Performance and operational feedback of T2K graphite target

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for
J-PARC neutrino facility / T2K collaboration

Outline

- Overview of the graphite target in J-PARC NU beam line
- Status of He cooling
- Electric potential
- Check after the earthquake in 2011
- Current status of T2K target

T2K target design

- Material : Isotropic graphite (IG-430 by Toyo. Tanso. Co. ltd.)
  - Tensile strength = 37.2MPa
  - Geometry: L = ~900mm (~2λ_{int}), ϕ=26mm (main part)

    (cf. proton beam size: σ_x=σ_y=4.2mm)
- Energy deposit: 41kJ/3.3×10^{14} proton (30GeV)
  - Thermal shock : ΔT = 200K, σ_{eq} = 7.2MPa

    → Safety factor = 3.5 (including cyclic fatigue)
- Heat load: 19.6kW for 750kW beam
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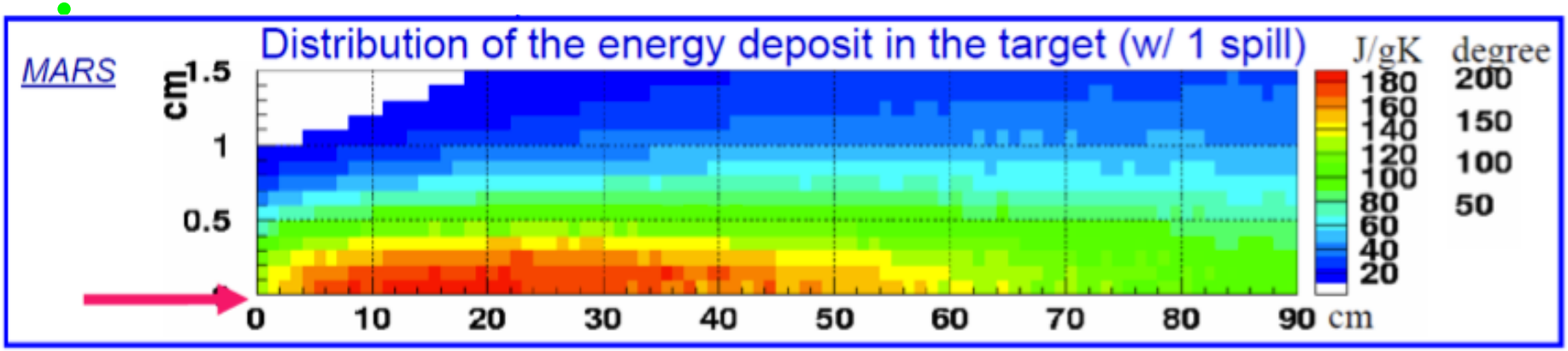
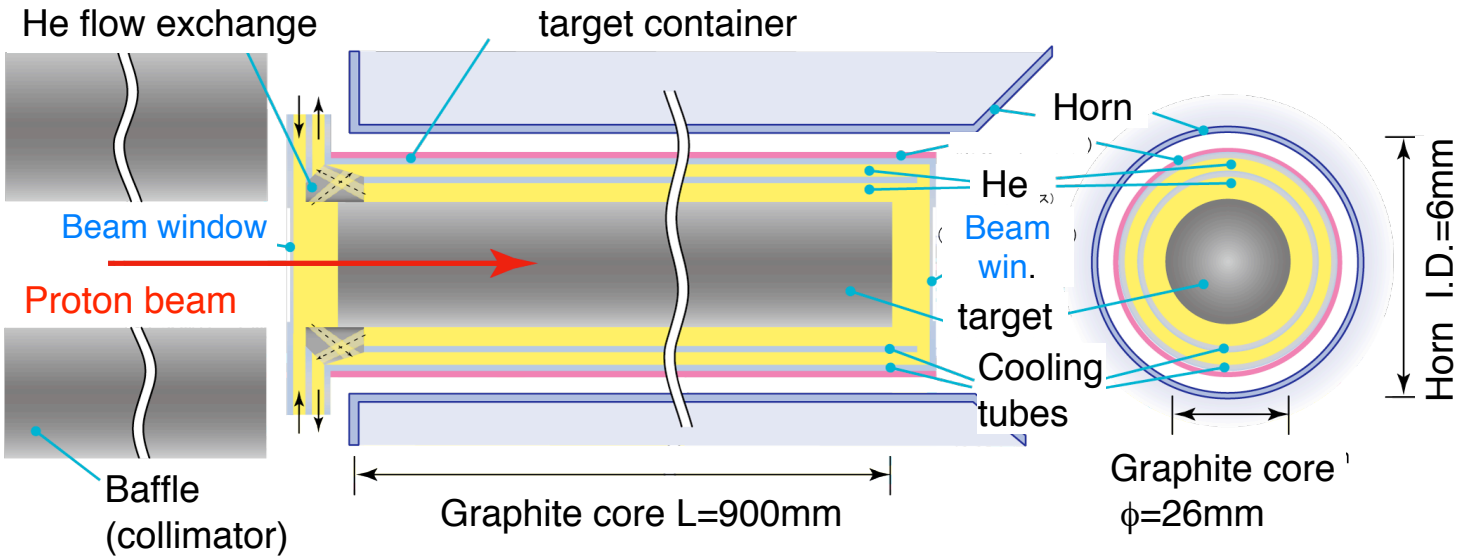
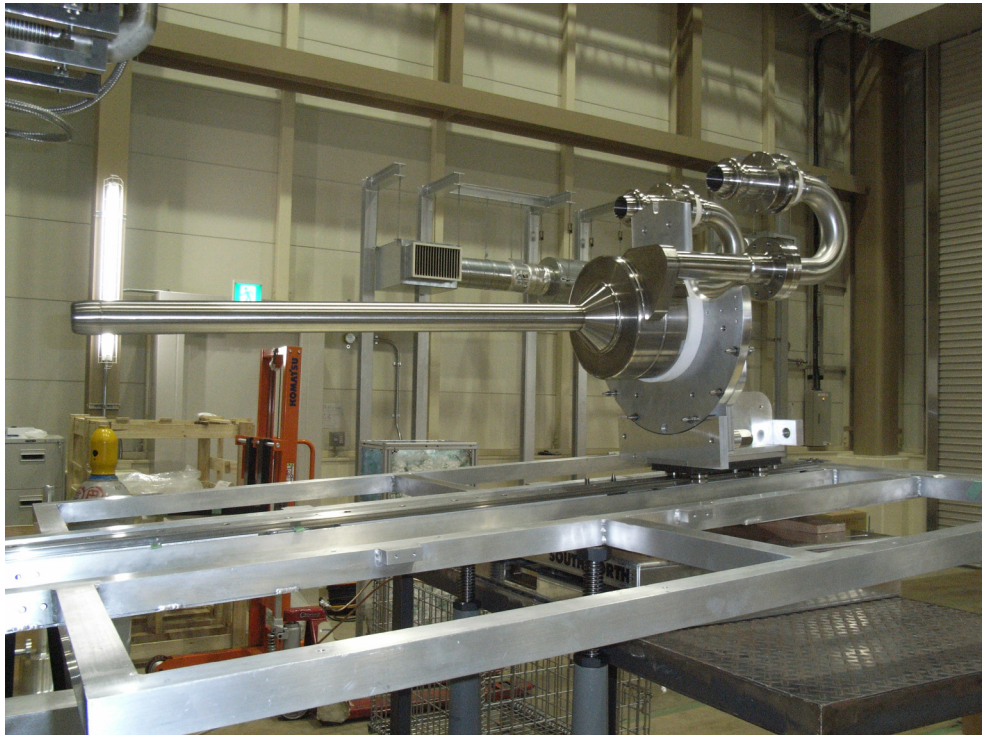


T2K target design

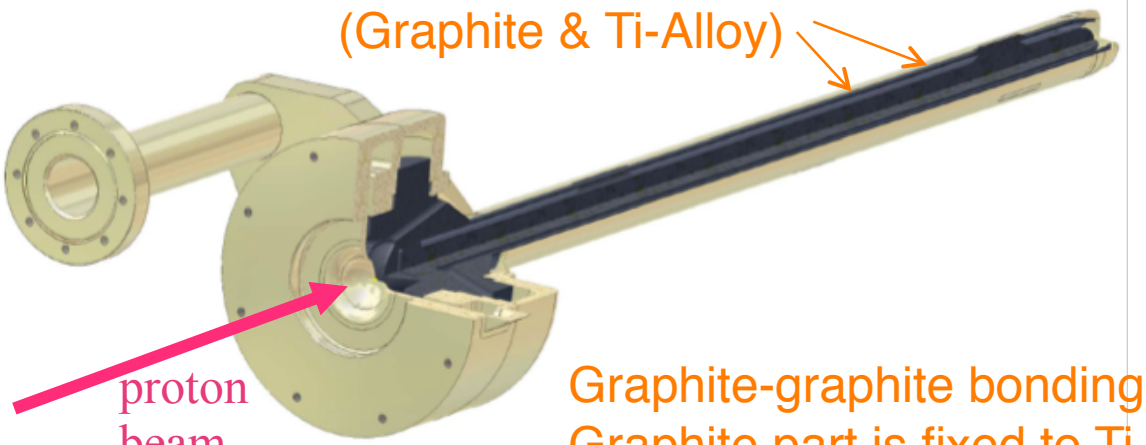
- He cooling for high temperature op. to reduce rad. damage.
  - Graphite: Max: ~800K, Surface: ~400K (for 750kW)
  - He gas: Flow rate = 560 Nm^3/h, ΔT = 170K (30K→200K)
  - Ti-alloy case. (Ti-6Al-4V): Case also cooled by He.
- Oxidization is determine the lifetime: Goal O_2 < 100 ppm
- Installed inside 1st horn inner conductor.
  - Cantilevered support for the remote maintenance.
    Install/Uninstall from 1st horn using the manipulator
  - Pulsed HV (~1kV) applied from horn via capacitive coupling with horn.



T2K target design

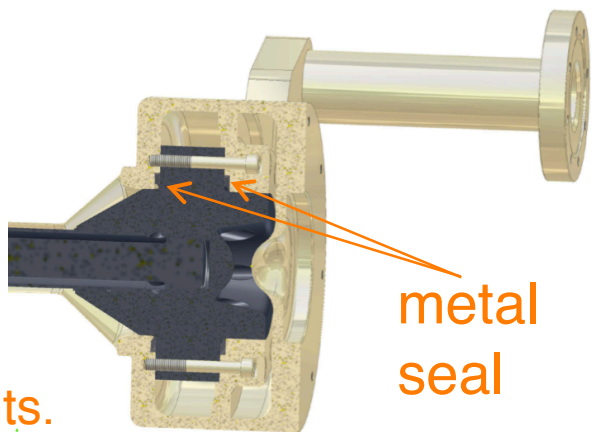


Co-axial 2 cooling pipe
(Graphite & Ti-Alloy)



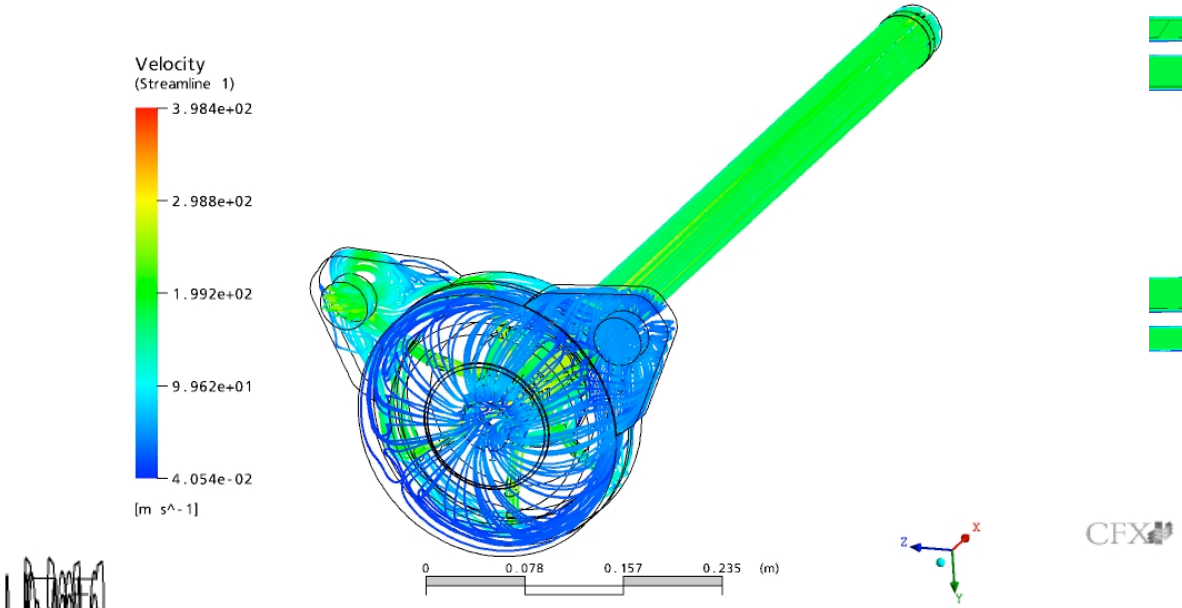
proton
beam

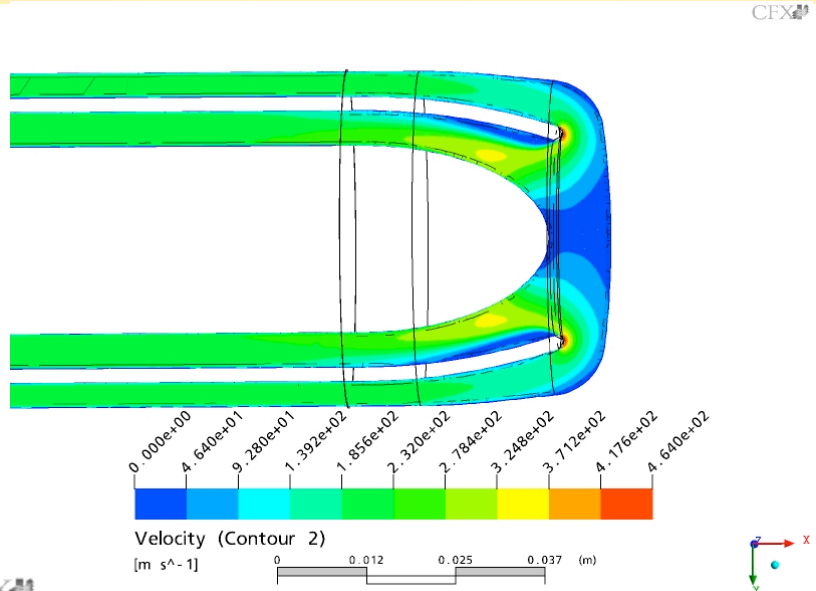
Graphite-graphite bonding with thread.
Graphite part is fixed to Ti parts with bolts.



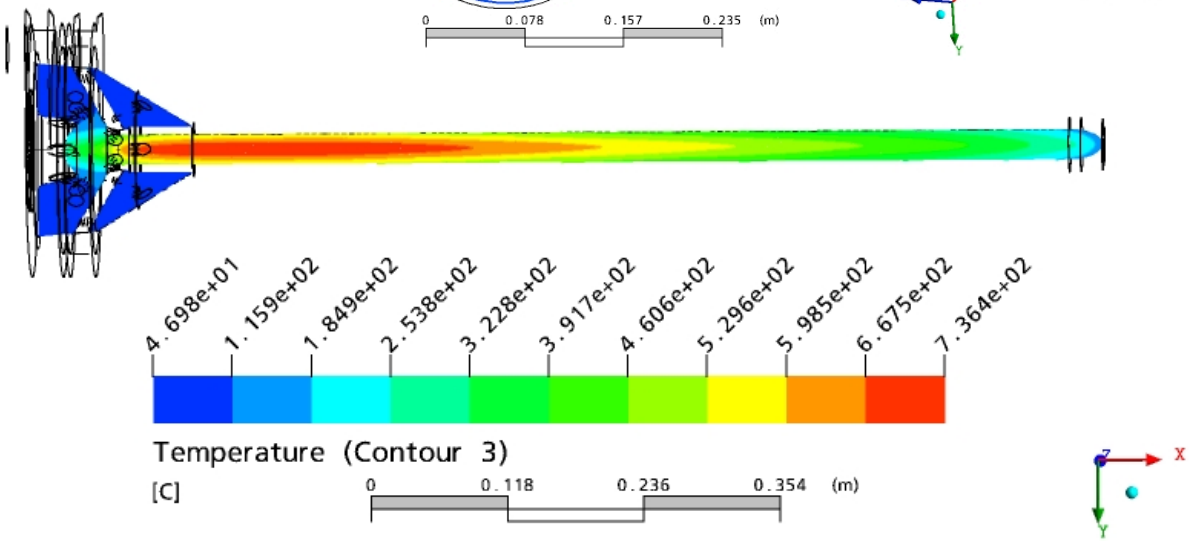
metal
seal

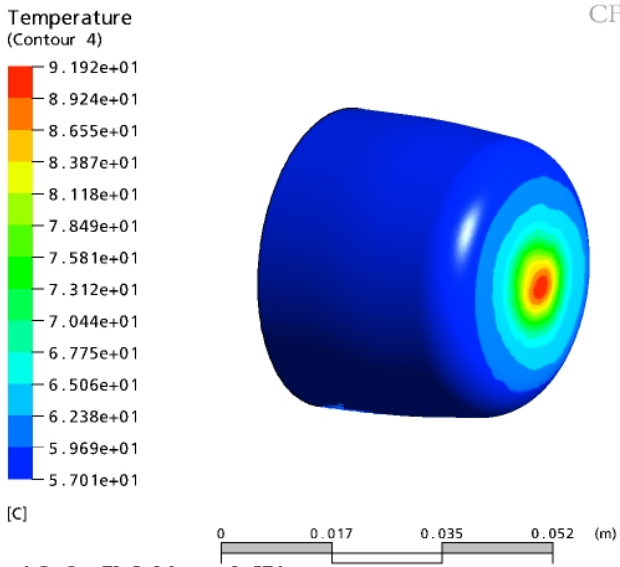
He cooling simulation





Downstream Window





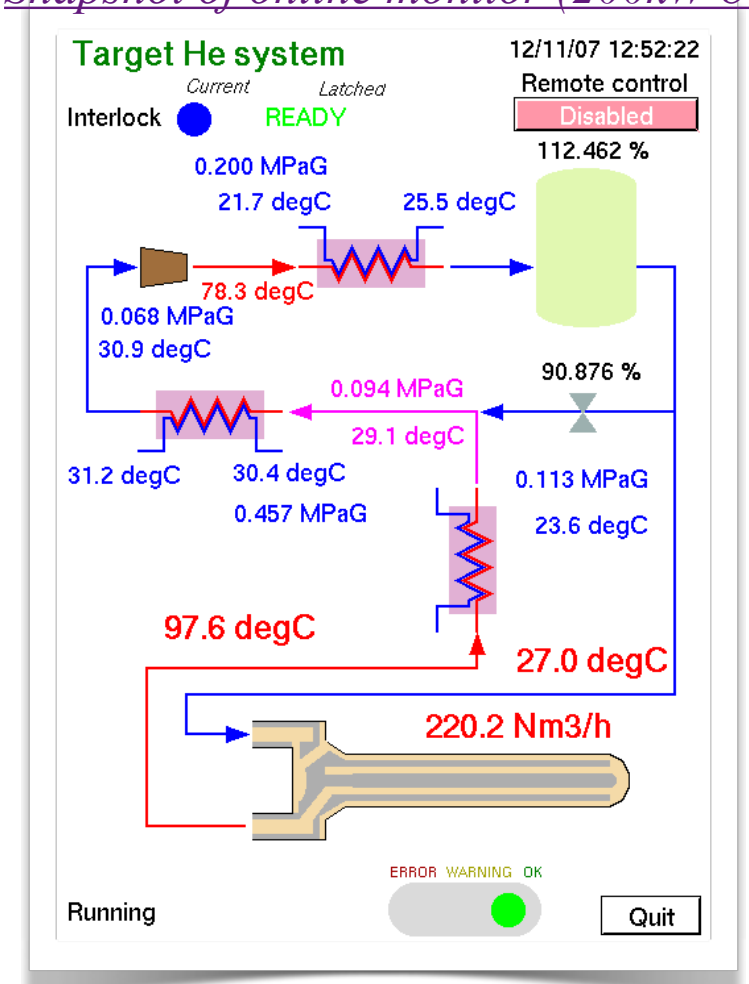
Mass flow rate = 32 g/s

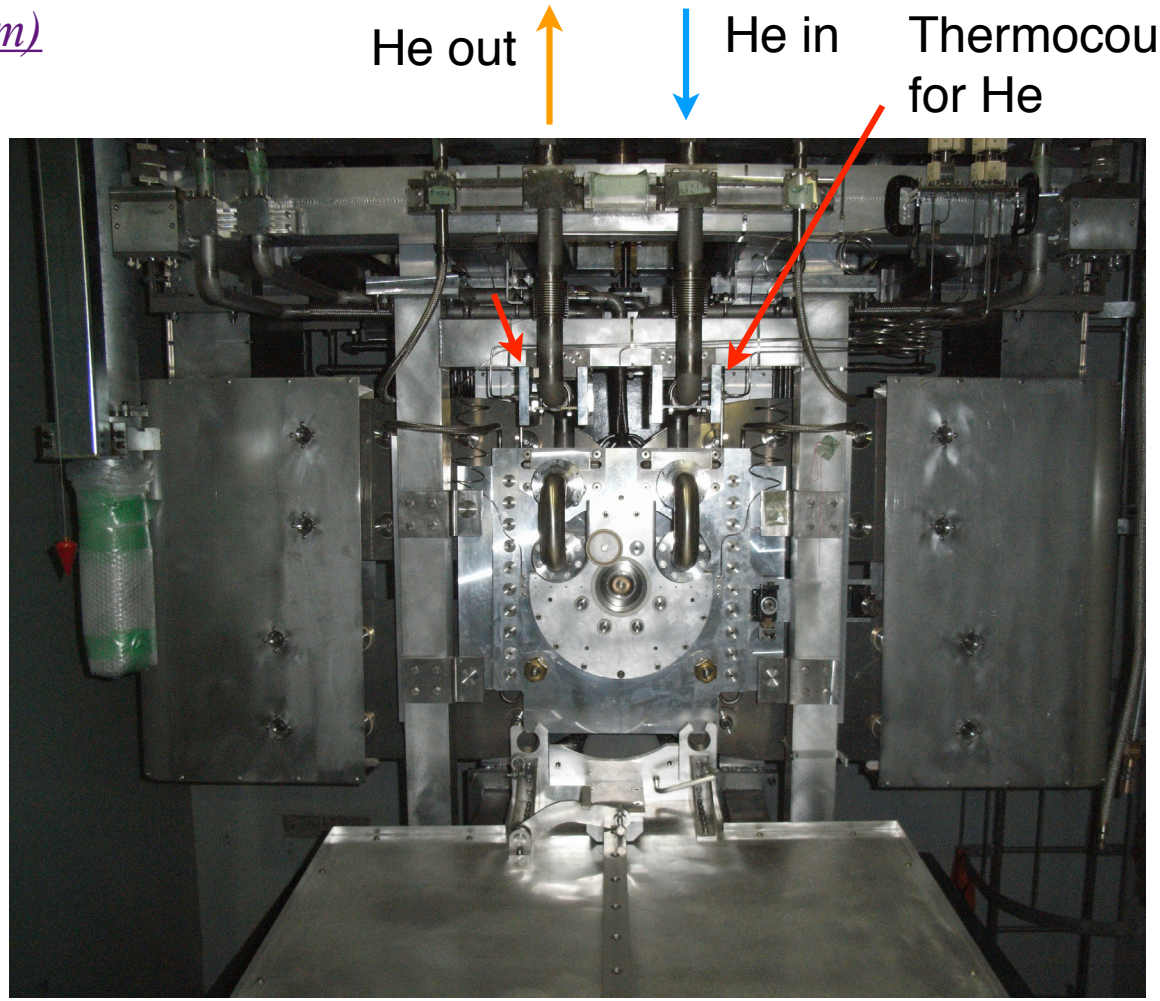
30 GeV, 0.4735Hz, 750 kW, Radiation damaged graphite (20 [W/m.K])

Target status monitoring

- The information on the target during the beam is very limited.
  - Temperature of cooling helium.
  - He circ. system: Pressure, by-pass ratio (He leak).

Snapshot of online monitor (200kW beam)

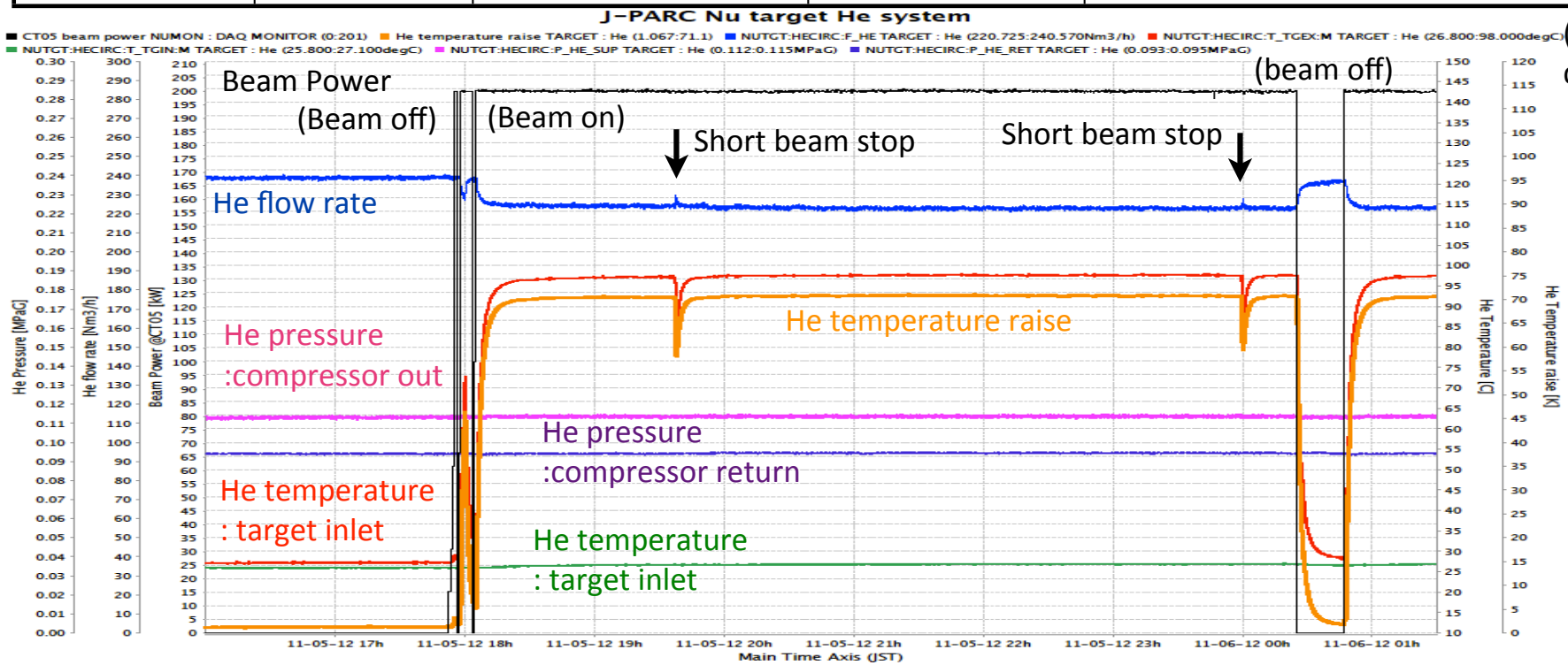




Measured He temperature

- Actual He temperature is consistent with expectation for 200kW beam operation.

	Helium gas			Target Max. Temperature [C] ***	Ti max. temperature [C]	
	flow rate [Nm³/h]	Pressure [MPa] @Target out	Temperature raise [K]		Upstream	Downstream
Simulation (200kW)	*202*	*0.09*	*~105*	*366*	*69*	*85*
	302	*0.09*	*~72*	*266*	*61*	*66*
Data	~225	~0.10	~70	(Not monitoring)		



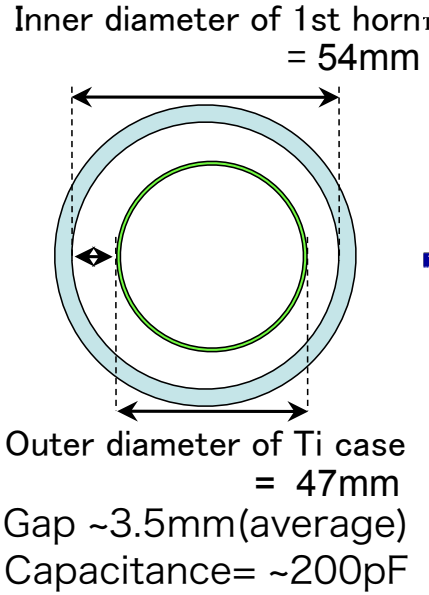
(*** No radiation damage is assumed.)

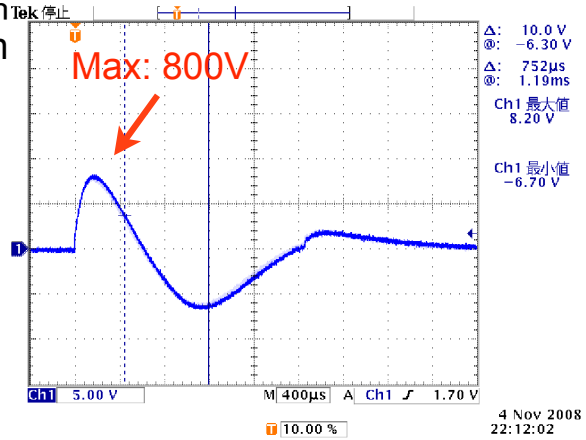
Degradation of the coolant He gas

- Tritium production due to the beam operation
  - ^{3}H 180[Bq/L] for T2K Run-3 (1.37×10^{20} POT)
    - HTO = 174 [Bq/L]
    - HT = 6 [Bq/L]
  - Regulation for the exhaust to outside: 5 [Bq/L] (3 month average)
    - × ~ 400 dilution is necessary.
      The He system was modified, and the volume other than the target itself can be a vacuum for He gas replacement.
    - The volume of He for target cooling is 4~6 m^3 (in atm. pressure) while the capacity of Target station ventilation is ~1300[m^3/h].
      → It is not difficult to dilute enough.
- Issue: No O_2 contamination measurement is installed.
  ← We can not find the O2 sensor which work at >0.2MPa.
  - We plan to install gas chromatograph in target station & gas sampling system from Target / TS He-vessel , etc

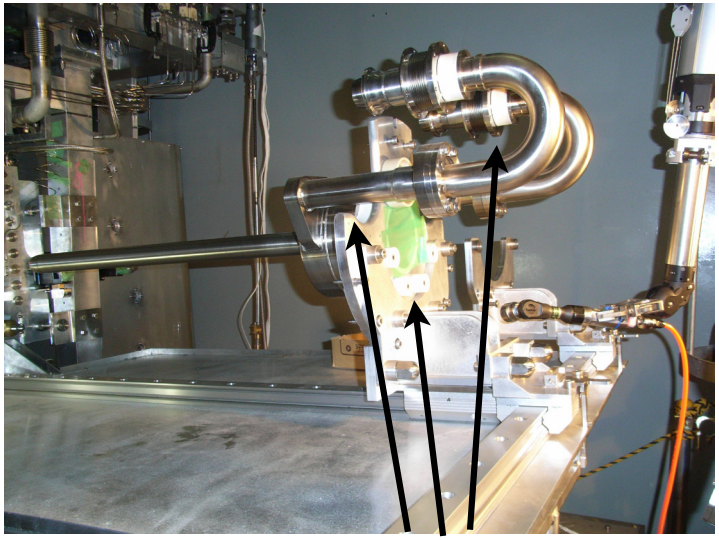
Target electric potential

- T2K target is installed in the 1st horn : the same voltage as 1st horn.
  - Electrical insulation is considered for the support structure and He tubing.
  - Ti-alloy case is connected to ground with high register (~8MΩ) in order not to be charged up.

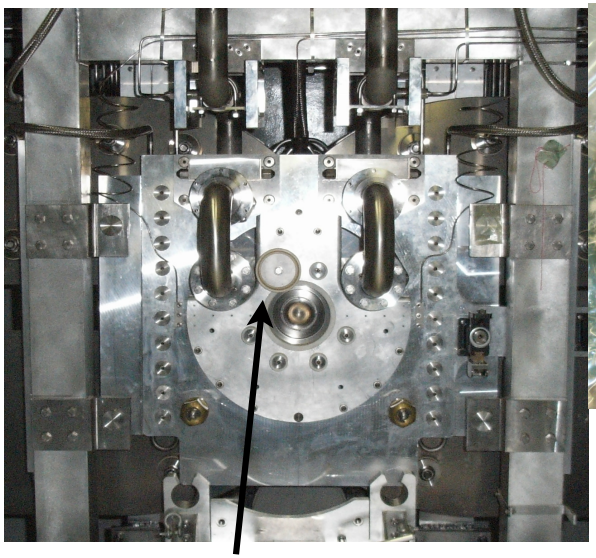


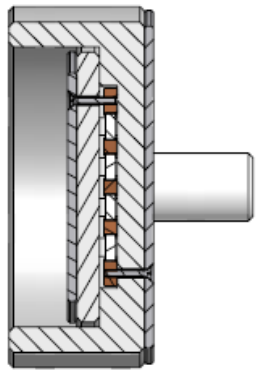


Measured electric potential during the test operation before the installation.



Ceramic insulator





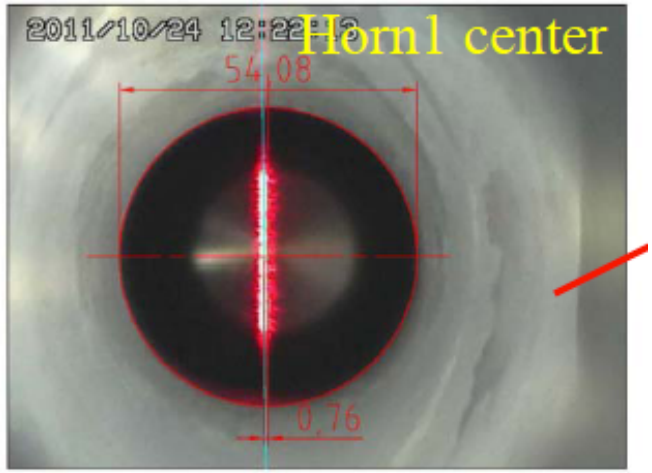
Resisters are installed in the ceramic parts

Checked item after the earthquake

Target was shaken together with the 1st horn which is hanged by the horn support frame.

- It is expected that the horn support frame collide with the TS He vessel and/or 2nd horn support module.

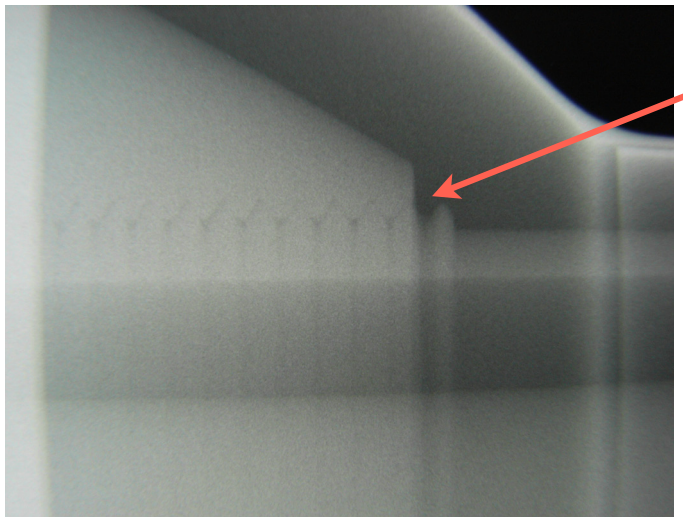
- Checked Item before beam
  - He flow : No significant change after earth quake.
  - X-ray inspection for spear targets → Next page.
  - Check by the web-camera : No damage was found. ↓
- Checked Item with beam
  - “Beam based alignment”
    : Check the muon yield/proton intensity



Inspection of the spares after the earthquake.

- At this moment, we have 2 spare targets.
  - One is same structure as the used one. (Machining precision is improved)
  - Another spare is made with new design by RAL group.
- When earthquake happened, the spares were also fixed as the cantilever. To expect the damage of the installed target, we did the X-ray inspection for the spares.

Edge position of core and inner pipe is OK.

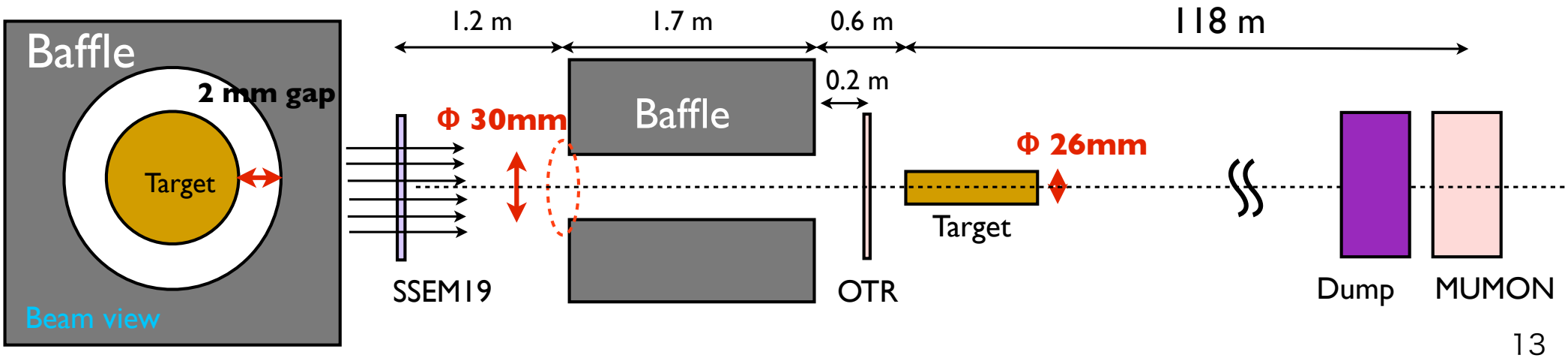


Most fragile part

No clack was observed.
Target and Inner tube are at correct position.
No graphite fragment observed at the bottom.
→ We judged that we will continue to use the installed target.

Beam based alignment of baffle, target.

- Scan the beam position using low intensity (~4×10^{11}p/pulse) and narrow size ($\sigma_{x,y}$=~2mm) beam.
- There is two change for the muon monitor signal
  - Muon yield / proton ... targeting efficiency
  - Muon profile width ... The muon produced by the interaction of protons at the beam dump.
- During the beam scan horns are turned off.
  - It is possible to check the horn alignment by comparing the muon profile w/ horn on.

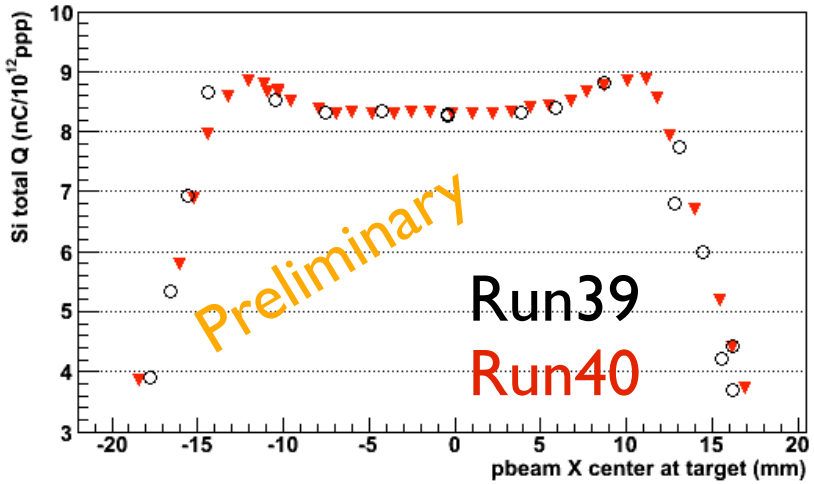


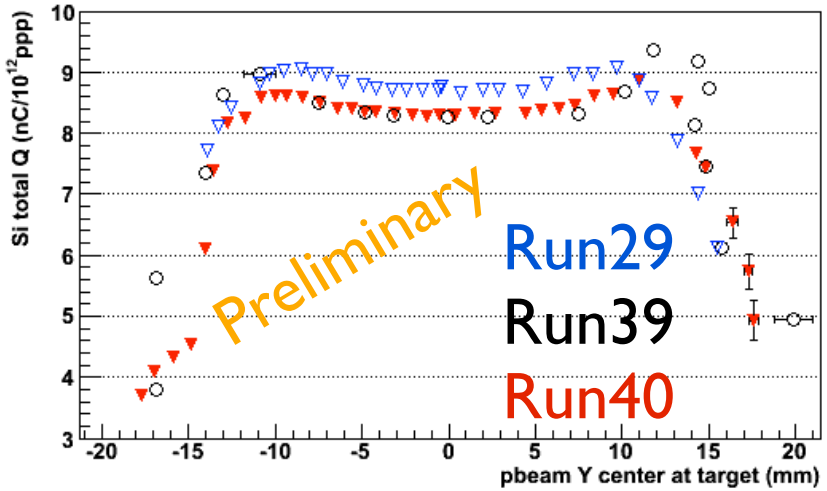
Beam based alignment using muon monitor

- Target/baffle position may be shifted by ~1mm.
  It is within the acceptable range.

Horizontal beam scan | Vertical beam scan

Muon yield / proton

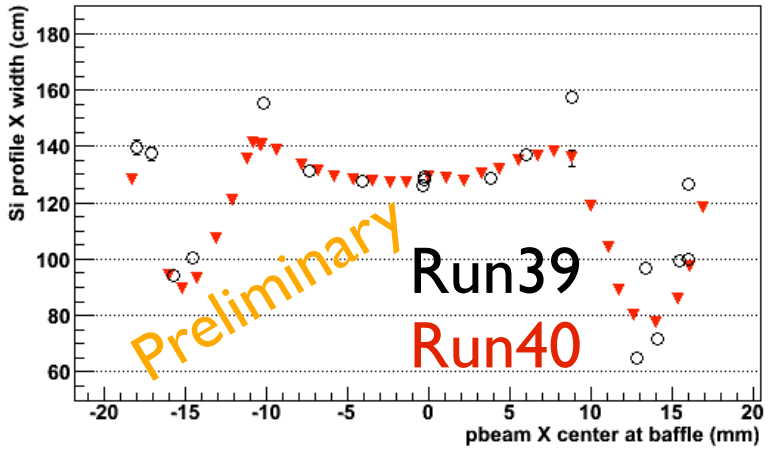


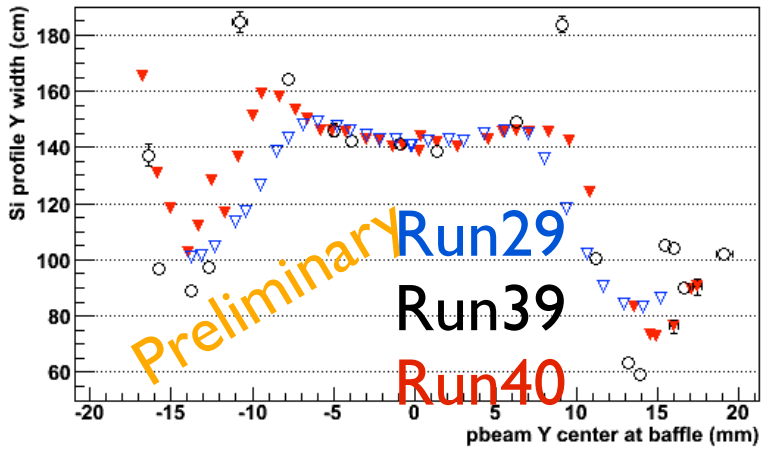


Run29 (Before EQ)

Run39, Run40 (After EQ)

Muon profile width

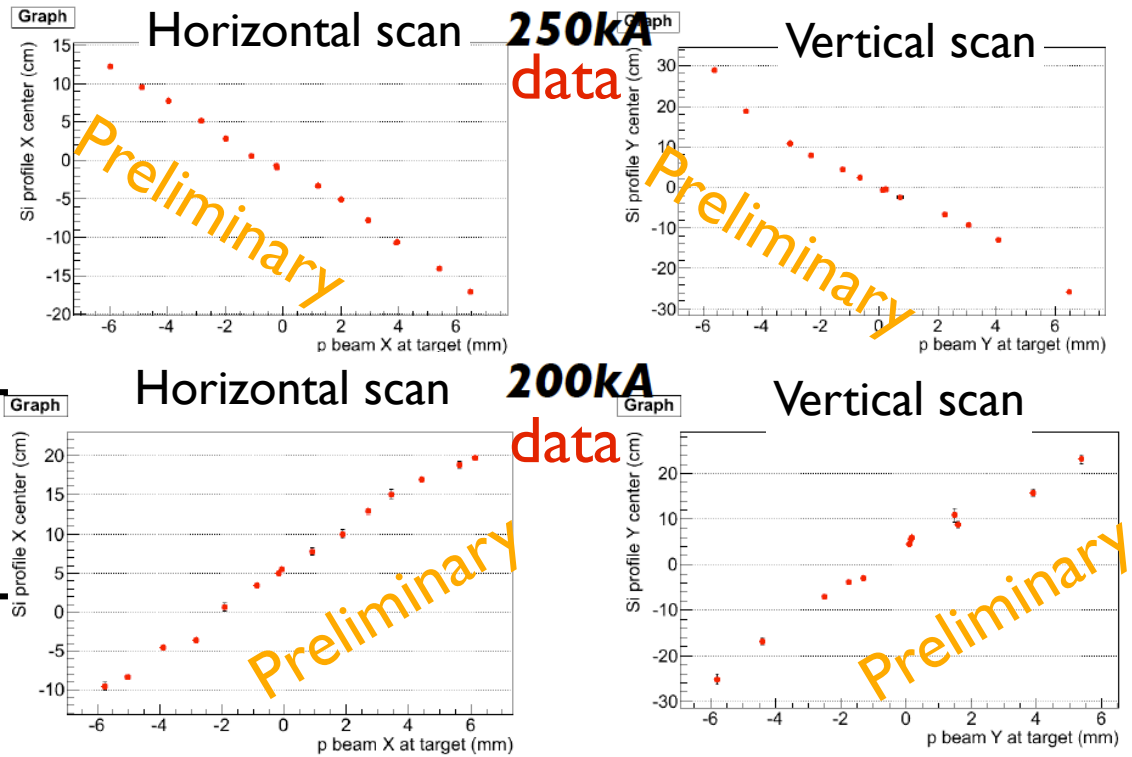


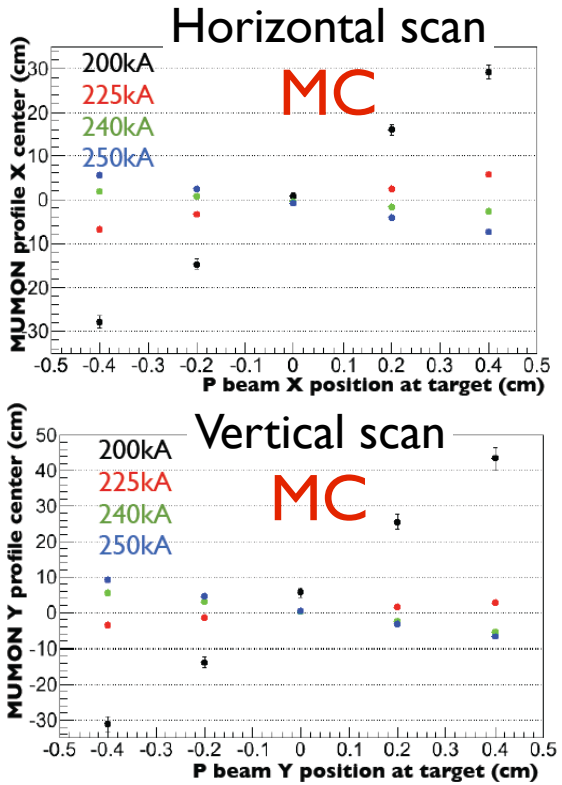


By the way, ...

- Relation between the muon profile center and proton beam position depends on the horn current. (It is reproduced by MC.)
  - Positive correlation in 250kA case ←→ Negative correlation in 200kA case
- For T2K horn, the muon direction is not depends on the proton beam position if the horn current is a certain value between 200kA and 250kA.
  - The neutrino beam direction become stable, but it is impossible to adjust proton beam position using muon measurement.

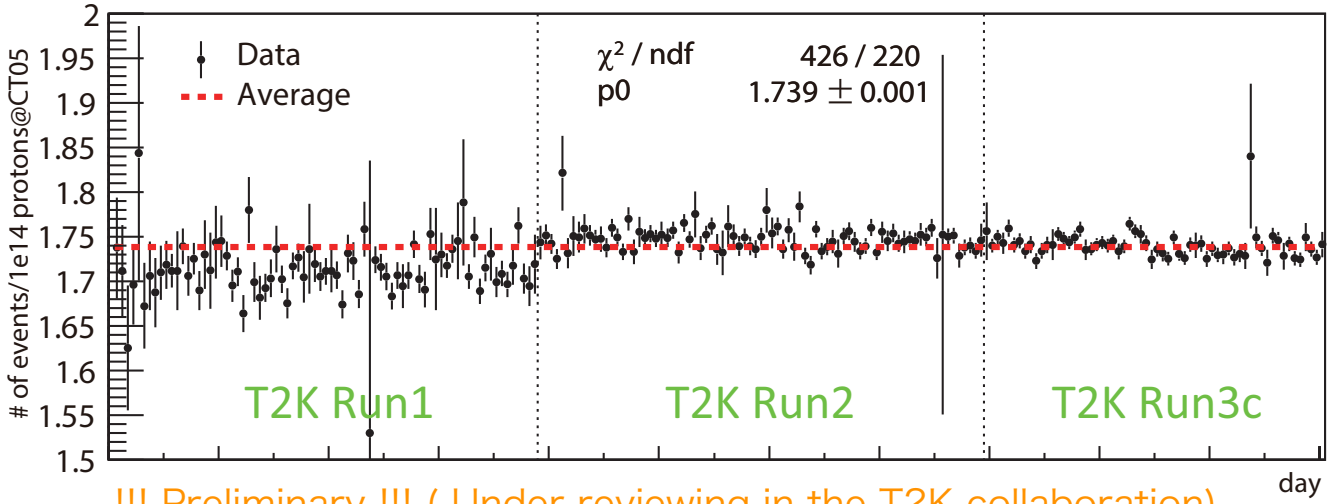
Muon profile center vs. proton profile center





Current status of T2K target

- 1st target is exposed to ~3.4×10^{20} POT as of Nov. 2012.
- No abnormal thing was observed.
  - There is no significant radioactivity in the strainer in He circulation system. We exhausted cooling He gas via the filter with 0.1μm and no radio activation was observed at the filter.
  - The neutrino yield normalized by the proton intensity is stable within the uncertainty of proton / neutrino intensity and horn current monitoring.
- Issues:
  - We do not have the system to monitor the Oxygen contamination in He cooling line. So we plan to install the gas chromatography system in TS.



!!! Preliminary !!! (Under reviewing in the T2K collaboration)

Neutrino yield (On-axis detector @ 280m) normalized by proton intensity.

Summary

- Design of T2K target is reviewed.
- He cooling is working as expected at this moment.
  - Current issue is the lack of O_2 contamination monitoring
- T2K target survive the large earthquake.
  - Alignment is checked using the muon monitor by scanning the proton beam orbit.
- No degradation of the graphite is observed for 3.4×10^{20} POT.