J-PARC Neutrino Beam-line Upgrade

T. Nakadaira
for
J-PARC neutrino beam-line construction group
T2K collaboration

Outline

- J-PARC neutrino beam-line
  - Achieved beam power: ~230kW
- Basic scenario for beam power upgrade
  - Key points for each components
    - Toward 750 kW (Design beam power)
    - Toward >1 MW beam in future
- Summary

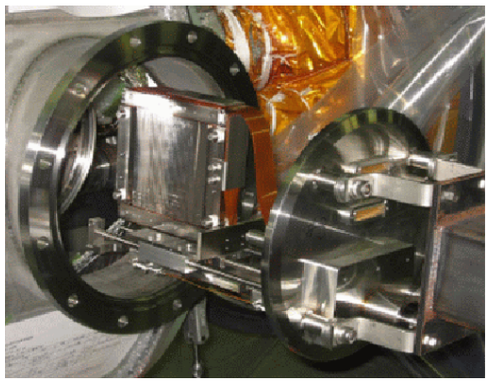
Proton beam parameters for J-PARC neutrino beam

- Design parameters for neutrino beam-line: (~2009)
  - 30GeV - 3.3×10^{14} [p/pulse] (4.1×10^{13} [p/bunch]×8[bunch]) Cycle 2.1[s]
- Current scenario to achieve 750kW
  - 30GeV - 2.0×10^{14} [p/pulse] (2.5×10^{13} [p/bunch]×8[bunch]) Cycle1.28[s]
- Impact to the requirements for neutrino beam-line.
  - Advantage: Thermal shock (due to instantaneous temperature raise due to beam) is relaxed by ~40%.
  - Disadvantage: Cyclic fatigue will be increased.
    - Pulse magnets (Horn) and its power supplies, current transformar
    - Temperature cycle: Target, beam-window.
  - Other conditions are same.
    - Radiation damage, Residual dose is proportional to integrated POT.
    - Required cooling power is not changed.

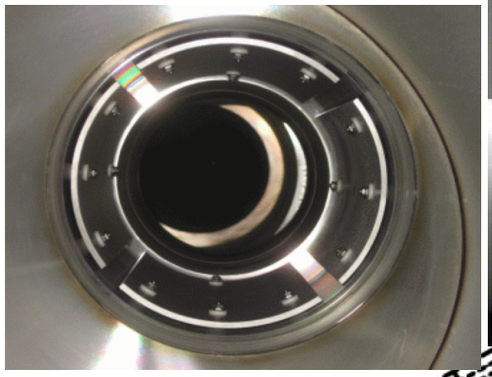
J-PARC ν beam line :Primary-line

Beam monitors are install along the proton beam transport

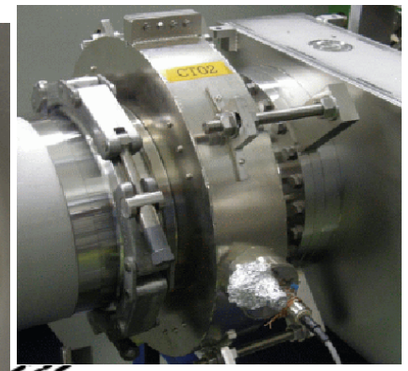
Profile (19)



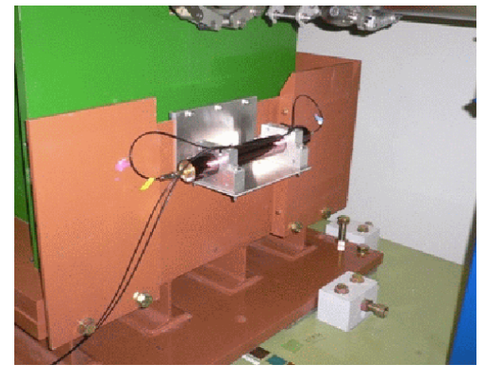
Position (21)



Intensity (5)



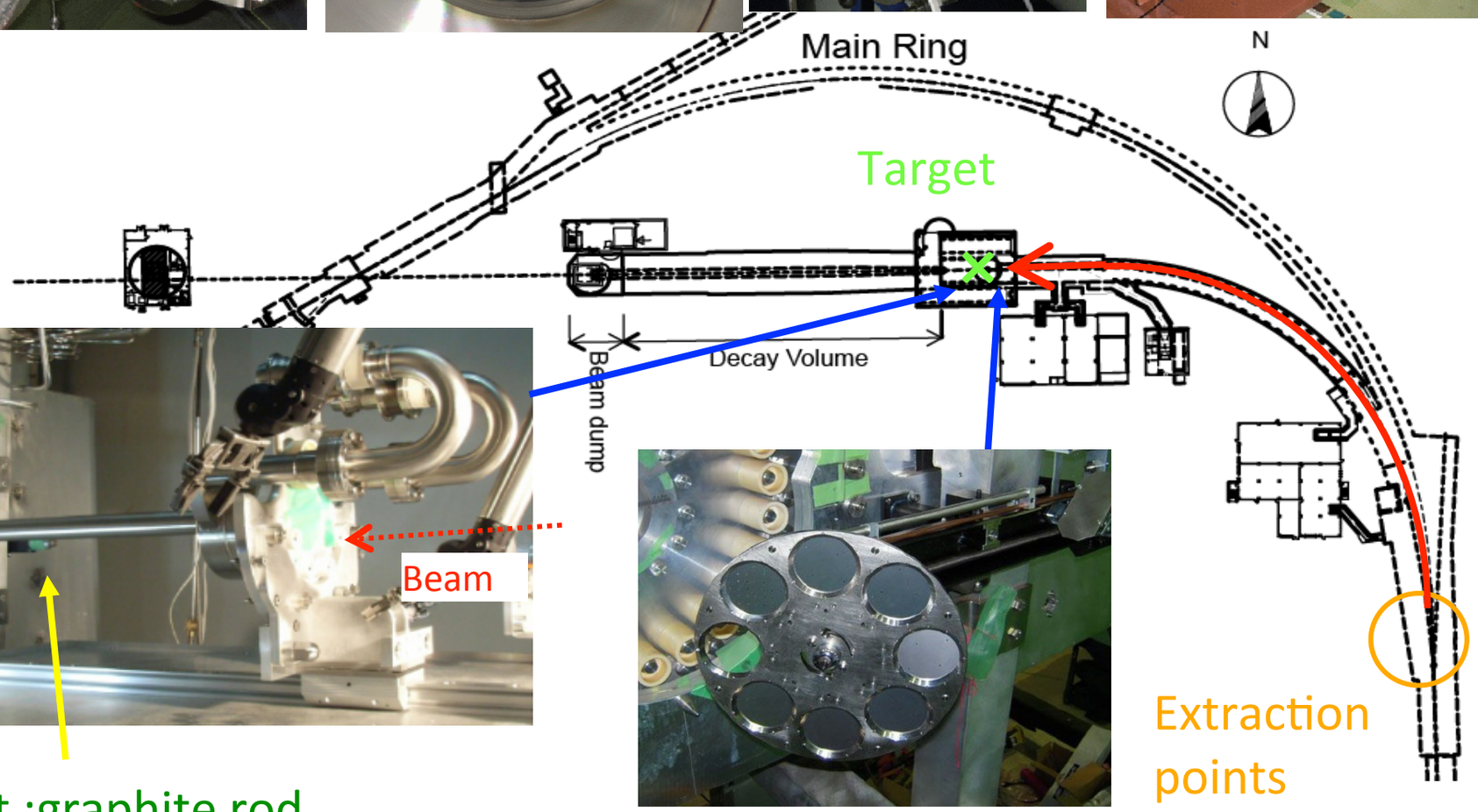
Beam loss (50)



Primary proton transport line

Super-conducting combined-function magnets

Normal-conducting magnets



Target :graphite rod
ϕ26mm,L=900mm

Optical Transition Radiation (OTR) Profile monitor

Requirements for primary-proton transport

- What is limiting the beam power? ⇒ Beam loss : < 1 W/m
  - Avoid the quench of SC-magnets
  - Control the the residual dose for “hands-on” maintenance.
- Recent improvement of the primary-beam transport:

1. All the old power supplies for the NC magnets that was made in ‘70s~80’s are replaced by newly build power supplies. (2014)
2. Enforcement of the collimator to protect SC magnets
3. Vacuum pump during beam-operation is replaced;
   Turbo Molecular Pumps → Ion Pumps.
   - This is one of the safety enforcement in case the beam-window between primary-line vacuum and 0.1MPa He at TS is broken.
   - To avoid that radio-active fragments from beam-window (Ti-alloy), SSEM foil (Ti) ,etc will be spread across the tunnel from vacuum pump exhaust.
4. Replacement of Stainless-steel beam duct by Ti-duct. (Partially)

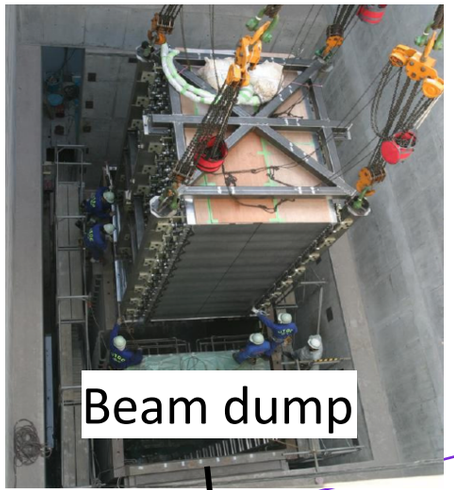
What we learn from ~5 years operation experience.

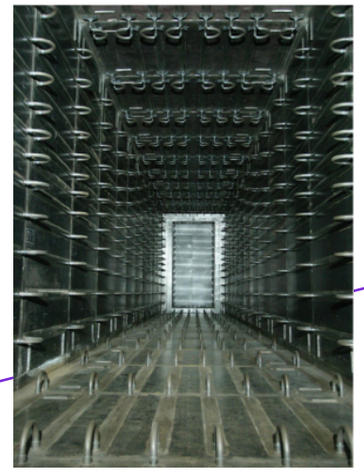
- Interlock system to guarantee the normal condition is important!
  - Two troubles due to loophole of the beam-interlock for beam-tuning mode.
    - Case 1: SSEMs can be inserted/extracted from the beam-orbit during beam tuning.
      - The proton beam spill was extracted to neutrino beam-line during the SSEM moving by mis-operation. Proton beam hits the frame of SSEM.
        ⇒ SC-magnet quench was happened due to bean-loss.
      - Fortunately, no hardware damage. Beam interlock was revised.
    - Case 2: One bending magnet was down without warning nor interlock-signal.
      - Proton beam hits the beam-ducts, beam-monitors and magnet, and lost at the primary proton transport.
      - There is no damage in beam-duct itself, but the feed-through of one beam position monitor was damaged and vacuum leak was happened.
      - Countermeasures:
        - More strict logic for the beam interlock during beam tuning.
        - Rotate the position monitor by 45-deg along the beam-axis so that the abnormal proton orbit does not pass the feed-through.

Possible upgrade for > 750kW operation

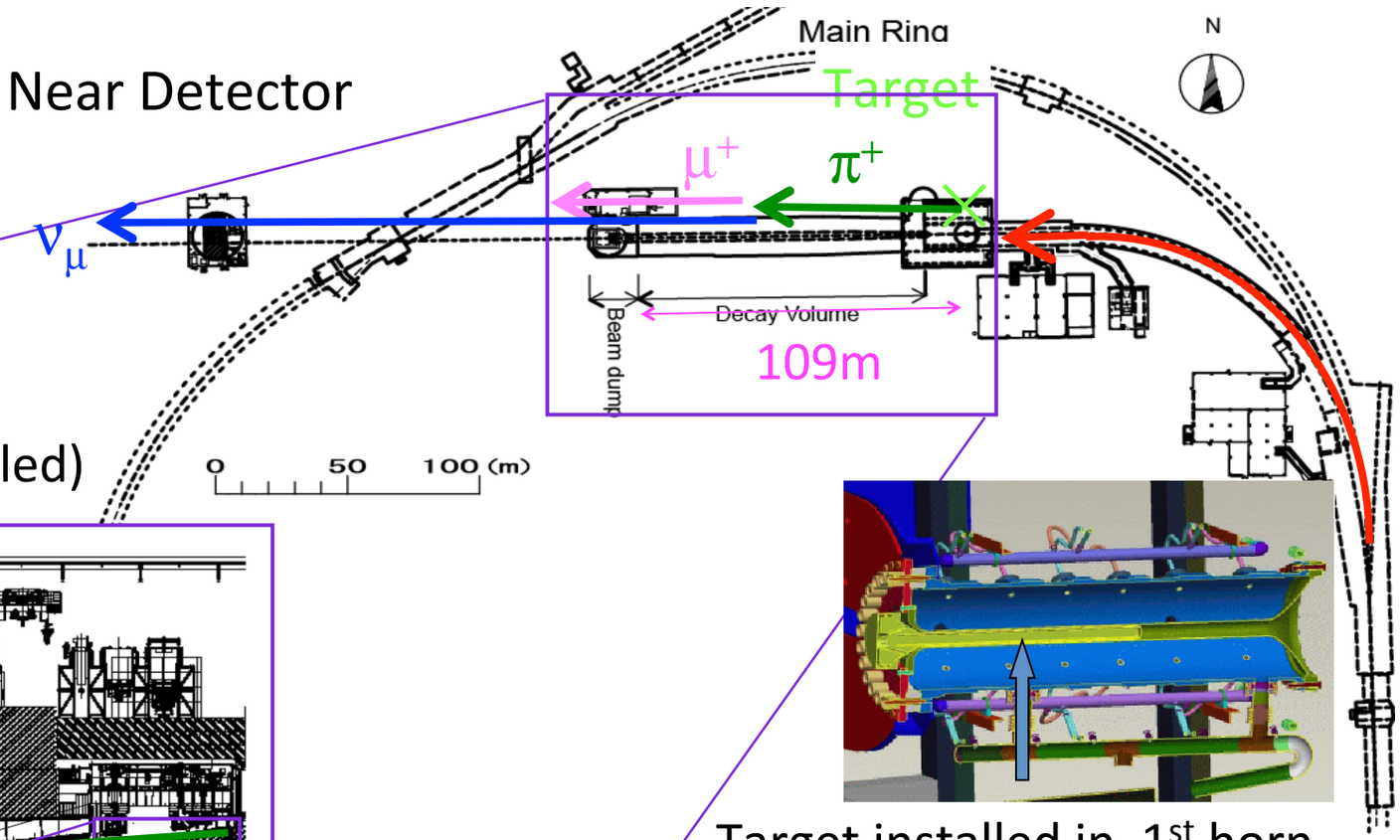
- Beam monitors with low beam-loss
  - Non destructive profile monitors is necessary. → M. Friend's talk
- Beam-line DAQ / control system improvement:
  - Policy of the current J-PARC beam-line DAQ/control.
    - For each beam spill, it is checked if all the proton beam parameters are normal.
      ⇒ If there is something strange, next proton beam spill will be aborted to MR abort dump.
      - If some trouble happens just before the MR fast extraction timing, it is impossible to stop beam.
      - Beam-line hardware was to be designed to stand against 1 abnormal beam hit, but it is difficult for >1MW beam.
        → Improving magnet trip interlocks and off-orbit blockers (collimator) is key issue.
    - Beam-line DAQ for beam monitors, online data analysis for interlock should be improved for ~1Hz Rep. rate.
      - R&D for Fast FADC is in progress.
- Optimization of the collimator?
  - It depends on the actual beam hallo condition.

J-PARC ν beam line: secondary line

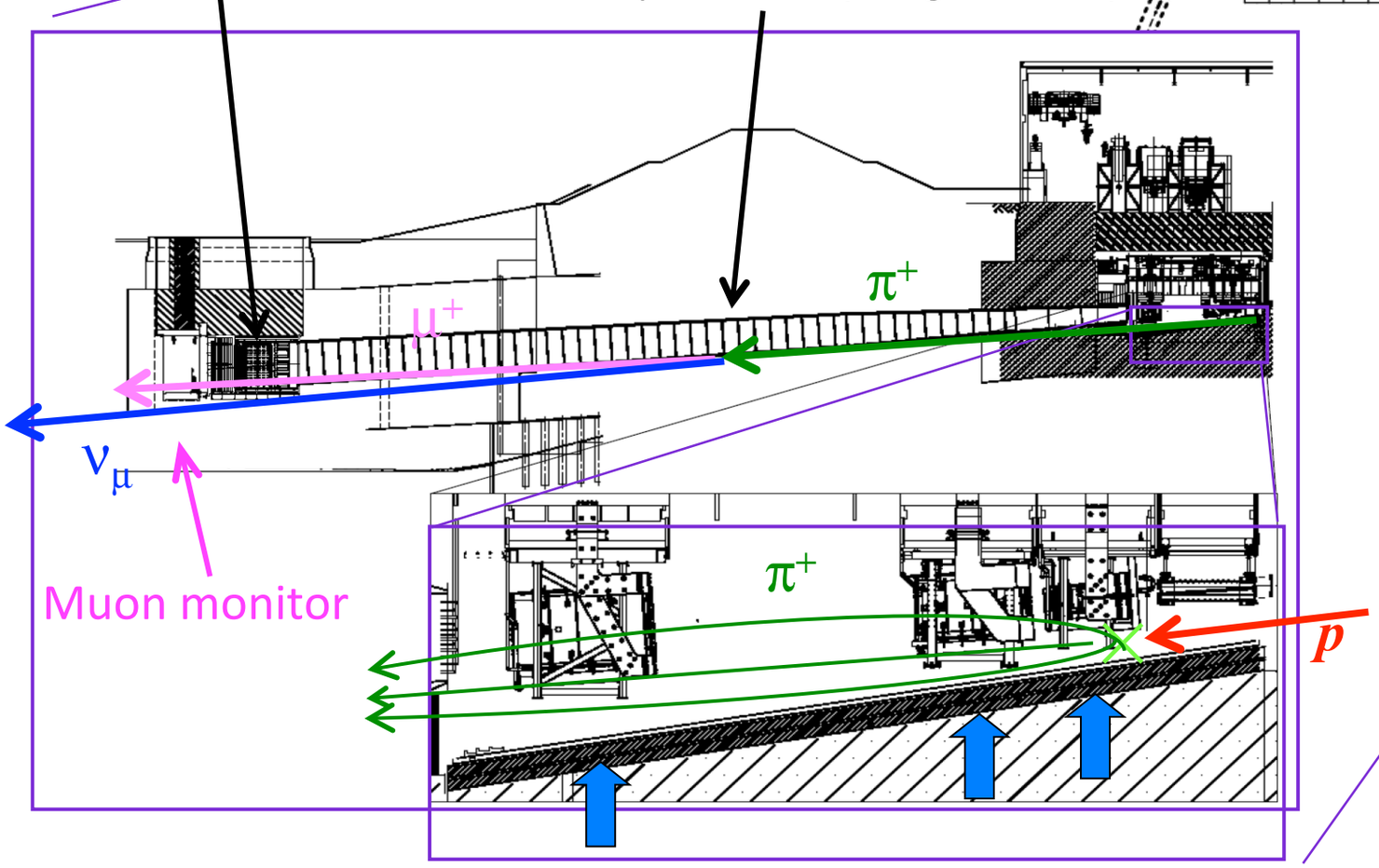




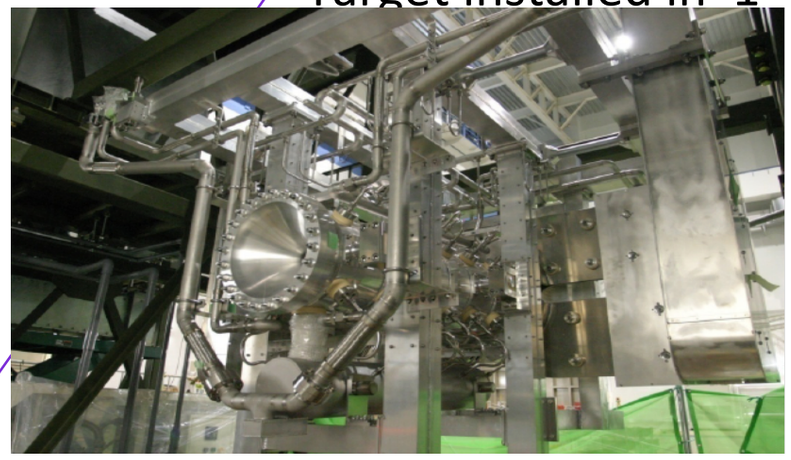
Near Detector



Decay volume (He gas filled)



Target installed in 1st horn.



Pions are focused by
3 electromagnetic Horns.

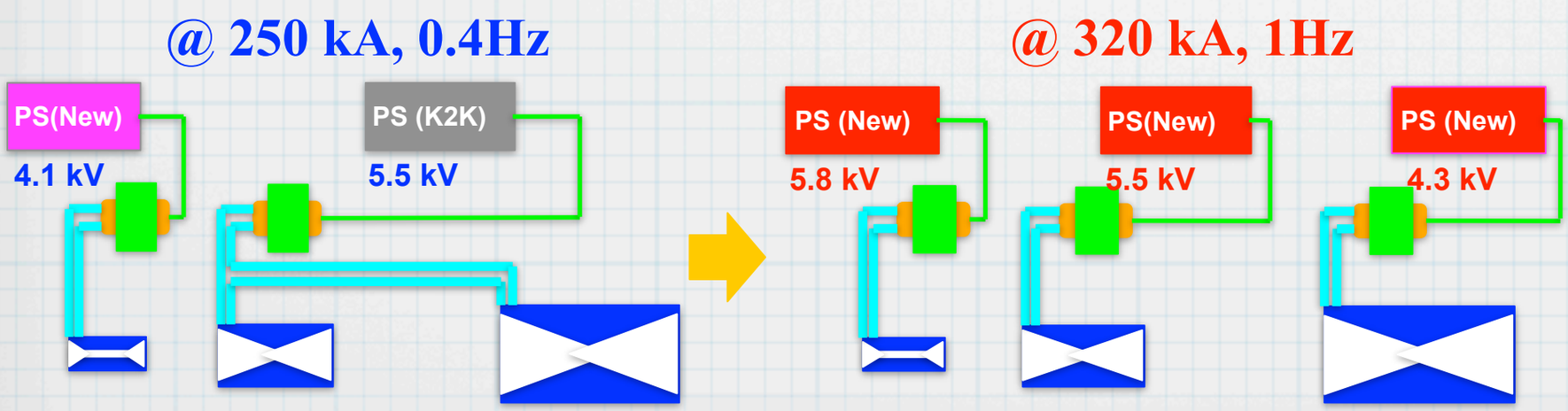
Target, Beam windows

- Heat load ∝ Beam Power
  - There is room to increase mass flow rate by enforcing the circulation system (compressor).
  - It is necessary to increase the pressure of He for target cooling.
- Thermal shock ∝ Protons / pulse @ profile peak.
  - Increasing Rep. rate: No effect.
  - Increasing # of protons/spill: Thermal shock is increased linearly.
    - Originally designed for 3.3×10^{14} p/spill with safety factor of ~3.
      ⇒ Now 40% margin exists for current 750kW scenario (2×10^{14} p/spill).
    - Relaxed by enlarging the beam-size: Thermal shock ∝ $1/\sigma_x\sigma_y$
      - The optimization considering the horn focusing is necessary.
      - Current design: $\sigma_x=\sigma_y=4.2$mm(target 26mmϕ)
        ⇒ If $\sigma_x=\sigma_y=4.8$mm(target 30mmϕ), thermal shock reduced by ~30%.
  - Example: Graphite target for 30GeV 4.1×10^{14} p/spill with $\sigma_x=\sigma_y=4.8$mm in 1Hz (= ~2MW) is feasible.
- Radiation damage, Residual Dose ∝ Integrated POT
  - Shorter target replacement cycle: Easier remote-maintenance is important.
  - *Uncertainty: Rad. damage of Ti-6Al-4V by the proton irradiation with > 1 d.p.a.*

Horns

→ T. Sekiguchi's talk

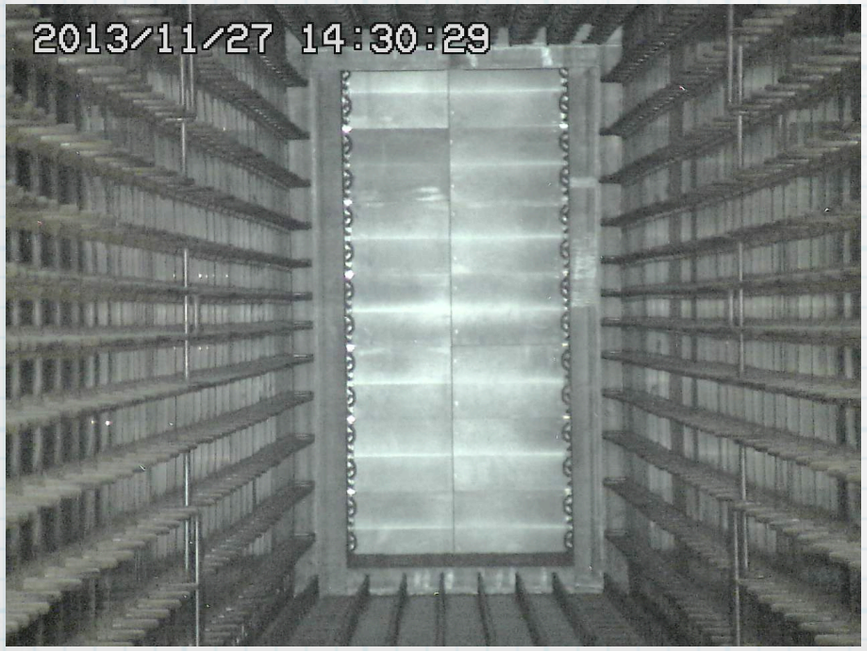
- Hydrogen production from cooling water:
- Strip-line cooling:
  - Improved horn is installed in 2013~2014 maintenance.
    → Acceptable beam power will be increased by enforcing He circulation system.
- High-repetition operation:
  - New power supply for 320kA -1Hz operation
    - Energy recovery (~50% of stored energy recycled)
    - Low input load
      - Each horn operated with individual PS
      - Low impedance strip-lines

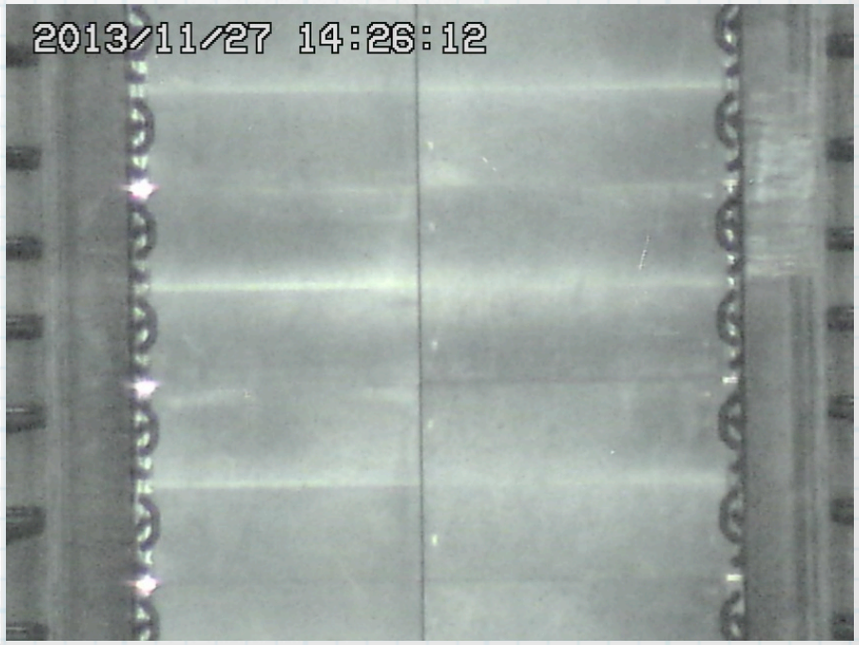


A New PS set up at NU2

Decay volume, Beam dump

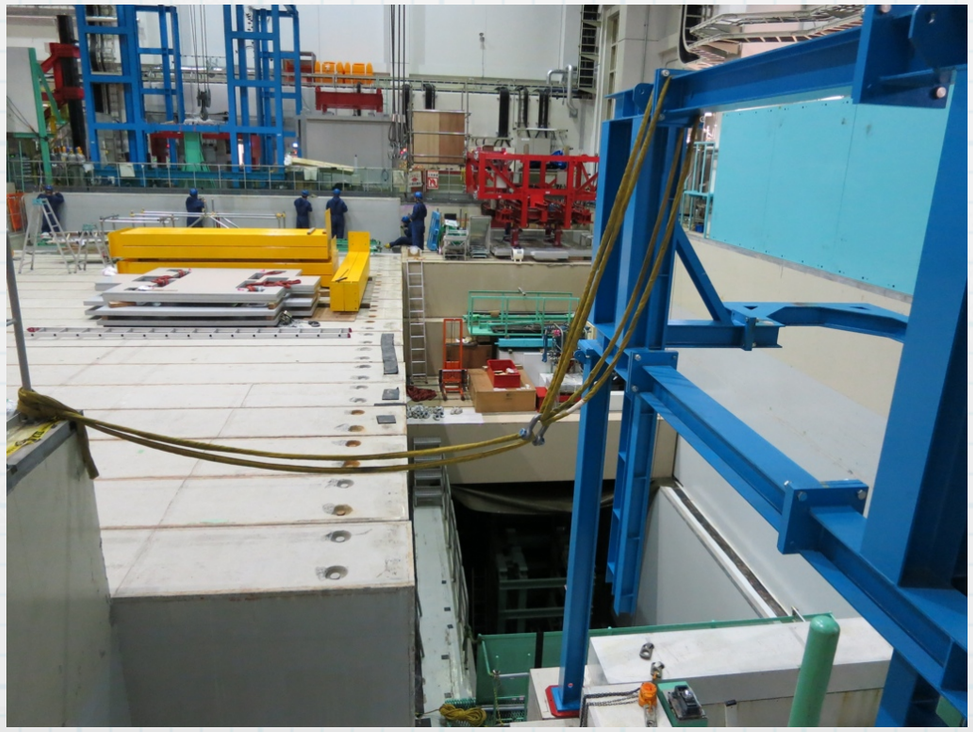
- Cooling capability and radiation shields of DV is designed for 4MW.
- Graphite beam dump is designed for 3MW.
  - Rad. shields for secondary-beam line is capable for 4MW by increasing the concrete block at TS.
  - No crucial damage at DV and dump is found so far.
- Technical challenges for > 1MW operation: → T. Ishida's talk
  - Maintenance of Cooling water circulation system with steel plumbing.
  - Treatment of ^{3}H produced by beam operation.





Additional TS concrete shields

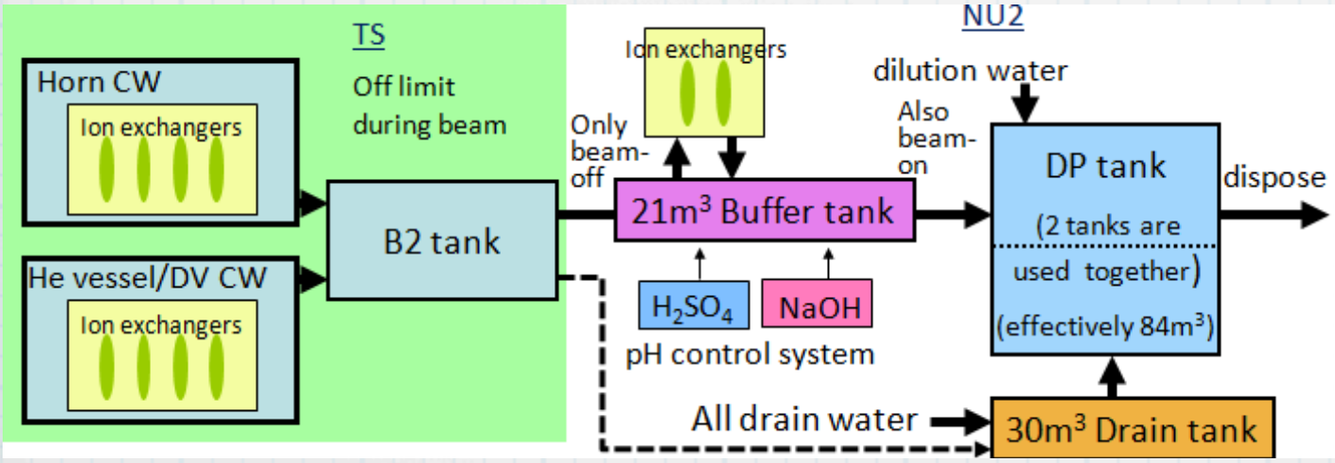
* Not only for beam operation, but also for the maintenance.



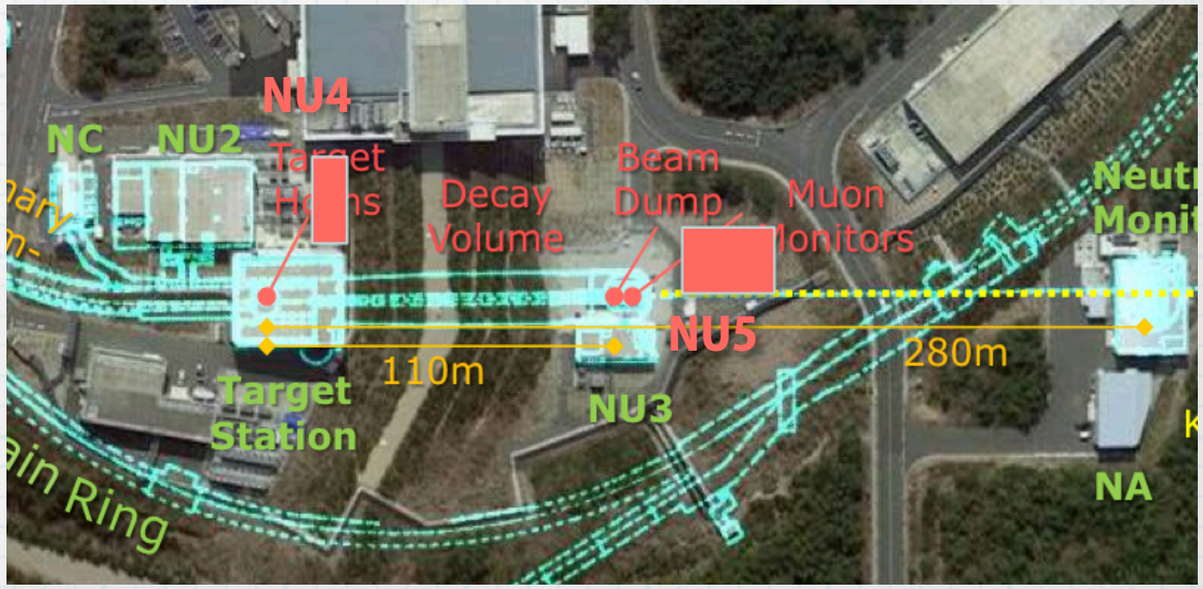
Treatment of activated waste.

→ Y. Oyama's talk

- Disposal of radioactive cooling water
  - 400GBq ^{3}H produced for 750kW × 120 days
  - Dilution to 60(42) Bq/cc
  - FY2013: 73.2GBq (106 kW×10^{7} sec equiv.)
  - Drainage from NU2(TS) =20 times, NU3=23 times, 3days each
- Current capacity = ~600kW × 100days
- Reinforce capacity of cooling power and irradiated water treatment is considered.
  - New facility buildings with large DP tanks are necessary.
  - Re-arrangement of current facility may be necessary...



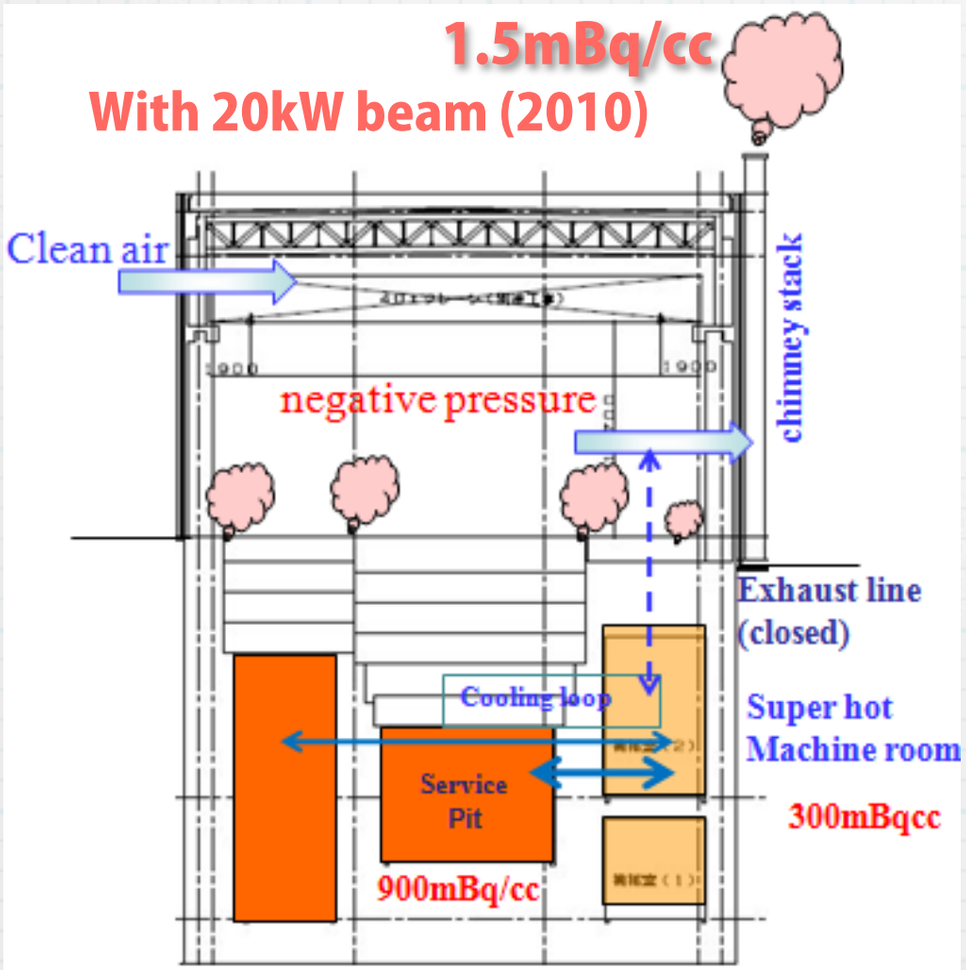
Effective removal of ^{7}Be by 99.99%



Treatment of activated waste.

→ Y. Oyama's talk

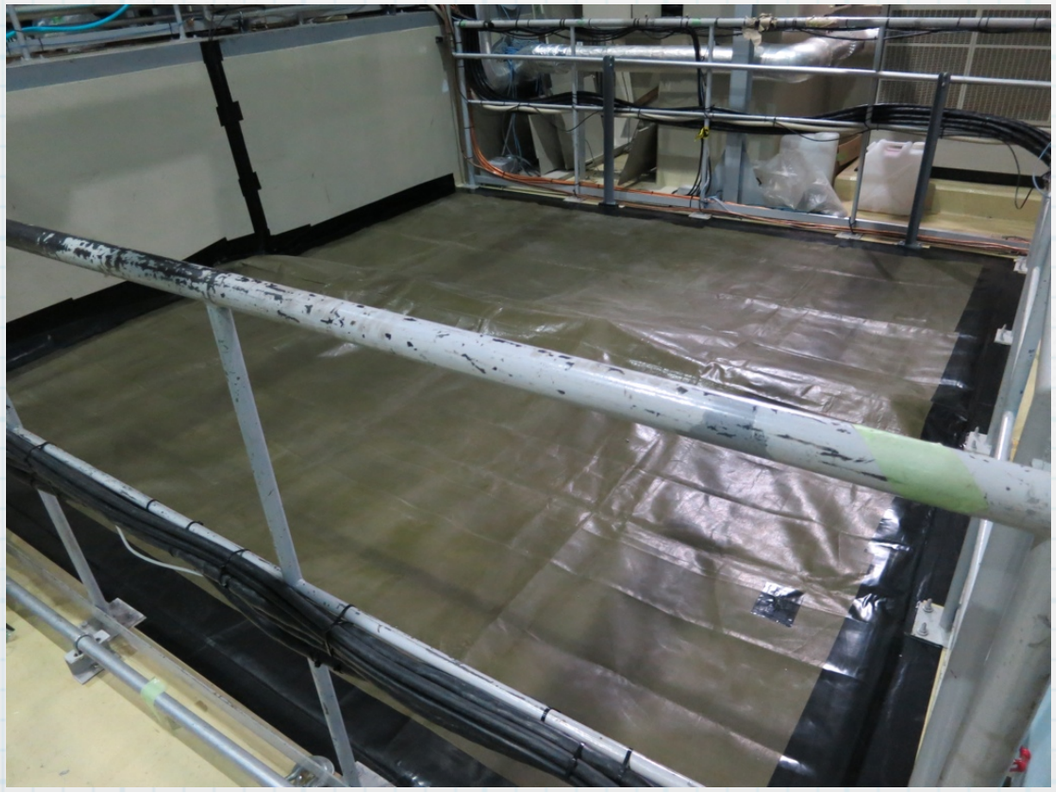
- Radiation in exhaust air of TS was being the bottleneck of beam power.
- By improving air-tightness of floor / through-going ducts / reinforce air ventilation system, acceptable beam is being improved by 2 order, now 500kW~1MW .



< 0.5 mBq/cc for 3 month average

Effort for Air-tightness at Target station

* Maintained by taping technic and careful daily check...



Summary of J-PARC ν beam-line upgrade scenario

Component	beam power / parameter limitation	upgrade
target	3.3×10^{14}ppp	
beam window	3.3×10^{14}ppp	
horn		
cooling for conductors	2MW	
stripline cooling	400kW	1~2MW
hydrogen production	300kW	1~2MW
horn current	250kA	320kA
PS repetition	0.4Hz	1Hz
decay colume	4MW	
hadron absorber / beam dump	3MW	
water cooling facilities	750kW	~2MW
radiation shielding	750kW	4MW
radioactive air leakage to the TS ground floor	500kW	~2MW
radioactive cooling water drainage	600kW	~2MW

- Primary Proton transport:
  - R&D of Non-destructive profile monitor
  - DAQ/Control system for 1Hz Rep. rate
- Target,Beam window
  - Enfacement of cooling
  - Optimizing beam size
- Horn
  - Enforcement of Strip-line cooling, H_2 removal: w/ increasing He flow rate
  - Horn Power supply upgrade for 1Hz, 250→320kA op.
- Decay Volume, Dump: 3~4MW is acceptable now.
- Target Station:
  - Increasing the concrete shields, Further improvement of Air-tightness
- Facility
  - Enforcement of cooling water system, water drainage capacity.
- Improvement of Remote-maintenance