LHeC LATTICE DESIGN

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Abstract

The Large Hadron Electron Collider (LHeC) aims at lepton-proton and lepton-nucleus collisions with centre of mass energies of 1–2 TeV at ep luminosities in excess of 10^{33} cm^{-2} s^{-1}. We present here a lattice design for the electron ring option, which meets the design parameters and also the constraints imposed by the integration of the new electron ring in the LHC tunnel.

INTRODUCTION

Presently two options are considered as electron accelerator: the so called linac-ring and ring-ring option [1]. Both options provide the possibility to operate in parallel with proton-proton or ion-ion collisions and imply either the construction of a linear accelerator with possibly energy recovery or the installation of a new electron storage ring on top of the LHC as illustrated in Fig. 1.

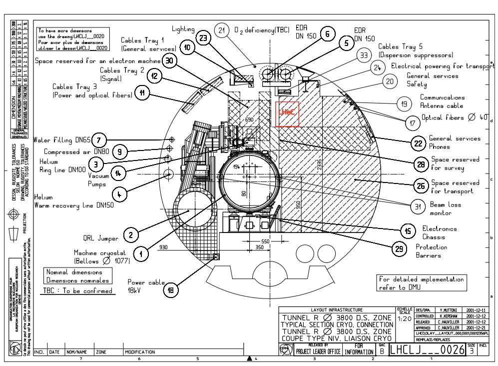

Figure 1: Cross-section of the LHC tunnel with the original space holder for the e-ring directly above the LHC cryostat and the shifted location (red) required to keep the overall circumference of e- and p-ring identical.

The general layout of the LHeC ring-ring option, which is described in this paper, is shown in Fig. 2. The e-ring bypasses the experiments in Point 1 and Point 5. The e-p collision experiment will be placed either in Point 2 or Point 8. We assume here Point 2 as the collision point.

Table 1: Design parameters of the LHeC ring-ring option

Beam energy	60 GeV
Particles per bunch	1.98×10^{10}
Number of bunches	2808
Synchrotron radiation power	< 50 MW
Damping partition $J_x/J_y/J_e$	1.5/1/1.5
Hor./vert. emittance ($\kappa = 0.5$)	5.0/2.5 nm

The design parameters are listed in Table 1. Damping partition number and betatron coupling are chosen in order to minimize aperture requirements and to facilitate the matching of the flat e-beam to the round p-beam at the IP [2].

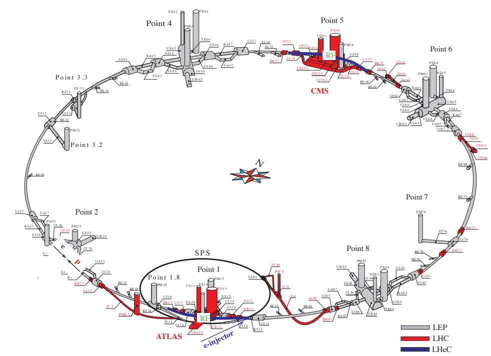

Figure 2: Schematic layout of the LHeC: In grey the LEP tunnel now used for the LHC, in red the LHC extensions. The two LHeC bypasses are shown in blue. The RF is installed in the central straight section of the two bypasses. The bypass around Point 1 also hosts the injection.

BYPASS DESIGN AND E-RING CIRCUMFERENCE

As electrons and protons only collide in one point the circumference of both rings can be either matched or differ by a multiple of the LHC bunch spacing. In order to avoid potential problems with beam-beam effects as discussed in [3], the e- and p-ring circumferences were chosen to be equal. Starting from a ring which exactly follows the LHC geometry the bypasses may increase or decrease the circumference depending on their design. This change in circumference can generally be compensated by a change in radius of the ring. Beside the constraint of equal circumferences, the main requirements for both bypasses in Point 1 and Point 5 are that all integration constraints are respected and synchrotron radiation losses are not significantly increased. Three different options are considered as basic bypass designs:

Vertical Bypass: A vertical bypass would have to pass above the LHC with a separation of about 20 to 25 m [1]. This can only be achieved by strong additional vertical bending that would increase synchrotron radiation losses and decrease the polarization compared to a horizontal bypass.

Horizontal Inner Bypass: A horizontal inner bypass can be constructed by simply decreasing the bending radius of some main bends. Consequently the synchrotron radiation losses for an inner bypass are larger than for a comparable outer bypass. The advantage of an inner bypass, if combined with an outer one, is that it reduces the circumference so the two bypasses could compensate each other's path length changes.

Horizontal Outer Bypass: A horizontal outer bypass uses the regular curvature of the ring instead of additional or stronger dipoles. In general this is the preferred option, because it does not increase the synchrotron radiation losses.

For both bypasses the design of a horizontal outer bypass was chosen and is illustrated in Fig. 3. The basic principle of a horizontal outer bypass is explained in [4].

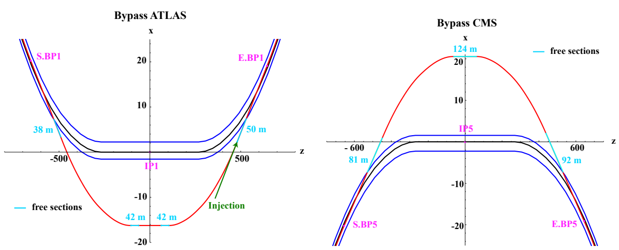

Figure 3: Final bypass design: The LHC p-ring is shown in black, the e-ring in red and the tunnel walls in blue. Dispersion free sections reserved for the installation of RF, wiggler(s), injection and other equipment are marked in light blue. The injection is marked in green in the right arc of the bypass in Point 1. Beginning and end of the bypass are marked as S.BP and E.BP.
(Left) Bypass at Point 1 using the survey gallery to reduce the separation [1].
(Right) Bypass at Point 5 fully bypassing the experimental hall.

In order to minimise the separation and the path length difference, the bypass in Point 1 passes through the existing survey gallery, which fixes the geometry of this bypass. The bypass in Point 5, on the other hand, is fully decoupled from the existing LHC cavern and tunnel and is therefore used for fine adjustment of the circumference. Both bypasses require approximately the same separation and a similar design was chosen for both. Given the separation $\Delta_{\mathrm{BP}_{1,5}}$ and angle θ_{BP}, the change in circumference can be compensated by a change in radius of the ring by [1]:

$$\Delta R = \frac{\Delta_{\mathrm{BP}}}{\pi \cot\left(\frac{\theta_{\mathrm{BP}}}{2}\right) - 2} \qquad (1)$$

where $\Delta_{\mathrm{BP}} = \Delta_{\mathrm{BP1}} + \Delta_{\mathrm{BP5}}$ is the total separation. Starting with the minimum separation values of $\Delta_{\mathrm{BP1}} = 16.25$ m and $\Delta_{\mathrm{BP5}} = 20.0$ m, the change of radius is about 61 cm, which was taken as baseline for the design of the e-ring geometry. The exact matching of the circumference was then performed by varying the length of the inserted straight section $\Delta s_{\mathrm{BP}_5} = 2\Delta_{\mathrm{BP}_5} \tan\left(\frac{\theta_{\mathrm{BP}}}{2}\right)$ and with it the separation in Point 5. The resulting design values of both bypasses are summarized in Table 2.

Table 2: Lengths characterising the bypasses.

	Point 1	Point 5
Total bypass length	1303.3 m	1303.7 m
Separation	16.25 m	20.56 m
Dispersion free straight section	172 m	297 m
Radius change	61 cm	

GEOMETRY

The geometry of the LHeC is to a large extent determined by the integration constraints imposed by the LHC. A detailed review of all constraints is given in [1]. In this first version of the lattice we concentrated on the main conflicts, namely the experimental halls in Point 1 and Point 5, the service modules in the arcs and the DFBs in the insertions. At the position of the service modules and DFBs no e-ring elements, particularly no dipoles, can be placed. In the main arcs, the service modules are installed at the beginning of each LHC arc cell. The insertions host varying numbers of DFBs with varying placements and lengths. The final difference between the LHC p- and e-ring without bypasses (idealised ring) avoiding service modules and DFBs is shown in Fig. 4 and fulfils the required precision. The reason for the relatively large differences is that the uneven distribution of dipoles necessary for the minimization of synchrotron radiation losses and simultaneous respect of the integration and optics constraints, had to be adapted to the symmetric LHC geometry. More details can be found in [1].

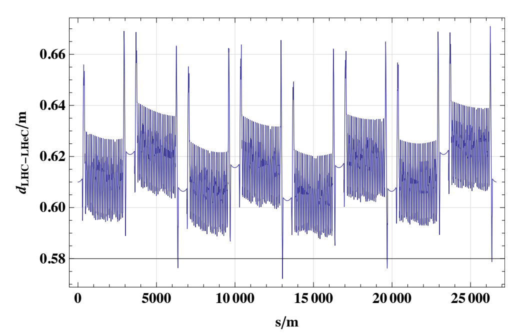

Figure 4: Radial distance between the p- and e-ring without bypasses.

LAYOUT AND OPTICS

Throughout the whole e-ring lattice, the choice of the optics is strongly influenced by the geometrical constraints and shortage of space in the LHC tunnel. The complete e-ring consists of various "modules": the arc module (8 in total), the insertion module (6 in total) and the two bypasses (Point 1 and Point 5).

Arc Module

The LHC service modules are placed at the beginning of each LHC main arc cell. In order to obtain a periodic solution of the lattice, the e-ring arc cell length can only be an integer multiple or fraction of the LHC FODO cell length. Given the same phase advance and bending radius, the emittance increases with the cell length L. In the case of the LHeC e-ring a FODO cell length corresponding to half the LHC FODO cell length delivers an emittance close to the design value, while the emittance of a cell with the full LHC FODO cell length is about a factor of four too large. Choosing half the LHC FODO cell length divides the arc into 23 equal double FODO cells with a symmetric configuration of the quadrupoles and an asymmetric distribution of the dipoles. A sufficiently small emittance is obtained with a phase advance of $180°/120°$ over the complete period, which corresponds to a phase advance of $90°/60°$ per FODO cell. Because of the asymmetry of the dipole configuration, the phase advance in the horizontal plane is not equally distributed with $89.4°/60°$ in the first half and $90.6°/60°$ in the second. The optics and layout of one arc period is shown in Fig. 5.

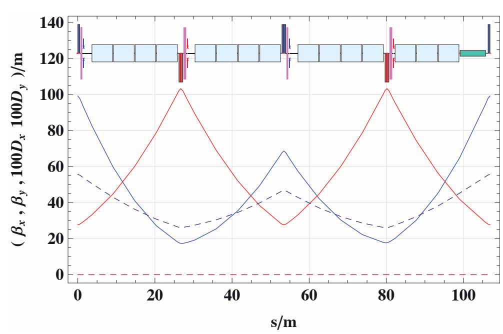

Figure 5: e-ring arc cell optics. One arc period consists of two asymmetric FODO cells. The horiz./vert. β-functions are shown in blue/red and the dispersion in dashed blue/red.

Insertion Module

In this first version of the lattice all even and odd insertions of the e-ring have the same layout. Each insertion is divided into three parts: the dispersion suppressor on the left side (DSL), the straight section and the dispersion suppressor on the right side (DSR). For geometric reasons, the ratio between the lengths of one arc cell and one dispersion suppressor cell of the e-ring has to be the same as for the LHC, i.e. 2/3 [1]. Each dispersion suppressor therefore consists of 20 dipoles and 8 quadrupoles. The position of the dipoles is determined by the geometry of the LHC and the position of the DFBs and is therefore not actively used for the dispersion suppression. The dispersion is matched with 8 individually powered quadrupoles. Layout and optics of the insertions at even points is shown in Fig. 6. At odd points the layout and optics are similar [1].

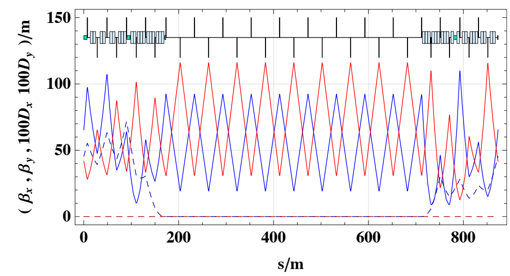

Figure 6: Insertion layout and optics at even points.

Bypasses

The general layout and nomenclature of the bypasses is illustrated in Fig. 7. The straight sections LSSL, LSSR and IR are dispersion free sections reserved for the installation of RF, wiggler(s), injection etc. Two normal arc periods (4 FODO cells), with 8 individually powered quadrupoles, are used as dispersion suppressor before the first straight section LSSL and after the last straight section LSSR. In the sections TLIR and TRIR the same configuration of dipoles is kept as in the idealised ring for geometric reasons. Among this fixed arrangement of dipoles, 14 matching quadrupoles per side are placed as evenly as possible. The complete bypass optics in Point 1 is shown in Fig. 7. At Point 5, layout and optics are roughly identical [1].

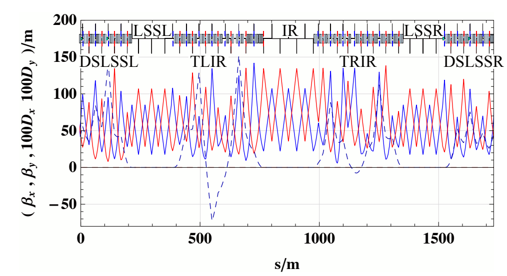

Figure 7: Bypass layout and optics in Point 1.

SUMMARY AND OUTLOOK

The design of the e-ring lattice presented in this paper is compatible with the most relevant LHC constraints and delivers the design parameters stated in the CDR [1]. So far only the linear optics have been investigated. Further steps would be non-linear optics and dynamics including the beam-beam interaction, which is already partly described in [1].

REFERENCES

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