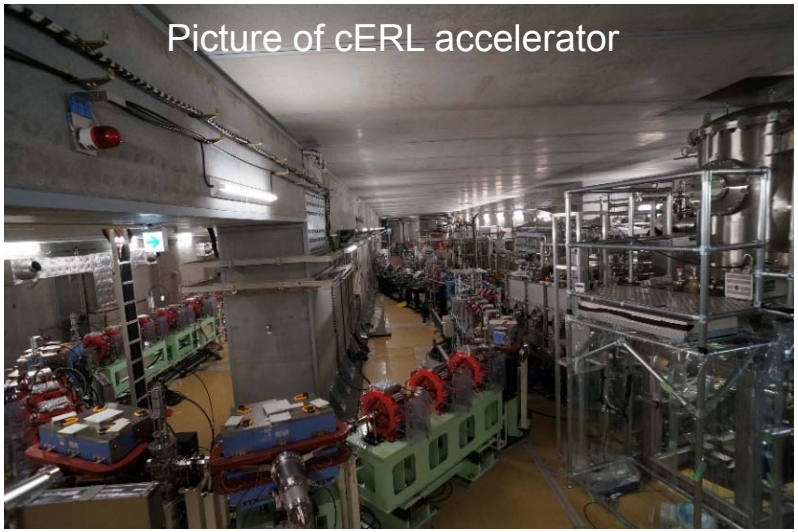
Microphonics Experience at Compact ERL

Compact ERL (**cERL**) is a test facility of 3-GeV ERL as a future light source.



- Completed in Dec. 2013.
- Commissioned during Dec. 2013 - .

RF = 1.3 GHz CW

Circumference ~ 90m

Requirements of RF stabilities for 3GeV-ERL
0.01%rms,0.01deg.rms

12 pages

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LLRF Group
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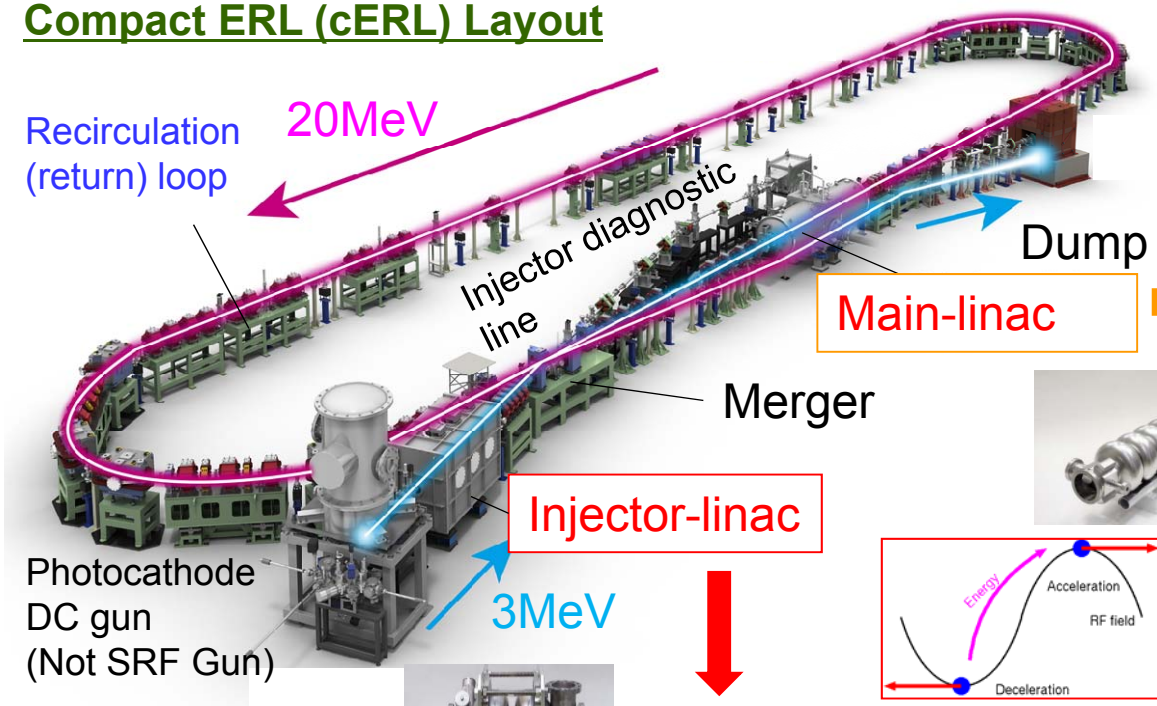
SRF Cavity Group
Eiji Kako, Takaaki Furuya, Hiroshi Sakai, Kensei Umemori, Taro Konomi, Masato Egi, Kazuhiro Enami (KEK), Masaru Sawamura (QST)

Introduction of cERL

H.Sakai and K.Kako et al.

Compact ERL (cERL) Layout

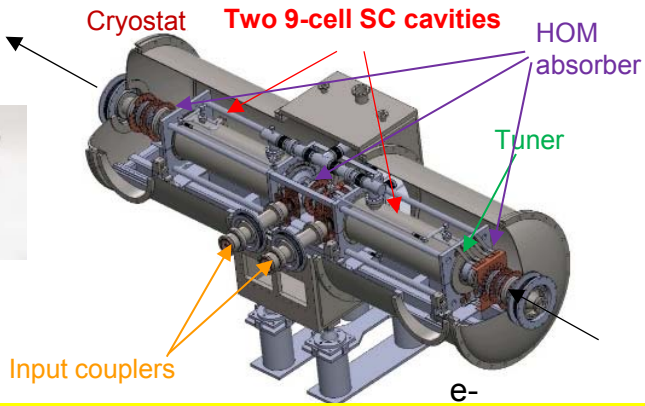


Main linac module

HOM damped (for 100mA circulation to suppress HOM-BBU in design)

9-cell cavity (ERL-model2)× 2

RF frequency: 1.3 GHz
Input power : 20kW CW (SW)
E_{acc}: 15 MV/m (design)
Unloaded-Q: $Q_0 > 1\times10^{10}$

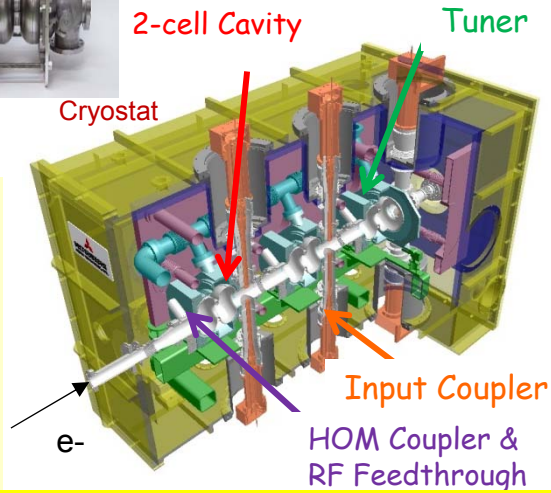


Requirement was satisfied at V.T. Heavy F.E was met @9-10MV/m after string assembly.

Injector module

2-cell cavity × 3
Double coupler

RF frequency: 1.3 GHz
Input power :
10kW/coupler (10mA, 5MeV)
180kW/coupler (100mA, 10MeV)
E_{acc}: 7.6MV/m (5MeV)
Unloaded-Q: $Q_0 > 1\times10^{10}$

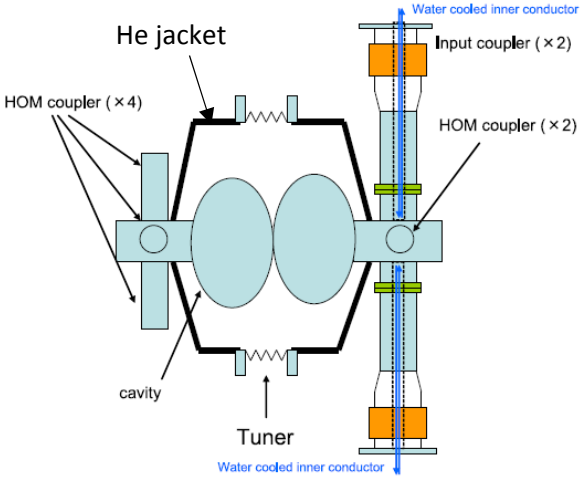


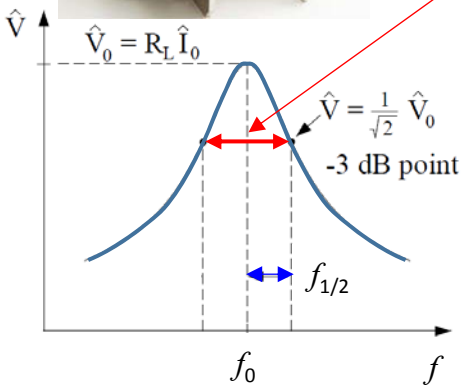
Requirement was satisfied at V.T and for initial 10mA requirement .

Design parameters of the cERL

Nominal beam energy	35 MeV → 20MeV
Nominal Injector energy	5 MeV →2.9MeV
Beam current	10 mA (initial goal) 100mA (final)
Normalized emittance	0.1 – 1 mm·mrad
Bunch length (bunch compressed)	1-3ps (usual) 100fs (short bunch)

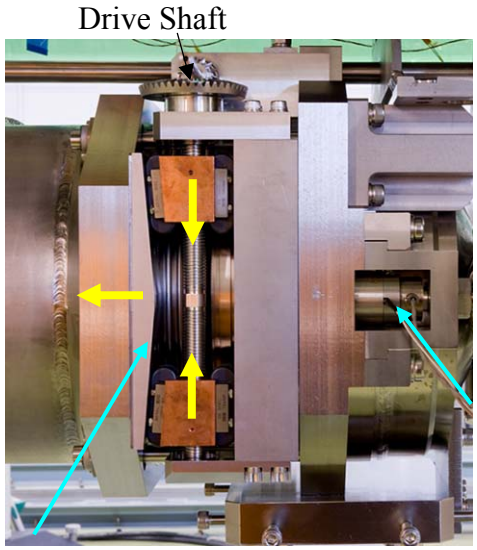
Tuner system of Injector Linac





Slide-Jack tuner

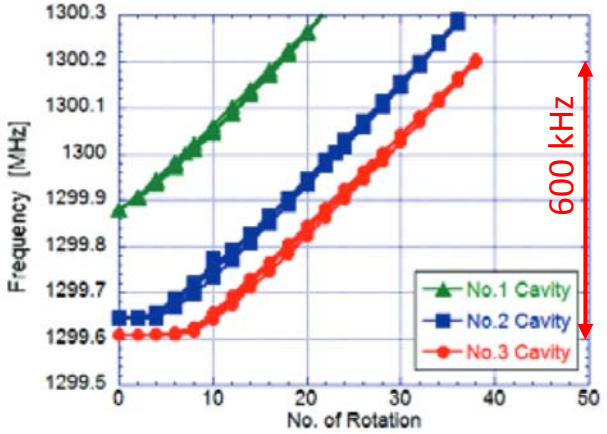
E. Kako, IPAC2013



Piezo tuner
0-500V
stroke= 4 μm@2K

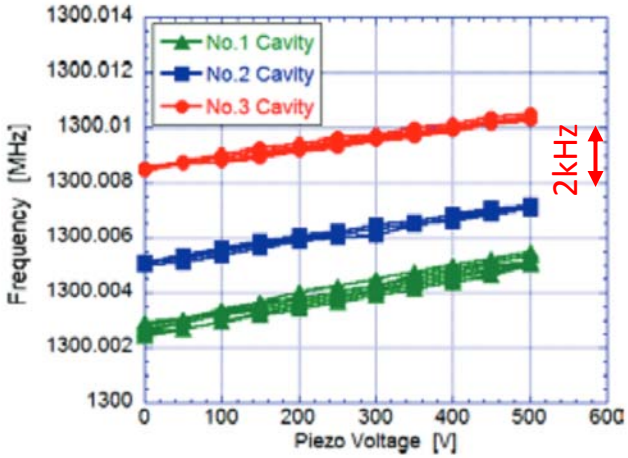
The same as KEK-STF tuner system

20 kHz/rotation



performance of slide-jack tuner

Piezo: 0-500V => 2 kHz



performance of piezo tuner

$2\Delta f_{1/2} = f_0 / Q_L$

Inj1: $Q_L = 1.2 \times 10^6$, $2\Delta f_{1/2} = 1.1$ kHz

Inj2: $Q_L = 5.8 \times 10^5$, $2\Delta f_{1/2} = 2.2$ kHz

Inj3: $Q_L = 4.8 \times 10^5$, $2\Delta f_{1/2} = 2.7$ kHz

Piezo tuner can cover the band width.

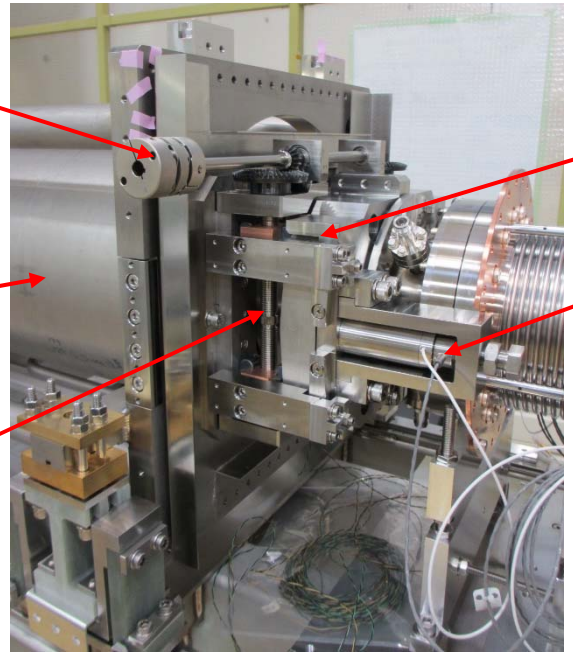
Tuner system of Main Linac

H. Sakai, SRF2013 @Paris

Shaft of slide-jack tuner

He jacket

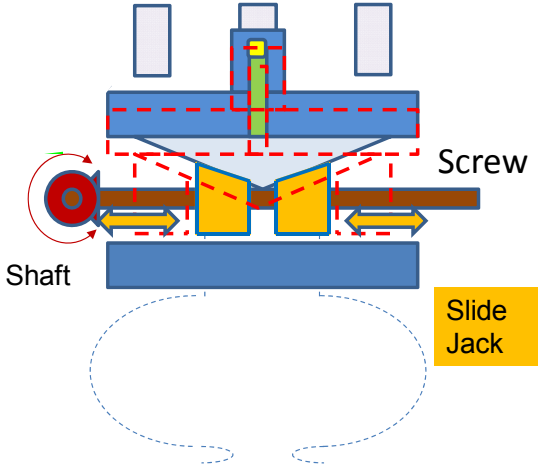
Slide-jack tuner



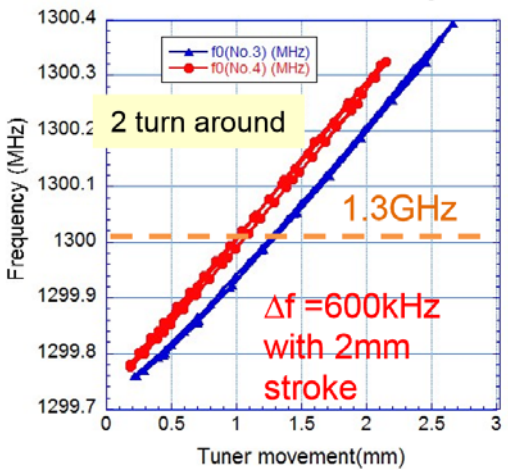
Cavity flange is fixed here

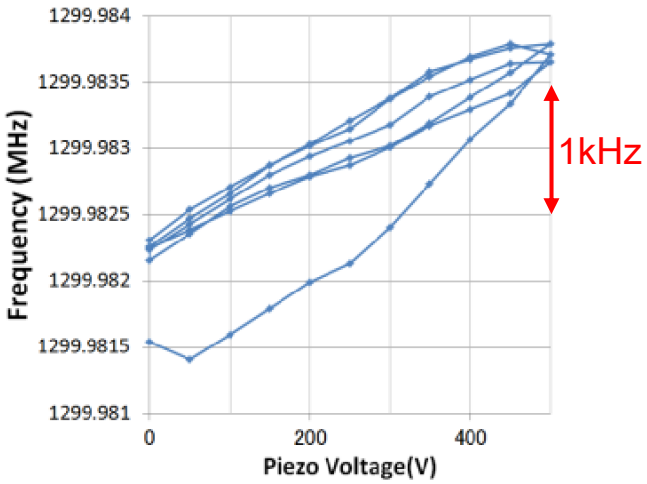
Piezo tuner
0V - 500V (offset=250V)
Stroke= 4 μm @ 2K
40 μm @ 300K
(1 μm: 300Hz)

$Q_L = 1 \times 10^7$
$2\Delta f_{1/2} = f_0 / Q_L = 130$ Hz



Coarse mechanical tuner stroke @ 2K





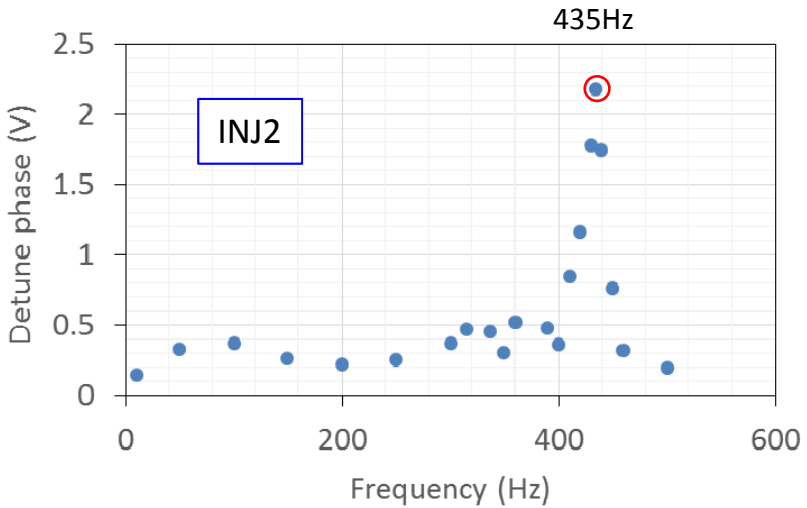
Mechanical Resonances of Injector Cavities

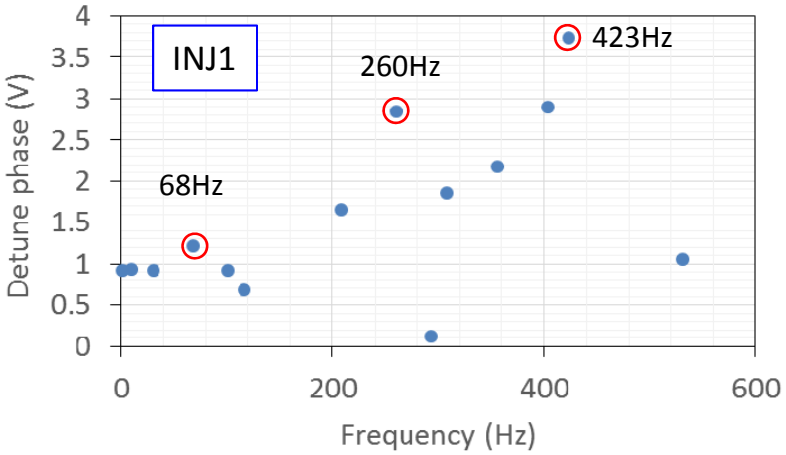
<Injector>

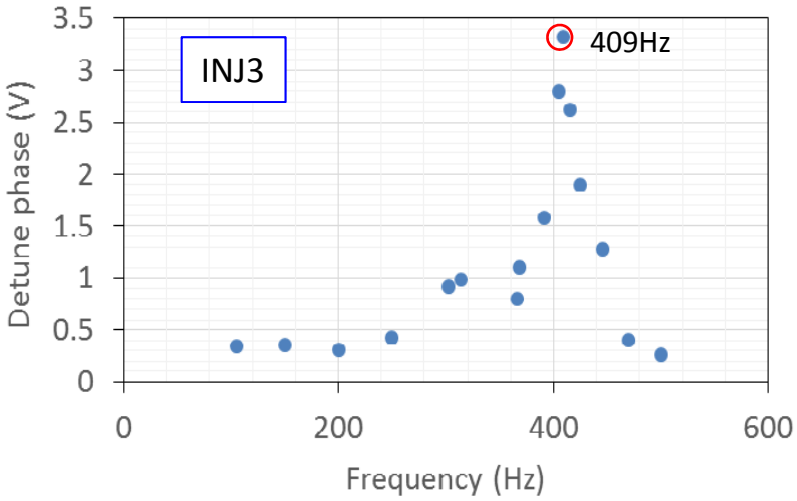
Eacc: 1MV/m

Sinusoidal wave ($40V_{pp}$) was fed to piezo tuner.
Mechanical resonance is scanned by sweeping the input frequency.

Phase detector : 20 mV/deg



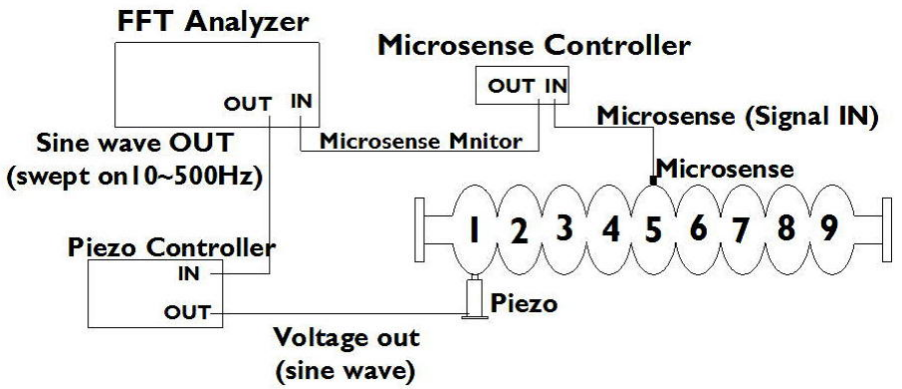


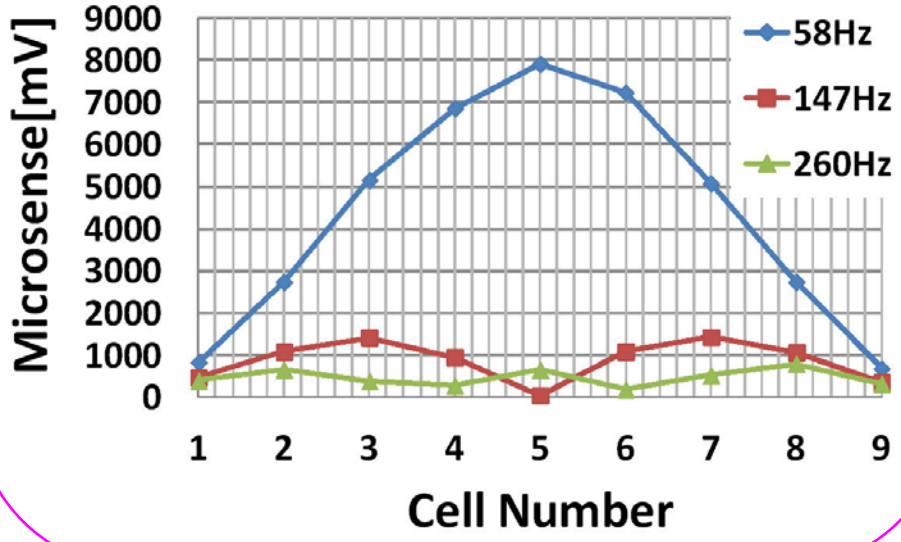


Large mechanical resonance exists around 400 Hz.

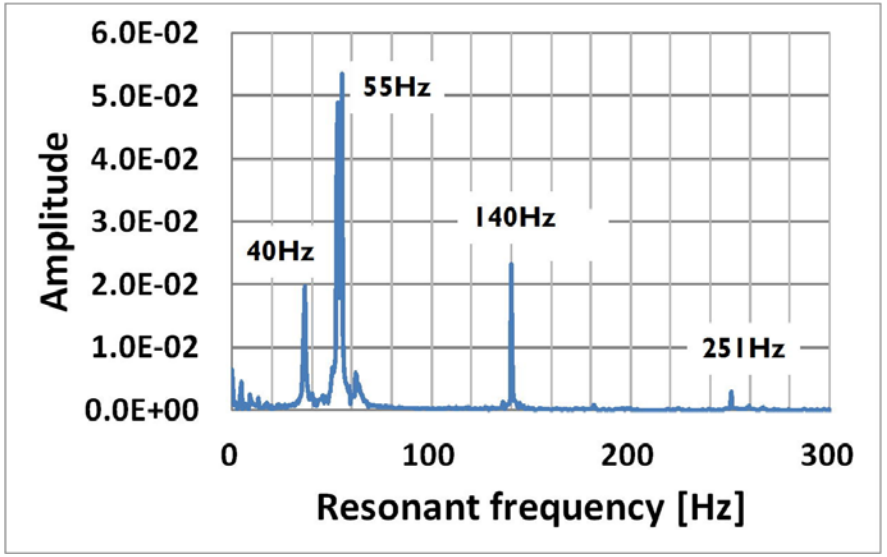
Mechanical Resonance of ML Cav

M. Satoh, IPAC2014



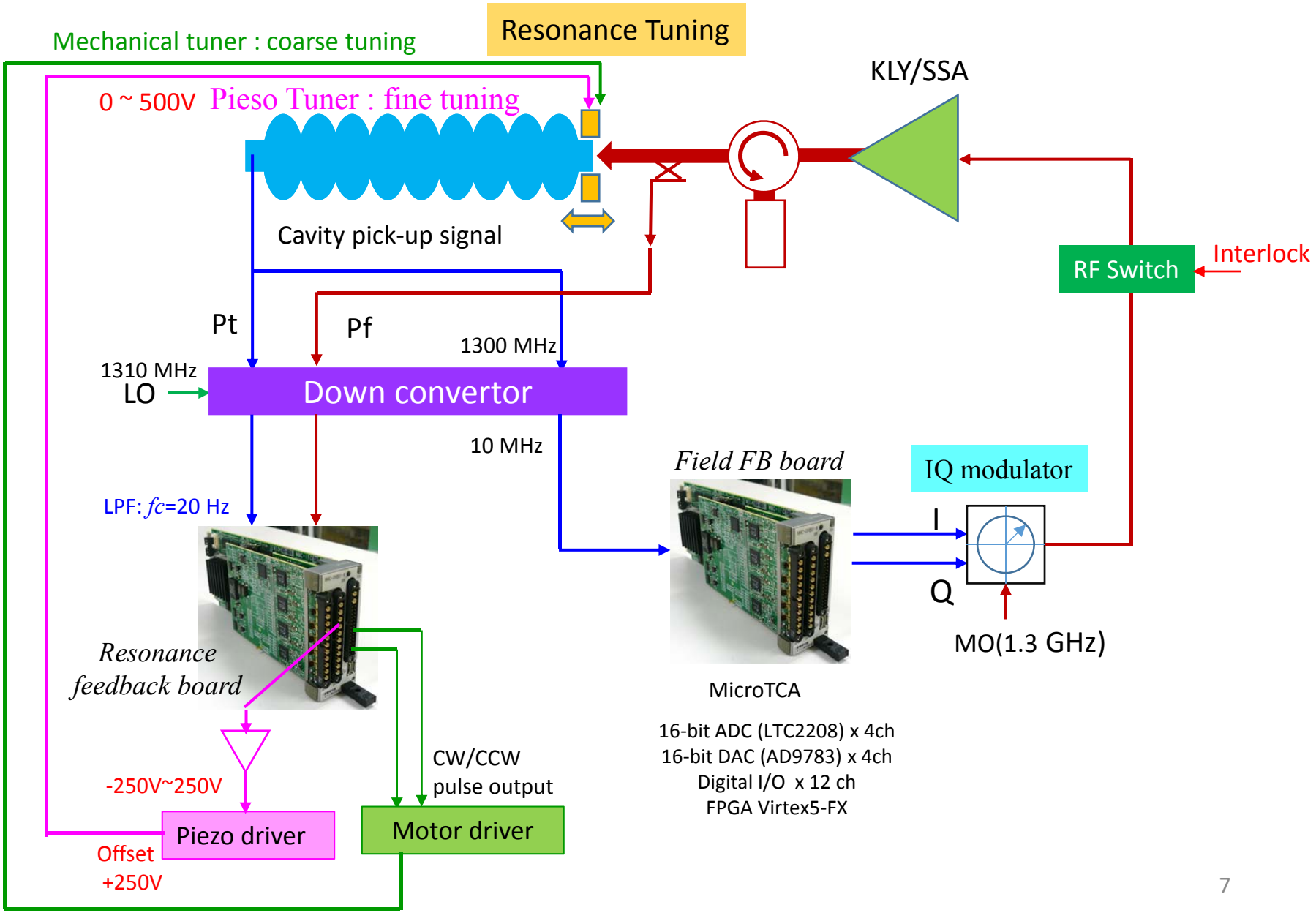


Impulse hammer response



Large mechanical resonance exist near 50 Hz.

Digital LLRF System at cERL



Waveform of ML Cavities

T. Miura, IPAC2014 @Dresden

ML1

ΔA = 0.012% rms
$\Delta\theta$ = 0.014° rms

ΔA = 0.035% rms
$\Delta\theta$ = 0.3° rms

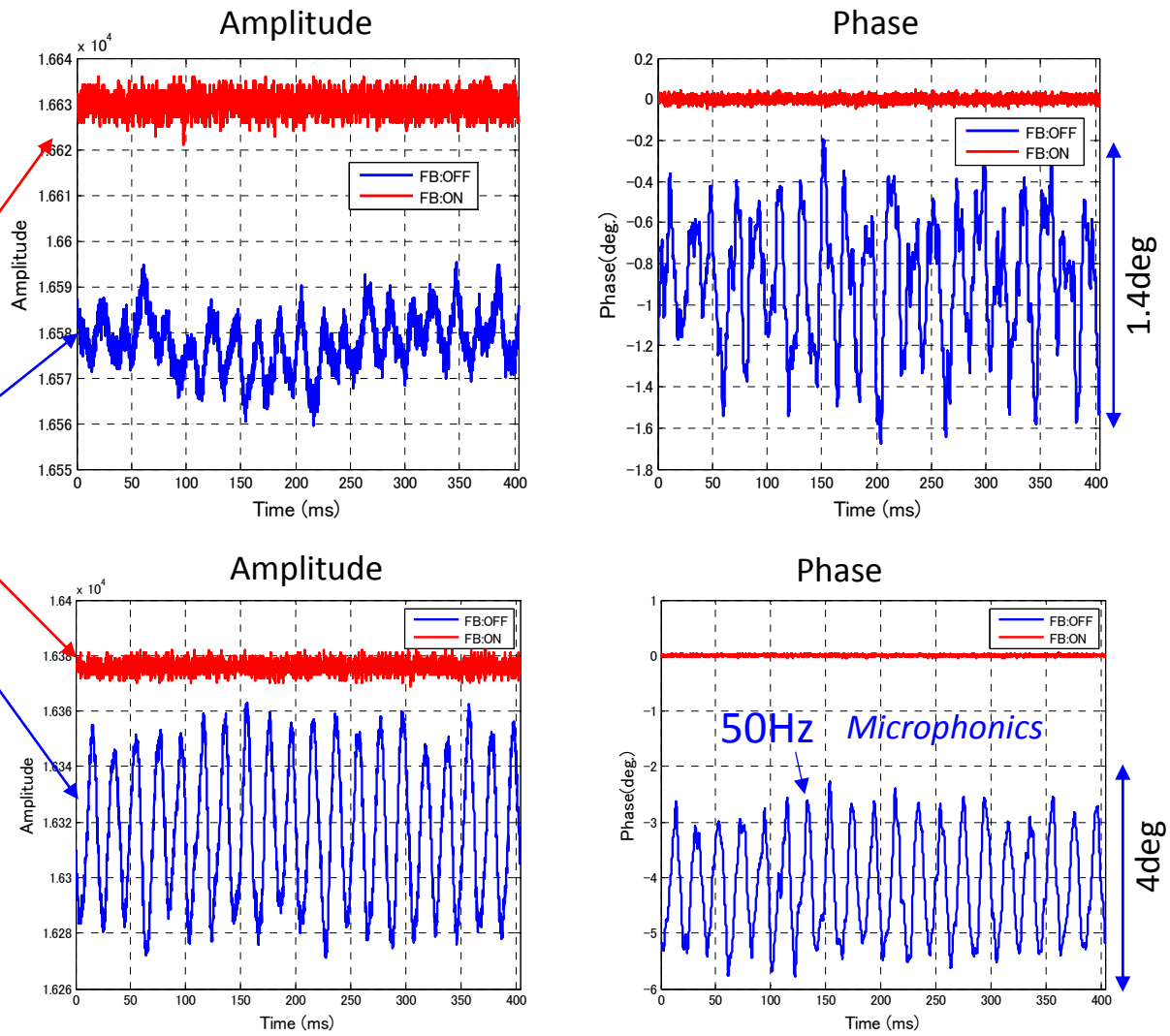
Vc: w field Feedback

Vc: w/o field Feedback

ML2

ΔA = 0.013% rms
$\Delta\theta$ = 0.015° rms

ΔA = 0.15% rms
$\Delta\theta$ = 0.6° rms

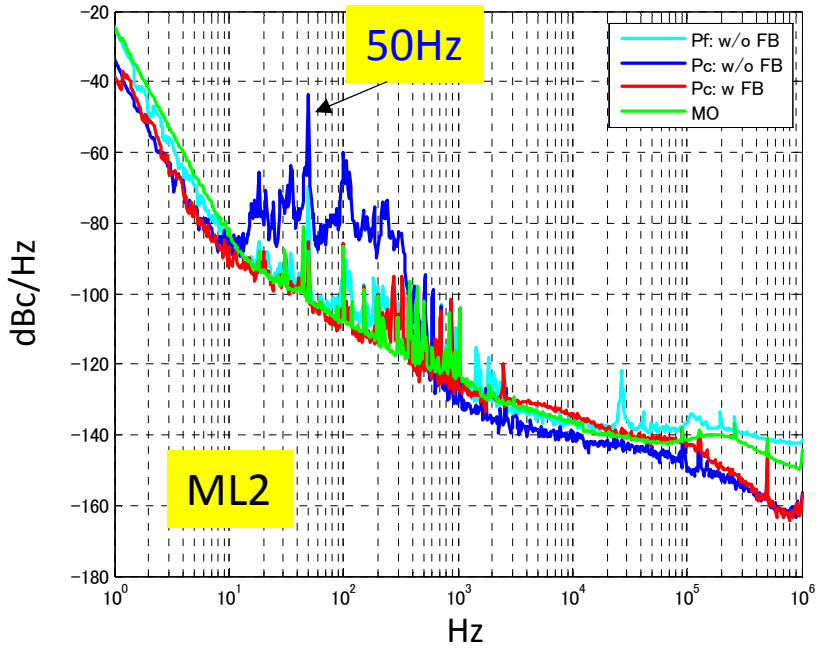


Field fluctuation by Michrophonics is stabilized by RF Feedback

Phase noise jitter measurement using Signal Source Analyzer

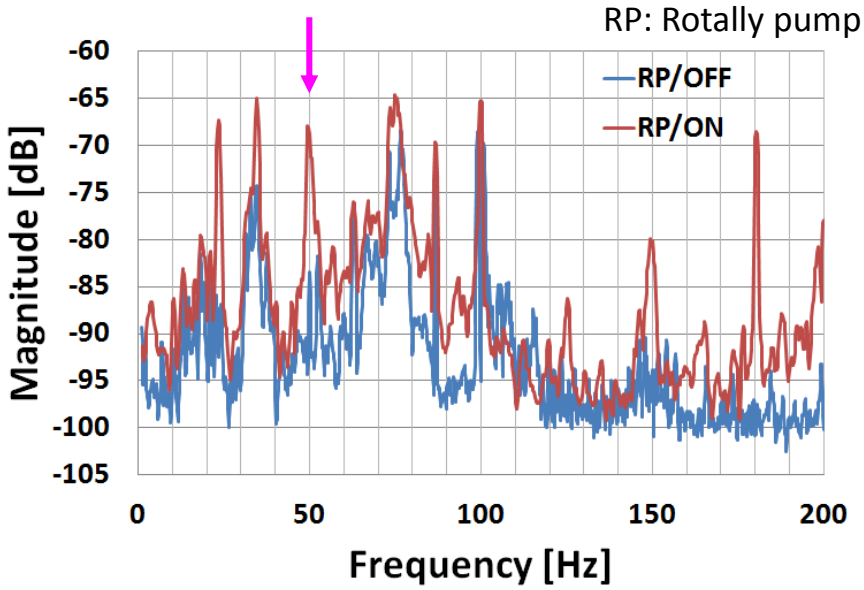
T. Miura, IPAC2014 @Dresden

Agilent E5052B



M.Egi, PASJ2016 (MOP025)

Vibrational state of "floor" around Main Linac



Vc Phase Noise with RF FB (10Hz-1MHz)=0.017deg

Vc Phase Noise w/o RF FB (10Hz- 1MHz)=0.73 deg

Microphonics is observed at 10 Hz - 400Hz.

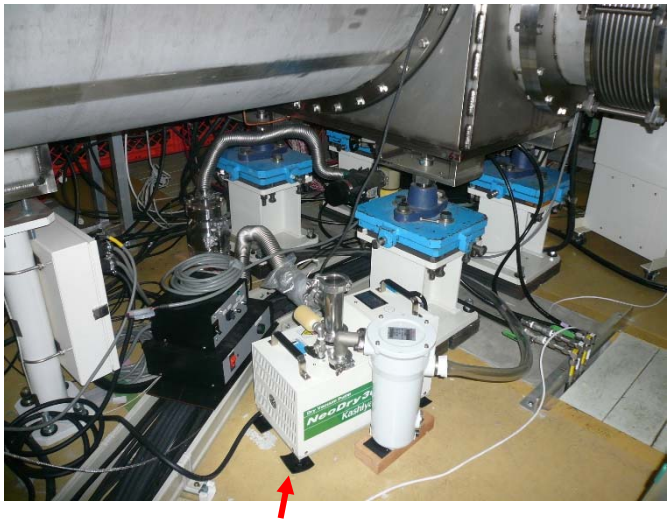
Phase noise by Microphonics was suppressed well by RF FB.

Phase noise of Vc with FB was almost the same as that of Master Oscillator.

Countermeasure against Scroll Pump Vibration

9-cell SC cavity: $Q_L=10^7$

Field gradient
8.3 MV/m : Operation point
(15 MV/m : Design)



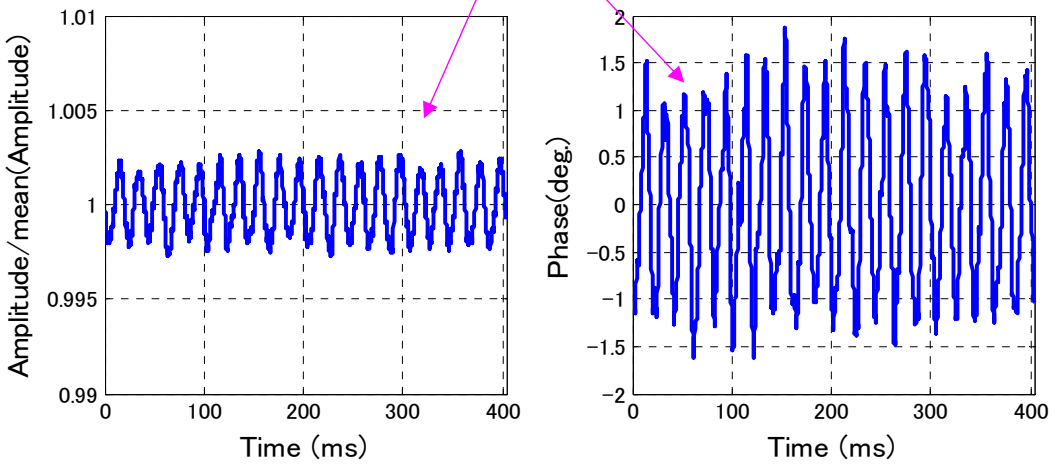
The rubber sheet was inserted under the scroll pump.
The 50 Hz vibration is suppressed.

For constant input RF power

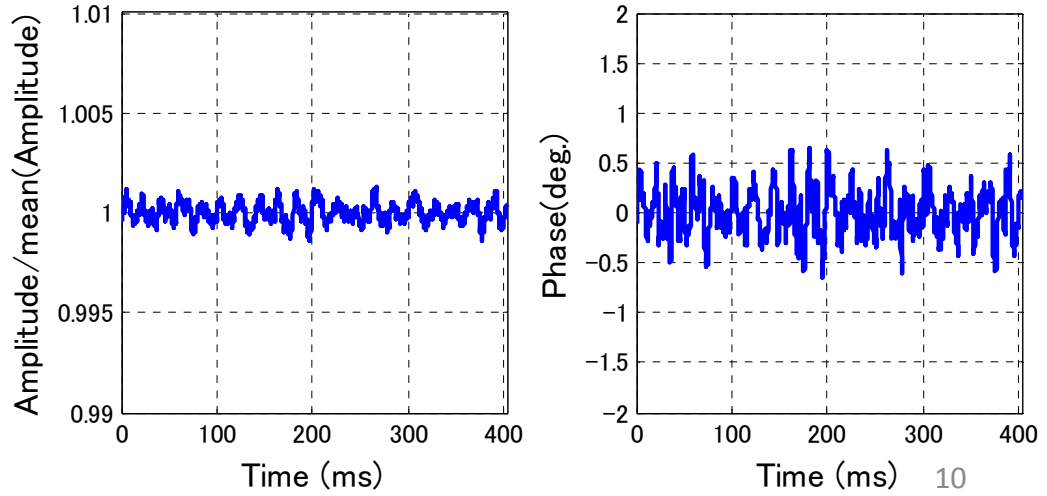
Before

50 Hz

vibration by scroll pumps

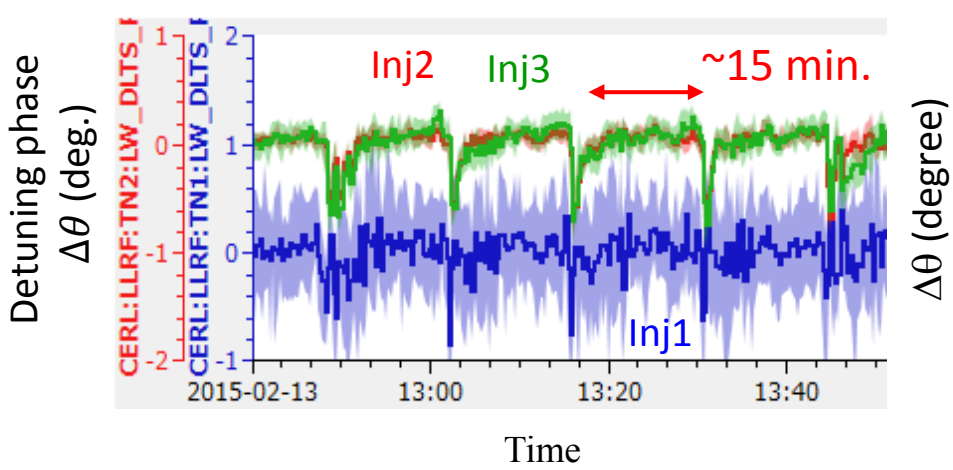


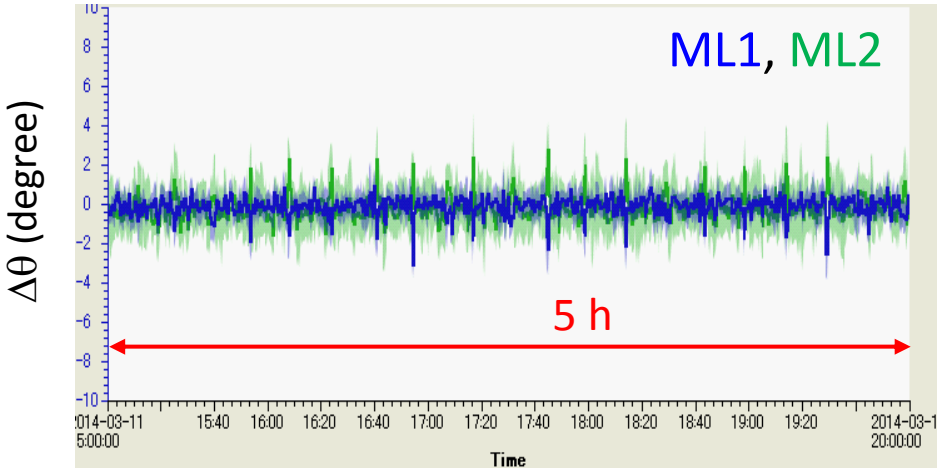
After



Detuning by Liquid N_2 and final results of FB control

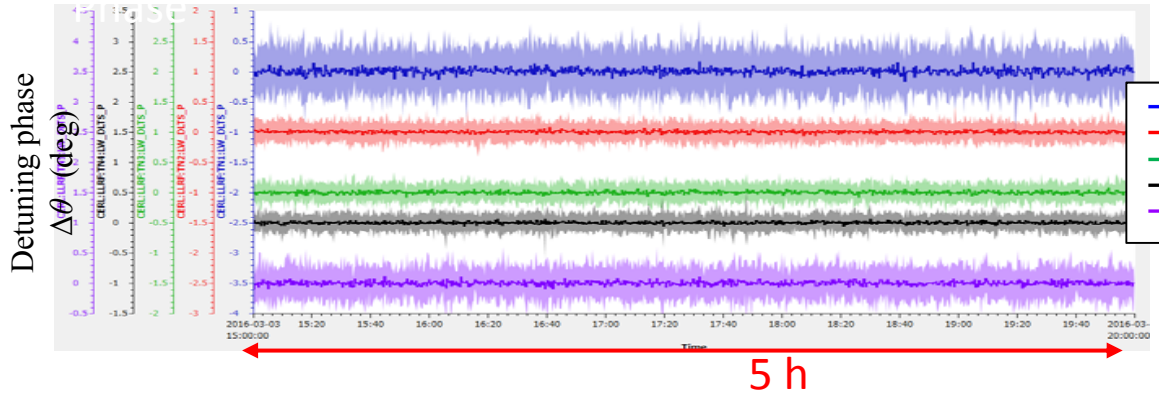
Detuning depending on valve control for liquid N_2 was observed.





Detuning

Result of Resonance FB Control



Cavity	Δθ deg (rms)	Δf Hz (rms)
INJ1	0.23	2.2
INJ2	0.10	2.0
INJ3	0.09	2.1
ML1	0.09	0.08
ML2	0.16	0.18

At the begging of cERL operation, feedback gain of the resonance control was low.
Detuning by liquid N2 was improved by adopting the high feedback gain.

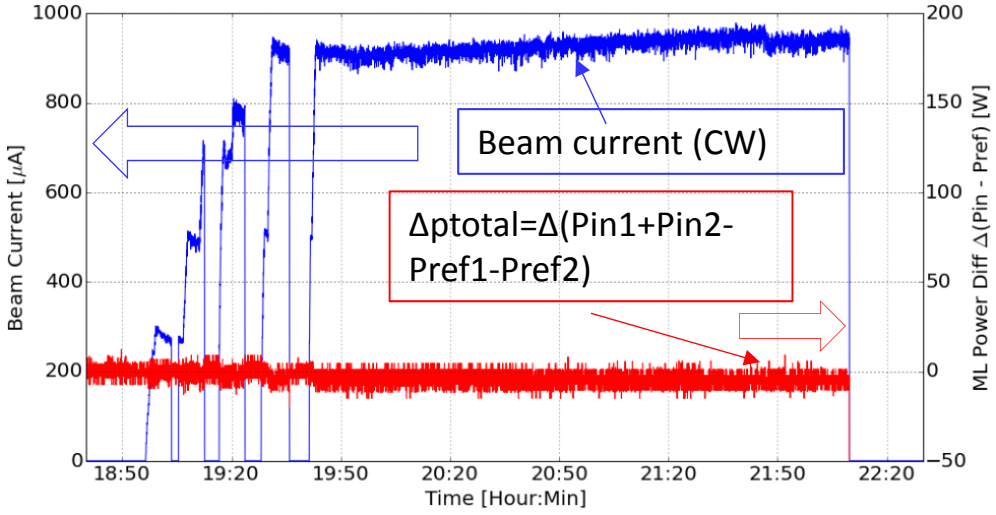
Summary

Resonance feedback control at cERL has been performed in lower frequency than mechanical resonance in current operation

In ML cavities, large Michrophonics of 50 Hz was excited by the scroll pump.
The Michrophonics was reduced by suppressing the vibration of the floor.

Detuning by cooling with Liquid Nitrogen was also observed.
That was improved by adopting high feedback-gain for resonance control.

This stable operation with 0.01 % amplitude and 0.01 deg phase control by LLRF gave the stable energy recovery operation of about 1 mA with no beam loss.



Achieve 0.9 mA with (100.00 +- 0.03) % energy recovery.
No beam instability was observed.

We plan to carry out CW **10 mA** in cERL with energy recovery.

Backup Slides

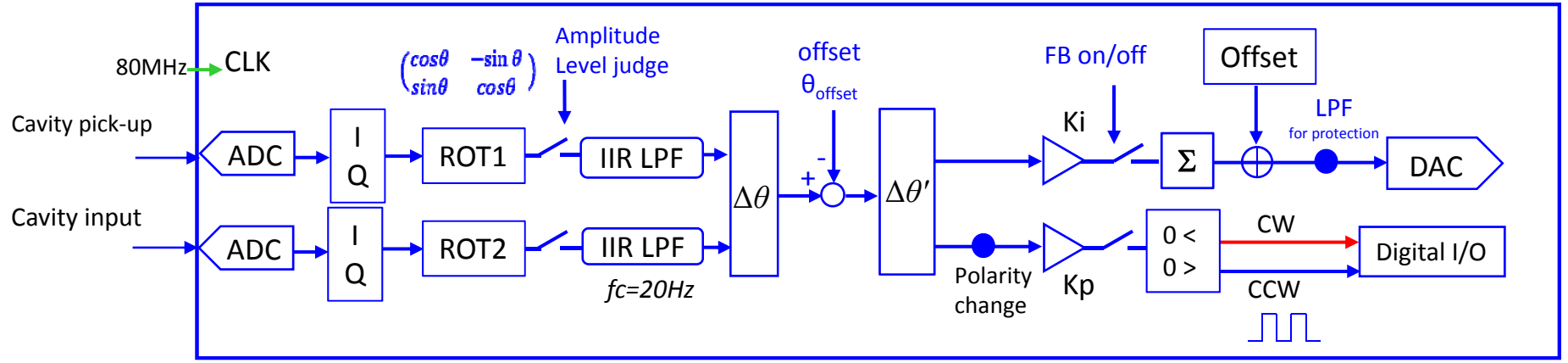
Block Diagram of Resonance Control

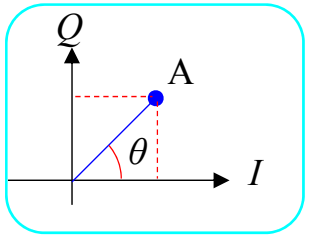
Feedback Control: $\Delta\theta = \theta_f(\mathrm{Pf}) - \theta_c(\mathrm{cav}) \Rightarrow 0$

DAC → Piezo Tuner

Digital I/O → CW / CCW → Mechanical Tuner (Stepper motor)

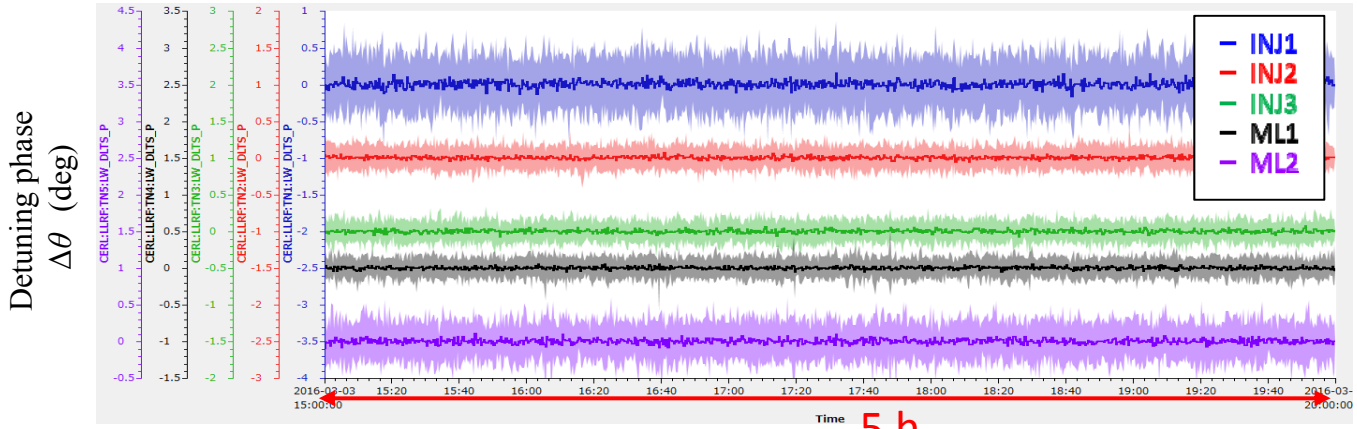
FPGA Board





Result of Resonance FB Control

Detuning Phase



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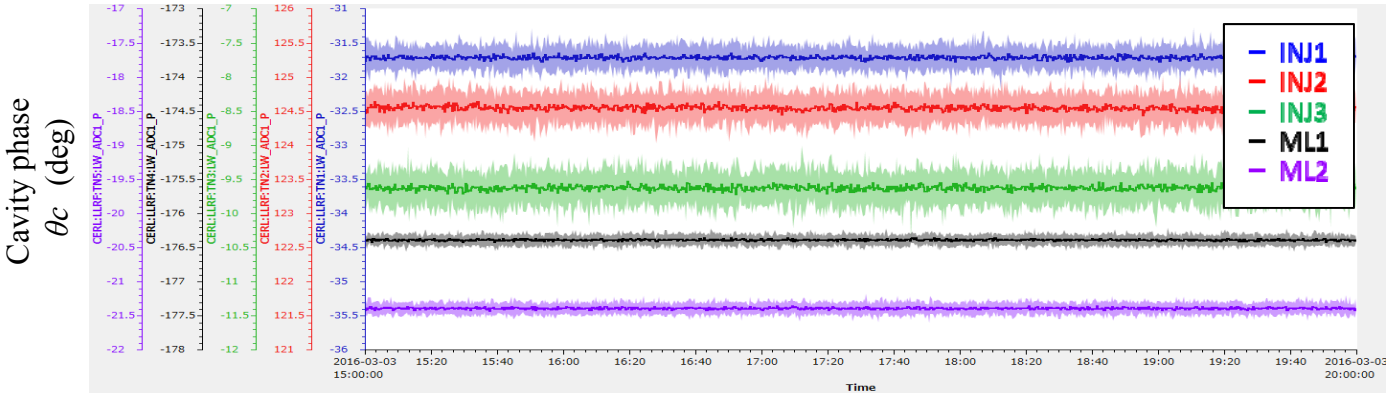
Cavity Phase



Inj2&Inj3 cavity phase become stable.