Operational experience at J-PARC

HB2010

46th ICFA Advanced Beam Dynamics Workshop
on High-Intensity and High-Brightness Hadron Beams
Morschach, Switzerland
Sep. 27-Oct. 1, 2010

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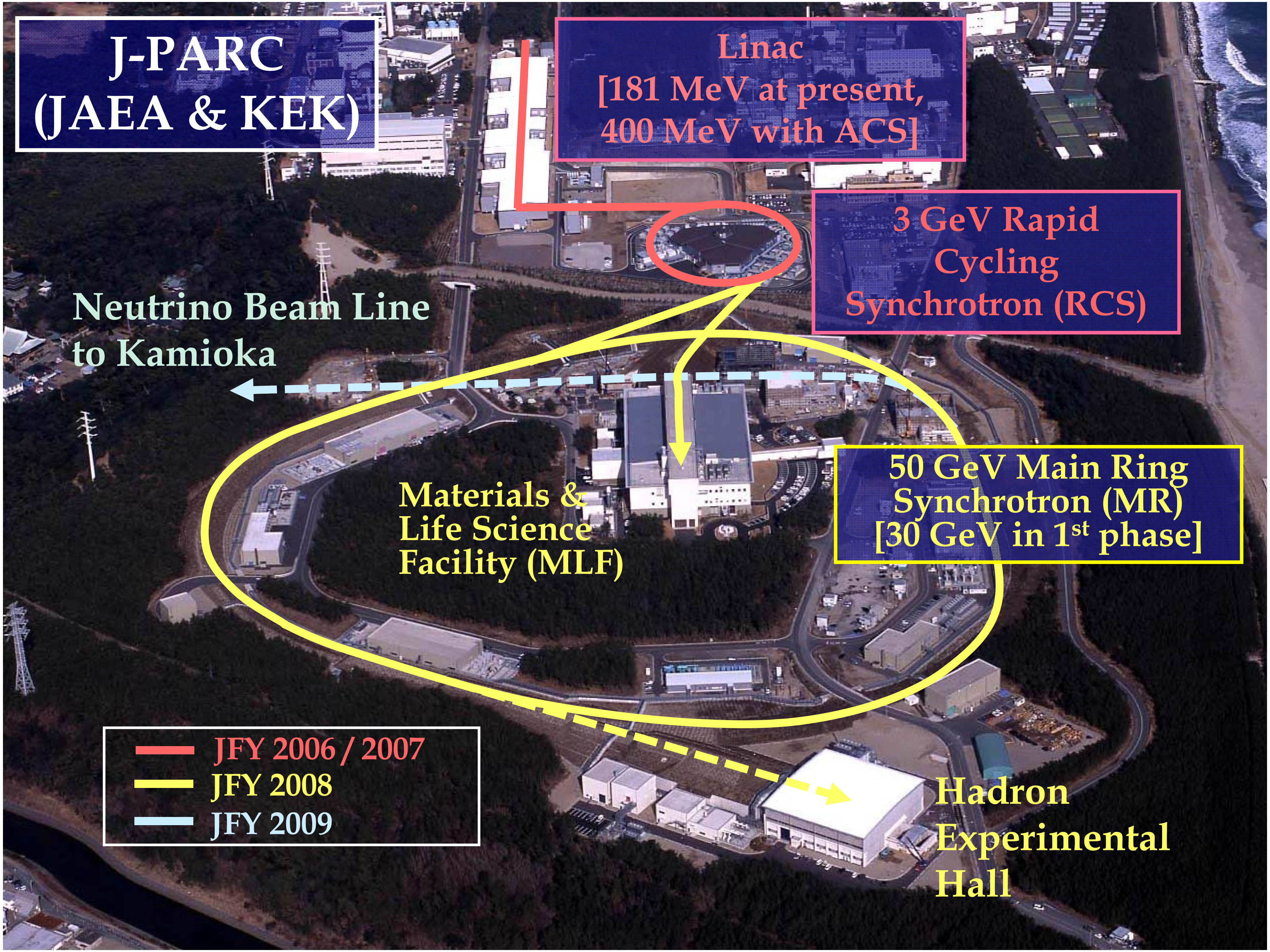
J-PARC
(JAEA & KEK)
Linac
[181 MeV at present,
400 MeV with ACS]
3 GeV Rapid
Cycling
Synchrotron (RCS)
Neutrino Beam Line
to Kamioka
Materials &
Life Science
Facility (MLF)
50 GeV Main Ring
Synchrotron (MR)
[30 GeV in 1st phase]
JFY 2006 / 2007
JFY 2008
JFY 2009
Hadron
Experimental
Hall

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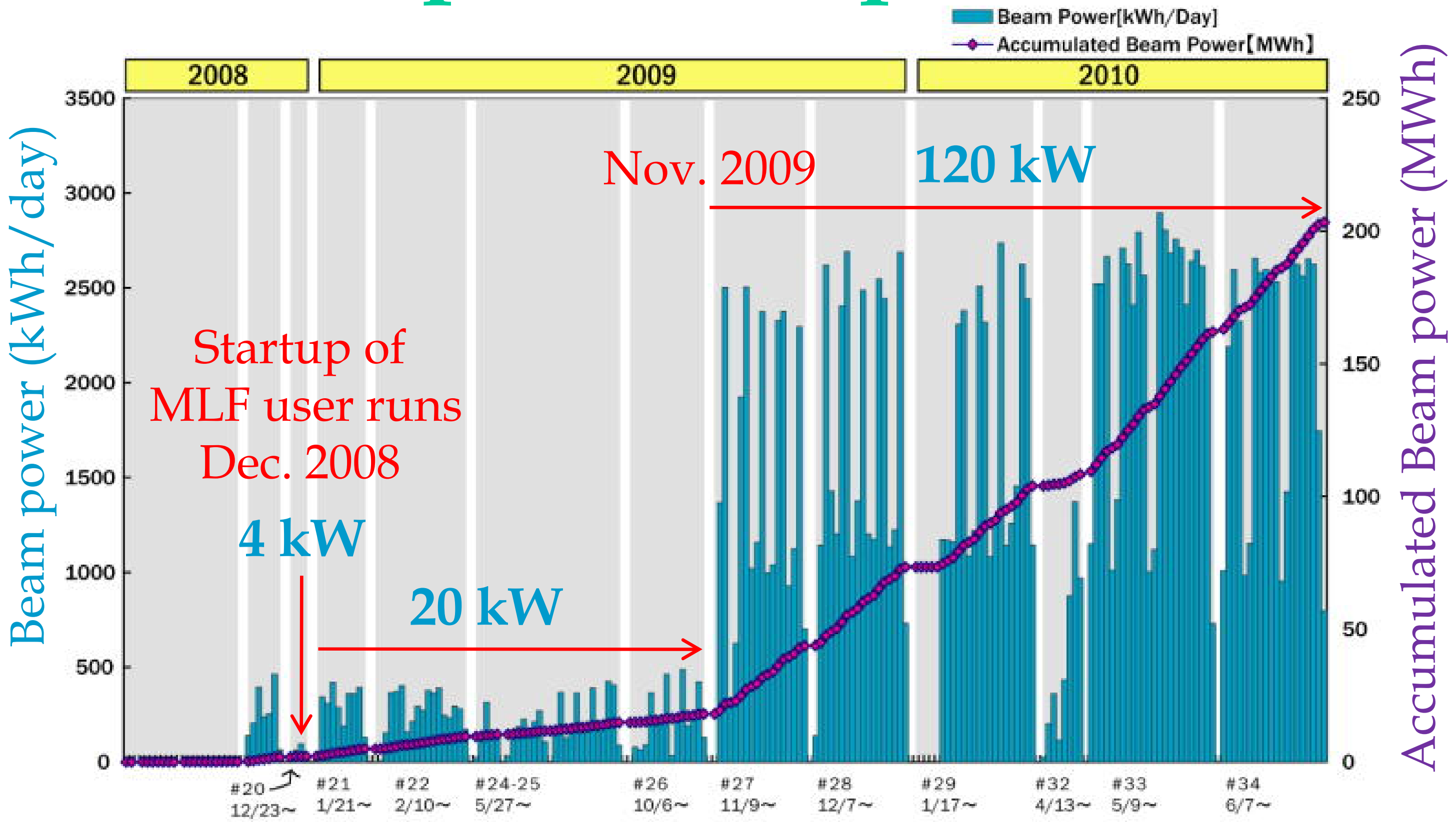
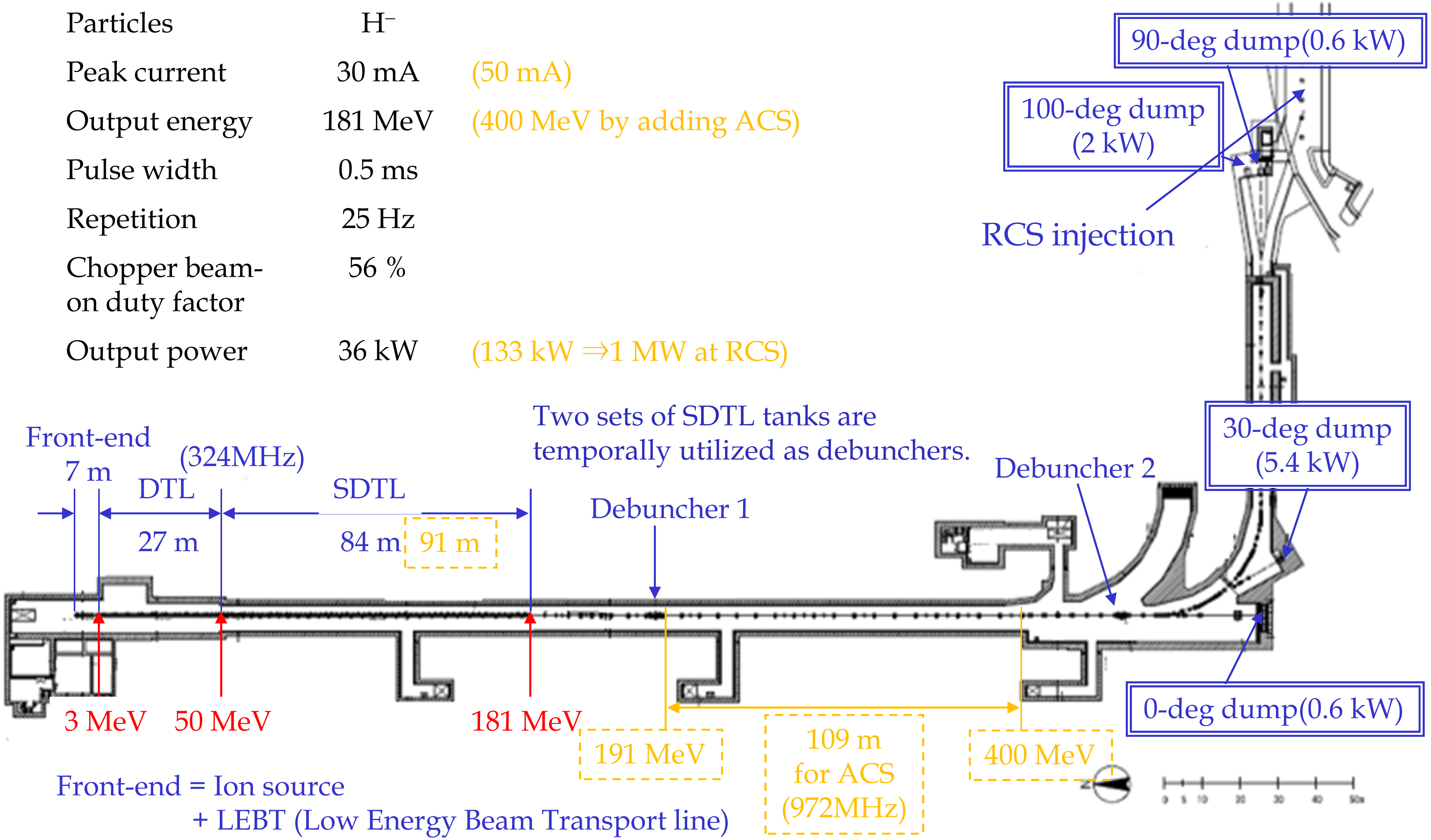
History of the output beam power to MLF



- The beam power was increased to 120 kW and its operation has been continued up to now.

Design parameters of Linac

Particles	H^-	
Peak current	30 mA	(50 mA)
Output energy	181 MeV	(400 MeV by adding ACS)
Pulse width	0.5 ms	
Repetition	25 Hz	
Chopper beam-on duty factor	56 %	
Output power	36 kW	(133 kW ⇒1 MW at RCS)



Front-end = Ion source
+ LEBT (Low Energy Beam Transport line)
+ RFQ
+ MEBT (Medium Energy Beam Transport line)

Typical residual radiation level in Linac

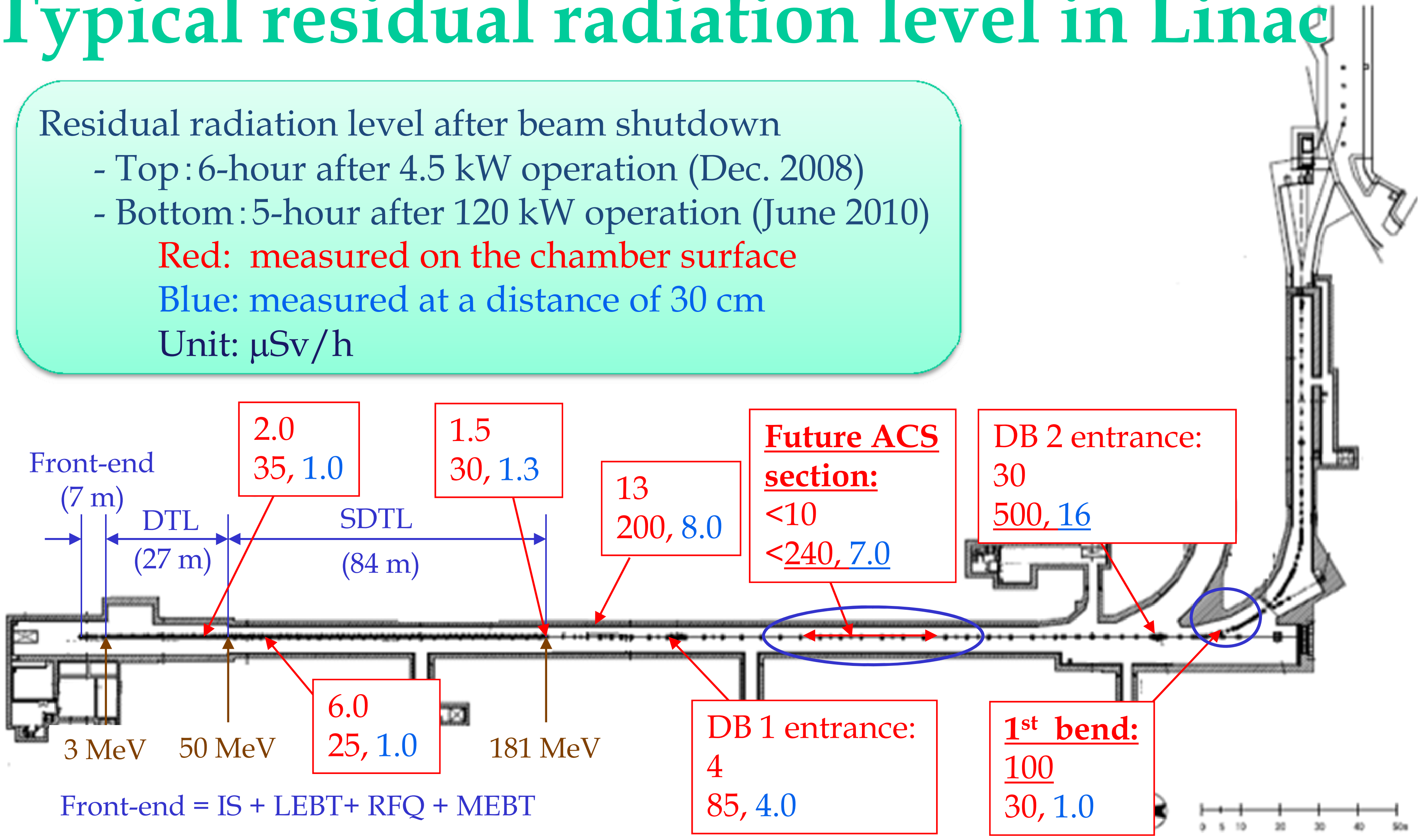
Residual radiation level after beam shutdown

- Top : 6-hour after 4.5 kW operation (Dec. 2008)
- Bottom : 5-hour after 120 kW operation (June 2010)

Red: measured on the chamber surface

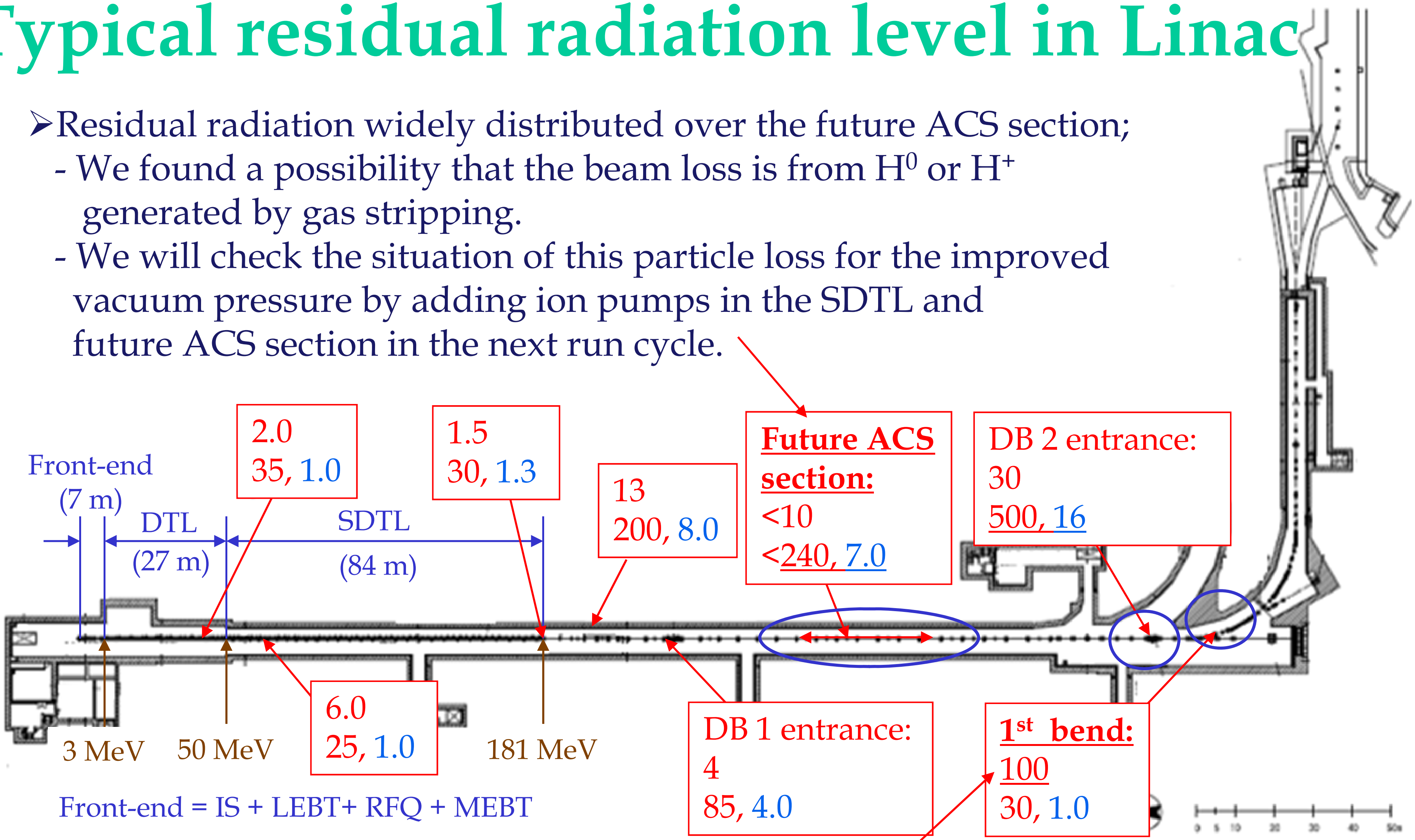
Blue: measured at a distance of 30 cm

Unit: μSv/h



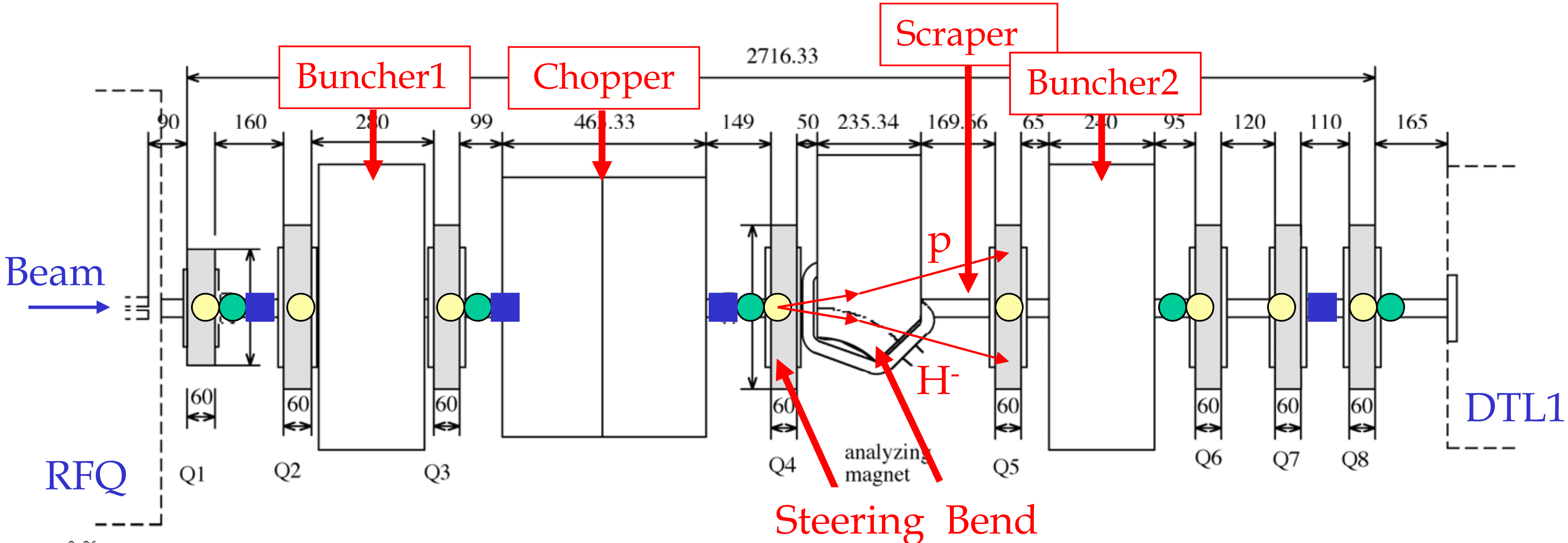
Typical residual radiation level in Linac

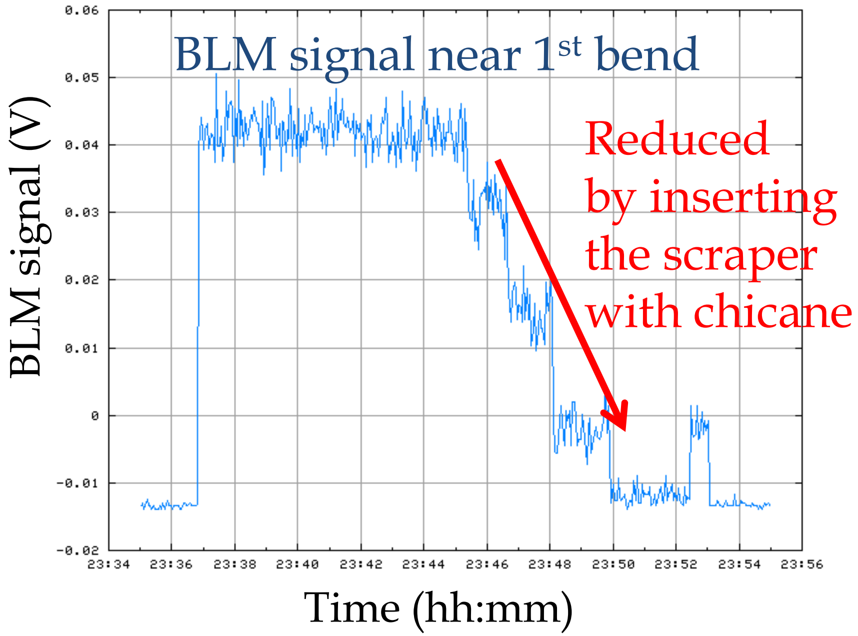
➢Residual radiation widely distributed over the future ACS section;
- We found a possibility that the beam loss is from H^0 or H^+ generated by gas stripping.
- We will check the situation of this particle loss for the improved vacuum pressure by adding ion pumps in the SDTL and future ACS section in the next run cycle.



➢Residual radiation at the 1st bend coming from proton components accelerated to around design energy generated by gas stripping in the LEBT

Proton removal at MEBT

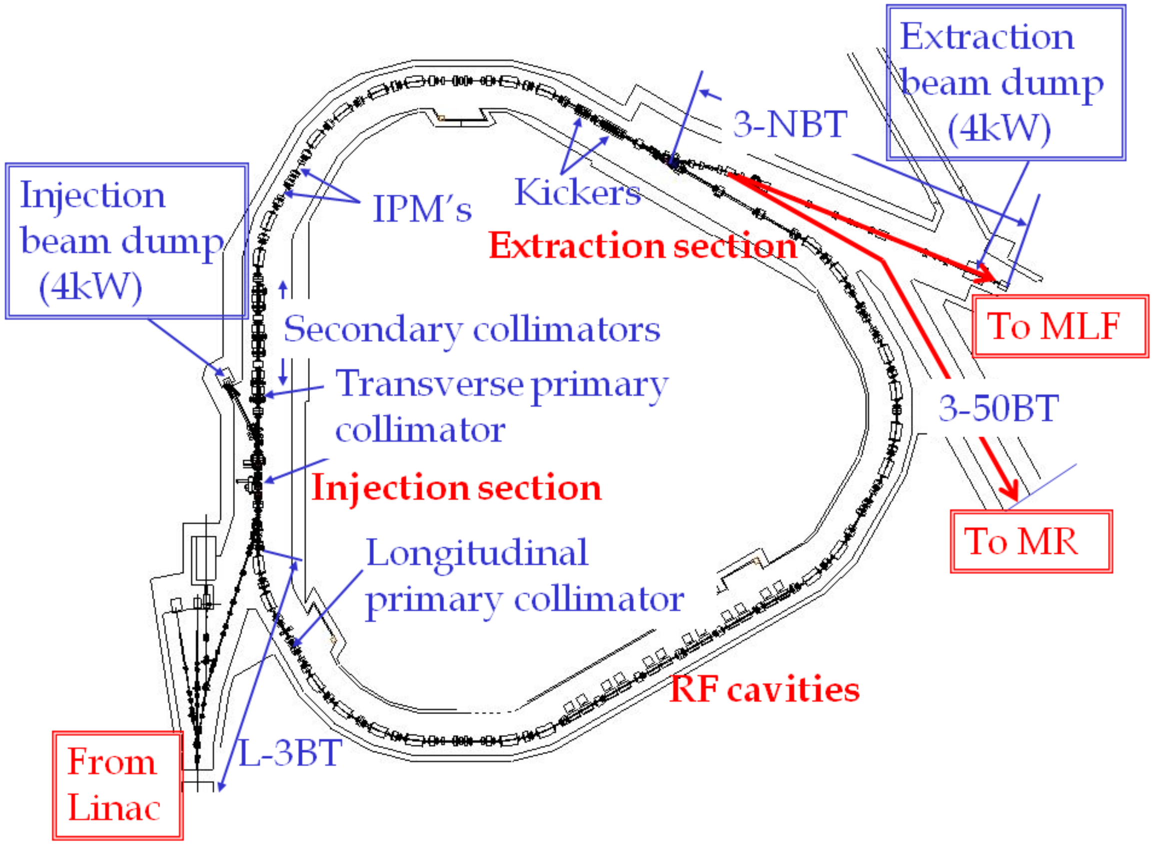




- We separated H+ and H- with Q4 steering and bend, and removed H+ with a scraper originally for chopping.
- The beam loss at the 1st bend is reduced to the negligible level in this way.
- We use this scheme for the routine operation, and the corresponding residual radiation is now reduced to 30 μSv/h at the surface for 120 kW operation.

Design parameters of RCS

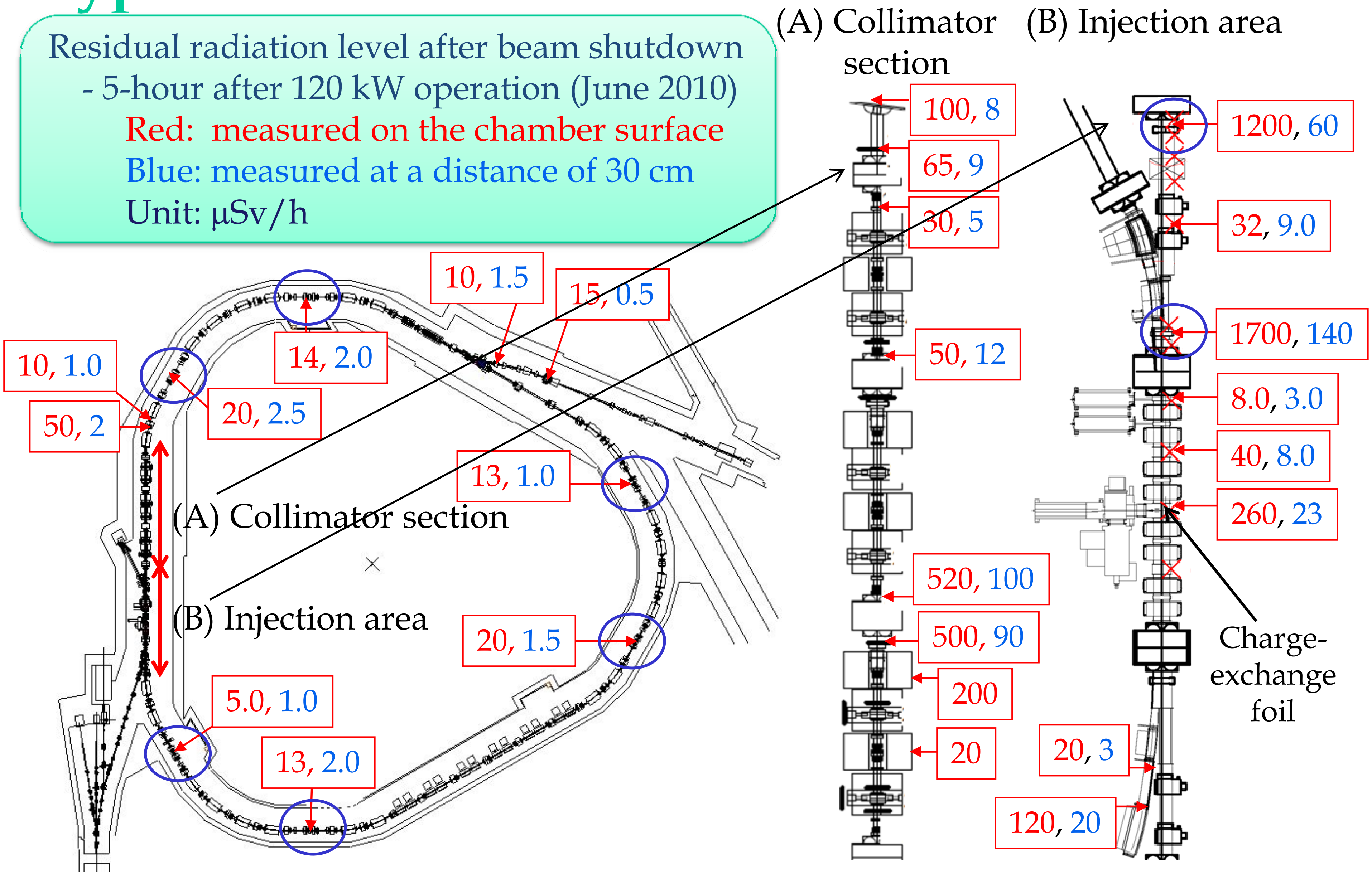
Circumference	348.333 m
Superperiodicity	3
Harmonic number	2
No of bunch	2
Injection energy	181 MeV (400 MeV)
Extraction energy	3 GeV
Repetition rate	25 Hz
Particles per pulse	2.5e13 - 5e13 (8.3e13)
Output beam power	0.3 - 0.6 MW (1 MW)
Transition gamma	9.14 GeV
Number of dipoles	24
quadrupoles	60 (7 families)
sextupoles	18 (3 families)
steerings	52
RF cavities	12 (10 at present)



The MLF user operation with 120 kW beam power has been performed since Nov. 2009.

Typical residual radiation level in RCS

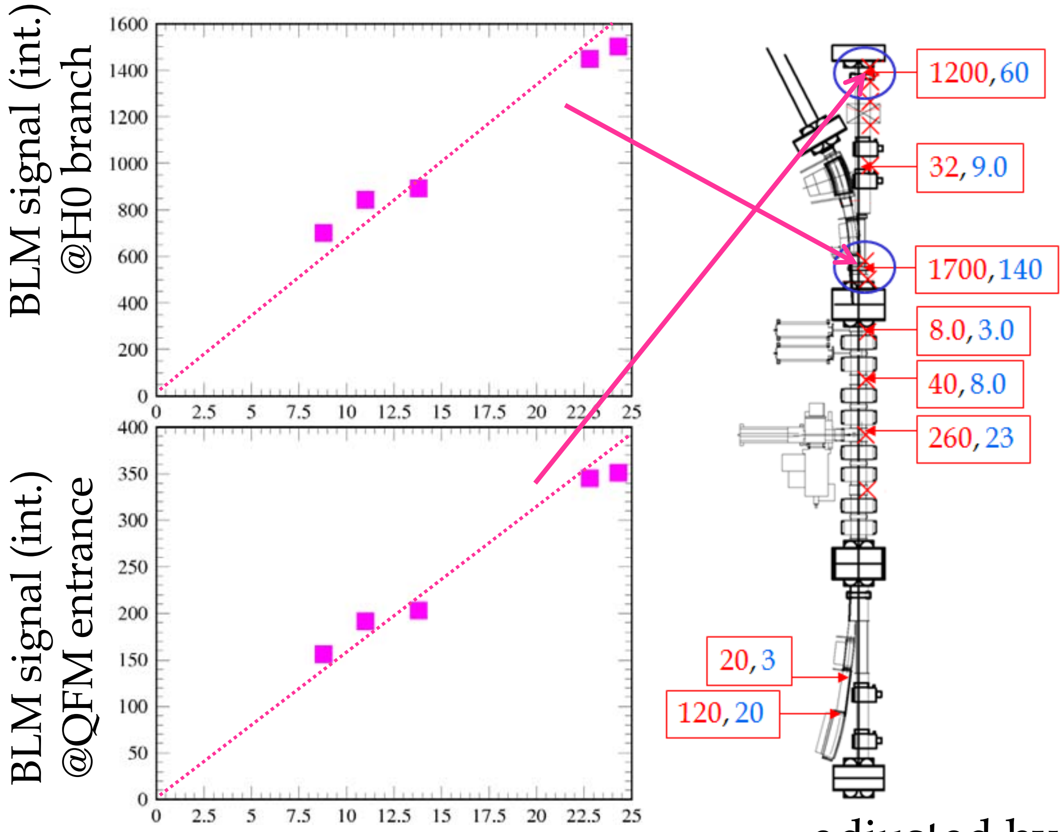
Residual radiation level after beam shutdown
- 5-hour after 120 kW operation (June 2010)
Red: measured on the chamber surface
Blue: measured at a distance of 30 cm
Unit: μSv/h



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

Beam loss downstream of the foil

- In the RCS, multi-turn charge-exchange injection with a carbon foil is adopted. In this way, the beam hits the foil many times during injection period.
- Most possible cause of the particle loss is large angle events generated by the foil scattering.

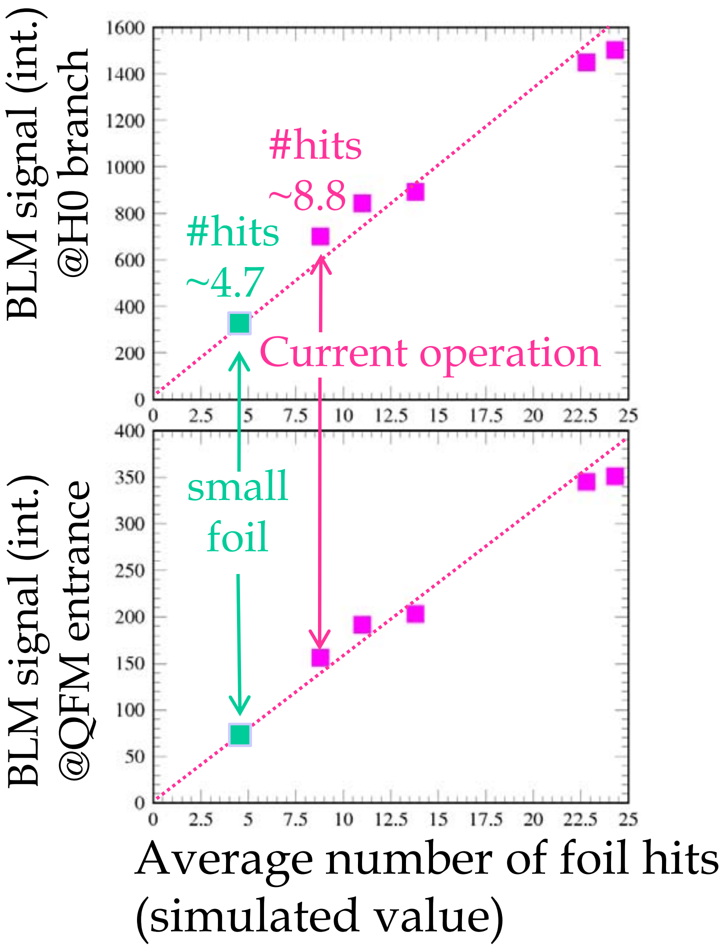


-The detected BLM signal is proportional to the average number of the foil hits.

- It suggest the beam loss comes from large angle events scattered on the foil.

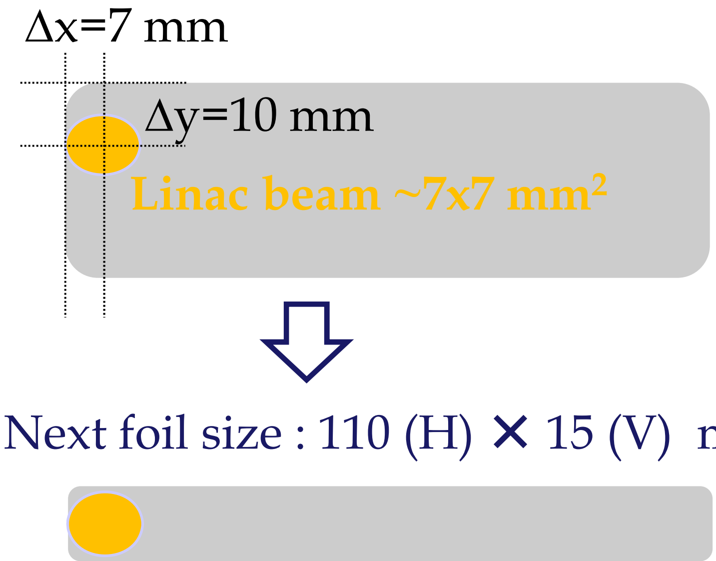
Average number of foil hits (simulated value) ← adjusted by combination of the transverse painting and the foil position in measurement

Reduction of the number of foil hits



For the further foil hit reduction,
we will install a smaller foil
in this summer maintenance period.

- Current foil size : 110 (H) ✕ 40 (V) mm^2



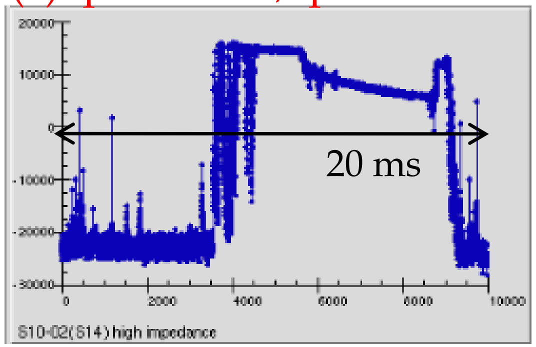
- Next foil size : 110 (H) ✕ 15 (V) mm^2

If using the small foil, we can reduce
the number of the foil hits from 8.8 to 4.7.
Accordingly the residual radiations
should be half of the current level.

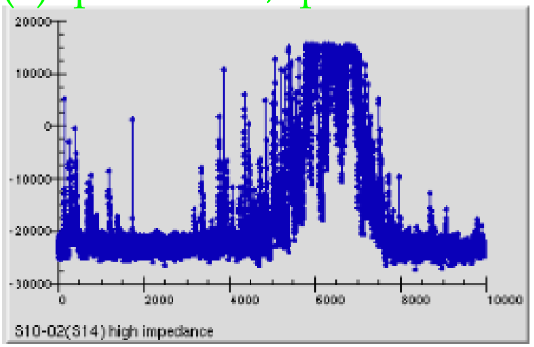
Beam loss at the arc

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

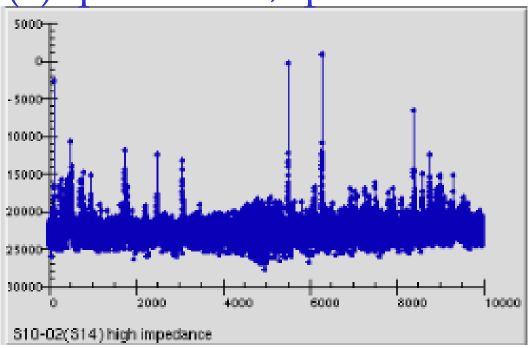
(1) qfm x1.000, qdl x0.990



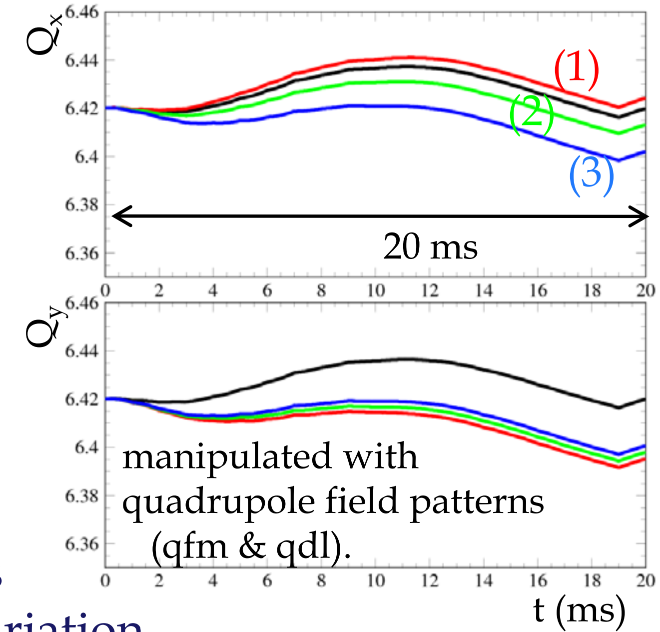
(2) qfm x0.990, qdl x0.990



(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 is now performed at injection with DC power supplies. So, the chromaticity gradually recovers as accelerated.

- We will introduce the AC power supplies for chromatic correction sextupoles in this summer maintenance period and try to minimize this beam loss by optimizing the chromatic correction and the tune variation during the acceleration process.

High power beam demonstration

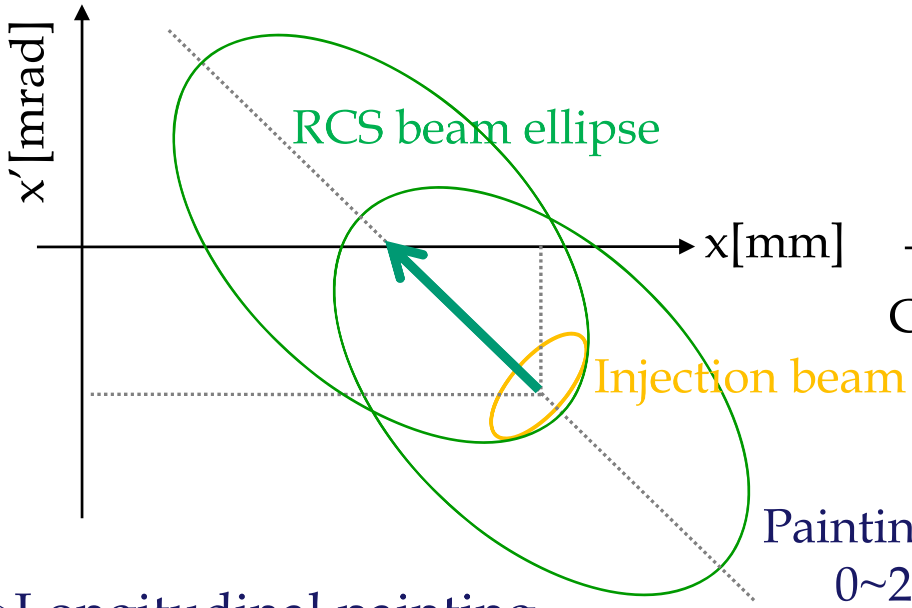
- We performed a systematic investigation with different intensities (up to 300 kW) and various painting parameters.
- We tried to minimize an intensity loss by optimizing the operation parameter including the painting injection.

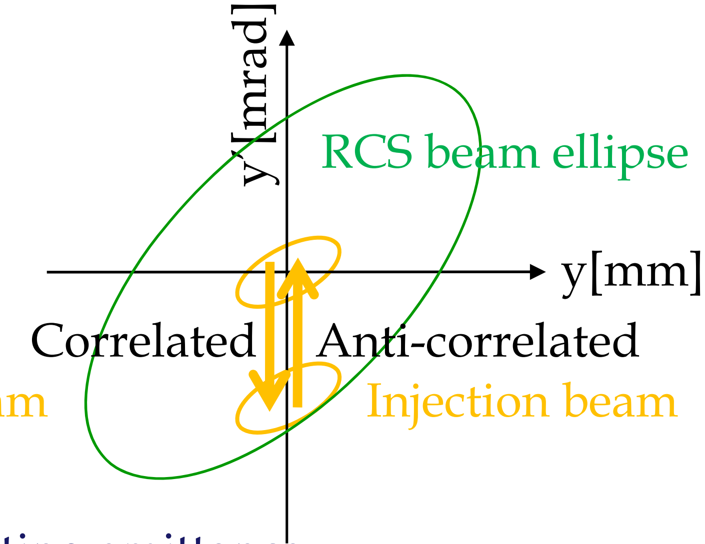
Data ID	I_{peak} (mA)	L_{macro} (ms)	Chop (%)	N_{bunch}	N_{part}	Intensity (kW)	ϵ_{tp} (π mm mrad)	V_{2nd} (%)	$\Delta\phi$ (deg)	Δp (%)
(1)	15	0.1	56	2	5.0×10^{12}	60	-	-	-	-
(2)	15	0.2	56	2	1.0×10^{13}	120	-	-	-	-
(3)	15	0.3	56	2	1.5×10^{13}	180	-	-	-	-
(4)	15	0.4	56	2	2.0×10^{13}	240	-	-	-	-
(5)	15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

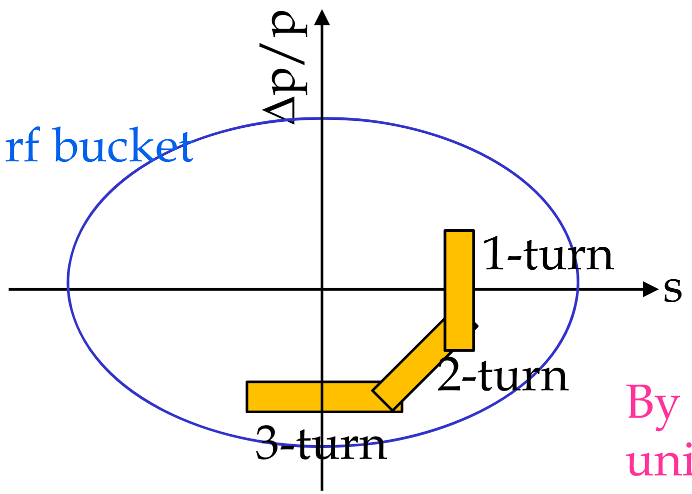
- Transverse painting





Painting emittance;
0~216 π mm mrad

- Longitudinal painting



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

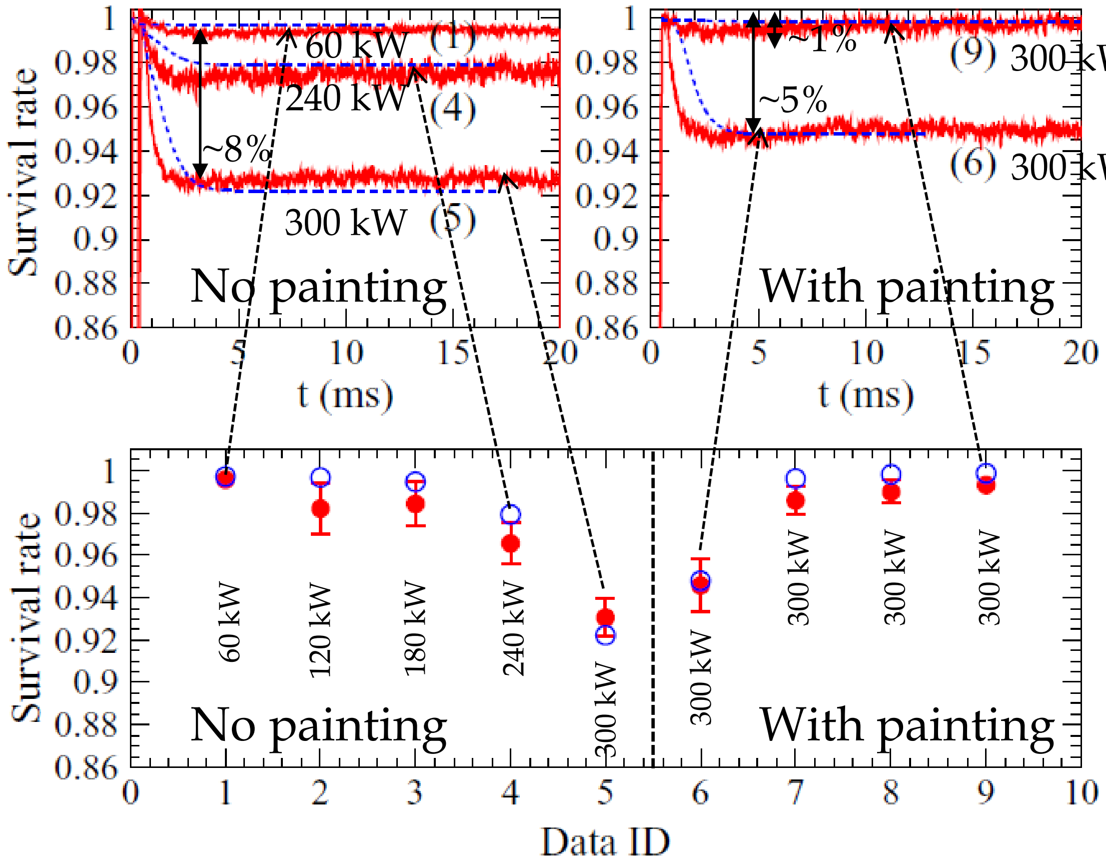
- Superposition of 2nd harmonic rf voltage;
80% of the amplitude of the fundamental one

- 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



(9) 300 kW with transverse & longitudinal painting
(V_{2nd}; 80%/Δϕ; -80 deg/Δp; -0.2%)

(6) 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.

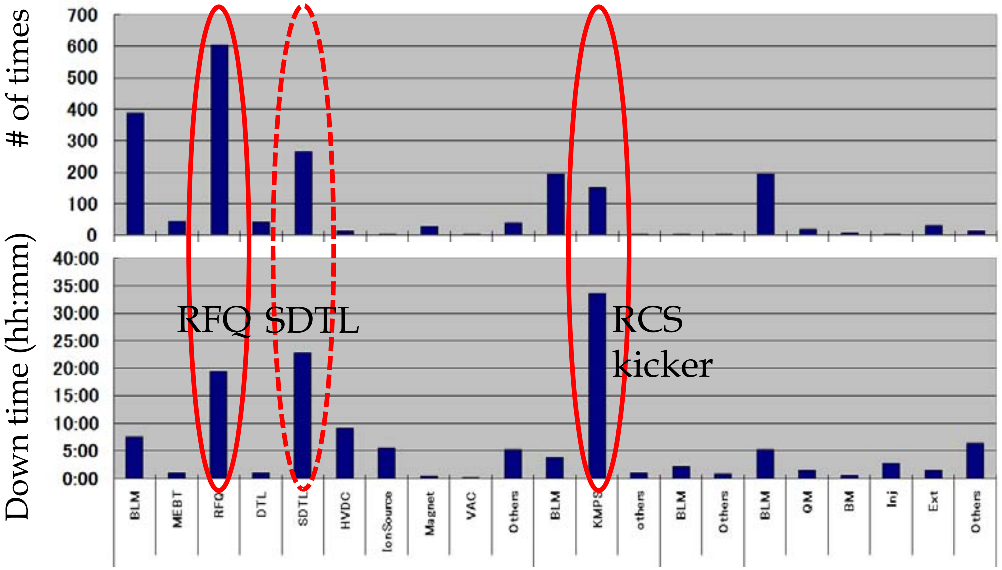
In this case most of the remaining particle loss was well localized on the collimator.

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

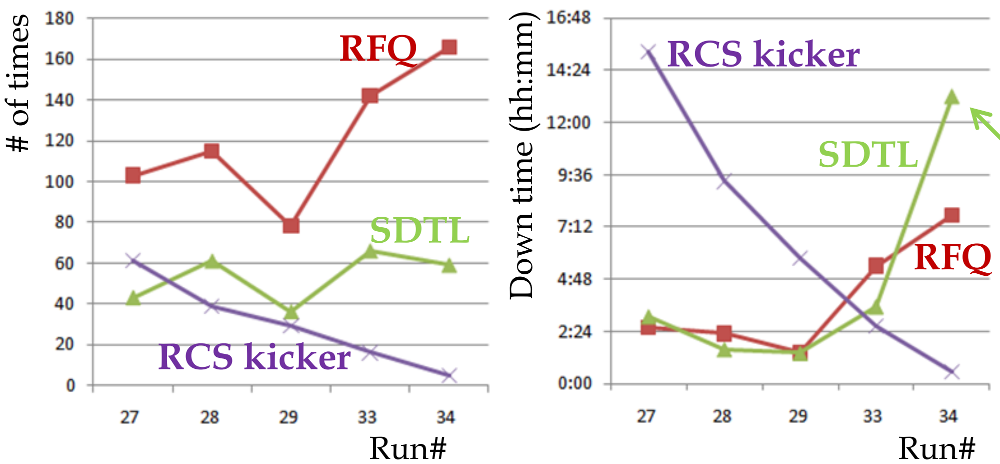
…..We will try to minimize such a unlocalized beam loss by using a small foil and by introducing AC power supplies for chromatic correction sextupoles.

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.

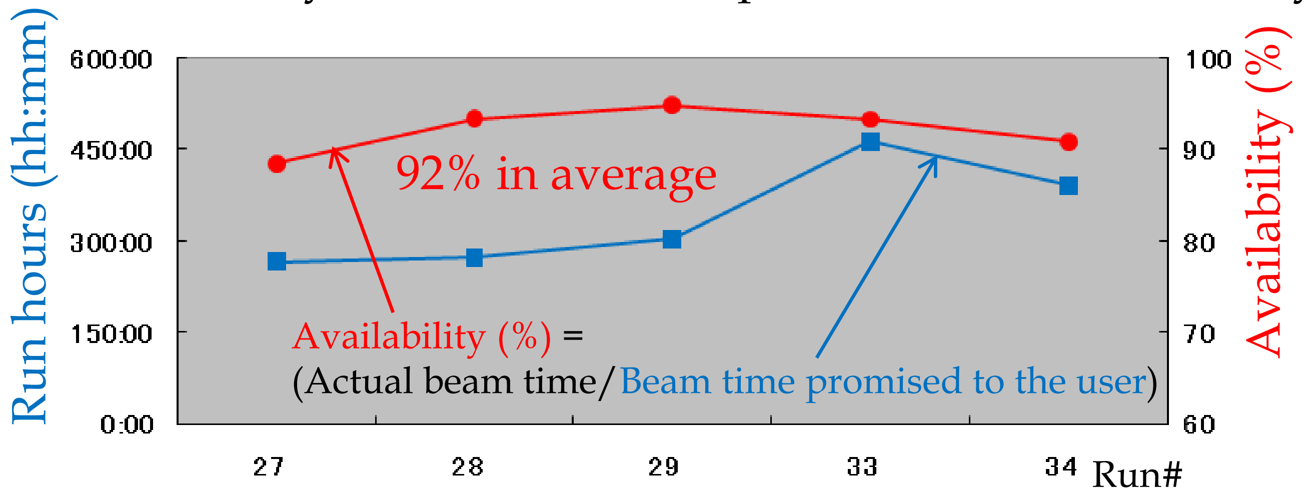
- ➢ Miss-fire, self-breakdown of RCS kickers
  - The kicker pulse is usually restarted manually by an operator typically spending 10~15 min.
  - The trip rate is now significantly reduced by optimizing the reservoir voltage of thyratrons used for the power supply.

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

Availability for the MLF user operation in the last 5 run cycles

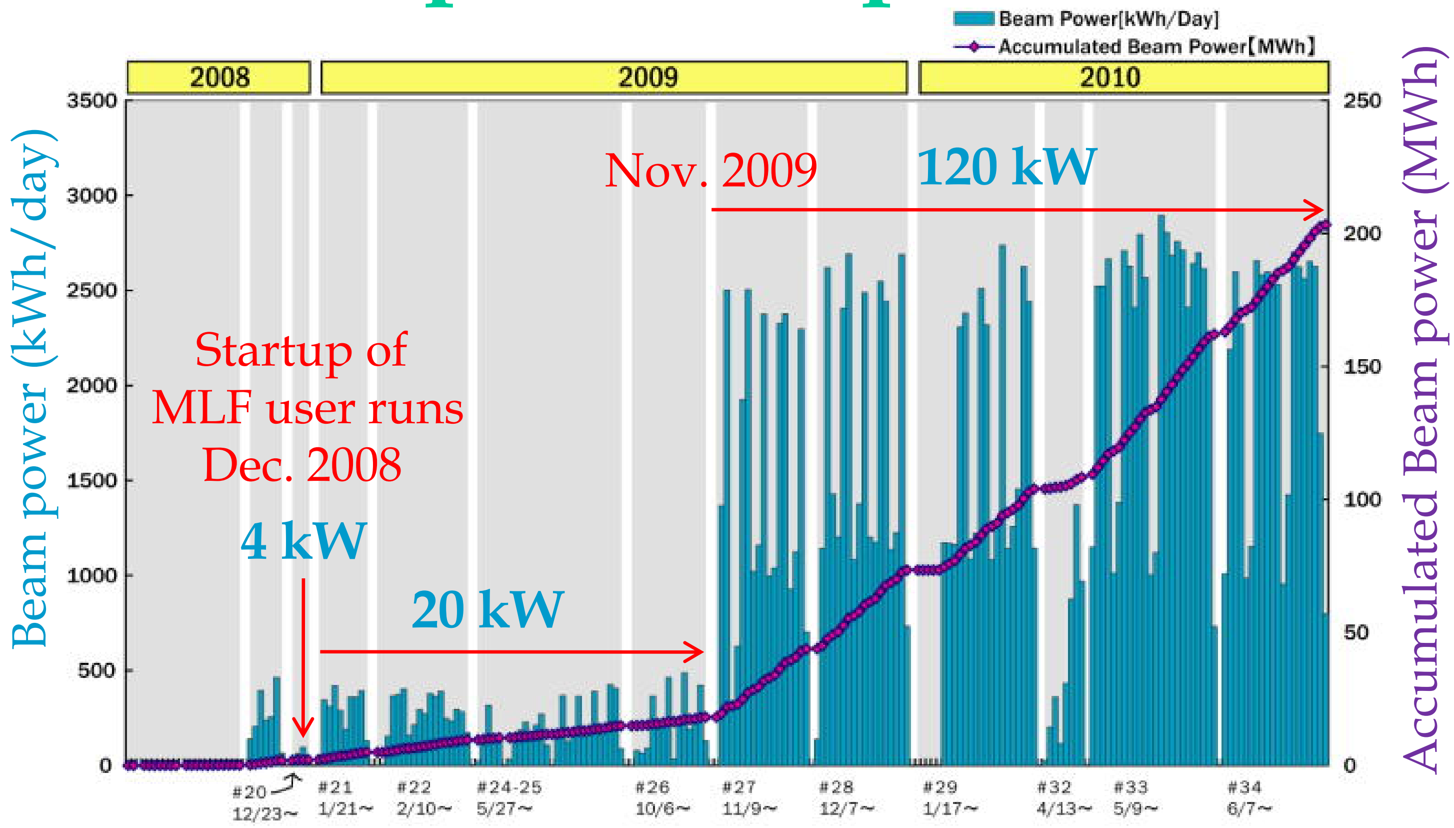


Summary

- 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 ….

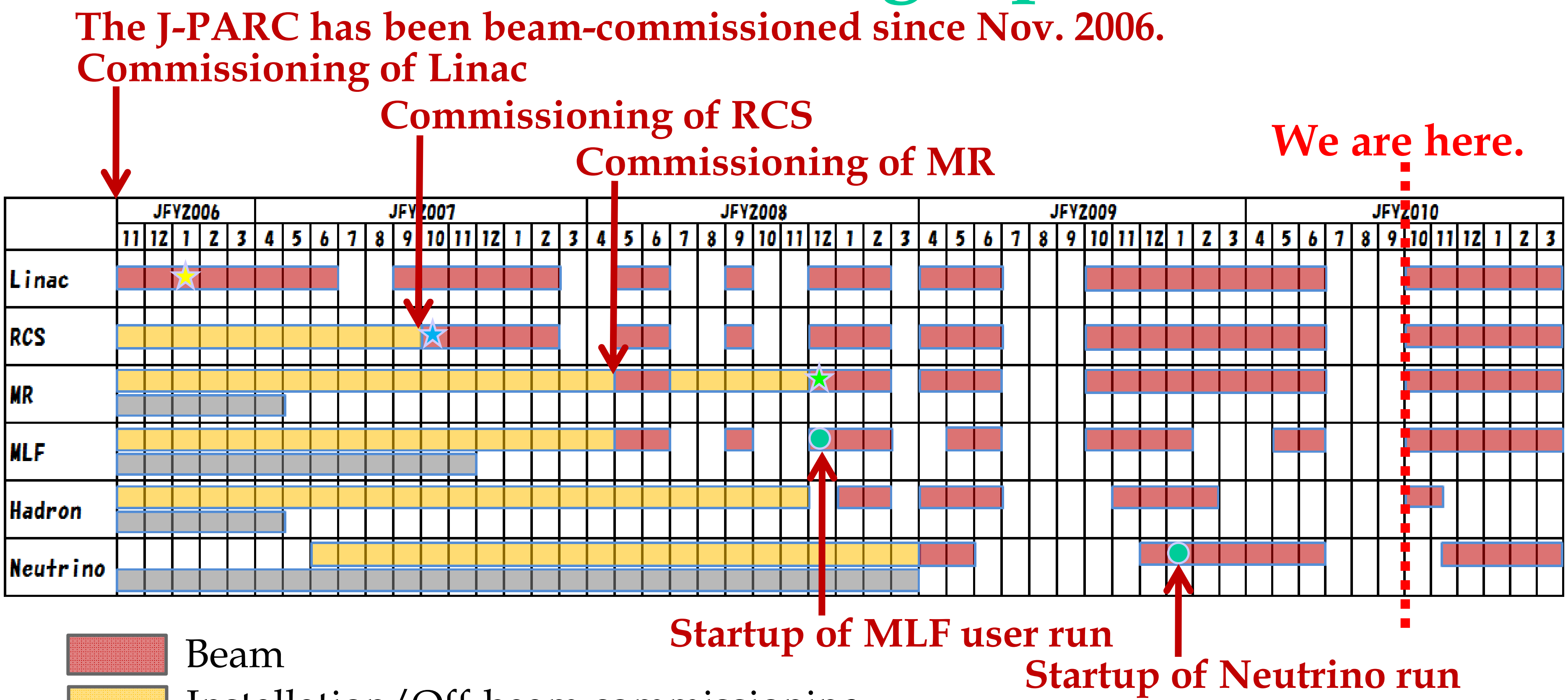
  we plan to gradually increase the output beam power,
  - 160 kW in December 2010
  - 200 kW in January 2011 . . . and then 300 kW.

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.

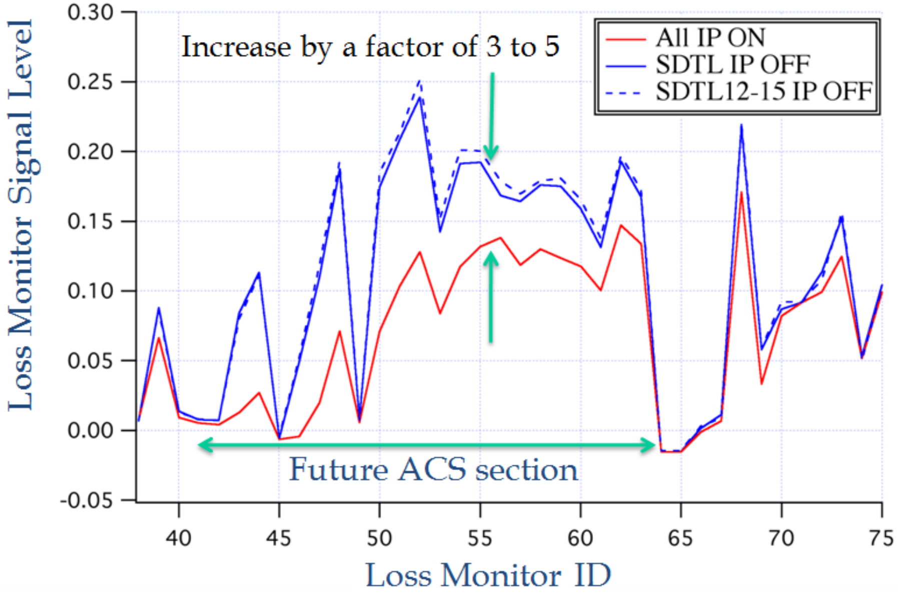
Timeline of the beam commissioning, operations

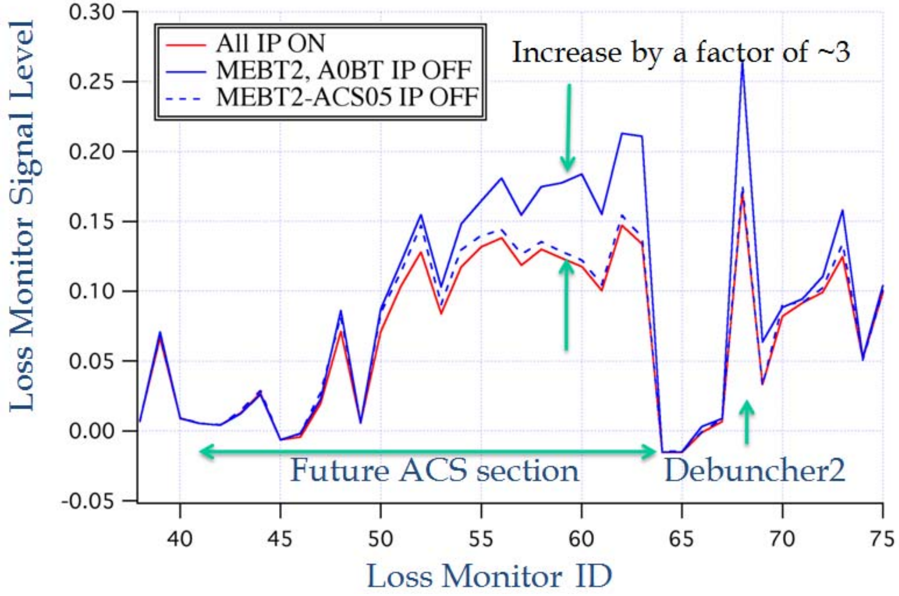


- Beam
- Installation/Off-beam commissioning
- Building construction
- ★ Accomplished 181 MeV acceleration in Linac
- ★ Accomplished 3 GeV acceleration in RCS
- ★ Accomplished 30 GeV acceleration in MR
- ● Startup of the user operations

Beam loss in the future ACS section

We measured the beam loss with higher gas pressure by turning off the ion pumps to find if it is cause by H^0 or H^+ generated by gas stripping.

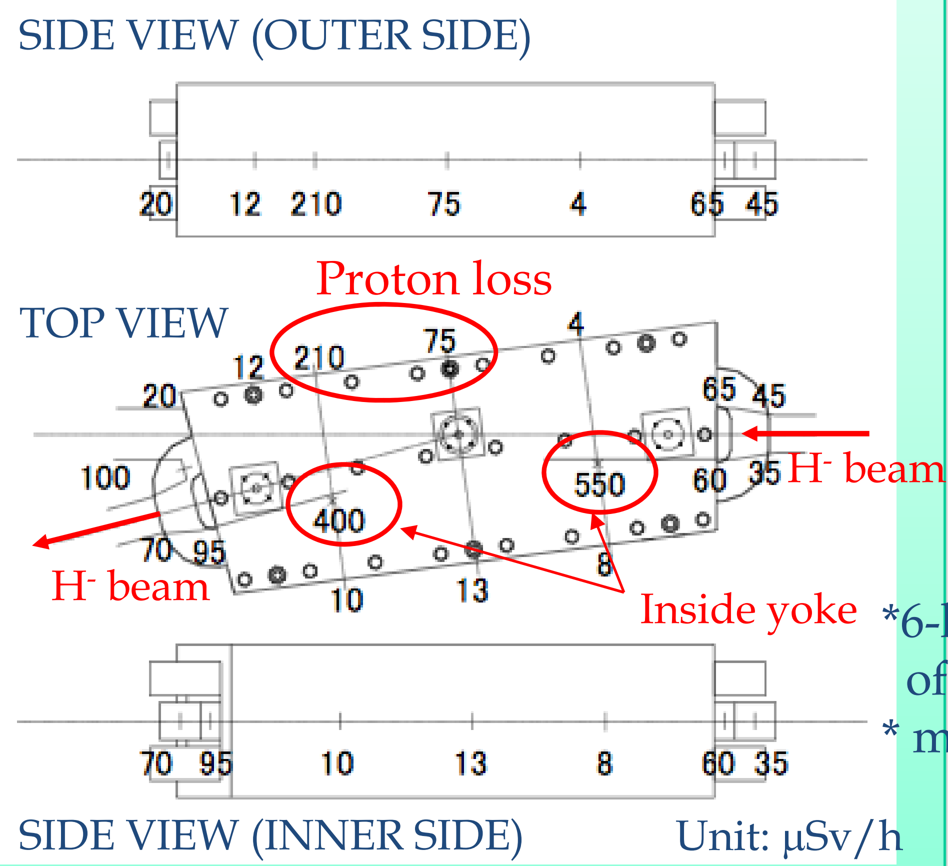




- The beam loss at the future ACS section is significantly increased (by a factor of 3 to 5) by turning off the ion pumps (with increasing the vacuum pressure typically by a factor of 10).
- It suggests that significant portion of the beam loss in this section is caused by H^0 or H^+ generated by gas stripping.
- To reduce the beam loss, we make an improvement of the vacuum system in the SDTL and future ACS section in this summer maintenance period.

Beam loss at the 1st bend

Residual radiation level at 1st bend of 1st arc



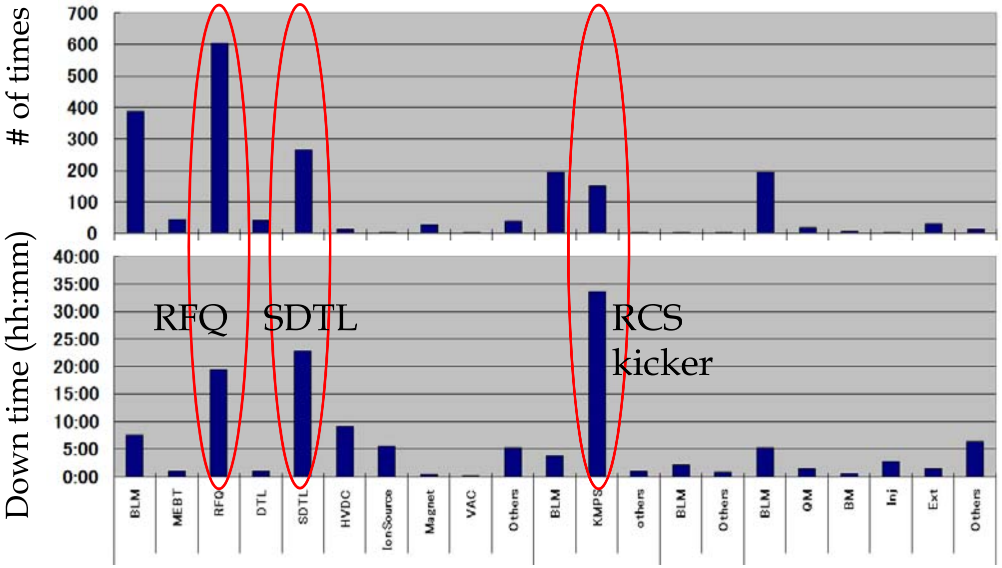
- The residual radiation on the outer side was higher than the inner side.
- The loss was mainly from proton components accelerated to around the design energy generated by gas stripping in the LEBT.

*6-hour after shutdown of 4.5 kW operation in Dec. 2008

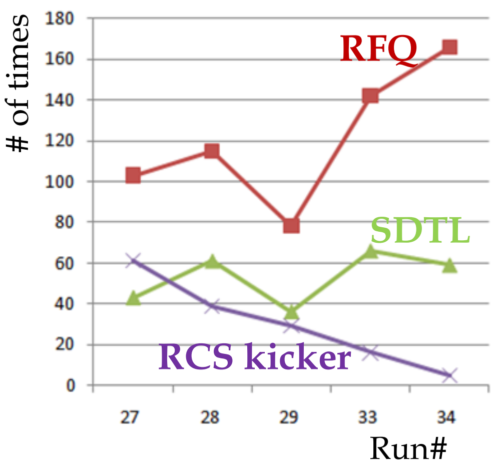
* measured at the surface

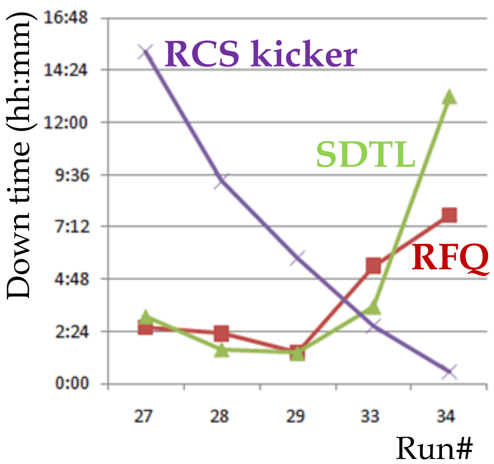
Beam fault statistics for MLF user operation

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



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





- RFQ
  - The RFQ pulse is usually recovered automatically, and the beam is resumed within 1~3 min in this case.
  - If the automatic recovery fails, an operator manually restarts the RFQ typically spending 5~15 min.
  - The failure rate of the automatic recovery is ~20% in average.
- Kickers
  - The kicker pulse is usually restarted manually by an operator, and the beam is typically resumed spending ~10 min.
  - The trip rate is now significantly reduced by optimizing the reservoir voltage of thyratrons.
- Events with a long downtime (>1 hour)
  - Adjustment of the reservoir voltage of a thyratron used for the RCS kicker ; ~2.8 hours in Run#27
  - Breakdown of a thyratron used for the RCS kicker ; ~1.6 hours in Run#28
  - Trouble of the interlock unit in the SDTL; ~2.2 hours in Run#34
  - Breakdown of the coaxial cable in the SDTL; ~7.0 hours in Run#34

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%

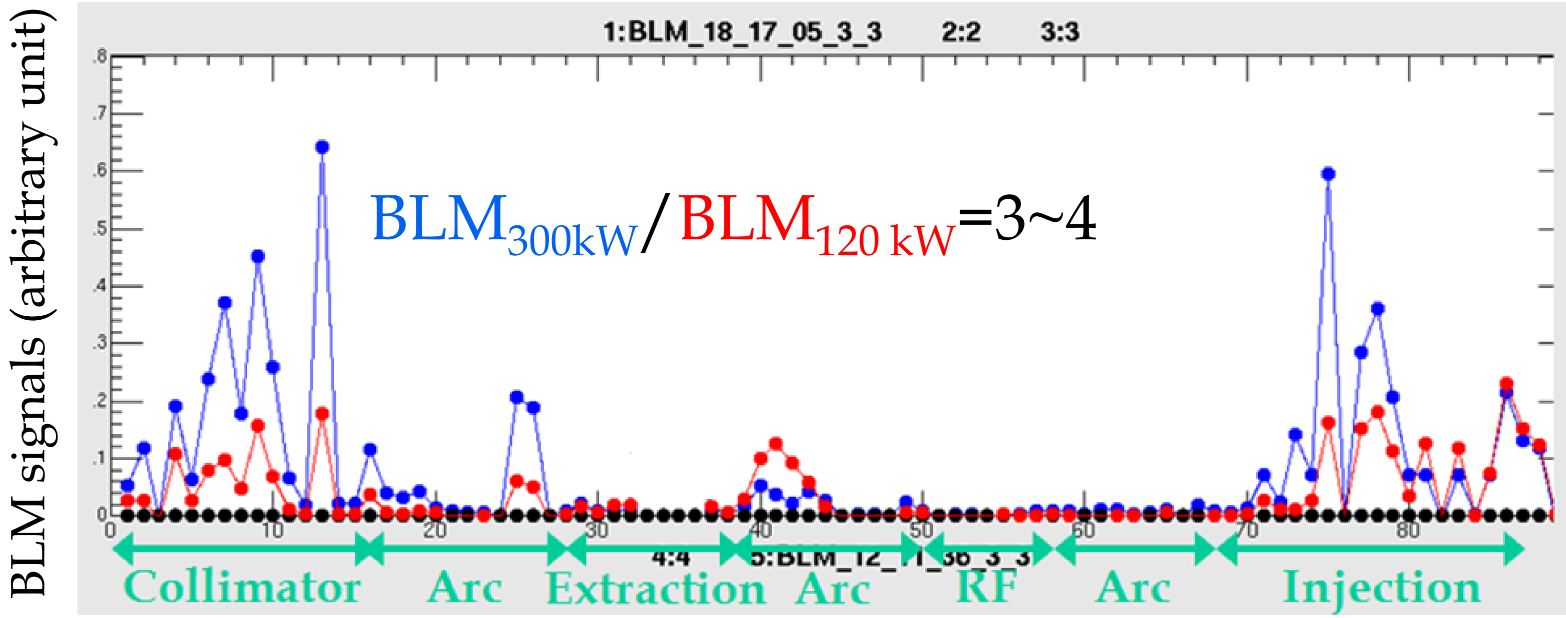
400 MeV injection
50 mA Linac peak current
x 0.56 chopping
x 307 turns (500 μsec)
→4.2E13/bunch
x 2 bunches
x 25 Hz
x 3 GeV
→1 MW
Permissible beam loss rate:
3% (at injection)
→ 4 kW(collimator capacity)

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%

Comparison of BLM signals for 120 kW and 300 kW operations

Beam loss distributions along the ring
observed for 120 kW (red) and 300 kW (blue) operations



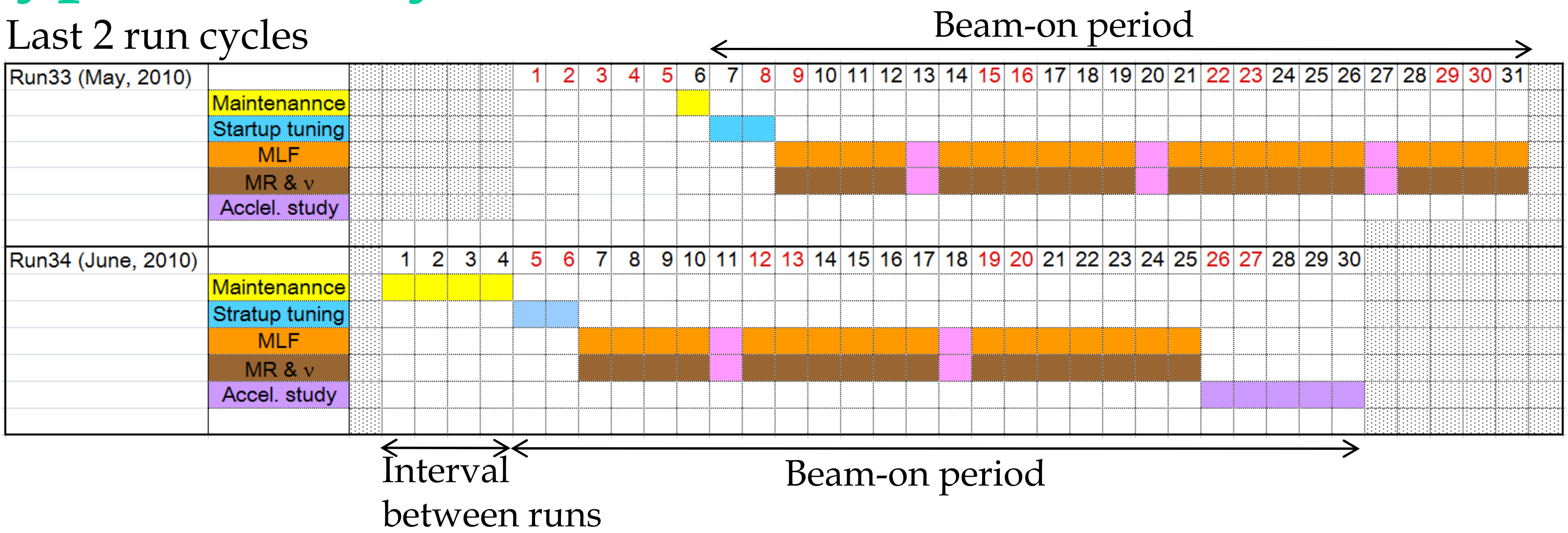
-Beam loss at the arc :
to be minimized by controlling the chromatic correction and tune variation during acceleration by introducing the AC power supply for the sextupoles

-Beam loss in the injection section:
to be half by introducing a small foil.

Try in Qct. 2010.

Typical run cycle

Last 2 run cycles

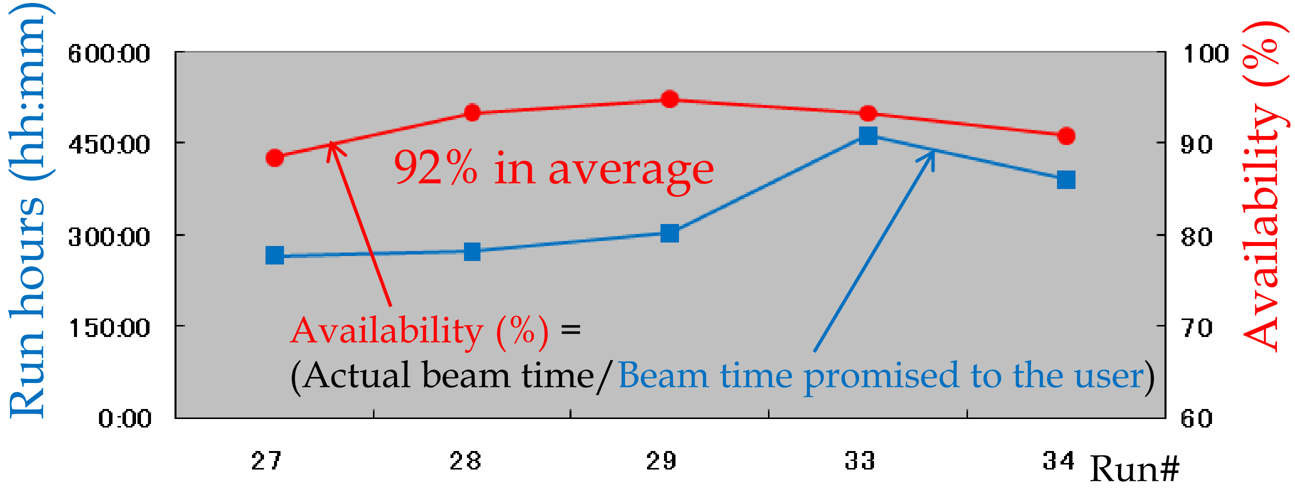


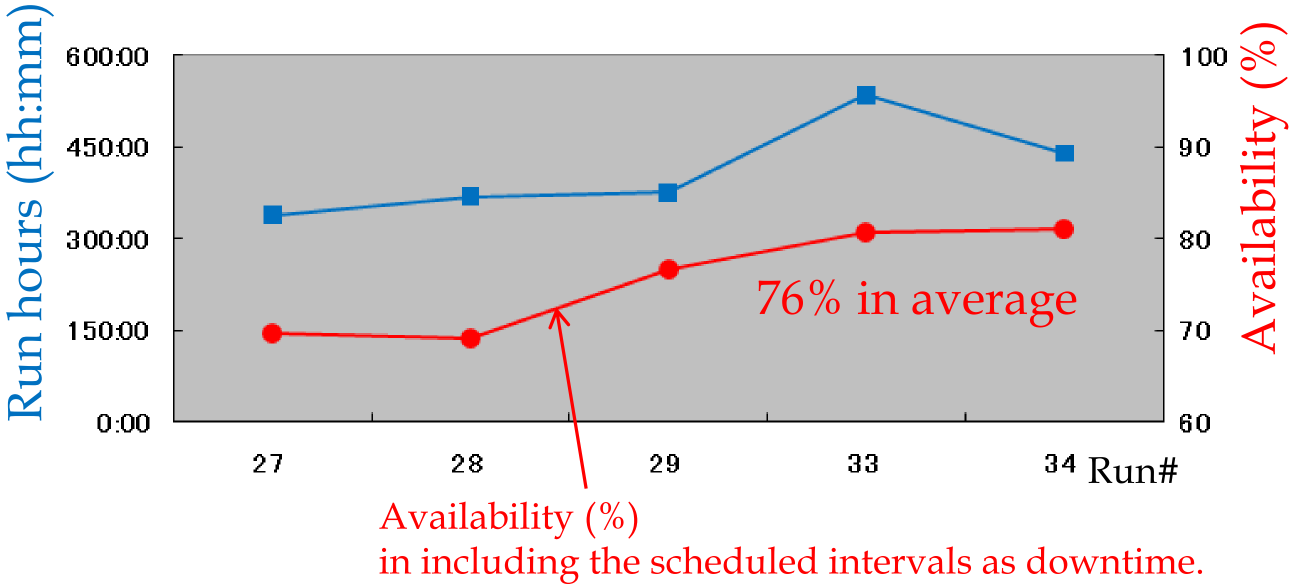
Recent typical run cycle consists of 4-week beam-on time with 4-day interval.

- ･･･Interval between runs mainly used for the iron source maintenance
- ･･･Startup tuning of Linac and RCS to check the reproducibility
- ･･･MLF user operation and beam delivery to MR
- ･･･Scheduled intervals mainly used for RFQ conditioning
- ･･･ Scheduled beam study period

Availability for the MLF user run

Availability for the MLF user operation in the last 5 run cycles





Scheduled intervals secured for RFQ conditioning for each run cycle

Run#27	4 days
Run#28	4 days
Run#29	3 days
Run#33	3 days
Run#34	2 days