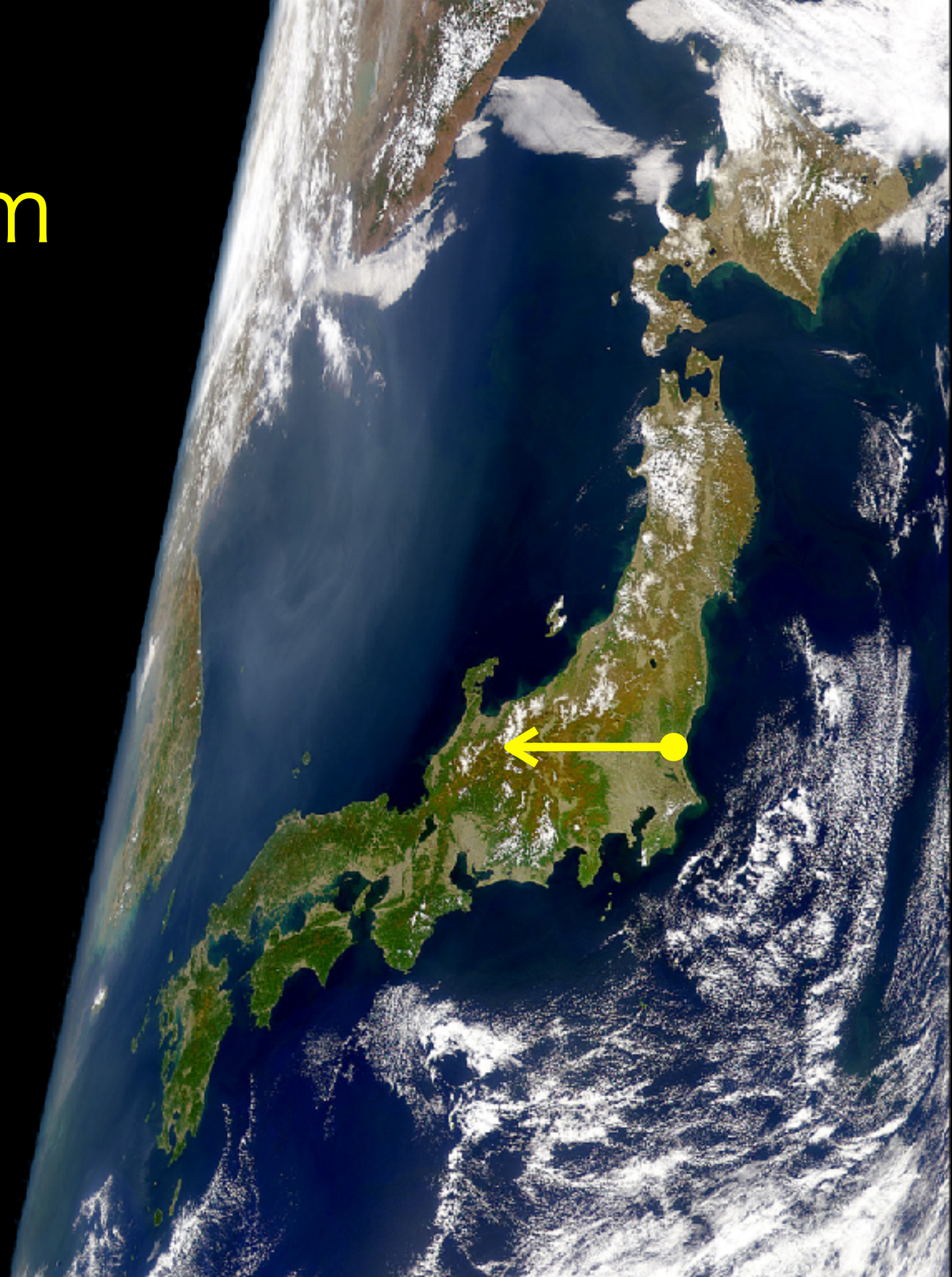
J-PARC neutrino beam status

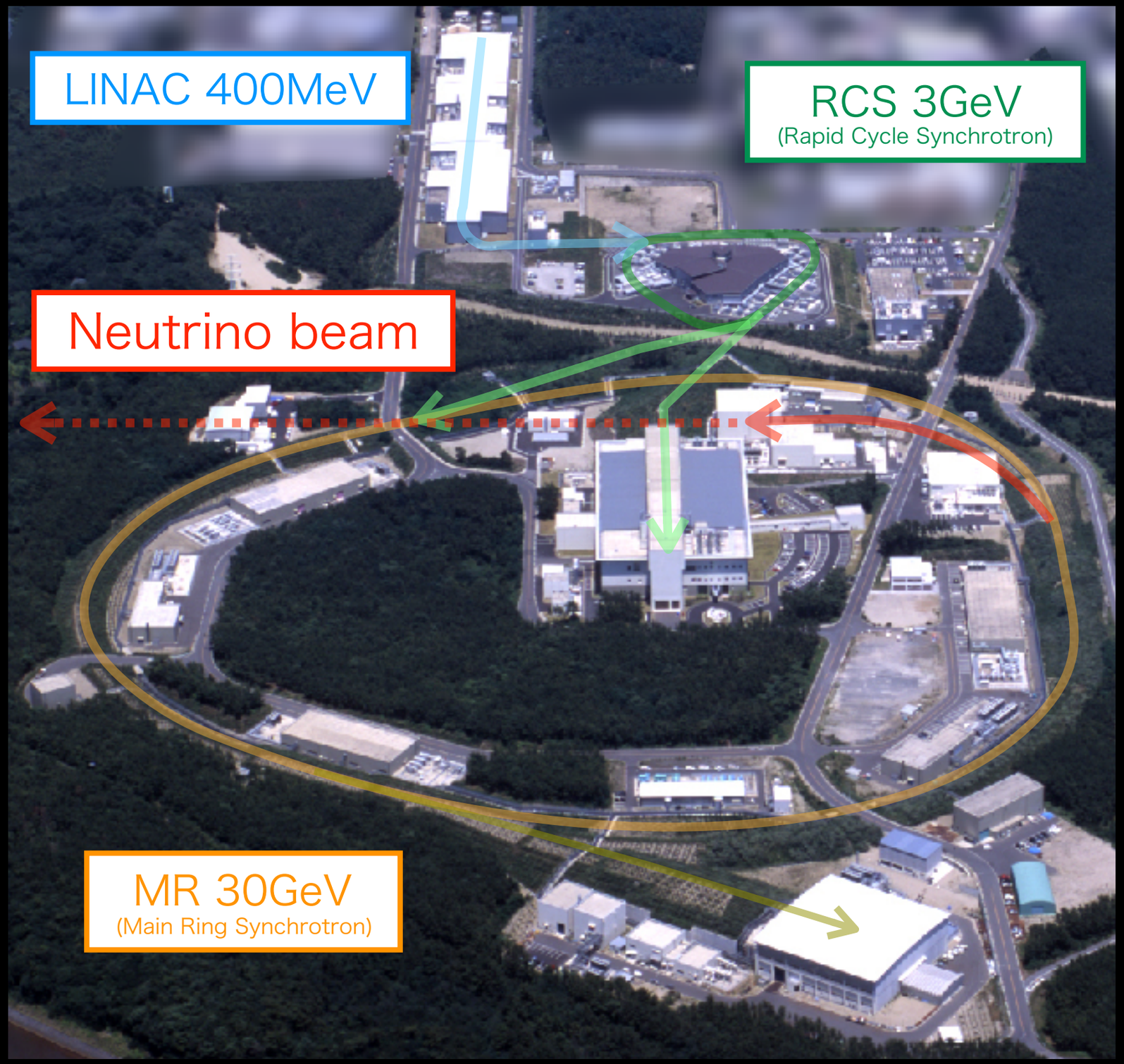
T. Nakadaira

Institute of Particle and Nuclear Studies / J-PARC center, High Energy Accelerator Research Organization(KEK)

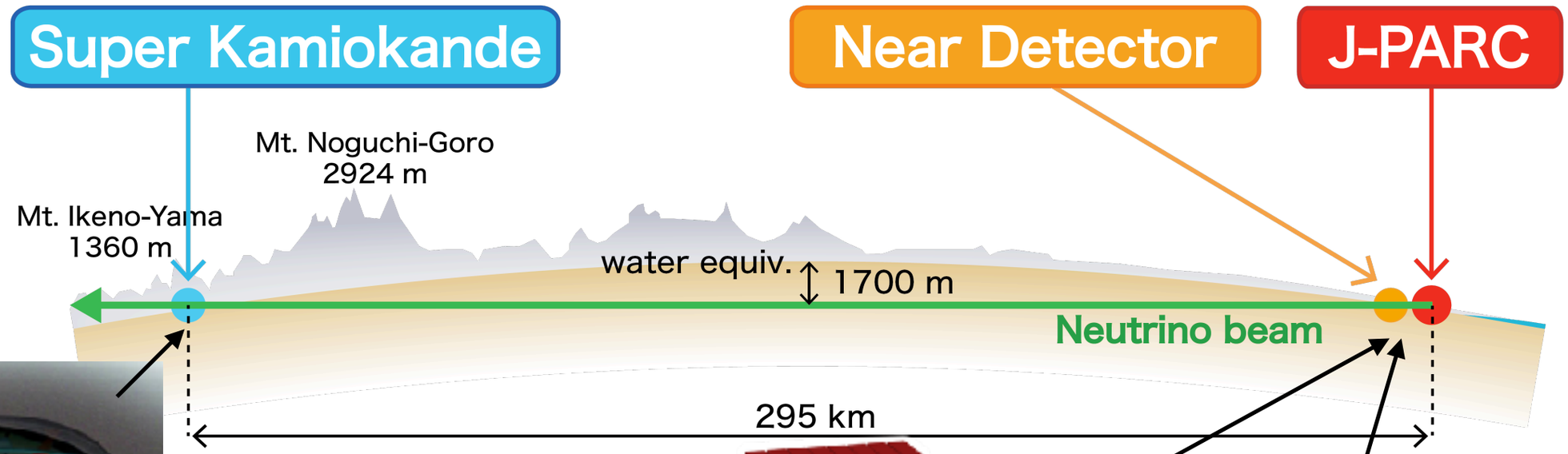


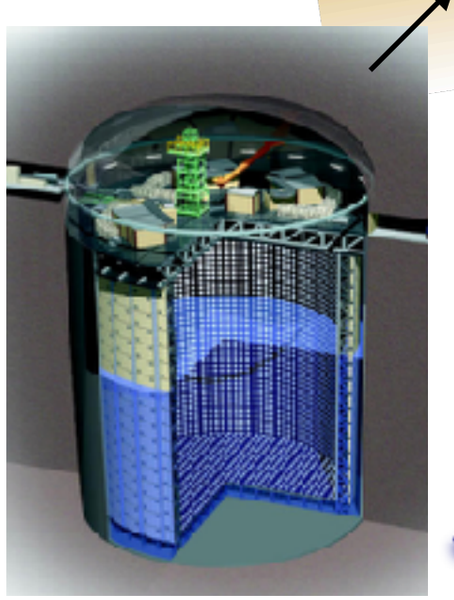
J-PARC Neutrino Experimental Facility

- Provide high intensity neutrino beam with 30GeV protons from J-PARC MR for the long-baseline neutrino oscillation experiment.
  - Operation from 2009
- J-PARC MR Original design
  - Beam power: 750 [kW] (3.3×10^{14} [p/pulse])
  - Repetition cycle: 2.1[s]
- Achieved MR performance for continuous user-beam:
  - Beam power: 490 [kW] (2.5×10^{14} [p/pulse])
  - Repetition cycle: 2.48[s]

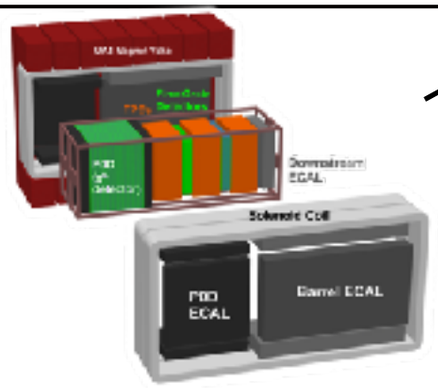


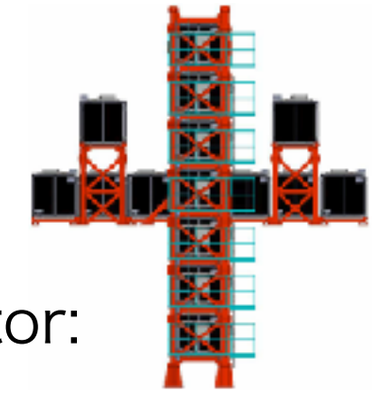
Long-baseline neutrino oscillation experiment: T2K



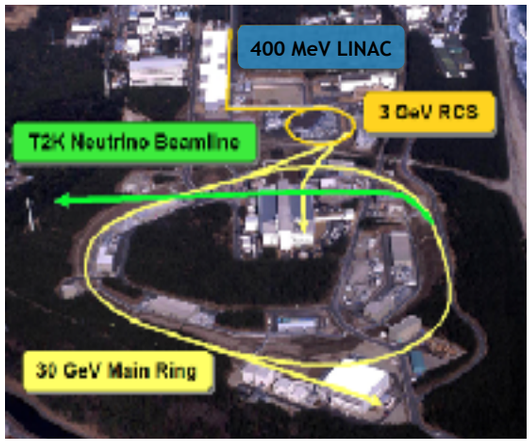


Off-axis detector:
ND280



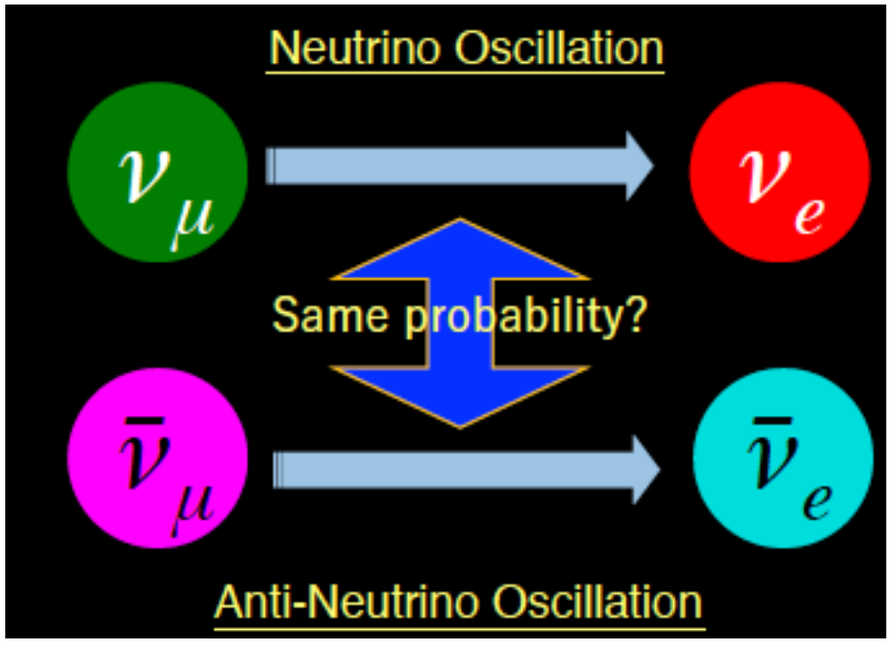


On-axis detector:
INGRID



Physics goals

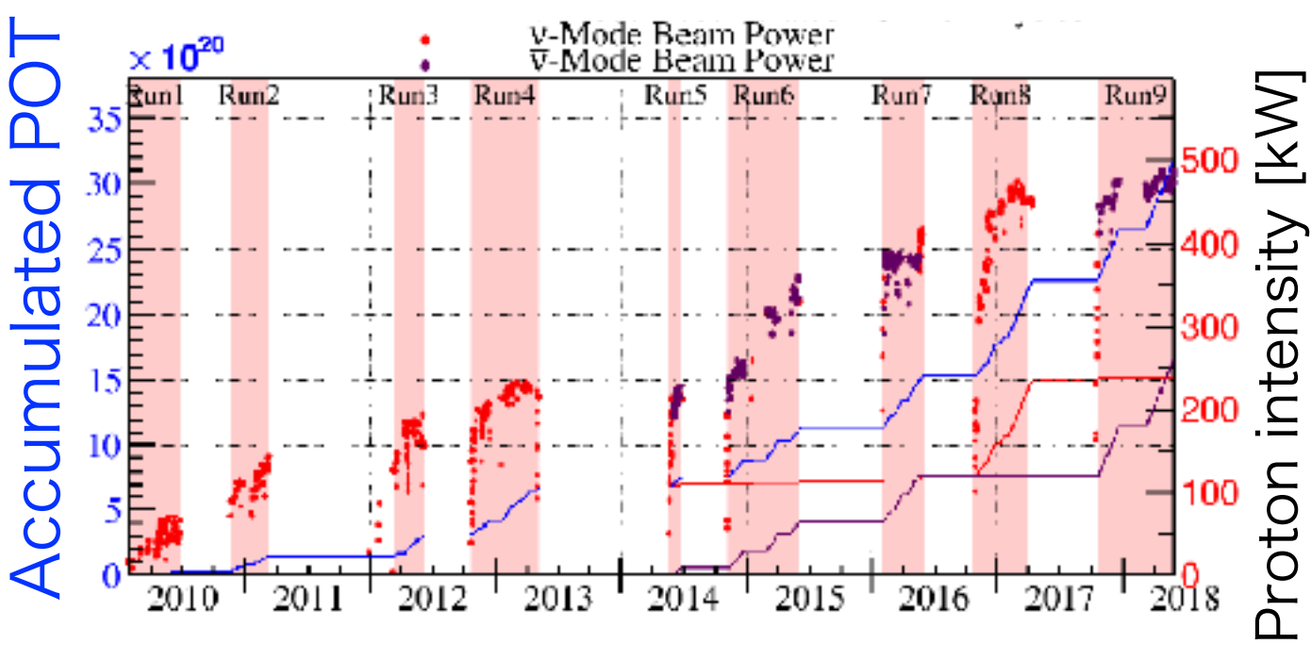
- Search for the new neutrino oscillation: $\nu_\mu \rightarrow \nu_e$ (~2013)
- **Search for CP violation in lepton sector (2014~)**

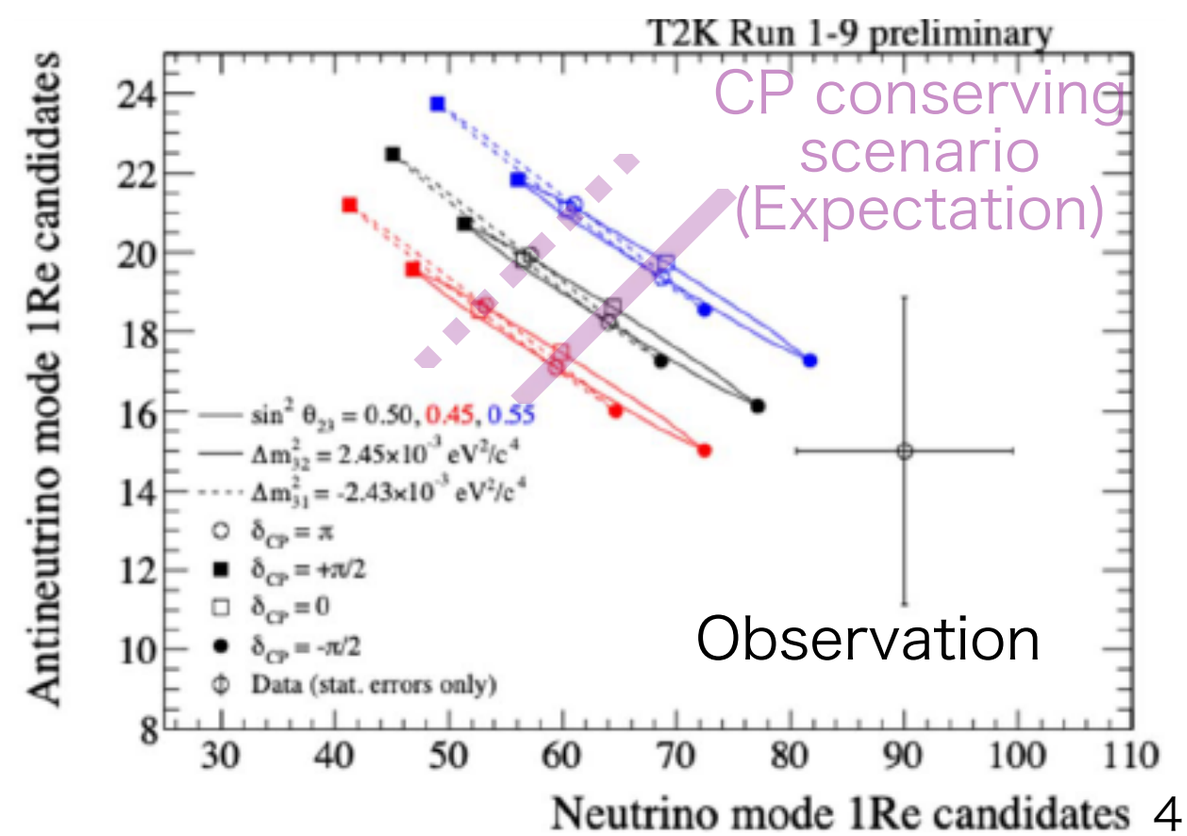


Current status of T2K

- Accumulate 3.16×10^{21} POT (40% of approved POT)
- Latest analysis results:
  - Excess of $\nu_\mu\rightarrow\nu_e$ observation for ν-beam data (1.51×10^{21}POT) w.r.t the expectation assuming NO CP violation.
  - Less $\bar{\nu}_\mu\rightarrow\bar{\nu}_e$ observation for $\bar{\nu}$-beam data (1.65×10^{21}POT)

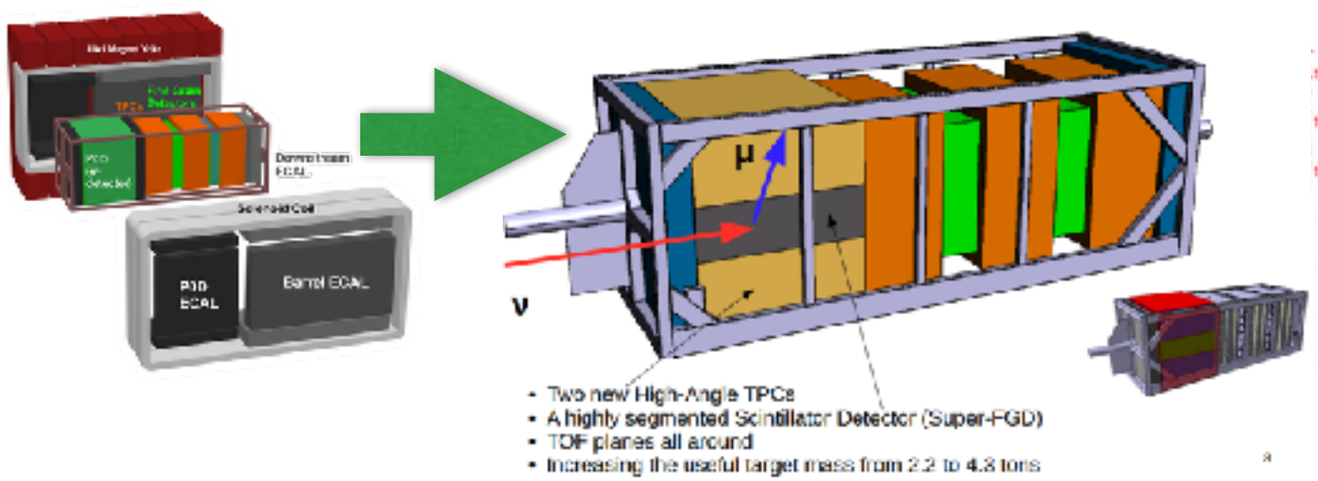
    → >2 σ rejection of CP conserving scenario.
- **Hint of Large CP violation in lepton sector?**
  - 2018 June~: T2K data taking is suspended for SK-tank refurbishment. Beam operation / T2K data taking will be resumed from Nov. 2019(.~Feb. 2019)
  - T2K requests MR beam time after SK upgrade work (SK-Gd: Mar. 2020~)

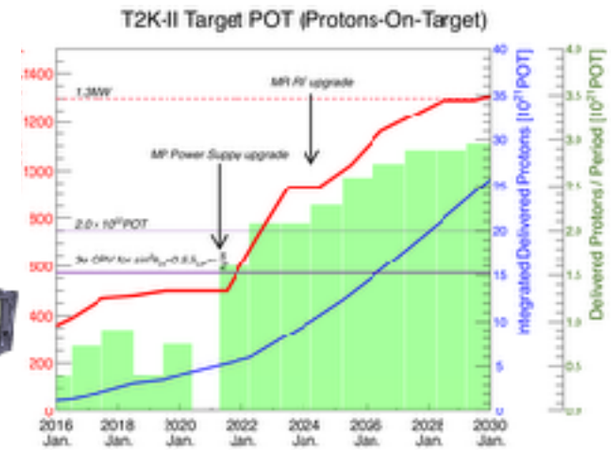


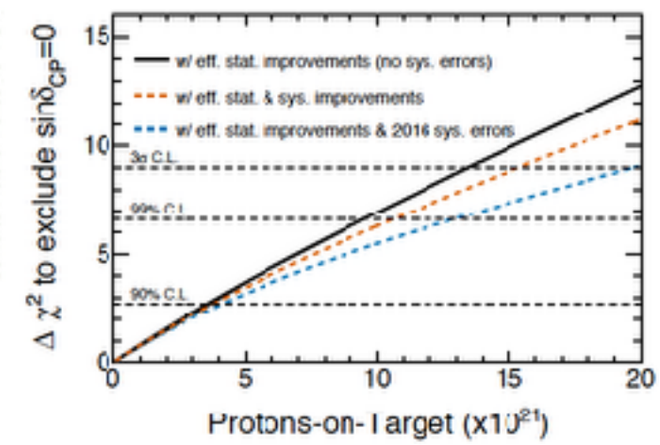


Progress of ν experiments at J-PARC

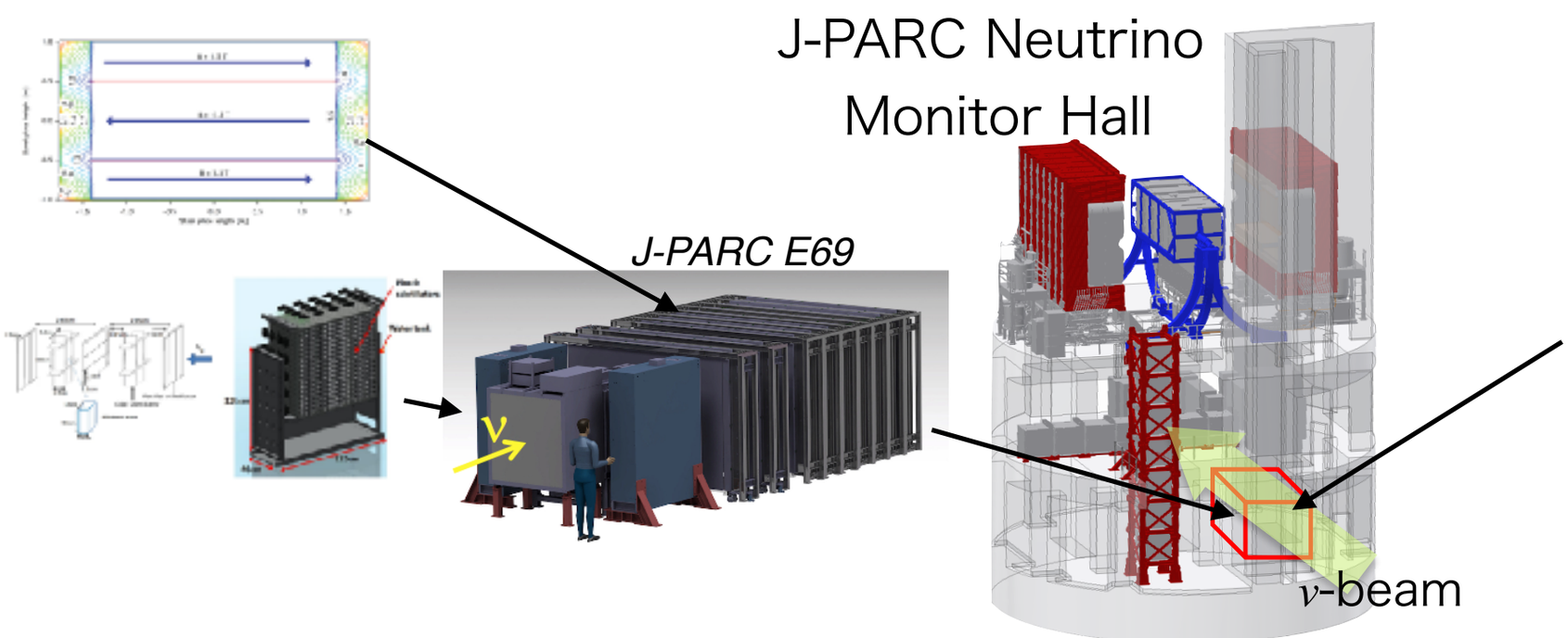
- T2K-II (T2K Extension): CPV search w/ 3σ sensitivity
  - ND upgrade + Beam power upgrade.

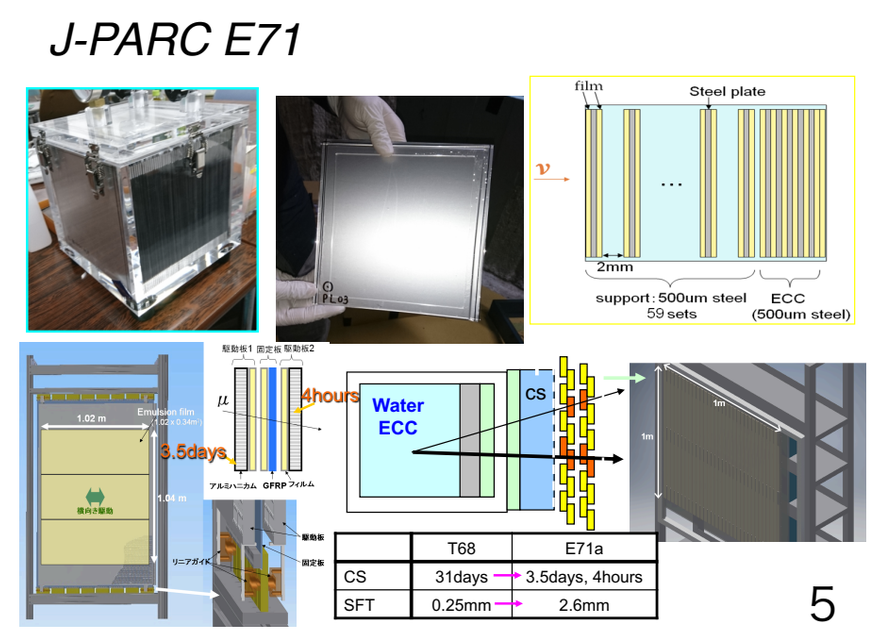






- E69 (WAGASCI), E71(NINJA): Neutrino-Nucleus interaction measurement with “New” neutrino detectors.

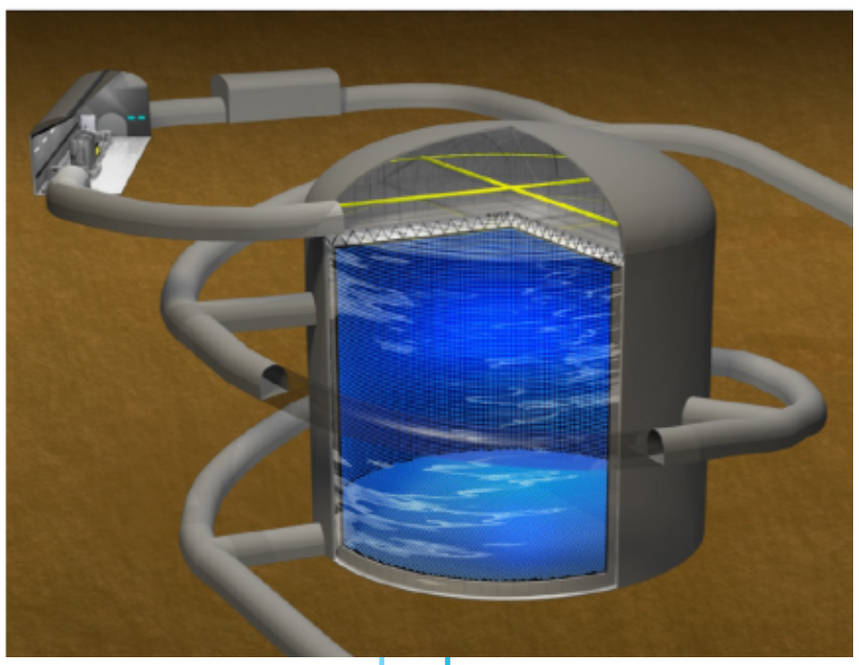




Next generation experiment: **Hyper-Kamiokande**

- Physics goal in LBL experiment: Discovery of CP violation in lepton sector
- Aiming to achieve >5 σ significance by accumulating ~2000 $\nu_\mu \rightarrow \nu_e$ events and ~2000 events in ~10 years (2027~)

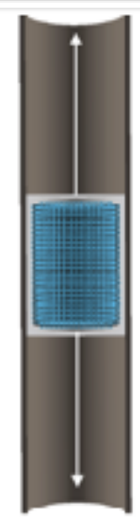
Hyper-Kamiokande



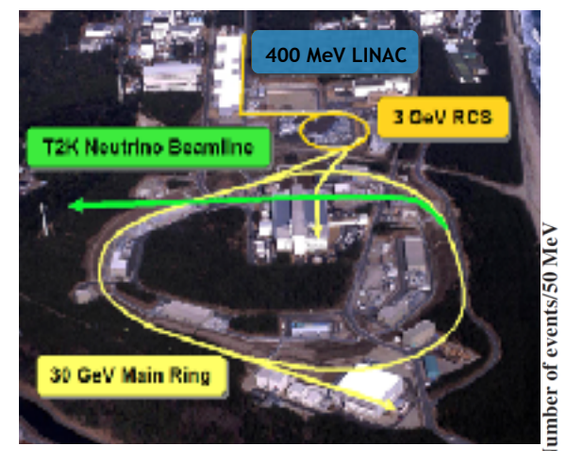
260kt

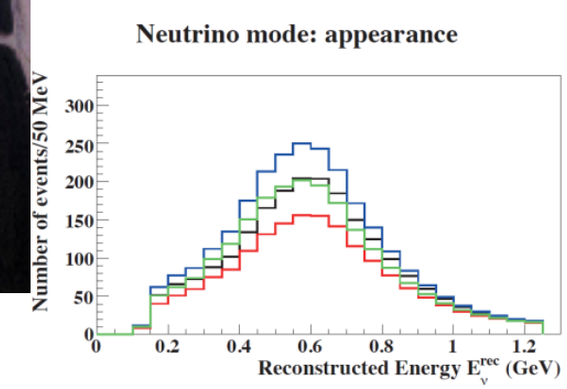
Cf: SK=50kt

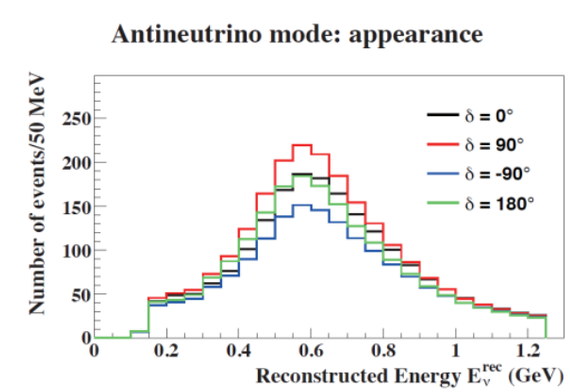
New near-detector

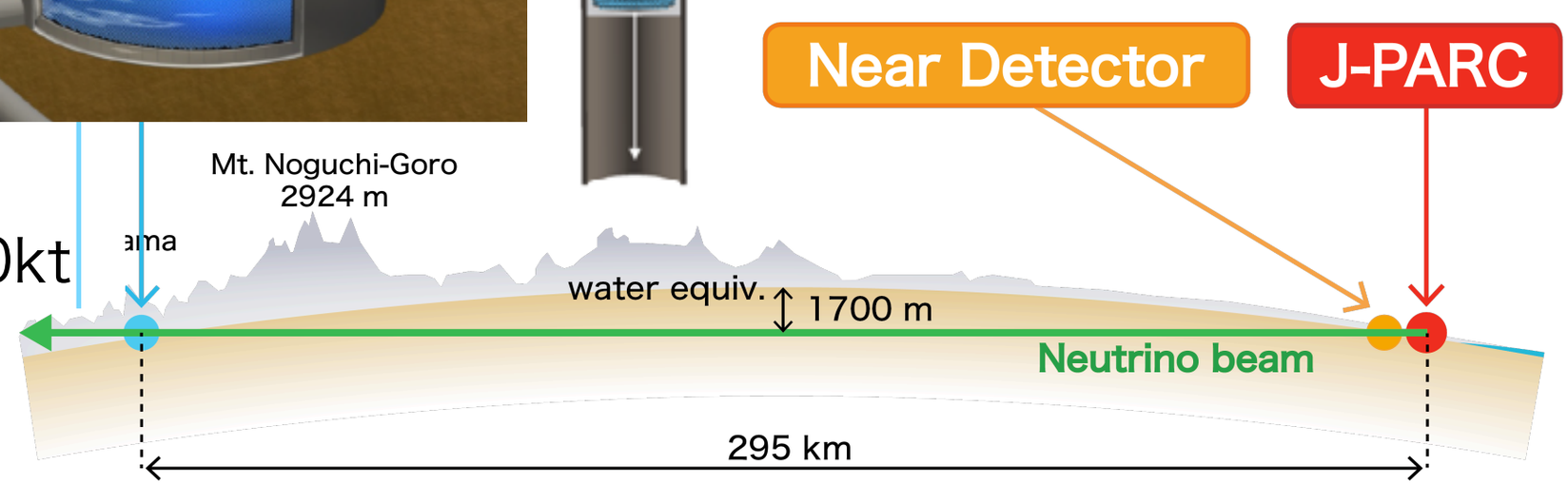


Beam power upgrade
750kW → 1.3MW





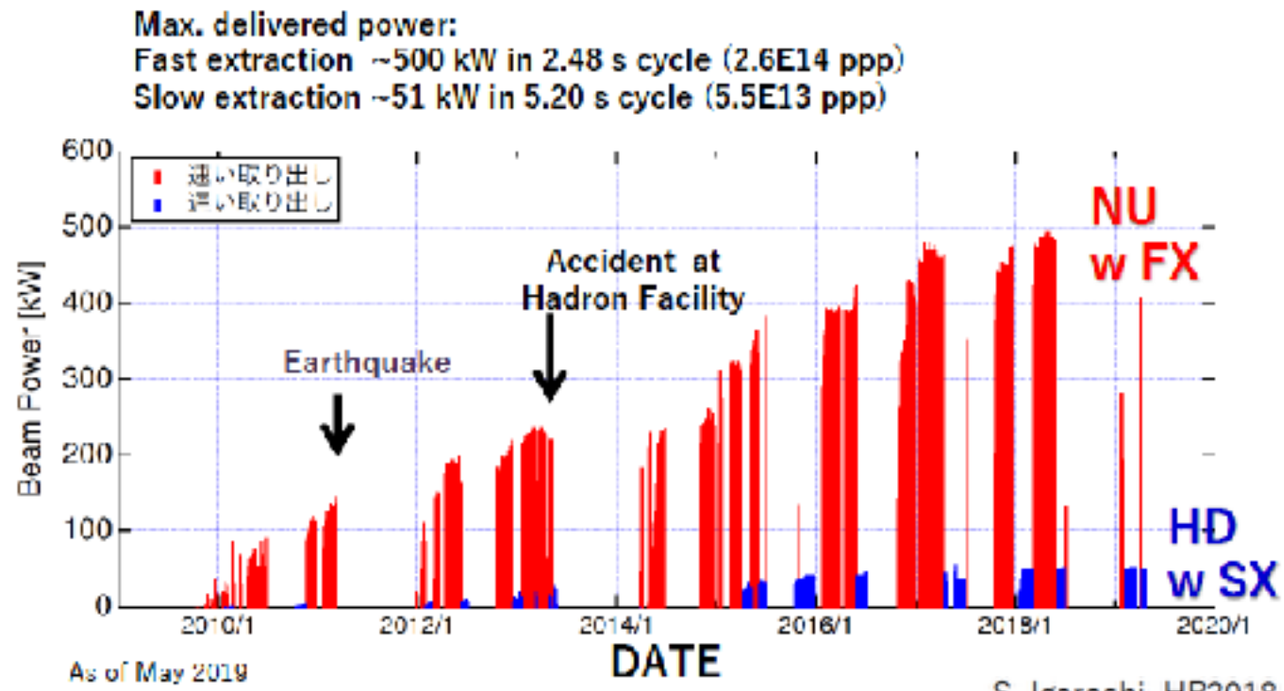




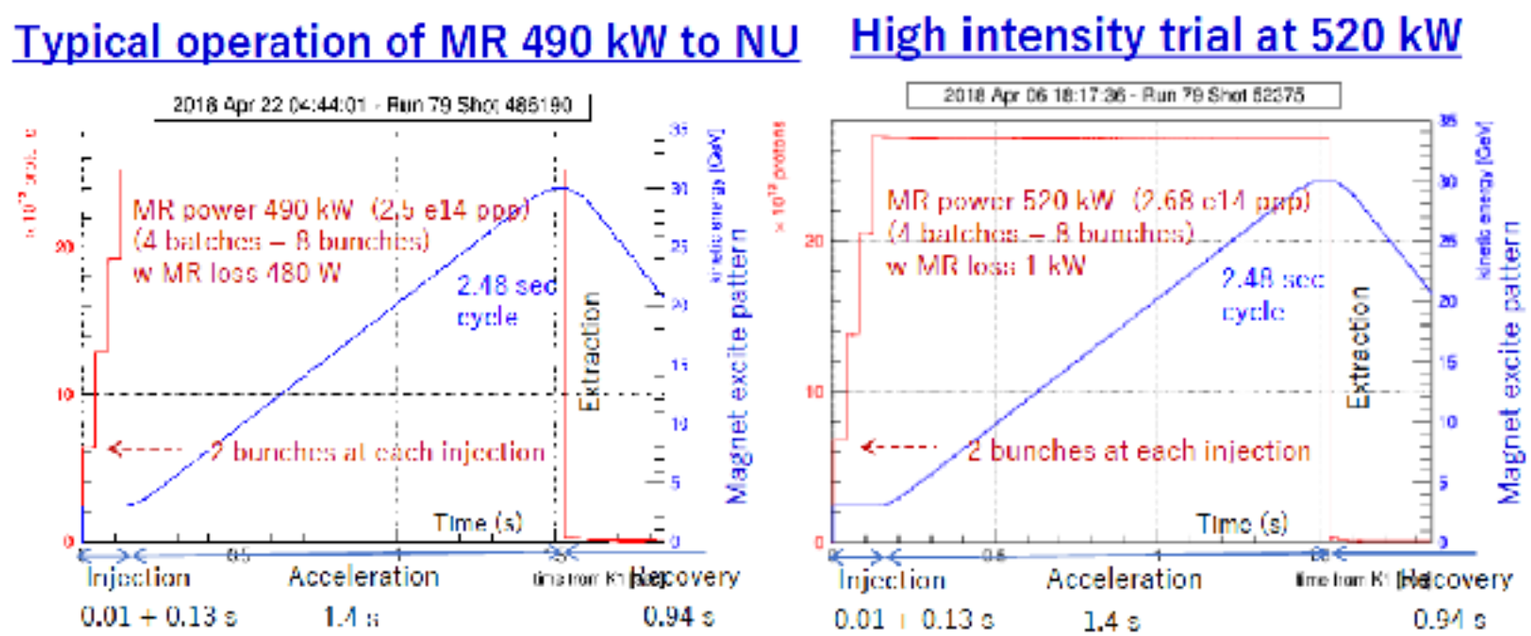
Intensity upgrade of J-PARC neutrino beam is essential.

J-PARC MR status

- Stable ~490kW NU user beam and trial 500kW continuous FX-extraction with acceptable beam loss in MR are achieved!
- Machine study to increase protons/pulse is in progress.
  - 520kW trial shows promising results to realize >1MW beam power with acceptable beam-loss.
- J-PARC+FNAL joint accelerator intensity improvement is performed by US-JP cooperation program from 2014



S. Igarashi, HB2018
Y. Sato, IPAC2018



MR power	490 kW → 500 kW	→ **520 kW**	**in 2.48 s cycle**
3-50BT loss	50 W	→ **200 W**	**< BT COL capacity 2 kW**
MR loss	480 W → 700 W	→ **1 kW** unoptimized	**< MR COL capacity 2 kW**

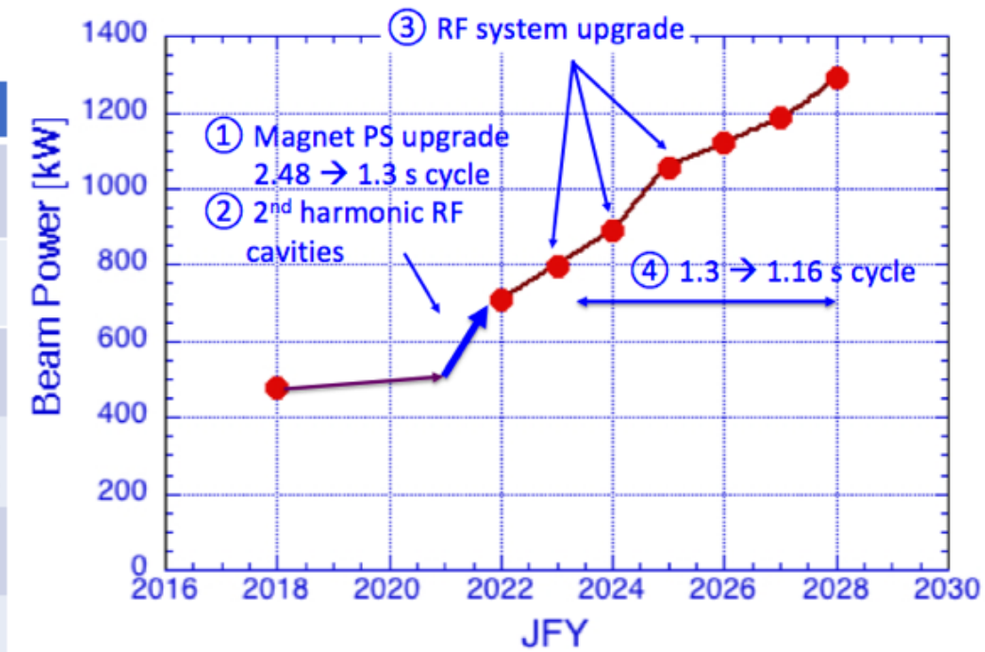
Beam loss fraction of 1kW for 520kW beam with 2.48s cycle is equivalent to 2kW loss for 1.1MW beam with 1.16s cycle.

J-PARC MR upgrade plan.

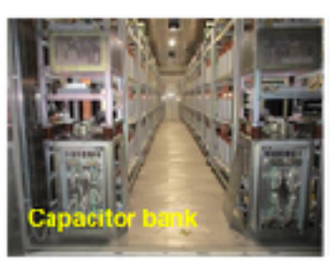
- Increasing both repetition rate & protons/pulse.

FX: Faster cycling: 2.48 s → 1.32 s for 750 kW → 1.16 s for 1.3 MW
SX: Mitigation of the residual radiation for 100 kW

JFY	2017	2018	2019	2020	2021	2022	2023	2024
Event	New buildings →		HD Target		Long shutdown			
FX power [kW]	475	500	500	500		>700	800	900
SX power [kW]	50	50	50	70		> 80	> 80	> 80
Cycle time of main magnet PS New magnet PS	2.48 s →	2.48 s Mass production/installation/test →	2.48s	2.48s		1.32 s →	<1.32s	<1.32s
High gradient rf system 2nd harmonic rf system	→	Manufacture, installation/test →				→	→	→
Ring collimators	Capacity 2 kW				Capacity 3.5kW			
Injection system FX system	Kicker PS improvement, Septa manufacture /test → Kicker PS improvement, FX septa manufacture /test →							



Main magnet power supply

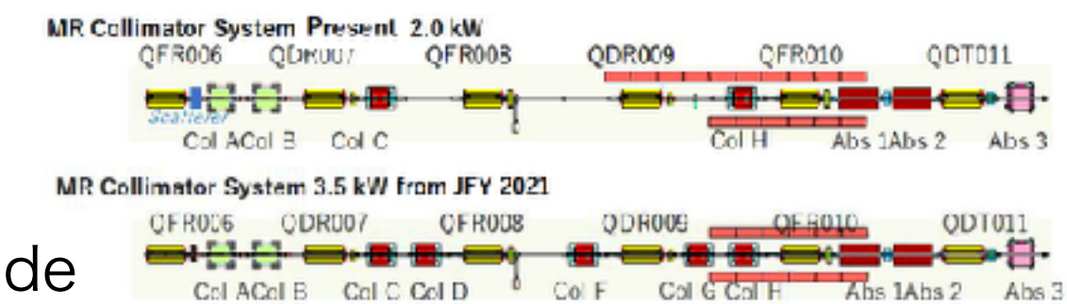


Upgrade plan of rf system

	Present	Upgrade
Events	2.48 s operation	1.16 s operation
FT3L cavity for fundamental	7	9
Additional fundamental		2
2nd harmonics	9	9
Accelerating voltage	990 kV in max	800 kV
2nd voltage	110 kV	120 kV

RF reinforcement

Injection/FX device upgrade

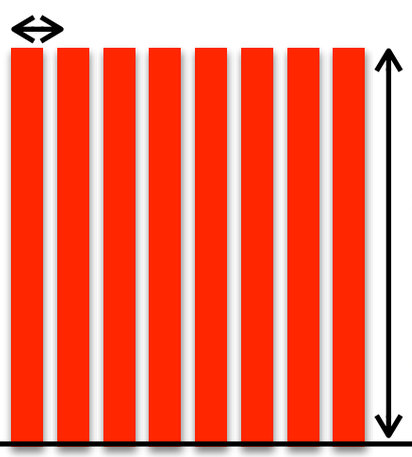


Ring collimator upgrade

Beam structure and effects for ν - facility

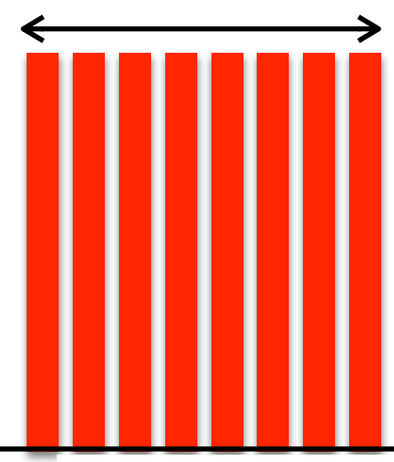
- Operation rate of beam-line equipment should be increased.
  - Horn, Beam-monitor DAQ, Beam interlock, etc
- Target protons/pulse is same as J-PARC original design.
  → Requirement for a single spill is not changed.
  - Thermal shock tolerance of target, beam window, etc
- Beam heat load, Radiation, Radio-activation will be increased w.r.t beam power or POT.
  - Cooling capability, radiation shields, radioactive waste treatment, etc

Bunch width 20~40 ns (FW)
Bunch interval 581ns (RF=1.72MHz)



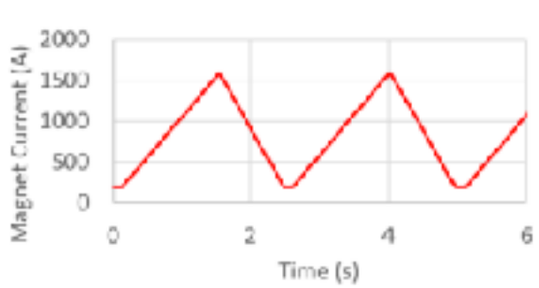
3.1×10^{13} [p/bunch]
= 150 [kJ/bunch] (now)
→ 4.1×10^{13} [p/bunch]
= 200 [kJ/bunch] (upgrade)

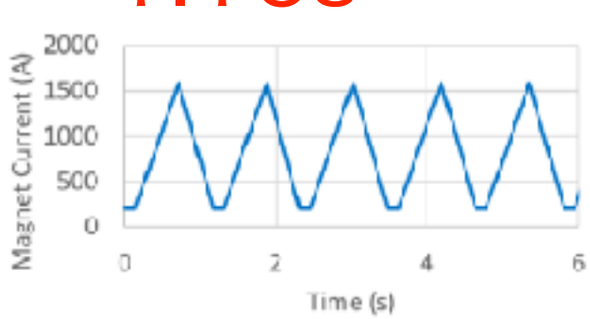
8 bunches / pulse
pulse width ~4.5μs



2.5×10^{14} [p/pulse]
= 1.2 [MJ/pulse] (now)
→ 3.3×10^{14} [p/pulse]
= 1.6 [MJ/pulse] (upgrade)

2.48s → 1.16s





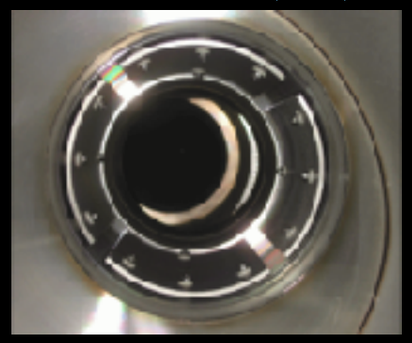
Beam Power	Cycle Time	Number of accelerated protons	Protons in each bunch
500 kW	2.48 s	2.6×10^{14} ppp	3.3×10^{13} ppb
750 kW	1.32 s	2.1×10^{14} ppp	2.6×10^{13} ppb
1.3 MW	1.16 s	3.3×10^{14} ppp	4×10^{13} ppb

J-PARC ν beam line :Primary-line

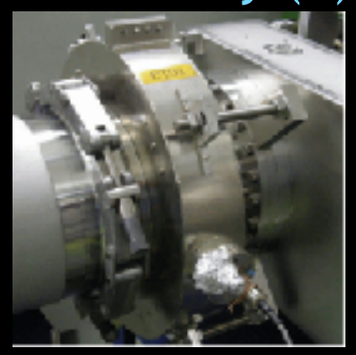
Beam monitors are install along the proton beam transport

Profile (19)

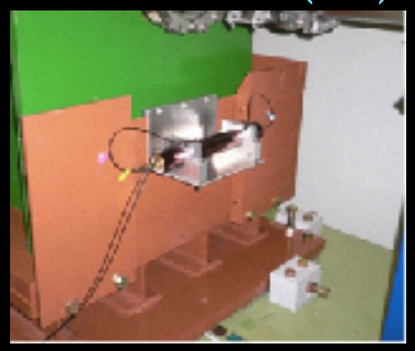
Position (21)



Intensity (5)



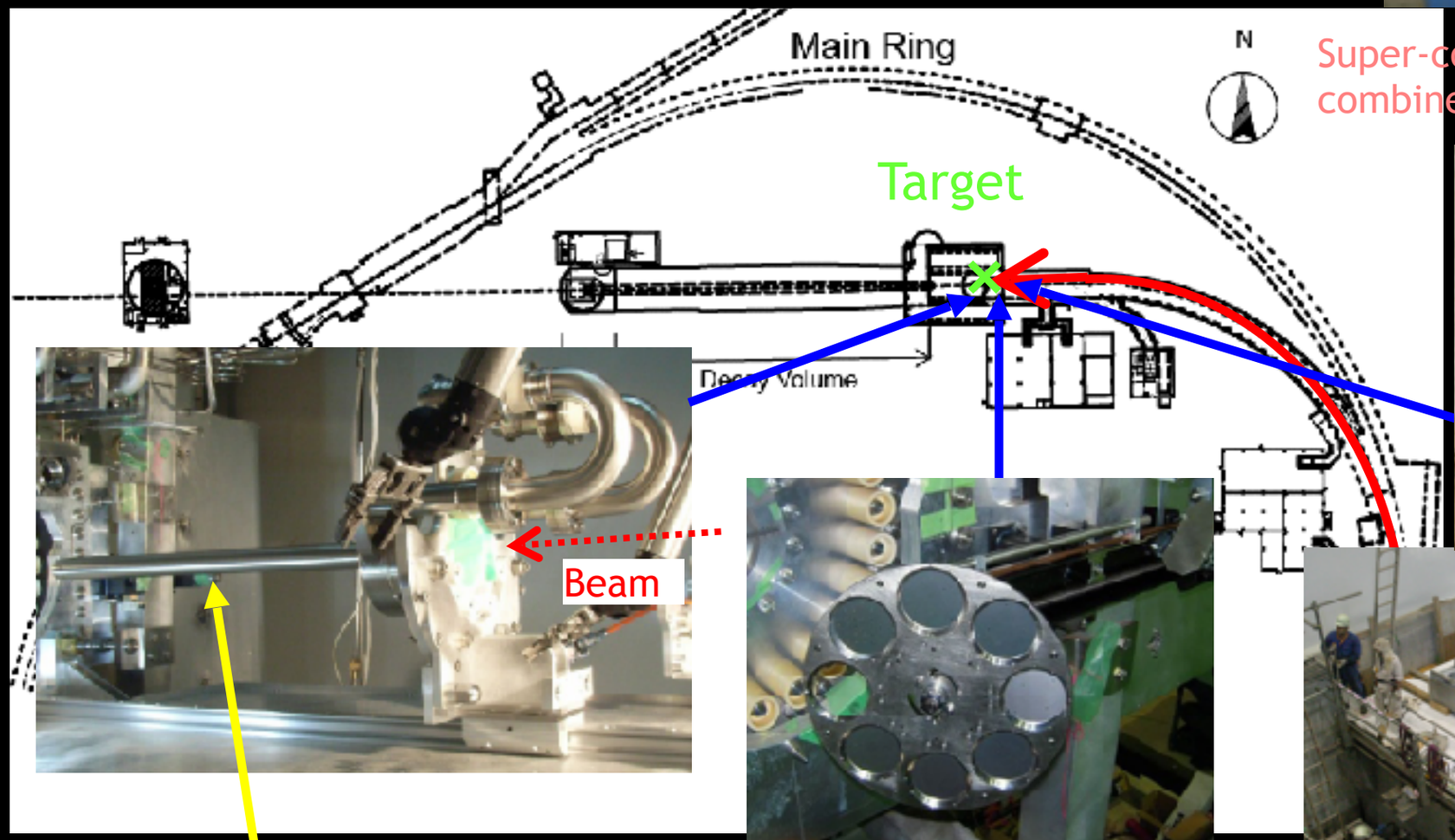
Beam loss (50)

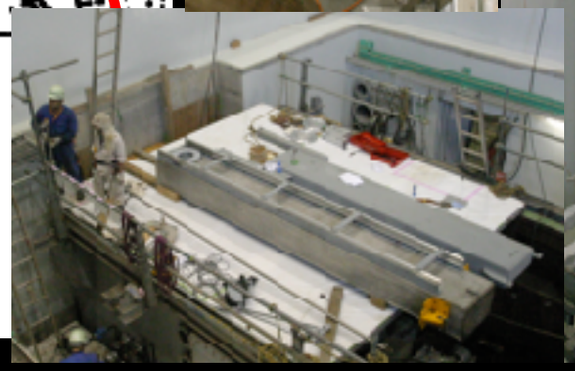


Primary proton transport line

Super-conducting combined-function magnets

Normal-conducting magnets





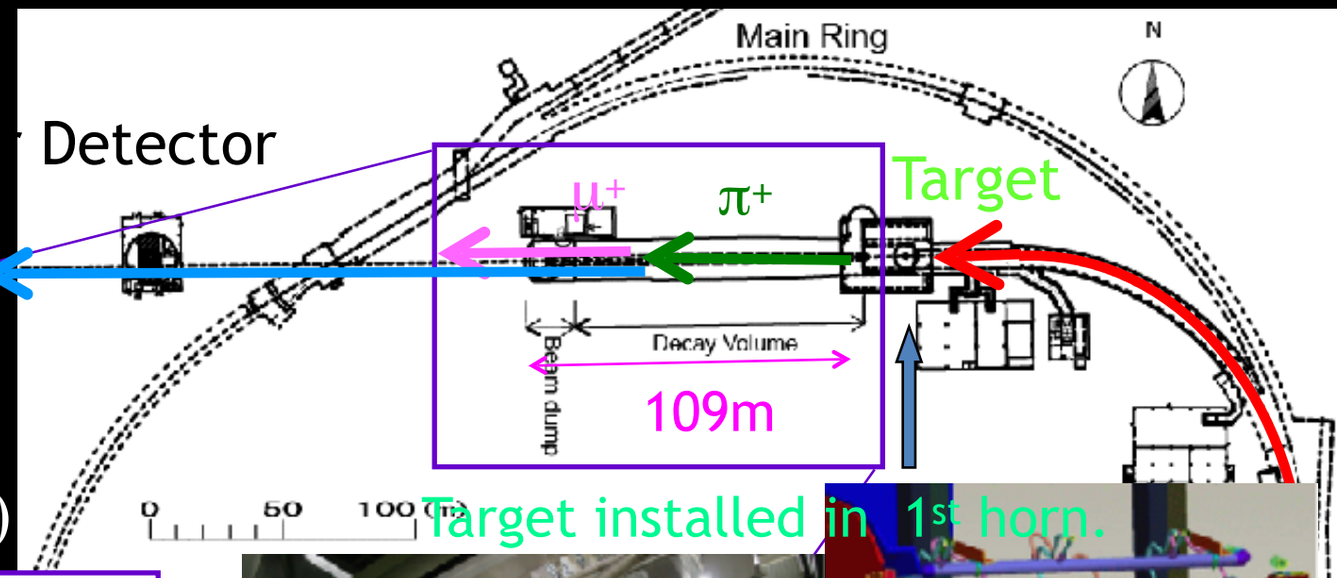
Target :graphite rod
ϕ26mm,L=900mm

Optical Transition Radiation (OTR) Profile monitor

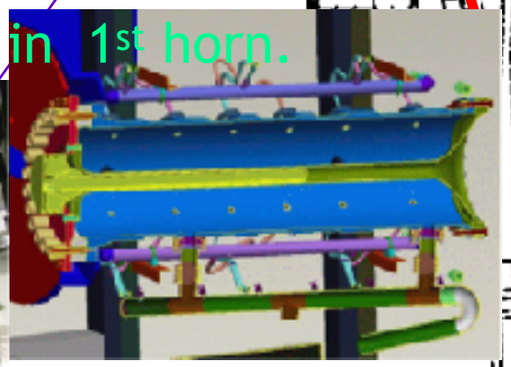
Vacuum chamber and structure for most downstream beam monitors

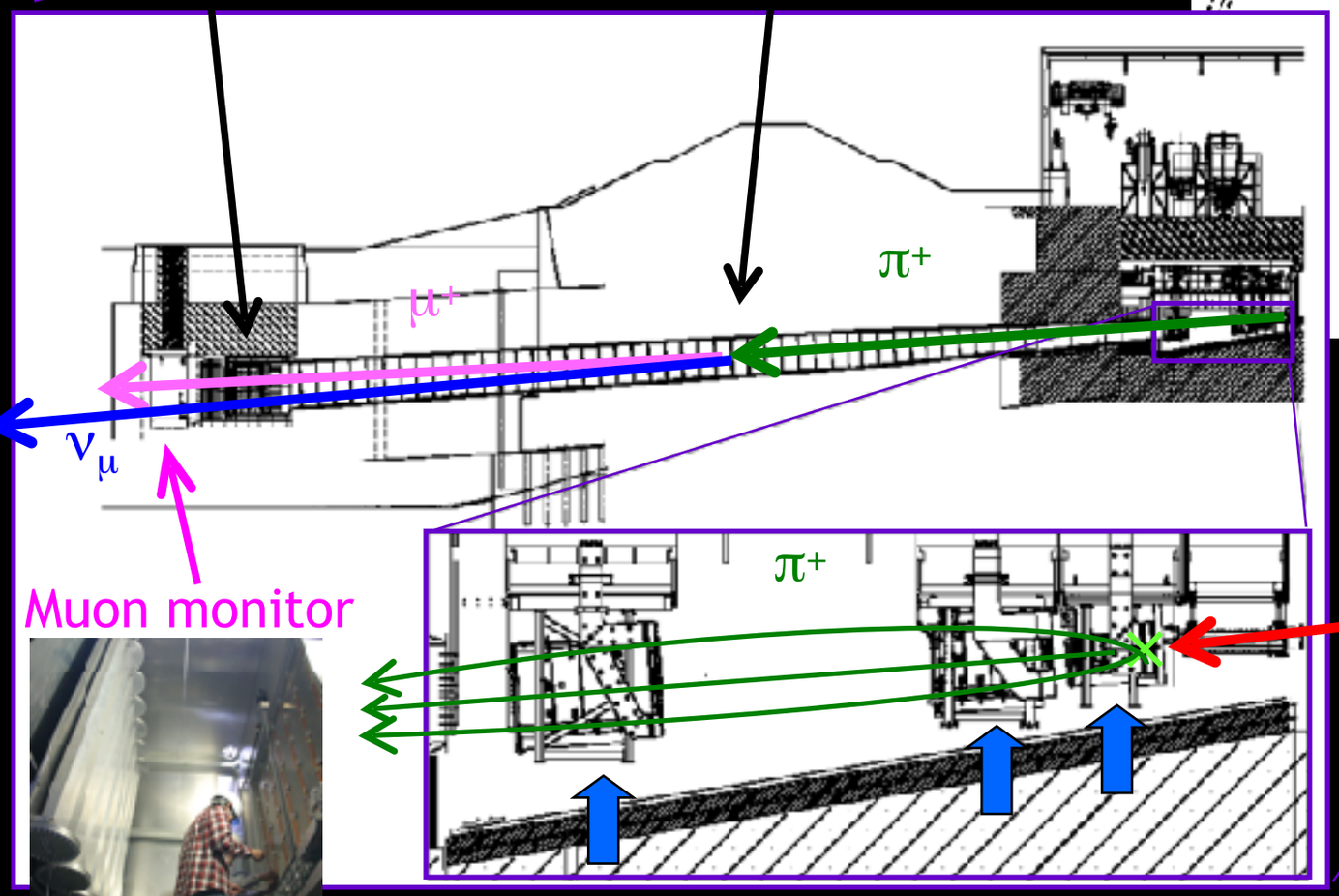
J-PARC ν beam line: secondary line

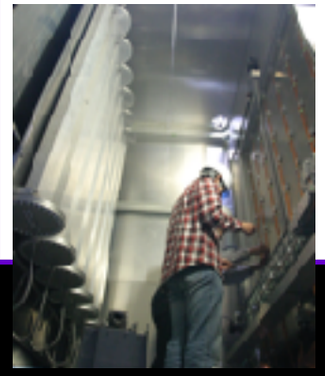
Decay volume (He gas filled)



Target installed in 1st horn.

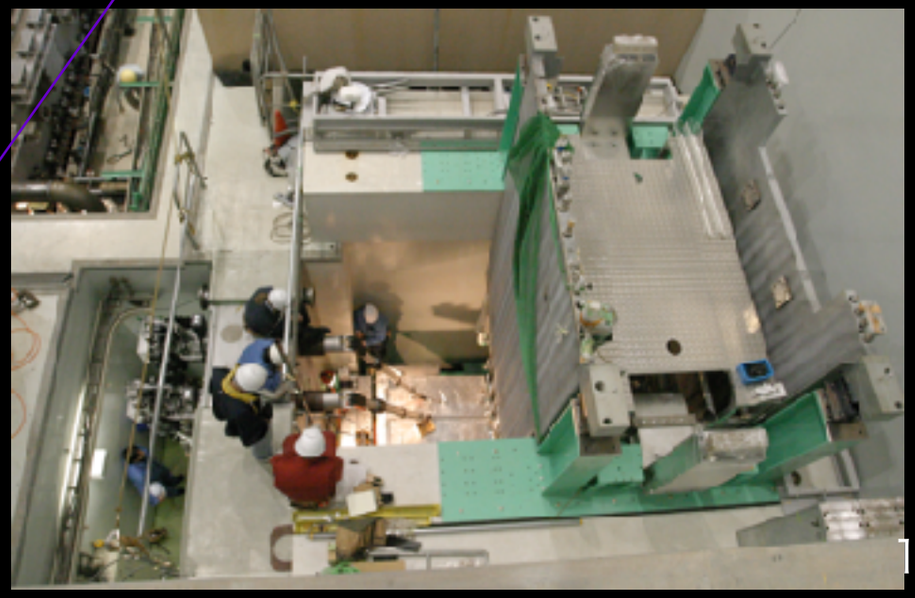






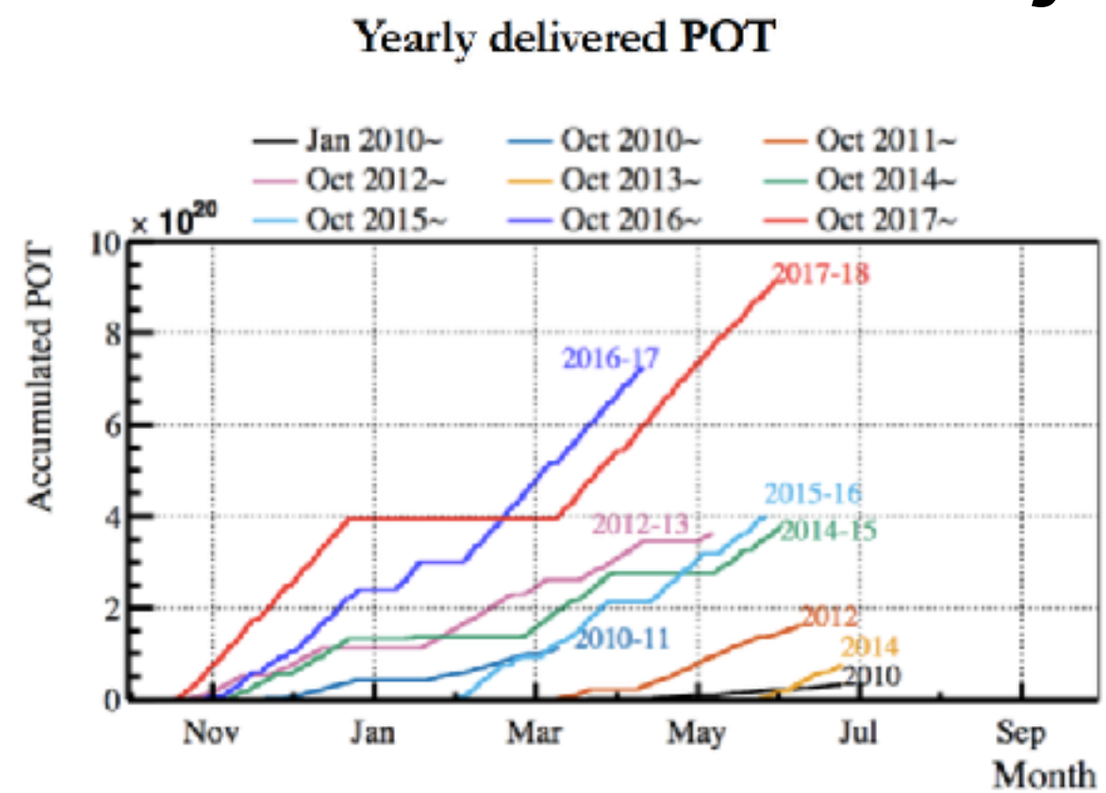
Pions are focused by 3 electromagnetic Horns.

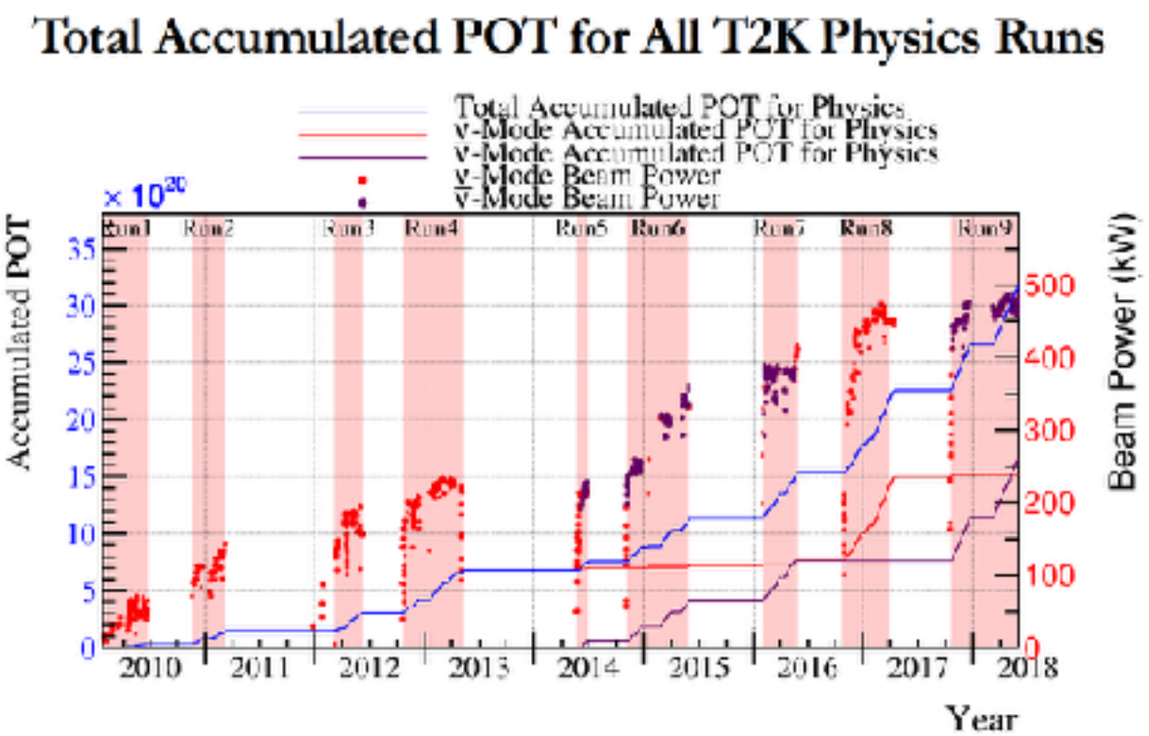
Target/Horn Remote Maintenance area.



Operation status of J-PARC neutrino facility.

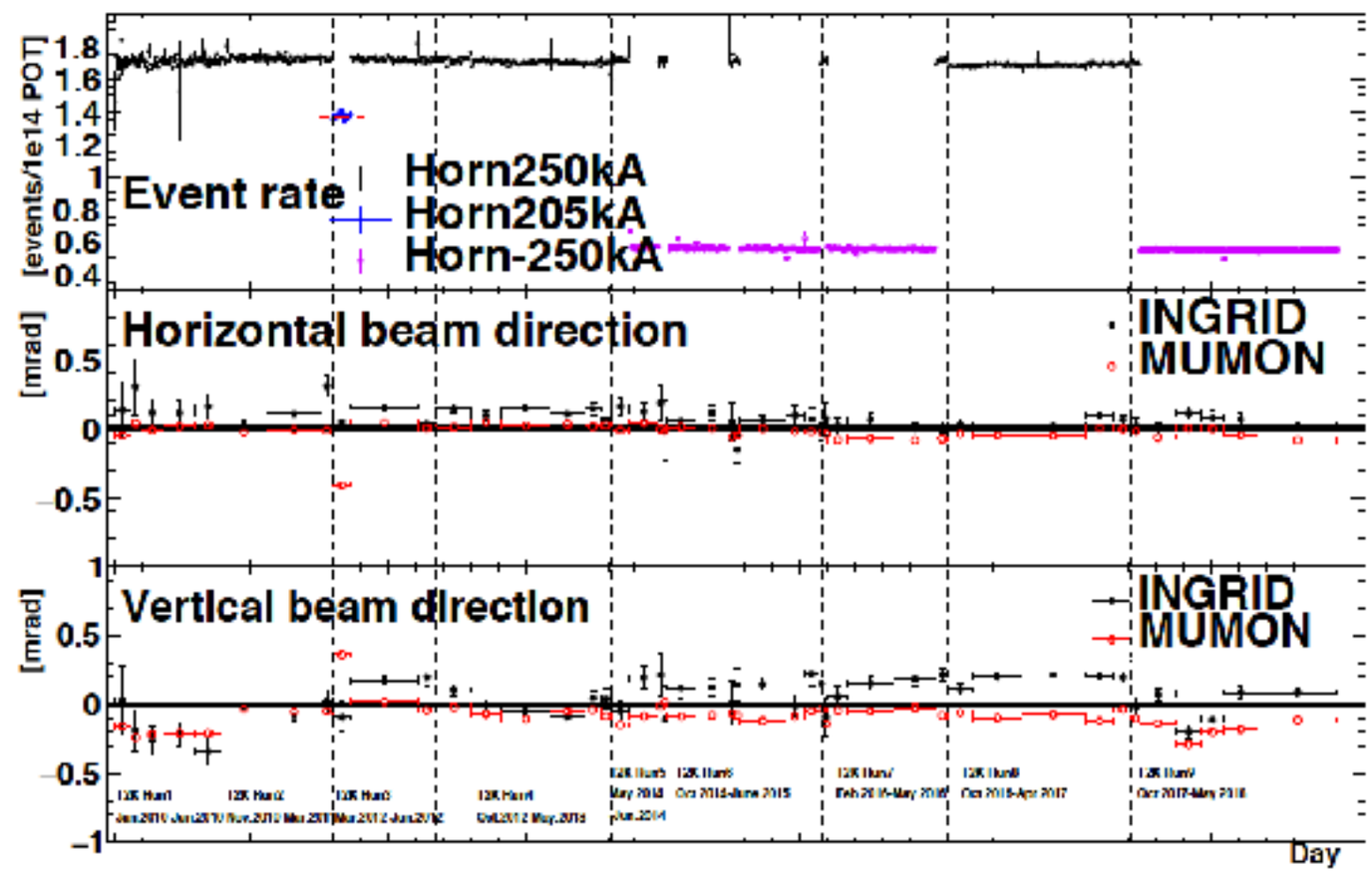
- From 2010~2018, 3.1×10^{21} POT is accumulated.
  - Max Beam power: 490kW (stable beam)
    510kW (trial)
- Stable beam quality is achieved.
  - Event rate of INGRID
  - Beam direction fluctuation.
- $\sim9\times10^{20}$ POT/year achieved.
  - Our next goal : 1.3 [MW・year]
    → $\sim3\times10^{21}$ POT/year





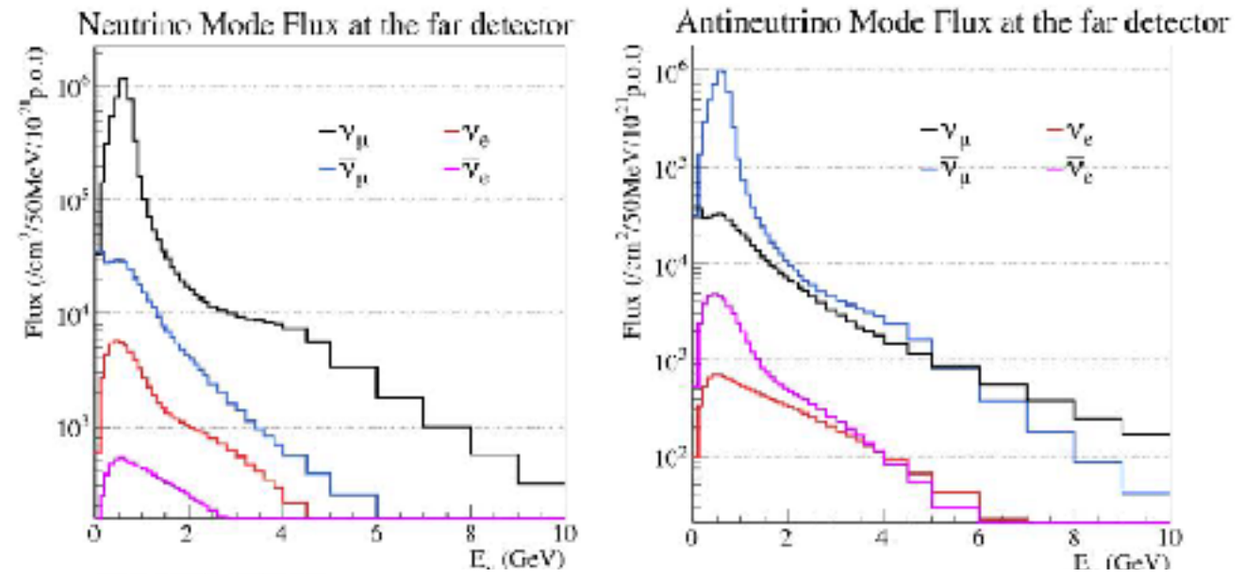
23 Jan. 2010 – 31 May 2018
POT total: 3.16×10^{21}

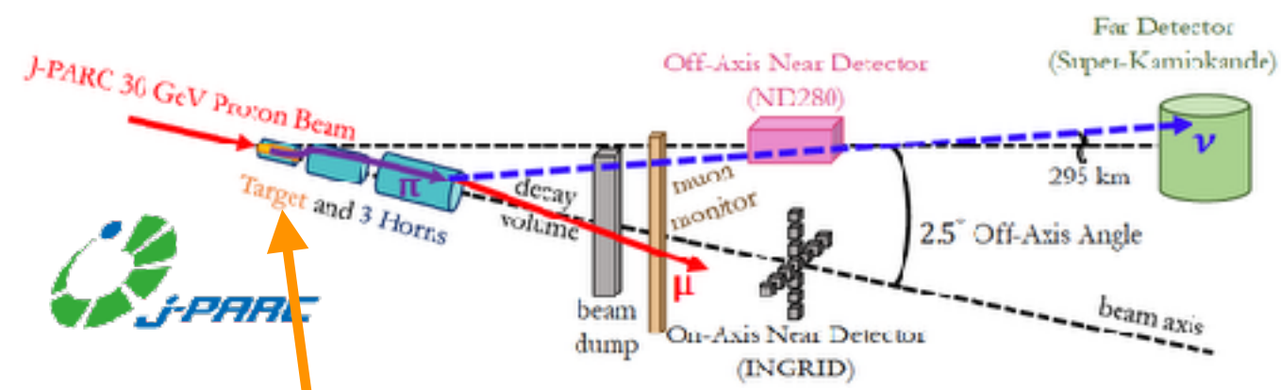
ν-mode 1.51×10^{21} (47.83%)
$\bar{\nu}$-mode 1.65×10^{21} (52.17%)

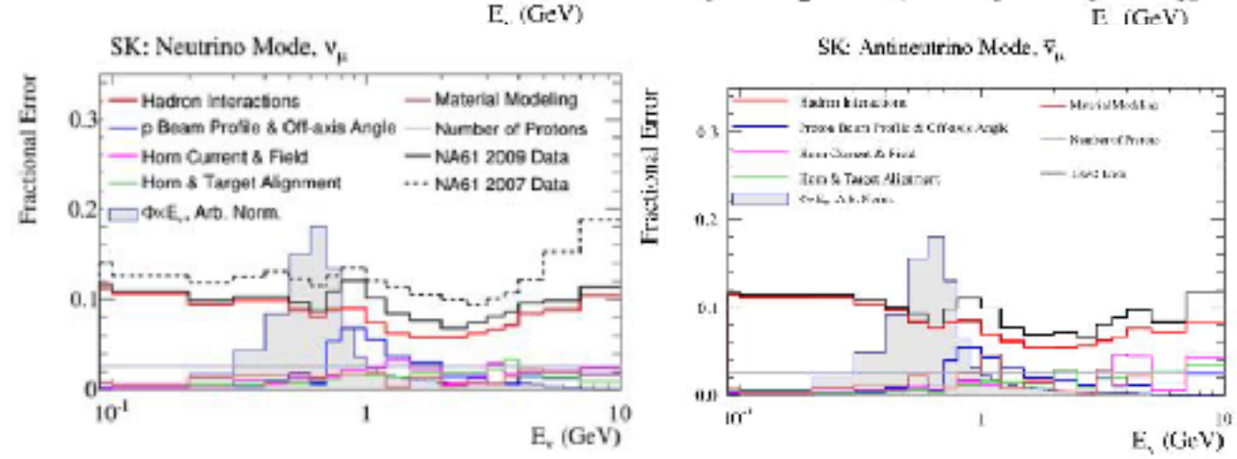


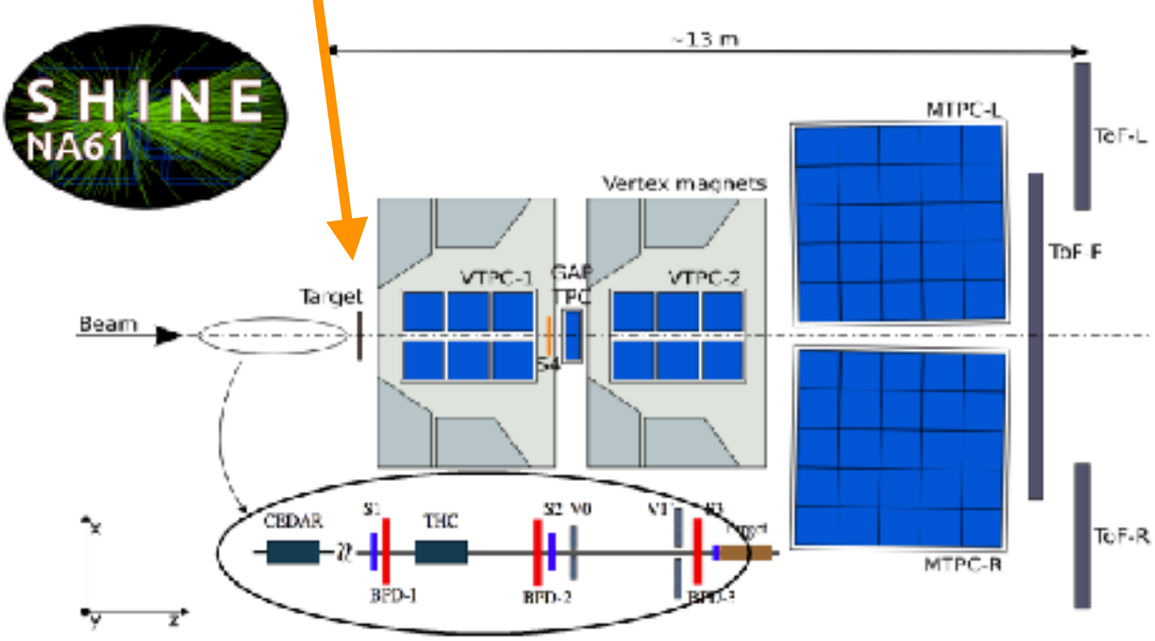
ν-flux prediction of J-PARC neutrino beam

- Prediction with ~10% uncertainty achieved using CERN NA61/SHINE "Thin" target data.
  → More improvement (~4% level) using "Replica" target data will come soon.
- Further data taking of NA61/SHINE is submitted.

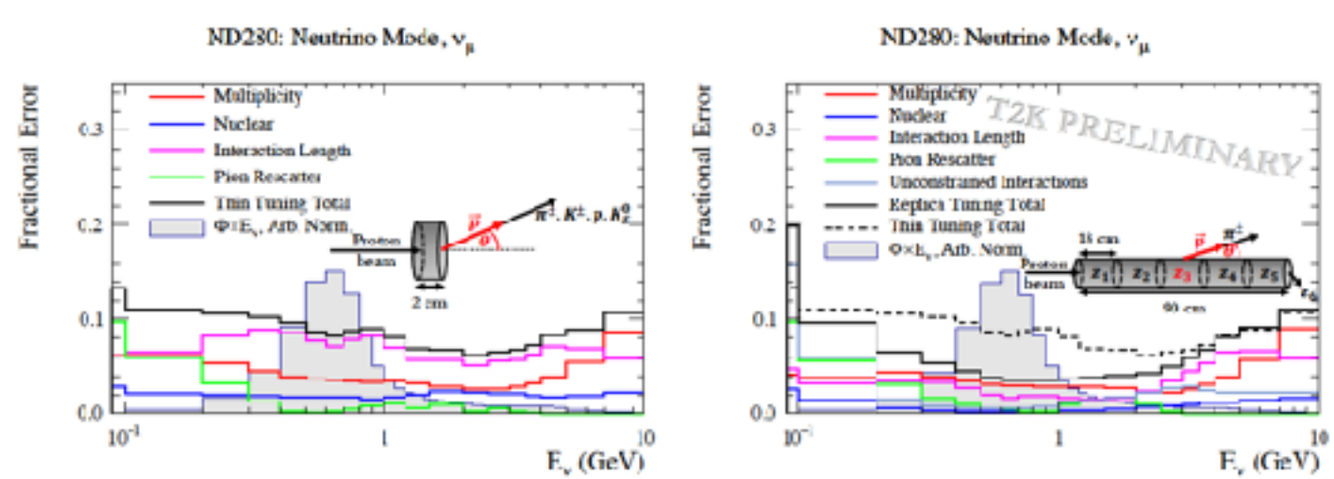






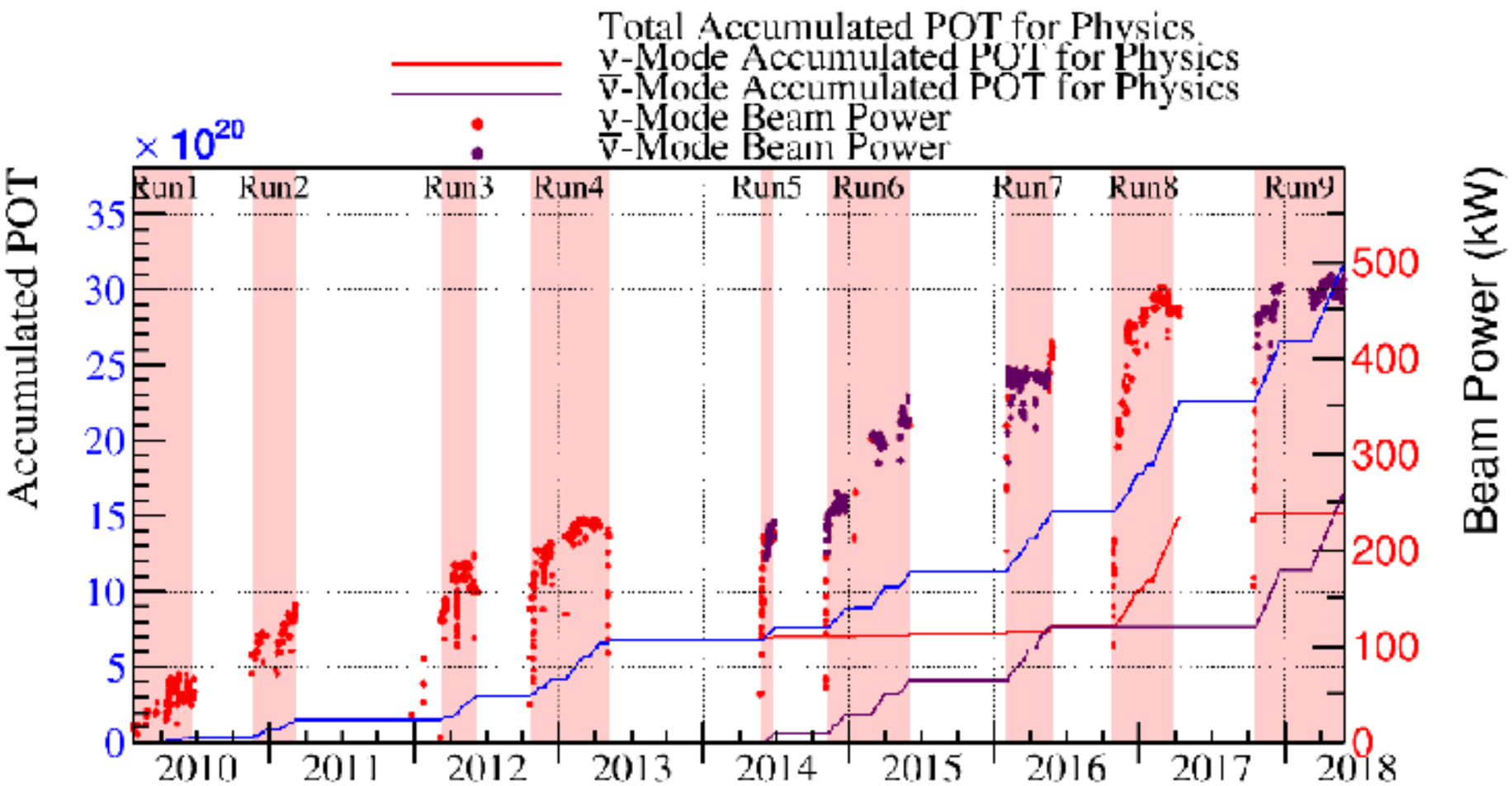


Improvement by "long" target data



10 years operation experience

- Remote maintenance method is established for horn and beam window.
  - Device exposed to beam survives >2×10^{21} POT, so far.



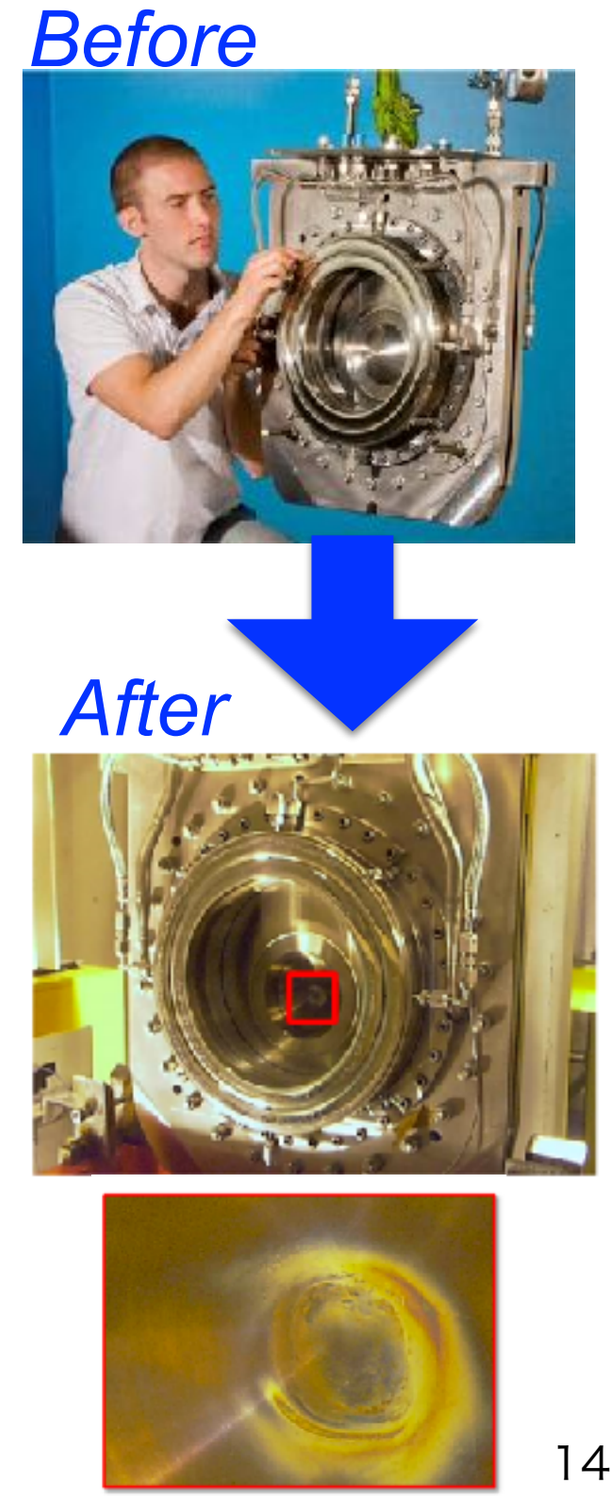
Target-1 → Target-2

OTR-1 → OTR-1

Horn ver.1 → Horn ver.2

Beam window-1 → BW-2

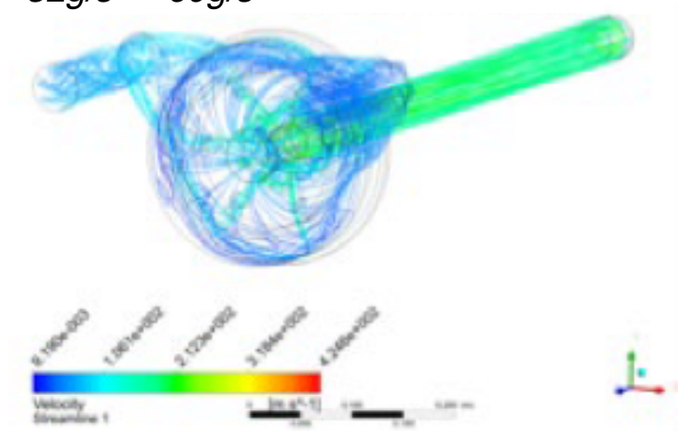
SSEM 19 foil



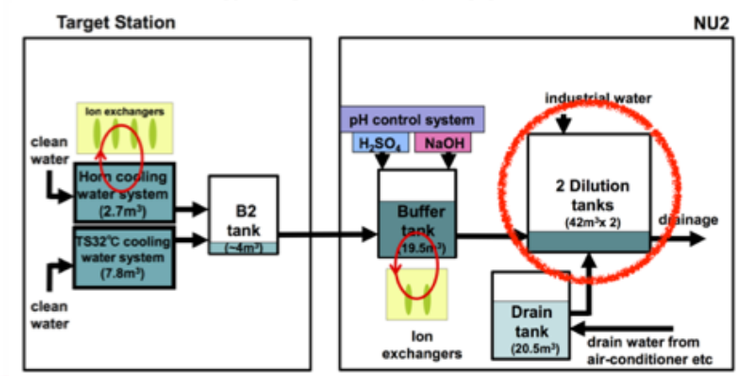
To achieve 1.3MW neutrino beam production

- Increase cooling capability
  - Target, Horn, He vessel, …
- Accepting 1Hz operation
  - Horn, DAQ
- Reinforce radiation protection
  - Radiation shield
  - Radio-activated water disposal
  - Study 3H production behavior
  - Remote maintenance method

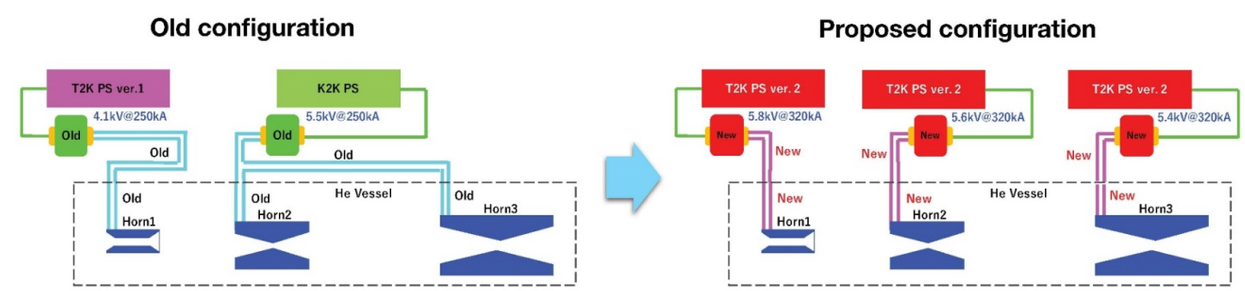
Target He cooling
32g/s → 60g/s



Radio-activated water disposal upgrade
Tank 84m³ → >400 m³



Horn Power supply upgrade for 1Hz operation

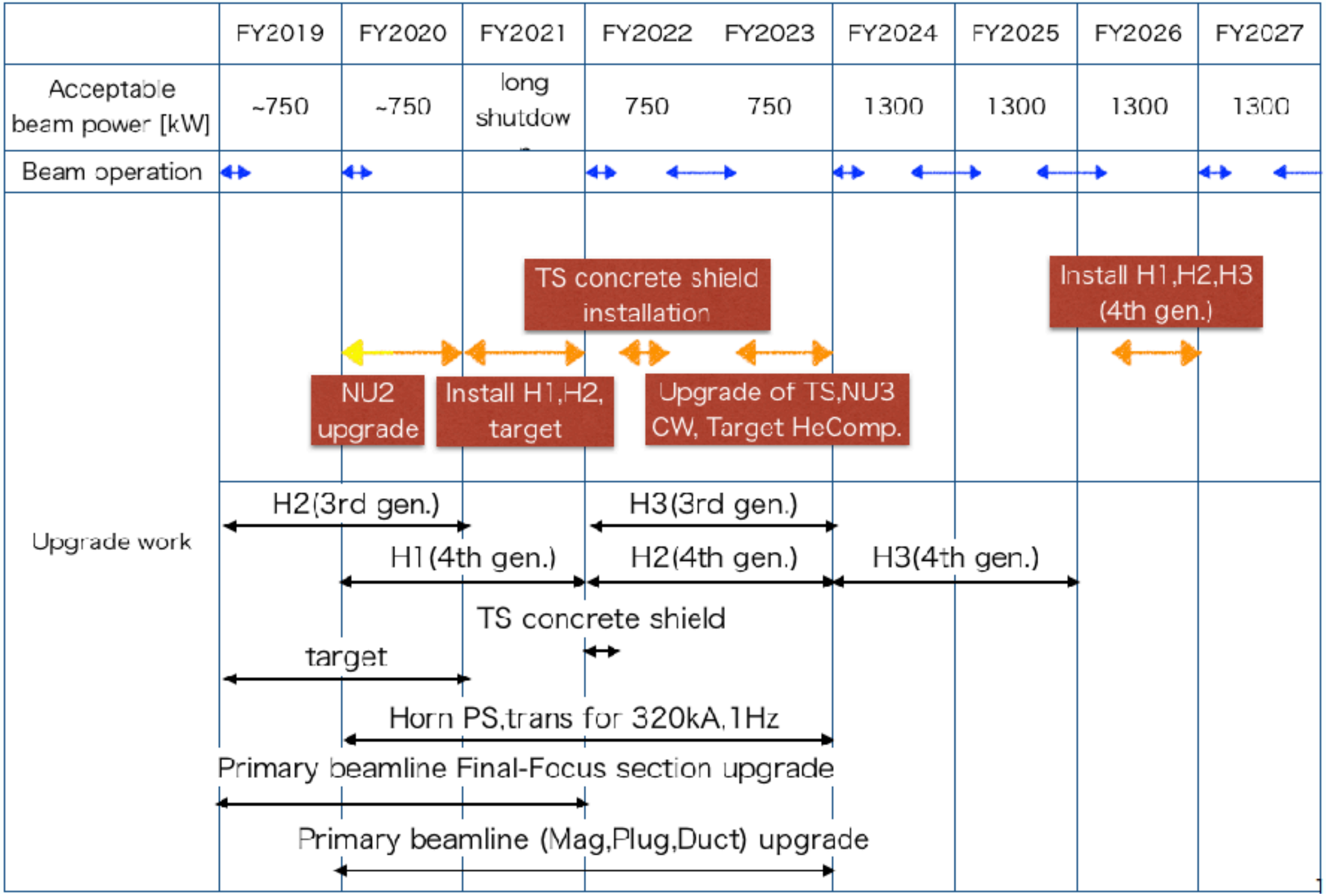


- Realize safe and stable proton beam operation with low beam-loss
  - Beam interlock system, beam monitoring, primary beam-line
- Understand the radiation damage of materials.

- Technical Design Report of J-PARC neutrino beam-line upgrade is now available: http://arxiv.org/abs/1908.05141
  - It has been reviewed by the KEK-IPNS review committee (2018~2019) and J-PARC PAC and its upgrade strategy has been endorsed.

Neutrino beam-line upgrade schedule

- Plan to make ready to accept 1.3MW beam by 2024.



Summary

- Experimental neutrino program at J-PARC shows exciting hints for lepton CP violation, and future project is about to take a step forward.
- J-PARC neutrino beam power upgrade is desired by T2K and HK.
  - ~3×10^{21} POT/year with 1.3MW beam is expected.
- J-PARC MR achieve ~500kW beam power with acceptable beam loss. Upgrade for 1.3MW beam power is planed.
- J-PARC delivered well-tuned neutrino beam using ~3×20^{21} POT from 2010 to 2018.
  - 9×10^{20} POT/year is achieved in Oct. 2017-May 2018
  - The neutrino flux is estimated with 10%→4%(near future) uncertainty.
- 10 years experience of J-PARC neutrino facility has been accumulated.
  - The device exposed to proton beam survives for >2×20^{21} POT.
- Technical design report of J-PARC neutrino beam-line upgrade for 1.3MW beam power (http://arxiv.org/abs/1908.05141) is reviewed and endorsed by KEK-IPNS/J-PARC committees.

  → Aiming to make ready to **accept 1.3MW beam power by 2024.**