Strawman optics design for the LHeC ERL Test Facility

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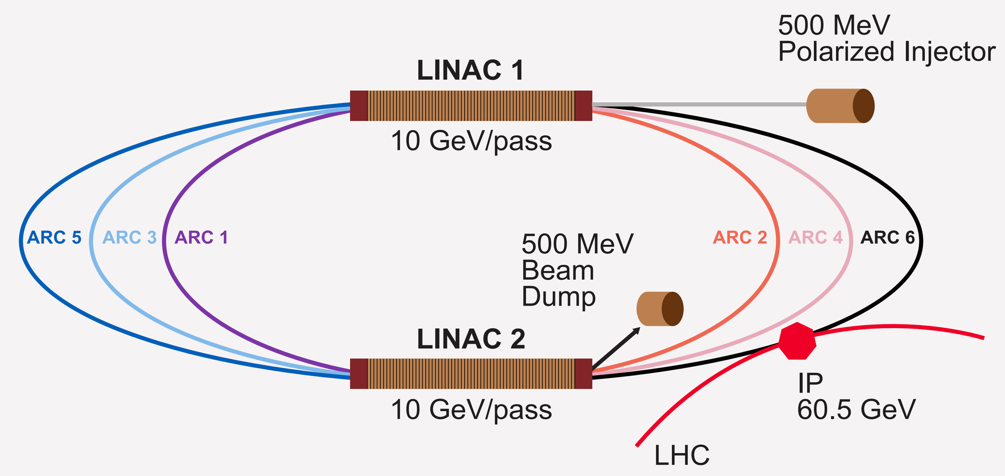
ABSTRACT

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. In this paper 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, 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	$2 \cdot 10^9$
INITIAL NORM. TRANSVERSE EMITTANCE	30 μm
BUNCH LENGTH	600 μm
BEAM SIZE AT IP (rms)	7 μm
NORM. TRANSVERSE EMITTANCE AT IP	50 μm
BEAM ENERGY AT IP	60 GeV
AVERAGE CURRENT	6.4 mA
LUMINOSITY	$>10^{33}$ $cm^{-2}s^{-1}$
TOT. WALL PLUG POWER	<100 MW

Optics choice:

Arc-to-Linac Synchronization ▶ Quasi-isochronous lattices
Arc optics ▶ Emittance preserving lattices ▶ Variation of Flexible momentum compaction cells (Imaginary γ_t, 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.

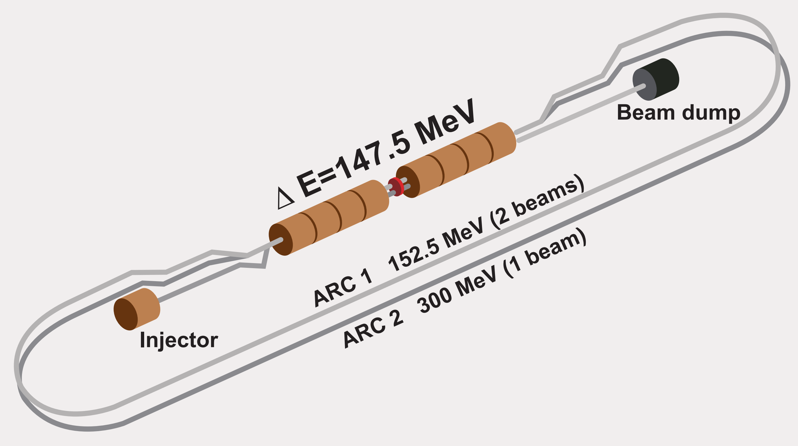
The main purposes are:

- 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.

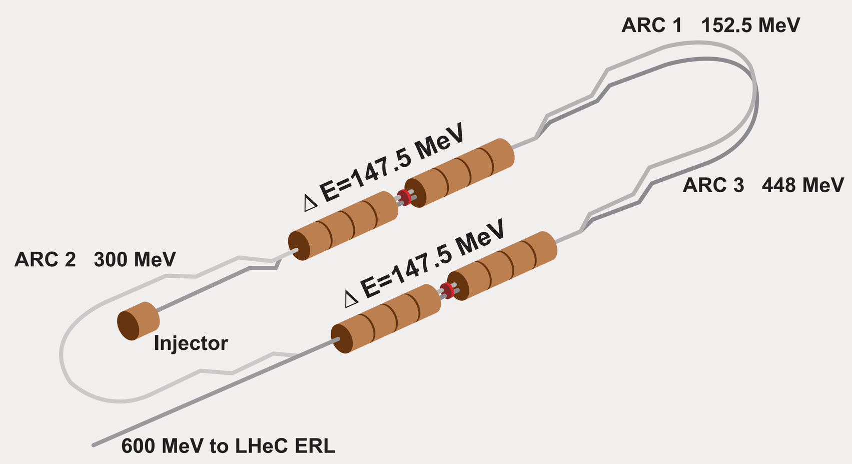
The facility will allow addressing several physics challenges such as maintaining high beam brightness through preservation of the six dimensional emittance, managing the phase space during acceleration and energy recovery, stable acceleration and deceleration of high current beams in CW mode operation.
The design must also allow addressing other performance aspects such as longitudinal phase space manipulations, effects of coherent synchrotron radiation (CSR) and longitudinal space charge, halo and beam loss and microbunching instability.

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 pC
BUNCH LENGTH (rms)	<3 mm
ENERGY SPREAD (rms)	<10 keV
NORM. TRANSVERSE EMITTANCE (rms)	<25 mm-mrad

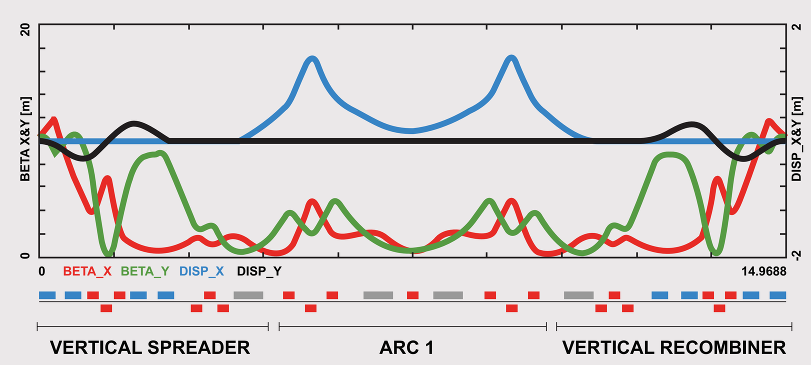
Transport optics

Appropriate recirculation optics are of fundamental concern in a multi-pass machine topreserve beam quality. The design comprises three different regions, the linac optics, the recirculation optics and the merger optics. The focusing strength of the quadrupoles along the linac needs to be set to transport two co-propagating beams of different energy and to support a large number of passes. Disturbing effects on the beam phase-space such as cumulative emittance and momentum growth have to be counteracted through a pertinent choice of the basic optics cell.

For beams with non-zero energy spread, one would like to employ a quasi-isochronous arc to limit bunch lengthening in the subsequent linac and the synchronous condition can by defined in terms of a tolerable RF phase delay for a given momentum acceptance.
Diverse plausible optics layouts are taken into consideration:

- FMC cell;
- 6-cell FODO lattice (with 60° horizontal phase advance and 90° vertical phase advance per cell) perturbed by a closed dispersion bump to control M_{56};
- compact FODO arc also based on 90°/60° horizontal/vertical phase advance per cell.

Due to the demand of providing a reasonable validation of the LHeC final system our plan is, at present, more oriented towards employing a FMC cell based lattice [3]. A next step will be the study of a hardware solution which could work at the same time as an FMC cell and as a FODO based second order achromat cell.



Optics based on an FMC cell of the lowest energy return arc at 152 MeV. 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.

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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