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Commissioning and Operation of SSRF

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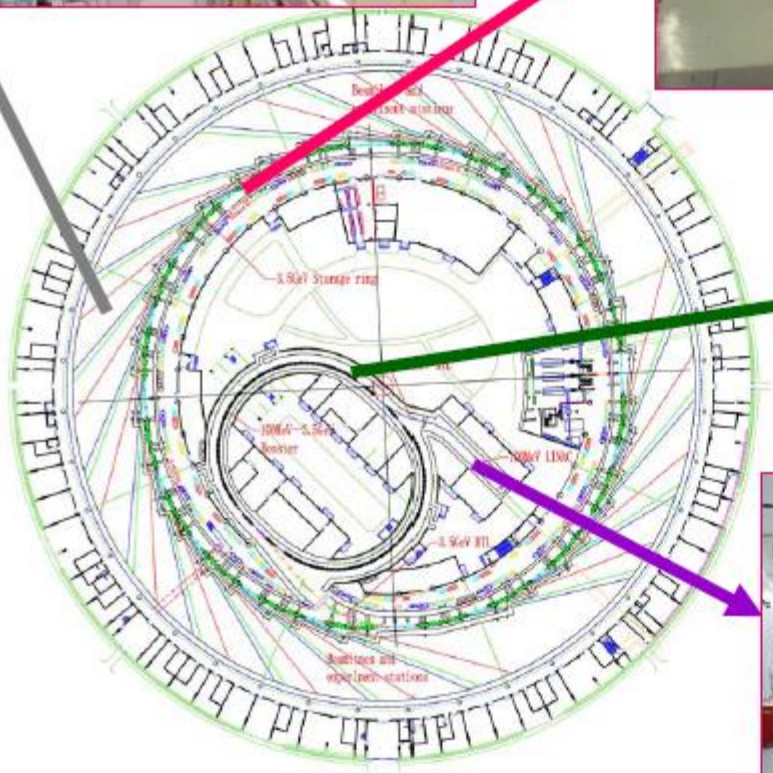
Shanghai Synchrotron Radiation Facility

- **SSRF is an intermediate energy 3rd generation light source funded by Chinese Academy of Sciences (CAS), Shanghai local government and central government of China;**
- **CAS and Shanghai local government made a joint proposal in 1995, and then a R&D program was carried out from Jan. 1999 to Mar. 2001; Later on this project was announced and fully approved in 2004, and its groundbreaking was made on Dec.25, 2004;**
- **The Linac and booster have been commissioned in 2007, the storage ring commissioning and the beamline commissioning started on Dec. 21, 2007 and May 9, 2008 respectively. The user operation is scheduled to start in May 2009**

SSRF Complex

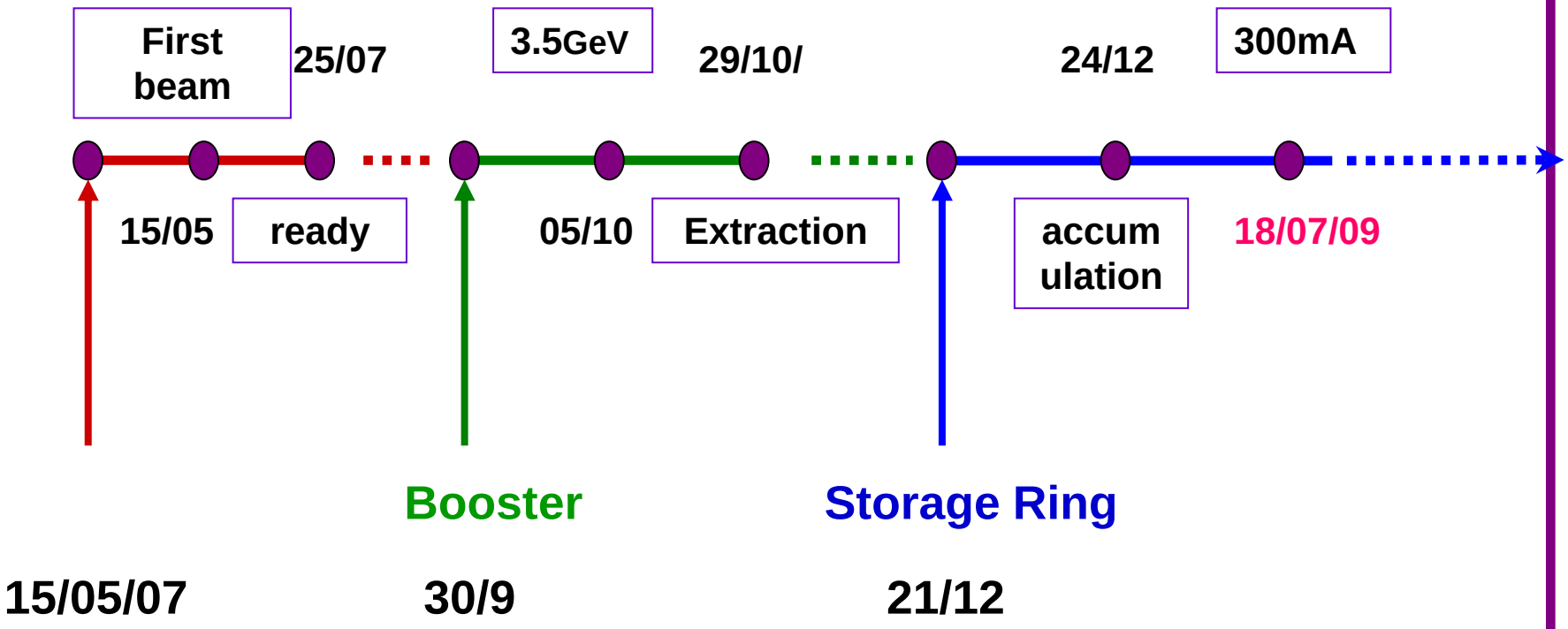
Storage Ring
3.5GeV, C=432m



Booster
3.5GeV, C=180m

Electron Linac
150MeV

Key Dates of the SSRF Commissioning



SSRF Booster

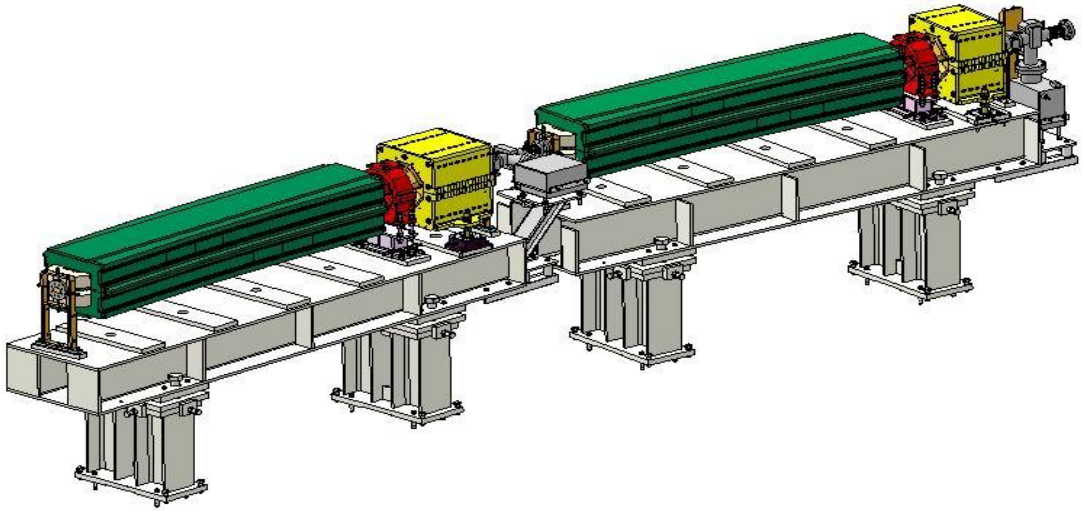
The SSRF Booster and its commissioning

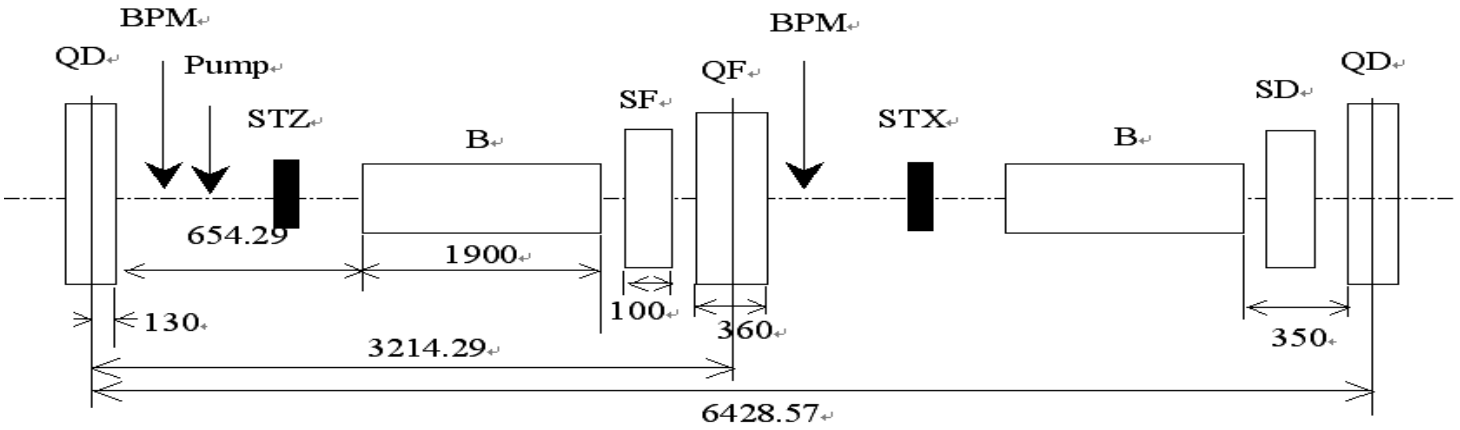
- A full energy booster optimized for top-up injection;
- Two fold Lattice configuration to accommodating 28 FODO cells with 8 missing dipole magnets;
- Extraction beam emittance designed at ~100 nm-rad for getting a clean top-up operation;
- A circumference of 180m and a injection energy of 150MeV;
- Repeat rates up to 2Hz

Main Parameters of the SSRF Booster

Injection energy	GeV	0.15	
Extraction energy	GeV	3.5	
Beam Current Single/Multi bunch	mA	1.6/15	
Circumference	m	180	
Cell number/Super periods		28/2	
Energy loss per turn at 3.5 GeV	MeV	0.915	
Natural emittance at 3.5 GeV		104	94.6
Betatron tune, ν_H / ν_V		8.181/5.229	8.416/5.389
Nature Momentum spread		7.799×10^{-4}	7.802×10^{-4}
Momentum compaction, α_P		0.01849	0.0176
Damping time, $\tau_{H,V,L}$	mS	4.8/4.6/2.3	4.8/4.6/2.3
RF Frequency	MHz	499.65	
Required RF voltage V_{RF}	MV	1.8	

One FODO cell



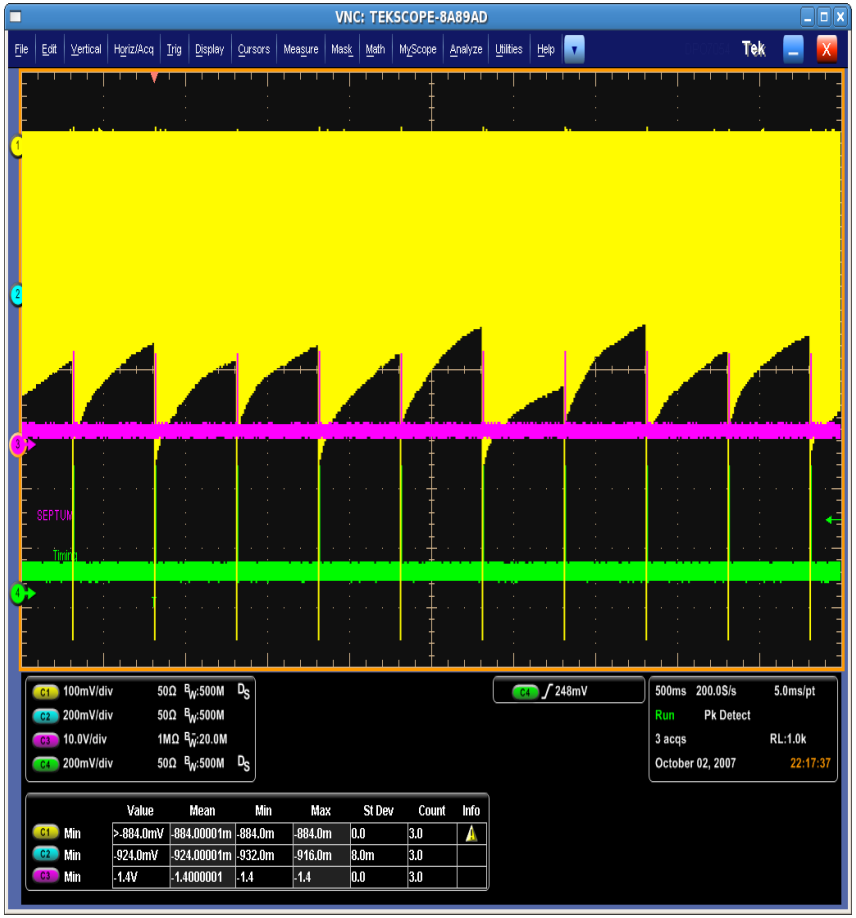


The SSRF Booster Installation

Booster Commissioning Milestones

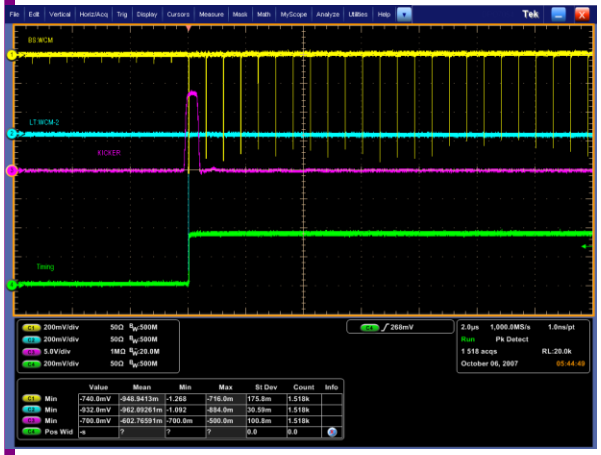
- **Sept. 30: Commissioning started at 20:30, and beam arrived at the booster entrance at 21:58;**
- **Oct. 01: First turns of the circulating beam in booster achieved at 17:00;**
- **Oct. 02: First stored beam in the booster obtained at 4:30;**
- **Oct. 05: Within 60 effective commissioning hours, first ramped beam (3.5GeV) obtained at 4:25;**
- **Oct. 29: First extract beam from the booster achieved**

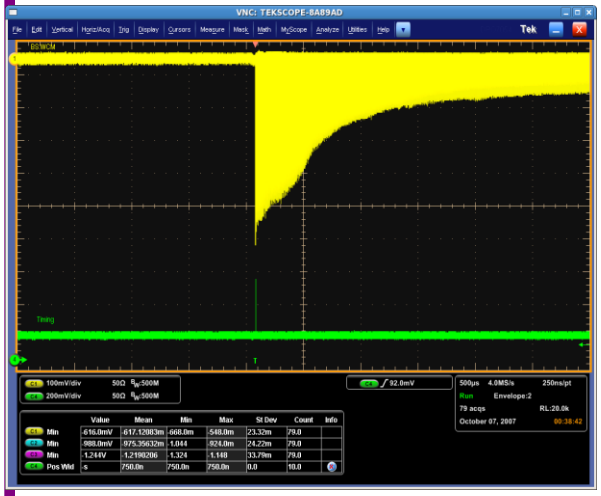
Oct. 1st, night, stored beam was observed by set the sextupoles, RF on

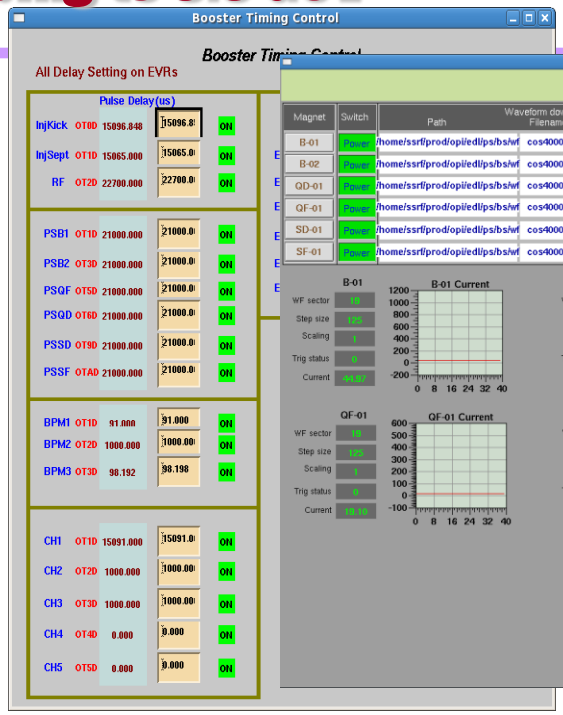


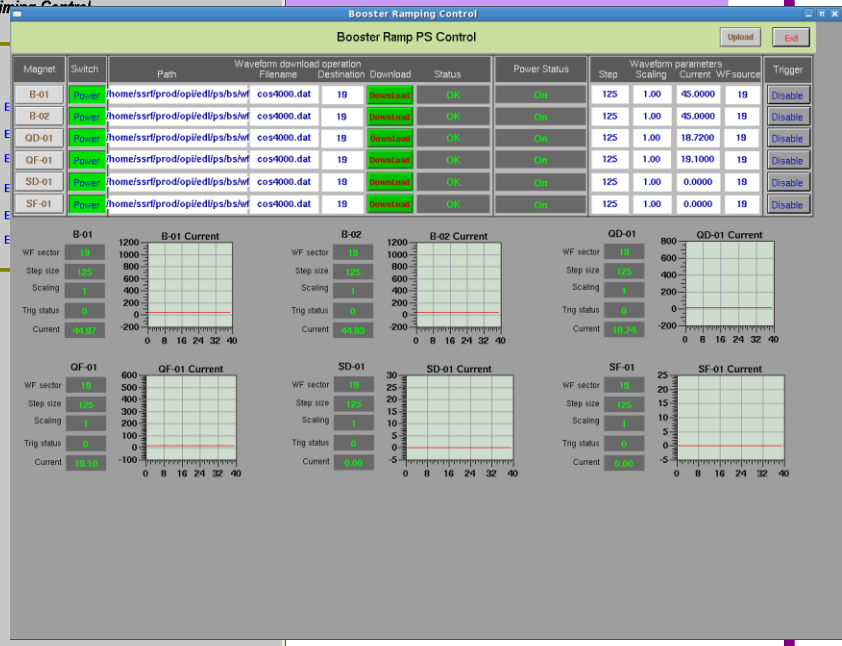
WCM

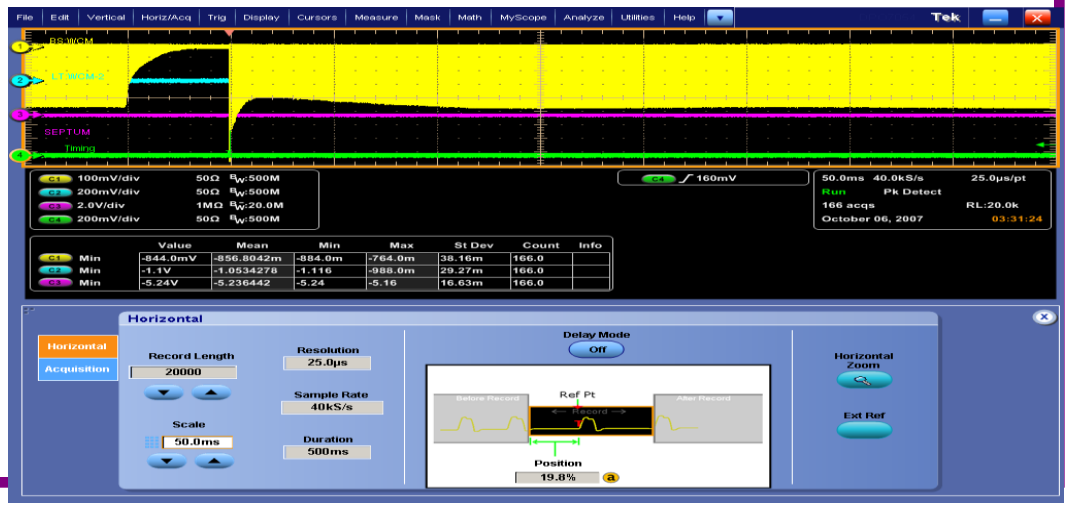
Oct. 5th, The beam was ramping to 3.5 GeV



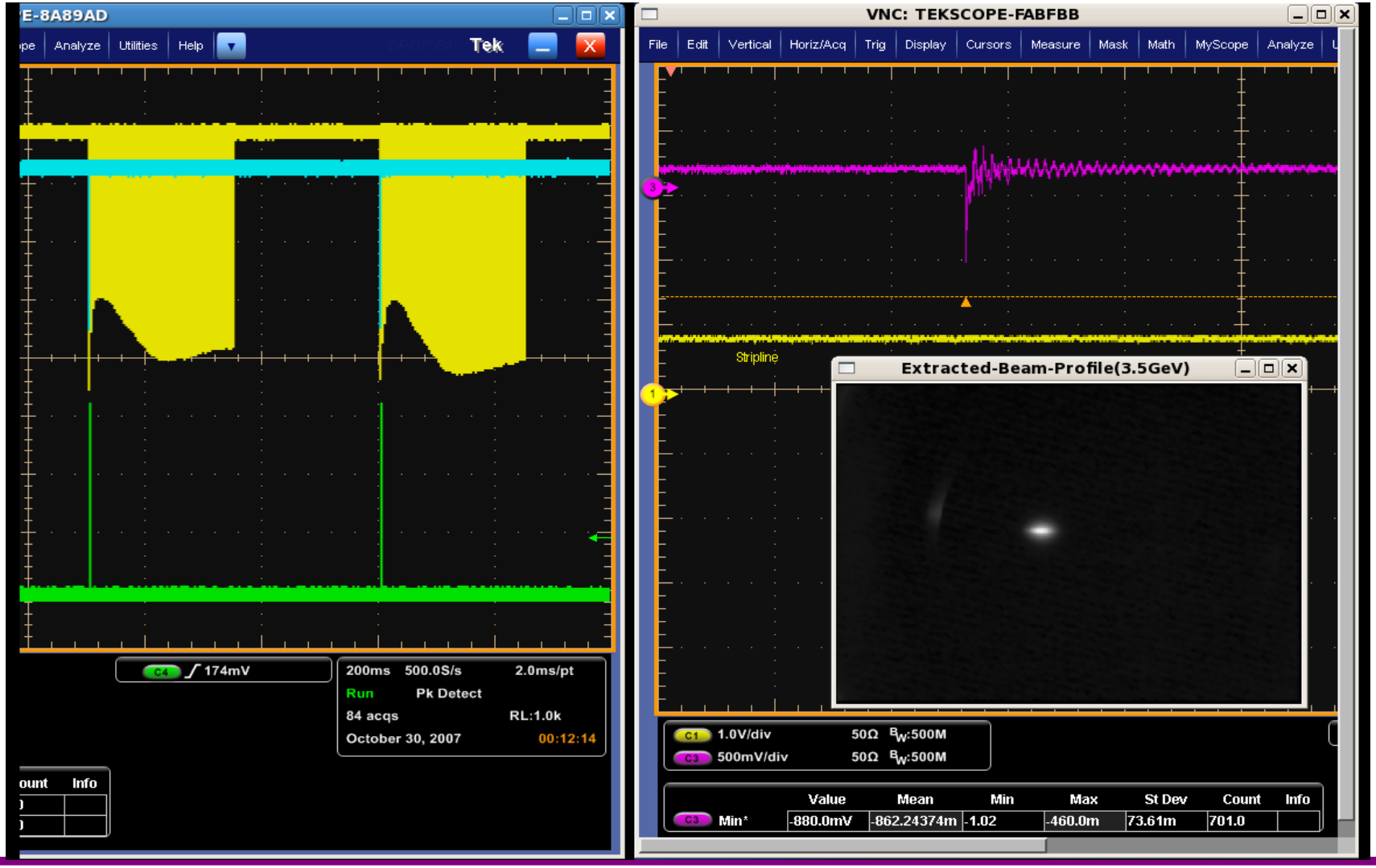








Oct. 29, Beam was extracted to the HBT



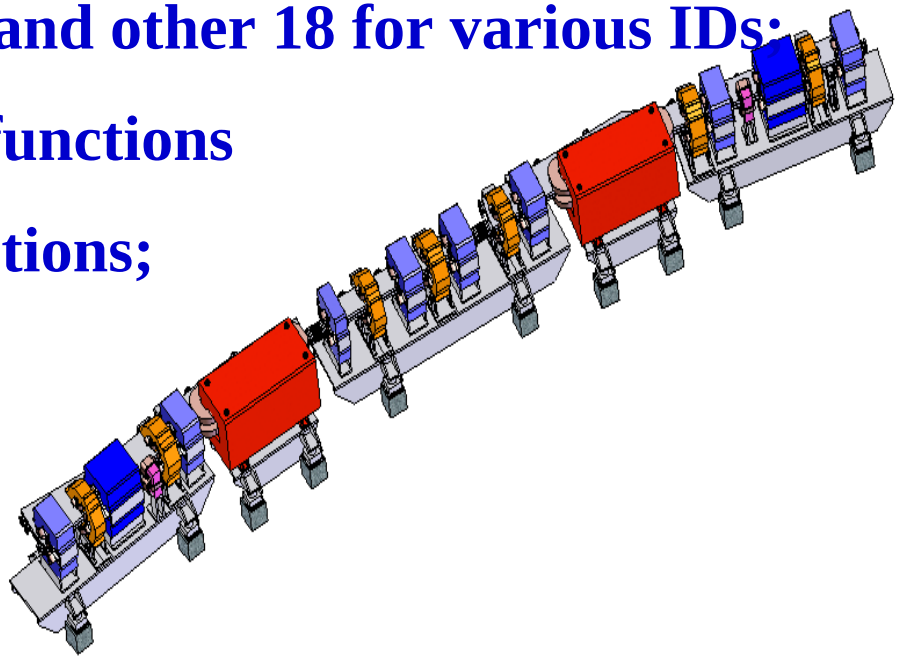
Overview of Storage Ring

Main Parameters of the SSRF Storage Ring

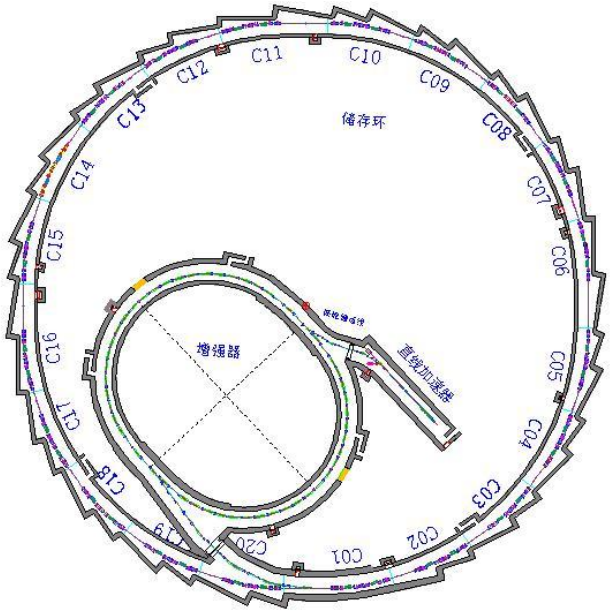
	DBA	Low-emittance mode	Normal Mode
Energy	GeV	3.5	3.5
Circomference	m	432	432
Natural Emittance	nm· rad	3.9	11. 2
Current：Multi-bunch（Single）	mA	200~300(5)	200~300(5)
Number of Cells		20/4	20/4
Straights: Length×Number	m	12×4、6.5×16	12×4、6.5×16
$\beta_x/\beta_y/\eta_x$ in middle of 12m straight	m	10.0/6.0/0.15	10.0/6.0/0.0*
$\beta_x/\beta_y/\eta_x$ in middle of 6.5m straight	m	3.6/2.5/0.10	3.6/2.5/0.0*
Betatron Tune Q_x/Q_y		22.22/11.32	22.22/11.32
Chromaticity ξ_x/ξ_y		-56/-19	-56/-19
RF Voltage	MV	4.0~6.0	4.0~6.0
Energy Loss Per Turn (Dipole)	MeV	1.448	1.448
Bunch Length	mm	4.0	4.0

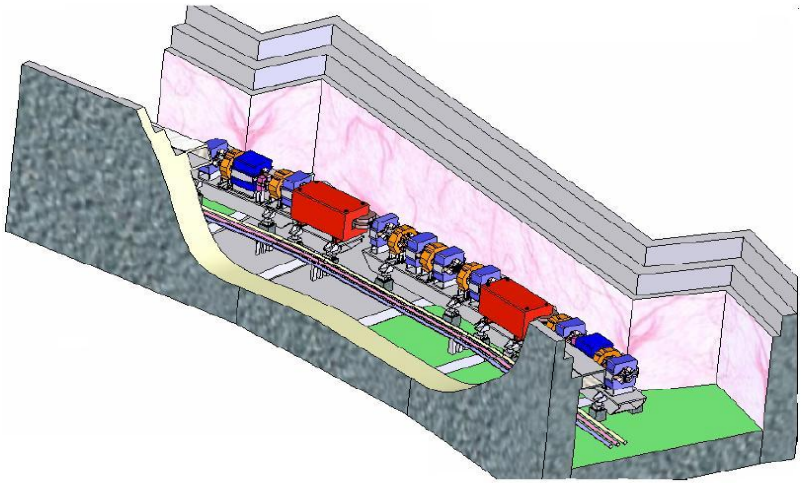
The SSRF Storage Ring

- A 20-cell double bend lattice structure with a circumference of 432 m and a natural emittance of 3.9nm-rad;
- 4 fold configuration with two types of straight sections (16x6.5m and 4x12m);
- One 12m straight for accommodating all injection elements, another one for SRF cavities and other 18 for various IDs;
- Reasonable beam sizes, beta functions and dispersion at straight sections;



Storage Ring

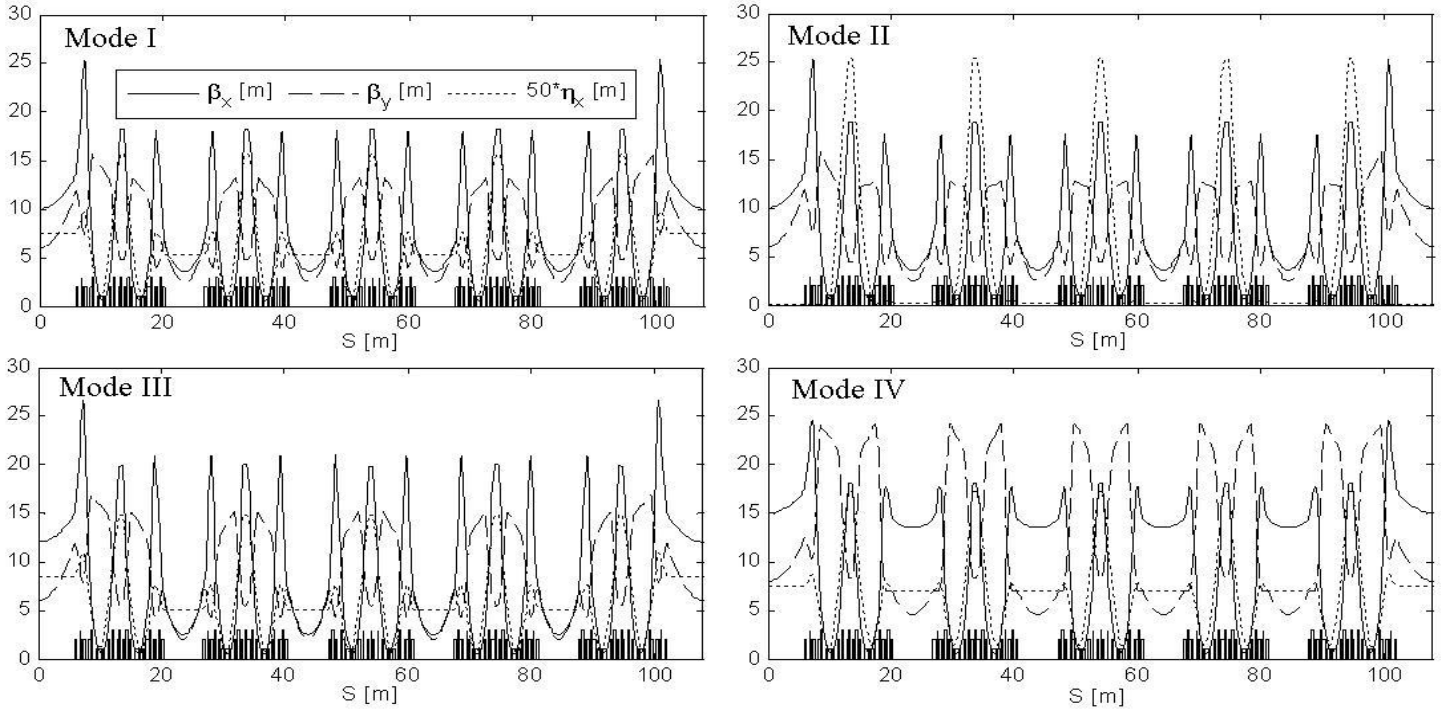




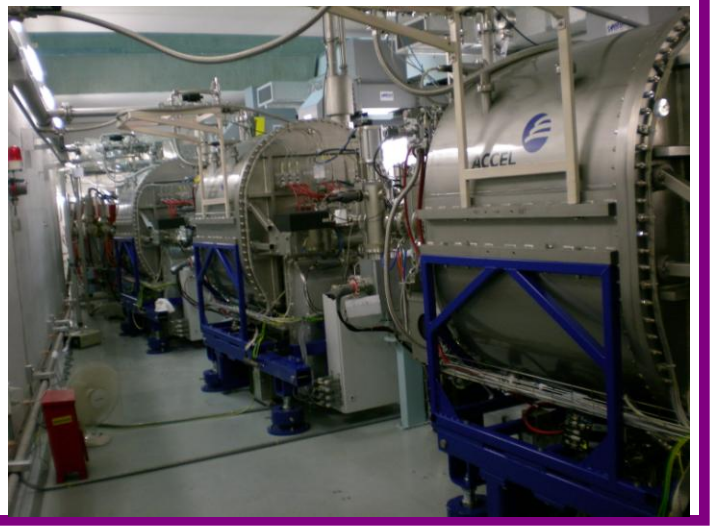
- Main parameters:
- Energy：3.5 GeV；
- Circumference：432m；
- Current：5/300 mA (S/M bunch)；
- emittance：3.9 mm-mrad；
- Strait section：4*12m，16*6.5m；
- RF voltage：4-6 MV
- Max Power：~600kW
- Orbit Stability：<10% beam size

Designed Lattice Parameters

	Mode I	Mode II	Mode III	Mode IV
Tune	22.22/11.29	22.22/11.29	23.32/11.23	19.22/7..32
emittance	3.92	11.4	3.36	5.42



The SSRF Storage Ring Installation



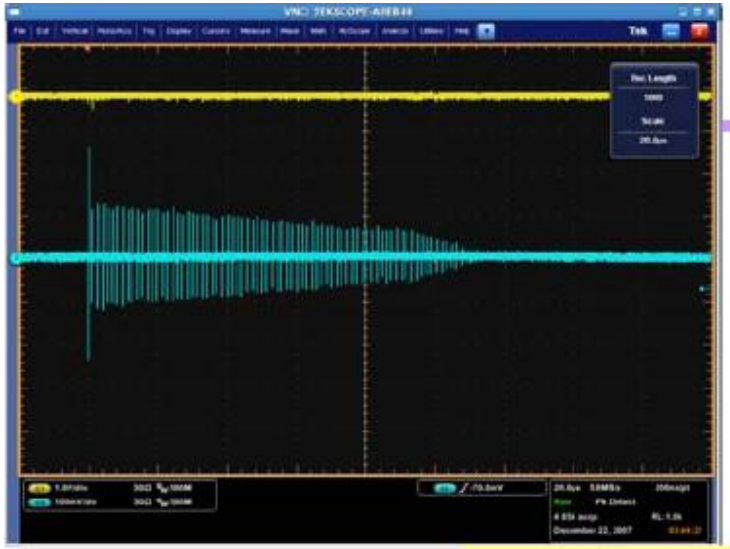
Commissioning of SSRF storage ring

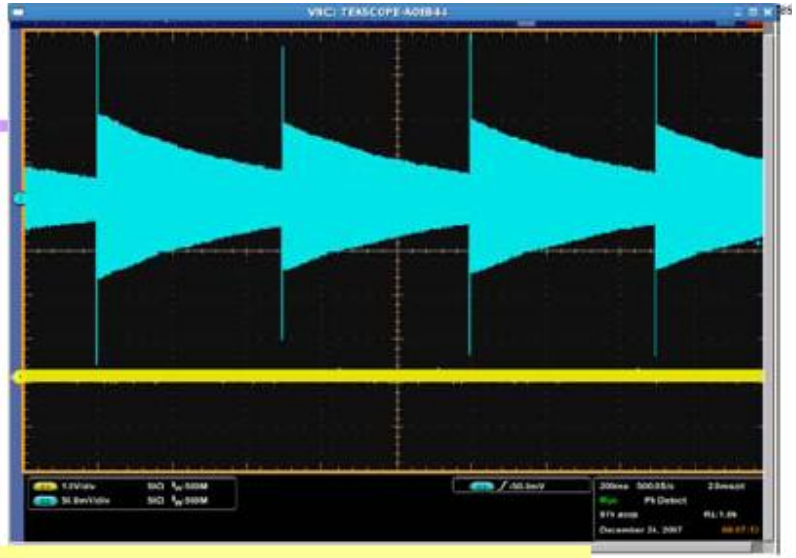
1. Commissioning Schedule:
   - First stage: with norm RF cavities (Vrf 2.0MV, Eb 3.0GeV)
   - Second stage: with supper-conducting RF cavities (Vrf 4MV, Eb 3.5 GeV)
   - Third stage: with insertion devices and beam lines
2. Commissioning procedures:
   - Beam injection: First turn and multi turns
   - beam current accumulation and Stored beam
   - COD
   - BBA
   - LOCO
   - Beam orbit stability and slow orbit feedback
   - Insertion devices
   - High current

Storage Ring Commissioning Milestones

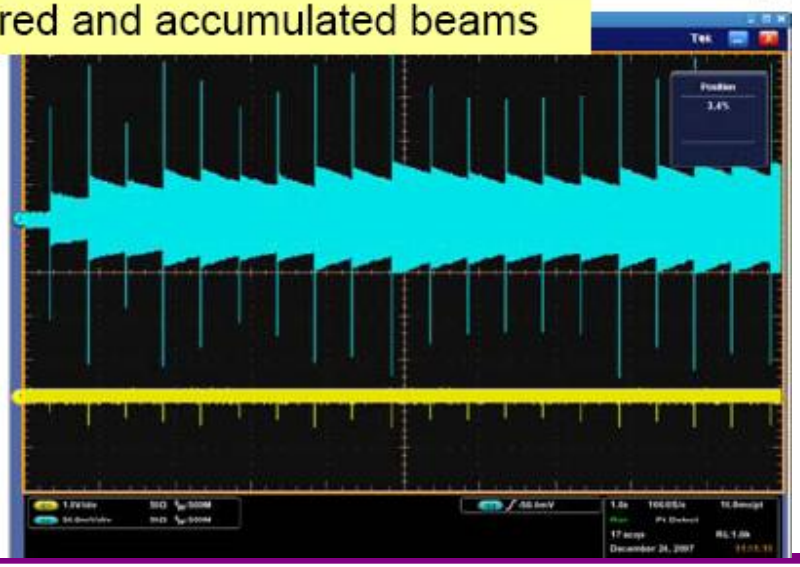
- Dec. 21, 2007: commissioning started at 18:20, one turn beam achieved at 21:08 and multi-turn beam at 21:18;
- Dec. 23, 2007: 2000~3000 turns achieved at 20:00;
- Dec.24, 2007: first stored beam obtained at 06:54 (in~60hrs)
- Jan.03, 2008: 100mA stored beam achieved at 20:20;
- Mar. 16, 2008: Both horizontal and vertical closed orbit corrected to <50um rms with 80 correctors (137BPMs);
- June 2008: a few of microns beam orbit stability achieved;
- June 15, 2008: Integrated beam current >150 Ahrs obtained;
- June 17 -18, 2008: 200mA at 2GeV and 300mA at 1.5GeV achieved.
- 2008.09.30 Reached 200mA@3.5GeV
- 2009.05.06 Open to user
- 2009.07.18 Reached 300mA@3.5GeV

Storage Ring Commissioning



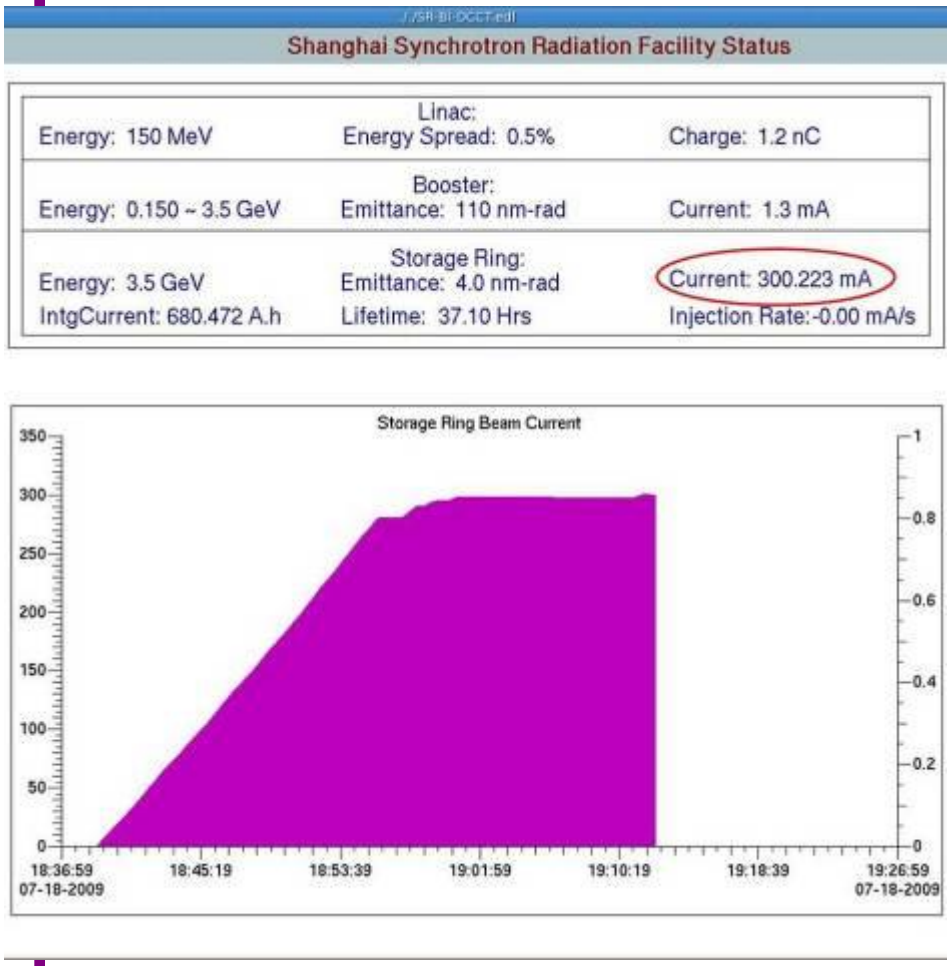


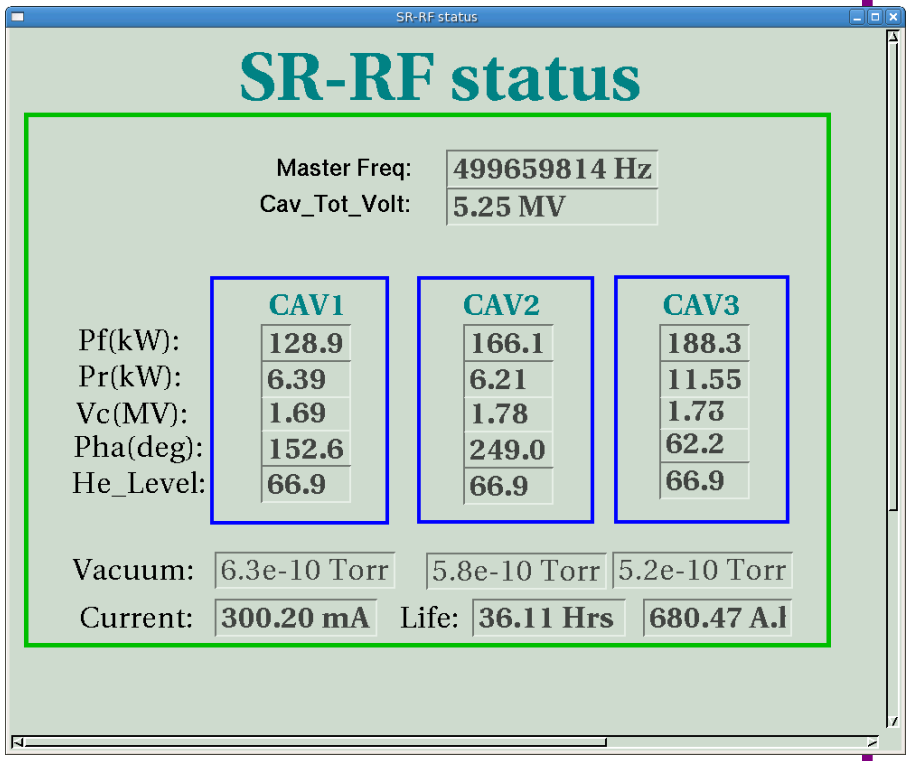
Circulated,Stored and accumulated beams



Celebrating the Stored Beam 06:55, Dec.24, 2007

On July 18, 2009 , the final important parameter 300mA was reached





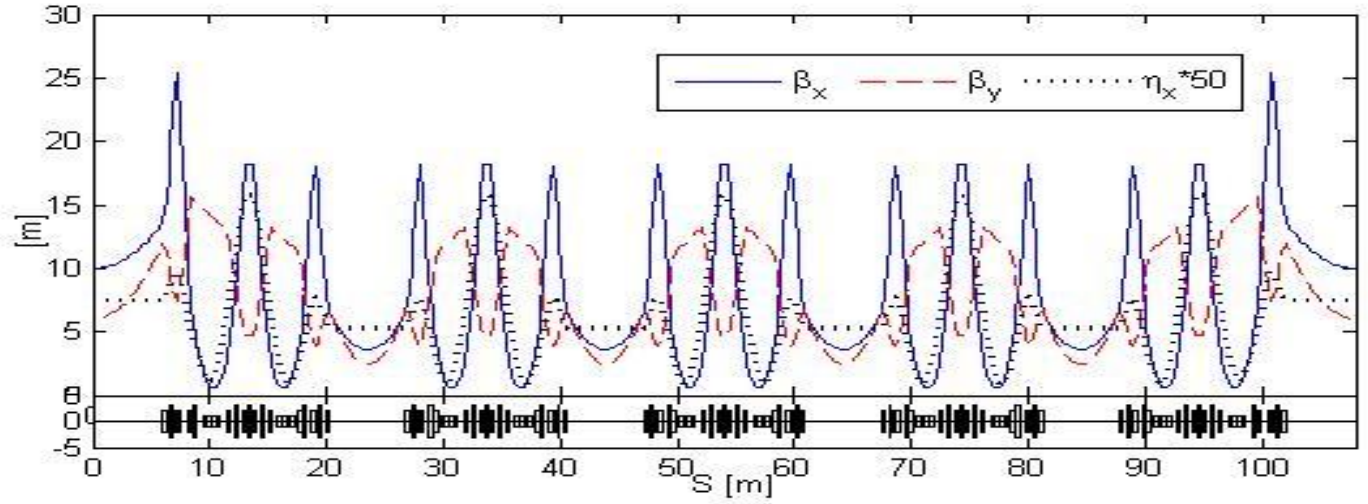
Model Calibration

The main design values of the two modes

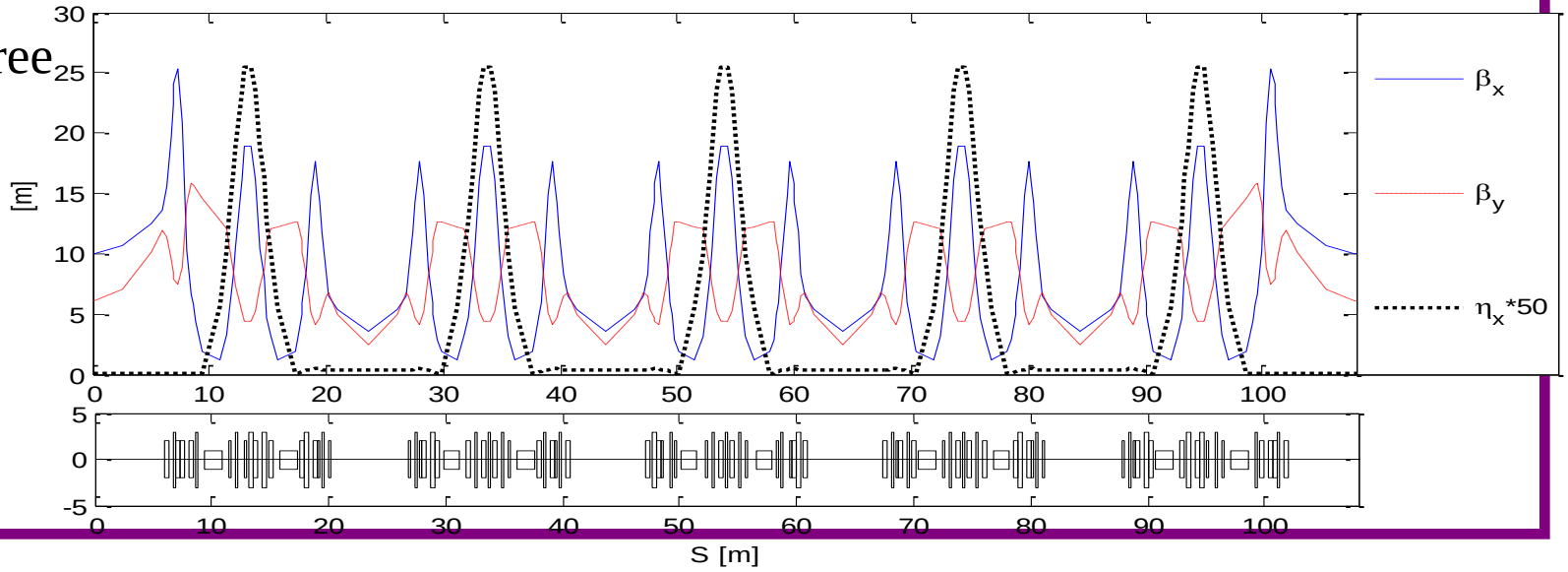
Parameters	Dispersion mode	Dispersion-free mode
Energy (GeV)	(3.0)3.5	(3.0)3.5
Circumference (m)	432	432
Cell	20(DBA)	20(DBA)
Super-period	4	4
Tune Q_x/Q_y	22.22/11.29	22.22/11.29
$\beta_x/\beta_y/\eta_x$(m) in the centers of straight sections	10/6.0/0.15 3.6/2.5/0.10	10/6.0/0 3.6/2.5/0.006
Natural emittance (nm.rad)	3.92 2.86@3.0GeV	11.4 8.4@3.0GeV
Natural chromaticity ξ_x/ξ_y	-55.64/-17.94	-55.56/-18.09
Momentum compactor	4.2118×10^{-4}	5.4249×10^{-4}
Damping partitions $J_x/J_y/J_s$	0.9968/1/2.0032	0.9960/1/2.0040
Natural energy spread (rms)	9.84×10^{-4} 8.44×10^{-4}@3.0GeV	9.84×10^{-4} 8.44×10^{-4}@3.0GeV

The optical functions of the two modes in one fold of the storage ring

Dispersion mode



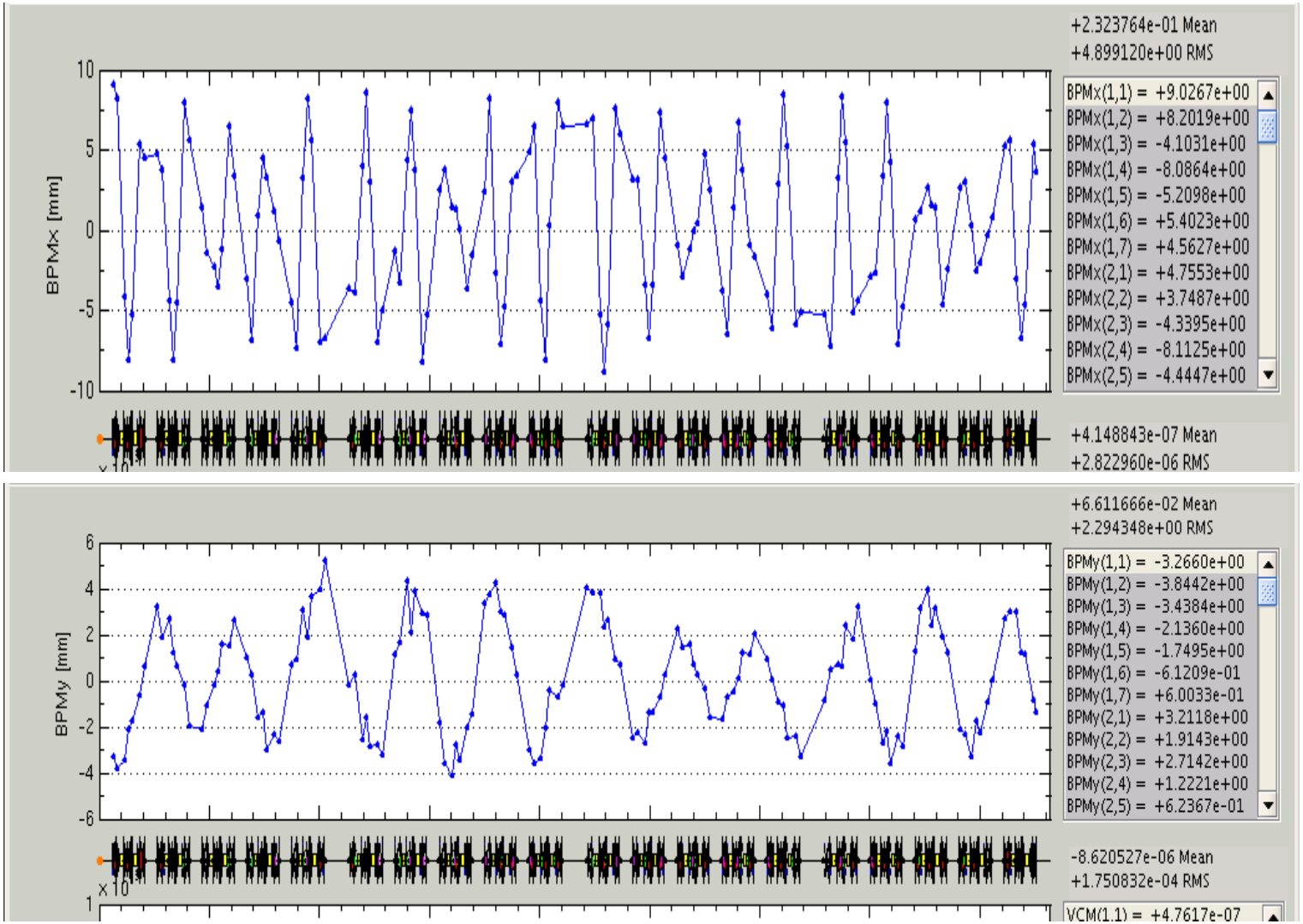
Dispersion-free mode



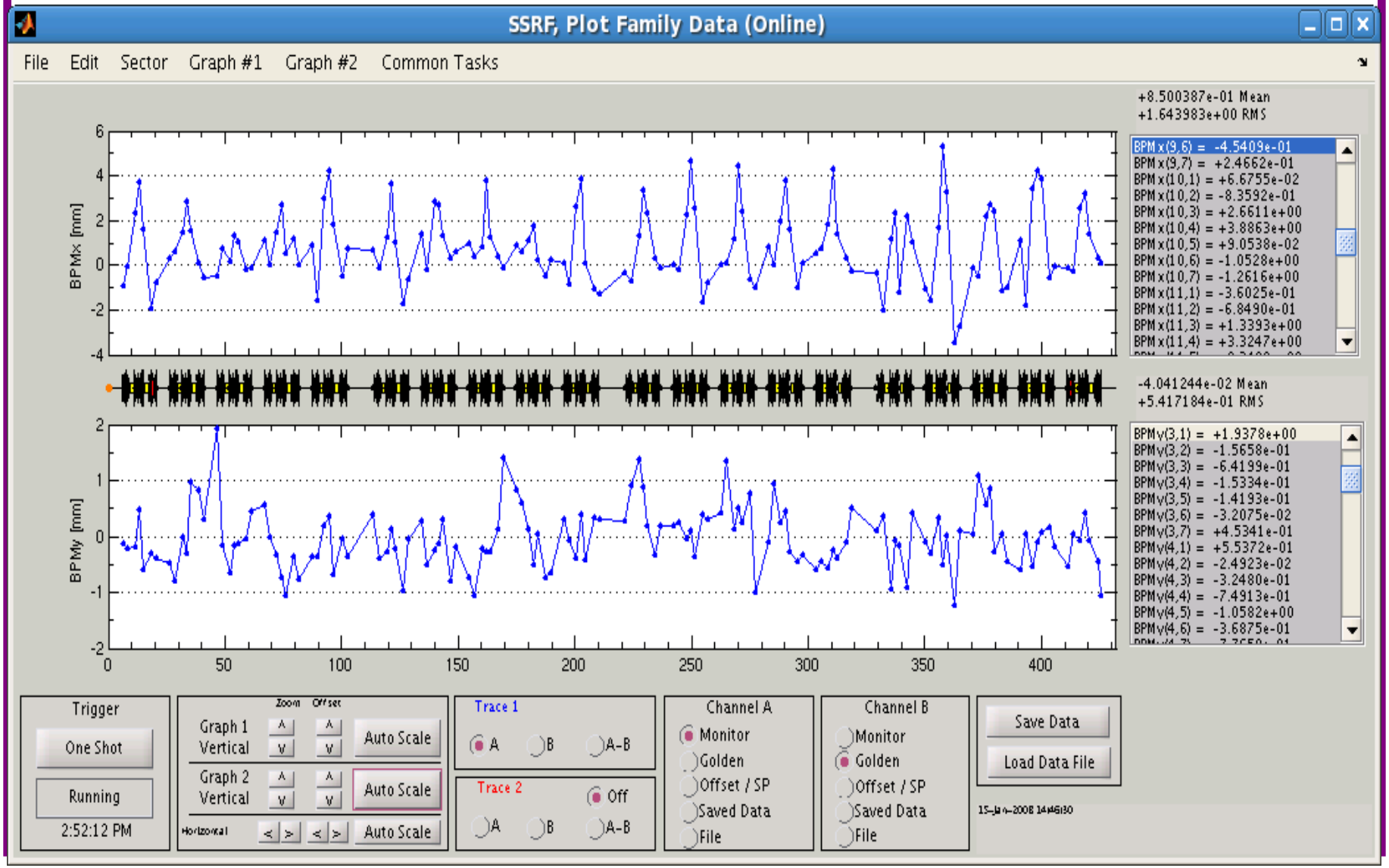
Calibration the model step by step

1. First commissioning
   - Tune difference from model: 1.5(H)/0.4(V)
   - rms value of COD is about 1mm in both plane
2. Model calibration after two rounds of BBA
   - Tune difference from model: 0.03(H)/0.07(V)
   - rms value of COD is about 0.08mm in both plane
   - Bad beta function distributions
3. Model calibration with LOCO: by family
   - The measured data are almost same with the model
   - rms value of COD is less than 0.05mm in both plane
   - Working with 100mA
4. Model calibration with LOCO: by magnets
   - Reduce the beta beating caused by the small errors

Bare COD

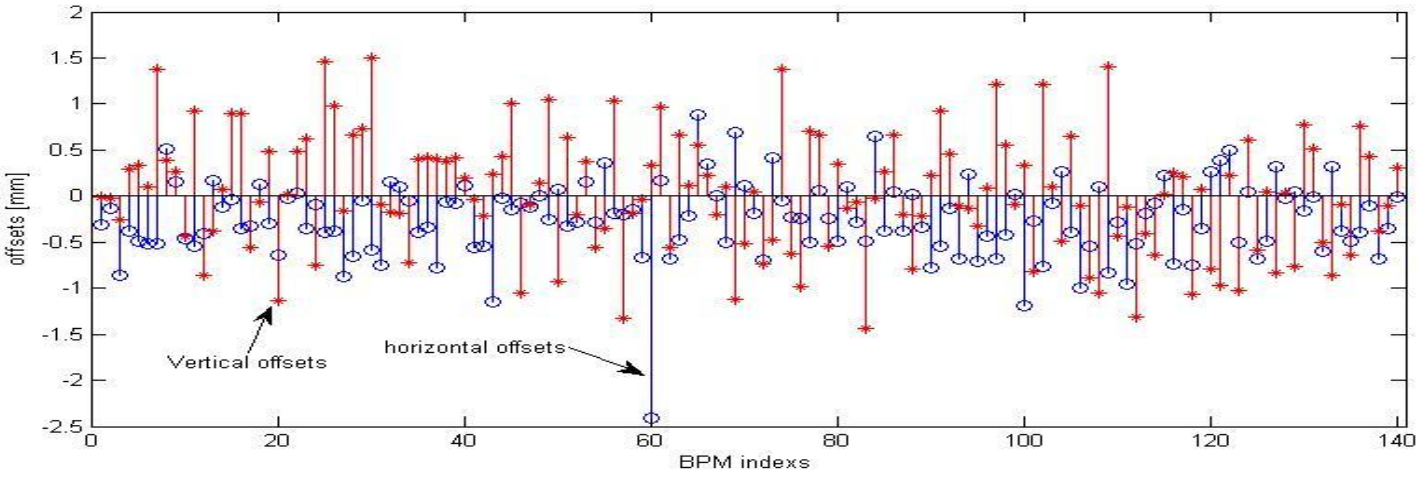

+2.323764e-01 Mean
+4.899120e+00 RMS
BPMx(1,1) = +9.0267e+00
BPMx(1,2) = +8.2019e+00
BPMx(1,3) = -4.1031e+00
BPMx(1,4) = -8.0864e+00
BPMx(1,5) = -5.2098e+00
BPMx(1,6) = +5.4023e+00
BPMx(1,7) = +4.5627e+00
BPMx(2,1) = +4.7553e+00
BPMx(2,2) = +3.7487e+00
BPMx(2,3) = -4.3395e+00
BPMx(2,4) = -8.1125e+00
BPMx(2,5) = -4.4447e+00
BPMx [mm]
+4.148843e-07 Mean
+2.822960e-06 RMS
+6.611666e-02 Mean
+2.294348e+00 RMS
BPMy(1,1) = -3.2660e+00
BPMy(1,2) = -3.8442e+00
BPMy(1,3) = -3.4384e+00
BPMy(1,4) = -2.1360e+00
BPMy(1,5) = -1.7495e+00
BPMy(1,6) = -6.1209e-01
BPMy(1,7) = +6.0033e-01
BPMy(2,1) = +3.2118e+00
BPMy(2,2) = +1.9143e+00
BPMy(2,3) = +2.7142e+00
BPMy(2,4) = +1.2221e+00
BPMy(2,5) = +6.2367e-01
BPMy [mm]
-8.620527e-06 Mean
+1.750832e-04 RMS
VCM(1,1) = +4.7617e-07

Step 1: Commissioning mode within the first month



Step 2: Commissioning mode after two rounds of BBA

BPM offsets
Feb. 23 2008

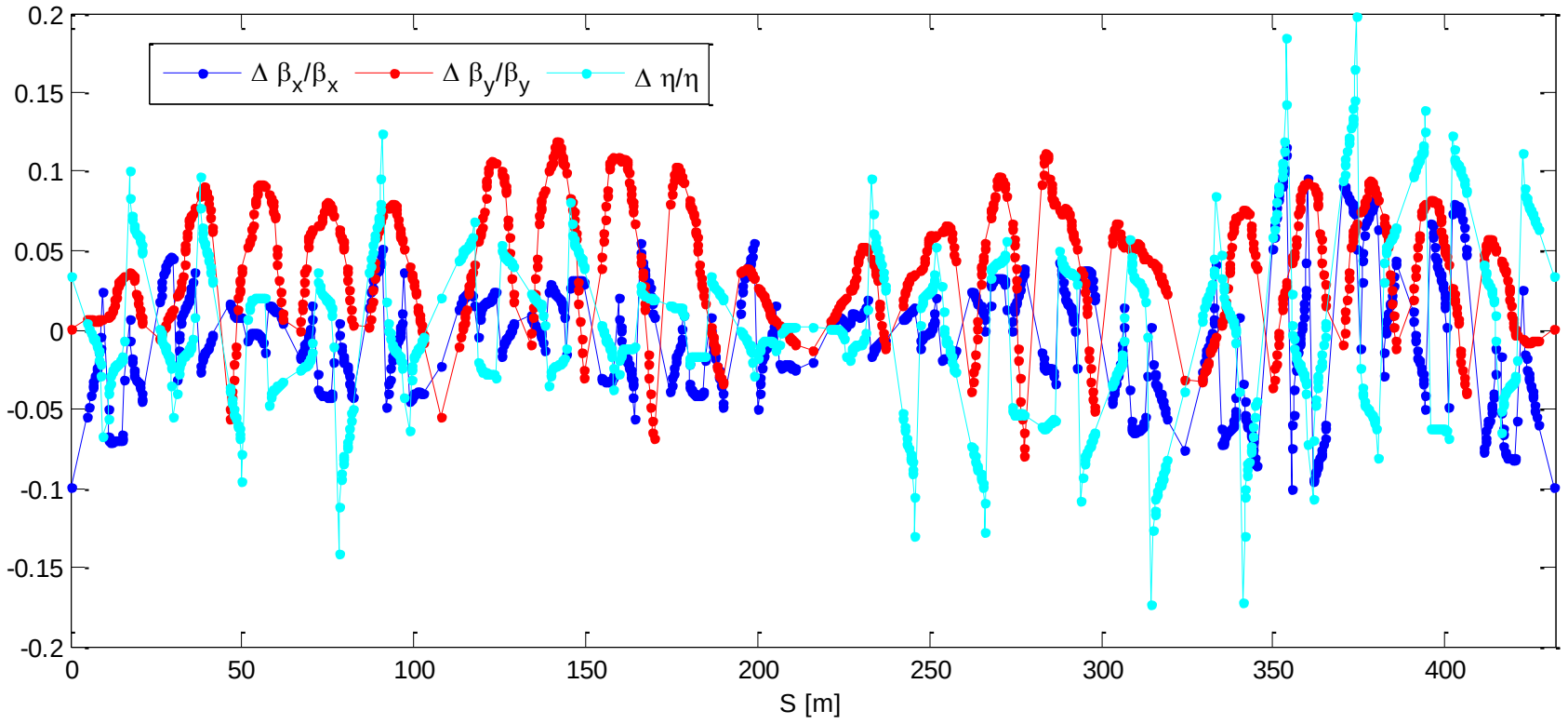


- After two rounds of BBA, the closed orbit can be corrected sufficiently, (x/y(RMS)=0.08mm/0.09mm @2008/2/24). With a simple scaling of magnetic coefficients, the measured optical parameters are close to the ones of the model.
- The measured tunes are 22.196/11.214, and the measured chromaticities are about -58/-16.
- Unfortunately, the measured beta functions show bad periods, and have much difference with the model!

Step 3: Commissioning mode with LOCO (By family)

- Correction of the B-I is done by fitting the quadrupole fields family-by-family with LOCO, and correction the magnetic coefficients.
- The commissioning is changed to dispersion mode after Mar. 5, 2008
- The closed orbit can be corrected to 0.07/0.08 mm (RMS) for horizontal and vertical plane respectively。
- The measured tunes (Qx/Qy) are 22.26/11.28, which is close to the designed value (22.22/11.29) further.
- The measured beta functions have good periods!

Beta and dispersion beatings between the LOCO model and the designed mode



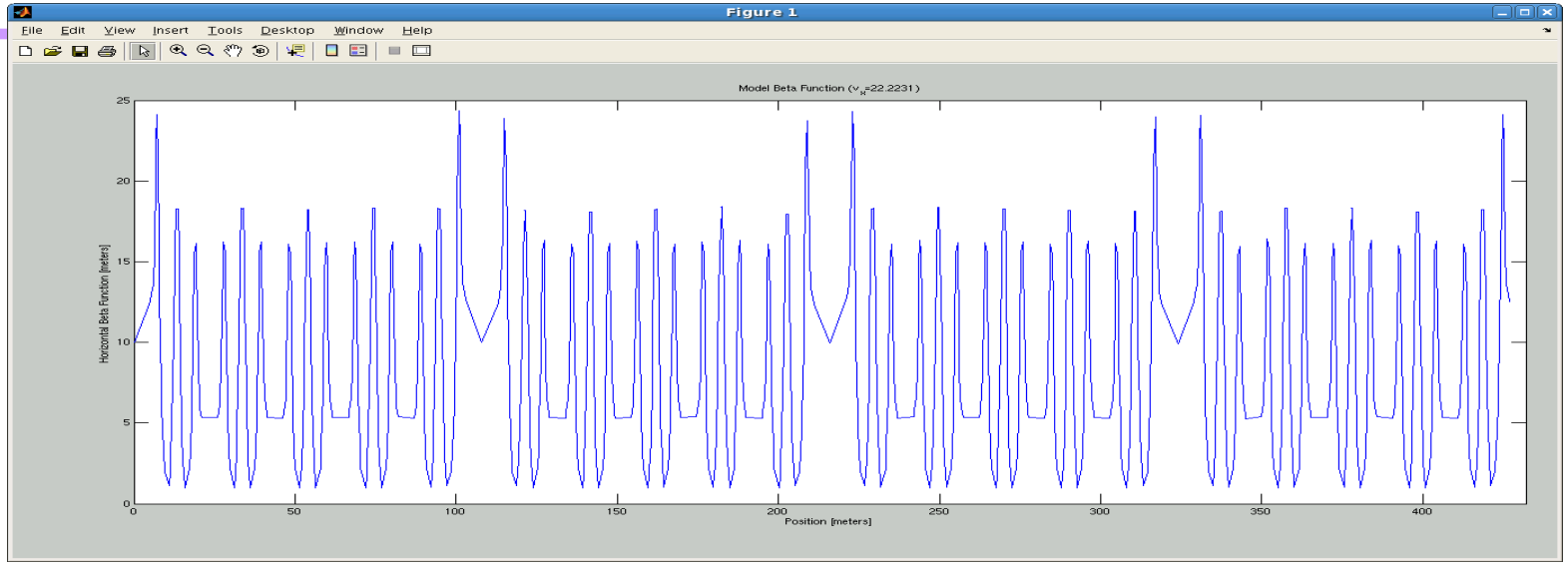
- Aberrations of the optical functions are obvious. The fact can be found both in direct measurements and LOCO measurements.

Step 4: Commissioning mode with LOCO (By magnets)

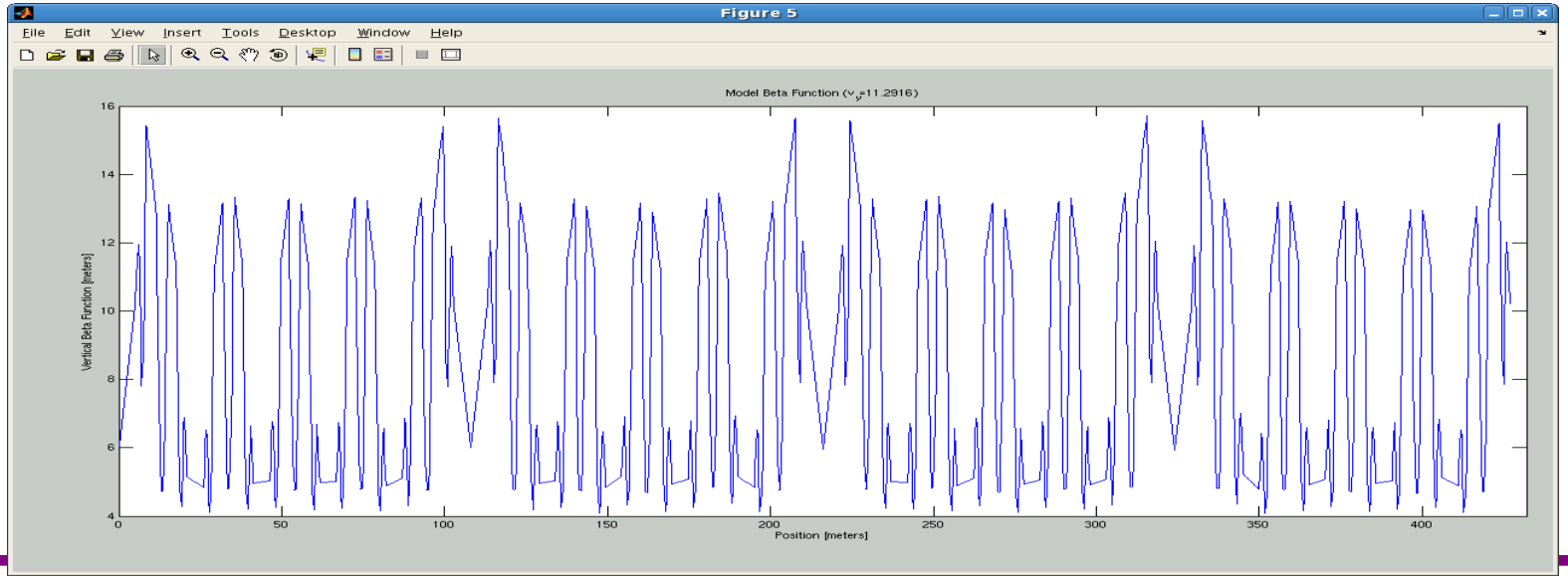
- With the little difference between model and measurement, one can use LOCO (fitting magnet-by-magnet) to calibrate the realistic mode to be closed to designed mode.
- After calibration of two rounds, the operational mode is tuned to designed mode, and the direct measured parameters are coherent to values resulting from LOCO measurements, and the designed mode.

Optical functions resulting from calibrated model with LOCO

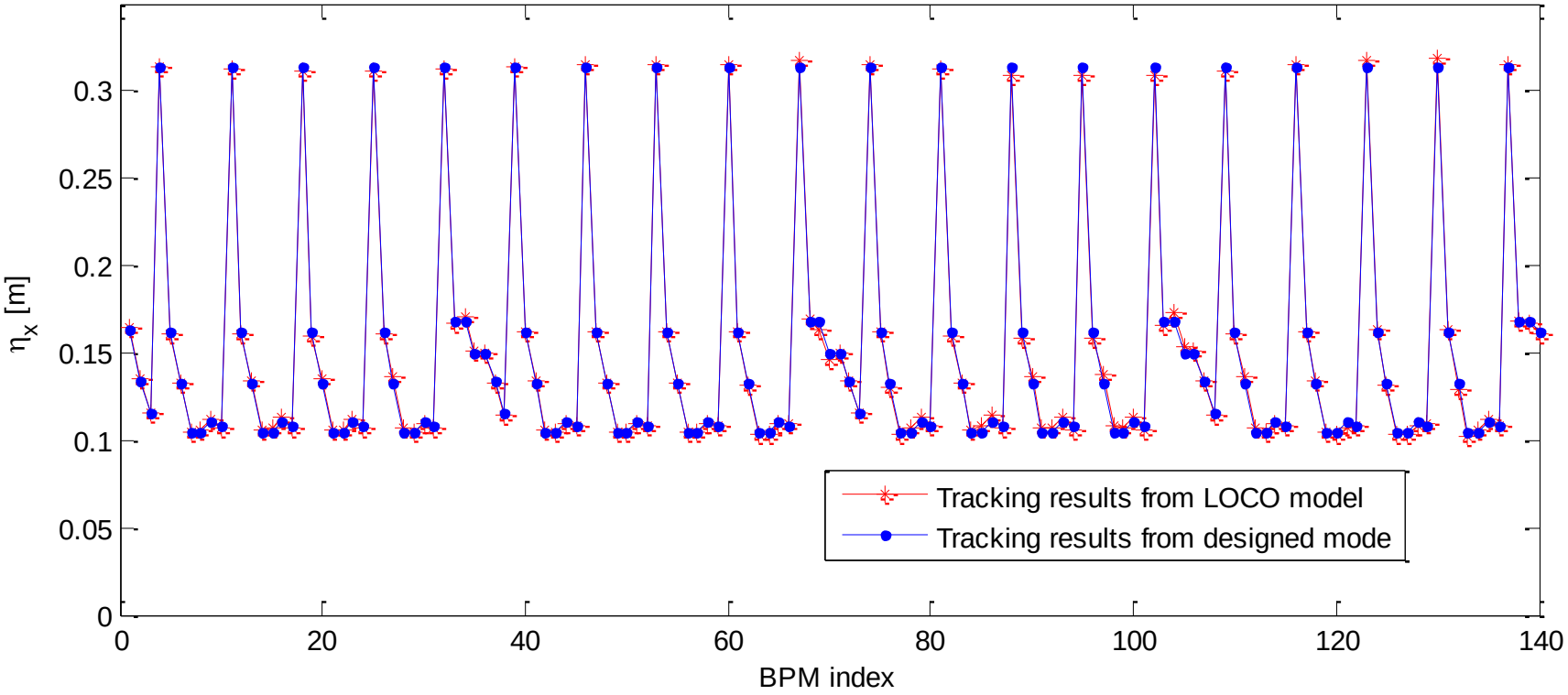
Hori. beta



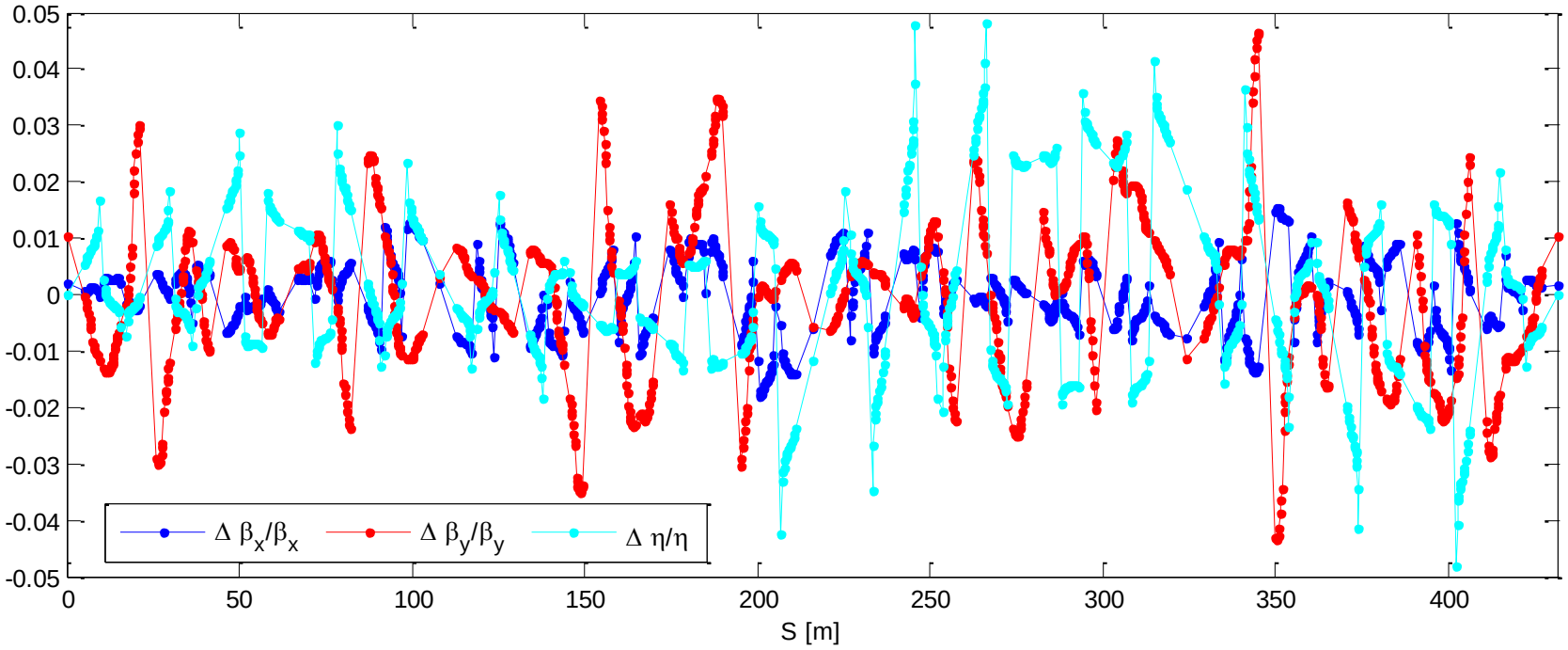
Vert. beta



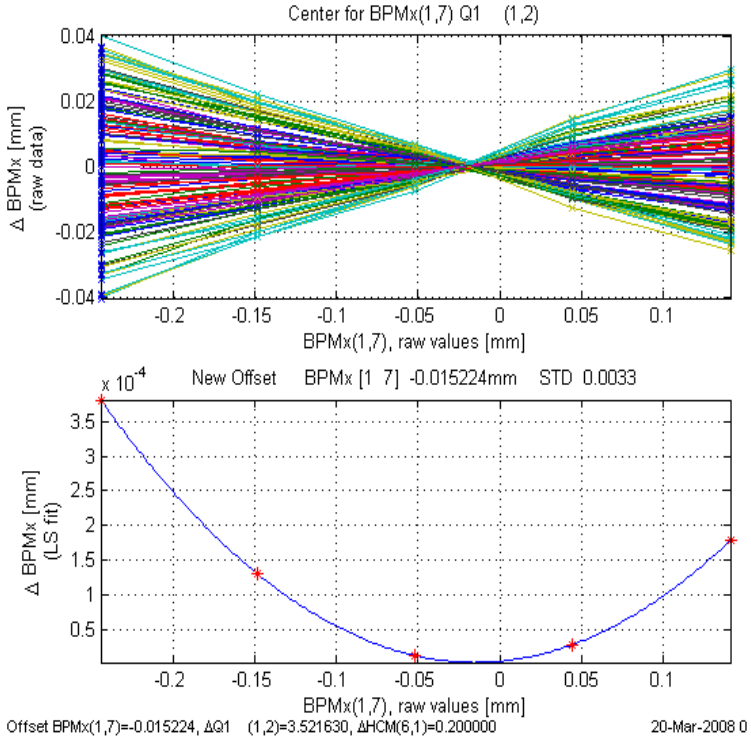
Comparison of the dispersion between the LOCO model and the designed mode tracked with AT code

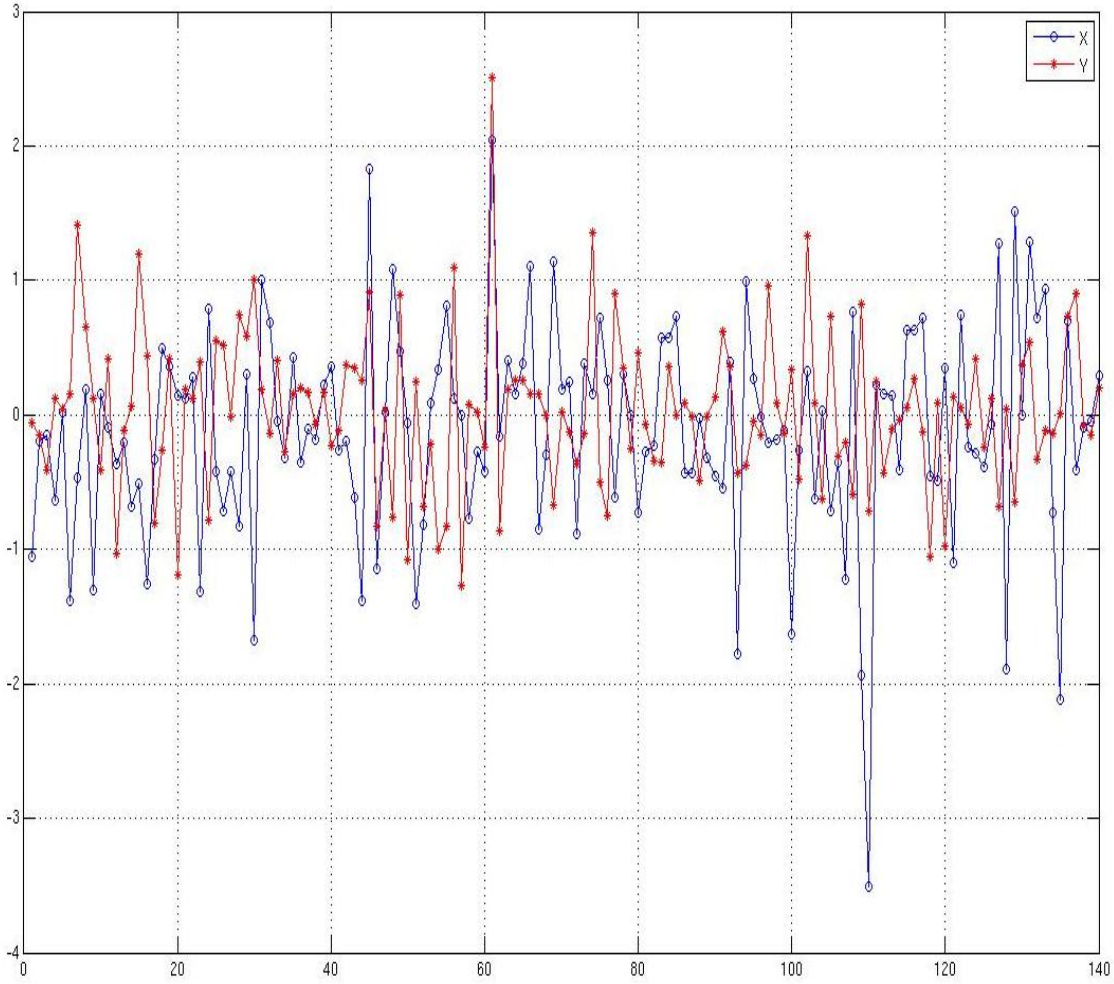


Beta and dispersion beatings between the LOCO model and the designed mode



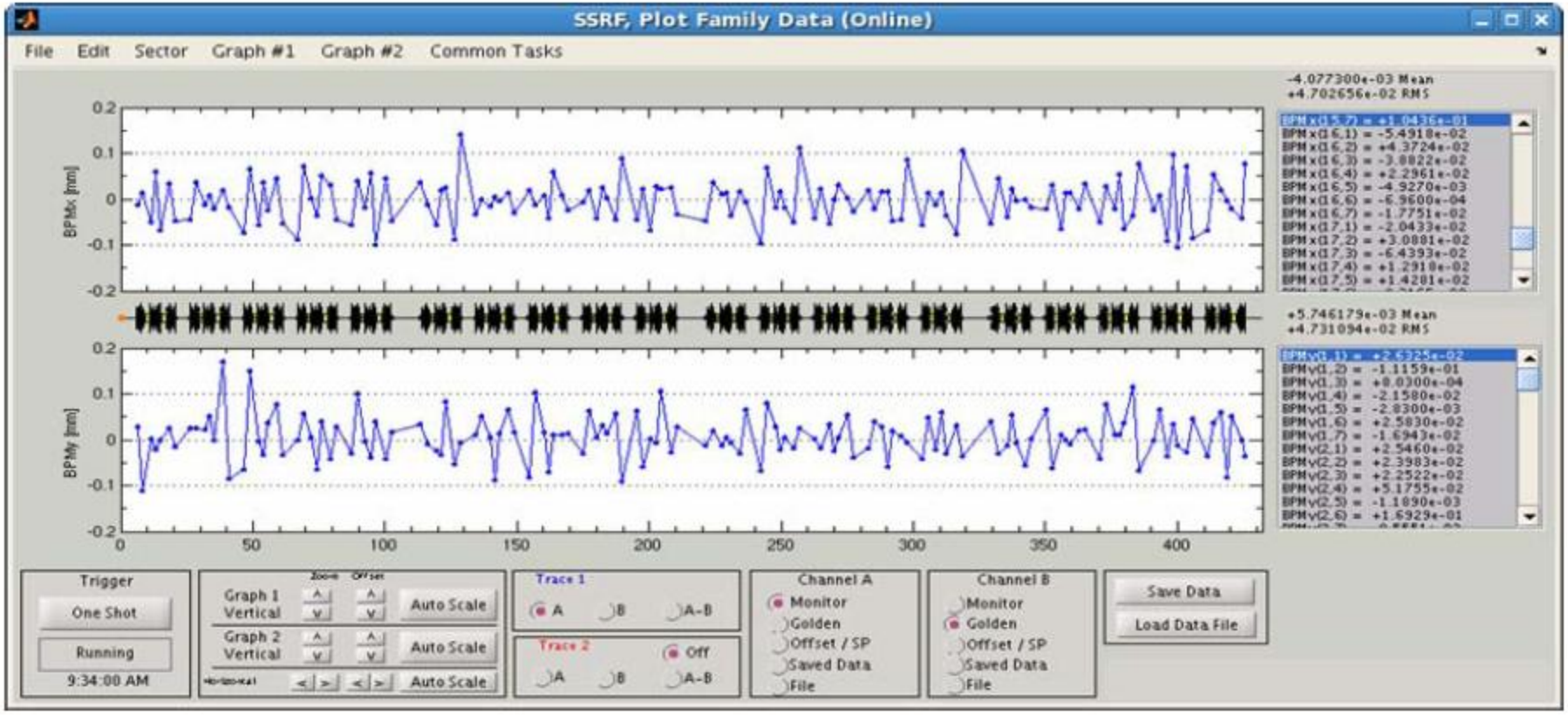
BBA measurement results





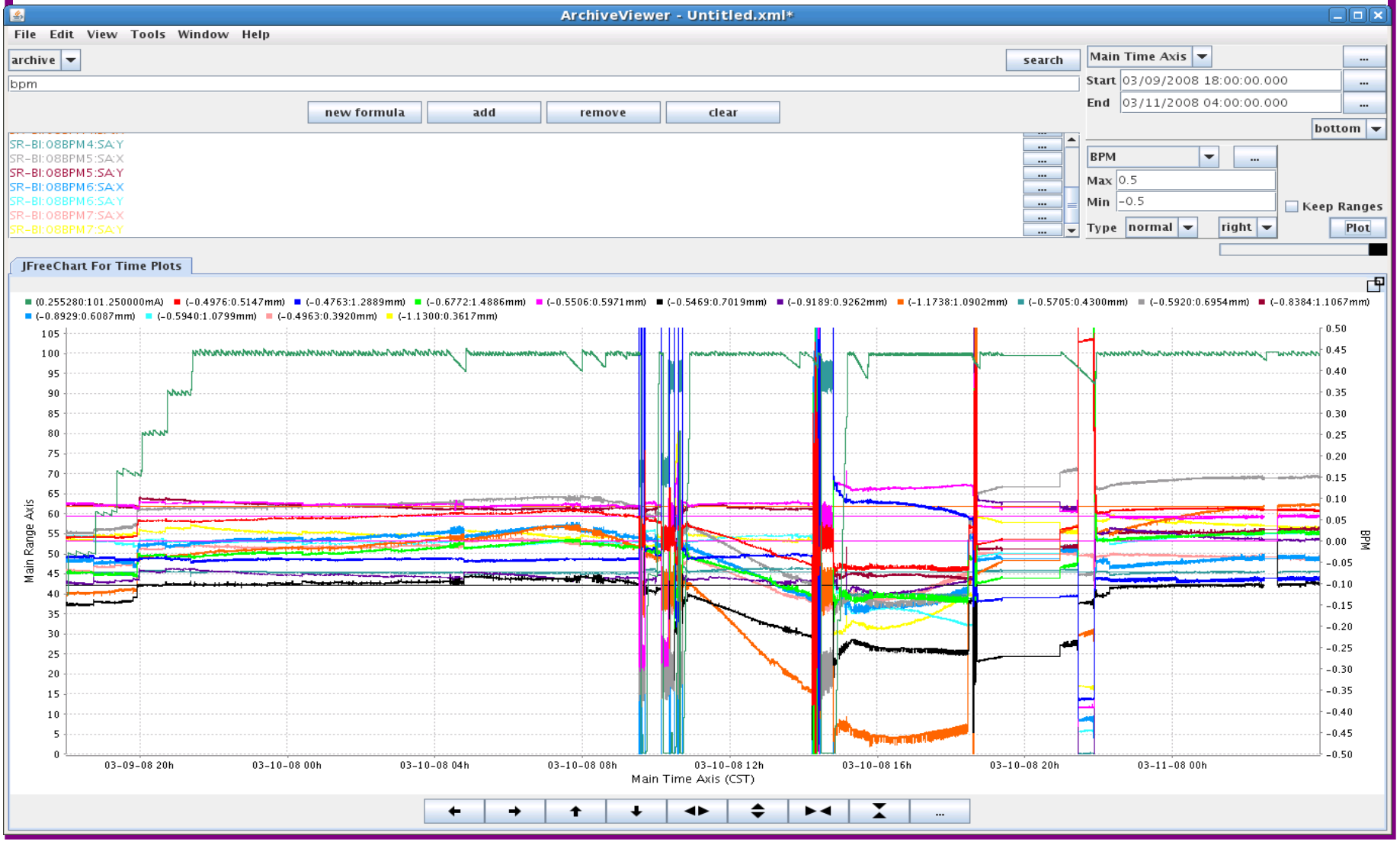
Residual closed orbit at 100mA: <50um rms

- With 137BPMs and 80 correctors for each of the horizontal and vertical planes
- Closed orbit was corrected to (rms): 47um (horizontal) and 47 um (vertical)
- Maximum corrector strengths are: 0.17mrad (horizontal) and 0.18mrad (vertical)



Orbit Stability

Orbit drift without feedback

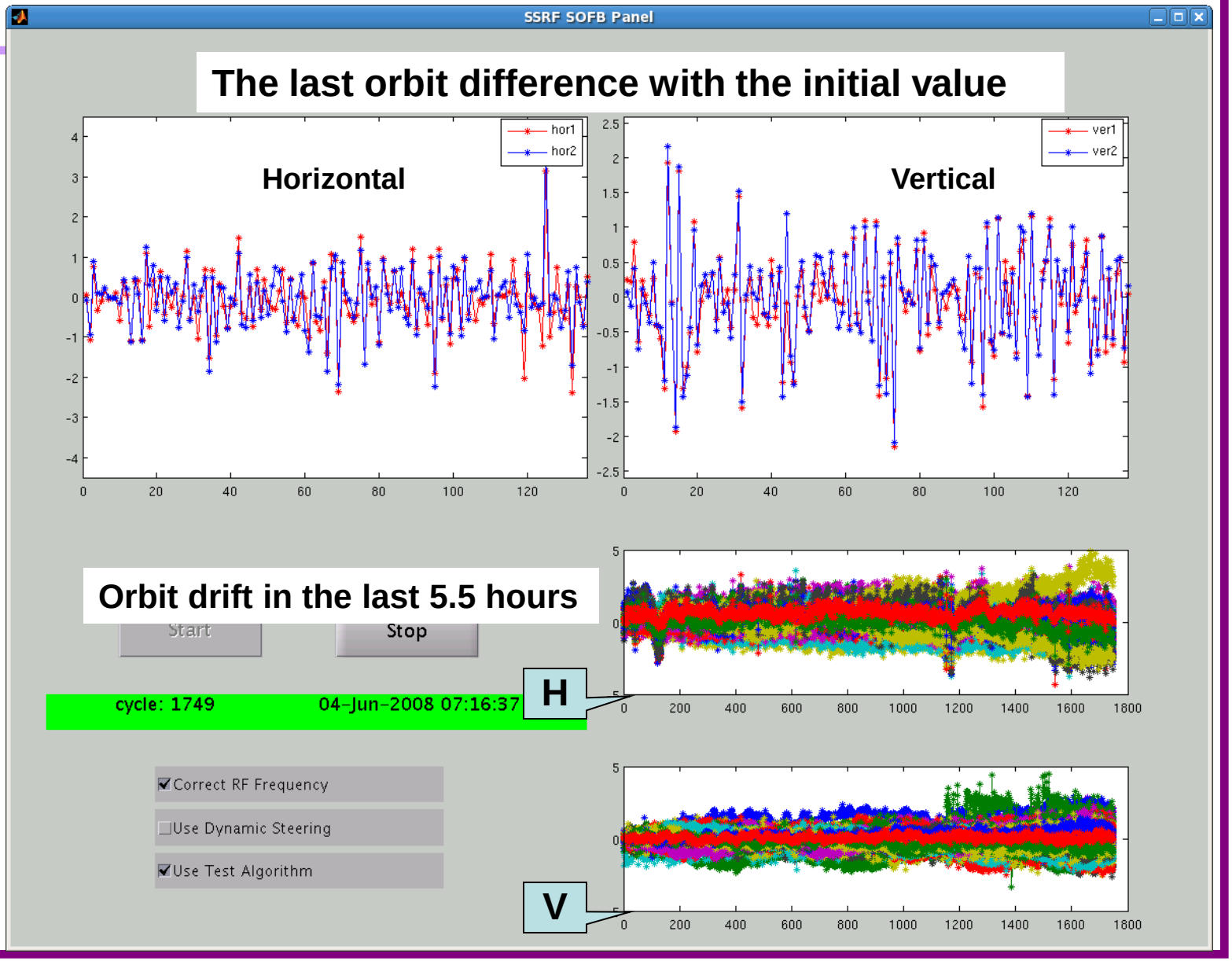


SOFB results on 2008.06.04

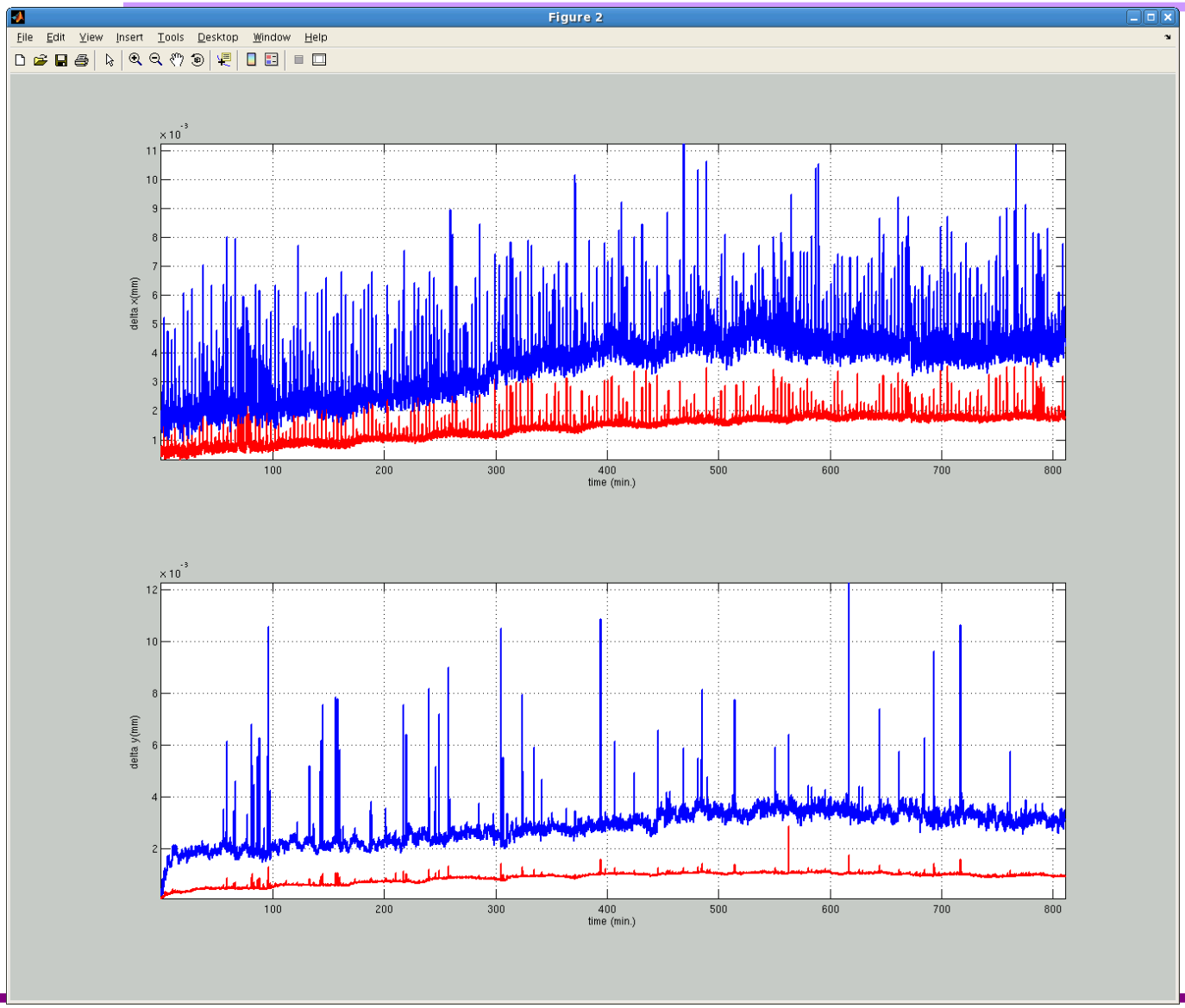
Total SOFB time: 5.5hours

BPM number: 135

Eigen Values: 60/60 (H/V)



SOFB results started from 2008.12.01 23:00, 14 hours



80个BPM

Eigen values

H : 40

V : 60

x/y (rms)

~ 2 μm /1μm

Operation Status

In 2009

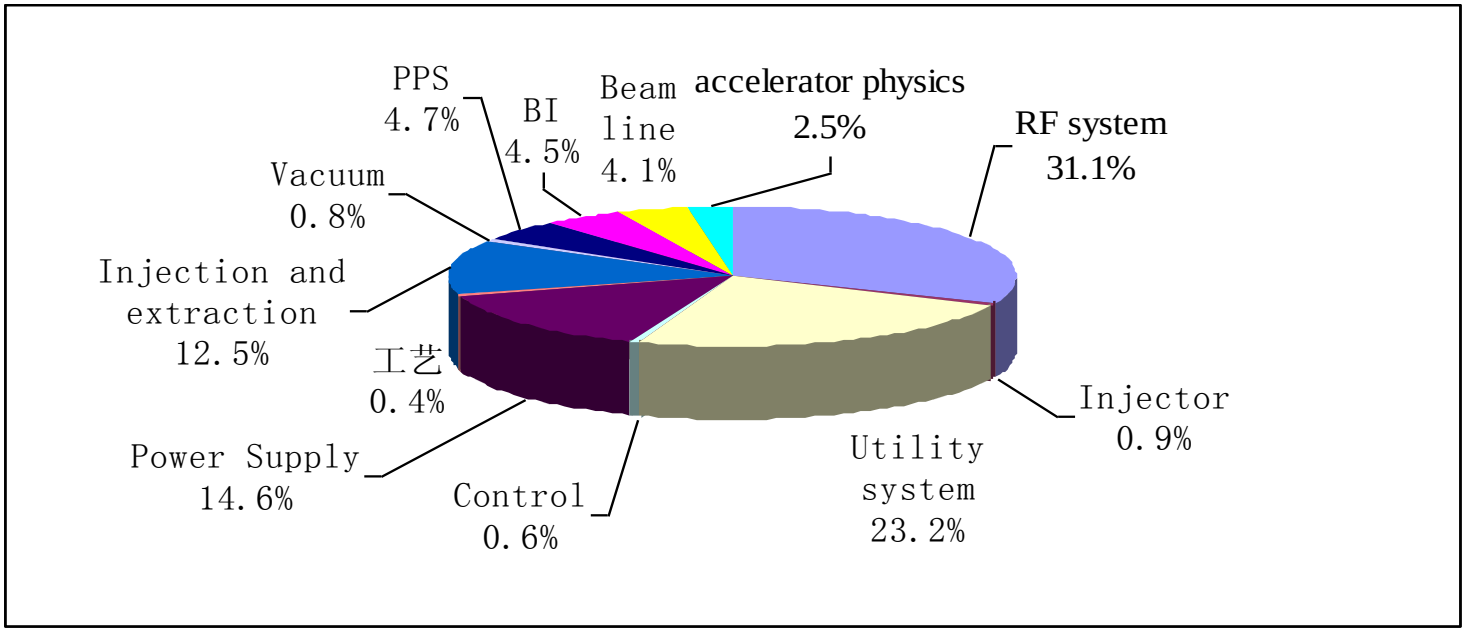
Accelerator Operation Status

- 2305 hours for machine study
- 4317 hours for beam line
  - 2620 hours for beam line commissioning
  - 2093 hours for user time operation
- 372 hours hardware failure
- 1286 hours for maintenance

Machine Statistics for user operation

- Total time : 2093 hours
- Hardware failure: 120.6 hours
- Availability: 94.6%
- MTBF: 31 hours
- MDT: 1.6 hours

Hardware failure statistics



Summary

- **The SSRF accelerator commissioning was carried out rapidly, smoothly and successfully;**
- **Some problems we have to solved in the future operation**
  - **BPM jump;**
  - **Decrease hardware failure time;**
  - **Increase MTBF > 50 hours;**
  - **SOFB and FOFB work together;**
  - **Top up Operation;**


THANKS