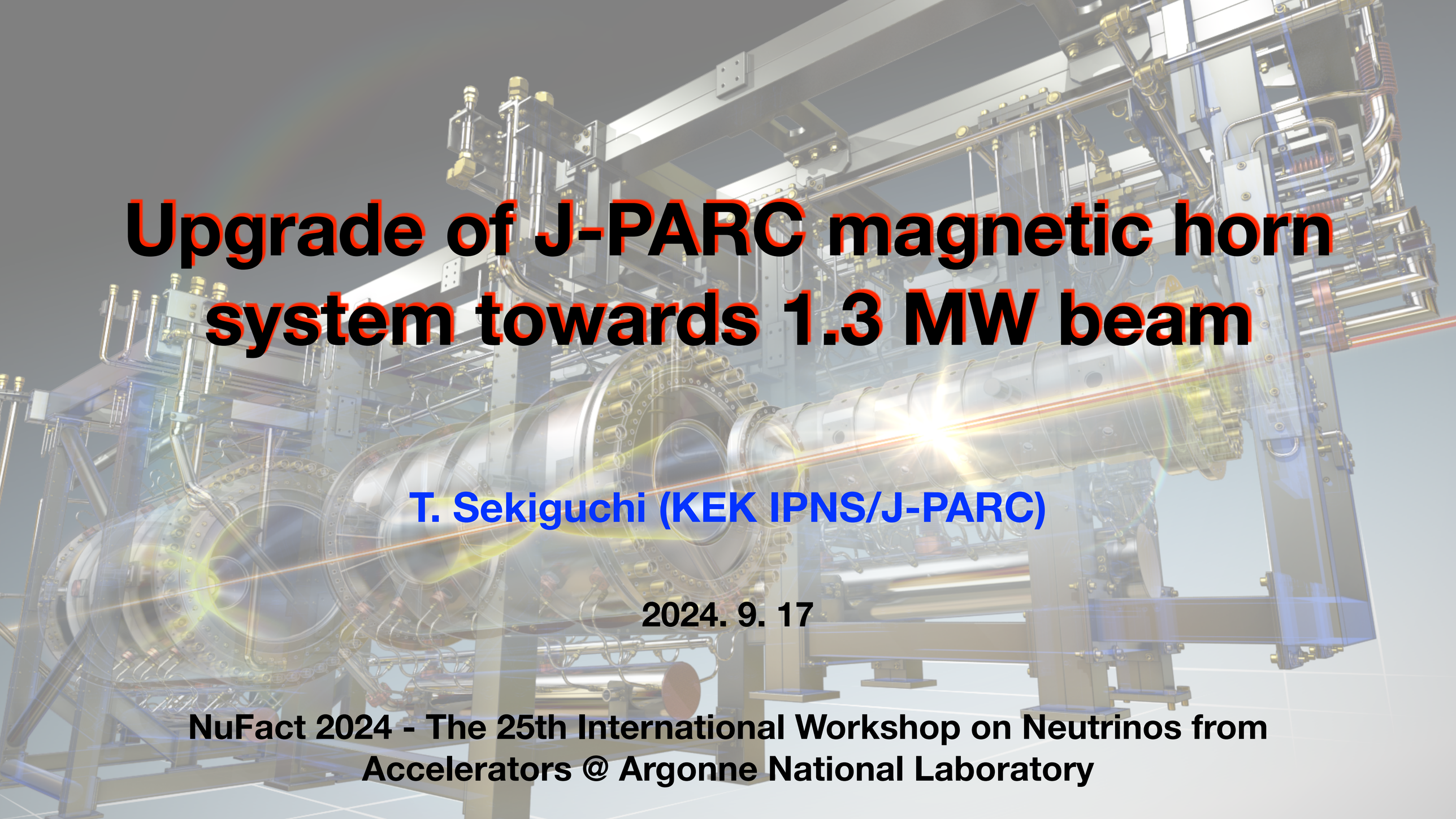


Upgrade of J-PARC magnetic horn system towards 1.3 MW beam

T. Sekiguchi (KEK IPNS/J-PARC)

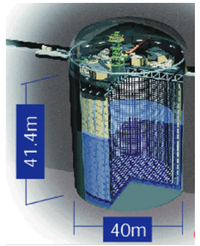
2024. 9. 17

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

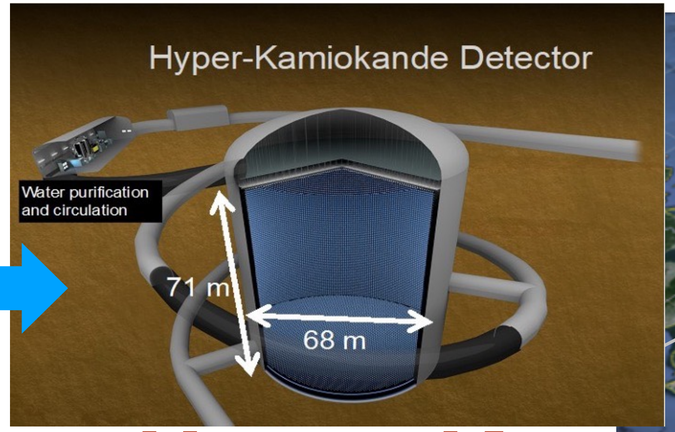
Contents

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

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



Super-K



Hyper-K
(Water Č)

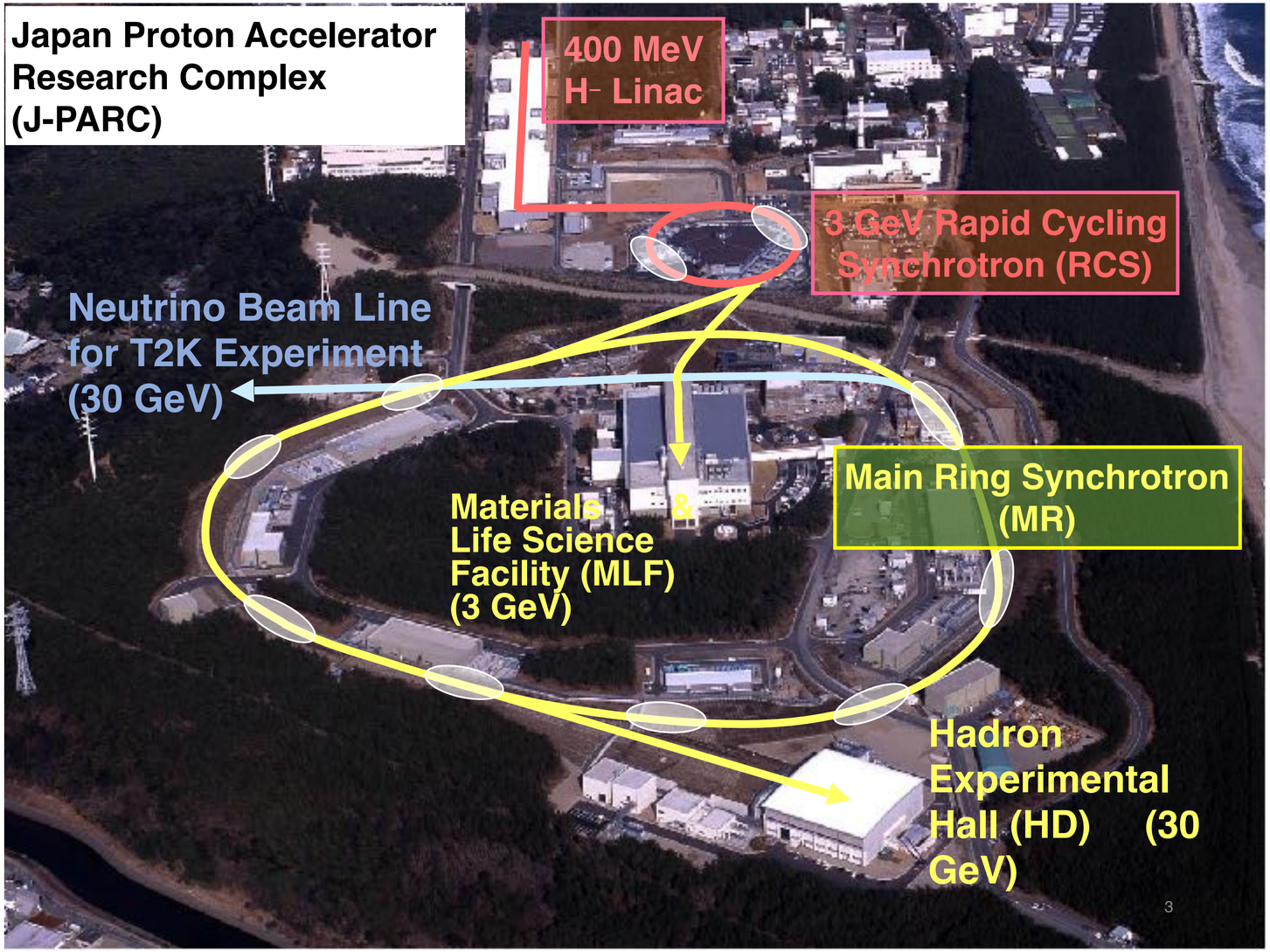
J-PARC
Accelerator Complex

- **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**

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

Beam power **Detector volume**

J-PARC & MR Upgrade

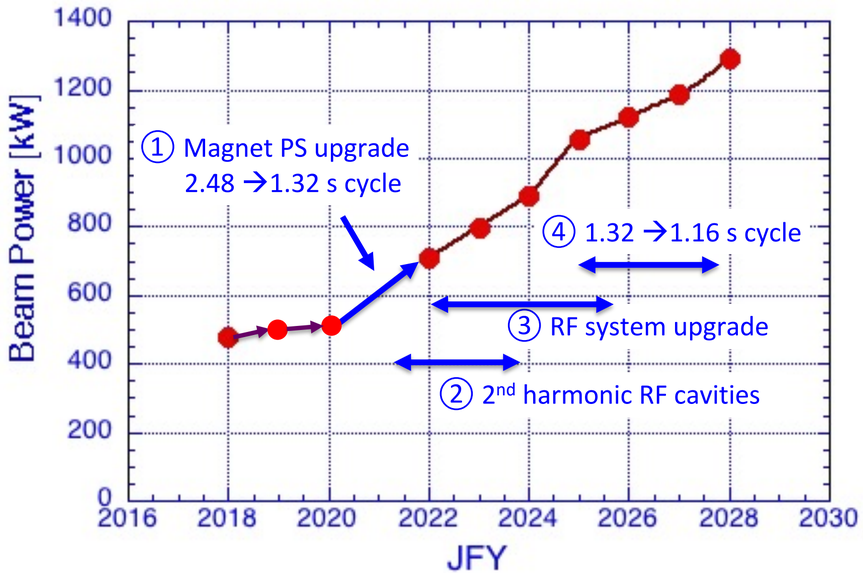


MR upgrade (500 kW → 1.3 MW)

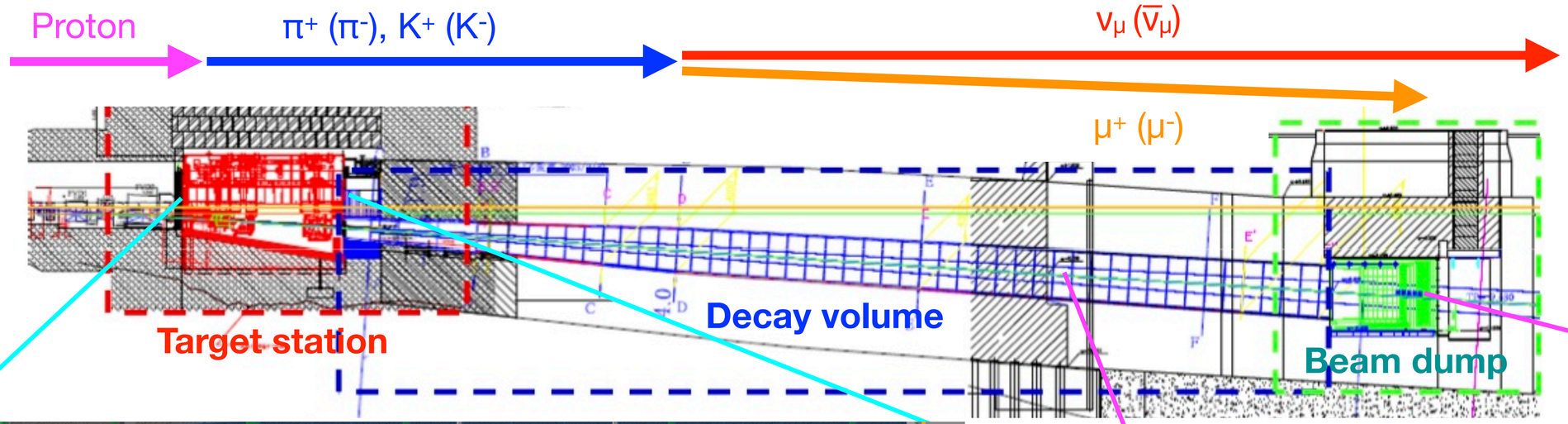
- Faster cycle (2.48→1.16 s) : MR PS upgrade
- More protons per pulse : MR RF upgrade

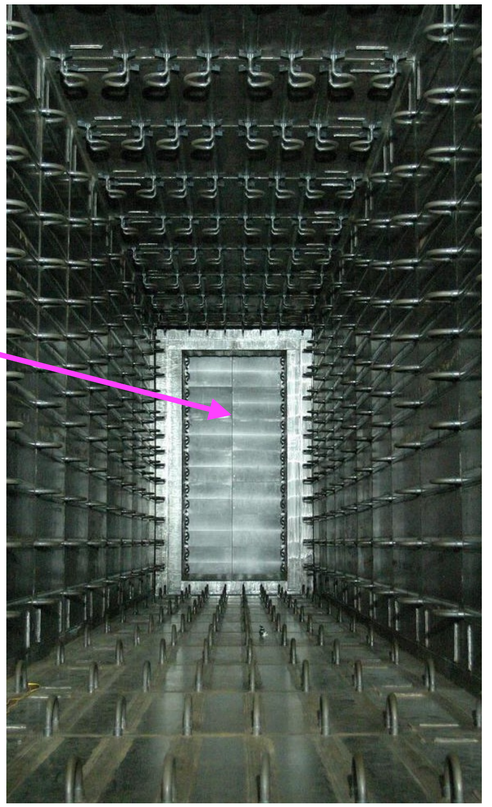
Neutrino beamline will also be upgraded

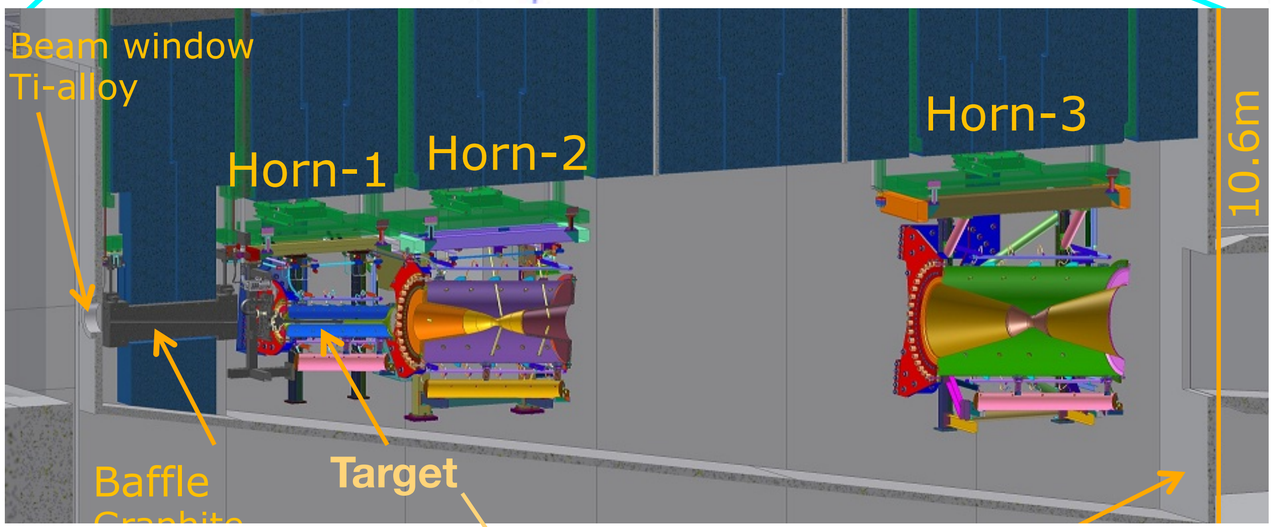
	Before upgrade	After upgrade
Beam power [MW]	0.5	**1.3**
Proton intensity [10^{14}/pulse]	2.6	**3.2**
Cycle [s]	2.48	**1.16**

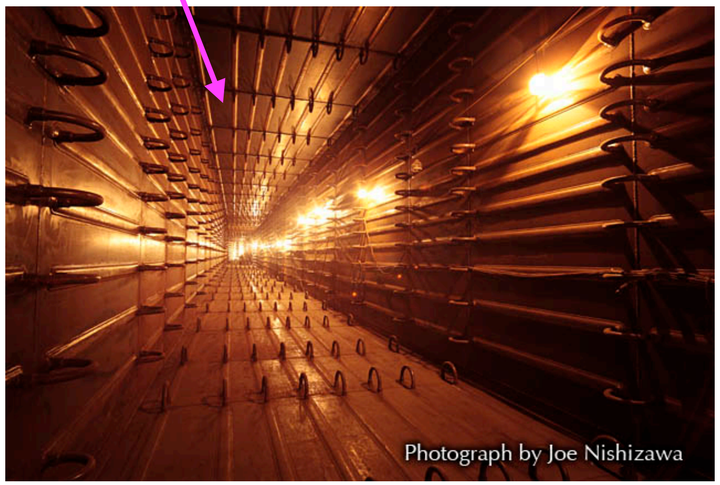


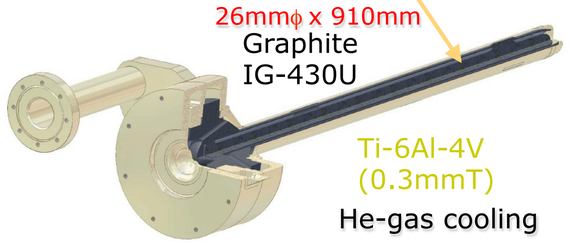
Secondary Beamline









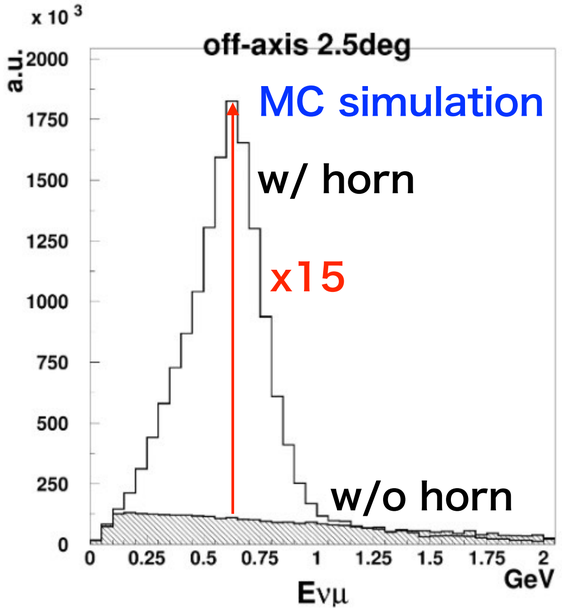


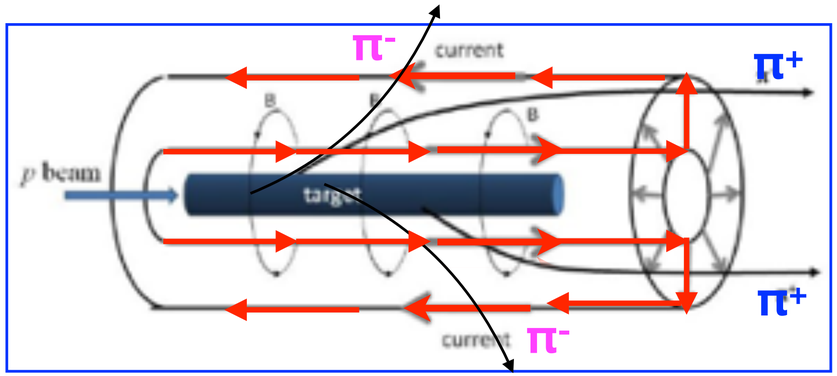
- Target and three horns inside TS He vessel
- 100m-long Decay Volume
- Beam dump at most downstream of DV

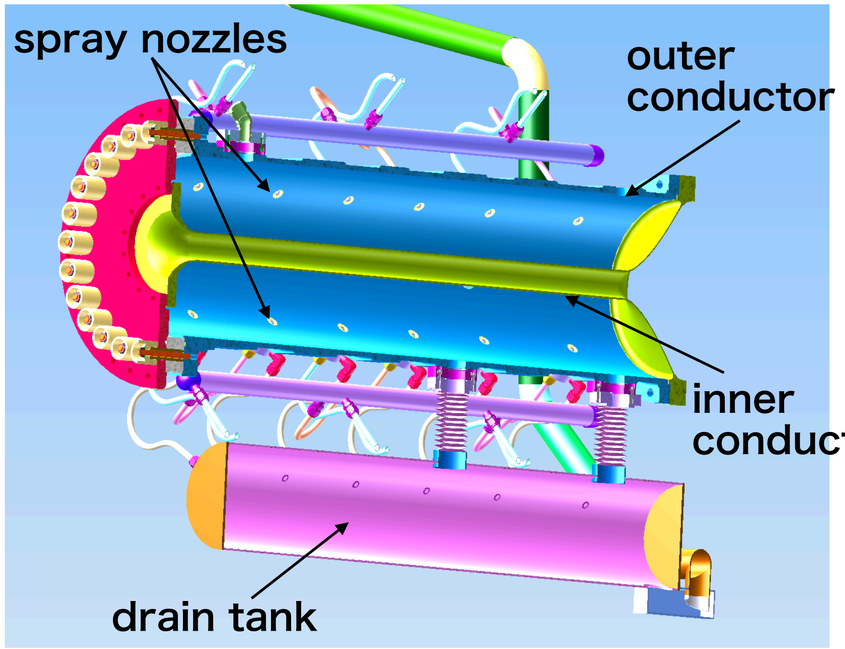
Magnetic Horn

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

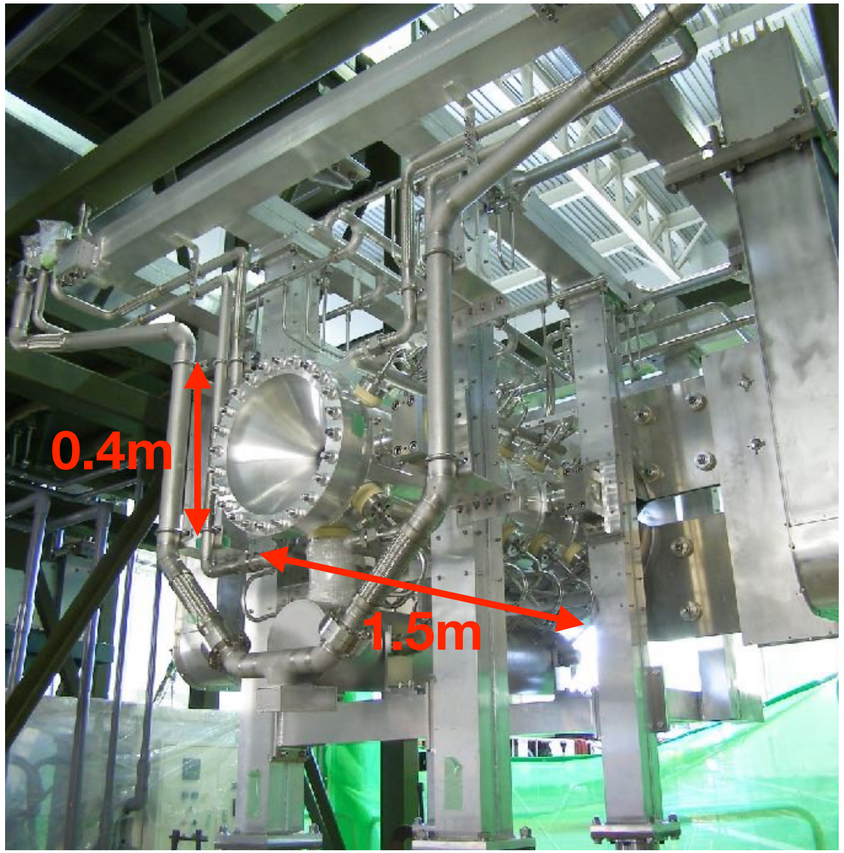




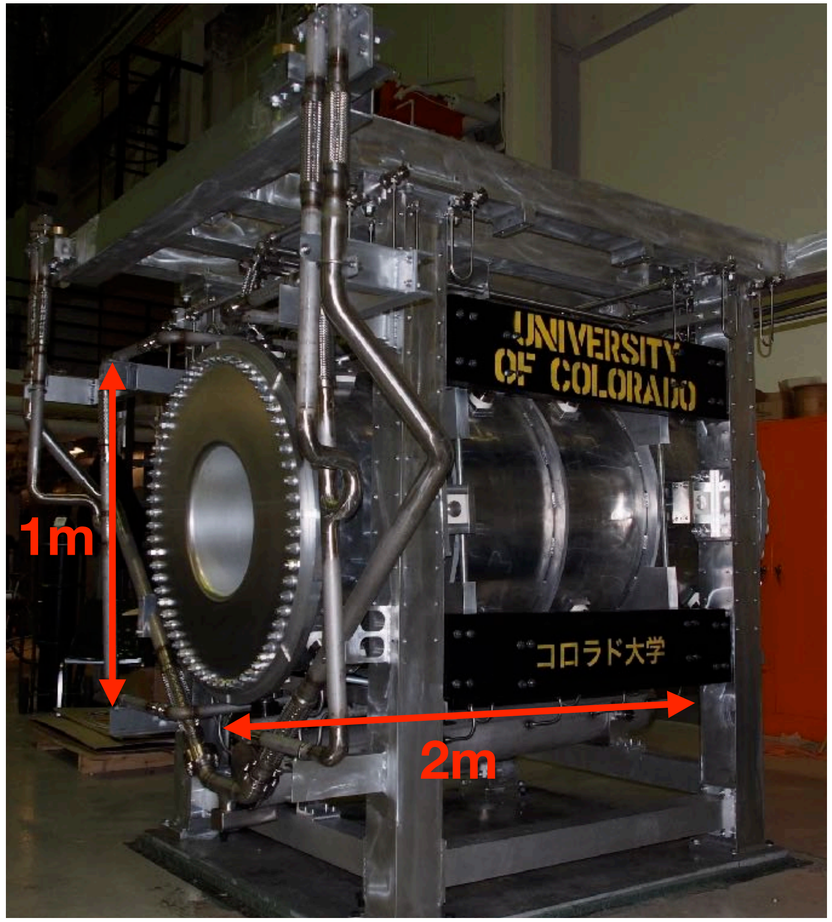


Magnetic Horns

Horn1



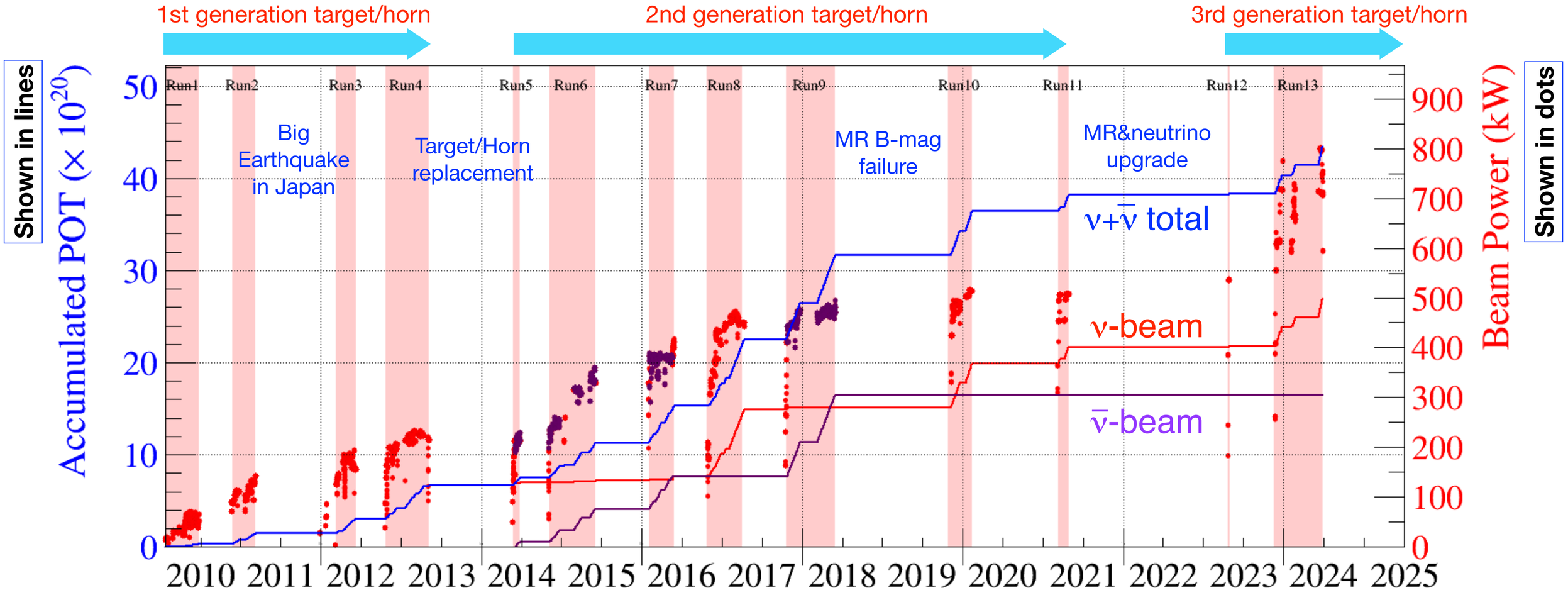
Horn2



Horn3

Beam Operation History

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



Total accumulated POT for T2K : 4.35 x 10^{21} POT (as of Jun. 2024) → 1.0x10^{22} POT (T2K goal)

c.f., 2.7x10^{22} POT (HK 10-years)

Horn Upgrade Overview

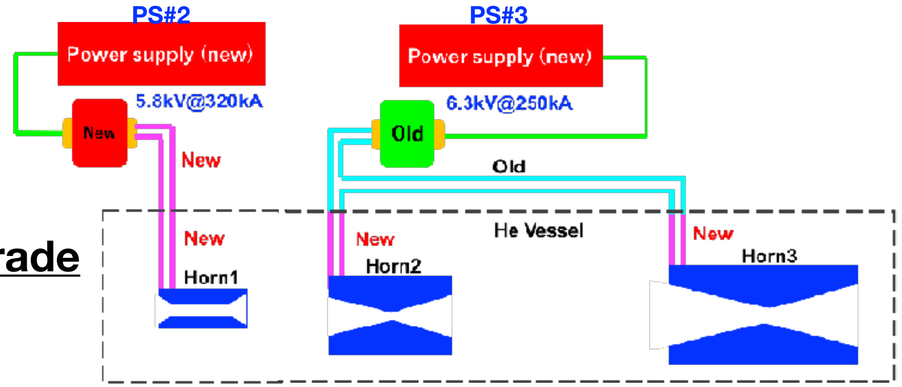
Horn PS upgrade for 250→320 kA at 1 Hz

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

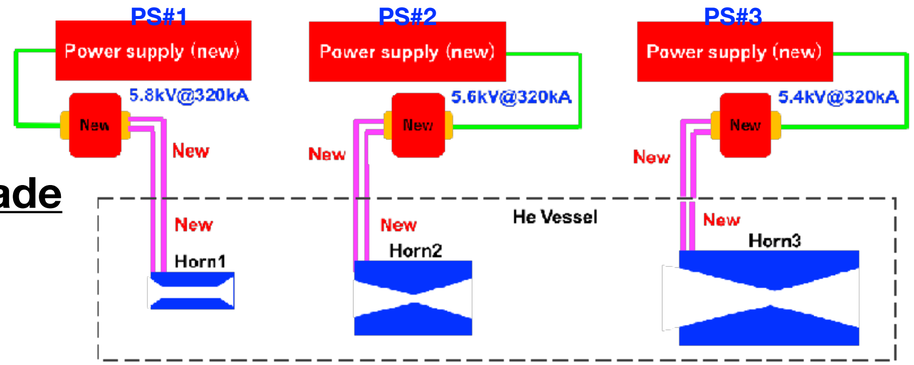
Horn replacement with upgraded horns

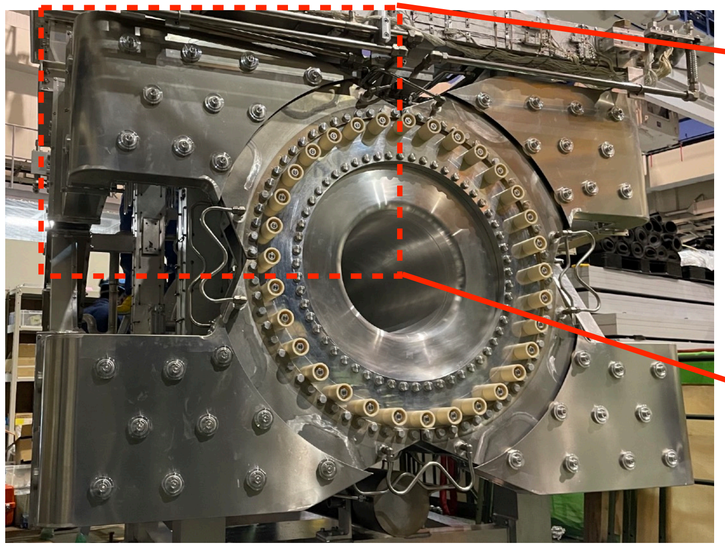
- New horn2 with improved cooling
- New horn1 with improved water sealing

Before upgrade

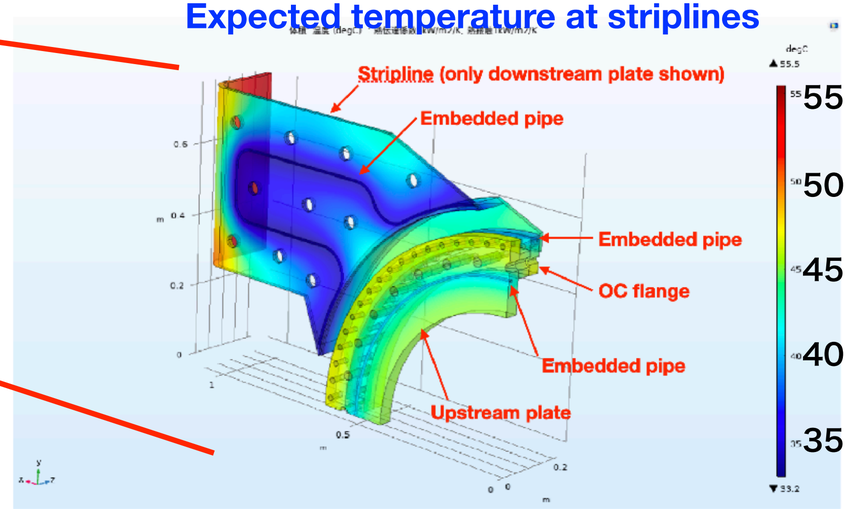


After upgrade



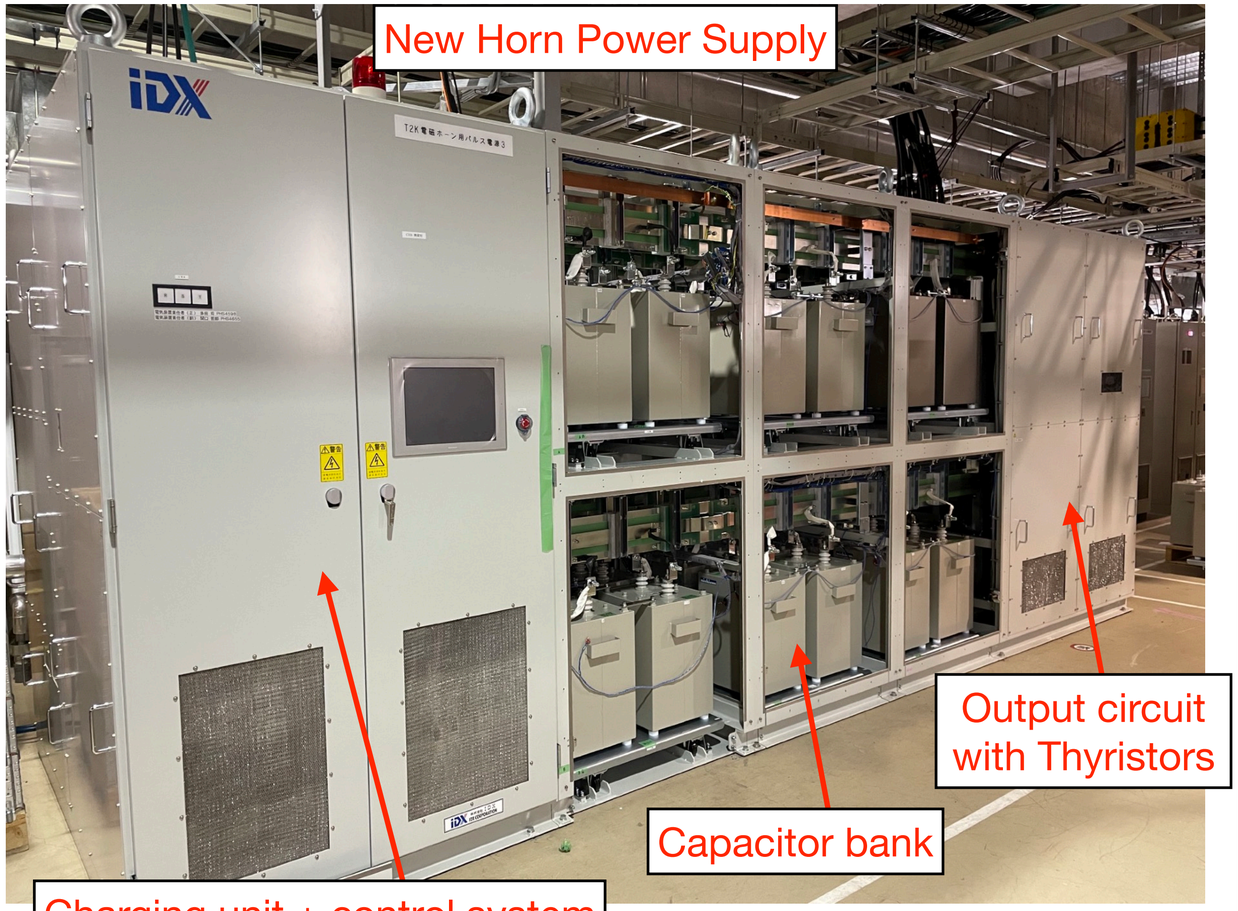


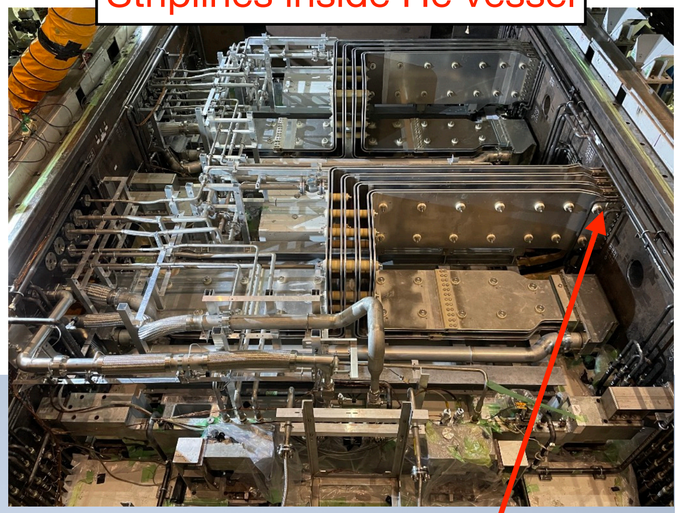
Expected temperature at striplines

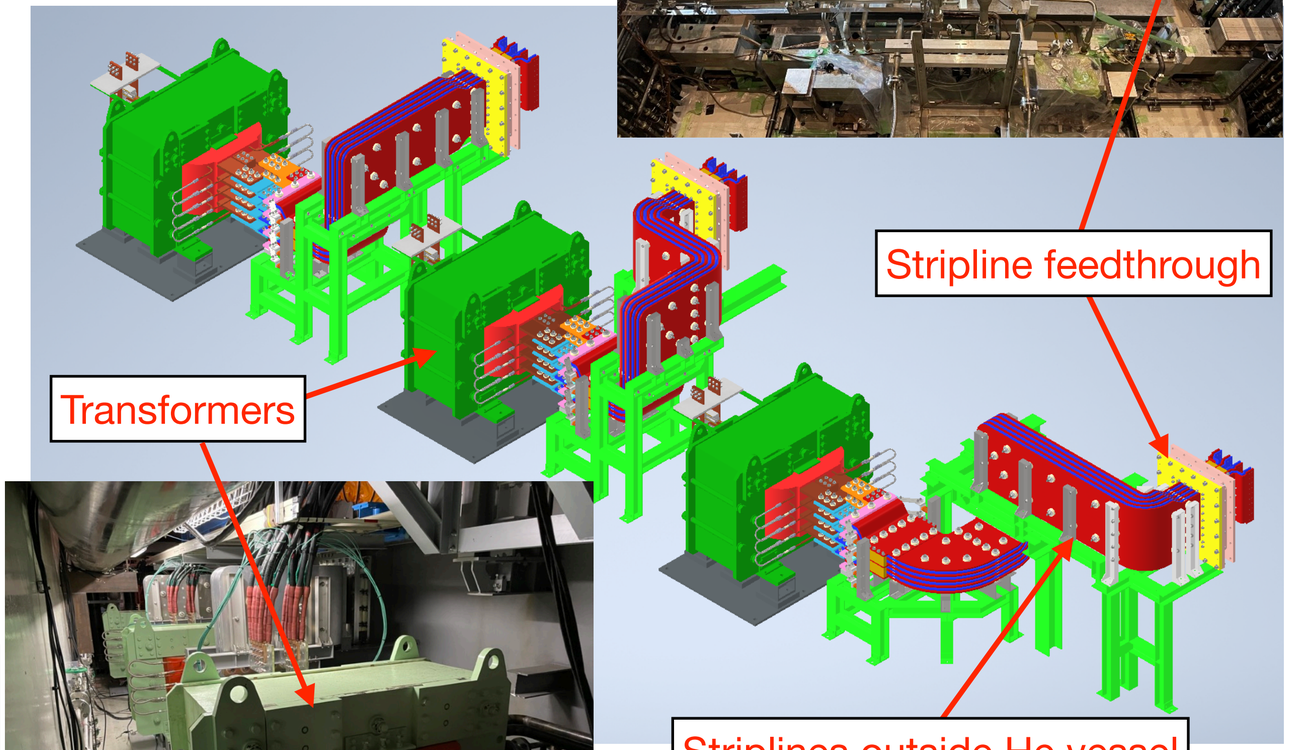


Horn Power Supply Upgrade

- 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



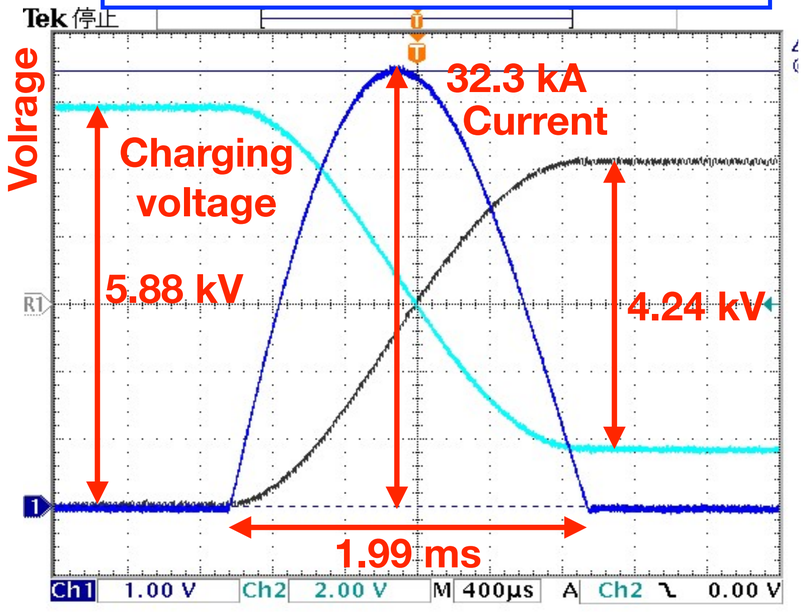




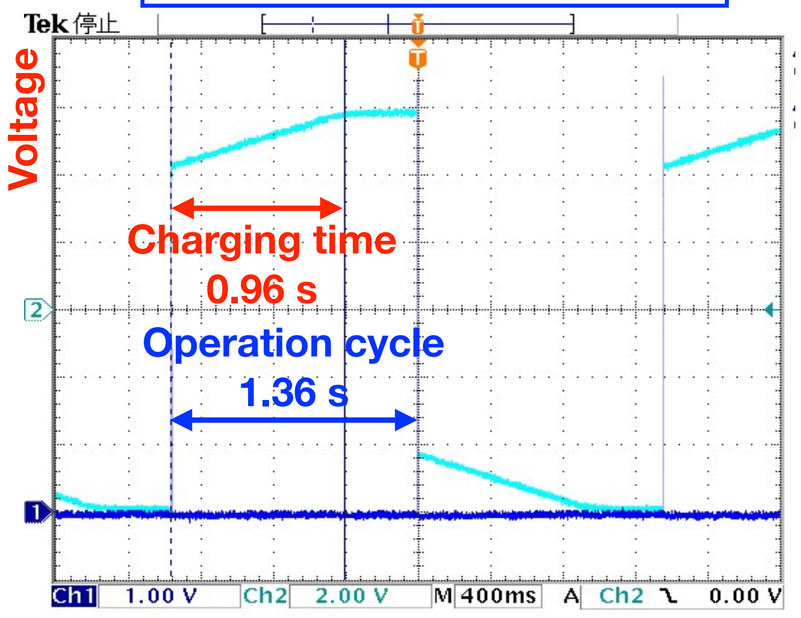
Horn Power Supply Upgrade

- 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

Current and voltage pulse shape



Charging pattern with 1.32 s



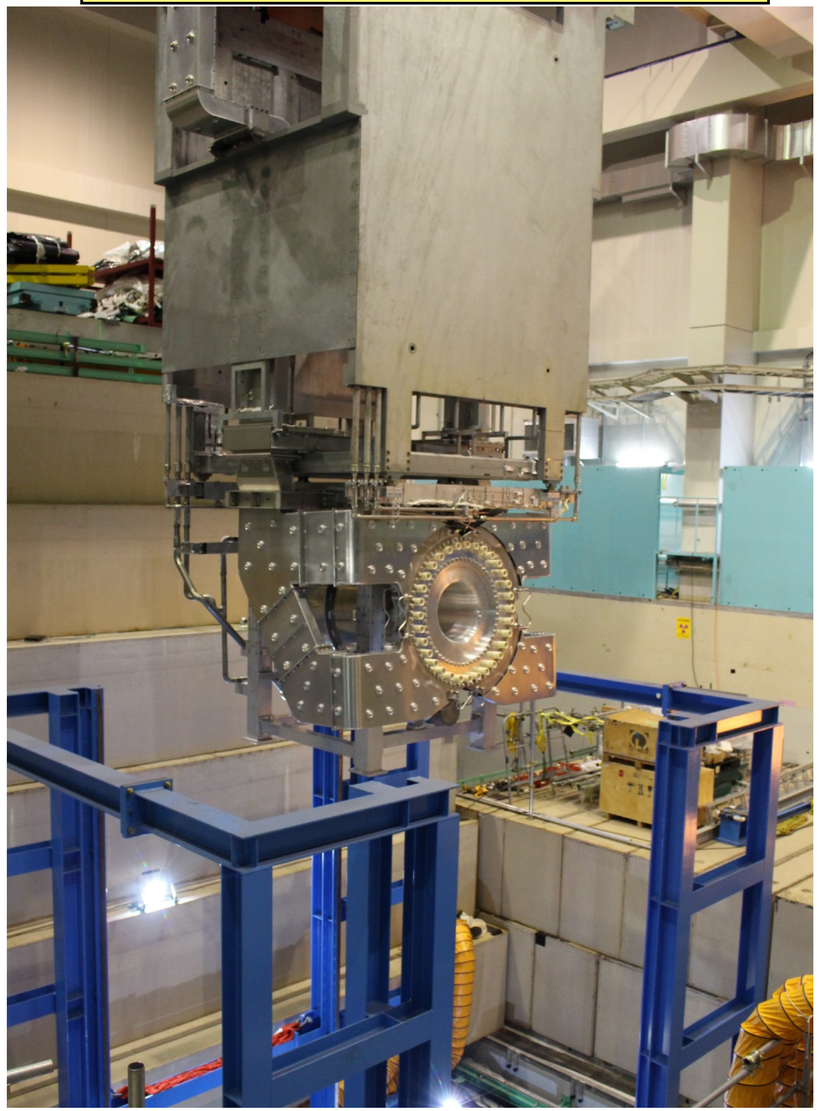
Parameters	Measured
PS Output current	32.3 kA
Pulse width	1.99 ms
Operation cycle	1.36 s
Charging voltage	5.88 kV
Reverse voltage	4.24 kV
Recovery rate	72.1%
Charging time	0.96 s

Replacement with High Power Horns

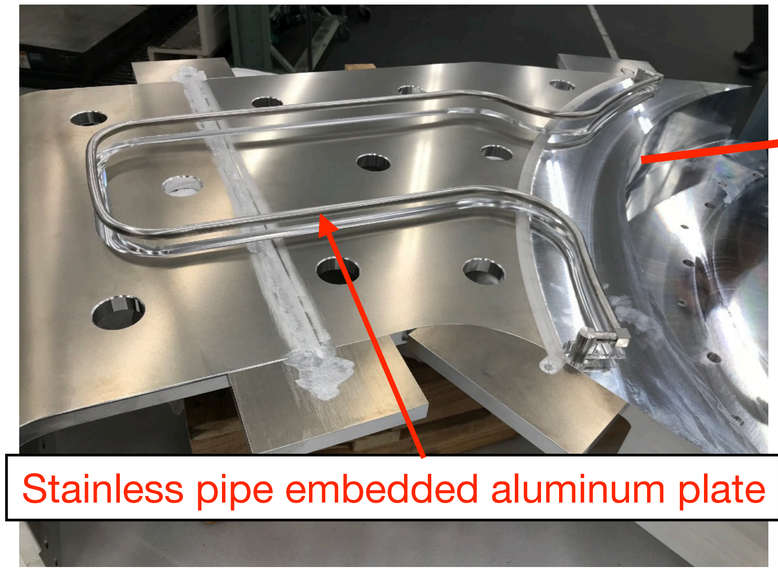
Remote handling using remote-controlled overhead crane and dedicated guide system

New Horn1 (3rd gen.) installation

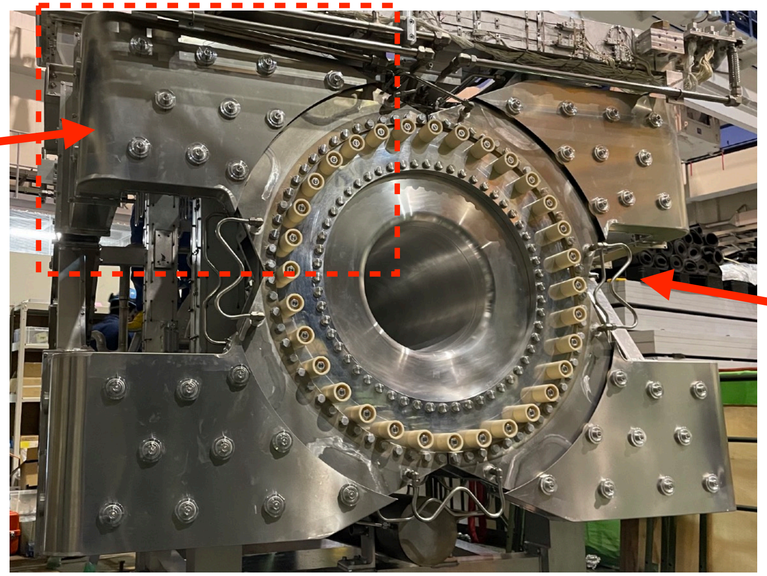
New Horn2 (3rd gen.) installation



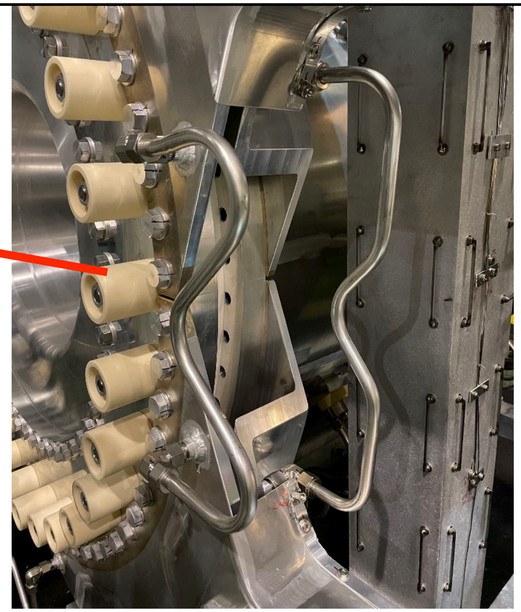
Features of New Horn2



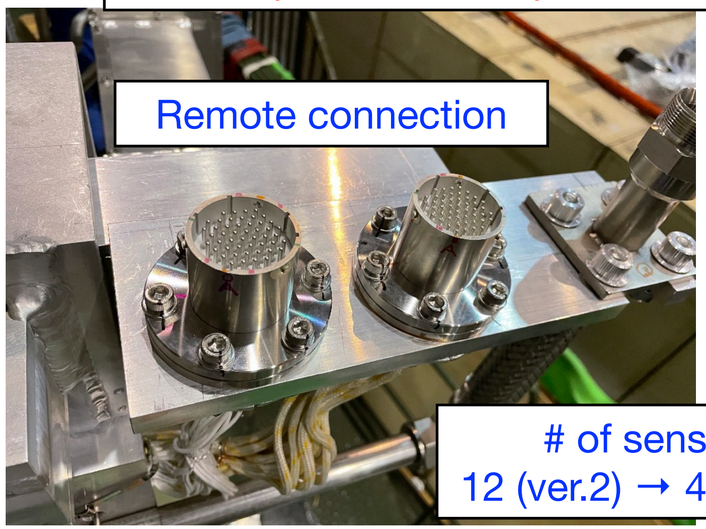
Stainless pipe embedded aluminum plate



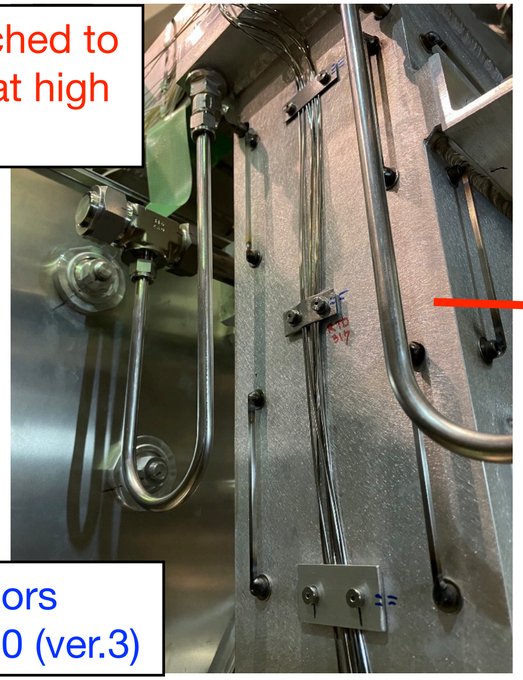
Bent tubes for stripline cooling loops



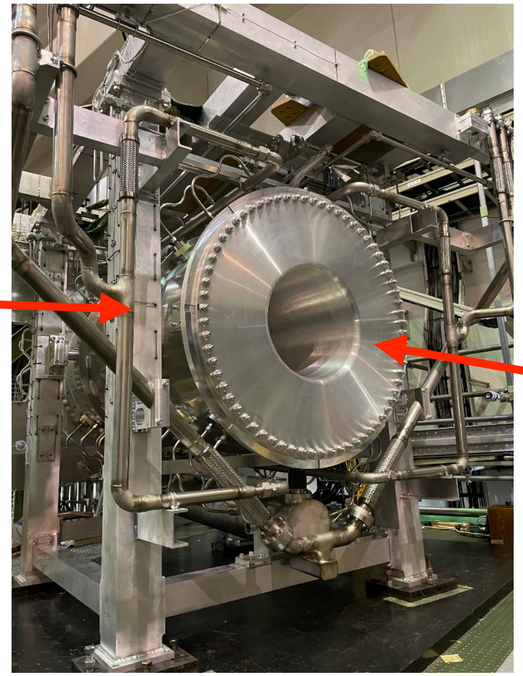
Many temperature sensors attached to measure temperature increase at high power beam operation

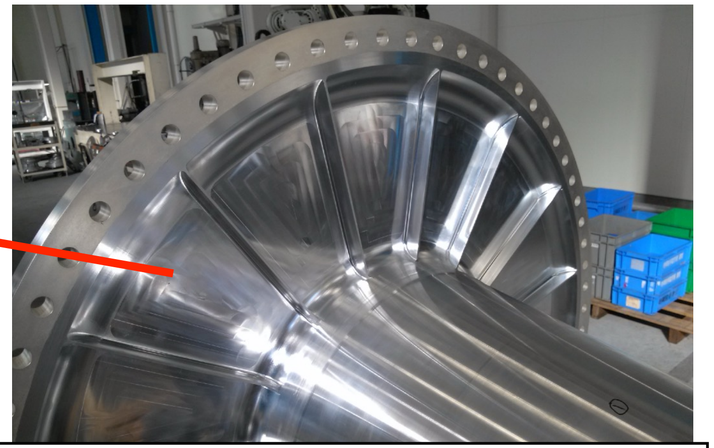


Remote connection



# of sensors
12 (ver.2) → 40 (ver.3)

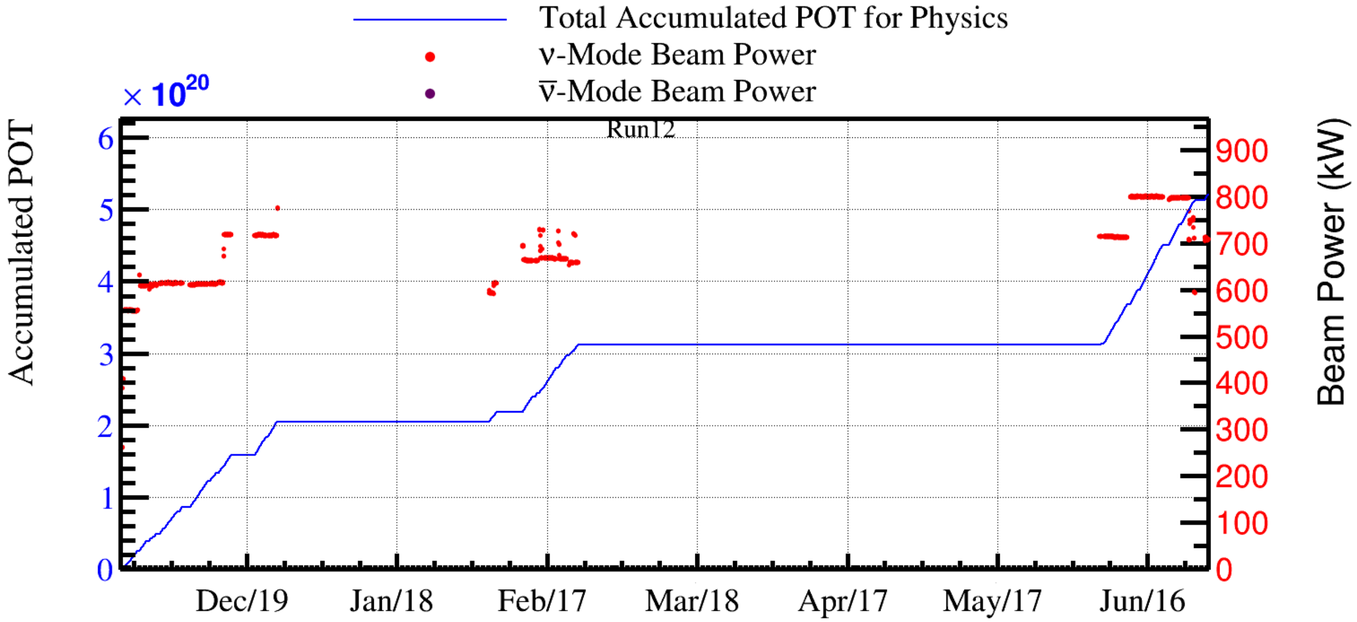




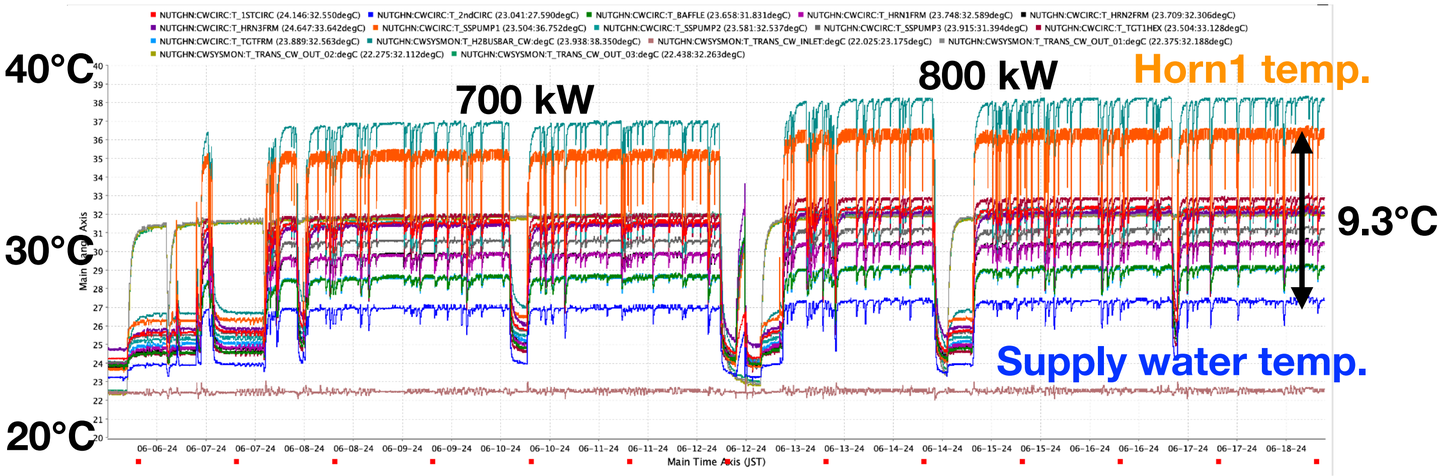
Ribbed upstream and downstream plates to strengthen the inner conductor

Beam Operation After Horn Upgrade

- Beam operation for physics run was resumed in Nov. 2023
- 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



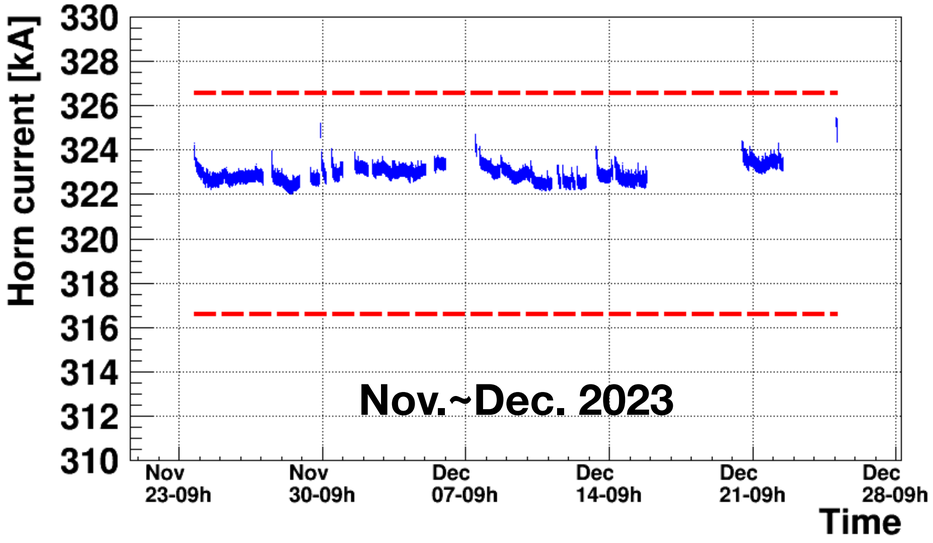
Observed cooling water temperature in Jun. 2024 run

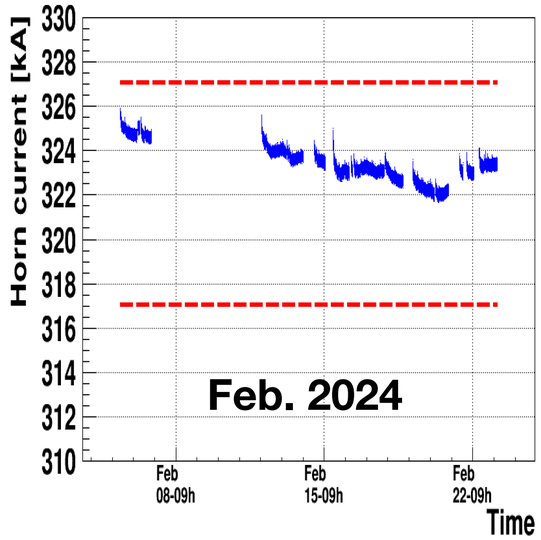


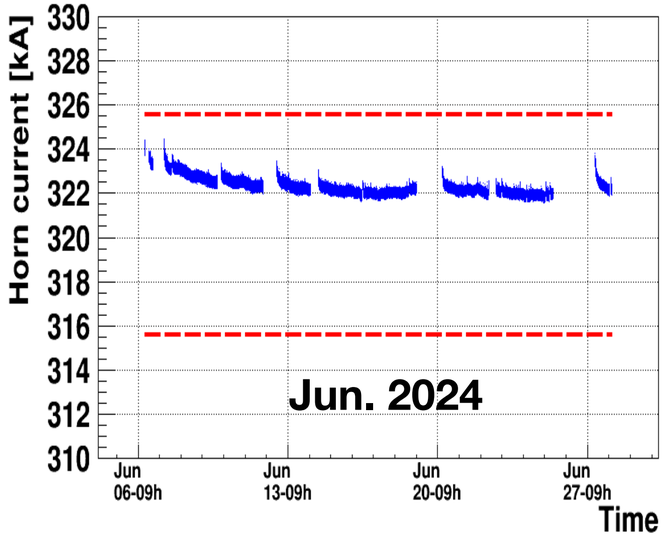
Heat load estimation for Horn1

Parameters	Measured	Expected
Water temperature rise	9.3 °C	7.7 °C
Calculated heat load @ horn1 conductors	38.8 kJ	32.2 kJ

Horn Current Measurement



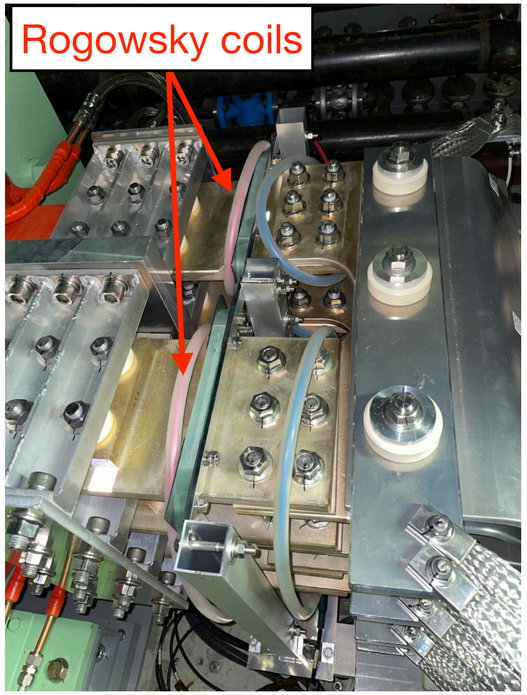




- Output current at transformers are monitored by Rogowsky coils
- Long-term current variation within 4 kA (→1.2% at full width, FW)
- Uncertainty on horn current measurement is estimated to be ±1.5% (1σ)

Error source	Uncertainty
Coil calibration	±1% (FW)
Coil shape	±1% (FW)
Electronics calibration	< ±1% (FW)
Monitor stability	1.2% (FW)
Magnetic field	±1.5% (FW)
Total uncertainty	±2.6% (FW)

$\times 1/\sqrt{12}$ → ±1.5% (1σ)



Summary

- 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
- Major horn upgrade completed in FY2021-2022
  - 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