Measured and calculated frequency maps for the BESSY storage ring

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BESSY

Experimental Setup:

- Hardware
- Software

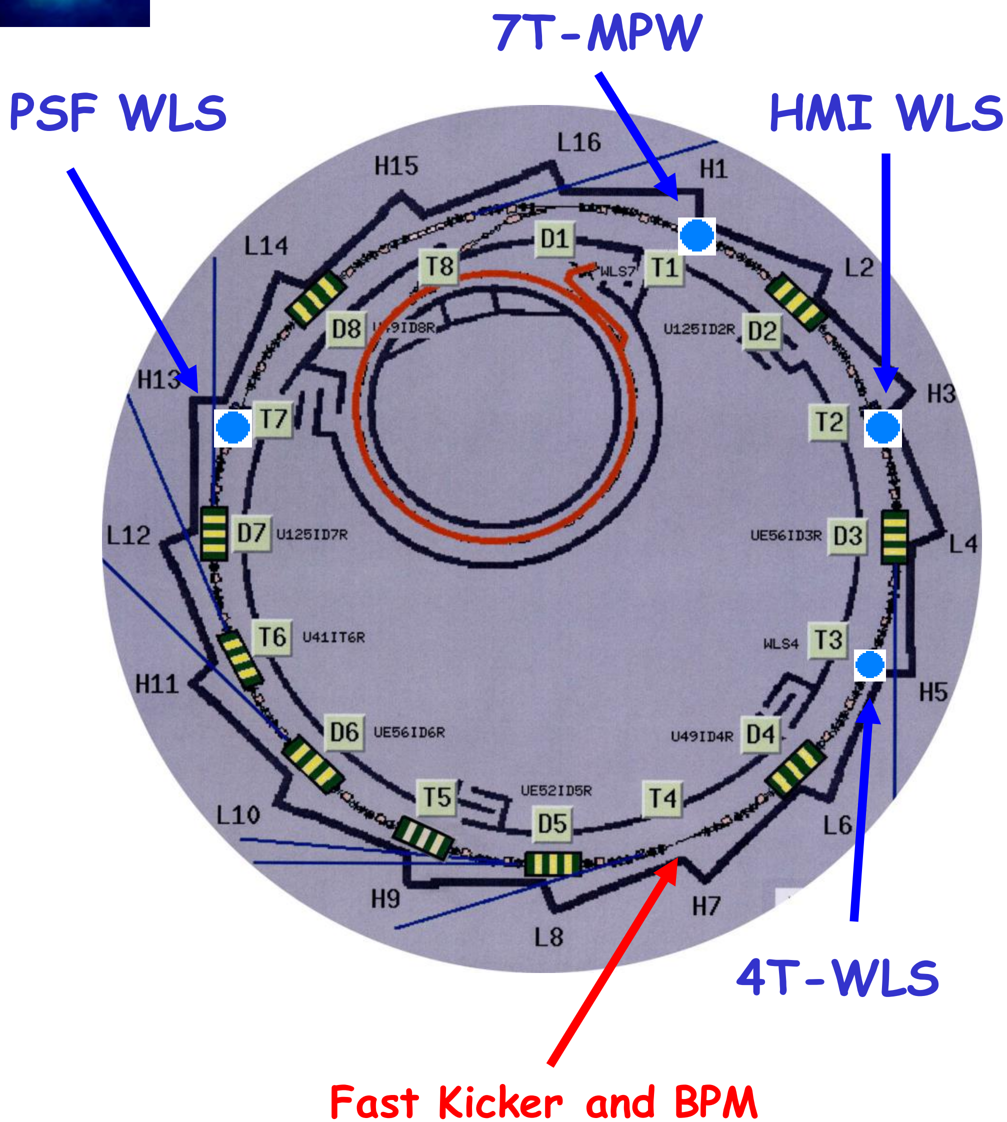
"Theoretical Setup"

Measured and Calculated Maps:

- Realistic Case without IDs
- For Different Initial Tunes
- Under Operating Conditions with IDs
- Momentum Dependent
- Academic Case
- Exotic Case

Conclusions

BESSY-Third Generation Light Source



Storage Ring:

Double Bend Achromat

8 cells, 30 m each, high-low

$\varepsilon = 6\ 10^{-9}$ m rad

1.7 GeV

16 straight sections

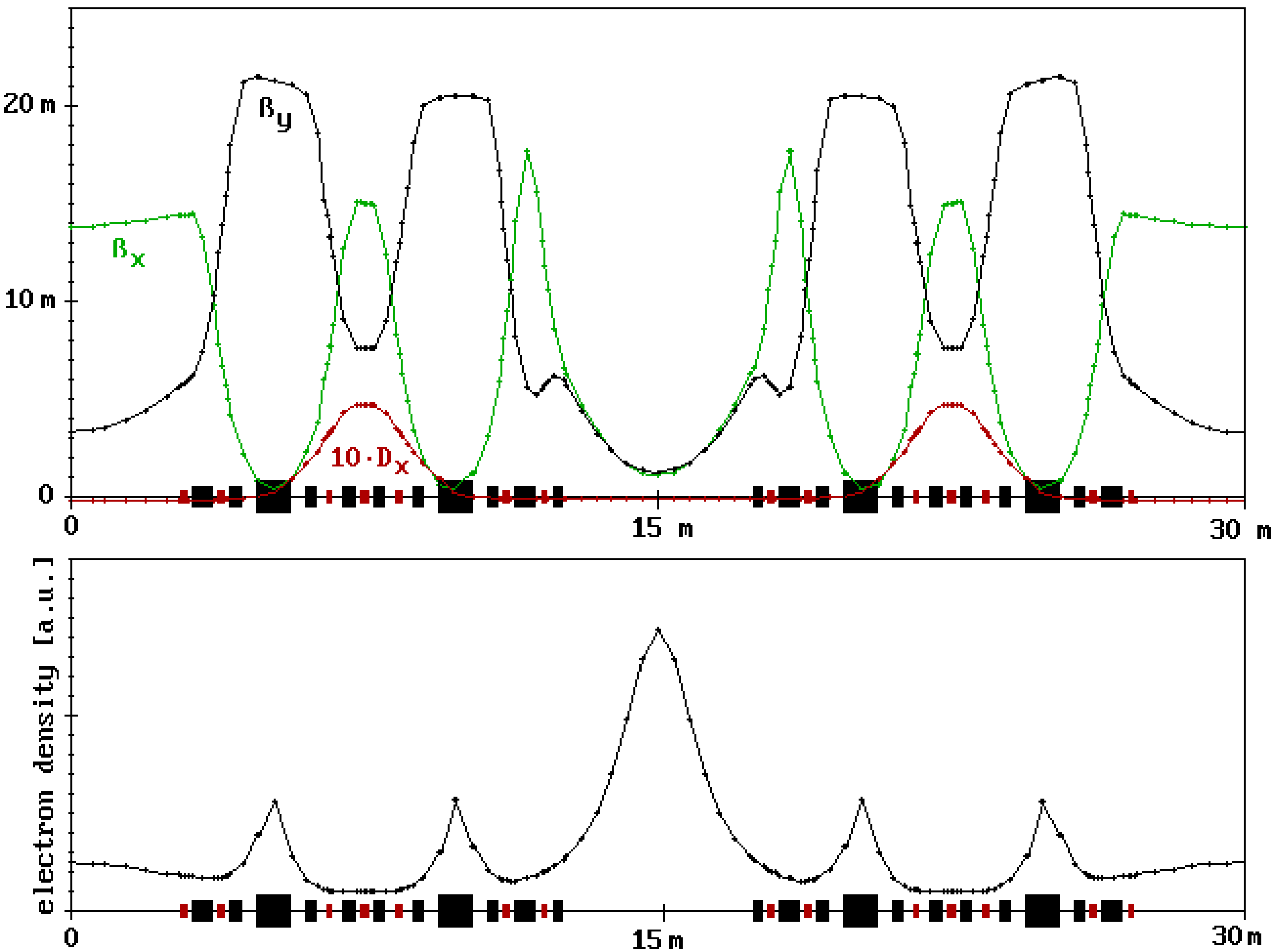
9 Undulators:

ID chamber 10 x 45 mm

4 Superconducting WLS

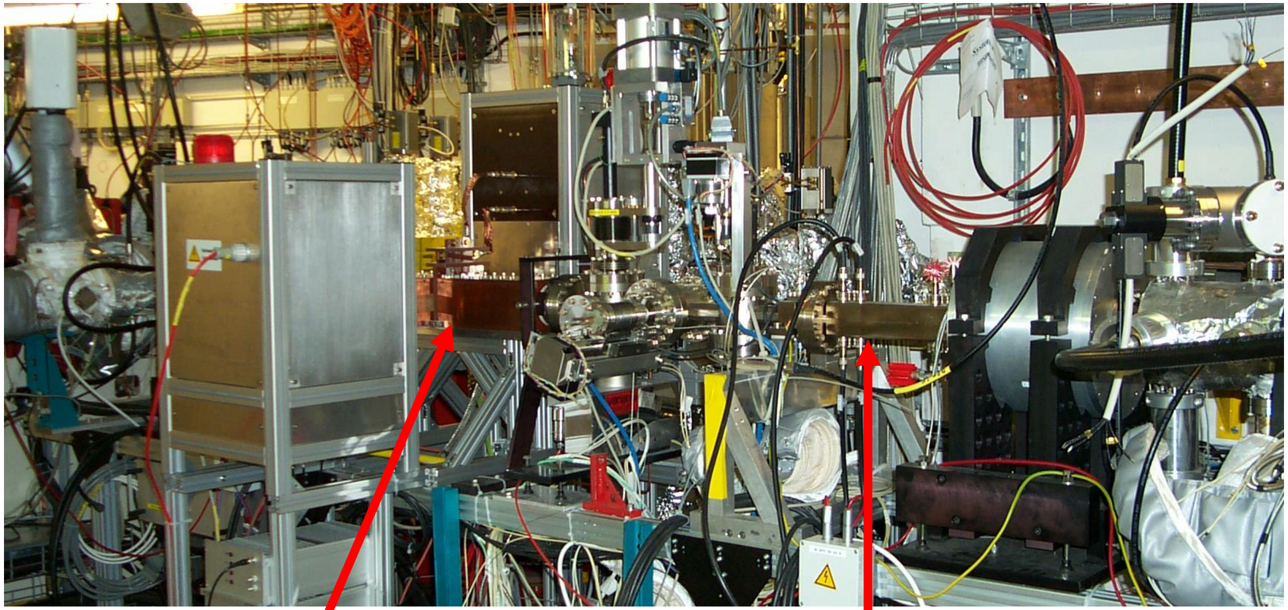
3 Injection, RF-Cavities, Feedback and Diagnostics

BESSY - Lattice Functions



Optics functions of 1/8 of the storage ring (top) and electron density relevant for Touschek scattering. The sextupole magnets are shown in red.

Experimental Setup - Hardware



Fast Kicker Magnets

Stripline BPM

Hardware in the storage ring tunnel used for frequency map measurements.

Kicker Magnets

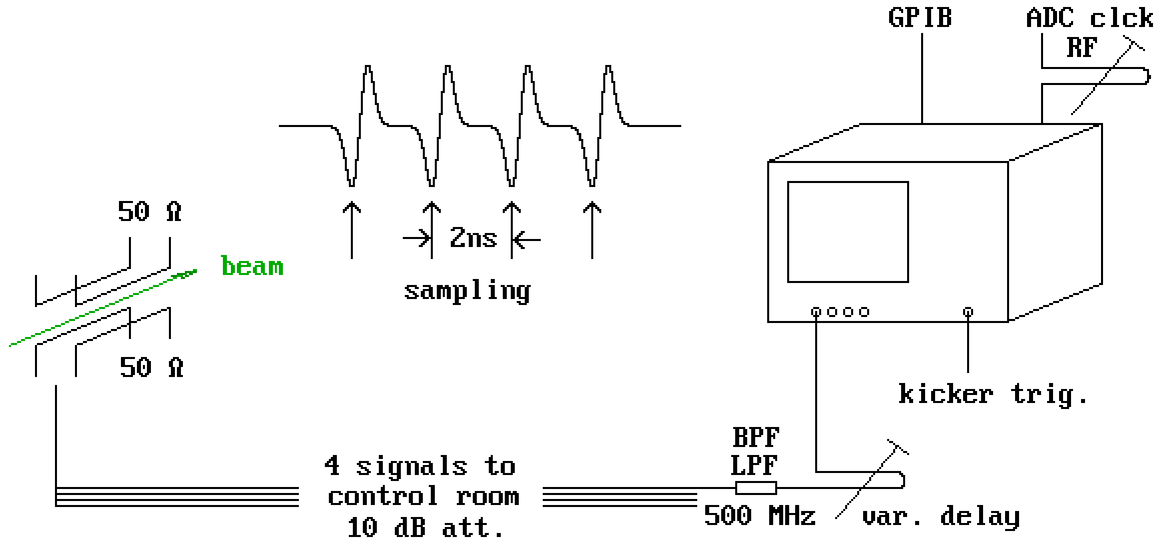
Horizontal and vertical sinusoidal half-wave Kickers

Max. kick = 3.5 mrad @ 1.7 GeV
Foot width = 1.2 μs (T_{rev}=800 ns)

Kicker Timing: Synchronized to revolution time
Variable delay
Coincidence with 50 Hz-mains

Rep. Rate determined by data collection process

Turn-By-Turn, Bunch-By-Bunch BPM



The position of each bunch is measured with the fast oscilloscope.

Features of the oscilloscope (LeCroy LC684DXL)

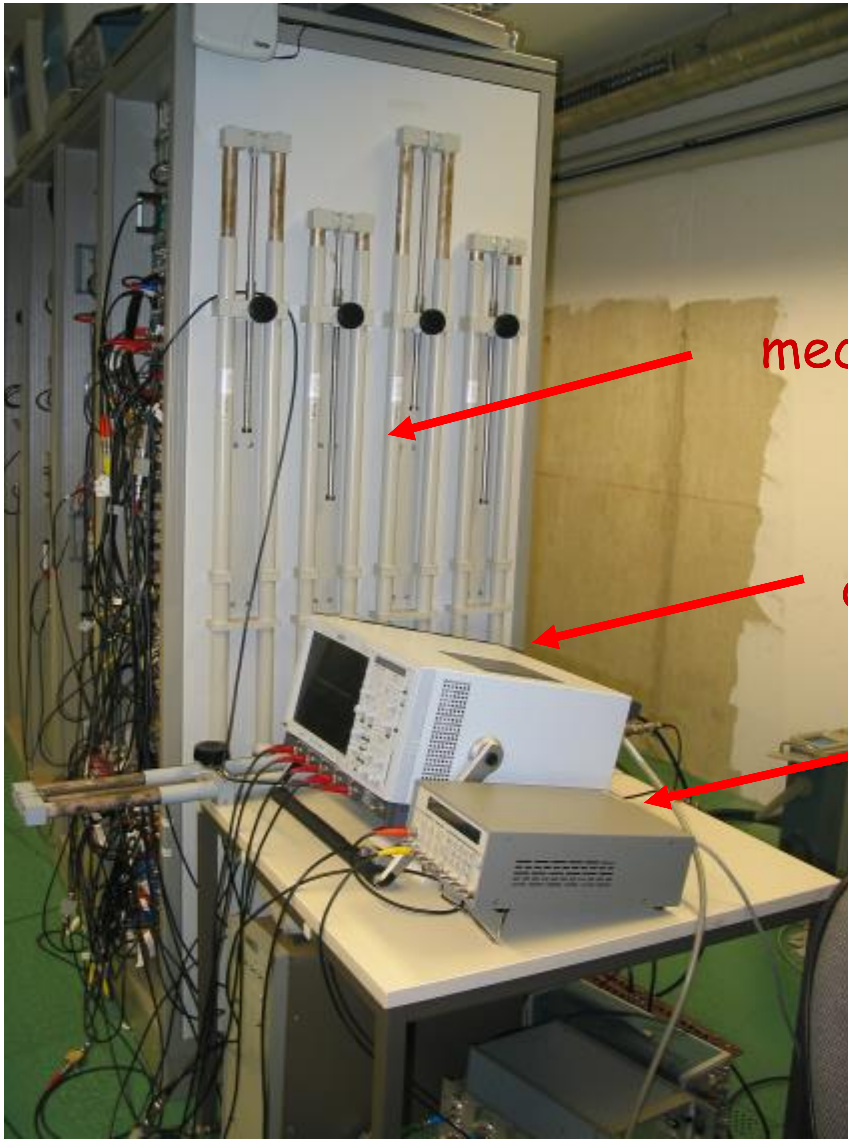
- 4 channels, 1 GHz analog bandwidth
- 8 bit ADC with 500 MHz sampling rate (ext. clck.)
- up to 2 Mbyte of data $\equiv$ 5000 recorded turns
- signal averaging

Limitation: 8 bit ADC $\Rightarrow$ single turn, single bunch resolution

$$\Delta \approx 15\ \text{mm} \cdot \Delta/\Sigma \approx 40\ \mu$$

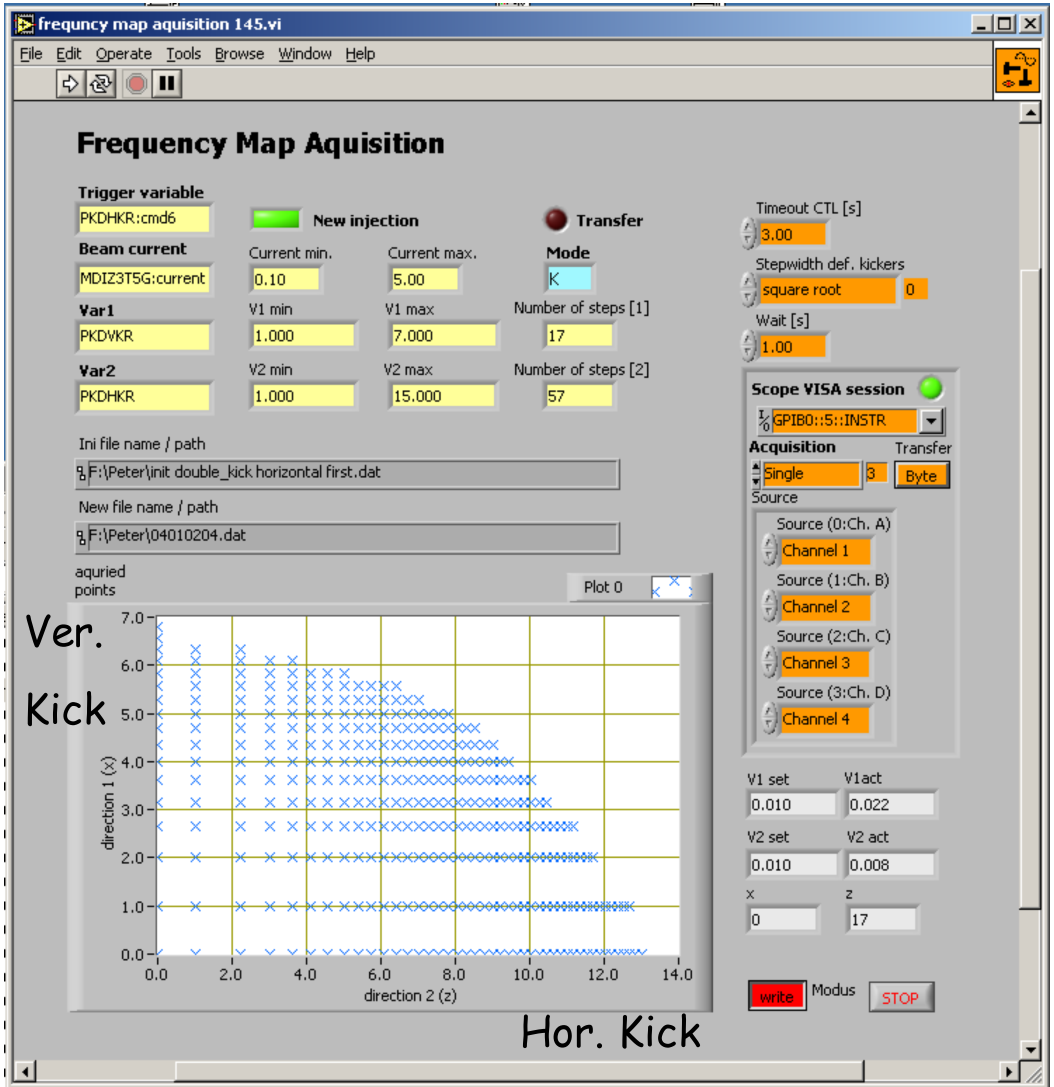
Solutions:

- Averaging
- Single bunch and bandpass filter
- Bunch train of 100 ns length $\Rightarrow$ 6 μ resolution



BPM hardware in the control room

Experimental Setup - Software



LabView-program on PC,

connected to the EPICS accelerator control system and to the scope via GPIB.

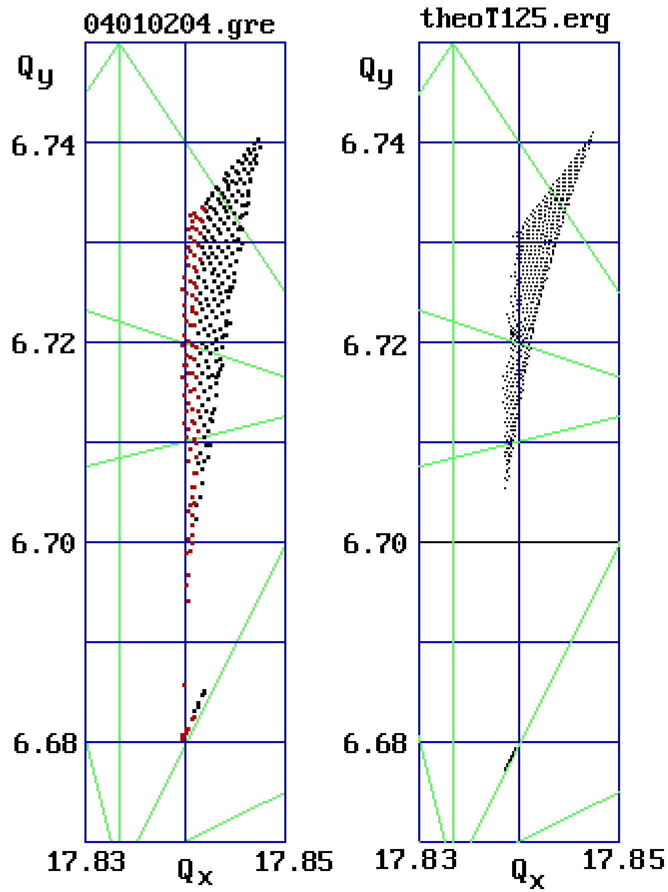
Data analysis on PC:

- conventional Fourier transf.
- no window function
- peak finding algorithm

"Theoretical Setup"

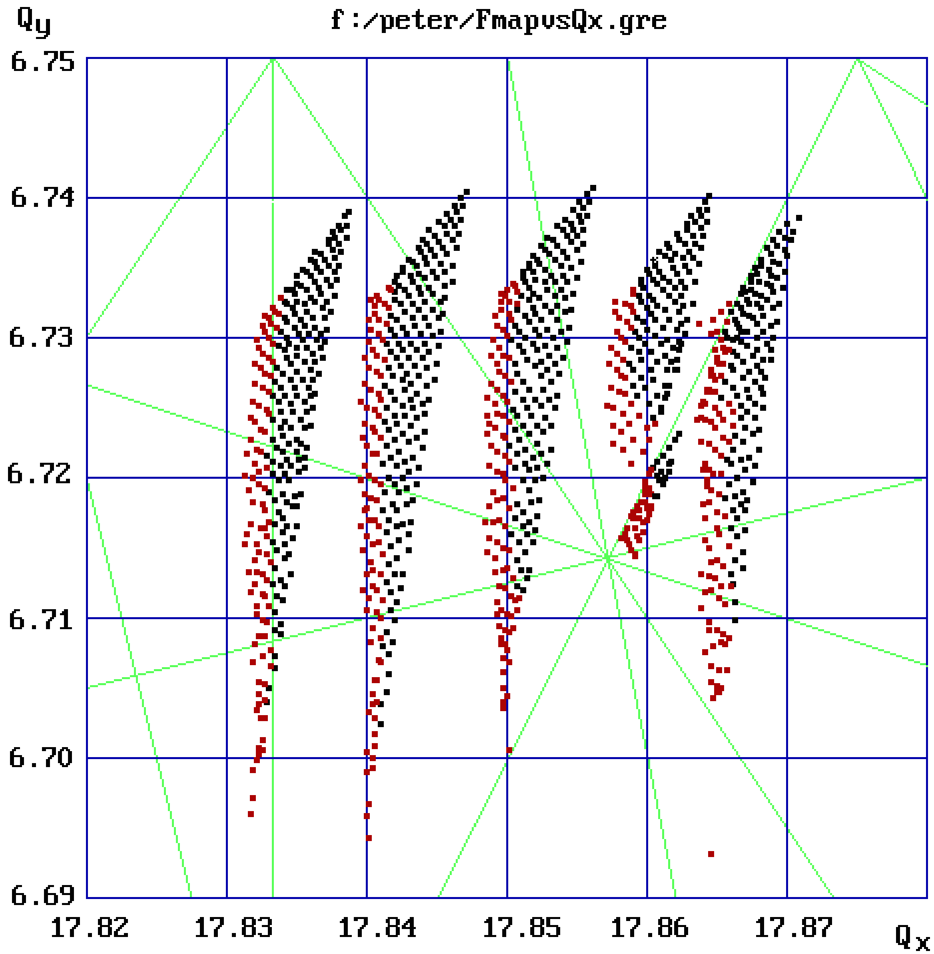
- Calculations based on linear model found by orbit response matrix analysis, coupling errors are included
- Symplectic tracking code - with 4th order integrator
- Sextupoles are modeled by 13 equal kicks
- Fringe fields of dipoles (measured) and quadrupoles (theoretical) are included
- Random sextupole and decapole components from horizontal steering coils in the sextupoles are included
- Small adjustments to the harmonic sextupole magnets are applied to get better agreement with experiments
- ID-vacuum chambers determine the physical apertures: 10 x 45 mm, full width
- Tracking for 128 or 256 turns, Hanning window and Fourier transform.

Frequency Maps without IDs



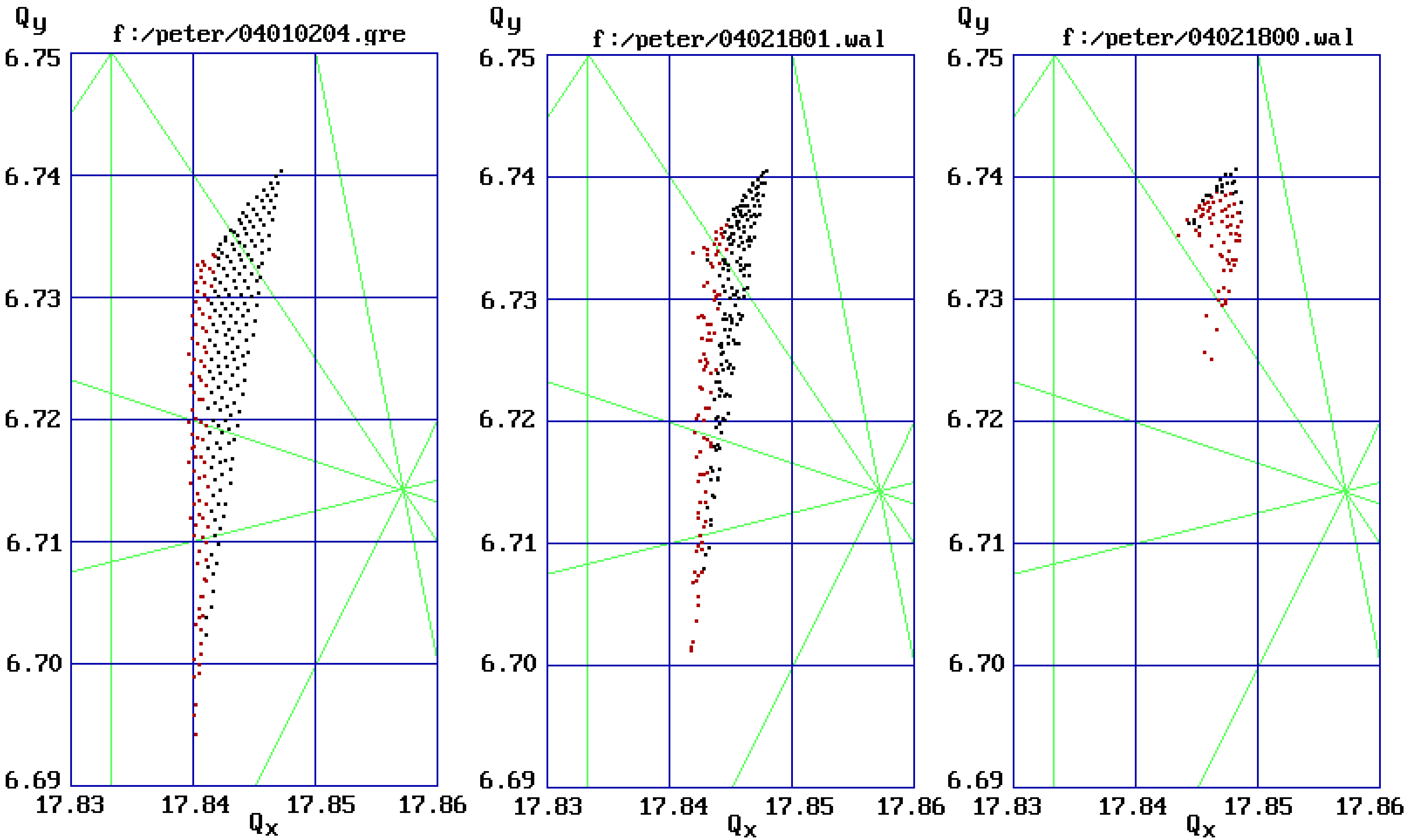
Experimental (left) and theoretical (right) frequency maps. Measurements shown in red correspond to more than 2% beam loss. Small coupling errors lead to the $2Q_x$-Q_y-resonance.

Frequency Maps for Different Initial Tunes



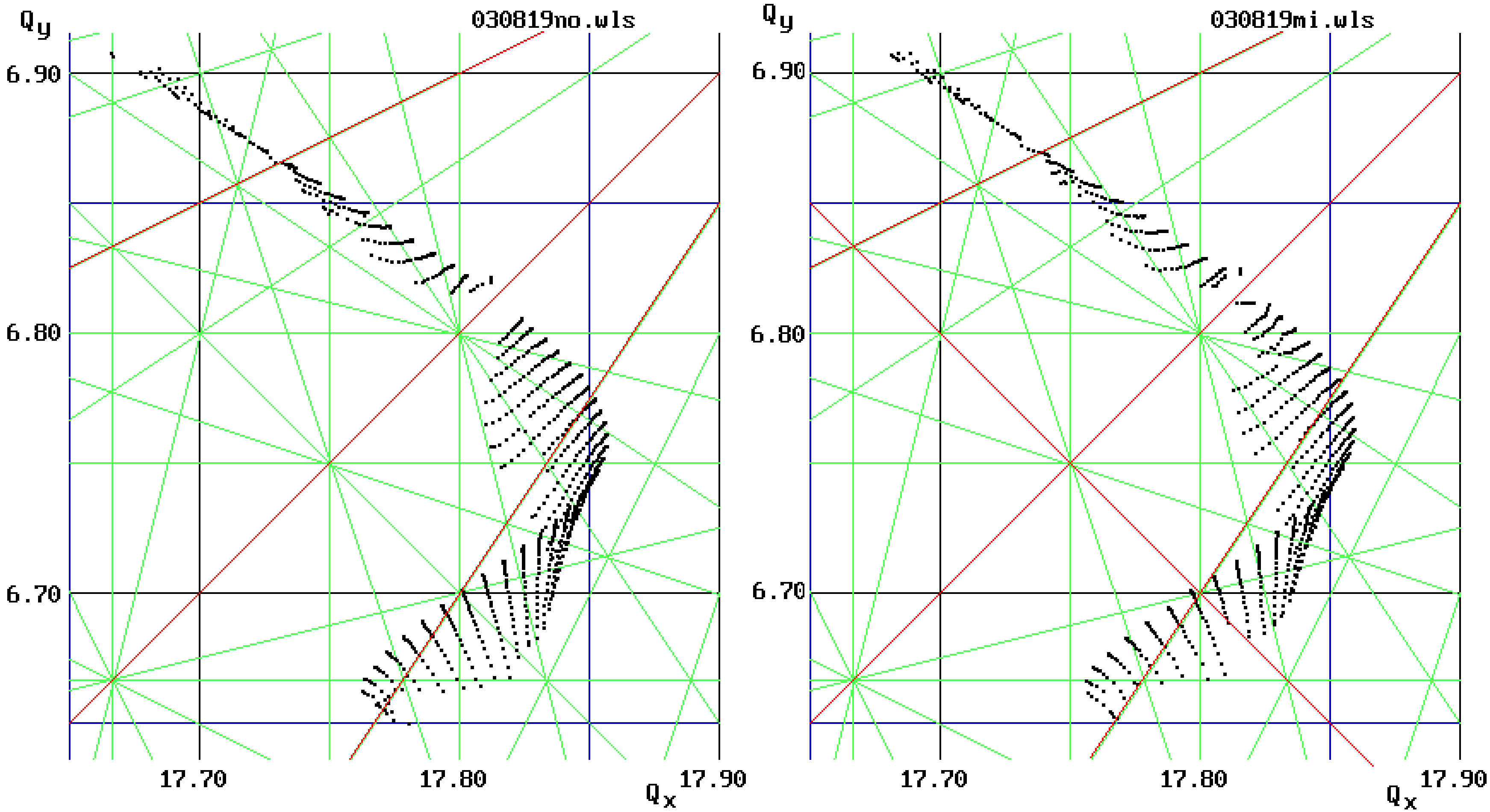
At higher horizontal tune the $2Q_x$-Q_y-resonance becomes more pronounced.

Frequency Maps Under Operating Conditions - with IDs



Left: bare storage ring. Center: with 3 sc WLS. Right: with UE56 set to smallest gap. Red dots are measurements where more than 2% beam was lost. The dynamical aperture is frighteningly small due to the $3Q_x+2Q_y$-resonance.

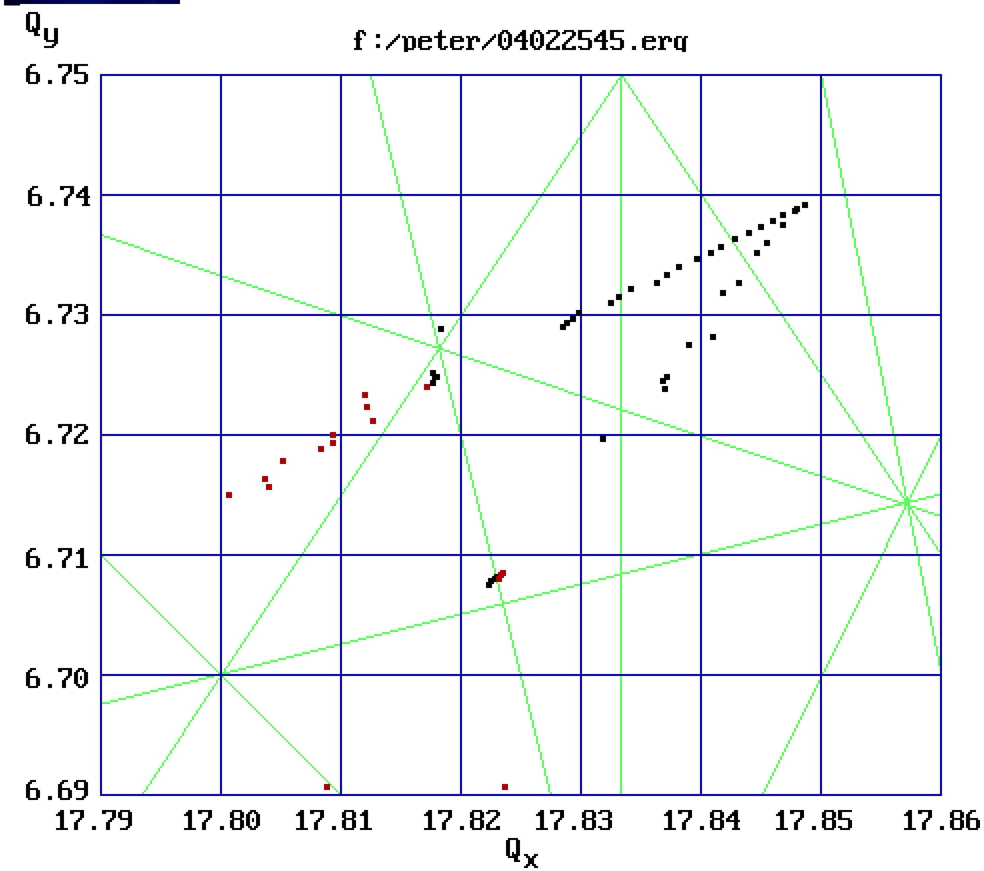
Tune vs. Momentum and Horizontal Amplitude

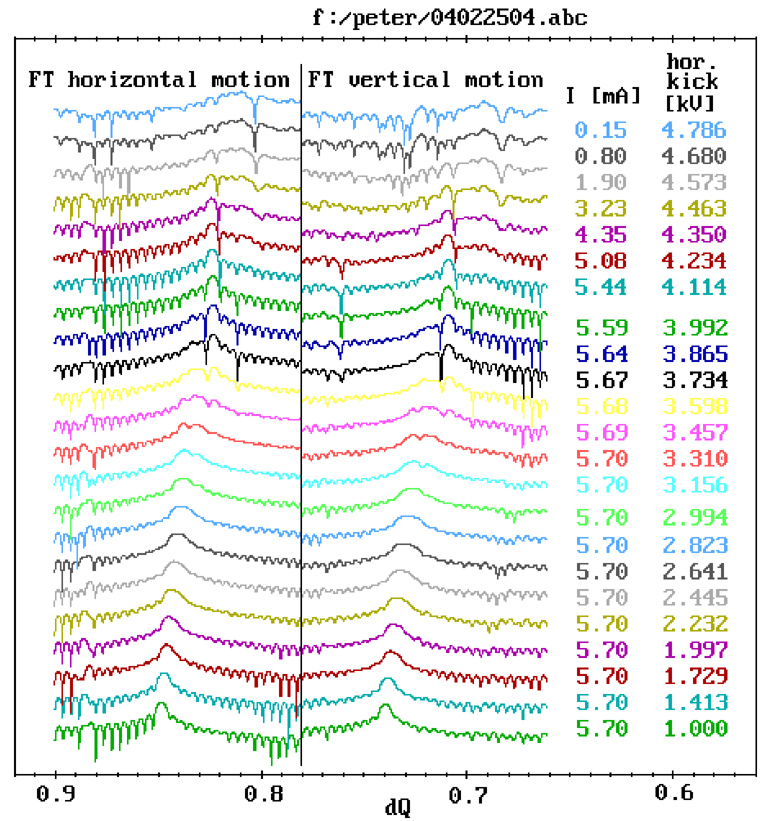


Nominal chromaticities. Left - without IDs, right - with 3 sc WLSs in operation. Resonances up to 5th order ($3Q_x$-$2Q_y$) are excited in both cases. The WLSs drive $2Q_x+2Q_y$-resonance.

Academic Case

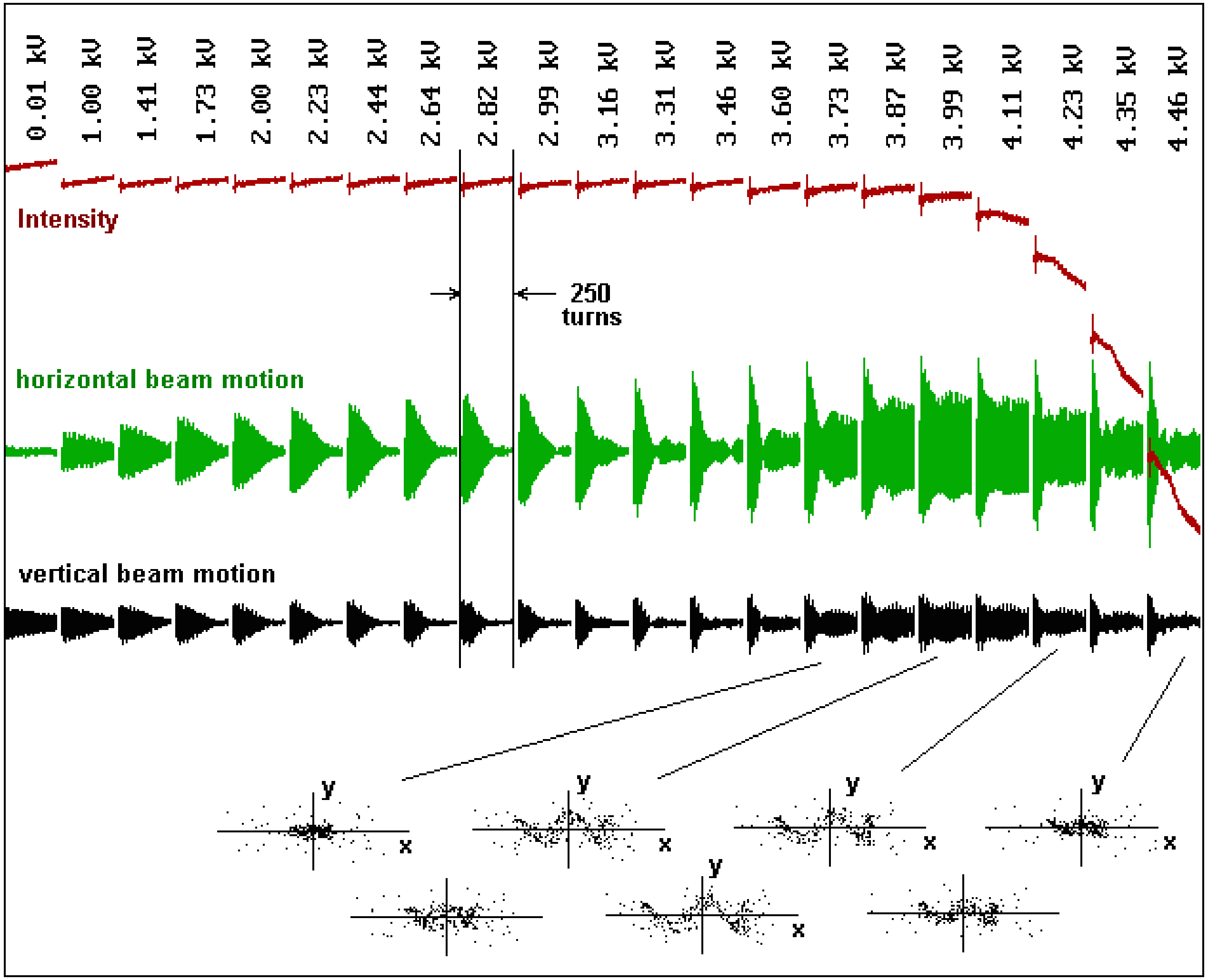
“Frequency maps“ without harmonic sextupoles





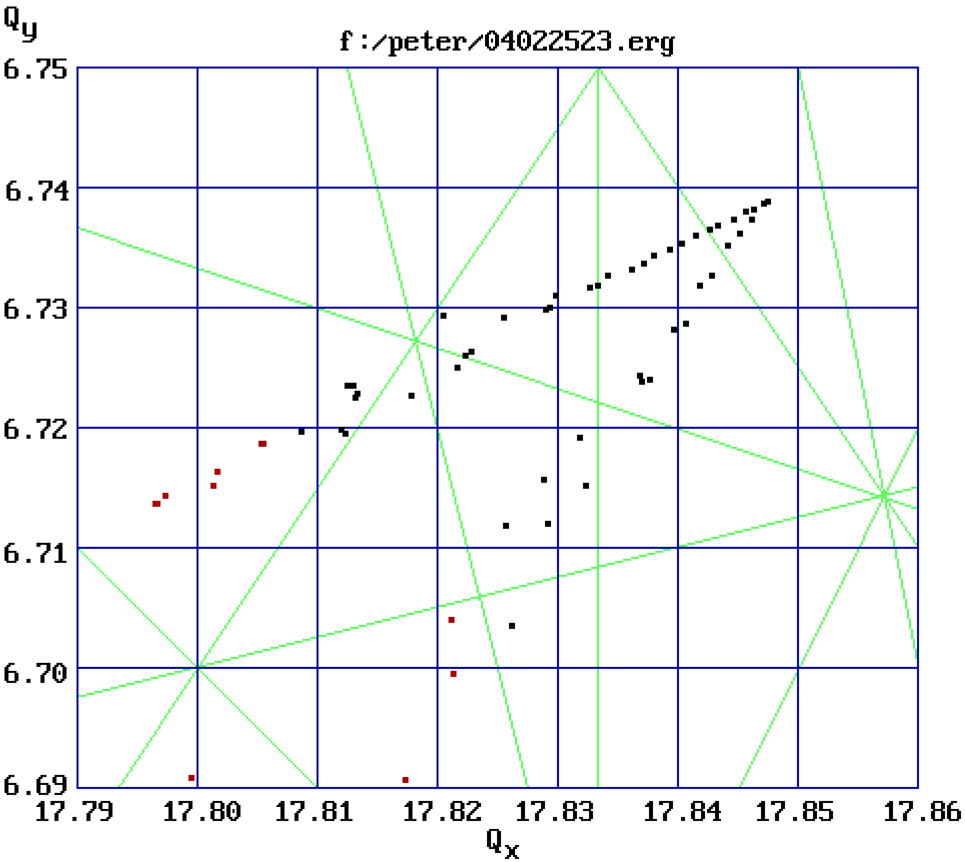
Tune shift vs. horizontal and vertical kick (left). Red dots represent measurements with more than 2% beam loss. Fourier transformed beam motion vs. horizontal kick (right): motion locks to the 4 Q_x + Q_y - resonance.

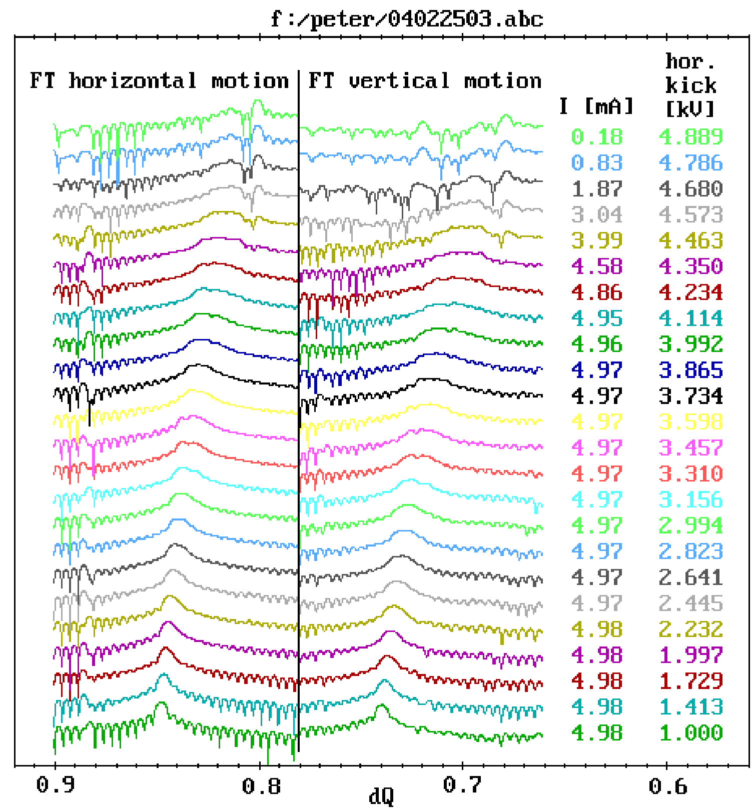
Measurement with the nominal distribution of compensating skew gradients.



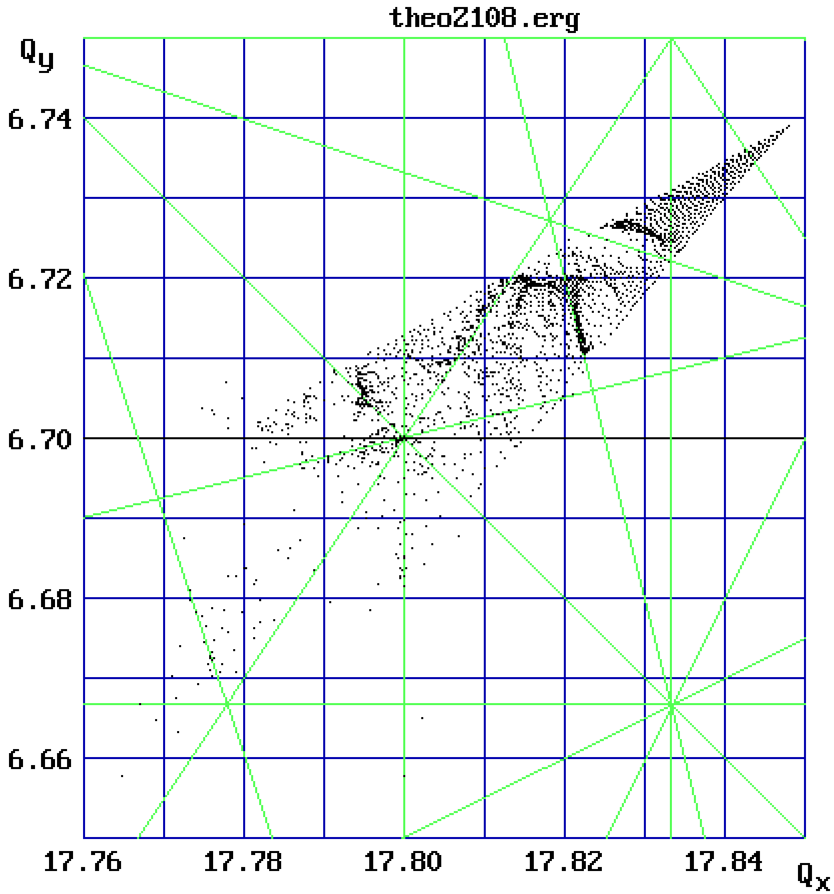
Beam motion for increasing horizontal kicks. With larger kick amplitudes the motion decoheres faster and faster. Around kicks with 4 kV the oscillations sustain for longer times and there is a strong correlation between the vertical and the horizontal planes.

“Frequency maps“ without any additional skew quadrupole and without harmonic sextupole components



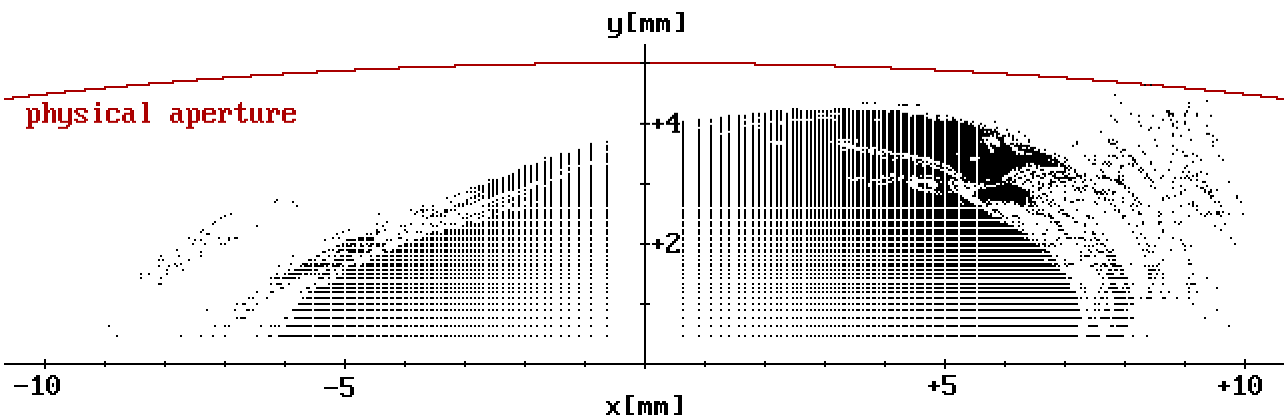


With different coupling correction locking to the 4 Q_x + Q_y- resonance dissappears.

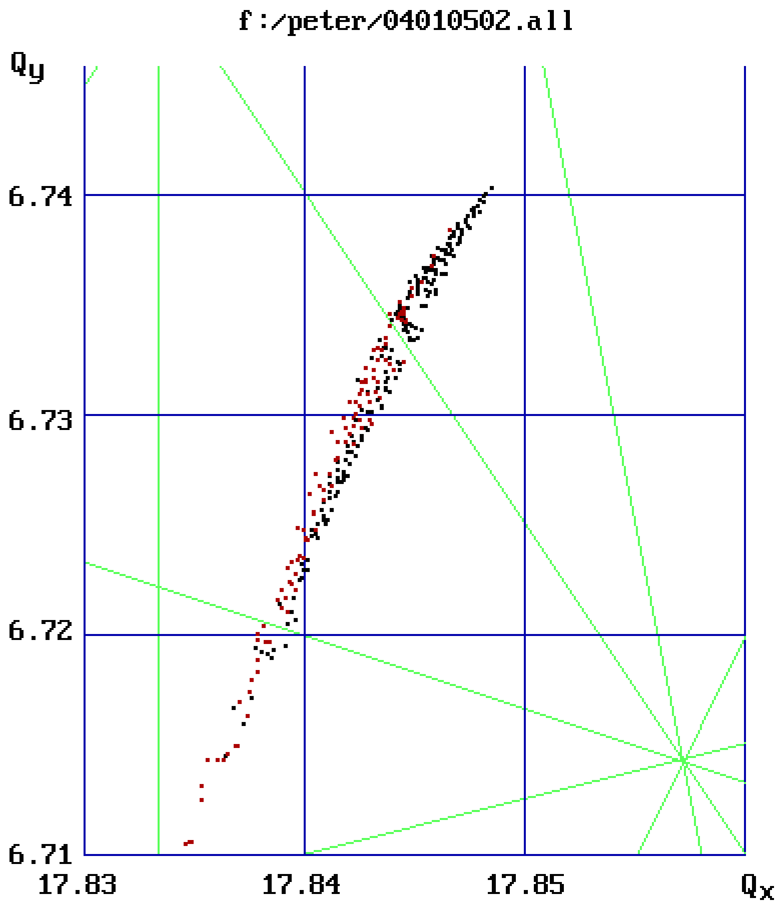


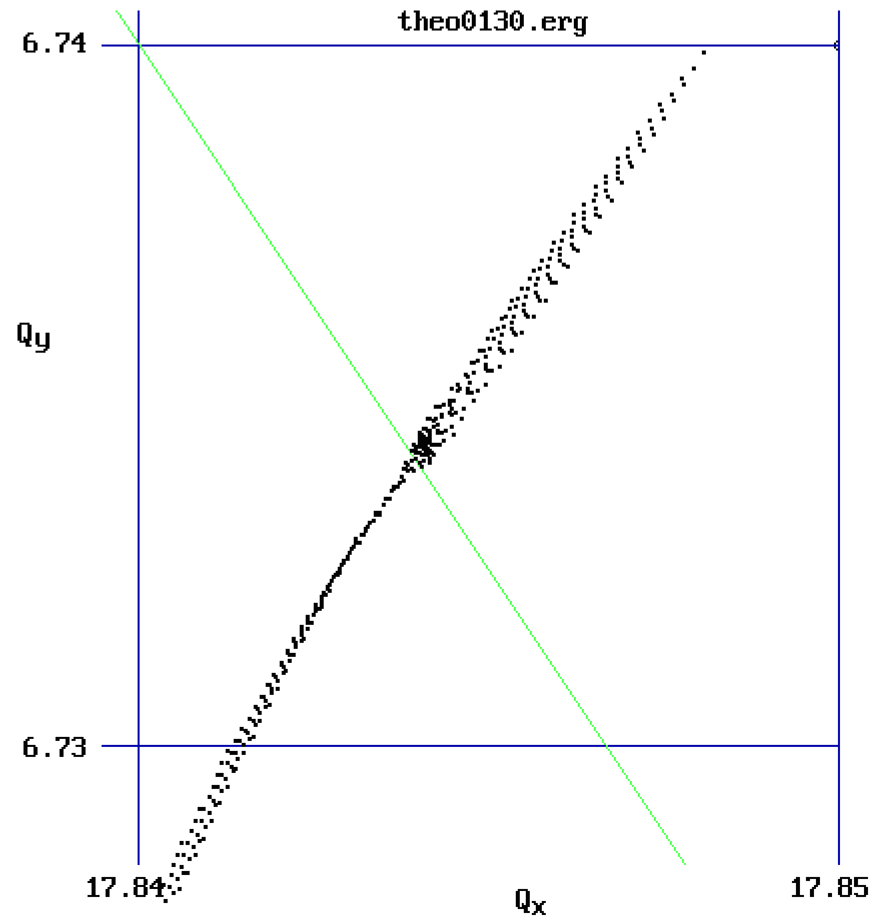
Theoretical frequency map - with small coupling errors and no harmonic sextupole magnets.

Appearance of the $3Q_x+Q_y$- and $4Q_x+Q_y$-resonance very similar to experiment.



Exotic Case- Strange Corrector Settings and $3Q_x+2Q_y$-resonance





Left - measured frequency map with zero chromaticities. Right - part of the theoretical map including decapole components as introduced by the horizontal corrector settings during the measurement.

Conclusions

Experimental as well as theoretical techniques for FMA are available at BESSY.

Data taking, data analysis and calculations are highly automated and quite flexible.

Predictions are good if fringe fields, coupling errors, and field perturbations in the sextupole magnets are included. 3rd generation light sources demand detailed modeling with realistic non-linear fields.

Importance of $2Q_x$-Q_y- and decapole-driven 5th order resonance was demonstrated.

Work will continue:

- Reducing the strength of the 5th order resonance and gain lifetime
- further improvements of the model in order to find better settings for the harmonic sextupole magnets