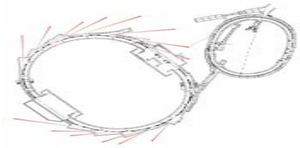
SPEAR3 Commissioning



J. Safranek for the SPEAR3 commissioning team

- SPEAR built 1972 e+/e- collider at Stanford/SLAC
- 1989 became dedicated light source
- 2003 – SPEAR3 installation
  - Complete rebuild, maintaining geometry for photon beamlines
  - Low emittance optics, ε_x = 18 nm
  - I = 500 (100) mA
  - 11 beamlines; 7 insertion devices

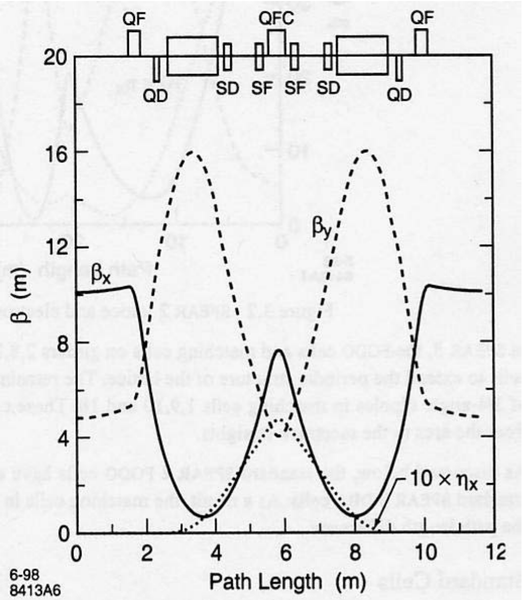
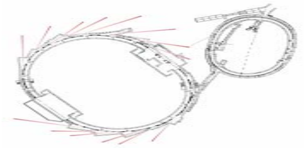
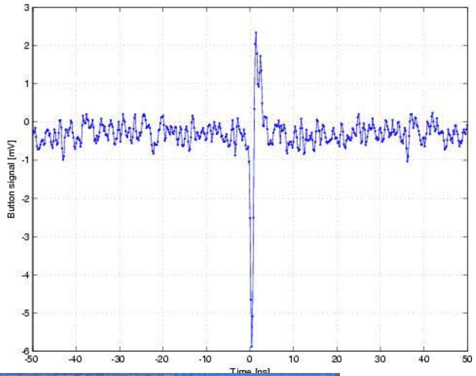


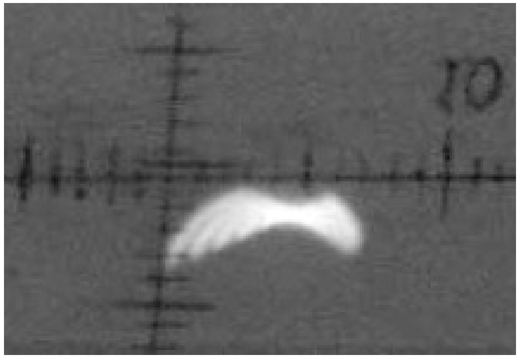
Figure 3.3 SPEAR 3 cell optics.

Commissioning milestones

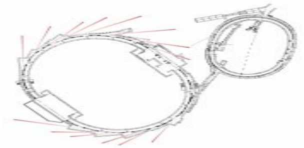


- **2003:**
- **1 April, SPEAR2 removal begins**
- **9 December, Transport line commissioning begins**
- **10 December, First beam to SPEAR**
- **15 December, First accumulation**
- **2004:**
- **22 January, 100 mA stored**
- **8 March, First photons**
- **15 March, Start of operations**





Commissioning Team



SSRL:
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D. Keeley
N. Kurita
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A. Terebilo
C. Wermelskirchen
M. Widmeyer
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+ SSRL staff

PAL:
M. Yoon
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J. Byrd
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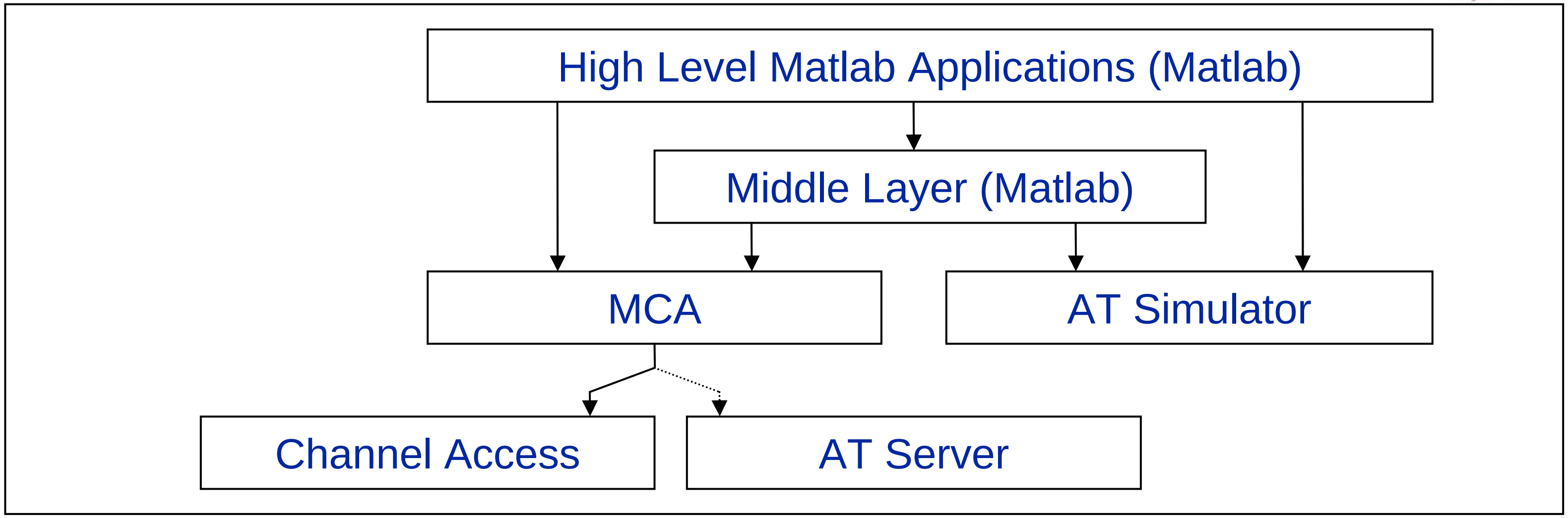
T. Scarvie
C. Steier
SOLEIL:
L. Nadolski
NSRRC:
H.P. Chang
C.C. Kuo
H.J. Tsai
NSLS:
S. Krinsky
B. Podobedov

DESY:
W. Decking
SLS:
M. Boege
ESRF:
A. Ropert
Australian Synch. Proj.:
M. Boland
E. Tan
CAMD:
M. Fedurin
P. Jines
APS:
K. Harkay
V. Sajaev

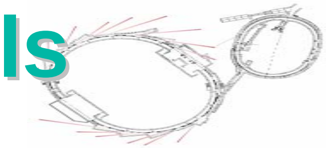
Matlab Software Tools



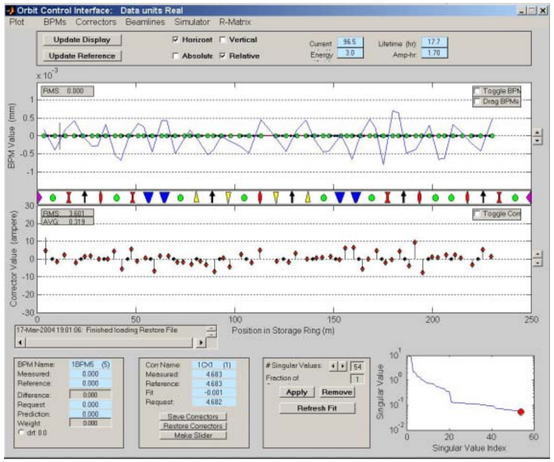
Matlab Toolboxes for Accelerator Simulation and Control:

- AT – Accelerator Simulation
- Middle Layer Software – Accelerator Control + Physics Functions
- MCA – Matlab to EPICS Library
- LOCO – Accelerator Calibration

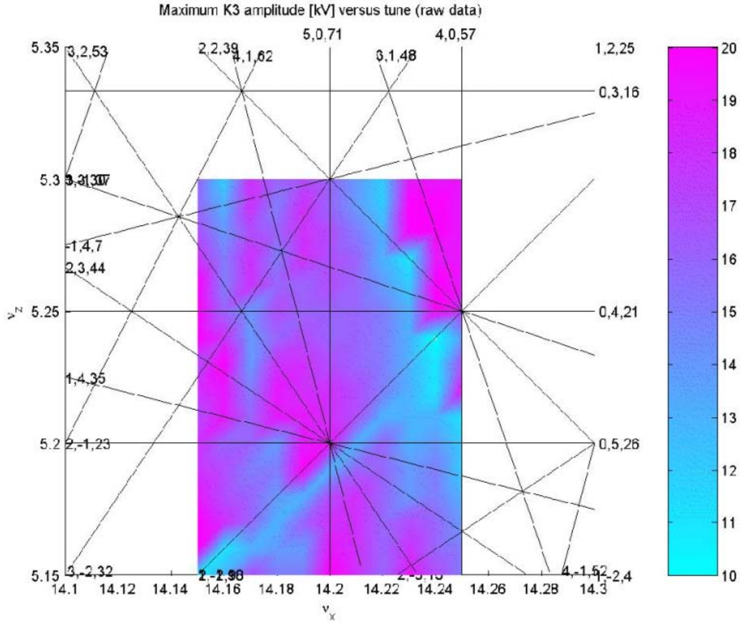
MATLAB commissioning tools



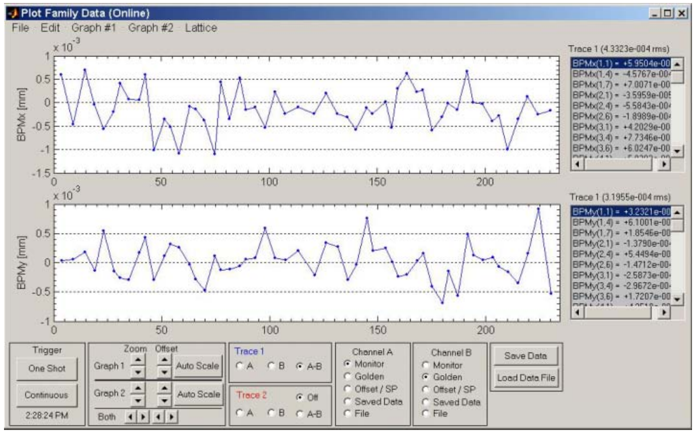
- **GUIs**
  - **Orbitgui**
  - **Plotfamily**



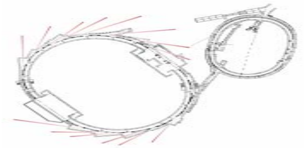
- **Fast scripting language for commissioning shifts**
- **Numerical algorithms and graphics for fast data processing**



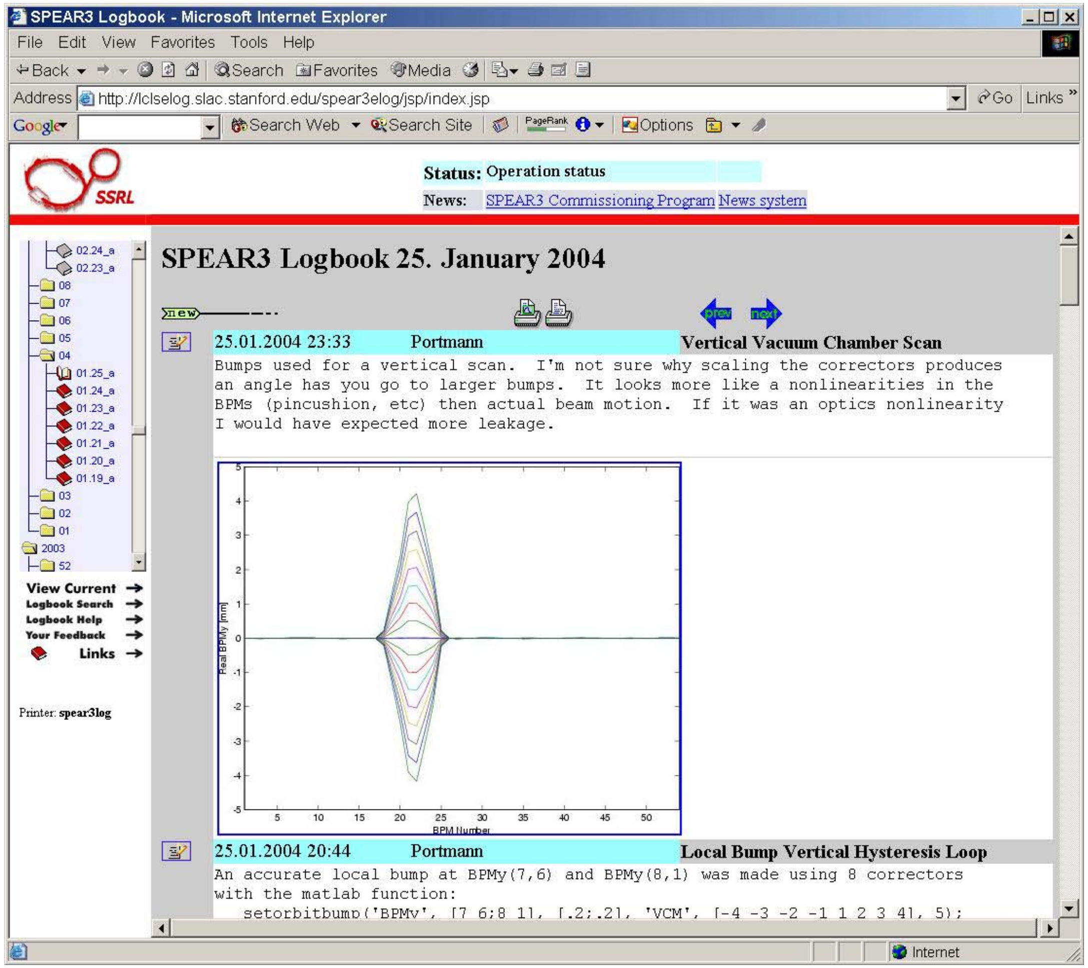
Dynamic aperture vs (ν_x, ν_y)



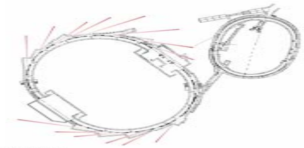
Electronic logbook



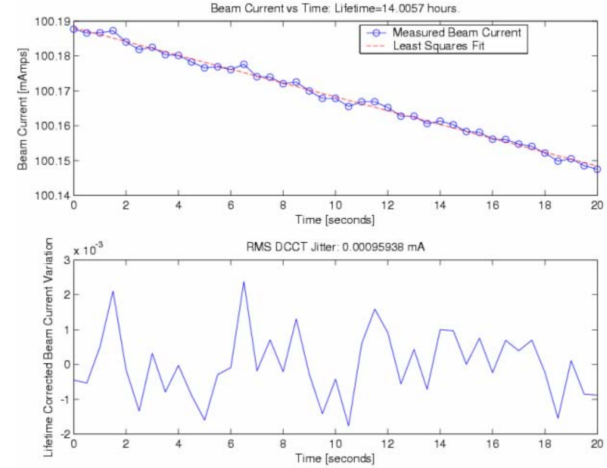
- Web-based, interactive browser
- Accepts graphics and text
- Searchable
- Backed up
- Authors: Kay Rehlich, Raimund Kammering, DESY
- Courtesy: Patrick Krejcik, SLAC



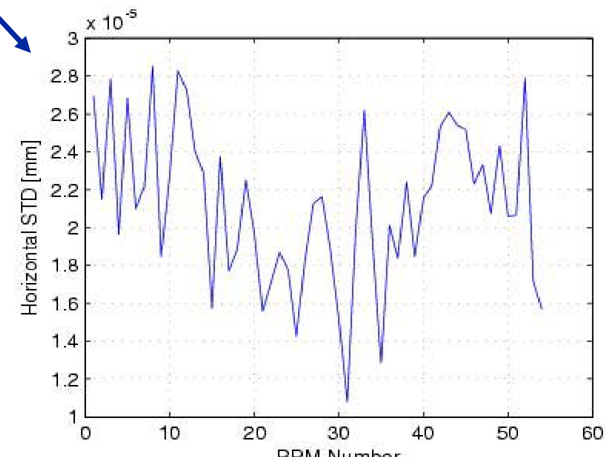
Diagnostics



- Bergoz DCCT, 1 μA in 1 second
- Bergoz on 54 BPMs
  - 4 kHz update
- Stripline tune driver
- Coming soon:
  - 112 BPMs
    - Echotek digital receivers
    - Turn-by-turn data
  - X-Ray pinhole camera
  - UV synchrotron light monitor
  - Scraper



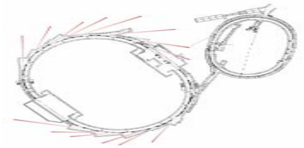
0.5 second DCCT data



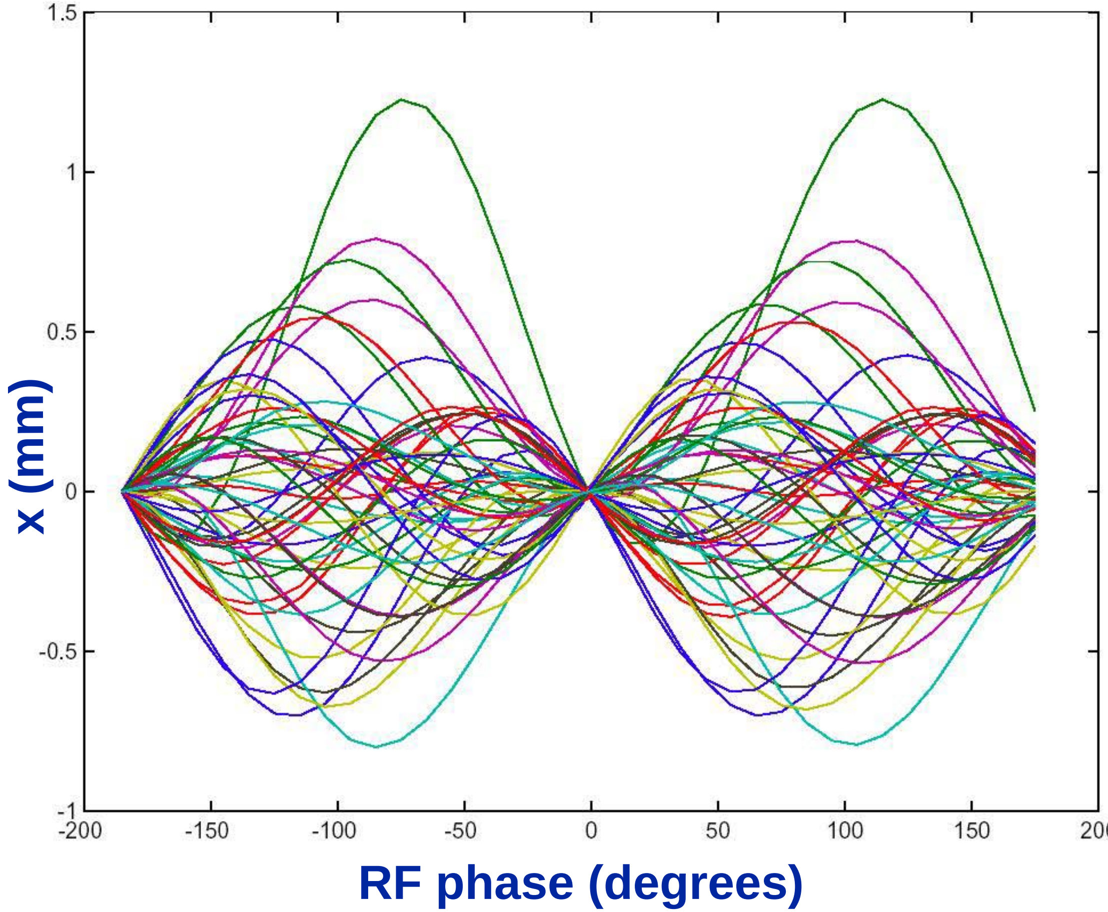
Orbit measurement:
20 nm in 0.5 second
~5 μm at 4 kHz

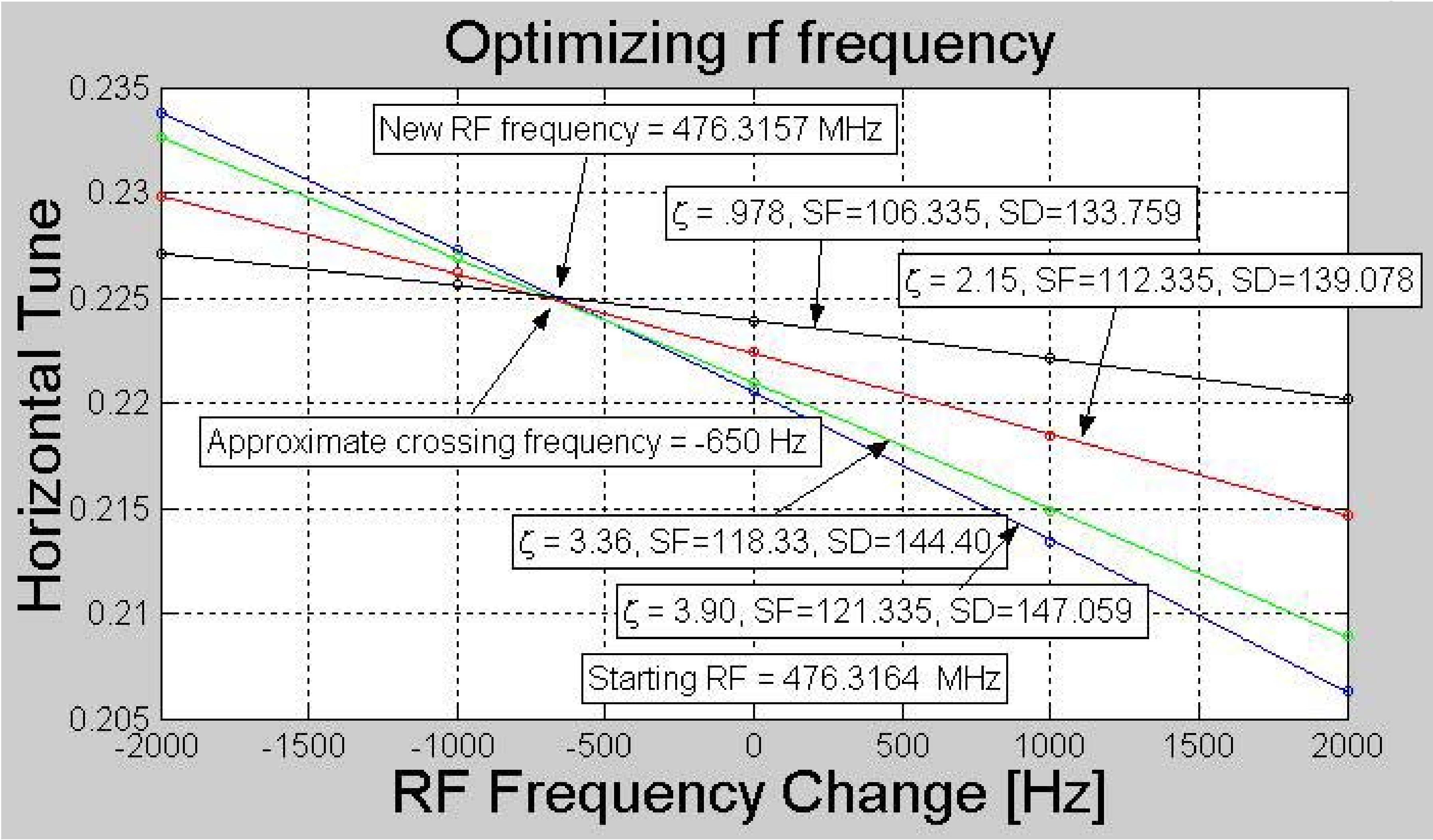
Tune driver

BPM IF frequency issue



- BPM troubles –
  - Fill-to-fill orbit not reproducible
  - Fill pattern dependence
  - Orbit dependence on RF phase
- Solution: unlock IF from RF frequency

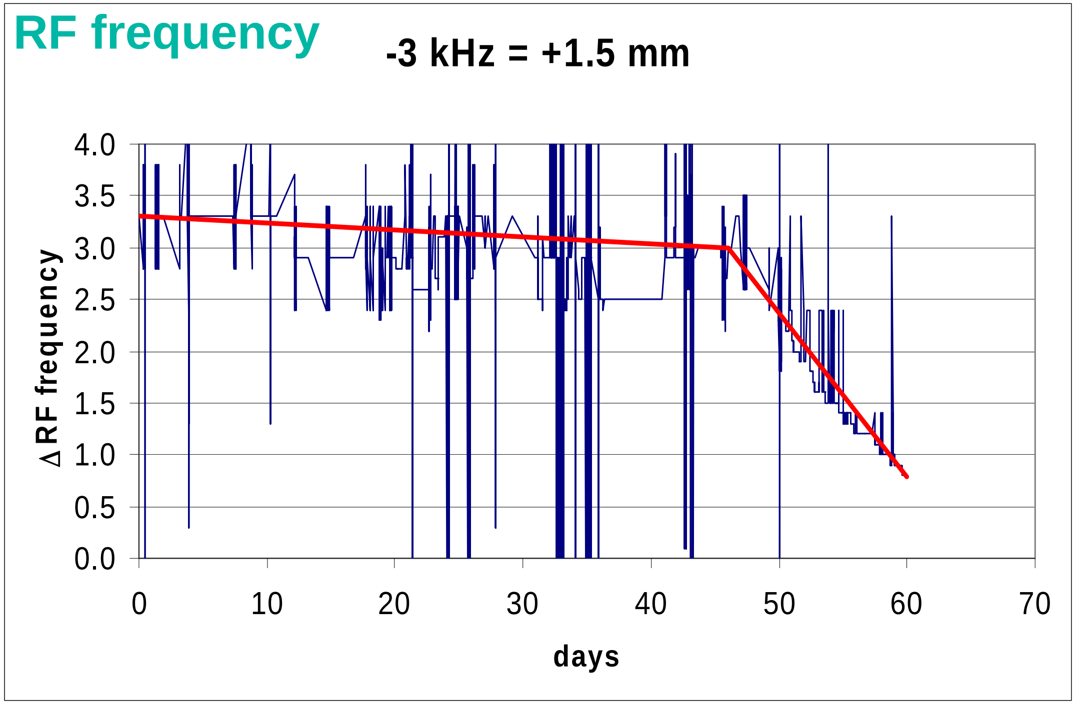


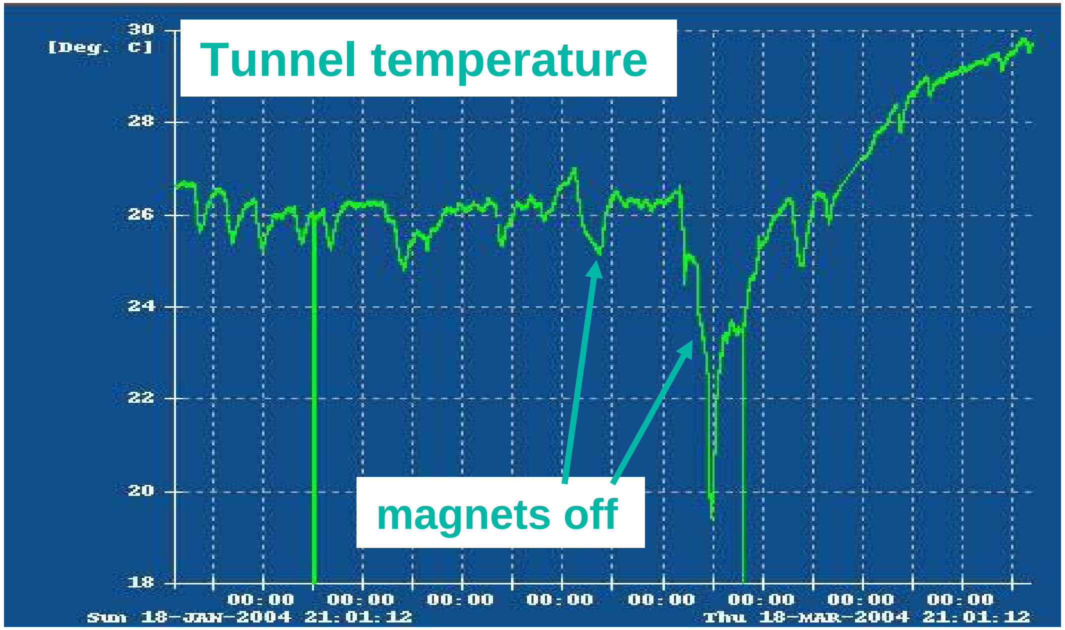


Find rf frequency that centers average orbit in sextupoles.

RF frequency, 60 days

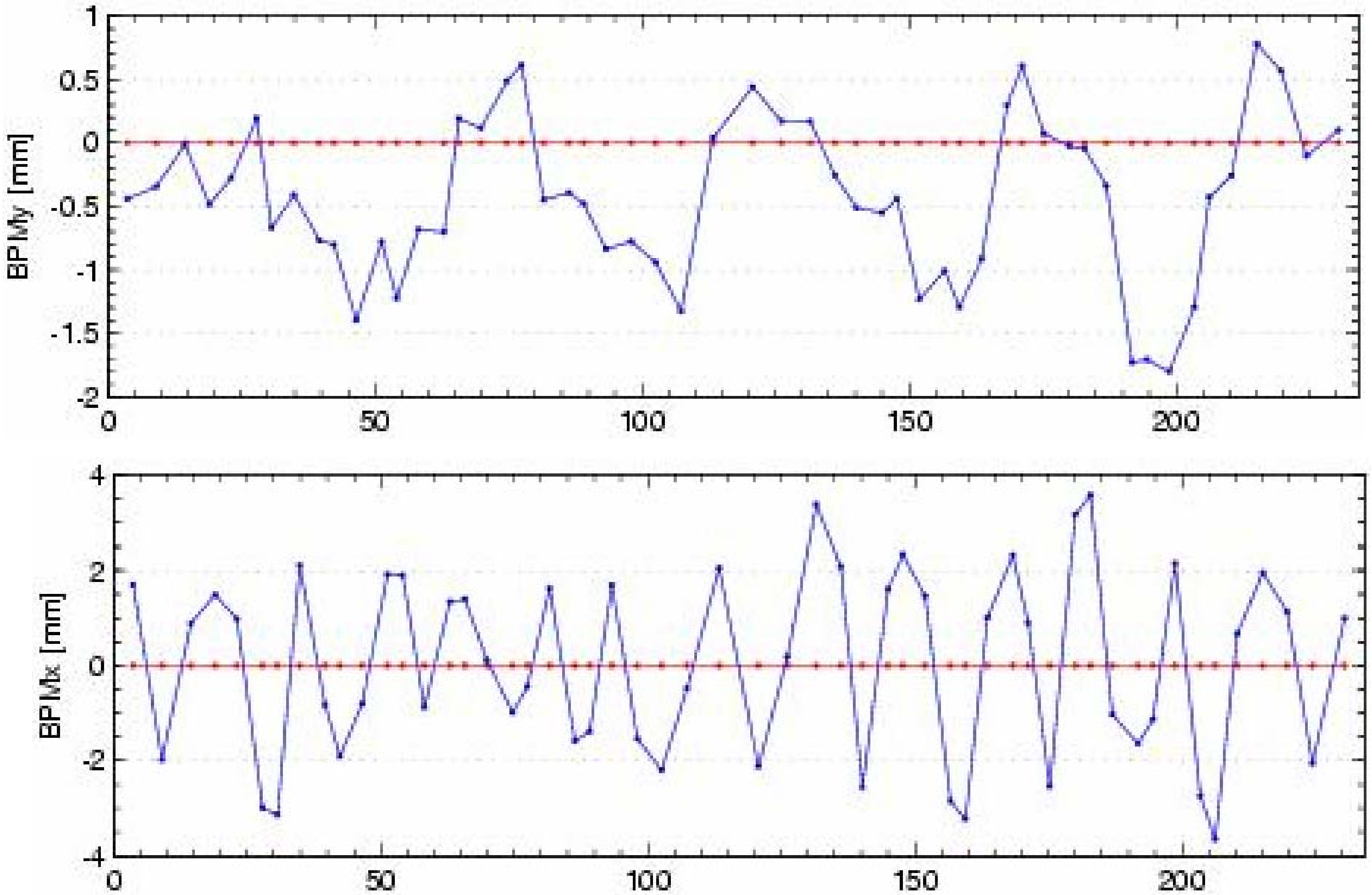
- RF frequency included in orbit correction/feedback
- In March temperature up, RF frequency down.



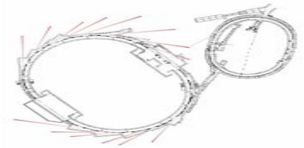


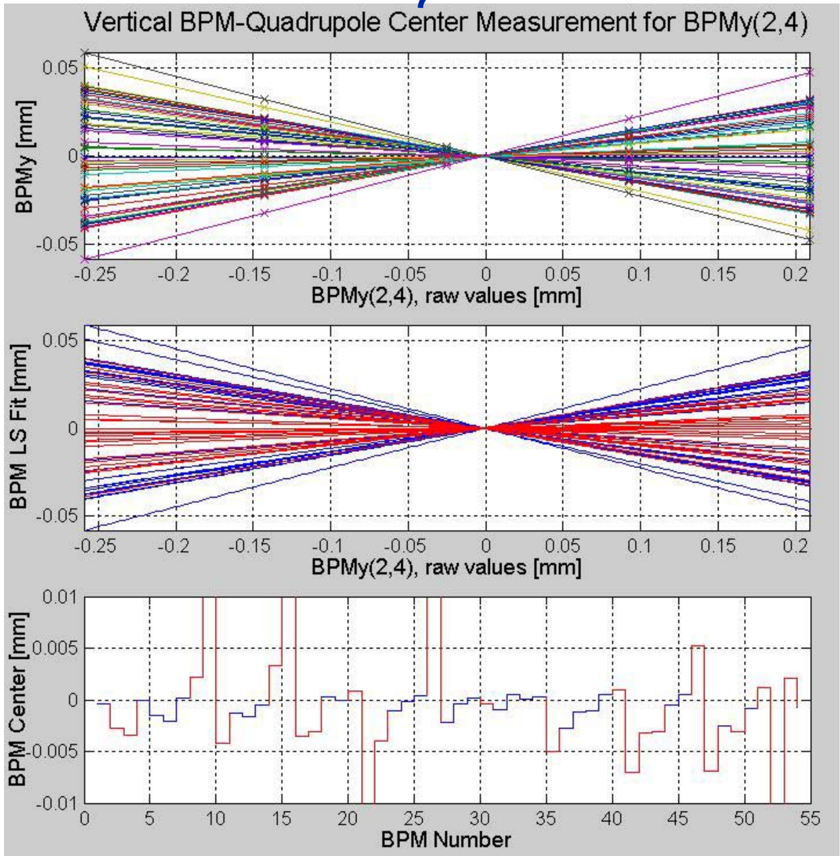
Closed orbit, steering magnets off

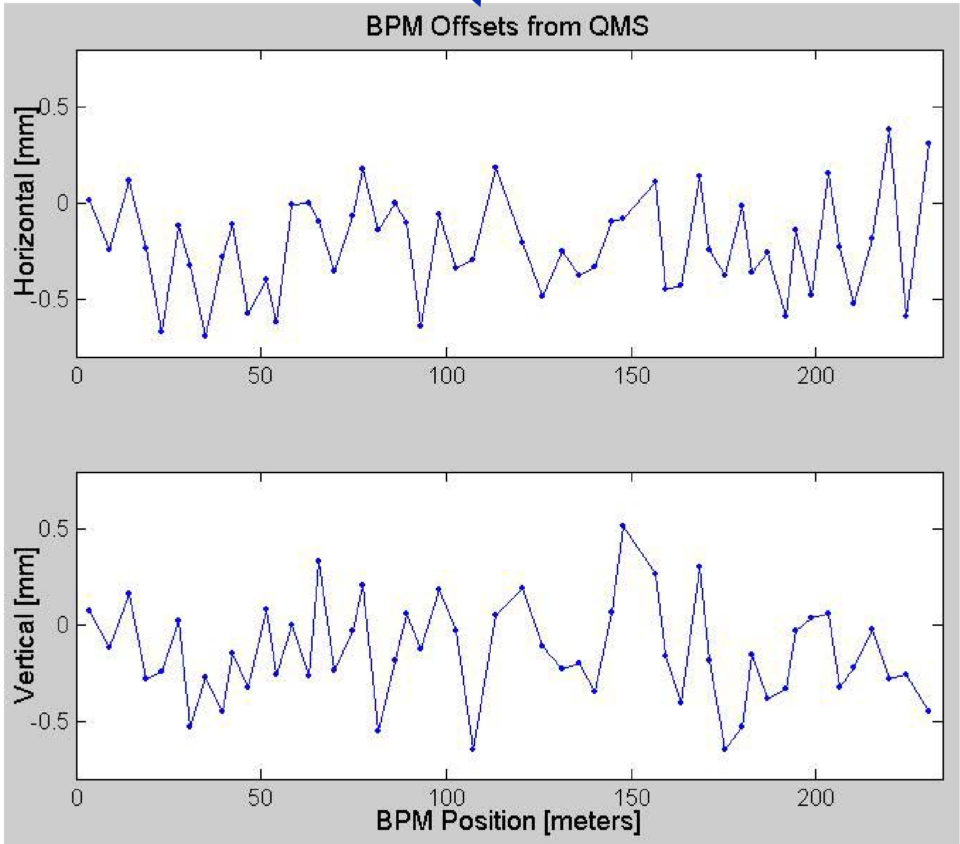
|y| < 2 mm, |x| < 4 mm



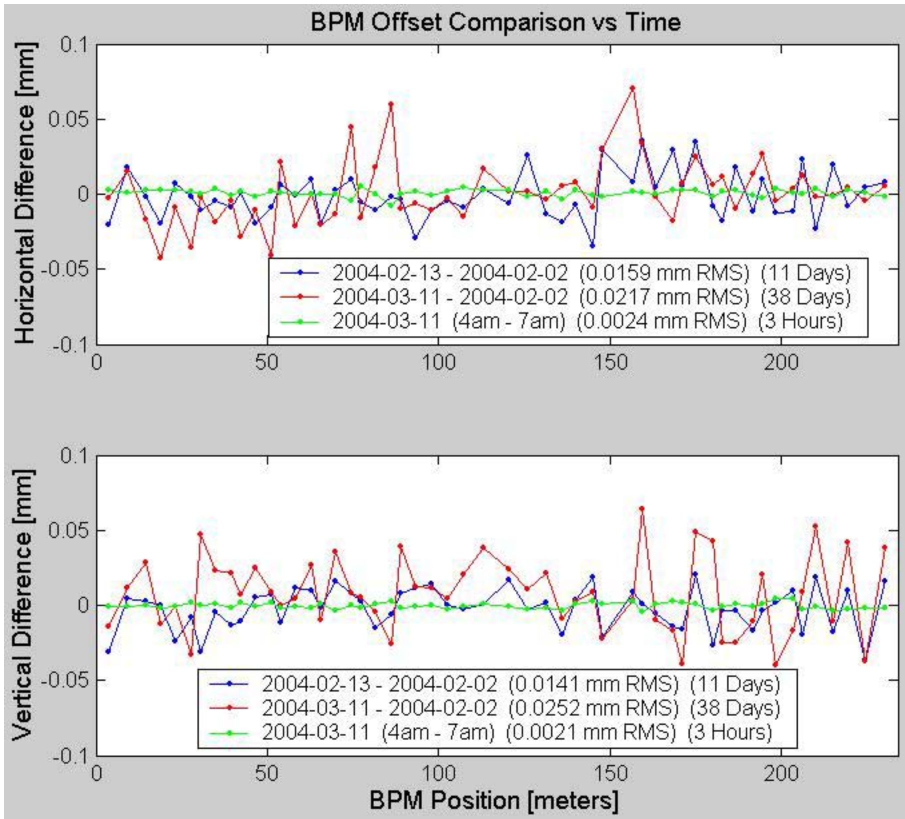
Beam-based alignment

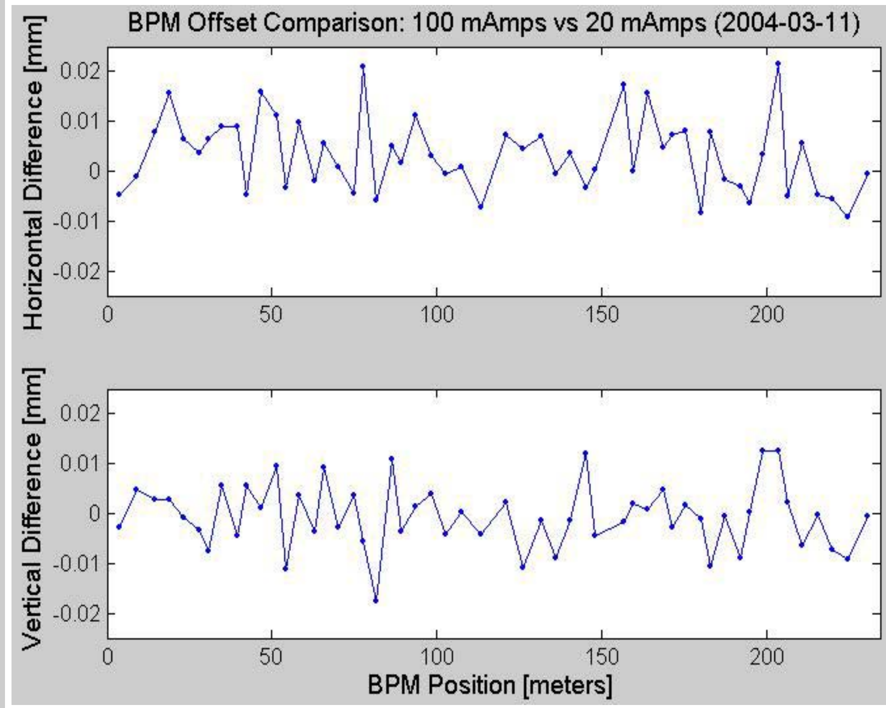




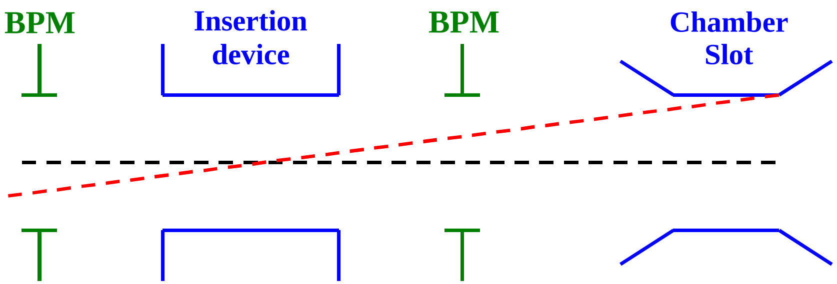


Beam-based alignment repeatability

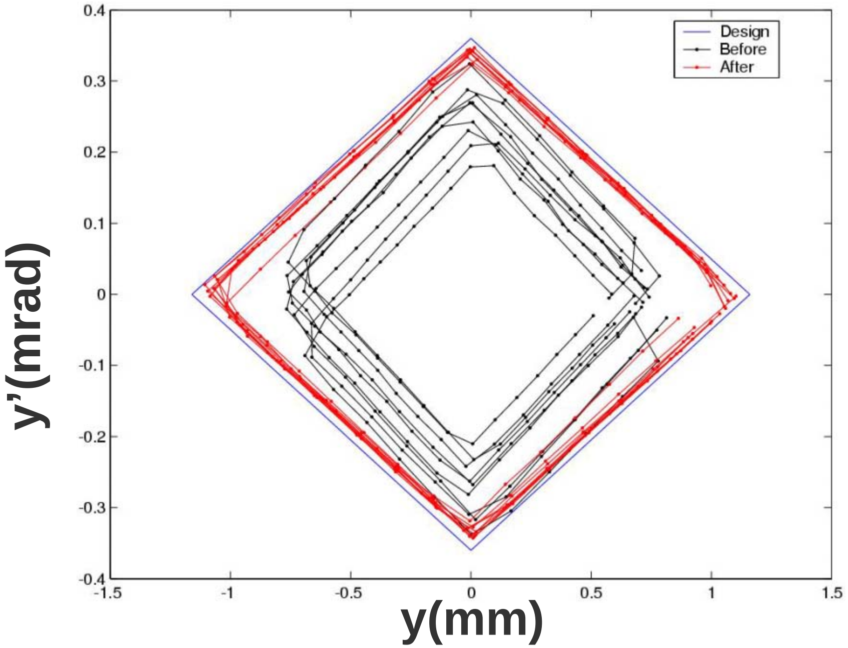


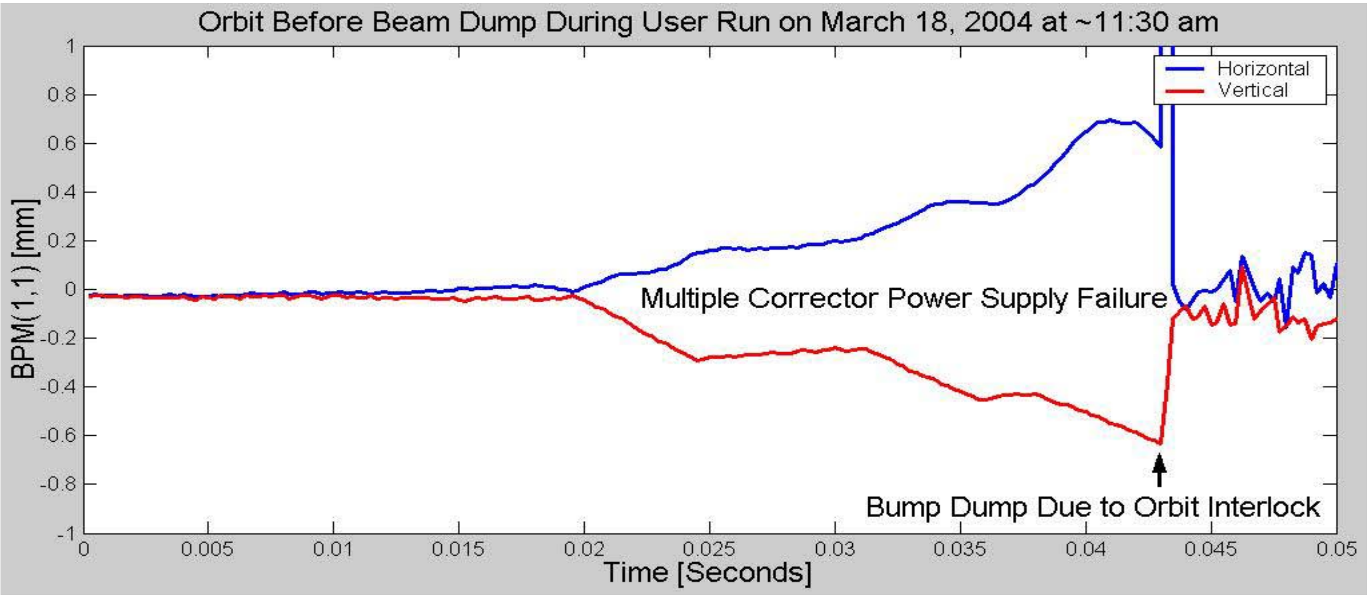


Orbit interlock

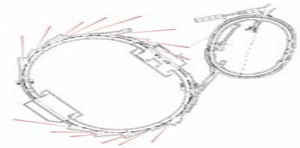


$$\frac{|y|}{y_{trip}} + \frac{|y'|}{y'_{trip}} < 1$$





SPEAR orbit stability



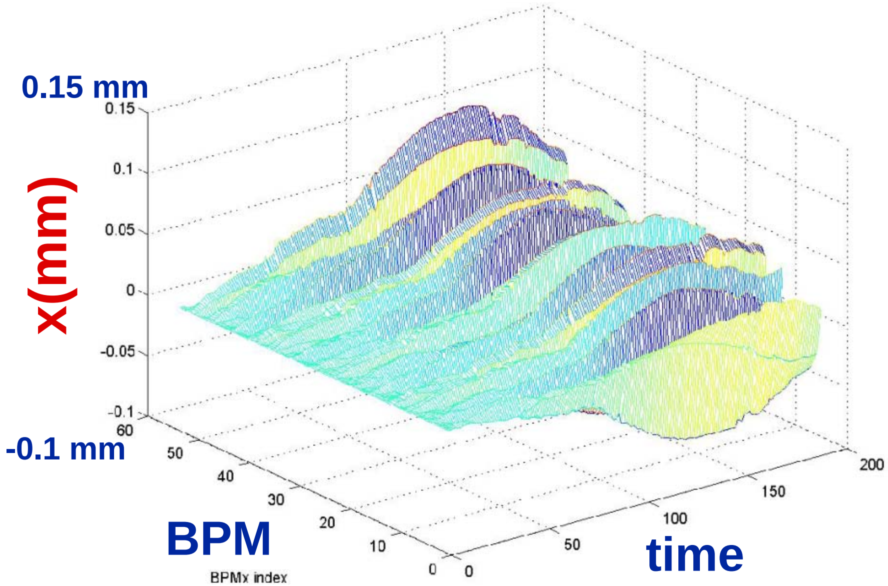
- Orbit stability specs.:
  - ~3-5 μm vertical
  - ~16-40 μm horizontal
- Girder frequencies ~20 Hz
- Invar struts supporting BPMs
- Most synchrotron radiation hits H2O-cooled masks
- Tight power supply stability specs.
- Bergoz BPM electronics
  - Low current dependence
  - Low fill pattern dependence
- Alignment < 150 μm

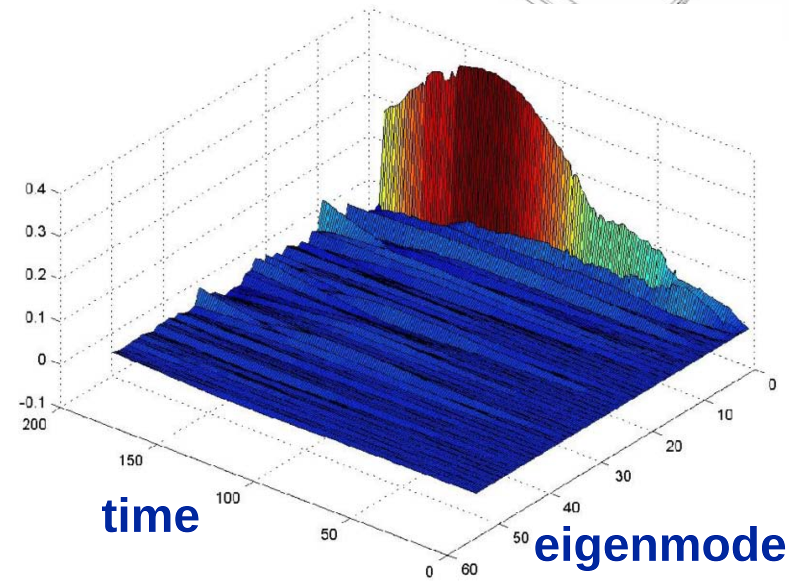
Table 3.23 RMS source point beam dimensions and stability requirements for SPEAR 3 (rms, 1% coupling).

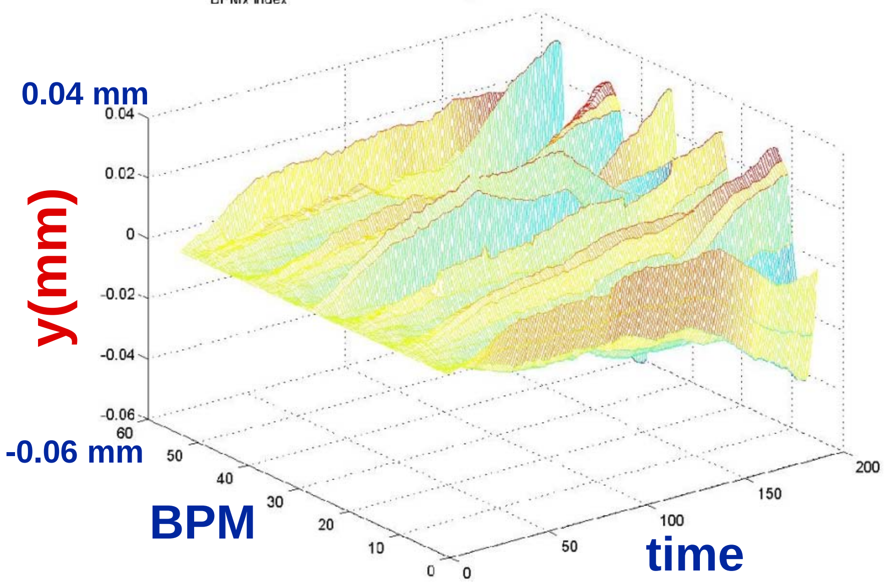
		Electron	Photon	10%
Dipole	σ_x (μm)	160	160	16
	$\sigma_{x'}$ (μrad)	236	mrads	< mrad
	σ_y (μm)	51	51	5
	$\sigma_{y'}$ (μrad)	11	136	14
ID-Wiggler	σ_x (μm)	435	435	43
	$\sigma_{x'}$ (μrad)	43	2–20 mrad	< mrad
	σ_y (μm)	30	30	3†
	$\sigma_{y'}$ (μrad)	6	136	14
ID-100 per und	σ_x (μm)	435	435	43
	$\sigma_{x'}$ (μrad)	43	43	4
	σ_y (μm)	30	30	3†
	$\sigma_{y'}$ (μrad)	6	15	1.5

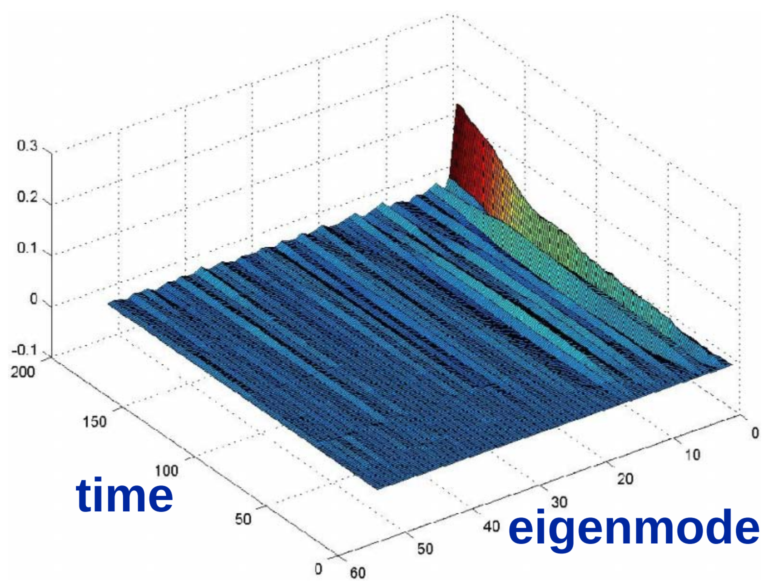
†. This requirement can be relaxed to 5 μm due to 50 μm minimum vertical spot size achieved from present focusing mirrors.

Orbit drift over 10 hours, feedback off



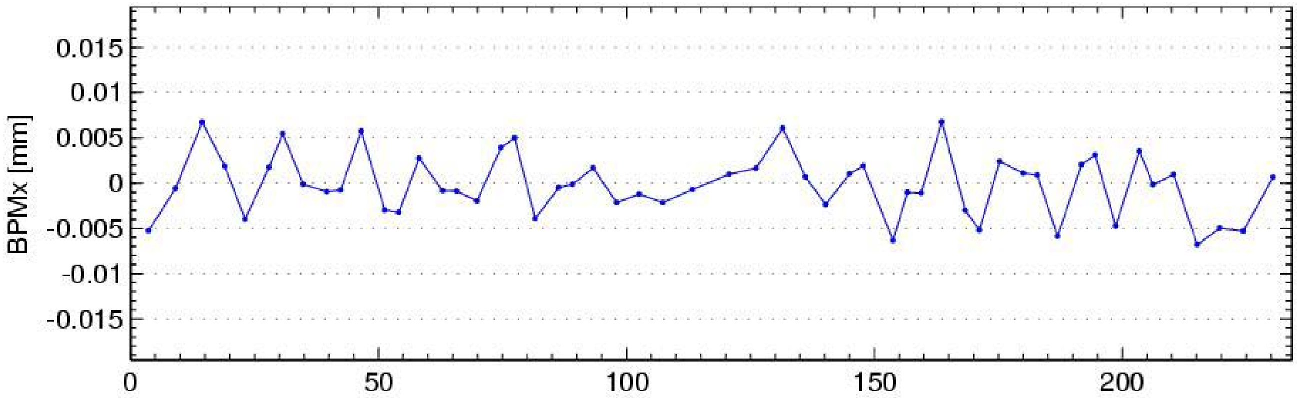




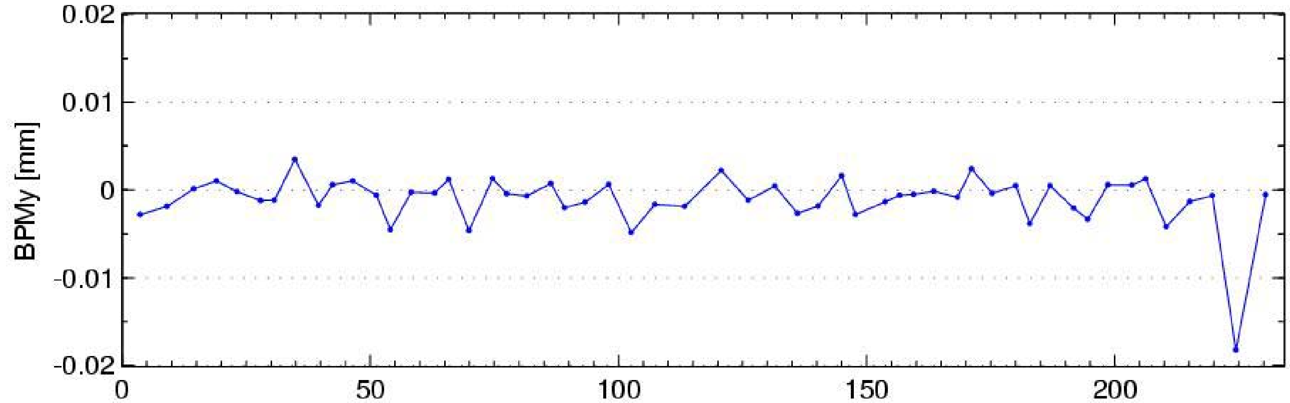


x(100mA)-x(50mA), BPM intensity dependence

- Δx_{rms} = 3.4 μm
- Δx_{peak} = 7 μm

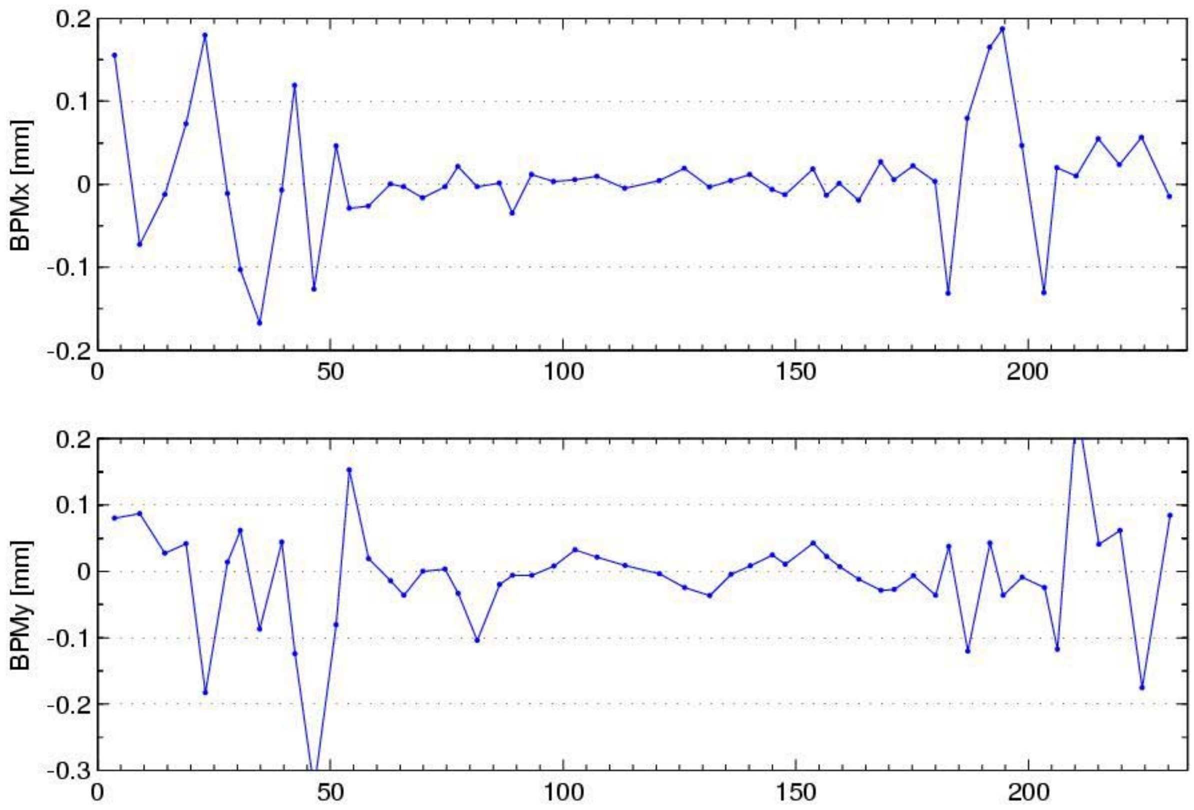


- Δy_{rms} = 3.0 μm
- Δy_{peak} = 18 μm

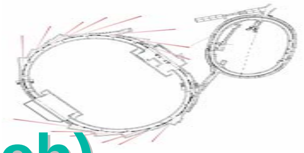


x(84mA)-x(1mA), BPM intensity dependence
476 MHz rf noise on ½ BPMs

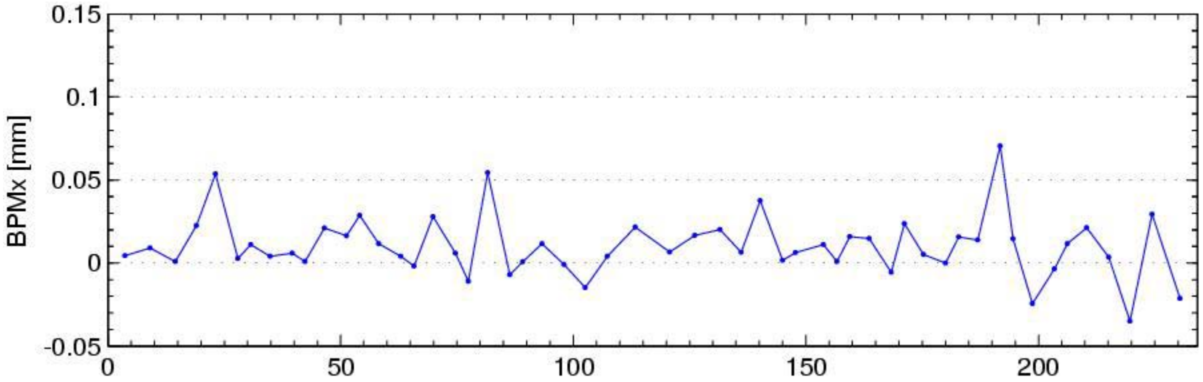
- Δx_{rms} = 69 μm
- Δx_{peak} = 190 μm
- Δy_{rms} = 84 μm
- Δy_{peak} = 310 μm



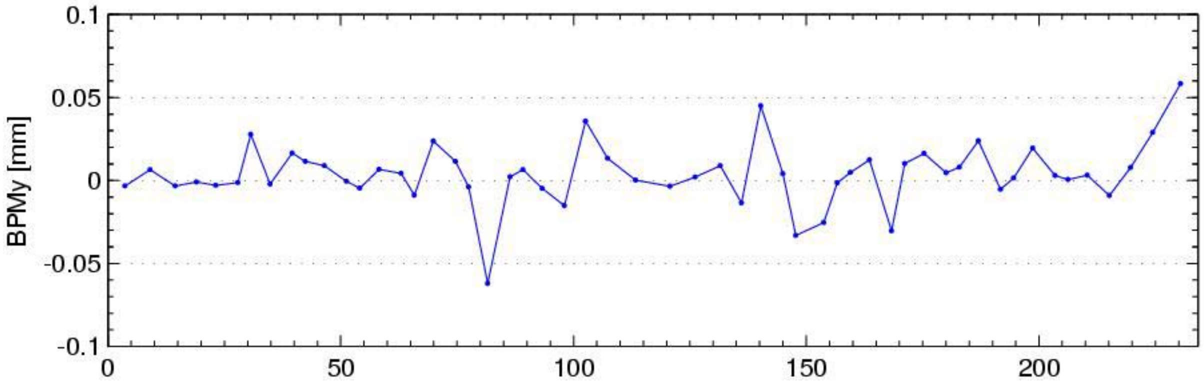
BPM fill pattern dependence
x(16mA, single bunch)-x(16mA, multibunch)



- Δx_{rms} = 18 μm
- Δx_{peak} = 70 μm



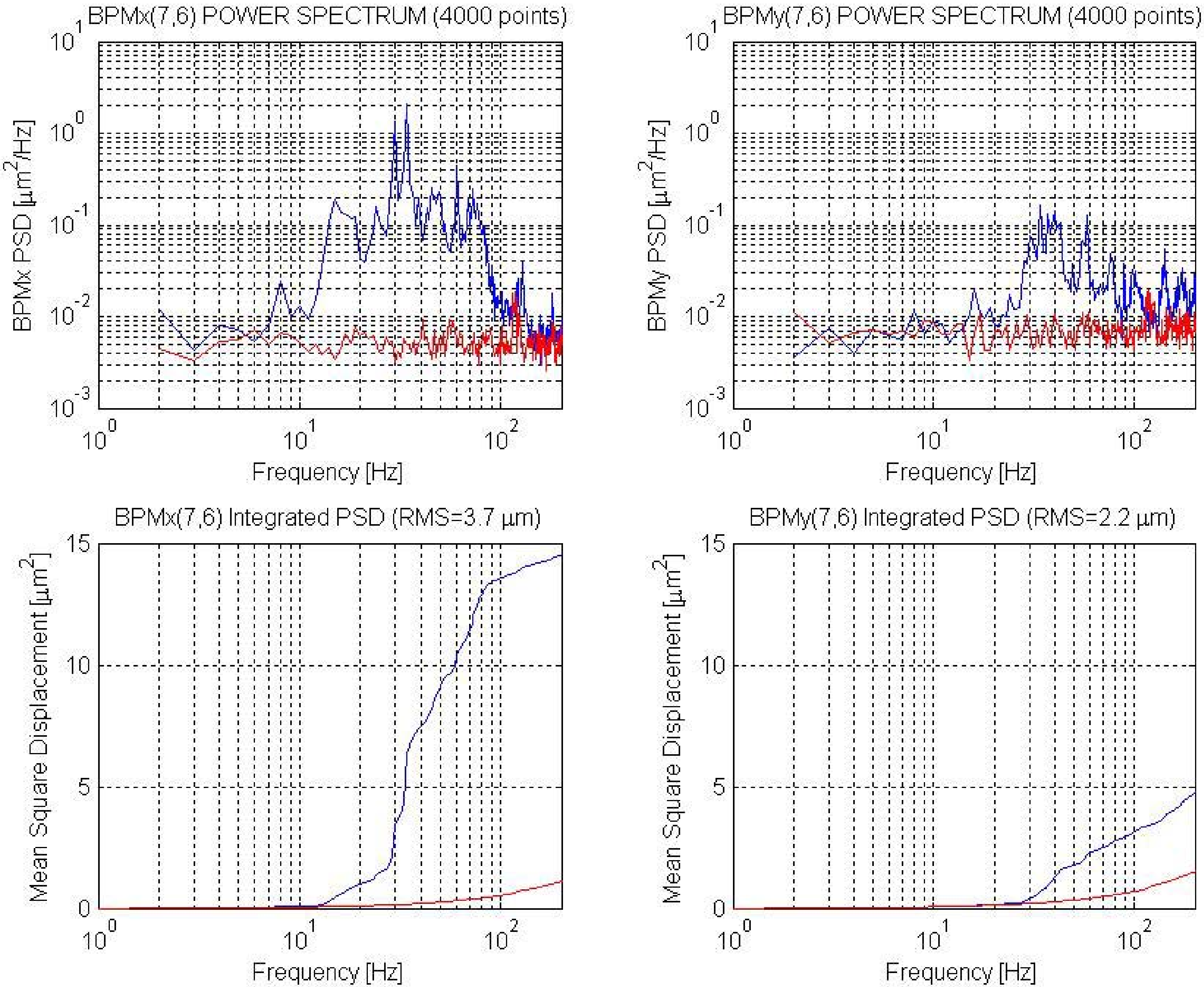
- Δy_{rms} = 18 μm
- Δy_{peak} = 60 μm



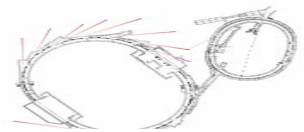
BPM PSD

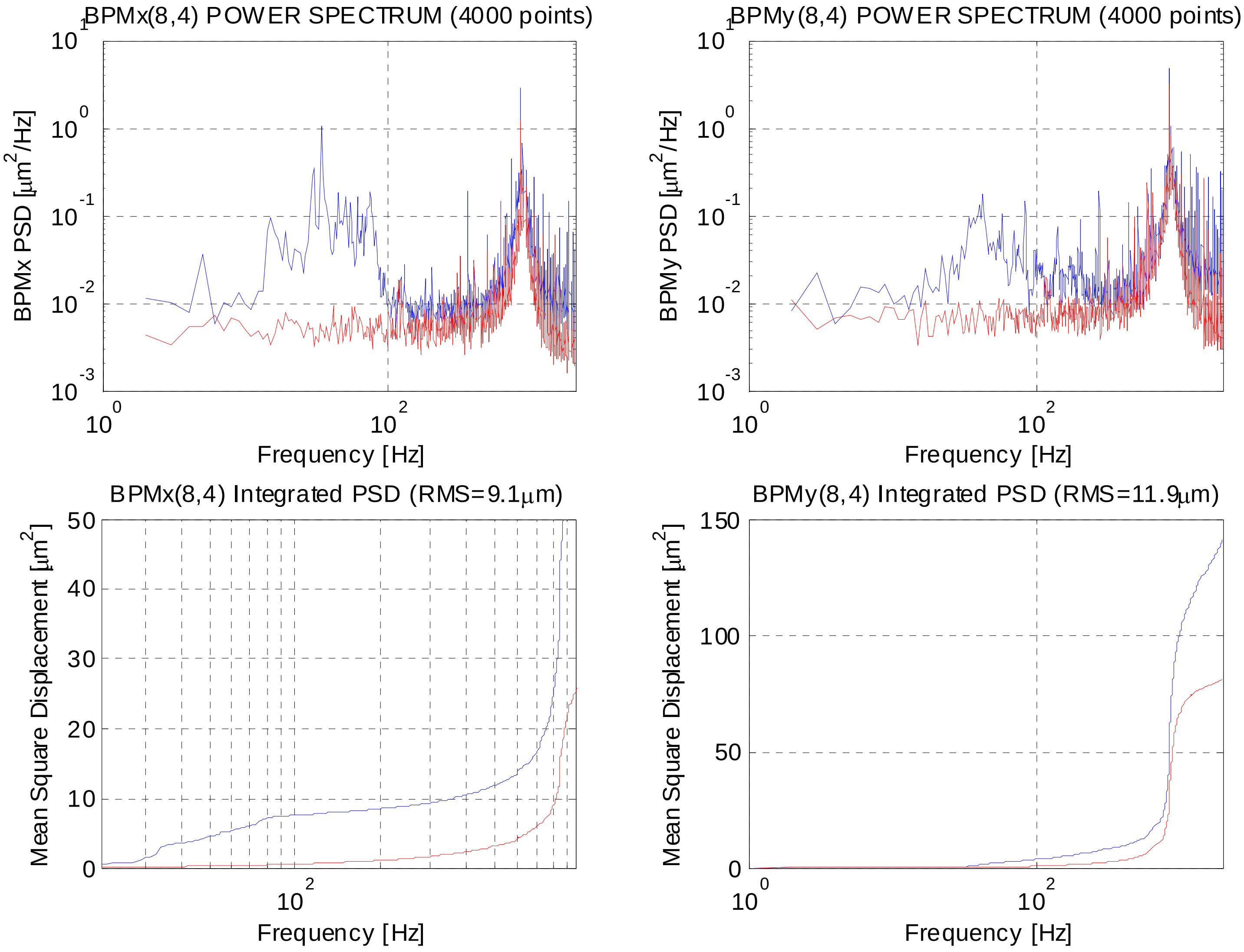
Blue: orbit motion

Red: BPM noise floor



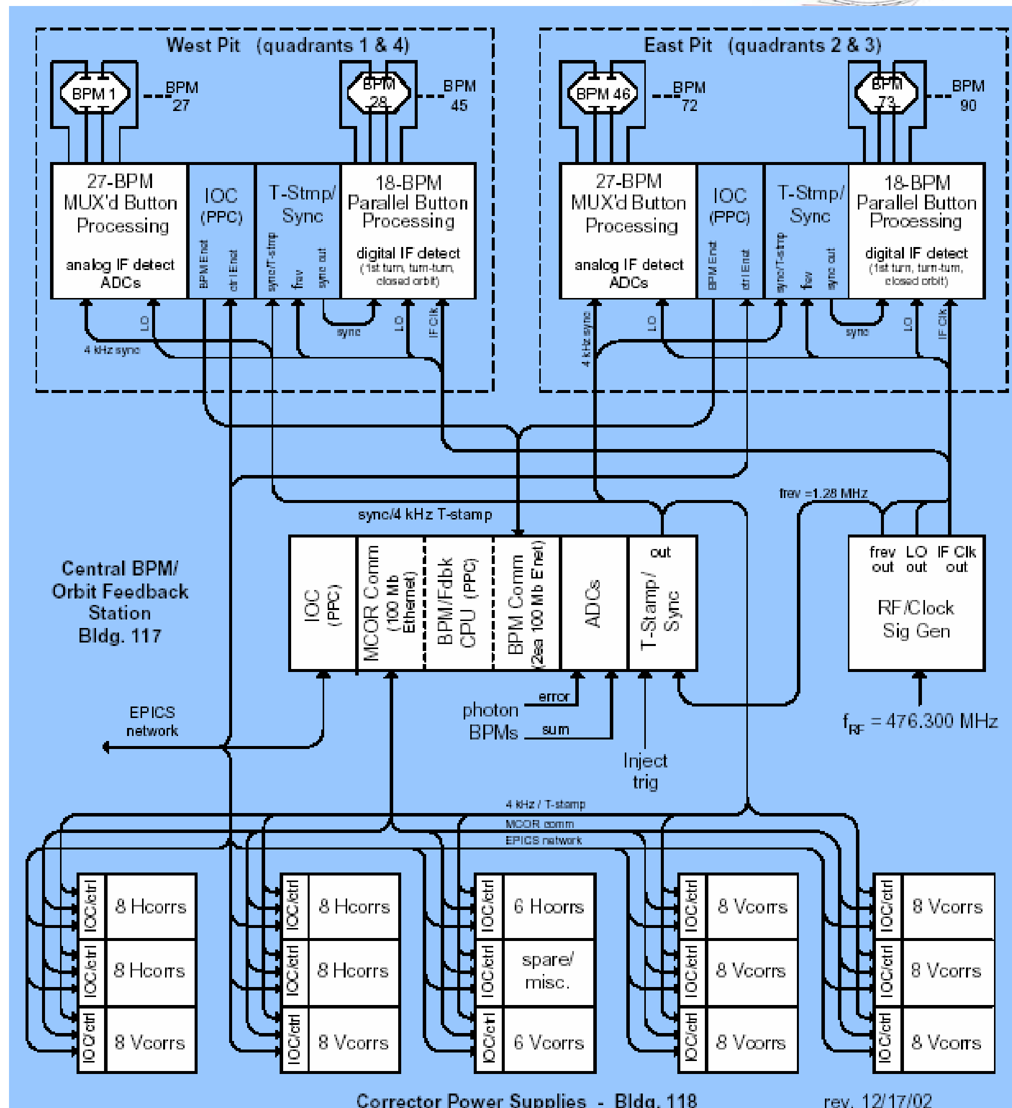
BPM PSD with ν_s noise



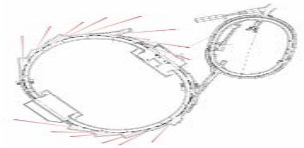


Fast orbit feedback

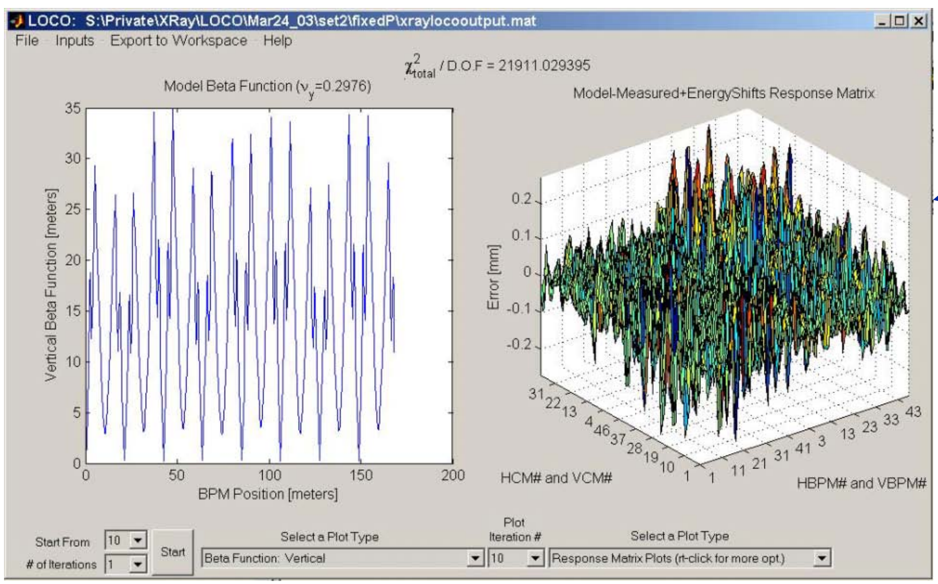
- Digital feedback
- Includes electron and photon BPMs.
- 4 kHz cycle rate.
- ~200 Hz bandwidth



LOCO optics analysis code



- Calibrate/control optics using orbit response matrix
- Determined quadrupole gradients
  - β functions, η
  - Found .017 ν_y error from excess dipole focusing
- Corrected coupling
- Calibrated BPM gains, steering magnets
- Measured local chromaticity and transverse impedance



New MATLAB version of code

- rewritten from FORTRAN
- linked to control system
- linked to AT simulator

G. Portmann

Linear optics calibration method

The orbit response matrix is defined as

$$\begin{bmatrix} \vec{x} \\ \vec{y} \end{bmatrix} = M \begin{bmatrix} \vec{\theta}_x \\ \vec{\theta}_y \end{bmatrix}$$

The parameters in a computer model of a storage ring are varied to minimize the χ^2 deviation between the model and measured orbit response matrices (M_{mod} and M_{meas}).

$$\chi^2 = \sum_{i,j} \frac{(M_{ij}^{\mathrm{meas}} - M_{ij}^{\mathrm{model}})^2}{\sigma_i^2} \equiv \sum_{k=i,j} E_k^2$$

The σ_i are the measured noise levels for the BPMs; E is the error vector.

The χ^2 minimization is achieved by iteratively solving the linear equation

$$E_k^{new} = E_k + \frac{\partial E_k}{\partial K_l} \Delta K_l = 0$$

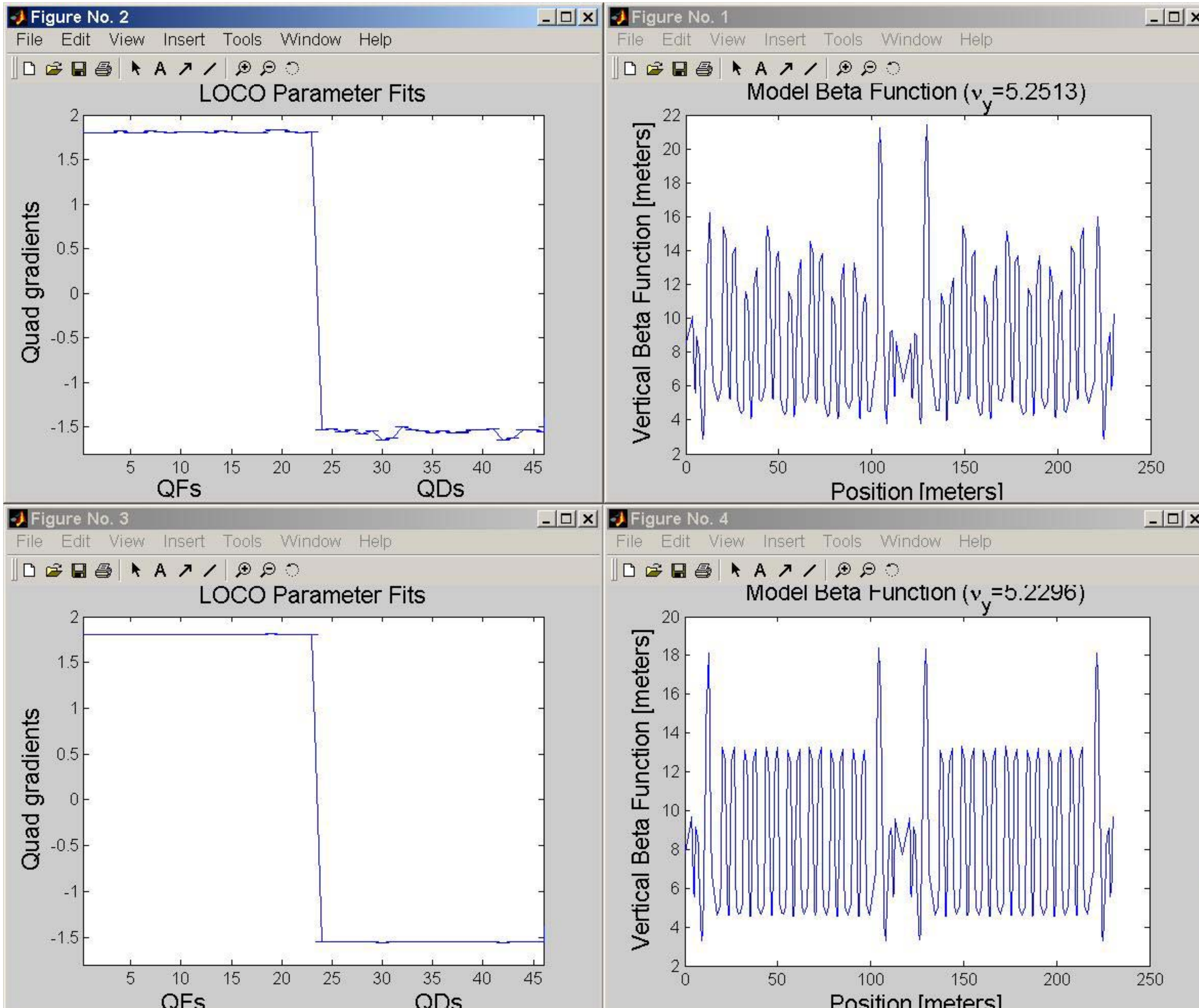
$$-E_k = \frac{\partial E_k}{\partial K_l} \Delta K_l$$

For the changes in the model parameters, K_l, that minimize $||E||^2 = \chi^2$.

ID focusing correction

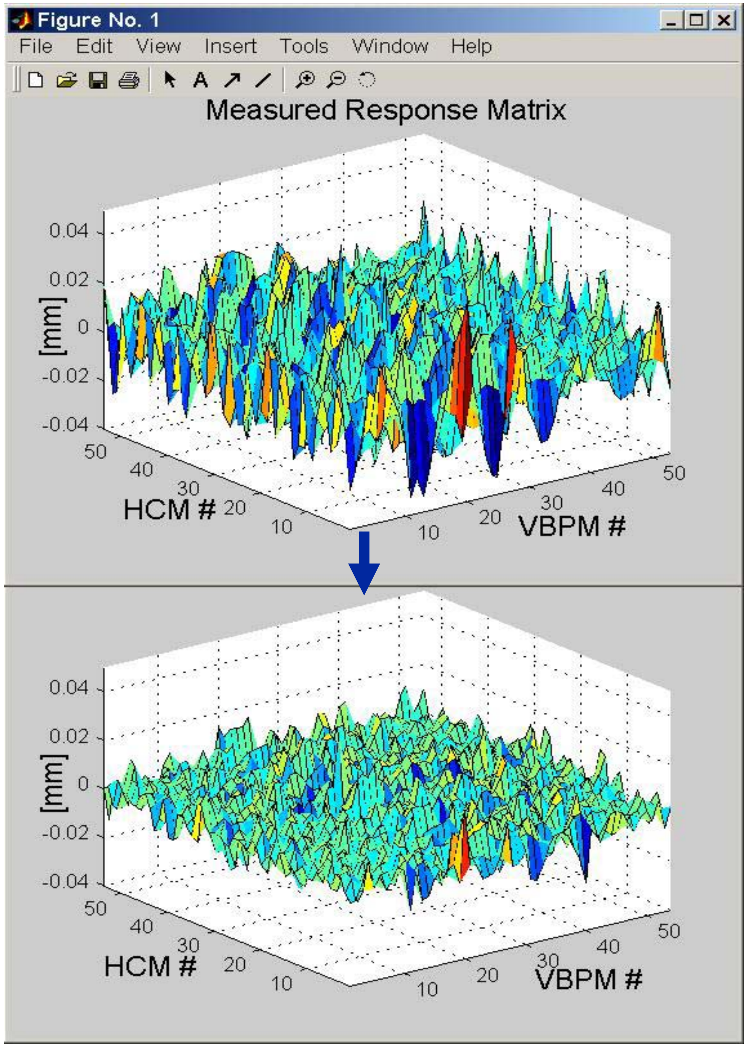
Before

After

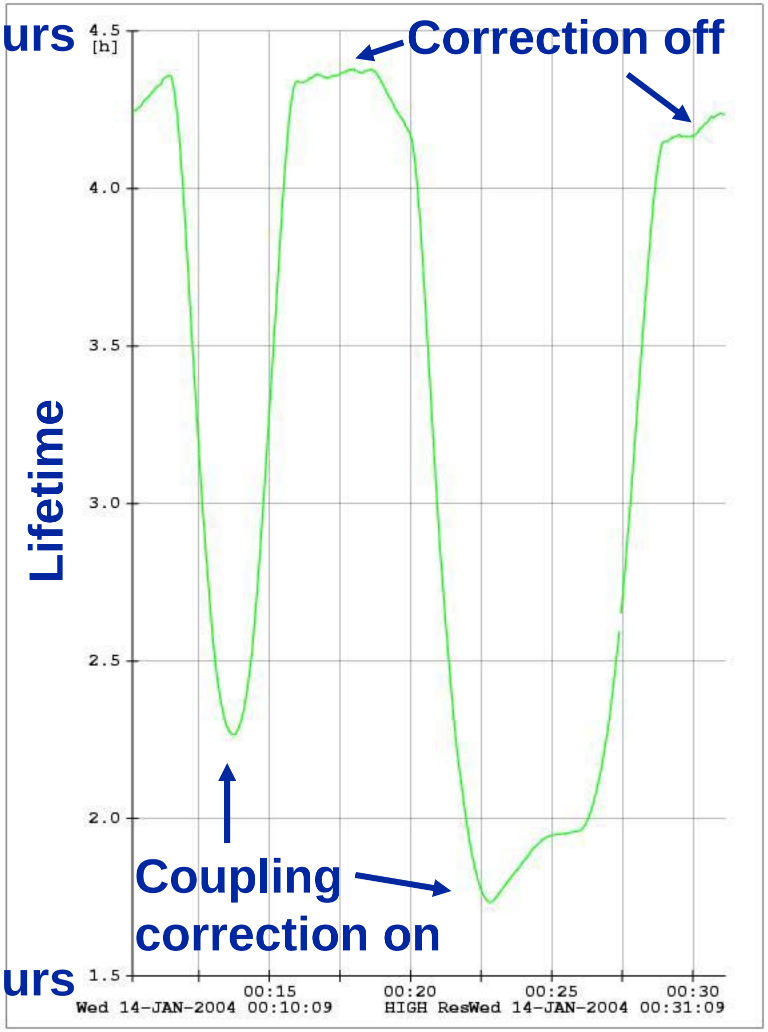


Coupling & η_y correction, LOCO

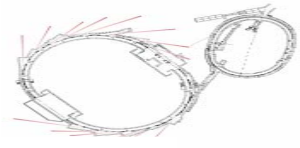
Minimize η_y and off-diagonal response matrix:

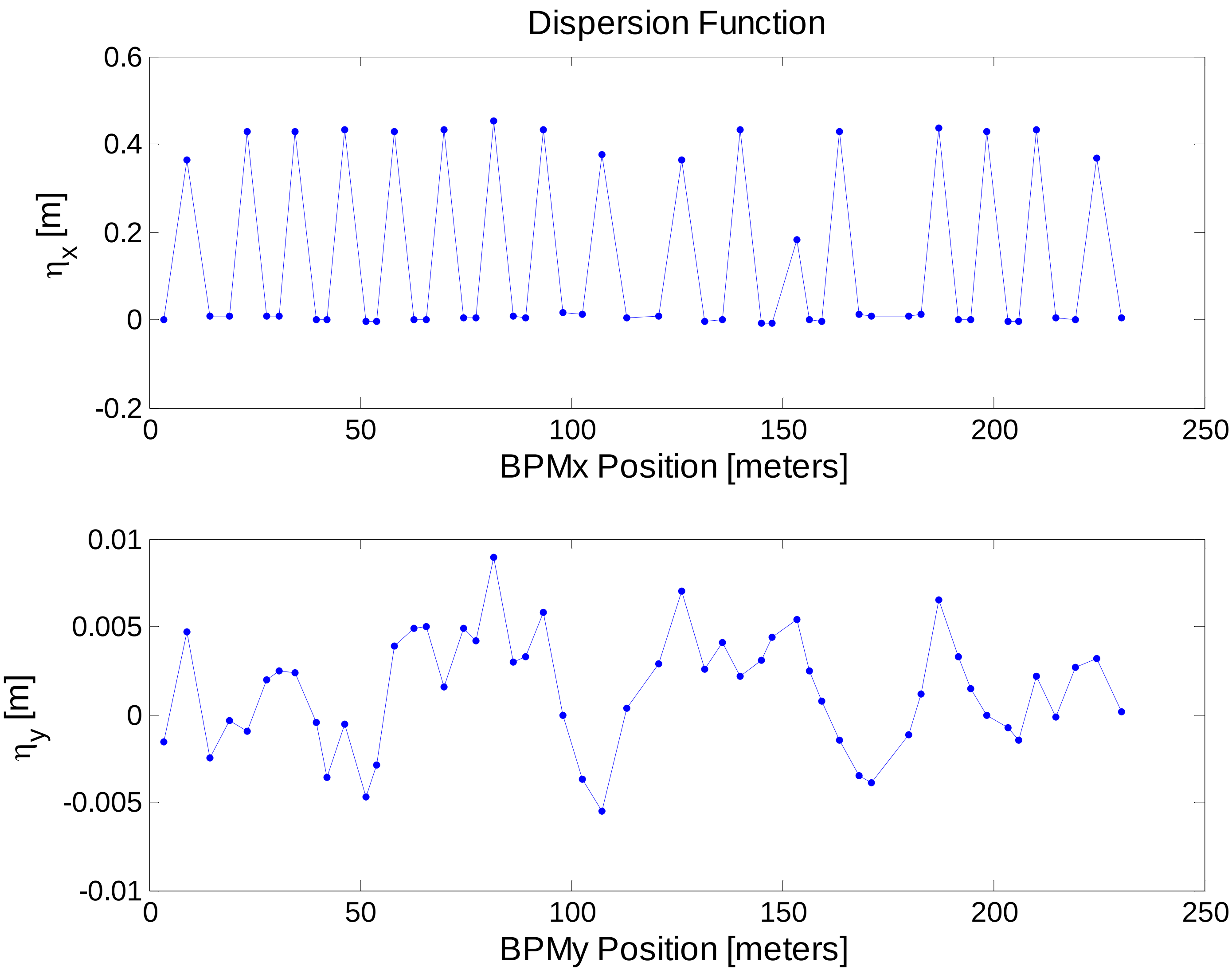


Lifetime, 19 mA, single bunch

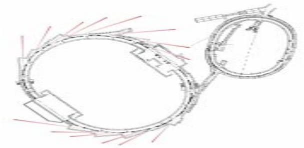


Measured dispersion





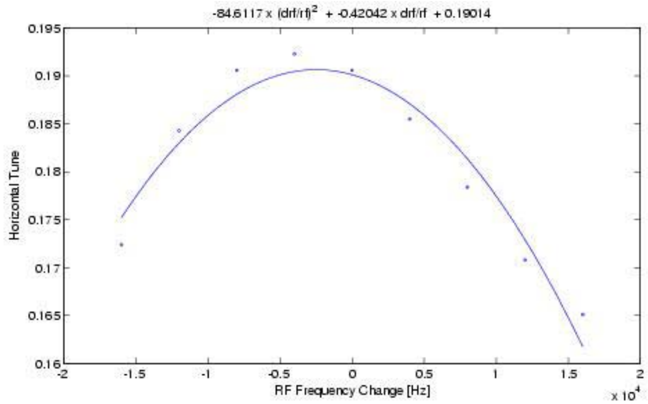
15

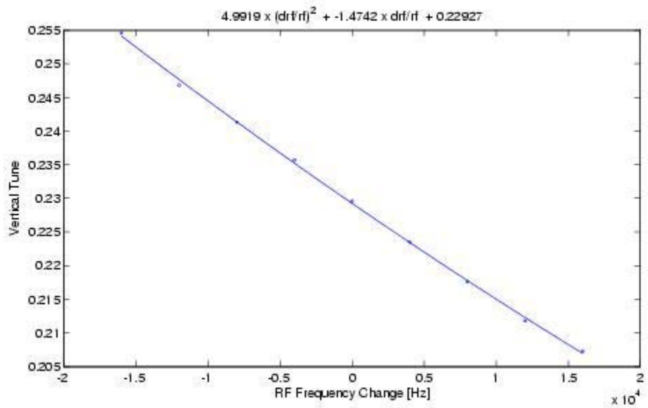


Chromaticity

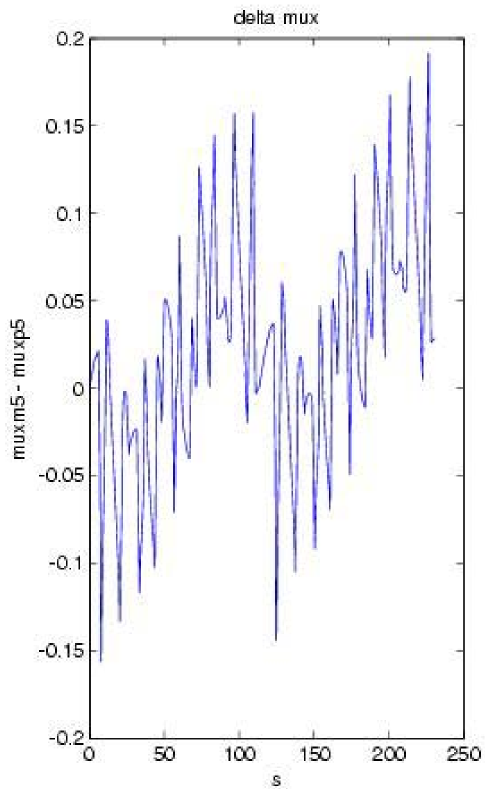
Nonlinear ξ:

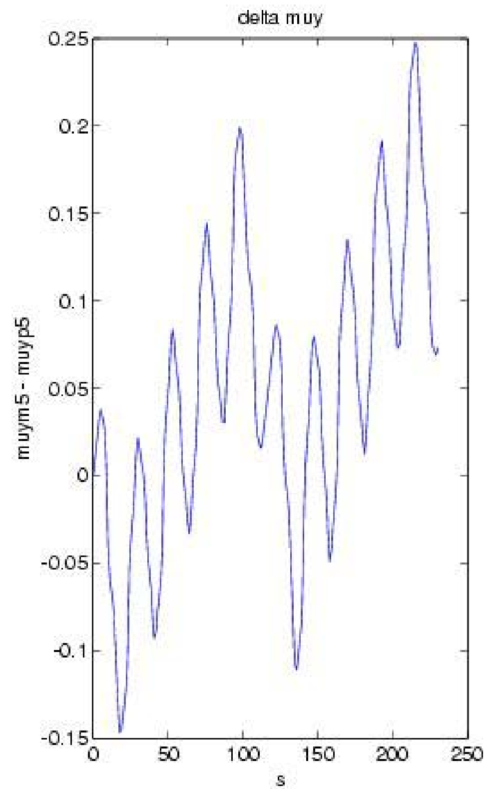
(ν_x, ν_y) vs. f_{rf} agrees with model.



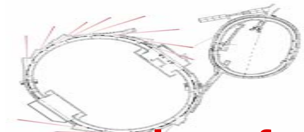


Local chromaticity calibrated with LOCO shows no sextupole errors:

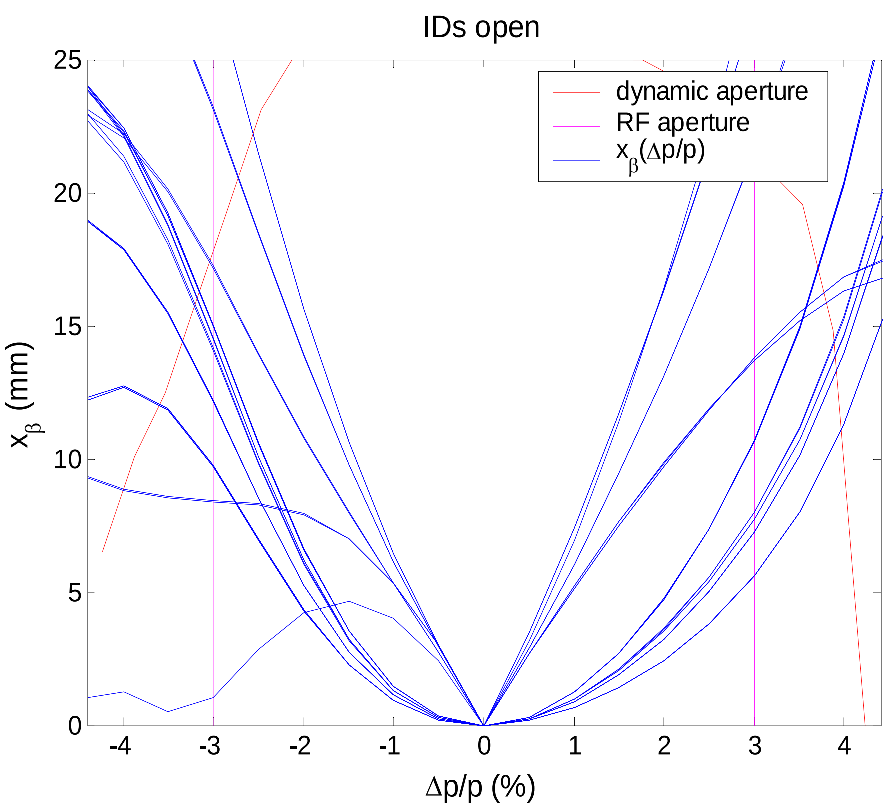




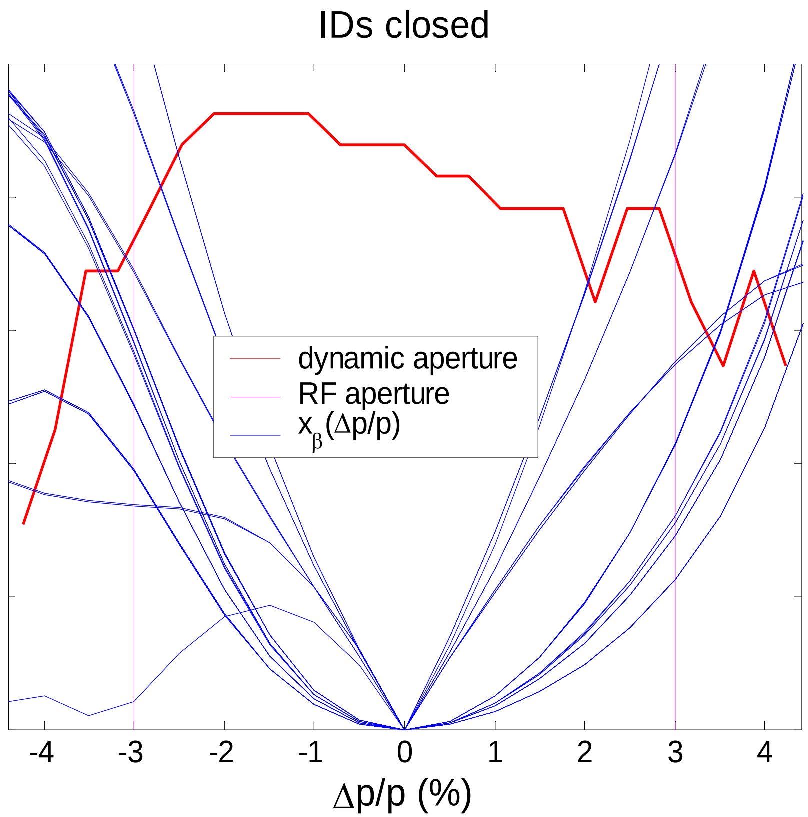
Dynamic aperture vs. Δp/p



- **Dynamic aperture measured with single injection kicker for varying rf frequency.**
- **$x_\beta(\Delta p/p)$ for different straight sections. (From model.)**
- **RF acceptance**



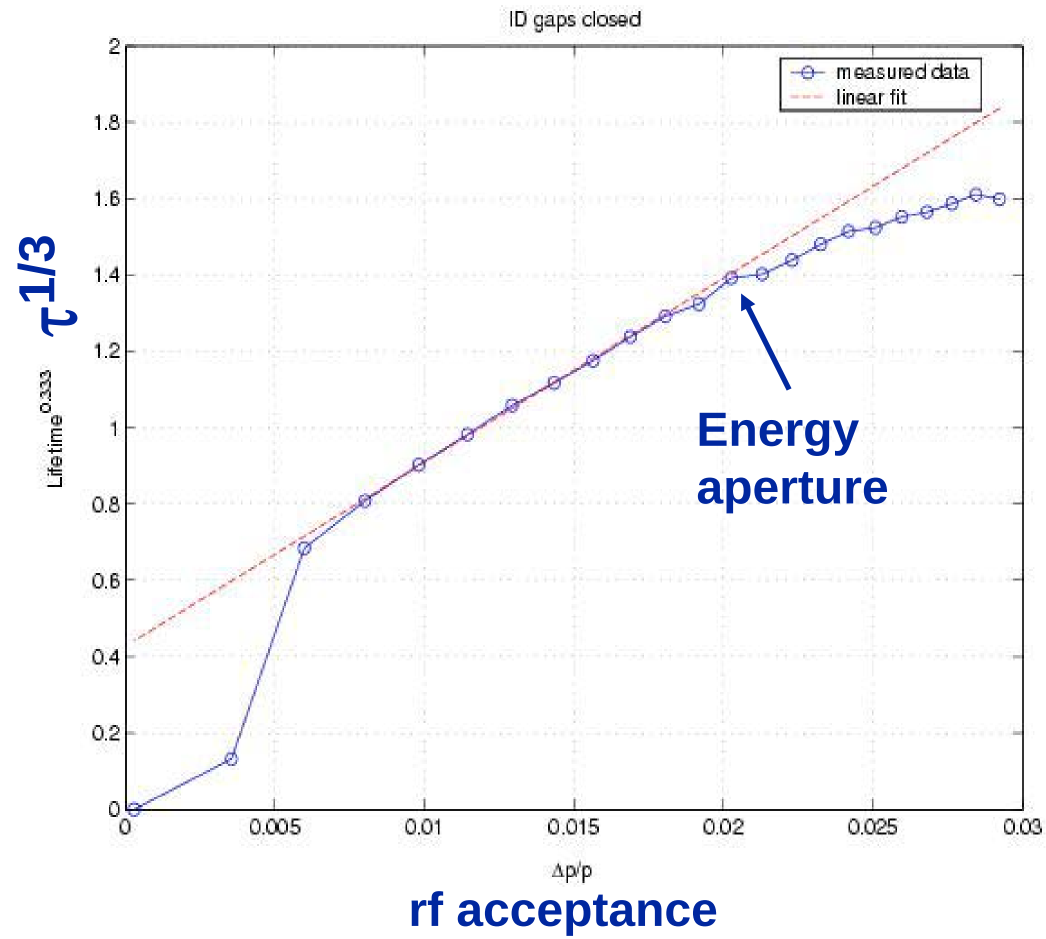
IDs open



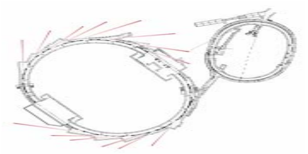
IDs closed

Dynamic energy aperture, 2

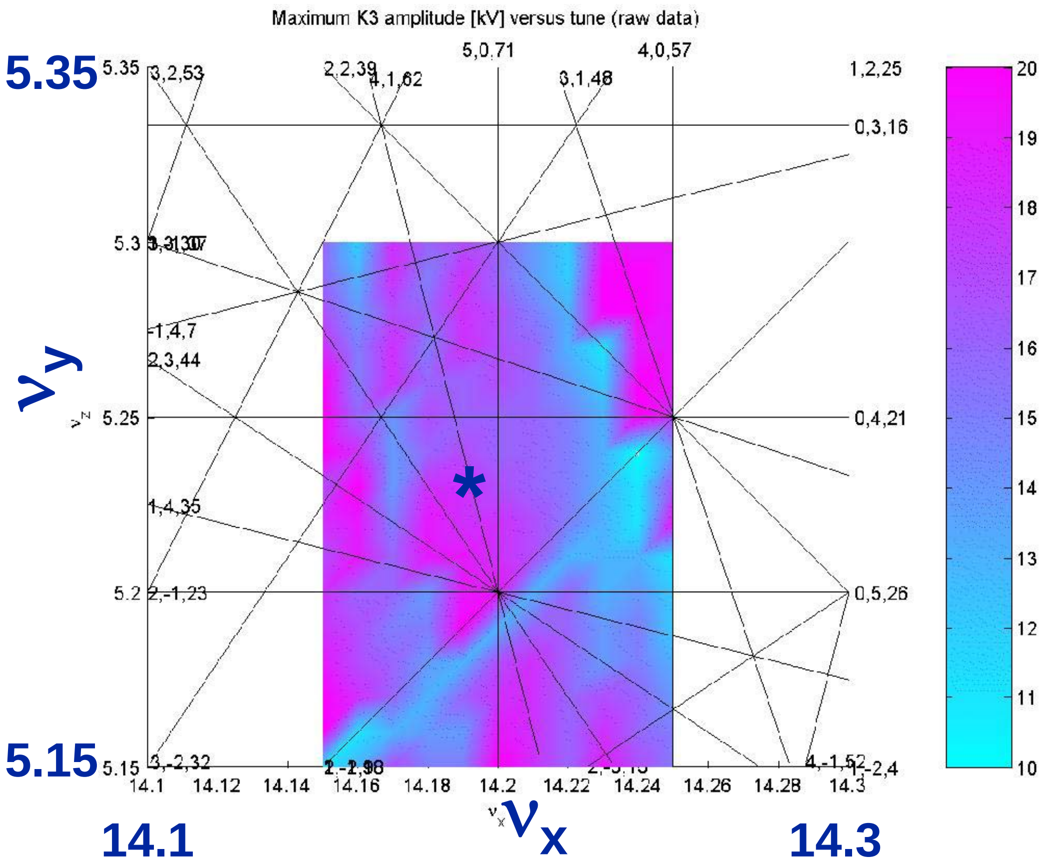
- Lifetime vs. V_{gap}, rf
- 8 mA, single bunch
  - Touschek regime
  - $\tau^{1/3}$ ~ rf acceptance



Dynamic aperture vs. tune

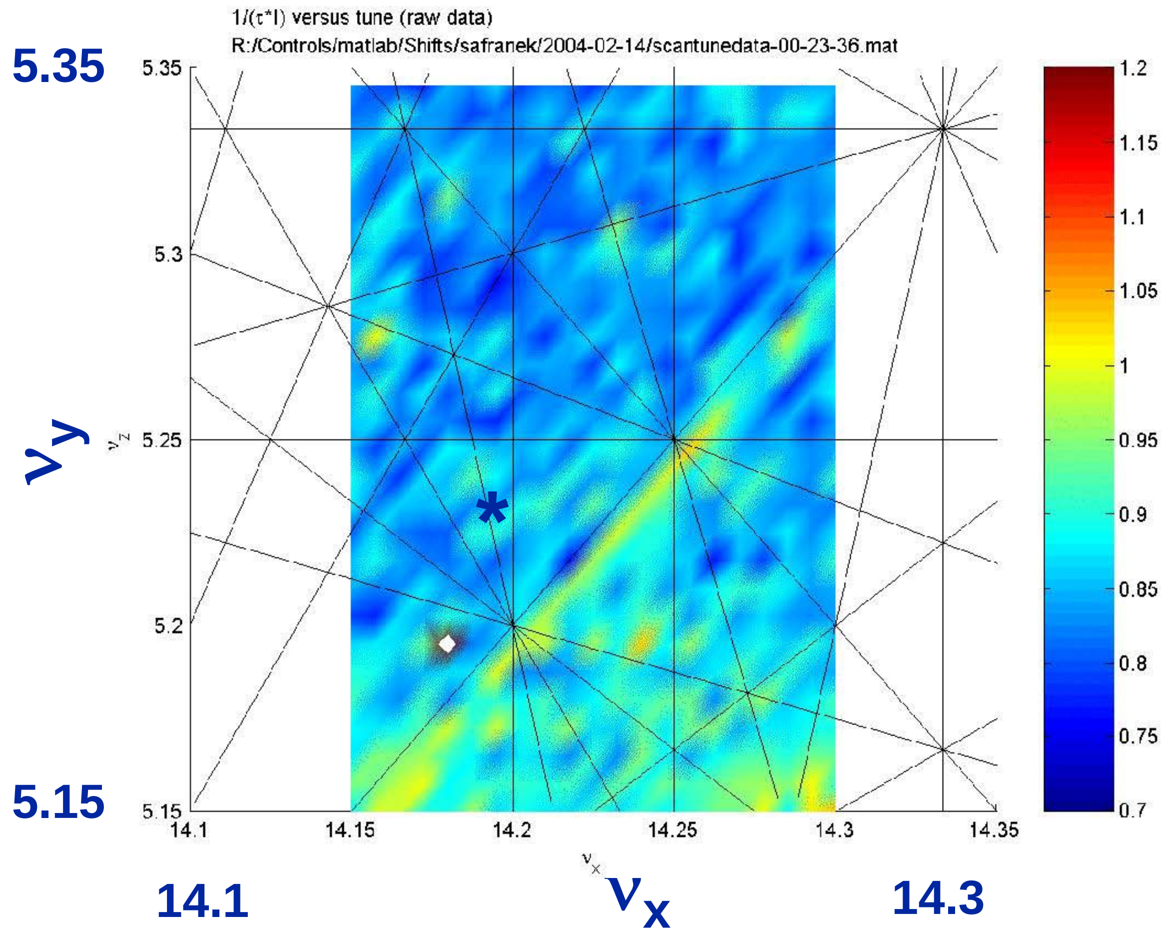


- Resonant lines:
  - $\nu_x - \nu_y = 9$
  - $3\nu_x + \nu_y = 48$
  - $4\nu_x + \nu_y = 62$
- Resonances offset from tune shift with amplitude.
- * = operating tunes (14.19, 5.23)
- Data gathered automatically on owl shift.



Lifetime vs. tunes

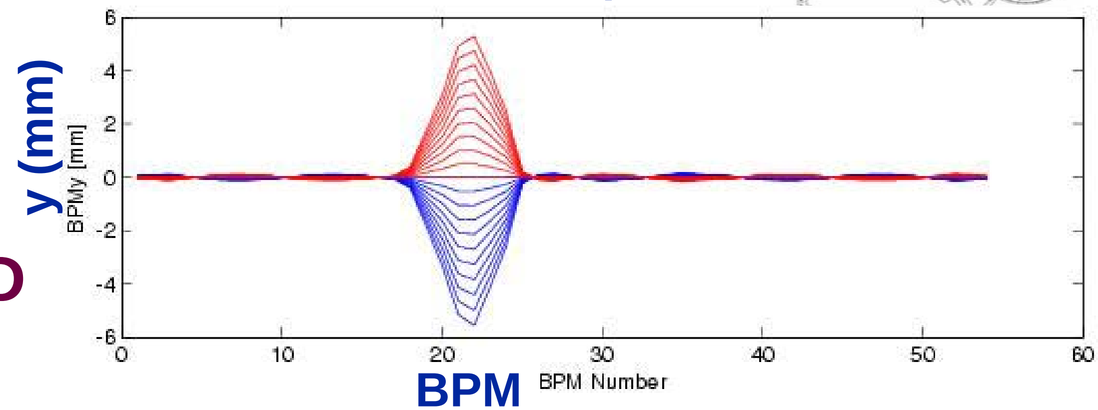
- Resonant line:
  - $\nu_x - \nu_y = 9$
- * = operating tunes (14.19, 5.23)
- Data gathered automatically on owl shift.

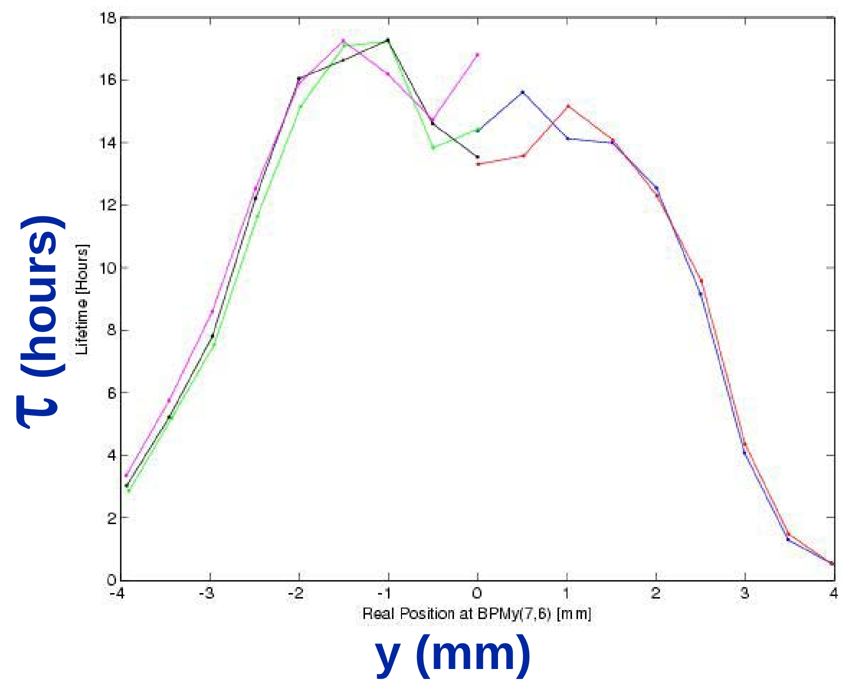


Aperture scans

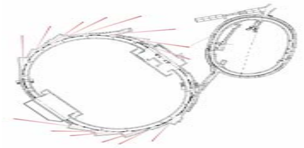
- τ vs y in small gap ID
  - Poor man's scraper
- Determine minimum gap for future IDs
  - 12 mm ⟶ 8 mm
  - Smaller still for reduced β_y
- Complications
  - Vacuum degrades with beam bump
  - Coupling, η_y degrades with beam bump
  - Need scraper

Vertical beam bump in ID chamber



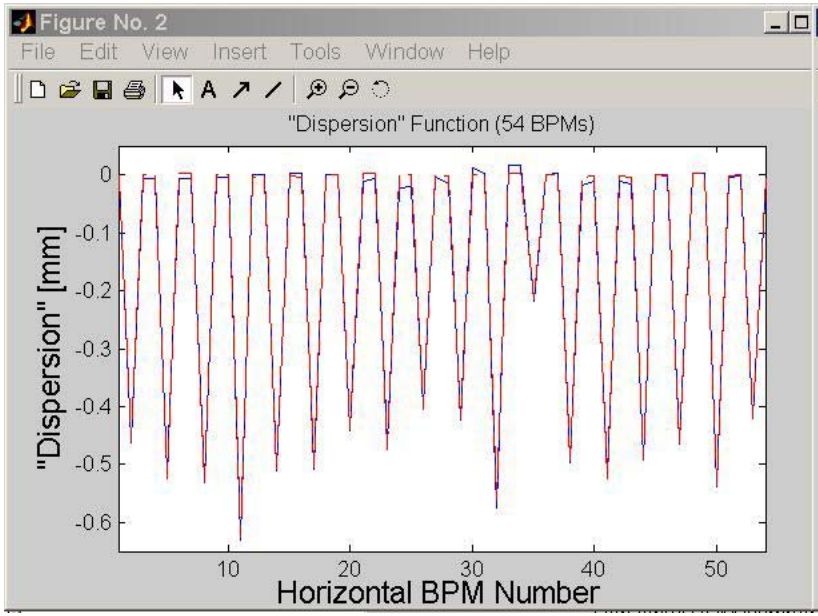


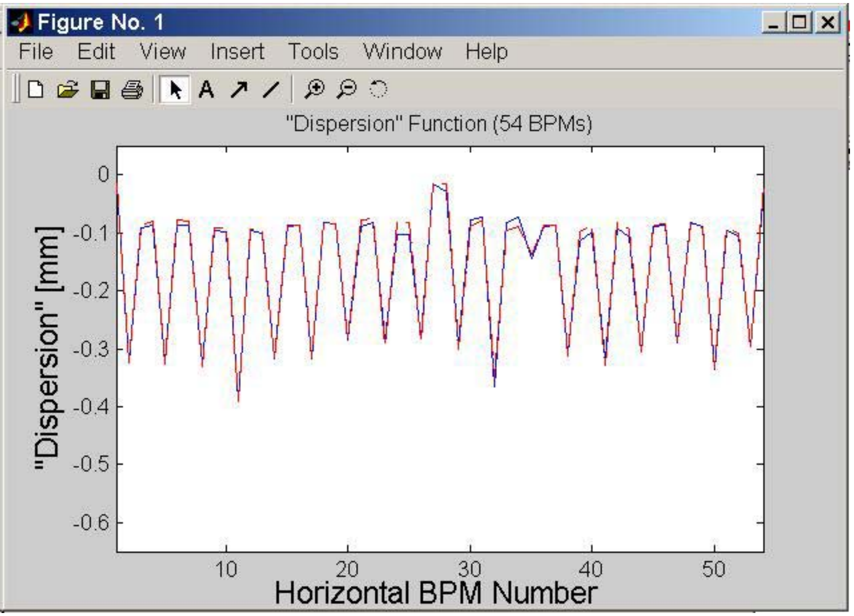
Low emittance optics test



- η = 10 cm in IDs
- ε_x: 18 nm ⟶ 12 nm
- Good lifetime, injection
- Reserved for later upgrade

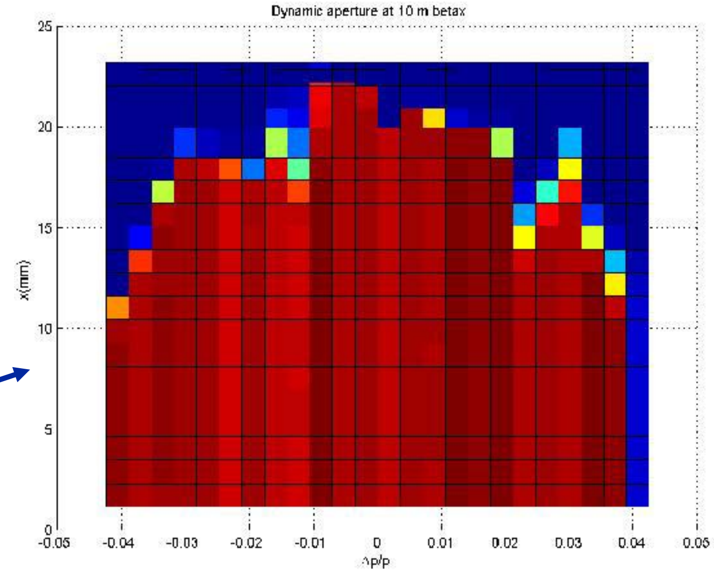
LOCO fit η: nominal optics **low emittance optics**



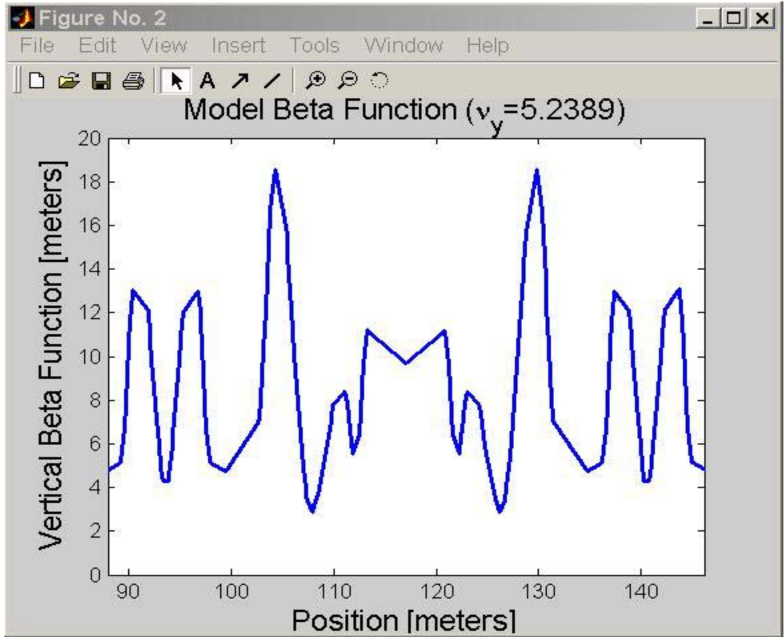


Low β_y optics

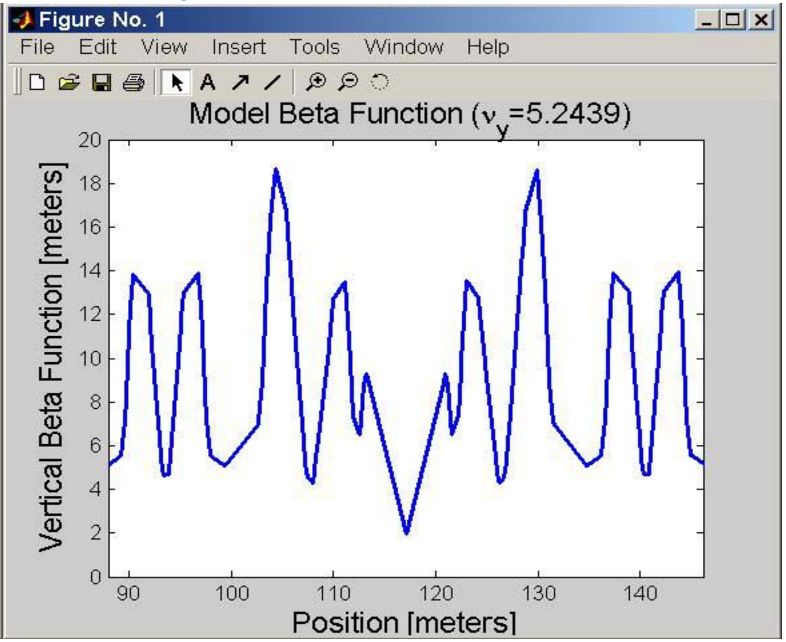
- **Reduced β_y in long straight**
  - **For future ID, small gap**
  - **β_y: 10 m 2 m**
- **Good dynamic aperture**



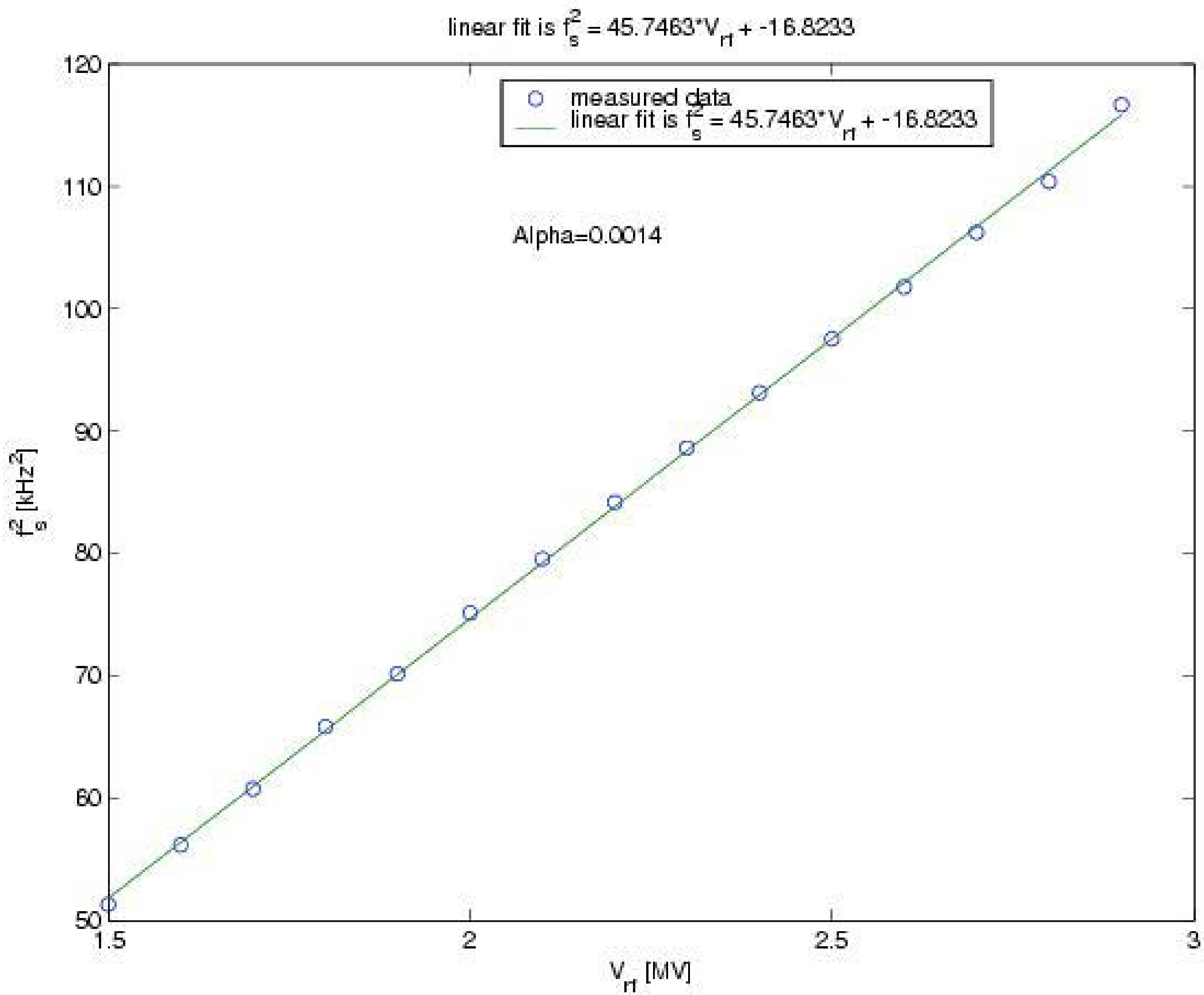
LOCO fit: β_y = 10 m



β_y = 2 m

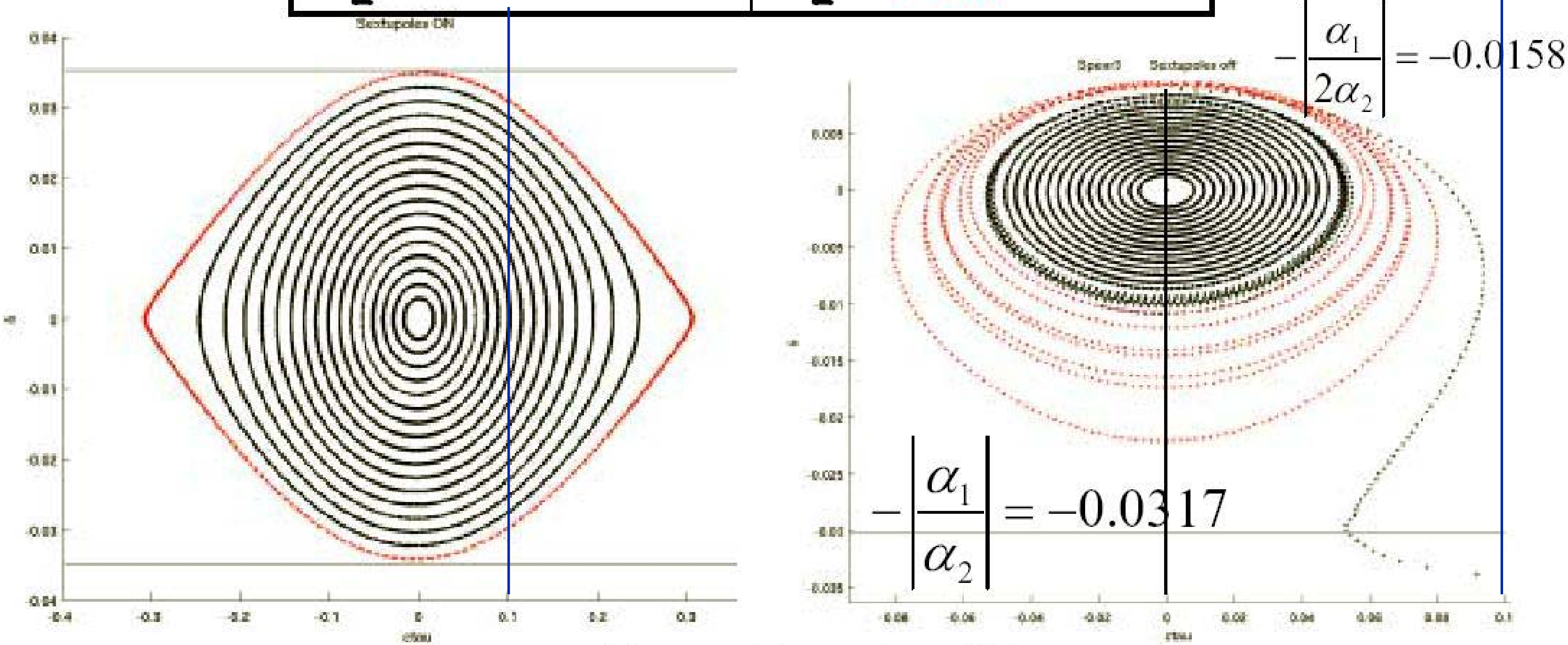


Momentum compaction measurement



SPEAR3: Longitudinal Dynamics

Sextupoles on	Sextupoles off
α_1 =1.19 E-3	
α_2 = -2.1E-3	α_2 = 37.4E-3



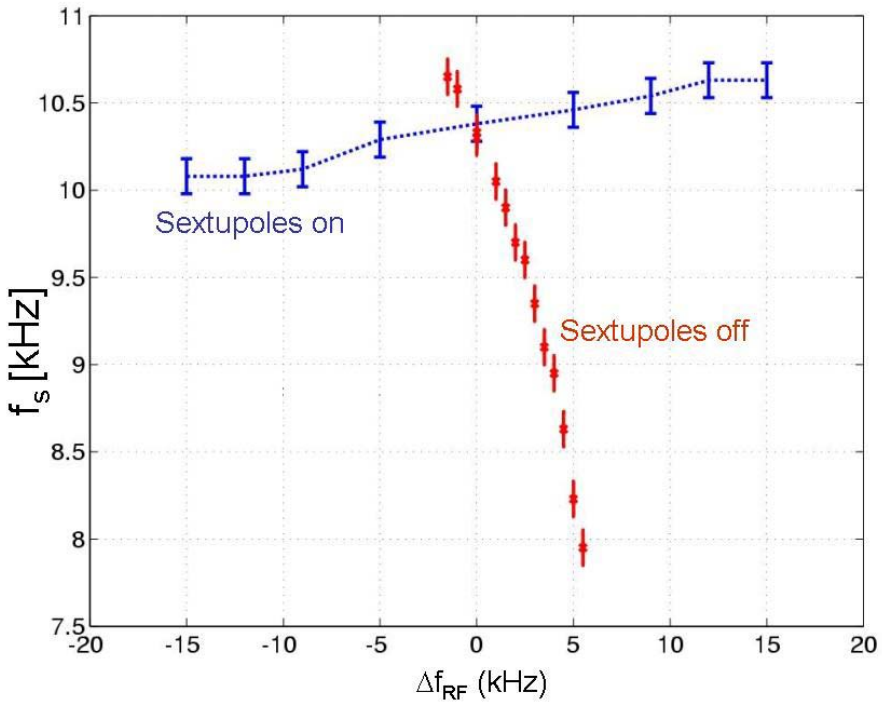
$$-\left|\frac{\alpha_1}{2\alpha_2}\right| = -0.0158$$

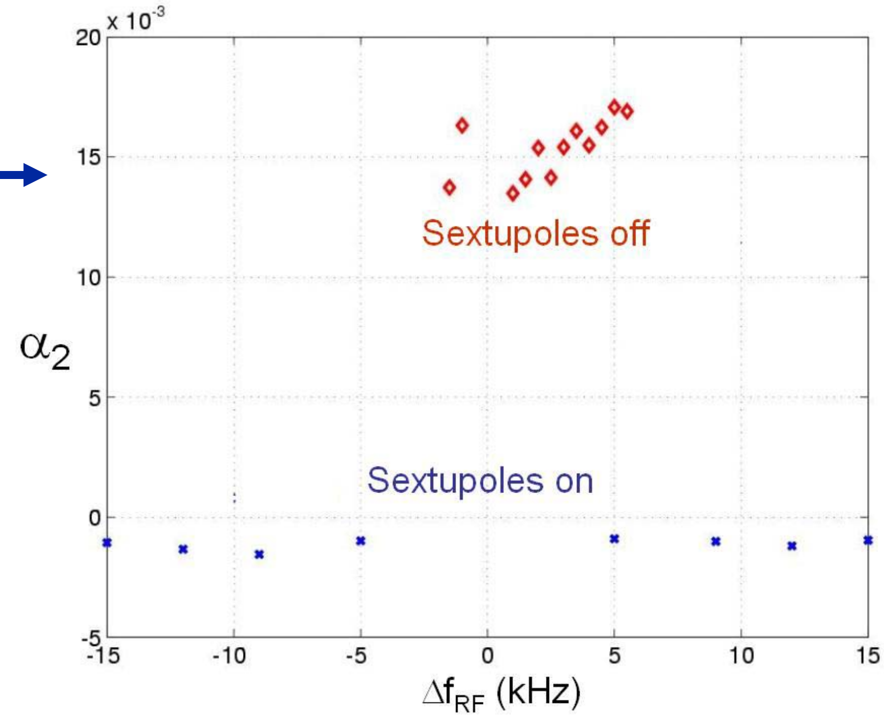
$$-\left|\frac{\alpha_1}{\alpha_2}\right| = -0.0317$$

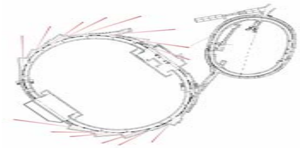
4D tracking using AT

α_2 measurement

- $|\alpha_2|$, sextupoles off >> $|\alpha_2|$, sextupoles on
- Energy aperture much reduced with sexupoles off



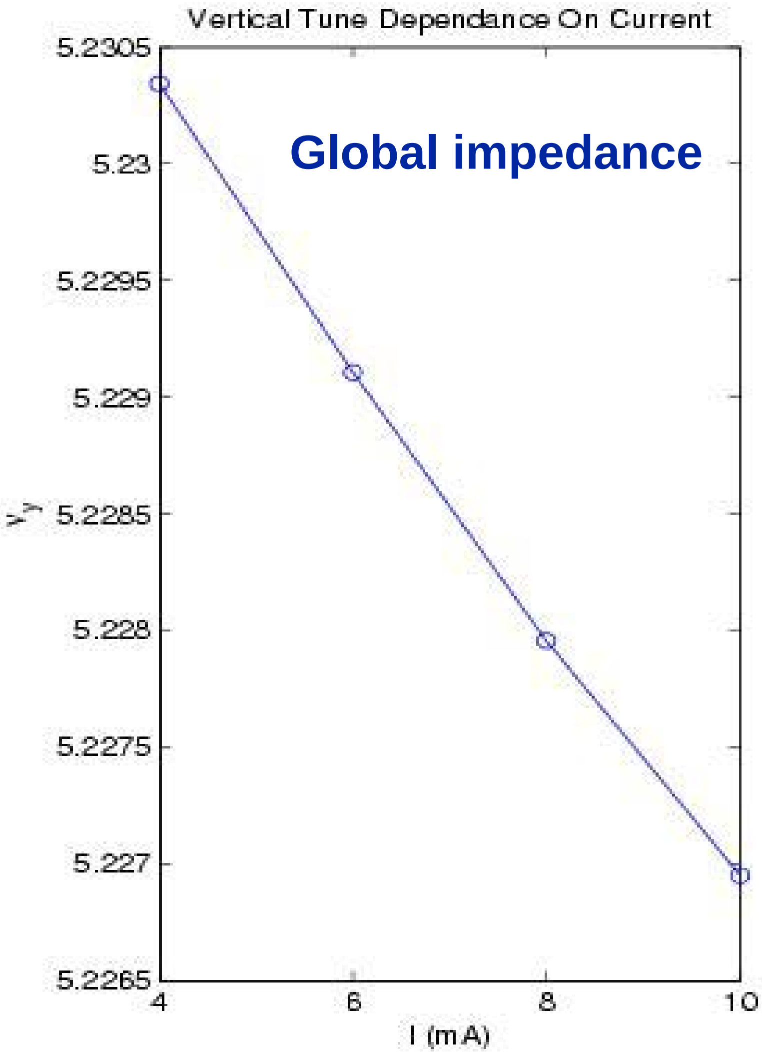


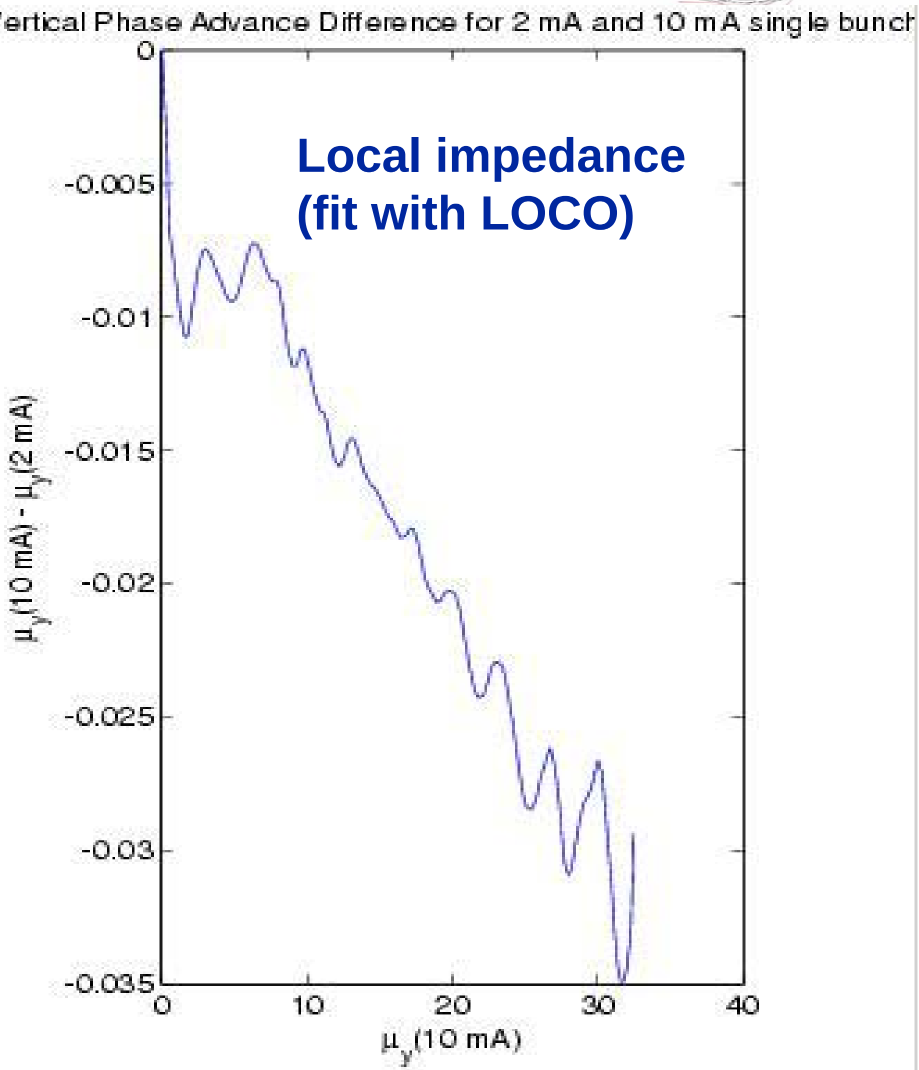


Impedance, instabilities

- 25 mA single bunch limit ($\xi_{x,y}$ = 1)
- Multibunch ν_y oscillations
  - Ion driven
  - Decreasing as vacuum improves
- ν_s oscillations driven by 360 Hz harmonics
- 200 mA tests ongoing
- Transverse impedance measurements

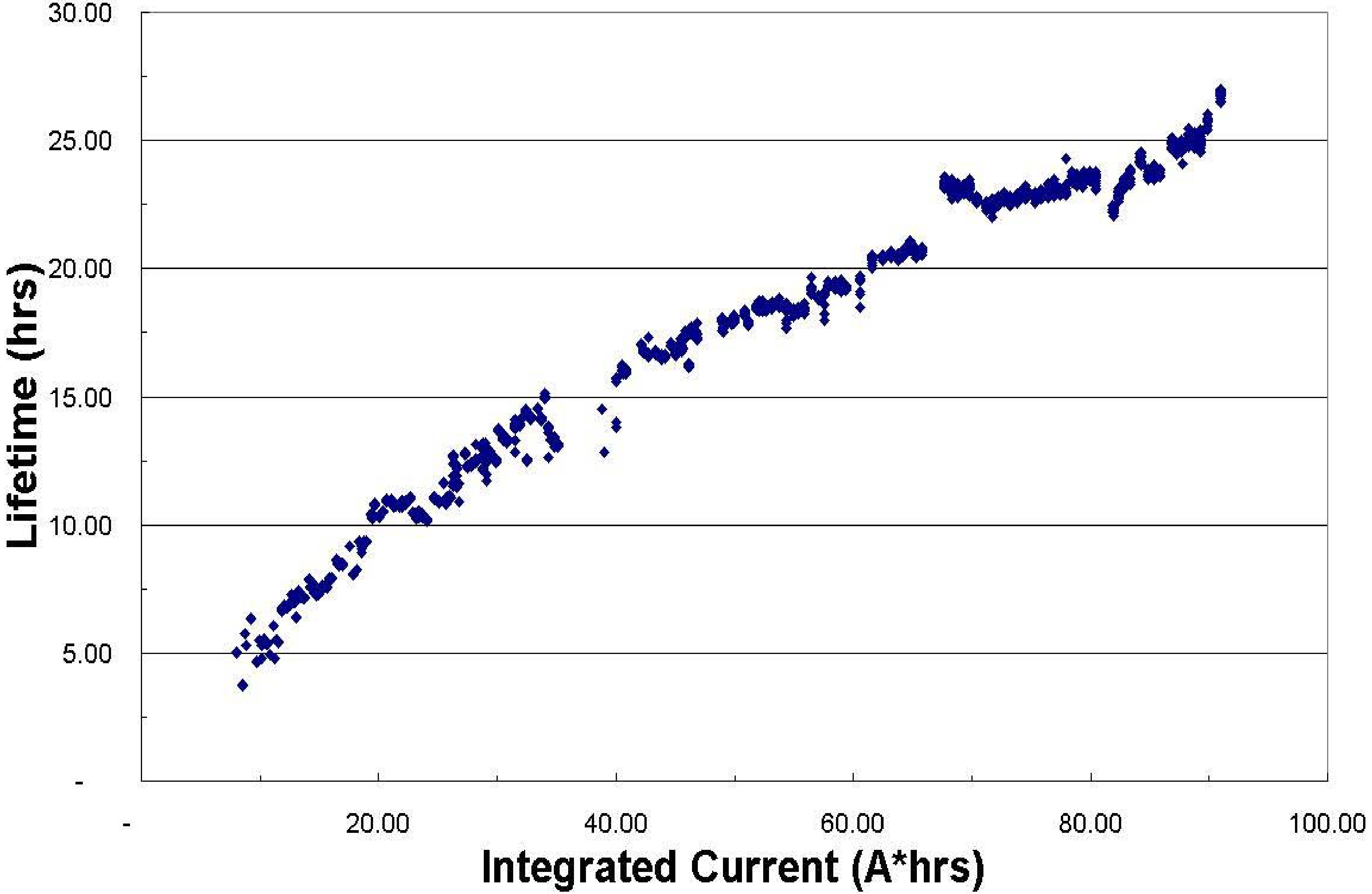
Transverse impedance measurement*

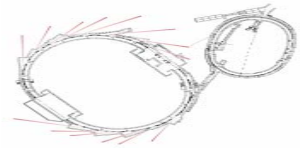




*see V. Sajaev, PAC03.

Lifetime (at 90 mA) vs. Integrated Current





Acknowledgements

I would like to express my appreciation for all the help SSRL received with the commissioning effort from accelerator physicists worldwide. I would also like to commend the SSRL staff. The speed at which commissioning proceeded is a testimony to the fine work that went into designing and building SPEAR3. Finally, thanks to the SSRL operations group. Their experience, expertise and energy was a great help.