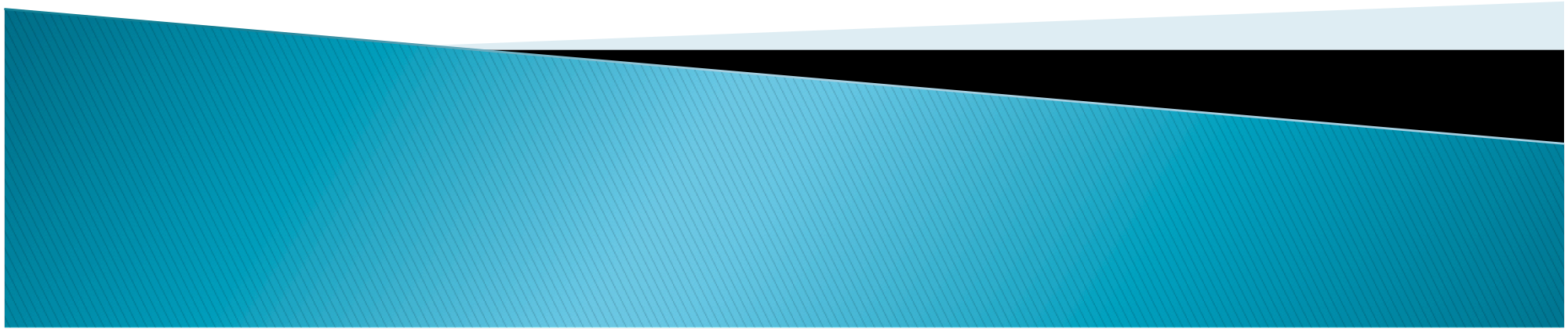
T2K Muon Monitor

Kento Suzuki (Kyoto University)

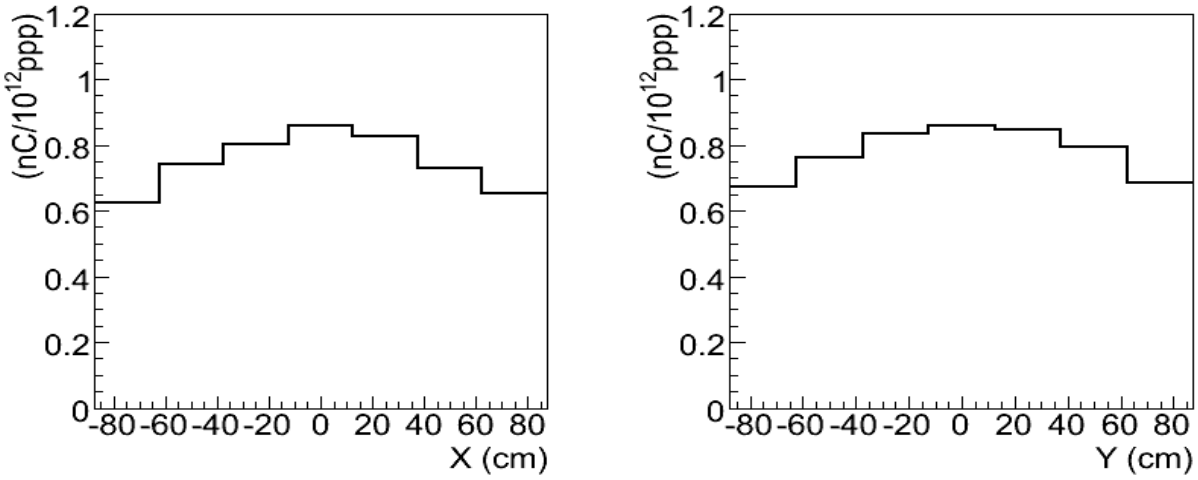
2010.08.31

NBI Talk



Role and Requirement

- Monitor ν beam direction and intensity by measuring μ
  - Beam direction by measuring μ beam profile center
    - Requirement : < 0.25mrad
  - Intensity by measuring μ yield
    - Requirement : < 3%
- Required dynamic range
  - 1% to 100% (=0.75MW)
    - Estimated muon flux (profile center):
      ~8×10^{7} μ/cm^2/spill at 0.75MW

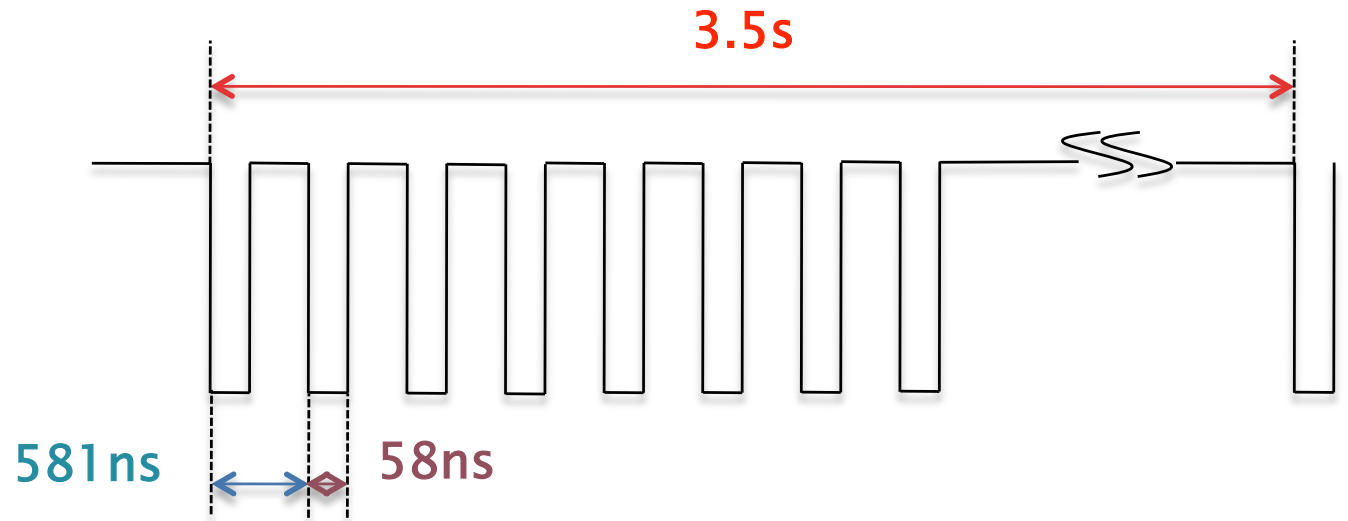


← Typical profile of μ beam measured by MUMON

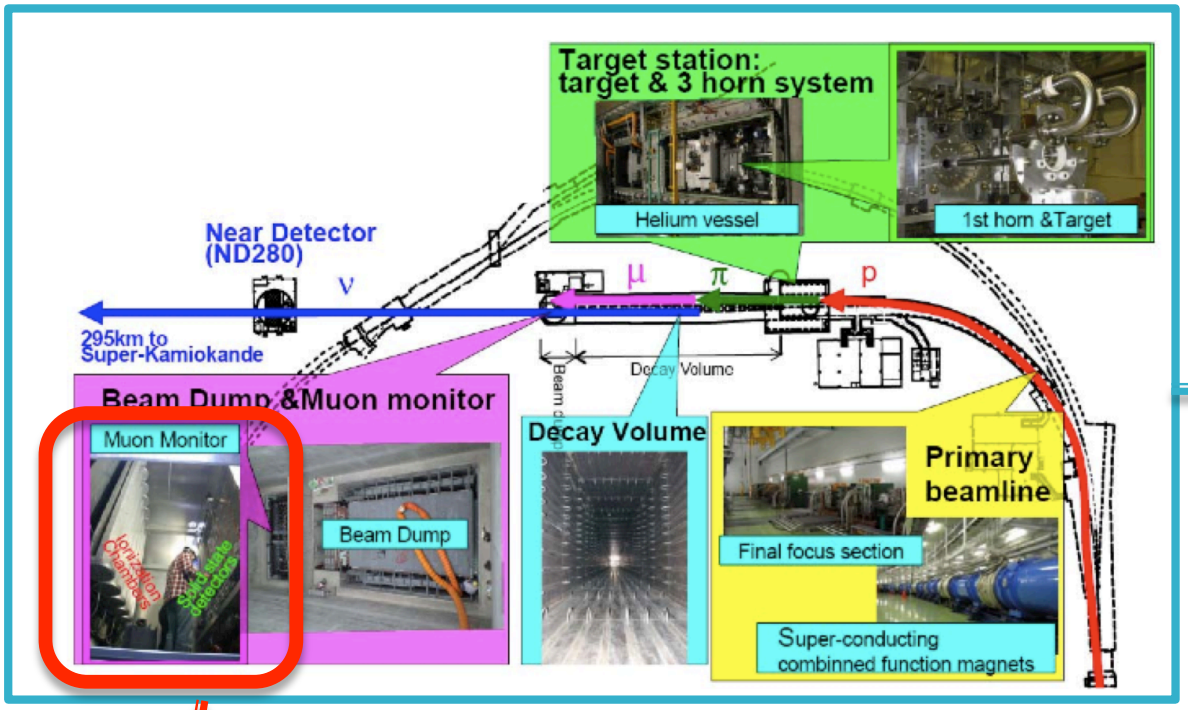
Role and Requirement

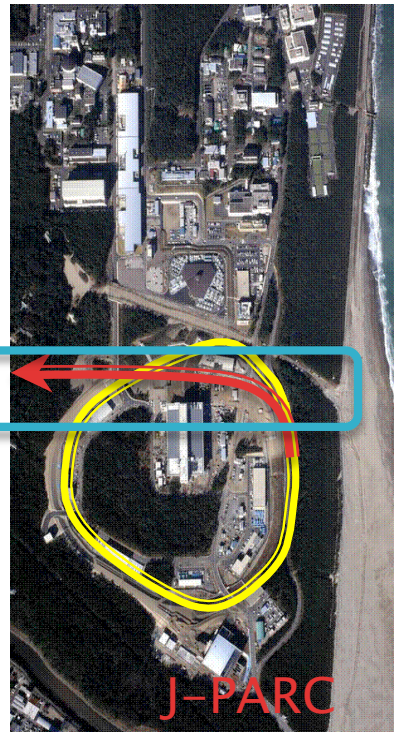
- Bunch by bunch measurement
  - Bottom fig.: structure of T2K beam
- Reliability
  - Beam operation will be stopped if MUMON has trouble
  - Need to work under high radiation environment
    - 100 kGy per year at 0.75MW operation

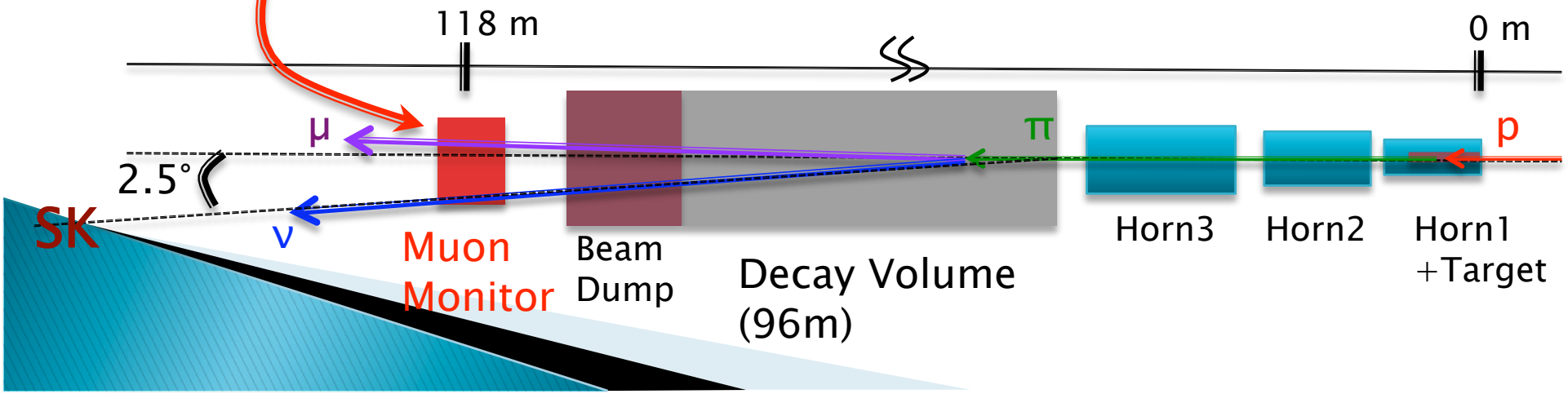
- Spill cycle:
  3.5s interval
- Bunch interval:
  581ns
- Bunch width :
  58ns



Location of T2K Muon Monitor

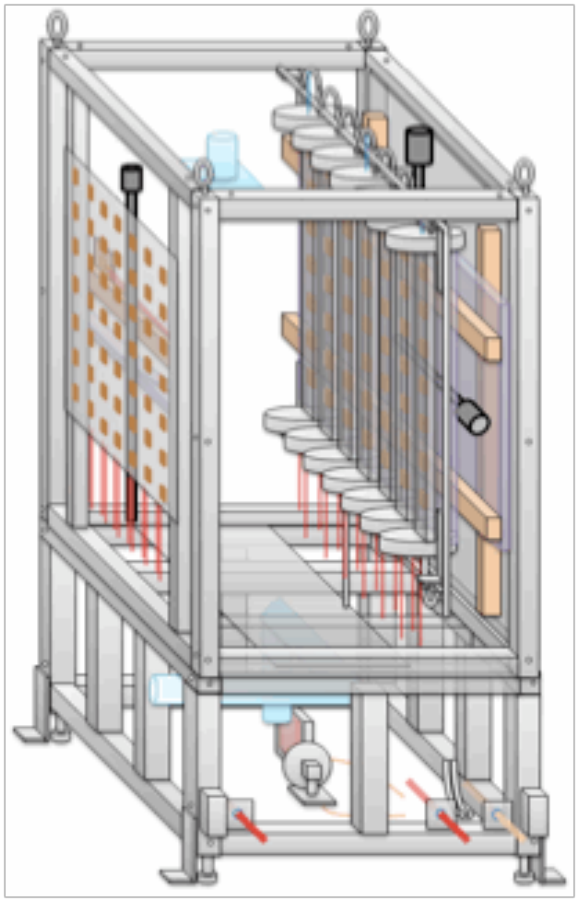




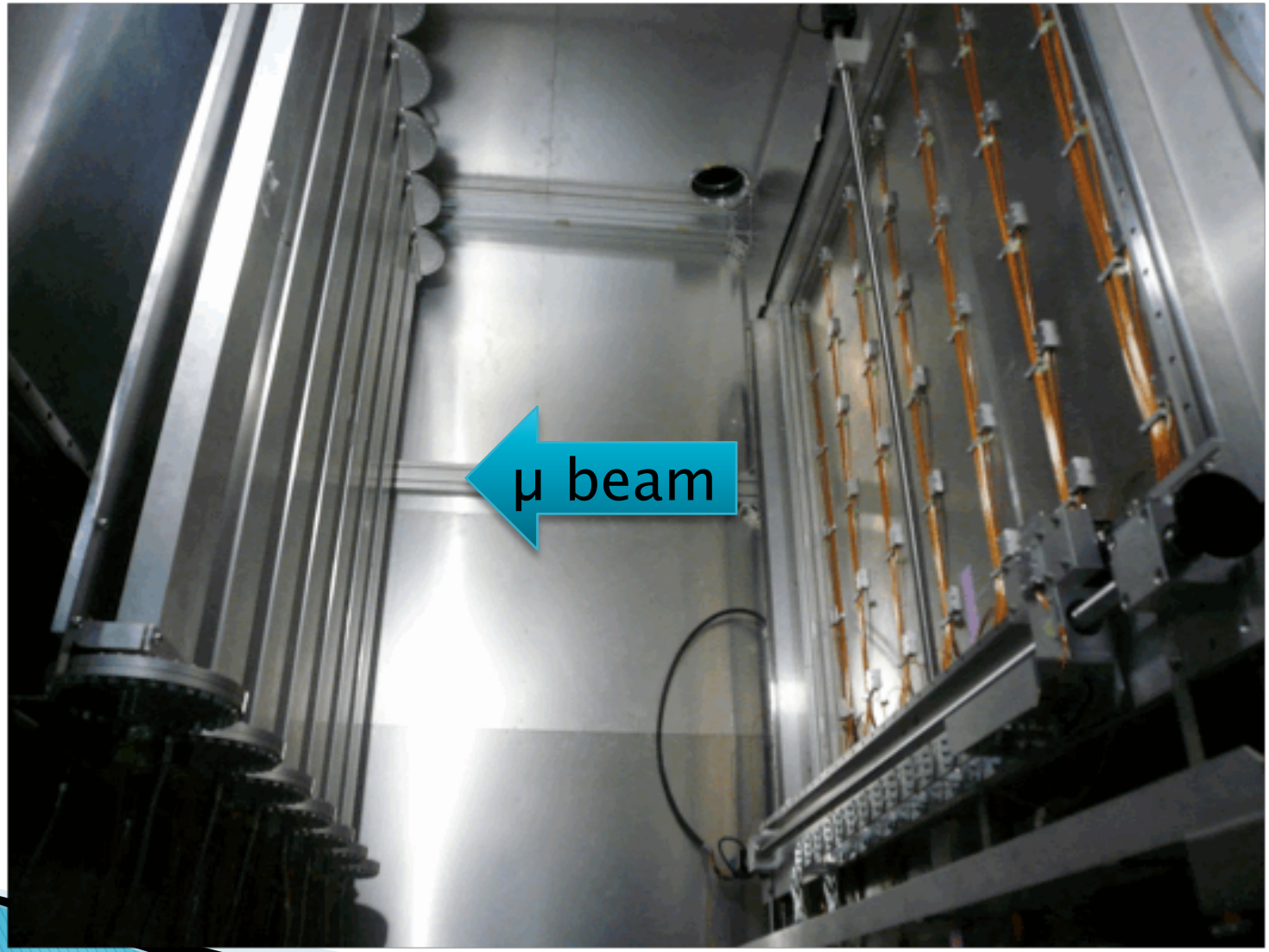


T2K Muon Monitor "MUMON"

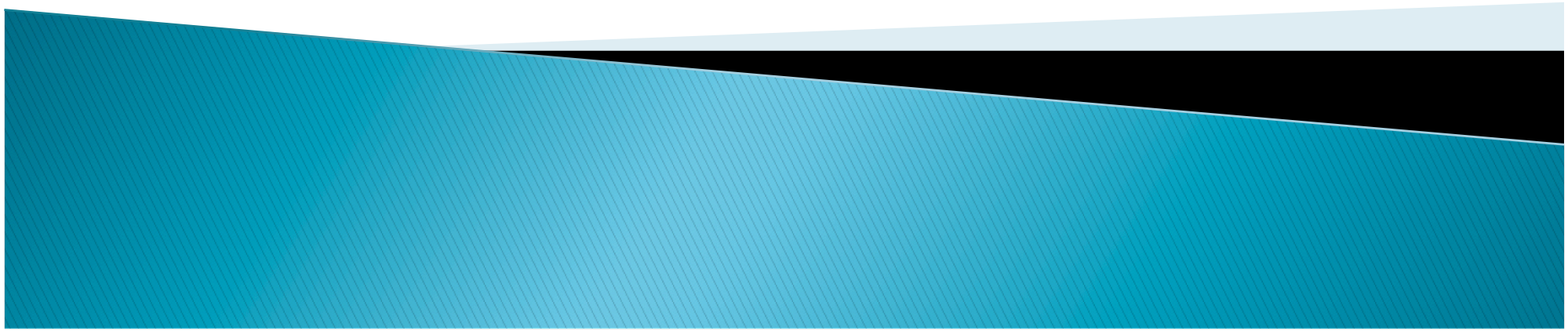
- Composed of two independent detector → redundancy and wide-dynamic range
  - Si PIN Photodiode : high S/N ratio even when beam intensity is low.
  - Ionization chamber : radiation tolerant
- Each detector has 49 sensors (7×7) which are arranged at 25cm intervals in each array.
- Covered Area: 150cm×150cm



Photo



Hardware

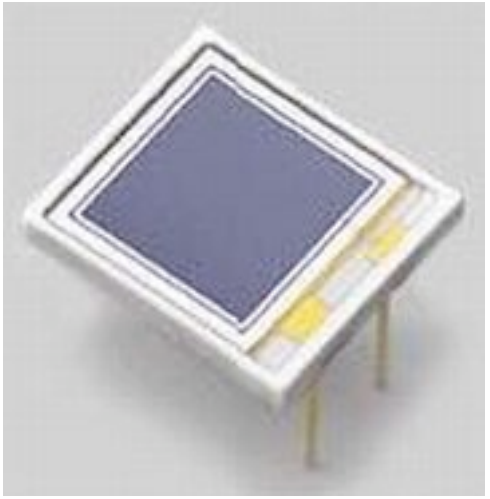


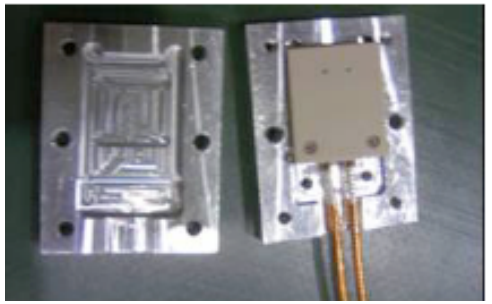
Measures for High Radiation

- We prepared for high rad. situation by making components of MUMON radiation tolerant.
  - Ionization chamber (detail is in later slide):
    - Almost all parts are composed of aluminum.
    - PEEK (Poly-Ether-Ether-Ketone) , ceramic or polyimide for insulator
  - Polyimide cable for electronics
  - Non-halogen polyethylene (PE) insulated cable and Ethylene-Propylene-Rubber (EPR) insulated cable for power supply cable.

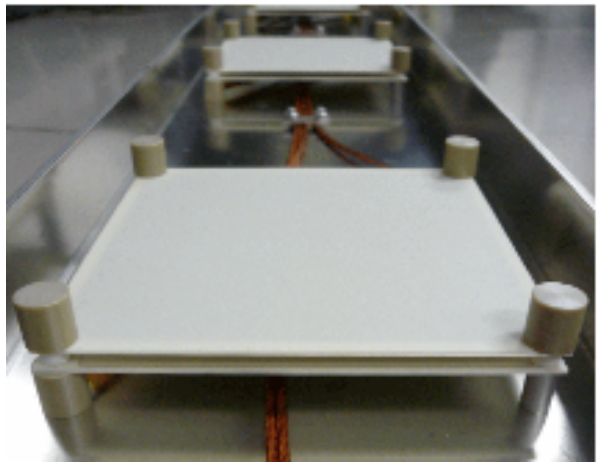
Si PIN Photodiode

- Product of “Hamamatsu Photonics“
- Active size: 1cm×1cm
- Wide dynamic range
  - S/N ~200 (even at 1% intensity)
- Weak against radiation
  - Expected life time is ~1 month at 0.75MW operation.
  - Exchange is needed for full beam intensity
- Covered up by aluminum package
  - Can exchange quickly under radiation environment.
  - PEEK is used for mounting Si PIN Photodiode and being put on the package.

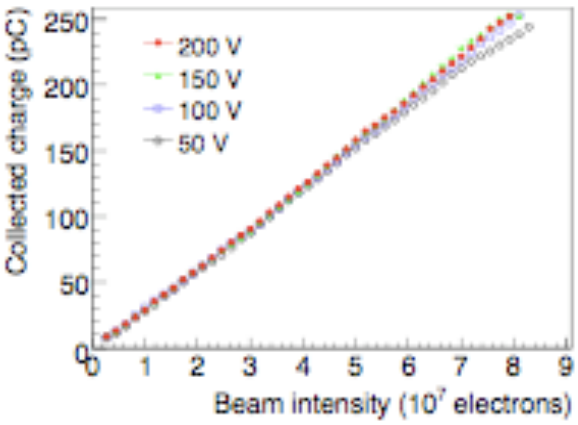


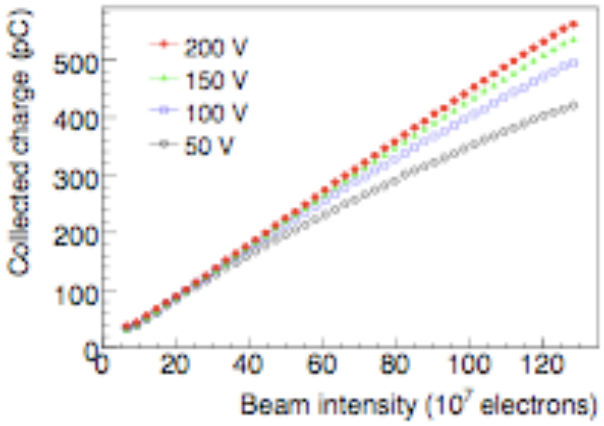


Ionization Chamber



- We referred NuMI Muon Monitor
- Active size: 7.5cm × 7.5cm
- Gap: 3mm
- Radiation tolerant.
- Gas (130kPa, 34℃)
  - Ar + N_2 (2%)
    - For low intensity (<200kW)
      - Avoid saturation of signal due to recombination b/w electrons and ions.
  - He + N_2 (1%)
    - For high intensity (>200kW)
      - Lower ionization yield than that of Ar.
  - Purpose of N_2 contamination
    - To get fast response of signal.
      - In case of He, this effect is smaller than case of Ar.
    - To avoid signal fluctuation.
  - Two types of gas system to cover required dynamic range.
    - Confirmed linearity at 200V in beam test.



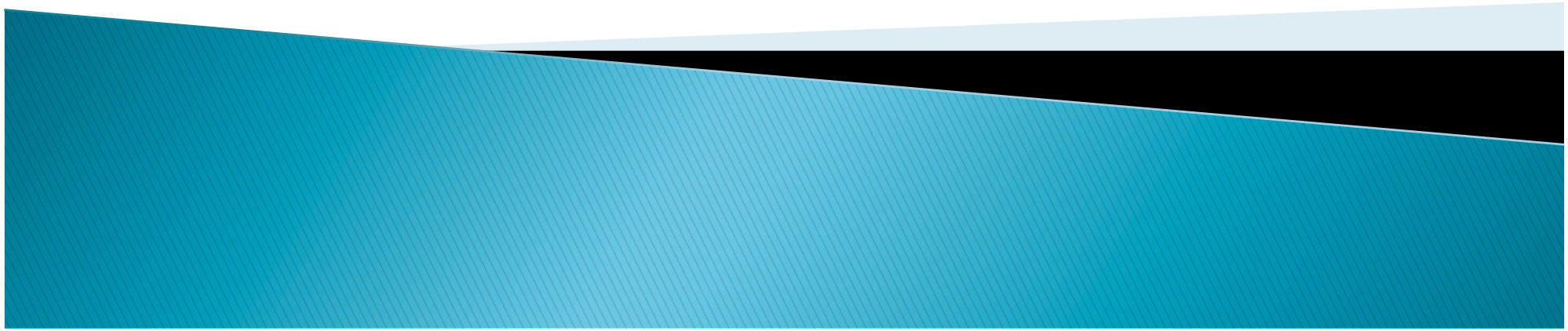


Left: Ar+N_2(2%)
Right : He+N_2(1%)

Control for gas and temperature for IC

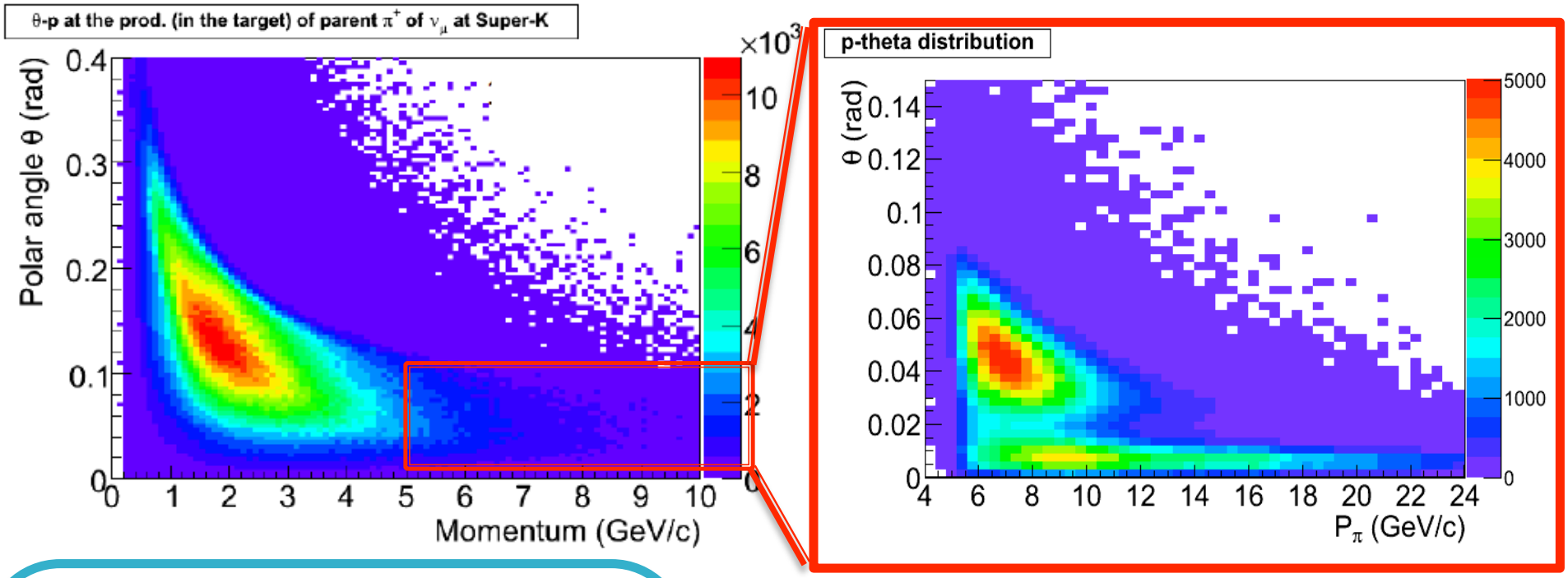
- Keep appropriate conditions strictly
  - Temperature: 34℃
    - Monitored by Pt100 resistance thermometer.
    - Kept by PID-controlled heater.
      - The deviation is within ±0.2℃.
  - Pressure: 130kPa
    - Monitored by pressure transducers.
    - PID control of solenoid valve is located at most downstream of exhaust line.
      - This keeps the pressure at 130 ± 0.1 kPa.
  - O_2 contamination <100ppm
    - Monitored by oxygen analyzer.
    - Absorption of drift electrons cause losses of signal.
      - More than 1% loss if O_2>100ppm
    - Gas flow ~ 100 cc/min
      - suppress O_2 increasing.
    - We already achieved around 5ppm during physics run.
- Monitor these values in real time

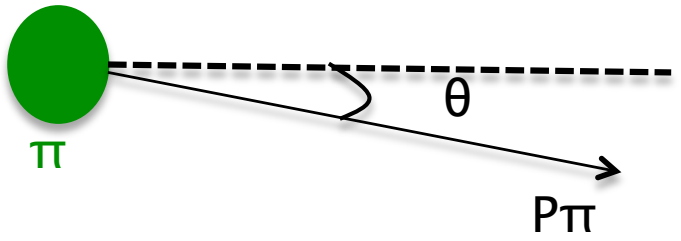
Measurement



What do we detect ?

Both are MC simulations



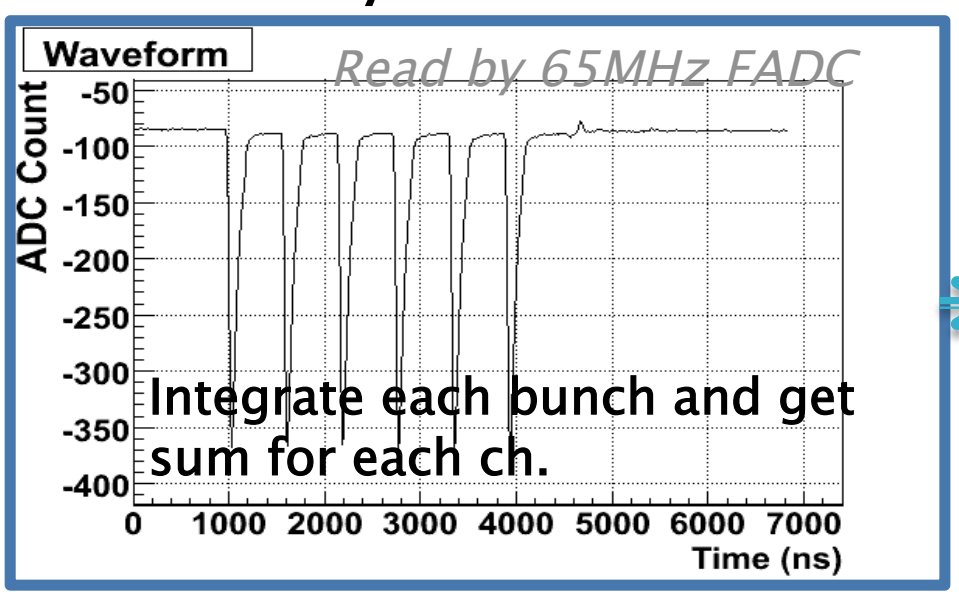


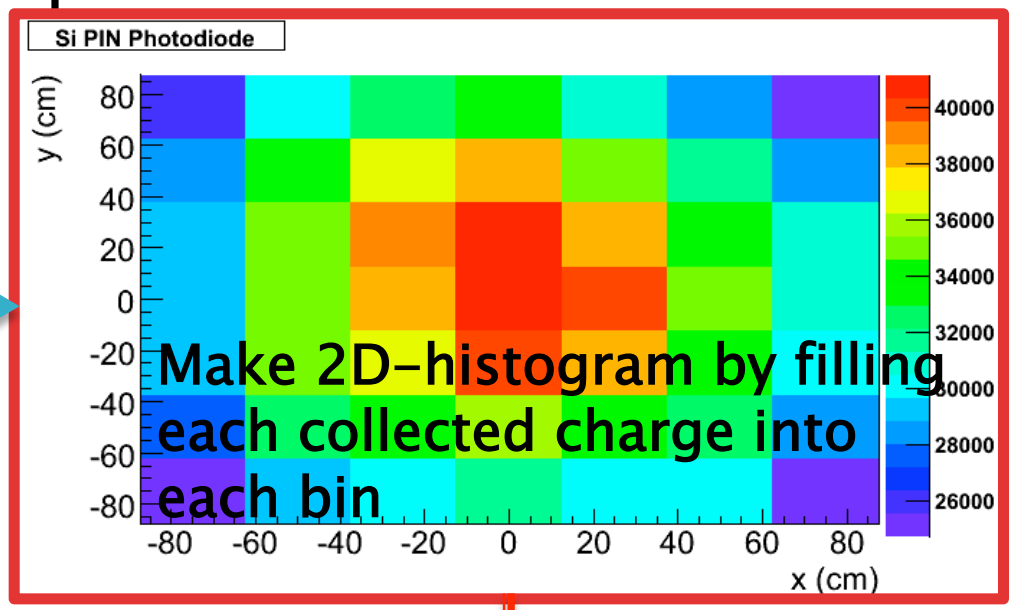
θ: emission angle of pion with respect to beam axis
Pπ: Momentum of pion

- Left fig.: p-θ distribution of π whose daughter (ν_μ) reaches at SK
- Right fig.: p-θ distribution of π whose daughter (μ) reaches at MUMON
  - Pπ>5GeV/c , θ<100mrad

How to Achieve Direction and Intensity of μ Beam

- Analysis method is simple





Fit w/ 2D Gaussian Function

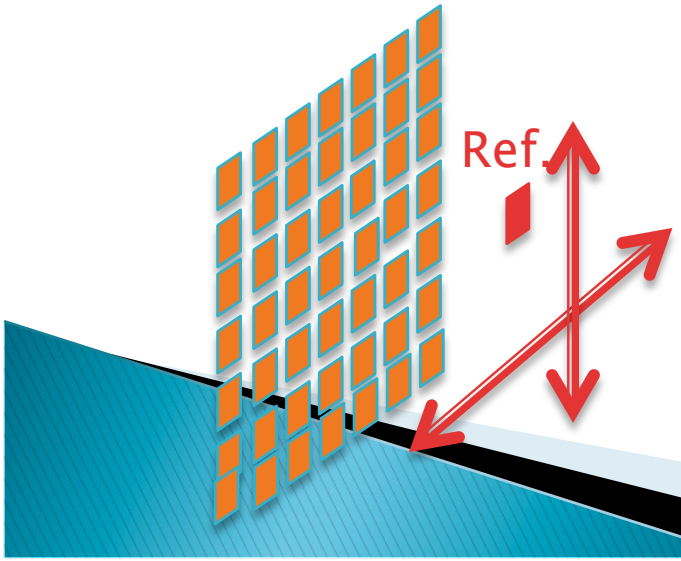
$$A\exp[-\frac{(x-x_0)^2}{2\sigma_x^2}-\frac{(y-y_0)^2}{2\sigma_y^2}]$$

Quote Fit Parameters
A: Peak Charge (nC)
x_0: Profile center in x direction
y_0: Profile center in y direction
σ_x: Profile width in x direction
σ_y: Profile width in y direction

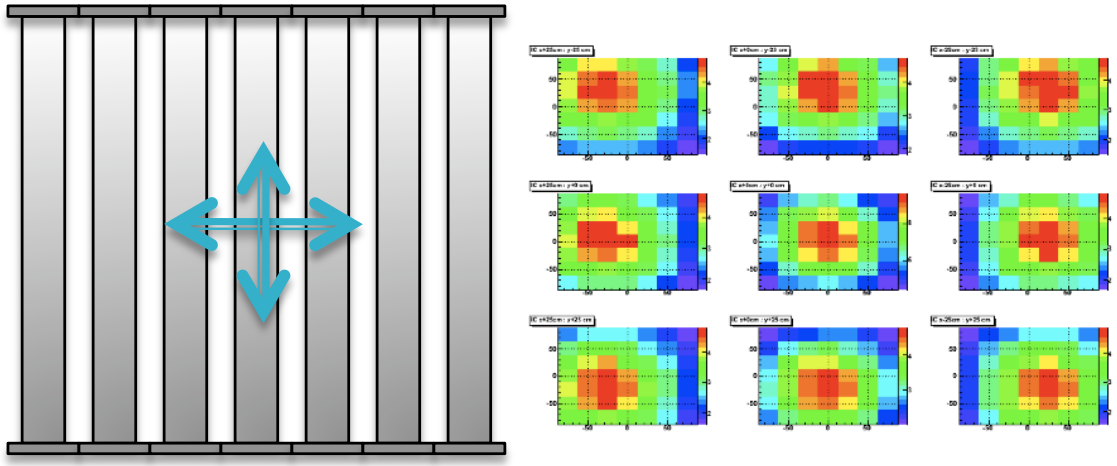
Calibration System

- MUMON has two movable stand for calibration
- Si PIN Photodiode
  - There is a reference detector which can be moved w/ moving stand behind the silicon arrays.
  - All channels (49ch) can be calibrated by using this ref. detector
- Ionization Chamber
  - Can be moved by ±25cm w/ moving stand attached to IC itself.
  - Measure at 9 positions and get relative gain of each channel.
- Can relatively calibrate with precision of 0.1% for Si and 0.4% for IC.

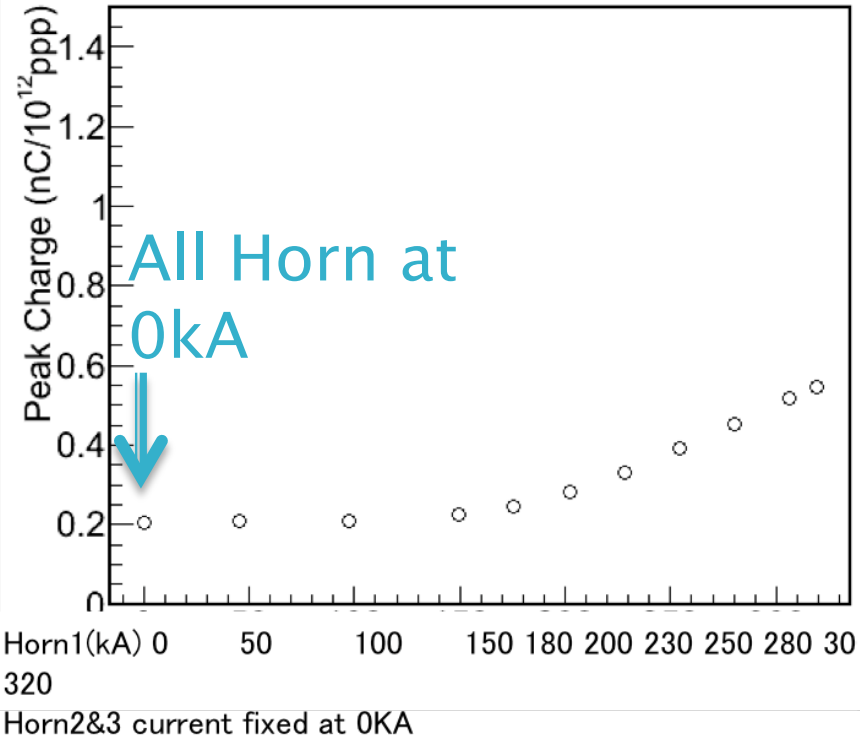
Si PIN Photodiode

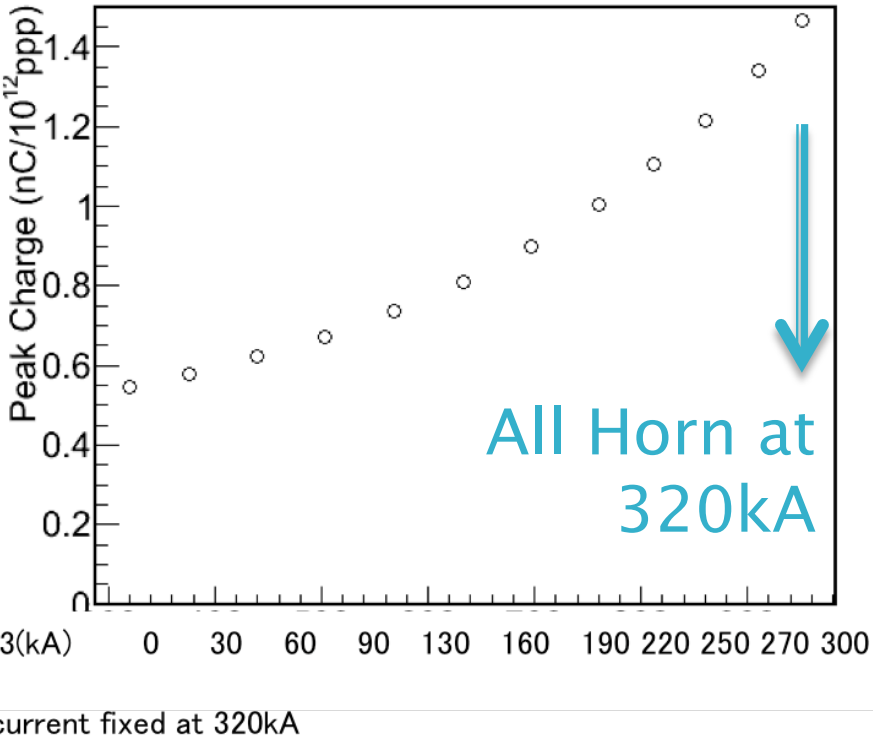


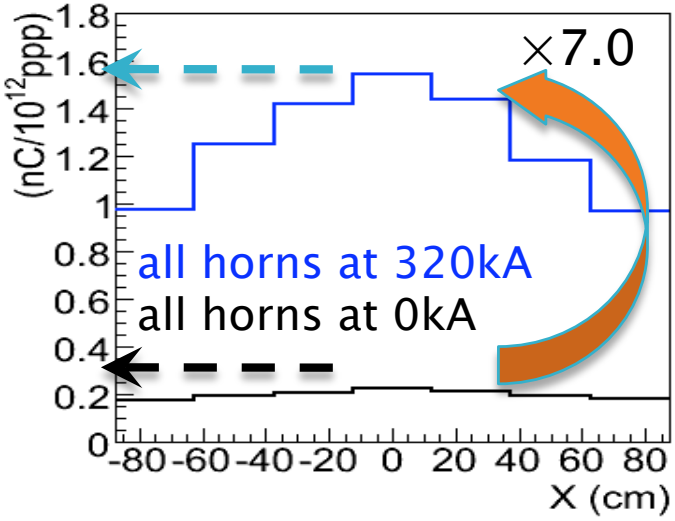
Ionization Chamber



Horn Focusing

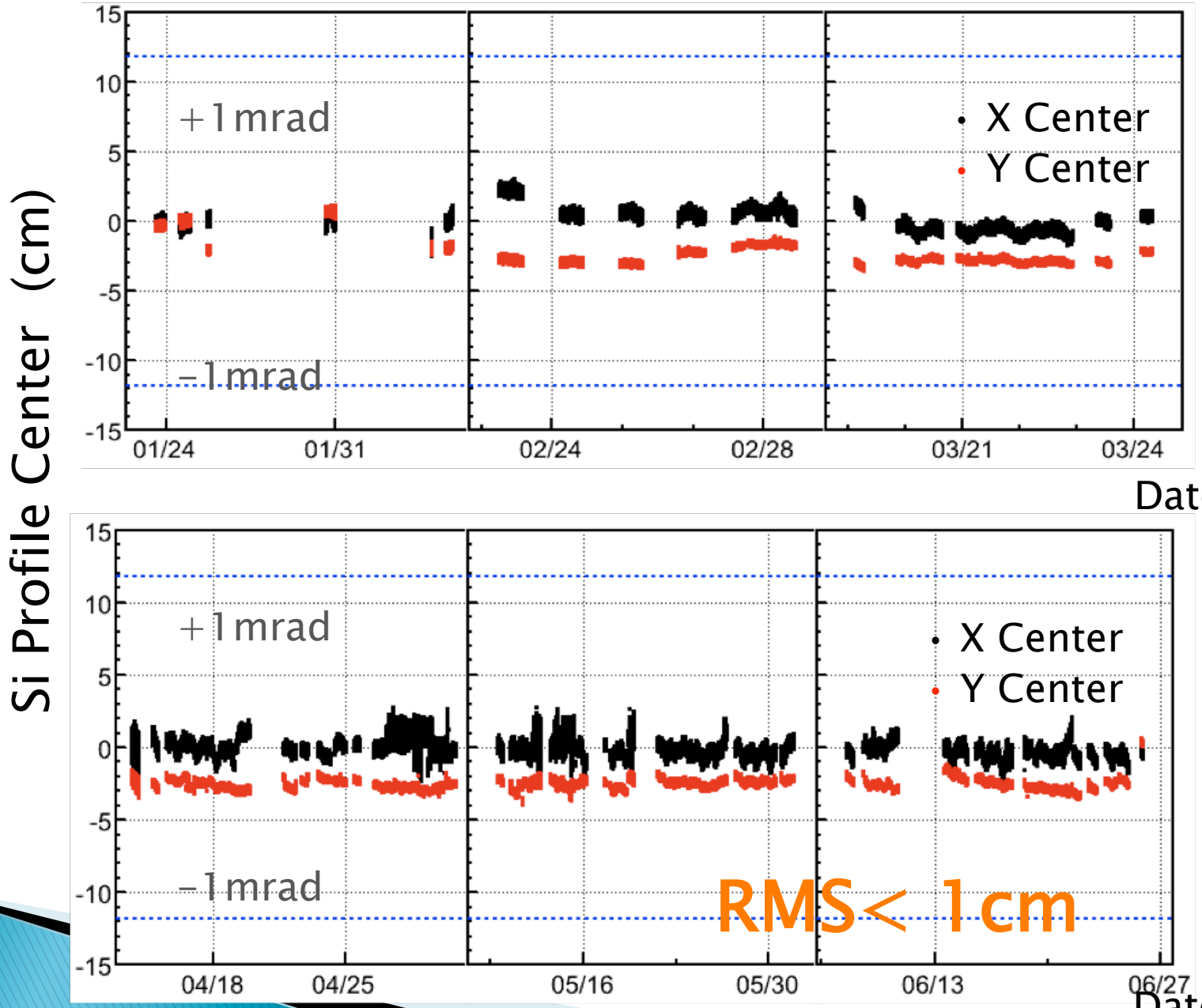




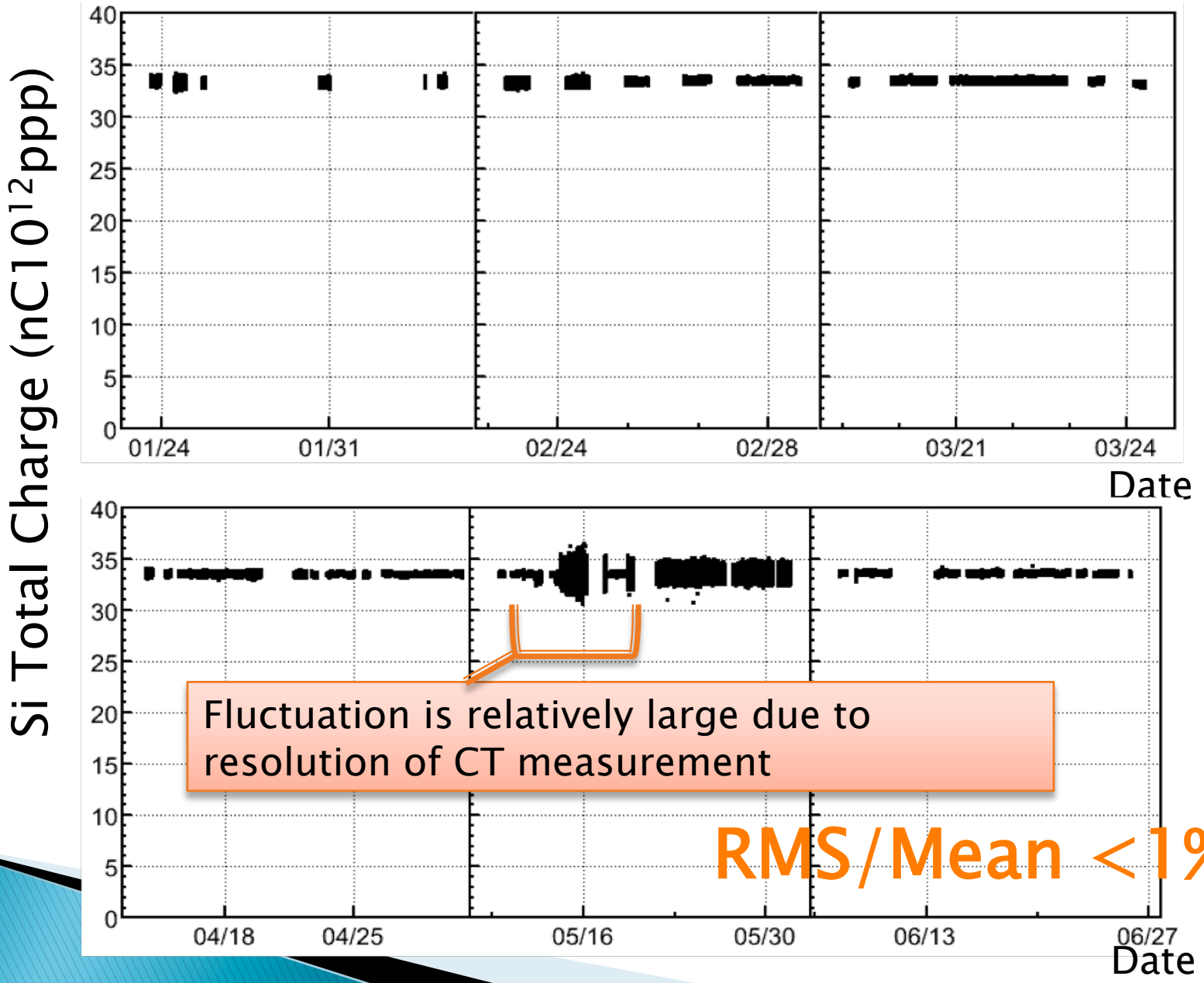


- Confirmed horn focusing by MUMON
  - Top fig. : horn current vs collected charge at center channel
  - Bottom fig. : profile of μ beam

Result of Measurement

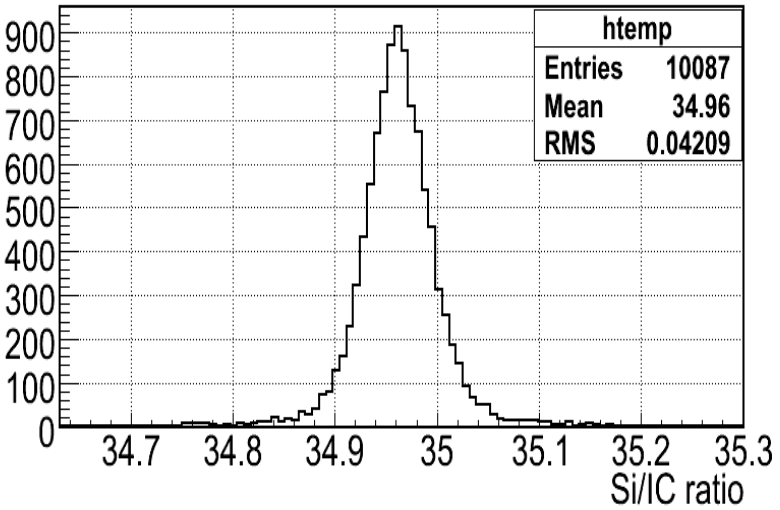


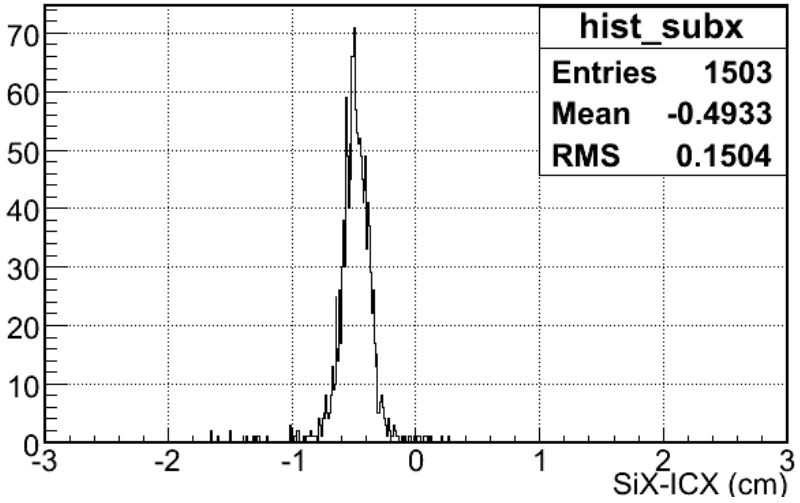
Result of Measurement



How About Resolution?

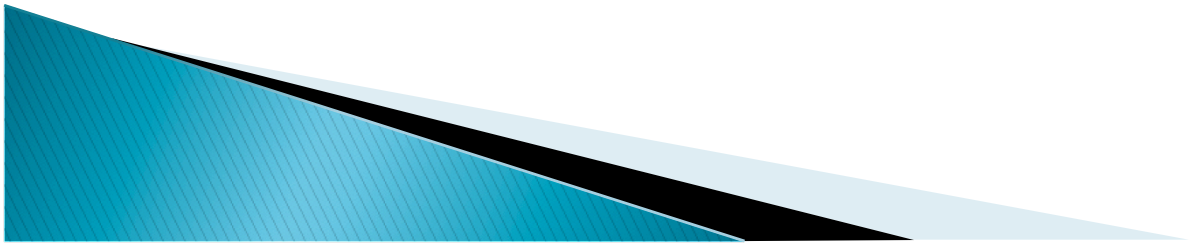
- Estimation by using beam.
  - By comparing two independent detectors, fluctuation of beam direction, intensity and horn current is canceled.
  - Resolution
    - For Intensity measurement (left): 0.12%
    - For direction measurement (Right): 1.5mm



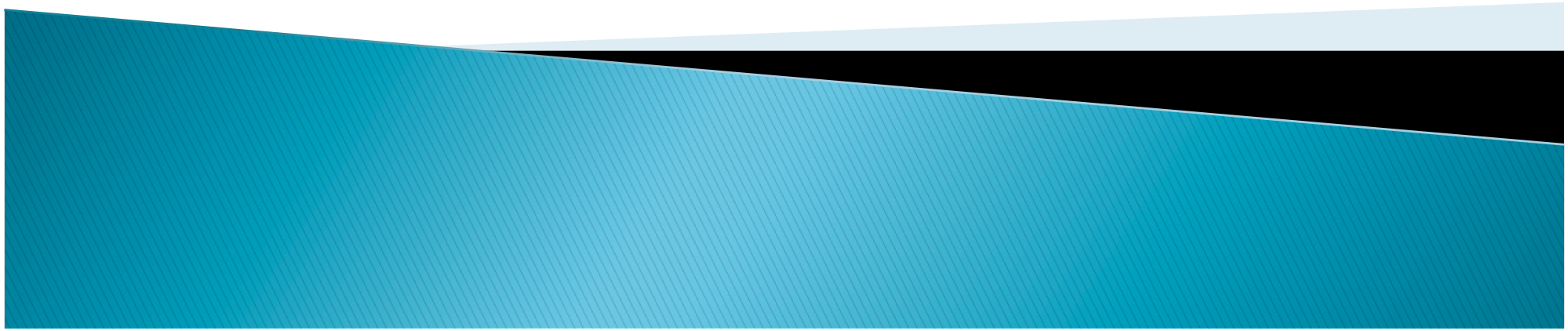


Summary

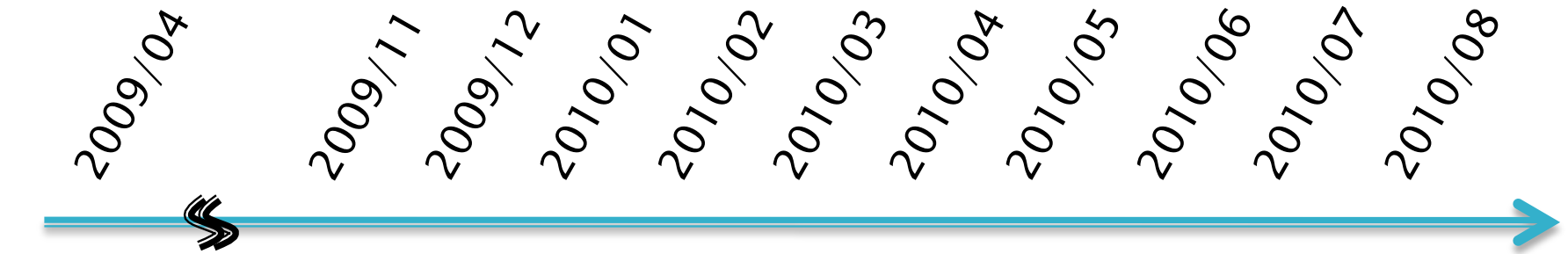
- T2K Muon Monitor “MUMON” measures ν beam direction and intensity by measuring μ.
- MUMON has two independent detectors, Si PIN photodiode and Ionization chamber.
- During physics run, MUMON had been very stable and had good data taking.
- We are waiting for more beam.



Back Up



T2K
Commissioning Run & Physics Run



Start T2K commissioning

~20kW

Commissioning Run (Beam study)

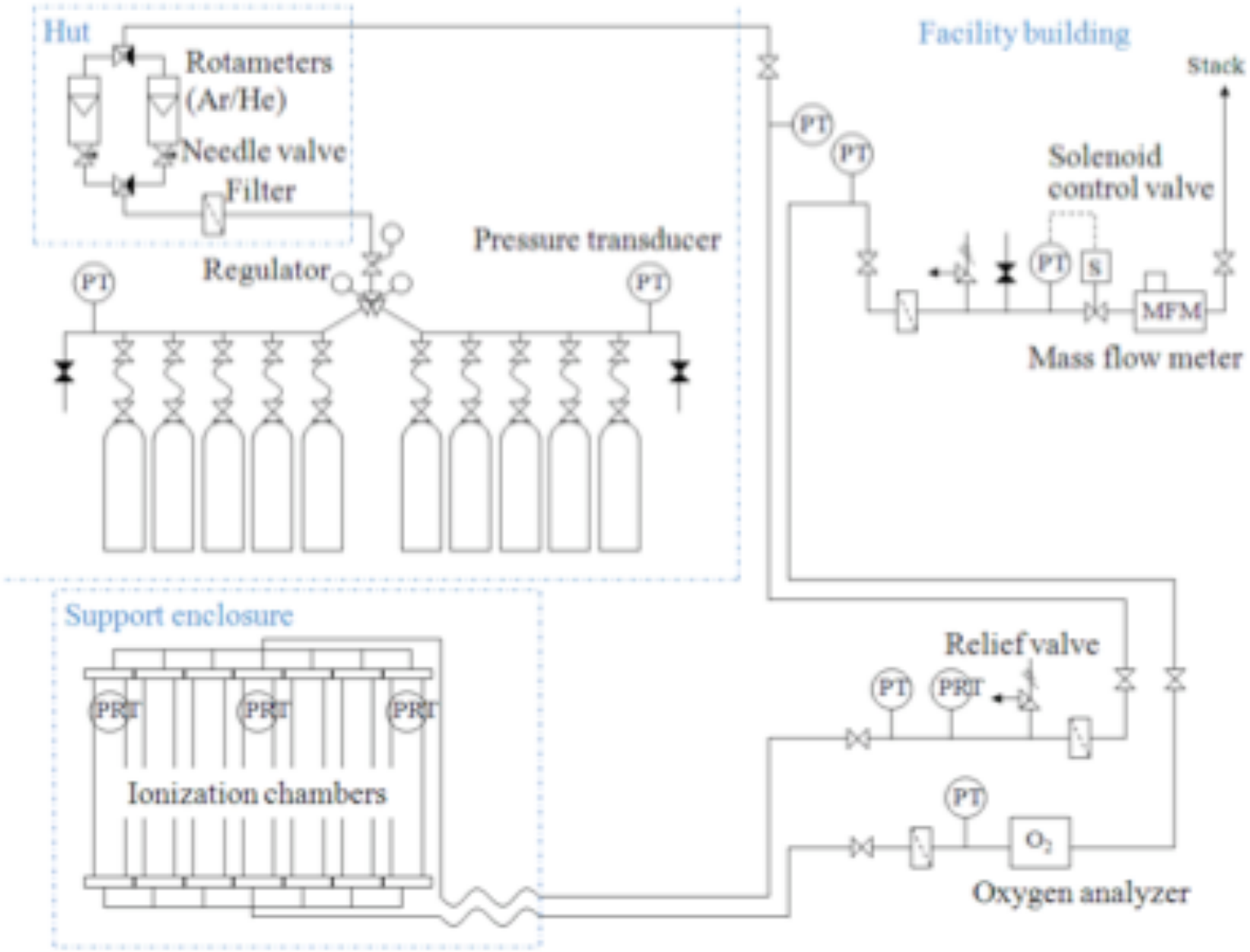
20kW ~ 70kW

Physics Run (including beam study time)

Next Run: Middle of Nov.~

Shut down (Upgrade of Hardware, installation of new detector)

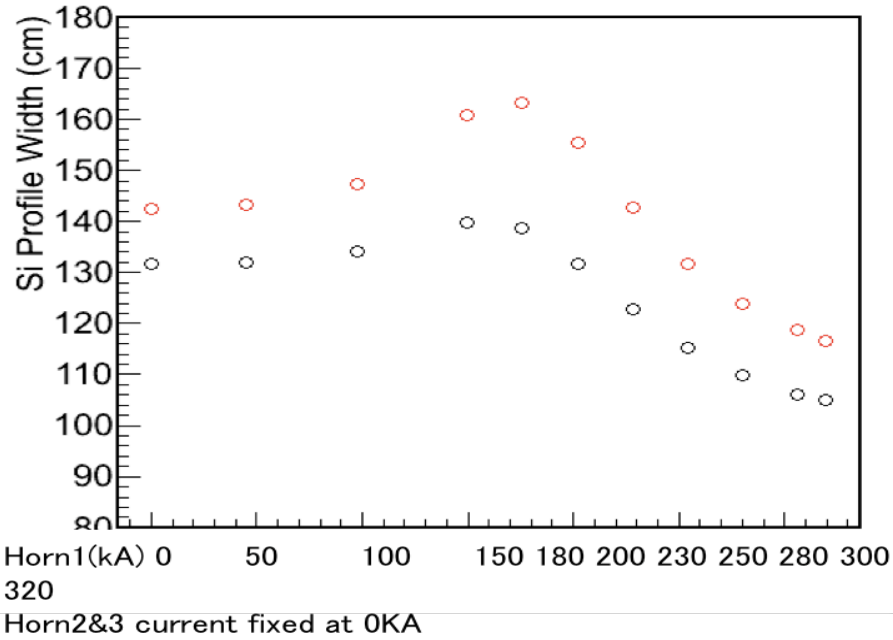
Gas System

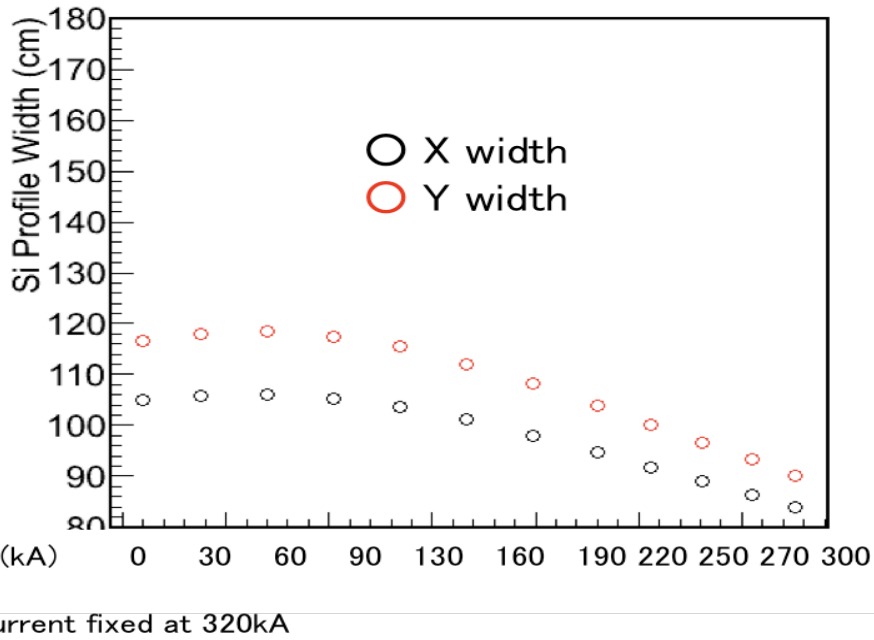

Hut
Rotameters
(Ar/He)
Needle valve
Filter
Regulator
Pressure transducer
PT
PT
PT
Facility building
Stack
Solenoid
control valve
PT
S
MFM
Mass flow meter
Support enclosure
PRT
PRT
PRT
Ionization chambers
Relief valve
PT
PRT
PT
O_2
Oxygen analyzer

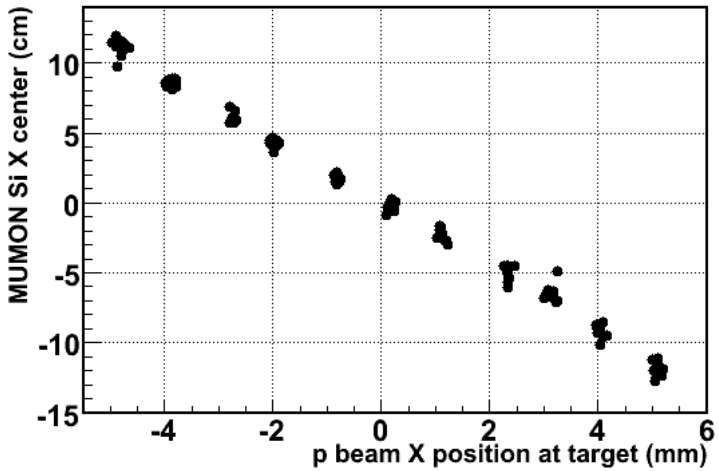
DAQ

- COPPER-FINNESSE Flash ADC
  - COPPER-FINNESSE:
    - Developed by KEK for Belle experiment
    - Mother board (COPPER) has ethernet ports as a external interface
    - Sub-board (FINNESSE) which is inserted to COPPER works as Flash ADC
  - Sampling rate: 65MHz
  - Accuracy: 12bit
  - Input range: ±1V
  - Shaping time: 52.8ns
- Trigger
  - We use timing of signal from CT as a trigger
    - CT also use COPPER-FINNESSE Flash ADC and its sampling rate is 160MHz
    - About CT, please hear Shibata-san's talk

Study for Understanding MUMON Performance







- Top fig. : profile width vs horn current
- Bottom fig. : proton position at target vs profile center
  - Parallel beam

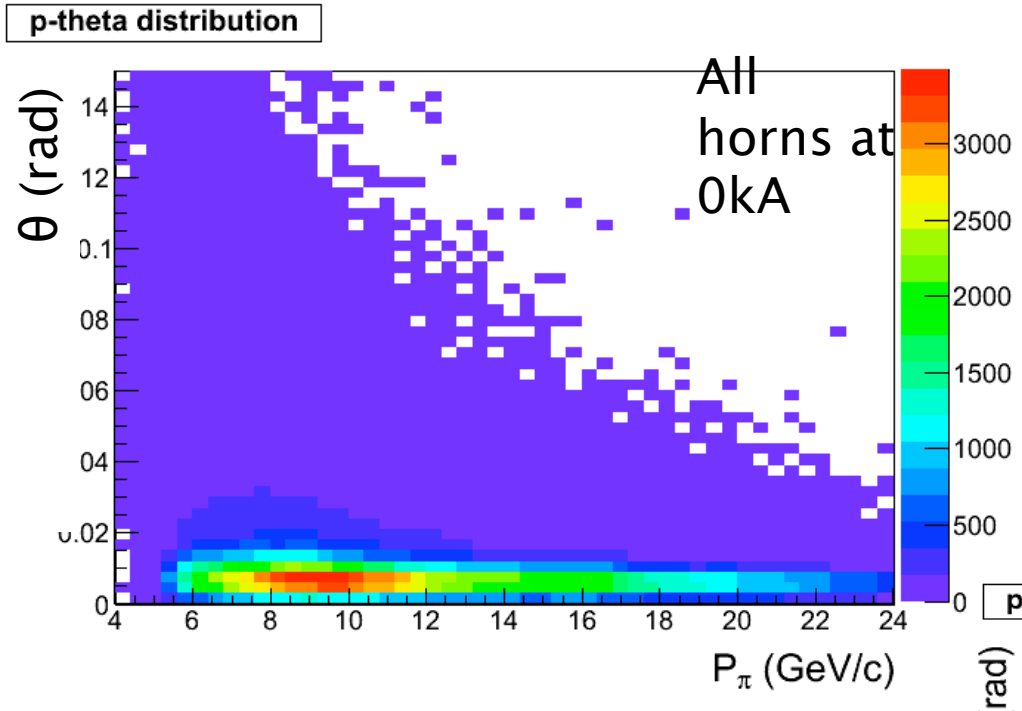
Systematic Error for Direction Measurement

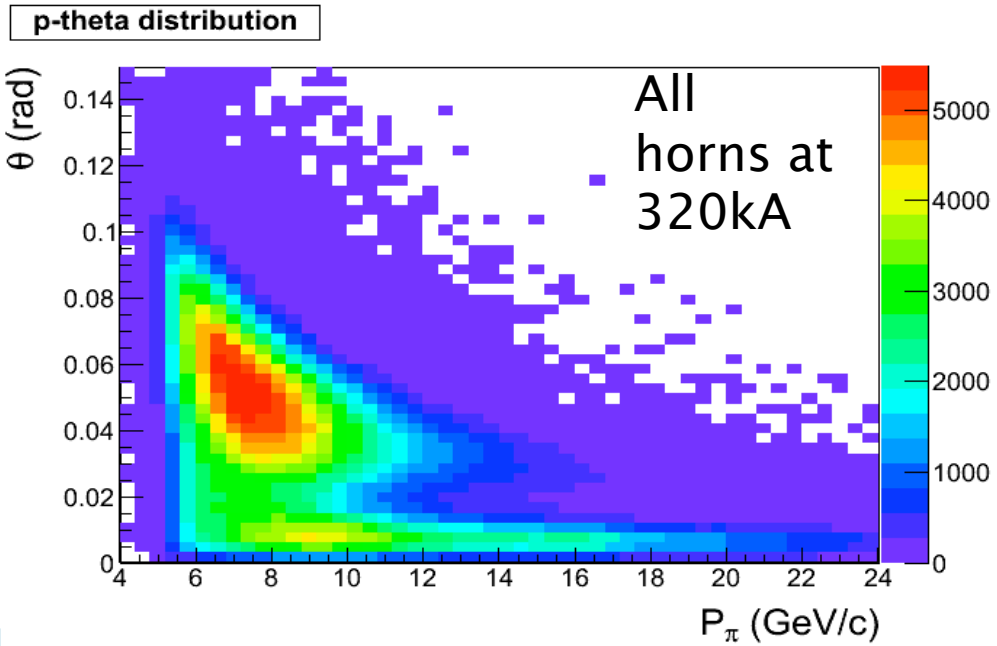
- For direction measurement

Error Source	Error Size
Detector Calibration	0.3 cm
Upstream Materials	~ 2.4 cm
Alignment	0.7 cm
Misalignment in target and horn	Under study
Total	2.5 + ? cm

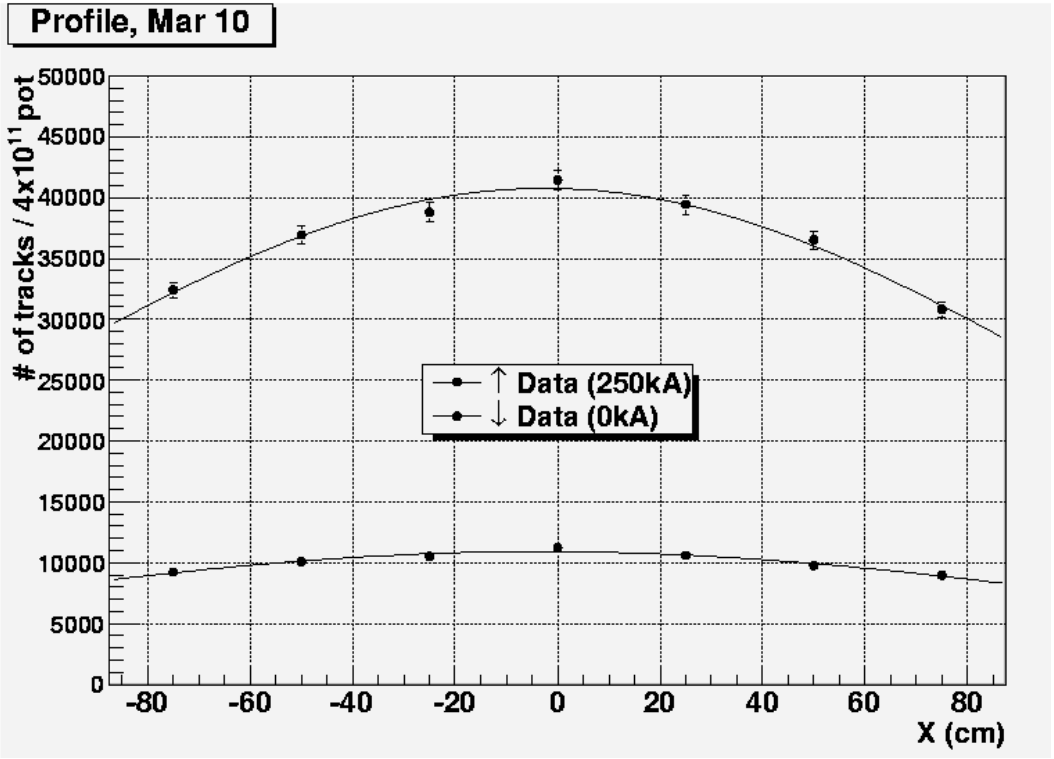
(11.8 cm = 1 mrad)

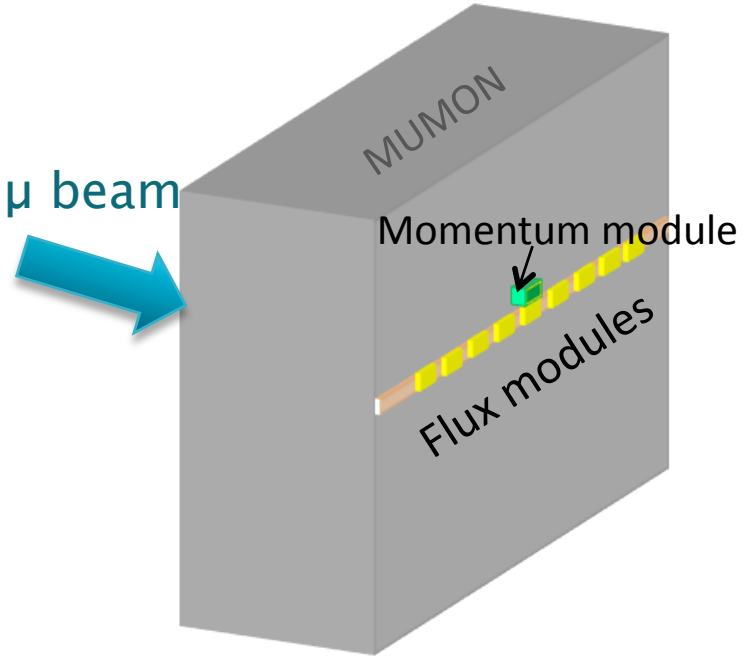
P-θ distribution of Pion



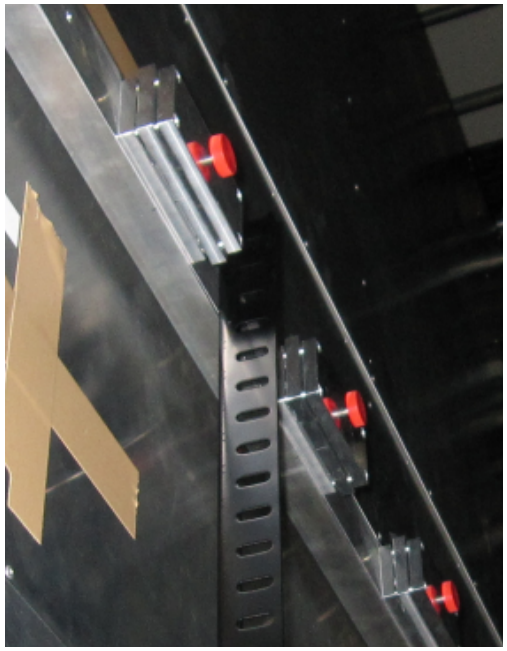


Flux Measurement

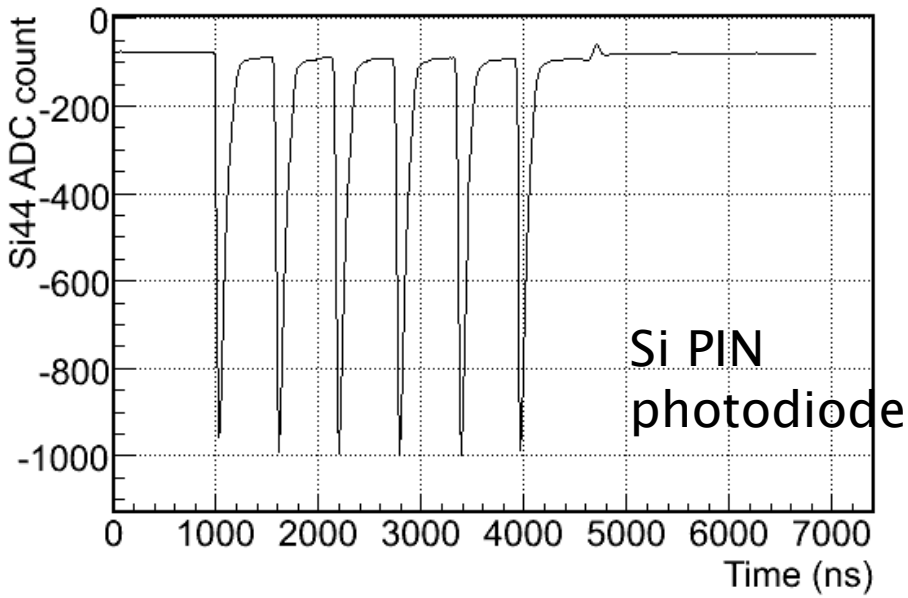


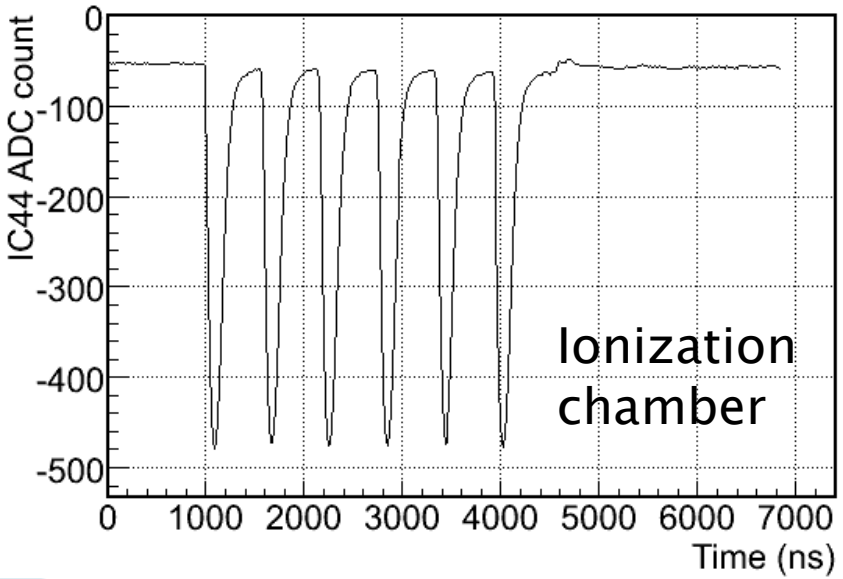


	0kA	250kA
Fit peak	10924±126	40768±468



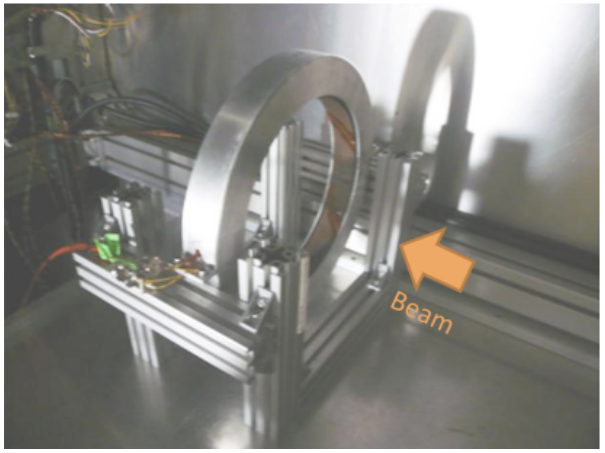
Signal Waveform

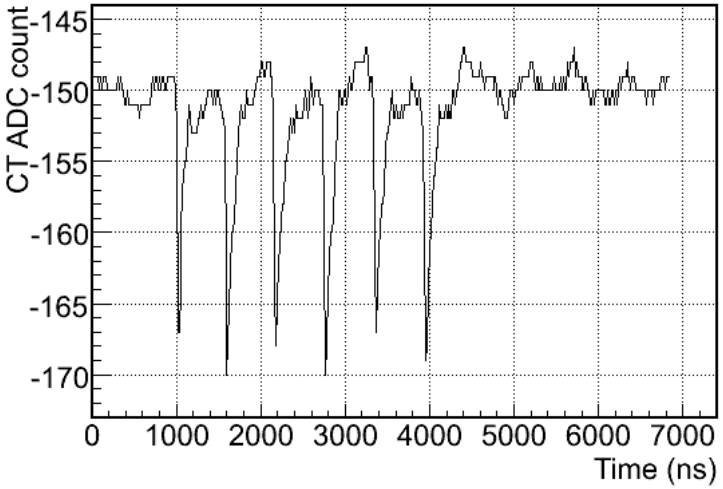




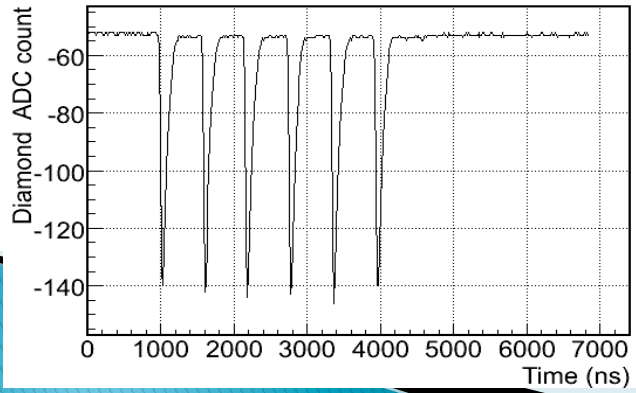
Candidate of detector in near future

- MCT





- Diamond detector



Study is ongoing