



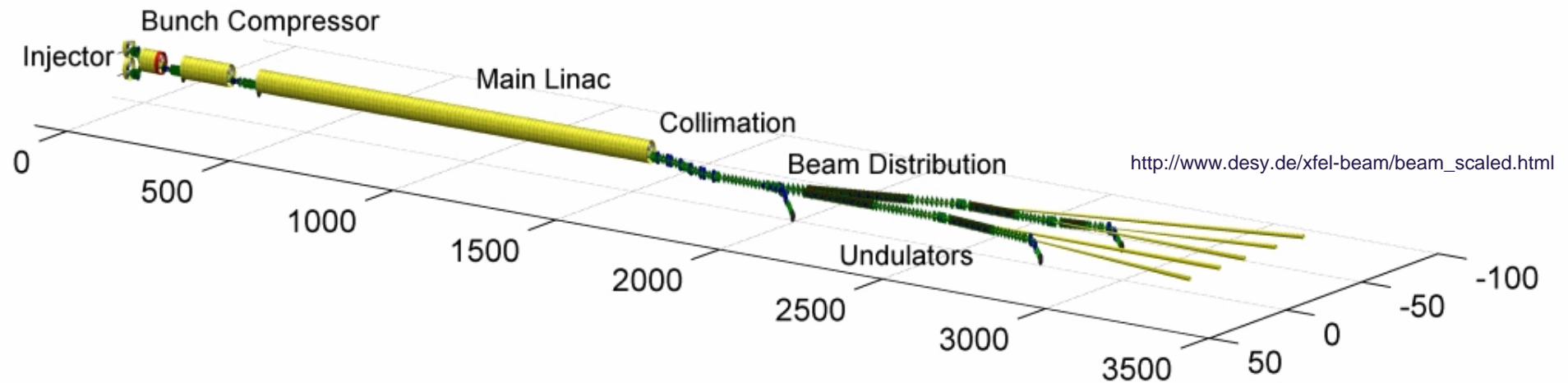
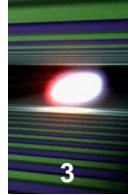
Status Cavity BPM's for E-XFEL

Dirk Lipka, MDI, DESY Hamburg



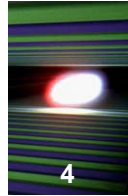


1. Requirements
2. Overview (all BPM's)
3. In kind contribution (Saclay, DESY, PSI)
4. Cavity BPM: principle
5. Design
6. Measurements:
 - a. Laboratory measurements: frequency and loaded Q, compare with expectation (second generation)
 - b. Beam measurement: sensitivity, orthogonal coupling, compare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



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



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] | Reasonable signal[2] | 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.



All BPM for European XFEL (cold and warm)

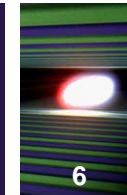
Collaboration (institutes and task)

- 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)

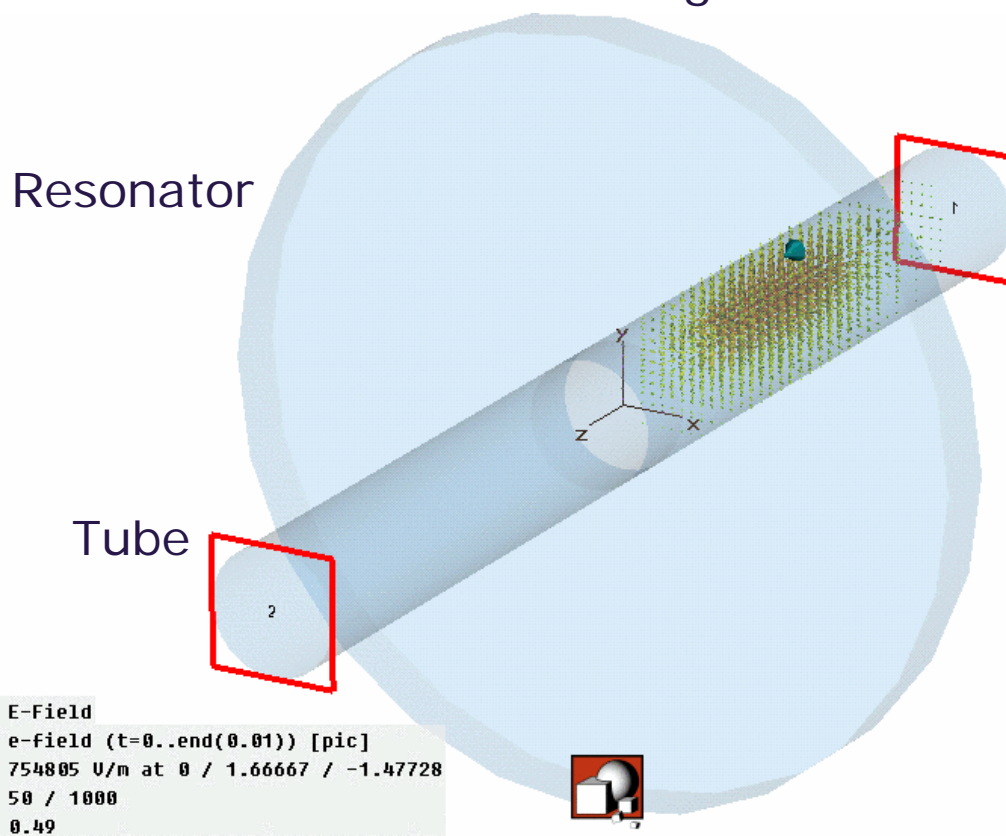
Subject of this talk:

Cavity BPM from DESY

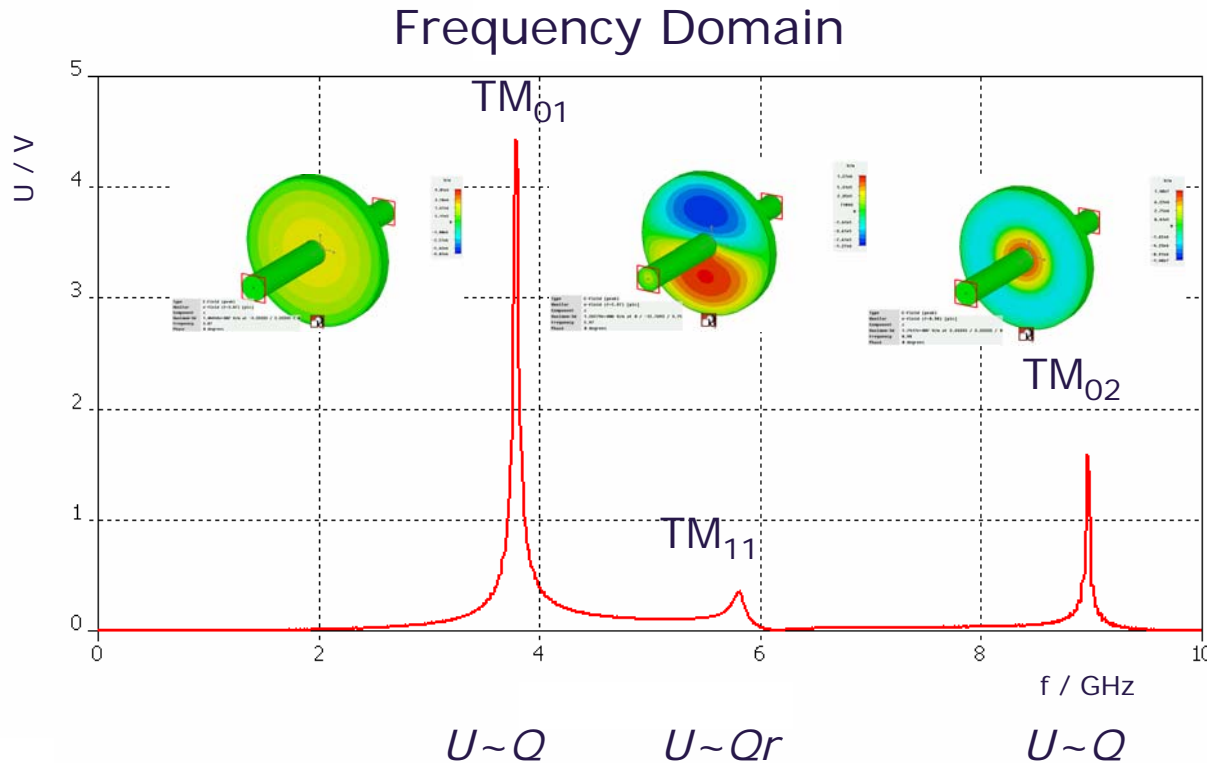
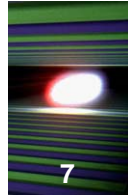




Electric Field of a charged Bunch



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



τ = decay time
 Q_L = loaded
 Quality factor

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

Q = Beam Charge
 r = Beam offset

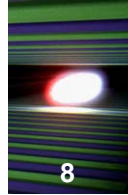
By measuring r the
 beam offset is
 obtained
 → Beam Position
 Monitor (BPM)

BTW: 2 ports per
 plane

For charge normalization and sign: Reference Resonator or
 Monopole Mode

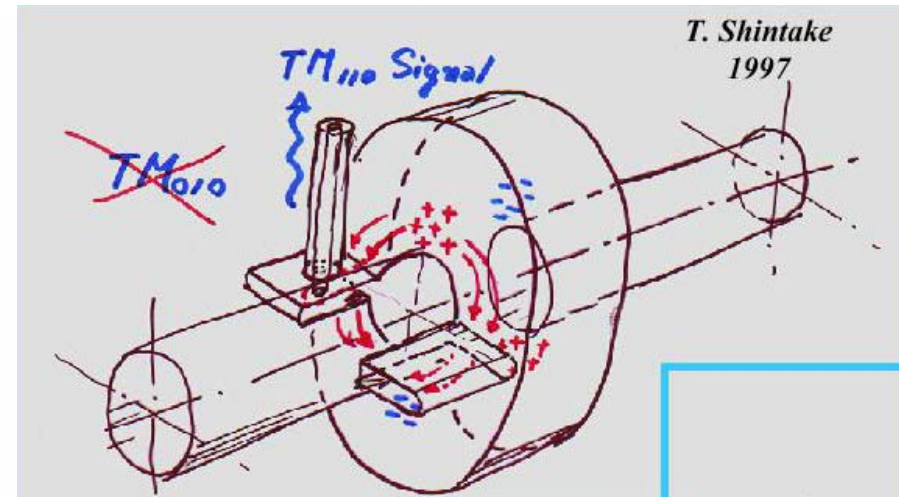
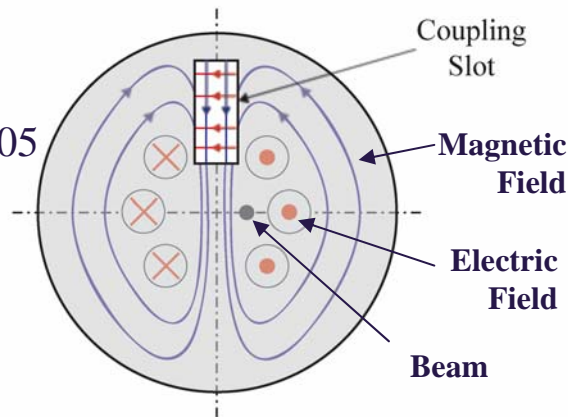
Problem: Monopole Mode (TM_0) leakage into Dipole Mode (TM_1)

Reject monopole mode



8

Ref: V. Vogel
Nanobeam 2005

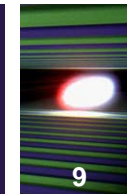


Dipole Mode is surrounded by magnetic fields

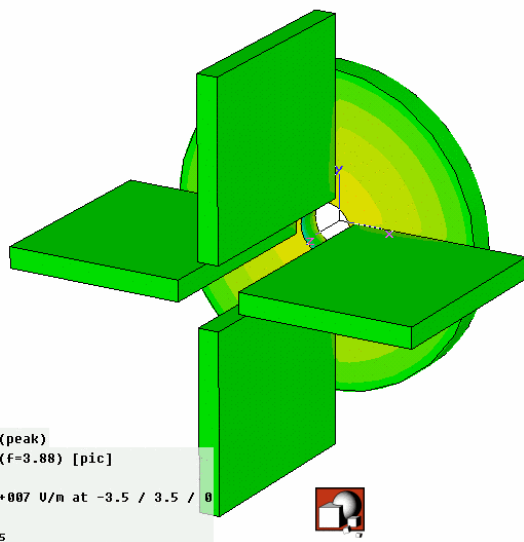
Between both magnetic fields a TE_{10} is produced which matches with boundary condition of wave guide and is propagating

Monopole Mode does not match with boundary condition of wave guide

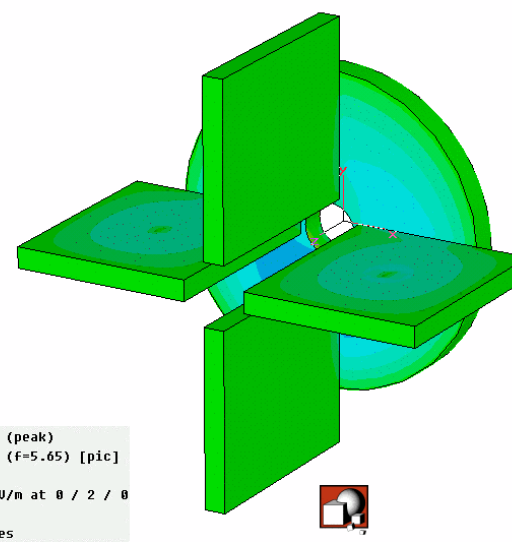
Ref: V. Balakin et al., PAC 1999



Monopole Mode

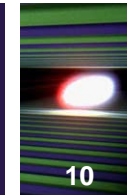


Dipole Mode



Simulation to show

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



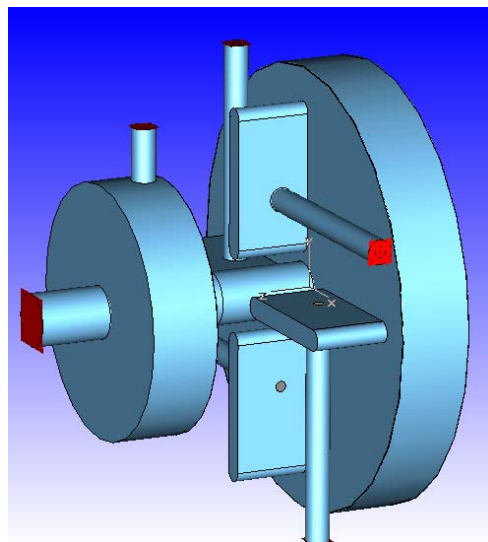
Based on a design from T. Shintake (SPring-8)



First DESY prototype,
4.4 GHz,
(first generation)

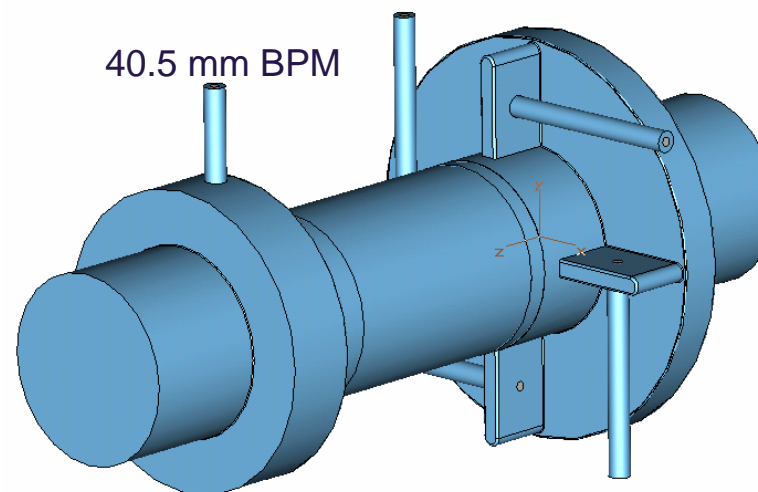


Second DESY prototype
Before brazing, 3.3 GHz,
(second generation)



Undulator BPM

Reference and Dipole resonator
Vacuum design view



40.5 mm BPM

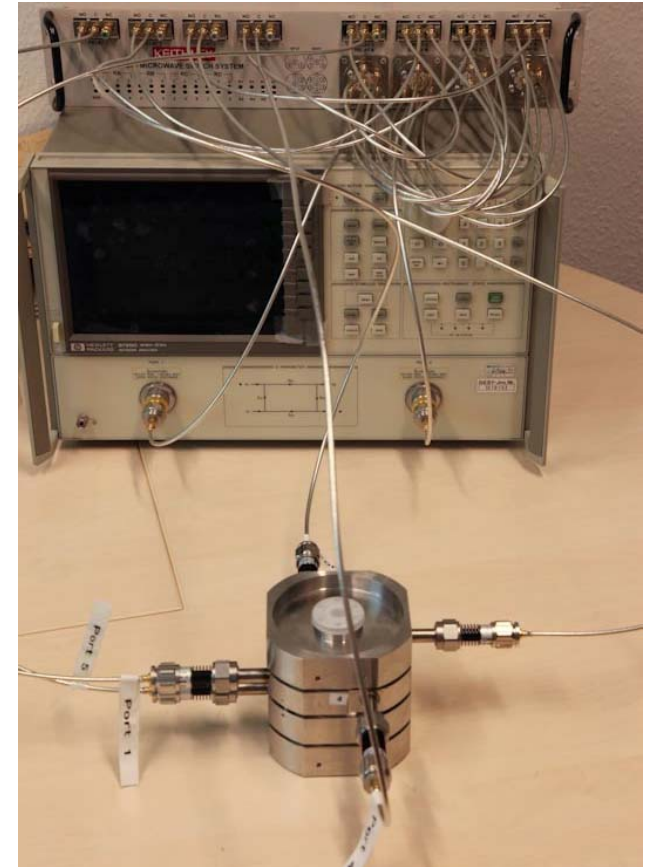
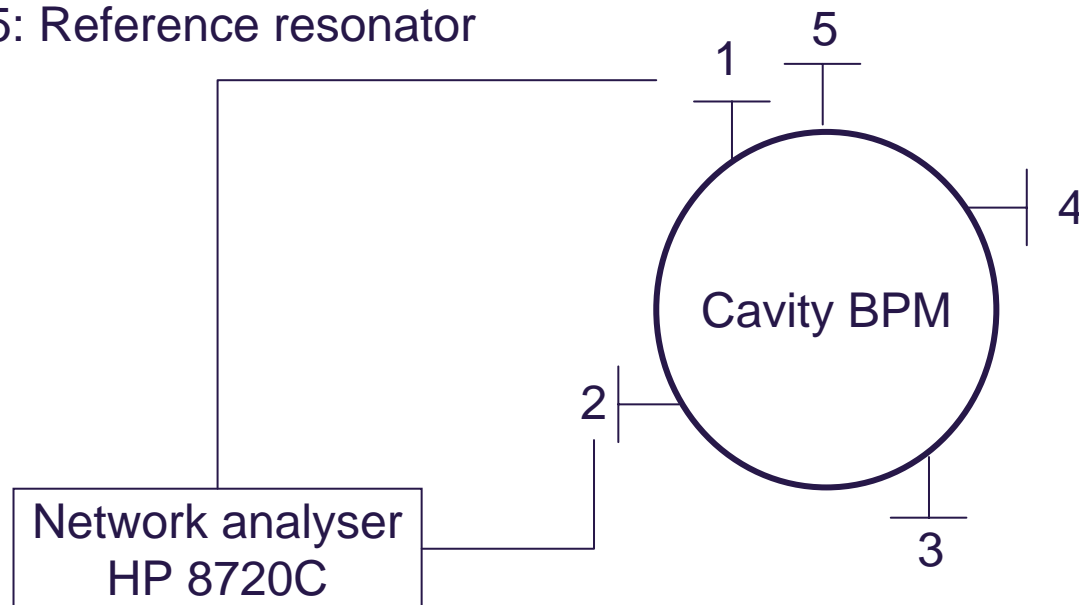
Reference and Dipole resonator
Vacuum design view



Setup

Port 1 – 4: Dipole resonator

Port 5: Reference resonator



2 channel network analyser (NWA), measurement of scattering matrix (S-parameter: S_{11} [reflection] and S_{12} [transmission])

Other ports terminated with 50 Ohm



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

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

$Q_L =$, loaded quality factor

$$BW = \frac{f_s}{Q_L}, \text{ bandwidth}$$

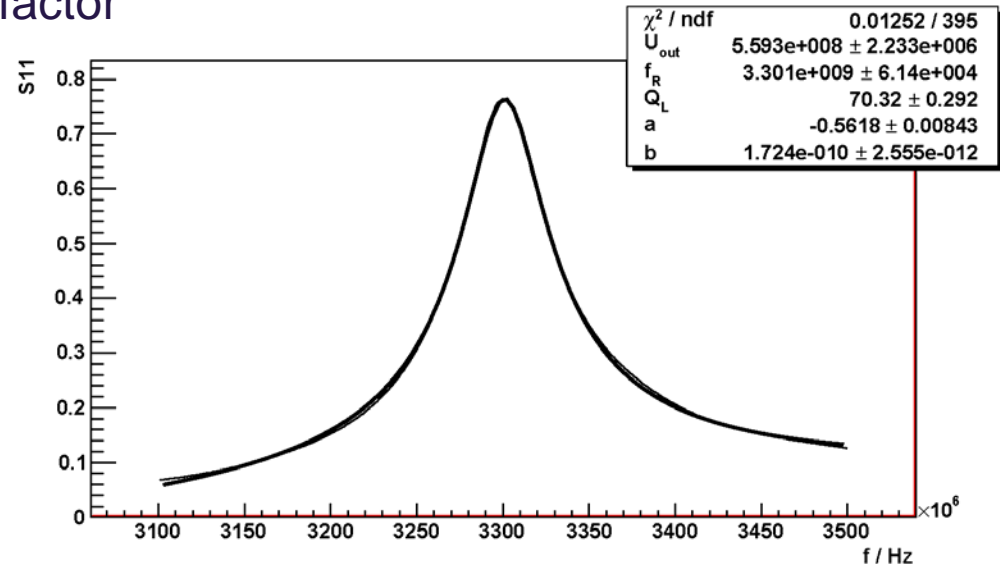
$$U_{out} \propto \text{beam offset}$$

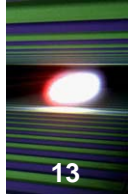
Fourier transformation

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





Transmission data results

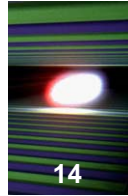
| BPM | f_R / GHz | | Q_L | |
|-----|-------------|-----------|-----------|-----------|
| | Ports 1-3 | Ports 2-4 | Ports 1-3 | Ports 2-4 |
| 1 | 3.301 | 3.301 | 68.2 | 70.3 |
| 2 | 3.303 | 3.305 | 70.8 | 67.9 |
| 3 | 3.309 | 3.310 | 78.1 | 77.8 |
| 4 | 3.307 | 3.308 | 68.8 | 66.7 |
| 5 | 3.310 | 3.310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

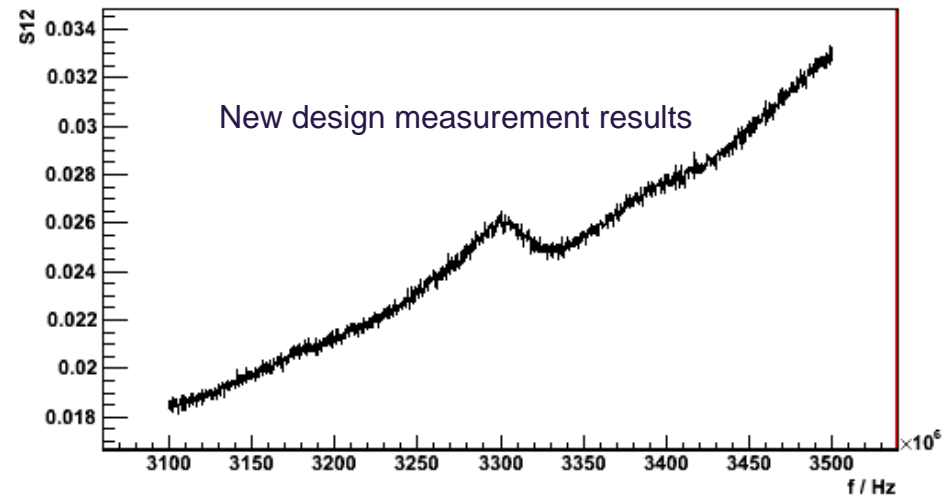
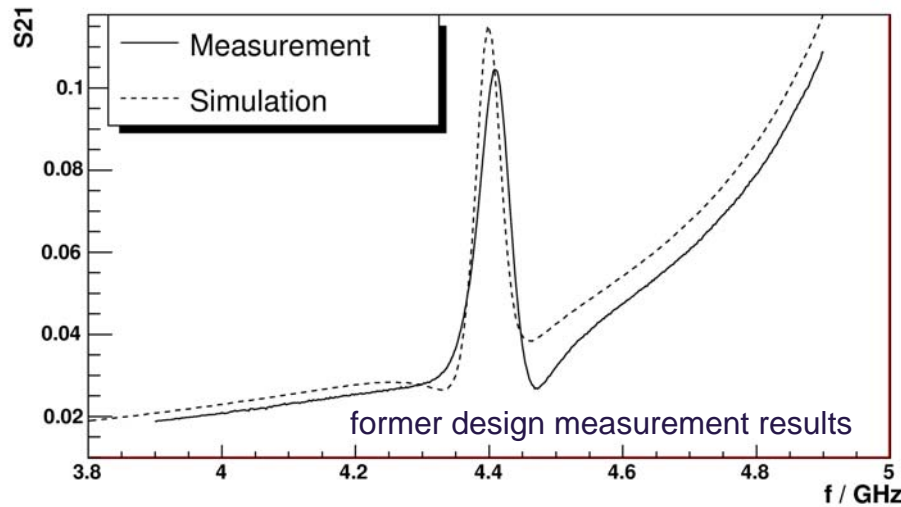
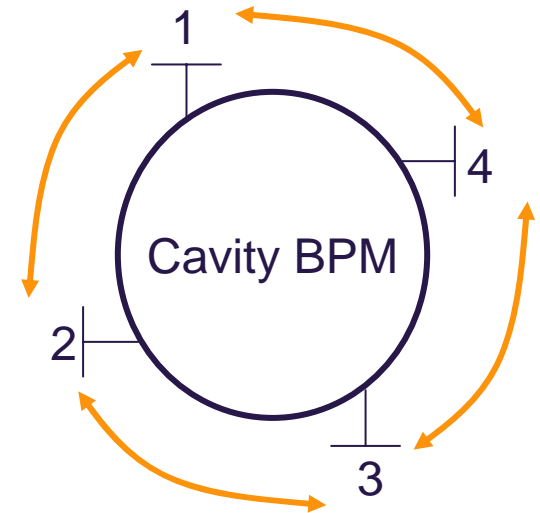
Expectation: $f_R = 3.30 \pm 0.01$ GHz, $Q_L = 70.0 \pm 15.0$

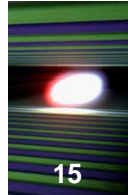
Compare Measurement and Simulation: all of the cavity BPM's are within tolerances



Coupling of orthogonal ports:

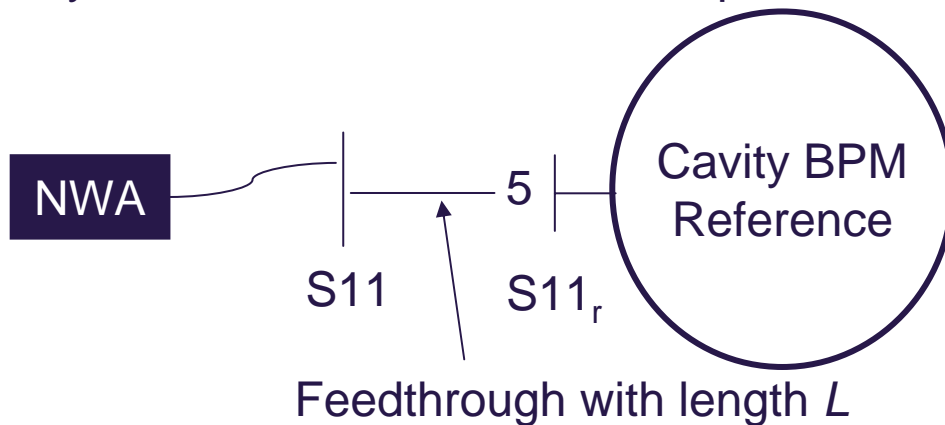
Results between -31 and -33 dB, compared to previous design coupling is decreased because of improved design and more restricted tolerances





Reference Resonator Analysis

Only Reflection S11 because one port on this resonator



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

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

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

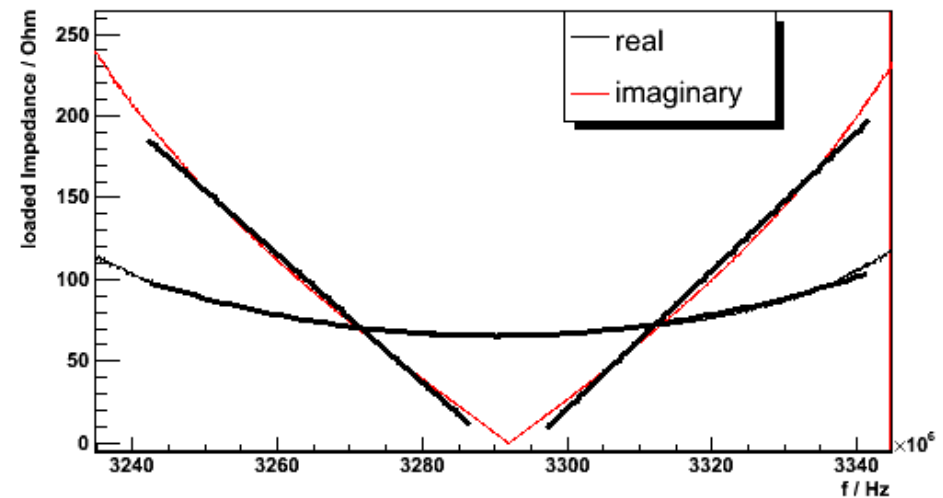
c – light velocity

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





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 |

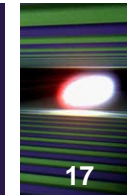
Errors:

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

Expectation: $f_R = 3.30 \pm 0.01$ GHz,
 $Q_L = 70.0 \pm 15.0$

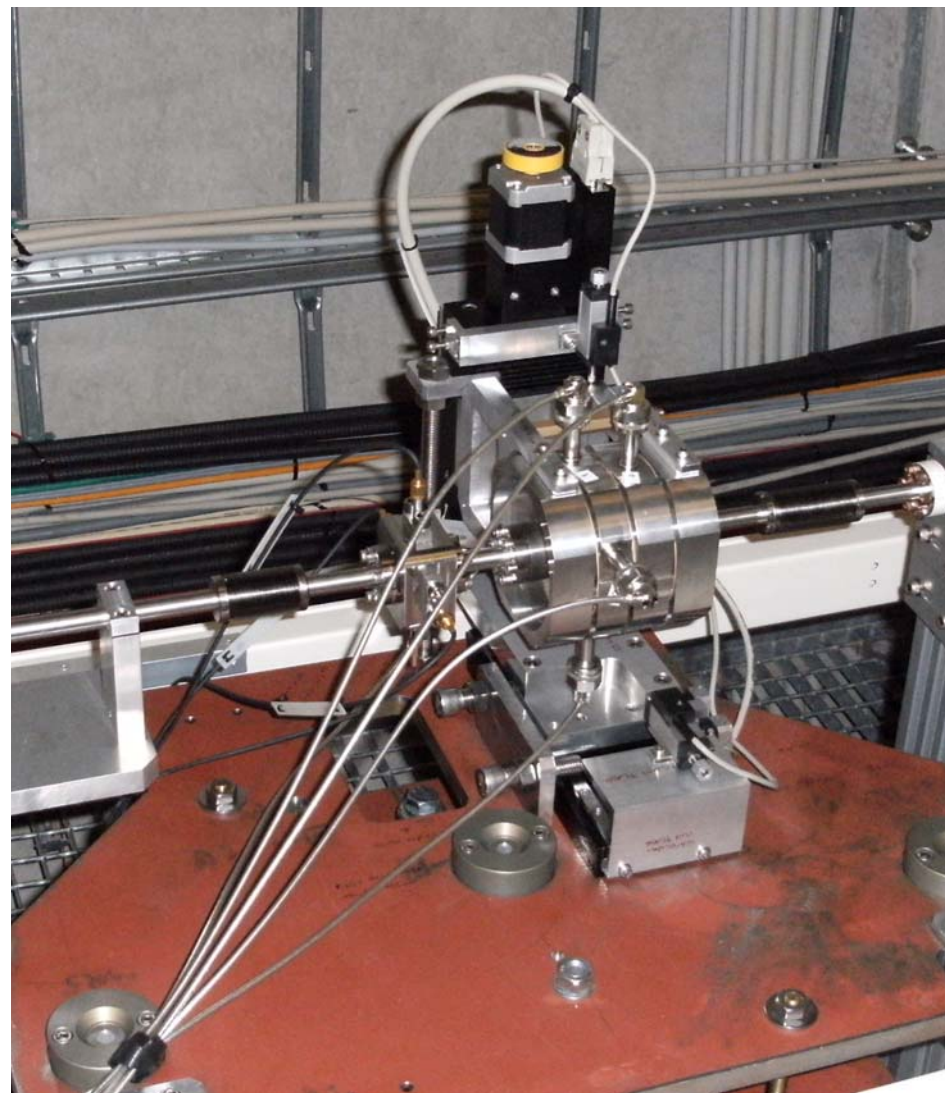
Compare Measurement and Simulation:

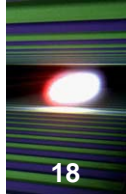
all of the cavity BPM's are within tolerances



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





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

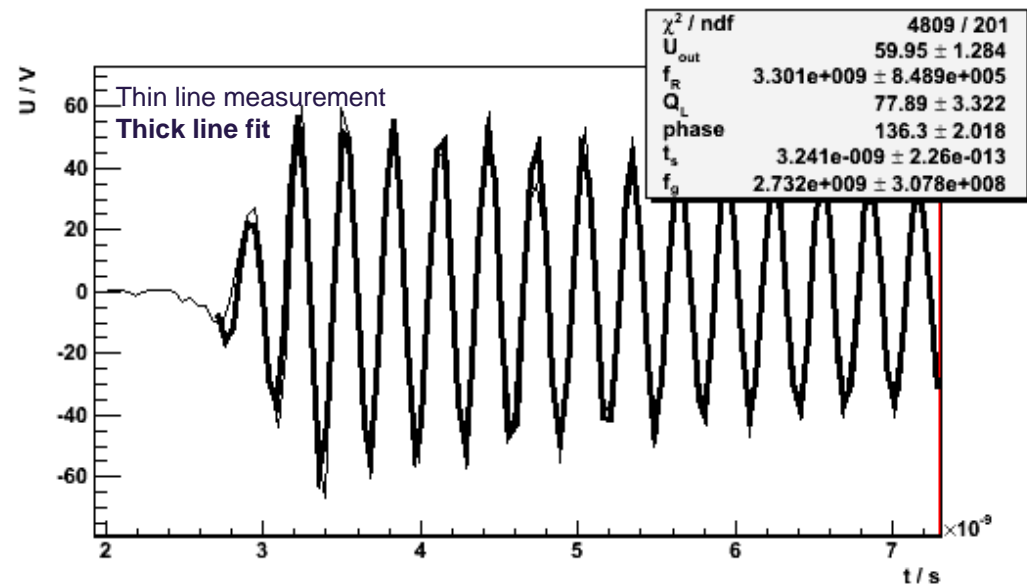
$$\tau = \frac{Q_L}{\pi f_R}, \text{ decay time}$$

Q_L loaded quality factor

$U_{out} \propto$ beam offset

ϕ phase offset

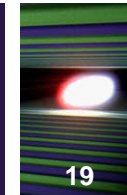
t_s end of transient oscillation



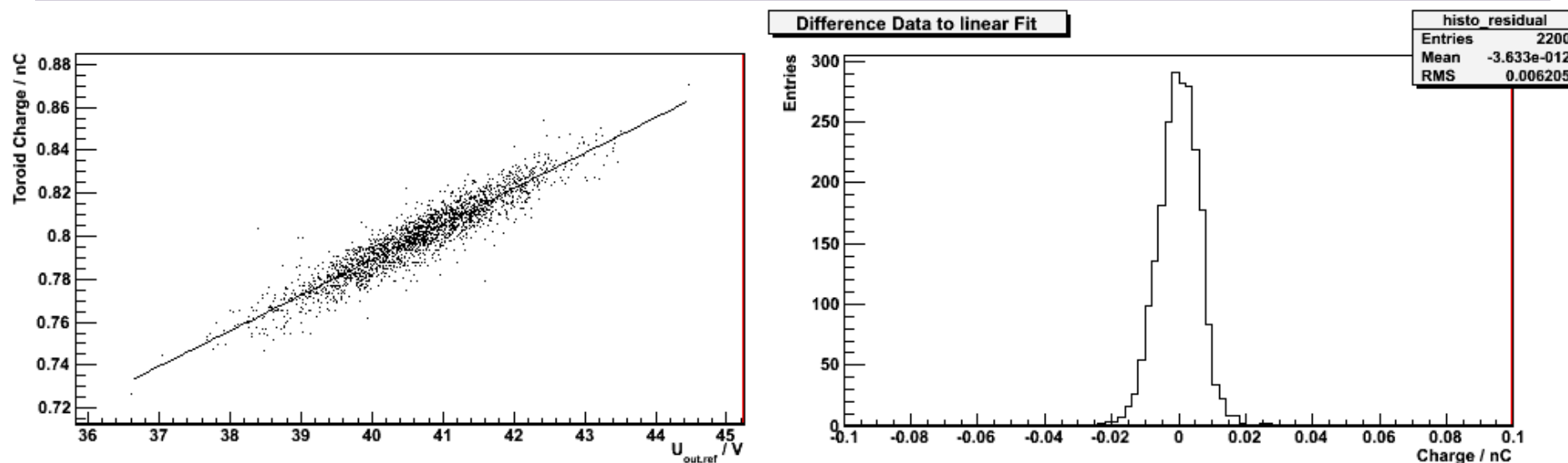
For time between $t_{trigger}$ and t_s
(transient oscillation):

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

f_g gradient frequency

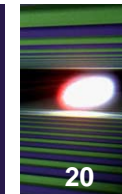


Stable beam conditions and monitored with Toroid and reference resonator

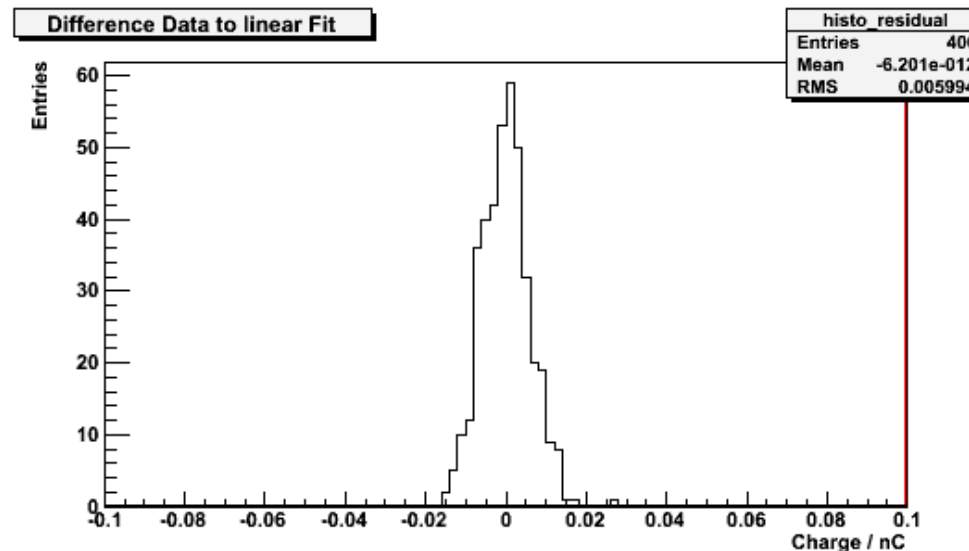
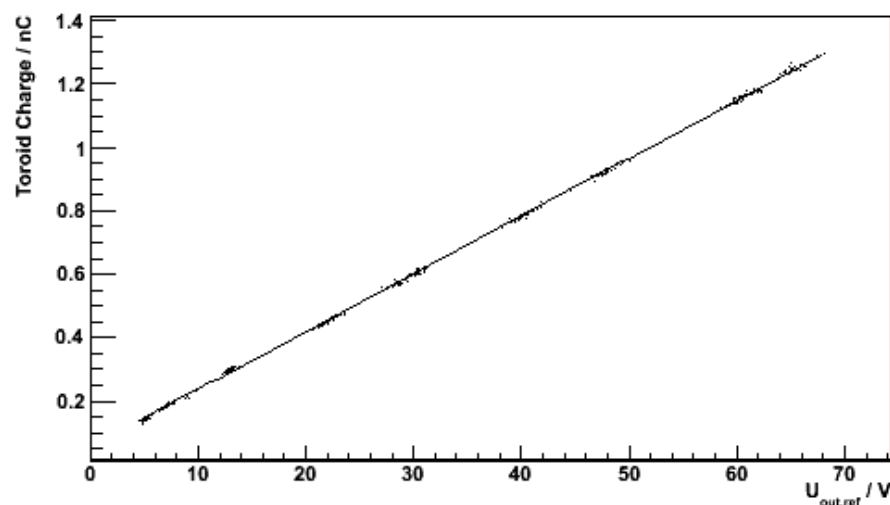


Result

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



Beam charge was changed and monitored with Toroid and reference resonator

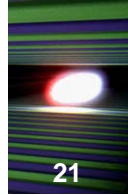


Sensitivity

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

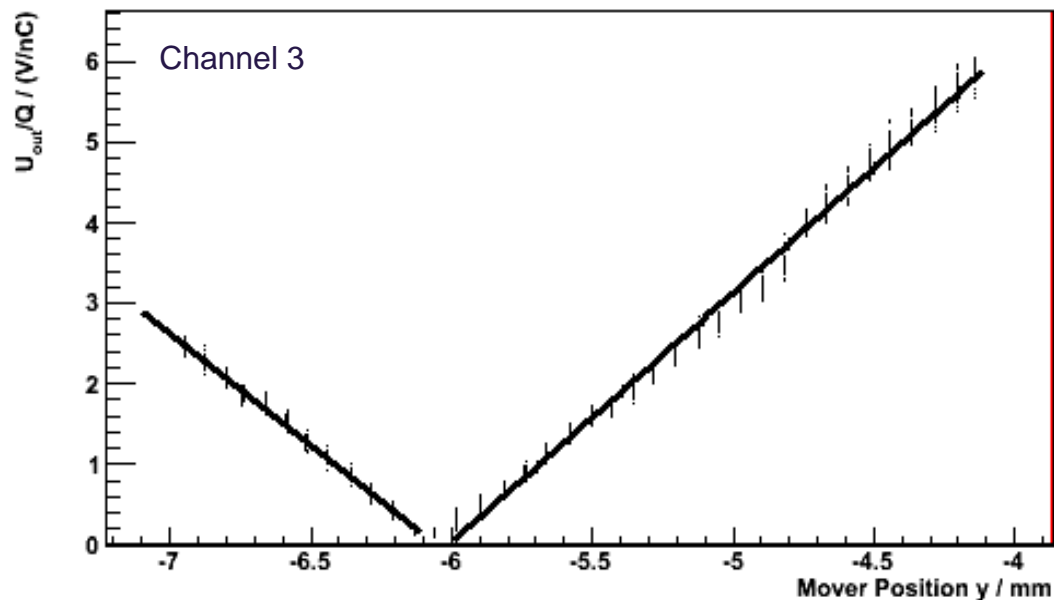
Difference between Linearity and Data: 6 pC (RMS)

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



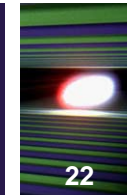
Sensitivity of dipole resonator

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



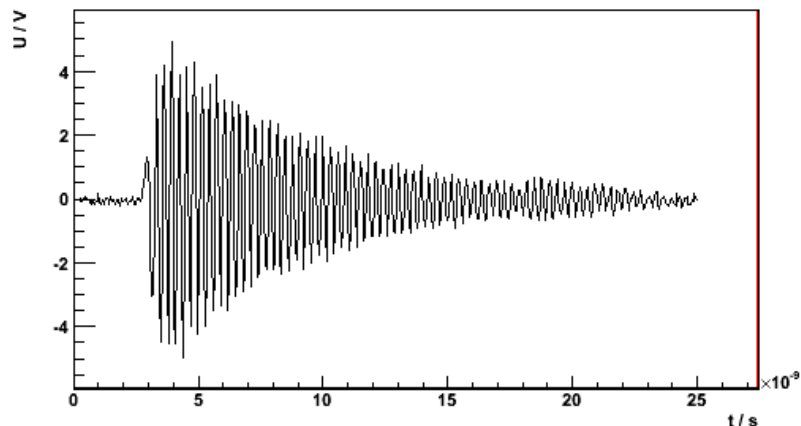
Sensitivity

- 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)

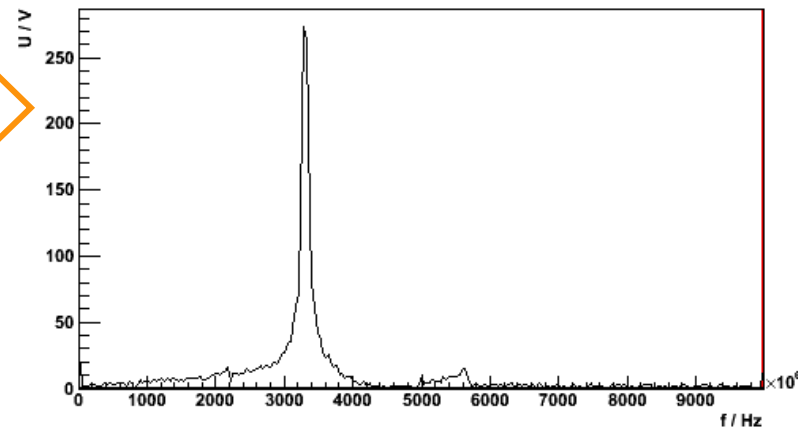


Spectrum dipole resonator

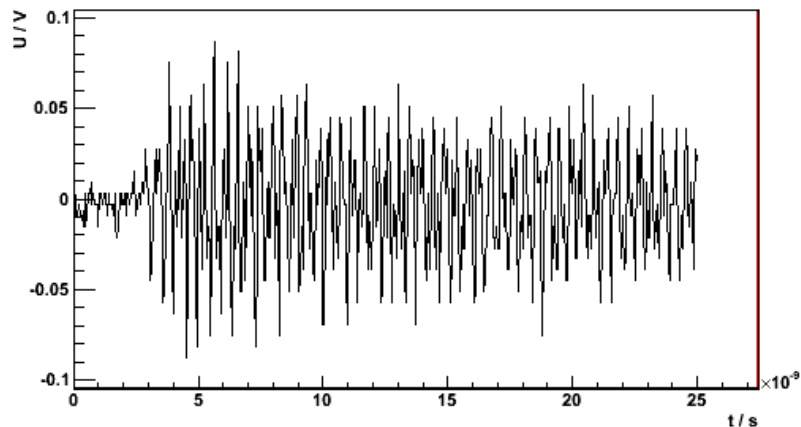
Channel 1



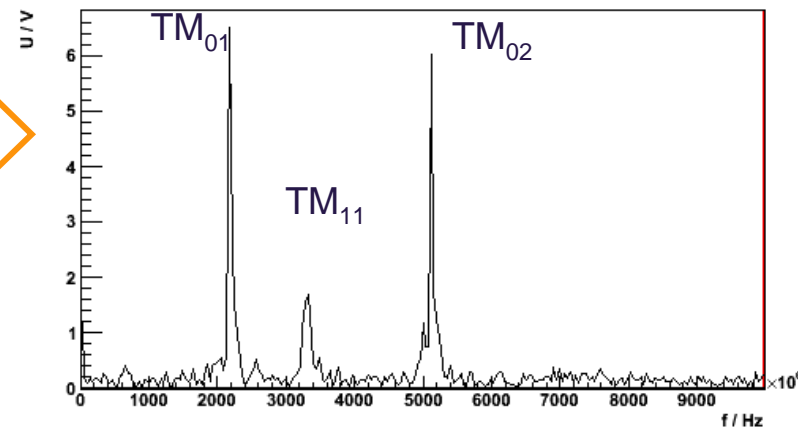
Ch1



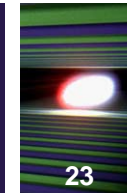
Channel 2



Ch2

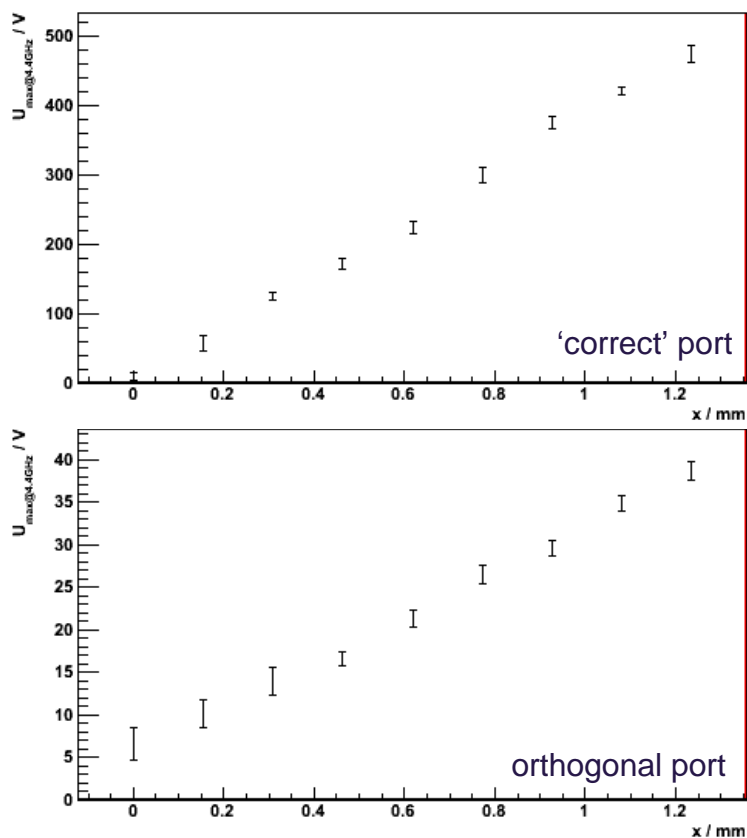


Y scan with largest y offset, x at axis



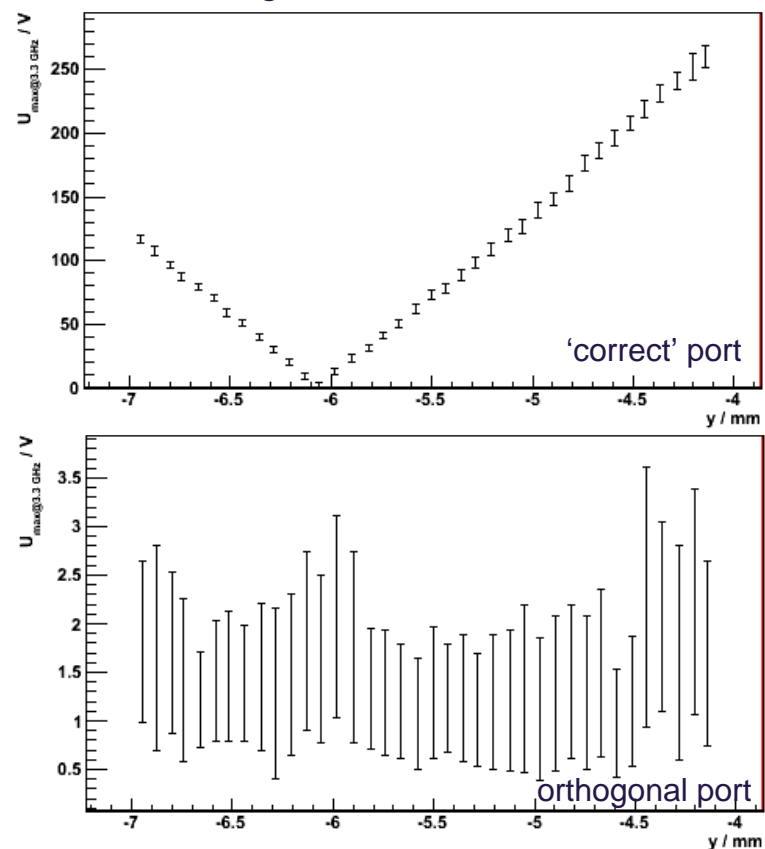
Orthogonal coupling of first and second prototype: Amplitude of spectrum at dipole resonance frequency as a function of mover position

First prototype, measured 2008

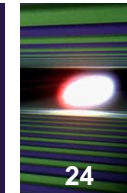


Coupling of dipole modes with -20 dB

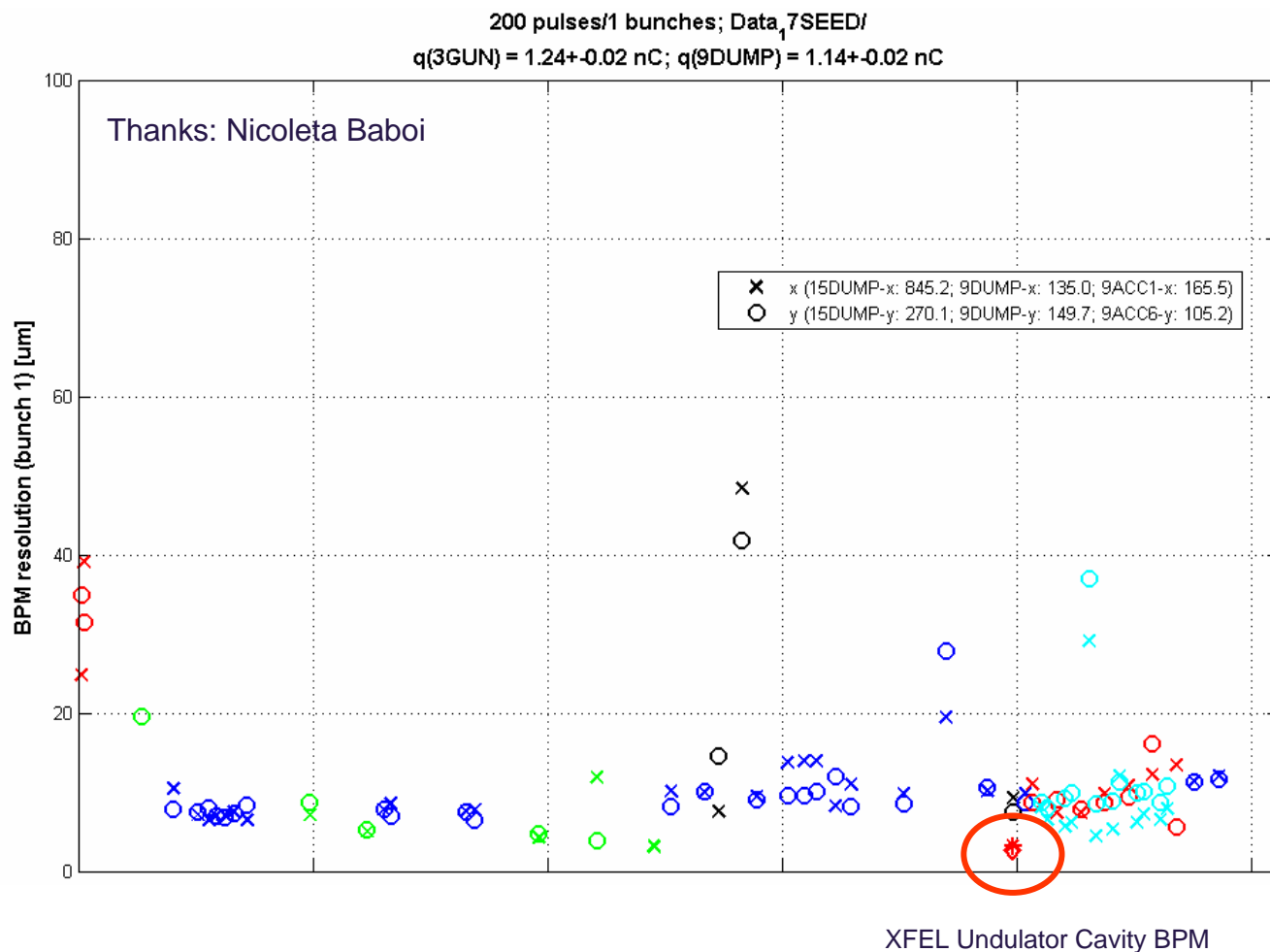
New design, measured Jan. 2009



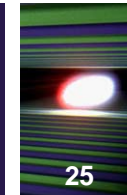
No coupling observed, lower than -43 dB, because improved design with tighter mechanical tolerances



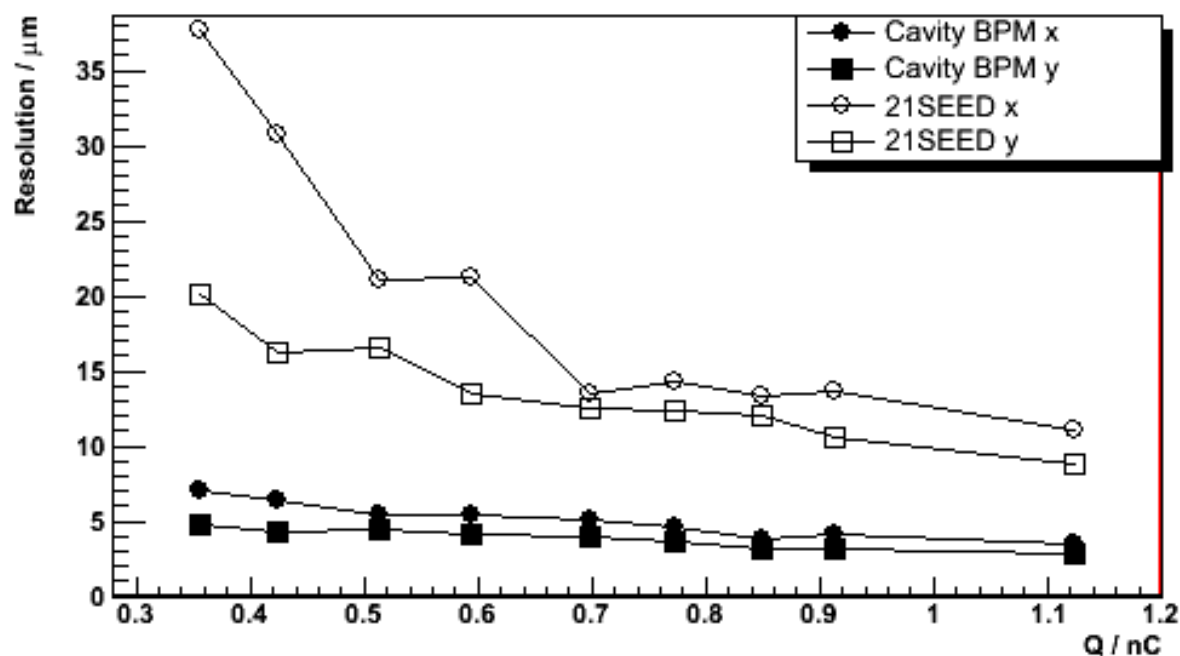
Resolution at FLASH



- 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



Resolution cavity BPM vs. bunch charge

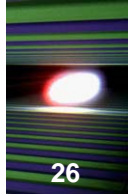


Resolution affected due to:

- 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.

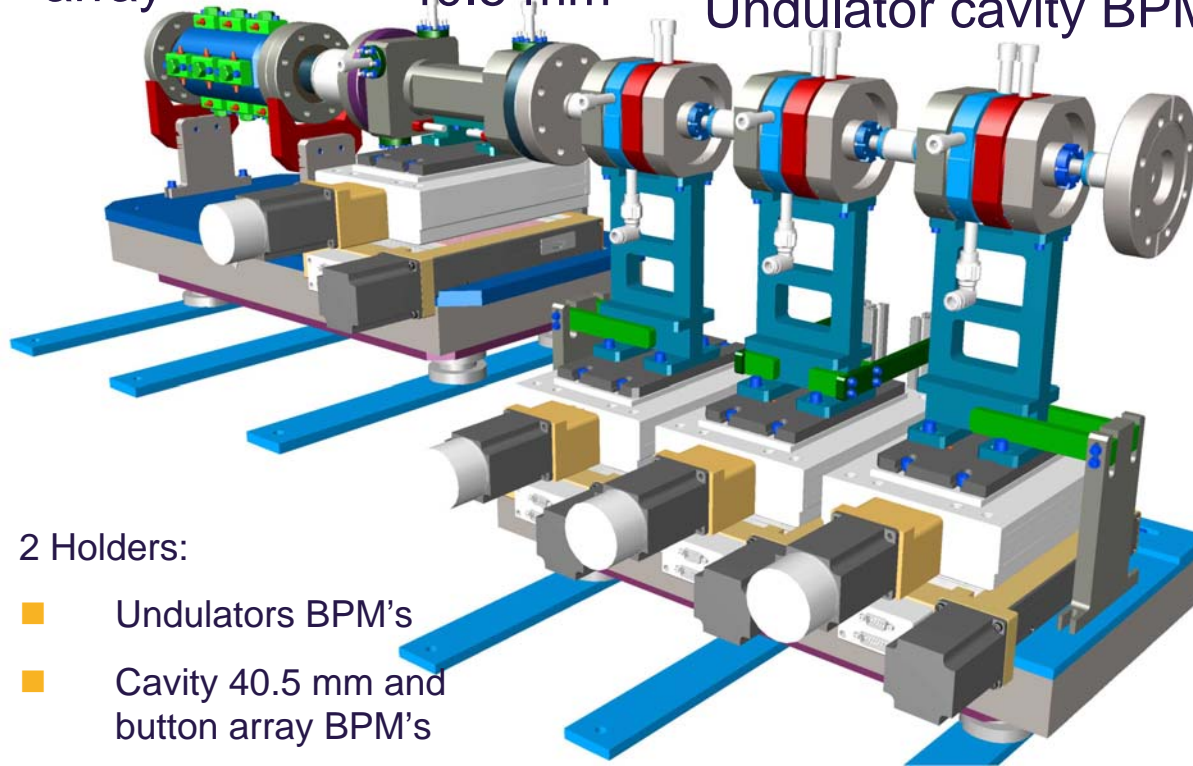
Beam measurement of Cavity BPM



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

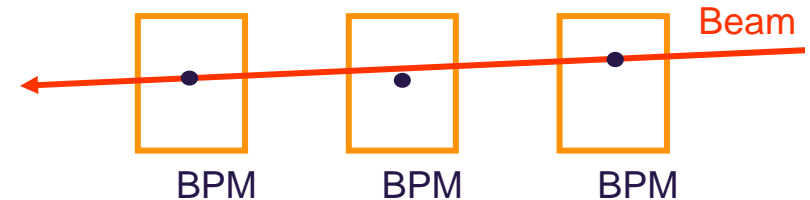
1. Undulator Cavity BPM
2. Cavity BPM 40.5 mm

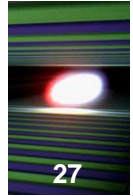
Button BPM separately

Design: Maike Siemens

Principle:

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





- 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.



- 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!



Headline

- first level
 - second level
 - ➔ third level

Headline

Texttext texttext
texttext texttext
texttext texttext

Keyword

1. Keyword
2. Keyword

- keyword
- keyword

Result Headline

- result text
- result text

Result headline

Result text, result text,
result text

Result headline

- result text
- result text
- result text