

A detailed 3D cutaway rendering of a magnetic horn system, a key component of a neutrino beamline. The structure is complex, featuring multiple cylindrical sections, support frames, and intricate piping. A bright orange-red beam of light is shown passing through the central axis of the horn, illustrating its function in focusing particles. The background is a light blue gradient.

Significant upgrades of magnetic horn system for J-PARC neutrino beamline towards 1.3 MW beam power

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- Overview
- Horn Upgrade
 - Horn PS upgrade
 - Replacement with high power horn
 - Operation status
- Summary



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



- **Search for CP violation in lepton sector**

- T2K (~2027) : **hint of CPV ($\sim 2\sigma$)** \Rightarrow Hyper-K (2027~) : **discovery of CPV ($>5\sigma$)**

- **High statistics measurement with**

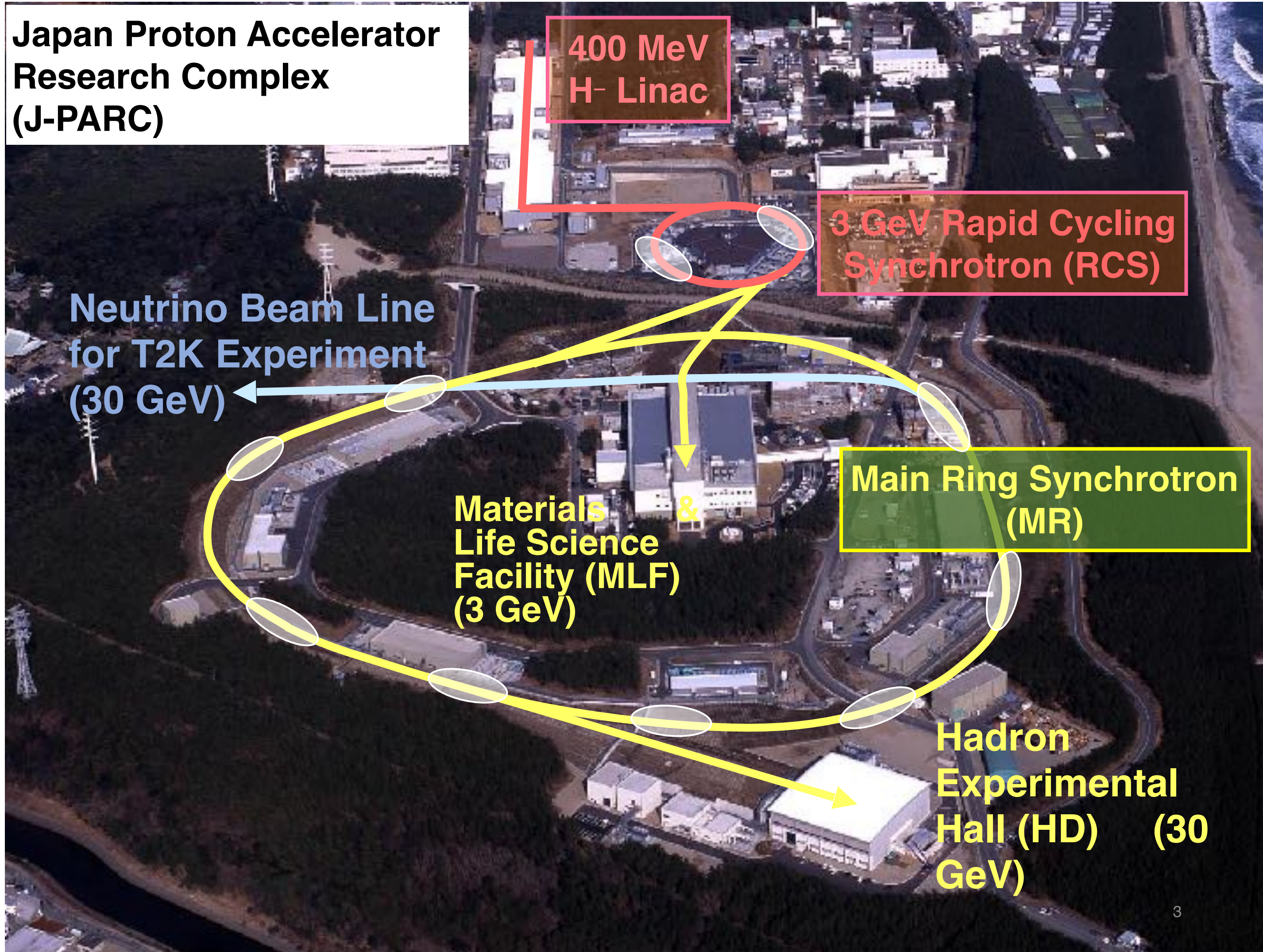
- **~ 8 x larger new detector**

- **High power neutrino beam over 1MW**

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

↓
Beam power

↓
Detector volume

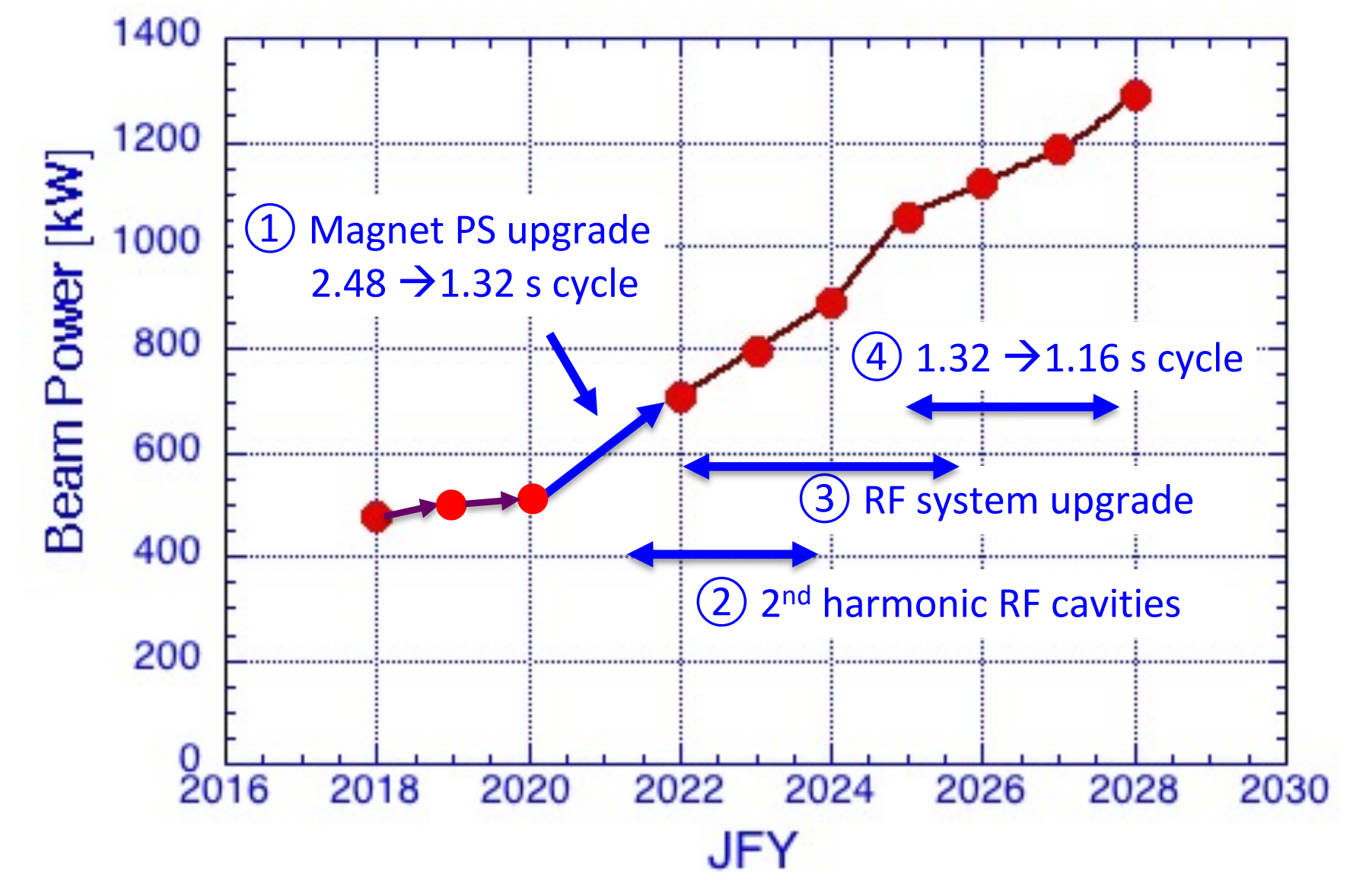


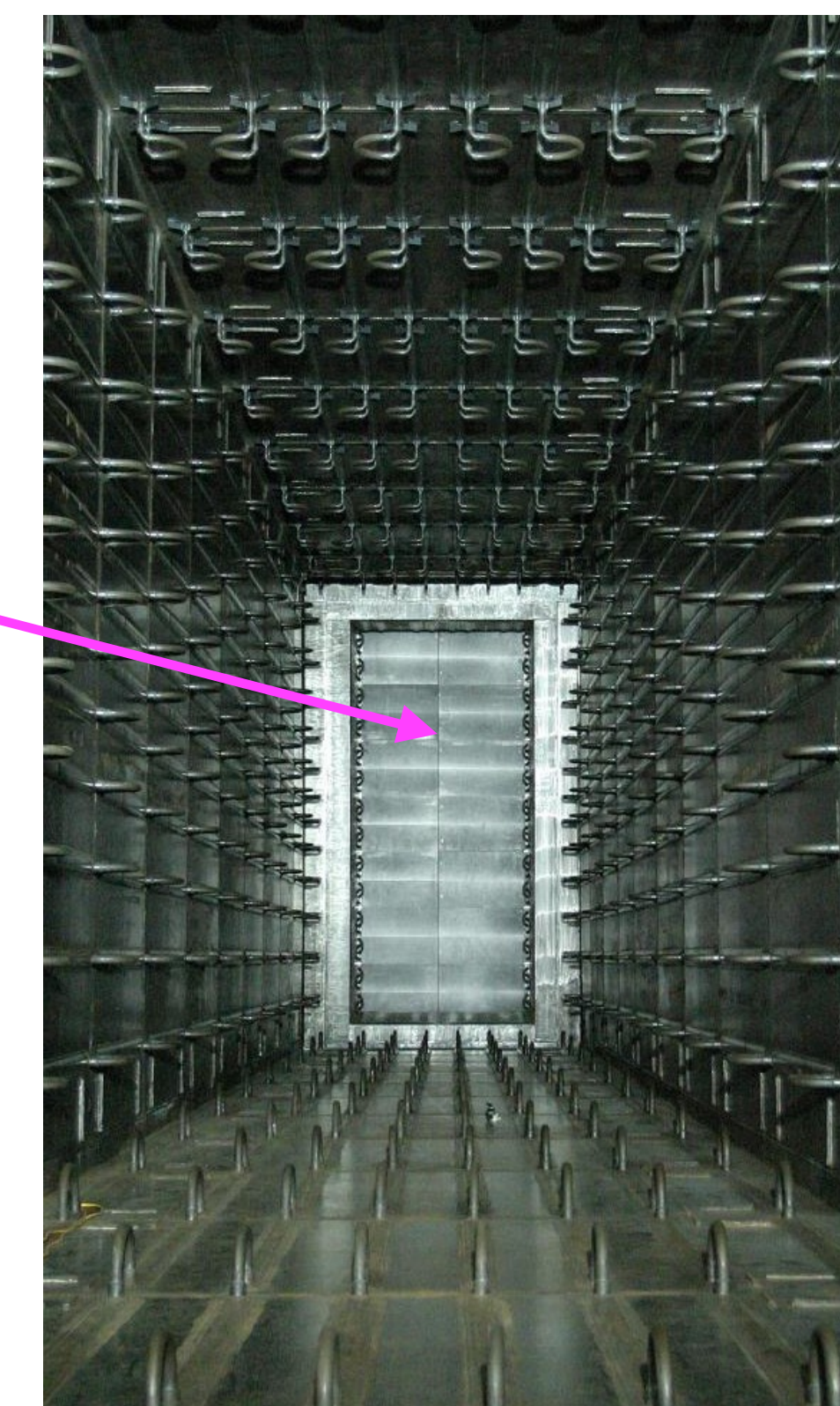
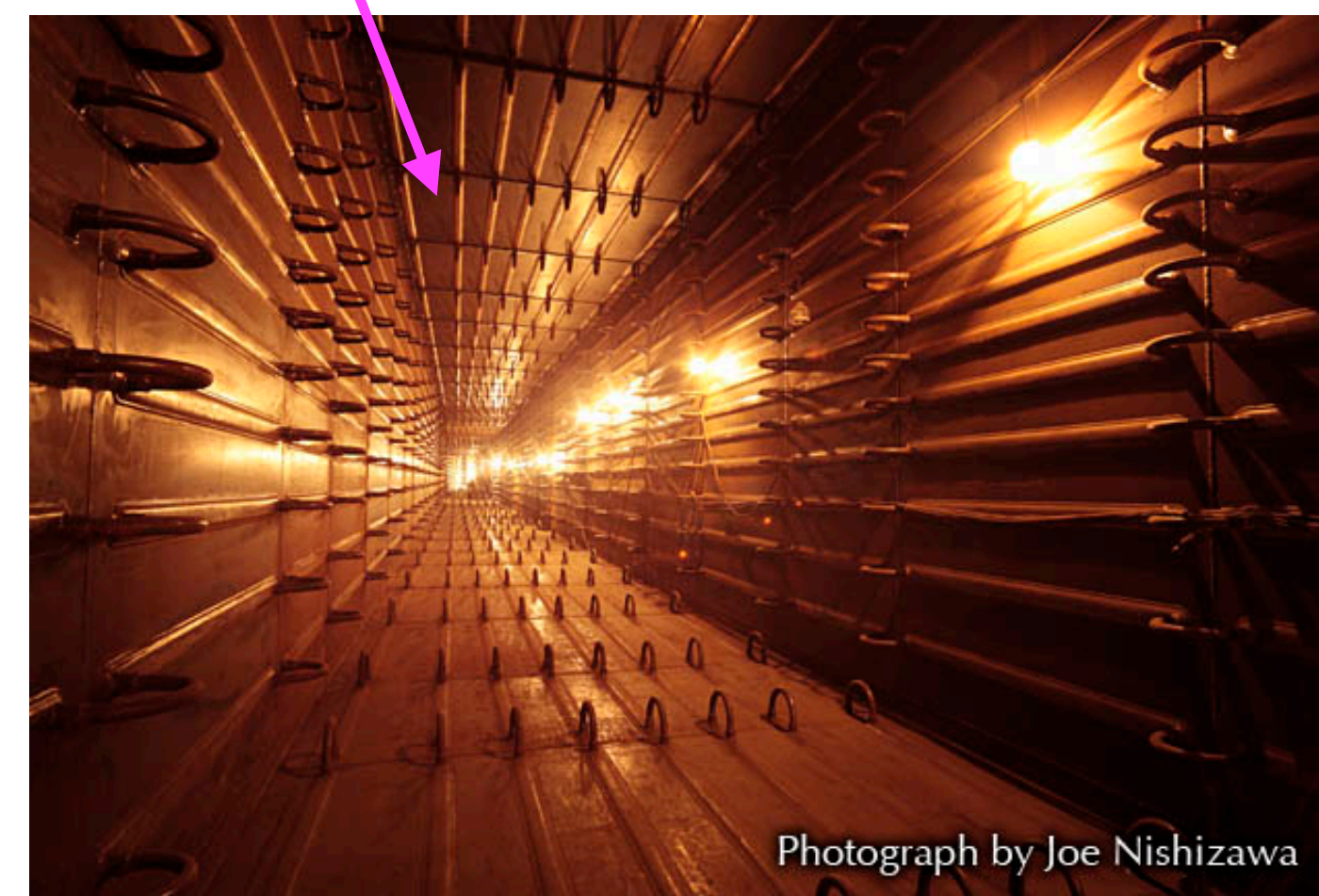
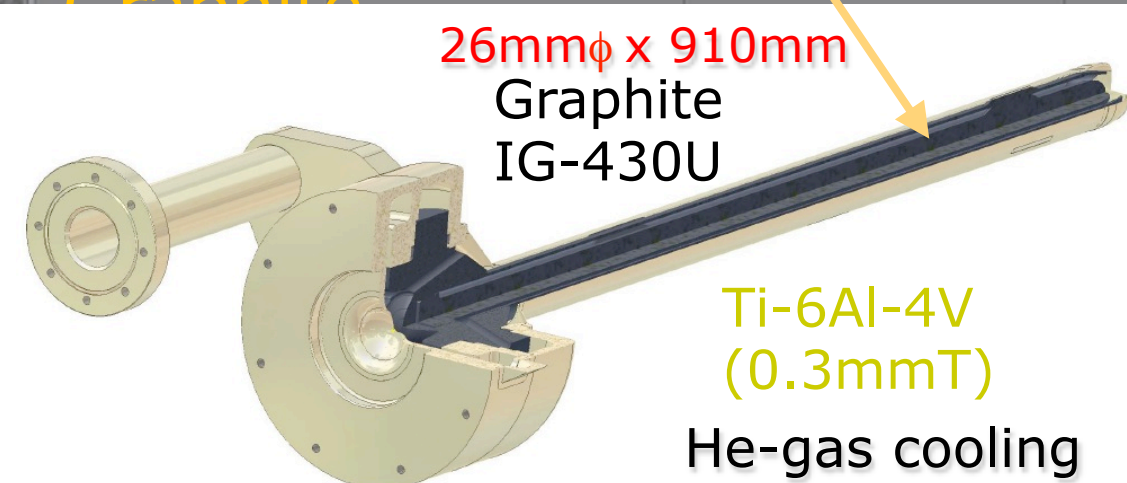
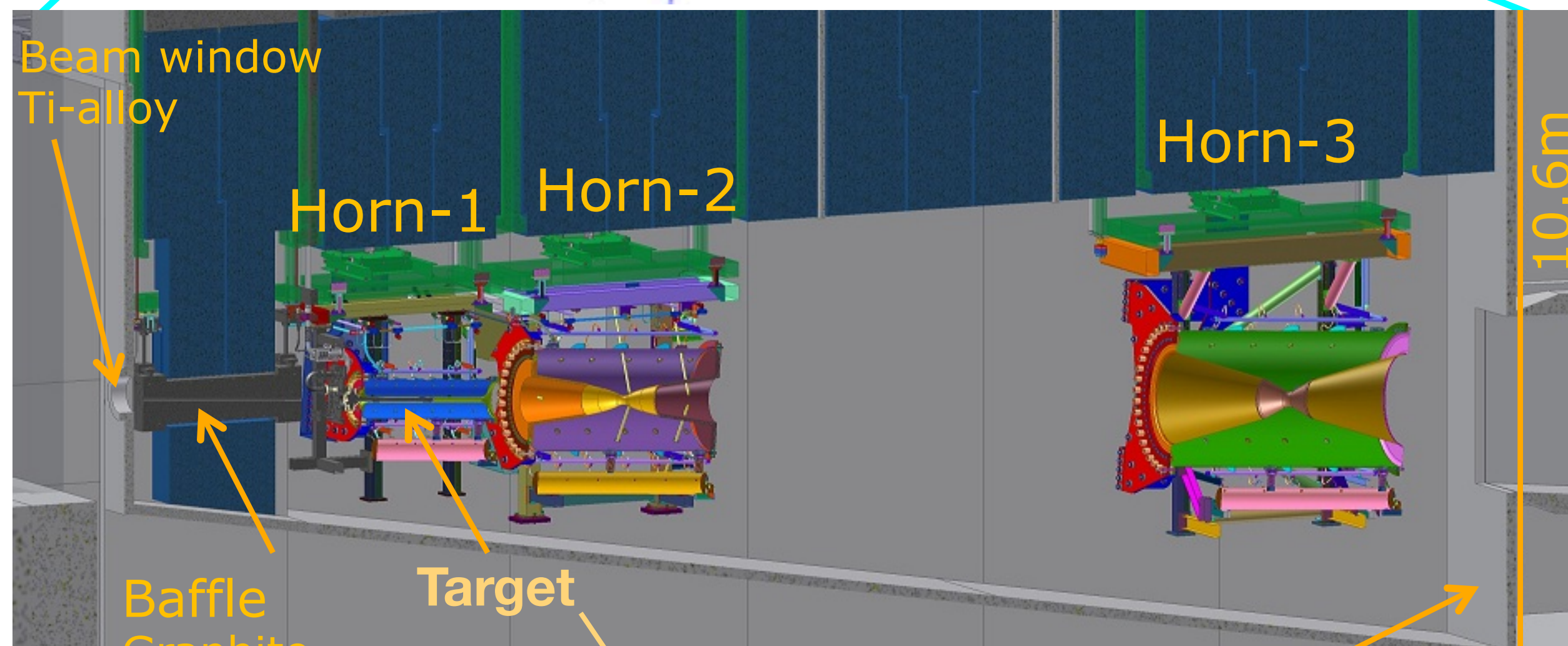
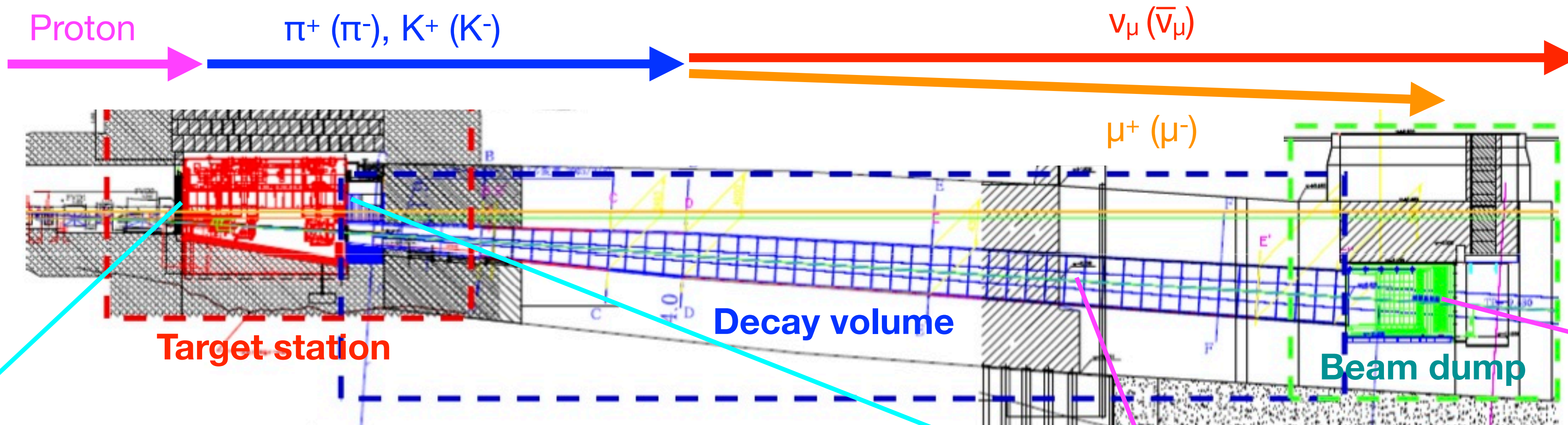
MR upgrade (500 kW → 1.3 MW)

- Faster cycle (2.48 → 1.16 s) : MR PS upgrade
- More protons per pulse : MR RF upgrade

Neutrino beamline will also be upgraded

	Before upgrade	After upgrade
Beam power [MW]	0.5	1.3
Proton intensity [10^{14} /pulse]	2.6	3.2
Cycle [s]	2.48	1.16





- Target and three horns inside TS He vessel
- 100m-long Decay Volume
- Beam dump at most downstream of DV

Magnetic horns intensify neutrino beam by a factor of 15

- **Aluminum conductors (A6061-T6)**

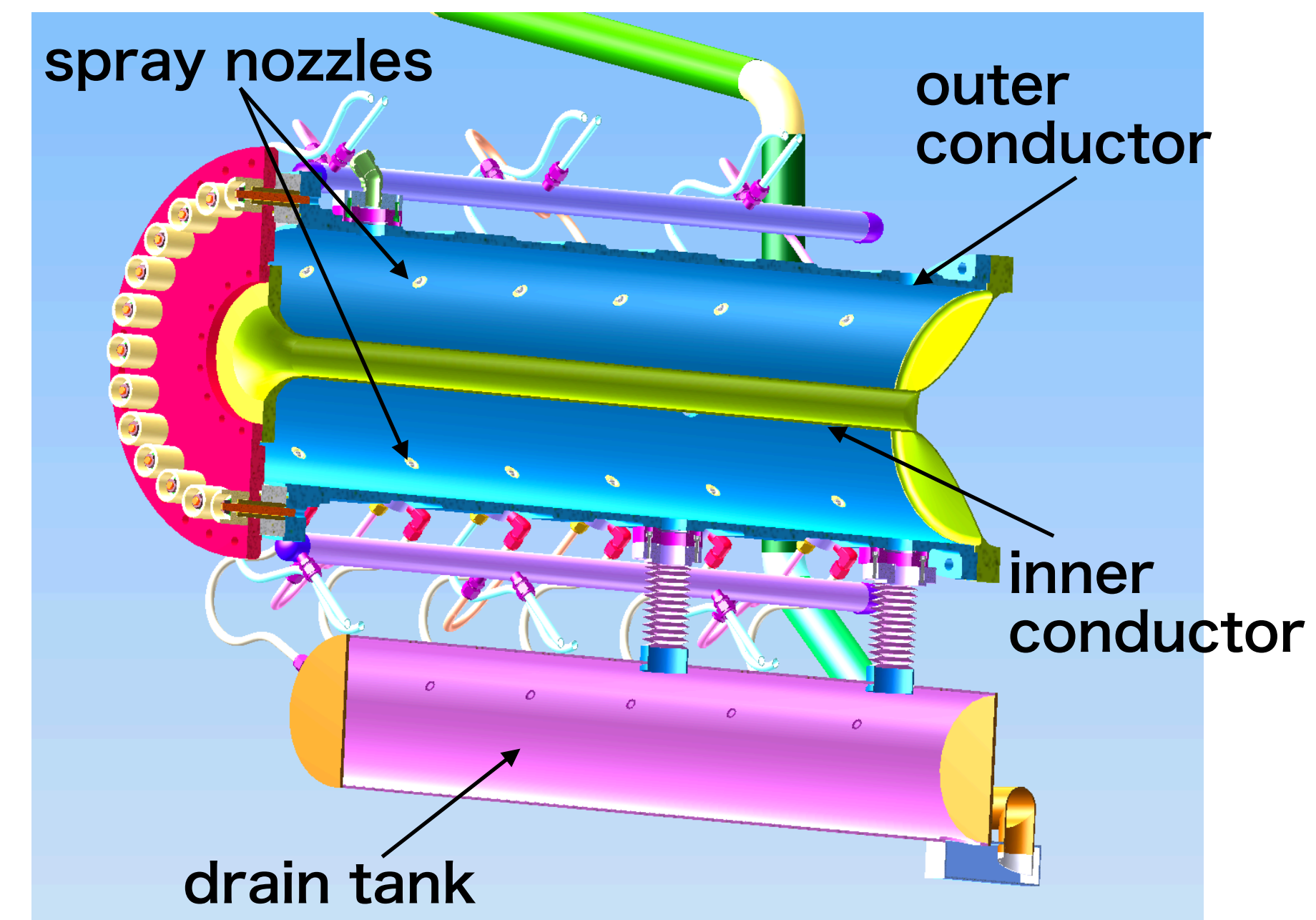
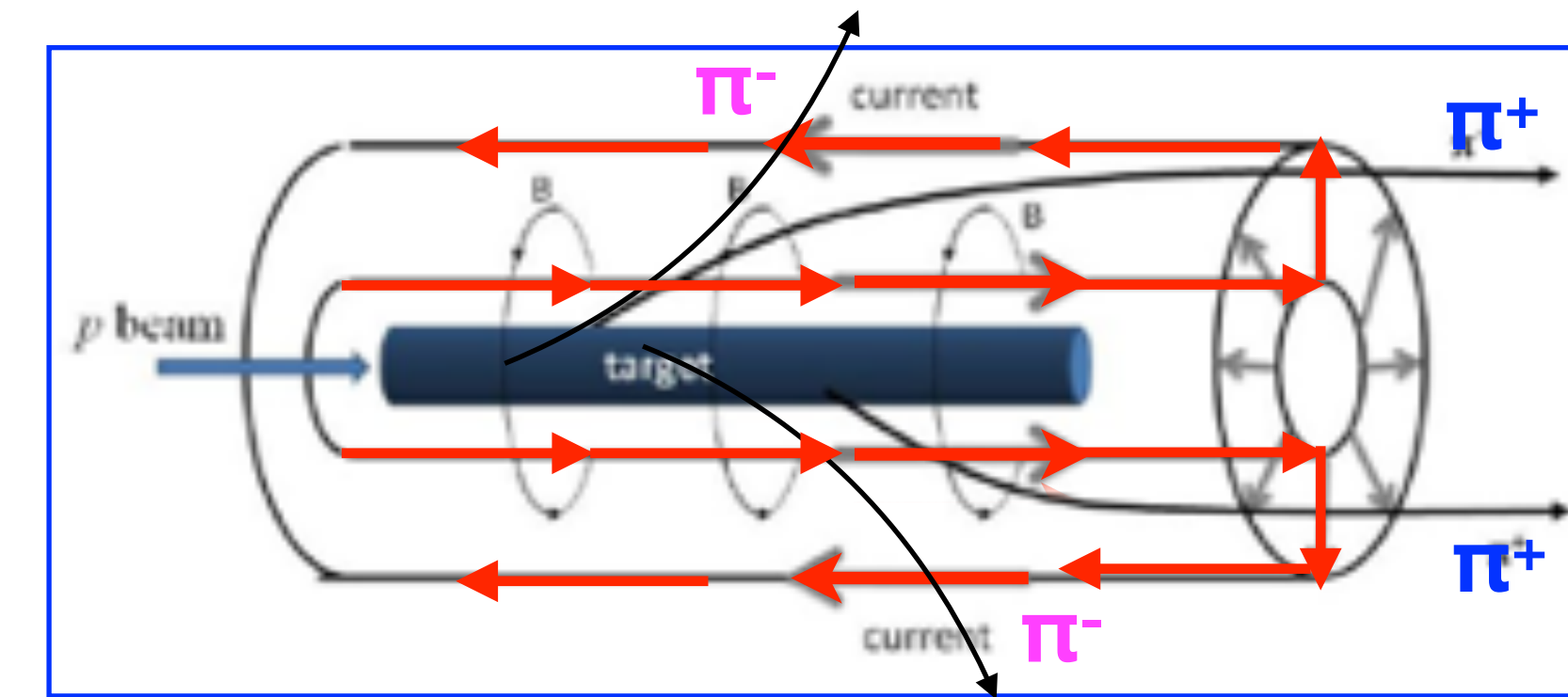
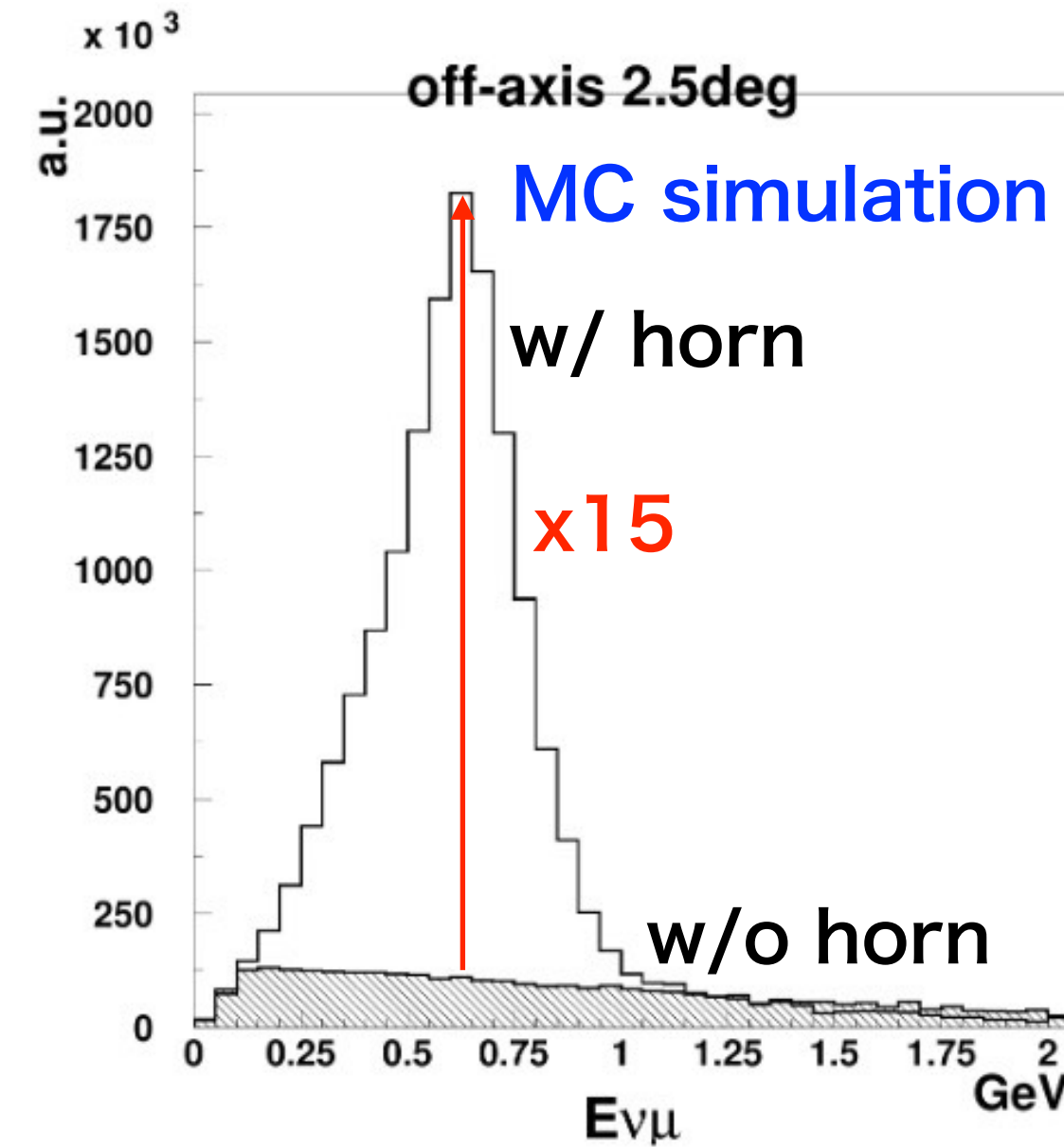
- 3mm-thick inner conductor
 - to reduce pion interaction
- 10mm-thick outer conductor

- **Pulsed high current**

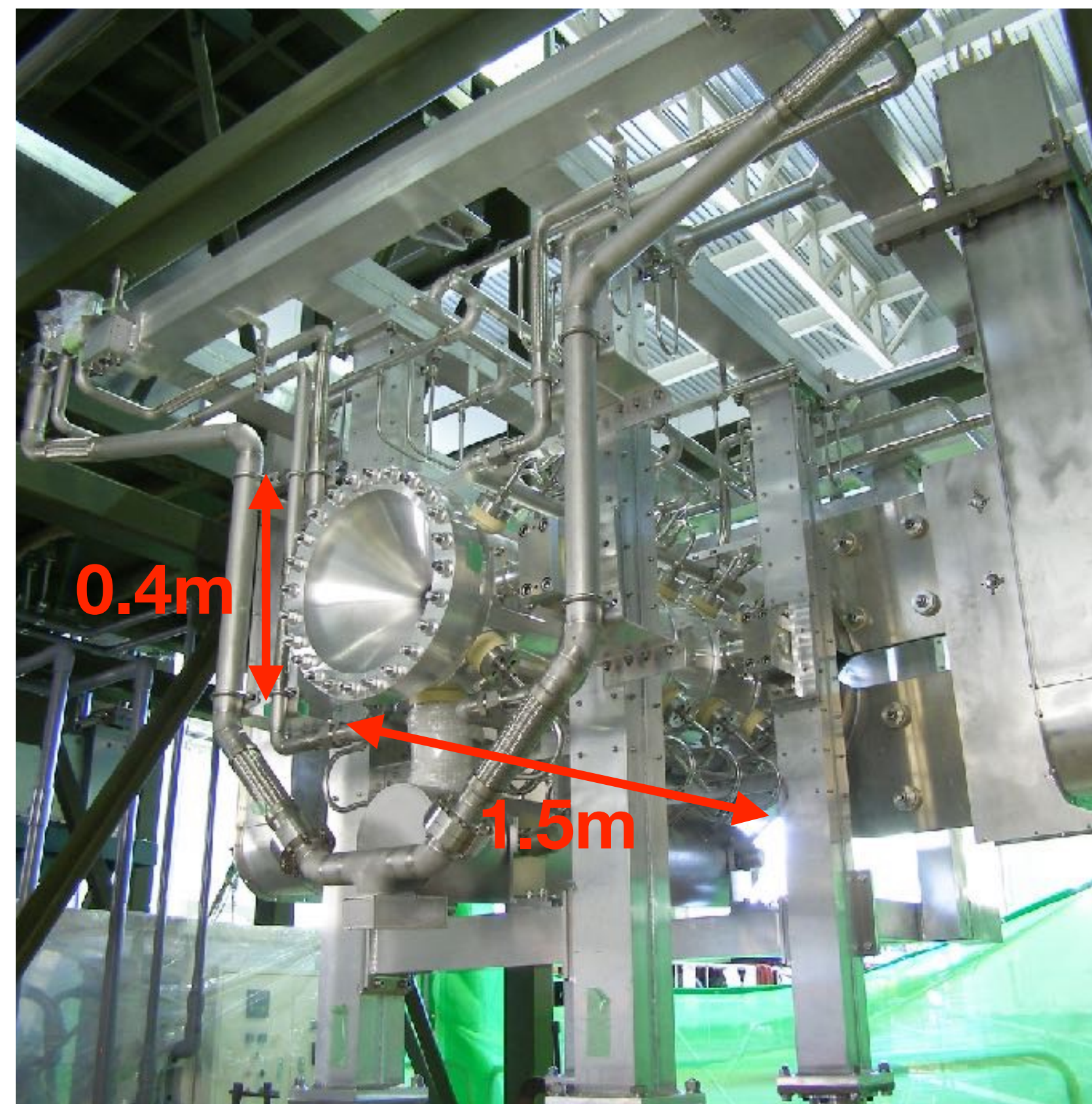
- 250 kA (2010~2021) → **320 kA** (2022~)
- Toroidal magnetic field: 2.1 T (max.)
- Pulse width: 2 ms
- Operation cycle:
 - 2.48 s (~2021) → **1.36 s** (2023~) → **1.16 s** (2027~)

- **Water cooling**

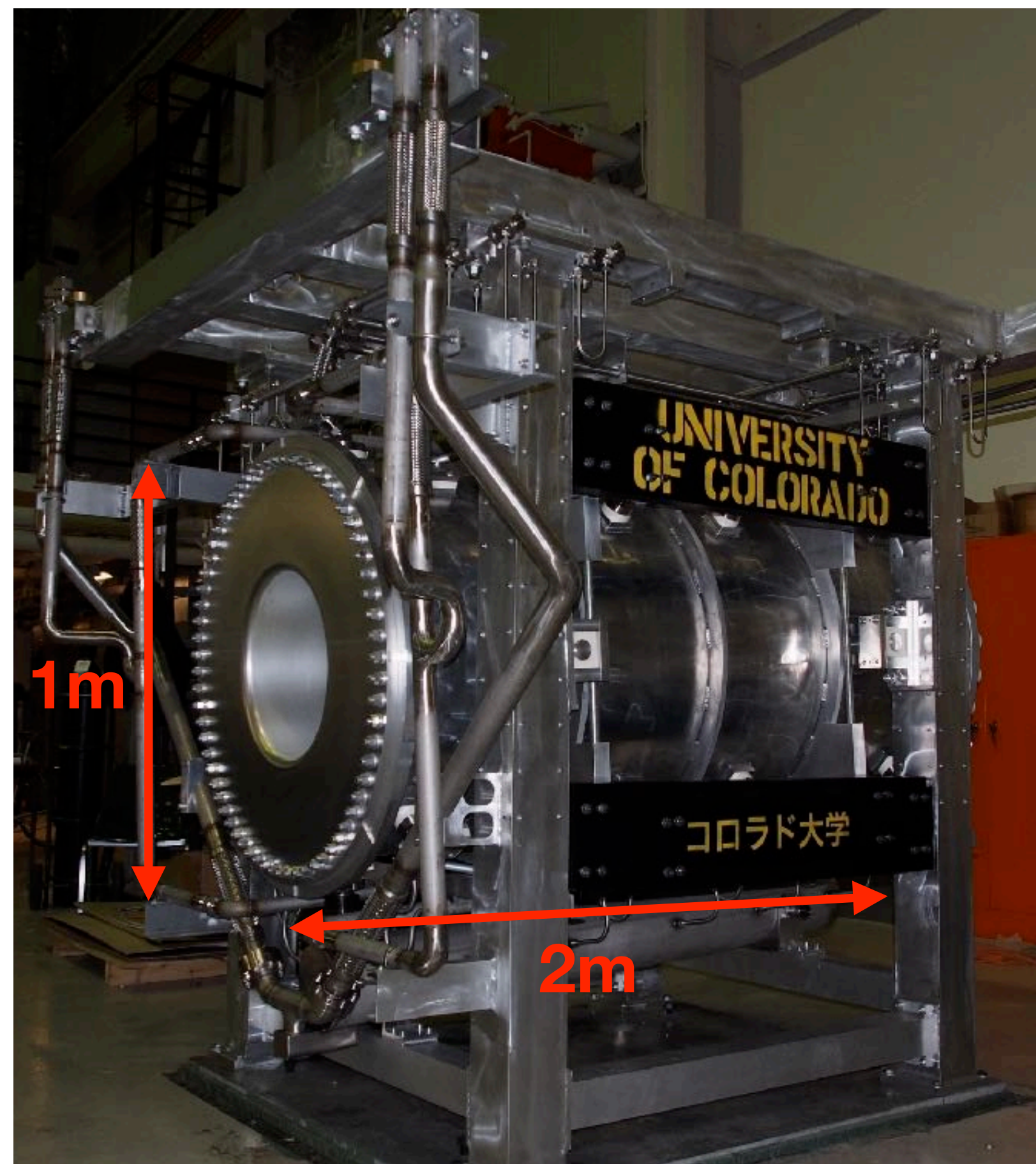
- **Spray water onto inner conductor**



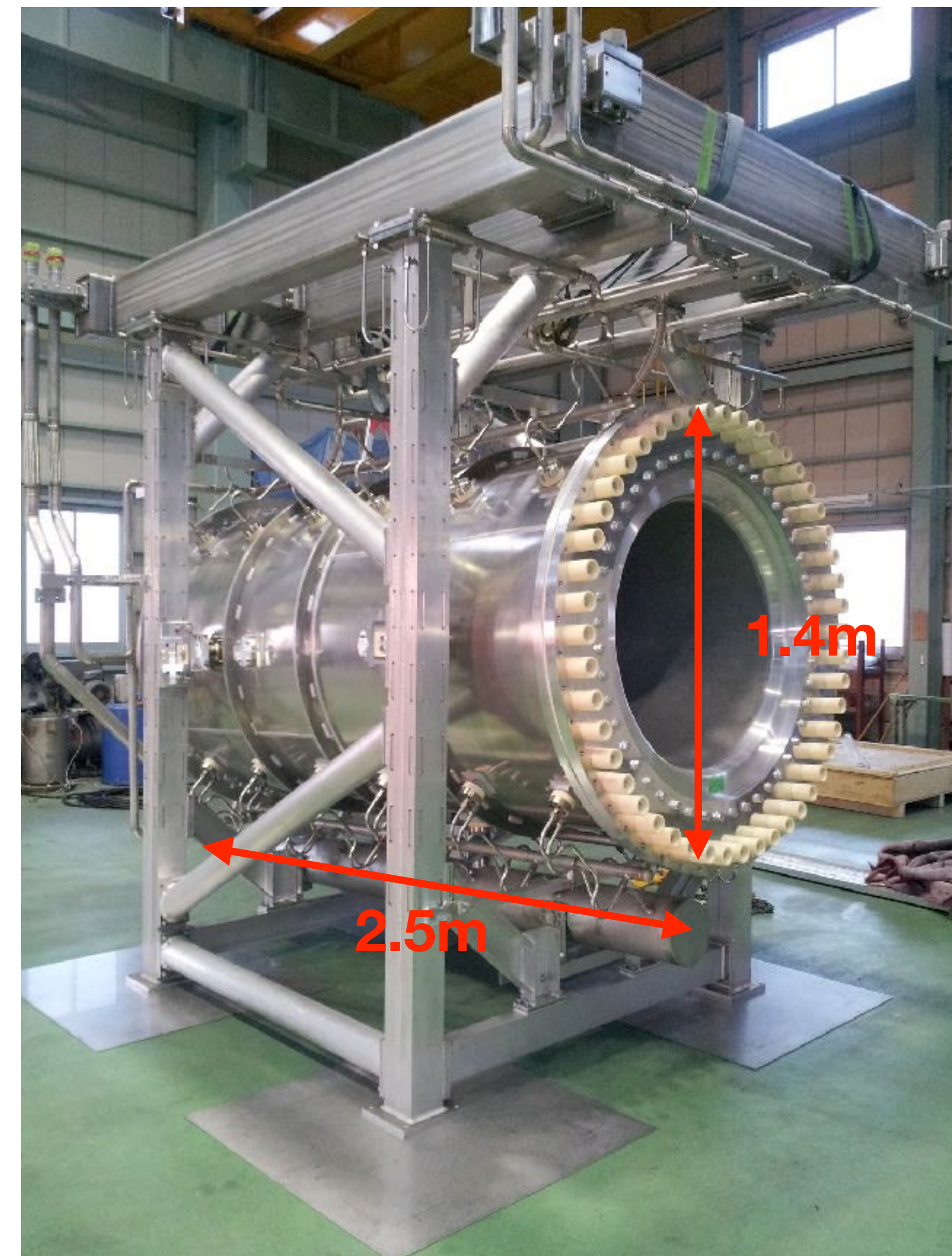
Horn1



Horn2



Horn3



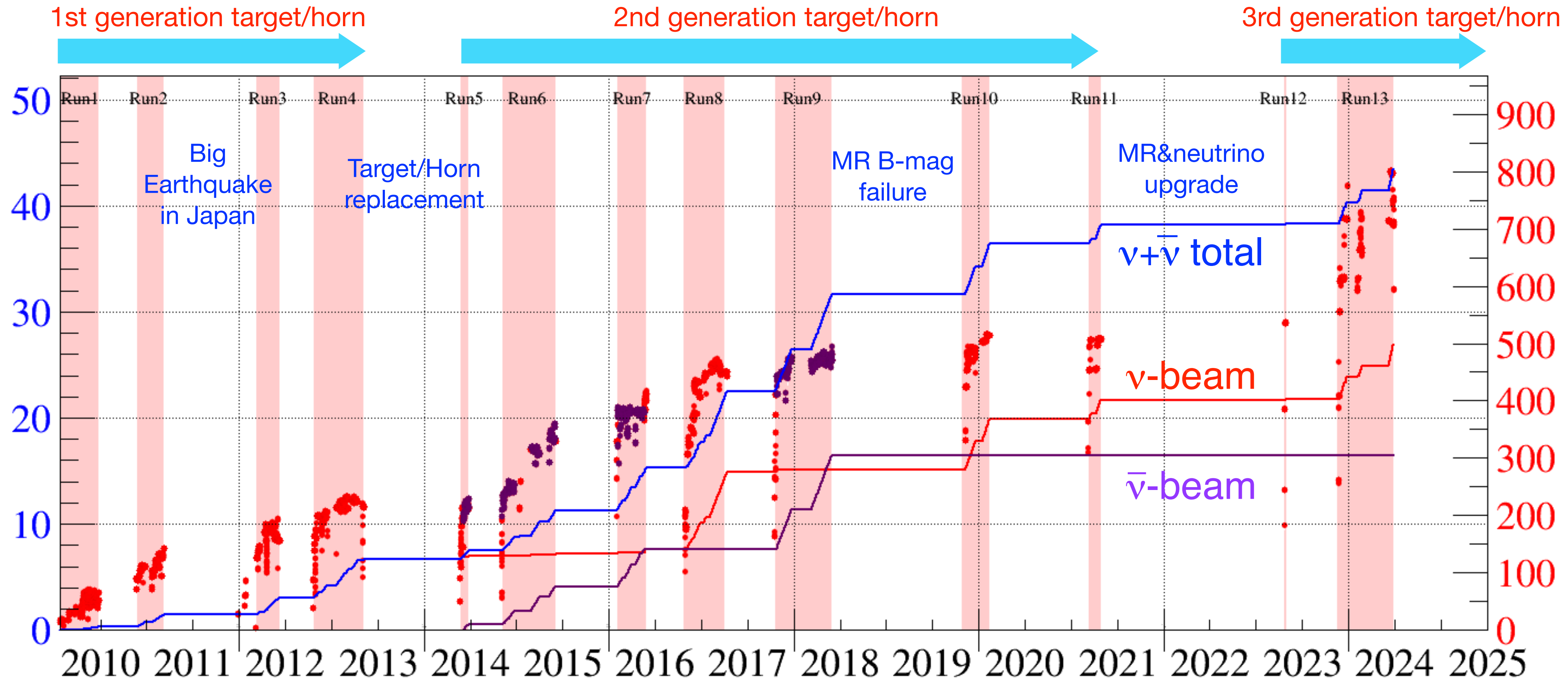


Beam Operation History

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

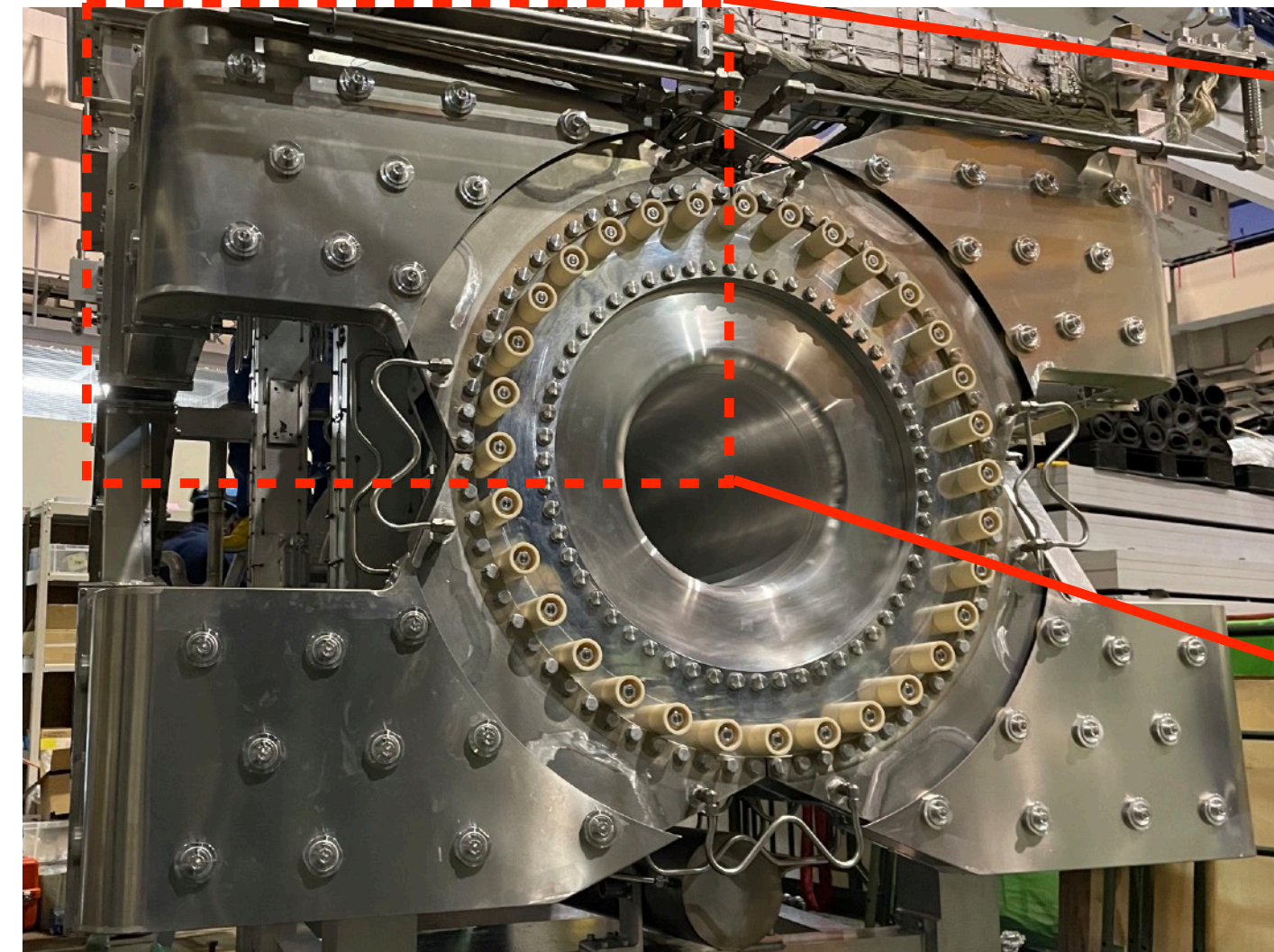
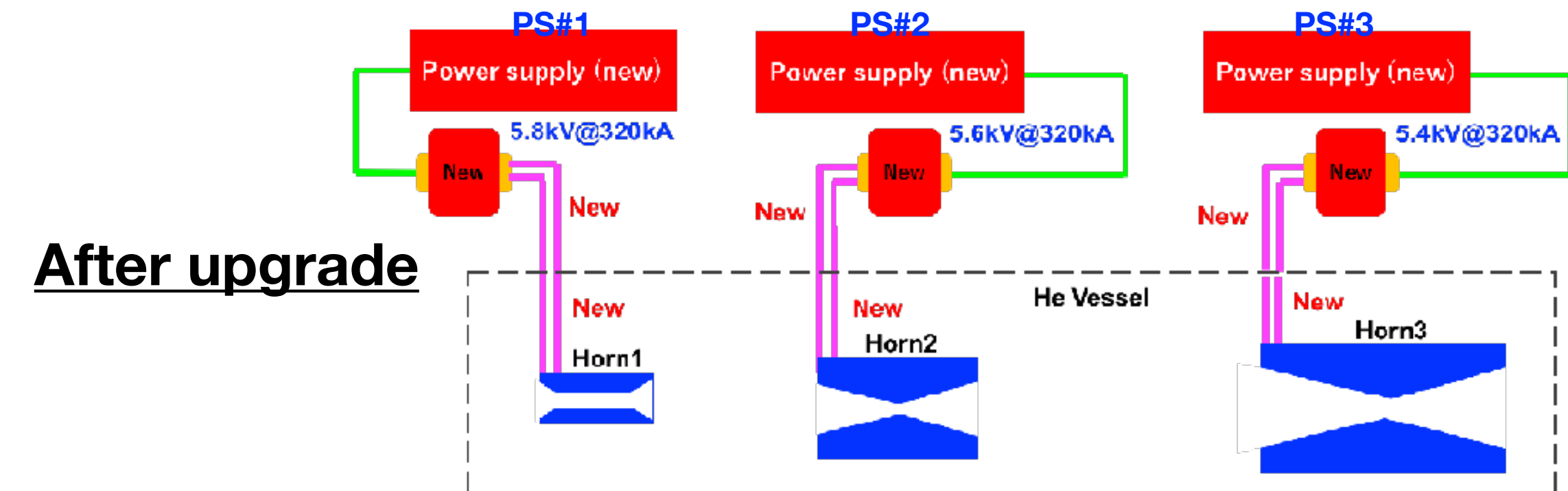
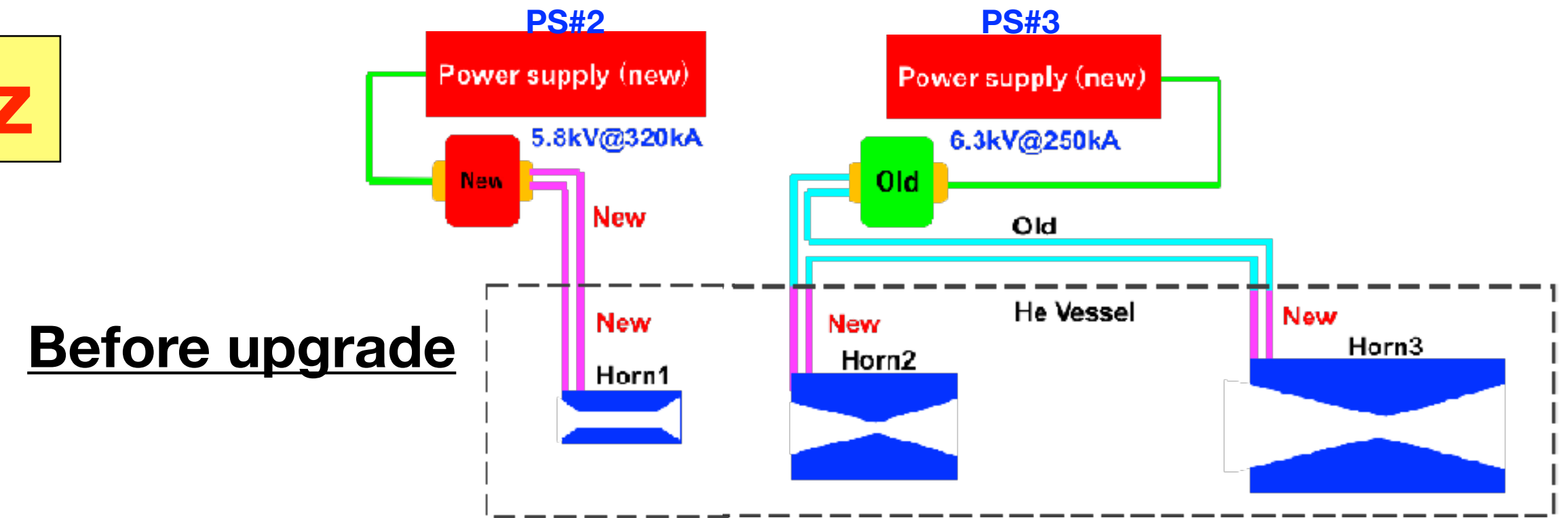
Total accumulated POT for T2K : 4.35×10^{21} POT (as of Jun. 2024) \rightarrow 1.0×10^{22} POT (T2K goal)
 c.f., 2.7×10^{22} POT (HK 10-years)

Horn PS upgrade for 250 → 320 kA at 1 Hz

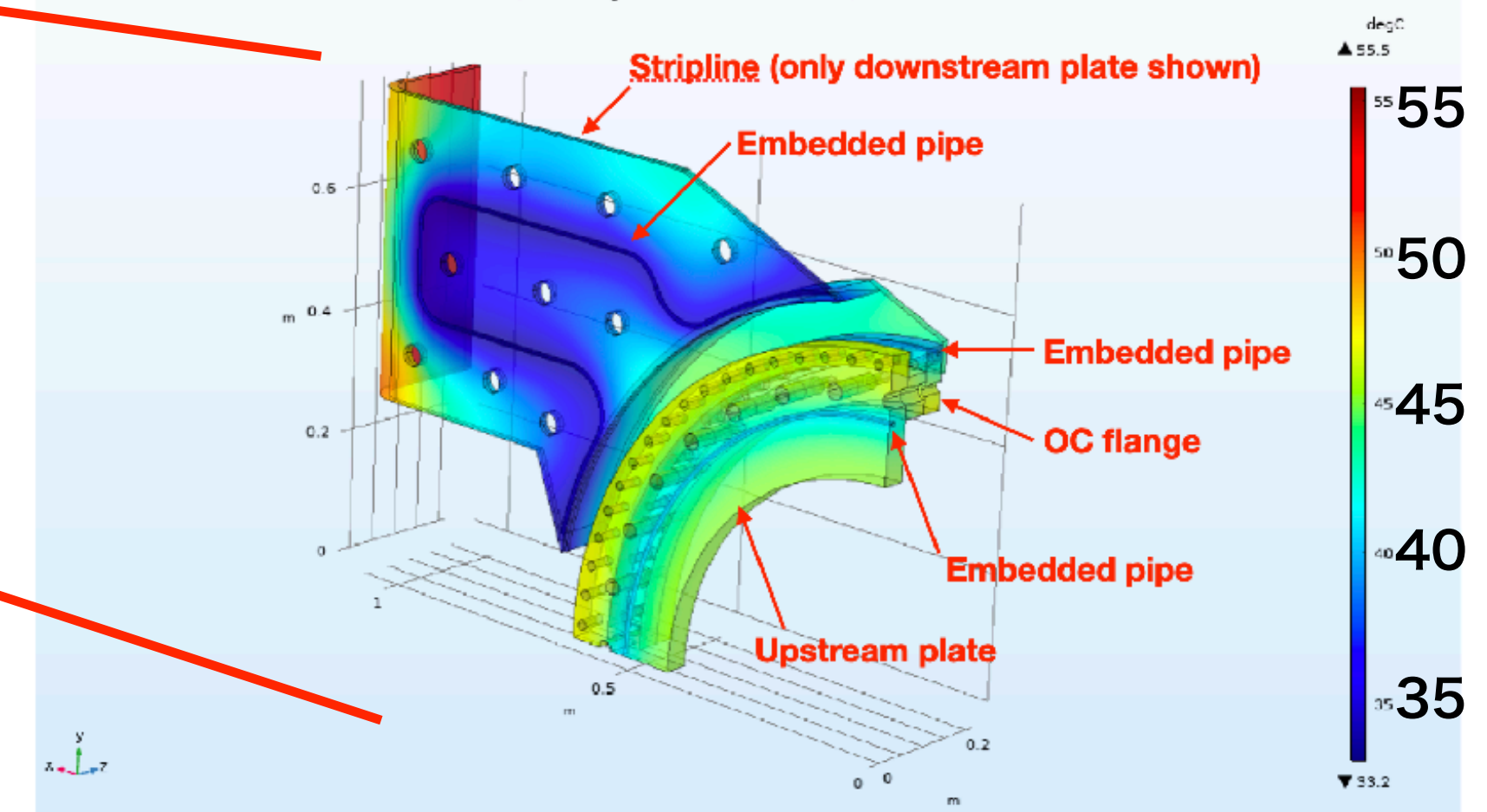
- 10% more neutrinos @ SK
- Two → Three PS system
- Upgraded all the electrical components

Horn replacement with upgraded horns

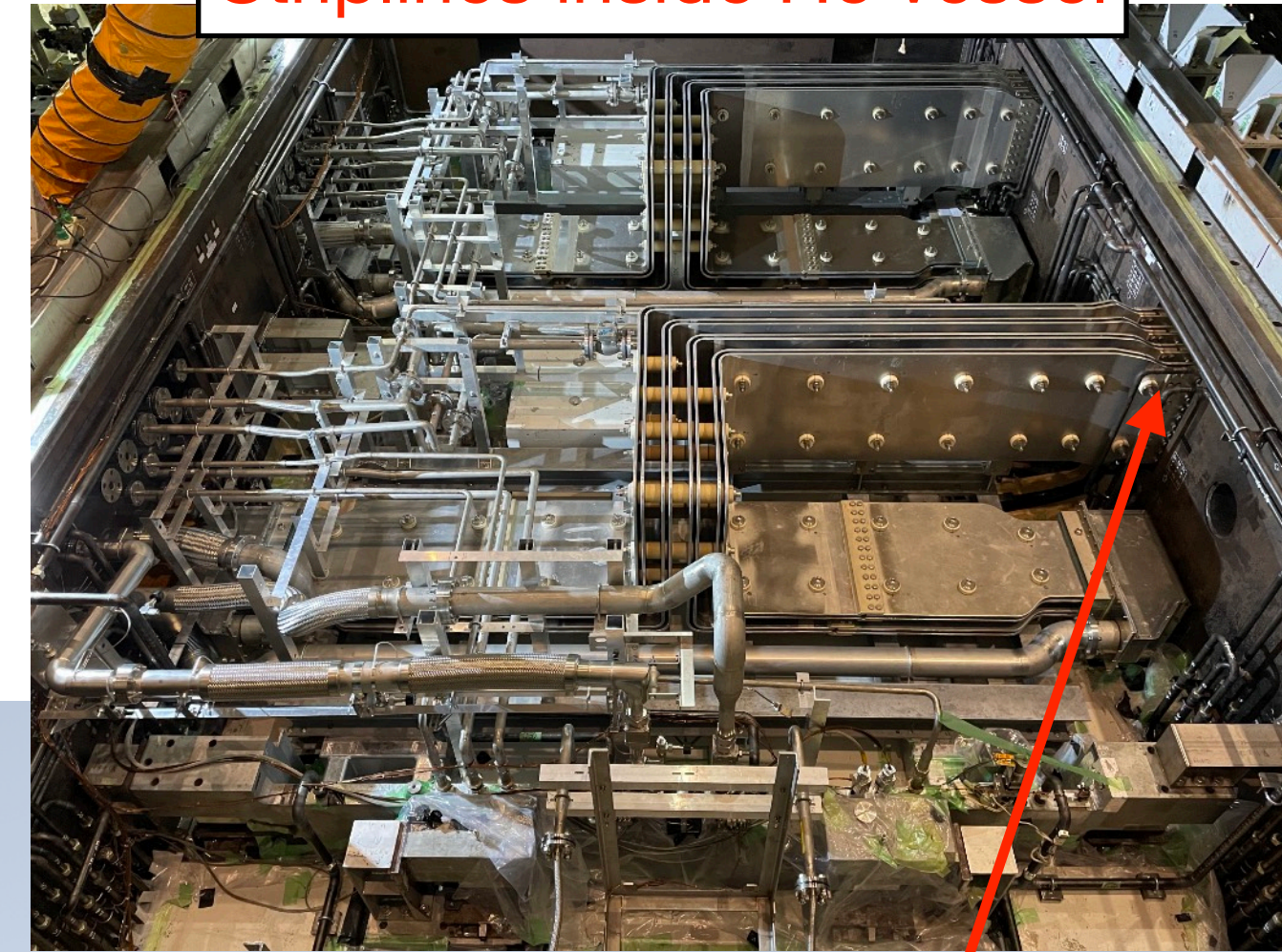
- New horn2 with improved cooling
- New horn1 with improved water sealing



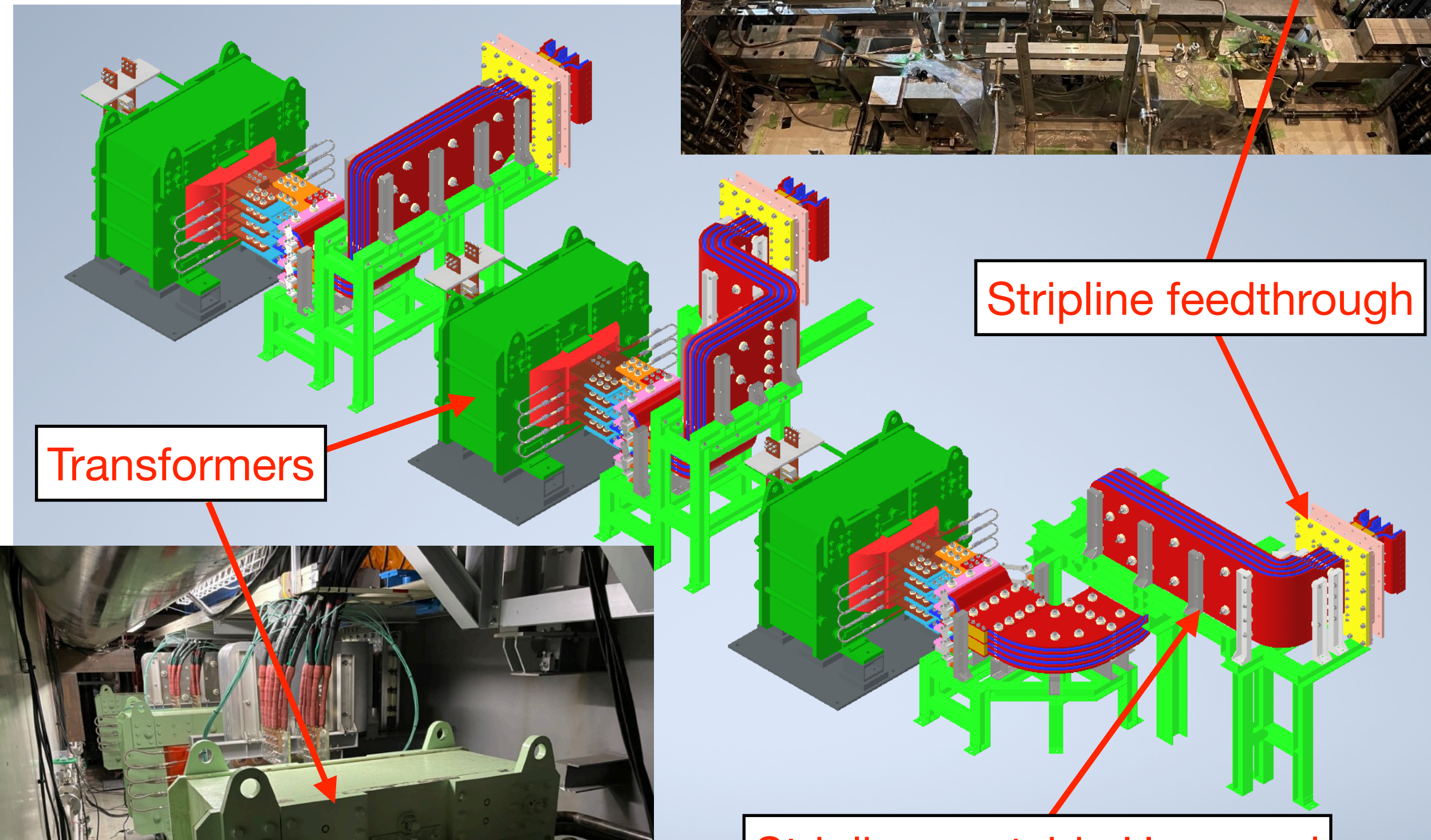
Expected temperature at striplines



Striplines inside He vessel

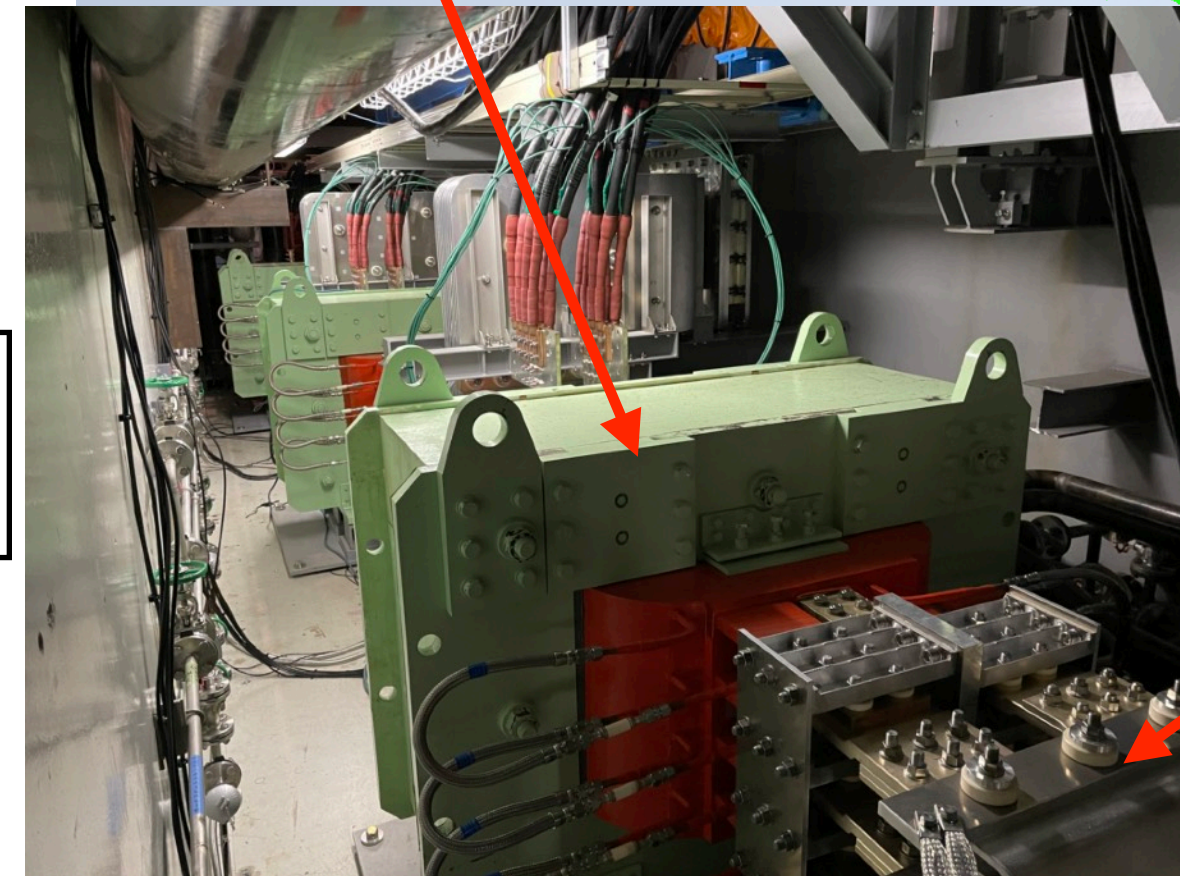


Stripline feedthrough

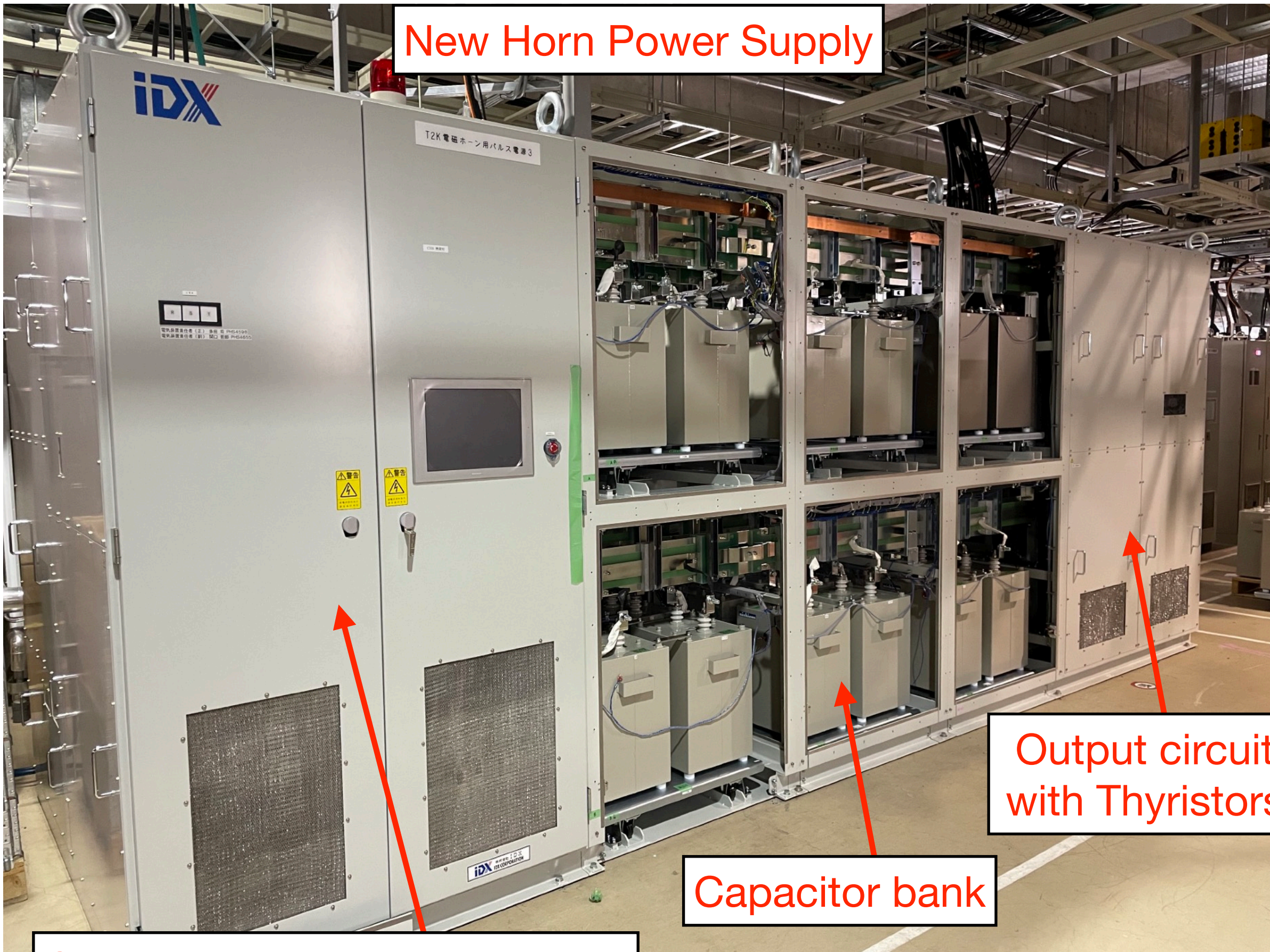


Transformers

Striplines outside He vessel



New Horn Power Supply



Output circuit with Thyristors

Capacitor bank

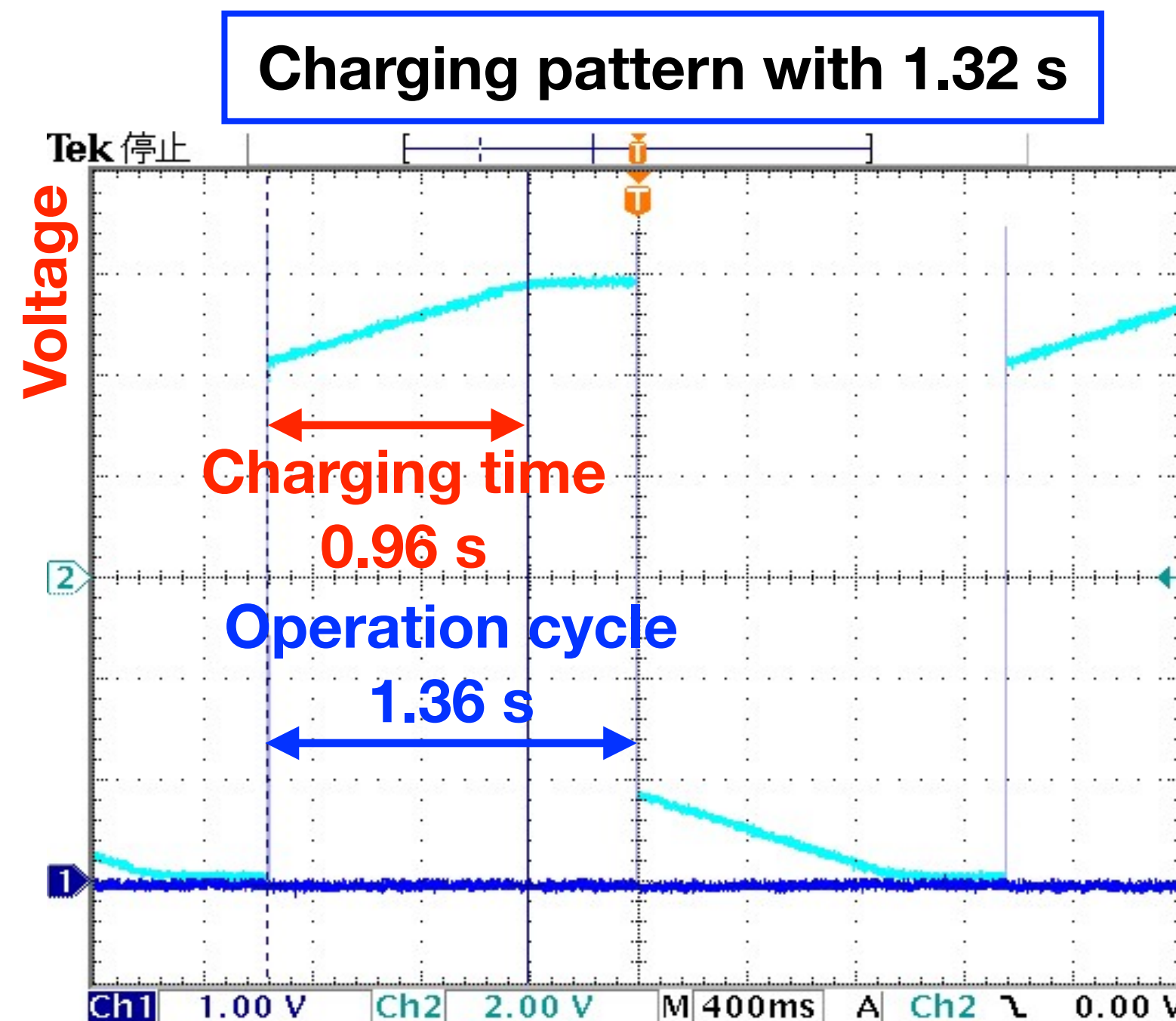
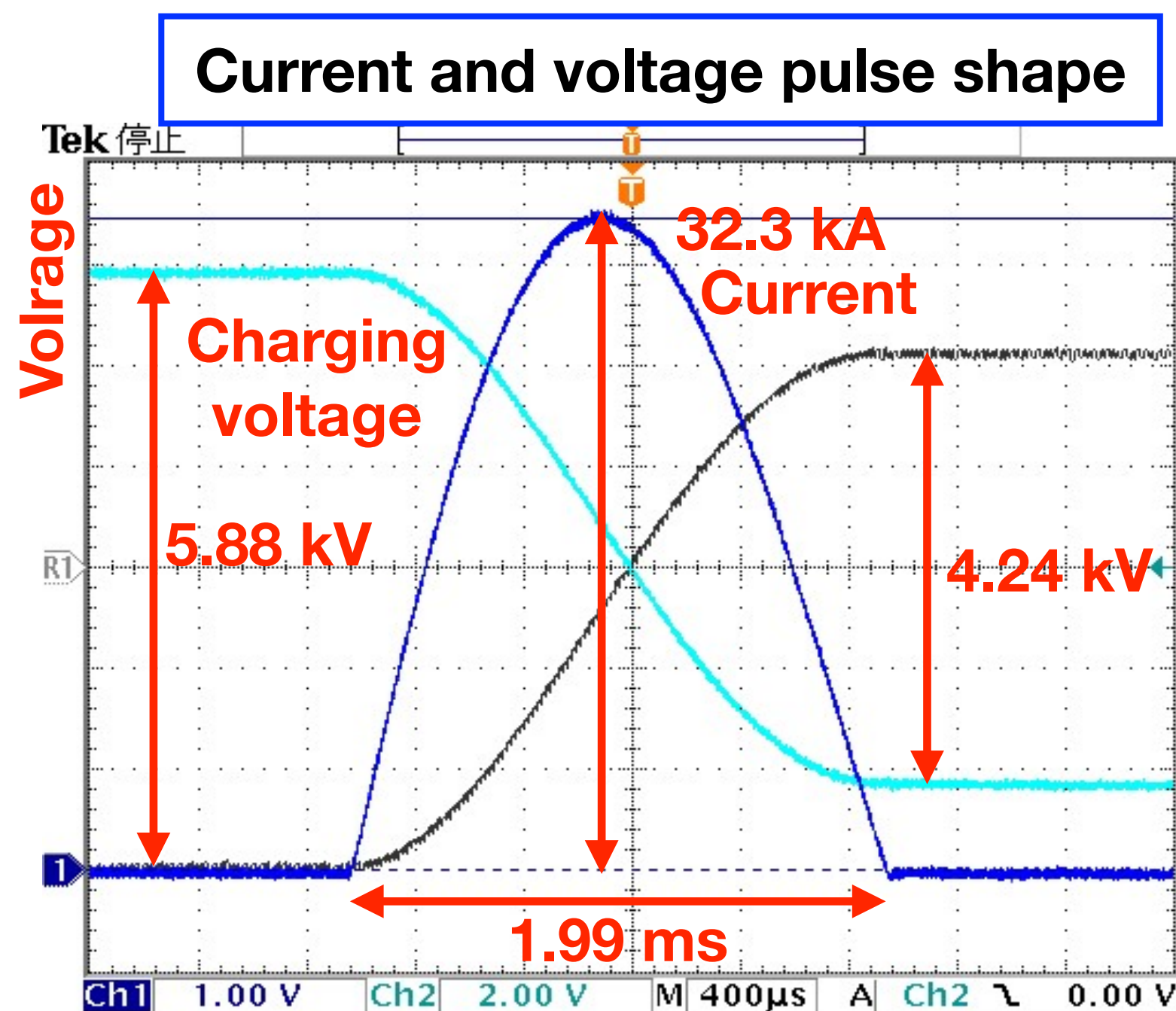
Charging unit + control system

- Horn power supply designed with energy recovery system
- Capacitor bank upgraded to overcome degradation of capacitors
- New transformers, striplines and cables developed for 320 kA operation



Horn Power Supply Upgrade

- The upgrade work in 2021-2022 long shutdown period
- All the upgrades for Horn PS system completed in Dec. 2022
- Measured operation parameters as expected



Parameters	Measured
PS Output current	32.3 kA
Pulse width	1.99 ms
Operation cycle	1.36 s
Charging voltage	5.88 kV
Reverse voltage	4.24 kV
Recovery rate	72.1%
Charging time	0.96 s

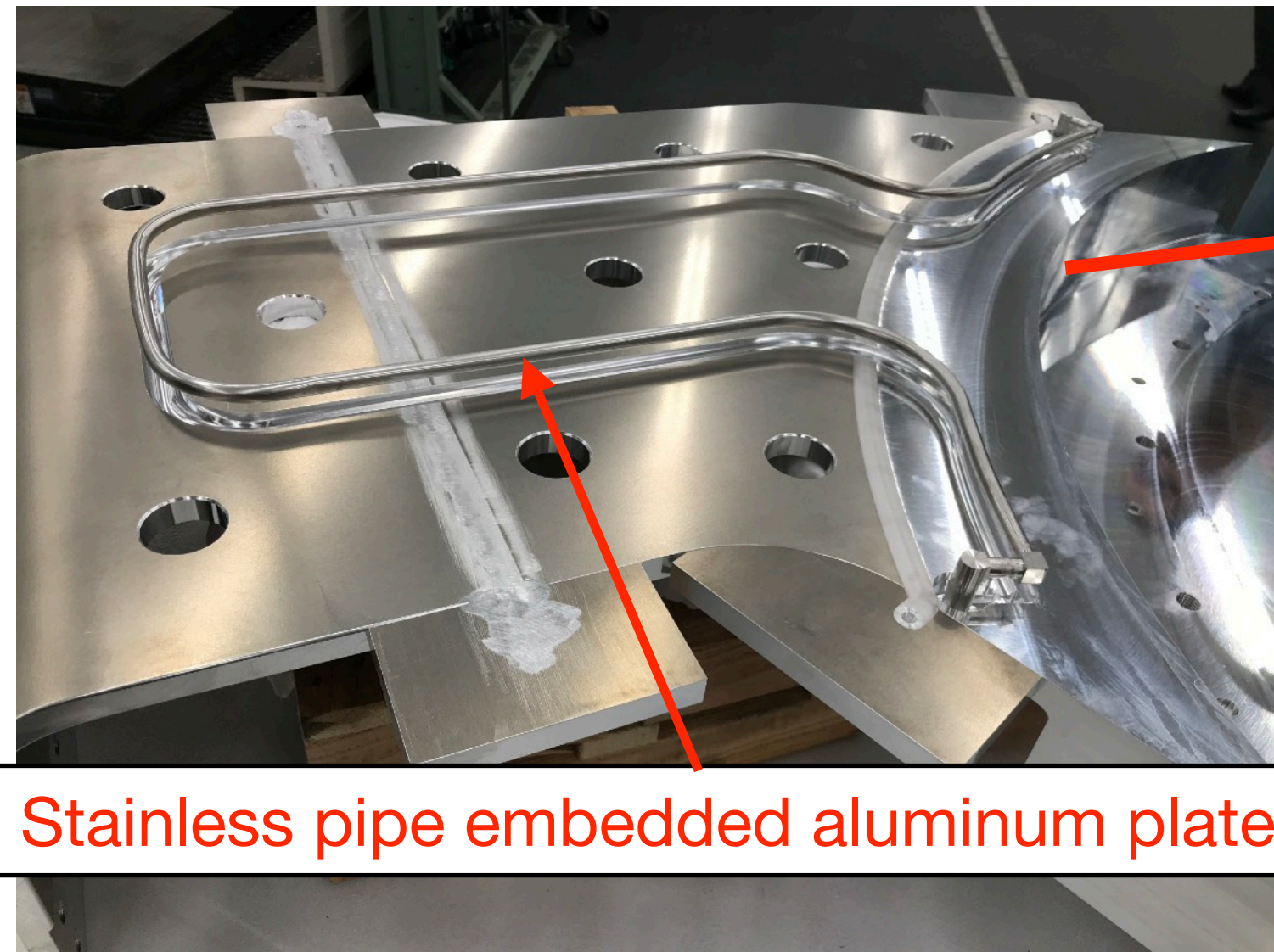
Remote handling using remote-controlled overhead crane and dedicated guide system

New Horn1 (3rd gen.) installation

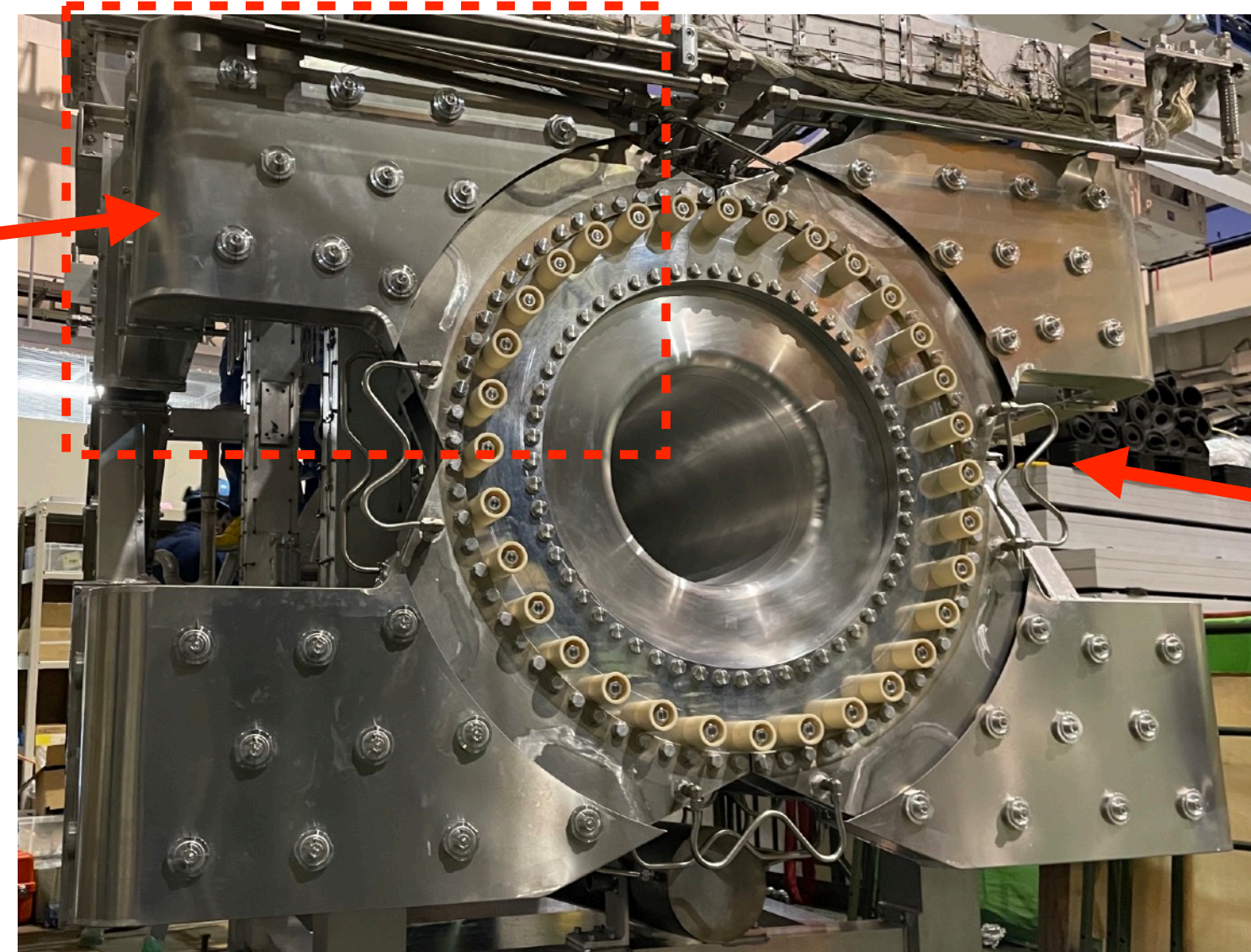


New Horn2 (3rd gen.) installation

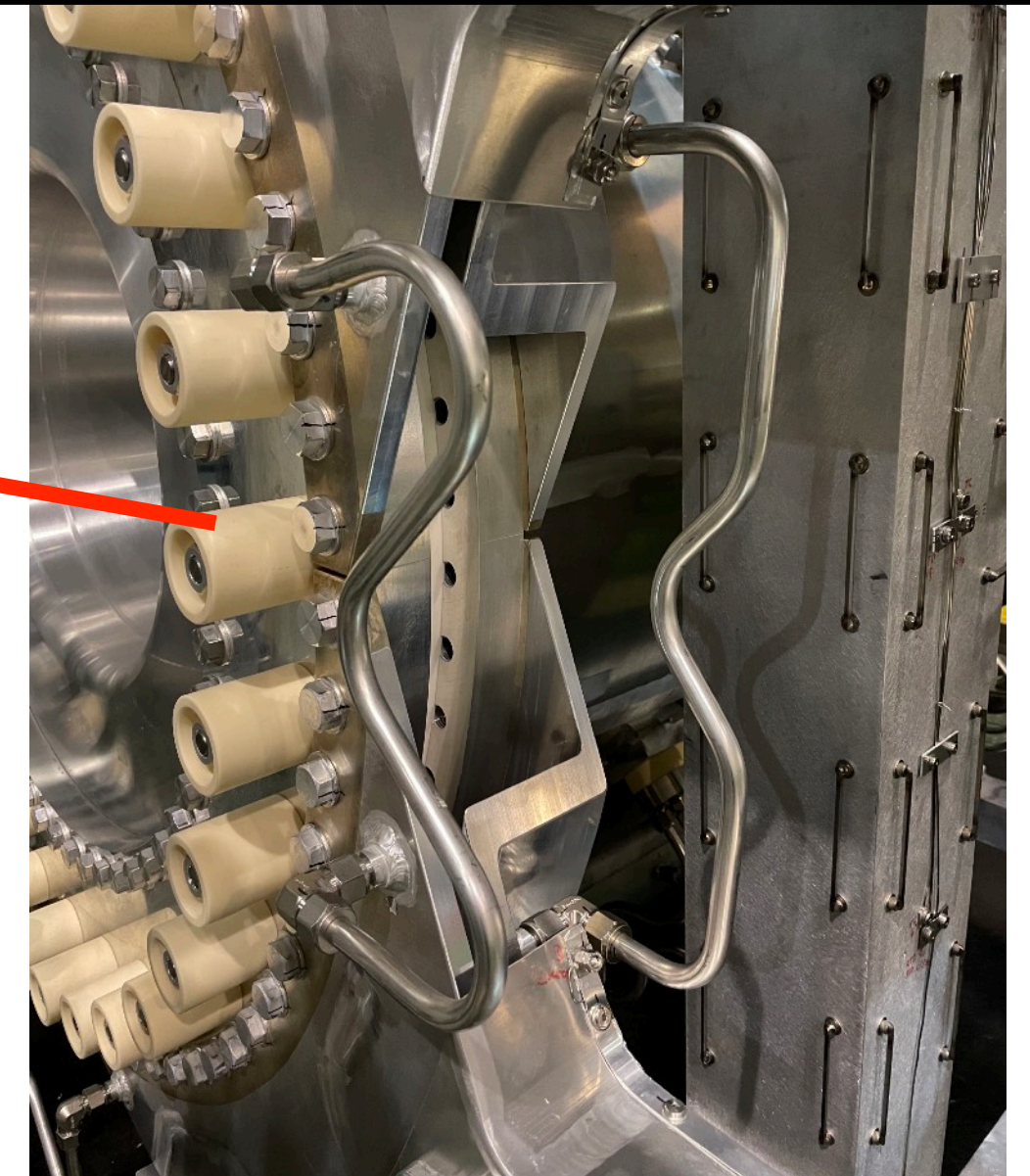




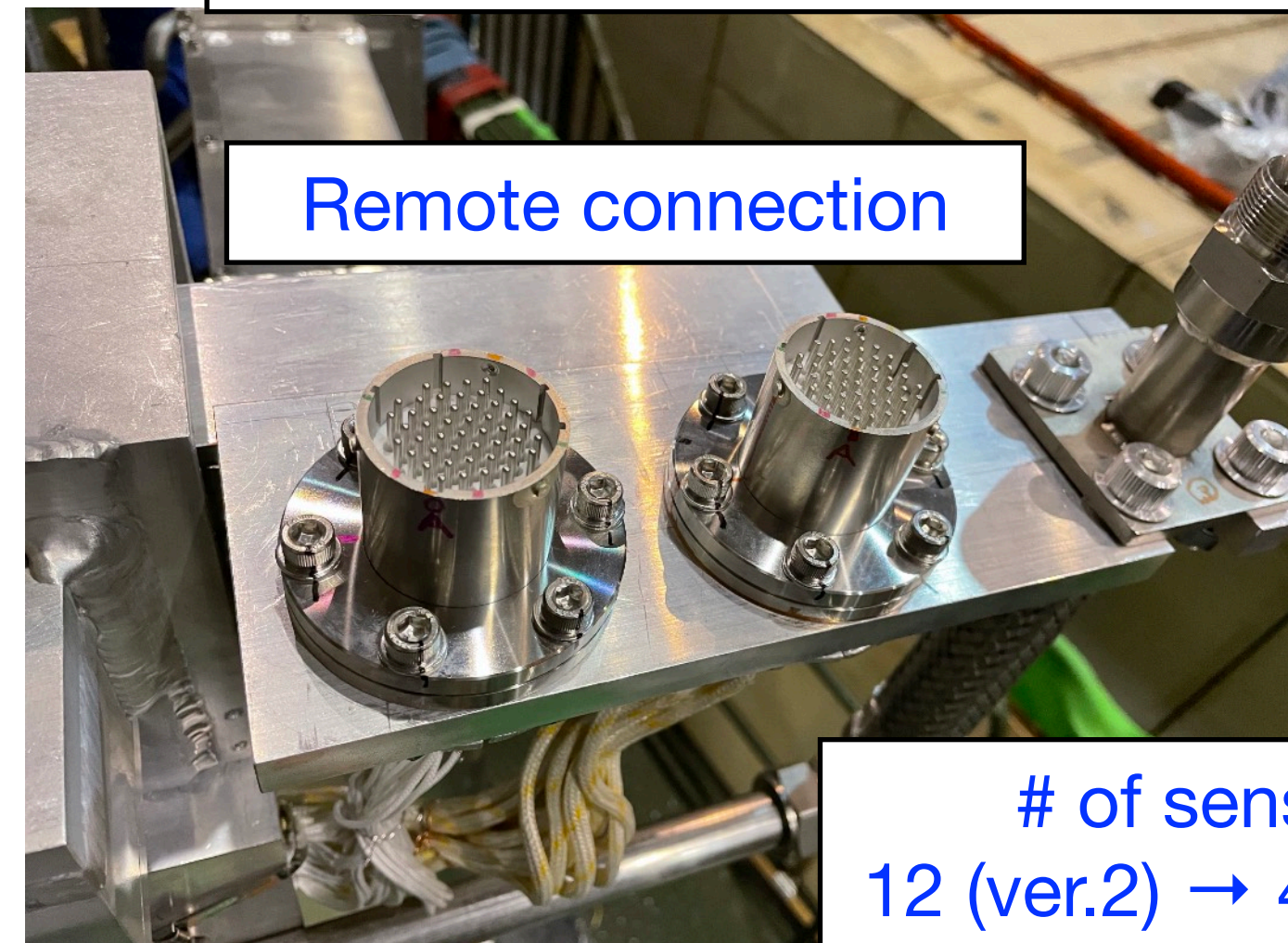
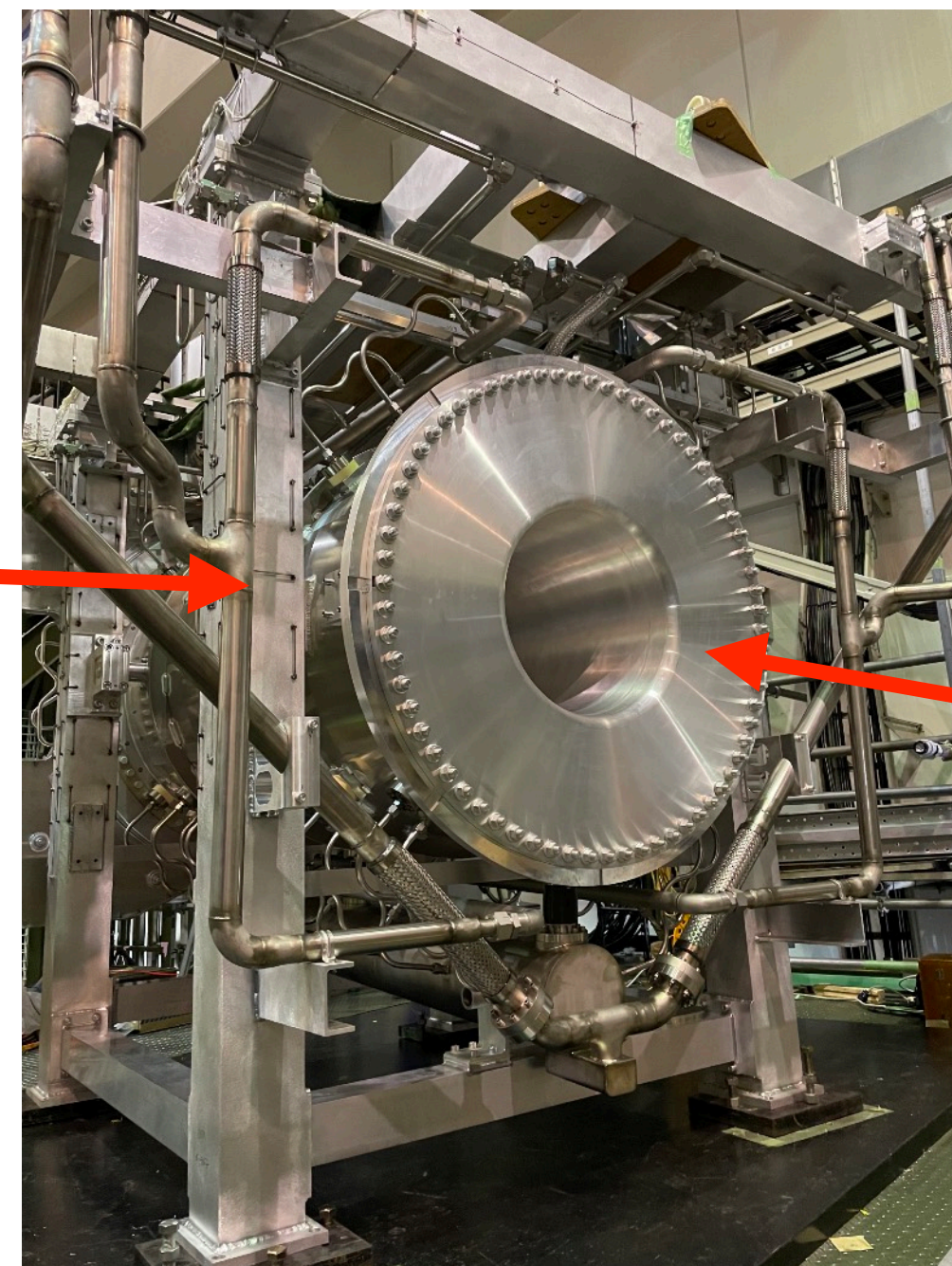
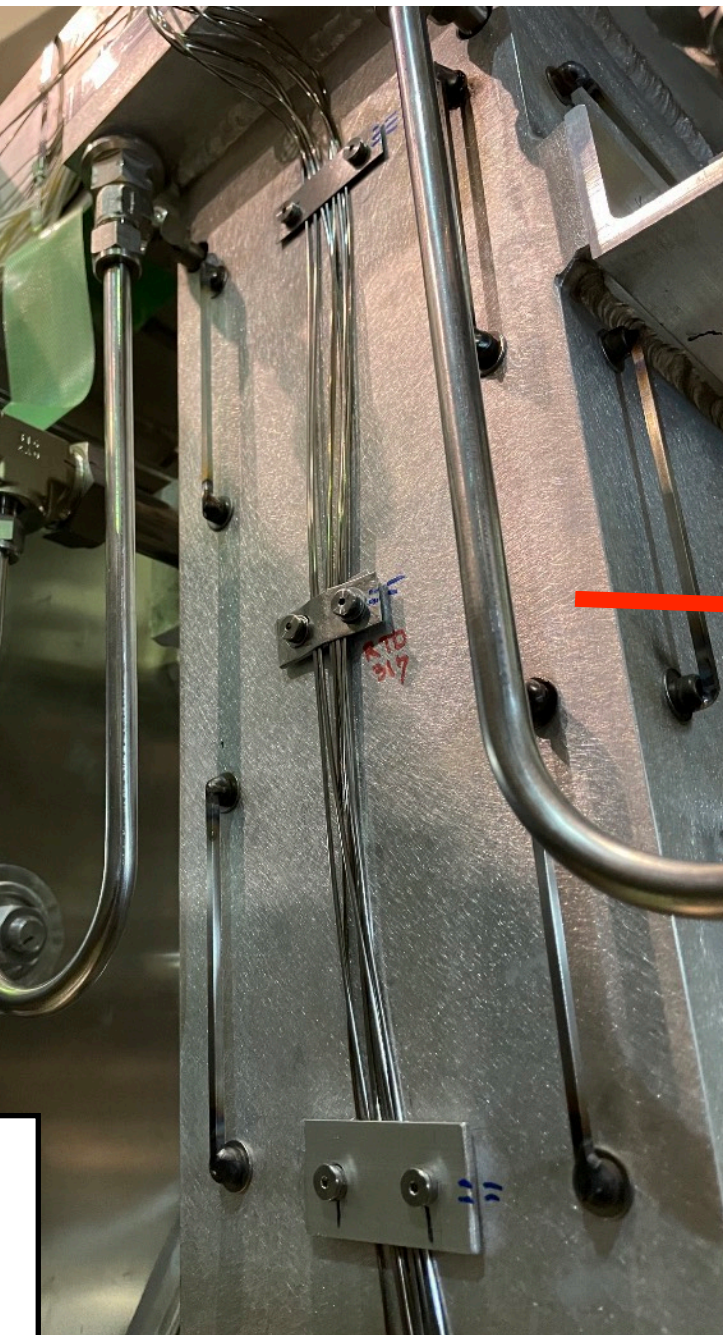
Stainless pipe embedded aluminum plate



Bent tubes for stripline cooling loops

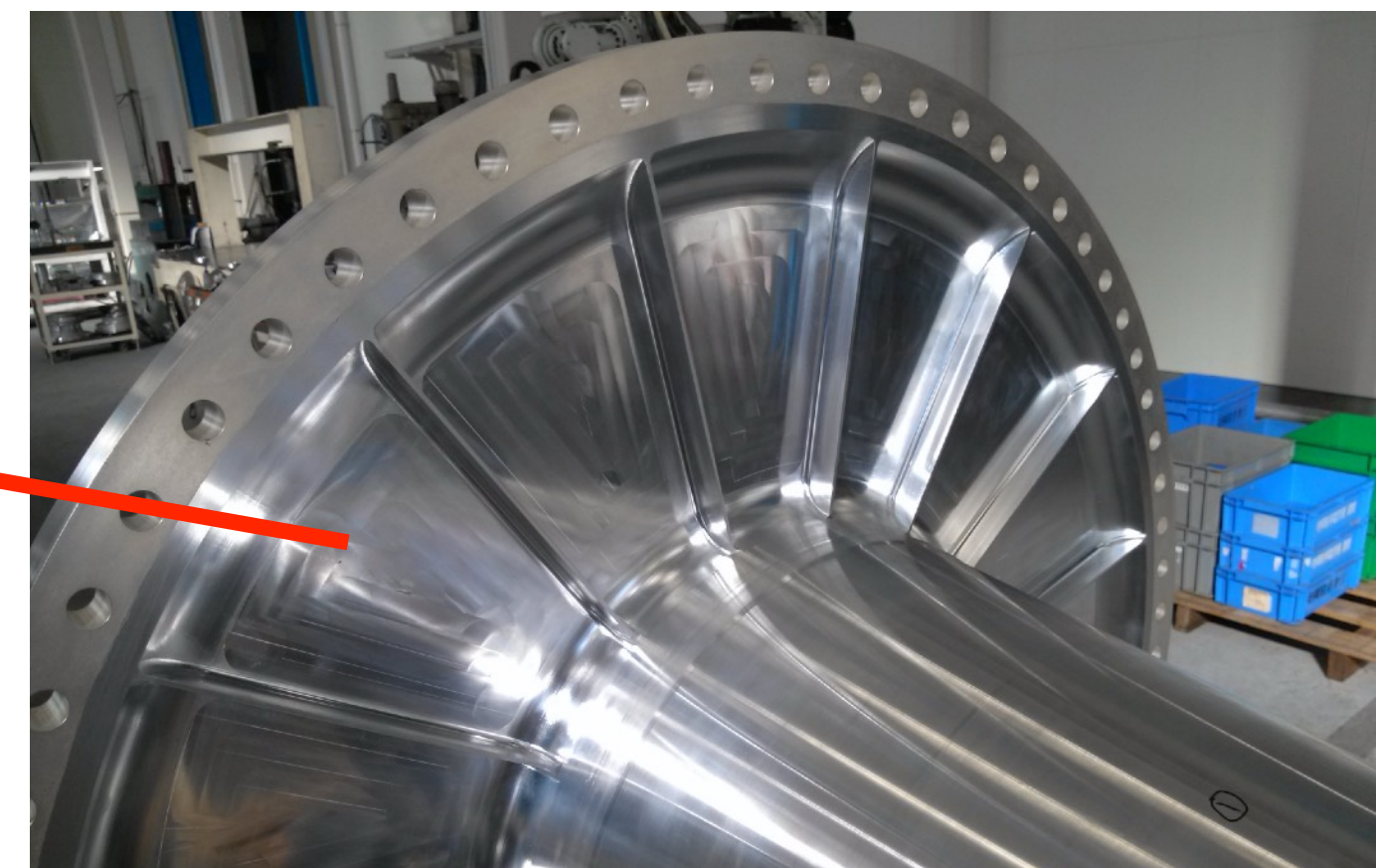


Many temperature sensors attached to measure temperature increase at high power beam operation



Remote connection

of sensors
12 (ver.2) → 40 (ver.3)

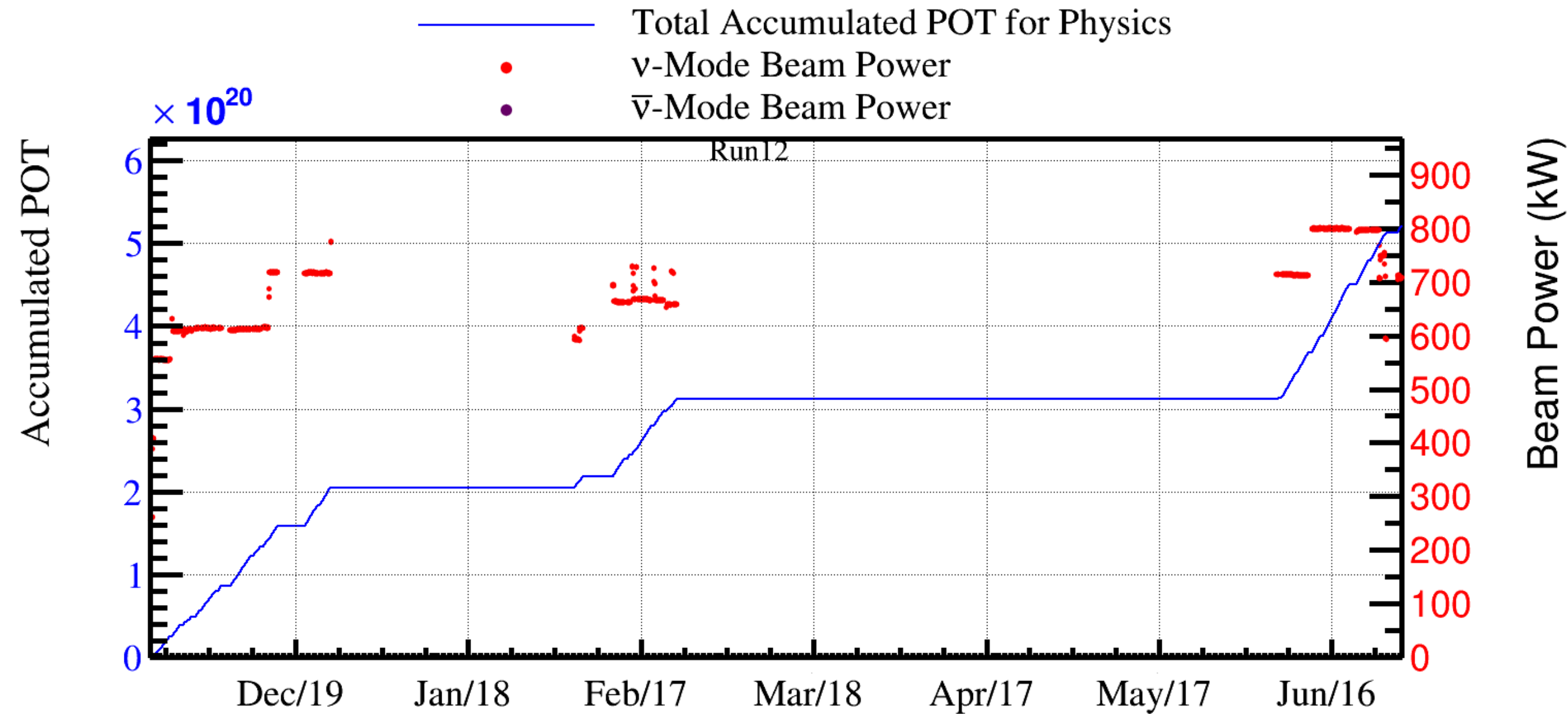


Ribbed upstream and downstream plates to strengthen the inner conductor

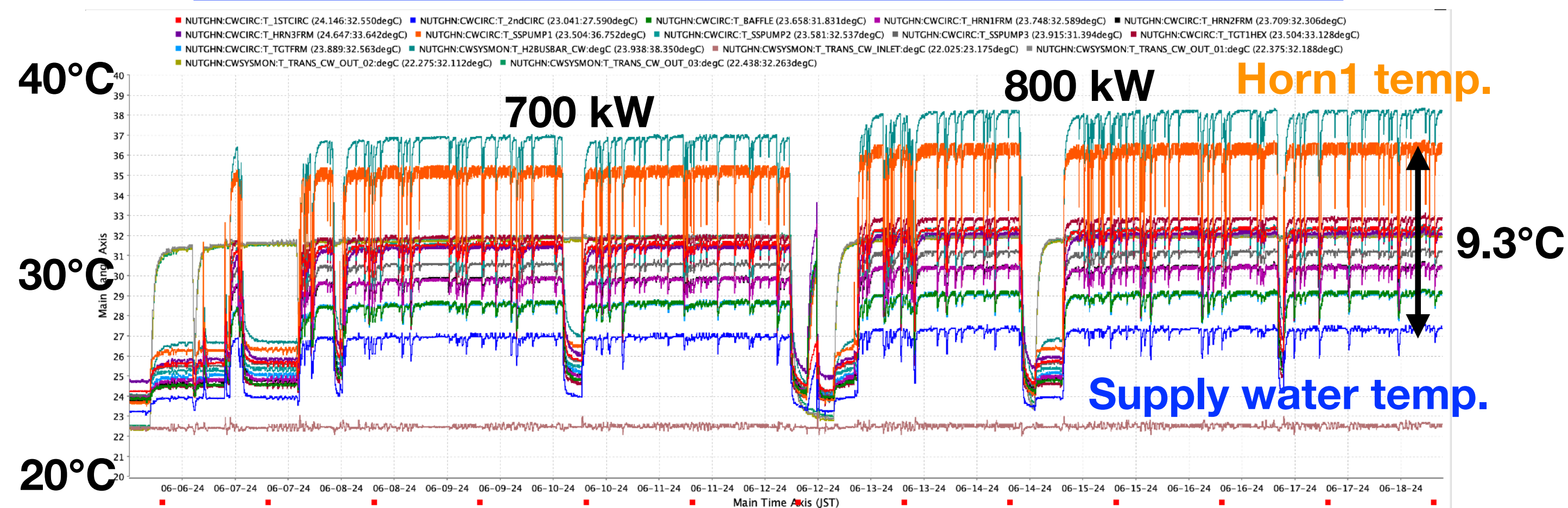


Beam Operation After Horn Upgrade

- Beam operation for physics run was resumed in Nov. 2023
- As of now, 800 kW stable operation was achieved in Jun. 2024
- The upgraded horns working stably
- Observed cooling water temperature rise consistent with expectation within 20% precision

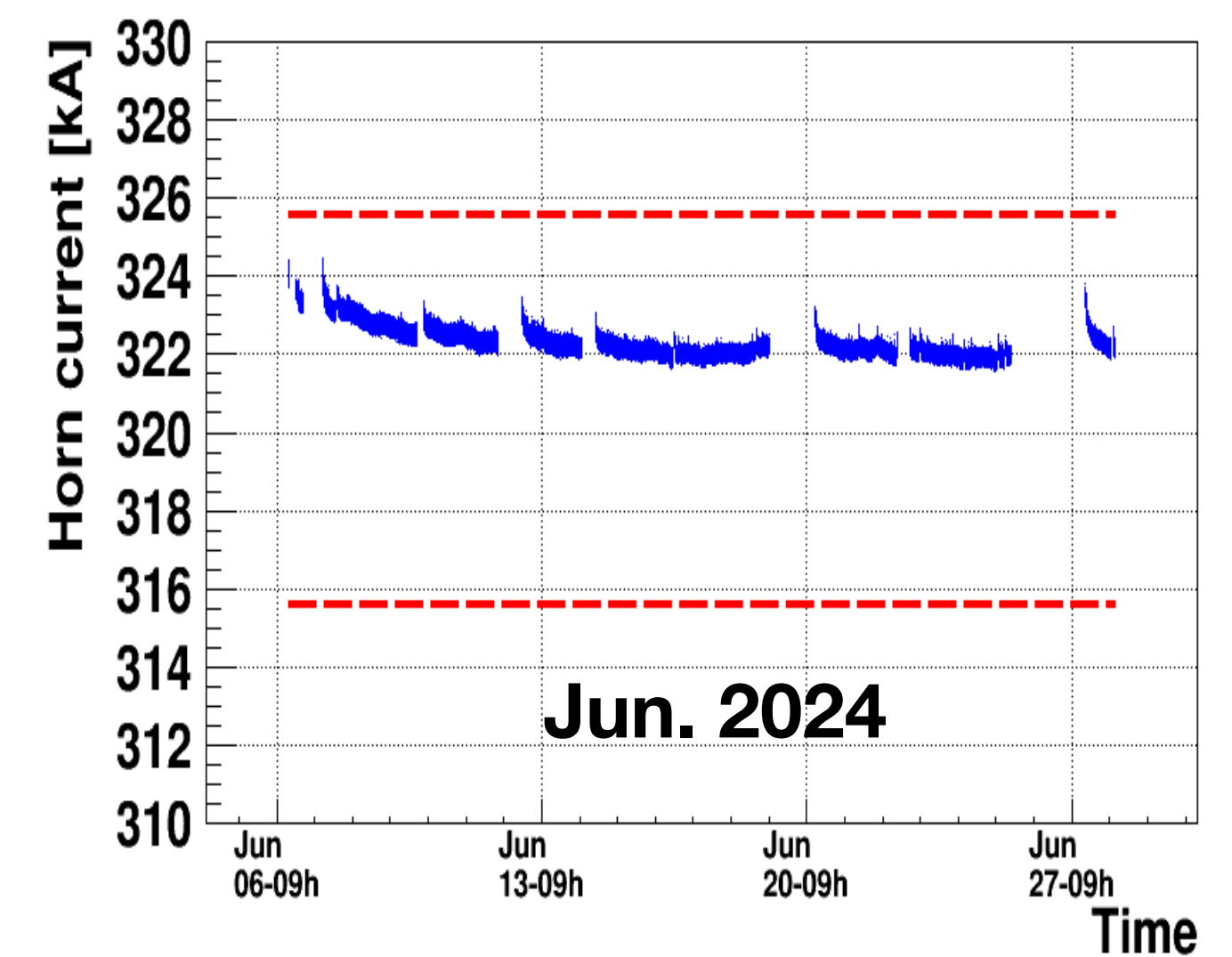
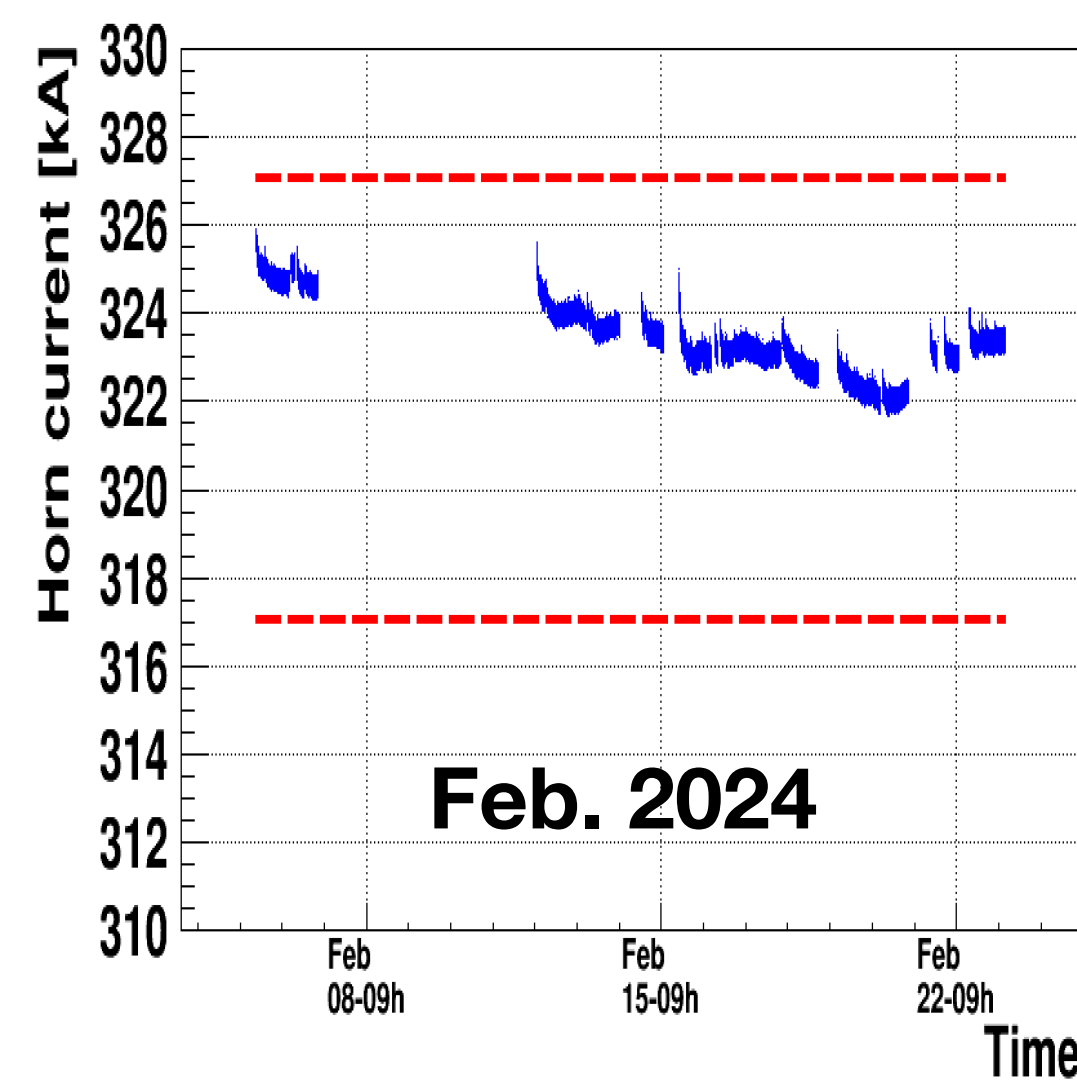
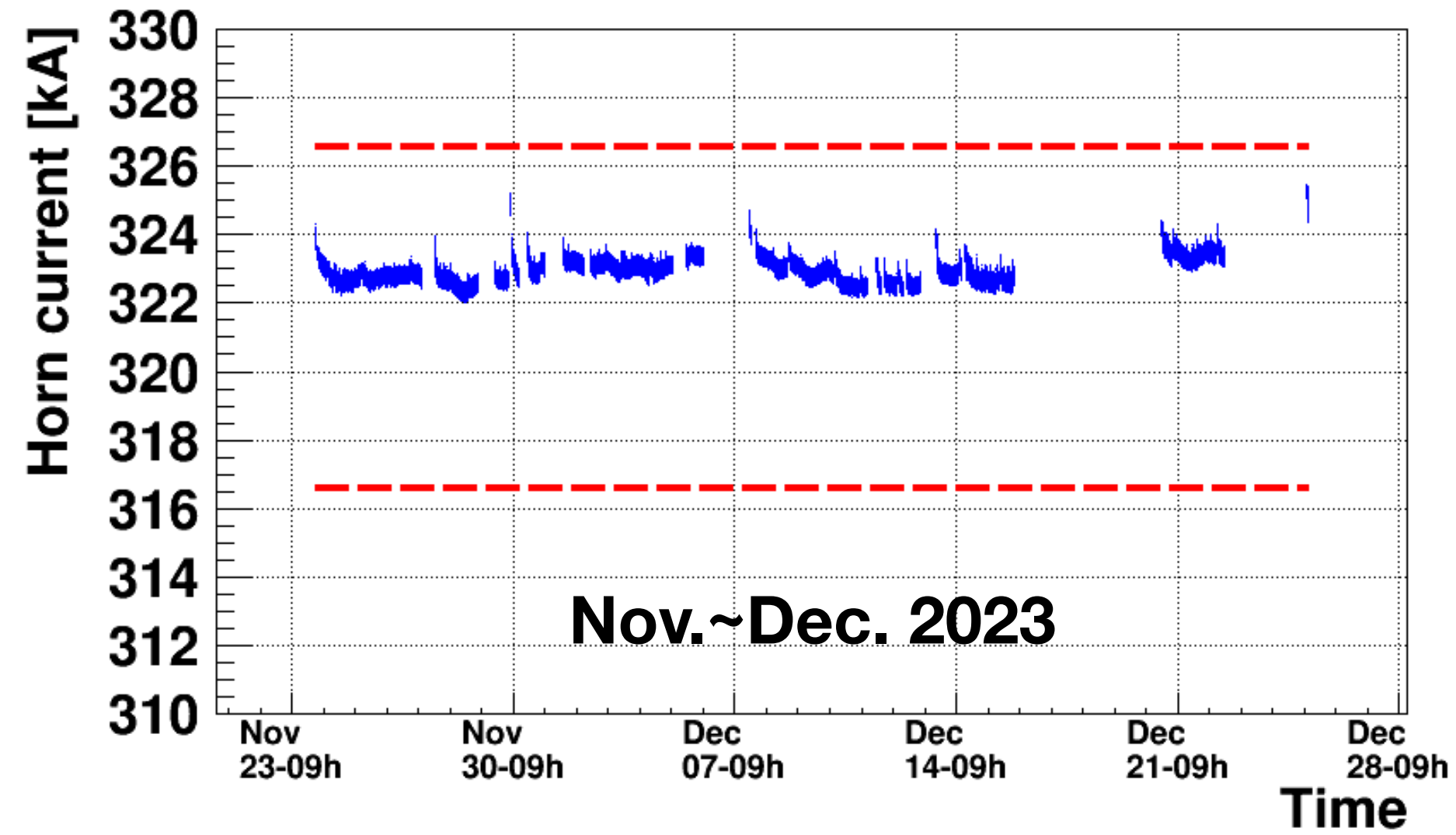


Observed cooling water temperature in Jun. 2024 run



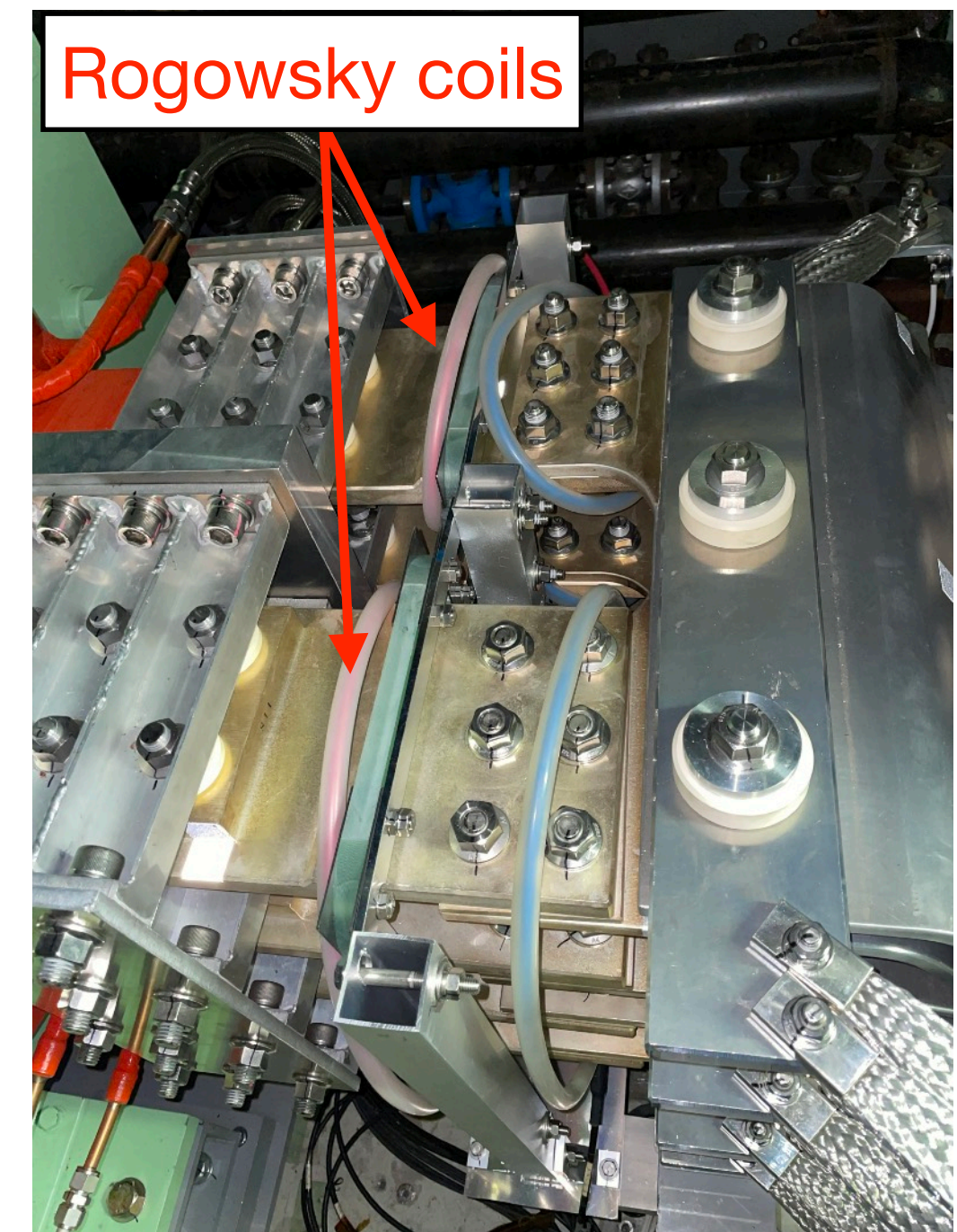
Heat load estimation for Horn1

Parameters	Measured	Expected
Water temperature rise	9.3 $^{\circ}\text{C}$	7.7 $^{\circ}\text{C}$
Calculated heat load @ horn1 conductors	38.8 kJ	32.2 kJ



- Output current at transformers are monitored by Rogowsky coils
- Long-term current variation within 4 kA (\rightarrow 1.2% at full width, FW)
- Uncertainty on horn current measurement is estimated to be $\pm 1.5\%$ (1σ)

Error source	Uncertainty
Coil calibration	$\pm 1\%$ (FW)
Coil shape	$\pm 1\%$ (FW)
Electronics calibration	$< \pm 1\%$ (FW)
Monitor stability	1.2% (FW)
Magnetic field	$\pm 1.5\%$ (FW)
Total uncertainty	$\pm 2.6\%$ (FW) $\xrightarrow{\times 1/\sqrt{12}}$ $\pm 1.5\%$ (1σ)





- J-PARC neutrino beam used for search for CP violation in lepton sector
- J-PARC and neutrino beamline upgrade toward 1.3 MW ongoing
- Magnetic horn is a focusing system with pulsed 320 kA current
- Horn upgrade
 - Horn PS upgrade completed and 320 kA operation successfully performed
 - Upgraded high power horns installed
- All the upgraded horn system are working very well at 800 kW operation