NP08, March 5, 2008

Status of J-PARC Accelerator

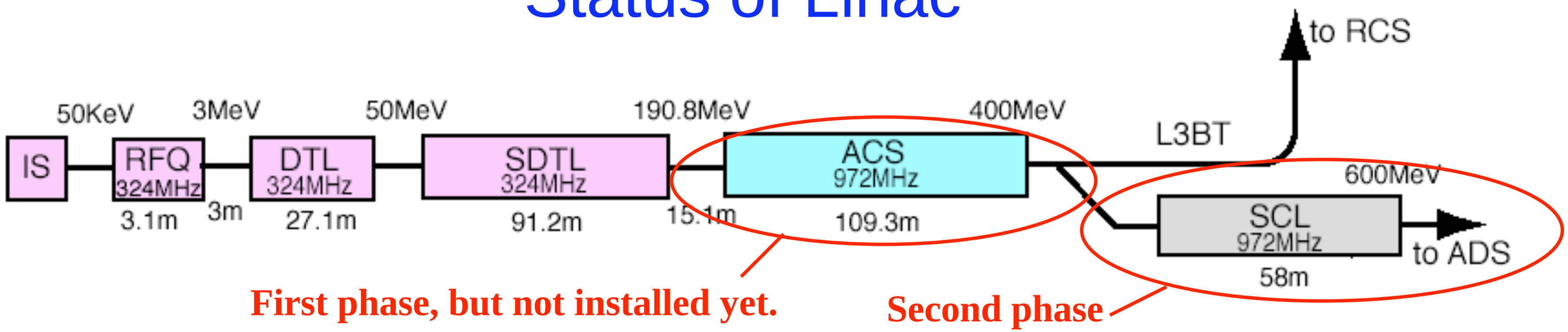
Tadashi Koseki (Accelerator Laboratory, KEK)
for the J-PARC accelerator group

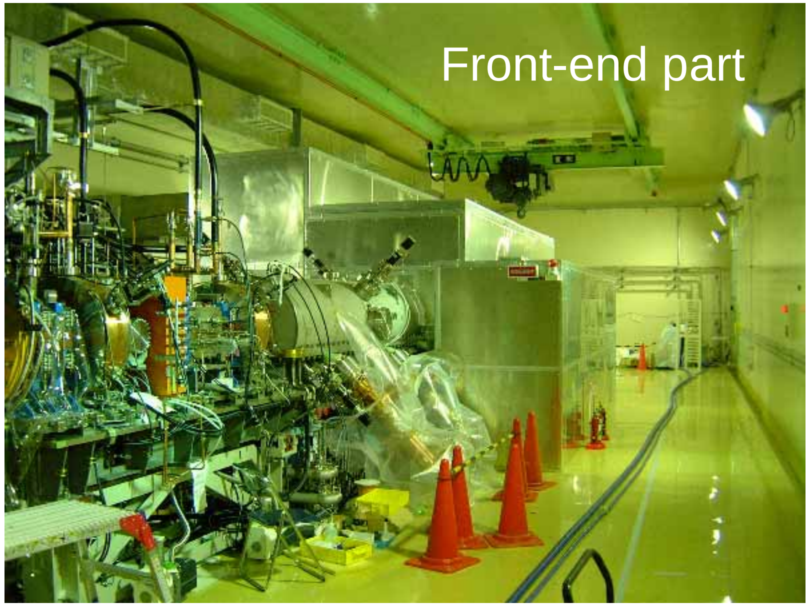
Milestones

- Linac Beam Commissioning was started in Nov., 2006.
- The linac accelerated the beam to a design value, 181 MeV on Jan. 24th, 2007.
- RCS Beam Commissioning was started in Oct., 2007.
- The RCS accelerated the beam to a design value, 3 GeV on Oct. 31st, 2007.

- Beam Commissioning of MR will be started in May, 2008

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	25 30 (RFQ)
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 positio 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, ATAC2008

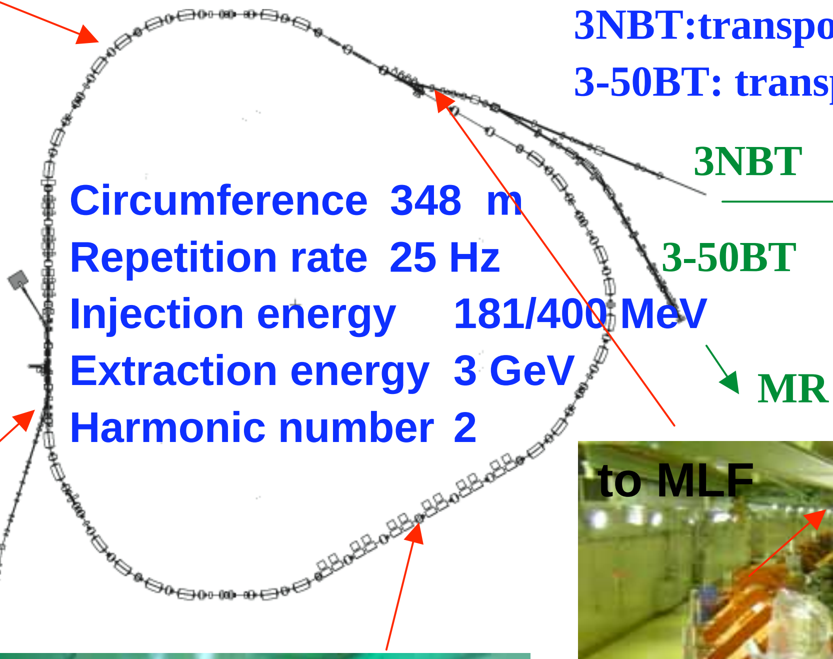
Status of RCS

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

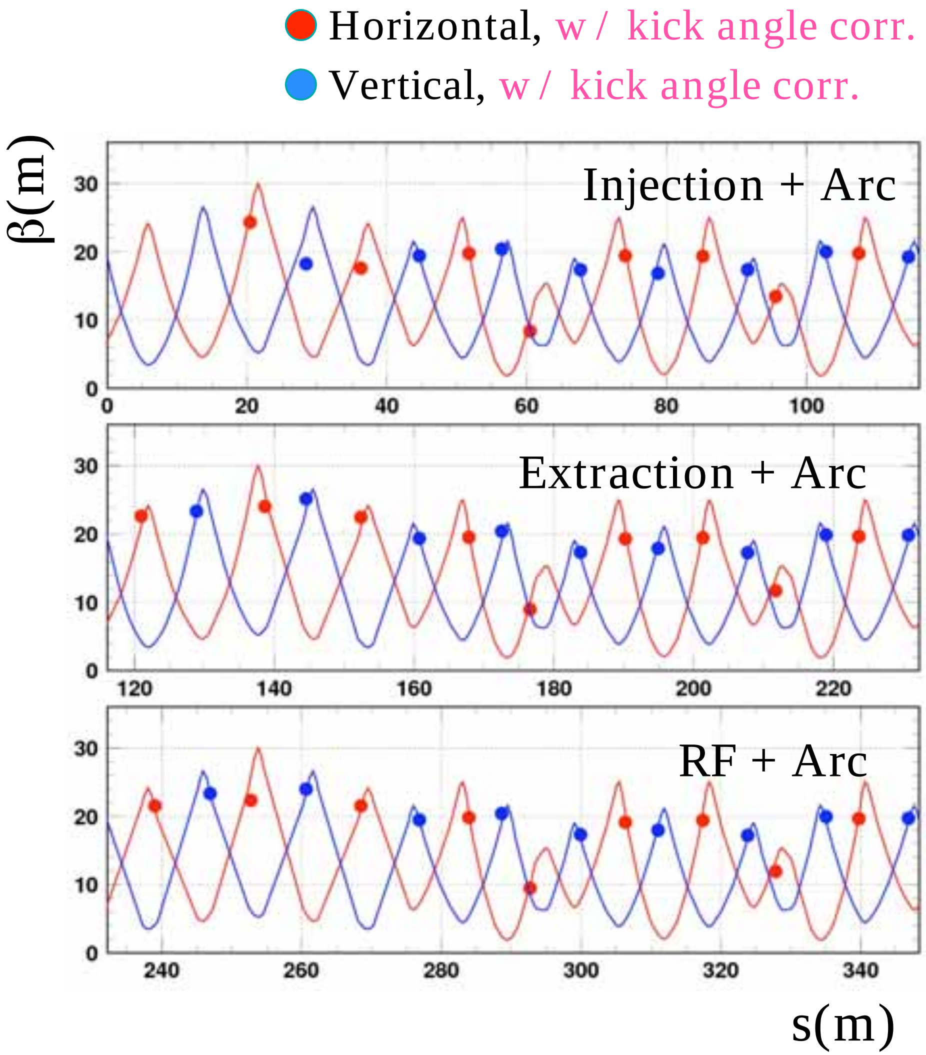
Extraction energy 3 GeV

Harmonic number 2

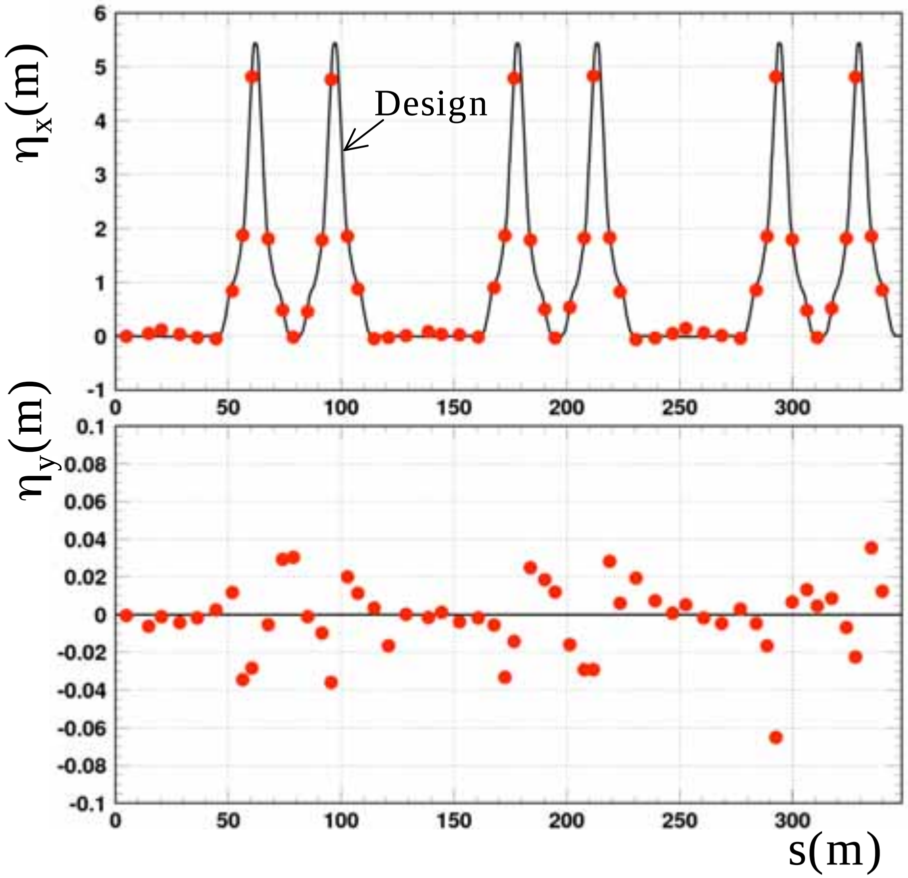
Beta function and dispersion

181 MeV DC mode

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



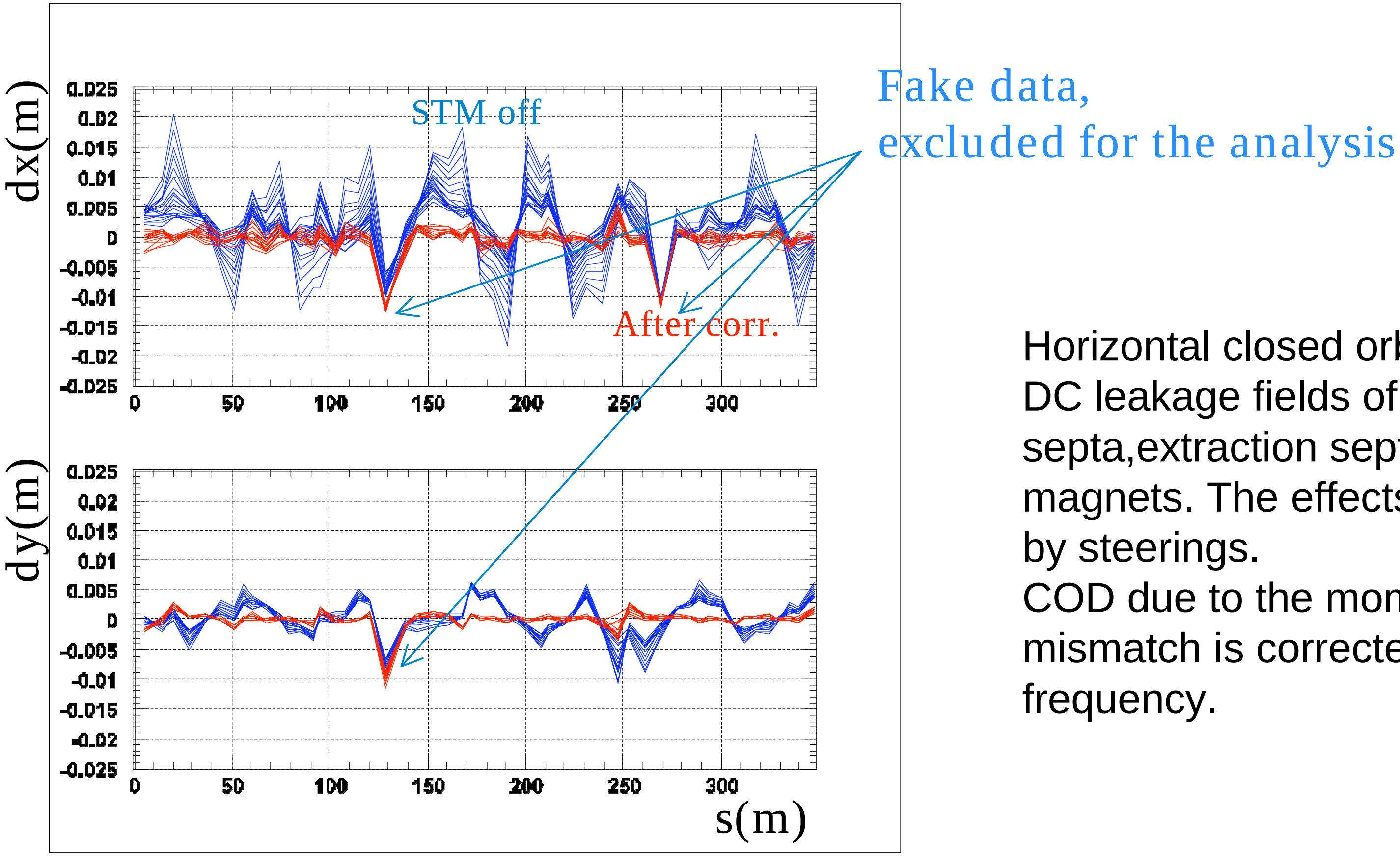
η: Measured from rf-frequency dependence of the closed orbit



Good agreement with the design.

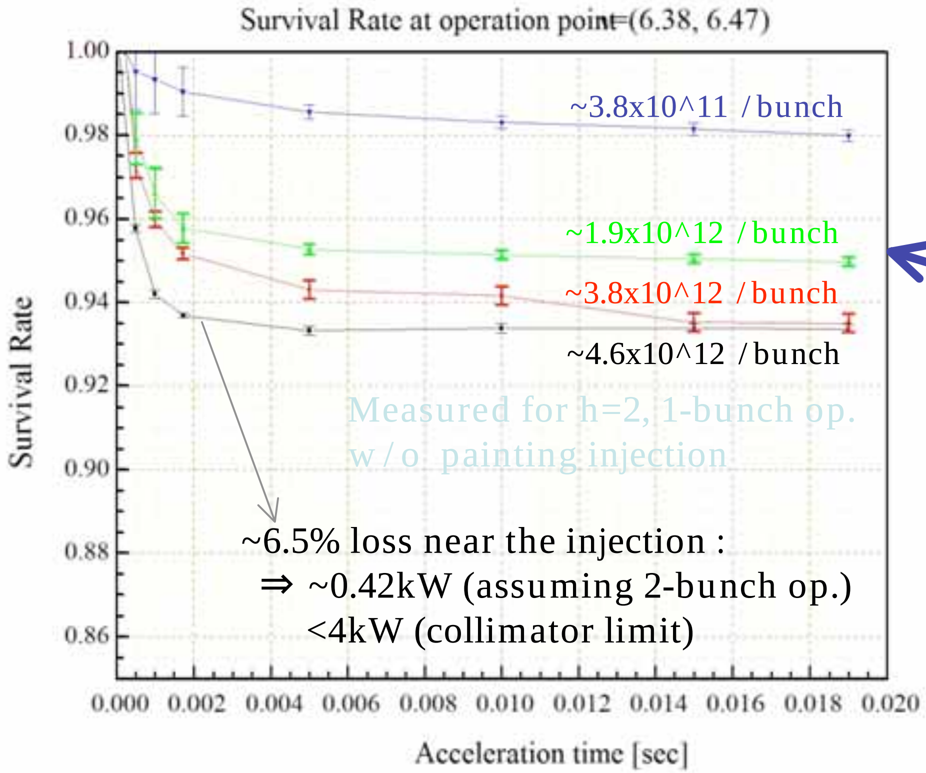
H. Hotchi, ATAC2008

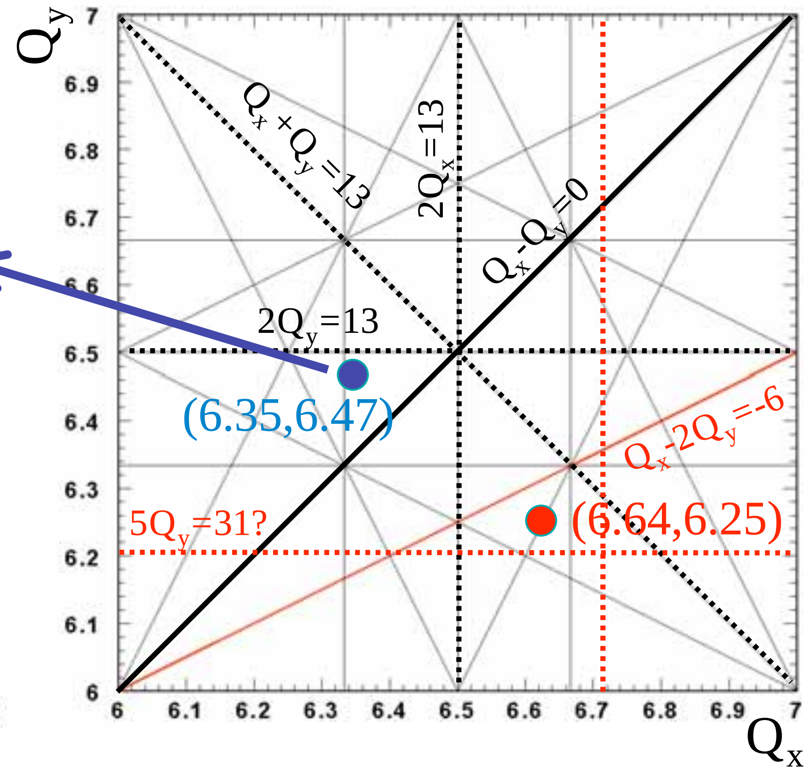
Closed orbit correction at 3 GeV acceleration mode



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





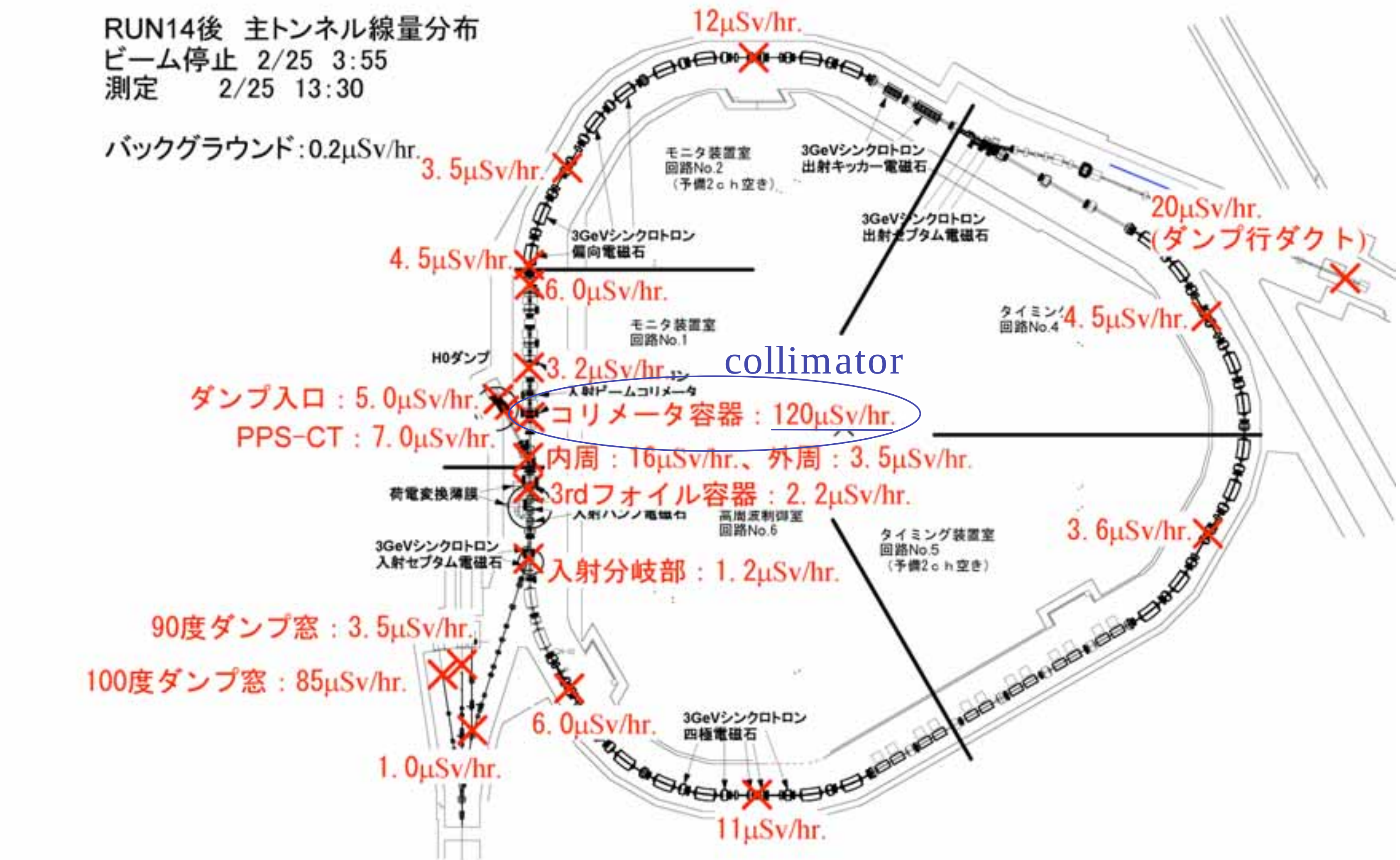
~3.8x10^11 /bunch (Peak: 22mA, Macro: 0.05ms, Medium: 112ns, Vrf~420kV)
~1.9x10^12 /bunch (Peak: 22mA, Macro: 0.05ms, Medium: 560ns, Vrf~420kV)
~3.8x10^12 /bunch (Peak: 22mA, Macro: 0.1ms, Medium: 560ns, Vrf~420kV)
~4.6x10^12 /bunch (Peak: 22mA, Macro: 0.12ms, Medium: 560ns, Vrf~440kV)

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, ATAC2008

Residual radiation level measured
after RUN#14 (w/ high current op.)



Particle losses are almost localized on the collimators

Summary of Linac/RCS

The linac and RCS have been commissioned successfully.

The stability of linac beam is sufficiently good for beam commissioning of RCS.

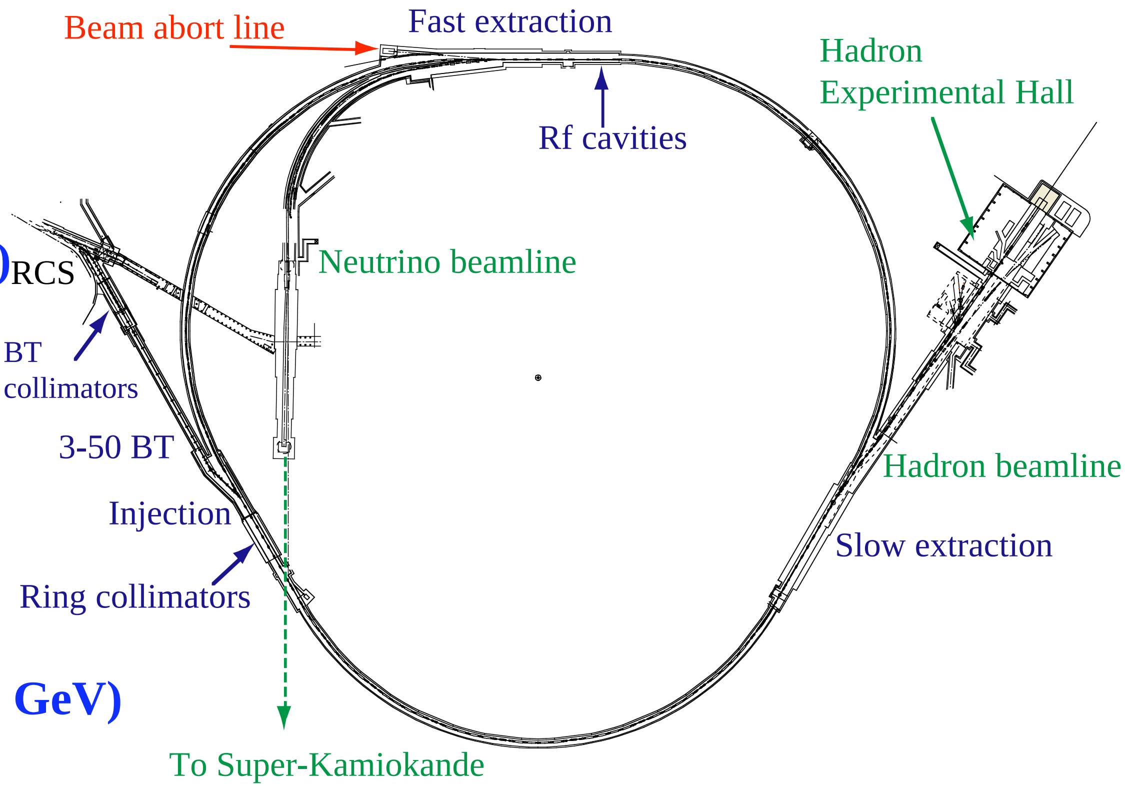
For RCS:

- The optics measurement and its correction were successfully performed.
- 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.
- The particle loss was almost localized on the collimators.
- The RCS is ready for the MR & MLF beam commissioning.
- Next goal is to achieved a “stable” operation with at least 20kW output in 2008.

- The foil exchange system was broken by shutting the gate valve while the foil holder was inside. -> Repaired system will be installed in the summer of 2008.
- Capacitors at ceramics vacuum chamber of the injection bump magnets were burned by the IGBT noise. Reduction of IGBT noise and replacement of capacitors are necessary.
- The DC leakage fields should be improved.
- More rf system should be installed for higher current operation .
- We need spare parts for the routine operation.
- and so on….

MR (slow cycling Main Ring synchrotron)

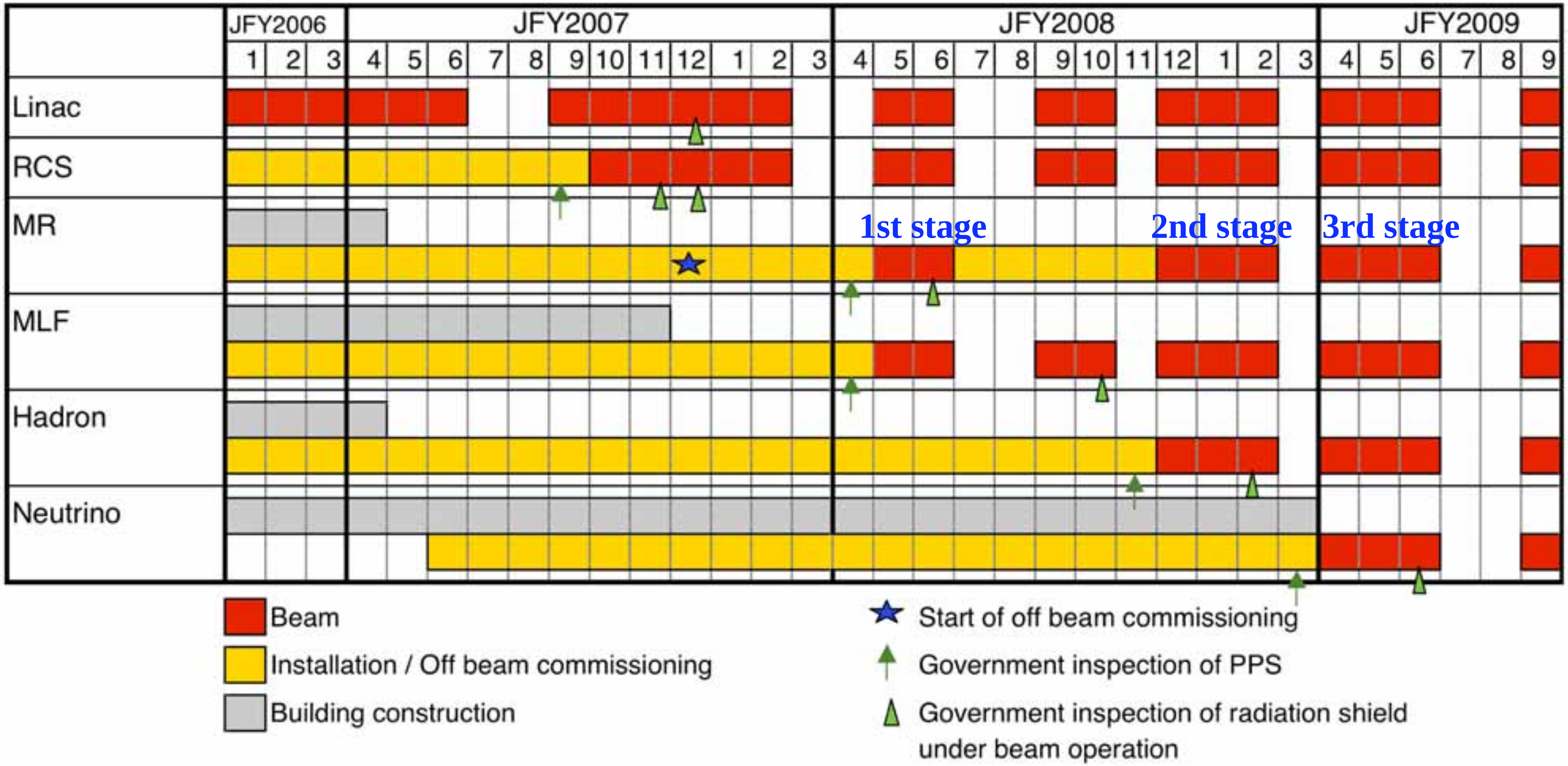
Circumference	**1567.5 m**
Repetition rate	**~ 0.3 Hz**
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
	50 GeV (2nd phase)
Superperiodicity	**3**
h	**9**
No of bunches	**8 (6 in day-one)**
Transition γ	**j 31.7**
Typical tune	**22.4, 20.8**
Transverse emittance	
At injection	**~54 πmm-mrad**
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 (Rare decay, hyper nucleus..)
- **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 located 300 km west)

Schedule of beam commissioning



MR schedule

Dec. 2007-April 2008 :Off beam commissioning

March-April 2008: Modification of the PPS (to add the interlock system of MR&MLF) and government inspection.

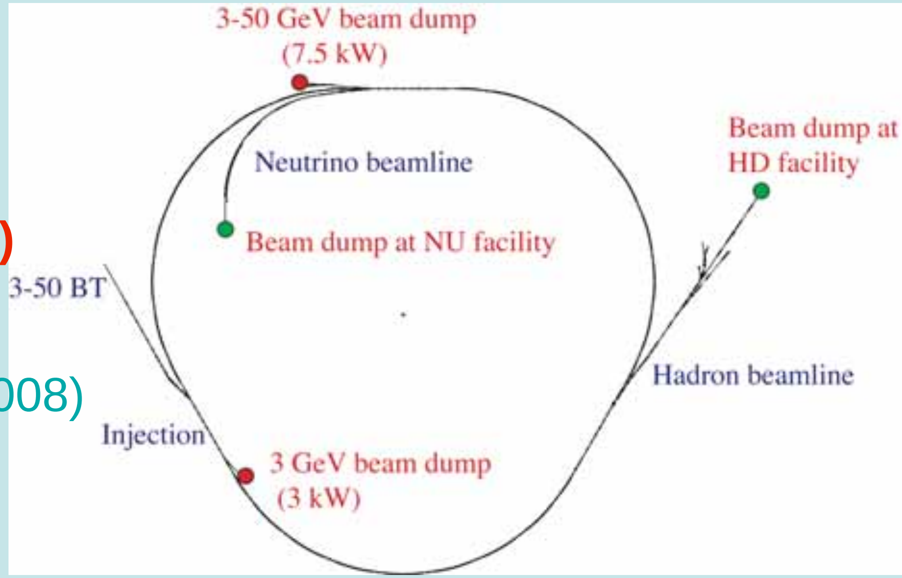
May 2008: MR (and MLF)beam commissioning starts.

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 components/
off beam commissioning(July 2008-Nov. 2008)
FX septa (SM1,2, SM33), FX kickers,
SX devices,
Neutrino beamline components….



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

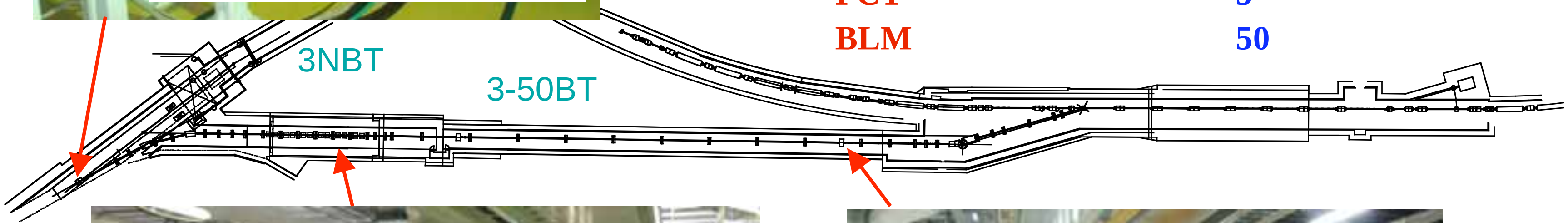
3rd stage(Apr. - June 2009):
The dump at the NU beamline is available
Extraction to Neutrino beamline

Status of 3-50 BT

Precise alignment of the B, Q magnets and installation of all power line cables have been finished.
Installation of vacuum chambers and monitors is almost completed.

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


Pulsed bending magnet




BT collimators


Slope section

Commissioning of magnet power supplies are now in progress. Almost ready for beam operation.

Magnet system

Main magnets	
Dipole	96
Quadrupole (11 family)	216
Sextupole (3 family)	72
Steering magnets	
H. Steerings	93
V. Steerings	93

Precise alignment of all the main magnets has been completed.

Hardware commissioning of the main and steering magnet systems have been started in December 2007 as scheduled.

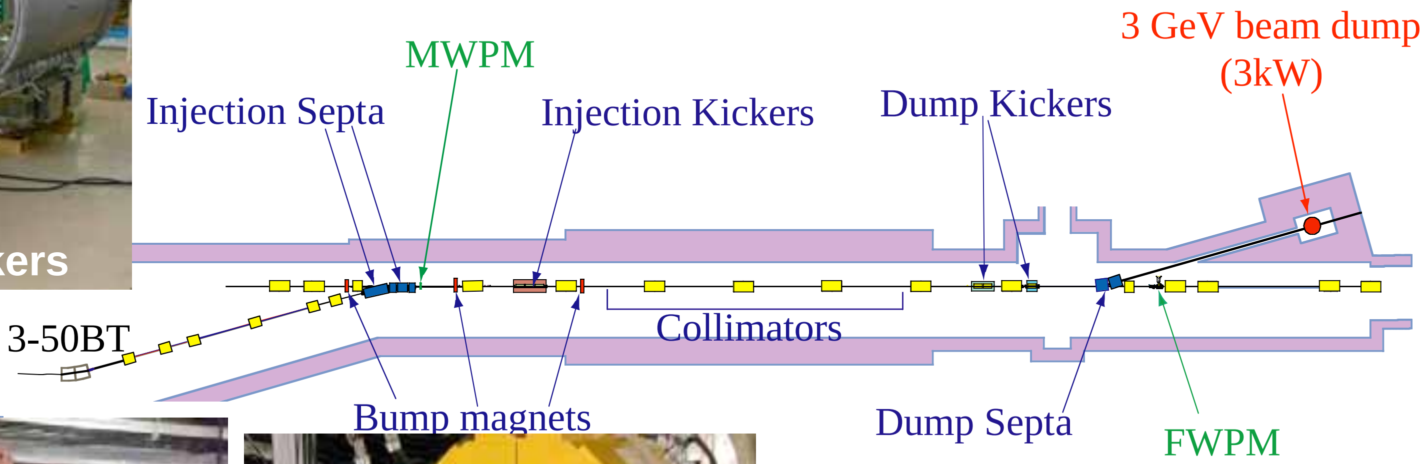
During the magnet power supply tests, it was found that even one power supply may violates the electric power company guide line, which is total harmonics distortion (THD) of AC voltage < 1%. This means a filter equipment is essentially important for the MR operation.

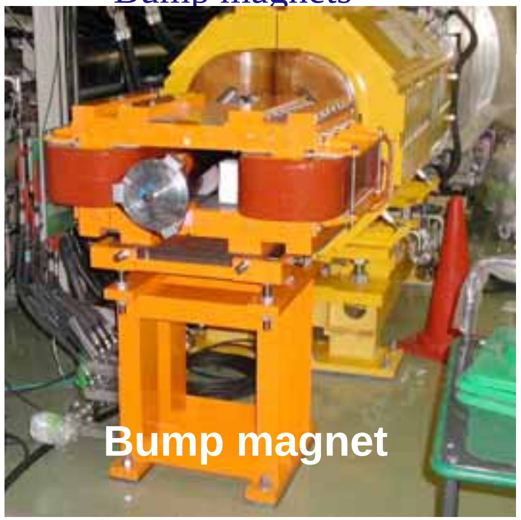
We have a harmonic filter of 6.5 Mvar unit. According to recent simulations, THD is ~1% when all the power supplies operated in 30 GeV with the filter.

We will measure THD is less than 1 % or not in this March. If the THD is larger than 1 %, we have to install some additional filter systems.

Injection devices (1)

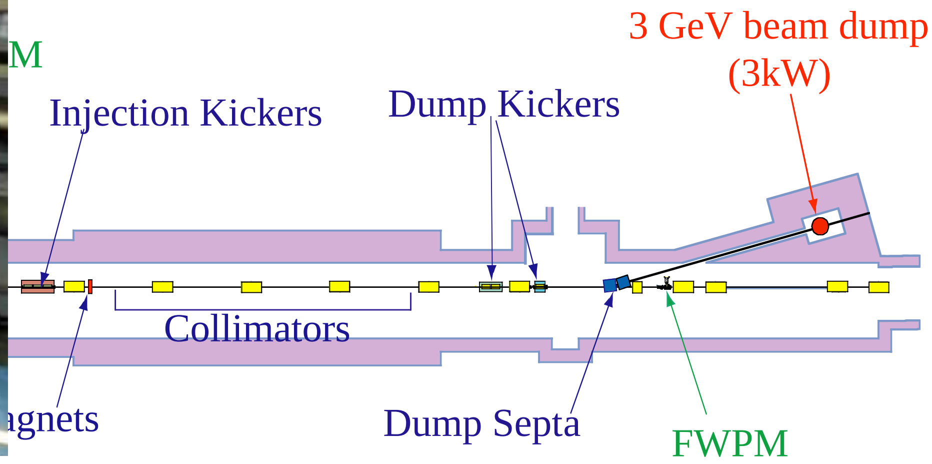
All the injection devices have been tested outside
and will be powered in the tunnel by the middle of March.





Injection kickers : Installed. Hardware commissioning is in progress.
Injection septum I : Installed. Hardware commissioning will be started in the middle of March.
Injection septum II : Installed. Hardware commissioning will be started in the middle of March.
Bump magnets : Installed. Hardware commissioning will be started in the middle of March.

Injection devices (2)



Collimators : Installed. Solenoid coils have been mounted on the beam ducts.
Injection dump kickers : Installed. Hardware commissioning will be started in the middle of March.
Injection dump septa : Installed. Hardware commissioning will be started in March.
Injection dump beamline : Vacuum evacuation will be started by April.

MA loaded rf cavity

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

At initial operation in the second stage of commissioning, required rf voltage is ~ 200 kV for 30 GeV (Nominal voltage is 45 kV/cavity).

Five rf systems should be installed by December 2008.

Long-term high power operation test of MA cores:

All 90 cores (for 5 cavities) have been tested > 300 hrs with nominal rf gap voltage of 15 kVp, 60% duty.

-> Serious core damages have not been observed.

For the first stage of beam commissioning, four cavities have been installed.

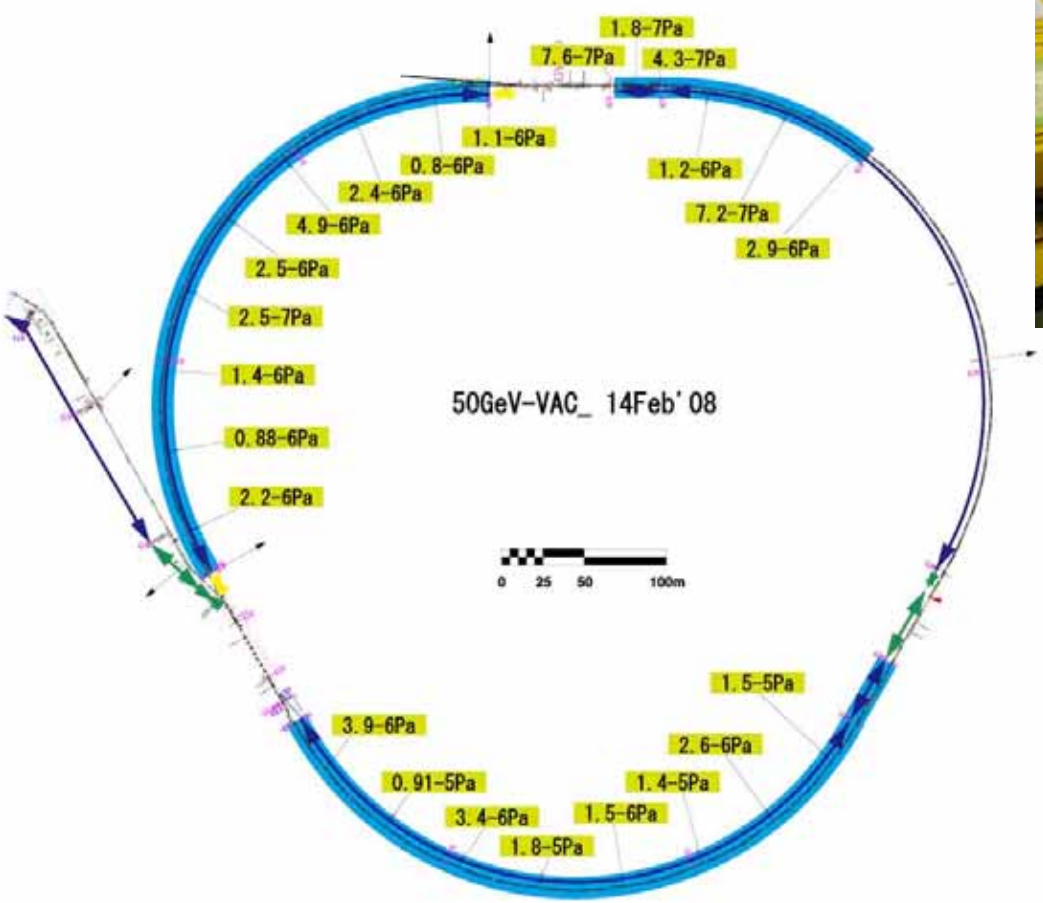
Hardware commissioning will be started in March.

The fifth system will be installed before the second stage of beam commissioning.

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

Status of Vacuum system

・All the arc sections are evacuated by ion/turbo pumps.



Connecting

Leak checking

Pumping by TMP

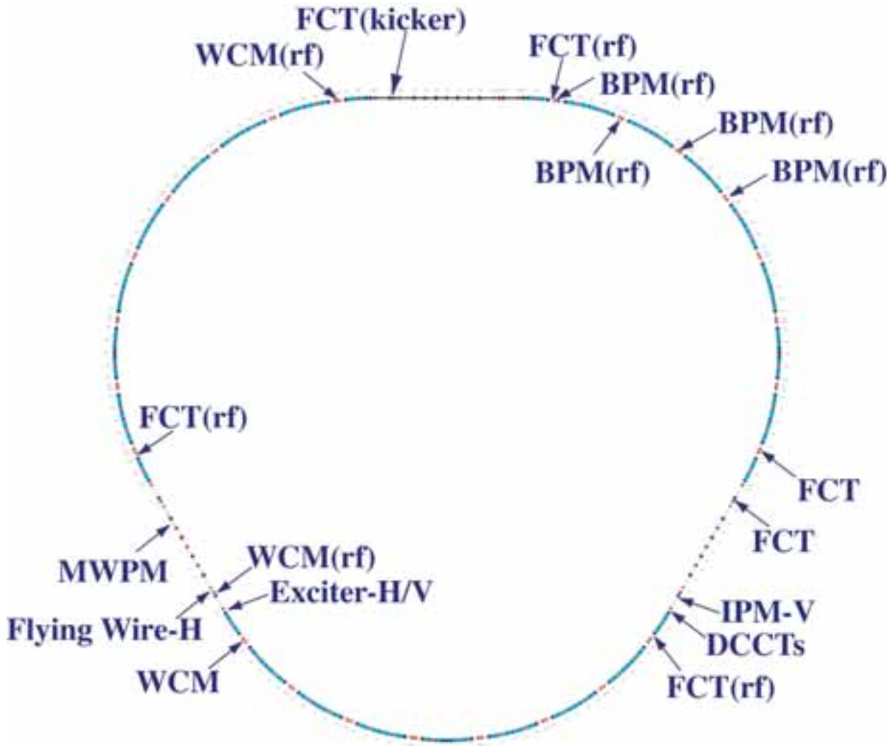
Pumping by SIP

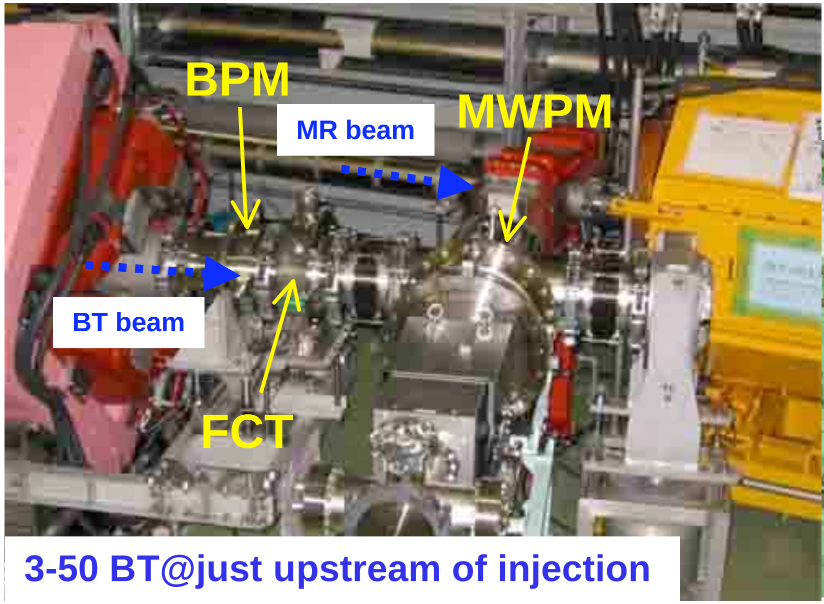
Typical pressure is several μPa.

・Connection of vacuum ducts in the injection and FX straight sections is in progress.

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



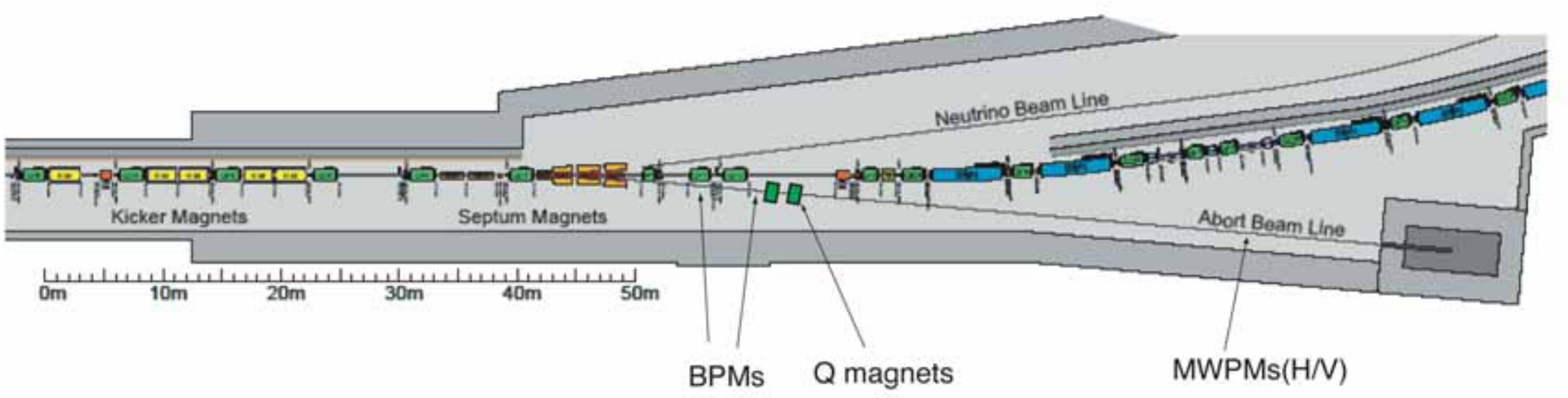


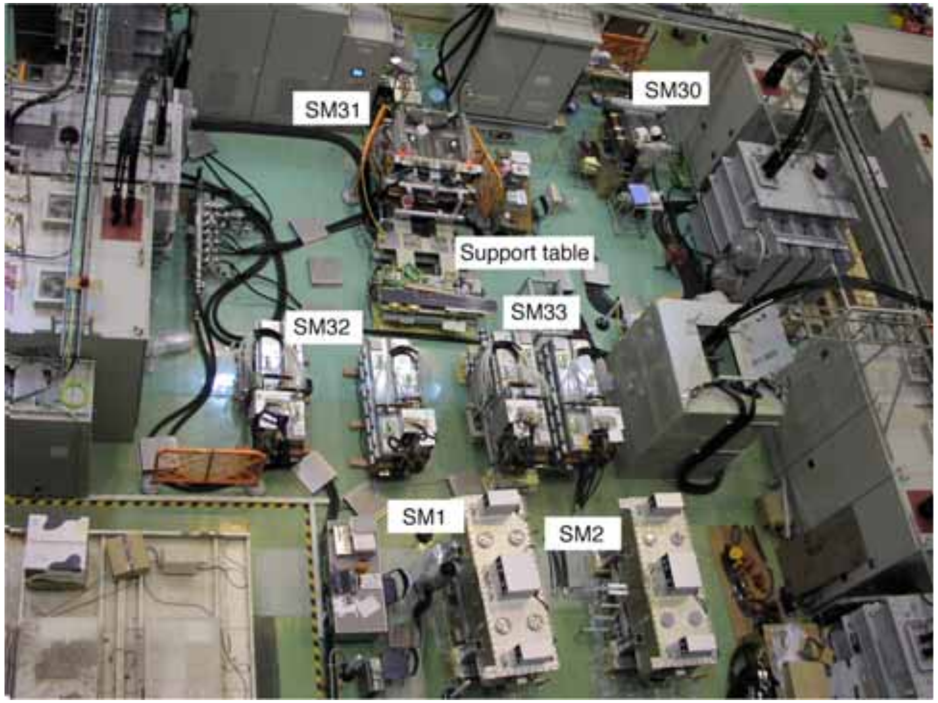
3-50 BT@just upstream of injection

Installation, cabling and calibration are in progress.

Fast extraction devices

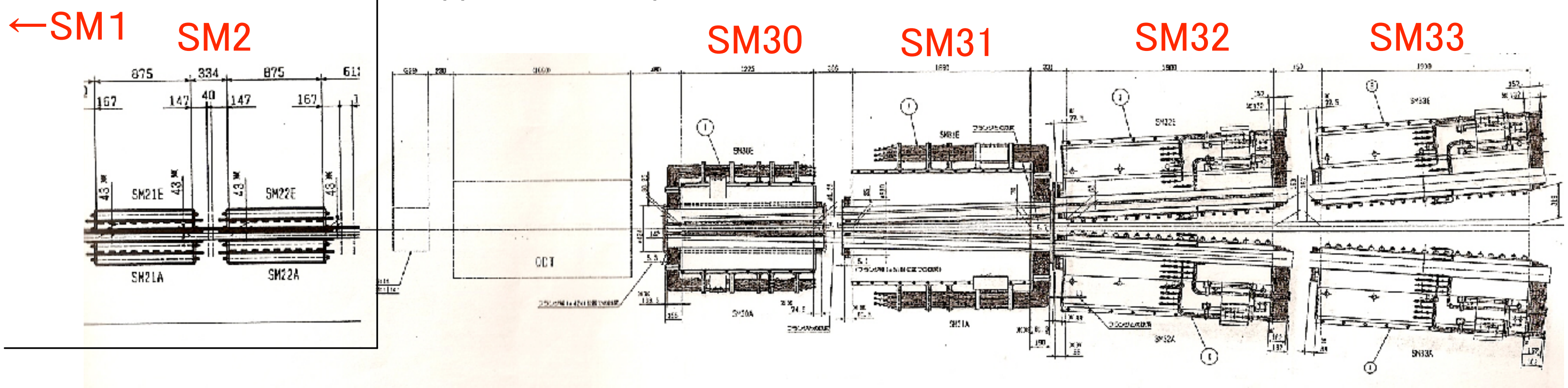
Fast extraction system comprises 5 bipoler kicker magnets and 8 bipolar septum magnet systems.

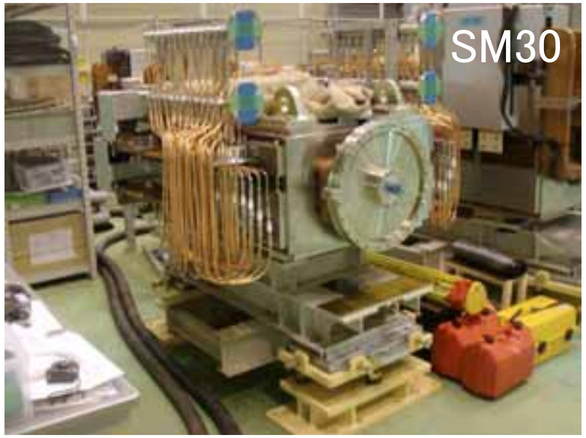




Fast extraction septum magnets

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.



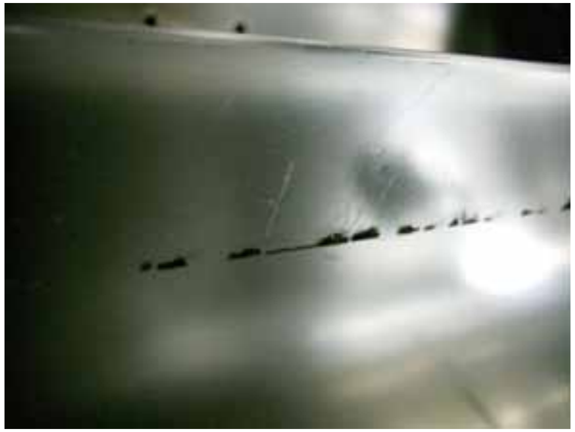


SM30-32 will be Installed in the ring tunnel in this weekend.
SM33, SM1,2 are planned to install in the summer of 2008.

Fast extraction kicker

Problems of the traveling wave type kicker

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

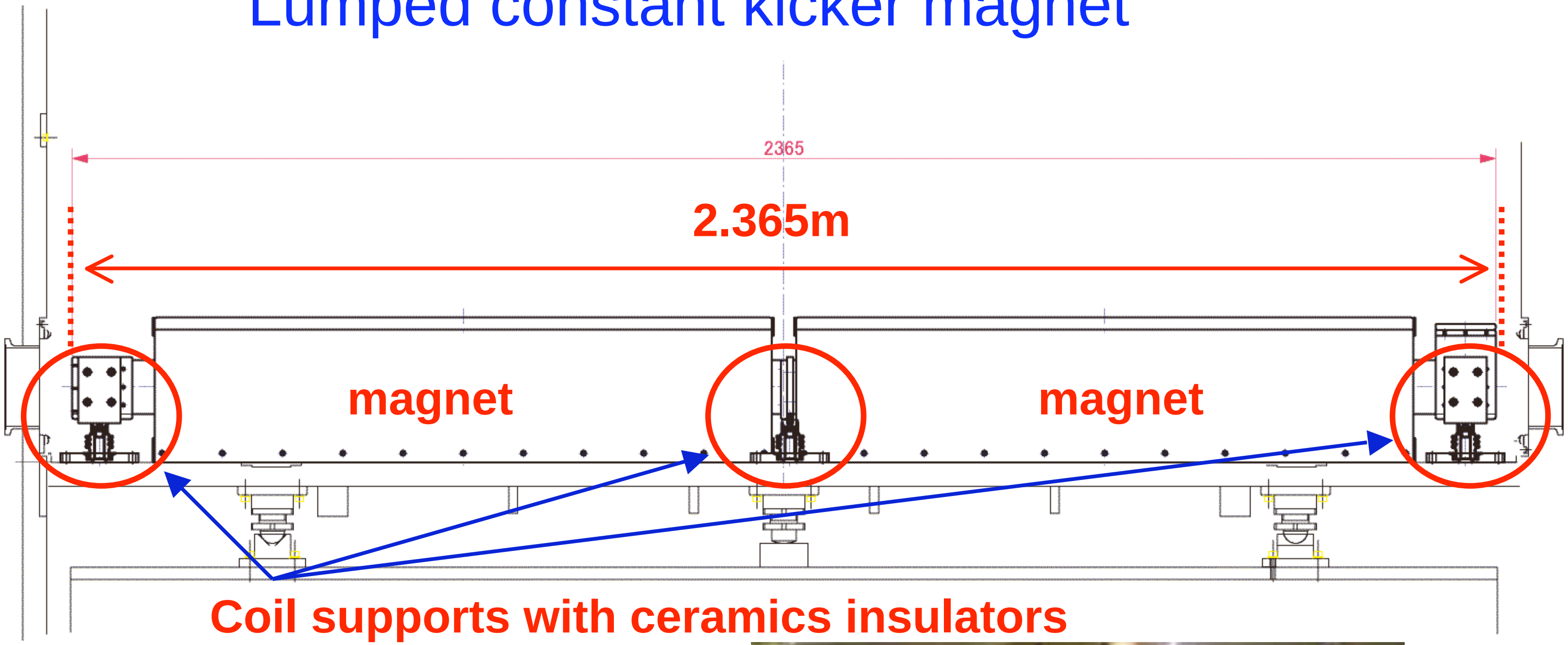


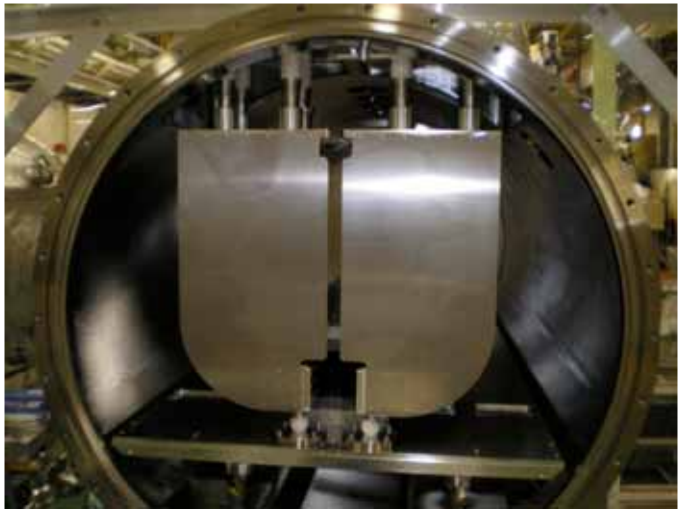
Discharge spots:
Discharge occurred between the electrode and ferrite cores.

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





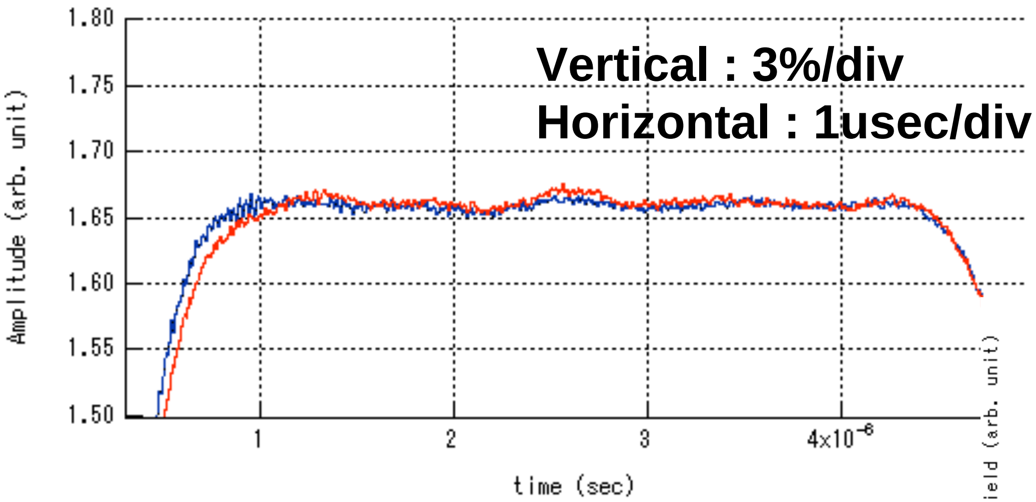
Vacuum chambers and ferrite cores of the traveling type kickers are used.

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

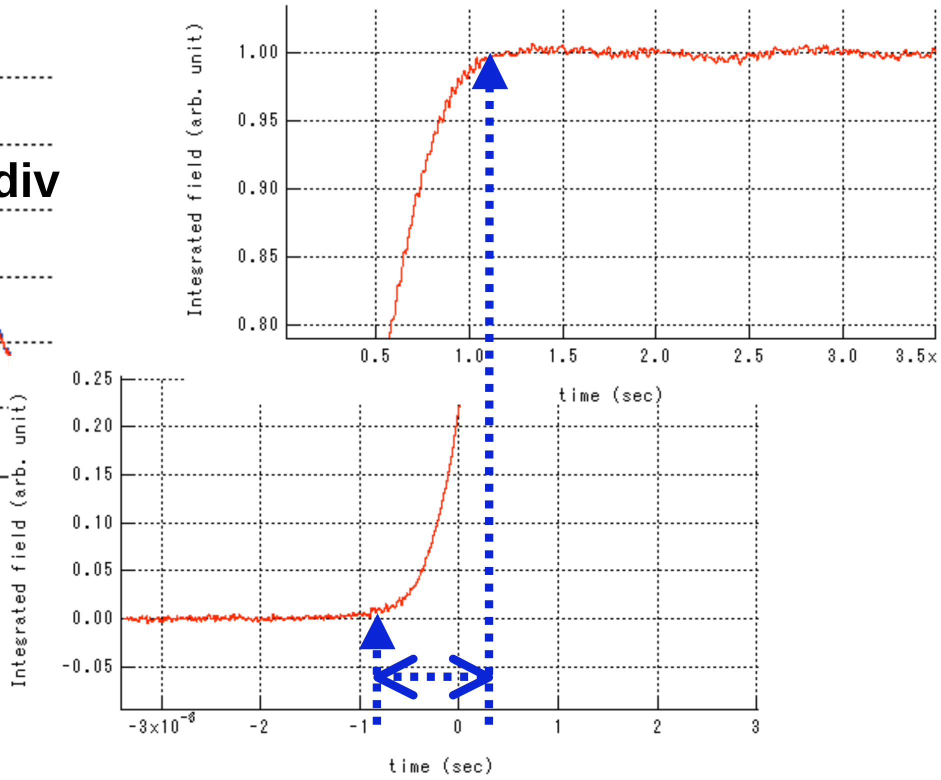
Test operation of lumped constant type kicker

- 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

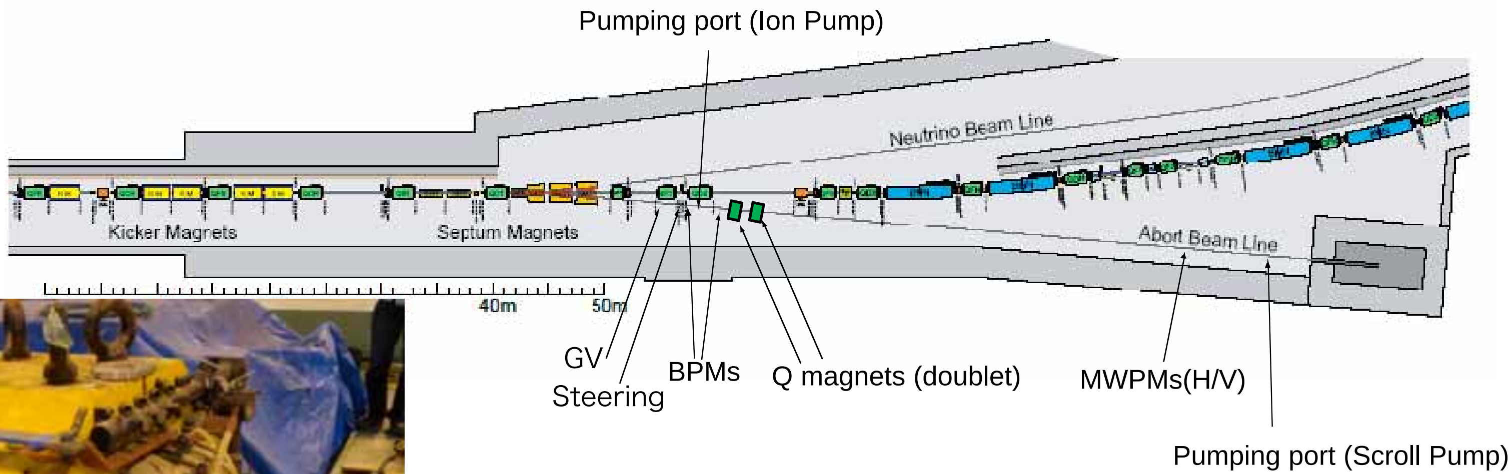


Rise time (1-99%) = 1.8072μsec
@ Vc=30kV (33 GeV)

Abort Beamline

Abort beam is bent outward in the fast extraction section and transported to 7.5 kW dump.

- Beamline length ~ 73 m
- DC Q-doublet is installed at 10 m from the extraction point.



Quadrupole (recycled)

DC PS (recycled)

ϕ 746 Beam duct

The abort beamline components will be installed in the summer of 2008.

Slow extraction system

Installed: Resonant Sextupole (8)

Manufactured in 2007, installed in the summer of 2008

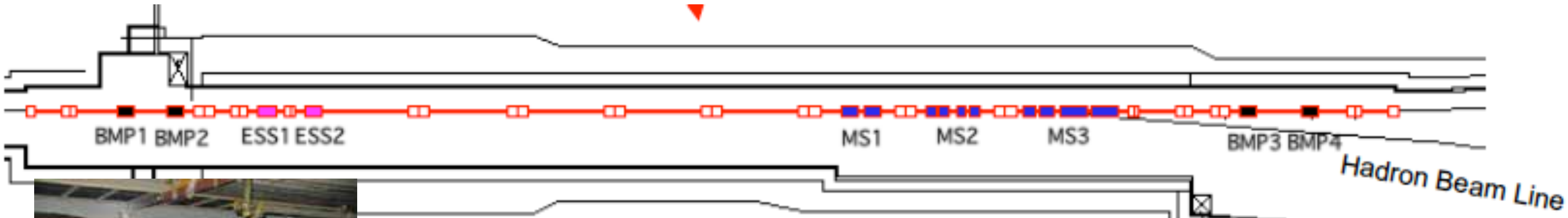
- Electro-static septum (2)
- Thin septum magnets, 1.5 mm (1), 3.5 mm(1), 7.5 mm (4)
- Strong field septum magnets(4)
- Shift bump magnet (4)
- Power supplies (recycled/manufactured)

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



Resonant sextupoles (8) have been installed.

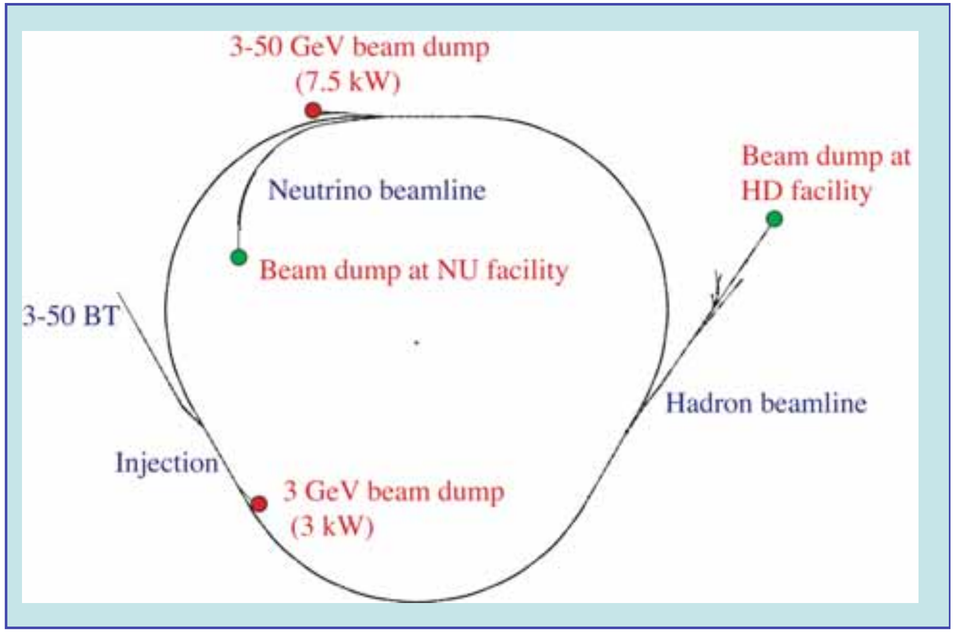
Vacuum vessel of ESS

Yoke and 30μm ribbon type septum of ESS

Details are given by M. Tomizawa

Procedure of beam commissioning(1)

Linac/RCS beam for MR commissioning
Start with following conditions:
Linac: 5 mA, 50 μsec, chopped beam
RCS: without painting,
~10 pimm-mrad
one bunch operation (h=2)
< 4e11 ppb (1 % intensity),
single shot



1st stage : Injection and 3 GeV DC operation	Beam dump
Injection tuning (3-50 BT and MR)	Injection dump
Establish closed orbit	Injection dump
RF capture	Injection dump
Establish optimum operating point	Injection dump

- COD correction
- Injection tuning
- Tune Survey
- RF parameter tuning
- Chromaticity correction

Procedure of beam commissioning(2)

2nd stage :Acceleration

Acceleraion	Abort dump

- ・RF parameter tuning
- ・Closed orbit tuning
- ・Abort line tuning
- ・FX devices tuning
- ・Confirmation of adiabatic damping

2nd stage :Beam extraction to HD beamline

Establish optimum operating point	Abort dump

- ・Tune Survey
- ・Physical aperture survey
- ・Dynamic aperture survey

Beam extraction tuning	HD dump

- ・HD beamline tuning
- ・SX devices tuning
- (・Spill control (Sep. 2009 ~))

3rd stage : Beam extraction to NU beamline

Establish optimum operating point	Abort dump
Beam extraction tuning	NU dump

- ・NU beamline tuning

Intensity upgrade plan of the first three years

JFY 2007

			8	9	10	11	12	1	2	3
LINAC	Output power <for RCS	kW		5.4<0.25>						
	Peak current	mA		5-25						
	Pulse width	μsec		50-100						
	Beam Rep.	pps		single - 25						
RCS	Output power	kW		4						
(MLF)	Typical Beam Rep.	pps		single - 25						
	No. of Bunches			1 - 2						
	Particles /bunch for MLF			4.2E11						
	Particles /bunch for MR									
	Particles /ring for MLF									
	Particles /ring for MR									
MR	Output power	kW								
	Energy	GeV								
	Typical Beam Rep.	pps								
	No. of Bunches									
	Particles /bunch									
	Particles /ring									
HD	Output power	kW								
	Energy	GeV								
	Particles /burst									
NU	Output power	kW								
	Energy	GeV								
	Particles /burst									

JFY 2008

			4	5	6	7	8	9	10	11	12	1	2	3
LINAC	Output power <for RCS	kW		5.4<0.6>				5.4<1.2			6			
	Peak current	mA												
	Pulse width	μsec		50-250										
	Beam Rep.	pps		single - 25										
RCS	Output power	kW		4				4			100			
(MLF)	Typical Beam Rep.	pps		single - 2				single - 25						
	No. of Bunches			1 - 2				1- 2			1- 2			
	Particles /bunch for MLF			4.2E11				8.5E11			4.2E12			
	Particles /bunch for MR										(4.2E11)			
	Particles /ring for MLF										8.3E12			
	Particles /ring for MR										(8.3E11)			
MR	Output power	kW		0.12							1.2			
	Energy	GeV		3							30			
	Typical Beam Rep.	pps		0.3										
	No. of Bunches			1 - 2							1 - 2			
	Particles /bunch			4.2E11							4.2E11			
	Particles /ring			8.3E11							8.3E11			
HD	Output power	kW									1.2			
	Energy	GeV									30			
	Particles /burst										8.3E11			
NU	Output power	kW												
	Energy	GeV												
	Particles /burst													

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			4	5	6	7	8	9	10	11	12	1	2	3
LINAC	Output power <for RCS	kW	15					<18>						
	Peak current	mA												
	Pulse width	μsec												
	Beam Rep.	pps												
RCS	Output power	kW	250					(280)						
(MLF)	Typical Beam Rep.	pps												
	No. of Bunches		1- 2					2						
	Particles /bunch for MLF		1.1E13					1.2E13						
	Particles /bunch for MR		(4.2E11)											
	Particles /ring for MLF		2.1E13											
	Particles /ring for MR		(4.2E11)											
MR	Output power	kW	3.6					100						
	Energy	GeV												
	Typical Beam Rep.	pps						0.3 - 0.5						
	No. of Bunches		6					6						
	Particles /bunch		4.2E11					1.2E13						
	Particles /ring		2.5E12					7.2E13						
HD	Output power	kW												
	Energy	GeV												
	Particles /burst													
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 of MR

Installation of accelerator components is now in progress as schedule.

Off beam commissioning has been started in Dec. 2007.

Beam commissioning is scheduled from May 2008.

1st stage (May-June 2008): 3 GeV DC opetration

2nd stage (Dec. 2007-Feb. 2008): Acceleration to 30 GeV, abort dump, beam extraction to hadron beamline

(Schedule is very tight.)

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

Higher harmonics components of the main magnet power supplies may exceed the guide line of the electric power company for 30 GeV operation from December 2008.

We are investigating additional filters are required or not.

Budget is too tight to have contingencies. No spare components..

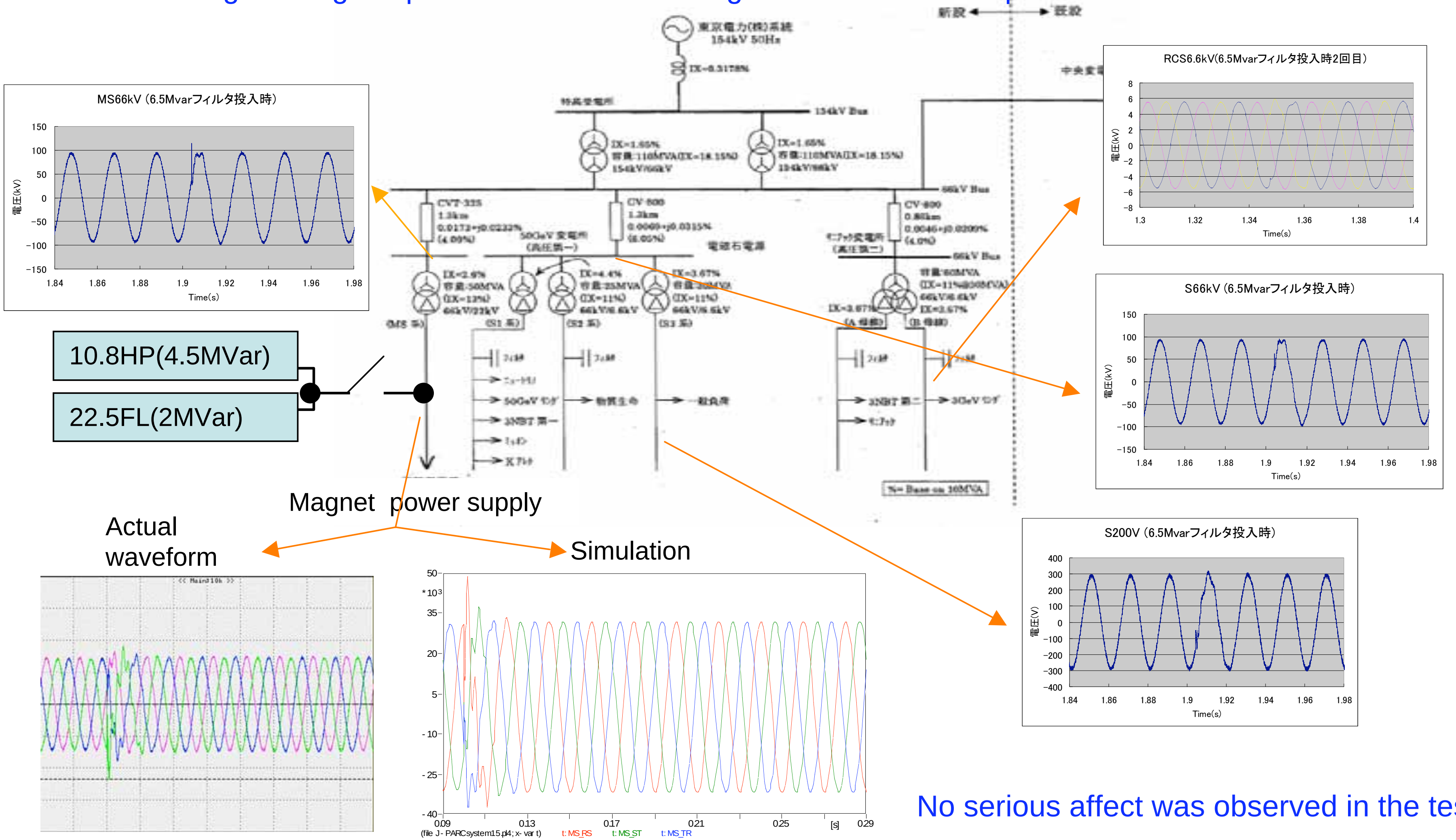
Thanks to users (Tohoku Univ. , ICEPP, Kyoto Univ. , RNCP and KEK) for their cooperation during component tests of the rf cavity , BPM and the charge exchange foil.

Harmonics issue (1)

During the magnet power supply tests, it was found that even one power supply may violates the electric power company guide line, which is total harmonics distortion (THD) of AC voltage < 1%. This means a filter equipment is essentially important for the MR operation.

We have a harmonic filter of 6.5 Mvar unit. (In general, filter is divided into 1 Mvar unit)

So before operation of the harmonic filter, impact of inrush current at the moment of connecting the large capacitor bank was investigated in a shutdown period of the reactors.



No serious affect was observed in the test.

Harmonics issue (2)

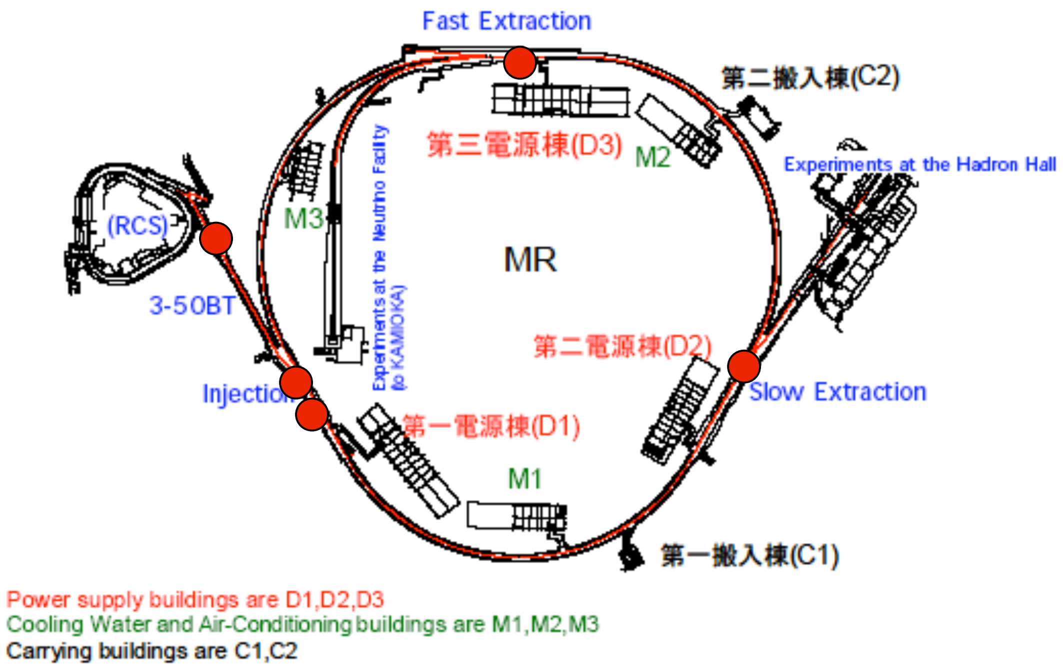
According to a simulation,

-THD is ~0.1% (with the filter) when all the power supplies operated in 3GeV DC
-THD is ~1 % (with the filter) when all the power supplies operated in 30GeV DC

In March 3rd, the harmonic filter will be switched on.
We start the tuning of 3 GeV DC operation for all the main magnet power supplies.
After the 3 GeV tuning, we move to 30 GeV DC operation tuning.
We will confirm THD is less than 1 % or not.

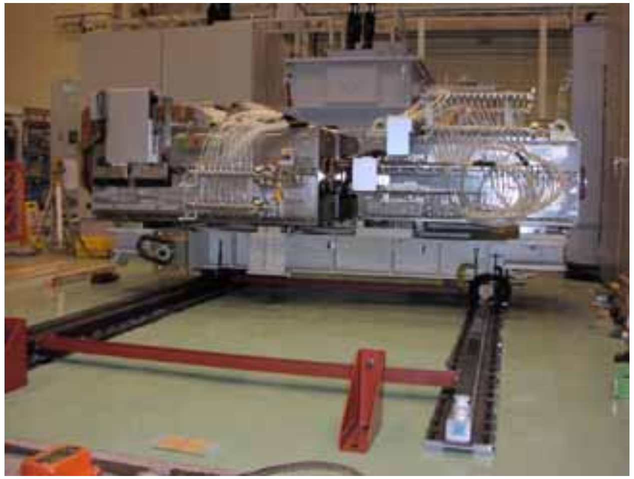
If the THD is larger than 1 %, we have to install some additional filter systems.
The problem is very long delivery time of the filter system (~ more than a half year ?).

Radiation maintenance



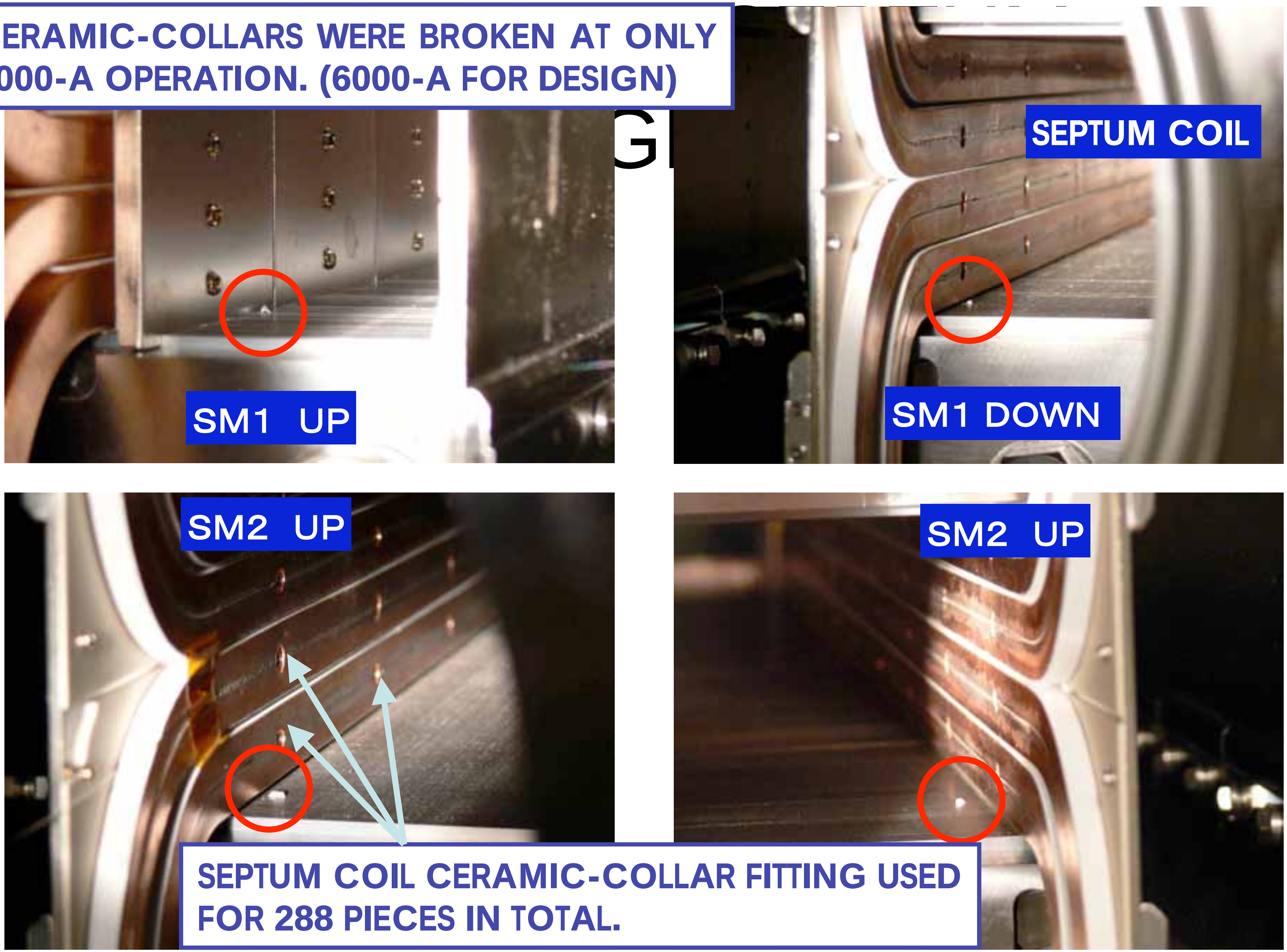
Movable local shield (Lead glass)

Semi-remote handling vacuum flange

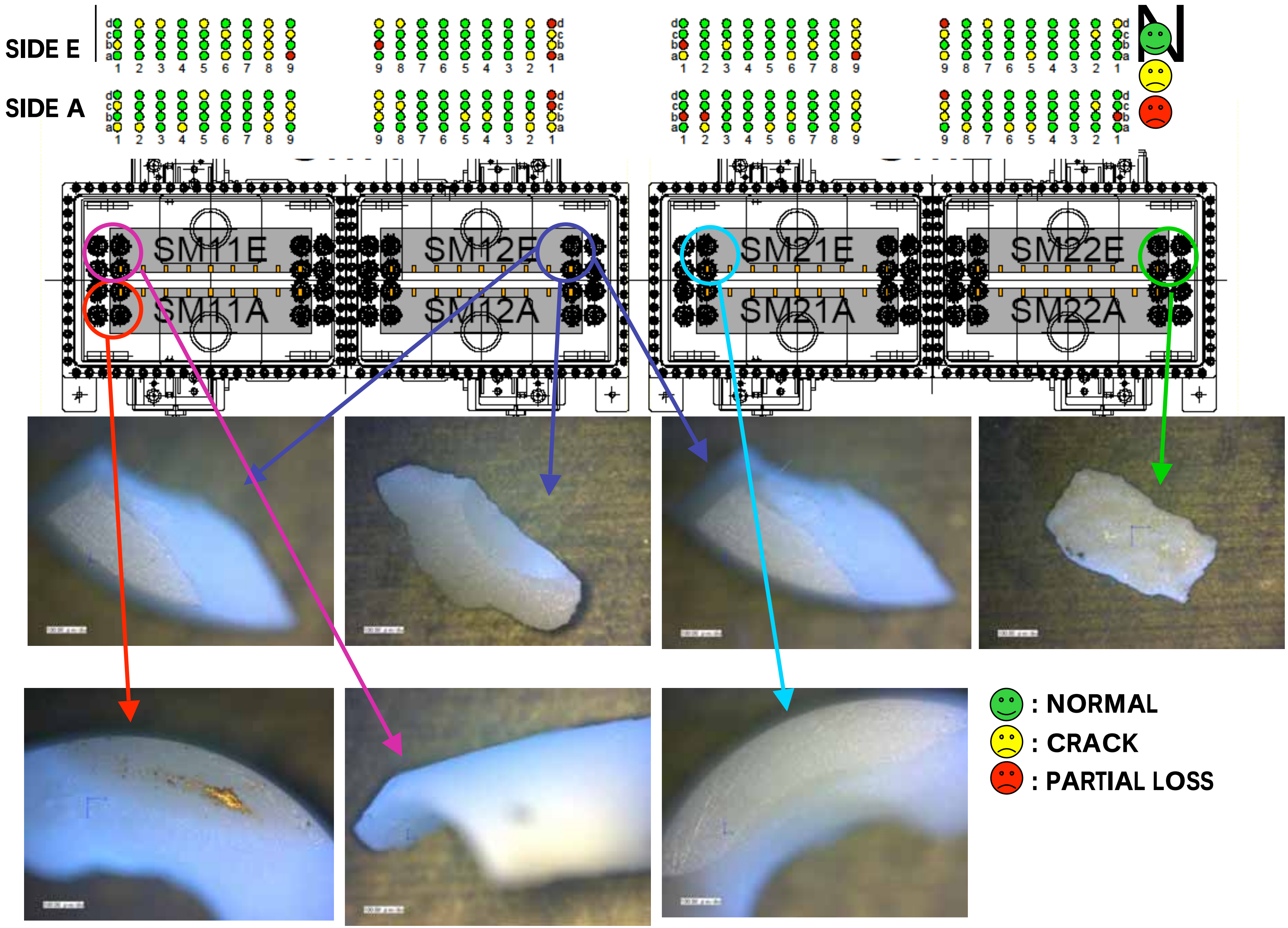


Detaching/reinstalling magnets using LMG

CERAMIC-COLLARS WERE BROKEN AT ONLY 2000-A OPERATION. (6000-A FOR DESIGN)



SEPTUM COIL CERAMIC-COLLAR FITTING USED FOR 288 PIECES IN TOTAL.



SIDE E
SIDE A
SM11E
SM12E
SM21E
SM22E
SM11A
SM12A
SM21A
SM22A
N
: NORMAL
: CRACK
: PARTIAL LOSS

POSSIBLE METHOD FOR COIL FIX