10. Lorentz Detuning

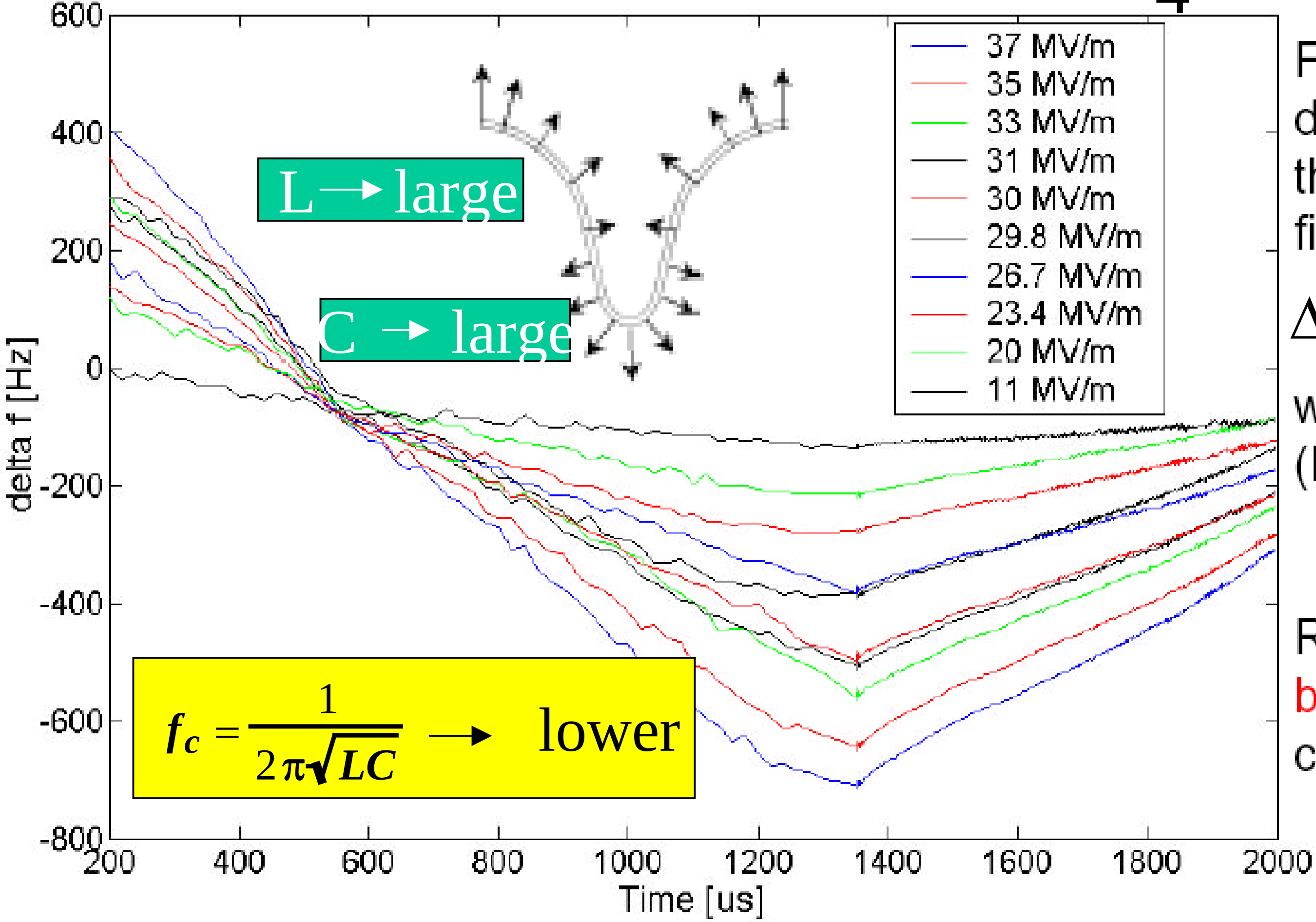
$$\sigma_L = \frac{1}{4}\left(\mu H_S^2 - \varepsilon E_S^2\right)$$

Frequency detuned by Lorentz force

Frequency Detuning during RF Pulse

Beam on

$$\sigma_L = \frac{1}{4}\left(\mu H_S^2 - \varepsilon E_S^2\right)$$



Frequency detuning due Lorentz forces of the electromagnetic field in the cavities:

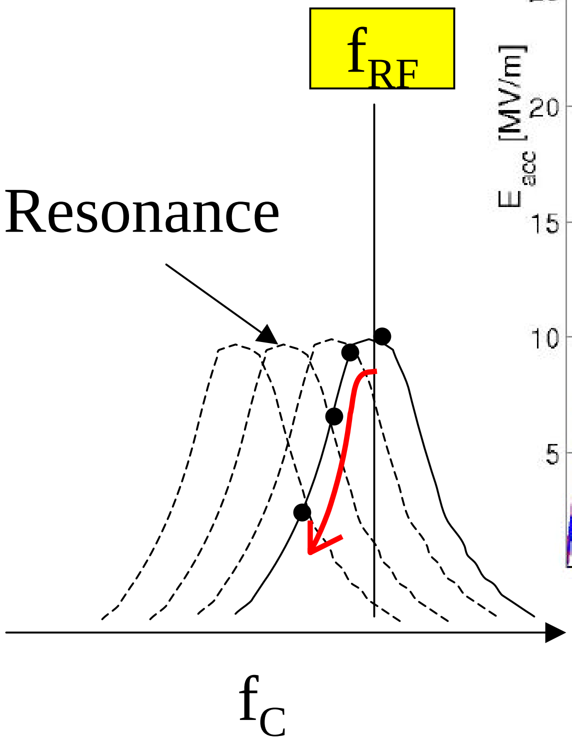
$\Delta f = -K \cdot E_{acc}^2$

where K " 1 Hz / $(MV/m)^2$

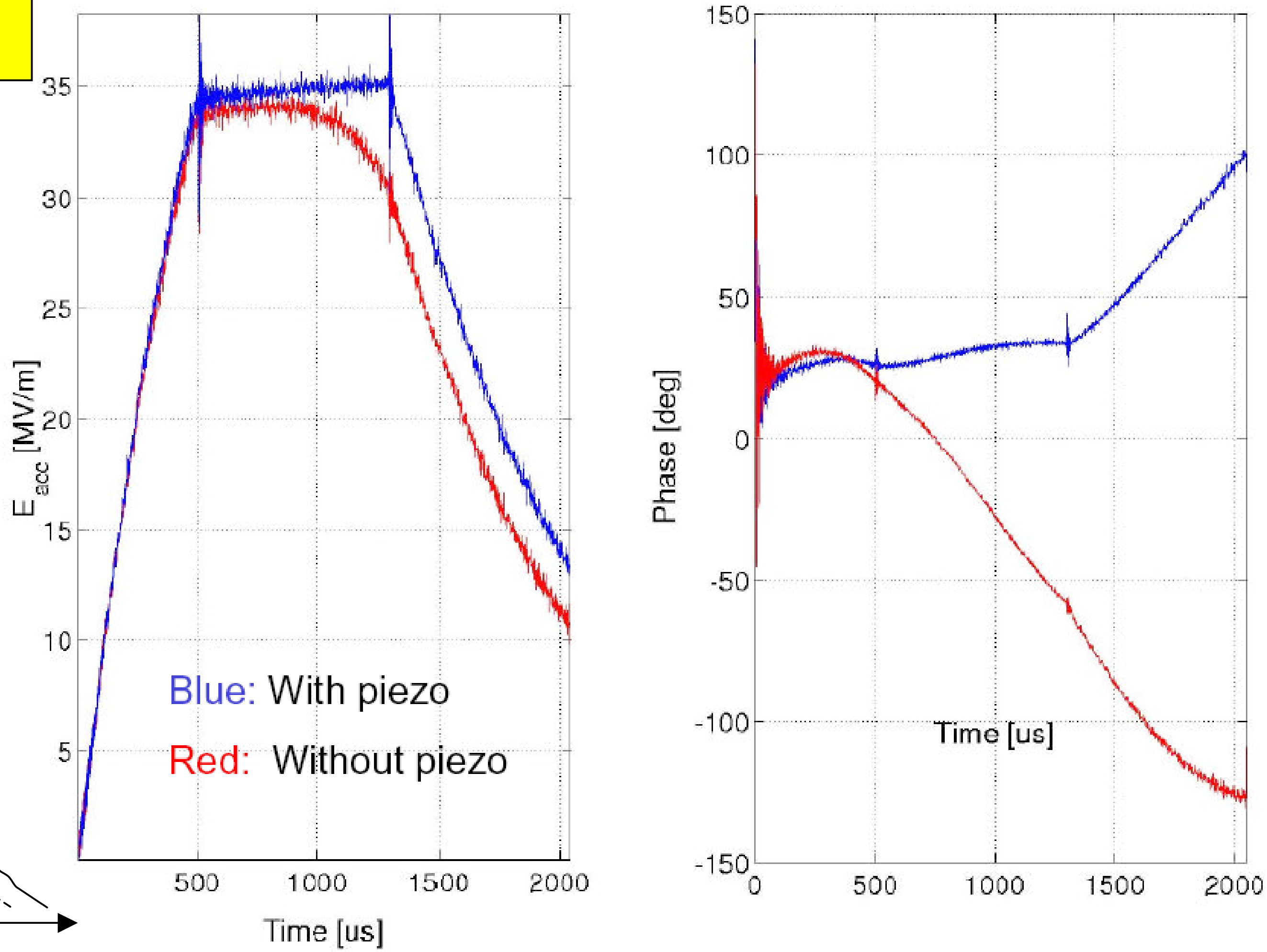
Remember: Cavity bandwidth with main coupler is " 300 Hz

Frequency and Phase Control by Piezo tuner

Lorentz detuning can be compensated with Piezo tuner control

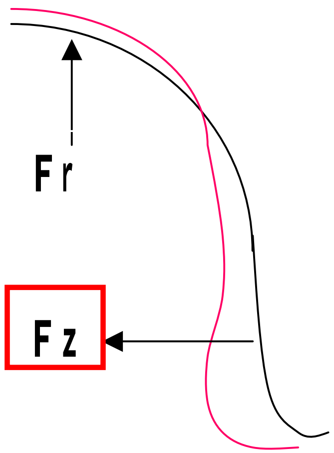


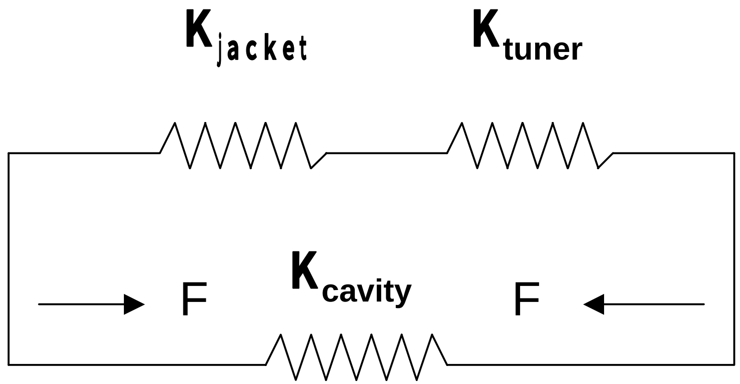
RF Signals at 35 MV/m



Tow components of Lorentz Deformation

Noguchi's slide in the 1st ILC school





$$\Delta f = \sum_{\text{mode}} a_k \, \delta f_k \approx \sum_{\Delta l = 0} a_k \, \delta f_k + \frac{d\,f}{d\,l}\frac{d\,l}{d\,F} F$$

$$= A\, E_{acc}^2 + \boxed{\frac{d\,f}{d\,l}\frac{B\,E_{acc}^2}{K_S}}$$

Rigid Stiffness at Jacket and Tuner are also Very important against the Lorentz Detuning.

		TESLA Blade	STF Slide Jack	STF Ball Screw
A	Hz/(MeV/m)^2	0.5	0.5	(1.2)
B	N/(MeV/m)^2	0.047	0.047	0.051
df/dl	Hz/µm	320	320	370
dF/dl	N/µm	3	3	1.8
KS	N/µm	13	80	60
Kjacket	N/µm	26	96	58
Ktuner	N/µm	26	500	1700
Δf (30MV/m)	Hz	1490	620	(1360)
Fine Tuning Stroke	µm	3.7	1	2.9

Lorentz Detuning Compensation Tuner System @ KEK

1) Use well established technology
2) Rigidity during handling
3) Wide Range Tuning Design
4) Easy Replacement
5) Less heat loss
6) Less X-ray Damage
7) Keep the possibility to move out of vacuum chamber

(1), 2) → Screw Ball Tuner

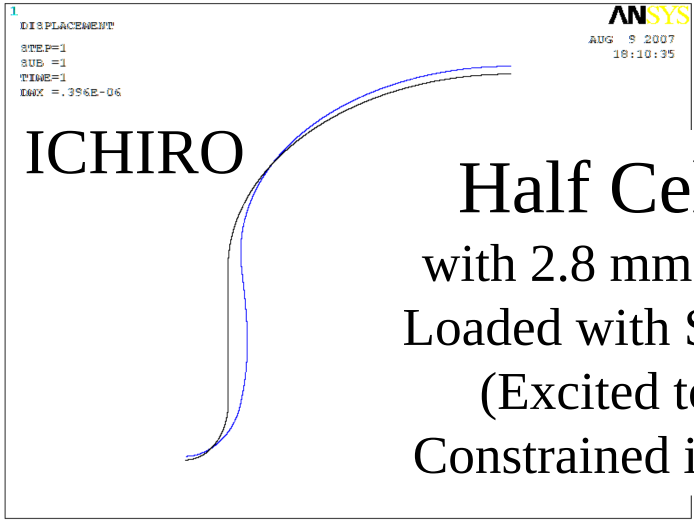
3) → Mechanical resonance

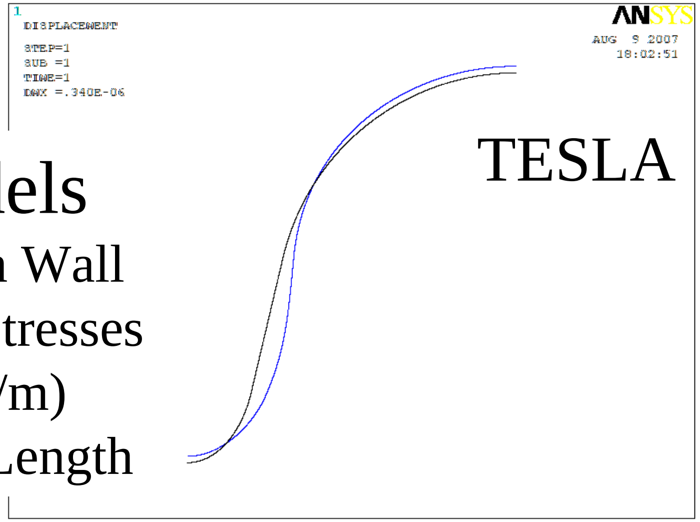
4)–6) → Locate both tuners around 100K shield

Coaxial screw ball tuner

NO BCD yet for ILC!

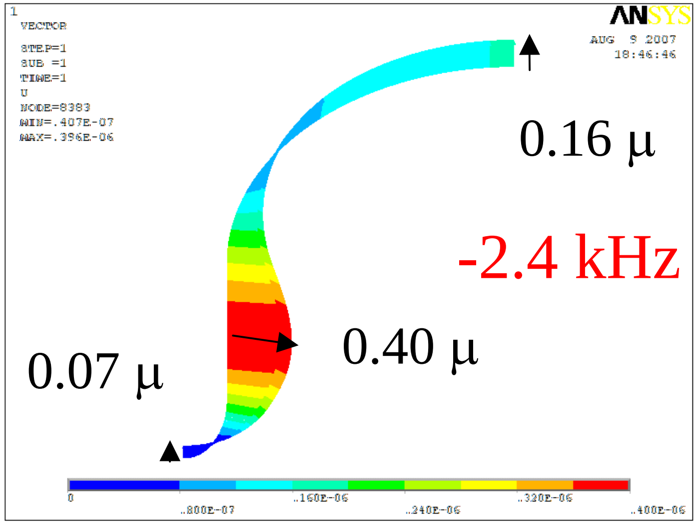
Comparison of Lorentz Force Deformation between different cell shapes

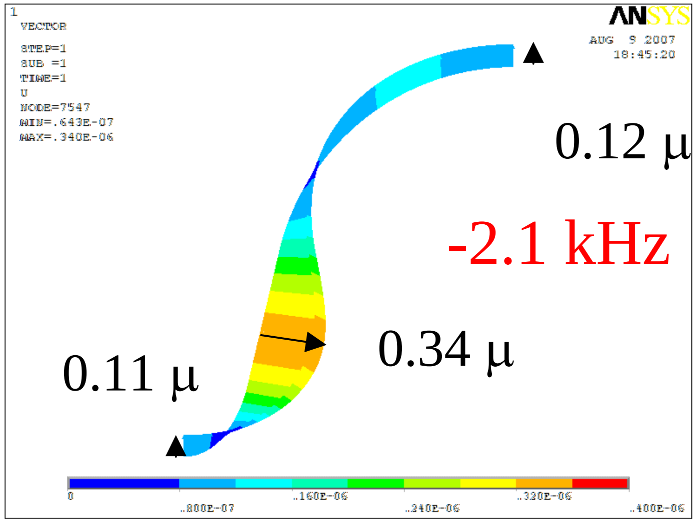




Half Cell Models

with 2.8 mm Niobium Wall
Loaded with Surface Stresses
(Excited to 40 MV/m)
Constrained in Axial Length

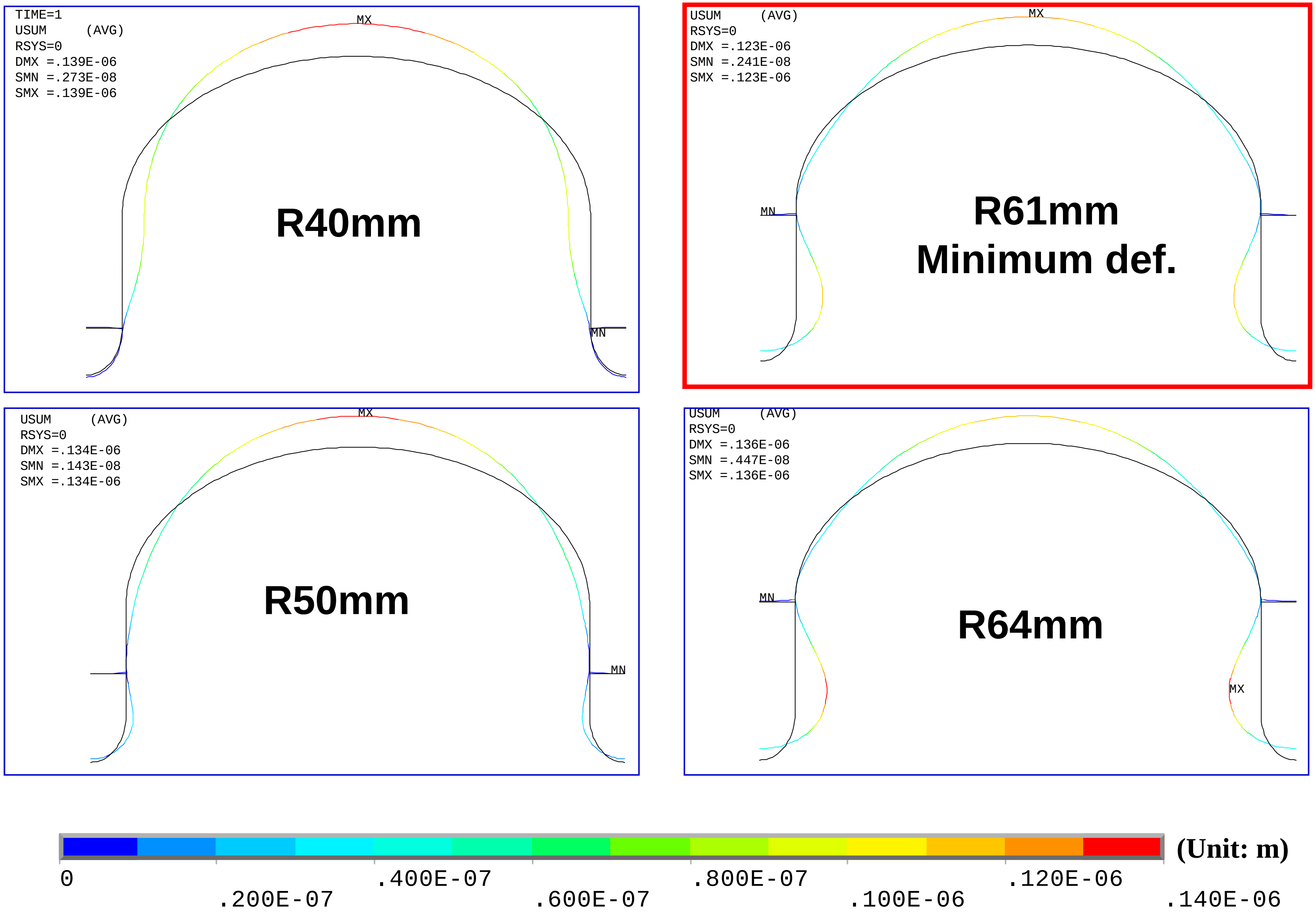




Optimization of Stiffener Location against Lorentz Detuning

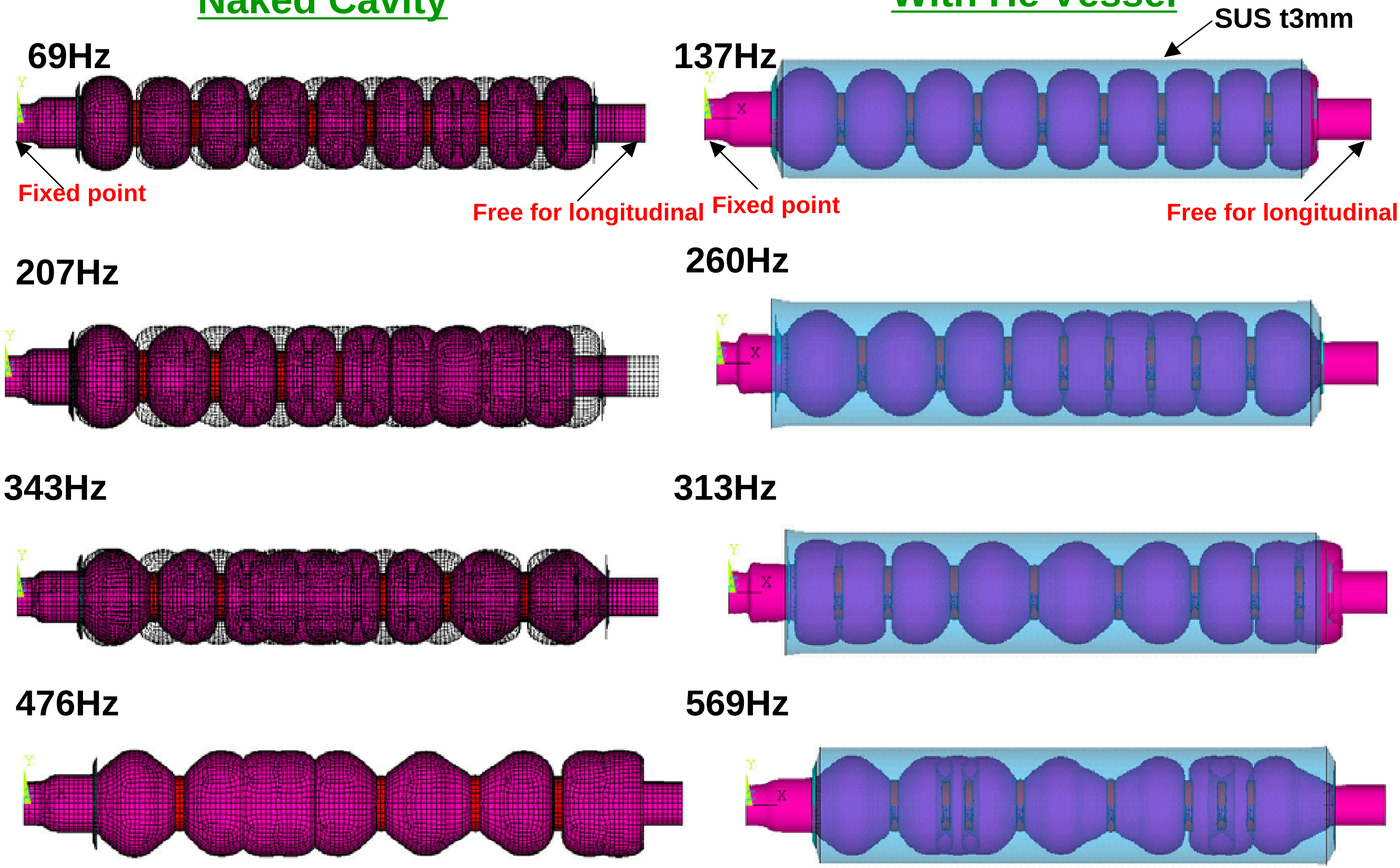
Eacc=38MV/m

by H.Yamaoka

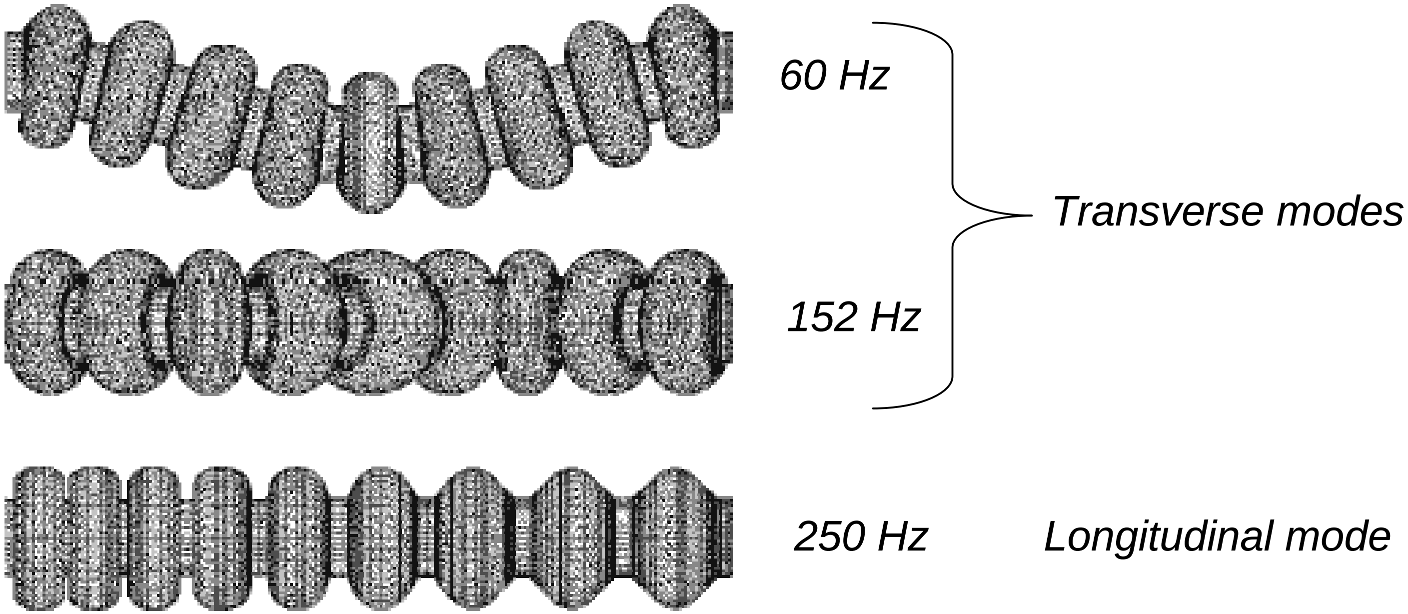


Calculation of longitudinal mechanical resonance w/wo He vessel by H.Yamaoka

Naked Cavity / With He Vessel



Mechanical Resonance of a multi-cell cavity

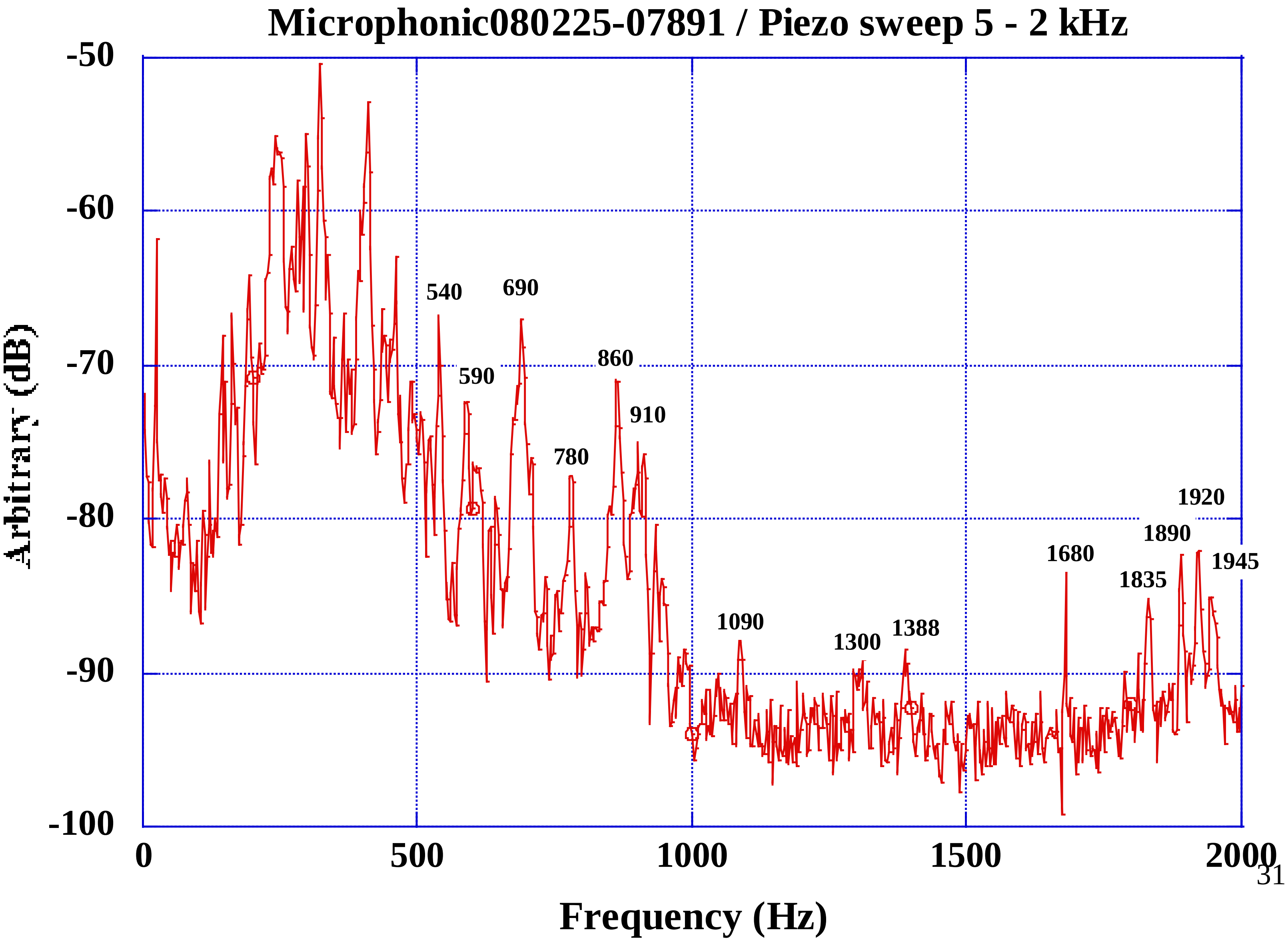


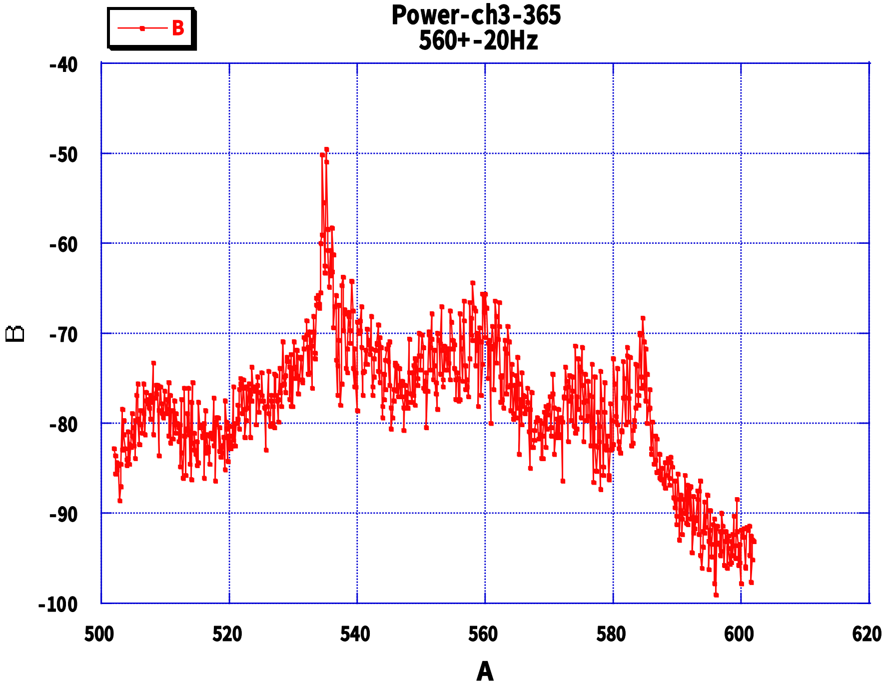
TESLA structure

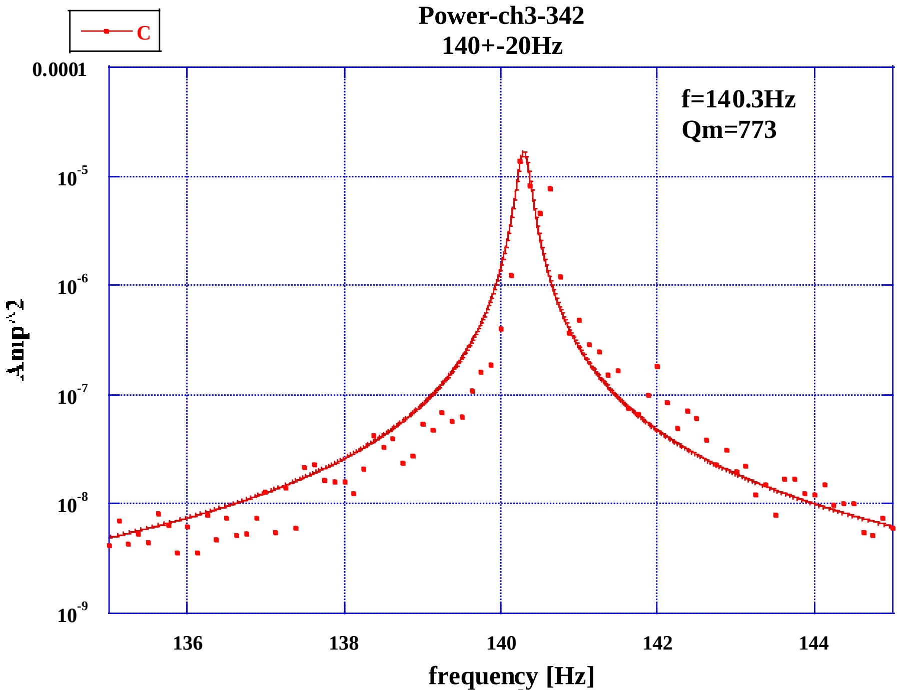
The mechanical resonances modulate frequency of the accelerating mode.
Sources of their excitation: vacuum pumps, ground vibrations…

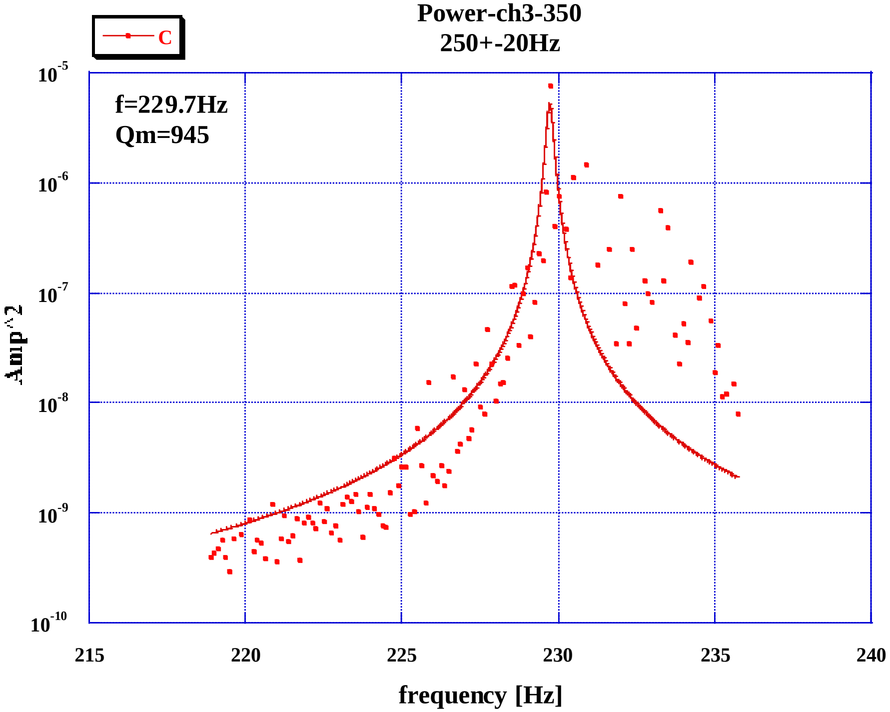
Mechanical Resonance Scan (0 – 2kHz)

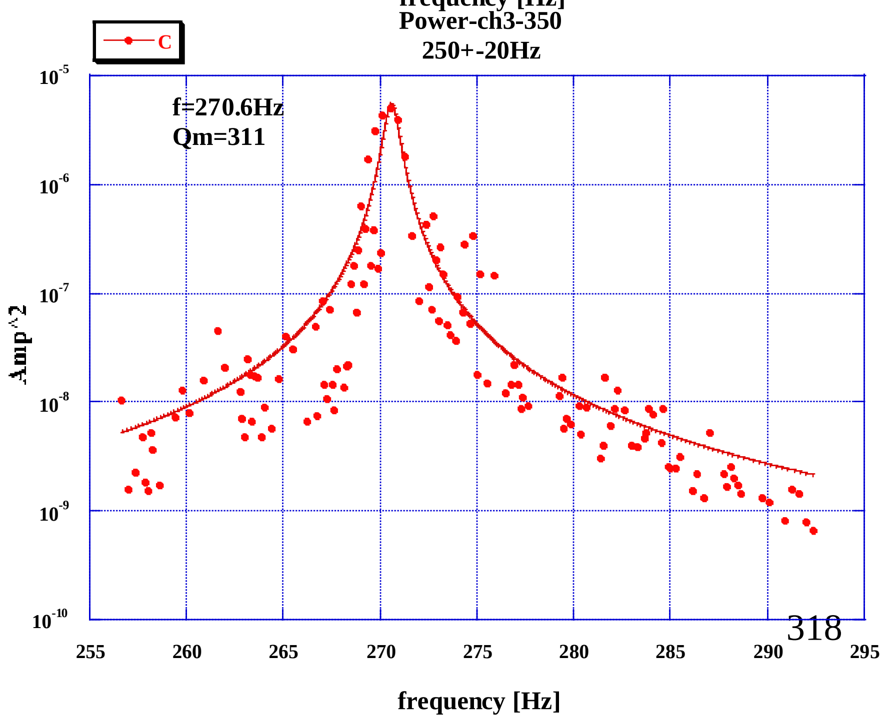
FFT of the mixer signal



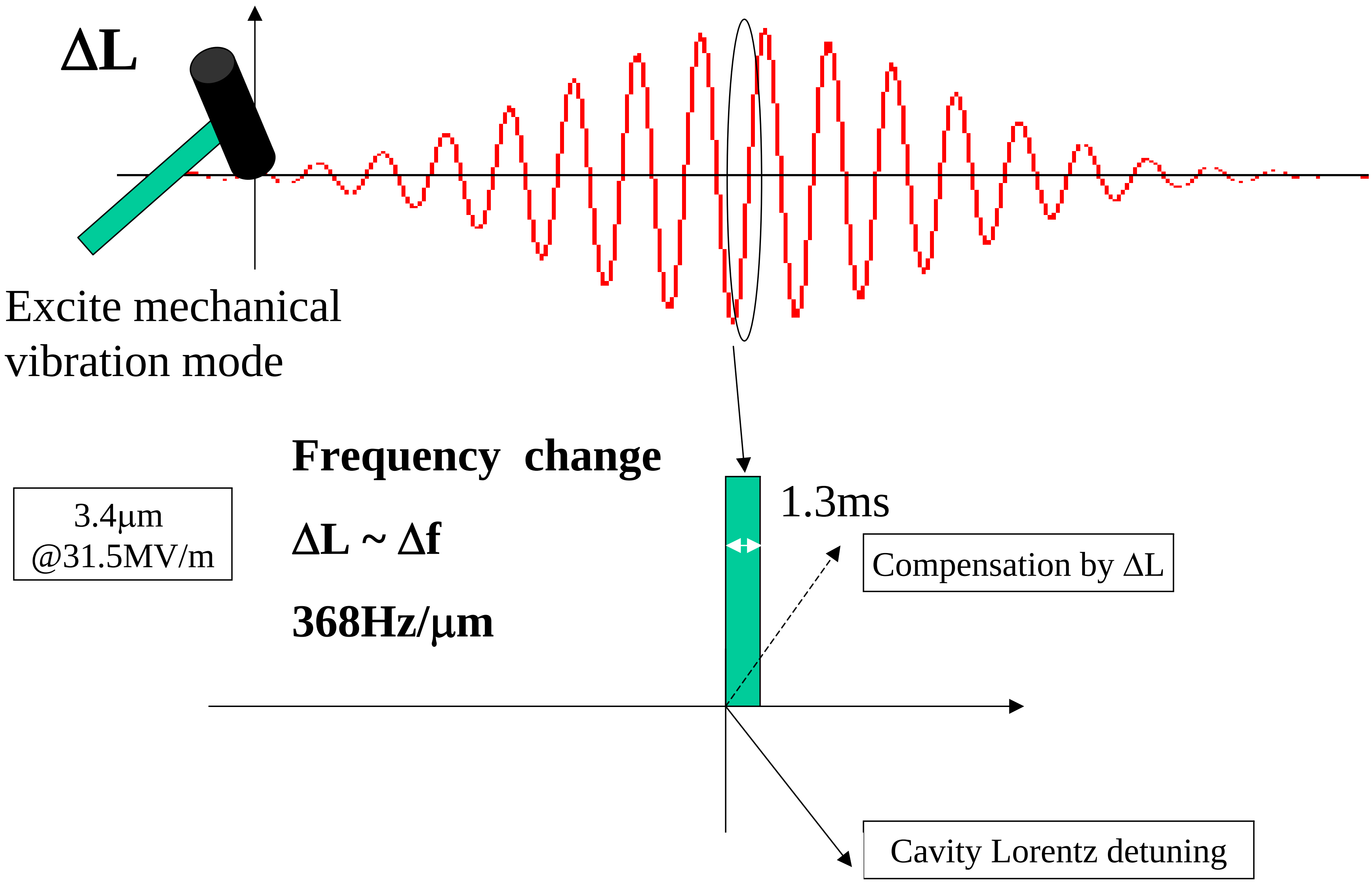

B
Power-ch3-365
560+-20Hz
-40
-50
-60
-70
-80
-90
-100
B
500
520
540
560
580
600
620
A


C
Power-ch3-342
140+-20Hz
f=140.3Hz
Qm=773
0.0001
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Amp^2
136
138
140
142
144
frequency [Hz]

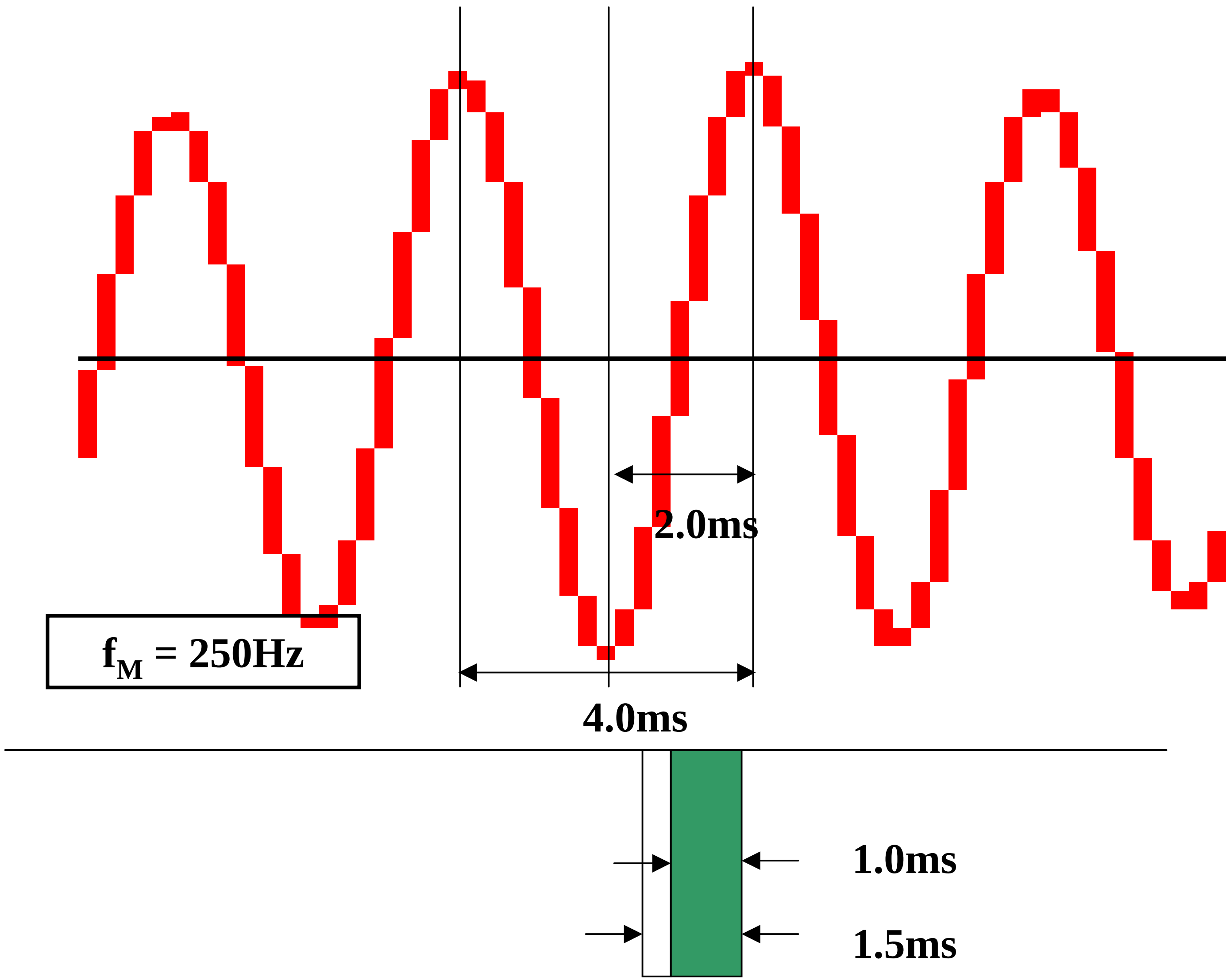

C
Power-ch3-350
250+-20Hz
f=229.7Hz
Qm=945
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Amp^2
215
220
225
230
235
240
frequency [Hz]


C
Power-ch3-350
250+-20Hz
f=270.6Hz
Qm=311
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Amp^2
255
260
265
270
275
280
285
290
295
frequency [Hz]

Principle of the Lorentz Detuning used mechanical resonance



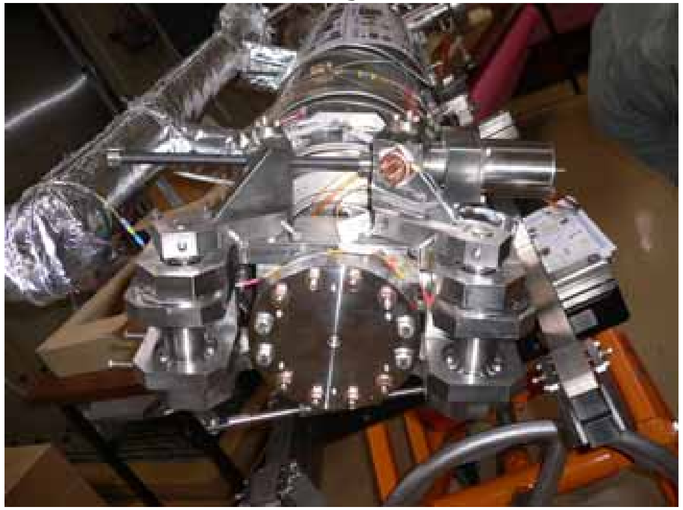
We can compensate the LD by exciting mechanical vibration with a f_M = 200-500Hz.



Comparison of Tuners (Now NO BCD for ILC)

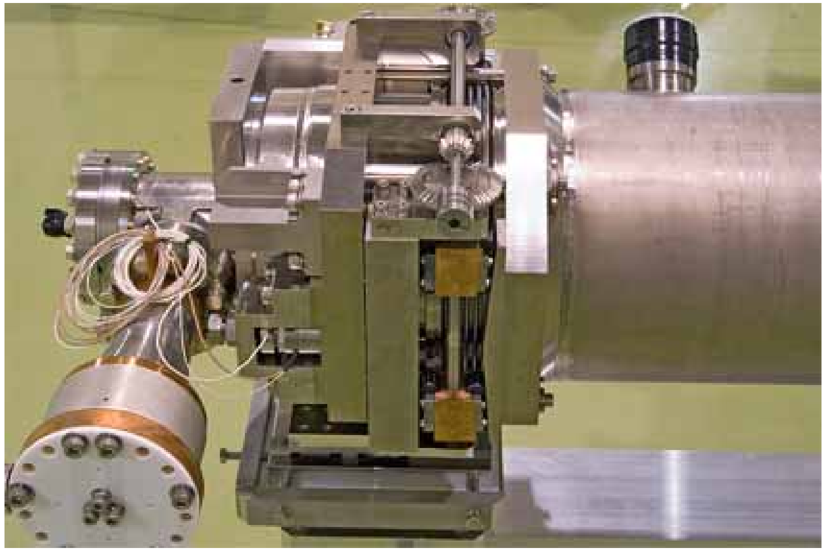
Screw Ball tuner

Saclay-II

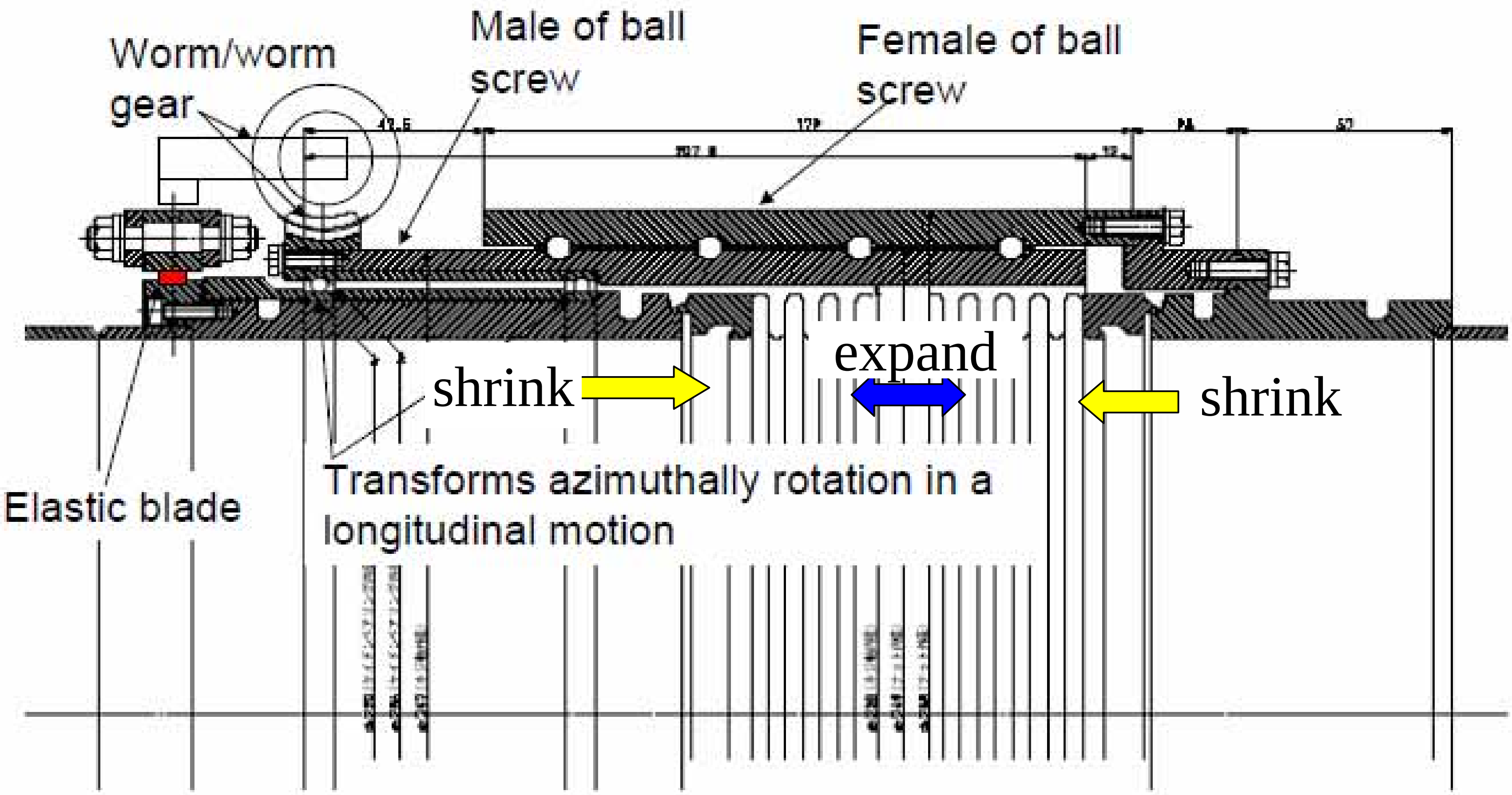


Blade Tuner

Jack tuner



Structure of the Screw Ball Tuner

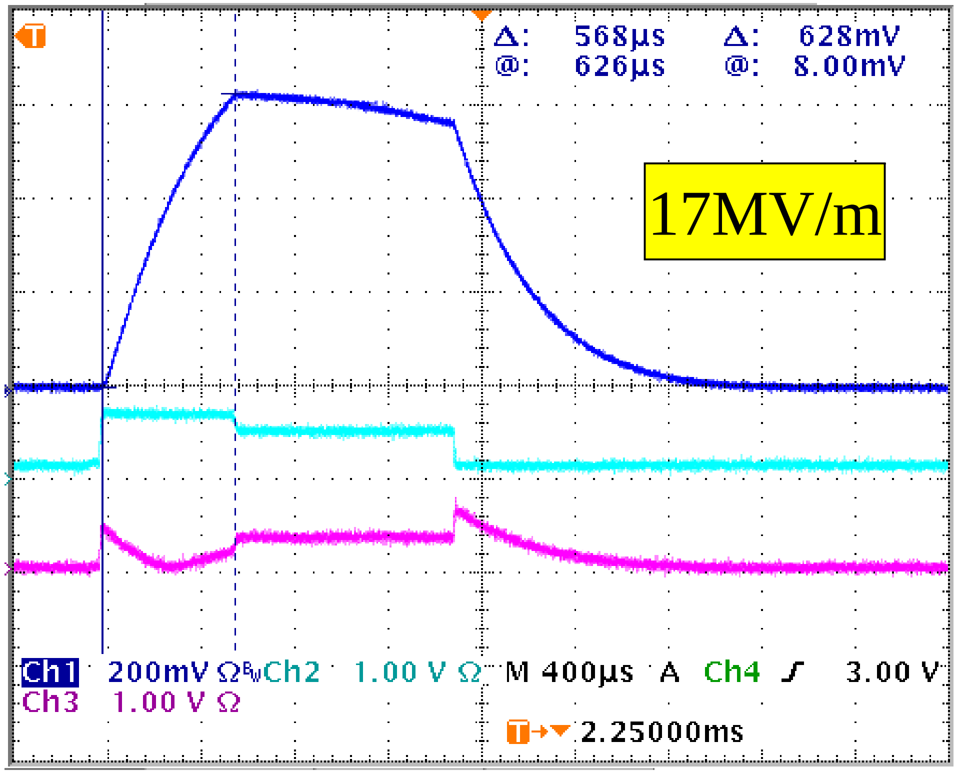


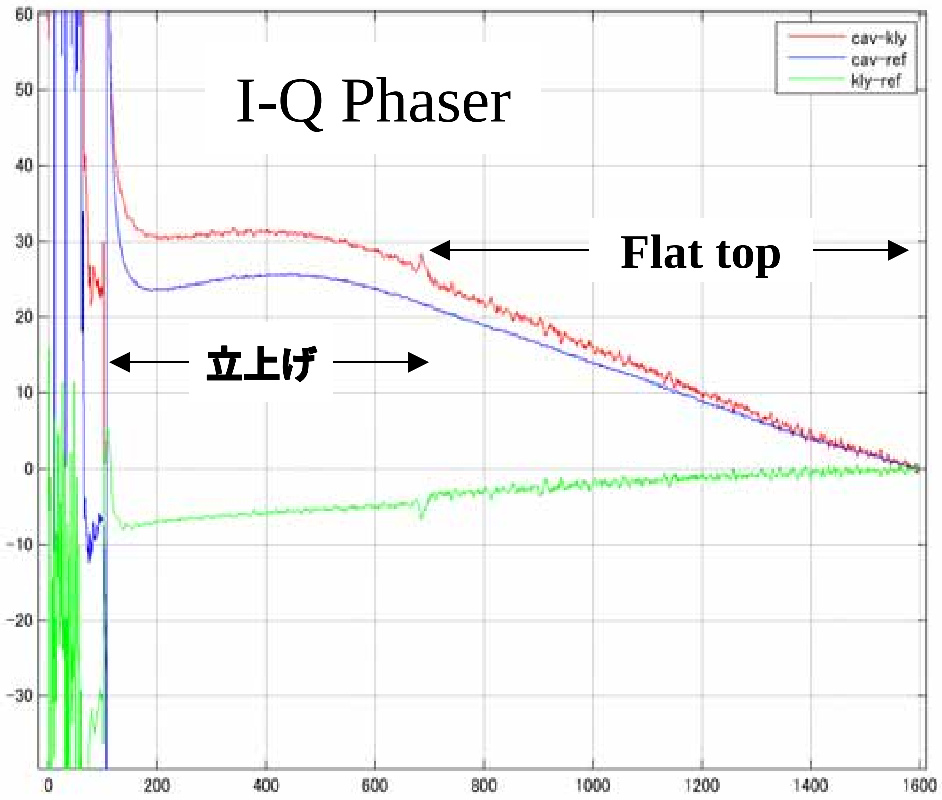
1.35 μm/1000pulse (for Pulse motor)

Comparison of Tuner Designs

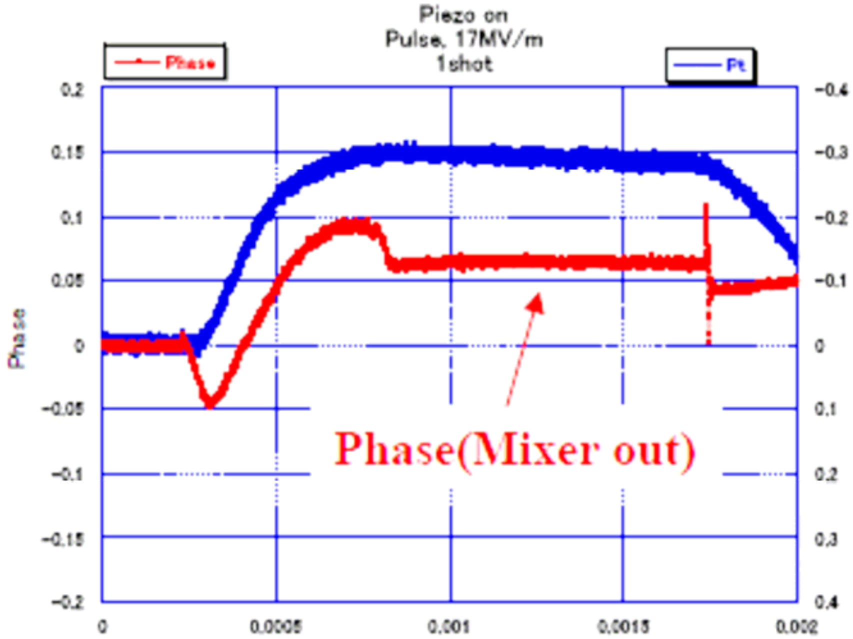
		Screw Ball	Jack	Blade	Saclay-II
Location	Motor	80K or out of vac. vessel	Out of Vac. vessel	He vessel	Beam tube
	Piezo	80K or out of Vac. vessel	End plate	He vessel	END plate
Tuner mechanism		Coaxial ball screw	Slide Jacky	Twist	Lever type
Motor driving power		0.06gf/μm, 0.1W			
Piezo tuning range		~3000			
Resolution [Hz]	Motor	0.1			
	Piezo	0.1			
$\frac{df}{dl}$ $[\mathrm{Hz}/\mu\mathrm{m}]$		368	320		320
$\frac{dF}{dl}$ $[\mathrm{N}/\mu\mathrm{m}]$		36.4	80	13	

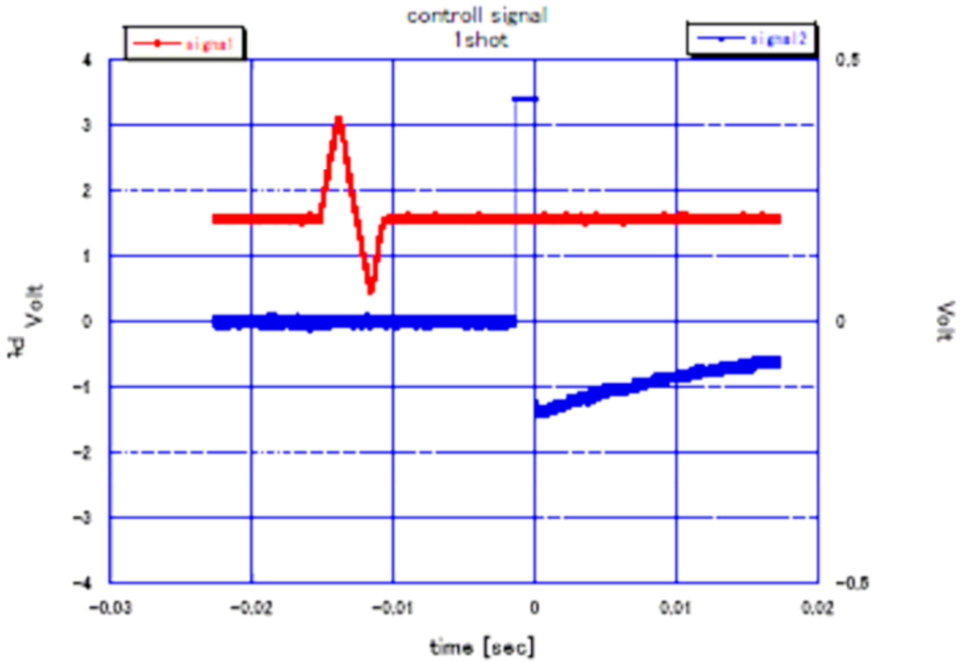
f=1300.133847MHz, Phase =20^O by I-Q Phaser with right P_k input power pattern, No Piezo

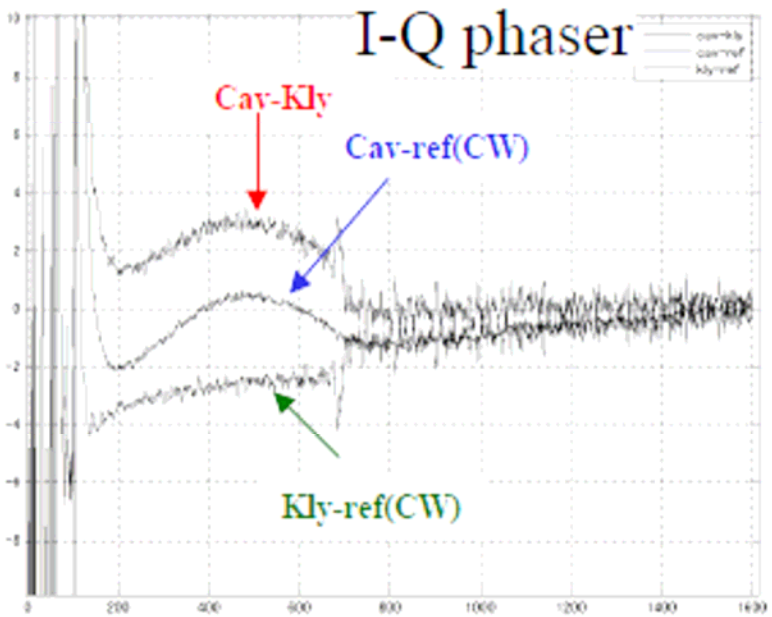


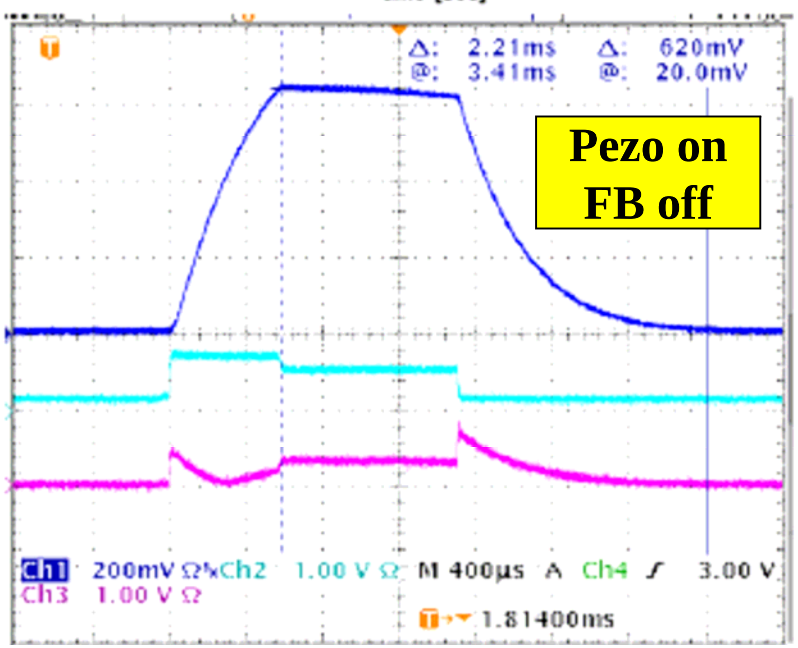


Succeeded L.D compensation @ 17.35MV/m by Piezo single shot

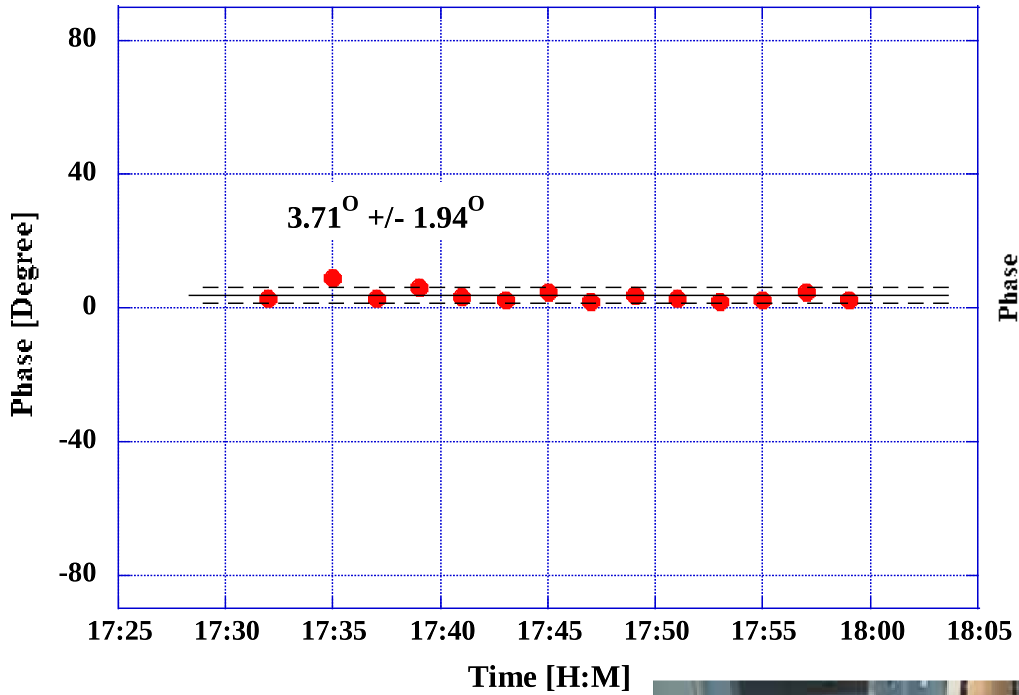


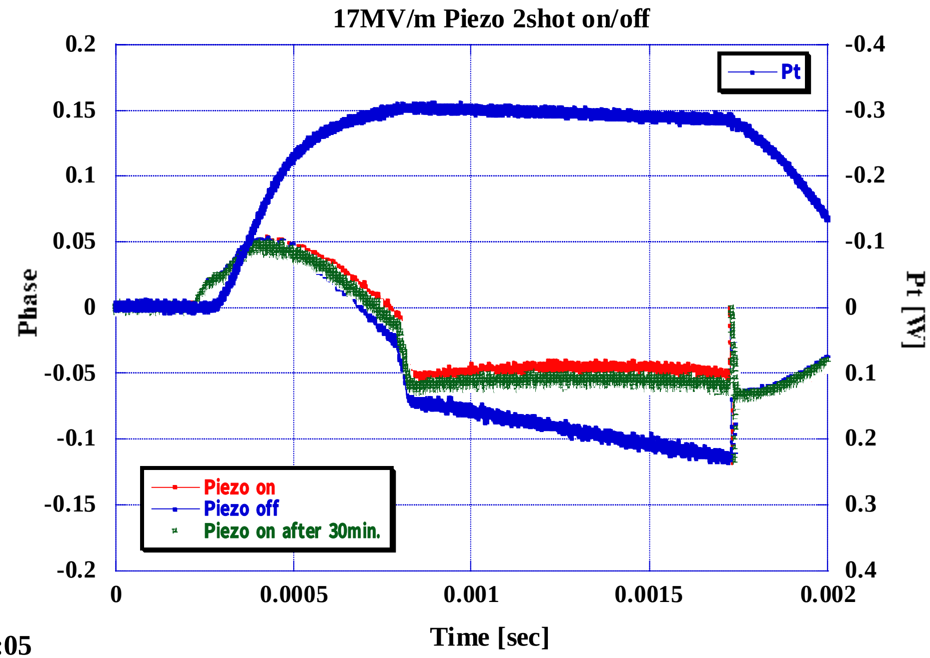






Phase variation in 30 minutes operation @ 17MV/m





Simulation Result for the Static

	Old Model (Asymmetric)	New Model (Symmetric)
Axial Force Deformation (Tuning)		
Axial Spring Constant (Measured)	48 N/μ	
Axial Spring Constant (Assumed)		48 N/μ
Axial Tuning Sensitivity (Measured)	0.32 kHz/μ	
Axial Tuning Sensitivity (Computed)	0.37 kHz/μ	0.38 kHz/μ
Lorentz Force Deformation (Detuning)		
Static Detuning @40 MV/m (Computed)		-2.0 kHz
Static Detuning Coefficient (Computed)		-1.3 $Hz/(MV/m)^2$
Maximum Radial Expansion @40 MV/m (Computed)		0.16 μ
Axial Length Contraction @40 MV/m (Computed)		1.4 μ
Sum of Axial Forces @40 MV/m (Computed)		49 N

~15 % lower than simulation

Static → **Mechanical Pulse response** → Pulse

15MV/m	-281Hz
31.5MV/m	-1240Hz
40MV/m	-2000Hz

Scaled the result of STF0.5

Should be smaller →

Similar to TESLA Cavity

15MV/m	-138Hz
31.5MV/m	~ -600Hz ?
40MV/m	~ -1000Hz ?