Transfer Matrix Measurements
(VUV-FEL KW46-47 and KW2)

Summary of 2 shifts beamtime during FEL Studies KW46-47 2005 and 2 shifts in KW02 2006:

- BPM calibration: Test measurements of the electronics
- Calibration measurements for Q9ACC7 and Q9/10ACC4 using the '180^o method'
- Matching in BC3 section and tracking
- Response Matrix Measurements in the Undulator

Motivation

GOAL: Understand the linear optics at on-crest acceleration (no collective effects), i.e. to be able to match the beam from diagnostics section (UBC2) up to undulator in accordance with linear optics programs with an accuracy of about 1%.

Prerequisites:

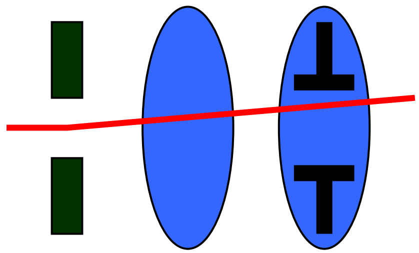
• Diagnostics (BPMs, OTRs, wire-scanners) need to be calibrated and understood

• Calibration constants of magnets need to be known precisely (beam energy needs to be known)

• Orbit and Dispersion correction

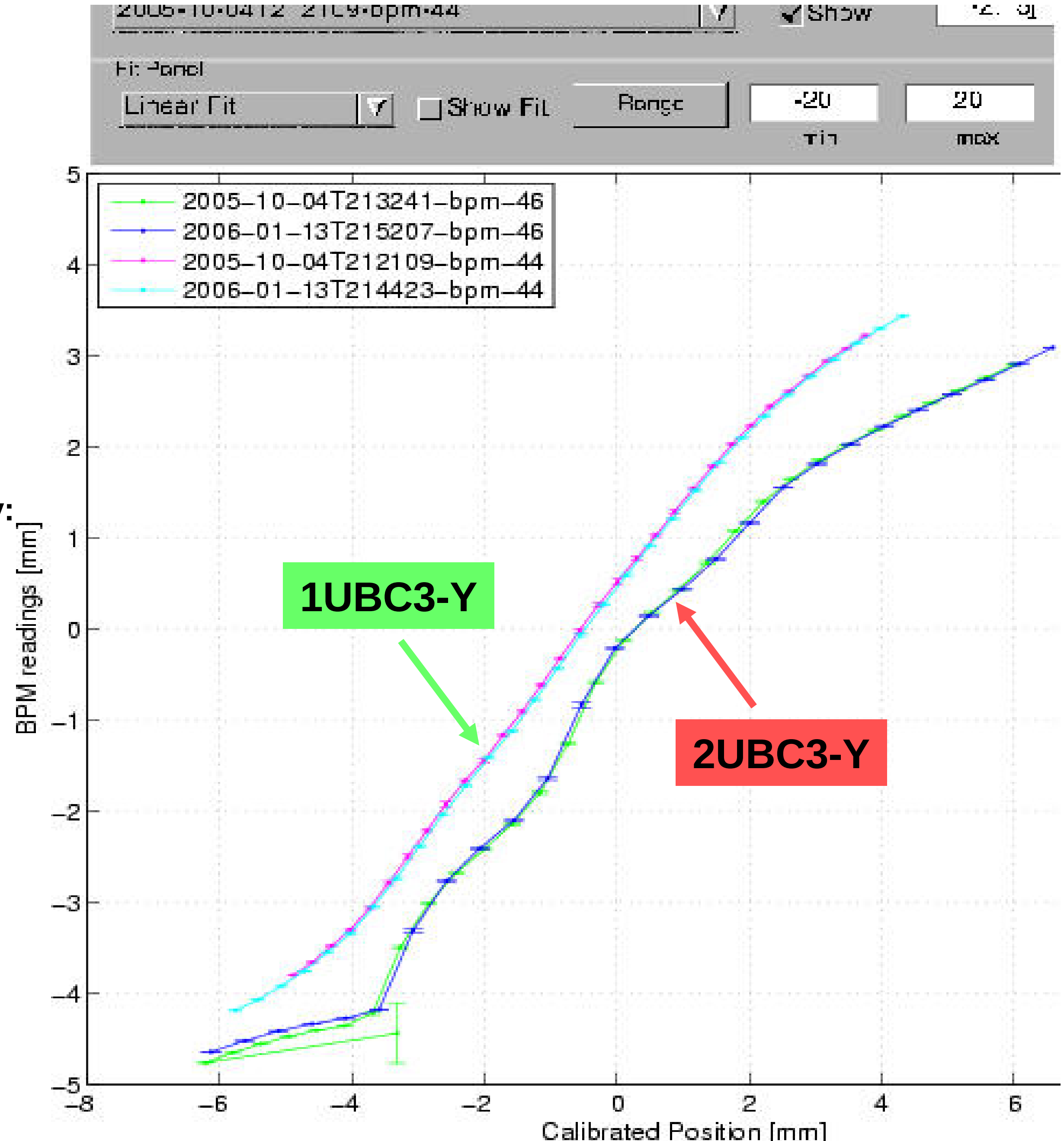
HOPE: To have gained sufficient knowledge about the optics that one is able to correct the optics at off-crest operation (bunch compression)

BPM Calibration: Test of electronics

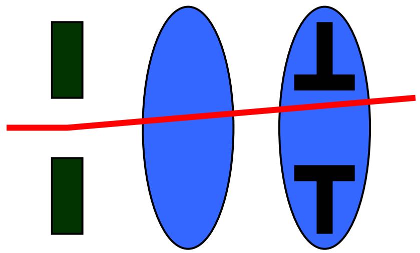


- **BPM response needs to be monitored:**
  Response has not changed over the past 3 months

- **Find/isolate source of non-linearity: Exchange electronics and recalibrate**



BPM Calibration: swap of electronics



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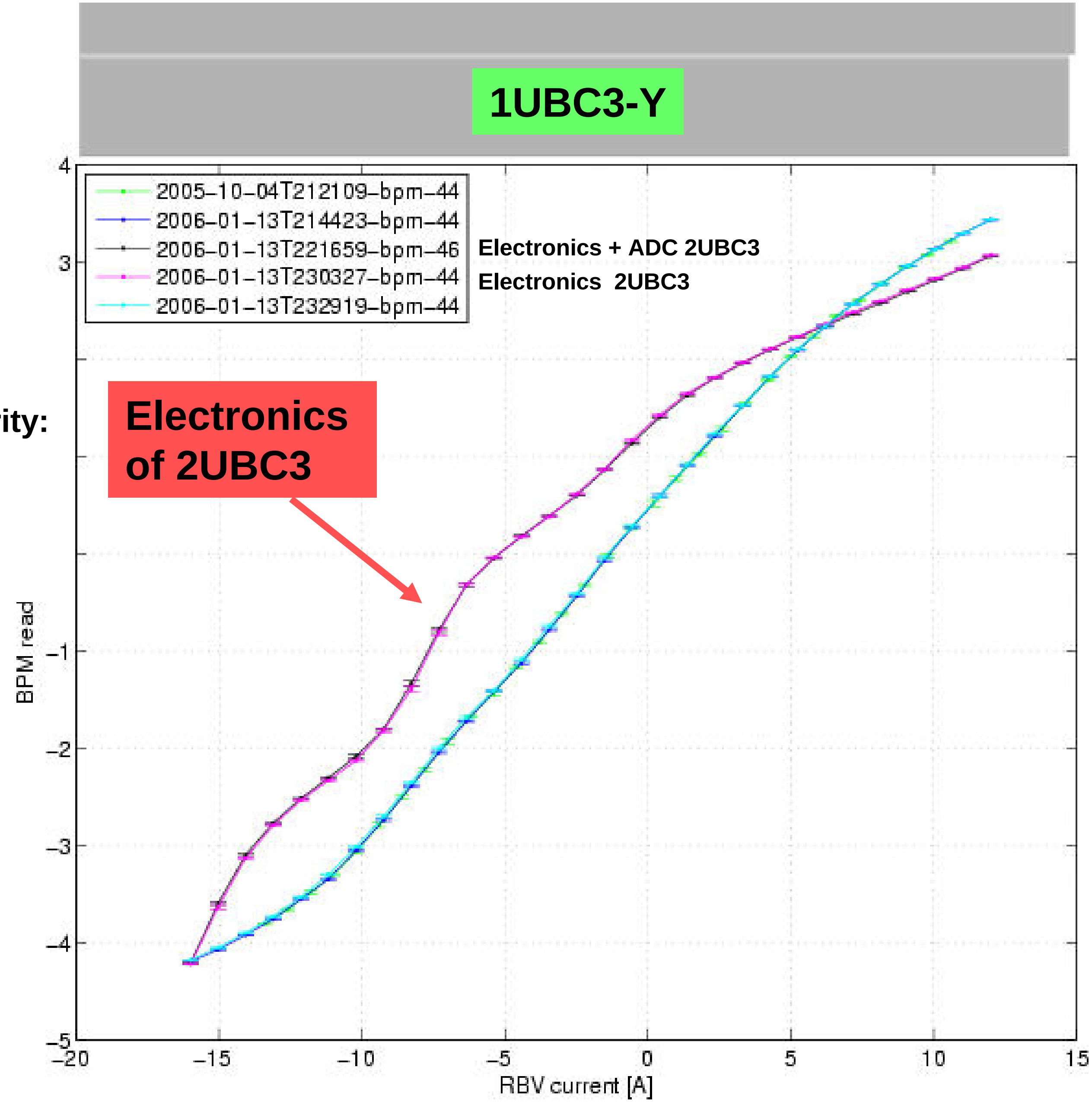
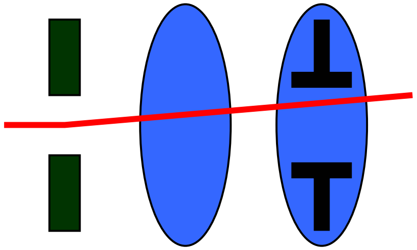
  Non-linearity connected to electronics



BPM Calibration: swap of electronics



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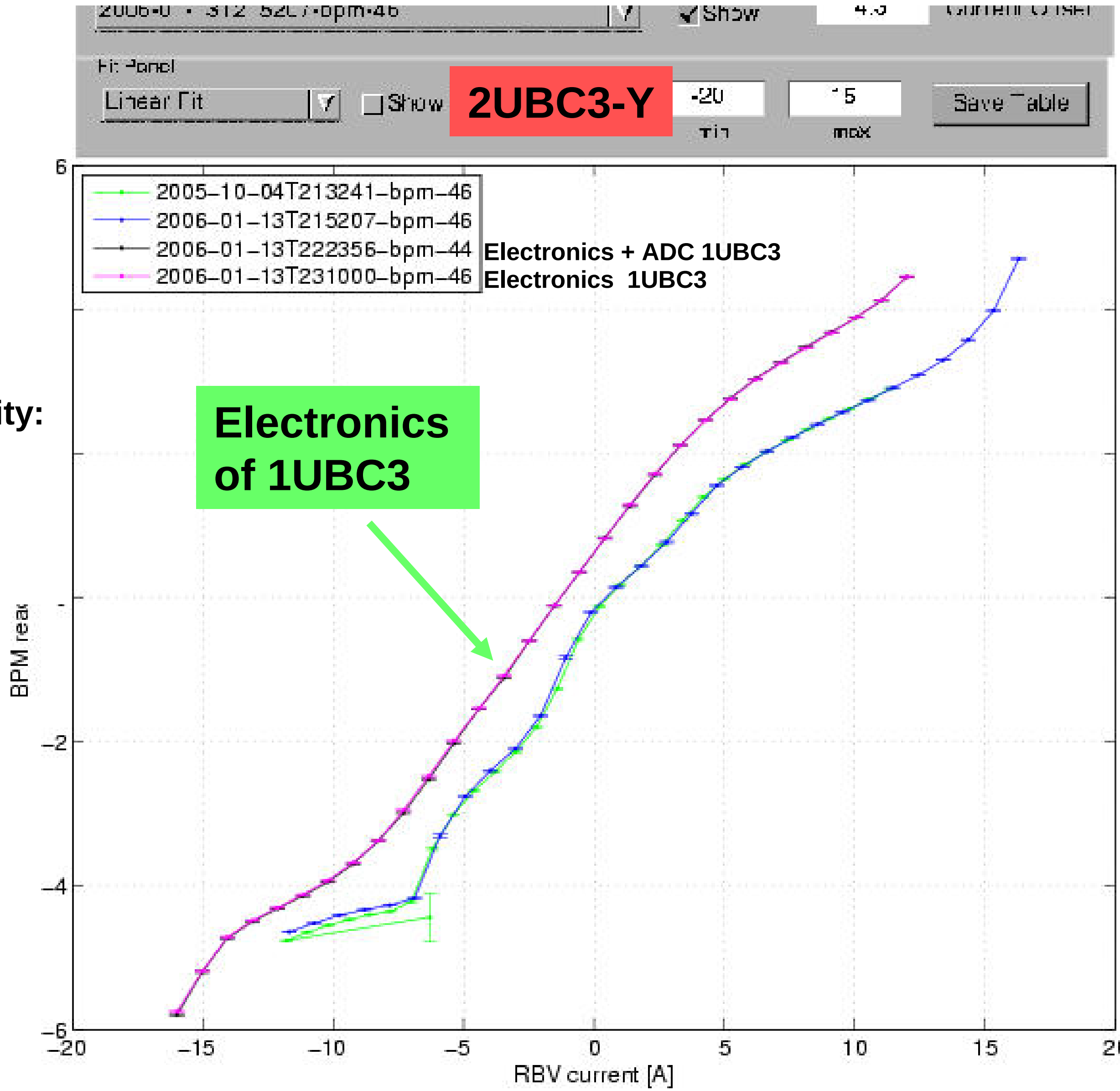
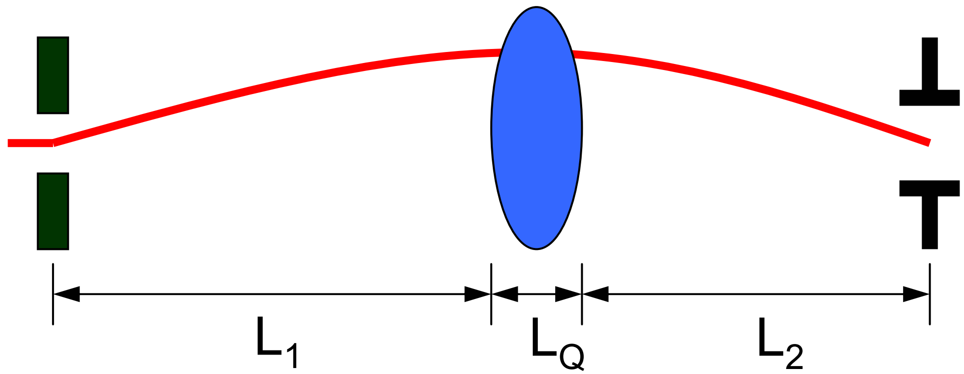


Quad Calibration: 180deg method



Transfer:

$$\begin{pmatrix} x_1 \\ x_1' \end{pmatrix} = R_{L1} R_{QF} R_{L2} \begin{pmatrix} x_0 \\ x_0' \end{pmatrix} = R \begin{pmatrix} x_0 \\ x_0' \end{pmatrix}$$

Difference Measurement:

$$\begin{pmatrix} x_2 \\ x_2' \end{pmatrix} = R \begin{pmatrix} x_0 \\ x_0' + \Delta x_0' \end{pmatrix}$$

$$\begin{pmatrix} x_2 \\ x_2' \end{pmatrix} - \begin{pmatrix} x_1 \\ x_1' \end{pmatrix} = \begin{pmatrix} \Delta x \\ \Delta x' \end{pmatrix} = R \left[\begin{pmatrix} x_0 \\ x_0' \end{pmatrix} - \begin{pmatrix} x_0 \\ x_0' + \Delta x_0' \end{pmatrix} \right] = R \begin{pmatrix} 0 \\ \Delta x_0' \end{pmatrix}$$

$$R_{12} = \frac{\Delta x}{\Delta x_0'}$$

Phase advance 180^0 $\iff \Delta x = 0 \iff R_{12} = 0$

$$R_{12} = (L1 + L2)\cos(\sqrt{k} L_Q) + (1 - \sqrt{k} L1 L2) sin(\sqrt{k} L_Q)$$

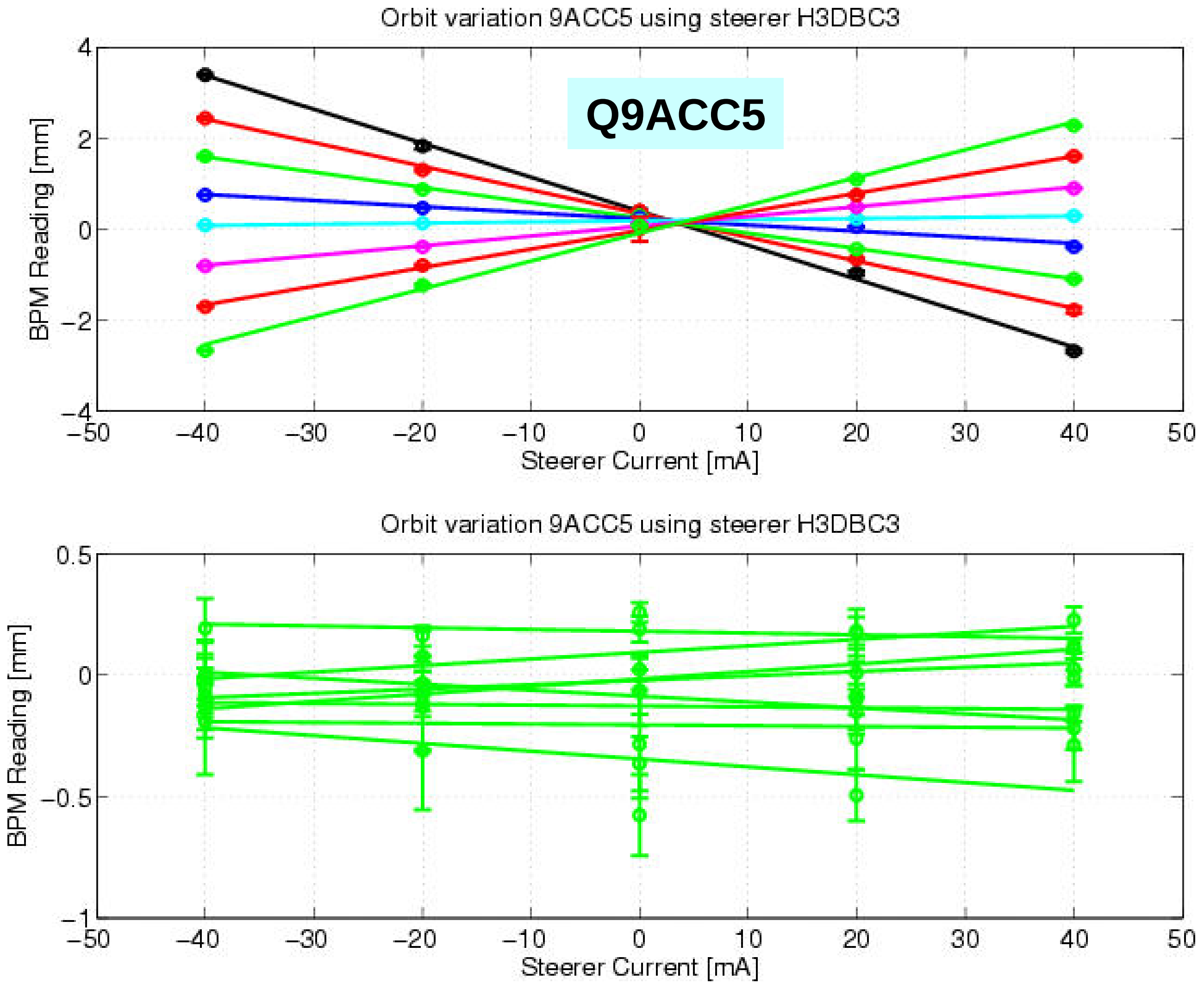
$$k = 299.8(A_0 + A_1 I)/E$$

Method independent of steerer and BPM calibration!

Only error sources: Lenghts L_1 and L_2 and Energy E

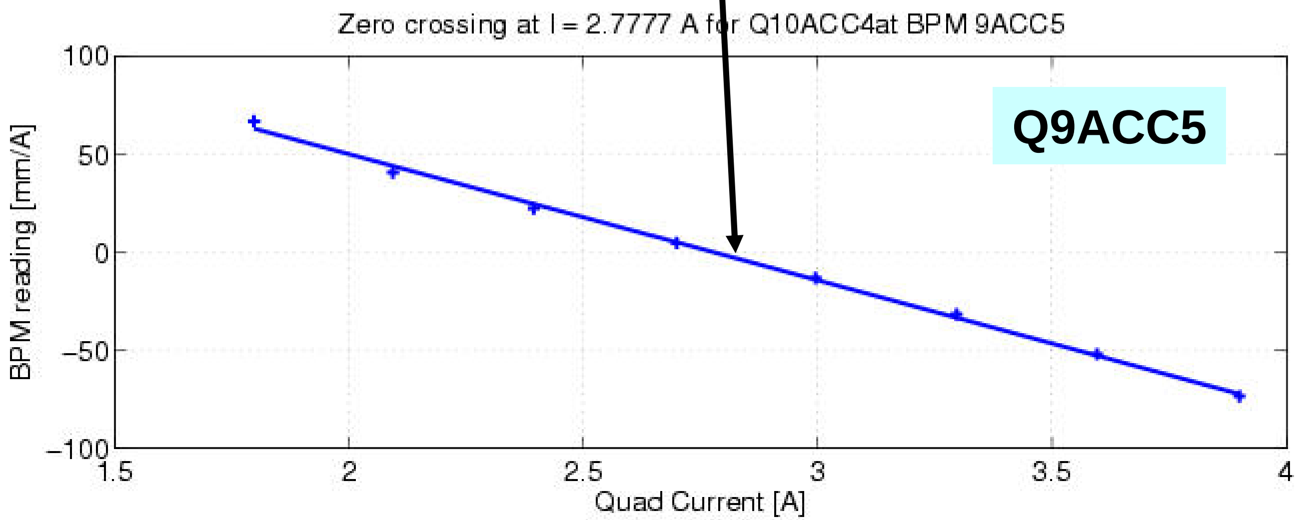
Quad Calibration: 180deg method

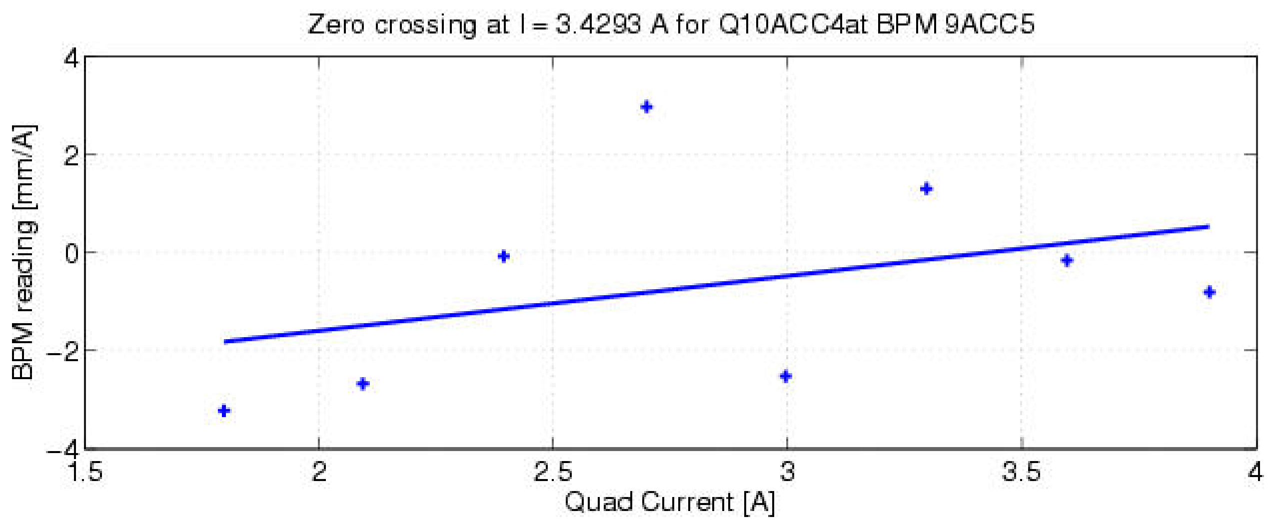
- Prerequisite: Only one Quad between steerer and BPM



Quad Calibration: 180deg method

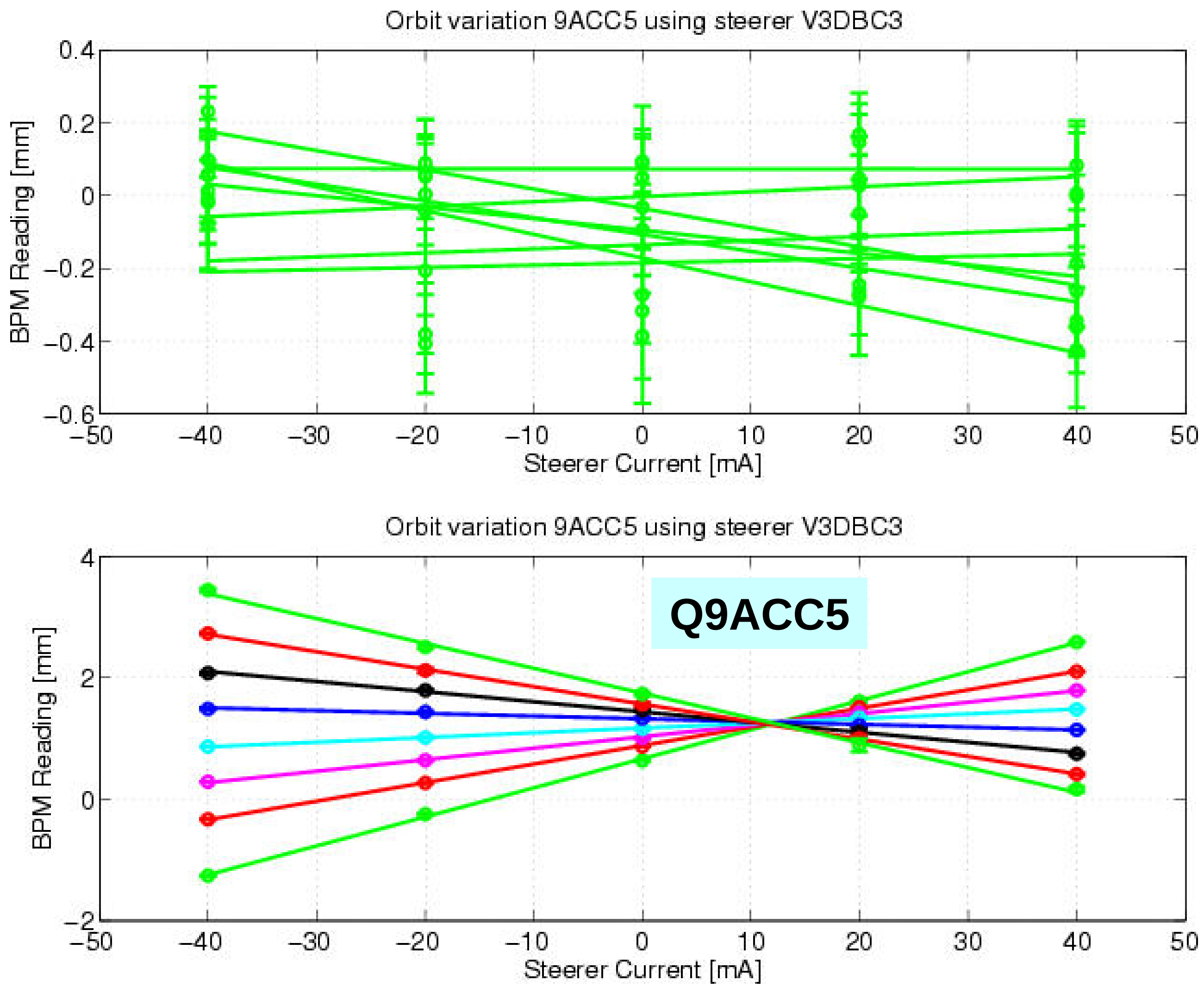
Fit inclinations of straights:
Zero crossing gives Quad current at 180deg phase advance



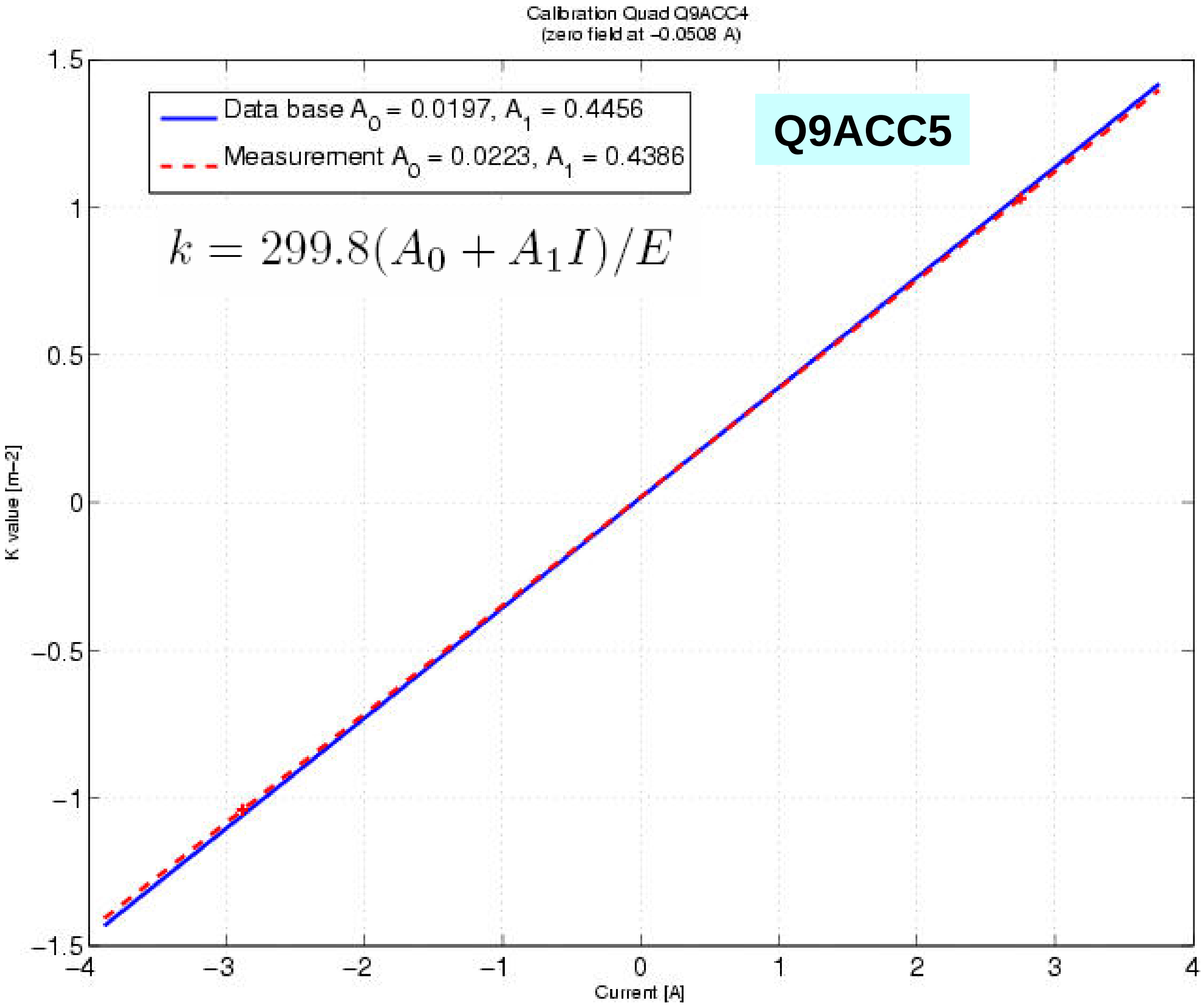


Quad Calibration: 180deg method

Same measurement for the vertical plane

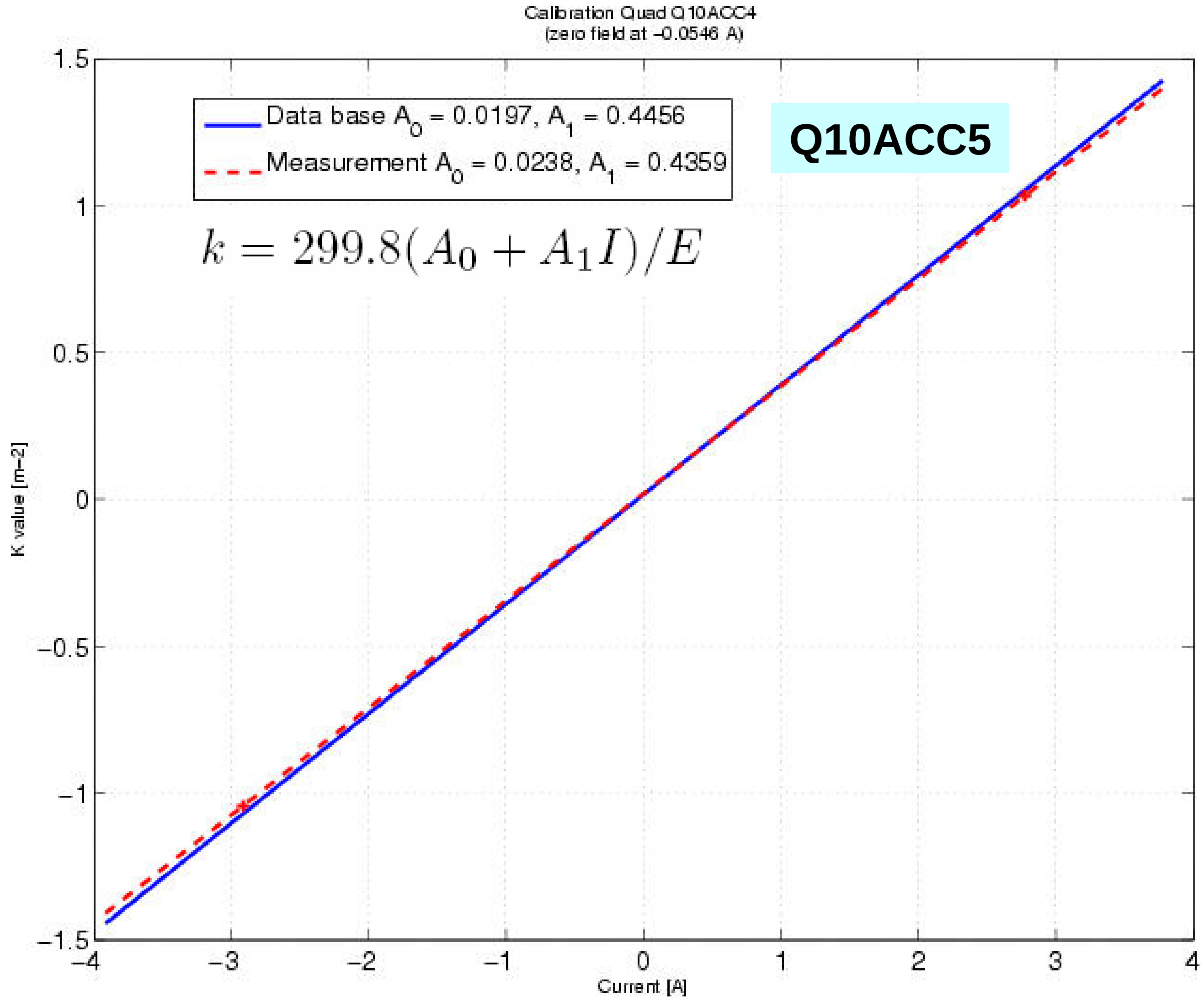


Quad Calibration: 180deg method



Good agreement with data from Hall probe measurements

Quad Calibration: 180deg method



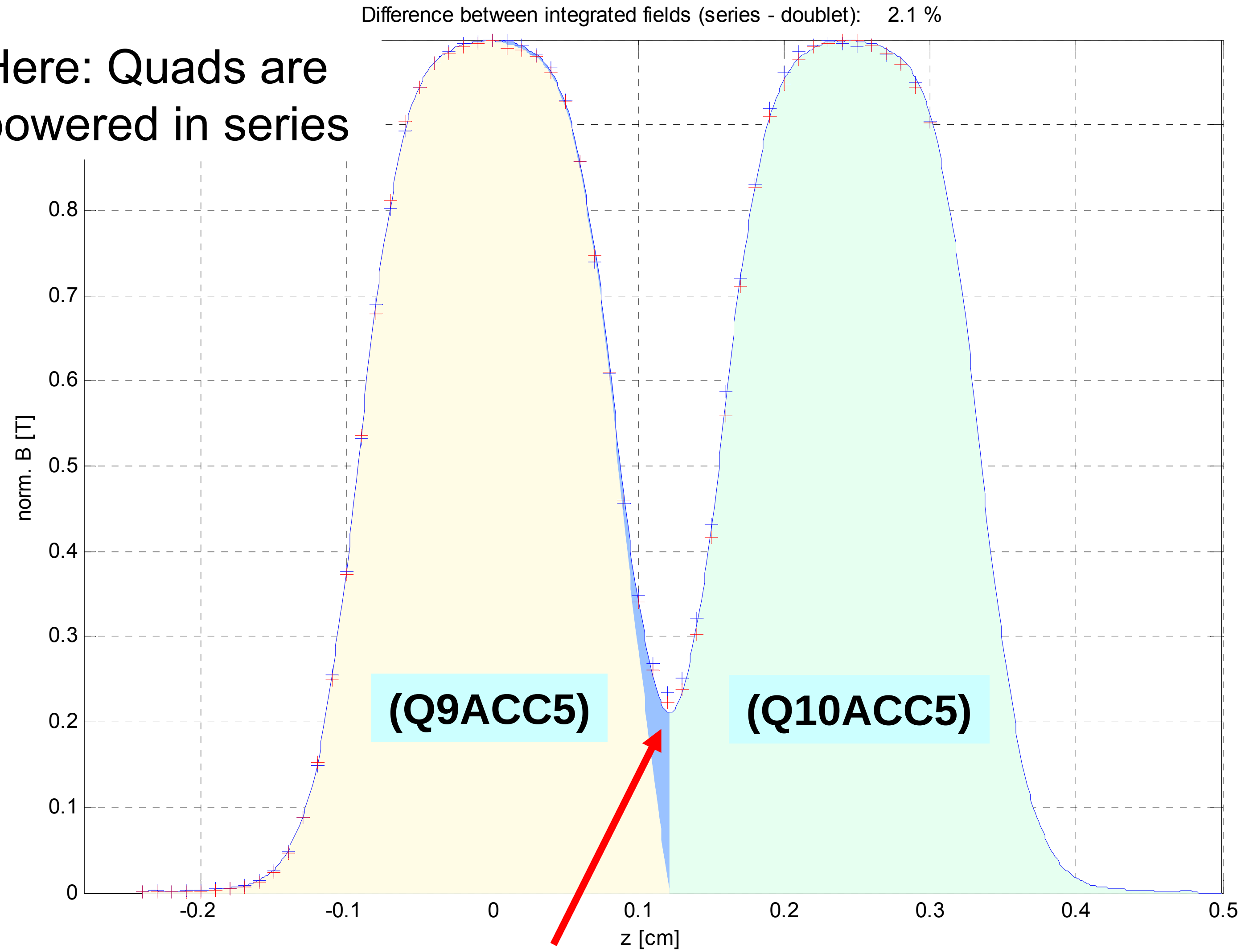
$$k = 299.8(A_0 + A_1 I)/E$$

1) Biggest Unknown: Beam Energy! BPMs and SR Monitors in BCs required

2) Energy measurement possible for a precisely measured Quad → XFEL?

What happens if magnets are operated as a doublet?

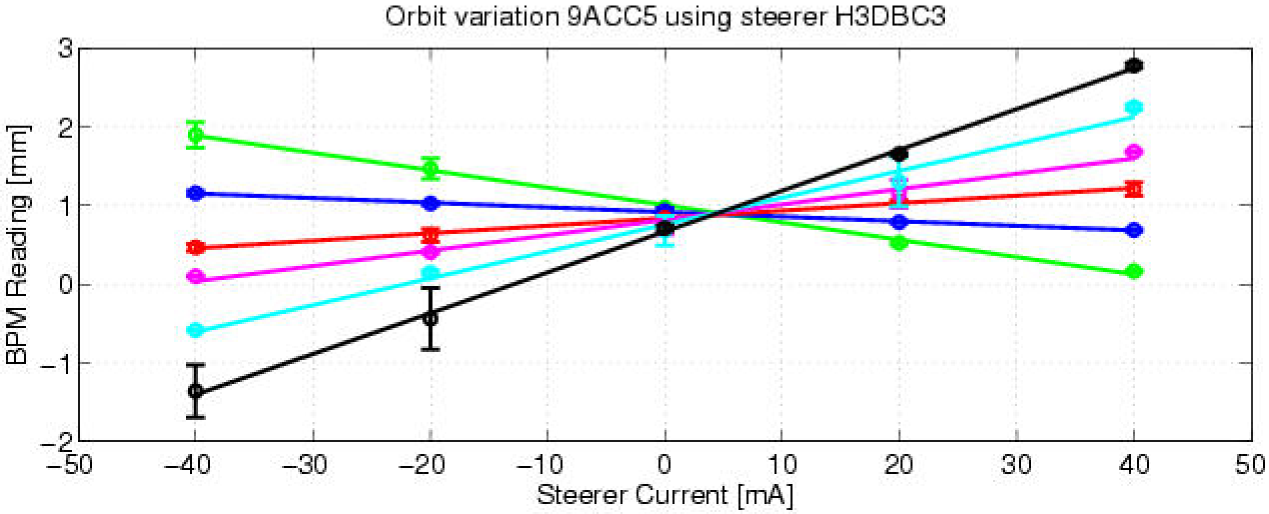
Here: Quads are powered in series

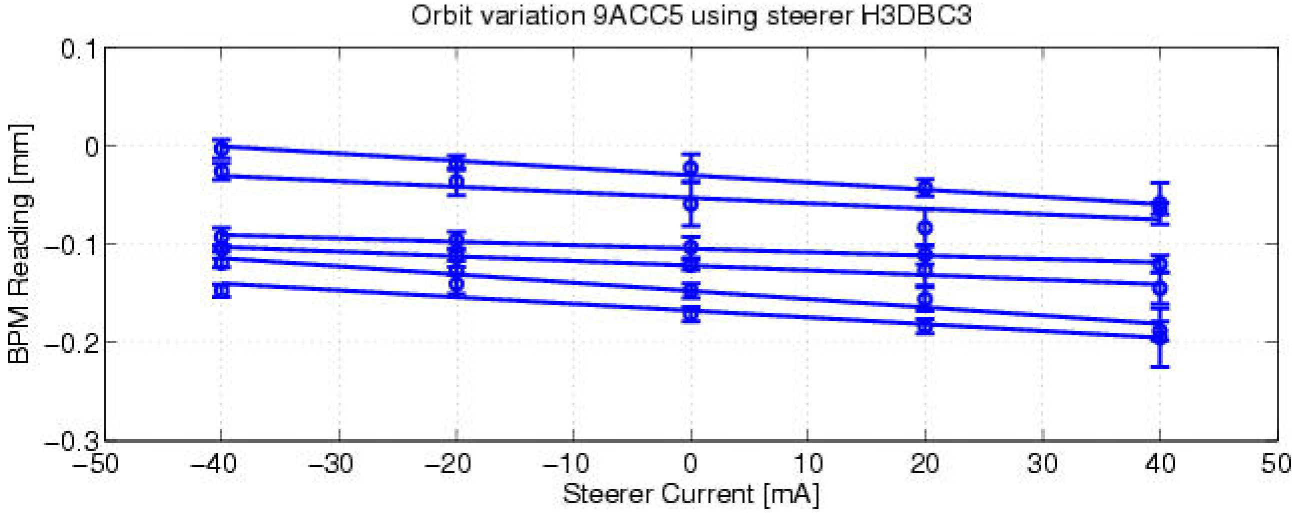


Magnetic fields overlap considerably!

Quad Calibration: 180deg method

Calibration measurement of Q9/10ACC5 Doublet:



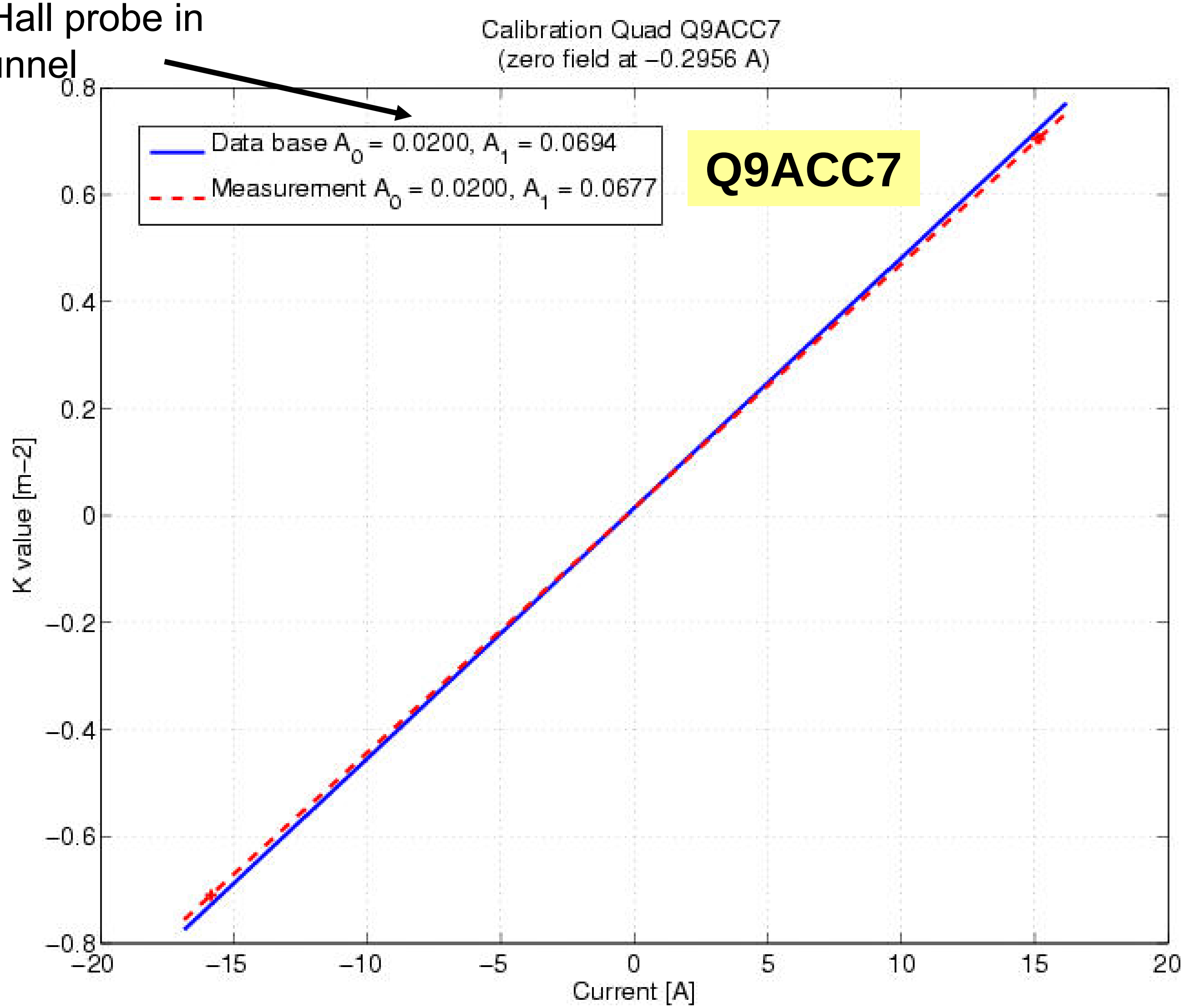


Measured K value 6.25% smaller compared to single Quad measurement!

Quad Calibration: 180deg method

Comparison Data Base and Measurement

Value measured with Hall probe in the tunnel

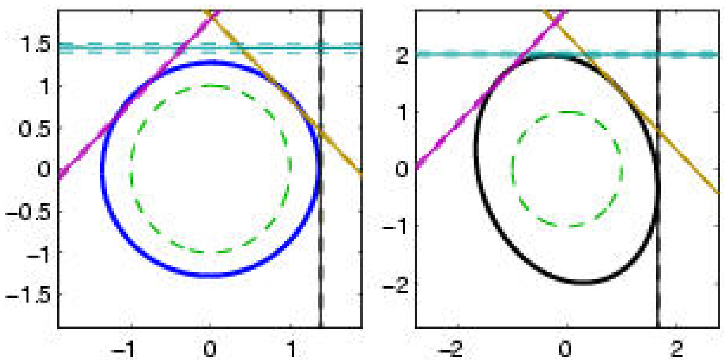


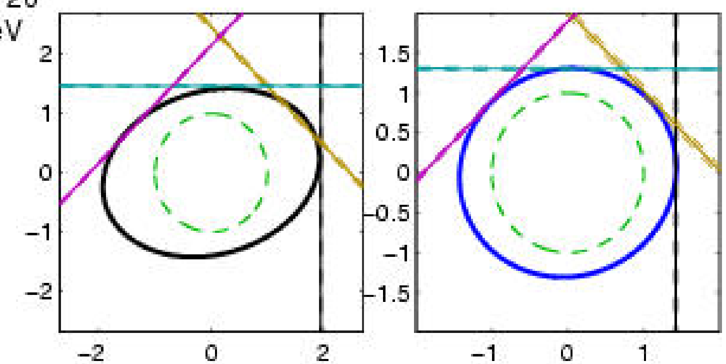
Matching at BC2 - BC3

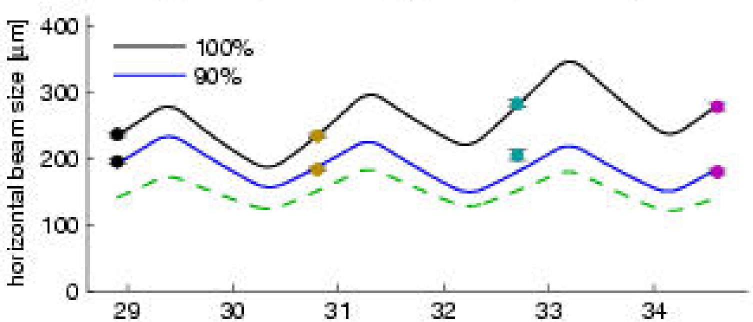
- On-crest operation ACC1, 1 nC
- Beam matched in DBC2

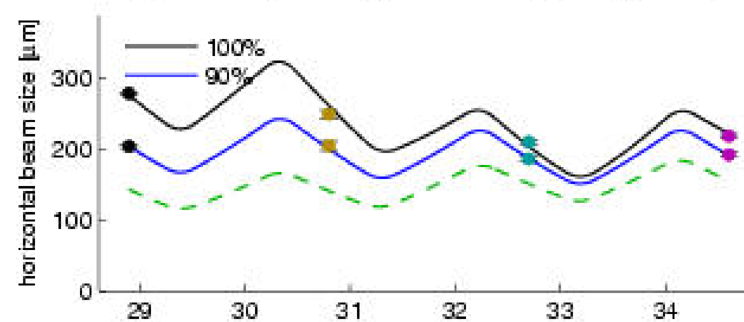
(90%)	x–plane	(100%)	11:17:13 14.01.2006	(100%)	y–plane	(90%)
3.475 ± 0.082	(2.0)	6.525 ± 0.098	$\gamma\varepsilon$ [mm mrad]	5.423 ± 0.093	(2.0)	3.728 ± 0.060
−1.279 ± 0.054	(−1.189)	−0.838 ± 0.031	α_{4DBC2}	1.503 ± 0.039	(1.219)	1.285 ± 0.039
2.639 ± 0.094	(2.474)	2.118 ± 0.044	β_{4DBC2} [m]	3.493 ± 0.072	(2.546)	2.783 ± 0.051
195.4 ± 2.8	(141.1)	236.4 ± 2.8	σ_{4DBC2} [μm]	278.8 ± 2.3	(143.1)	203.8 ± 2.2
183.5 ± 3.1	(141.1)	234.5 ± 2.7	σ_{6DBC2} [μm]	249.4 ± 5.2	(143.1)	204.9 ± 6.6
205.2 ± 7.4	(141.1)	282.8 ± 5.9	σ_{8DBC2} [μm]	210.3 ± 3.9	(143.1)	186.4 ± 2.8
179.9 ± 3.8	(141.1)	278.3 ± 5.1	σ_{10DBC2} [μm]	218.7 ± 3.0	(143.1)	192.2 ± 3.2
4.558	(2.0)	7.056	$\gamma\varepsilon_1$, $\gamma\varepsilon_2$	4.690	(2.0)	2.273
0.068	(0.0)	0.282	beta beating	0.415	(0.0)	0.105
1.002	(1.0)	1.031	B_{mag}	1.061	(1.0)	1.005

# images / screen = 20
energy = 127.00 MeV
charge = 0.98 nC



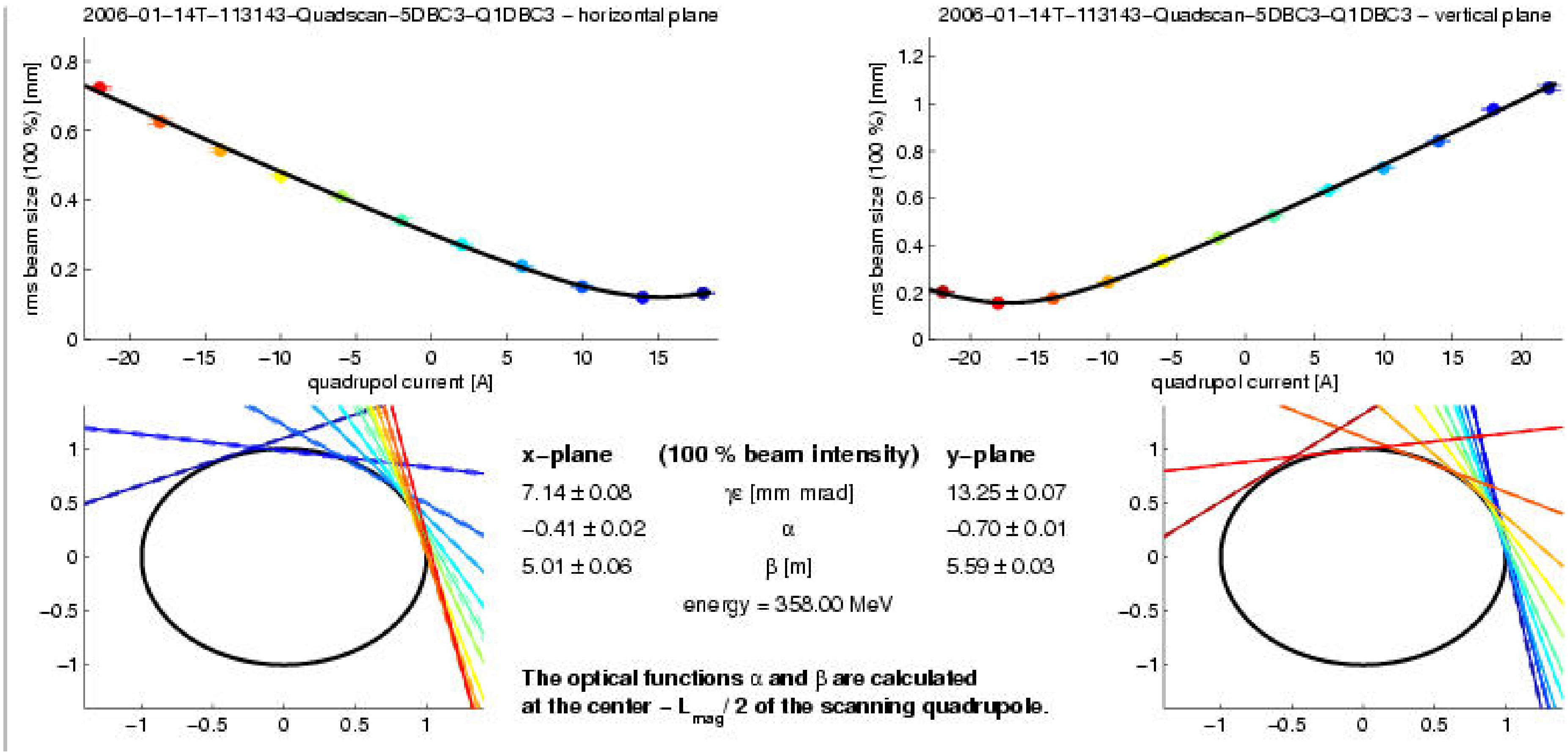






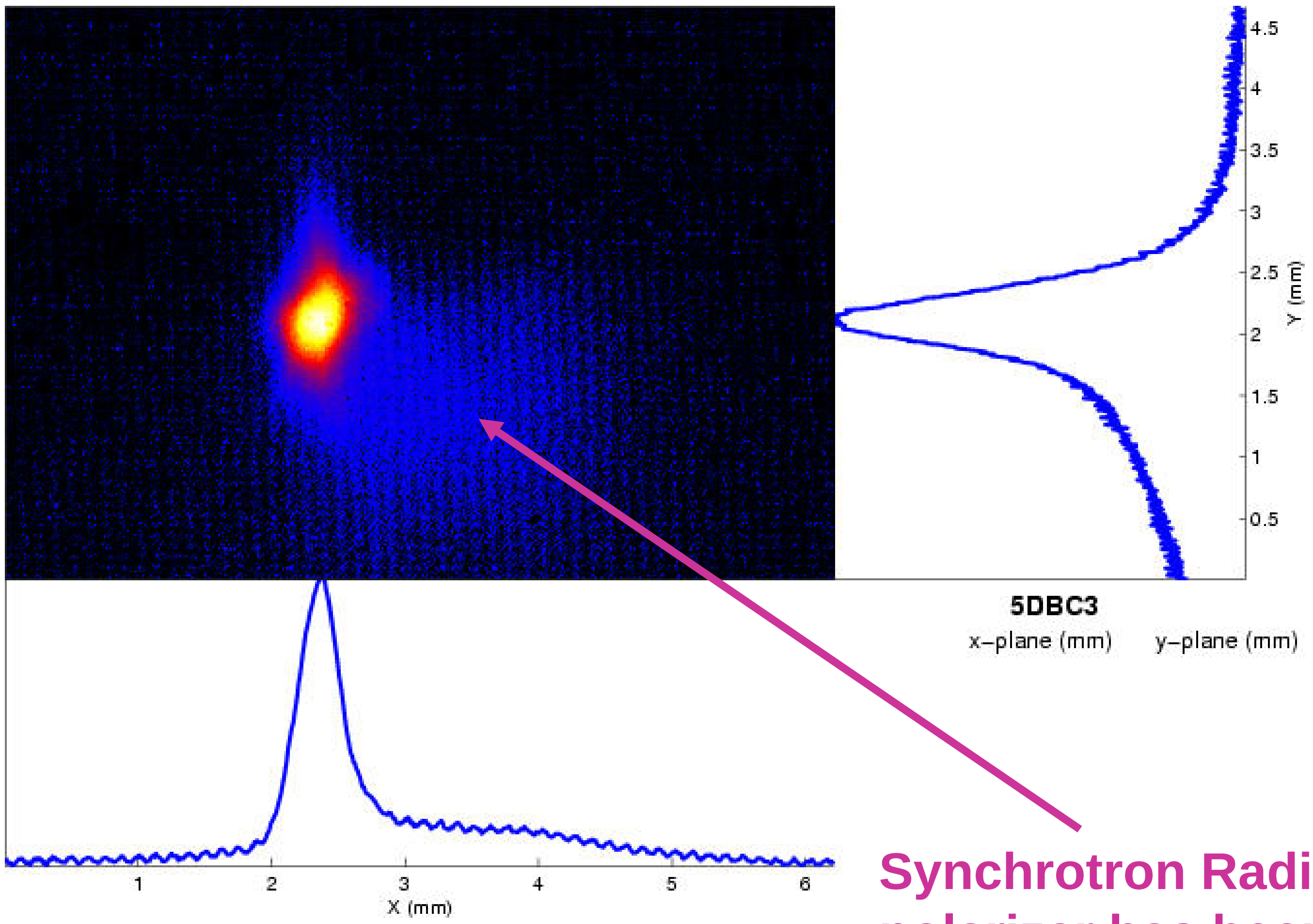
Matching at BC2 - BC3

- On-crest operation ACC2/3, 1 nC
- Quad scan at Q1DBC3



Matching at BC2 - BC3

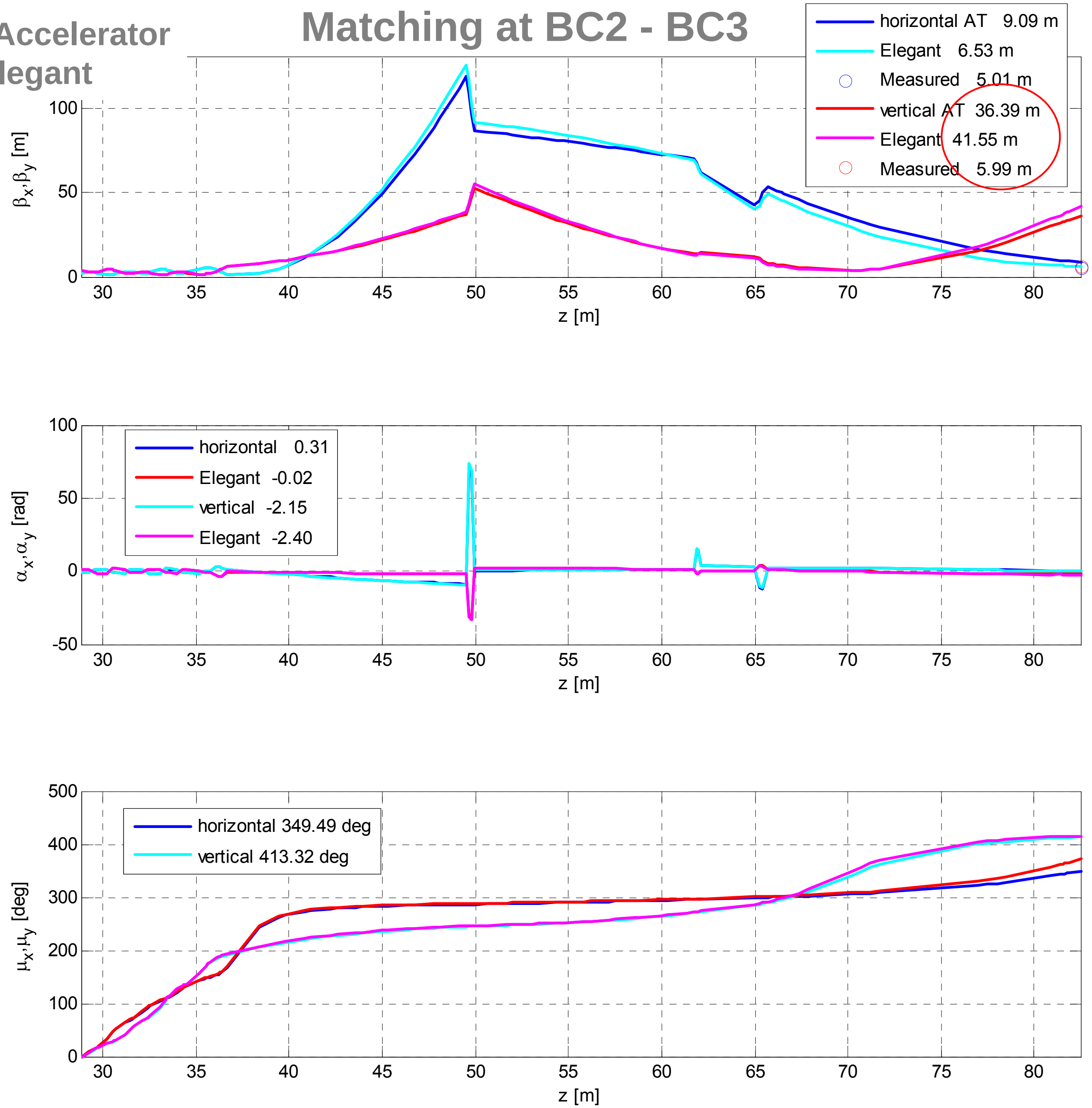
Quad Scan data evaluation was only possible with Gauss Fits



Synchrotron Radiation?
polarizer has been installed

Tracking with Accelerator Toolbox and Elegant

Matching at BC2 - BC3

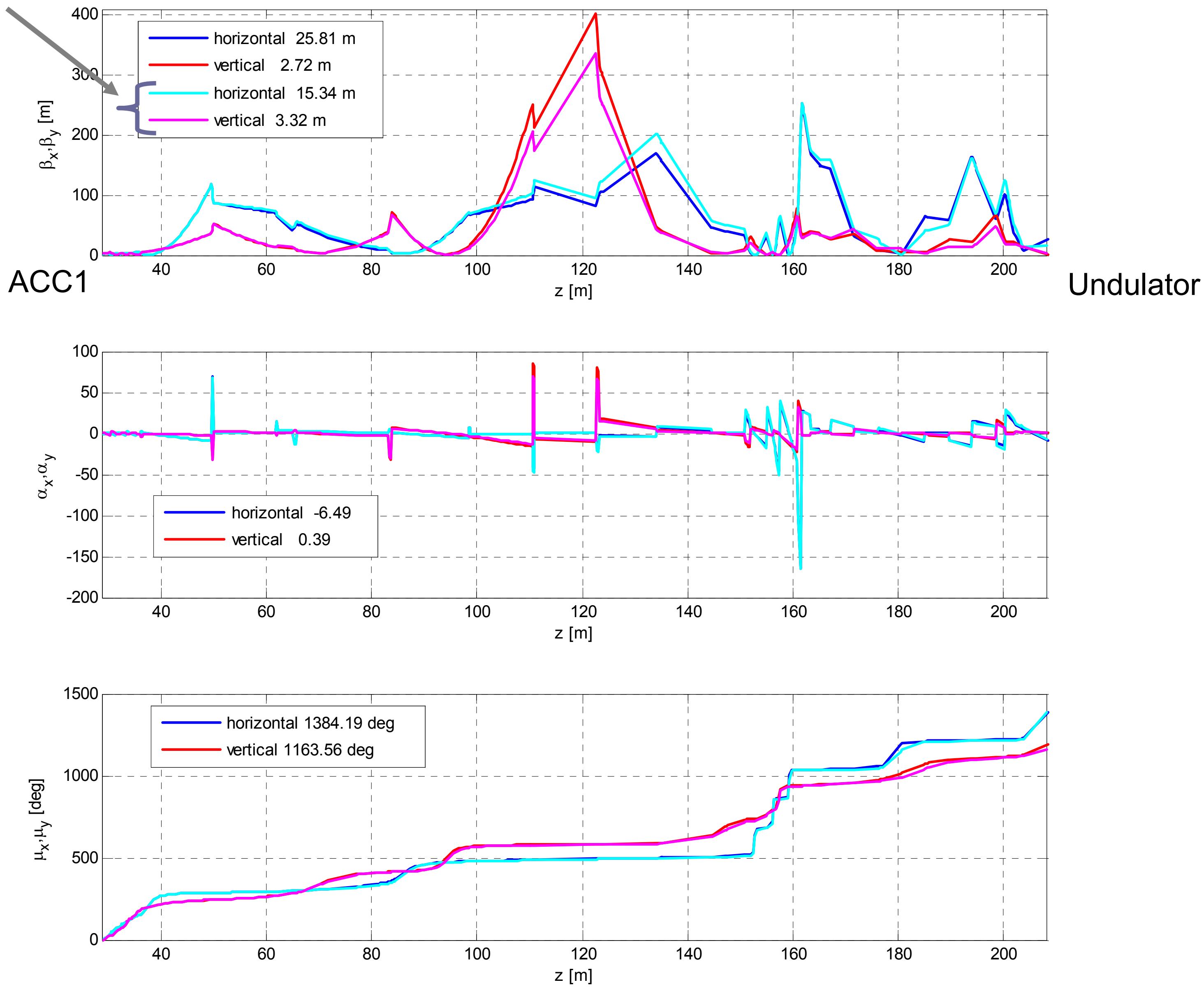


Large deviation in vertical plane: Measurement or Model?

Next time: Take images at intermediate OTRs !

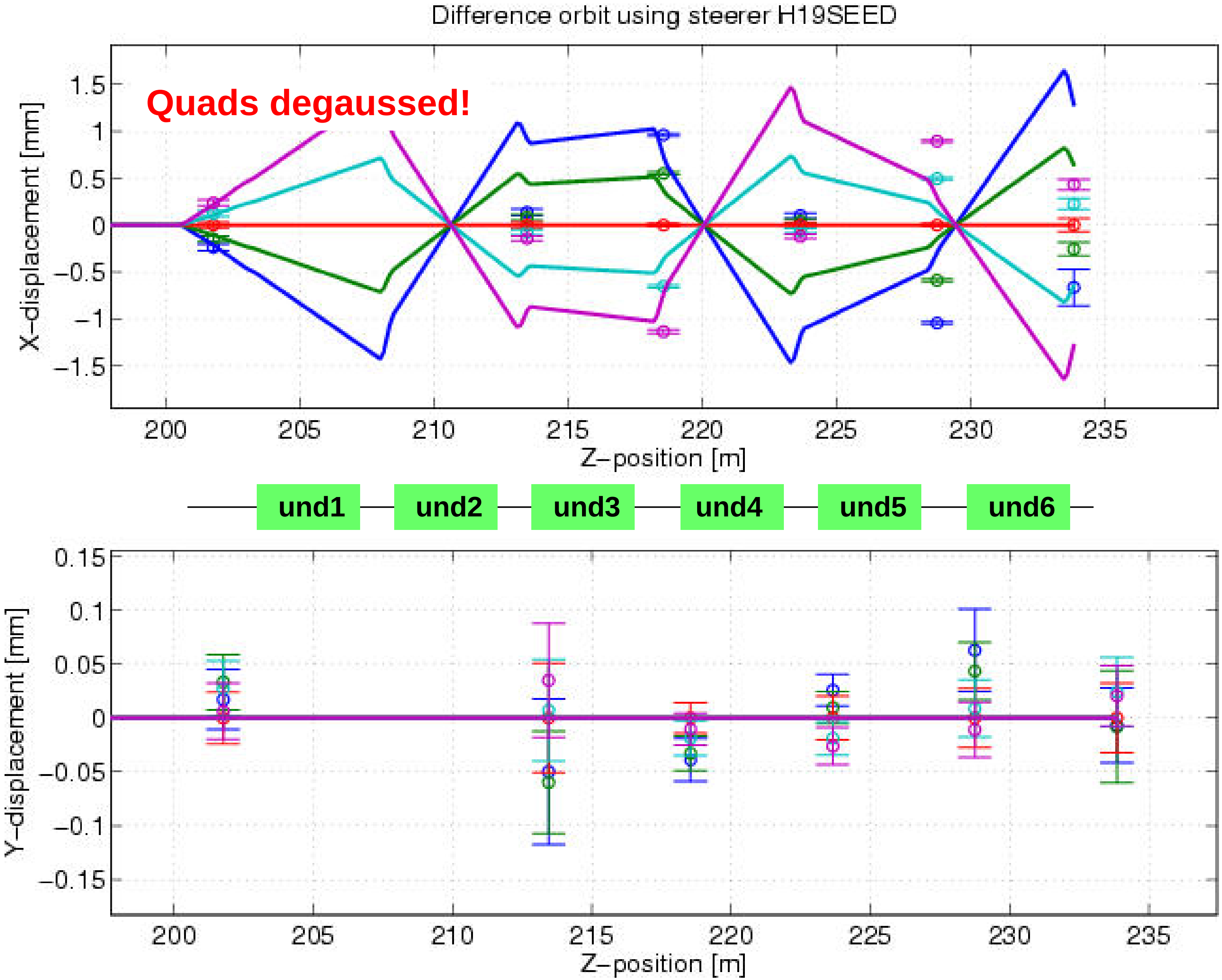
Tracking for 1% Energy Deviation

1% energy deviation for comparison

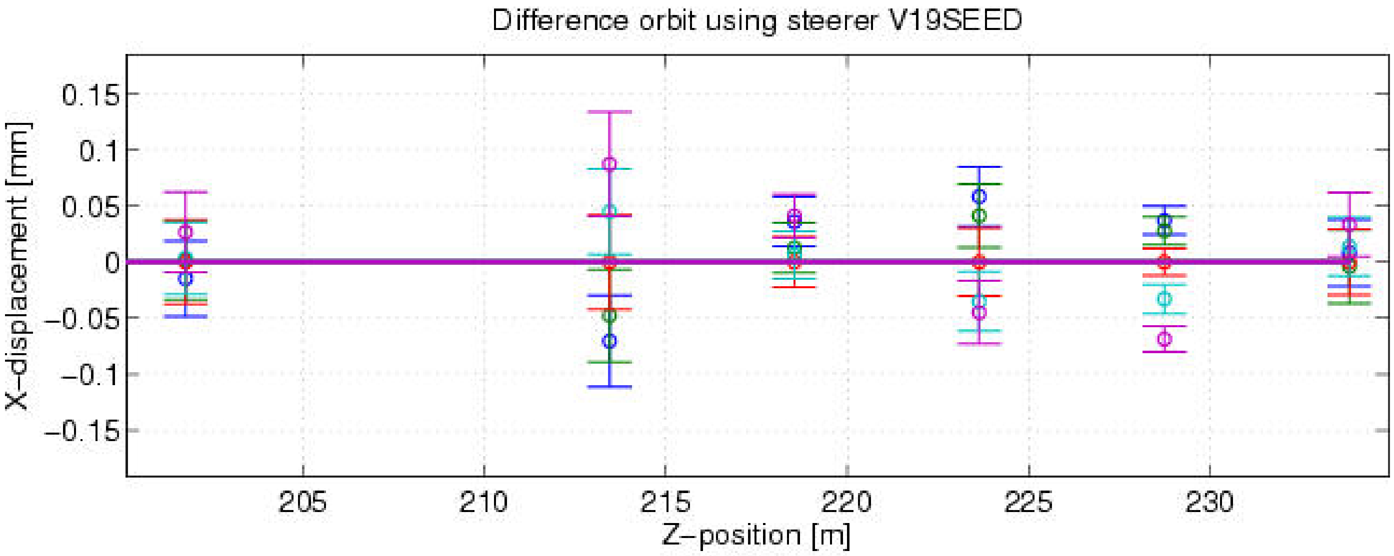


To get a feeling how sensitive the tracking is to energy errors, the gradient in the individuals modules was changed randomly by up to 1% whilst the total energy after ACC5 was kept constant at 445 MeV. Precise knowledge of the energy along the linac is required for accurate modelling!!

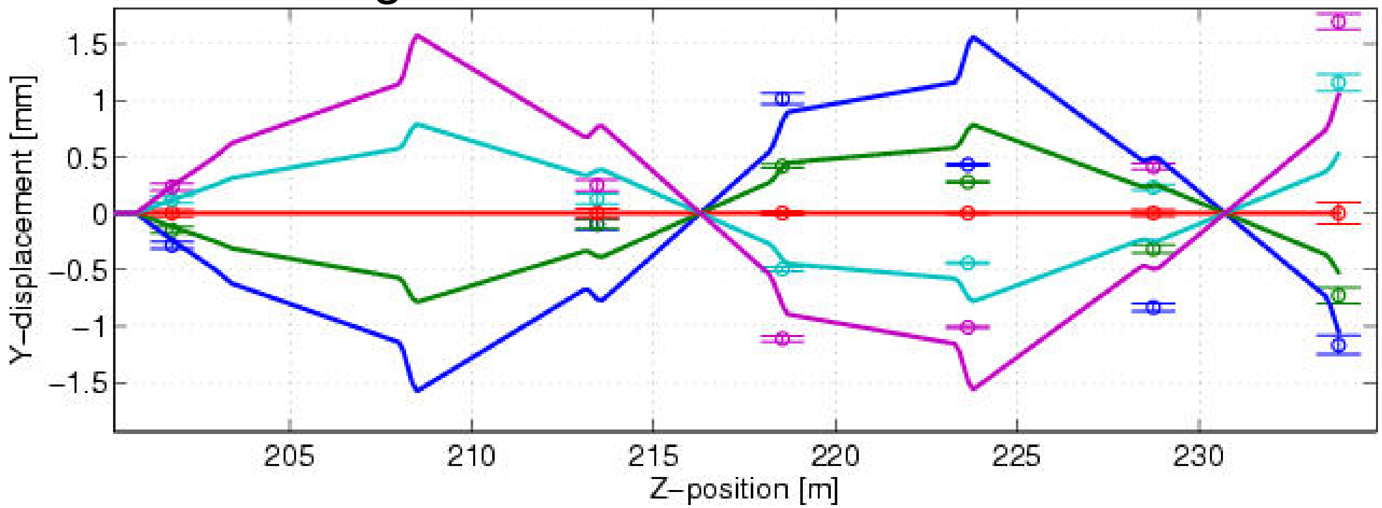
Response Matrix Undulator



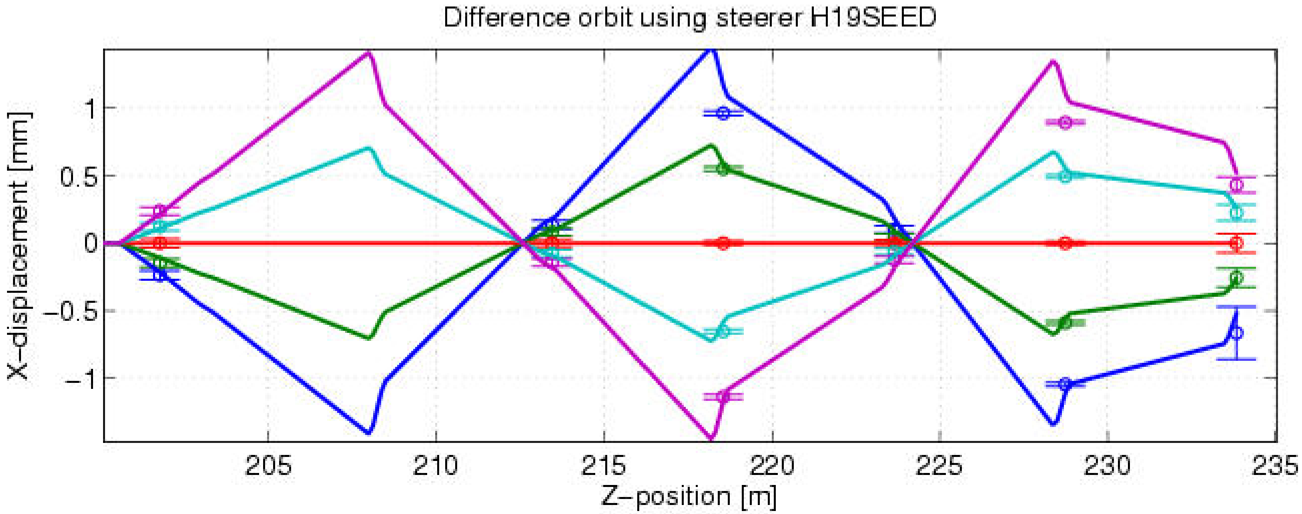
Response Matrix Undulator

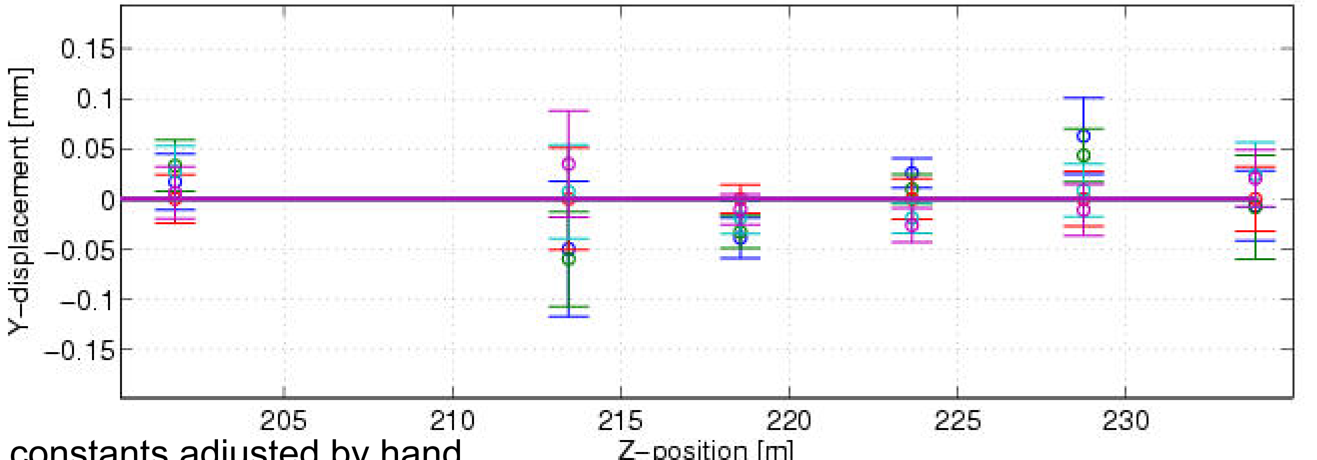


Natural Focusing included



Response Matrix Undulator

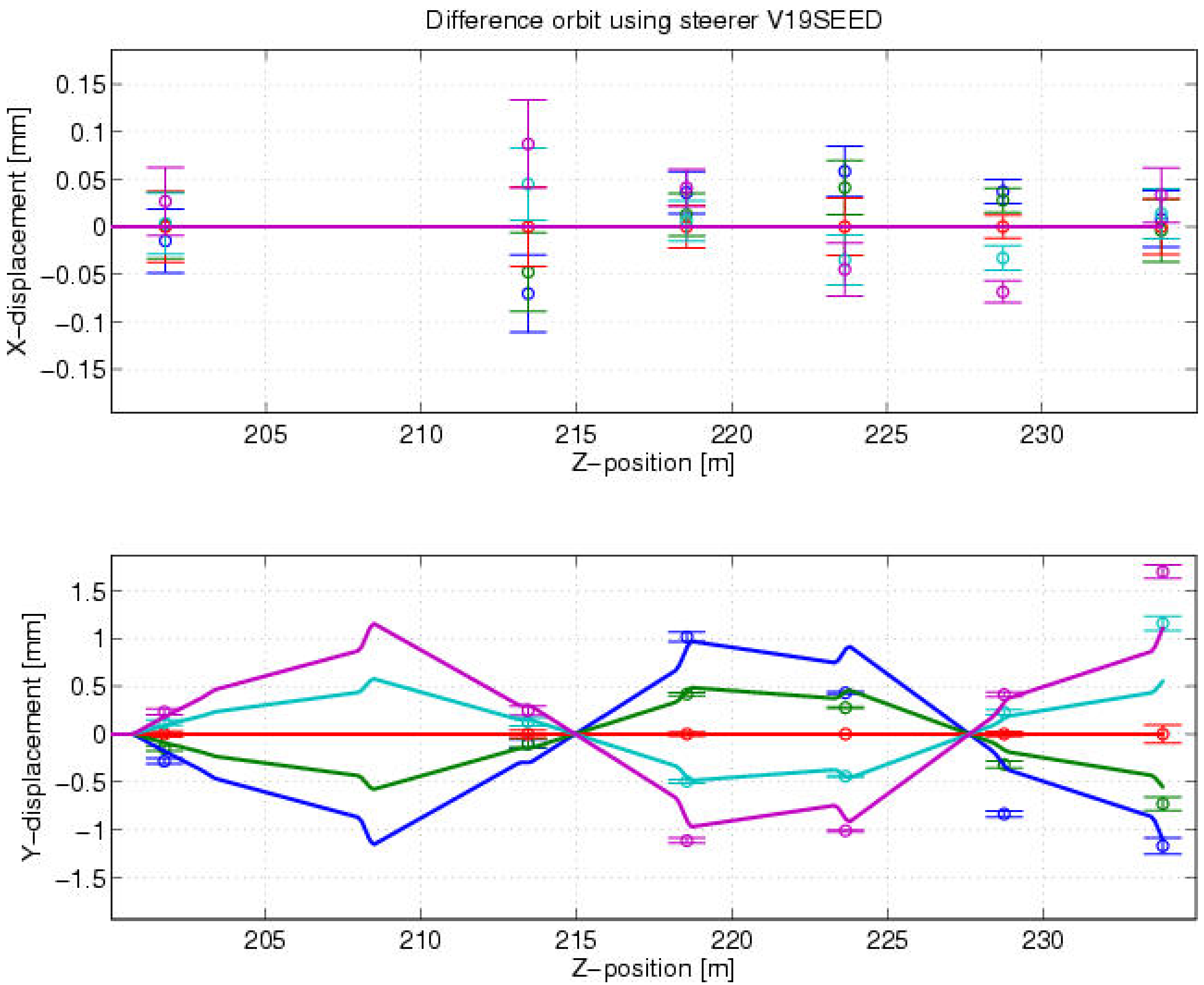




Calibration constants adjusted by hand

	data base	'adjusted' value	
A0_FIELD	0.6	0.05	← Magnets degaussed: Remnant field zero!
A1_FIELD	0.67	0.61	← 10% deviation in parameter A1???

Response Matrix Undulator



Measurements for different Quad currents required for accurate determination of calibration constants

People involved

Nicoleta Baboi, Vladi Balandin, Bolko Beutner, Pedro Castro, Winni Decking, Chris Gerth, Nina Golubeva, Torsten Limberg, Dirk Noelle, Holger Schlarb