BBU simulation for KEK 3-GeV ERL

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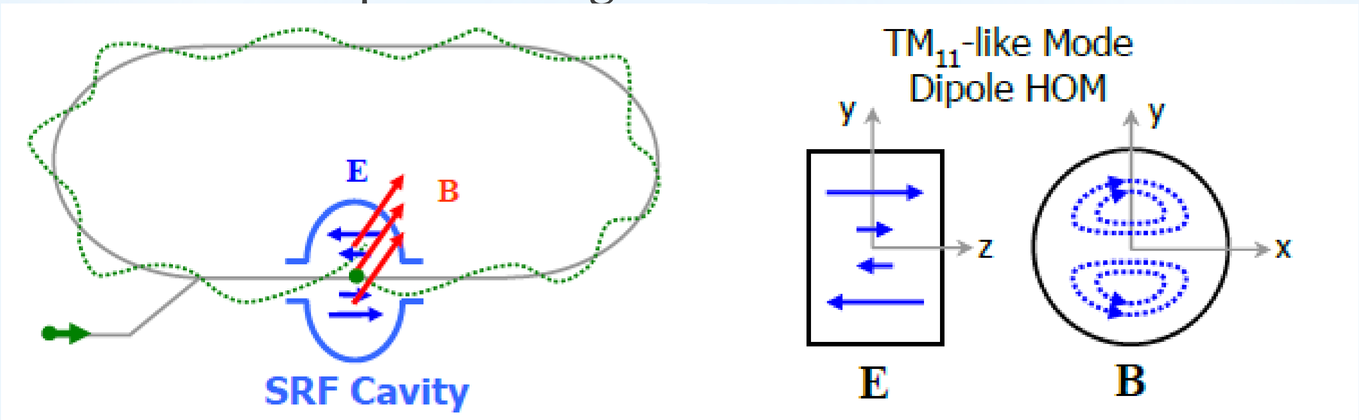
Outline

* Multi-pass, multi-bunch beam breakup
* Threshold current simulation
* Frequency randomization and quality factor randomization
* Arrival time scan
* Summary

Multipass, multibunch beam breakup

* Describes a positive feedback process between beams and HOMs in RF cavities at the second pass through the linac.



Courtesy of Chris Tennant

* A 2-D, single cavity, single HOM formula of BBU threshold current(E. Pozdyev, PRST-AB 8 074401(2005))

$$I_{th} = -\frac{2pc}{e\left(\frac{\omega}{c}\right)\left(\frac{R}{Q}\right)Q_{ext}T_{12}^{*}\sin\omega T_r}$$

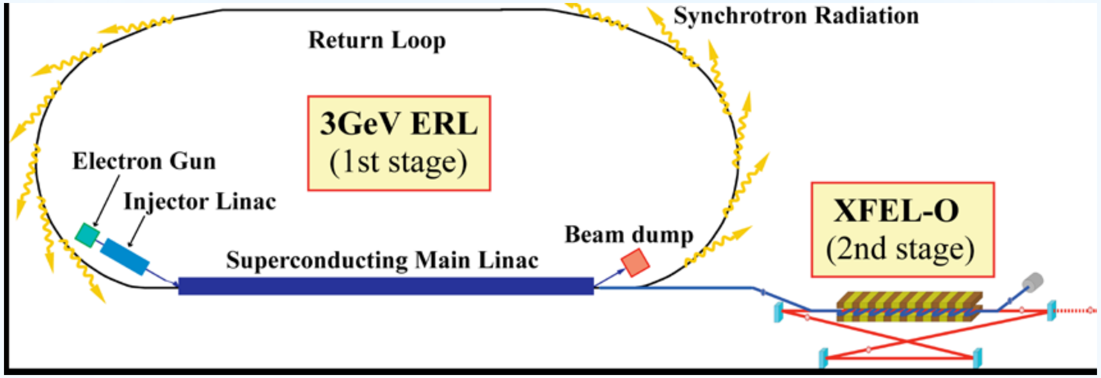
$$T_{12}^{*} = T_{12}\cos^2\theta + (T_{14} + T_{23})\sin\theta\cos\theta + T_{34}\sin^2\theta$$

* The multipass, multibunch BBU instability is mainly correlated with the momentum of beam, HOMs parameters and transport lattice parameters.
* Note: The applicability of this formula is limited.

This work

Mission

* Study the BBU instability of KEK 3-GeV ERL. Calculate the threshold current



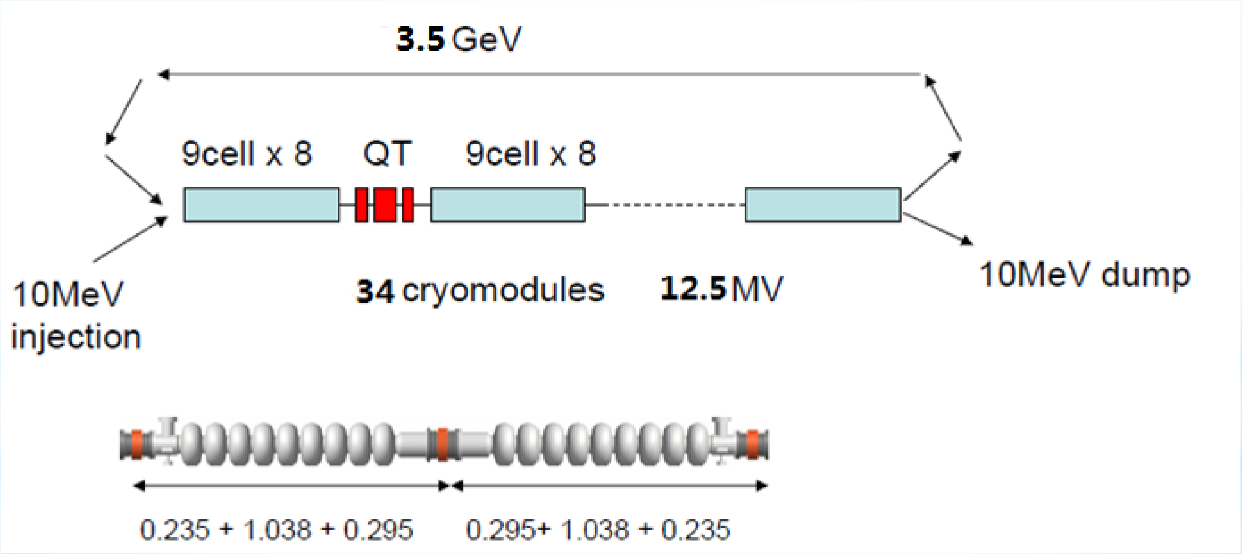
N. Nakamura, Proceedings of IPAC2012

Methods

* *bi* code (I. Bazarov, Cornell University)
* betatron phase advance scan
* frequency randomization
* quality factor randomization
* arrival time variation
* some comparison (5GeV ERL, 6GeV ERL, TESLA-type cavity)

Parameters

* Injection beam energy 10 MeV, full energy 3.5 GeV,
* The lattice of linac was provided by M. Shimada.
* 34 cryomodules, 8 KEK-ERL 9-cell cavities in each cryomodule. Cavity voltage 12.5MV. Triplets between two cryomodules. Total length of the linac is 628.93m.



Modified from the picture in R. Hajima, R. Nagai, Proceedings of ERL07

Parameters

* HOM parameters (R. Hajima, R. Nagai, Proceedings of ERL07)

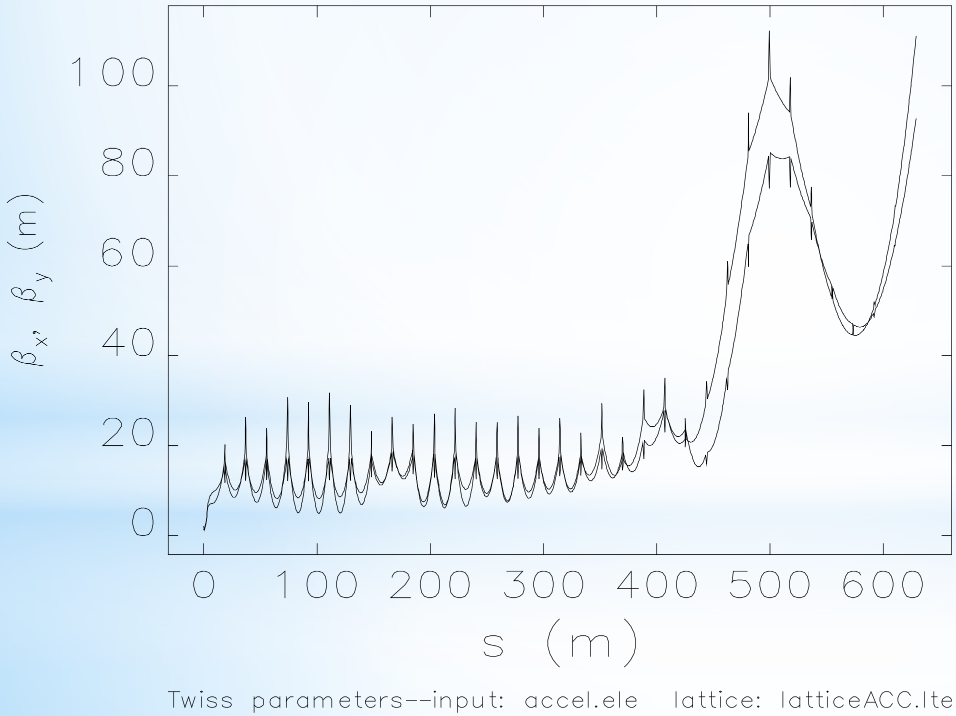
$R/Q(\Omega)$	Q_{ext}	$freq.$ (GHz)	$(R/Q)Q*f$	$(R/Q)Q/f$
54.6800	1.1010E+03	1.8350	1.1047E+05	3.2808E+04
48.3200	1.6980E+03	1.8560	1.5228E+05	4.4207E+04
26.2600	1.6890E+03	2.4280	1.0769E+05	1.8267E+04
0.8210	2.9990E+04	3.0020	7.3915E+04	8.2018E+03
4.5420	1.1410E+04	4.0110	2.0787E+05	1.2921E+04
0.0219	6.0680E+05	4.3300	5.7436E+04	3.0634E+03

Parameters

The lattice of return loop is flexible. We mainly concern about the arrival time(i.e. the length of return loop) and the T_{12} of transport matrix.

$T_{12} = \sqrt{\frac{\beta\beta_0}{pp_0}} \sin\Delta\psi$ (G.H. Hoffstaetter & I. Bazarov, PRST-AB 7, 054401(2004))

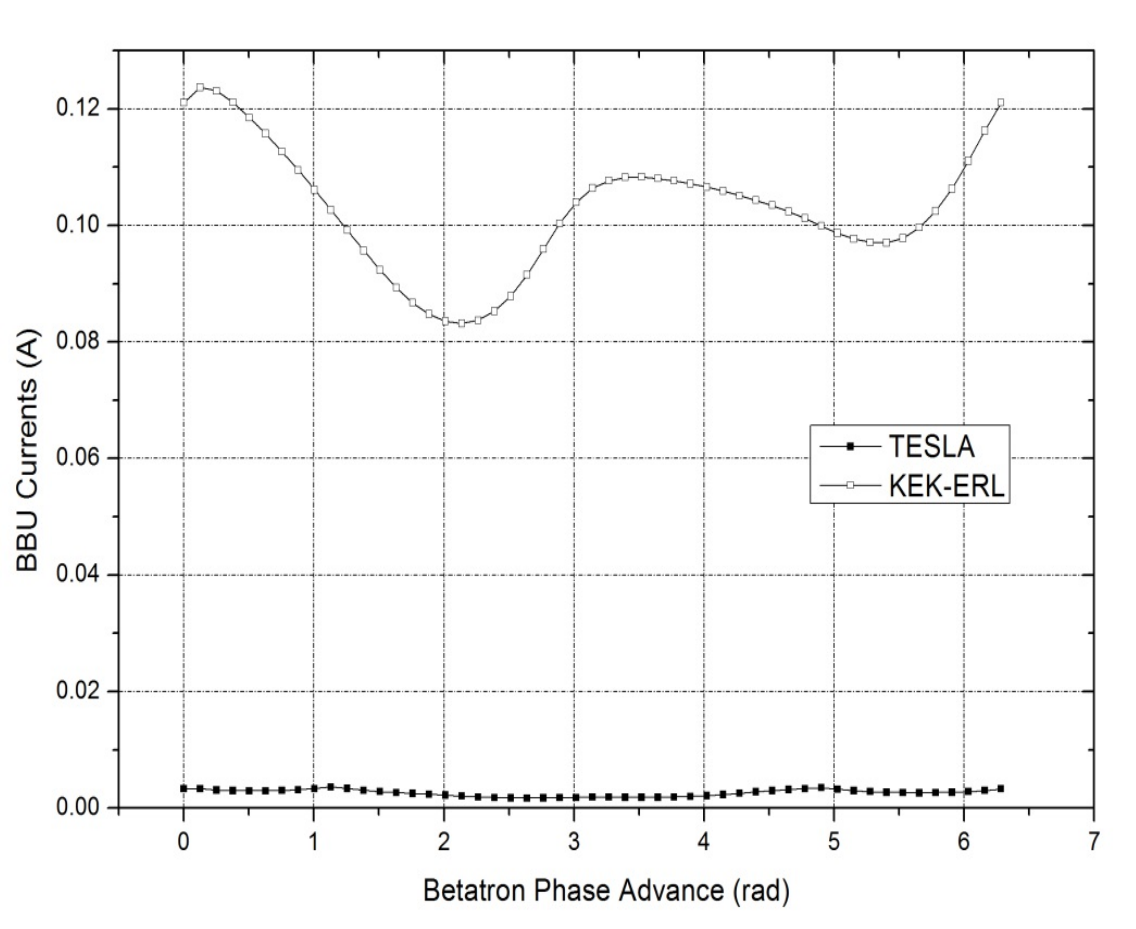
Where β_0, p_0 and $\beta, p$are the beta-function and momentum at the start and the end of return loop respectively. Twiss parameters $\beta_0 = \beta = 100m$, $\alpha_0 = -1$ and $\alpha = 1$. the length of return loop chose to be 628.92m

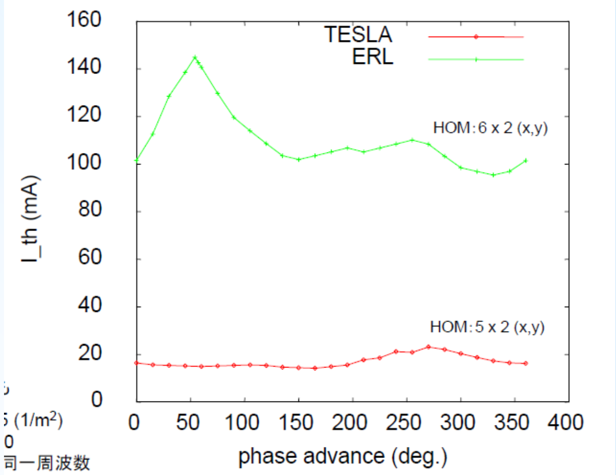


Beta-functions of the linac. Generated by elegant.
Lattice was provided by M. Shimada

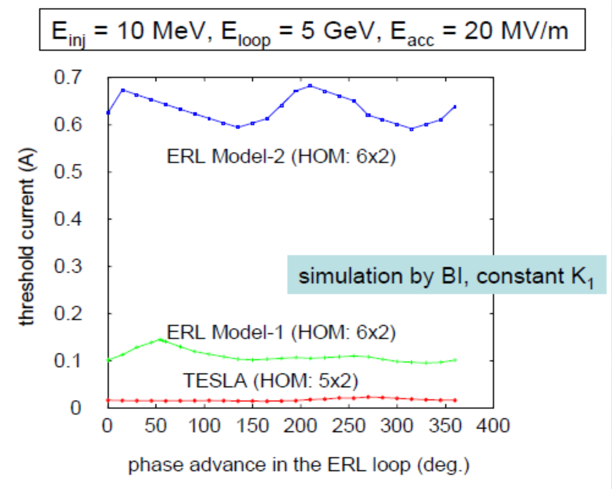
Betatron phase advance scan

*BBU currents for HOMs with no freq. randomization.



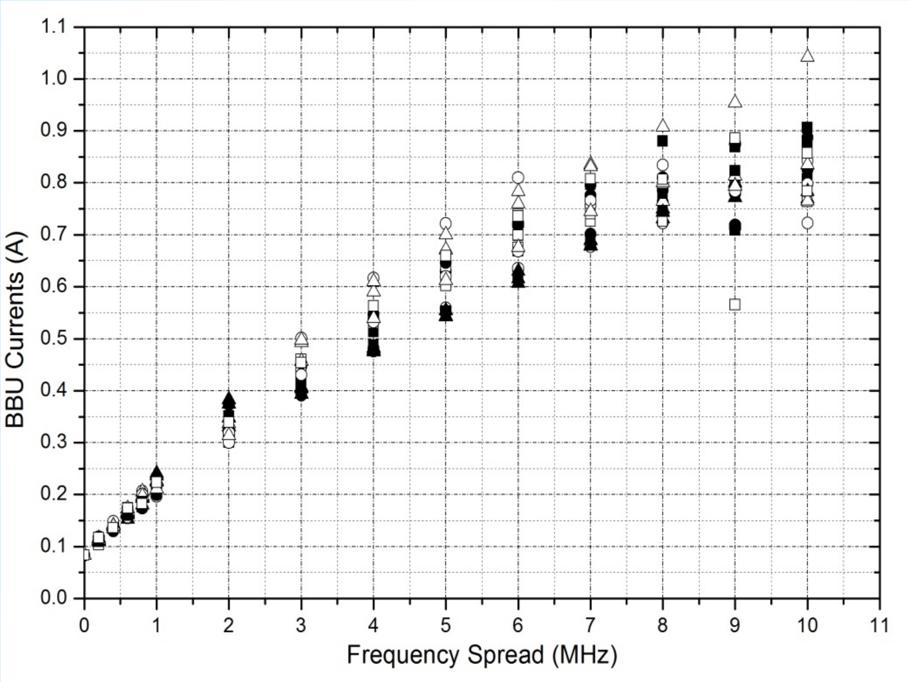


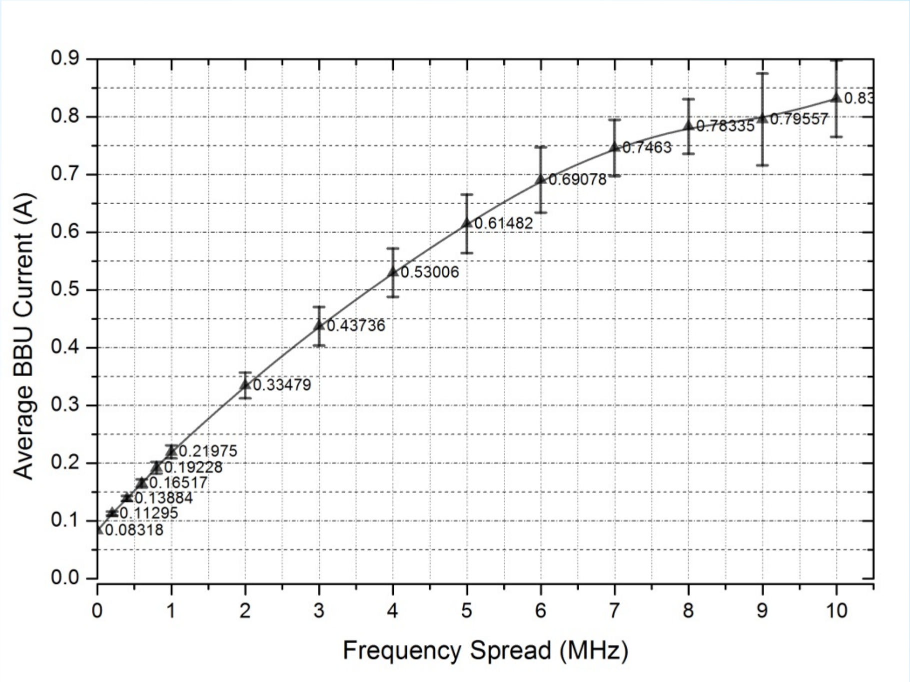
6-GeV ERL,. R. Hajima, R. Nagai,ビームダイナミクスWG(2006)



5-GeV ERL,. R. Hajima, R. Nagai, Proceedings of ERL07

Frequency randomization



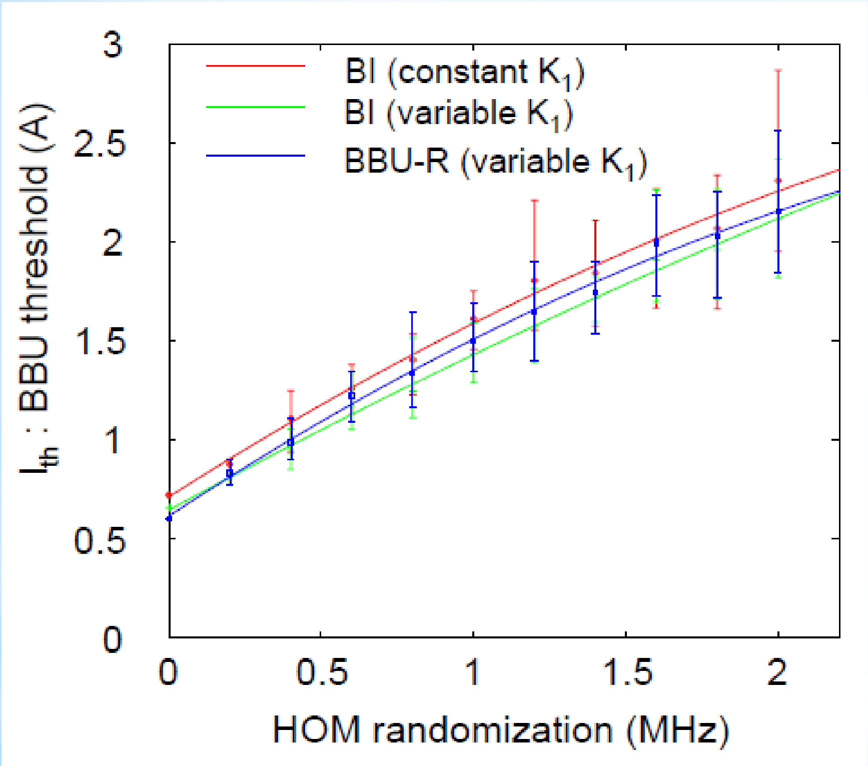


The betatron phase advance of return loop was chosen to be corresponding to the minimum value of BBU current without frequency spread, i.e. **83mA**.

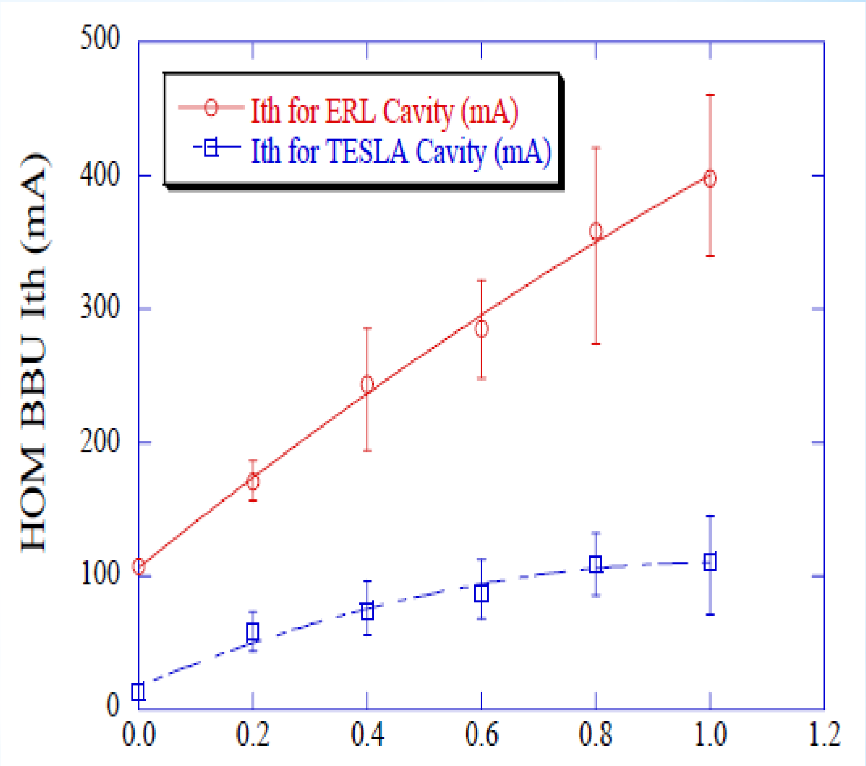
The left curve shows the BBU currents of 20 Gaussian random seeds at each value of frequency spread. The right curve shows the average BBU currents at each value of frequency spread.

Frequency randomization

* Previous works



5-GeV ERL,. R. Hajima, R. Nagai, Proceedings of ERL07



6-GeV ERL,. R. Hajima, R. Nagai, ビームダイナミクスWG(2006)

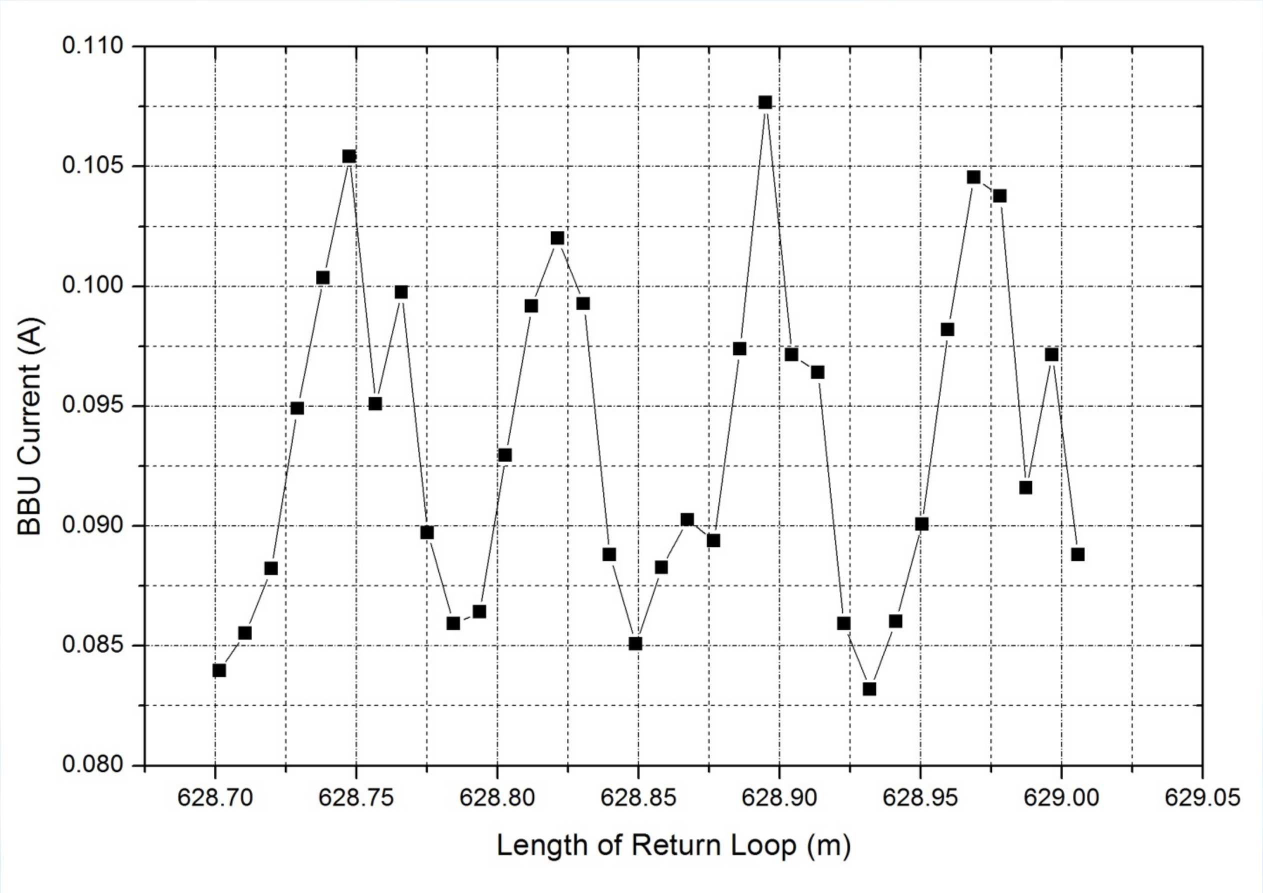
Quality factor randomization

Because of a large cavity number (272), the Quality factor randomization doesn't show significant influence to the BBU current.

The BBU current of **100** Gaussian random seeds of an order of magnitudes of the original quality factor, with a **4MHz** random seed of frequency spread, was calculated.

The BBU current with no quality factor randomization is **507 mA**. Well the maximum value of results with randomization is **517 mA**, the minimum value is **488 mA**. Average value is **506 mA** with a standard deviation of **3.1 mA**.

Arrival time variation



The interval between two peaks of the curve is 0.073798m, which is corresponding to a frequency of 4.065GHz.

Comparison

parameters	3-GeV	5-GeV	6-GeV
Injection energy	10MeV	10MeV	10MeV
Full energy	3.5GeV	5GeV	6GeV
cryomodule	34	31	40
Cavity voltage	12.5MV	20MV	18MV
Threshold current (0 freq. spread)	83mA	580mA	100mA

A formula of the cavity matrix (J. Rosenzweg, L. Serafini, PR B 42,2(1994))

$$T_{cav} = \begin{bmatrix} \cos\alpha - \sqrt{2}\sin\alpha & \sqrt{8}\dfrac{\gamma_i}{\gamma'}\sin\alpha \\ -\dfrac{3\gamma'}{\sqrt{8}\gamma_f}\sin\alpha & \dfrac{\gamma_i}{\gamma_f}\left(\cos\alpha + \sqrt{2}\sin\alpha\right) \end{bmatrix}$$

Where $\alpha = \frac{1}{\sqrt{8}} \ln \frac{\gamma_f}{\gamma_i}$

The smaller E_{acc}, the larger T_{12}

Summary

* The threshold current of KEK 3-GeV ERL was calculated. (34 module, 10MeV injection, 12.5MV)
  - $I_{th} = 83mA$ with no HOM frequency randomization
  - $I_{th} = 530mA$ with 4MHz frequency spread

* The dominant HOM in the cavity is 4.011GHz.
* Quality factor randomization does not affect the threshold current significantly.

* Ways to improve the threshold current
  - Use higher cavity voltage, decrease the cavity number.
  - Introduce larger frequency randomization manually.
  - Optics control: length of return loop, x-y phase space coupling?

Thanks for your attention!