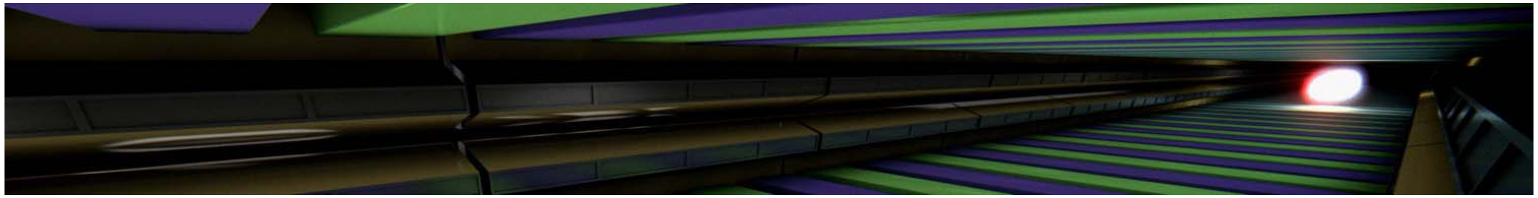


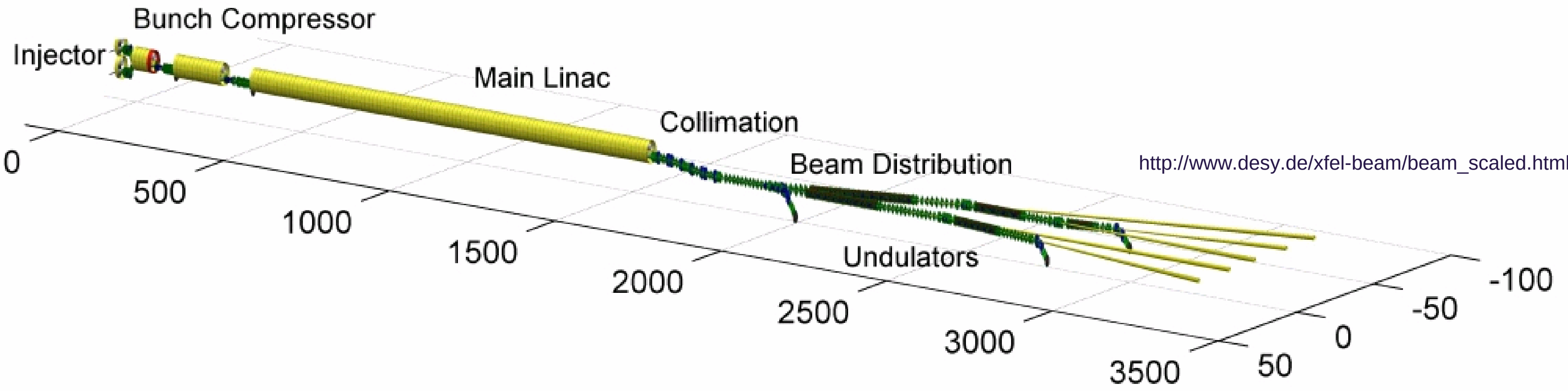
Status Cavity BPM's for E-XFEL

Dirk Lipka, MDI, DESY Hamburg

Content

1. Requirements
2. Overview (all BPM's)
3. In kind contribution (Saclay, DESY, PSI)
4. Cavity BPM: principle
5. Design
6. Measurements:
   a. Laboratory measurements: frequency and loaded Q, compare with expectation (second generation)
   b. Beam measurement: sensitivity, orthogonal coupling, compare first and second generation, compare with expectation, resolution measurement
7. Outlook: New teststand
8. Status
9. Summary

Overview



http://www.desy.de/xfel-beam/beam_scaled.html

Kind of BPM

- Cold button: accelerator modules
- Cold re-entrant cavity: accelerator modules
- Warm button: distribution system, compressor
- Warm cavity: intra bunch feedback system (IBFB), matching
- Undulator cavity: undulator

Requirements

Specified by Beam dynamics group

beam charge range: 0.1 – 1 nC

BPM Type	#	Beam Pipe Diameter	Maximum Length	Type	Single Bunch Resolution (RMS)	Drift over Bunch Train	Drift over 1 hour	Drift over 1 week	Max. resolution[1] range	Reasonable signal[2] range	Linearity	x/y cross-talk	Bunch to bunch crosstalk
		mm	cm		µm	µm	µm	µm	mm	mm	%	%	µm
Standard	219	40.5	20	Button	50	1	5	50	± 3.0	± 10	5	1	5
Cold	104	78.0	17	Button/ Re-entrant	50	1	5	50	± 3.0	± 10	10	1	5
Precision	12	40.5	20	Cavity	10	1	1	10	± 1.0	± 2	2	1	1
IBFB	2	40.5	20	Cavity	1	0.1	0.1	1	± 1.0	± 2	1	1	0.1
Precision	117	10.0	10	Cavity	1	0.1	0.1	1	± 0.5	± 2	2	1	0.1

[1] Maximum resolution means that within this operating range the BPM works according to the specifications within this table.
[2] Reasonable signal means that the BPM provides at least the correct sign for absolute position and position changes.

In kind contribution

All BPM for European XFEL (cold and warm)

Collaboration (institutes and task)

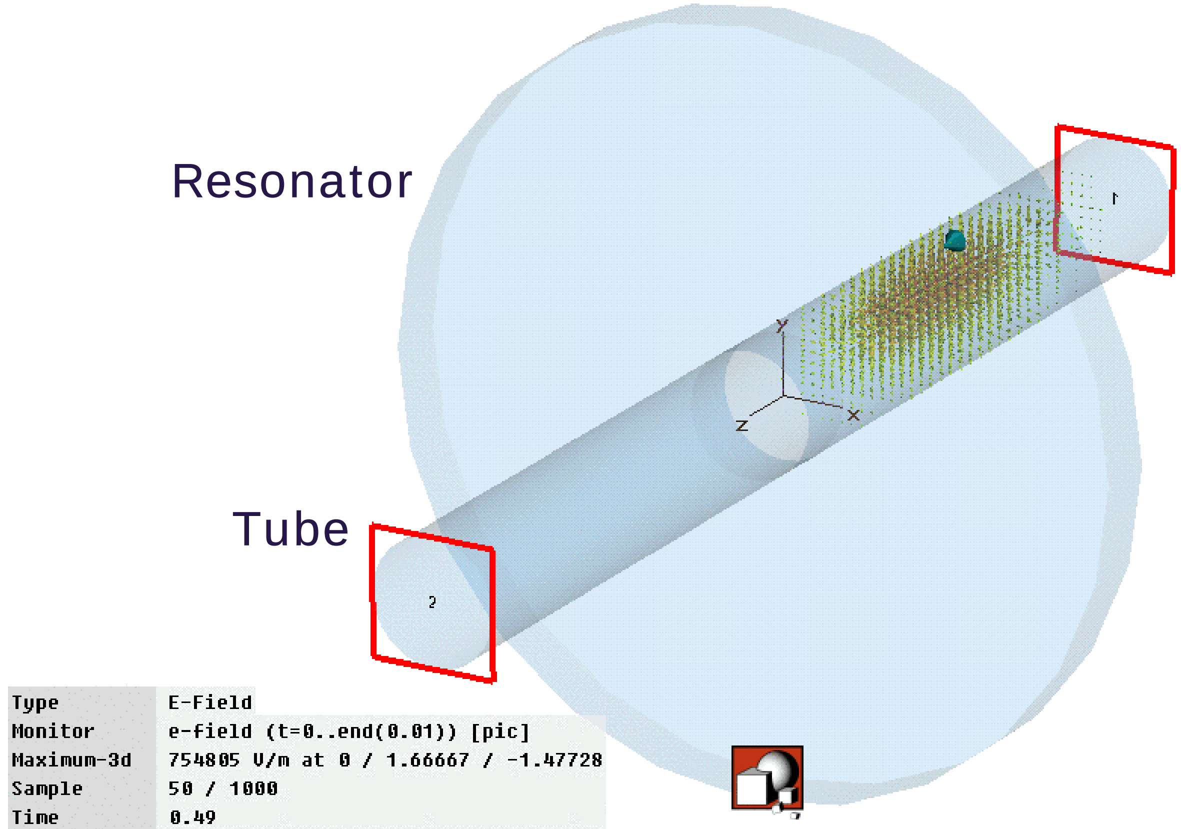
- Saclay: re-entrant cavity BPM for cold module including front end electronics
- DESY: button and cavity BPM mechanics
- PSI: front end electronics (button and cavity BPM) and digitalization (all)

Subject of this talk:

Cavity BPM from DESY

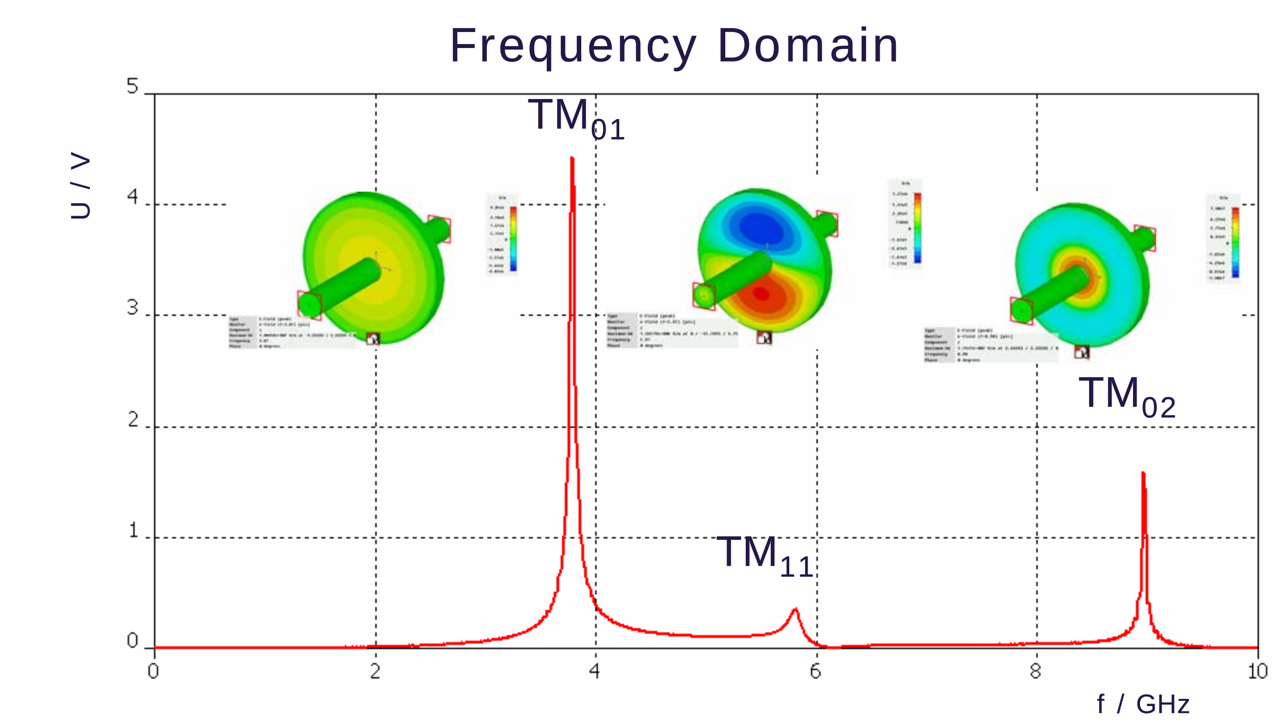
Basic principle

Electric Field of a charged Bunch



- Resonator can be produced with high accuracy
- With antenna: Measured voltages can be used to characterize beam with high resolution
- Non destructive Monitor

Basic principle



$U \sim Q$ $U \sim Qr$ $U \sim Q$

τ = decay time
Q_L = loaded Quality factor

Damping of resonance with $\exp(-t/\tau)$

Q = Beam Charge
r = Beam offset

By measuring r the beam offset is obtained
→ Beam Position Monitor (BPM)

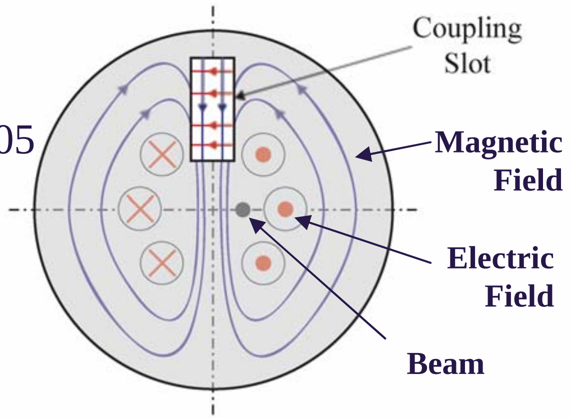
BTW: 2 ports per plane

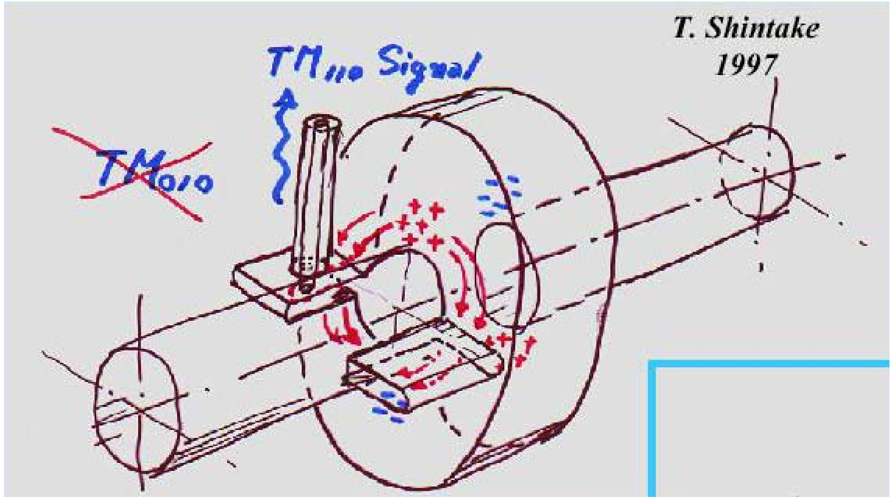
For charge normalization and sign: Reference Resonator or Monopole Mode

Problem: Monopole Mode (TM_0) leakage into Dipole Mode (TM_1)

Reject monopole mode

Ref: V. Vogel
Nanobeam 2005





Dipole Mode is surrounded by magnetic fields

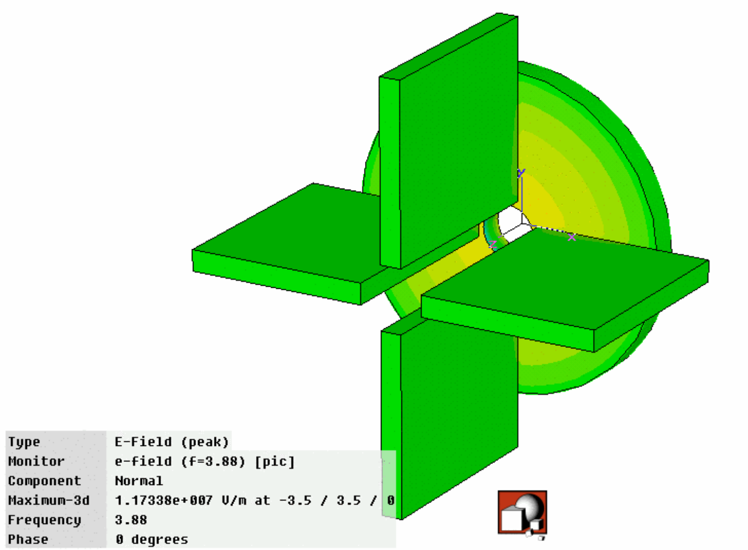
Between both magnetic fields a TE_{10} is produced which matches with boundary condition of wave guide and is propagating

Monopole Mode does not match with boundary condition of wave guide

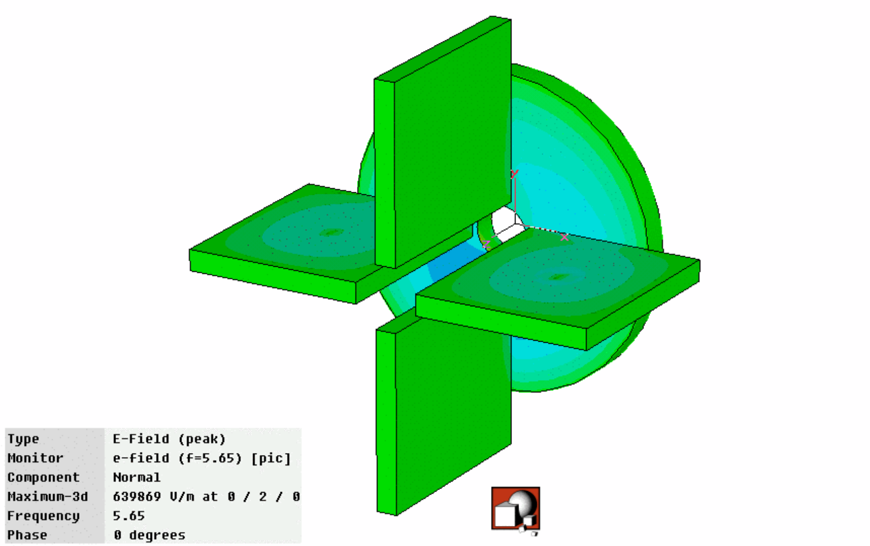
Ref: V. Balakin et al., PAC 1999

Reject monopole mode

Monopole Mode



Dipole Mode



Simulation to show

- propagation of dipole mode in waveguide
- monopole mode no propagation in waveguide

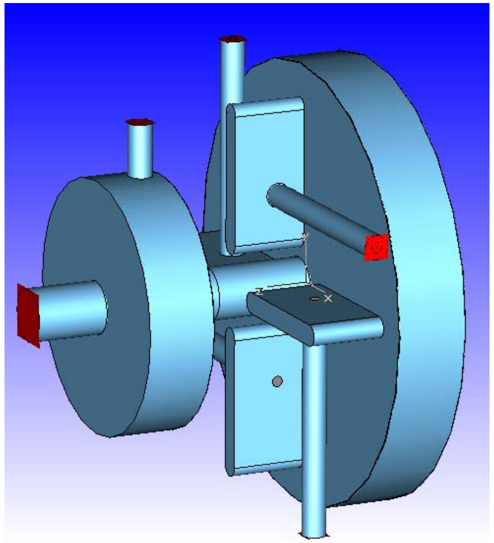
Design

Based on a design from T. Shintake (SPring-8)

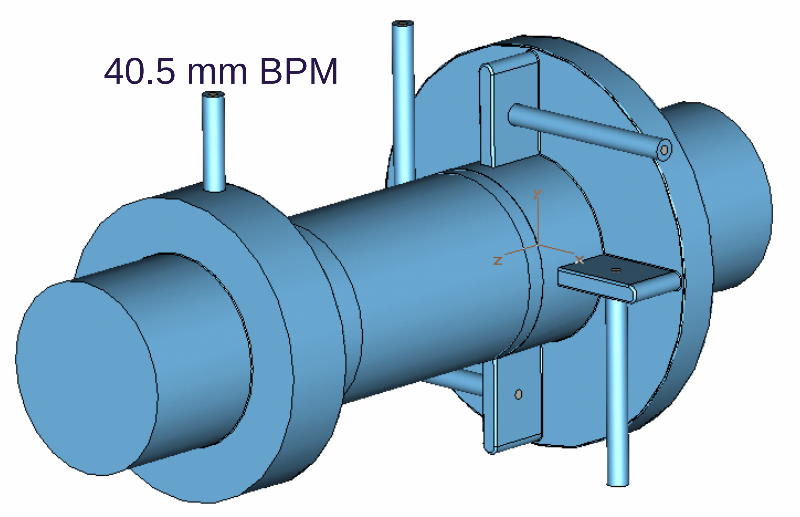
First DESY prototype,
4.4 GHz,
(first generation)

Second DESY prototype
Before brazing, 3.3 GHz,
(second generation)

Undulator BPM



Reference and Dipole resonator
Vacuum design view



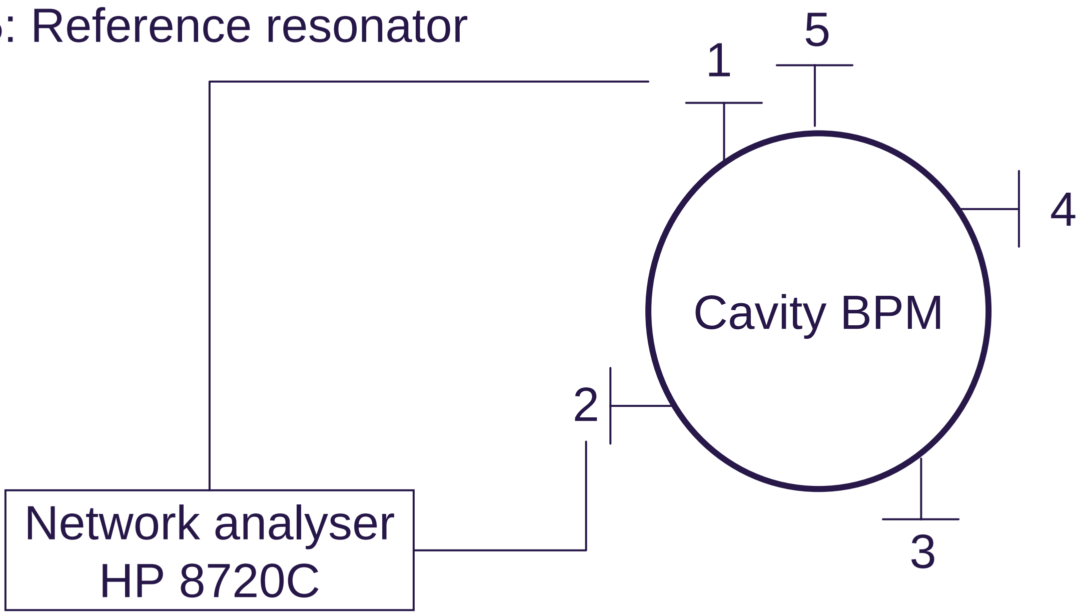
Reference and Dipole resonator
Vacuum design view

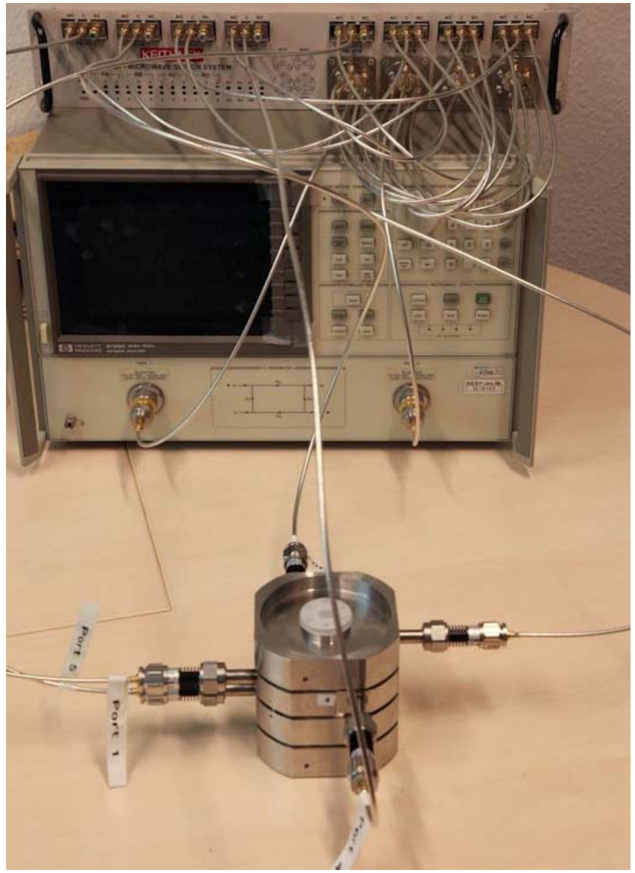
Laboratory measurements of Undulator cavity BPM

Setup

Port 1 – 4: Dipole resonator

Port 5: Reference resonator





2 channel network analyser (NWA), measurement of scattering matrix (S-parameter: S11 [reflection] and S12 [transmission])

Other ports terminated with 50 Ohm

Laboratory measurements of Undulator cavity BPM

Transmission data analysis

Time domain

$$U(t) = U_{out} e^{-\frac{t}{\tau}} \cos(\omega_R t)\Theta(t)$$

$$\omega_R = 2\pi f_R$$

$$f_R = resonance\ \ frequency$$

$$\tau = \frac{Q_L}{\pi f_s},\ decay\ time$$

$$Q_L =,\ loaded\ quality\ \ factor$$

$$BW = \frac{f_S}{Q_L},\ bandwidth$$

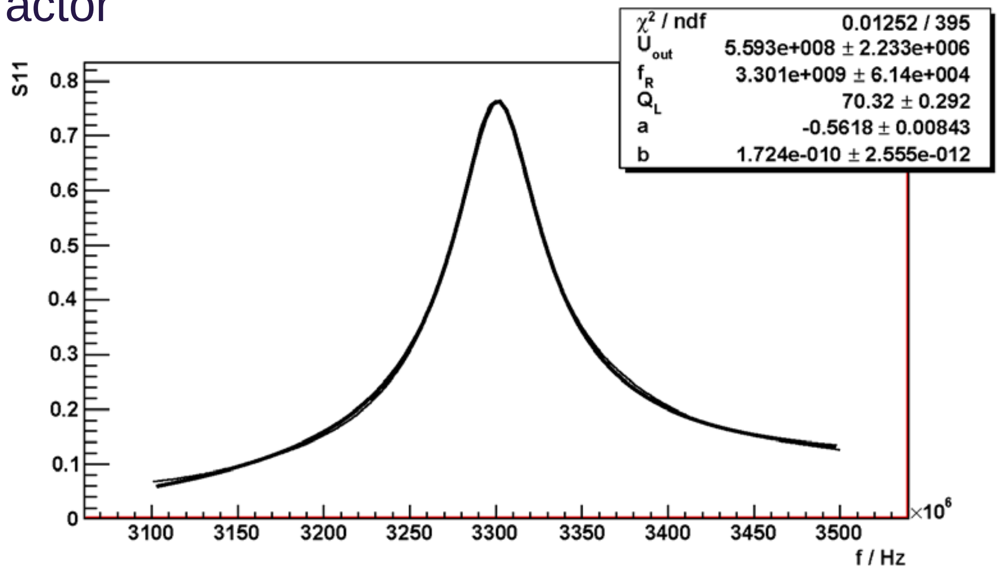
$$U_{out} \propto beam\ offset$$

Fourier transformation

Frequency domain

$$F(\omega) = \frac{U_{out}}{\sqrt{2\pi}} \frac{\frac{1}{\tau} + i\omega}{\left(\frac{1}{\tau} + i\omega\right)^2 + \omega_R^2}$$

Adapting $|F(\omega)|$ to transmission data gives resonance frequency and loaded quality factor



Laboratory measurements of Undulator cavity BPM

Transmission data results

BPM	f_R / GHz		Q_L	
	Ports 1-3	Ports 2-4	Ports 1-3	Ports 2-4
1	3.301	3.301	68.2	70.3
2	3.303	3.305	70.8	67.9
3	3.309	3.310	78.1	77.8
4	3.307	3.308	68.8	66.7
5	3.310	3.310	76.0	80.5
6	3.302	3.301	67.9	66.7

Errors:

- Resonance frequency:
  - Stat. = 0.01 MHz
  - Syst. = 5 MHz
- Loaded quality factor:
  - Stat. = 0.3
  - Syst. = 5

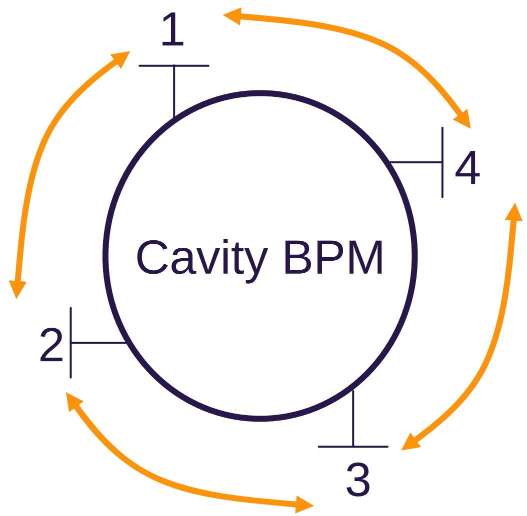
Expectation: f_R = 3.30 ± 0.01 GHz, Q_L = 70.0 ± 15.0

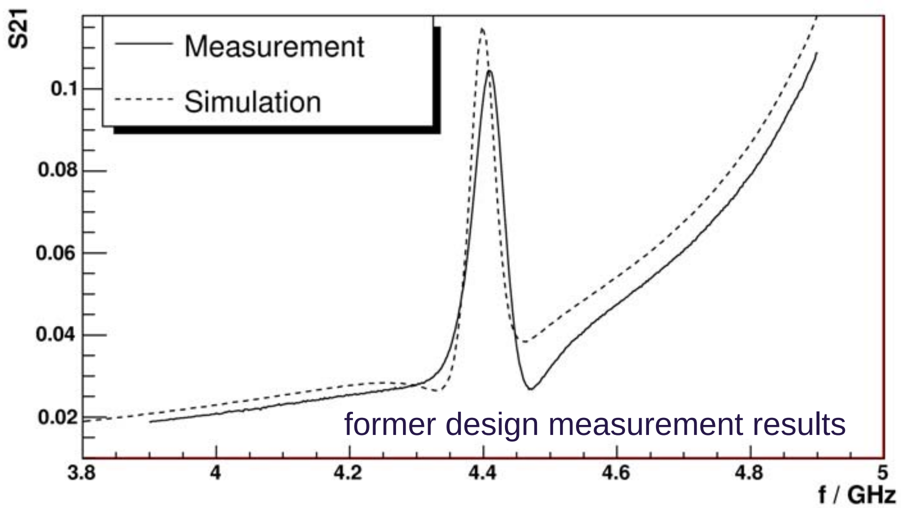
Compare Measurement and Simulation: all of the cavity BPM's are within tolerances

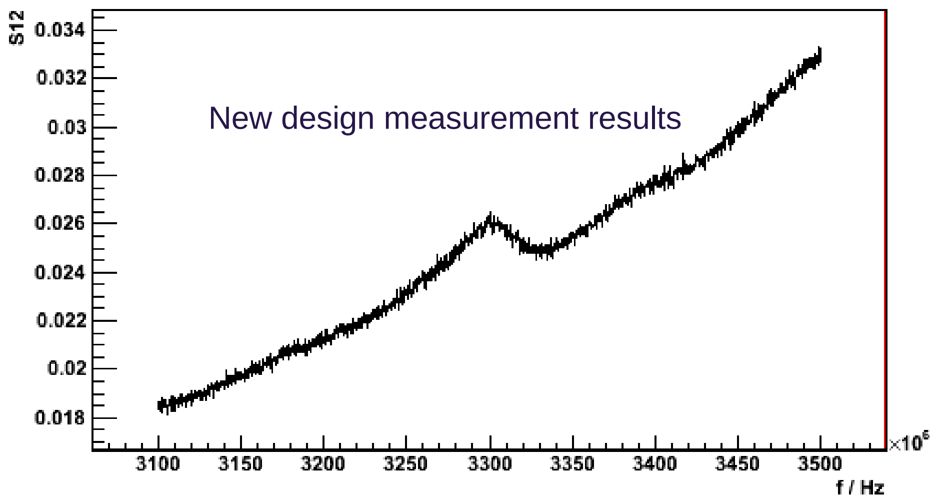
Laboratory measurements of Undulator cavity BPM

Coupling of orthogonal ports:

Results between -31 and -33 dB, compared to previous design coupling is decreased because of improved design and more restricted tolerances



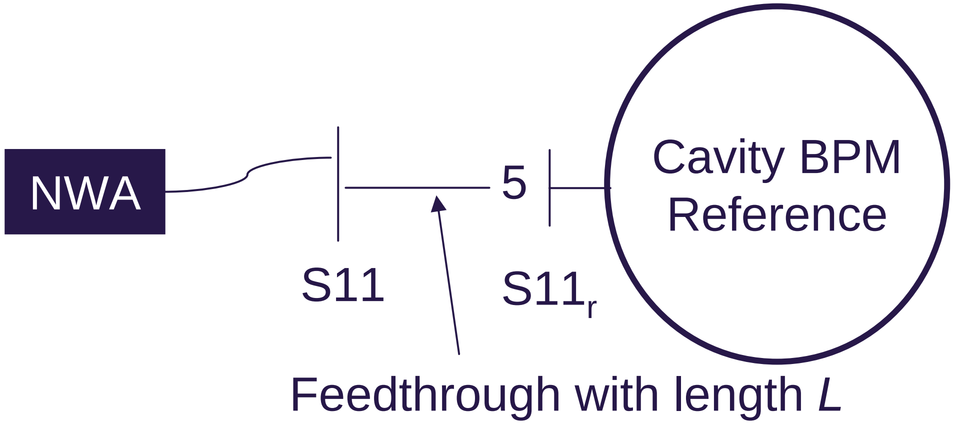




Laboratory measurements of Undulator cavity BPM

Reference Resonator Analysis

Only Reflection S11 because one port on this resonator



$$S11_r = S11e^{j2\beta L}$$

$$\beta = \frac{2\pi}{v_p}$$

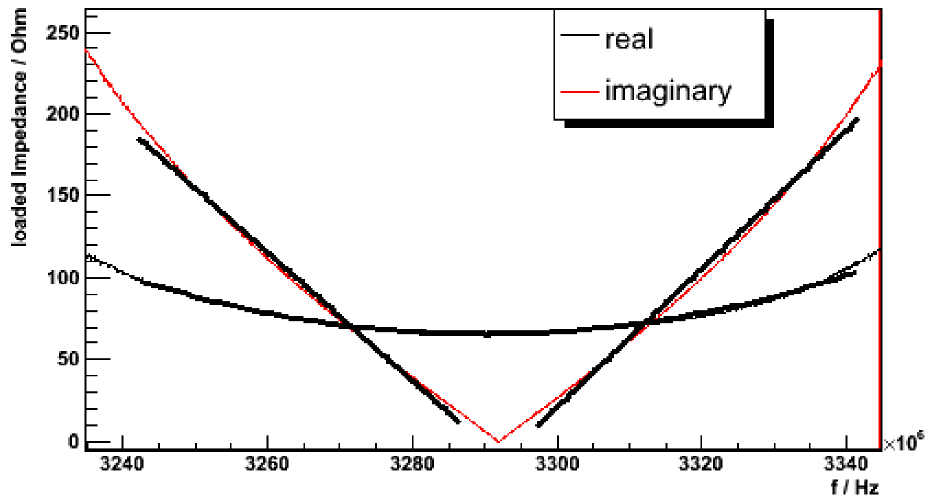
$$v_p = \frac{c}{\sqrt{\varepsilon_r}}$$

c – light velocity

ε_r – dielectric

$$Z_r = 50\Omega \frac{1+S11_r}{1-S11_r}$$

Measured S11 -> recalculate to $S11_r$ -> recalculate to impedance *Z*



Adjust *L* until *Re(Z_r)* is almost constant, point of intersection between *Re* and |*Im*| gives bandwidth for Q_L with Z_r + 50 Ohm

Laboratory measurements of Undulator cavity BPM

Reference Resonator Results

BPM	f_R / GHz	Q_L
1	3.297	77.8
2	3.297	79.5
3	3.289	82.5
4	3.293	83.2
5	3.295	79.5
6	3.292	80.8

Errors:

- Resonance frequency:
  - Stat. = 7 MHz
  - Syst. = 5 MHz
- Loaded quality factor:
  - Stat. = 0.5
  - Syst. = 10

Expectation: f_R = 3.30 ± 0.01 GHz, Q_L = 70.0 ± 15.0

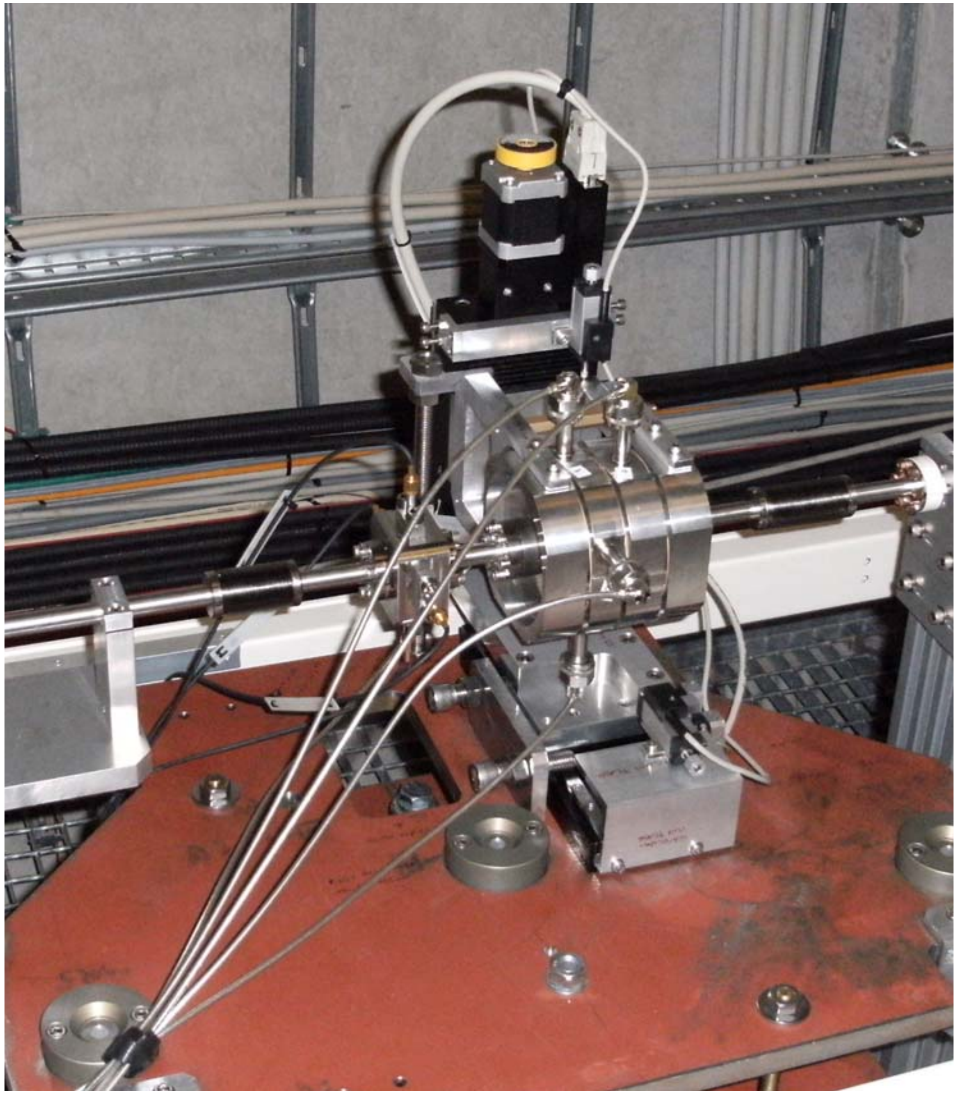
Compare Measurement and Simulation:

all of the cavity BPM's are within tolerances

Beam measurement of Undulator cavity BPM

Cavity BPM included in FLASH beamline at Christmas shutdown 2008

- Beam measurement with oscilloscope (6 GHz, 20GS/s), 123 m cable between BPM and oscilloscope
- Available: stepper motor in x and y, Toroid and button BPM
- Test of movement range, boundaries determined by beam loss monitor



Beam measurement of Undulator cavity BPM

Analysis: To increase oscilloscope resolution for amplitude a fit is applied to the time signal, in addition resonance frequency and loaded quality factor is observed:

$$U(t) = U_{out} e^{-\frac{t-t_s}{\tau}} \cos(\omega_R t + \phi)\Theta(t_{trigger} + t_s)$$

$$\omega_R = 2\pi f_R$$

f_R *resonance frequency*

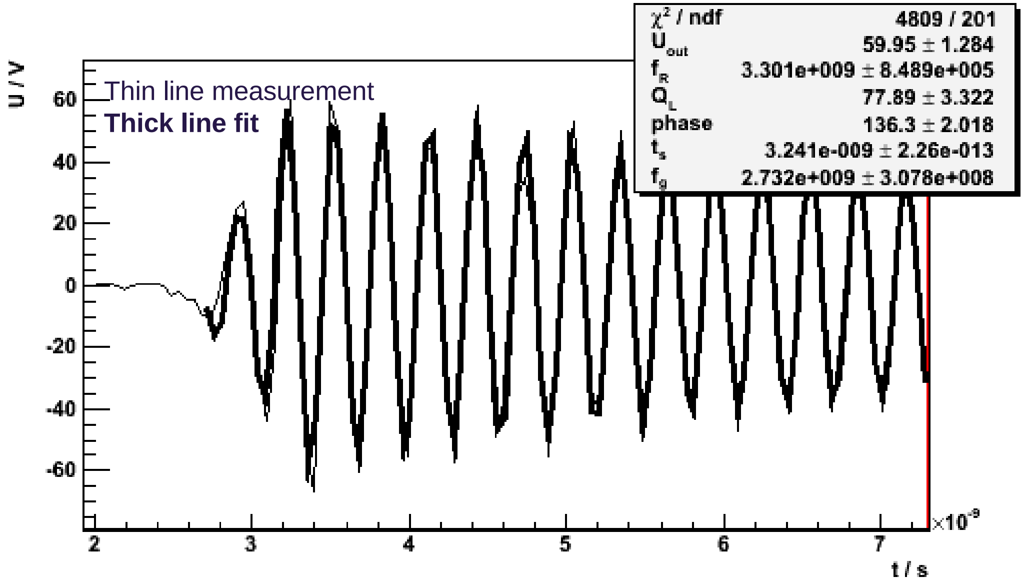
$$\tau = \frac{Q_L}{\pi f_R}, \text{ decay time}$$

Q_L *loaded quality factor*

$U_{out} \propto$ *beam offset*

ϕ *phase offset*

t_s *end of transient oscillation*



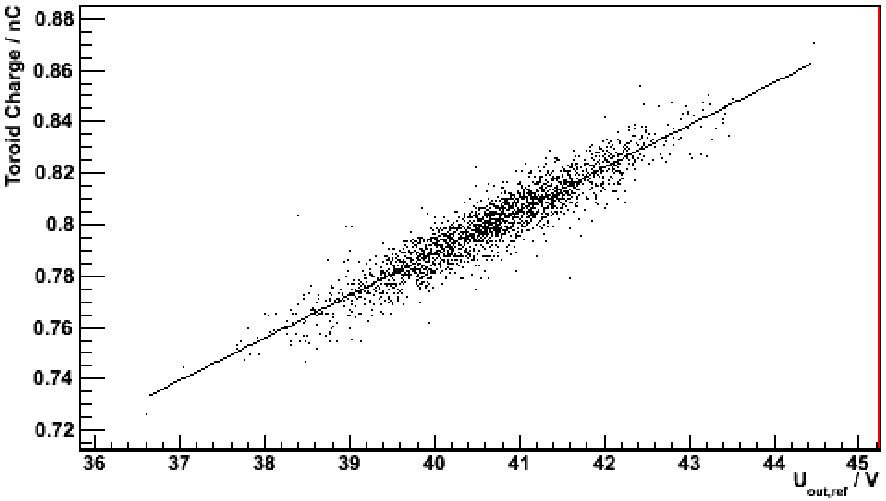
For time between $t_{trigger}$ and t_s (transient oscillation):

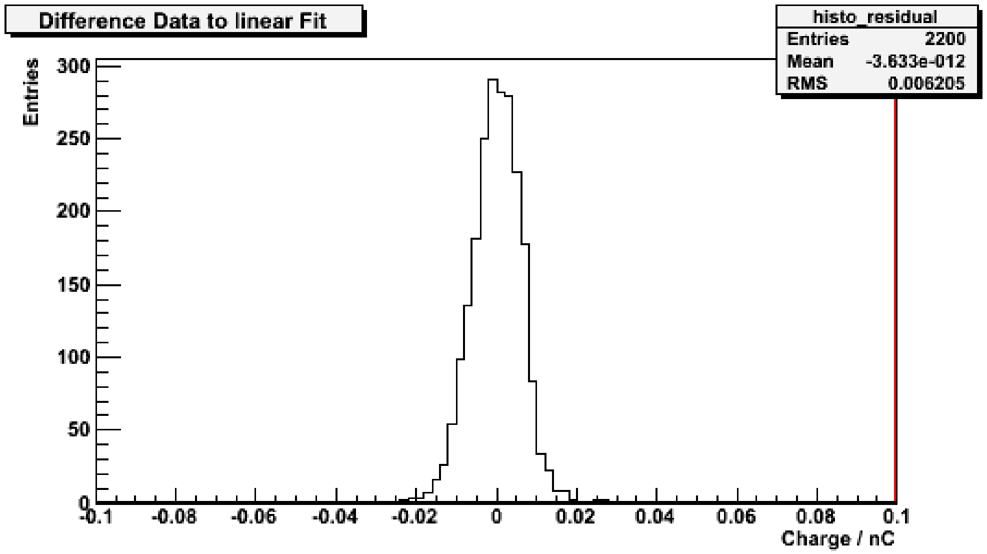
$$U(t) = U_{out} e^{(t-t_s) f_g} \cos(\omega_R t + \phi)$$

f_g *gradient frequency*

Beam measurement of Undulator cavity BPM

Stable beam conditions and monitored with Toroid and reference resonator



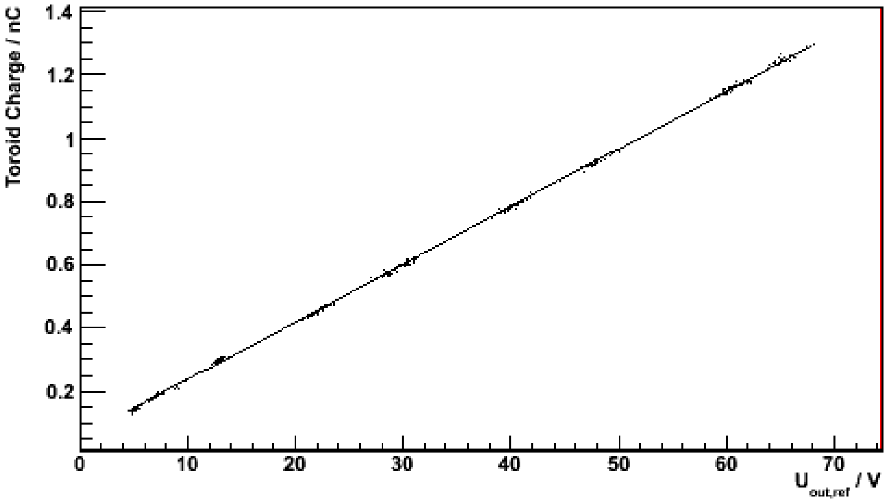


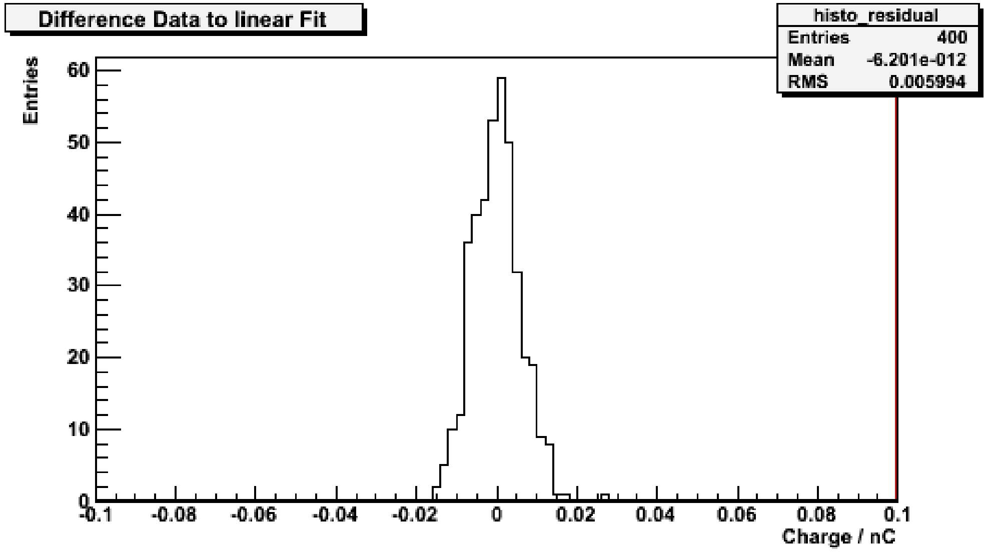
Result

- Linear dependence between reference resonator and Toroid
- Resolution of both together: 6.2 pC

Beam measurement of Undulator cavity BPM

Beam charge was changed and monitored with Toroid and reference resonator





Sensitivity

- Result from linear fit: (54.92±0.05) V/nC
- Expectation: 43.5 V/nC

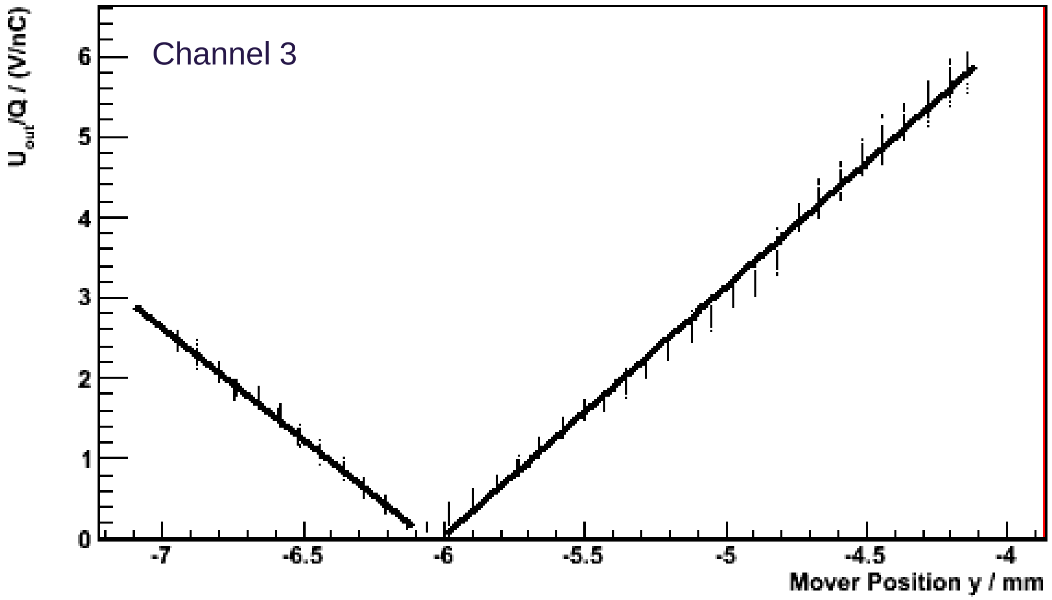
Difference between Linearity and Data: 6 pC (RMS)

- Resolution of Toroid 5 pC
- Resolution of oscilloscope about 3 pC

Beam measurement of Undulator cavity BPM

Sensitivity of dipole resonator

Cavity BPM was moved in one direction, other direction was settled to beam on axis

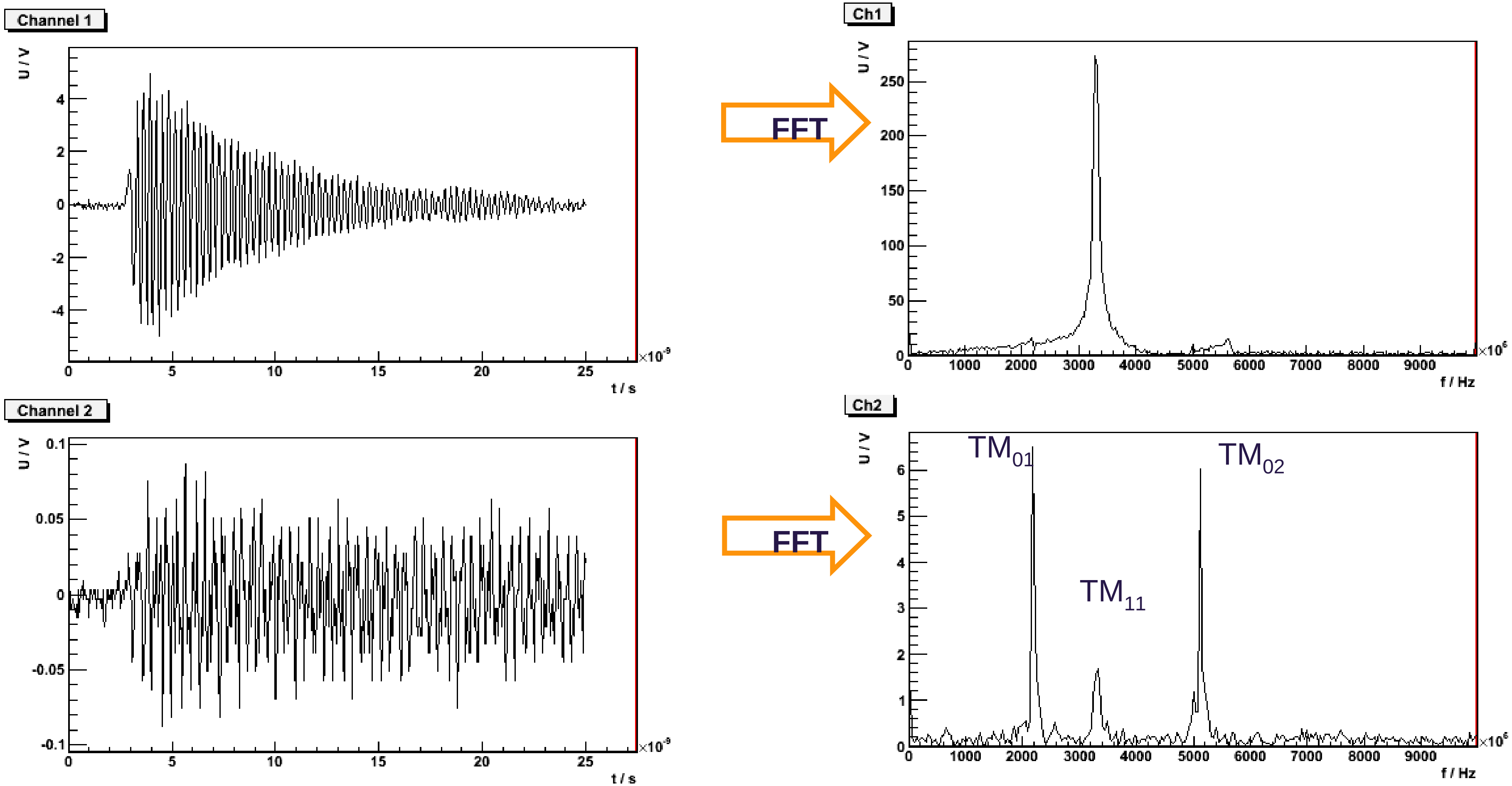


Sensitivity

- Result from linear fit of both sides and of all measured ports: (2.71±0.30) V/(nC mm)
- Expectation: 2.84 V/(nC mm)

Beam measurement of Undulator cavity BPM

Spectrum dipole resonator



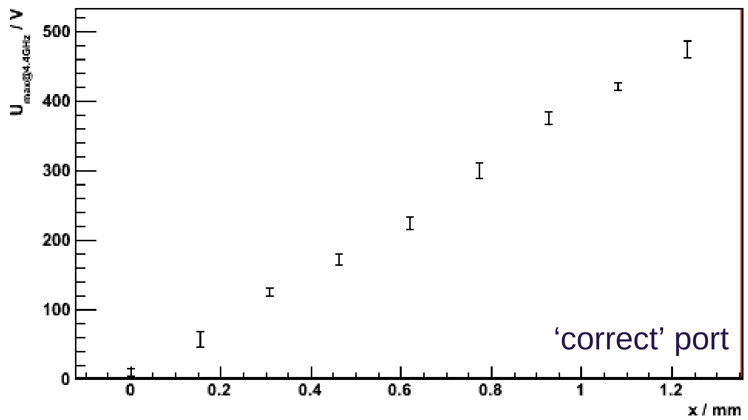
Y scan with largest y offset, x at axis

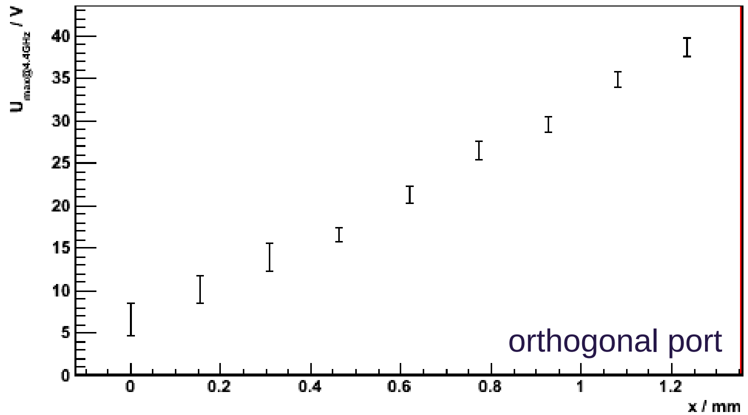
Beam measurement of Undulator cavity BPM

Orthogonal coupling of first and second prototype:

Amplitude of spectrum at dipole resonance frequency as a function of mover position

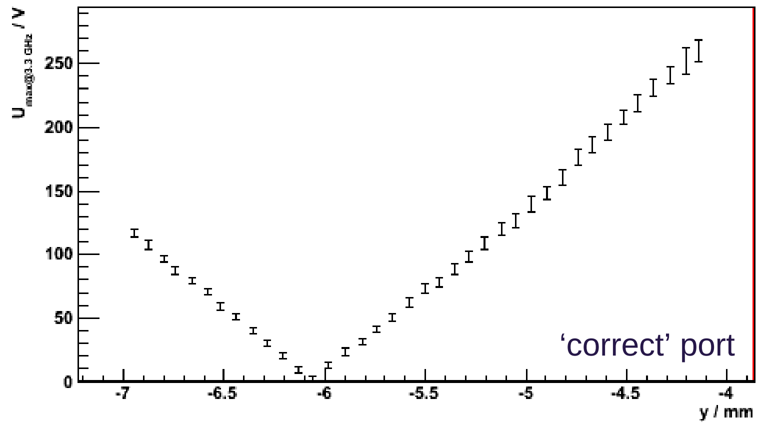
First prototype, measured 2008

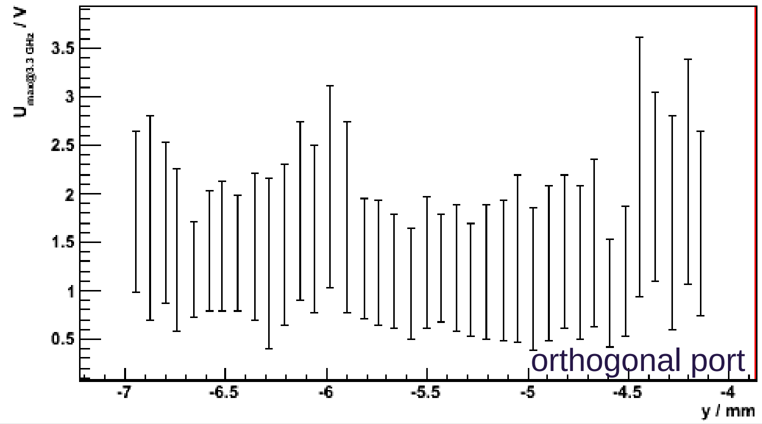




Coupling of dipole modes with -20 dB

New design, measured Jan. 2009

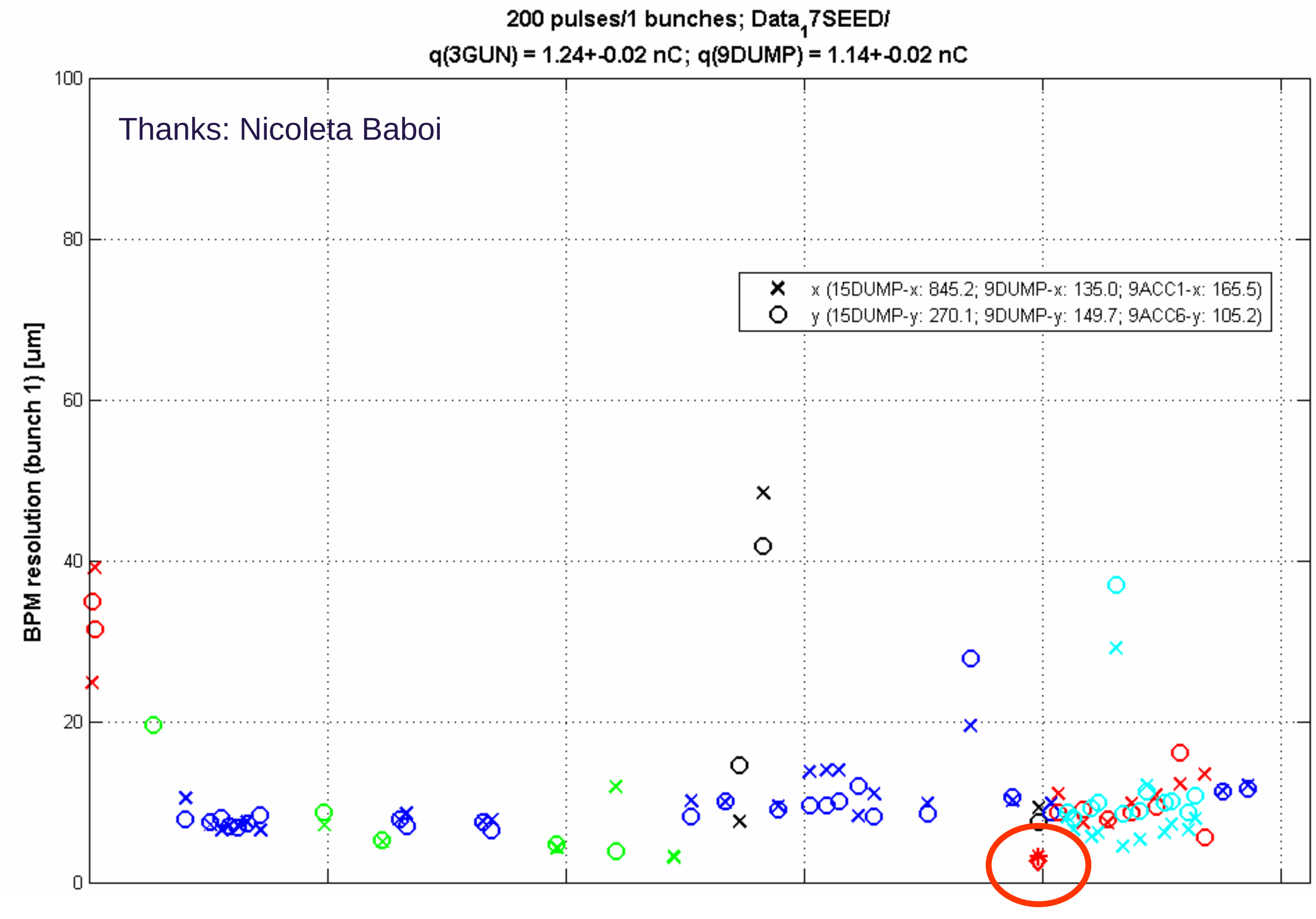




No coupling observed, lower than -43 dB, because improved design with tighter mechanical tolerances

Beam measurement of Undulator cavity BPM

Resolution at FLASH

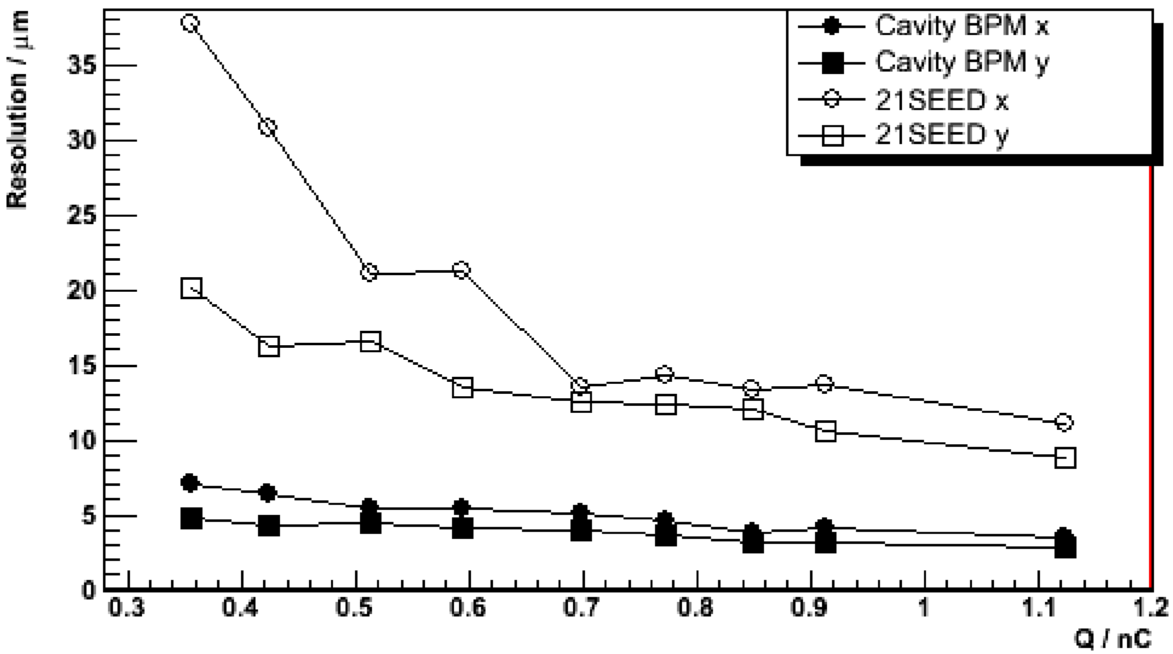


XFEL Undulator Cavity BPM

- Resolution measurement with cross correlation of all BPM at FLASH
- Problem: timing because oscilloscope not included in control system; solved by bunch repetition rate of 1 Hz
- XFEL Undulator Cavity BPM shows lowest resolution at FLASH

Beam measurement of Undulator cavity BPM

Resolution cavity BPM vs. bunch charge



Resolution affected due to:

- Oscilloscope ADC 8 bit, estimated influence of 10 µm, improved due to spectral analysis
- Sampling rate of oscilloscope: 20 GS/s, results in 6 points per period
- Resolution of other BPM at FLASH (for decreasing charge the resolution of other BPM is increasing), other BPM’s are assumed to be noise free, only an upper limit can be estimated,

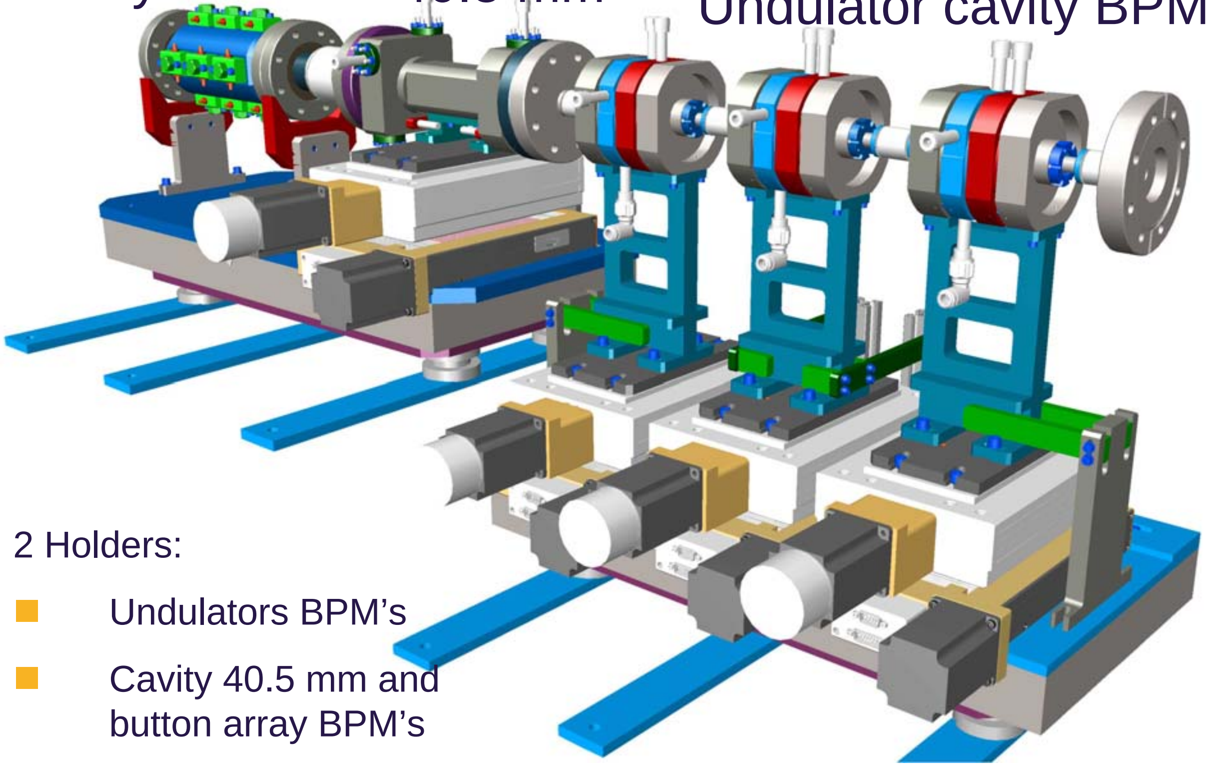
Resolution of XFEL Cavity BPM will be dominated by electronics, here only an oscilloscope is used. When electronics ready an improved resolution is expected.

Beam measurement of Cavity BPM

Button BPM array

Cavity BPM 40.5 mm

Undulator cavity BPM's



New Teststand at FLASH

Installation: 01/2010

2 Holders:

- Undulators BPM's
- Cavity 40.5 mm and button array BPM's

Resolution measurement order

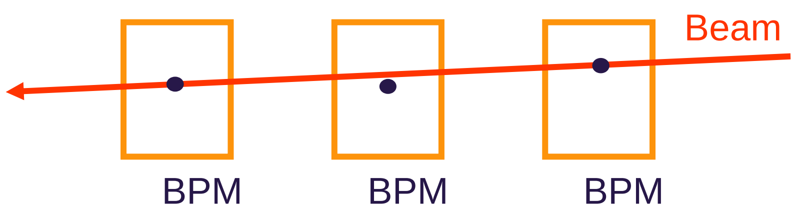
1. Undulator Cavity BPM
2. Cavity BPM 40.5 mm

Button BPM separately

Design: Maike Siemens

Principle:

Two BPM's are measuring position and predict position at the third BPM, residual corresponds to resolution of system



Status

- Design of Undulator cavity BPM for XFEL Undulator intersection ready, prototypes from DESY workshop within expectation
- Production of improved Undulator cavity BPM's for Teststand ongoing, preseries at industry
- Production of cavity BPM 40.5 mm for Teststand ongoing, preseries at industry
- Electronics Status 08/2009: 4 front end prototypes produced at PSI without clock, functionality test successfully, not yet tested with beam, digital part not yet ready. Will be ready for beam test 2010.

Summary

- Requirements for observing beam position fixed
- In kind contribution
- Cavity BPM principle
- Produced two generation with improvements, measurements
- New teststand for measurement of resolution

Thank you for your attention!

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Headline

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  - second level
    - → third level

Headline

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Keyword

1. Keyword
2. Keyword

- keyword
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Result Headline

- result text
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Result text, result text, result text

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