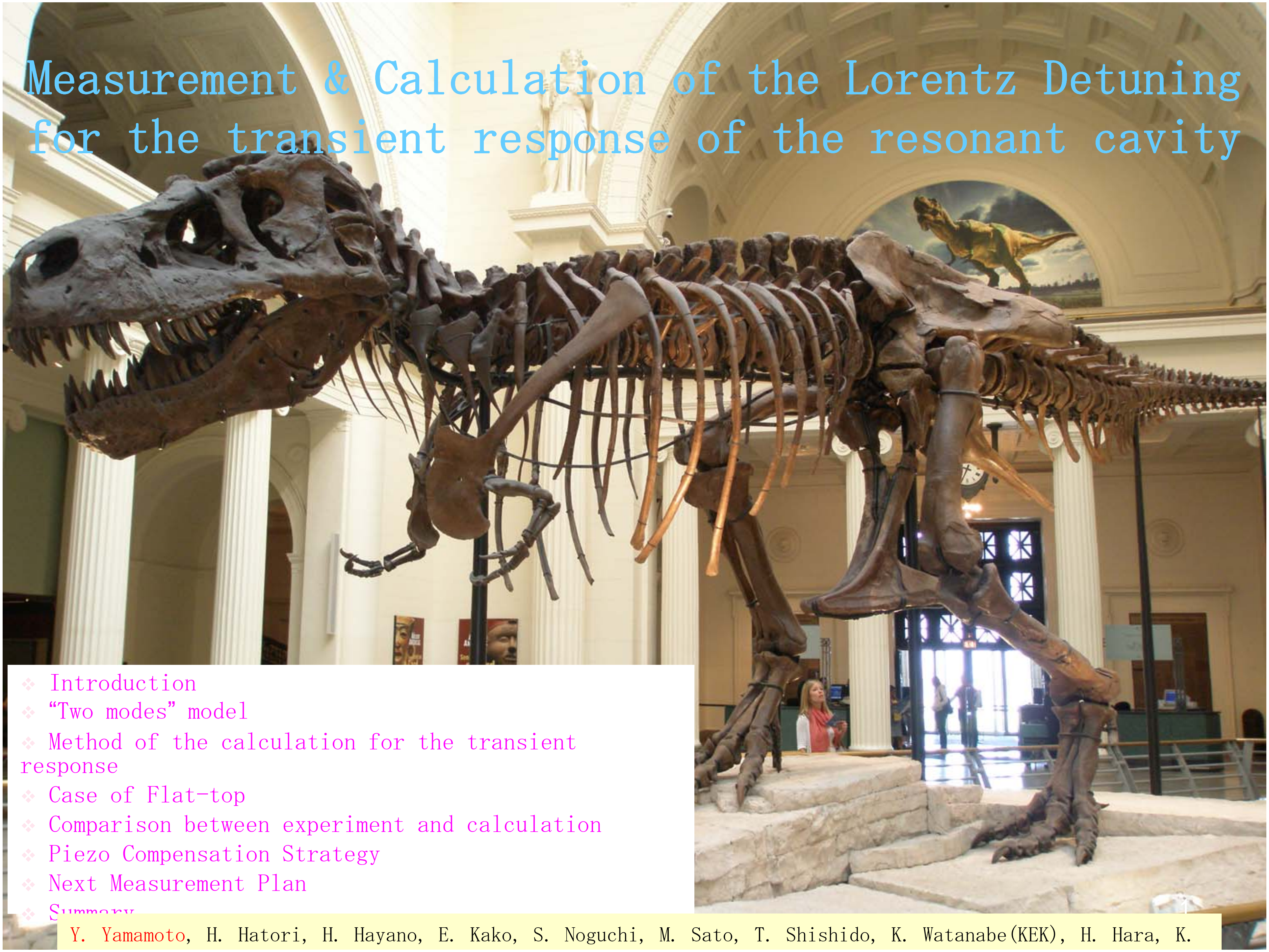

Measurement & Calculation of the Lorentz Detuning for the transient response of the resonant cavity

- Introduction
- “Two modes” model
- Method of the calculation for the transient response
- Case of Flat-top
- Comparison between experiment and calculation
- Piezo Compensation Strategy
- Next Measurement Plan
- Summary

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Introduction

The shape of the resonant cavity is generally deformed by the Lorentz force.

⇩

The frequency of the cavity is changed according to the square of the field strength.

⇩

The cavity is detuned, and the field may not be constant during the flat-top of the pulse.

⇩

It is necessary to compensate or lower the detuning by the Lorentz force.

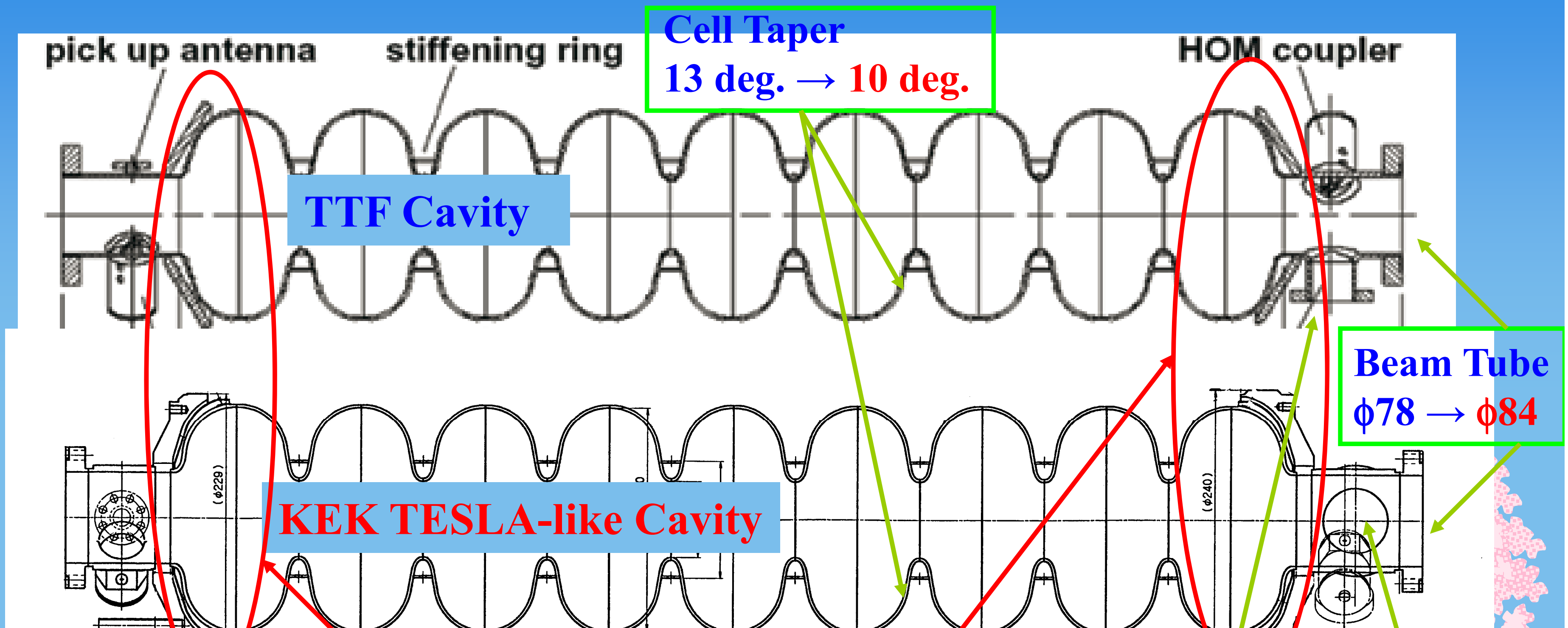
⇩

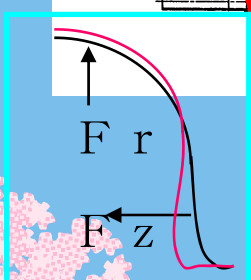
The methods to do it are following…

(1) Using Piezo
(2) Putting the initial offset to the cavity frequency
(3) Increasing the mechanical strength of the cavity support

STF B.L. cavity is mechanically stronger than TESLA's one!

Improvement in the KEK TESLA-like Cavities

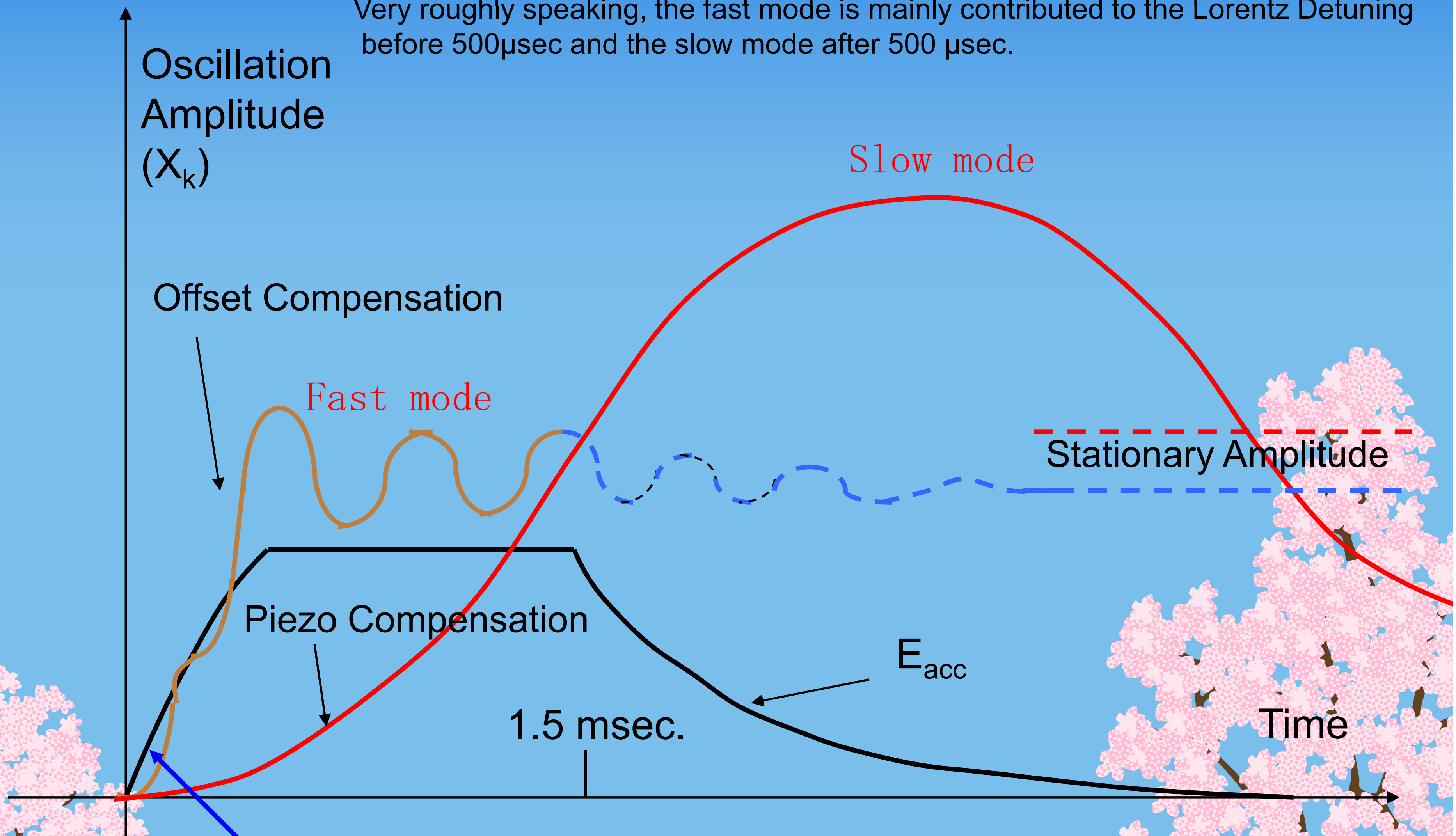




	KEK TESLA-like Cavity	TTF Cavity	
Stiffness of Cavity			
Fixing Support	80 kN/mm	13 kN/mm	
Lorentz Detuning	-480 Hz	-1050 Hz	(31.5 MV/m)

Mechanical Oscillation (Two Modes Model)

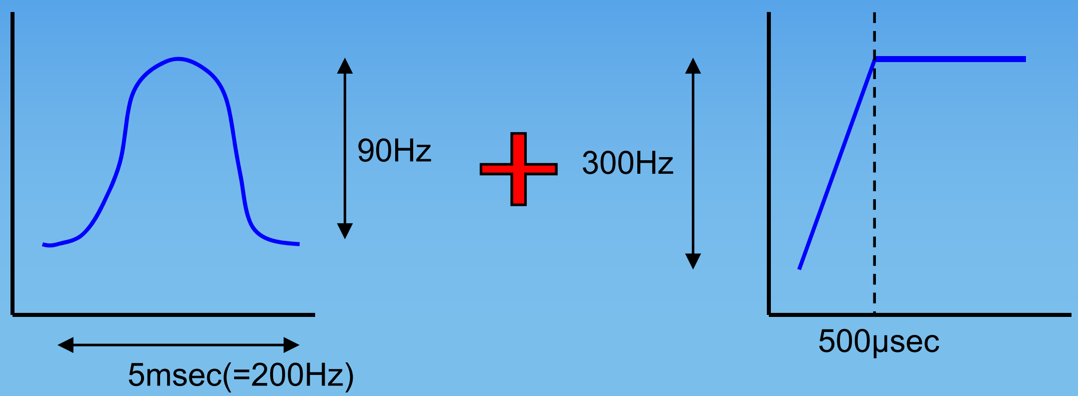
Very roughly speaking, the fast mode is mainly contributed to the Lorentz Detuning before 500μsec and the slow mode after 500 μsec.



The behavior of the filling is considered not to be different between on resonance and the slight detuning.

Two Modes Model

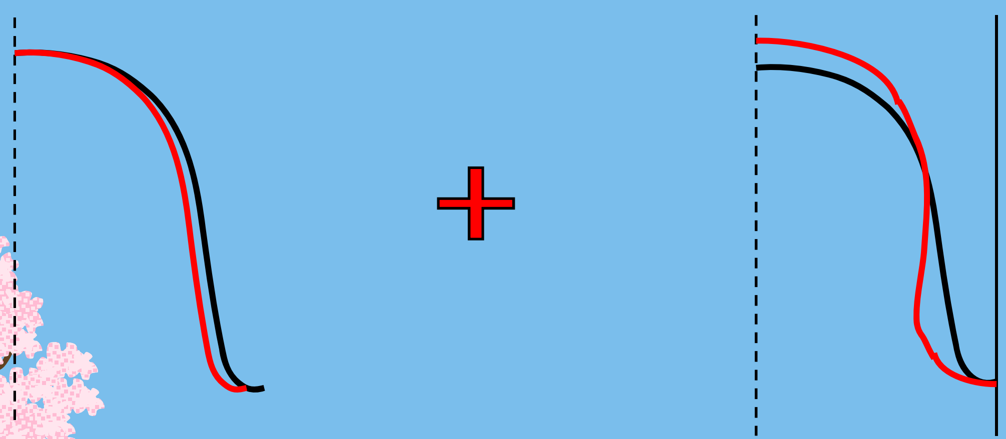
In this model, the Lorentz detuning is generated by two modes.
One is the “slow mode” and the other is “fast”.



slow mode
(sine)

fast mode
(linear)

In the simulation



From the mechanical calculation

Actually, so many modes exist
in 9-cell cavity!
But, these modes are mainly effective.

slow mode

fast mode

Cavity Voltage Equation

From J. Slater

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

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

Equi-angular Spiral

If the factor in each term is constant in time, this equation can be solved analytically.
But, if not so…

Method of the calculation for the transient response

Within the very short period (Δt), the following equation is filled and solved analytically.

$$\tilde{V}_n = \tilde{V}_{g,n} + \left(\tilde{V}_{n-1} - \tilde{V}_{g,n}\right)\exp\left(-\frac{\Delta t}{T_F}\right)\exp\left(j\tan\psi_{n-1}\frac{\Delta t}{T_F}\right)$$

$$= \tilde{V}_{n-1}\exp\left(-\frac{\Delta t}{T_F}\right)\exp\left(j\tan\psi_{n-1}\frac{\Delta t}{T_F}\right)$$

$$+\tilde{V}_{g,n}\left(1-\exp\left(-\frac{\Delta t}{T_F}\right)\exp\left(j\tan\psi_{n-1}\frac{\Delta t}{T_F}\right)\right)$$

1 μ sec

$$\tilde{V}_{g,n} \propto \cos\psi_{n-1}\exp\left(j\psi_{n-1}\right)$$

Generally normalized by 1

Expressions and values for the calculation

Used expressions

$$\tilde{V}_n = \tilde{V}_{g,n} + \left(\tilde{V}_{n-1} - \tilde{V}_{g,n}\right)\exp\left(-\frac{\Delta t}{T_F}\right)\exp\left(j\tan\psi_{n-1}\frac{\Delta t}{T_F}\right)$$

$$= \tilde{V}_{n-1}\exp\left(-\frac{\Delta t}{T_F}\right)\exp\left(j\tan\psi_{n-1}\frac{\Delta t}{T_F}\right)$$

$$+\tilde{V}_{g,n}\left(1-\exp\left(-\frac{\Delta t}{T_F}\right)\exp\left(j\tan\psi_{n-1}\frac{\Delta t}{T_F}\right)\right)$$

$$\tilde{V}_{g,n} \propto \cos\psi_{n-1}\exp\left(j\psi_{n-1}\right)$$

Used numerical values

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

filling time : $T_f = 2Q_L/\omega_0$

$f_0 = 1300.25MHz$

$Q_L = 1.15x10^6$ *(from horizontal test for STF B.L. #3 cavity)*

$\Delta t = 1\mu sec$ *(sufficiently short)*

$\Delta f = sine + linear$ *(t<500μsec)*

→ sine (t>500μsec)

After 500μsec, the fast mode disappears, because the damping is very fast.

Example of the calculation for the transient response

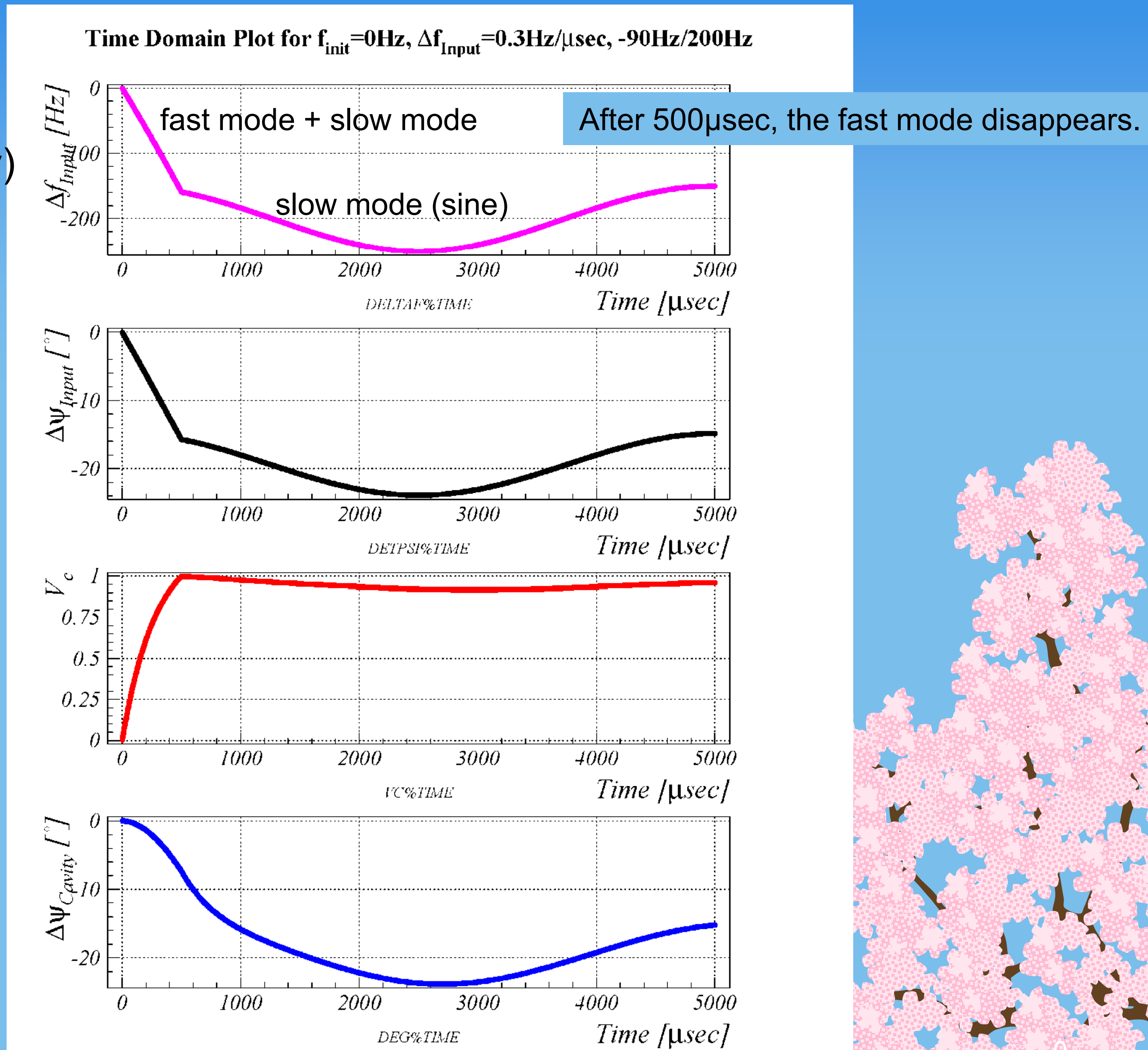
Input data (frequency)

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

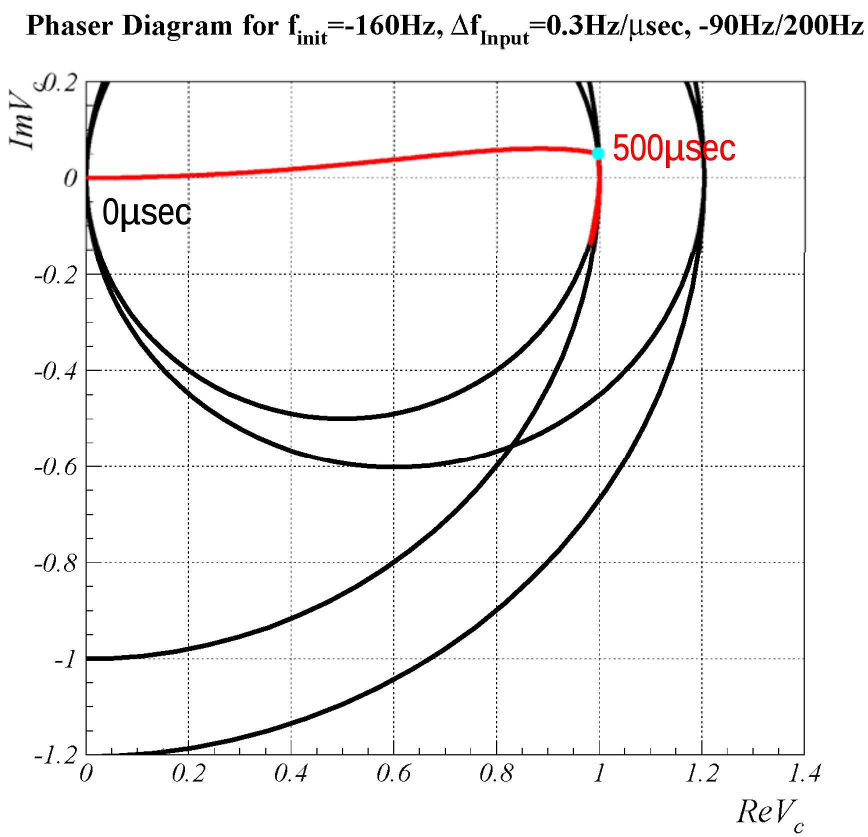
Input data (degree)

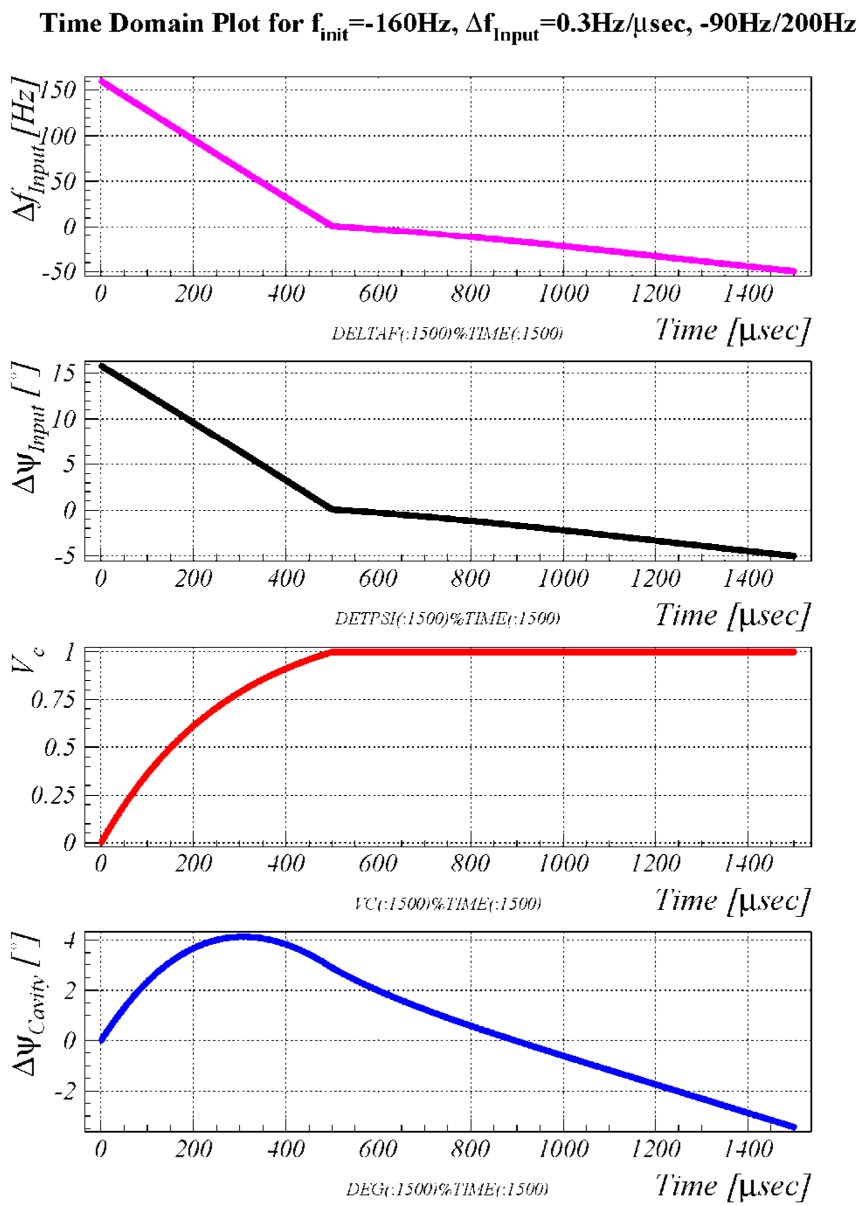
Output data (V_C)

Output data (Ψ_{Cavity})

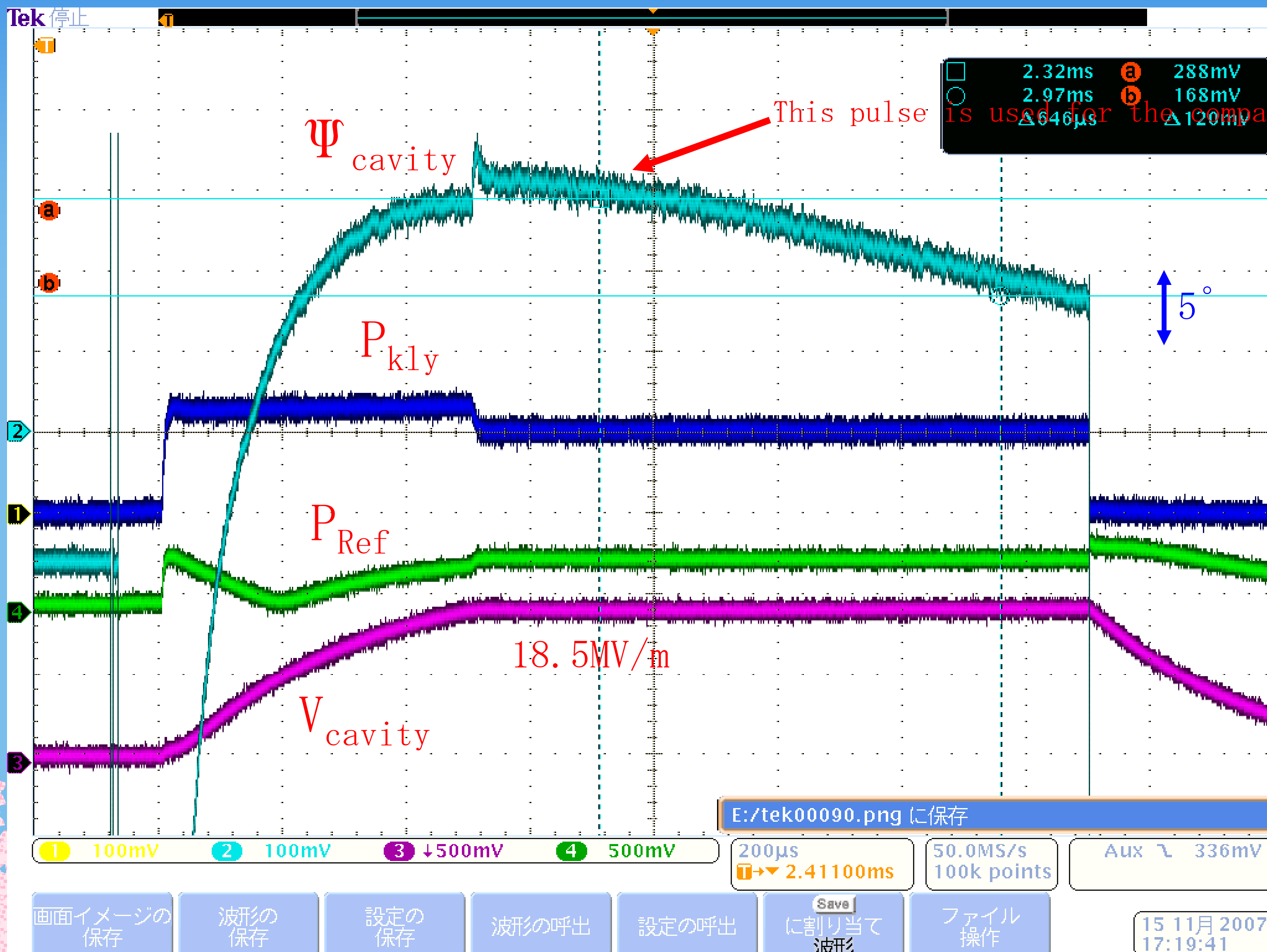


Case of Flat-top (offset +160Hz, w/o Piezo)





One pulse during High-Power Test (+160Hz Offset, w/o Piezo)

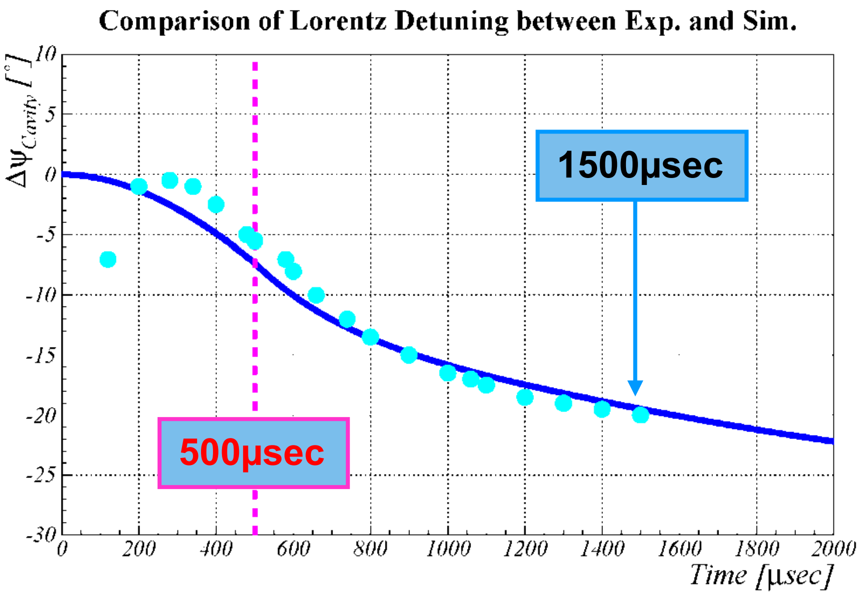


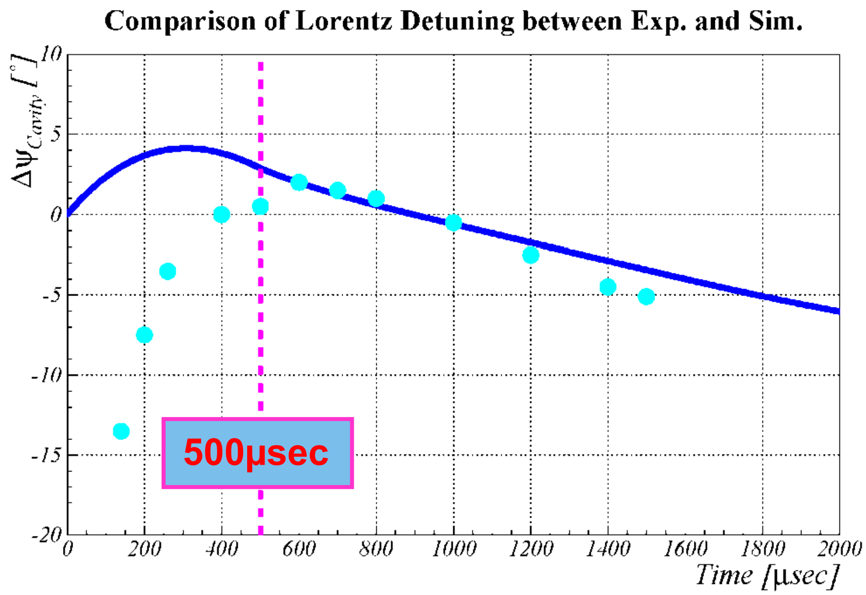
Comparison between experiment and calculation ①

Preliminary

No offset

+160Hz offset





Before 500μsec, the response of the phase detector is probably significant.
After that, it is consistent between the experiment and the calculation.

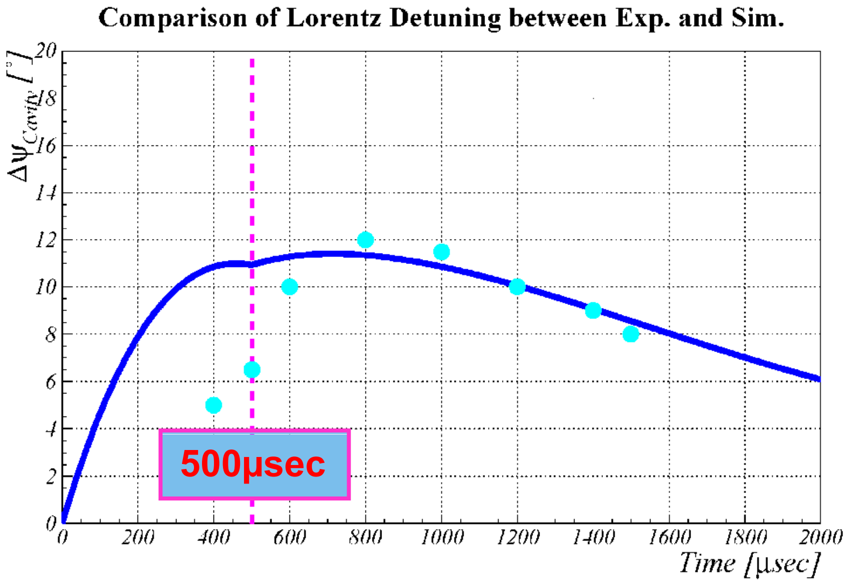
"Two modes model" is valid!

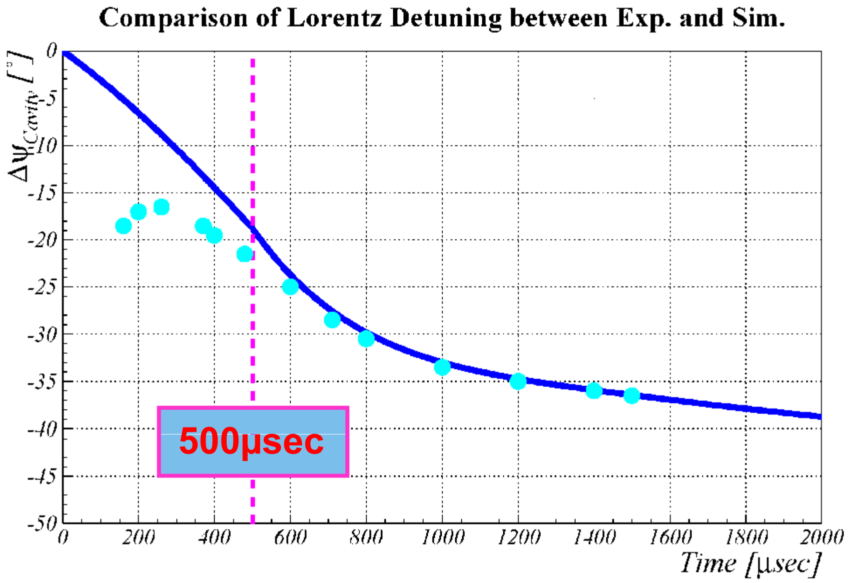
Comparison between experiment and calculation ②

Preliminary

+300Hz offset

-160Hz offset





"Two modes model" is valid!

For the real operation with Piezo, the calculation is modified for a few parameters.

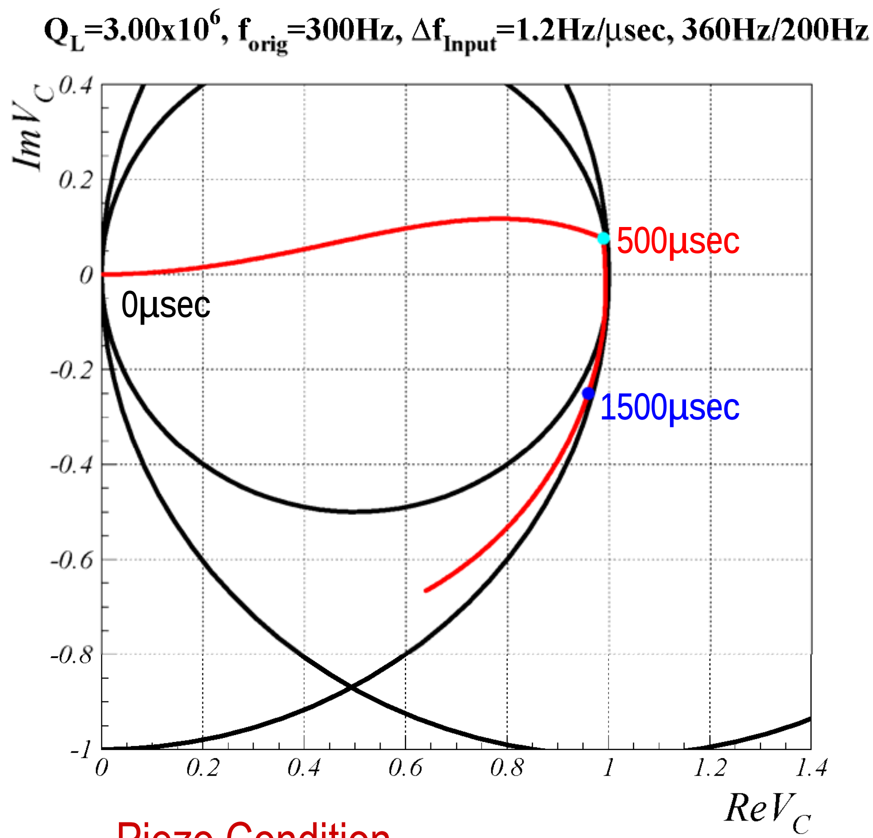
$$E_{acc} = 18.5 \rightarrow 35MV/m$$

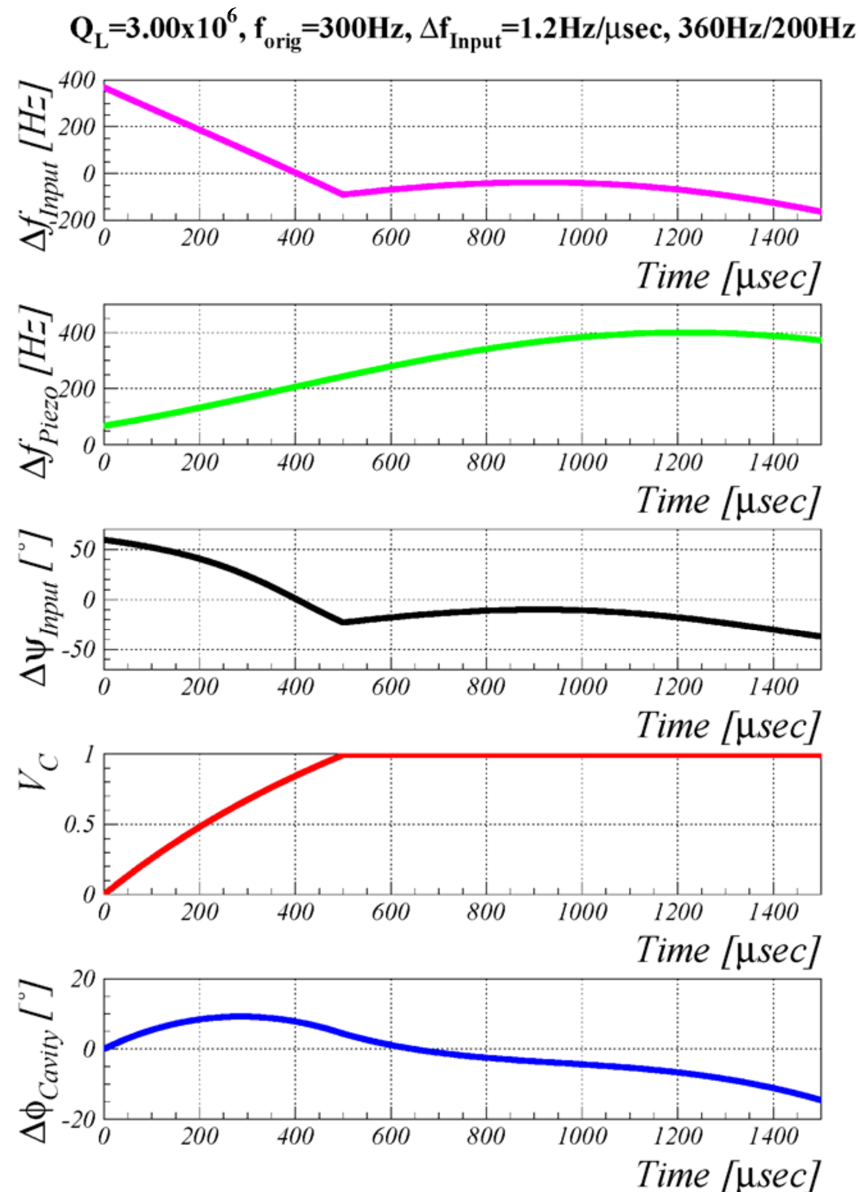
$$Q_L = 1.15x10^6 \rightarrow 3.00x10^6$$

Sorry! There is not the experimental data around 35MV/m.
The result around 30MV/m will be obtained in STF Phase-1.0 on June or July.

Example of Piezo Compensation (#1)

Preliminary





Piezo Condition

Amplitude : 400Hz (300Hz=1µm)

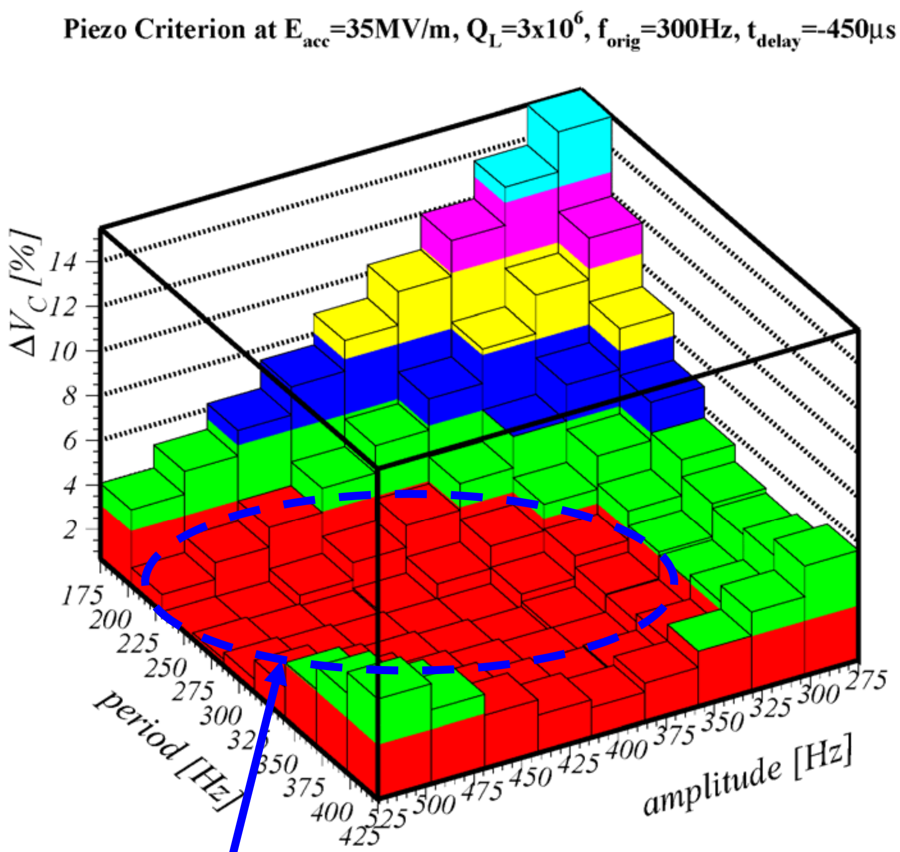
Period : 300Hz

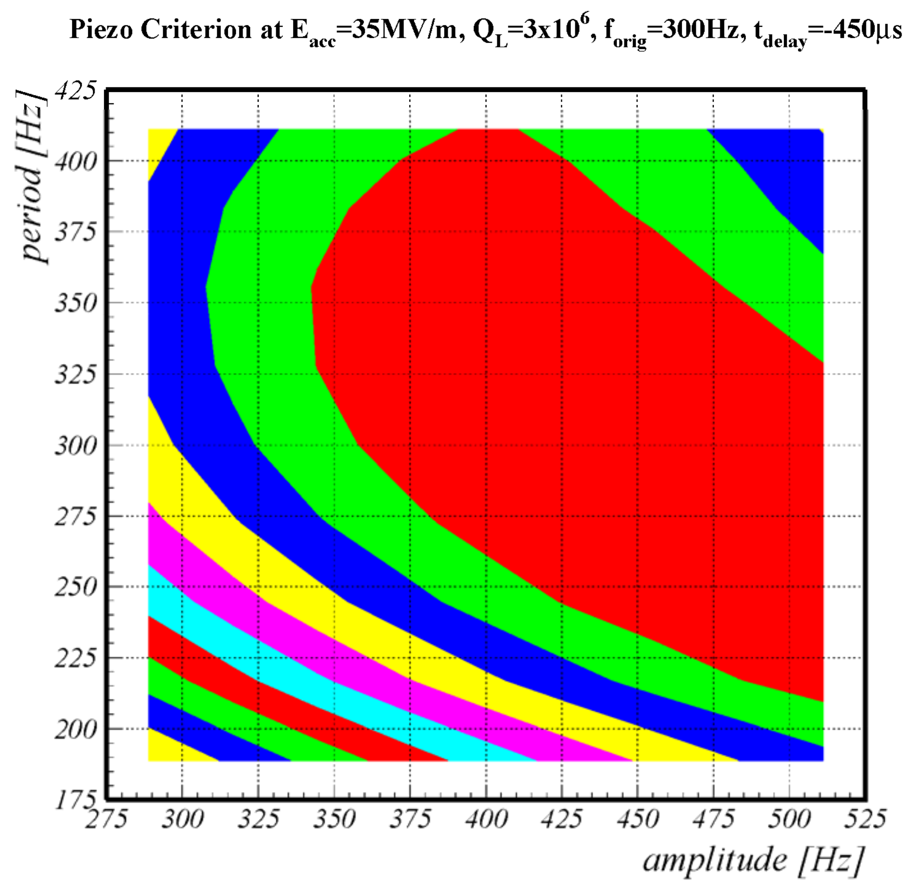
Delay time : –450µsec (fixed!)

} ← Variously changing

Criteria of Piezo parameters (#1)

Preliminary

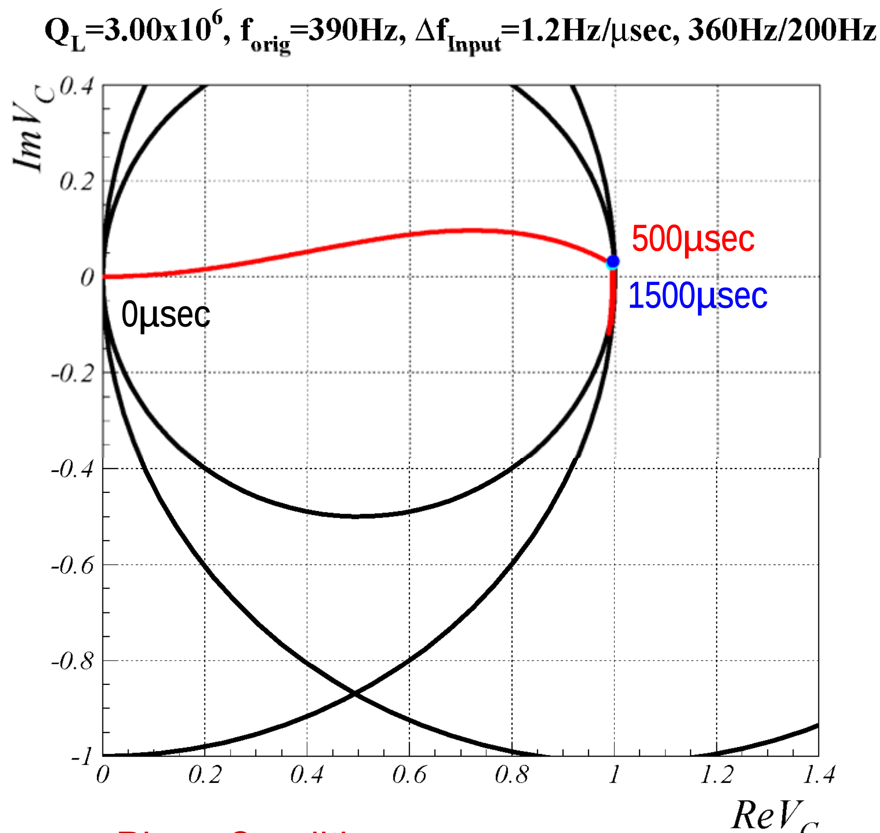


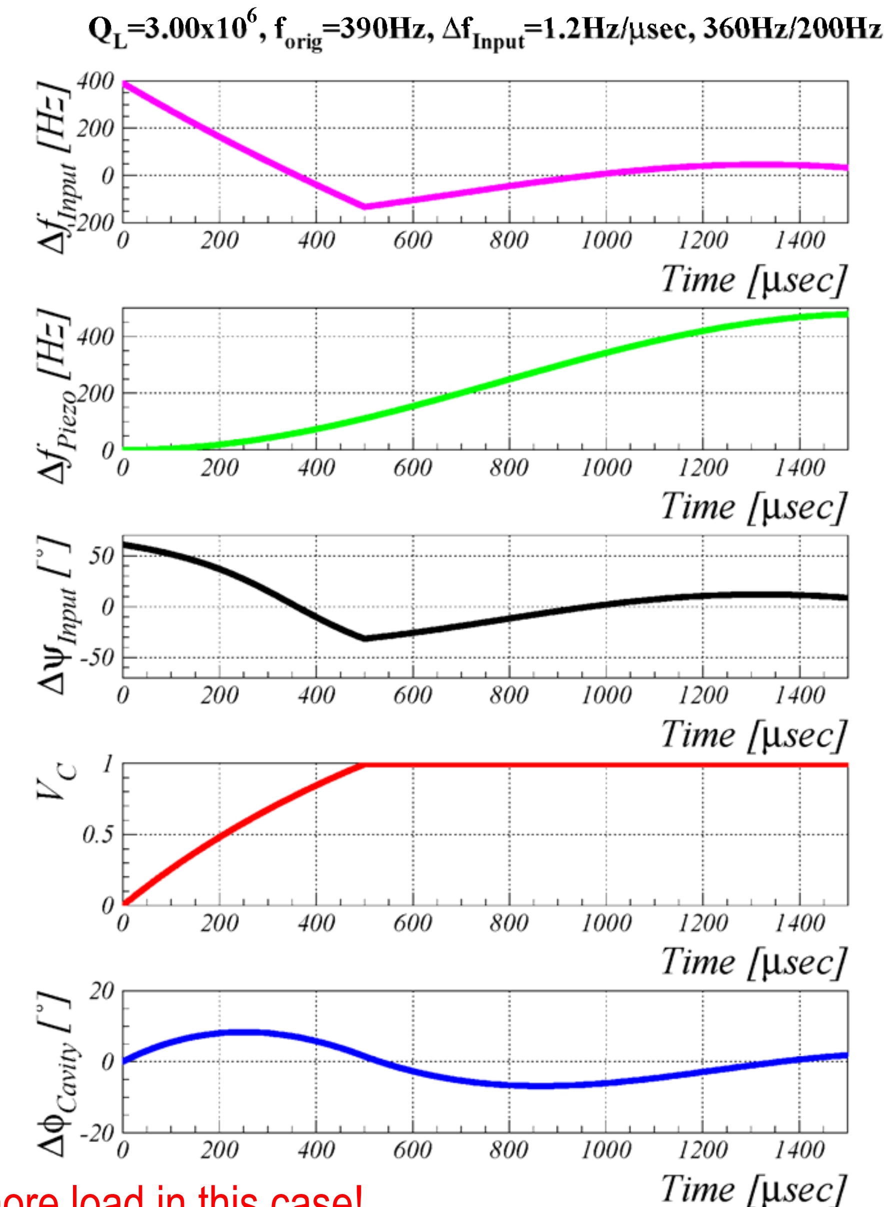


Good operational region for the stable cavity voltage

Example of Piezo Compensation (#2)

Preliminary





Piezo Condition

Amplitude : 480Hz (300Hz=1μm)

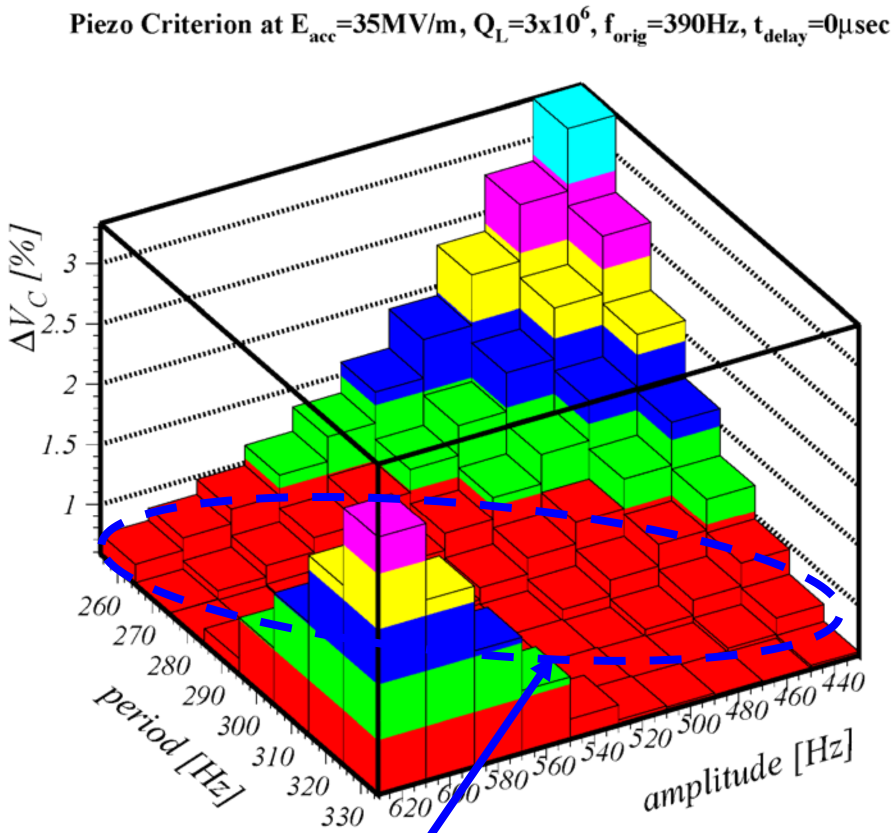
Period : 320Hz

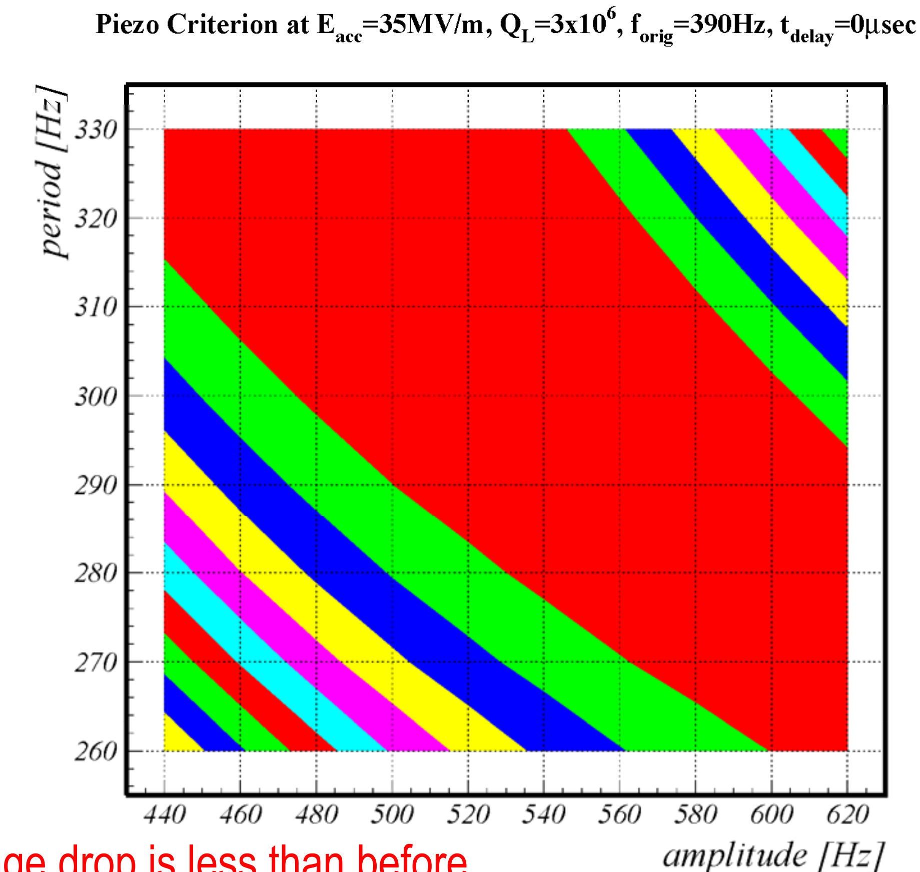
Delay time : 0μsec

The Piezo is added more load in this case!

Criteria of Piezo parameters (#2)

Preliminary





Good operational region
for the stable cavity voltage

In this case, the voltage drop is less than before,
but the added load to the Piezo is larger!
This may cause the breakdown of the Piezo or the lifetime may be shorter.

And, the cavity phase should be also considered!

Next Measurement Plan

- Comparing between two types of Piezo actuator
  - High voltage type
    - 40μm/1000V@Room Temp. (2μm/1000V@2K)
  - Low voltage type
    - 20μm/200V@Room Temp. (?μm/1000V@2K)

300Hz/μm for Δf_{cavity}

- Measurement of the Lorentz detuning around 30MV/m
  - STF #2 B.L. cavity achieved 29.4MV/m in the V.T.
- Measurement of the detuning angle during the RF decay
  - This was already demonstrated in the horizontal test of LL cavity.
- Cavity voltage control using Piezo
  - If the cavity voltage is dropped, the Piezo may work for the control.
- Checking the response of the phase detector

Suggestion to the compensation method for the Lorentz Detuning

- Put the initial offset for the cavity frequency
  - During the filling time, the cavity frequency is gradually decreased by the Lorentz force.
- Work Piezo with the small load
  - Avoid the breakdown of the Piezo by the larger load
  - Longer lifetime of Piezo
- Increase the mechanical strength of the cavity support
  - It is difficult to deform the cavity.

Summary

- "Two modes model" is valid for the transient response of the STF B.L. #3 cavity in the horizontal test at STF Phase-0.5.

- It is effective to increase the mechanical strength of the cavity support structure for the reduction of the Lorentz detuning.

- It is similarly effective to set the initial offset to the cavity frequency around the high field.

- In STF Phase-1.0, we will compare between the experimental data around 30MV/m and the simulation.

We will re-examine "two modes model" for more optimization.

Backup Slides

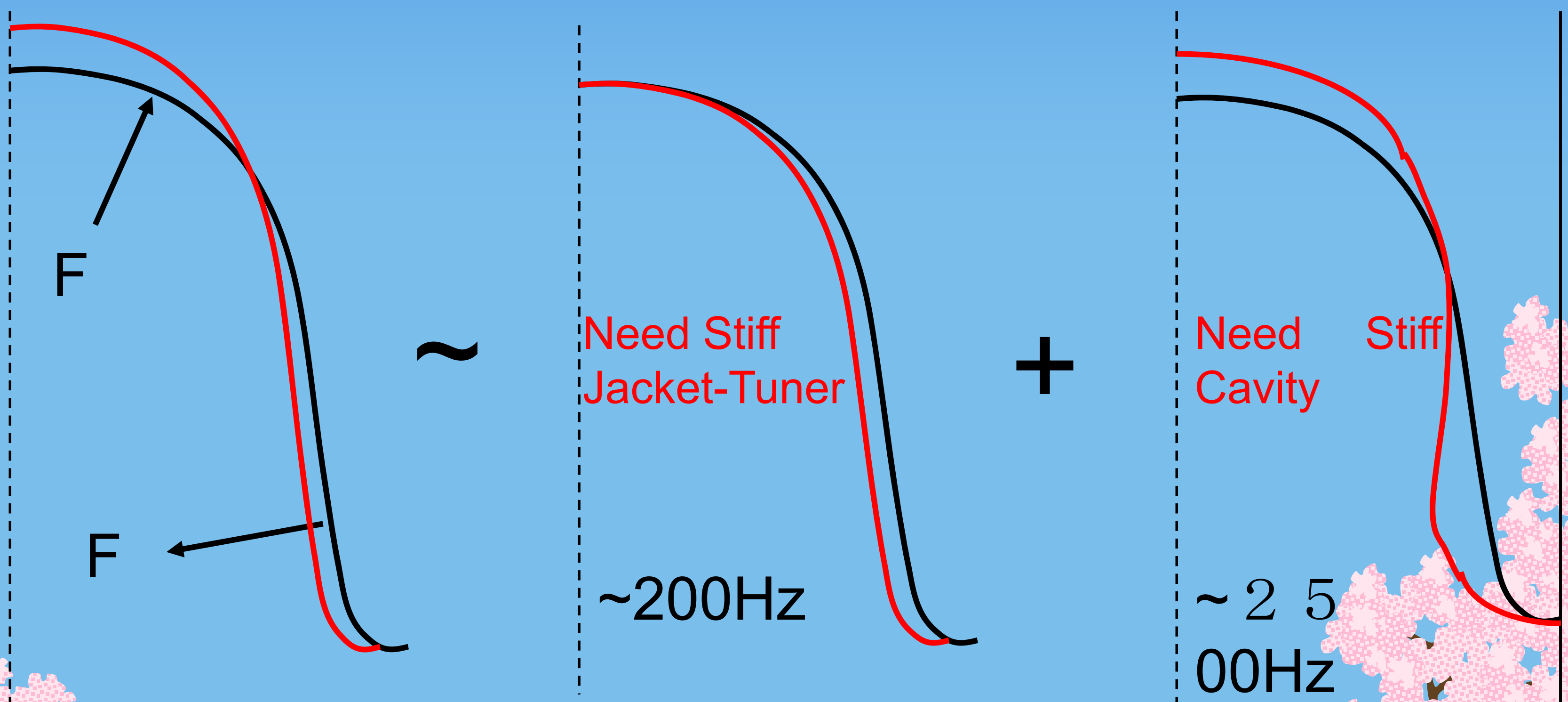
Mechanical Detuning Equation

$$x(s,t) = \sum_k x_k(s,t); \qquad F = \sum_k F_k$$

$$\frac{d^2 x_k}{dt^2} + \frac{\omega_k}{Q_k}\frac{dx_k}{dt} + \omega_k^2 x_k = \frac{F_k}{m_k}$$

It is expected that there are two modes from the calculation of the mechanical oscillation.
One is the fast mode and the other is slow.

Two Dominant Mechanical Modes



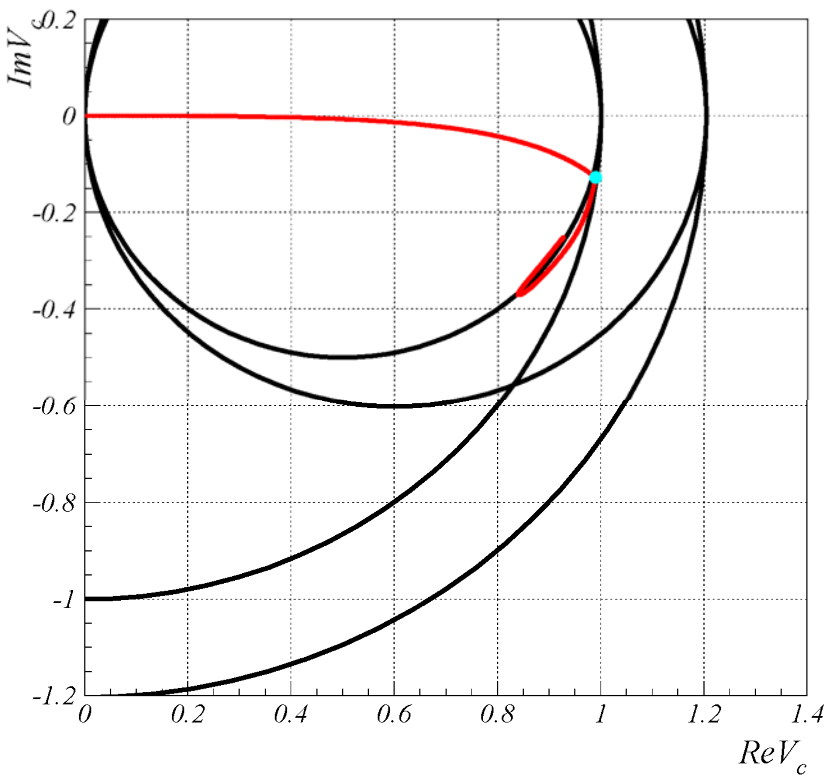
Fundamental mode
(Slow mode)

2-nd order mode
(Fast mode)

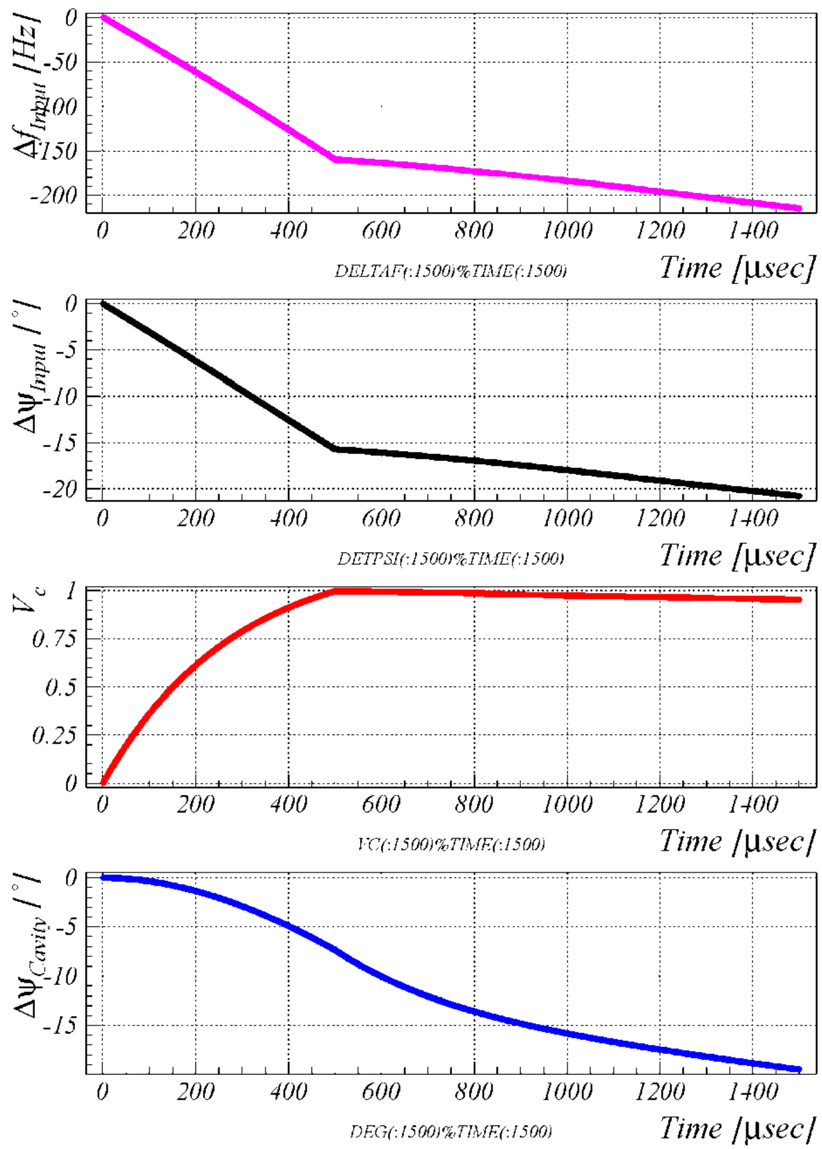
Case of Flat-top ① (no offset)

Phaser diagram

Phaser Diagram for f_{init}=0Hz, Δf_{Input}=0.3Hz/μsec, -90Hz/200Hz

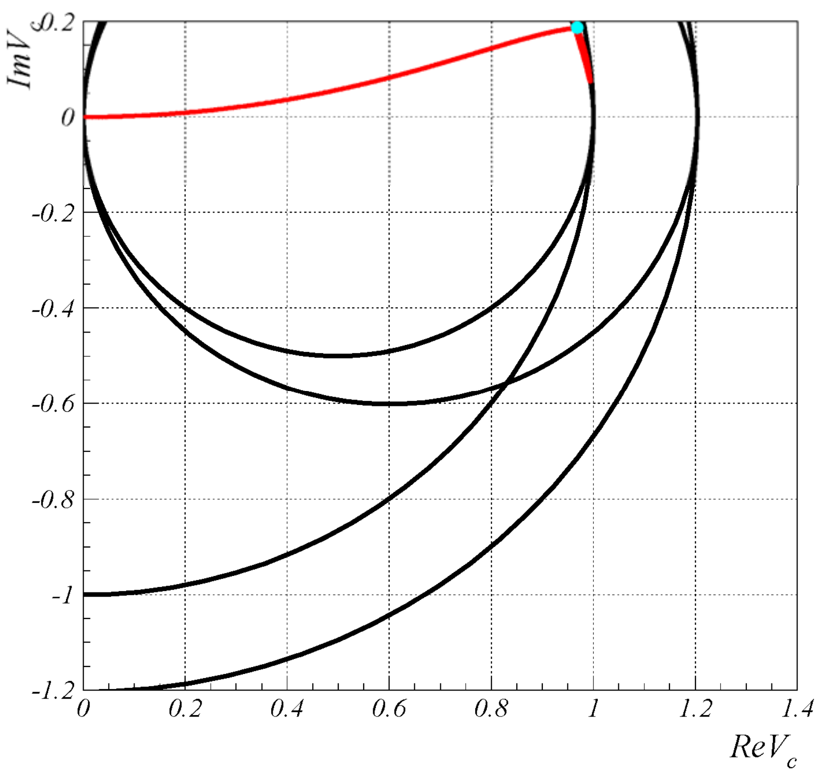


Time Domain Plot for f_{init}=0Hz, Δf_{Input}=0.3Hz/μsec, -90Hz/200Hz

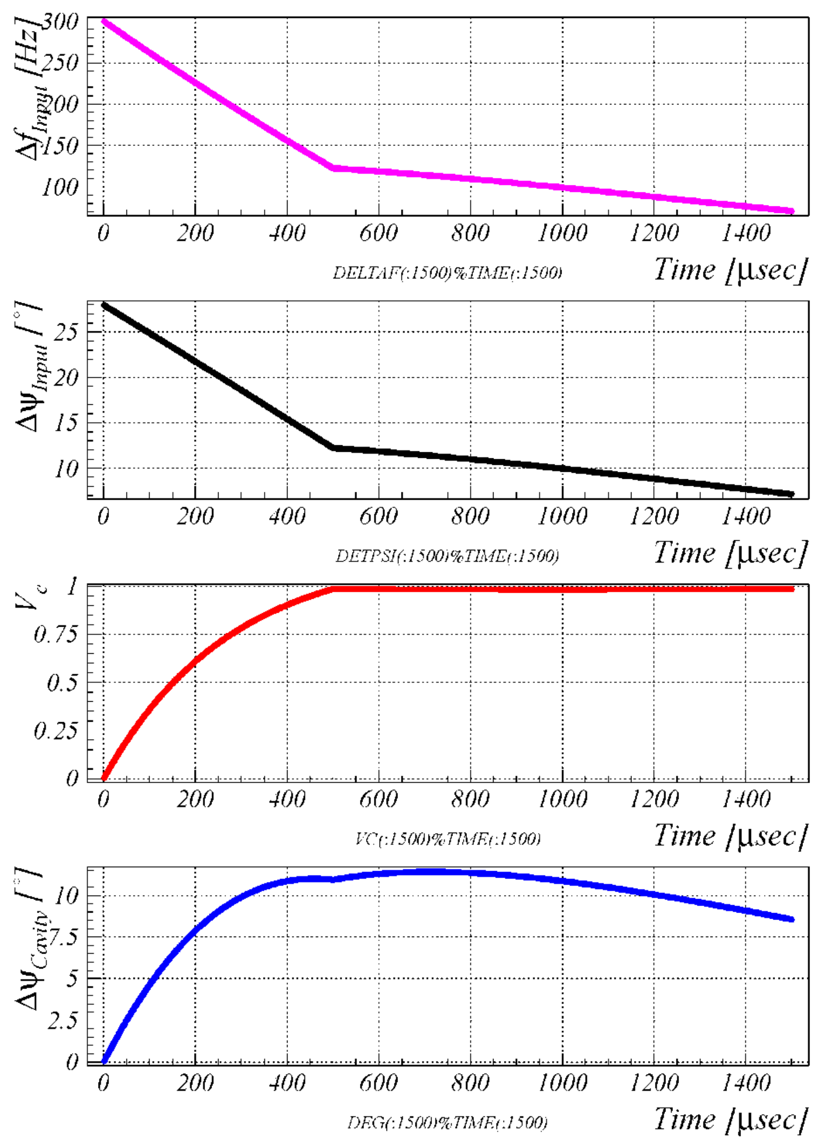


Case of Flat-top ③ (offset +300Hz)

Phaser Diagram for f_{init}=-300Hz, Δf_{Input}=0.3Hz/µsec, -90Hz/200Hz

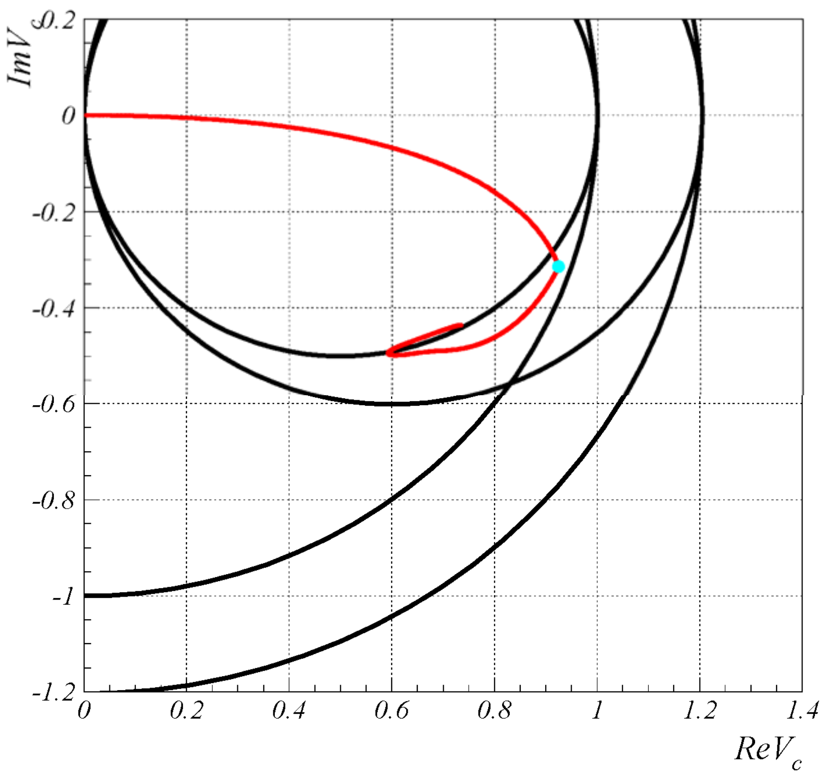


Time Domain Plot for f_{init}=-300Hz, Δf_{Input}=0.3Hz/µsec, -90Hz/200Hz

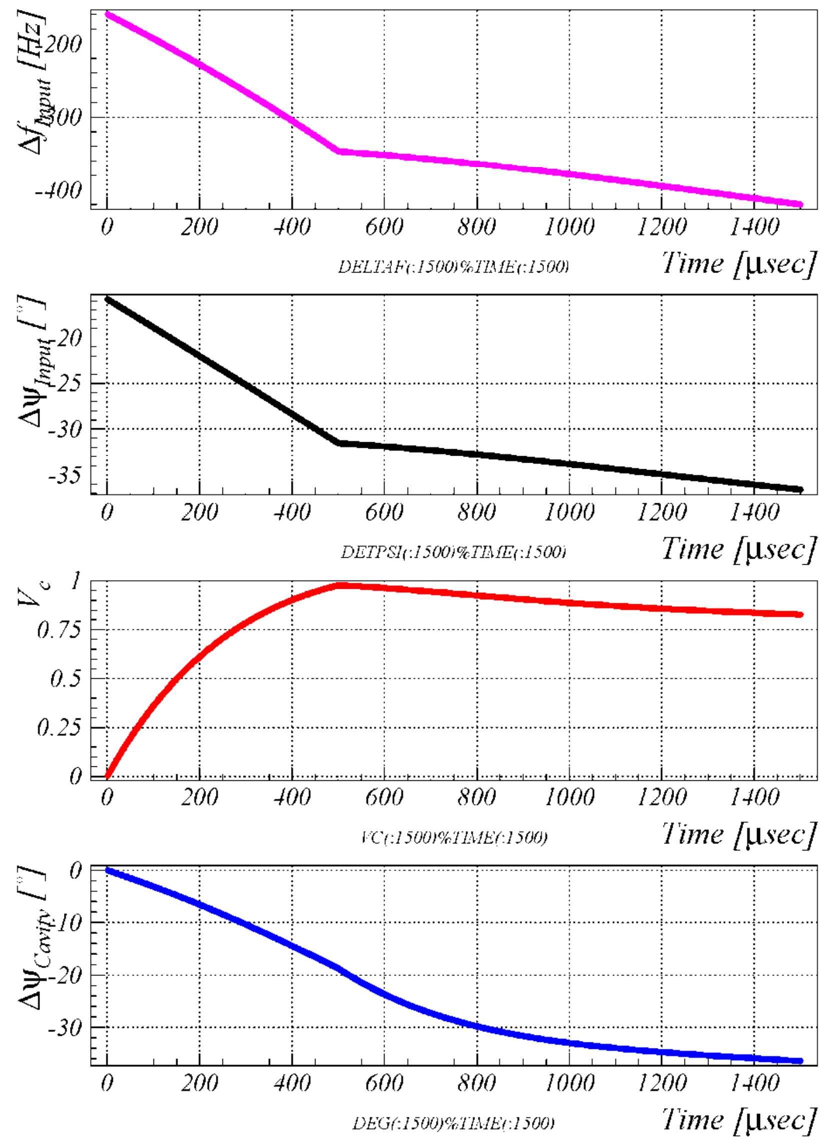


Case of Flat-top ④ (offset -160Hz)

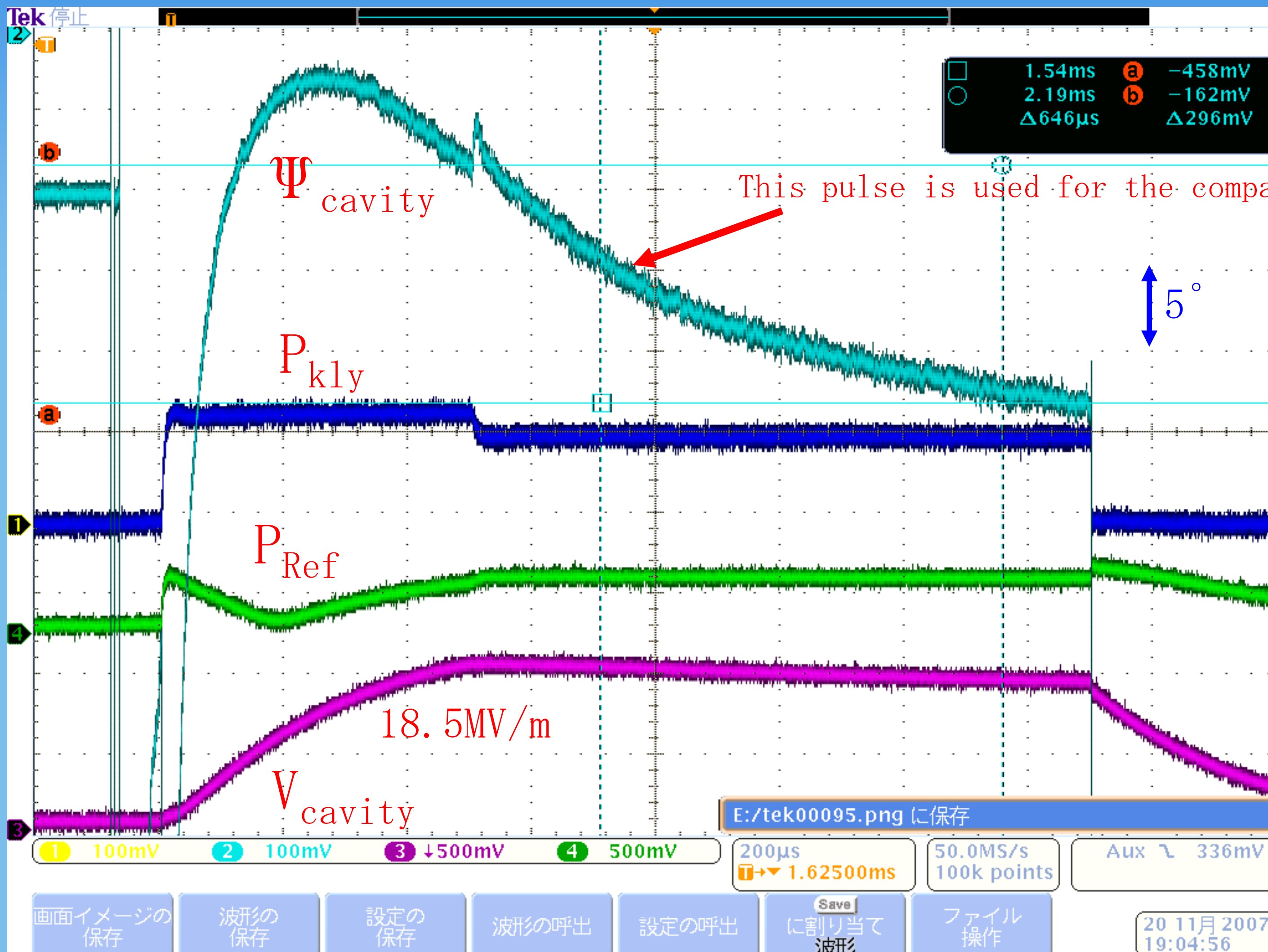
Phaser Diagram for f_{init}=+160Hz, Δf_{Input}=0.3Hz/μsec, -90Hz/200Hz



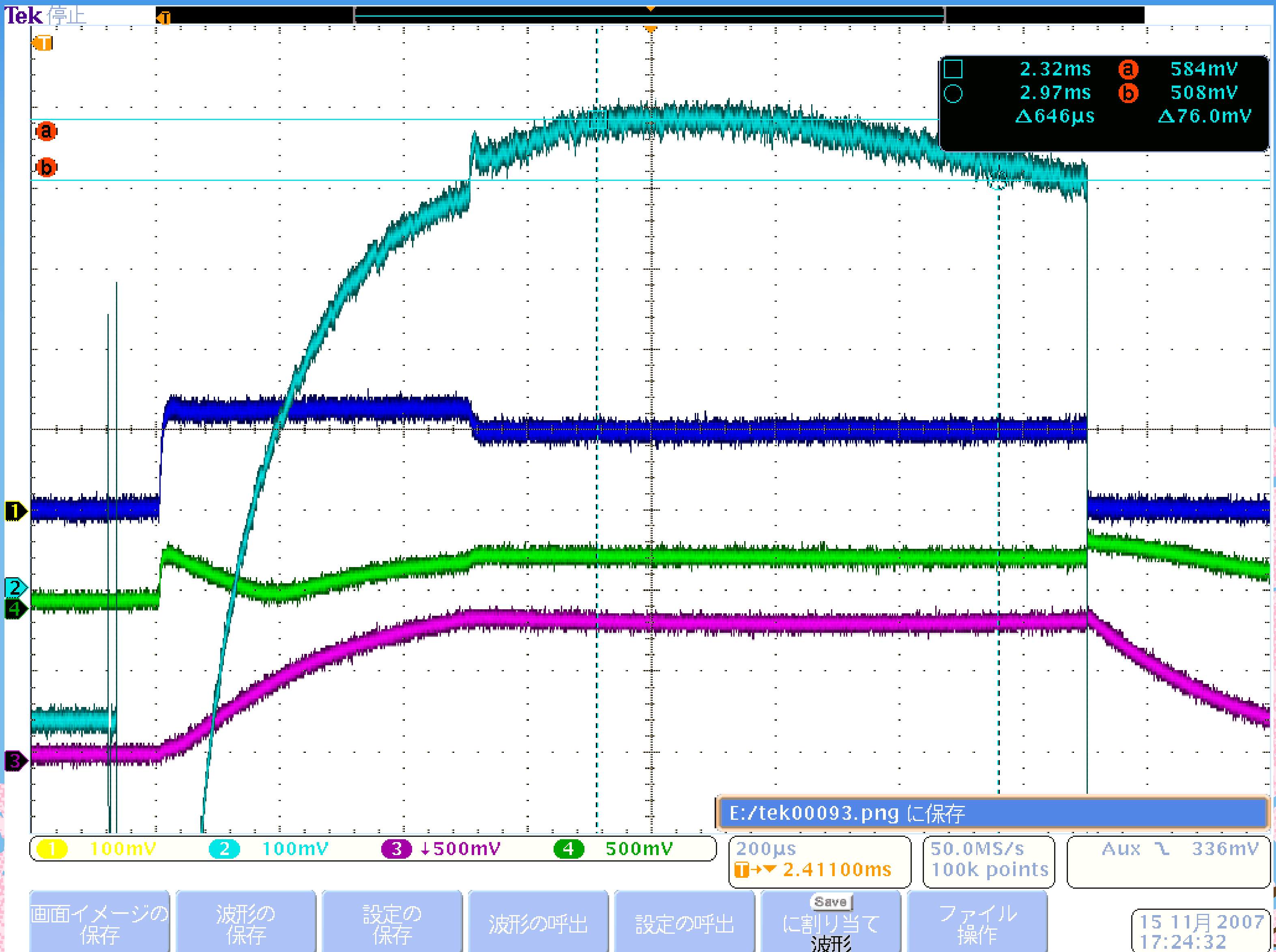
Time Domain Plot for f_{init}=+160Hz, Δf_{Input}=0.3Hz/μsec, -90Hz/200Hz



One pulse during High-Power Test (No Offset)



One pulse during High-Power Test (+300Hz Offset)



One pulse during High-Power Test (-160Hz Offset)