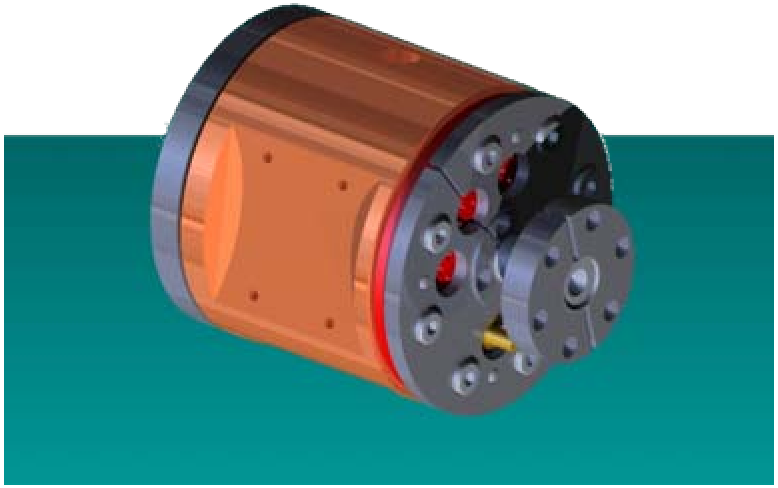
Status of the Precision Beam Position Monitor (PBPM) for EUROTeV



L. Soby, I. Podadera Aliseda
AB-BI-IP

Goal

Measurement of the beam position and current in the main linac (attached to the quadrupoles) of the next generation colliders (ILC and CLIC) with the specifications:

- **R**esolution:100 nm.
- **A**perture: 4-6 mm.
- **A**bsolute precision: 10 μm.
- **R**ise time: 15 ns.

Important parameter for the beam-based alignment

PBPM-specifications

EUROTeV	Aperture	4mm
	Resolution	100nm
	Absolute precision	10µm
	Rise time	<15ns
Extended specifications	Dynamic range	±1.5mm (15 bits)
	Linearity error	< 1% (±1.5mm)
	24H stability	1µm
	Droop	< 5%
	Low frequency cutoff	100kHz *(3.6% droop, CLIC 58ns pulse)*
	High frequency cutoff	30MHz
	CMRR	>90dB
	Bake out temperature	150ºC
	Vacuum	10^{-9} Torr
	Operating temperature	~20°C

Inductive pick-up: basic scheme

The electron beam induces an image current in the surrounding vacuum pipe...

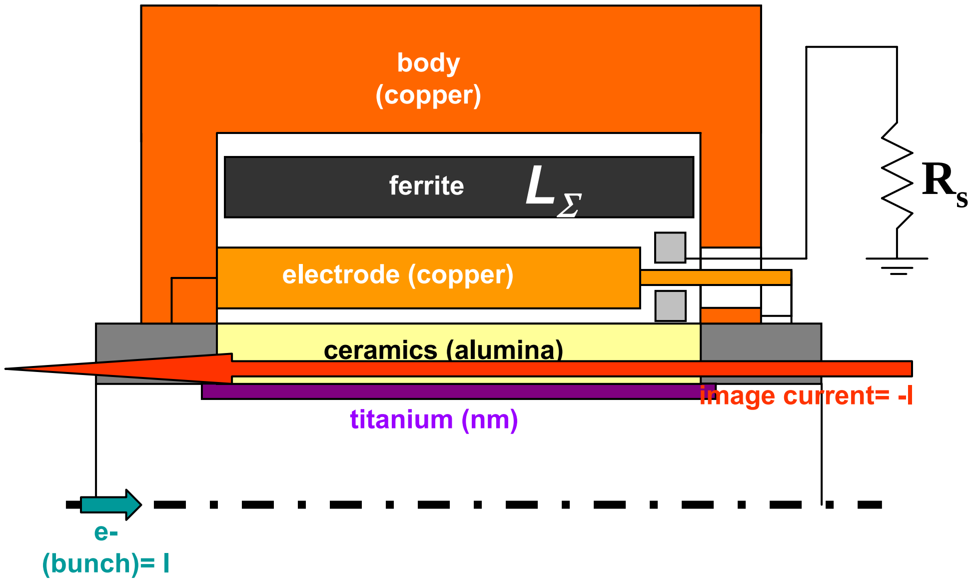
... the beam position (image current distribution) is picked outside the vacuum by the signal combination transformed by current transformers from strip electrodes (inductances L_Δ). The transformers are loaded in the secondary by a resistor R_s

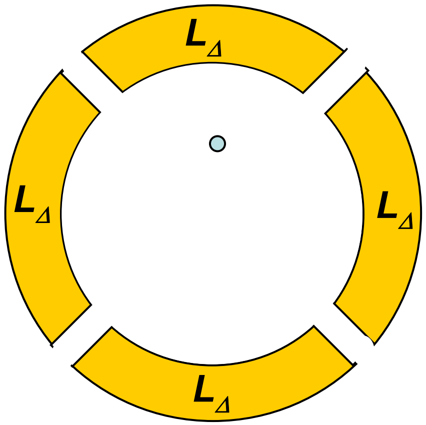
... the beam pipe is disrupted by a ceramics insertion in alumina which maintains the vacuum inside...

... a body shields the pick-up from environment perturbances...

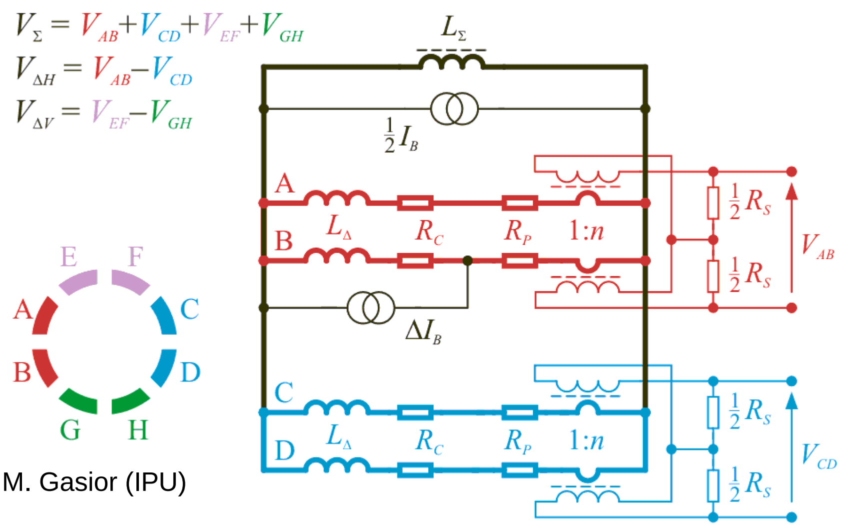
... the low frequency cutoff is decreased by the addition of a ferrite external to the electrodes...

... the longitudinal impedance at high frequencies and the wakefields are limited by a titanium resistive coating in the internal face of the ceramics. Big enough to avoid signal losses at low frequencies and low enough for the impedance budget of the accelerator.

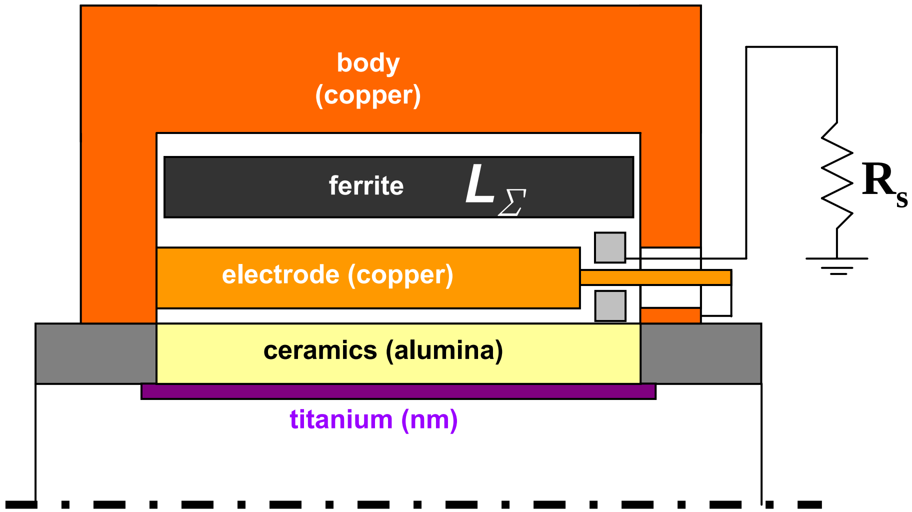




Inductive pick-up: basic scheme



M. Gasior (IPU)



Coupling impedance

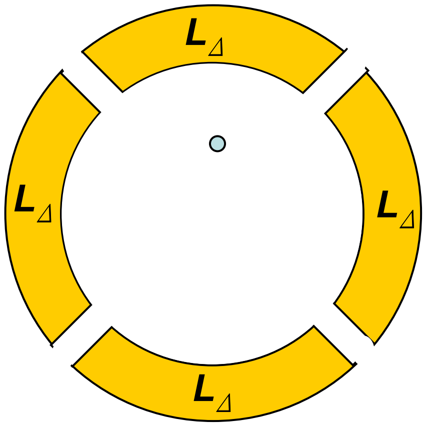
$$V_\Sigma = \frac{R_s}{n} I_B$$

Low cutoff (difference signal)

$$f_{L_\Delta} = \frac{R_s/n^2}{2\pi L_\Delta}$$

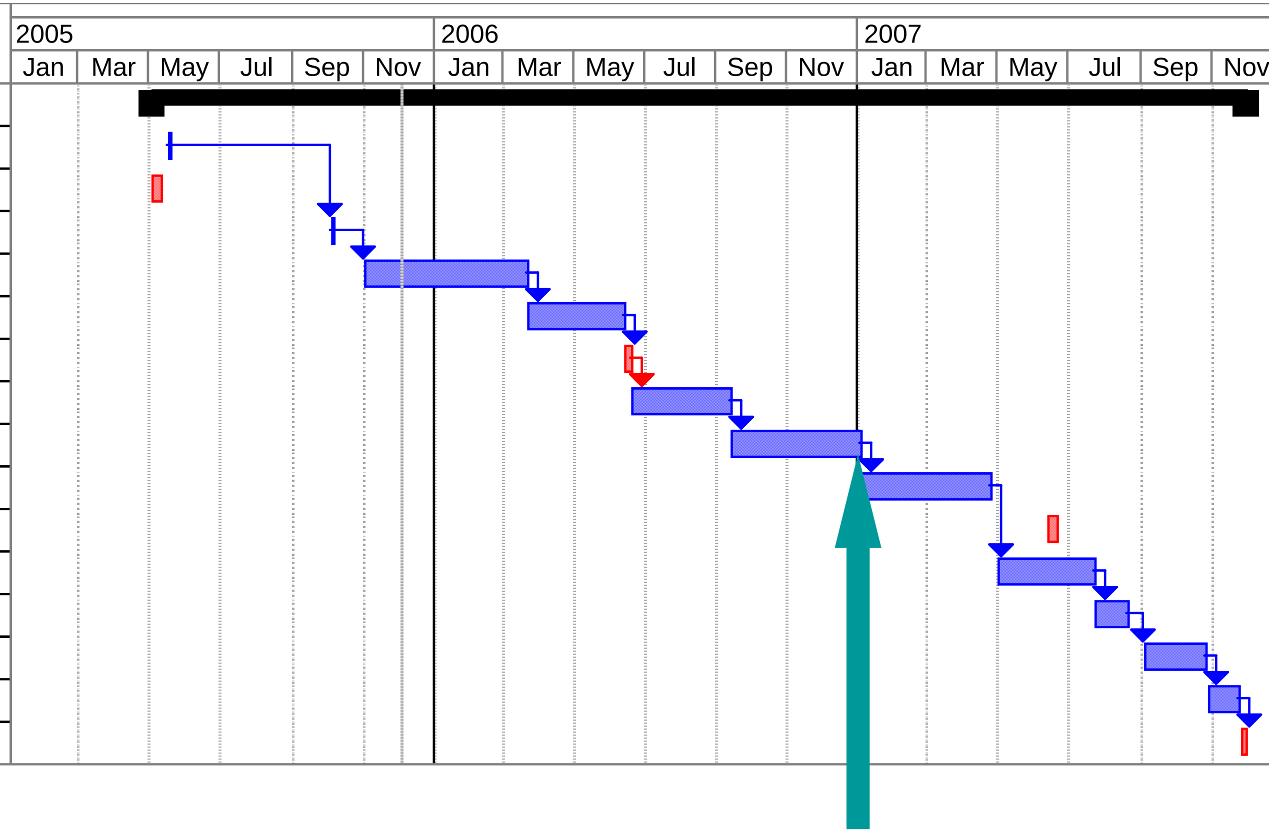
Low cutoff (sum signal)

$$f_{L_\Sigma} = \frac{R_s/n^2}{2\pi L_\Sigma}$$



PBPM planning

ID	Task Name
1	**PBPM**
2	Publish fellow post
3	Present work plan for EUROTeV
4	Hire fellow
5	Design PBPM
6	Simulate PBPM
7	Present design for EUROTeV
8	Fabrication drawings
9	Fabrication of 1BPM
10	Tests on bench
11	Present Results for EUROTeV
12	Manufacture 3 PBPMs
13	Tests on bench
14	Tests in CTF3
15	Write report
16	Send report to EUROTeV



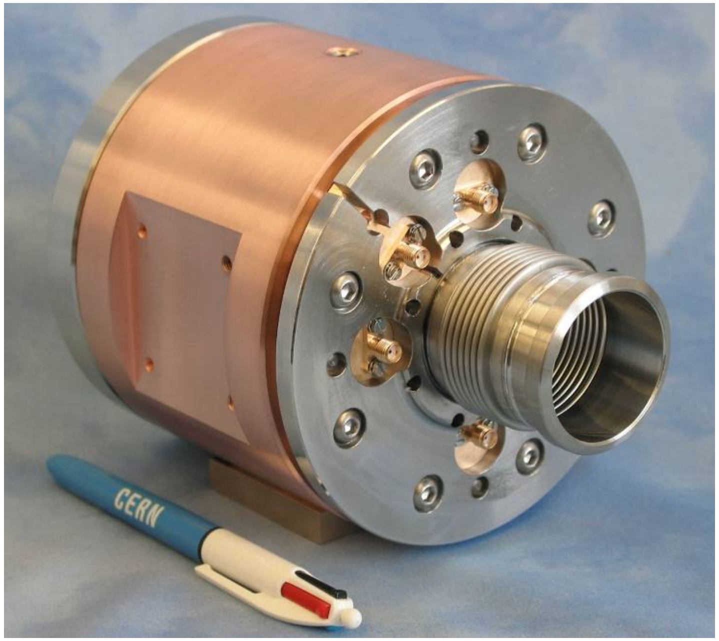
According to the schedule!

The design

From...

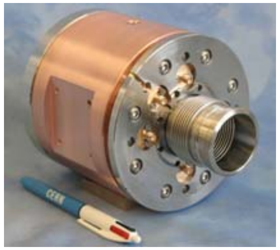
IPU (CTF3)

M. Gasior, *An Inductive Pick-Up for Beam Position and Current Measurements*, CERN-AB-2003-053-BDI

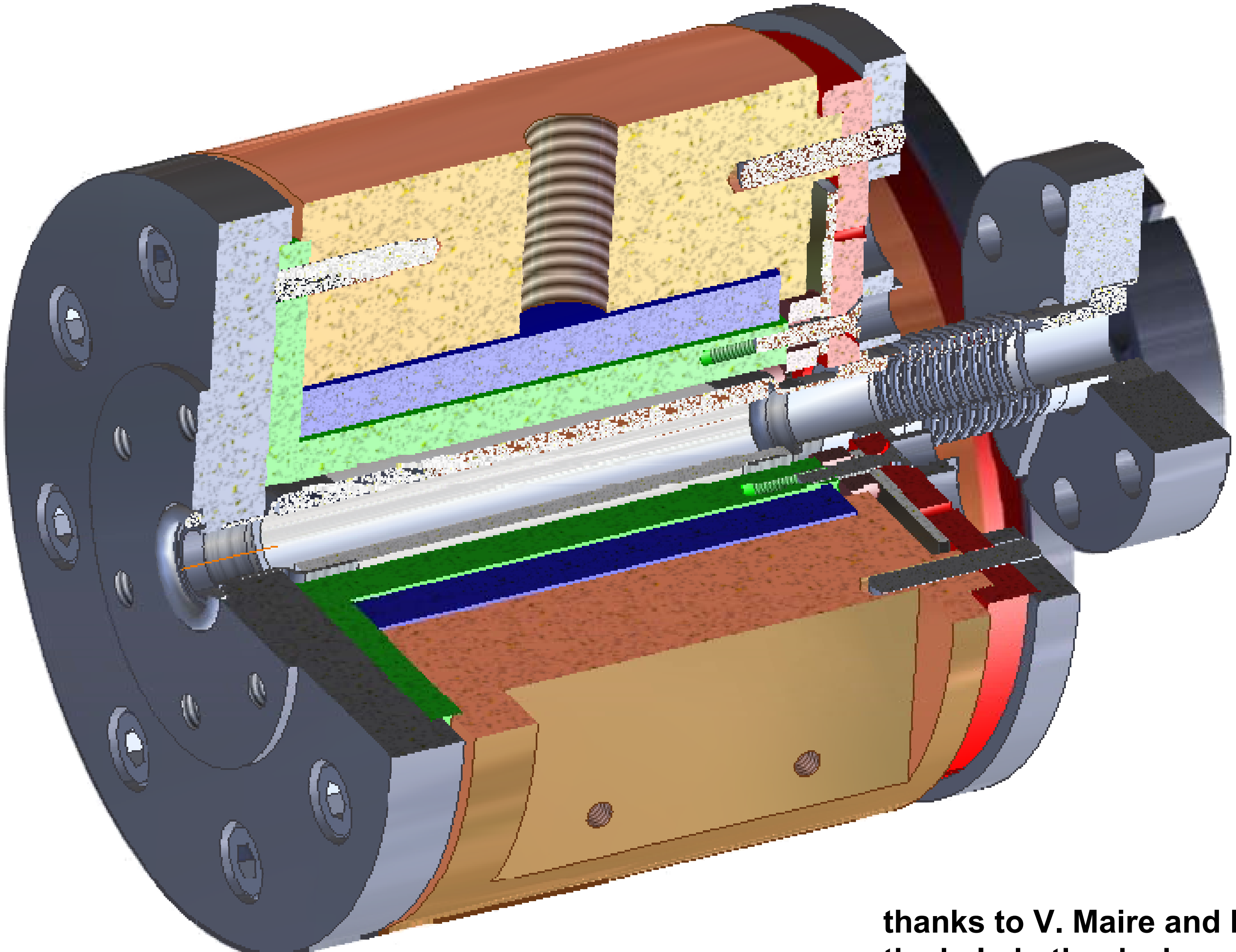


To...

PBPM

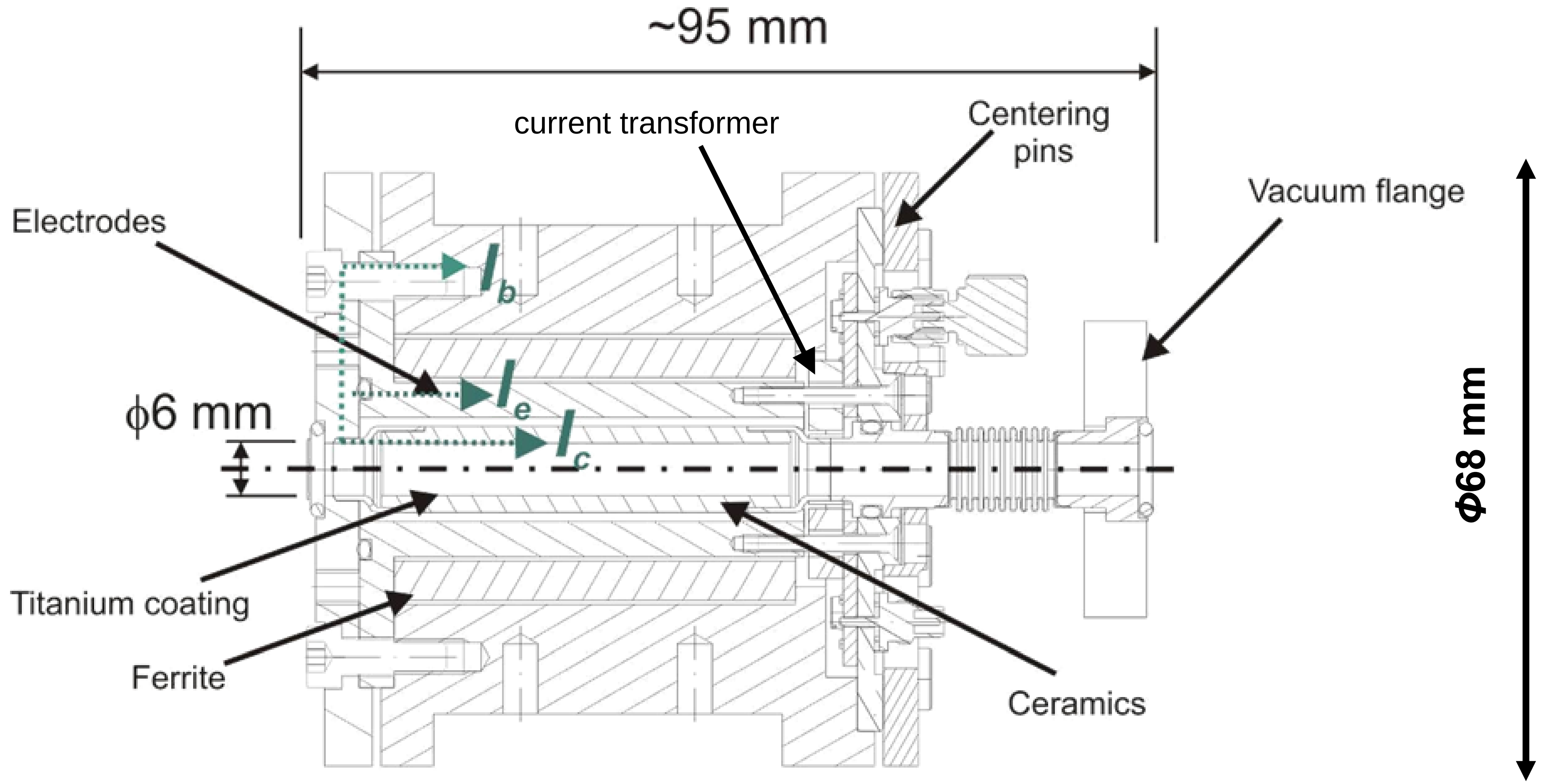


Final design

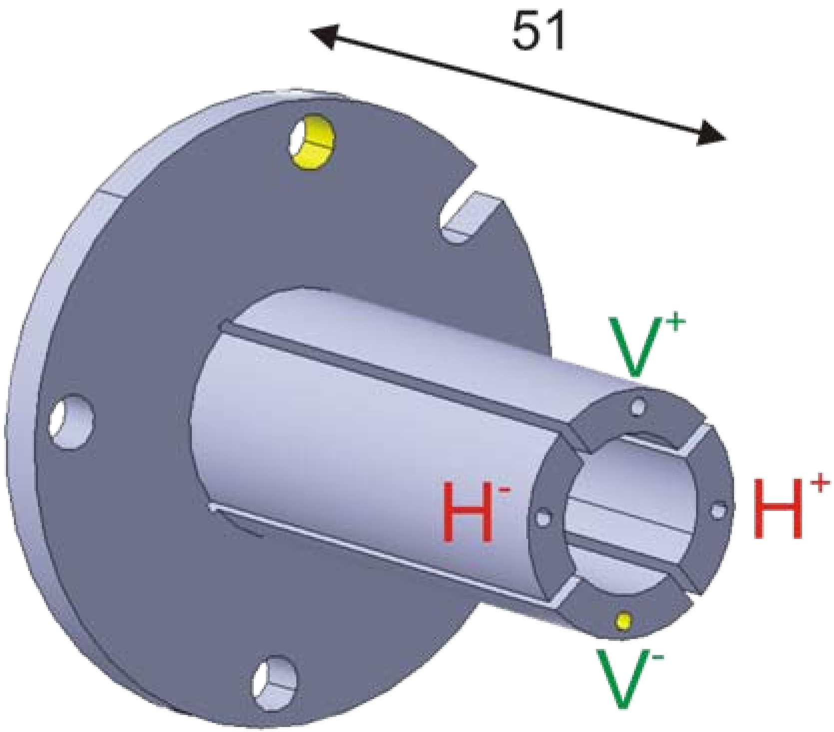


thanks to V. Maire and B. Favrat for the help in the design

Final design



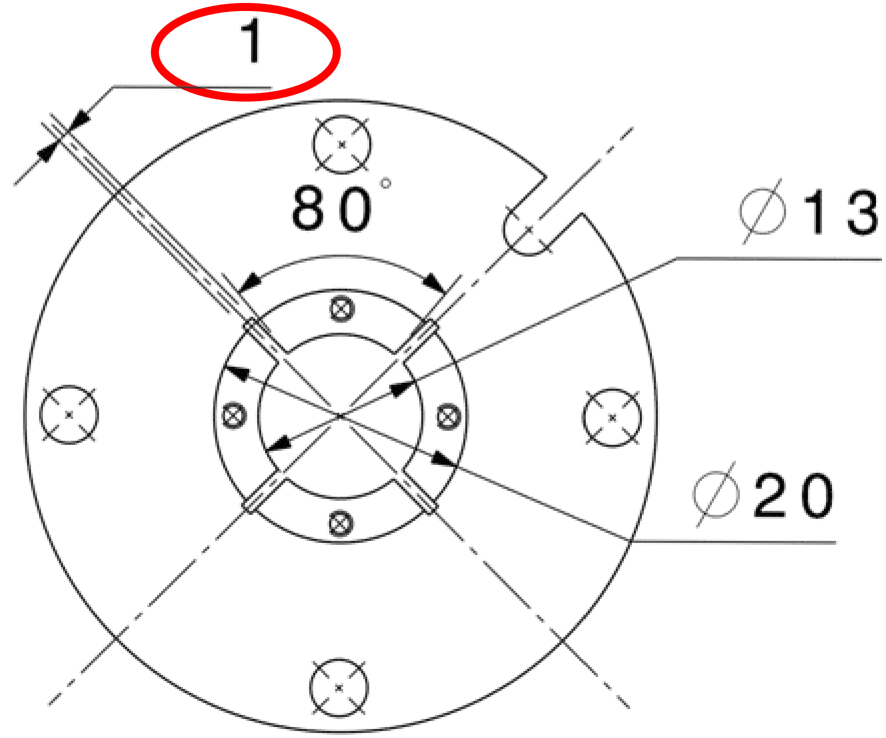
The electrodes



$\Delta_H = H^+ - H^-$

$\Delta_V = V^+ + V^-$

tests with 2mm and 3mm



Dimensions in mm

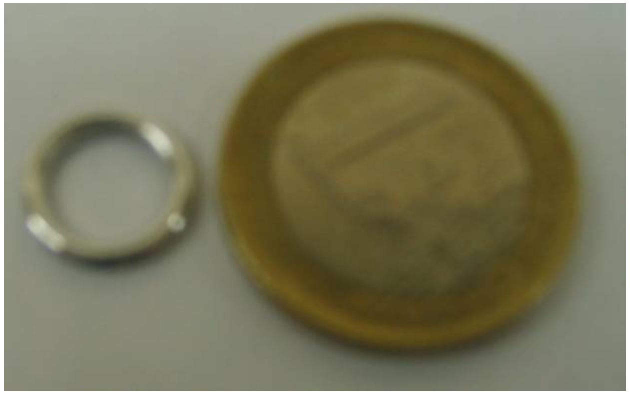
Design challenges

Mechanics

- **Sputtering of the ceramics:**
  - Very small diameter.
  - Deposition thickness of the coating proportional to distance titanium wire-ceramics wall: uniformity problems. Last tests 0.2 μm in the edges and 1.5 μm in the center.
  - Work developed by H. Neupert and S. Calatroni.
- **Vacuum chamber:**
  - Welding of all the pieces by electron beam with demanding accuracy (T. Tardy, L. Leggiero).
  - Brazing of the small bellow.
- **Tolerances imposed to the most important parts:**
  - Three reference planes in the body machined with at least 10 μm precision from the axis of the body. Very good precision of the mechanical center from the reference planes even without metrology.
  - The mechanical axis of the electrodes is coaxial in 5 μm with the axis of the body. The offset between the mechanical and "electrical" center is minimized.
  - Two positioning pins (10 μm) in each reference plane.
  - Good coaxility coating-ceramics-electrodes to define a constant impedance along the coaxial line.
  - Great help from V. Maire, B. Favrat for the design and P. Frichot for the manufacturing.

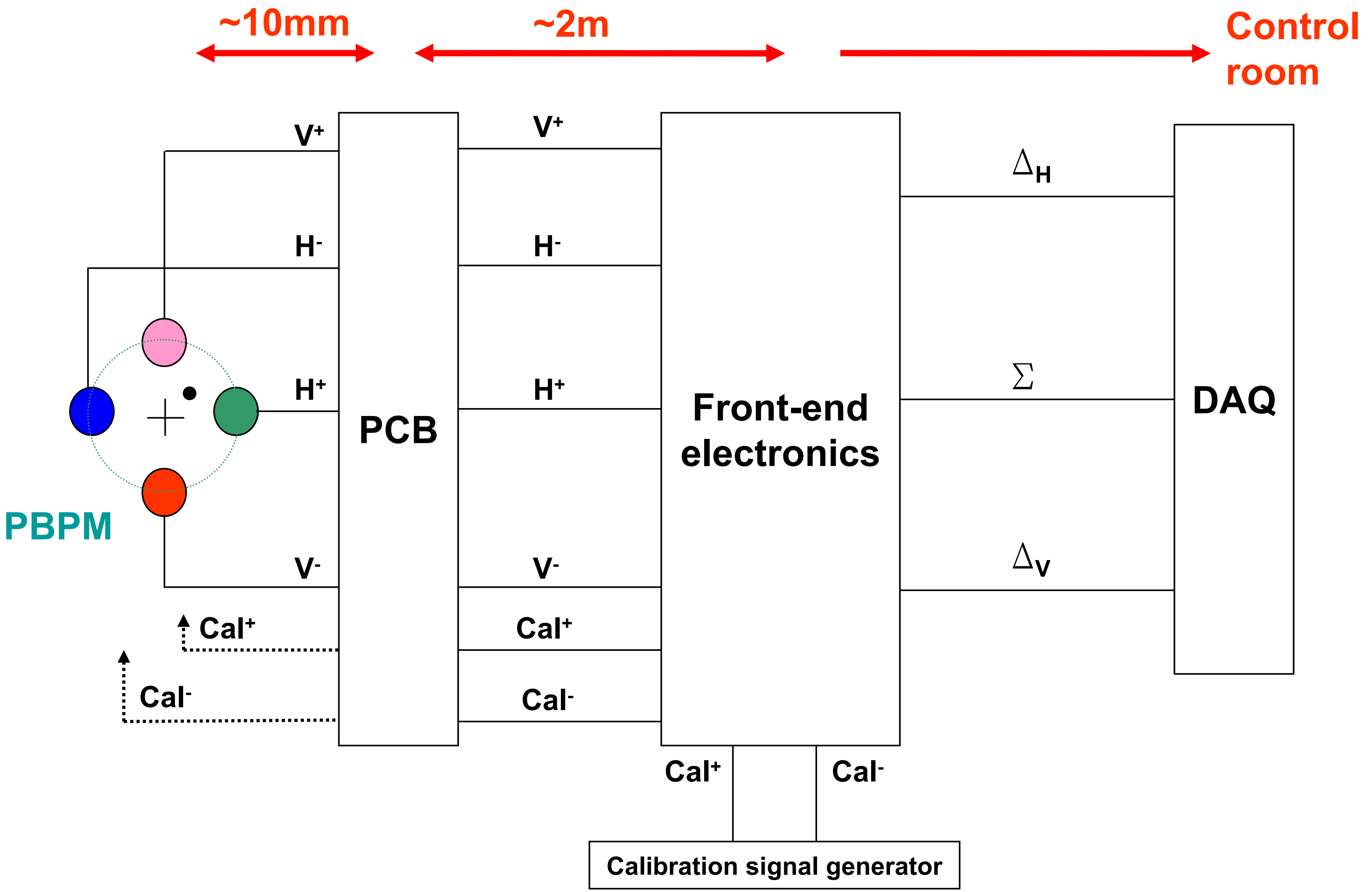
Design challenges

- **Vacuum flanges:**
  - To our knowledge, CLIC flanges are not yet defined.
  - Possible assembly in different machines to take into account (CTF3, ATF-2).
  - Small flange in order to have small electrodes and pick-up. In addition it minimizes the cavity and resonances.
  - Solution: small **helicoflex seal (Ø7.7 x Ø10.9 mm) with screws adapted to standard CF-16**.



- **Use of SMC connectors instead of SMA.**

PBPM electronics



PBPM front-end electronics

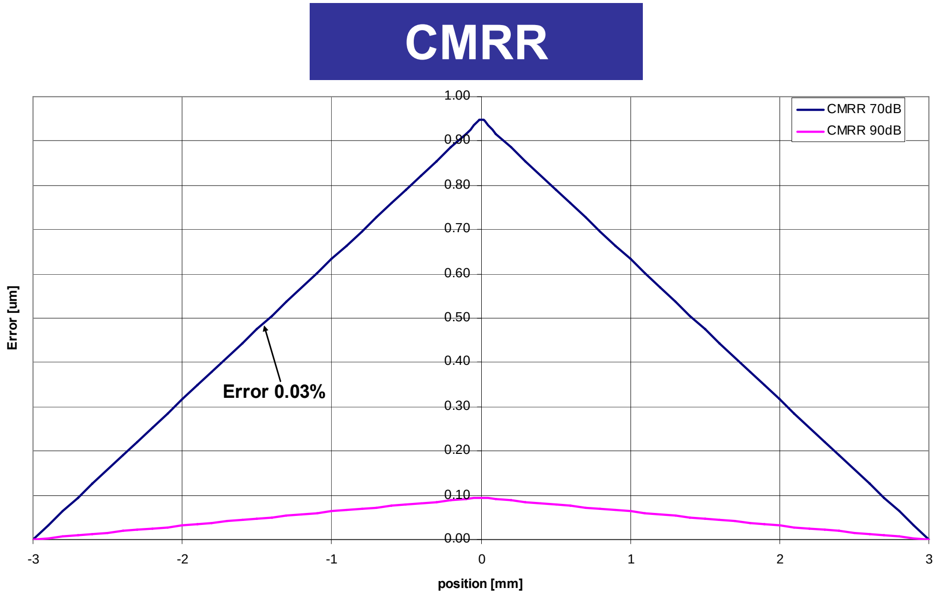
- **Test IPU electronics and Passive front-end hybrid *(radiation hard)* to generate Δ and Σ signals (BW=100kHz-30MHz).**

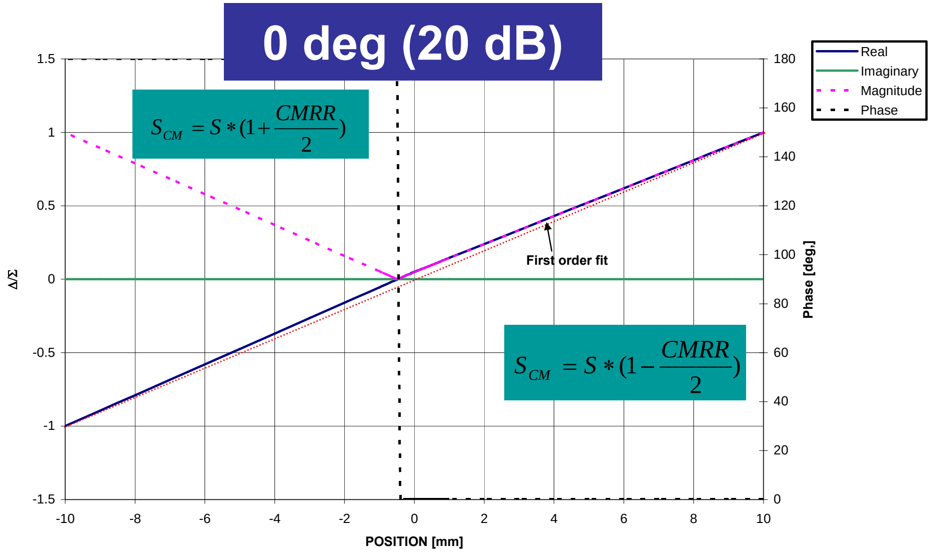
- **Difference must have CMRR >95 dB (100nm over 6mm) to minimize offset error.**

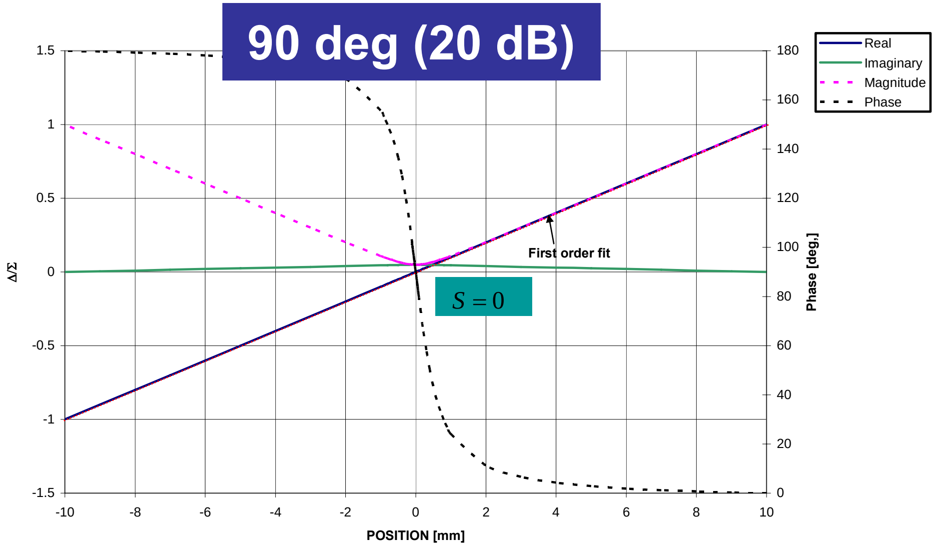
- **ILC version must include 10MHz Bessel filter to dilute 1ps bunch to ~60ns.**

- **Fast 200MS ADC, 12 or more bits (or oscilloscope).**

CMRR error


CMRR
CMRR 70dB
CMRR 90dB
Error 0.03%
Error [um]
position [mm]


0 deg (20 dB)
$S_{CM} = S*(1+\frac{CMRR}{2})$
$S_{CM} = S*(1-\frac{CMRR}{2})$
First order fit
Real
Imaginary
Magnitude
Phase
Δ/Σ
Phase [deg.]
POSITION [mm]


90 deg (20 dB)
$S = 0$
First order fit
Real
Imaginary
Magnitude
Phase
Δ/Σ
Phase [deg.]
POSITION [mm]

Resolution limitation

- **CMRR$_{3mm}$ = 20 log(6mm/100nm) ~ 95 dB.**

- **Thermal noise from the resistors:**

$$\Delta V_{noise} = \sqrt{4kTR_s\Delta f} = 5\ \mu\mathrm{V}$$

(with simulated sensitivity of 0.125 nm and for CLIC pulse):

$$\Delta \mathrm{x}_{\mathrm{noise}} = \mathrm{k}_{\mathrm{x}} \frac{\sqrt{2}\Delta V_{noise}}{\mathrm{V}_{\mathrm{pulse}} Att_{cable}} \approx 0.353\mathrm{nm}$$

- **Quantization error:**

(number bits required)

$$\mathrm{B} = \log_2\left(\frac{2\cdot \mathrm{Dynamic\ Range}}{\mathrm{Resolution}}\right) = \log_2\left(\frac{2\cdot 1.5\ \mathrm{mm}}{100\ \mathrm{nm}}\right) \approx 15\mathrm{bits}$$

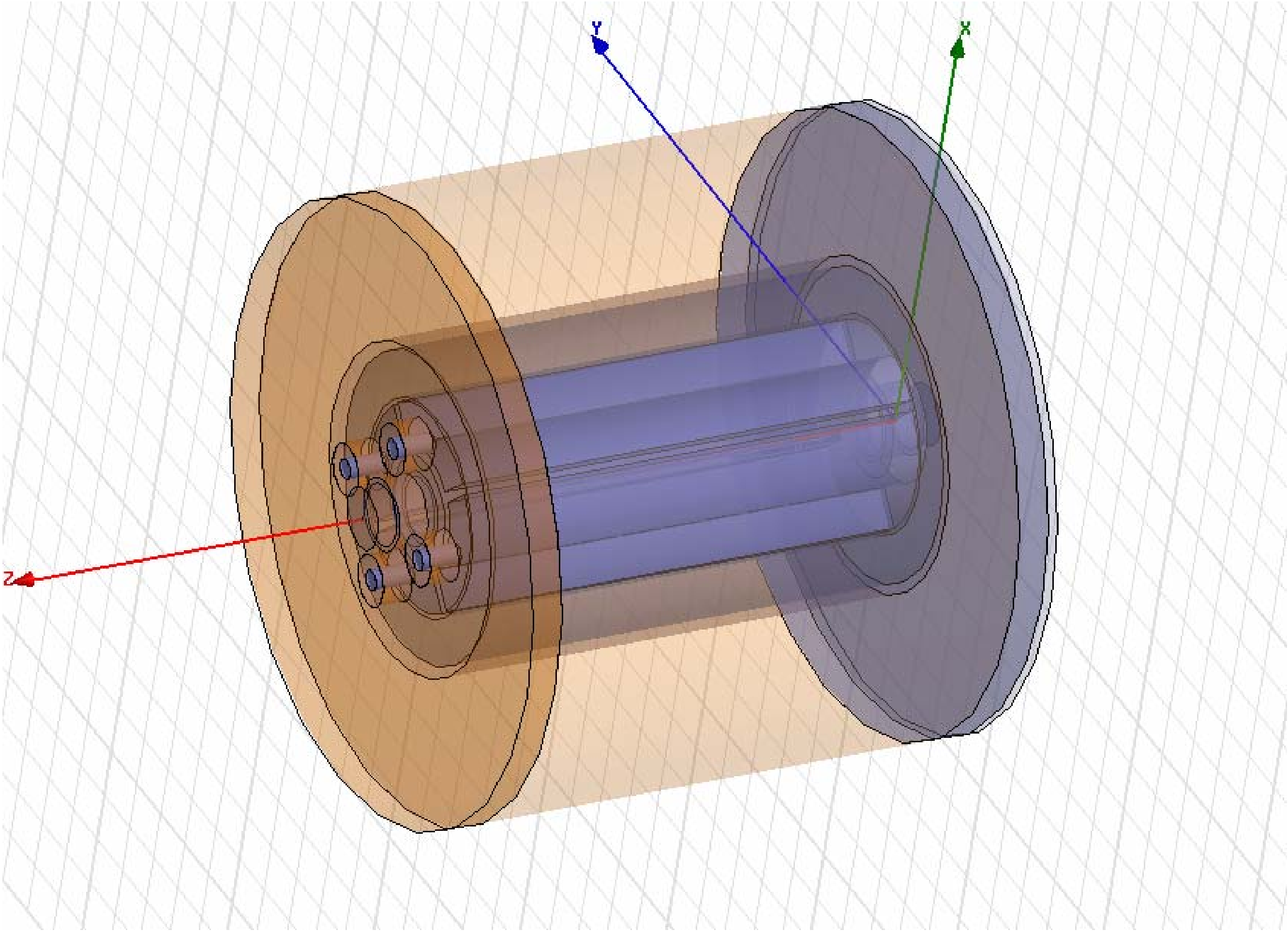
$$\Delta \mathrm{x}_{\mathrm{ADC}} = \mathrm{k}_{\mathrm{x}} \frac{1}{\sqrt{2}\cdot 2^{B}} = 2.69\ \mathrm{nm}$$

Total rms error (without CMRR) = 2.7 nm

Electromagnetics simulations: validation and optimization of the design

Beam position linearity

HFSS model



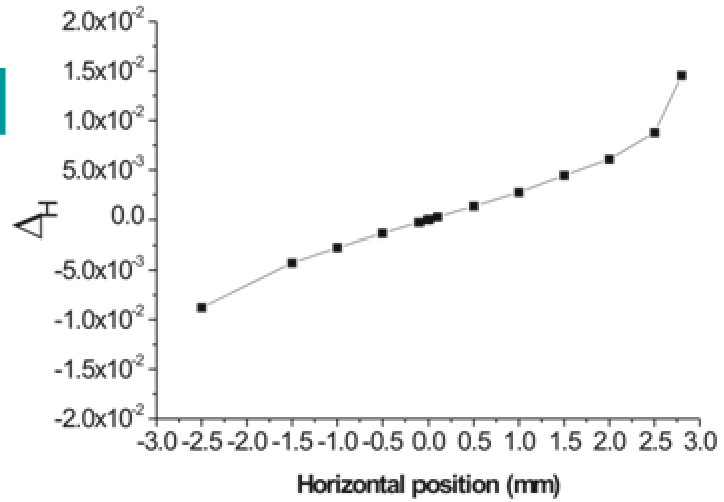
Wire radius 0.1 mm

- **Position evaluated at a single frequency 10 MHz**
- **Primary load resistance of 100 mΩ for the 4 electrodes.**
- **Complex substraction and sum of the S-parameters.**
- **50 Ω wire system gives worse accurate results in terms of linearity.**

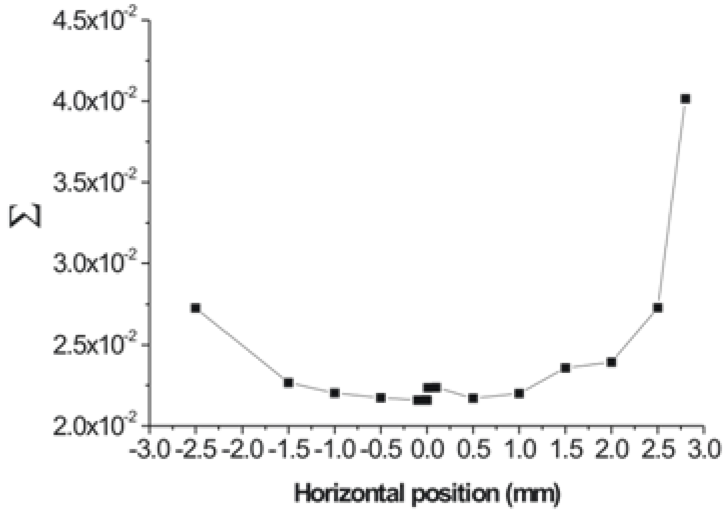
Position linearity

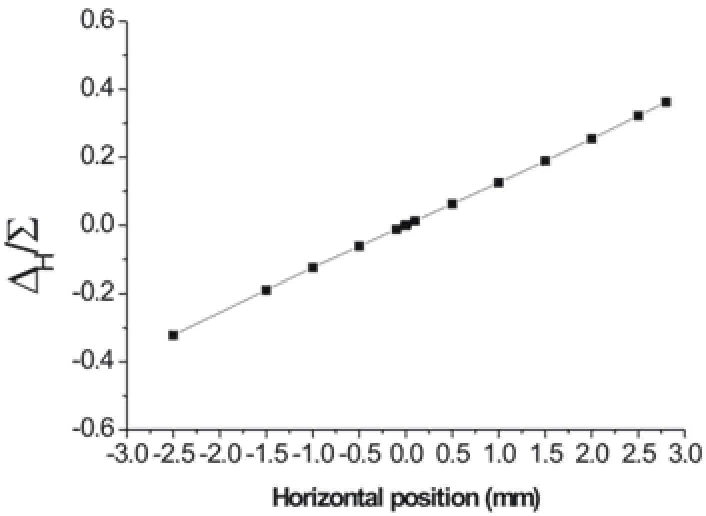
Horizontal movement of a thin wire

Sensitivity~0.128 (Δ/Σ) / mm



The accuracy of the simulation depends very much on the mesh (number of passes).

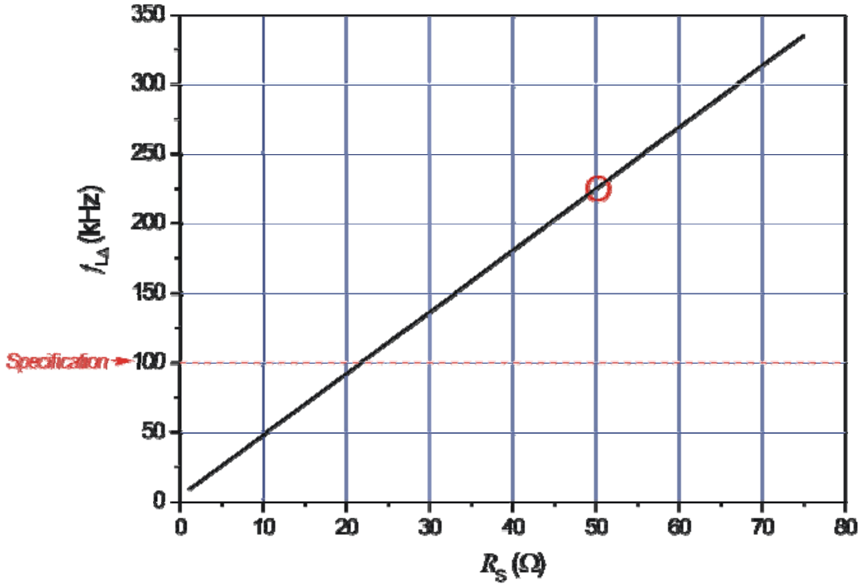




Low frequency cut-off

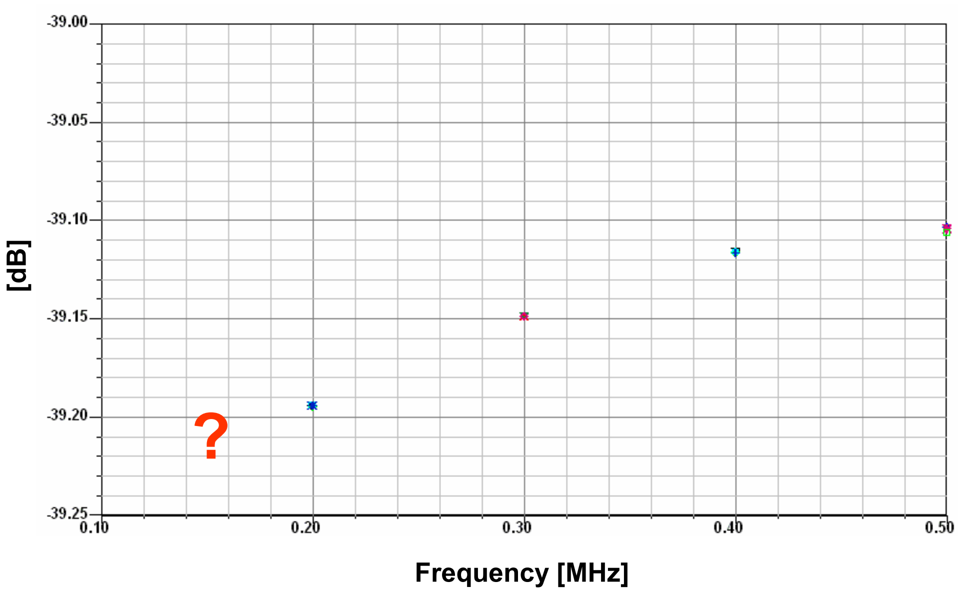
Electrical model

$f_{L\Delta}$



HFSS

$f_{L\Sigma}$



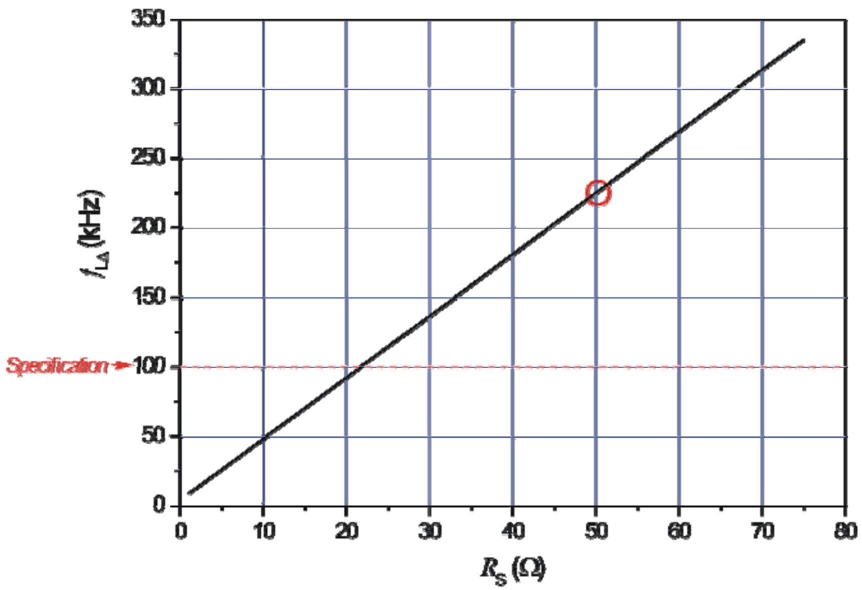
Transformer: 30 turns

L_{Δ} = 20 nH

Low frequency cut-off

Electrical model

$f_{L\Delta}$



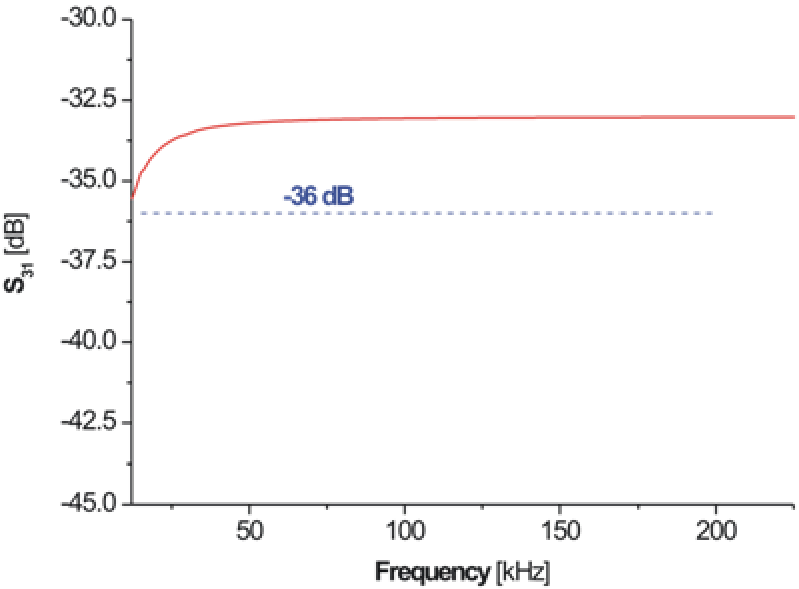
Transformer: 30 turns

L_Δ = 20 nH

f_Δ = 220 kHz

Microwave

$f_{L\Sigma}$

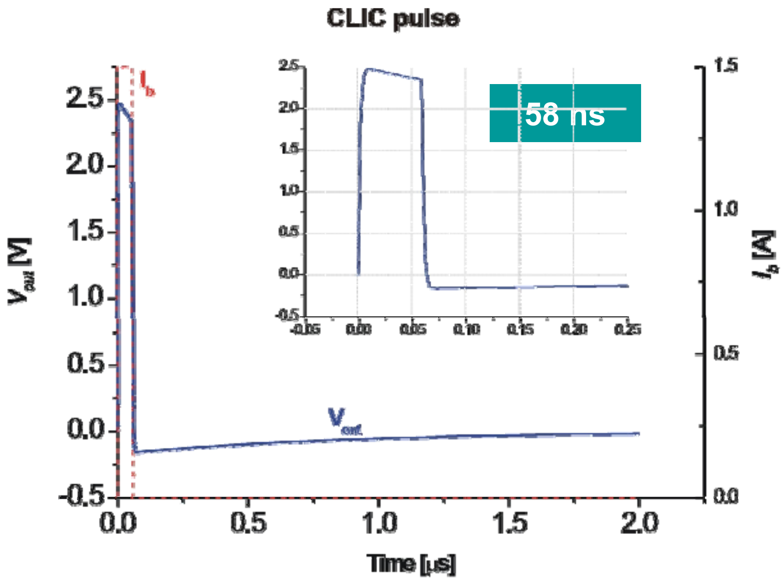


R_s = 100 mΩ

f_Σ ~ 10 kHz

L_Σ ~ 1.5 μH

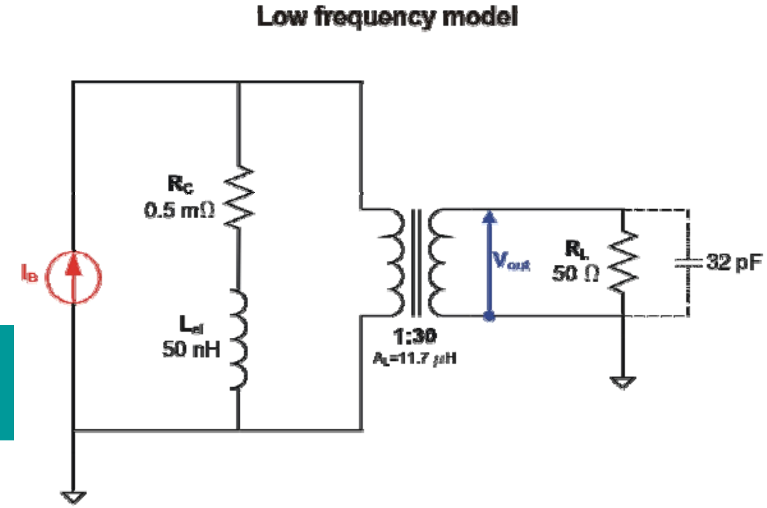
Time domain response



PSPICE

τ_{Δ} ~ 0.9 µs

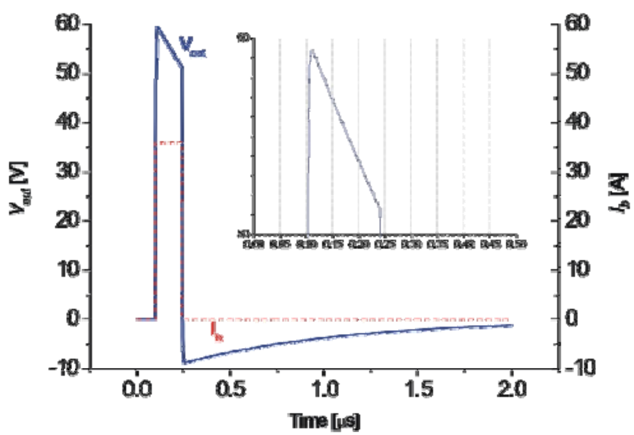
Droop (Δ) ~ 5%



CTF3 pulse

140 ns

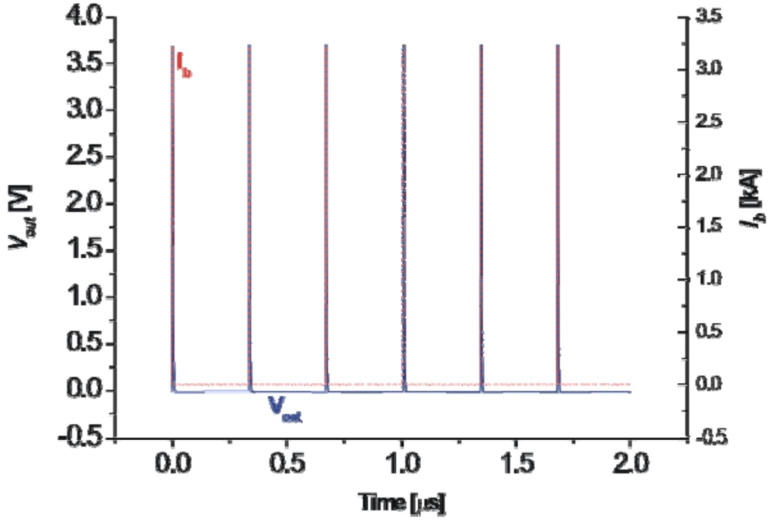
(exit combiner ring)

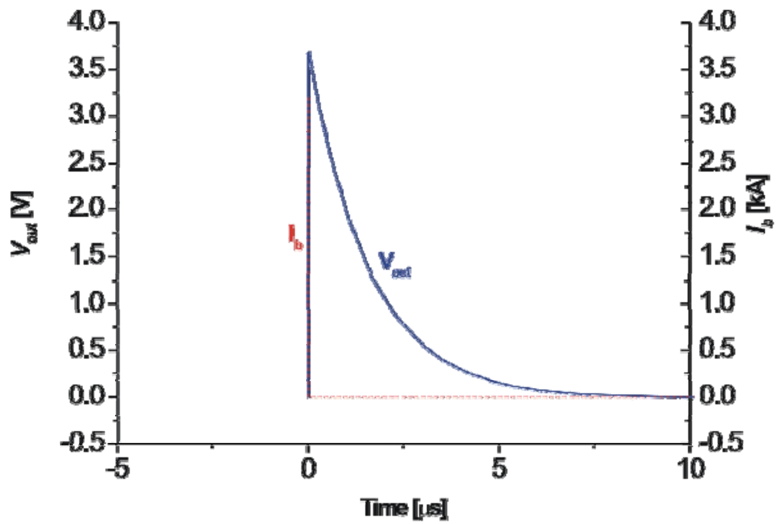


Droop (Δ) ~ 14%

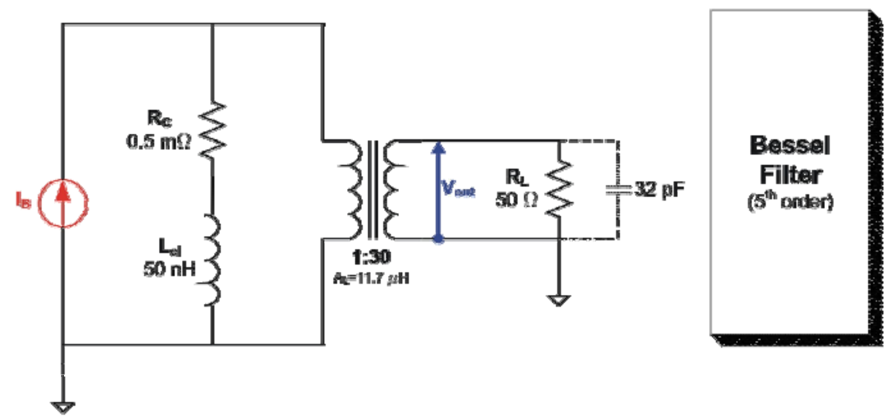
Time domain response

ILC bunches

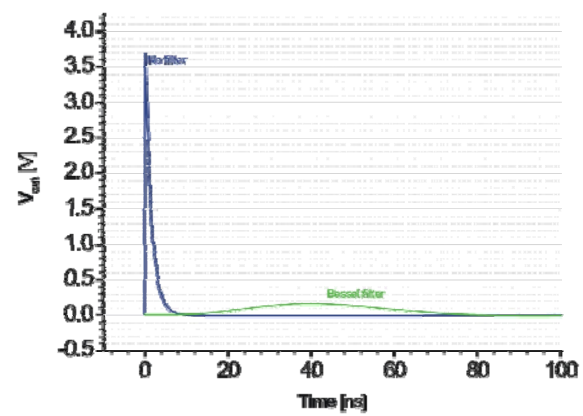




Time domain (PSPICE)

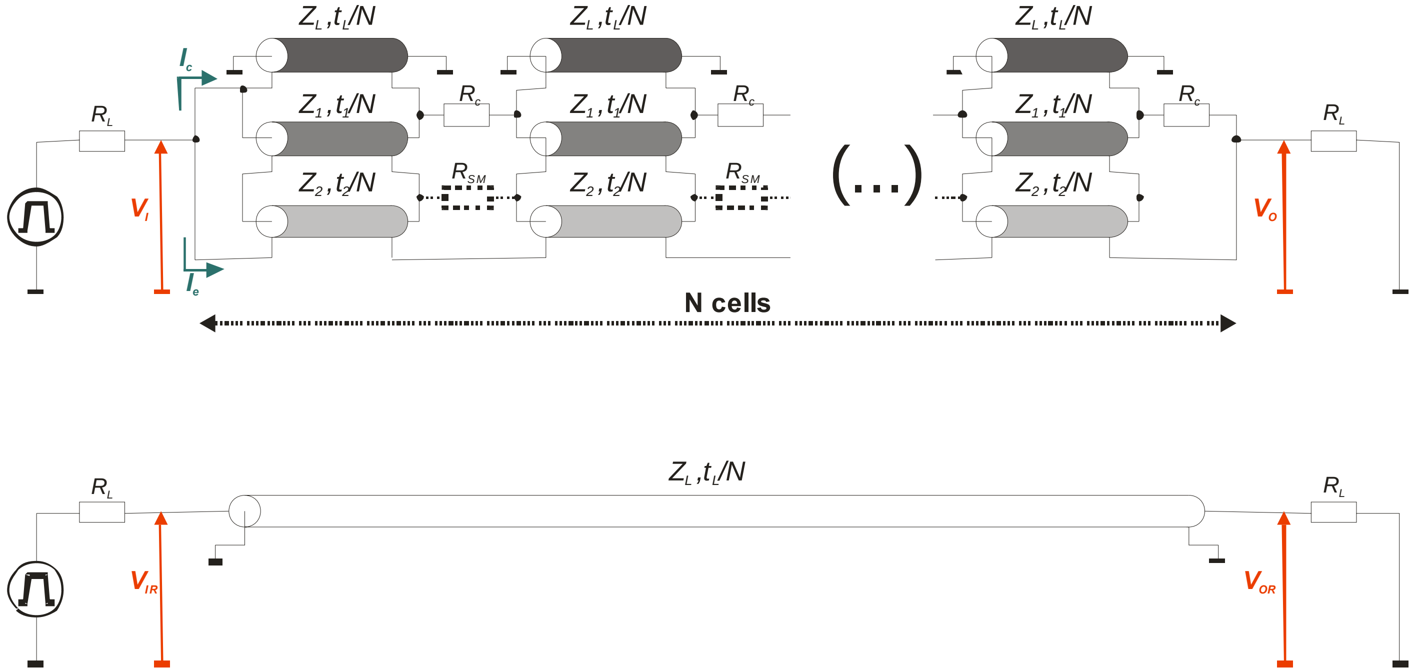


Droop (Δ) ~ 5%



High frequency cut-off

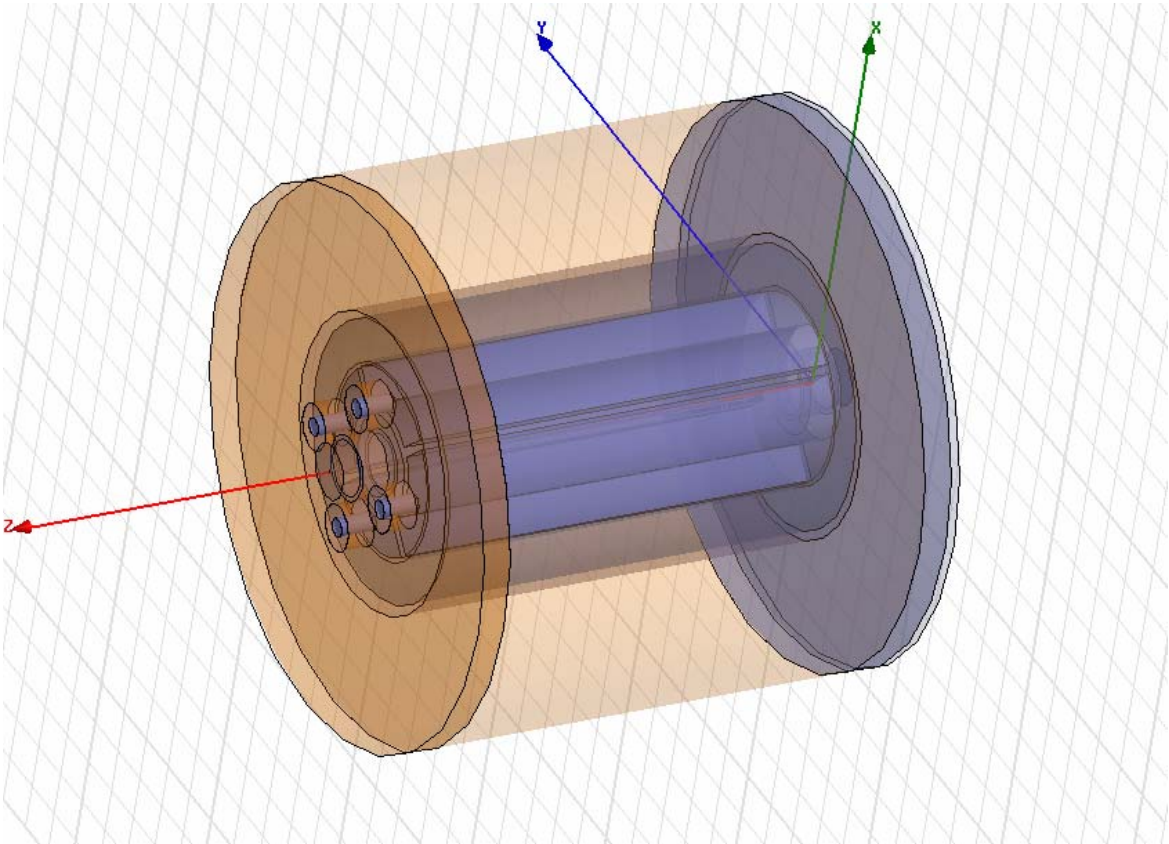
PSPICE model



Developed from the model proposed by M. Gasior

High frequency cut-off

HFSS model



Titanium coating included

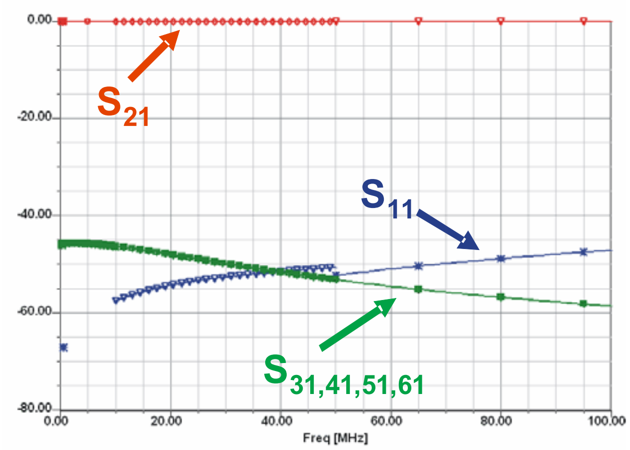
$$R_{sq} = R_{Ti} \frac{2\pi r_{i,ceramics}}{L_{ceramics}}$$

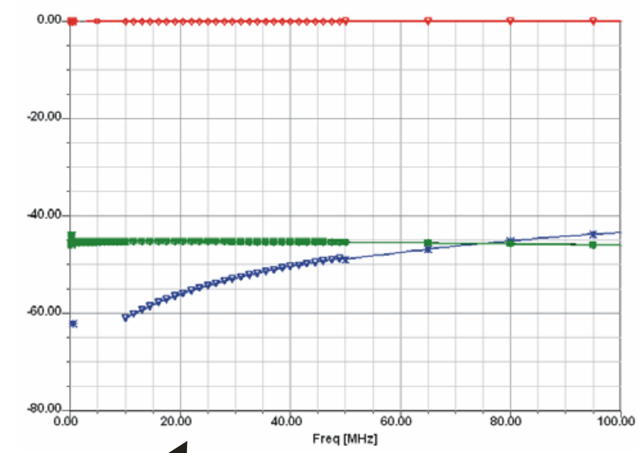
Optimization of:

- **Internal diameter of the electrodes.**
- **Thickness ceramics.,**
- **Length ceramics-electrodes.**
- **Value of resistive coating.**

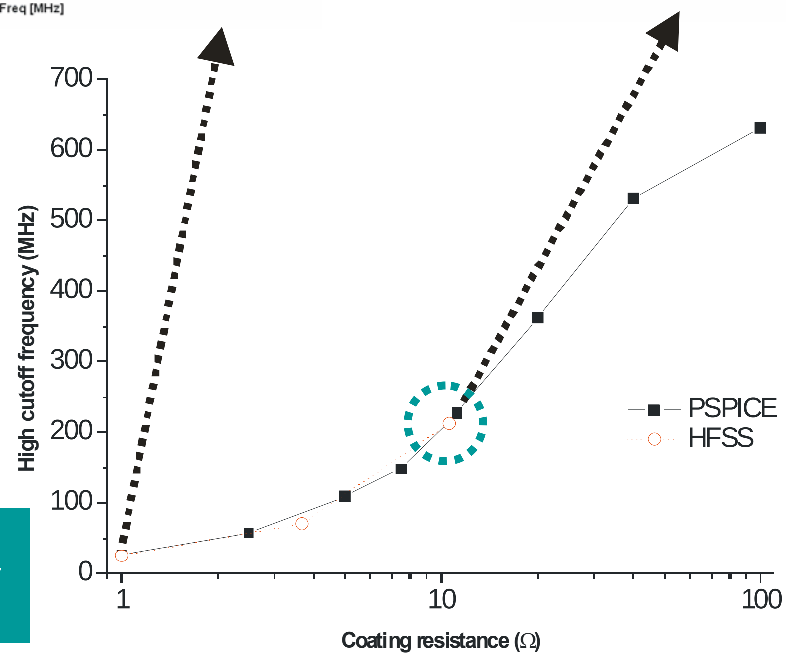
High frequency cut-off

Coating resistance





Good agreement HFSS and PSPICE models!

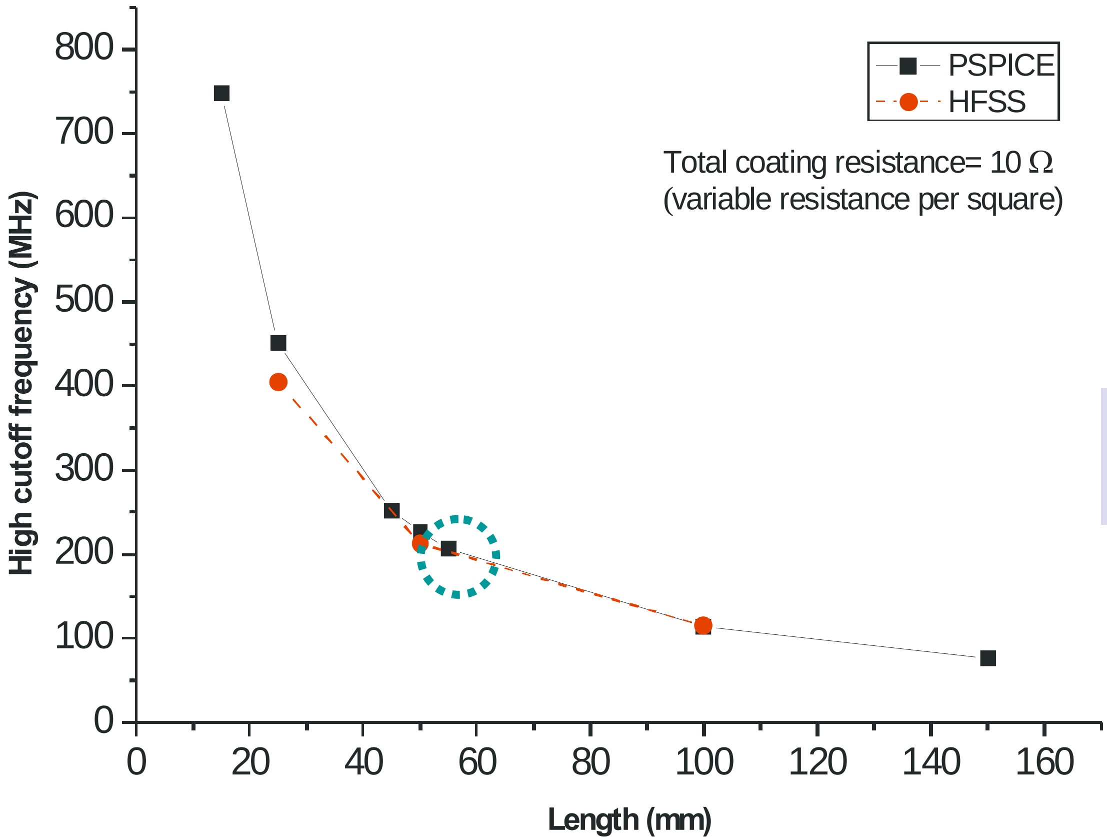


- **Transformer losses not included (bandwidth limitation up to 100 MHz).**
- **Secondary resistance included (assuming ideal transformer).**
- **1 Ω would mean a thick layer of coating. Penetration problems?**
- **10 Ω to be in the safe side.**

Longitudinal impedance drops are damped above 50 Ω. Higher for small resistance values

High frequency cut-off

Length of the electrodes



The smaller the length the higher the high frequency cutoff.

But... low frequency cutoff increases with smaller electrode lengths...

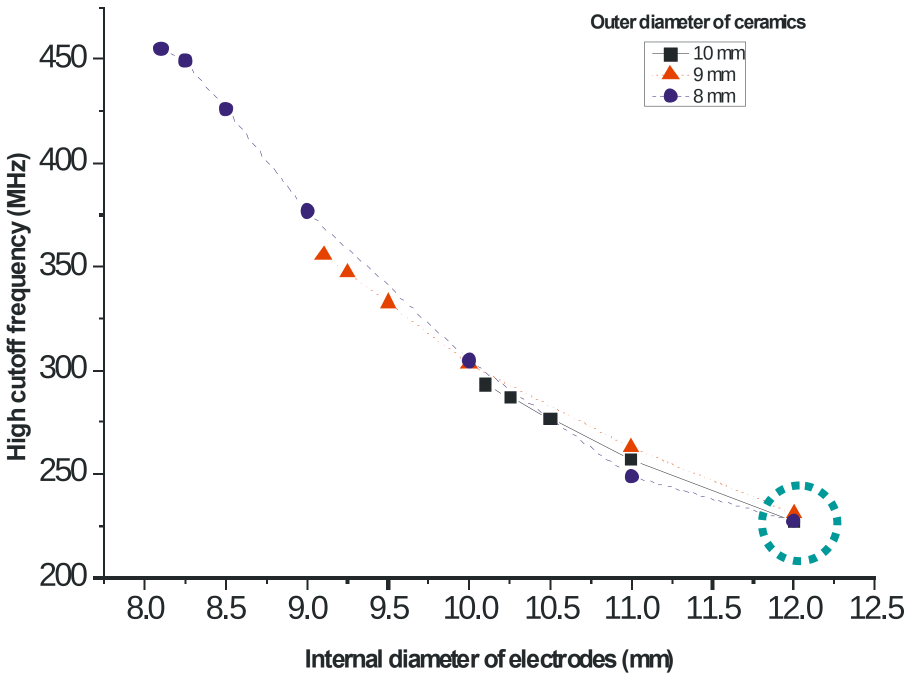
$$L_{\Delta} \approx 2l \cdot 10^{-7}\left(\ln\left(\frac{2l}{B+C}\right) - \ln\alpha + \frac{1}{2}\right) \quad \text{[H]}$$

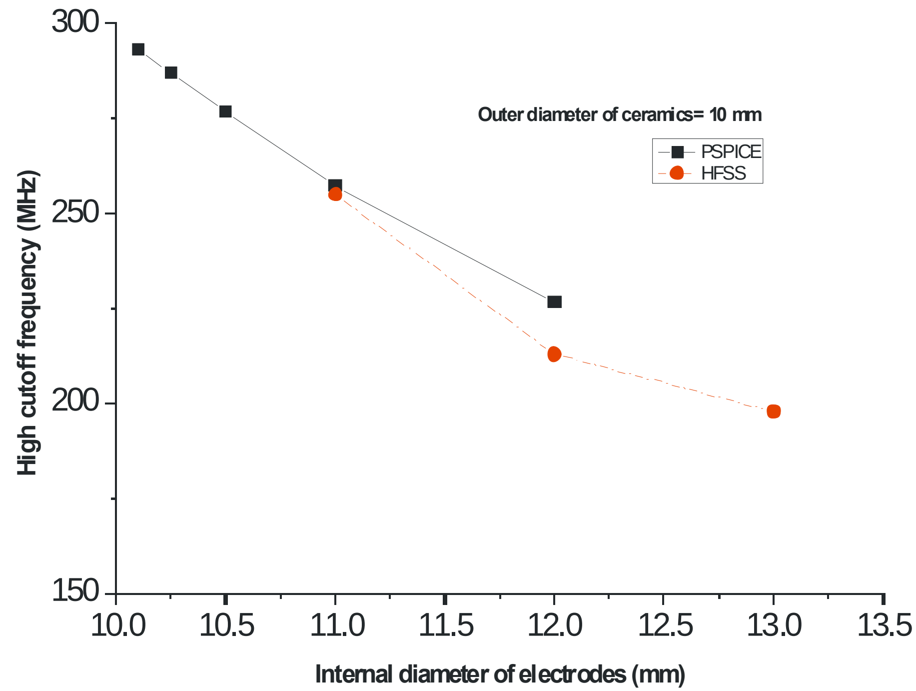
compromise...

The length does not seem to affect too much the longitudinal impedance oscillations.

High frequency cut-off

Distance ceramics-electrodes





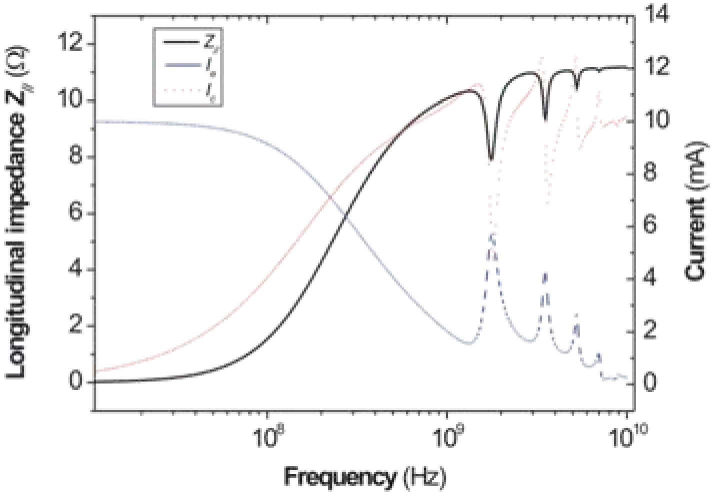
Impedance oscillations are damped for spacing between the ceramics and the electrodes below 0.5 mm but...

The helicoflex seal, the bellow and other mechanical components of the vacuum chamber limit the gap available.

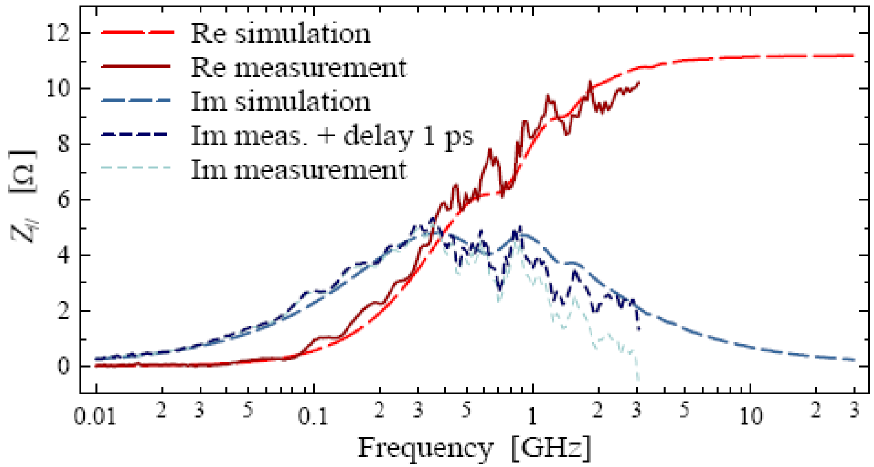
High frequency cut-off

Longitudinal impedance (PSPICE model)

PBPM



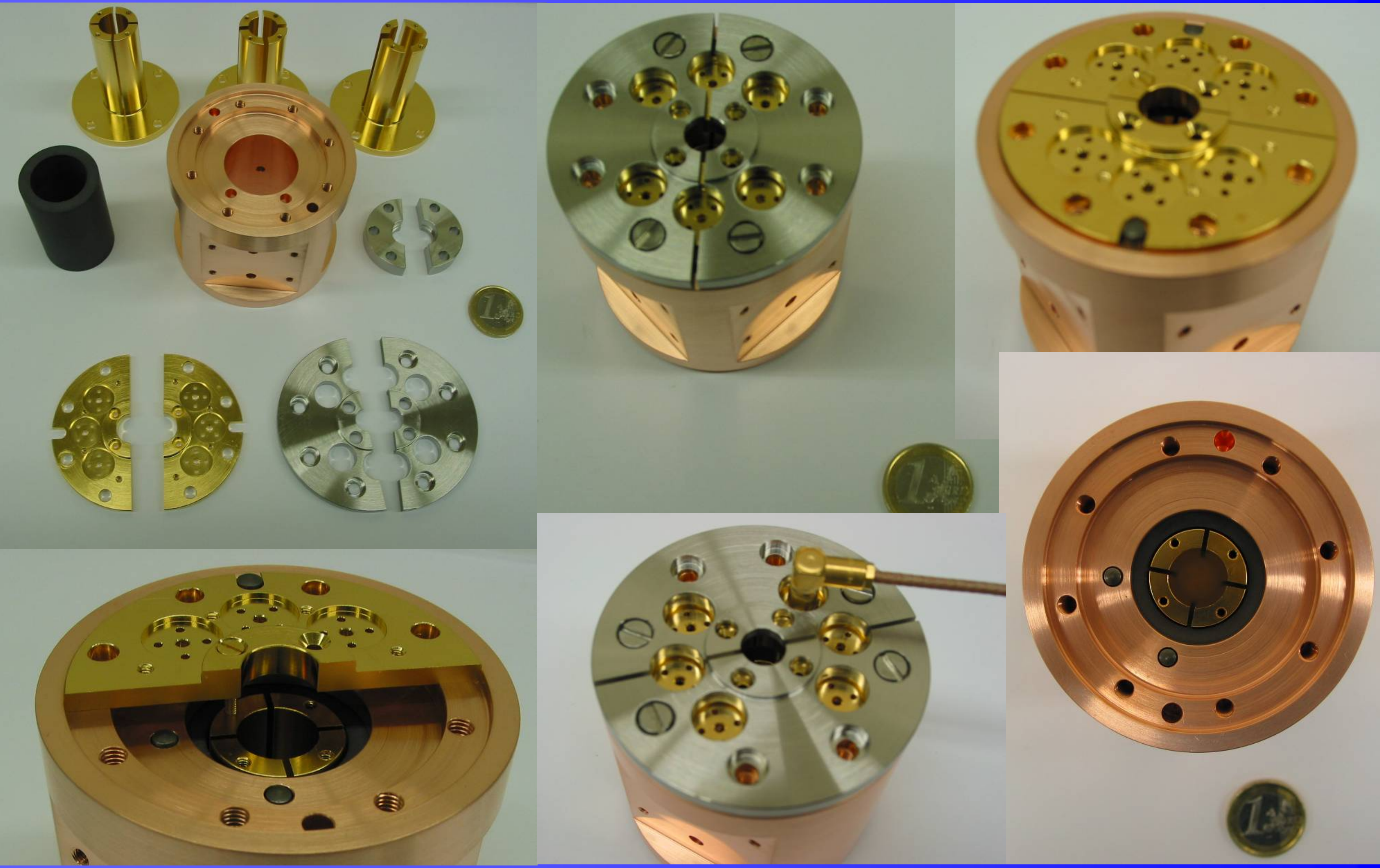
IPU-CTF3



M. GASIOR, *LIMITING HIGH FREQUENCY LONGITUDINAL IMPEDANCE OF AN INDUCTIVE PICK-UP BY A THIN METALLIC LAYER*, CERN-AB-2004-090
CLIC Note 609

The increase in line impedances in the PBPM with respect to the simulated IPU version provokes some small dumps in the longitudinal impedance of the PBPM.

Preliminary assembly

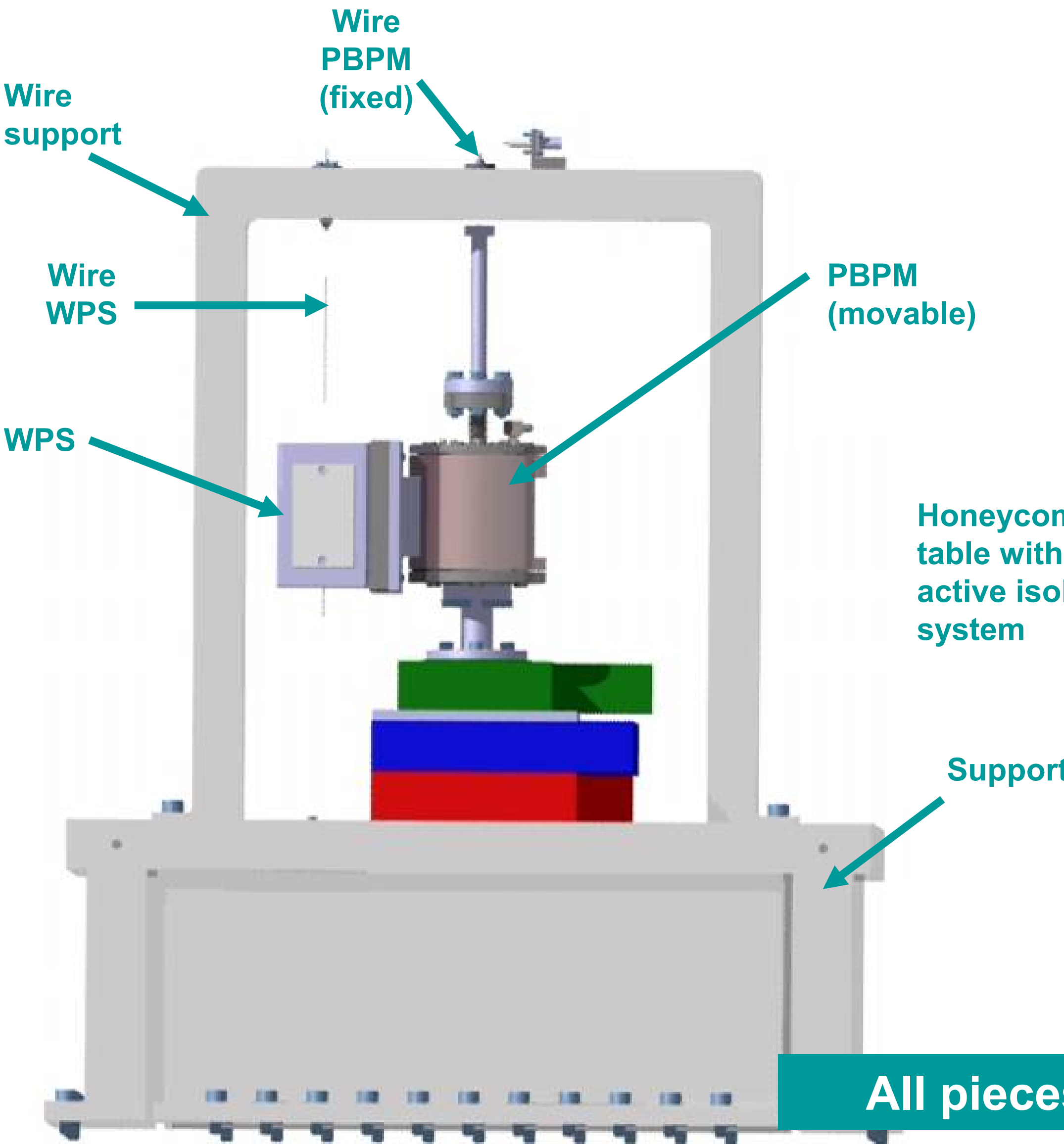


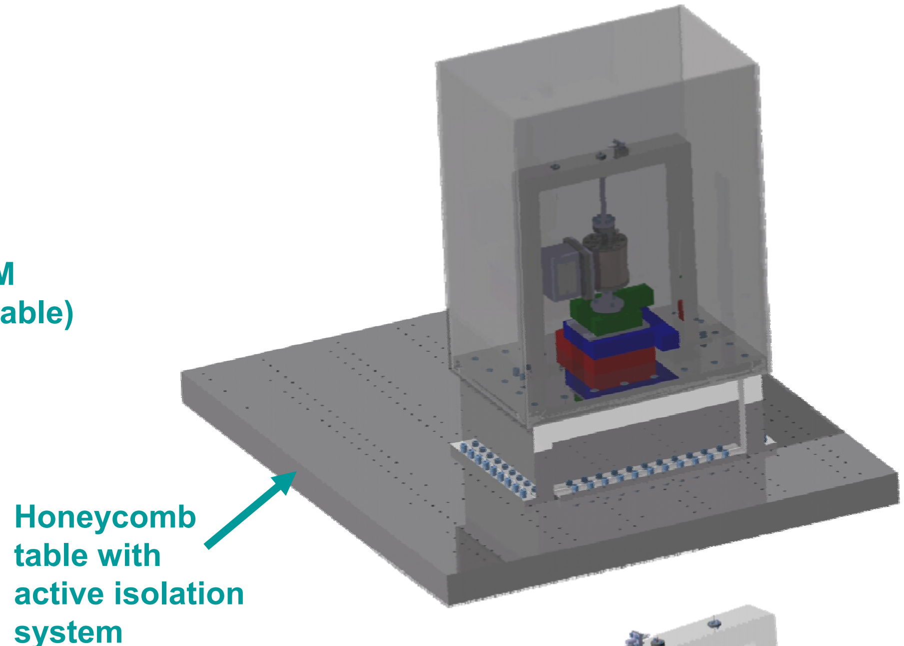
Test bench design

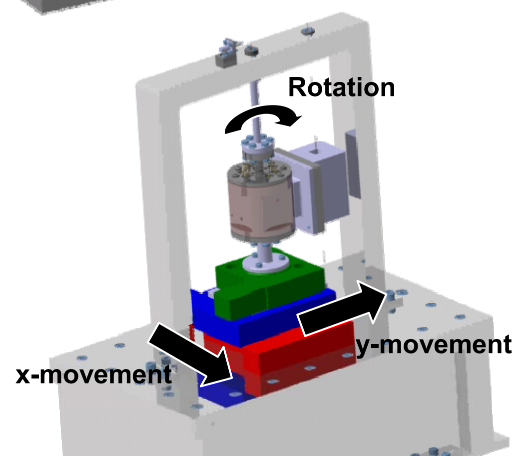
Test bench measurements

- **Resolution with CLIC and ILC type beams *(1.5A / 0.1A, 60ns pulse)*. Use of a network analyzer to obtain the information of the real and imaginary part *(sinusoidal signals)*.**
- **Sensitivity and Linearity (in both planes and in diagonal).**
- **Electrical offset (with respect to the mechanical center).**
- **Position stability with respect to temperature fluctuations 15-25°C.**
- **24 hours stability.**
- **Long term stability.**
- **Longitudinal impedance (50 Ω setup).**

Final design







All pieces to be delivered this week

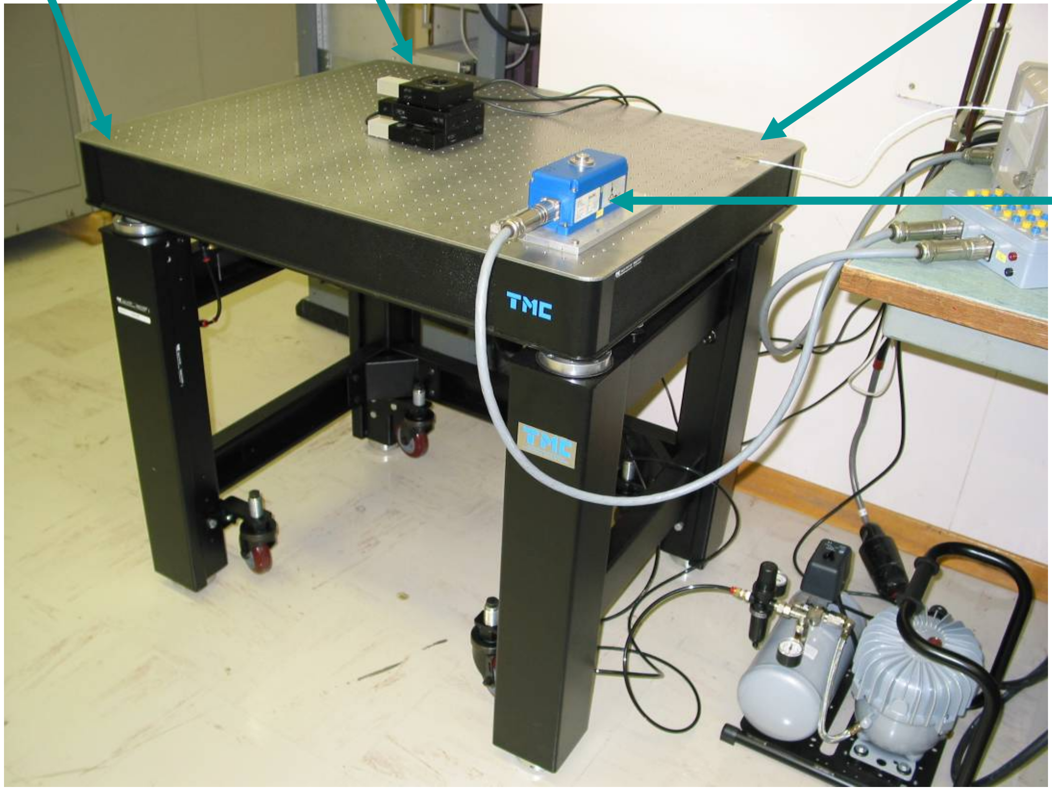
Test bench

Stable environment (active isolation, <100nm)

Motors x-y-ϑ (supports at end of the month)

Temperature monitoring (thermistor)

Vibration monitoring (geophone)

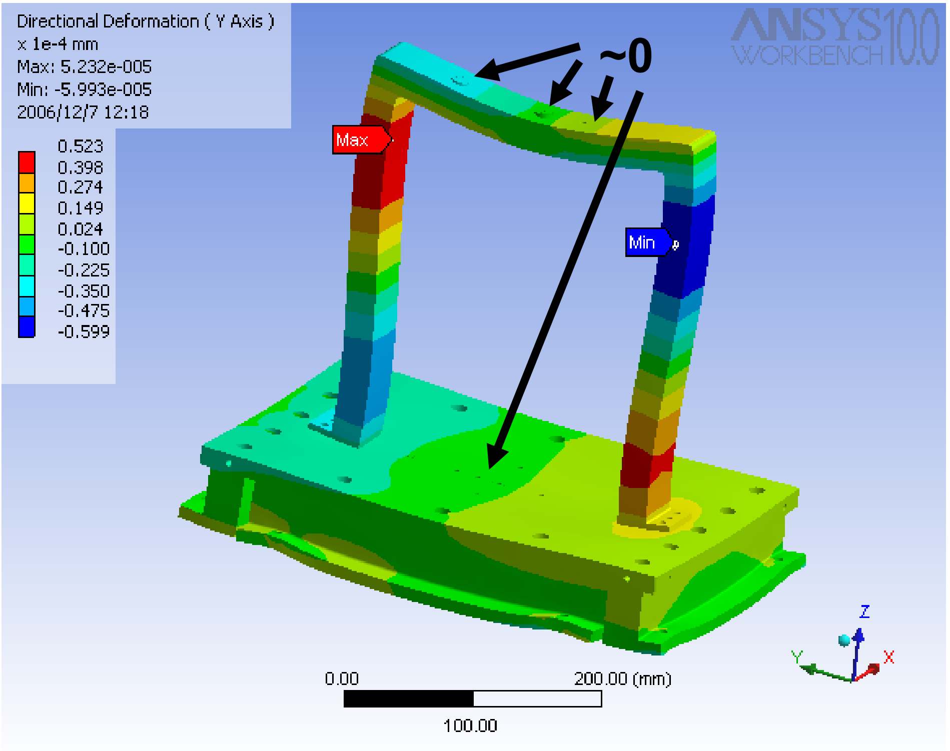


- Labview automatic control for the measurements.
- GPIB (Agilent 34410A and HP8753C), USB (motors).
- Wind shield.

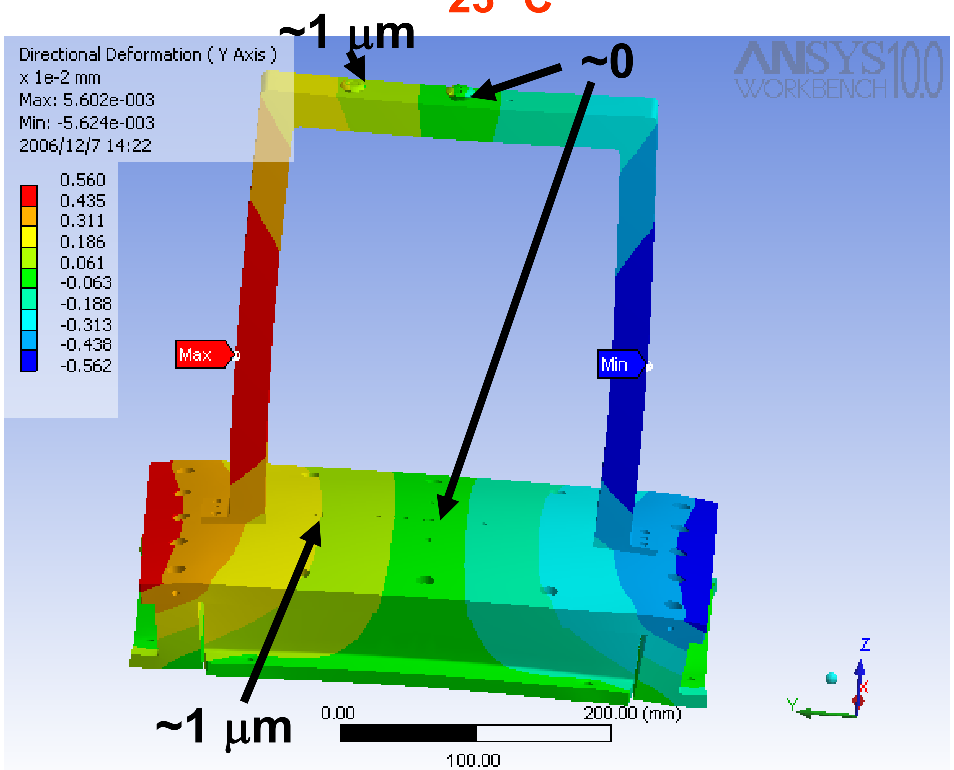
Support simulations

Wire support- 4 feet *(WPS resolution ~1μm)*

22º C *(reference)*



23º C



But same direction of deformation (no position change)

Assuming honeycomb table as a fixed reference

Preparation tests at CTF3

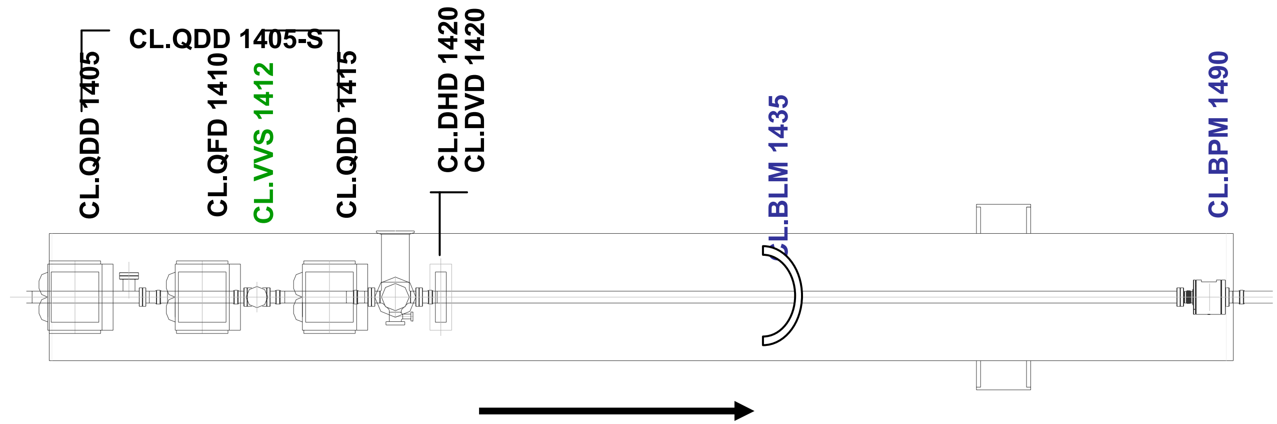
(autumn 2007)

Tests at CTF3

Installation of 3 PBPM in CTF3 in autumn 2007 to evaluate their resolution (disentangle position and angle jitter).

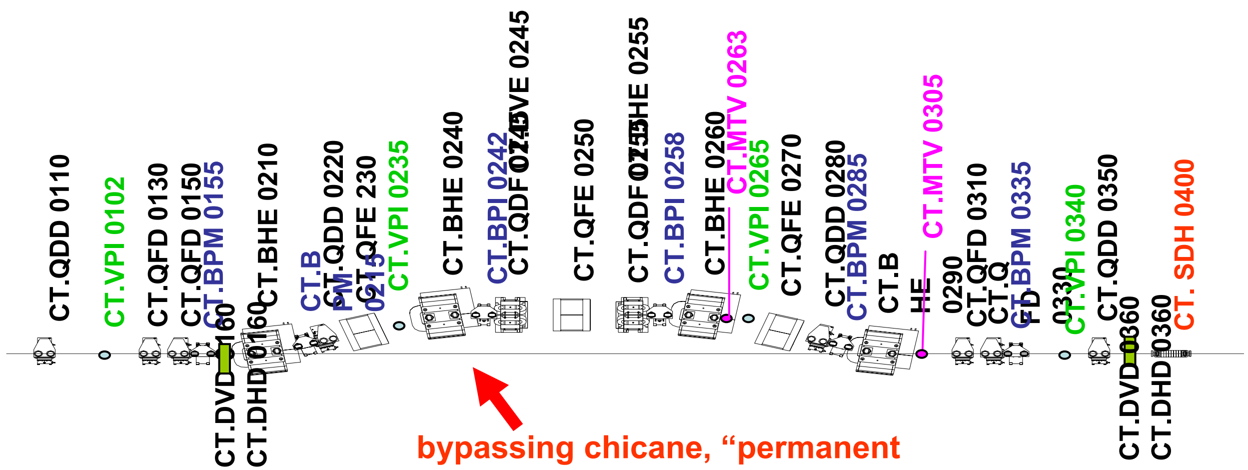
Each PBPM with individual micromovers.

Girder 14 (CL)



2 proposed locations:

Magnetic chicane (CT)



bypassing chicane, "permanent installation", but support? beam dump?

Other issues

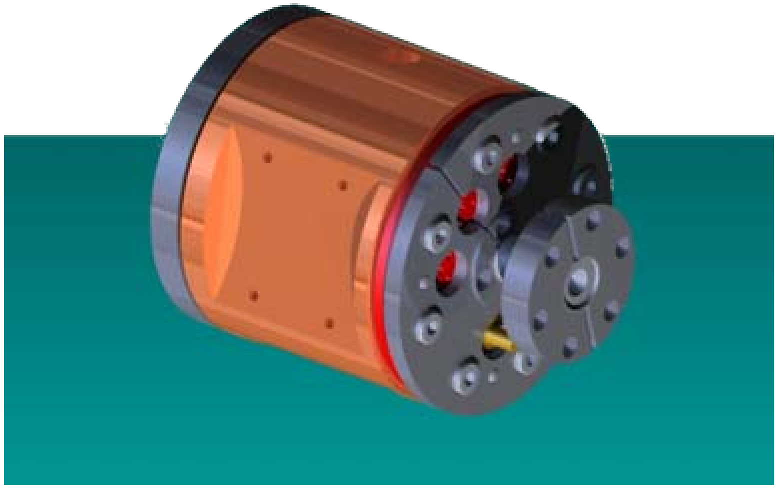
Not addressed in this talk:

- **Coupling between electrodes. Phase offset between electrode signals. Evaluation during the test bench measurements.**

- **Influence of the magnetic field from near quadrupoles. So far not a problem in CTF3 but for CLIC?...**

Acknowledgments

Many thanks to all the people that help in this project!



R. Boudot, M. Gasior, F. Guillot-Vignot, V. Maire, B. Favrat, H. Mainaud-Durand, H. Neupert, S. Calatroni, T. Tardy, L. Leggiero, P. Frichot, T. Kroyer, F. Caspers, J. Belleman, S. Redaelli, J-M. Wickham, P. Odier...