The Commissioning Workshop of ESS- J-PARC collaboration

10-12 October, 2022

J-PARC's Accelerator construction, commissioning and operation (400MeV-linac, 3GeV-ring) -I

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Talks related to J-PARC accelerator

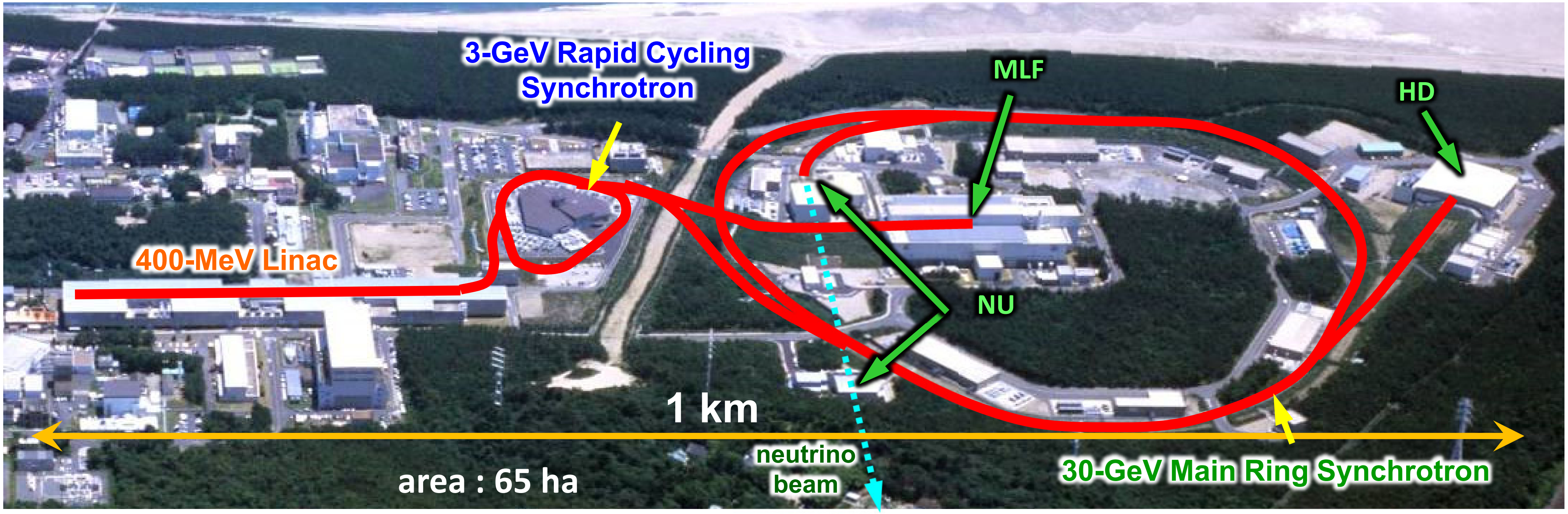
*The 1st day:

- J-PARC's accelerator construction, commissioning and operation
  - 400MeV Linac, 3GeV-ring (H. Oguri, Y. Liu)

*The 2nd day:

- Experience with machine protection system at J-PARC (N. Hayashi)
- Experience with control tools at J-PARC (H. Takahashi)
- Beam commissioning at the MLF target station (S. Meigo)
- Recent progress in LLRF (K. Futatsukawa)
- Experiences of klystron operation (Y. Fuwa)
- Status of accelerating cavities (Y. Kondo)
- Status of beam monitor for linac (K. Moriya)

J-PARC Accelerators



● Linac

- **H⁻ beam** acceleration
- Beam energy : **400 MeV**
- Beam current:
  50 mA for user operation
  60 mA for beam study
  (peak current at linac exit)
- Pulse length : < 0.5 ms
- Repetition: 25 Hz

● Rapid Cycling Synchrotron(RCS)

- Charge-exchange injection **H^--> H^+**
- Beam energy :**3 GeV**
- Injection into MR
- Delivery to MLF
- Beam supply to MLF with the beam power of **740 kW** (in 2021)

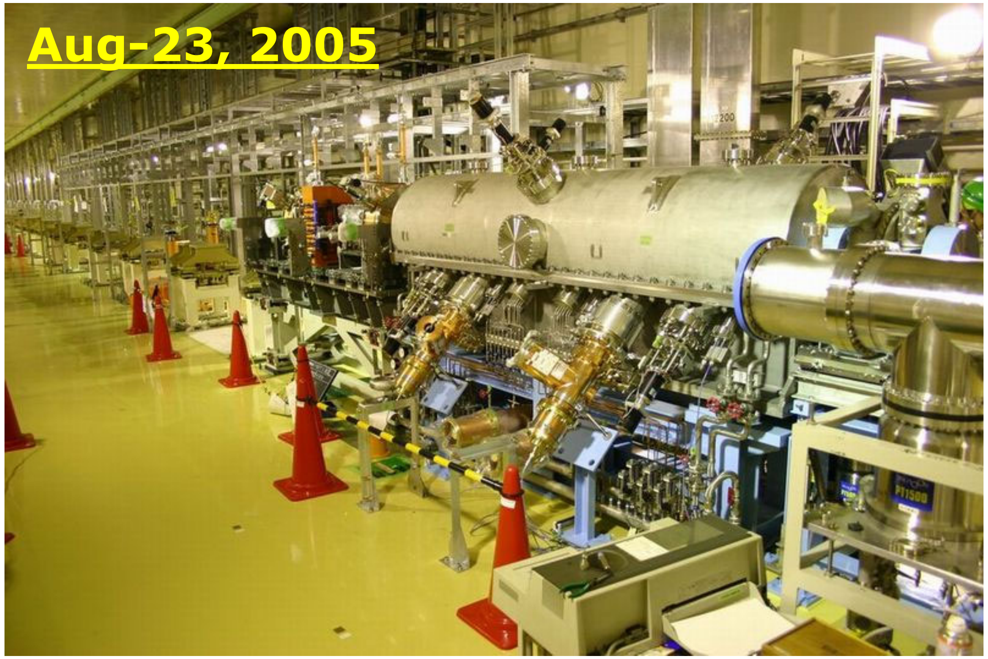
● Main Ring (MR)

- Beam energy :**30 GeV**
- Beam power:
  510 kW (in 2021) to NU
  64 kW (in 2021) to HD

Construction and operation history

Year	Event
2002	• Linac bldg. construction start • MR bldg. construction start • RCS bldg. construction start
2005	• RCS bldg. is completed • Linac bldg. is completed
2006	• Beam commissioning start (Linac)
2007	• 181 MeV acceleration is achieved at linac • MR bldg. is completed • 3 GeV acceleration is achieved at RCS
2008	• 30 GeV acceleration is achieved at MR
2014	• Linac upgrade (energy & intensity) plan is completed
2015	• Single shot mode operation with a beam power equivalent to 1MW is achieved
2018	• Continuous operation with a beam power equivalent to 1 MW is succeeded

Construction (linac)



Construction (RCS)

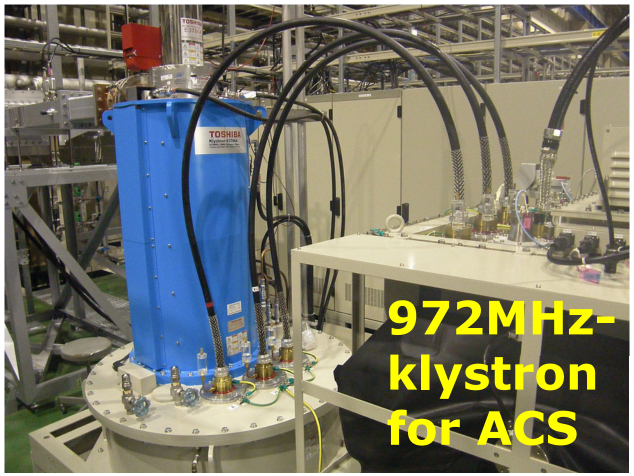
Construction (MR)

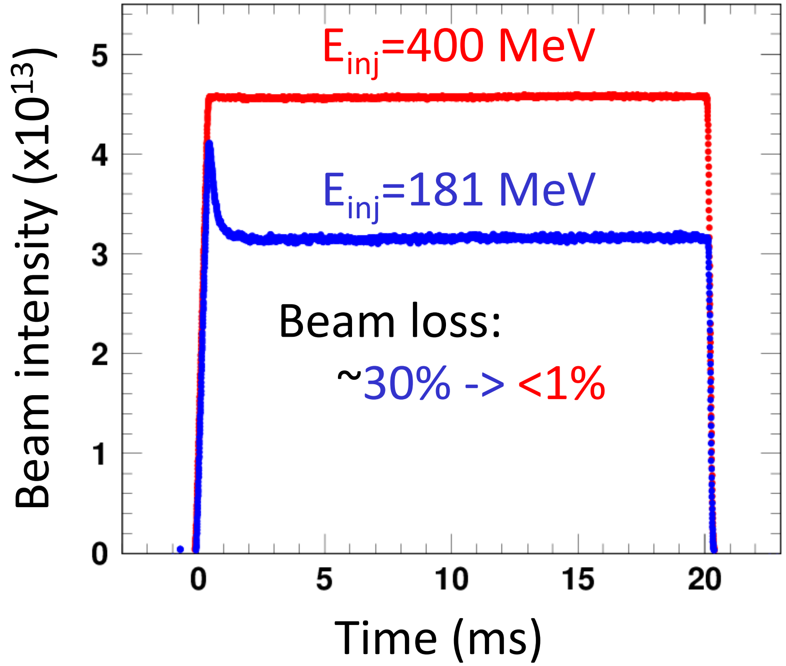
Linac upgrade (energy)

■ To suppress the space-charge effect, which limits the obtainable beam power at the RCS, the beam energy from the linac was increased from 181 MeV to 400 MeV by adding ACS cavities in 2014.

□ History of the ACS

- In the end of 2010, the first mass-produced ACS module was completed and its high-power test was performed.
  - ➢ Only five of the 25 total modules could be tested before the installation due to the huge earthquake in 2011.
- In Aug. 2013, installation to the beam line was started.
  - ➢ It took one day to complete for one ACS cavity.
- In Nov. 2013, high-power conditioning was started.
  - ➢ An average conditioning time is 149 hours.
- In Dec. 2013, the beam commissioning was started.
  - ➢ **400 MeV was achieved in Jan. 2014.**





Beam intensity at RCS

By increasing the injection energy, the beam loss was dramatically reduced. (~30% -> <1%)

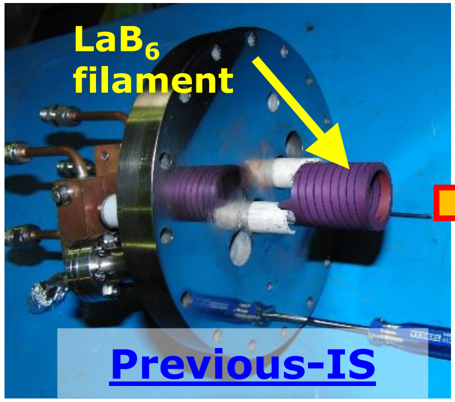
Linac upgrade (intensity)

- A front-end part (ion source & RFQ) was replaced for increasing peak beam current from 30 mA to 50 mA in 2014.

Ion source

- To achieve 50 mA, we changed the type of ion source from the arc-discharge to the RF-discharge for source plasma production.

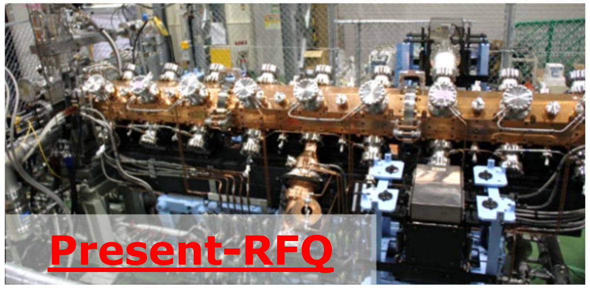
	Previous IS	Present IS
Source plasma production	Arc discharge (LaB_6 filament) , (Cs free)	RF discharge (int. antenna), (Cs injection)
H^- beam current	20mA (user op) 32mA (max)	60mA (user op) 72mA (max)
Cont. op. time	~1,000 hours @20mA	4,001 hours @60mA



RFQ

- At the beginning of the J-PARC linac operation, an RFQ with a design current of 30 mA was used. To achieve 1 MW, we replaced the new RFQ with a design current of 50 mA.
- The major engineering change between the two is the design of the RF cavity structure.

- The RF cavity is installed in a large vacuum vessel. It is difficult to obtain good vacuum quality because the surface area is very large.

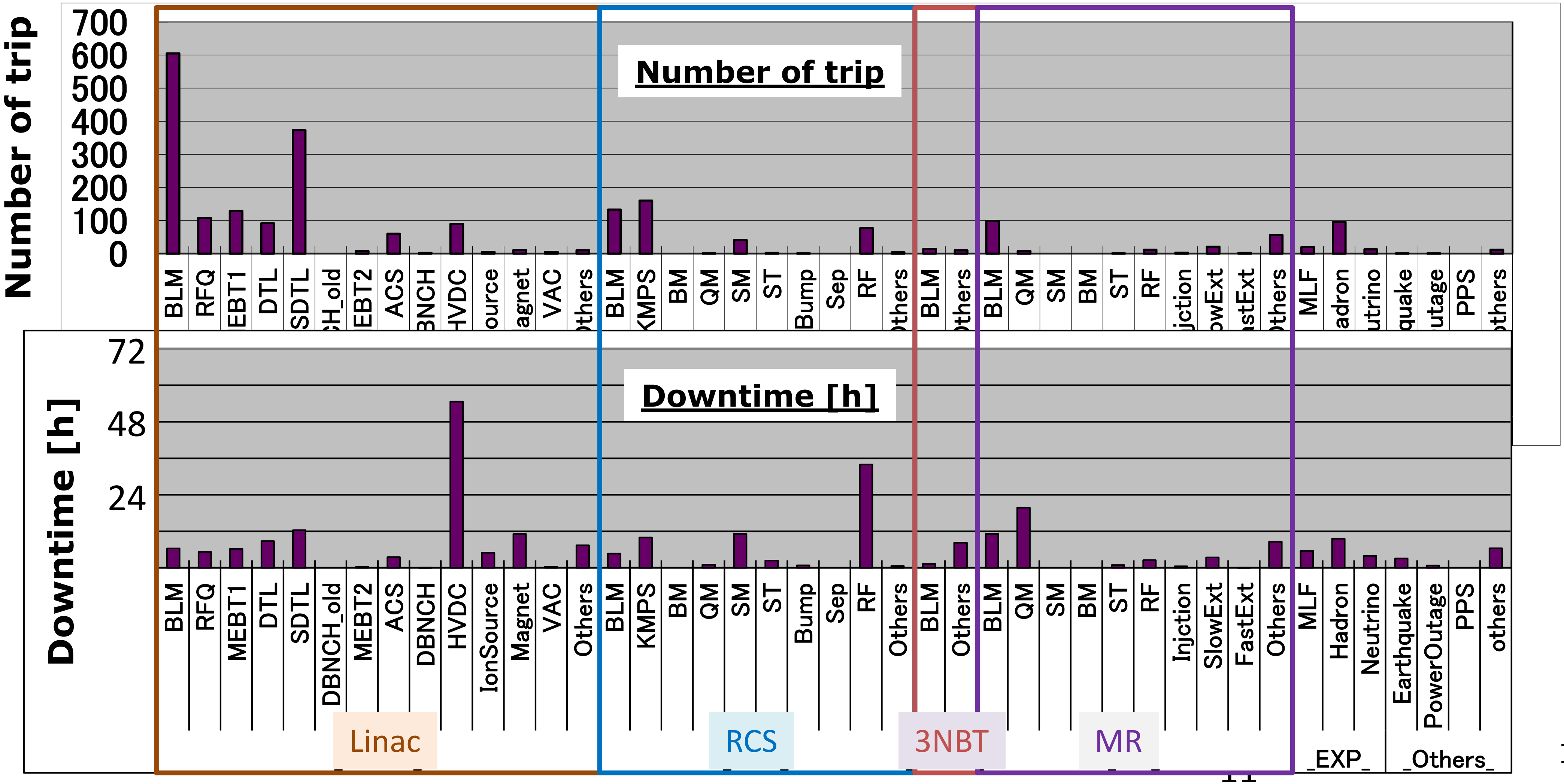


- Vacuum-tight cavity structure is adopted. To this end, we adopted brazing for the assembly method.

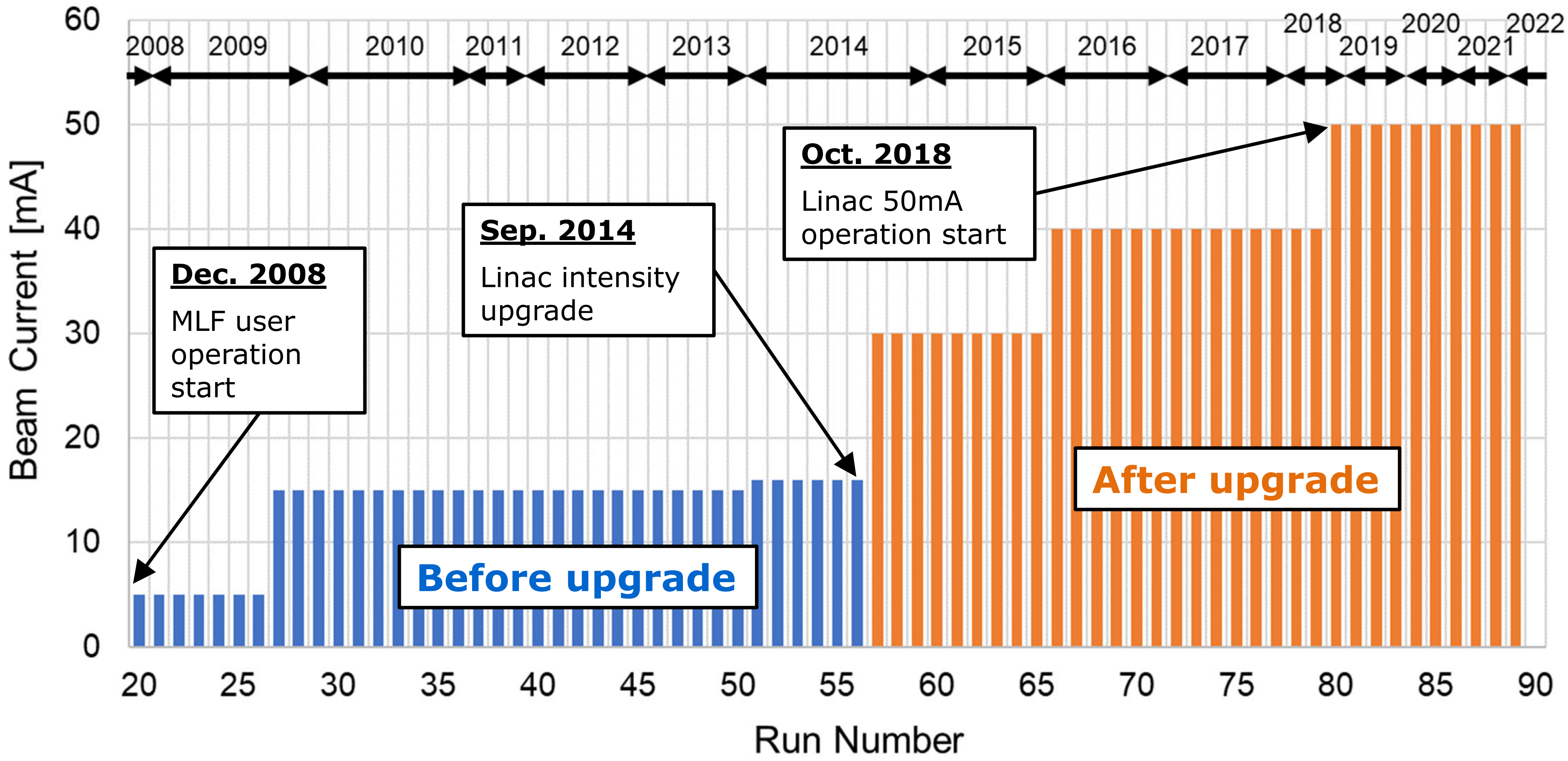
Operation status
(Linac, RCS)

Accelerator status for one year (JFY2021)

Facility	User time [h]	Net time [h]	Beam power [kW]	Availability [%]
MLF	3,608	3,480	630/740	96.4
Neutrino (FX)	371	347	~ 510	93.6
Hadron (SX)	1,016	952	Max. ~64	93.7



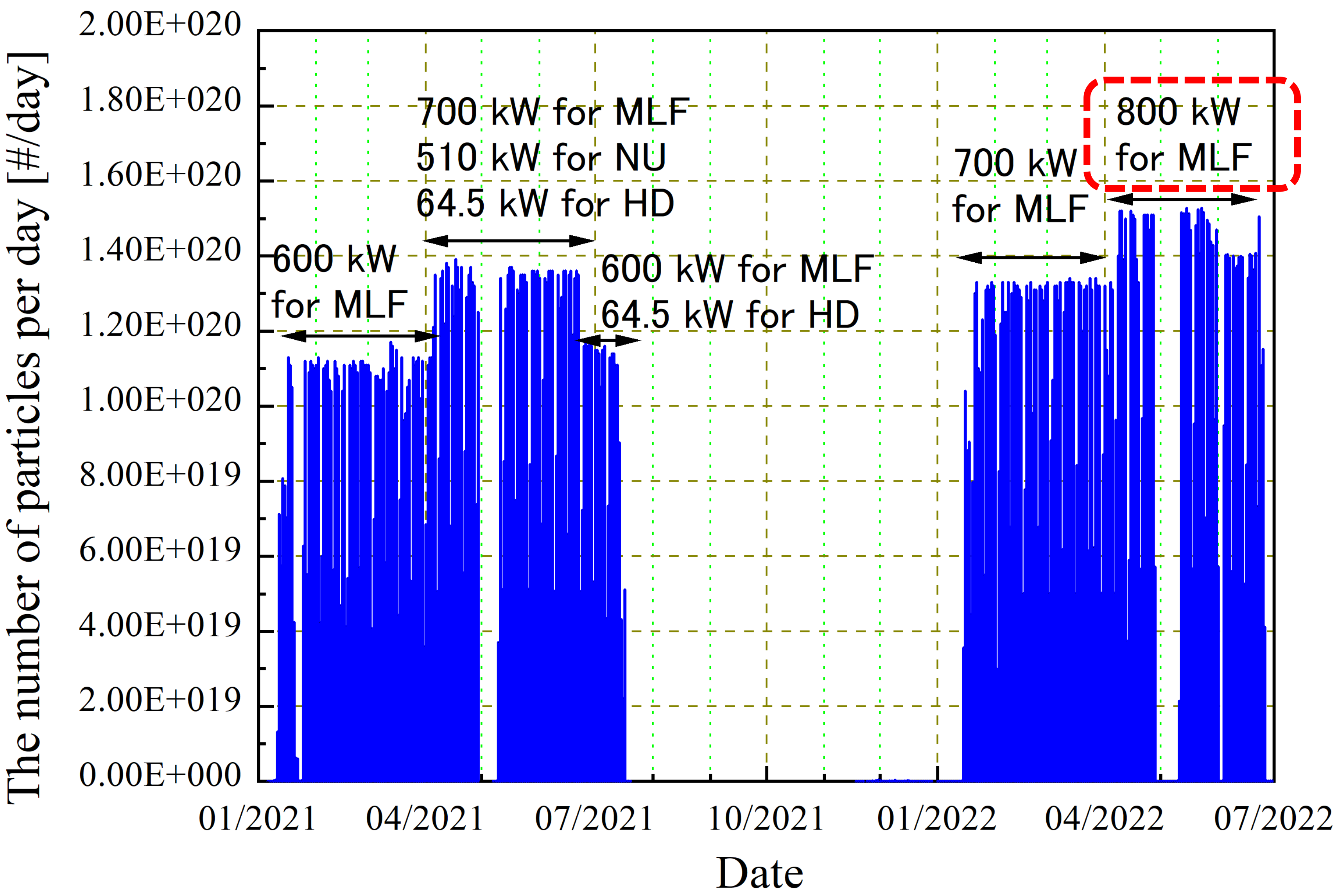
Linac beam intensity



Operation history of the linac beam intensity

- In 2008, MLF user operation started with linac beam current of 5mA.
- In 2009, beam current was increased to 15mA and operated for about next five year.
- In 2014, after linac upgrade was completed, 30mA operation started.
- In 2018, **50mA (nominal)** operation was started.

RCS beam power

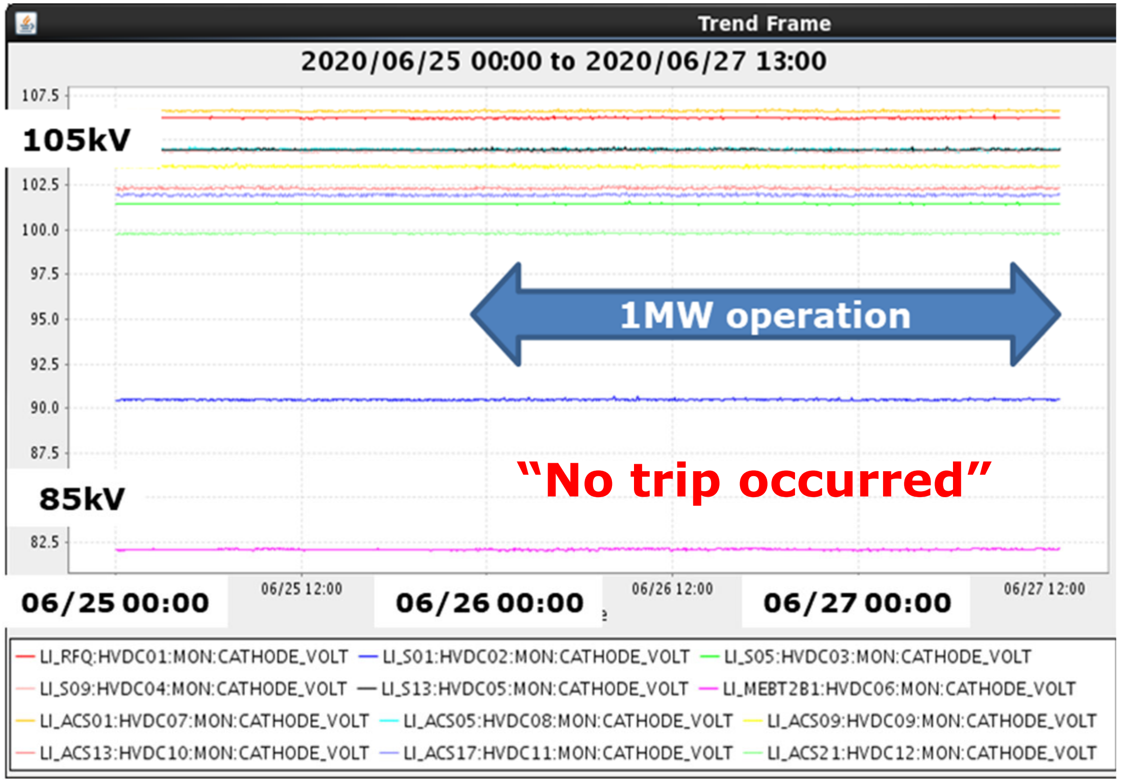


- In JFY2022, 800-kW beam is delivered to the MLF with **>95 %** availability.

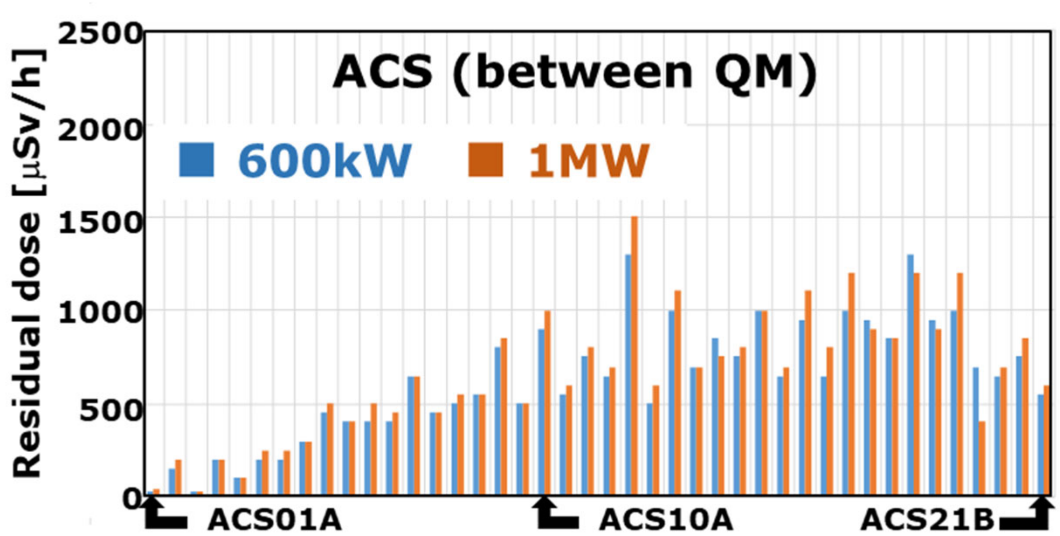
Continuous operation with 1MW (linac)

At the end of June 2020, we conducted continuous operation with 1MW for about 40 h.

Time variation of output voltage of each HVDC power supply



Comparison of residual dose at 1-MW and 600-kW operation

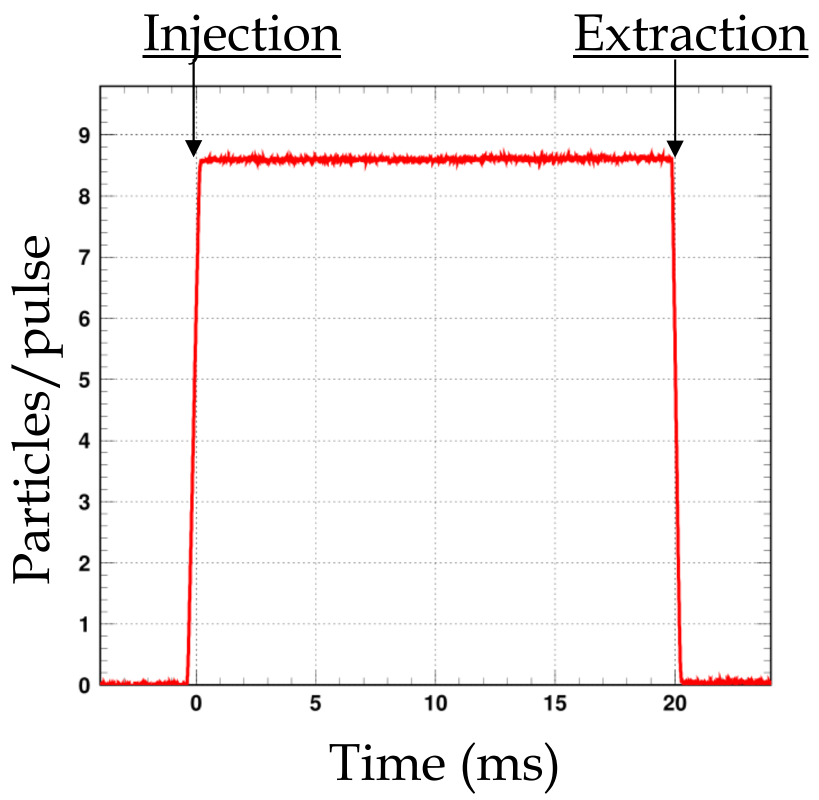


Down time:
- HVDC power supply: 0 min
- Accelerating cavity: ~ 6 min
  (This data is not shown on this slide)

Residual dose is almost proportional to the beam power.
- ➢ No beam loss specific to 1-MW operation was observed.

Continuous operation with 1MW (RCS)

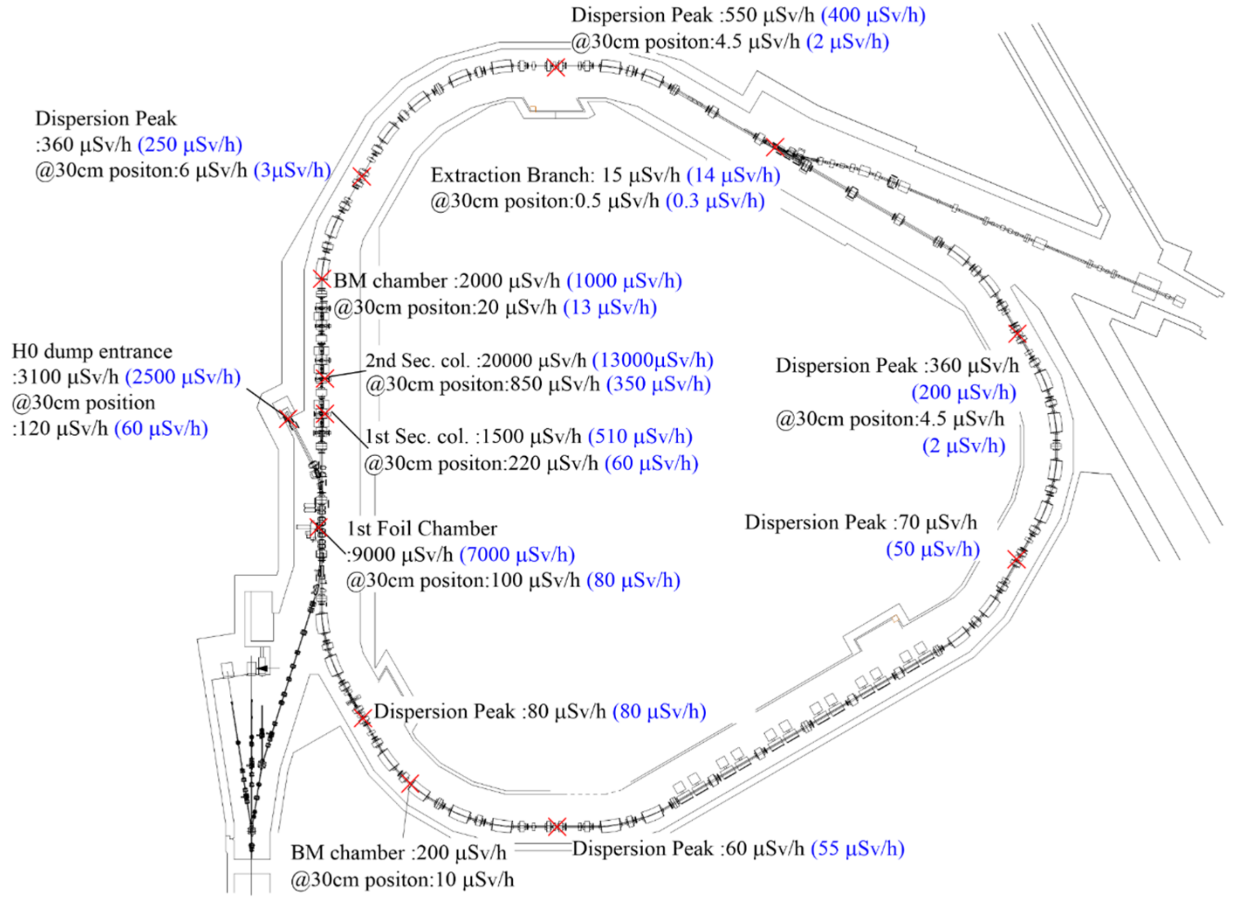
Beam current at 1 MW



✓ **No significant loss**

Comparison of residual dose at 1-MW and 600-kW operation

After 1 MW, 40 hr trial for MLF (27th Jun. 2020), Measurement after 5 hours from beam stop
600 kW user operation (24th Jun. 2020) , Measurement after 4 hours from beam stop



- Residual dose is almost proportional to the beam power.
  - ➢ No beam loss specific to 1-MW operation was observed as well as linac.

Summary

Summary

- Beam commissioning of the J-PARC accelerator started in 2006 (linac).
- In JFY2021, the accelerator provided beams of up to 740 kW to MLF, 510 kW to Nu, and 64 kW to HD, respectively.
- In JFY2021, the availability of the accelerator achieved 96% for MLF and 93% for NU and HD.
- In JFY2022, the MLF beam power is increased to 800 kW for user operation.
- Continuous operation with a beam power equivalent to 1 MW was conducted, and it was confirmed that there were no critical issues in both linac and RCS, such as a significant increase in beam loss or an increase in the trip rate of the accelerator components.

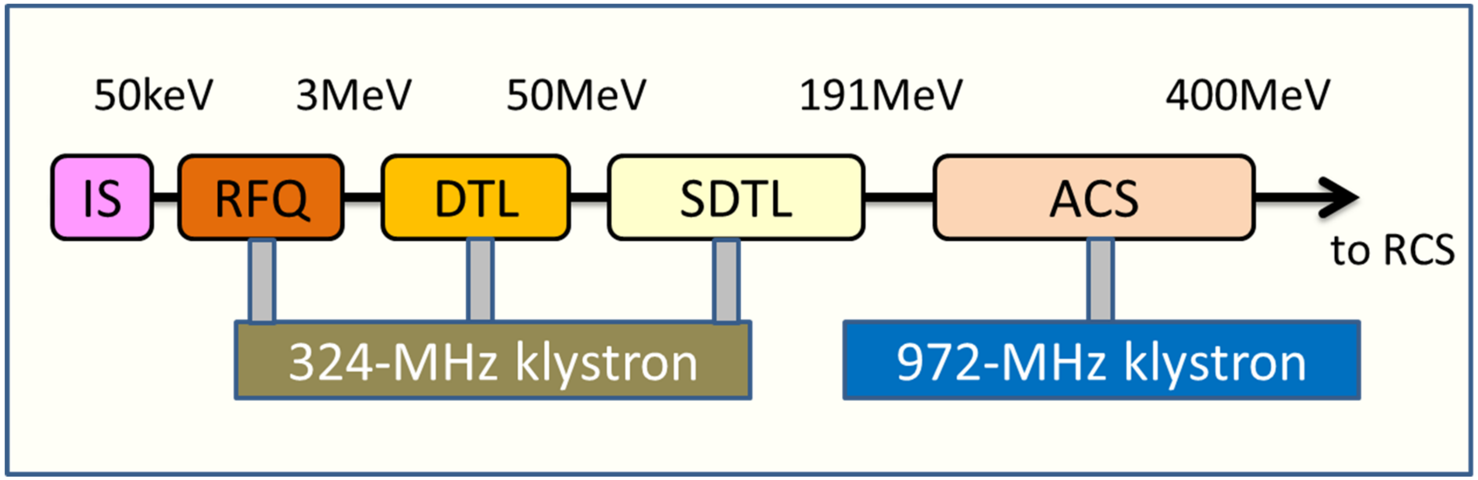
Thank you for your attention !

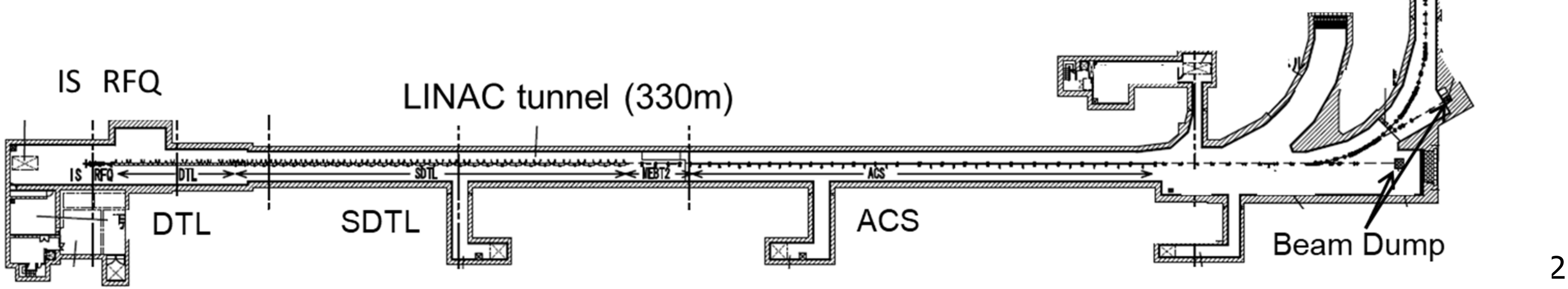
Buck up slide

Layout of linac components

- The J-PARC linac consists of an ion source and four types of accelerating cavities (RFQ, DTL, SDTL and ACS), and is installed in an accelerator tunnel approximately 13 meters underground.

- The RFQ, DTL and SDTL are driven by 324-MHz klystrons, and the ACS is driven by 972-MHz klystrons. These klystrons are installed in a 330-m-long room called the klystron gallery at ground level.



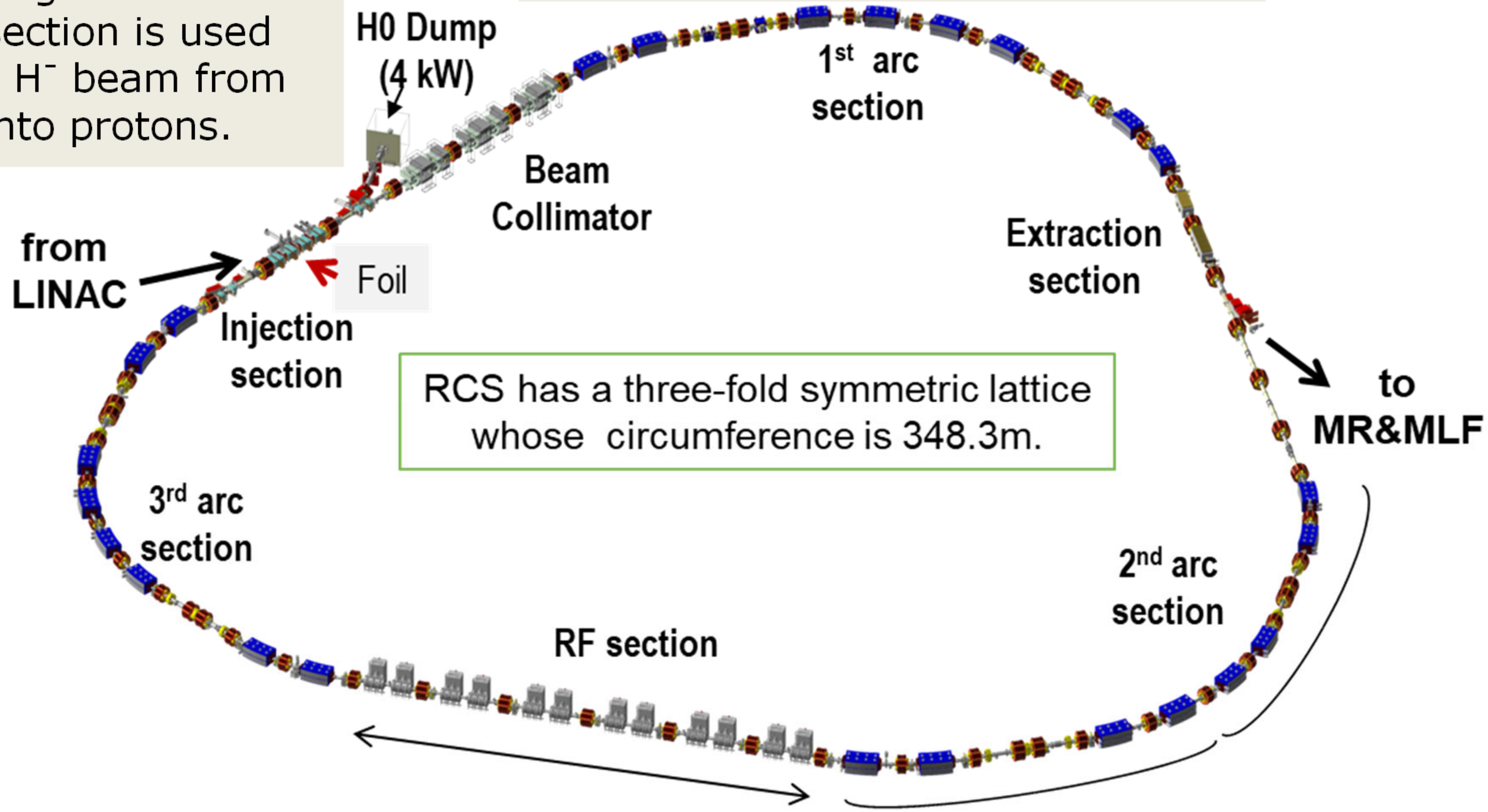


Layout of RCS components

- We have chosen the lattice with three-folding symmetry in order to keep three long straight sections (injection section, RF acceleration section and extraction section).

The H0 dump is used to dump un-stripped beams at the stripping foil. The capacity is 4kW.

The stripping foil in the injection section is used to convert H⁻ beam from the linac into protons.

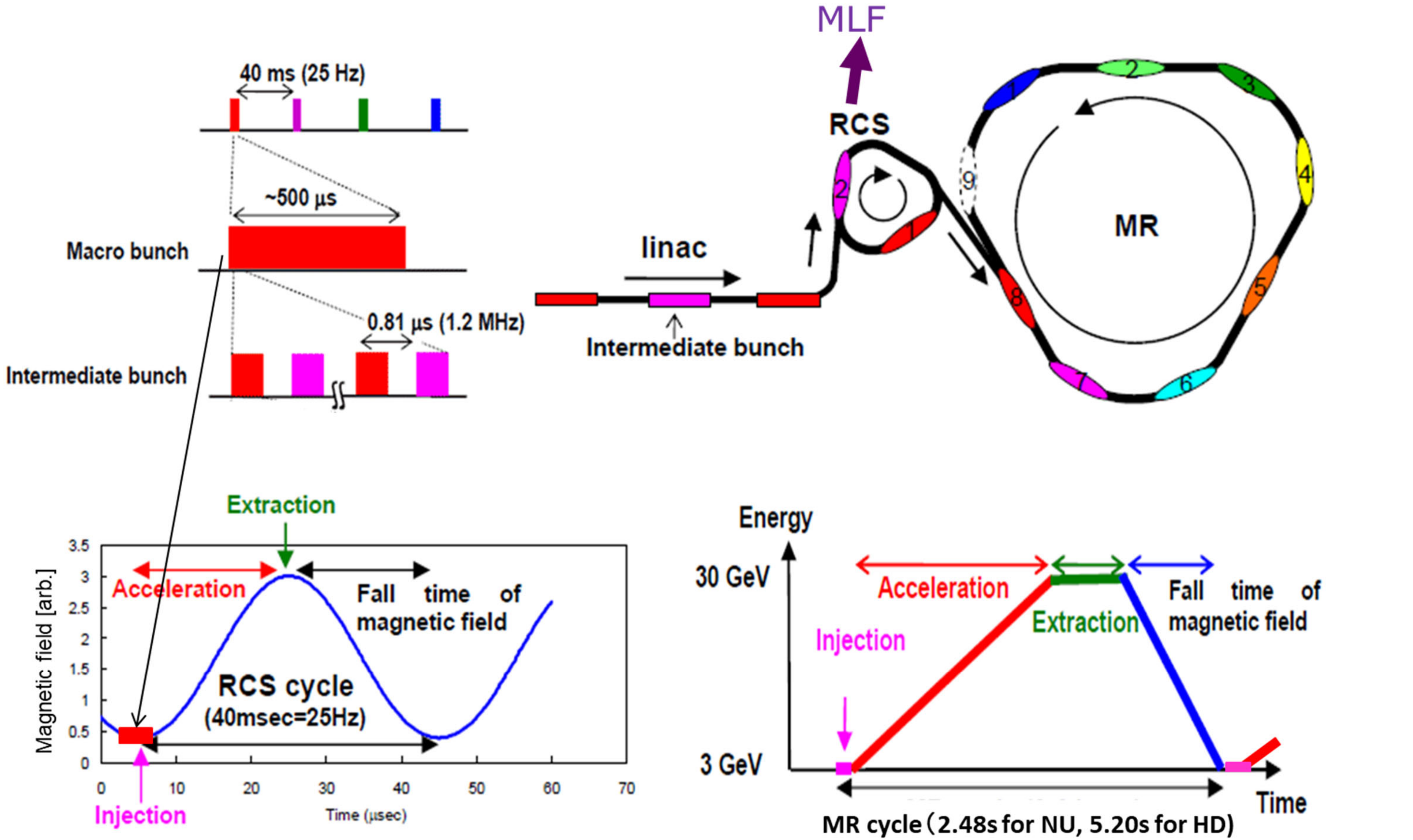


RCS has a three-fold symmetric lattice whose circumference is 348.3m.

The beams are extracted by kicker magnets and DC septum magnets at the extraction section, and then transported either to MLF or to MR with a pulsed bending magnet placed in the 3NBT line.

Twelve RF cavities in total are installed in the tunnel, whereas an accelerating electric field is excited by applying an RF power fed using the tetrode.

Time structure of accelerator operation



RCS operation cycle

MR operation cycle