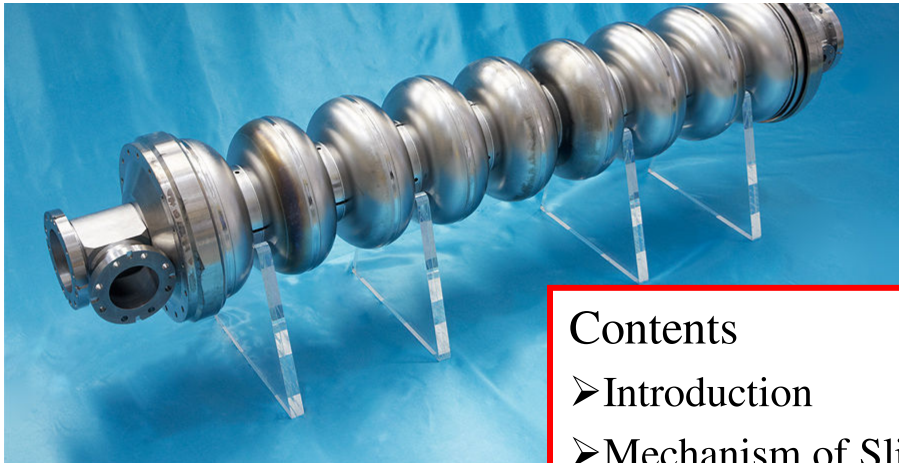
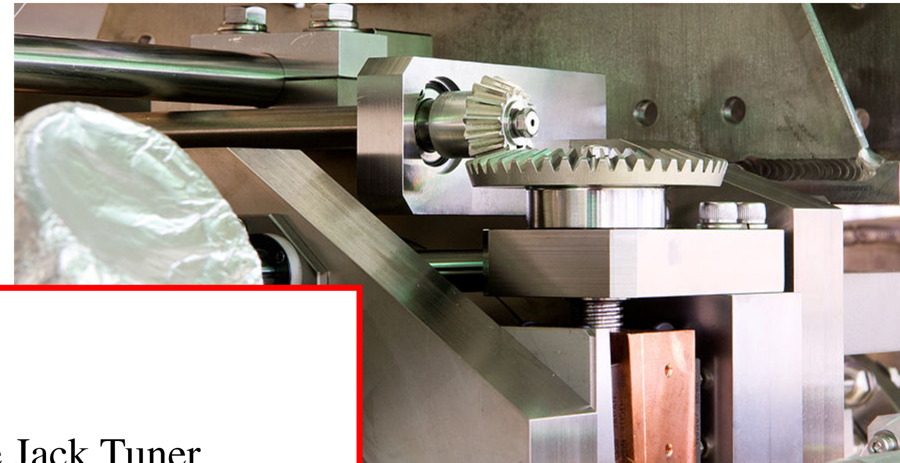
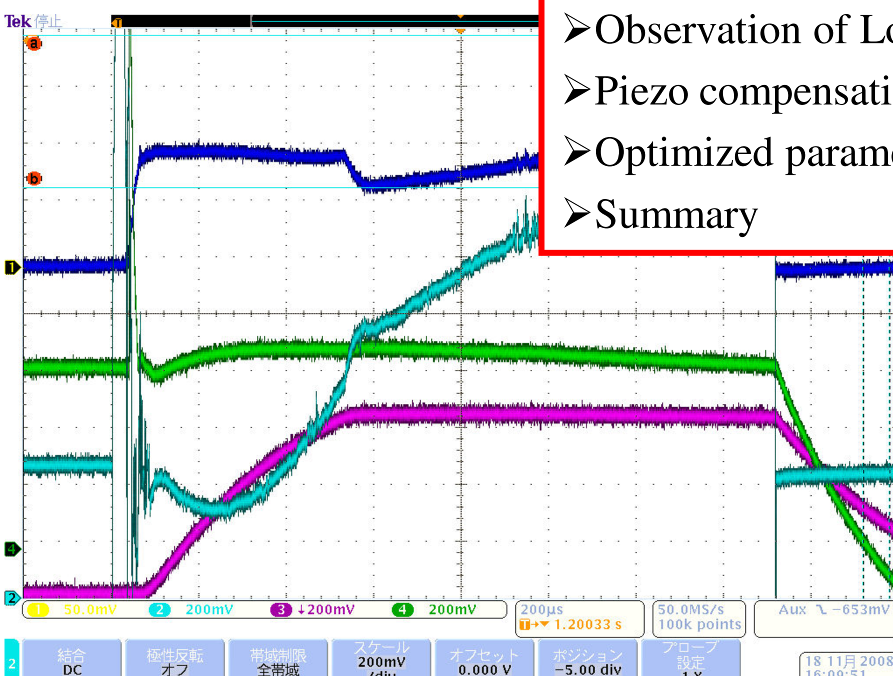
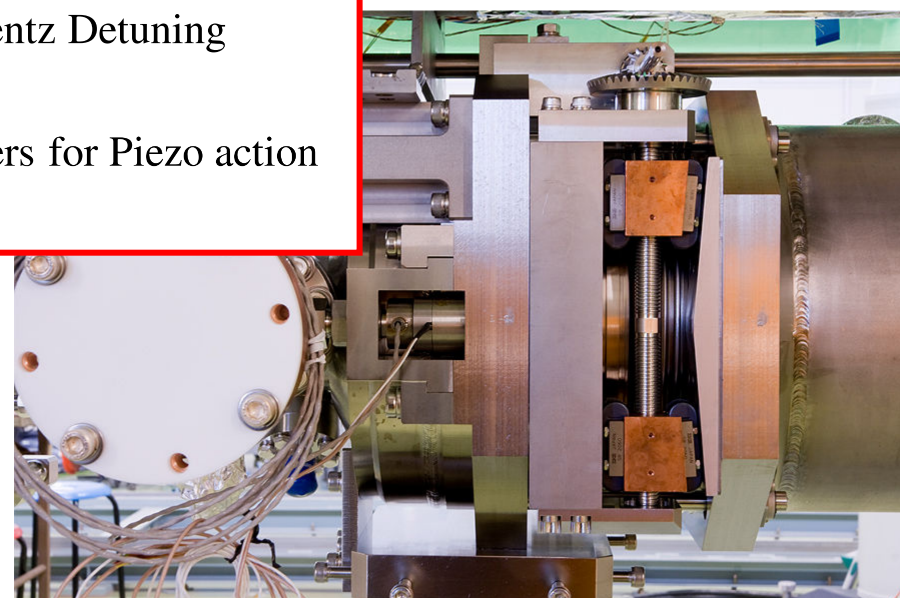
Lorentz Force Detuning Studies at STF (Phase–1.0)





Contents





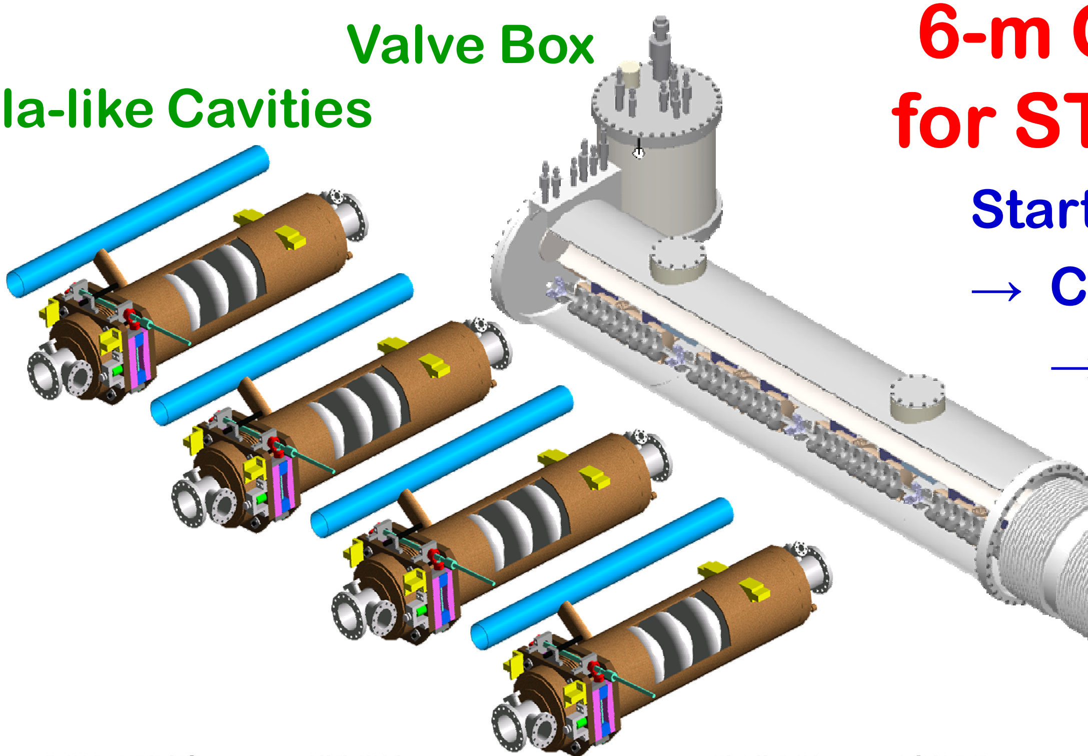
Introduction

- We have already presented the result of Lorentz Force Detuning at STF (Phase–1.0) in several conferences.
  - TU3RAI04(E. Kako), TU5PFP075(Kirk) @PAC09
  - TUPPO007(Kirk), TUPPO021(E. Kako) @SRF09
- Since last year, we do not do a cryomodule test with a high power klystron.
- Therefore, the same result will be presented here again using the above presentation.
- I already reported the similar presentation at TILC09.

Superconducting rf Test Facility (STF)

Valve Box

Tesla-like Cavities

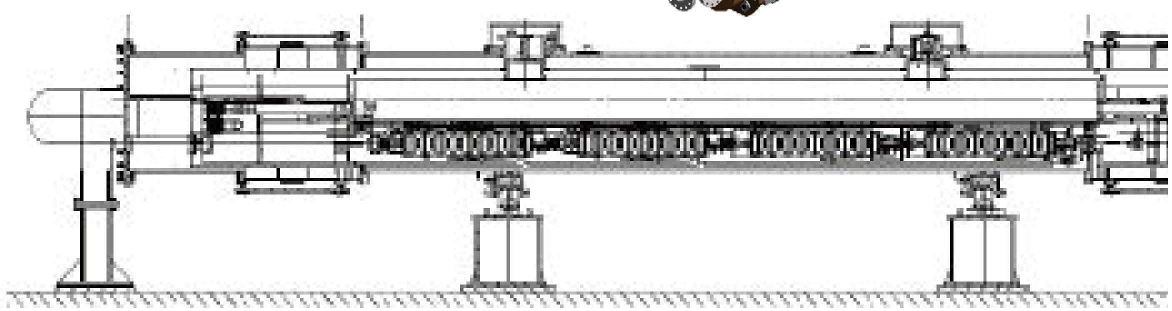


6-m Cryomodule for STF Phase-1.0

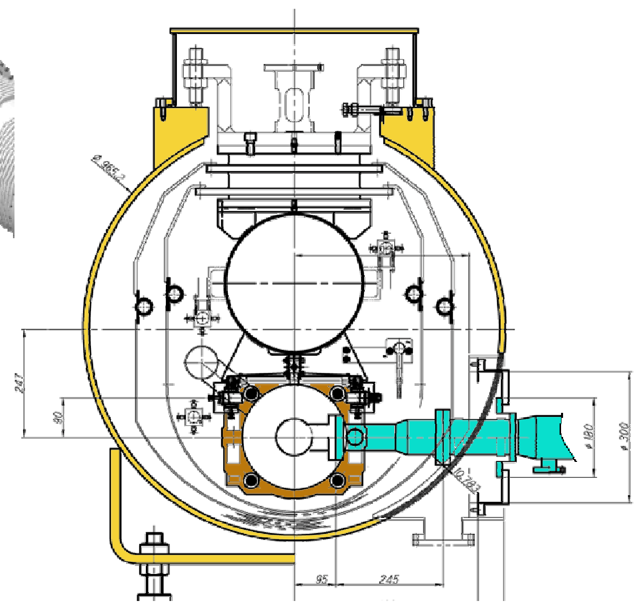
Started in April 2005'

→ Completed in Mar. 2008'

→ Cool-down in May 2008'



Four 9-cell cavities in the STF tunnel

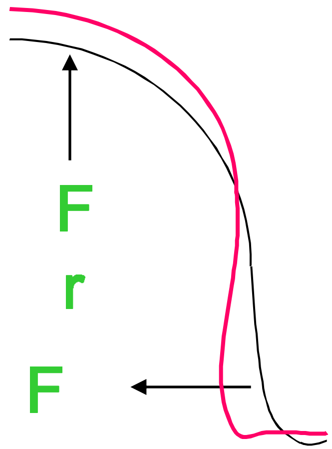


Cryomodule Cross-section

Purpose of STF Cryomodule Test

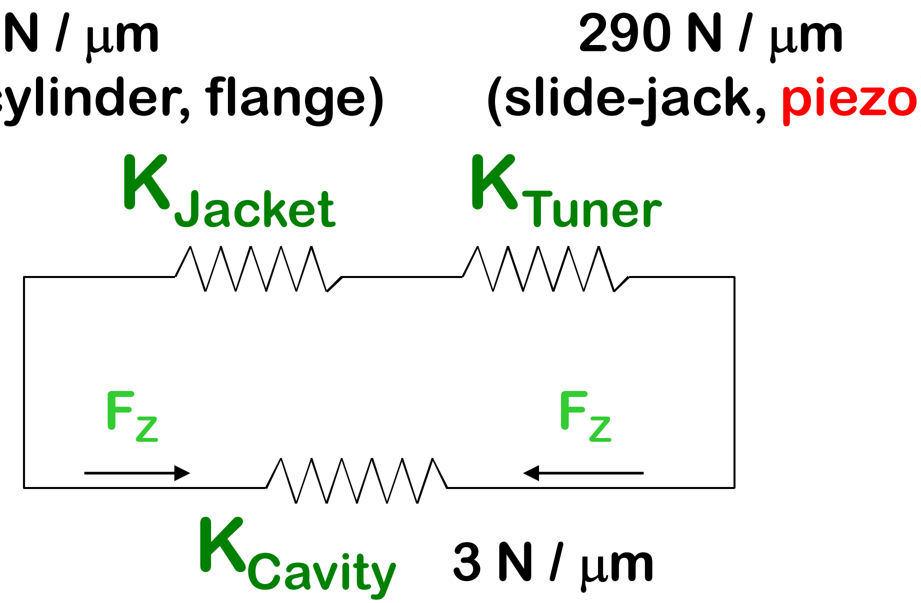
- To check the performance as a total superconducting cavity system, and to find out the improvement points for the future project.
- To confirm a stable pulsed operation at higher fields, and to compare the achieved $E_{acc,max}$ in the cryomodule tests with the results in the vertical tests.
- To demonstrate a compensation of Lorentz force detuning by a piezo tuner, and to establish the effectiveness of an improved stiffness in a cavity support structure.

Stiffness of STF-BL Cavity-Tuner System

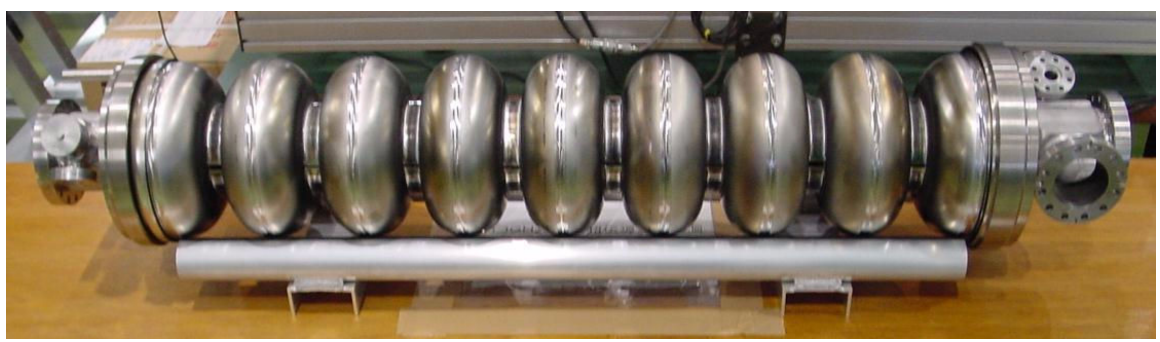


Lorentz Force Detuning

$$\frac{1}{K_S} = \frac{1}{K_{Jacket}} + \frac{1}{K_{Tuner}}$$

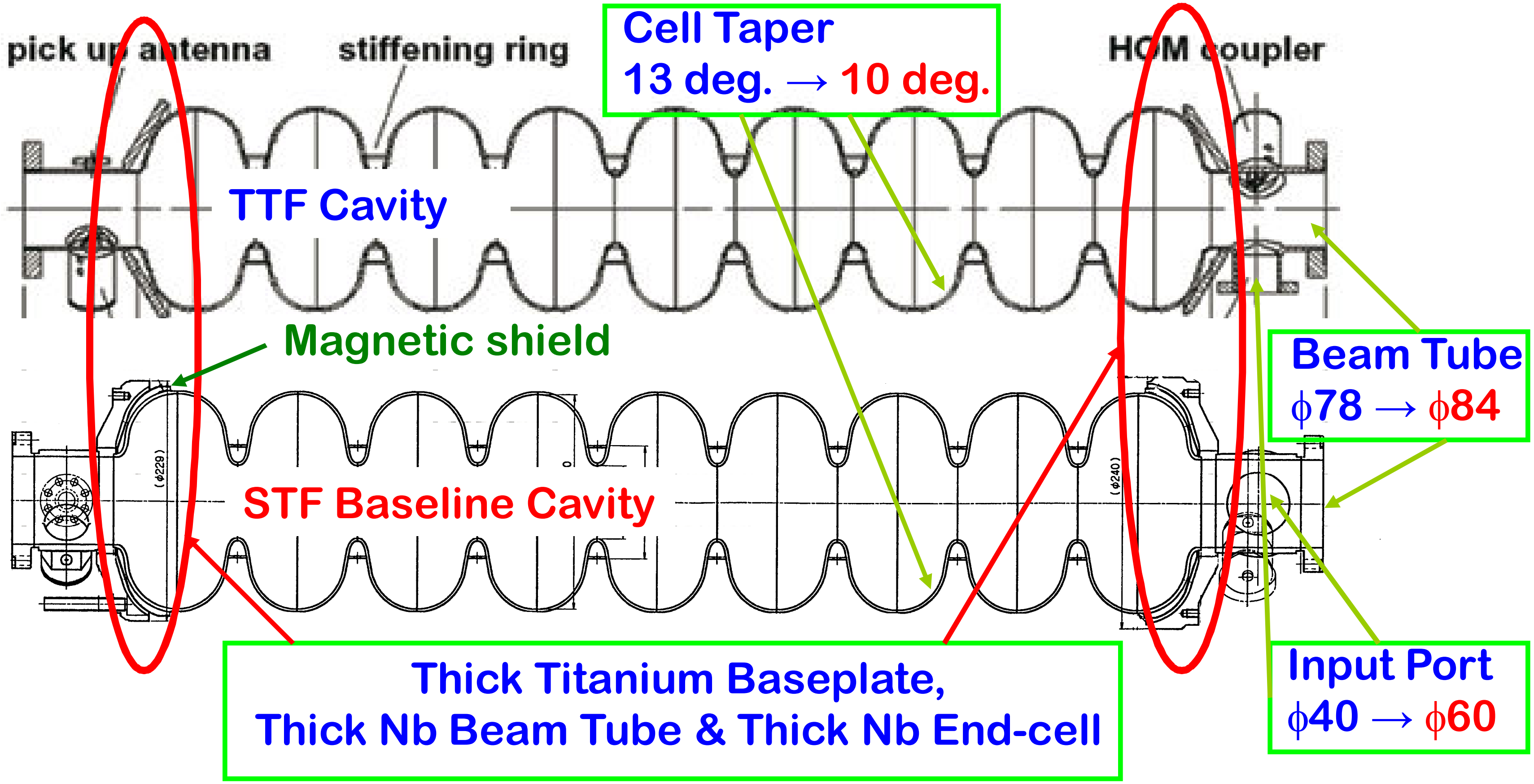


K_S = 72 kN / mm



from E. Kako

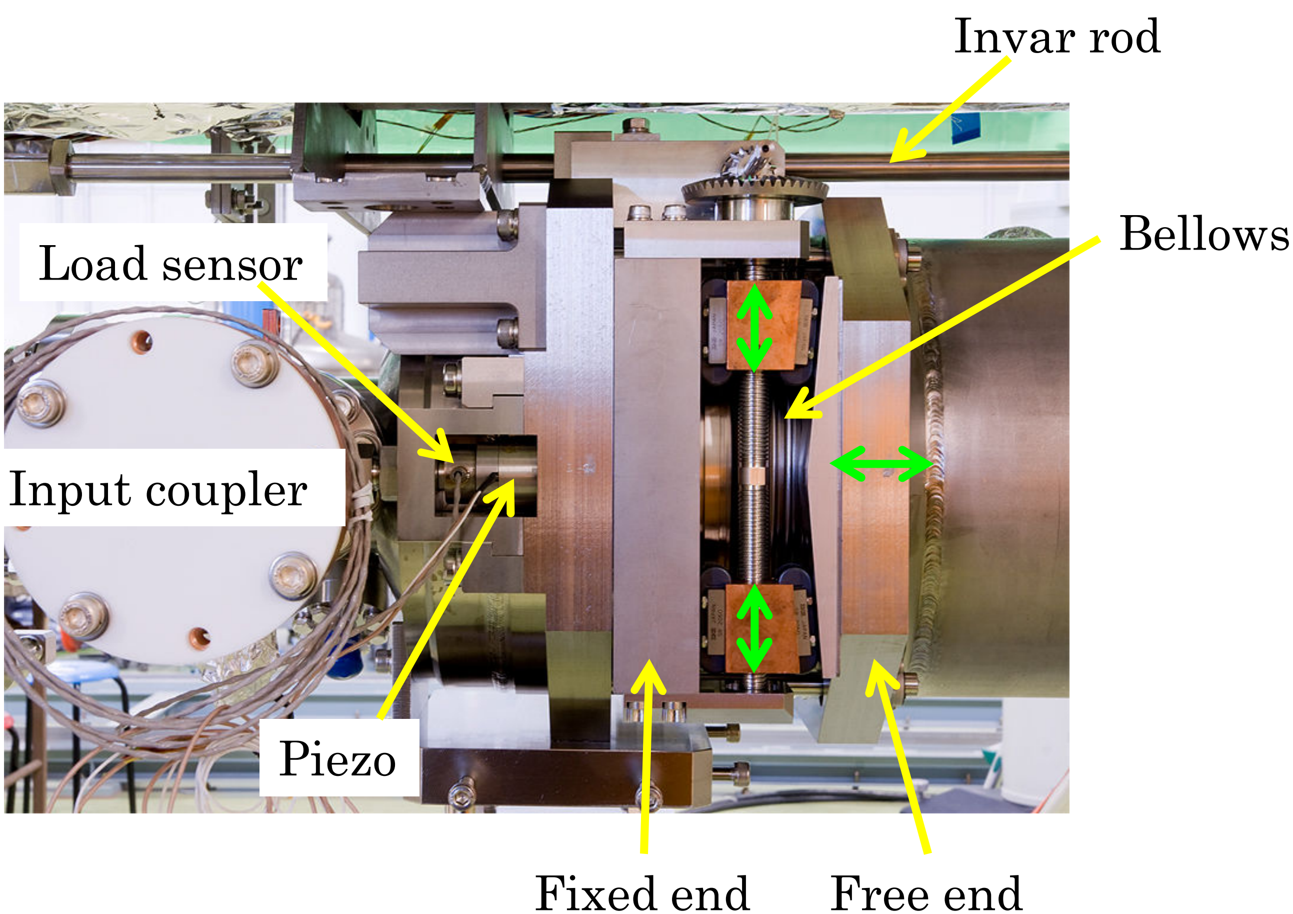
STF Baseline Cavity ; Improved Stiffness



	STF Baseline Cavity	TTF Cavity	
Stiffness of Cavity Sys.	72 kN/mm	22 kN/mm	
Lorentz Detuning at flat-top	Δf = - 150 Hz	Δf = - 500 Hz	Estimation at 31.5 MV/m

from E. Kako

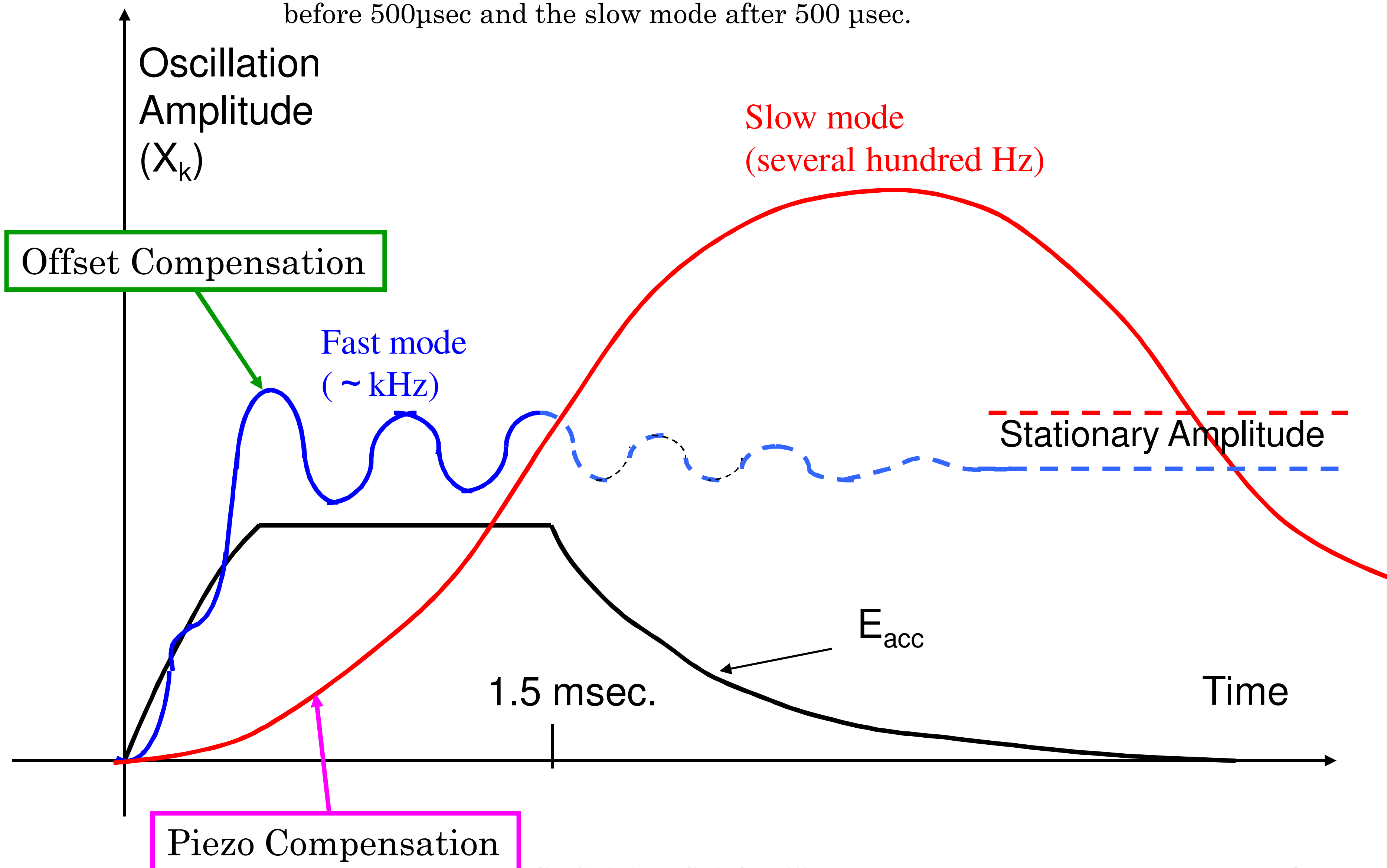
Mechanism of Slide-Jack Tuner



The Piezo performance was good for the pulse operation using a function generator, although it was not good for the manually slow operation due to some friction.
We are investigating the cause by checking the movement at the room temperature.

Mechanical Oscillation (Two Modes Model)

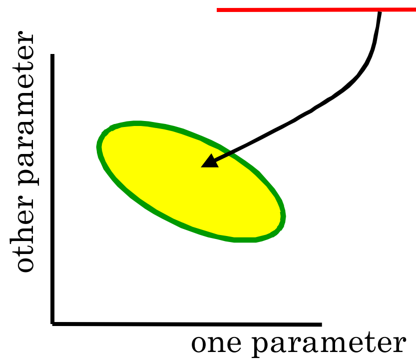
Very roughly speaking, the fast mode is mainly contributed to the Lorentz Detuning before 500µsec and the slow mode after 500 µsec.



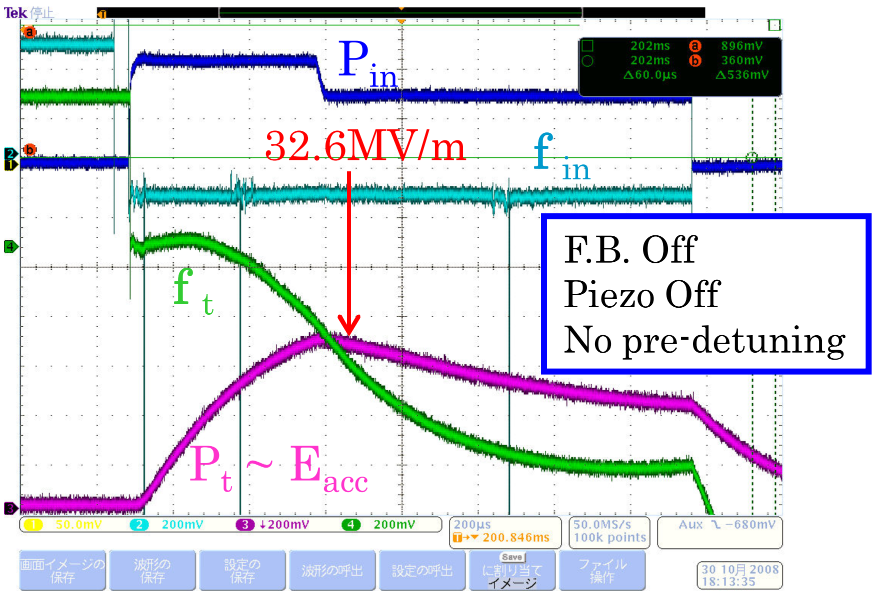
Adjustable parameters for compensation of Lorentz Detuning

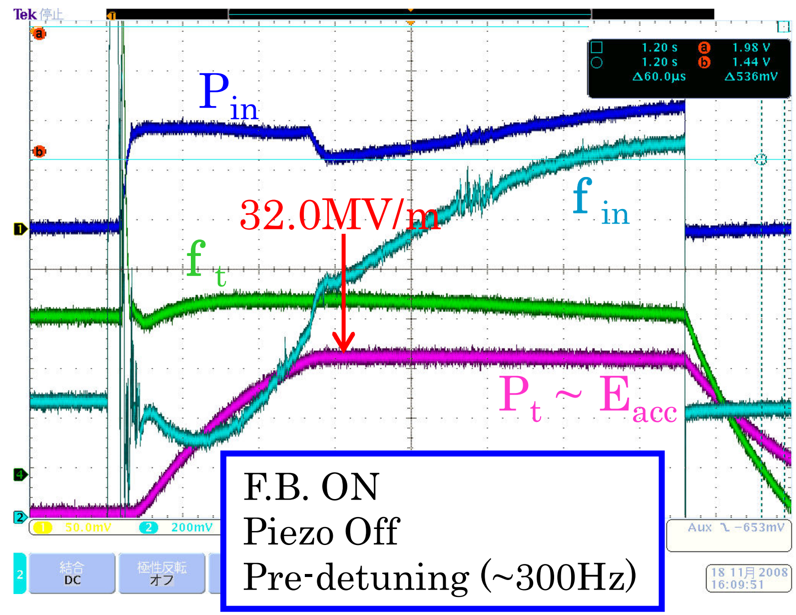
- f_{offset} : Initial offset of cavity frequency
- V_{Piezo} : Driving voltage of Piezo actuator
- f_{Piezo} : Driving frequency of Piezo actuator
- t_{delay} : Timing difference between RF pulse and Piezo action

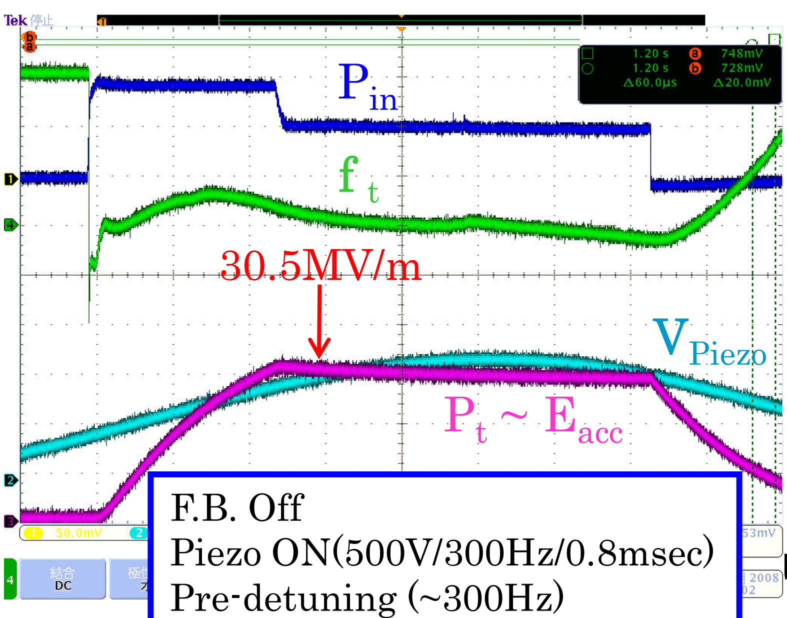
If two parameters are fixed within these four parameters,
we can obtain matrix data for optimum region of Piezo action.

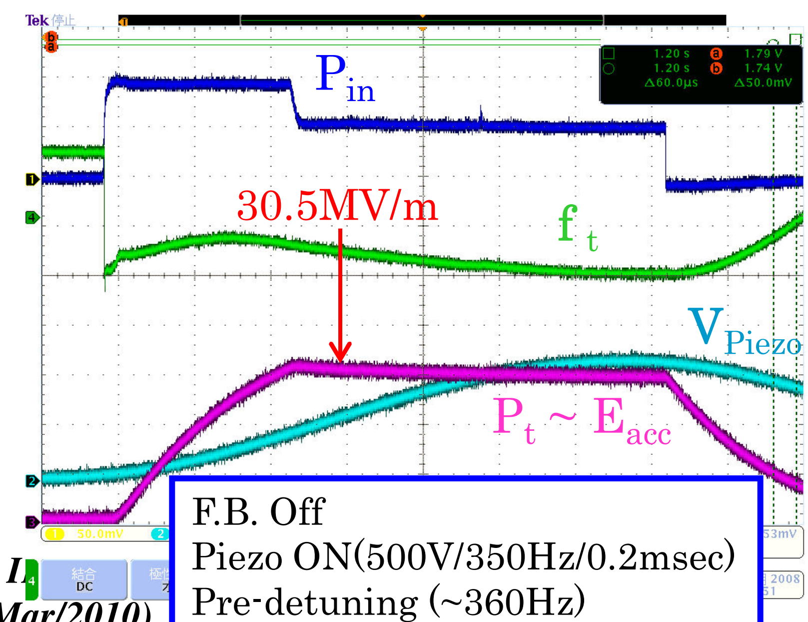


Observation of Lorentz Detuning



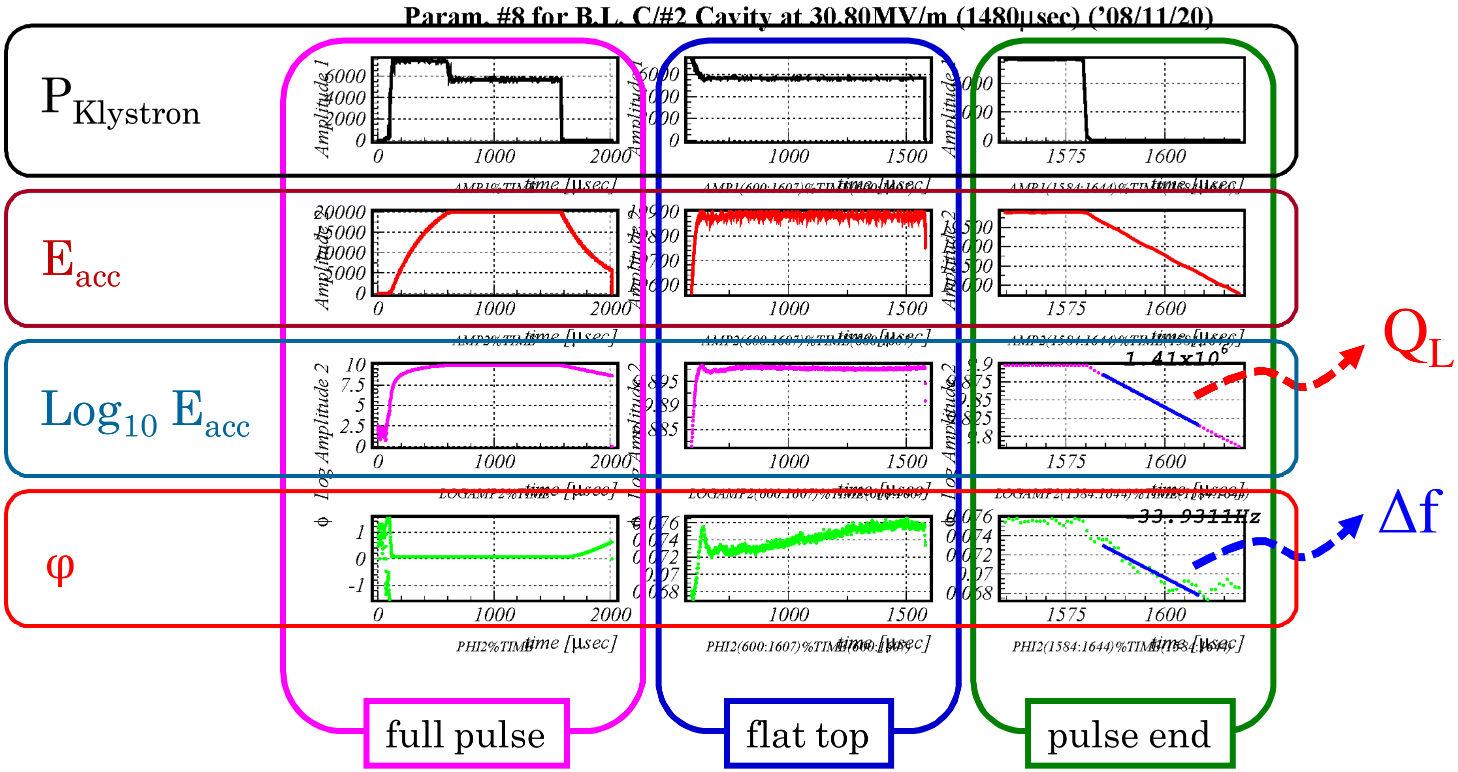






Example of measurement for Q_L & Δf

We usually use the pulse-shortening method for the measurement of Lorentz Detuning.
It takes about 10minutes to take data for one parameter of Piezo action.
But it will be much faster for S-1 Global project!

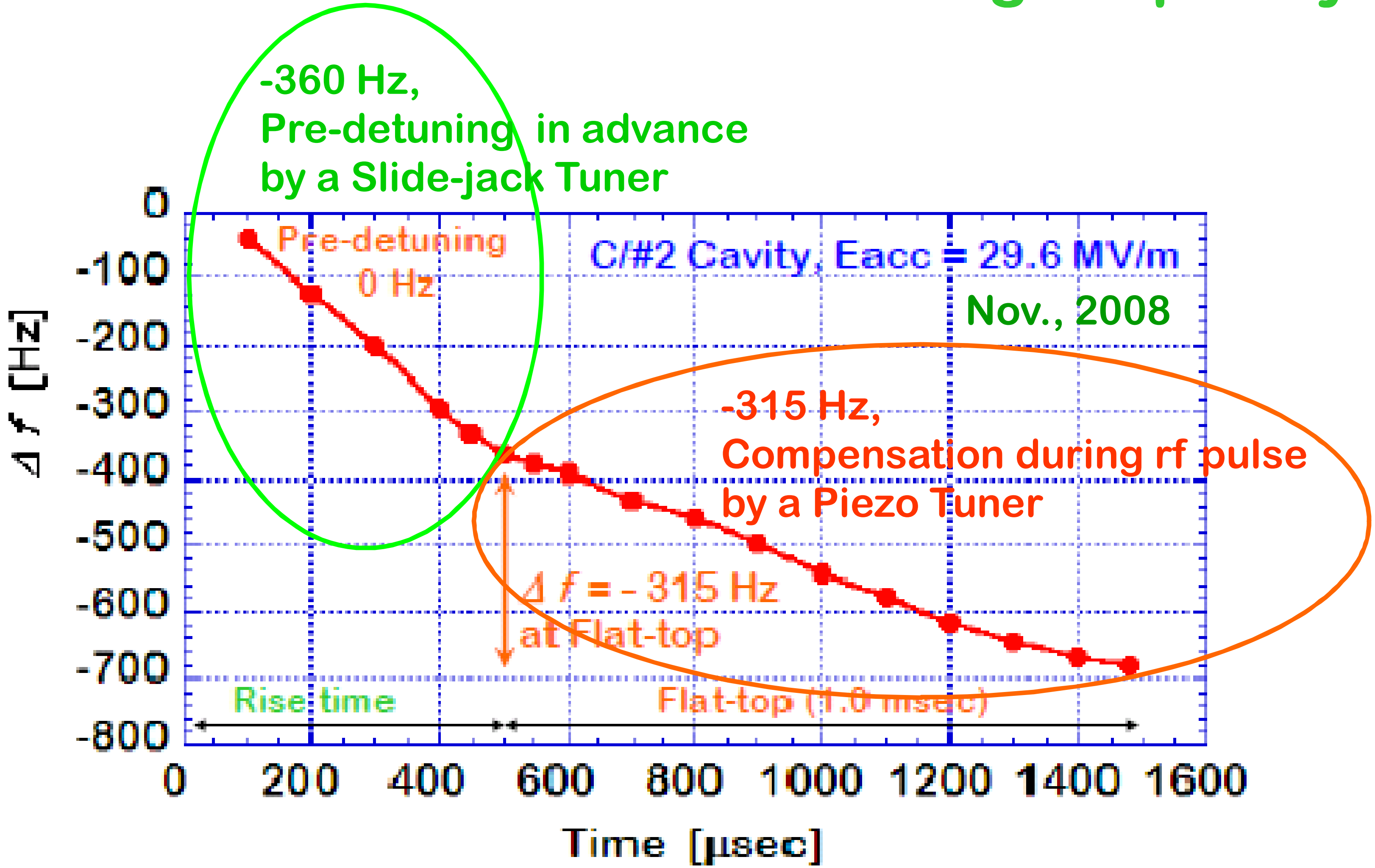


measurement timing:
100, 200, 300, 400, 450, 500, 550, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1480μsec

totally 17 points!

Lorentz Force Detuning (1)

Observation of Lorentz-detuning frequency



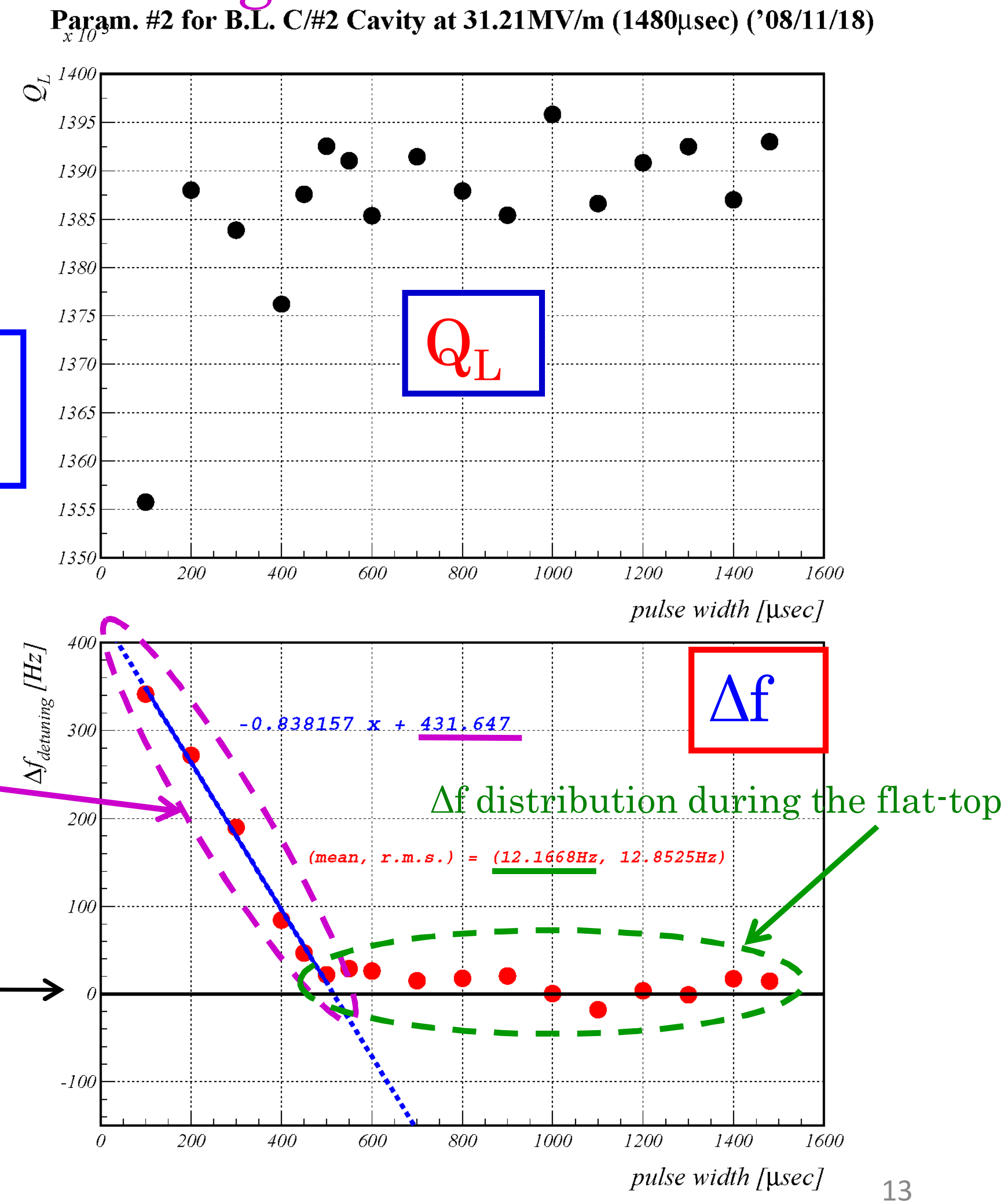
Evaluation of Lorentz-Detuning by pulse-shortening method

Piezo Condition :
$V_{piezo}/f_{Piezo}/t_{piezo}$ = 500V/250Hz/0.2msec

measurement timing:
100, 200, 300, 400, 450, 500, 550, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1480μsec

f_{offset} from linear fitting

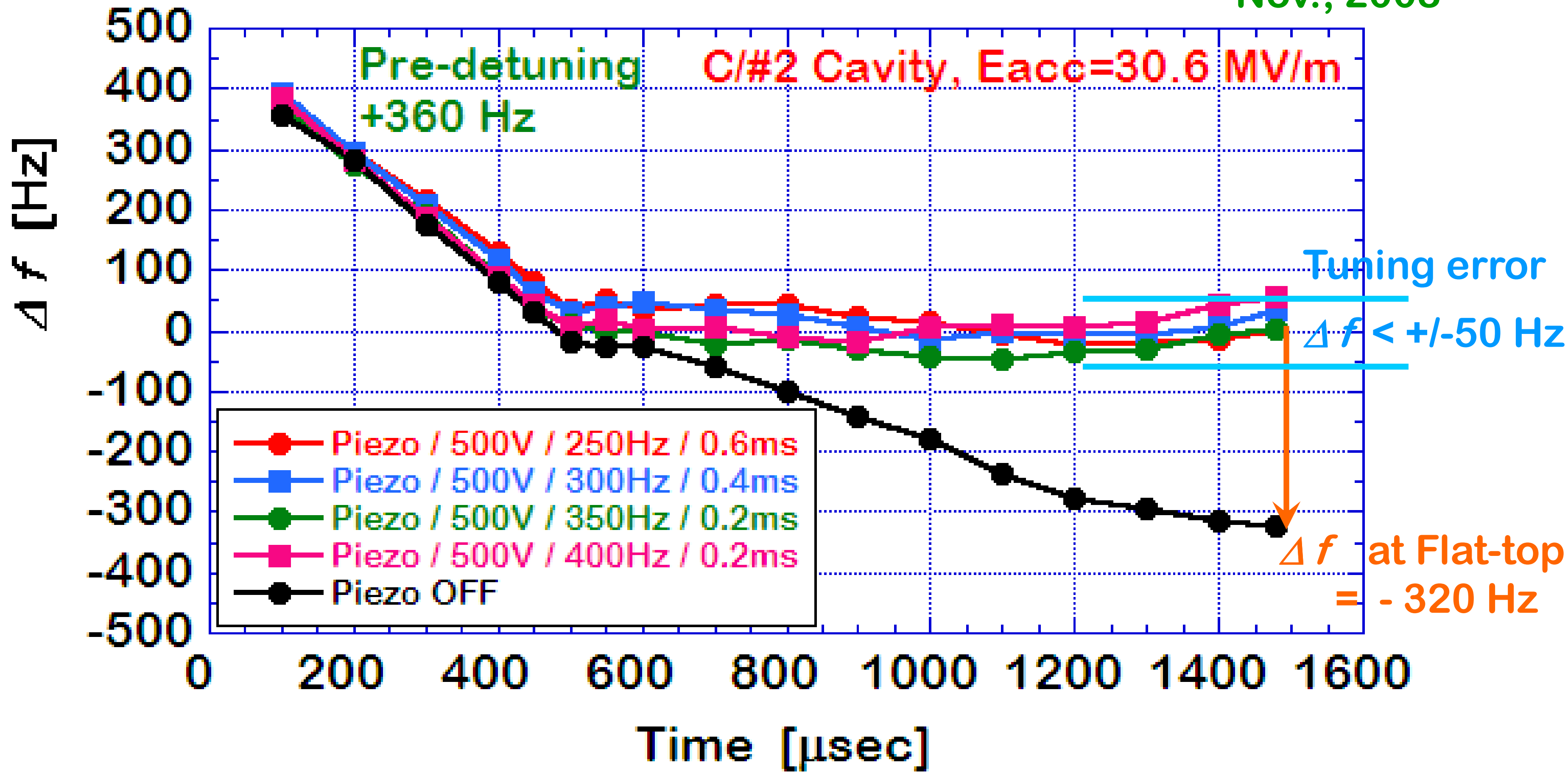
On resonance



Lorentz Force Detuning (3)

Compensation of Lorentz-detuning by Piezo Tuner

Nov., 2008

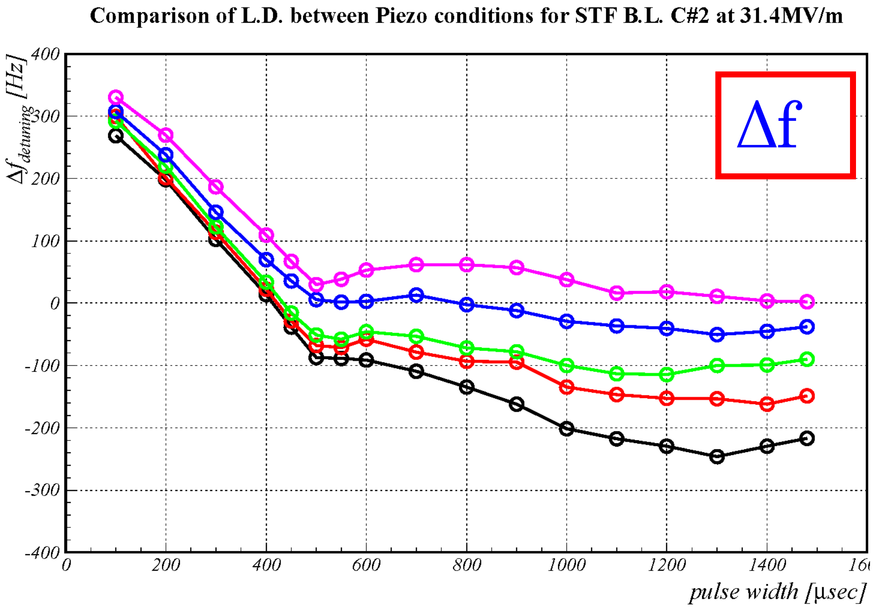


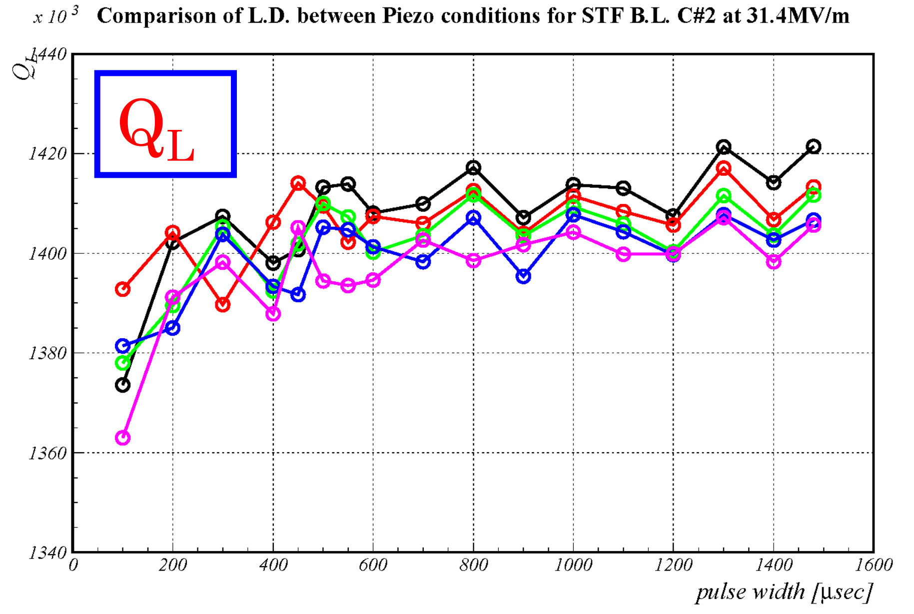
Piezo Compensation ①

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 300Hz/500V/250Hz

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec





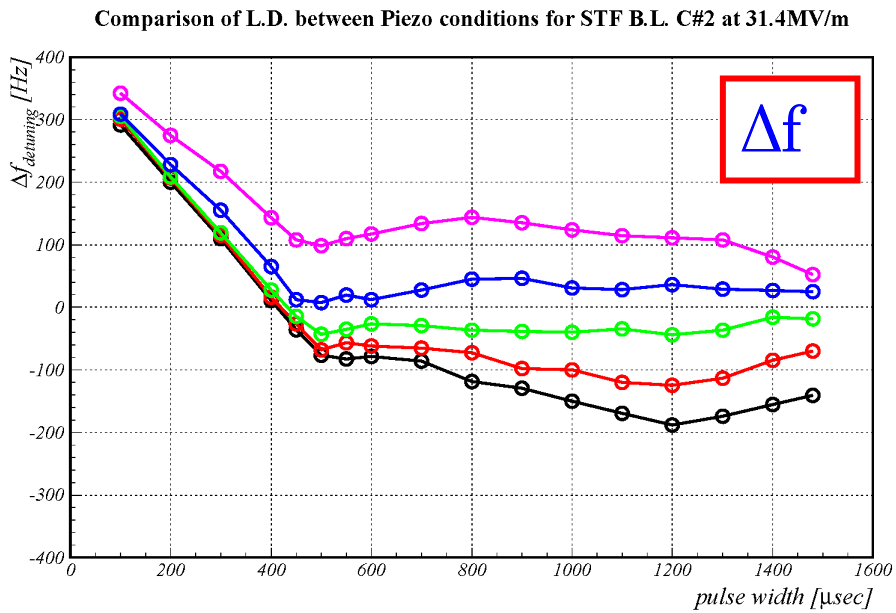
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

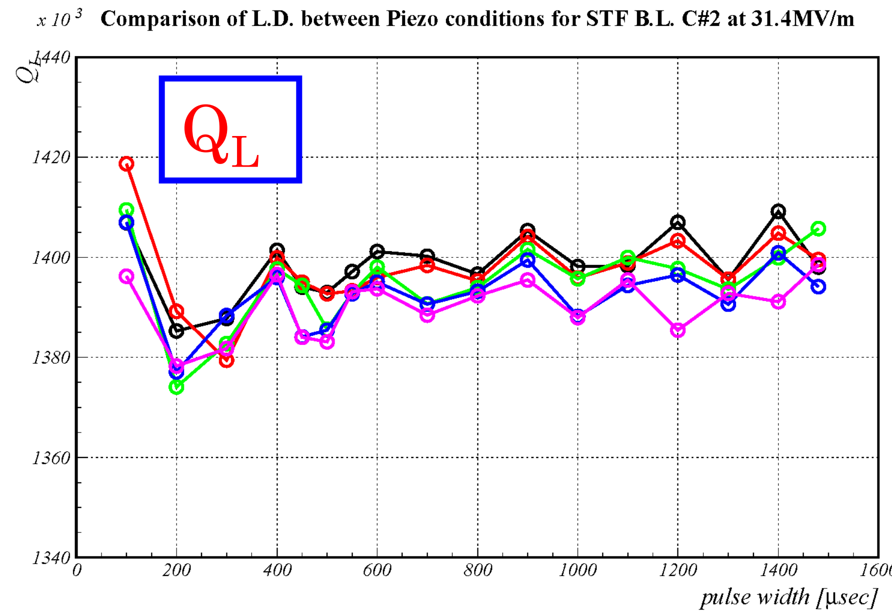
Piezo Compensation ②

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 300Hz/500V/300Hz

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec





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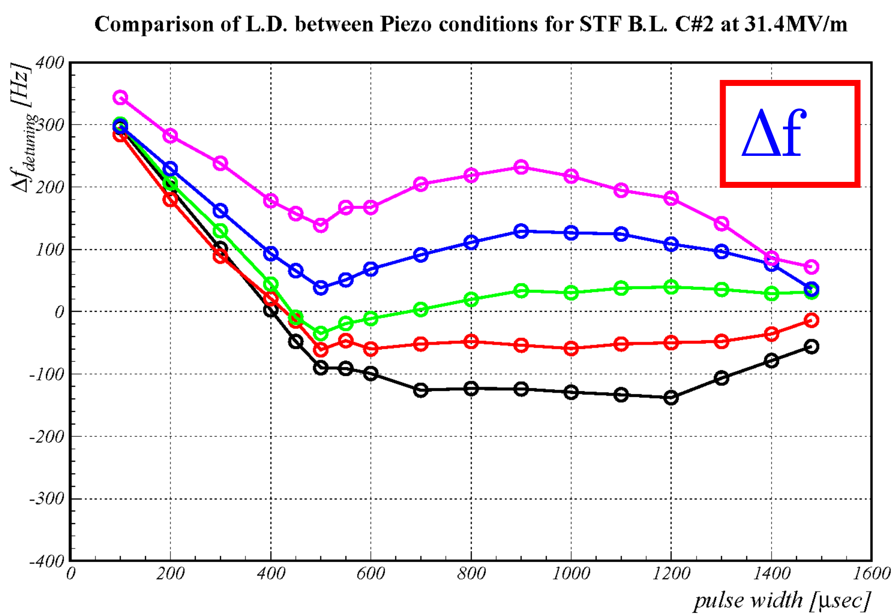
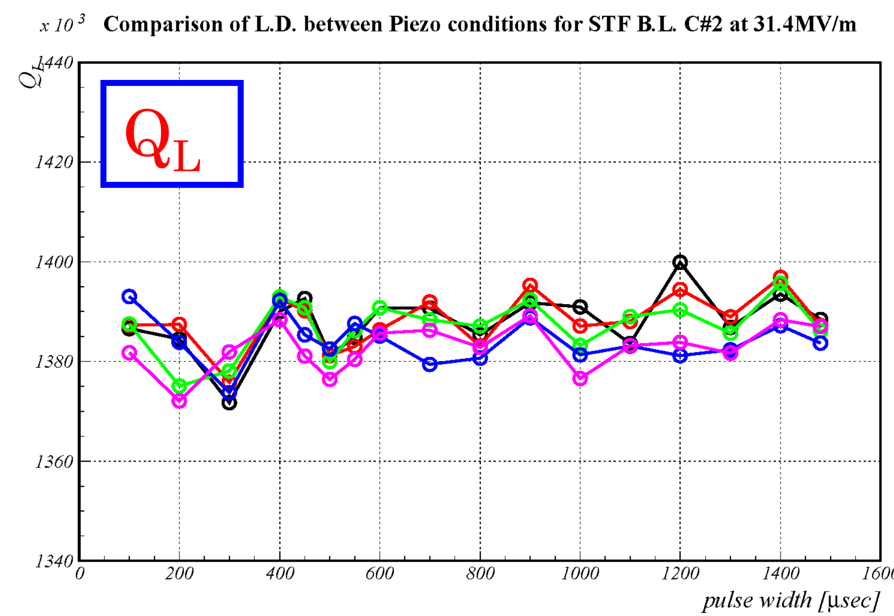
Piezo Compensation ③

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 300Hz/500V/350Hz

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec





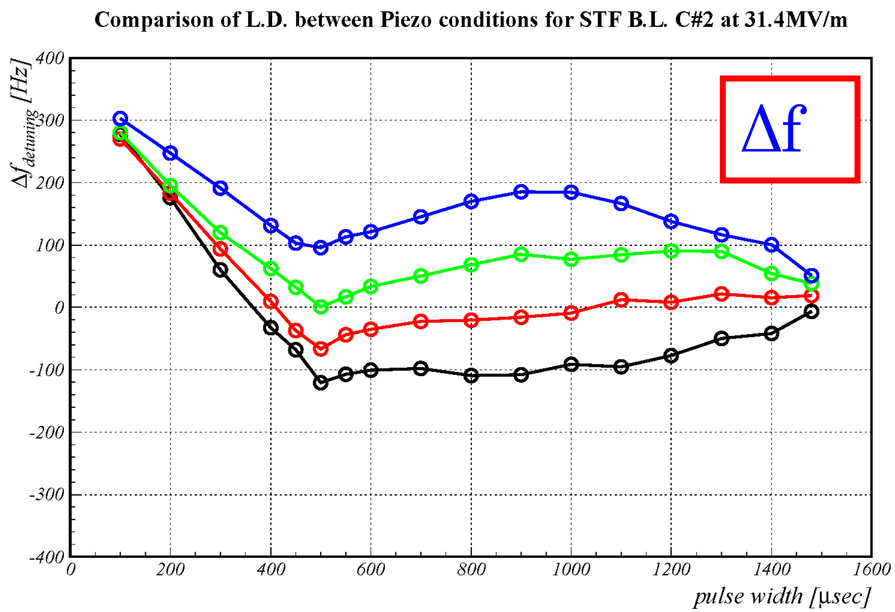
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

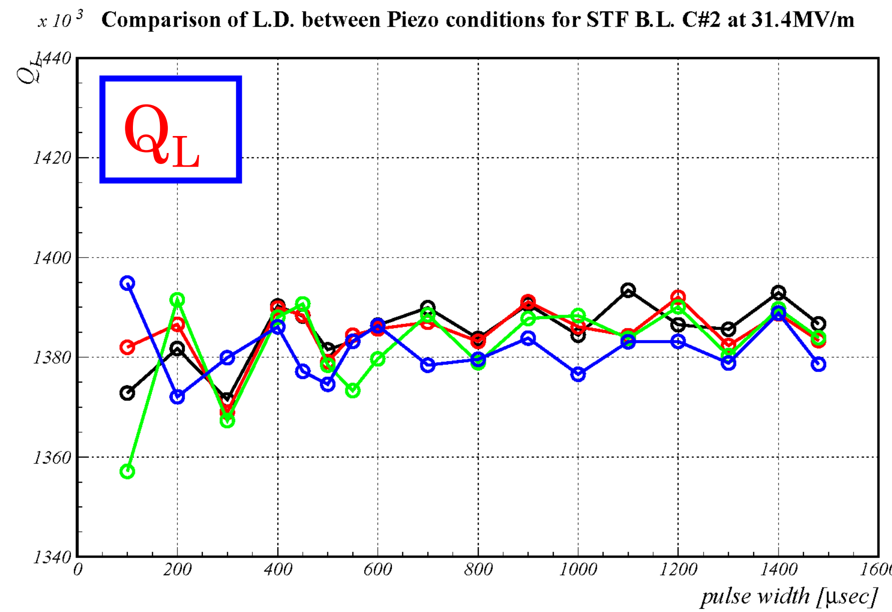
Piezo Compensation ④

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 300Hz/500V/400Hz



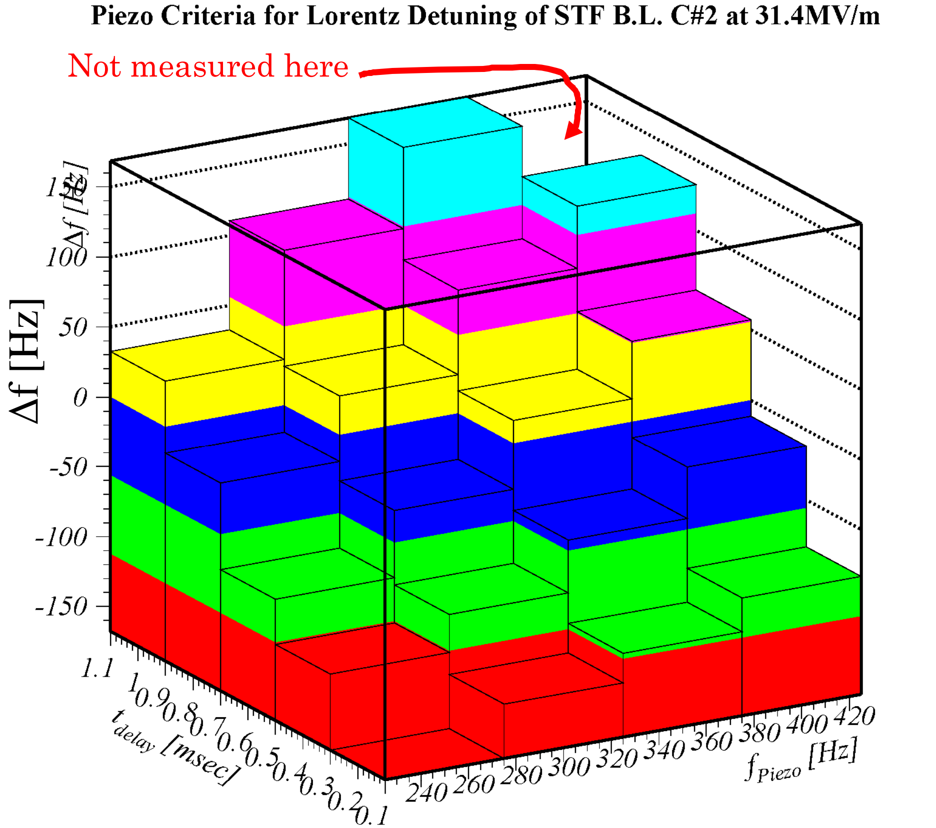


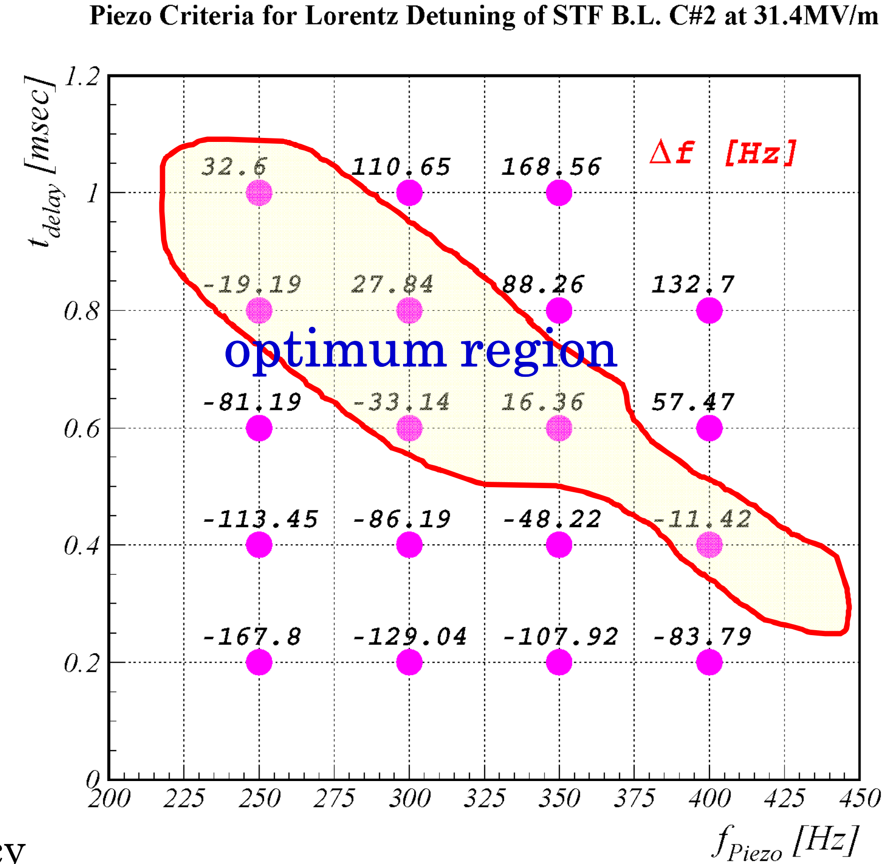
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

Optimum condition of Piezo action ①

f_{SG}=1300.500000MHz, Feed Back Off

f_{offset}/V_{piezo}=300Hz/500V

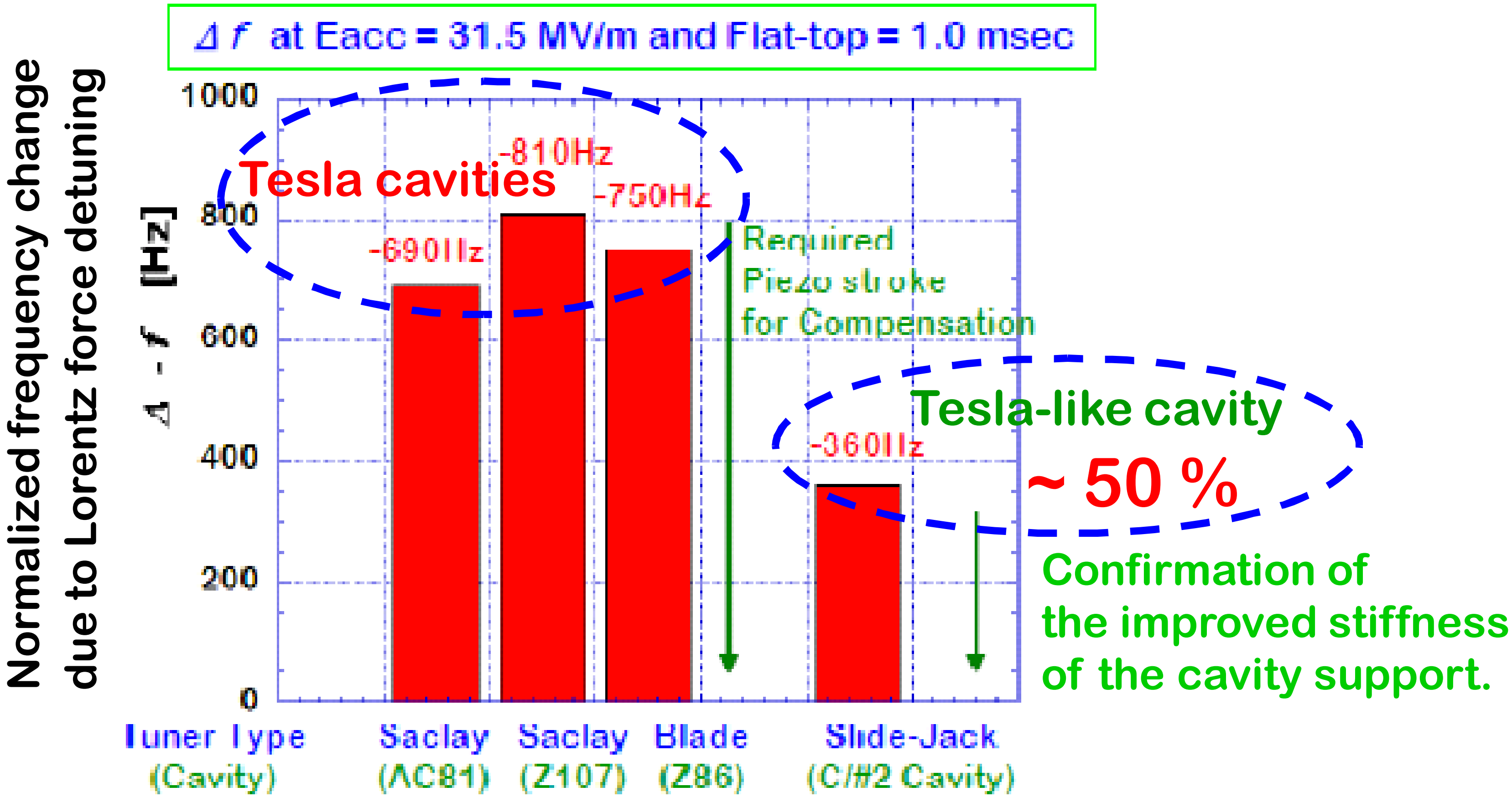




f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

Comparison between STF and other labs for Lorentz Force Detuning

(comparison of required Piezo Stroke)



Required piezo stroke for compensation at 31.5 MV/m in Tesla-like cavity was reduced ~50 % of that in the Tesla cavities.

Pulse stability test

2000 pulses data

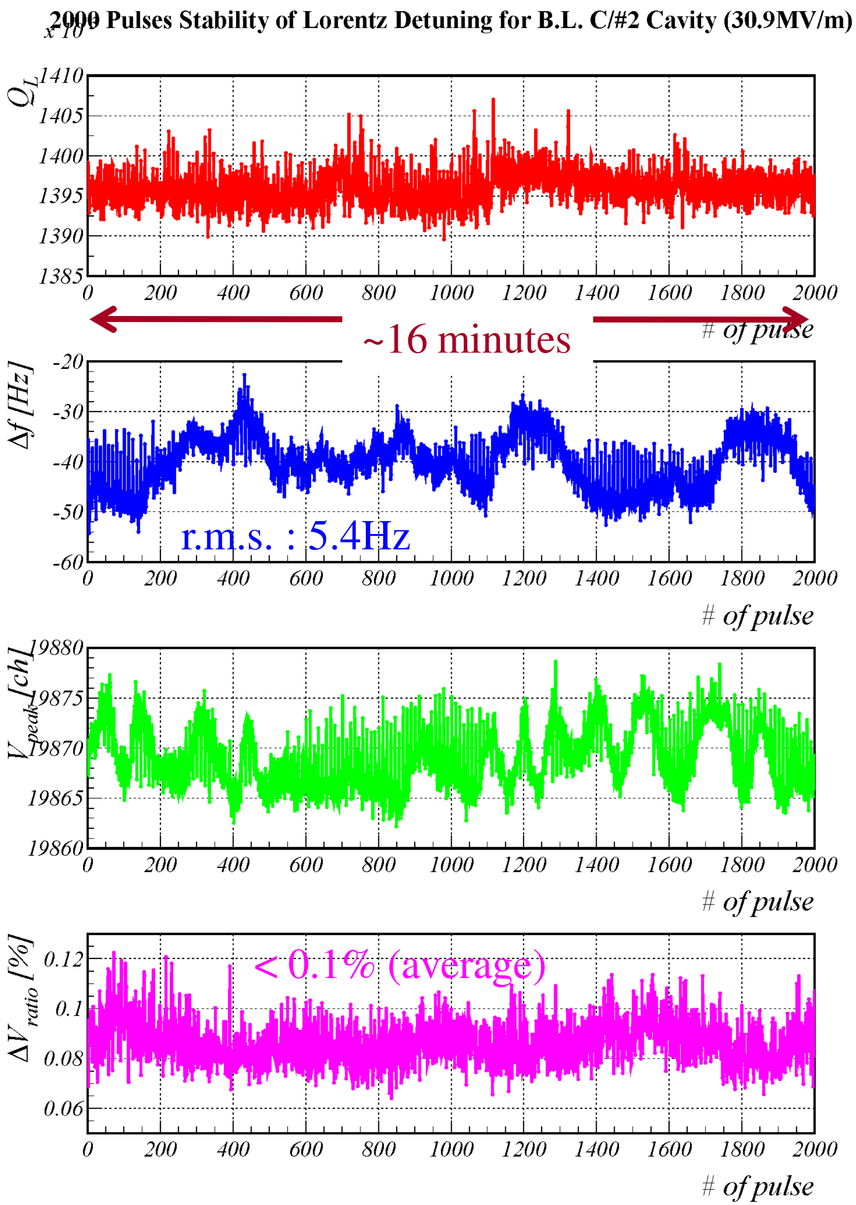
F.B. ON

Q_L

Δf

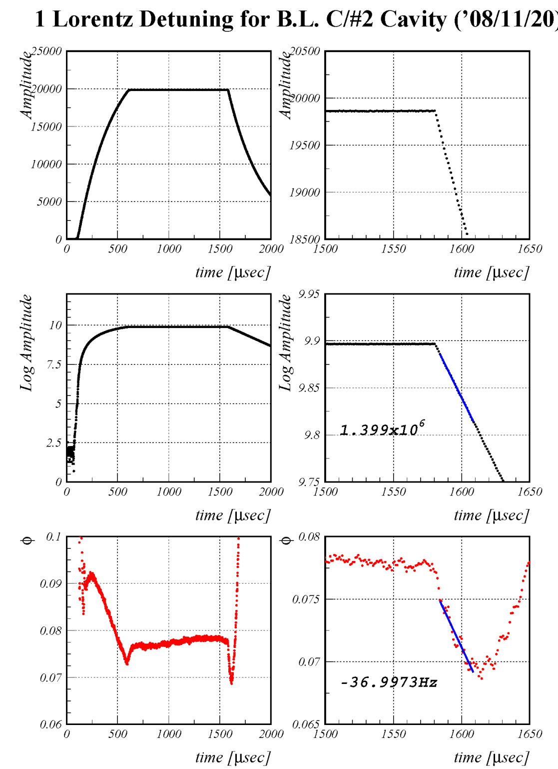
peak field at flat-top
(ADC counts)

peak-to-peak ratio
at flat-top
(field degradation)



During the high power test, one situation was kept for 16 minutes at the driving condition of Piezo. ($V_{piezo}/f_{Piezo}/t_{piezo}$ = 500V/350Hz/0.5msec)

example of one pulse



We will try the stability test for a longer time in S1-Global project again!

Summary

- Piezo compensation at STF Phase–1.0 was successful within ±30Hz.
- Optimum condition of Piezo operation was relatively wide.
- High power operation with Piezo compensation was stable at 30MV/m over 3 hours twice.
- DAQ system of LLRF was useful for measurement of Lorentz Detuning.

Thank you for your attention!

H. Hayano, E. Kako, S. Noguchi, M. Sato,
T. Shishido, K. Watanabe, Y. Yamamoto(KEK)

We already presented these results in detail at PAC09 & SRF09!

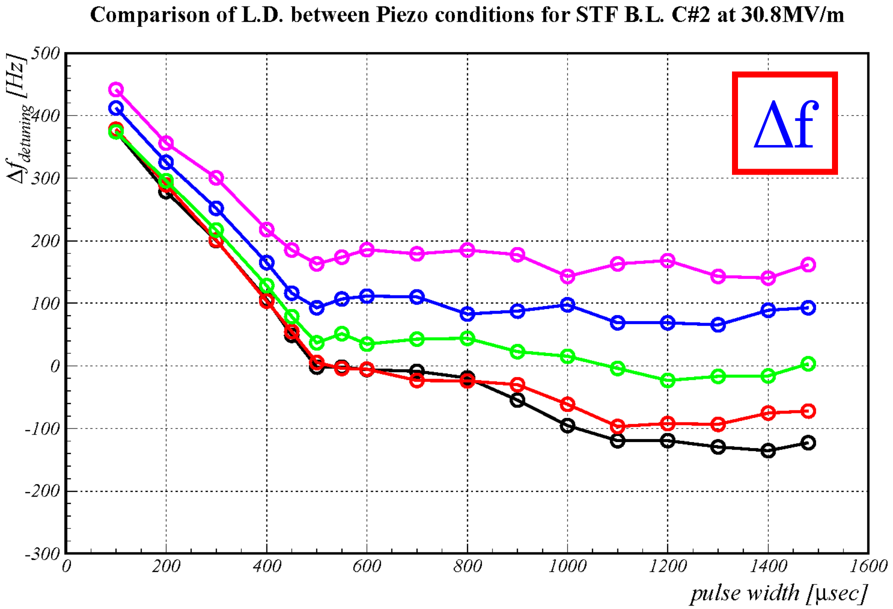
Back-up slides

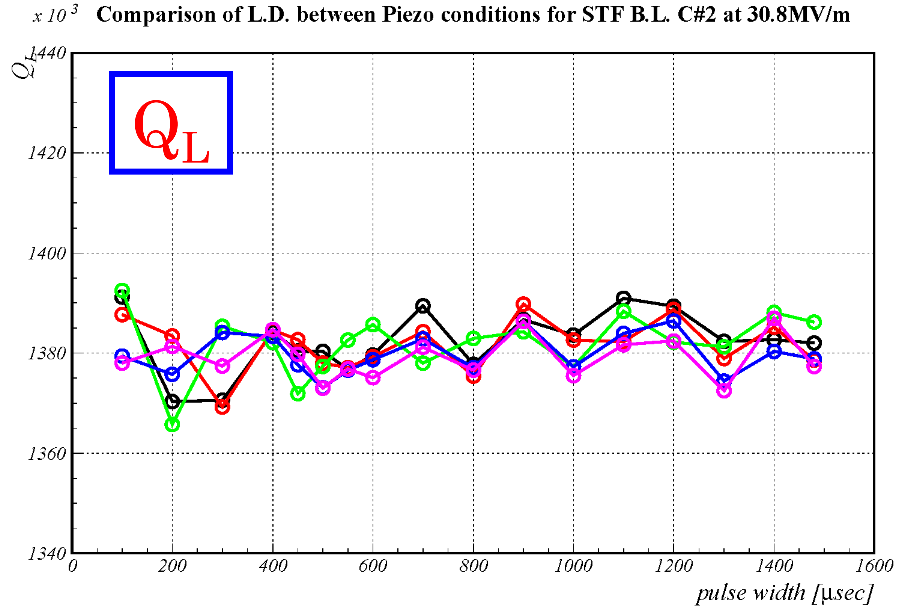
Piezo Compensation ⑤

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 360Hz/500V/250Hz

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec





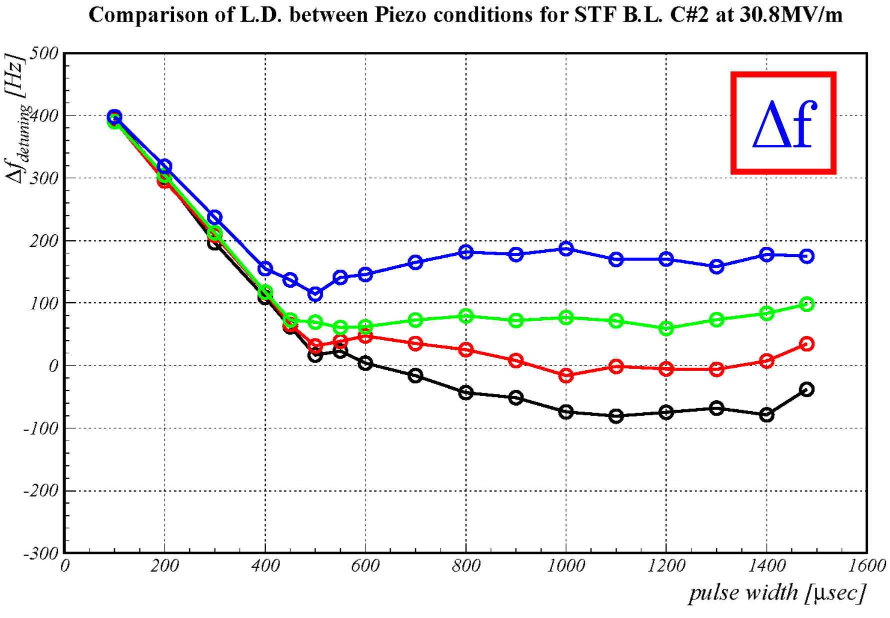
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

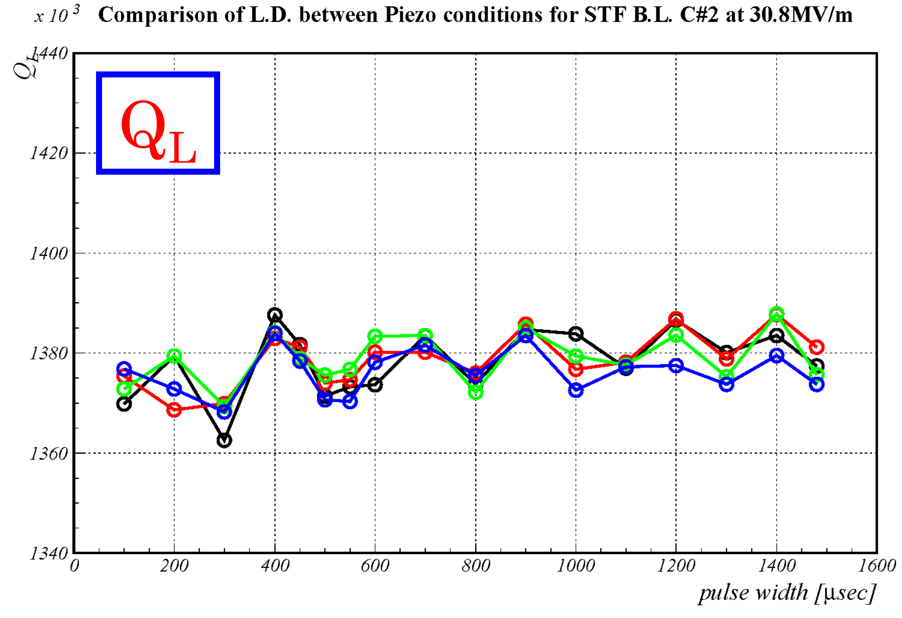
Piezo Compensation ⑥

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 360Hz/500V/300Hz





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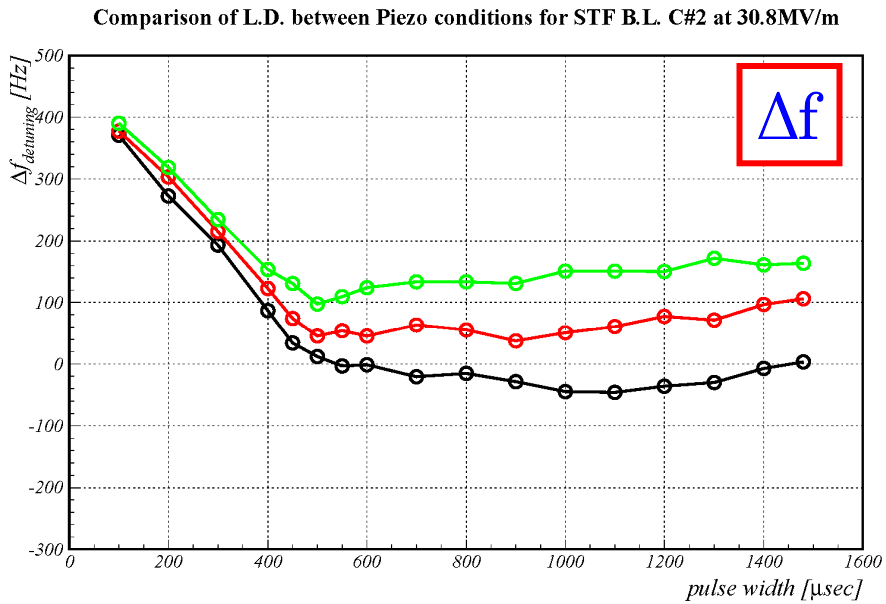
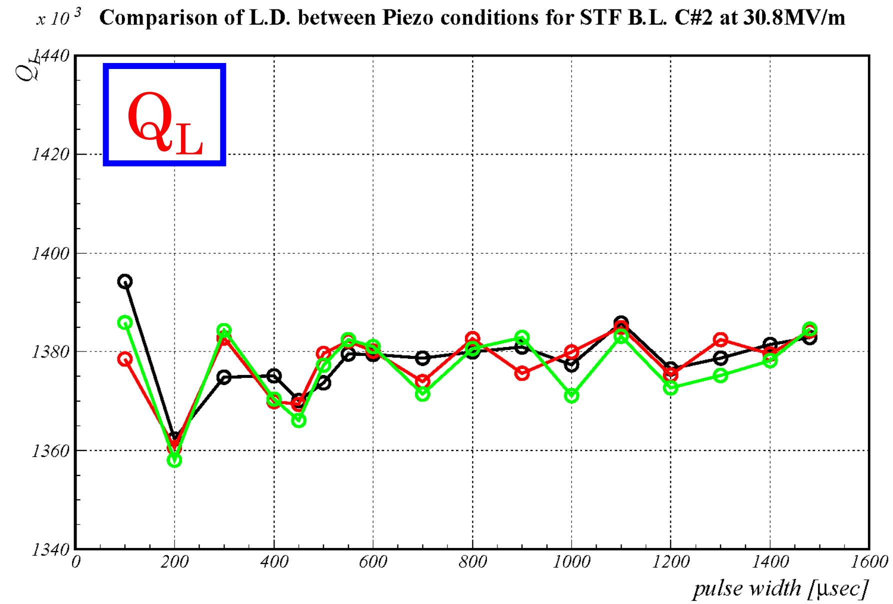
Piezo Compensation ⑦

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 360Hz/500V/350Hz

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec





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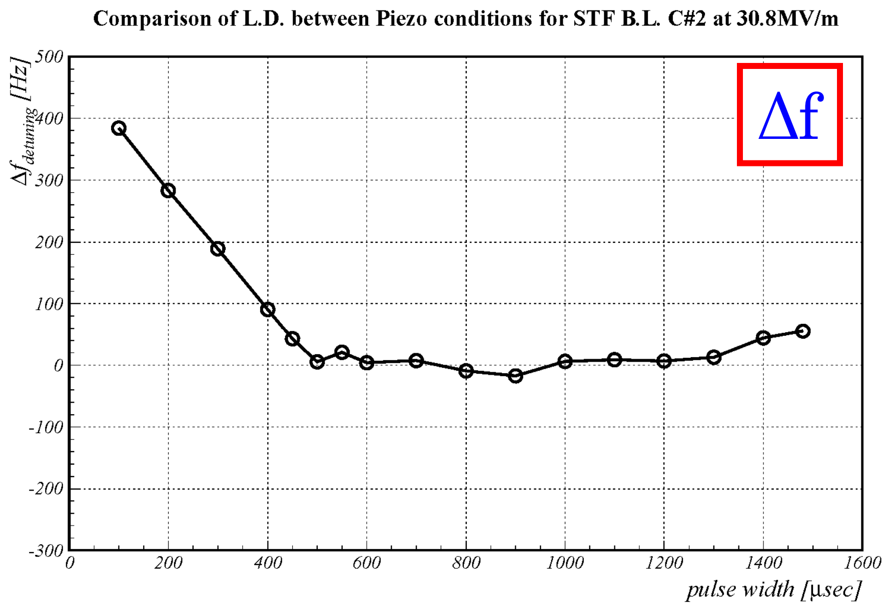
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

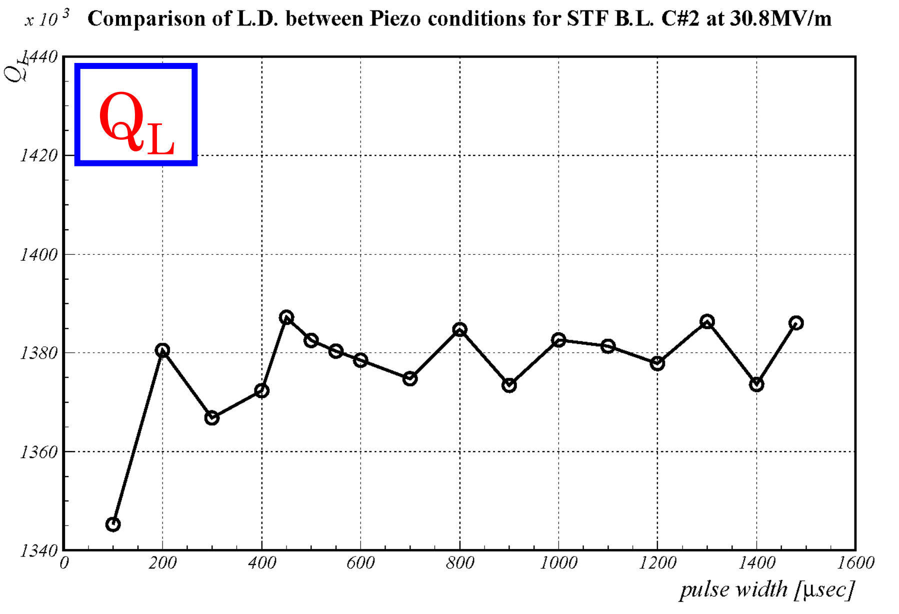
Piezo Compensation ⑧

t_{delay}
0.2msec
0.4msec
0.6msec
0.8msec
1.0msec

f_{SG}=1300.500000MHz, Feed Back Off

$f_{offset}/V_{piezo}/f_{Piezo}$ = 360Hz/500V/400Hz



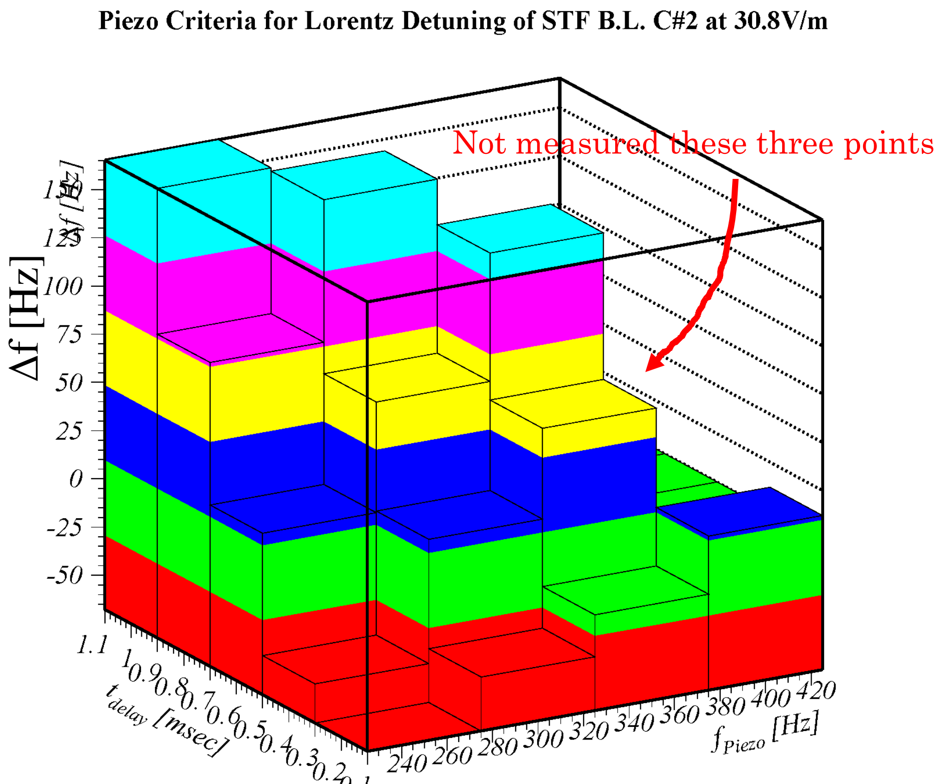


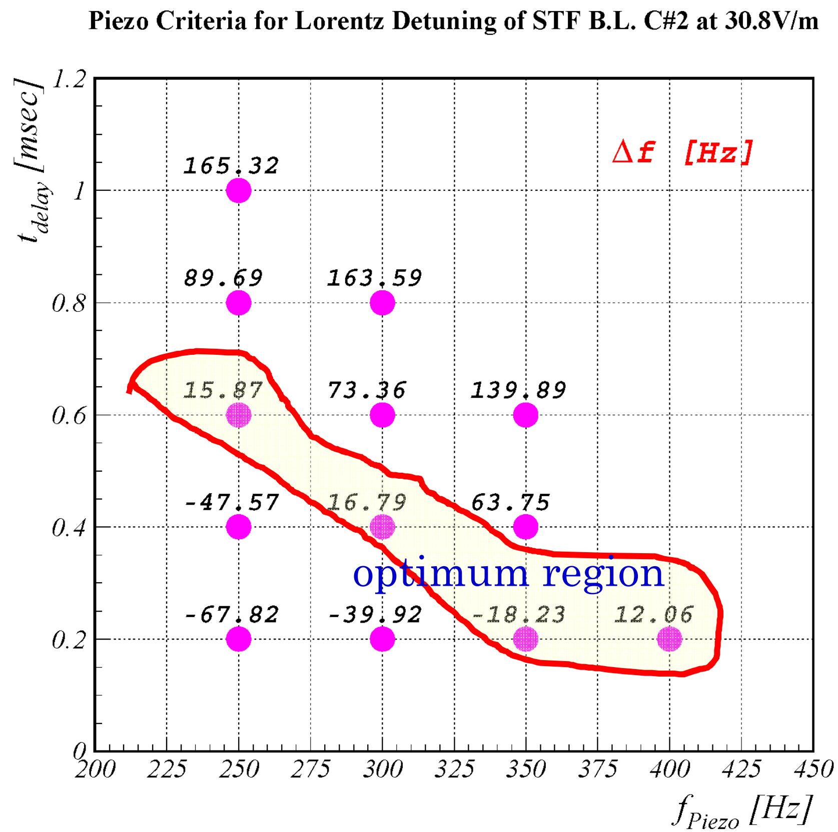
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

Optimum condition of Piezo action ②

f_{SG}=1300.500000MHz, Feed Back Off

f_{offset}/V_{piezo}=360Hz/500V





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f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

Schilcher & Brandt's Method

Schilcher

The solution for $\mathbf{V}(t) = \begin{pmatrix} V_r \\ V_i \end{pmatrix}$ is defined on intervalls with continuous function $f(t)$. In the case of $Q_L \gg 1$, $\omega_{1/2} \ll \omega_0$ and $\Delta\omega \ll \omega_0$, we obtain the approximation

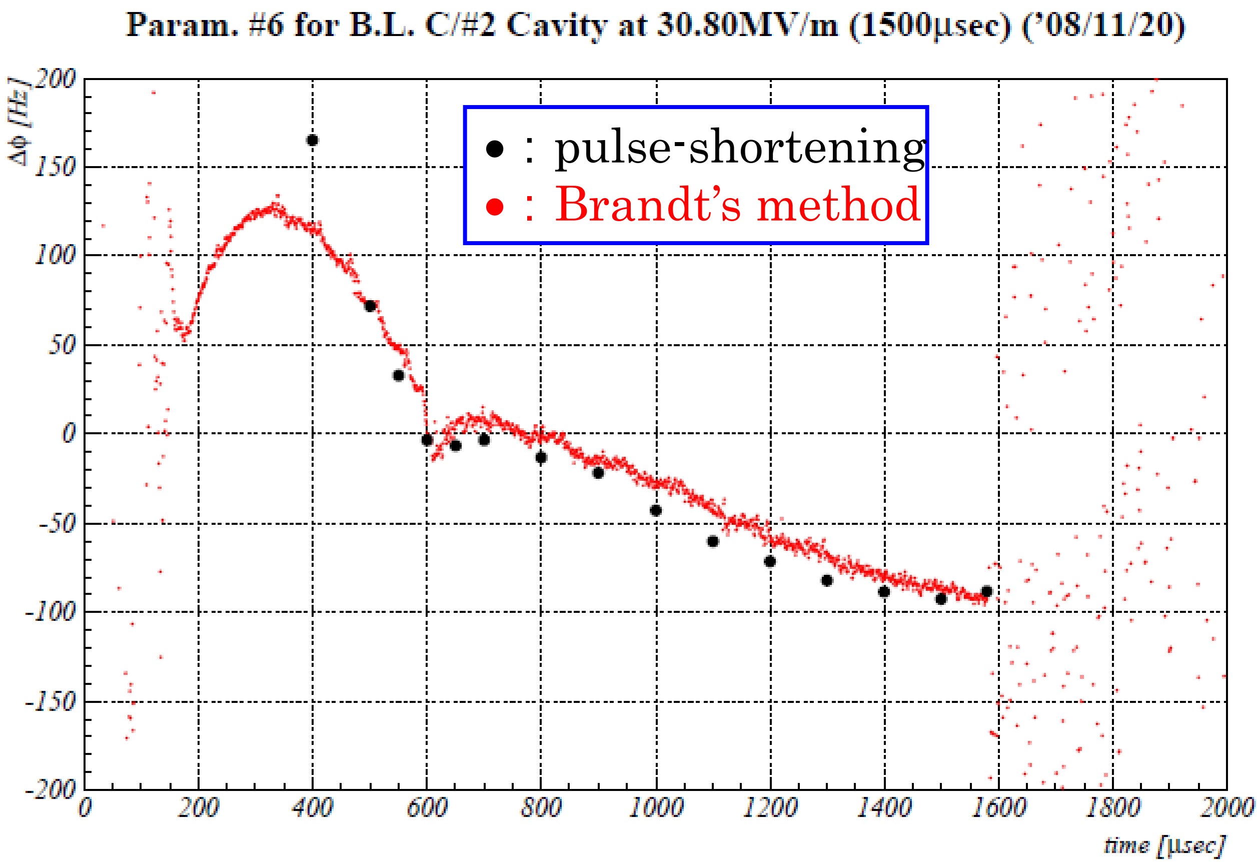
$$\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix} V_r \\ V_i \end{pmatrix} = \begin{pmatrix} -\omega_{1/2} & -\Delta\omega \\ \Delta\omega & -\omega_{1/2} \end{pmatrix} \cdot \begin{pmatrix} V_r \\ V_i \end{pmatrix} + \begin{pmatrix} R_L\omega_{1/2} & 0 \\ 0 & R_L\omega_{1/2} \end{pmatrix} \cdot \begin{pmatrix} I_r \\ I_i \end{pmatrix} .$$

Brandt

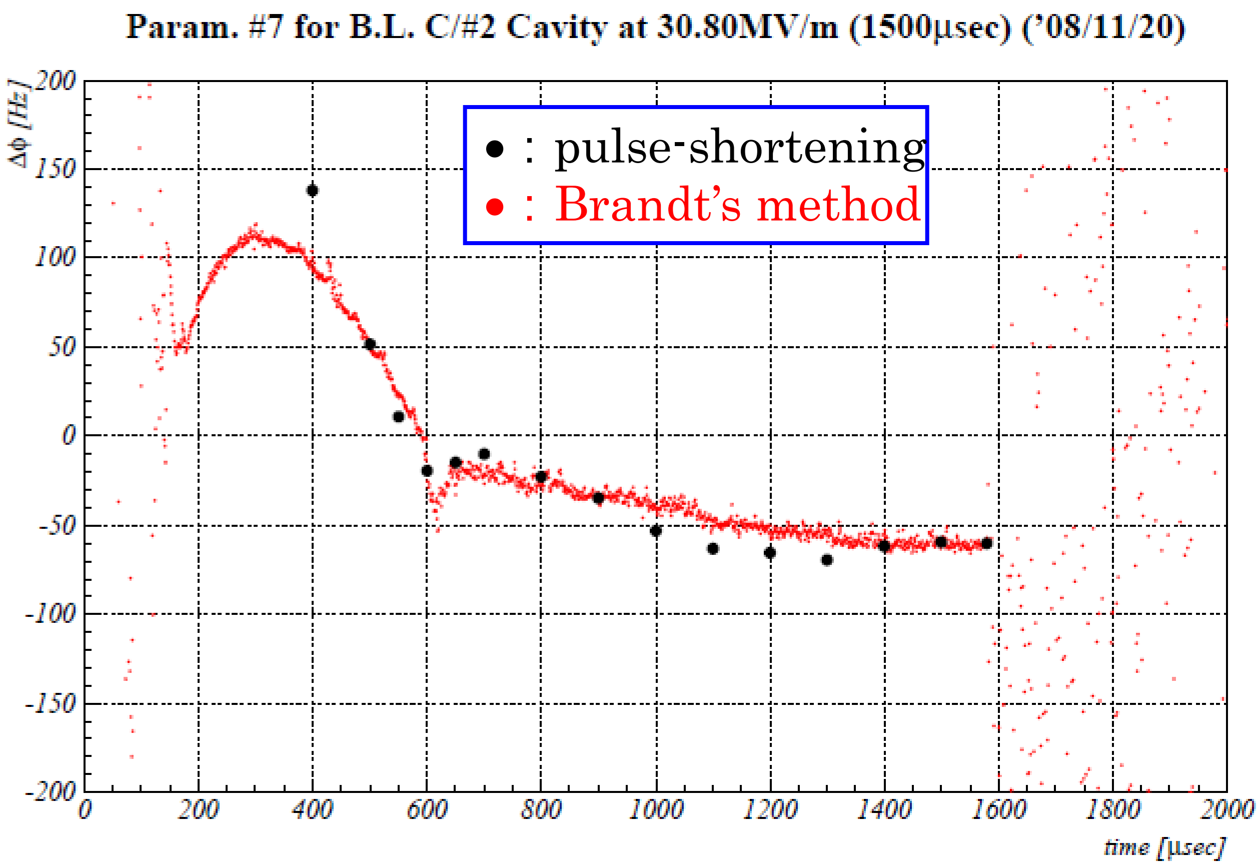
$$\Delta\omega = \dot{\varphi} - \omega_{1/2}\frac{\rho}{r}\sin(\theta - \varphi). \qquad (4.37)$$

Only the phase difference between input and output to cavity is effective!

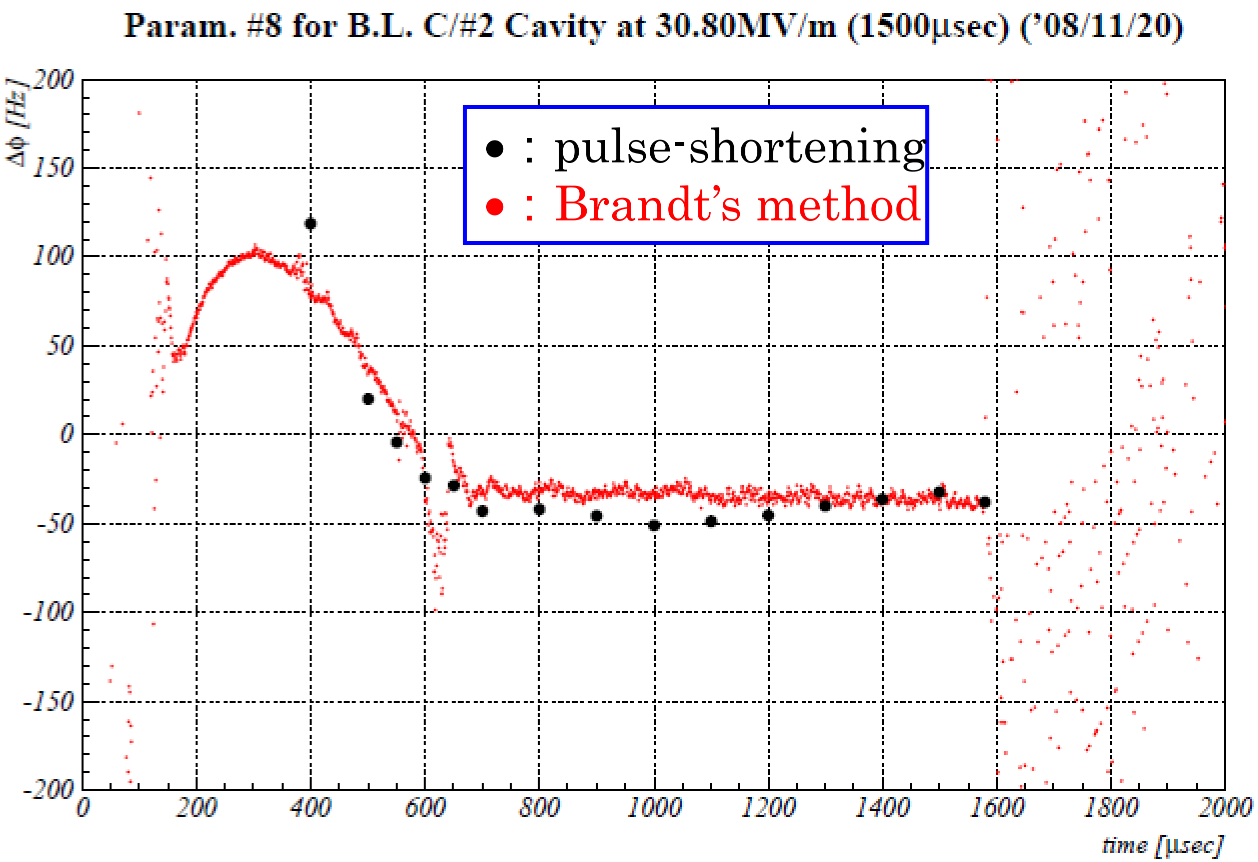
Best Compensation #1 @C/#2 (2008/11/20)



Best Compensation #2 @C/#2 (2008/11/20)



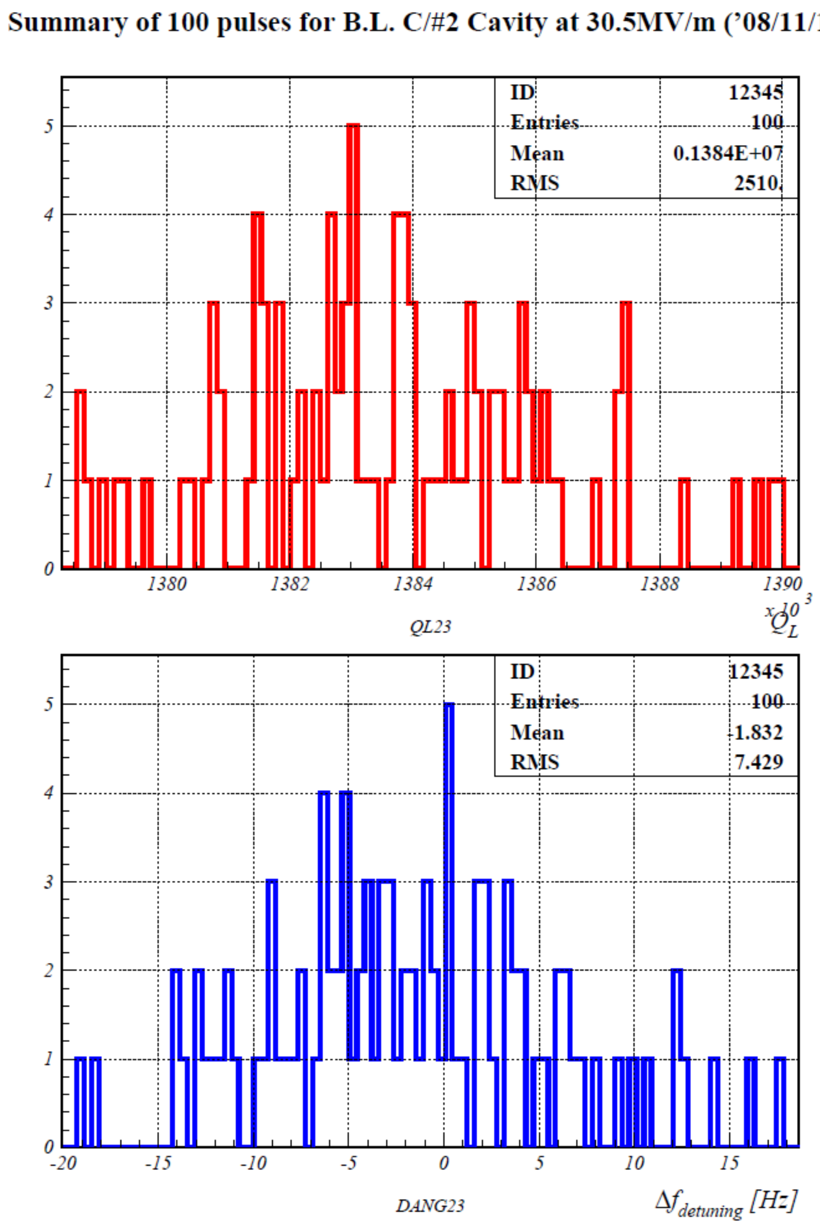
Best Compensation #3 @C/#2 (2008/11/20)



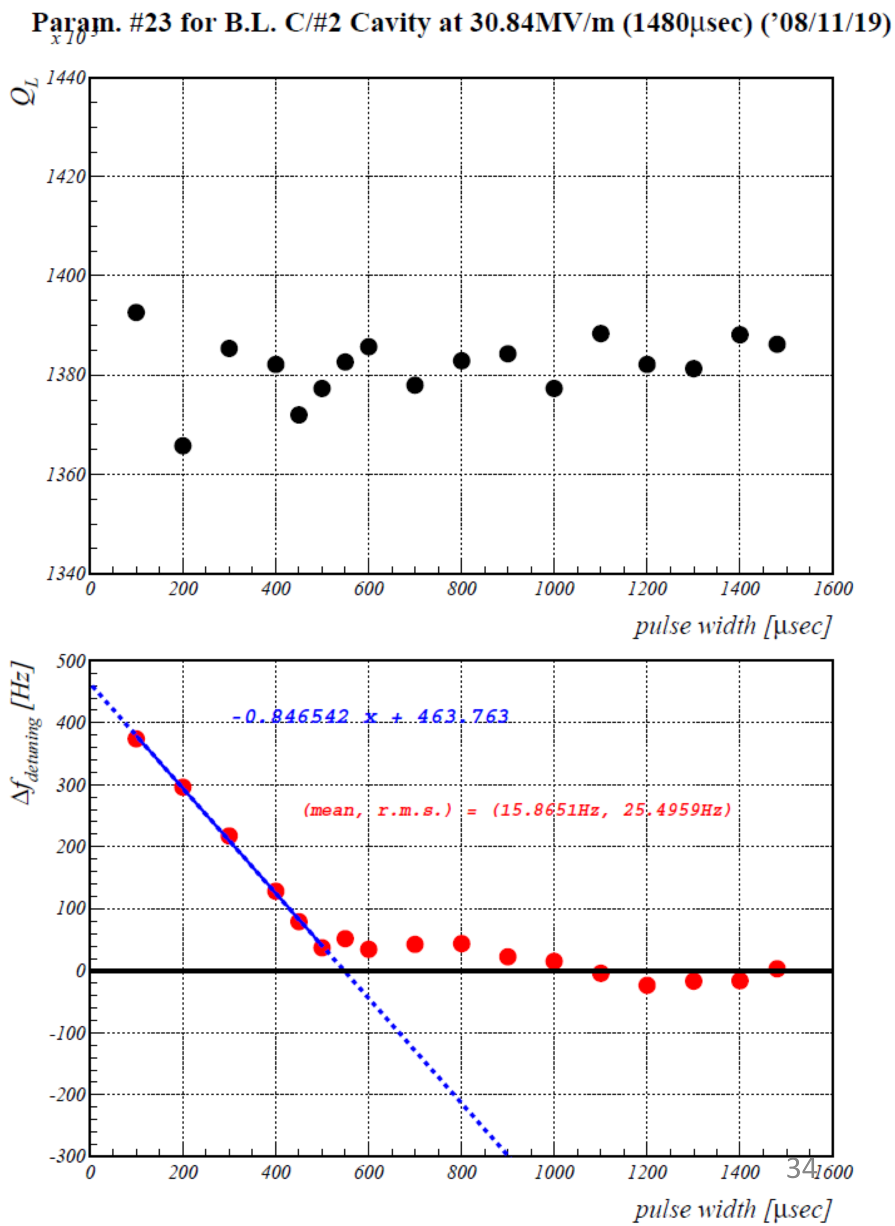
These two results are consistent each other.

１００パルスとパルスカットの結果との比較①

100パルスの結果



パルスカットによる結果



5種のパラメータの比較のまとめ

	f_{offset} / V_{piezo} / f_{piezo} / t_{delay}					
Parameter	peak-to-peak for amplitude for 100p	peak-to-peak for phase for 100p	Q_L for 100p	ψ for 100p	Q_L for p.c.	ψ for p.c.
#23	360Hz / 500V / 250Hz / 0.6msec					
	5.0%	13.4°	1.38×10^6	-1.8Hz	1.38×10^6	15.9Hz
#27	360Hz / 500V / 300Hz / 0.4msec					
	5.2%	11.3°	1.38×10^6	21.0Hz	1.38×10^6	16.8Hz
#30	360Hz / 500V / 350Hz / 0.2msec					
	5.6%	13.6°	1.38×10^6	15.0Hz	1.38×10^6	-18.2Hz
#33	360Hz / 500V / 400Hz / 0.2msec					
	5.6%	8.6°	1.38×10^6	60.0Hz	1.38×10^6	12.1Hz
#35	360Hz / 400V / 350Hz / 0.4msec					
	5.6%	12.7°	1.39×10^6	-7.5Hz	1.38×10^6	8.3Hz

パラメータ#33のみやや差が大きいように見えるが、その他は概ね一致してい

Cavity Voltage Equation

From J. Slater

$$\frac{d^2}{dt^2}V(t)+(1+j\frac{Q_L}{Q_o})\frac{\omega_o}{Q_L}\frac{d}{dt}V(t)+\omega_o^2V(t)=U(t)$$

$$\tilde{V}=\tilde{V}_d+(\tilde{V}_o-\tilde{V}_d)\boxed{\exp(-\frac{t}{T_F})\exp(j\frac{\tan\psi}{T_F}t)}$$

Equi-angular Spiral

各項の係数が時間に関して一定であるなら解析的に解けるが、そうでない場合はどうす

Example of the calculation for the transient response

Q_L=1.49x10^6, f_{init}=0Hz, Δf_{Input}=0.5Hz/μsec, 180Hz/370Hz

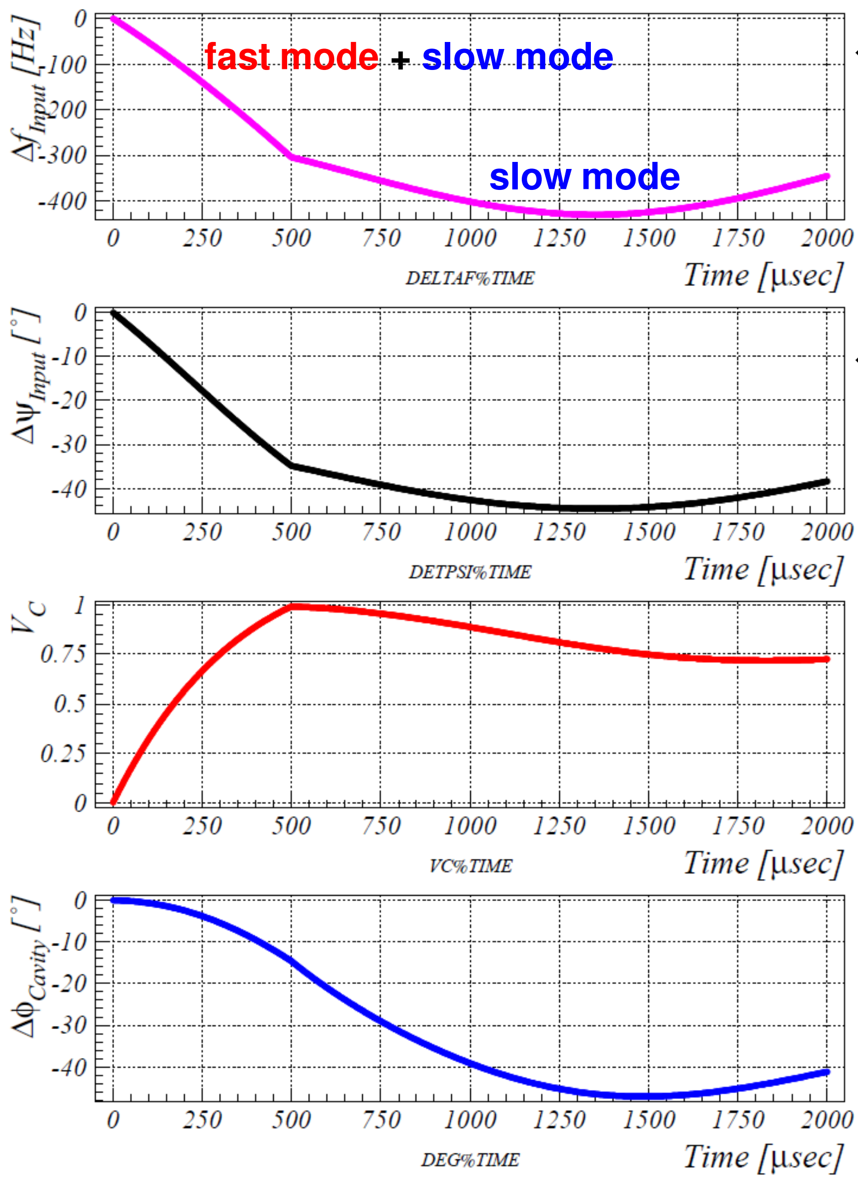
Input data (frequency)

$\tan\Psi = -2Q_L\Delta f/f_0$

Input data (degree)

Output data (V_C)

Output data (φ_{Cavity})

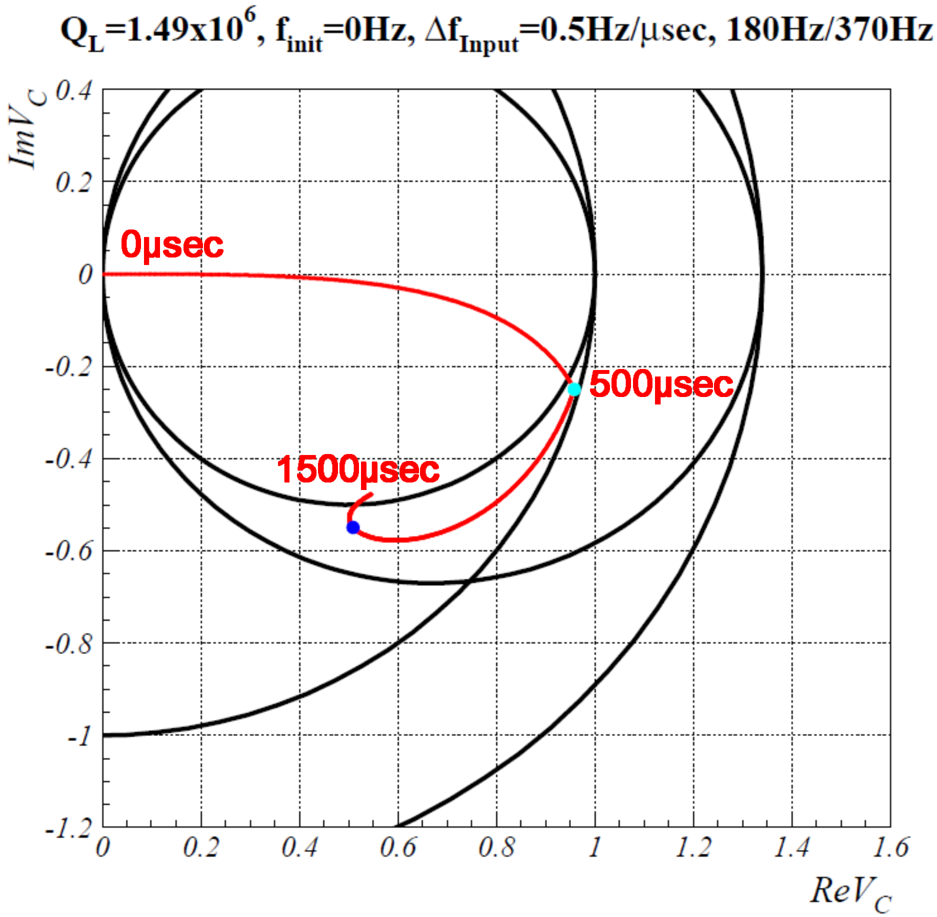


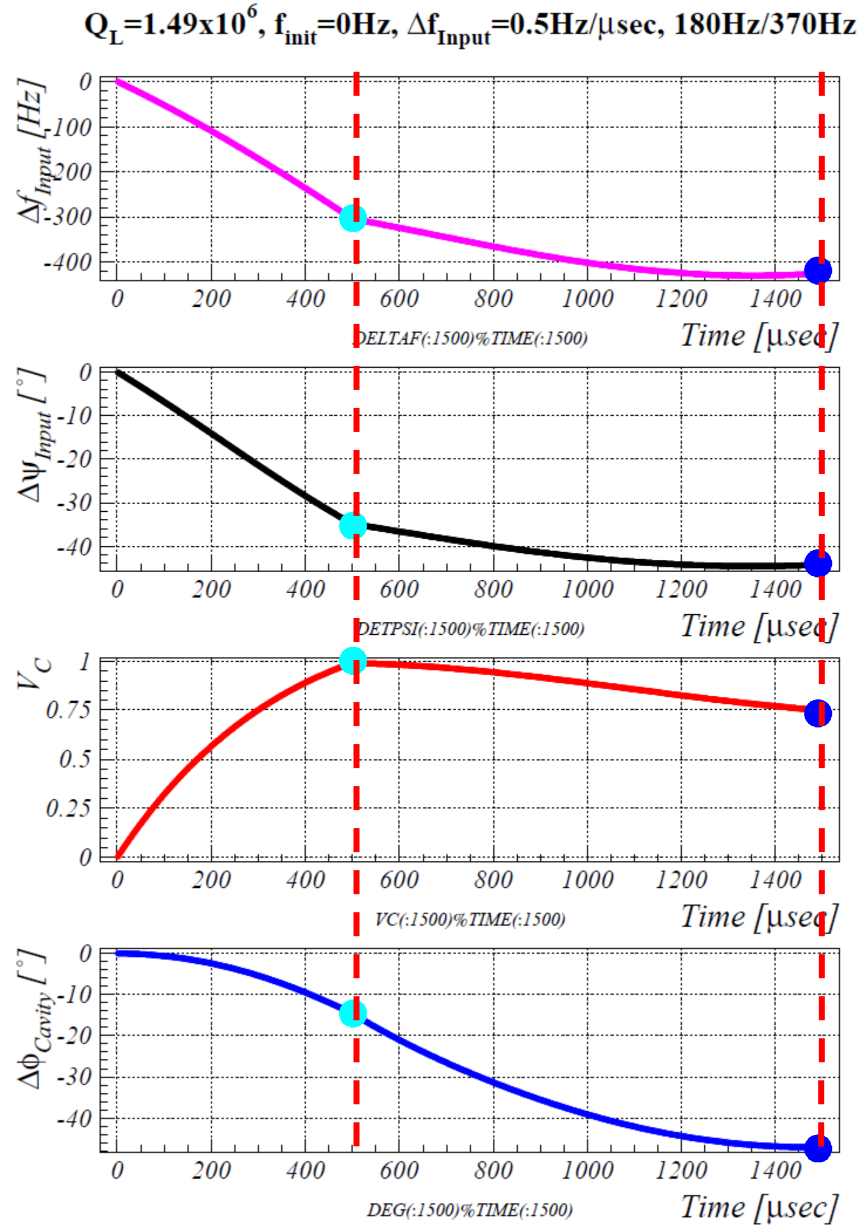
仮定①
立ち上がりはfastとslowの
2つのモードが混在する。
flat-topではslowモードのみが
寄与し、fastは無くなる。

仮定②
fast modeは時間に対して
直線的に変化するものとする
一方、slow modeはsine的な
変化をするものとする。

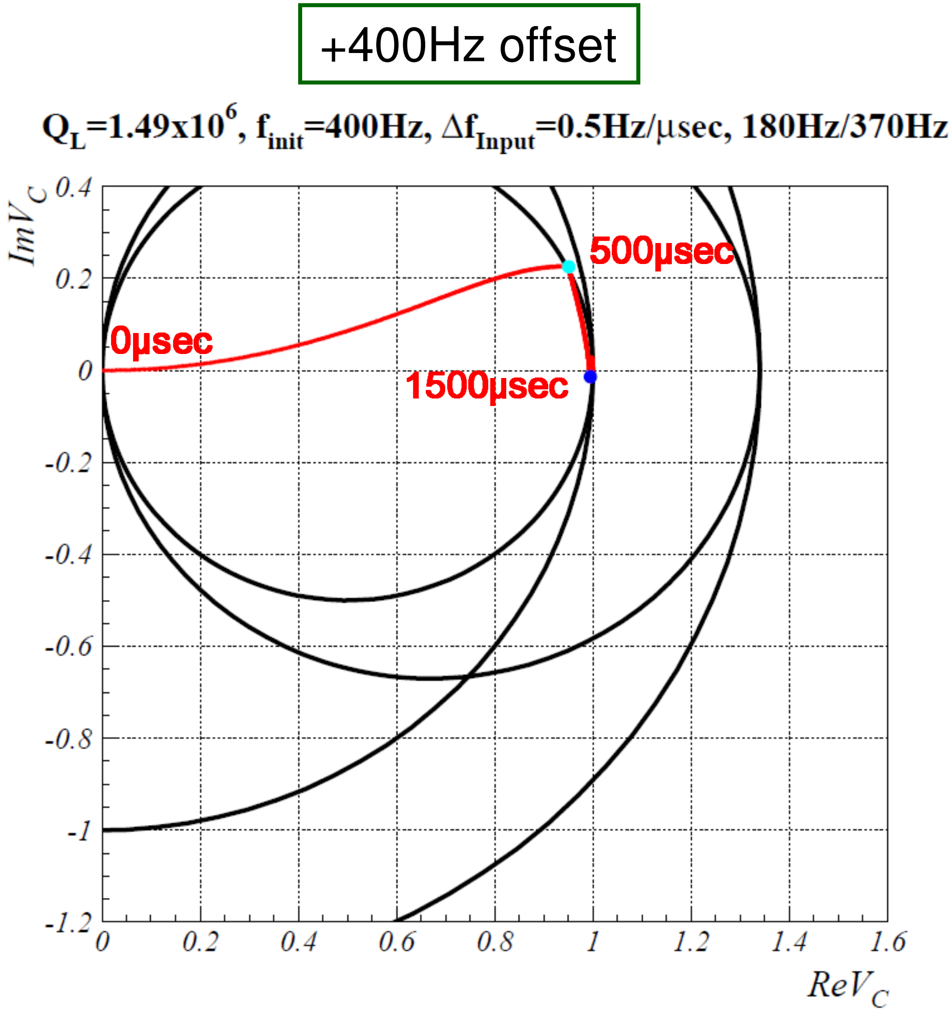
Example of the calculation for the transient response①

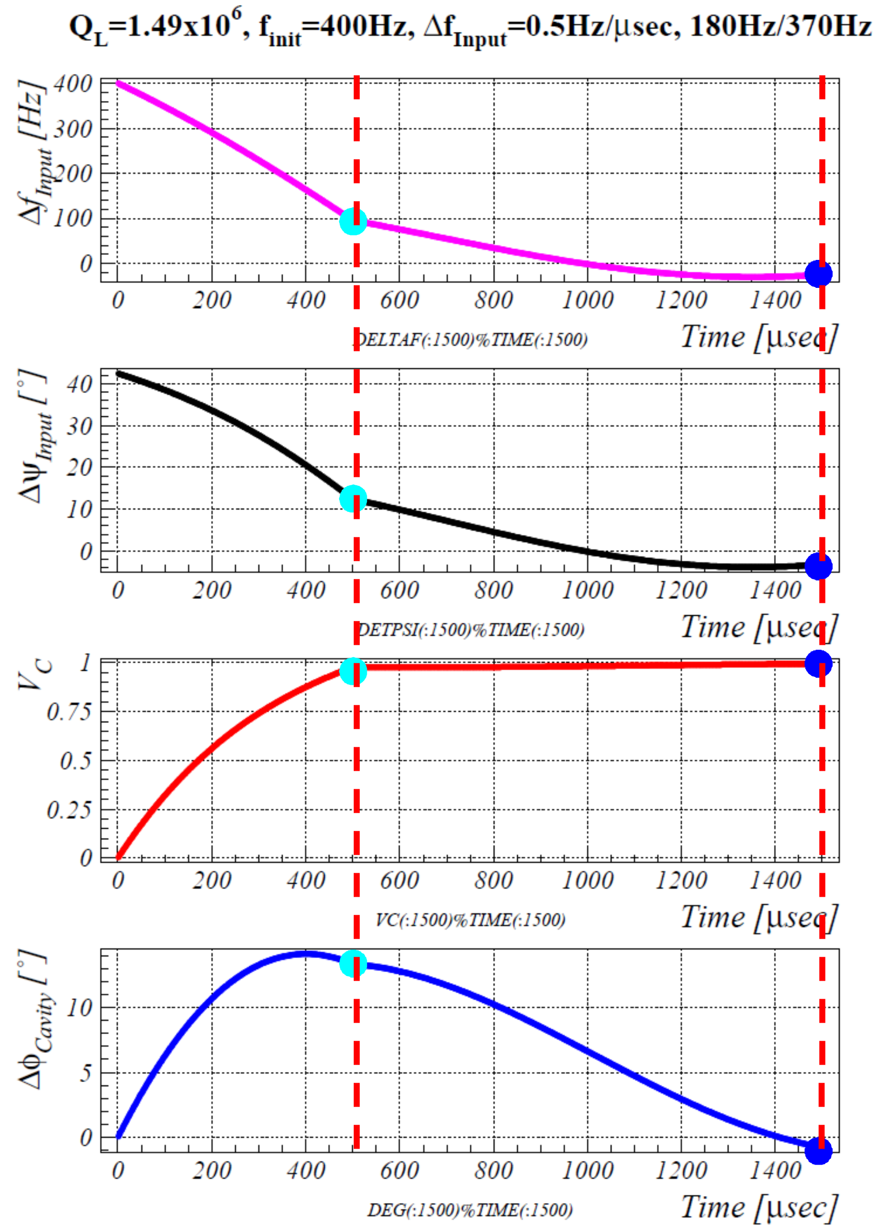
No offset





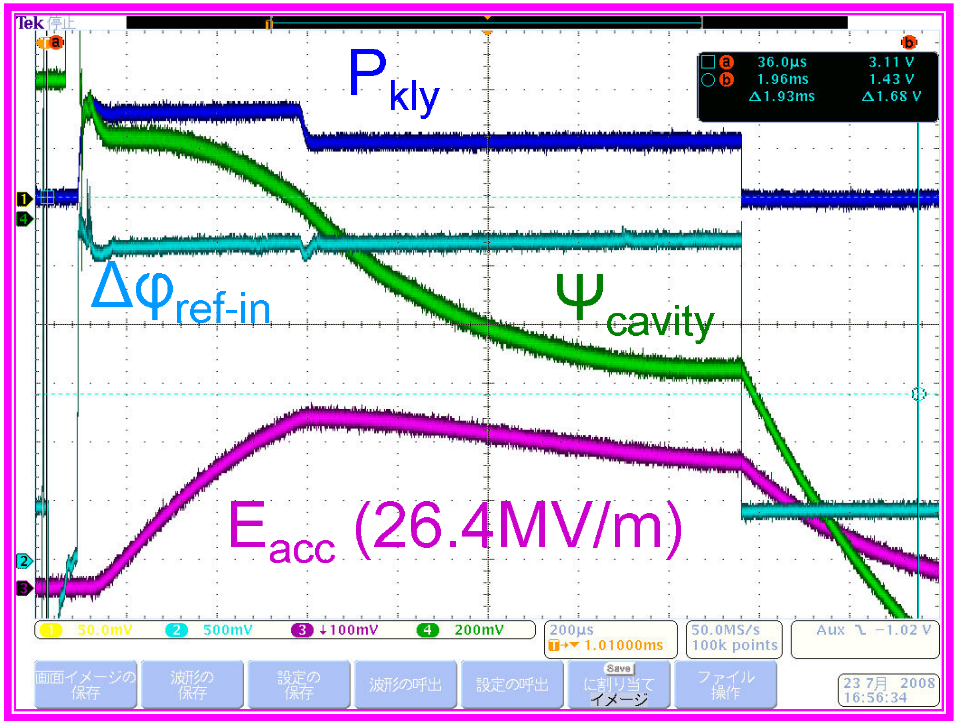
Example of the calculation for the transient response②



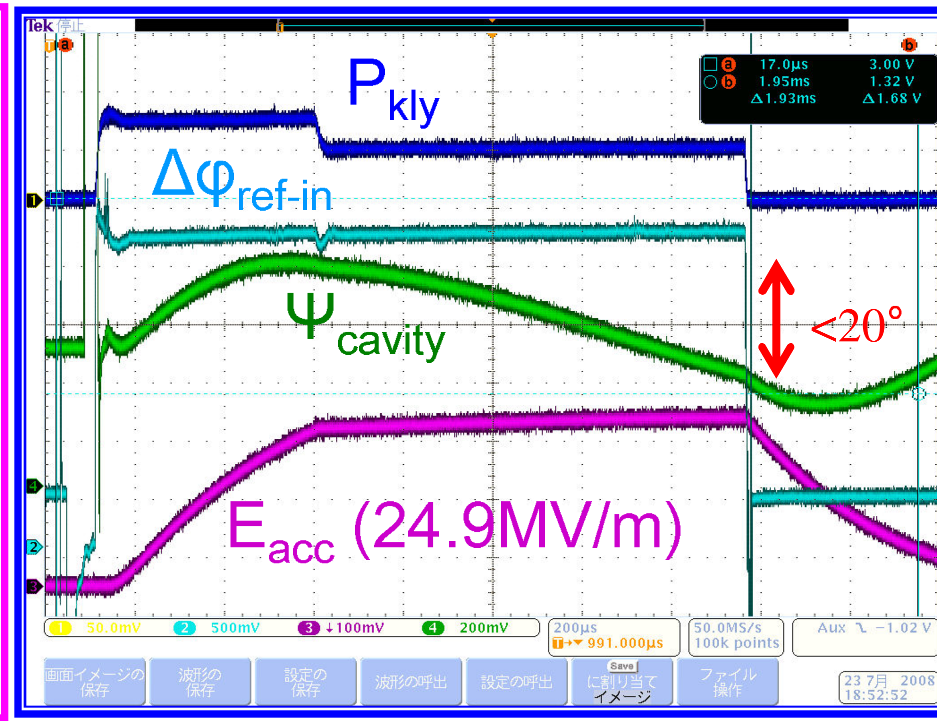


ハイパワーテスト時の波形

No offset

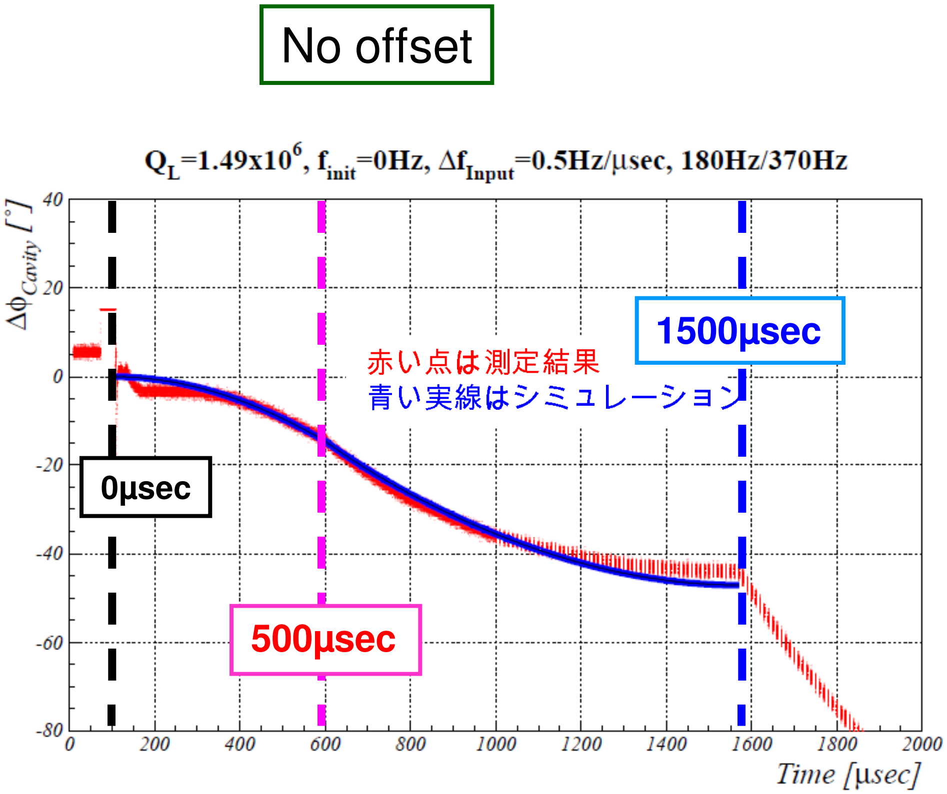


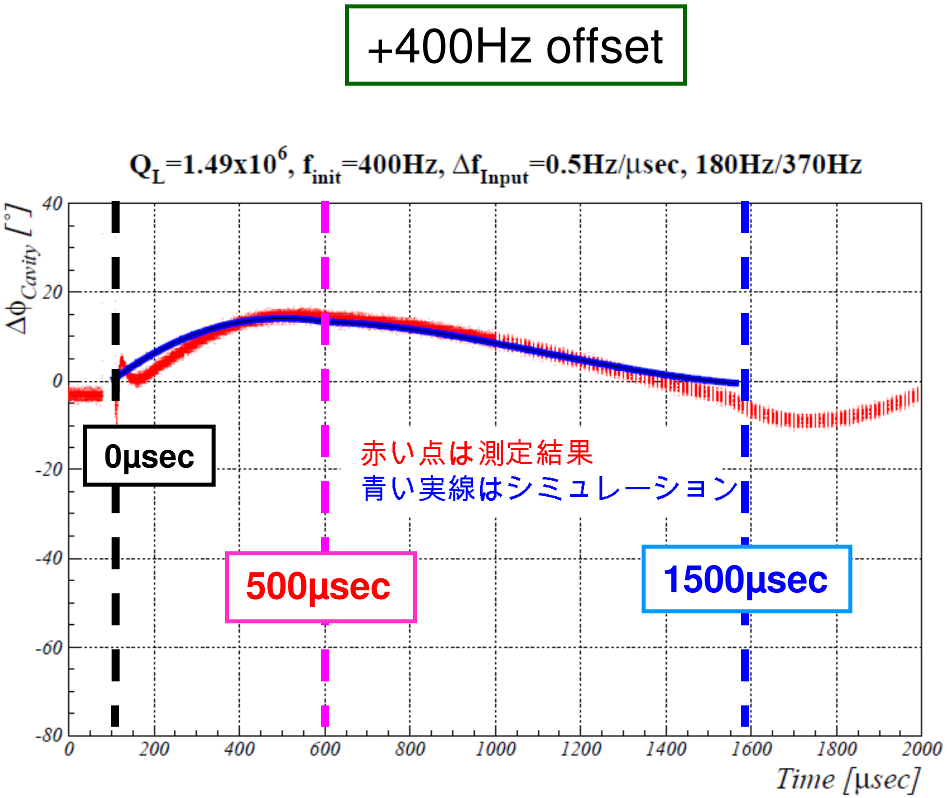
+400Hz offset



周波数にオフセットが無い場合は、観測される空洞の位相は大きく変化し、
かつフィールドも傾いてしまう。
しかし、少しオフセットを持たせると位相の変化は少なく、フィールドもほぼflatにな
この状態から残っているずれ量をピエゾで補正すればよい。
オフセットの量が適当でないとピエゾに過度の負担がかかり消耗が激しくなると予想さ

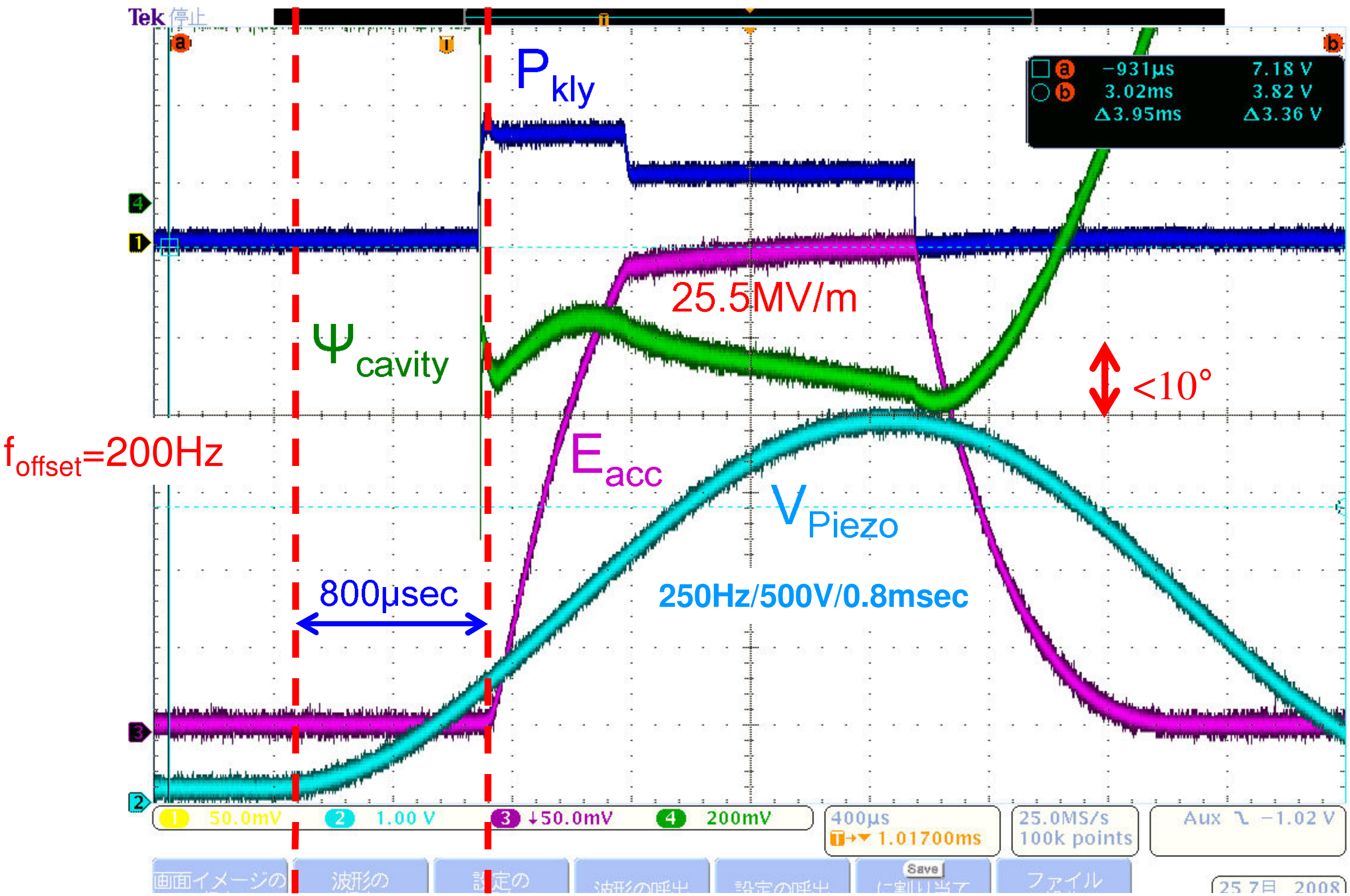
Comparison between experiment and calculation





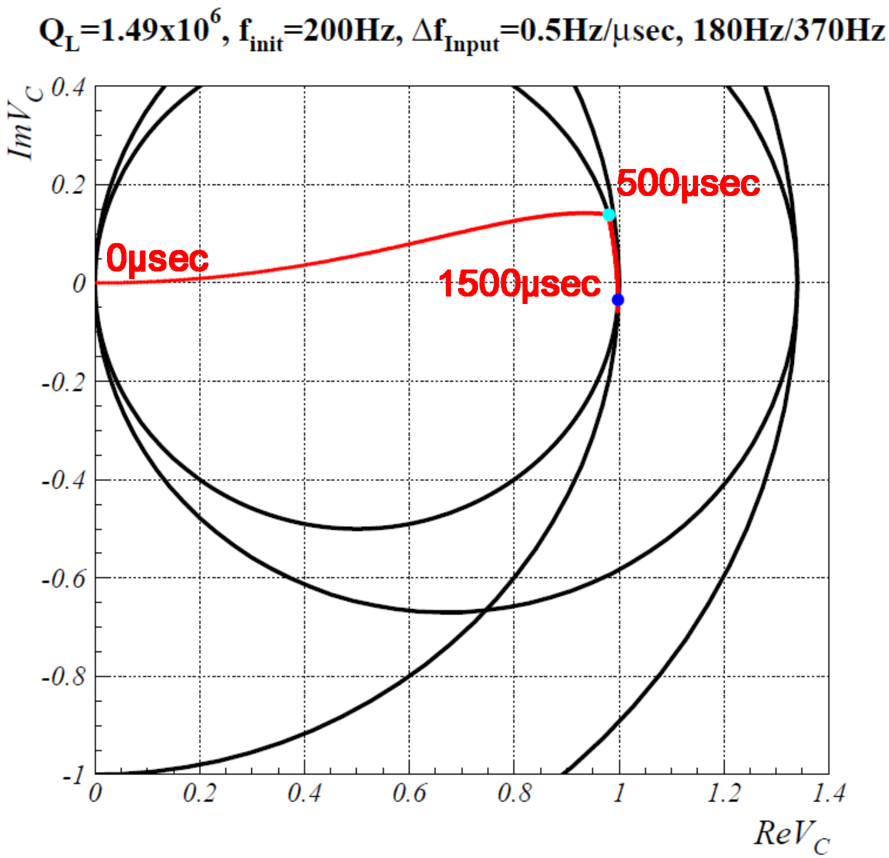
計算結果は実験データを良く再現している。
“Two Modes Model”が妥当であることを意味している。

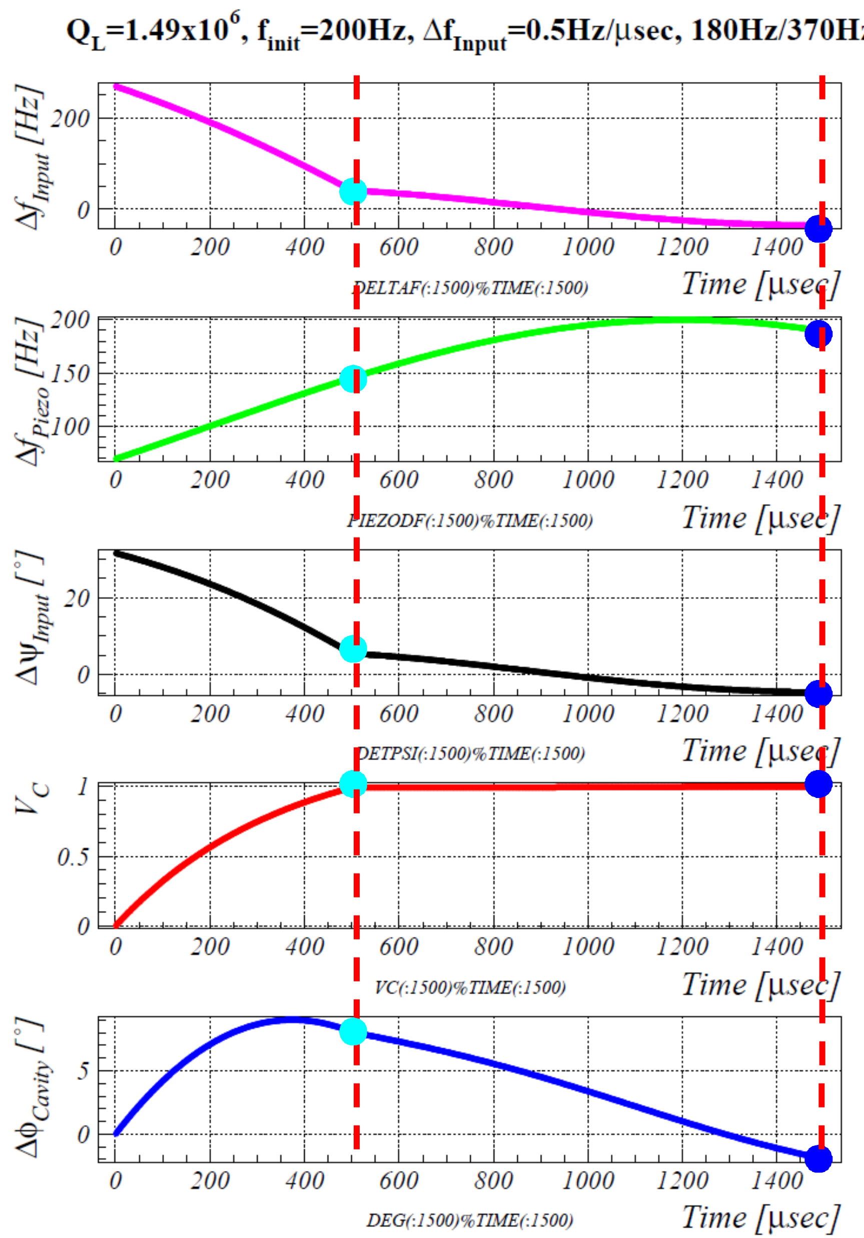
Piezo Compensationの測定例



resonanceからのずれを±50Hz(6.5°)程度に収めるには、空洞周波数に初期オフセットを設
さらにPiezoを振って補正する必要がある。

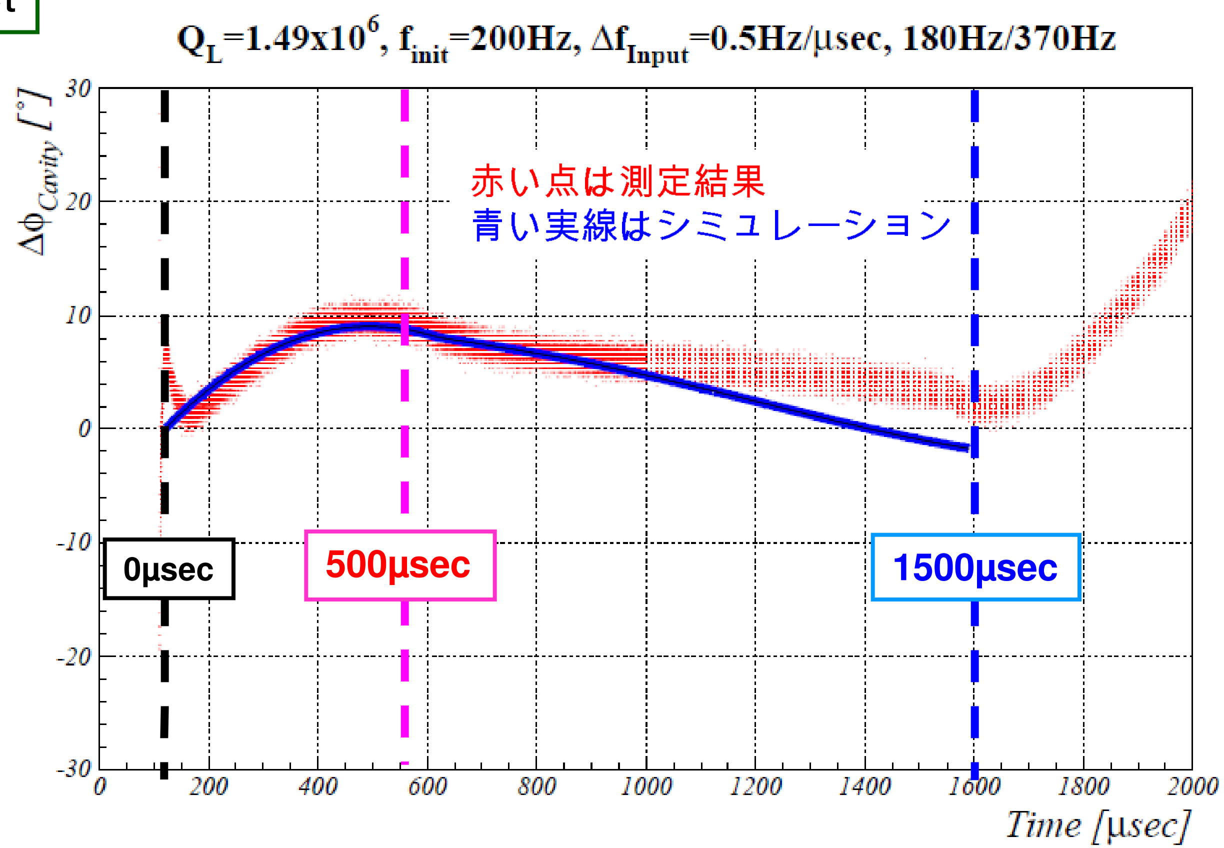
Example of the calculation for the Piezo compensation





Comparison between experiment and calculation for Piezo compensation

+200Hz offset



flat-topの振る舞いがデータと微妙に異なるが、状況をほぼ再現しているといえる