Status of 3GeV- RCS in J-PARC

Michikazu Kinsho
（J-PARC, JAEA）

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   - ✓ Reduction of beam losses
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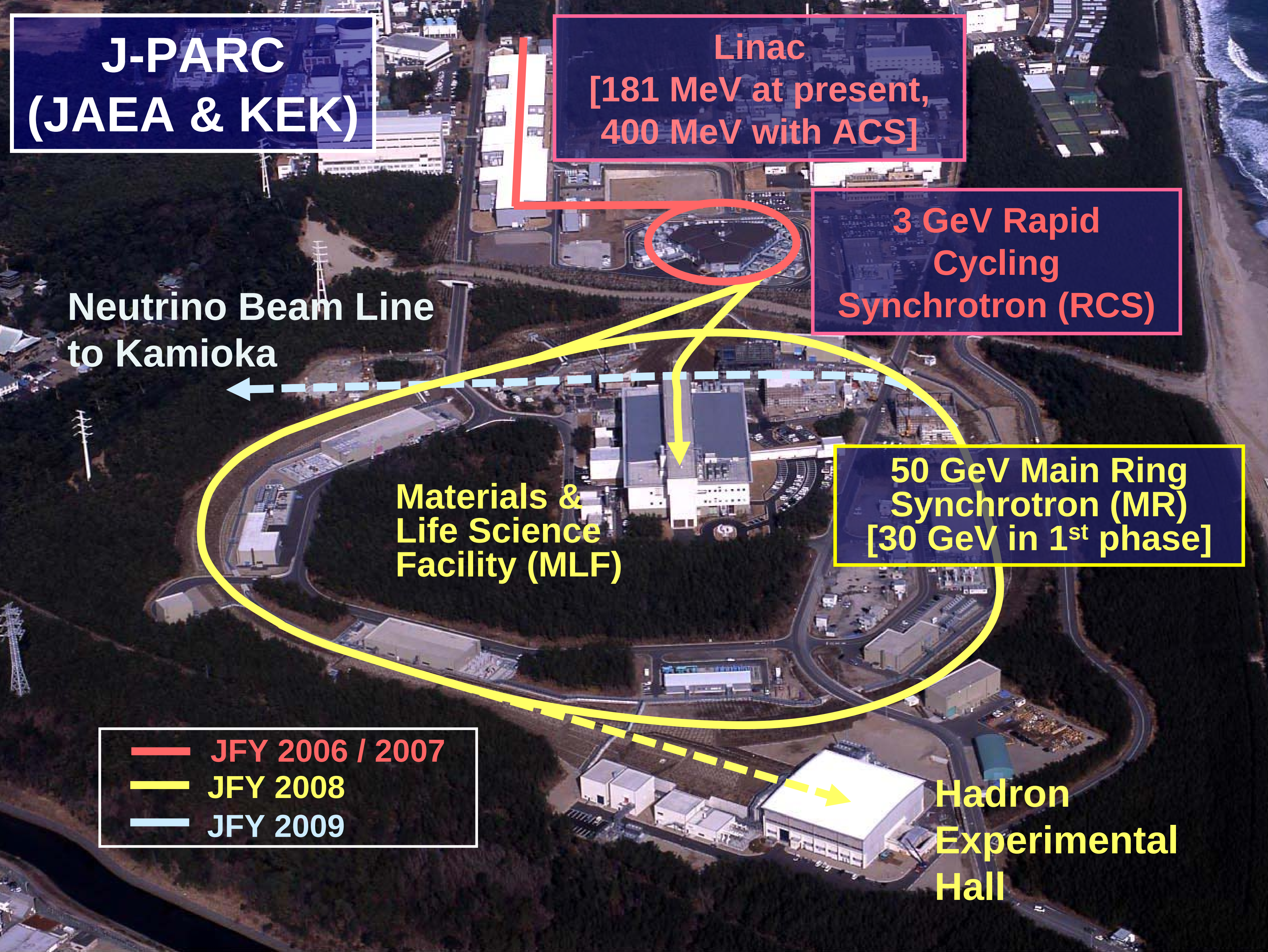
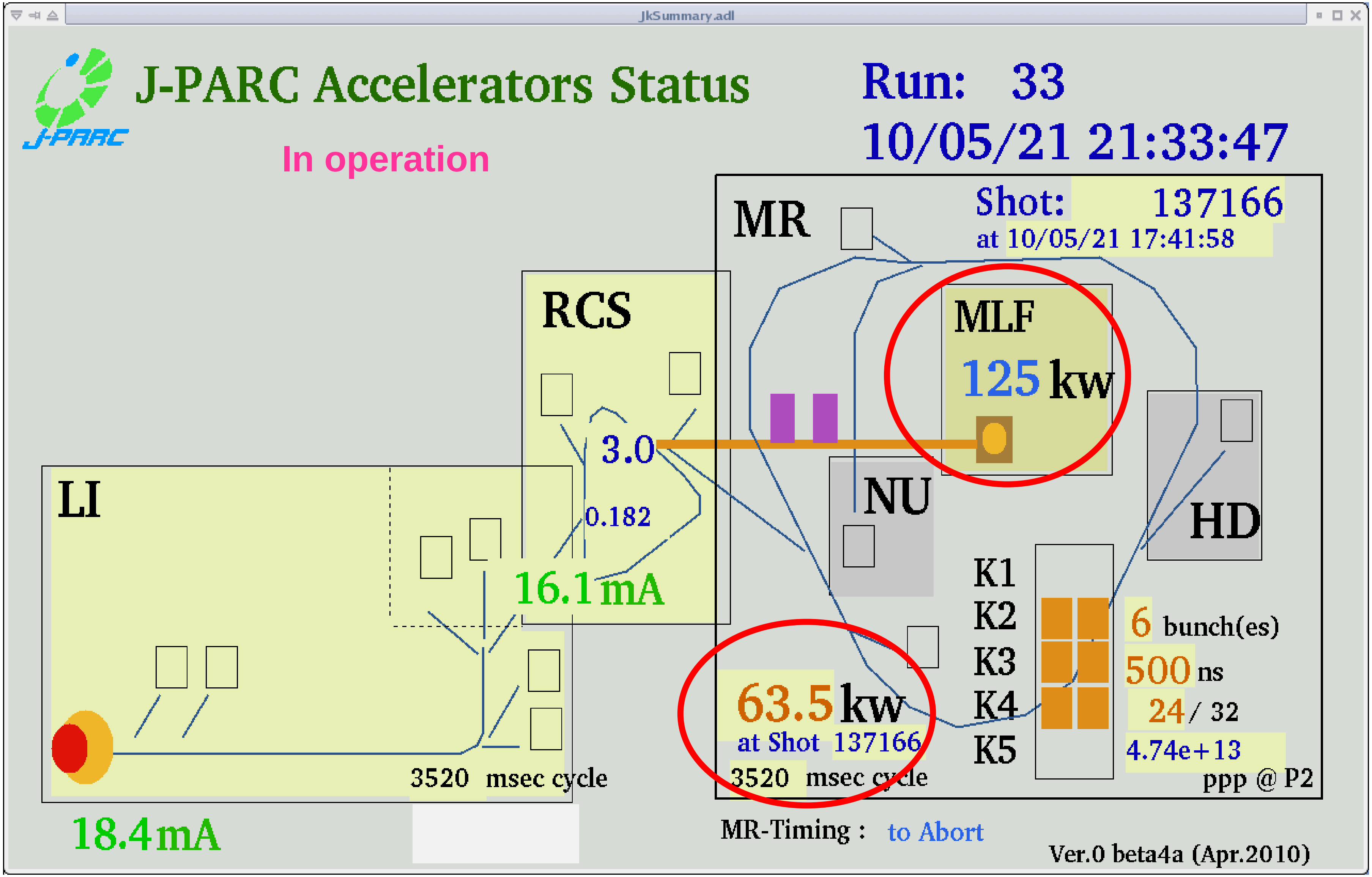
FFAG10 Oct. 28-31


J-PARC
(JAEA & KEK)
Linac
[181 MeV at present,
400 MeV with ACS]
3 GeV Rapid
Cycling
Synchrotron (RCS)
Neutrino Beam Line
to Kamioka
Materials &
Life Science
Facility (MLF)
50 GeV Main Ring
Synchrotron (MR)
[30 GeV in 1st phase]
JFY 2006 / 2007
JFY 2008
JFY 2009
Hadron
Experimental
Hall

J-PARC today



JkSummary.adl
J-PARC
J-PARC Accelerators Status
In operation
Run: 33
10/05/21 21:33:47
MR
Shot: 137166
at 10/05/21 17:41:58
RCS
MLF
125 kw
3.0
0.182
16.1mA
NU
HD
LI
K1
K2
K3
K4
K5
6 bunch(es)
500 ns
24 / 32
4.74e+13
ppp @ P2
63.5 kw
at Shot 137166
3520 msec cycle
3520 msec cycle
18.4mA
MR-Timing : to Abort
Ver.0 beta4a (Apr.2010)

Brief history

2007

- 04/Oct. : Beam commissioning was started.
- 31/Oct. : Successfully accelerated to the designed beam energy of 3GeV
- 23/Dec. : The official permission was obtained from the authority for the radiation safety.

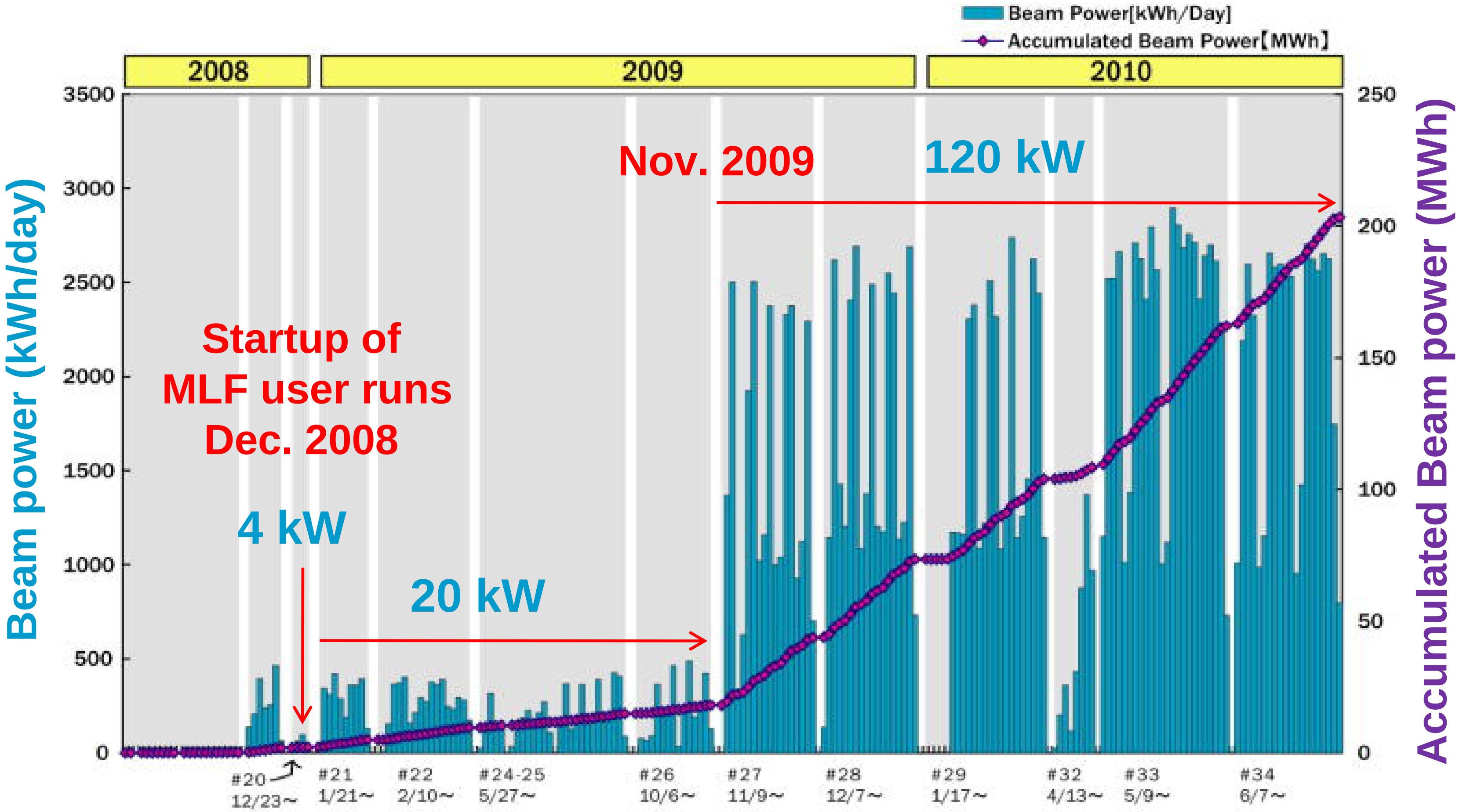
2008

- 13/May. : Startup of the beam delivery for the MLF and the MR for their beam commissioning.
- 18/Sep. : *210 kW (1.77 x10^{13} ppp)* was demonstrated for 70 seconds.
- 23/Dec. : Startup of MLF-user operation with a beam power of 20 kW. and also Startup of 25-Hz switching beam operation for the MLF and the MR

2009

- Nov. : *120kW* power user operation for the MLF was started
- 10/Dec. : *300 kW (2.53x10^{13} ppp)* output operation for 1 hour to the MLF target

History of the output beam power to MLF



- Due to the discharge problem of the RFQ, the RCS beam power was limited to 20 kW for a long period.
- By the vacuum improvement of the RFQ section, the performance of the RFQ was recovered.
- Then the RCS beam power was increased to 120 kW and its operation has been continued up to now.

What is 3GeV-RCS in J-PARC

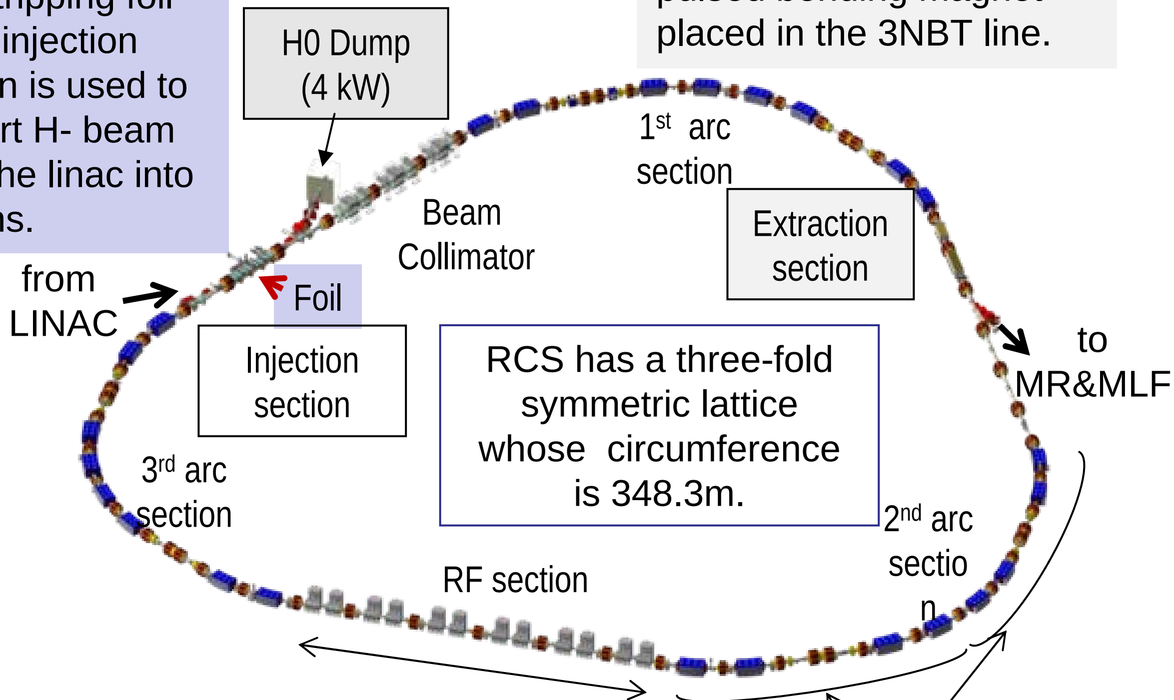
Design parameters

Circumference	348.333 m
Superperiodicity	3
Harmonic number	2
No of bunch	2
Injection energy	181 MeV (400 MeV)
Extraction energy	3 GeV
Repetition rate	25 Hz
Particles per pulse	2.5e13 - 5e13 (8.3e13 with 1 MW)
Output beam power	0.3 - 0.6 MW (1 MW)
Transition gamma	9.14 GeV
Number of dipoles	24
quadrupoles	60 (7 families)
sextupoles	18 (3 families)
steerings	52
RF cavities	12 (11 at present)

The H0 dump is used to dump unstripped beams at the stripping foil. The capacity is 4kW.

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.

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.

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

Each arc module has a missing-bend cell.

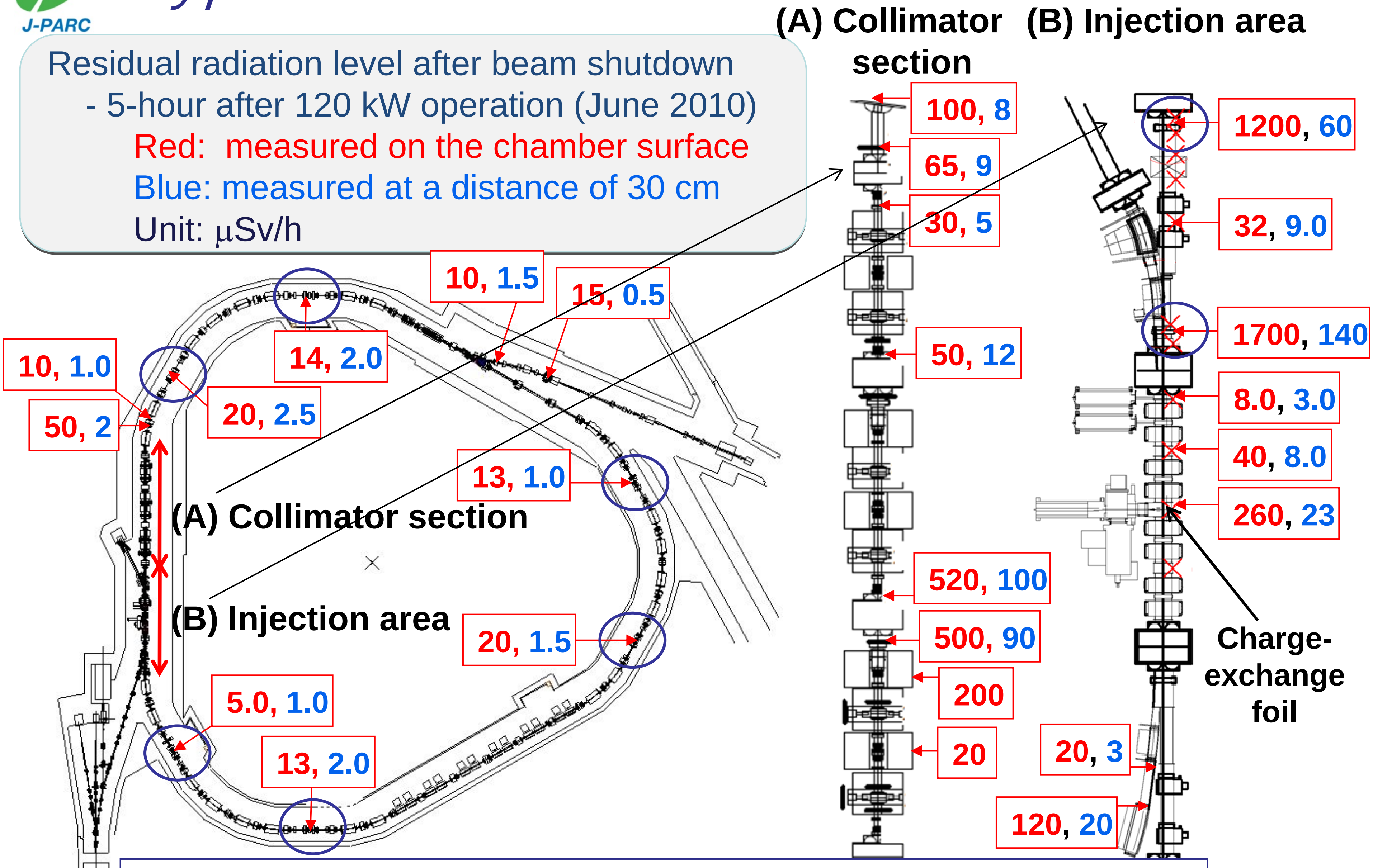
Issues for high power operation

- Reduction of beam losses
  - Activation
    - After 2 weeks user operation with 120kW.
      - Maximum value of activation on surface of the component was about 1.5 mSv/h. This value was not so high but not low.
      - ➢ Reduction of beam loss is essential to realize a higher power operation.
    - After 1 hour-300kW operation
      - An outstanding increasing of activation was not found with 300kW operation for 1 hour.

- Beam quality
  - Satisfies the requirements as a high power injector to the MR as well as a high power beam source to the MLF.

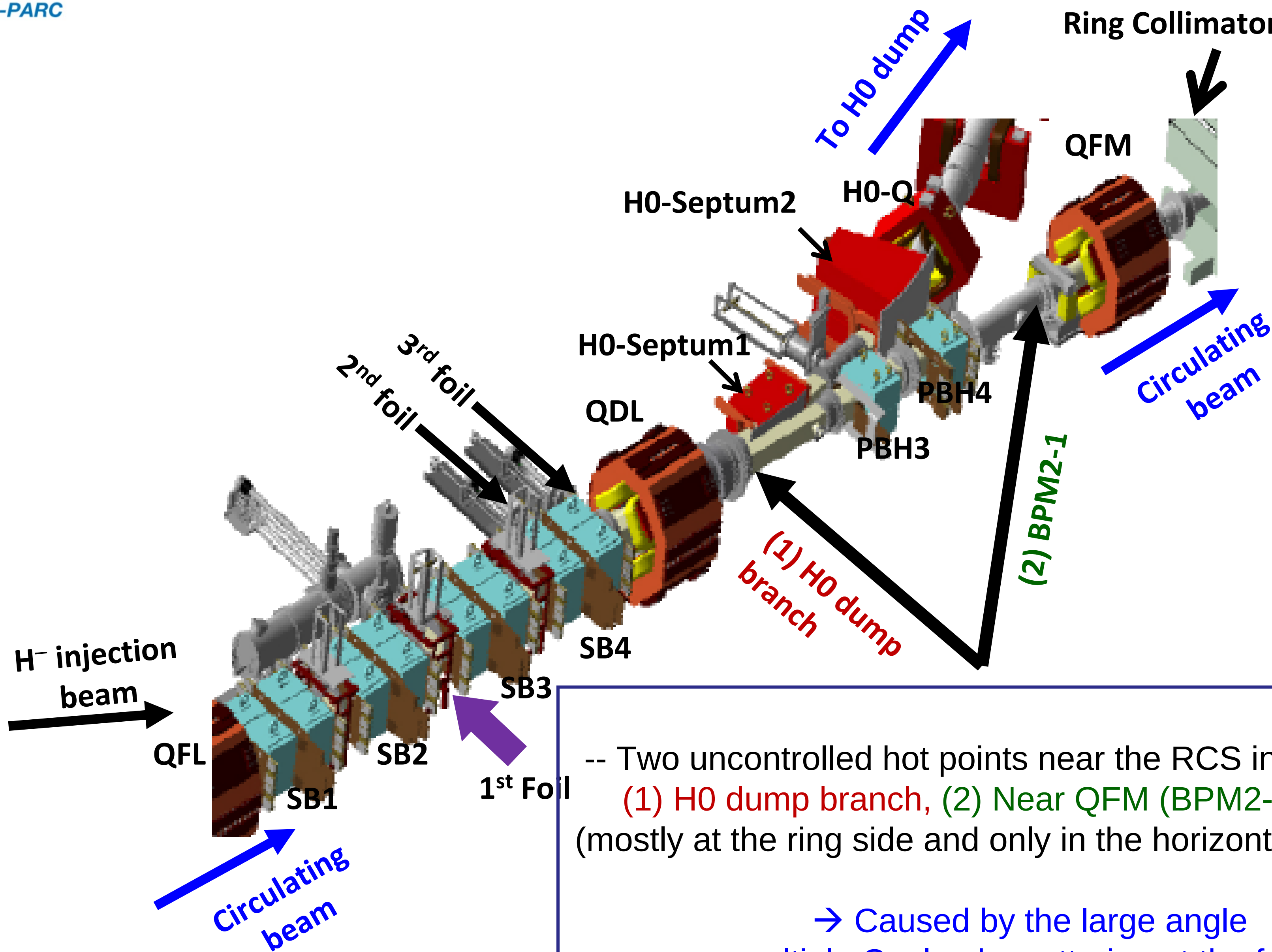
Typical residual radiation level in RCS

Residual radiation level after beam shutdown
- 5-hour after 120 kW operation (June 2010)
  - Red: measured on the chamber surface
  - Blue: measured at a distance of 30 cm
  - Unit: μSv/h



- ➢Residual radiation downstream of the 1st foil in the injection section
- ➢Residual radiation at the arc section with dispersion maximum

Beam loss in the injection section



-- Two uncontrolled hot points near the RCS injection area
(1) H0 dump branch, (2) Near QFM (BPM2-1)
(mostly at the ring side and only in the horizontal direction)

→ Caused by the large angle
multiple Coulomb scattering at the foil !

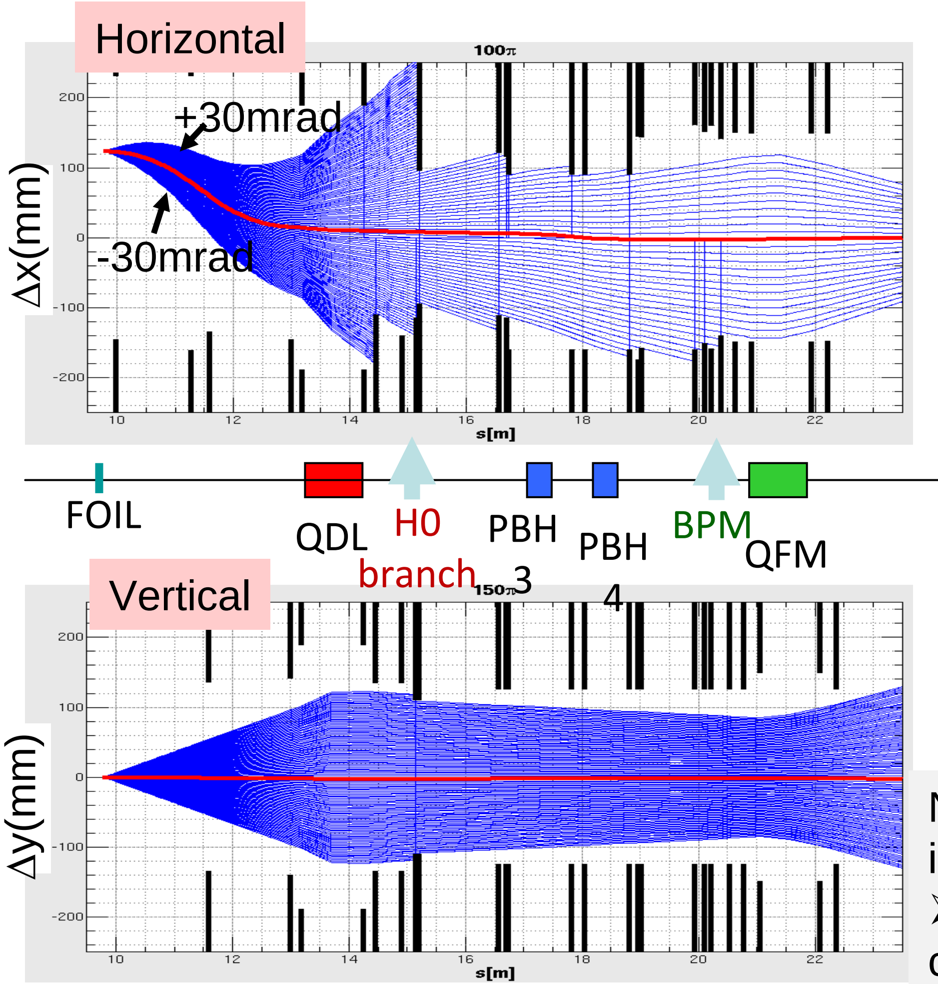
Acceptance simulation

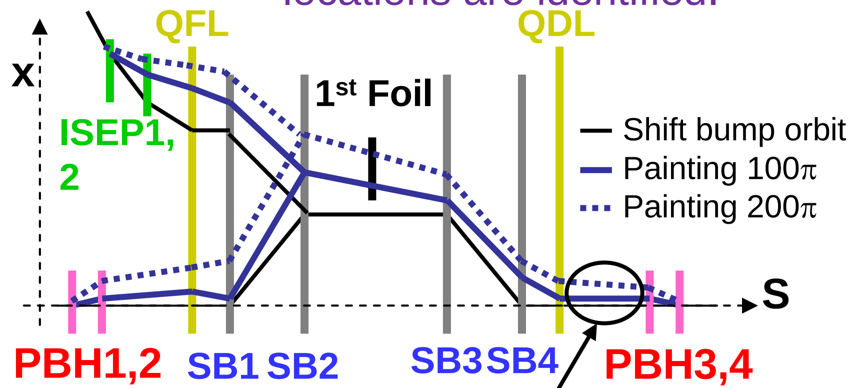
To identify the loss sources, a detail experimental study as well as simulation were carriedout, where the real experimental condition, a comparatively large number of macro particle as well as a very realistic and precise machine aperture were taken into account.

➢ As a result, a very realistic distribution of the beam loss peaking exactly at (1) and (2) and consistent with the beam loss monitor signal were obtained.

Geant + SAD
w/ 10^8 macro particles

Two hot points only in the horizontal direction at the H0 branch and BPM locations are identified.





Orbit moves towards outer side w/ larger painting area
→ Loss reduced in the inner side!

No noticeable loss as well as residual activation in the vertical direction

➢ the vertically focusing quadrupole QDL as confirmed in the simulation.

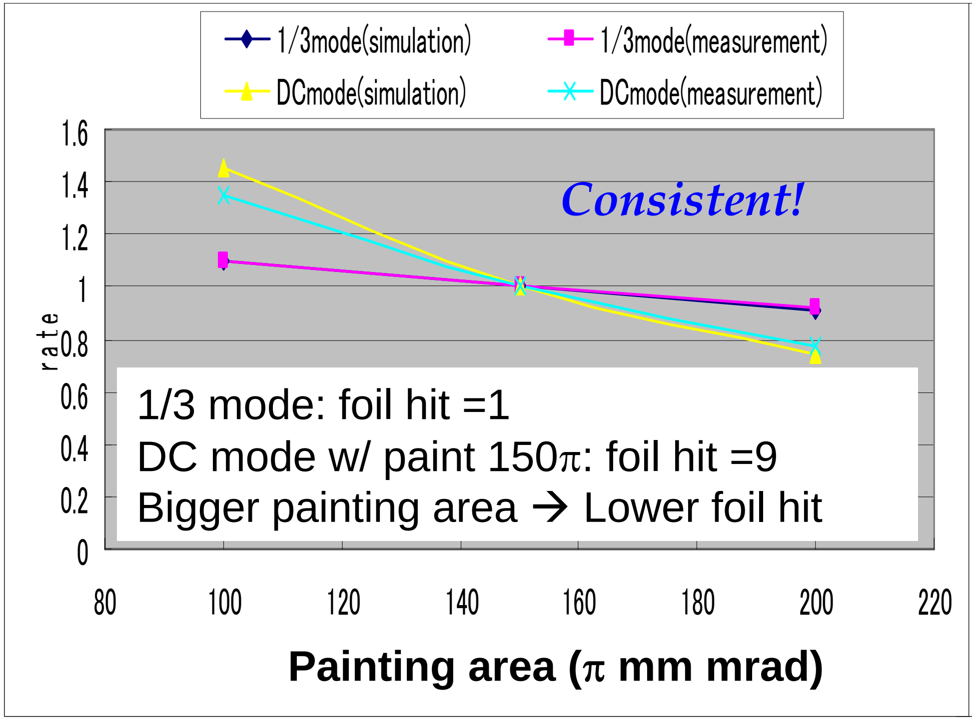
Comparison of beam loss between simulation and experiment

Figures show a comparison of the measured beam loss rate to that with the simulation. The beam loss monitor gain for each mode was adjusted and was different in order to measure even a lower beam loss for the former mode or the signal not to saturate in case of much higher beam loss for the later mode.

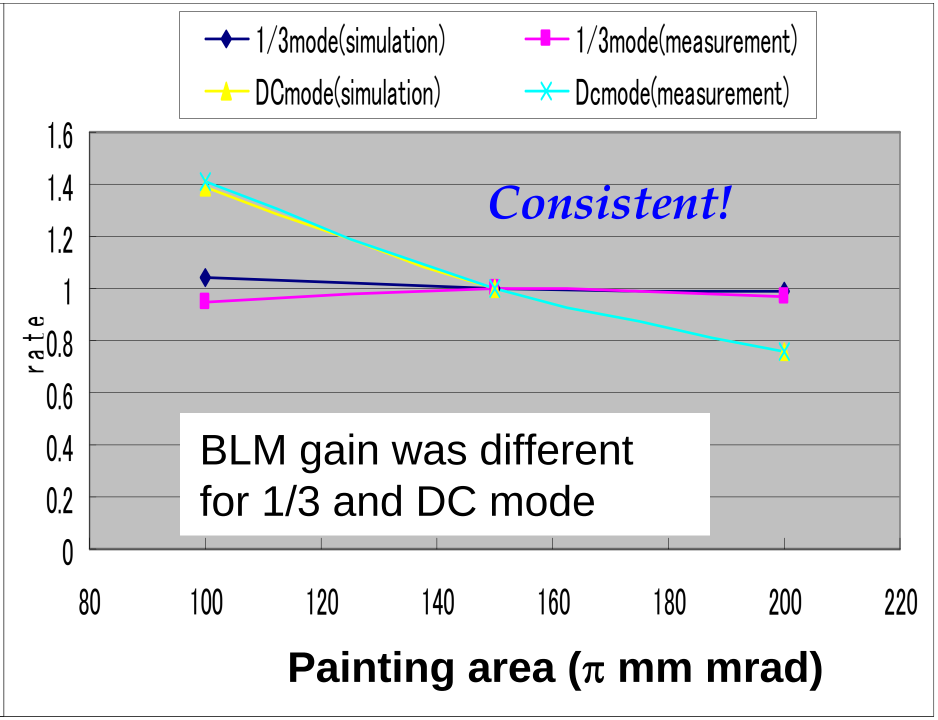
The experiment was done for three different painting areas of 100π, 150π and 200 π mm mrad in the horizontal direction. The loss particles found in the simulation and integrated beam loss monitor signal for each case were normalized by the data with a painting area of 150 π mm mrad.

The trend of the beam loss rates were found to be consistent each other and were proportional to the foil hitting rate.

(1) H0 branch (ring side)



(2) Near QFM (ring side)

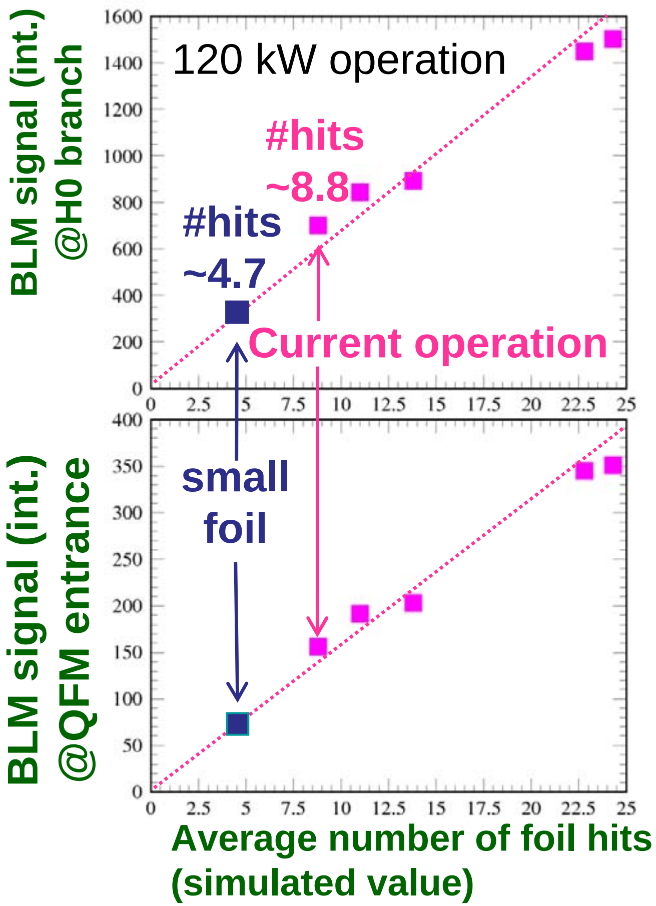


Solutions

To reduce such a uncontrolled beam losses, two actions are in consideration.

➢ The first one is to use a smaller size foil and is very simple to adopt. It will directly reduce such a beam loss as the foil hitting particles will be reduced. The present foil size especially in the vertical direction is quite big (40 mm) and already replaced with a size of 15 mm.

1. Optimized foil size → reduce foil hit rate ~ 1/2



However, there is no change in the horizontal direction as foil position is adjustable very precisely and also circulating beam orbit goes away from the foil with decay patterns of the horizontal painting bump magnets.

The foil hitting rate are expected to reduced about a half and thus the corresponding beam losses as well.

Already installed and checked this run!!
➔ Beam loss became **1/2**

➔ Not sufficient !!
Residual radiation with 300 kW operation might left about 1.5 mSv/h !

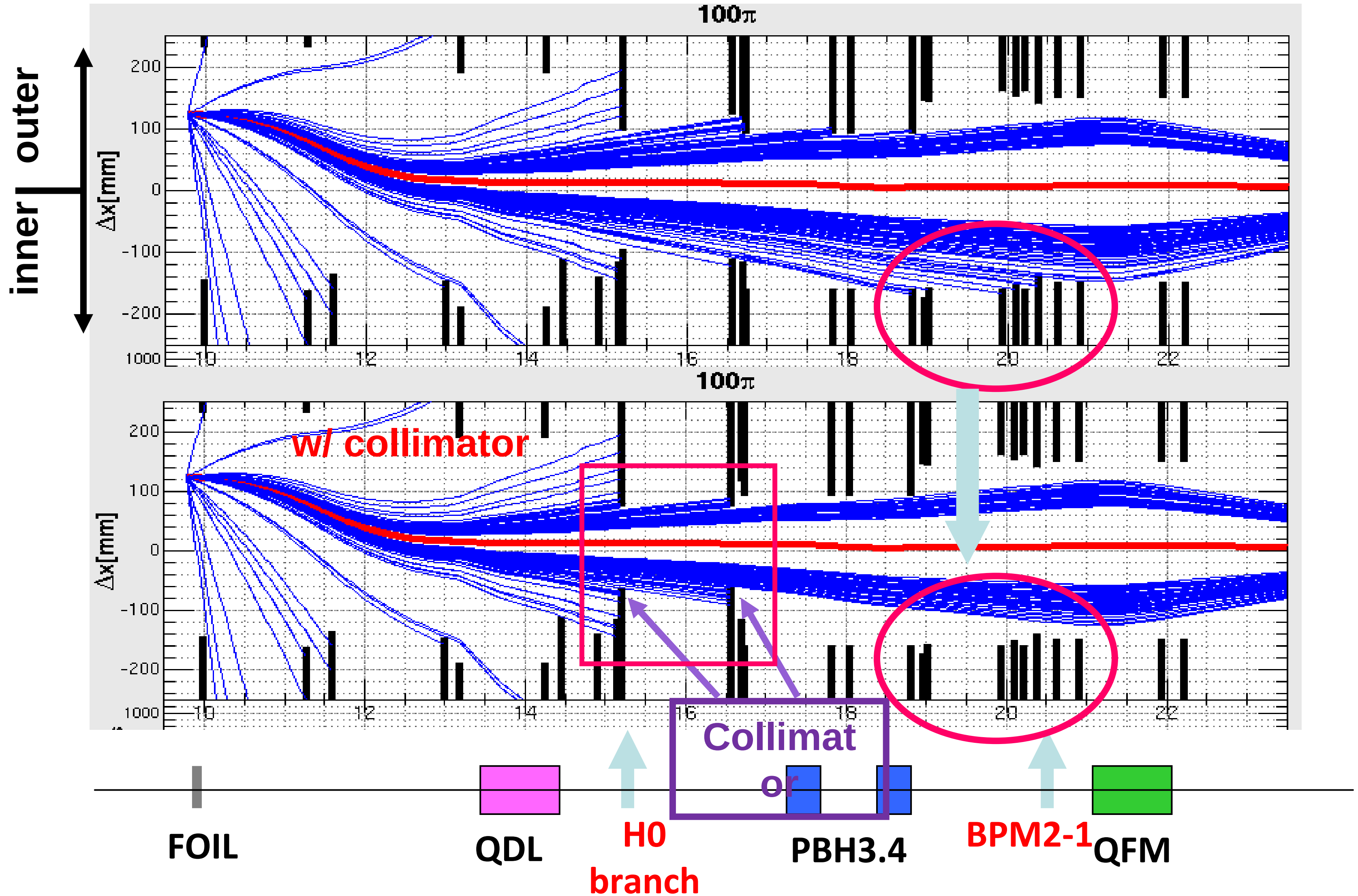
➢ 2nd action is to place a new collimator system at the H0 branch location (1st loss point) in order to localize those uncontrolled beam losses and will be installed in the 2011 maintenance period.

Example of localization

2. Local shield ≈ Collimator is in consideration!

→ Simulation shows that can localize the beam losses.

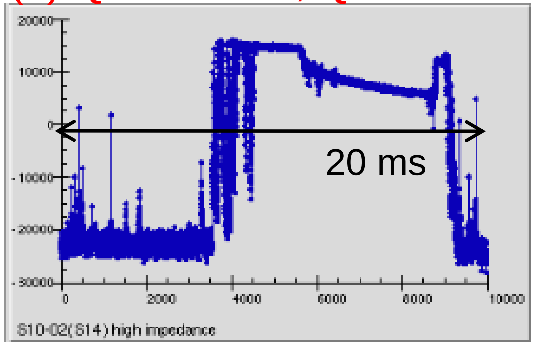
To be installed in 2011 maintenance period!



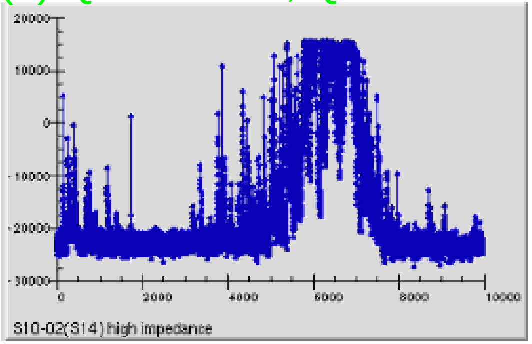
Beam loss at the arc

BLM signals from injection to extraction
at the arc with dispersion maximum (~6 m)

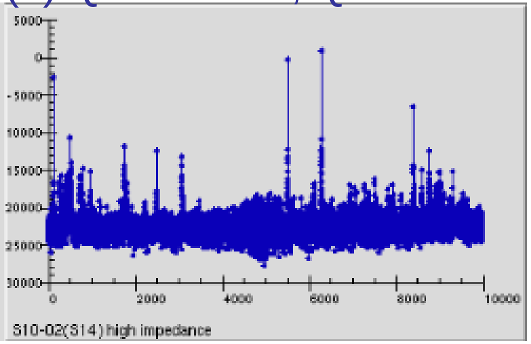
(1) Qfm x1.000, Qdl x0.990



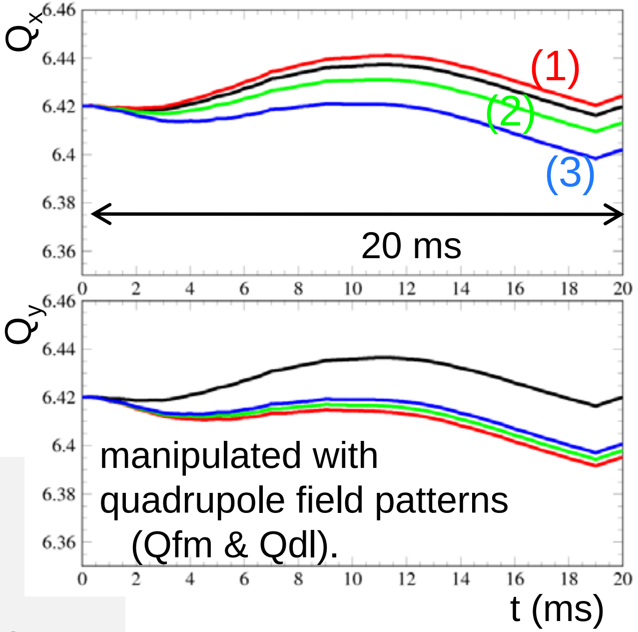
(2) Qfm x0.990, Qdl x0.990



(3) Qfm x0.980, Qdl x0.990



Tune variations
over the acceleration process



The beam loss :
- takes place at the middle of the acceleration process
- is sensitive for the tune variation and also the longitudinal profile during acceleration.

-Such a future implies that the beam loss comes from the chromatic tune spread.

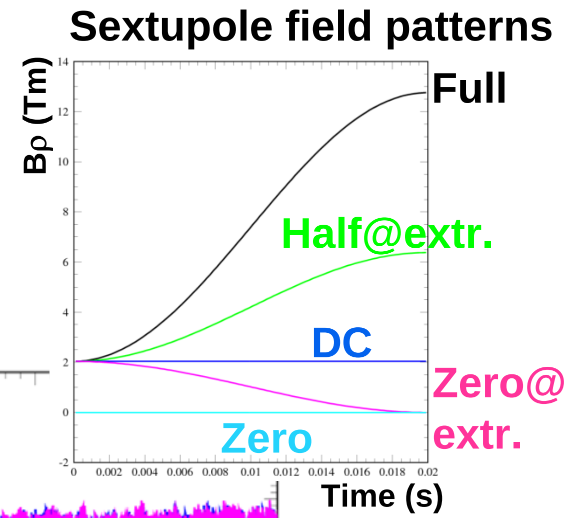
In the RCS the chromatic correction was performed at injection with DC power supplies. So, the chromaticity gradually recovers as accelerated.

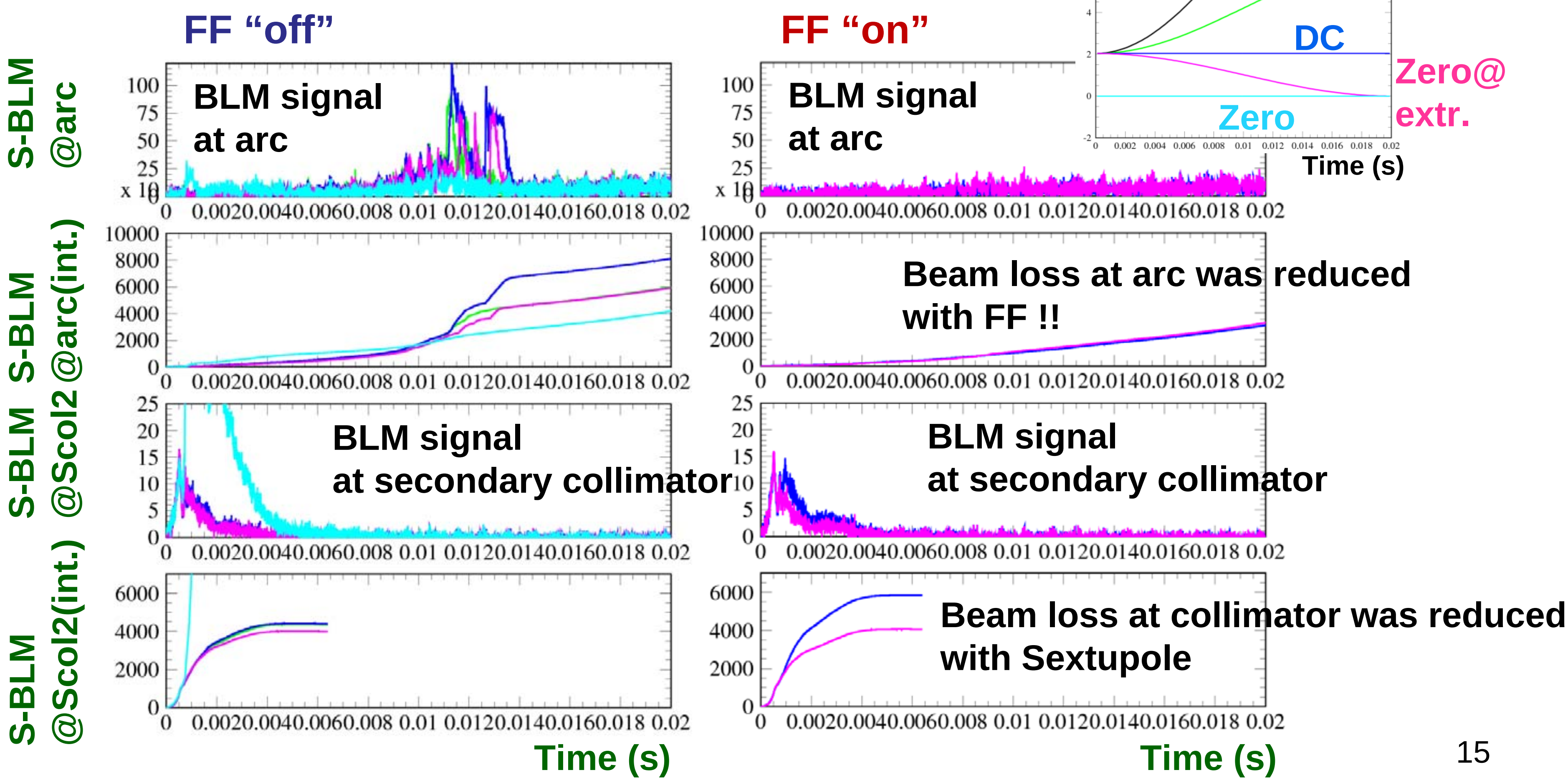
-We introduced the AC power supplies for chromatic correction sextupoles in this summer maintenance period and just started to study for minimizing this beam loss by optimizing the chromatic correction and the tune variation during the acceleration process.

Beam loss vs. FF, sextupole field pattern

Preliminary !!

15 mA/0.5 ms/600 ns/2 bunches; 300 kW-eq.
Transverse paint : 150π in the horizontal plane
Longitudinal paint : 80%/-100 deg/-0.3%





High power beam demonstration

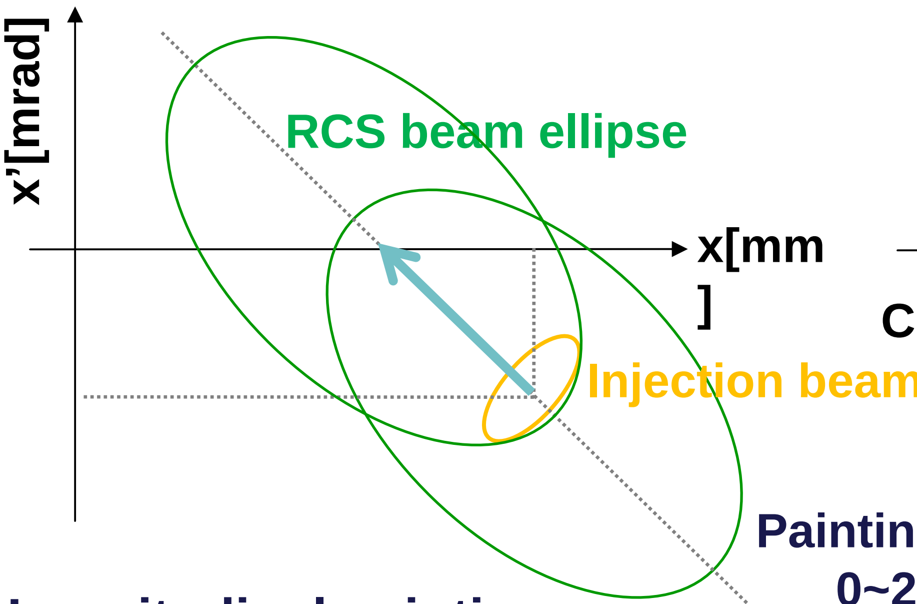
- We performed a systematic investigation with different intensities (up to 300 kW) and various painting parameters.
- We tried to minimize an intensity loss by optimizing the operation parameter including the painting injection.

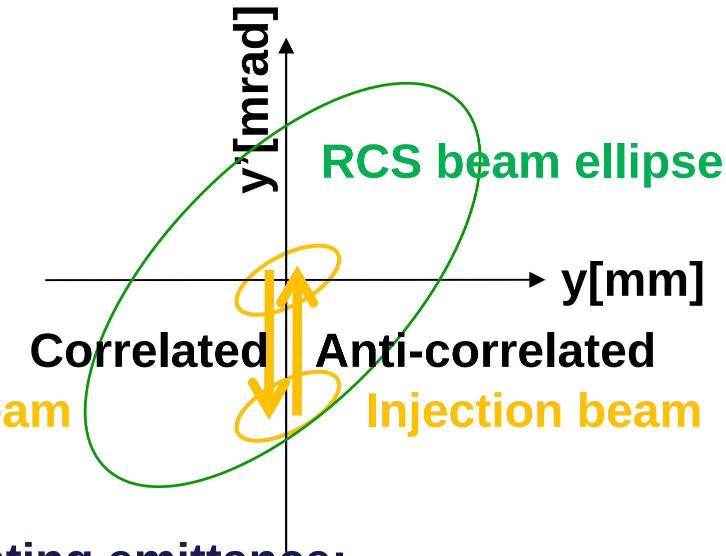
Data ID	I_{peak} (mA)	L_{macro} (ms)	Chop (%)	N_{bunch}	N_{part}	Intensity (kW)	ϵ_{tp} (π mm mrad)	V_{2nd} (%)	$\Delta\phi$ (deg)	Δp (%)
(1)	15	0.1	56	2	5.0×10^{12}	60	-	-	-	-
(2)	15	0.2	56	2	1.0×10^{13}	120	-	-	-	-
(3)	15	0.3	56	2	1.5×10^{13}	180	-	-	-	-
(4)	15	0.4	56	2	2.0×10^{13}	240	-	-	-	-
(5)	15	0.5	56	2	2.5×10^{13}	300	-	-	-	-
(6)	15	0.5	56	2	2.5×10^{13}	300	100	-	-	-
(7)	15	0.5	56	2	2.5×10^{13}	300	100	80	-80	-
(8)	15	0.5	56	2	2.5×10^{13}	300	100	80	-80	-0.1
(9)	15	0.5	56	2	2.5×10^{13}	300	100	80	-80	-0.2

- I_{peak}/L_{macro}/Chop show
  peak current/macro-pulse length/chopper beam-on duty factor of the injection beam,
- N_{bunch}/N_{part} are number of bunches/particles per pulse,
- ε_{tp} is the transverse painting emittance, and
- V_{2nd}/$\Delta\phi$/Δp/ show
  amplitude of 2nd harmonic rf voltage (ratio to the fundamental one)/
  phase sweep of 2nd harmonic rf voltage relative to the fundamental one/
  momentum offset applied in the longitudinal painting.

Painting injection

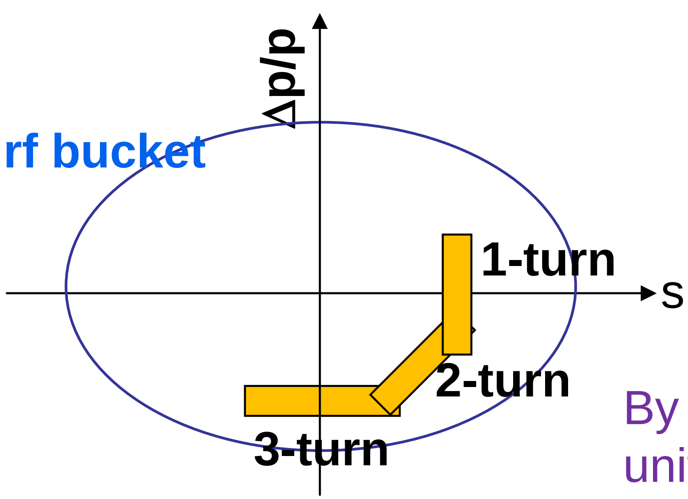
➢Transverse painting





Painting emittance;
0~216 π mm mrad

➢Longitudinal painting



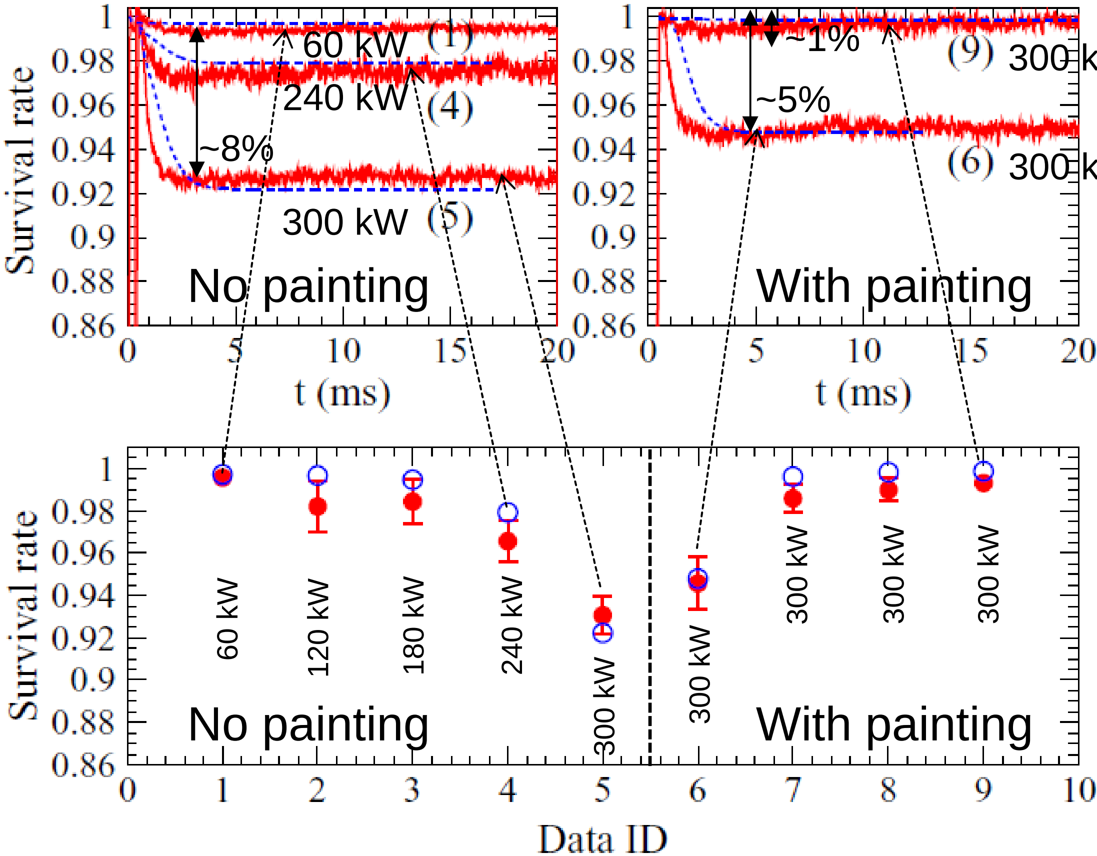
-Momentum offset (=offset of rf frequency);
0~-0.2% in momentum

- Superposition of 2nd harmonic rf voltage;
80% of the amplitude of the fundamental one
- Phase sweep of the 2nd harmonic rf voltage;
-80 to 0 deg relative to the fundamental one

By combination of these manipulations, we make a uniformly shaped beam in both the transverse and longitudinal plane to mitigate the space charge effect.

Intensity loss observed for 300 kW beam

Beam survival rates at the RCS measured with DCCT
for different intensities and painting parameters



300 kW with transverse & longitudinal painting
(V_{2nd}; 80%/$\Delta\phi$; -80 deg/Δp; -0.2%)

300 kW with transverse painting
(ε_{tp}; 100π mm mrad, correlated)

Red - measured with DCCT
Blue - simulations

The intensity loss for 300 kW beam was finally minimized to 1% level by painting.

In this case most of the remaining particle loss was well localized on the collimator.

The BLM signals downstream of the foil and at the arc with dispersion maximum was 3~4 times larger than those in the current 120 kW operation

…..We have tried to minimize such a unlocalized beam loss by using a small foil , by introducing AC power supplies and by introducing new knobs.

Our goal for the moment

Laslett space-charge tune shift :

–0.15 for both cases

(B_f=0.4, 216π painting)

181 MeV injection
15 mA Linac peak current
x 0.56 chopping
x 230 turns (500 μsec)
→1.3E13/bunch
x 2 bunches
x 25 Hz
x 3 GeV
→300 kW

Our goal; loss<3%

400 MeV injection
50 mA Linac peak current
x 0.56 chopping
x 307 turns (500 μsec)
→4.2E13/bunch
x 2 bunches
x 25 Hz
x 3 GeV
→1 MW

Permissible beam loss rate:
3% (at injection)
→ 4 kW(collimator capacity)

Achieving 300 kW output with less than 3% intensity loss for 181 MeV injection energy is the first matter to realize 1 MW output with 400 MeV injection energy.

Intensity loss achieved ~1%

Issues for high power operation

- **Beam quality**

  Satisfies the requirements as a high power injector to the MR as well as a high power beam source to the MLF.

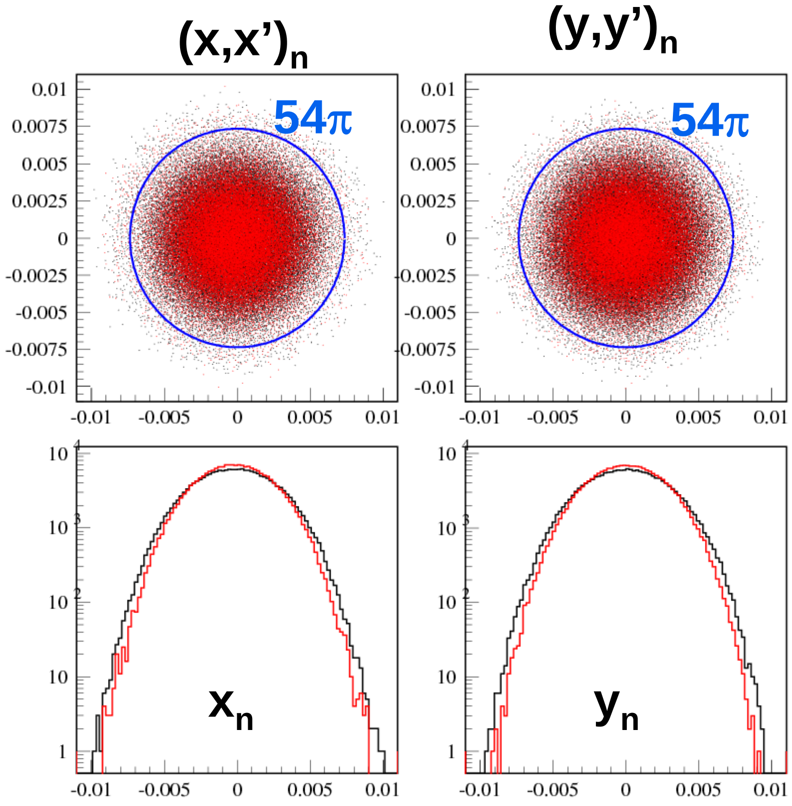
- What is the key issues ?
  - High power beam source for MLF

    How to realize big beam size and uniform beam on neutron production target ?
    - To manipulate the optics of the 3NBT and to be considering how 8-pole magnets install in the beam line.
    - 3NBT aperture is 324π mm mrad. This is same as the RCS ring collimator aperture. Beam halo is not so serious issue for the MLF.
  - For injector of MR

    How to realize small beam size and small emittance ?
    - To reduce the beam halo is essential in the case of high intensity beam because the 3-50BT collimator aperture is 54 π mm mrad and current collimator limit is 450 Watt.

Issues : extraction beam halo

- 181MeV Injection / 300kW



Phase plots at extraction

- Expected loss at the collimator (simulation)
  - Black; no painting
    2.1% loss at 3-50BT collimator
    corresponding to 212 W
  - Red; w/ painting
    0.9% loss at 3-50BT collimator
    corresponding to 90W

- Permissible loss power at the 3-50BT collimator : 450 W
- Collimator aperture : 54π mm mrad

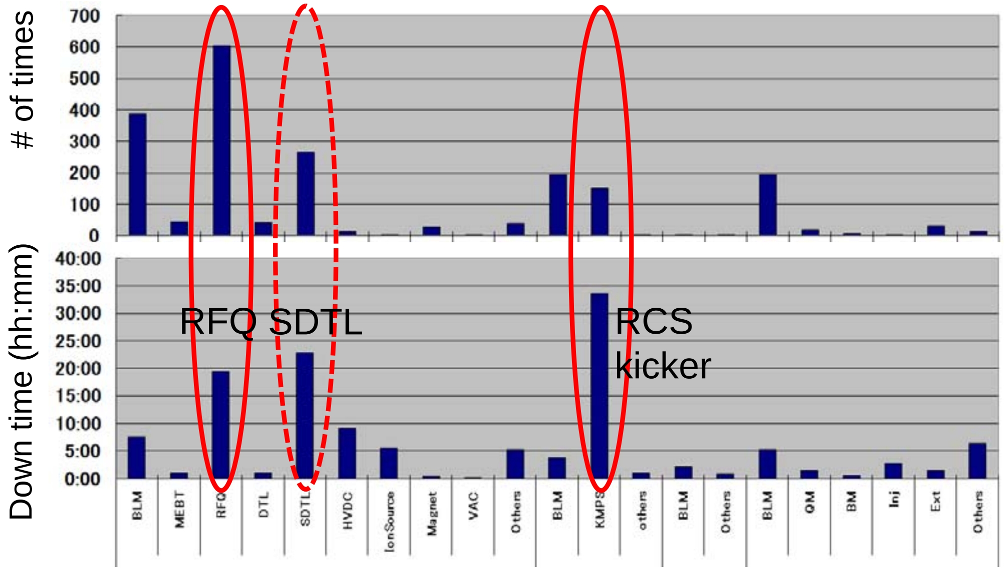
Beam loss power at 3-50BT collimation is still small compared with the capacity of the beam collimator.

➢It is possible to deliver 300kW beam to MR

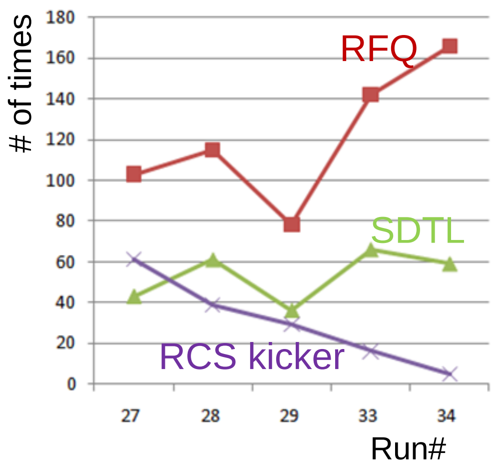
We have been simulated and measured the beam halo of the RCS beam for several beam power levels. When the beam intensity extracted from RCS becomes more than 300kW, beam halo reduction is a key issue especially, for the MR injection.

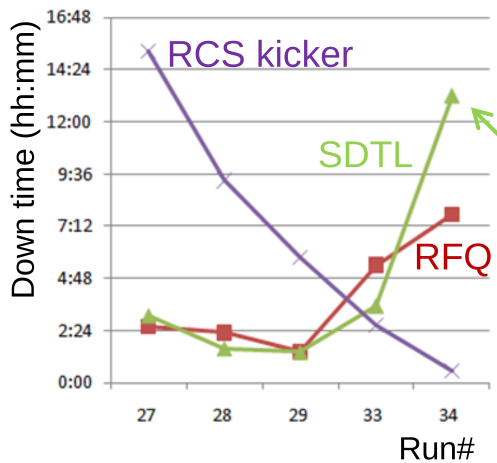
Beam fault statistics for MLF user operation

Beam fault statistics for the MLF user operation
in the last 5 run cycles



Trip rates of RFQ, SDTL and RCS kickers
for each run cycle



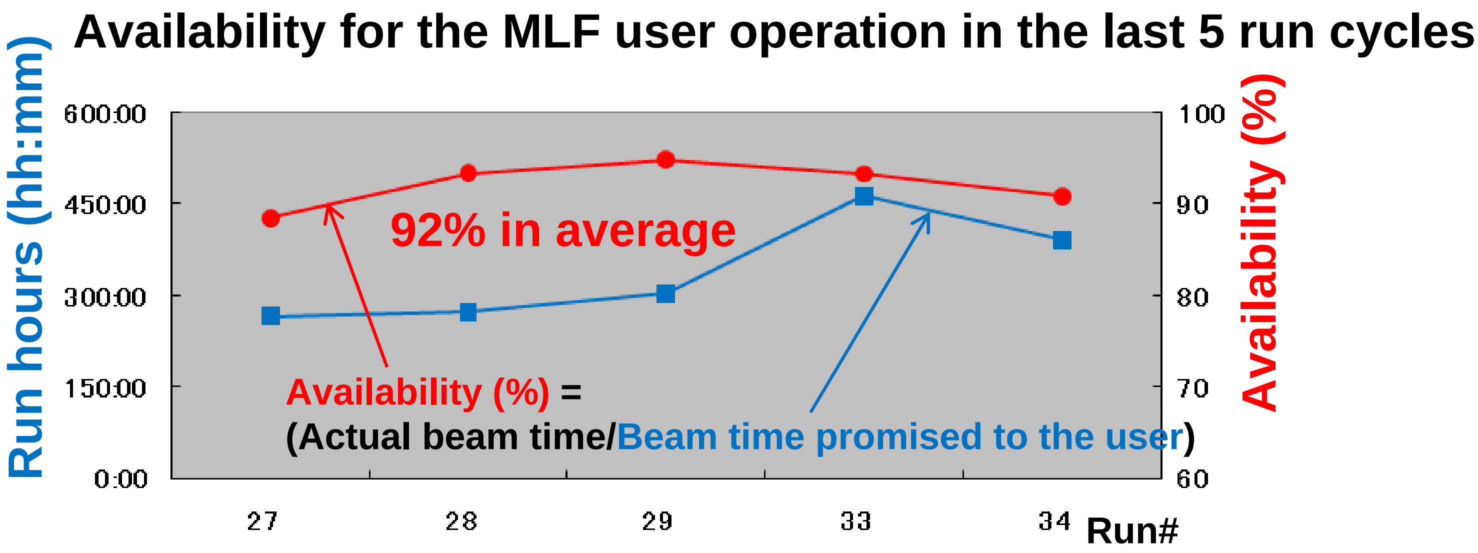


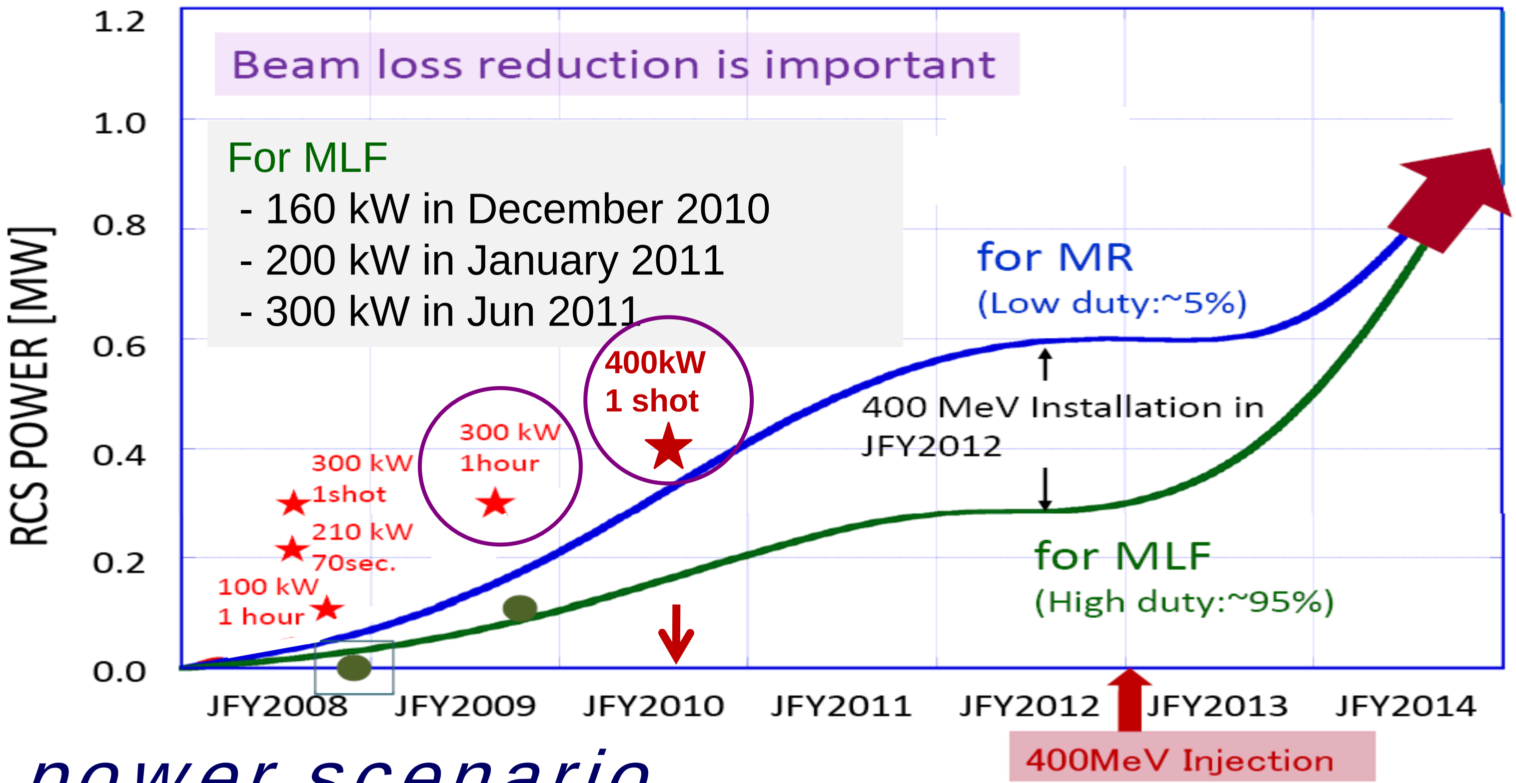
- Trip of RFQ (mainly due to discharge)
  - The RFQ is usually recovered automatically within 1 min.
  - If the automatic recovery fails, an operator manually restarts the RFQ typically spending 3~10 min.
  - The failure rate of the automatic recovery is ~20% in average.

- Miss-fire, self-breakdown of RCS kickers
  - The kicker pulse is usually restarted manually by an operator typically spending 10~15 min.
  - The trip rate is now significantly reduced by optimizing the reservoir voltage of thyratrons used for the power supply.

The increase of the downtime of SDTL in Run#34 is from the following rare events with longer downtime;
- Trouble of the interlock unit; ~2.2 hours
- Breakdown of the coaxial cable ~7.0 hours

Availability for the MLF user run





RCS power scenario

Date	Beam power (kW)	Required items
2010.10-	for MLF : 100-200 for MR : 100-400	• Cure for foil-scattering loss • AC power supply for full chromatic correction
2011-	for MLF : 200-300 for MR : 100-400	・12 sets of RF cavities
2012.7-11		• RCS injection system for 400 MeV installed . -injection bump, paint bump, and … • New knob for loss reduction
2012.12-	for MLF : >300 for MR : >600 ?	• **Beam commissionig will be started**

Summary

- We started the MLF user operation in December 2008 with 4 kW output beam power.
- After the recovery of the RFQ discharge problem, the beam power for MLF was increased to 120 kW in November 2009.
- We successfully demonstrated a 300 kW output operation with a low intensity loss of 1% at the RCS by optimizing the painting injection.
- After completing the following hardware improvements in this summer maintenance period,
    - vacuum improvement in the SDTL and future ACS section
    - introduction of AC power supplies for chromatic correction sextupoles
    - introduction of a small charge exchange foil ….

  we plan to gradually increase the output beam power,
    - 160 kW in December 2010
    - 200 kW in January 2011 . . . and then 300 kW.