PAC meeting, June 5, 2008

Status of J-PARC Accelerator

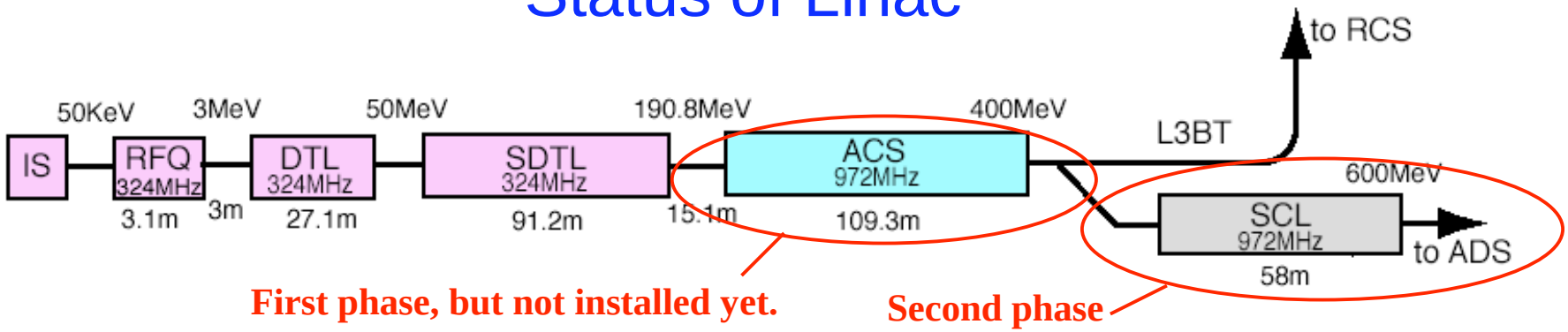
Tadashi Koseki (Accelerator Laboratory, KEK)
for the J-PARC accelerator group

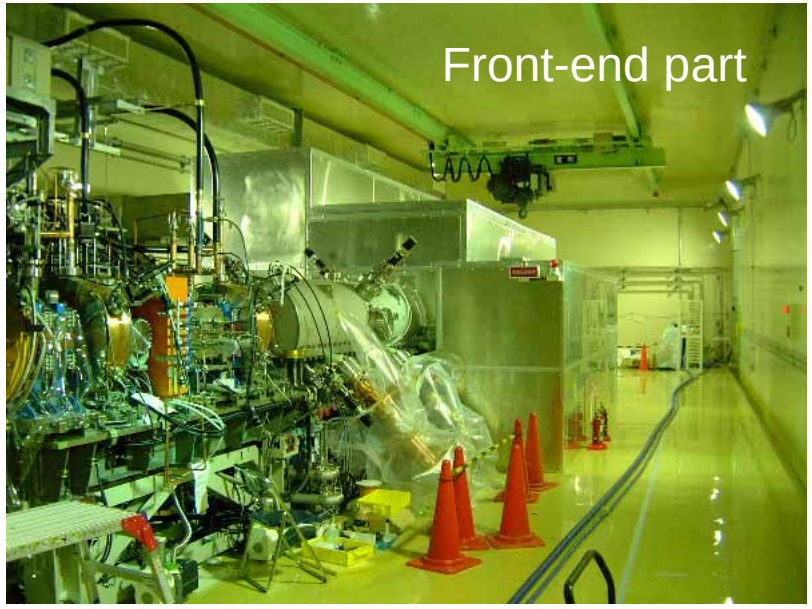
■**Beam injection, rf capture and beam extraction to beam dump were successfully demonstrated on May 22, 2008.**

The next step is to accelerate beams to 30 GeV. It will start in December of this year.

Status of Linac/RCS

Status of Linac





Ion source, LEBT, RFQ,
MEBT(2 choppers, 2 bunchers)

- **Particle:** H^-
- **Energy:**
  - **on day-one** **181 MeV**
  - **with ACS** **400 MeV**
- **Peak current:**
  - **at 181 MeV** **30 mA**
  - **at 400 MeV** **50 mA**
- **Repetition:** **25 Hz**
- **Pulse width:** **0.5 msec**

Summary of achieved beam parameters

Parameter	Unit	Design	Commissioning goal *	Achieved to date
Output energy	MeV	181	181	181
Peak current	mA	30	25	30
Linac beam power	kW	36 600 @ 3 GeV	1.2 20 @ 3GeV	1.2 (w/o chop) 0.68 (w/ chop)**
Pulse length /Repetition/ Chopper beam-on duty	ms/Hz/%	0.5/25/53	5 mA: 0.20/25/26 25ma: 0.04/25/26	5 mA: 0.25/5/100 0.05/25/60 25mA: 0.05/2.5/100** 0.05/25/100(RFQ)
Momentum spread	%	< ± 0.2 includig jitter	< ± 0.2 includig jitter	25 mA: 0.16 (FWHM)***
Norm 99.5 % emittance H/V	πmm-mrad	4.0/4.0	4.0/4.0	5 mA: 7/10**** 25mA:7/10****
Orbit distorsion	mm	± 1	± 1	± 1
Beam position jitter	mm	± 0.1	± 0.1	± 0.2*****
Peak current fluctuation	%	± 1	± 1	± 1******

* Corresponding to 20 kW beam power from RCS

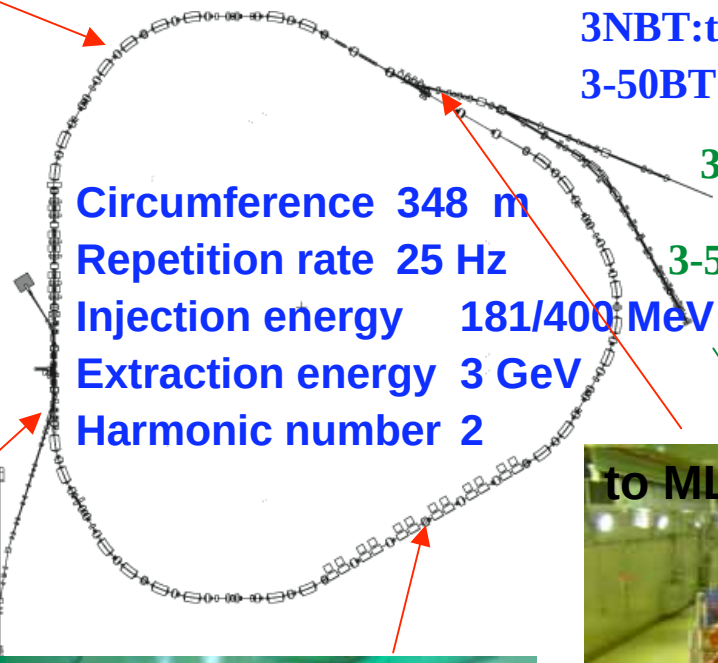
**3.5kW (0.12ms/25Hz/26%) has been demonstrated for a few minutes.
*** Estimated from the minimum bunch length and the applied RF field in RCS (storage mode).
**** Inferred from RMS emittance and the tail shape of the profile. Collimator is not used.
***** During several hours.
****** During several hours. With the peak current and pulse width of 25 mA and 0.25 ms, respectively.

Values in gray are preliminary

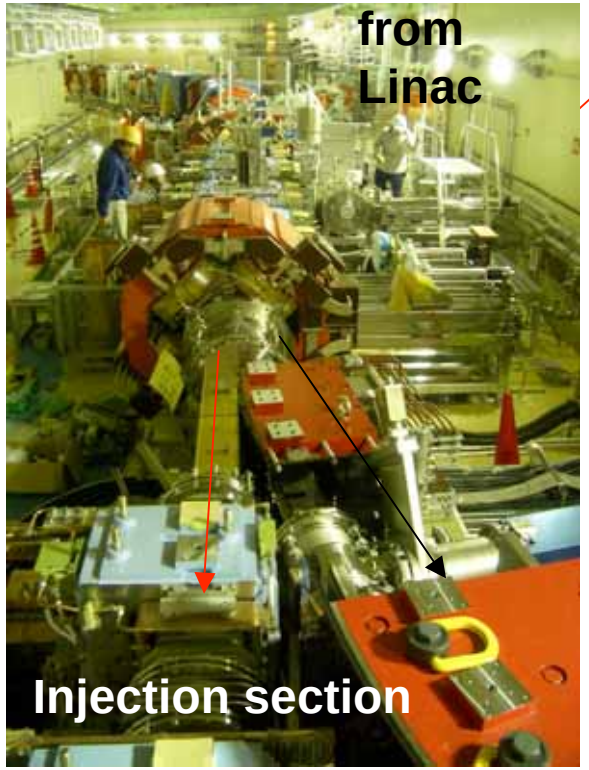
M. Ikegami

Status of RCS

Neutron/Muon source and booster of the MR.
Two beam transport lines
3NBT:transport line to the MLF
3-50BT: transport line to the MR



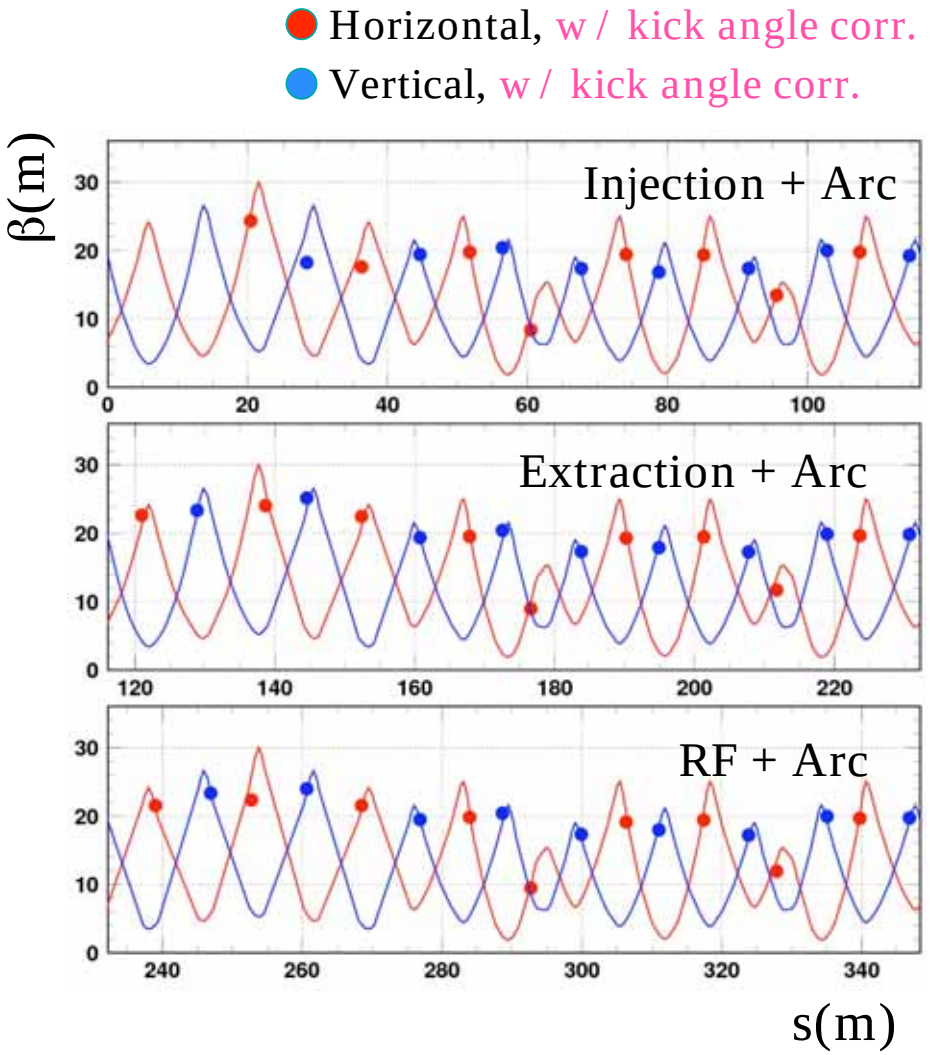
Circumference 348 m
Repetition rate 25 Hz
Injection energy 181/400 MeV
Extraction energy 3 GeV
Harmonic number 2



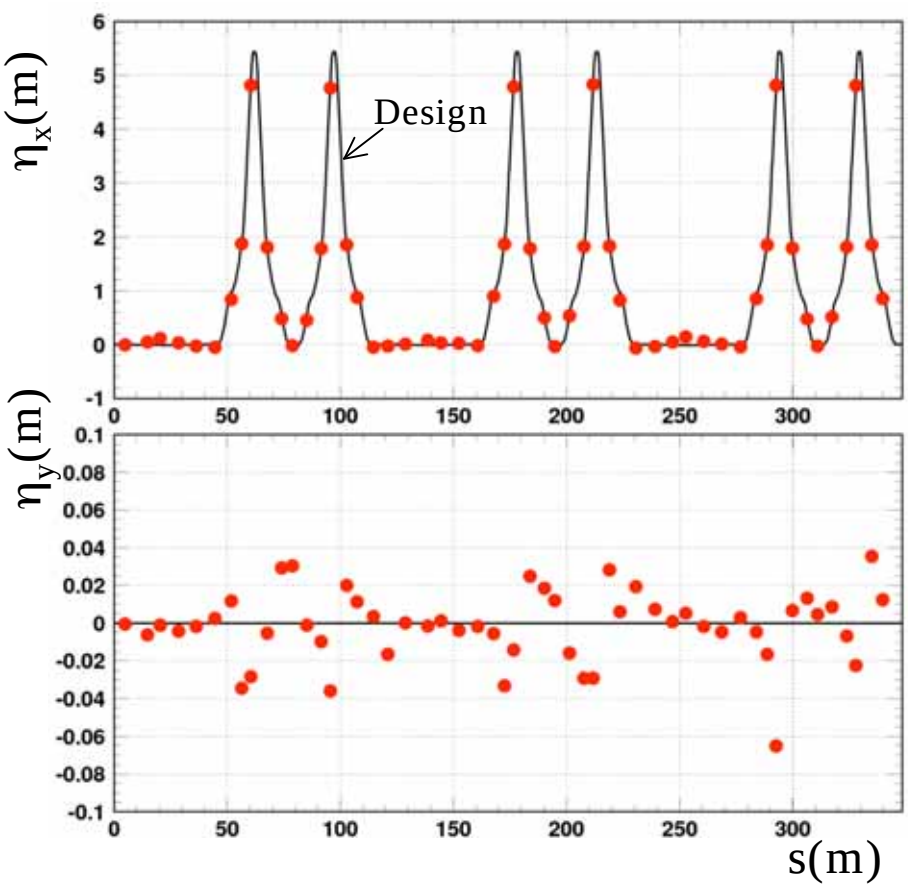
Beta function and dispersion

181 MeV DC mode

β: measured from the response
of the closed orbit for a dipole kick (STM)



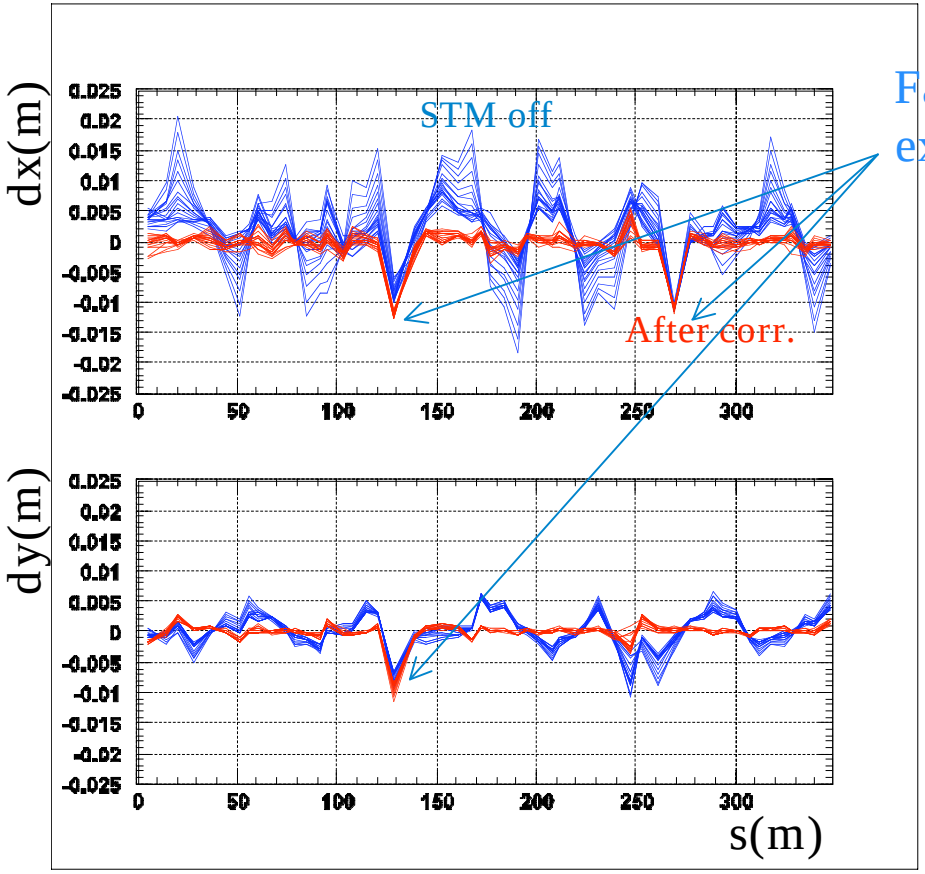
η: Measured from rf-frequency dependence
of the closed orbit



Good agreement with the design.

H. Hotchi

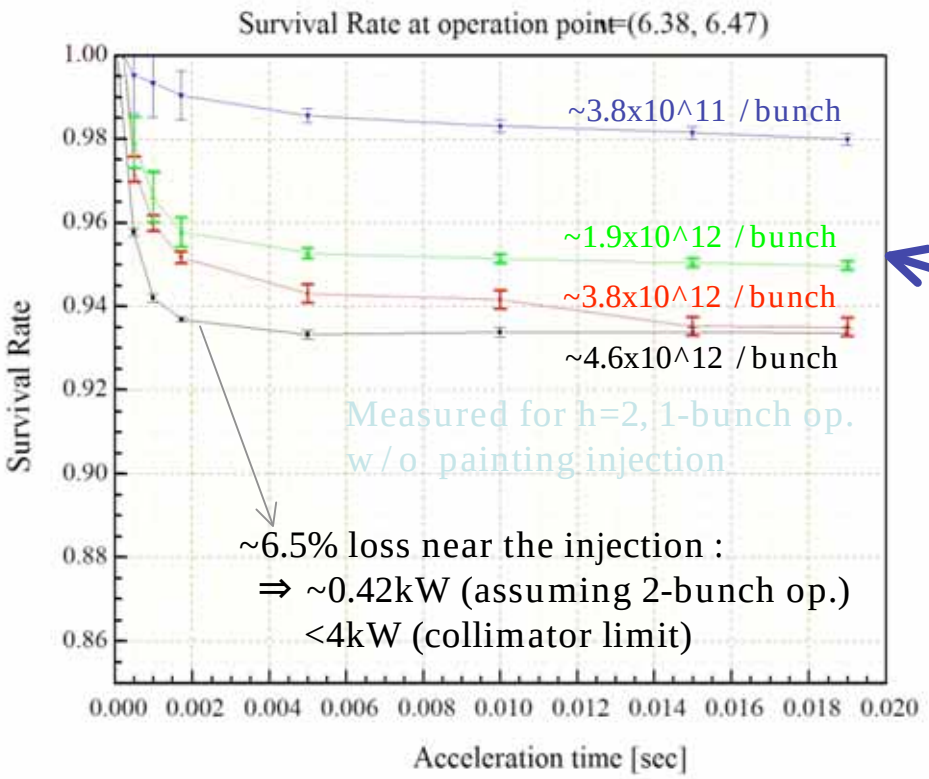
Closed orbit correction at 3 GeV acceleration mode

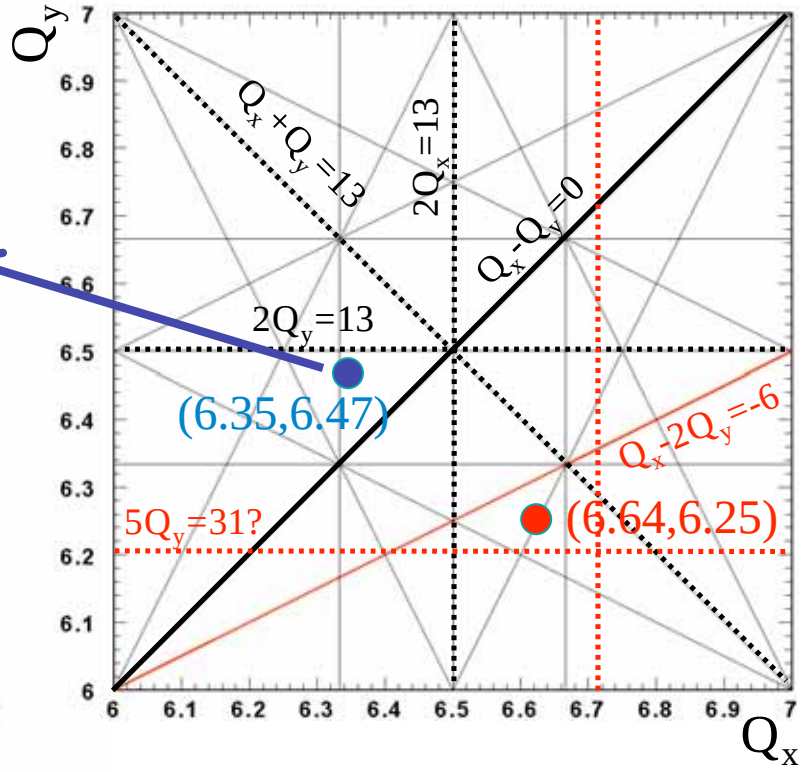


Fake data,
excluded for the analysis

Horizontal closed orbit is affected by DC leakage fields of injection dump septa,extraction septa and 3NBT magnets. The effects are corrected by steerings.
COD due to the momentum mismatch is corrected by adjusting rf frequency.

Current dependence of the beam loss





~3.8x10^11 /bunch (Peak: 22mA, Macro: 0.05ms, Medium: 112ns, Vrf~420kV)

~1.9x10^12 /bunch (Peak: 22mA, Macro: 0.05ms, Medium: 560ns, Vrf~420kV)

~3.8x10^12 /bunch (Peak: 22mA, Macro: 0.1ms, Medium: 560ns, Vrf~420kV)

~4.6x10^12 /bunch (Peak: 22mA, Macro: 0.12ms, Medium: 560ns, Vrf~440kV)

corresponding to 100 kW in terms of particles per bunch

"~4.6x10^12/bunch; h=2, 1bunch; 25Hz" operation Successfully performed !!!!!

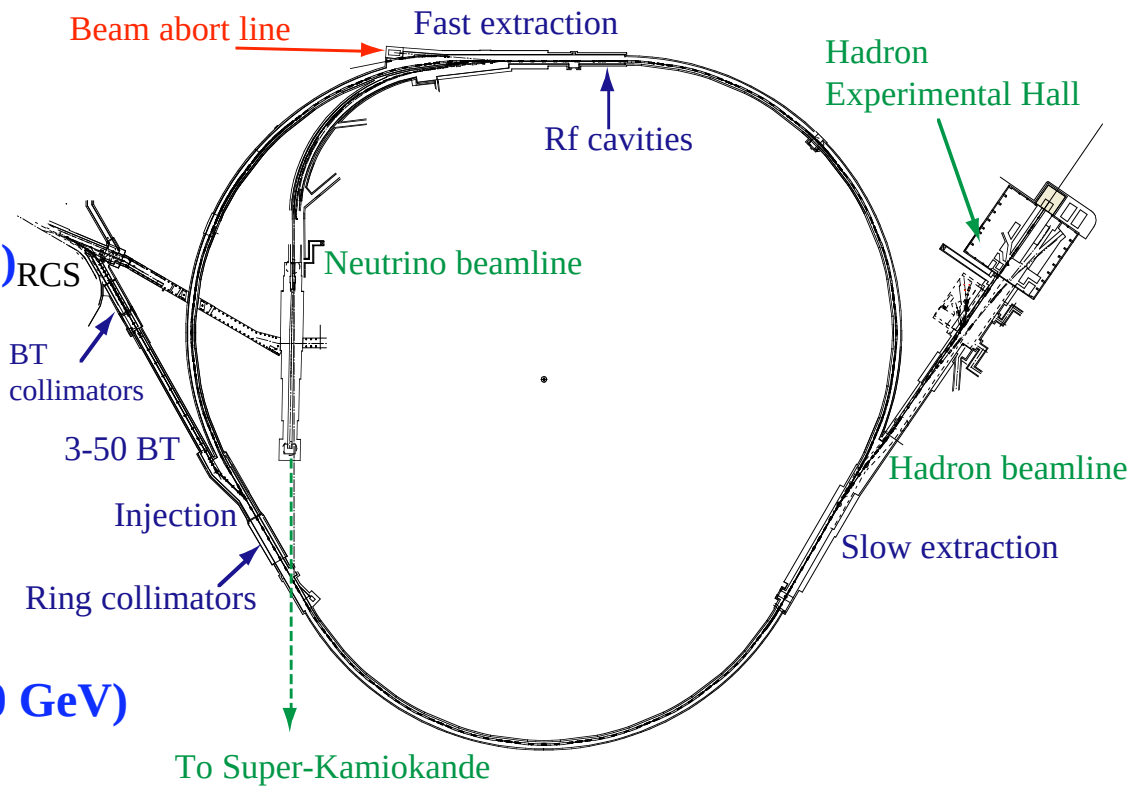
(only in a few minutes due to the dump limit of 4kW)

H. Hotchi

Status of MR

MR (slow cycling Main Ring synchrotron)

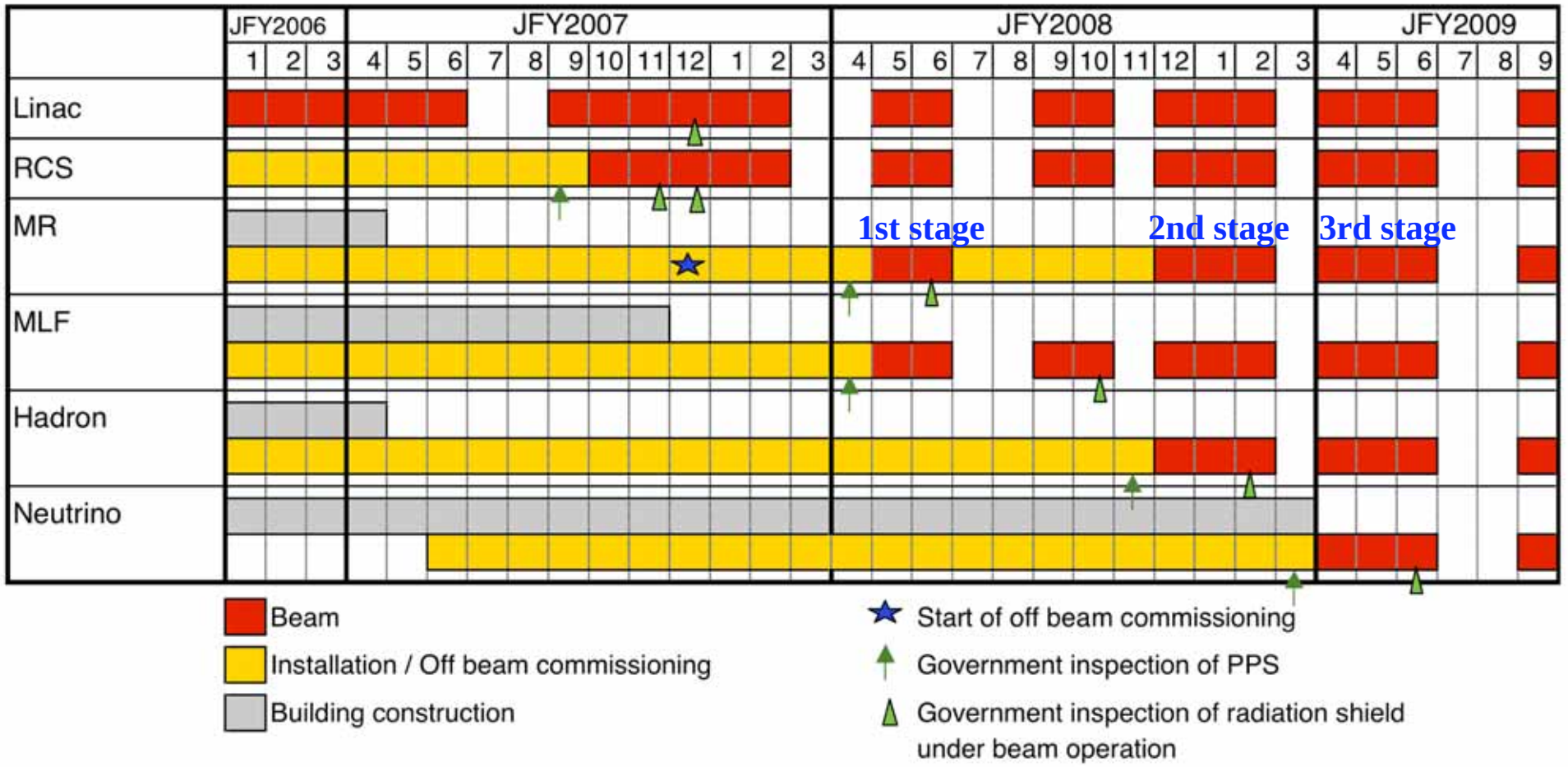
Circumference	**1567.5 m**
Repetition rate	**~ 0.3 Hz**
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
	50 GeV (2nd phase)
Superperiodicity	**3**
h	**9**
No of bunches	**8 (6 in day-one)**
Transition γ	**j 31.7**
Typical tune	**22.4, 20.8**
Transverse emittance	
At injection	**~54 πmm-mrad**
At extraction	**~10 πmm-mrad(30 GeV)**



Three dispersion free straight sections of 116-m long:

- **Injection and collimator systems**
- **Slow extraction（SX)**
  to Hadron experimental Hall
- **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)

Schedule of beam commissioning



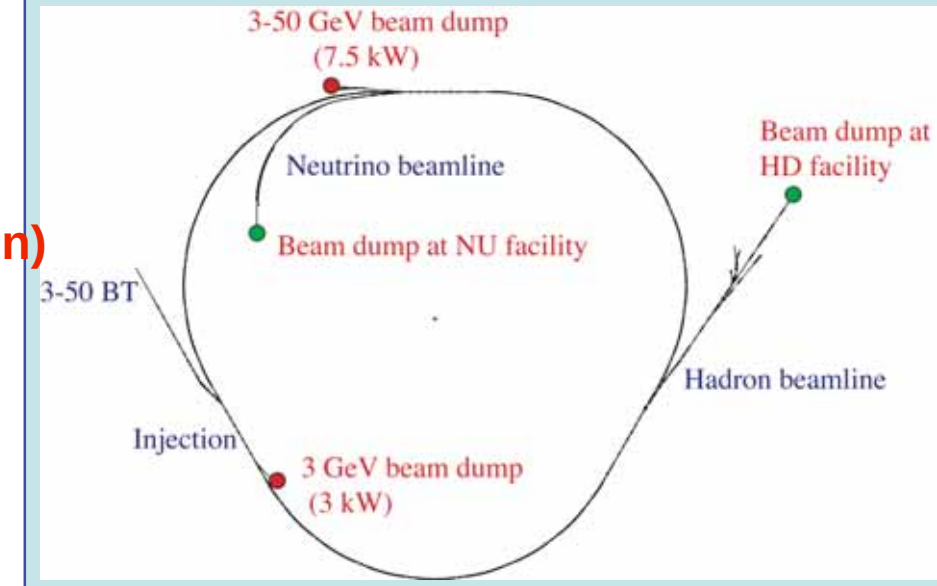
MR schedule

May 2008: MR (and MLF) beam commissioning starts.
July -Nov. 2008 : Installation of slow extraction devices, some fast extraction devices and neutrino beamline components.

MR beam commissioning plan

1st stage (May 2008-June 2008):
Available dump is the injection dump
Beam transport of 3-50 BT, injection, closed orbit, rf capture (3GeV operation)

Installation of FX and SX components/ (July 2008-Nov. 2008)
FX septa (SM1,2, SM33), FX kickers,
SX devices,
Neutrino beamline components….
Tuning of main magnet power supplies..



Layout of beam dumps

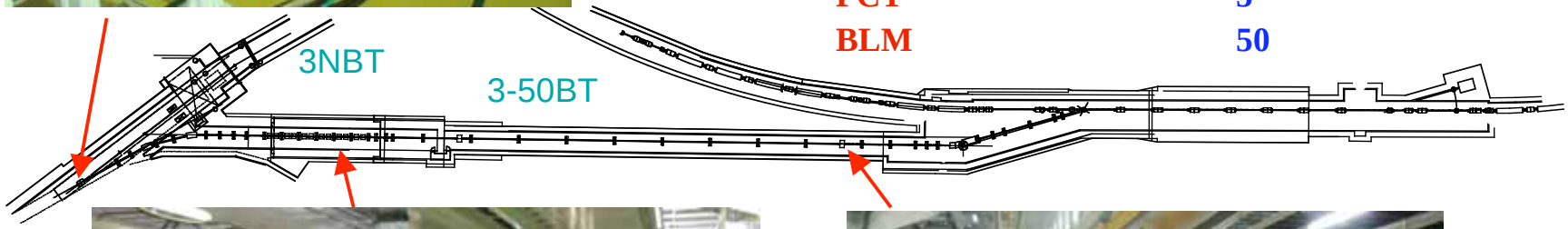
2nd stage(Dec. 2008-Feb. 2009):
The dumps at the abort beamline and HD beamline are available
Acceleration from 3 to 30 GeV,
Extraction to abort line
Extraction to HD beamline

3rd stage(Apr. - June 2009):
The dump at the NU beamline is available
Extraction to Neutrino beamline

3-50 BT


Pulsed bending magnet

Length	230 m
Pulse bend	1
dipole	3(h), 2 (v)
quadrupole	38
Steering	14
Collimator system	1
BPM	14
MWPM	9 (6 in day-one)
FCT	5
BLM	50




BT collimators


Slope section

Magnet system

Main magnets

Dipole	96
Quadrupole (11 family)	216
Sextupole (3 family)	72

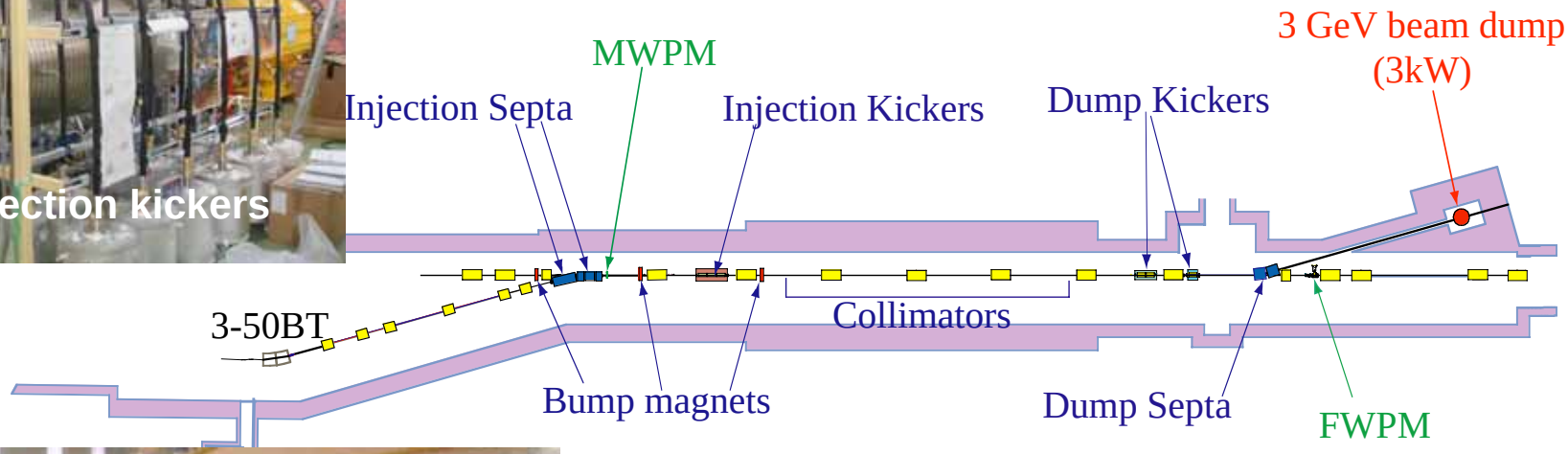
Steering magnets

H. Steerings	93
V. Steerings	93

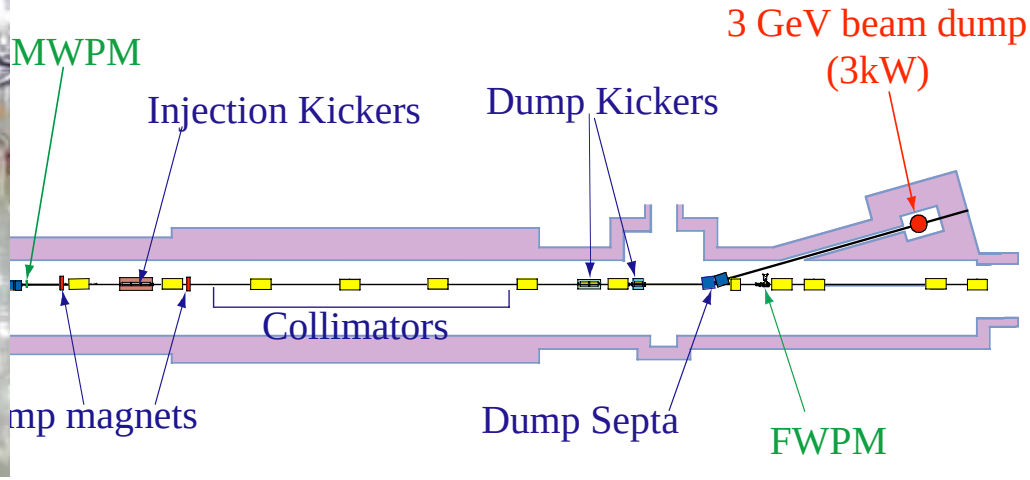
For the 30 GeV operation, the main magnet power supplies are required high level performance ; current ripple < 1e-6, current stability < 5e-5 and tracking error < 5e-5.

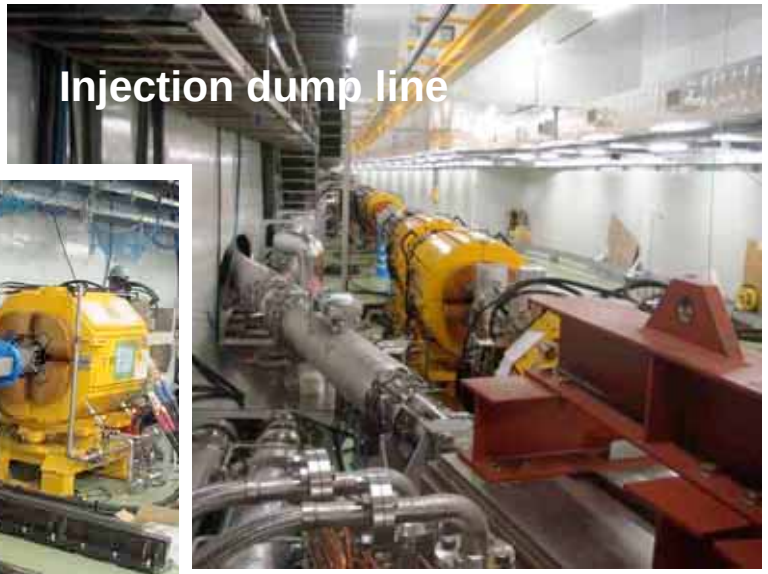
Tuning of power supplies are one of the most important subjects in the 2008 summer/autumn shutdown.

Injection devices (1)



Injection devices (2)





MA loaded rf cavity

The MA (magnetic alloy) cut core is adopted to the MR cavity.

In the first stage of beam commissioning, four cavities have been installed and operated.

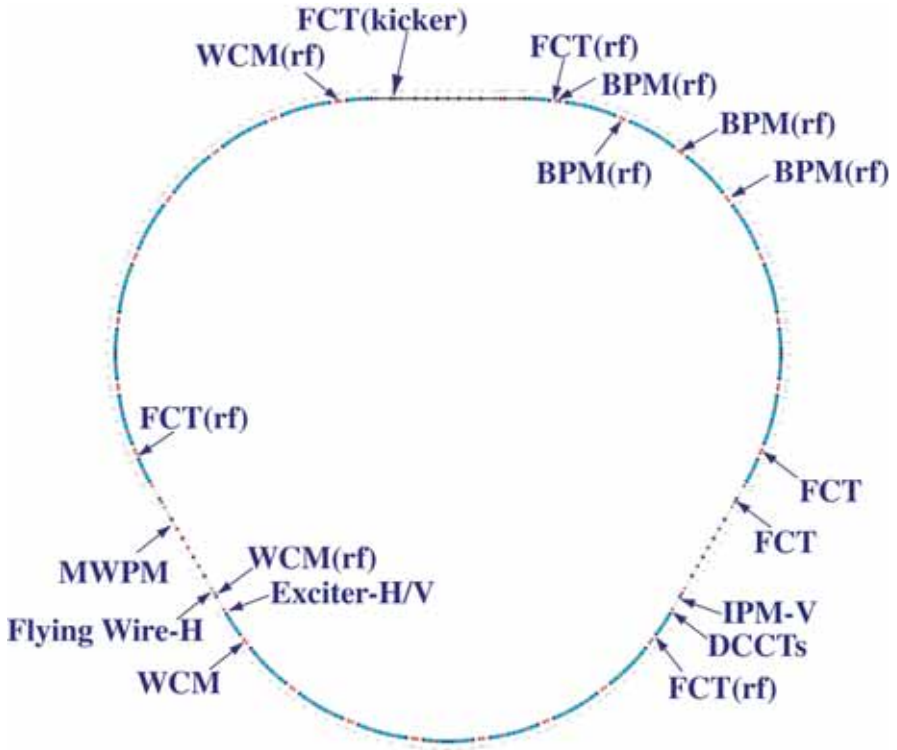
For the acceleration, nominal rf voltage is ~ 200 kV for 30 GeV (gap voltage is 45 kV/cavity).

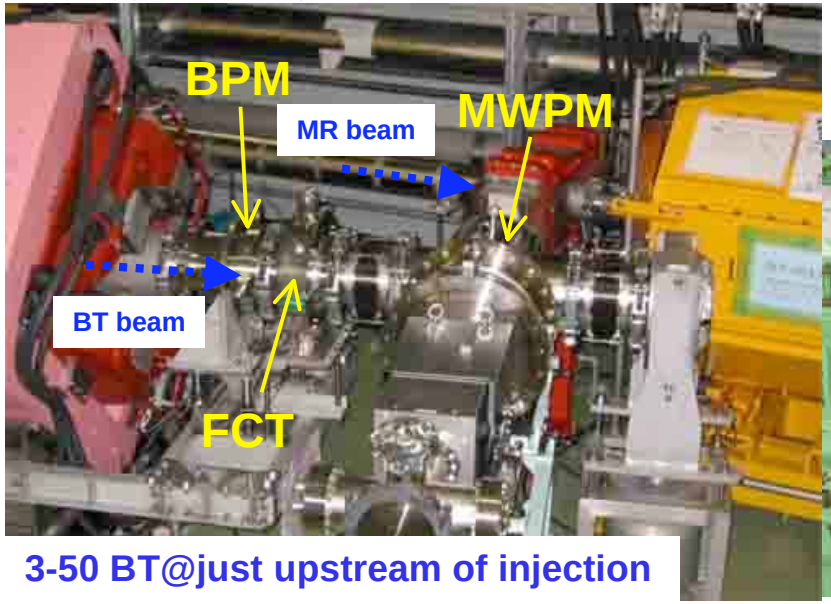
The fifth system will be installed in JFY 2009.

(Budget is so tight but manufacturing of fifth cavity is the first priority in the JFY2008)

Monitors available on day-one

BPM	186
Abort/dump BPM	2+2
WCM (>100 MHz)	3
FCT (~ 20 MHz)	6
DCCT(DC - 30 kHz)	2
MWPM	1(inj.)+1(Sx)+1(abort)
FWPM(H/V)	1/0
IPM(H/V)	0/1
Tune meter (H/V)	1/1
Quad. mode BPM	2
BPM (BT)	14
FCT (BT)	5
MWPM (BT)	6
BLM(BT&MR)	338

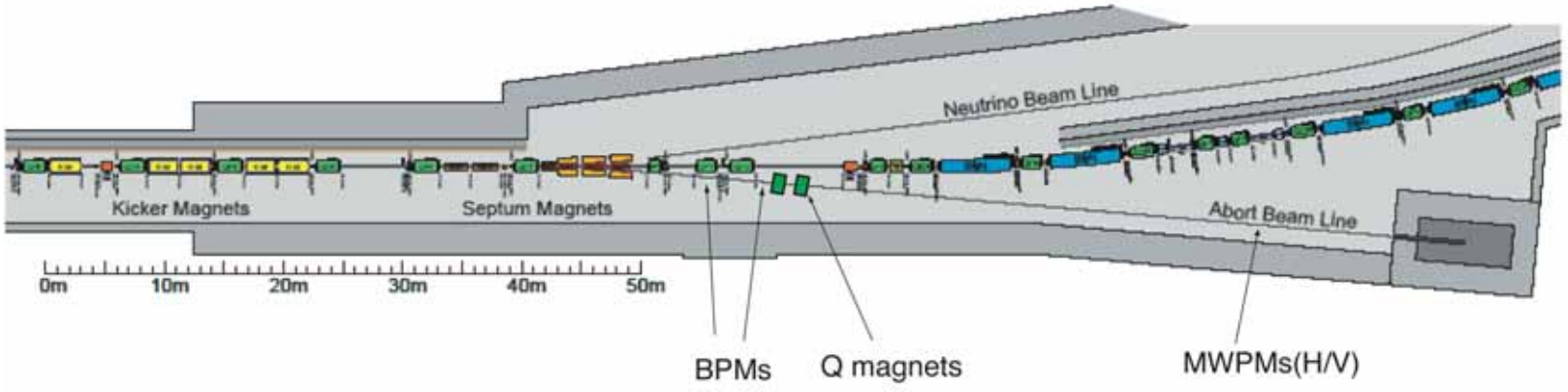


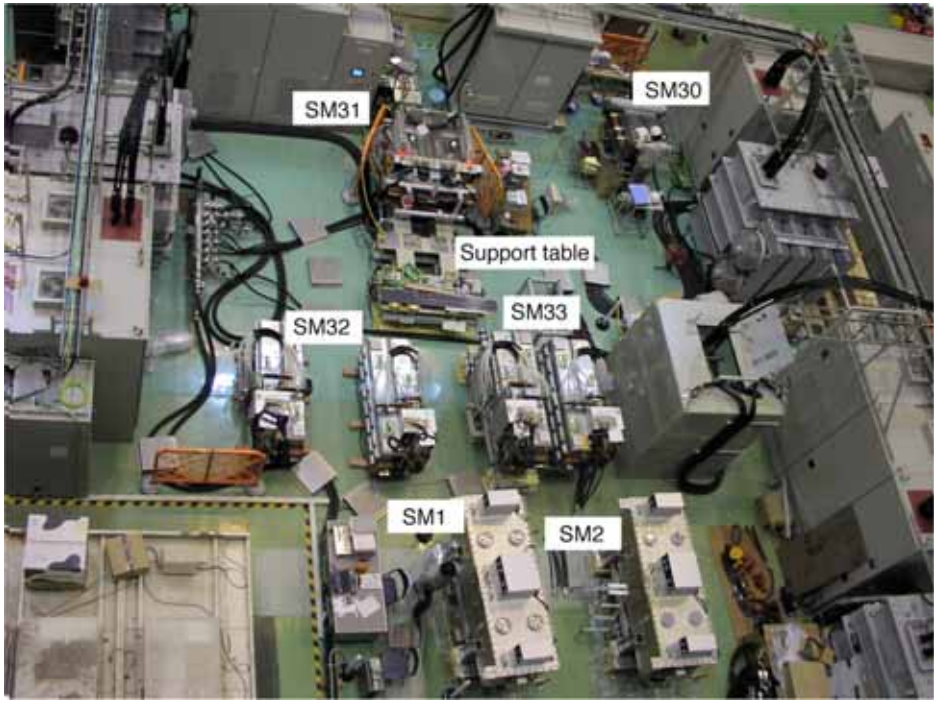


3-50 BT@just upstream of injection

Fast extraction devices

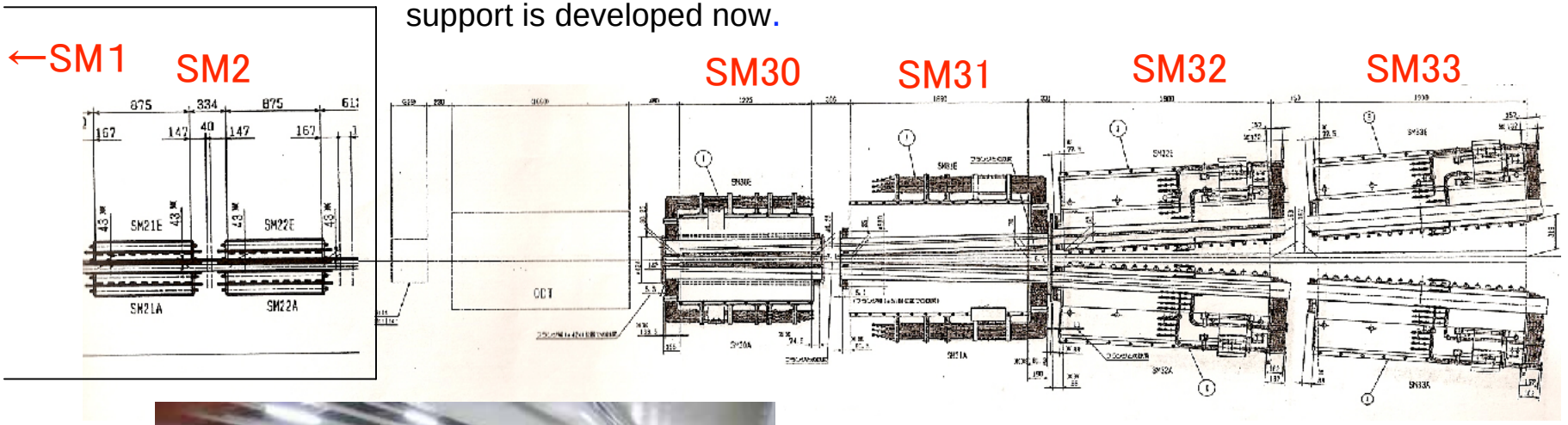
Fast extraction system comprises 5 bipoler kicker magnets and 8 bipolar septum magnet systems.





Fast extraction septum magnets

SM30-33: Performance test has been finished.
SM1, 2 : Ceramic collars of coil support were broken. New design of the coil support is developed now.



SM30-32 has been Installed in the ring tunnel.
SM33, SM1,2 will be installed in this summer

Fast extraction kicker

Problems of the traveling wave type kicker

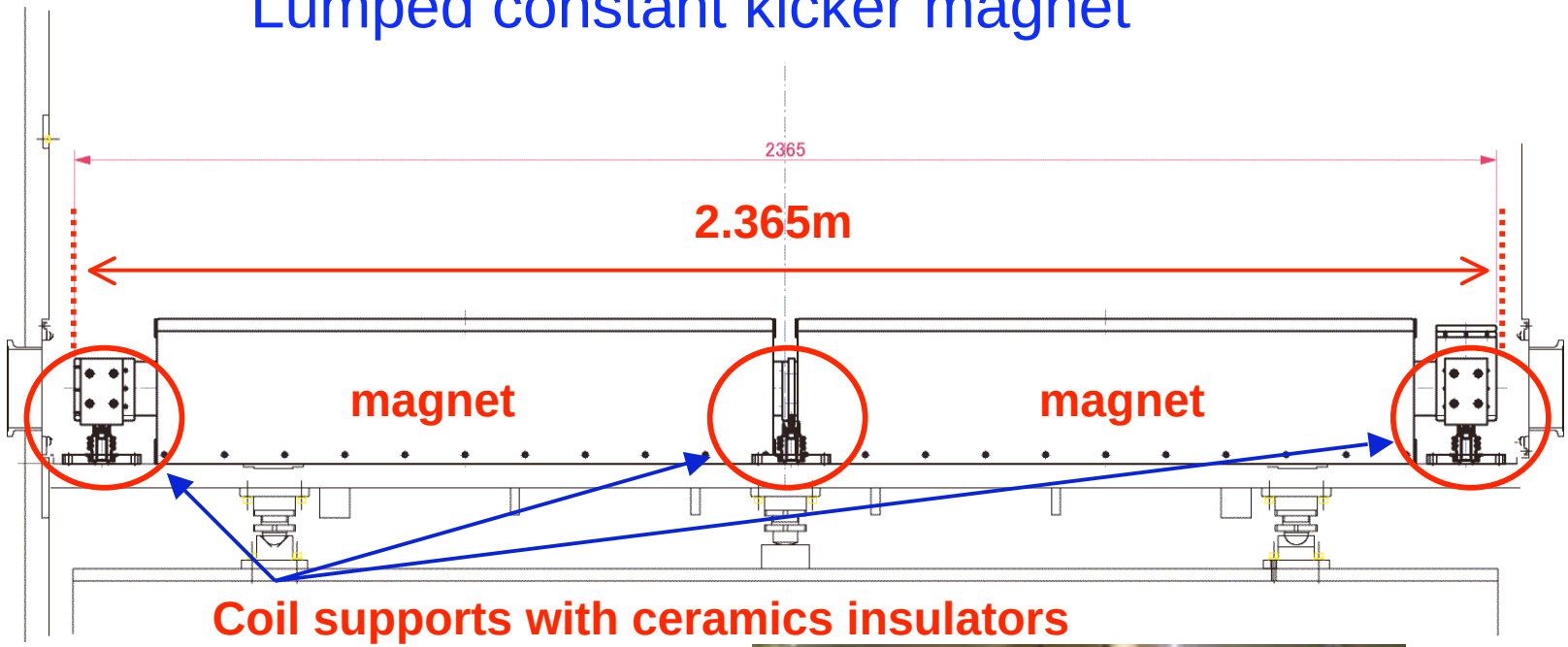
- Slow rise time （~1.6μsec)　→ 6 bunch operation on day-one.
- Discharge problems

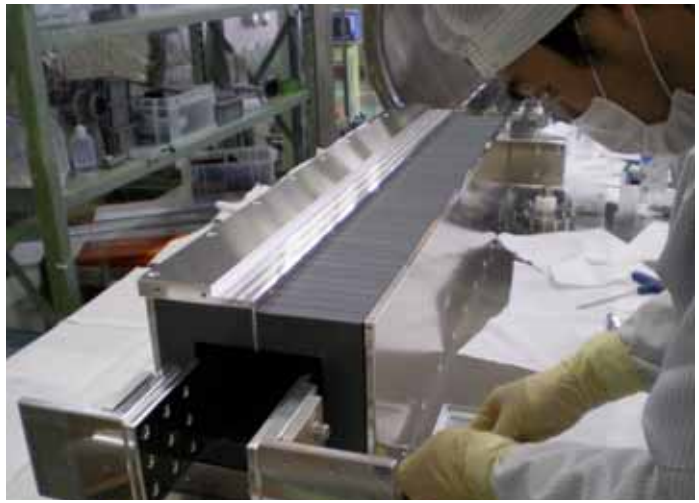
Discharge spots:
Discharge occurred between the electrode and ferrite cores.

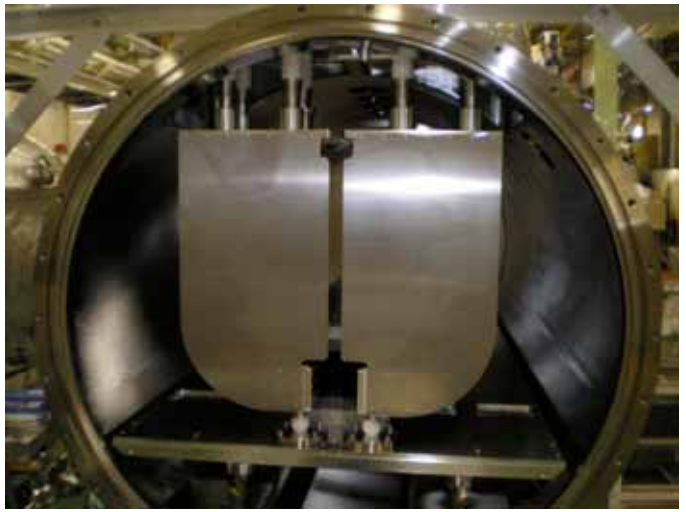
Lumped constant kicker for the day-one scheme

- Simple structure→high breakdown voltage
- Required rise time for 6 bunch operation (< 2 μsec) can be achieved.

Lumped constant kicker magnet







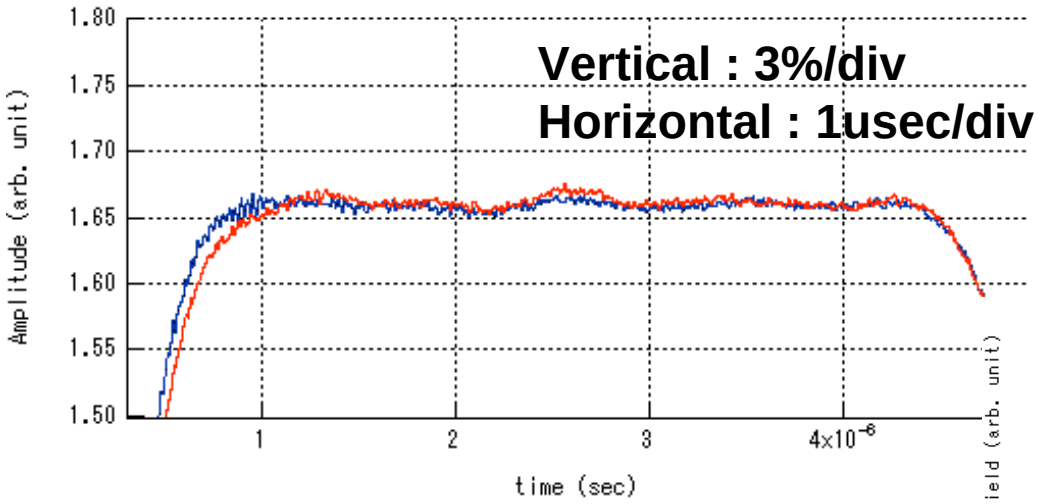
Vacuum chambers and ferrite cores of the traveling type kickers are used.

The maximum voltage between coil and ferrite cores is <1.5 kV/mm .

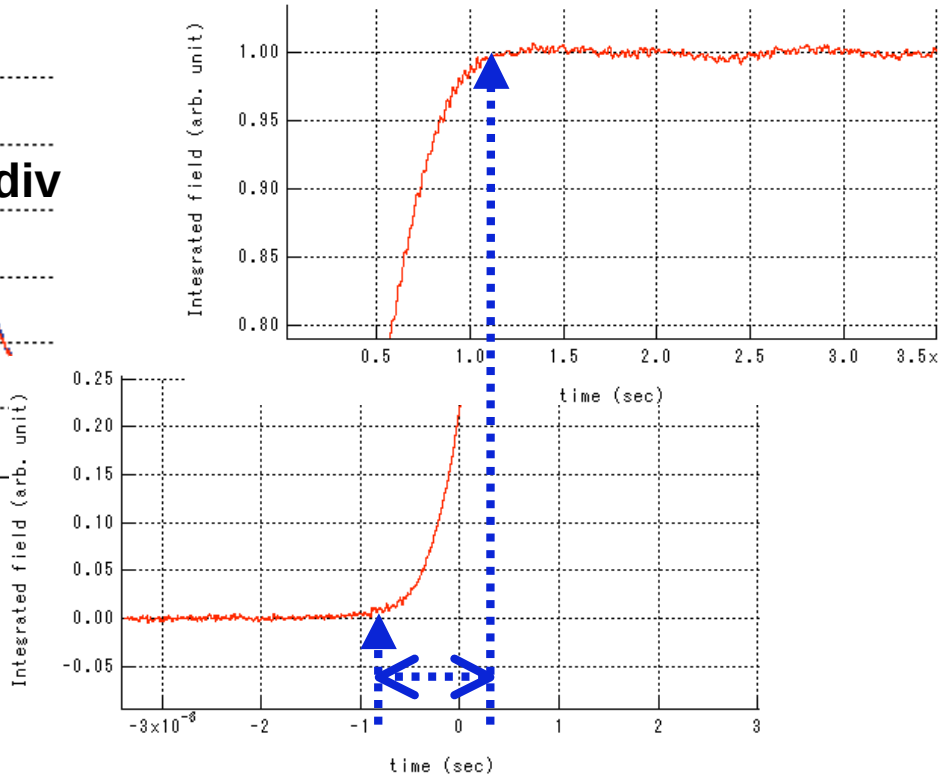
Test operation of lumped constant type kicker

- Pulse operation in atmospheric pressure
  No discharge up to Vc=44 kV (corresponds to 49 GeV operation)
- Long-term pulse operation in vacuum :
  Stable operation with Vc=35 kV for 1 hour and 30 kV for 11 hours.
- Rise time ~1.8 μsec

→We adopt the lumped constant type kicker. Five kickers will be installed in the summer of 2008.



Blue: integrated field
Red: Current



Rise time (1-99%) = 1.8072μsec
@ Vc=30kV (33 GeV)

Slow extraction system

Installed: Resonant Sextupole (8)

Manufactured in 2007, installed in the summer of 2008

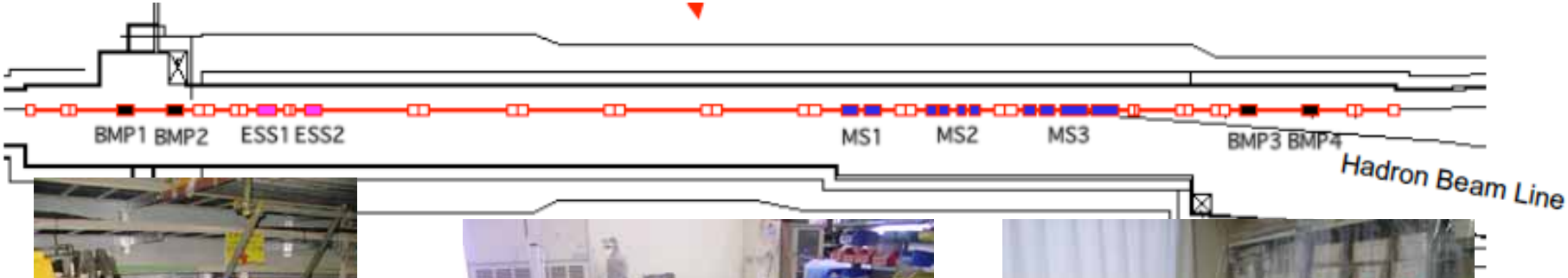
- Electro-static septum (2)
- Thin septum magnets, 1.5 mm (1), 3.5 mm(1), 7.5 mm (4)
- Strong field septum magnets(4)
- Shift bump magnet (4)
- Power supplies (recycled/manufactured)

Manufactured in 2007-2008, installed in the summer of 2009

- Extraction Q for spill control (prototype)

Manufactured in 2008, installed in the summer of 2009

- Qs for spill control



Vacuum vessel of ESS

Yoke and 30μm ribbon type septum of ESS

Resonant sextupoles (8) have been installed.

Beam commissioning -1st stage-

The first stage of MR beam commissioning has been started on May 19, 2008

RUN #16: May 19 - 24
RUN #17: June 14 - 25

Conditions of Linac/RCS beam for MR commissioning

Linac: 5 mA, 100 μsec, chopped beam with 280 nsec
RCS: without painting,
~15 pimm-mrad
one bunch operation (h=2)
< 4e11 ppb (1 % intensity),
single shot

Commissioning RUN #16

May 19:
-Tuning of 3-50 BT

May 20 :
- Injection tuning, and beam dump tuning
- Demonstration of beam storage in the ring without RF

May 21:
-Injection tuning
-RF tuning

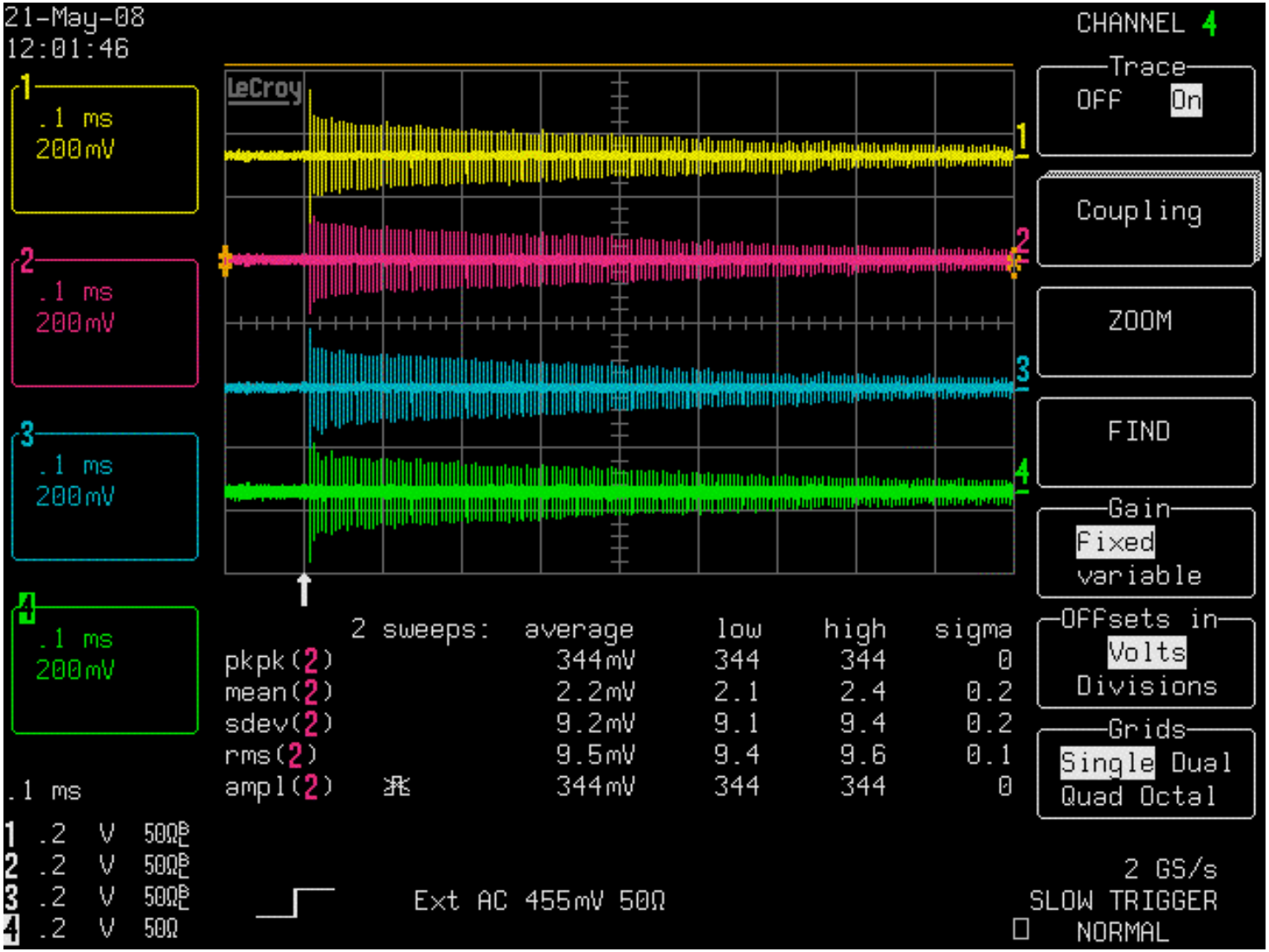
May 22:
-RF capture and beam extraction to injection beam dump

May 23:
-1 sec storage with RF capture
-Continuous operation with 3.64 sec cycle for 1 hour.

May 24:
-Injection tuning
-Tune measurement

MR beam commissioning –first circulation–

9:13 pm on May 21, beam circulation without RF was successfully demonstrated.
This figure shows the raw signal data of BPM taken on the next day with the same condition to check the reproducibility.



Injection tuning

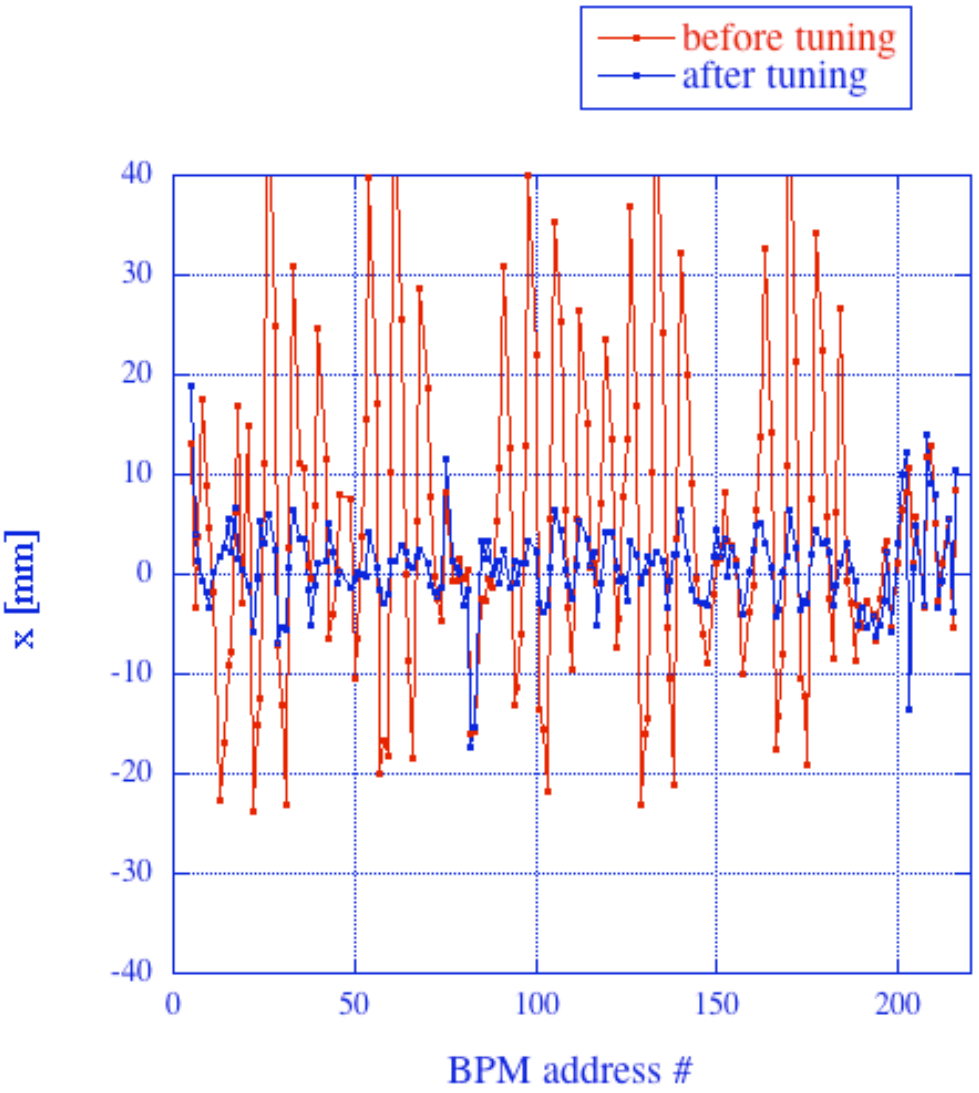
BPM:

Turn-by-turn measurement mode

Horizontal tuning

（1）Matching between momentum of the injection beam and magnetic field of bending magnet

（2）Magnetic field of injection septum I.

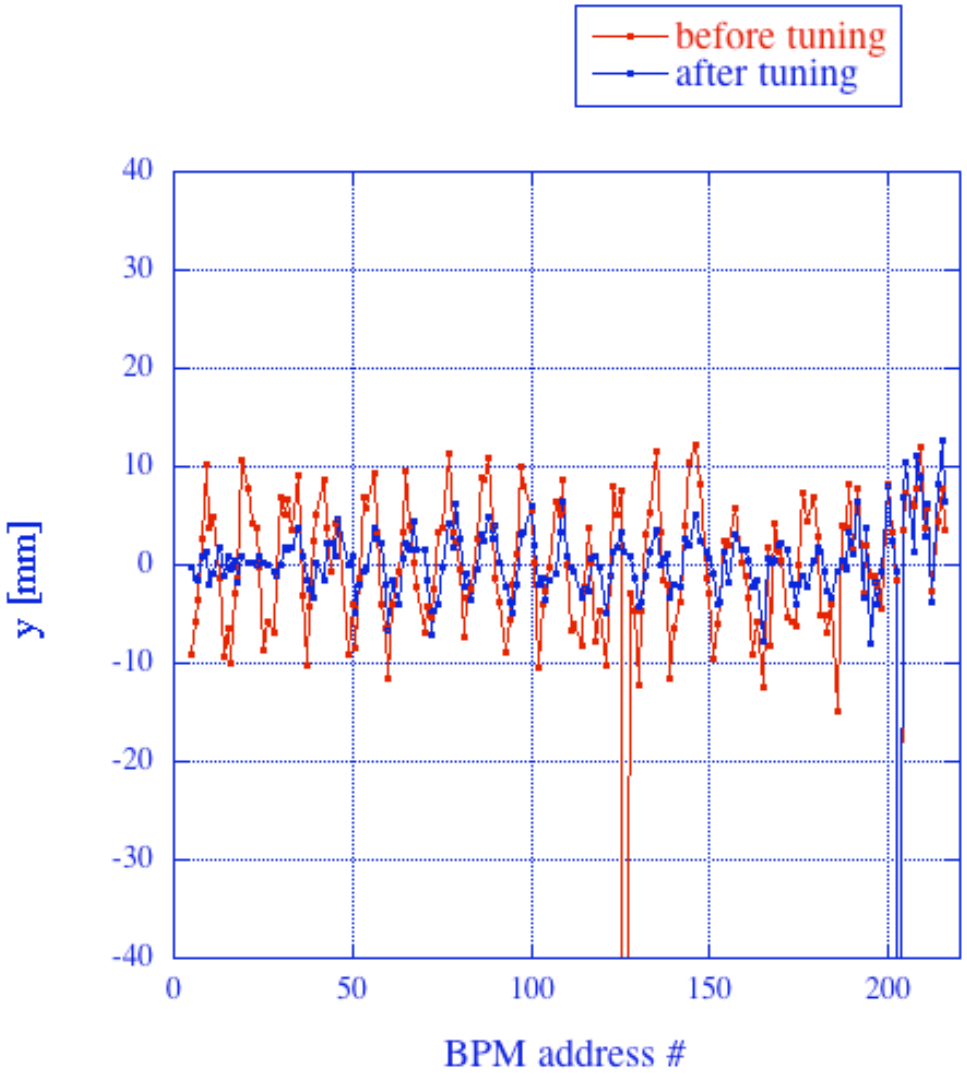


Injection tuning(cont')

BPM: Turn-by-turn measurement mode

Vertical tuning

Vertical steering magnet
in the most downstream part of the 3-50 BT is tuned.

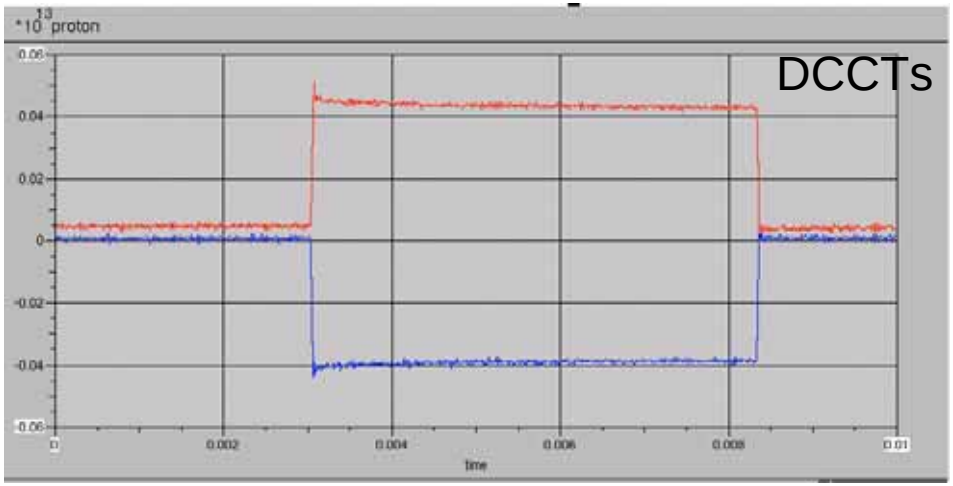


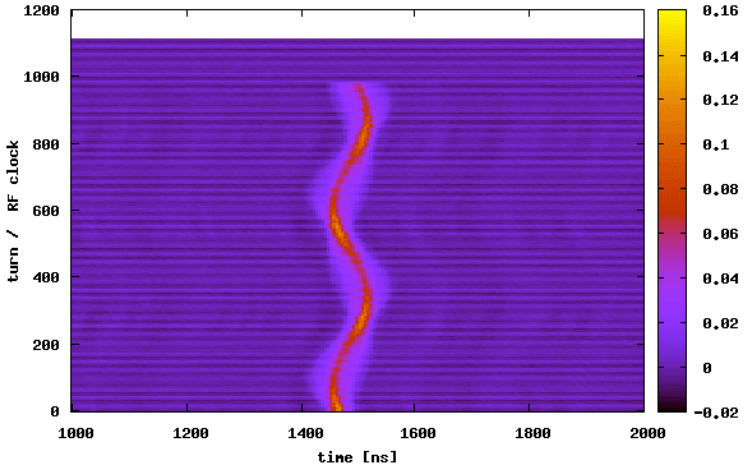
RF capture

- f_{rf}=1.671459 MHz： RF frequency of MR is adjusted to the frequency of RCS
- V_{gap}=160 kV.
- Dump kickers are switched on after 1000 turns from beam injection (5.384msec).

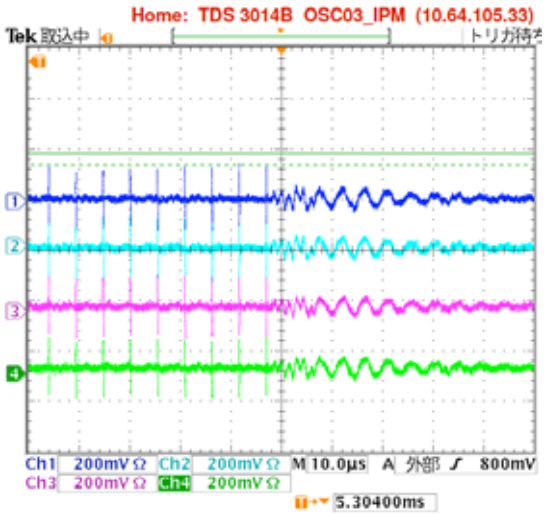
Operating point:
ν_x=22.34, ν_y=20.77

At 10:27pm on May 22,
3 GeV proton beam successfully captures by RF and extracted to injection beam dump.

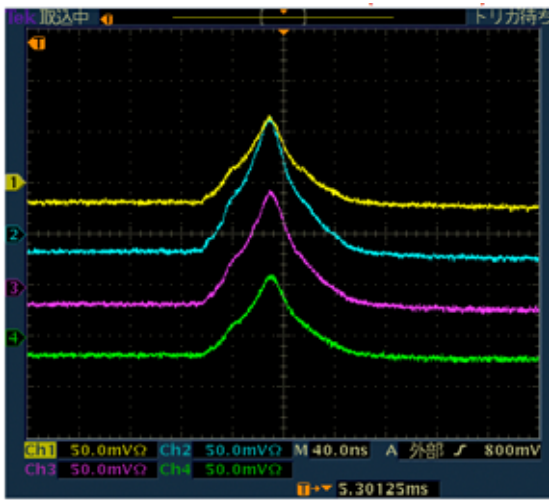




WCM



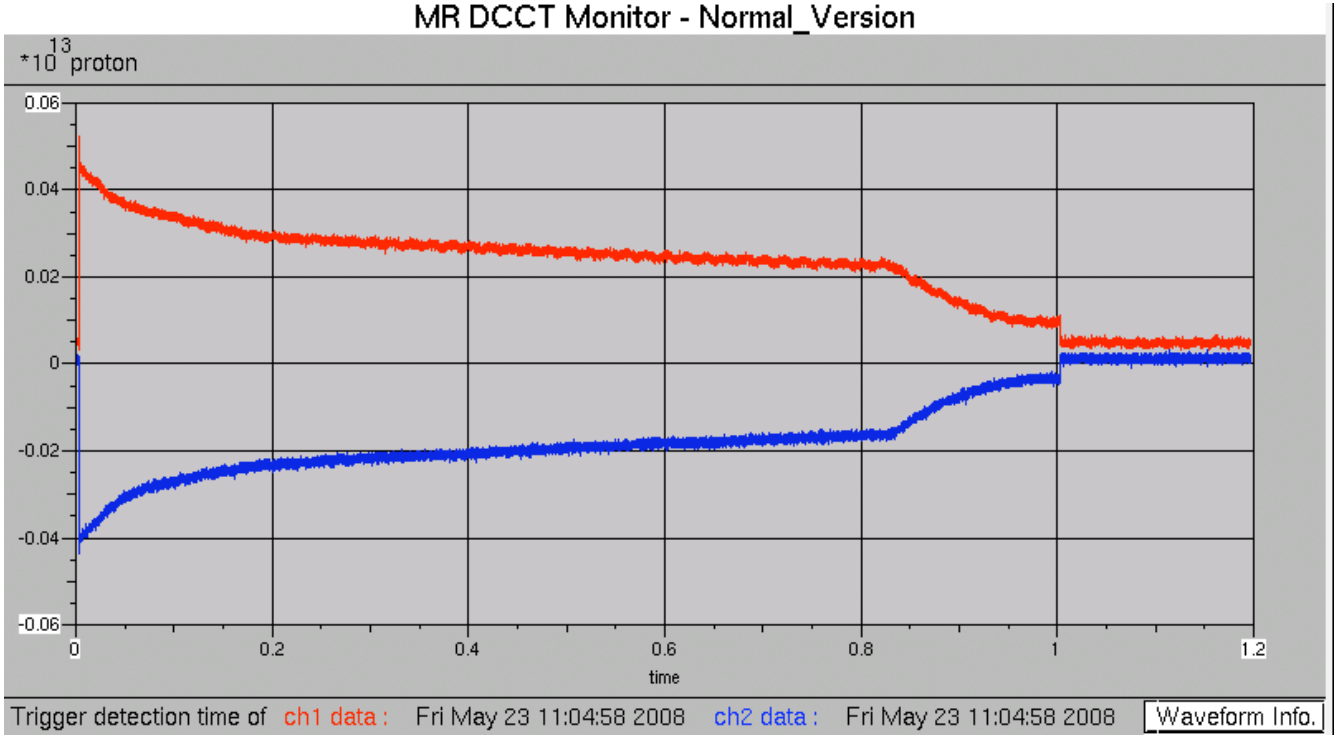
BPM in the ring



BPM in the dump line

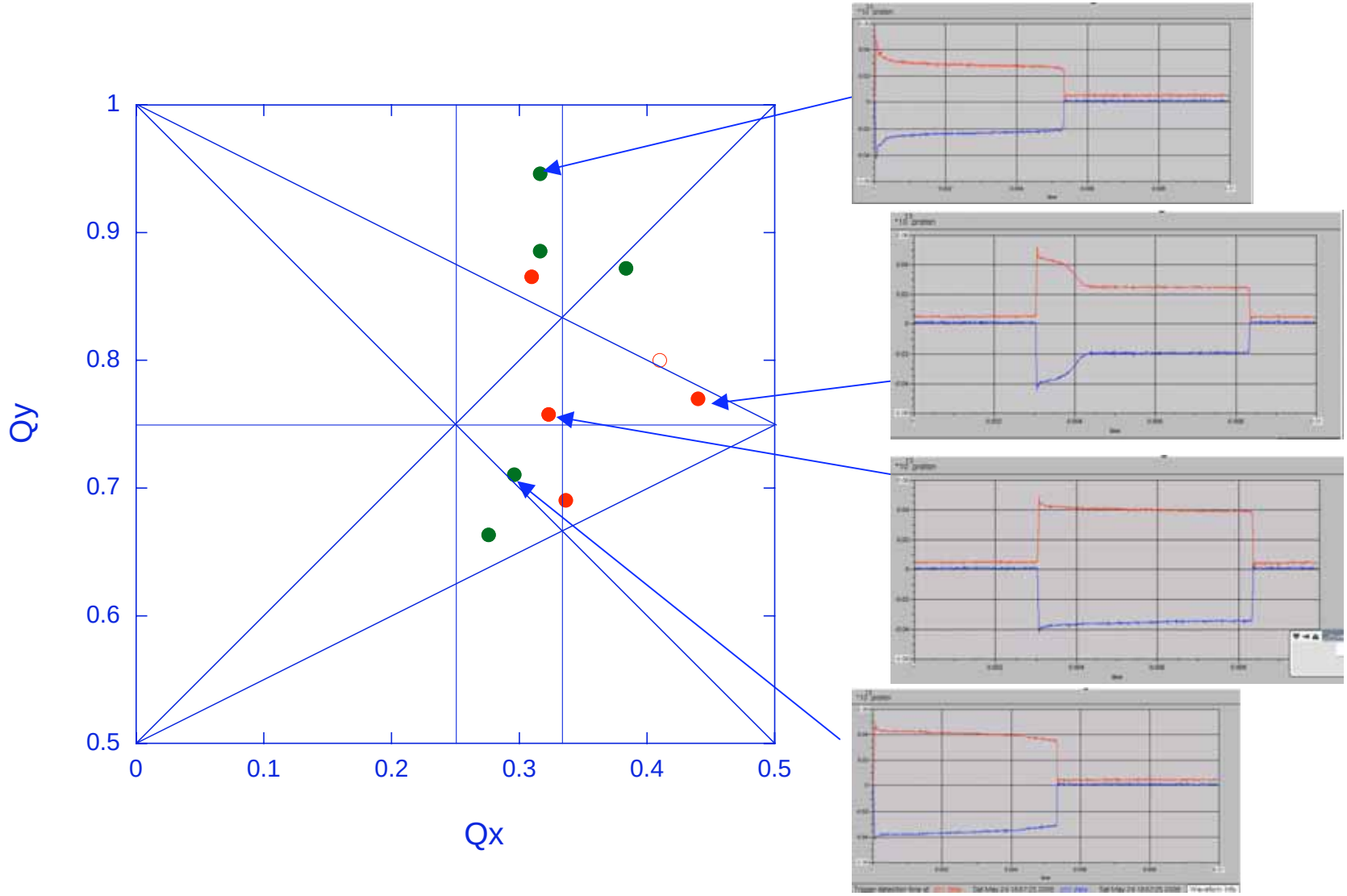
1 sec storage

- Dump kickers are switched on after 1 sec from beam injection.

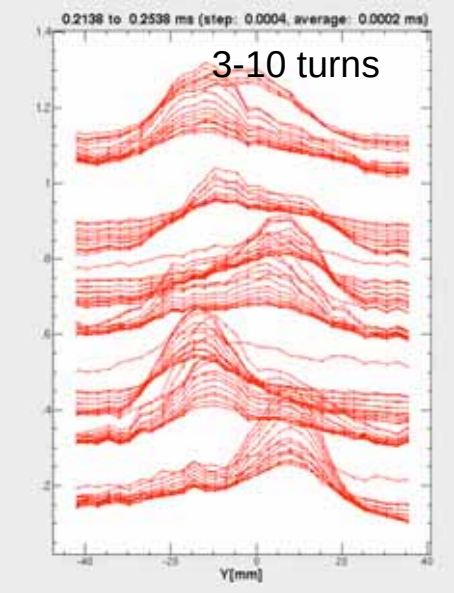


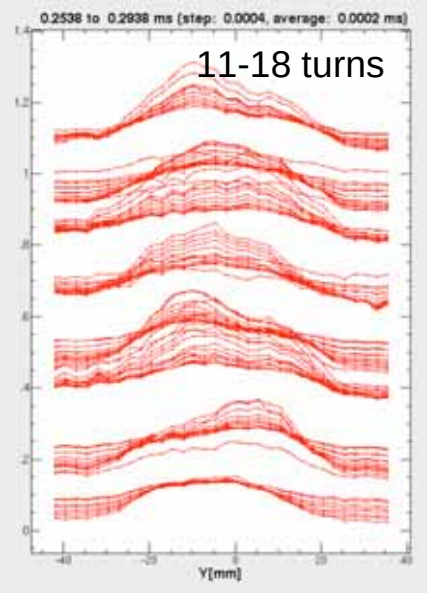
Beam loss after 0.85 sec is caused by leakage field of dump septum.
Details will be studied in the next RUN from June 11.

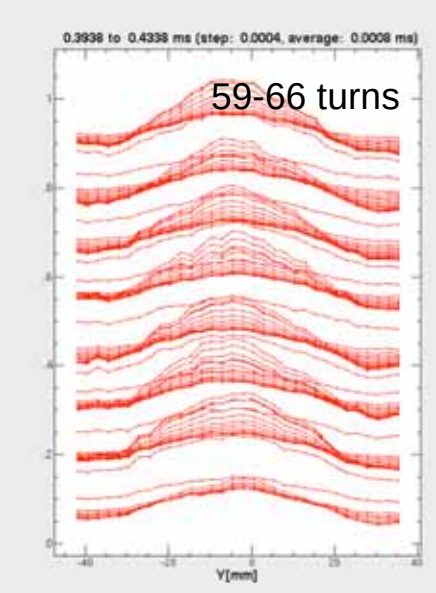
Tune measurement

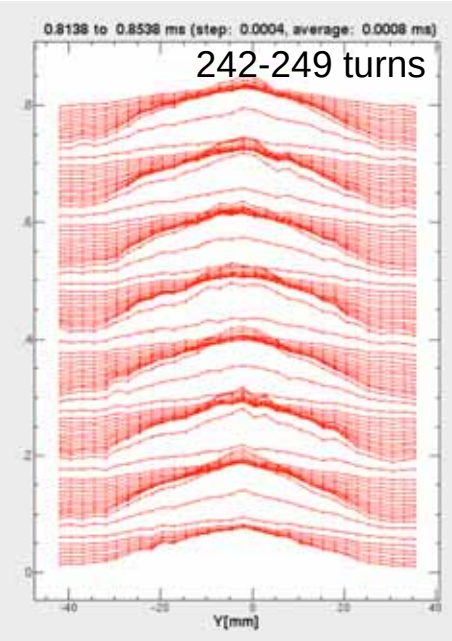


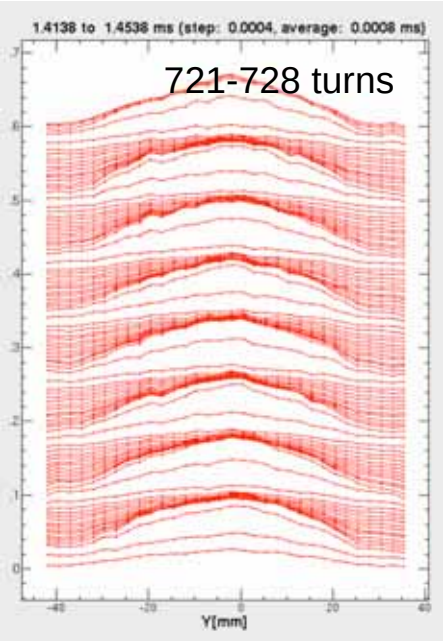
Vertical beam profile measured by IPM

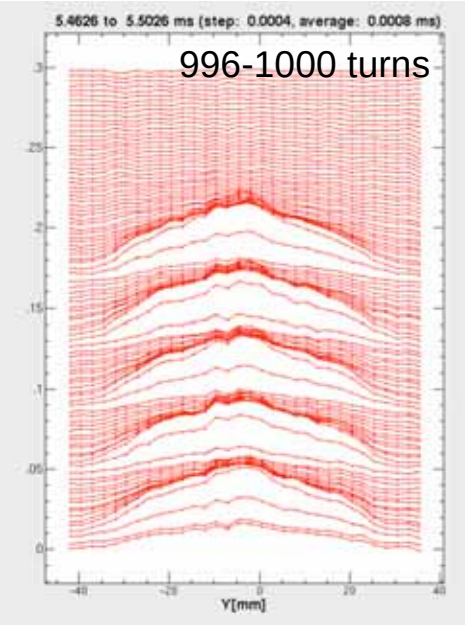












Intensity upgrade plan of the first three years

			JFY 2007								JFY 2008												JFY2009											
			8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
LINAC	Output power <for RCS	kW		5.4<0.25>								5.4<0.6>				5.4<1.2			6					15					<18>					
	Peak current	mA		5-25																														
	Pulse width	nsec		50-100								50-250																						
	Beam Rep.	pps		single - 25								single - 25																						
RCS	Output power	kW		4								4				4			100					250					(280)					
(MLF)	Typical Beam Rep.	pps		single - 25								single - 2				single - 25																		
	No. of Bunches			1 - 2								1 - 2				1- 2			1- 2					1- 2					2					
	Particles /bunch for MLF			4.2E11								4.2E11				8.5E11			4.2E12					1.1E13					1.2E13					
	Particles /bunch for MR																		(4.2E11)					(4.2E11)										
	Particles /ring for MLF																		8.3E12					2.1E13										
	Particles /ring for MR																		(8.3E11)					(4.2E11)										
MR	Output power	kW										0.12							1.2					3.6					100					
	Energy	GeV										3							30															
	Typical Beam Rep.	pps										0.3																	0.3 - 0.5					
	No. of Bunches											1 -2							1 - 2					6					6					
	Particles /bunch											4.2E11							4.2E11					4.2E11					1.2E13					
	Particles /ring											8.3E11							8.3E11					2.5E12					7.2E13					
HD	Output power	kW																	1.2															
	Energy	GeV																	30															
	Particles /burst																		8.3E11															
NU	Output power	kW																						3.6					100					
	Energy	GeV																						30										
	Particles /burst																							2.5E12					7.2E13					

- Requirement from T2K: 2.0E20 protons on the ν target by the 2010 summer shutdown.
- Guideline :Beam loss at each extraction point < 25 -100 W to keep residual radiation level < 1mSv/h.

Summary

The linac and RCS have been commissioned successfully.

For RCS:

- We achieved the acceleration of 4.6x10^12 particles (h=2, 1bunch) with 25 Hz repetition (in a few minutes due to the dump limit), corresponding to 100 kW operation in terms of particles per bunch.

- **Next goal is to achieved a "stable" operation with at least 20kW output in 2008.**
- **For this purpose, study of painting injection has been started in this May.**

For MR:

Beam commissioning has been started in May 2008.

1st stage (May-June 2008):

Beam injection , rf capture and extraction were successfully performed.

2nd stage (Dec. 2007-Feb. 2008): Acceleration to 30 GeV,

beam extraction to abort dump and hadron beamline

3rd stage (April -June 2009): Beam extraction to neutrino beamline