J-PARC Neutrino Primary Beamline Upgrade Plan

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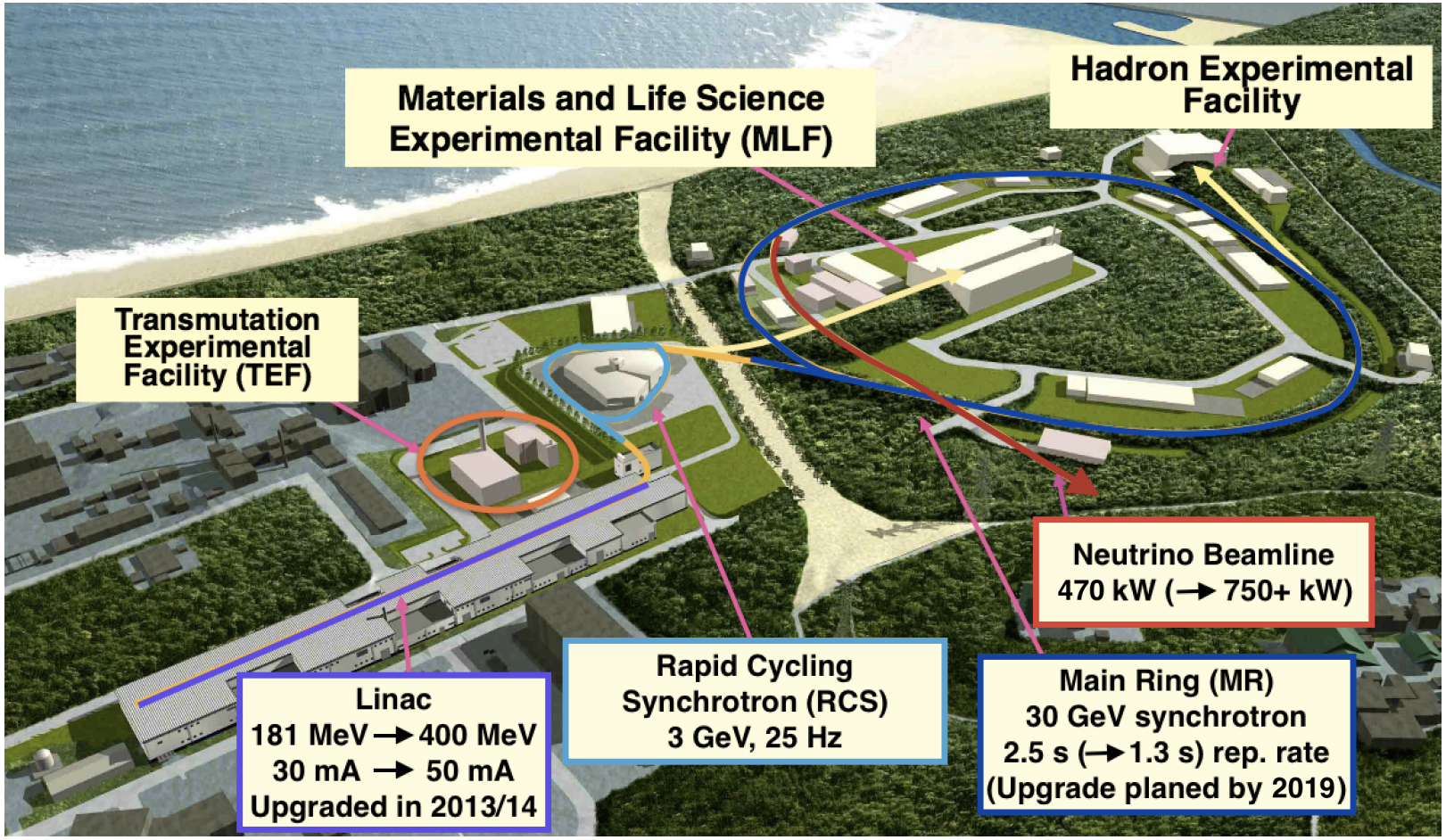
Outline

- Overview of J-PARC Neutrino Primary Beamline
- Primary Beamline Upgrades
    - Downstream End Maintenance Scheme Upgrades

J-PARC Accelerator



- J-PARC = Japan Proton Accelerator Research Complex
- Accelerates proton beam to 30 GeV by:
  - 400 MeV Linac (linear accelerator) → 3 GeV RCS (Rapid Cycling Synchrotron) → 30 GeV MR (Main Ring)
- MR design beam power: 750 kW (currently ~485 kW)

J-PARC Beam Power Upgrades

Beam Power	485kW (achieved)	750kW (proposed) [original]	1MW (demonstrated)	1.3MW (proposed)
# of protons/ pulse	2.4×10^{14}	2.0×10^{14} [3.3×10^{14}]	2.6×10^{14}	3.2×10^{14}
Operation cycle	2.48 s	1.3 s [2.1 s]	1shot	1.16 s

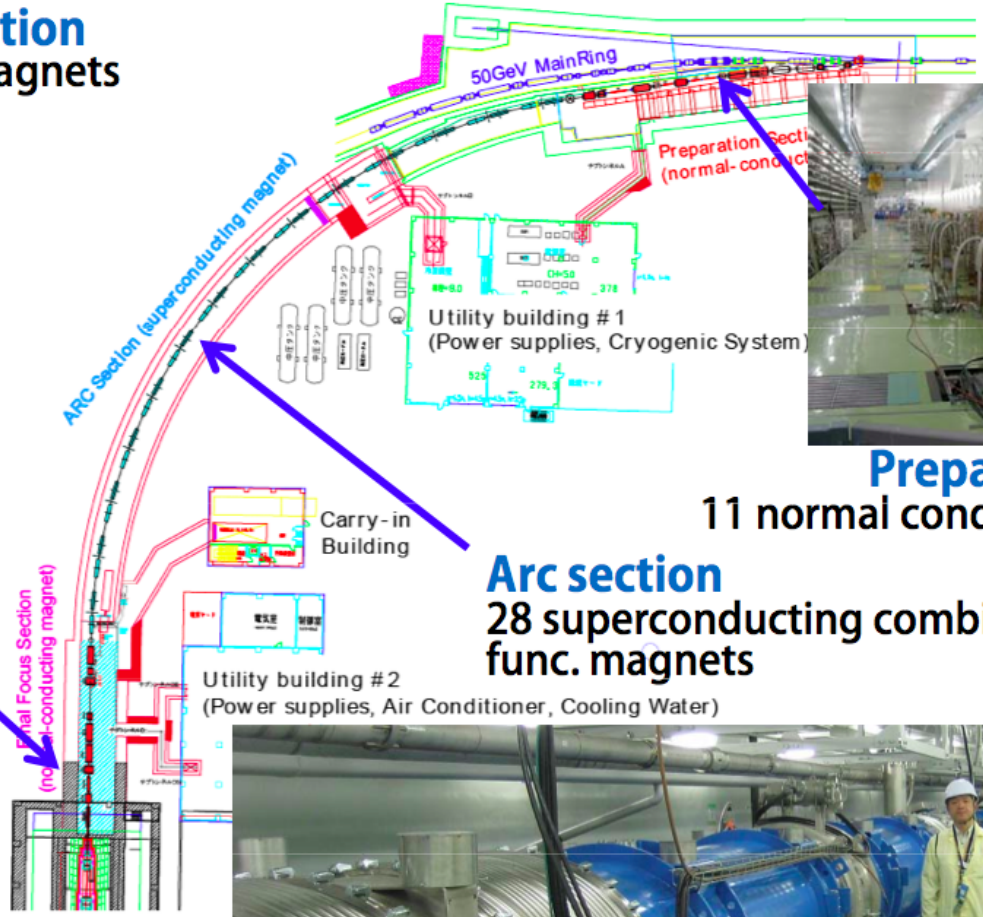
+25% +18%

- Currently : 485 kW with 2.48 s repetition rate
  - 500+ kW achieved during beam tests
- Plan to upgrade MR power supplies in 2021/2022 to reach 1.3 s repetition rate
  - RF improvements can allow for further decrease to 1.16 s
- Plan to improve beam stability, reduce MR beam losses to increase number of protons per pulse

- Upgrades to J-PARC neutrino beamline needed to accept high power beam

Neutrino Primary Proton Beamline

Final focusing (FF) section
10 normal conducting magnets

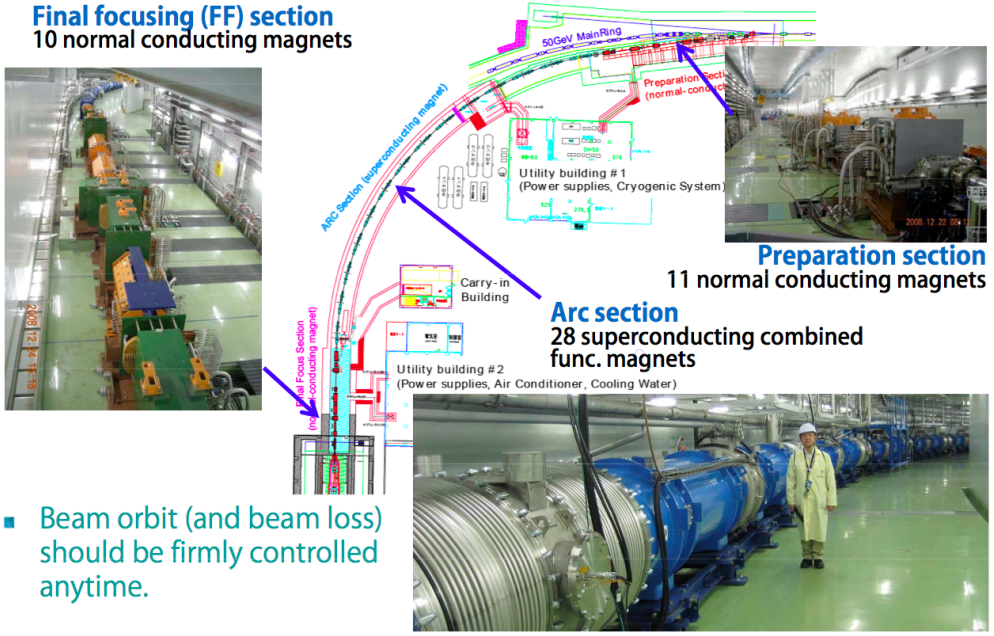


Preparation section
11 normal conducting magnets

Arc section
28 superconducting combined func. magnets

- Beam orbit (and beam loss) should be firmly controlled anytime.

Neutrino Primary Proton Beamline



- Beam orbit (and beam loss) should be firmly controlled anytime.

- Arc section : superconducting combined-function magnets
  - Used to sharply bend the beam towards the Super-Kamiokande direction

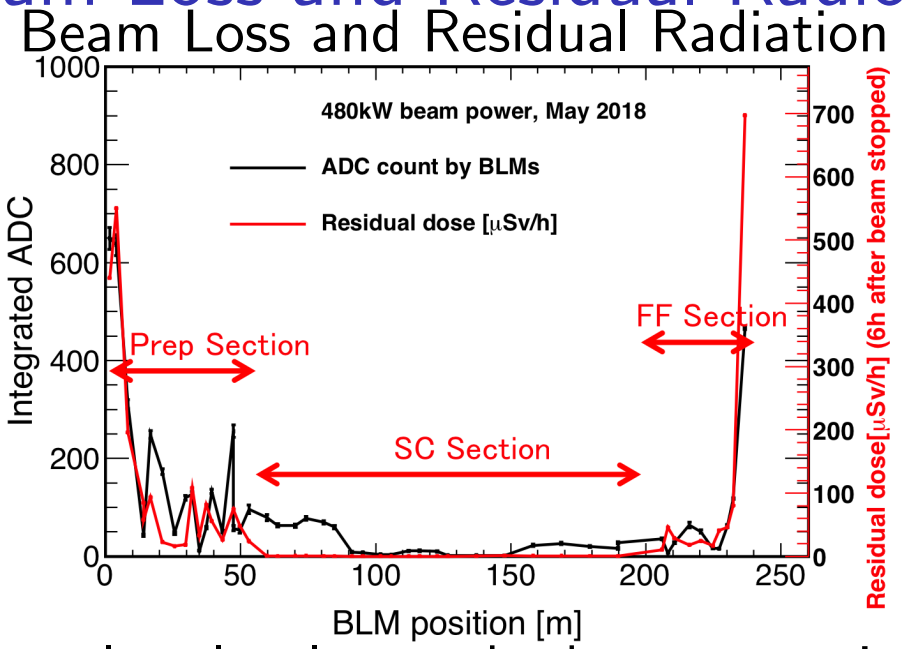
- Preparation section : normal conducting dipole and quadrupole magnets
  - Used to bend and focus the proton beam extracted from the MR accelerator
  - Prepare the beam to be safely transported through the superconducting Arc section

- Final Focusing section : normal conducting dipole and quadrupole magnets
  - Used to bend and focus the proton beam correctly onto the neutrino production target
  - Proton beam position, angle, size at the target are carefully monitored and controlled

Magnets in the Primary Beamline

- Magnets in the Preparation Section of the Primary Beamline (NC) :
  - 4 Steering magnets (ie prep-section vertical steering, PV1)
  - 2 Dipole magnets (ie prep-section dipole PD1)
  - 5 Quadrupole magnets (ie prep-section PQ1)
- Magnets in the Arc Section of the Primary Beamline (SC) :
  - 14 doublets (focus/defocus) and 3 pairs (normal/skew)
- Magnets in the FF Section of the Primary Beamline (NC) :
  - 4 Quadrupole magnets (ie FQ1)
  - 4 Steering magnets (ie FH1)
  - 2 Vertical dipole magnets (ie VD1)
- Upstream Prep. section magnets have non-organic coil material – high radiation resistance
- Other magnets use organic material and are expected to have poorer radiation resistance
- However, current beam loss is two orders of magnitude lower than the expected loss during the design stage
  → All magnets should be fine, even at much higher beam power

Beam Loss and Residual Radioactivity



- The future beam loss level must be kept approximately as low as the present loss level
- The beam loss, and residual radioactivity, of the most upstream part of the Prep. section is high even at 485 kW
  - Possibly due to beam halo from the MR + the PV1 aperture – aperture could be increased if necessary
- The FF FQ2 and FQ3 may also need larger apertures for large emittance beam at increased protons per pulse

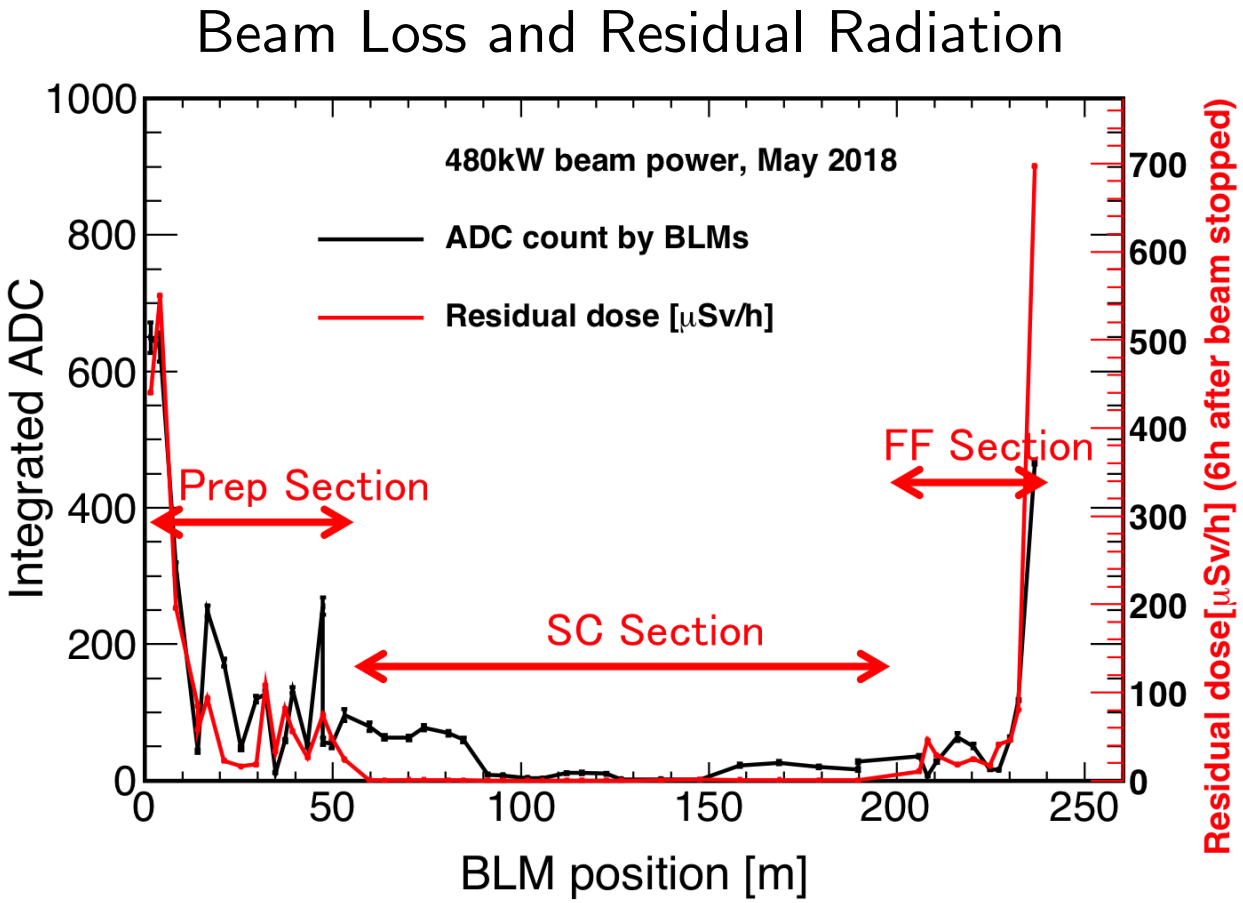
→ The necessity of increasing magnet apertures will be considered based on results of future beam tests using higher PPP beam from the MR

Collimator Upgrades

Name	Distance from GV [mm]	Entrance half aperture		Exit half aperture	
		x [mm]	y [mm]	x [mm]	y [mm]
PC1	28492	63	33	63	33
PC2	31895	No installation plan at present			
PC3	36842	No installation plan at present			
PC4	46162	31	33	33	30

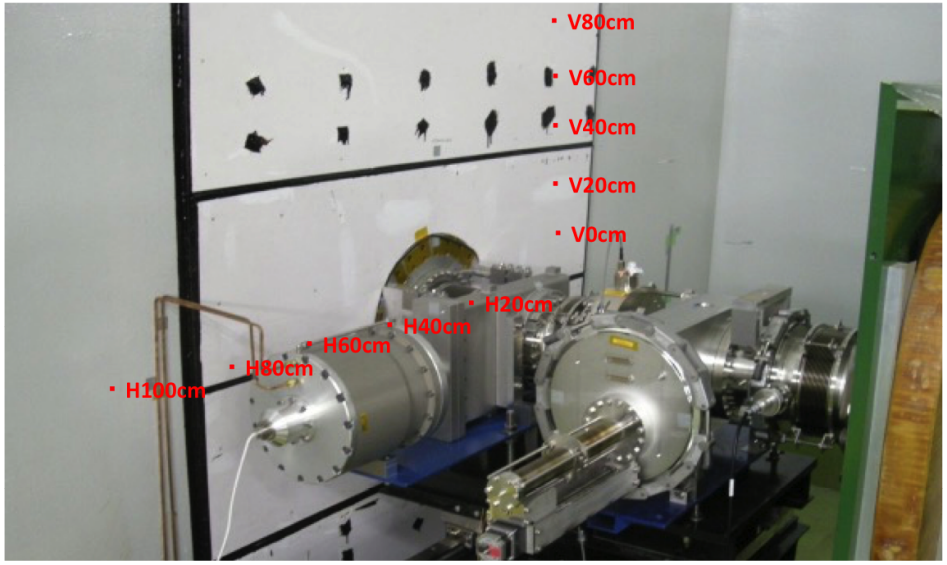
- The 2 collimators have a much smaller aperture than the magnets in order to block off-orbit beam
  - Therefore, they are very sensitive to the beam tail
  - At 485 kW the beam halo is not significant – collimators are not scraping off the halo and the heat load is negligible
  - 750 kW operation will be achieved by simply increasing repetition rate, and no significant increase of heat load is expected
  - 1.3 MW operation requires an increase in the number of protons per pulse, and the beam halo condition may drastically change
    - In that case, water cooling of the collimators could be necessary
    - Can be done by replacing the copper bulk block inserted between the collimator jaw and iron shield by a water-cooled copper block

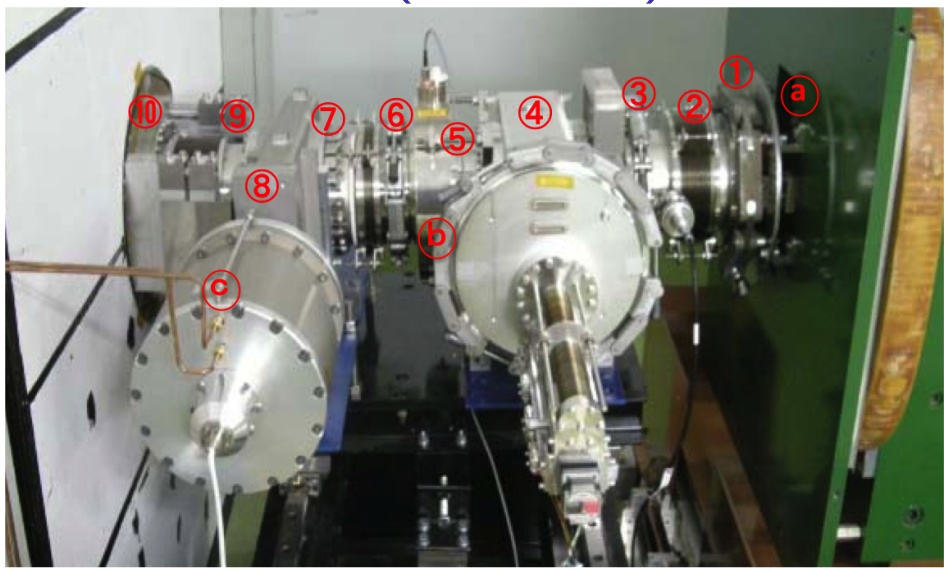
Beam Loss and Residual Radioactivity

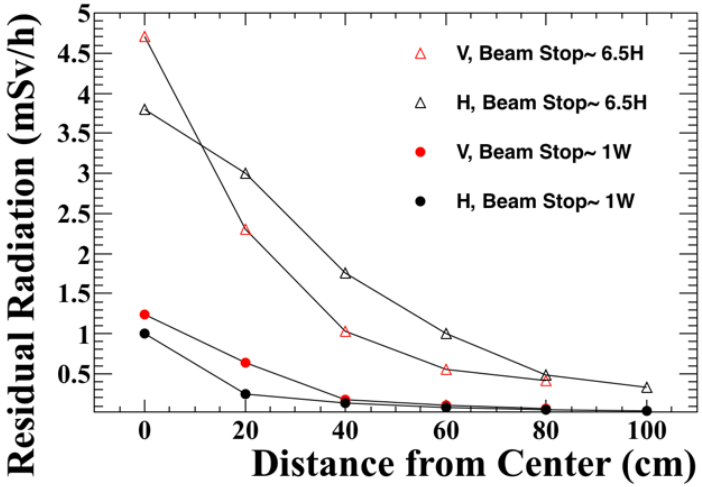


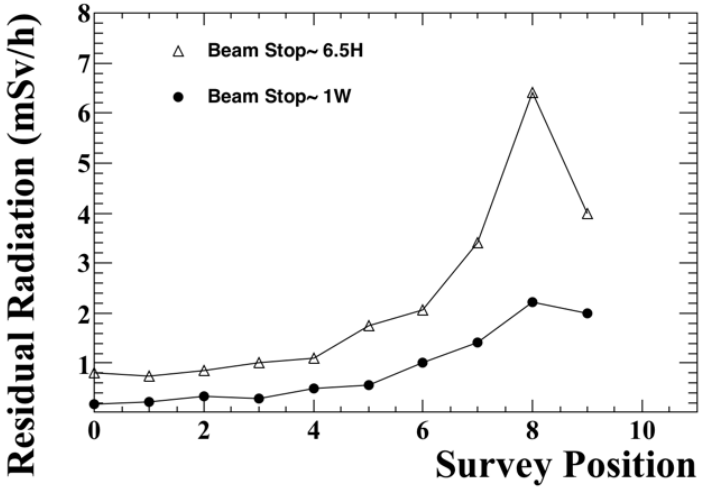
- The beam loss and residual radioactivity are highest at the most downstream end of the neutrino primary beamline
  - Due to scattering from the beam window, target, etc.
- Essential equipment sits in this high-radiation area
  - Need upgrade to maintenance scheme in case of equipment failure

Primary Beamline Residual Radiation at FF Downstream (475kW)









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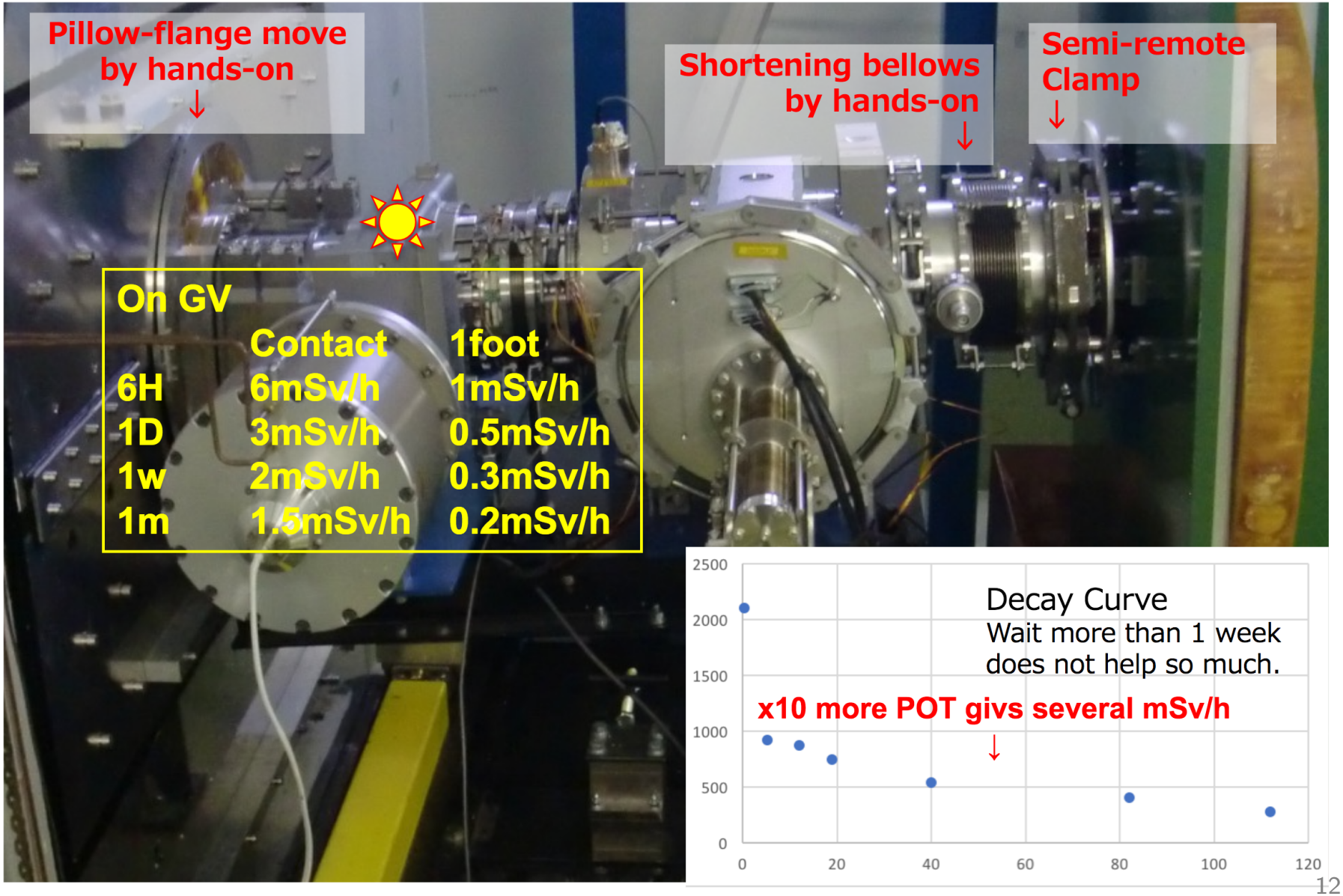
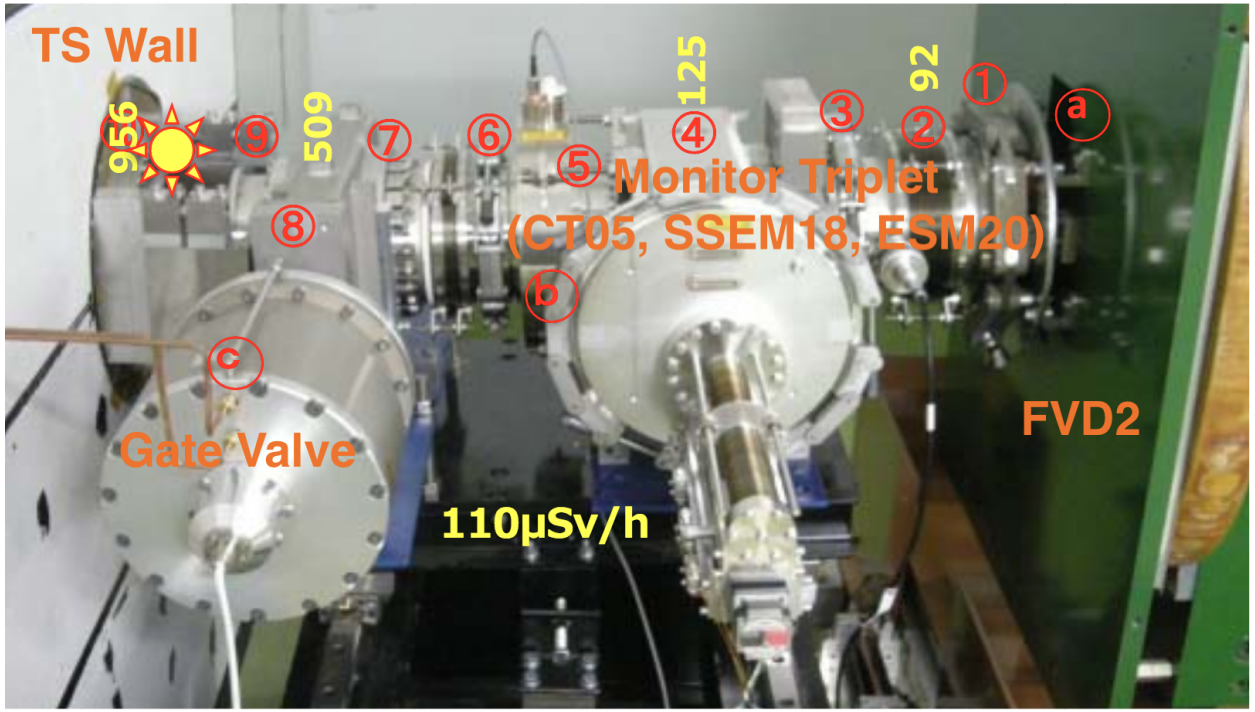


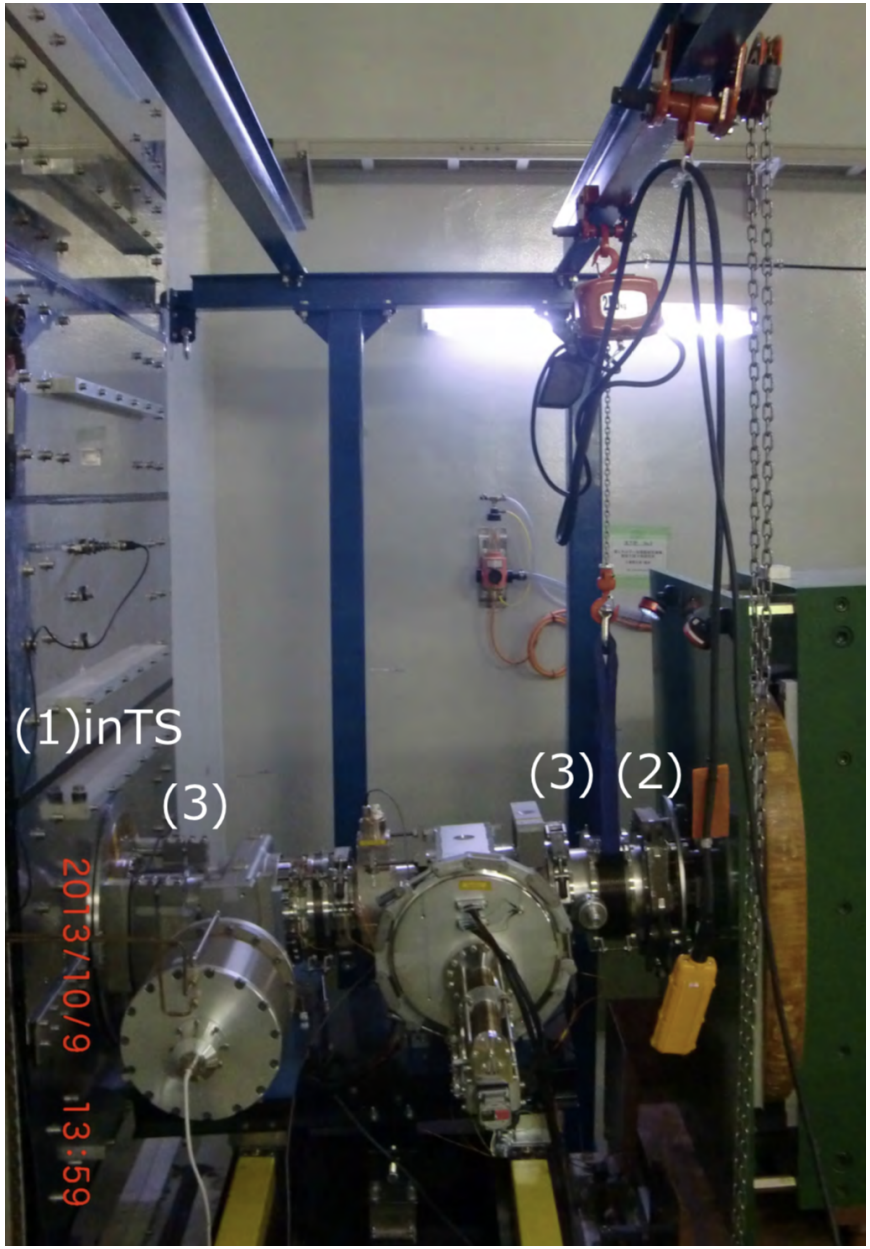
Downstream FF Area



Four months after the beam stop.

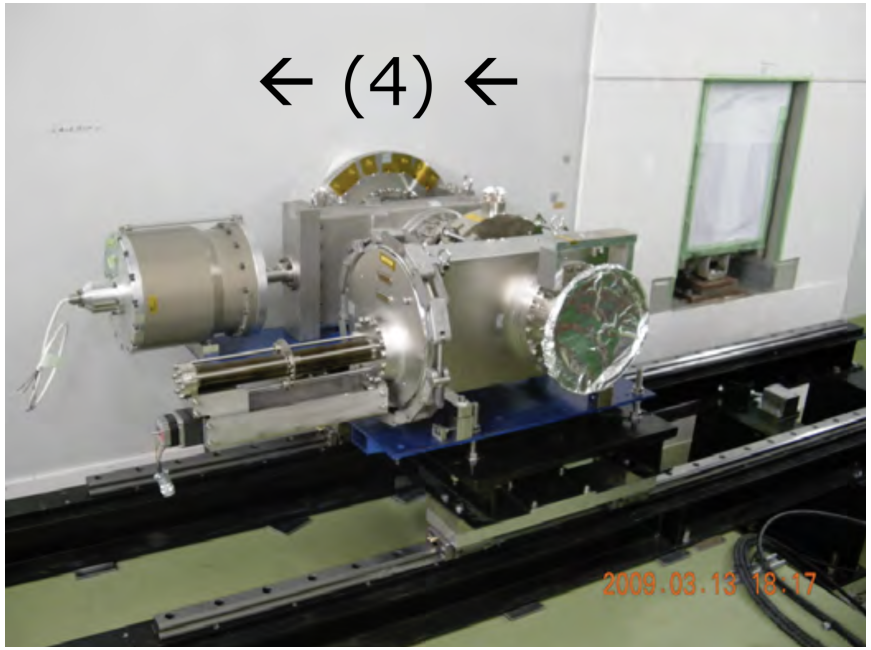
- Residual dose reaches >1mSv/hr on contact weeks after beam stop, even at current beam power
  - Will increase with higher beam powers
- Gate Valve + beam monitor triplet (SSEM, ESM, CT) sit here → must have scheme for maintenance in case of any issue
  - Original scheme using downstream pillow seal + line out of all components on rail system is not preferable

Original FF Maintenance Scheme



- Hands-on quick/semi-remote operation
- Line out work order :
  - (0) Loosen caulking at TS wall
  - (1) Shorten pillow seal (operation at TS)
  - (2) Loosen quick/remote clamp
  - (3) Shorten bellows and disconnect flanges
  - (4) Slide everything out from the beamline

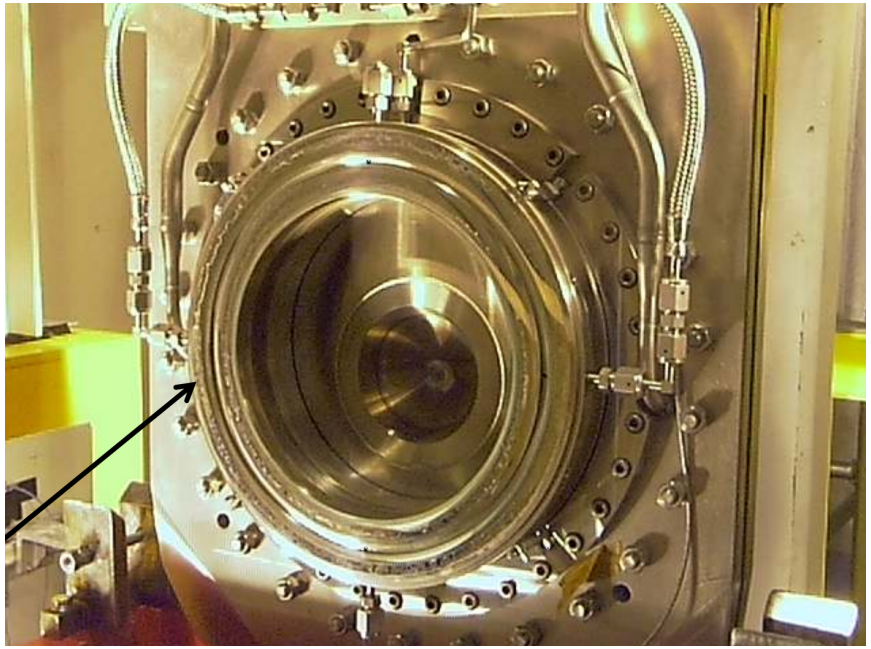
→ Work at low-radiation environment



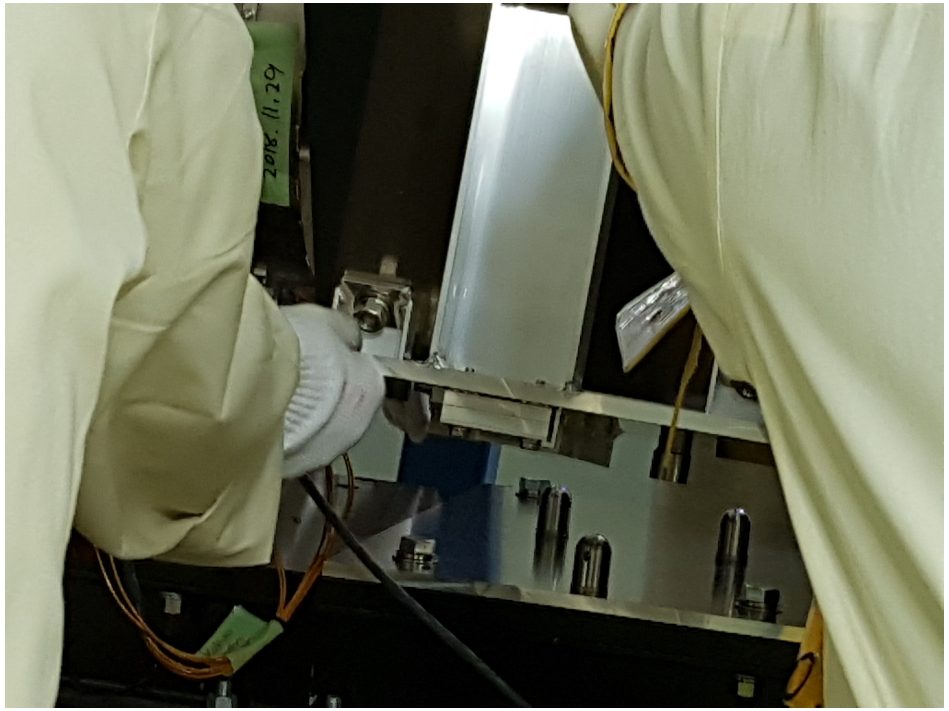
Issues with Original Maintenance Scheme

- Originally planned hands-on, quick and/or semi-remote operation
  - Present radiation level is higher than assumed at the design stage
    - 2mSv/h on contact, 300μSv/h at 1foot, 1 week after beam stop – can work only 20minutes/person/day
- Shorten pillow seal and slide everything out from the beamline

- Pillow seal operation is not so easy
  - In 2017, found that present pillow seal cannot be re-used after shortening
  - After long-term continuous compression, the pillow surface is deformed
- Components are radioactive
  - Line-out does not decrease radiation level so much
- Caulking necessary for air-tightness between FF and TS
  - Removing/re-caulking takes time

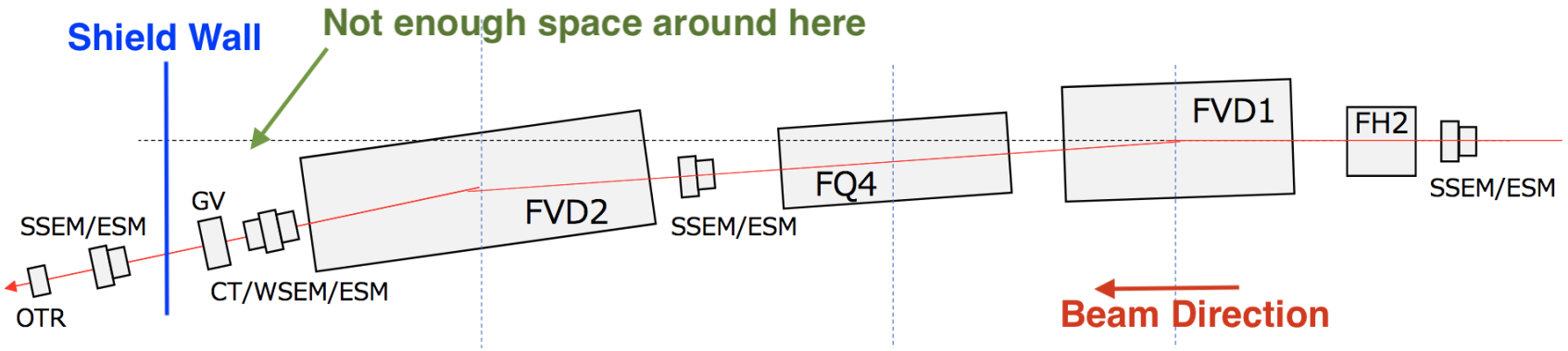


FF Short-Term Upgrade Status and Plans

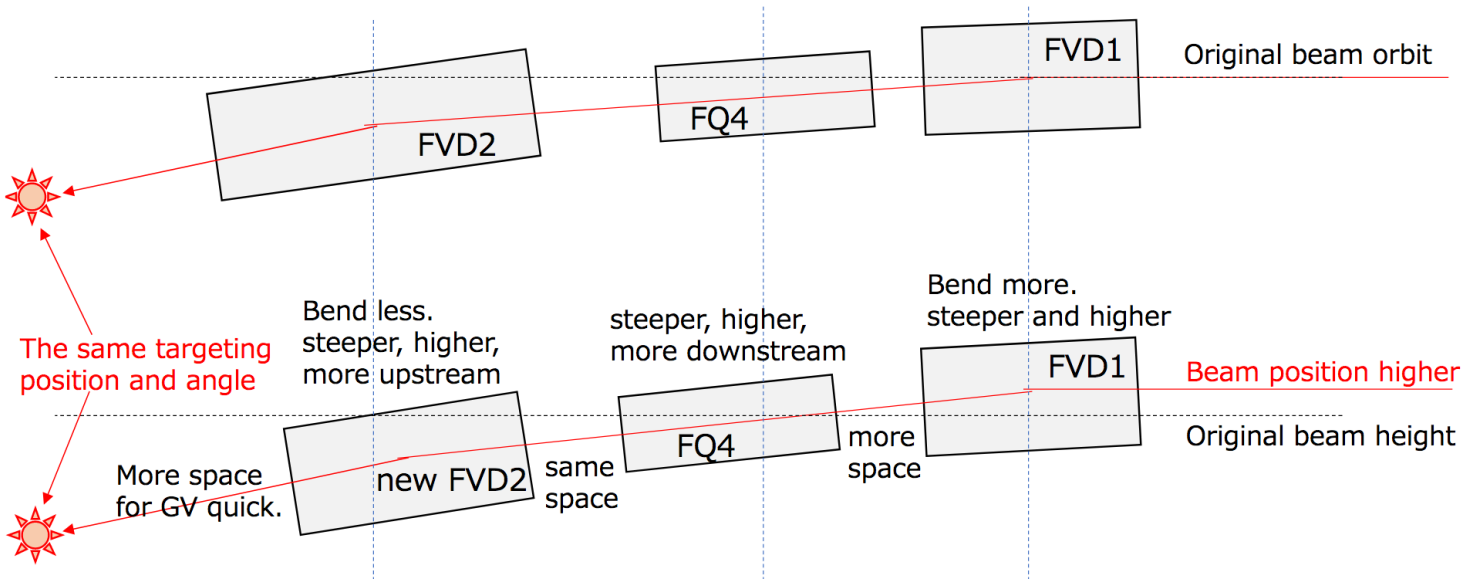


- A quick bellows mover and positioning keys/keyholes were installed for the beam monitor triplet in summer 2018
- A similar quick system was planned for the downstream Gate Valve, but could not be installed due to insufficient space
  - Now considering how to make more space
  - Feasibility studies underway for reducing the length of the most downstream bending magnet (FVD2)
    - This would require a change to the beam optics
    - This may also require shifting the alignment of other FF magnets
    - Shorter magnet may allow for the addition of a new beam monitor
    - Need to consider cost and feasibility
  - New system should be implemented during 2021 shutdown

Example Downstream FF Layout Update



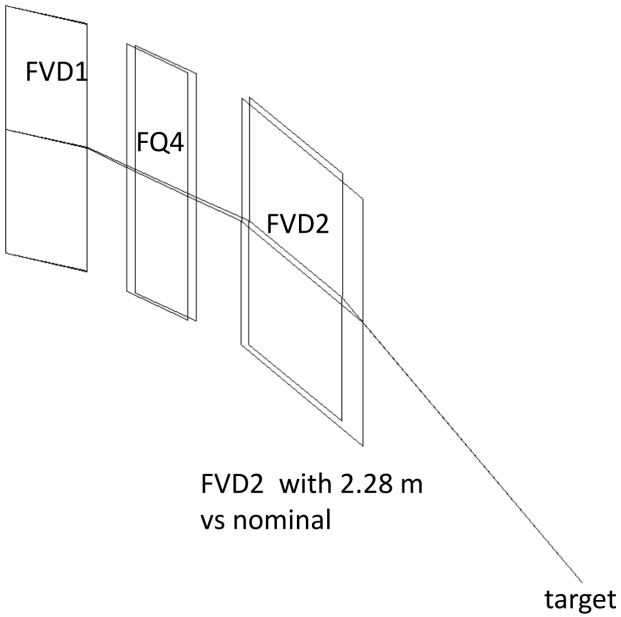
Example upgrade scenario :

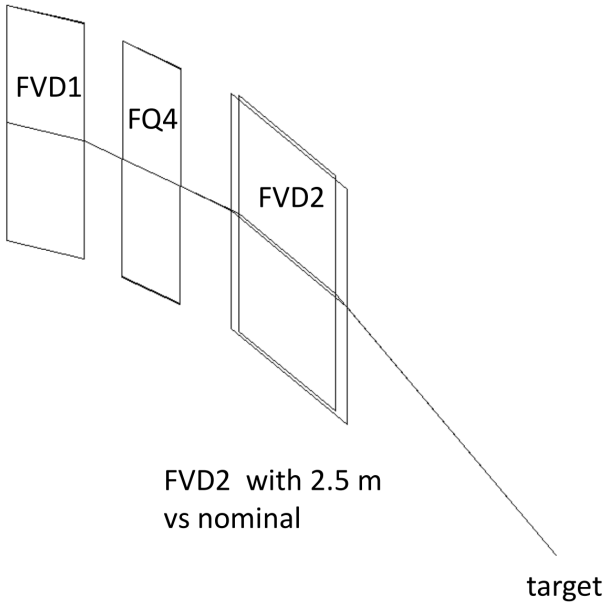


- Several possible upgrade scenarios are considered so far
  - Optics modeling + feasibility checks underway

Example Downstream FF Layout Updates

- Optics modeling underway for follow scenarios
- Shorten FVD2 3m→2.28m or less + shift FQ4 and FVD2 central positions
- Beam orbit is kept the same upstream of FVD1
- Increase nominal field 1.22T→1.676T (1240A→1917A) for 2.28m FVD2
  - Field must be further increased by ~10% for complete target scan during beam commissioning (→1.84T, 2280A when accounting for saturation of iron)
- Power supply (+ cable) maximum current must be increased from 1500A→>2000A to accommodate higher field
  - Build new PS or operate 2 PSs in parallel ? – now under consideration + optimization





FF Longer-Term Upgrade Status and Plans

- Based on experience so far, after 1.3MW x40 months operation, residual dose at 1 foot will reach 600 μSv/h
  - Quick/hands-on work will basically no longer be possible
  - Need a new, fully remote maintenance solution for T2K2, HK era
- Some possible ideas :
  - Preemptively replace all components every few years to prevent residual radiation build-up
    - Not desirable..
  - Replace several flanges with pillow seals
    - Pillow seals are expensive and not easy to work with – not desirable..
    - Alternative remote flange technologies possible ? – self-aligning flanges, etc under consideration
  - Improved crane system

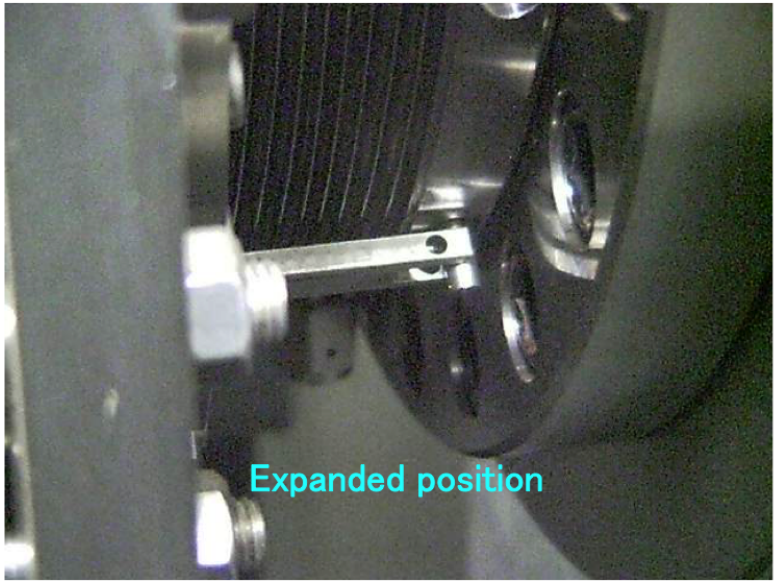
→ Starting discussion about possible long-term upgrade ideas

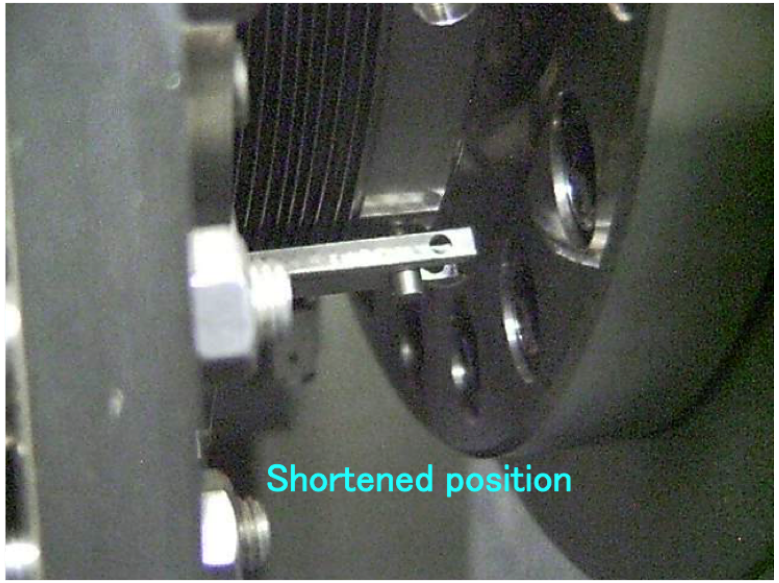
Conclusion

- Neutrino primary beamine components are basically working well and are designed to continue to work well at high power
  - Continue watching to understand if beam loss, halo from MR is acceptable, even as number of protons per pulse is increased
- Upgrade of the maintenance scheme for components at the most downstream end of the neutrino primary beamline is necessary
  - Short-term upgrade – reduce most downstream magnet length to make space for quick components
  - Longer-term upgrade – fully remote maintenance scheme

Backup Slides

J-PARC Pillow Seal





Pillow seal deformed after long-term use

- Pillow seal remote operation is performed by flowing high-pressure gas
- Gas pressure should be continuously kept to keep vacuum seal
- Worry about operation after long-term use, reuse, etc..