Recent Progress on Beam-Breakup Calculations for the Cornell X-Ray ERL

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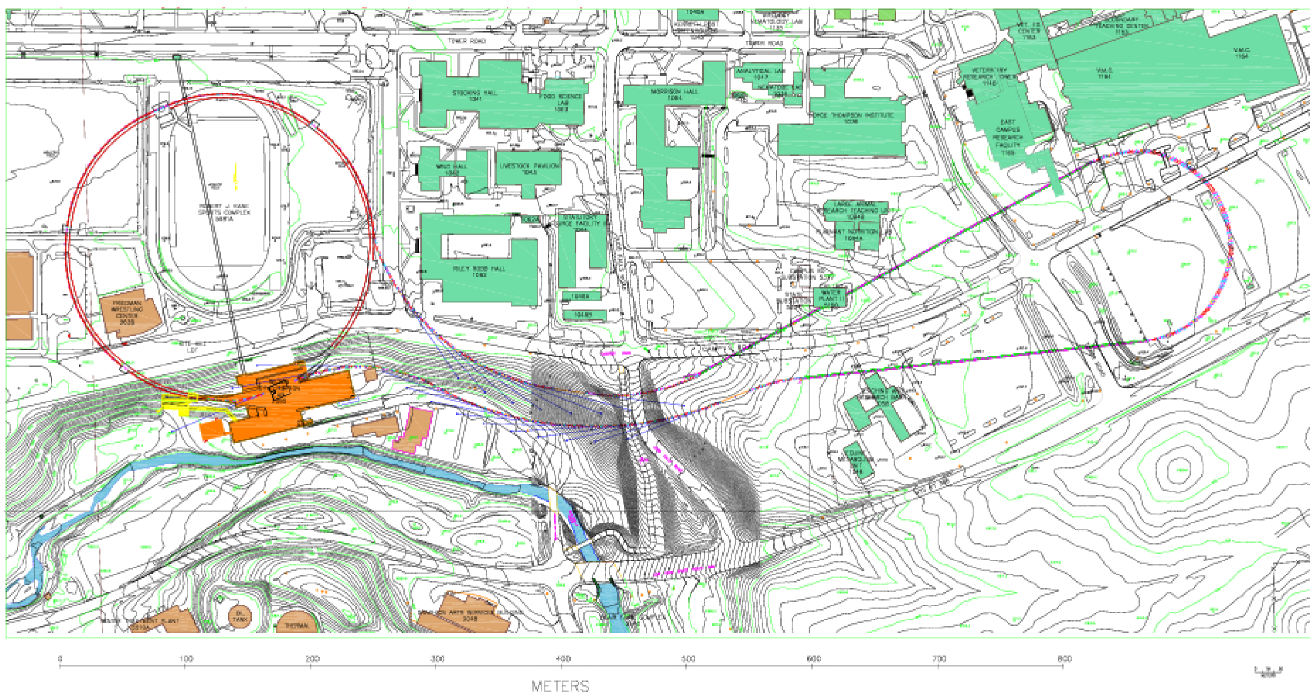


Beam-breakup (BBU)

Beam-breakup instabilities arising from the excitation of higher-order modes in the RF cavities are important contributions to the operational current limit in multi-pass linacs.

Continuous wave (all buckets filled) recirculator theory: J.J.Bisognano and R.L.Gluckstern, PAC 1987
Two-dimensional simulations: G.A.Krafft and J.J.Bisognano, PAC 1987
Extension to ERLs: G.H.Hoffstaetter and I.V.Bazarov, PRSTAB 7, 054401 (2004)
Generalization to coupled optics and polarized HOMs: G.H.Hoffstaetter, I.V.Bazarov and C.Song, PRSTAB10, 044401 (2007)
Detailed numerical analysis of threshold current tracking calculations, C.Song and G.H.Hoffstaetter, Cornell-ERL-06-1

Detailed solutions for the instability current threshold can be accurately approximated by simple formulae for the case of a single HOM in a single cavity where the HOM decay time is short or long relative to the return time.

$$\epsilon = \frac{\omega_\lambda}{2\,Q_\lambda} t_b$$

$$\kappa = t_b \frac{e}{c^2} (R/Q)_\lambda \frac{\omega_\lambda^2}{2}$$

$$I_{th} = \frac{-2}{\kappa} \frac{\epsilon}{T_{12} \sin(\omega_\lambda t_{return})} \qquad \epsilon \frac{t_{return}}{t_b} \ll 1$$

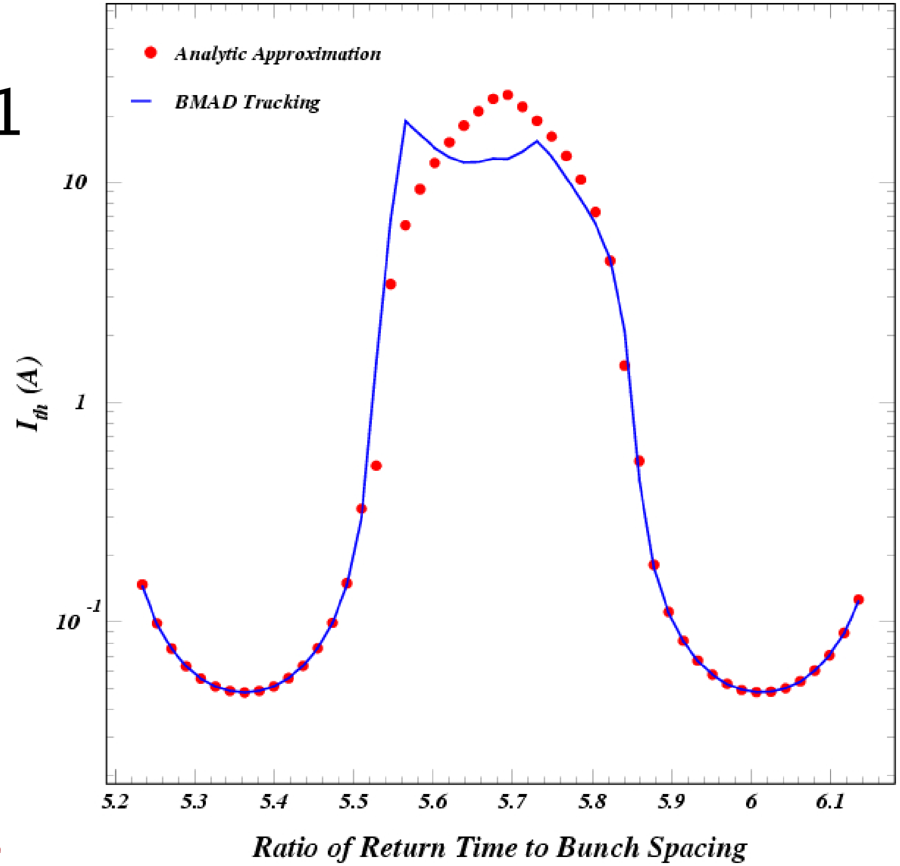
$$I_{th} = \frac{-2}{\kappa} \frac{\sqrt{\left(\epsilon^2 + \frac{1}{(t_{return}/t_b)^2} mod\left(\omega_\lambda t_{return} + \frac{\pi}{2}, 2\pi\right)^2\right)}}{T_{12}} \qquad \epsilon \frac{t_{return}}{t_b} \gg 1$$

Recently developed tracking calculations in the Cornell BMAD software library

The 2007 tracking calculations of Hoffstaetter, Bazarov and Song have been generalized, and can now be used for multi-pass ERLs.

Algorithm:
Choose an initial beam current with all RF buckets filled, track initial off-axis beam for four turns to load HOM power, then test for beam loss over a predetermined number of turns. Repeat while performing binary search for threshold current limit to chosen accuracy.

$$\epsilon \frac{t_{return}}{t_b} \ll 1$$



Apply to toy model discussed in Hoffstaetter & Ivanov, PRST-AB 7 (2004)

Analyze lattices of varying return time with identical optics and one HOM in one cavity

BBU Tracking Calculations Incorporated into General-Purpose Beam Physics Design Tool

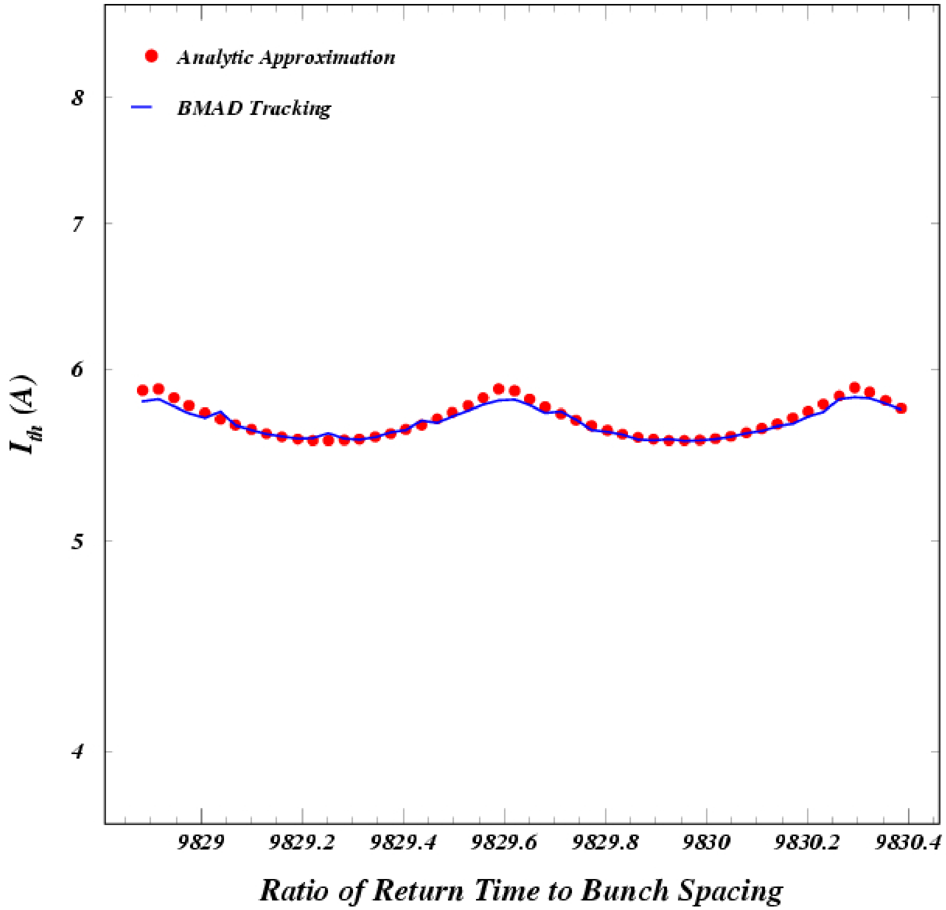
D.Sagan, The TAO Accelerator Simulation Program, PAC05, and Upgrading BMAD for Combined Beam and X-Ray Optics Design, this workshop

- Multi-pass beamline elements
- Optics optimization for multiple beams in a linac
- Tracking through wake fields
- Calculations of beam-breakup stability thresholds
- Modeling of coherent synchrotron radiation
- Modeling of intra-beam and Touschek scattering
- Spurs for extracted beams
- X-ray beamline design (under active development)

BBU Threshold with BMAD Tracking for Full Cornell ERL Optics

C.E.Mayes, Ph.D. Dissertation, Cornell University (2009)

$$\epsilon \frac{t_{return}}{t_b} \gg 1$$



HOM Parameters (TTF)

f_λ	1.86137 GHz
Q_λ	4967.8
$(R/Q)_\lambda$	5.4403 Ω / cm^2

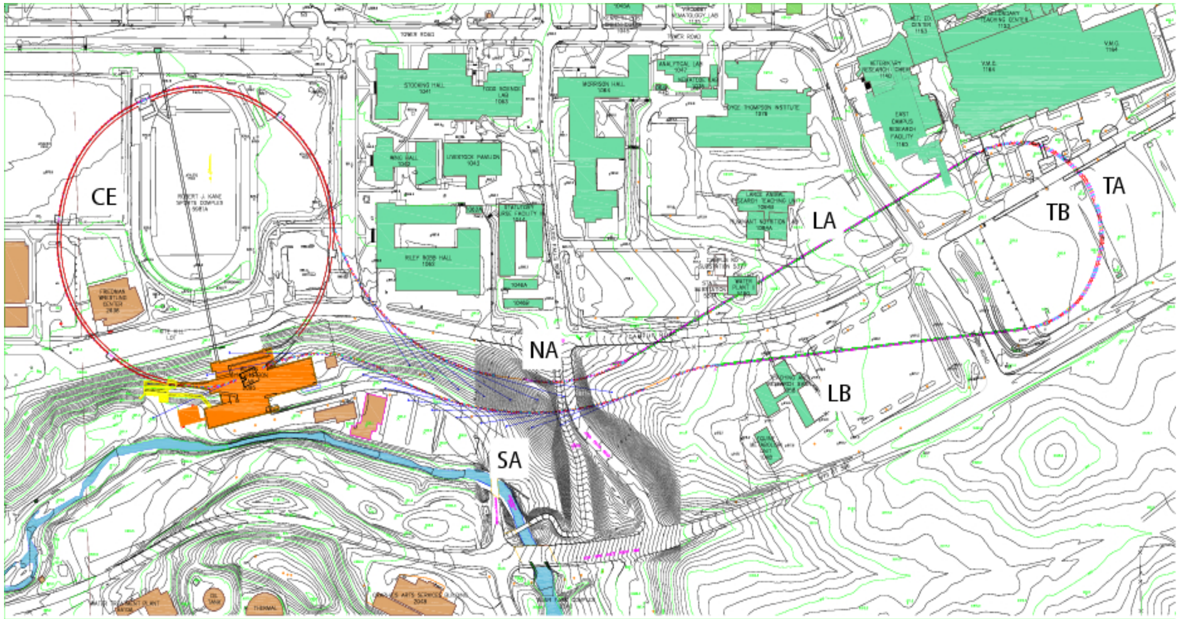
Compare analytic approximation for a single HOM in a single cavity of the full Cornell ERL optics.

BBU instability for I > 5 A.

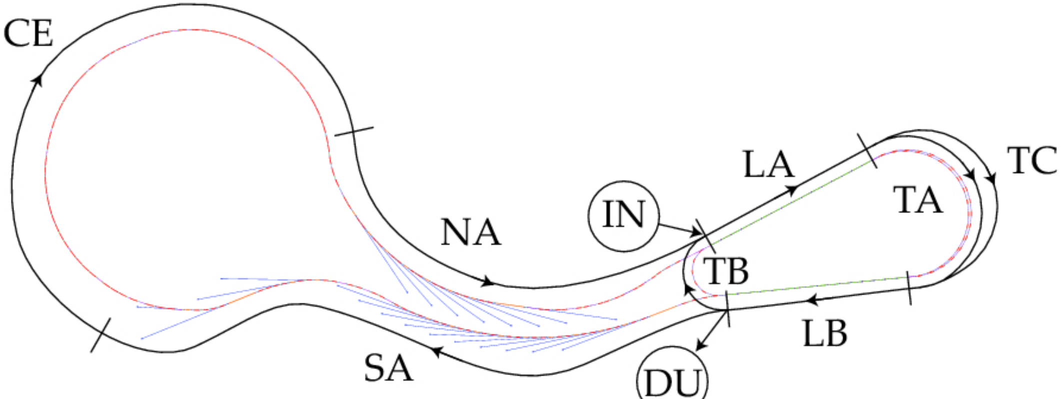
Two-Turn ERL Optics Design Under Study

G.H.Hoffstaetter, Analysis of Multi-turn ERLs for X-ray Sources, this workshop

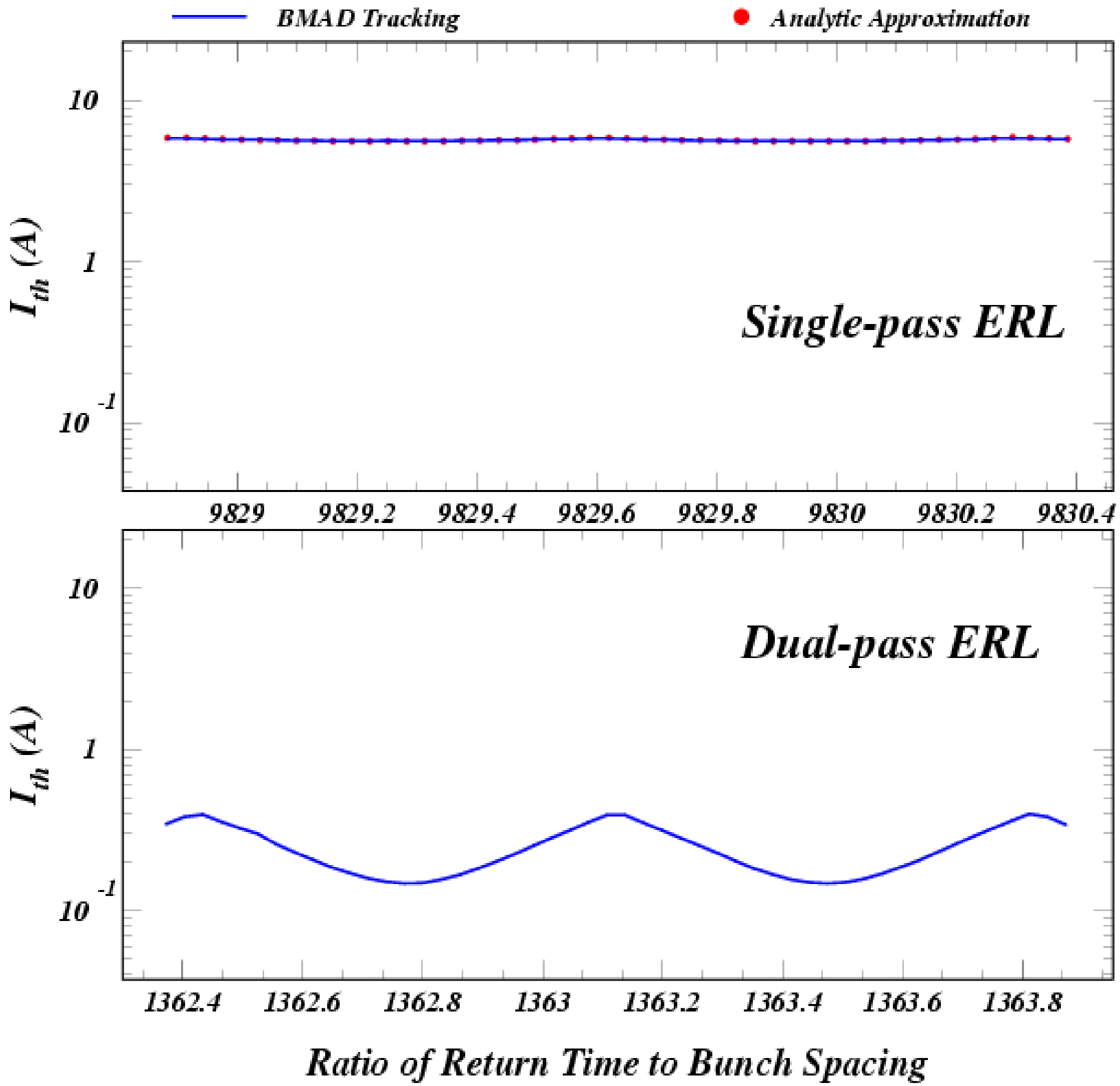
Cornell X-Ray ERL



Two-turn ERL under study



Application to Comparison of Cornell Single-Pass and Two-Pass ERL Lattices



HOM Parameters (TTF)

f_λ	1.86137 GHz
Q_λ	4967.8
$(R/Q)_\lambda$	5.4403 Ω / cm^2

For a single HOM in one cavity, the BBU instability threshold is lower by a factor of 50 for the dual-pass optics for this simple test case.

BBU Threshold Comparisons for New Cavity Design

M.Liepe, SRF System Optimization Process, this workshop

	Cavity Parameters from PRSTAB 2007 (TTF)			New 55-55 mm Design		
	f_λ [Mhz]	Q_λ	$(R/Q)_\lambda$ [Ω/cm²]	f_λ [Mhz]	Q_λ	$(R/Q)_\lambda$ [Ω/cm²]
Mode 1	1861.37	4968	5.4403	2512.896	8867	2.1880
Mode 2	1873.94	20912	8.4409	2513.556	1472	7.6777
Mode 3	1881.73	13186	2.1629	2514.671	8557	8.1083
Mode 4	2579.66	1434	15.7821	3068.192	186198	0.0632
Mode 5				3073.245	64567	0.3971
Cornell ERL		12 mA			36 mA	
Two-turn		6 mA			8 mA	
Cornell ERL (σ_f/f=0.4%)		235 mA			307 mA	
Two-turn (σ_f/f=0.4%)		53 mA			87 mA	

These new results are consistent with the detailed published results for the Cornell ERL design.

The calculations for the two-turn lattice remain under development.

Future Plans

These BBU instability threshold calculations will be an important tool for the optimization of the evolving design of the Cornell ERL X-ray source.

The lattice optics design must depend on fabrication tolerances of the superconducting RF cavities.

Mitigating effects such as the cavity-to-cavity RF frequency spread and the introduction of coupling in the transverse planes will be quantitatively studied.