Control of Microphonics and Lorentz Force Detuning with a Fast Mechanical Tuner

S. Simrock, DESY
for the TESLA collaboration

Outline

- Motivation for Detuning Control
- Lorentz Force and Microphonics
- Actuators and Sensors for Detuning Control
- Feedforward vs Feedback
- Performance of Resonance Control
- Conclusion

Motivation for Detuning Control

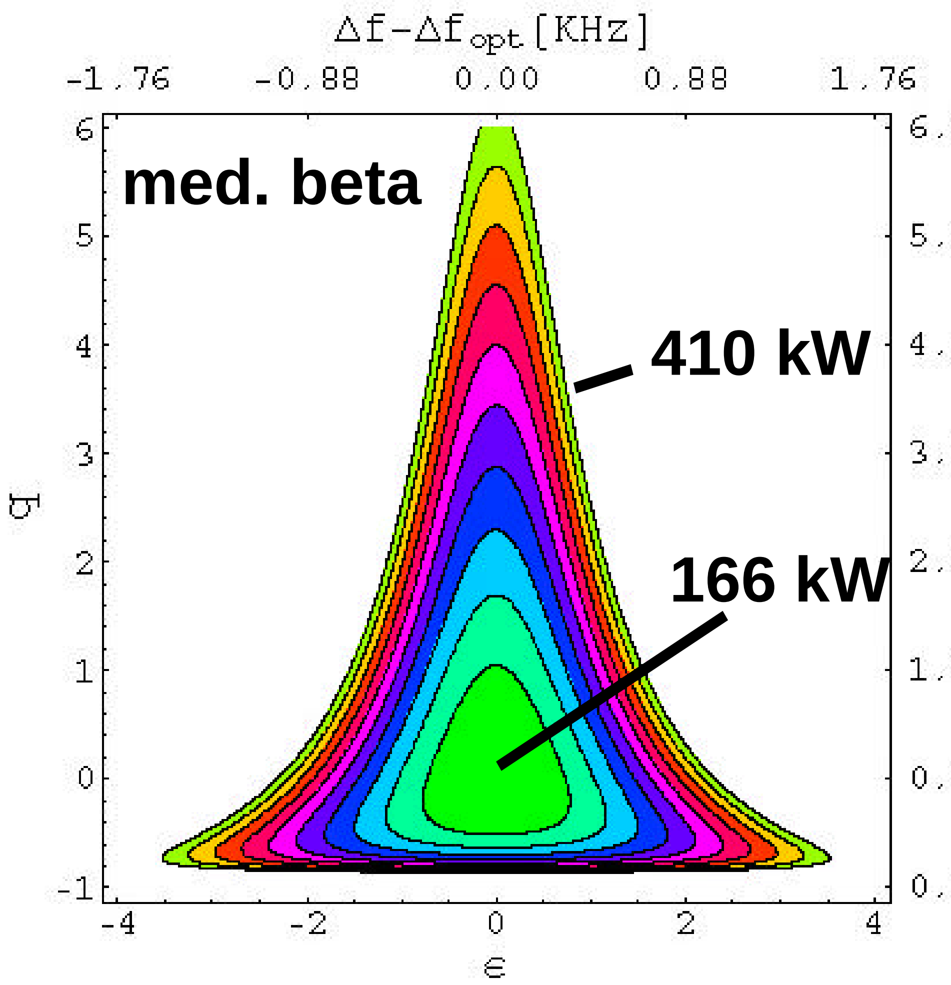
- Microphonics (vibrations) modulate the cavity resonance frequency $\Longrightarrow$ Amplitude and phase error of accelerating field
- Regulation of the accelerating field requires additional rf power due to the time varying cavity de-tuning $\Delta f(t)$
- $$\frac{P}{P_0} = 1 + 0.25 \cdot \left(\frac{\Delta f(t)}{f_{12}}\right)^2$$ with beam (matched conditions)

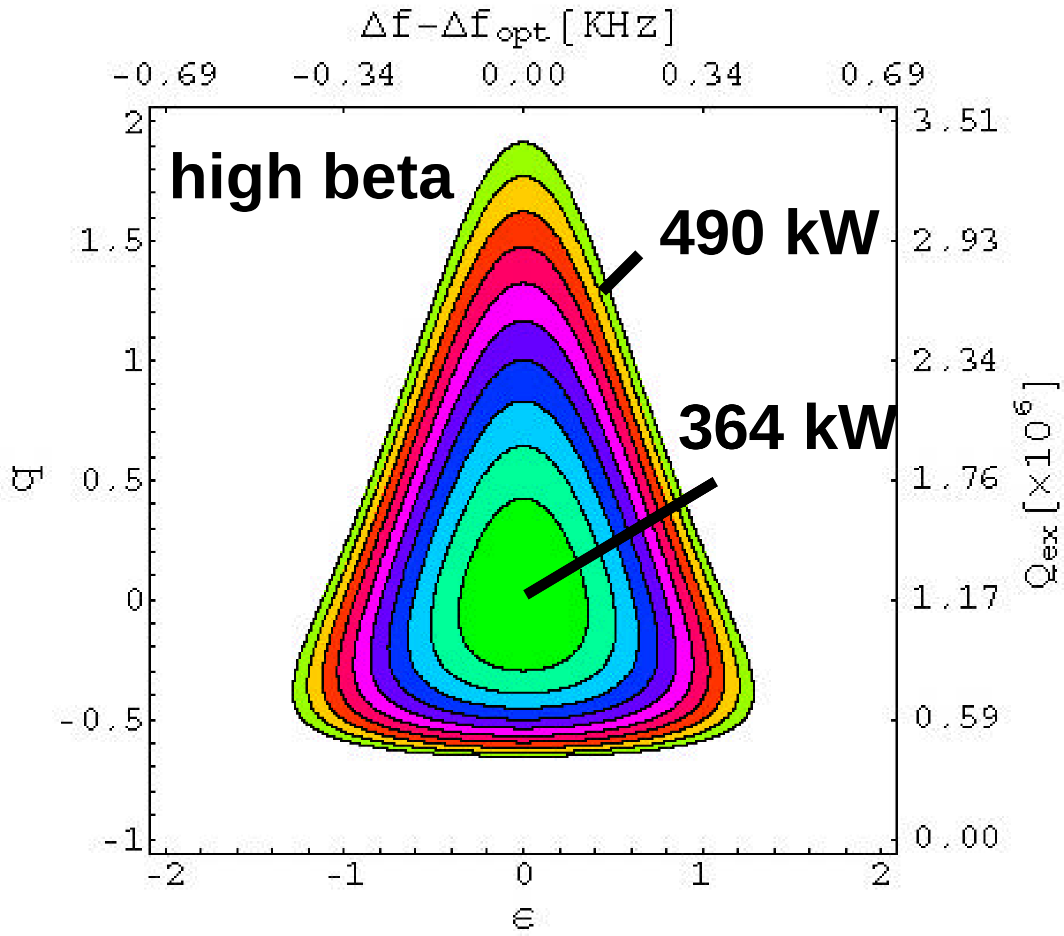
  $$\frac{P}{P_0} = 1 + 1 \cdot \left(\frac{\Delta f(t)}{f_{12}}\right)^2$$ without beam

  where Δf : cavity detuning, f_{12} : cavity bandwidth (HWHM)

- Potential Solution: Fast piezo tuner in feedback loop

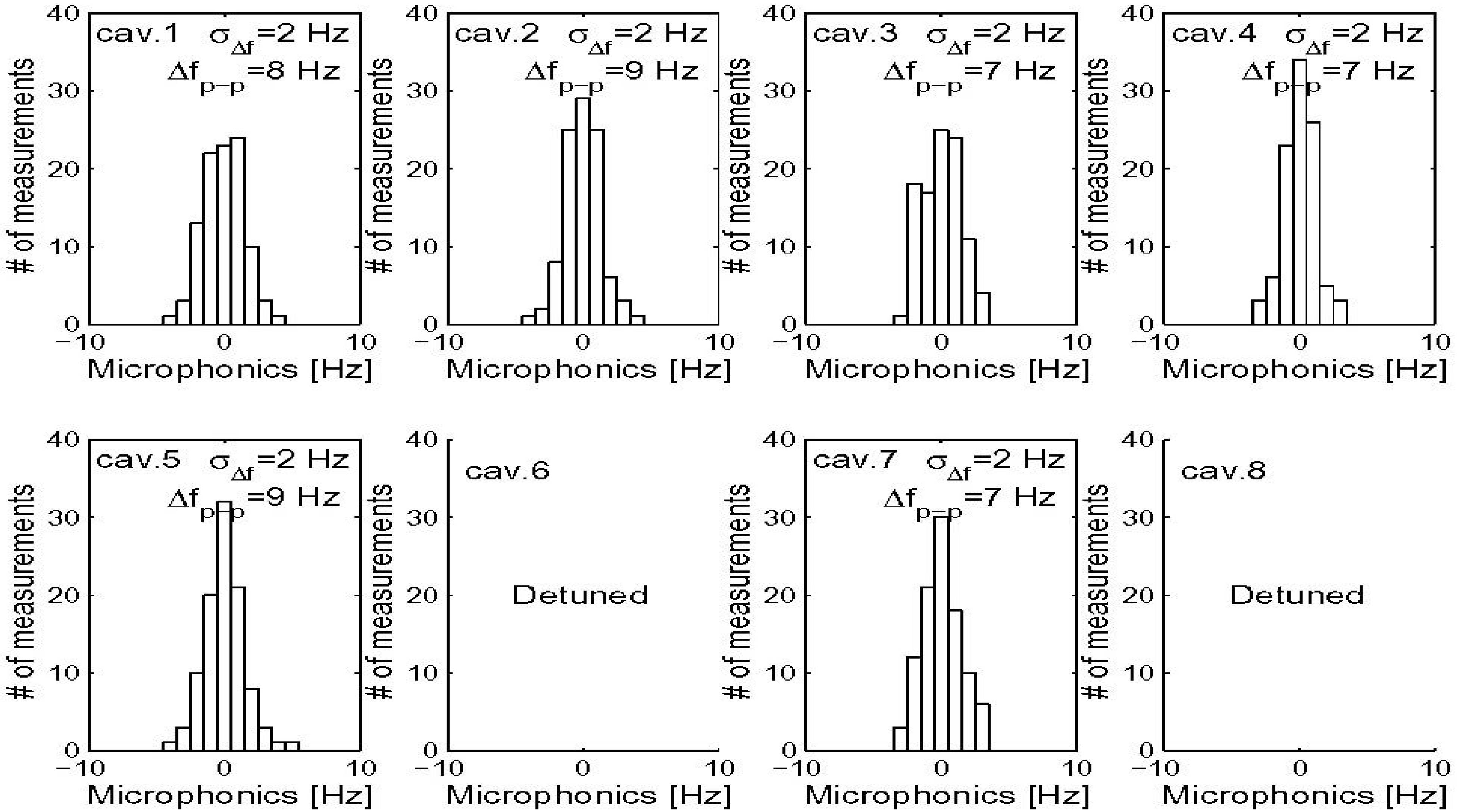
Detuning Limit for SNS Cavities





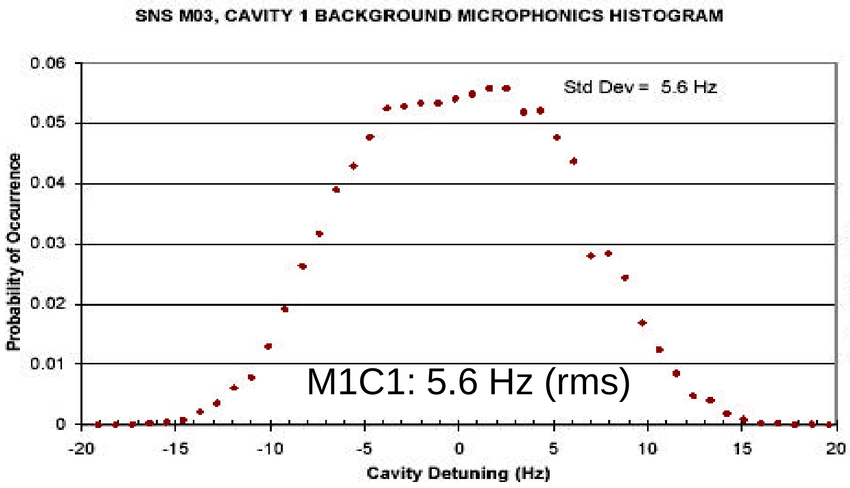
courtesy: M. Doleans, ORNL

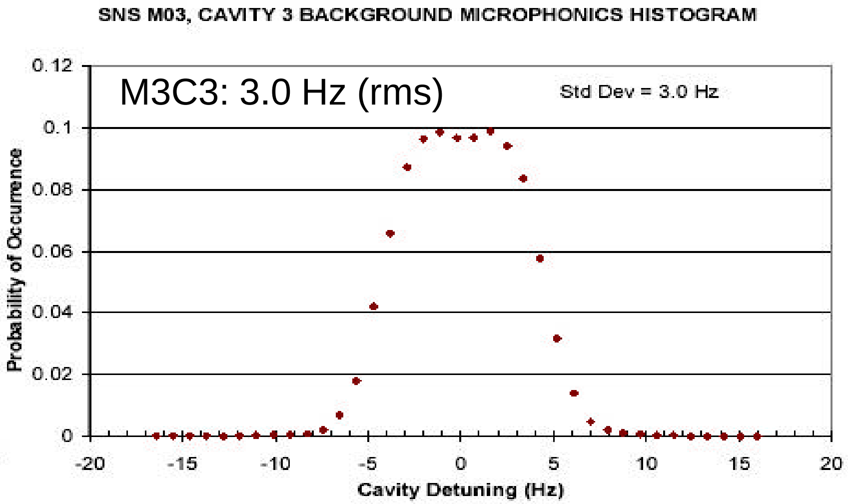
Microphonics at TTF (ACC 5)

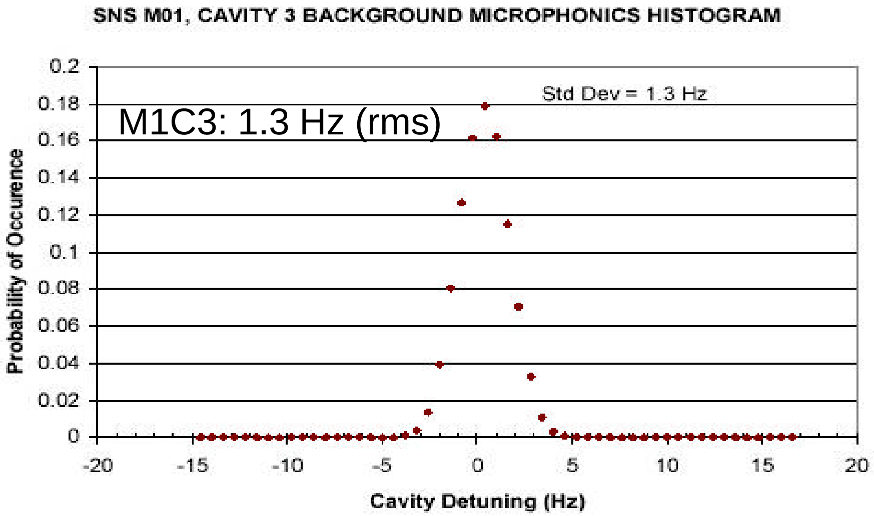


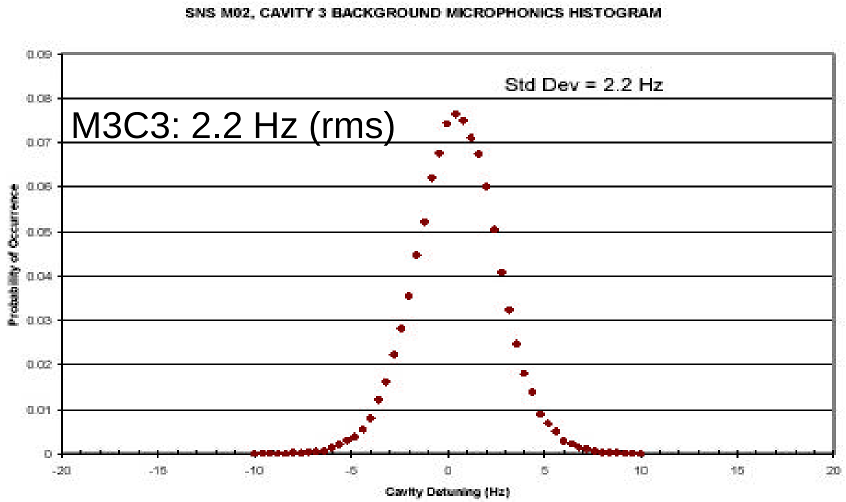
courtesy: V. Ayvazyan, DESY

Microphonics in SNS Cavities



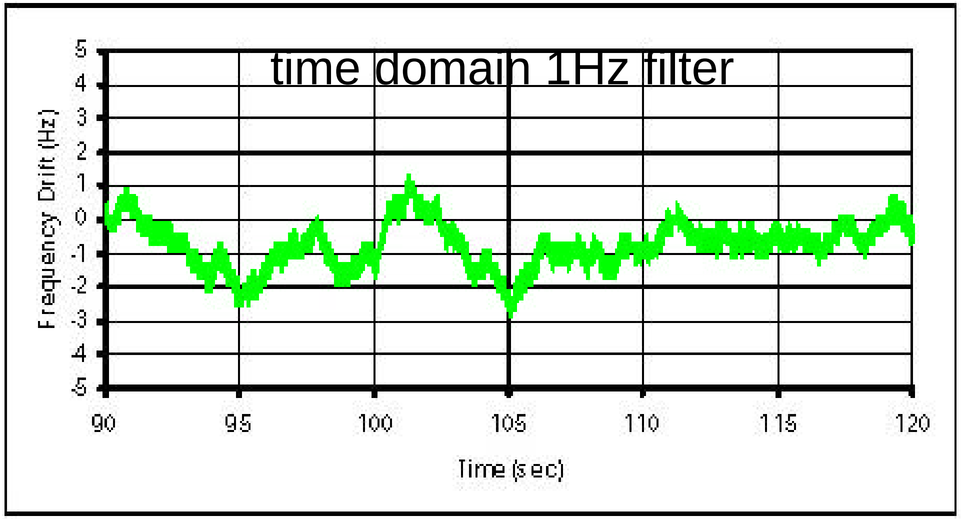


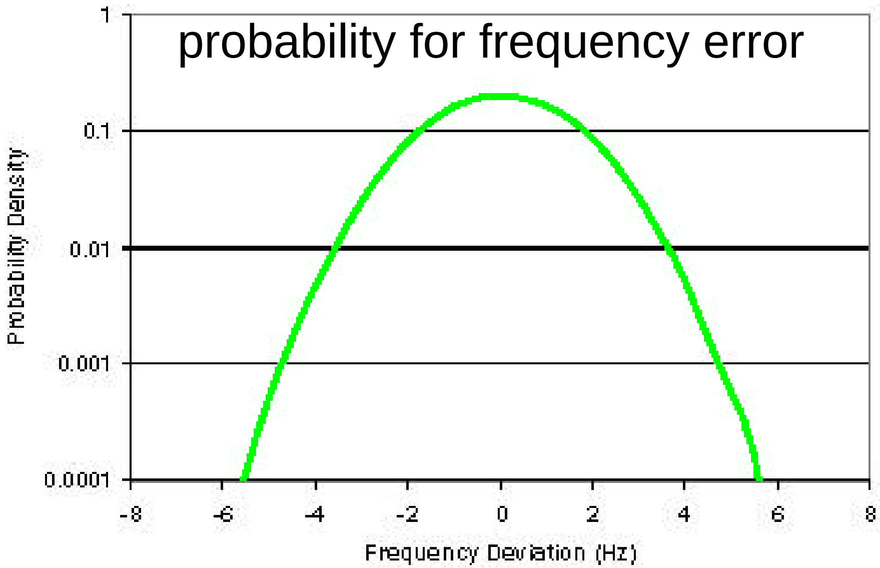


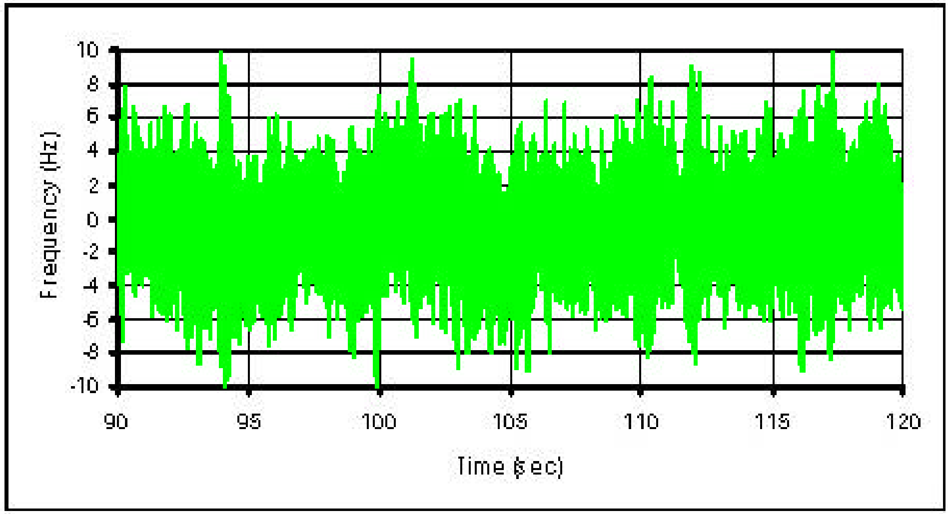


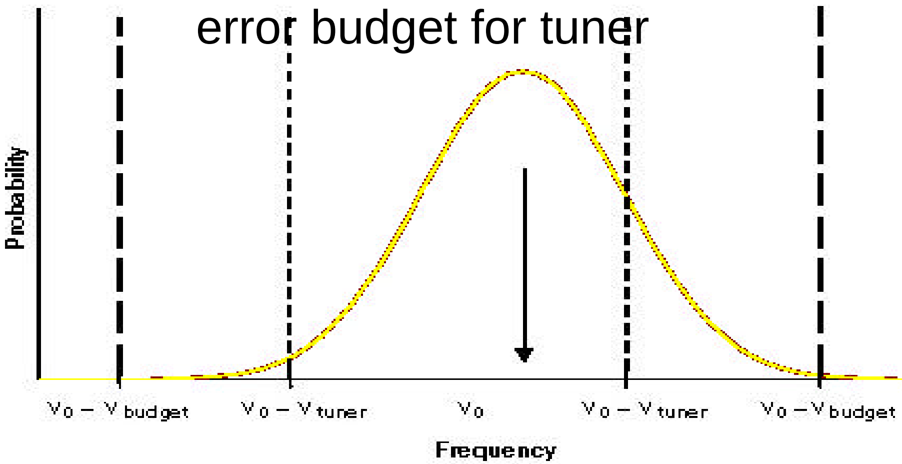
courtesy : J. Delayen, JLAB

Microphonics for SNS Cavities



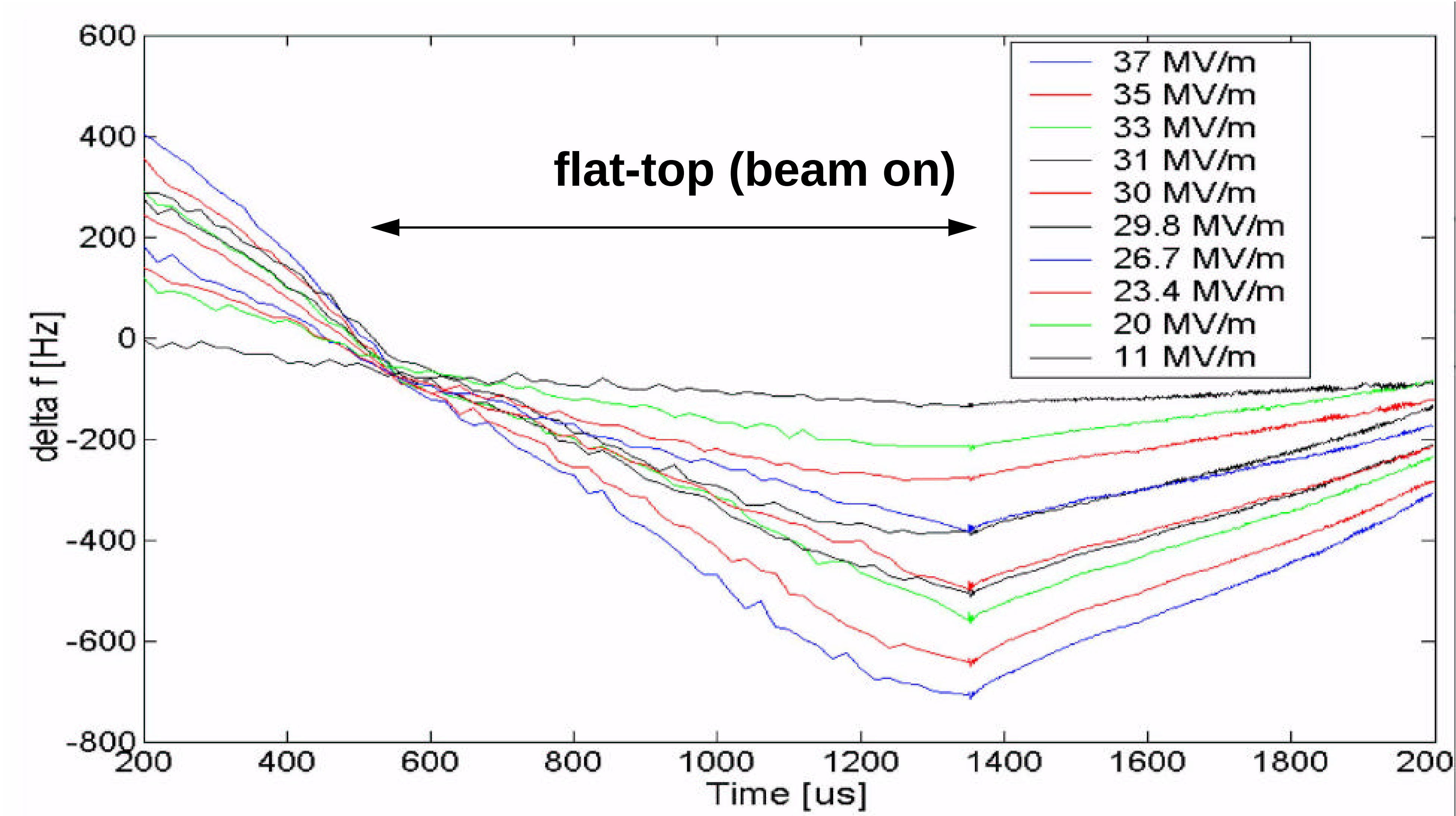






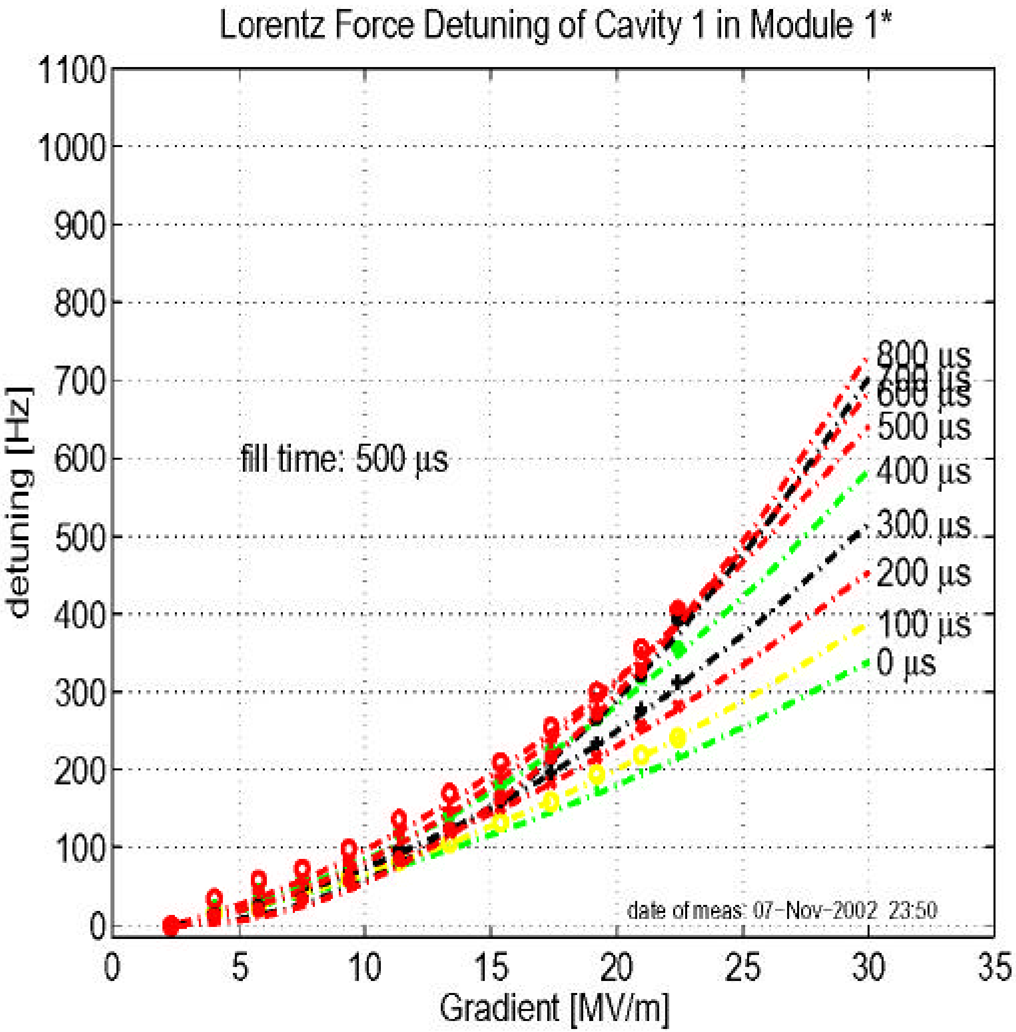
courtesy : J. Delayen, JLAB

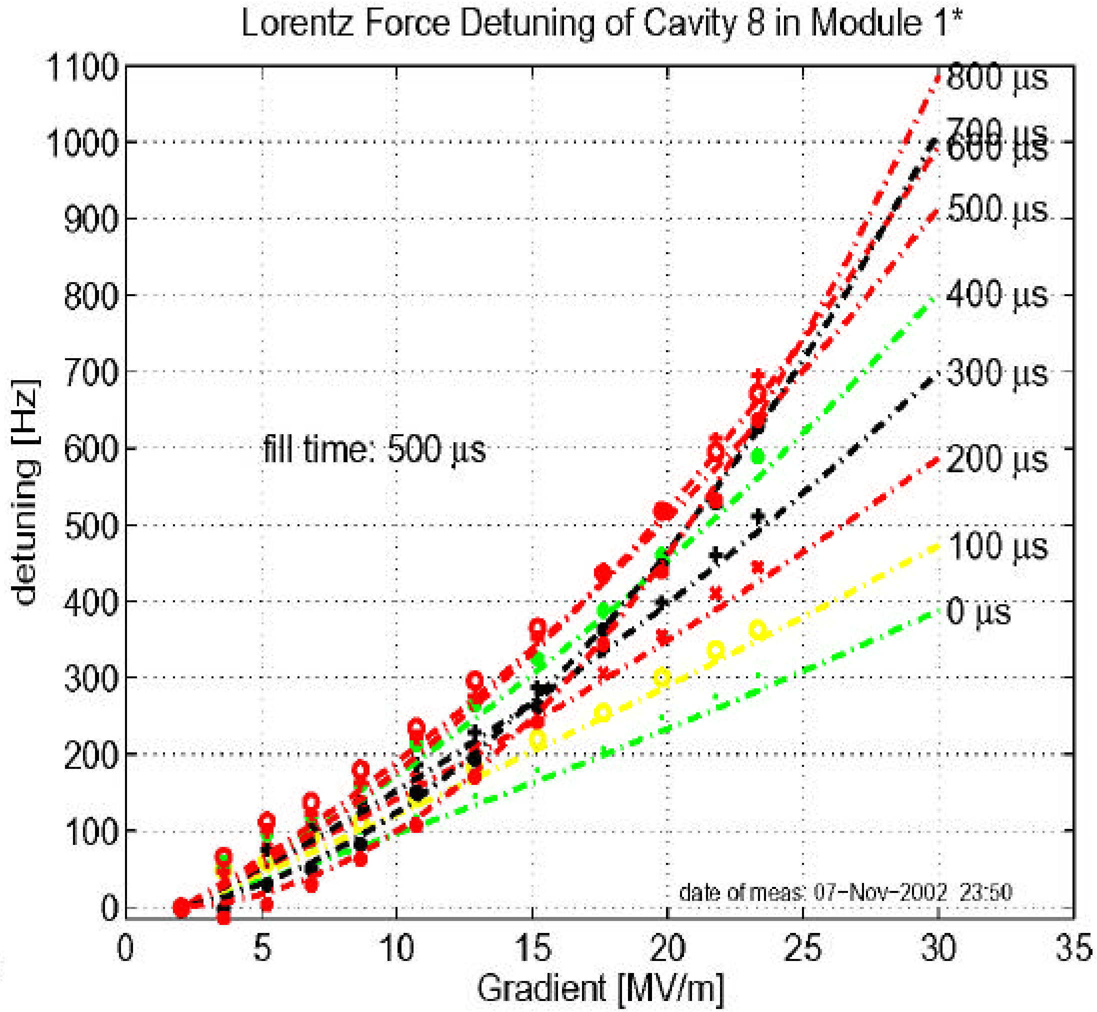
Lorentz Force Detuning (AC73)



courtesy L. Lilje

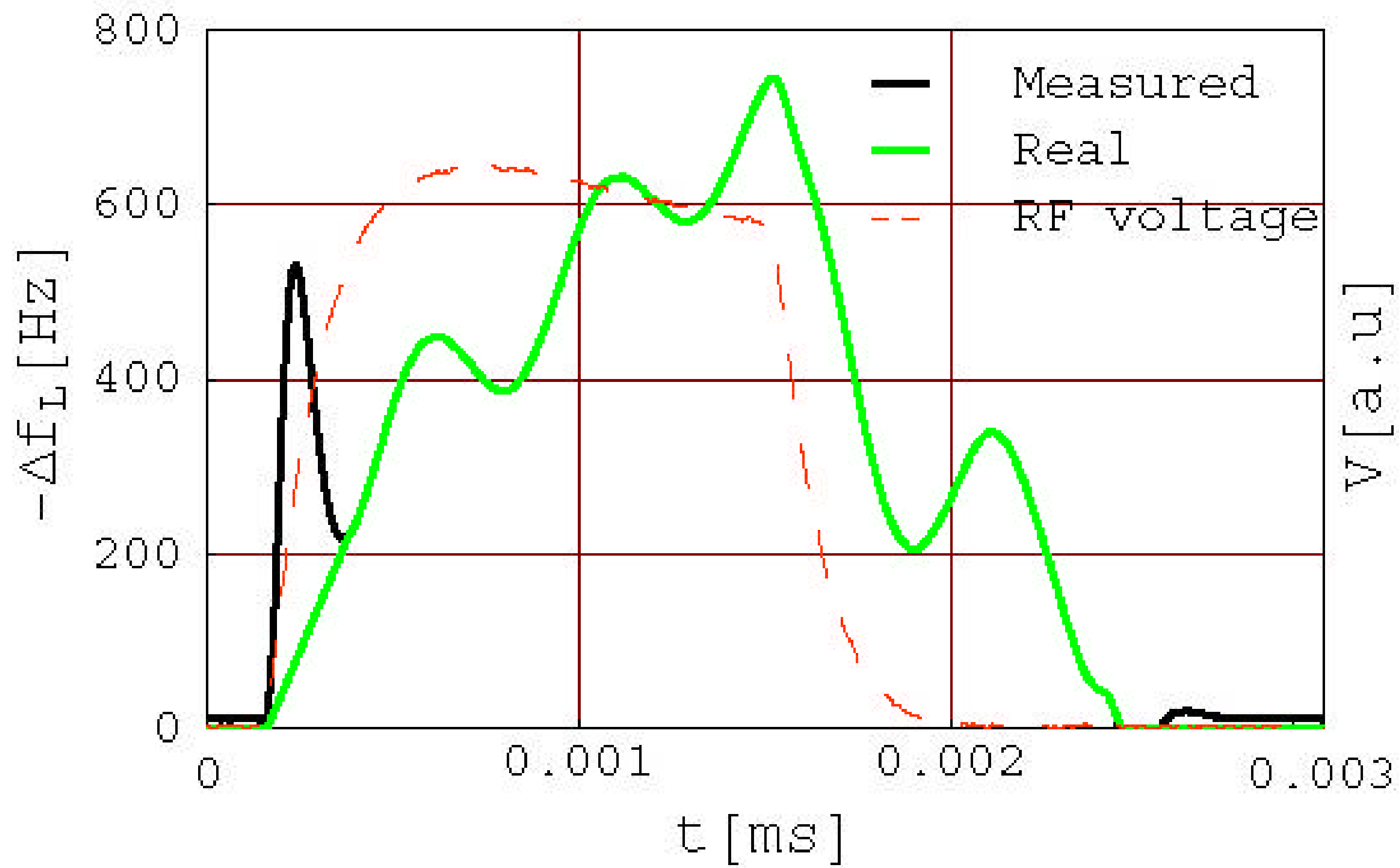
Spread of Lorentz Force Detuning at TTF





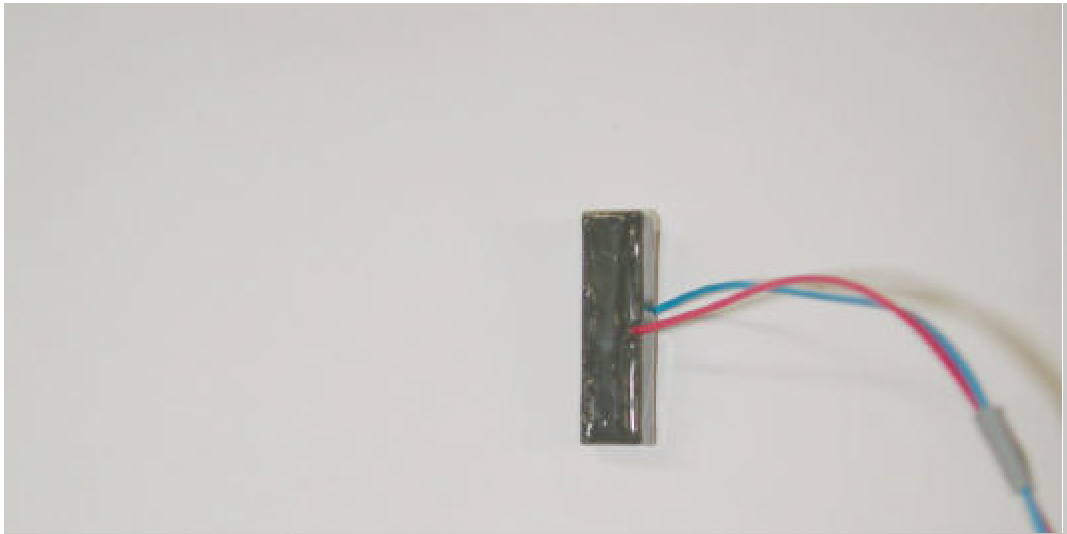
courtesy V. Ayvazyan

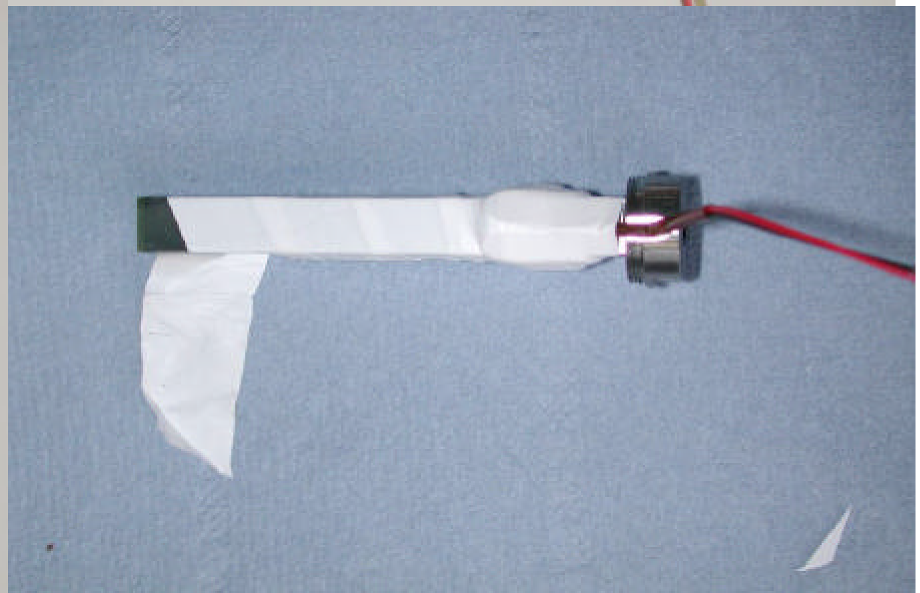
Lorentz Force Detuning for SNS cavity



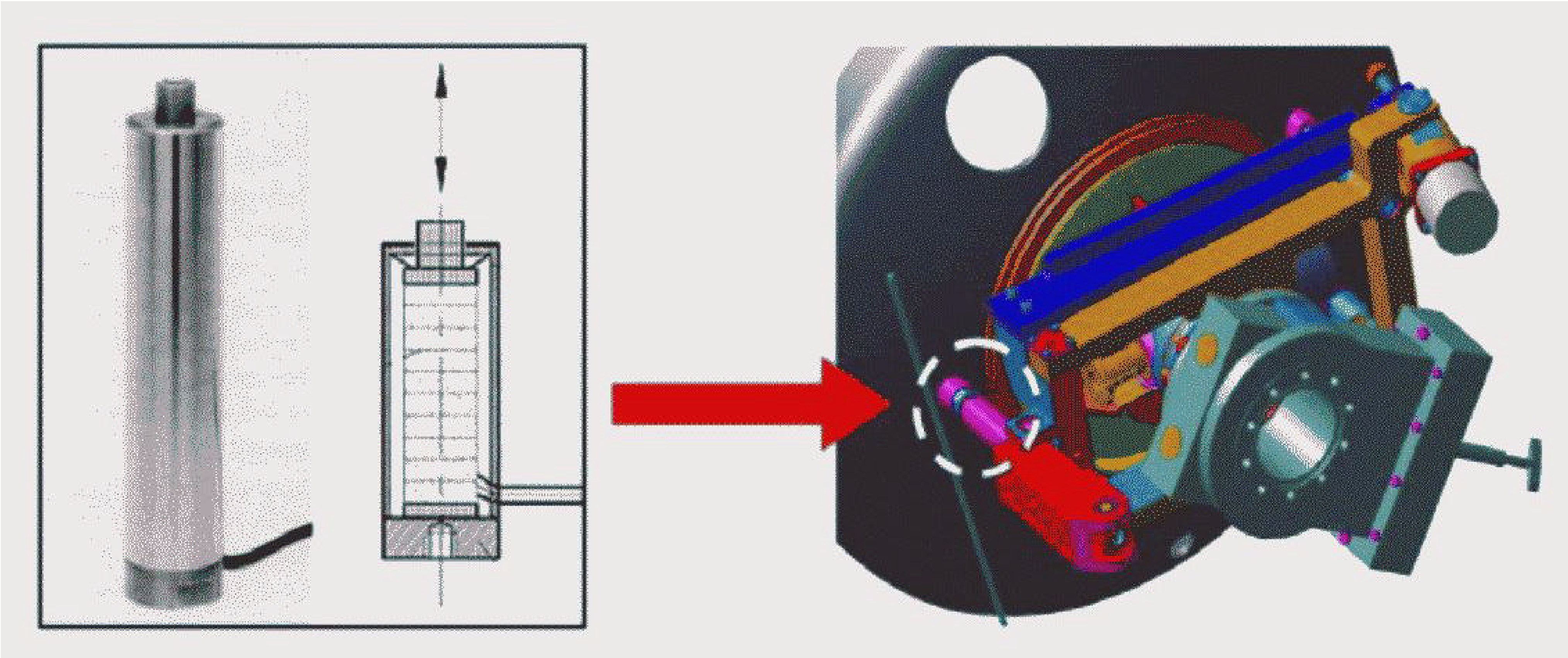
courtesy : J. Delayen, JLAB

Actuators for Detuning Control Actuators

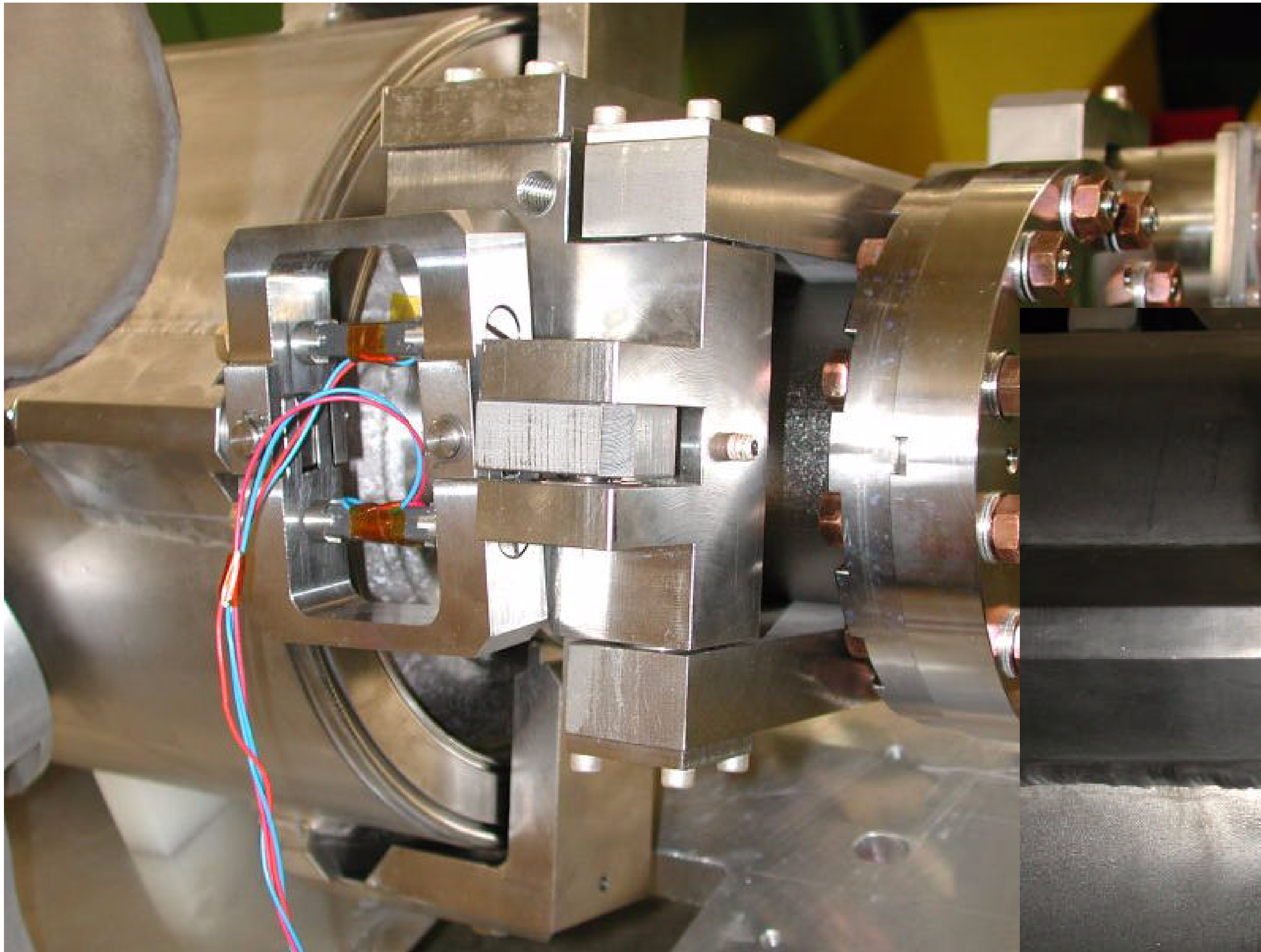


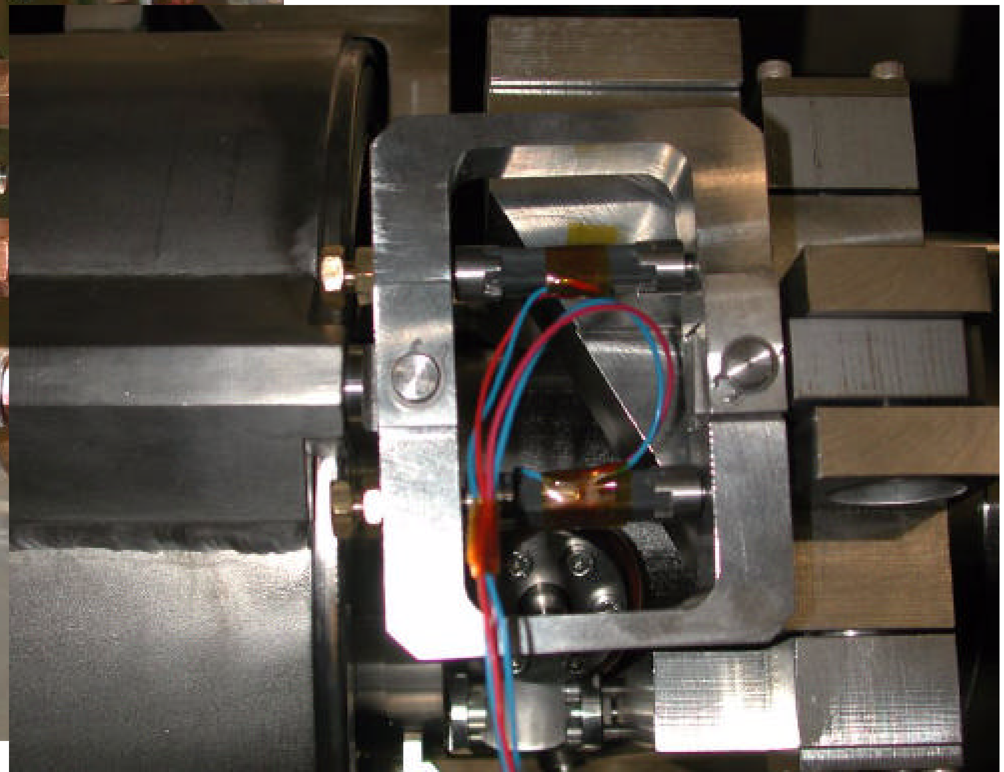


Integration of Piezo Tuner for SNS

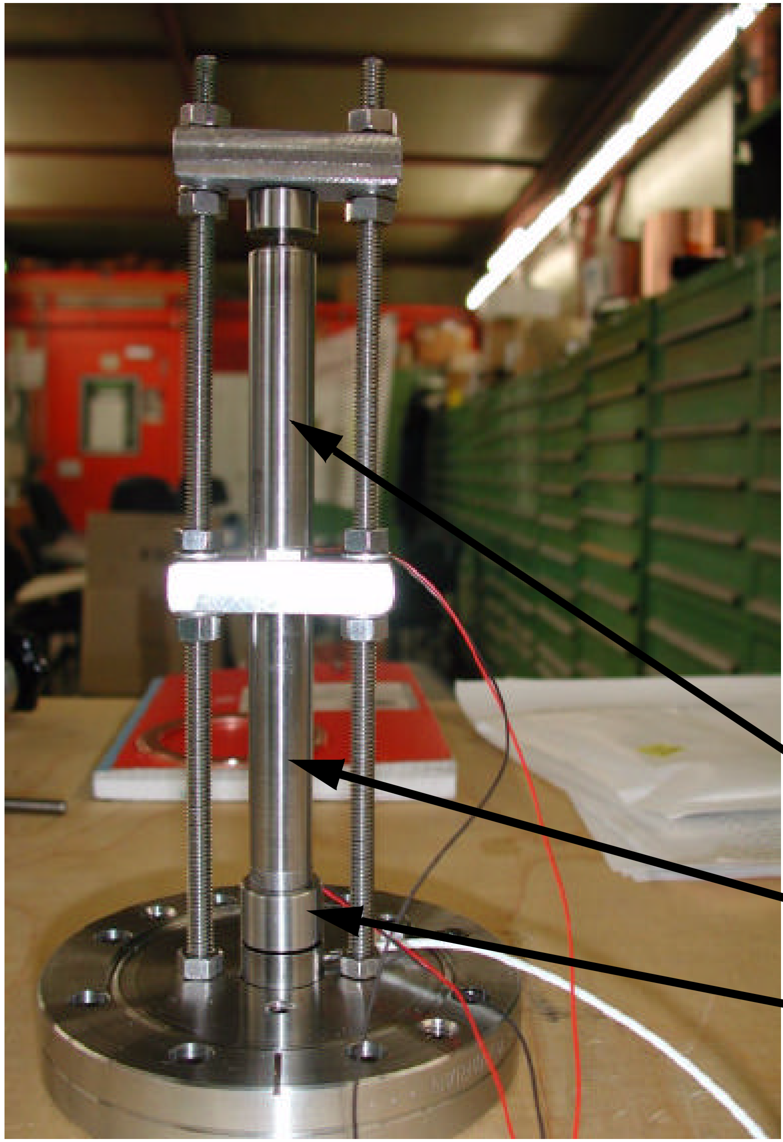


Integration of Piezo Tuner for TTF

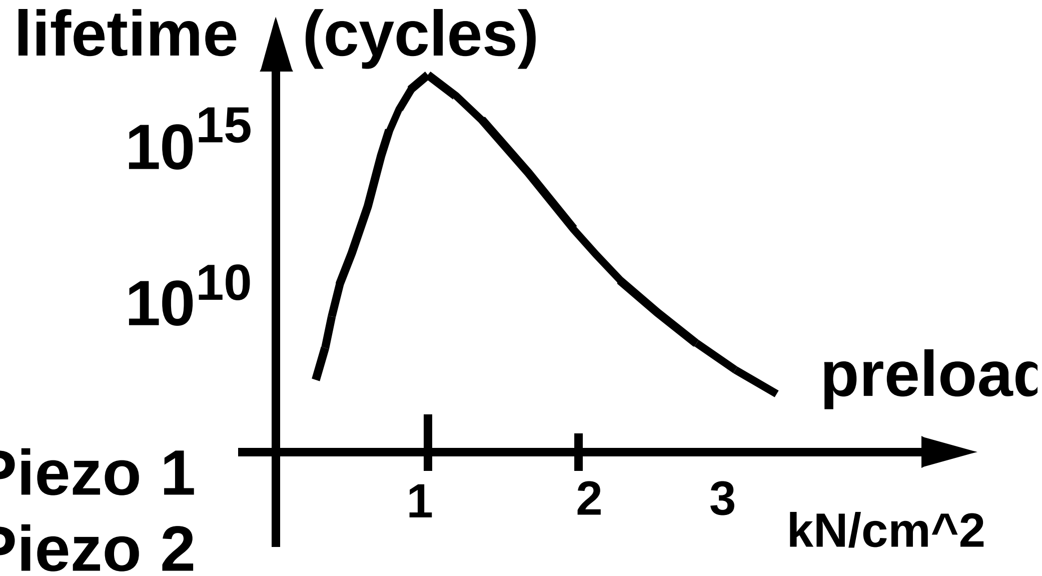




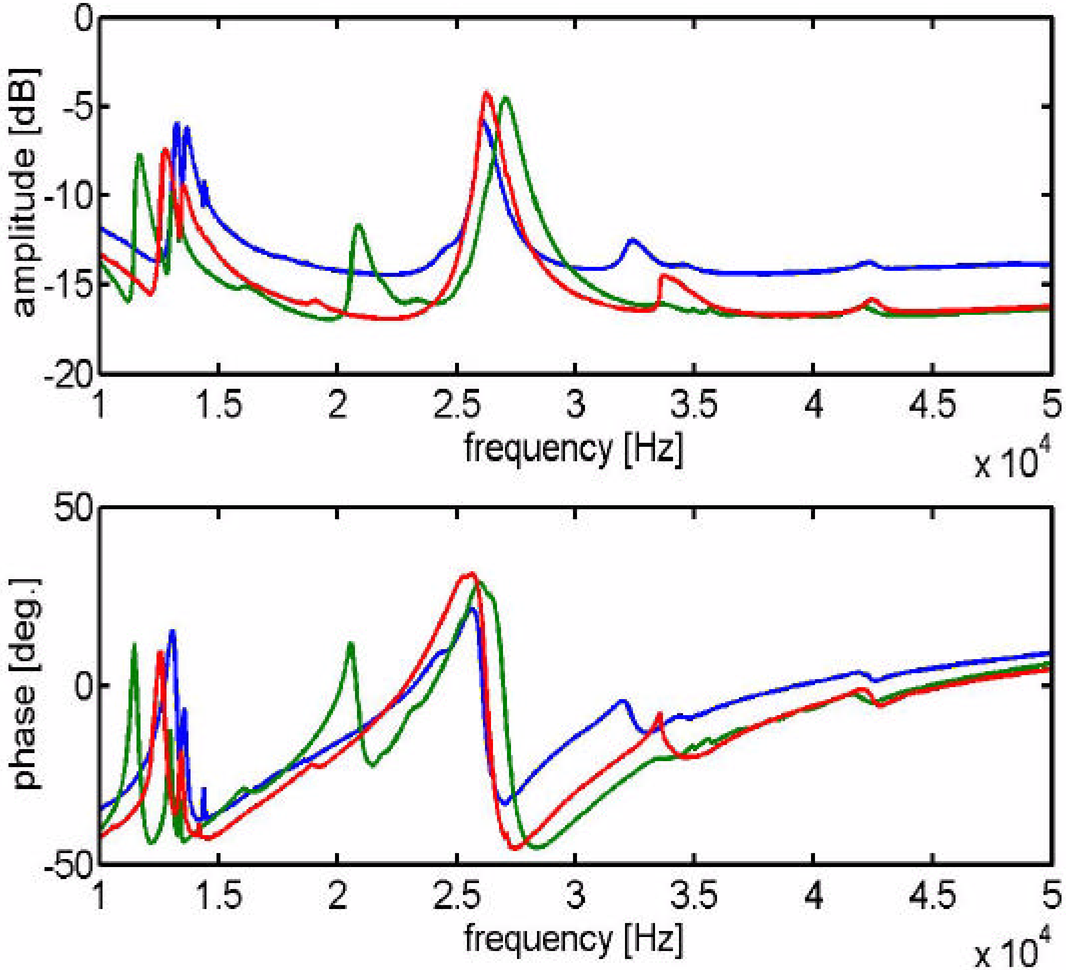
Measurement of Mechanical Preload



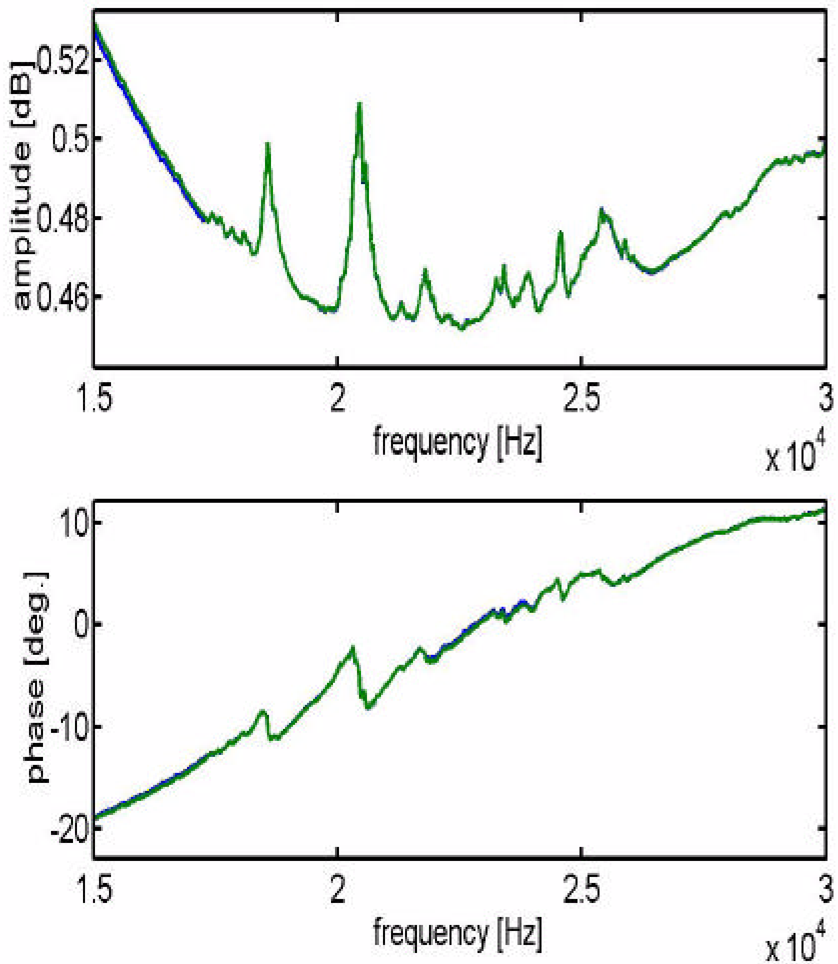
Lifetime of piezo depends strongly on mechanical preload. Optimum around 1 kN/ cm^2.



Piezo Imp. Meas. as Potential Diag. Tool

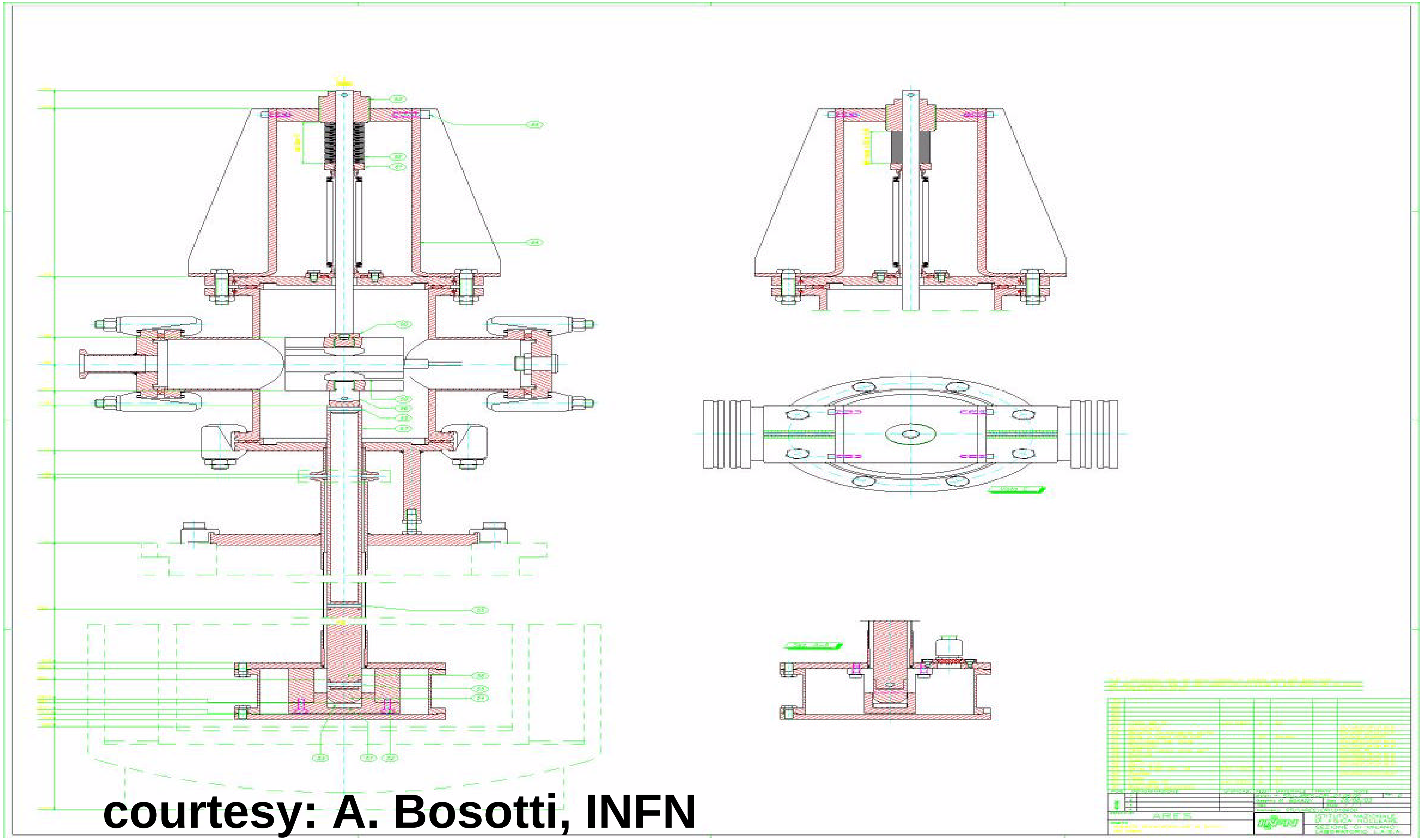


3x Piezomechanik Piezo



Noliac Piezo in Chechia

Measurement of Preload and Stroke



courtesy: A. Bosotti, INFN

Measurement of Preload and Stroke

courtesy: A. Bosotti, INFN

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Tuner Specifications:

Parameter	Specification
Dimensions:	61.8 mm High x 50 mm Wide x 22 mm Deep
Stroke:	20 µm
Resolution:	better than 0.2 µm
Slew rate:	0.15 µm/ µsec
Operating Temp:	2.1 K
Load:	3 kN
Stray magnetic field:	< 25mG at 30 mm from actuator
Pulse Length:	1.6 ms
Repetition Rate:	60 per second
Heat Load to 2.1 K:	< 0.1 W
Lifetime:	5 x 10^{10} Cycles

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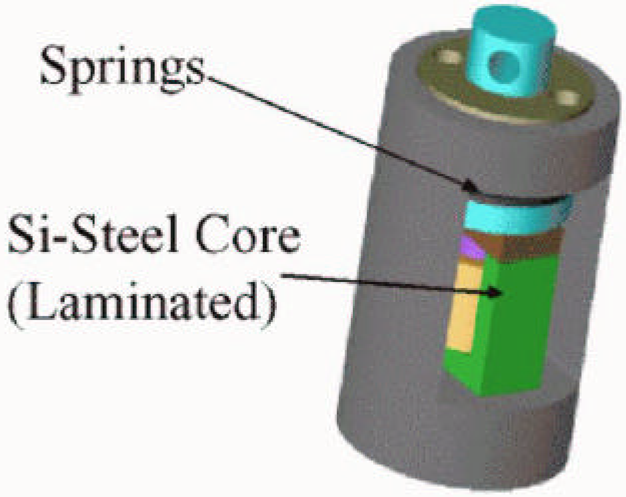
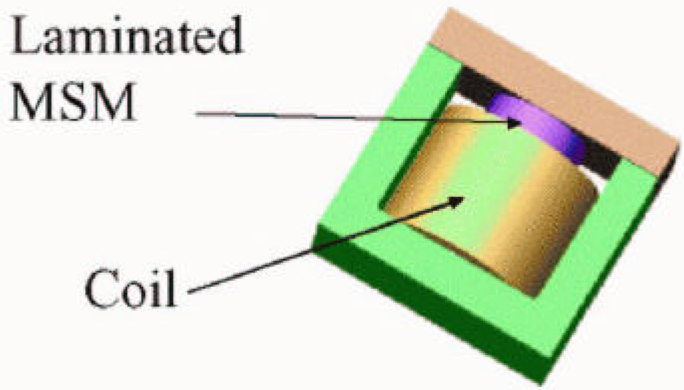
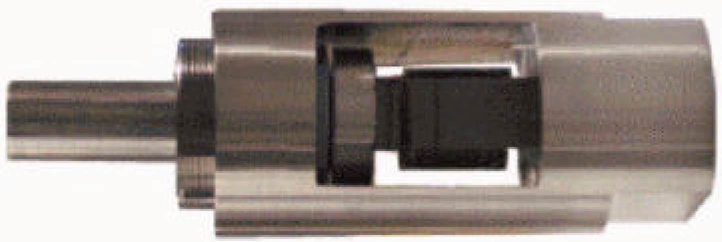
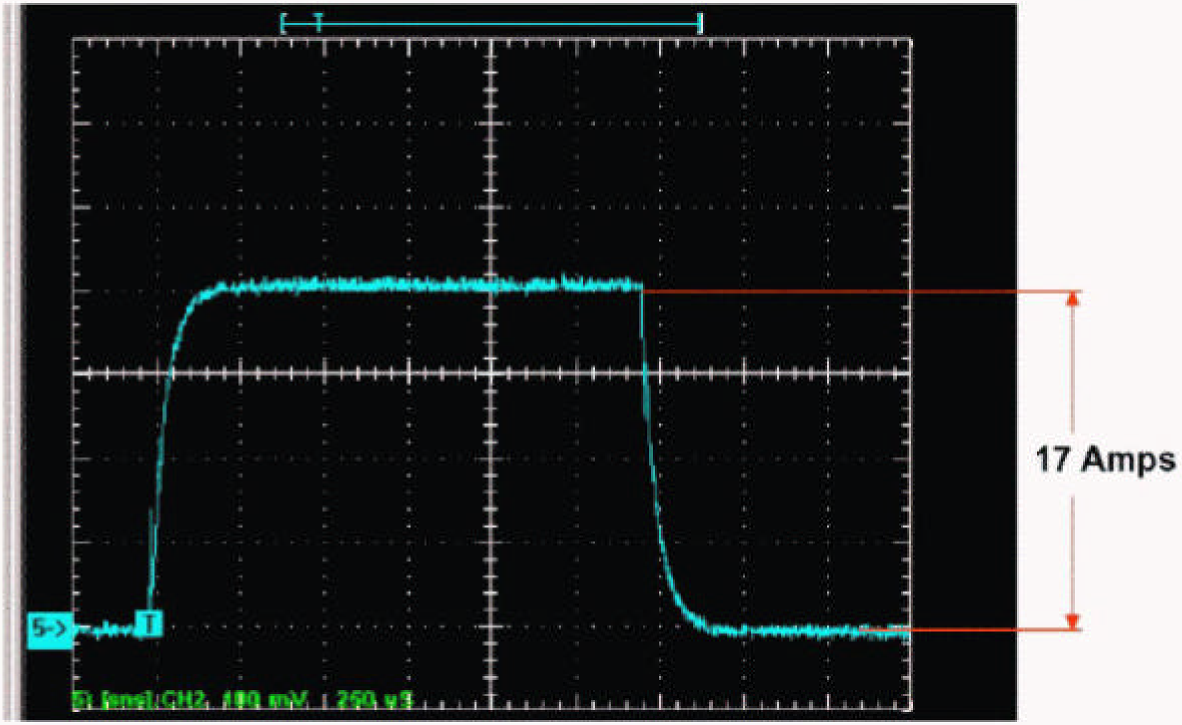
The Fast Tuner







Fast Tuner Ramp Rate Testing



- The response of the superconducting coil to a step input.
- Takes 130 µS for the current to ramp up and down.

ENERGEN, INC.

Results:

- Total stroke of 20 µm
- 0 to full stroke in 130 µsec
- Stray field at a distance of 30 mm from the surface of the actuator is <20mG
- Tested to 100 million cycles with no change in performance
- Fatigue analysis is underway

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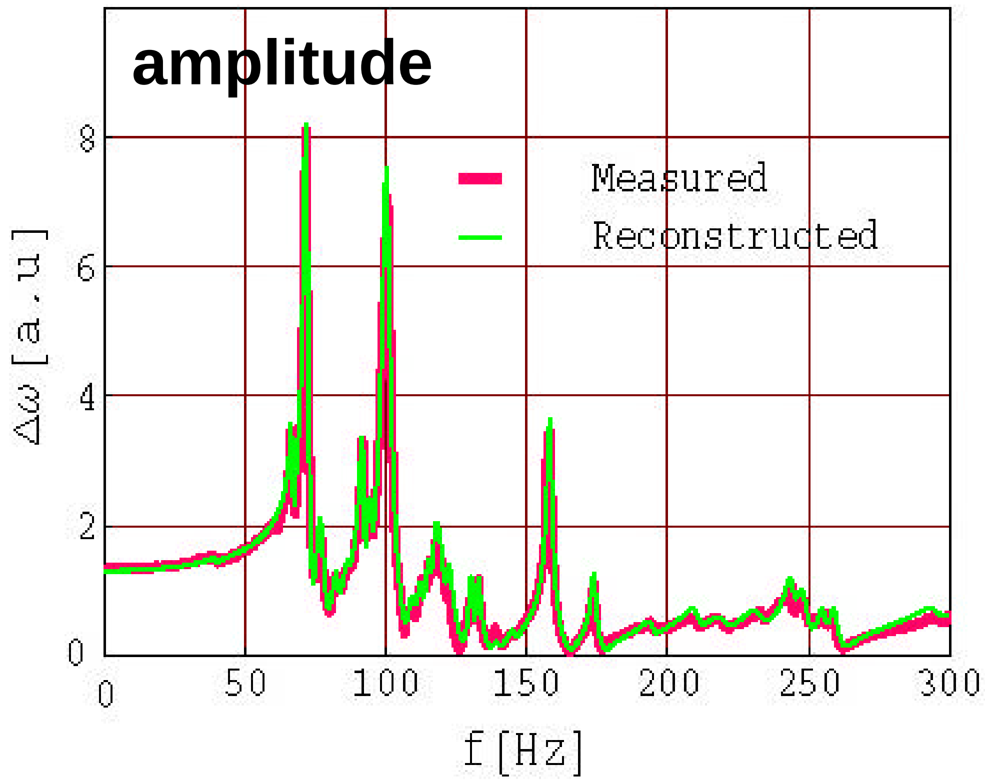
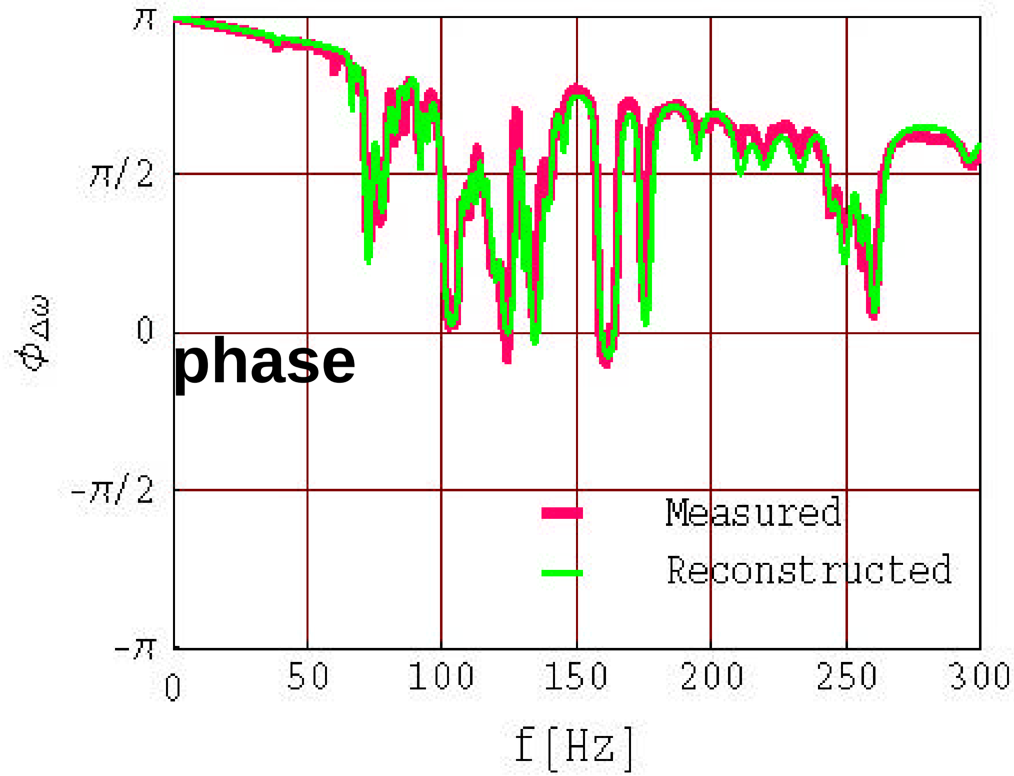
Control of Cavity Detuning

- Feedforward applicable to correct repetitive errors such as Lorenz Force detuning
  - coupling of Lorentz force and piezo actuator to cavity detuning must be similar
  - slow parameter changes can be corrected with adaptive feed-forward
- Feedback required for stochastic errors such as micro-phonics
  - transfer function from piezo actuator to detuning must allow controller design which allows stability of closed loop
  - transfer function must be stable for timescale of adaptation of controller

Transfer Function

Transfer function Lorentz Force --> Detuning, SNS cavity

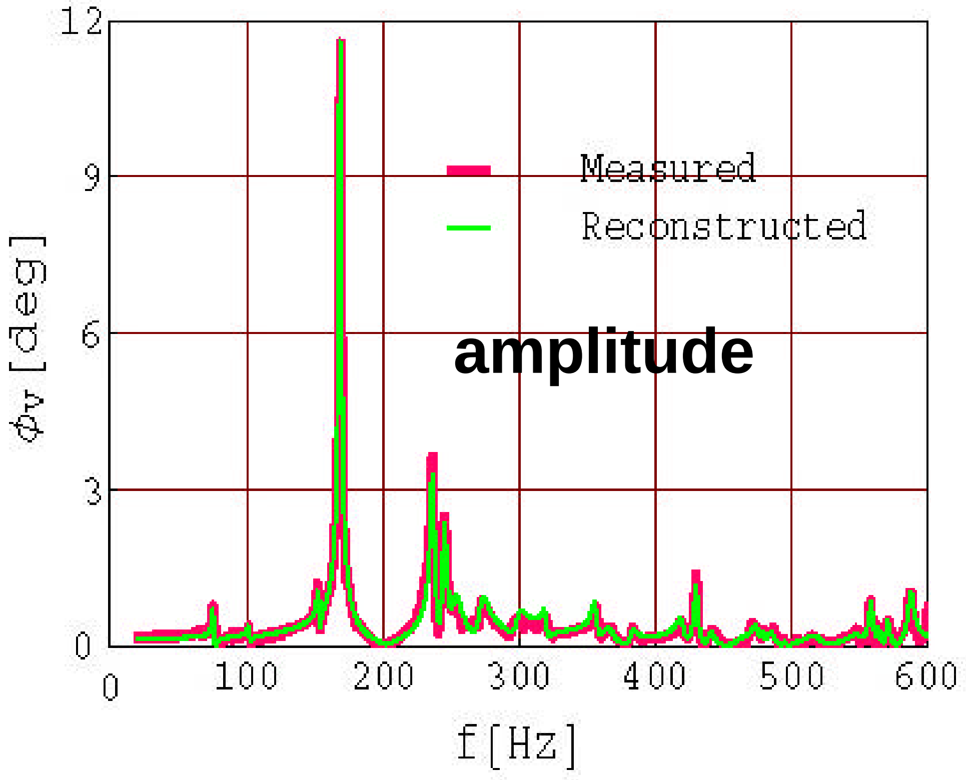


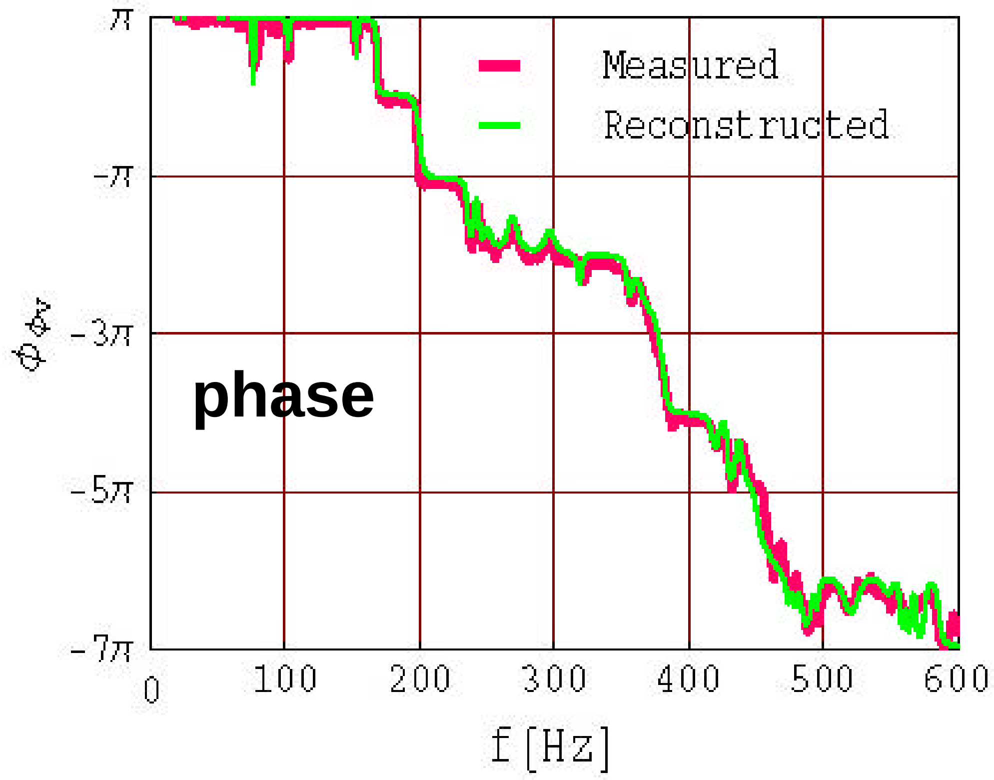


courtesy: J. Delayen, JLAB, M. Doleans, ORNL

Transfer Function

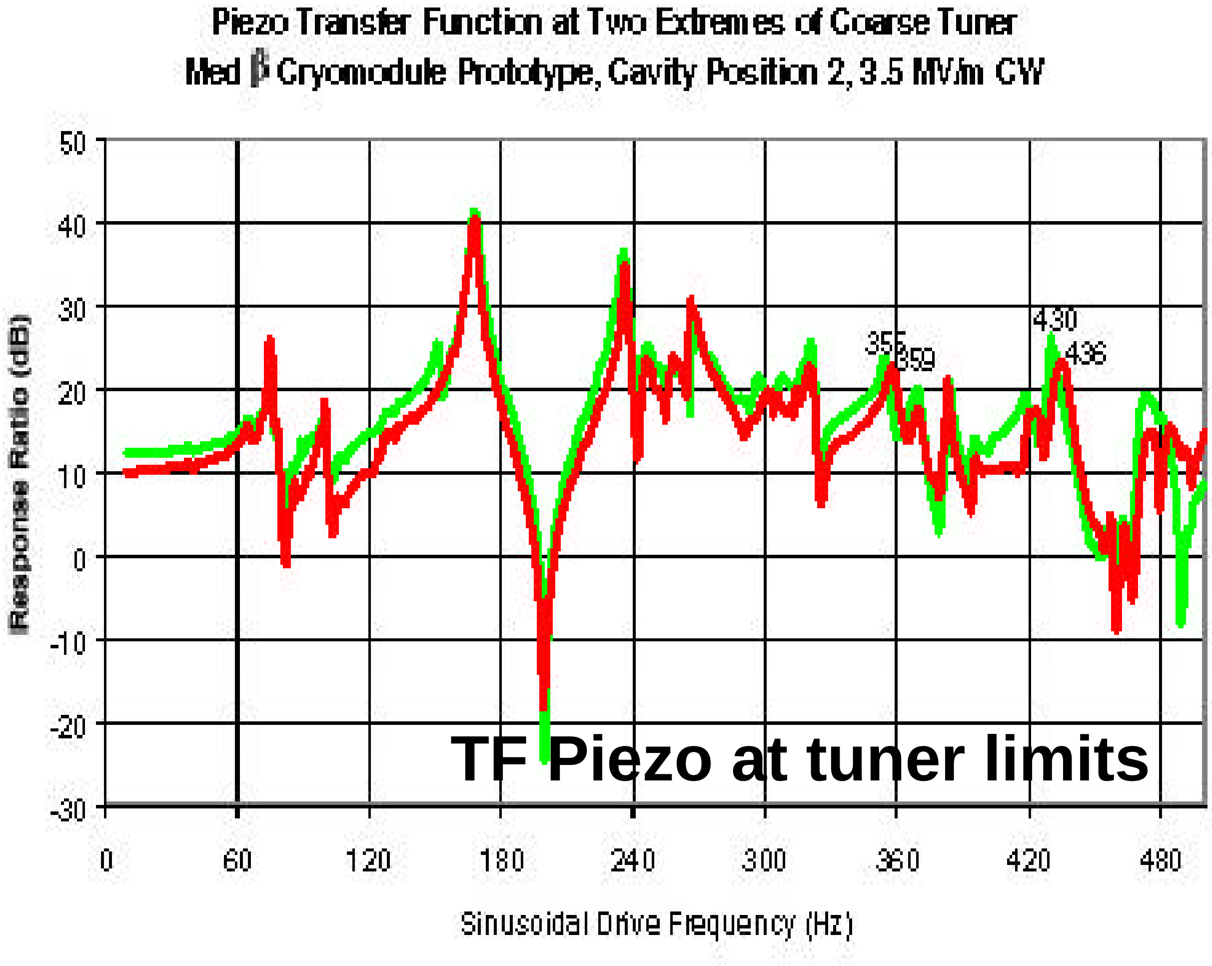
Transfer function Lorentz Force --> Detuning, SNS cavity



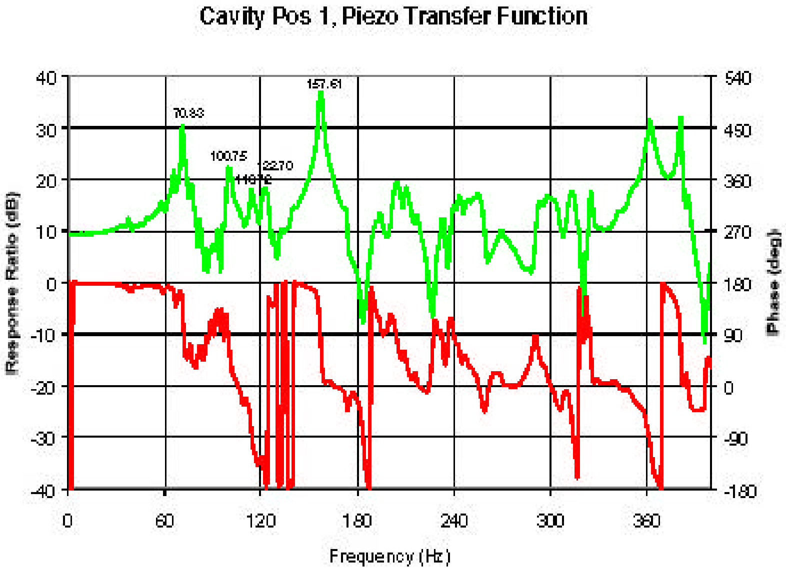


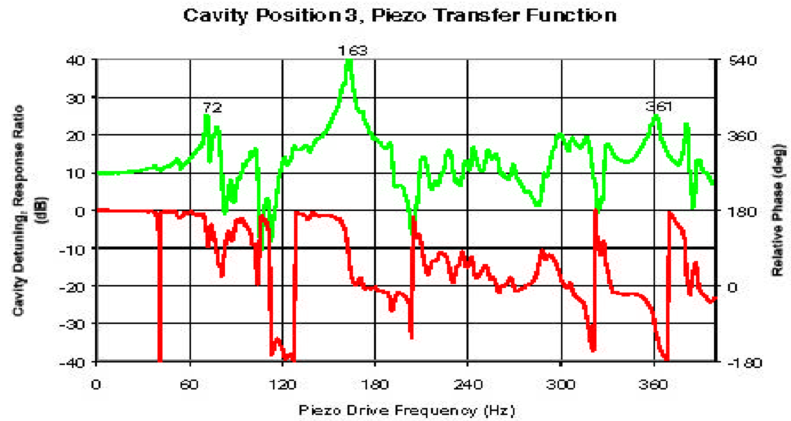
courtesy: J. Delayen, JLAB, M. Doleans, ORNL

Transfer Function Piezo for SNS Cavities



TF Piezo at tuner limits

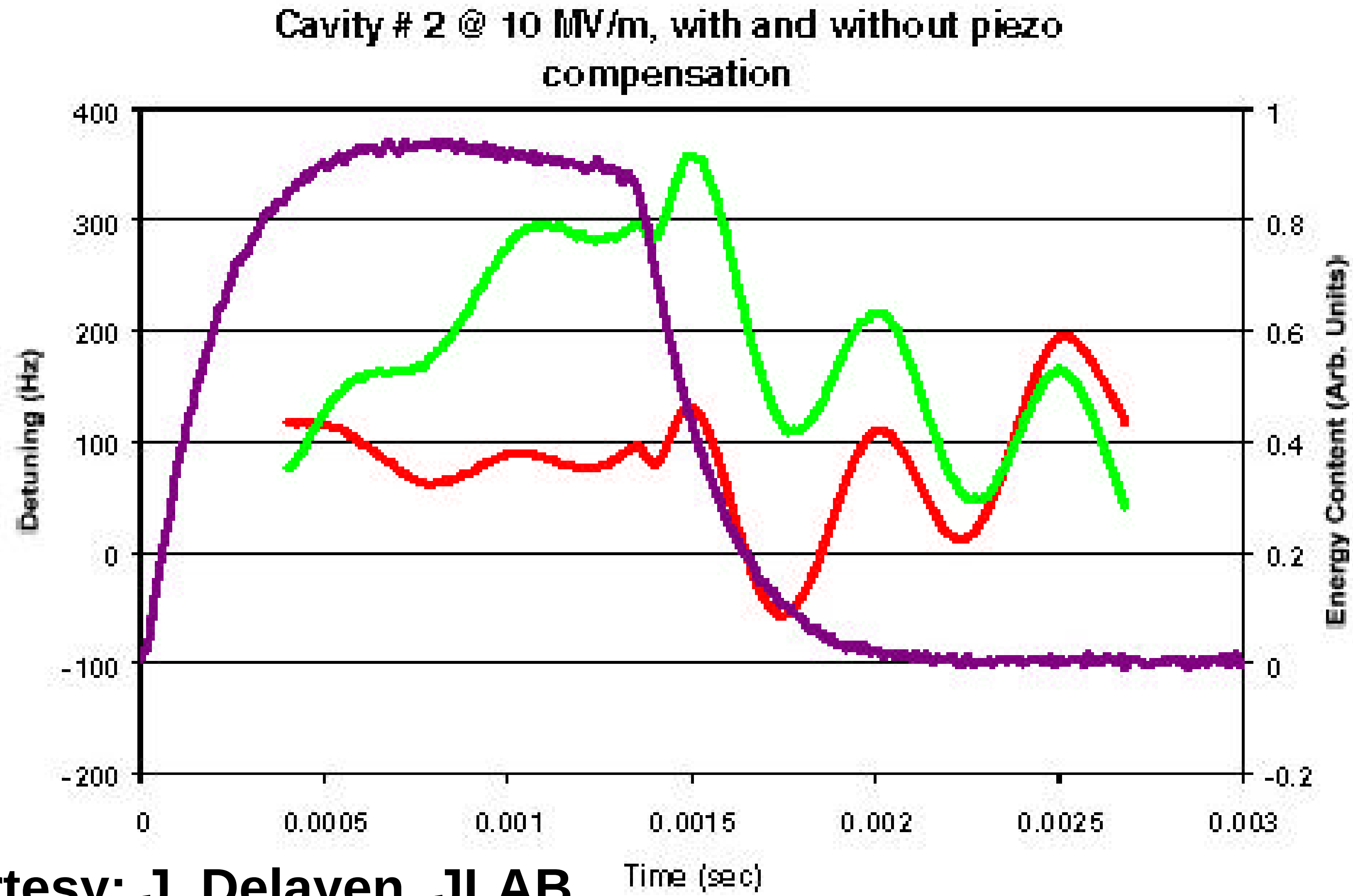




TF Piezo for 2 cavities

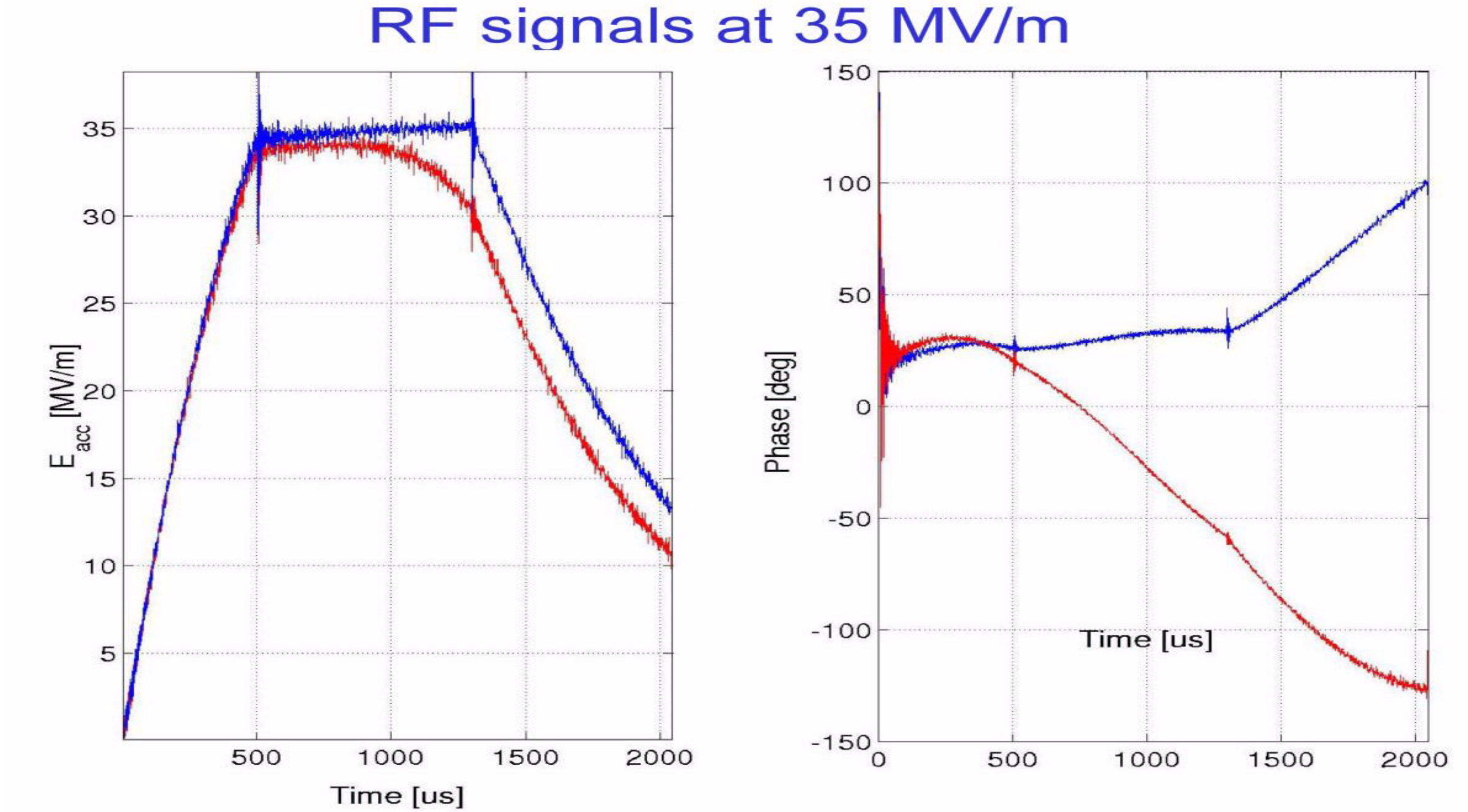
courtesy: J. Delayen, JLAB

Control of Lorentz Force Detuning



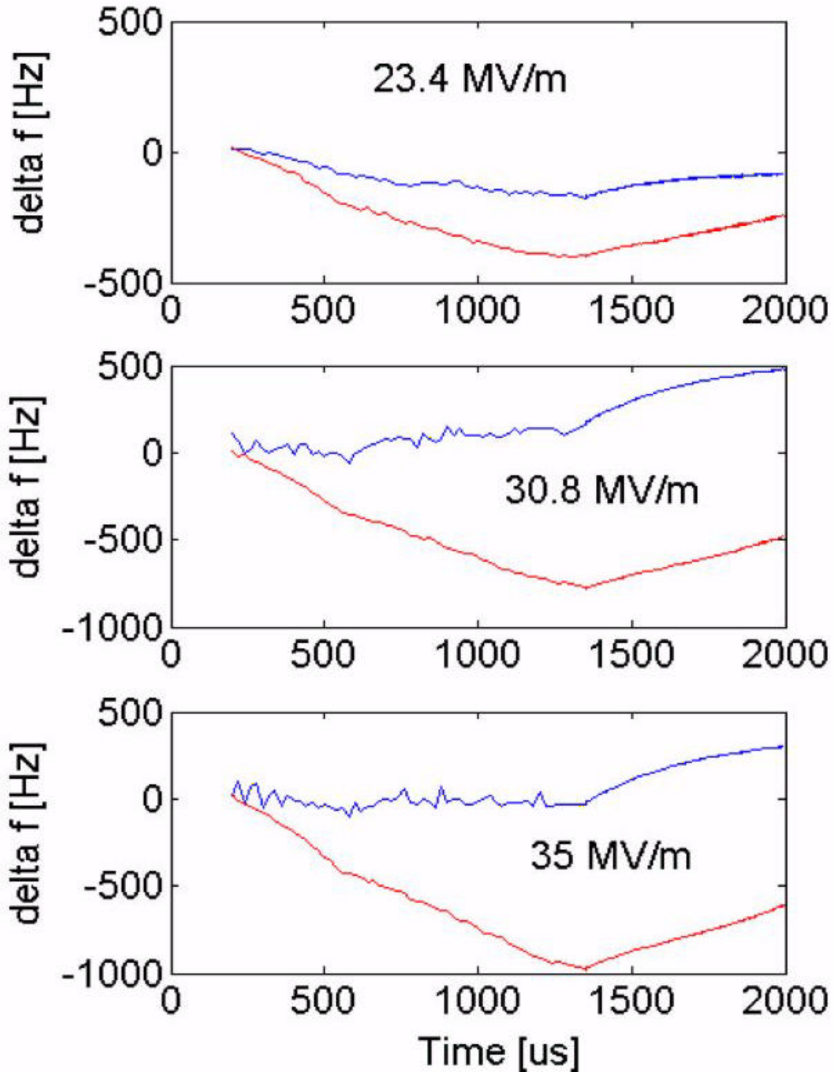
courtesy: J. Delayen, JLAB

Control of Lorentz Force Detuning Control



courtesy: L. Lilje, DESY

Control of Lorentz Force Detuning (TTF)



Frequency stabilization at 35 MV/m

Blue: With piezo

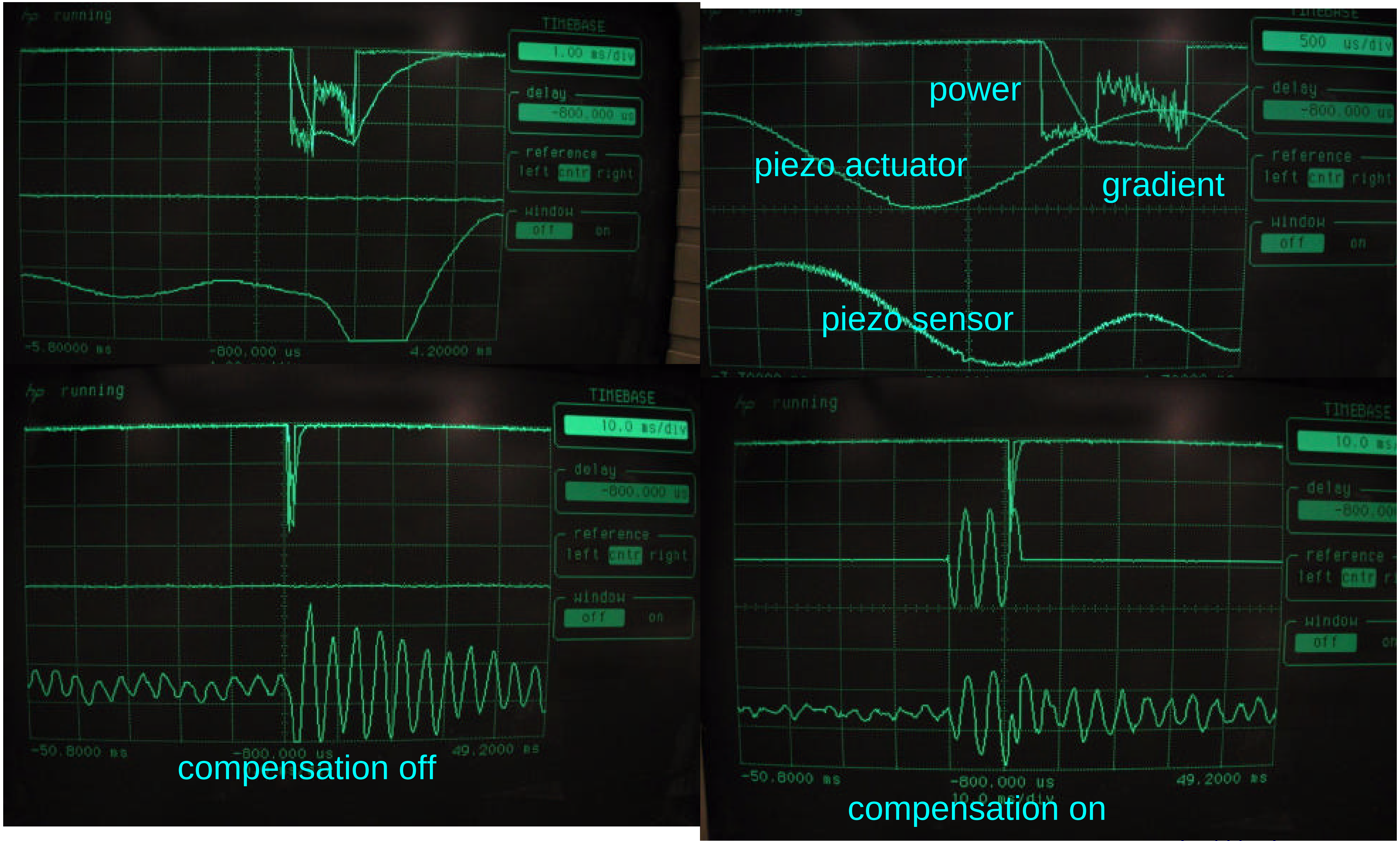
Red: Without piezo

Frequency detuning of ~1000 Hz compensated with resonant excitation of a mechanical cavity resonance at 230 Hz.

NOTE: This is rather an demonstration of the capability of active tuning. Application in a real machine is probably difficult/impossible.

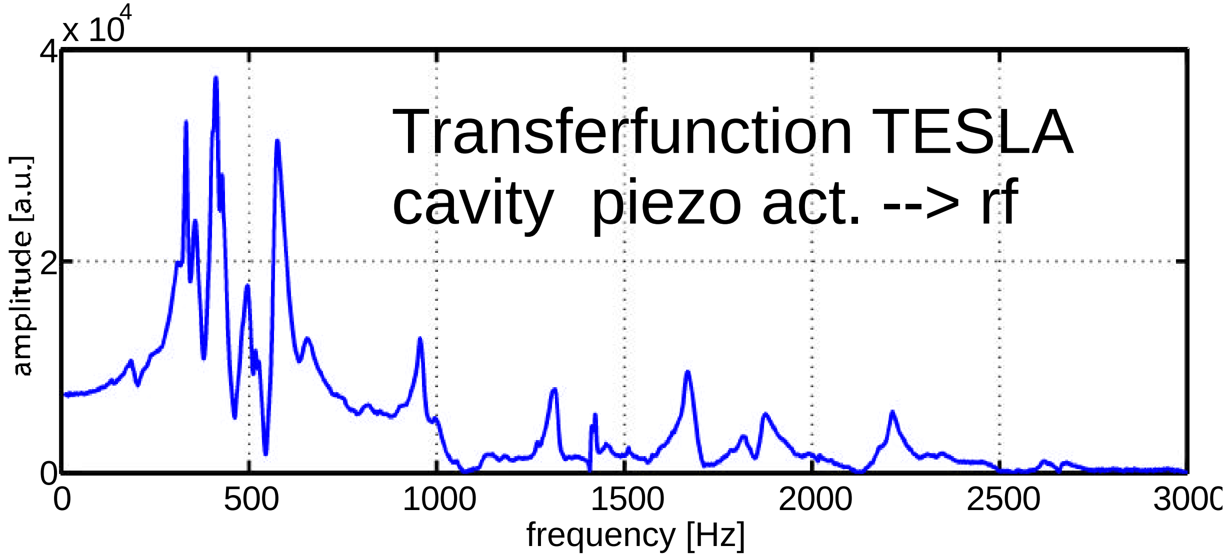
courtesy: L. Lilje, DESY

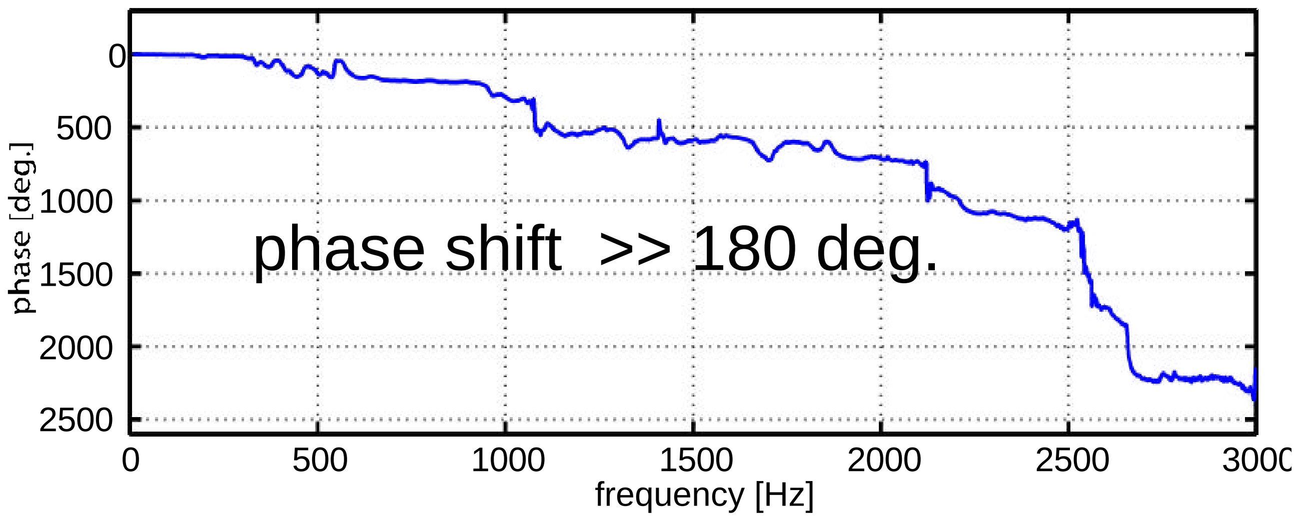
Control of Lorentz Force Detuning (TTF)



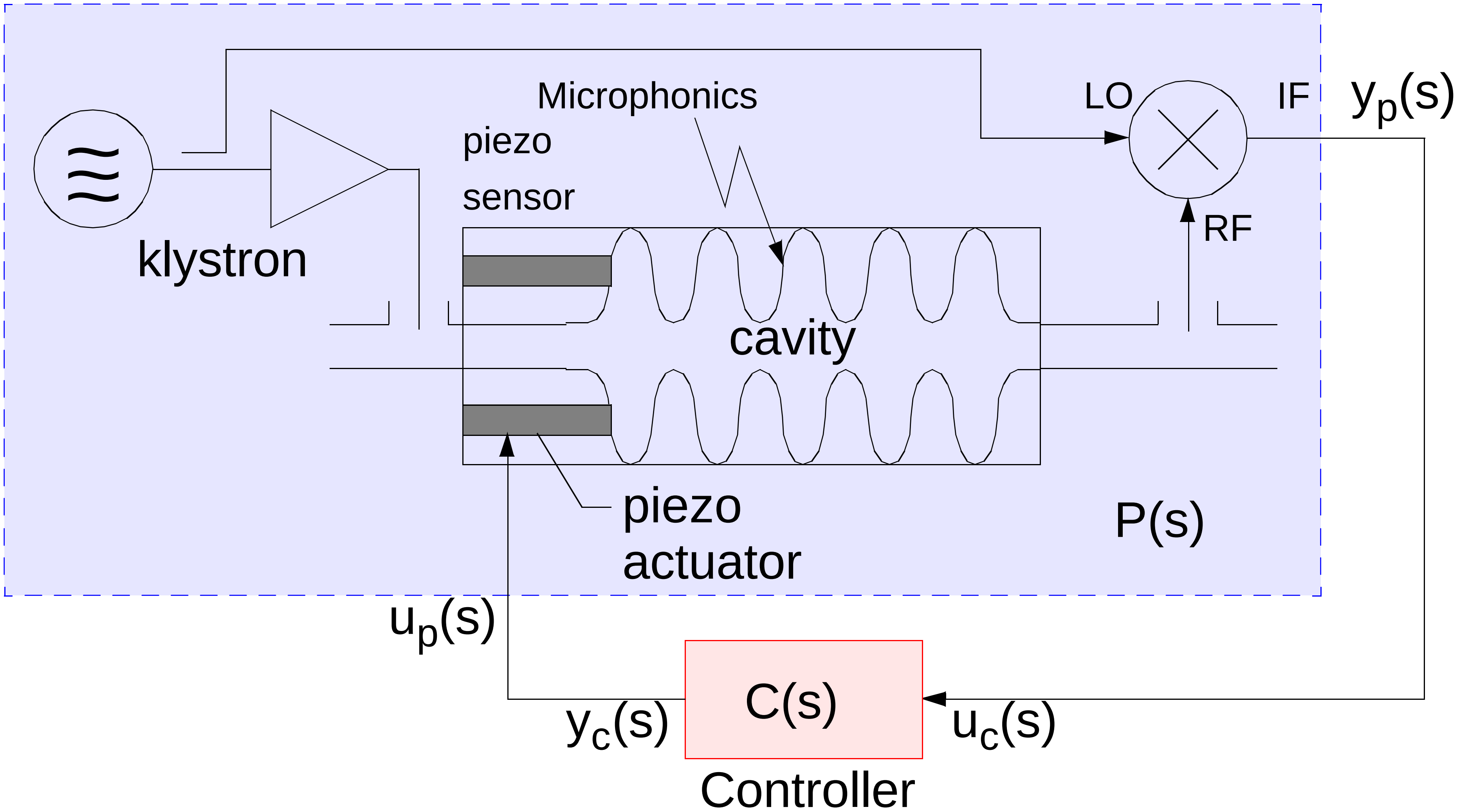
Microphonics Control Problem

- Feedback is required due to stochastic nature of micro-phonics
- Transfer function piezo actuator --> cavity detuning shows many mechanical res-onances from cavity
- Stability of Feed-back loop ?

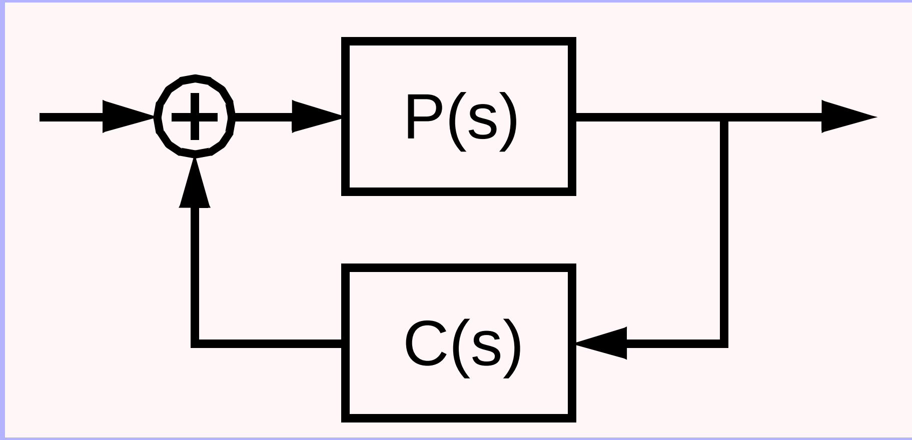




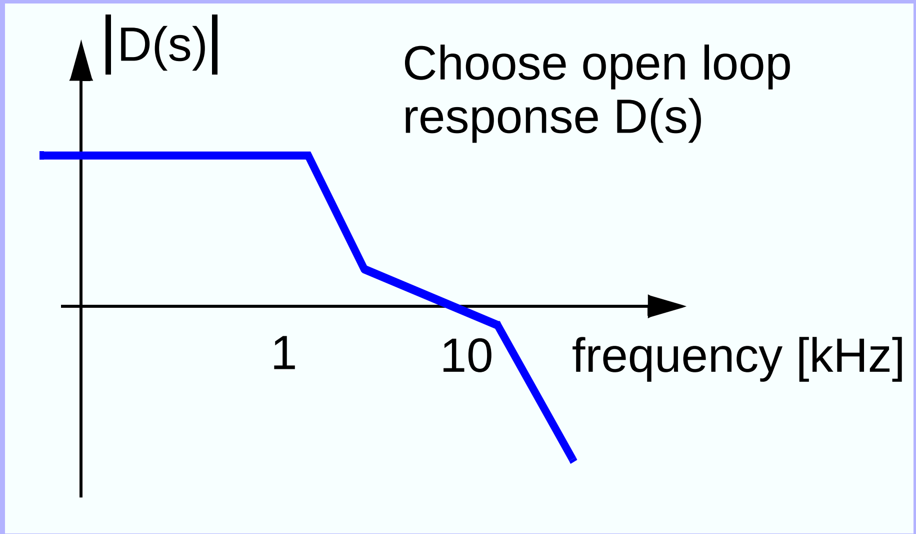
Microphonics Control



Controller Design



$$\Rightarrow \quad C(s) = \frac{D(s)}{P(s)}$$



D(s) : stability criteria fulfilled
high gain at low freq.
fast roll-off at high freq.

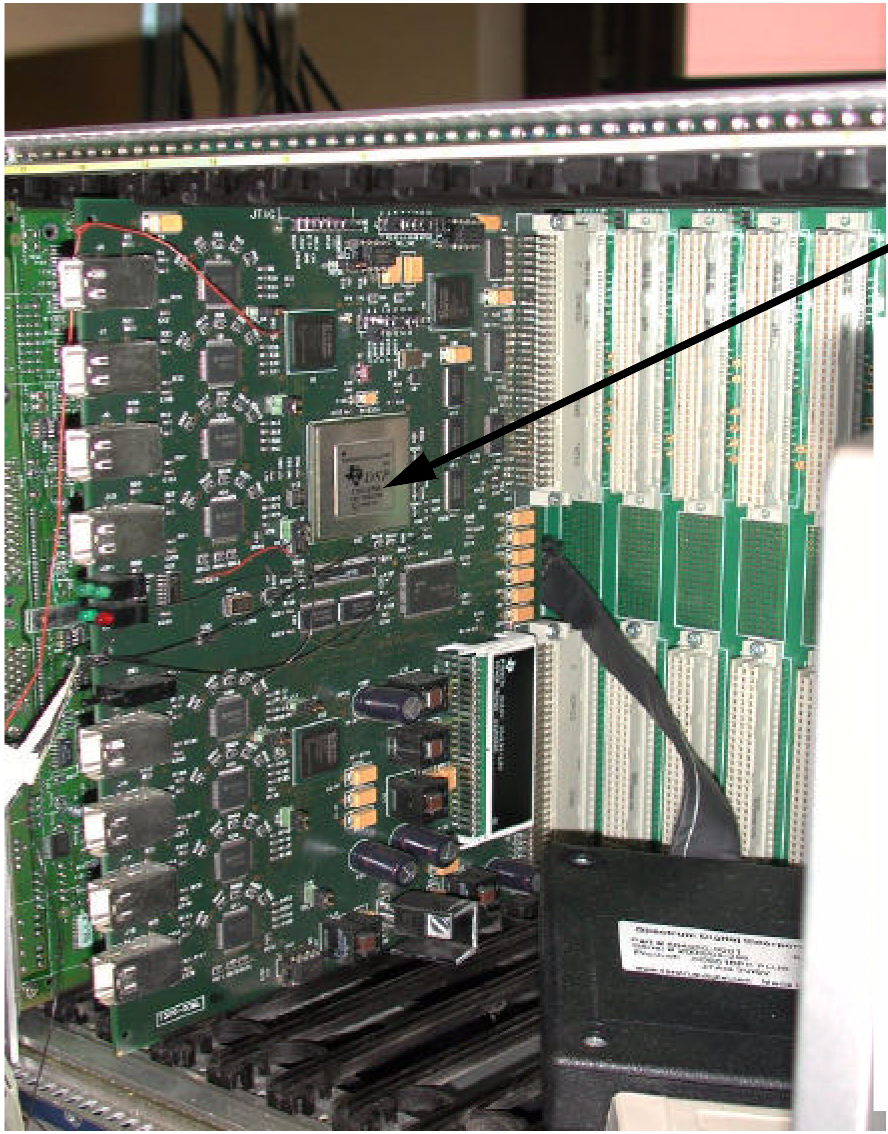
Feedback Successfully Applied to QWR

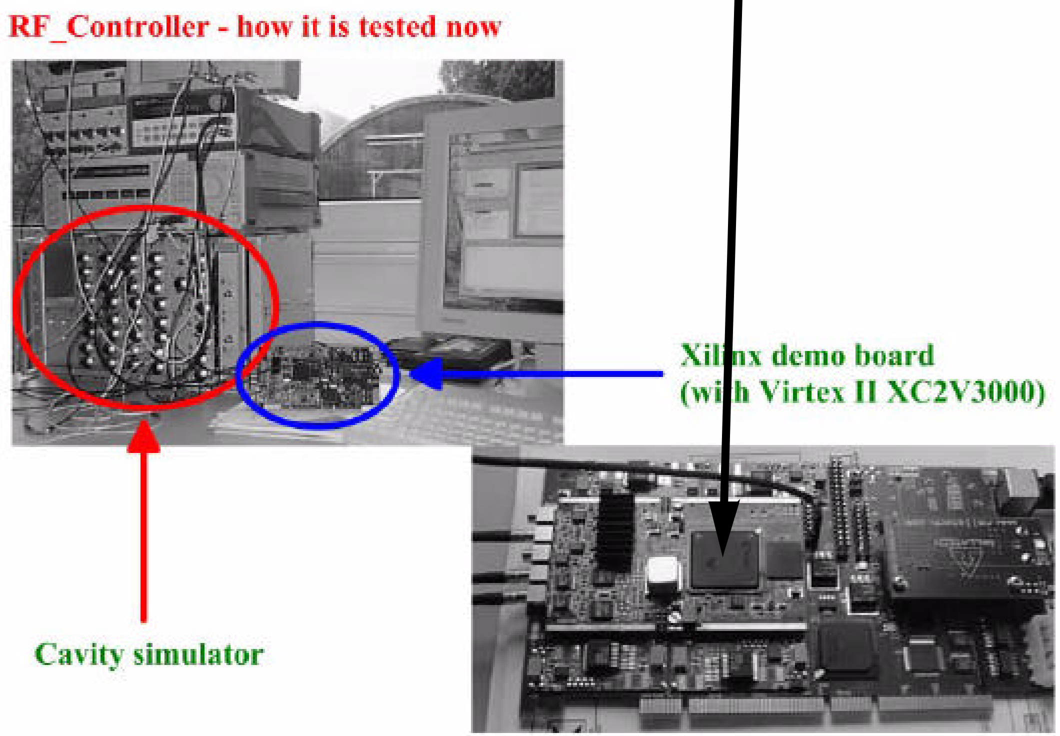
- C6701 processor from TI on PCI board (M67) with 4 ADCs and DACs (200kHz sampling rate)
- Programmed state space equation for 20th order system:

$$\vec{x}_{k+1} = A\vec{x}_k + B\vec{u}_k$$
$$\vec{y}_{k+1} = C\vec{x}_{k+1} + D\vec{u}_{k+1}$$

- Latency only 20 μs for 20x20 matrix multiplication (C++)
- Applied only notchfilter (672 Hz) and low pass (1kHz) to control microphonics in QWR

Digital Controller





Conclusion

- Mechanism of Lorentz force detuning well understood
- Successful demonstration of Lorentz force compensation for TESLA and SNS cavities
- Differences in coupling from Lorentz force and piezo to cavity detuning may result in suboptimal performance of compensation scheme
- Lifetime issue for piezo actuator requires careful design of piezo tuner
- Limited Feedback control of microphonics in multicell cavities appears potentially possible but requires sophisticated controller design.