Aug. 27, 2008
HB2008 in Nashville

Beam Commissioning of J-PARC MR

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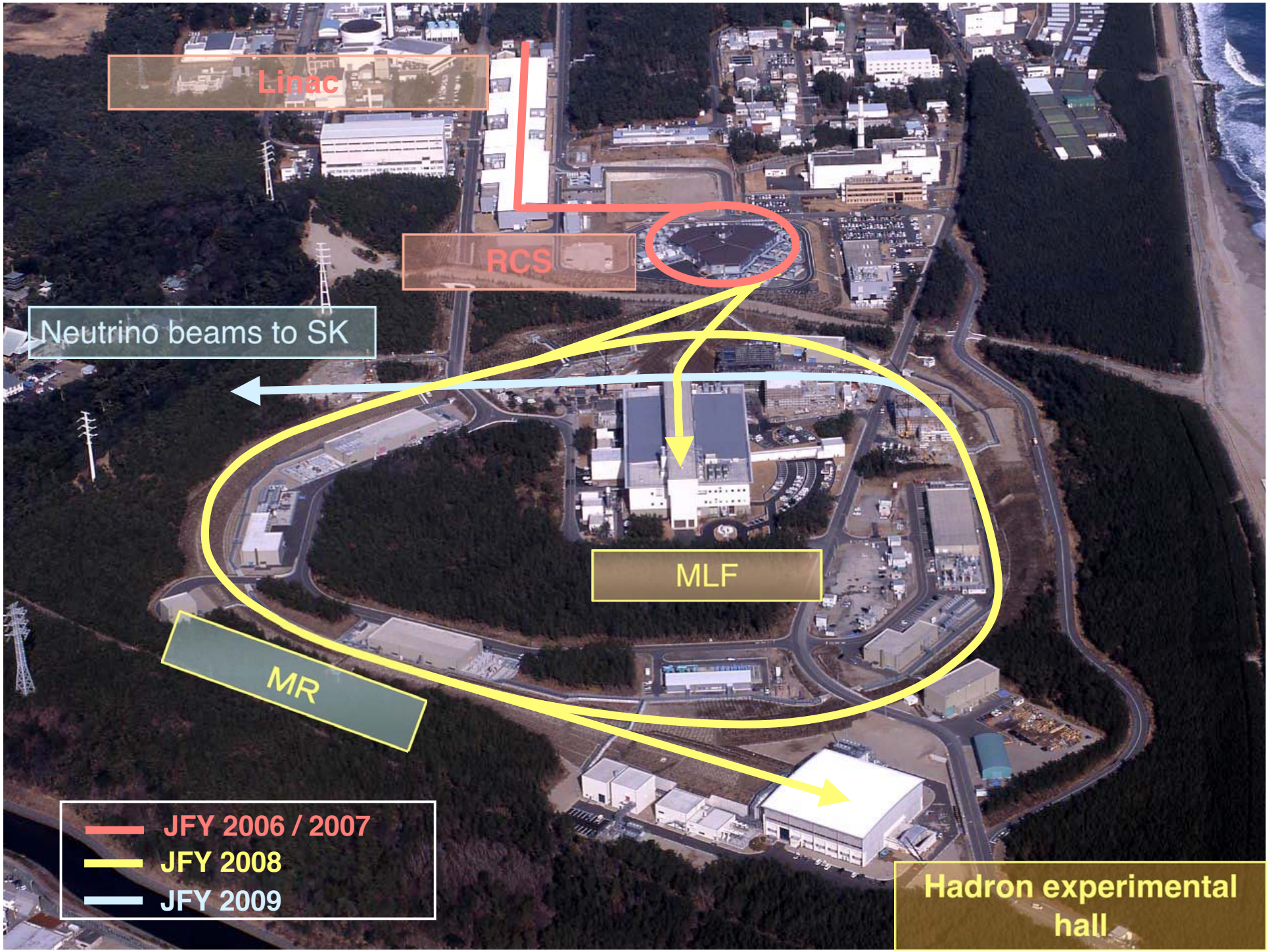
J-PARC center, KEK and JAEA

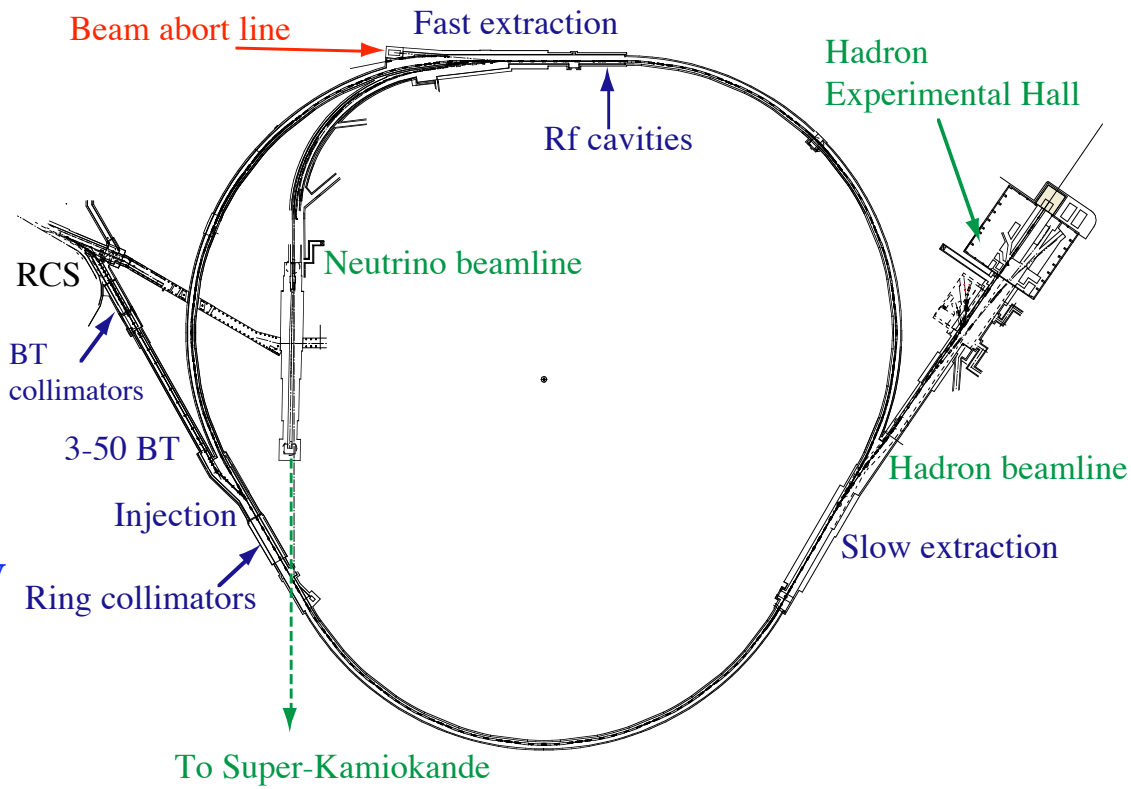
At 10:27pm on May 22, 2008:
MR has accomplished 1000 turns with rf capture and beam extraction to the injection beam dump

Contents


Linac
RCS
Neutrino beams to SK
MLF
MR
JFY 2006 / 2007
JFY 2008
JFY 2009
Hadron experimental hall

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)
Nominal Intensity	3e14 ppp
	~ 0.75 MW at 50 GeV
Number of dipoles	96
quadrupoles	216 (11 families)
sextupoles	72 (3 families)
steerings	186
Number of cavities	4 in day-one

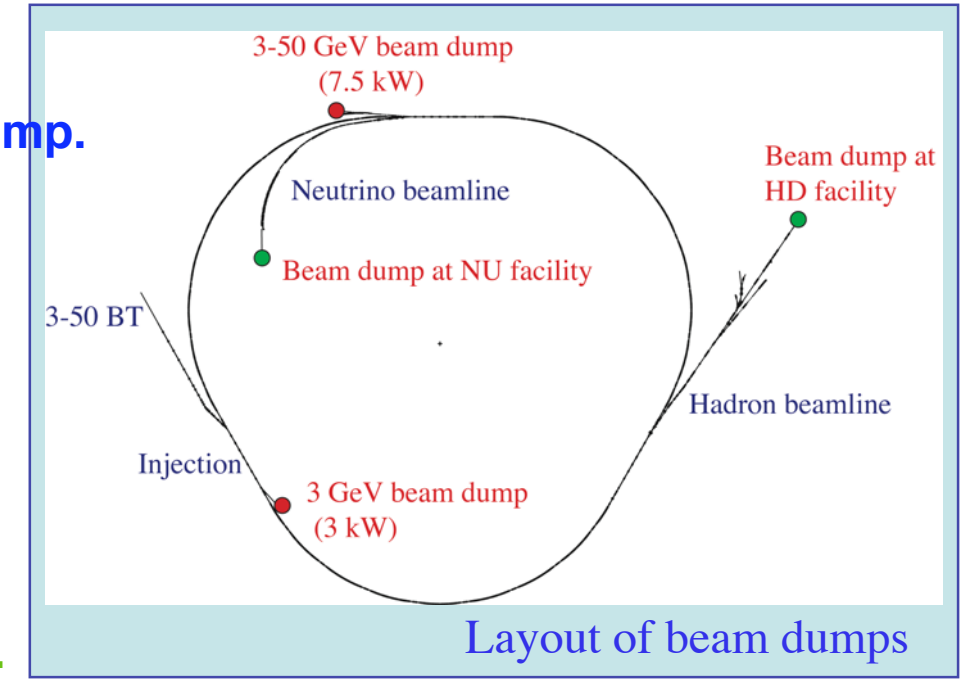


Three dispersion free straight sections of 116-m long:
- Injection and collimator systems
- Slow extraction（SX）
  to **Hadron experimental Hall**
- MA loaded rf cavities and Fast extraction(FX) (beam is extracted inside/outside of the ring)
  outside: Beam abort line
  inside: **Neutrino beamline** (intense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

MR beam commissioning schedule

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

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 hadron beamline..

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

Outline of the 1st stage of Beam commissioning

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

RUN #16: May 19-24 (6 days)
- May 19: Beam was transported to injection Kickers
- May 20: First beam circulation without rf capture
- May 22: 1000 turns circulation with rf, beam extraction to the beam dump
- May 23: Circulation for one sec, continuous operation with 3.64 sec for 1 hour

RUN #17: June 14-21 (8 days, but time shared with the MLF for 4days)
- June 19: Government inspection of radiation shield under operation
- June 22: MR study in RUN#17 was terminated due to a trouble of RCS magnet PS.

Total operation time ~ 12 hours*12 days.

Outline of the 1st stage of Beam commissioning (cont.)

Beam conditions of Linac and RCS

Linac:

E=181 MeV, Ip=5 mA, τ=0.1 msec, chopping =280 nsec,

- Intensity in the RCS ~ 4e11 ppb (1 % of the nominal intensity)

Repetition=single shot /0.27 Hz

RCS:

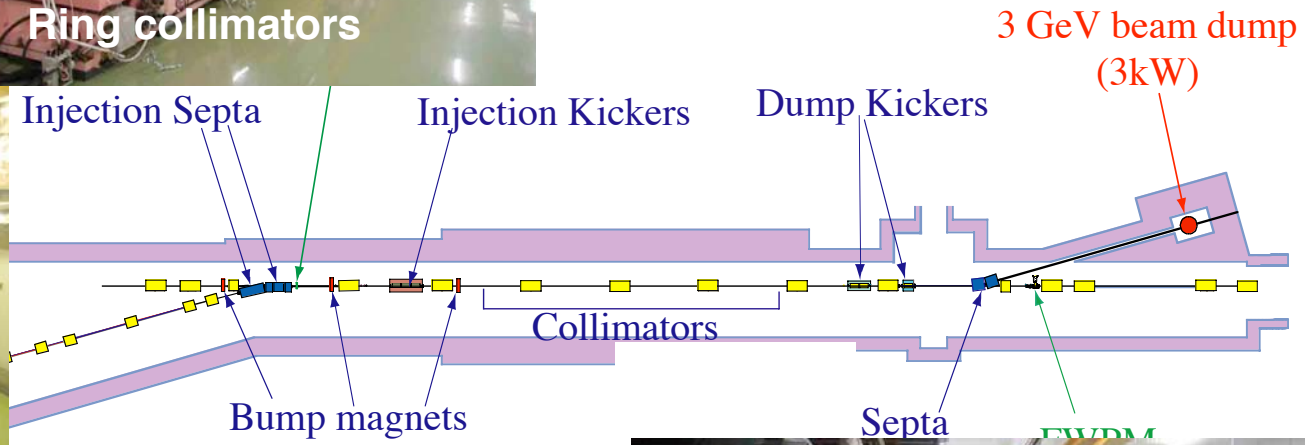
E=3 GeV, single bunch

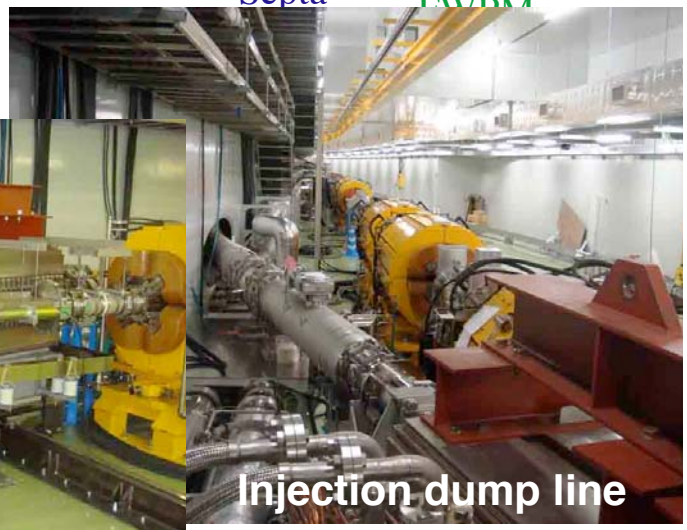
dP/P~±0.2%, emittance ~15 πmm.mrad, position jitter ~ 0.4 mm(RMS)

Operation mode of MR

- 3 GeV storage mode : storage times are 100 turns, 1000 turns, 1sec.
- Injection dump mode : injection beam is directory extracted to beam dump without circulation (useful for initial tuning of 3-50 BT, inj. devices)

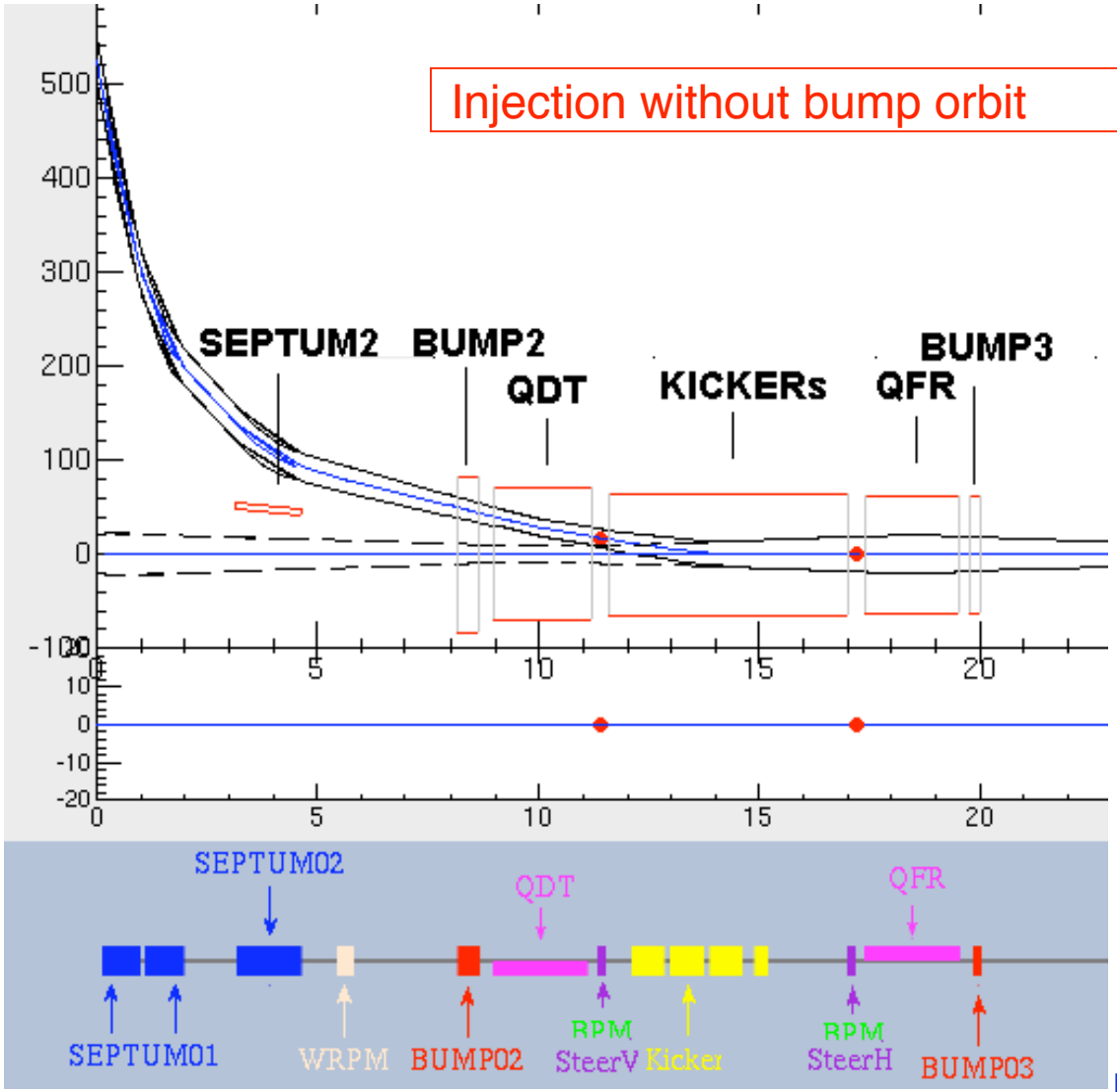
Injection devices





Injection tuning

Injection beam envelope and layout of the components



Bump magnets are installed to make a local bump to secure the large physical aperture for the circulating beam. But we did not use the local bump in the 1st stage because of the small beam size.

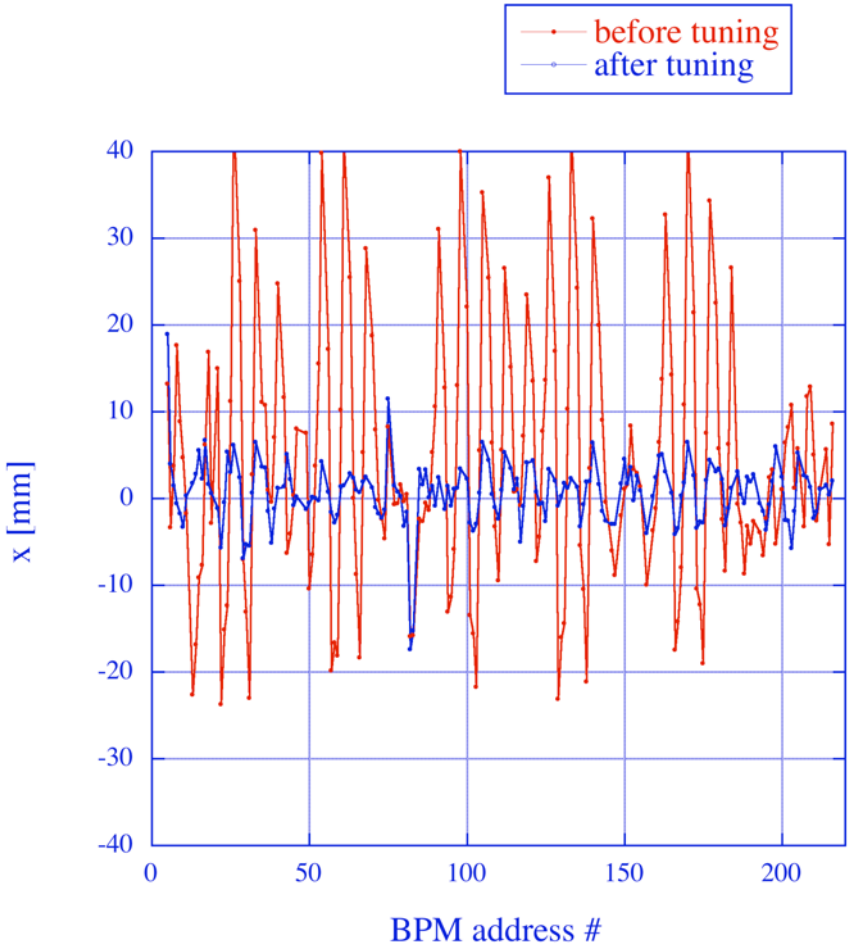
	x (cal)	y (cal)	x (meas	y (meas)
BPM 5 [mm]	17.2	0.0	17.8	0.53
BPM 6 [mm]	0.0	0.0	0.25	-0.49

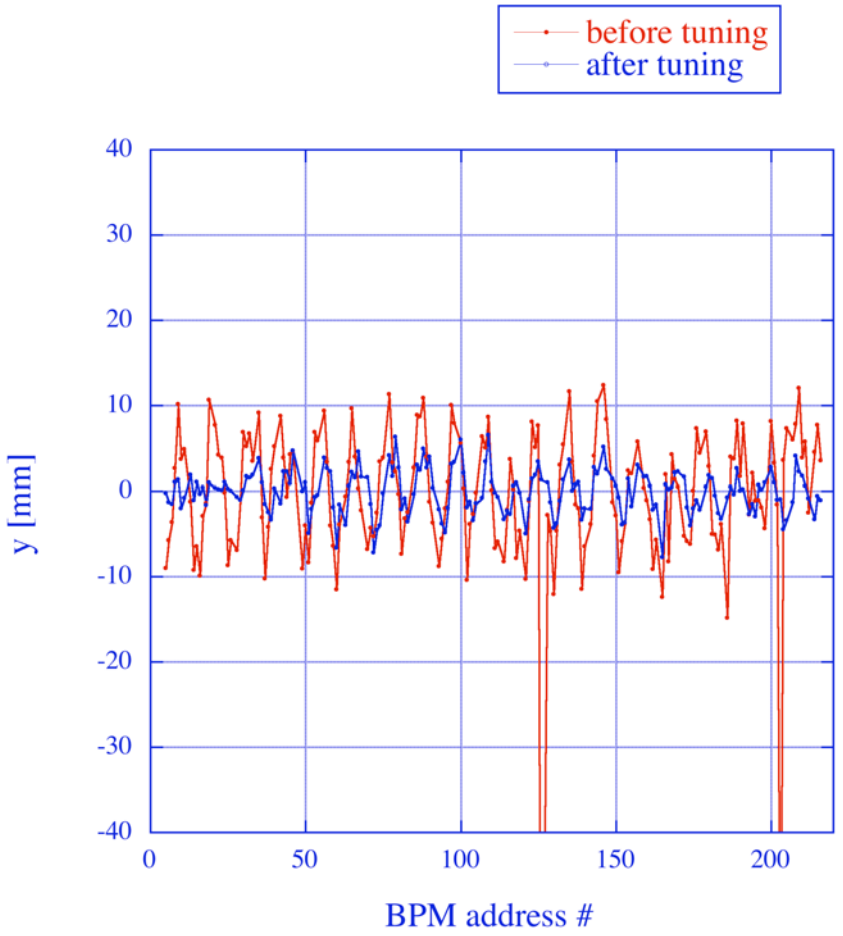
	Design	Set
Sep 1 [mrad]	224.0	221.4
Sep 2 [mrad]	39.1	39.1
kicker1 [mrad]	1.8	1.6
kicker2 [mrad]	1.8	1.6
kicker3 [mrad]	4.0	3.6
ZSV11 [mrad]	0.0	0.2

Discrepancies from the design are small.

Injection error correction and P-B matching

BPM's in turn-by-turn mode:
Beam orbit for the first turn just after beam injection



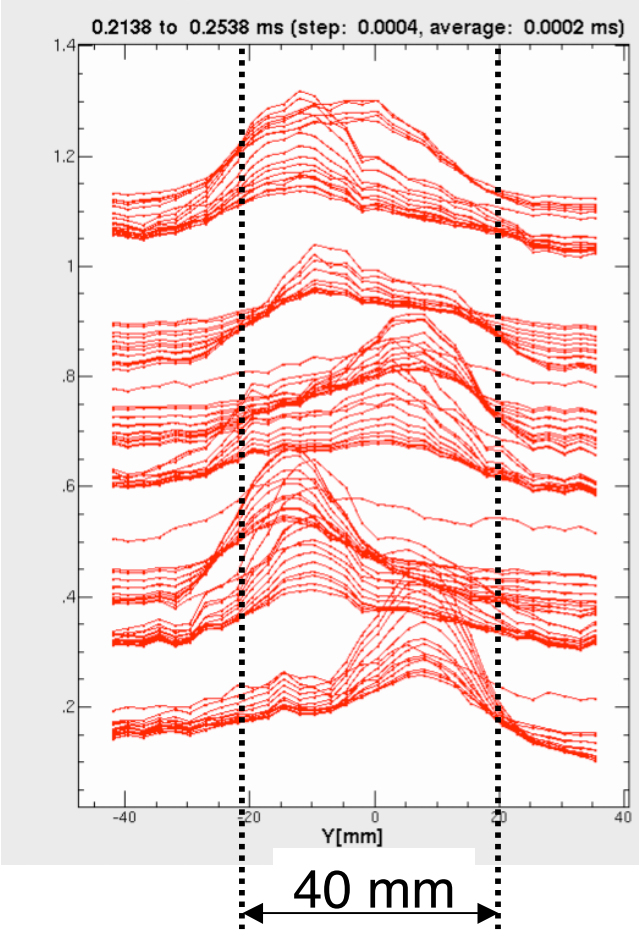


Dipole magnets:BL=0.84662 Tm
(+0.15 %)

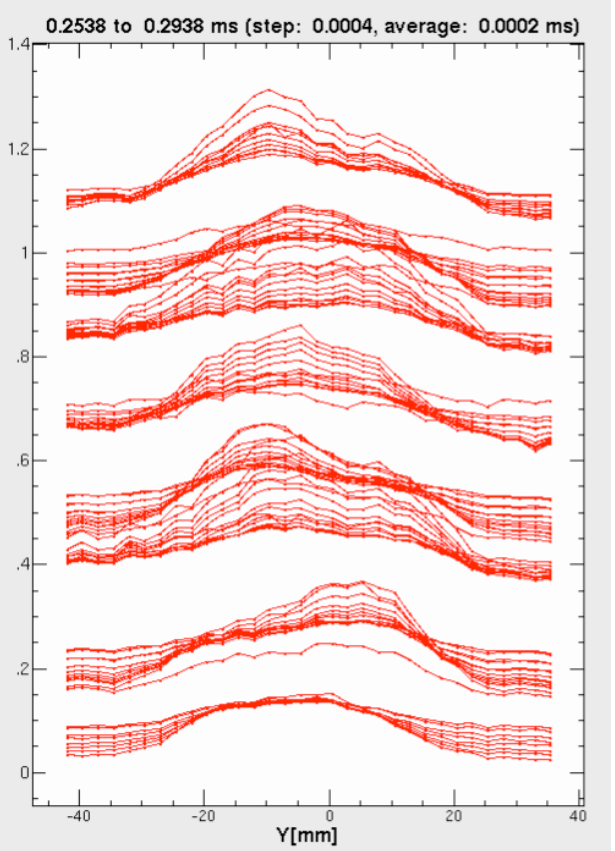
Vertical beam profile measured by IPM

- Before injection error correction-

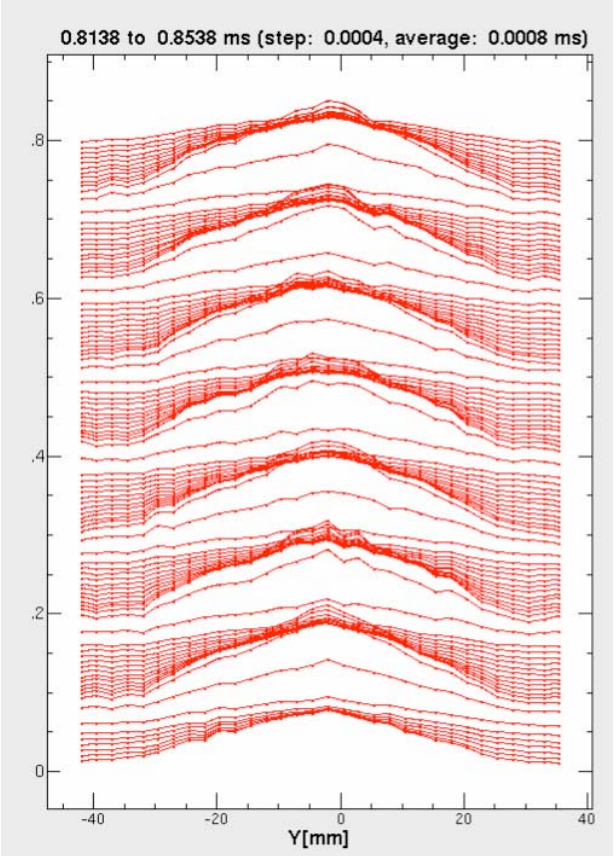
3-10 turns after beam injection



11-18 turns



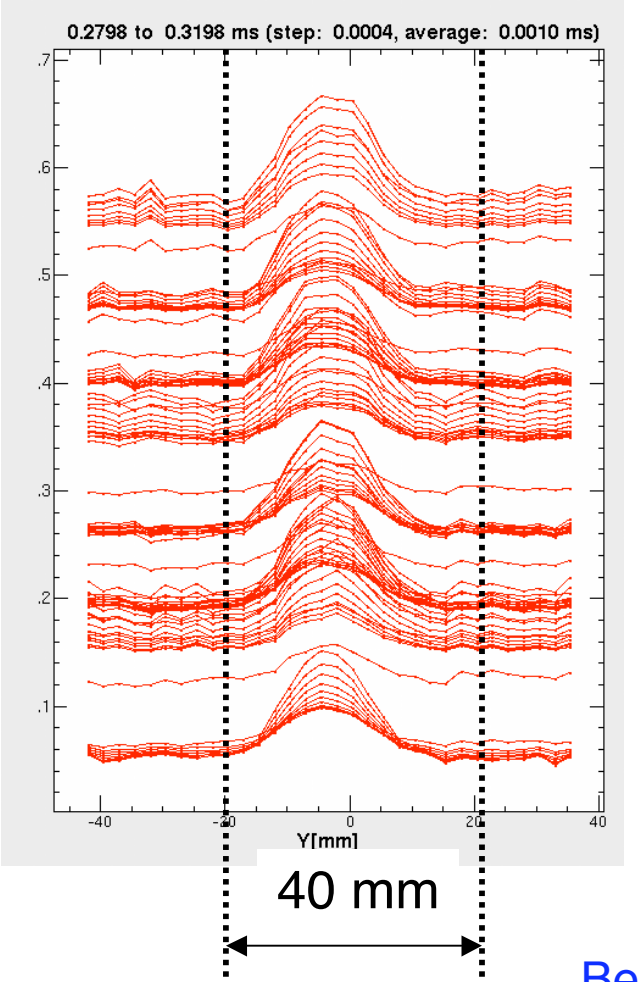
242-249 turns



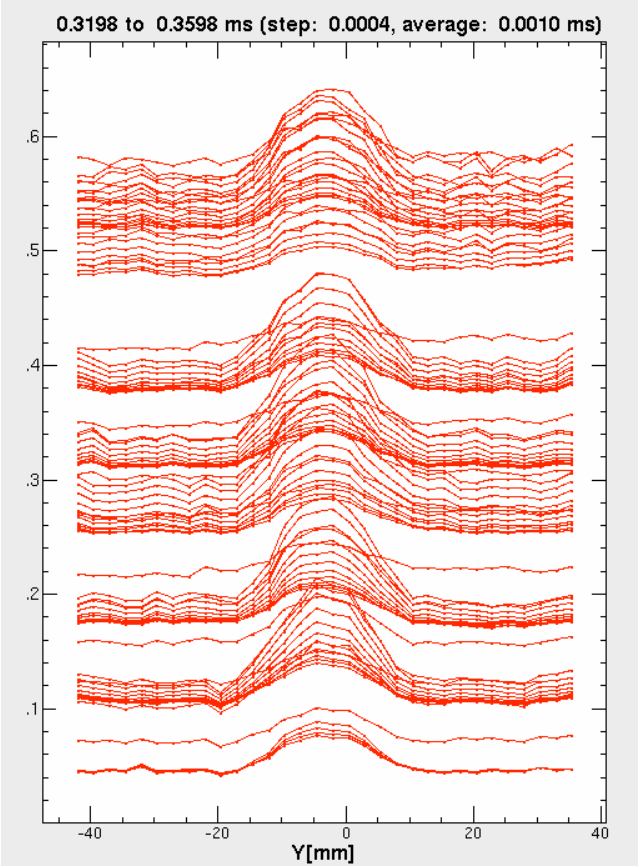
Large betatron oscillation just after the injection is smear out within a few hundred turns and beam size becomes larger.

Vertical beam profile measured by IPM
-After injection error correction-

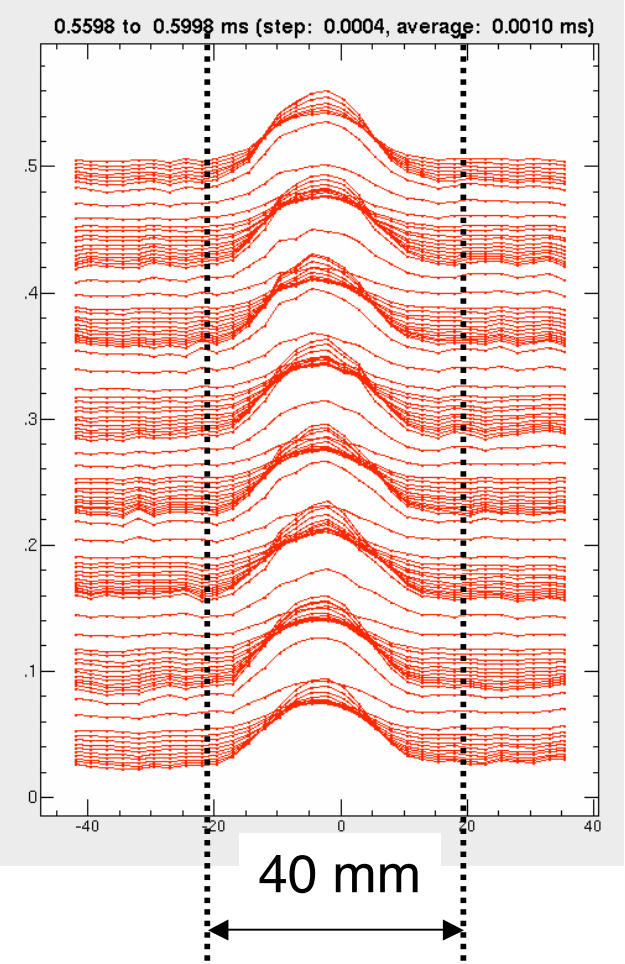
16-23 turns after beam injection



24-31 turns



72-79 turns

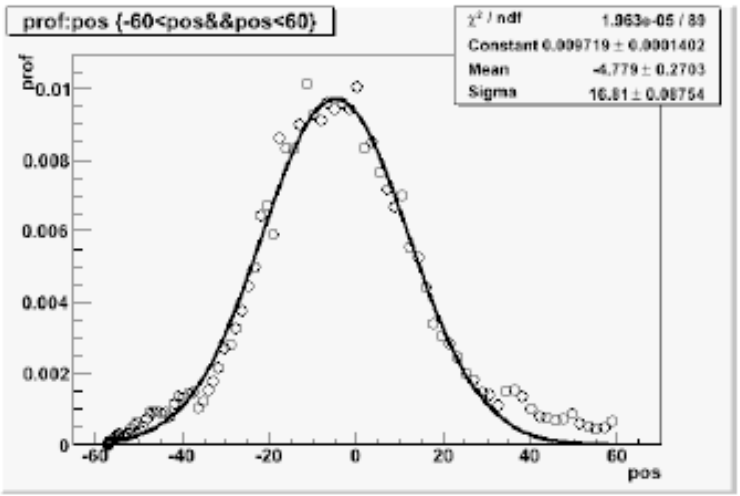


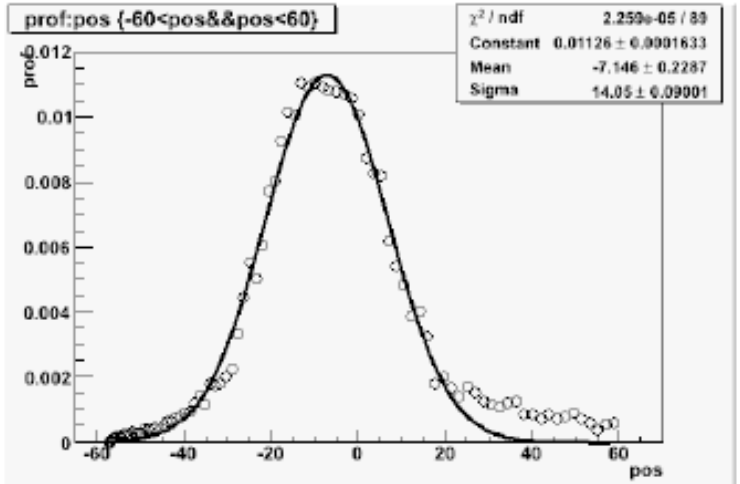
Beam size (beam core) ~ + - 20 mm.

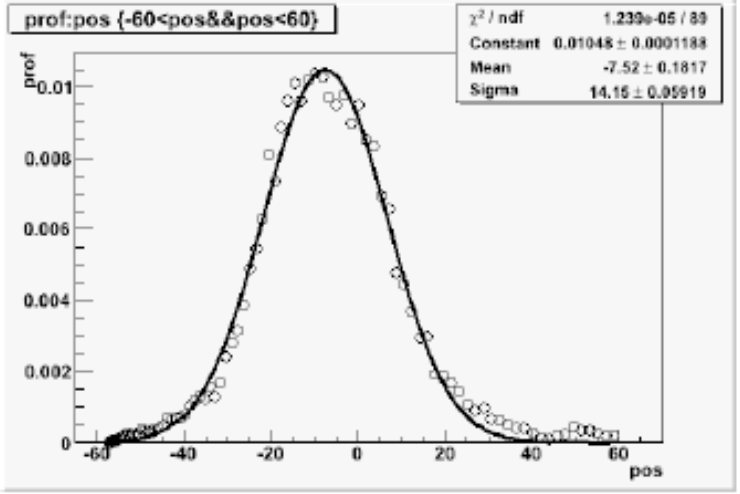
--> Emittance ~ 14 π mm.mrad for designed β

Horizontal profile measured by Flying Wire Profile Monitor

Data was taken at 0.62 sec after the beam injection.



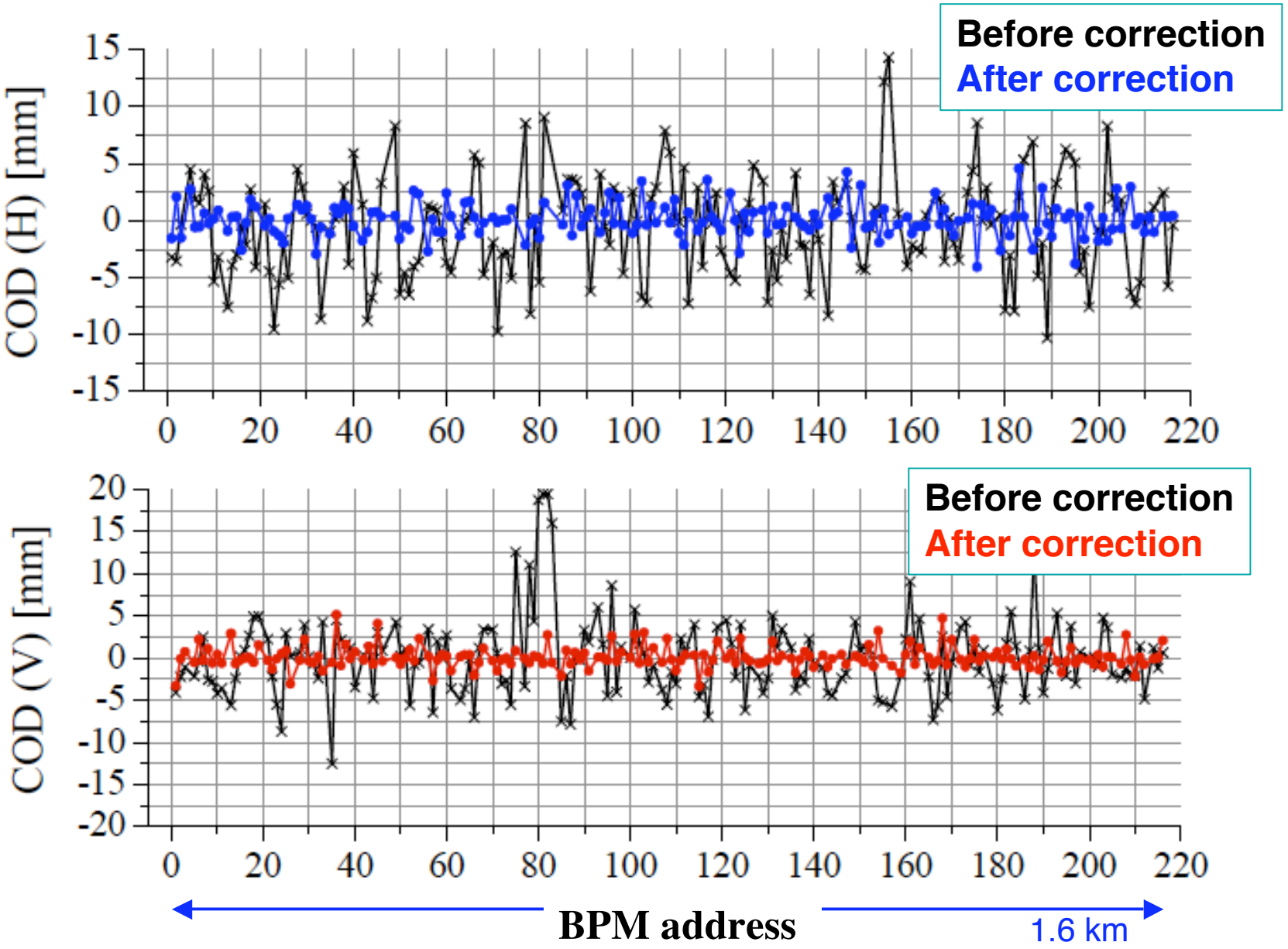




shot	σ (mm)	ε (π mmmrad)
1	16.8	28.1
2	14.1	20.0
3	14.1	20.0

COD correction

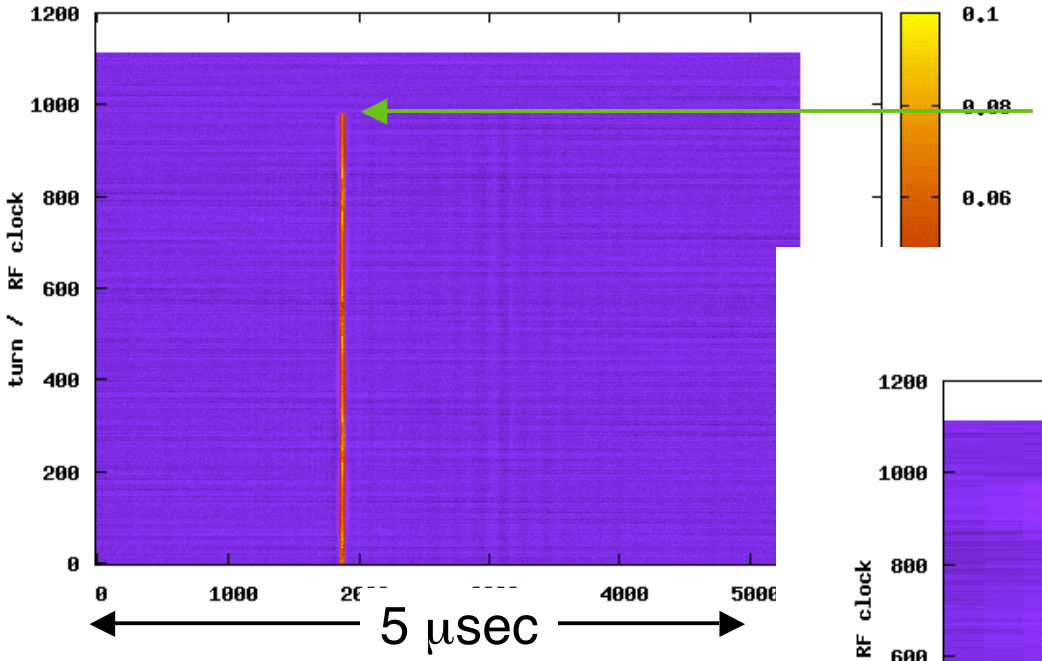
Closed orbit measured at 0.3 sec from the injection for the 1 sec storage



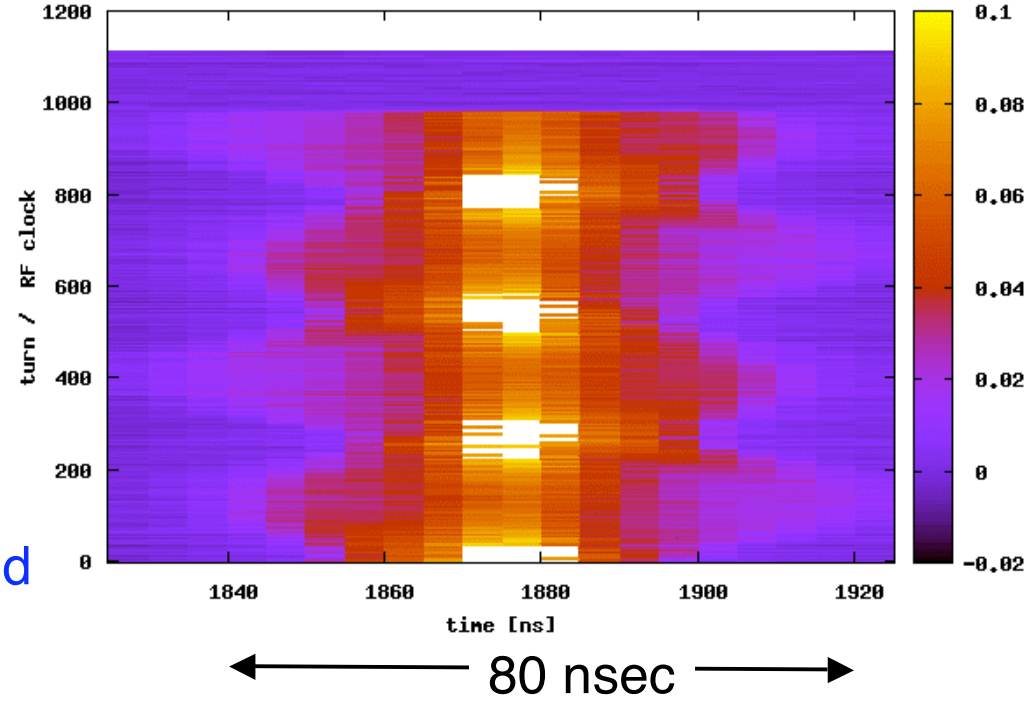
RF frequency tuning

Matching between field of dipole magnet and rf frequency

Mountain plot of longitudinal beam profile measured by WCM



1000 turn mode:
Beam is extracted after 1000 turns from the injection.

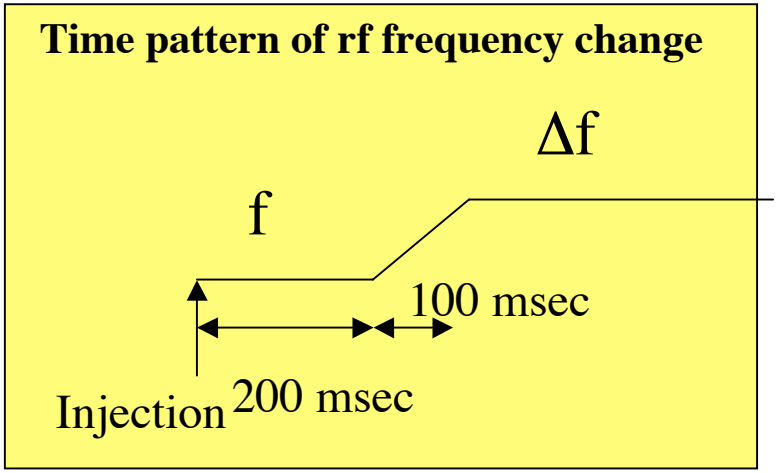


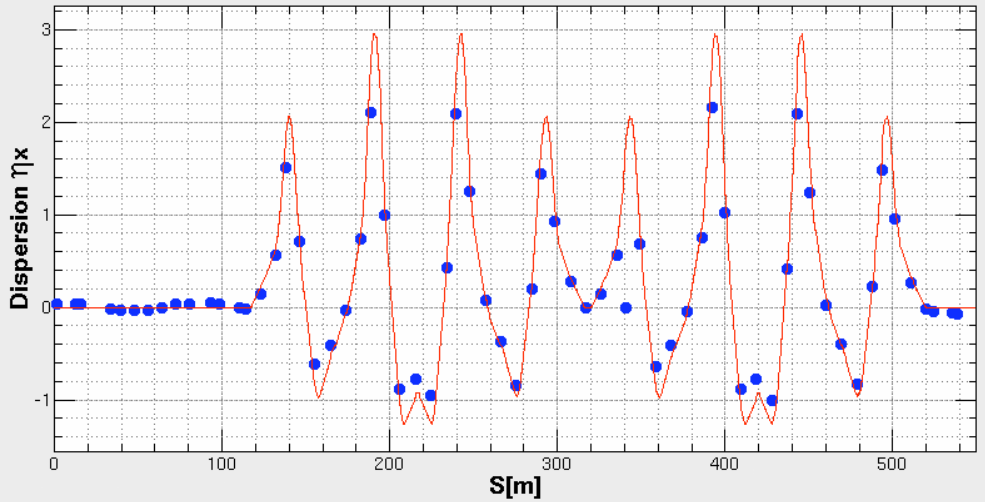
f_{rf}=1.6715MHz
V_{rf}=160 kV

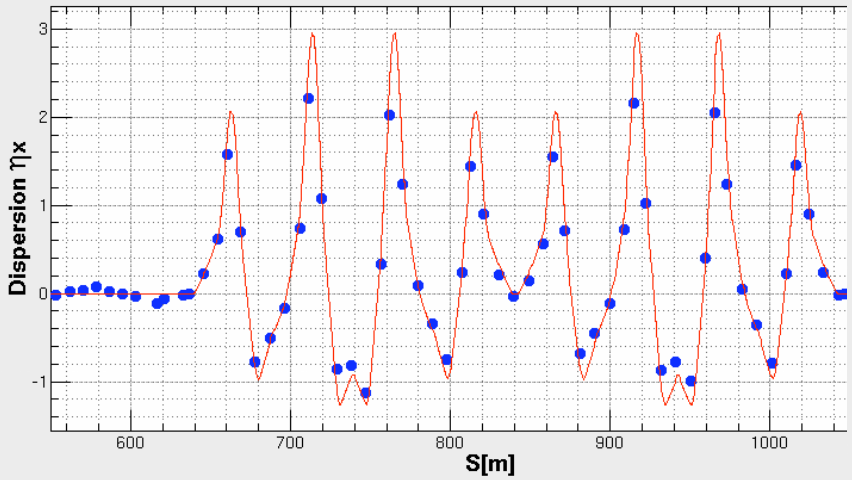
The frequency is well matched and no dipole oscillation is observed.

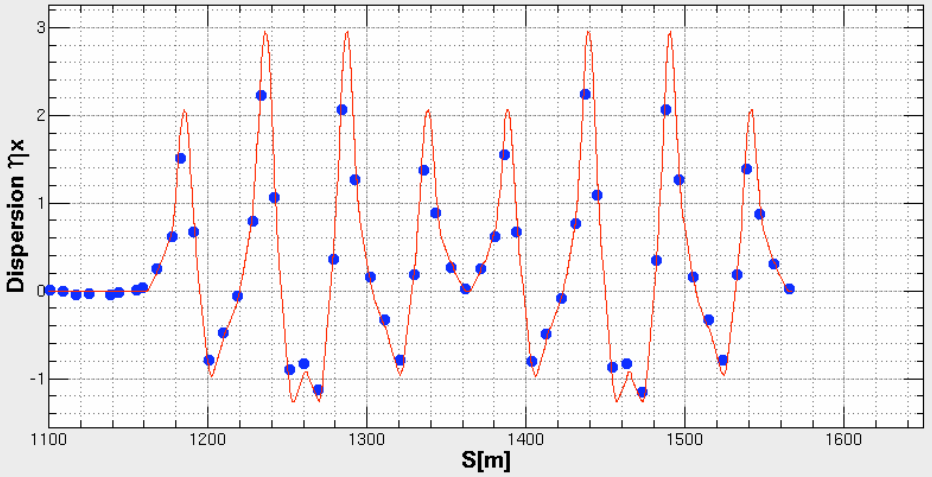
Measurement of dispersion function

The dp/p dependence of the closed orbit is measured by changing rf frequency.





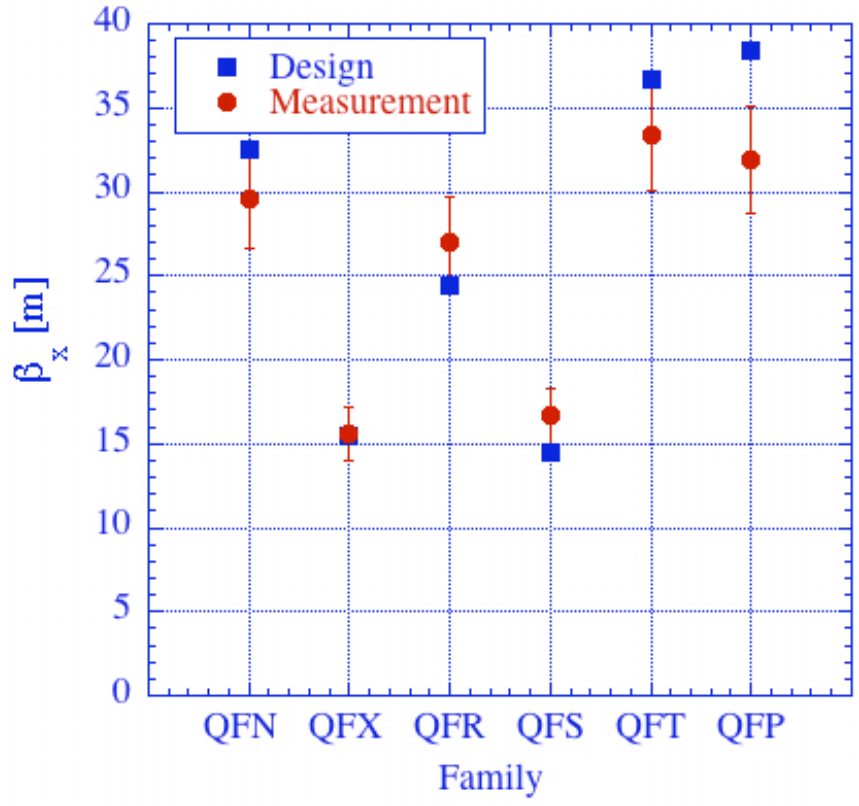


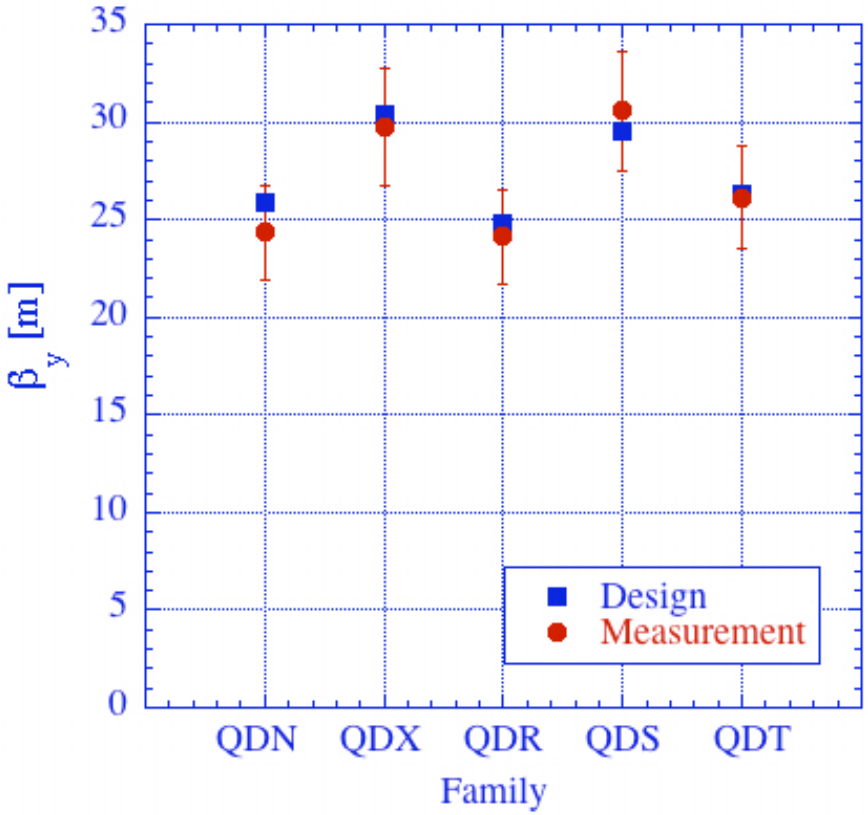


Measured results agree well with design.

Measurement of beta function

- We measured β function using the relation **Δk -> Δν :**
  Averaged β at the position of each Q families
- Measurement error : δβ/β **~10 %.**

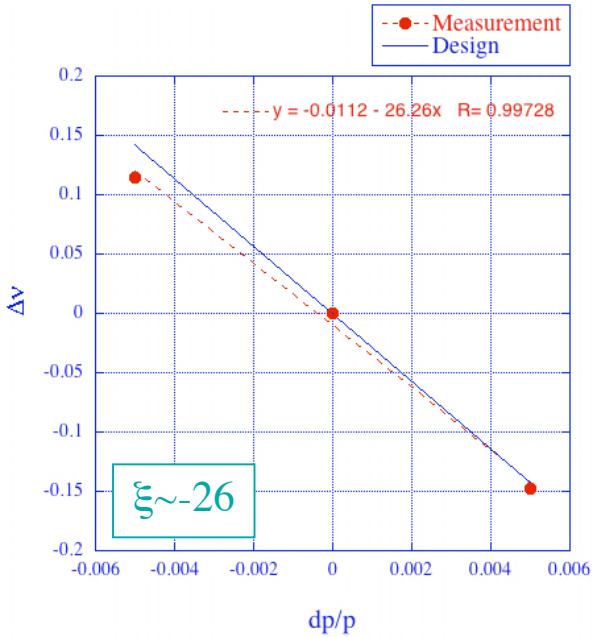


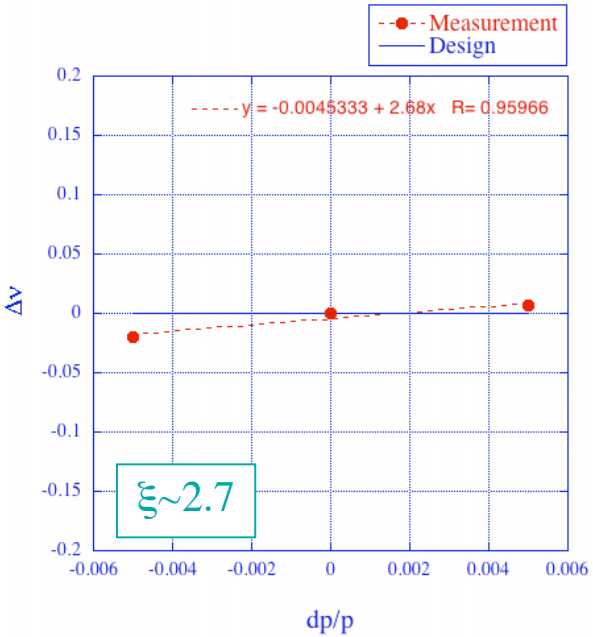


Measured results agree with the designs within the measurement error (except for QFP).

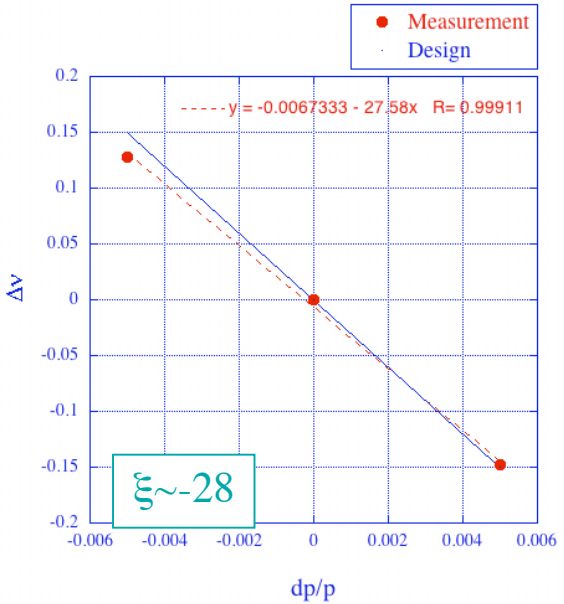
Chromaticity measurement and correction

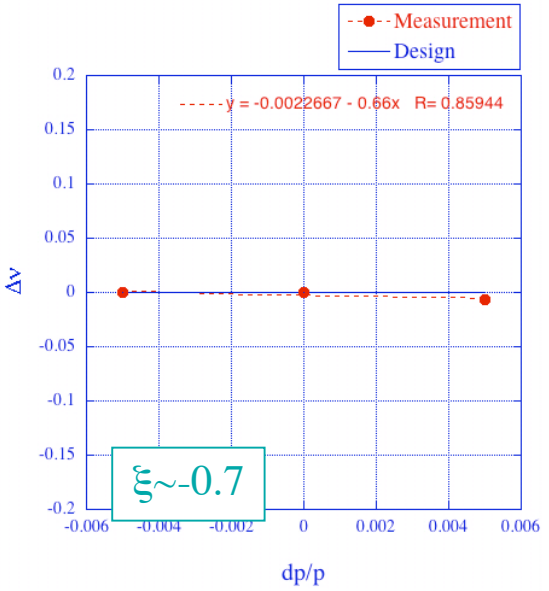
Horizontal





Vertical

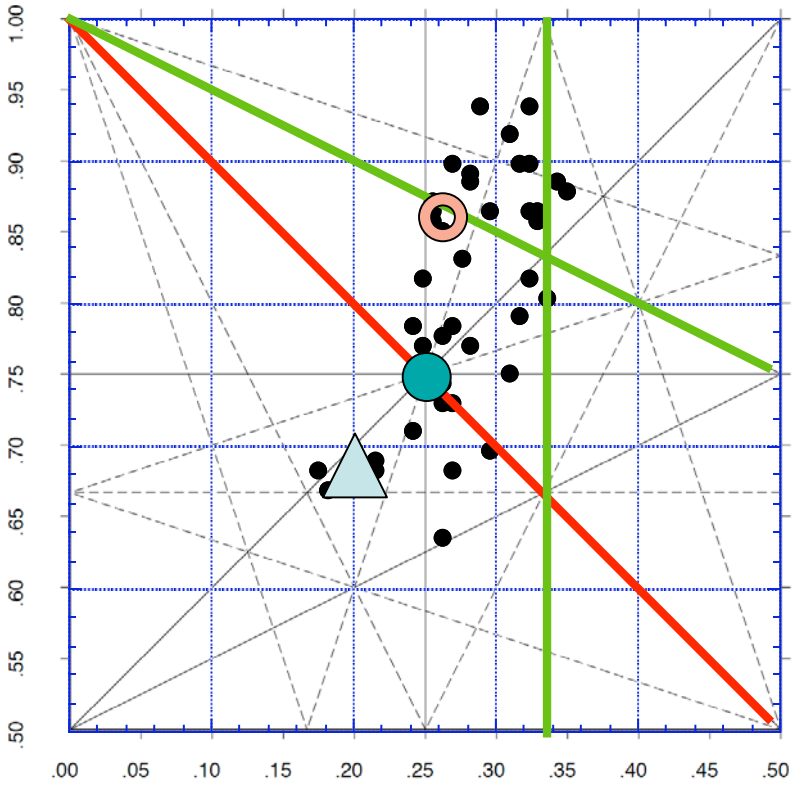




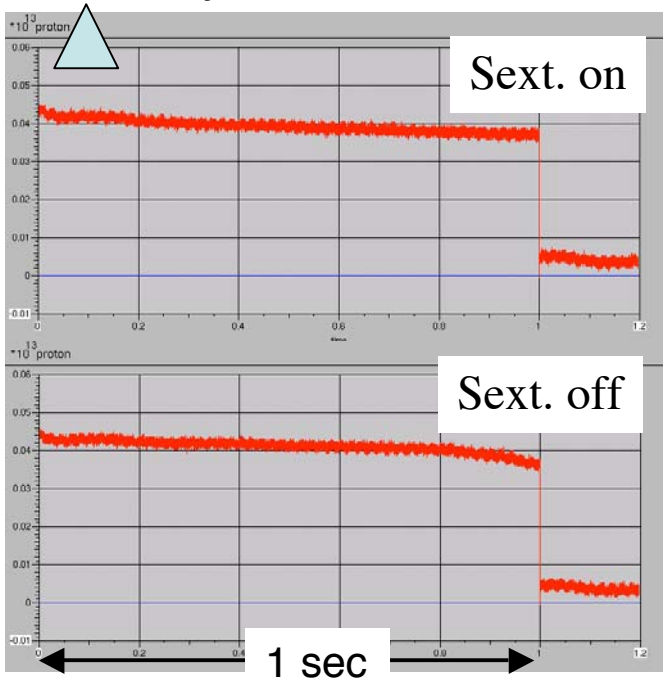
- Measured ξ agrees with design
- ξ is corrected well by the sextupole strengths estimated from design optics.

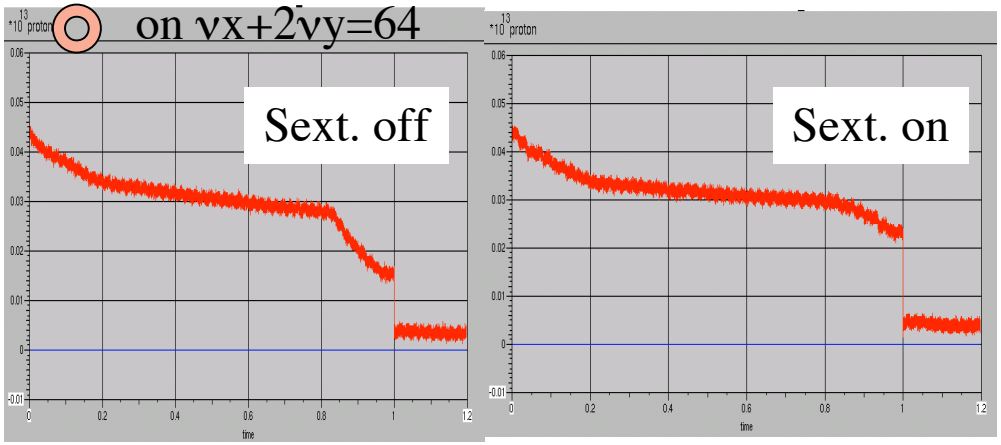
Tune survey

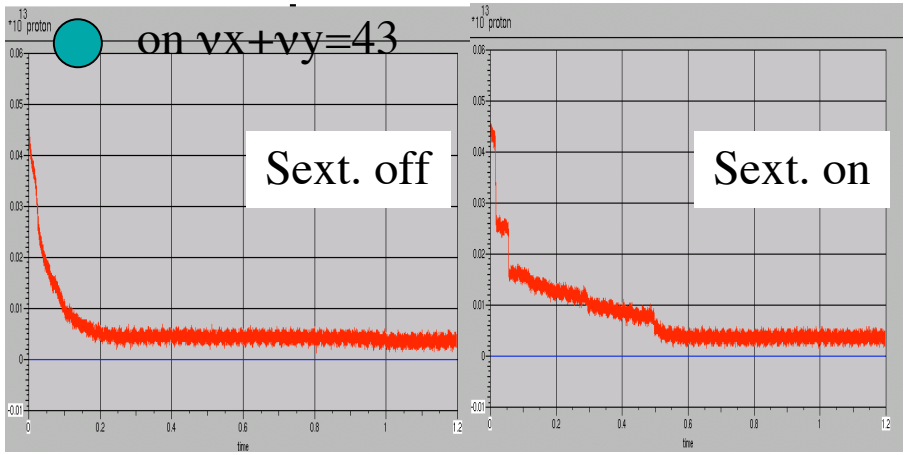
We investigated roughly the relation between operating tune and beam loss with Sext. on/off



Time dependence of beam current measured by DCCT in the 1sec storage .

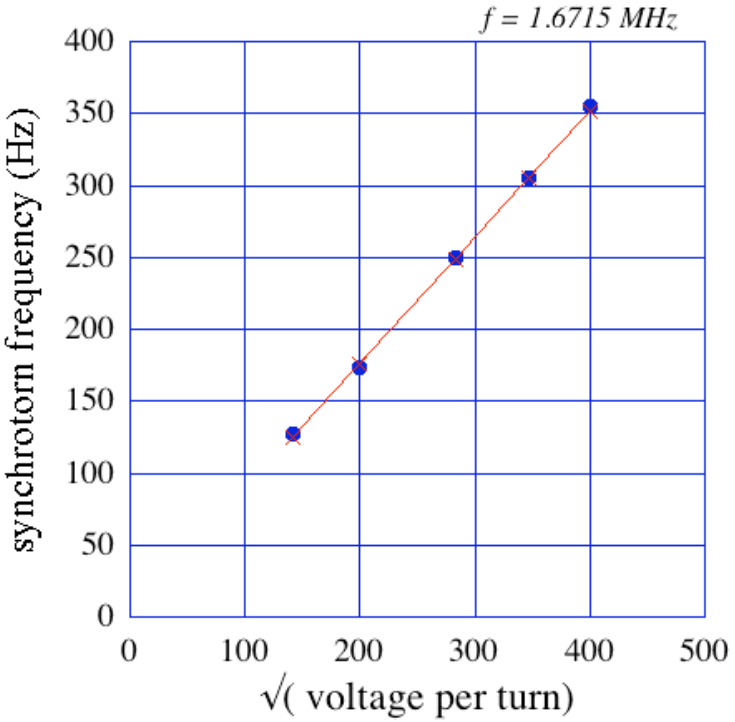




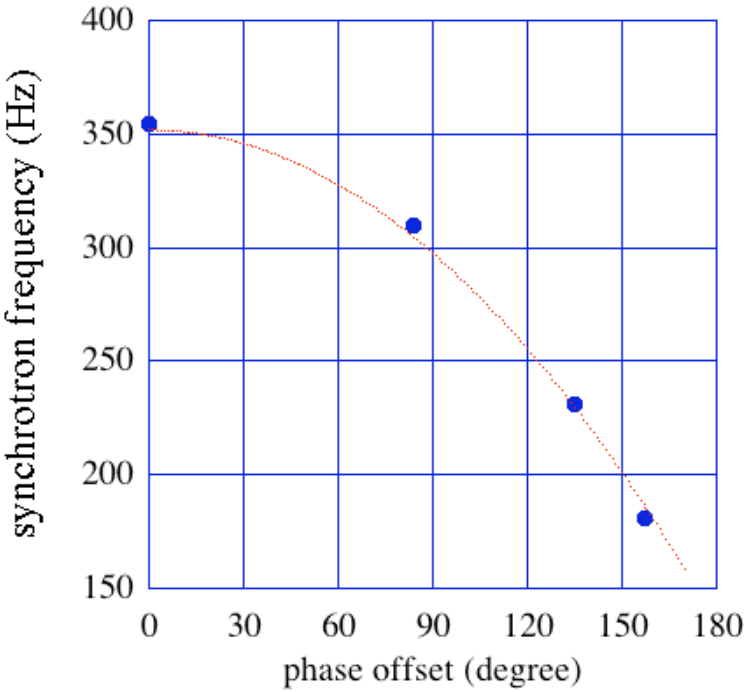


Measurement of synchrotron frequency

Gap Voltage dependence of synchrotron frequency



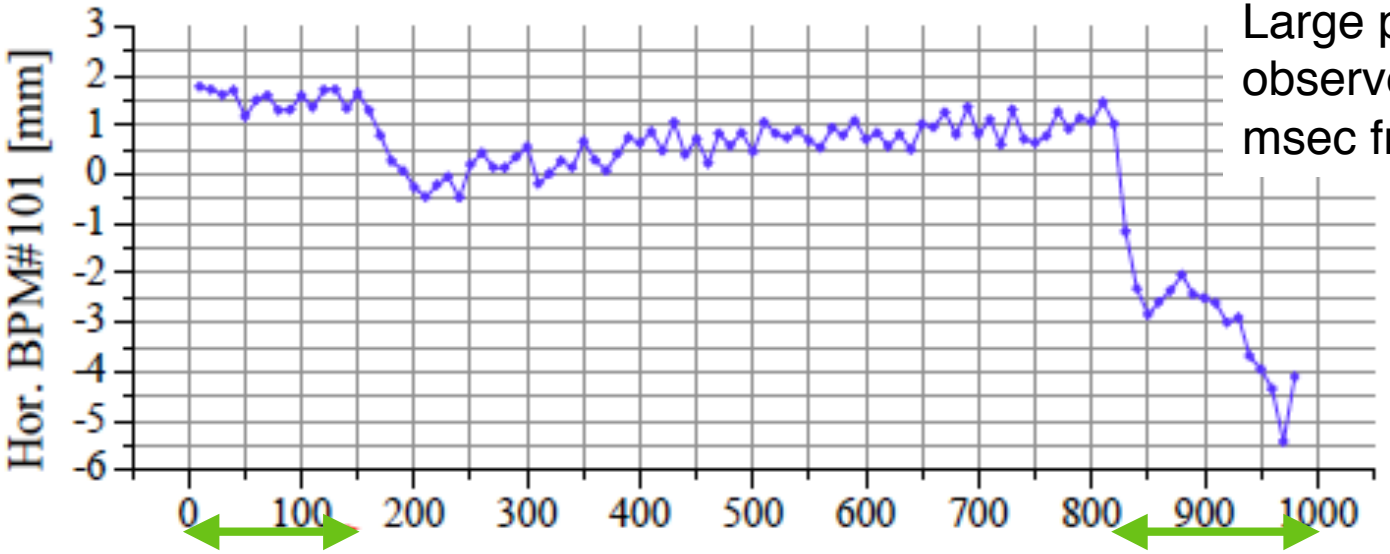
Injection phase dependence of synchrotron frequency



Measured results agree well with calculated ones.

Error source of COD
-leakage fields of septa-

Horizontal beam position measured by the BPM #101 for 1 sec storage



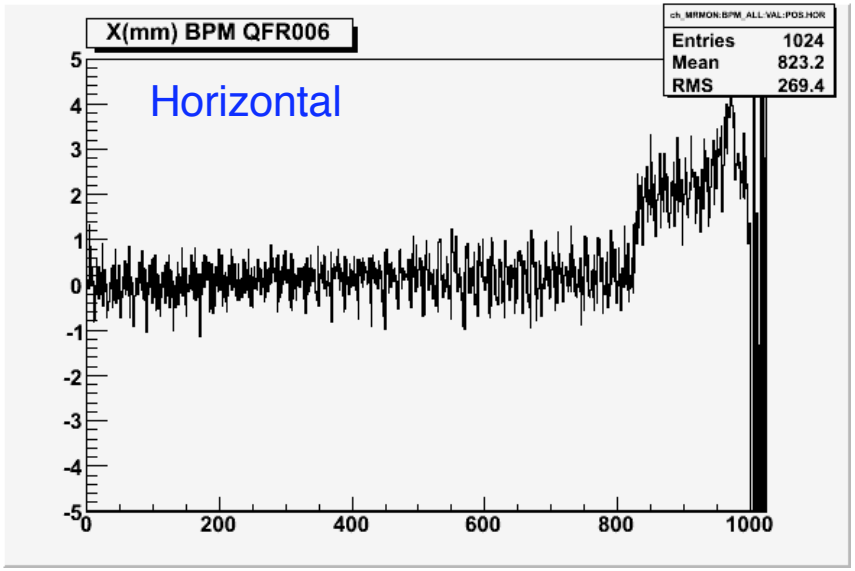
Large position shifts were observed at 160 and 830 msec from the injection

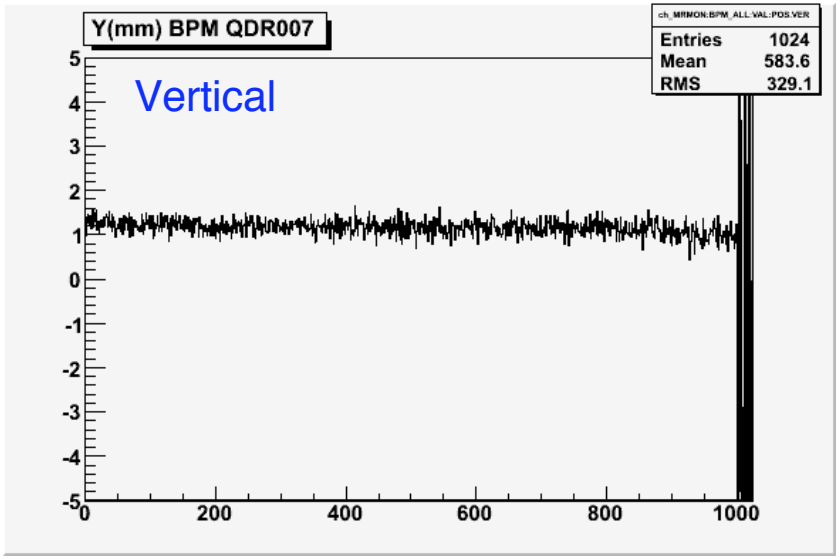
These orbit shifts may be caused by leakage field of septa.
Orbit analysis also shows that the each orbit shift is explained well by single kick at the position of septum magnet.

We will add magnetic shields to beam ducts of the septa in this shutdown period.

Ripple on beam

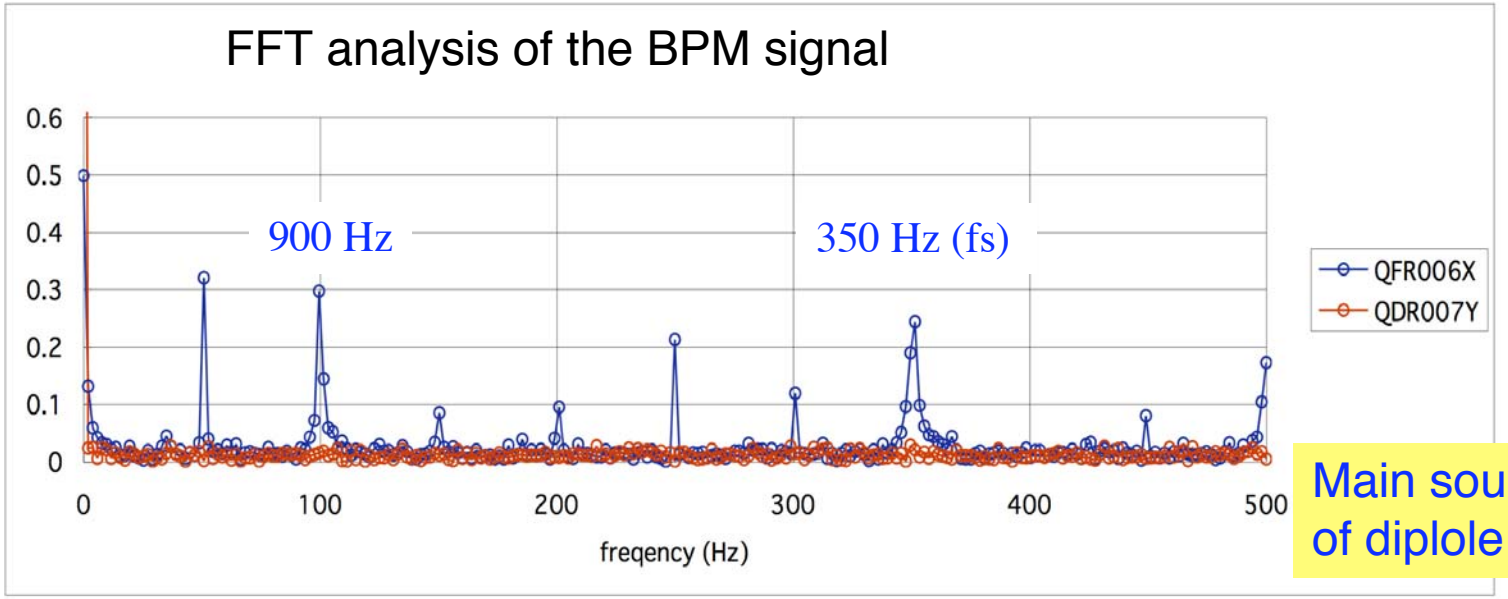
Beam position measured by BPMs in the straight section with 1 msec sampling





Horizontal ripple ~2 mm

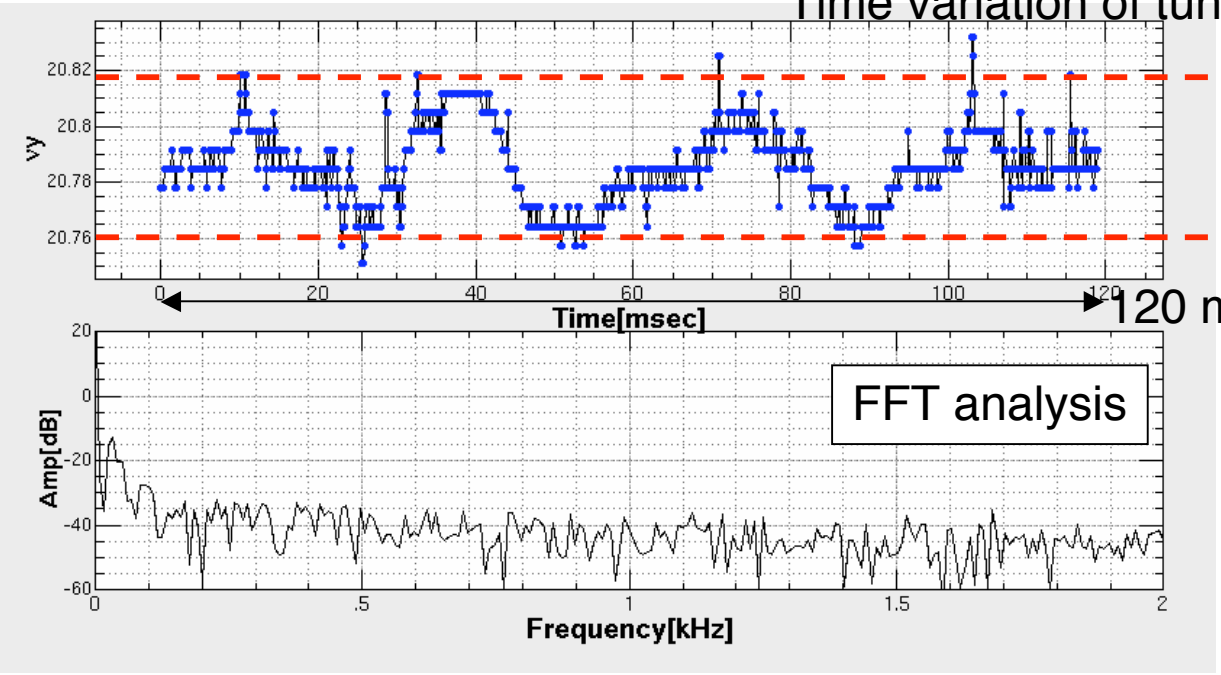
Vertical ripple <1 mm



Main source is ripple of diplole magnet PS.

Effect of Q-magnet PS ripple

Time variation of tune measured using an excitor.



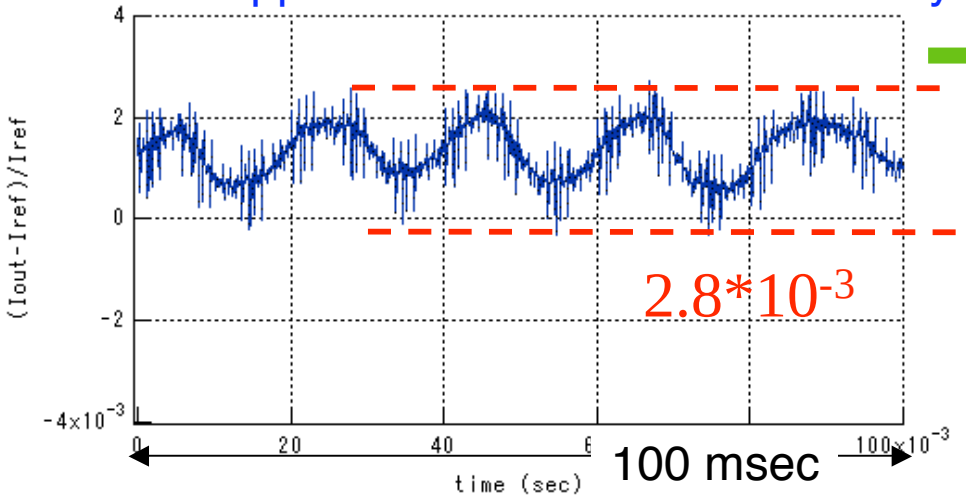
$\delta\nu \sim +/- 0.03$

120 msec

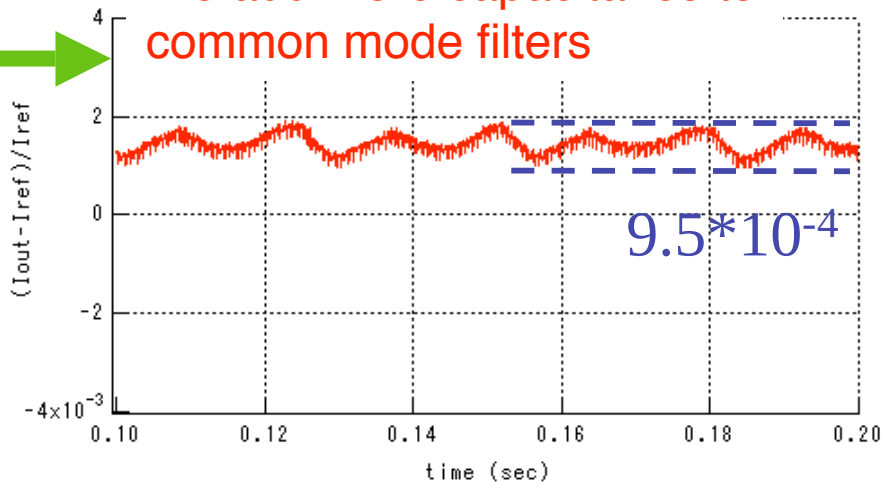
Source is quadrupole magnet PS.

After the 1st stage, we try fine tuning and to make some improvements for the PS's.

Current ripple of the PS for the QFX family



We add more capacitance to common mode filters

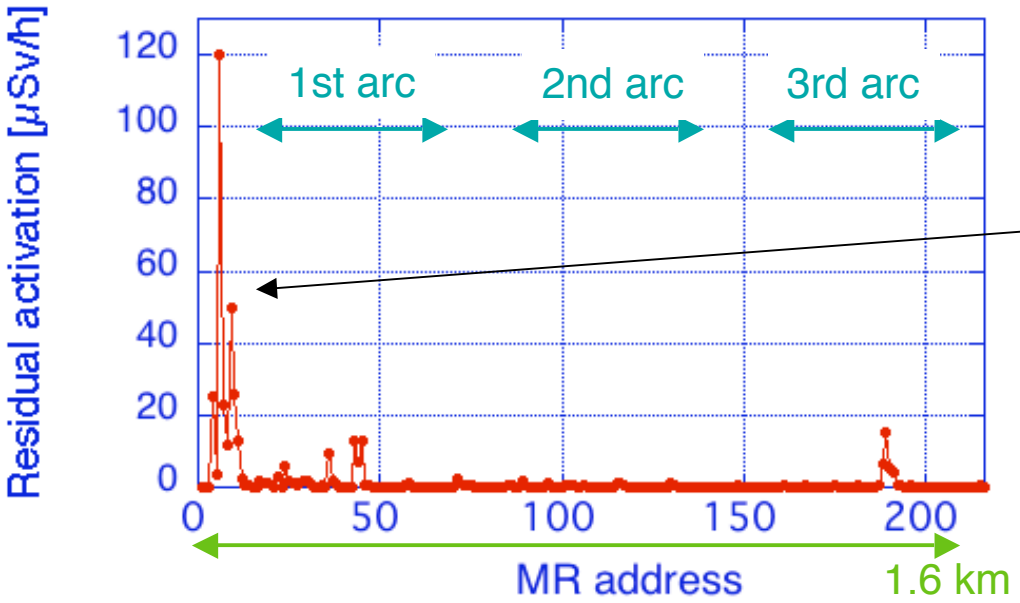


Residual activation

Shutdown: 6/21 23:00 (after eight days operation of RUN#17)

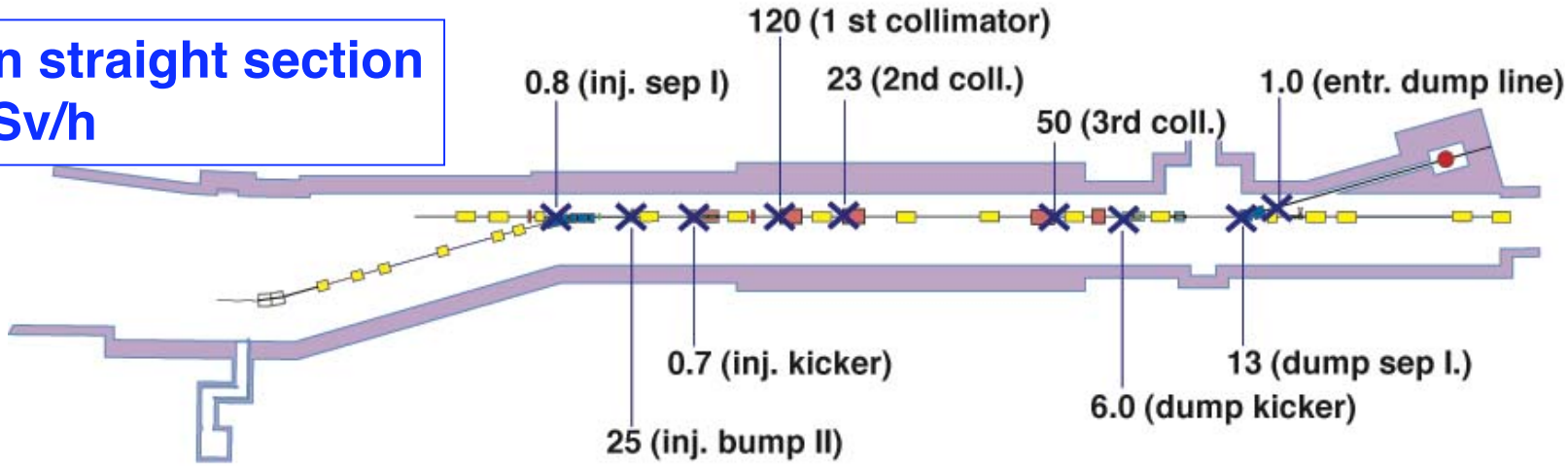
Survey: 6/23 14:00- (1.5 days after the shutdown), measured by contact on the beam ducts

Background : 0.2 μSv/h



Beam loss almost concentrated in the collimator section

Injection straight section
Unit: μSv/h



Summary

1st stage of beam commissioning has been done :

RUN #16: May 19-24 （6days）

RUN #17: June 14-21 （8days but shared with MLF commissioning）

Total operation time ~12 hrs. * 12 days

- **Beam transportation in the 3-50 BT**
- **Injection**
- **Circulation with rf capture**
- **Beam extraction to beam dump --> accomplished within 4days form the start**

- **Continuous operation with 0.27 Hz**
- **COD measurement and correction**
- **ξ measurement and correction**
- **Tune survey**
- **Parameter measurements and correction (β, η, fs, ...)**

Problems:

- **Beam ripple caused by main magnets PS's -> Improve current stability of PS's**
- **Effect due to leakage field of injection/dump septa --> add magnetic shields**

The next milestones are acceleration up to 30 GeV and beam extraction to abort beamline and HD beamline in the 2nd stage, which will be started in Dec. 2008.

Backup slides

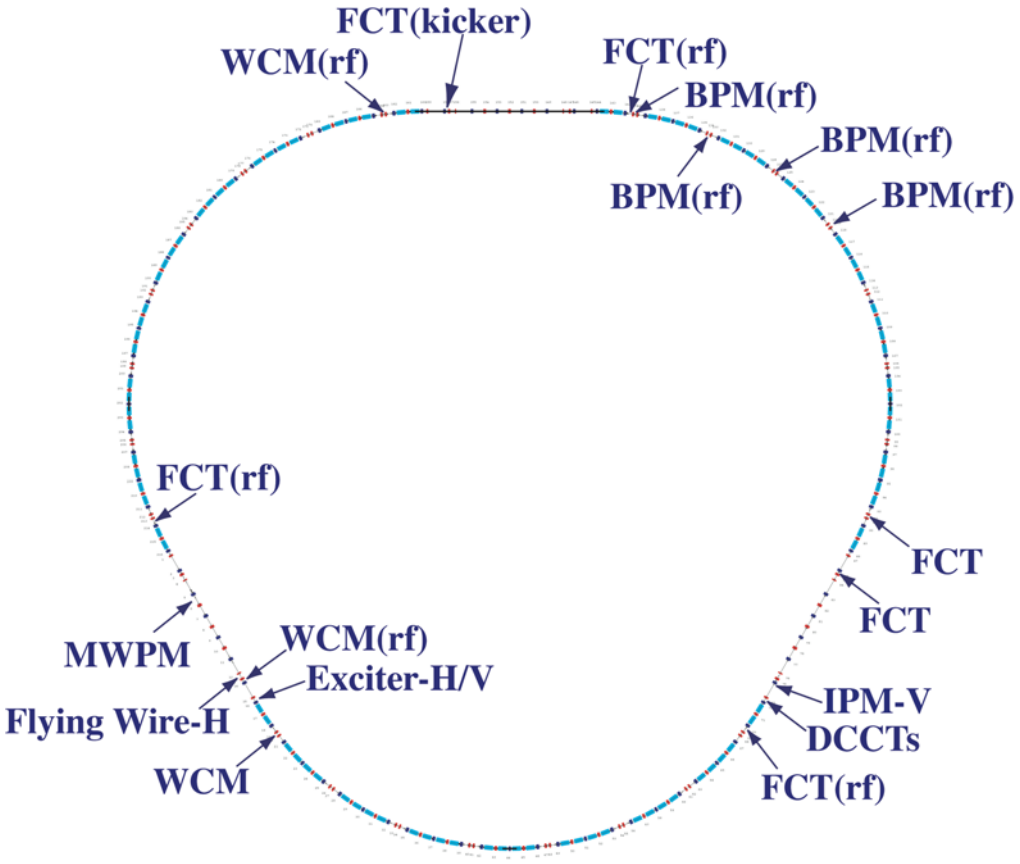
Intensity upgrade plan of the first three years

			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				7.2					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				8.3E11					1.2E13						
	Particles /ring											8.3E11							8.3E11				5.0E12					7.2E13						
HD	Output power	kW																	1.2															
	Energy	GeV																	30															
	Particles /burst																		8.3E11															
NU	Output power	kW																					7.2					100						
	Energy	GeV																					30											
	Particles /burst																						5.0E12					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.

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)	(2)/1
Tune meter (H/V)	1/1
Quad. mode BPM	2
BPM (BT)	14
FCT (BT)	5
MWPM (BT)	6
BLM(BT&MR)	338

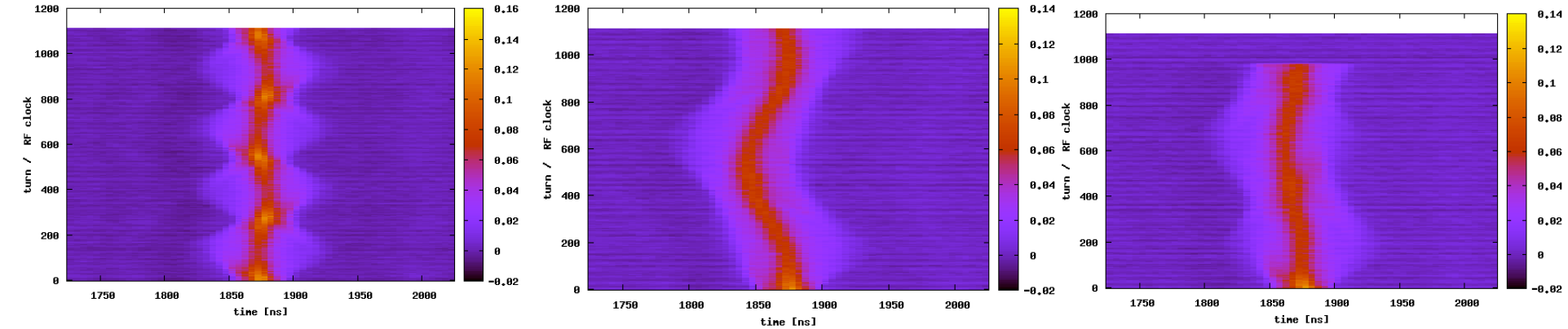


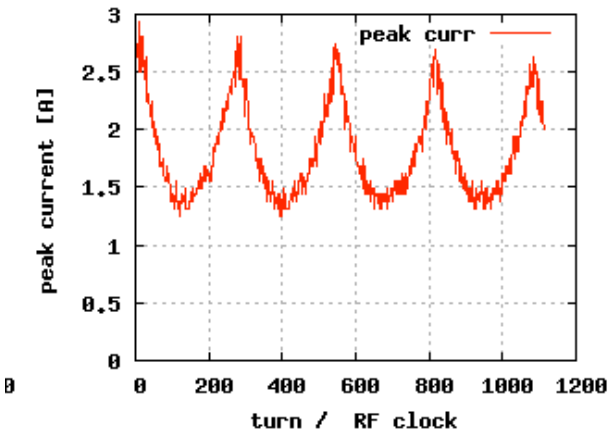
Detailes will be given by K. Satou in the WGF session

Suppression of quadrupole oscillation

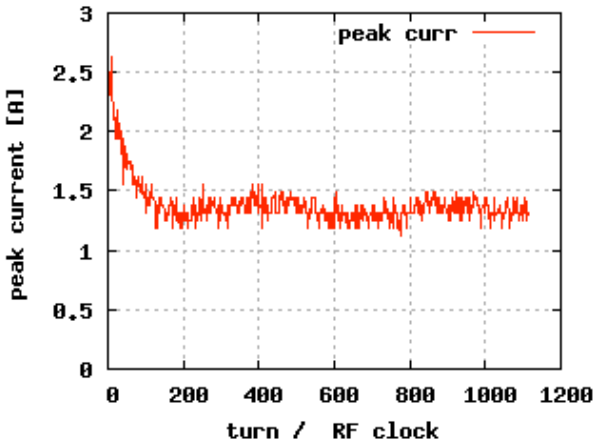
- Matching of rf voltages-

At the 1/4 rotation timing in phase space, gap voltage is changed from 160kV to 53 kV.

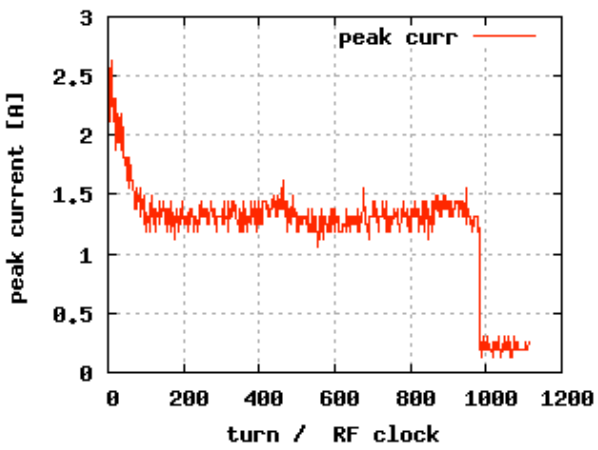




Before tuning



After voltage tuning

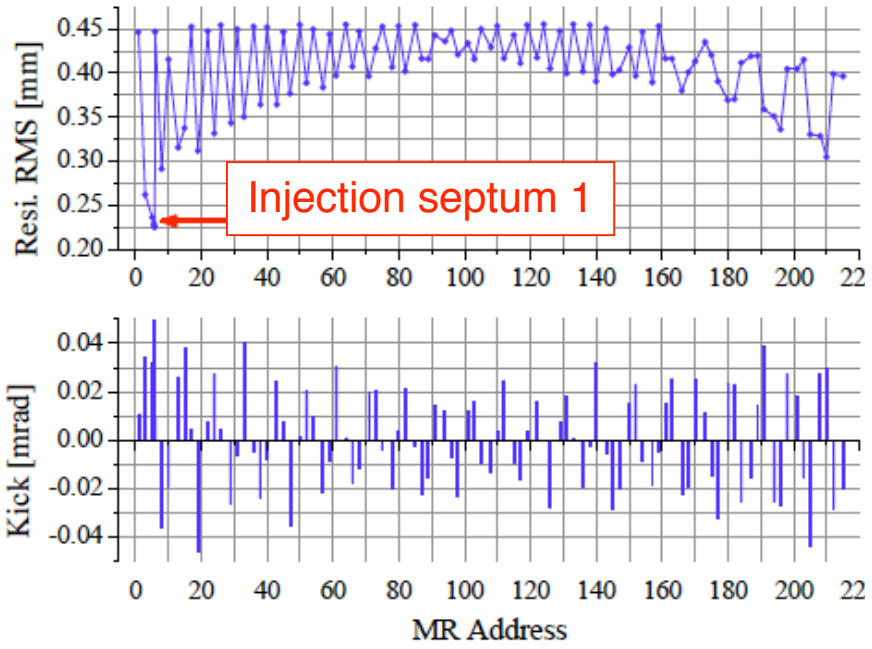


After voltage/ phase tuning

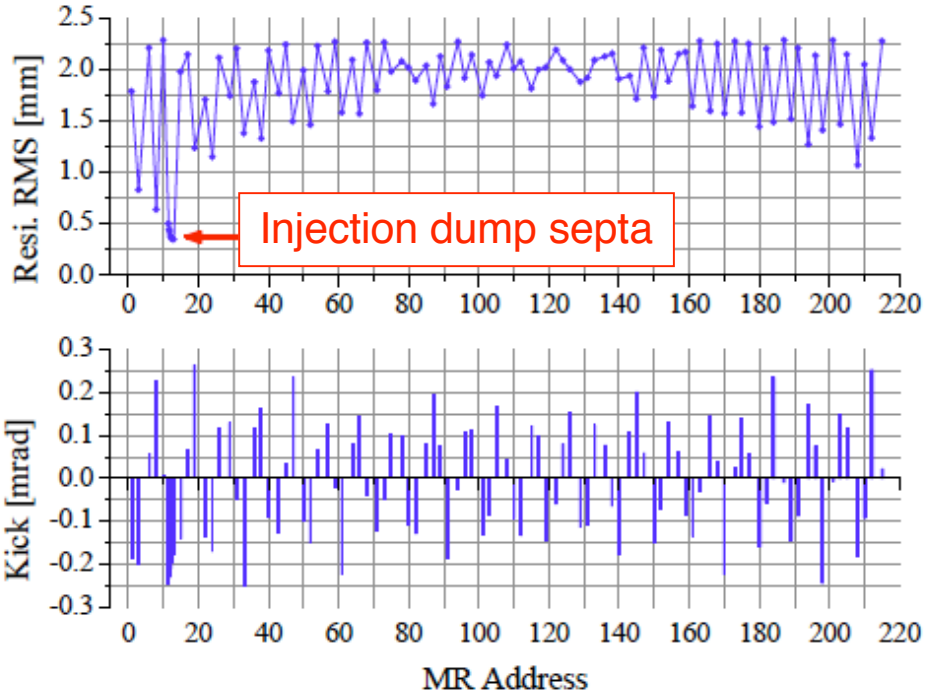
Single kick solutions for Δx1 and Δx2 using steering magnets

We calculate time-averaged deviations of closed orbit, Δx1 and Δx2.
Δx1=Avr(20~160 msec)-Avr(210~820msec): deviation due to the injection septum1
Δx2=Avr(850~950 msec)-Avr(210~820msec): deviation due to the dump septa

For Δx1(20~160 msec)



For Δx2 (850~950 msec)



Estimated leakage field at Inj. Sep1
~ 4.9e-4 Tm (kick inside the ring)
Field calculated by EM simulation code
~ 1.8e-3 Tm (kick inside the ring)

Estimated leakage field at dump septum (STH#6)
~ 2.6e-3 Tm (kick outside the ring)
Field by EM simulation code
~ 9 e-3 Tm (kick outside the ring)