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Challenges and solutions for J-PARC commissioning and early operation

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Accelerator Laboratory, KEK

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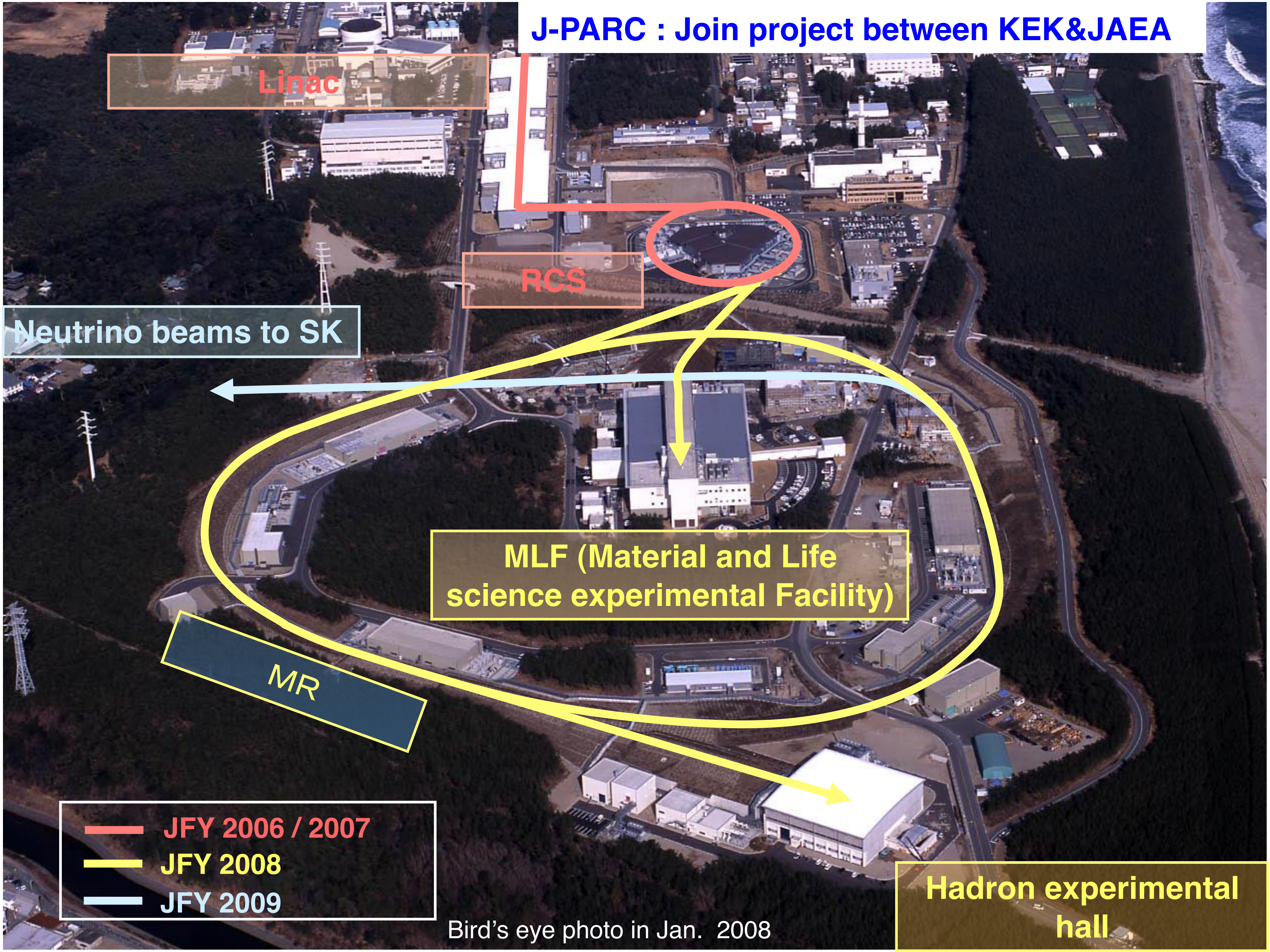
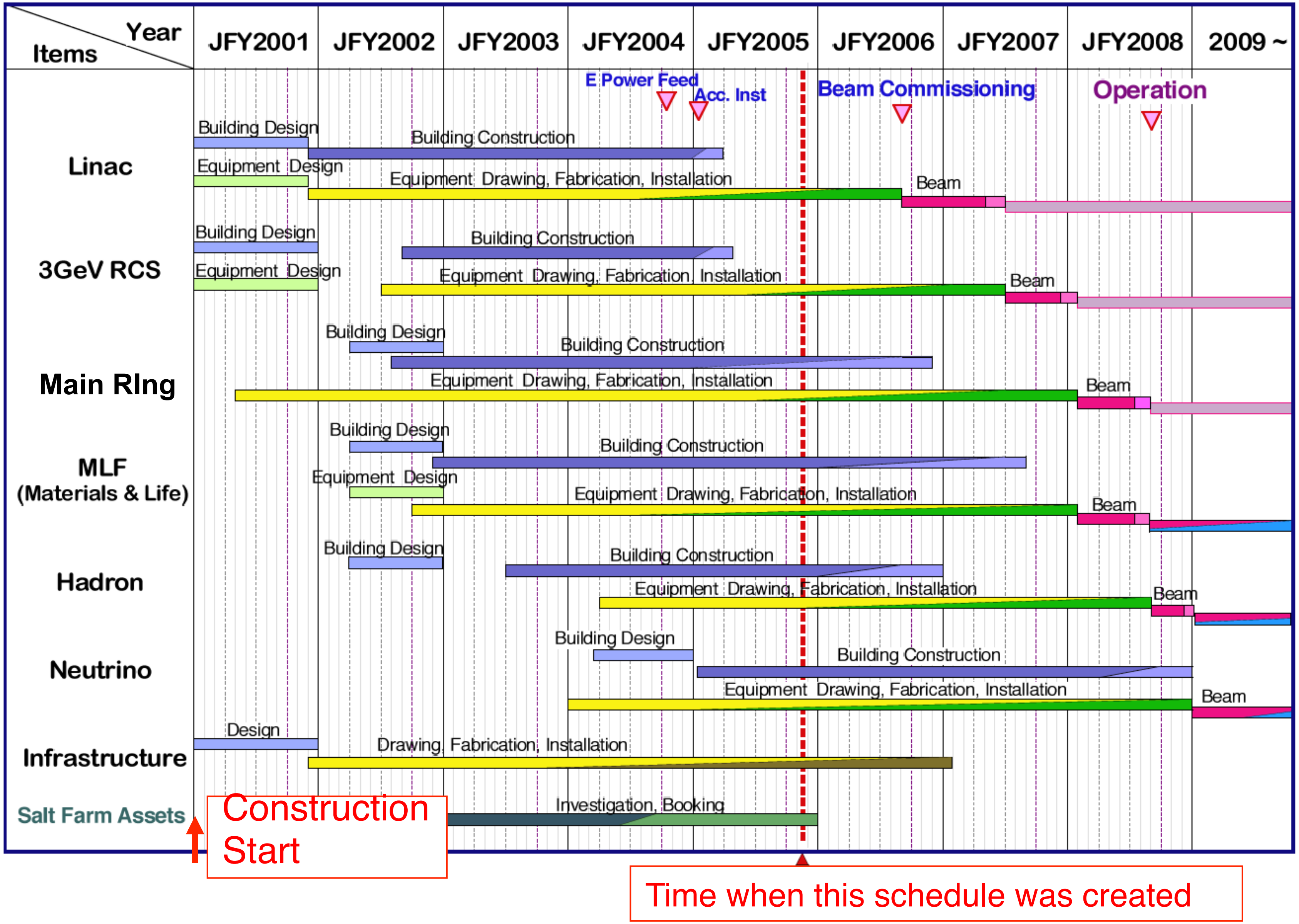


J-PARC : Join project between KEK&JAEA
Linac
RCS
Neutrino beams to SK
MLF (Material and Life science experimental Facility)
MR
Hadron experimental hall
JFY 2006 / 2007
JFY 2008
JFY 2009
Bird's eye photo in Jan. 2008

J-PARC Construction Schedule

Feb. 27 2006



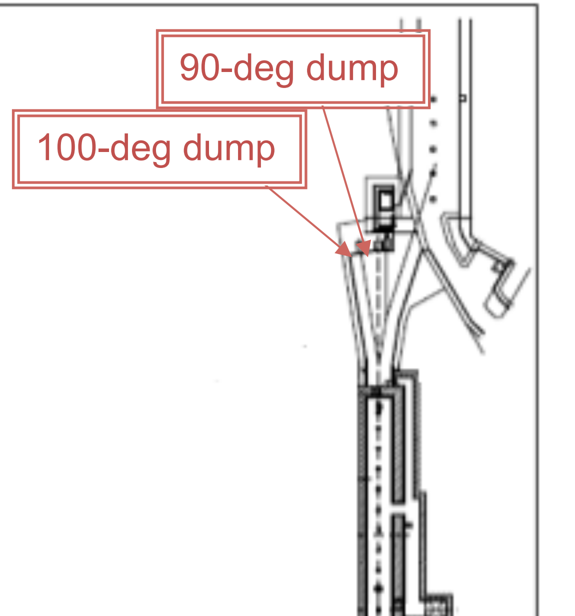
The beam commissioning of the J-PARC facility was started from the upstream accelerators while the construction of the downstream facilities was in progress. All the facilities started the beam commissioning on schedule.

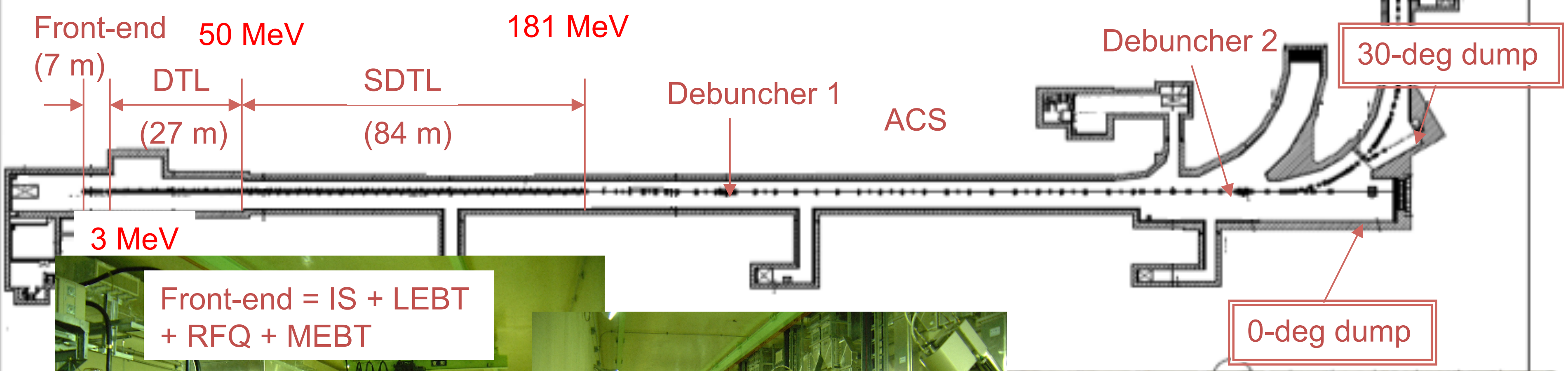
Status of the Linac/RCS

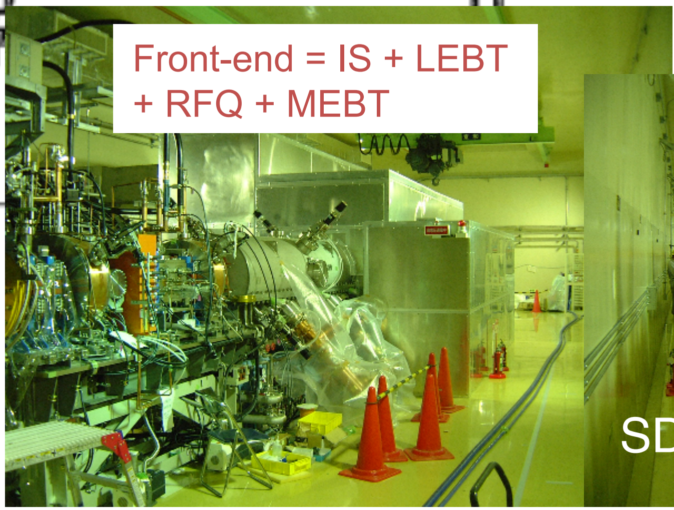
- challenges and solutions -

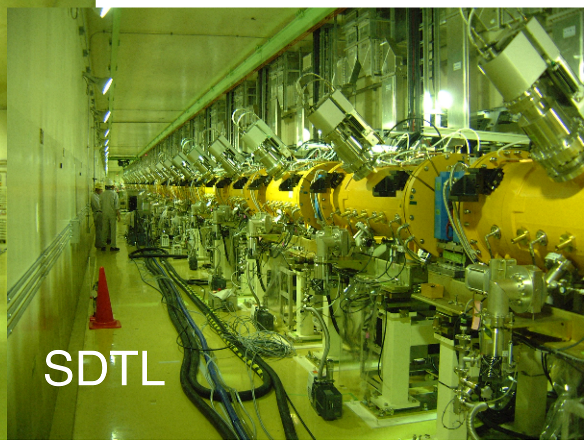
Linac

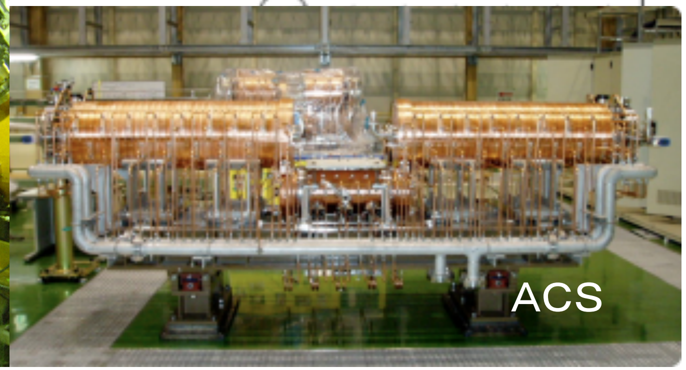
- **Particle:** H⁻
- **Energy:** 181 MeV at present
  400 MeV by installing ACS in 2012
  (Construction of ACS has been started.)
- **Peak current:** 30 mA at 181 MeV
  50 mA at 400 MeV in the future
- **Repetition:** 25 Hz
- **Pulse width:** 0.5 msec





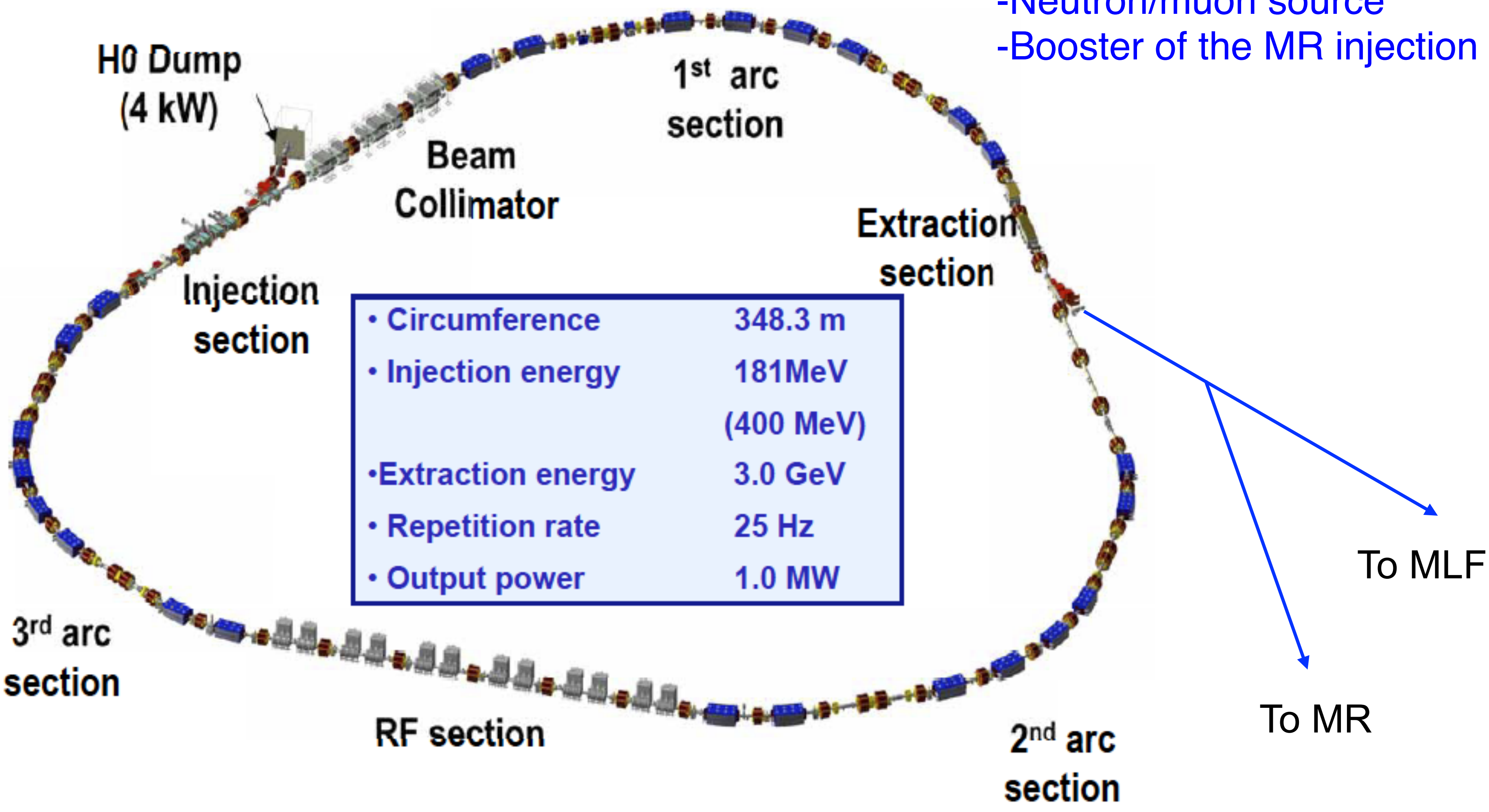






RCS (Rapid Cycling Synchrotron)

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

Performance recovery of LINAC-RFQ

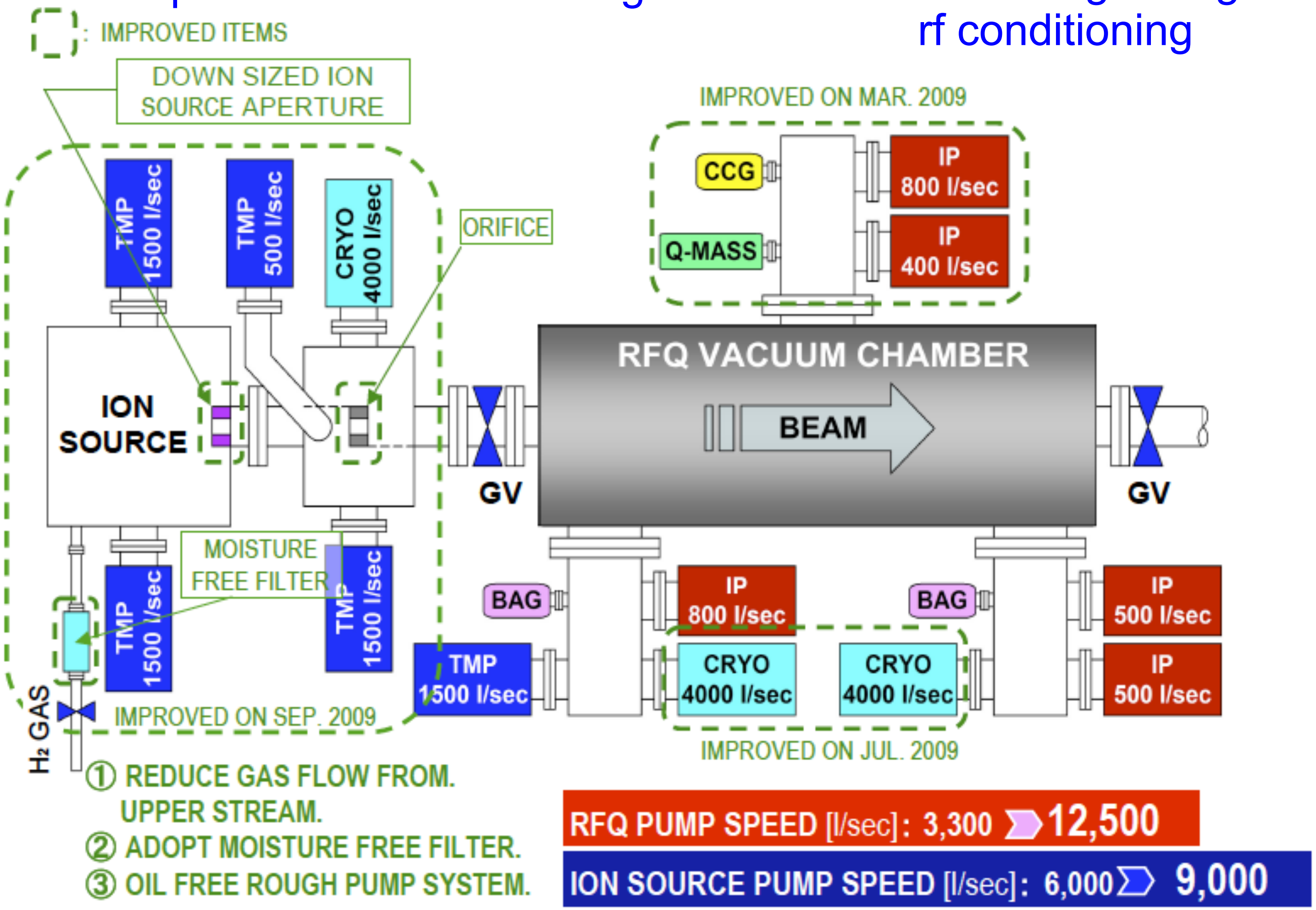
Since the autumn of 2008, the most urgent issue of the linac was discharge in the RFQ. The RCS beam power for users was limited at 20 kW due to the RFQ problem.

In the 2009 summer shutdown,

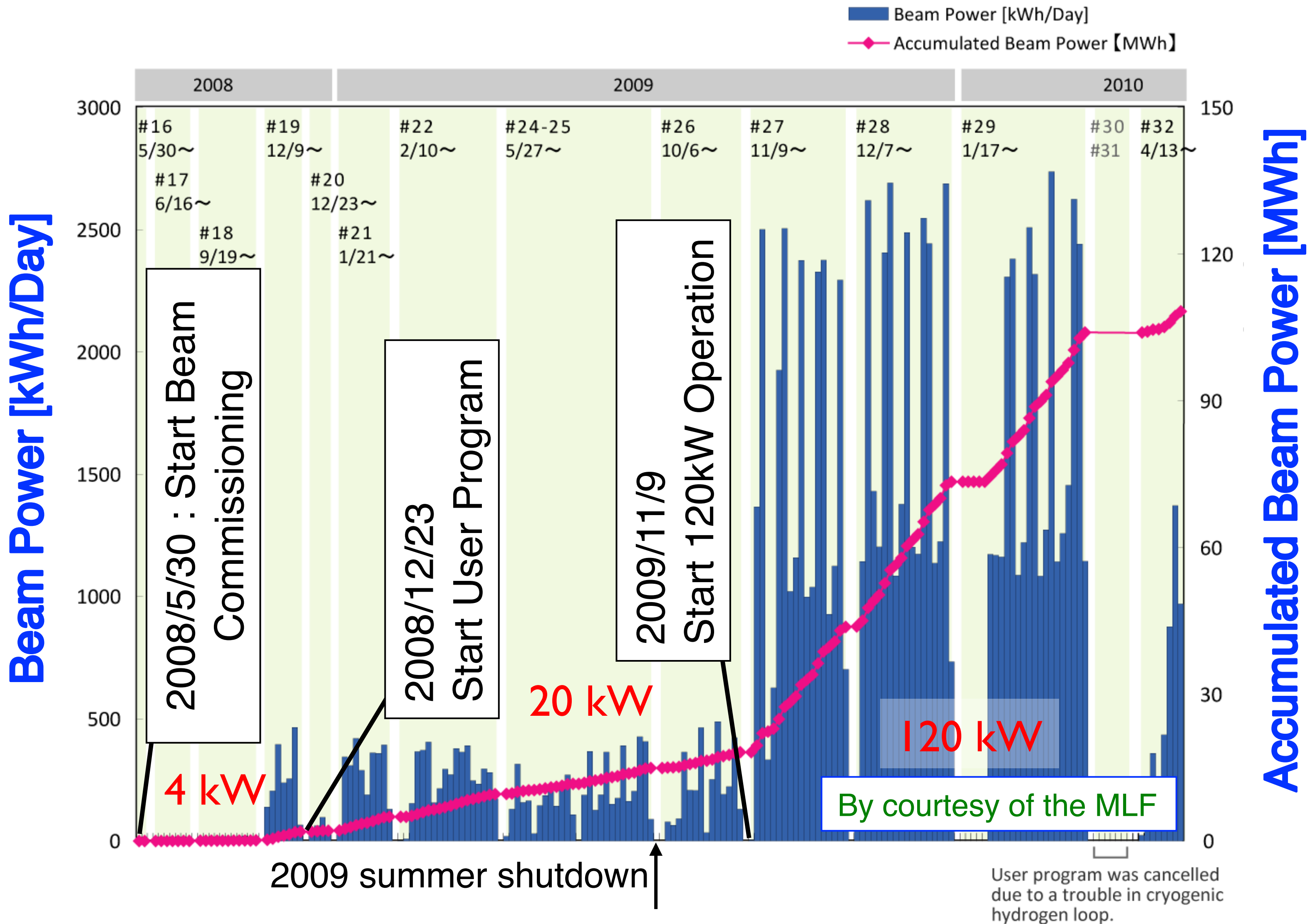
- improved vacuum system
- performed in-situ baking

→

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



History of beam delivery to MLF

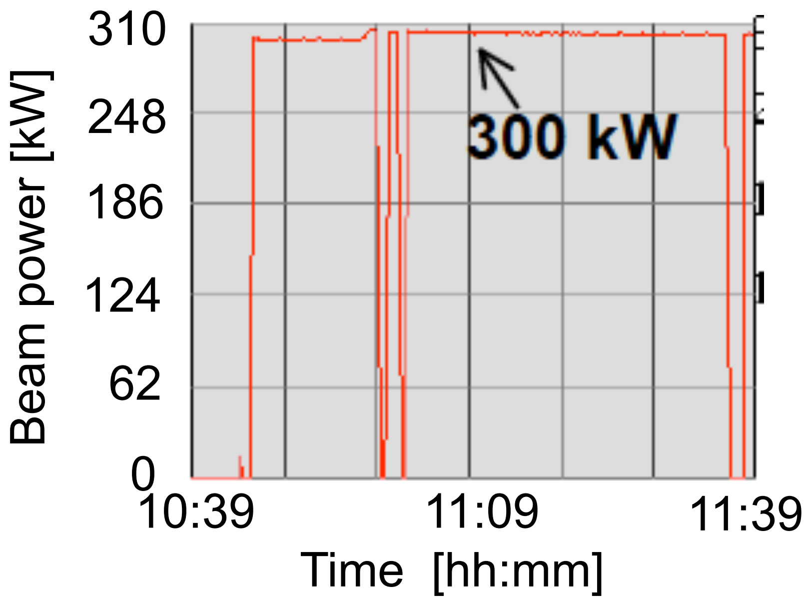


After the recovery of Linac-RFQ, high power operation of the RCS has became possible and 120 kW operation has started for the MLF users.

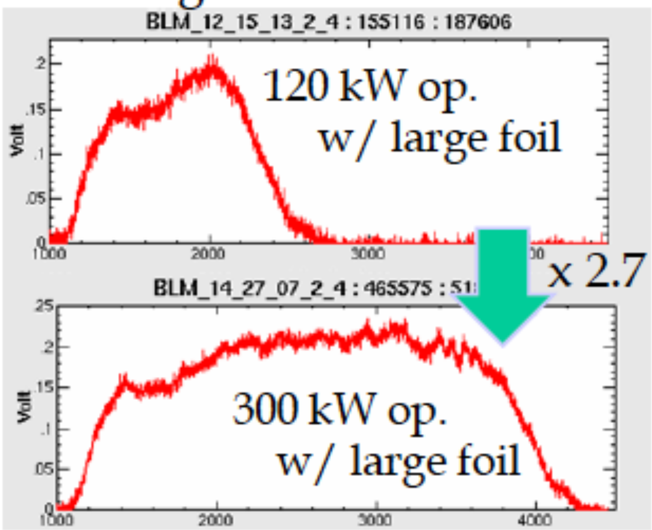
Neutron beamline : 12 beamlines are now under commissioning and open for users.

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

300 kW operation : achievement and issues



BLM signals @ H0 branch



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

Issue to be solved before starting the routine operation of 300 kW for the MLF users is the beam loss problem.

The following improvements planned in this summer shutdown:

(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

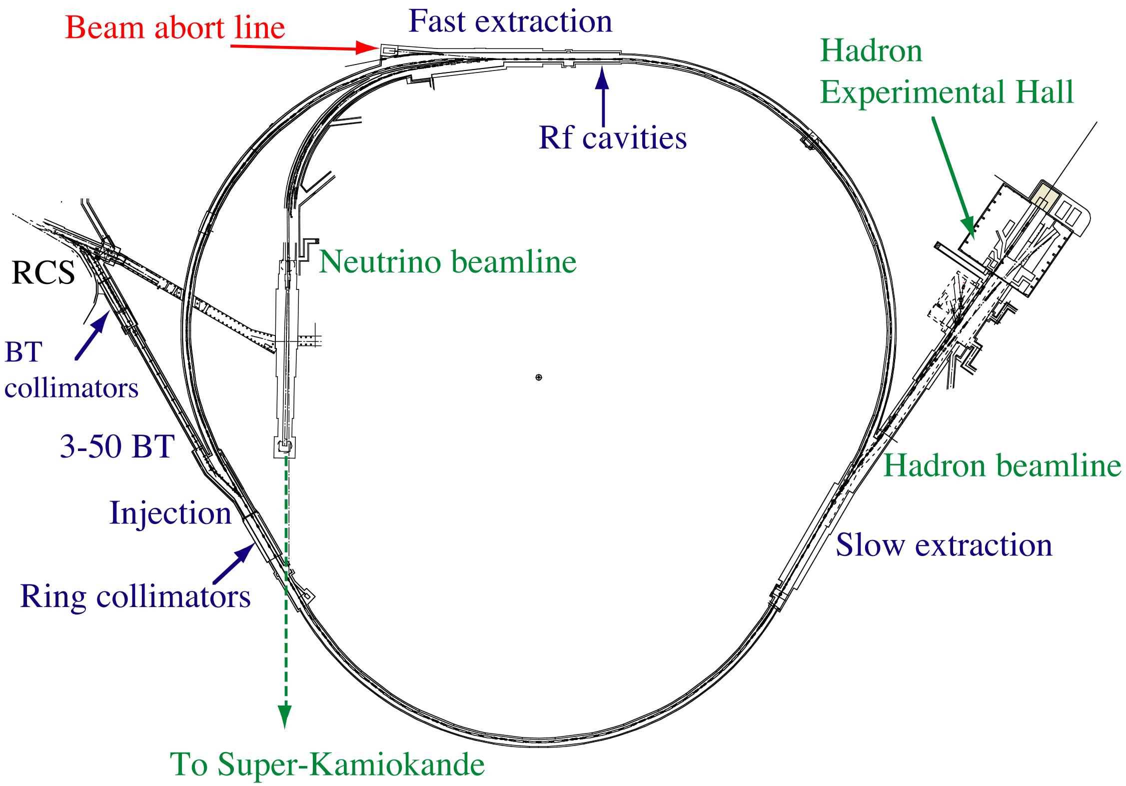
The sextupoles are driven by DC power supplies and chromaticity is corrected only at the injection energy. AC power supplies are necessary to reduce beam loss during acceleration .

Status of the Main Ring

- challenges and solutions -

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**

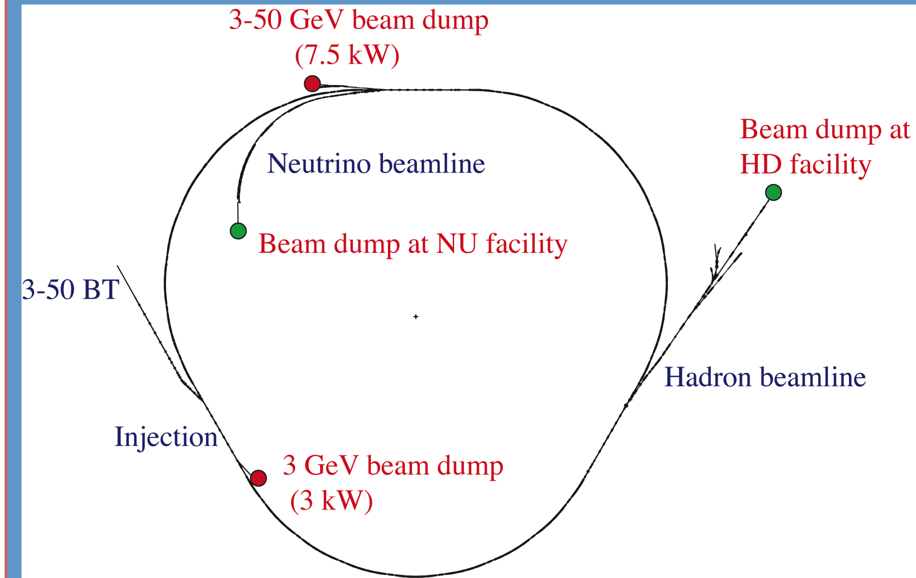


Three dispersion free straight sections of 116-m long:
- **Injection and collimator systems**
- **Slow extraction (SX)**
  to Hadron experimental Hall

-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)

Brief history of MR initial beam commissioning

Just after the success of
30 GeV acceleration



Layout of beam dumps

First stage: 2008/5-6 (~12 days)
- May 20:First beam circulation without rf capture
- May 22:1000 turns circulation with rf, beam extraction to the injection beam dump

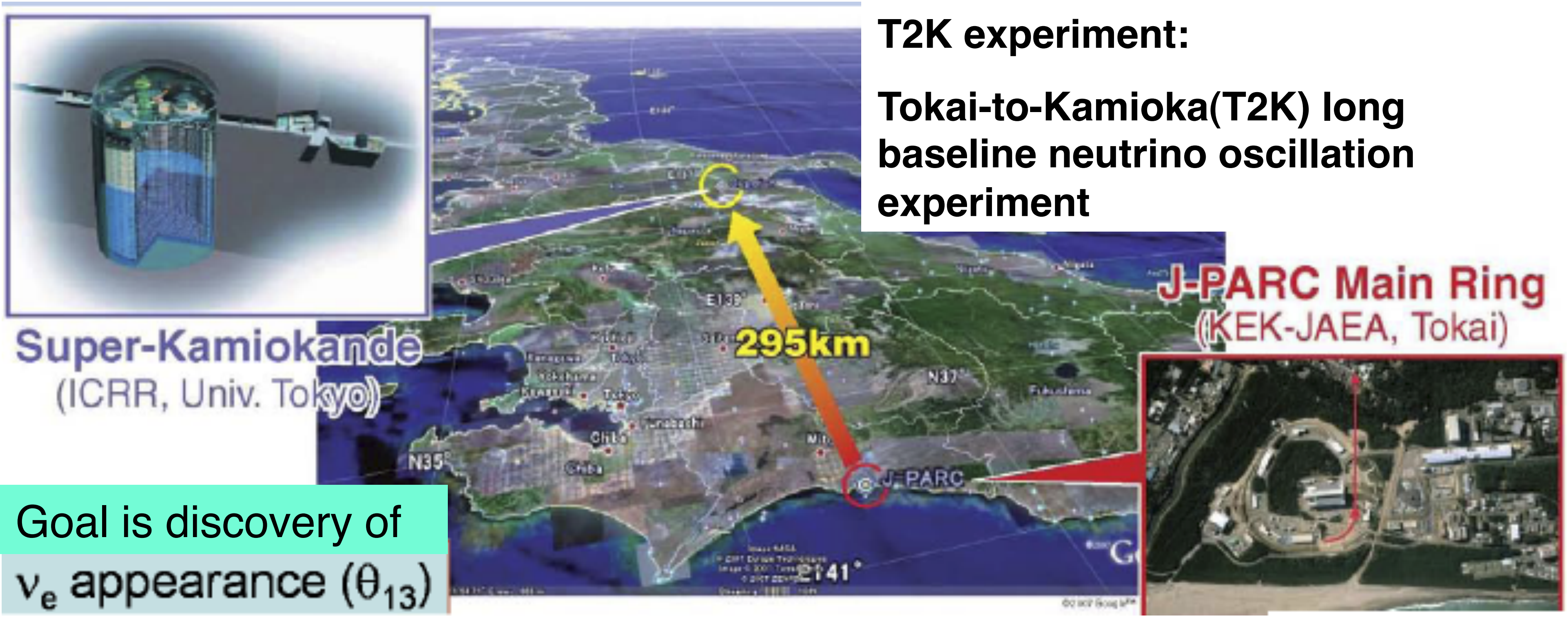
2008 summer/autumn shutdown: 2008/7-11

Second stage: 2008/12- 2009/2 (~26 days)
- Dec 23: Acceleration from 3 GeV to 30 GeV and beam extraction to abort beam dump using fast extraction system.
- Jan 27: Beam extraction to the hadron beam line using slow extraction system.

Third stage: 2009/4-6 (~27 days)
- April 23: Beam extraction to neutrino beam line using the fast extraction system.

2009 summer shutdown: 2009/7-9

Fast Extraction



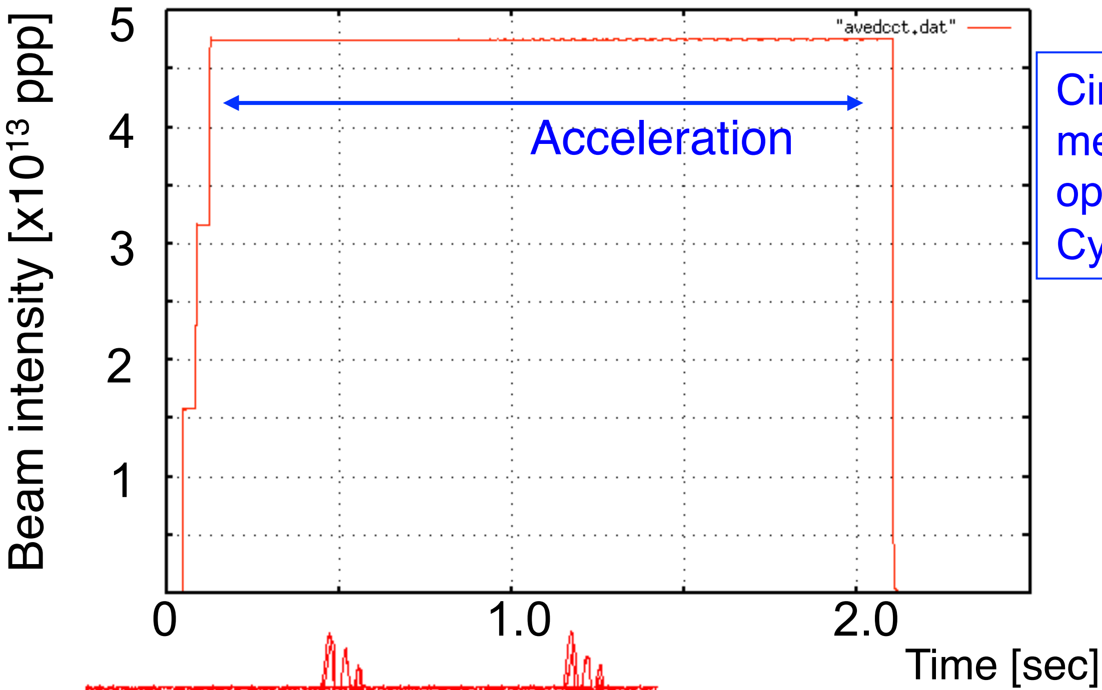
T2K experiment:

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

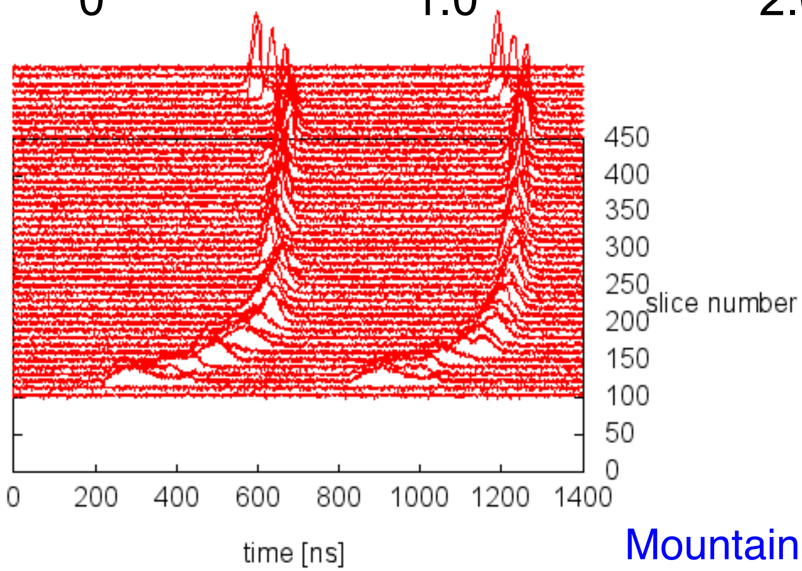
Goal is discovery of
ν_e appearance (θ_{13})

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.



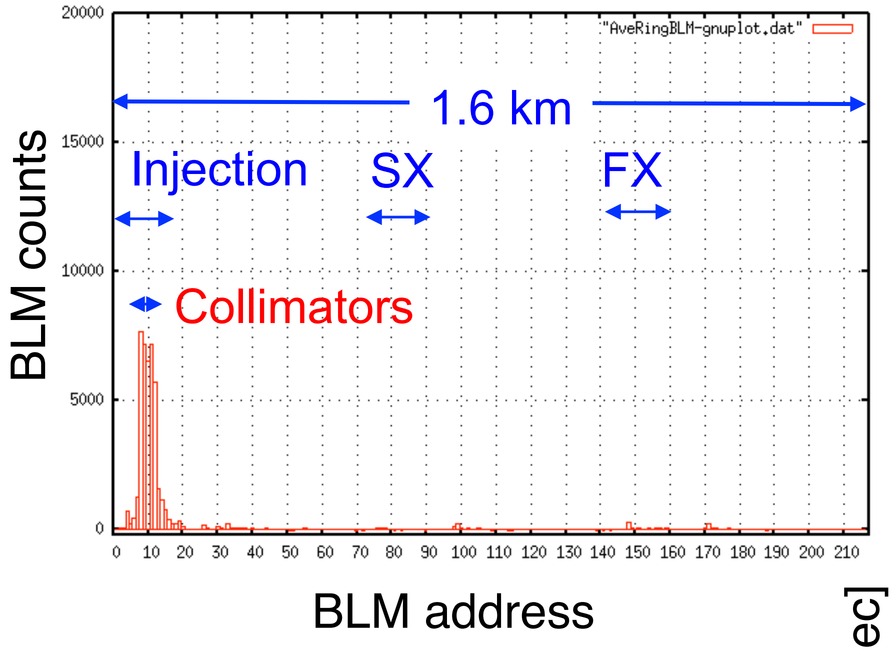
RCS :
Transverse painting:
150 πmm.mrad
Longitudinal painting:
Momentum offset 0.2 %
Phase sweep -100 deg
2nd Harmonics ON

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.

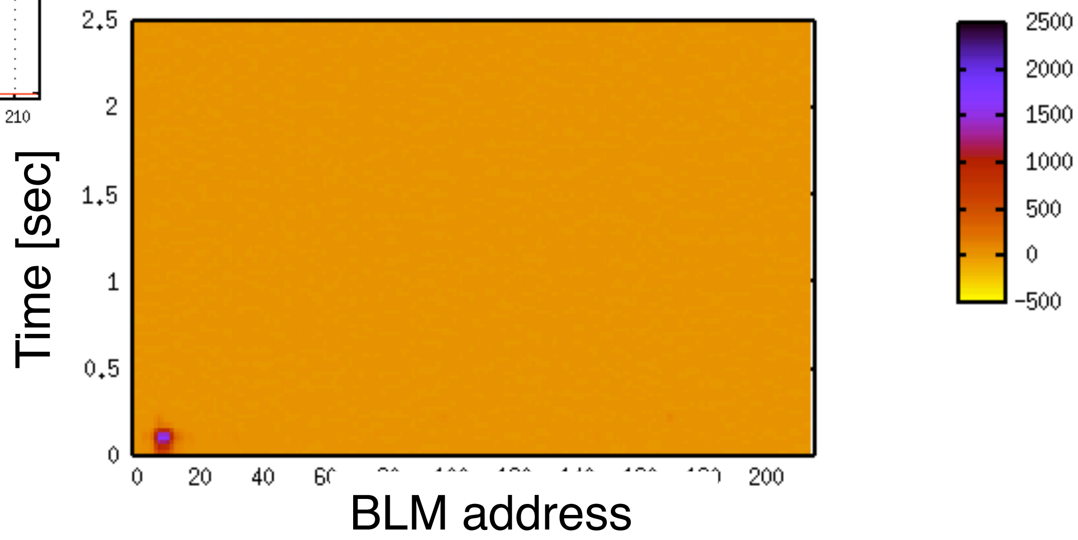
Beam delivery to T2K (2)

Integrated loss counts for one shot measured by BLM in the 65 kW operation



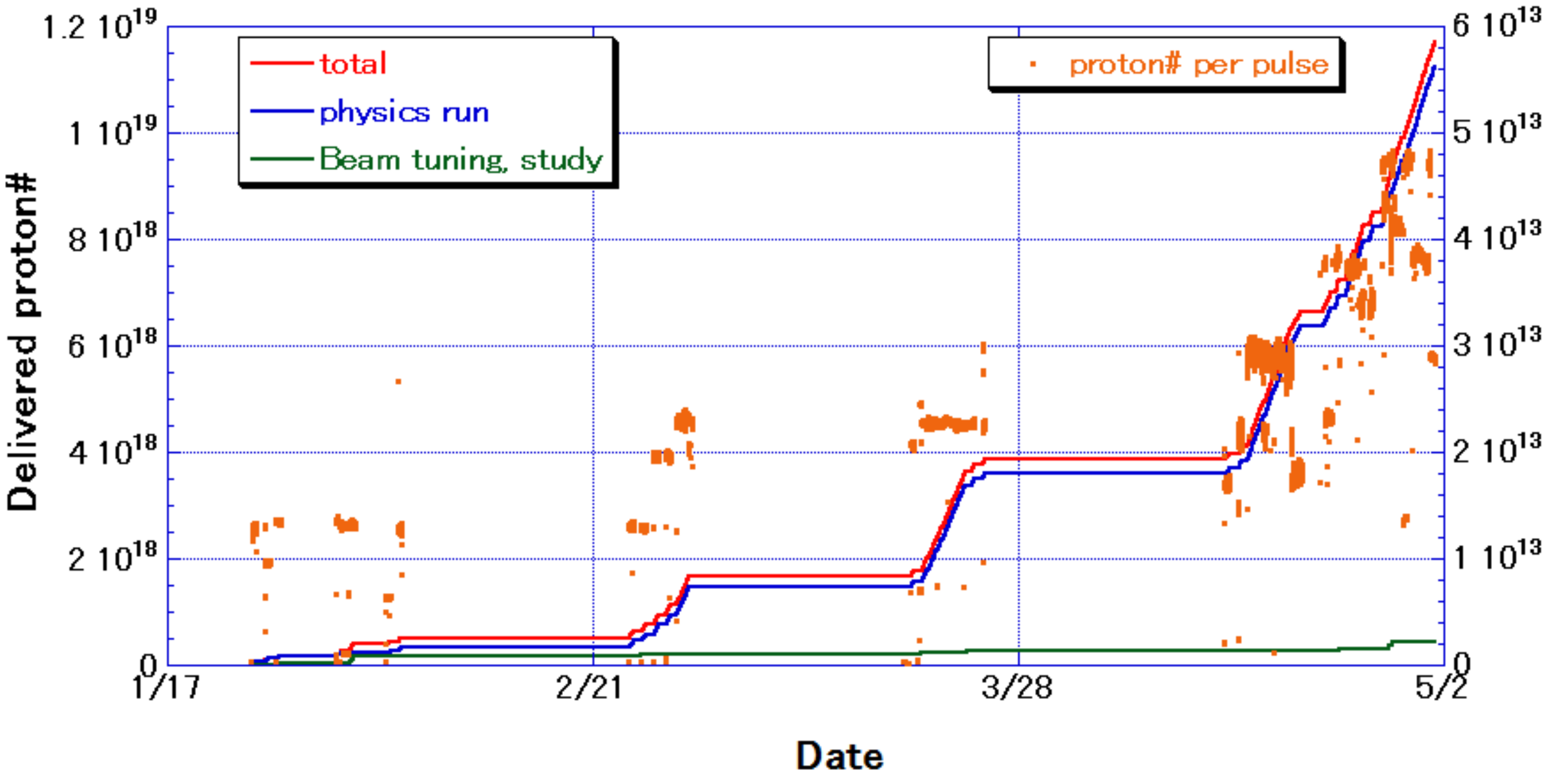
Beam loss localizes on the ring collimator section.

No beam loss during acceleration.



So far, the beam power of 70 kW in maximum has been delivered to the T2K experiment.

Delivered proton number on the graphite target



68 kW

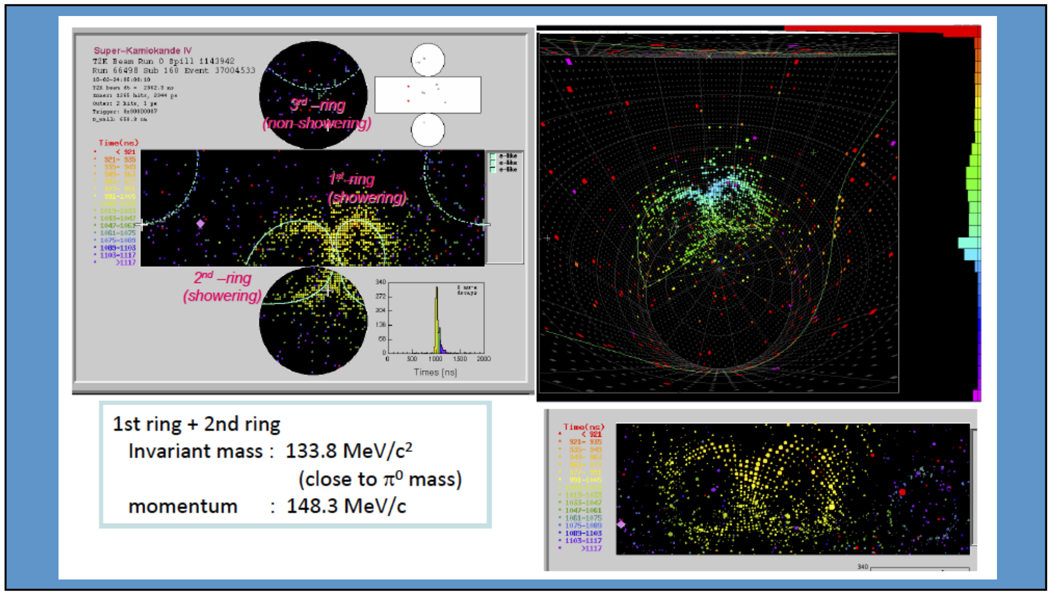
55 kW

41 kW

28 kW

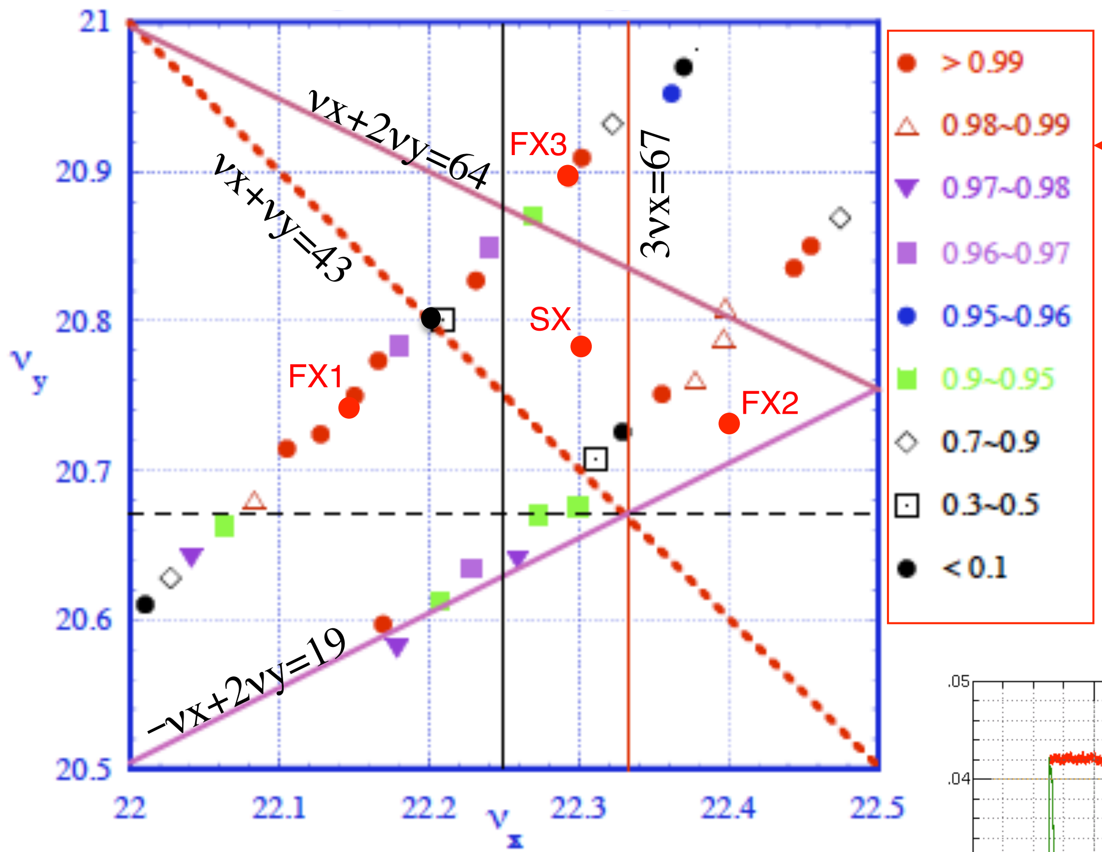
14 kW

First neutrino event at SK on Feb. 24, 2010.



By courtesy of the T2K group

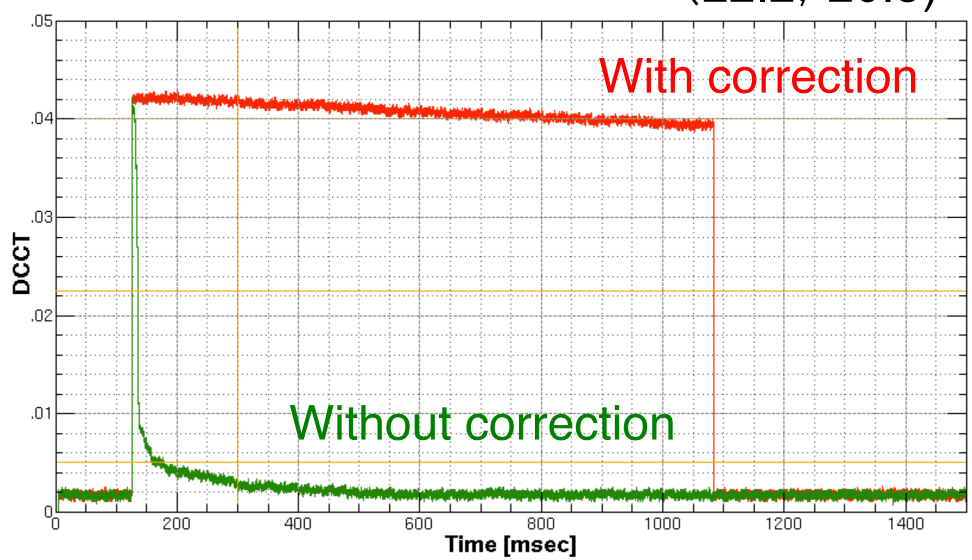
Linear coupling resonance correction



3 GeV DC mode
4e11 ppb ×1 bunch
Beam survival after 1.9 sec storage

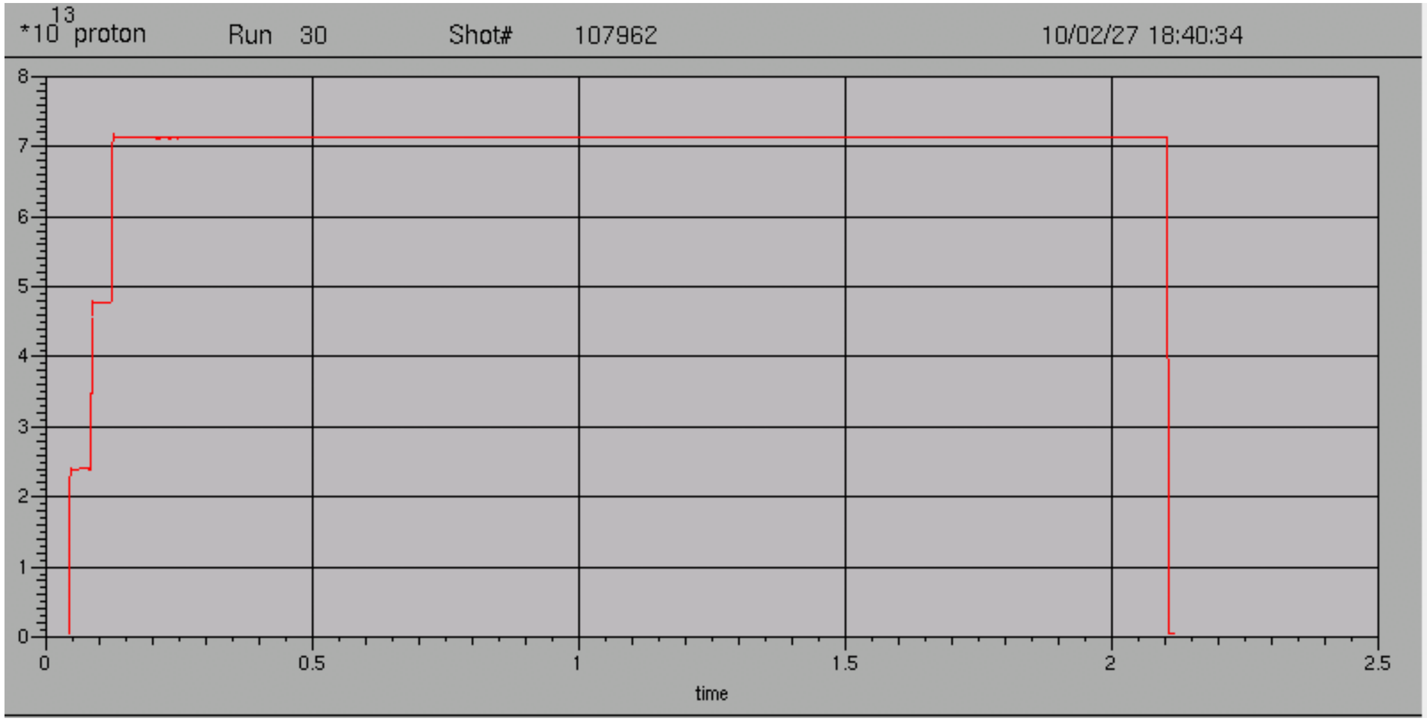
On the linear coupling resonance, we have large beam loss. Correction of the linear coupling resonance is important for high power operation in the MR.

(22.2, 20.8)



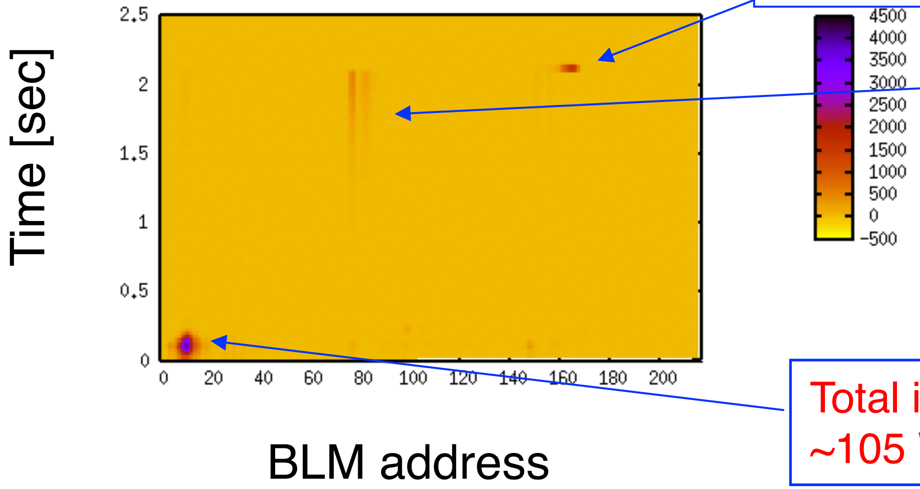
Linear coupling resonance correction Is performed using vertical local bumps in two SDs,SDA019 and SDB028. A pair of bump heights of +4 mm in SDA019 and -5 mm in SDB028 is effective for the correction.

Demonstration of 100 kW equivalent beam



Tune (22.40,20.76)

The extracted particles to abort dump is 7.2e13 ppp, it corresponds to 100 kW if operated in 3.52 sec cycle.

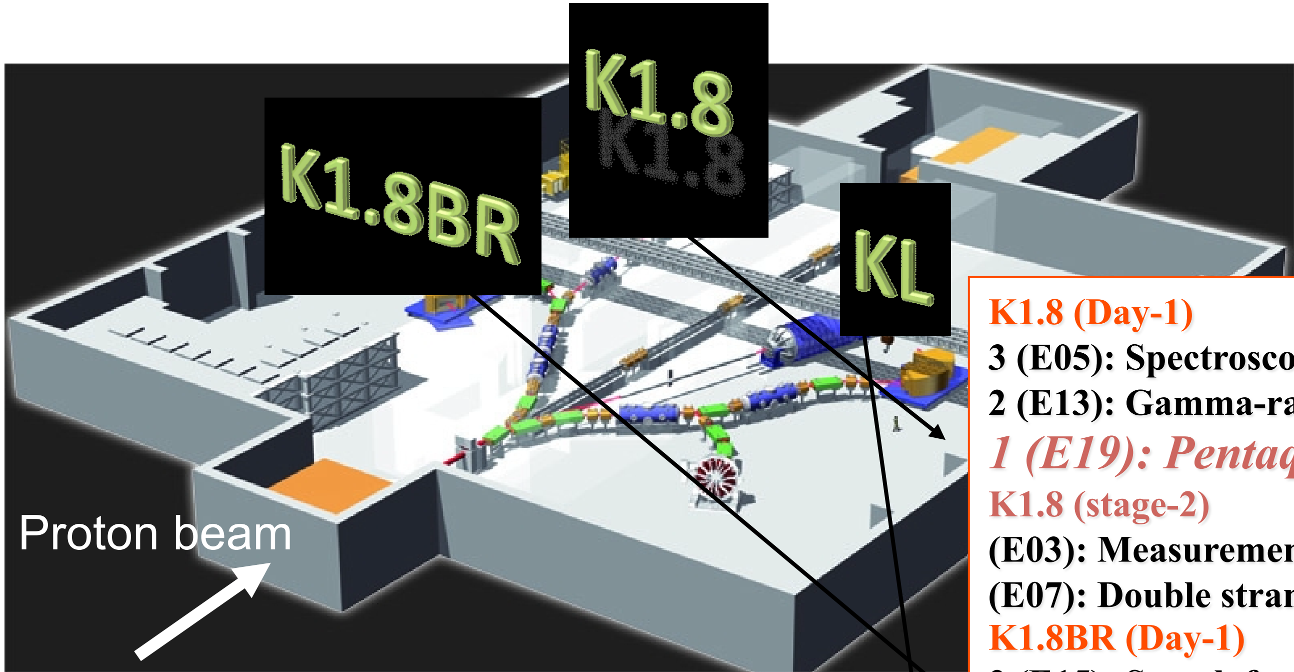


Not a real beam loss: reflection from the beam dump

Beam loss of 10^9 due to pressure rise.
-> Continuous beam operation will decrease the loss.

Total injection loss is 7.7 e11
~105 W < collimator limit 450 W

Slow extraction



Layout of beam lines at hadron experimental facility in February 2010.

K1.8 (Day-1)

3 (E05): Spectroscopic study of hypernuclei

2 (E13): Gamma-ray spectroscopy of light hypernuclei

1 (E19): Pentaquark search in $\pi p \rightarrow K^- X$

K1.8 (stage-2)

(E03): Measurement of X-rays from Ξ Atom

(E07): Double strangeness system

K1.8BR (Day-1)

2 (E15): Search for deeply-bound kaonic nuclear states

1 (E17): Precision spectroscopy of kaonic ^{3}He

K1.1

K1.1BR (stage-1)

(E06): Measurement of T-violation in $K^+ \rightarrow \pi^0 + \mu^+ + \nu$

High-P (stage-1)

(E16): Chiral symmetry in QCD

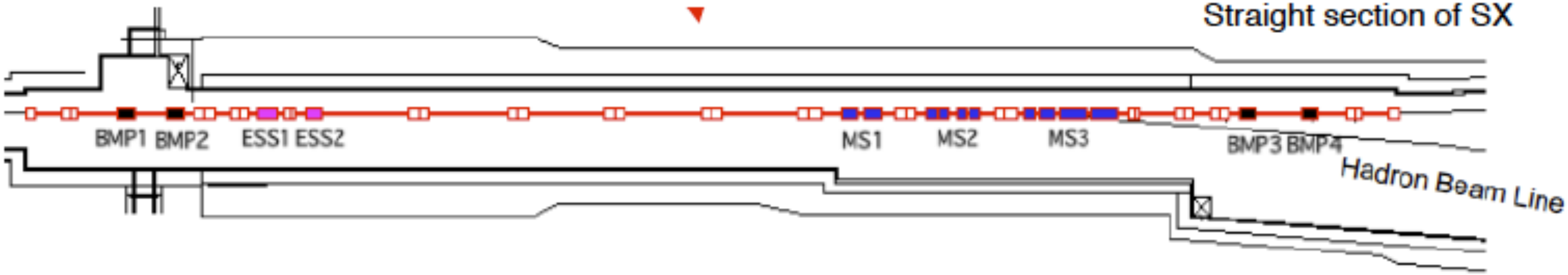
KL (stage-2)

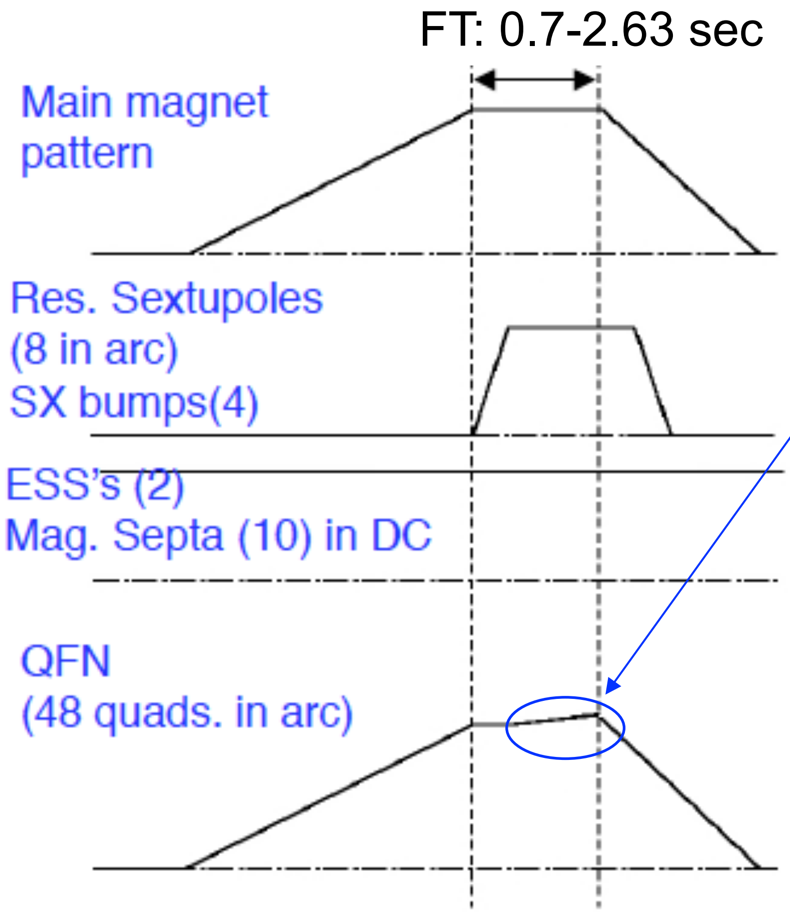
(E14): $K_L \rightarrow \pi^0 + \nu\nu$

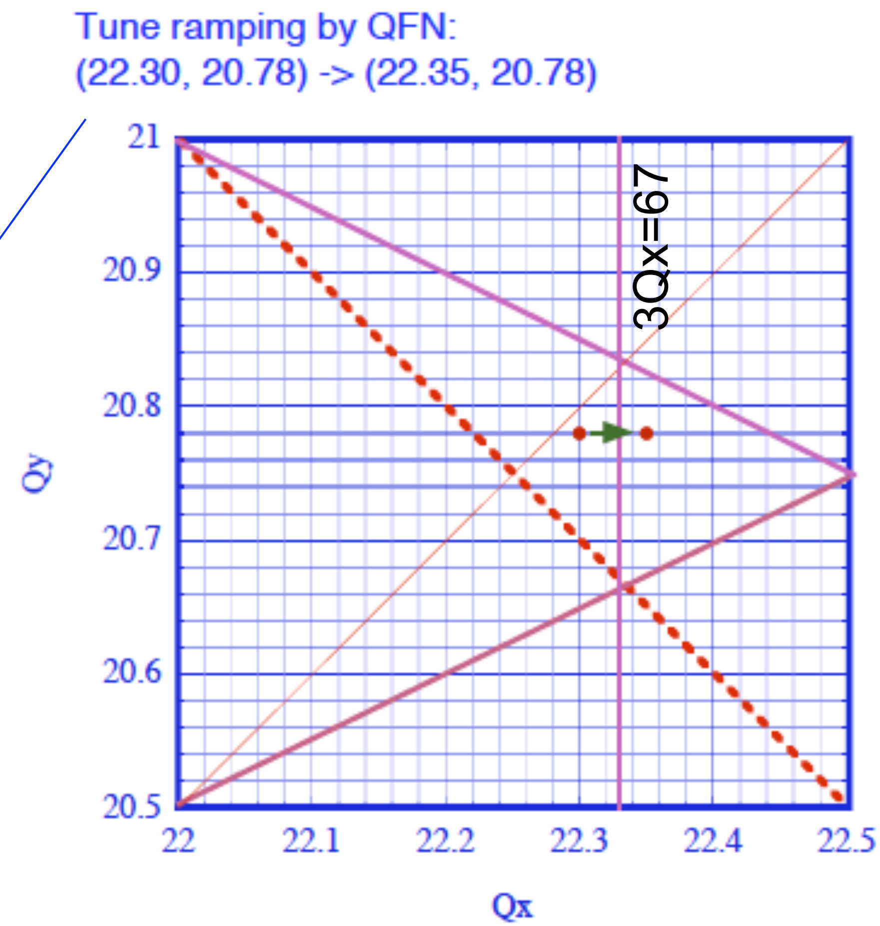
COMET (New beam line, deferred)

μ-e conversion experiment at sensitivity of 10^{-16}

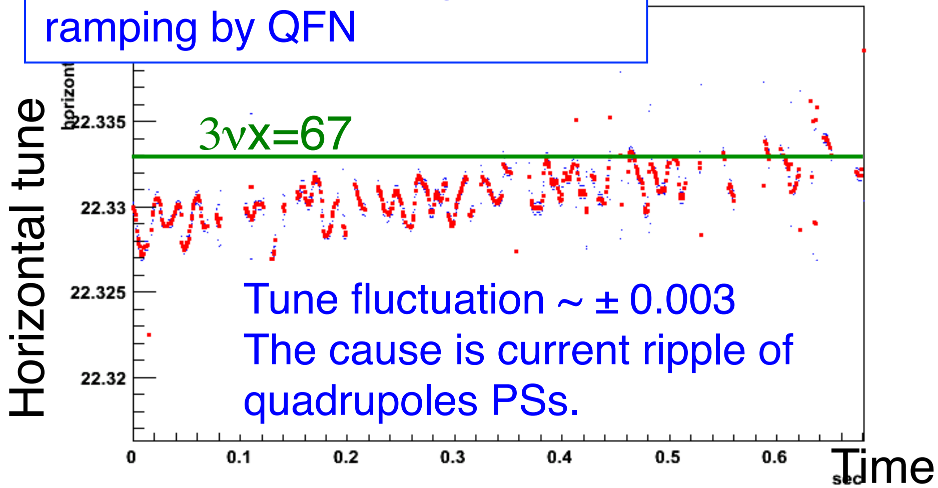
Slow extraction





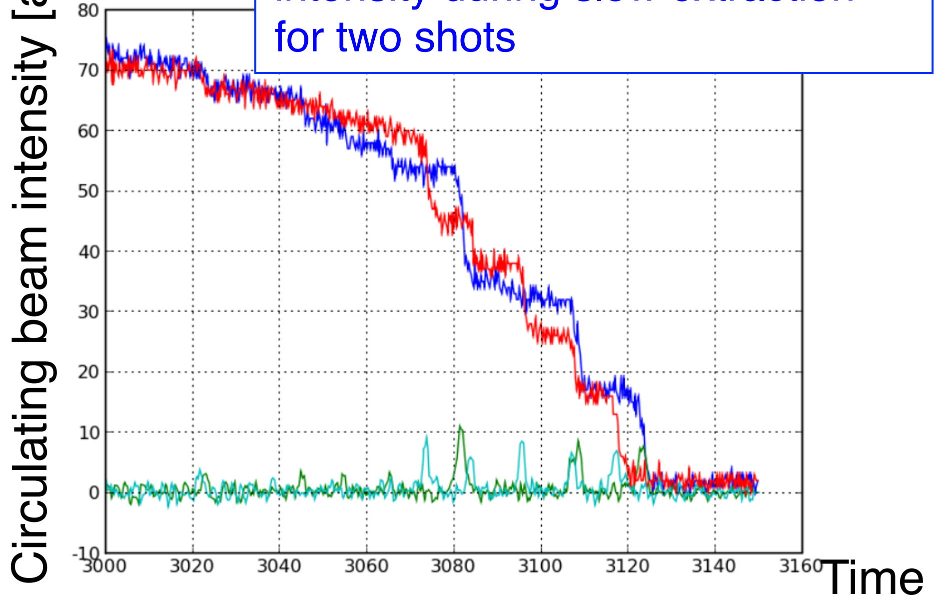


Measured tune during the tune ramping by QFN



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

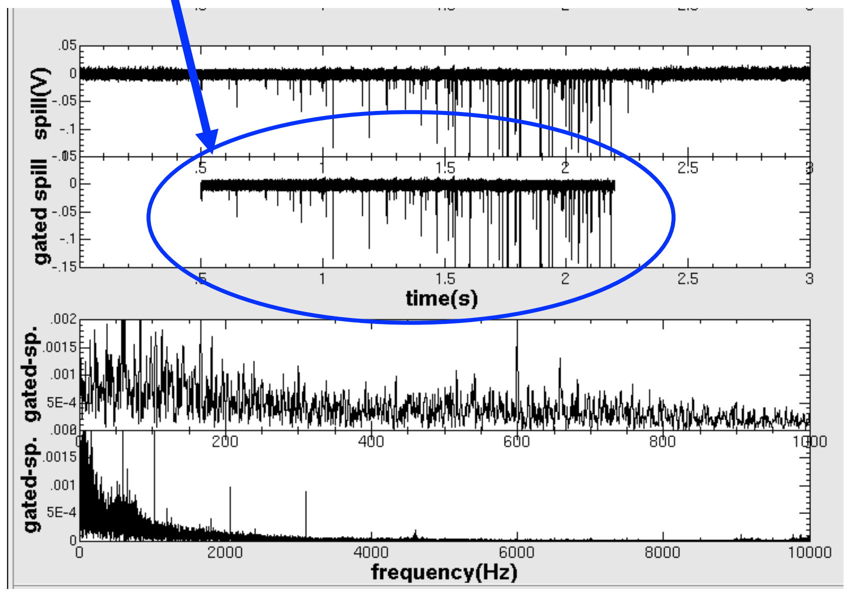
Variation of circulating beam intensity during slow extraction for two shots



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

Spill monitor signal in HD beam line

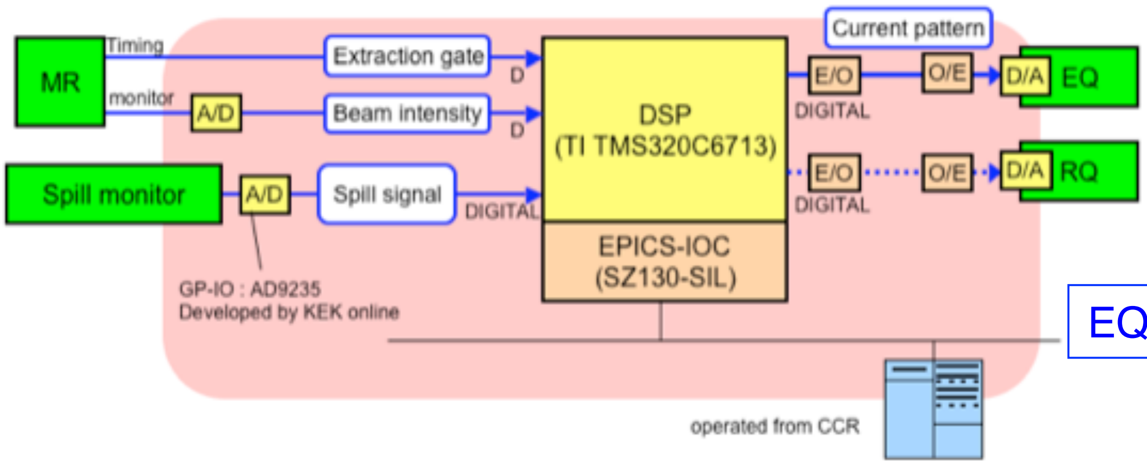
Extracted beam has many sharp peaks.



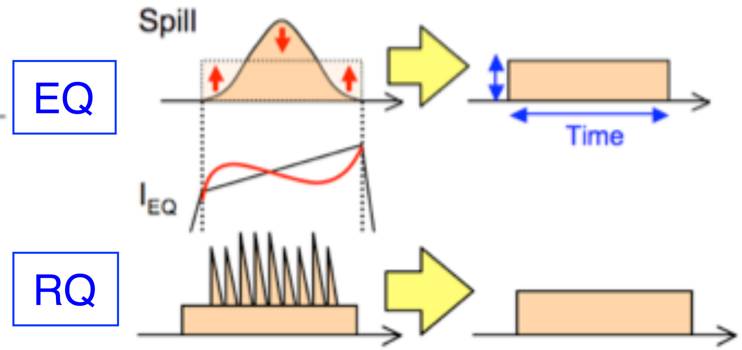
$$Duty = \frac{\left(\int_0^T I dt\right)^2}{\int_0^T dt \int_0^T I^2 dt} \quad \sim 1\ \%$$

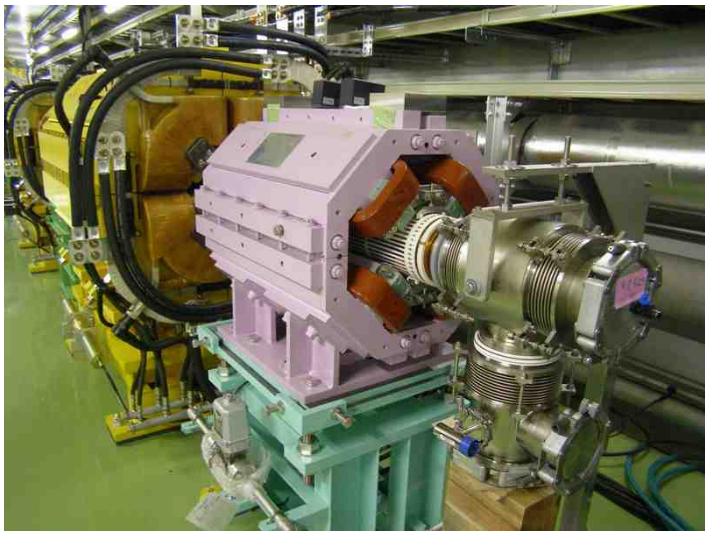
Improvement of spill structure (1)

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

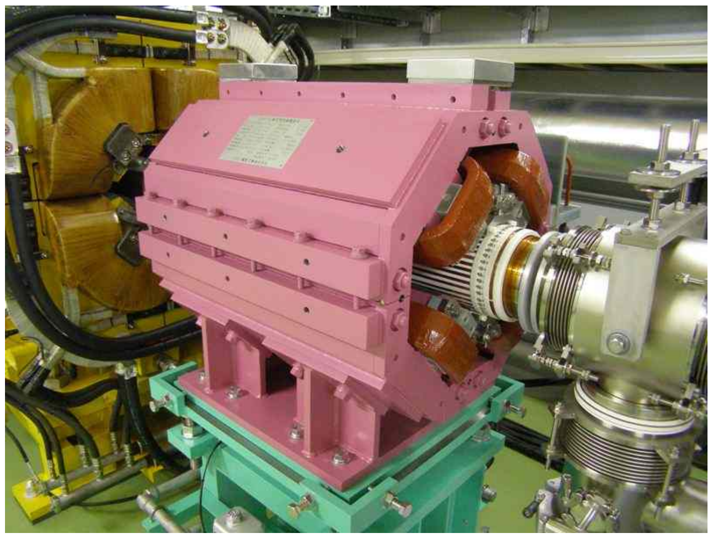


Beam spill signal is fed into the DSP system and current pattern of the correction is sent to PSs of feedback quadrupoles.





EQ: for constant spill structure (< 100 Hz)

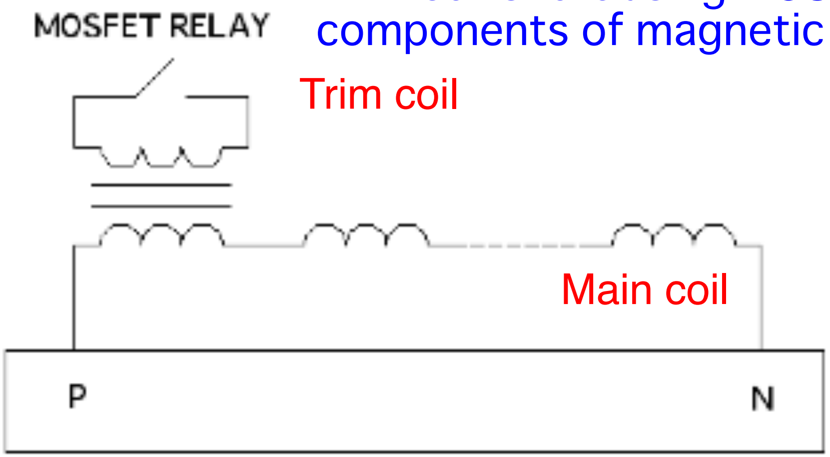


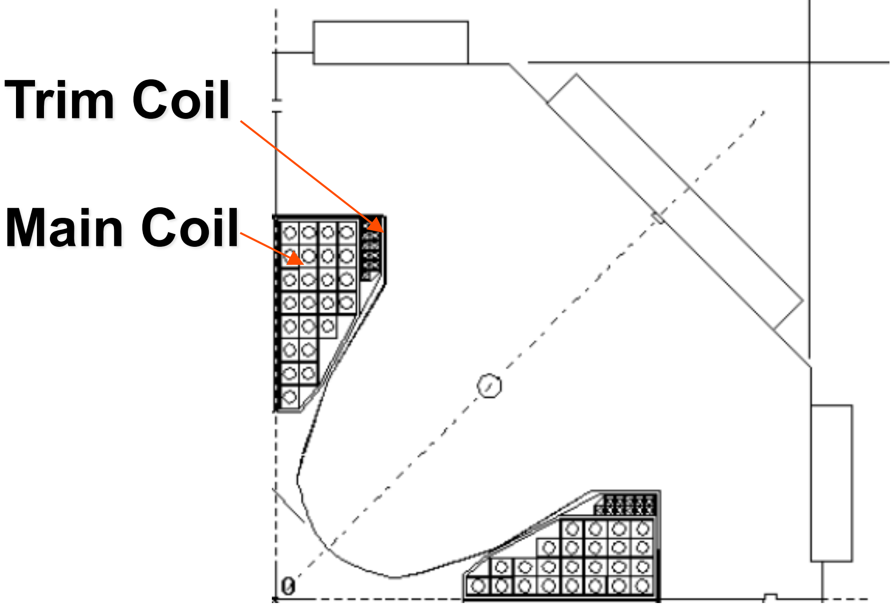
RQ: for ripple compensation (< 3 kHz)

Improvement of spill structure (2)

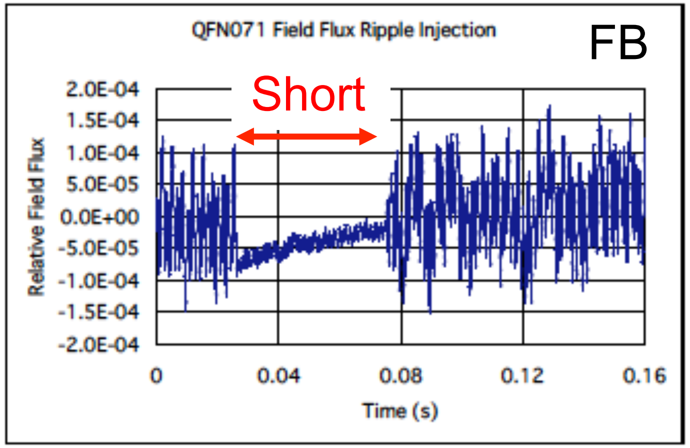
All the quadrupoles has trim coils. We set MOSFET RELAY to the trim coil circuit.

Trim coil short using MOSFET RELAY reduces the AC components of magnetic field

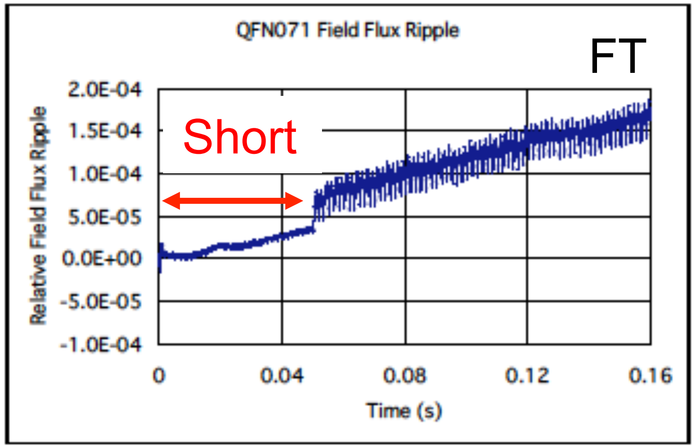




Injection
Ripple(p-p)
Open
3.1×10-4
Short
3.9×10-5



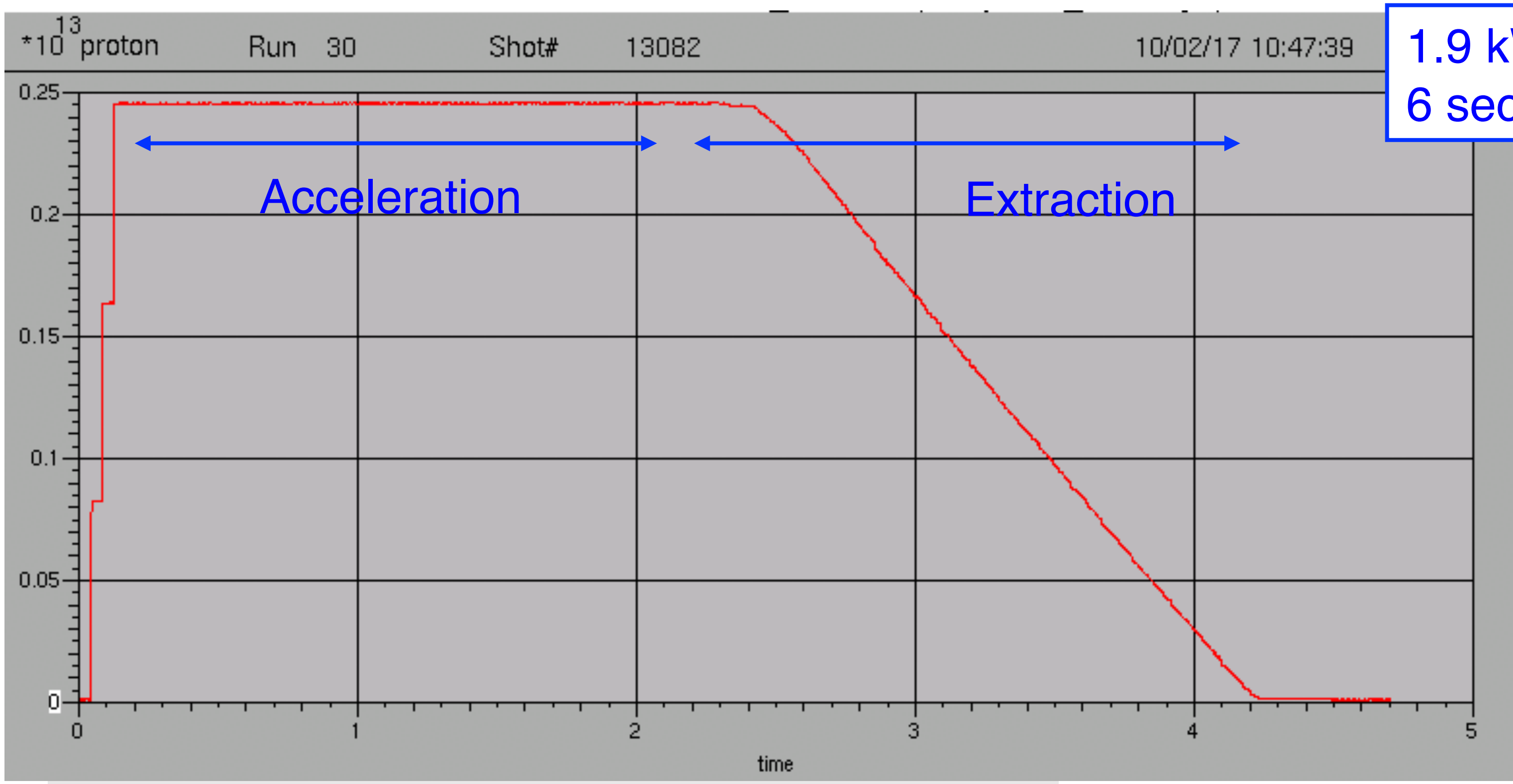
Flat top
Ripple(p-p)
Open
4.4×10-5
Short
9.1×10-6



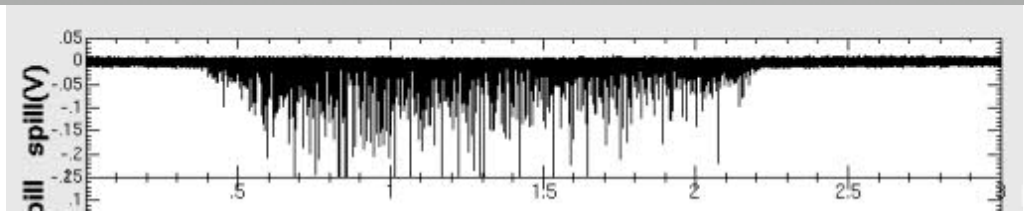
Ripple ~1/6

Operation for users in hadron experimental facility

With spill Feedback EQ/RQ+trim coil short



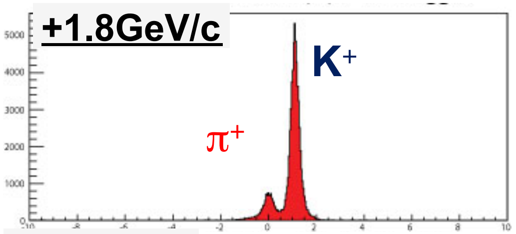
1.9 kW at
6 sec cycle

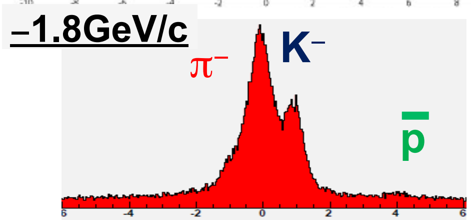


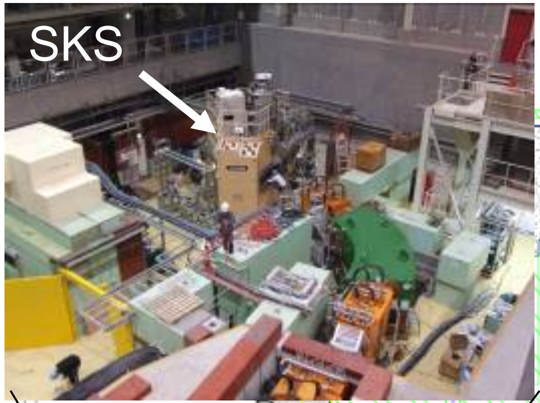
Duty of the spill
Improved from 1 % to 11 %

Estimated extraction efficiency ~ 98.5 %

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

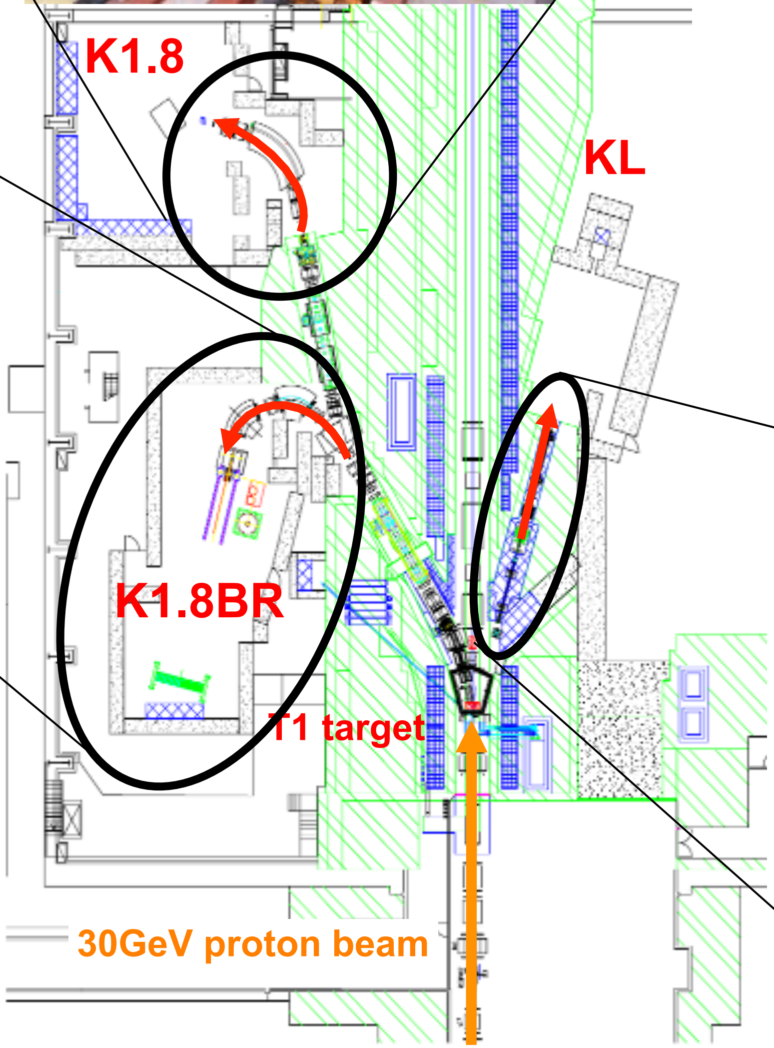


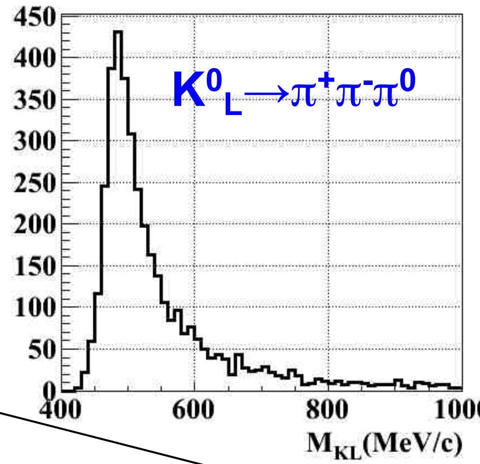


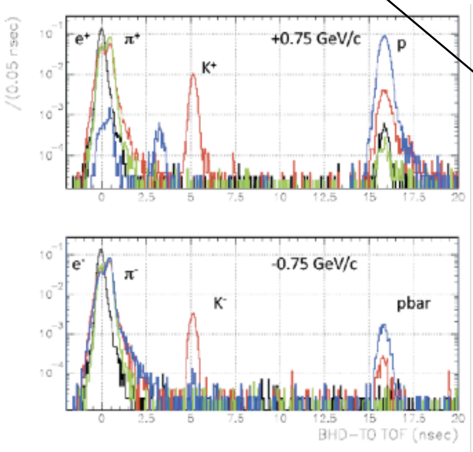


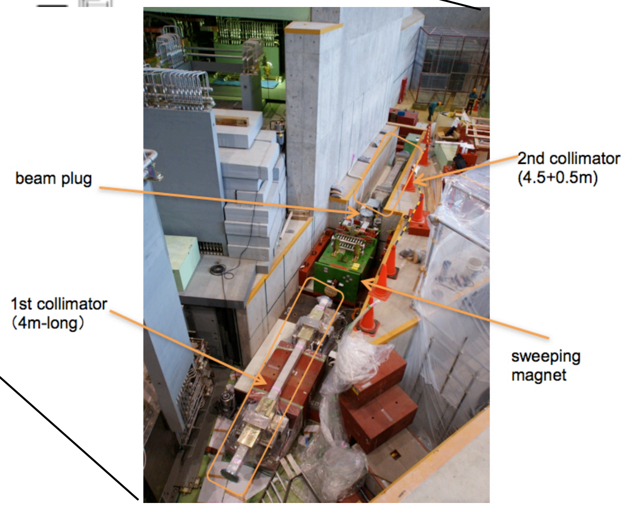
We have observed charged and neutral kaons in the secondary beam lines (**K1.8BR**, **K1.8** and **KL**) of Hadron Experimental Hall.

By courtesy of the Hadron Gr.









Plan of the MR in JFY2010

Fast Extraction:

Beam delivery larger than 100 kW to the T2K experiment

Installation of additional shields of 3-50 BT collimators:

Loss power capacity will be increased form 0.45 to 2 kW.

Replacement of the FX kicker system:

Issues of the present kicker system:

- The present system has a rise time ~ 1.6 μsec, larger than a required rise time for the originally designed 8 bunch operation.
- The kicker has a large impedance. Heating problem occurs in the high intensity operation.

Features of the new kicker system has :

- fast rise time < 1 μsec , and 8 bunch operation will be available
- lower beam coupling impedance

Installation of 2nd harmonics cavity

Slow Extraction:

Beam delivery larger than 5 kW to the HD users

For higher extraction efficiency :

- Dynamic bump scheme will be adopted from the 2010 Autumn run

For improvement of spill structure :

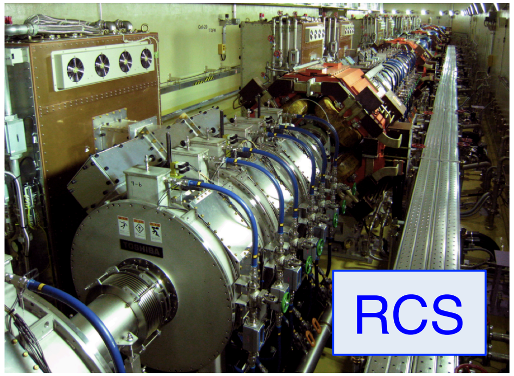
- Main PS tuning to reduce 600 Hz ripple
- Feedback operation with RF noise
- Ripple cancellation system using the trim coils

Status of MA loaded rf cavities

MA (Magnetic Alloy) loaded rf cavity is adopted to the RCS and MR.

Feature of the rf system:

- High field gradient > 20 kV/m
- No tuning loop because of the broadband characteristics
- Precise control by full digital LLRF, high reproducibility and reliability



	RCS	MR
Number of fundamental cavities	11	6*
Number of 2nd harmonic cavities		3**
Impedance / gap [Ohm]	840	1000
Q value	2	26
Core type	MA uncut core	MA cut core
Core sizez [cm]	OD85/ID37.5/T35	OD80/ID24.5/T35
Average power dissipation / core [kW]	5	9

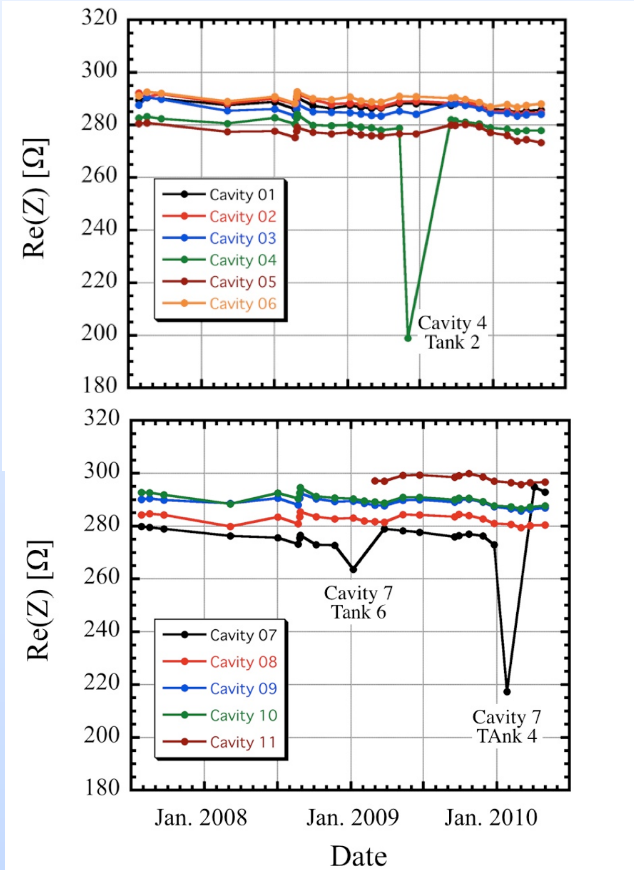
*5 at present

** No 2nd cavities at present. One 2nd cavity will be installed in the 2010 summer

Status of MA loaded rf cavities (2)

Impedance reduction is observed in the RCS and MR cavities

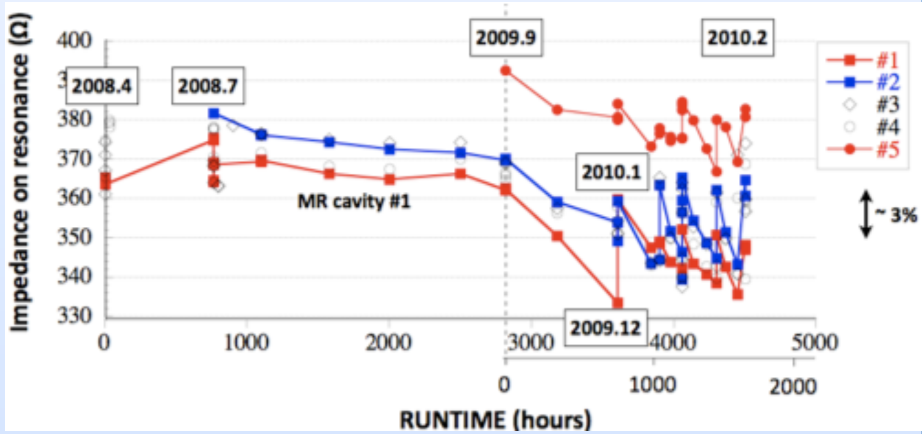
RCS (uncut core)



-Core buckling and crack caused by deformation due to thermal stress

-The manufacturing process is improved. The new cores are manufactured without impregnation of epoxy resin.

MR (cut core)



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

-Atmospheric exposure recovers the impedance. This procedure is regularly performed.

-To recover the impedance, the cutting surface of the cores will be re-polished in shutdown periods.

-SiO2 coating on the cutting surface is now under development.

-There are some correlations between contamination of Cu in the cooling water and impedance decrease(?).

Summary(1)

Beam commissioning of J-PARC accelerators has been started on schedule.
The accelerator study and users operation are well in progress.

The linac and RCS deliver the stable beam to the downstream facilities.
Recent highlights :
-120 kW beam delivery to the MLF
- 300 kW operation for 1 hour was successfully demonstrated

Recent highlights of the MR:
- Beam delivery of 70 kW in maximum to the NU beamline by FX
-100 kW equivalent beam extraction by FX was demonstrated.
- Beam delivery of 2.6 kW in maximum to the HD beamline by SX.

Summary (2)

Issues and solutions

Discharge in RFQ:

It has limited the delivered beam power to the MLF since September 2008.

Vacuum system improvement recovered the performance.

Low duty beam spill of the SX beam:

Tune fluctuation due to current ripple of main magnet PS's deteriorates the spill structure of the SX beam. The extraction with spill feedback and trim-coil short improved the duty. More efforts to reduce the effects of ripple are necessary; PS tuning to reduce 600 Hz ripple, feedback with rf noise, noise cancelling system will be tested soon.

Damages of rf cores in RCS/MR:

Manufacturing process of the core is improved for the RCS

SiO2 coating of cutting surface of the core is under development for the MR core.

There are many presentations of J-PARC accelerators in IPAC10.
Please refer to them and discuss with the J-PARC stuff members.

Thank you for your attention