大強度陽子加速器施設
J-PARC

Recent Results of Beam Loss Mitigation and Extremely Low Beam Loss Operation of J-PARC RCS

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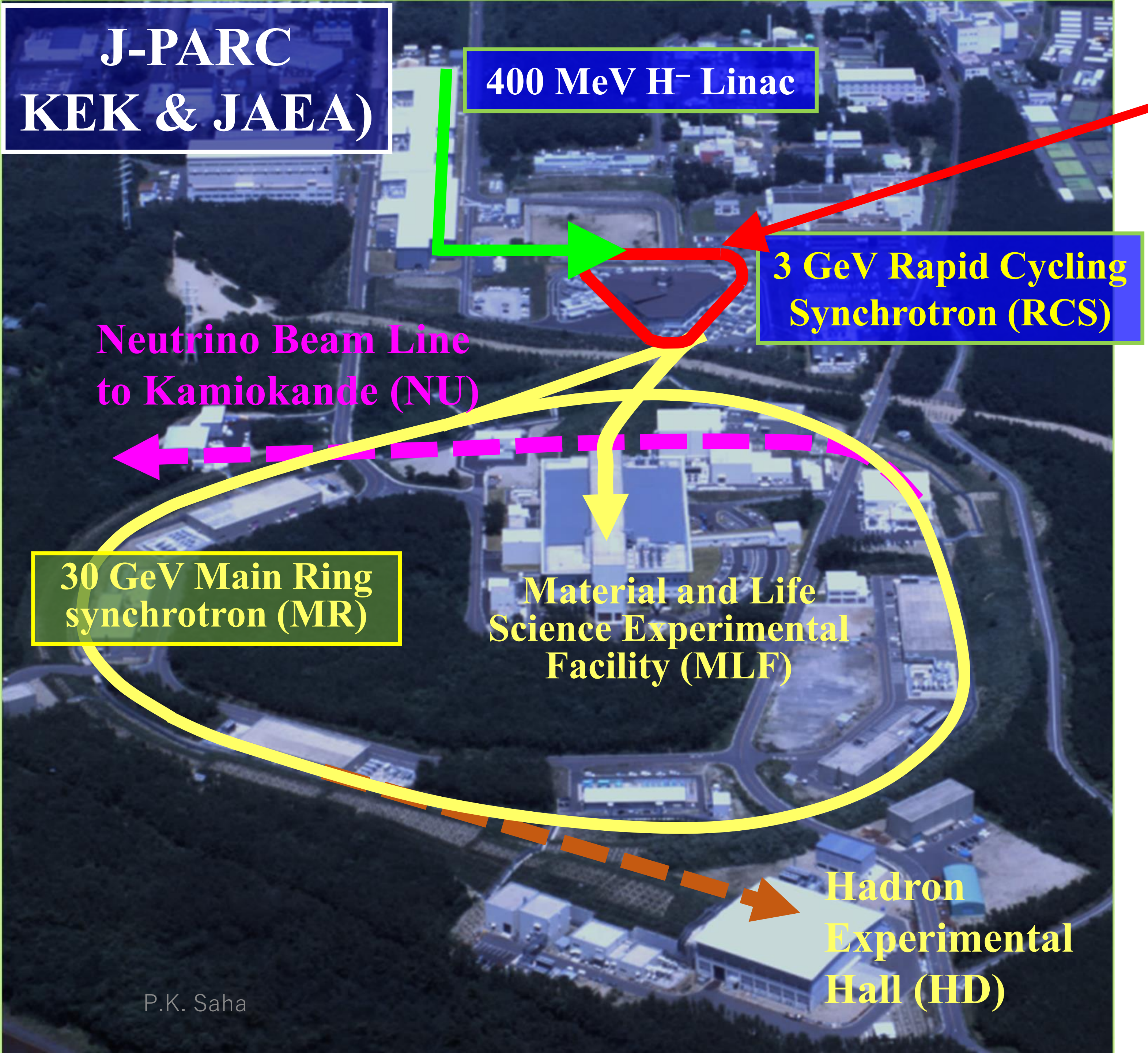


This talk is about RCS

J-PARC at a glance

J-PARC is a world class high-energy proton accelerator complex comprising

- ● A 400 MeV H^- Linear Accelerator (LINAC)
- ● A 3-GeV Rapid Cycling Synchrotron (RCS)
- ● A 50 GeV (currently 30 GeV) Main Ring (MR)

J-PARC provides high intensity beam for multi-dimensional experimental research such as

- ◆ Material and Life Science
- ◆ Particle Physis
- ◆ Nuclear Physics

…….

Operating jointly by KEK and JAEA

Contents:

J-PARC 3-GeV Rapid Cycling Synchrotron (RCS)

Circumference : 348.333 m

Superperiodicity : 3

Harmonic number : 2

Number of bunches : 2

Injection : Multi-turn charge-exchange injection of H^- beam

Injection energy : 400 MeV

Injection period : 0.5 ms (307 turns)

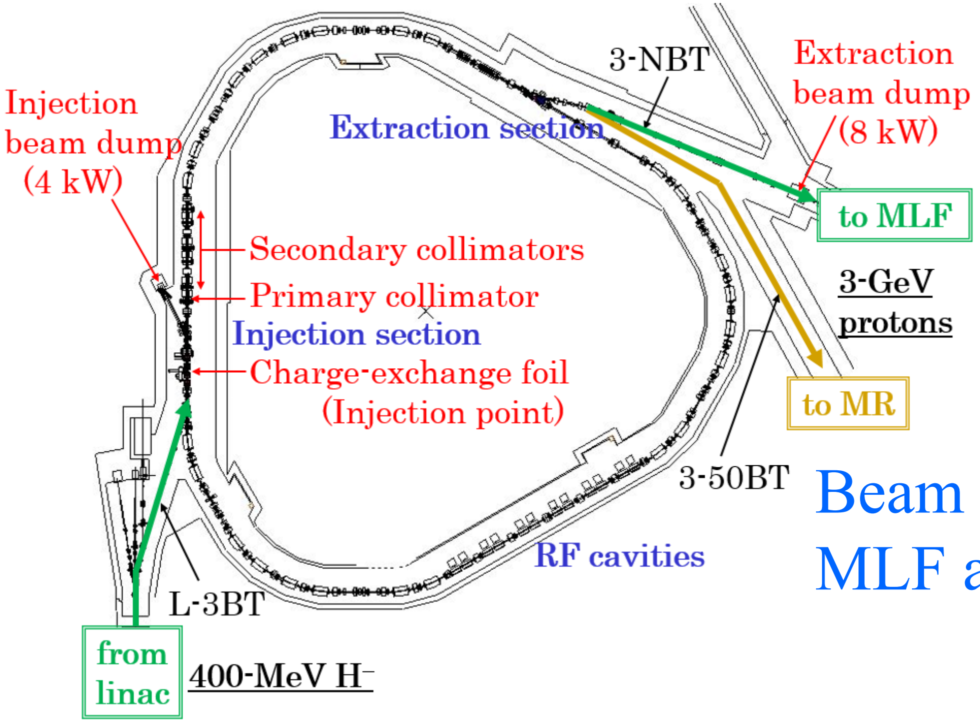
Injection peak current : 50 mA

Extraction energy : 3 GeV

Repetition rate : 25 Hz

Particles per pulse : 8.33 x 10^{13}

Beam power : 1 MW



Beam sharing between MLF and MR ~ 9:1

Demonstrated 1 MW operation to the MLF several times (2 days)

At present,

Beam power to the MLF: 840 kW

Beam power to the MR: ~800 kW-eq.

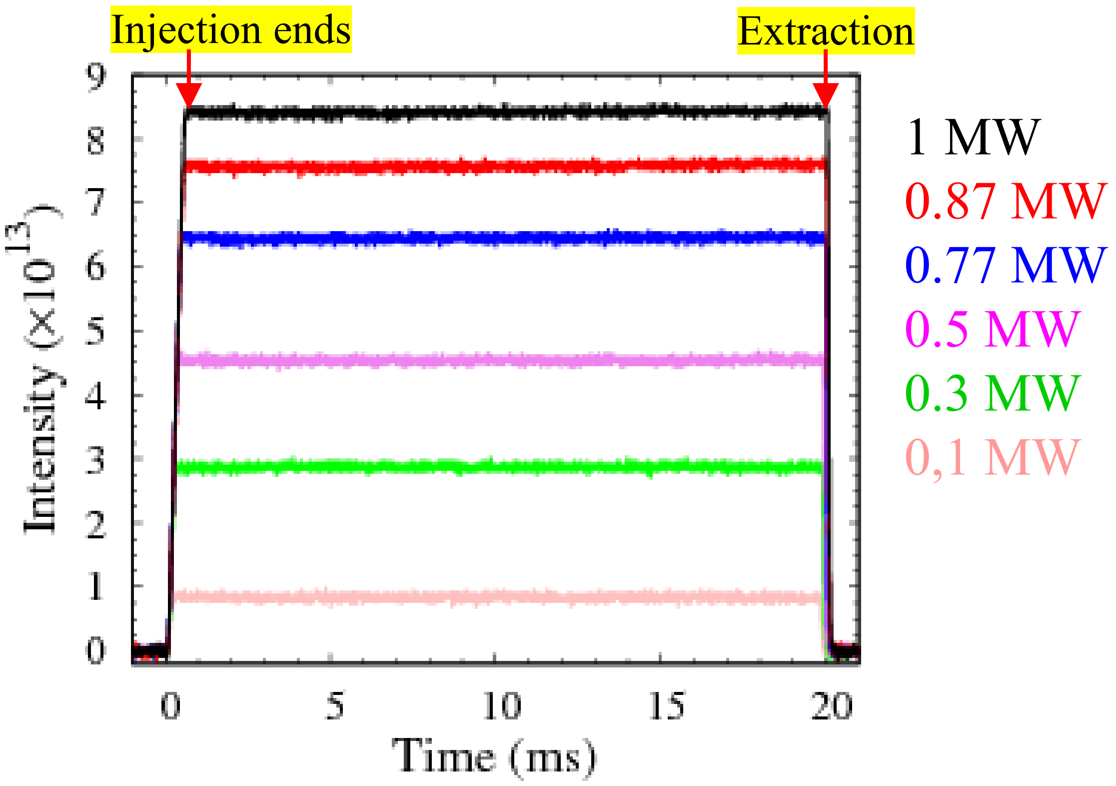
Beam loss mitigation in the RCS

■ The residual radiation in the RCS is mainly determined by beam operation to the MLF.

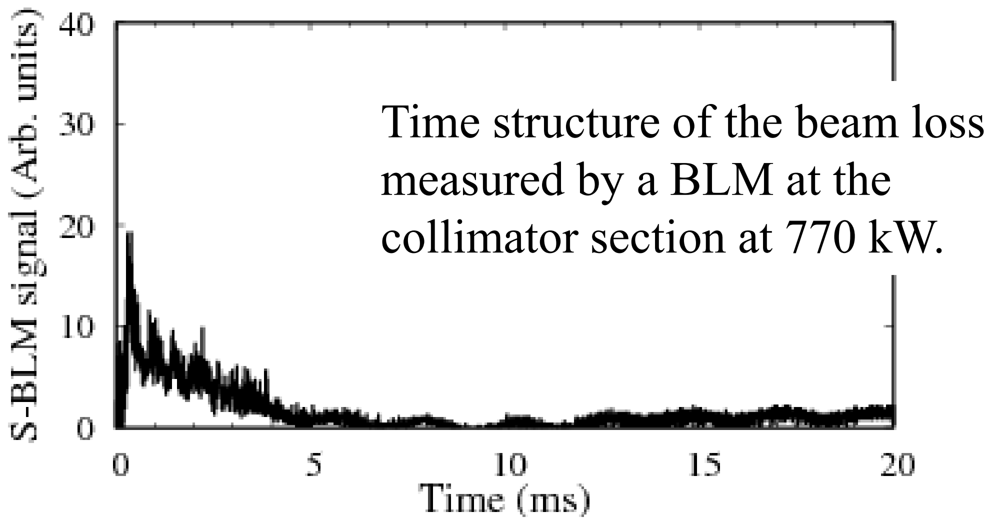
— Beam loss reduction for operation to the MLF is thus highly essential.

◆ Longitudinal and transverse paintings at injection have been adopted for mitigating the space charge (SC) effect to minimize the beam loss.

◆ The circulating beam hitting rate on the foil and the corresponding **foil scattering beam losses** is minimized by applying a large transverse painting (TP) for the MLF beam.



Circulating beam intensity measured by an SCT.
There is no detectable intensity loss even at 1 MW.



◆ The beam loss in well controlled, occurring at around injection energy.

— Estimated to be <<0.1% at 740 kW operation.

◆ The beam loss is dominated by foil scattering of the circulating beam.

Motivation of the present research

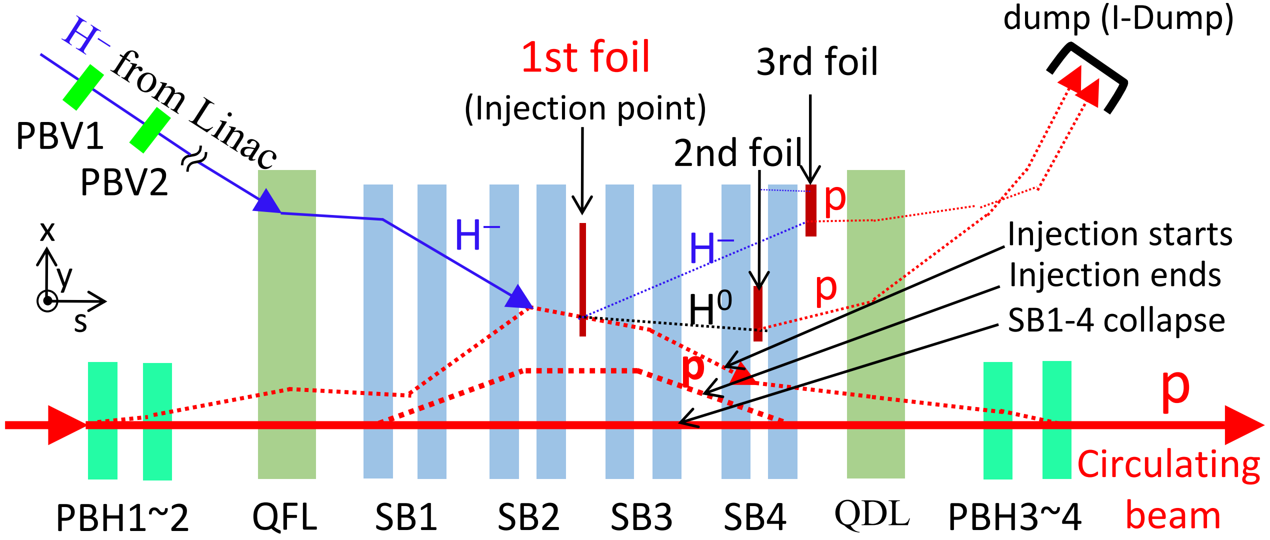
◆ Although foil hitting rate is reduced by applying a large TP (200π mm mrad), but we still have **a high residual radiation at the injection area.**

→ Caused by uncontrolled beam losses due to large angle foil scattering of the circulating beam.

(1) **It is highly essential to reduce foil scattering beam losses at the injection area.**

(2) Beam loss at the collimator section and its downstream (uncontrolled) due to beam halos caused by the foil scattering and SC effect also **needs further mitigation at high-intensity**.

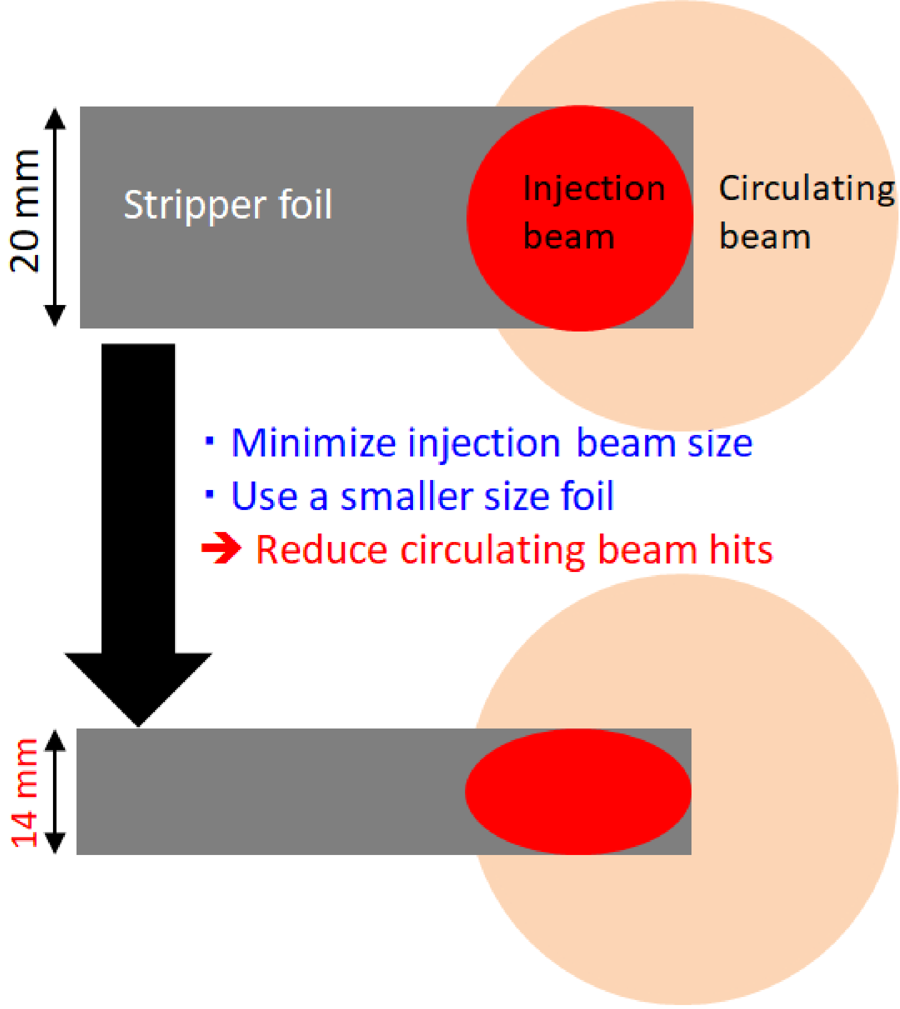
PBH : Hori. painting magnet
PBV : Vert. painting magnet



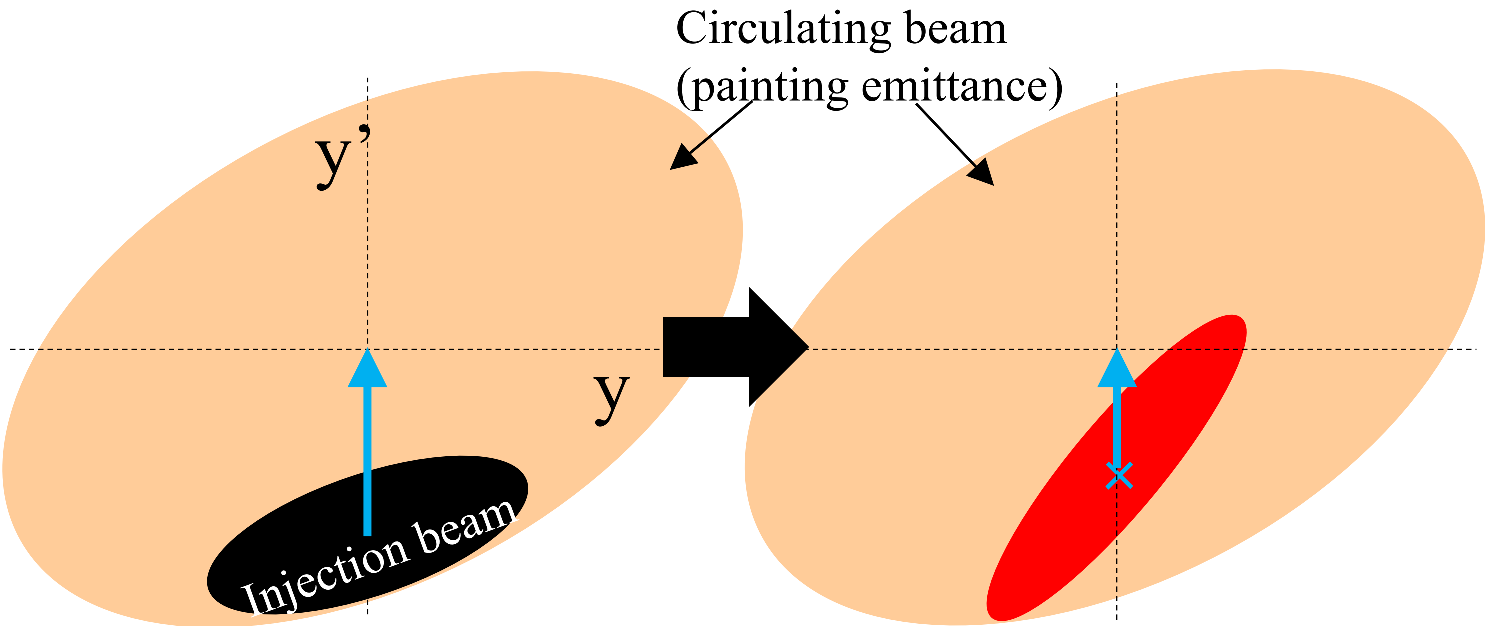
We aim to reduce the beam losses at the injection area, collimator section, and also downstream of the collimator section (1st arc)

Present approach for further beam loss mitigation

1. Reduce foil hits by minimizing **vertical beta (β_y) of the injection beam** and **reduce vertical size of the foil.**

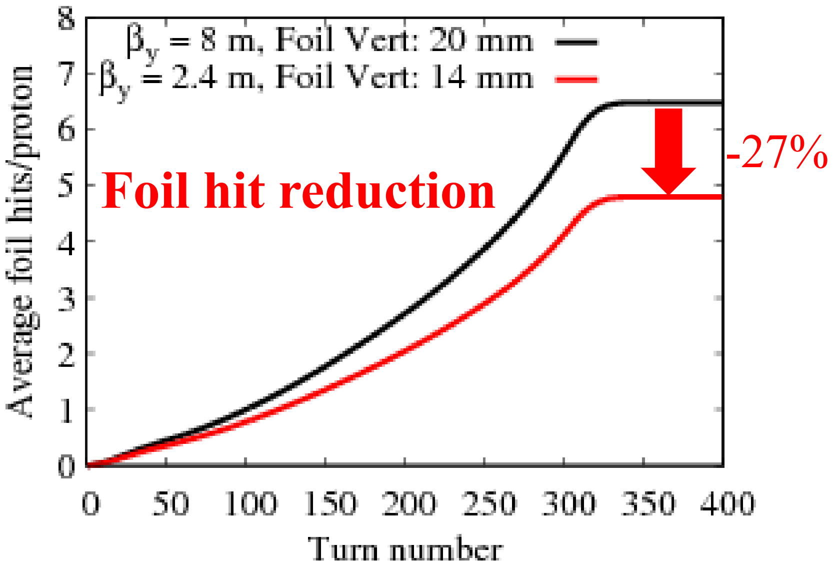


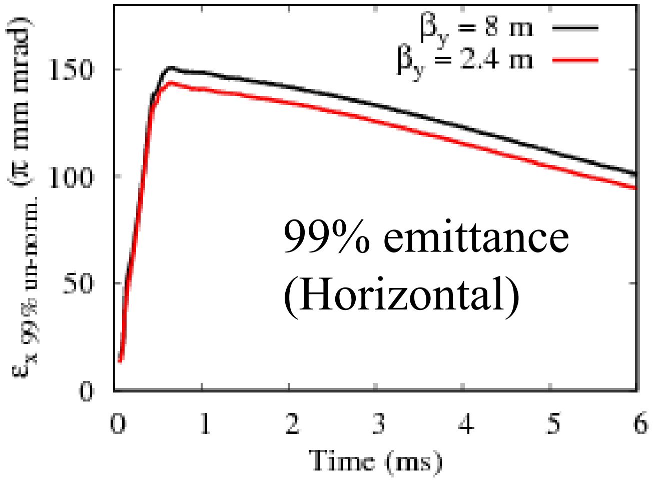
2. Optimize vertical painting distribution to reduce large amplitude particles (beam halos).

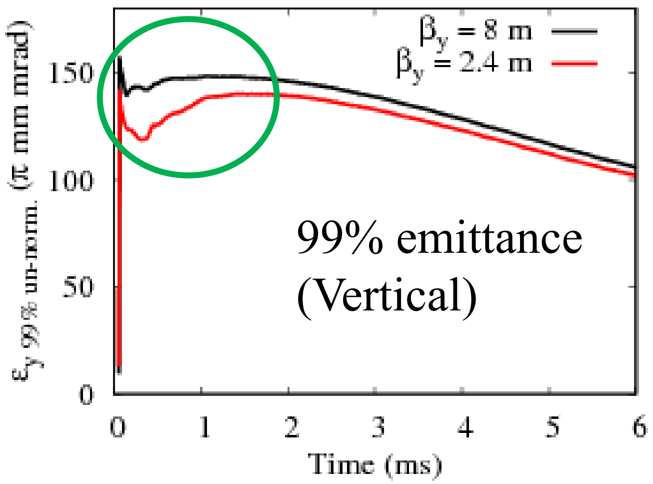


Transverse painting in the vertical plane is done by changing vertical angle (y’) of the injection beam during injection period.
The edge of the injection beam determines the painting area.
The injection beam cam be put more inside of the circulating phase space.
→ Reduce the number of large amplitude particles.

Simulation results



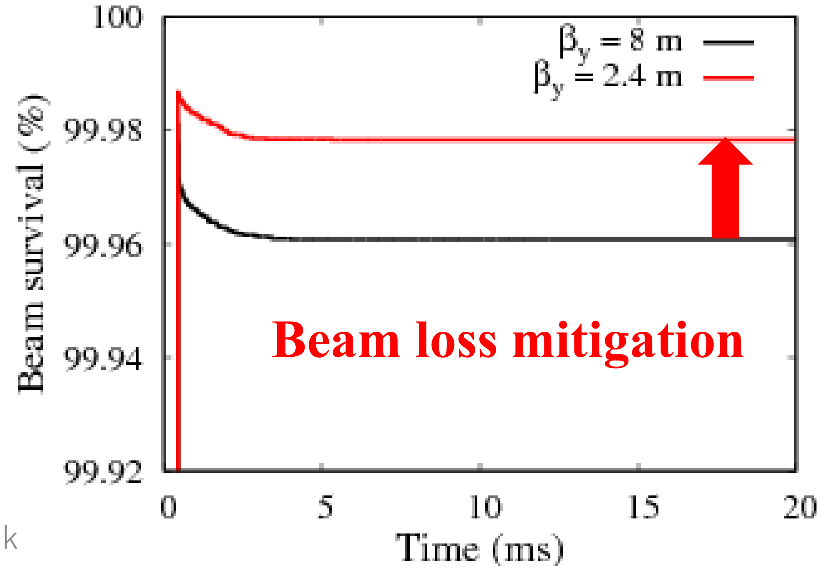




● Transverse emittance improved by an optimizing vertical painting area possible with a smaller injection β_y.

◆ Foil hitting of the circulating beam can be 27% reduced by minimizing injection β_y and using a smaller size foil.

◆ Beam survival at 770 kW can also be significantly improved by reducing the beam loss as much as 45%.

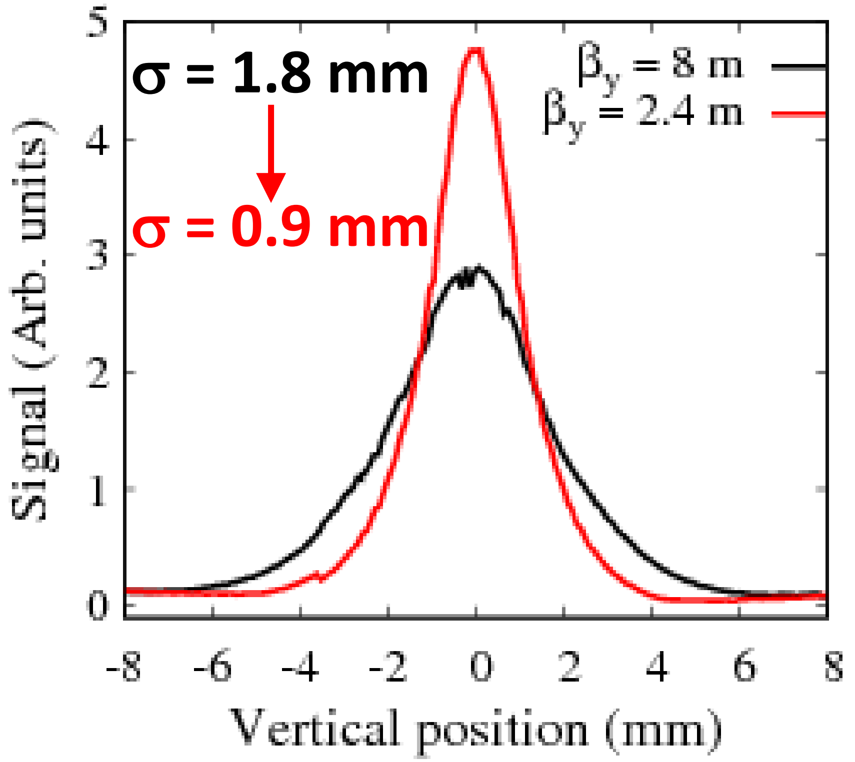


Experimental results

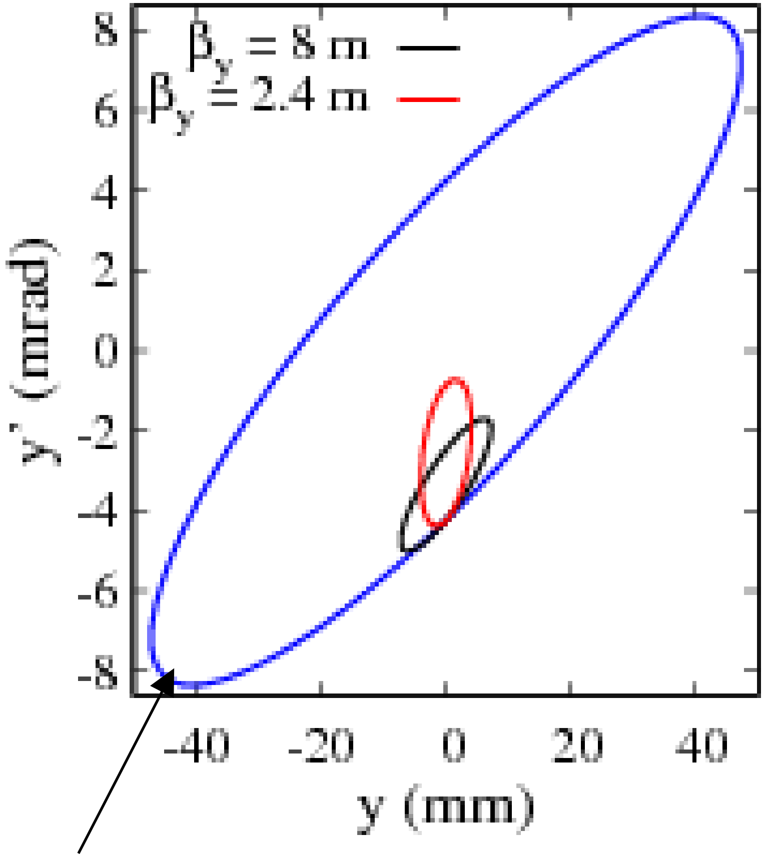
Minimized injection β_y at the injection point (stripper foil) by using 4 QMs at the injection BT.

Measured twiss parameters at the injection point

Parameter	Design	This study
α_x	-0.51	-0.32
α_y	-1.57	-0.40
β_x [m]	6.19	6.29
β_y [m]	8.17	**2.4**
ε_x (σ) [π mm mrad]	0.52	0.53
ε_y (σ) [π mm mrad]	0.40	0.43



Measure vertical injection beam profile at the injection point.



Vert. painting area (200π mm mrad)

Inj. beam y' = -3.4 mrad for β_y = 8 m

→ Inj. beam y' = -2.6 mrad for β_y = 2.4 m

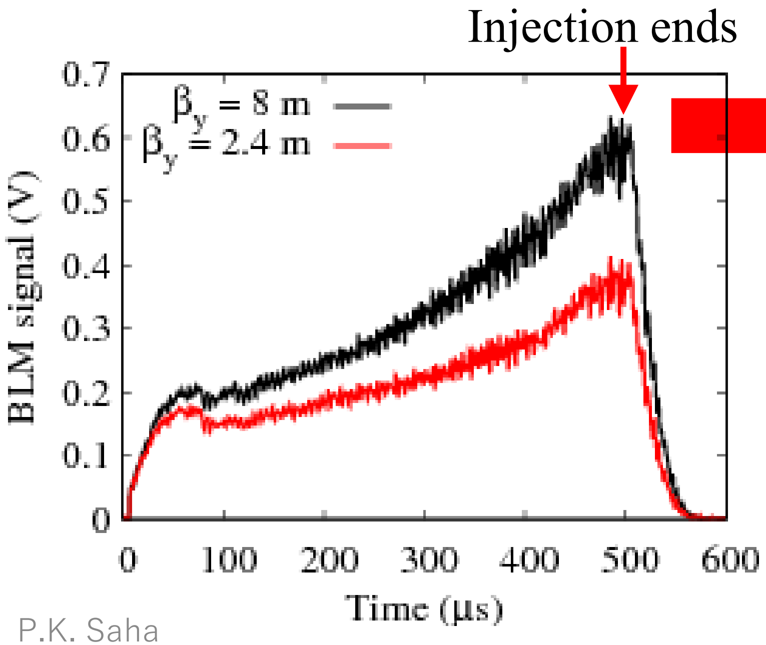
Keeps max painting area same.

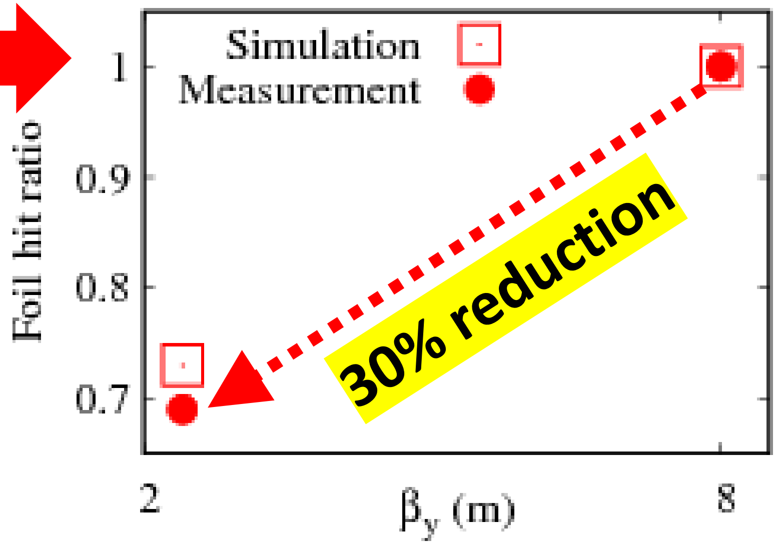
Measurement of foil hit reduction by minimizing injection β_y

For β_y = 8m

For β_y = 2.4m

- Measured for a beam intensity of 1 MW-eq.
- A small plastic scintillator counter type BLM placed at 90-deg. from the foil.
- Measured γ-rays from lost particles caused by large angle scattering at the foil.

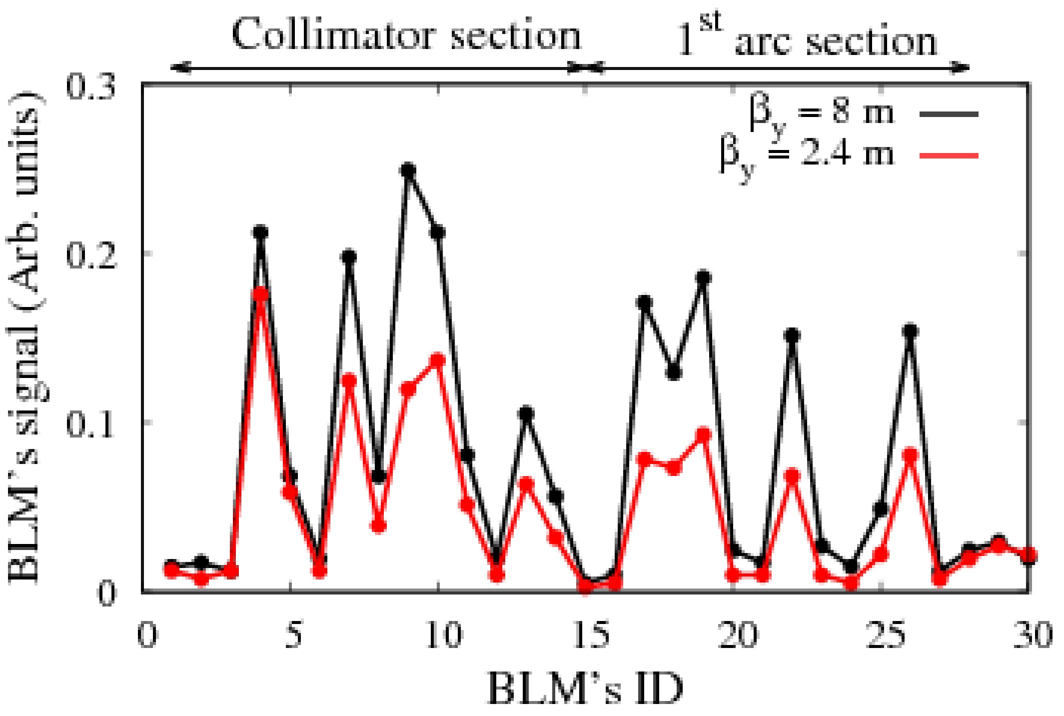


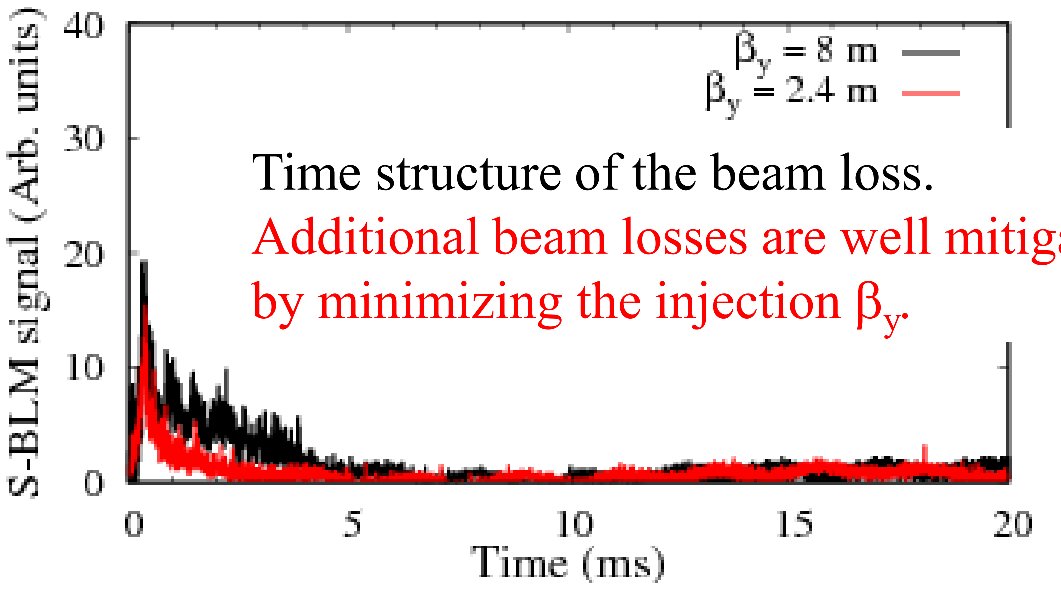


- 30% foil hit reduction obtained by minimizing injection β_y and placing a smaller size foil.

→ **Consistent with numerical estimation.**

Measurement of beam loss reduction by minimizing injection β_y

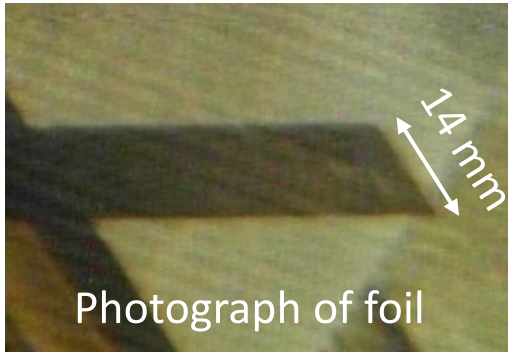




- Measurement was done for a beam power of 770 kW-eq. (6.4E13/ppp)
- Achieved a more than 40% beam loss reduction (in average).
- The additional beam loss appeared beyond 1 ms is well mitigated.

- **The measurement result of beam loss reduction is also quite consistent with simulation results.**
- **Then, we have implanted a smaller β_y and smaller size foil for RCS operation at 740 kW.**

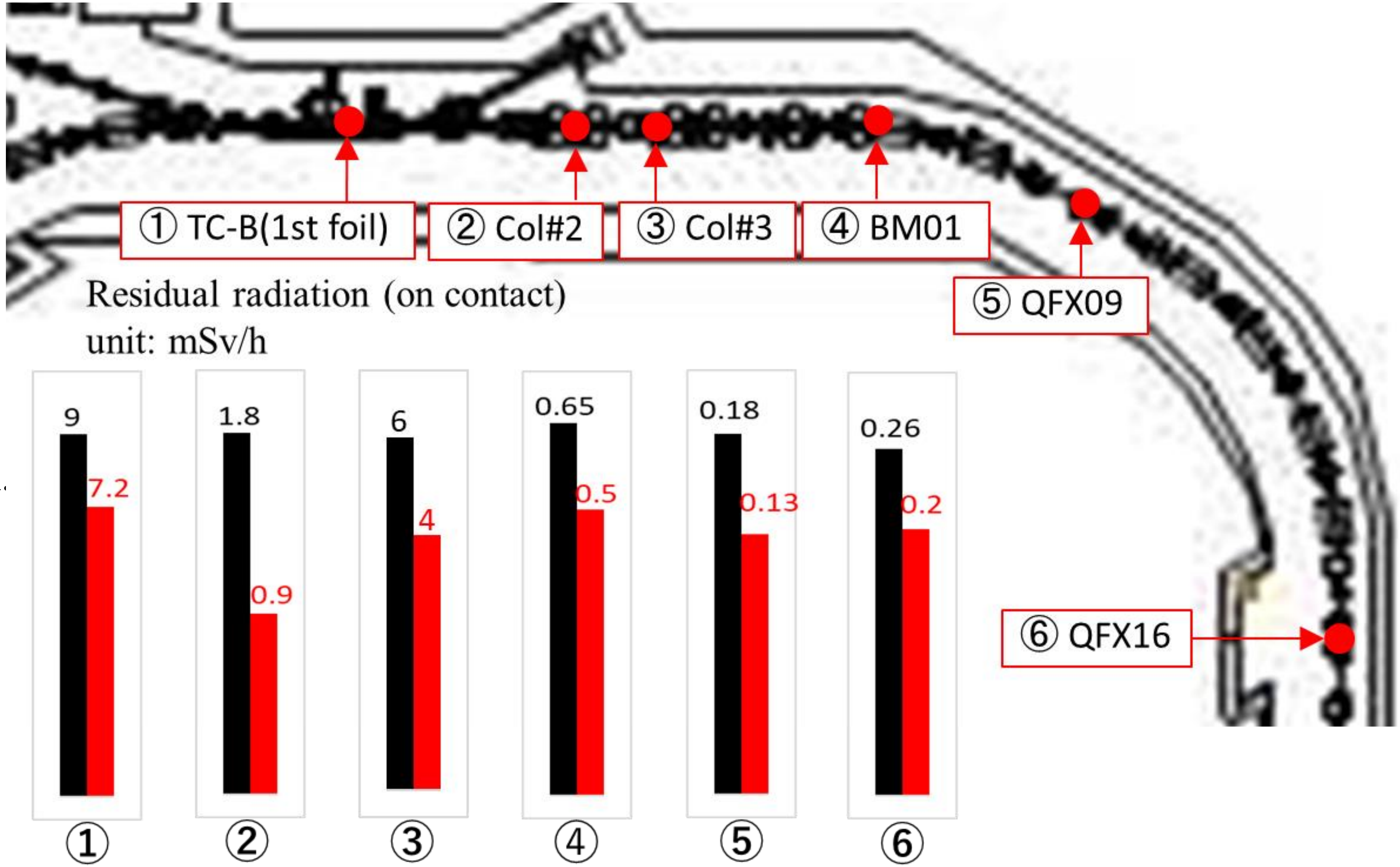
Implementation of a smaller injection β_y for RCS operation



At 740 KW 1 month operation.
Measured after 4h cooling.

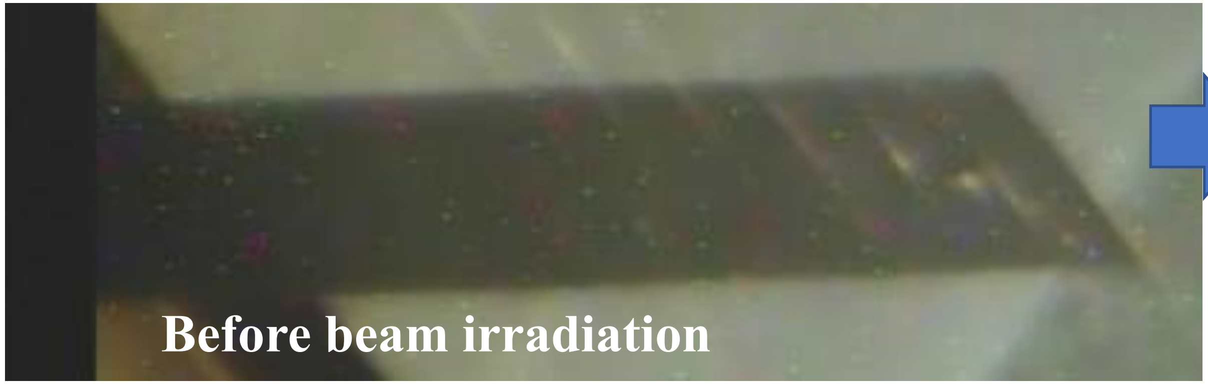
$\beta_y = 8$ m

$\beta_y = 2.4$ m



Residual radiation at injection and collimator sections including 1st arc section reduced by implementing a smaller β_y and a smaller size foil.

Performance of stripper foil at operation



A broken supporting fiber was hanging through the beam sweeping direction and was highly heated.

- The foil was in service for nearly two months with 740 kW (1 month) and 840 kW (3 weeks).
- It was then replaced to test another foil. → Tested for more than a month at 840 kW.
- We will test a smaller foil for 1 MW operation next week.

Summary and outlook

◆ We proposed to minimize vertical beta (β_y) of the injection beam to minimize vertical beam size at the foil.
This allows us to use a smaller size foil to reduce uncontrolled foil scattering beam losses as well as beam losses at the collimator section and its downstream.

◆ A β_y of 8 m at the stripper foil was minimized to 2.4 m to reduce the beam size from 1.8 mm to 0.9 mm.

◆ The vertical foil size of 20 mm was reduced to 14 mm.

− As expected a 30% reduction of the foil hitting rate was achieved.

− The beam loss at 770 kW was 50% reduced, which was also quite consistent with expectation.

◆ A smaller β_y with a smaller foil have also been implemented to RCS operation.

− The residual radiation at the injection area, collimator section and it's downstream were significantly reduced.

◆ A smaller foil is in service at 840 kW regular operation at present.

◆ **We will also test a smaller foil for 1 MW operation next week.**