: K. G. Nakamura (2014~2017?)
- 5th expert: Uno, Asida ? (2016~)

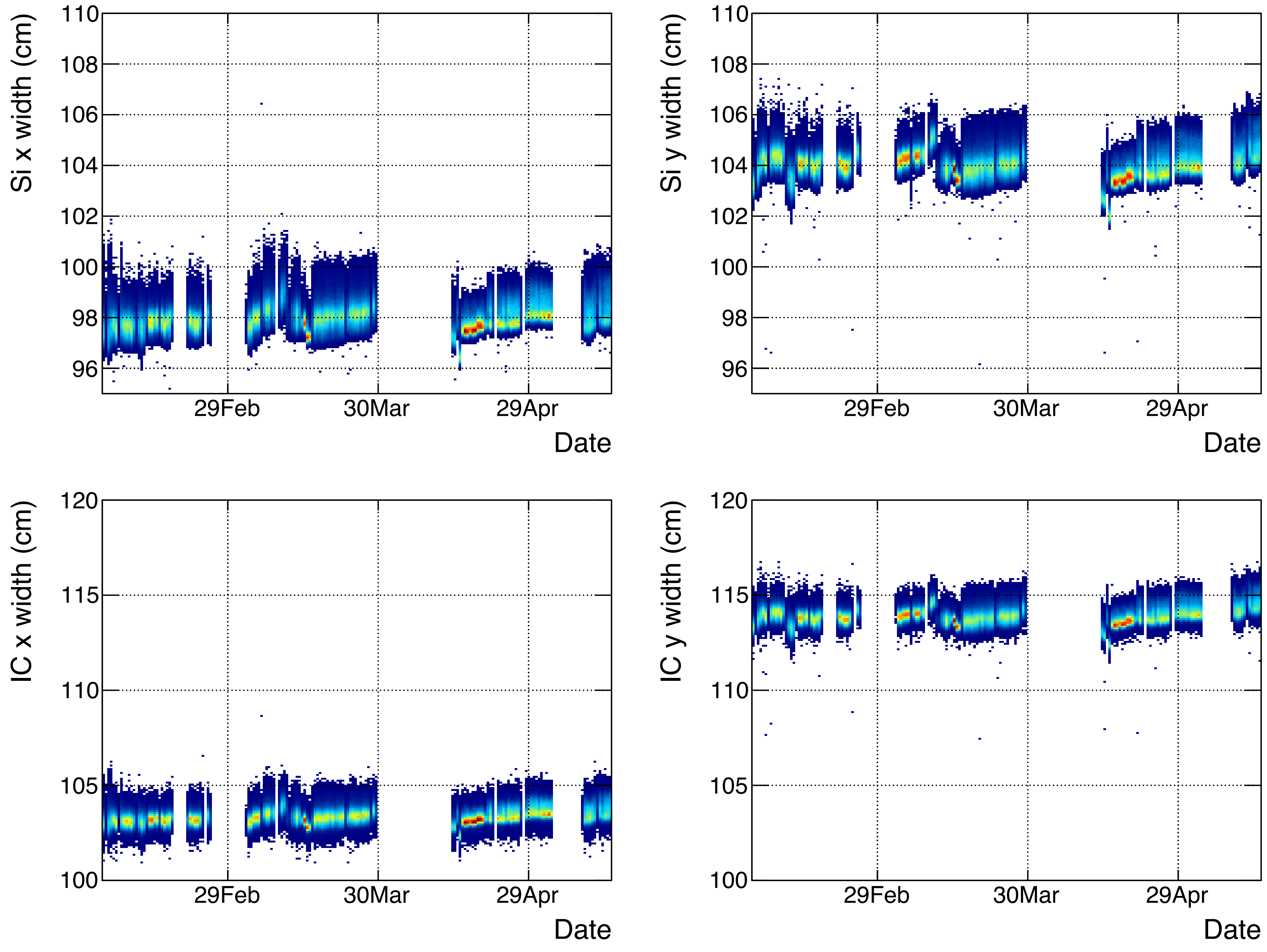
requirement for MUMON

- For physics,
  - the beam direction is within 1mrad (±10cm)
    - Cross check with INGRID (on-axis neutrino detector)
  - Si total yield (pC)/CT (ppp) is within mean ±5%
- For beam operation
  - Measure the beam bunch by bunch and feedback to the beam operation quickly.
  - Check the stability or reproductivity of the 2nd beam line.

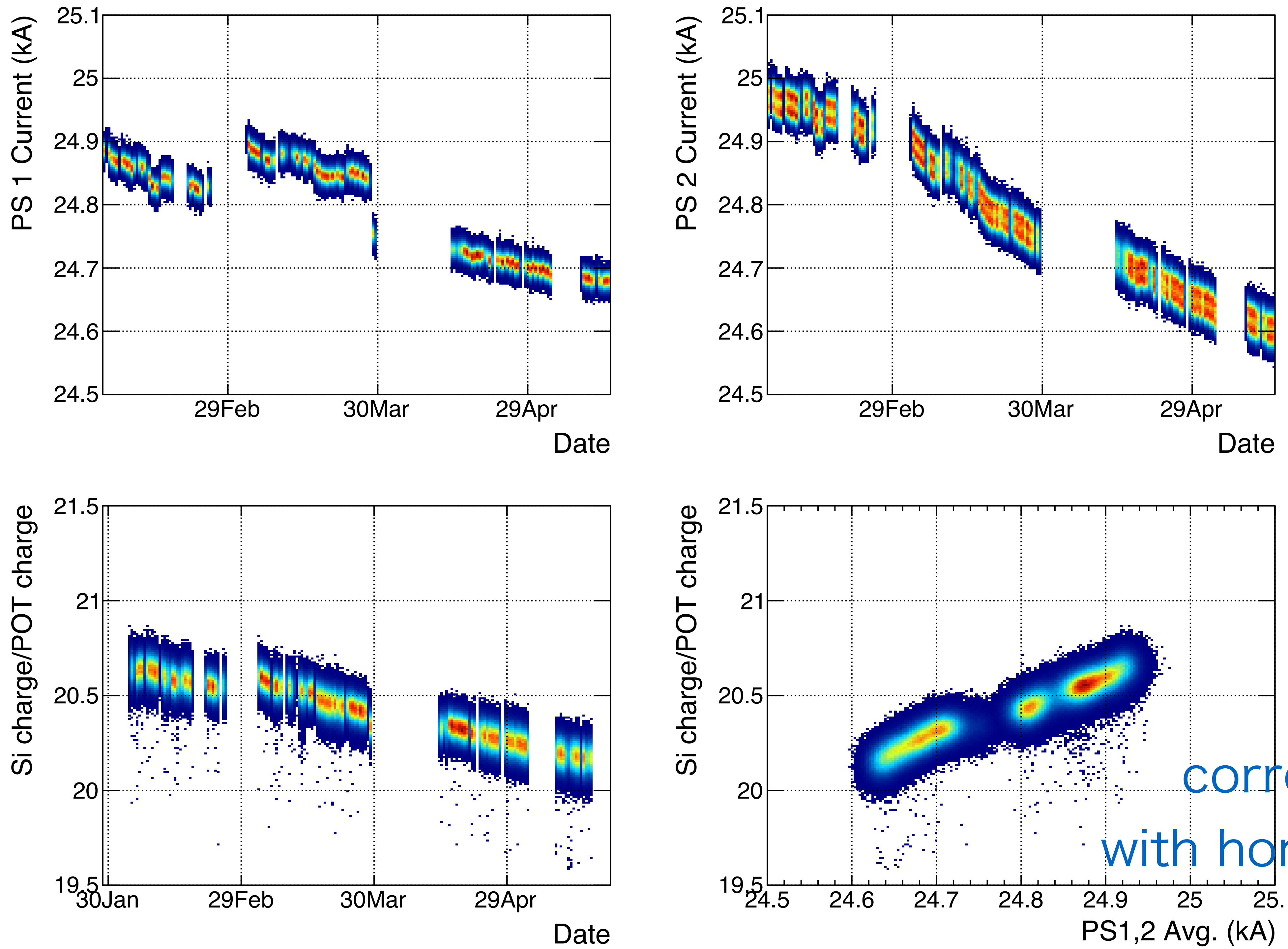
center stability for one run



width stability for one run



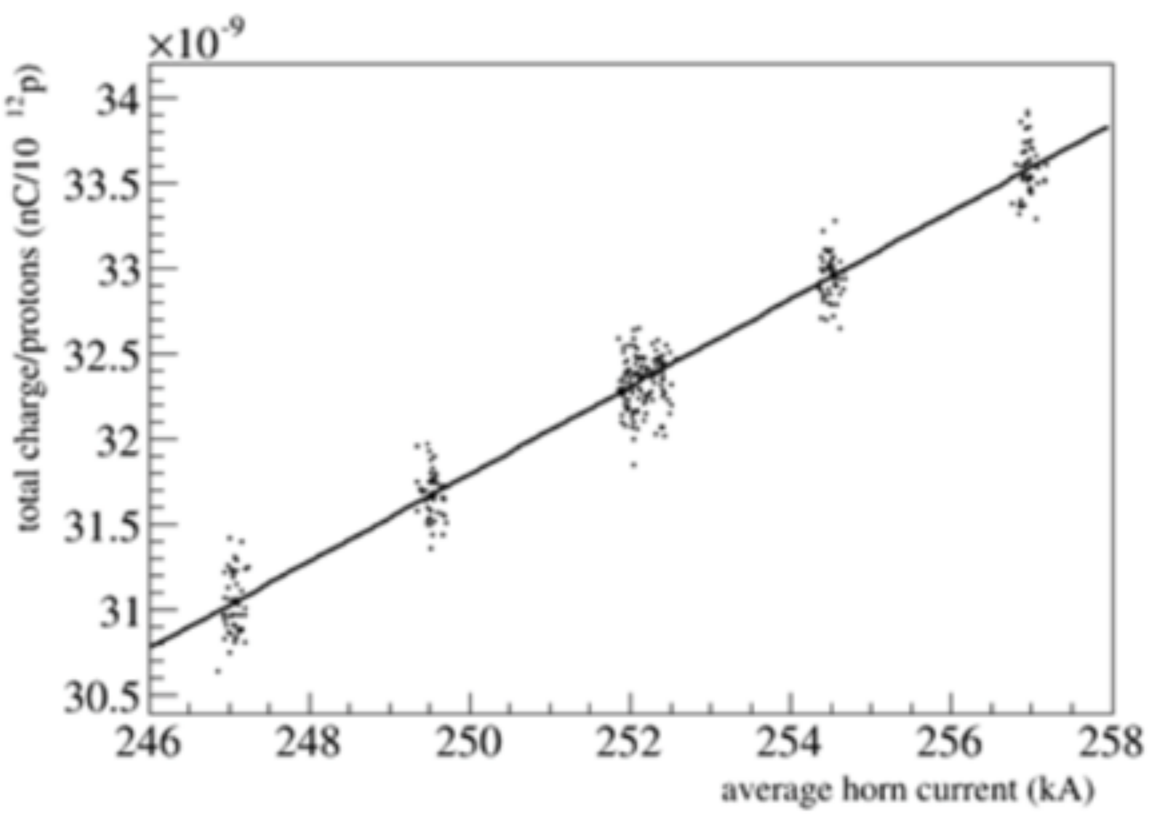
Si yield and horn current stability for one run

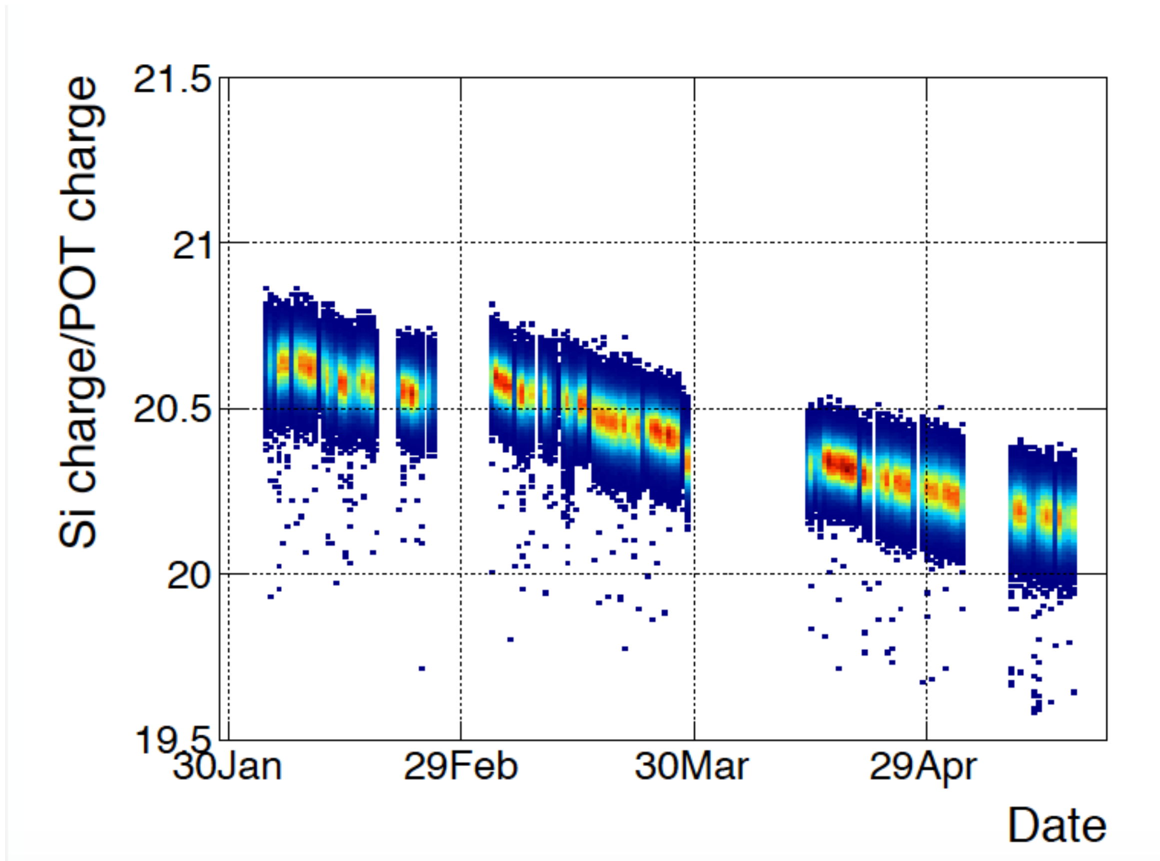


correlation
with horn current

Horn current correction

- separate the horn current effect from other effect (e.g. degradation of Si)
- Measure the yield by changing horn current and calculate the correction factor.
- We noticed the horn current at Power supply and the one at target.
  - Corrected with the current at power supply.





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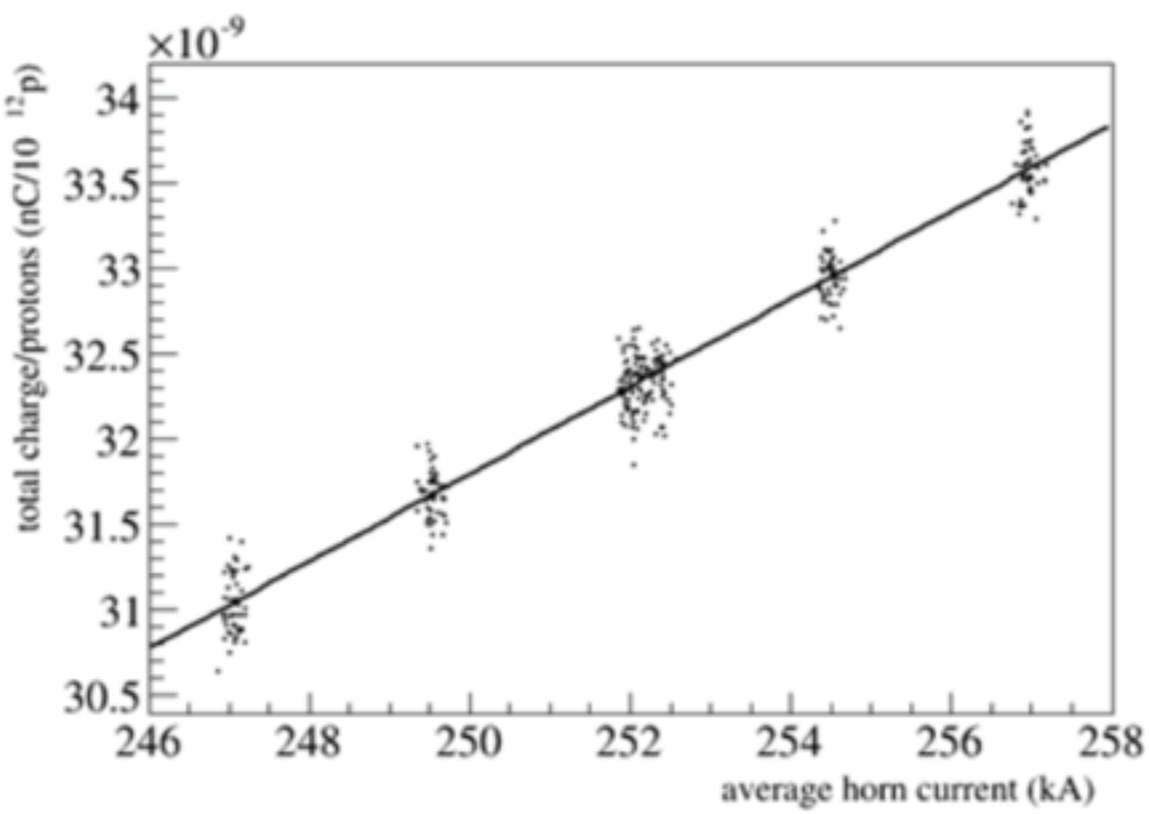
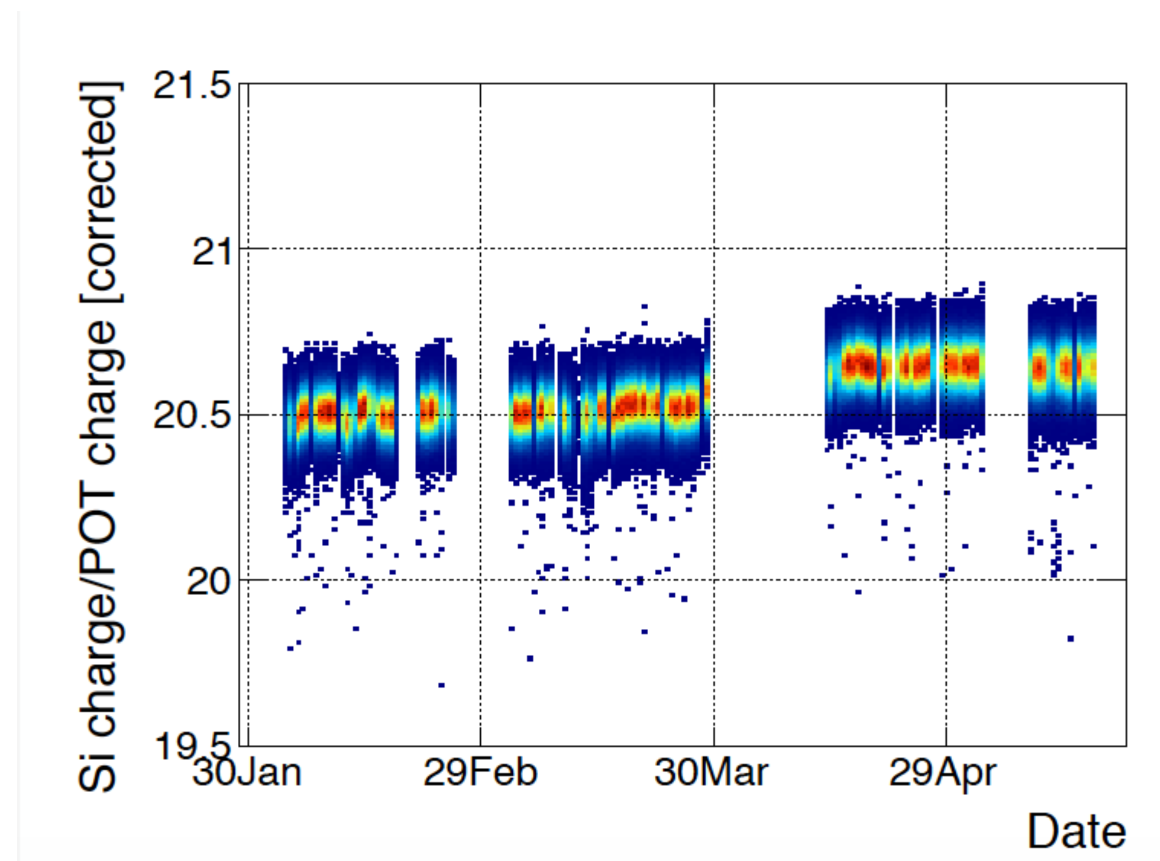
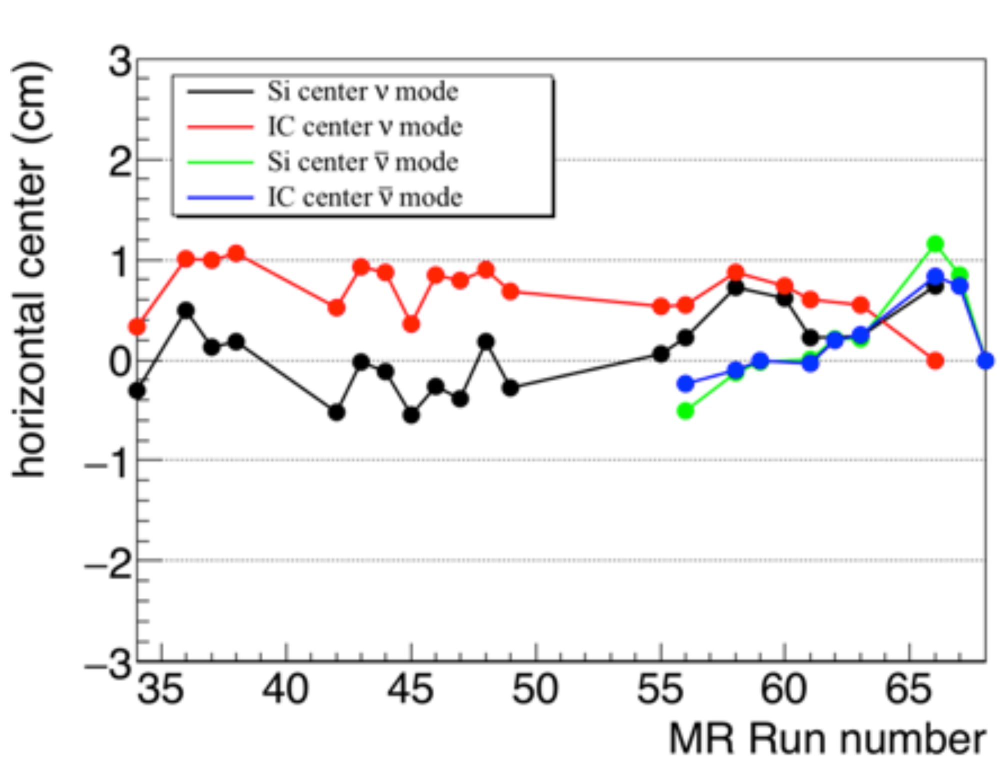
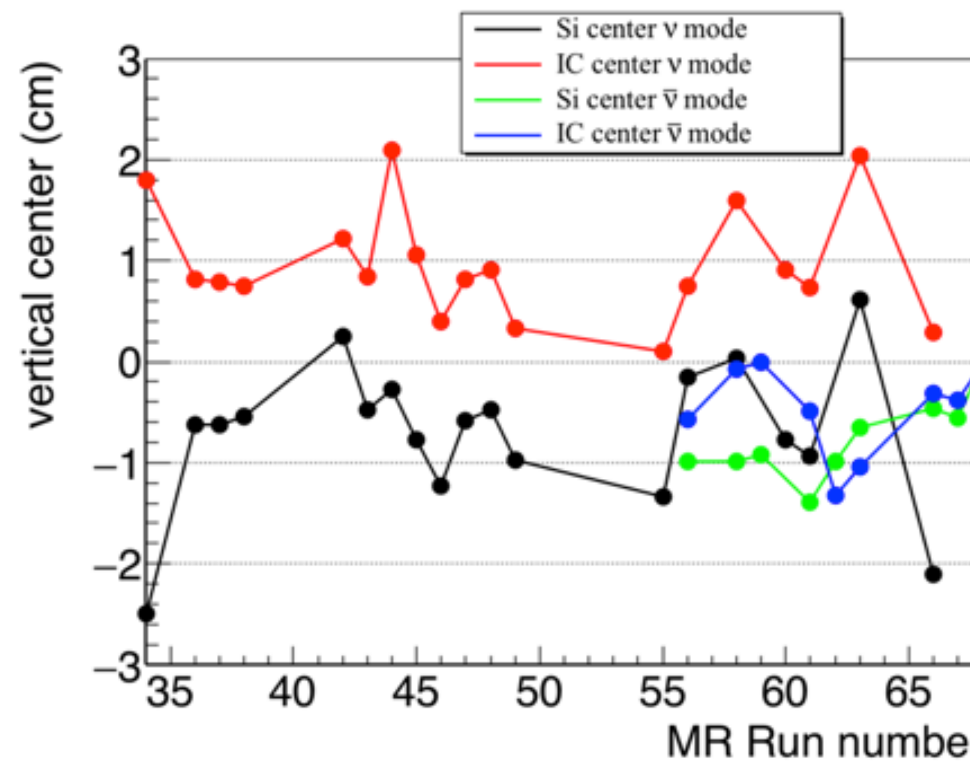
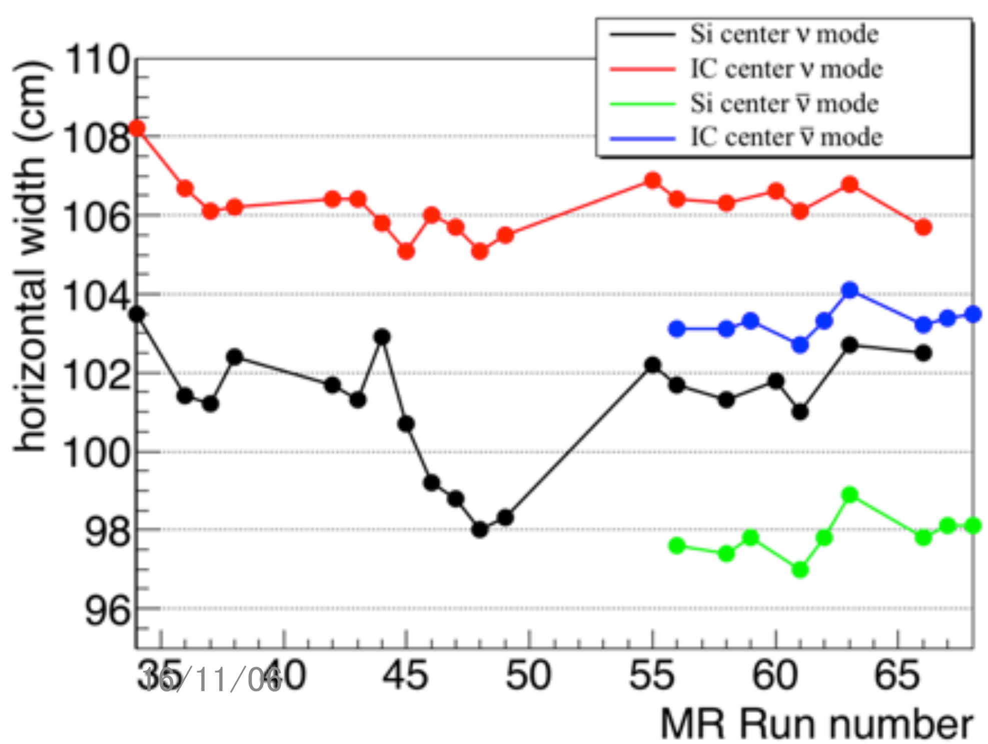


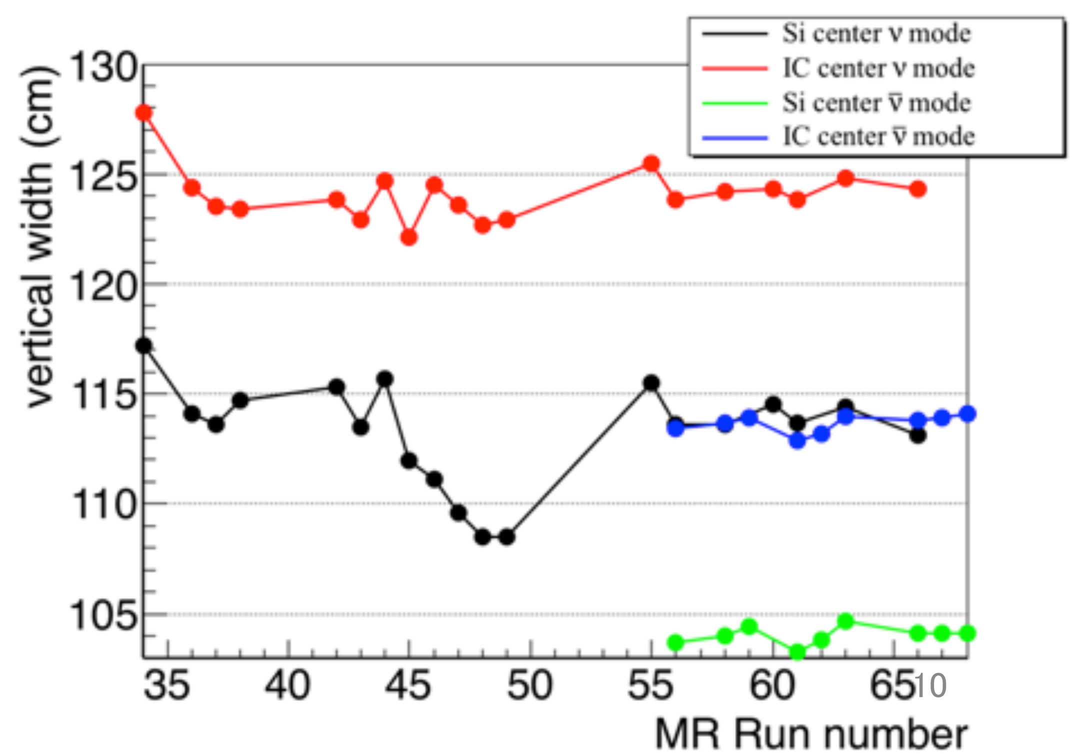


Long term history plot

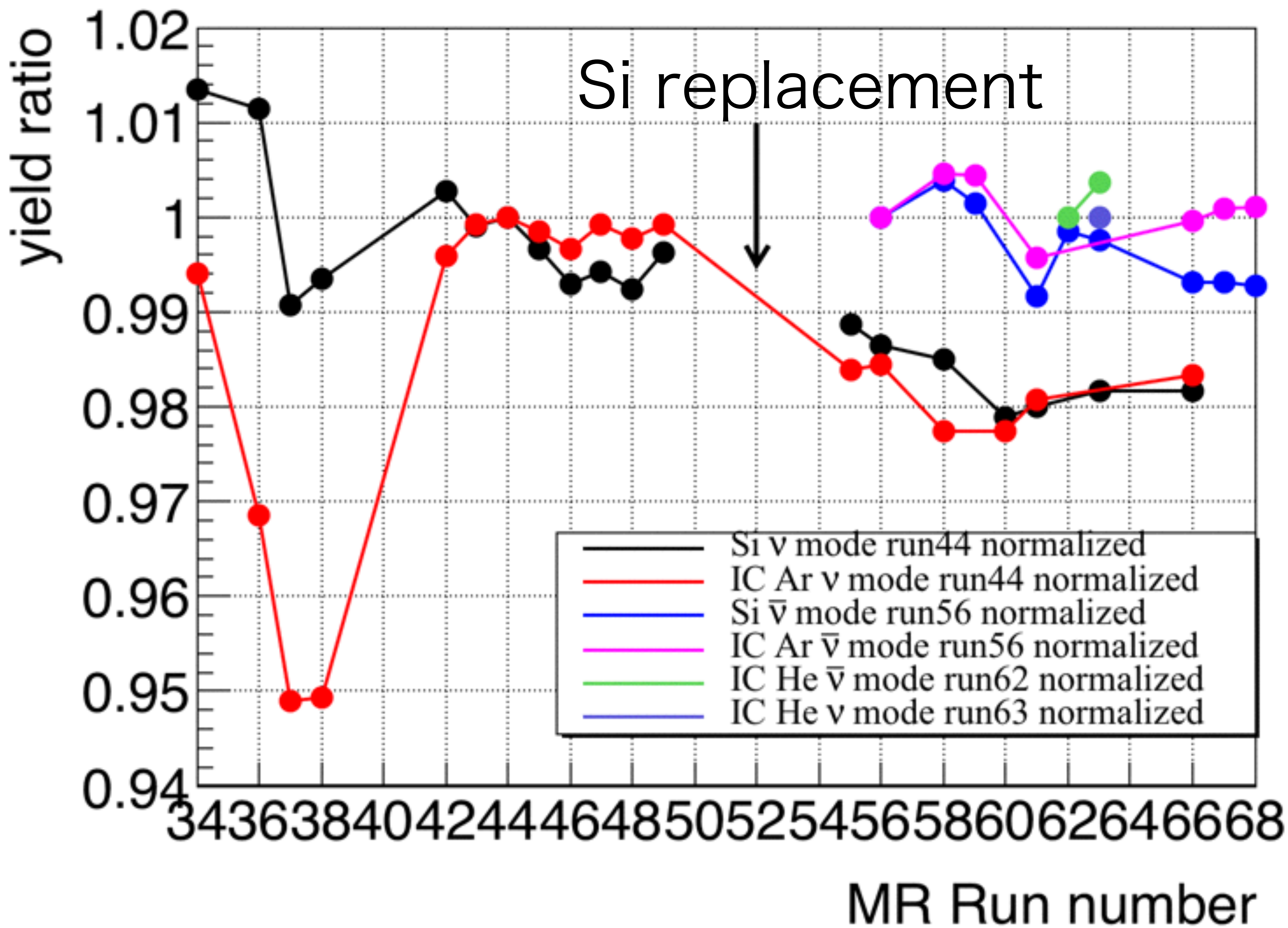




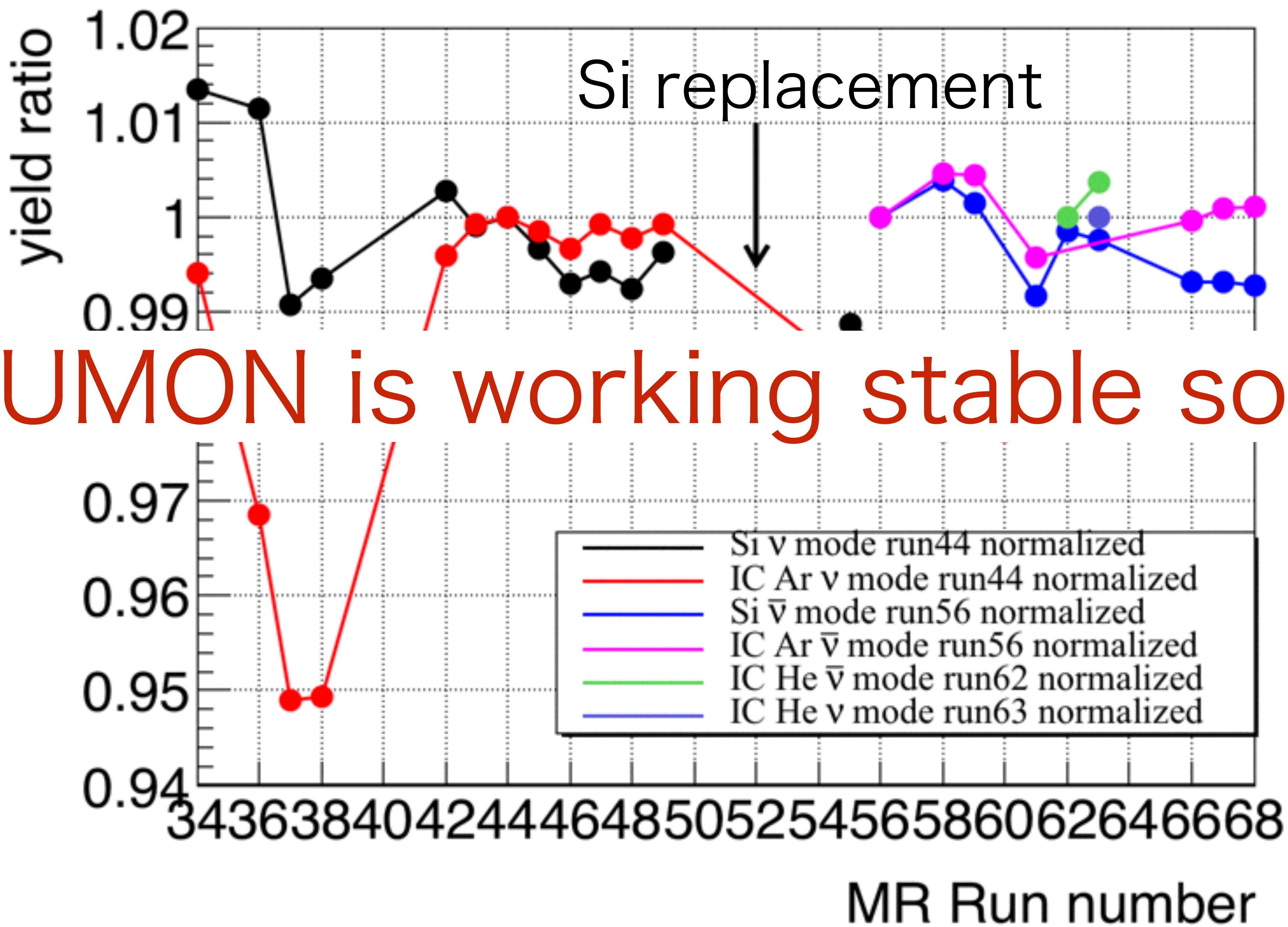




Long term yield plot



Long term yield plot

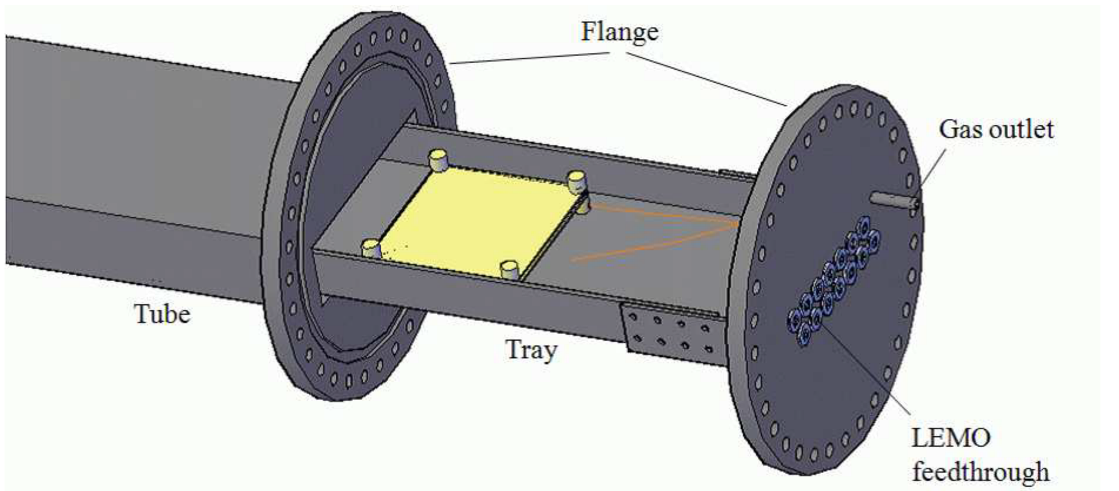


MUMON is working stable so far!

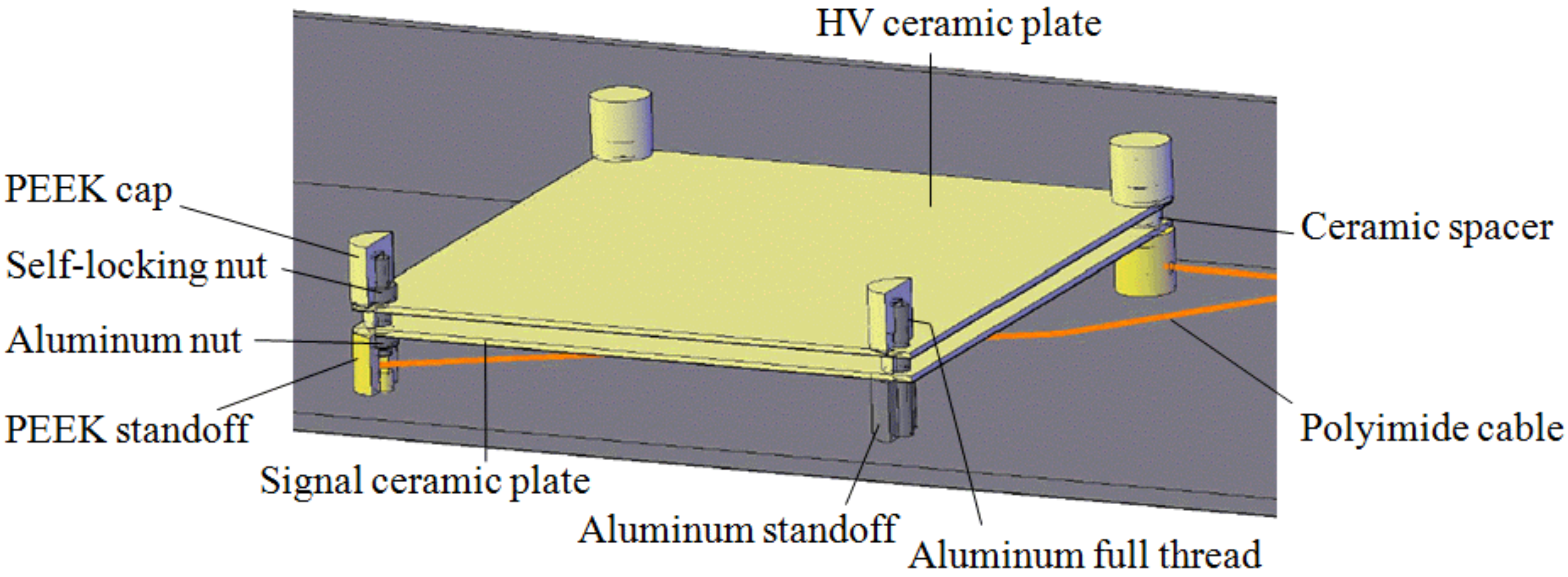
R&D
for Ionization chamber

Ionization chamber

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

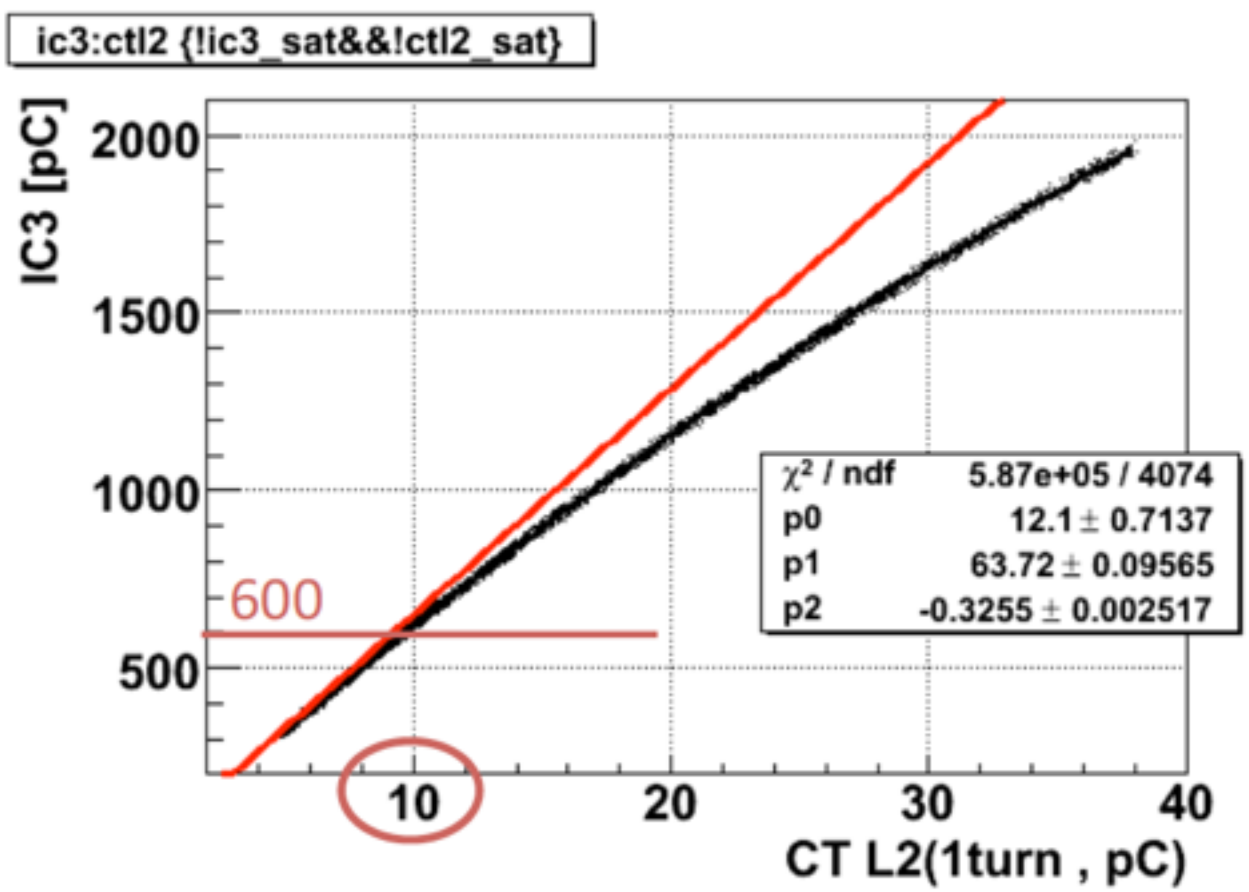


- N_2 gas : mixed for faster and stable response
- HV:200V



Gas change

- Previous strategy for the gas is changing Ar -> He to avoid the effect of non-linearity.
- We tested He in 2014.
- Established gas change procedure.-> Developed gas sampling system.

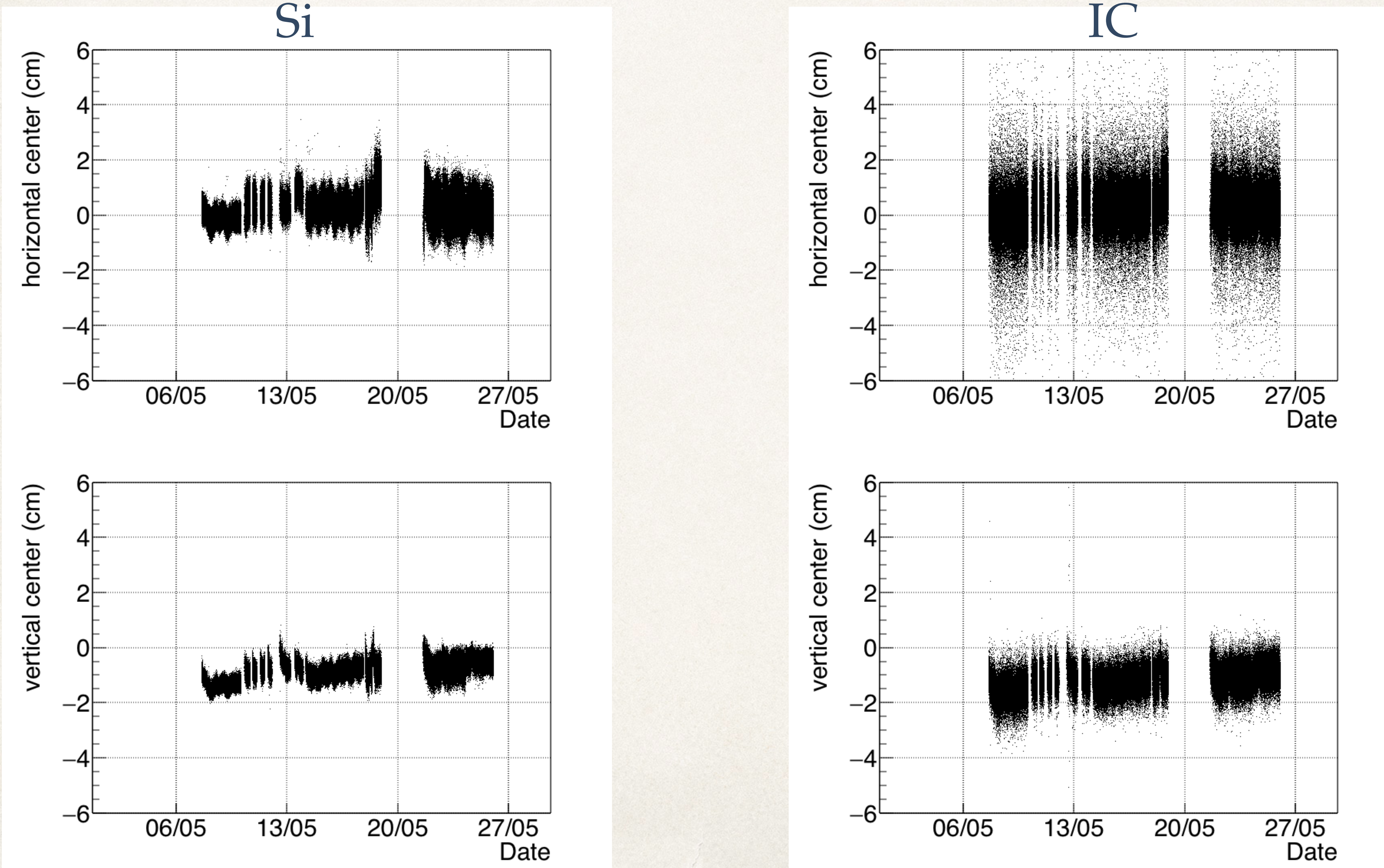


Linearity in beam test

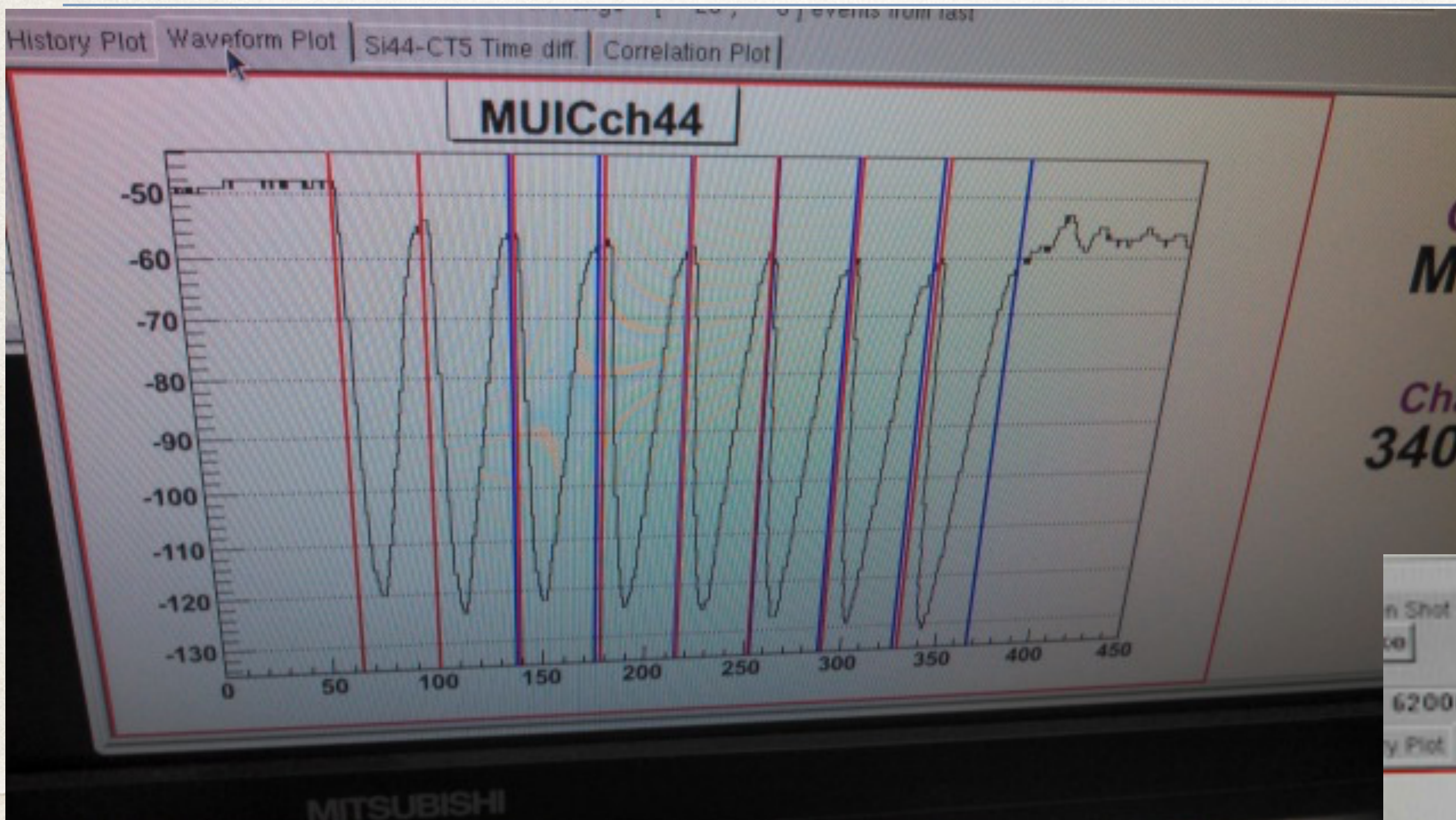
Gas sampling system

direction stability in run62 & run63

RHC mode



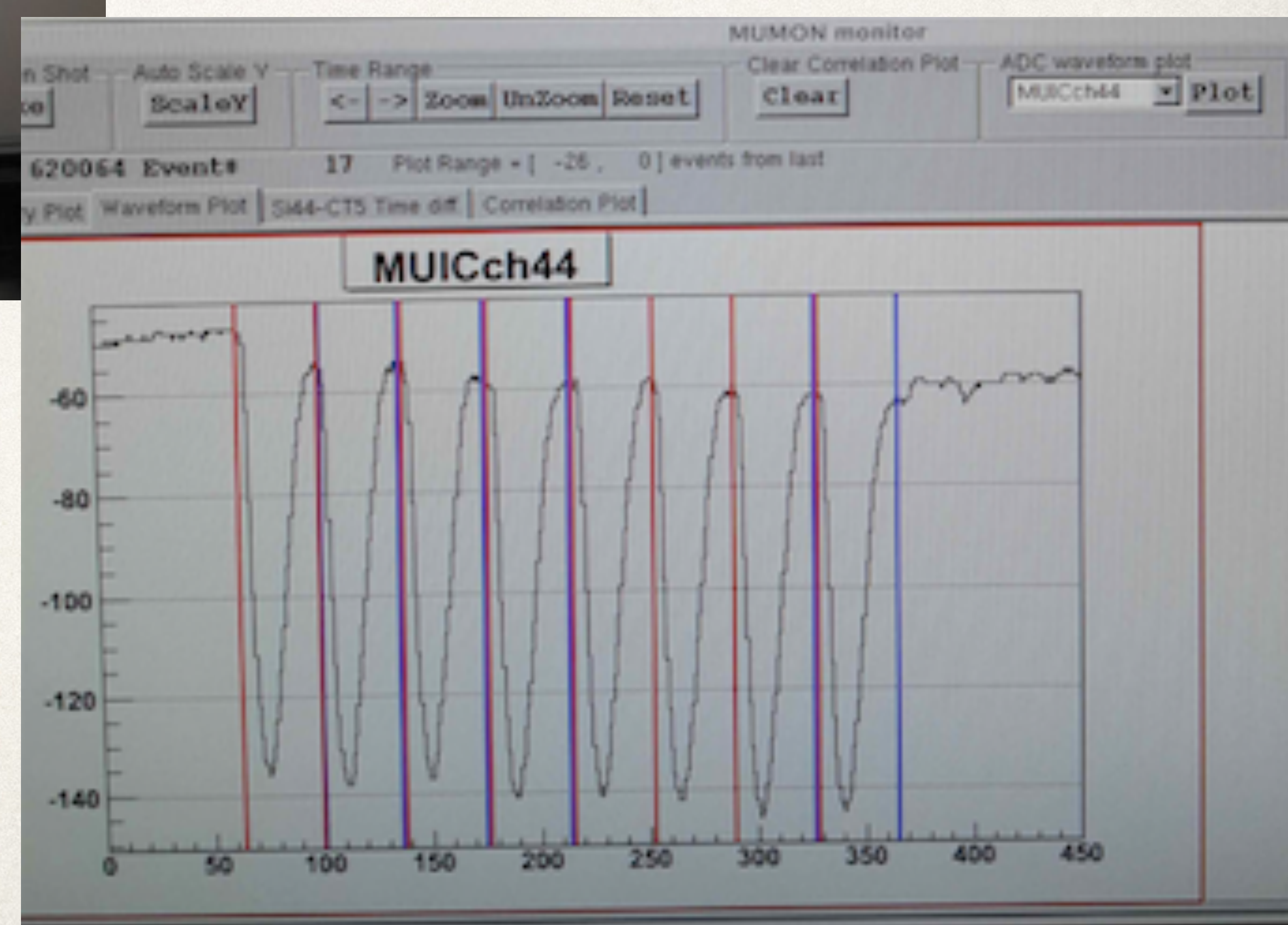
waveforms



The time decay constant become narrower when we applied higher voltage.

↑HV200V

HV250V→

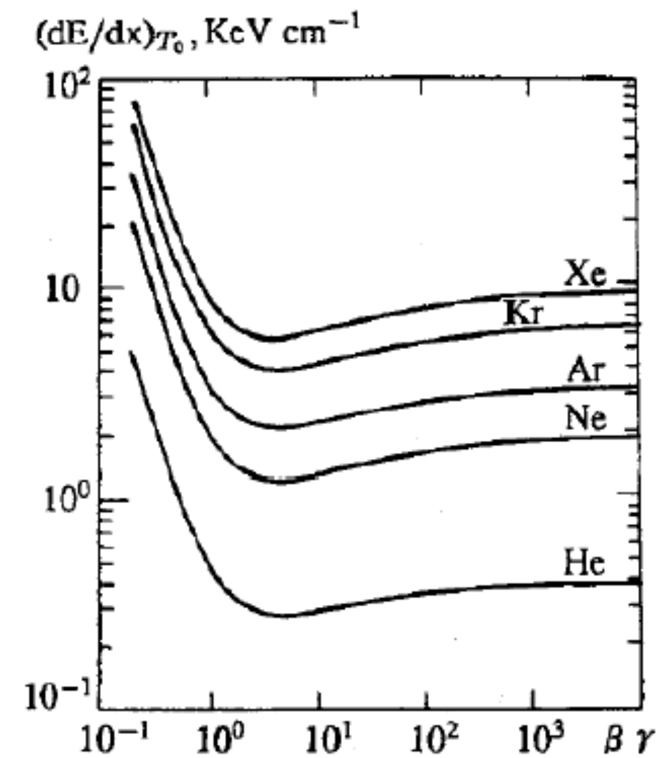


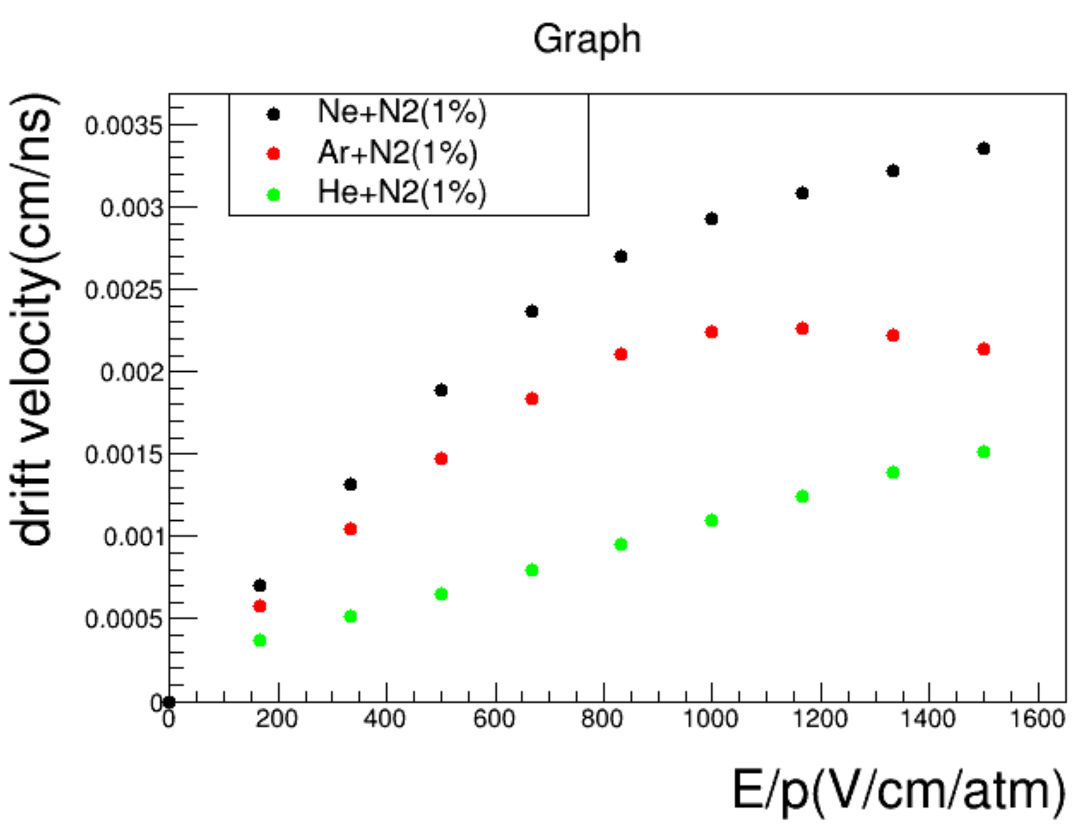
Signal

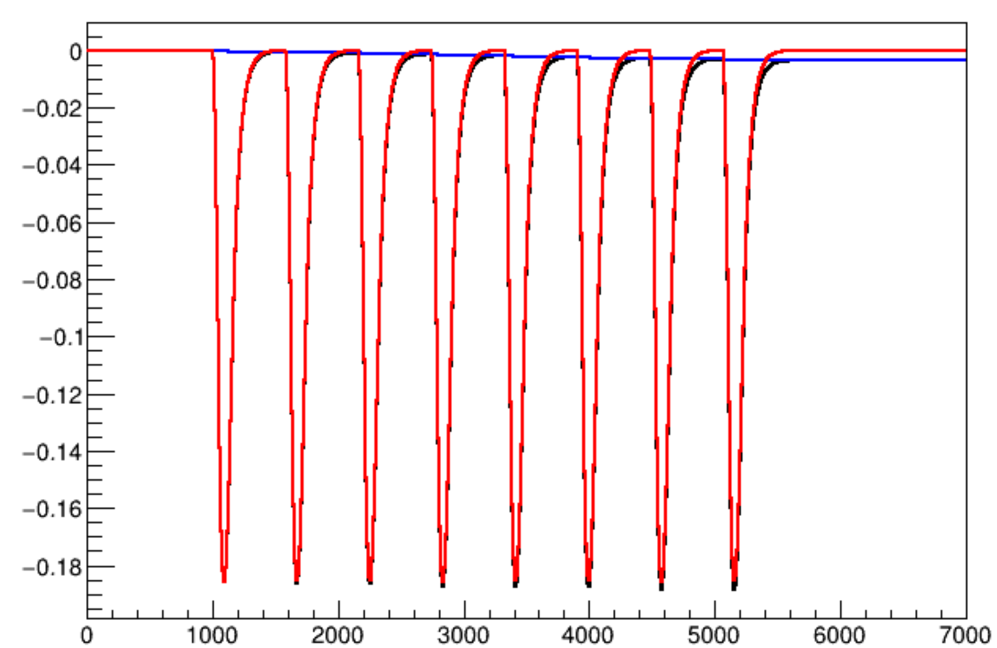
- Pileup due to the ion was observed.
  - Ionized He makes He2 molecules and quickly transfers its charge to N2 in our situation.
  - N2+He2 drift velocity is faster than Ar one.
  - Slower decay constant than Ar.
- Large fluctuation due to small S/N ratio.
  - The yield become 2/3 for RHC.
  - Gas replacement takes ~10 days and can’t change so frequently.

Other Gas ?

- Simulated by Garfield++
- calculated drift velocity of Ne.
- seems good property but it's too expensive now!



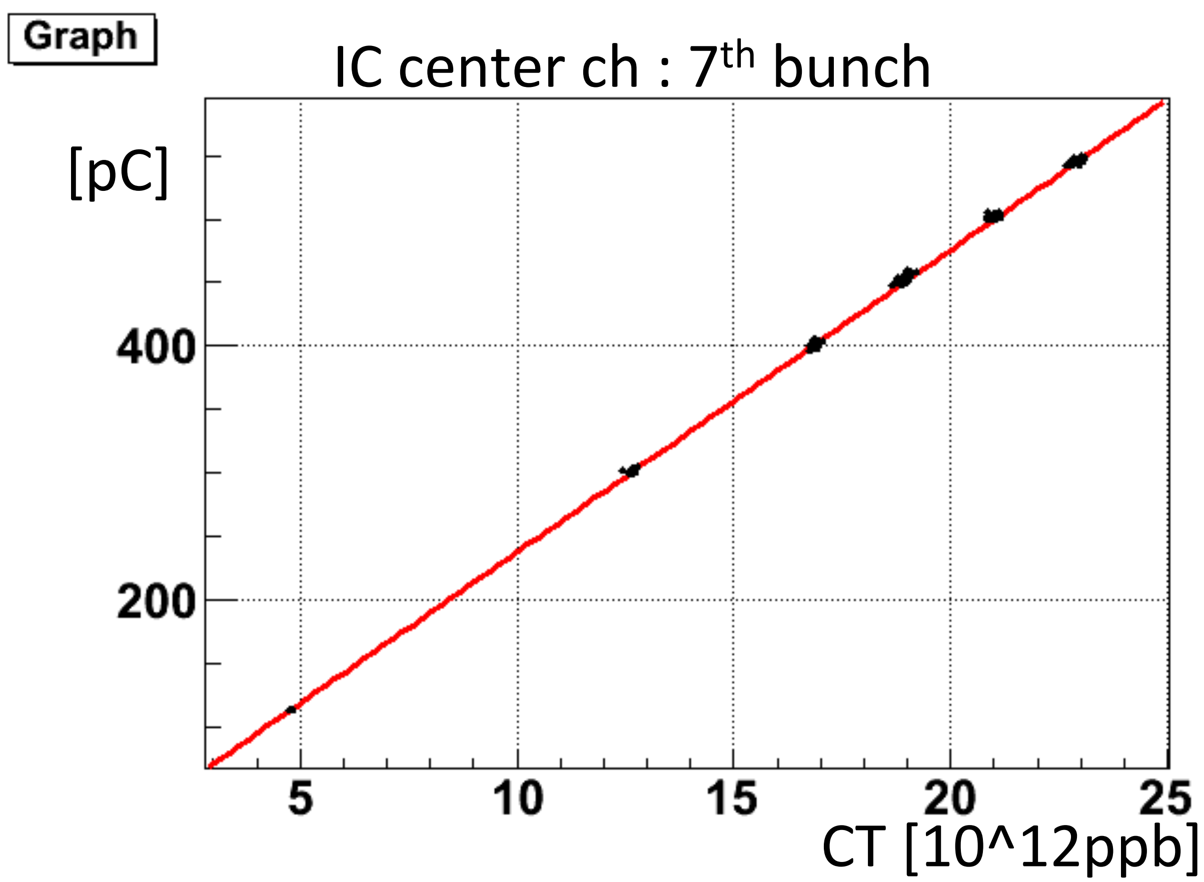




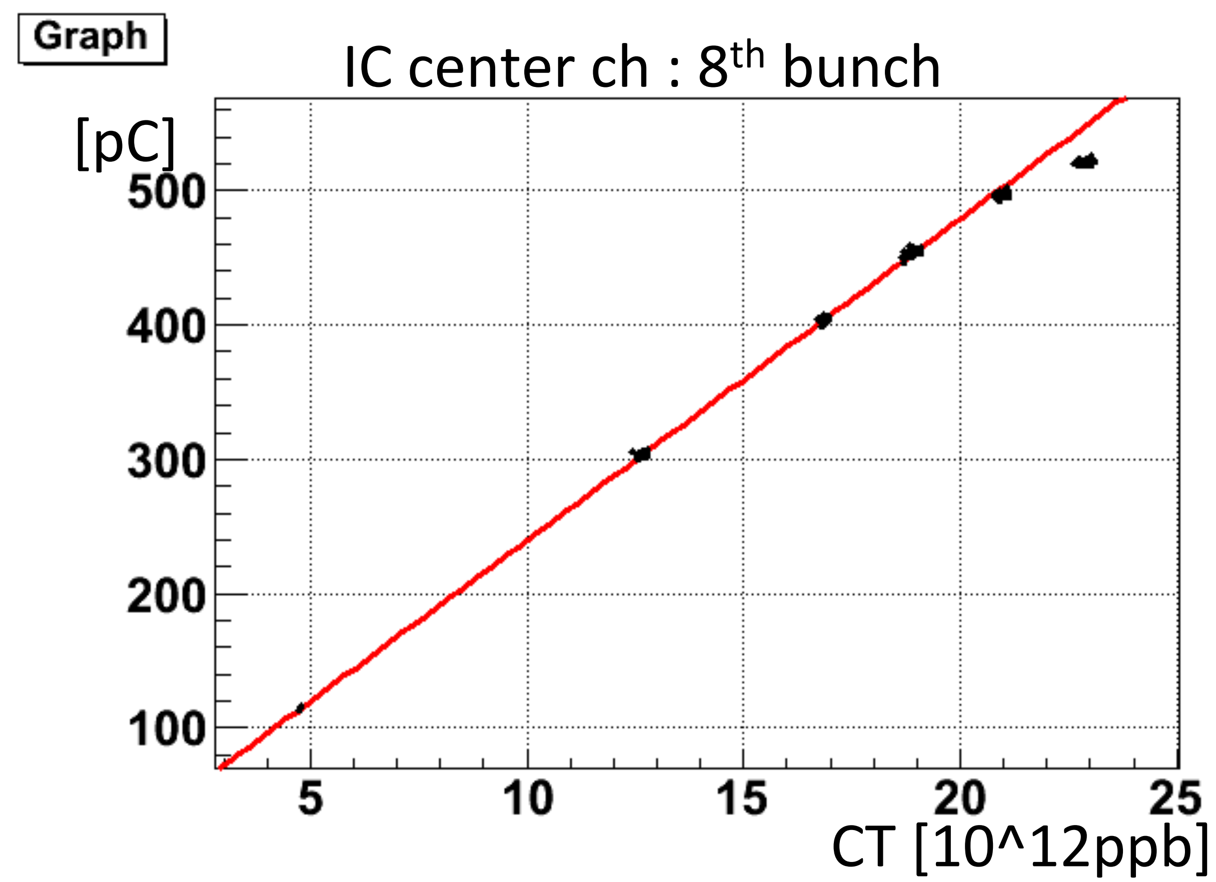
simulated signal

Non linearity at last bunch

- We decided to keep using Ar for a while.
- non-linearity was observed in the latter bunches.
- Expected electron recombination but this may happen another reason.

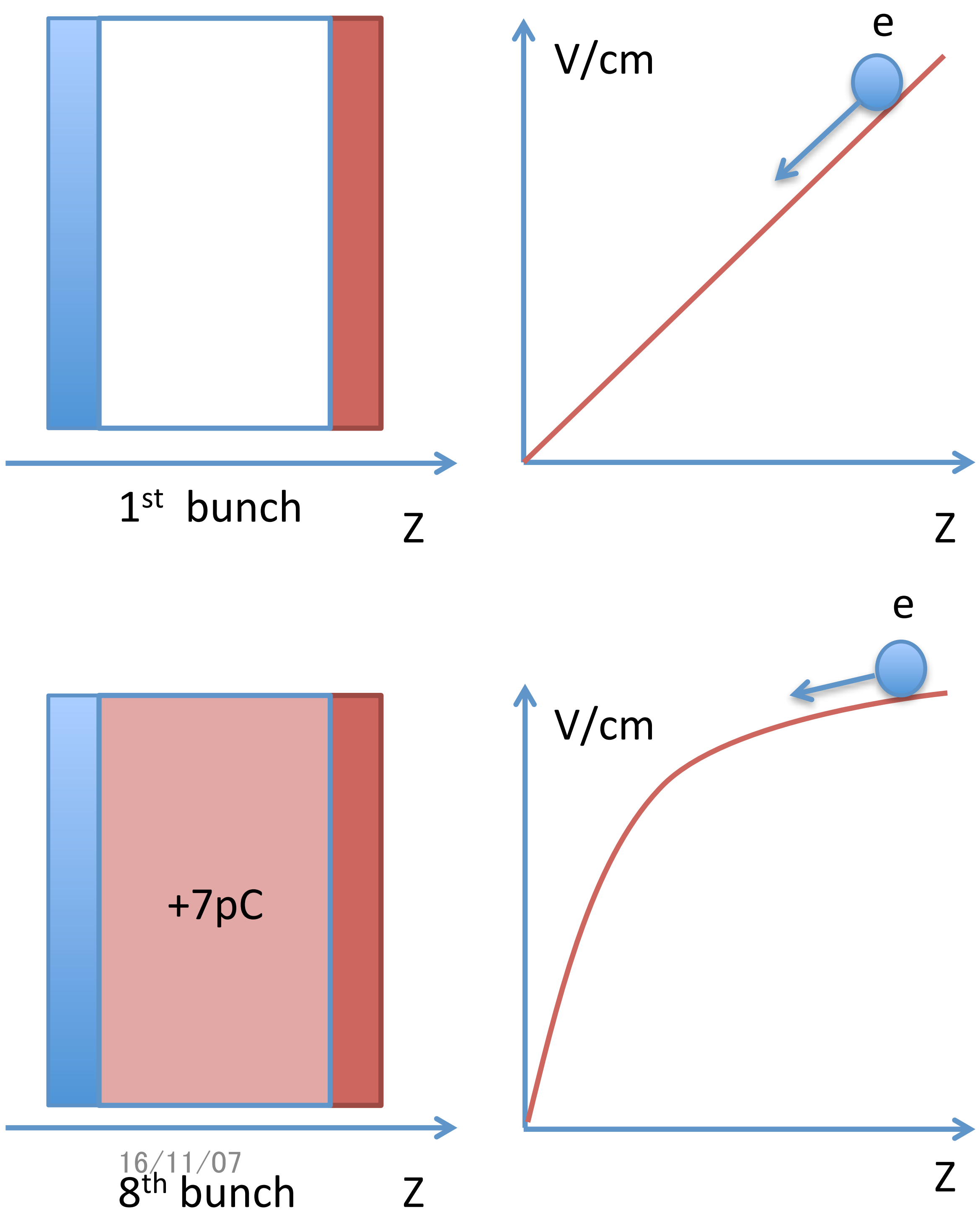


7th bunch

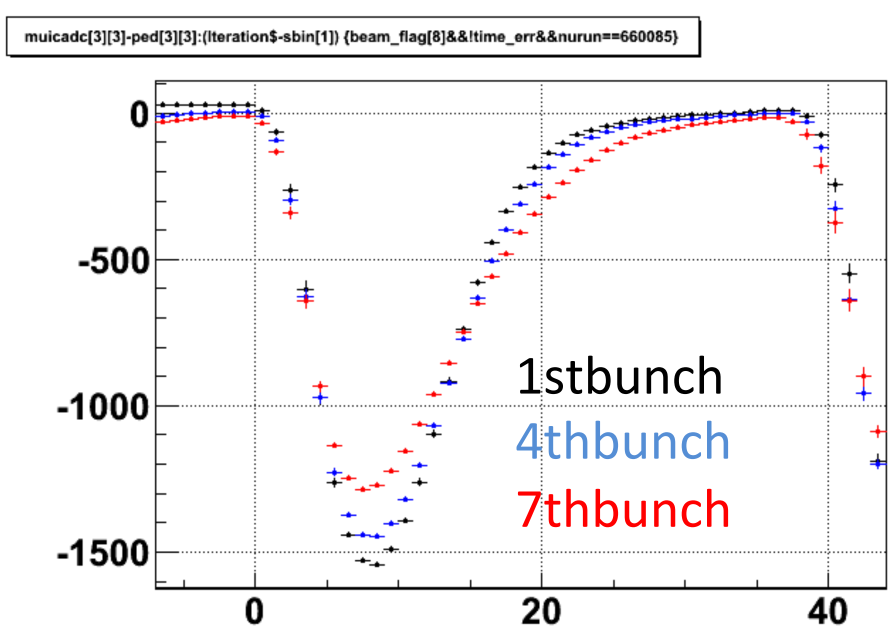


8th bunch

electric field distortion by ion



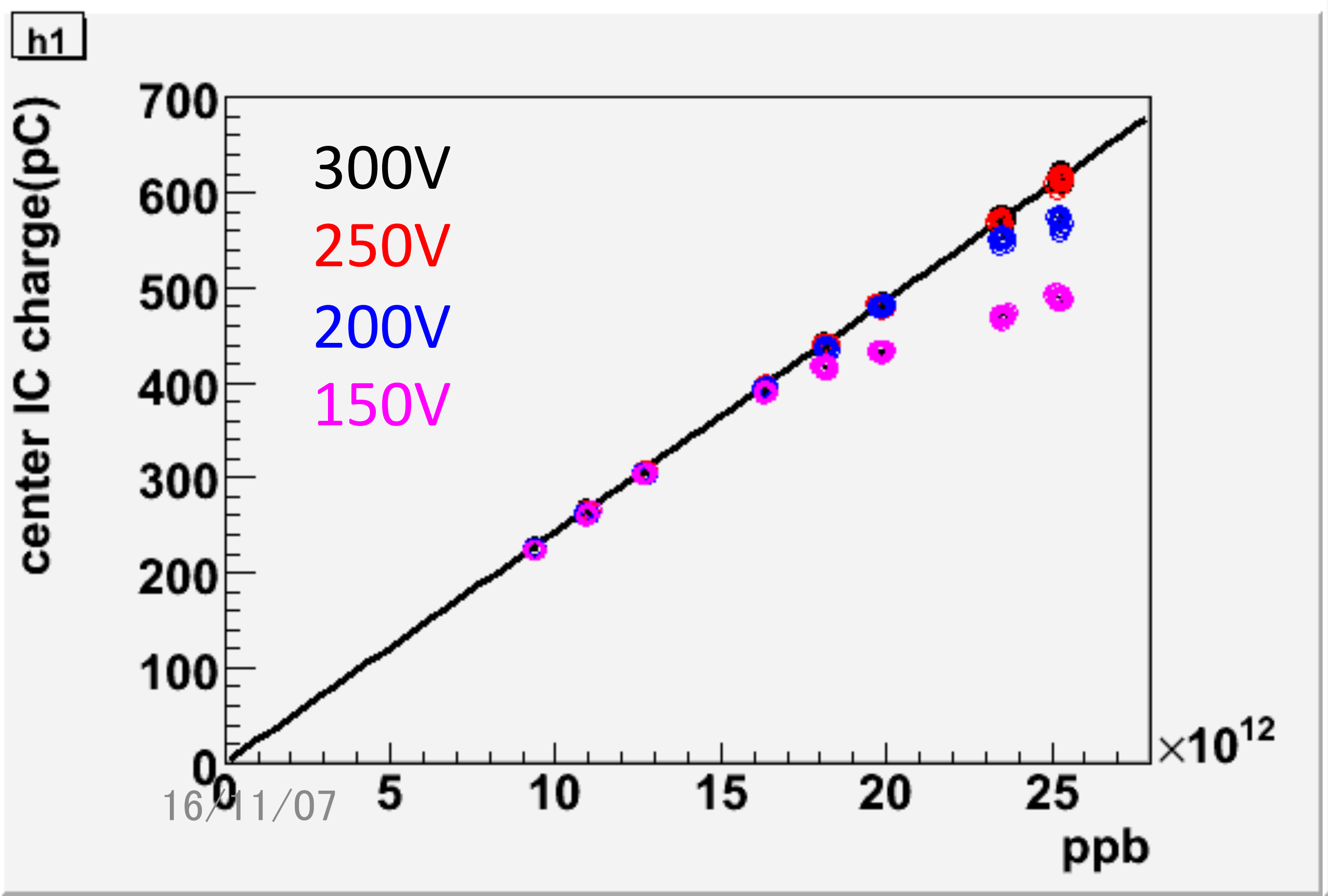
- Due to the ions, the E fields distorted and make the drift velocity slower
  - Can't reach to the electrodes within the integration time.
  - Signal shape is also changed.



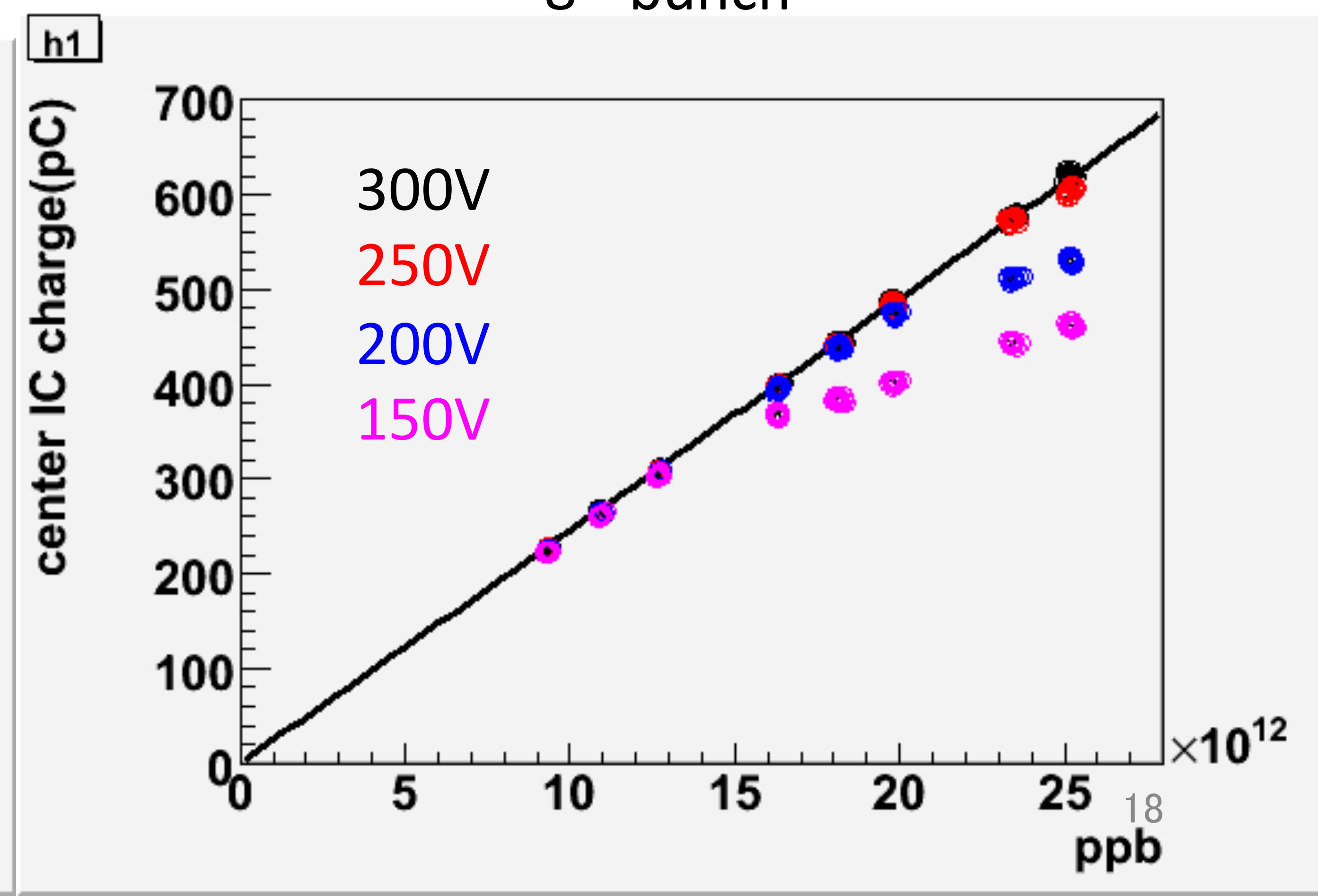
Operation with higher bias voltage

- Applying higher voltage the easiest way.
- Intensity scan with various HV
- Linearity recovered with higher voltage

7th bunch



8th bunch



remaining concern

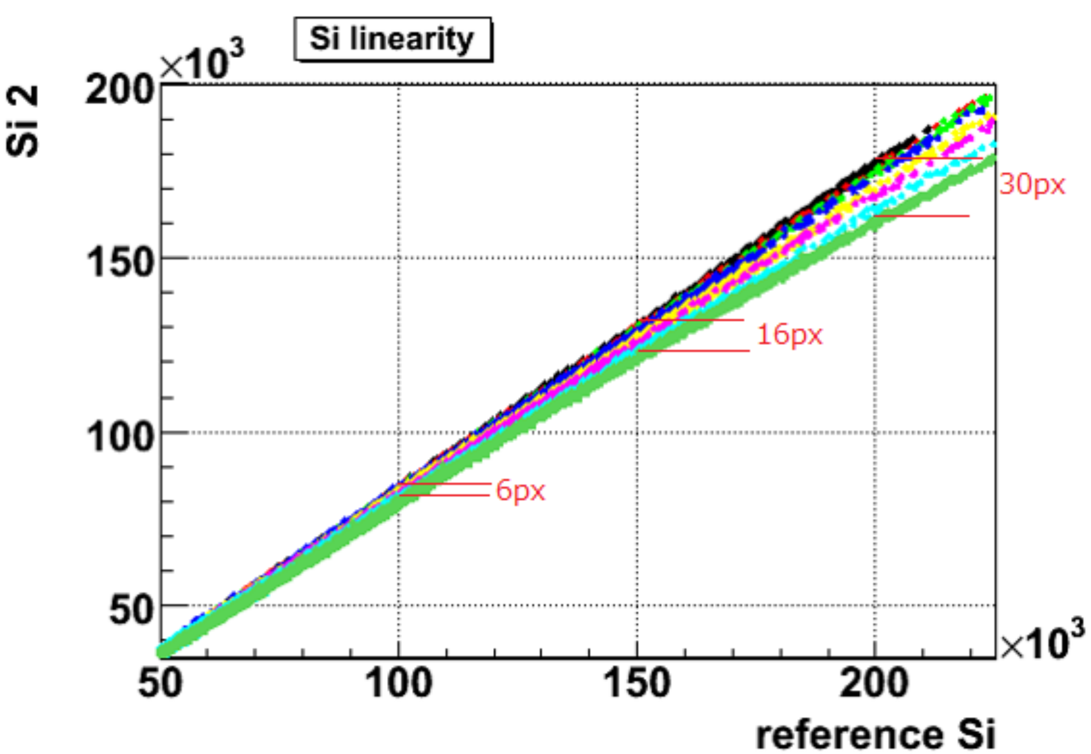
- Leak current was observed ~300V and we cannot apply higher voltage.
- Operating 270V now (~420kW).
  - If we can apply higher voltage ~400V(?) 1.3MW beam operation will be possible…
- Another option
  - Lower gas pressure operation ?
  - Thin gap (1mm spacing?) chamber ?
  - Giving up using Ar when FHC?

- Similar problem was already studied by Bob Zwaska in his Ph.D thesis.
- He did some theoretical calculation in his thesis and we are trying to evaluate it qualitatively with his calculation.

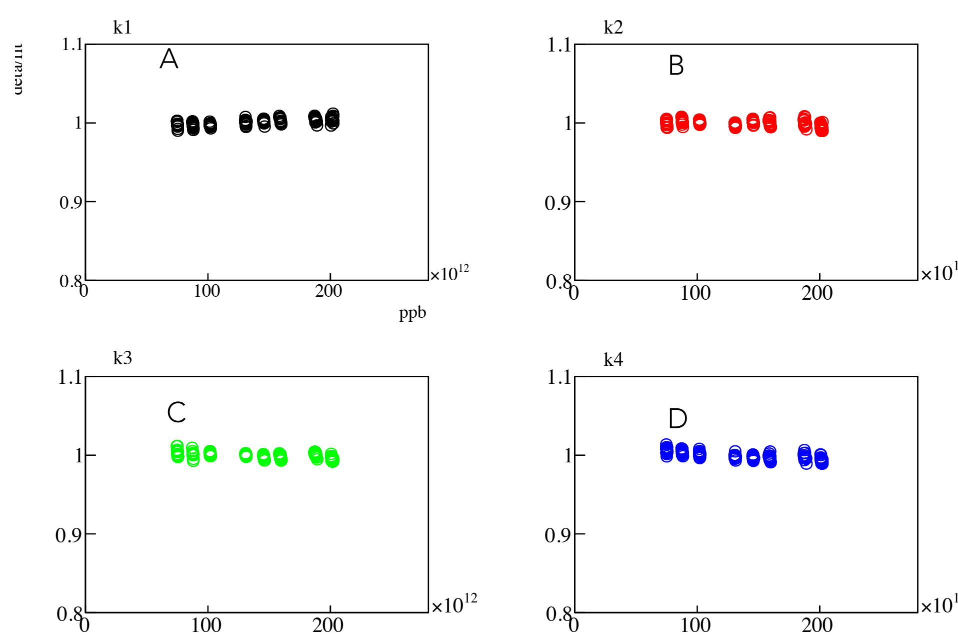
Other R&D status

R&D for semiconductor detector

- Si is believed to be not so radiation-hard.
  - Previous study Si yield will decrease after 8.0x10^20 POT for FHC(->3.2x10^20POT?).
- In this estimation NIEL scaling is used.
  - electron dose -> neutron dose.
  - Unreliable these estimations.
- Hints from non-linearity but too small effect in our situation (just 1% difference)

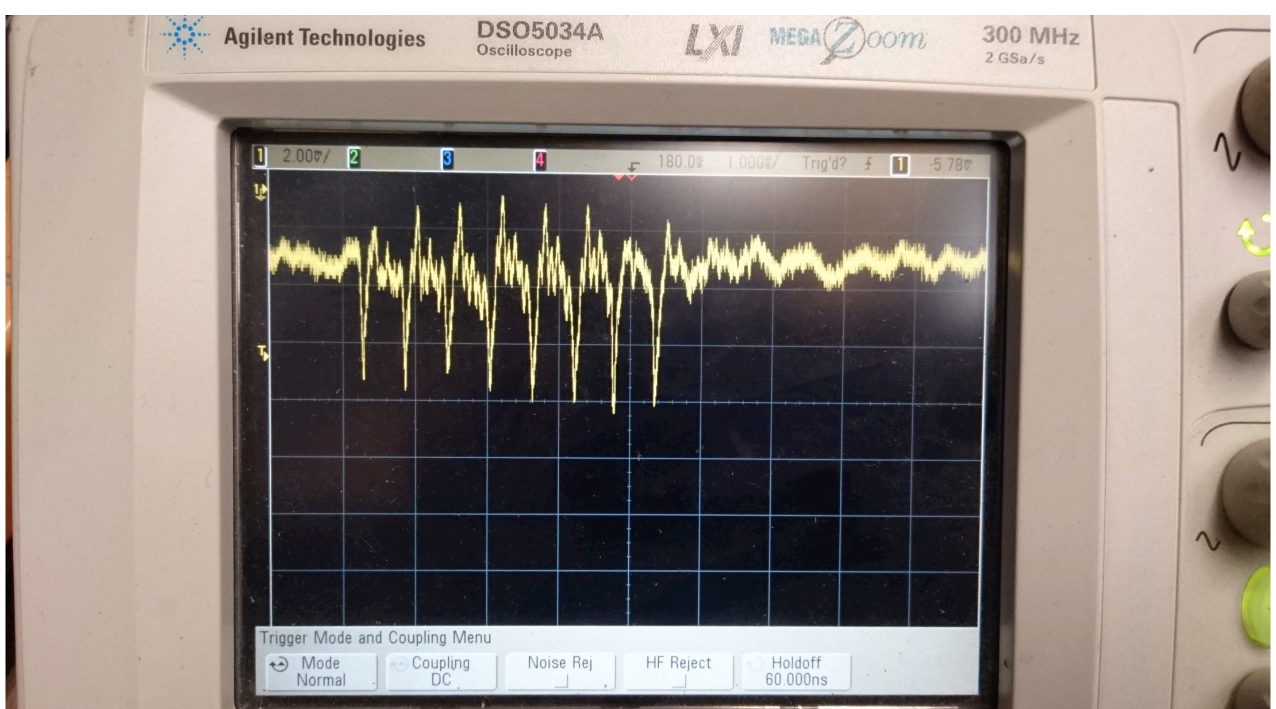


Data/Fit for each Si

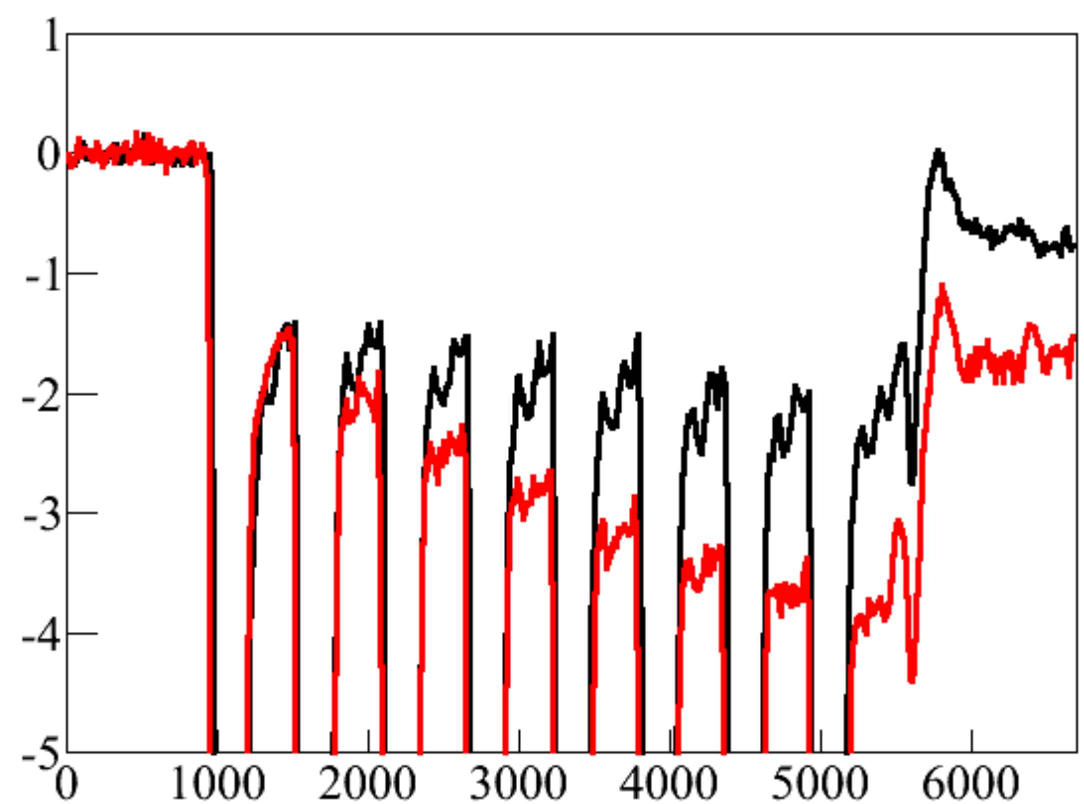


Diamond and SiC detector

- Similar structure to Si.
- Both of them is believed to be radiation hard.
- SiC signal is too small to use as muon monitor.
- Diamond detector response depends on the crystal quality.
- Study is stacked mainly due to lack of man power…



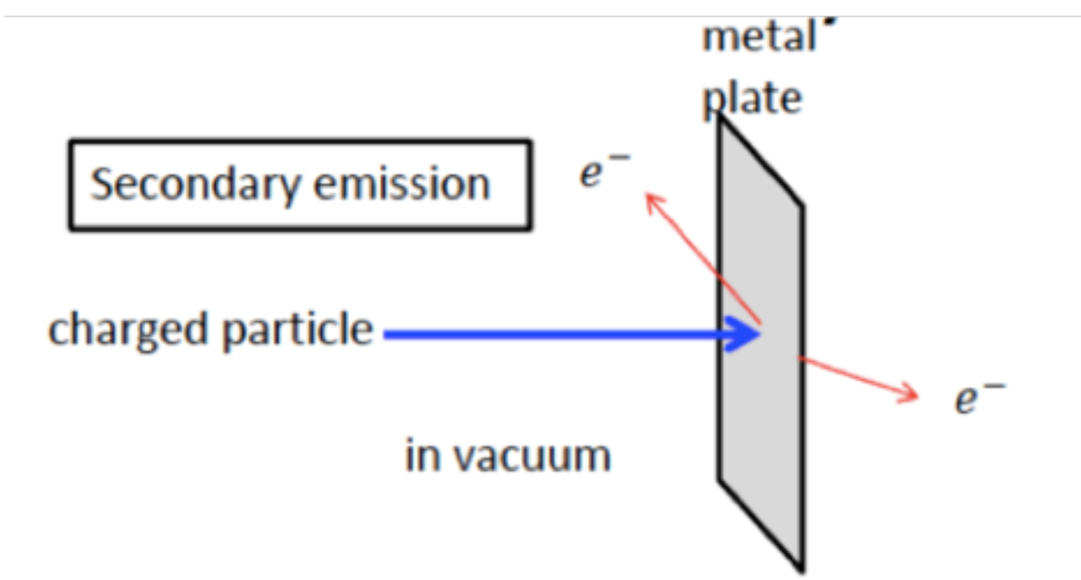
SiC detector signal



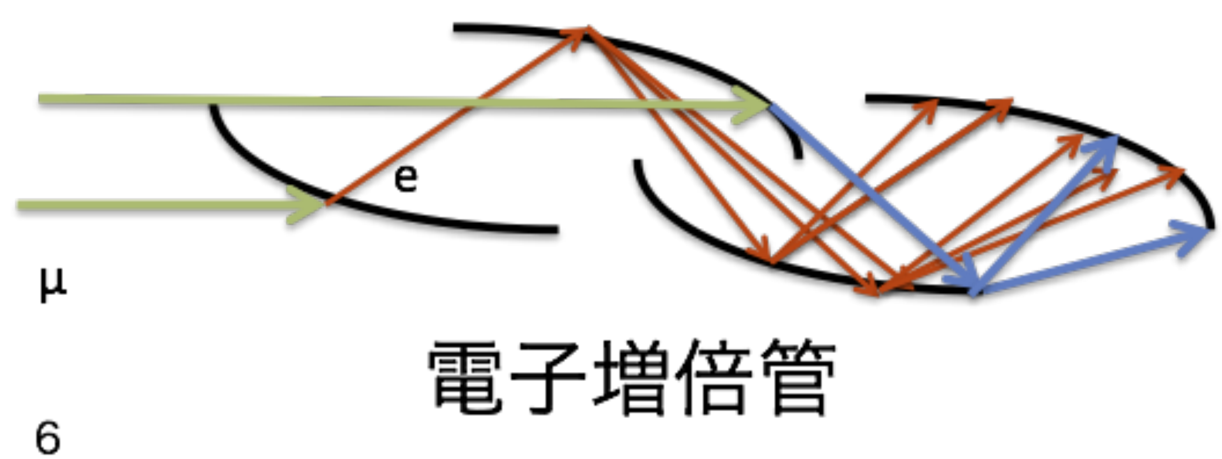
diamond detector signal

PMT as Muon Monitor

- based on Secondary Emission Monitor
  - SEM is working stable in rad-hard environment.
- SE yield should be small for muon
  ->Multiplication-> EMT!
- PMT is the easiest for demonstration of this principle.



信号は初段でのSEがdominant



電子増倍管

gain calculation

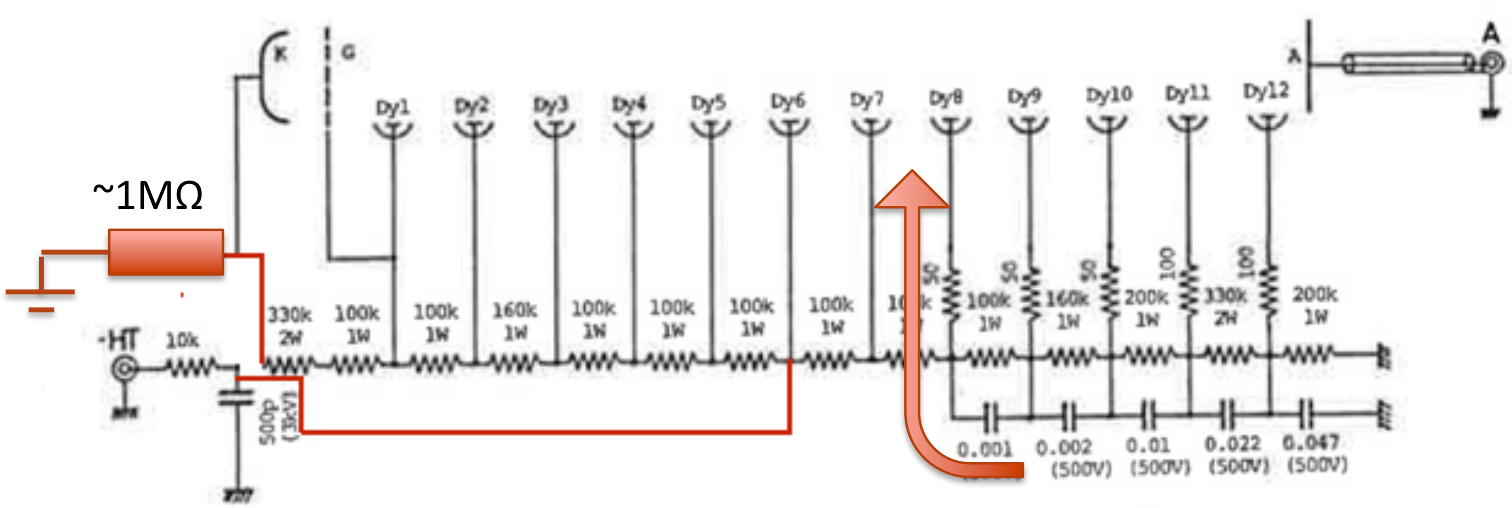
- Assuming SE electrons are emitted only from the first dynode, the yield can be written as:

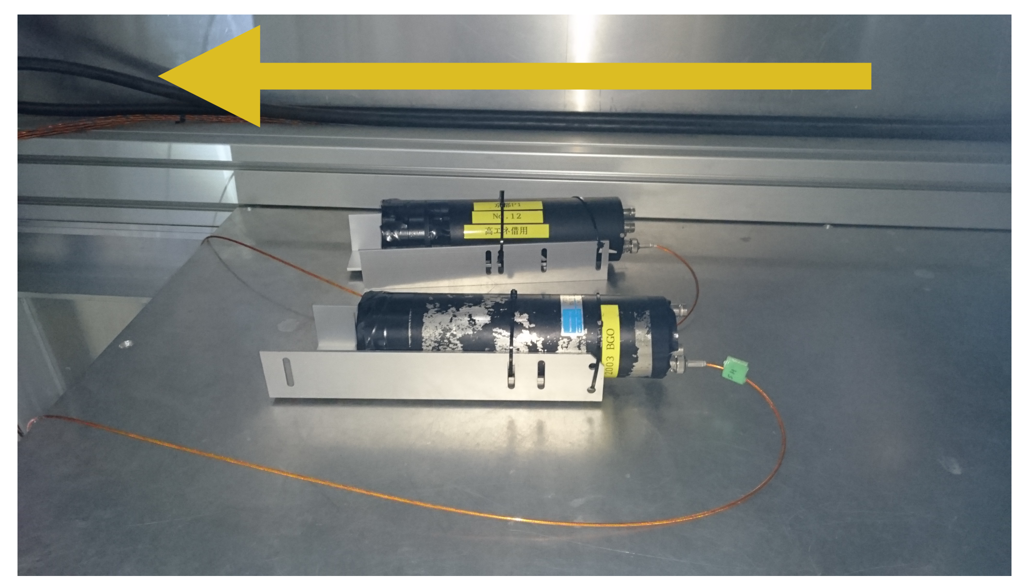
$$Q = e \cdot A \cdot \phi \cdot \delta \cdot N \cdot G(C)$$

ϕ:flux: 9.72e4/cm2/10^{12}POT A:area of detector: 2.5x2.5cm^2 δ: SE yield G:gain

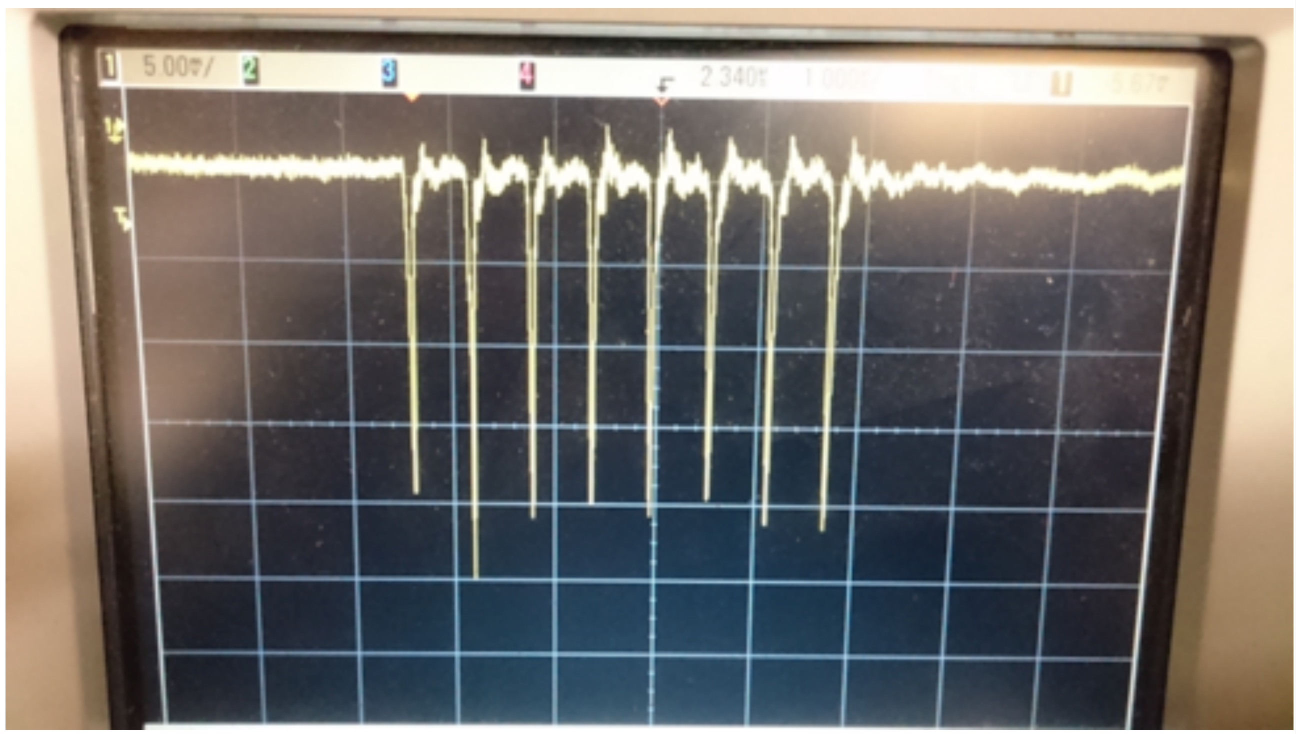
- G=10^3-10^4 gain is needed in our case.

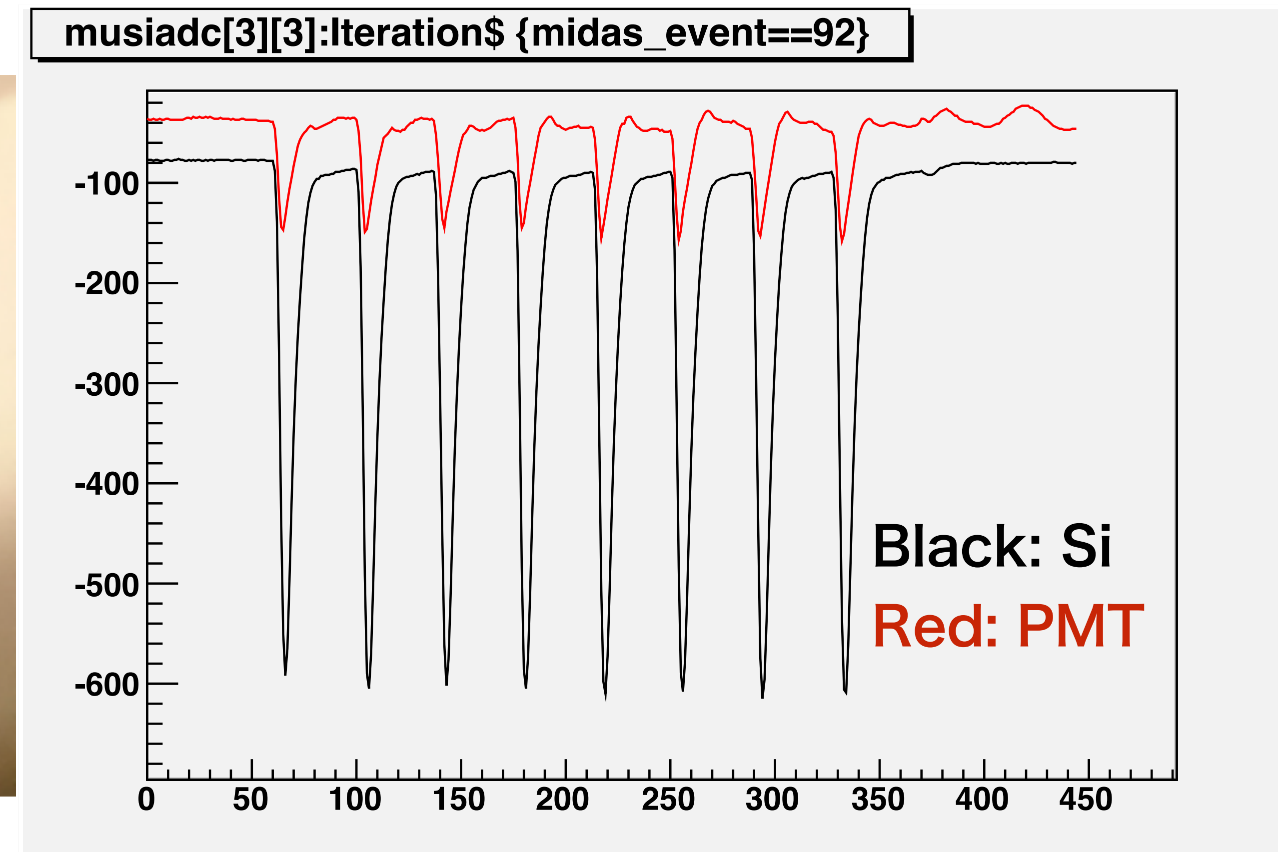
- Typical PMT has ~10^6 gain modified base circuit





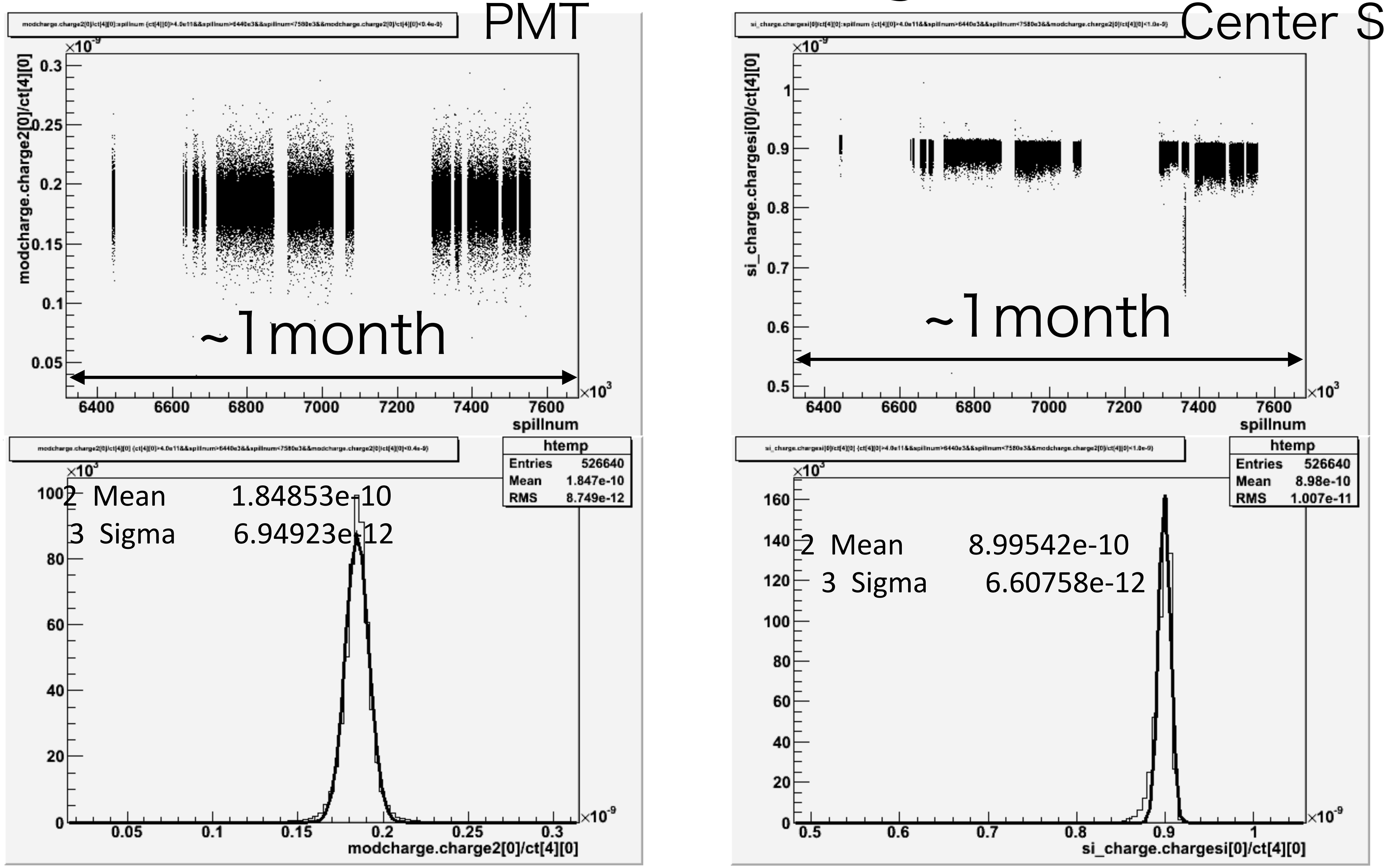
signals





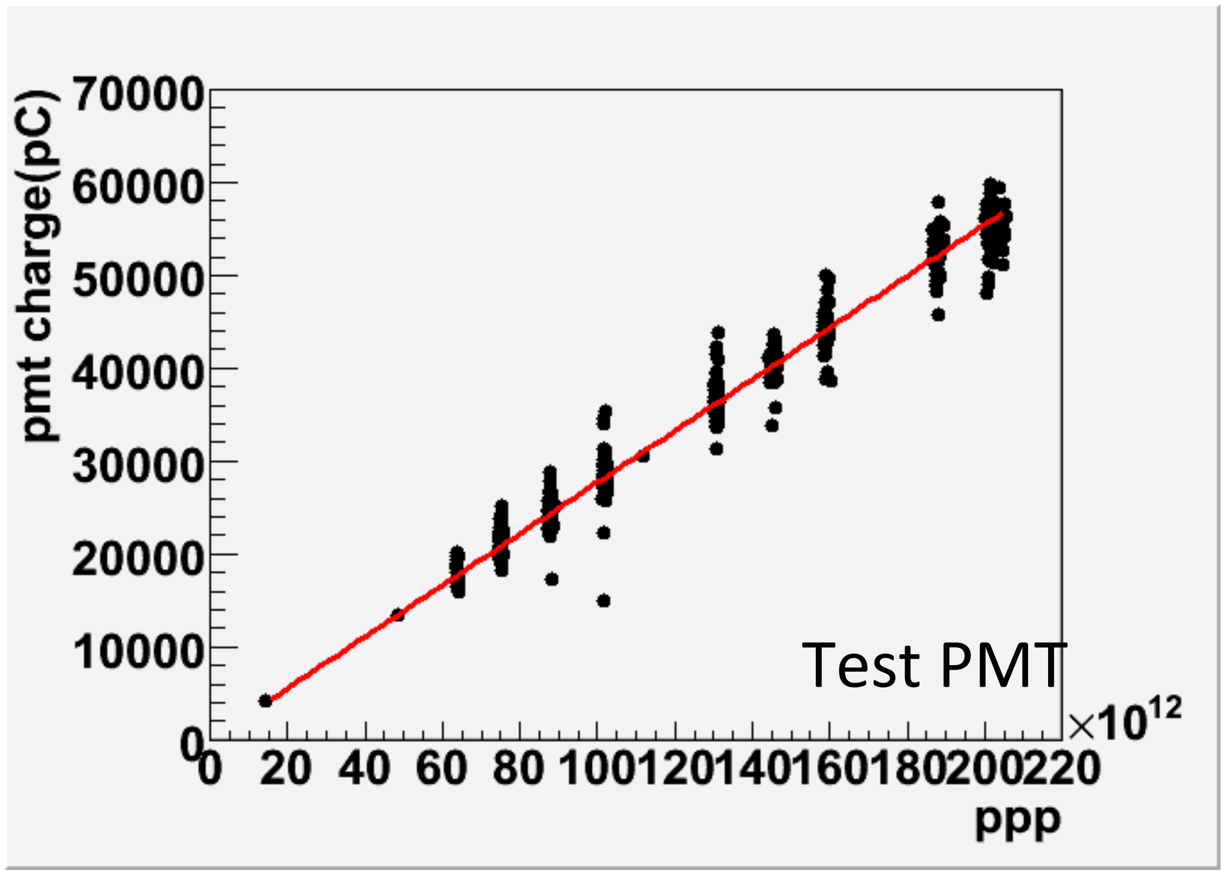
- Clear signal was observed!

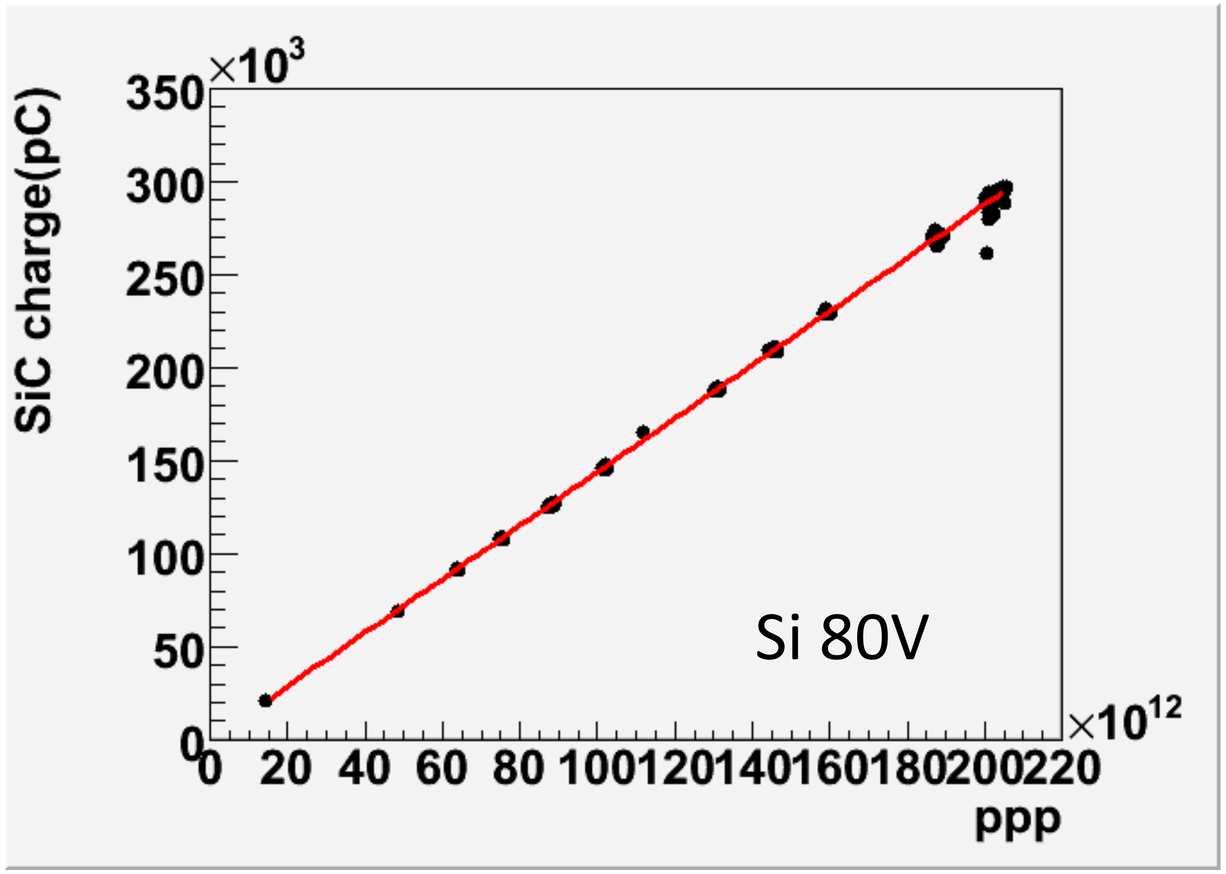
Stability



Signal is smaller than Si but the fluctuation is same as Si

Linearity

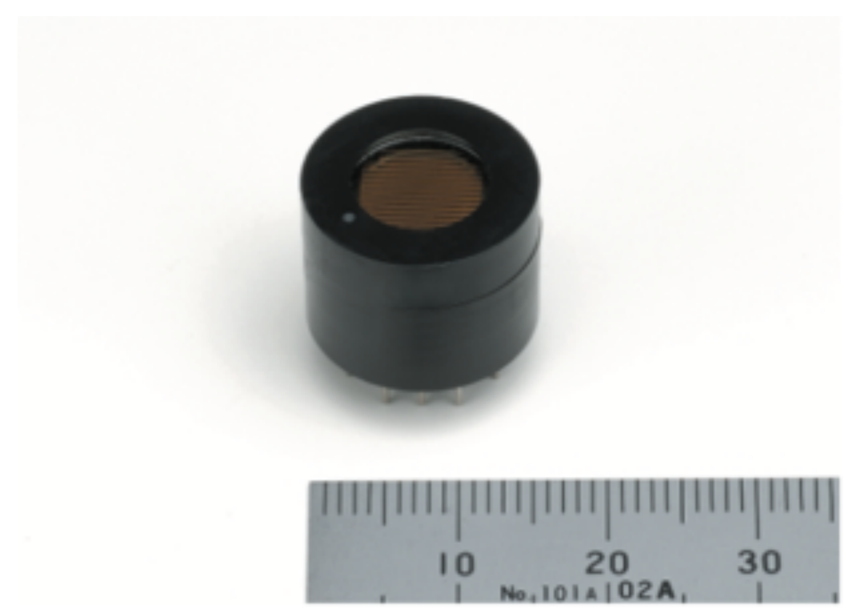




- Fluctuation is large due to small yield but PMT seems to have good linearity.

Future Prospect

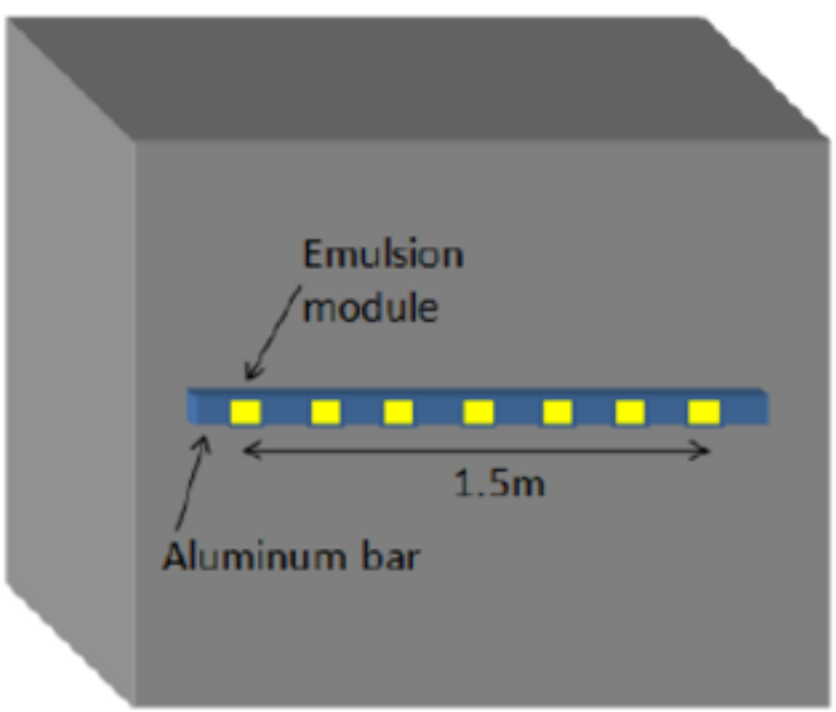
- new PMT without photo-cathode was purchased.
- will be installed soon.
- Check long term stability



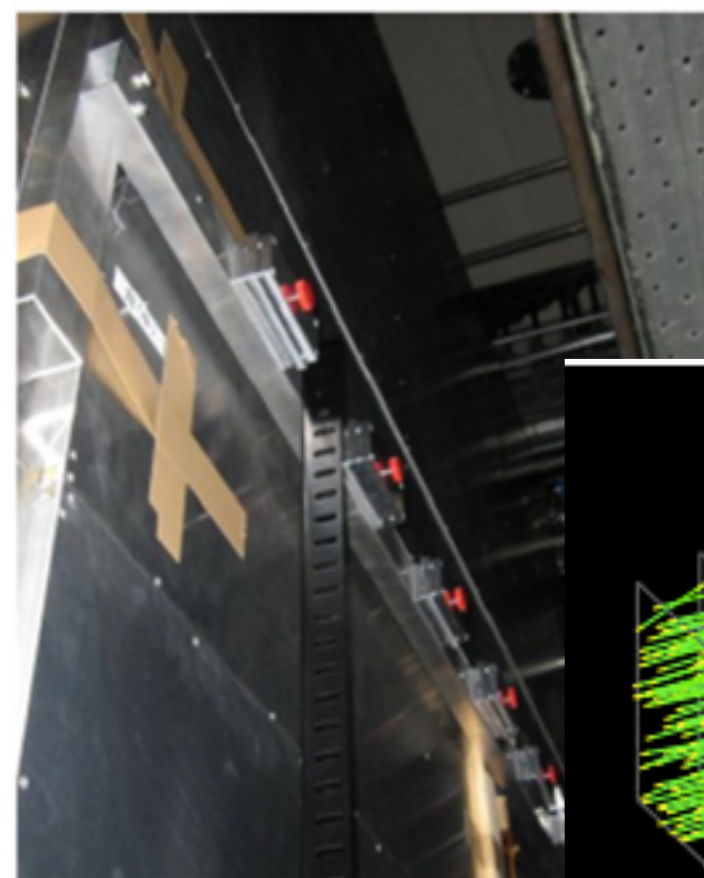
muon flux measurement

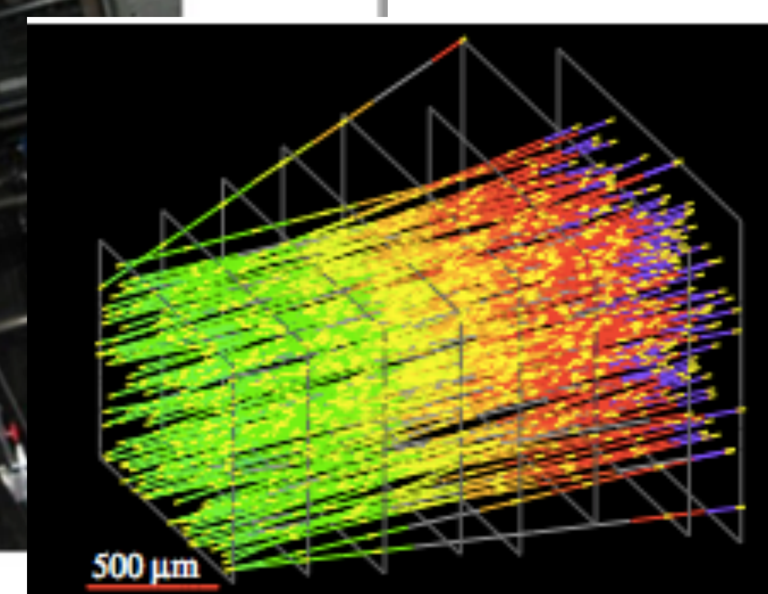
emulsion measurement

- in 2010, Bern&Kobe group conducted an emulsion measurement @MUMON.
- a horizontal array of emulsion trackers were put on downstream end of MUMON and irradiated low intensity shots



Downstream of MUMON





Our beam MC and MC tuning

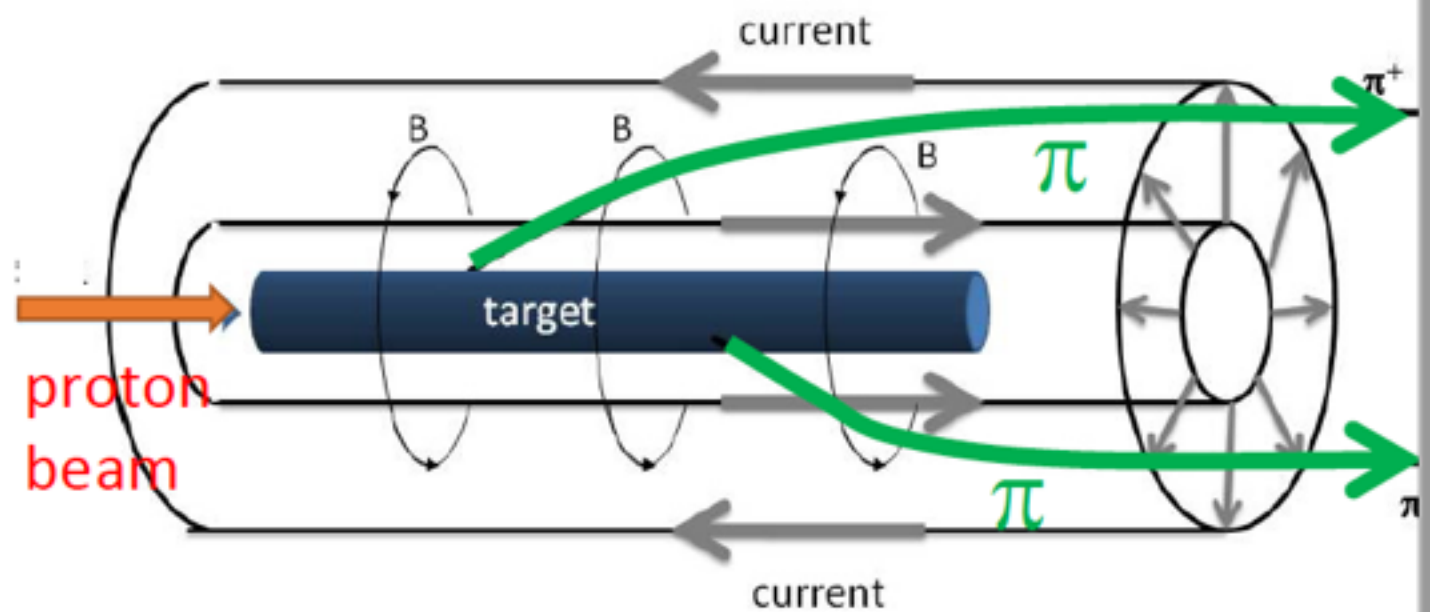
FLUKA simulation
- p+C interaction in the target

JNUBEAM (GEANT3 base)
- tracking & horn field
- neutrino-producing decays

hadron production tuning
- input from CERN NA61

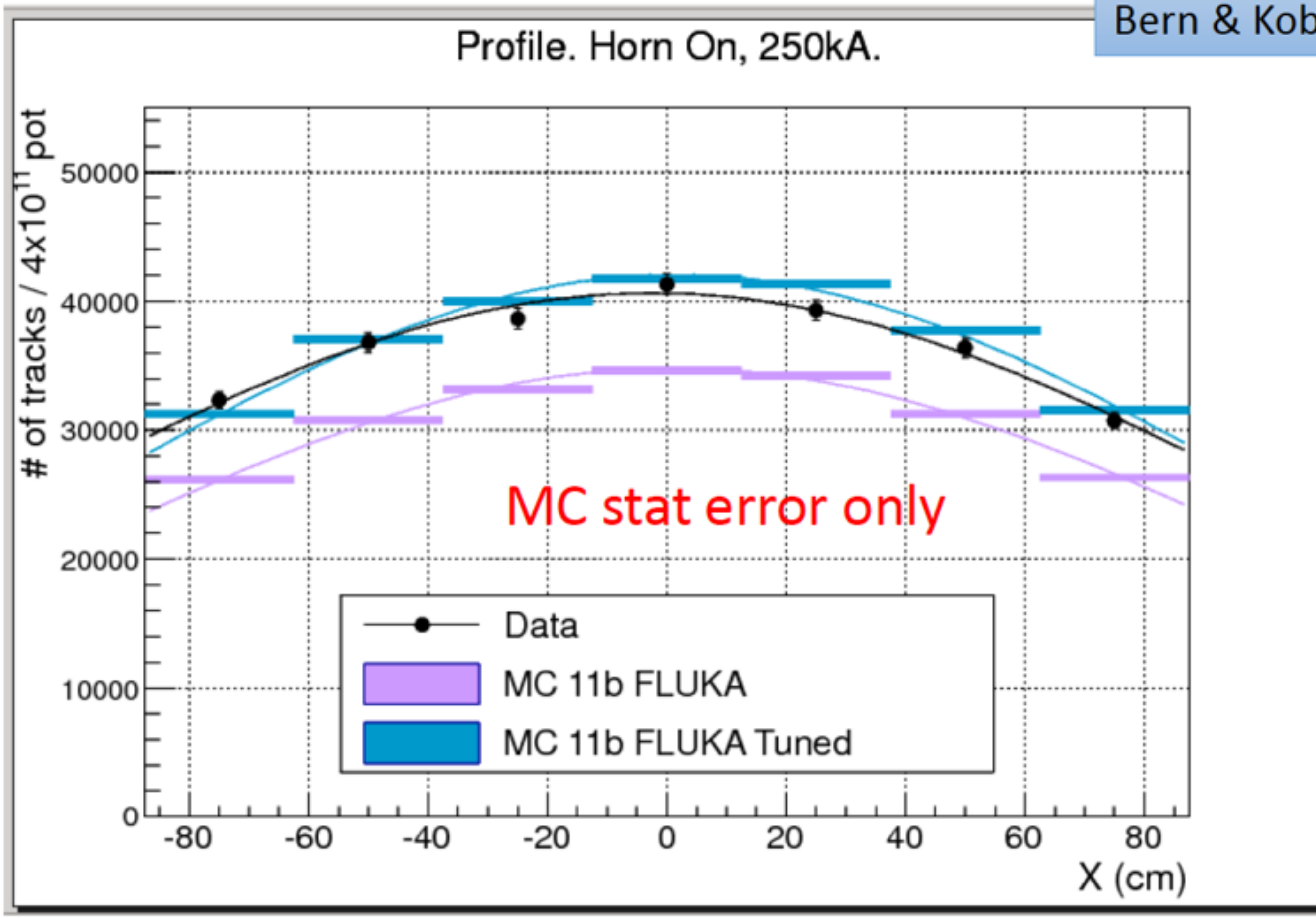
Flux predictions

based on reliable experimental results



data MC comparison (250kA)

Bern & Kobe group



tuned/FLUKA = 1.20

- We updated flux tuning with NA61/SHINE 30GeV/c short replica target data.
- We took RHC data for emulsion in 2014.
- MC is updating now.

Future upgrade?

- We have no concrete plan yet…

Summary

- T2K Muon Monitor is working very stable so far.
- Several R&D is ongoing including new detector.
- We don't have any concrete upgrade plan yet.
  - Any idea and requests are welcome.

PMT with low bias voltage