HK Neutrino Beam

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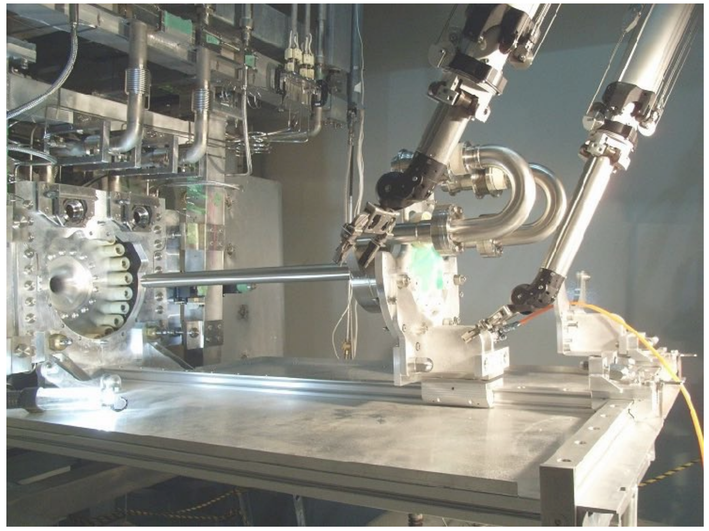
for J-PARC Neutrino Beamline Group

June 4, 2022



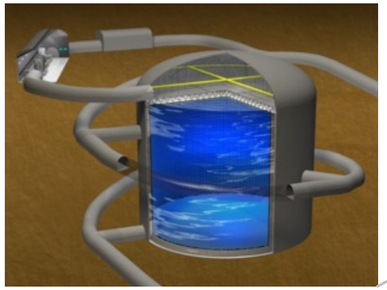
XXX International Conference on Neutrino Physics and Astrophysics (NEUTRINO 2022)

Outline

- Overview of accelerator neutrino beam
- J-PARC upgrade towards 1.3 MW
  - Accelerator upgrade
  - Neutrino beamline upgrade
- Summary

Overview

J-PARC neutrino beam to Kamioka (T2K / Hyper-K)



Hyper-K
(Water Č)

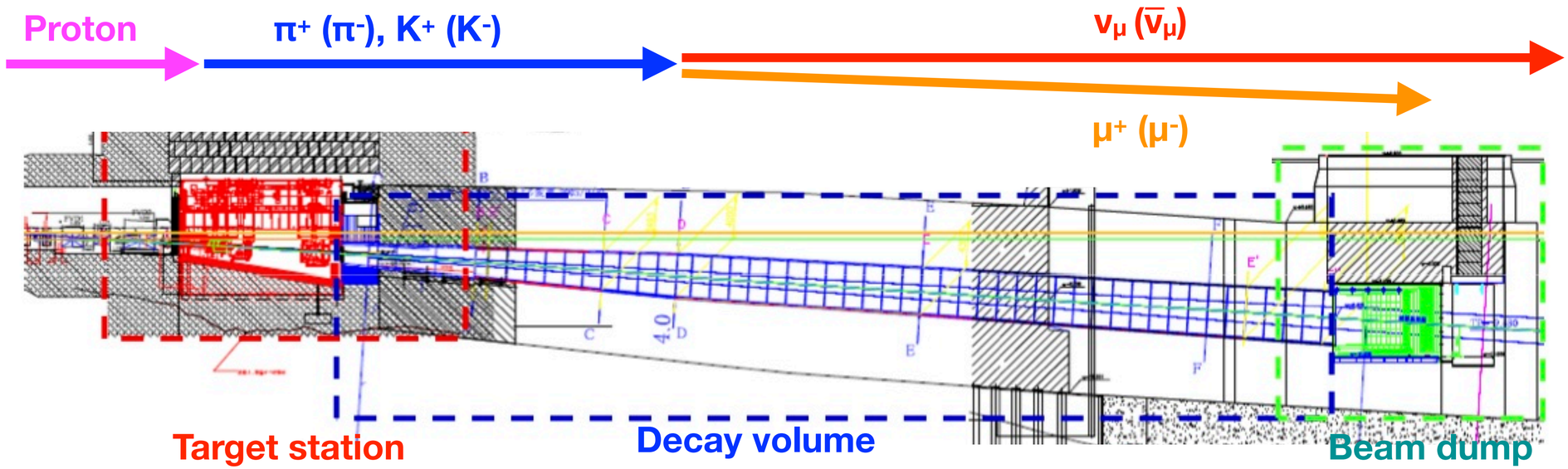
J-PARC
Accelerator Complex

- **Accelerator-based neutrino oscillation experiments are playing an important role in neutrino physics since 1999**
  - Recent T2K results showed **a hint of large CP violation** in neutrino sector
- **Next generation experiments (Hyper-K/DUNE) are aiming to reveal full picture of neutrino oscillation with precise measurements of CP and mixing parameters, and determination of mass ordering**
  - Sensitivity for CP violation 2~3σ (current) → **>5σ** (future)
  - ~10 times statistics needed
- To achieve it,
  - **~10 x larger new detectors**
  - **>1MW-class beam power needed**

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

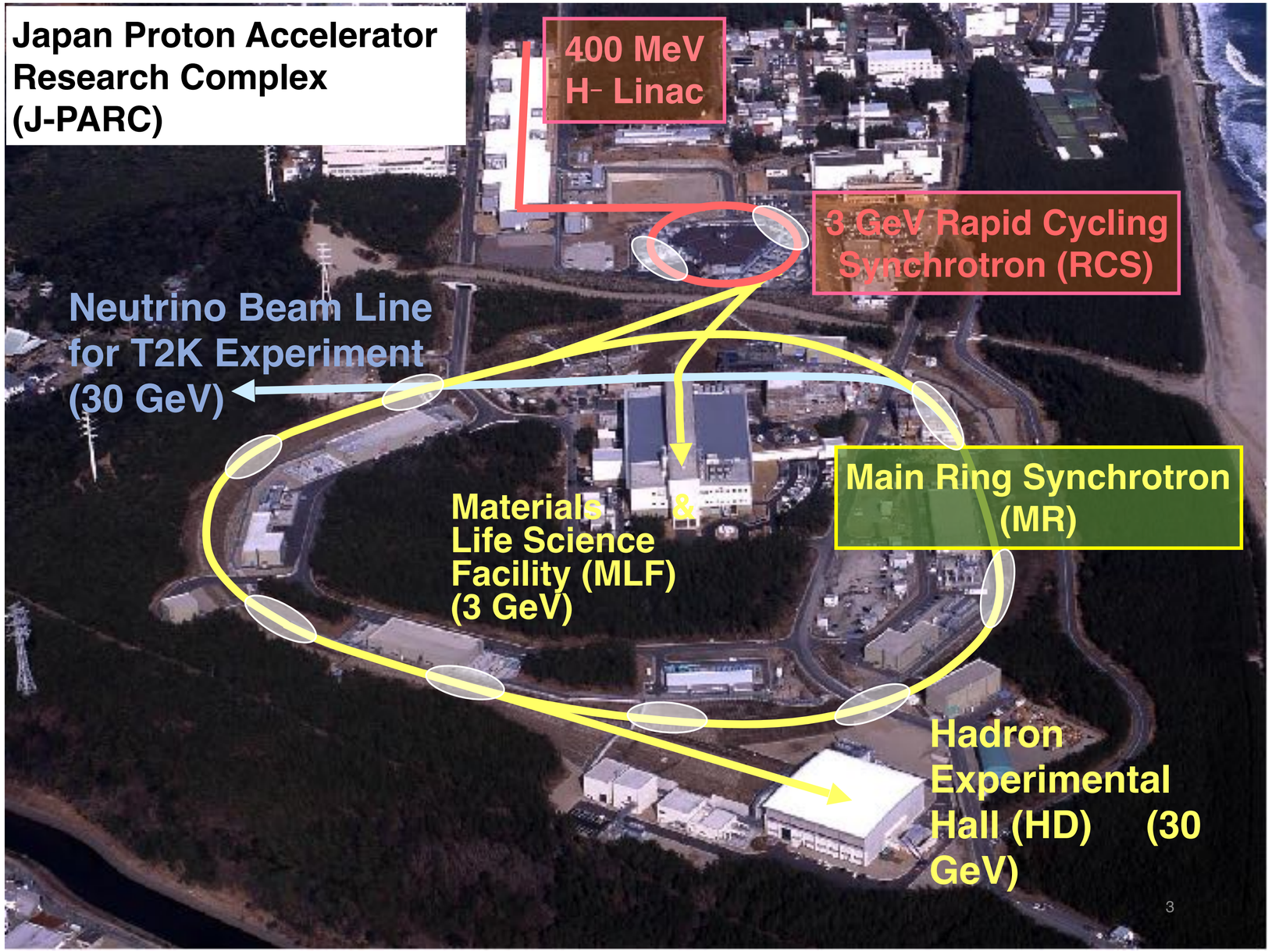
Beam power **Detector volume**

Neutrino Beam Production



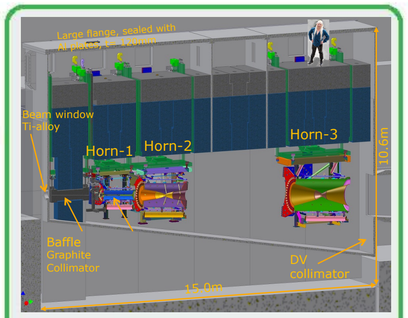
- High intensity proton beam hit a graphite target
- Secondary π/K's focused by magnetic horns and decay to neutrinos
  - Neutrino beam from $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - Antineutrino beam from $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
  - Sign-selected neutrino beam by flipping the horn polarity
- All hadrons absorbed by beam dump
- High energy muons penetrating beam dump measured by muon monitors

J-PARC


Japan Proton Accelerator Research Complex (J-PARC)
400 MeV H⁻ Linac
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Beam Line for T2K Experiment (30 GeV)
Main Ring Synchrotron (MR)
Materials & Life Science Facility (MLF) (3 GeV)
Hadron Experimental Hall (HD) (30 GeV)
3

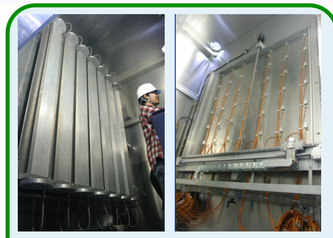
Neutrino Beamline

Target-Horn System



Target Station

Primary Beam-line



Muon monitors

295km to
Super-Kamiokande

Muon neutrino

muon

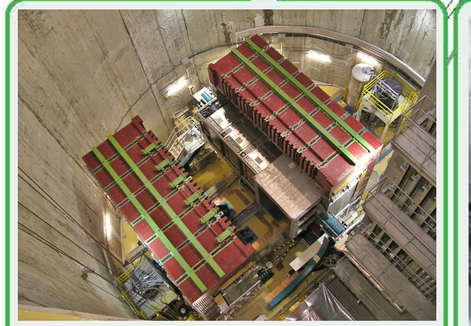
π-meson

Final Focusing
Section

Proton

110m

280m

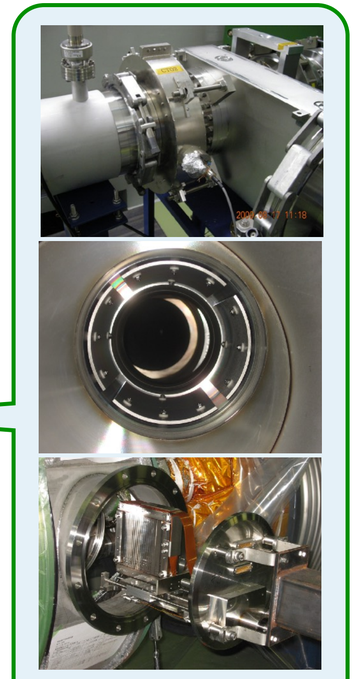


Near Neutrino Detector

Beam Dump

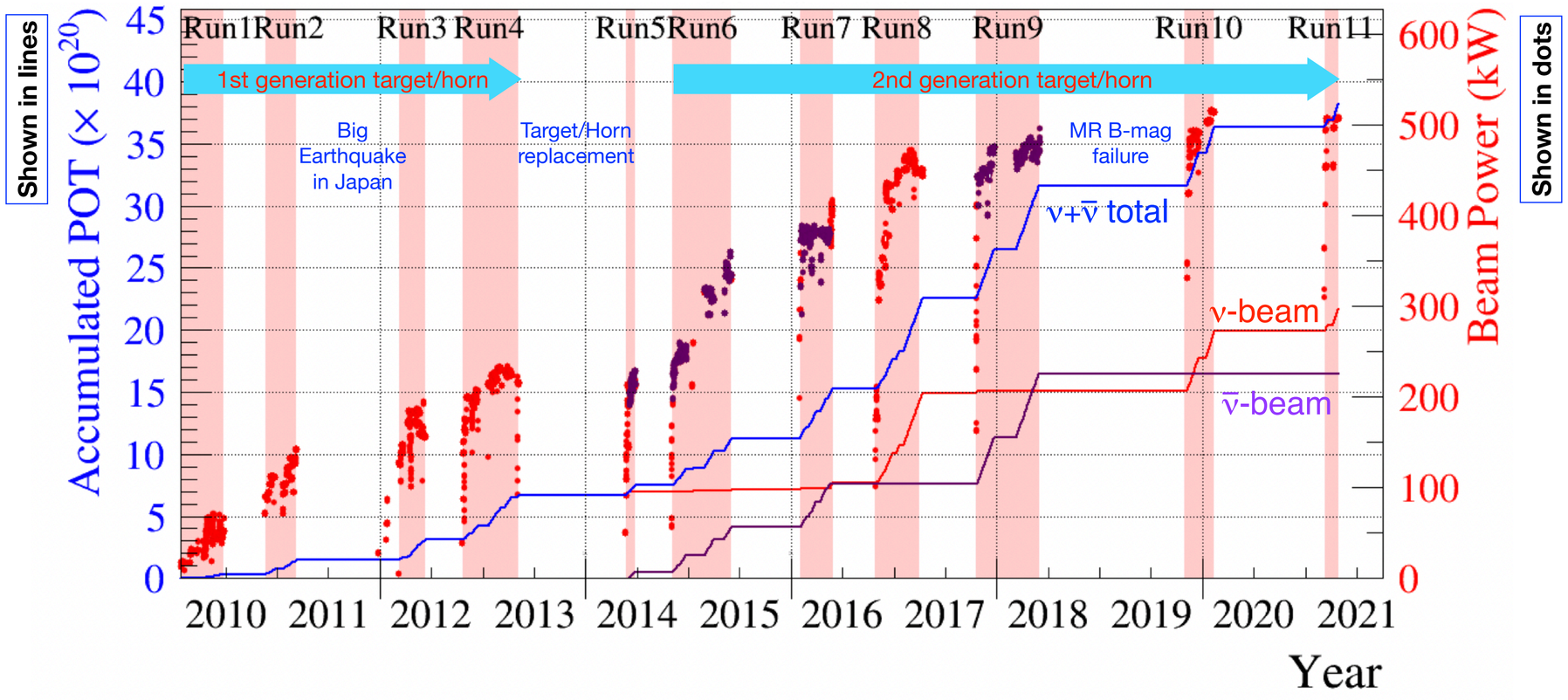
Decay Volume

Superconducting combined
function magnets at ARC Section



Proton beam monitors

Status of J-PARC Neutrino Beam



- Started physics data taking in January 2010
- **510 kW** stable operation achieved : **2.6x10^{14}** protons/pulse

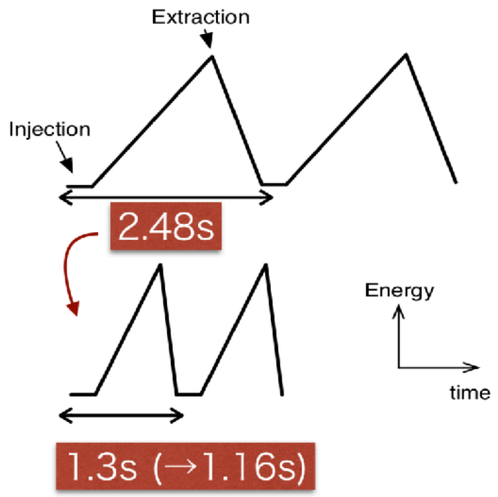
  ⇒ World-highest intensity (# of protons/pulse) in fast-extracted beam from proton synchrotron
  - Beam power limited by space charge effect, beam instability due to insufficient RF voltage
- Provide **3.82x10^{21}** protons on target (POT) to T2K
  - ν mode POT : 2.17x10^{21} (56.8%), anti-ν mode POT : 1.65x10^{21} (43.2%)

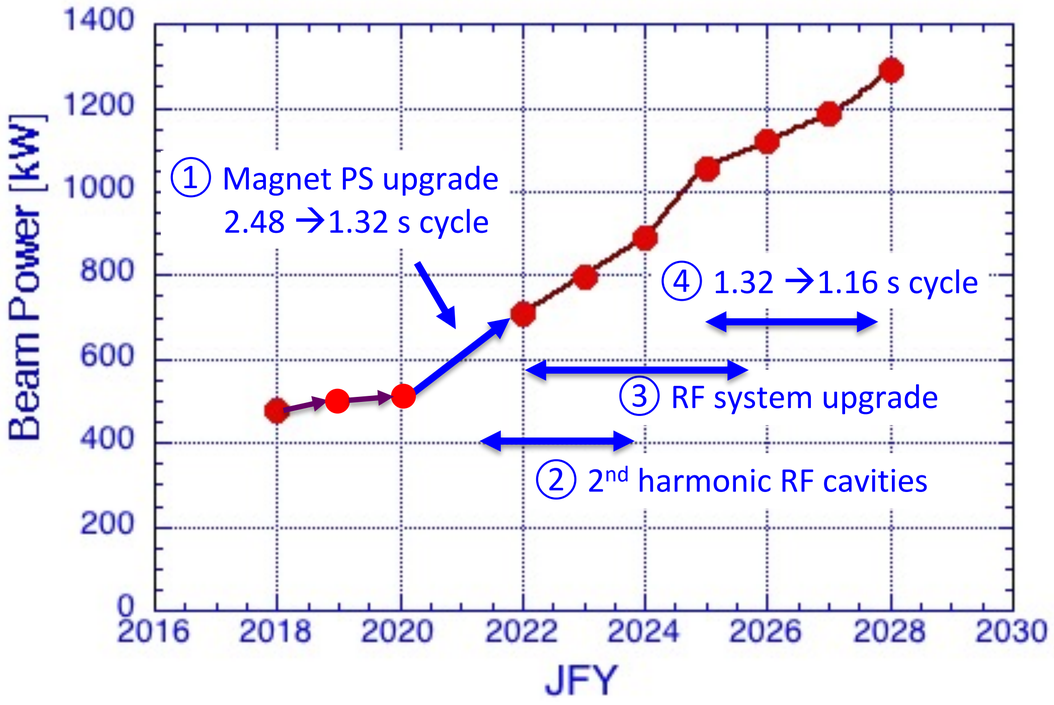
J-PARC Upgrade Toward 1.3 MW

- **Staged accelerator upgrade toward 1.3 MW**
  - **Shorter cycle** (2.48s→1.36s) for >750 kW (FY2022)
    - MR magnet PS upgrade
    - 2nd harmonic RF cavities
  - **Higher beam intensity** for 1.3 MW (~FY2028)
    - Increase # of RF cavities (9 → 11)
    - RF anode PS upgrade
- **Upgrade of neutrino beamline is also needed**

	Previous (until FY2021)	Upgrade
Beam power [MW]	0.5	**1.3**
Proton intensity [10^{14} / pulse]	2.6	**3.2**
Cycle [s]	2.48	**1.16**

Power ∝ E_{beam} x Intensity x 1/cycle

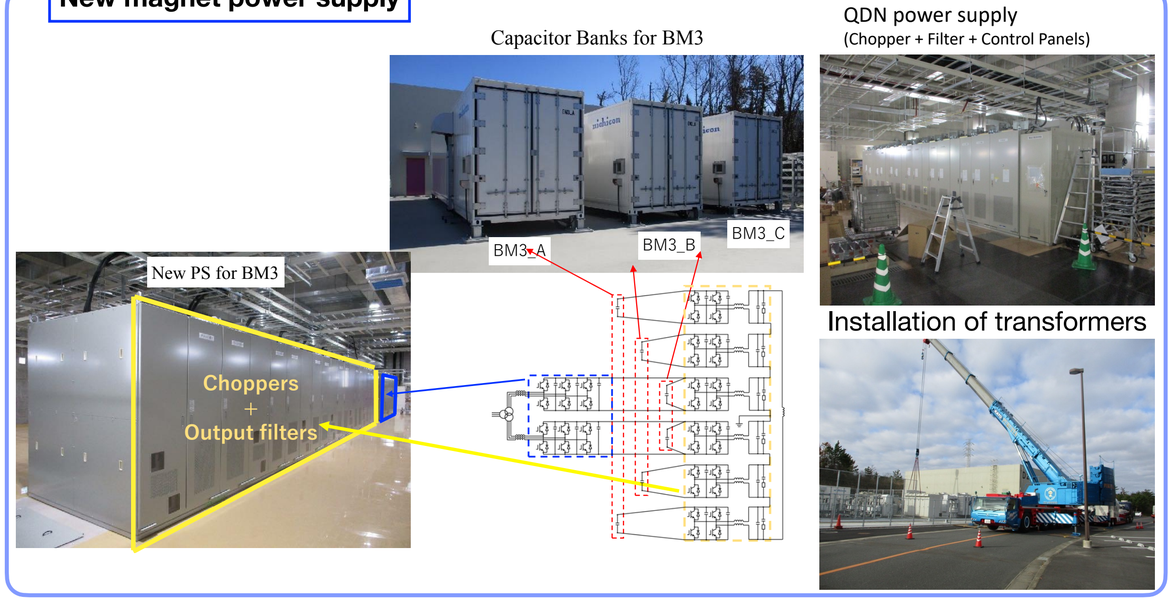




MR Upgrade

- **Power supply upgrade**
  - New MR magnet PS with large capacitor bank (for B-&Q-magnets)
  - Installation of all new magnet PSs completed in JFY2021
  - PS operation test of 1.3 s cycle was succeeded in April-May 2022
- **RF system upgrade**
  - Higher RF voltage is required for higher rep. rate
  - Additional 2 fundamental RF cavities (9→11) **JFY2022~2025**
  - New 2nd harmonic RF system **JFY2021~2023**
  - Anode PS upgrade (15→19 units) **JFY2022~2025**
- **Other upgrades**
  - New fast-extraction devices (kicker, septum) **~JFY2022**
  - Collimator capacity upgrade (2kW→3.5kW) **~JFY2022**
- **Beam commissioning in June 2022 → Beam operation from Fall 2022**

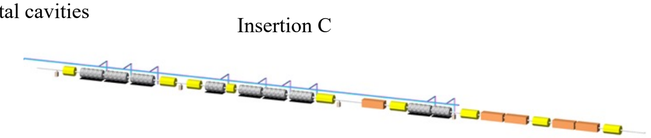
New magnet power supply



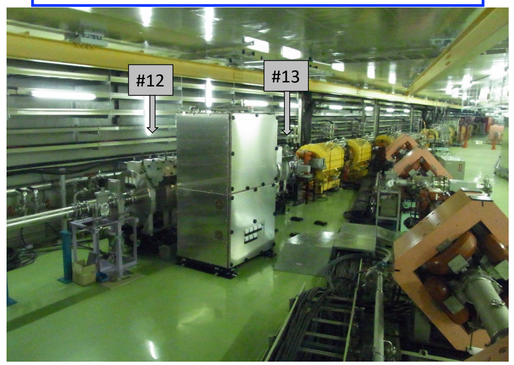
RF system upgrade

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

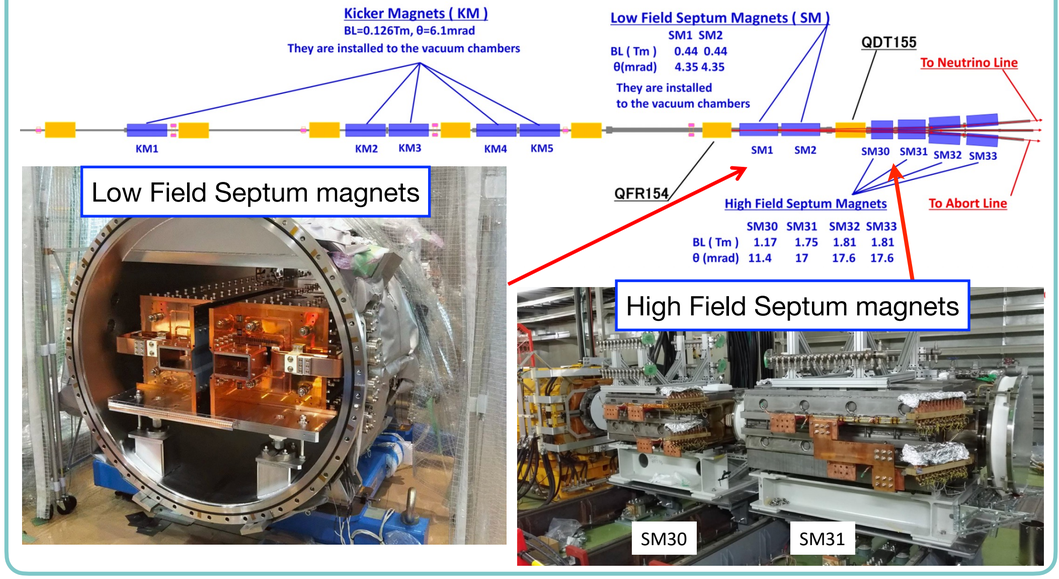
Ins A: 2 2nd harmonic cavities
Ins C: 11 fundamental cavities



New 2nd harmonic cavities installed



New fast-extraction devices



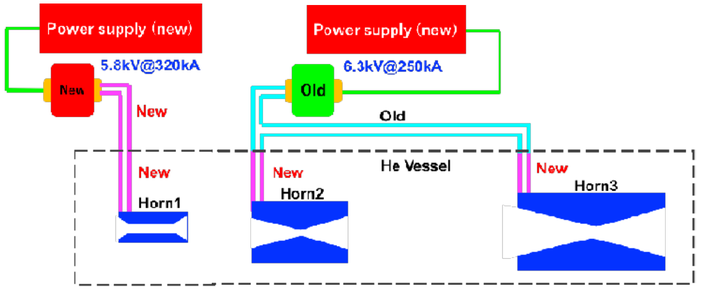
J-PARC Neutrino Beamline Upgrade

- **Baseline design**
  - Beamline components designed to accept **3.3x10^{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 horn, He vessel etc
  - Accommodate shorter cycle operation ⇒ Horn operation, DAQ
  - Accommodate larger amount of radioactivity ⇒ Radioactive waste disposal facility upgrade
  - Safe and reliable control of higher power beam ⇒ Improved control system and beam monitors
- **Major upgrade work during JFY2021-2022 long shutdown period (LS2021-2022)**
  - Horn PS upgrade, Horn replacement, radioactive water disposal upgrade, etc

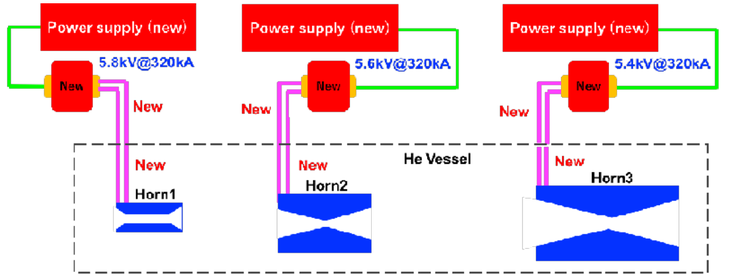
Horn Upgrade #1

- **Horn electrical system upgrade for 320 kA at 1 Hz**
  - **Horn current to be 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
      - Some devices have already been used since 2014
        - Some feedback for further improvement (capacitor upgrade, striplines, etc)
      - All the other devices installed during LS2021-2022
    - Initial commissioning succeeded at 320 kA operation at 1.32 s cycle

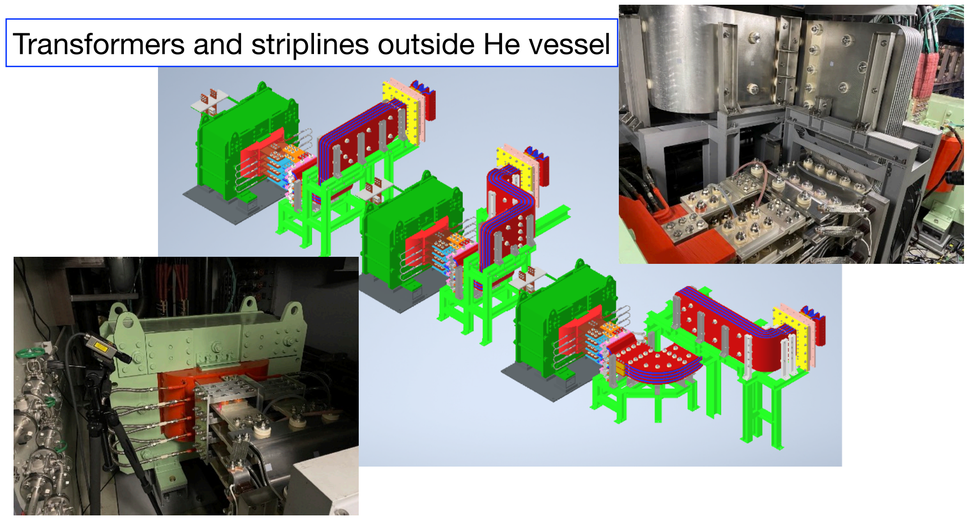
Previous configuration (~2021)



Upgraded configuration (2022~)

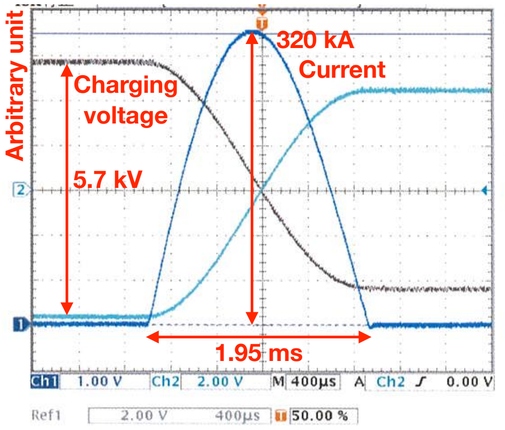


Transformers and striplines outside He vessel

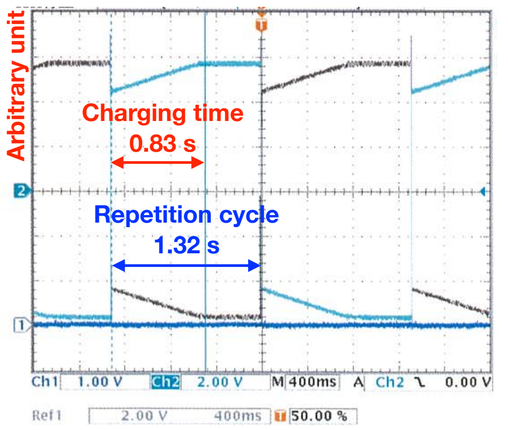


3rd PS and new capacitors installed

Current and voltage pulse shape

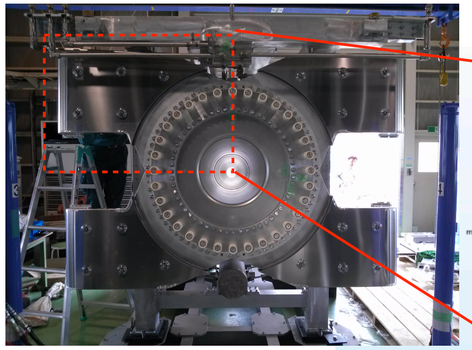


Charging pattern with 1.32 s

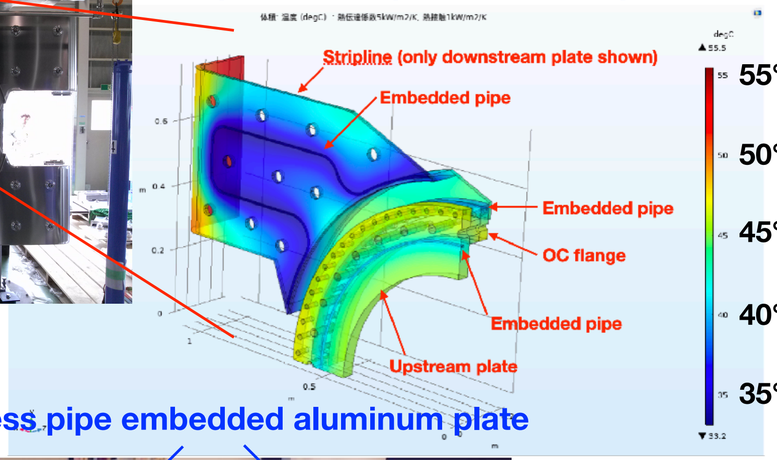


Horn Upgrade #2

- **Conductor cooling improvement (for Horn2)**
  - Large heat load at Horn2 due to defocused particles by Horn1
  - **Stripline cooling**
    - Forced He flow scheme not enough for 1.3 MW
    - **Water-cooled striplines** established
  - **Upstream conductor cooling implemented**
  - **New Horn2 production in Colorado** ⇒ Final assembly in J-PARC ongoing
- **Horn replacement**
  - New Horn1 (with improved water sealing) and new Horn2 to be installed during LS2021-2022
  - Removal of old Horn1 and Horn2 completed

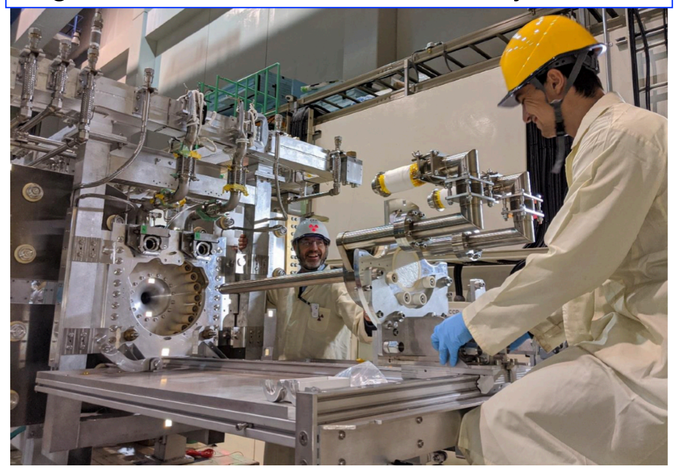


Expected temperature at striplines



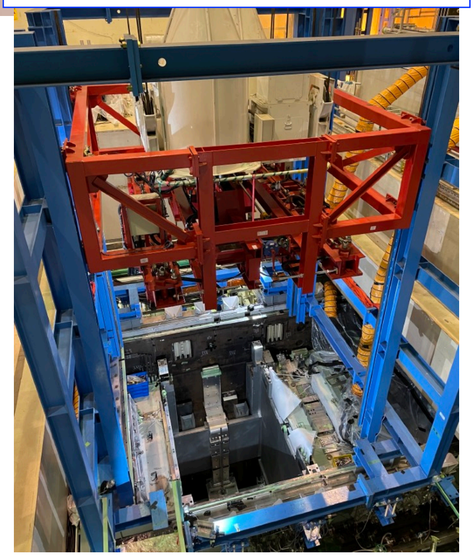
Stainless pipe embedded aluminum plate

Target installation test to new Horn1 by RAL team



New Horn2 production at Colorado

Old Horn2 removal from He vessel



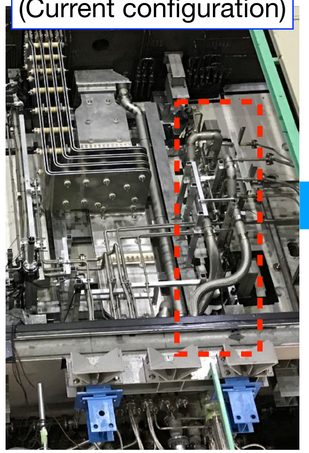
Target Upgrade

- **Original target design**
  - To accept **3.3x10^{14}** protons/pulse beam
  - He cooling ⇒ capacity only **900 kW**
- **Target He cooling improvement**
  - **Higher He flow rate** to improve cooling performance
    - 0.16 MPaG → 0.5 MPaG ⇒ **high pressure tolerance needed**
    - **He compressor upgrade** ⇒ production already started
  - Thermal analysis for 1.3 MW ⇒ max temp. **~900°C** expected
  - **Vacuum insulation pipes** developed for higher temp. (~200°C) He flow ⇒ to be installed in **FY2022**
  - **Prototyping of new target with high pressure tolerance ongoing by RAL team** ⇒ to be installed in **FY2025**
  - He circulation system upgrade scheduled in **FY2025**

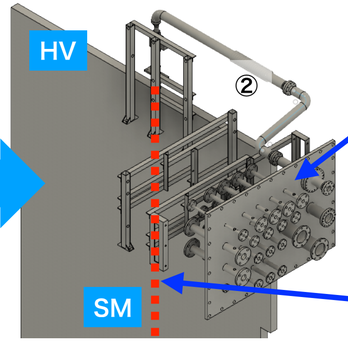
	0.75 MW	1.3 MW
Helium pressure	1.6 bar	5 bar
Pressure drop	0.83 bar	0.88 bar
Helium mass flow	32 g/s	60 g/s
Heat load	23.5 kW	40.8 kW
US window temp	105 ° C	157 ° C
DS window temp	120° C	130° C
Targe core temp	736 ℃	909 ℃

Existing He compressor for target

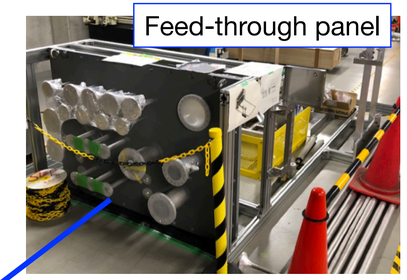
Target plumbing in HV (Current configuration)

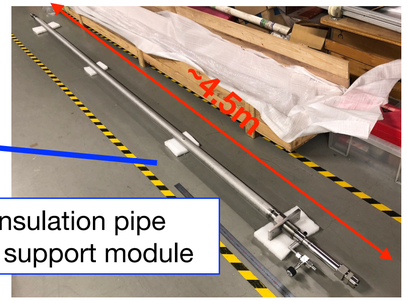


Modified target plumbing



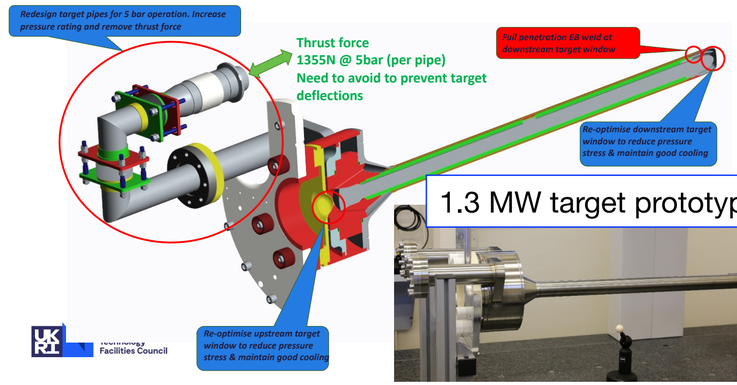
Feed-through panel





Vacuum insulation pipe penetrating support module

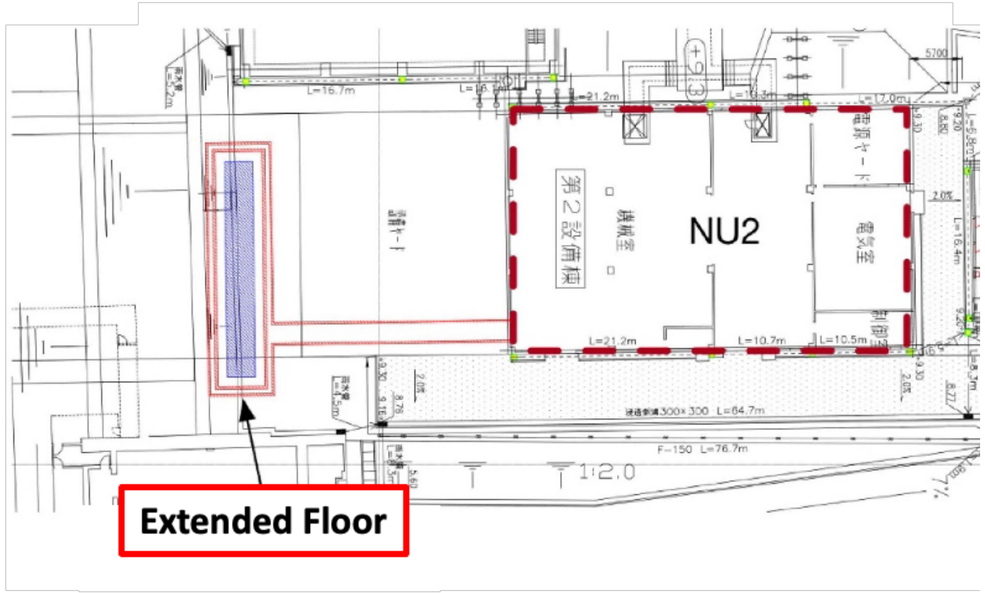
Required Target upgrades for operation at higher pressure



1.3 MW target prototype

Radio-active Water Disposal Facility Upgrade

- Production of tritiated water and its treatment are one of the big issues in high power target facilities in the world
- Produced tritiated water is diluted and disposed at J-PARC neutrino facility
- Current limitation comes from capacity of dilution tank 84 m^3
- Additional dilution tanks (2 x 253 m^3) for 1.3 MW operation
- Construction of the new tanks was started in FY2021 and completed in February 2022



Timeline for Neutrino Beamline Upgrade

Acceptable beam power

1.3 MW

900 kW

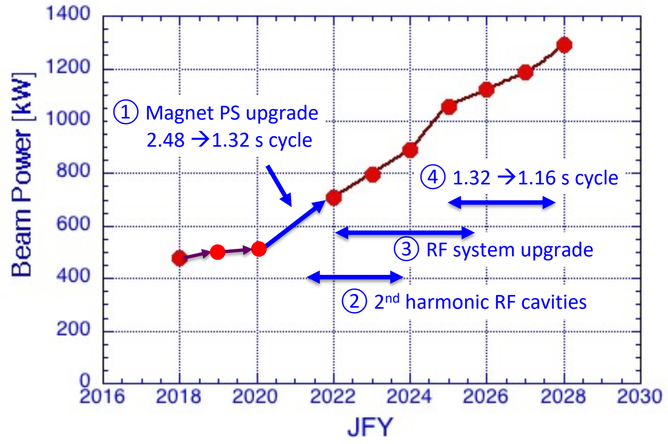
750 kW

500 kW

	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025	FY2026
Horn PS	Production → Install		320 kA @ 1Hz				
DAQ/control upgrade	Production → Install		1Hz				
Horn stripline cooling	Development	Install					
High power horn	Production	Install					
Radio-active water disposal	Construction						
Target He cooling	Vac. insulation pipes				Production	Install	
HV/DV/BD water cooling		Production			Production	Install	
High power target	Development			Production		Install	

Installation plan still under discussion

Upgrade plan of MR



Summary

- **High power neutrino beam is a key for future neutrino programs**
- **J-PARC Neutrino Beam**
  - 10-year running for T2K physics data taking since 2010
  - 510 kW stable operation achieved so far
- **J-PARC upgrade towards 1.3 MW** ⇒ **3.2x10^{14}** protons/pulse and **1.16 s** cycle
  - **Accelerator upgrades**
    - Magnet PS, RF system, etc
  - **Neutrino beamline upgrade**
    - Major upgrade during FY2021-2022 long shutdown
      - Horn replacement, Horn PS upgrade, new radio-active water disposal facility, DAQ upgrade
    - Other upgrades around FY2025
      - Cooling capacity improvement, high-power target installation
  - Massive upgrade work during LS2021-2022
    - We will run at >750 kW in the next beam time from Fall 2022