HB2010
Sep 27, 2010

High intensity aspects of the J-PARC facility

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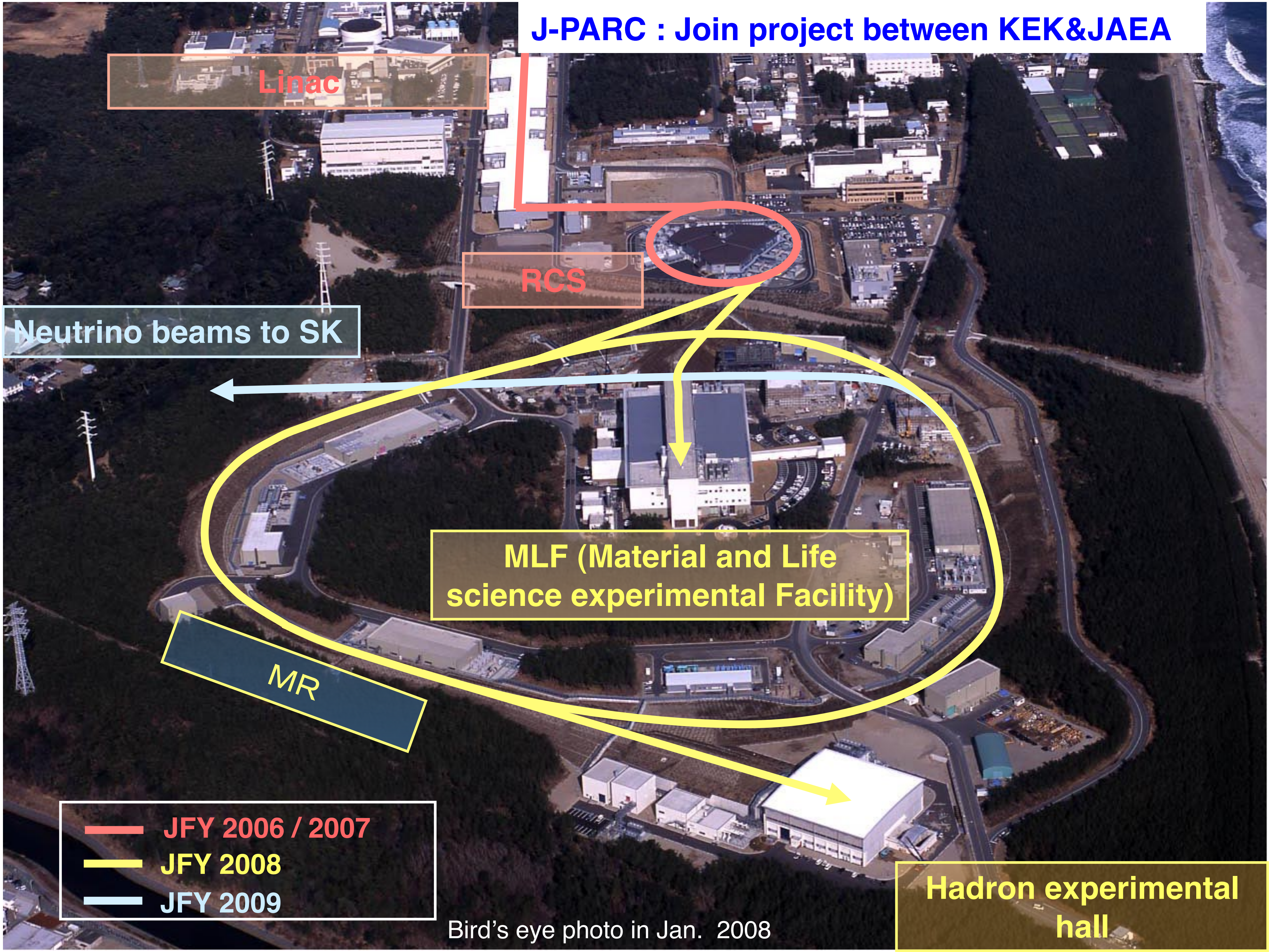
J-PARC center, KEK and JAEA

Contents

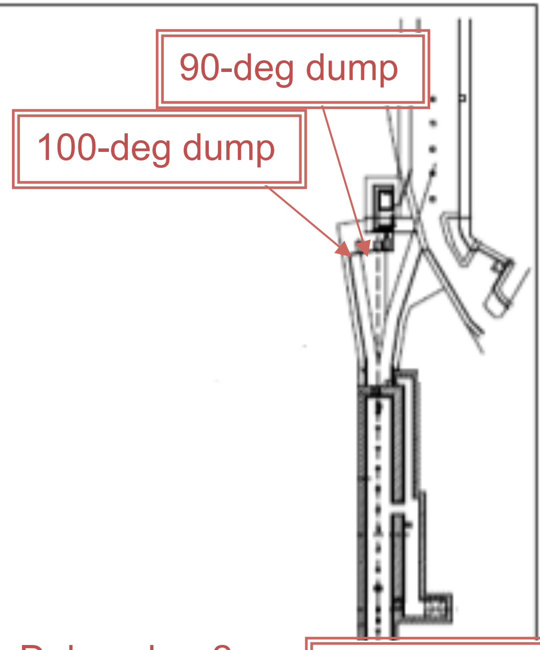
J-PARC : Join project between KEK&JAEA

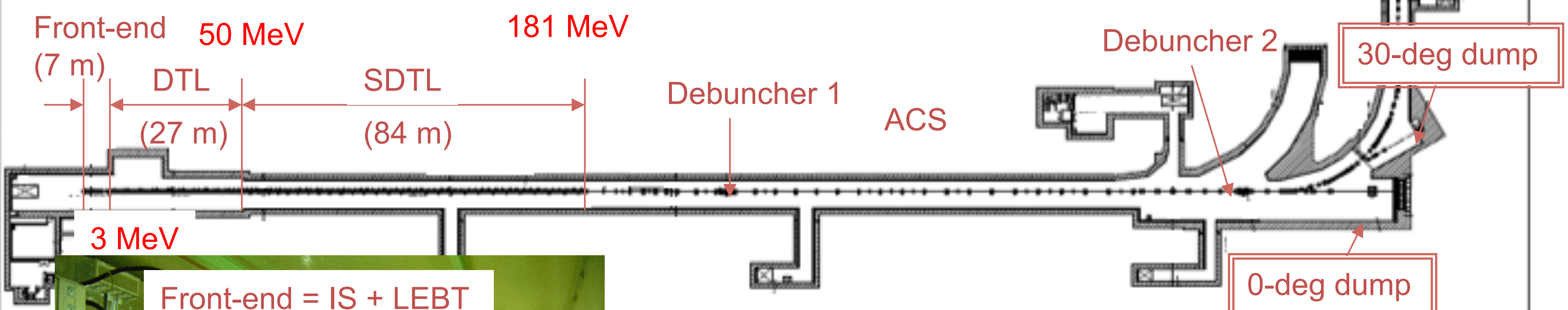


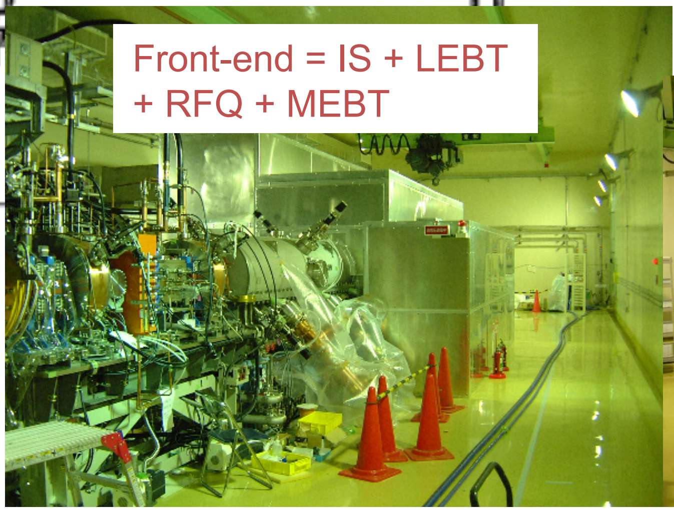
Bird’s eye photo in Jan. 2008

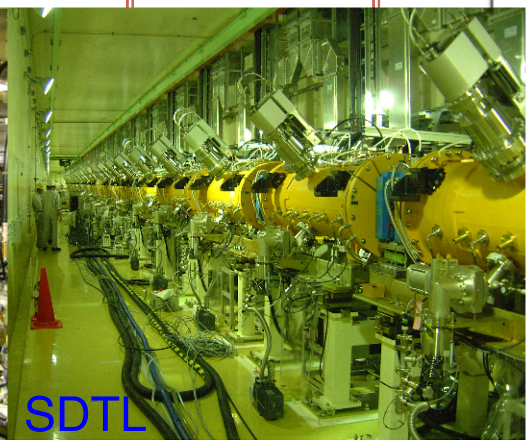
Linac

- **Particle:** H^-
- **Energy:** 181 MeV at present
  400 MeV by installing ACS in 2012
  (Construction of ACS has been started.)
- **Peak current:** 30 mA at 181 MeV
  50 mA at 400 MeV in the future
- **Repetition:** 25 Hz
- **Pulse width:** 0.5 msec



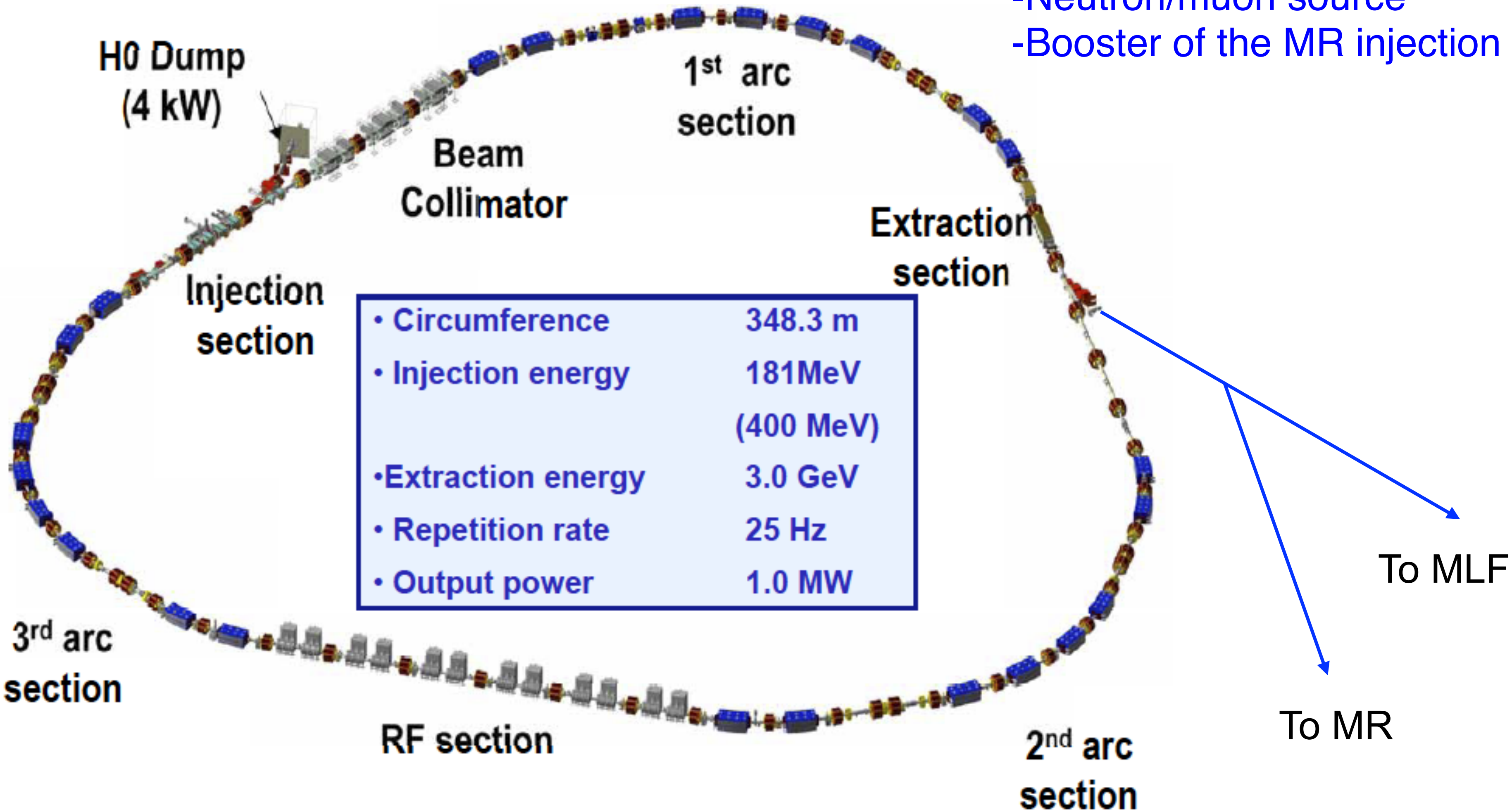






RCS (Rapid Cycling Synchrotron)

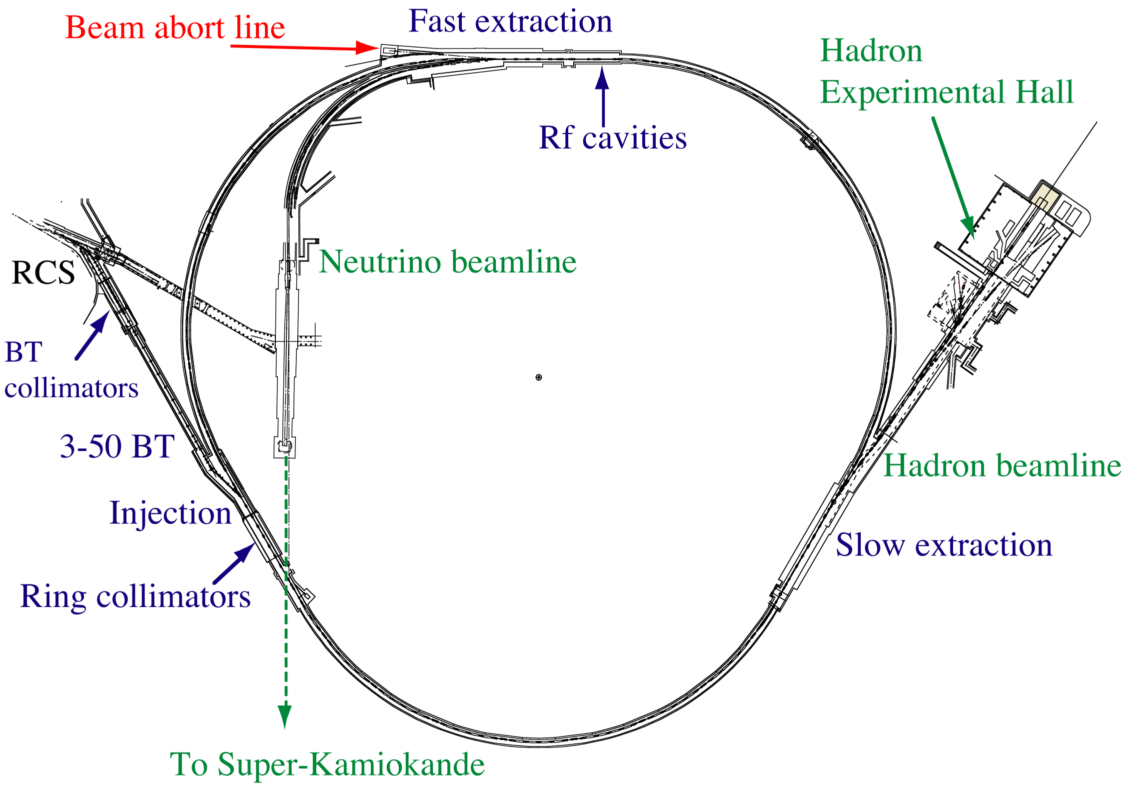
Multi-purpose machine:
- Neutron/muon source
- Booster of the MR injection



• Circumference	348.3 m
• Injection energy	181MeV
	(400 MeV)
•Extraction energy	3.0 GeV
• Repetition rate	25 Hz
• Output power	1.0 MW

Main parameters of MR

Circumference	**1567.5 m**
Repetition rate	**~ 0.3 Hz**
Injection energy	**3 GeV**
Extraction energy	**30 GeV(1st phase)**
	50 GeV (2nd phase)
Superperiodicity	**3**
h	**9**
Number of bunches	**8**
Rf frequency	**1.67 - 1.72 MHz**
Transition γ	**j 31.7 (typical)**
Number of dipoles	**96**
quadrupoles	**216 (11 families)**
sextupoles	**72 (3 families)**
steerings	**186**
Number of cavities	**5**



Three dispersion free straight sections of 116-m long:
- **Injection and collimator systems**
- **Slow extraction (SX)**
  to Hadron experimental Hall
- **MA loaded rf cavities and Fast extraction(FX) (beam is extracted inside/outside of the ring)**
  outside: Beam abort line
  inside: Neutrino beamline (intense ν beam is send to SK)

Status of high intensity operation of the Linac / RCS

Performance recovery of LINAC-RFQ

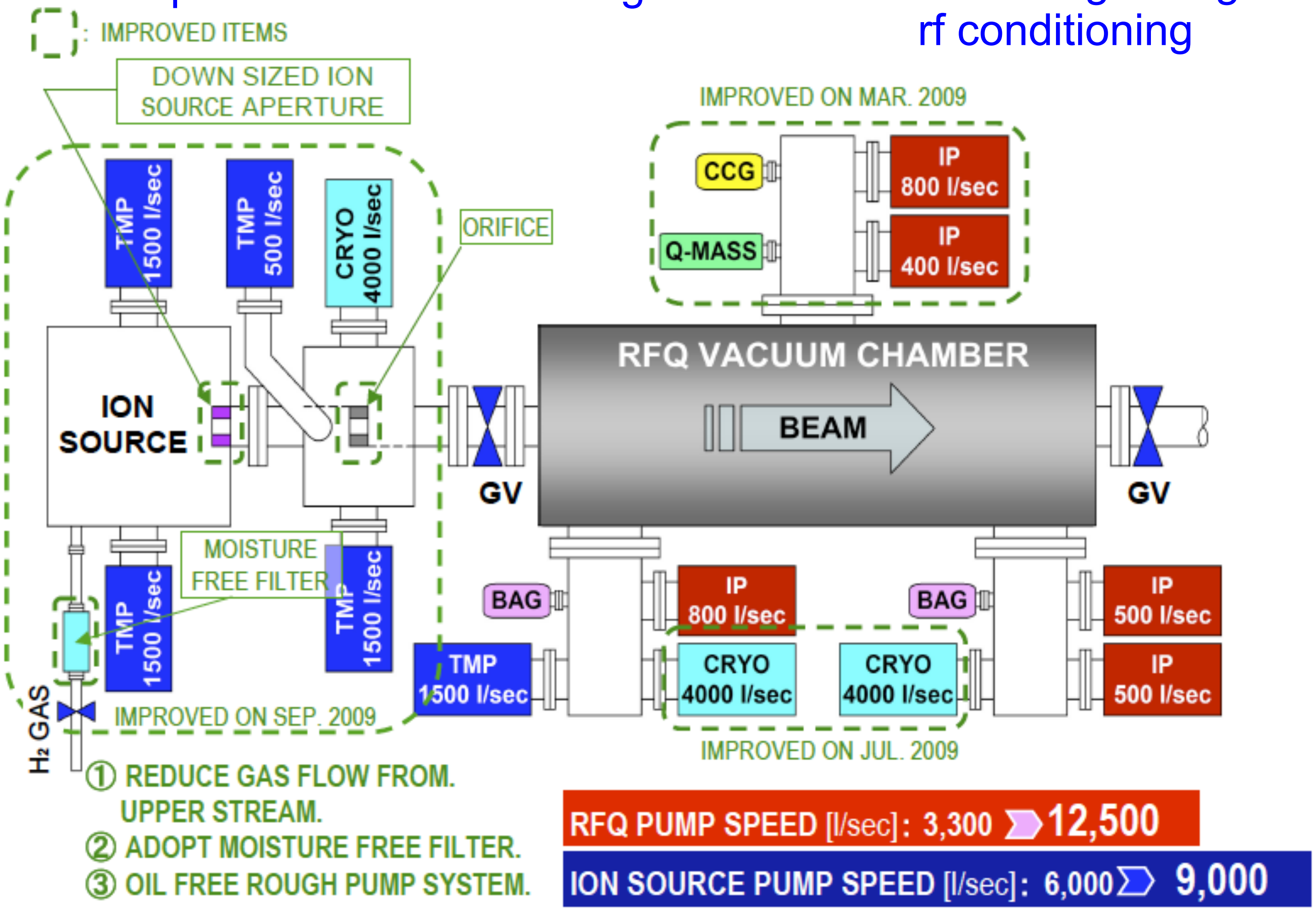
Since the autumn of 2008, the most urgent issue of the linac was discharge in the RFQ. The RCS beam power for users was limited at 20 kW due to the RFQ problem.

In the 2009 summer shutdown,

- improved vacuum system
- performed in-situ baking

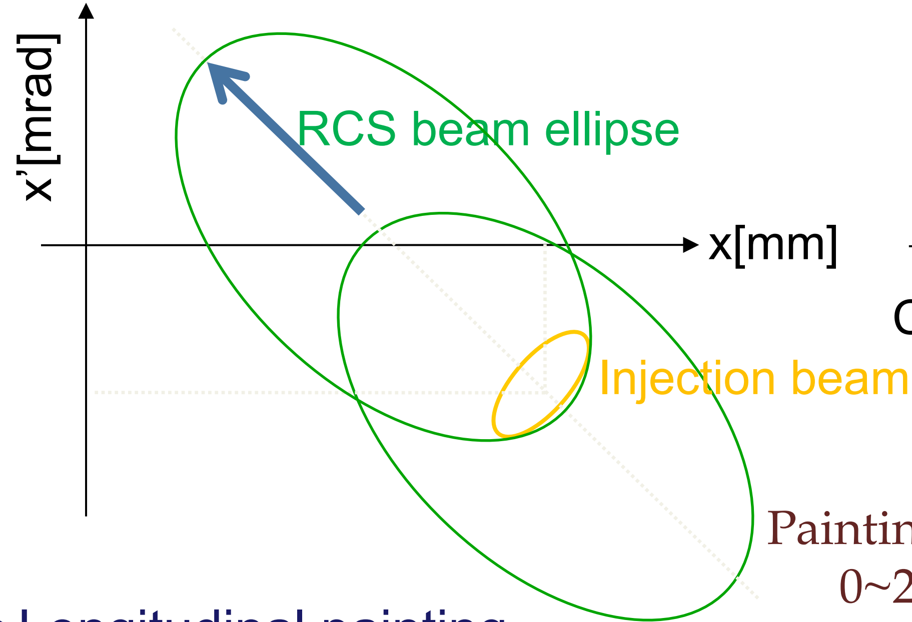
→

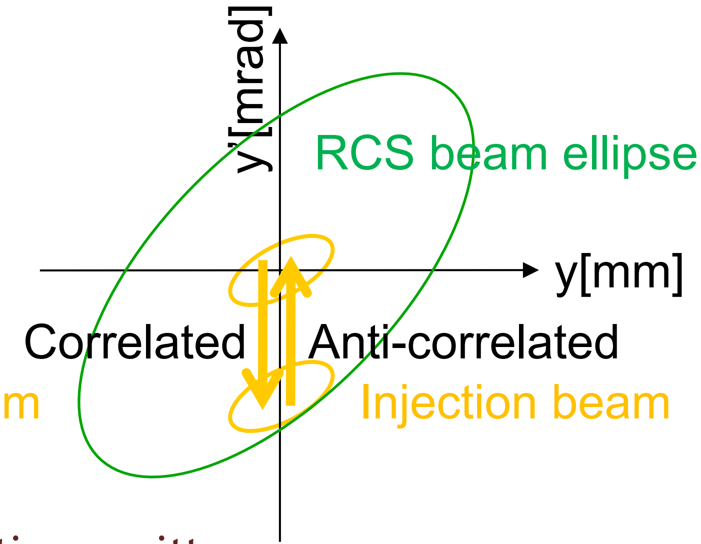
- Base pressure is ~several x 10^{-7} Pa
- Hydro-carbon components in residual gases gradually reduce during rf conditioning



Painting injection of RCS

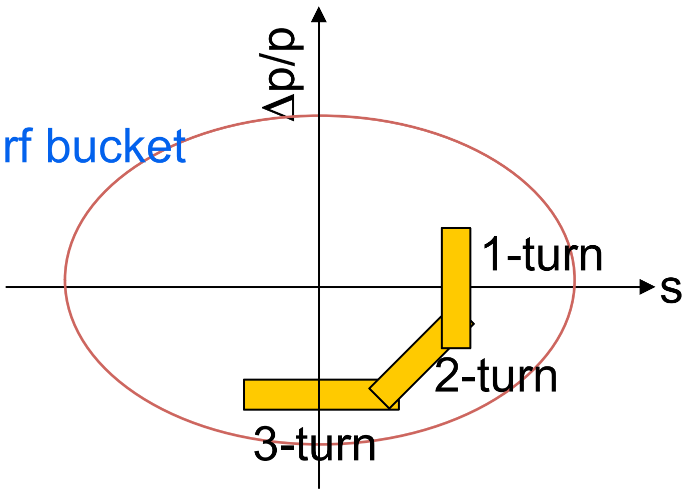
➢Transverse painting





Painting emittance;
0~216 π mm mrad

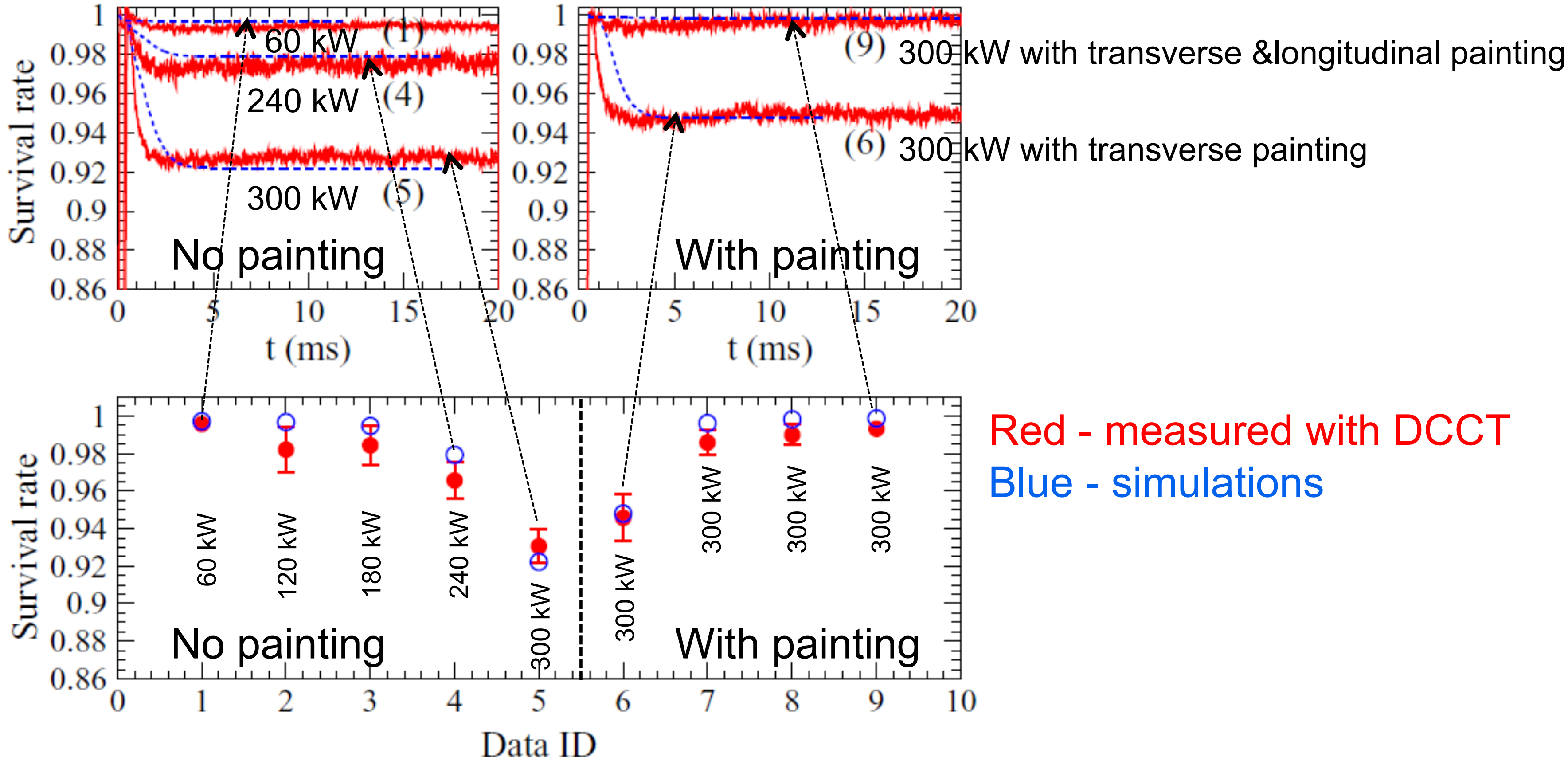
➢Longitudinal painting



-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

H. Hotchi

Beam loss reduction by the painting



Intensity loss observed for 300 kW-equivalent intensity beam;

~7% with no painting – (5)

~5% with the transverse painting - (6)

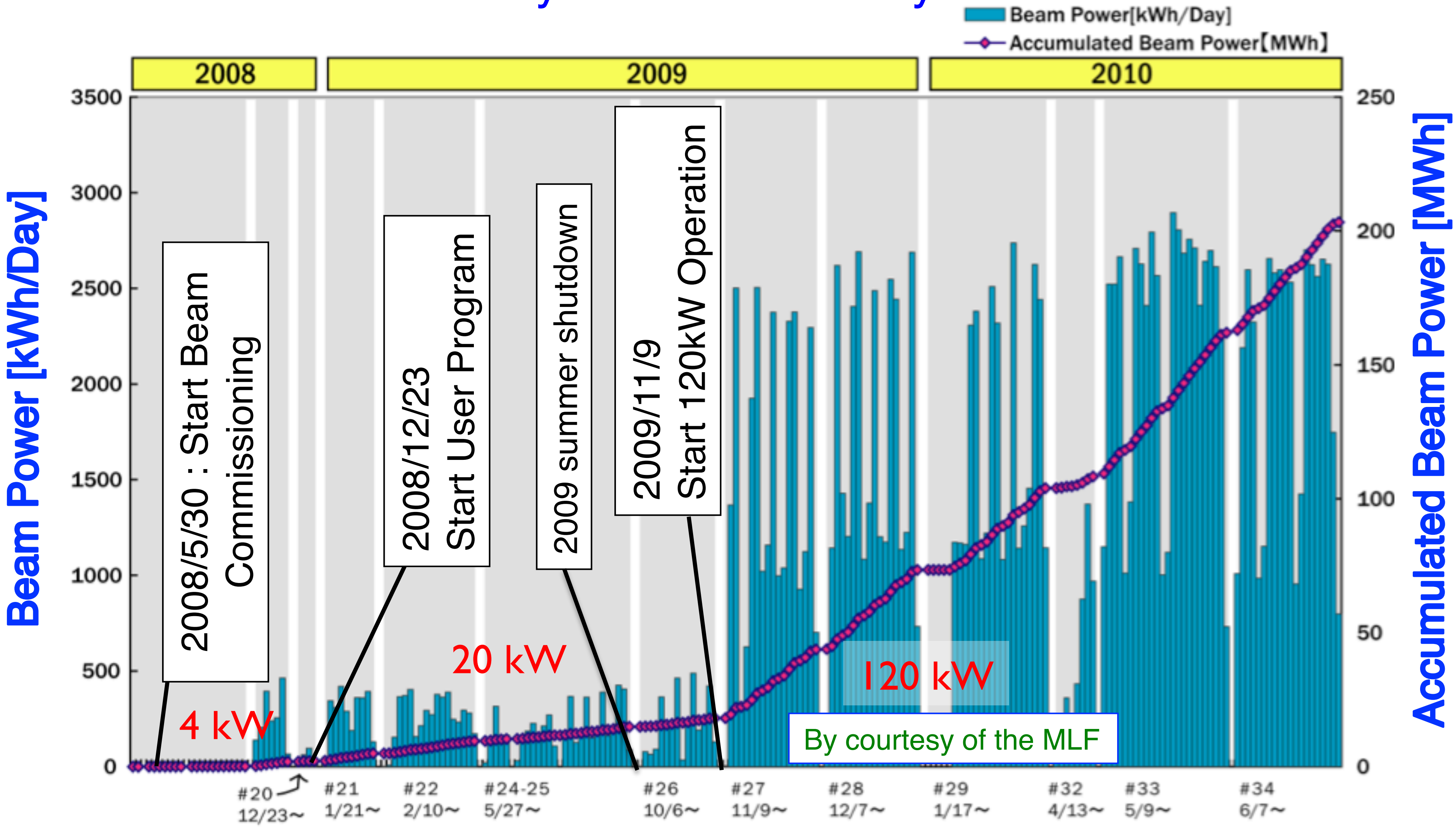
(ε_{tp}; 100π mm mrad, correlated)

~1% by adding the longitudinal painting – (9)

(V_{2nd}; 80%/$\Delta\phi$; -80 deg/Δp; -0.2%)

H. Hotchi

History of beam delivery to MLF

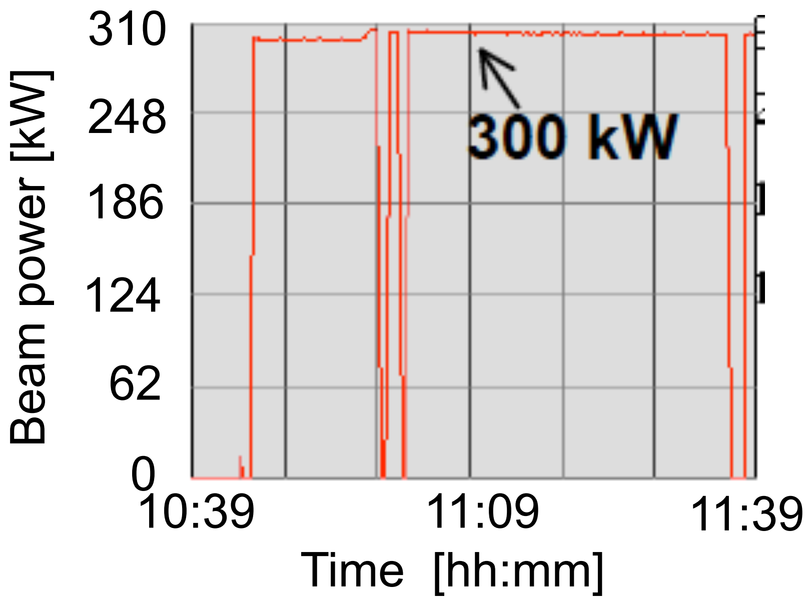


After the recovery of Linac-RFQ, high power operation of the RCS has became possible and 120 kW operation has started for the MLF users.

Neutron beamline : 12 beamlines are now under commissioning and open for users.

Muon beamline: The highest intensity pulsed muon source in the world with the 120 kW beam.

300 kW operation : achievement and issues



On Dec.10, 300 kW-1hours beam delivery from the RCS to the MLF was successfully demonstrated.

The laslett tune shift at the injection energy of 181 MeV for the 300 kW operation is equivalent to the value at the injection energy of 400 MeV for 1 MW operation, design goal of the RCS.

$$\Delta\nu = -\frac{r_p n_t}{2\pi\beta^2\gamma^3\varepsilon B_f}$$

~ -0.15

($B_f=0.4$, $\varepsilon=216\pi$ mm mrad)

Design goal:
400 MeV
50 mA Linac urrent:
4.2E13 ppb
→1 MW

At present:
181 MeV
15 mA Linac current
1.3E13 ppb
→0.3 MW

The 300 kW demonstration showed the beam loss issues should be solved before starting users operation. Following improvements are in progress :

(1) Installation of the small foil (40 mm-> 15 mm in vertical) to reduce the number of foil hits during painting injection

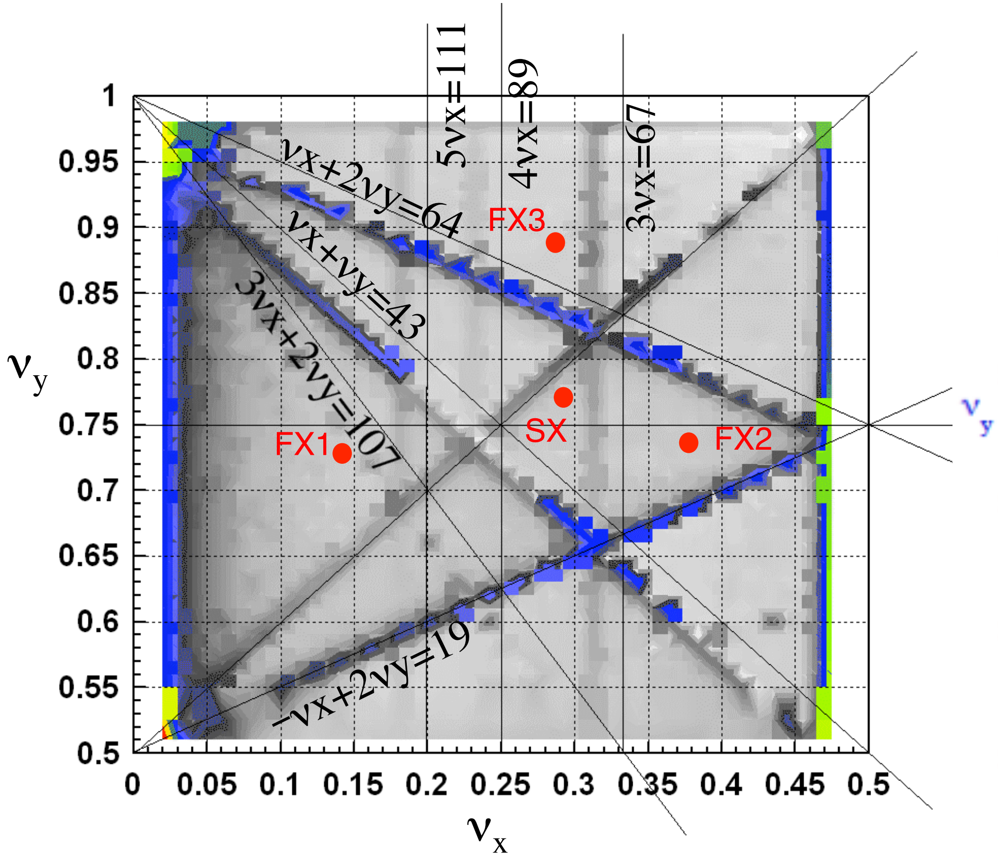
(2) Installation of AC power supplies for sextupoles

Before 2010 summer shutdown, the sextupoles were driven by DC power supplies and chromaticity is corrected only at the injection energy. AC power supplies are necessary to reduce beam loss in the acceleration.

Status of the Main Ring

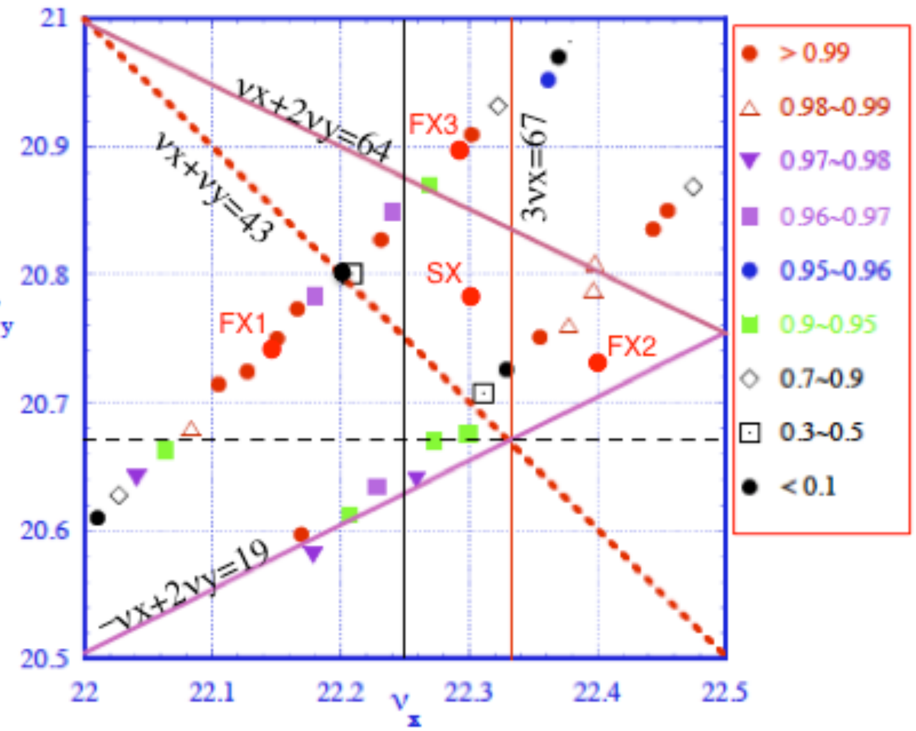
Operating points of the FX and SX

Simulation result with various ring imperfections, field errors, high field components, fringe fields, alignment errors. (A. Molodozhentsev)



Measured results with 3 GeV DC beam of 4e11 ppb ×1 bunch (1% intensity)

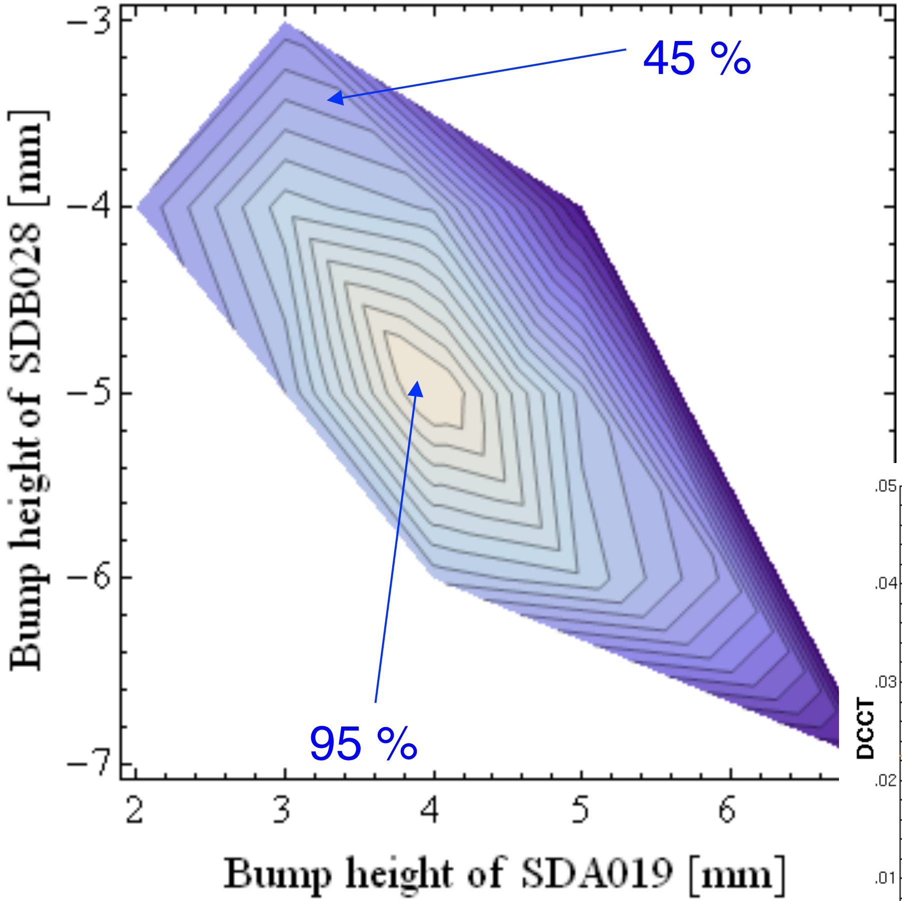
Beam survival after 1.9 sec storage



On the linear coupling resonance, we have large beam loss.
Correction of the linear coupling resonance is important for high power operation in the MR.

Correction of linear coupling resonance

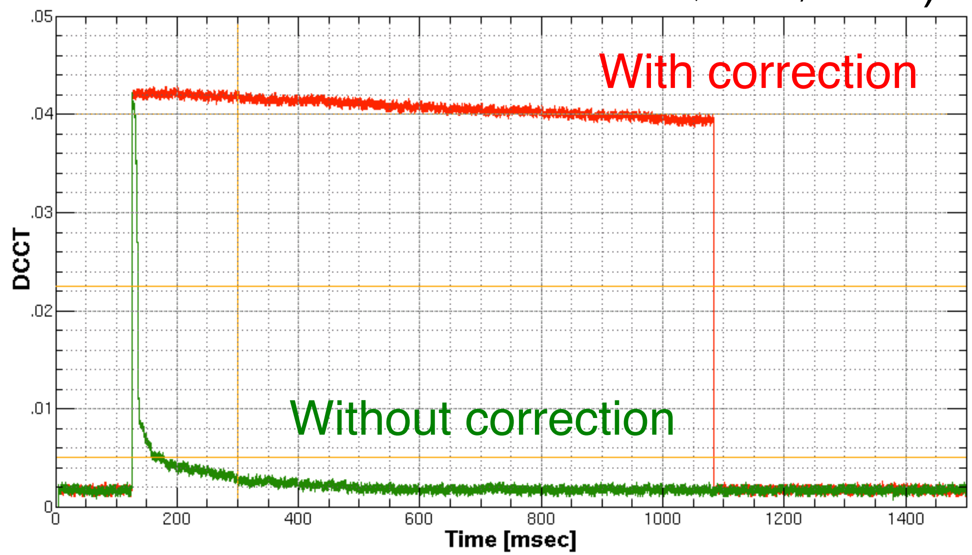
Linear coupling resonance correction is performed using vertical local bumps in two SDs,SDA019 and SDB028.



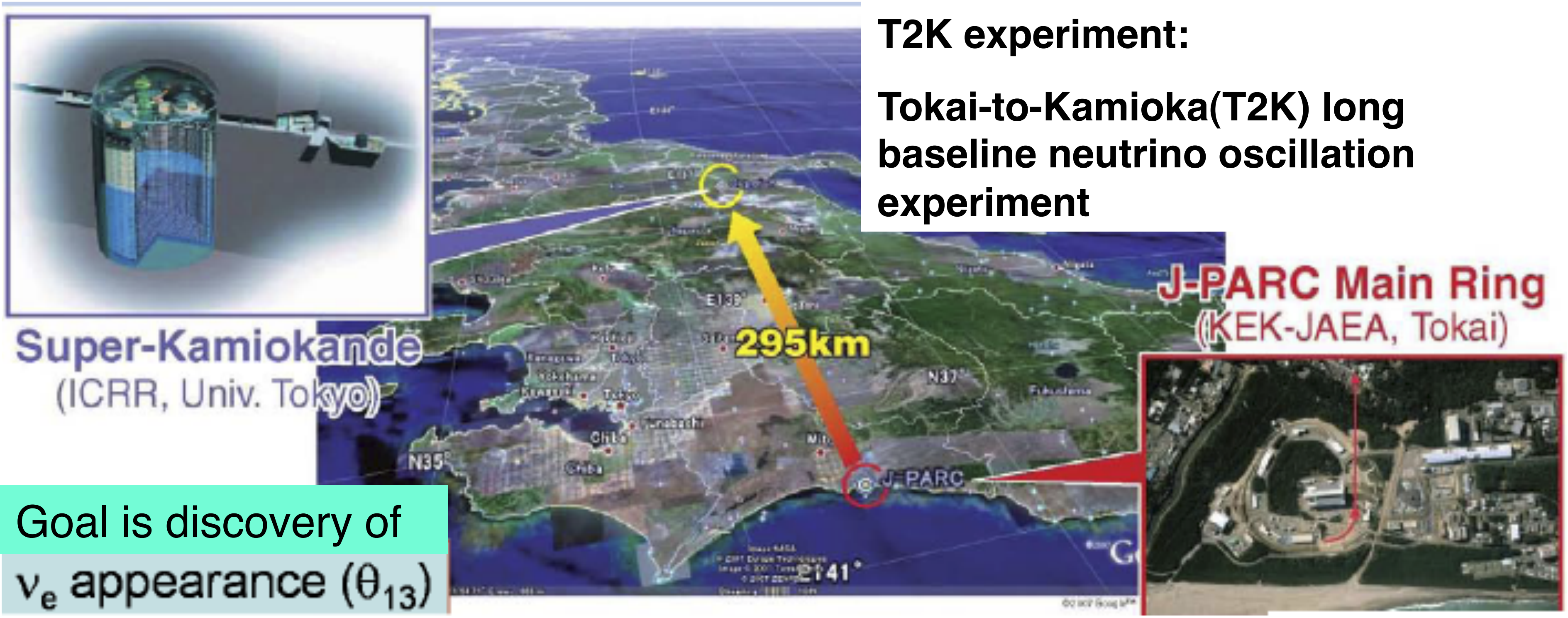
Measured beam loss on the linear coupling resonance for various pairs of bump heights.

A pair of +4 mm in SDA019 and -5 mm in SDB028 is effective for the correction.

(22.2, 20.8)



High power operation with the fast extraction



T2K experiment:

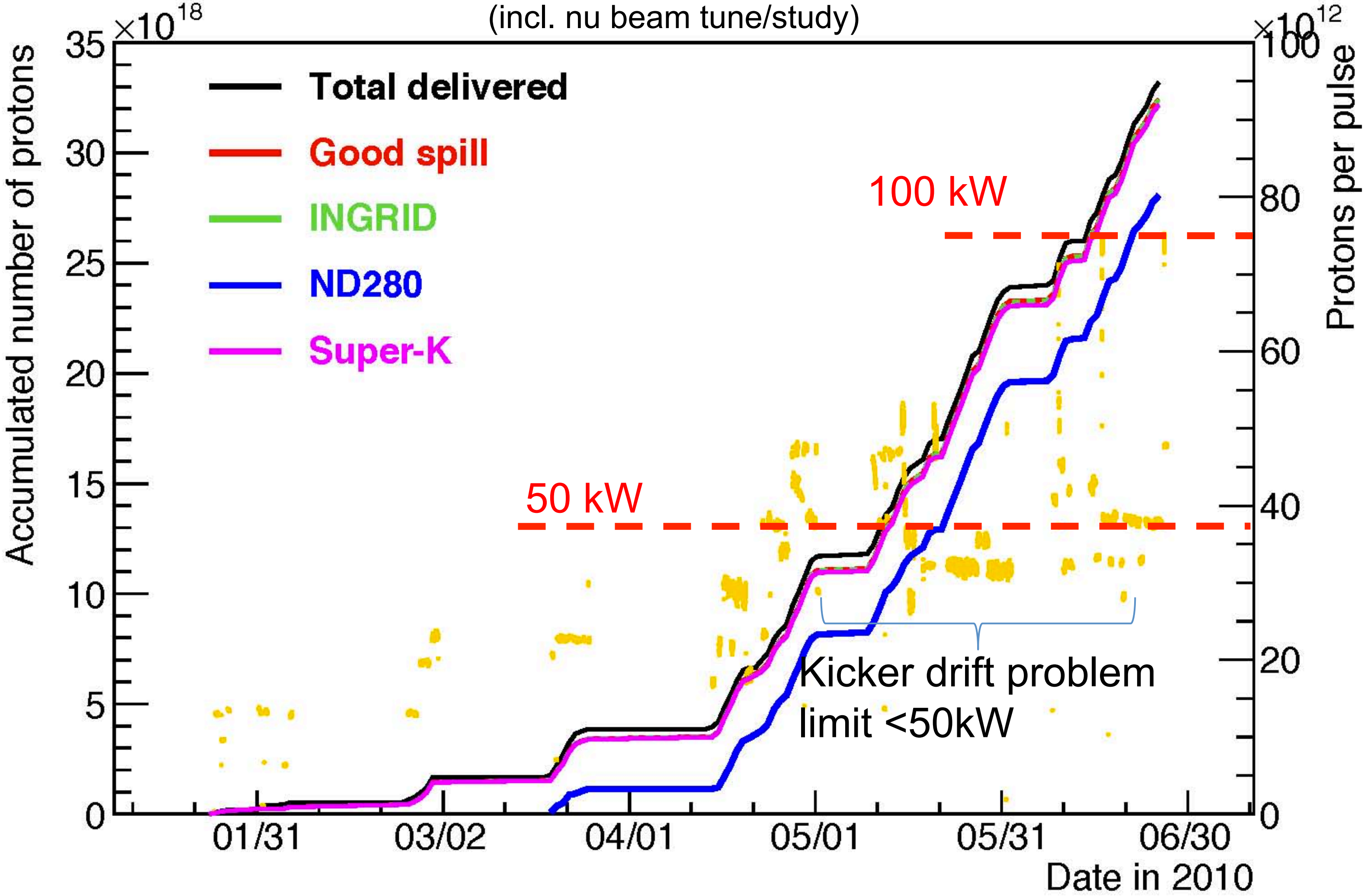
Tokai-to-Kamioka(T2K) long baseline neutrino oscillation experiment

Goal is discovery of

ν_e appearance (θ_{13})

History of beam delivery to the T2K experiment

The T2K group has started physics data taking since January 17, 2010

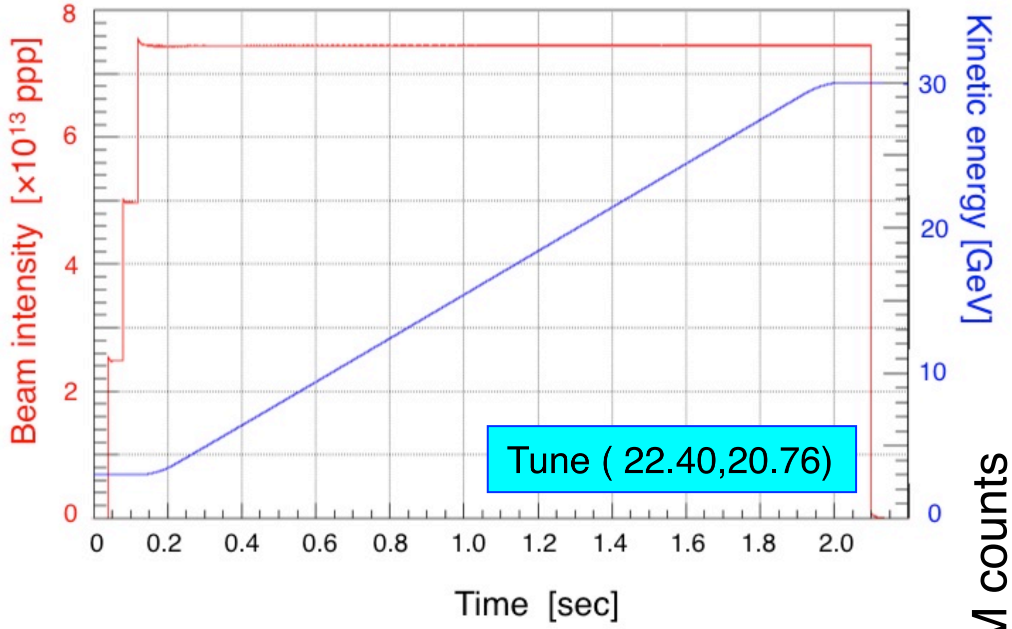


- Beam power up to 100 kW is delivered to T2K experiment.
- Power of long term stable operation is limited up to ~ 50 kW due to kick angle drift.

The kicker system is replaced in the 2010 summer shutdown period.

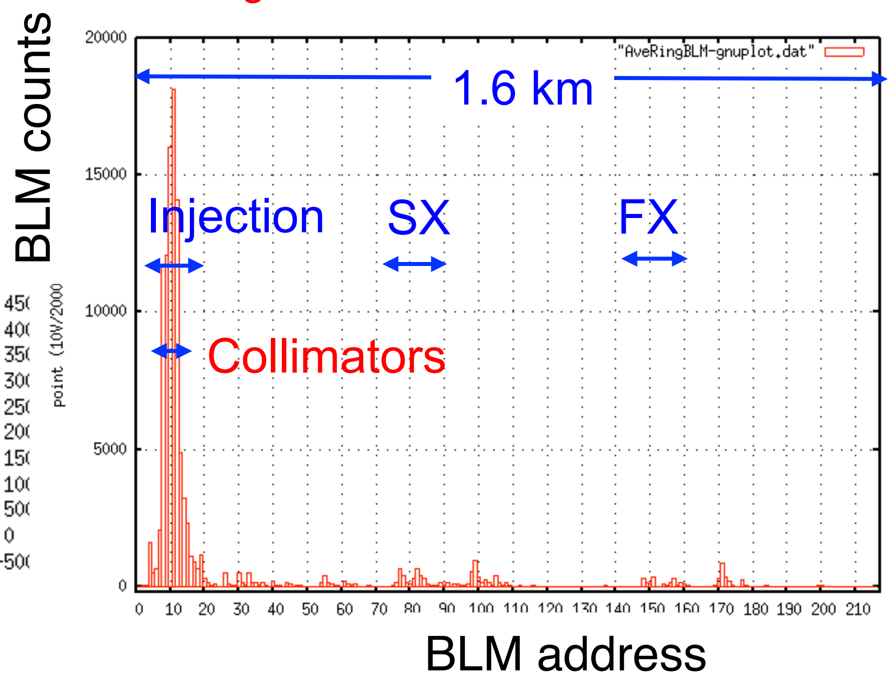
100 kW operation

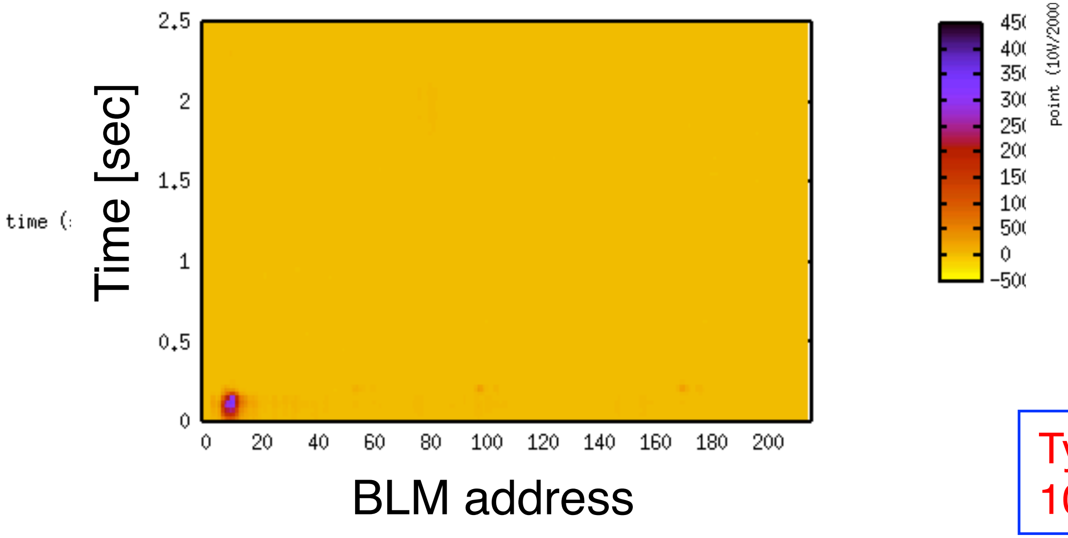
100 kW continuous beam delivery to the NU beam line were demonstrated in June 2010.



The extracted particles to the NU beamline is 7.5e13 ppp:
The world highest level of ppp in synchrotrons.

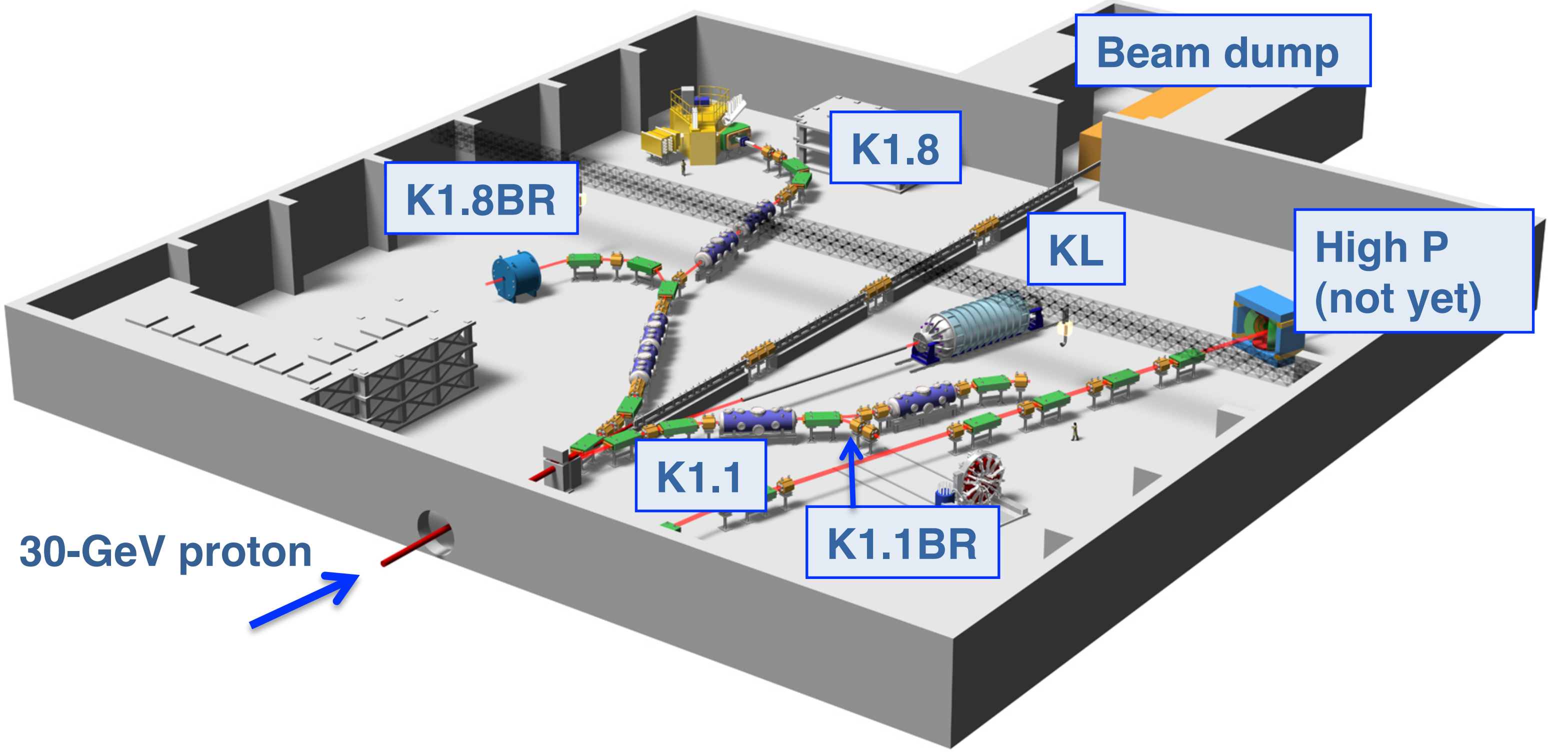
Beam loss localizes on
the ring collimator section.





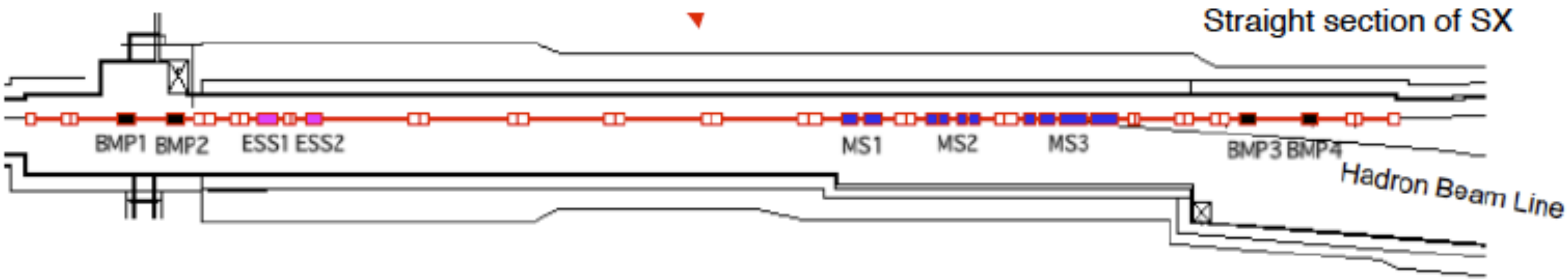
Typical injection loss is
100~200 W < present collimator limit 450 W

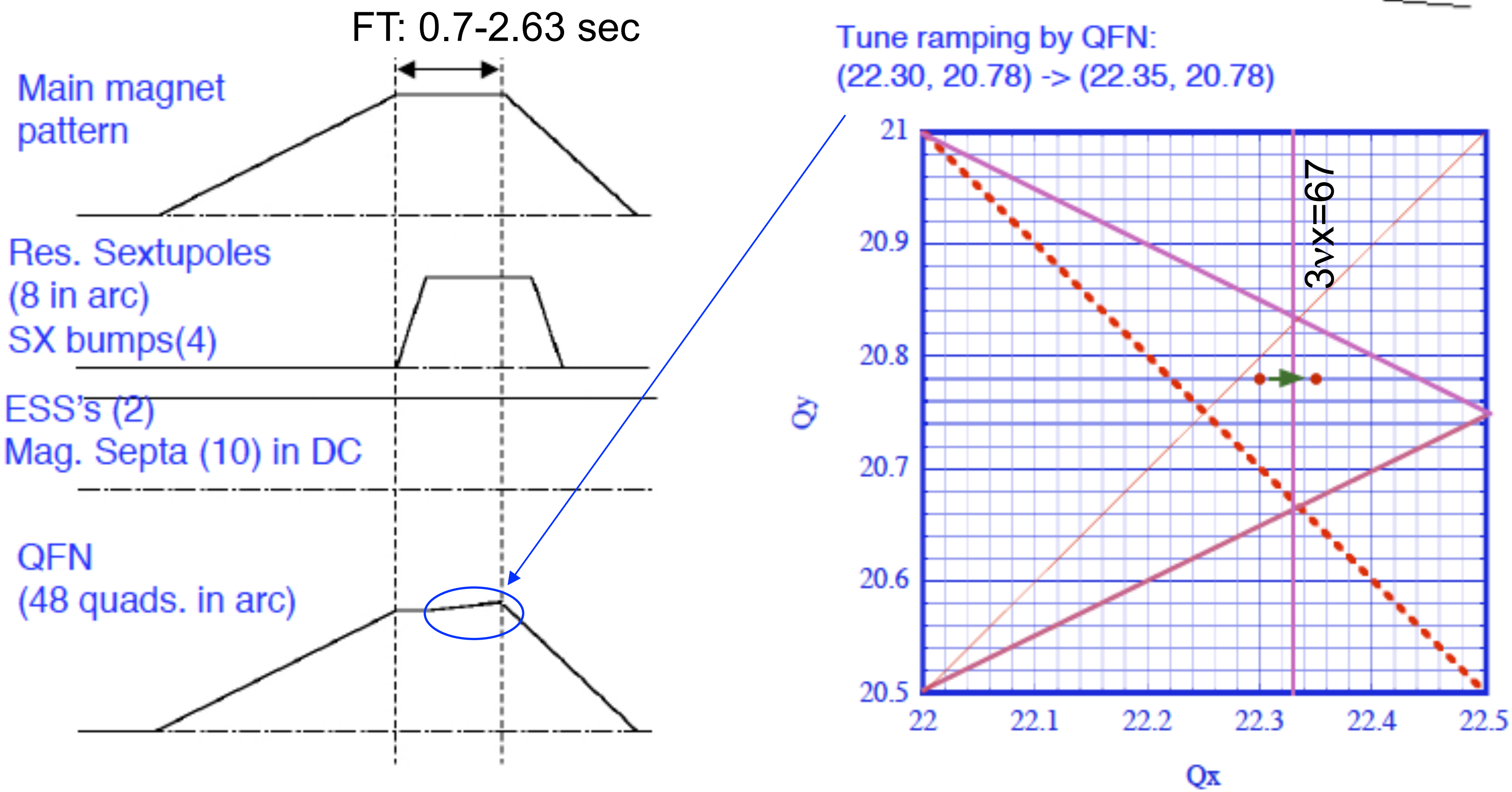
Slow extraction commissioning



Layout of beam lines at the hadron experimental hall.
Three beamlines (K1.8, K1.8BR, K1.1) are in operation. K1.1BR will be commissioned in October 2010.

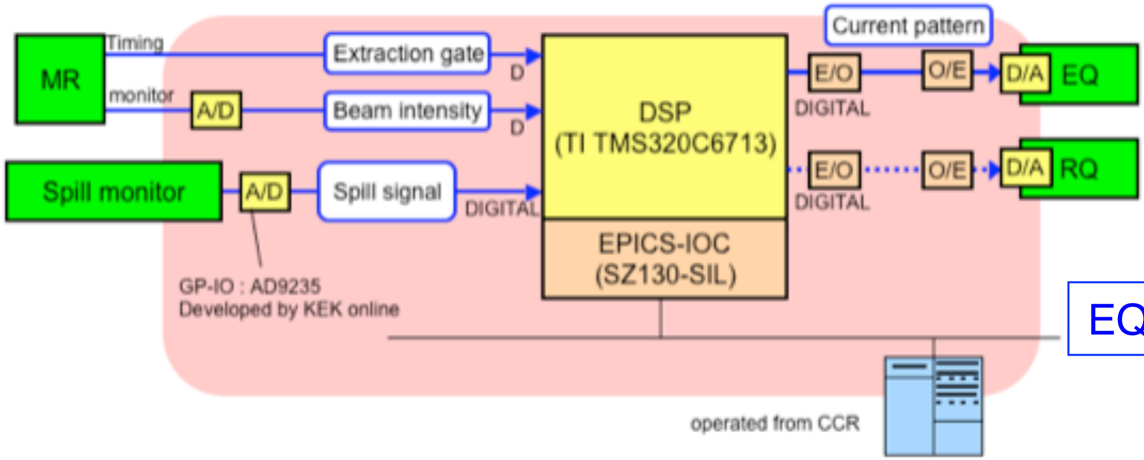
Slow extraction



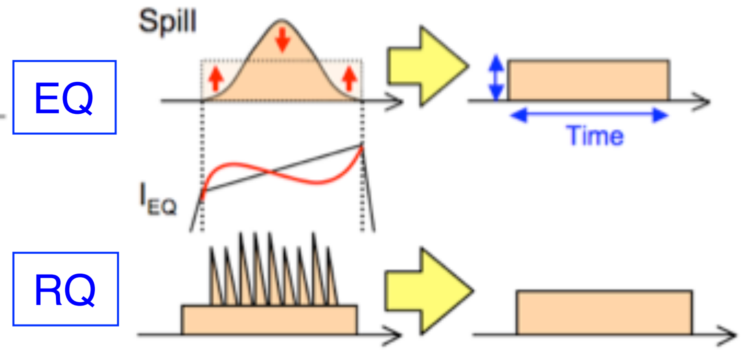


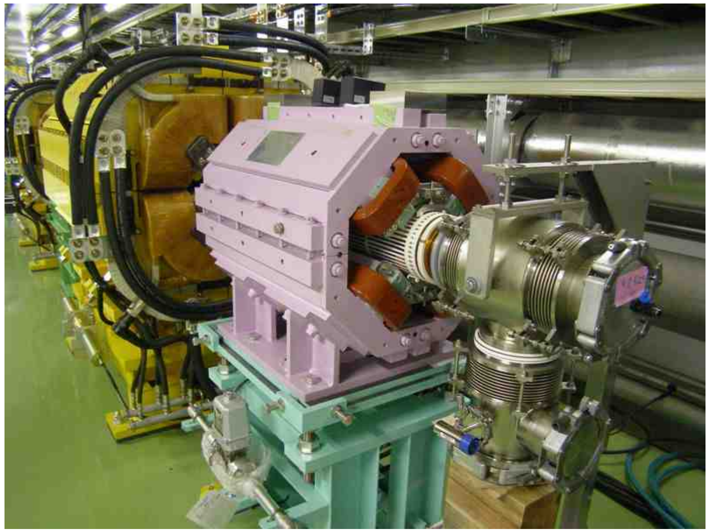
Spill feedback system

Spill feedback using EQ, RQ and DSP system was installed in the 2009 summer shutdown

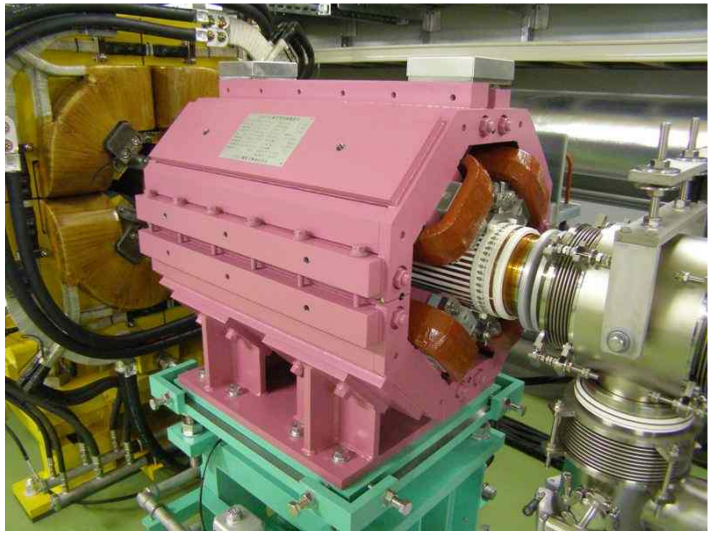


Beam spill signal is fed into the DSP system and current pattern of the correction is sent to PSs of feedback quadrupoles.





EQ: for constant spill structure (< 100 Hz)

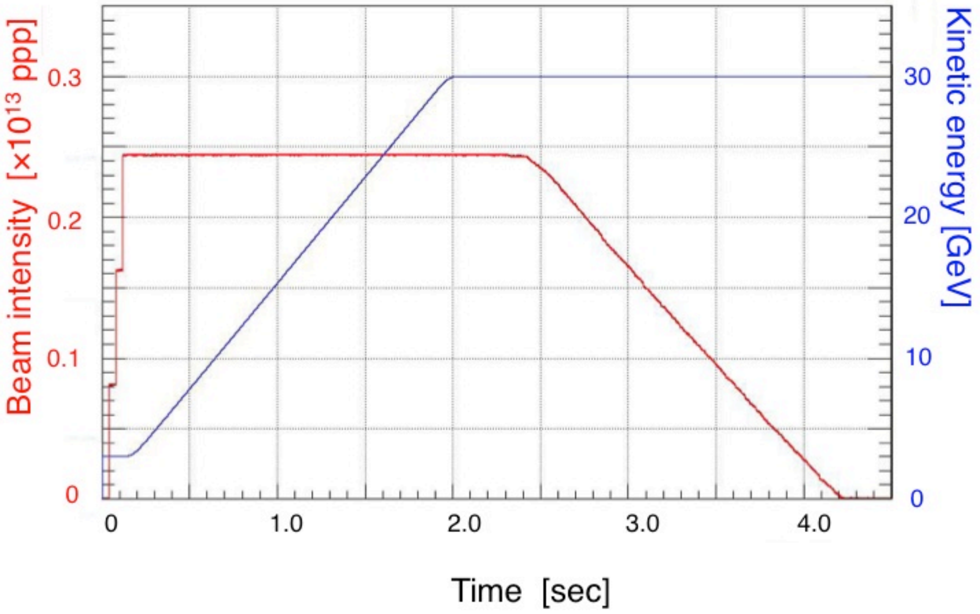


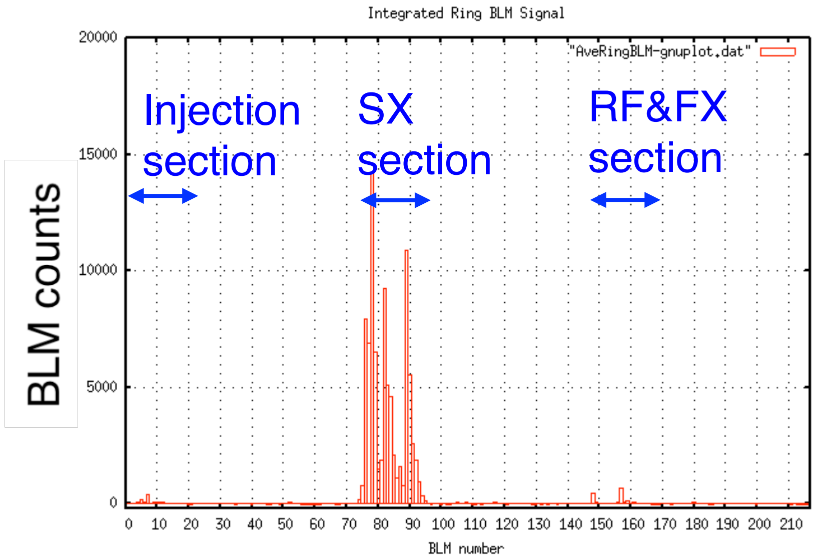
RQ: for ripple compensation (< 3 kHz)

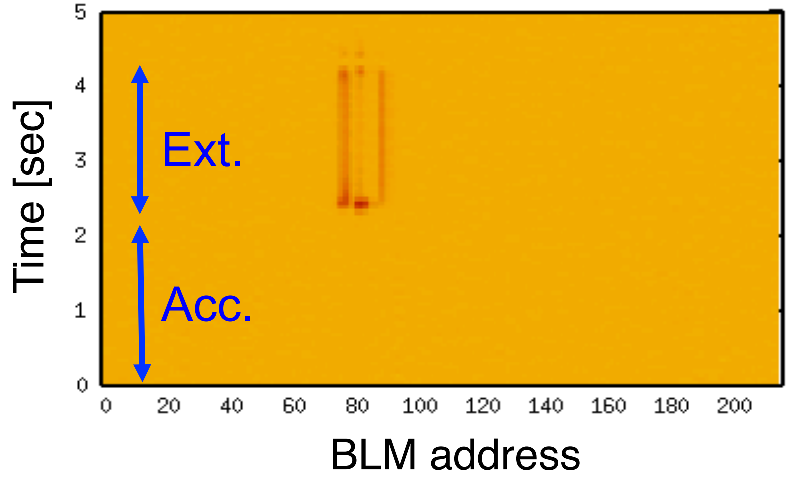
SX operation

Beam commissioning of the SX with spill feedback system has been started in October 2009. Commissioning of secondary beam lines in the HD hall and partial users experiments have been carried out from October 2009 to February 2010.

1.9 kW at
6 sec cycle





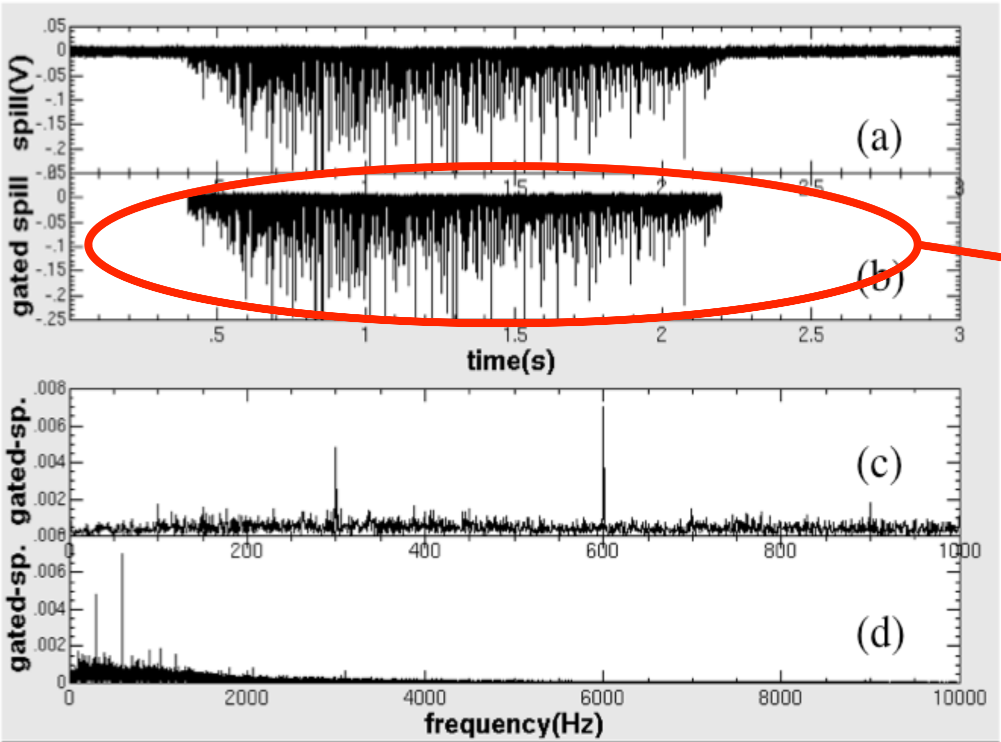


So far, the maximum beam power of 2.6 kW has been delivered to the HD facility.

Estimated extraction efficiency from the BLM counts is ~ 98.5 %

Spill structure of the extracted beam

The spill measured by PMT with scintillator
in the HD beam line



The spill has many sharp peaks, which come from fluctuation of tune due to current ripple of magnet power supplies.

$$Duty = \frac{\left(\int_0^T I dt \right)^2}{\int_0^T dt \int_0^T I^2 dt} \sim 11\%$$

For improvement of the spill structure ;
- operation with transverse rf noise (rf knock out)
- main PS tuning to reduce 600 Hz ripple using a trap filter

The slow extraction study will be resumed in October run.

Improvements performed in 2010 summer shutdown for higher intensity operation of MR

1. New FX kicker system in the 2010 summer shutdown

2. Additional shields for the collimators:
   3-50 BT collimators in the 2010 summer
   (ring collimators in the 2011 and 2012 summer shutdown periods)

3. Installation of 6th rf system :
   It can be operated as a 2nd harmonic system for manipulation of longitudinal bunch form to reduce the effect of space charge force

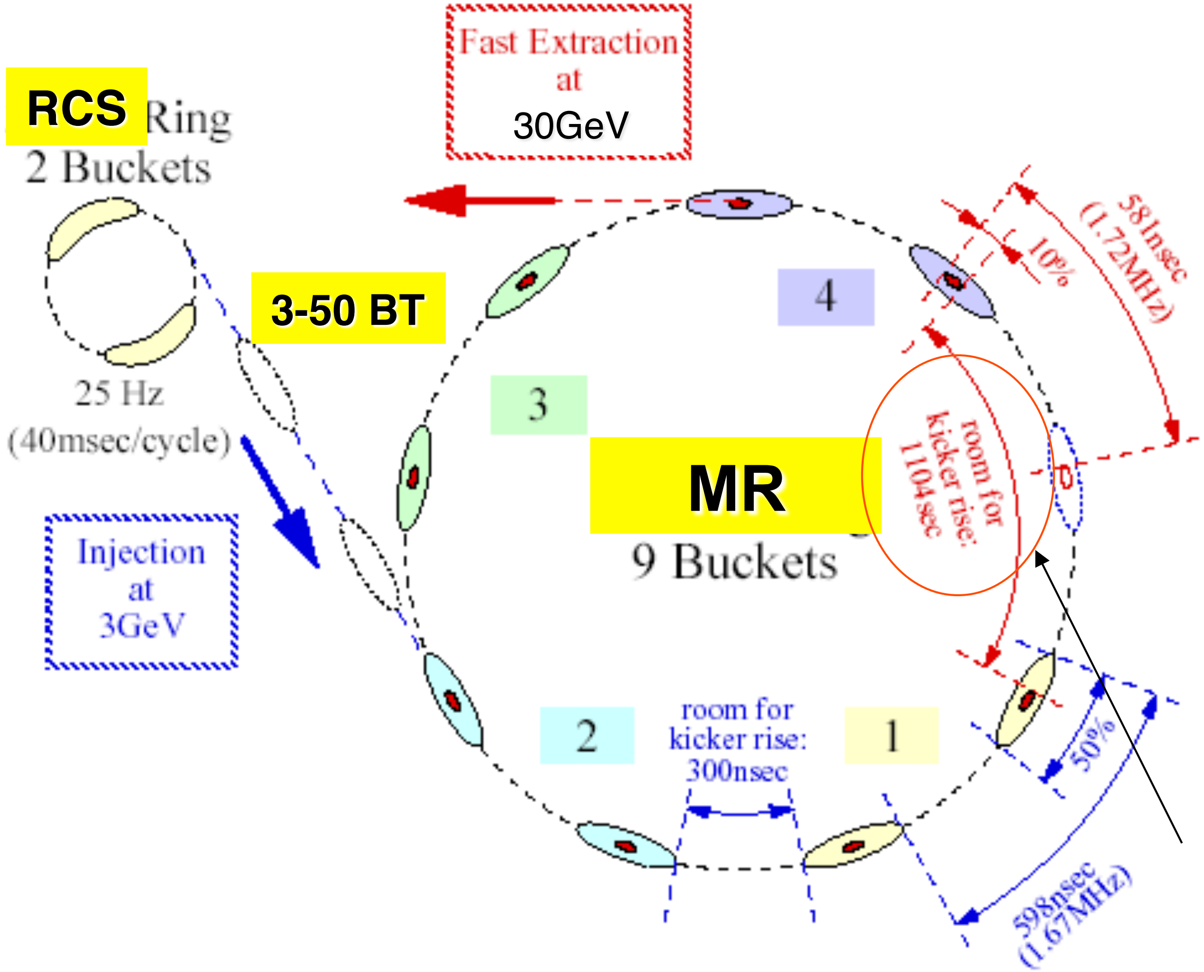
4. Impedance recovery of the MA loaded rf cavities
   Impedance reduction of the cavities was observed. Polishing and coating of cutting surfaces of the MA cores recover the impedance

5. Main magnet tuning for higher rep. rate:
   3.52 s (present) -> 3.2 s (from November of 2010) -> 2.6 sec (Before 2011 summer)

6. Physical aperture of the injection dump section is enlarged by replacing the duct. :
   Narrow aperture of dump septum cased high residual activation.

New FX kicker magnets

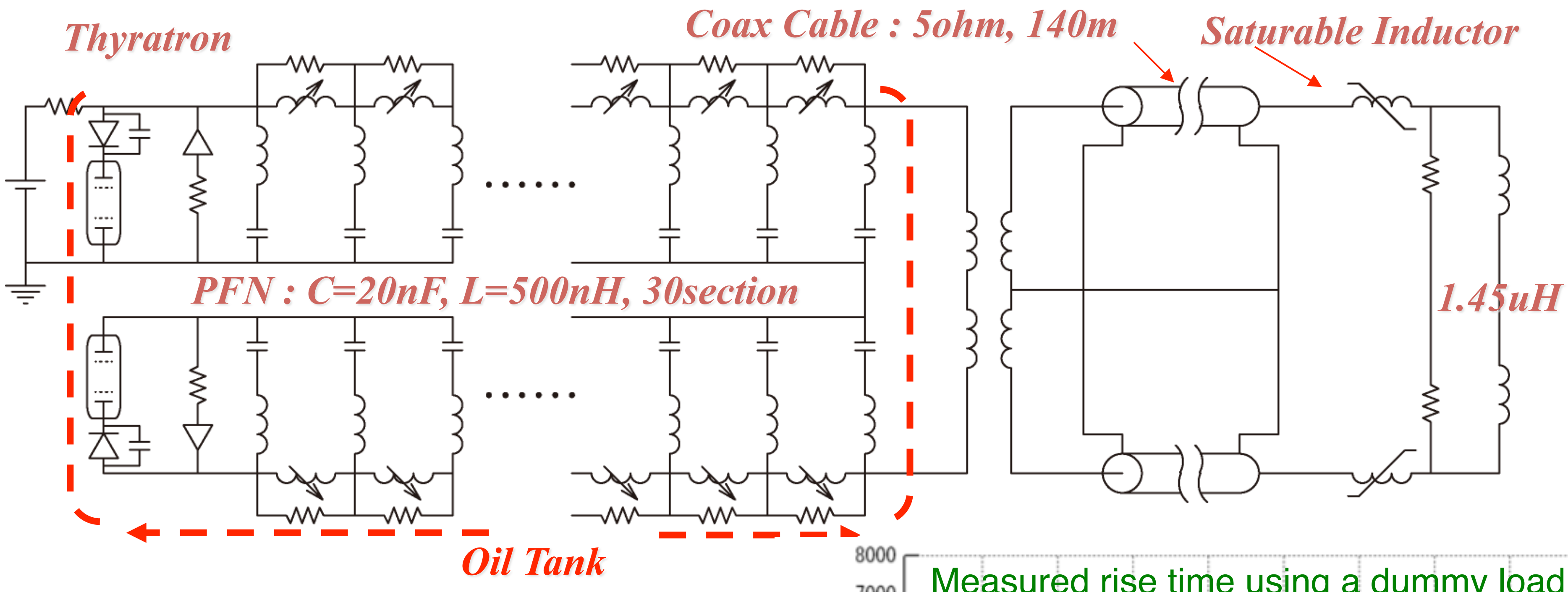
Original injection scheme:
4 batch injection from the RCS to MR
-> 8 bunch operation in the MR

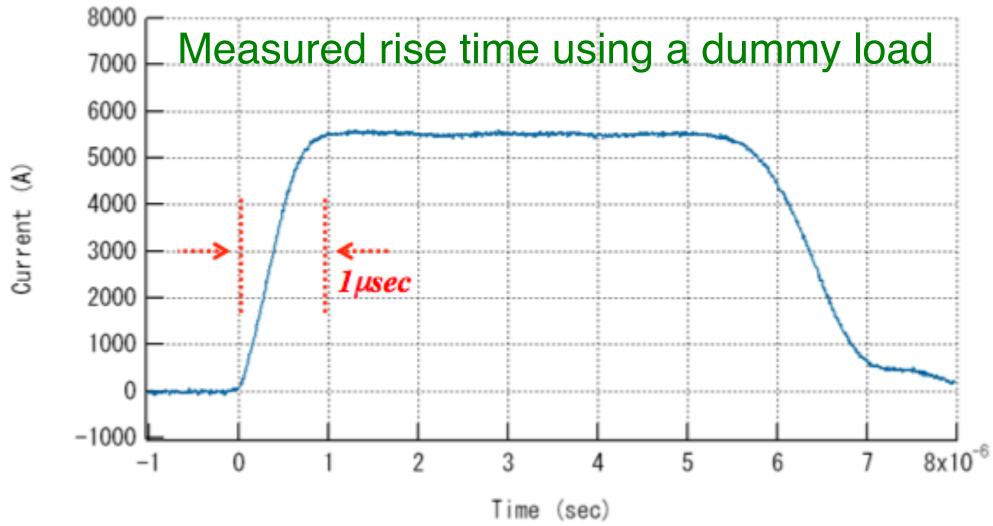


Harmonic number of the MR is nine and one vacant bucket makes the 1.1 μs room for the rise time of kicker.

Before the 2010 summer shutdown, the MR operated with 6 bunches.
It is limited by the performance of extraction kicker magnets.
The pulse rise time of 1.6 μsec is too long to receive 8 bunches.
→New kicker system with the shorter rise time than 1.1 μsec is installed in the 2010 summer shutdown.

Circuit and performance of the new FX kicker



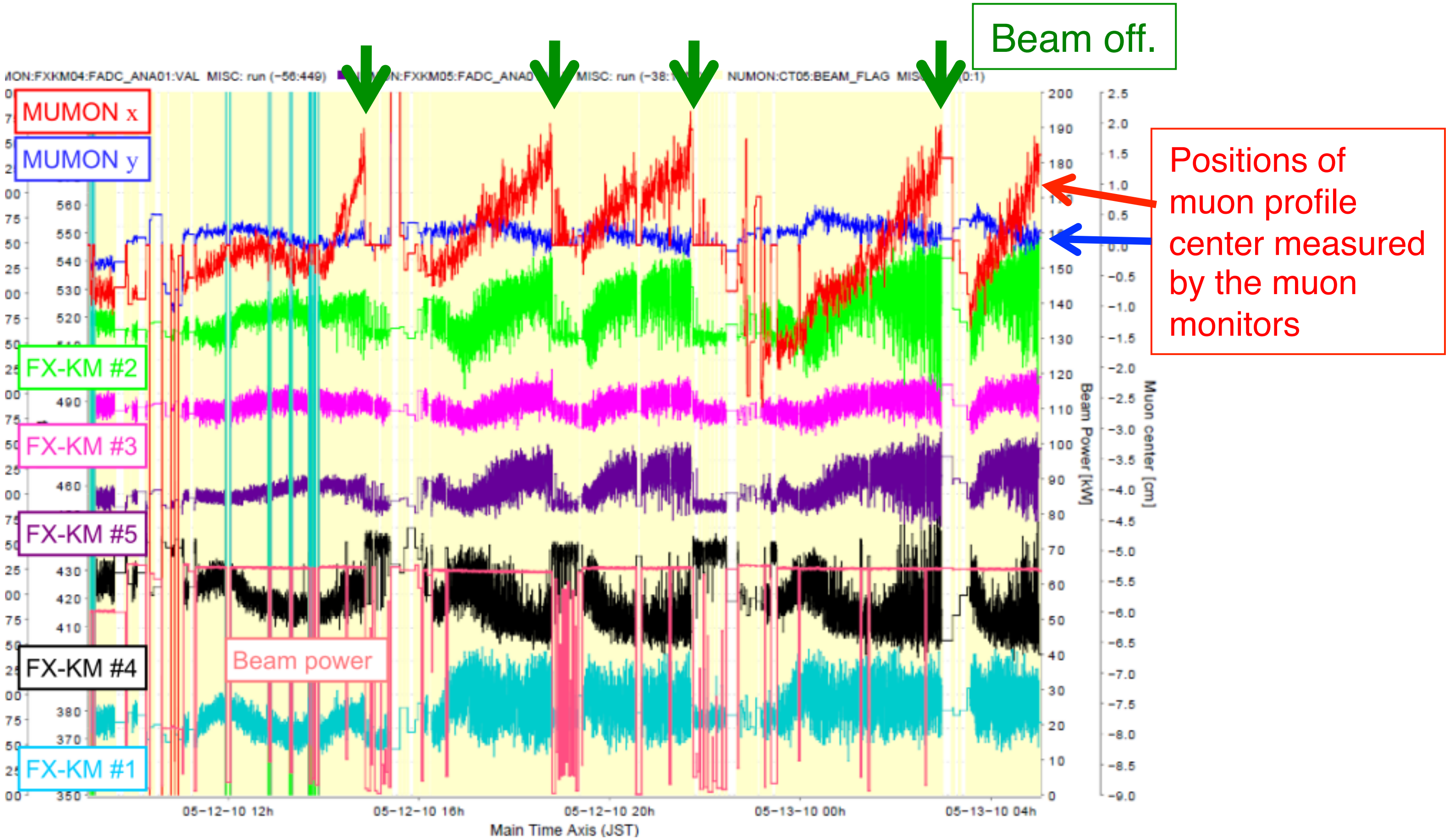


- Thyratron & PFN capacitor should be in coaxial copper shield for faster rise time
- All connection should be done by Cu plate to reduce parasitic inductance
- Connector for high voltage cable should be "Low Inductance"
- Saturable inductor should be installed for faster rise time & to reduce beam impedance

Short rise time less than 1 μsec is achieved.

Orbit drift of the extracted beam

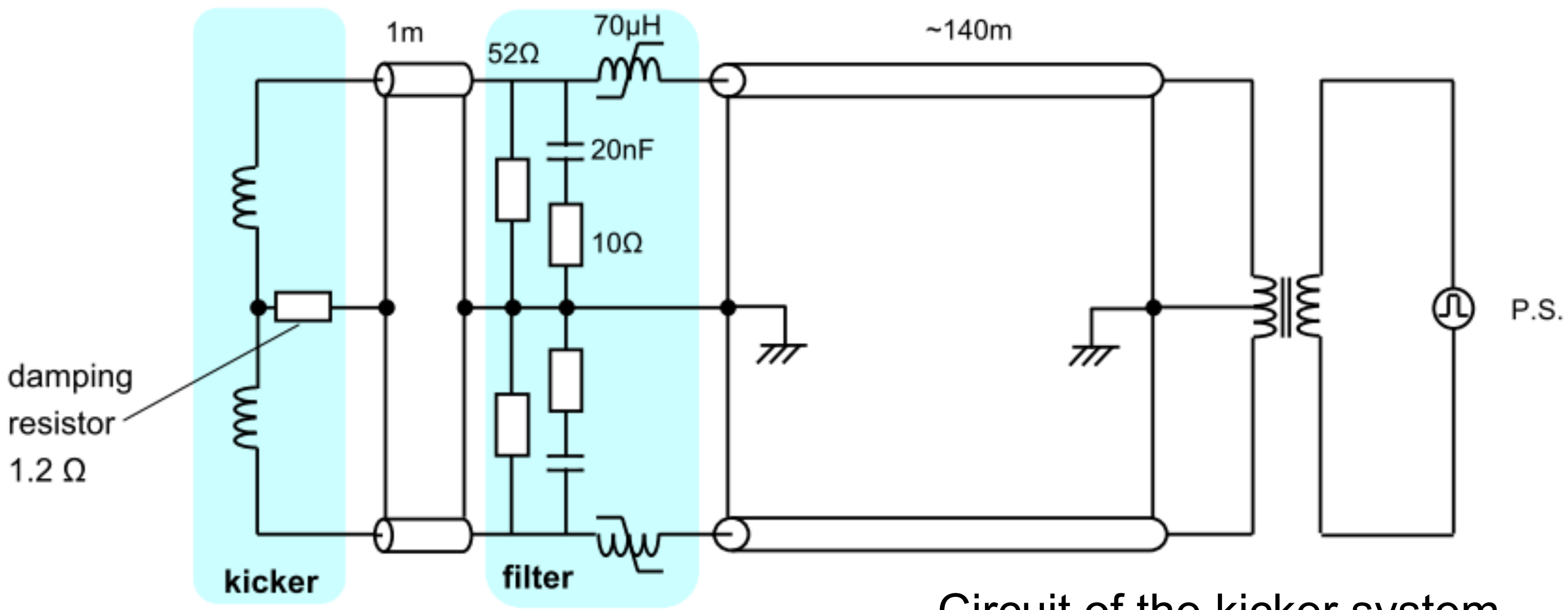
Orbit drift of the extracted beam occurred during the continuous operation with beam power ＞50 kW. Horizontal beam position drifted ~ 1 mm (tolerable limit) on the graphite target and ~10 mm in the muon monitor of the neutrino facility for 1~2 hours continuous operation of 65 kW.



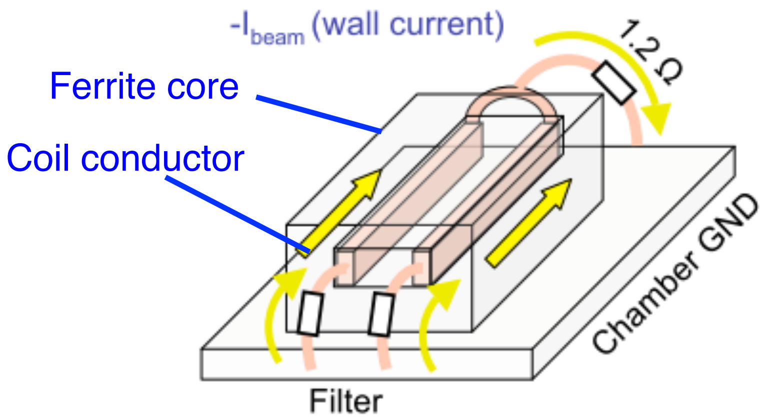
When the operation was resumed after ~30 min beam off, the beam came back to the initial position.
The orbit drift comes from the kick angle drift due to heating of ferrite cores by the beam induced field.

Solution of the heating problem of ferrite cores

Reduction of the beam coupling impedance by damping resistor.



Circuit of the kicker system



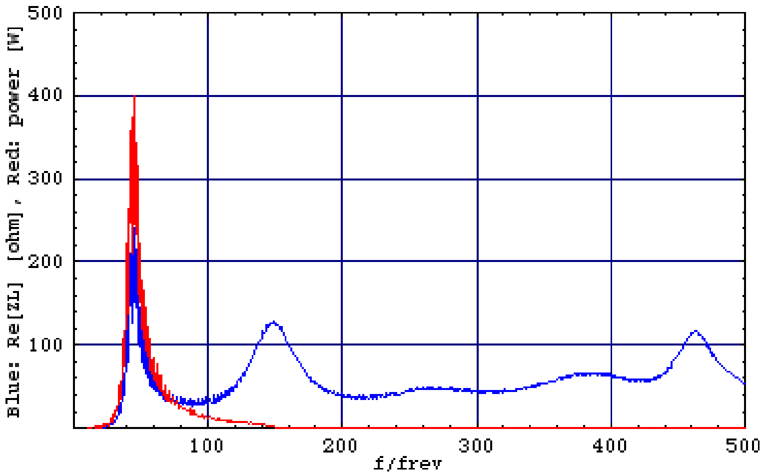
Ferrite core and coil conductor

Beam induced wall current goes to the chamber GND. It cancels the induced magnetic fluxes in the ferrite cores.

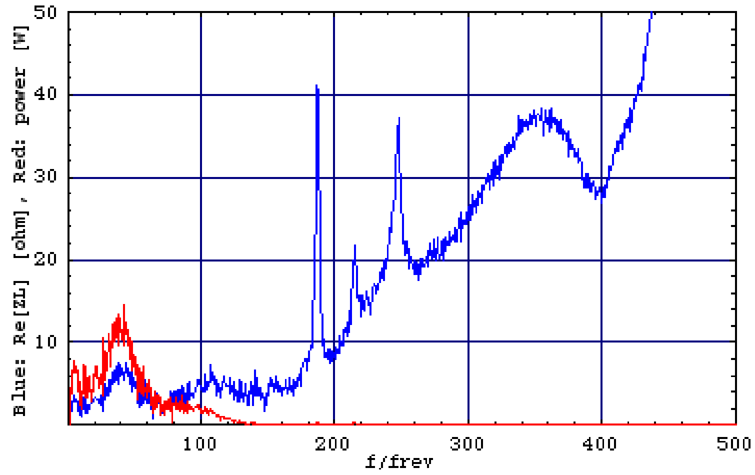
Measurement of rf power spectrum in test bench

T. Toyama

The old kicker (before the 2010 summer)



New kicker with damping resistor



Beam power spectrum : $R_e[Z_L] \times I_B(\omega)^2$

Impedance of kicker : $R_e[Z_L]$

Estimated power loss for 80 kW beam

Beam energy : 30 GeV, bunch width : 47 ns

number of particles : 10^{13} ppb x 6 bunches

using measured bunch form, duty factor: 60%

Old Kicker (before 2010 summer)	New kicker with damping resistor
1900 W loss	210 W loss (20 W loss in ferrite)

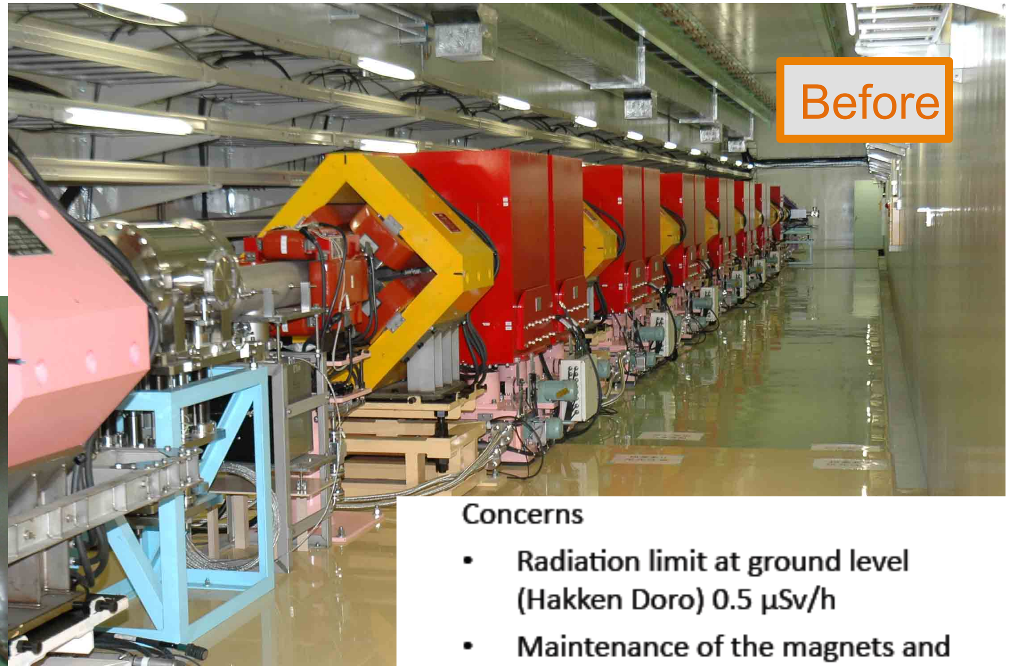
Power loss in the new kicker is estimated to be ~10 % of the old kicker.

Water cooling channels are attached on the ferrite cores.

It is expected to reduce the temperature rise to ~1/5 for the case of 1kW power loss.

Installation of additional shields of 3-50 BT collimators

Loss power capacity increased from 0.45 kW to 2 kW



Concerns

- Radiation limit at ground level (Hakken Doro) 0.5 μSv/h
- Maintenance of the magnets and collimator devices

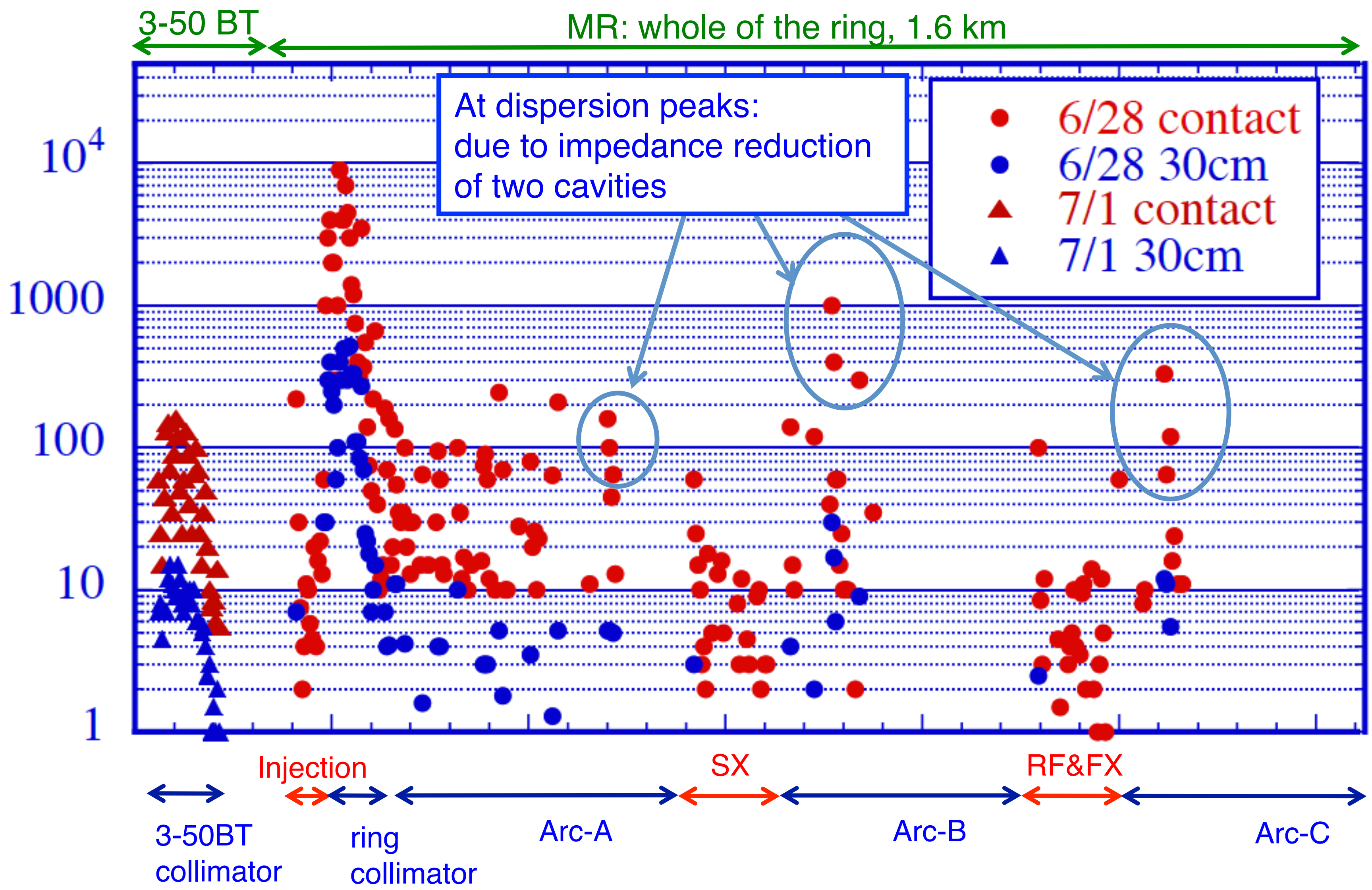
Solutions

- More shield 20 ~ 50 cm thick (iron equivalent)
- Potentiometers and switches with radiation hardness

MARS calculation has indicated that hands on maintenance and accidental jaw replacement are possible. Radiation doses have been estimated to be ~10 mSv/h at the surface of 30 cm thick iron.

Installation has been completed on September 6.

Residual activation data taken on duct surface and at 30 cm after RUN#34 (run in June 2010.)
The RUN#34 (for T2K exp., 50-70 kW beam delivery) stopped at 7:00 on June 26.

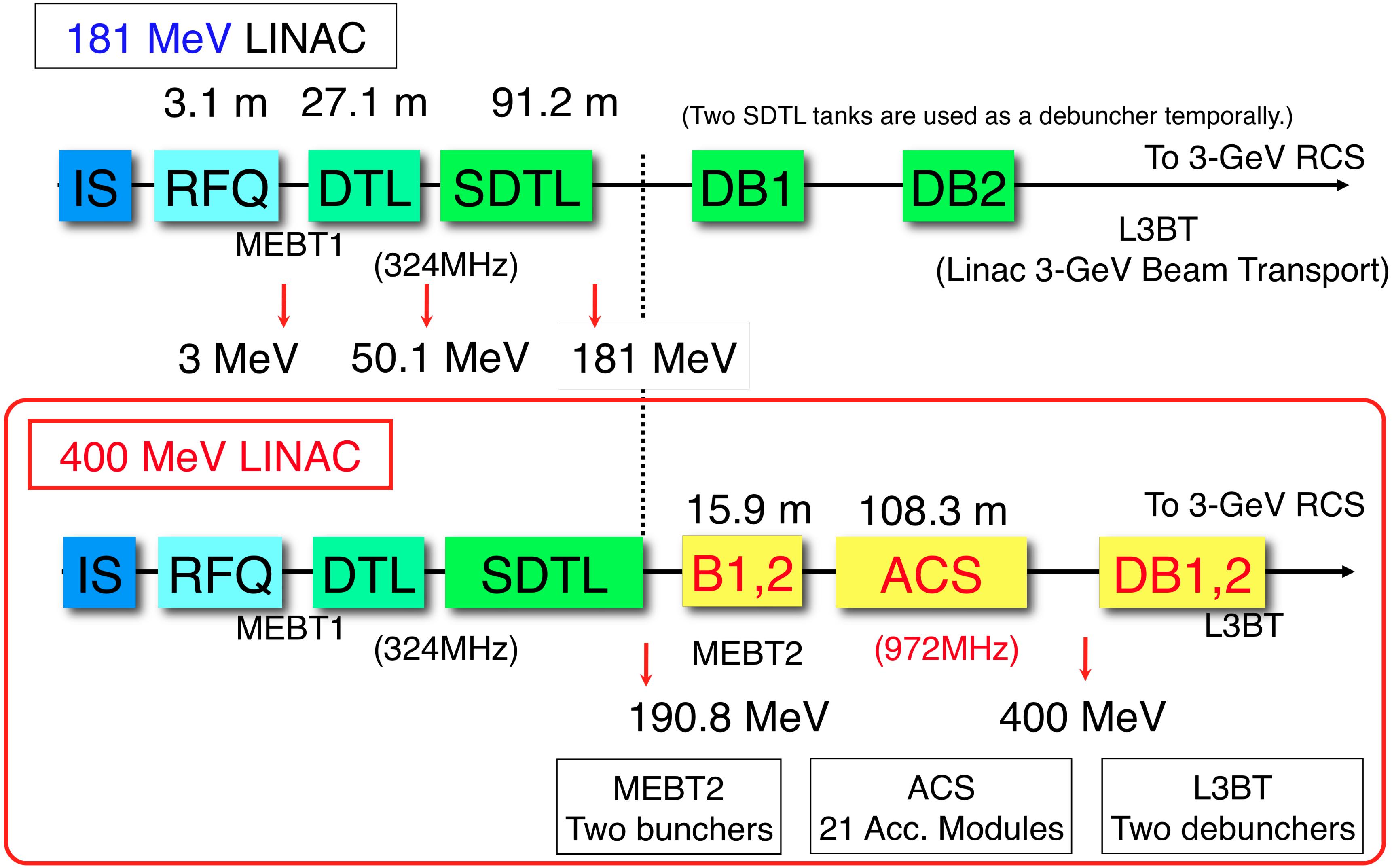


The aperture of the 3-50 BT collimator was set larger(~70 pi), because the installation of the additional shield was scheduled to start in the beginning of July. It can be used to reduce the loss in the ring collimators from the autumn run.

Energy upgrade of the linac

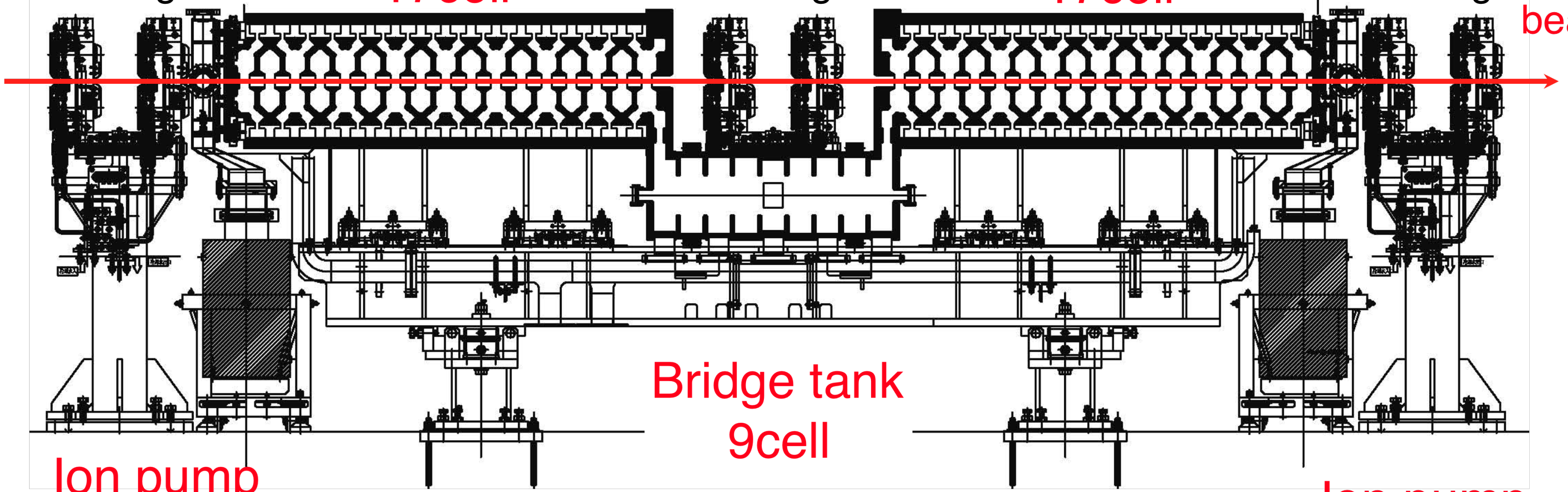
The full potential of the J-PARC facility cannot be realized with a 181 MeV linac.
(e.g. 1MW@RCS, 0.75MW@MR)

The construction of 181 to 400MeV part of the linac was funded through the supplementary budget of JFY2008 (four years).

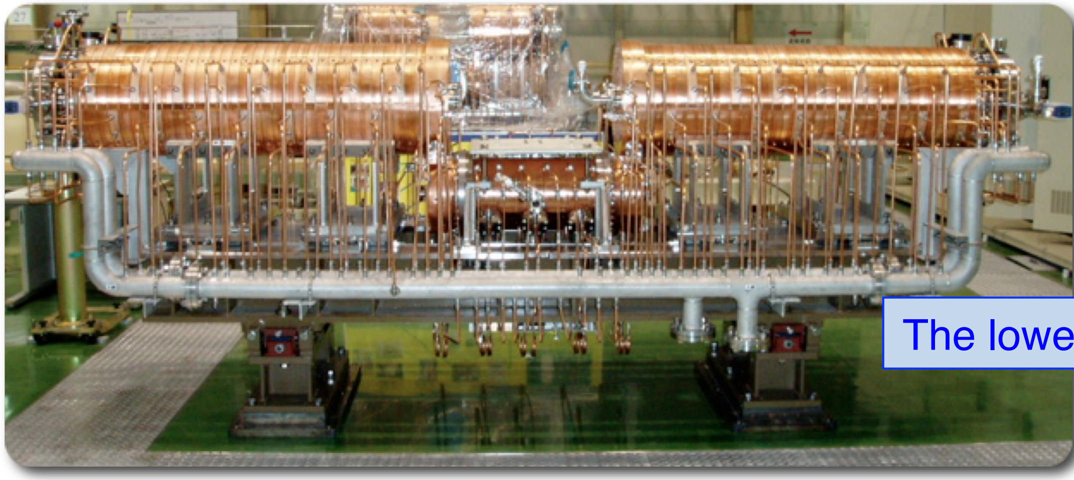


ACS accelerating modules

H. Ao



Two acc. tanks have the same geometrical β.

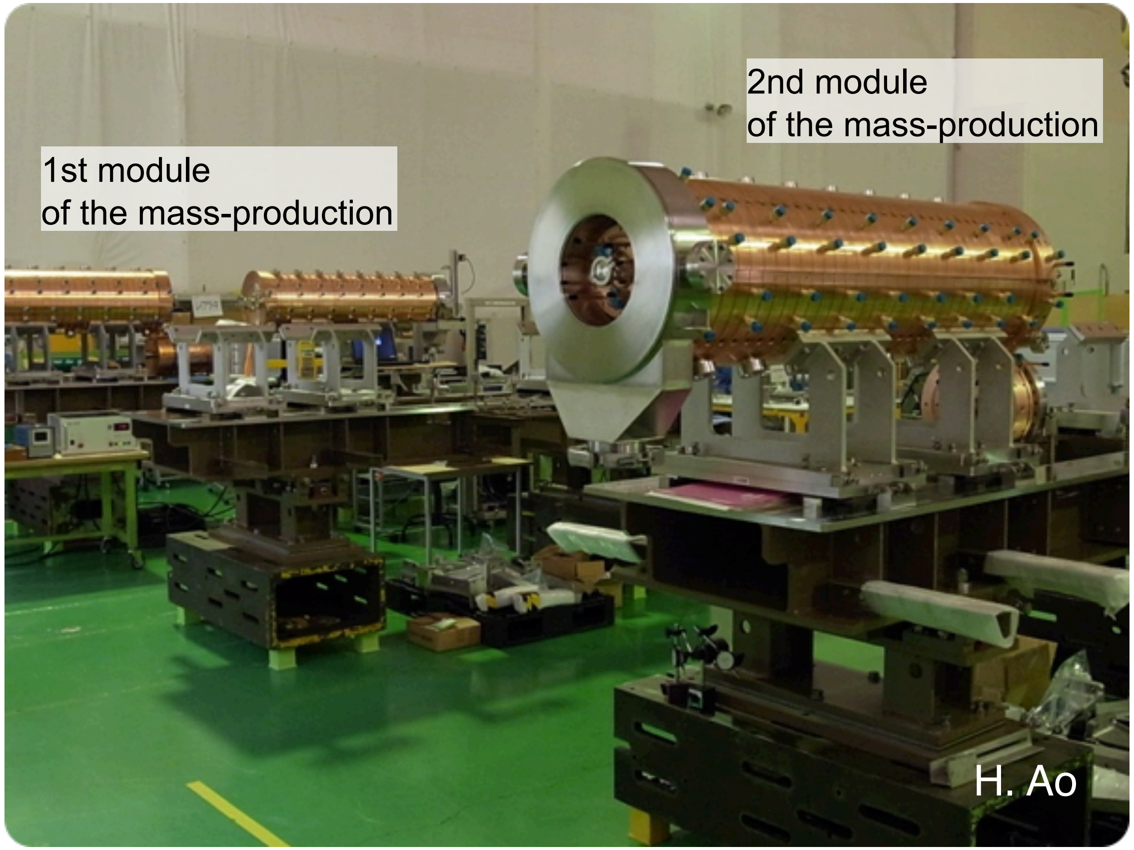


The lowest energy module

25 ACS cavities will be manufactured in 3 years.

Final brazing and assembling

Module set into a vacuum furnace



Modules being assembled on the support

So far, the construction is on schedule. The ACS will be installed in the 2012 summer and beam commissioning of the 400 MeV will be started in the 2012 autumn/winter.

Summary

The linac and RCS deliver the high power and stable beam to the downstream facilities.

Recent highlights :

-120 kW beam delivery to the MLF

-300 kW operation for 1 hour was successfully demonstrated

160kW beam delivery to the MLF is planned from December 2010

200 kW from January 2011

Recent highlights of the MR:

-Beam delivery of 100 kW in maximum to the NU beam line by FX

-Beam delivery of 2.6 kW in maximum to the HD hall by SX.

Continuous beam delivery > 100 kW will be started in the 2010 autumn.

Beam delivery > 5 kW will be started in this autumn : limited by radiation shield of beam dump of the HD hall. It will be increased 50 kW in the 2011 summer shutdown

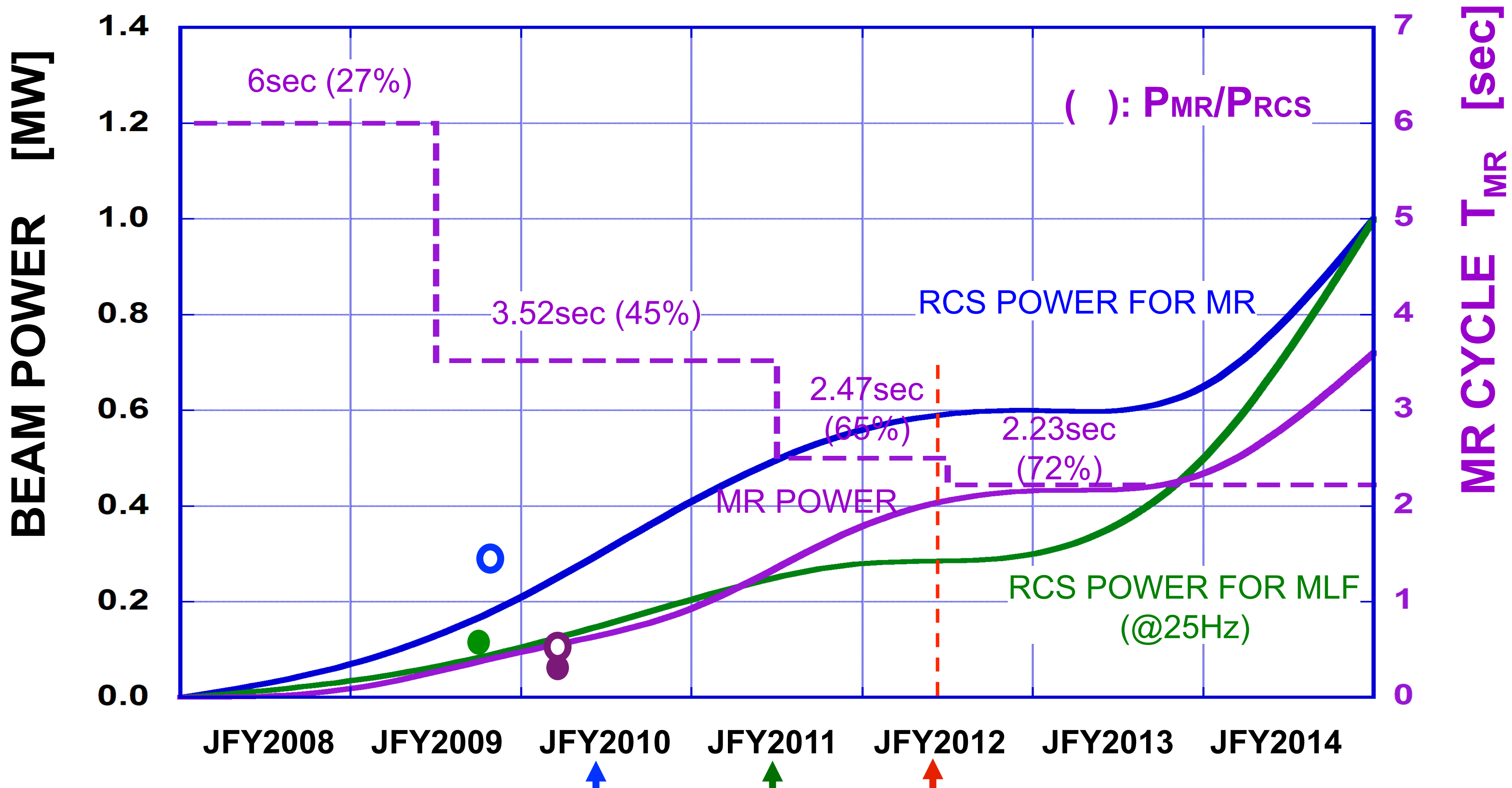
The construction of the ACS cavities are well in progress.

The beam commissioning of the 400 MeV operation is scheduled to start in 2012.

Thank you for your attention

Power upgrade plan of RCS and MR(FX)

For 8 bunches, 30 GeV at MR: $P_{MR}=1.6 \times (P_{RCS}/ T_{MR})$



3-50BT collimator shields,
RF (1st HH), FX kickers

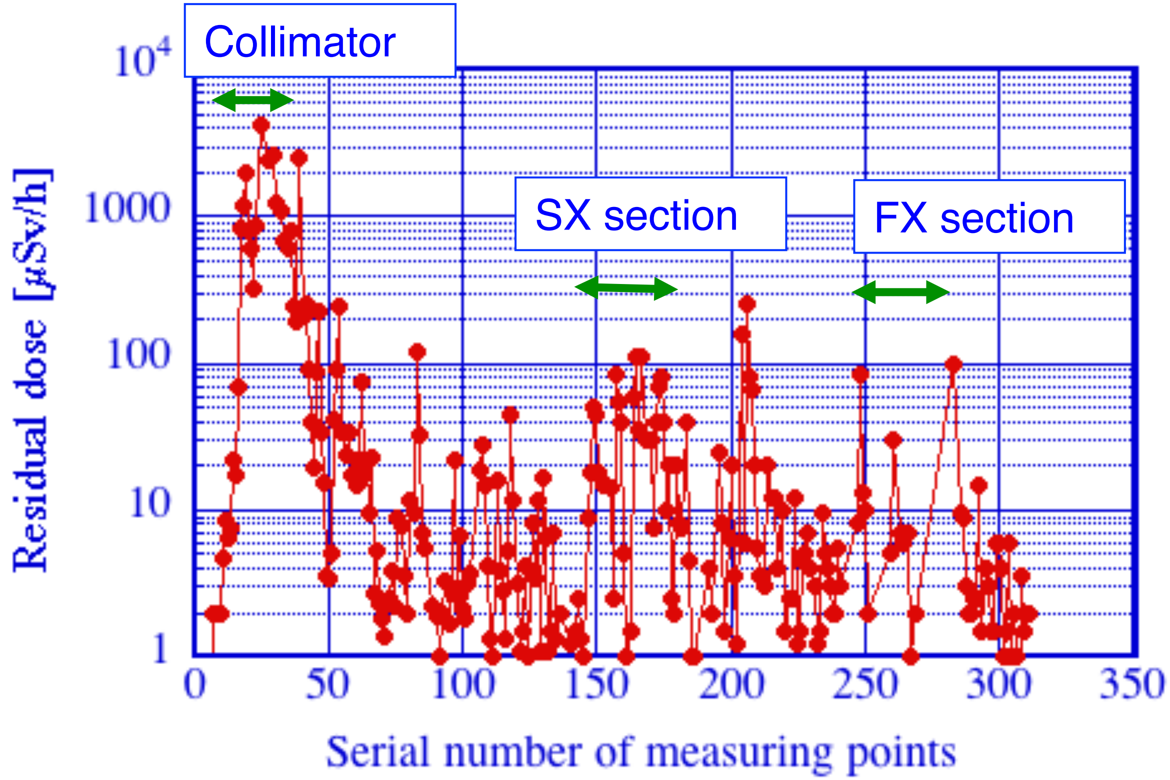
Ring collimator shields, RF (6th F, 2nd HH), Inj. Sep 1

ACS Installation in JFY2012
400 MeV injection in the RCS

RF (3rd HH), Inj. Sep 2, FX Septa, ..

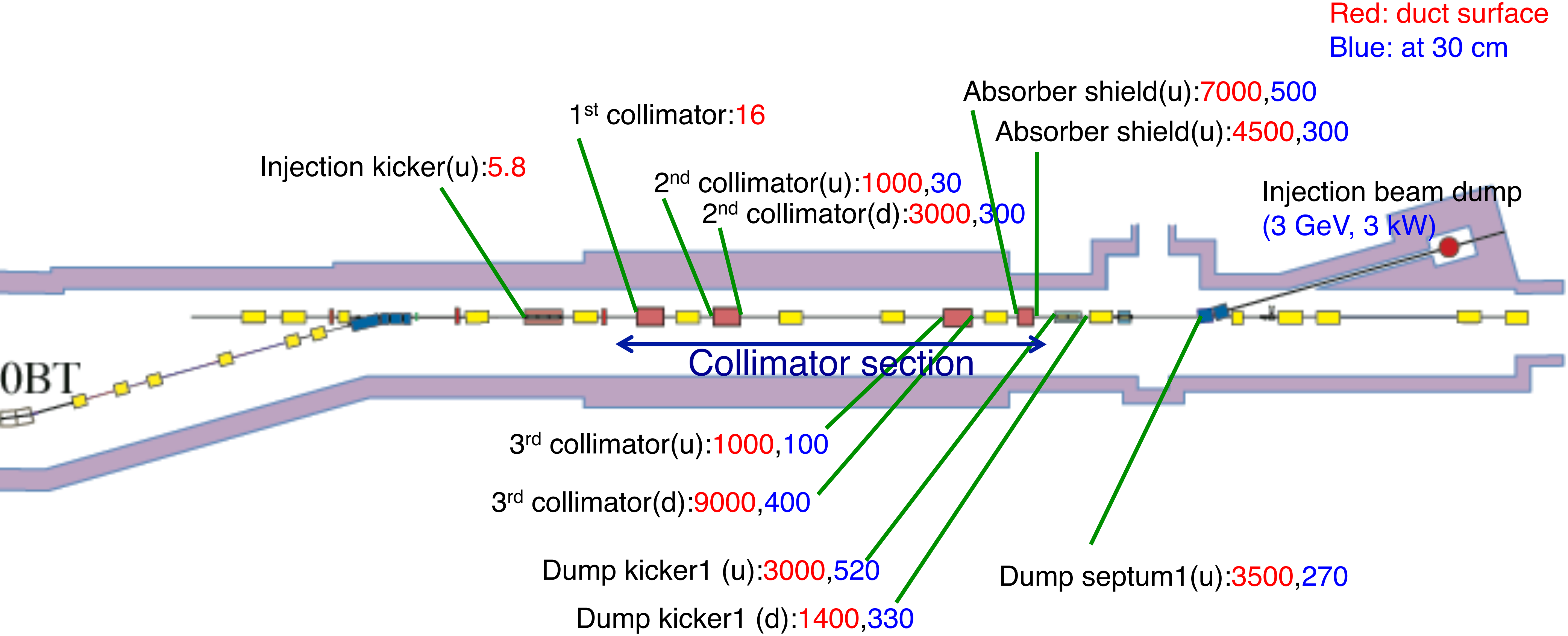
Residual activation after RUN#30

February RUN (RUN#30):
Total deliver time to HD is 122 hrs. (5 days) : 1 kW(106.5 hrs.), 2 kW (2 hrs.), 1.5 kW (13.5 hrs.)
Total deliver time to NU is 72 hrs. (3 days) : 18 kW(19 hrs.), 27 kW (21 hrs.), 31 kW (32 hrs.)
Survey: 4 hours after the beam stop, measured by contact on the beam ducts.
(7days after the stop of the beam delivery to HD)



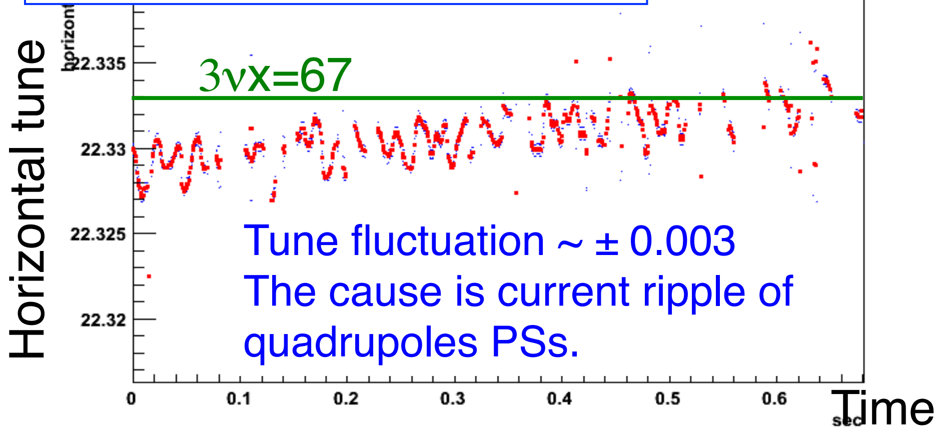
The residual activation in SX section 1 week after beam stop is less than 100 μSv/h on contact.
(The guide line of activation max. is 1 mSv/h to allow hands on maintenance.)

Residual activation in the injection straight section



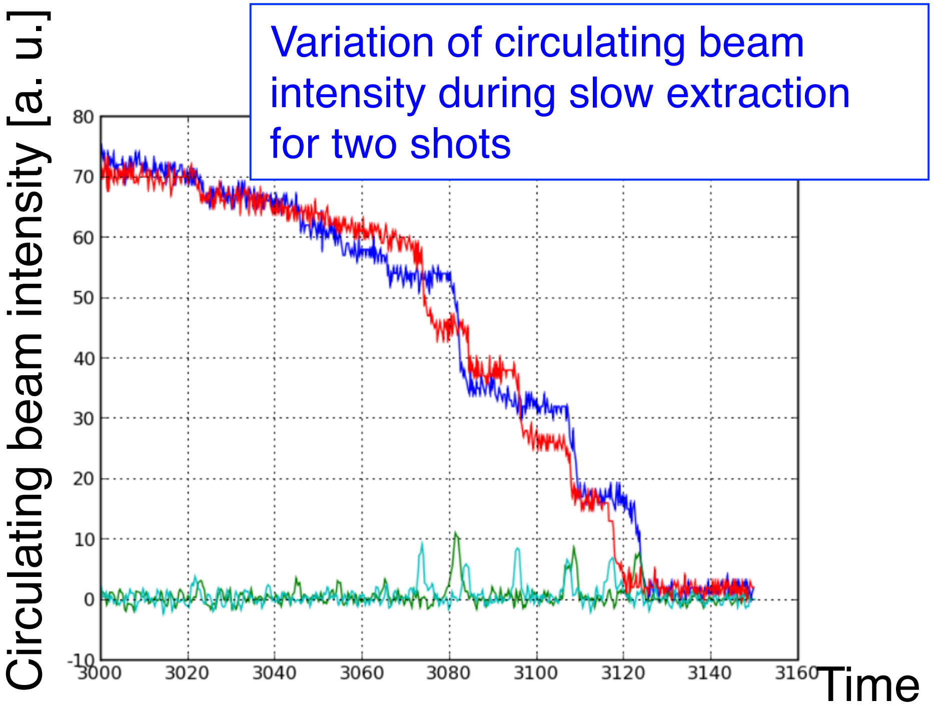
Injection dump system has high activation level because of the narrow aperture.
We replace the beam ducts with larger ones in this summer shutdown.

Measured tune during the tune ramping by QFN



Tune fluctuation ~ ± 0.003
The cause is current ripple of quadrupoles PSs.

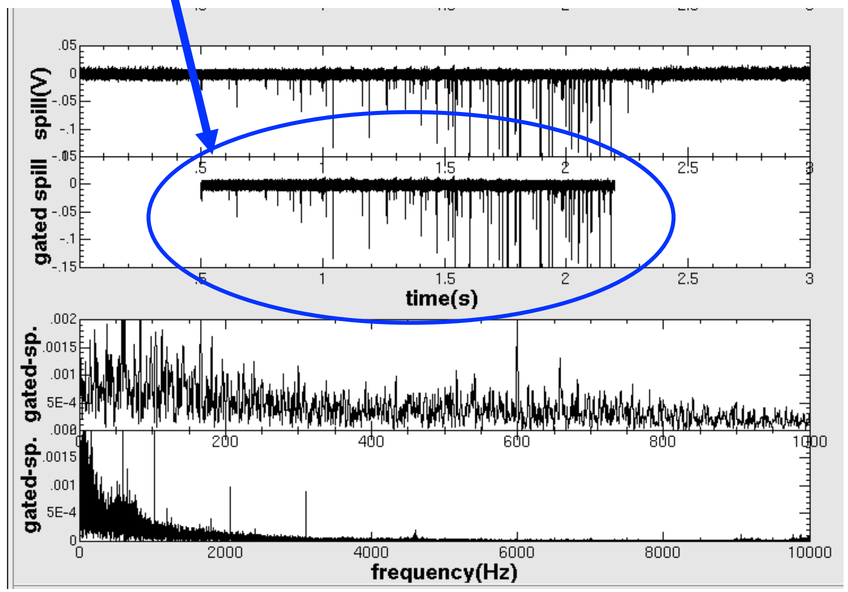
Variation of circulating beam intensity during slow extraction for two shots



Because of the tune fluctuation, the circulating beam decreases in the step-like shape

Spill monitor signal in HD beam line

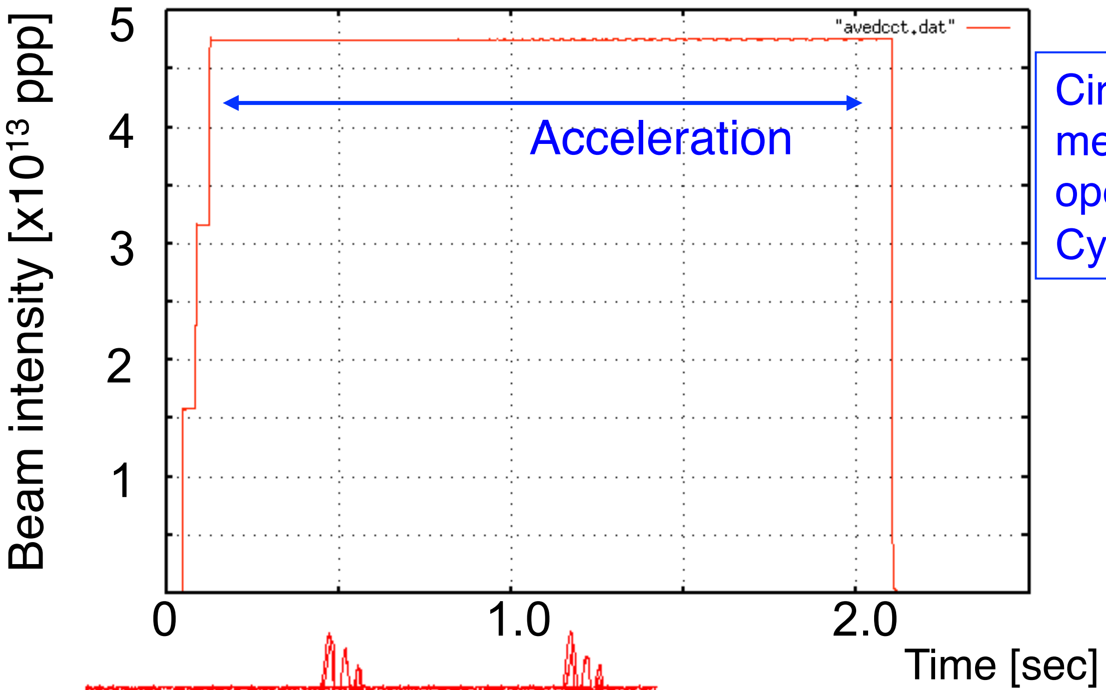
Extracted beam has many sharp peaks.



$$Duty = \frac{\left(\int_0^T I dt\right)^2}{\int_0^T dt \int_0^T I^2 dt} \sim 1\ \%$$

Beam delivery to T2K (1)

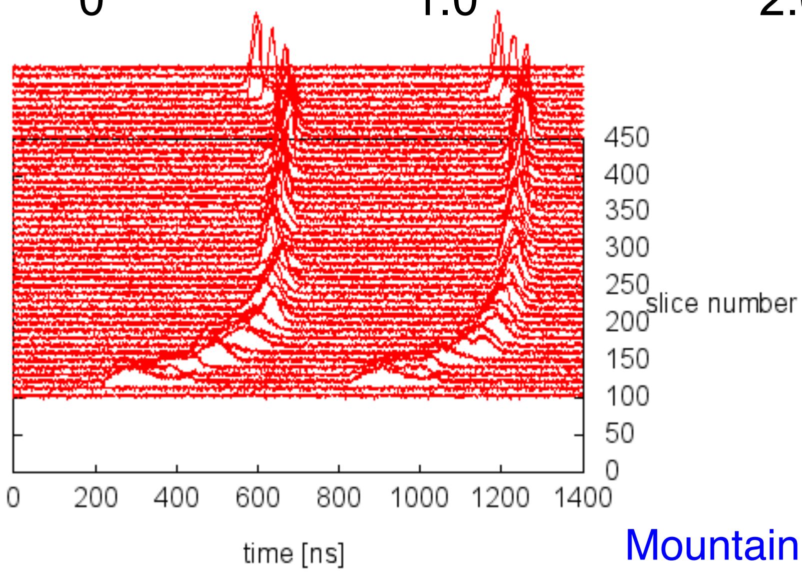
The T2K group has started physics data taking since January 2010.



Circulating beam intensity measured by DCCT for 65 kW operation.
Cycle time is 3.52 sec.

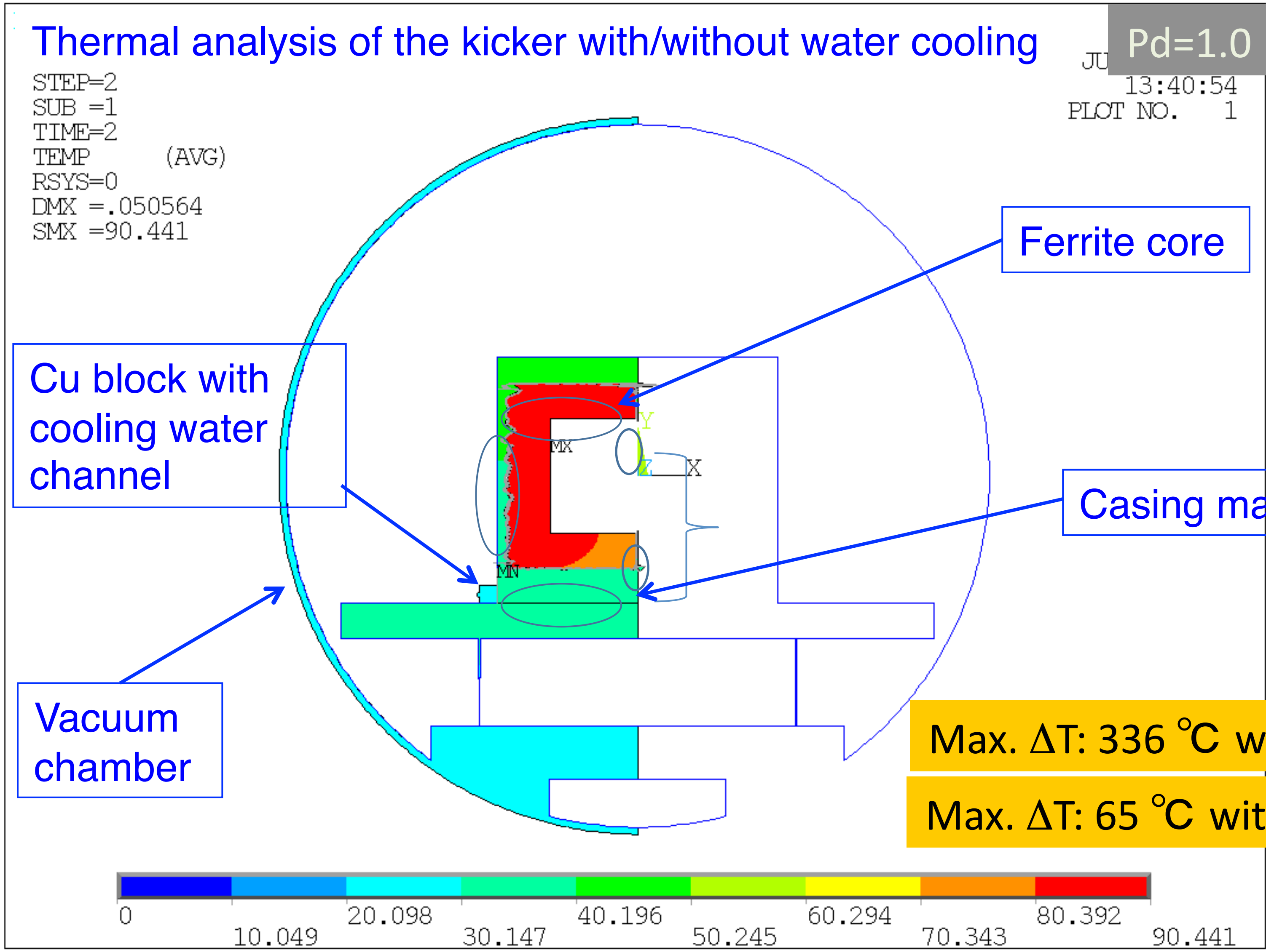
RCS :
Transverse painting:
150 πmm.mrad
Longitudinal painting:
Momentum offset 0.2 %
Phase sweep -100 deg
2nd Harmonics ON

MR :
Ring collimator aperture:
54 π for both H and V
RF: 80 -> 160 kV (100 msec)



Mountain plot of WCM signal :
Time variation of longitudinal profile for two bunches.

Cooling water system of the kicker



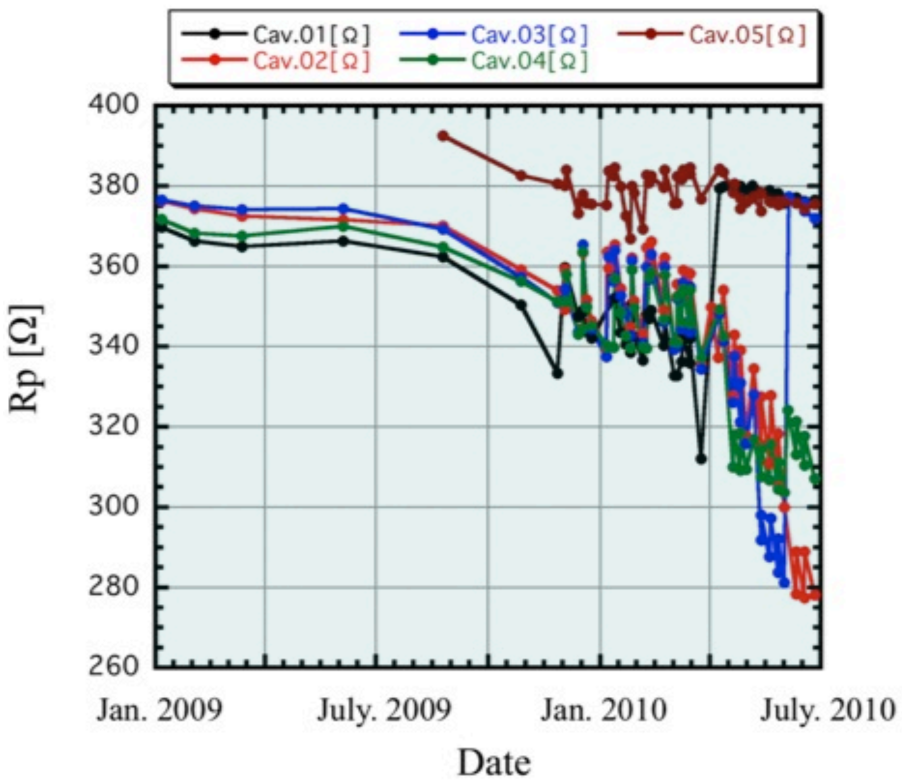
Max. ΔT: 336 °C without cooling

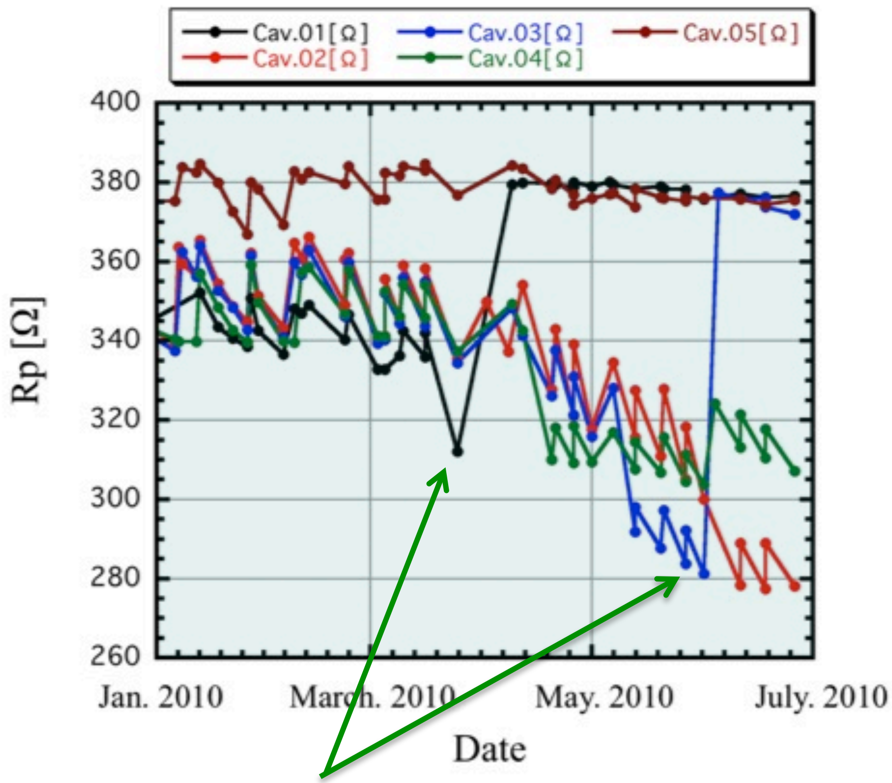
Max. ΔT: 65 °C with cooling

Y. Hori
Y. Hashimoto

The water cooling system decrease the temperature rise in the ferrite core ~ 1/5

Impedance reduction in MR cavities





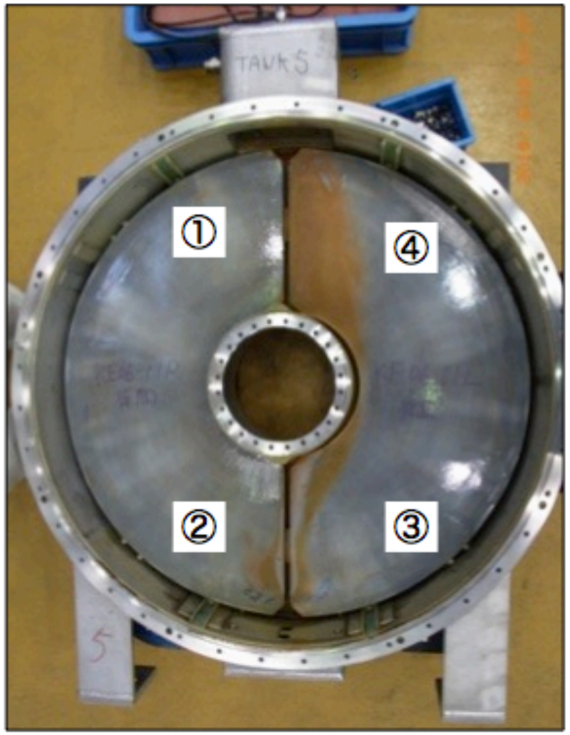
All cores were replaced for Cav. #1 and #3

-Impedance reduction was observed in all the cavities.

-Atmospheric exposure recovers the impedance. This procedure was regularly performed from January to June 2010.

-Oxidization/Deoxidization of cutting surface of the cores may be related to the impedance reduction.

Impedance reduction in MR cavities (cont'd.)



Cut cores in the cooling water tank

Cutting surfaces of the cut core:
damaged due to severe corrosion

-Polishing the cutting surface recovers the impedance.
The cutting surface of all the damaged cores are re-polished in this shutdown periods.

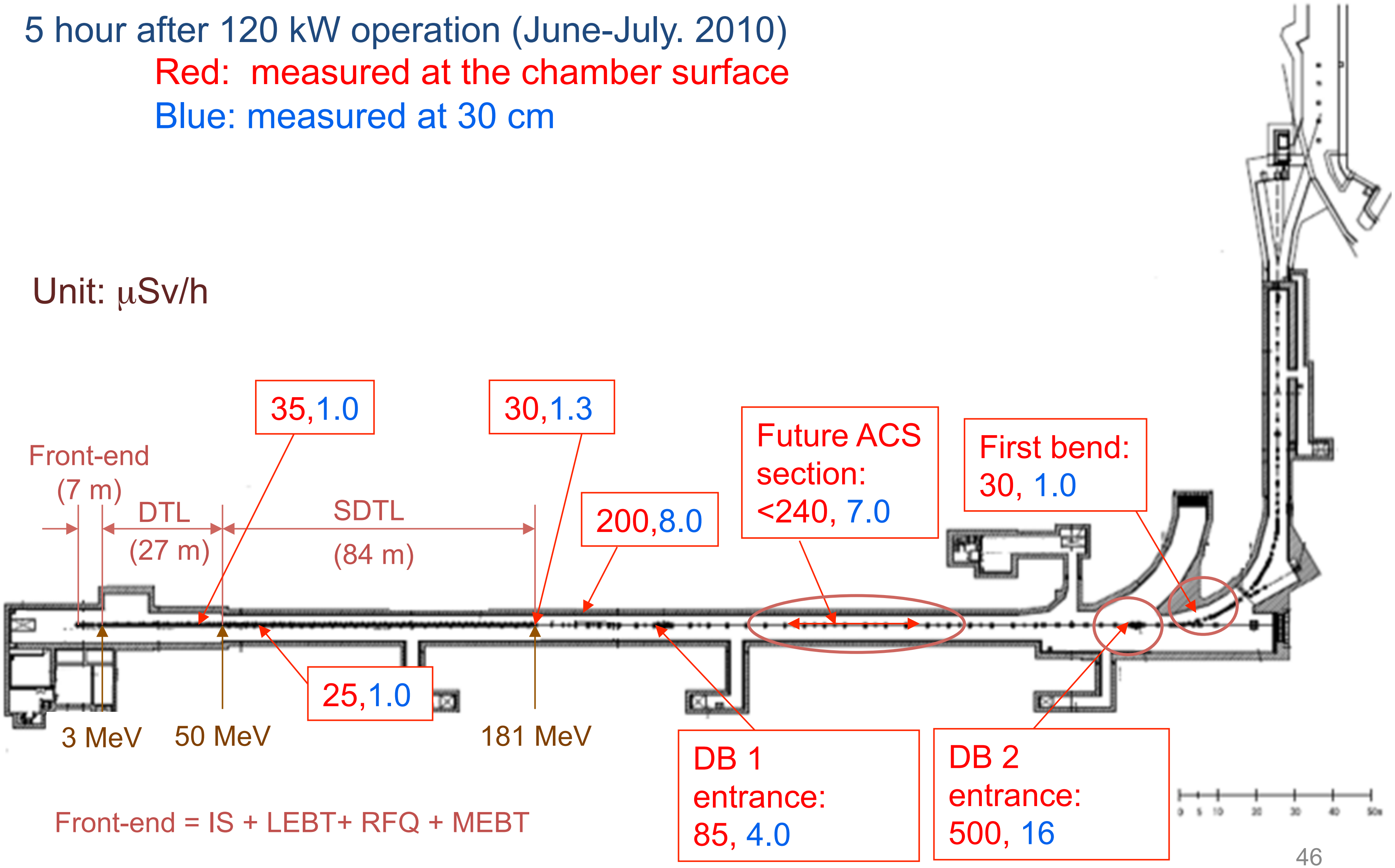
-Coating of cutting surface is under development. SiO2 coating seems to be effective and now testing.

Residual activation of the linac

K. Yamamoto

Residual radiation level after beam shutdown
5 hour after 120 kW operation (June-July. 2010)
Red: measured at the chamber surface
Blue: measured at 30 cm

Unit: μSv/h



Front-end = IS + LEBT+ RFQ + MEBT

Residual activation of the RCS

K. Yamamoto

Residual radiation level after beam shutdown
5 hour after 120kW operation (July, 2009)
Red: measured at the chamber surface
Blue: measured at 30 cm
Unit: μSv/h