Development of a new Beam Position Monitor for FLASH, XFEL and ILC Cryomodules

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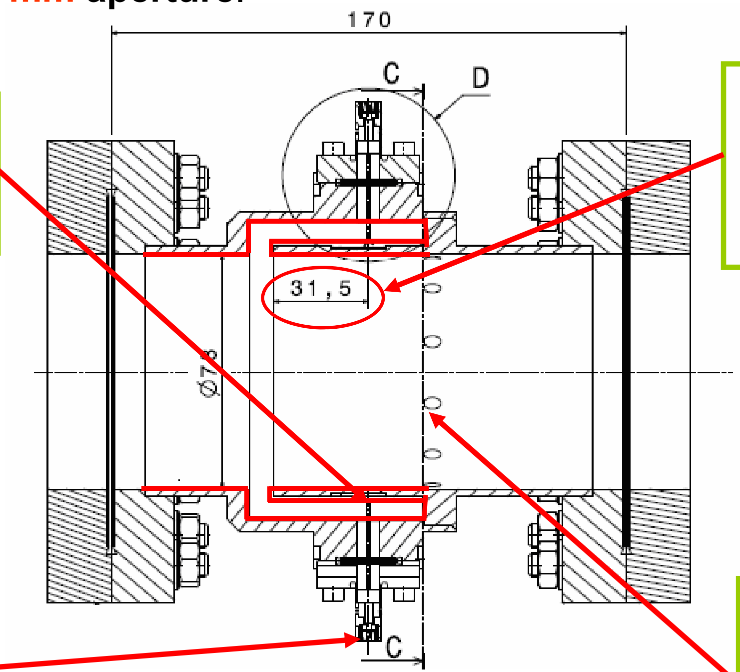
Re-entrant Cavity BPM

- It is arranged around the beam tube and forms a coaxial line which is short circuited at one end.

- The cavity is fabricated with stainless steel as compact as possible :

170 mm length (minimized to satisfy the constraints imposed by the cryomodule)

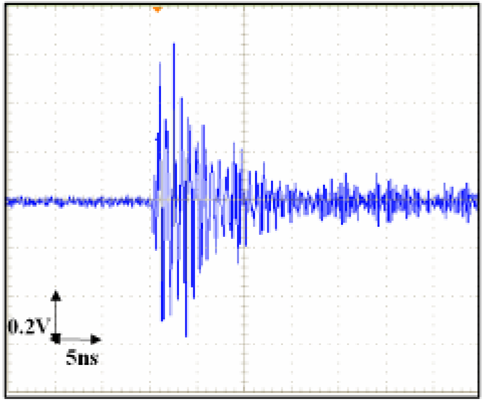
78 mm aperture.



Cu-Be RF contacts welded in the inner cylinder of the cavity to ensure electrical conduction.

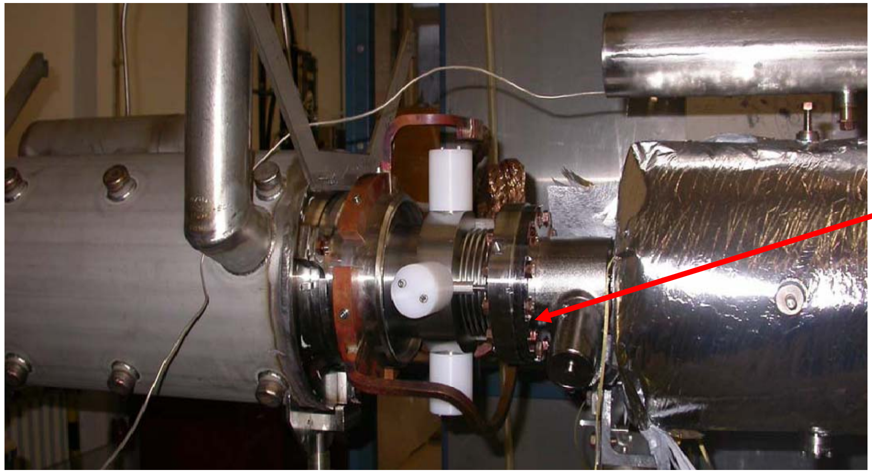
Feedthroughs are positioned in the re-entrant part to reduce the magnetic loop coupling and separate the main RF modes (monopole and dipole)

Twelve holes of 5 mm diameter drilled at the end of the re-entrant part for a more effective cleaning (Tests performed at DESY).



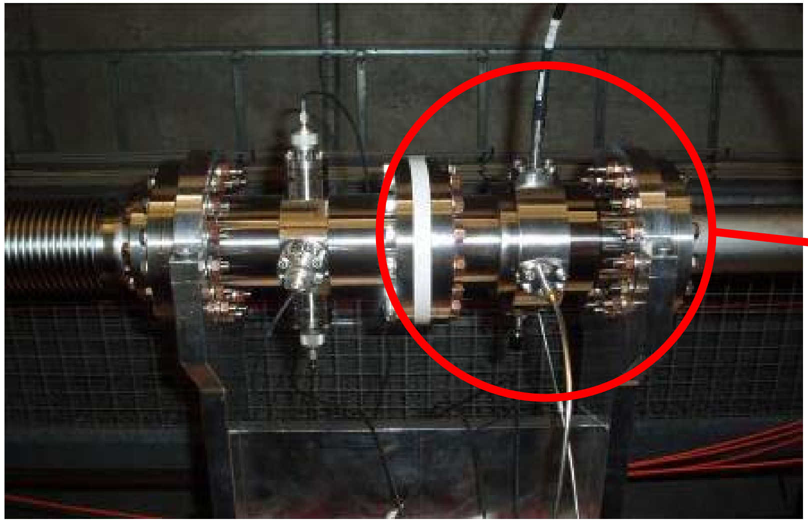
Signal from one pickup

Re-entrant Cavity BPM



Re-entrant cavity BPM located at cryogenic temperature inside the cryomodule (ACC1).

Re-entrant cavity BPM installed in a warm section on the FLASH linac



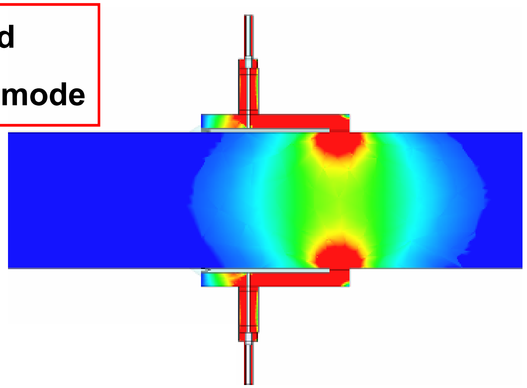
RF Characteristics of the BPM

- RF characteristics of the cavity: frequency, coupling and R/Q

Eigen modes	F (MHz)		Q_l		$(R/Q)_l$ (Ω) at 5 mm	$(R/Q)_l$ (Ω) at 10 mm
	Calculated with HFSS in eigen mode	**Measured in the tunnel**	**Calculated with HFSS in eigen mode**	**Measured in the tunnel**	**Calculated**	**Calculated**
Monopole mode	1250	1255	22.95	23.8	12.9	12.9
Dipole mode	1719	1724	50.96	59	0.27	1.15

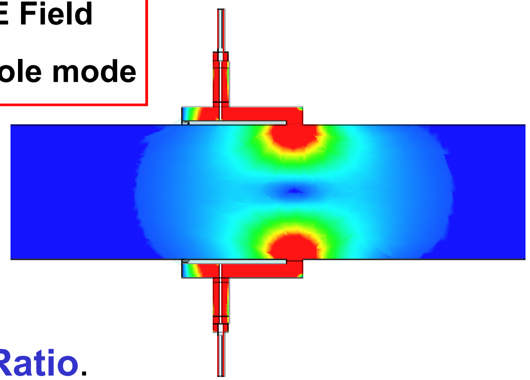
E Field

Monopole mode



E Field

Dipole mode



- With **Matlab and the HFSS calculator**, we computed **R/Q Ratio**.

R: the Shunt impedance and Q: the quality factor

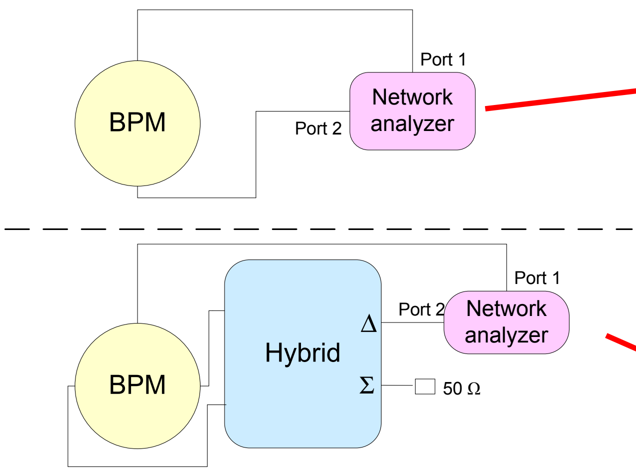
$$\frac{R}{Q} = \frac{V^2}{2 * \pi * f * W} \qquad V = \left| \int E(z) * e^{jkz} dz \right| \quad \text{and} \quad k=w/c$$

Cross Talk of the Cavity BPM

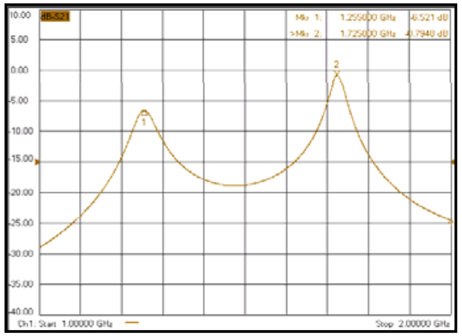
- **Due to tolerances in machining, welding and mounting, some small distortions of the cavity symmetry are generated**.

A beam displacement in the 'x' direction gives not only a reading in that direction but also a non zero reading in the orthogonal direction 'y'.

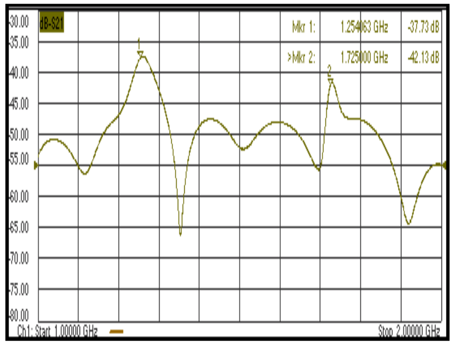
This **asymmetry** is called **cross talk**.



Representation of the cross-talk measurement



Monopole and dipole transmission measured by the network analyzer



Transmission of 2 antennas positioned at 90°

From those measurements, the **cross-talk isolation** value is estimated around 33 dB.

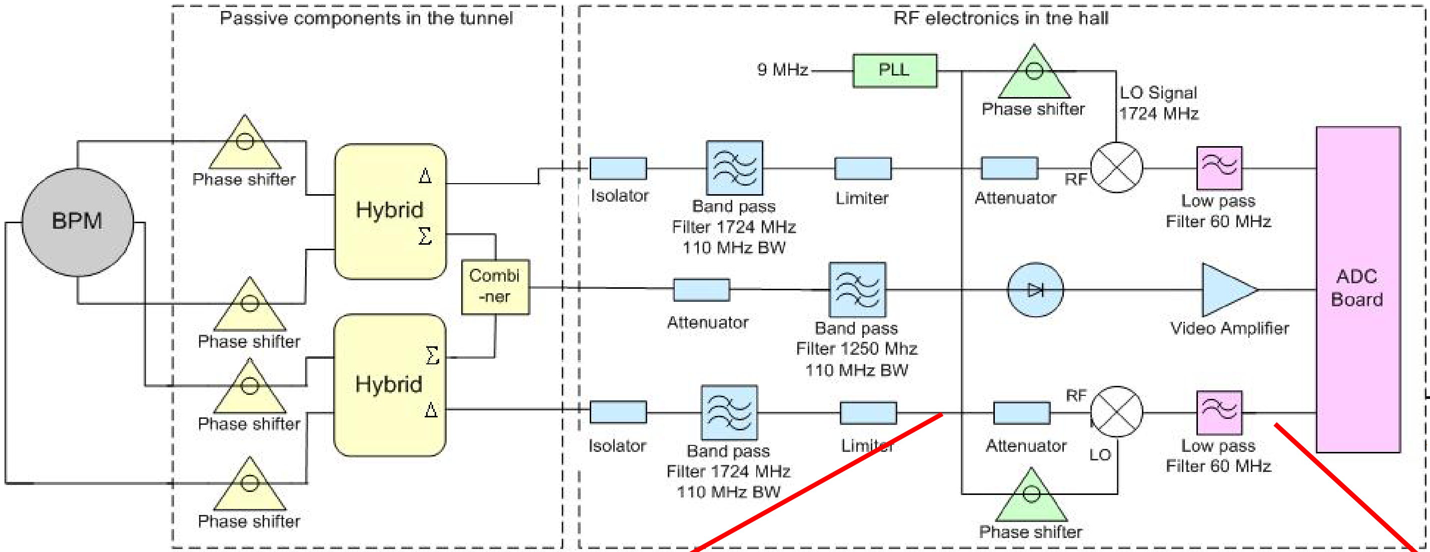
Signal Processing

- The rejection of the monopole mode, on the Δ channel, proceeds in **three steps** :

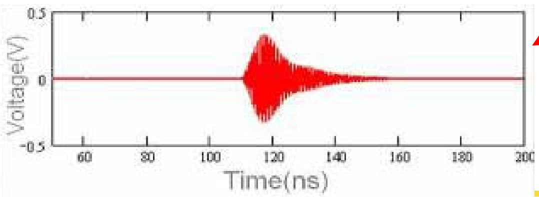
  - a rejection based on a hybrid coupler having isolation higher than 20 dB in the range of 1 to 2 GHz.

  - a frequency domain rejection with a band pass filter centered at the dipole mode frequency. Its bandwidth of 110 MHz also provides a noise reduction.

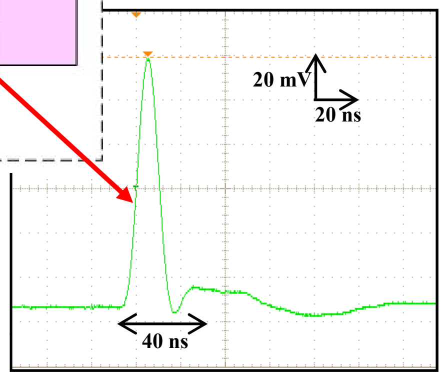
  - a synchronous detection.



RF signal



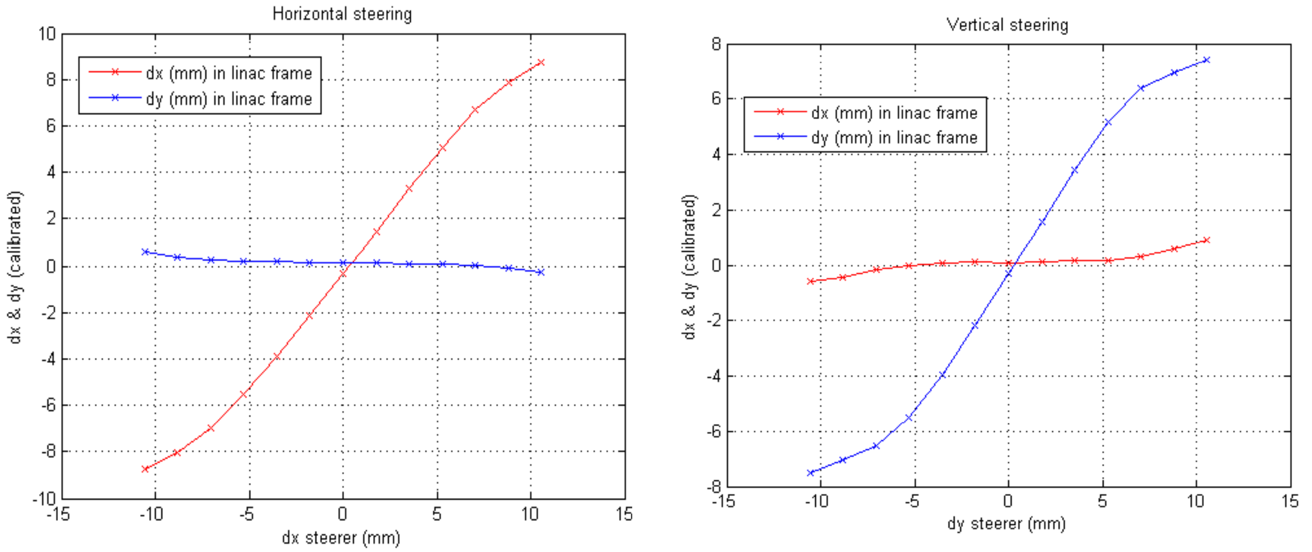
IF signal behind Lowpass Filter on channel Δ



Beam tests on the BPM (1)

❖ To calibrate the BPM:

- Beam is moved with one steerer.
- Calculate for each steerer setting, the relative beam position in using a transfer matrix between steerer and BPM (magnets switched off to reduce errors and simplify calculation).
- Average of 500 points for each steerer setting.



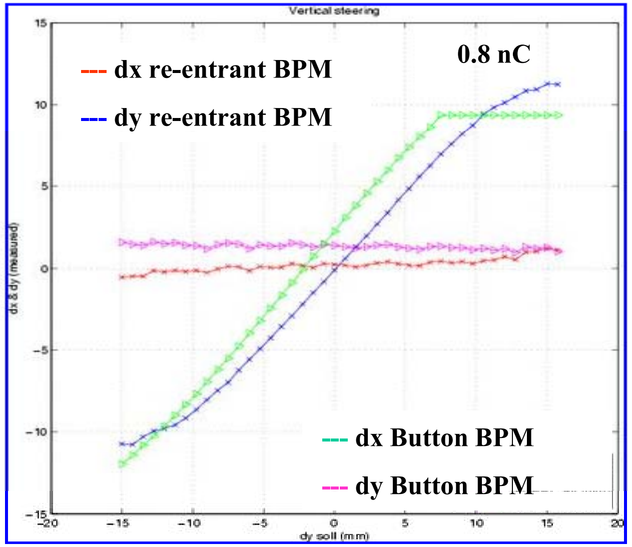
Calibration results from horizontal (left) and vertical (right) steering

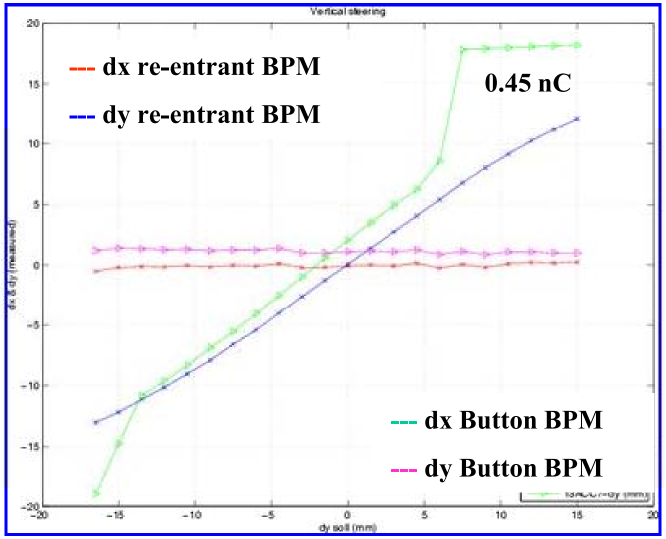
➡ **Good linearity in a range ± 5 mm**

➡ **RMS resolution: ~4 µm on the Y channel**
~8 µm on the X channel } **with 1 nC**

Beam tests on the BPM (2)

With an attenuator 6 dB on each channel





Good linearity : ± 10 mm @ 0.8 nC

± 15 mm @ 0.45 nC

Resolution measurement:

correlation of the reading of one BPM in one plane against the readings of all other BPMs in the same plane (using linear regression).

Charge	Resolution Re-entrant	Resolution Re-entrant+ 6 dB attenuator
1.0 nC	~ 4 µm	
0.8 nC		~ 12 µm
0.5 nC	~ 11.8 µm	~ 21 µm
0.2 nC	~ 30.1 µm	~ 55 µm

Time Resolution

➢ **Damping time** is given by using the following formula : $\tau = \frac{1}{\pi * BW}$

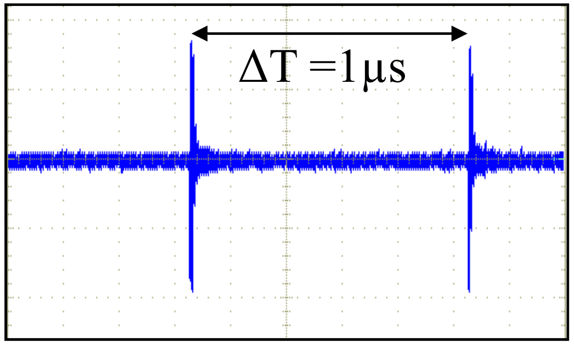
With $BW = \frac{f_d}{Q_{ld}}$

fd: dipole mode frequency
Q_ld: loaded quality factor for the dipole mode

➢ Considering the system (**cavity + signal processing**), the **time resolution** is determined, since the rising time to 95% of a cavity response corresponds to 3τ.

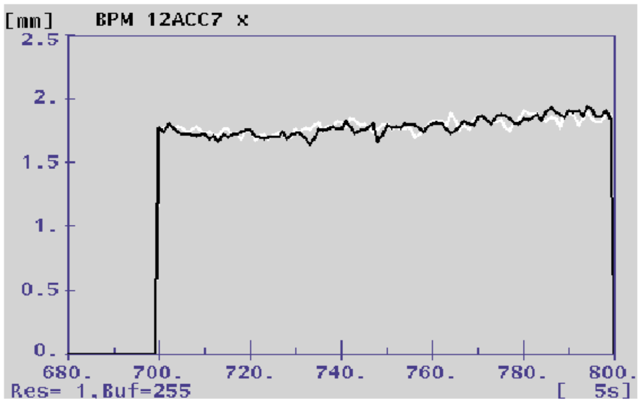
	Damping Time cavity only	Time resolution cavity + electronics
BPM	9.4 ns	40 ns

Time resolution for re-entrant BPM



RF signal measured at one pickup

100 bunches read by the re-entrant BPM

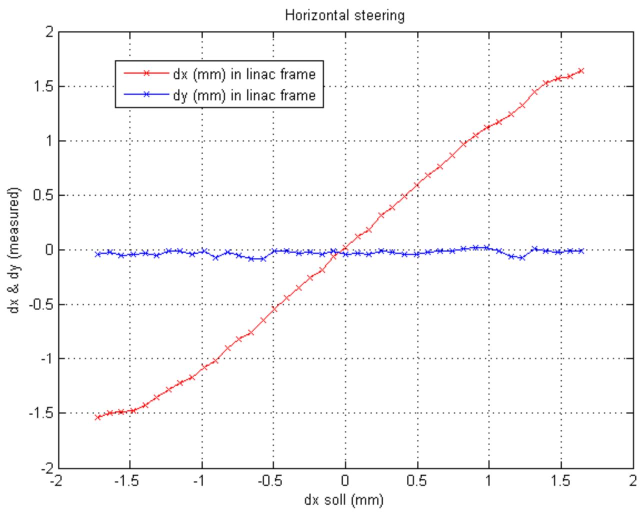


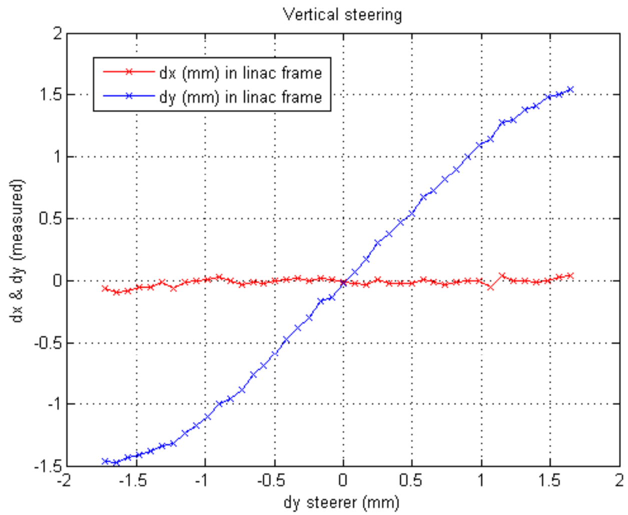
Possibility bunch to bunch measurements

Last beam measurements

❖ Measurements carried out with an amplifier added in the electronics box.

- Should have reduced the dynamic range to have a better resolution





Calibration results from horizontal (left) and vertical (right) steerings with the "new" electronics

→ **Good linearity in a range ± 1.5 mm**

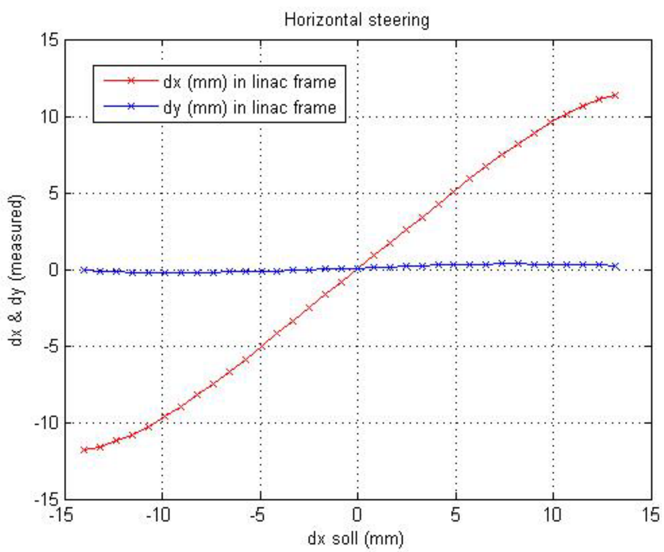
→ **RMS resolution: ~8 μm on the Y channel**
~5 μm on the X channel } **with 0.9 nC**

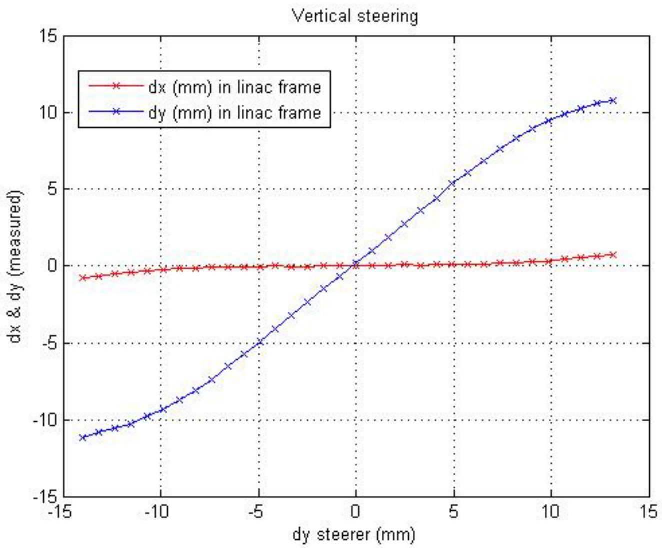
❖ Resolution with this amplifier is similar to the resolution without amplifier

→ Need to analyze the problem

Last beam measurements

- ❖ Adjustment of the RF phase because the 9 MHz reference signal was changed
- ❖ Checking of the measurements carried out in last August.





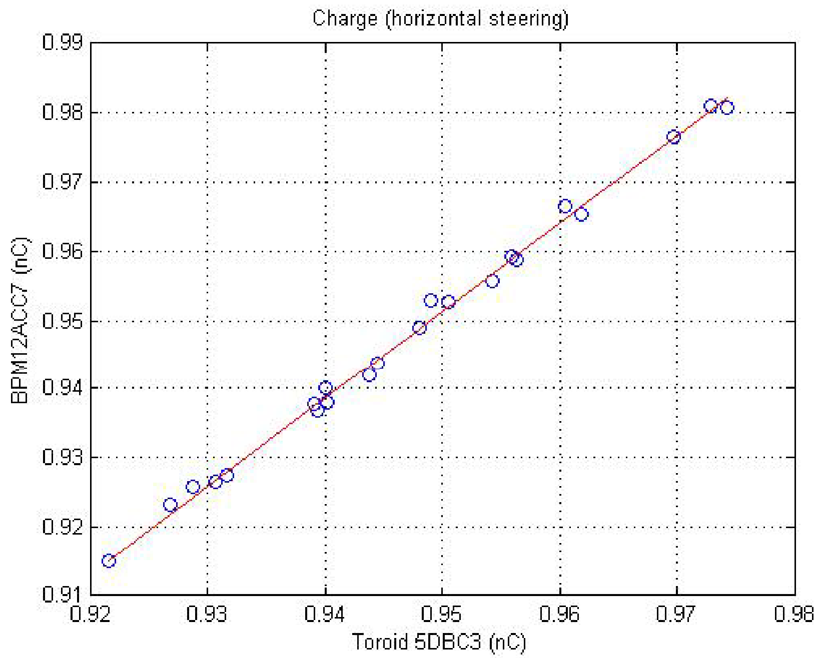
Calibration results from horizontal (left) and vertical (right) steering

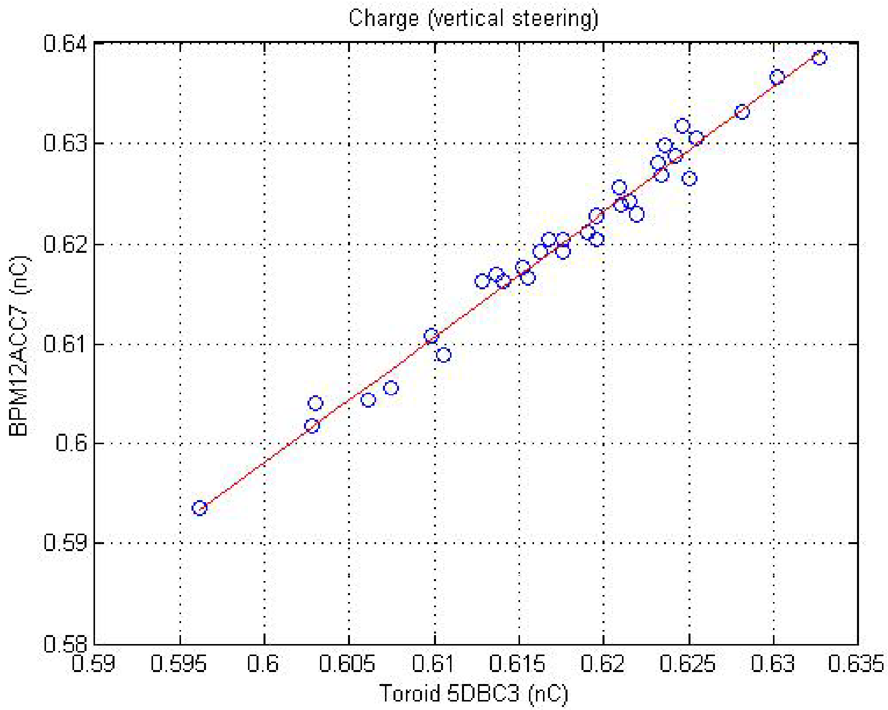
➡ **Good linearity in a range ± 12 mm**

➡ **RMS resolution: ~7 μm on the Y channel**
~8 μm on the X channel } **with 0.9 nC**

Last beam measurements

❖ Calibration of the charge





dapnia

cea

saclay

Summary

❖ **High resolution re-entrant cavity BPM features:**

- **Effective in clean environment**
- **Operation at room and cryogenic temperature**
- **Large aperture of the beam pipe (78 mm)**
- **Position resolution around 4 µm measured with a measurement dynamic range around ± 5 mm**
- **Time resolution around 40 ns**
- **A new prototype will be produced in 2008 with modified mechanics**
- **~ 30 BPMs will be installed in the XFEL cryomodules.**

❖ **This BPM appears as a good candidate for being installed in the ILC cryomodules.**

❖ More work is needed to obtain < 1µm resolution