Letter of Interest to AF2 and AF7: US-Japan Collaboration on Accelerator and Beamline Research and Technology Development for High-Power Neutrino Beams

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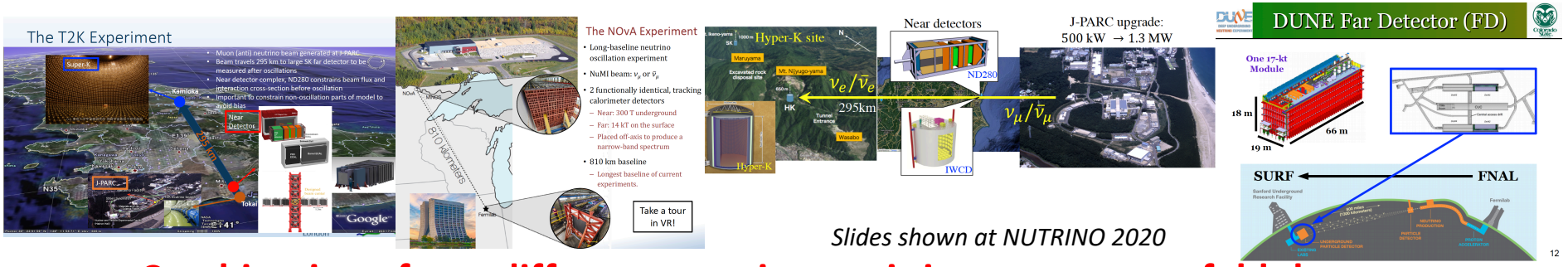
Overview

- Long Base-line Neutrino Oscillation experiment searching for the CP violation phenomena at lepton sector is one of the main topics in high energy physics.
  - On-going experiments, T2K (JP) and NOvA (US) reports very interesting results.
  - Construction of next experiments, HyperK (JP) and DUNE(US) is on-going, and aiming to start in the late 2020s.



Slides shown at NUTRINO 2020

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Combination of two different experiments is important to unfold the matter-effect (mass order) and CPV effects in neutrino oscillation.

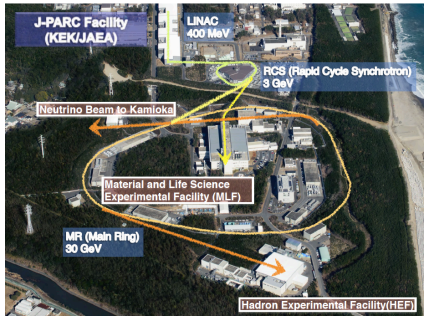
→ Realizing both US and JP projects is quite important for neutrino physics.

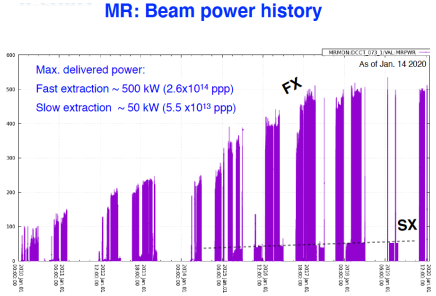
- "High intensity neutrino beam" and "Huge neutrino detector" are the essential to obtain physics results.

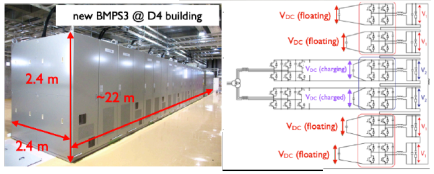
- Joint R&D to realize "high intensity neutrino beam by >1MW proton driver" by US-JP cooperation program started from 2014 and continues > 5 years.

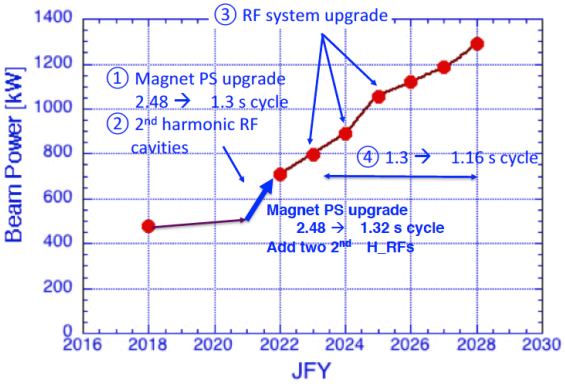
Towards >1MW: proton driver

- J-PARC-MR records ~520kW beam power.
  - JFY2021~: Upgrade for 1.3MW beam

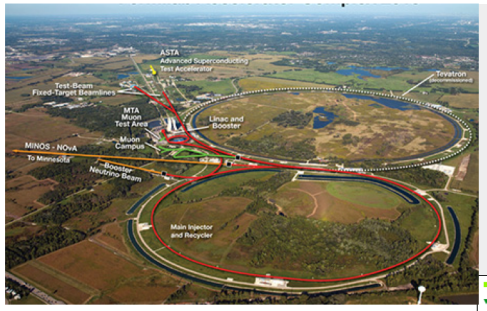


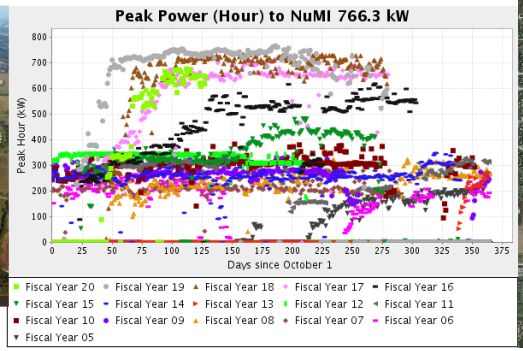


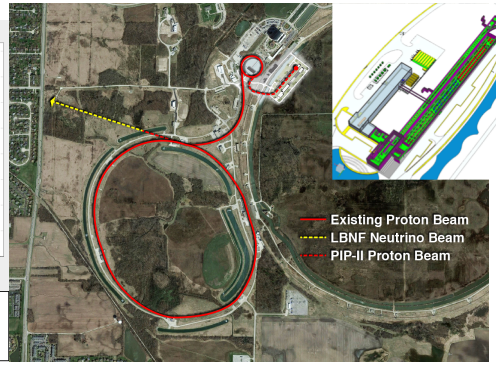


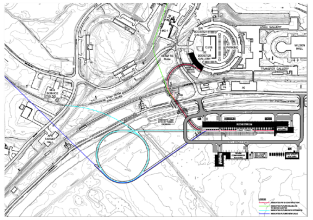


- FNAL MI records > 760 kW for NuMI.
  - Injector upgrade (PIP-II) for 1.2MW beam is on-going. Further accelerator upgrade for 2.4MW is considered.









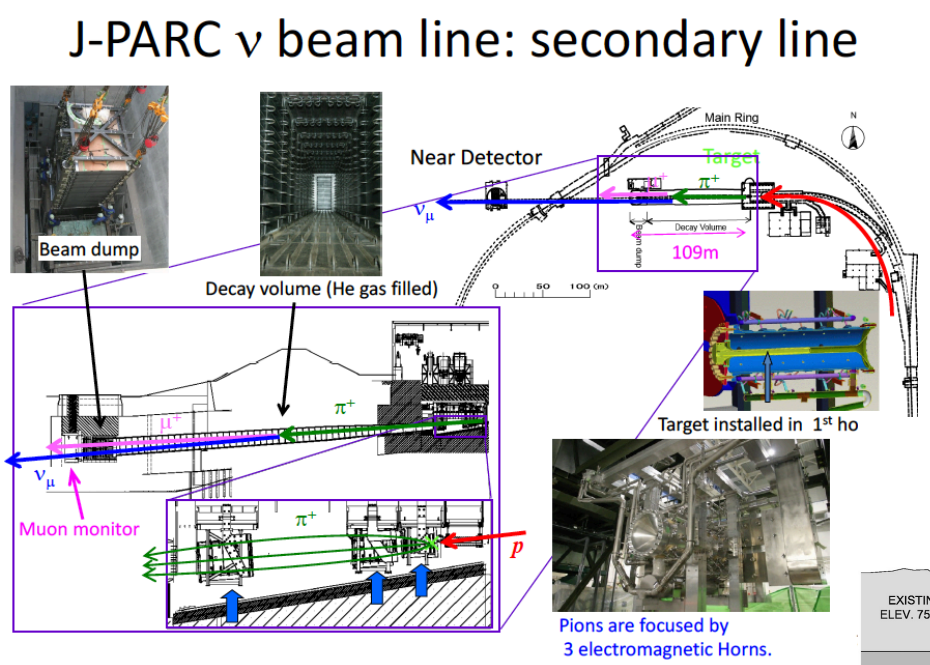
- Challenges to achieve unprecedented instantaneous proton intensity

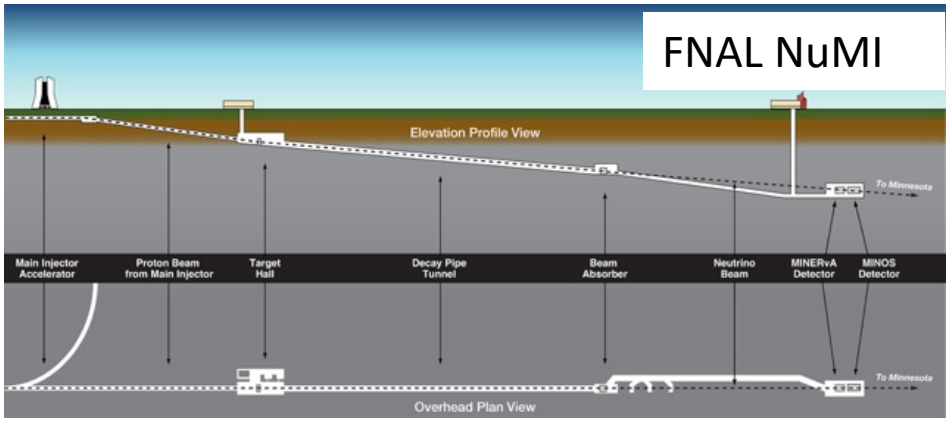
Towards >1MW: neutrino beam facility

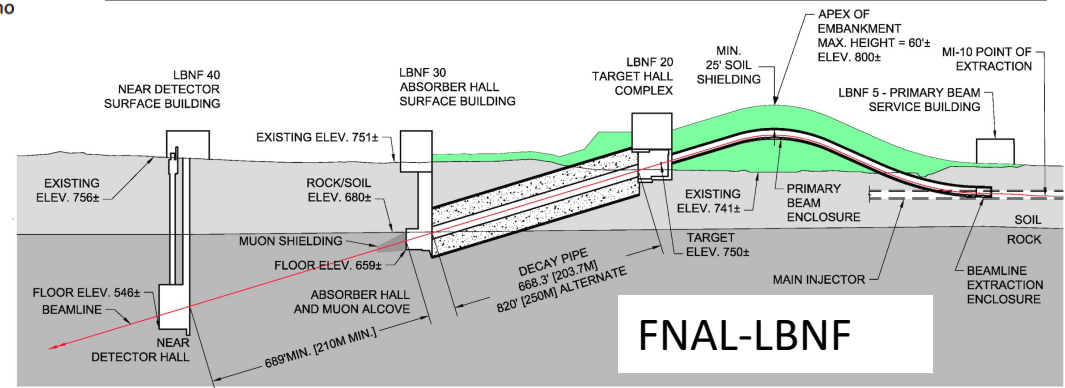
- J-PARC neutrino beam-line:
  - 2021~: Upgrade to reinforce equipment and facility.
- FNAL:
  - New beam-line (LBNF) will be constructed.

Many common technical challenges;

Robust target against high-intensity proton beam, focusing device under high radiation environment, safety for radio-activated materials, ….







Joint R&D works

- Discussion by face-to-face meeting is quite useful to share the experience obtained by experts in J-PARC and FNAL.
- Applying the experimental method to another machine is useful to expand the technique further.
  - e.g. J-PARC accelerator tuning method is applied at FNAL accelerator, and the proton beam behavior is confirmed.
  - e.g. Beam monitor (component) developed at FNAL is introduced at J-PARC neutrino beam-line.
- Collaboration topics is expanding:
  - Beam dynamics studies for beam loss reduction
    - New RCS design for high intensity proton beams
    - Booster accumulator ring design (discussions, idea exchanges)
    - Resonance correction
    - Impedance – tune shifts
  - Electron cloud studies
  - Proton beam Instrumentation
    - Halo monitor (new topic)
    - New signal acquisition system for high precision beam position measurement
    - Extracted beam monitoring
    - Gated ionization profile monitor
    - LINAC instrumentation
    - BSM, low energy loss monitor, drift tube
  - Laser manipulation of H- beams
  - High-power target Facility issues
    - Water cooling strip-lines
    - Autonomous Robotics and Remote Handling for Mega Watt Target System
    - Muon monitoring

Following slides describes about each R&D topics.

Beam dynamics studies

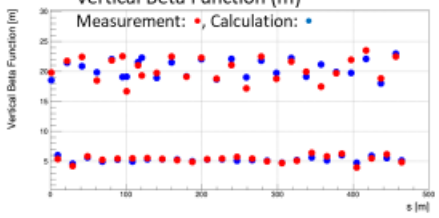
- Purposes of beam studies
  - Resonance correction
  - Impedance – tune shifts
  - Exchange of experience on high intensity beam tuning
- Join Beam Studies continues from 2018
  - J-PARC experts visited FNAL in Mar 2018
  - 2 FNAL experts visited J-PARC in Jun-Jul 2018.
  - J-PARC experts visited FNAL in Mar 2019
  - 3 FNAL Scientists visited J-PARC between 2019 Mar.-2020 Jan. 2 persons were invited as KEK short-term visitors.

Beam dynamics studies

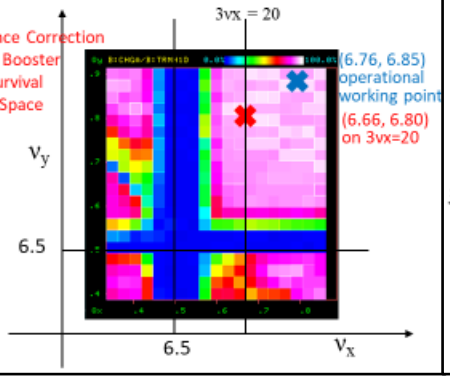
Progress in JFY2019 and Plans in JFY2020 for Beam Dynamics Studies for Beam Loss Reduction

- Beta function measurements at FNAL Booster
  - A method used at J-PARC MR for the beta function measurement has applied to the FNAL Booster. Oscillations at the beam position monitors were measured when coherent oscillations were excited. The beta functions were reconstructed using the amplitudes and phases.
- Third order resonance study at FNAL Booster
  - The correction of the resonance 3vx=20 was tested with the sextupole magnets.
  - Beam loss was reduced with the correction at the tune of (6.66, 6.80) on the resonance.
  - However, beam loss was not improved at the operational working point with the same correction. Further study is necessary.

Fermilab Booster Joint Study



Resonance Correction at FNAL Booster Beam survival in Tune Space

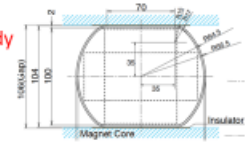


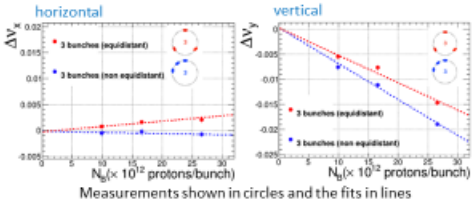
Progress in JFY2019 and Plans in JFY2020 for Beam Dynamics Studies for Beam Loss Reduction

Fermilab researcher visited J-PARC and participated in the beam studies in Oct. 2019.

- Tune shift measurements with high intensity beams at J-PARC MR
  - Tune shifts were observed depending on the number of injection bunches and the intensity.
  - Tune shift measurements were compared with calculations considering the effect of the impedances of the surrounding instruments such as vacuum chambers.
  - Measurements at FNAL Recycler are valuable for further understanding of the model calculation.

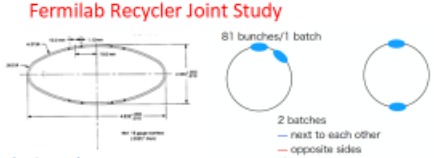
J-PARC MR Joint Study

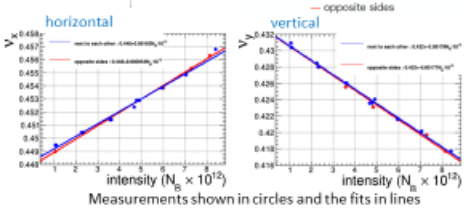




Measurements shown in circles and the fits in lines

Fermilab Recycler Joint Study





Measurements shown in circles and the fits in lines

- Two accelerator design studies in FNAL
  - New RCS design for high intensity proton beams
  - Booster accumulator ring design (discussions, idea exchanges)

Electron cloud studies

Motivation

- Electron cloud (EC) in ring is a potential concern for both J-PARC and FNAL; it can drives the EC beam instability and limits the maximum beam power output
- J-PARC and FNAL have different EC detectors
- EC simulation works have been conducting with different codes at higher intensities however, there is a need to benchmark these codes

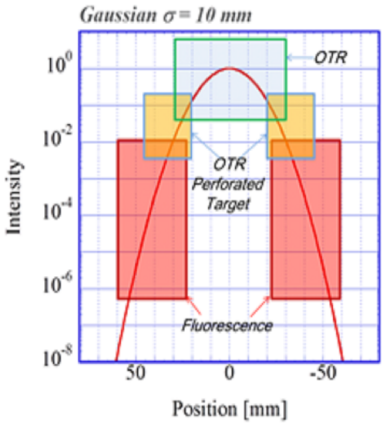
Plan

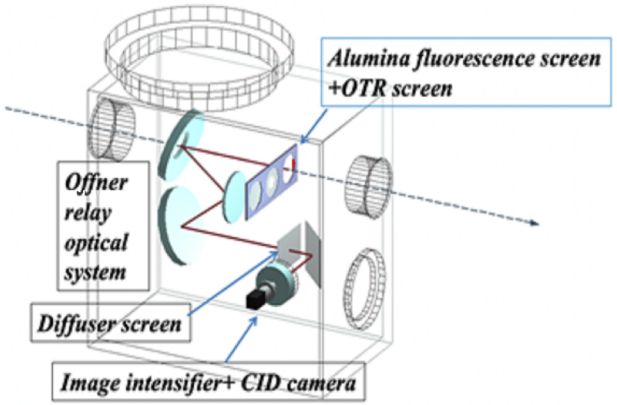
- Preparing the substrate made of stainless steel as test samples with J-PARC's DLC (Diamond Like Carbon) coating
- In addition, the J-PARC team plans to develop the electron cloud test-bench in JFY2021.

Proton beam Instrumentations

- Halo monitor (new topic) –
- New signal acquisition system for high precision beam position measurement
- Extracted beam monitoring
- Gated ionization profile monitor
- LINAC instrumentation
  - BSM, low energy loss monitor, drift tube

- Halo Monitor
  - OTR has been used in J-PARC. The OTR screen is able to measure the high intensity core while the Fluorescence screen measures the tails and halo.



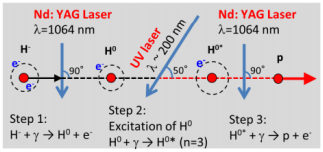


Laser manipulation of H- beams

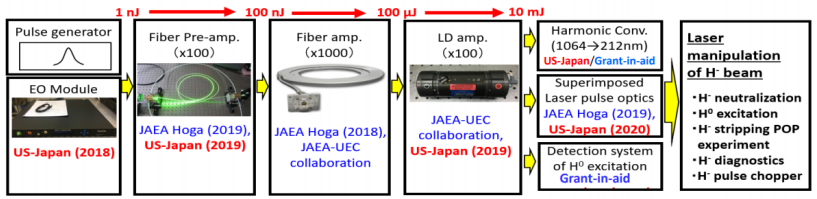
- The laser manipulation of H^- ion beams by single or double neutralization becomes a promising technique to be utilized in accelerator processes such as injection, chopping, collimation, extraction, and beam diagnostics.
- At Fermilab, bunch-by-bunch H^- neutralization utilizing a two-mirror laser cavity has been successfully integrated into operations to produce a time structure in the 0.750 MeV H^- linac beam (called laser notching).
- The H^- stripping by using only lasers is under development at J-PARC to eliminate the lifetime and beam loss issues associated with foils used for charge exchange injection.
- **Recently, neutralization study for 3 MeV H- has been performed at J-PARC**.

Laser system for the POP demonstration of 400 MeV H^- stripping to proton

- US-Japan fund
- JAEA innovation research fund (Houga)
- JSPS Grant-in-aid (KAKENHI)



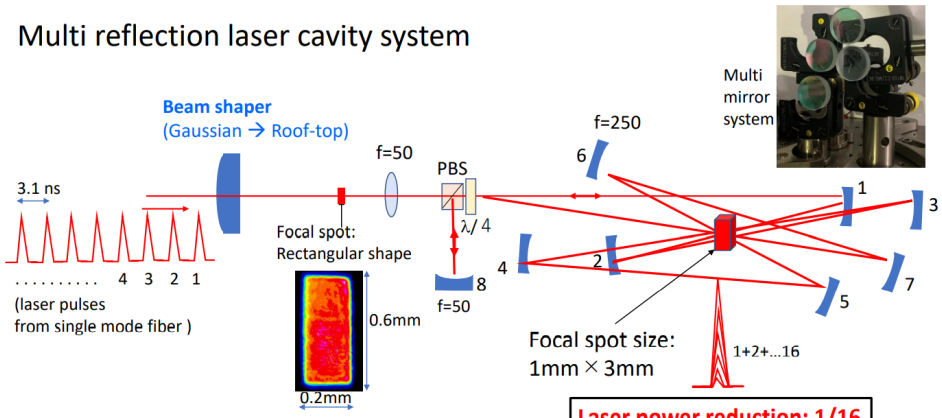
Principle of 400 MeV H^- laser stripping



Laser system with multi-stage amplifications and applications

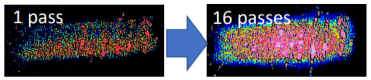
◆ A prototype YAG laser system has been developed at the UEC, Tokyo.
Specification: ~100 ps, 324 MHz, ~mJ/pulse. It will be tested for 3 MeV H^- neutralization next month.
◆ YAG laser system for 400 MeV H^- test is under development at J-PARC.
◆ Crystal purchased for higher harmonic (UV) light generation. Development of the UV laser has also been started at the UEC.

Multi reflection laser cavity system



Laser power reduction: 1/16

◆ Superimposition of 16 roof-top pulses succeeded.
→ 1/16 reduction of the seed laser energy.
◆ We are also studying Fermilab type two mirror laser cavity.
◆ Will be tested for 3 MeV H^- manipulations starting next month.

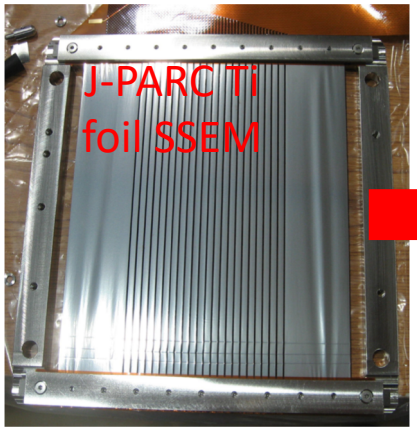


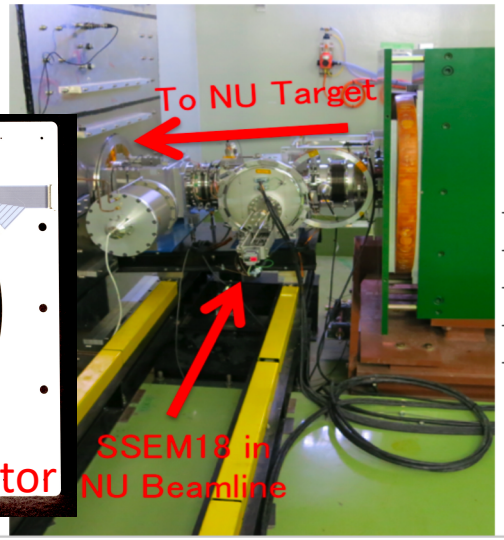
Extracted Beam Profile Monitoring

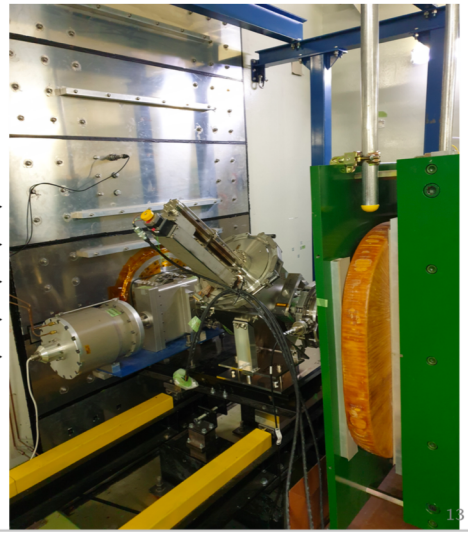
- Proton beam profile monitors in the J-PARC neutrino extraction beamline are essential for:
  - Protecting beamline equipment
  - Understanding proton beam for high-precision physics results
- Monitor degradation has been observed; profile monitors also cause significant beam loss
- New profile monitor developed jointly with FNAL experts now in use at the J-PARC extraction beamline
  - Ti or carbon nano-tube wires (rather than Ti foils) reduce beam loss by factor of 1/10 and are more robust
  - Newly developed monitor working well in beam since 2018
  - Further upgrades to mover system, wires underway

SSEM18→WSEM Exchange

- Replaced SSEM18 with WSEM Dec. 2018
  - Since beam loss is significantly lower with WSEM, can use WSEM18 continuously in case of SSEM19 failure

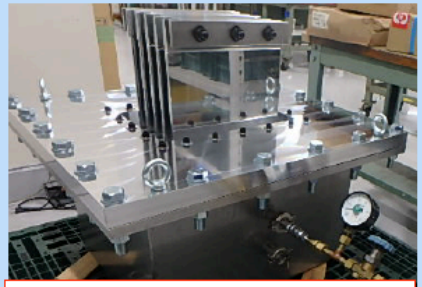






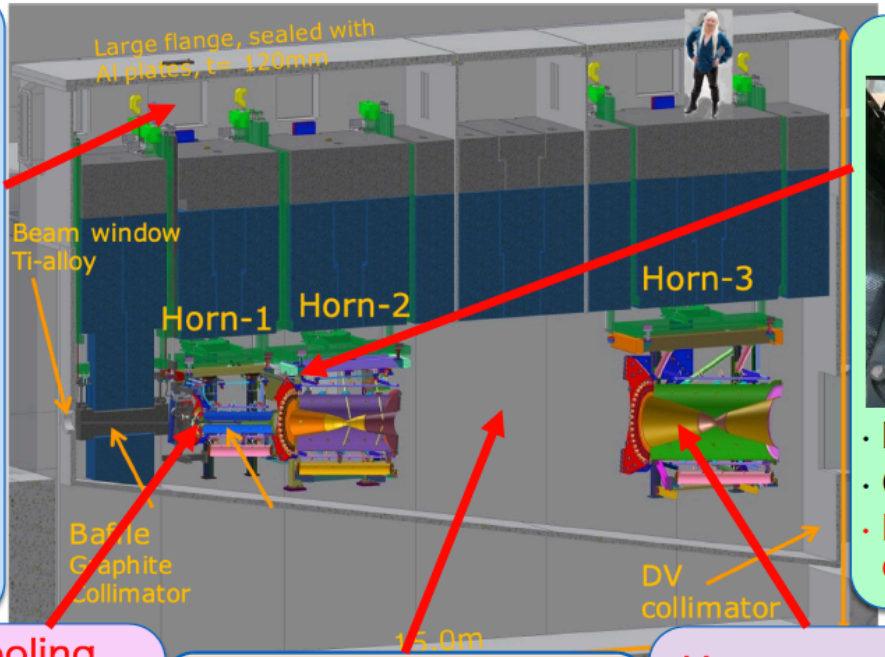
High Power Target Facility Issues

Many challenges towards high power beam !!
KEK/Fermilab cooperation to realize >1MW beam.

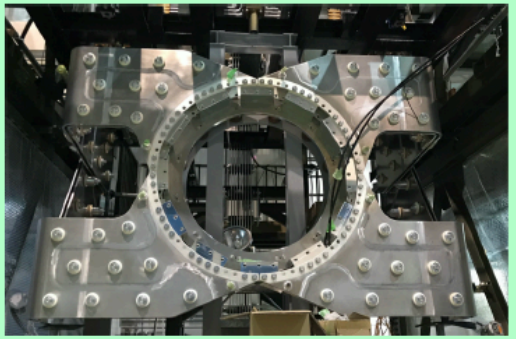


Prototype for current testing

- High current feedthrough for high repetition operation under high radiation environment
- Design improvement and protype test revealed promising results.



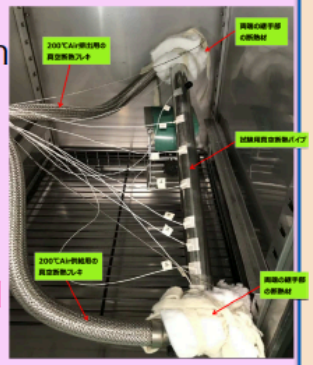
Cooling improvement



- Large heat load at striplines
- Cooling improvement needed
- New water cooling striplines developed

Improved target He cooling

- High heat load at target → Circulation of high temp. He gas needed
- Improved He circ. system
- Vac. insulation pipe developed for good thermal insulation
- Promising results from prototype tests.



Vacuum insulation pipe prototype

Tritium production and release from metals

- Tritium release from metal became an issue on high power operation.
- Its mechanism under investigation.
- Measurements on tritium release rate in both US and Japan.

H_2 removal for Horn cooling water

- H_2 production is a critical issue and H_2 must be removed.
- Long-term R&D in J-PARC over 10 years
- H_2 recombination sufficiently remove H_2 from 5%/day to 0.1%/day
- Addition of new ion-exchanger and O_2 de-gasifier for safer operation.

H_2 recomb. catalyst