Simulation of Normal conducting Active-HC on SOLEI-U case, II

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2022/09.27

In the previous meeting, the results with > 2 HC were shown.
Here, the results with 1HC are mainly presented.

*I will introduce the fast feedback in MBTRACK, if time allows.

Introduction & precondition

- Feasibility of active HC is numerically investigated for the SOLEIL-U ring.
- EU-type main cavity and 2-cell ESRF 4^{th} harmonic cavity are assumed for the rf system.

Table 1: SOLEIL Upgrade parameters (v0356)

Parameter	Unit	Value
Energy, E_0	GeV	2.75
RF frequency	MHz	351.6
Energy loss per turn (no ID), U_0	keV	458
Main RF voltage, $V_{c,1}$	MV	1.80
Energy spread		8.9×10^{-4}
Momentum compaction factor, α		1.1×10^{-4}
Longitudinal damping time, τ_e	ms	12.2
Synchrotron frequency w/o. HC	kHz	1.78
Natural rms bunch length	ps	8.5

<u>Cavity Parameters</u>

Main cavity : EU-type cavity
- Shunt impedance = 5 MΩ ($P_c=V_c^2/2/R_s$)
- Unloaded-Q = 35,000
- Beta coupling = 5.0
- Slow RF feedback to keep Vc

HC: 2-cell ESRF HC
- Harmonic = 4.0
- Shunt impedance = 2.4 MΩ ($P_c=V_c^2/2/R_s$)
- Unloaded-Q = 27,000
- Beta coupling = 0.0 or 1.0
- NO RF feedback
- Maximum dissipation Pc,max = 40kW

<u>Broad band impedance</u>

0.069 Ω/GHz/m for pure copper

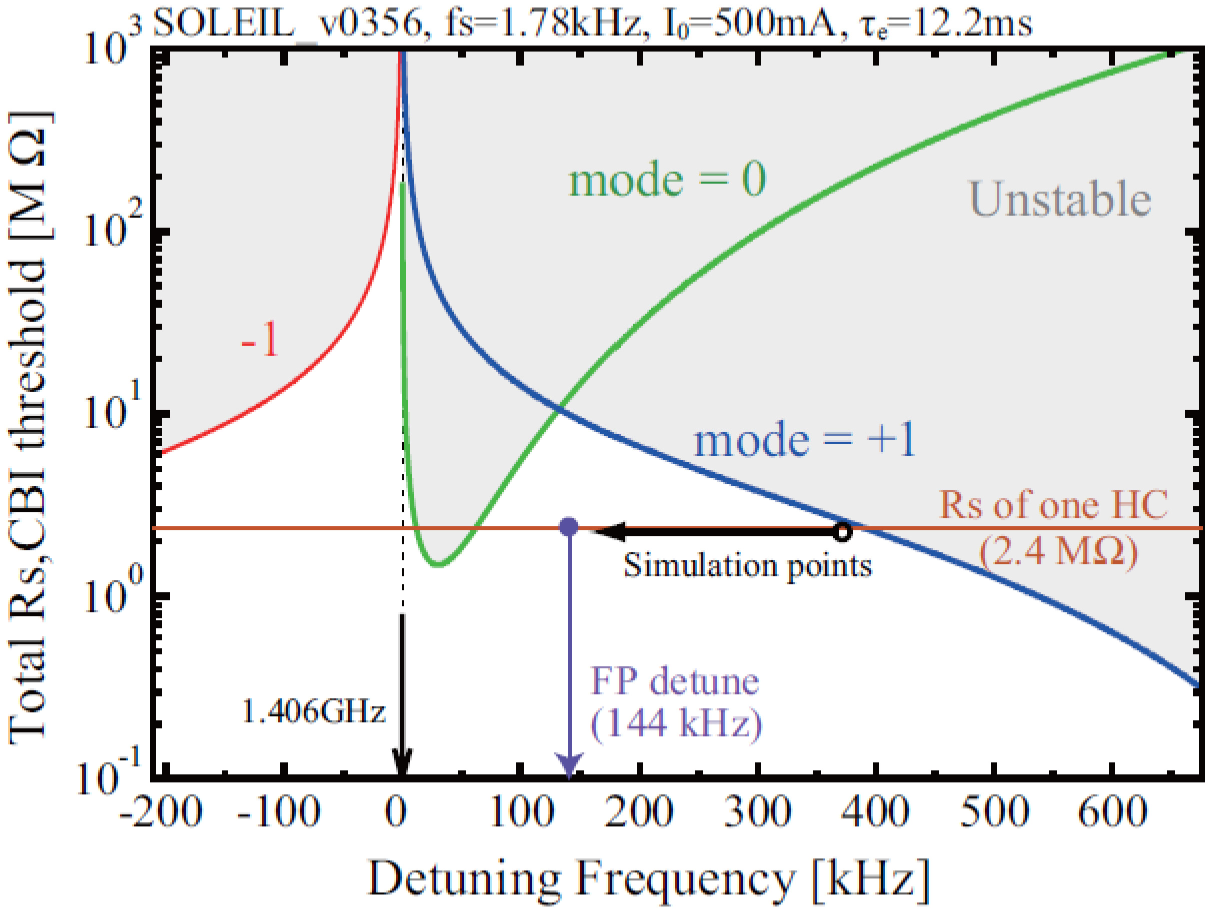
Design of 4th harmonic system for SOLEIL-U

- Following two operation modes are needed;
  - ☐ Multi bunch (500mA) mode
  - ☐ 8-bunch (100mA) mode
  - ☐ Single bunch (< 20 mA) mode
- Requirement parameters to achieve the flat potential condition ($V'(0)=V''(0)=0$),
  - ☐ Total cavity voltage of 434 kV ($V_{c,main}$ = 1.8 MV)
  - ☐ Cavity synchronous phase of -1.641
  - ➢ In this situation, maximum bunch length 40 ps (rms), which is BL factor of 4.7, is expected.

The maximum dissipation $P_{c,max}$ = 40 kW for one 2-cell cavity corresponds to the cavity voltage of 438kV, which is close to the required voltage of 434kV .

MBTRACK result for Multi bunch mode (500mA)

Rs threshold of conventional CBI*
including main cavity and radiation damping



Longitudinal coupled-bunch instability

- Rigid bunch model (each bunch is assumed to be a point charge)
- Equally spaced M bunches
- Coherent frequency close to the incoherent synchrotron frequency.

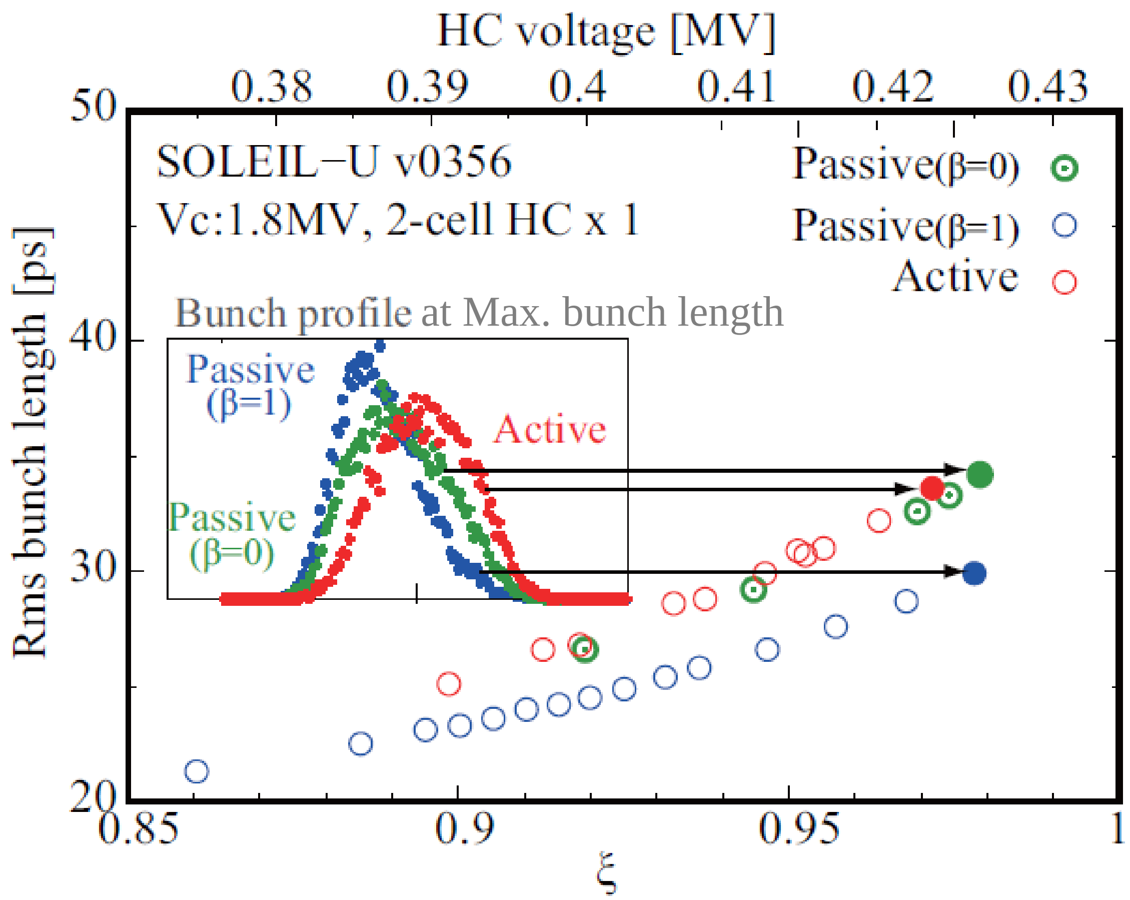
Growth rate of μ-th coupled-bunch mode:

$$\tau_g^{-1} = \frac{e\alpha I_0}{4\pi E\nu_s}\left\{\sum_{n=0}^{\infty}\omega_{\mu,n}^{+}\,\mathrm{Re}\left[Z(\omega_{\mu,n}^{+})\right] - \sum_{n=1}^{\infty}\omega_{\mu,n}^{-}\,\mathrm{Re}\left[Z(\omega_{\mu,n}^{-})\right]\right\}$$

$$\omega_{\mu,n}^{\pm} = \{nM \pm (\mu + \nu_s)\}\omega_0 \qquad R = \left(R_s/Q_0\right)Q_L$$

$$Z(\omega) = \frac{R}{1 + iQ_L\left(\frac{\omega_r}{\omega} - \frac{\omega}{\omega_r}\right)}$$

MBTRACK result for Multi bunch mode (500mA)



$$\xi = \frac{-nV_{c,n}\sin\phi_n}{V_{c,1}\sin\phi_1}$$

$$V'(0) = -(1-\xi)V_{c,1}\sin\phi_1,$$

$$V''(0) = -V_{c,1}\left(\cos\phi_1 - \xi n\frac{\sin\phi_1}{\tan\phi_n}\right)$$

Maximum BL (shown in solid circles)

Active (β=1) ; BLF 4.0, ξ =0.97

Passive(β=0); BLF 4.0, ξ =0.98

Passive(β=1); BLF 3.4, ξ =0.98

The BLF 4.0 is comparable to that of the SC passive HC case.

Above the points shown solid circles, unstable beam motion with bunch length fluctuations along the bunch train, prevents further bunch lengthening.
This instability is considered to be of the same nature as the one reported by M. Venturini and T. He under the name, "coupled bunch mode l = 1 instability" and "periodic transient beam loading instability", respectively.

MBTRACK result for Multi bunch mode (500mA)

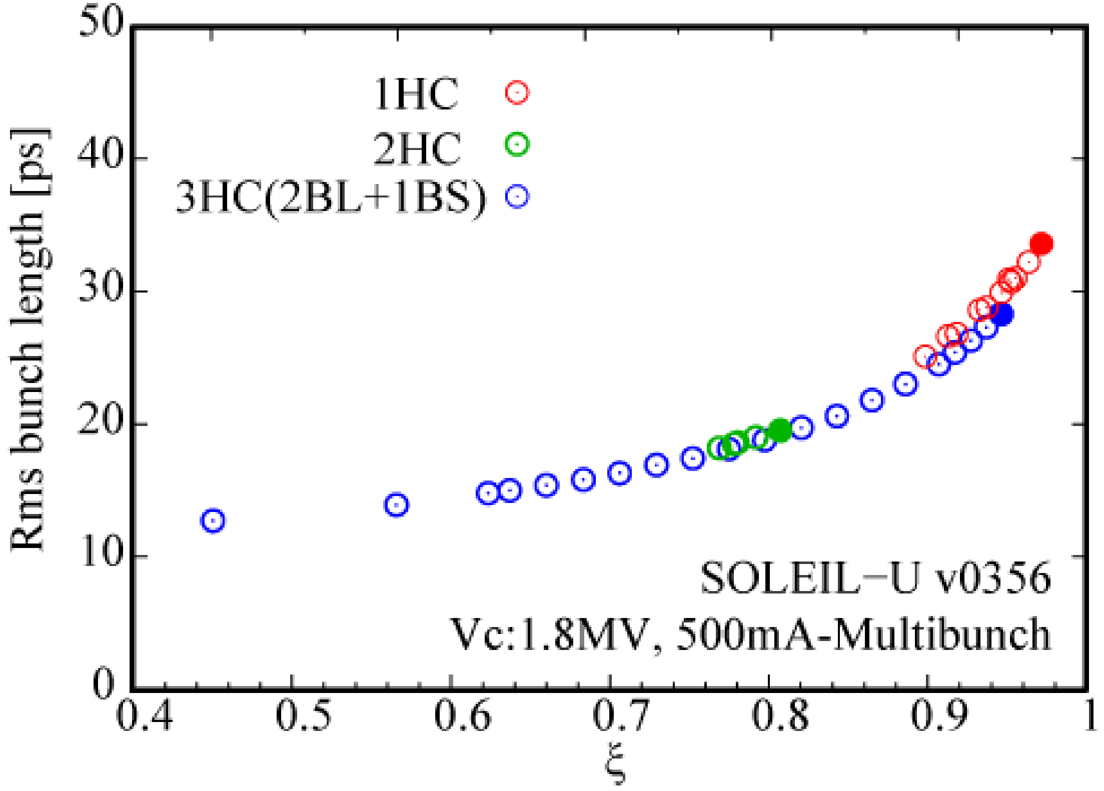
Comparison with other Active HC (β=1.0) setups,

1 HC,

2HC,

3HC (2BL+1BS; 2 HCs in bunch lengthening & 1 HC in bunch shortening)

→ introducing a third HC with negative detuning as a counter force to the instability



Maximum BL (shown in solid circles)

1HC (β=1) ; BLF 4.0, ξ =0.97

2HC(β=1); BLF 2.3, ξ =0.81

2BL+1BS(β=1); BLF 3.3, ξ =0.95

As the total Rs increases, ξ threshold of unstable beam motion decreases.

The introduction of the BS cavity has a significant effect on suppressing the mode +1 instability that occurs near the FP.

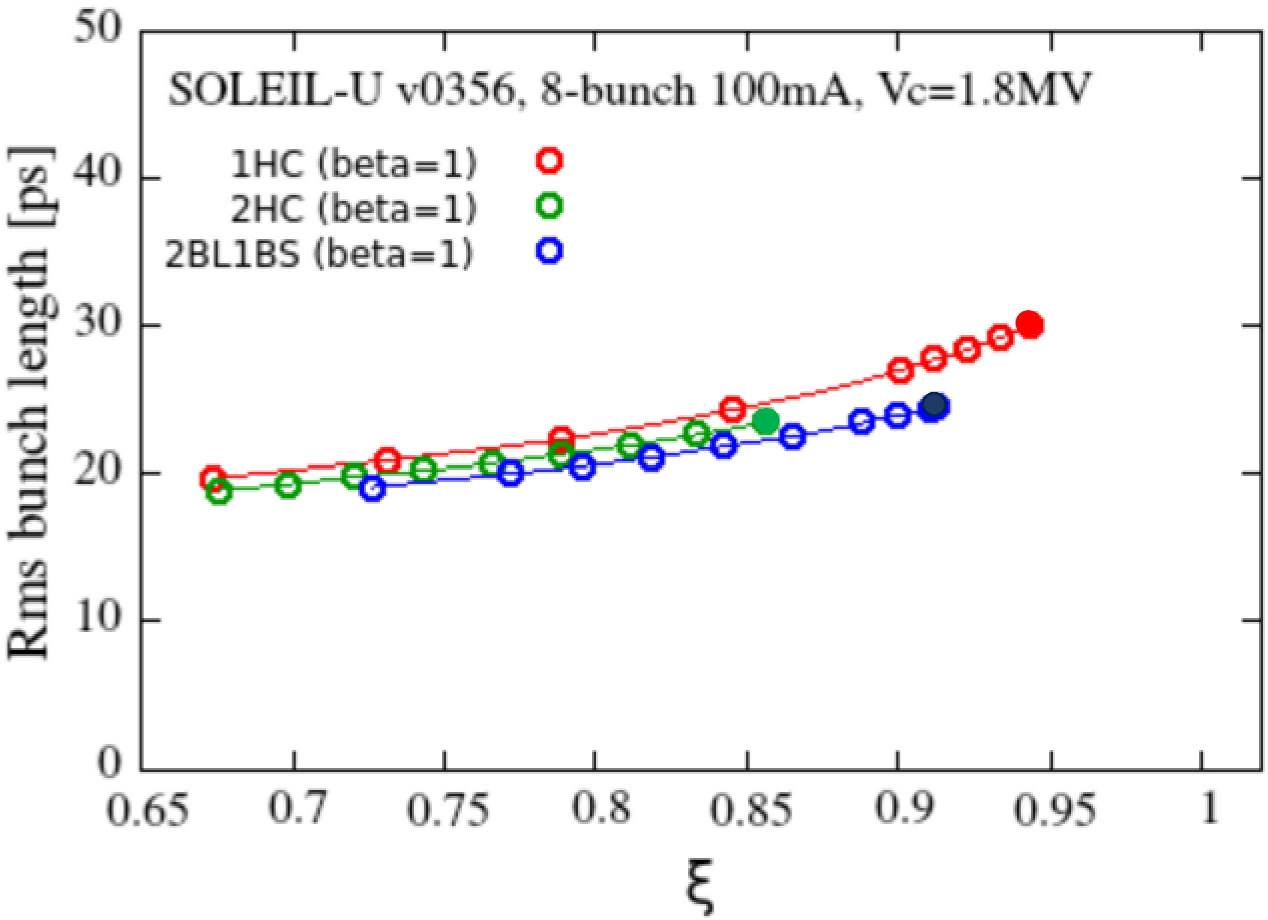
MBTRACK result for 8-bunch mode (100mA)

Comparison with other Active HC (β=1.0) setups,

1 HC,

2HC,

3HC (2BL+1BS; 2 HCs in bunch lengthening & 1 HC in bunch shortening)



Maximum BL (shown in solid circles)

1HC (β=1) ; BLF 3.5, ξ =0.94

2HC(β=1); BLF 2.8, ξ =0.86

2BL+1BS(β=1); BLF 2.9, ξ =0.91

As the total Rs increases, ξ threshold of unstable beam motion decreases.

The introduction of the BS cavity has a significant effect on suppressing the mode +1 instability that occurs near the FP.

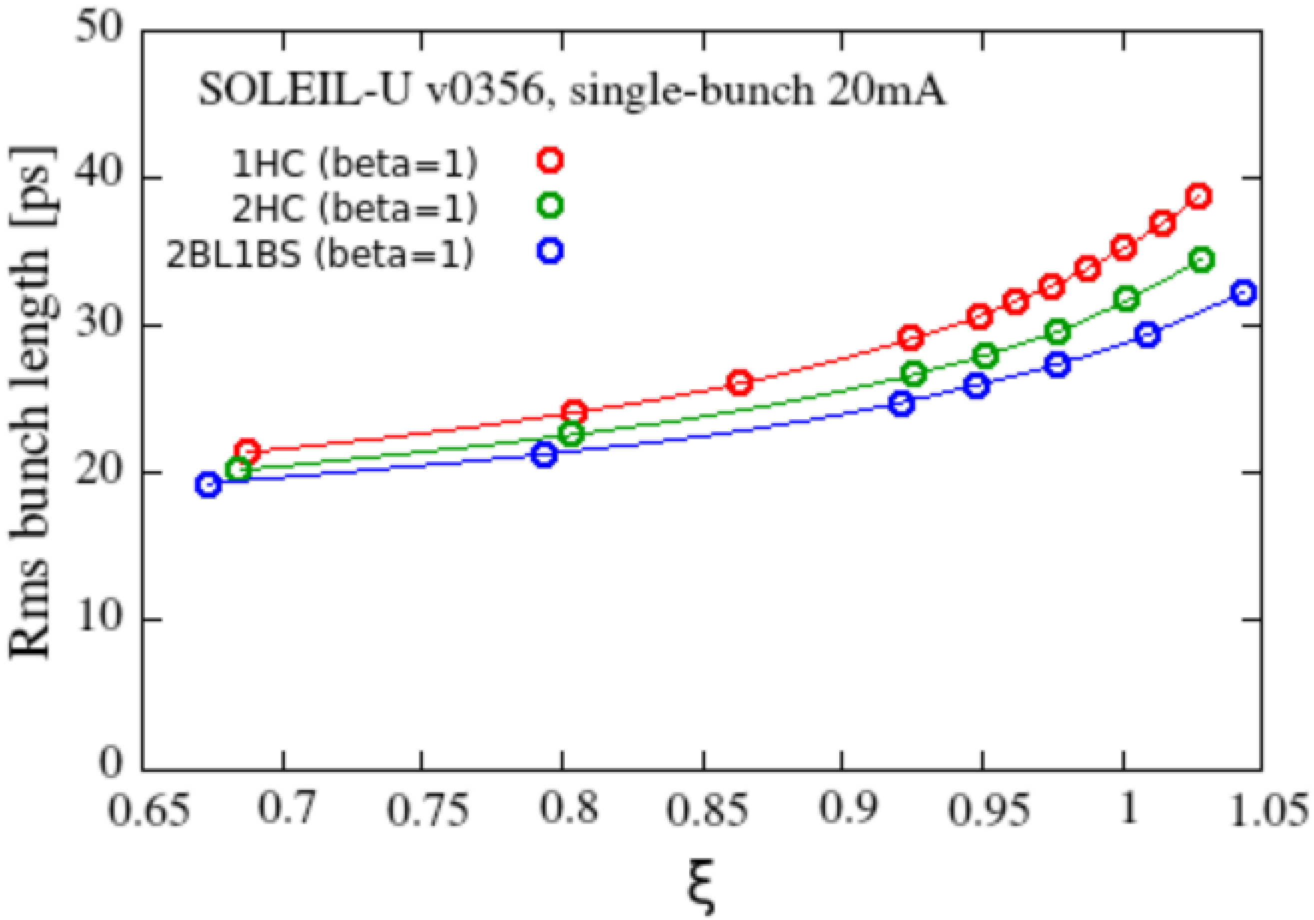
MBTRACK result for single-bunch mode (20mA)

Comparison with other Active HC (β=1.0) setups,

1 HC,

2HC,

3HC (2BL+1BS; 2 HCs in bunch lengthening & 1 HC in bunch shortening)



Maximum BL (shown in solid circles)

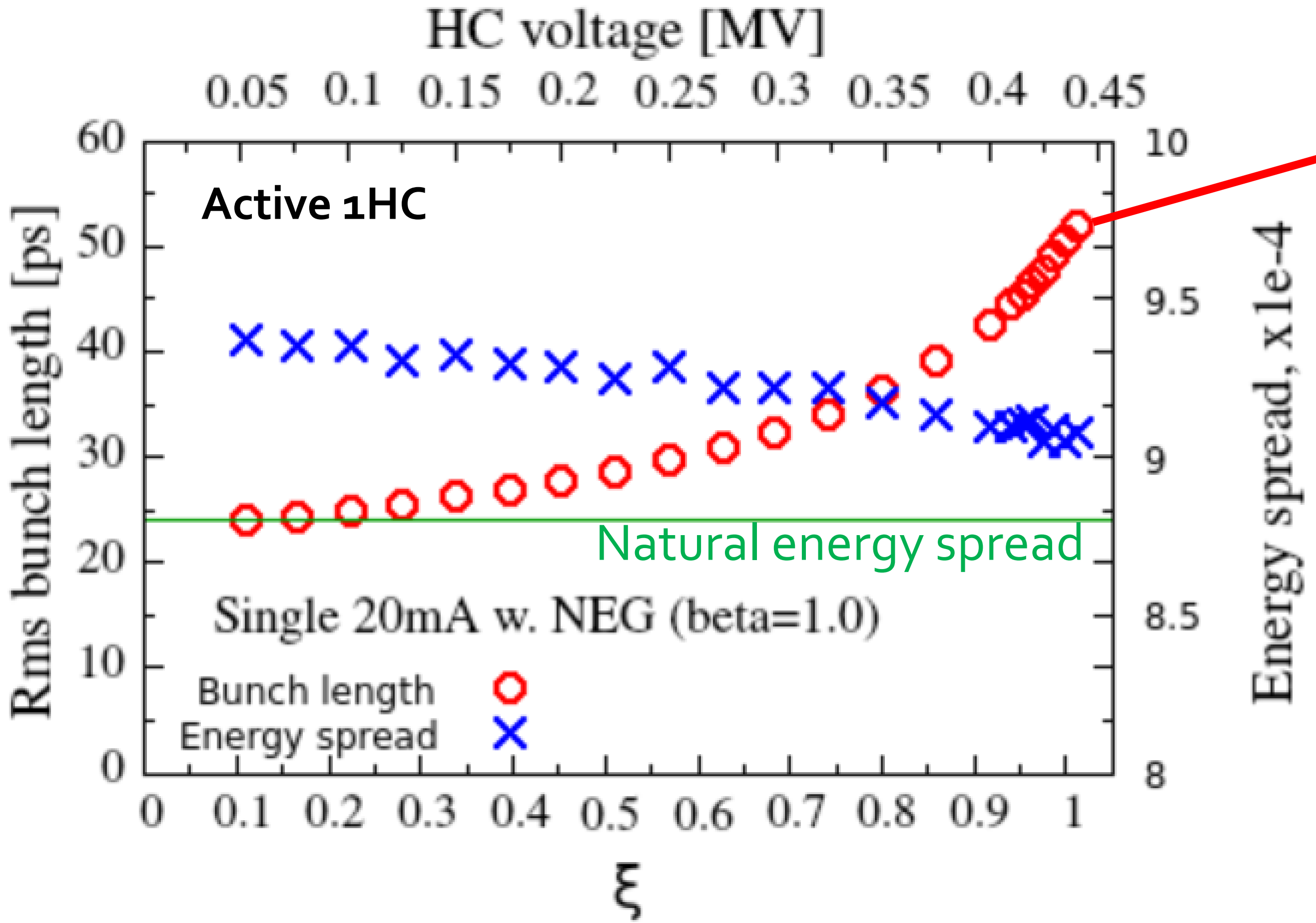
1HC (β=1) ; BLF 4.6, ξ > 1.0

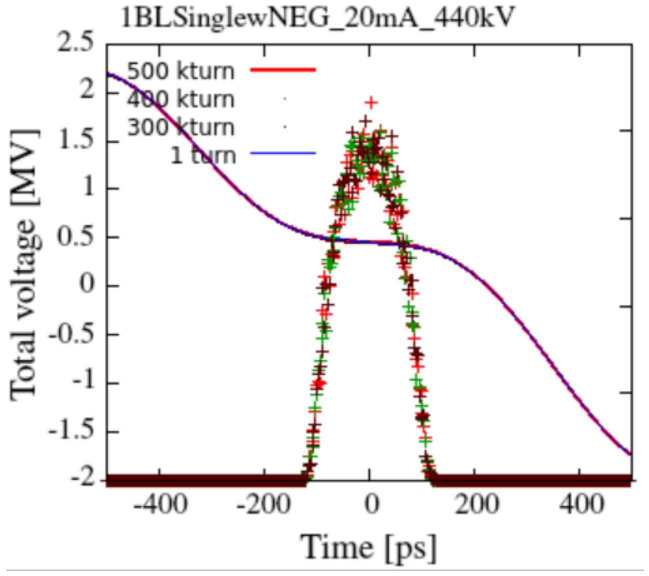
2HC(β=1); BLF 4.1, ξ > 1.0

2BL+1BS(β=1); BLF 3.8, ξ > 1.0

MBTRACK result for single-bunch mode (20mA)

Including the NEG impedance (0.077 + j 0.27 ohm/GHz/m),





- The increase of energy spread is observed with/without HC.
- As the bunch length increases (HC voltage increases), energy spread becomes closer to the natural value.
- FP (ξ >= 1.0) and the bunch length 52 ps is achieved without coupled-bunch instabilities.

Summary

HC setup	Bunch length	BLF
Multi bunch 500 mA		
one HC	33.6 ps	4.0
two HCs	19.6 ps	2.3
2BL & 1BS HCs	28.4 ps	3.3
Single bunch 20 mA		
one HC	38.8 ps	4.6
two HCs	34.5 ps	4.1
2BL & 1BS HCs	32.3 ps	3.8
8-bunch 100 mA		
one HC	30.0 ps	3.5
two HCs	23.4 ps	2.8
2BL & 1BS HCs	24.5 ps	2.9

BL factor > 3.5 can be achieved with one active NC HC for all assumed operation mode at SOLEIL-U.

The result in three (2BL & 1BS) HCs case is better than that in two HCs case except for single bunch 20 mA, although the total impedance of the former case is larger.

It is considered that introducing another HC with opposite detuning can reduces the effective shunt impedance that causes instability and prevents the stable bunch lengthening.

Summary

- A feasibility of the active HC system is numerically investigated assuming the SOLEIL-U ring with EU-type main cavity and 2-cell ESRF 4^{th} harmonic cavity.
- Enough bunch length (> a factor of 3.5) can be obtained by installing 1 ESRF HC for all assumed operation mode.

- Introducing another HC with opposite detuning can reduces the effective shunt impedance that causes instability and prevents the stable bunch lengthening. [2BL+1BS vs 2HC]

- The impact due to the TBL should be investigated if empty buckets are

introduced in the bunch train to avoid ion trapping.

- We continue to investigate the impact of the recently developed rf techniques such as mode damper, direct rf feedback and feedforward TBL compensation.