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THE LHeC PROJECT DEVELOPMENT BEYOND 2012

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LHEC PROJECT DESCRIPTION

The Large Hadron electron Collider (LHeC) project provides the unique possibility of exploring lepton-proton collisions in the TeV Center of Mass (CM) range. The LHeC would use one of the proton beams of the LHC. It therefore represents an interesting possibility for a further exploitation of the LHC infrastructure investment. Aiming at CM collision energies in the TeV range, by using the 7 TeV proton (and few TeV / nucleon ion) beam, implies lepton beam energies significantly exceeding the electron beam energy of HERA, the first ep collider built. For the Conceptual Design Report [1], an electron beam energy of 60 GeV is chosen, an energy between LEP I and LEP II. The CDR envisages the LHeC exploitation in parallel with the HL-LHC operation (at a time scale of approximately 10 years). Synchronous ep and pp operation provides the possibility to collect a total integrated luminosity of the order of 100 fb^{-1} based on ep peak luminosities of about $L = 10^{33}\text{cm}^{-2}\text{s}^{-1}$. The luminosity prospects are thus exceeding the HERA result by a factor of 100. In order to keep the power consumption of the facility at a realistic level, a limit of the total power for the LHeC electron branch is set at 100 MW. The CDR was worked out by a team of nearly 200 physicists and engineers from 60 institutes, with the support of ECFA and NuPECC. The latter included it in its long range plan for European nuclear physics due to the high interest in deep inelastic electron-ion scattering.

The CDR describes two options for the LHeC implementation in some detail: i) A Ring-Ring collider configuration with the installation of a new lepton storage ring inside the LHC tunnel. This option is technically relatively straightforward in view of the LEP experience. However, it requires additional bypasses around the existing experiments for the HL-LHC and challenging installation work inside a tunnel with an already operational accelerator infrastructure. ii) A Linac-Ring configuration with the construction of a new linear accelerator for the electron beam acceleration that intersects with the LHC machine in IP2. Several options have been considered for the linear accelerator, pulsed linac, recirculating linac and energy recovery linac (ERL) configurations, that provide a range of energy and luminosity combinations.

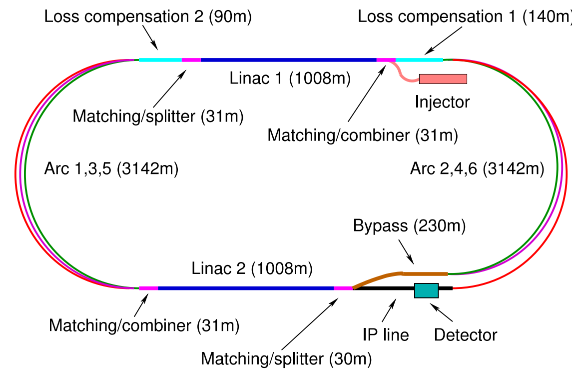

Figure 1: LHeC energy recovery linac configuration.

The CDR was reviewed by an external panel of experts evaluating the physics programme, the basic accelerator solutions and auxiliary systems and the concept of a new detector. The accelerator review confirmed that both options are feasible and can reach the requested performance level within the given parameter space.

Two novel, compact dipole-magnet designs (diameter of 35 cm and weight of 280 kg/m magnetic length) have been developed at BINP (Novosibirsk) and at CERN and first prototypes were produced. Both models demonstrated that these normal conducting magnets can achieve a high field quality and reproducibility of 10^{-4} at an operating range of approximately $0.013 - 0.076$ T as is required by the 10 GeV injection beam energy into an LHeC storage ring. With their parameters, these normal conducting magnets are also close to the specifications posed by the dipoles in the return arcs for a racetrack linac configuration.

Recent discussions at CERN have underlined that the integration and planning aspects for the installation of a new machine inside the LHC tunnel represent difficult challenges, which make the Ring-Ring option less favorable. This led to the decision to pursue only the Linac-Ring option for further studies with the goal of developing a 60 GeV ERL, in a configuration as sketched in Figure 1. Table 1 presents a summary of key parameters of the 60 GeV ERL along with a 140 GeV pulsed linac configuration. In the following some major items for further development are sketched.

LHEC R&D REQUIREMENTS

Conventional Magnet Design

The racetrack linac configuration comprises 3-fold return arcs in about 6 km of tunnel. Each arc segment accommodates 600 dipole magnets of 4 m length, with field

Table 1: Parameters for the Linac-Ring Configuration.

Parameter	**ERL**	**max Energy**
Energy [GeV]	60	140
Luminosity [$cm^{-2}s^{-1}$]	10^{33}	$4 \cdot 10^{31}$
Cavity Gradient [MV/m]	18	32
Mode	CW	Pulsed
RF Power Loss [W/cavity]	13-37	11
Watt per W (1.8K to RT)	700	700
Power loss/GeV at RT	0.51-1.44	0.24
RF length [km]	2	7.9
Total length [km]	9	7.9
Beam current [mA]	6.4	0.27
Repetition rate	-	10Hz
Pulse length	-	5ms

strength between 0.046 T and 0.264 T corresponding to the respective electron beam energy in the arc, and in addition 240 quadrupole magnets (of 4 different types). These magnets are less demanding in terms of field reproducibility than for the ring option. For the ERL configuration it yet is of interest to find a cheap and reliable solution. One option worth pursuing is whether such magnets, quadrupoles and dipoles, could share a common iron yoke, electrical circuit, or vacuum chamber. Similar to the study of the ring-ring dipoles, a return arc magnet study is planned for the preparation of the technical design.

Superconducting Magnets

The operation of a pp and ep collider facility requires, for the ep interaction region, the development of novel superconducting magnets with apertures for three beams of widely different beam energies (two proton beams at 7 TeV and one lepton beam at 60 GeV). A conceptual design for such magnets, documented in the CDR, is under further study at CERN [2]. The demonstration of the technical feasibility (field, aperture, mechanics) of the design of the two focusing magnets closest to the interaction point, Q_1 and Q_2, requires the construction of first models (of about 1 m length).

Superconducting RF

The LHeC ERL will constitute the highest energy application of the energy recovery technique worldwide. The construction of an efficient Energy Recovery Linac requires the development of:

- High gradient superconducting cavities;
- RF coupler optimized for ERL operation;
- Maximum unloaded Q values which directly impact on the required cryogenics power for the facility;
- Development of RF diagnostics and feedback loops for operating a multi-pass ERL over a wide range of beam energies (a few MeV to 60 GeV).

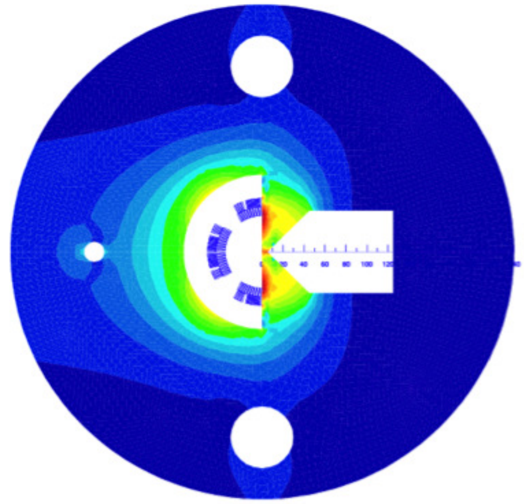

Figure 2: Conceptual cross section design of a superconducting half quadrupole magnet.

The LHeC design aims at maximum cavity gradients of 18 MV/m in CW mode (compared to approximately 7 MV/m for the LEP SC RF system), which is close to the limit of state of the art RF developments (e.g. SPL cavity design with 25 MV/m in pulsed operation mode) for Q values above $2 \cdot 10^{10}$. The feasibility of these parameters needs first to be demonstrated in a prototype cavity, optimized for the LHeC application with RF couplers designed for ERL operation. It then needs to be demonstrated that the design parameters are within reach for a realistic series production of the cavities. Moreover, new RF tools for the operation of a multi-turn re-circulating ERL (diagnostics tools, feedback loops etc.) need to be tested in operation of an ERL test facility, which is required to be built for the LHeC.

Beam Pipe Development and Interaction Region

The asymmetric e and p beam energy configuration of the LHeC poses a severe constraint on the detector acceptance such that 1° polar angle acceptance has to be realized both for the electrons scattered in the e beam direction, and also for the hadronic final state, emitted in the p beam direction. The bending of the electron beam close to the interaction point causes a wide synchrotron radiation fan. The detector beam pipe in transverse directions therefore has to be strongly asymmetric: wide enough to let the synchrotron fan pass on one side and narrow to allow for a small-angle acceptance and heavy flavor tagging on the other; see Fig. 3. For the beam pipe several challenges need to be faced: the beam pipe has to provide a high transparency to allow particle detection and must be of a complex shape to adapt to the needs of circulating electrons and protons. The integration of two 9-m long 0.3-T separation dipoles deep inside the detector and the various effects of the resulting synchrotron radiation – induced power, backscattering of synchrotron light into the

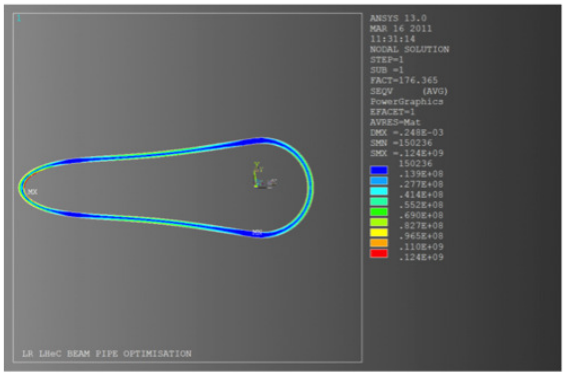

Figure 3: Transverse cross section and stress calculations for the detector beam pipe of the LHeC detector in the linac-ring configuration.

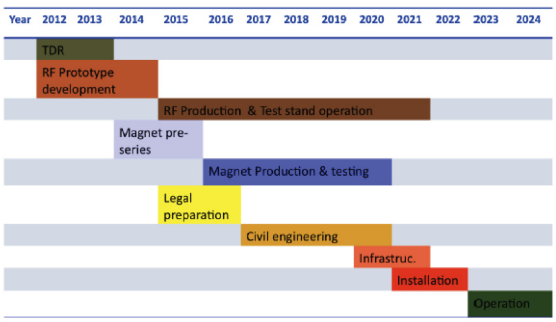

Figure 4: Schematic schedule for the LHeC, from the CDR.

detector, photo-electron induced electron cloud build-up – are to be addressed with further detailed studies.

TIME LINE AND NEXT STEPS

Based on the experience with other projects such as LEP, LHC, LINAC4 at CERN and the XFEL at DESY, one should plan for approximately 10 years for the project finalization. Smaller projects such as ESS and PSI XFEL plan for 8 to 9 years, from a TDR to project start, while the EU XFEL plans for 5 years from construction begin to operation start. HERA required approximately 10 years from project proposal to start of operation. A time line of 10 years for a project of the scale of the LHeC is ambitious but appears to be feasible and necessary to be consistent with the LHC planning and a project exploitation start by the mid 2020ies. Figure 4 shows a schematic LHeC schedule as has been part of the CDR.

In 2012, first steps towards R&D activities will focus on preparations and the exploration of possible collaborations with other research laboratories for the projects sketched above. For the ERL this includes the choice of the preferred RF frequency. In 2013 the LHeC aims at the construction of a first SC IR model of the quadrupole magnet with measurements on the short SC mirror quadrupole magnet in 2014. In 2014 the LHeC aims at starting the construction of a prototype cavity and coupler with the goal of having a final prototype RF cryostat ready by 2015. A prototype of the IR beam pipes can be targeted for 2014. After 2015 the LHeC project would pursue the construction of a dedicated LHeC ERL test facility (Fig. 5), either at CERN or possibly at another collaborating laboratory, with the goal of finalizing beam measurements by 2017. The above steps are in line with an LHeC exploitation in parallel to the HL-LHC project and allow a project decision on the LHeC by the time when results from the 7 TeV beam energy operation of the LHC can be expected to be available.

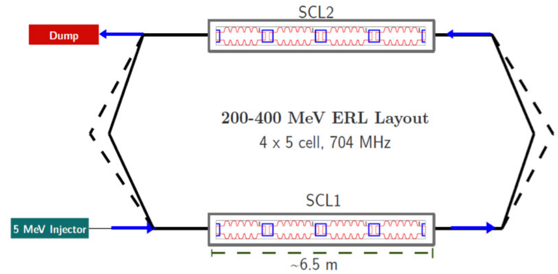

Figure 5: Schematic layout of a CERN ERL test facility using one LHeC SC RF prototype cryo module and an SPL cryo module.

The developments as sketched here will be accompanied by the formation of a proto-collaboration, which will scrutinize the detector design with simulations and prototypes such that an in-time detector construction and installation is enabled. Detector and accelerator are naturally linked, mainly by the design of the interaction region, which combines the constraint of head-on ep collisions with the need to let the spectator p beam pass through for pp collisions to simultaneously take place at IP 1, 5 and likely 8. Realization of the LHeC project will extend the physics potential of the LHC significantly and allow to realize a second collider for the exploration of the TeV energy scale at CERN.

Thanks are due to the many colleagues who took part in the CDR and to CERN, ECFA and NuPECC for supporting this development.

REFERENCES

[1] LHeC Study Group, C. Adolphsen et al, “A Large Hadron Electron Collider at CERN,” LHeC-Note-2011-003 GEN, CERN, 2011, to be published.

[2] Stephan Russenschuck, this conference.