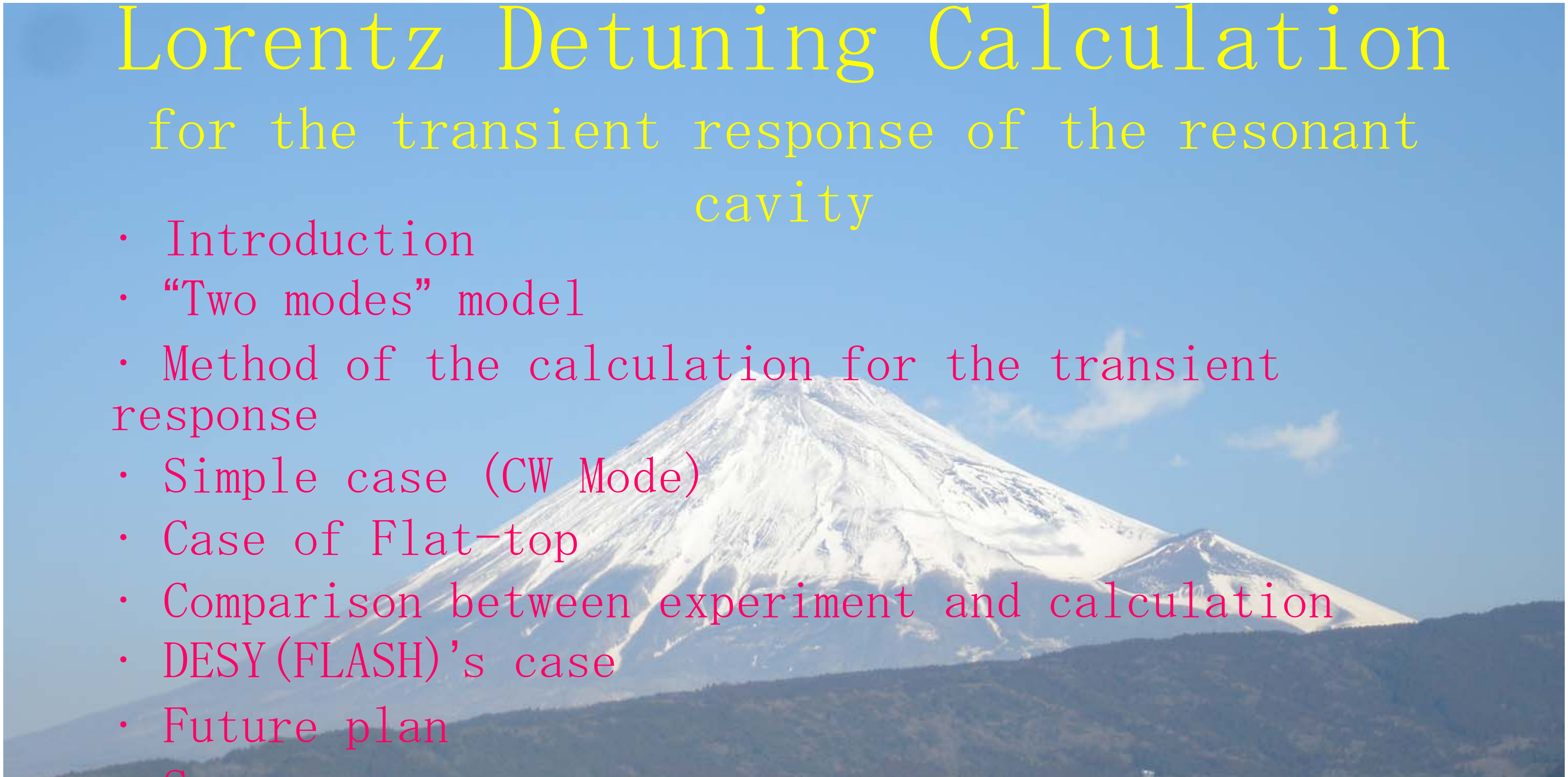
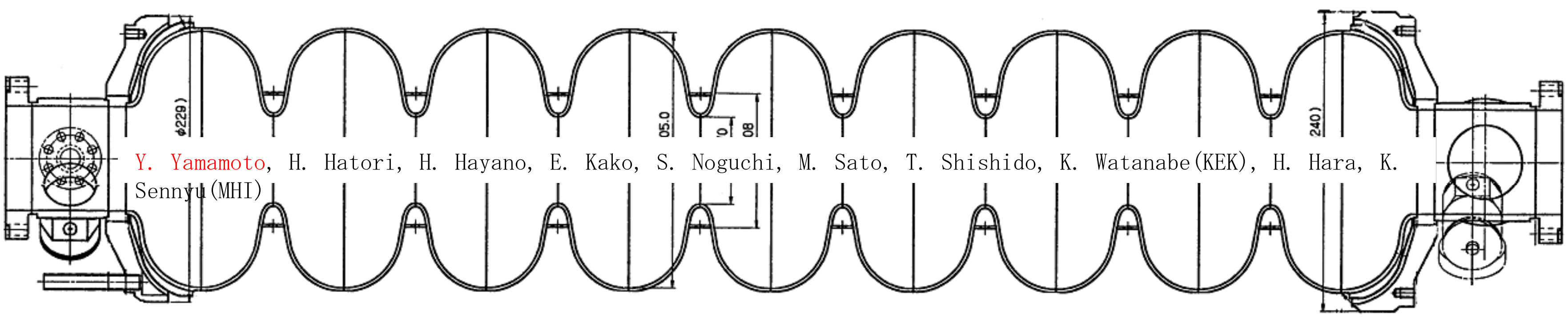
Lorentz Detuning Calculation

for the transient response of the resonant cavity



- Introduction
- “Two modes” model
- Method of the calculation for the transient response
- Simple case (CW Mode)
- Case of Flat-top
- Comparison between experiment and calculation
- DESY(FLASH)’s case
- Future plan
- Summary



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

Introduction

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

↓

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) Setting the initial offset of the frequency to the cavity
(3) Increasing the mechanical strength of the cavity

STF base-line cavity is mechanically stronger than TESLA's one!

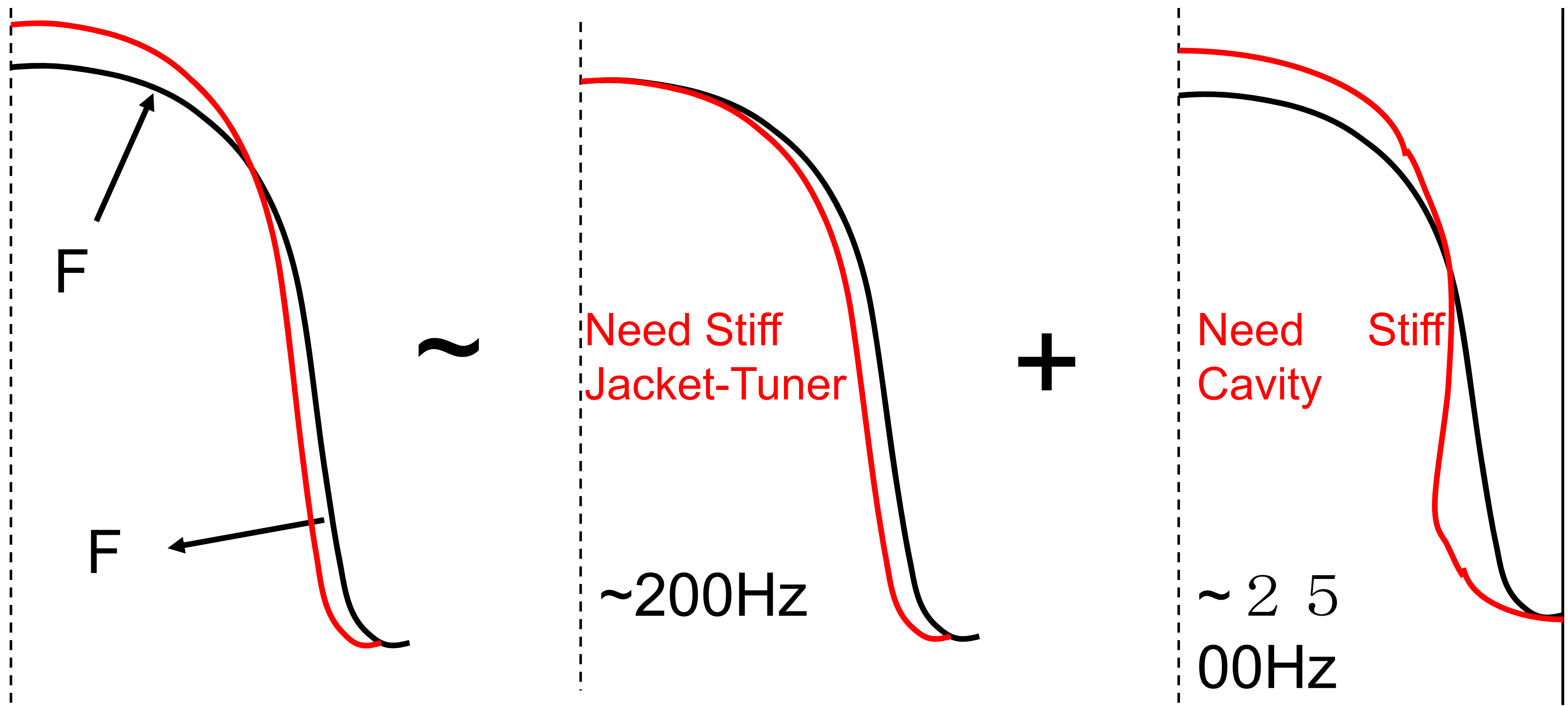
Mechanical Detuning Equation

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

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

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

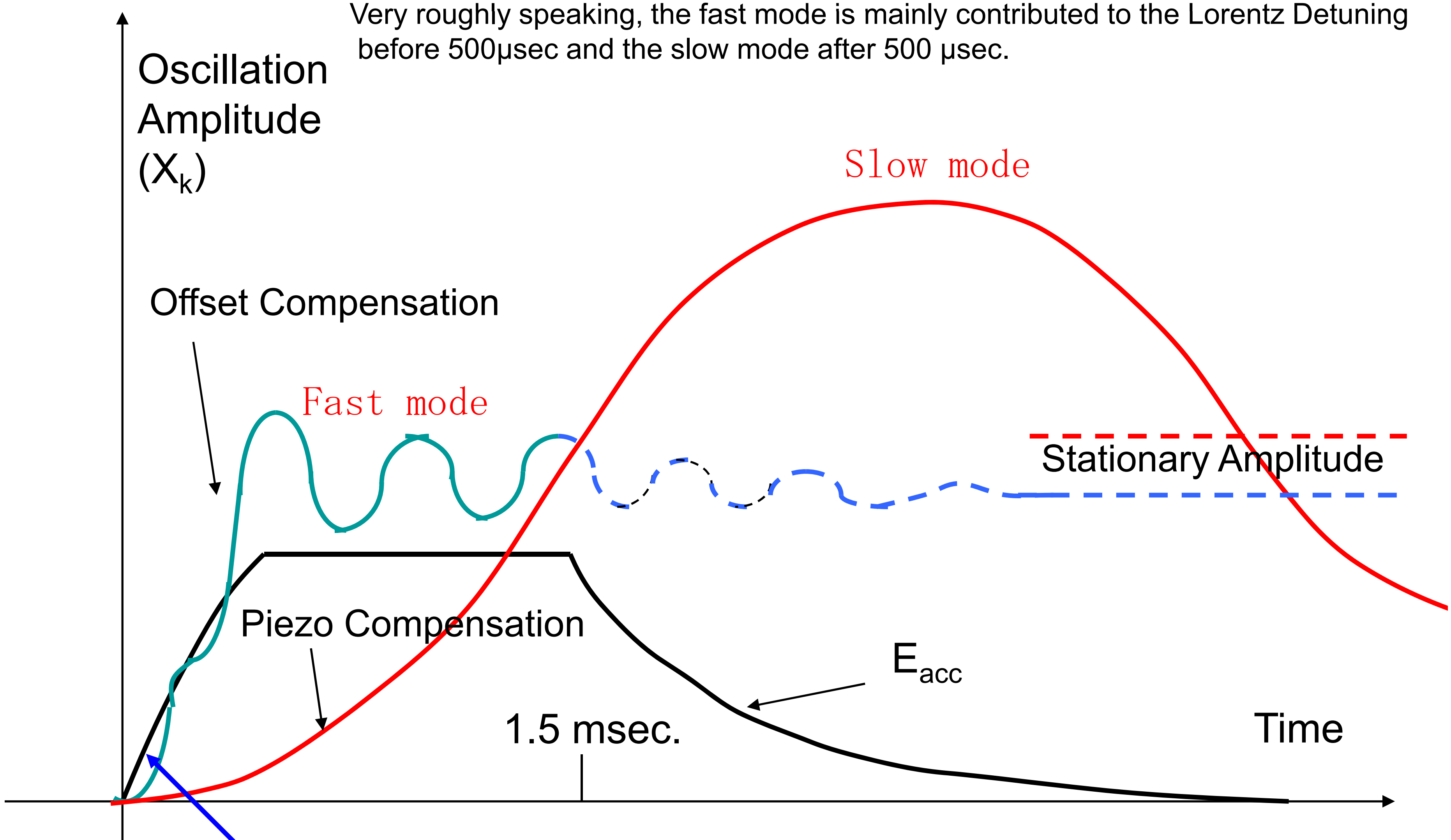


Fundamental mode
(Slow mode)

2-nd order mode
(Fast mode)

Mechanical Oscillation (Two Modes Model)

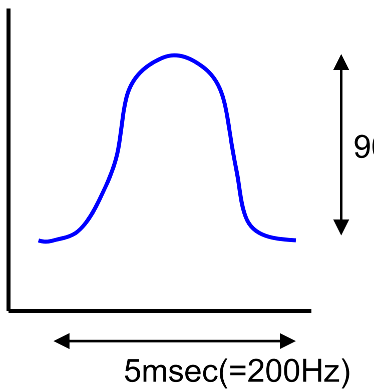
Very roughly speaking, the fast mode is mainly contributed to the Lorentz Detuning before 500μsec and the slow mode after 500 μsec.



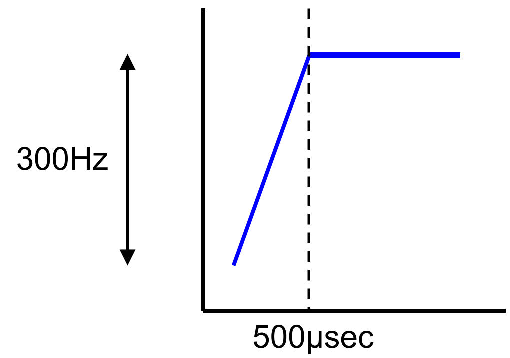
The behavior of the filling is considered not to be different between on resonance and the slight detuning.

Two Modes Model

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

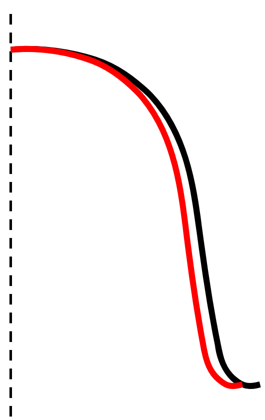


slow mode
(sine)

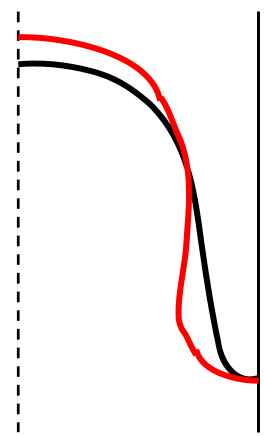


fast mode
(linear)

In the simulation



slow mode



fast mode

From the mechanical calculation

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

Cavity Voltage Equation

From J. Slater

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

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

Equi-angular Spiral

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

Voltage Solution

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

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

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

$f_0 = 1300.25\,\mathrm{MHz}$

$Q_L = 1.15\times10^6$ (from horizontal test for STF B.L. #3 cavity)

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

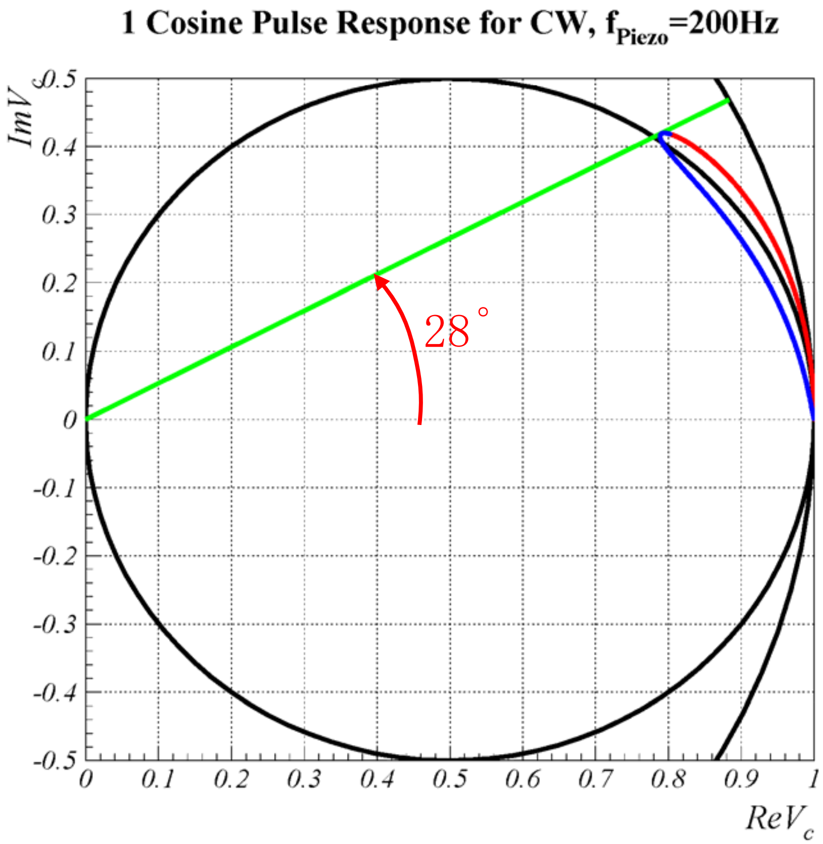
Δf = sine + linear ($t<500\,\mu$sec)

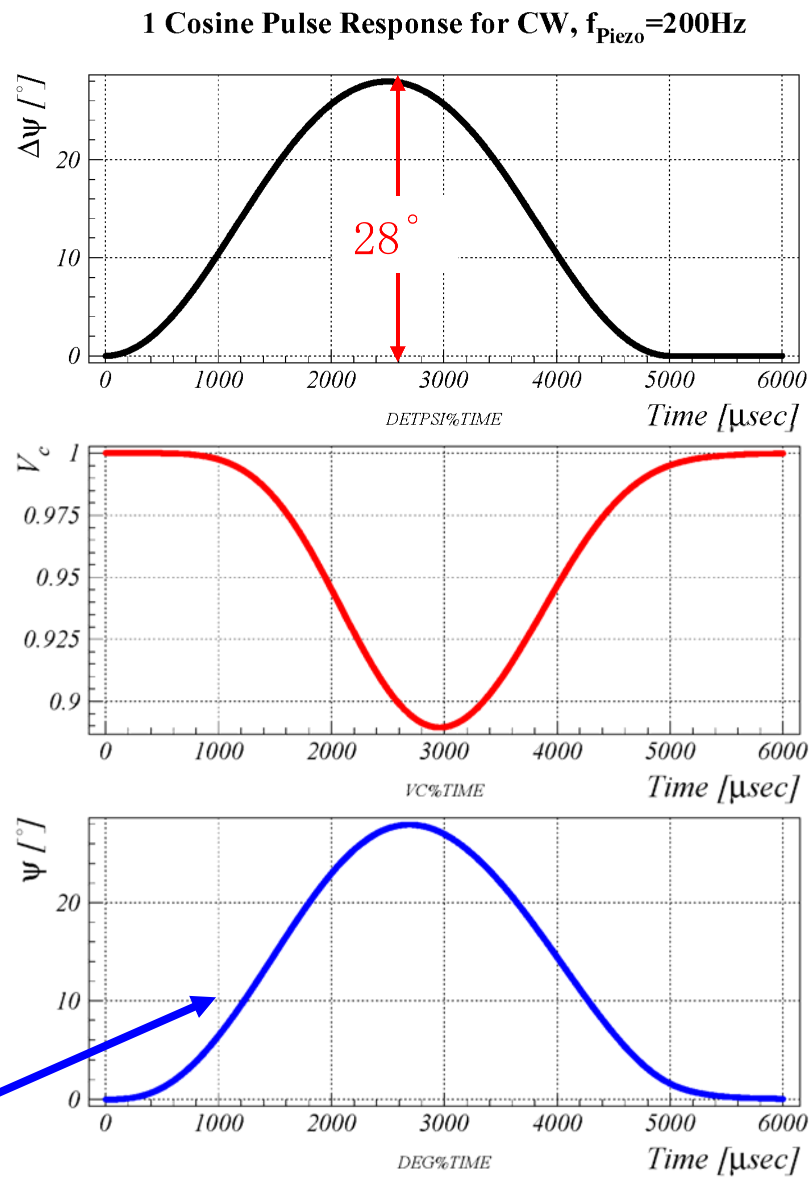
→ sine ($t>500\,\mu$sec)

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

Case of CW (f_{Drive}=200Hz)

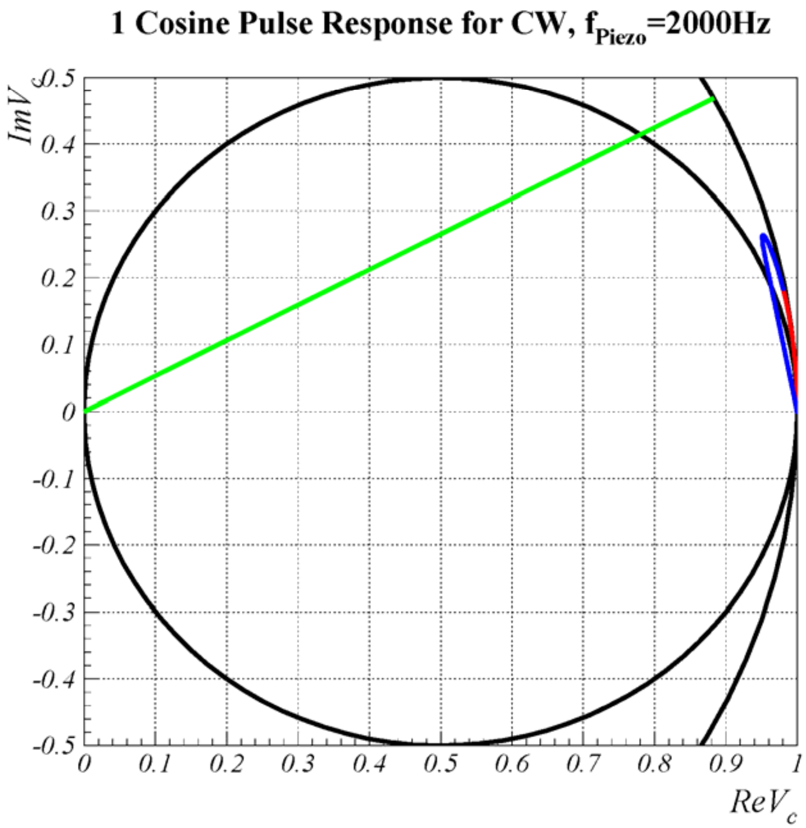
Phaser diagram

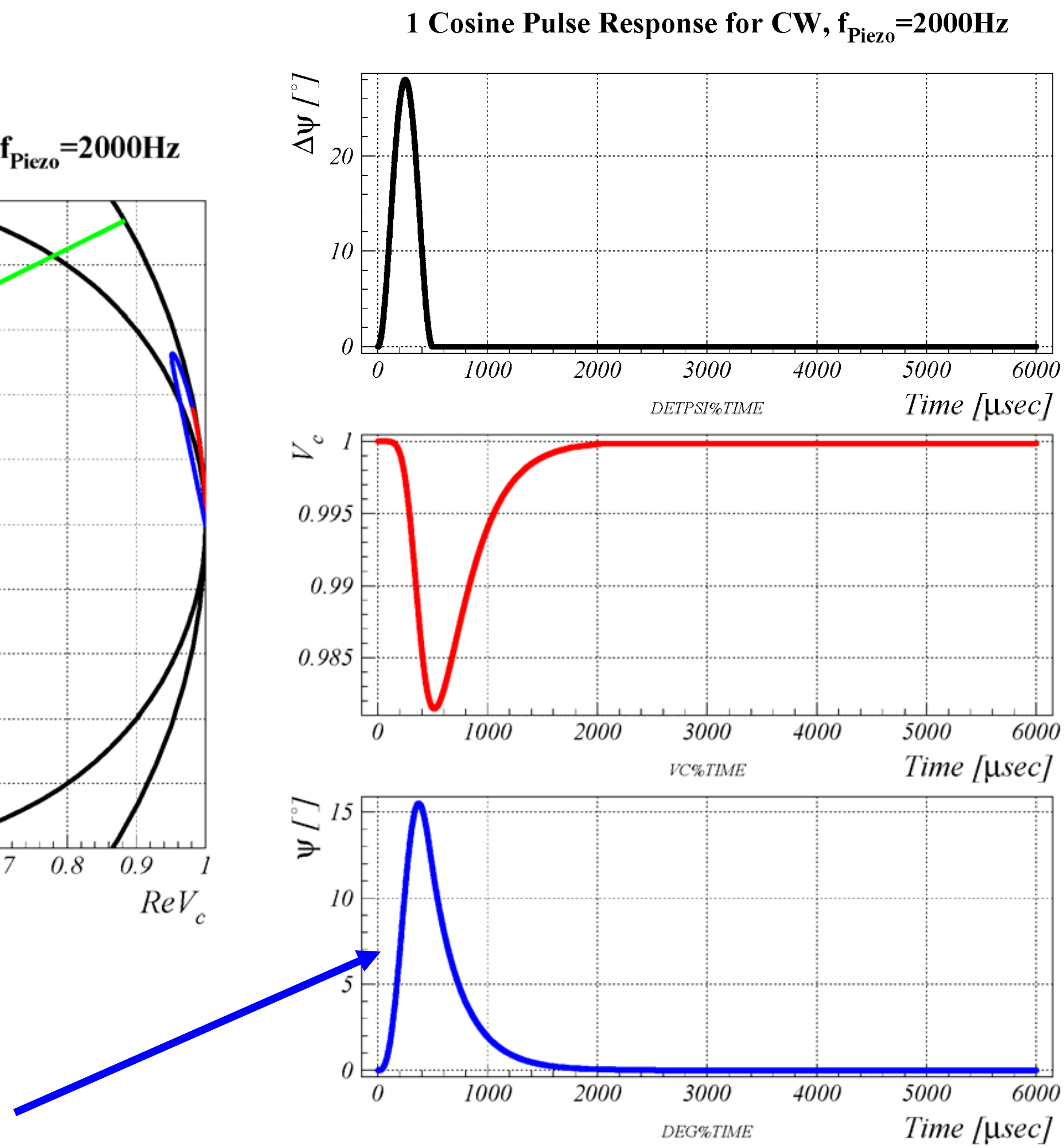




The response of the cavity is slightly delayed and damped by the filling time.

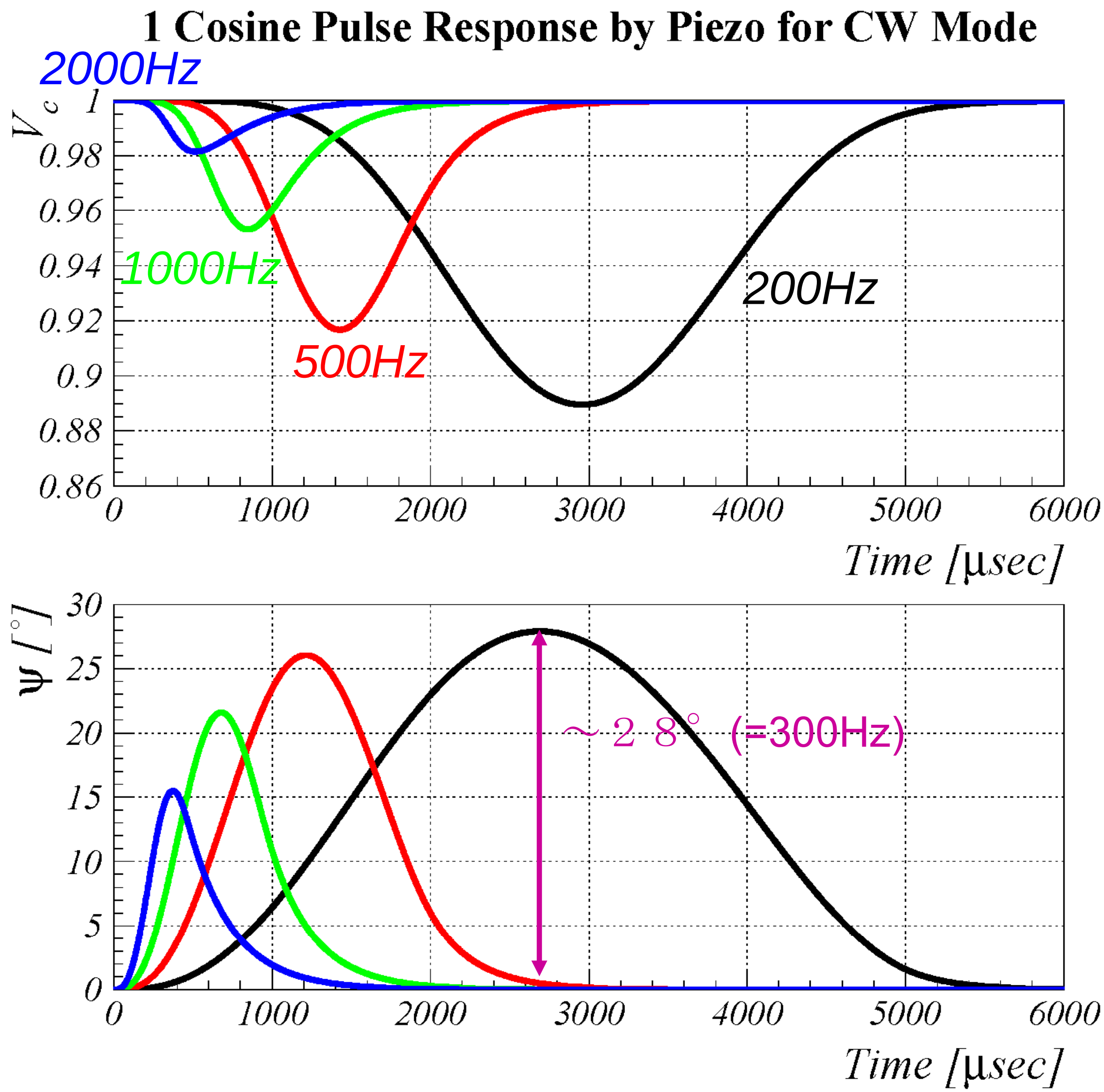
Case of CW (f_{Drive}=2000Hz)



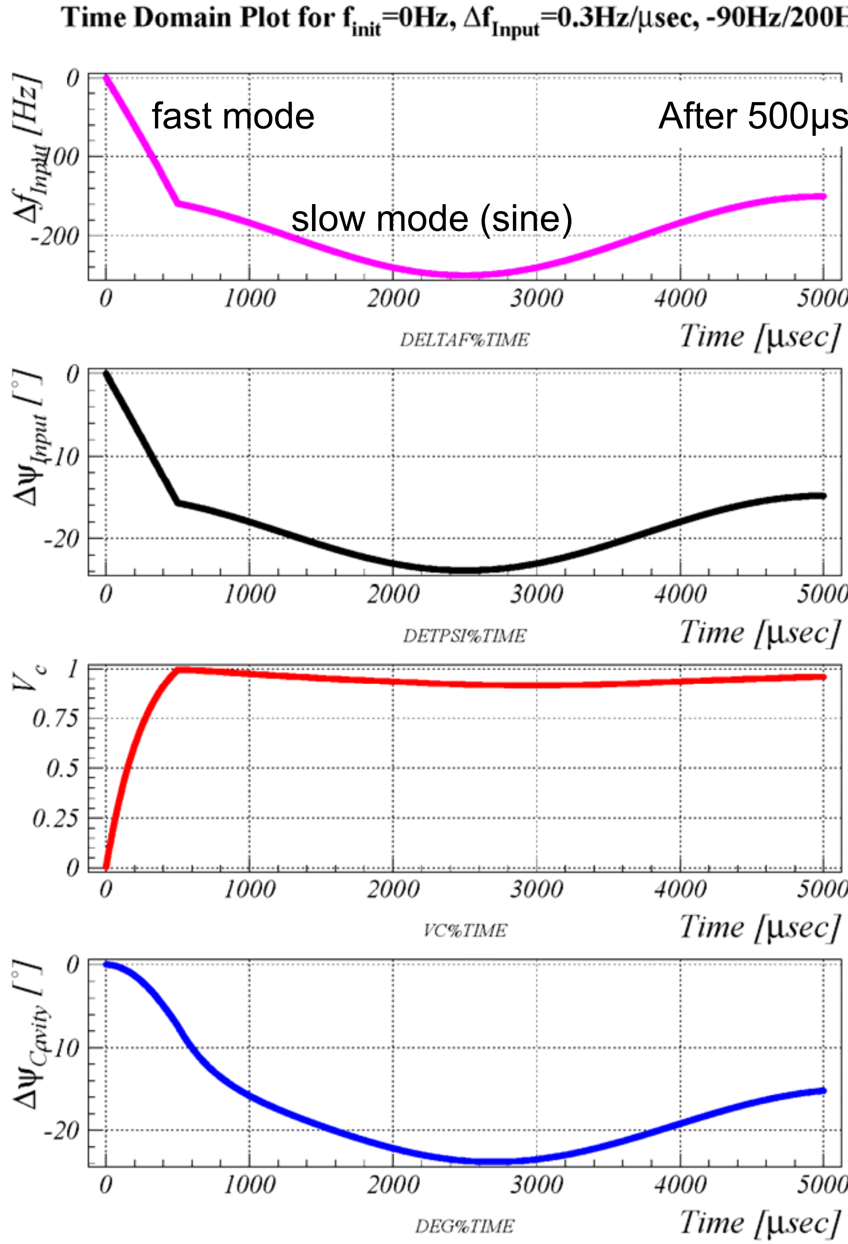


The response of the cavity is largely delayed and damped by the filling time.

1 Pulse Response in CW Operation

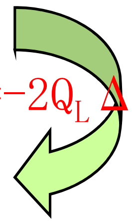


Example of Flat-top calculation



After 500μsec, the fast mode disappears.

Input data (frequency)



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

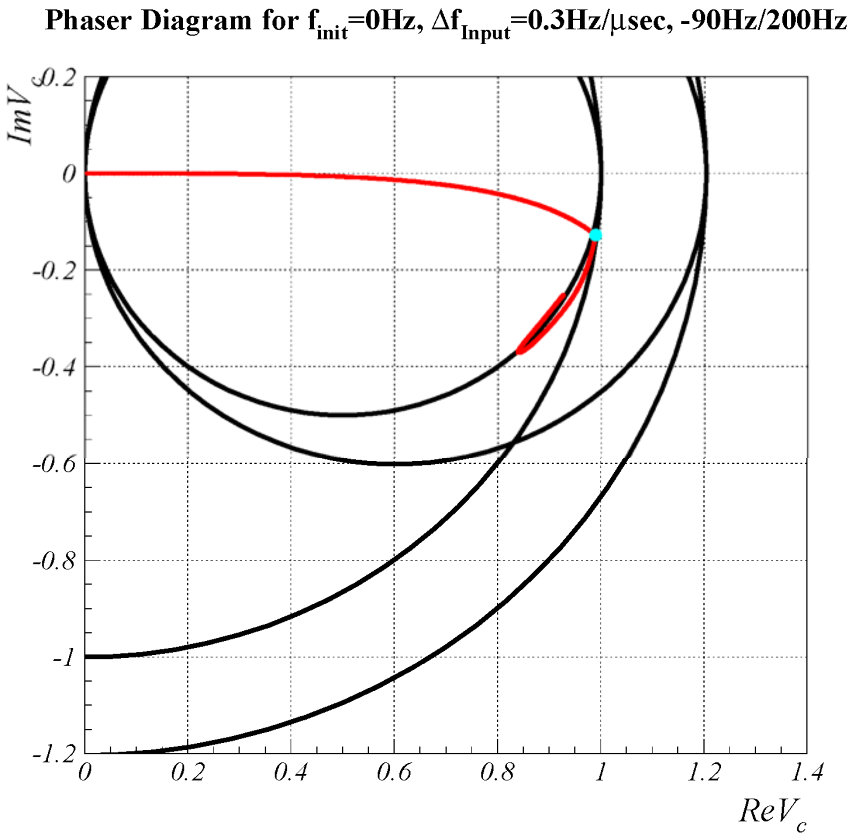
Input data (degree)

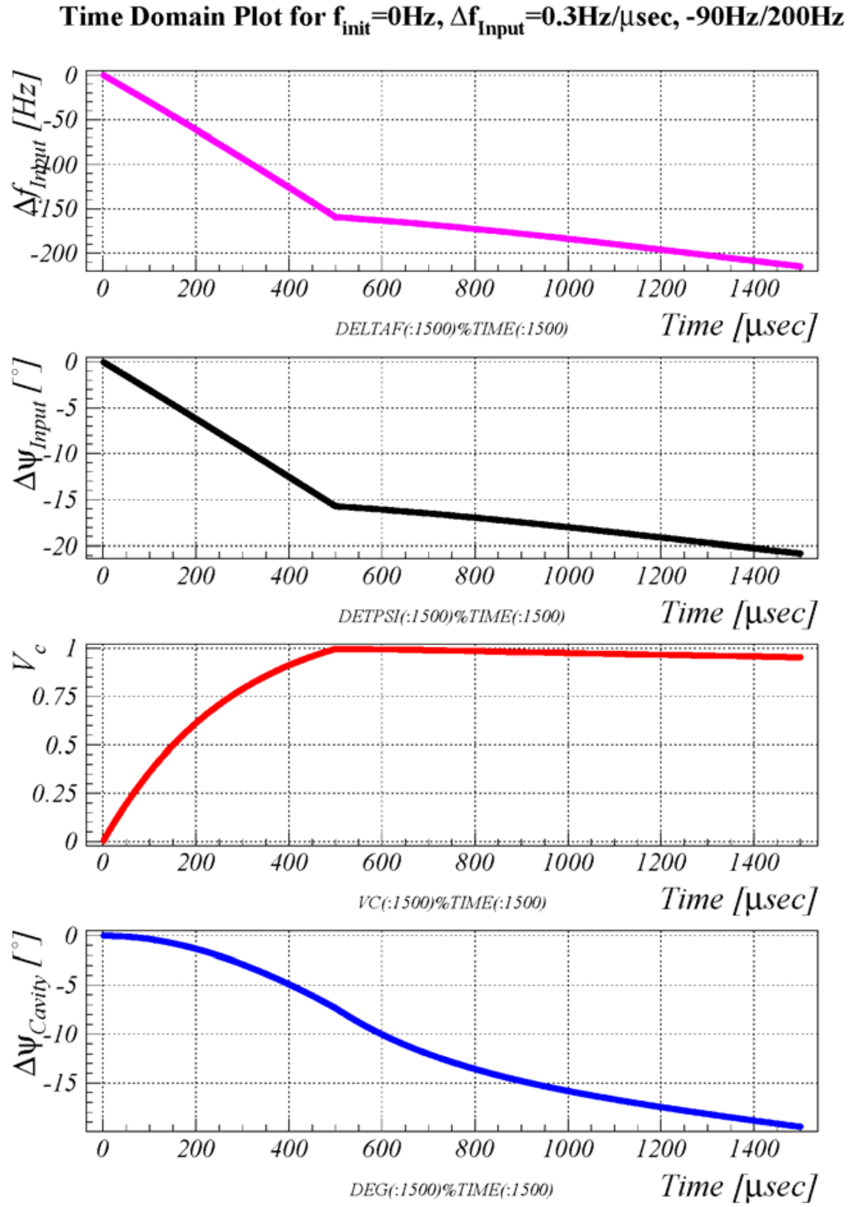
Output data (V_C)

Output data (Ψ_{Cavity})

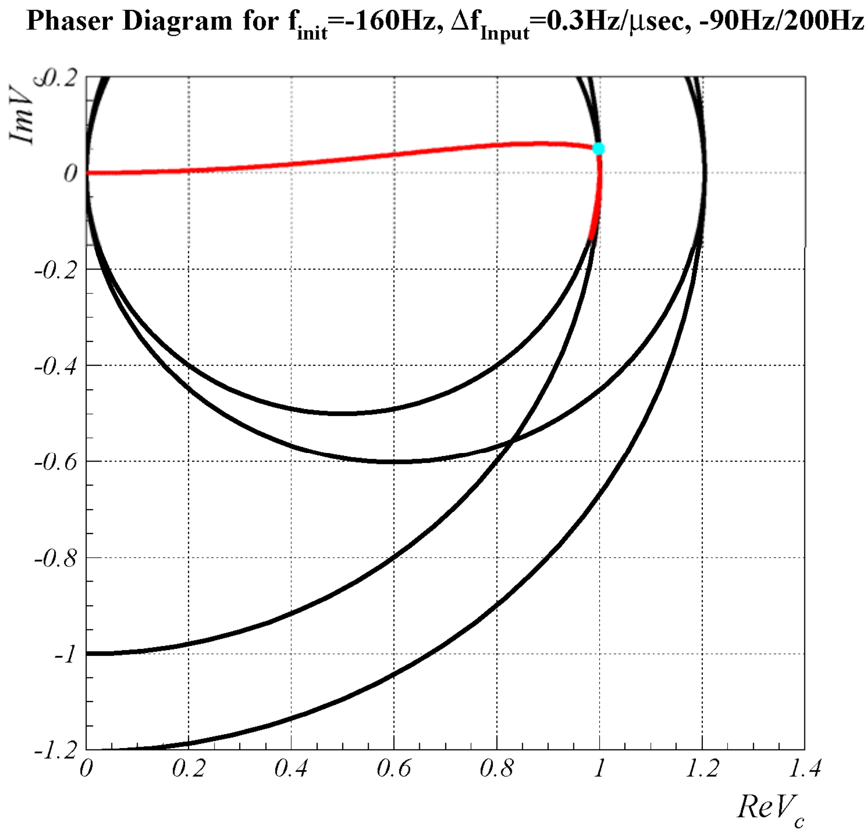
Case of Flat-top ① (no offset)

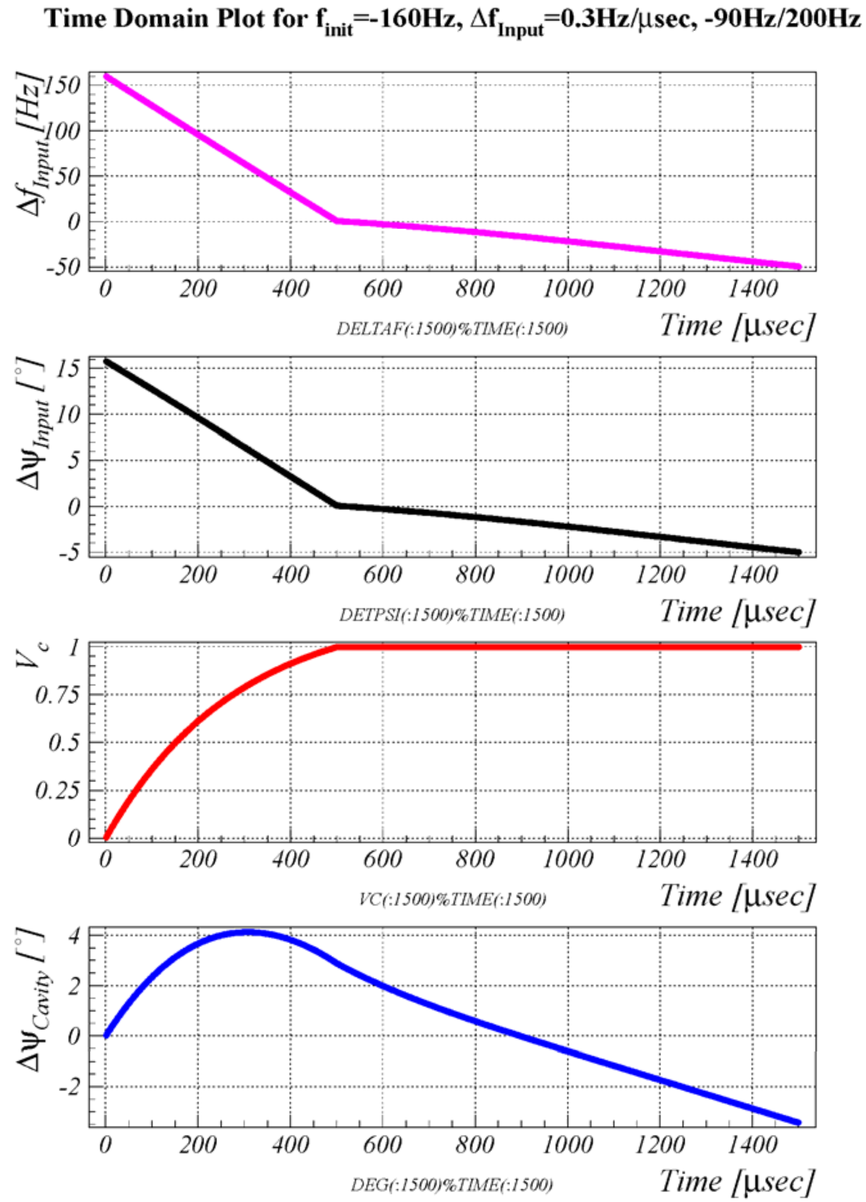
Phaser diagram



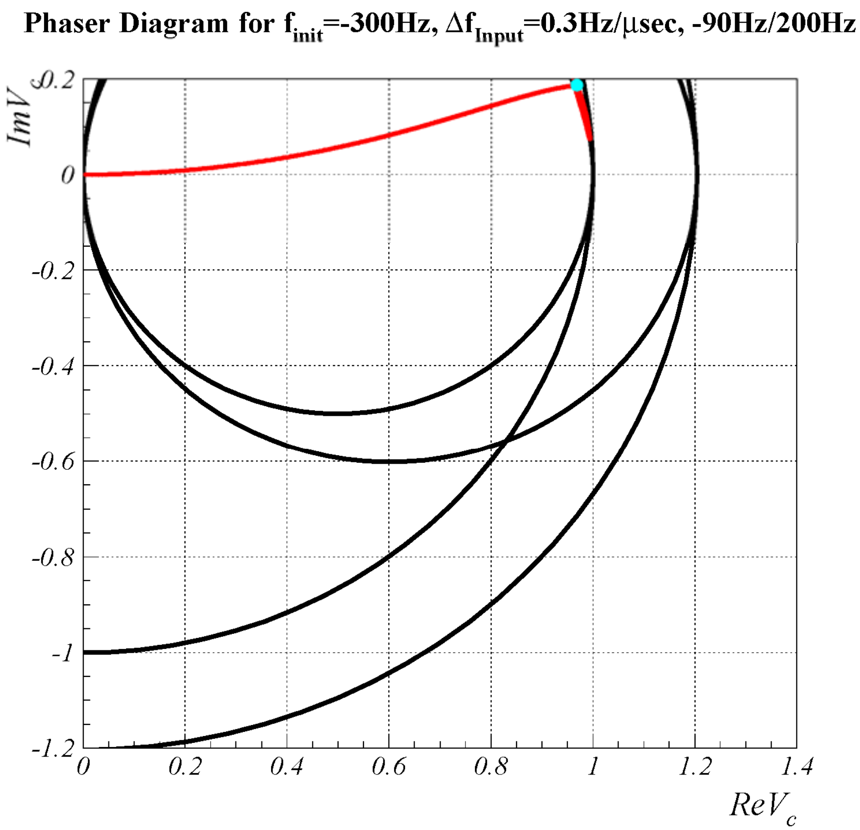


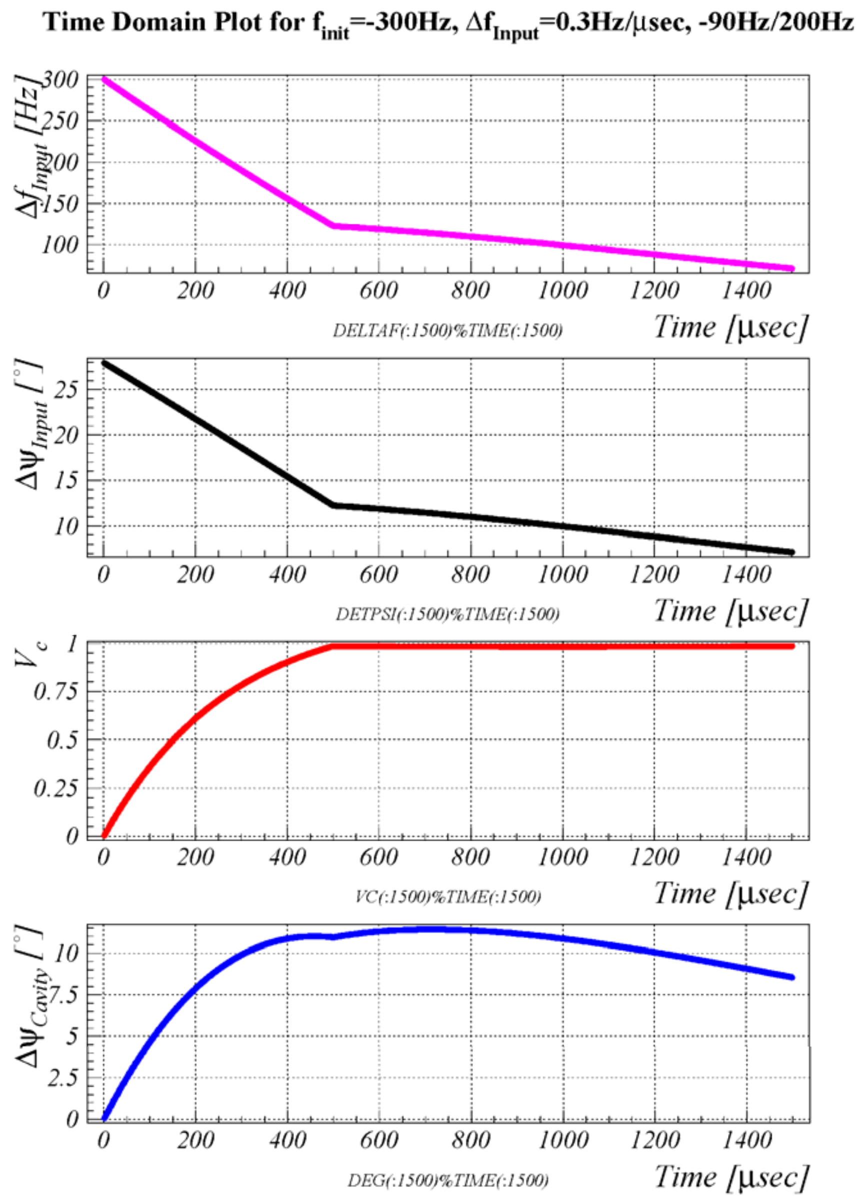
Case of Flat-top ② (offset +160Hz)



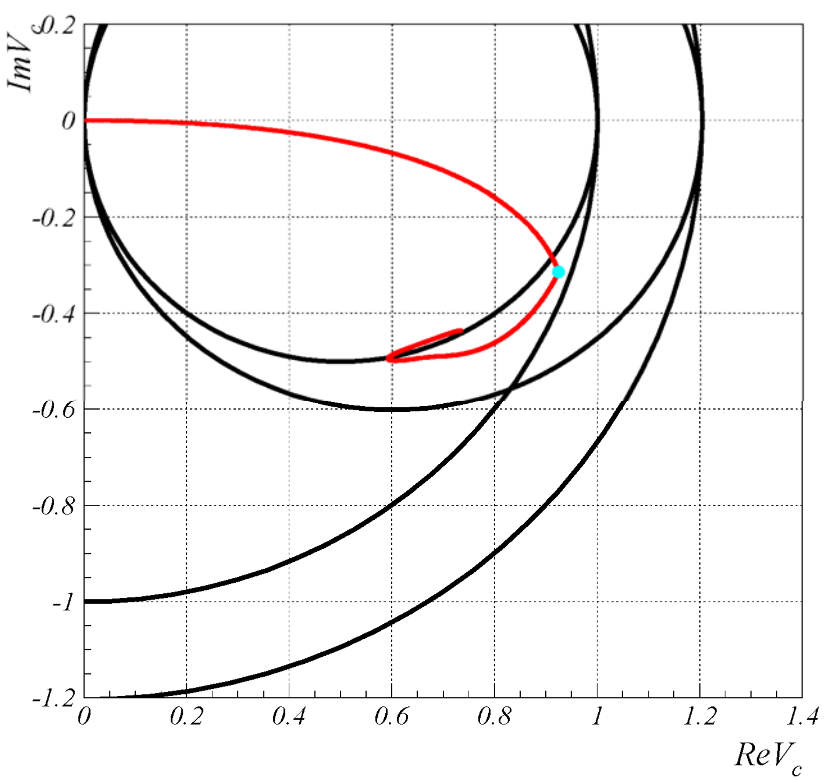


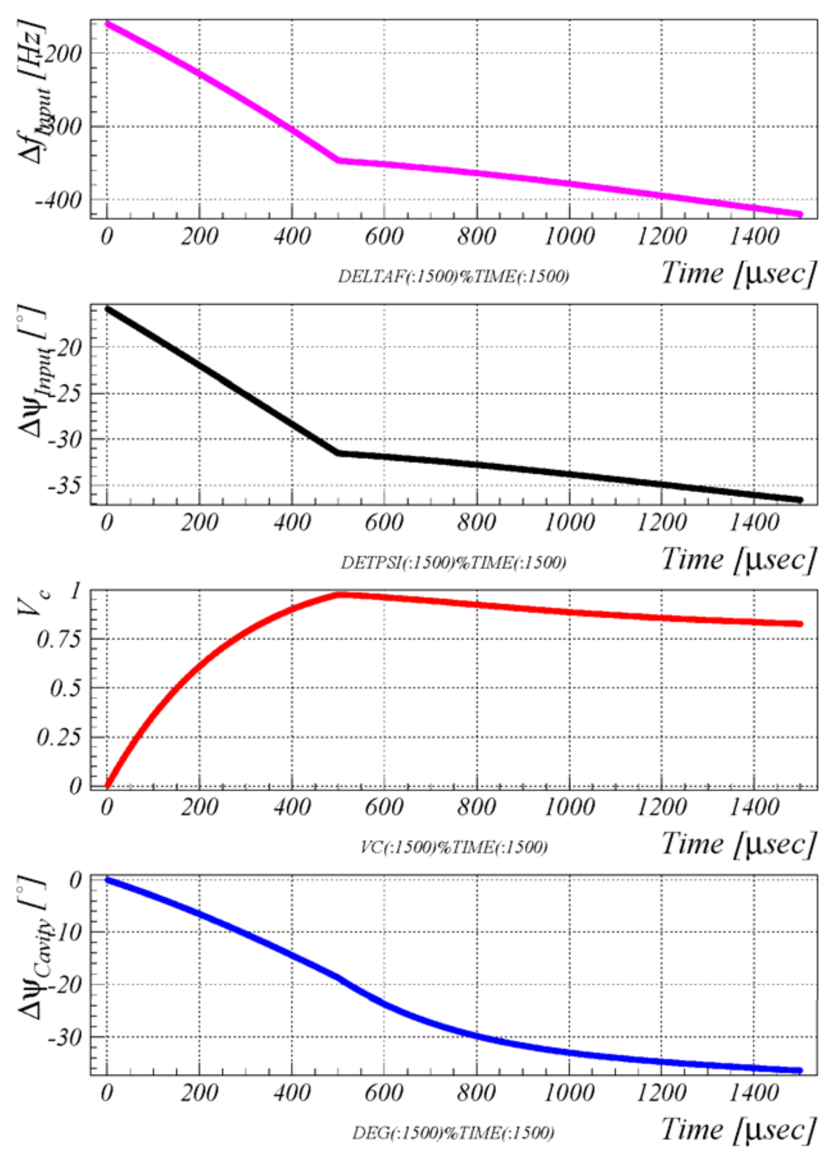
Case of Flat-top ③ (offset +300Hz)



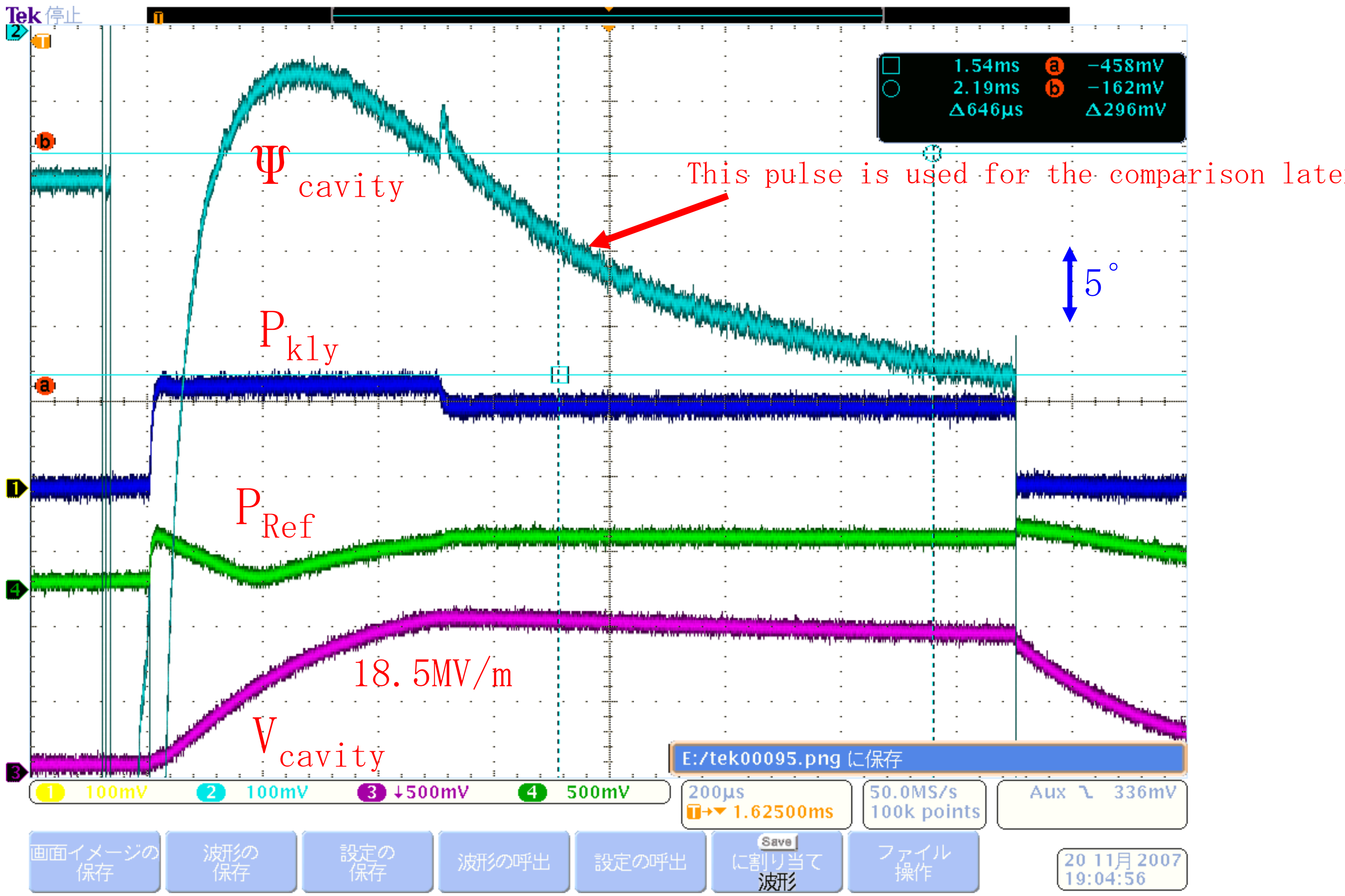


Case of Flat-top ④ (offset -160Hz)

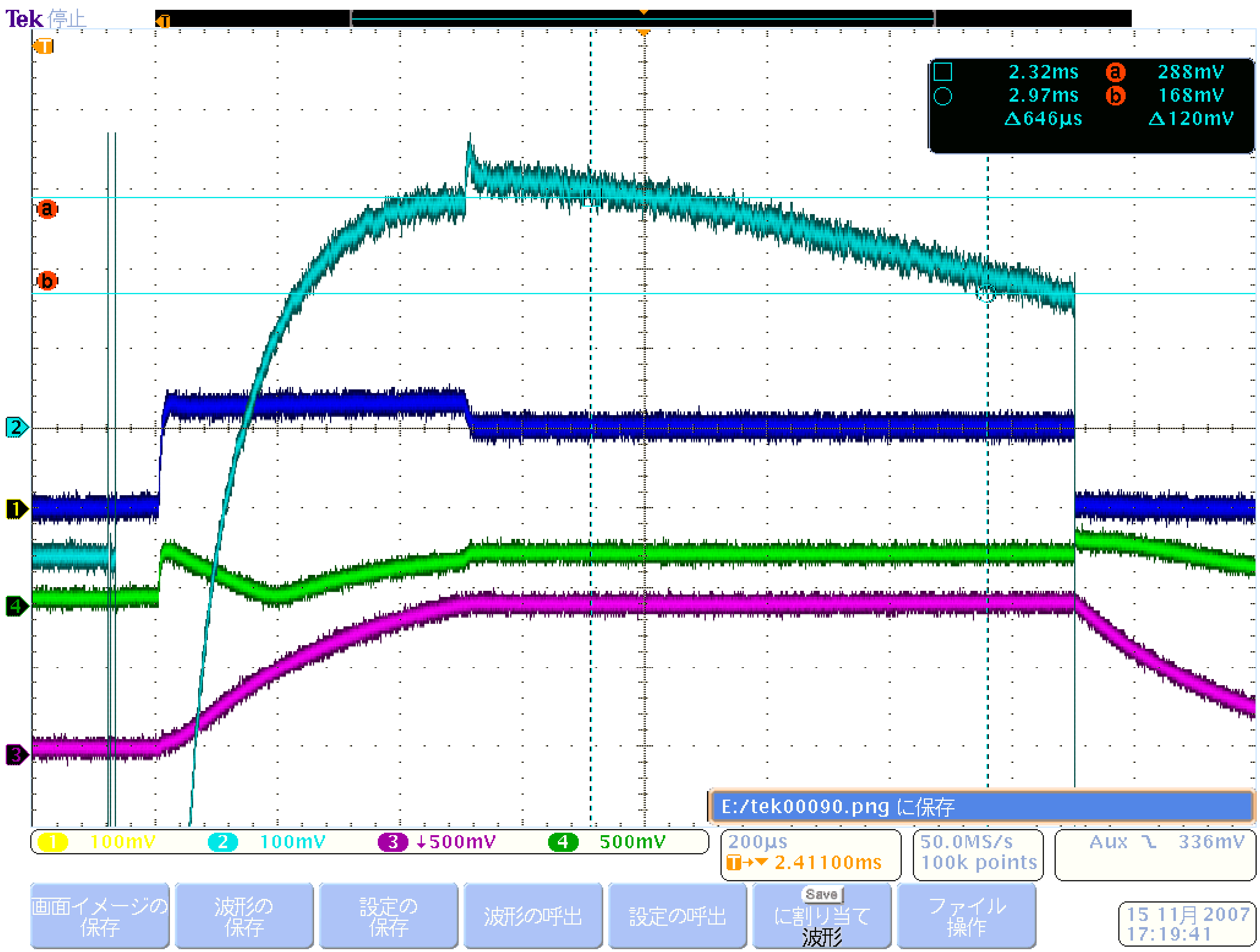




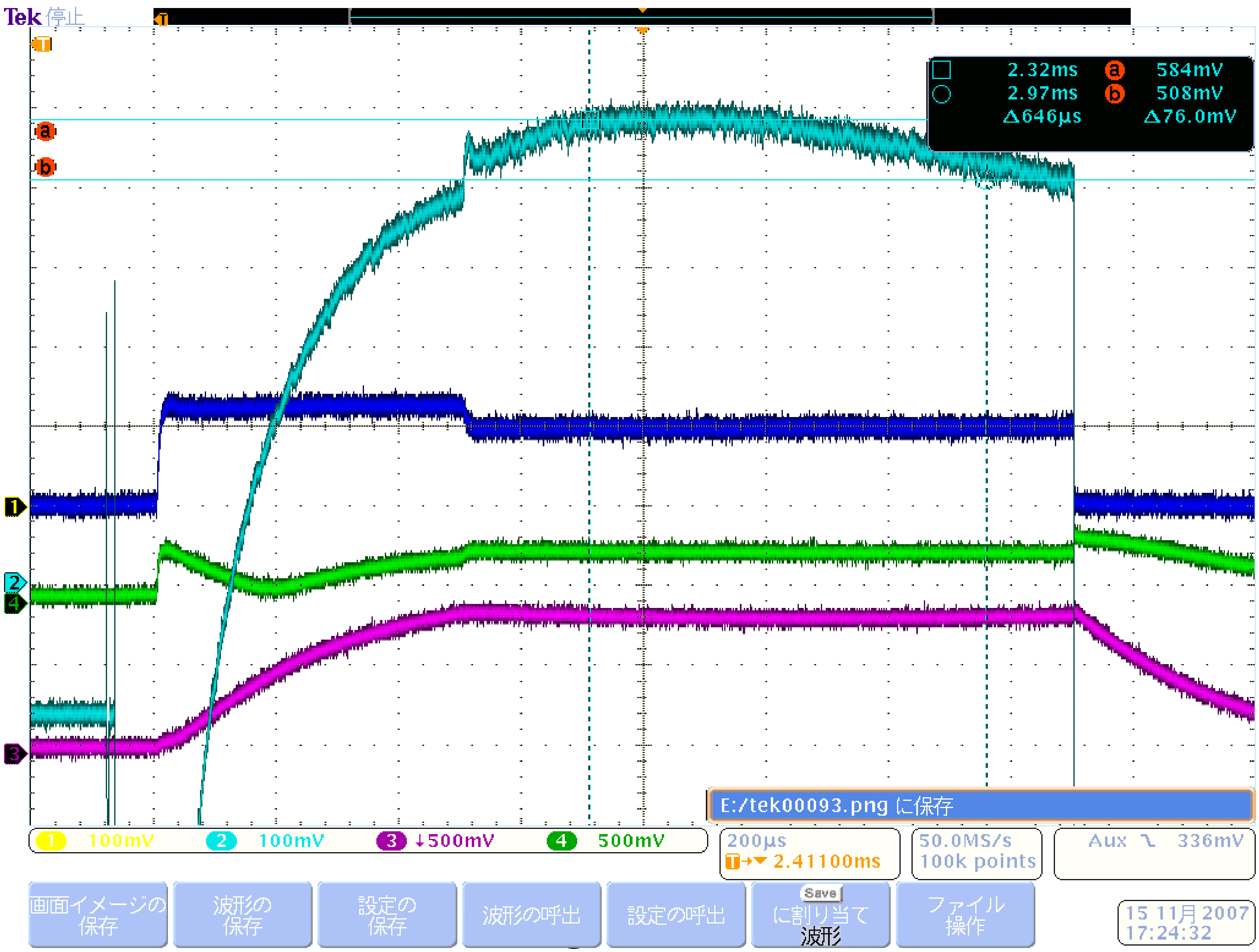
One pulse during High-Power Test (No Offset)



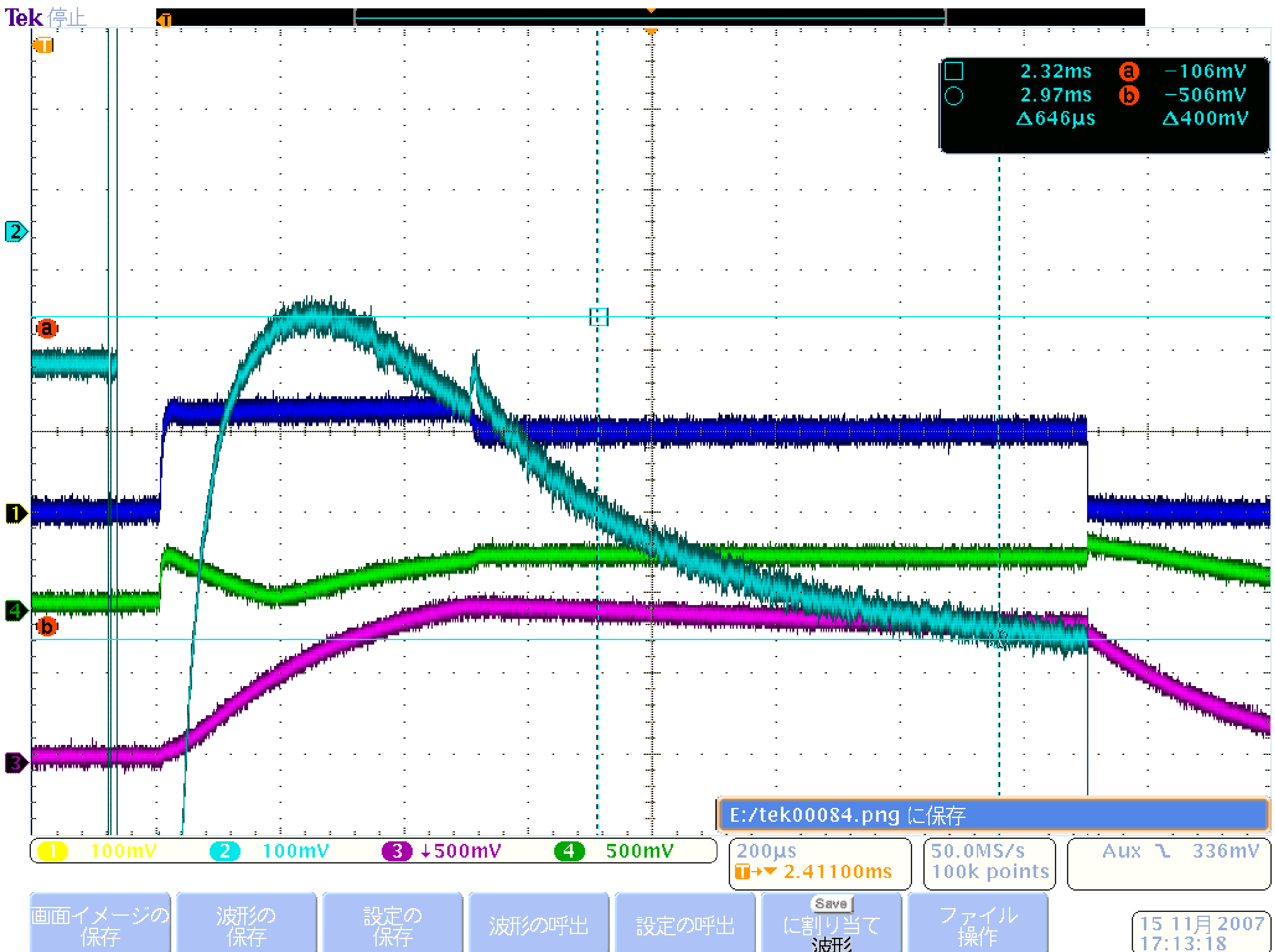
One pulse during High-Power Test (+160Hz Offset)



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



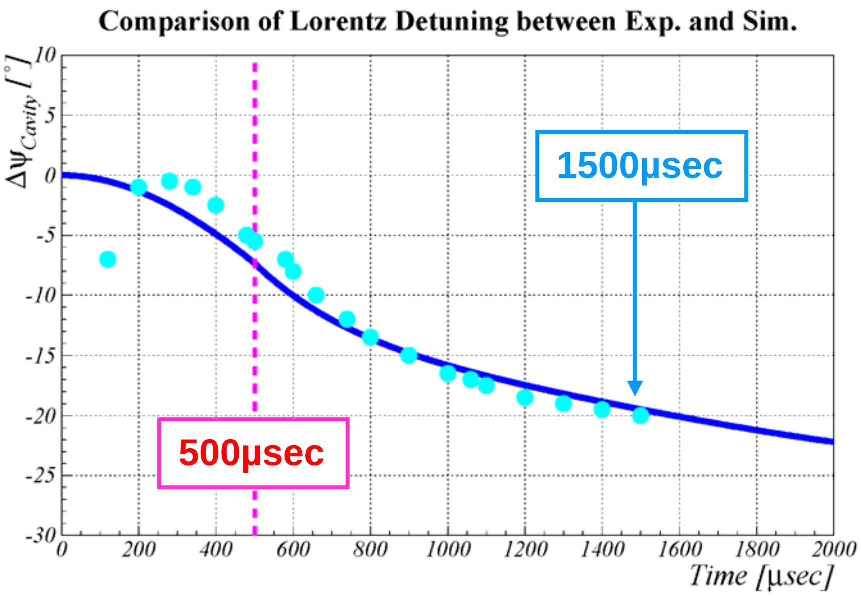
One pulse during High-Power Test (-160Hz Offset)



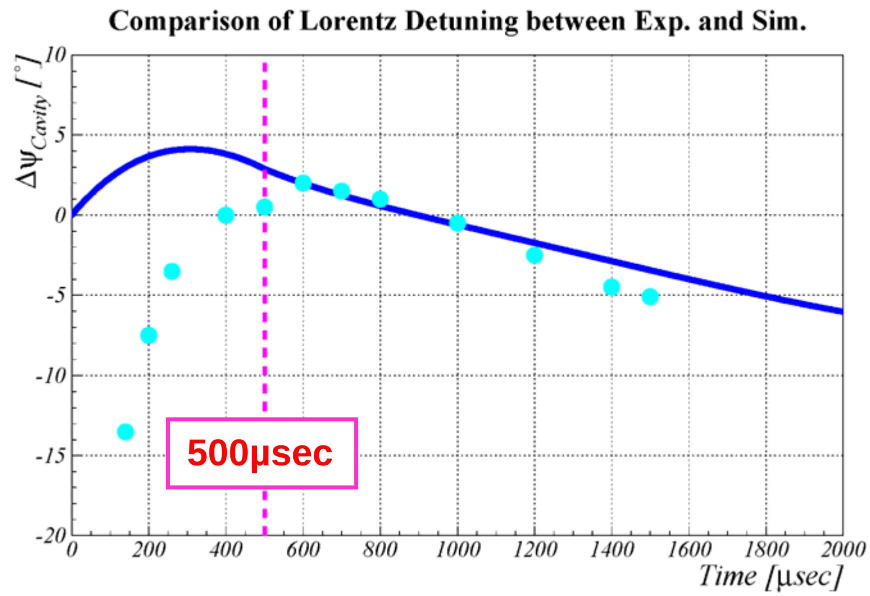
Comparison between experiment and calculation ①

Preliminary

No offset



+160Hz offset



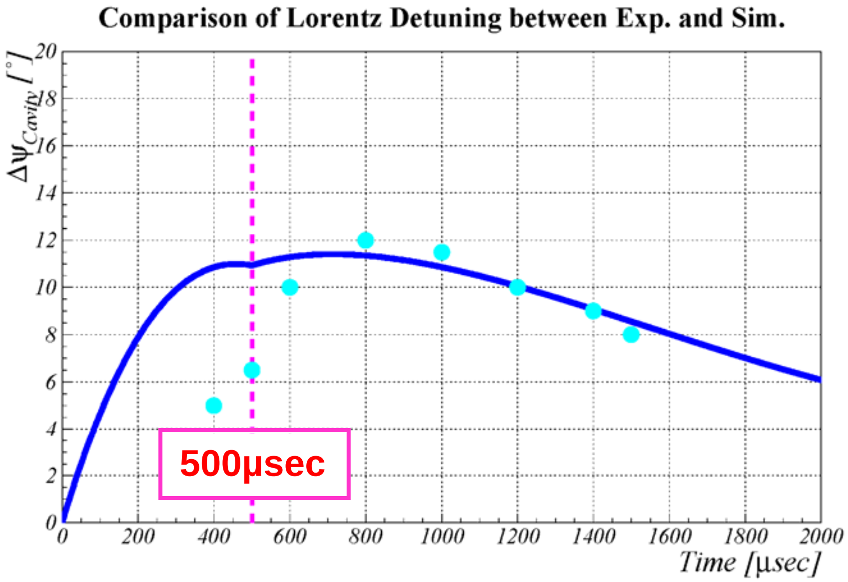
Before 500μsec, the response speed of the phase detector is probably significan
After that, it is consistent between the experiment and the calculation.

"Two modes model" is valid!

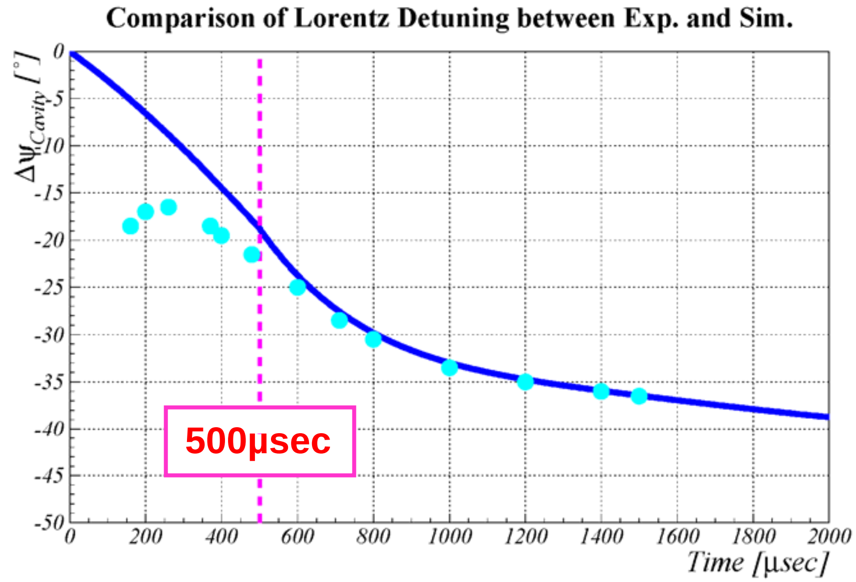
Comparison between experiment and calculation ②

Preliminary

+300Hz offset



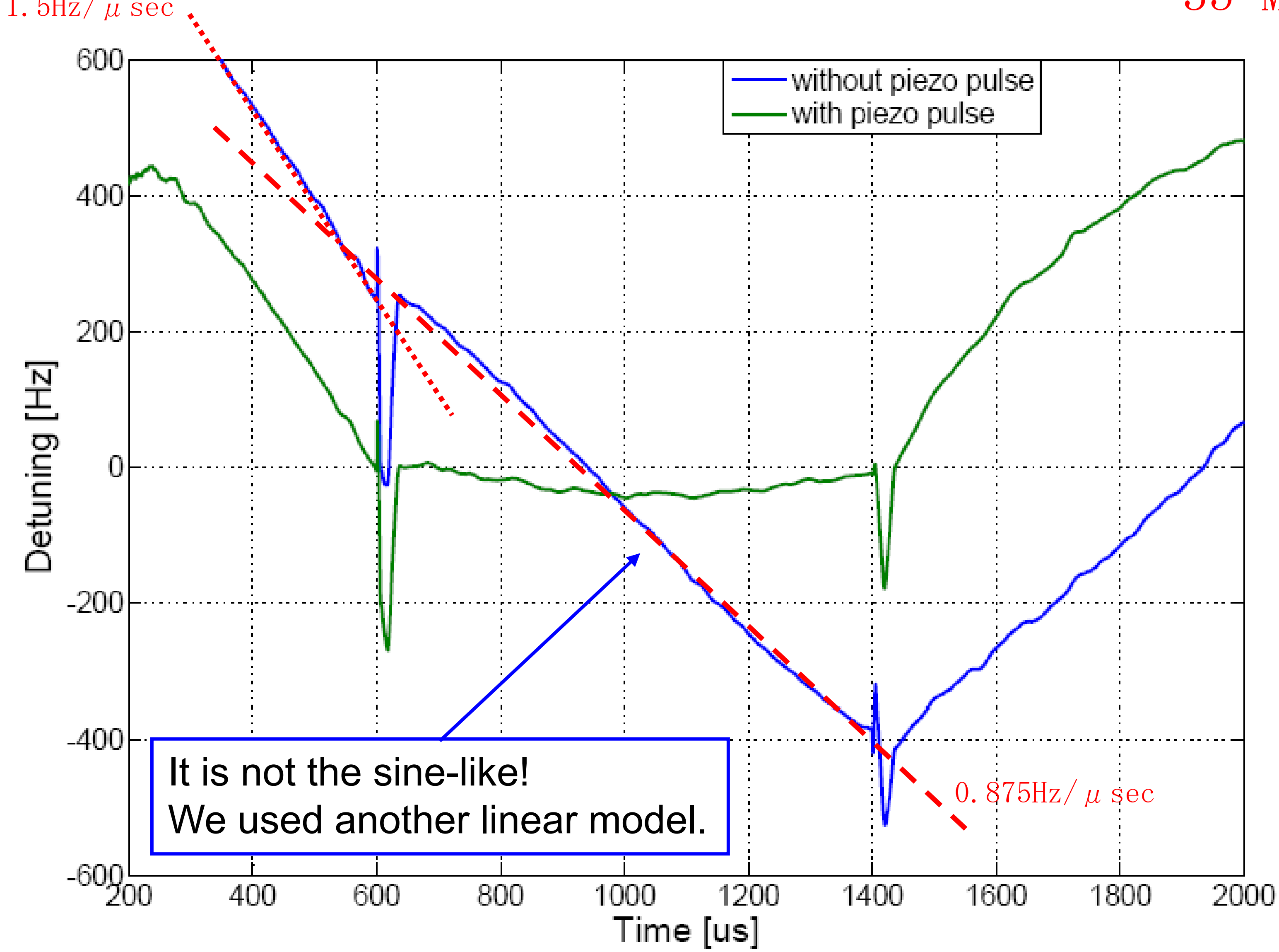
-160Hz offset



"Two modes model" is valid!

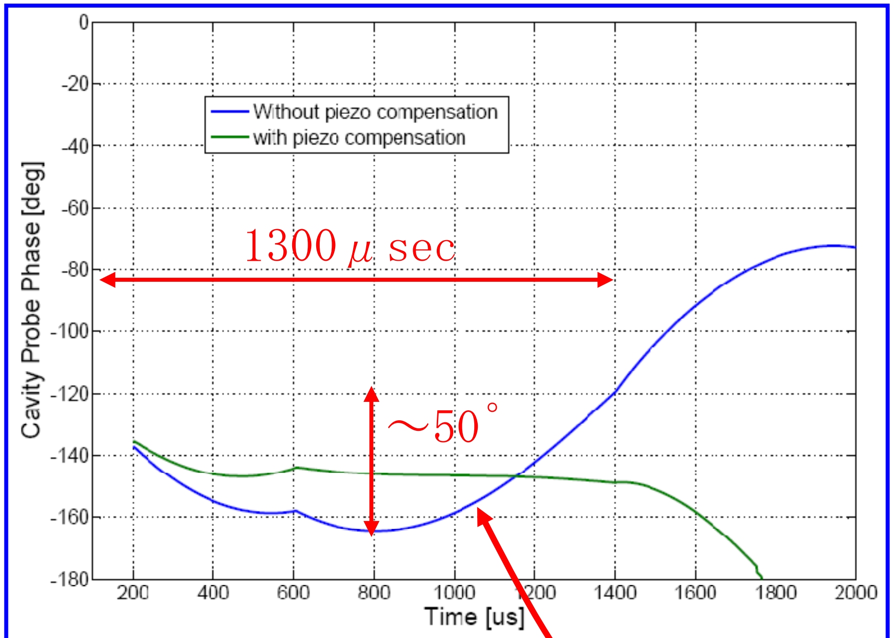
DESY(FLASH)'s case (Q_L=3x10^6)

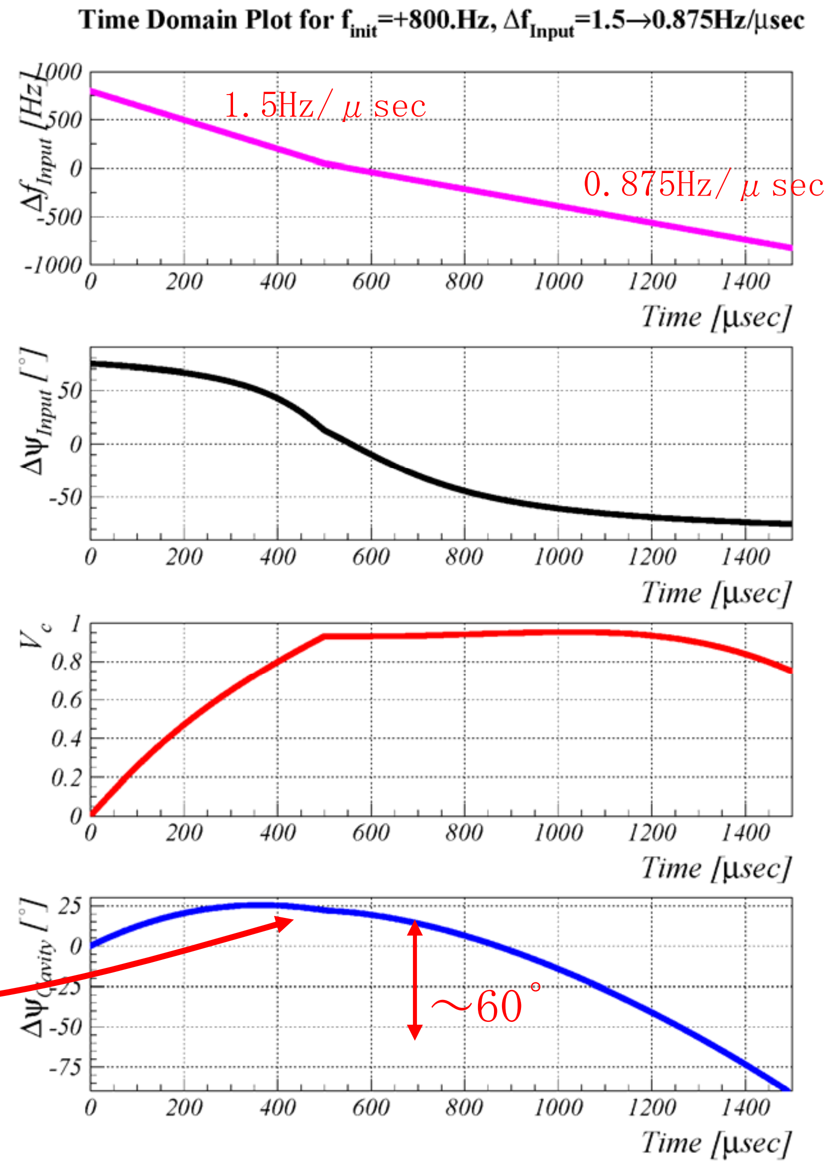
35 MV/m



DESY(FLASH)'s case (Cavity Phase)

Preliminary





consistent

"Two modes model" is also valid in DESY's case!

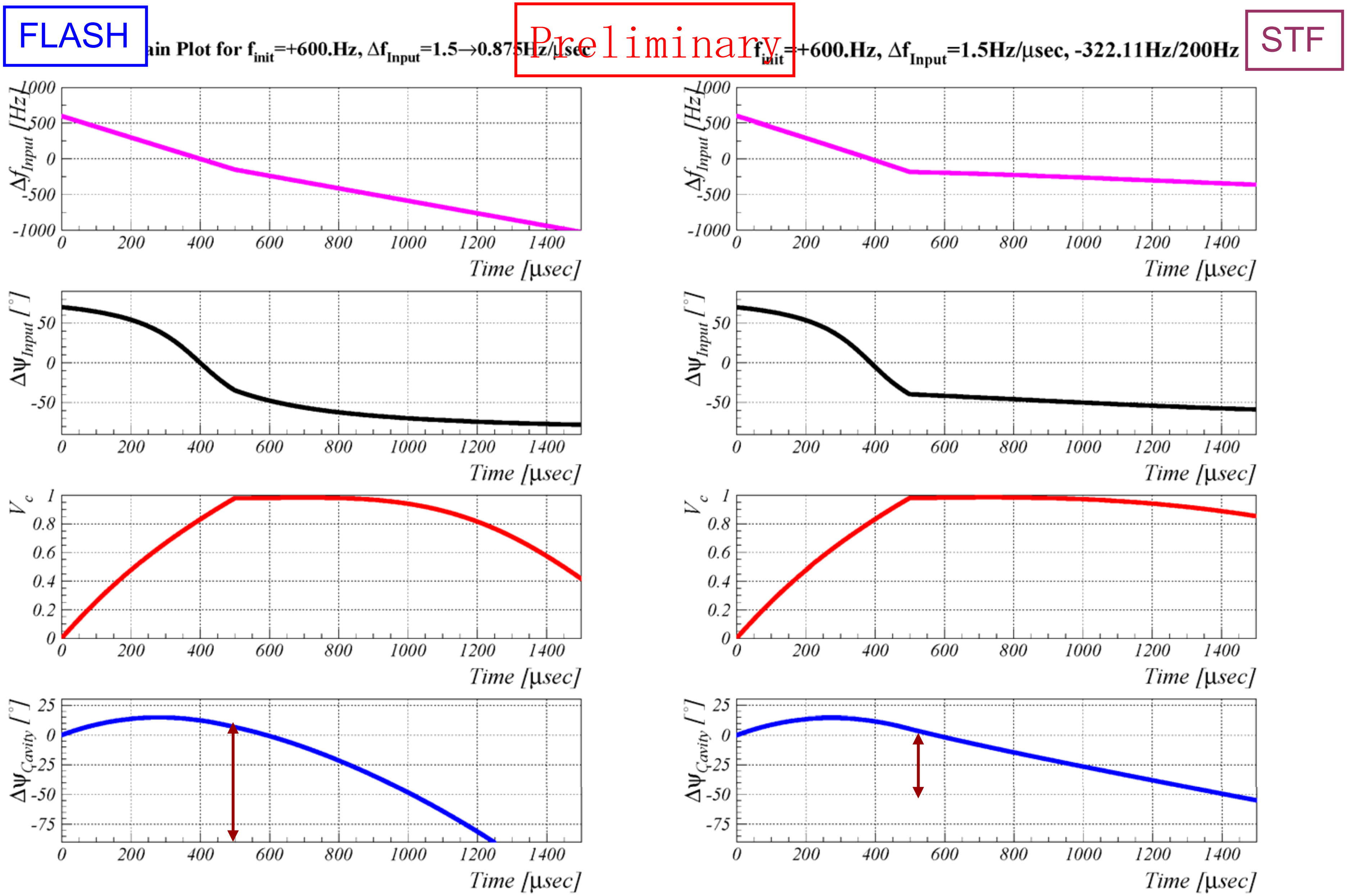
For comparison, the calculation is modified for a few parameters.

E_{acc} = 18.5 → 35MV/m

Q_L = 1.15x10^6 → 3x10^6

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.

Comparison between STF and FLASH



Although, in FLASH, it is possible to compensate the detuning, the amount of the detuning is smaller in STF.

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 detuning.
- Work piezo with the small oscillation
  - Avoid to break out the Piezo by the large oscillation
  - Longer lifetime of Piezo
- Increase the mechanical strength of the cavity
  - It is difficult to deform the cavity.

Future plan

- Re-producing the case of the Piezo compensation
- Comparison between the experimental data around 30MV/m in STF-Phase 1.0 and the calculation
- Reproducing the experimental data in the other laboratories
- More optimizing “two modes model”?
    - Three modes or so?

Summary

- "Two modes model" is valid for the transient response of the cavity in the horizontal test at STF Phase-0.5.
- It is effective to increase the mechanical strength of the cavity 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.