LHeC ERL Design and Beam-Dynamics Issues

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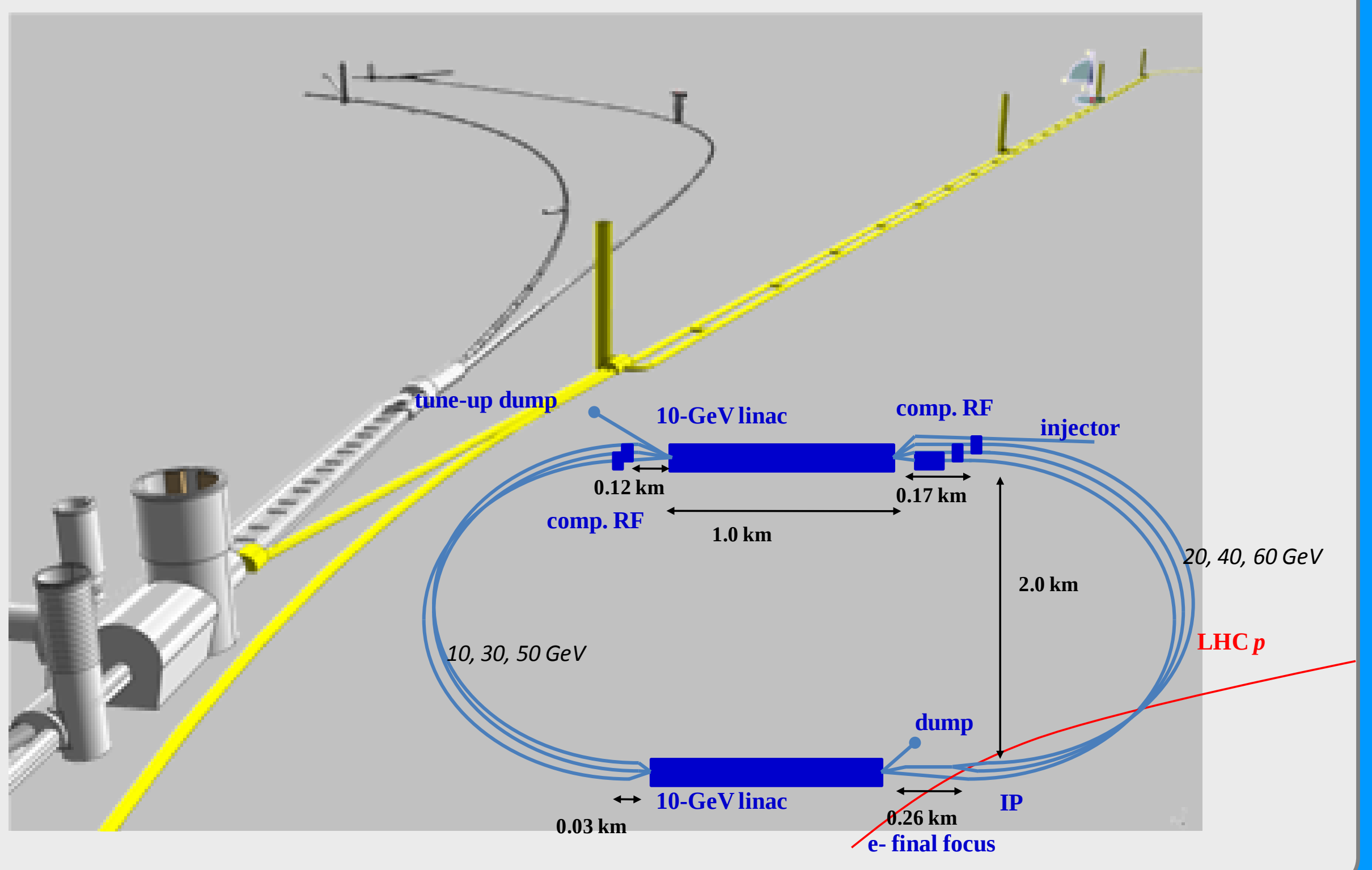
Abstract

We discuss machine and beam parameter choices for a Linac-Ring option of the Large Hadron electron Collider (LHeC) based on the LHC [1]. With the total wall-plug power limited to 100 MW and a target current of about 6 mA the desired luminosity of 10^{33} $cm^{-2}s^{-1}$ can be reached, providing one exploits unique features of the Energy Recovery Linac (ERL). We describe the overall layout of such ERL complex located on the LHC site. Multi-pass linac optics enabling operation of the proposed 3-pass Recirculating Linear Accelerator (RLA) in the Energy Recovery mode is presented. We also describe emittance preserving return arc optics architecture; including layout and optics of the arc switchyard. Furthermore, we discuss importance of collective effects such as multi-pass beam breakup instability (BBU) in ERL.

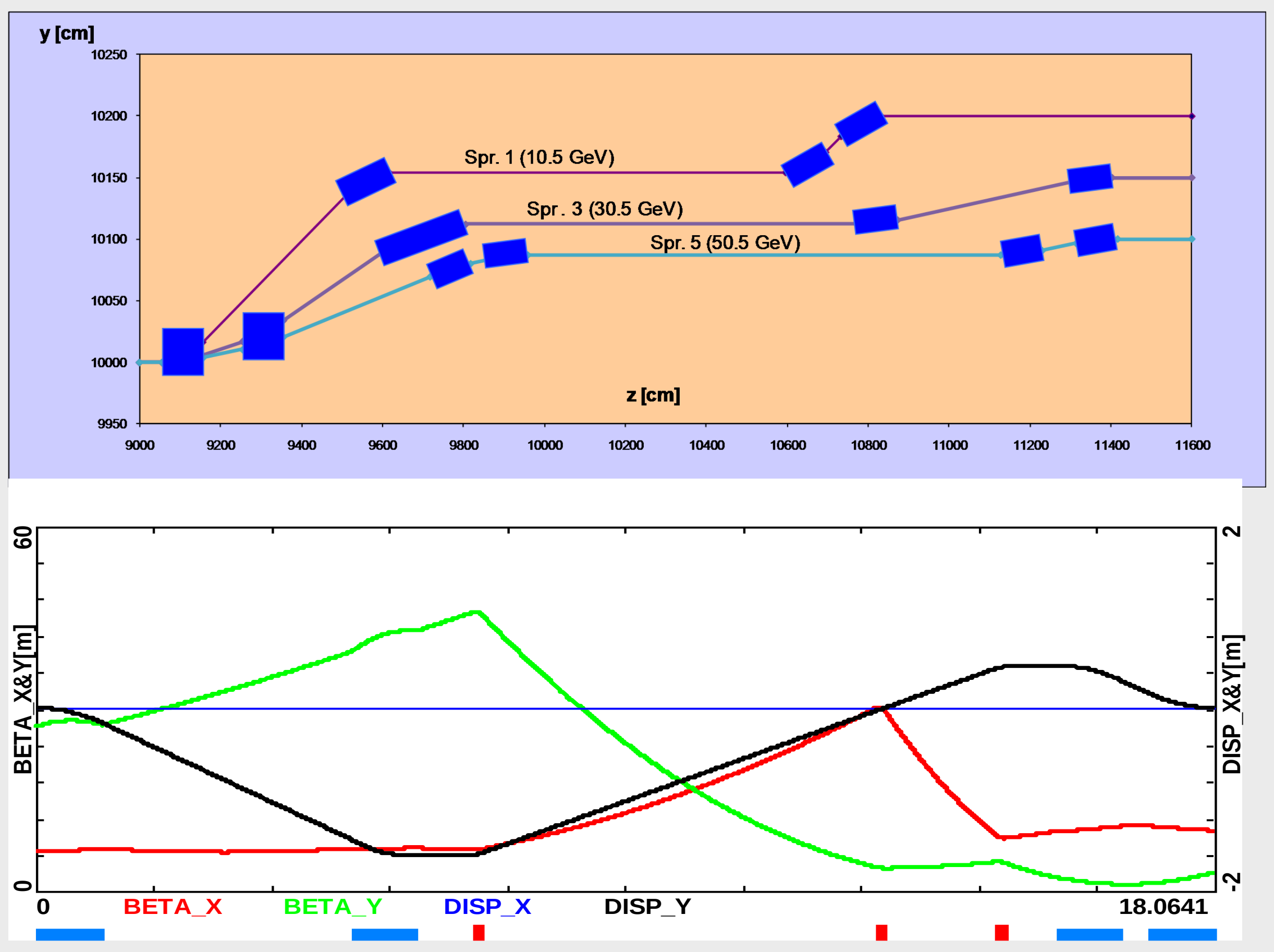
ERL Recirculator Complex



Why Energy Recovery?

ERL – a powerful alternative accelerator concept, which combines characteristics of both storage rings and linacs, and is potentially capable of accelerating tens of milliamperes of average current to several tens of GeV. In contrast to storage rings, which store the same electrons for hours, ERLs store the energy of the electrons instead. Because the time individual electrons spend in an ERL is short compared to a typical radiative emittance build-up time, equilibrium is never established. The principle of energy recovery is that the same RF, by proper choice of the time-of-arrival of the electron bunches, may be used to both accelerate and decelerate the same beam. As a result, the RF power required for acceleration becomes nearly independent of the beam current.

Switchyard



Similar to CEBAF, two-step-achromat spreaders and mirror symmetric recombiners have been implemented. The switchyard separates all three arcs into 1 meter high vertical stack . The vertical dispersion created by the first step (a pair of opposing vertical bends) is suppressed by two quadrupoles located appropriately between the two steps, which makes a very compact switchyard system (~20 meter long) based on achromatic spreader optics illustrated above.

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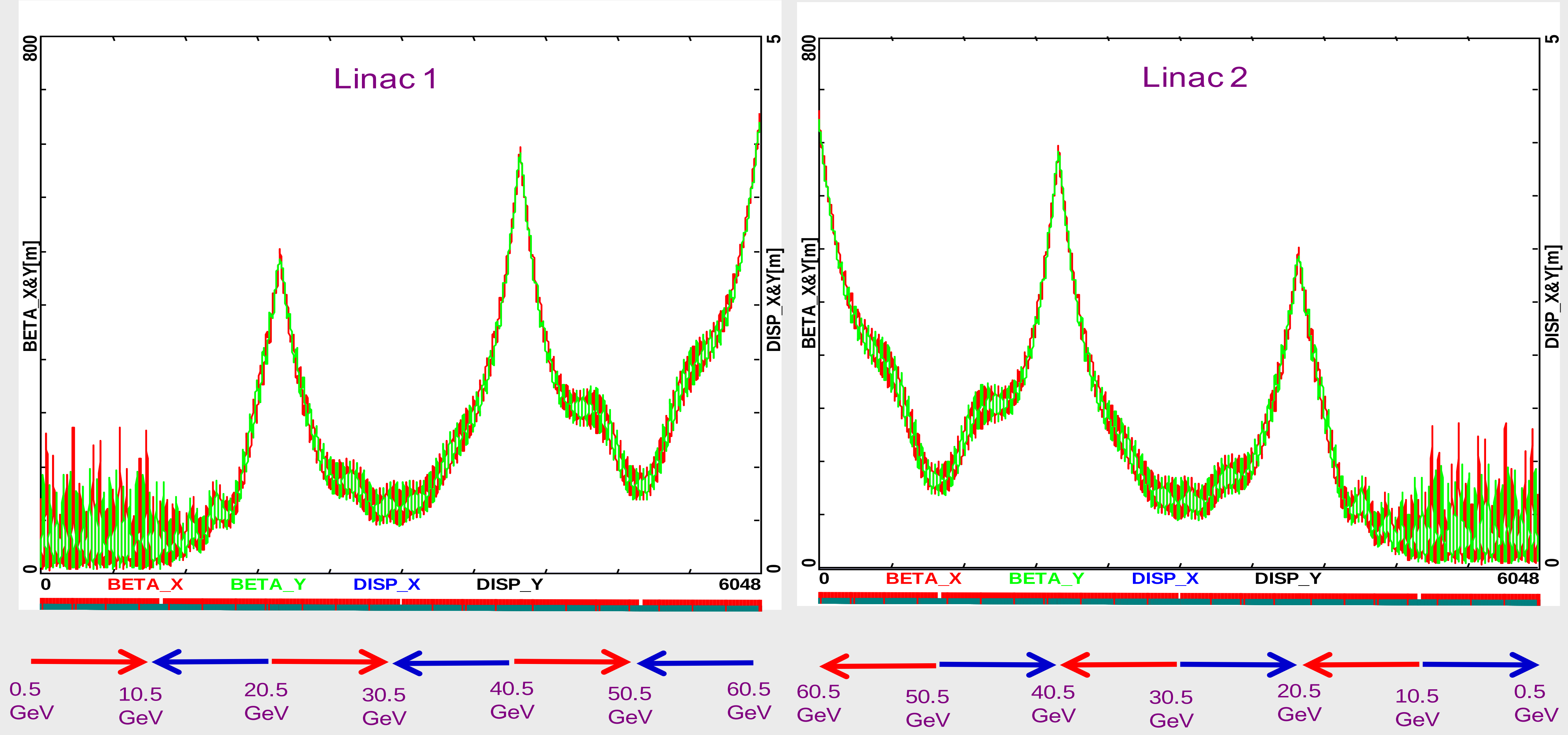
Multi-Pass Linac Optics



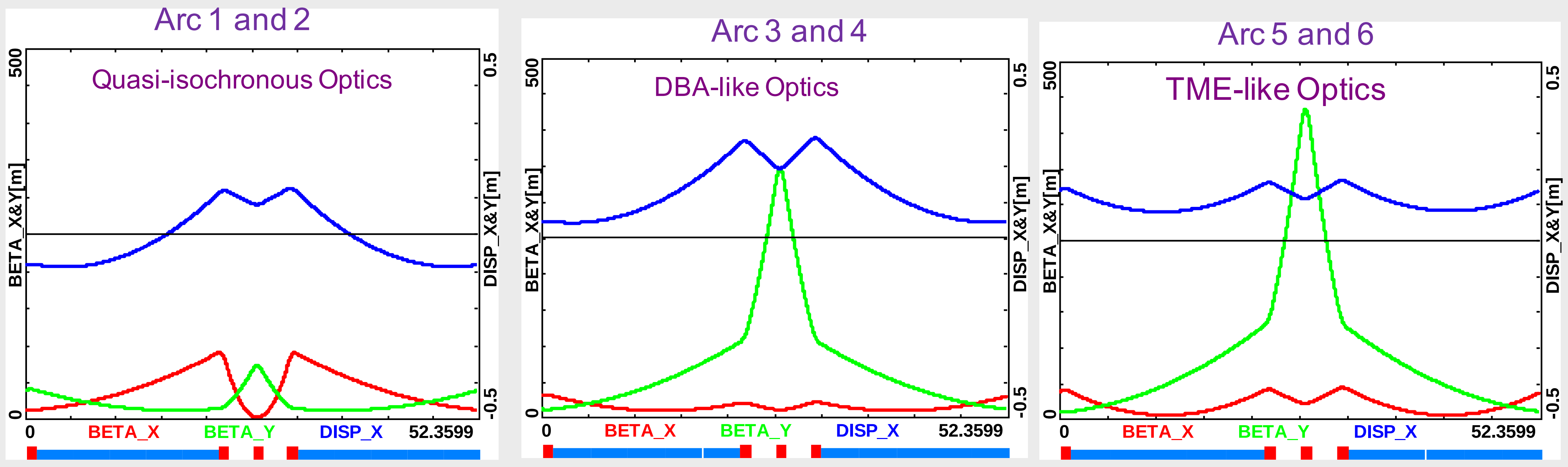
Concise representation of multi-pass ERL linac Optics for all six passes, with constraints imposed on Twiss functions by 'sharing' the same return arcs by the accelerating and decelerating passes. As a virtue of ER, Optics of Linac 1 and Linac 2 are mirror reflections of each other.

Emittance Preserving Arc Optics

Adverse effects of synchrotron radiation on electron beam phase-space, such as cumulative emittance and momentum growth due to quantum excitations needs to be addressed by proper lattice design in the arcs for a high luminosity collider that requires normalized emittance of 50 mm mrad. The normalized emittance increase is given by the following formula:

$$\Delta\varepsilon^N = \frac{2}{3} C_q\, r_0\, \gamma^6 \langle H \rangle \frac{\pi}{\rho^2} \qquad H = \gamma D^2 + 2\alpha D D' + \beta D'^2$$

$\langle H \rangle$ is the emittance dispersion averaged over the bends



$\langle H \rangle = 8.8 \times 10^{-3}\ m$ $\langle H \rangle = 2.2 \times 10^{-3}\ m$ $\langle H \rangle = 1.2 \times 10^{-3}\ m$

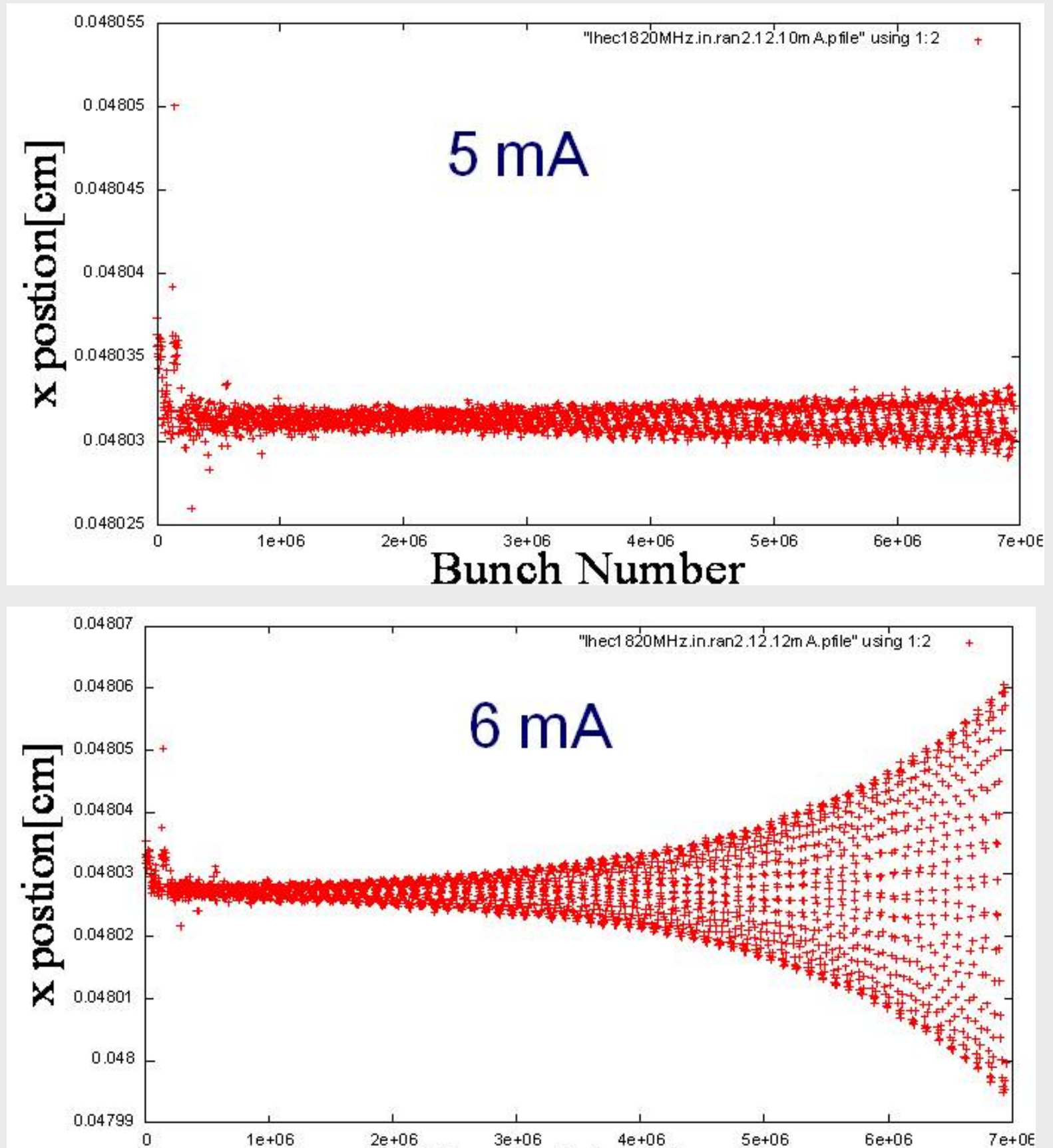
Various flavors of Flexible Momentum Compaction Optics used for different energy arcs. The highest energy arc (before the final collision), Arc 5 at 50.5 GeV, gives the net emittance increase of 4.5 μ rad. All the lower arcs, with less emittance preserving optics, illustrated above, contribute a total of about 25% of the value for Arc 5; the total emittance dilution is 5.6 μ rad. Assuming the initial injection emittance of 44 micron radian our arc-by-arc optimized FMC Optics allows us to deliver beam with emittance not exceeding 50 μ rad required for the LHeC luminosity.

Multi-pass BBU

The beam travelling along each linac experiences cumulative transverse deflection from each cavity HOMs. To gain confidence that electron current of 6.5 mA, required for the LHeC luminosity is feasible, we will summarize results of a recent numerical study using TDBBU code [3].

The 703.79MHz BNL3 5-cell SRF cavity data would serve as close reference for the HOM [4]. Our study assumed the 'worst case' interpretation of HOM's measurement for a cavity with limited HOM suppression of only one pair 120˚ HOM dampers per cavity Three offending HOMs summarized in the table below:

Frequency[MHz]	Q_l	R/Q[Ohm]
1003	1×10^6	32
1337	1×10^6	32
1820	1×10^6	32



At 5 mA the transverse beam position is increasing slightly, which indicates onset of the instability; at 6 mA one explicitly observes an exponential increase in transverse beam position - a vivid case of beam instability. The BBU threshold current can be inferred somewhere around 5mA..

References

[1] M. Klein et al., LHeC CDR, August 2011 http://cdsweb.cern.ch/record/1373421.
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[3] G. Krafft, J. Bisognano, 'Two-Dimensional Simulations of Multipass Beam Breakup' PAC 1987
[4] S. Belomestnykh et al., 'High Current SRF Cavity Design for SPL and eRHIC', PAC 2011.