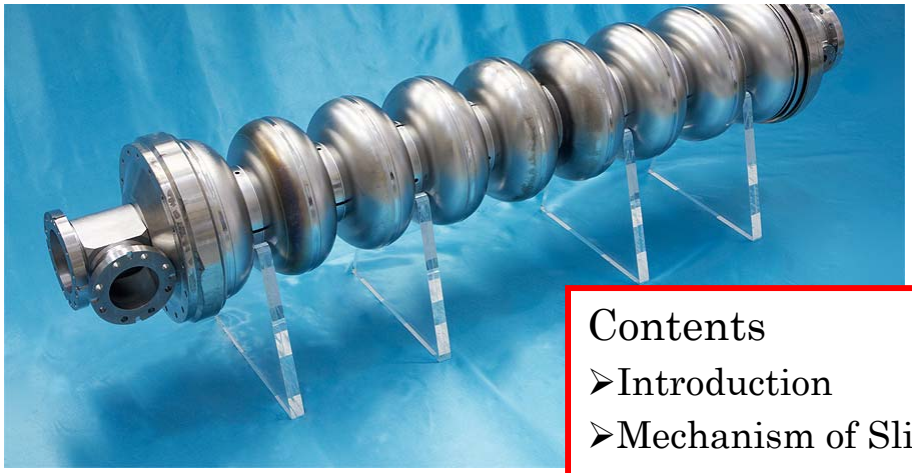
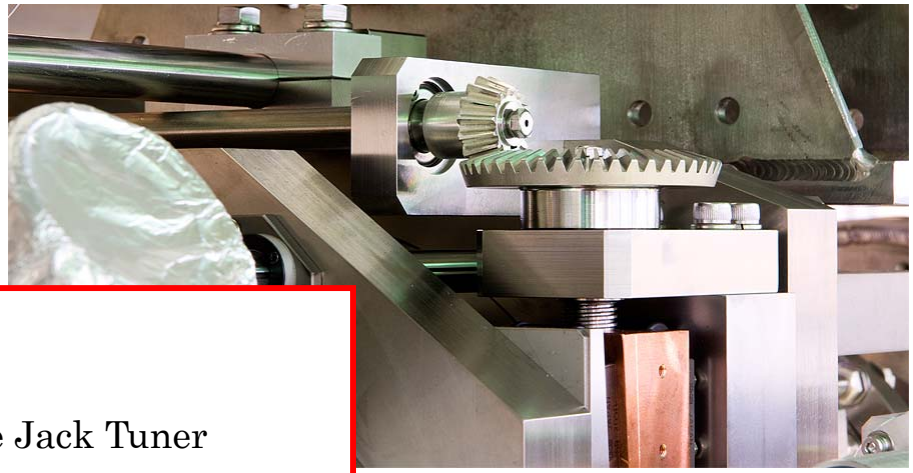
Measurement and Compensation of Lorentz Detuning at STF Phase-1.0





Contents

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- Mechanism of Slide Jack Tuner
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- Piezo compensation
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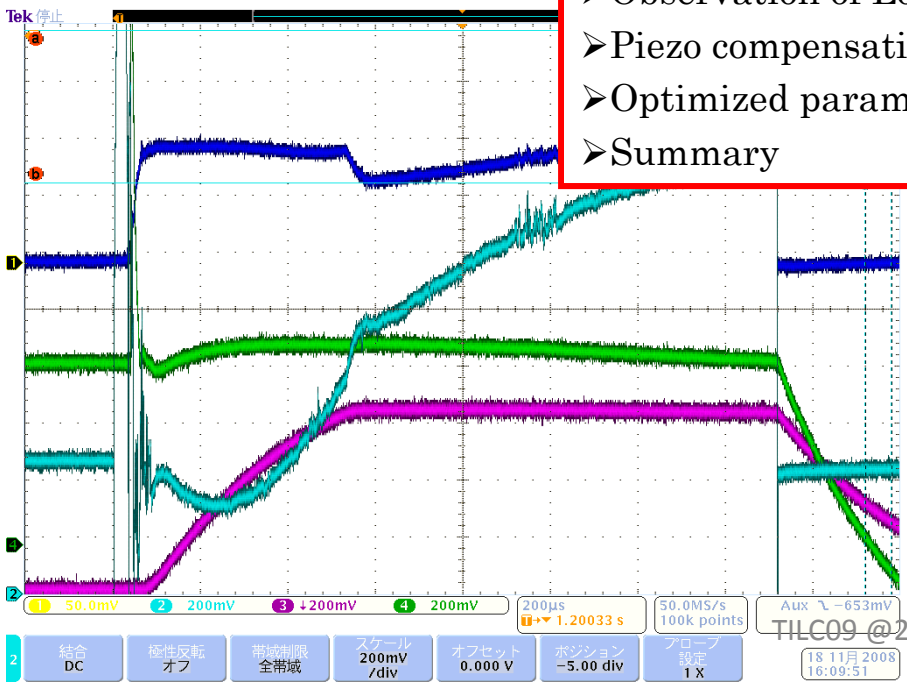
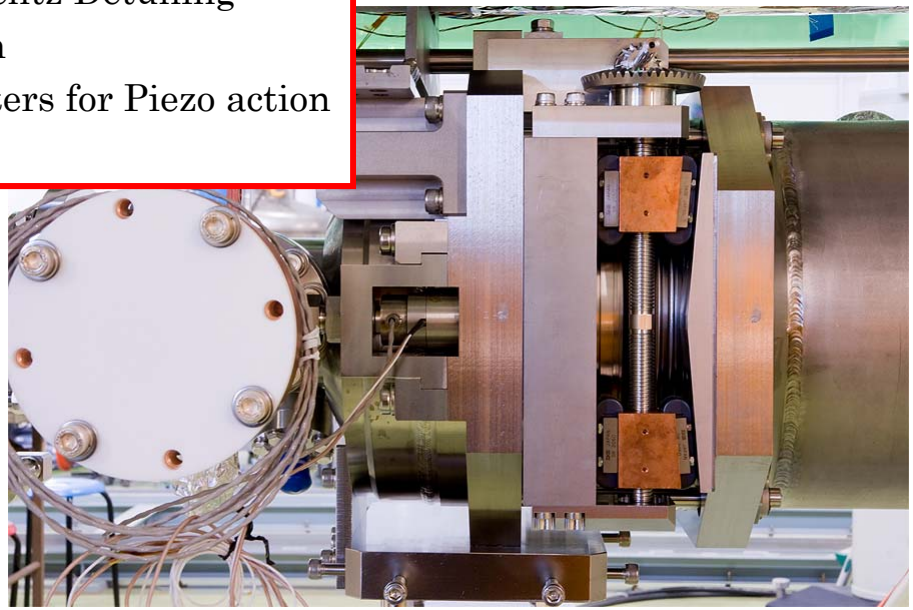
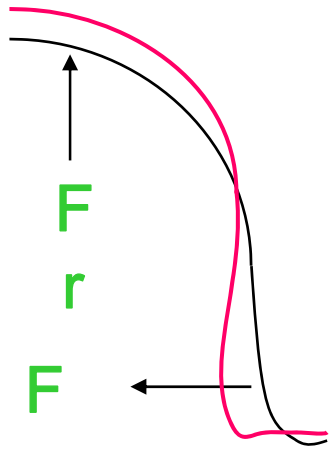




Kirk

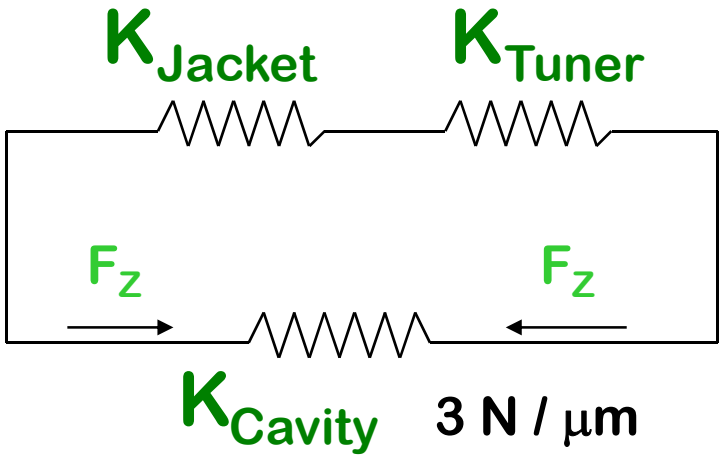
Stiffness of STF-BL Cavity-Tuner System



Lorentz Force Detuning

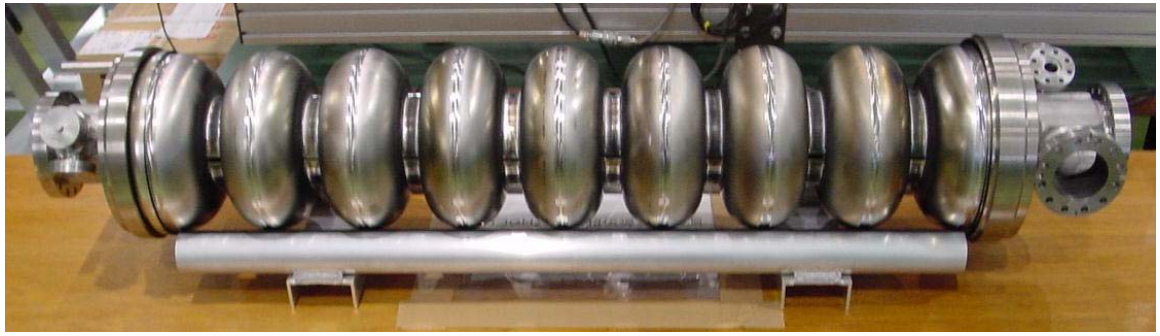
95 N / μm
(endplate, cylinder, flange)

290 N / μm
(slide-jack, piezo)



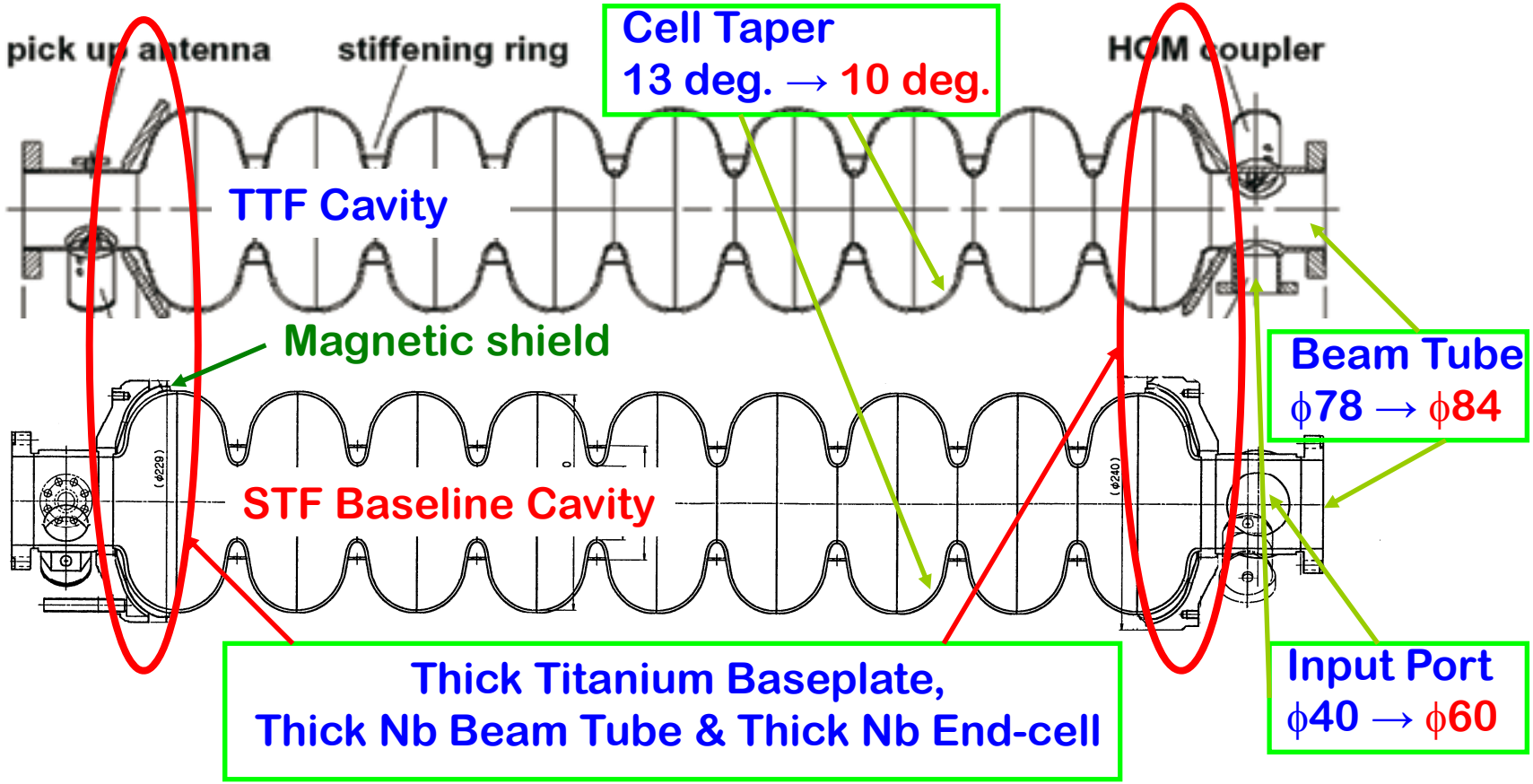
$$\frac{1}{K_S} = \frac{1}{K_{Jacket}} + \frac{1}{K_{Tuner}}$$

K_S = 72 kN / mm



from E. Kako

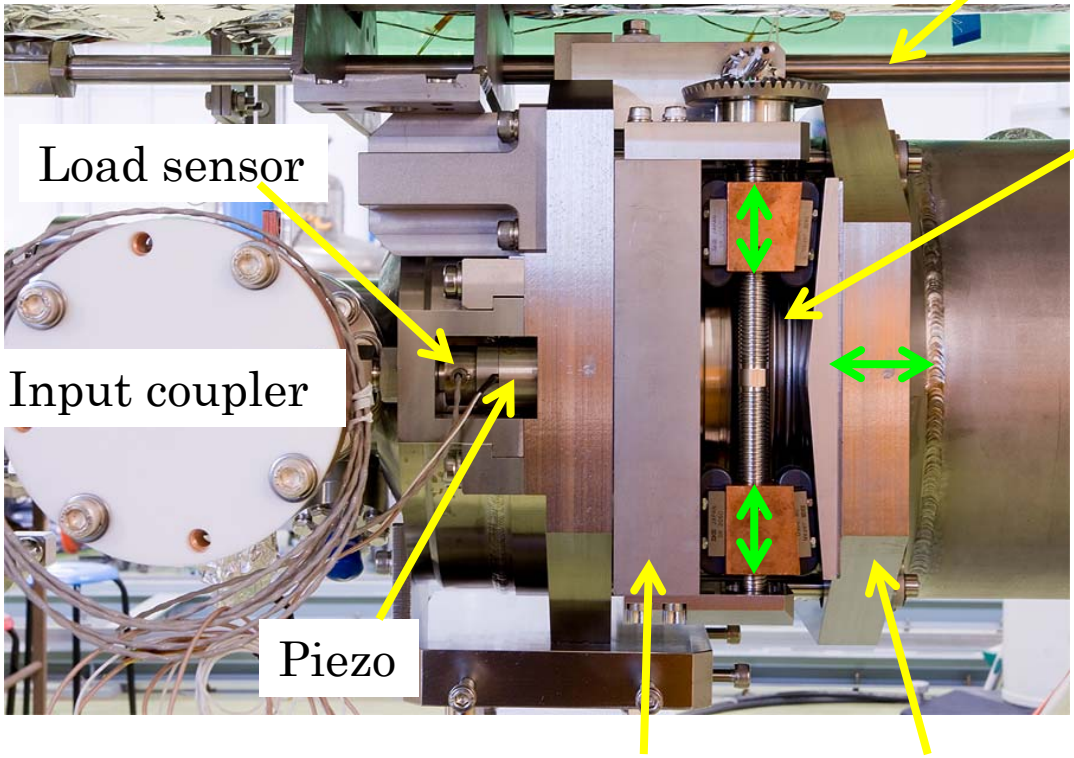
STF Baseline Cavity ; Improved Stiffness



	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

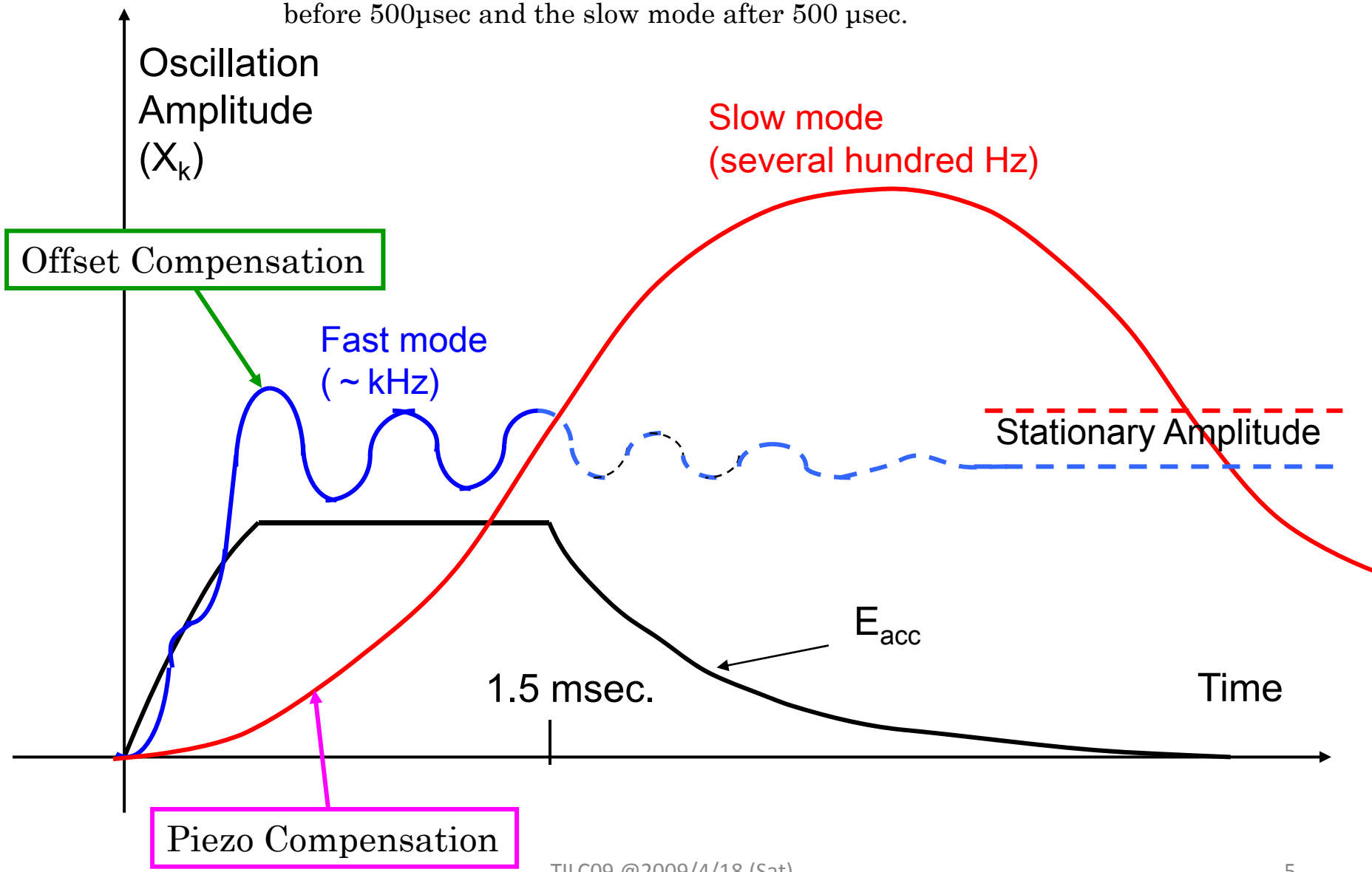
Mechanism of Slide-Jack Tuner



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)

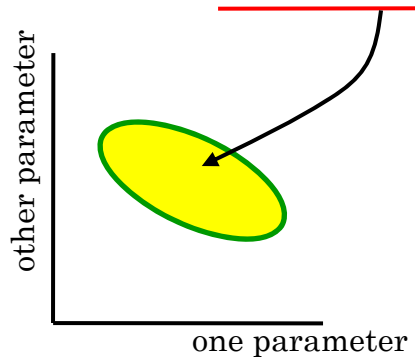
Very roughly speaking, the fast mode is mainly contributed to the Lorentz Detuning before 500μsec and the slow mode after 500 μsec.



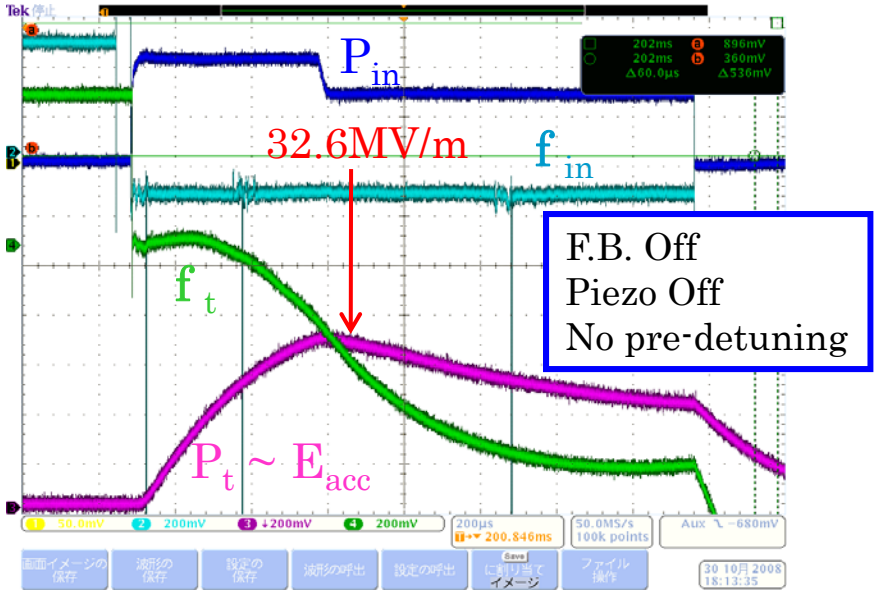
Adjustable parameters for compensation of Lorentz Detuning

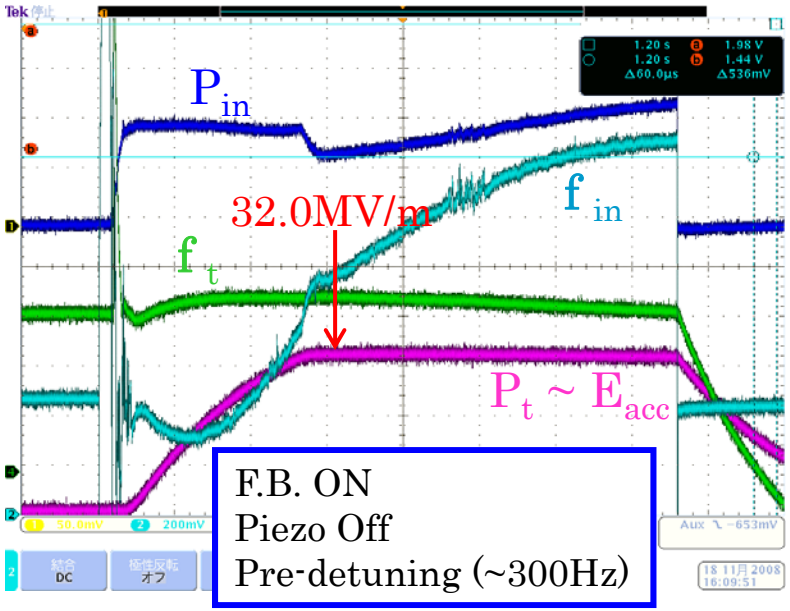
- f_{offset} : Initial offset of cavity frequency
- V_{Piezo} : Driving voltage of Piezo actuator
- f_{Piezo} : Driving frequency of Piezo actuator
- t_{delay} : Timing difference between RF pulse and Piezo action

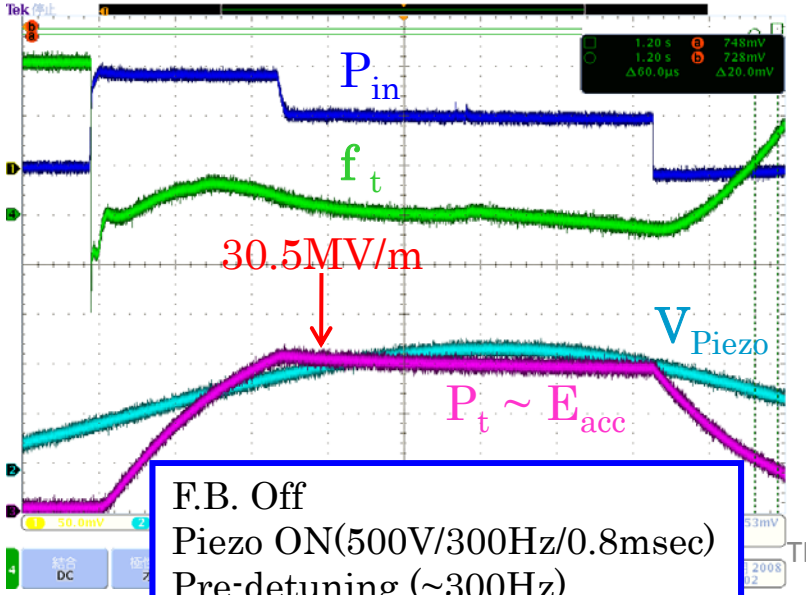
If two parameters are fixed within these four parameters, we can obtain matrix data for optimum region of Piezo action.

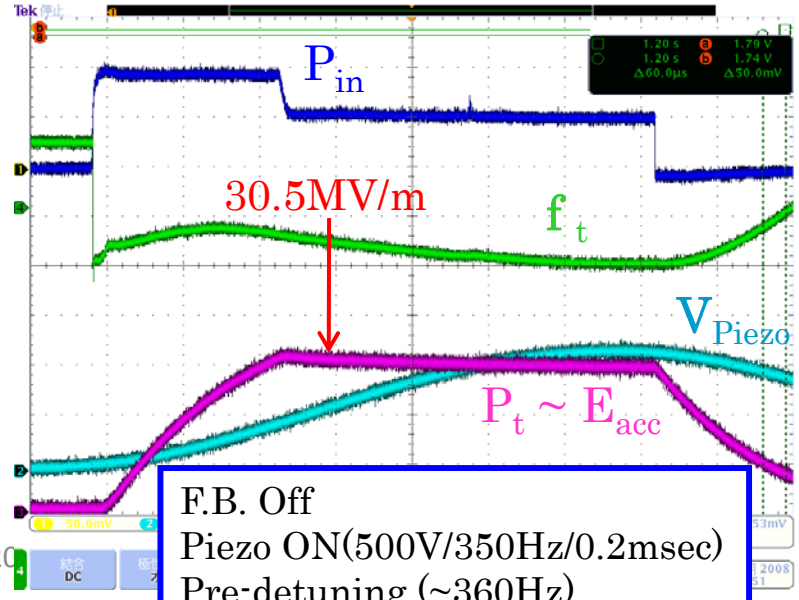


Observation of Lorentz Detuning



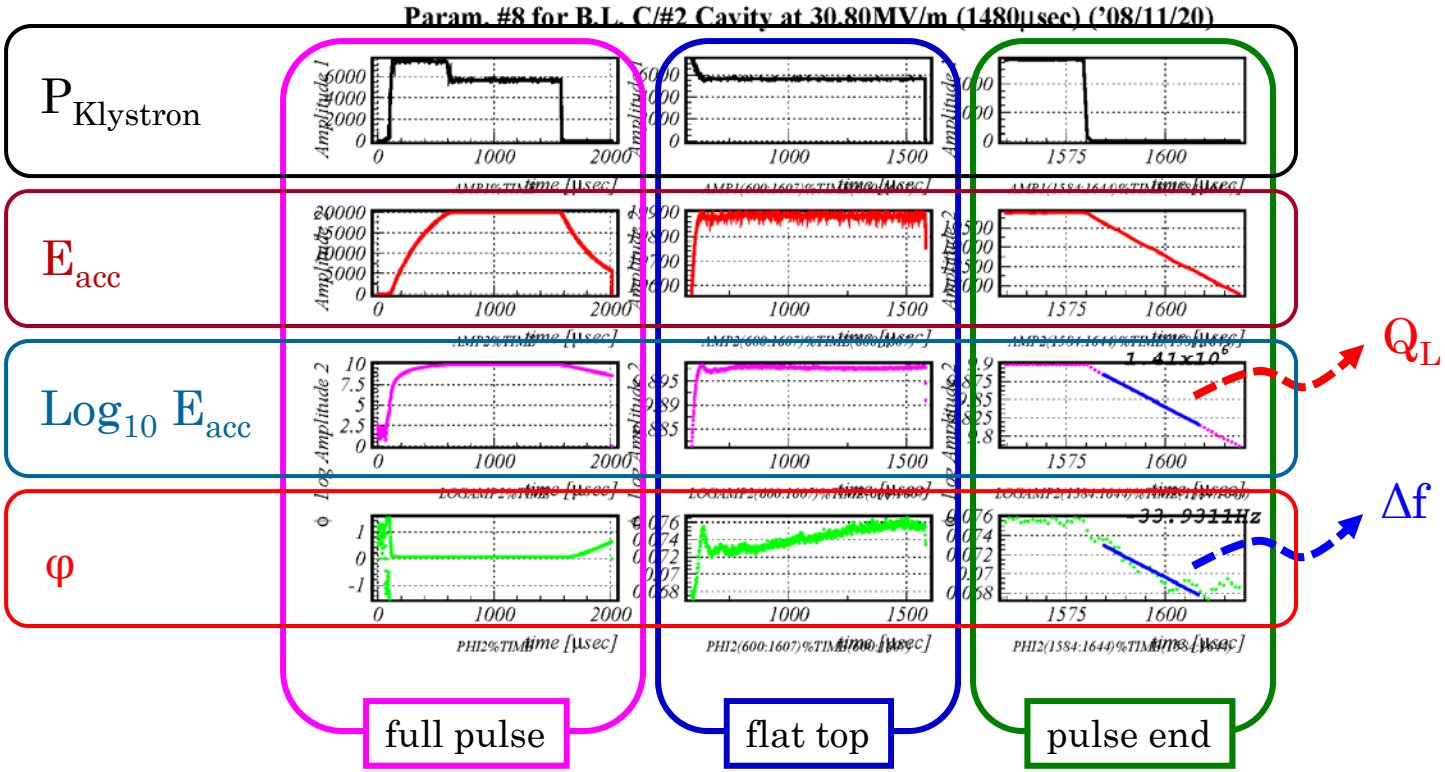






Example of measurement for Q_L & Δf

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!



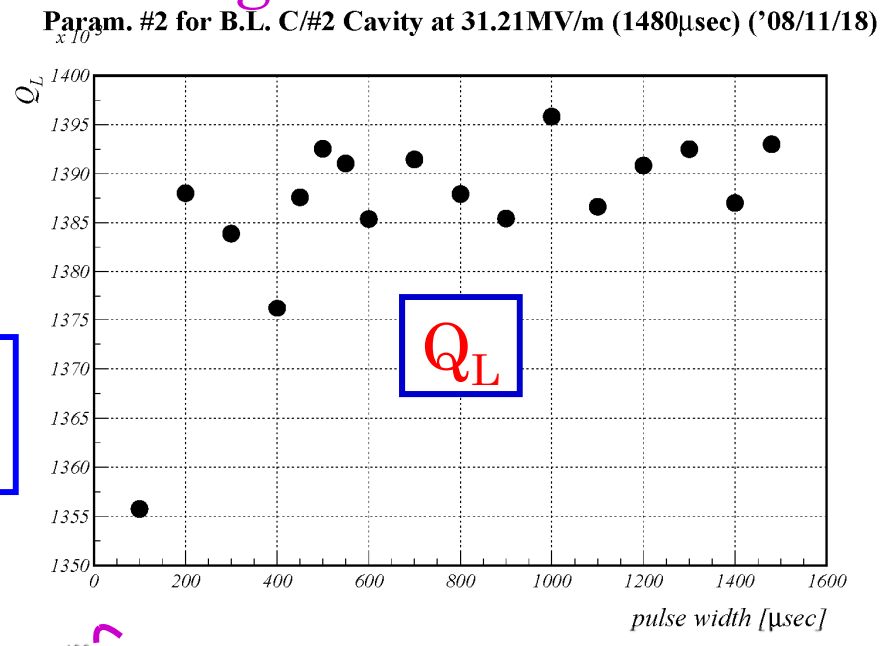
measurement timing:
100, 200, 300, 400, 450, 500, 550, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1480μsec

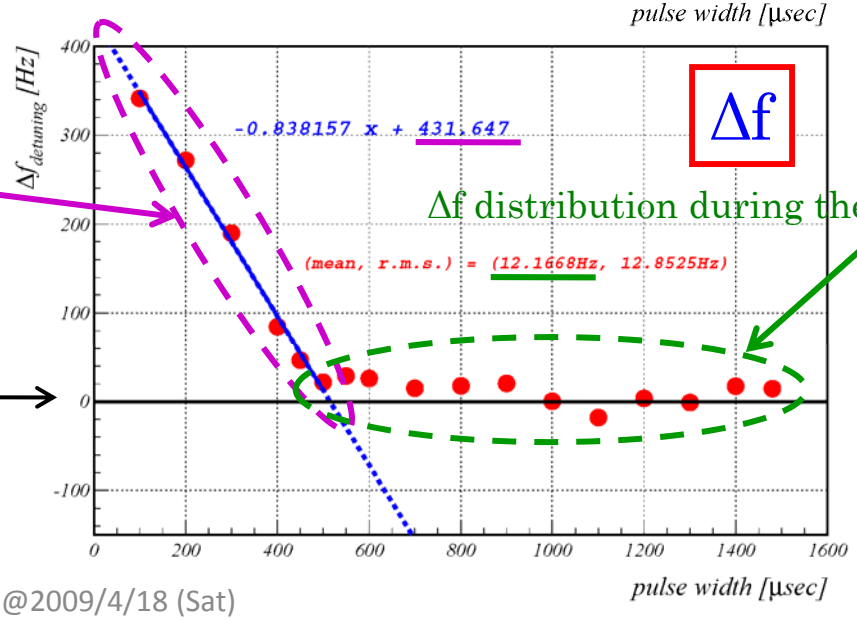
totally 17 points!

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

Δf distribution during the flat-top

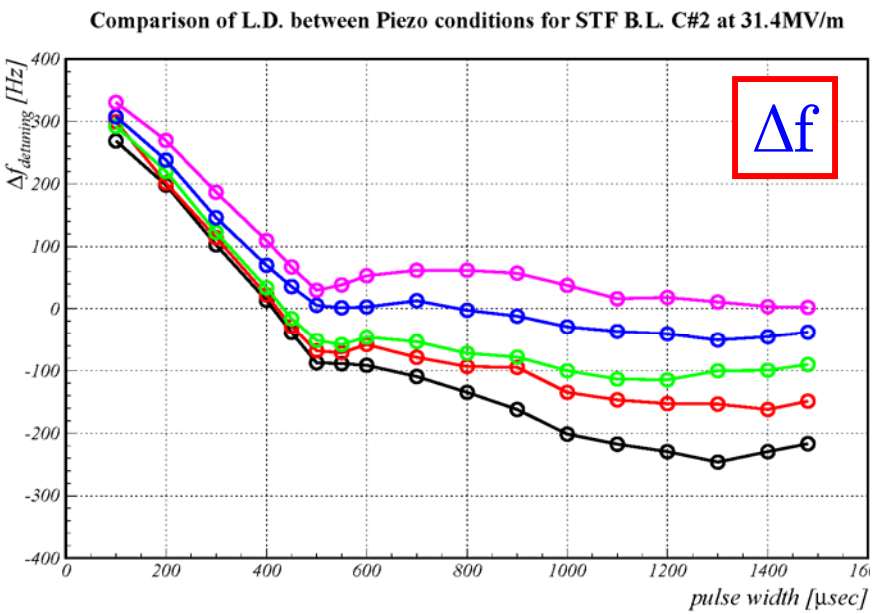
On resonance

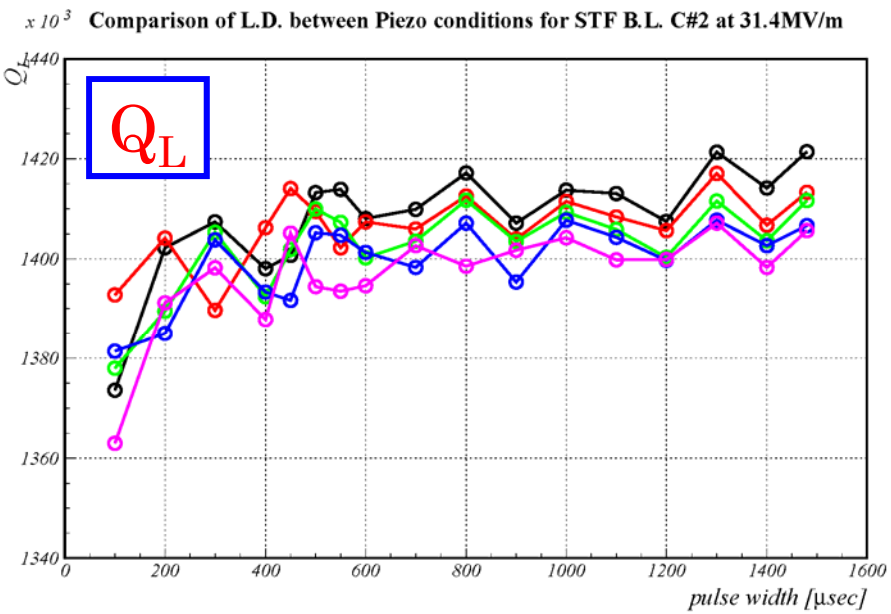
Piezo Compensation ①

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/250Hz





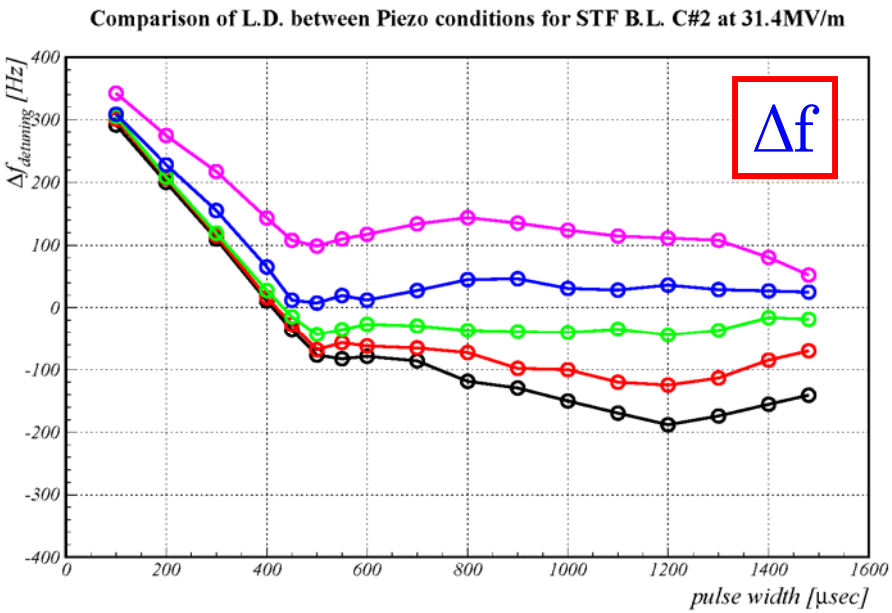
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

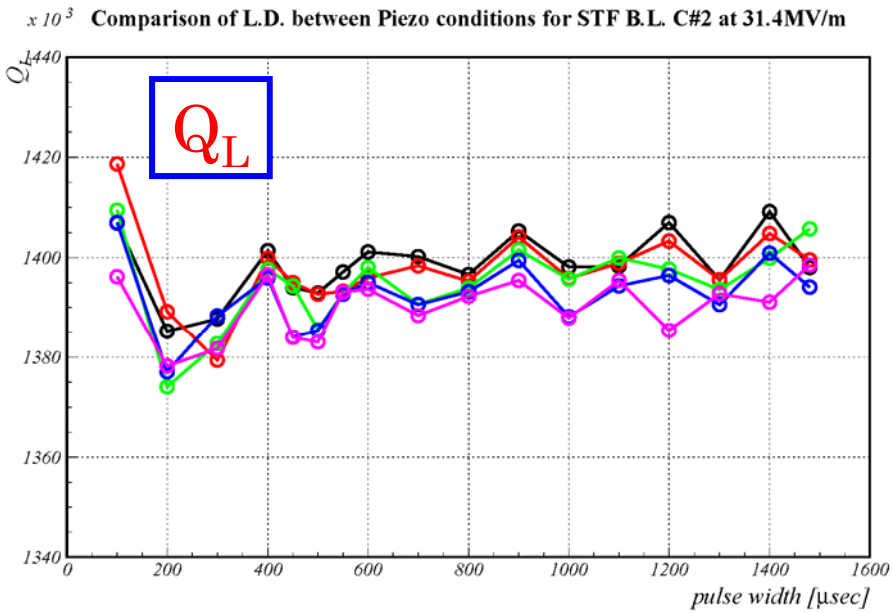
Piezo Compensation ②

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/300Hz





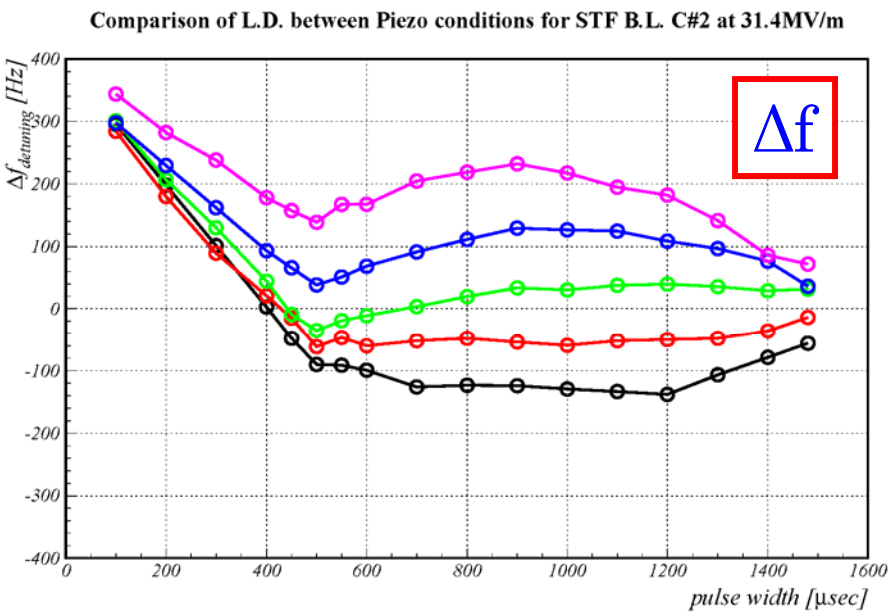
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

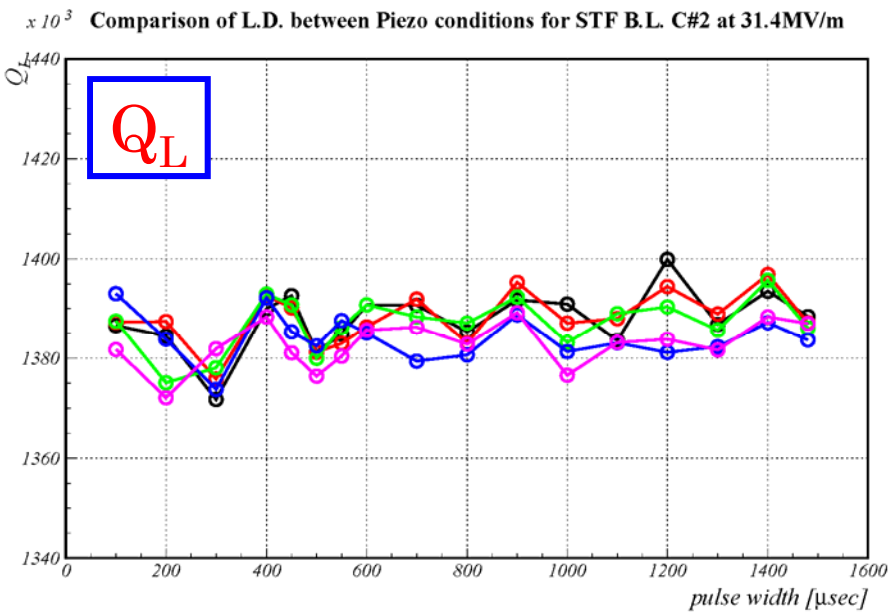
Piezo Compensation ③

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/350Hz





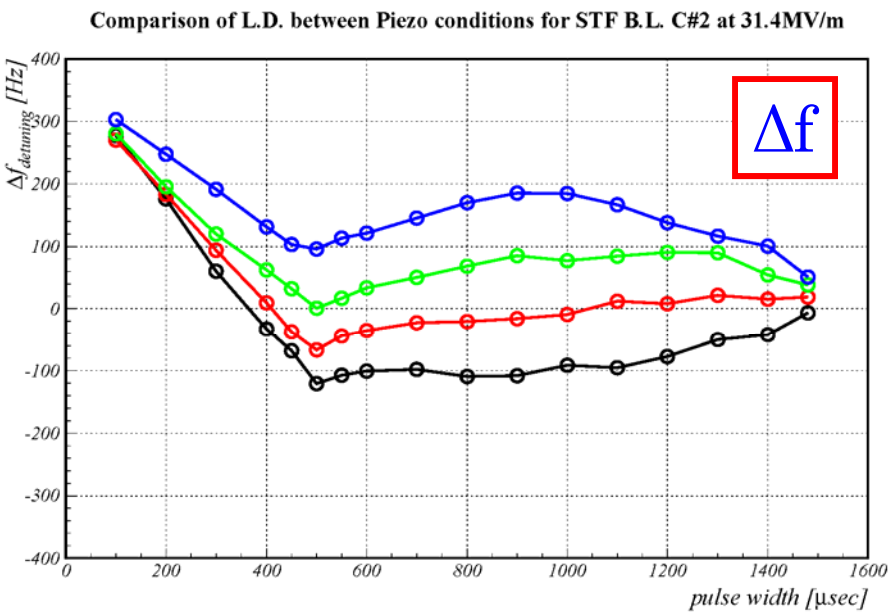
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

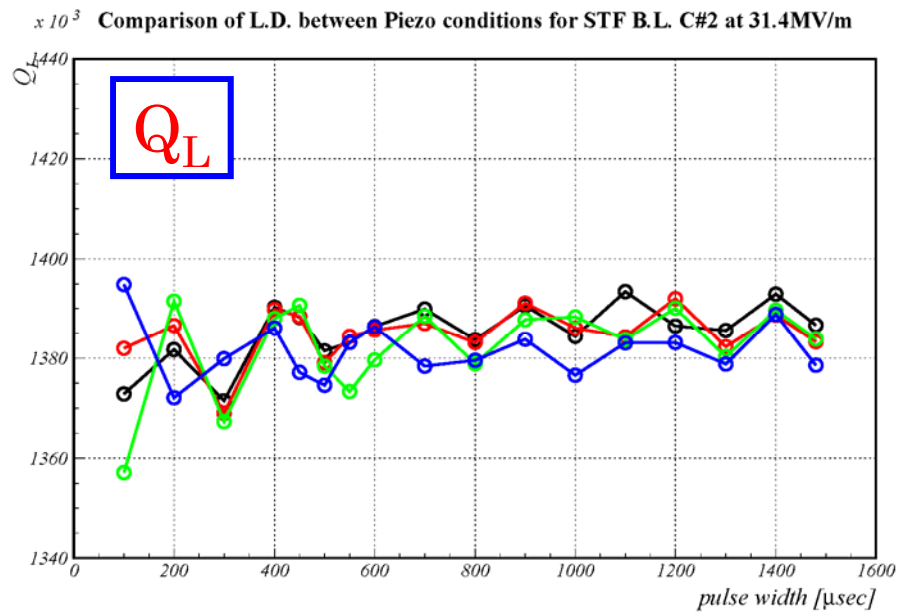
Piezo Compensation ④

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



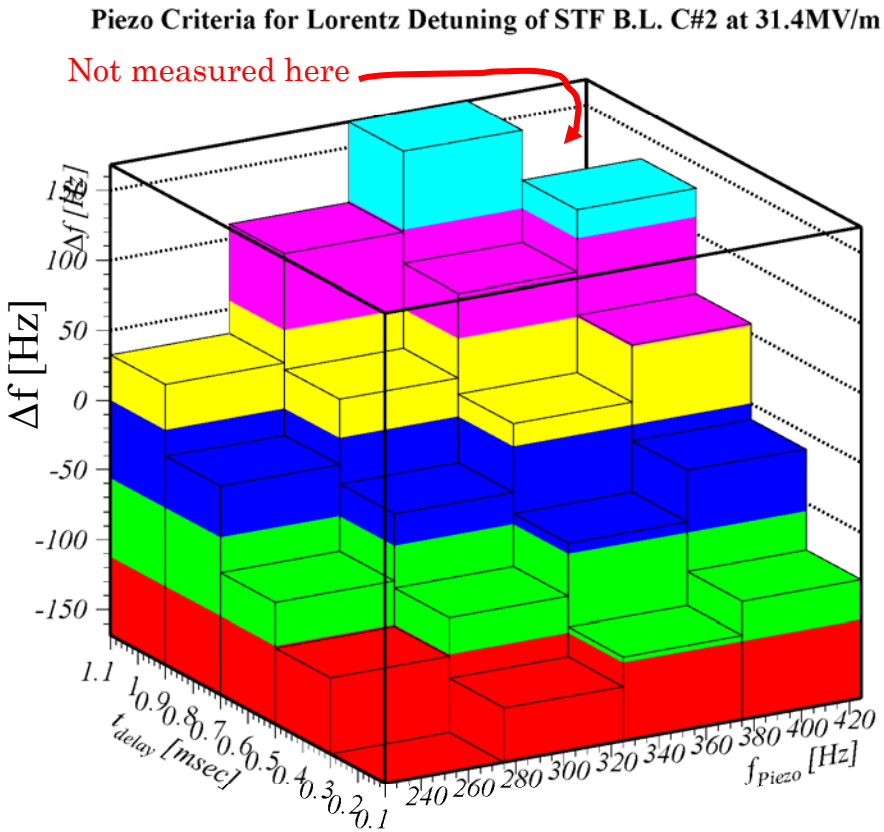


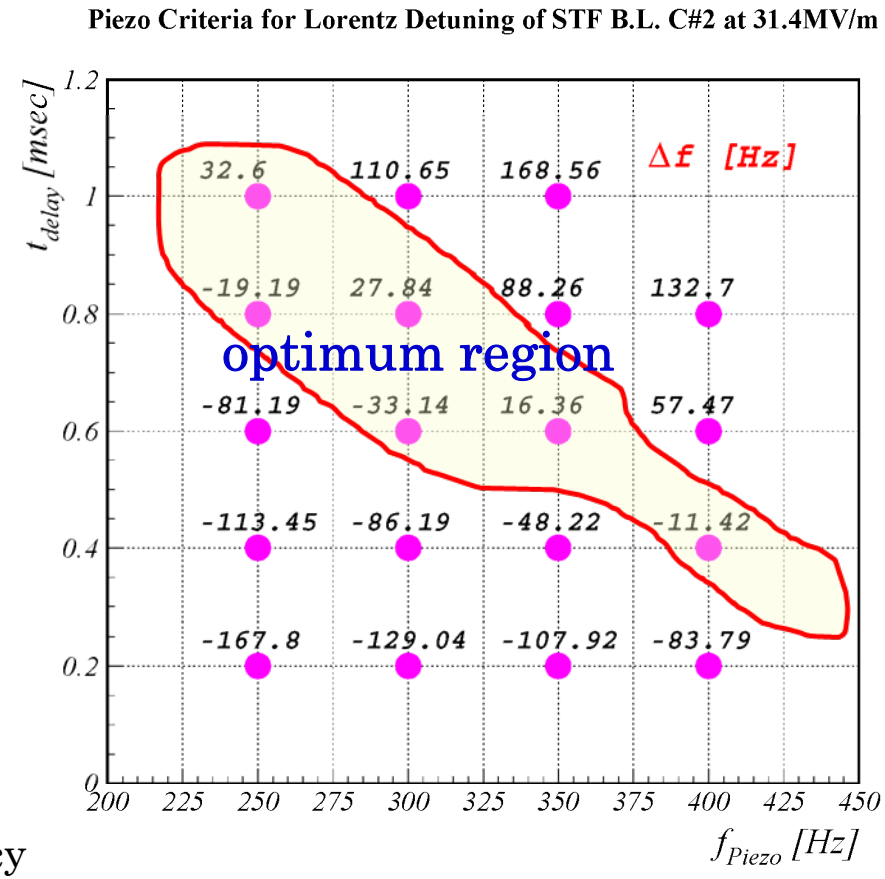
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

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

Pulse stability test

2000 pulses data

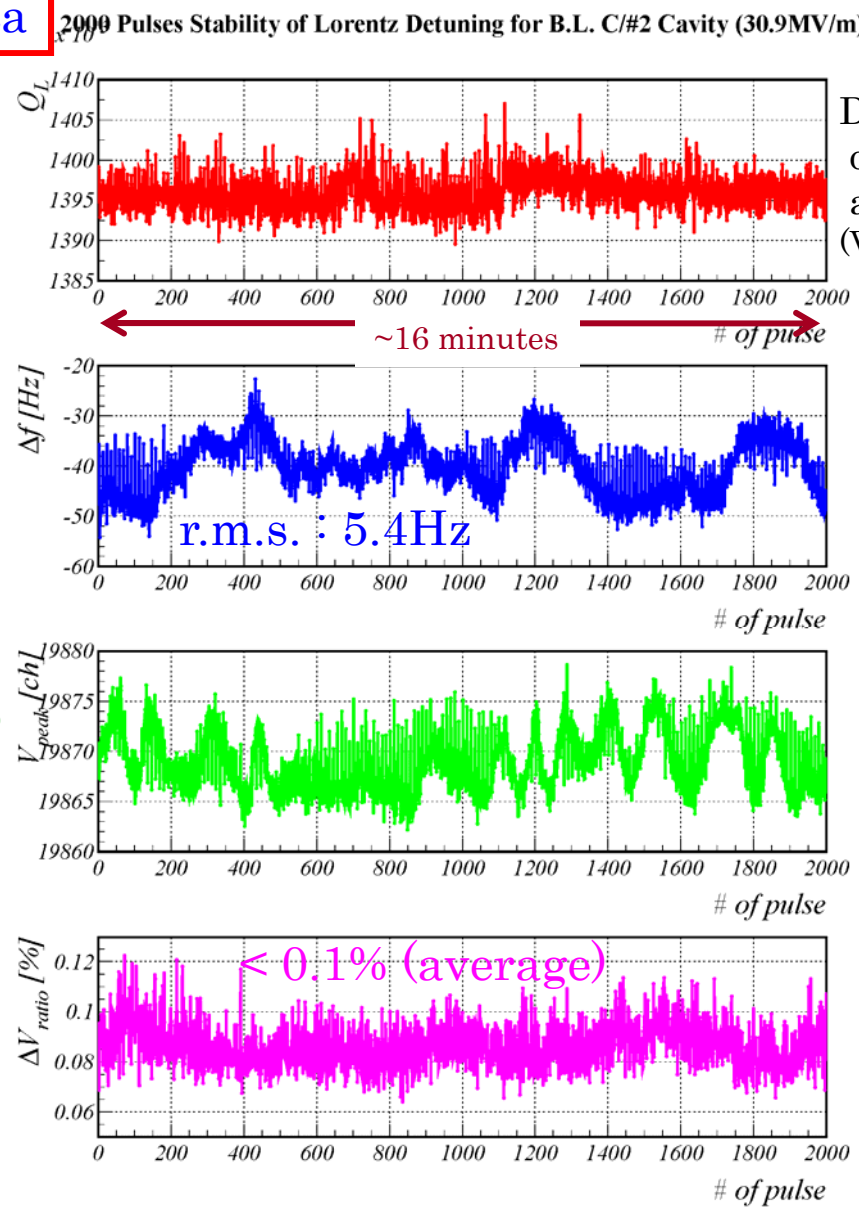
F.B. ON

Q_L

Δf

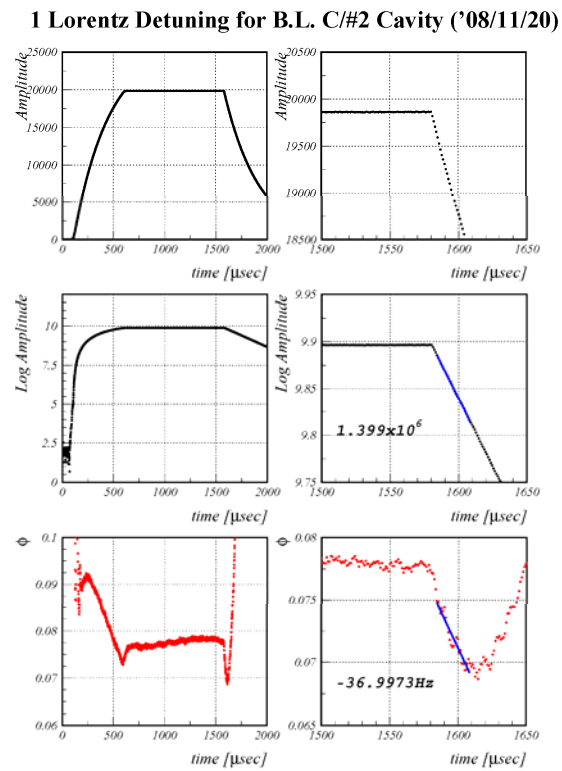
peak field at flat-top
(ADC counts)

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 1 pulse



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

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 will present these results in detail at PAC09!

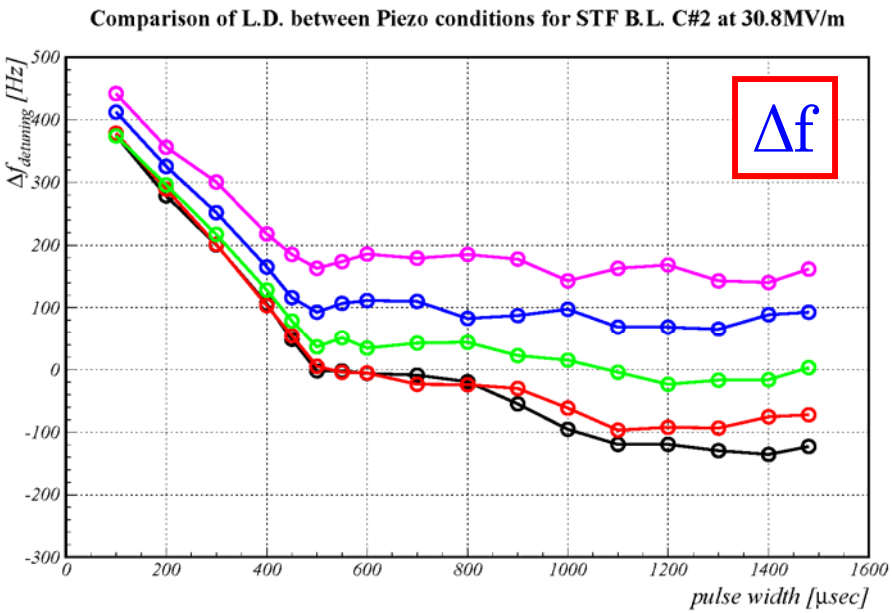
Back-up slides

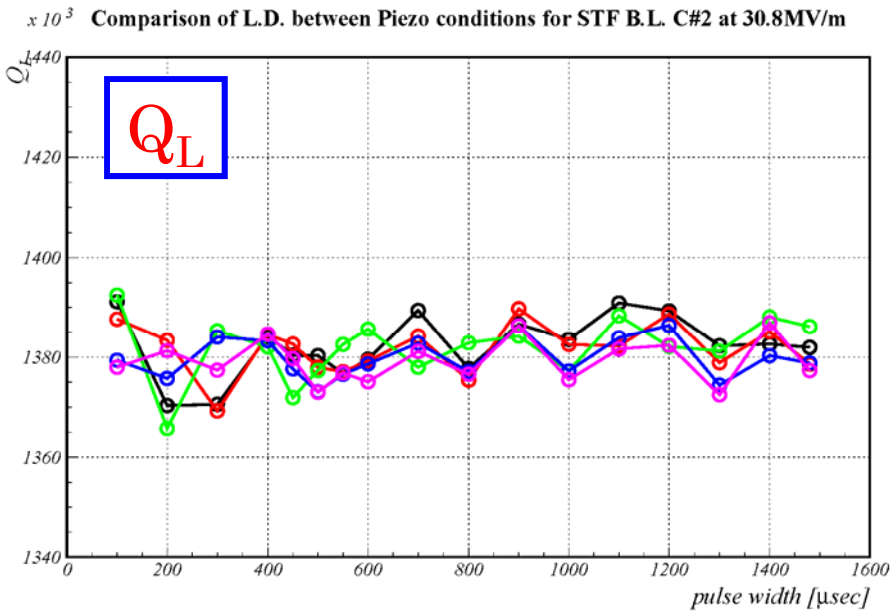
Piezo Compensation ⑤

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/250Hz





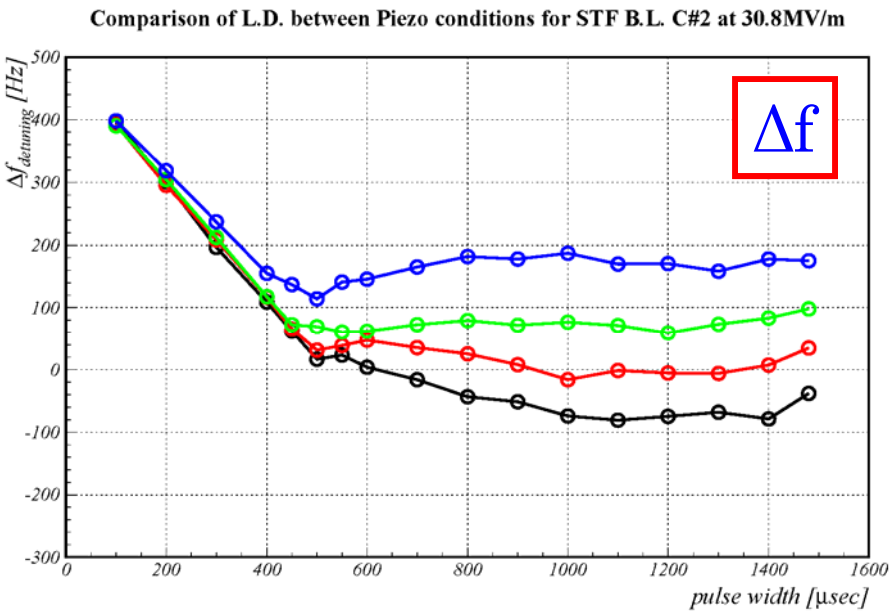
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

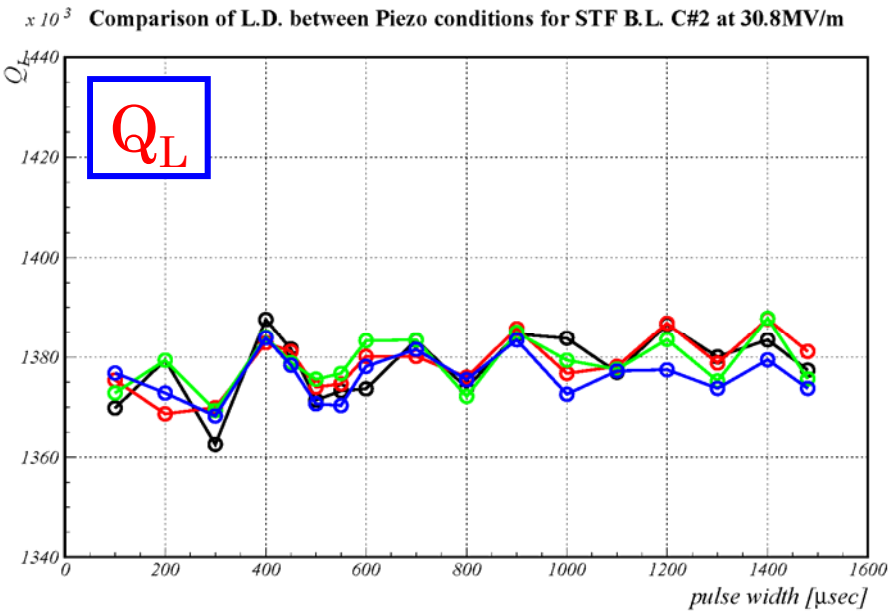
Piezo Compensation ⑥

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





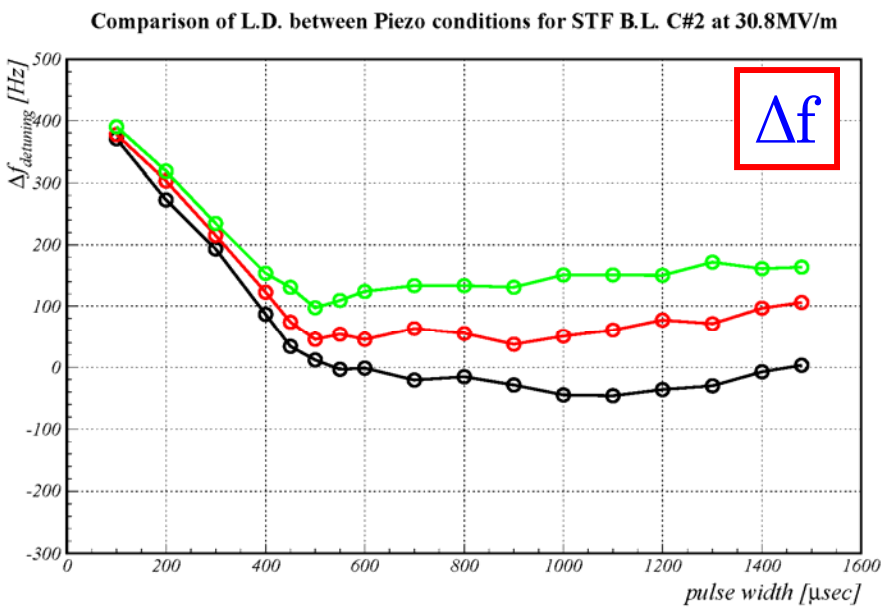
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

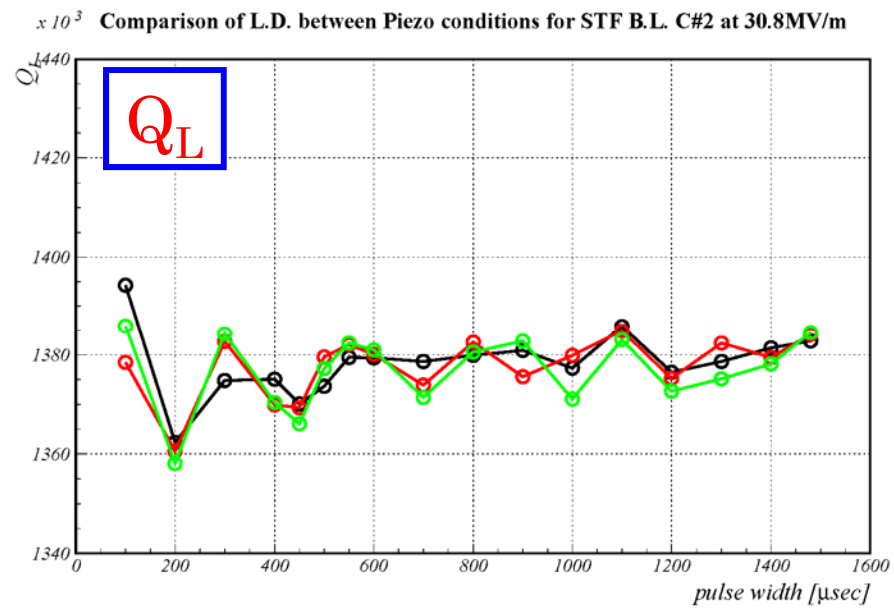
Piezo Compensation ⑦

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/350Hz





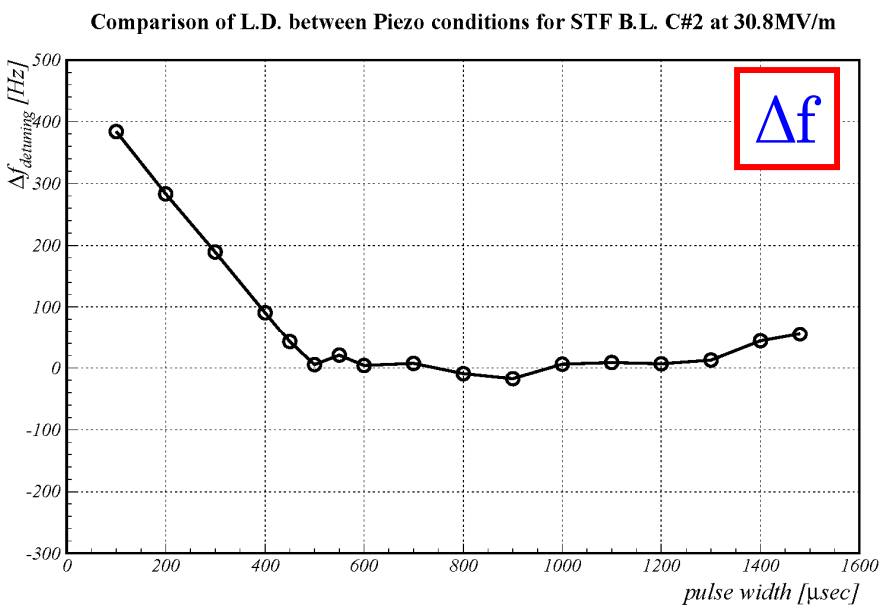
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

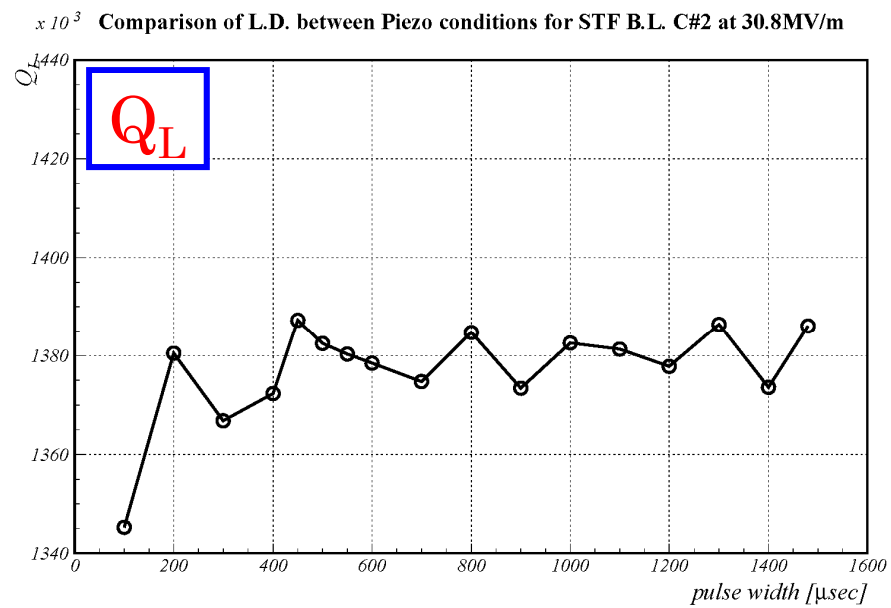
Piezo Compensation ⑧

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



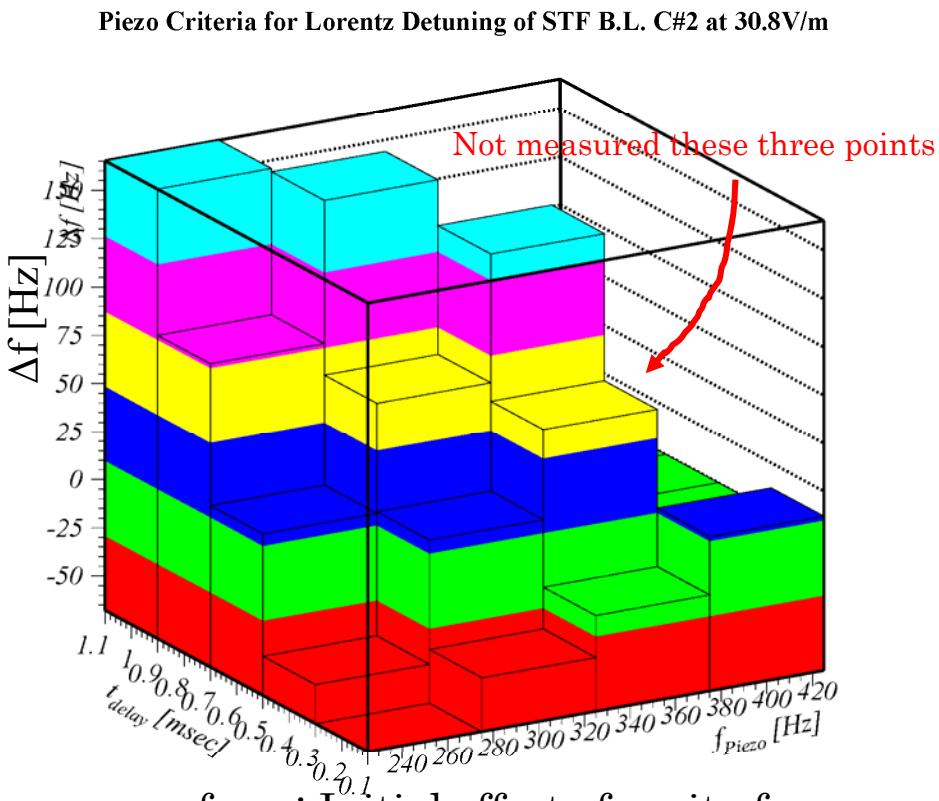


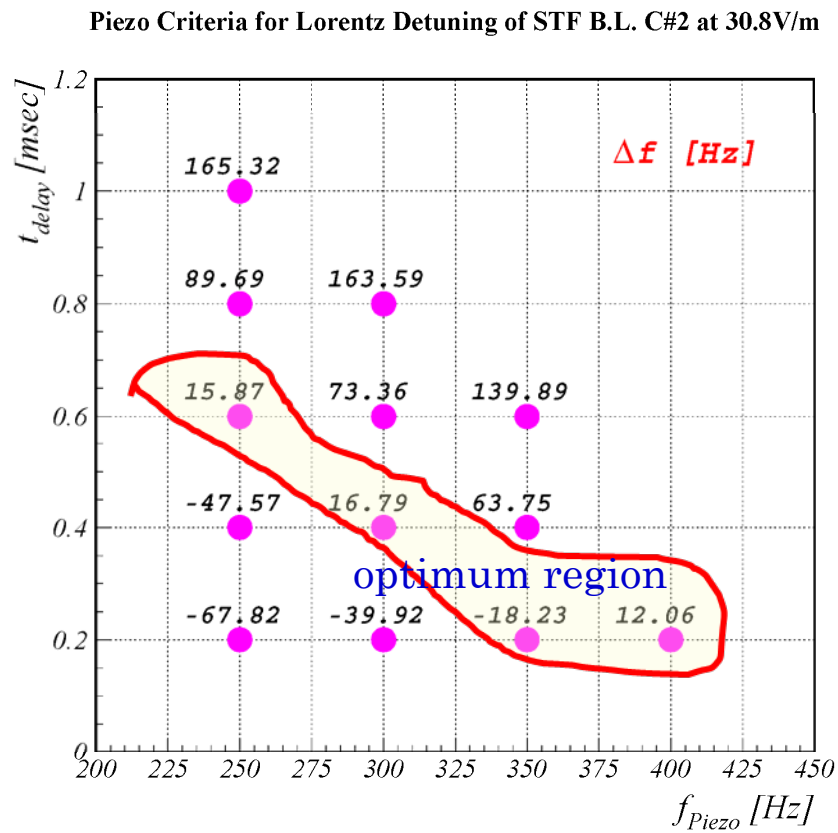
f_{offset} : Initial offset of cavity frequency
f_{Piezo} : Drive frequency of Piezo
V_{Piezo} : Drive voltage of Piezo
t_{delay} : Time difference between starting time of Piezo action and RF pulse

Optimum condition of Piezo action ②

f_{SG}=1300.500000MHz, Feed Back Off

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





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

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

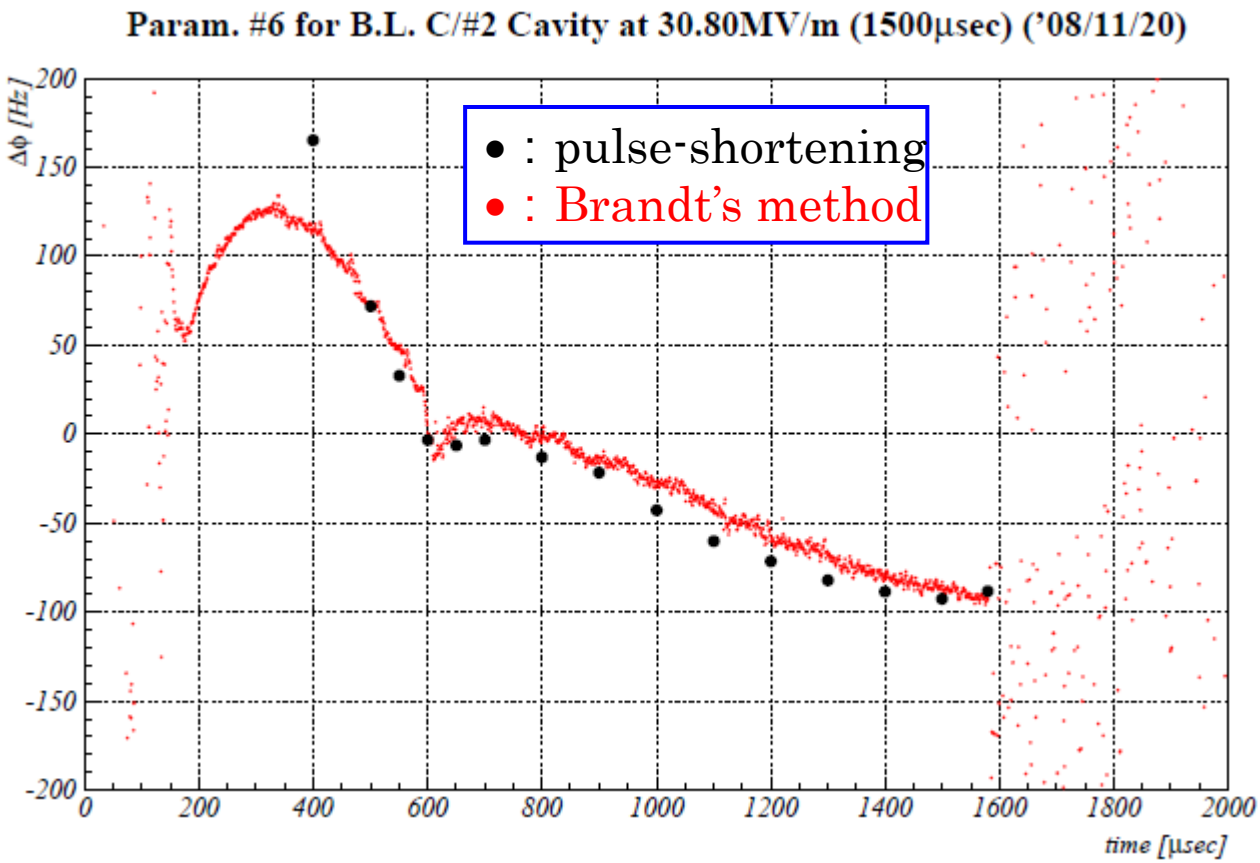
$$\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix} V_r \\ V_i \end{pmatrix} = \begin{pmatrix} -\omega_{1/2} & -\Delta\omega \\ \Delta\omega & -\omega_{1/2} \end{pmatrix} \cdot \begin{pmatrix} V_r \\ V_i \end{pmatrix} + \begin{pmatrix} R_L\omega_{1/2} & 0 \\ 0 & R_L\omega_{1/2} \end{pmatrix} \cdot \begin{pmatrix}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

Brandt

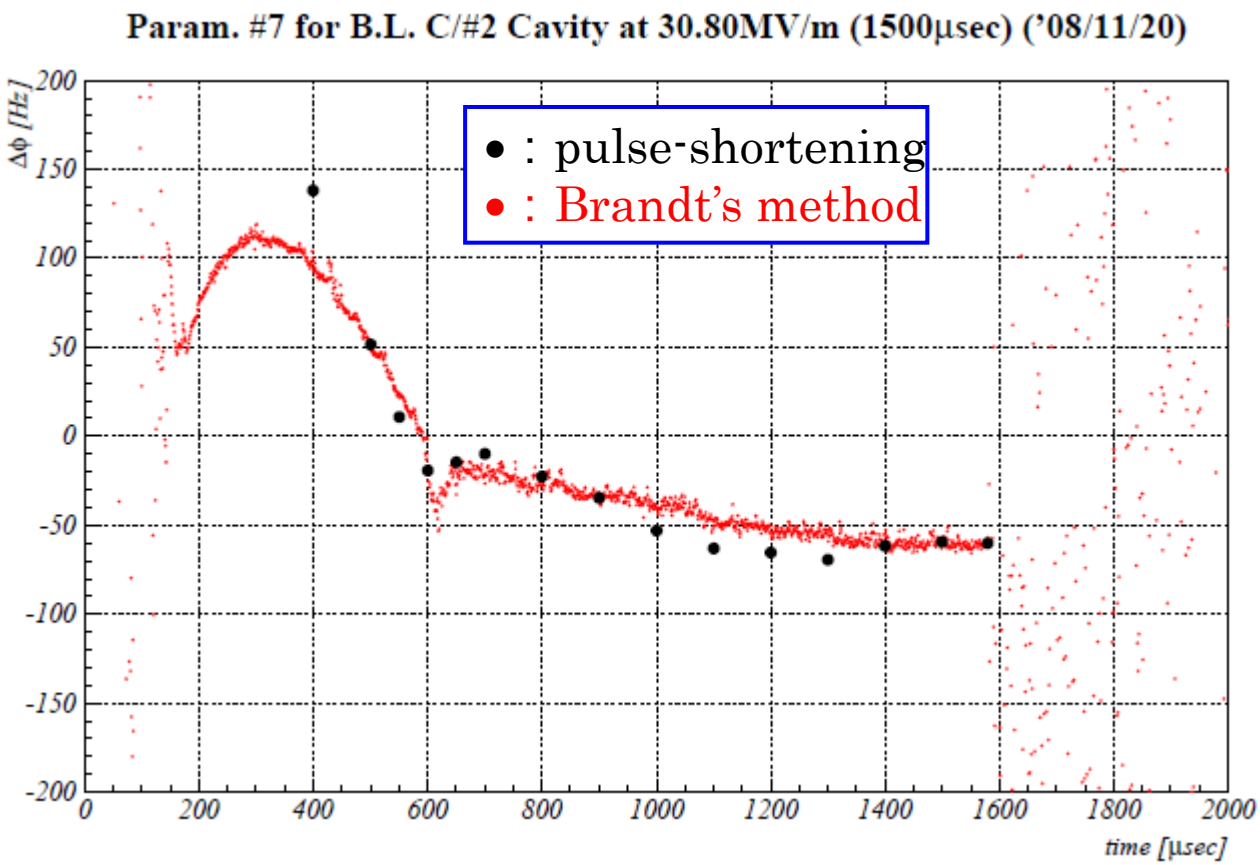
$$\Delta\omega = \dot{\varphi} - \omega_{1/2}\frac{\rho}{r}\sin(\theta - \varphi). \qquad (4.37)$$

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

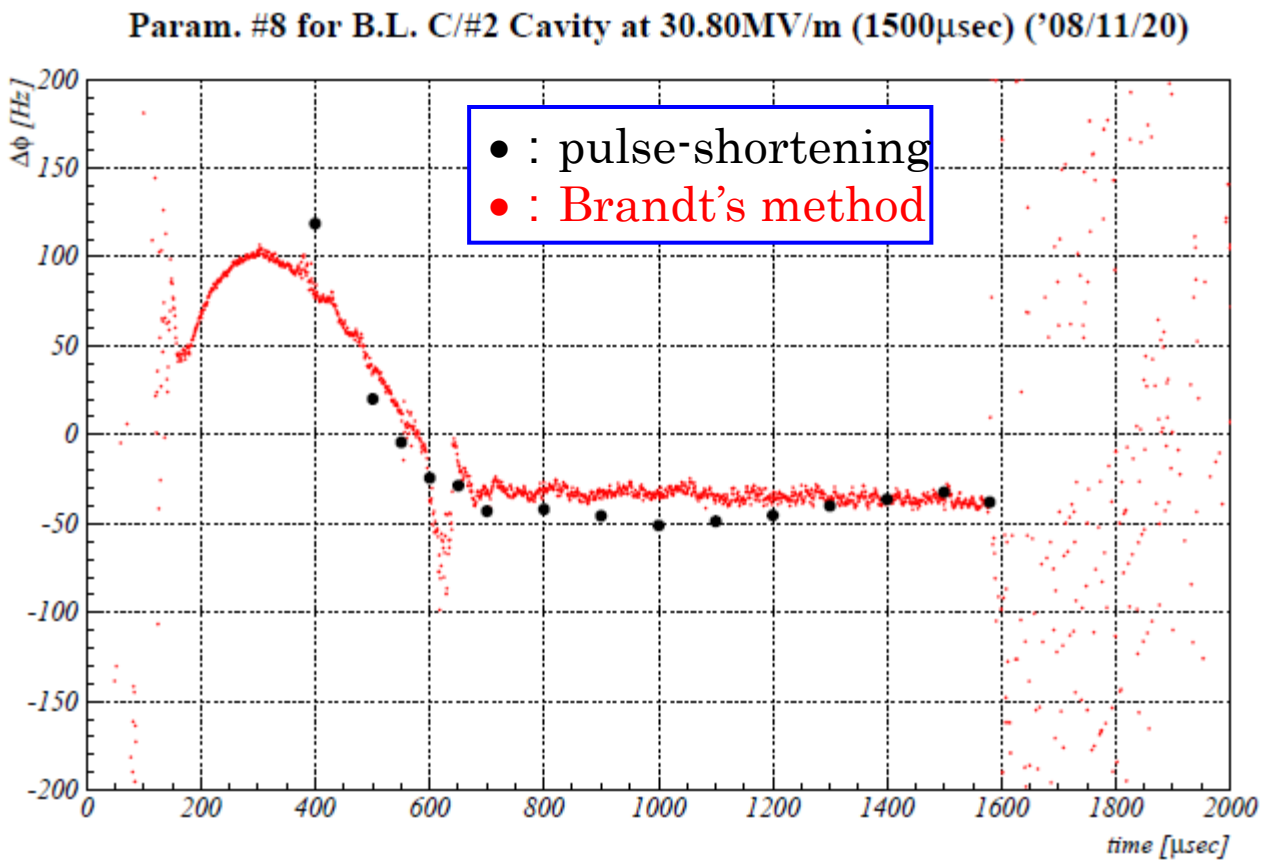
Best Compensation #1 @C/#2 (2008/11/20)



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



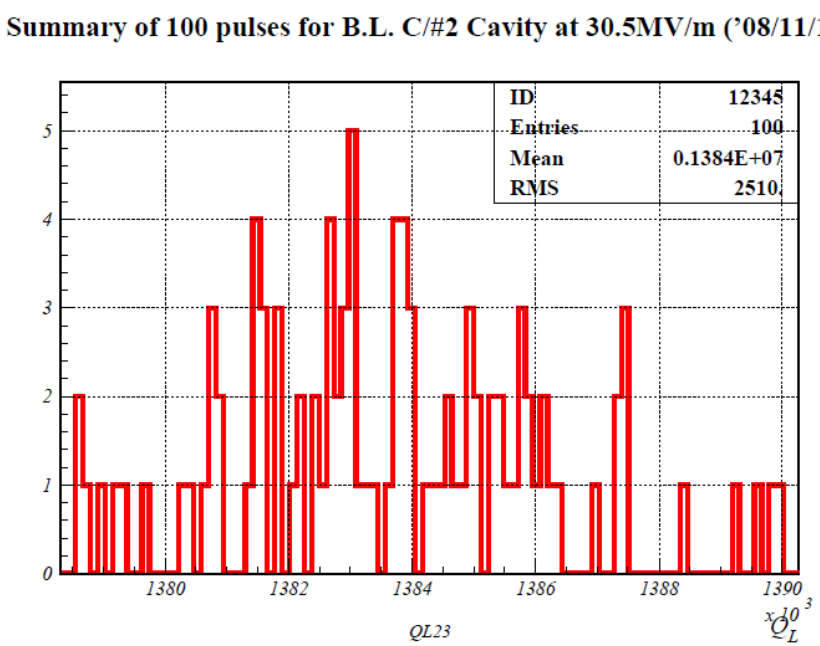
Best Compensation #3 @C/#2 (2008/11/20)

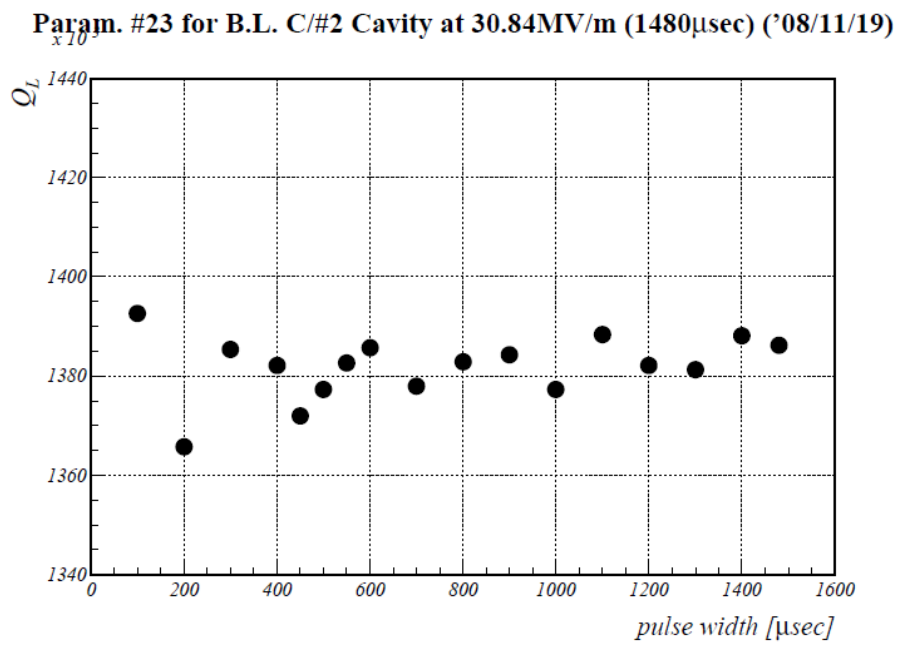


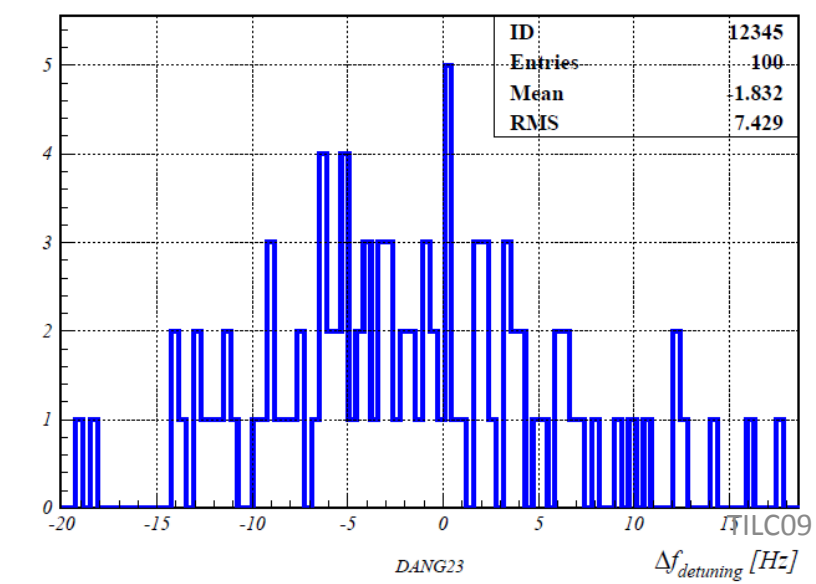
These two results are consistent each other.

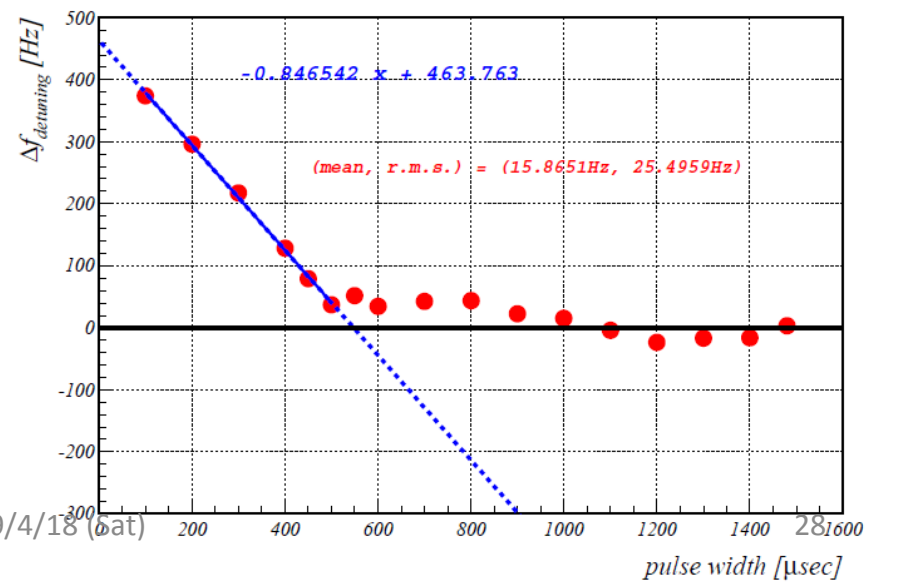
１００パルスとパルスカットの結果との比較①

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る

Example of the calculation for the transient response

$Q_L=1.49\times10^6$, $f_{init}=0$Hz, $\Delta f_{Input}=0.5$Hz/μsec, 180Hz/370Hz

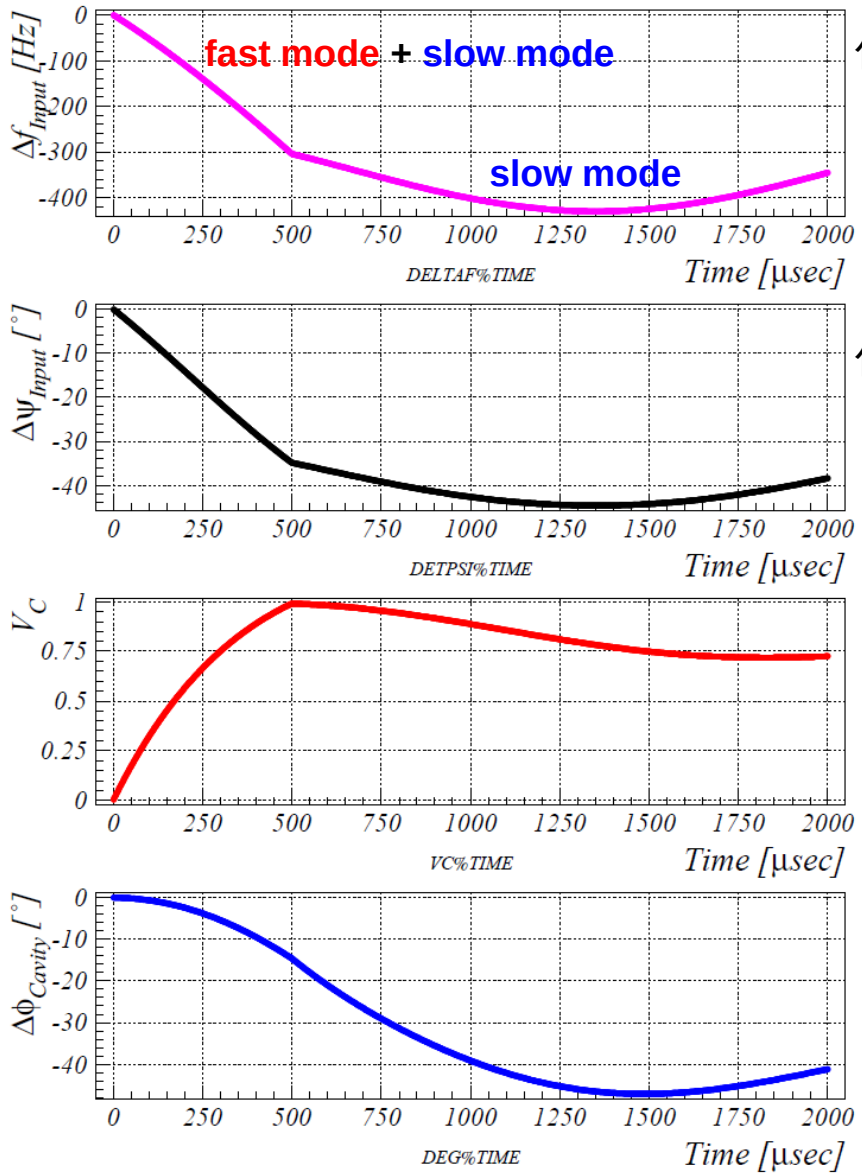
Input data (frequency)

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

Input data (degree)

Output data (V_C)

Output data (φ_{Cavity})

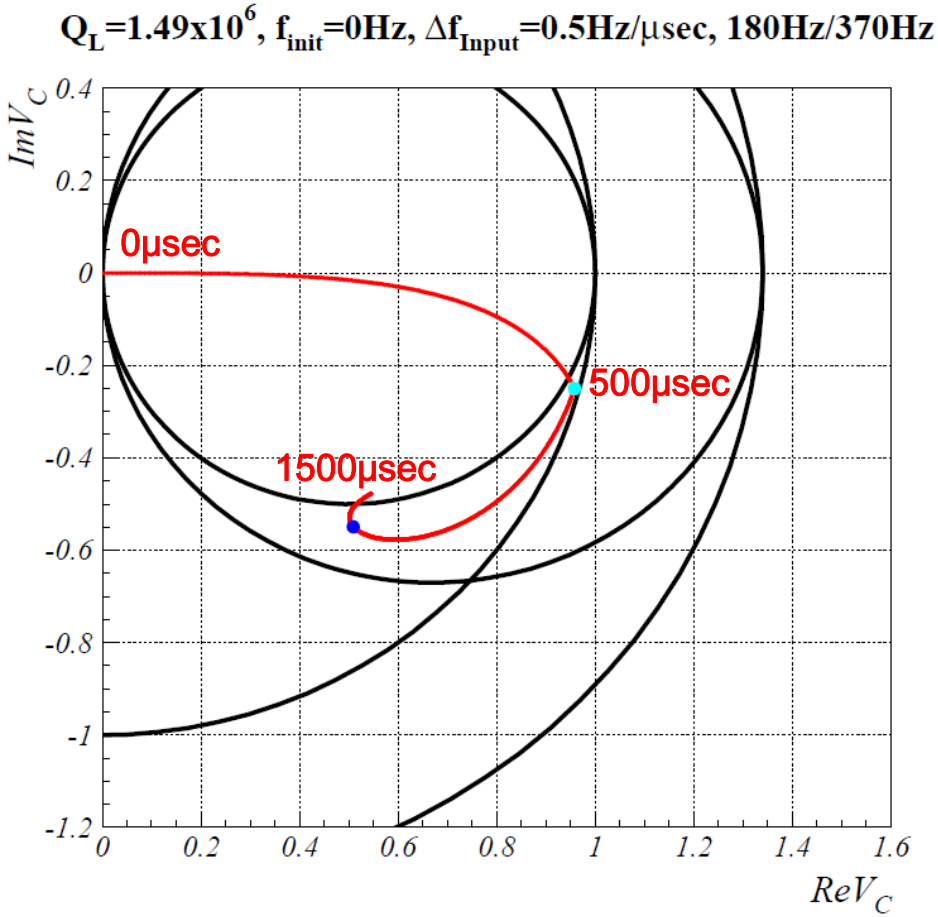


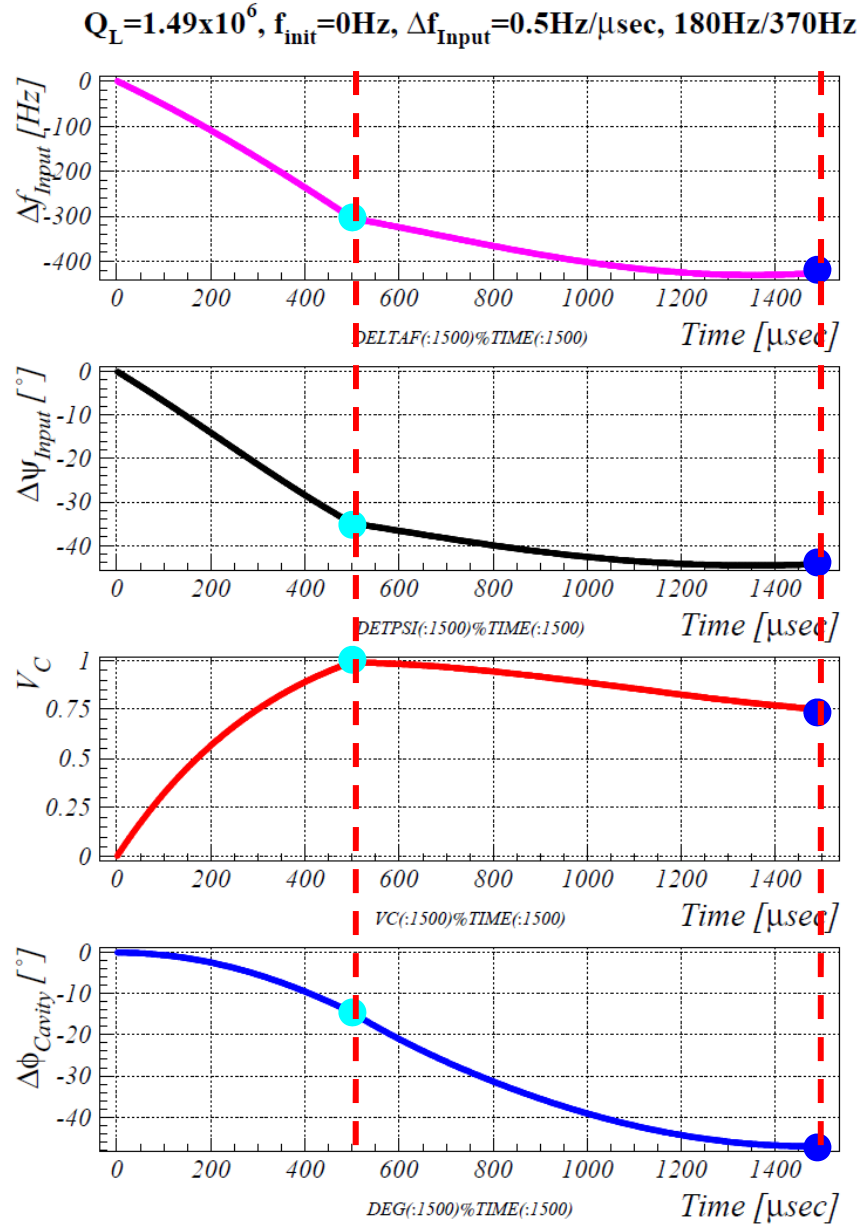
仮定①
立ち上がりはfastとslowの2つのモードが混在する。flat-topではslowモードのみが寄与し、fastは無くなる。

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

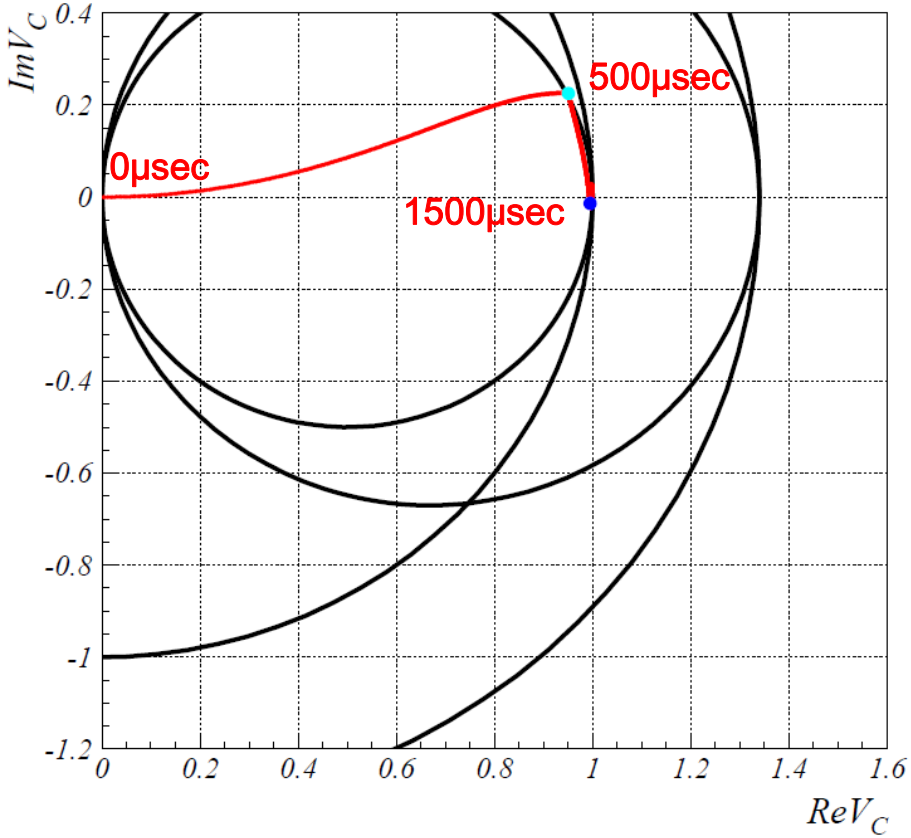




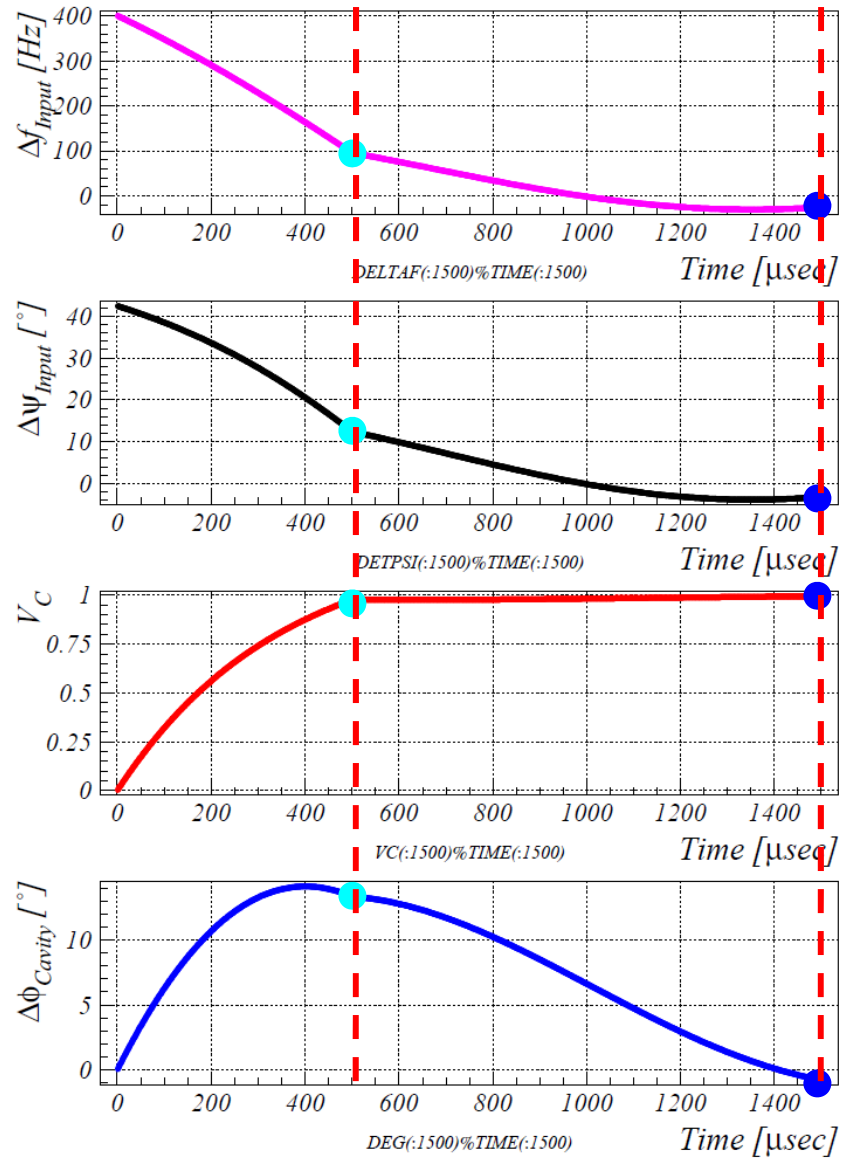
Example of the calculation for the transient response②

+400Hz offset

Q_L=1.49x10^6, f_{init}=400Hz, Δf_{Input}=0.5Hz/μsec, 180Hz/370Hz

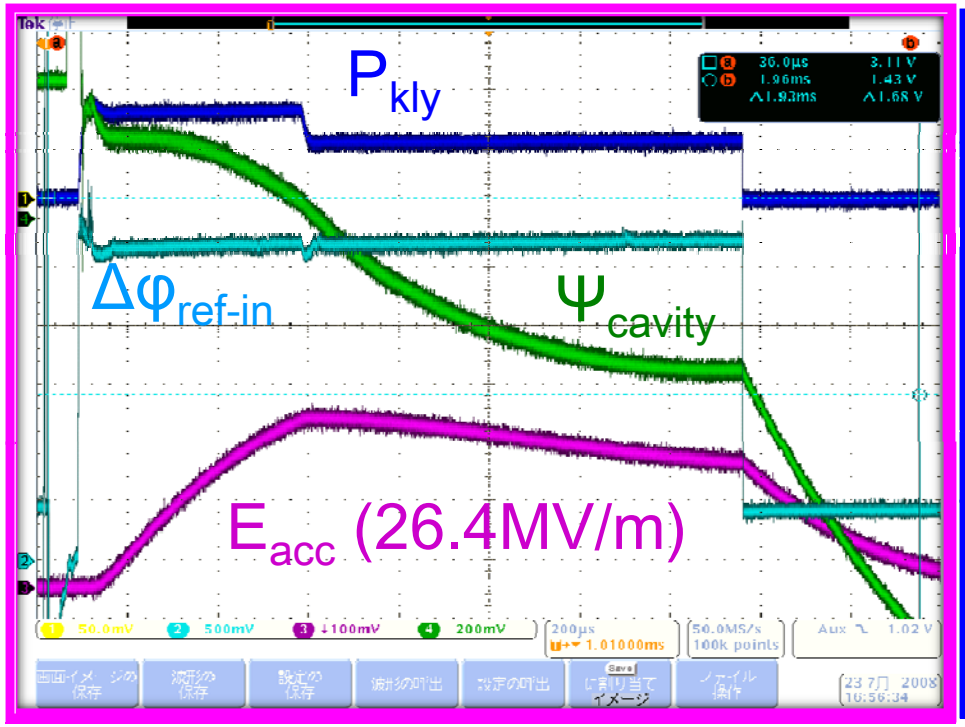


Q_L=1.49x10^6, f_{init}=400Hz, Δf_{Input}=0.5Hz/μsec, 180Hz/370Hz

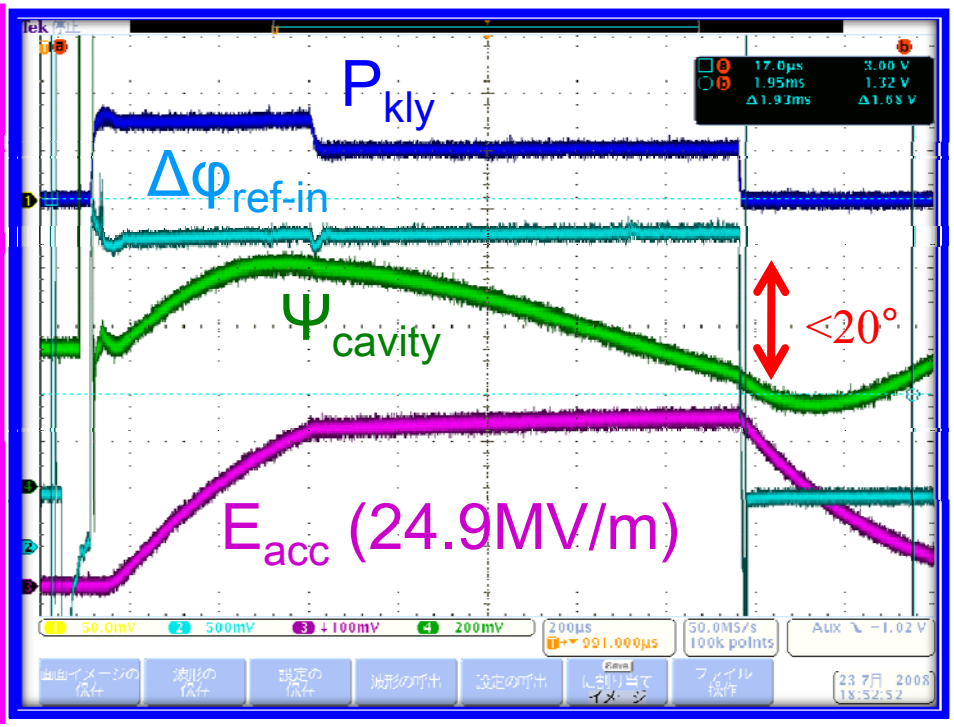


ハイパワーテスト時の波形

No offset



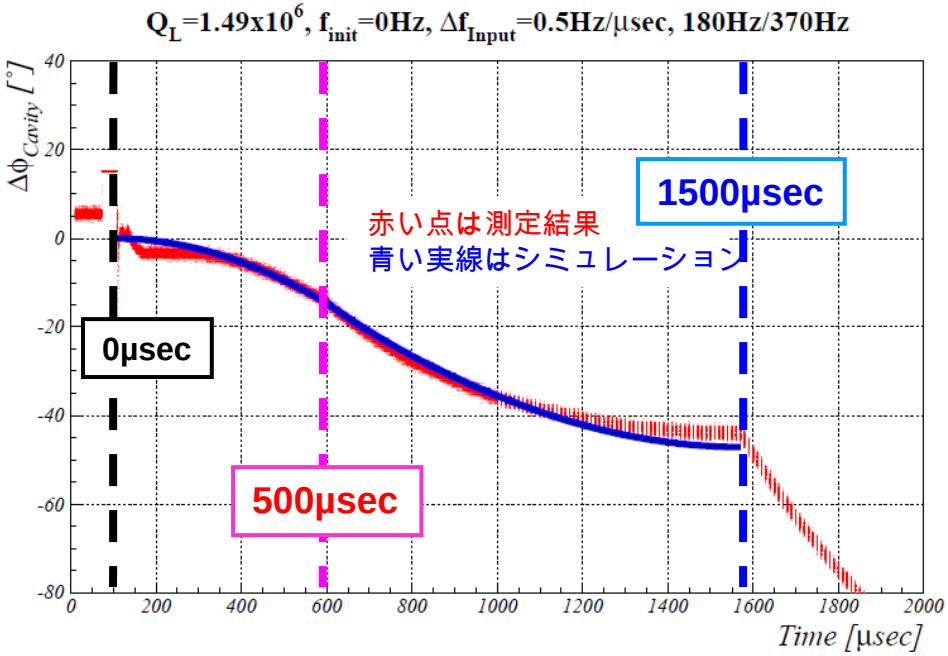
+400Hz offset



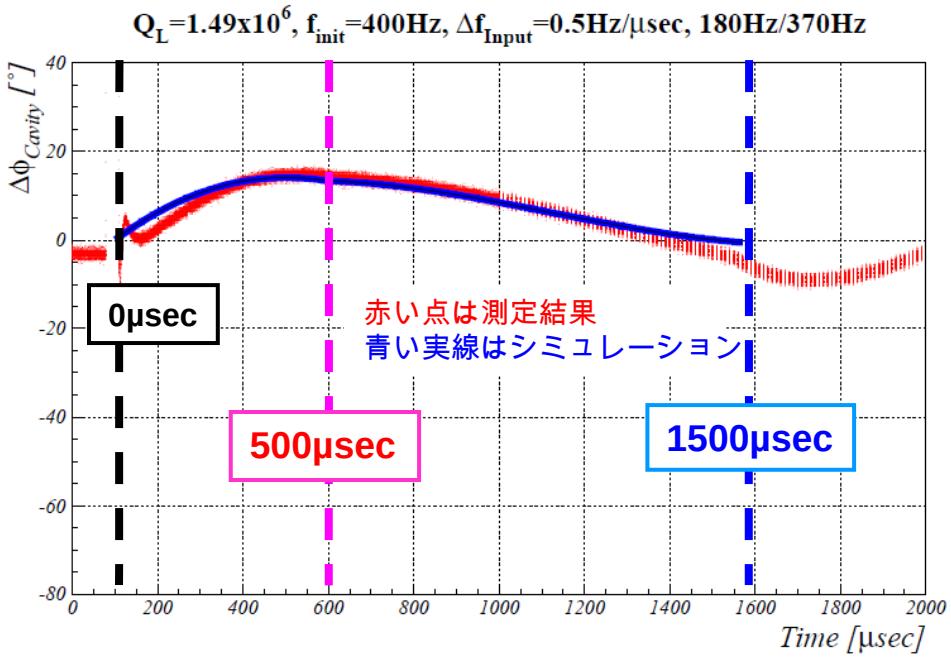
周波数にオフセットが無い場合は、観測される空洞の位相は大きく変化し、
かつフィールドも傾いてしまう。
しかし、少しオフセットを持たせると位相の変化は少なく、フィールドもほぼflatになる
この状態から残っているずれ量をピエゾで補正すればよい。
オフセットの量が適当でないとピエゾに過度の負担がかかり消耗が激しくなると予想さ

Comparison between experiment and calculation

No offset

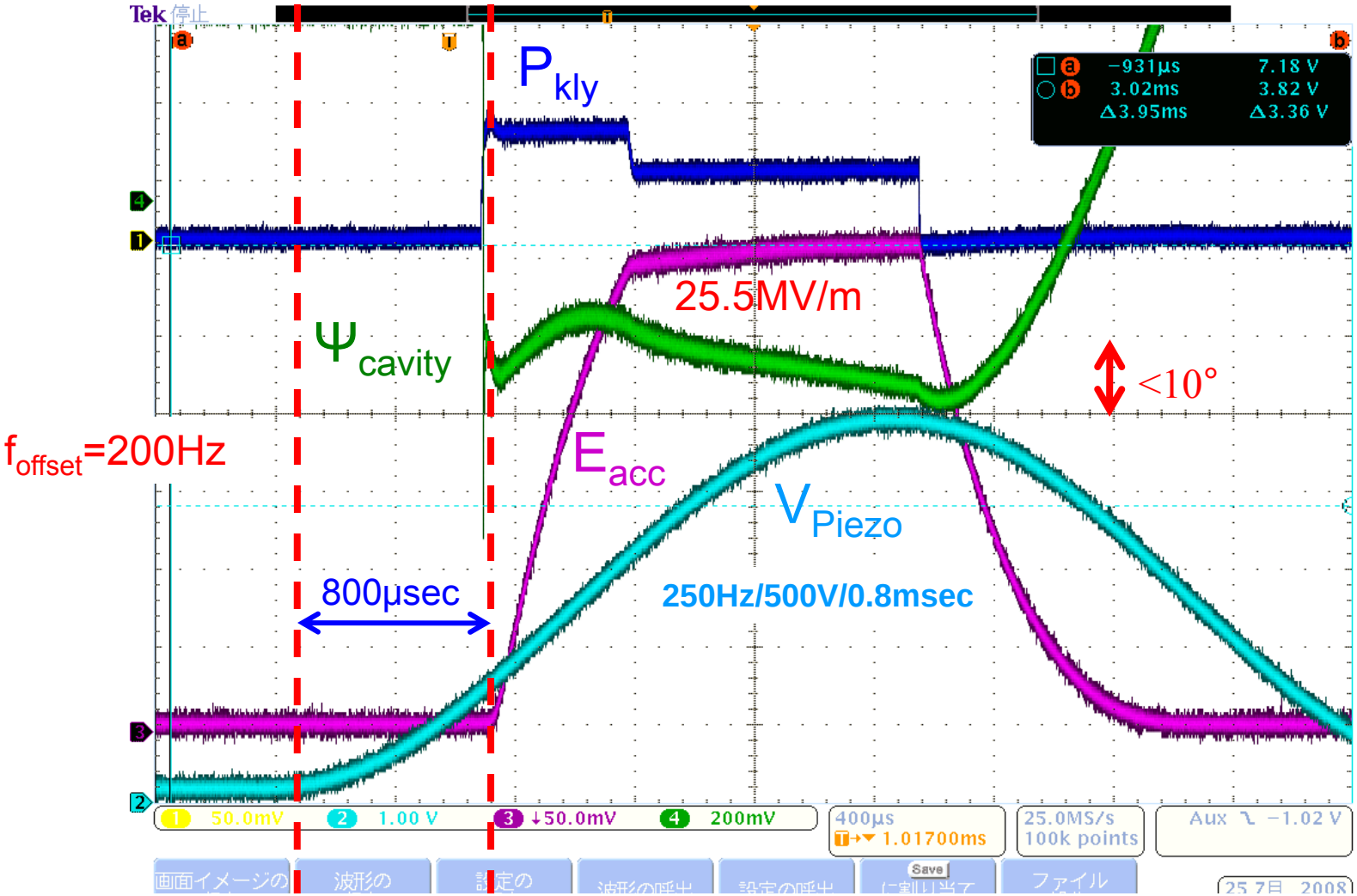


+400Hz offset



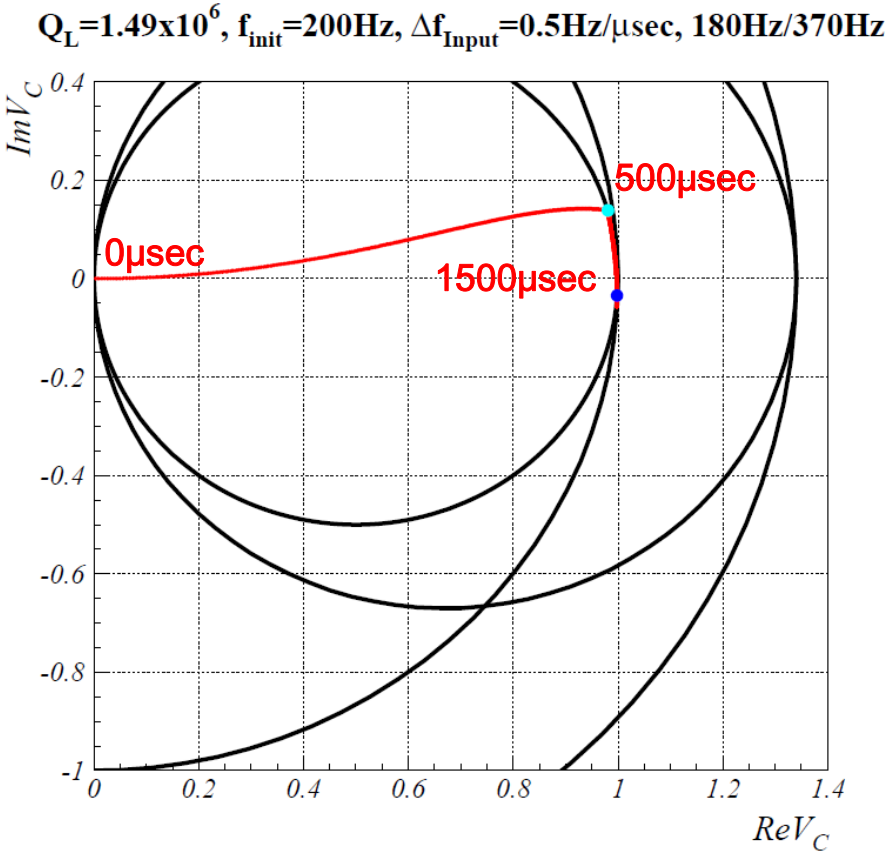
計算結果は実験データを良く再現している。
“Two Modes Model”が妥当であることを意味している。

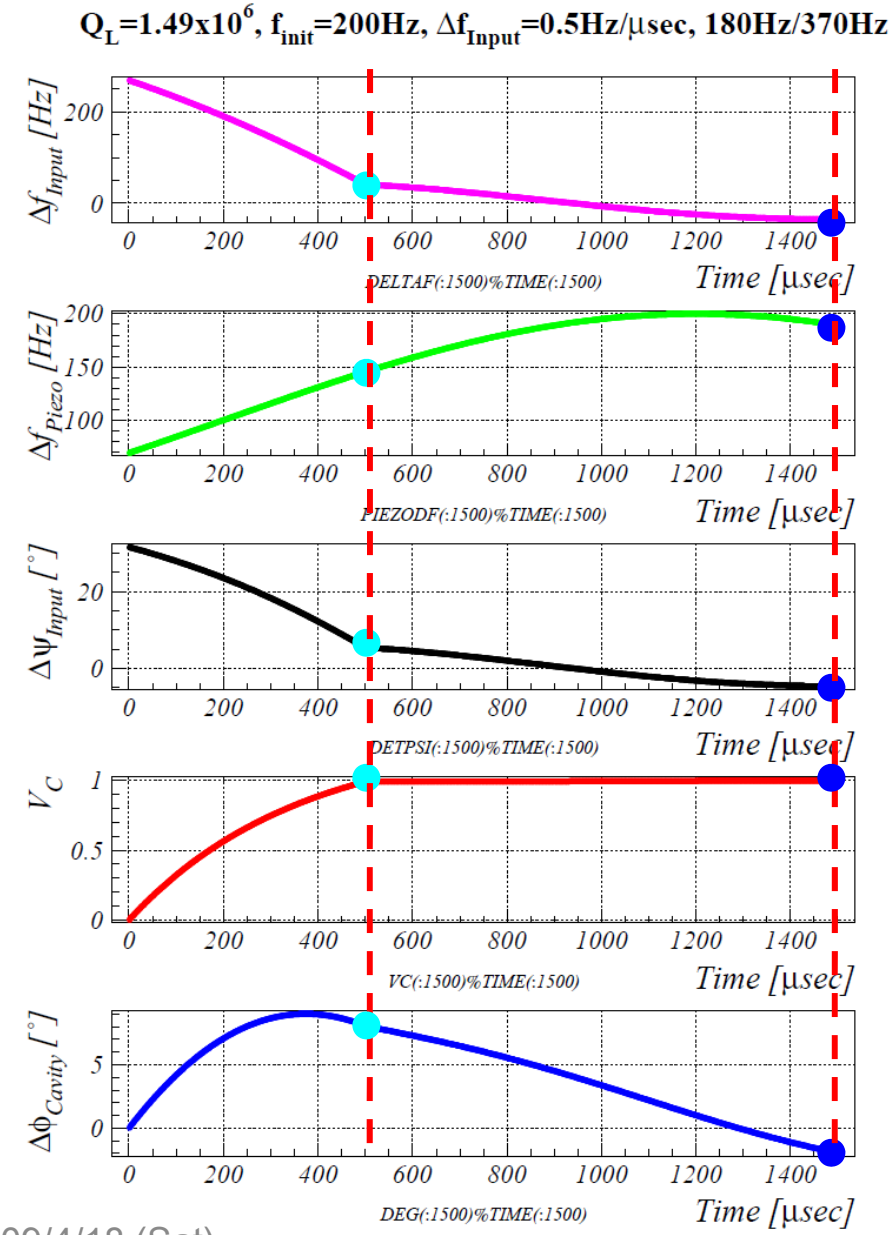
Piezo Compensationの測定例



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。

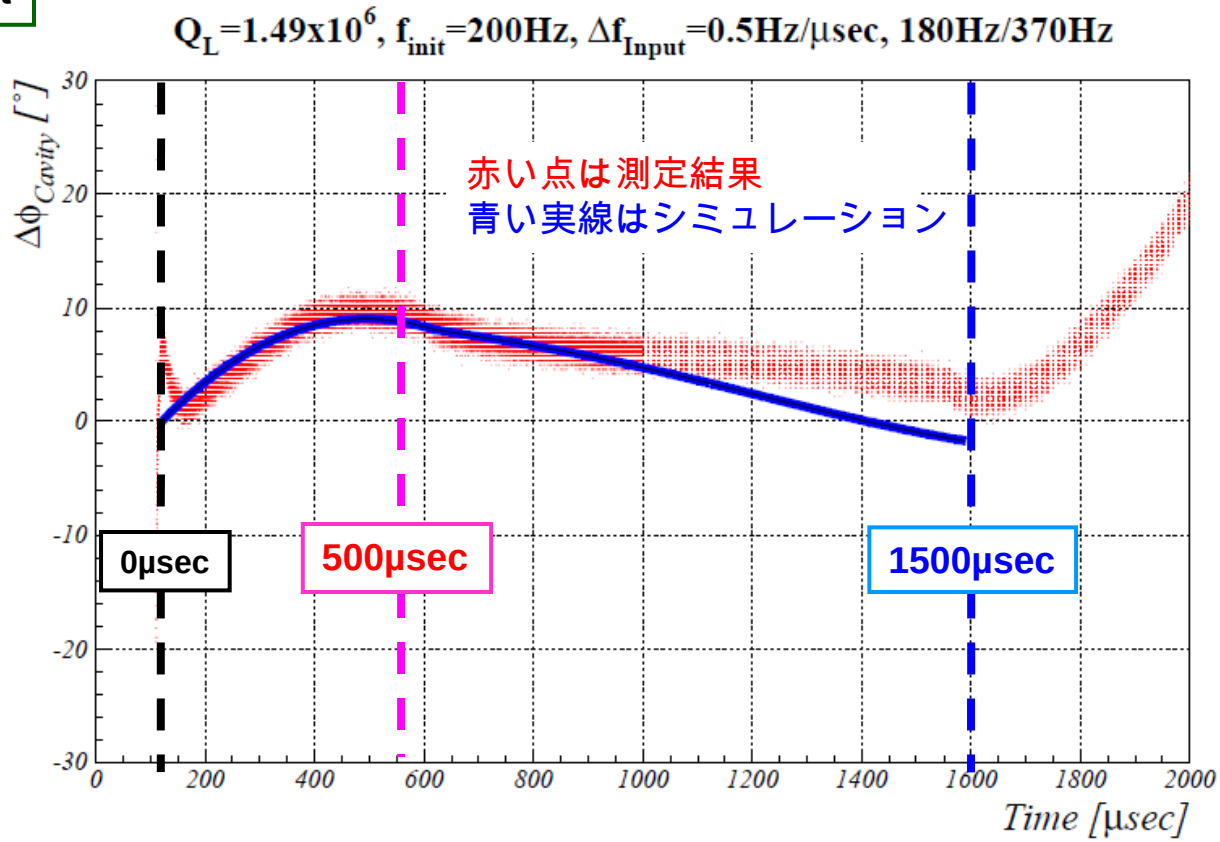
Example of the calculation for the Piezo compensation





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。