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Thomas Jefferson National Accelerator Facility

LHeC

OPAC

Preliminary optics design studies for the LHeC ERL test facility

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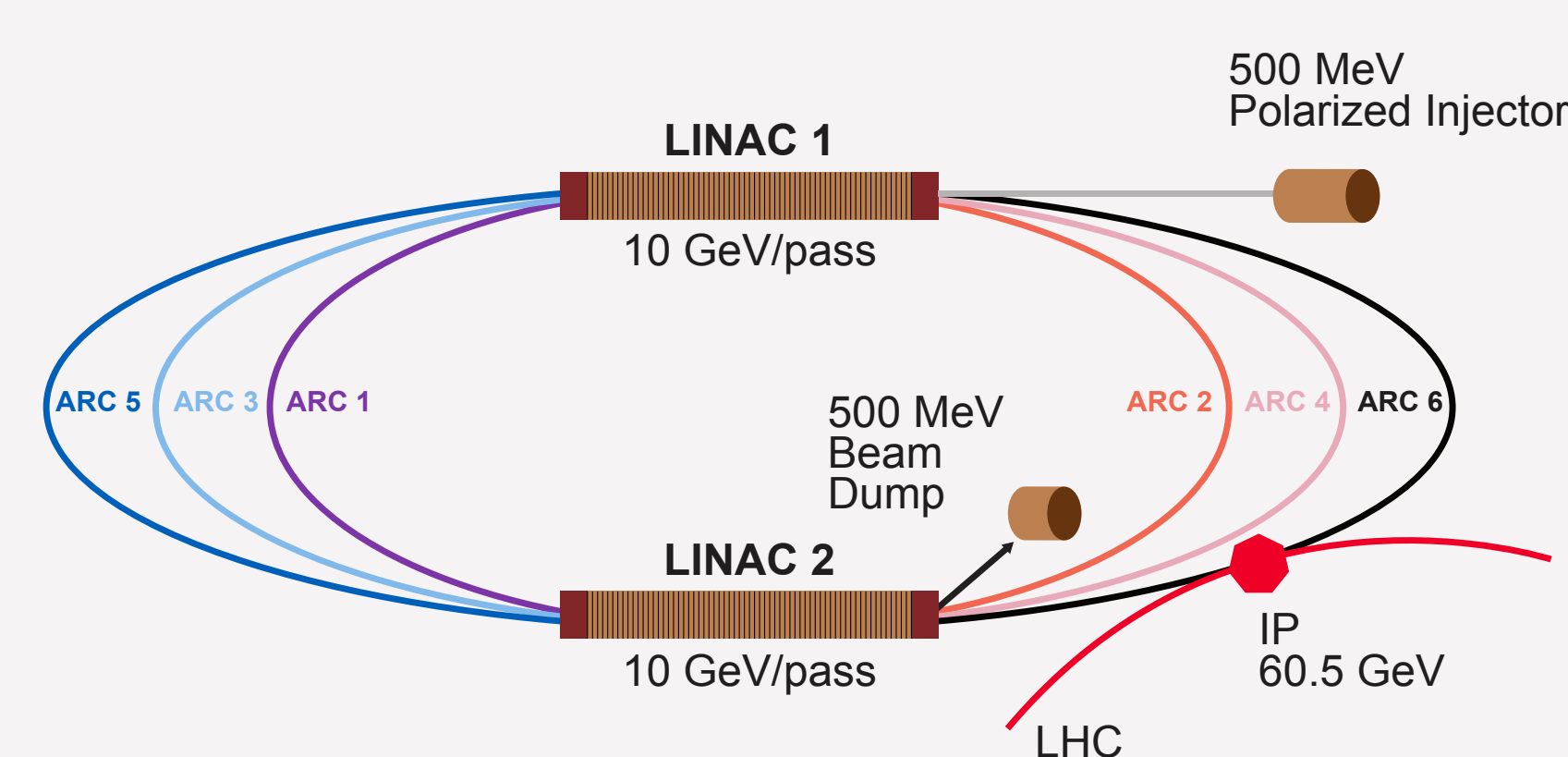
ABSTRACT

In preparation for a future Large Hadron electron Collider (LHeC) at CERN, an ERL test facility is foreseen as a test bed for SRF development, cryogenics, and advanced beam instrumentation, as well as for studies of ERL-specific beam dynamics. The CERN ERL test facility would comprise two linacs, each ultimately consisting of 4 superconducting 5-cell cavities at ≈ 802 MHz, and two return arcs on either side; a final electron energy of about 300 MeV is reached. The average beam current should be above 6 mA to explore the parameter range of the future LHeC. We present a preliminary optics layout.

LHeC Recirculator with ER

The LHeC is a proposed new machine at CERN which will collide the 7-TeV protons circulating in the Large Hadron Collider (LHC) with a high-energy lepton beam at a single collision point [1].

The LHeC ERL approach allows a comparable or even higher machine performance as compared to the LHeC Ring-Ring option.



Overall layout:

- A 0.5 GeV injector with an injection chicane;
- Two SCRF linacs (Energy gain of 10 GeV per pass);
- Six 180° arcs, and for each arc one re-accelerating station that compensates the SR emitted;
- Switching stations to combine/distribute the beams over different arcs;
- An extraction dump at 0.5 GeV.

LHeC ERL main parameters

PARAMETER	VALUE
PARTICLES PER BUNCH	$2 \cdot 10^7$
INITIAL NORM. TRANSVERSE EMITTANCE	$30 \mu\text{m}$
BUNCH LENGTH	$600 \mu\text{m}$
BEAM SIZE AT IP (rms)	$7 \mu\text{m}$
NORM. TRANSVERSE EMITTANCE AT IP	$50 \mu\text{m}$
BEAM ENERGY AT IP	60 GeV
AVERAGE CURRENT	6.4 mA
LUMINOSITY	$>10^{33} \text{cm}^{-2}\text{s}^{-1}$
TOT. WALL PLUG POWER	$<100 \text{MW}$

Optics choice:

Arc-to-Linac Synchronization \blacktriangleright Quasi-isochronous lattices

Arc optics \blacktriangleright Emittance preserving lattices \blacktriangleright Variation of Flexible momentum compaction cells (Imaginary Y_1 , Double-Bend Achromat (DBA), Theoretical Emittance Minimum (TEM))

An LHeC ERL Test Facility at CERN

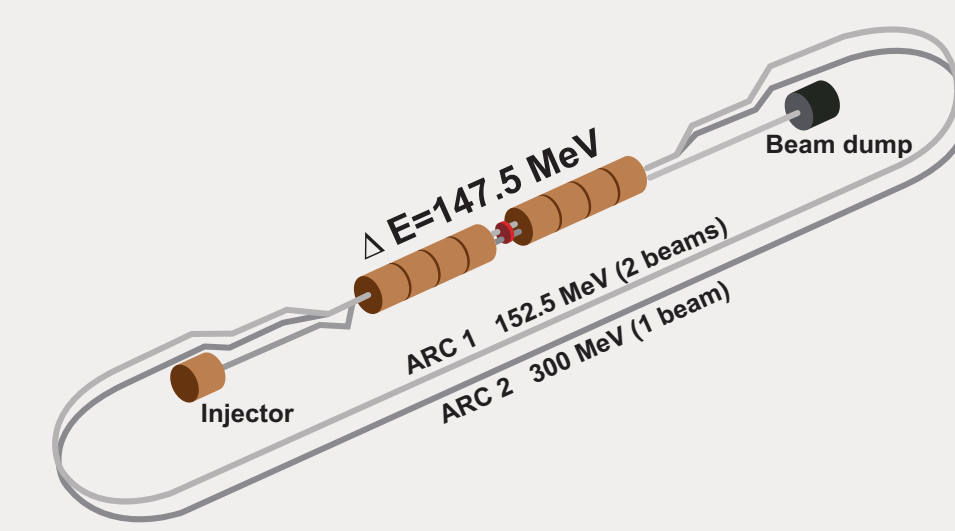
The ERL test facility foreseen at CERN aims at a 100-MeV scale energy recovery demonstration of a recirculating superconducting linear accelerator.

The main purposes are:

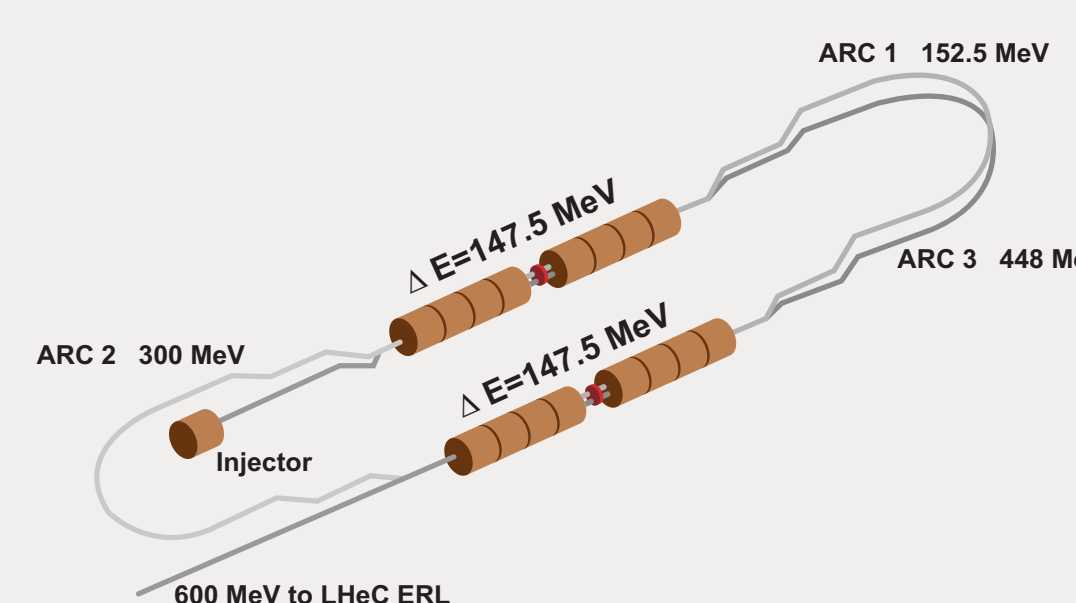
- confirming the feasibility of the LHeC ERL design by demonstrating stable intense electron beams with the intended parameters (current, bunch spacing, bunch length);
- testing novel components such as a (polarized) DC electron gun, superconducting RF cavities, cryomodule design and feedback diagnostics;
- experimental studies of the lattice dependence of stability criteria.

System architecture

1. A 5 MeV in-line injector with an injection chicane;
2. Superconducting linacs consisting of two (or one) cryomodules of in total eight 5-cell SC structures operating at 802 MHz [2];
3. Optics transport lines including spreader regions at the exit of each linac to separate and direct the beams via vertical bending, and recombiner sections to merge the beams and to match them for acceleration through the next linac;
4. Beam dump at 5 MeV.



ERL test facility providing increased operational flexibility. A two-pass recirculating linear accelerator enables operation in the energy recovery mode. The prototype architecture produces 300 MeV beams with a target current of about 6 mA. Arc 1, at 152 MeV, is shared by the accelerating and decelerating beam. Flexibility in the design will eventually permit to support additional passes to increase the final beam energy.



Subsequent upgrade to LHeC pre-accelerator. By modifying the machine backleg to include a second full cryomodule, the recirculator can deliver a higher beam energy of 600 MeV. The facility, in this new configuration, could represent, in principle, a smaller clone of the final LHeC project and could, undoubtedly, be adopted as an injector to the final 60 GeV machine.

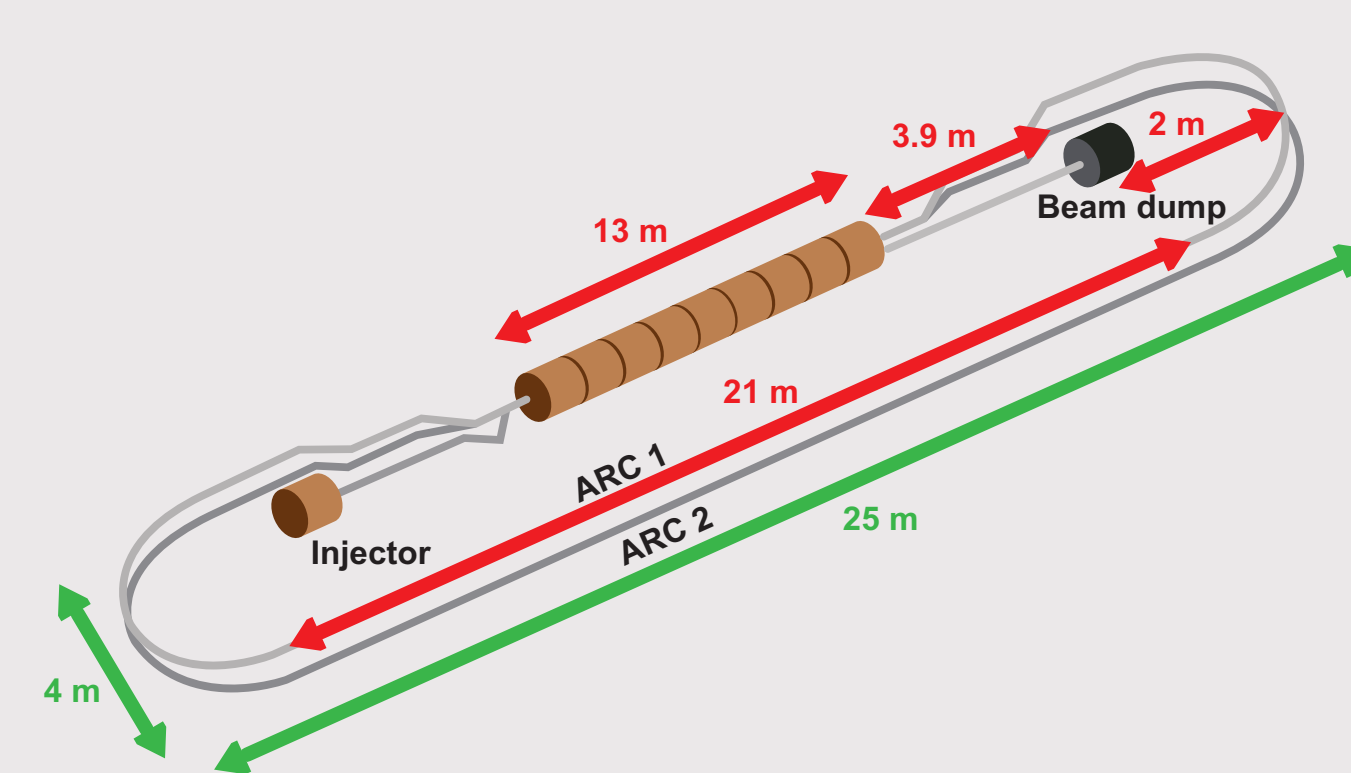
Use of separated transport lines along the whole system, except for the single linac, facilitates management of the 6-D beam phase space throughout the machine, a complete understanding of the limitation to the average current imposed by BBU, and optimization of transport system aberrations by means of the choice of betatron match and phase advance.

Relevant beam parameters for the injector

PARAMETER	VALUE
ENERGY	5 MeV
BEAM CHARGE	$>300 \text{pC}$
BUNCH LENGTH (rms)	$<3 \text{mm}$
ENERGY SPREAD (rms)	$<10 \text{keV}$
NORM. TRANSVERSE EMITTANCE (rms)	$<25 \text{mm-mrad}$

Transport optics

Appropriate recirculation optics are of fundamental concern in a multi-pass machine to preserve beam quality. The design comprises three different regions, the linac optics, the recirculation optics and the merger optics [3].

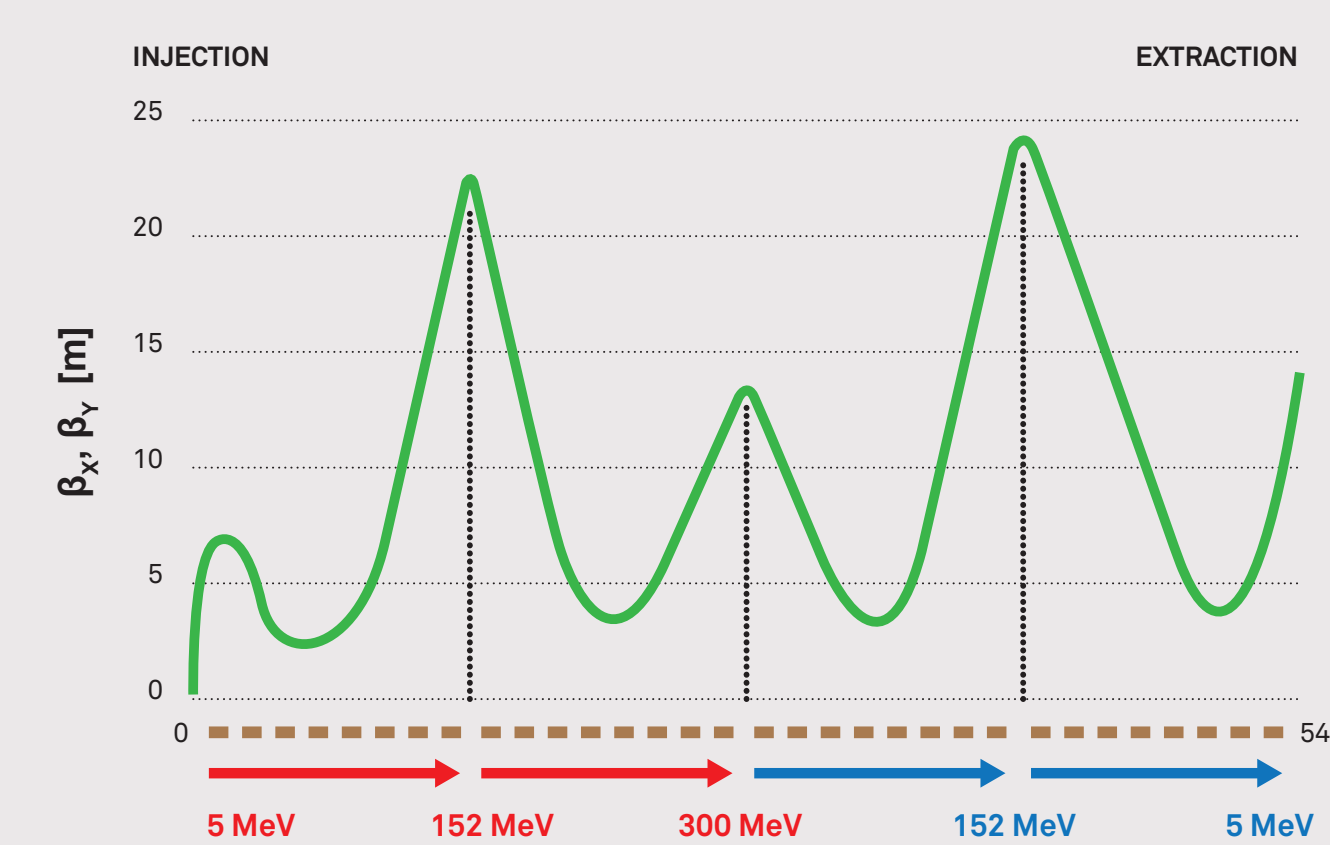


PARAMETER	VALUE
INPUT ENERGY	5 MeV
ΔE	147.5 MV
ENERGY @ FIRST PASS	152.5 MeV
ENERGY @ SECOND PASS	300 MeV
TOTAL LENGTH (ONE CRYO)*	13 m

*One Cryomodule: 8 RF cavities/5 cells per cavity

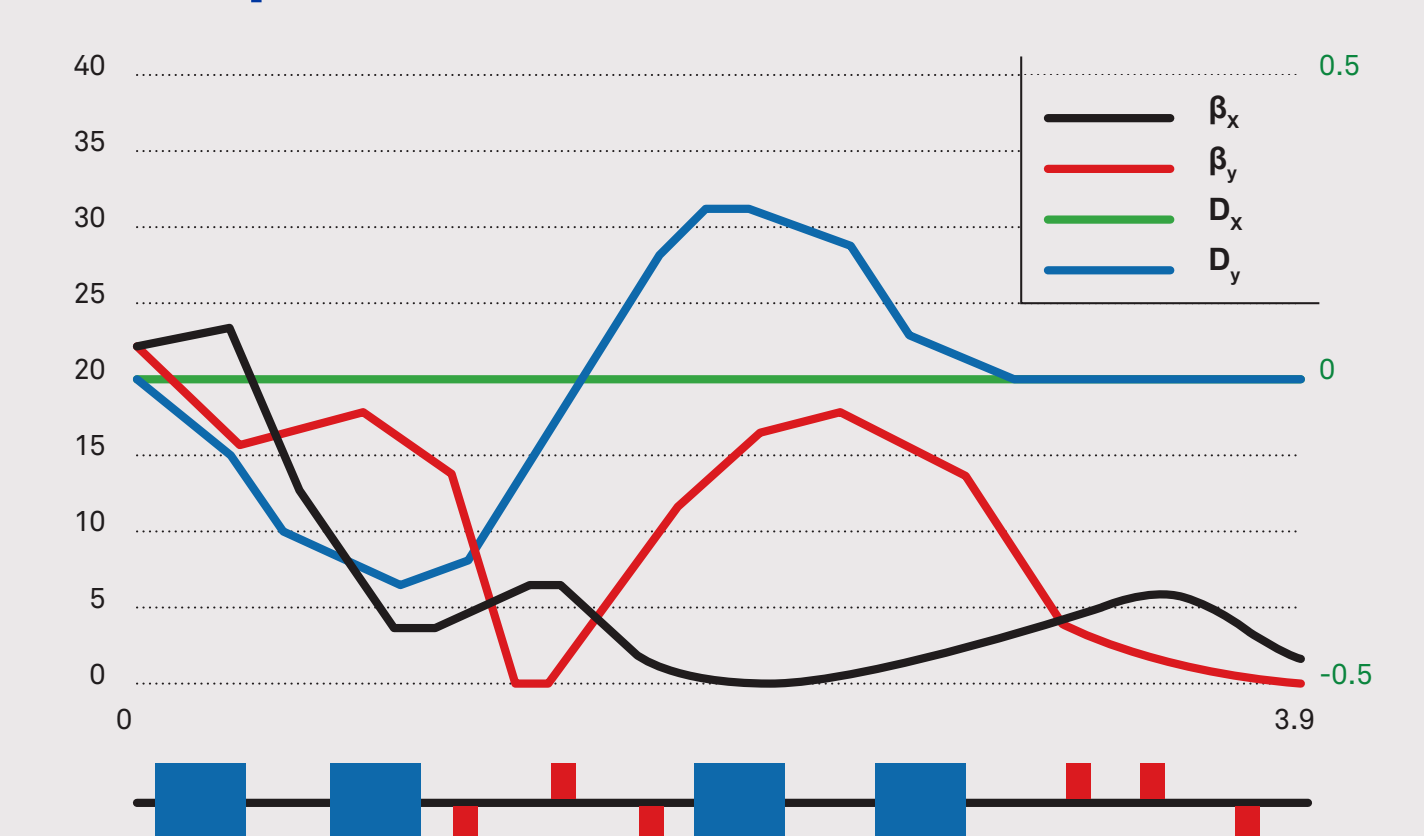
Multi-Pass Linac Optics

PARAMETER	VALUE
FREQUENCY	801.58 MHz
WAVELENGTH	37.4 cm
LCAVITY = $5\lambda/2$	93.5 cm
GRAD	20.02 MeV/m
ΔE	18.71 MV per cavity

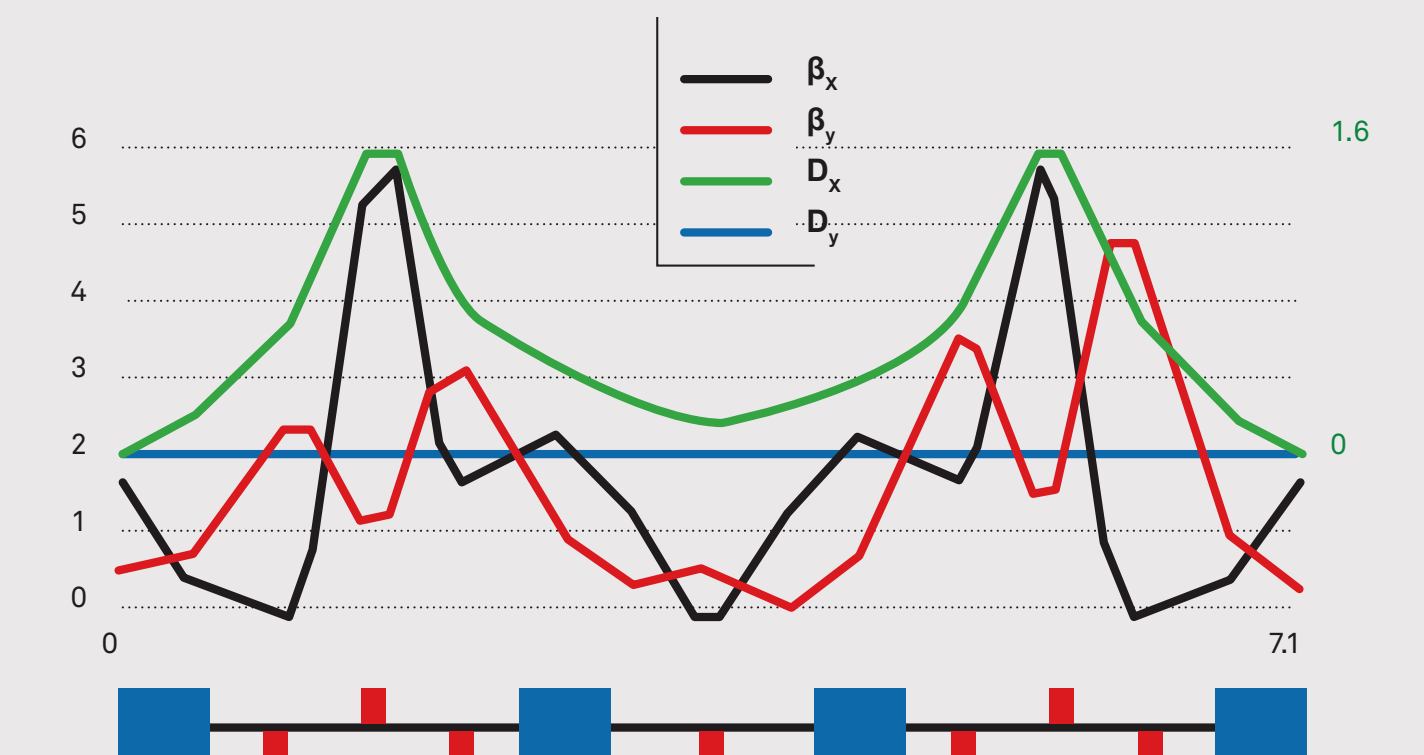


Concise representation of multi-pass ERL linac optics for all four passes, with constraints imposed on Twiss functions by 'sharing' the same return arcs by the accelerating and decelerating passes.

Arc Optics



Two-step spreaders and mirror symmetric recombiners have been implemented. The switchyard separates the two arcs into a vertical stack. The vertical dispersion created by the first step (a pair of opposing vertical bends) is suppressed by the first two quadrupoles located appropriately between the two steps.



Arc Optics (152 MeV)
Optic based on an FMC cell of the lowest energy arc.

CONCLUSIONS

An ERL based collider in which a newly provided electron beam collides with the intense hadron beams of the LHC represents a major opportunity for progress in particle physics. A proposal for a scientific and technical R&D facility preparing to LHeC is now under active development. Here we have described the CERN ERL test facility purposes and specific requirements along with two conceivable layout schematics. The ultimate goal is a design that operates on a multiple operating points in order to allow for a comprehensive validation testing of the key concepts for the final LHeC.

ACKNOWLEDGMENT

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REFERENCES

- [1] J. L. Abelleira Fernandez, et al. [LHeC Study Group Collaboration], J. Phys. G 39 (2012) 075001 [arXiv:1206.2913 [physics.acc-ph]].
- [2] R. Calaga, E. Ciapala and E. Jensen, Proposal for an LHeC ERL Test Facility at CERN, CERN-LHeC-Note-2012-006 ACC.
- [3] S.A. Bogacz, I. Shin, D. Schulte, F. Zimmermann, LHeC ERL Design and Beam-dynamics Issues, in Proceedings of the 2011 International Particle Accelerator Conference, San Sebastian, Spain.