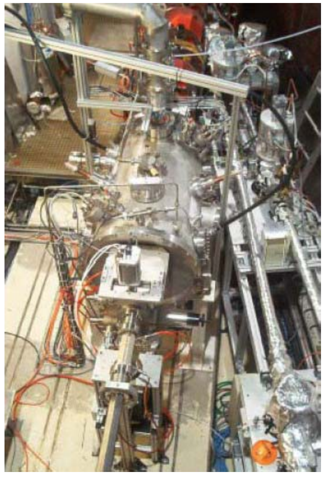
Introduction

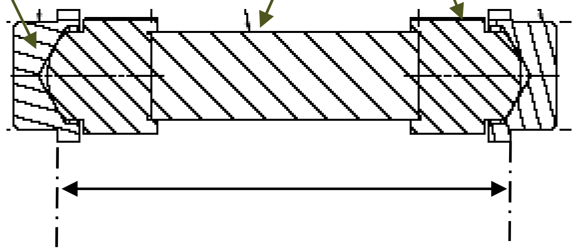
Cold tuning system design started at Saclay for the MACSE cryomodule, early in the 90's, followed by the TTF, SOLEIL and Super3-HC cryomodules.

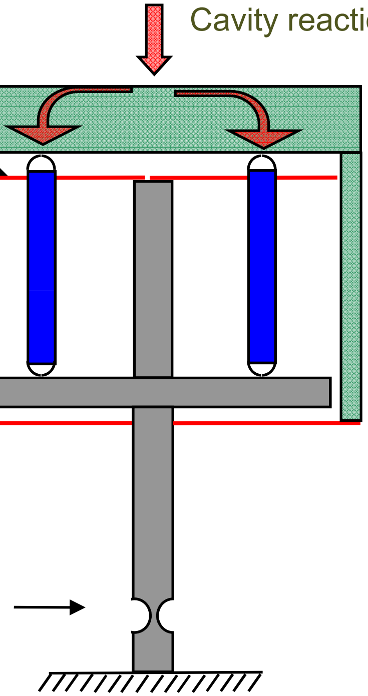


In the 6th European Framework Program, a new cold tuner implemented with fast piezoelectric actuators has be developed (CARE/SRF) based on the experience gained from the former cold tuner designs. This new tuner should meet the needs for Lorentz forces or microphonics compensation on the 9-cell elliptical cavities used in the future linear collider (ILC) or Free Electron Laser linacs.

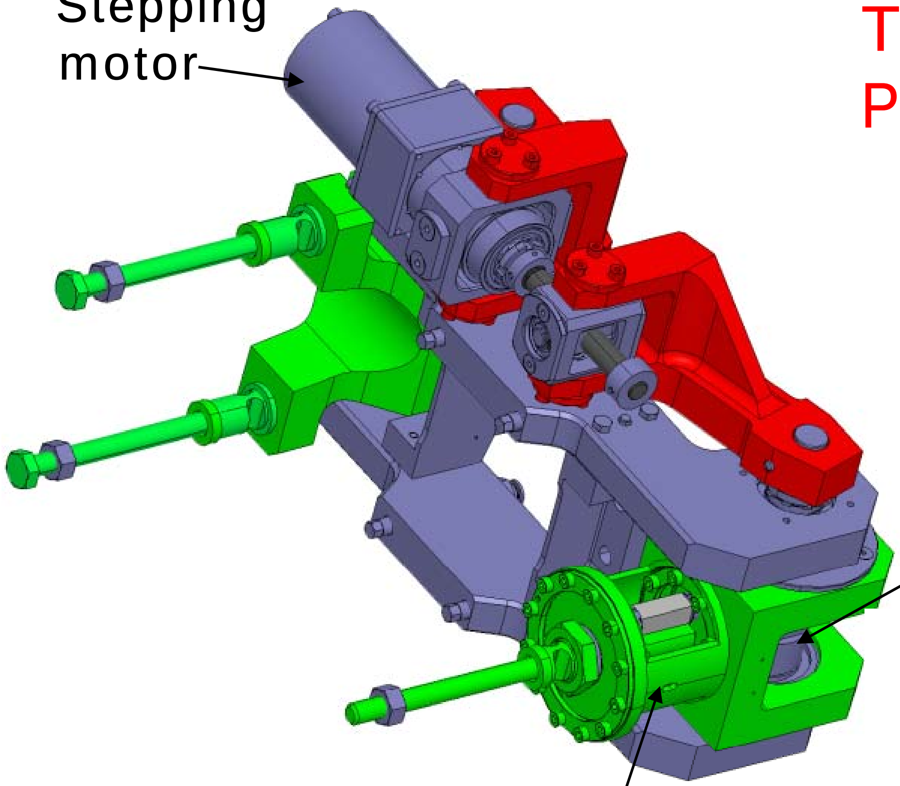
Mechanical Design of a Fast Piezo Cold Tuner

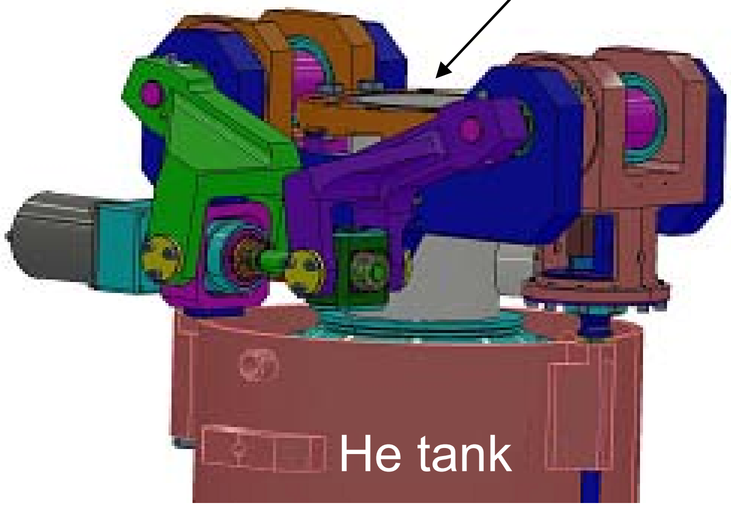
- Excentric rods transfer rotation into displacement like for all Saclay tuners
- Typical fast tuning range +1kHz to compensate for the LFD i.e. 3 micrometers cavity lengthening
- Use the cavity reaction to elongation to preload the PZTs (aiming at $F_{preload}$ > 500 N)
- Remove the neutral point from the tuning range to suppress backlash





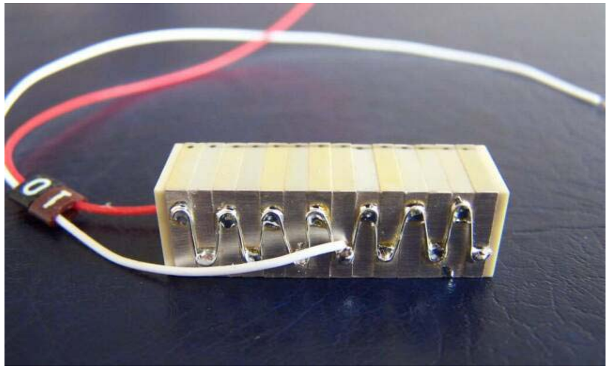
The CARE-SRF Piezo Tuning System





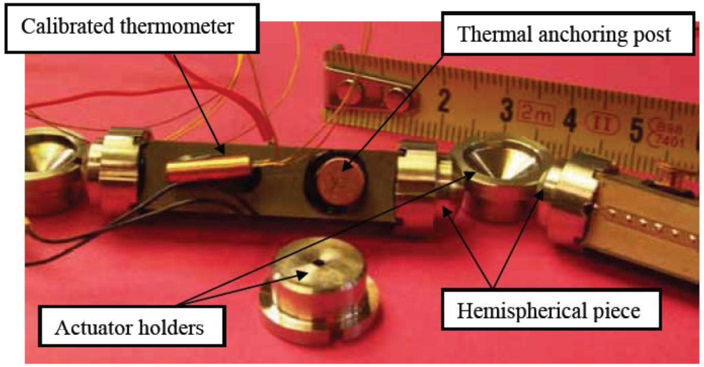
Piezo Stack Actuators

Tests with two different piezo stacks



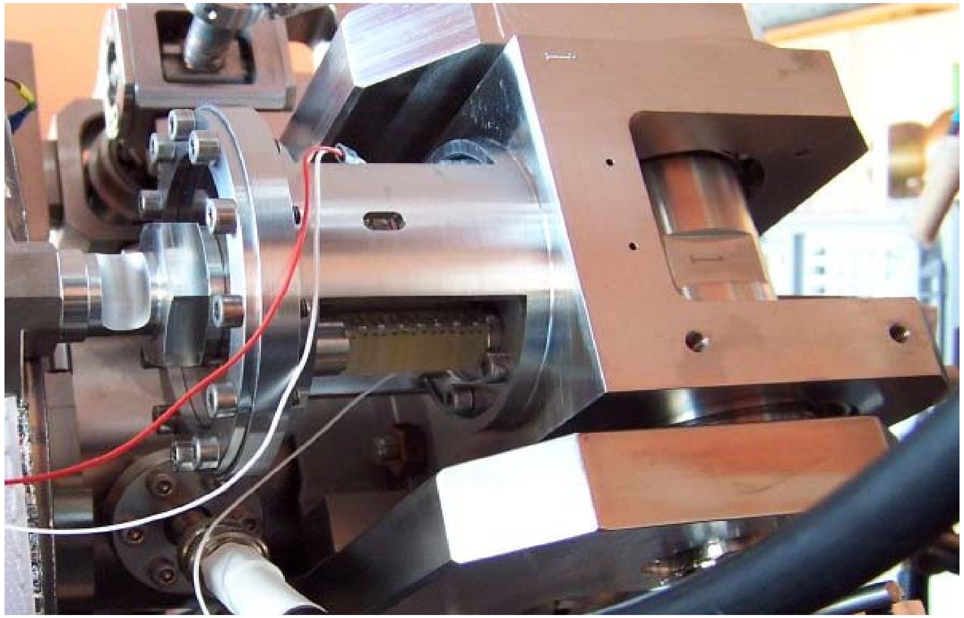
NOLIAC PZT stack actuator

L= 30 mm V_{max} = 200 V



PICMA PZT stack actuator

L= 36 mm V_{max} = 120 V



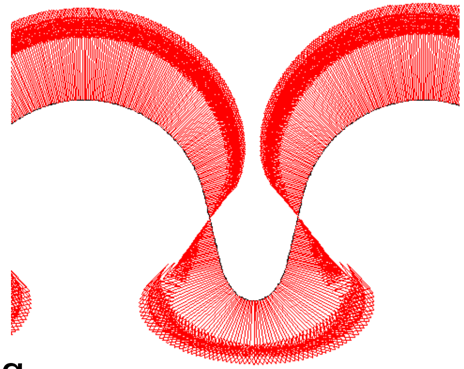
Piezo support

irfu cea saclay

Lorentz Force Detuning (LFD)

radiation pressure is generated by EM field on the cavity walls

$$P_{Lorentz} = 1/4\ (\mu_0\ \mathbf{H}^2 - \varepsilon_0\ \mathbf{E}^2)$$



resulting in cavity deformation and detuning

$$\Delta f = -k_L\ E_{\mathbf{acc}}^2 \quad \text{(static case – CW)}$$

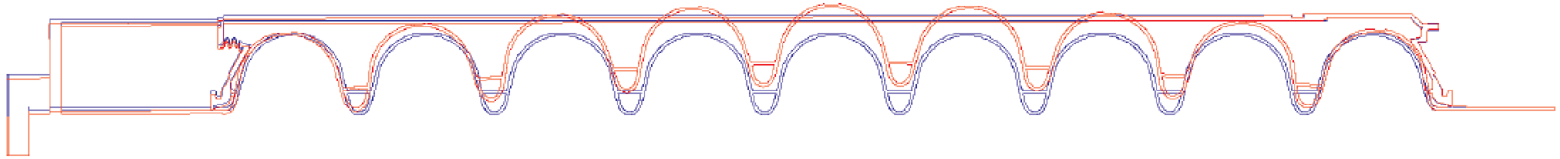
The static Lorentz coefficient k_L depends on :

- cavity wall thickness
- extra stiffening design (rings)
- tuner/tank stiffness

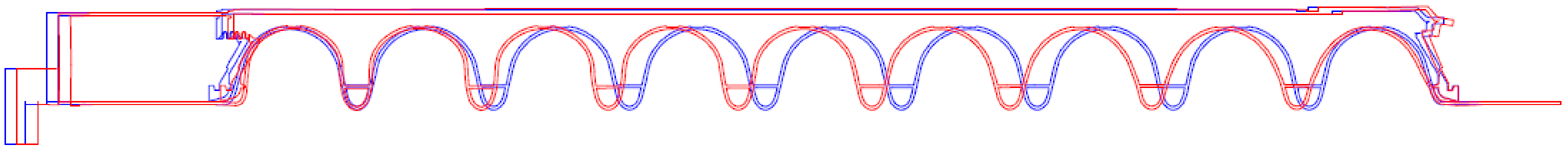
Mechanical eigenmodes/dynamical behaviour

examples for a TTF 9-cell cavity (CASTEM FEM simulations)

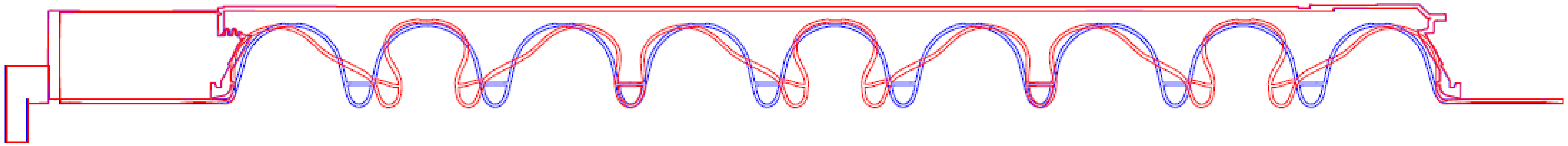
Transverse mode 52 Hz



Longitudinal mode 222 Hz



Longitudinal mode 2275 Hz

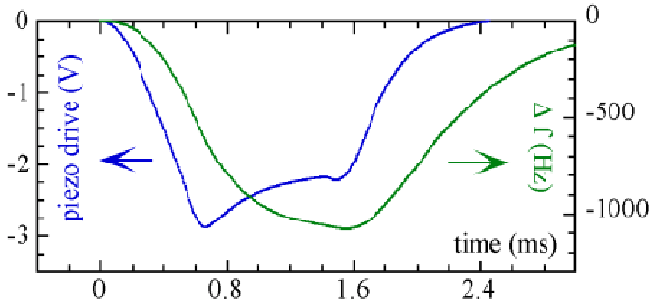


For each mechanical mode :

- resonant frequency
- Quality factor
- coupling coefficent to the cavity detuning

In pulsed operation :

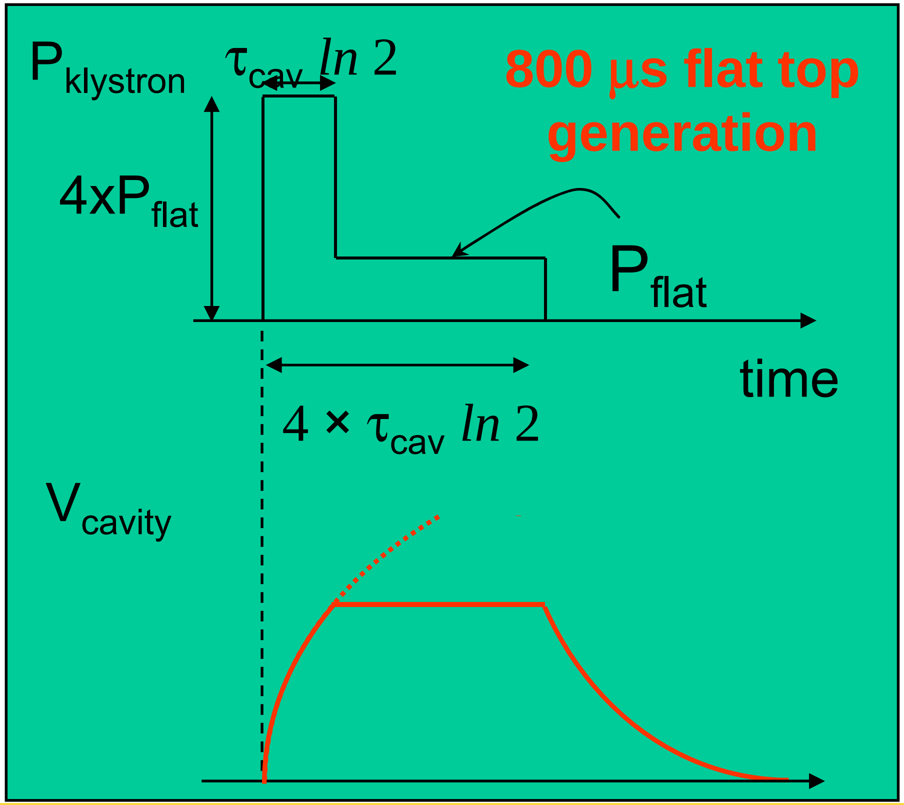
- Lorentz force is an impulse-like excitation
- The time varying cavity detuning is the sum of the contribution of individual modes



fully numerical modeling of LDF compensation @ 35 MV

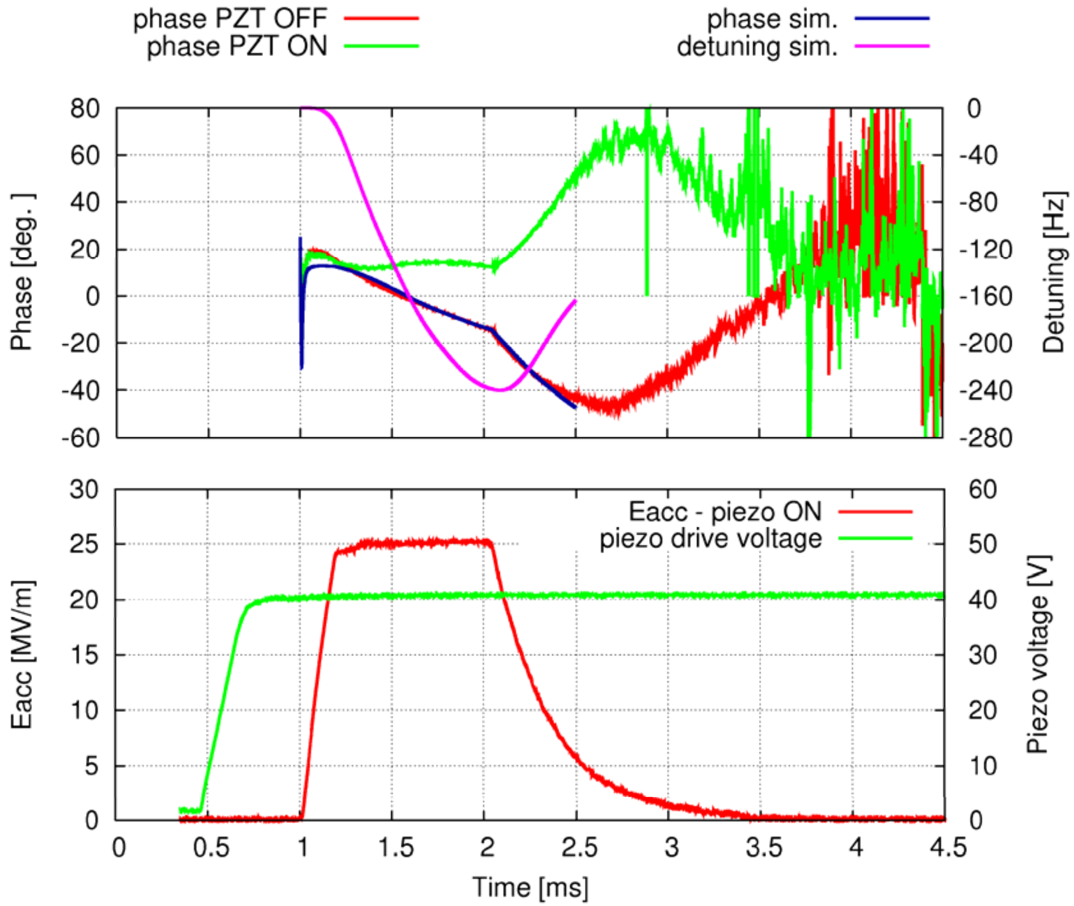
Pulsed operation in CryHoLab

- RF source : 1.5 MW, 1ms pulse, 6.25 Hz max
- Rep. rate for the LFD experiments is 0.87 Hz
- DESY TTF-III coupler – Measured Q_{ext} = 1.34 10^6
- Maximum E_{acc} = 25 MV/m, limited by field emission on the test cavity (C45)
- RF pulse is different from TTF pulse:
  - Faster rise time = 200 µs instead of 500 µs
  - Same flat top 800 µs



LFD compensation with the fast piezo tuner (CARE-SRF)

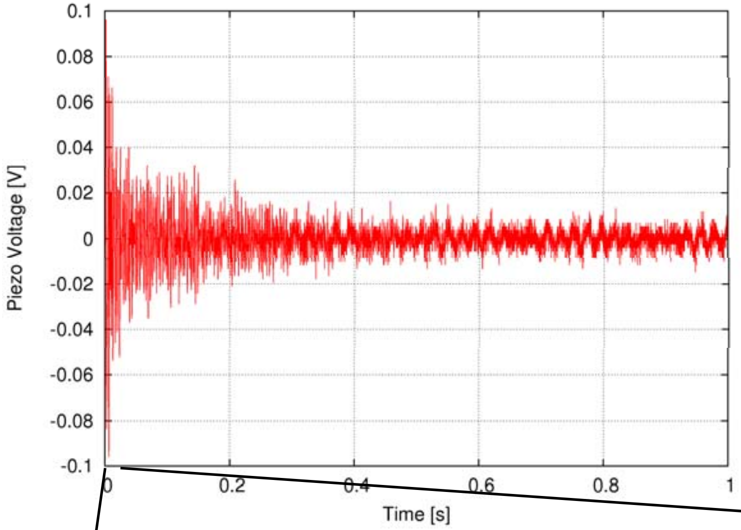
- minimize the cavity voltage phase excursion during the flat top
- Parameters for a simple PZT driving pulse : pre-delay, amplitude, rise time



The detuning of -240 Hz is derived using a numerical model of the cavity and fitting the measured amplitude and phase.

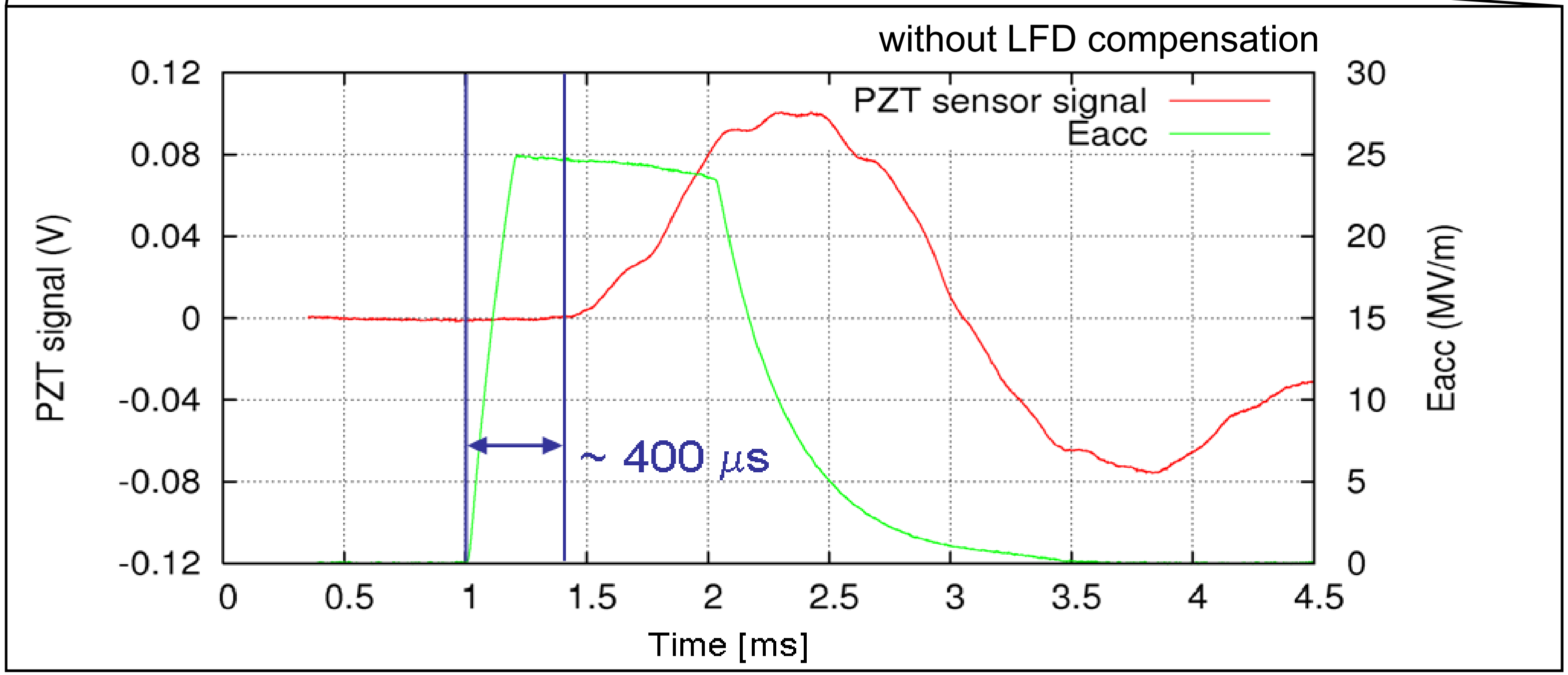
With compensation the detuning is reduced to 20 Hz peak-peak during the flat top.

Piezo signal @ 25 MV/m



Piezo signal is the superposition of the response to Lorentz force (≈ impulse response) and to background vibrations (He, pumps, site) which cause microphonics

Major contribution of LFD through the 306 Hz mode (Qm ≈100)



Transfer Function Measurements (1)

Transfer function ≡ harmonic response of the piezo tuner

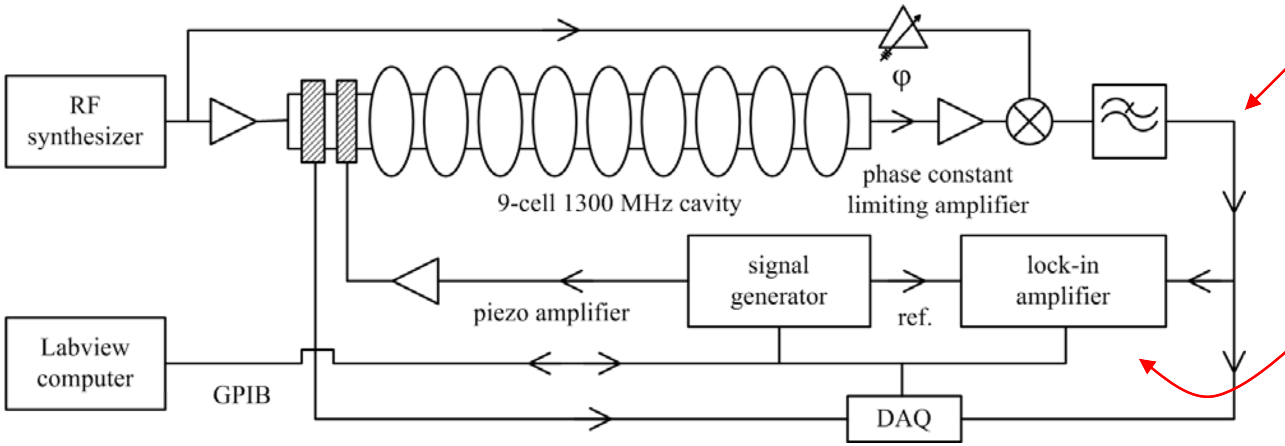
cavity detuning (Hz)

$$\tilde{H}_{PZT}(f_m) = \frac{\tilde{\Delta f}(f_m)}{\tilde{\Delta V}(f_m)} = A\, e^{j\varphi}$$

Piezo actuator driving voltage (V)

Measurement: For moderate loaded quality factor (Q_L ~10^6), i.e. cavity bandwidth about 1300 Hz for a 1.3 GHz 9-cell cavity, detuning can be measured with a phase detector.

$$\Delta f = -\frac{f_0}{2Q_L}\tan\left[\arcsin\left(\frac{V}{V_0}\right)\right] \approx -\frac{f_0}{2Q_L}\frac{V}{V_0}$$



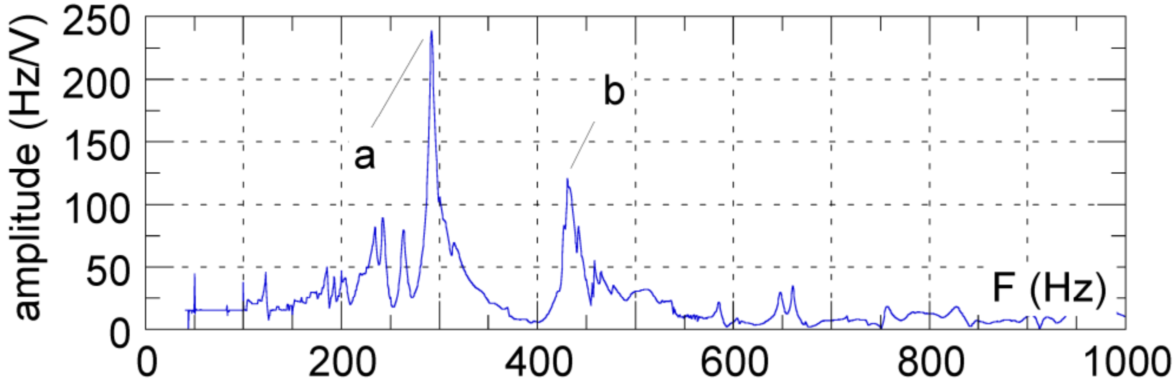
V

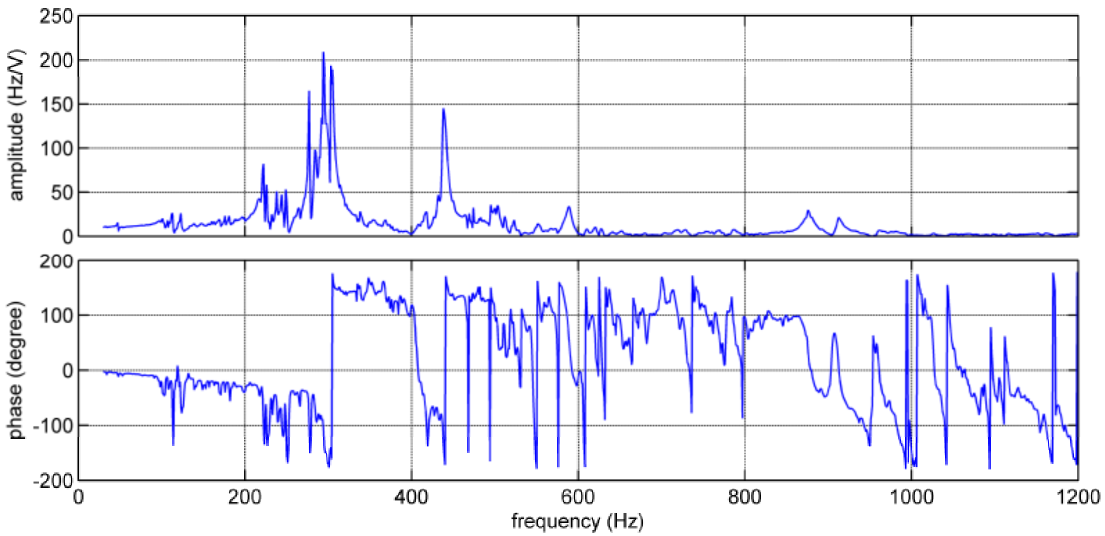
phase measurement

Best noise rejection

Measured Transfer Function at 300 K and 4.2 K

At 300 K





At 4.2 K, $Q_L = 1.3\ 10^6$

From the phase slope at low frequencies, the piezo tuner mechanical latency can be derived: ~ 400 µs.

The piezo tuner transfer function can significantly change with temperature !
(also a difference between 4.2 K and 1.8K piezo TF)

Transfer Function Modeling

Analytical model: simultaneous contribution of mechanical eigen-modes

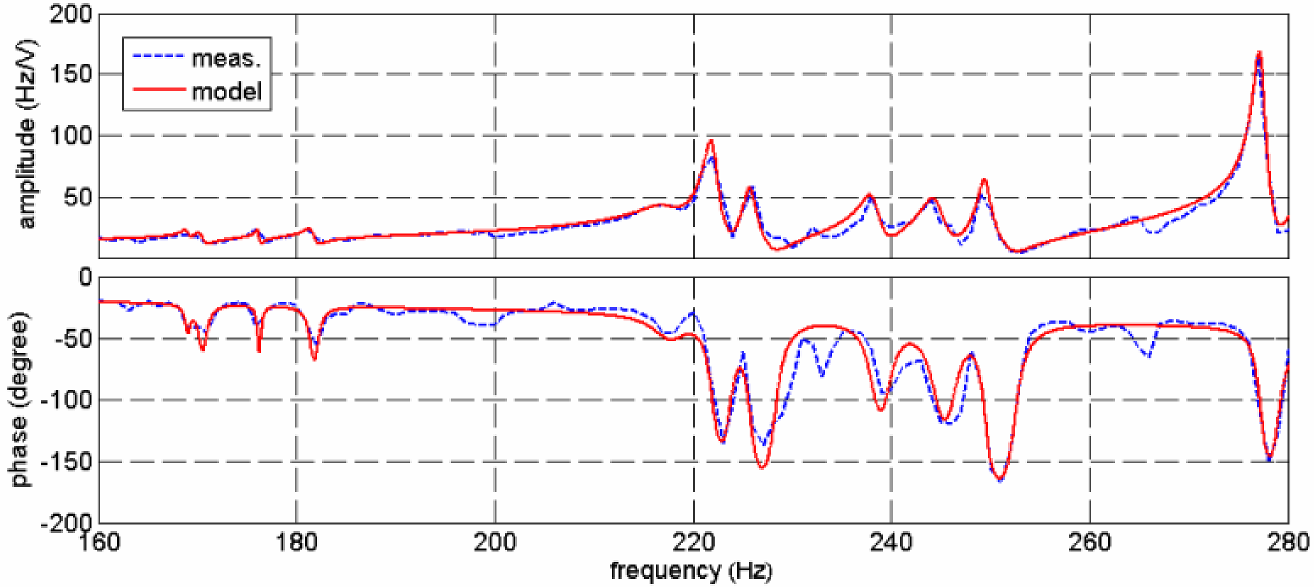
$$H(s) = H^1(s) + \sum_{i=1}^{N} H_i^2(s), \quad H^1(s) = \frac{K_0}{\tau s + 1},$$

$$H_i^2(s) = \frac{\omega_i^2 K_i}{s^2 + 2\xi_i \omega_i s + \omega_i^2}, \quad \xi_i = \frac{\delta\omega_i}{\omega_i}, \quad K_i = \pm 2\xi_i \Delta f_i,$$

$\Rightarrow$ Fitting procedure from experimental data

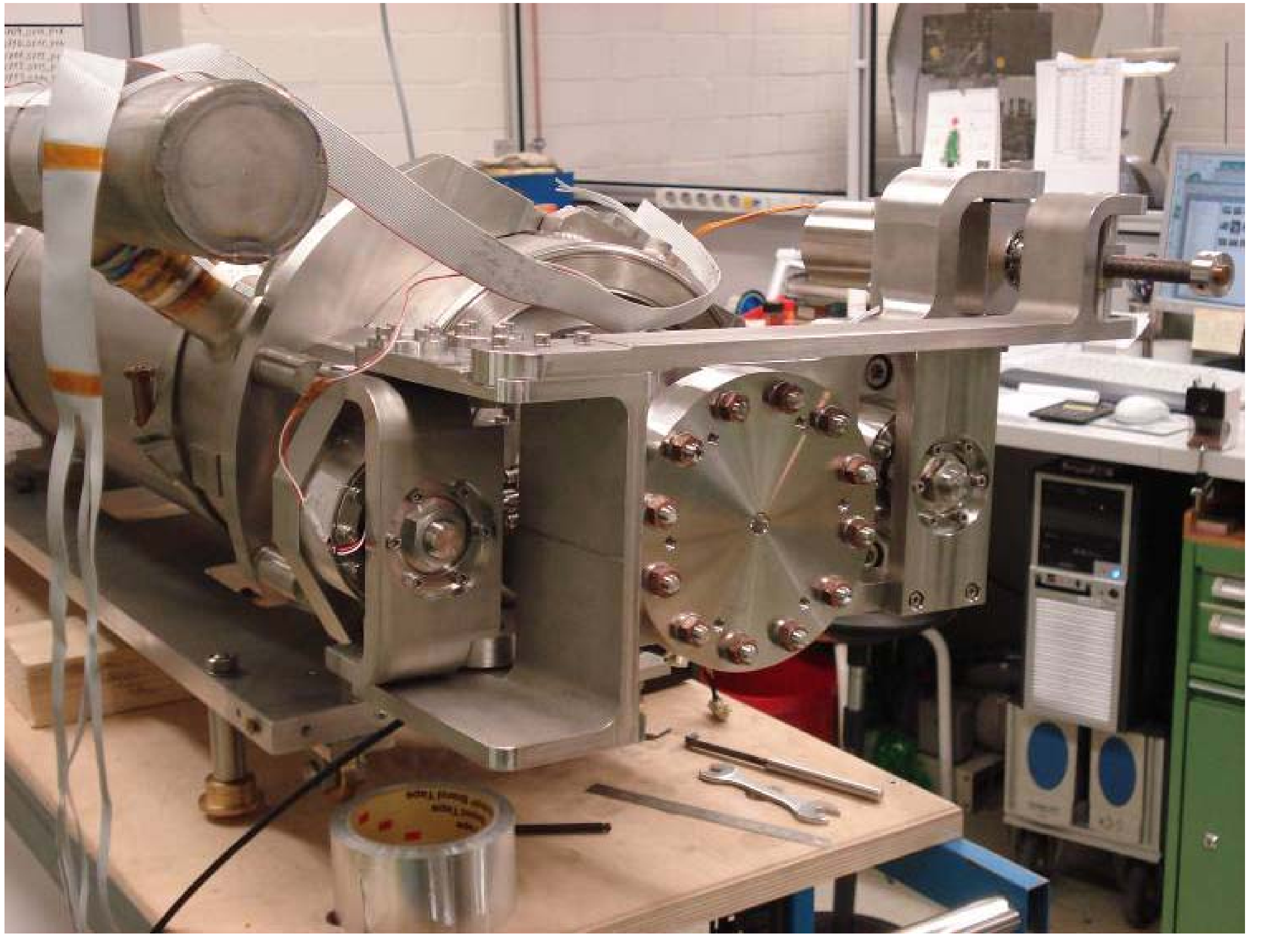
Model test result

Transfer function measured at 4.2 K

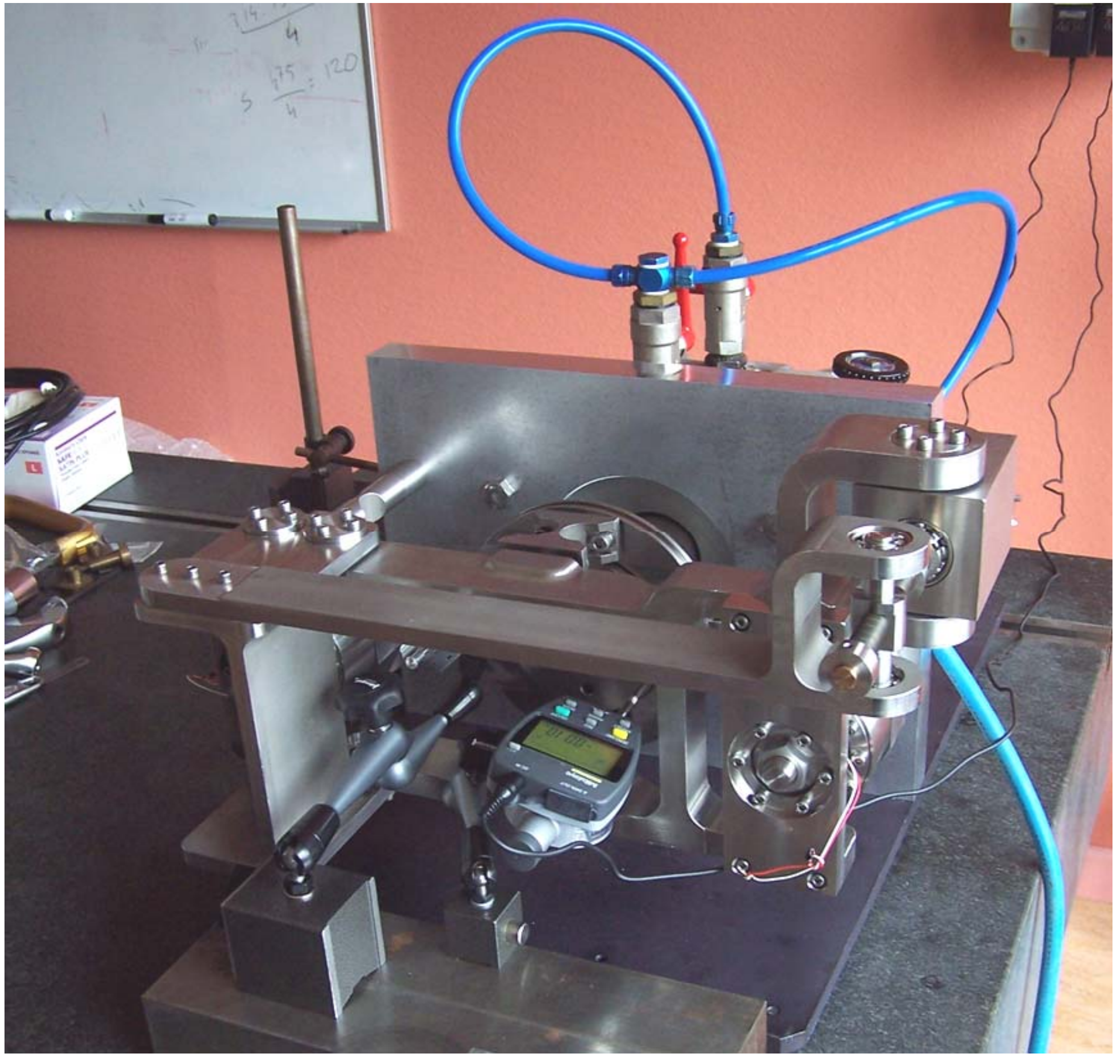


Saclay IV

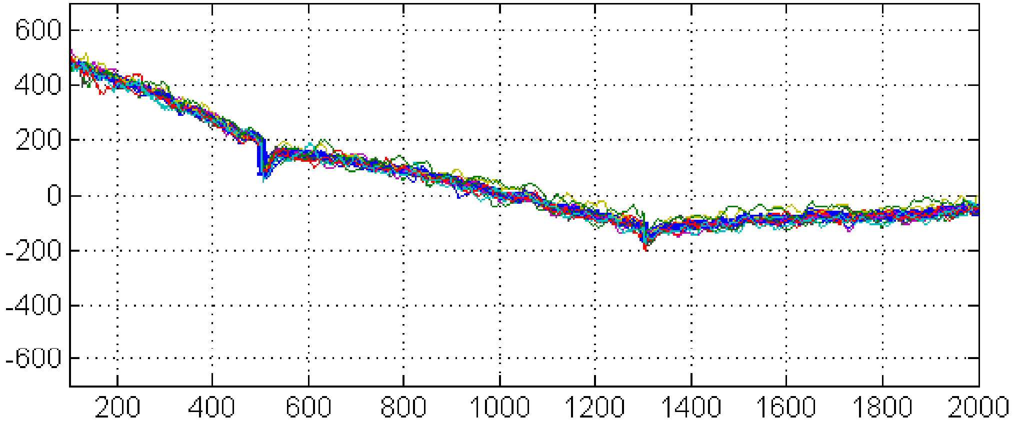
- for 1.3 GHz 9-cell cavities
- asymmetrical (like Saclay-I, TTF and XFEL tuner)
- 2 piezos (one on each side of the flange)



stiffness measurements with the hydraulic jack



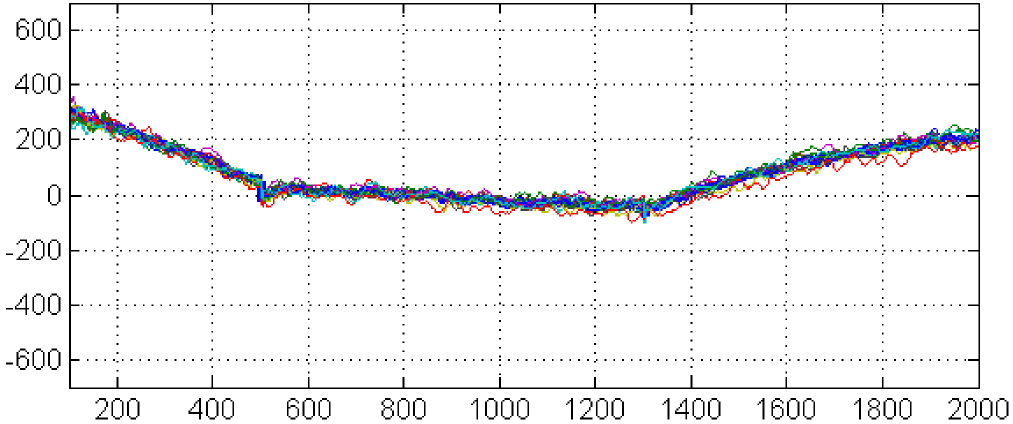
kext =15.5 kN/mm



LORENTZ DETUNING
at 25 MV/m

compensation OFF

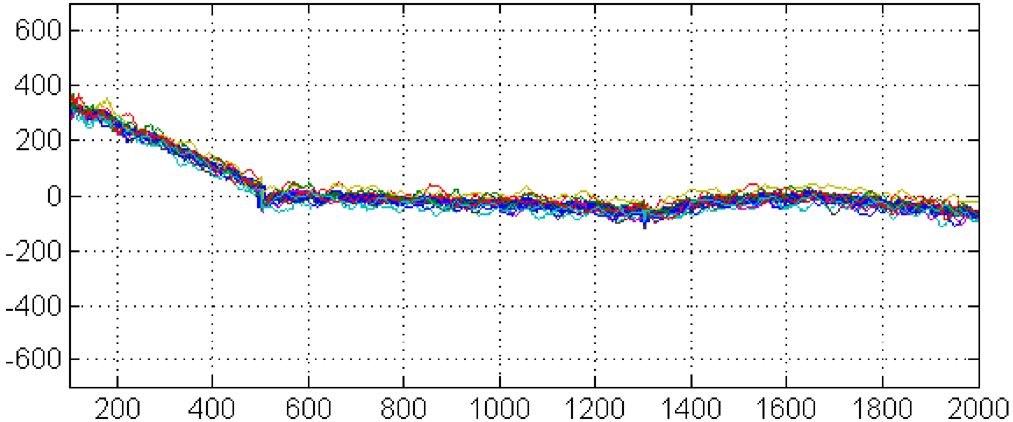
ΔF = -300 Hz



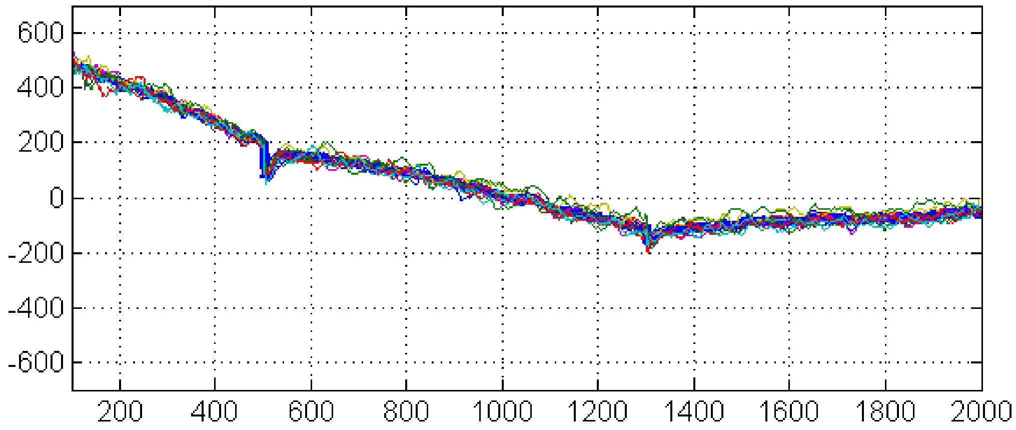
piezo1 only

compensation ON

ΔF = -40 Hz



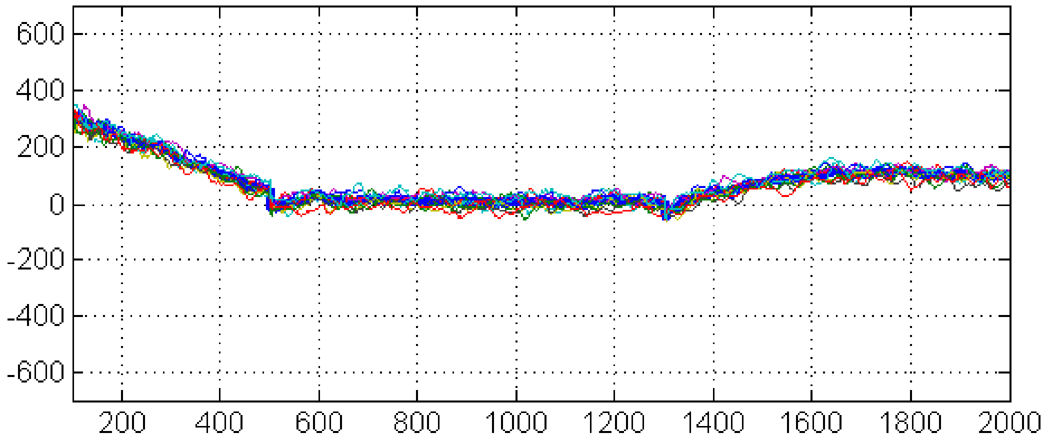
piezo 2 only



LORENTZ DETUNING
at 25 MV/m

compensation OFF

ΔF = -300 Hz

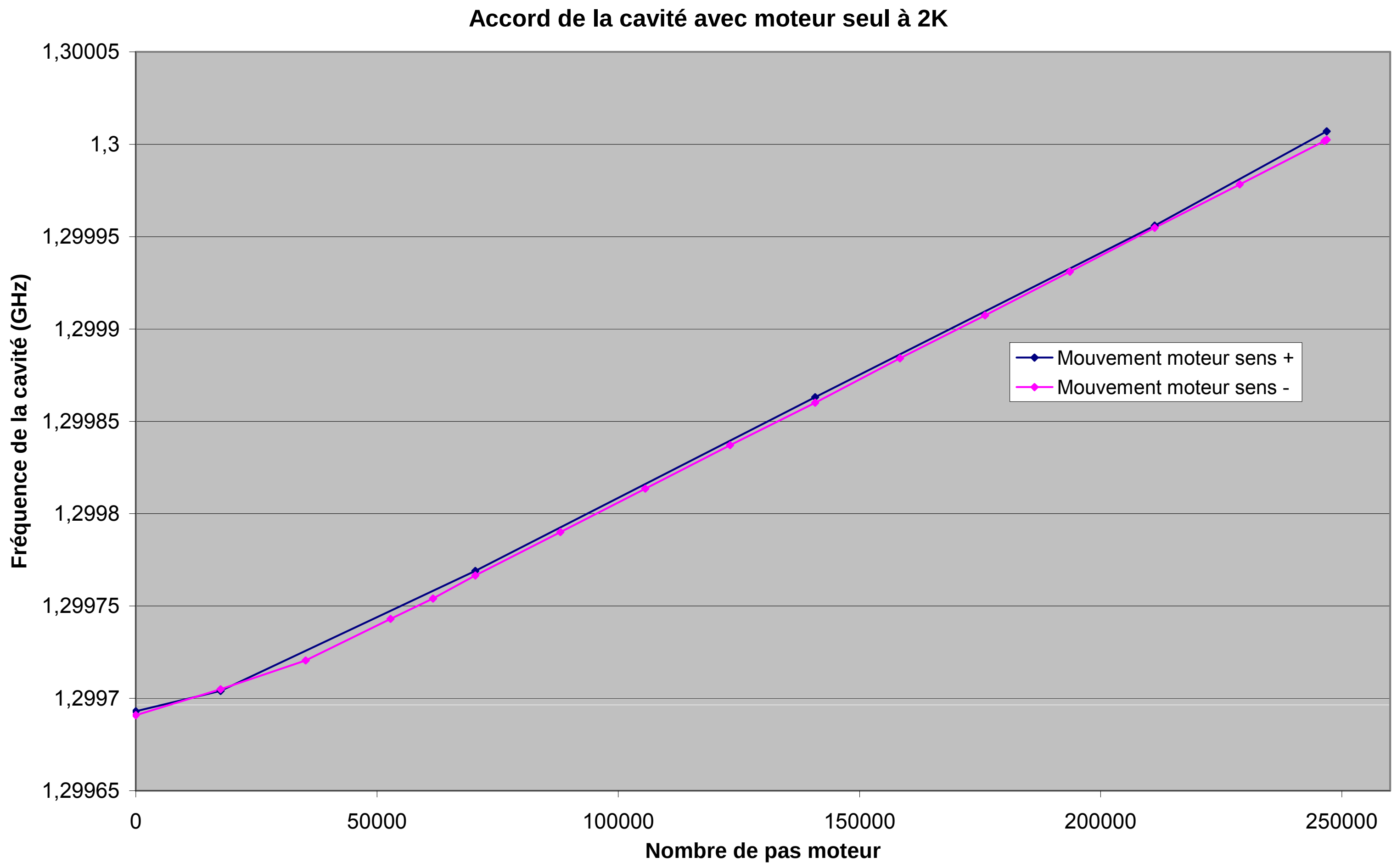


compensation ON

ΔF = ?? Hz

both piezo activated

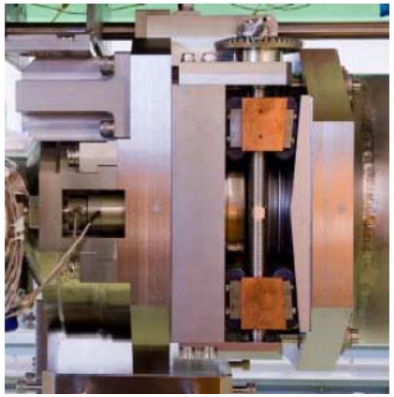
slow tuning

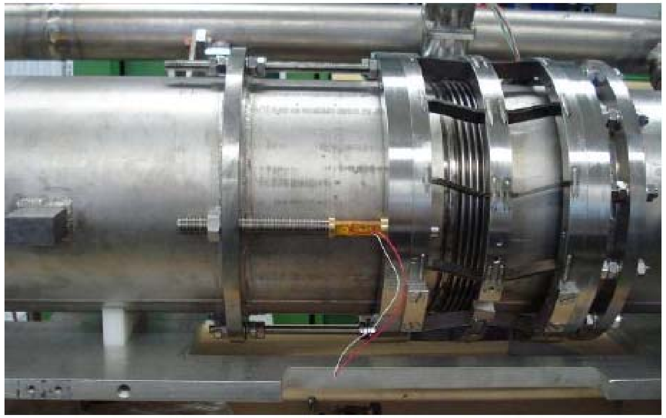


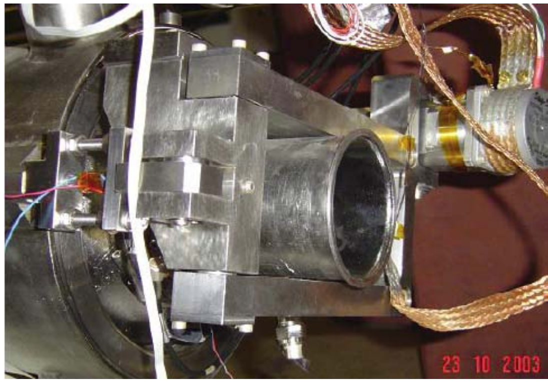
Accord de la cavité avec moteur seul à 2K
1,30005
1,3
1,29995
1,2999
1,29985
1,2998
1,29975
1,2997
1,29965
Fréquence de la cavité (GHz)
0
50000
100000
150000
200000
250000
Nombre de pas moteur
Mouvement moteur sens +
Mouvement moteur sens -

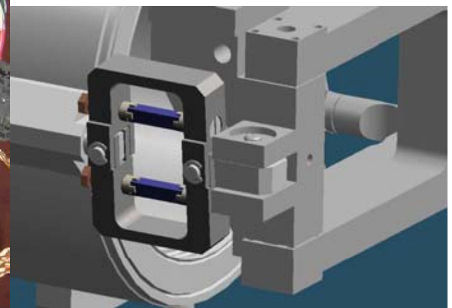
piezo tuners 1.3 GHz

KEK slide-jack	compensation at 18 MV/m, Vp=500V (HV piezo)
INFN blade tuner	compensation at 35 MV/m Vp=80V
Saclay I + DESY piezo frame	compensation at 35 MV/m Vp=80V
Saclay II & IV	compensation at 25 MV/m Vp=40V





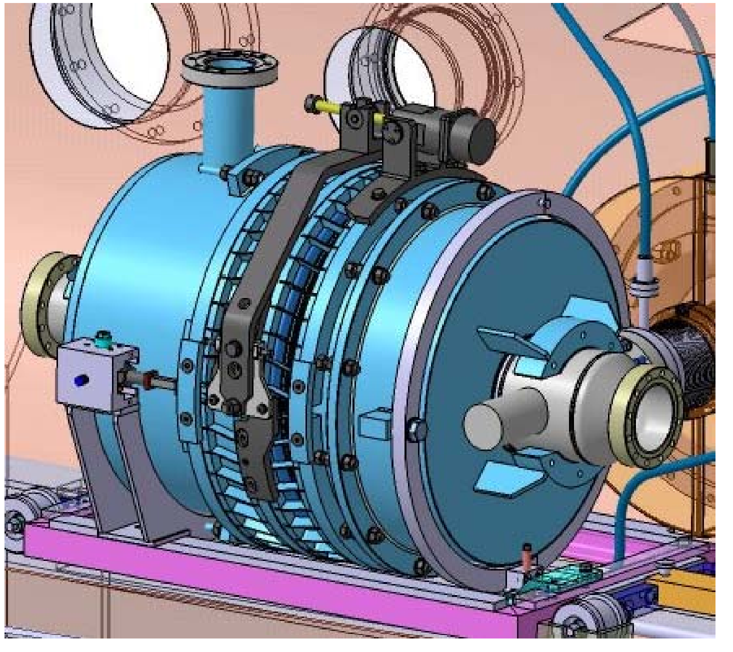




piezo tuners 704 MHz

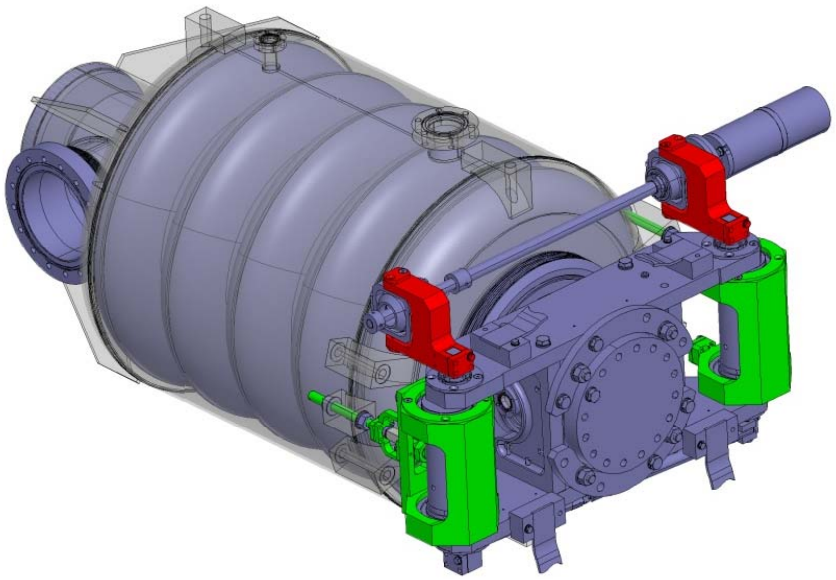
2 models from CARE HIPPI program

INFN blade tuner



piezo tuners 704 MHz

Saclay



- design based on Soleil, 3HC, CARE-SRF (aka Saclay-II) family of tuners
- symmetric slow tuning +/- 2.5 MHz
- planetary gear box for reliability
- single piezo frame with preload independent of cavity tuning
- does not increase cavity length
- manufacturing process started
- expected end of february 2009