



# **J-PARC**

## **Accelerator and Neutrino Beamline Plans and Schedule**

**T. Sekiguchi (KEK IPNS/J-PARC)**

**2024. 9. 18**

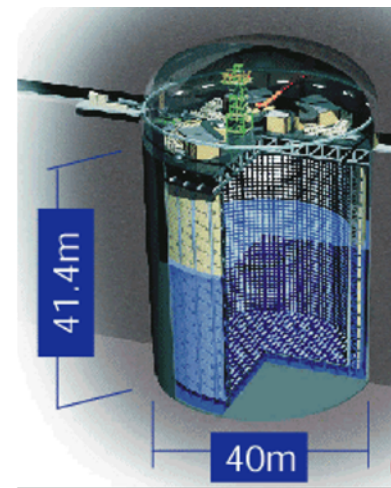
**NuFact 2024 - The 25th International Workshop on Neutrinos from  
Accelerators @ Argonne National Laboratory**



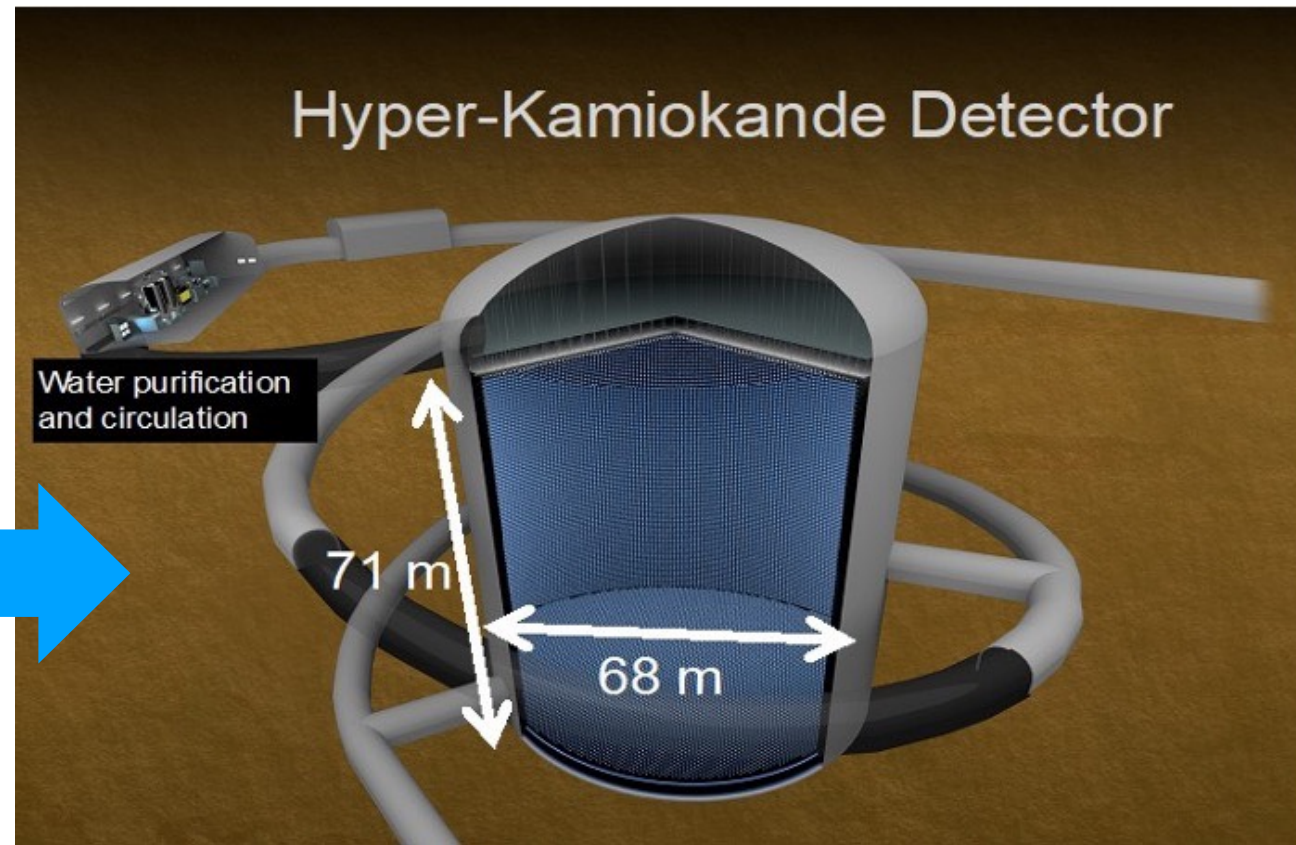
- Overview of J-PARC Neutrino Beamline
- J-PARC and Neutrino Beamline Upgrade
  - Major upgrade in FY2021-2022
  - Operation status in FY2023-2024
  - Prospect and plan toward 1.3 MW
- Summary



# J-PARC Neutrino Beam to Kamioka (T2K/Hyper-K)



Super-K



**Hyper-K**  
(Water Č)



**J-PARC**  
Accelerator Complex



- Search for CP violation in lepton sector

- T2K (~2027) : hint of CPV (~2σ) ⇒ Hyper-K (2027~) : discovery of CPV (>5σ)

- High statistics measurement with

- ~8 x larger new detector

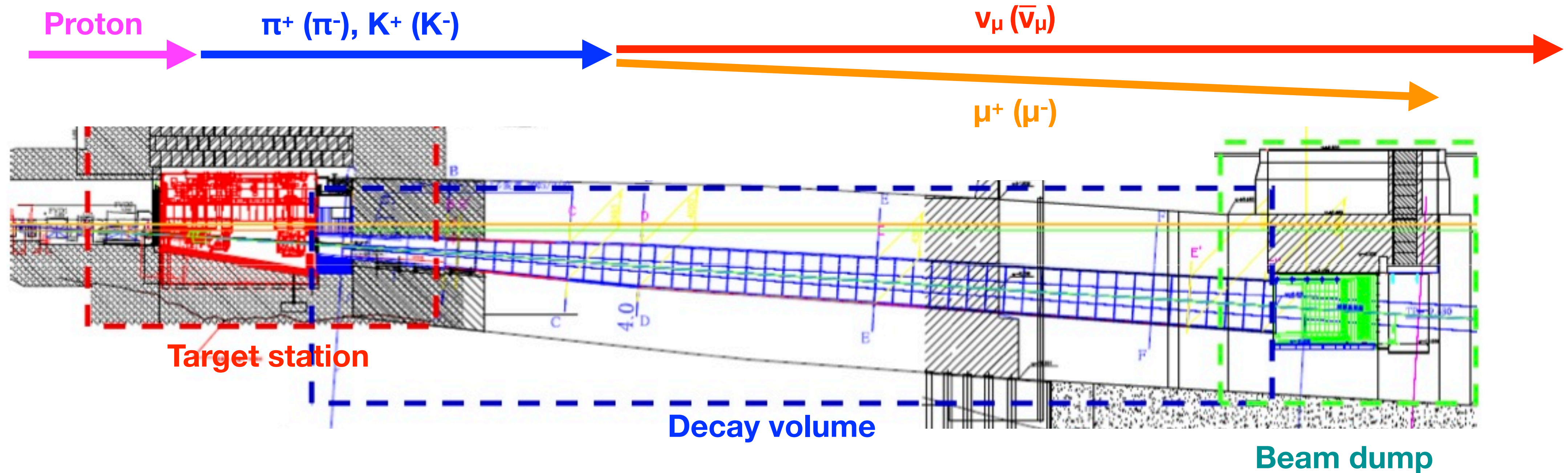
- High power neutrino beam over 1MW

Beam power

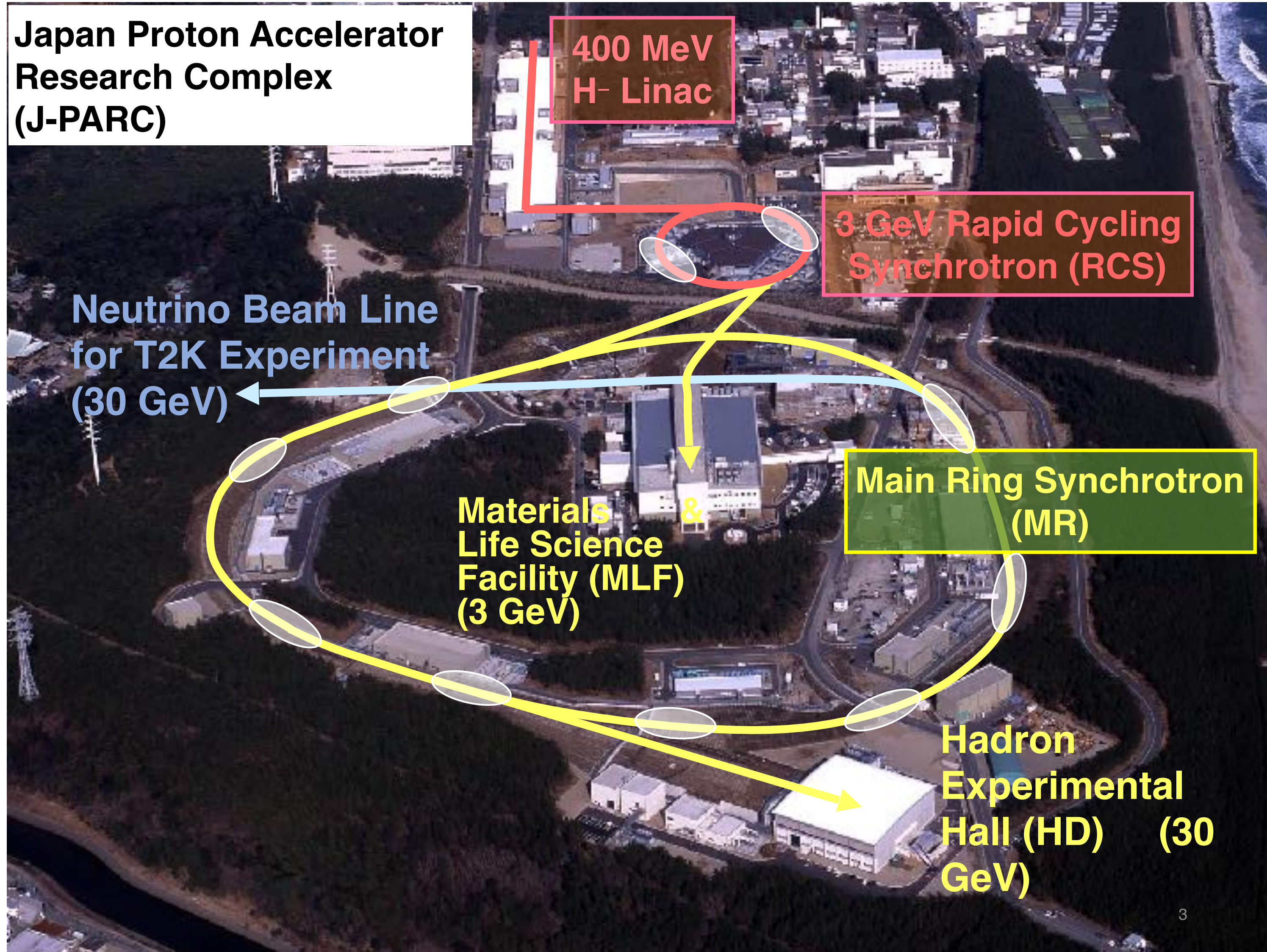
Detector volume

$$N_\nu \propto \Phi_\nu(E) \times \sigma_\nu(E) \times \text{target}$$

# of detected neutrinos

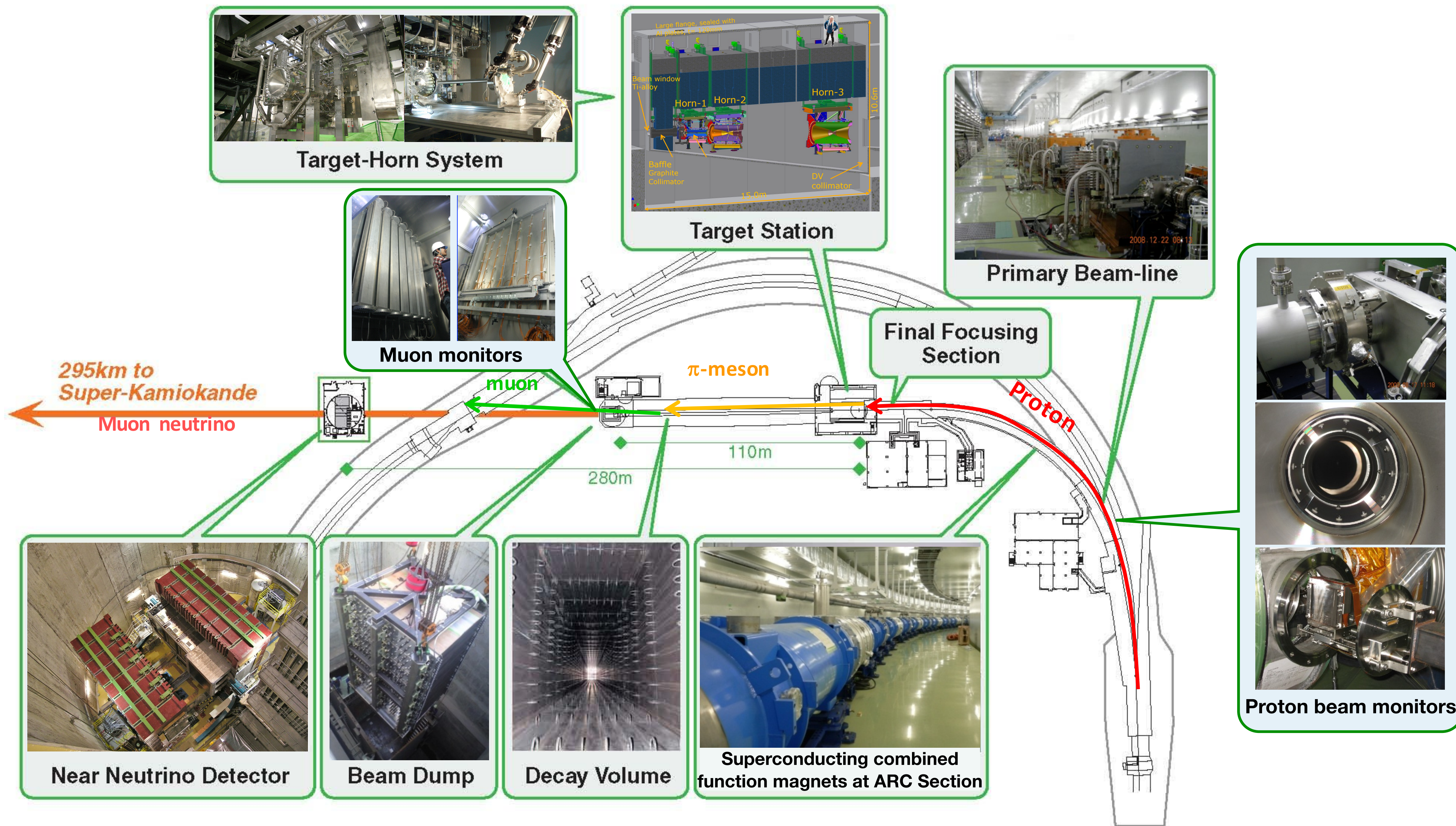


- High intensity proton beam hits a graphite target
- Secondary  $\pi/K$ 's focused by magnetic horns and decay to neutrinos
  - Neutrino beam from  $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - Antineutrino beam from  $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
  - Sign-selected neutrino beam by flipping the horn polarity



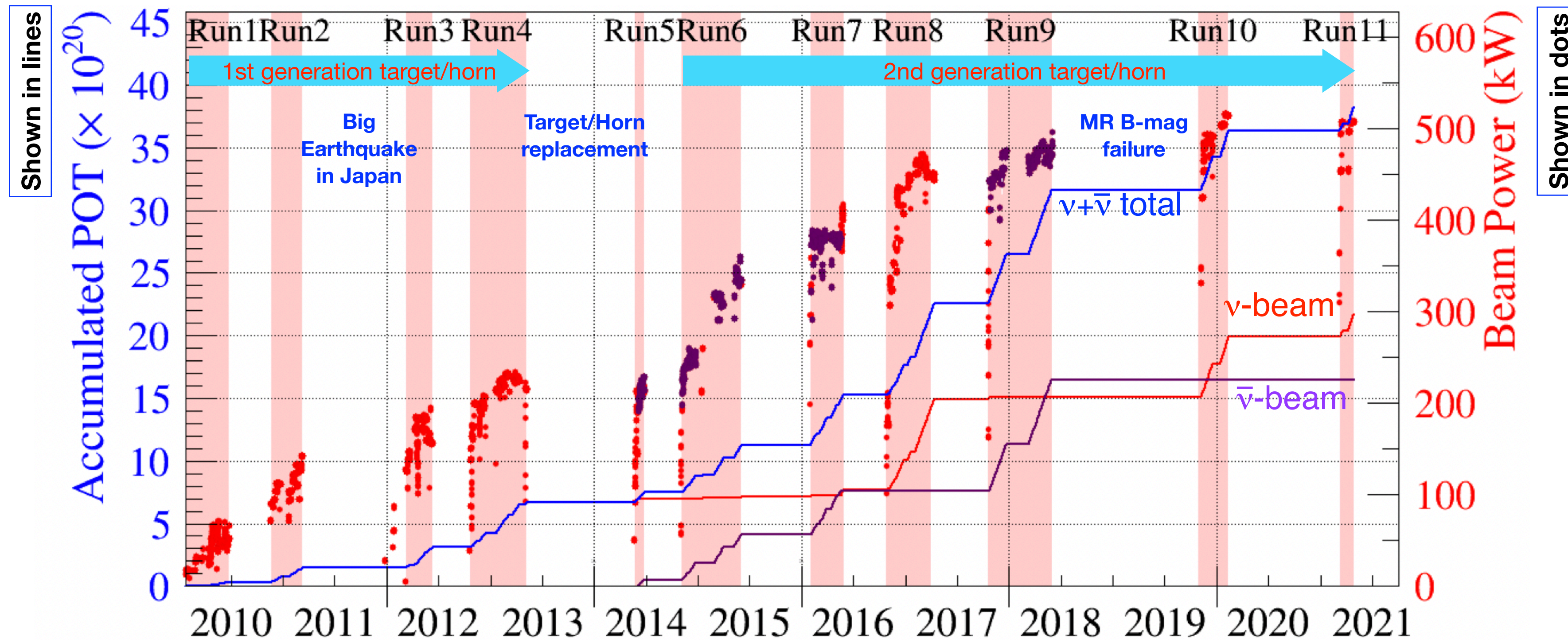
## J-PARC Accelerators

- 400 MeV Linac
- 3 GeV Rapid Cycling Synchrotron (RCS)
  - Material and life science, muon science
- 30 GeV Main Ring Synchrotron (MR)
  - Fast-ext.(FX): Neutrino experiment (T2K→HK)
  - Slow-ext.(SX): Nuclear and particle physics experiments
  - The original design beam power for FX operation is **750 kW**



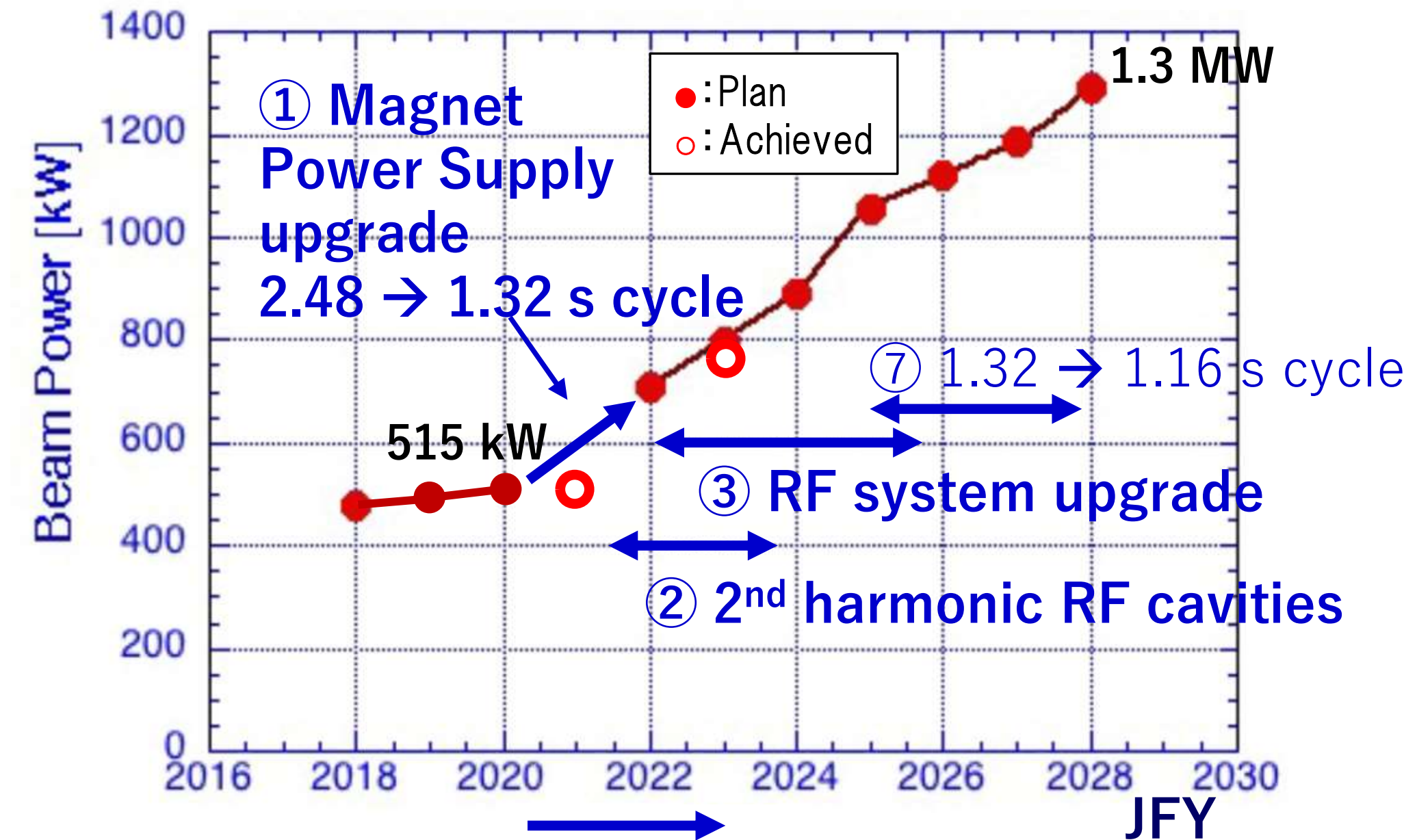


# Neutrino Beamline Operation Until 2021



- Started physics data taking in January 2010
- **510 kW** stable operation achieved  $\Rightarrow$  proton beam intensity :  **$2.6 \times 10^{14}$**  protons/pulse  
 $\Rightarrow$  World-highest intensity (# of protons/pulse) in fast-extracted beam from proton synchrotron
- Beam power limited by space charge effect, beam instability due to insufficient RF voltage
- Provide  **$3.82 \times 10^{21}$**  protons on target (POT) to T2K
  - $\nu$  mode POT :  $2.17 \times 10^{21}$  (56.8%), anti- $\nu$  mode POT :  $1.65 \times 10^{21}$  (43.2%)

- **Staged accelerator upgrade toward 1.3 MW**
  - **Shorter cycle** (2.48s → 1.36s) for >750 kW (~FY2023)
    - MR magnet PS upgrade
  - **Higher beam intensity** for 1.3 MW (~FY2028)
    - RF system upgrade
    - Reinforcement of MR magnet PS system (1.36s → 1.16s)
- **Upgrade of neutrino beamline is also needed**



	Before Upgrade	After Upgrade
<b>Beam power [ MW ]</b>	<b>0.51</b>	<b>1.3</b>
<b>Proton intensity [ 10<sup>14</sup> / pulse ]</b>	<b>2.6</b>	<b>3.2</b>
<b>Cycle [ s ]</b>	<b>2.48</b>	<b>1.16</b>

S. Igarashi, *et. al.*,  
PTEP vol 2021,  
Issue.3,p33

- ④ Collimator system
- ⑤ Injection/FX system
- ⑥ Beam Monitors (BPM circuits)

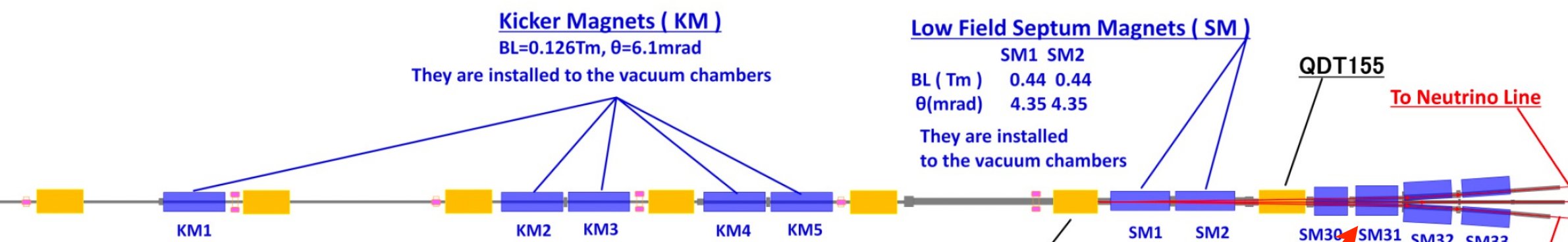
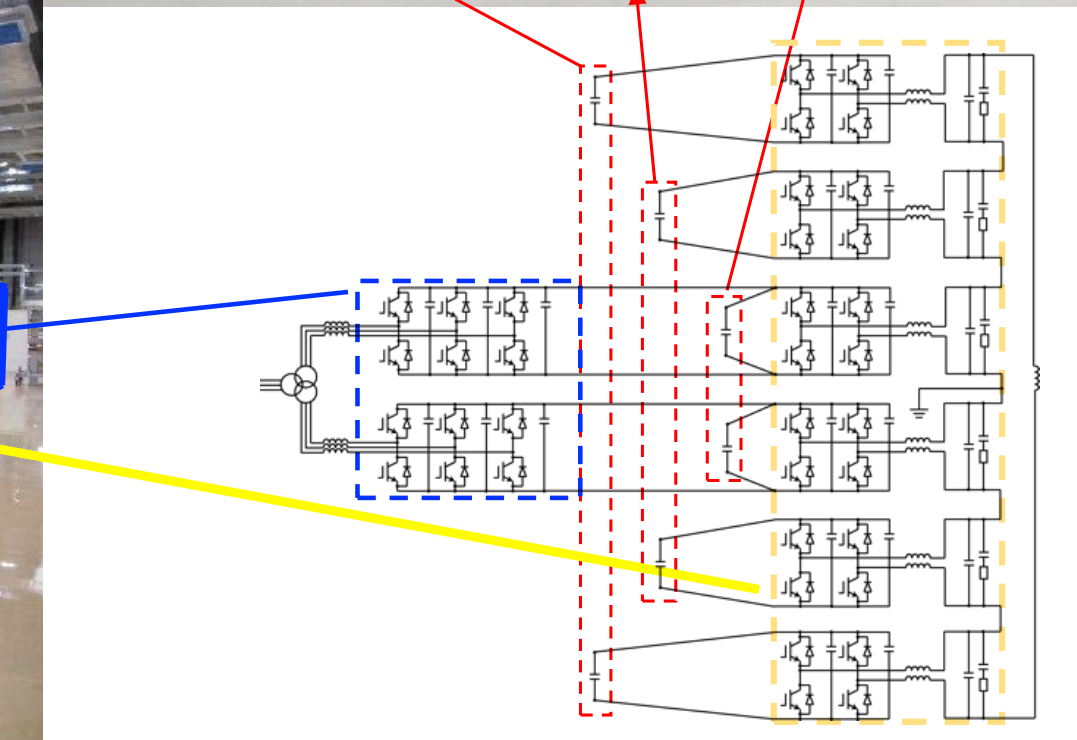


- **Power supply upgrade**
  - **New MR magnet PS with large capacitor bank** (for B-&Q-magnets)
  - Installation of all new magnet PSs in JFY2021
  - PS operation successfully performed in physics operation
- **Other upgrades**
  - New fast-extraction devices (kicker, septum) **~JFY2022**
  - Collimator capacity upgrade (2kW→3.5kW) **~JFY2022**

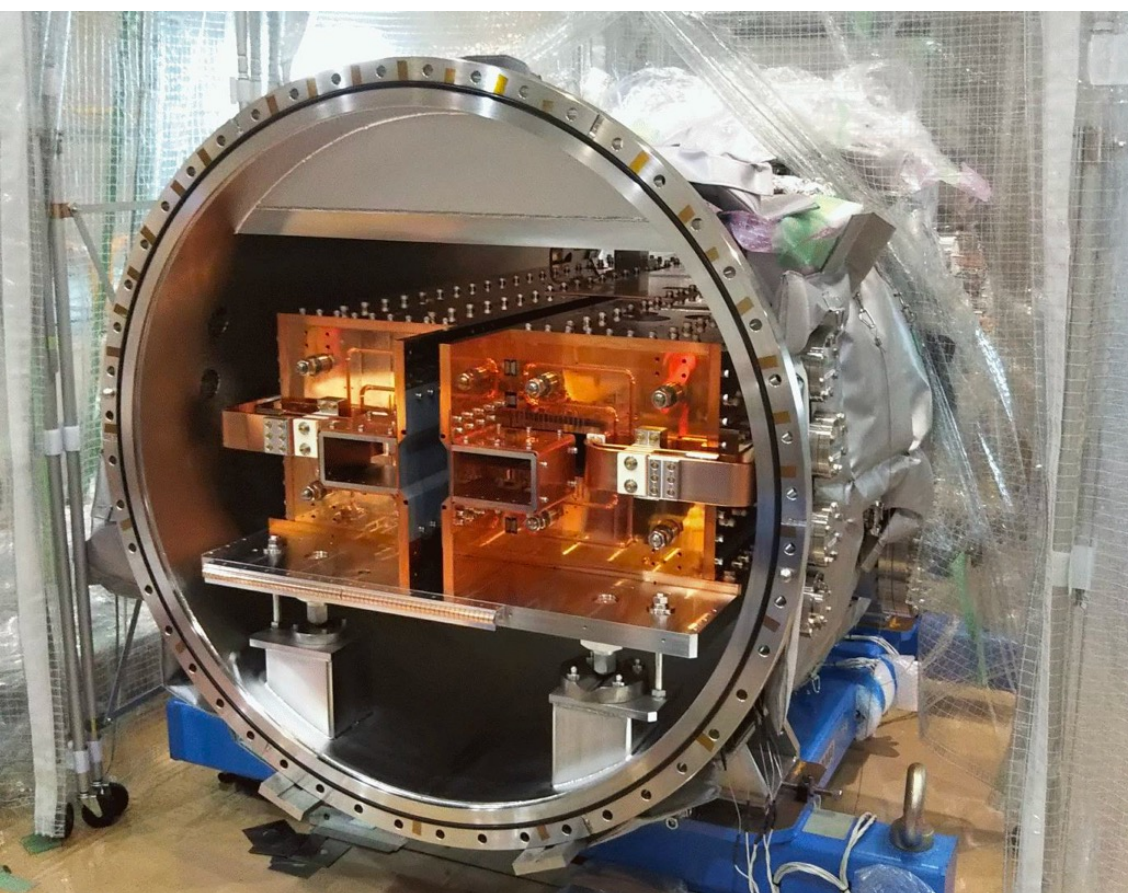
Capacitor Banks for BM3



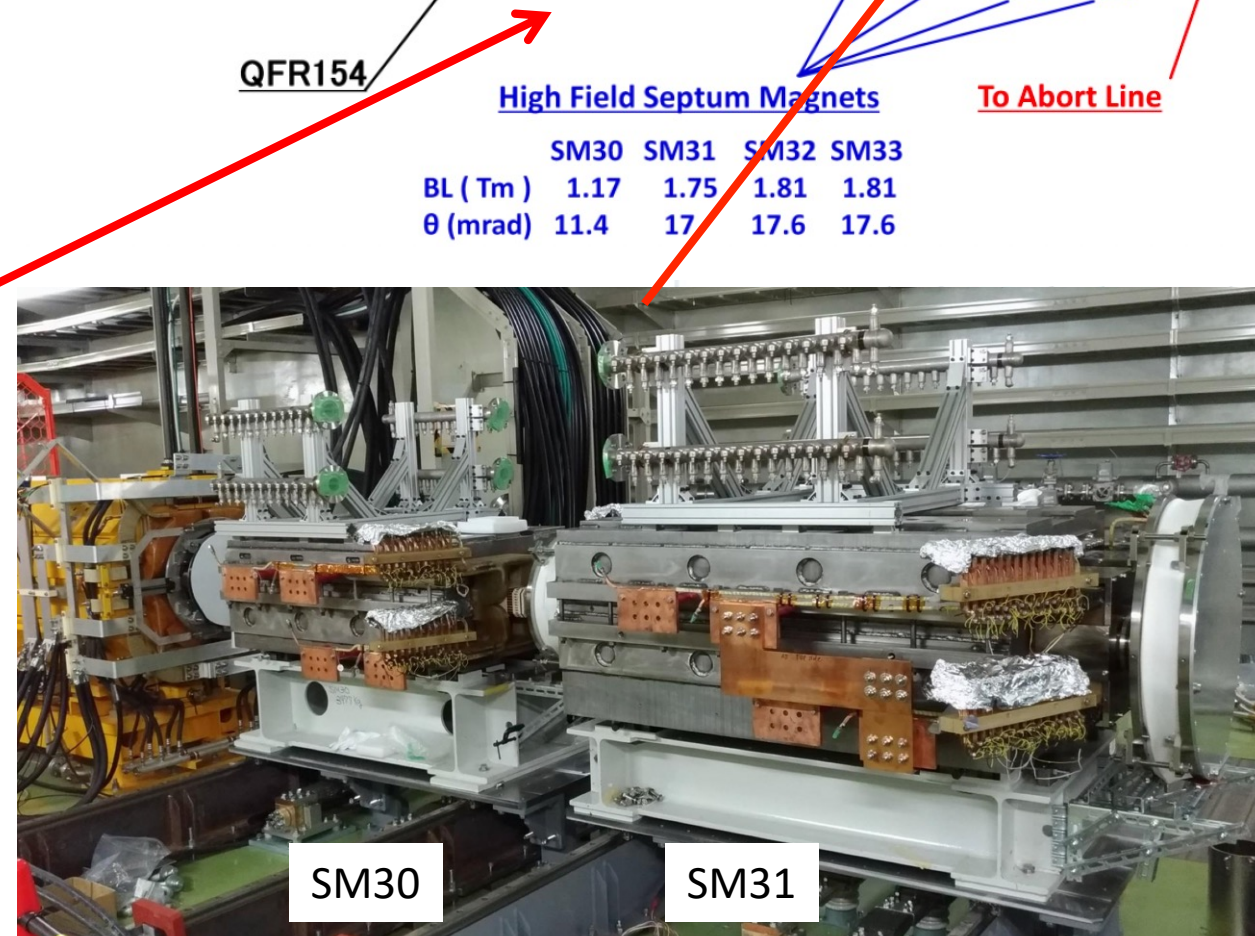
New magnet power supply



QDN power supply  
(Chopper + Filter + Control Panels)



Low Field Septum magnets



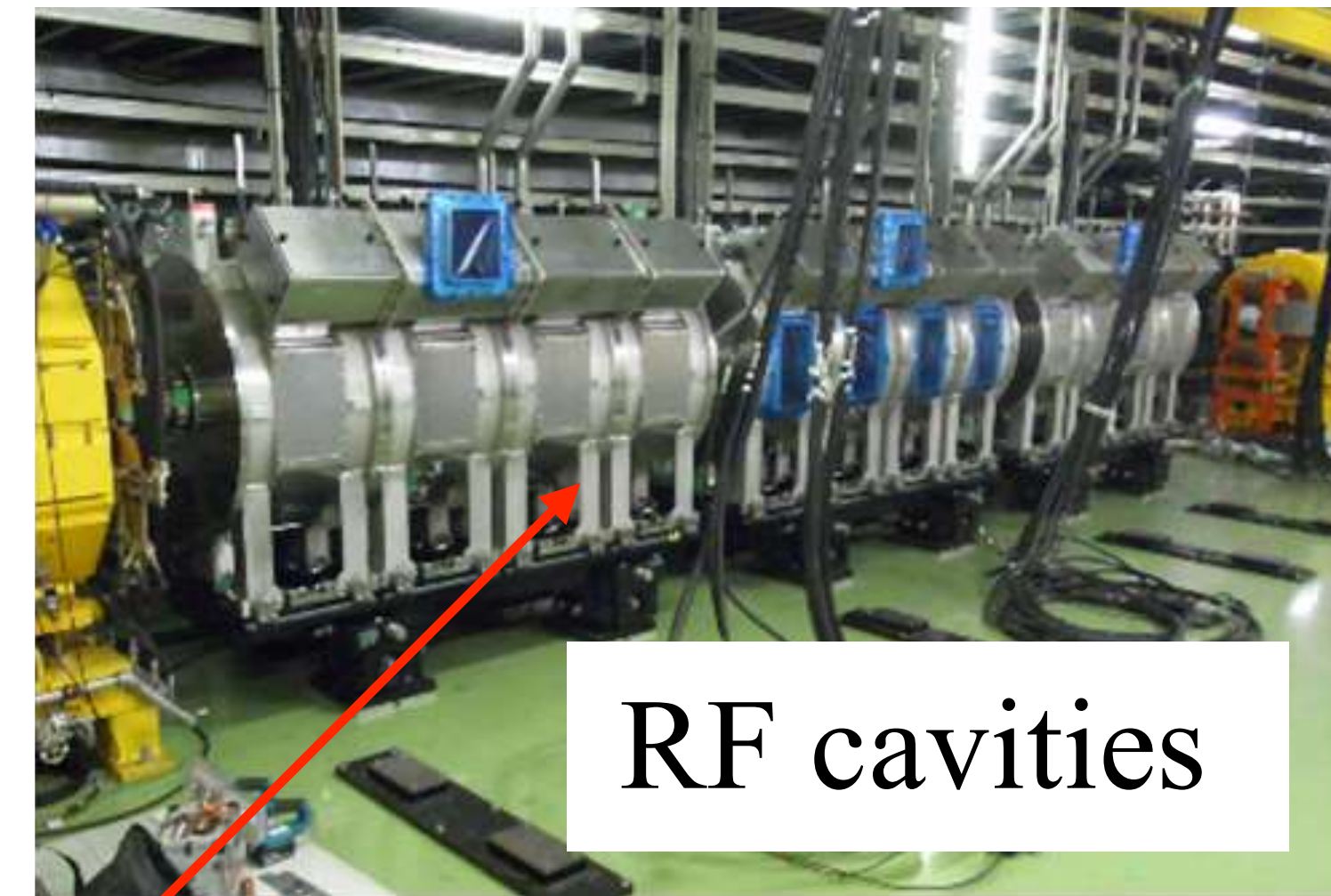
High Field Septum magnets

Newly installed Col. G Col. H



- RF system upgrade**

- Higher RF voltage is required for higher rep. rate
- New 2nd harmonic RF system JFY2021~2023**
- Additional 2 fundamental RF cavities (9→11) JFY2022~2026**
- Anode PS upgrade (15→19 units) JFY2022~2026**



RF cavities

	Present	2022	2026
MR Cycle	2.48 s	1.32 s	1.16 s
Fundamental Cavities	7	9	11
2 <sup>nd</sup> Harmonic Cavities	2	2	2
Accelerating Voltage	300 kV	510 kV	600 kV
2 <sup>nd</sup> Harmonic Voltage	110 kV	110 kV	110 kV



Cavities at MR Insertion C

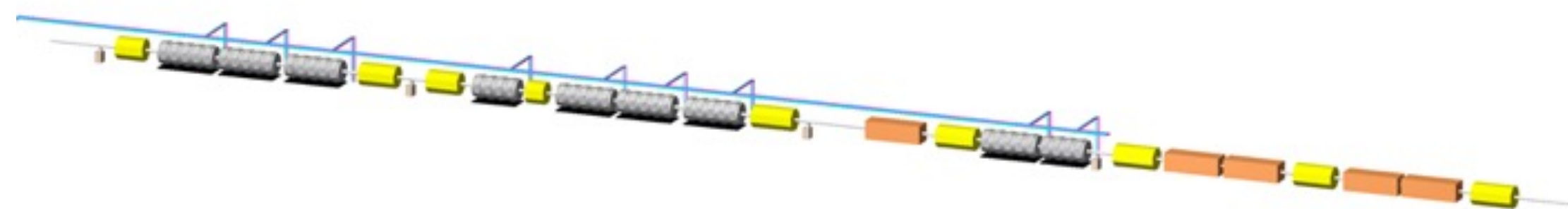
New 2nd harmonic RF cavities to mitigate space charge effect

Enhancement for RF anode PS



Ins A: 2 2<sup>nd</sup> harmonic cavities  
 Ins C: 11 fundamental cavities

Insertion C





- **Baseline design**
  - Beamline components designed to accept  **$3.3 \times 10^{14}$**  ppp
  - Replaceable components designed for **750 kW** (can be upgraded later)
  - Non-replaceable components (HV, DV, BD) designed for **3-4 MW**
- **Necessary upgrade toward 1.3 MW**
  - Cooling capacity improvement
    - **Target He cooling**
    - **Water cooling for horns, He vessel, DV, BD**
  - Shorter cycle operation
    - **Horn operation**
    - **DAQ**
  - Accommodate larger amount of radioactivity
    - **Water disposal facility upgrade**

# Summary of 2021-2022 upgrade works

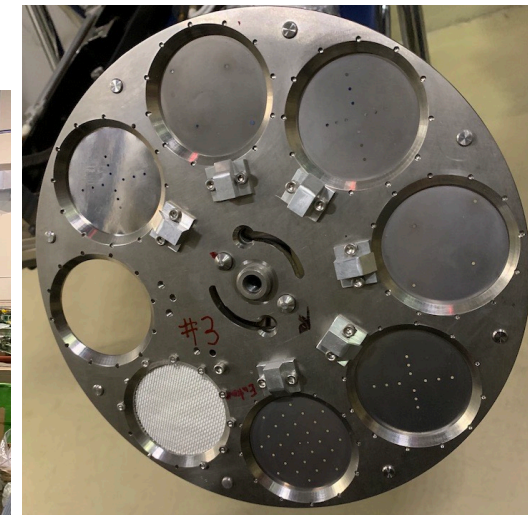
New Horn PS/  
trans/strip-lines  
for 320kA, 1Hz



New Horn1, 2



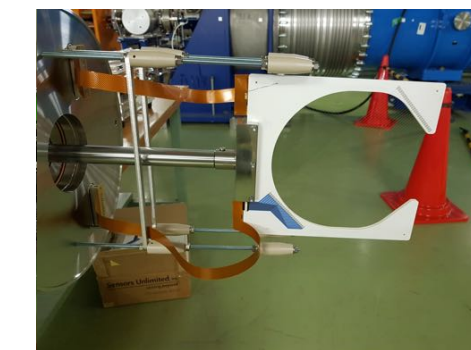
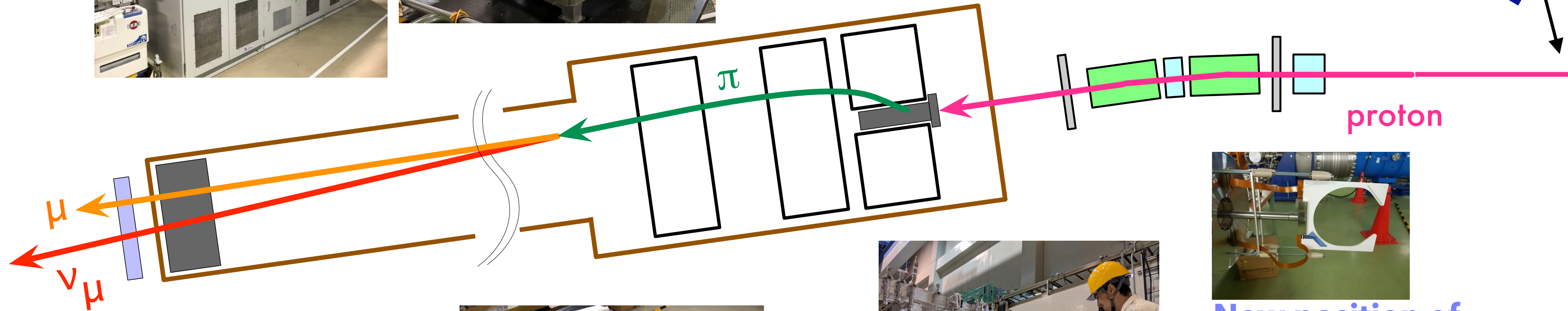
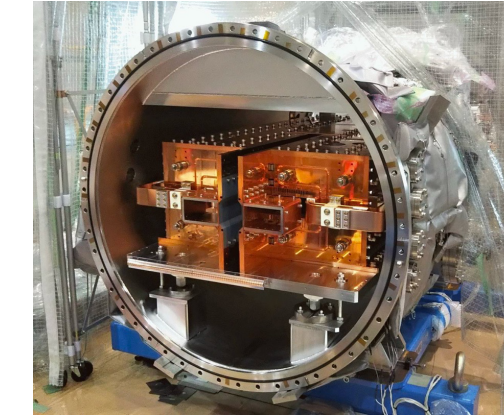
New OTR



New  
FVD2 magnet



New FX  
Septum  
magnets  
(MR)



New position of  
proton beam monitor  
(WSEM18,ESM20) +  
new monitor



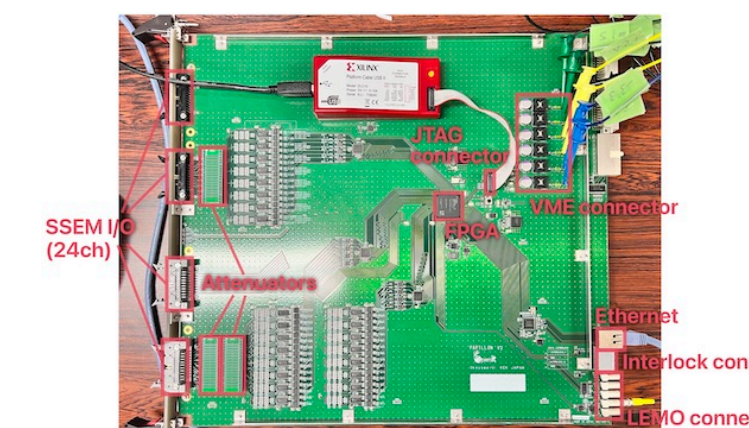
New target



New target cooling system



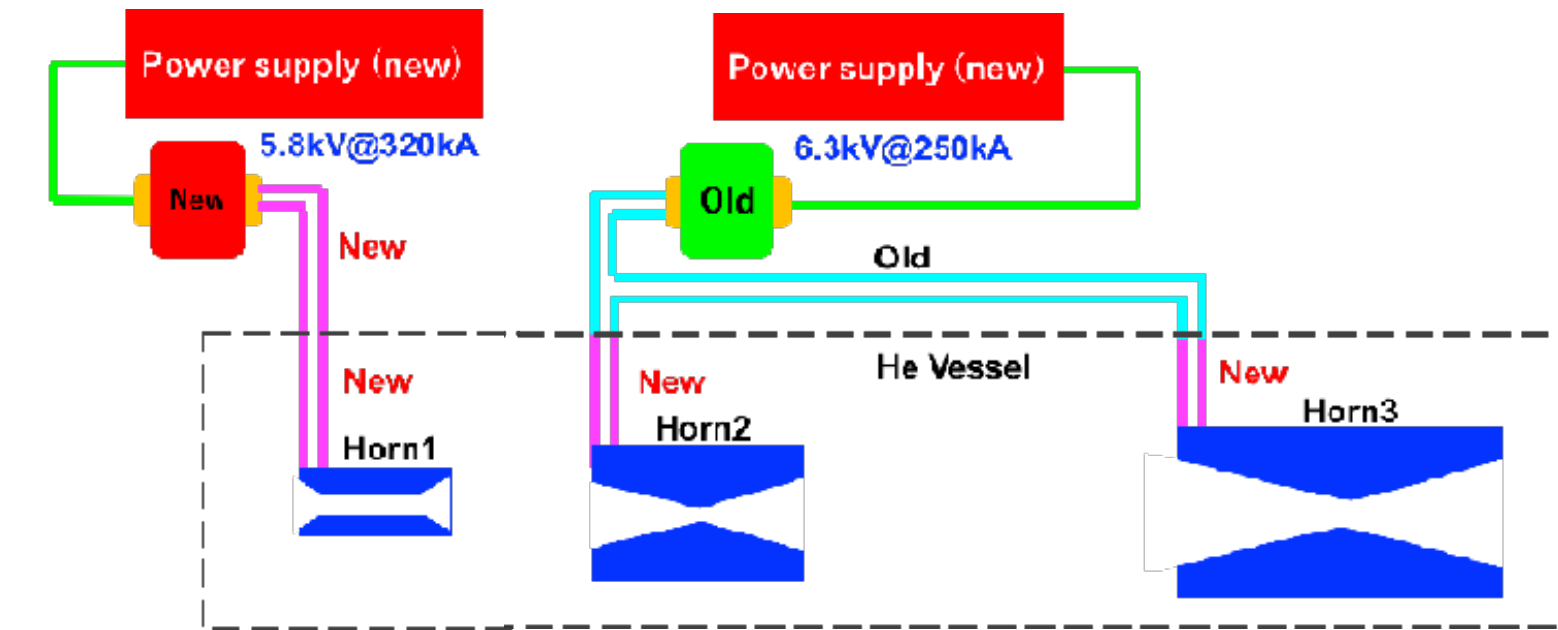
New mumon Si (half of sensors)



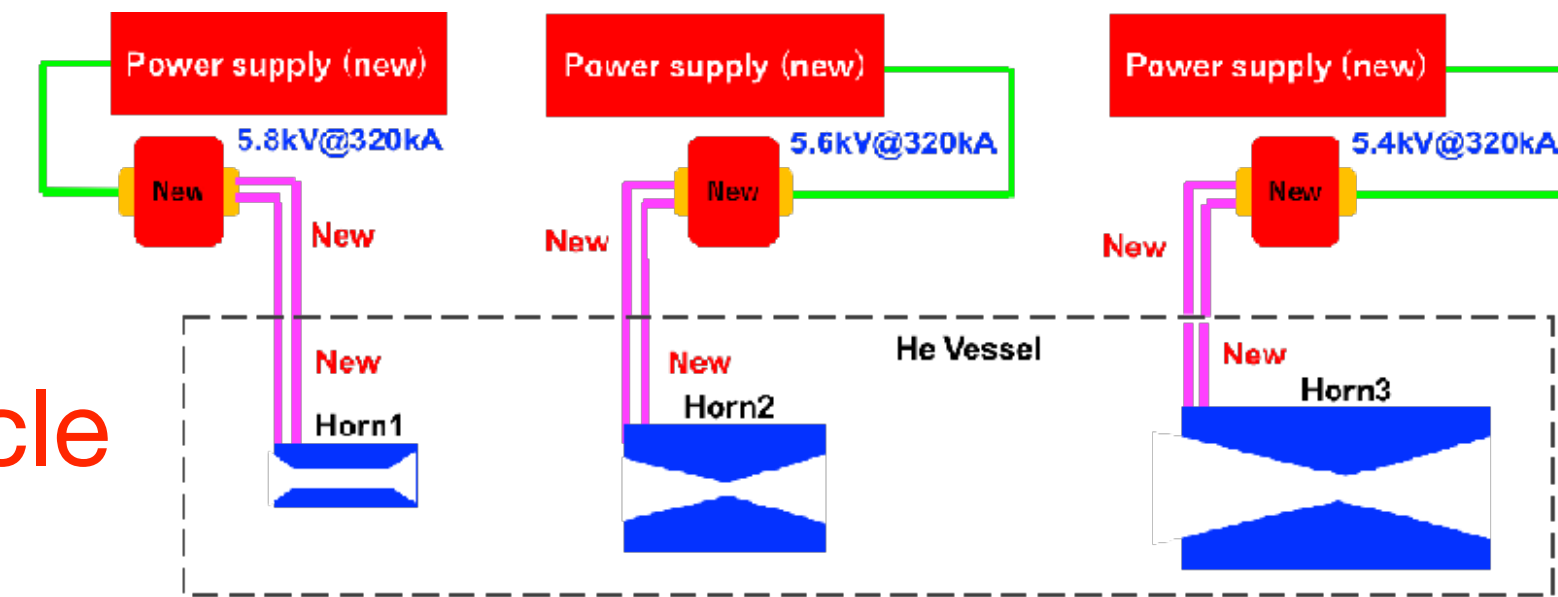
+ New beam interlocks

- Horn electrical system upgrade for **320 kA at 1 Hz**
  - Horn current increased from 250 kA to 320 kA (design)
    - ~10% flux gain for right-sign neutrinos
    - 5~10% flux reduction for wrong-sign neutrinos
  - Three power supplies to drive three horns (one-by-one)
    - New electrical system (PS, transformer, striplines) developed for 320 kA at 1 Hz operation
      - All the devices installed during LS2021-2022
  - Initial commissioning succeeded at 320 kA operation at 1.36 s cycle

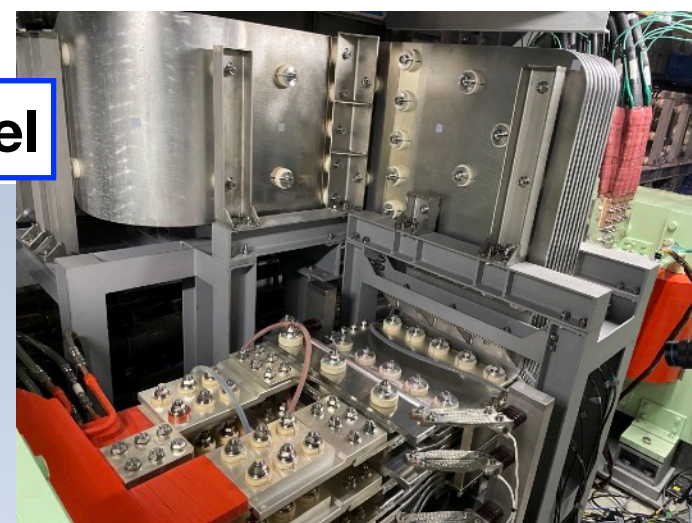
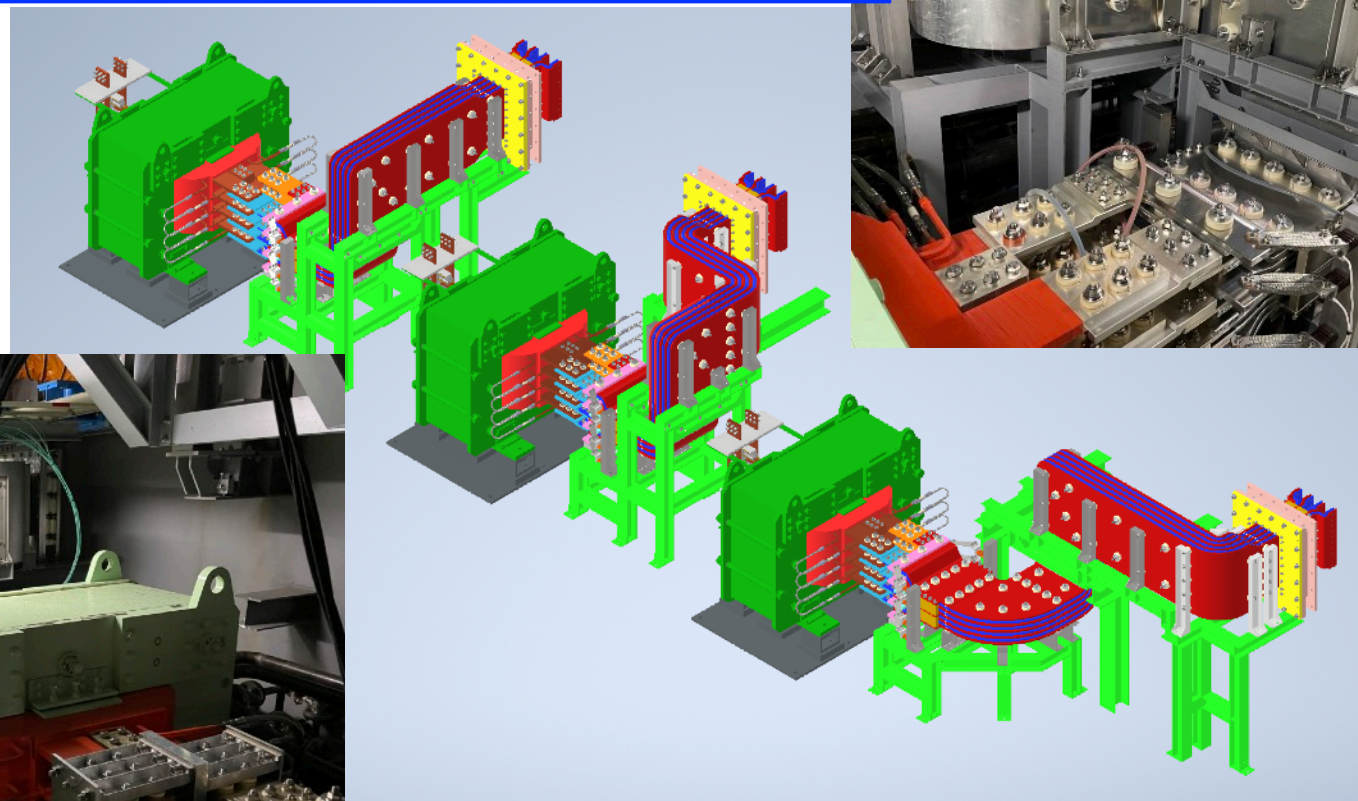
Previous configuration (~2021)



Upgraded configuration (2022~)



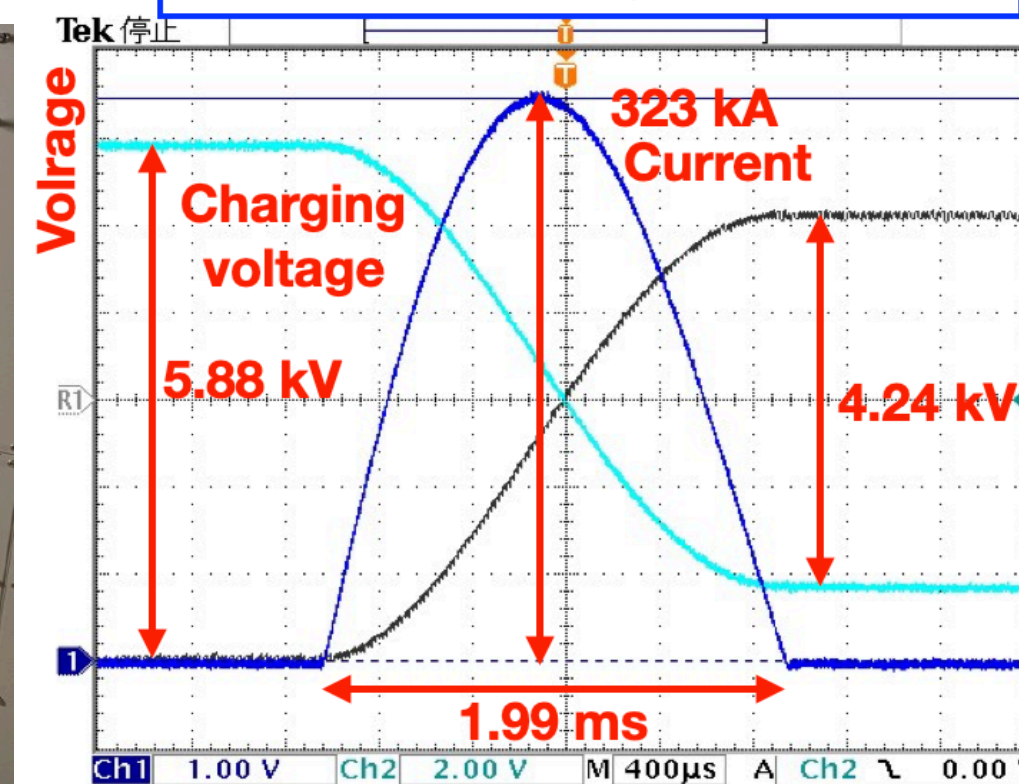
Transformers and striplines outside He vessel



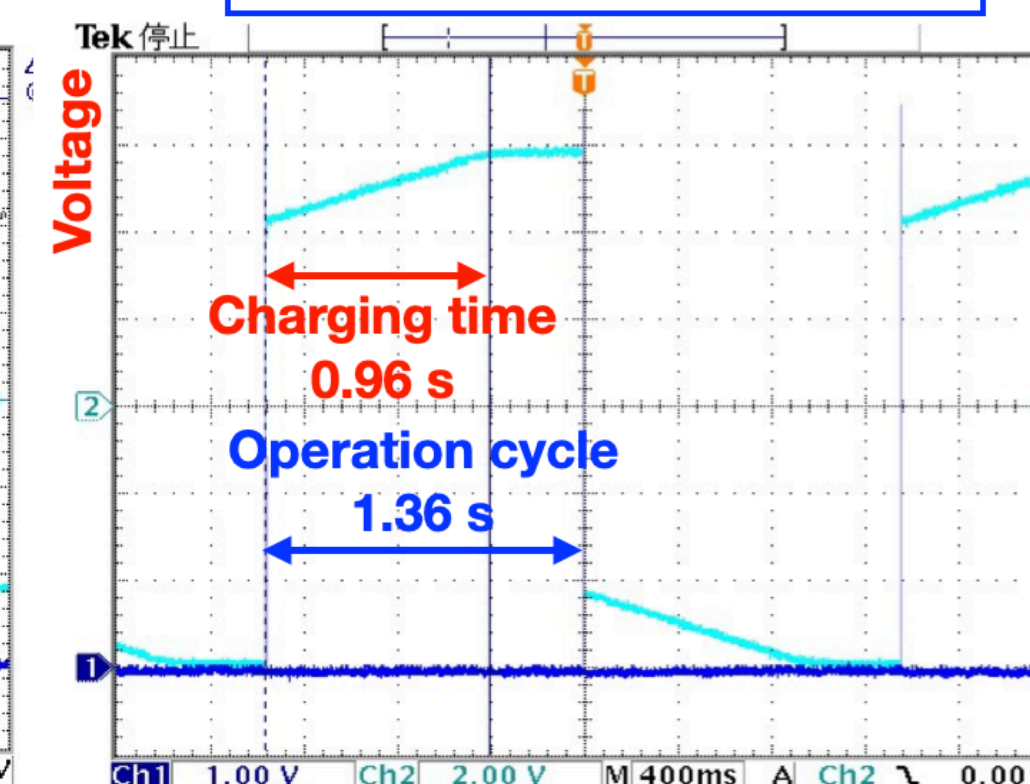
3rd PS and new capacitors installed



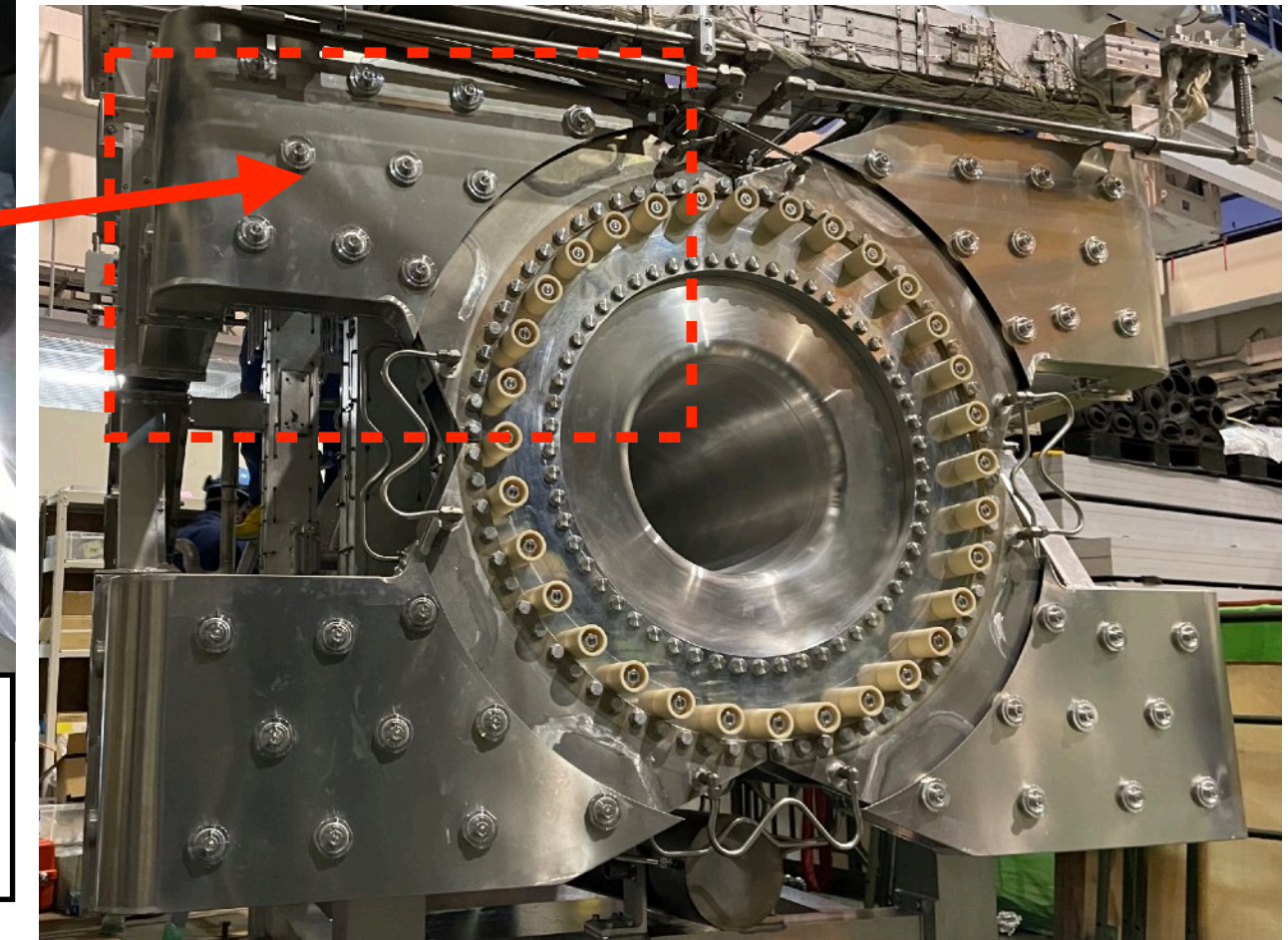
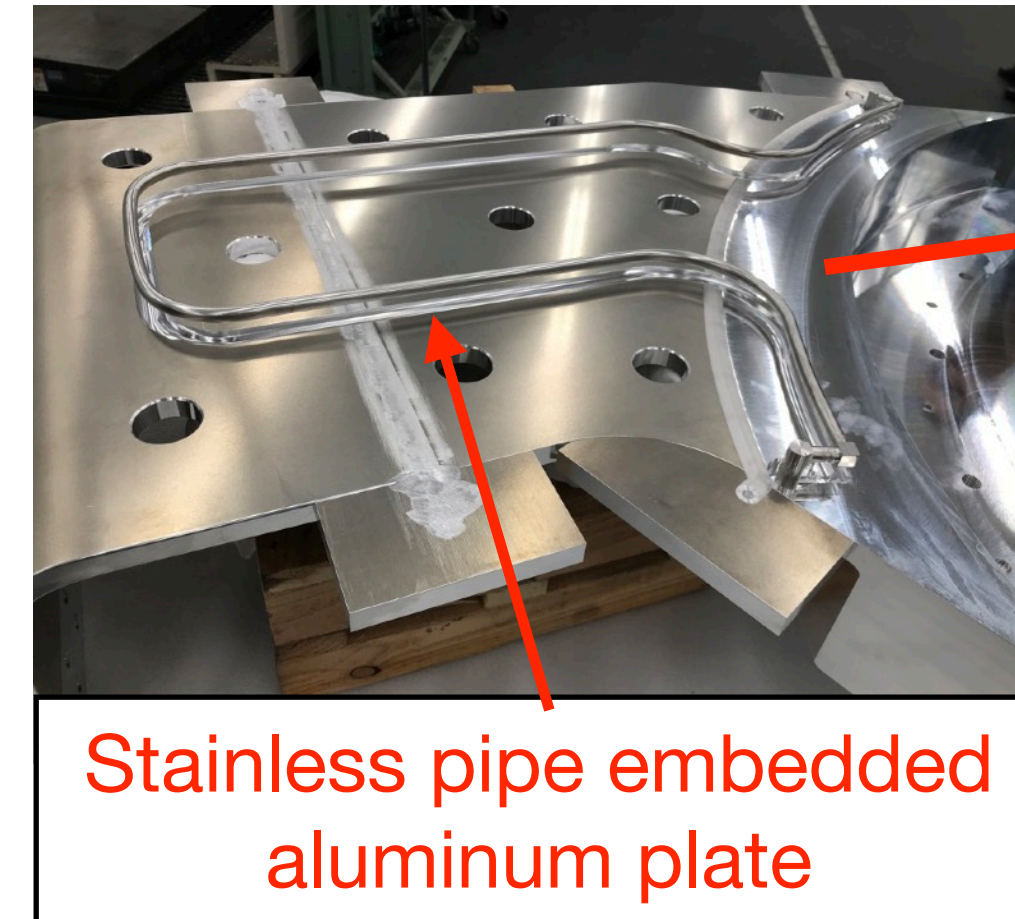
Current and voltage pulse shape



Charging pattern with 1.36 s

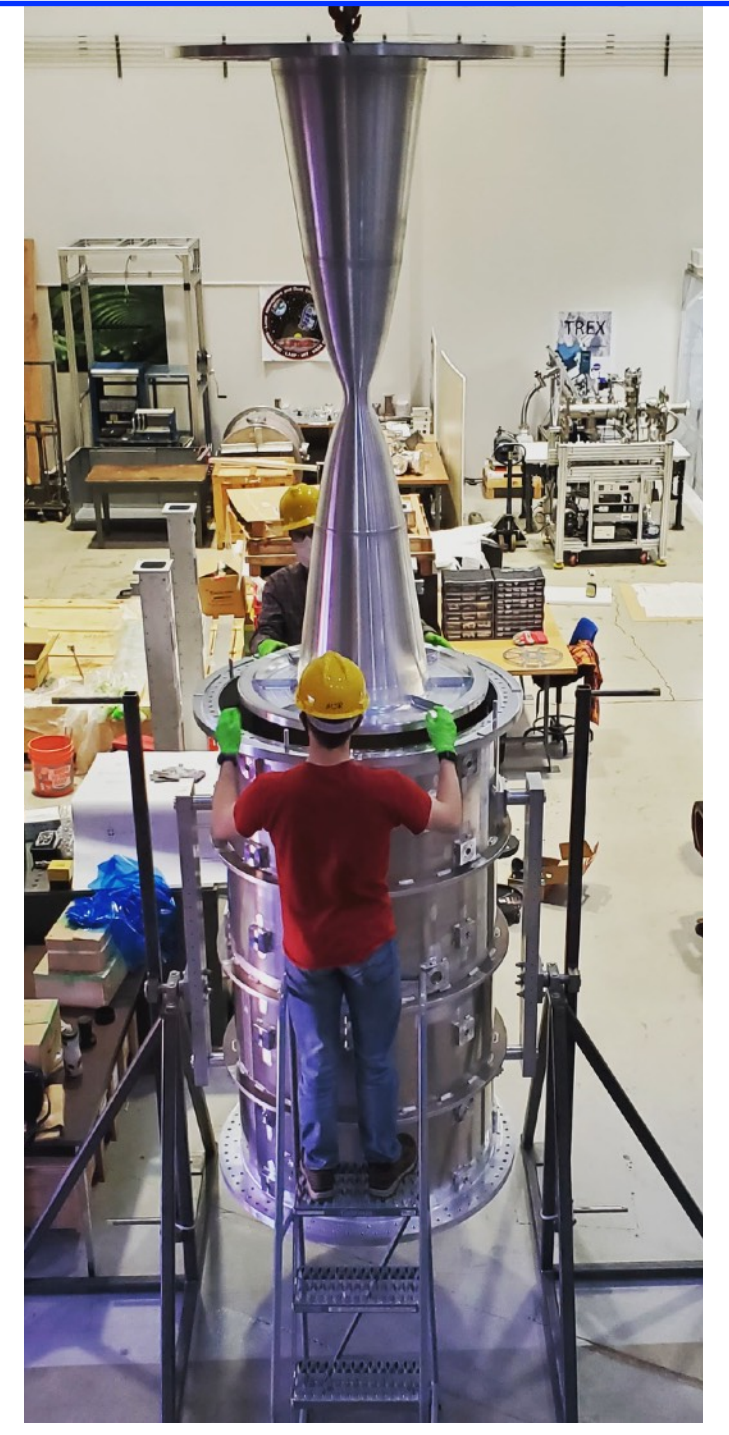
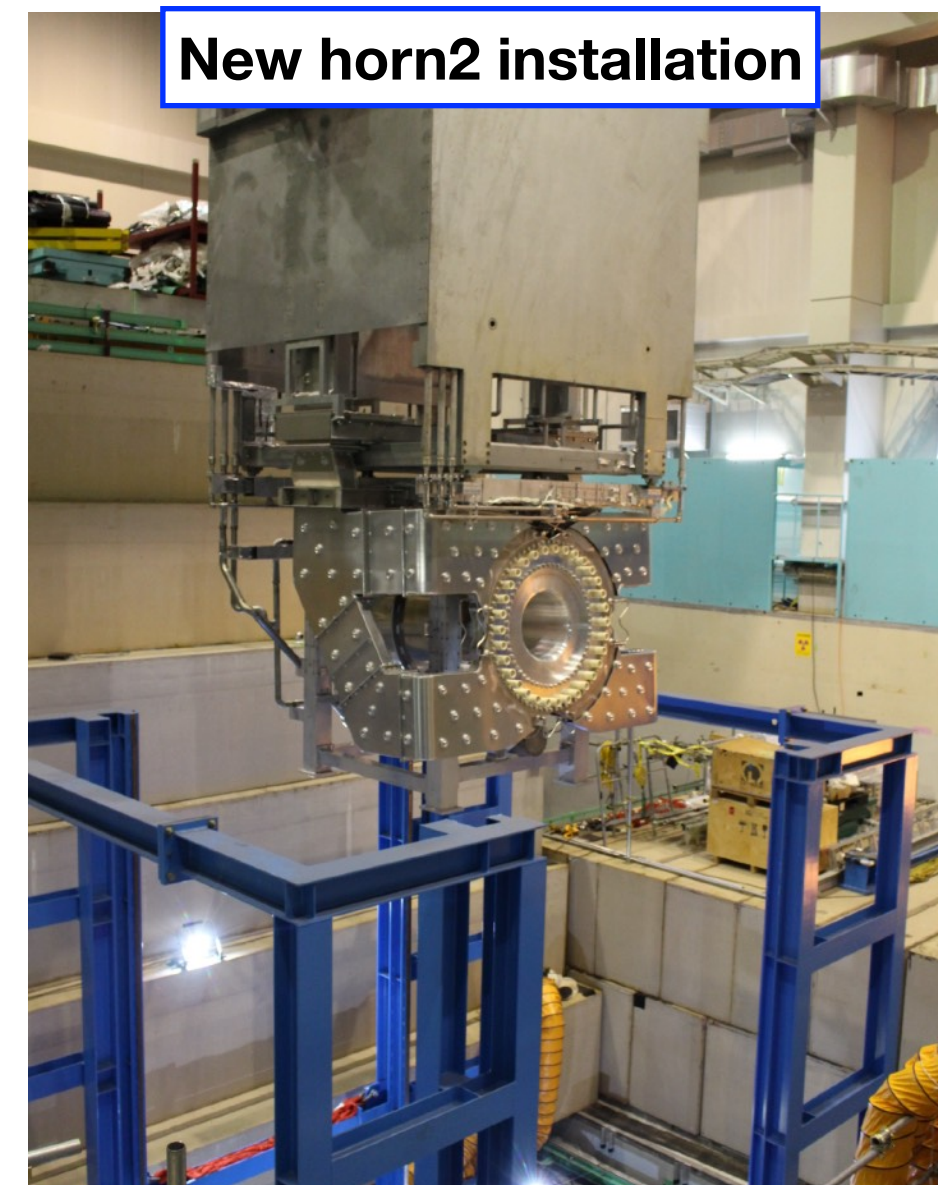


- **Conductor cooling improvement (for Horn2)**
  - Large heat load at Horn2 due to defocused particles by Horn1
  - **Striplines and upstream conductor cooling**
  - **New Horn2 production in Univ. of Colorado Boulder**
- **Horn replacement**
  - **New horn1 (with improved water sealing) and new horn2 installed during LS2021-2022**



Target installation to new Horn1

Horn2 production at Colorado



- The original cooling capacity : 750 kW + 20% margin → **900 kW**
- Need high He flow rate by applying higher pressure : 0.16 → 0.4 MPaG
- Upgrade of He circulation system
  - New compressor already produced (FY2022)
  - Production of other components ongoing
  - Installation of all the He circulation system scheduled in **FY2026**
- **Vacuum insulation pipes** developed to accommodate high temp. He gas (~200°C)
  - All pipes inside He vessel were replaced in FY2022

New He compressor delivered to KEK



Vacuum insulation pipe penetrating support module

HV

②

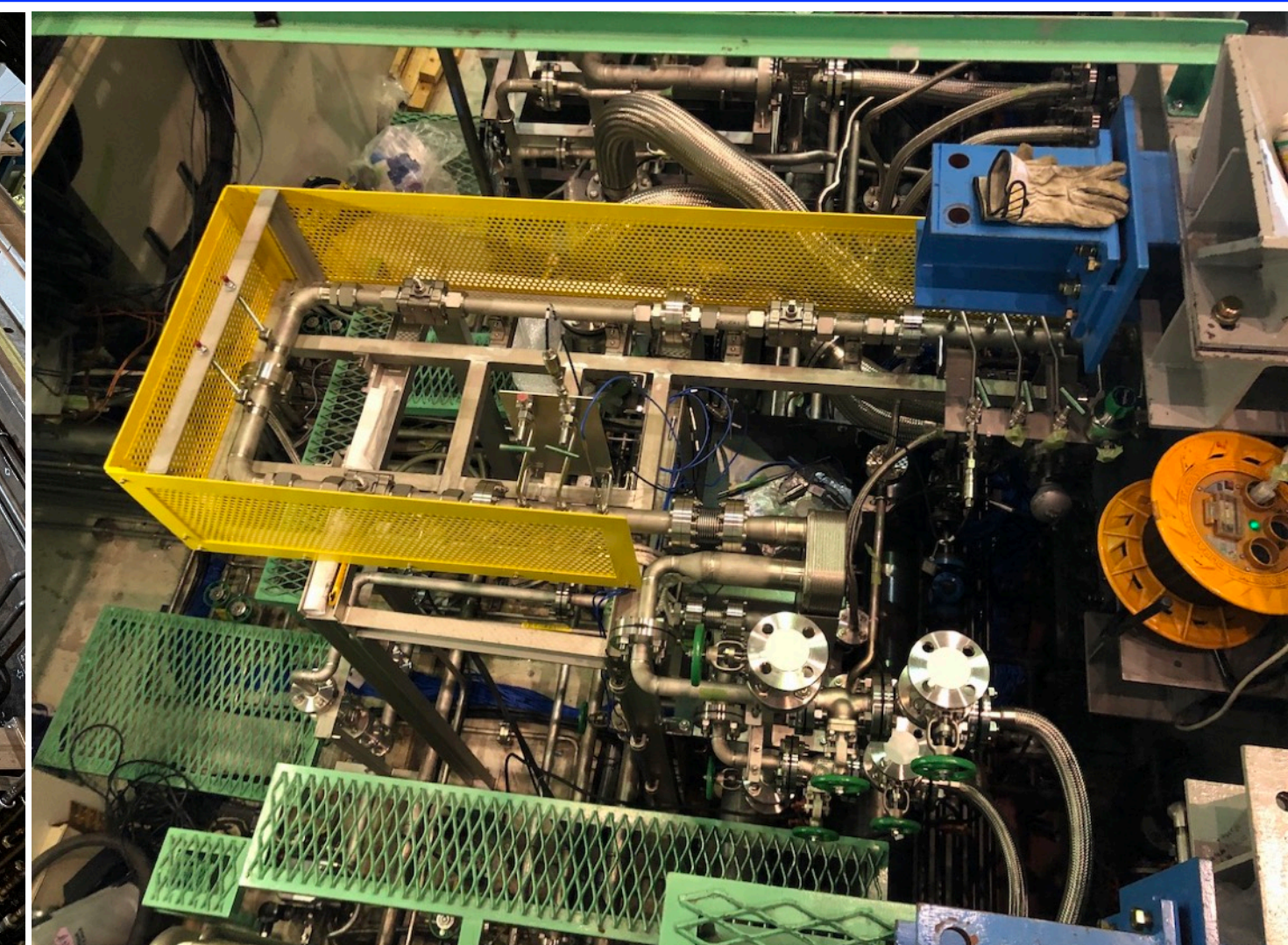
SM

~4.5m

Modified target plumbing



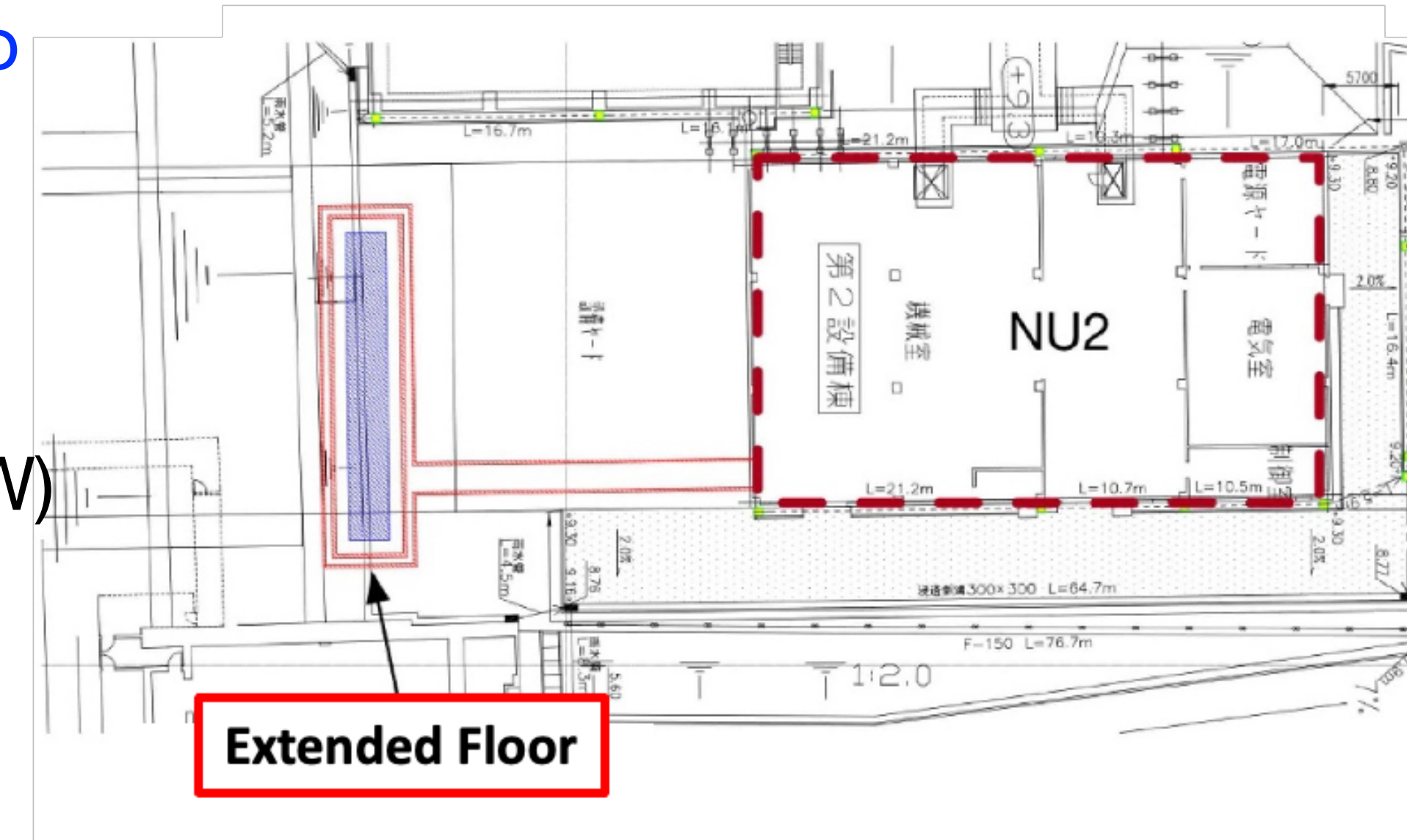
New heat exchanger outside He vessel





# Radio-active Water Disposal Facility Upgrade

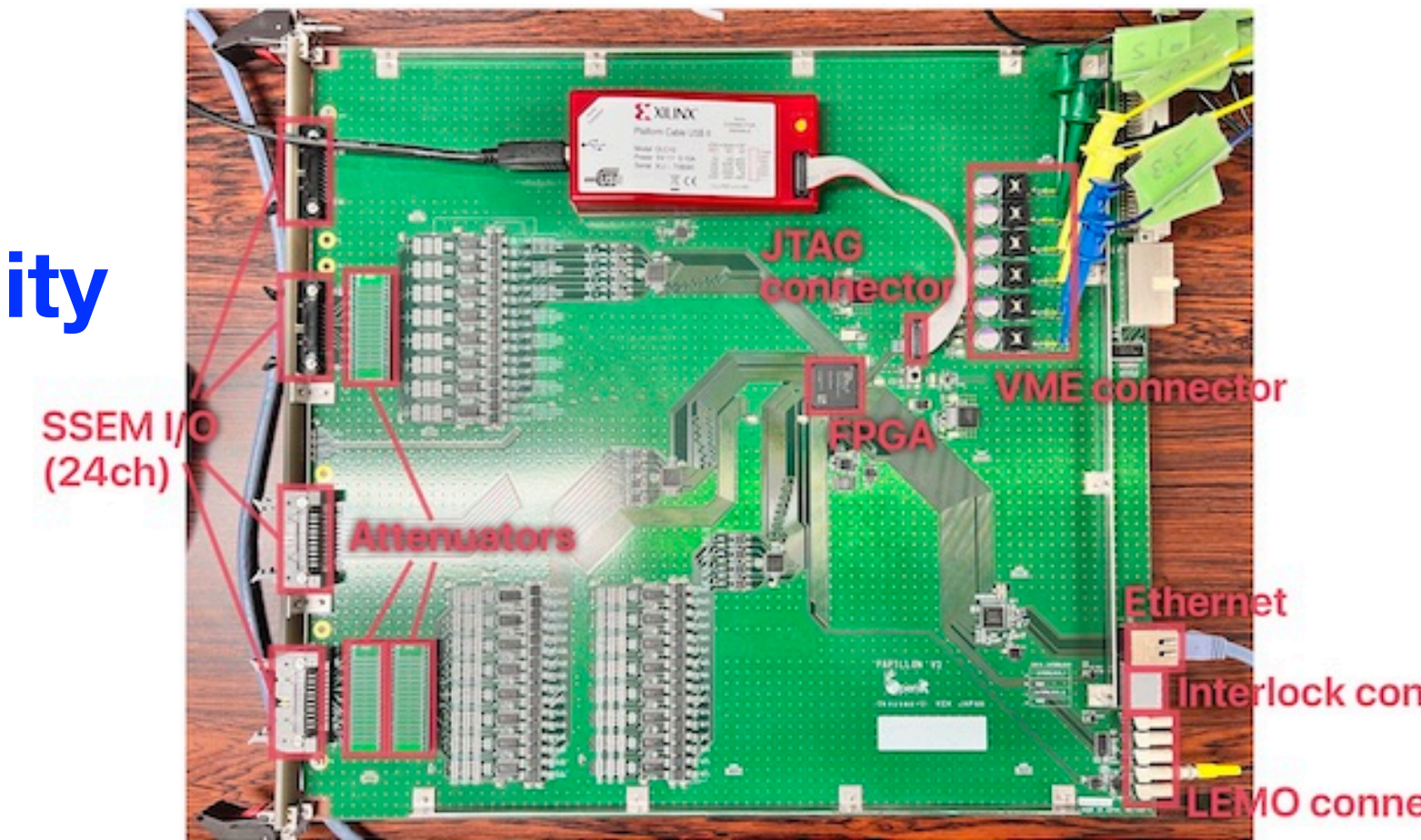
- Produced tritiated water is diluted and disposed at J-PARC neutrino facility
- Current limitation comes from capacity of dilution tank 84 m<sup>3</sup>
- Neutron irradiation to iron wall at TS He vessel
  - Large amount of tritium to be created (~5800 GBq/year @1.3 MW)
  - Contamination to cooling water is an issue
- Additional dilution tanks (2 x 253 m<sup>3</sup>) for 1.3 MW operation
- Construction of the new tanks completed in February 2022





- **Control/DAQ upgrade for 1 Hz operation**
  - Improve beam interlock system toward high intensity operation
  - **Upgraded system working well in recent runs**
- **Primary beamline Final Focusing Section upgrade for high maintainability**
  - Installed **new bending magnet** and rearranged beamline components
  - Semi-remote exchange system → To be upgraded to **full-remote system**
  - Development and installation to be done by FY2026

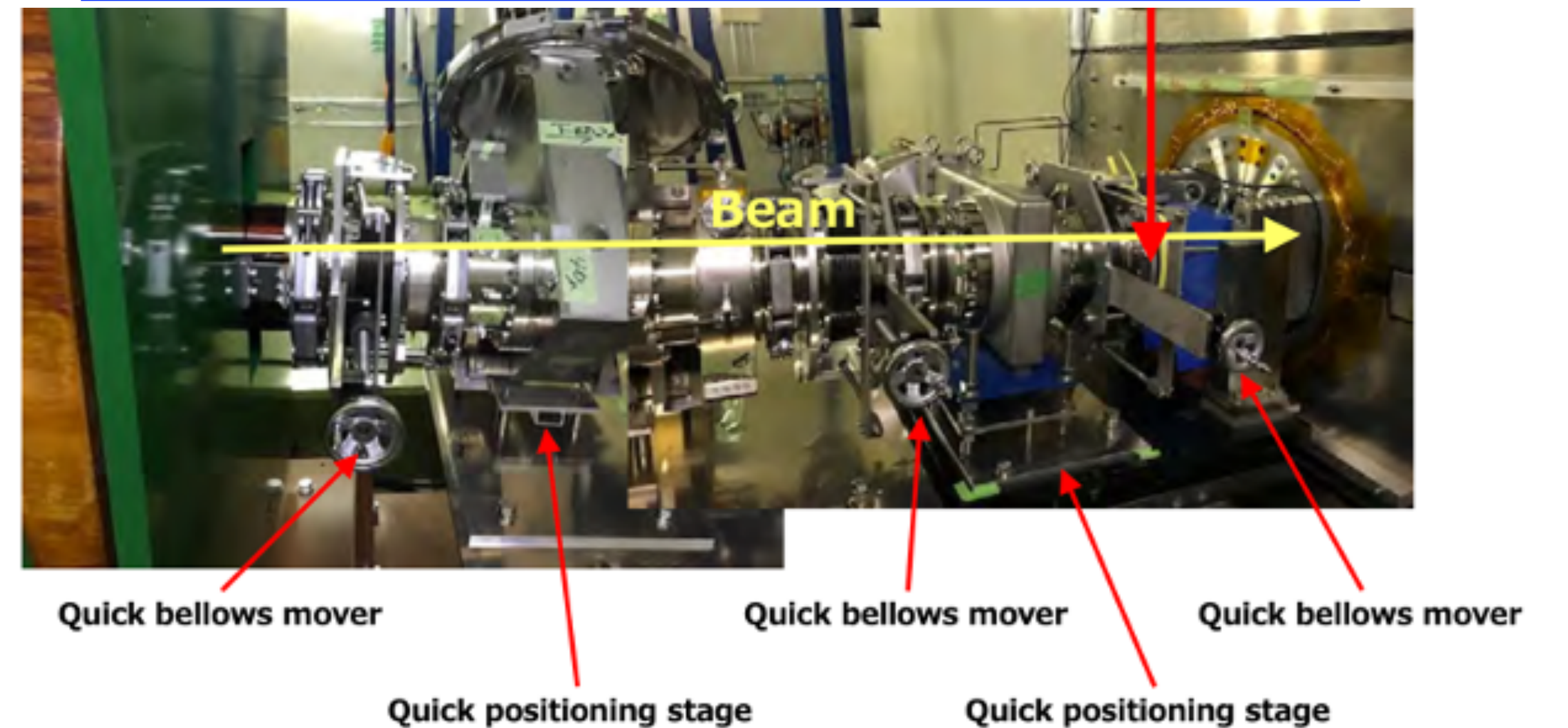
**New interlock electronics for beam position calculation**



**Installation of new bending magnet**



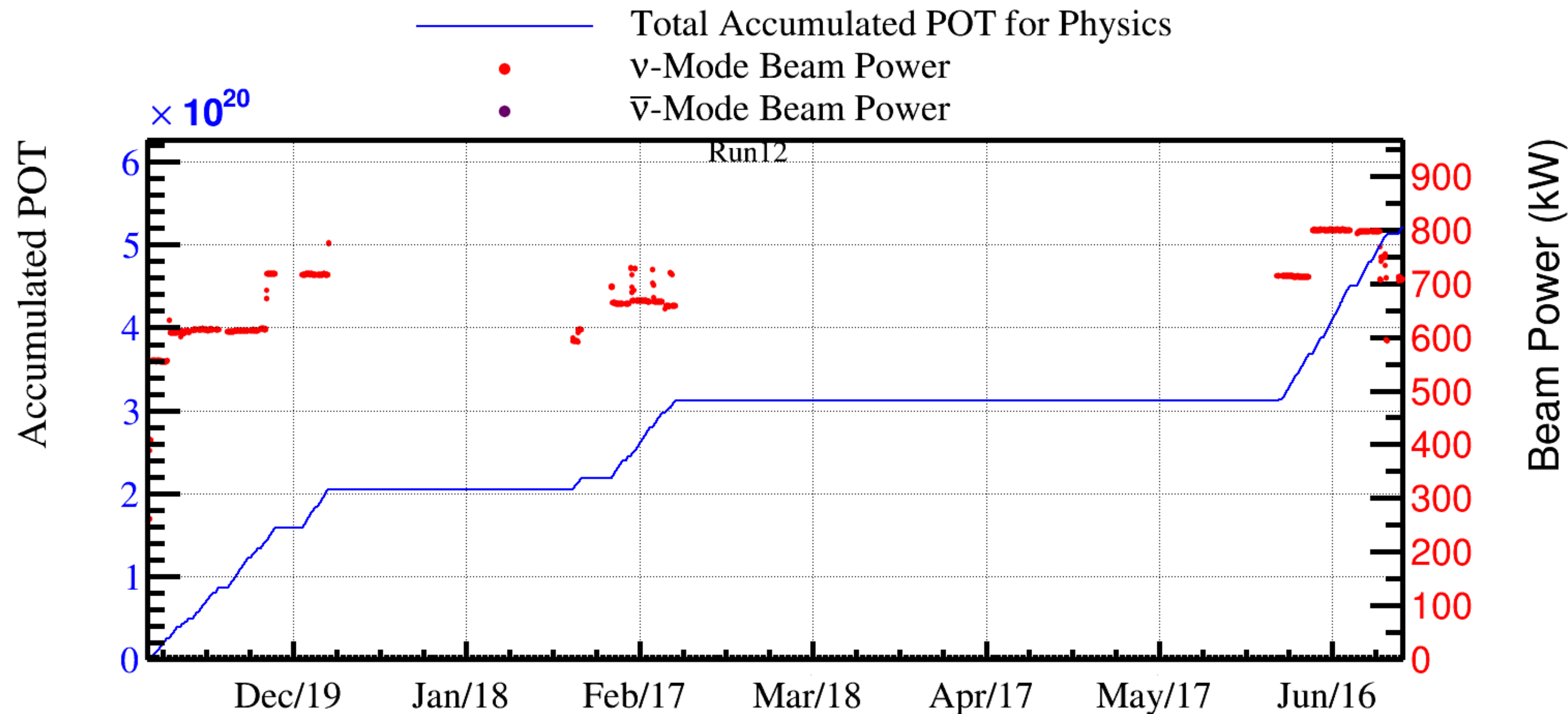
**Beam equipment requiring remote maintenance**



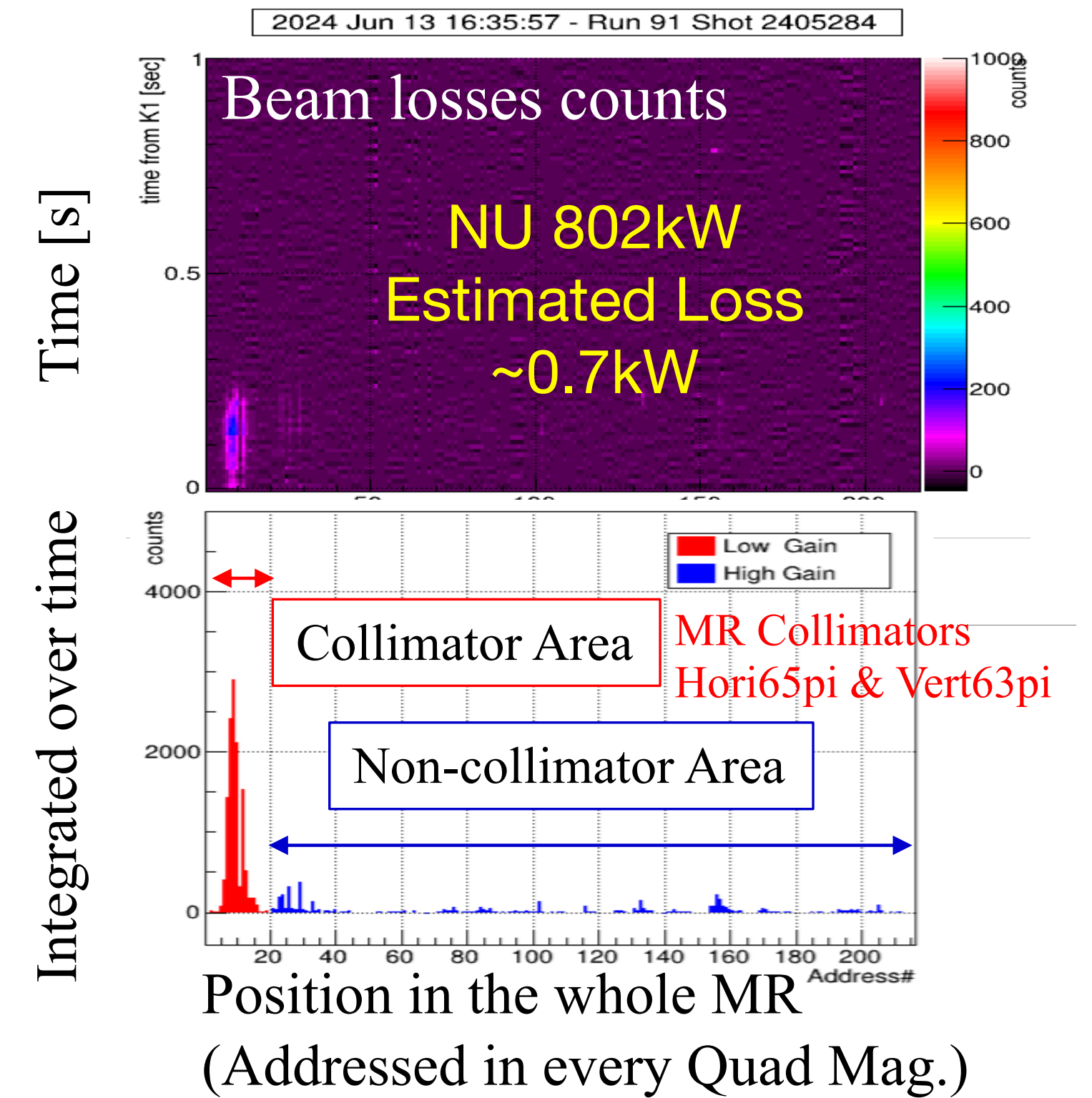


# Beam Operation After FY2021-2022 Upgrade

- **Beam operation for physics run resumed in Nov. 2023**
  - First physics data taking with **320 kA horn operation** → **10% more neutrinos** at SK
  - 710 kW stable operation in Nov.-Dec. 2023 run
  - **760 kW stable operation** successfully demonstrated on Dec. 25, 2023 (just for 40 minutes)
- **800 kW stable operation achieved in Jun. 2024 !**

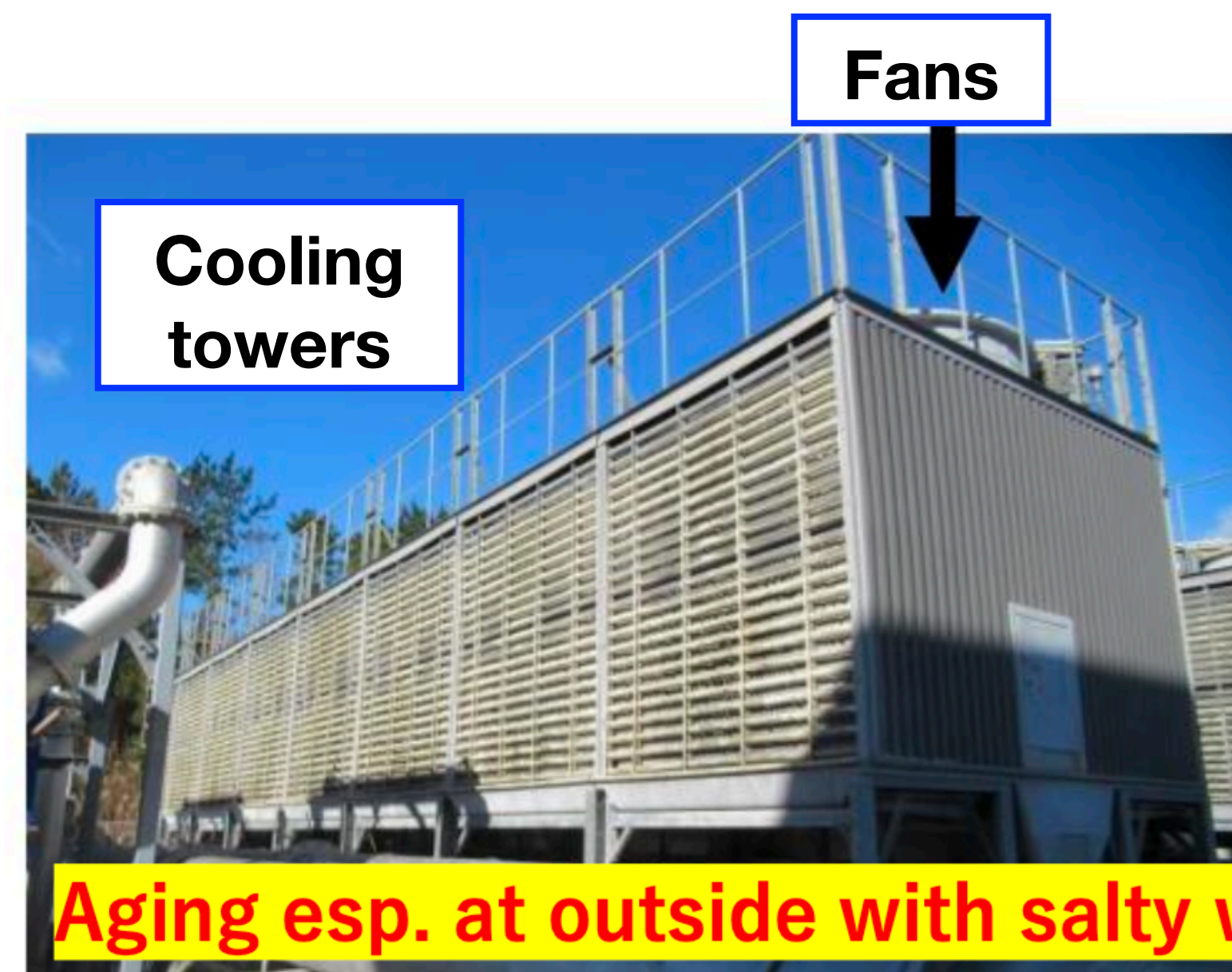


NU 802 kW ( $2.27 \times 10^{14}$  ppp) in 1.36 s cycle



- However,,,
  - Serious He compressor problem in neutrino beamline occurred in Feb. 2024
    - Part of the beam operation cancelled
  - Long-term large vibration caused break of plumbing → Similar problem occurred in 2017
  - Repairs and countermeasures have been implemented.
  - Problem on MR RF cooling system happened → Old equipments have been gradually broken
  - Part of the beam time cancelled
- **Maintenance or replacement of old equipments becomes a serious issue in J-PARC**
  - Now working on countermeasures for this issue

He compressor before installation in 2017



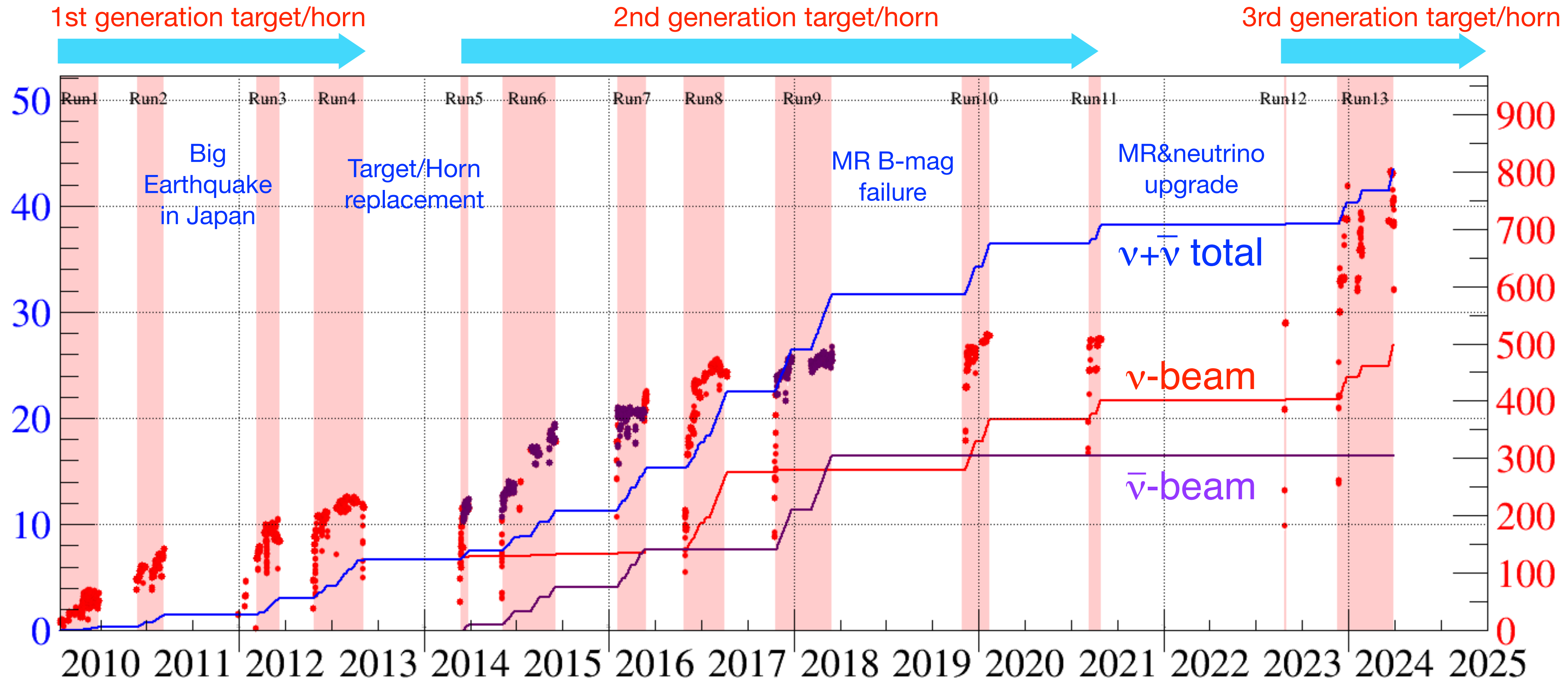


# Beam Operation History

Stable operation at 800 kW after MR PS upgrade achieved in Jun. 2024 run

Shown in lines

Accumulated POT ( $\times 10^{20}$ )



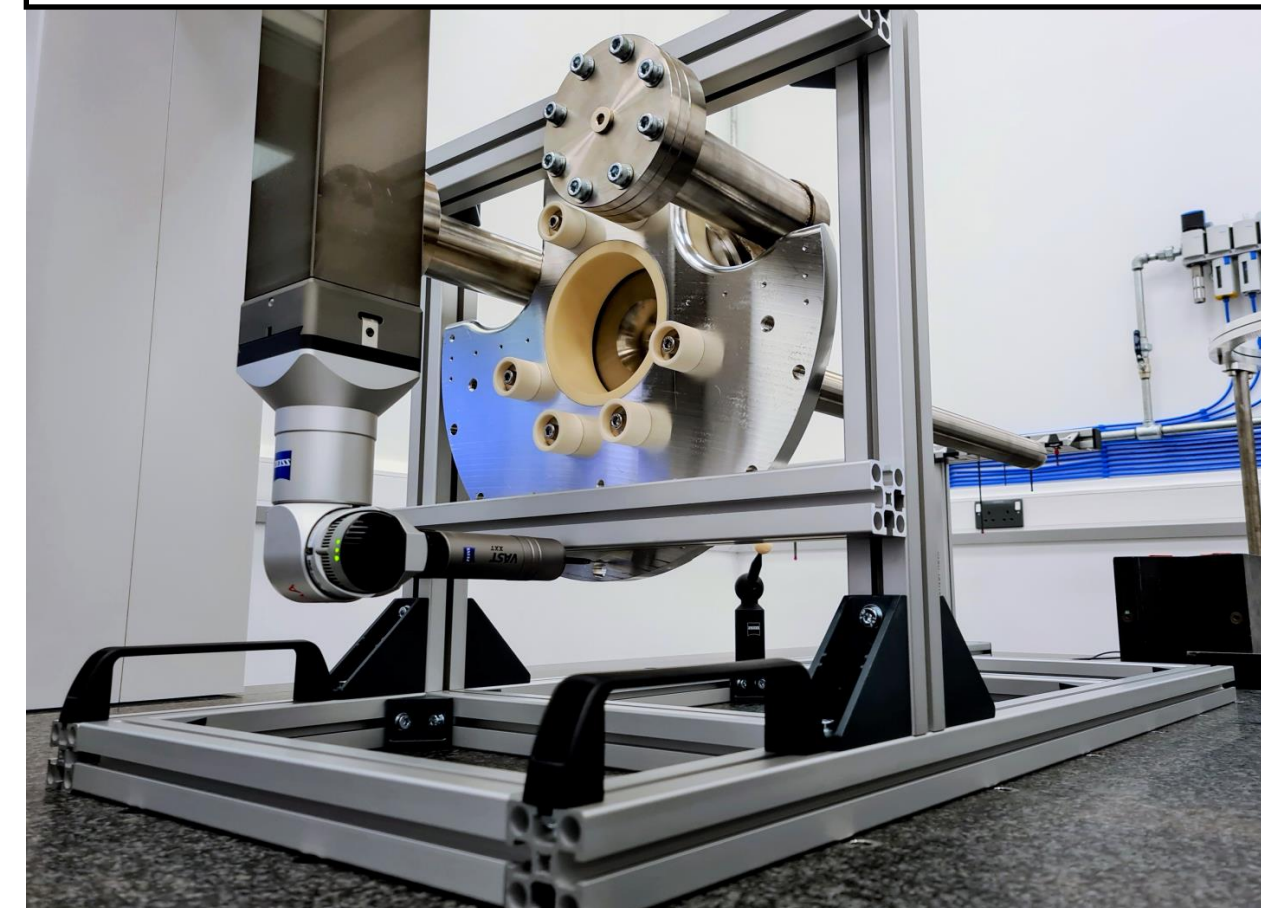
Shown in dots

Beam Power (kW)

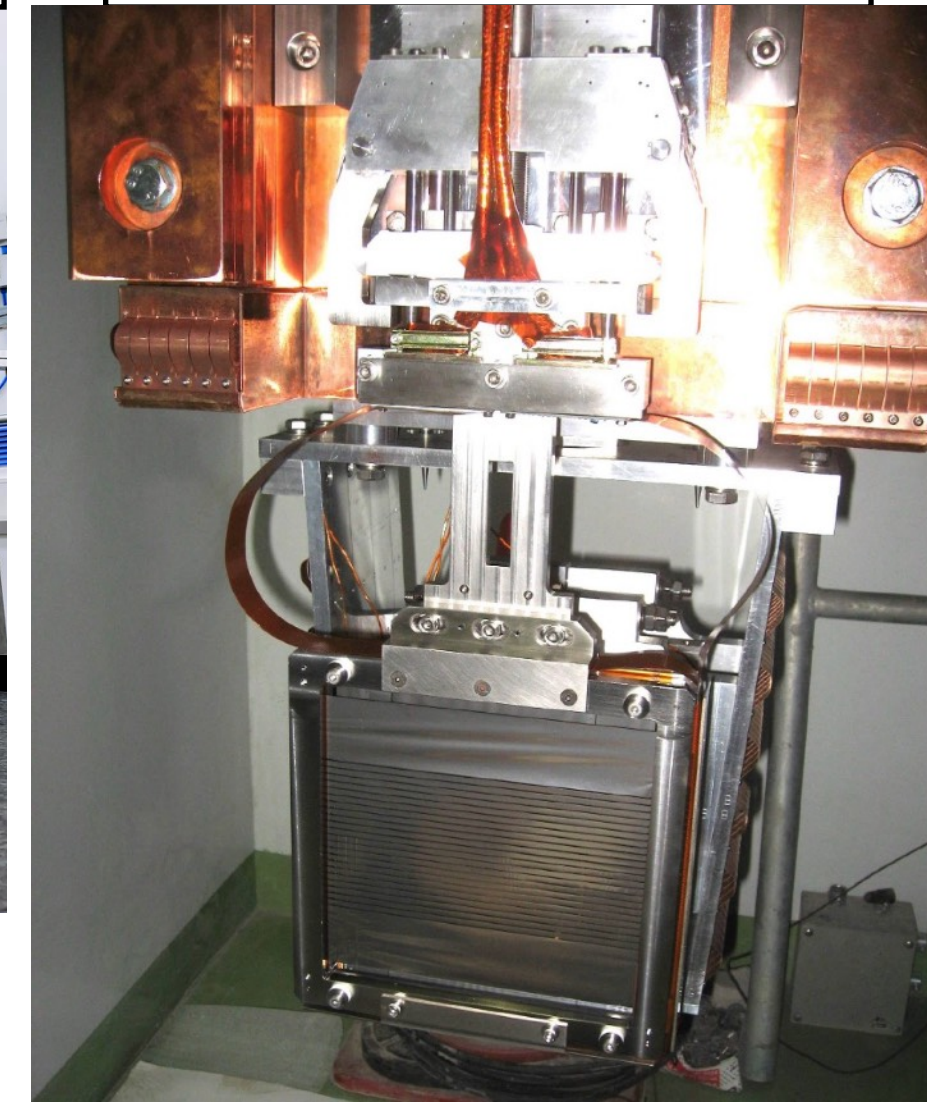
Total accumulated POT for T2K :  $4.35 \times 10^{21}$  POT (as of Jun. 2024)  $\rightarrow$   $1.0 \times 10^{22}$  POT (T2K goal)  
c.f.,  $2.7 \times 10^{22}$  POT (HK 10-years)

- **Remaining major upgrades**
  - **SSEM19 replacement to be completed soon (FY2024)**
  - **Beam window replacement (FY2025)**
  - **Target (FY2026)**
    - New He compressor installation
    - 1.3 MW prototype target installation
  - **Cooling system upgrade for Secondary beamline (FY2026)**
  - **Full remote maintenance of Primary Beamline Final Focus section (FY2026)**
- **Spare Horn production**
  - Horn3(v3) production completed
  - Horn1(v4) production completed at Colorado (USA)
  - Horn2(v4) production to be started at Colorado (USA)

1.3 MW prototype target by RAL



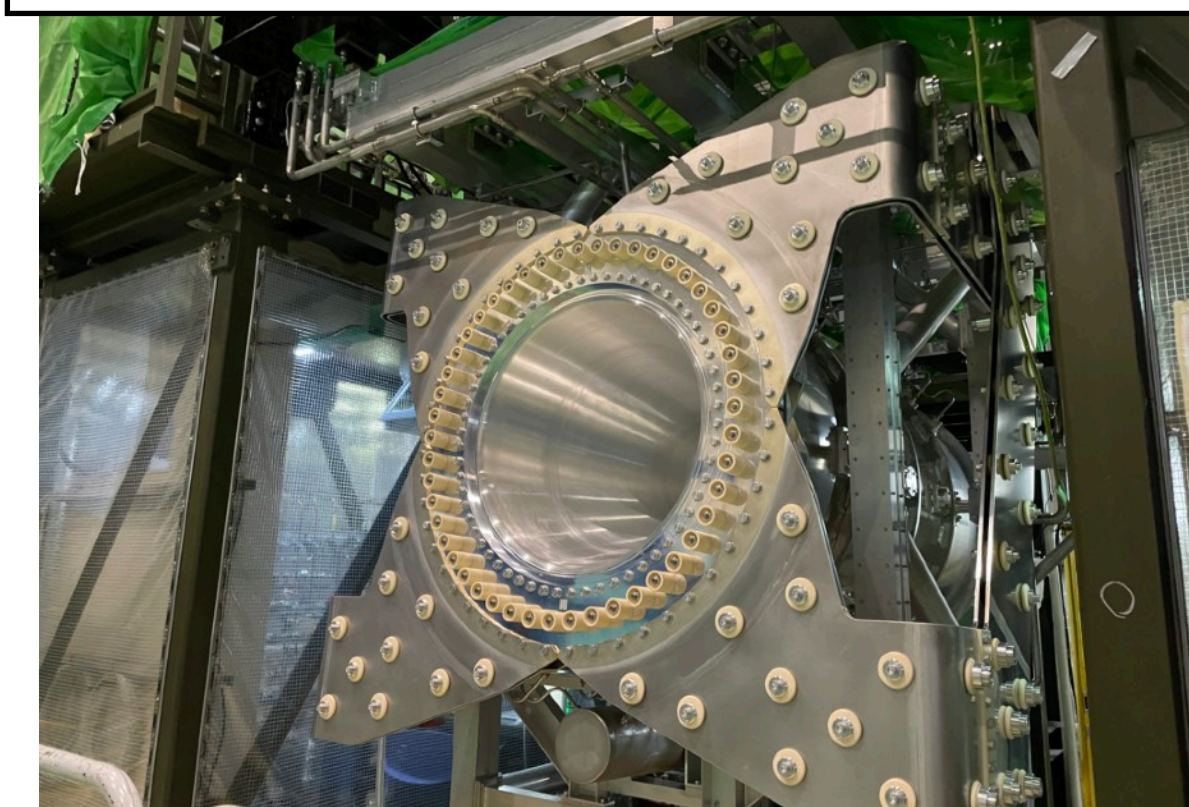
SSEM replacement



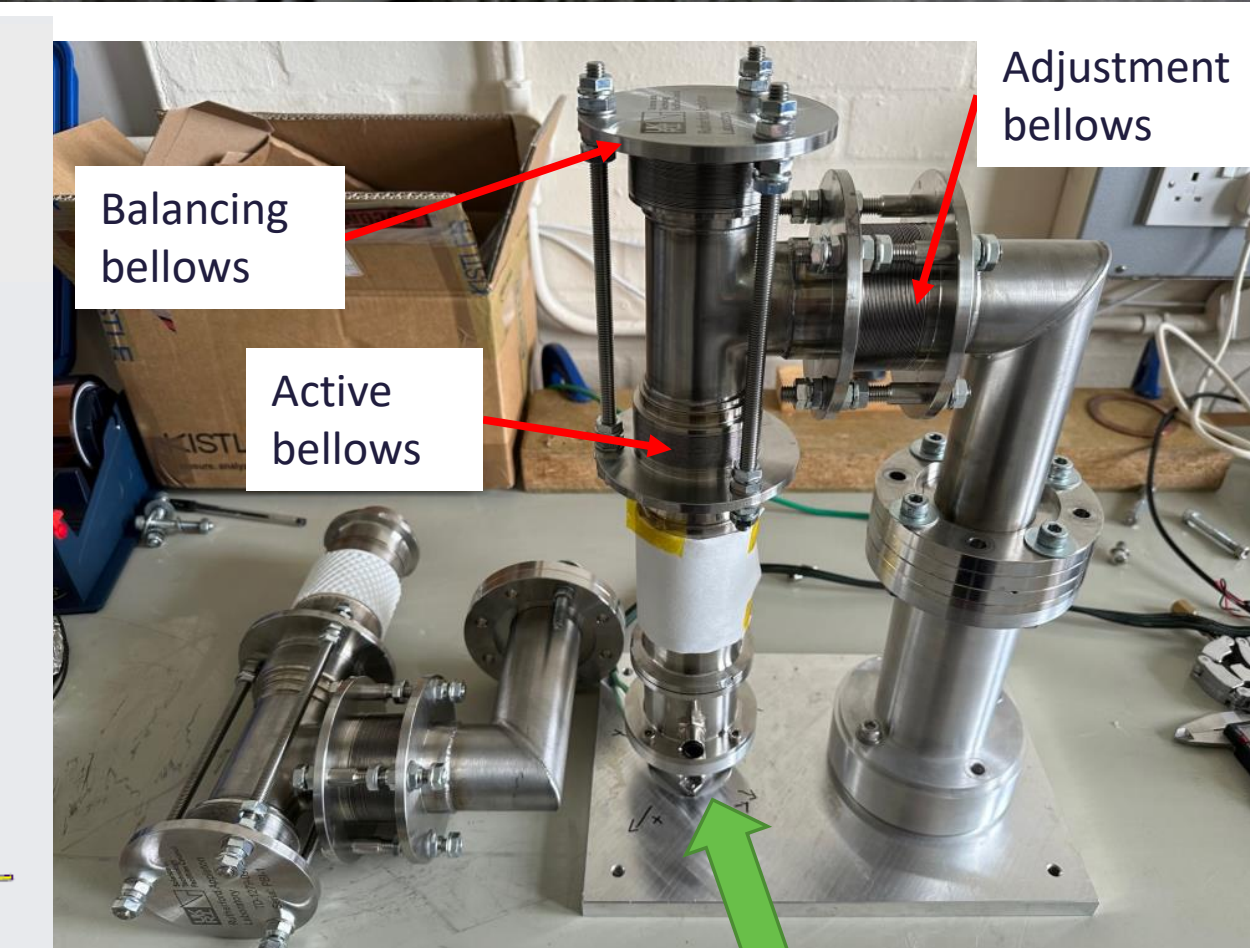
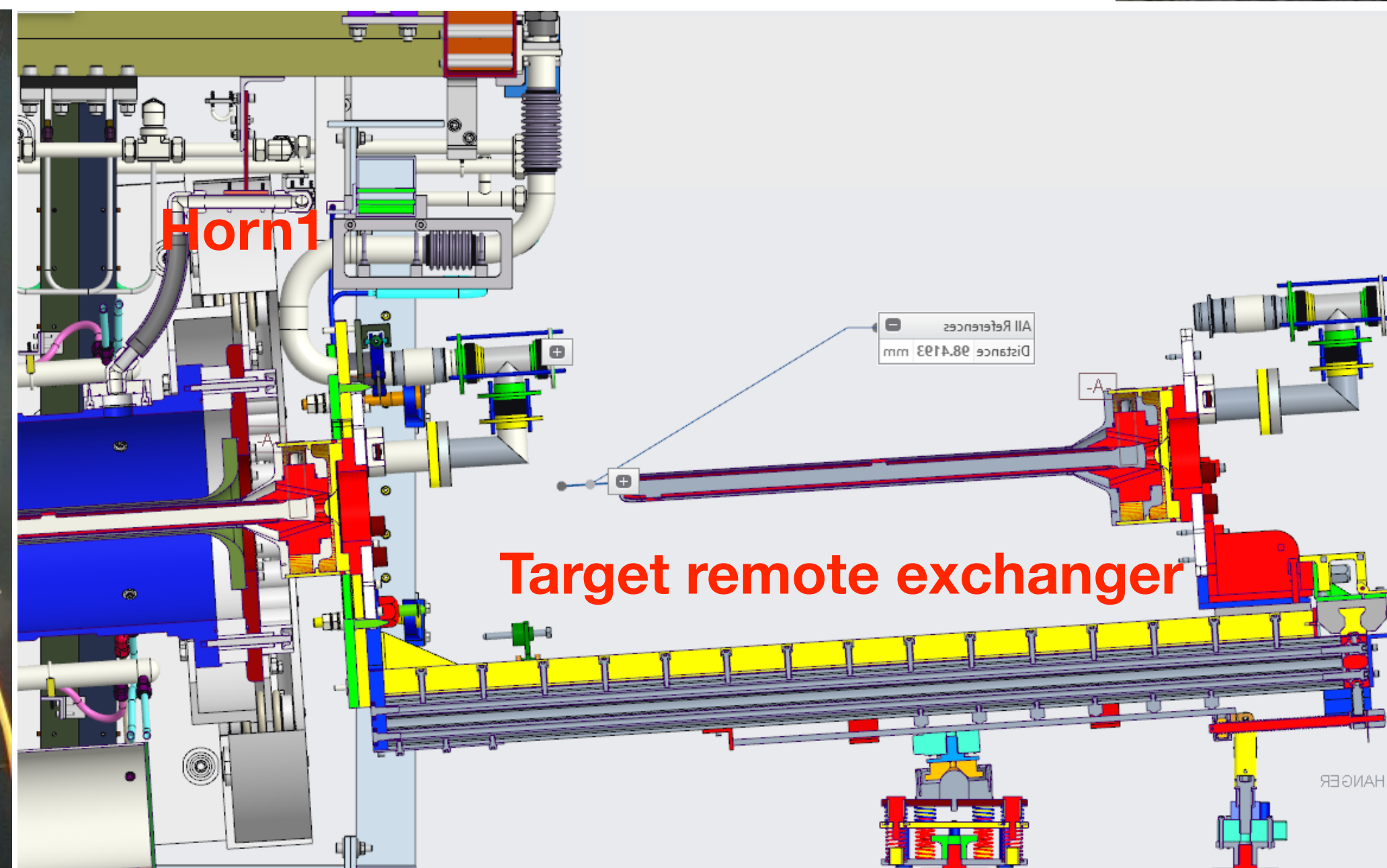
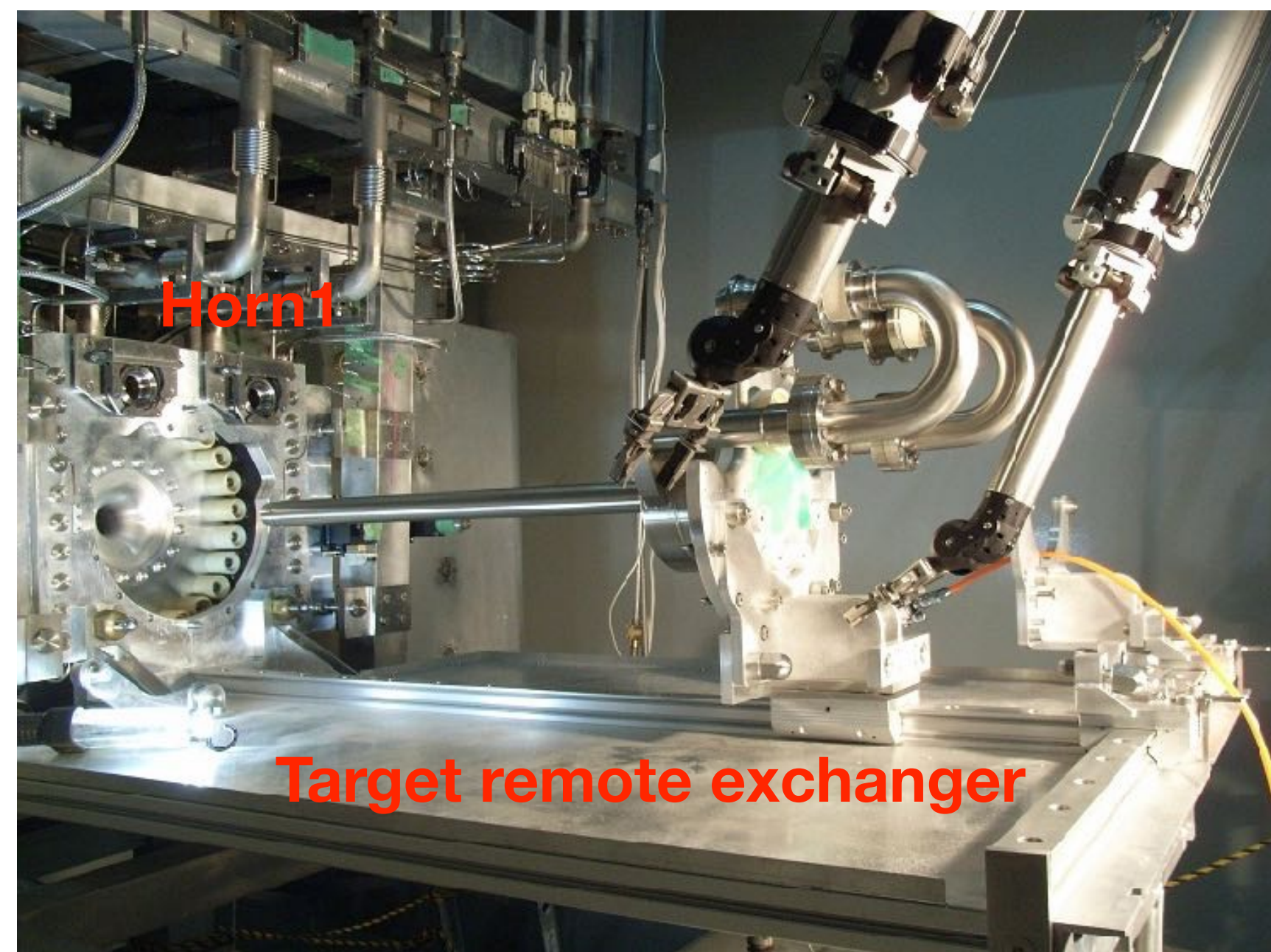
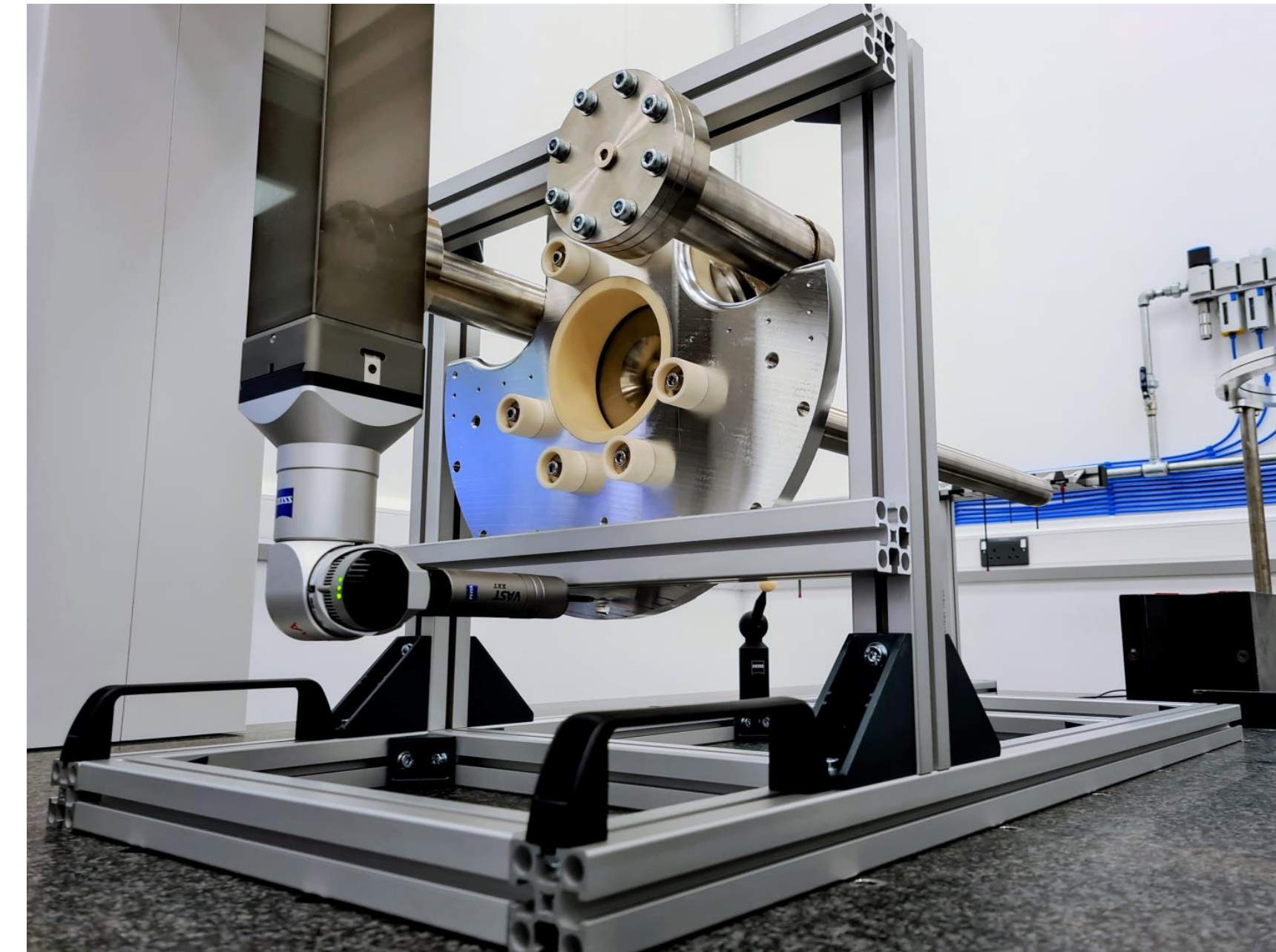
Horn1 assembly at Colorado



Horn3 current test at J-PARC



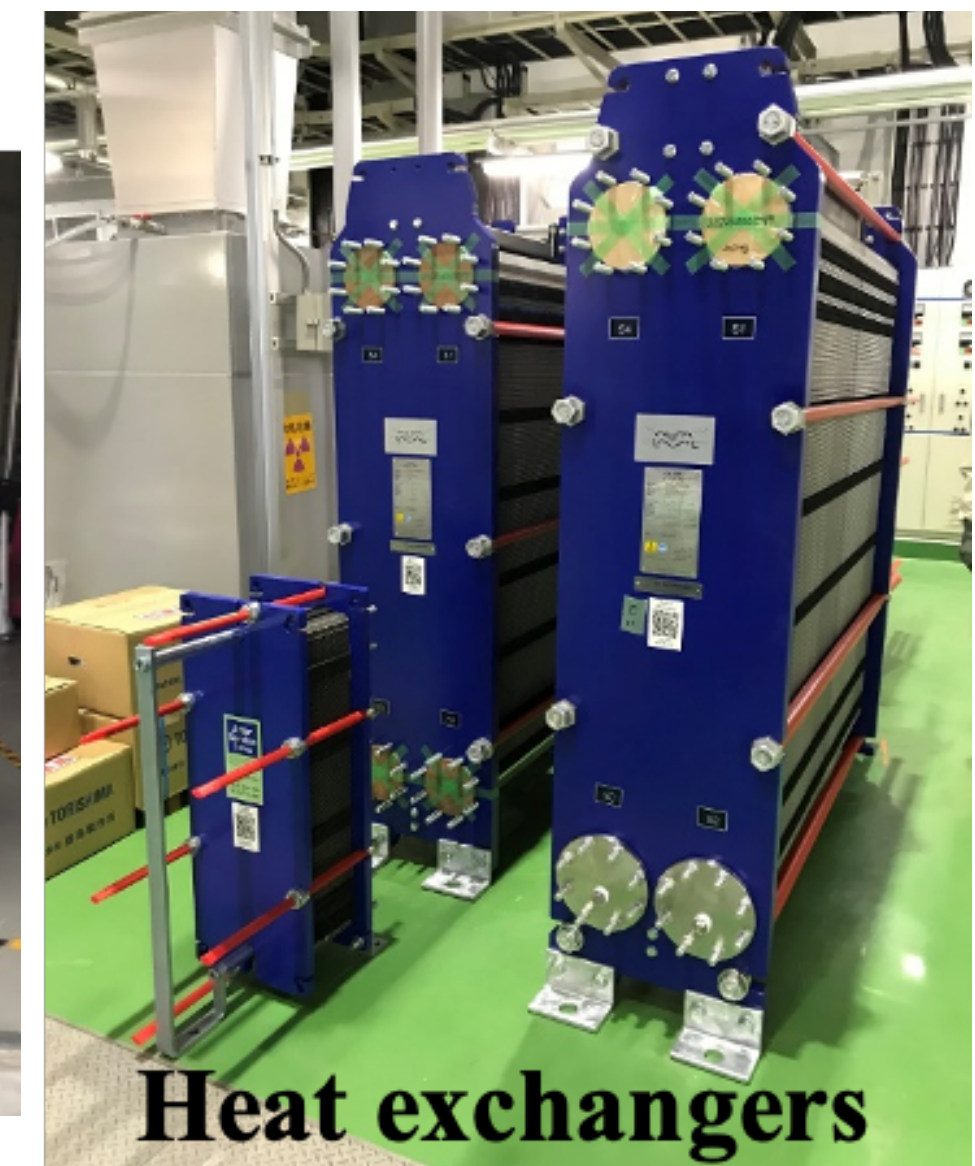
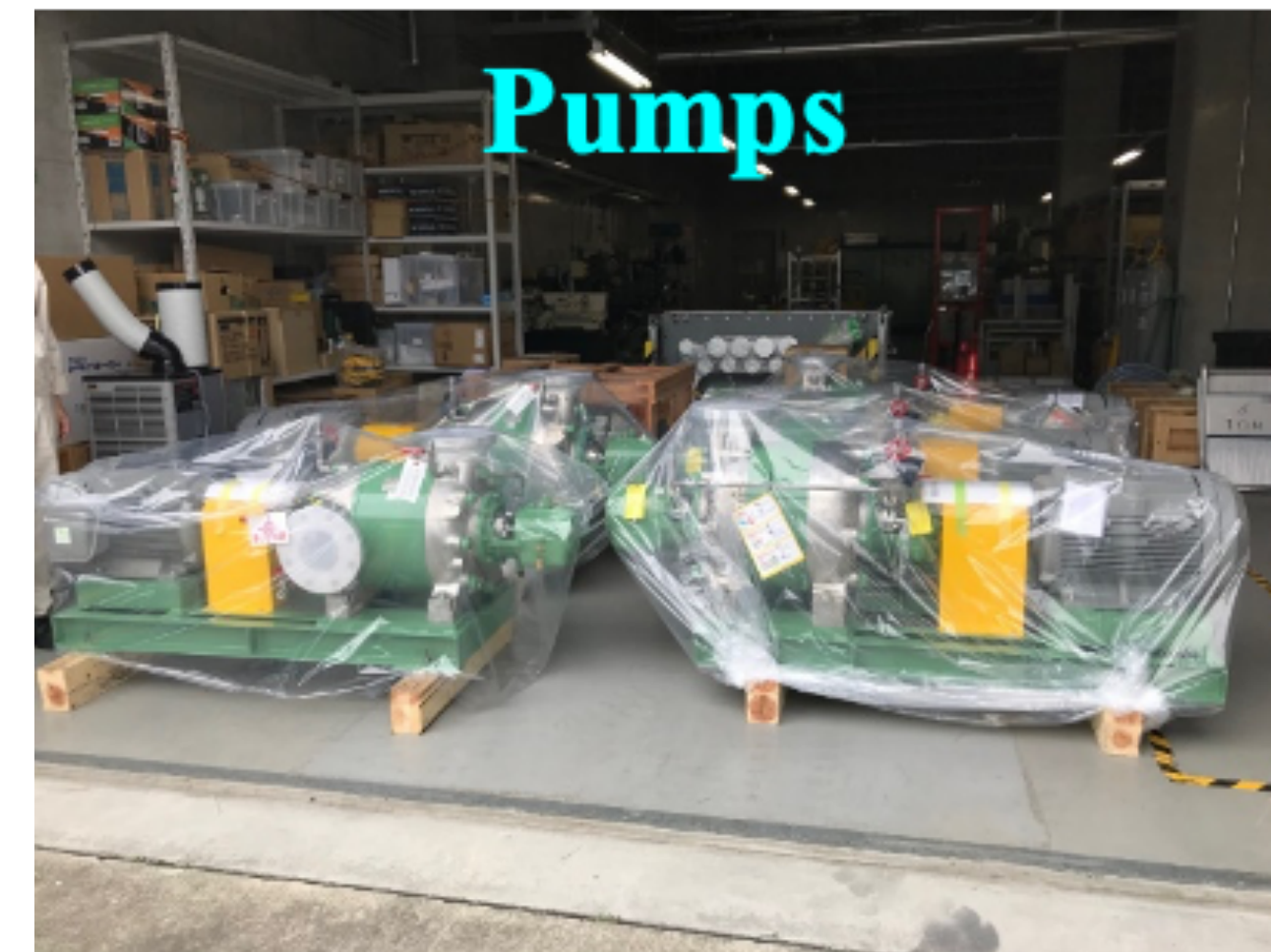
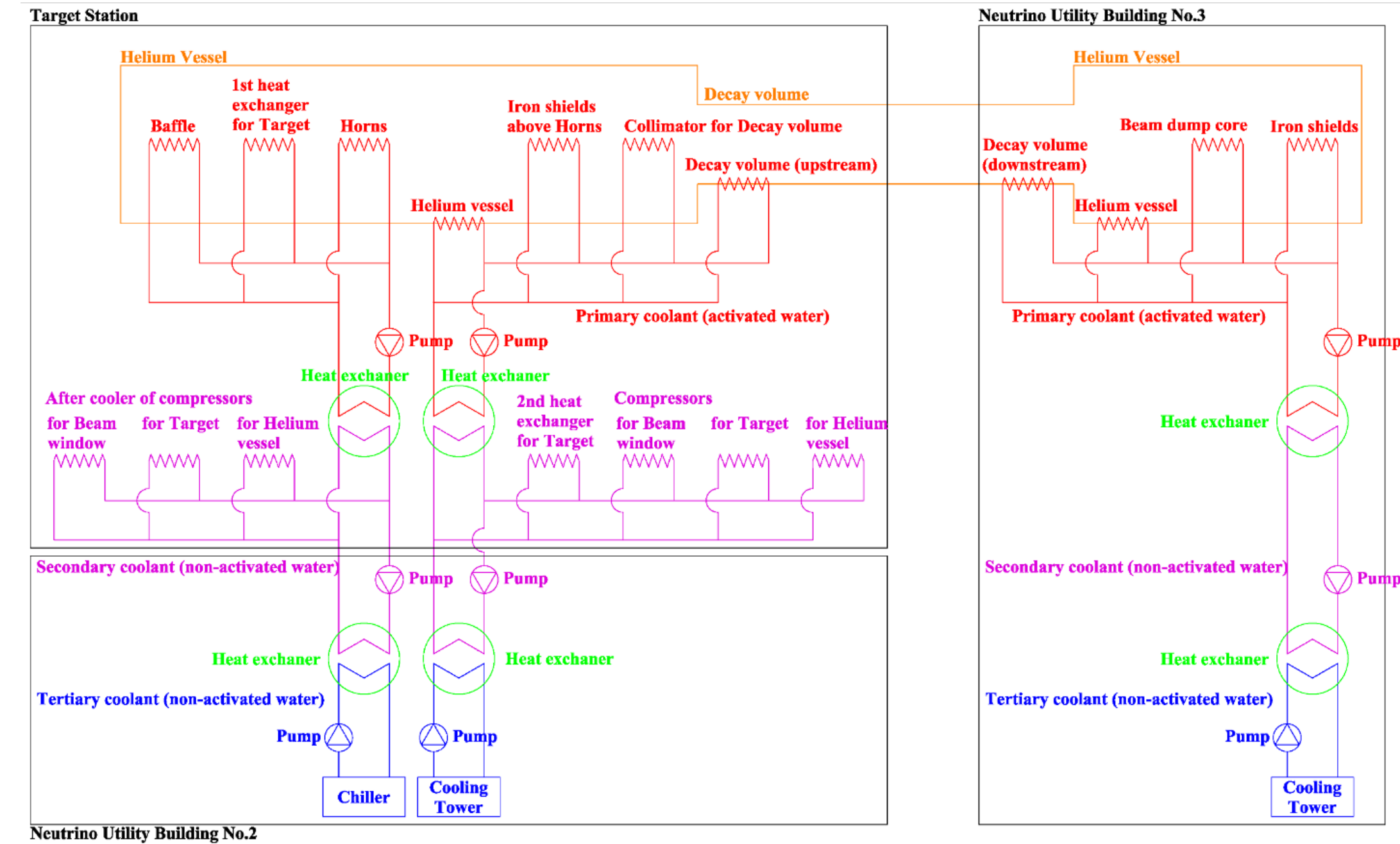
- **1.3 MW prototype target successfully produced by RAL group**
  - Can be used for beam operation
- **Target installation will require a full remote exchange**
  - We will still use 3rd horn1 for HK era
- **A full remote target exchange system has been developed**
- **To be installed in FY2026**



**Developed target He tube to mitigate stress by thermal expansion**

- He vessel, DV, BD designed for 3-4 MW beam
- **Need to increase flow rate and heat removal capacity**
- **Upgrade items**
  - Replacement of pumps and heat exchangers
  - Reinforcement of chillers and cooling towers
- **Status and plan**
  - Pumps and heat exchangers already produced (FY2022)
  - Production of chillers and cooling towers (FY2025)
  - Installation (FY2026)

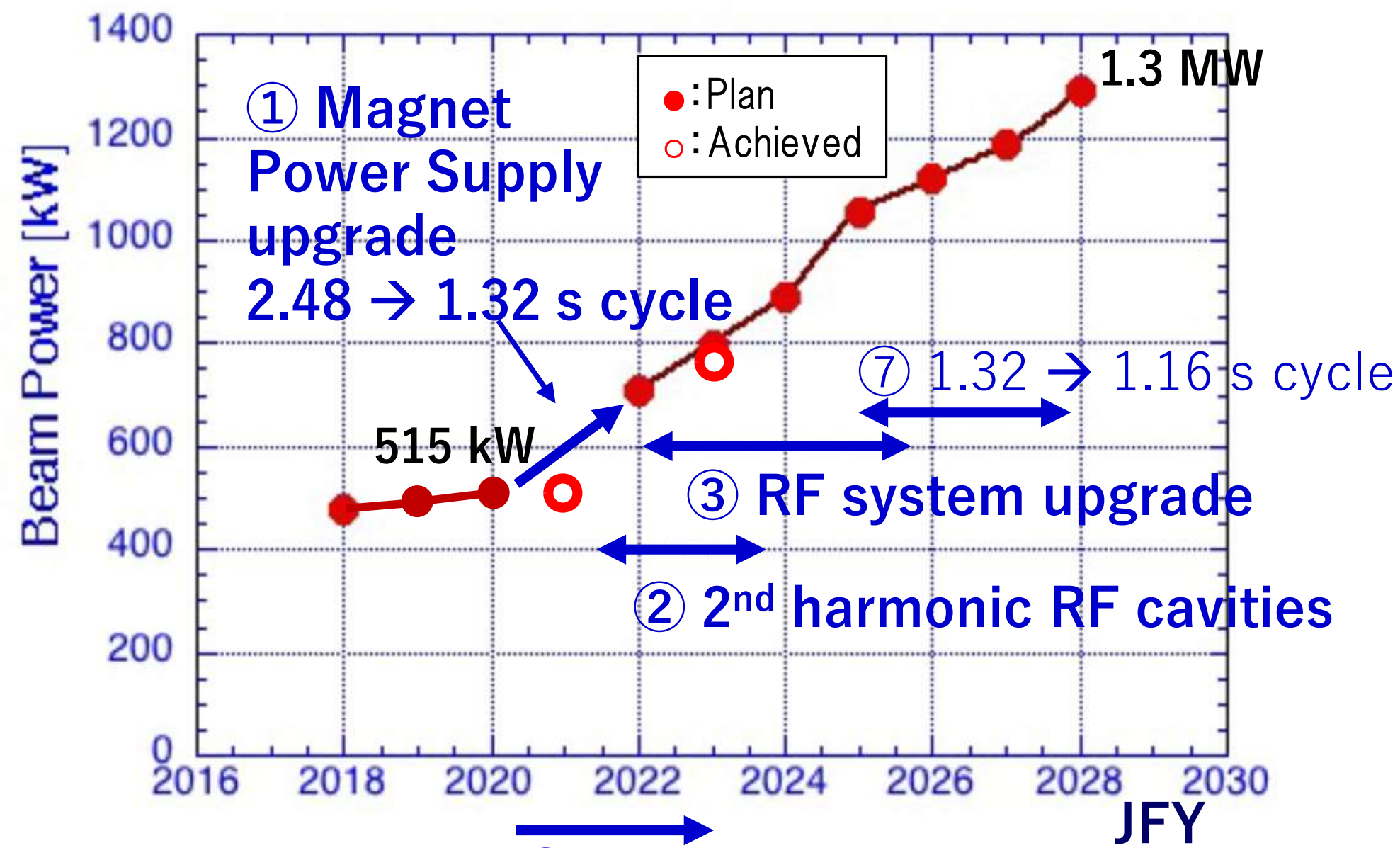
Schematic diagram of water cooling system





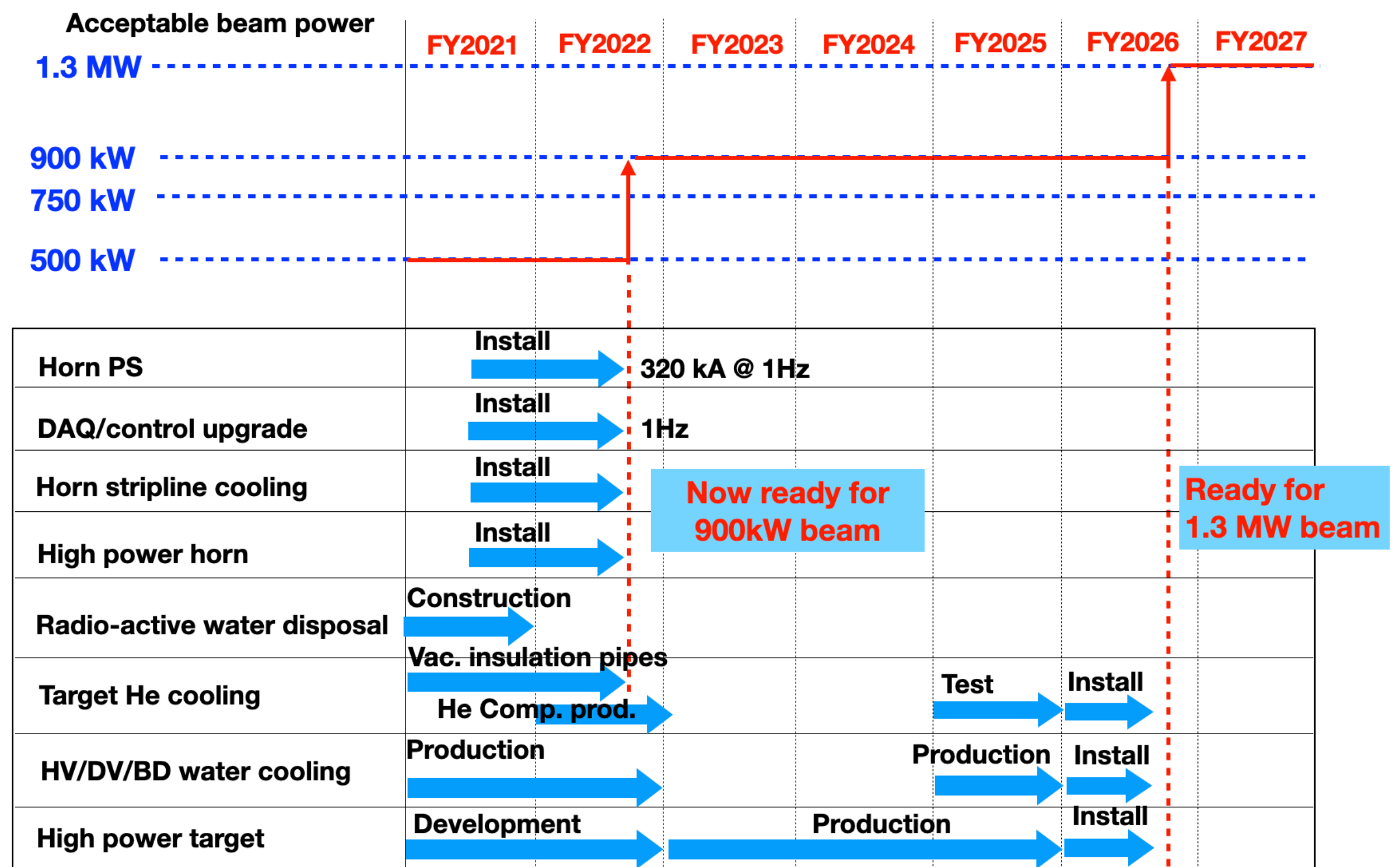
# Timeline for Neutrino Beamline Upgrade

- Both hardware upgrade and beam operation are important
  - Beamline should be ready to take beam for more than 4 months/year for T2K operation
- Second major upgrade planned in FY2026
  - 8 months shutdown required for the remaining upgrades
- Beamline will be ready for 1.3 MW after FY2026 ⇒ J-PARC accelerators aim to achieve 1.3 MW by FY2028



- ④ Collimator system
- ⑤ Injection/FX system
- ⑥ Beam Monitors (BPM circuits)

S. Igarashi, *et. al.*,  
PTEP vol 2021,  
Issue.3,p33







- J-PARC neutrino beam for CP violation search in lepton sector
- J-PARC accelerator and neutrino beamline upgrade toward 1.3 MW ongoing
  - MR upgrade toward 1.3 MW by 2028
  - 1st stage major upgrade completed in FY2021-2022
  - 2nd stage major upgrade in FY2026
- All the upgraded systems are working very well at 800 kW operation
- Working on countermeasures for aging of old equipments