High power study of J-PARC Rapid Cycling Synchrotron (RCS)

1st Muon Community Meeting
20th May, 2021

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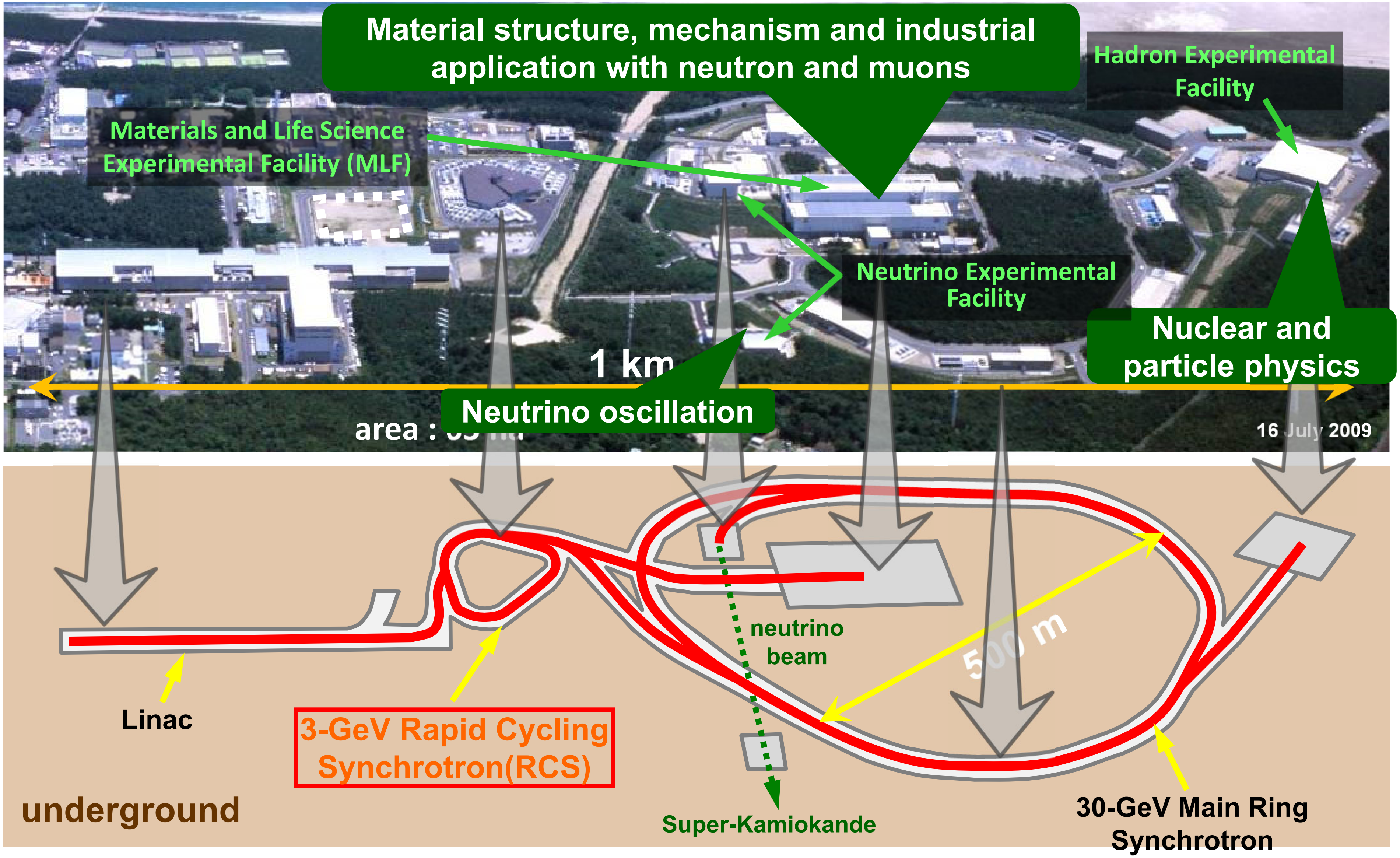
on behalf of J-PARC Center
Accelerator Division

Outline

- ✓ **Overview of J-PARC RCS**
- ✓ **High power study results**

Japan Proton Accelerator Research Complex

J-PARC

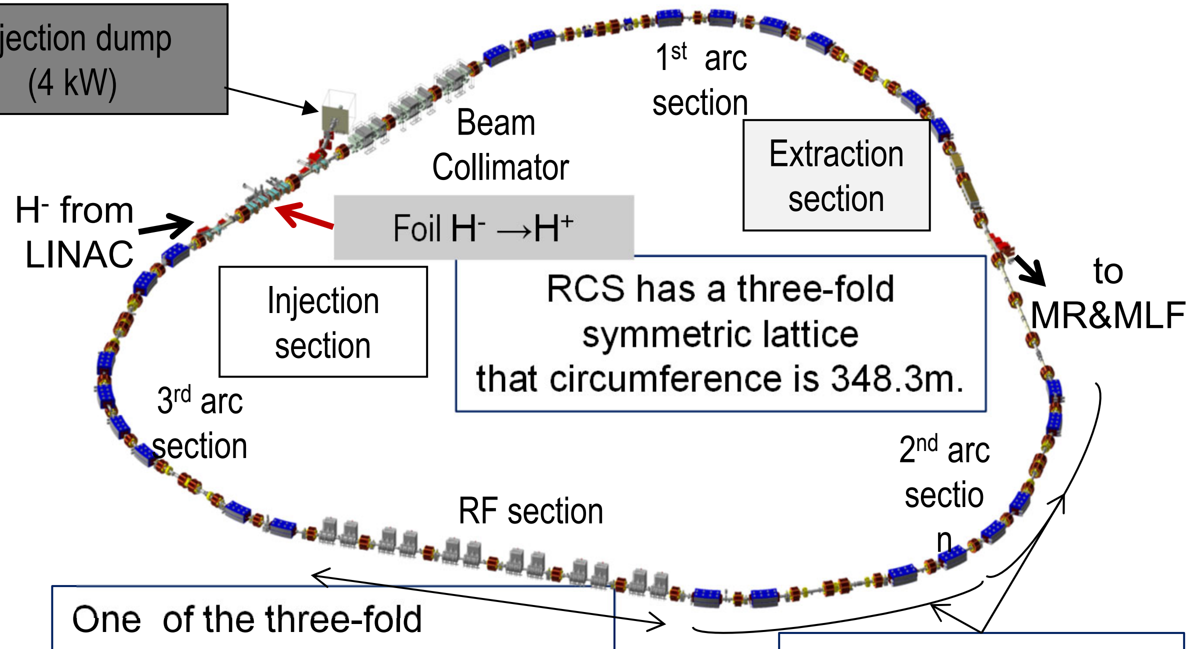


3 proton accelerators and (3+1) experimental facilities

3GeV-RCS in J-PARC

Design parameters

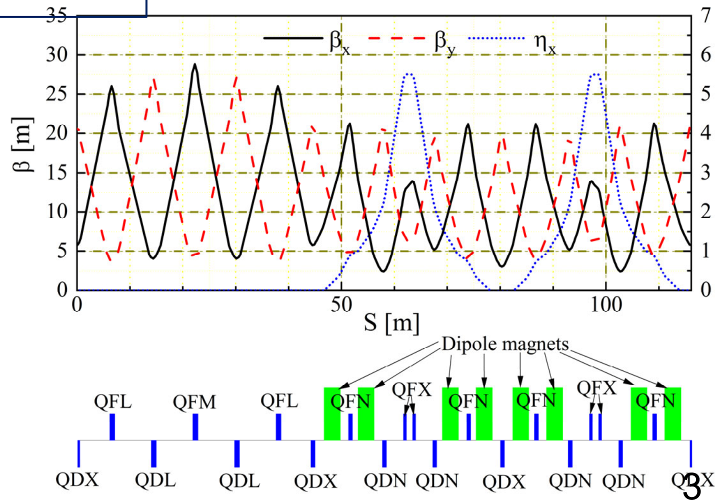
Circumference	348.333 m
Superperiodicity	3
Harmonic number	2
F_{rev}	0.61-0.84 MHz
F_{rf}	1.23-1.67 MHz
Injection energy	400 MeV
Extraction energy	3 GeV
Repetition rate	25 Hz
Particles per pulse	8.3e13 with 1 MW
Output beam power	0.75 MW in ordinal operation (1 MW for two days)
Transition gamma	9.14
Number of dipoles	24
quadrupoles	60 (7 families)
sextupoles	18 (3 families)
steerings	52
RF cavities	12



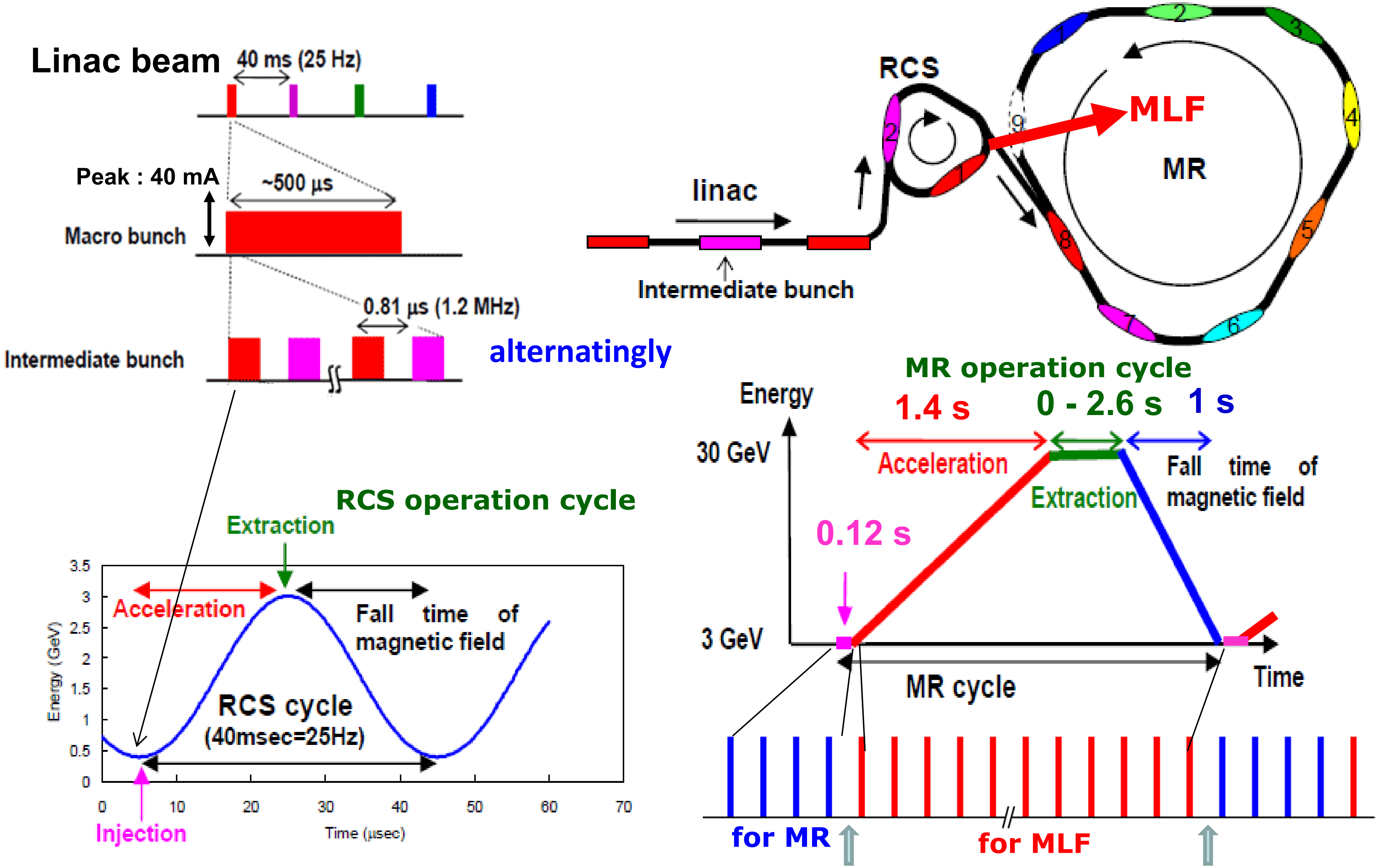
One of the three-fold symmetric lattice comprises two arc modules and a long straight insertion.

Each arc module has a missing-bend cell.

Note:
Beam power is limited not the beam loss but the durability of the neutron target (and cooling water performance in summer).

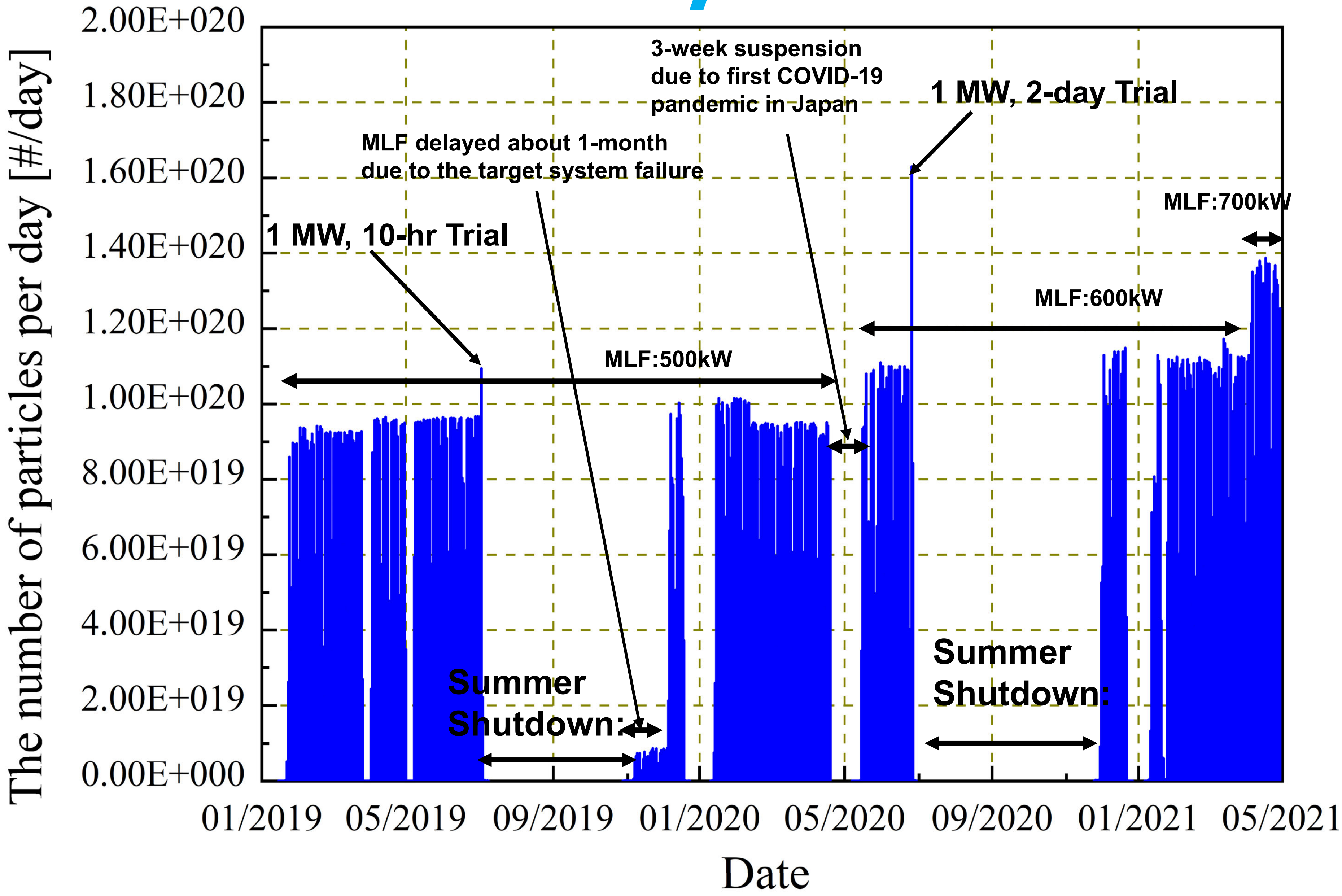


Time Structure of accelerator operation



Switch the parameters of RCS between MLF ⟷ MR during 20 ms interval

Recent beam power of RCS



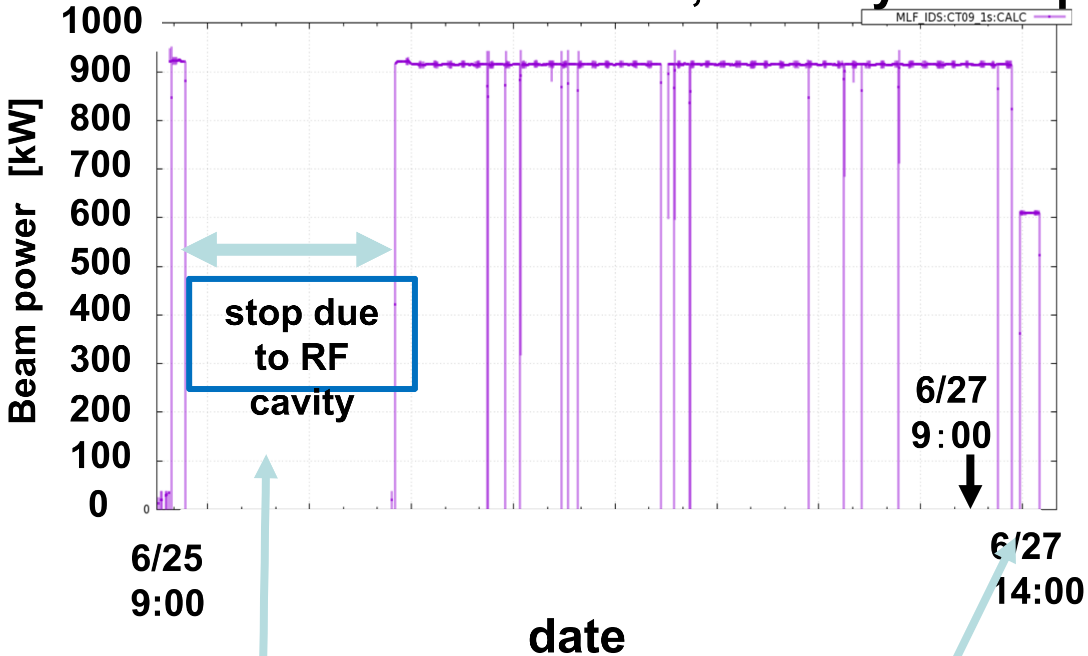
Availability : around 95% for MLF for the last several years

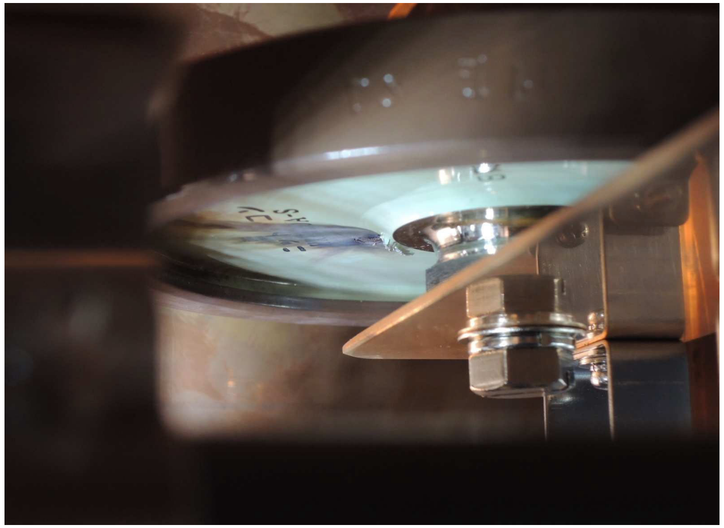
High power study results

- 1 MW stable operation
- Trial beyond 1 MW
- Numerical simulation

1 MW operation of 2020(about 36 h)

We tried 1-MW, two-day user operation on Jun 2020.





Summary of 1-MW user operation in 2020

— Foil keeps its function.

— Beam loss is within expectation

— 12hr stop due to RF cavity #3 & 8 failure(deterioration of the capacitor(#3) and vacuum tube(#8))

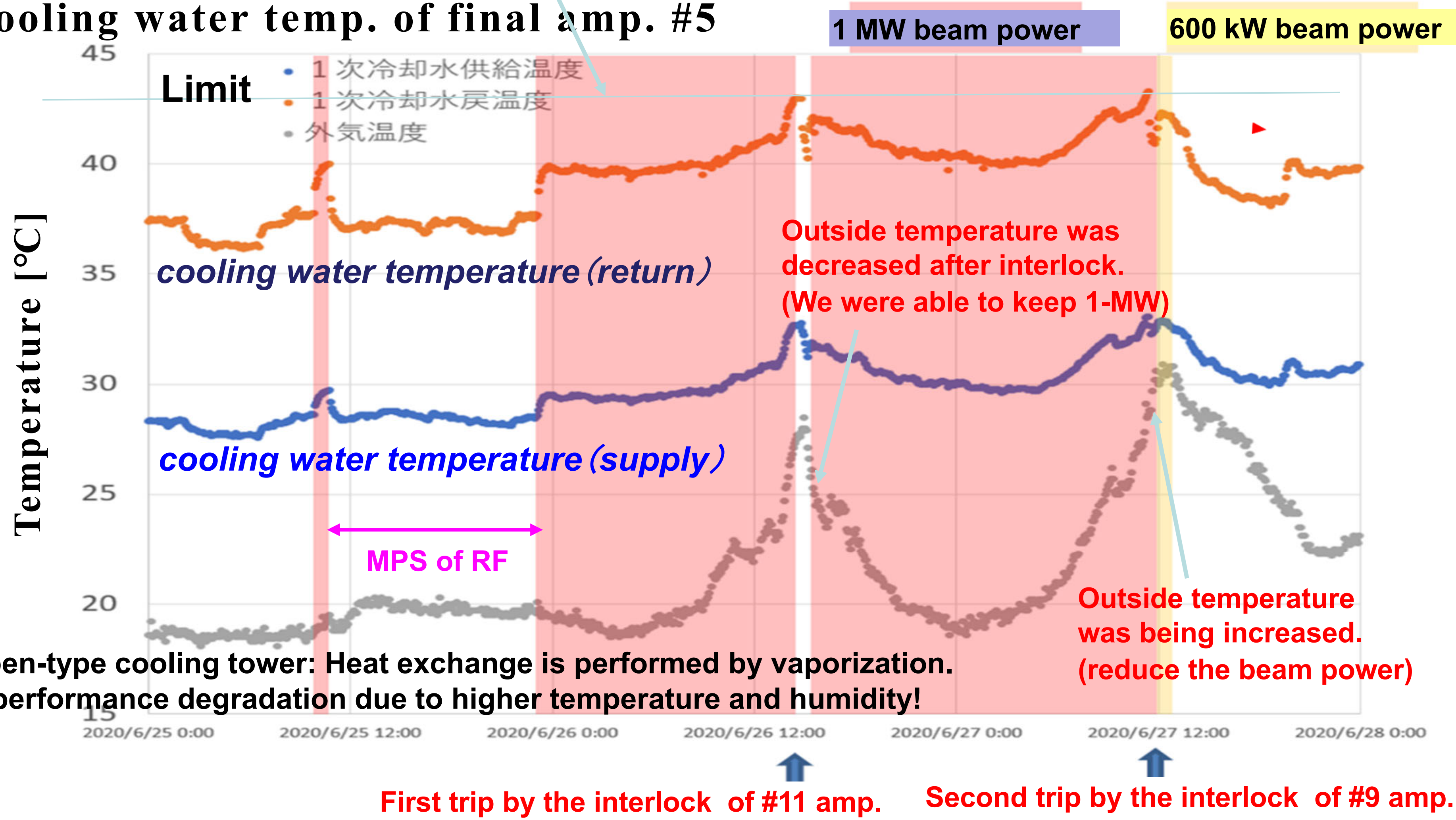
— The cooling water temperature cannot be maintained at a 1-MW power when the outside air temperature becomes high.(next slide)

Courtesy M. Nomura

Issue : Interlock due to higher temperature of the cooling water

RF need more power to compensate the beam loading at 1-MW power!
→Increases the power consumption in the vacuum tube and the return cooling water temperature exceeded limit twice.

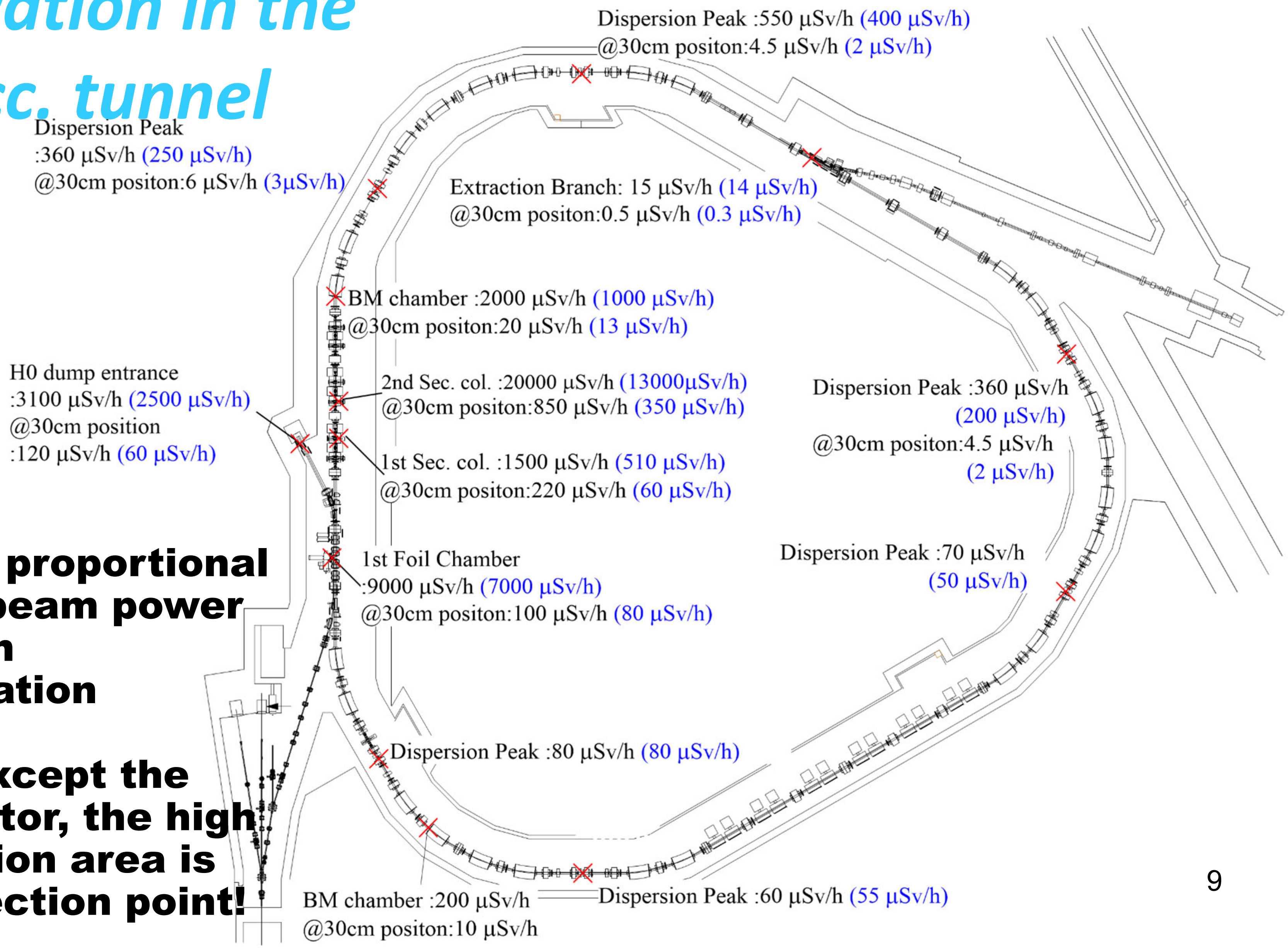
Cooling water temp. of final amp. #5



Open-type cooling tower: Heat exchange is performed by vaporization.
→performance degradation due to higher temperature and humidity!

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

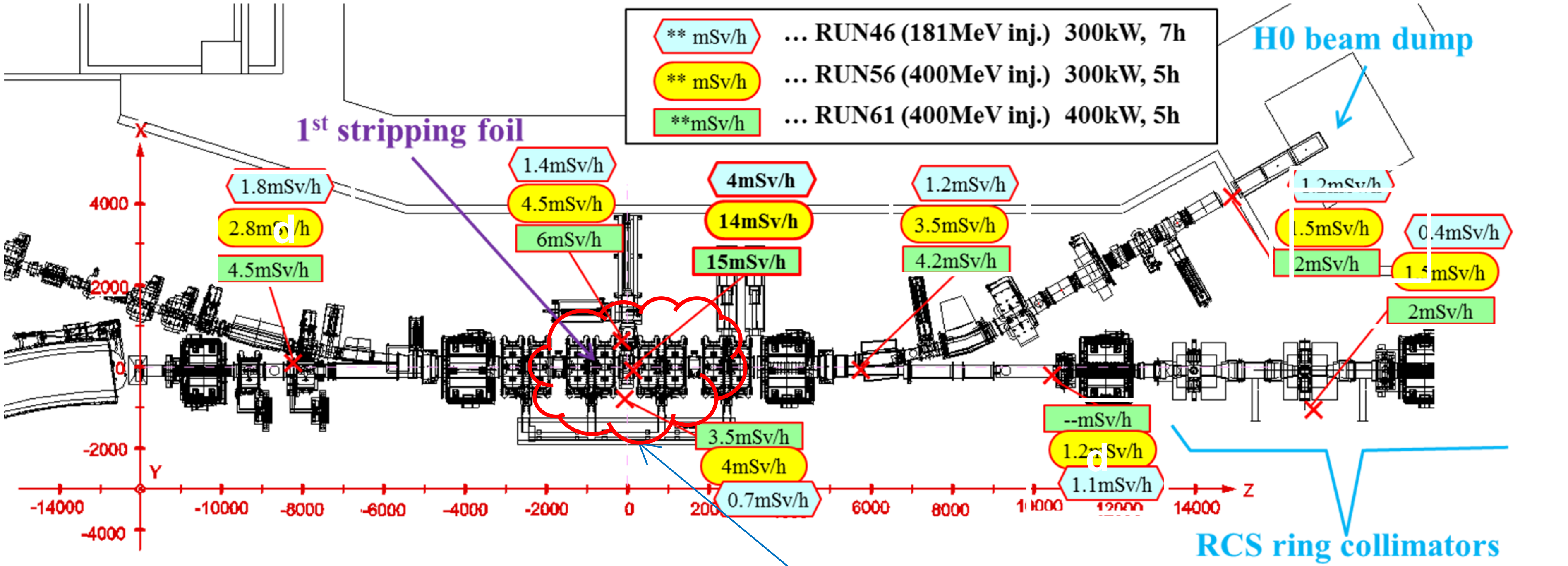
Activation in the acc. tunnel



Almost proportional to the beam power →within expectation

Now, except the collimator, the high activation area is the injection point!

High activation around the injection point



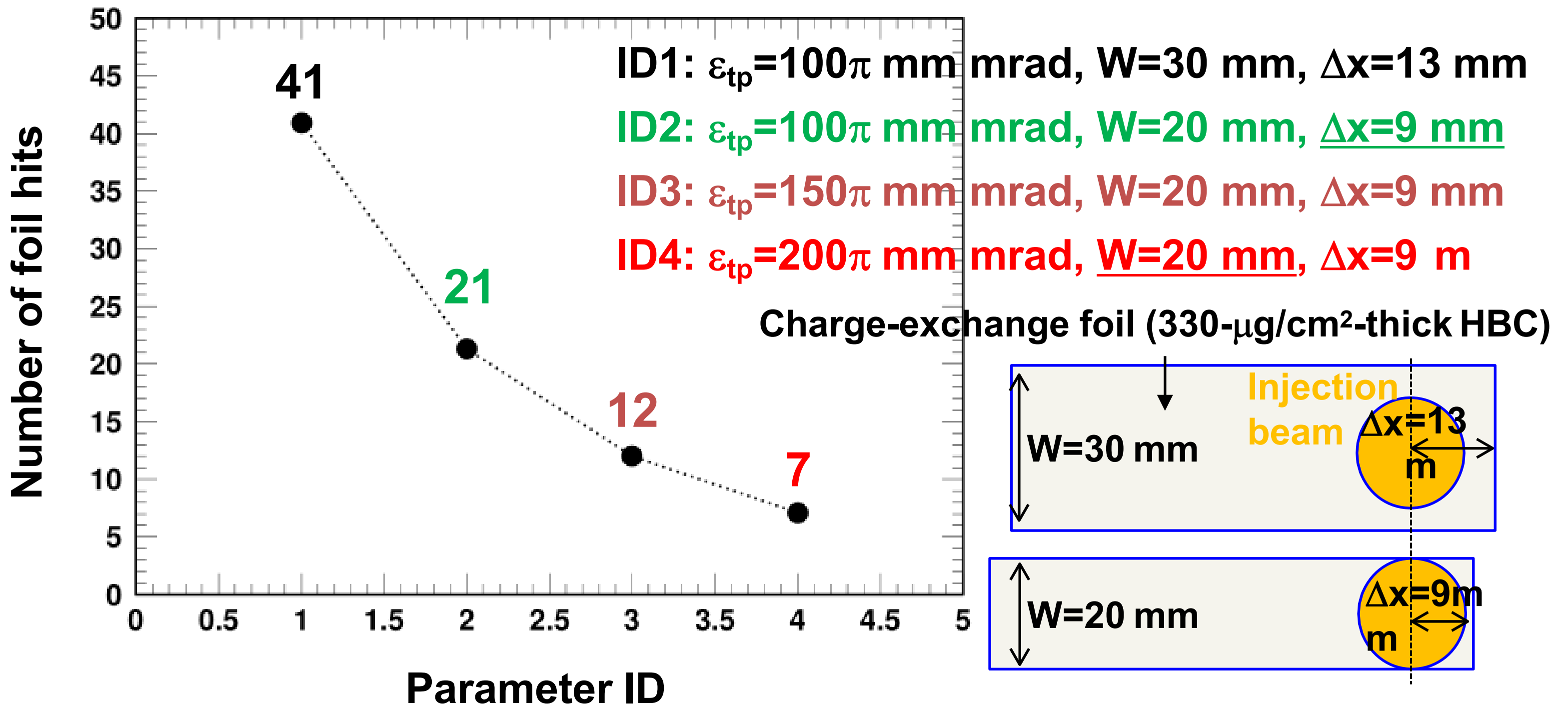
- Residual dose around the stripper foil is caused by *secondary particles (protons and neutrons) generated by the nuclear reactions* at the stripper foil.
- Maximum worker dose around the injection area was about 500 μSv during summer long shutdown maintenance.

→ As long as we use the foil for injection, we can't completely avoid this loss!
(However, we have to use it for charge exchange injection at present.)

We tried to mitigate it…

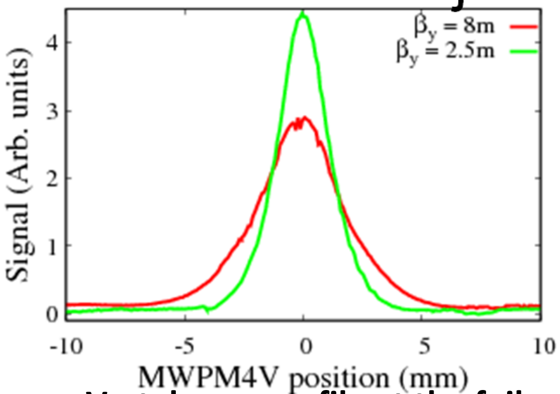
High activation around the injection point(Cont'd)

- How to mitigate the effect of the foil loss?
  - ➢Large painting area
  - ➢Smaller foil



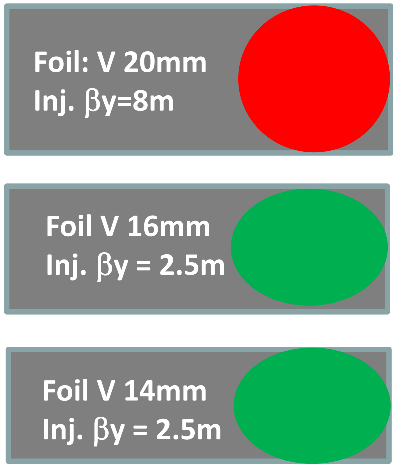
High activation around the injection point(Cont'd)

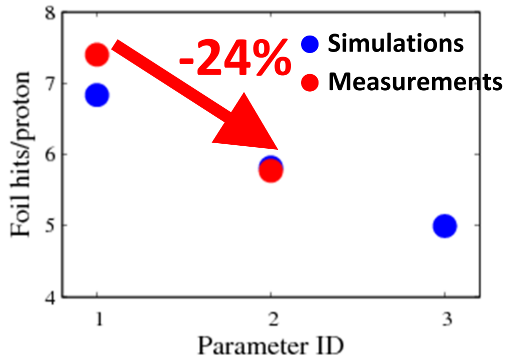
- Recent improvements
  - Smaller injection beam



Vert. beam profile at the foil

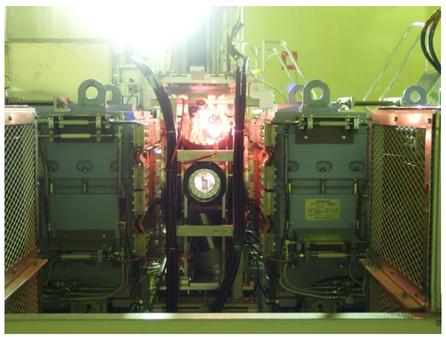
ID	Foil Vert size & βy
1	V 20 mm, β_y =8m
2	V 16 mm, β_y =2.5m
3	V 14 mm, β_y =2.5 m

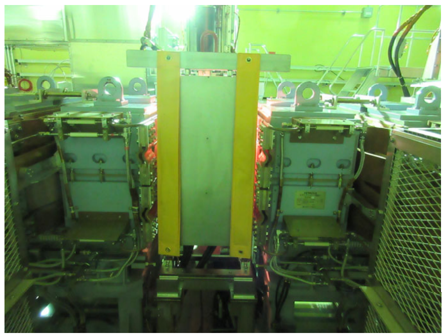


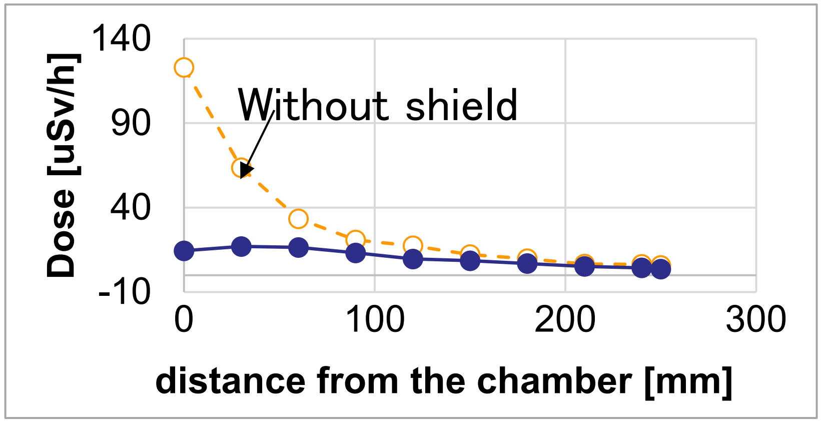


The number of foil hit BLM and residual dose value showed same tendency.

  - Additional local shielding

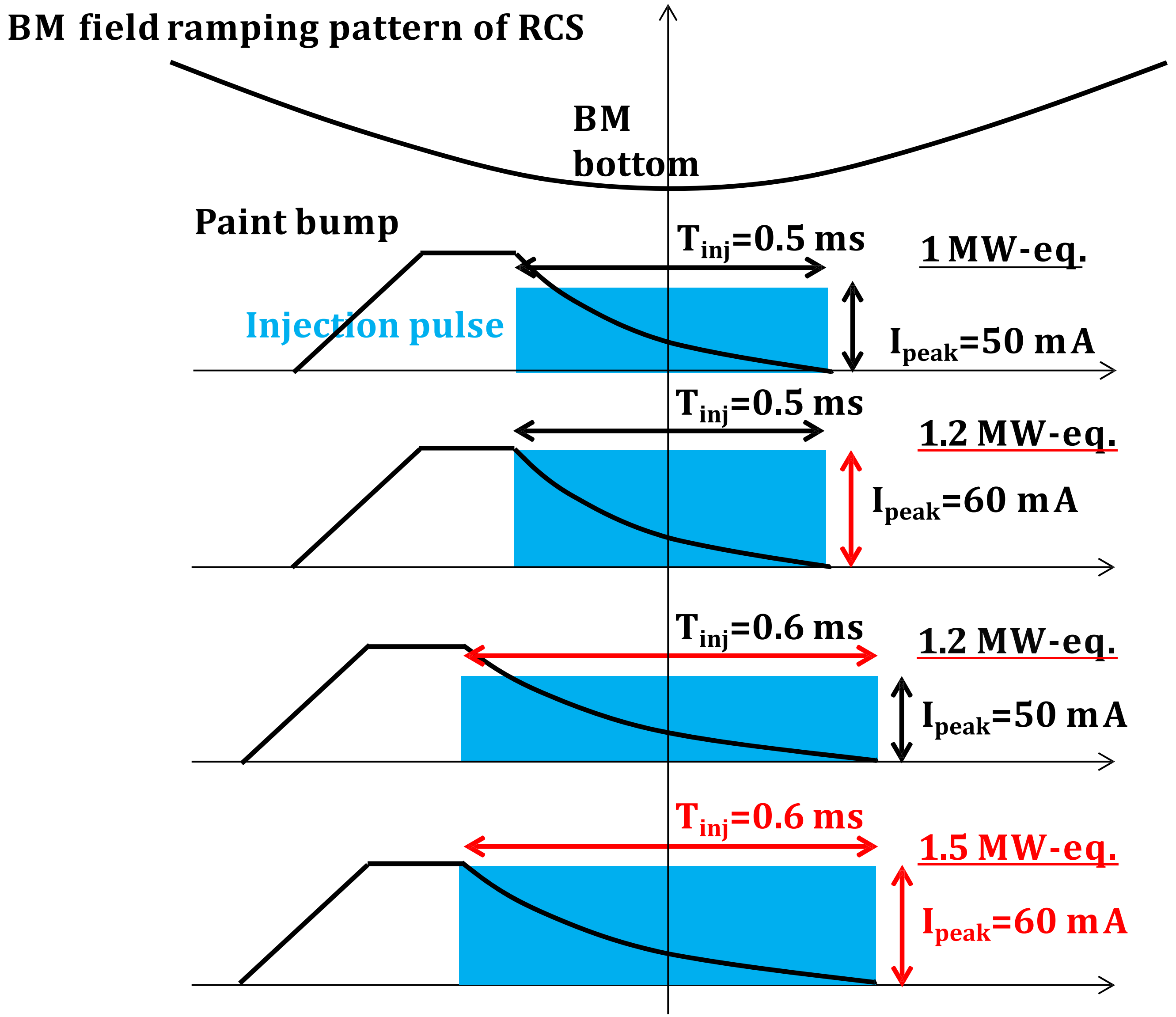






The foil loss would be a key issue to realize multi-MW beam at the proton synchrotron.

Trial beyond 1-MW



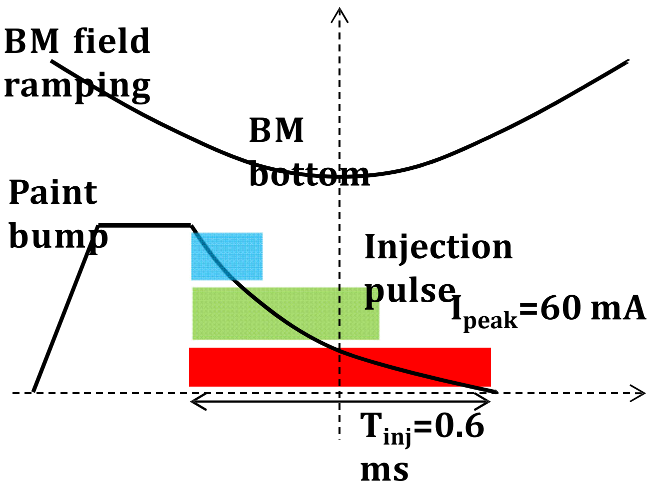
Original 1 MW acceleration scheme

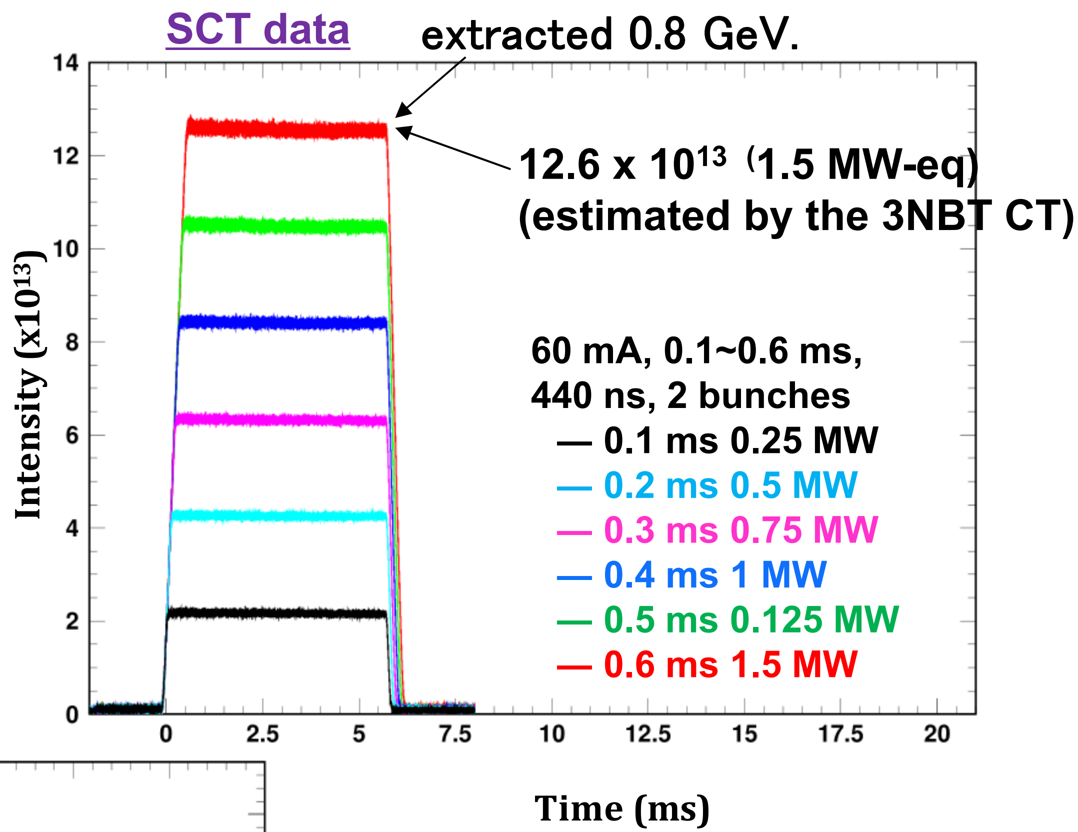
- ✓ **1 GeV acceleration achieved on Dec. 2018**
- ✓ **1 GeV acceleration achieved on Oct. 2018**
- ✓ **0.8 GeV acceleration achieved on Dec. 2019**

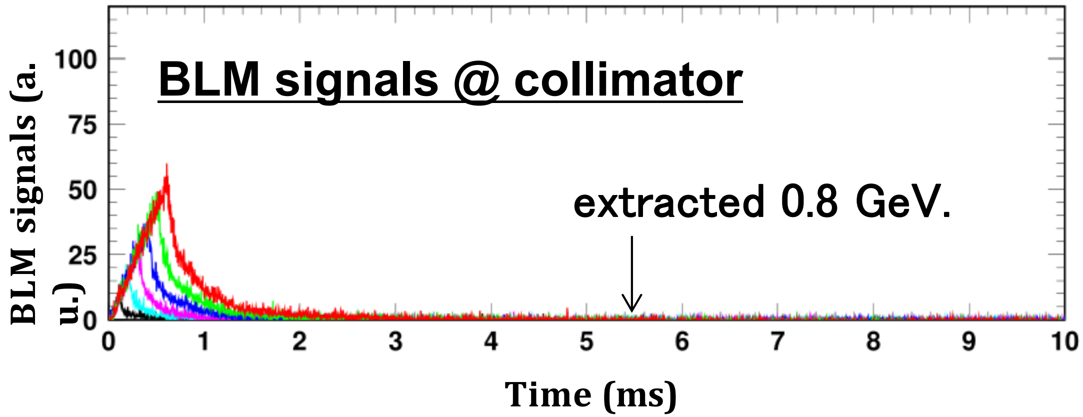
Trial beyond 1 MW (Cont'd)

Courtesy **of H. Hotchi**

- ✓ **Injection pulse length were changed to investigate the beam loss as a function of the injection beam current.**



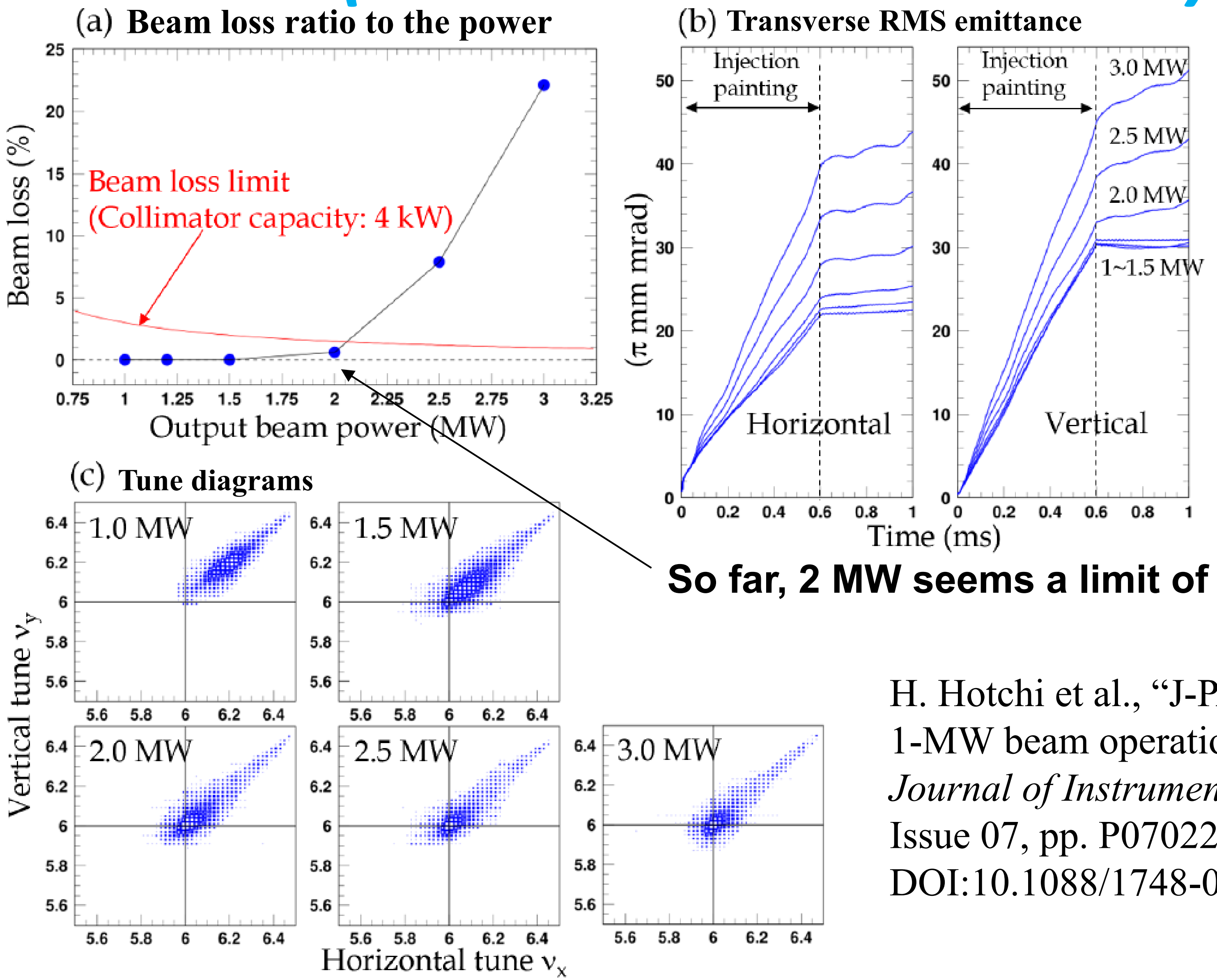




- ✓ Beam loss were proportional to the beam current.

→well controlled!

Beyond 1 MW (Numerical Simulations)



So far, 2 MW seems a limit of RCS

H. Hotchi et al., "J-PARC 3-GeV RCS: 1-MW beam operation and beyond", *Journal of Instrumentation,* Volume **15**, Issue 07, pp. P07022 (2020). DOI:10.1088/1748-0221/15/07/P07022

Summary

Operation

- RCS is almost continuing stable user operation.
  - At present, ***6.2e13 ppp (750-kW)*** beam delivers to the MLF and ***6.7e13 ppp (515-kW in MR)*** beam to the MR.
  - So far, the neutron target limits the operation beam power. We will increase the beam power with carefully monitoring the target status and the beam loss.

High power study

- We tried 1-MW, 2-day continuous operation, but it revealed some issues to achieve stable user operation with 1-MW.
- From our experiences, design of the injection is quite important to realize multi-MW beam.
- Trials beyond 1-MW were carried out. Results indicated RCS has enough capability to accelerate 1.5-MW beam if RF system would be reinforced.