PROCEEDINGS OF SCIENCE

PoS(EPS-HEP2011)040

The LHeC: A Lepton-Proton Collider at CERN using the LHC infrastructure

---

Oliver Brüning[*][†]
CERN
E-mail: `oliver.bruning@cern.ch`

Max Klein
University of Liverpool, CERN
E-mail: `max.klein@cern.ch`

The paper summarizes design concepts for a high luminosity electron-nucleon collider of 1.3 TeV centre of mass energy at CERN using the existing LHC infrastructure. The paper discusses two distinct design options: A ring-ring and a linac-ring collider option.

The 2011 Europhysics Conference on High Energy Physics-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes France

---

[*] Speaker.

[†] on behalf of the LHeC Study Group.

1. INTRODUCTION

Based on an extensive report [1], which at the time of EPS-HEP, Genoble exists as a first draft [1], main design considerations and solutions are presented of a new electron-hadron collider, the LHeC, in which electrons of 60 to possibly 140 GeV collide with LHC protons of 7000 GeV. With an *ep* design luminosity of about $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, the Large Hadron Electron Collider exceeds the integrated luminosity collected at HERA by two orders of magnitude and the kinematic range by a factor of twenty in the four-momentum squared, Q^2, and in the inverse Bjorken x. The physics programme is devoted to an exploration of the energy frontier, complementing the LHC and its discovery potential for physics beyond the Standard Model with high precision deep inelastic scattering (DIS) measurements. These are projected to solve a variety of fundamental questions in strong and electroweak interactions. The LHeC thus becomes the world's cleanest high resolution microscope, designed to continue the path of deep inelastic lepton-hadron scattering into unknown areas of physics and kinematics. The physics programme also includes electron-ion (eA) scattering into a $(Q^2,\ 1/x)$ range extended by four orders of magnitude as compared to previous lepton-nucleus DIS experiments, which will revolutionise the physics of the partonic nuclear medium.

The LHeC may be realised either as a ring-ring (RR) or as a linac-ring (LR) collider. A choice between the two options will precede the technical design phase which begins in 2012. The design is for synchronous *pp* and *ep* operation to be able to collect high integrated luminosity with the LHeC in parallel to the HL-LHC operation phase and as is required for rare and new physics processes, preferentially occuring at high Q^2 and large Bjorken x. Following current and tentative time schedules, which account time for the TDR, the civil engineering, the industrial production of the about 5000 normal conducting magnets and superconductive cavity components and their installation, the LHeC may begin its operation in 2023, when the LHC commences its second, the maximum luminosity phase of operation.

2. LAYOUTS

The default electron beam energy is chosen to be 60 GeV. For the design study it has been assumed that *ep* collisions take place at point 2 which currently houses the ALICE experiment. The electron ring (Fig. 1) bypasses CMS and ATLAS towards the outside of the ring in separate tunnels of about 1.3 km length each, which also host the electron rf and cryogenics equipment. Similar bypass may be foreseen for the LHCb experiment or at other insertions where the lepton beam might interfere with the operation of the high intensity proton beams (e.g. the LHC cleaning insertions). However, aiming at an equal circumference for the Lepton and the Proton rings, a minimum number of such bypasses is clearly desirable. The maximum energy one may achieve with the ring arrangement could reach about 120 GeV requiring, however, many parameters to be extreme as the rf power and synchrotron radiation effects increase $\propto E_e^4$. The linac layout (Fig. 2) is similarly optimised for luminosity and cost. This results in two s.c. linacs of 1 km length each, which are traversed three times to achieve the 60 GeV energy while the luminosity is enhanced, by likely more than an order of magnitude, using energy recovery by decelerating the spent beam. Energies significantly higher than 60 GeV can be achieved with a straight linac

---

[1] The list of authors can be found in [1].

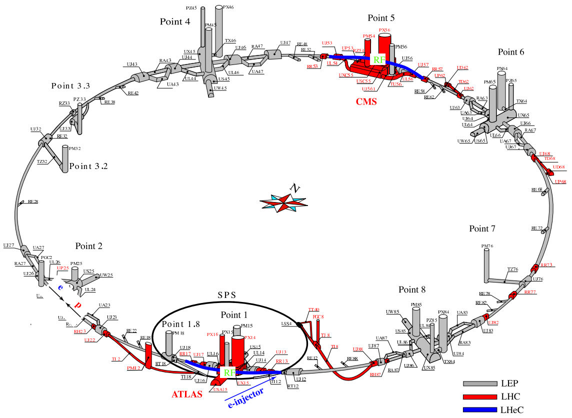

Figure 1: Schematic Layout of the LHC (grey/red) with the bypasses of CMS and ATLAS for the ring electron beam (blue) in the RR version. The *e* injector is a 10 GeV superconducting linac in triple racetrack configuration which is considered to reach the ring via the bypass around ATLAS.

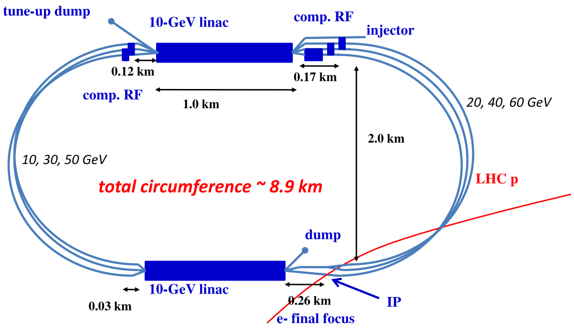

Figure 2: Schematic layout of the 60 GeV linac in racetrack configuration. The circumference matches $1/3$ of the LHC.

arrangement for which a principle design, choosing 140 GeV, is included in the design report, possibly complemented with 10 GeV stages for energy recovery.

3. PARAMETERS

The parameters of the *ep* collider are determined by the LHC hadron beams. A selection of the parameters is given in Tab. 1 for $E_e = 60$ GeV. For the RR configuration, the $\beta_{x,y}$ functions and luminosity values correspond to the 1° optics, in which the first *e* beam magnet is placed 6.2 m apart from the IP. In a further, the high luminosity option the β functions are smaller and the luminosity is enhanced by a factor of 2. This is achieved by placing the first magnet at 1.2 m distance from the IP which restricts the polar angle acceptance to $8-172^\circ$. The e^+ intensity value in the LR configuration reflects current expectations and may be surpassed with dedicated R&D. The LR luminosity may be reduced to about $2/3$ for a clearing gap to avoid fast ion instabilities, at fixed bunch intensity.

4. COMPONENTS

Parameters of magnet, rf and cryogenics components for the RR and the LR configuration are summarised in Tab. 2. The total number of magnets (dipoles and quadrupoles excluding the few

Table 1: Parameters of the RR and RL configurations.

	Ring	**Linac**
electron beam		
beam energy E_e	60 GeV	
e^- (e^+) per bunch N_e [10^9]	20 (20)	1 (0.1)
e^- (e^+) polarisation [%]	40 (40)	90 (0)
bunch length [mm]	10	0.6
tr. emittance at IP $\gamma\epsilon^e_{x,y}$ [mm]	0.58, 0.29	0.05
IP β function $\beta^*_{x,y}$ [m]	0.4, 0.2	0.12
beam current [mA]	131	6.6
energy recovery intensity gain	–	17
total wall plug power	100 MW	
syn rad power [kW]	51	49
critical energy [keV]	163	718
proton beam		
beam energy E_p	7 TeV	
protons per bunch N_p	$1.7\cdot10^{11}$	
transverse emittance $\gamma\epsilon^p_{x,y}$	3.75 μm	
collider		
Lum e^-p (e^+p) [10^{32}cm^{-2}s^{-1}]	9 (9)	10 (1)
bunch spacing	25 ns	
rms beam spot size $\sigma_{x,y}$ [μm]	30, 16	7
crossing angle θ [mrad]	1	0
$L_{eN} = A\,L_{eA}$ [10^{32}cm^{-2}s^{-1}]	0.3	1

special IR magnets) and cavities is 4058 for the ring and 6132 for the linac. The majority are the 3080 (3600) normal conducting dipole magnets of 4 (5.4) m length for the ring (linac return arcs) for which first prototypes have been successfully built at BINP Novosibirsk and at CERN. The number of high quality cavities for the linac is below 1000. The CDR study assumes a frequency of 721 MHz which would provide synergies with SPL and EES RF developments. Alternatively, one could also foresee an RF frequency of 1.3 GHz providing synergies between the LHeC and the Tesla and ILC R&D developments. The cavity is operated in CW mode at about 20 MV/m for the energy recovery configuration at 60 GeV. The cavity demands of the LHeC are therefore considerably lighter than those from the ILC.

The cryogenics system of the ring accelerator is of modest demand. For the linac it critically depends on the cooling power per cavity which for the draft design is assumed to be 32 W at 2° K. This leads to a cryogenics system with a total electric grid power of 21 MW. The projected development of a cavity-cryo module for the LHeC, in conjunction with ongoing developments for the SPL at CERN and eRHIC at BNL, is directed to achieve a high Q_0 value and to reduce the dissipated heat per cavity.

Special attention is devoted to the interaction region design, which comprises beam bending, direct and secondary synchrotron radiation, vacuum and beam pipe demands. It requires a number

Table 2: Components of the electron accelerators.

	Ring	**Linac**
magnets		
beam energy	60 GeV	
number of dipoles	3080	3600
dipole field [T]	0.013 – 0.076	0.046 – 0.264
total nr of quads	866	1588
RF and cryogenics		
number of cavities	112	944
gradient [MV/m]	11.9	20
RF power [MW]	49	39
cavity voltage [MV]	5	21.2
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5\ 10^{10}$
cooling power [kW]	5.4@4.2 K	30@2 K

of focussing magnets with apertures for the two proton beams and field-free regions to pass the electron beam after the IP. The field requirements for the ring-ring option (gradient of 127 T/m, beam stay clear of 13 mm (12 σ), aperture radius of 21 (30) mm for the p (e) beam) allow a number of different magnet designs using the well proven $NbTi$ superconductor technology and making use of the cable (MQY) development for the LHC. The requirements for the linac are more demanding in terms of an about twice larger gradient and tighter aperture constraints which may be met better with Nb_3Sn superconductor technology. The preferred design for the two nearest quadrupoles is shown in Fig. 3.

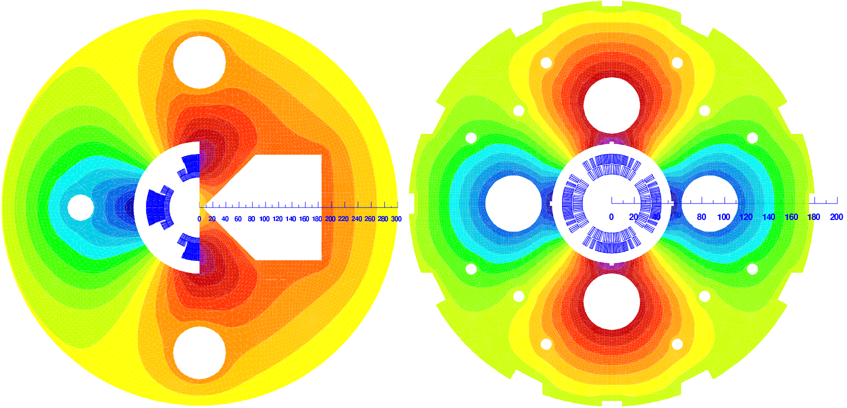

Figure 3: Cross-sections of the insertion quadrupole magnets for the linac-ring option. Left: Half quadrupole with field-free region (Q_1). Right: Single aperture quadrupole (Q_2).

First considerations have been made for the civil engineering. The ring requires for each bypass a new tunnel of about 1.3 km length. The ring injector has a length of about 150 m and may be placed at the Prevessin site on surface, which would require a transfer tunnel to reach the

ATLAS bypass, or possibly in a new cavern underground. The 60 GeV racetrack arrangement for the linac requires a new tunnel of about 9 km length. It is envisaged to place it inside the LHC, at the depth of the LHC, in order to minimize the interference with land surrounding the CERN site. With modern tunnel boring machines one can expect to advance about 150 m per week which corresponds to 60 weeks for drilling the whole LHeC linac tunnel. Drilling a bypass can be made within about 10 weeks, which is comparable to an annual LHC shutdown time.

5. STATUS AND NEXT STEPS

The draft design report is the result of a three years process, under the auspices of CERN, ECFA and NuPECC. Currently the report is being reviewed by referees appointed by the CERN directorate, for the physics, accelerator, detector and special aspects of the project, including a cost estimate. The updated report is being prepared for publication. The LHeC has to run while the LHC is still operational. This defines 2023 (the long shutdown LS3) as the natural and mandatory timeline of its realization. The tentative schedule foresees to begin the rf and magnet production in 2016, and the civil engineering in 2017. This requires preseries and legal preparations in the about two years before. A TDR has to be worked out until 2015. First critical components under consideration for design in 2012/13 are: an rf and cryomodule, a 1:1 dipole prototype and a prototype of the s.c. combined function magnet near the IP. Figure 4 shows a resulting schematic timeline for the project evolution over the next years.

The LHeC represents a unique opportunity for building and operating a further TeV energy scale collider. It builds on the gigantic investments in the LHC and its intense hadron beams. The Tevatron, LEP and HERA have established the Standard Model of particle physics. The LHC, a pure lepton collider and the LHeC are expected to explore it at deeper levels and to eventually lead particle physics further beyond.

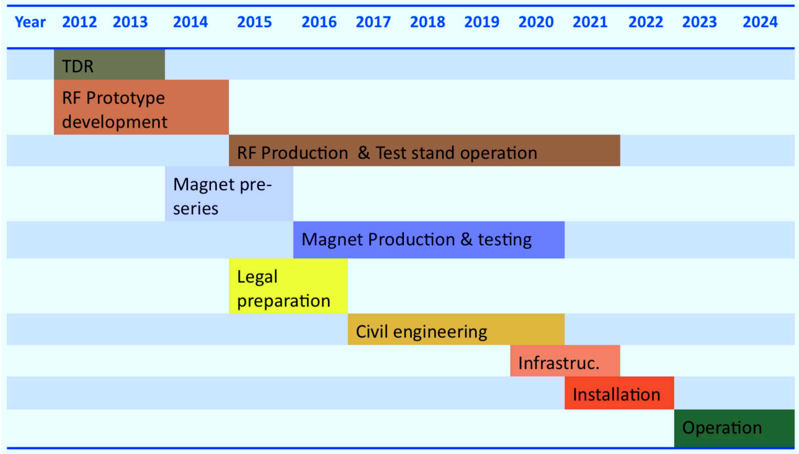

Figure 4: Schematic timeline for the LHeC project development.

References

[1] LHeC Study Group, “A Large Hadron Electron Collider at CERN", Draft Design Report, LHeC-Note-2011-003 GEN, to be published (2011).