# RF feedback on MBTRACK

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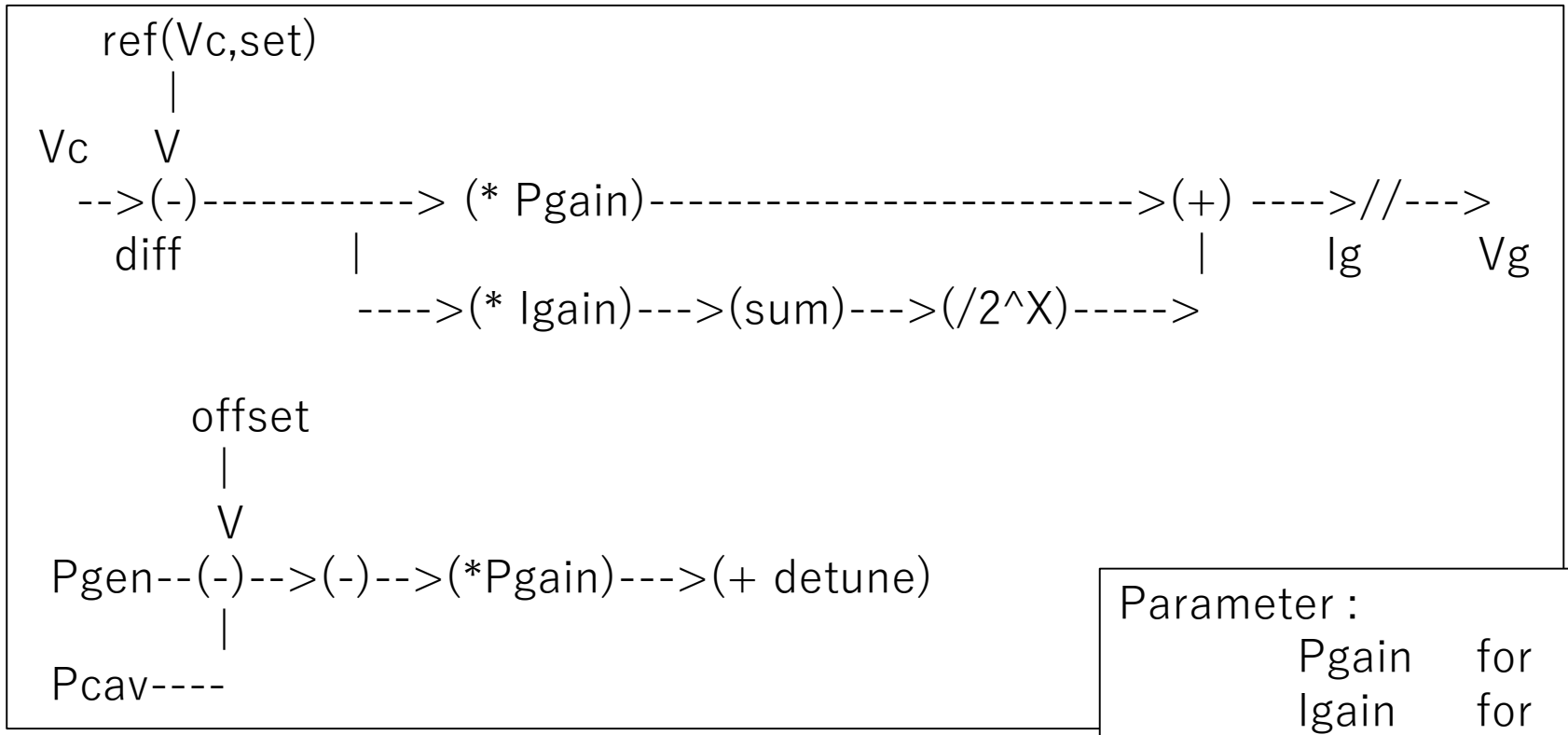
2022/09.27

- PI feedback
- Direct RF feedback
- Mode damper

# Digital PI feedback of MBTRACK

- Fast PI-FB control is introduced as a Cavity voltage(Vc) feedback system.
  - It is modeled as a Direct sampling FPGA based FB control which is developed for new PF LLRF system
- In the PI control, the generator current (Ig) values are controlled while monitoring Vc.
- With the consideration of  cavity response (Q, R/Q and Detune), Ig values are converted to the cavity induced generator voltage (Vg)  at every turn.




**MBTRACK parameter**

For Ig control,
- Pgain,  Igain
- LoopDelay
- Sampling period (Control inteval)

For tuner control (slow FB)
- Pgain

Parameter :

| | | |
|---|---|---|
| Pgain | for | IQ (or Amp., Phase) and Tuner |
| Igain | for | IQ (or Amp. and Phase) |

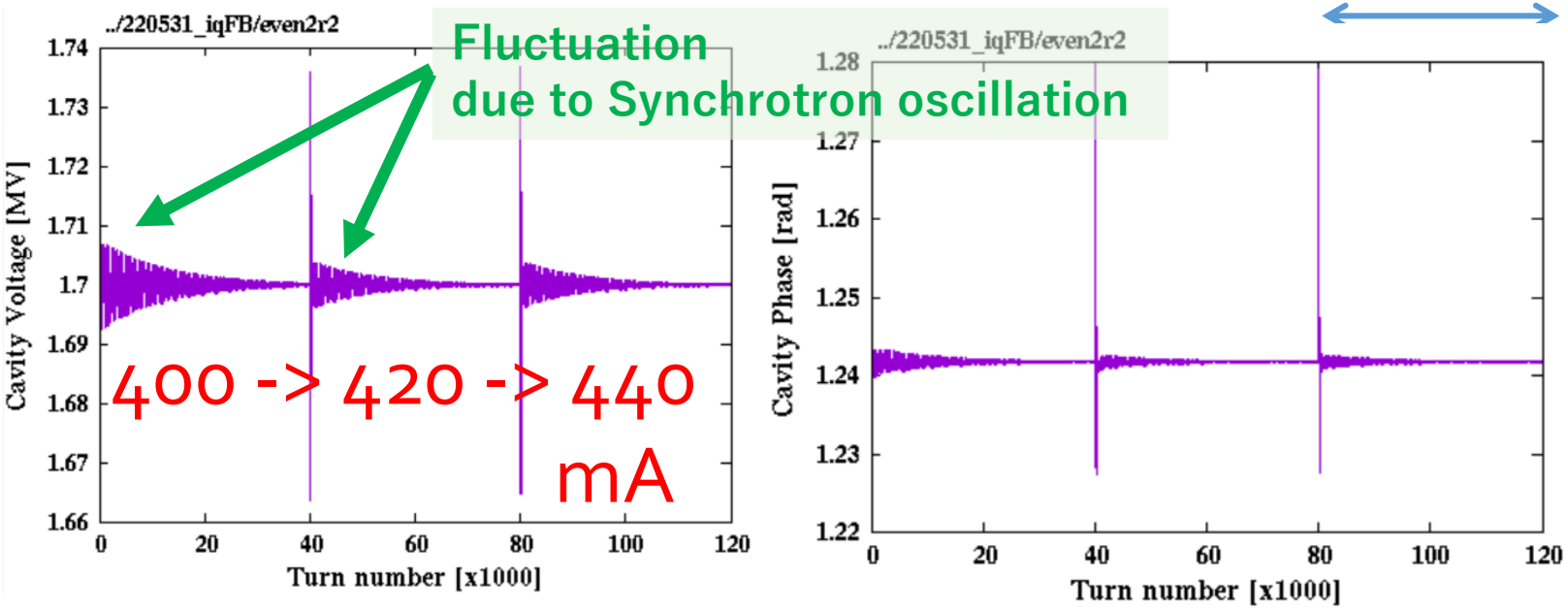
# Example : Multi bunch (400 -> 420 -> 440 mA)

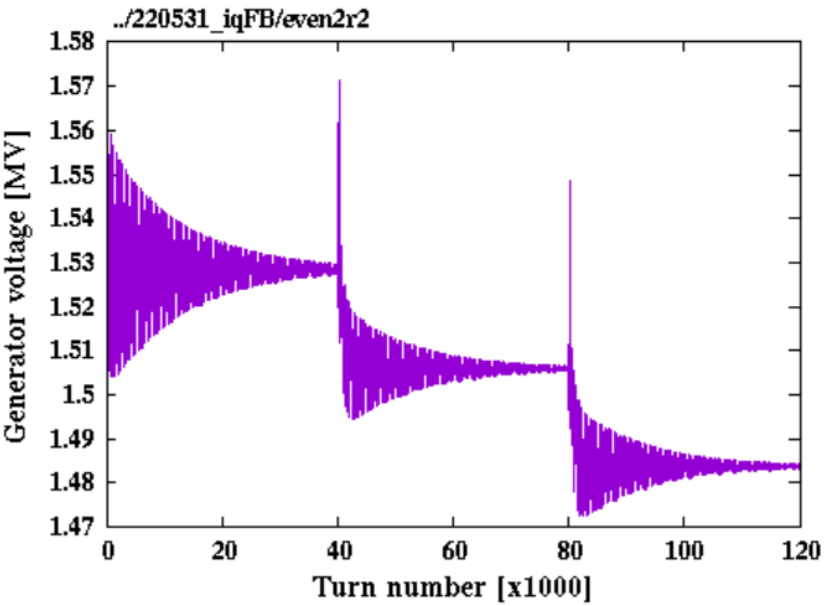
47 ms

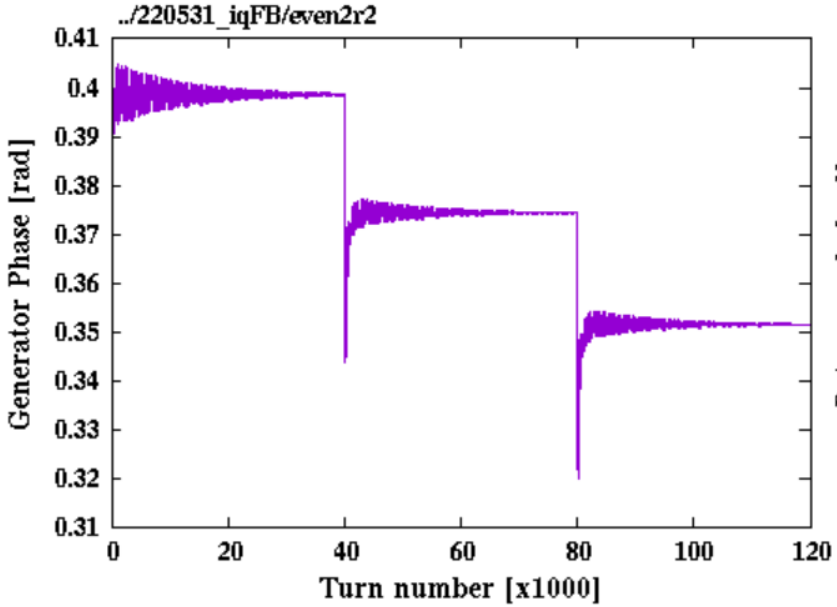
Ig :
- Pgain = 0.5
- Igain = 100

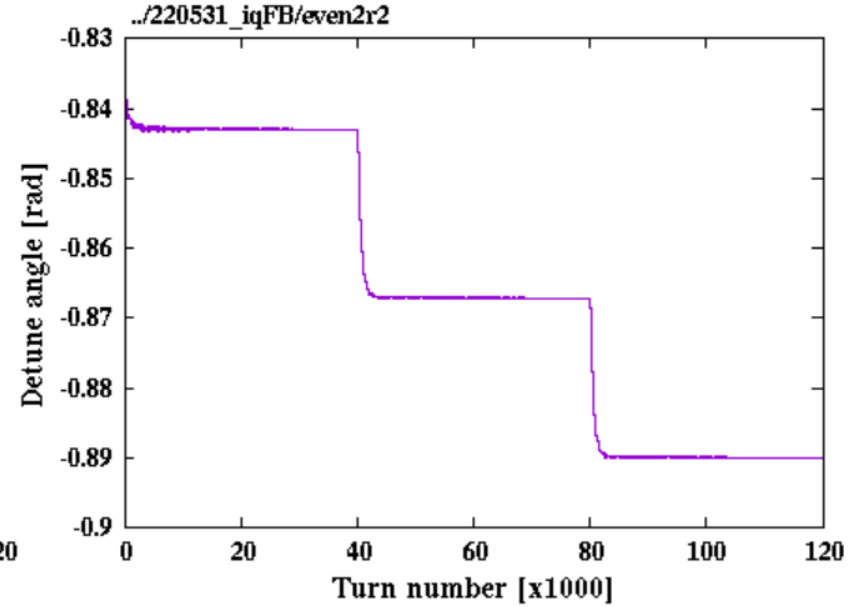
Tuner :
- Pgain = 1

LoopDelay = 1.42 us (500 bucket)
Sample [0] = 4 bucket



# Impact for a bunch lengthening system

- Single bunch (< 20 mA) mode
  - 3Hc case : 33.0 ps (BL factor = 4.2) -> **34.1 ps (4.4)**
- Multi bunch (500mA) mode
  - 2BL+1BS Active case : 22.6 ps (BL factor = 2.9) -> **25.0 ps (3.2)**

*At first, I applied the FB only to MC.*

Table 1. SOLEIL upgrade parameters

| Parameters | Values |
|---|---|
| Harmonic number $h$ | 416 |
| Circumference $L$ $(m)$ | 354.74 |
| Reference energy $E_0$ $(GeV)$ | 2.75 |
| Revolution frequency $f_0$ $(kHz)$ | 845.1 |
| RF frequency $f_1$ $(MHz)$ | 351.57 |
| Momentum compaction factor $\alpha_c$ | $9.12 \times 10^{-5}$ |
| Natural bunch length $\sigma_0$ $(ps)$ | 8 |
| Energy spread $\sigma_\delta$ | $9 \times 10^{-4}$ |
| Synchrotron damping time $\tau_s$ $(ms)$ | 11.7 |
| Losses per turn $U_0$ $(keV)$ | 515 |
| Main cavity voltage $V_c$ $(MV)$ | 1.7 |

Cavity Parameters

Main cavity : EU-type cavity
- Shunt impedance = 5 MΩ (Pc=Vc²/2/Rs)
- Unloaded-Q = 35,000
- Beta coupling = 6.0
- **PI-FB (LoopDelay = 2.84 us)**

HC: 2-cell ESRF HC
- Harmonic = 4.0
- Shunt impedance = 2.4 MΩ (Pc=Vc²/2/Rs)
- Unloaded-Q = 27,000
- Beta coupling = 1.0

# MBTRACK result for Multi bunch mode (500mA)

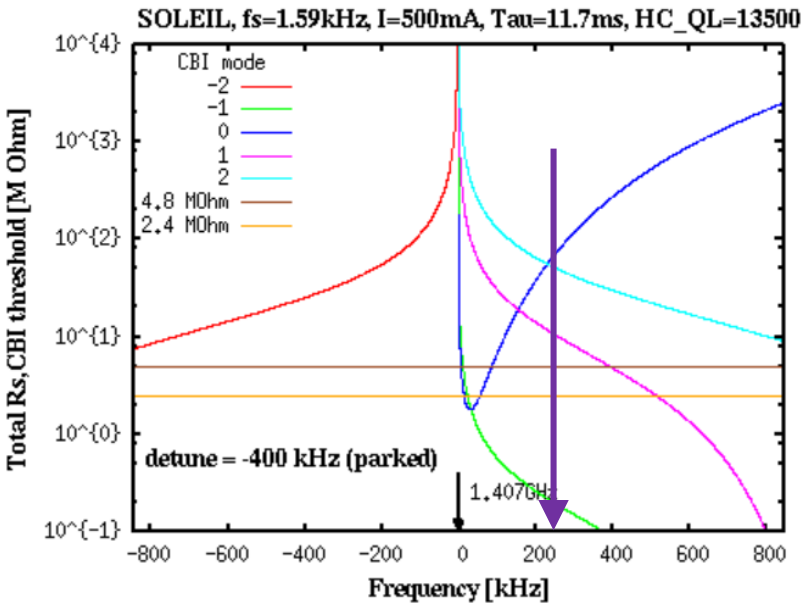
Main cavity : EU-cavity x 3
HC cavity : ESRF 4th HC x 1,2

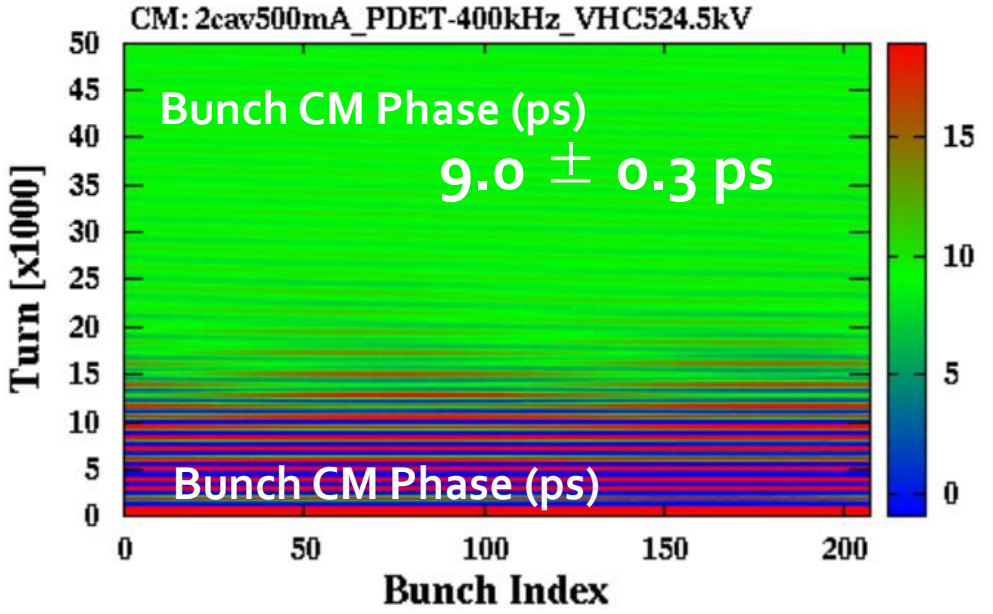
## 2 BL cavities & 1 detuned (-400kHz), Active operation

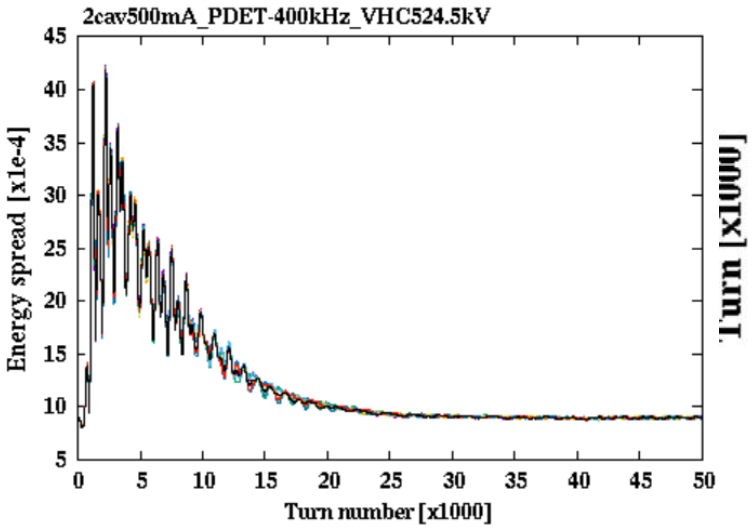
**Active HC case:**

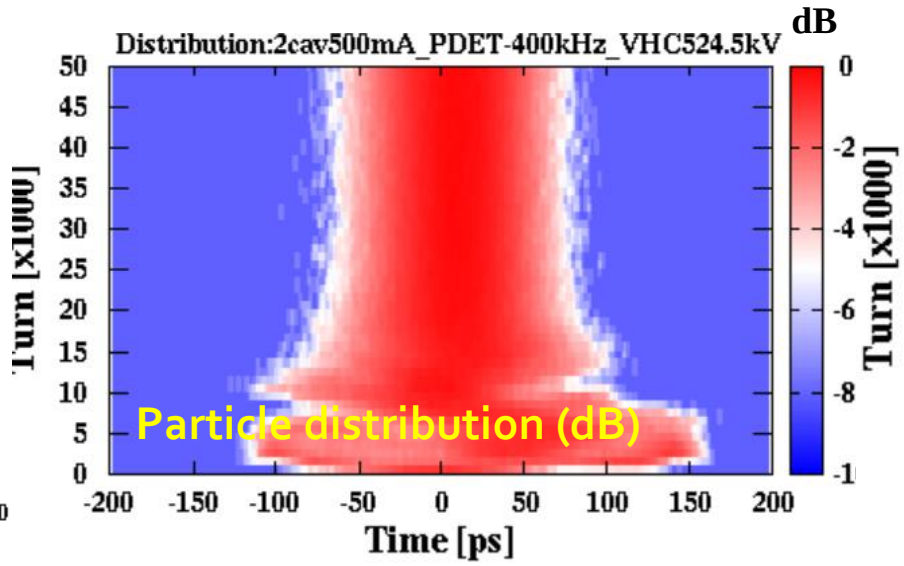
- Iring = 500 mA
- Vc_mc = 1.7MV
- Pg_mc = 389 kW
- Vc_hc = 519, 152 kV
- Pc_hc = 28.1, 4.8 kW
- Pg_hc = 11.0, 0 kW
- Δf_hc = 237.7, -400 kHz

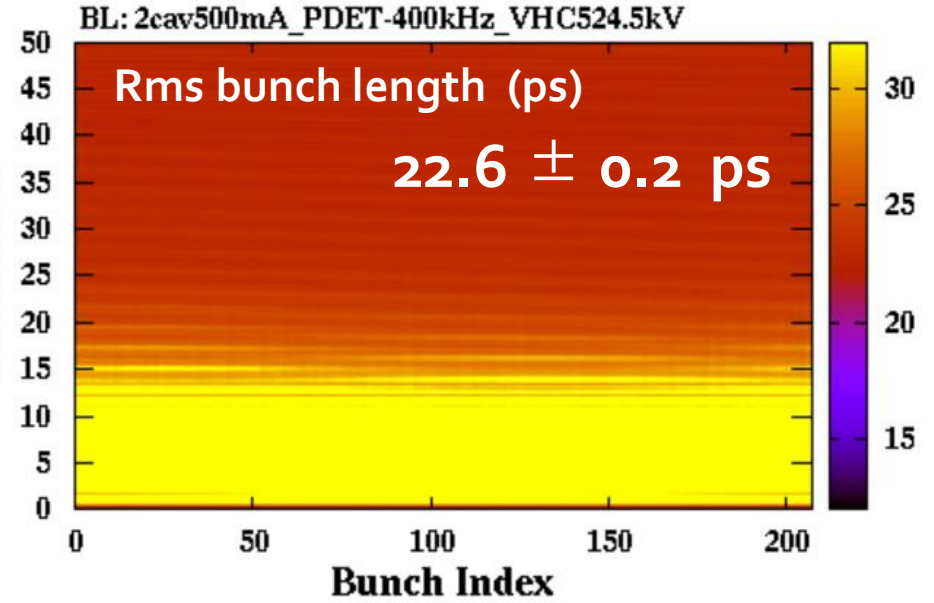
Stable
BL factor = 2.9



# MBTRACK result for Multi bunch mode (500mA)

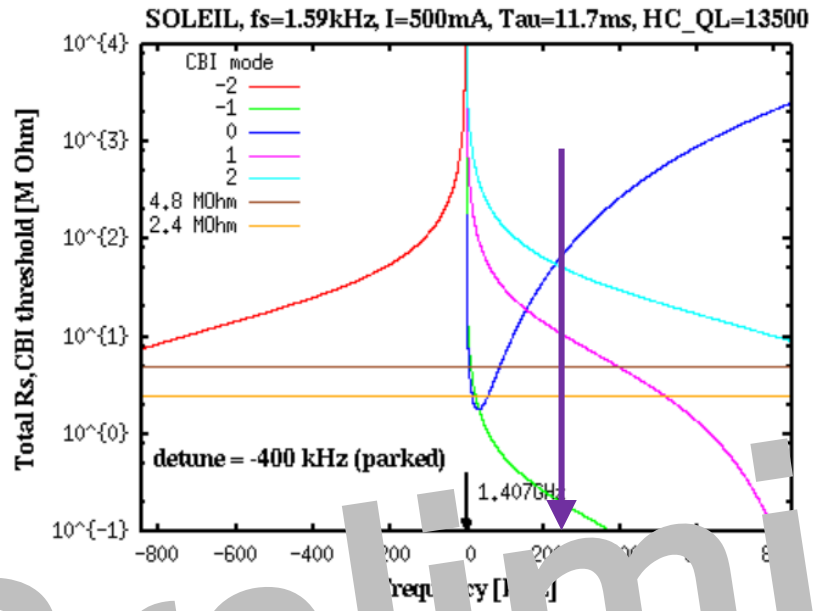
Main cavity : EU-cavity x 3
HC cavity : ESRF 4th HC x 1,2

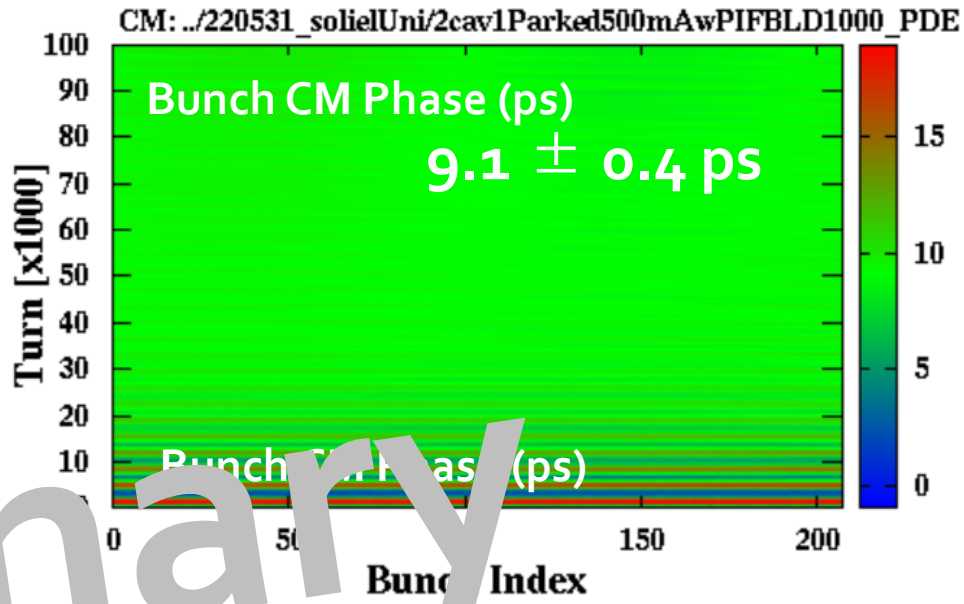
## 2 BL cavities & 1 detuned (-400kHz) & Digital PI Cavity FB (2.8 us LoopDelay)

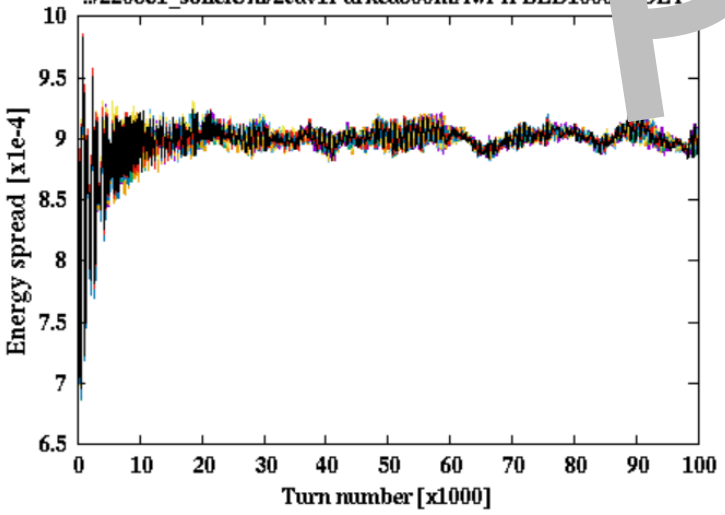
**Active HC case:**

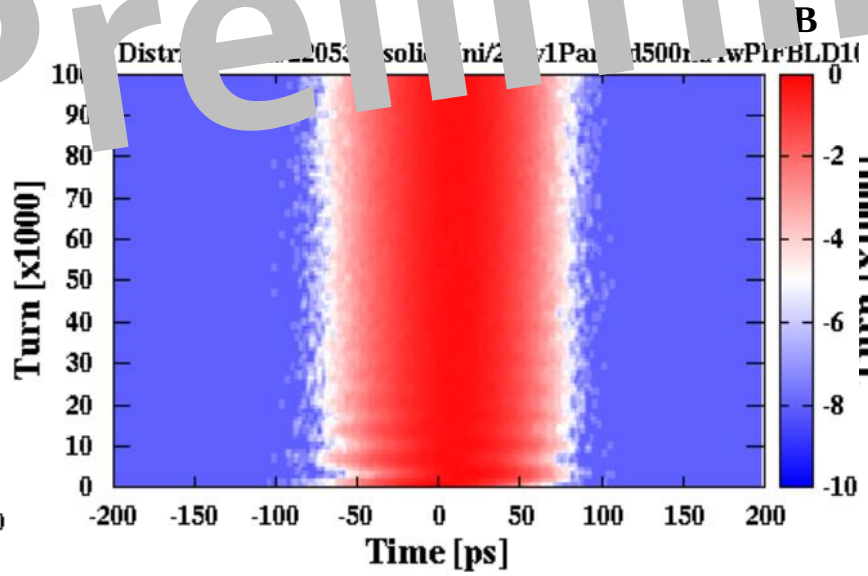
- Iring = 500 mA
- Vc_mc = 1.7MV
- Pg_mc = 389.2 kW
- Vc_hc = 527, 151 kV
- Pc_hc = 28.9, 4.8 kW
- Pg_hc = 11.8, 0 kW
- Δf_hc = 233.1, -400 kHz

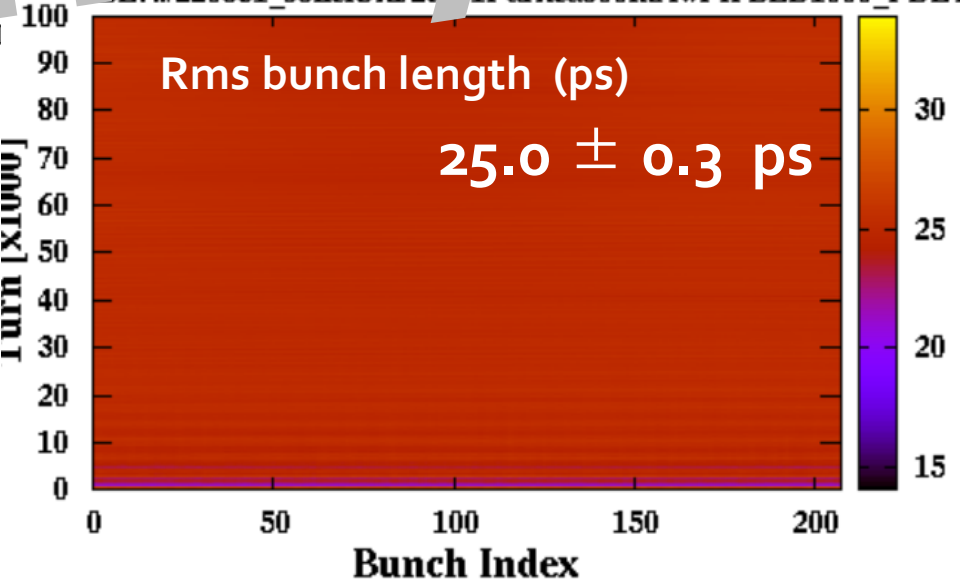
**Stable**
**BL factor = 3.2**



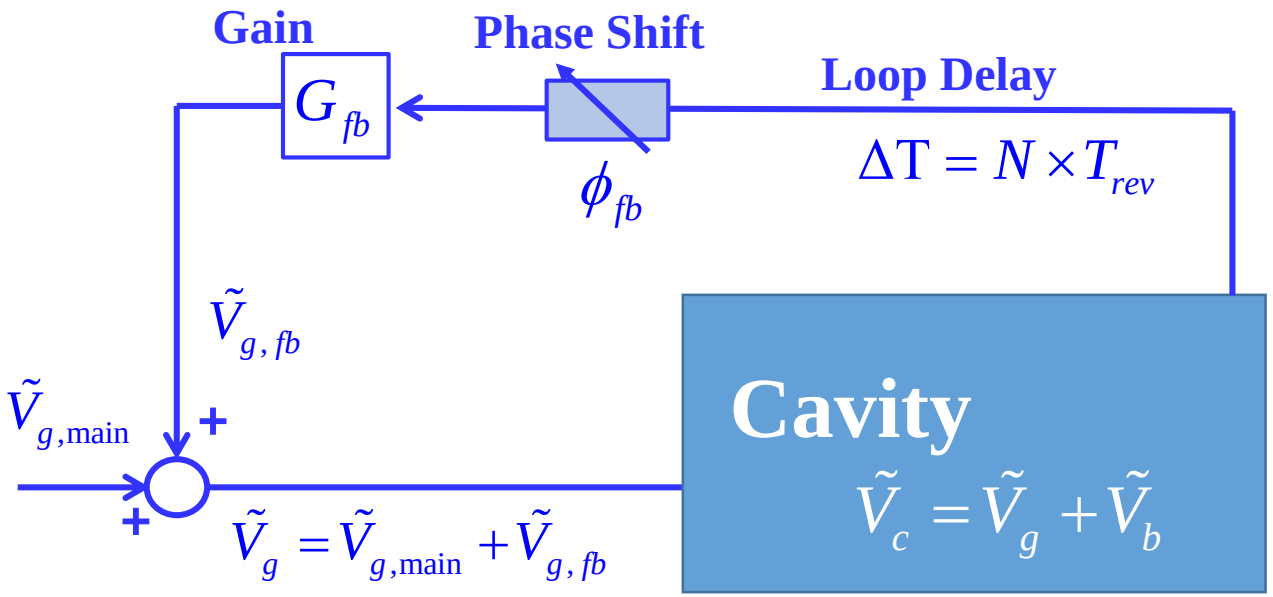



# Direct RF Feedback in MBTRACK

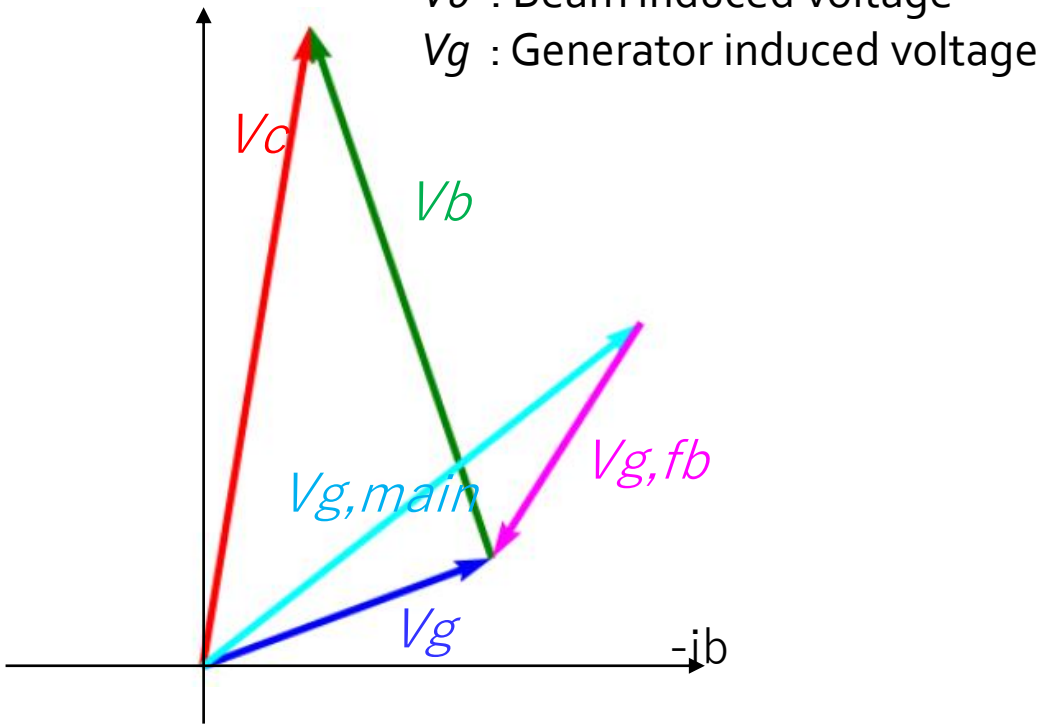
Characteristic parameter for DRFB
: Feedback gain, $G_{fb}$
: RF phase shift $\phi_{fb}$
: Loop delay $\Delta T$ (turn number)

$$V_{g,fb} = G_{fb} \cdot V_c(\Delta T)$$
$$\angle V_{g,fb} = \angle V_c(\Delta T) + \phi_{fb}$$

Schematic of feedback circuit




*Vc* : Cavity Voltage
*Vb* : Beam induced voltage
*Vg* : Generator induced voltage



# Benchmark test with SuperKEKB parameter

*K. Akai et al., PASJ2020, WEPP35

## SuperKEKB parameter

Table 3: Machine Parameters at Beam Study in HER

| | |
|---|---|
| Max. beam current allowed | 900 mA |
| RF voltage/cavity [MV] | 1.35 (SCC) / 0.425 (ARES) |
| Loading angle ($\phi_L$) [deg] | -8 (SCC) / -5 (ARES) |
| DRFB gain | off, -6.0 dB, -4.5 dB |
| ZMD | off, ON |

## Feedback parameter (MBTRACK)

Direct RF feedback;
FB Gain = 1.0
Loop Delay= 0
Phase shift = 30
Zero-mode damper ; OFF

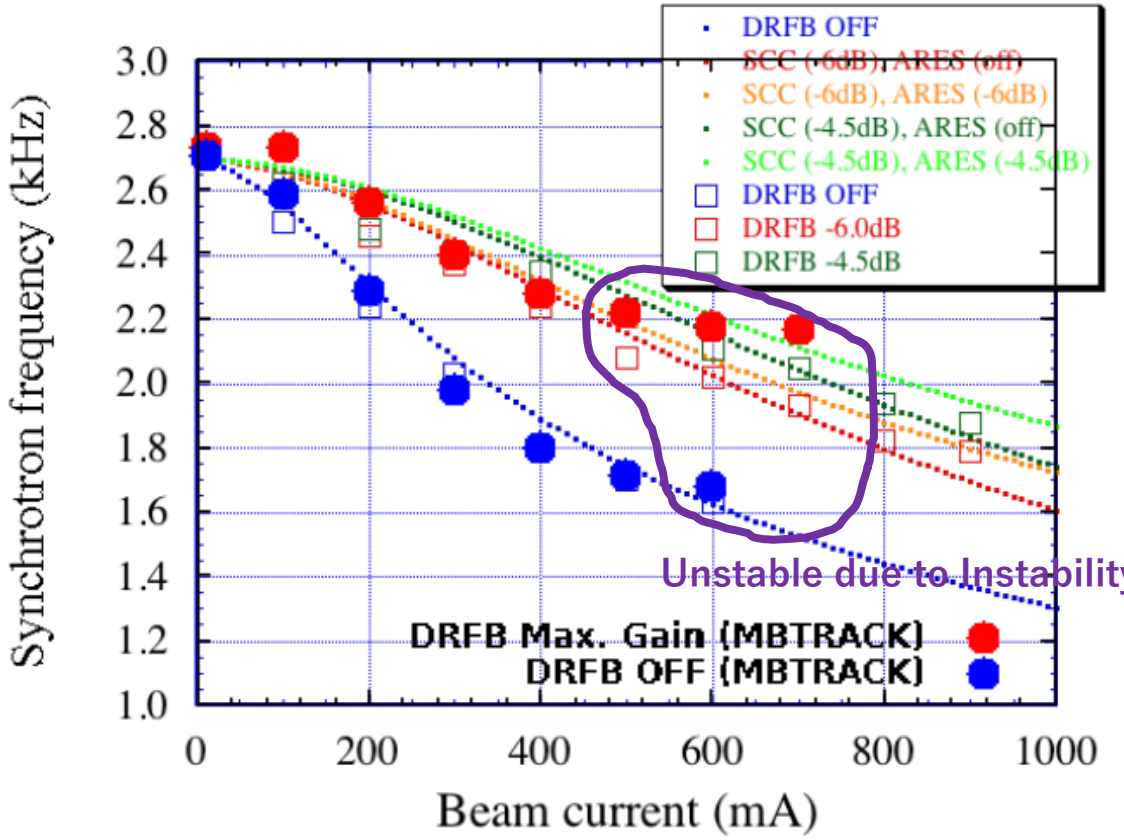


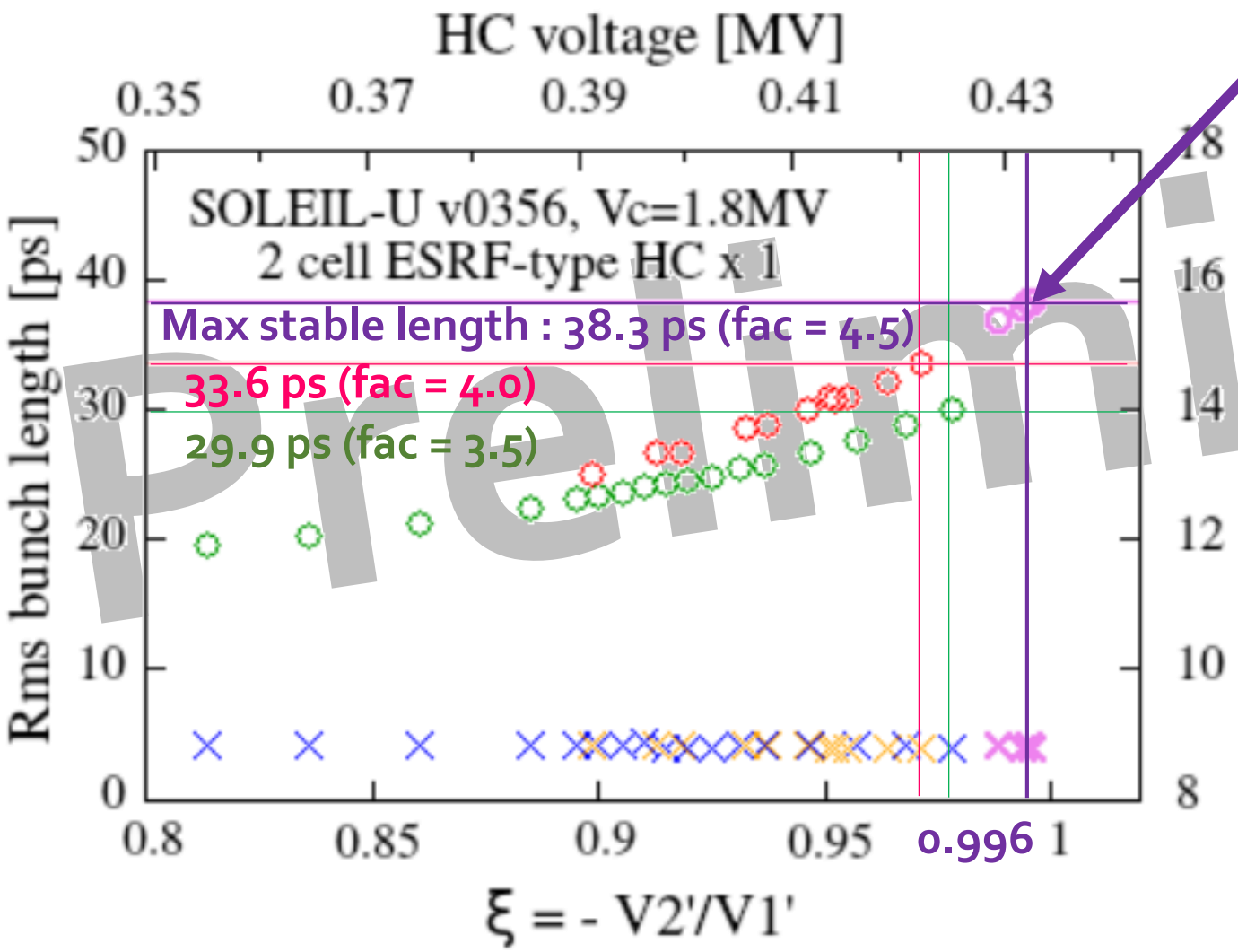

Fig. Calculation result compared with SuperKEKB experimental result.
The mbtrack results are plotted as solid circles (●, ●).

In the mbtrack calculation,
AC Robinson (CBI mode 0) instabilities are observed in the beam current > 500mA since the zero-mode damper is “OFF.”

# Impact for a bunch lengthening system
# One HC for multi bunch (Active case)

Main cavity : EU-cavity x 4
HC cavity : ESRF 4th HC x 1

## Active HC ($V_{g,hc} \neq$ 0 kW) & Direct RF-FB on HC

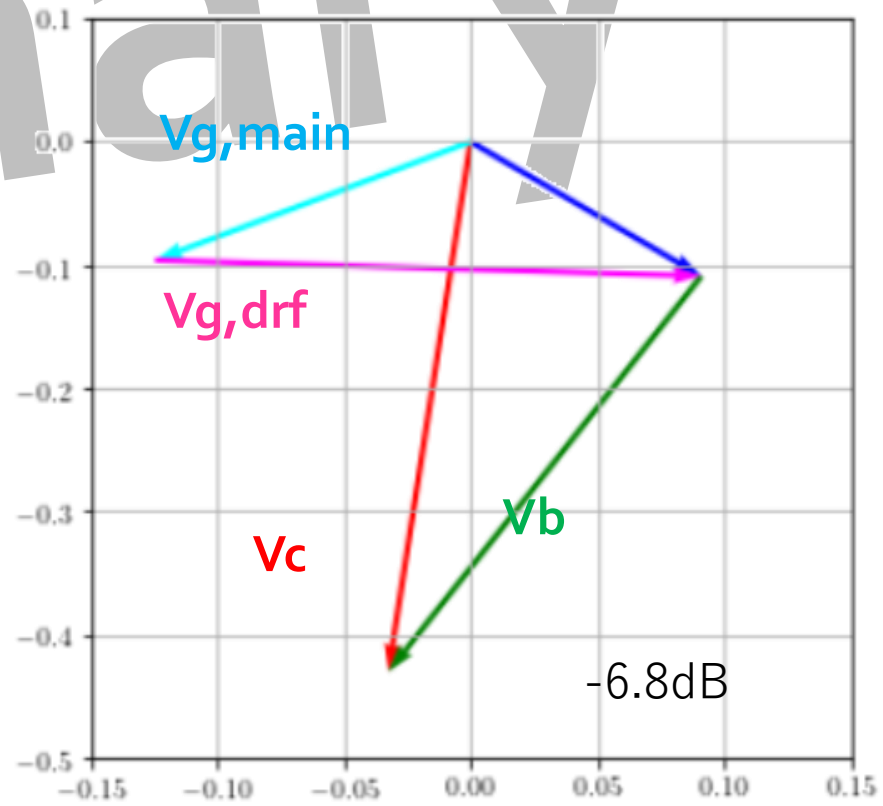



**Max stable length @ Vhc = 432kV**

**Pg_hc = 23.7 kW** **Vg,main = 98 kV**

**Δf_hc = 135.6 kHz** **Vg,drf = 216kV**

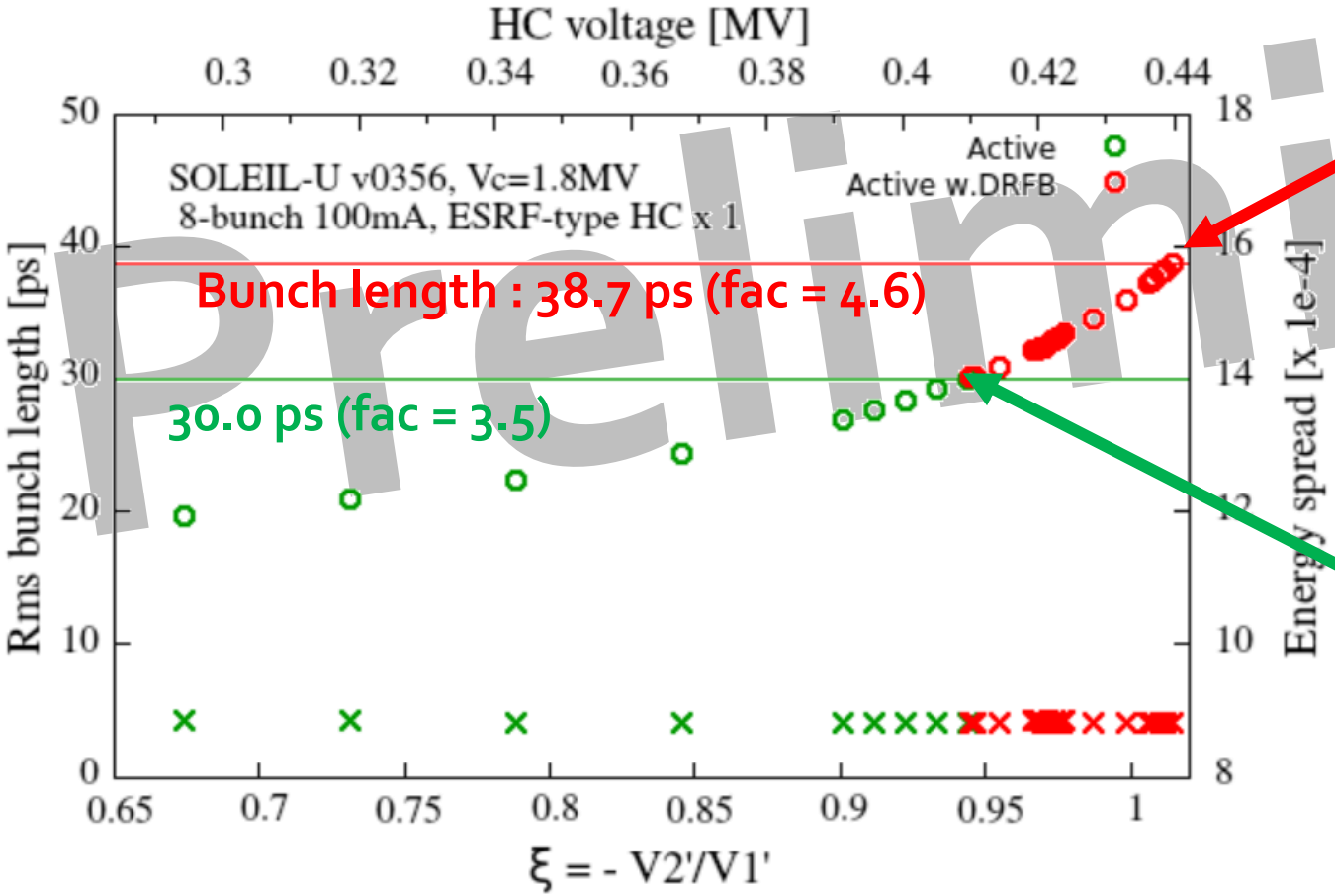
```
NewVgVmp = 5.718e-05,  newVgPhase = -2.484,
drfVgAmp = 7.849e-05,  drfVgPhase = -0.060
VbAmp = 1.252e-04,  drfVgPhase = -1.938
VcAmp = 1.569e-04,  VcPhase = -1.646
```



# Impact for a bunch lengthening system
# One HC for 8 bunch 100 mA

Main cavity : EU-cavity x 4
HC cavity : ESRF 4th HC x 1

By acting the direct RF-FB on HC,
FP (ξ >= 1.0) and the bunch length 38.7 ps were achieved.
The threshold of the instability was at ξ = 0.94 and the bunch length 30.0 ps.




**Vhc = 440kV, Δf_hc = 27.7 kHz**
**Pc_hc = 40.4 kW, Pg_hc = 40.2 kW**

**Direct RF-FB:**
**Gfb = 0.7, LoopDelay = 1.1us**

**Vhc = 410kV, Δf_hc = 29.7 kHz**
**Pc_hc = 35.0 kW, Pg_hc = 33.9 kW**

**w/o. Direct RF-FB:**

# Practical Damper at super KEKB

Proceedings of IPAC2017, Copenhagen, Denmark THPAB115

**DEVELOPMENT OF A LONGITUDINAL FEEDBACK SYSTEM FOR COUPLED BUNCH INSTABILITIES CAUSED BY THE ACCELERATING MODE AT SuperKEKB**

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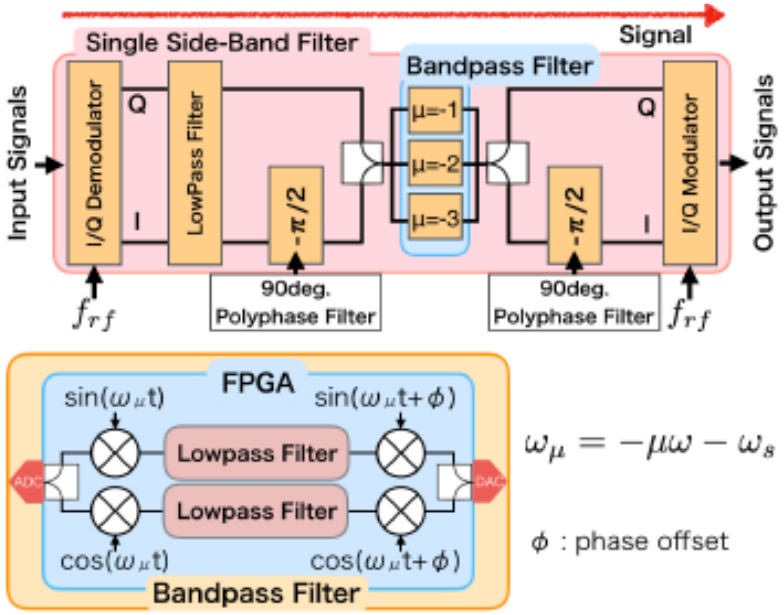



Figure 4: Block diagram of a new LCBI damper. Upper figure is entire structure of LCBI damper, and lower figure is internal structure of BPF.

the test-bench measurement of impedance damping with a simulant cavity(Q = 9000).

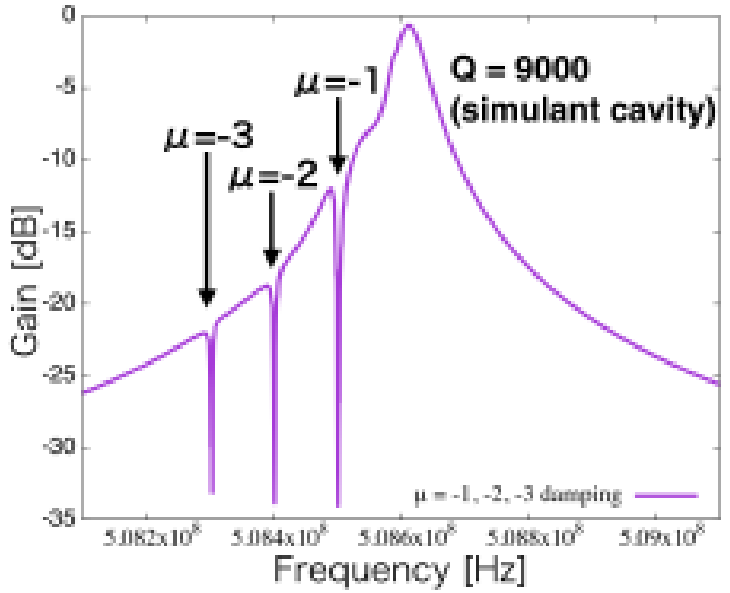
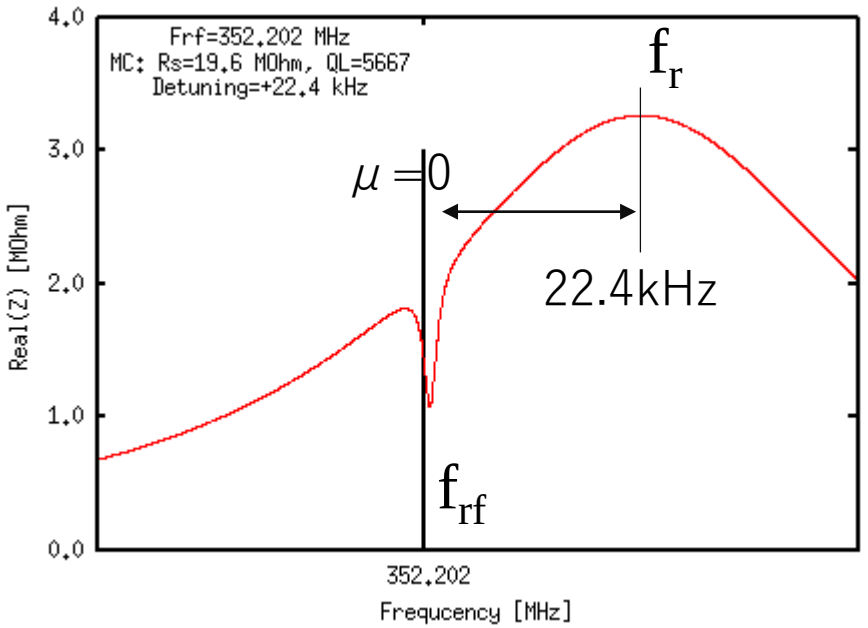



Figure 6: Block diagram for the FB loop evaluation (Top), and the damping characteristics for the FB loop (Bottom).

# Resonator damper model in mbtrack

This damper is introduced as a resonator model.

**Bench mark test**




This method can be used for $\mu = 0, \pm 1, \pm 2,,,$ by changing the "fr" value.
Furthermore, the damping rate can be controlled by changing the "R" value.

Iring=10mA (single bunch)
Fs= 1.4 kHz

Main Cavity:
Vc=1.4 MV
R= 19.6 MΩ, QL = 5667,
Detuning = +22,4 kHz
=> Growth Rate = 6.47 $s^{-1}$
(Analytical estimation)

Damper:
fr = 352.2027 MHz
R = -1 MΩ, QL = 2e5
=> Damp Rate @mode 0 = 16 $s^{-1}$
(Analytical estimation)

# Resonator damper model in mbtrack

This damper is introduced as a resonator model.

**Bench mark test**