Design Studies for the LHeC ERL Test Facility

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ABSTRACT

The Large Hadron Electron Collider (LHeC) is a proposed facility for deep-inelastic electron-proton/nucleus scattering, realized by colliding one of the two LHC proton (or heavy-ion) beams with 60 GeV electrons provided by a new accelerator. Following the release of its conceptual design report in 2012, the configuration of an energy recovery linac with racetrack shape has been chosen as the LHeC baseline.

In parallel the design of an LHeC Test Facility (LTF) has been advanced. Aside from various other technical and physics goals, this test facility will, in particular, aim at investigating the ERL principle in an LHeC-like configuration, including electron injector and return-arc magnets, at providing a test stand for superconducting SRF cavity modules, as well as at performing some LHeC-related detector R&D. One possible user application of the LTF beam is for generating controlled beam induced quenches of SC magnets. A planned staged construction of the LTF, including a number of well-defined intermediate steps, will lead to an ultimate beam energy of about 1 GeV.

Proposed Staged Design

The ERL test facility is designed to be constructed in stages. A first phase with recirculation would only use two 4-cavity cryomodules and single recirculation – it could reach 150 MeV [Fig. 1].

A second phase could feature multi-pass operation to reach 300 MeV (2 passes) or 450 MeV (3 passes) [Fig. 2]. Adding two more cryomodules could boost the top energy to 900 MeV [Fig. 3].

FIGURE 1

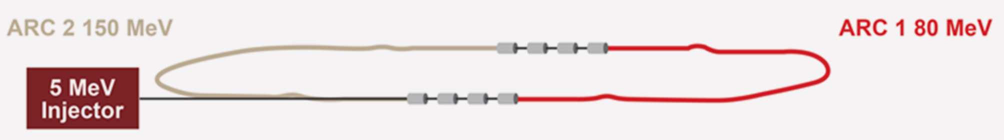
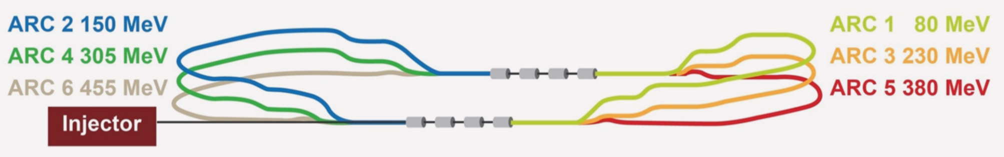


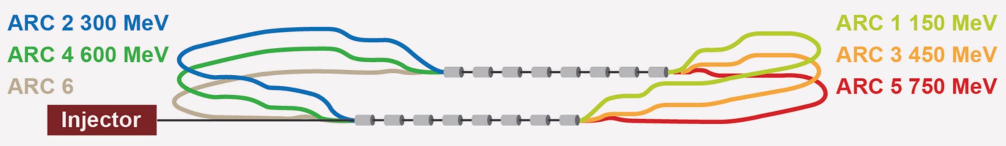
FIGURE 2



In its full energy version, the ERL test facility will consist of two anti-parallel linacs with two 4-cavity cryomodules in each.

Vertical spreaders/combiners separate the beams into up to 3 vertically separated arcs, each of which is optimized for its nominal energy. The highest energy arc is adjusted in length to assure arrival in the decelerating phase when entering the linac again.

FIGURE 3



Overall layout:

- A 5 MeV injector with an injection chicane;
- Two SCRF linacs (energy gain of ~300 MeV per pass);
- Six 180° arcs;
- Switching stations to combine/distribute the beams over different arcs;
- An extraction dump at 5 MeV.

LHeC ERL main parameters

TARGET PARAMETER	VALUE
INJECTION ENERGY [MeV]	5
FINAL BEAM ENERGY [MeV]	900
NORMALIZED EMITTANCE γεx,y [μm]	50
BEAM CURRENT [mA]	>10
BUNCH SPACING [ns]	25 (50)
PASSES	3

Potential applications

- Magnet and cable quench facility: Development of new cables and future high field SC magnets (e.g. FCC hh)
- Test facility for SC RF with beam: Development of new SC RF components, e.g. crab cavities and SCRF for FCC ee, etc.
- Test beam for detector component developments
- Dedicated Physics Facility

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. Due to the demand of providing a reasonable validation of the LHeC final system our designed is, at present, involving a FMC cell based lattice. Specifications require isochronicity, path length controllability, large energy acceptance, small higher-order aberrations and tunability.

An example layout which fulfills these conditions is shown in Fig. 4 and it describes the optics solution for the lower energy arc.

It includes a two-step achromat spreader and a mirror symmetric recombiner to direct the beam into the appropriate arc. The vertical dispersion introduced by the first step bend is suppressed by the quadrupoles located appropriately between the two stages. The switchyards separate all three arcs into 90 cm high vertical stack, the highest energy arc (Fig. 6) is not elevated and remains at the linac-level.

A horizontal dogleg, used for path length adjustment, is placed downstream of each spreader. The recirculating arc at 155 MeV is composed of 4 – 90 cm long dipoles to bend the beam of 180° and of a series of quadrupoles in two triplets and a singlet.

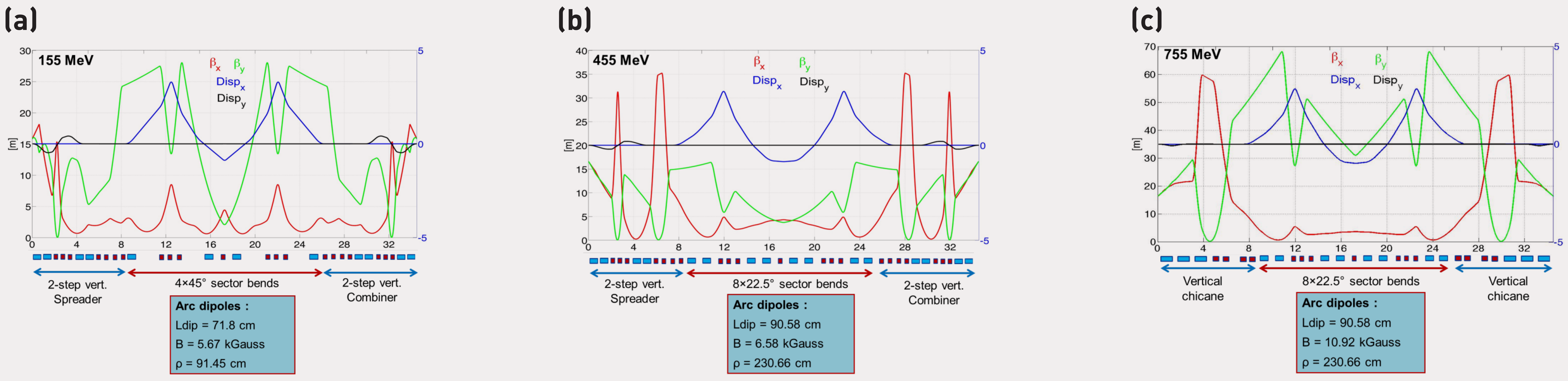


FIGURE 4

Optics based on an FMC cell of the lowest (a), medium (b) and highest (c) energy return arc. Horizontal (red curve) and vertical (green curve) beta-functions amplitude are illustrated. Blue and black curves show, respectively, the evolution of the horizontal and vertical dispersion.

Diverse plausible optics layouts have been taken into consideration. A possible option would consist of arcs with identical configurations in order to have compact magnets stacked on top of each other.

A complete first-order layout for switchyards, arcs and linac-to-arc matching sections has been accomplished for the arcs on both side of the ERL.

The total beam path for a full three pass accelerating cycle is around 280 m. This leads to a total magnet count of approximately 200.

Linac Design

Multi-Pass Linac Optics

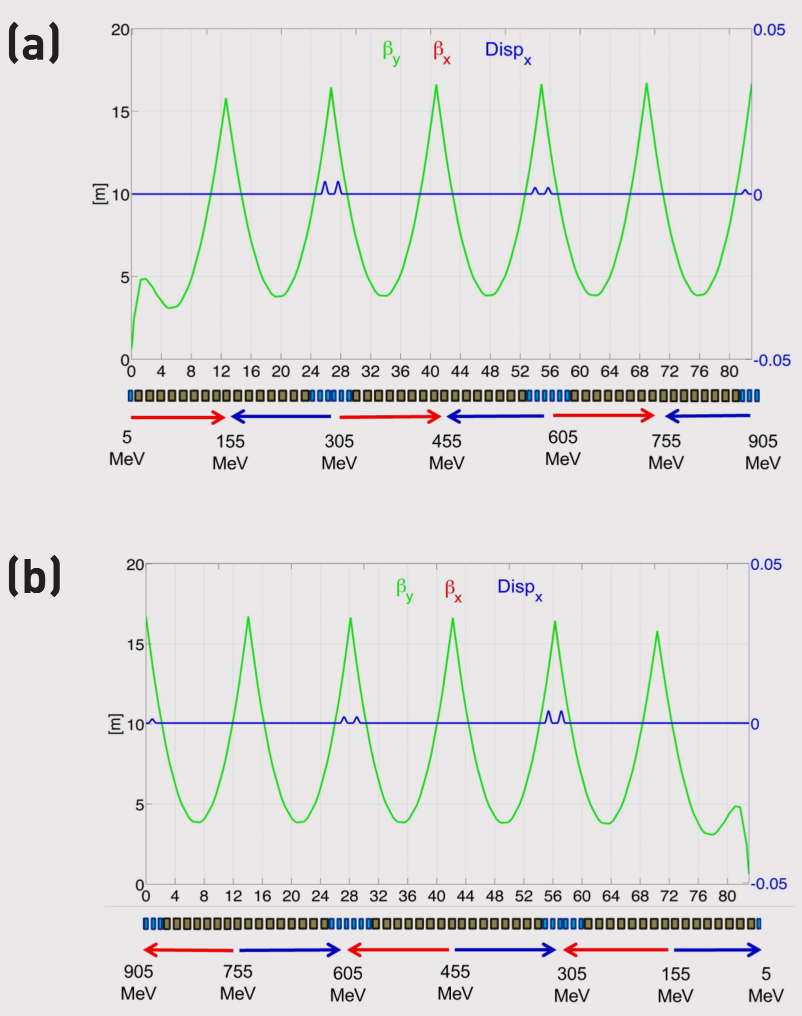
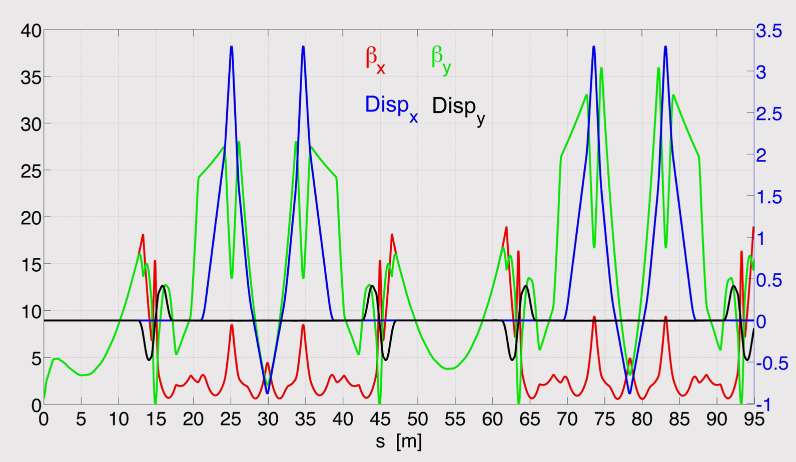


Figure 5. Concise representation of multi-pass ERL linac optics for all six passes, with constraints imposed on Twiss functions by 'sharing' the same return arcs by the accelerating and decelerating passes. Green and blue curves show, respectively, the evolution of the beta-functions amplitude and the horizontal dispersion for Linac 1 (a) and Linac 2 (b).



Complete lattice for Pass 1 including Linac1 (5 MeV to 155 MeV), Arc1 (155 MeV), Linac2 (155 MeV to 300 MeV), Arc2 (300MeV).

Horizontal (red curve) and vertical (green curve) beta-functions amplitude are illustrated. Blue and black curves show, respectively, the evolution of the horizontal and vertical dispersion.

Cavity and cryomodule concepts

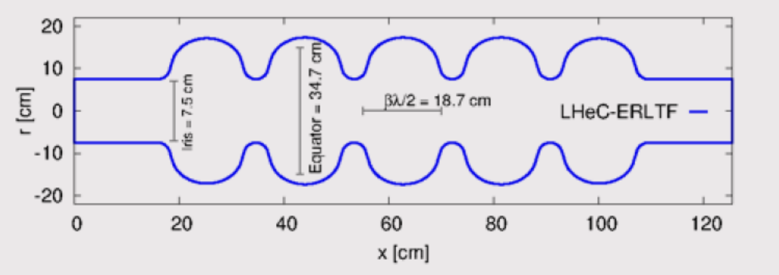
The frequency for the RF cavities has been chosen to be 801.58 MHz aiming at low RF power loss, high beam stability thresholds and synergies with the existing SPS RF system and HL-LHC upgrade project by providing a higher harmonic RF system for the HL-LHC.

The cavity design is based on existing SPL and JLAB experience.

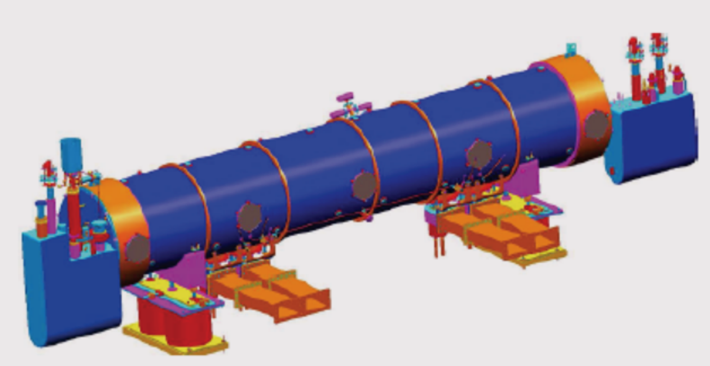
HOM dampers will have to be designed for 3 accelerating and 3 decelerating passes, adding up to 80 mA and thus have to cope with substantial power.

JLAB has already designed an 805 MHz cryomodule for SNS, which is a good starting point for the 802 MHz design.

BASIC PARAMETER	VALUE
RF FREQUENCY [MHz]	801.58
ACC. VOLTAGE PER CAVITY [MV]	18.7
NUMBER OF CELLS PER CAVITY	5
CAVITY LENGTH [m]	1.2
NUMBER OF CAVITIES FOR CRYOMODULE	4
NUMBER OF CRYOMODULES	3
RF POWER FOR CRYOMODULE [kW]	<50
DUTY FACTOR	CW



Approximate dimensions of a 5-cell cavity for ~802 MHz



The cryo-cavity module being designed by the CERN-Jlab-Mainz collaboration.
Image credit: SRF Institute, Jefferson Lab.

INTERNATIONAL COLLABORATIONS

Strong synergy has been identified with the MESA project at Mainz University; help with the design and construction of the 802 MHz cavities and cryomodules will result from collaboration with JLAB, who have already contributed significantly to the lattice and with their relevant experience operating CEBAF in ERL mode.

ACKNOWLEDGMENT

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289485.

CONCLUSIONS

The test facility would have a variety of important goals: the development of superconducting RF at CERN under realistic operational beam conditions, with high gradients for continuous-wave operation (< 20 MV/m) and of high quality ($Q_0 > 10^{10}$); the development of high-current electron sources, which are also required for the FCC-ee; and further applications, such as magnet quench tests in a low-radiation environment and detector tests with an electron beam on-site of up to 1 GeV energy.

A first cost estimate will be given with a preliminary Conceptual Design Report by the end of 2014.

FURTHER READINGS

[1] J. L. Abelleira Fernandez, et al. [LHeC Study Group Collaboration], J. Phys. G 39 (2012) 075001 [arXiv:1206.2913 [physics.acc-ph]].

[2] A. Valloni et al., "Strawman Optics Design for the LHeC ERL Test Facility", Proceedings of IPAC2013, Shanghai, China[TUPME055].

[3] E. Jensen et al., "Design Study of an ERL test facility at CERN", Proceedings of IPAC2014, Dresden, Germany [TUOBA02].

[4] http://lhec.web.cern.ch