PROTON BEAM DYNAMICS FOR CONCURRENT OPERATION OF THE LHeC AND THE HL-LHC

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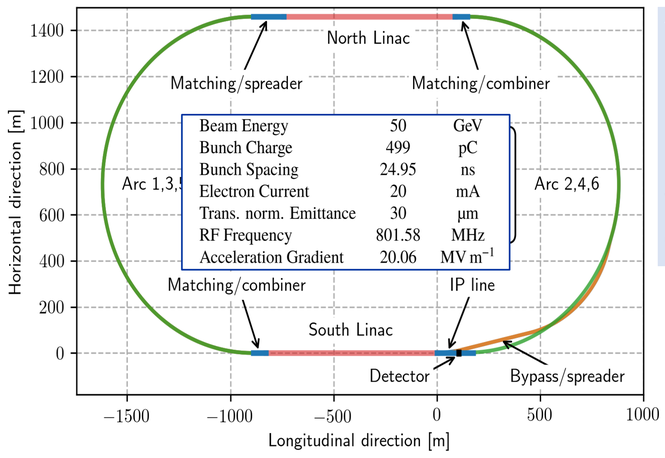
Introduction

The Large Hadron electron Collider (LHeC) is a feasibility study that investigates the possibility of high luminosity **electron-proton collisions** in one of the four interaction points of the High Luminosity Large Hadron Collider (HL-LHC). In the e-p interaction region design presented here, two modes of operation would be possible for the HL-LHC. Either hadron-hadron collisions in the four interaction points or e-p collisions in one of the interaction points, simultaneous to p-p collisions in the remaining three interaction points.

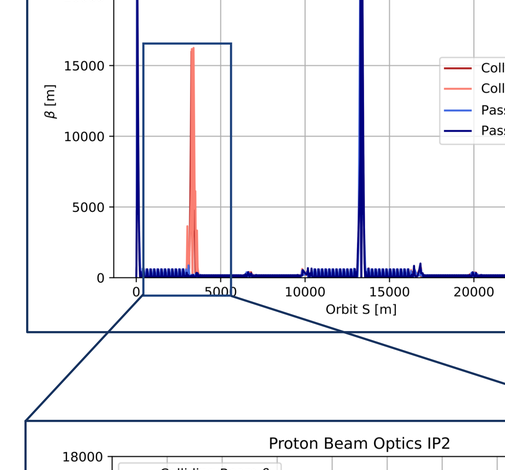
Overview of the LHeC



The electrons are accelerated in an Energy Recovery Linac (ERL) to a final energy of **50 GeV**.

Schematic of the energy recovery linac with its main parameters [2] [3] .

The two proton beams collide in point 1 (ATLAS), point 5 (CMS) and point 8 (LHCb). In P2, **p-p operation** (ALICE) **OR e-p operation** (LHeC) are possible.

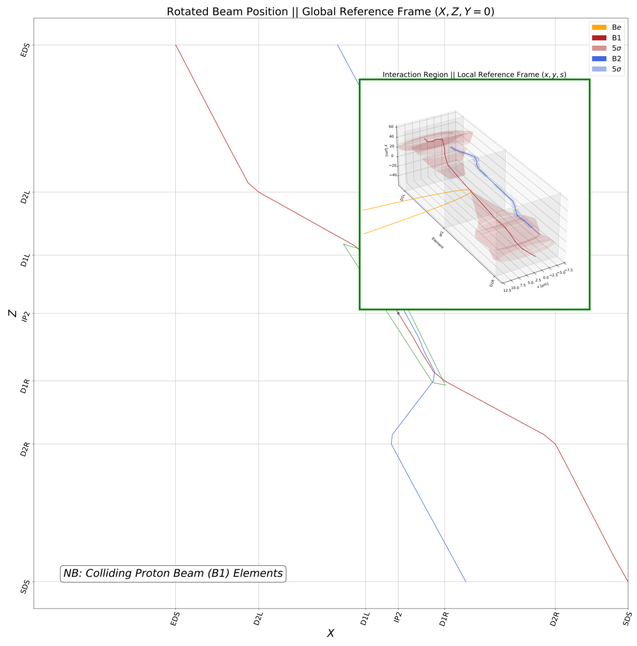


Layout of the LHeC. It shows the existing LHC infrastructures (grey), the high luminosity upgrades (blue) and the ERL (yellow) [1].

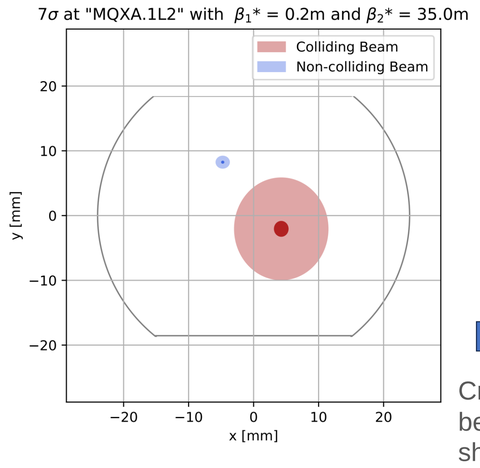
During **LHeC operation** the colliding proton beam (B1) collides head on with the electrons with a center of mass energy of $\sqrt{s} = 1.2$ TeV. The spectator proton beam (B2) is guided through the same beam pipe but spatially distanced from the e-p collision.

The e-p Interaction Region

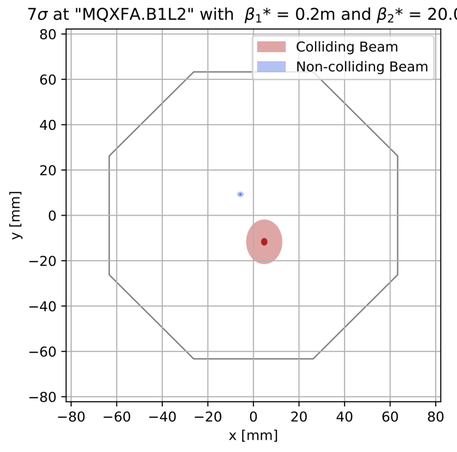
Schematic view of the **electron-proton** collision mode of the LHC with zoom into the interaction region.
The two proton beams, B1 and B2, are guided into a shared beam pipe.
Only the colliding proton beam (B1) collides head on with the electrons. These are first bent into the collision and then back into the ERL racetrack after collision.
The spectator proton beam (B2) is guided through the same beam pipe but spatially distanced from the e-p collision and continues to collide with B1 in the remaining three interaction points.



Installation of new Quadrupole Triplet Magnets



The existing NbTi triplet has been replaced with the Nb3Sn triplet designed for the HL-LHC upgrade.



Cross-section of the two proton beams in the quadrupole magnet shortly before collision.

Asymmetric Beam Optics

The two proton beams have asymmetric optics in the LHeC Interaction region.

The colliding proton beam (B1) optics is focused to low β* values for high luminosity collisions.

The spectator proton beam (B2) optics is relaxed to high β* values and to low γ* values, to maximize the distance between the two proton beams in the shared beam pipe.

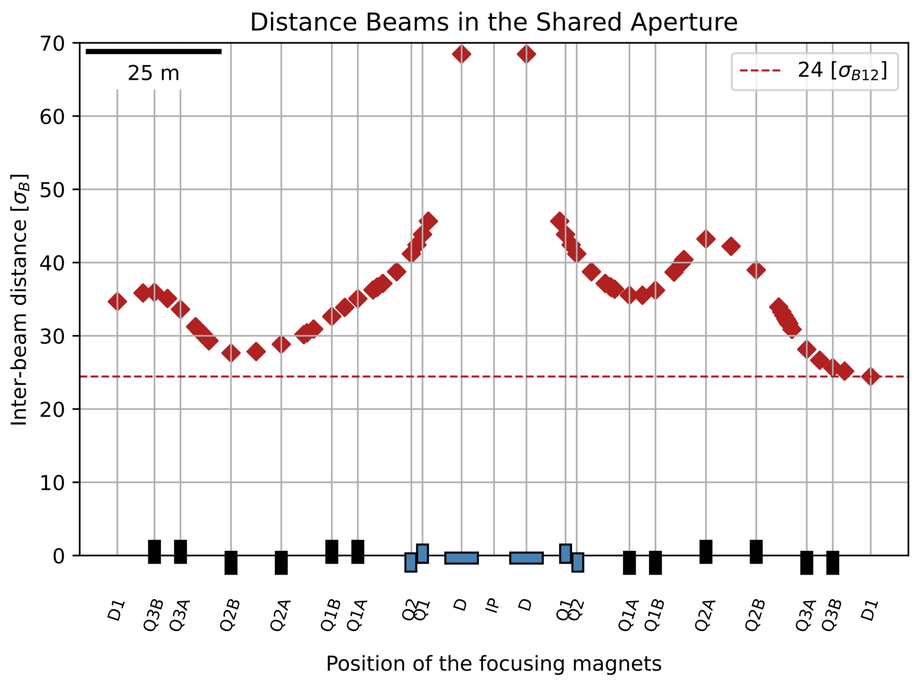
Optics of the two proton beams along the LHC, with a zoom into the LHeC interaction region. The optics of the colliding beam B1 are shown in red and the optics of the non-colliding beam B2 are shown in blue.

Summary & Outlook

Different and **modular proton beam optics** for concurrent e-p and p-p collisions in the HL-HLC have been **designed and optimized** for two different proton quadrupole triplets.

$ß_1$* [m]	0.2	0.25	0.3	0.35
$ß_2$* [m]	18-24	18-24	18-24	18-24
Luminosity [cm^{-2} s^{-1}]	2.5×10^{33}	2.0×10^{33}	1.67×10^{33}	1.4×10^{33}

Available optics for LHeC with β* values for proton B1 and proton B2 and the corresponding resulting e-p luminosity.



Distance between the two proton beams in their shared beam pipe in units of the mean σ beam size of B1 and B2. The electron dipoles and quadrupole doublet are shown in blue and the proton quadrupole triplet in black. The minimal distance between the beams amounts to 24σ in the separation dipole.

With this new design the proton beams can be separated by at least 24σ in the critical shared beam pipe aperture.

This is the first optics for LHeC to enable **concurrent e-p and p-p operation**, as well as **alternate h-h** operation in the HL-LHC.

Future research including beam-beam and additional high order effects in this collider is foreseen to finalize the design.

[1] P. Agostini, H. Aksakal, S. Alekhin, P. Allport, N. Andari, K. D.J. André, D. Angal-Kalinin, S. Antusch, L. A. Bella, L. Apolinario, et al., *The Large Hadron–electron Collider at the HL-LHC,* Journal of Physics G: Nuclear and Particle Physics, arXiv:2007.14491, 2007.
[2] K. D. J. André, *Lattice Design and Beam Optics for the Energy Recovery Linac of the Large Hadron-Electron Collider,* PhD thesis, University of Liverpool, DOI: 10.17638/03161486, 2023.
[3] K. D. J. André and B. Holzer, *Front-to-end simulations of the energy recovery linac for the lhec project*, IPAC Proceedings, 2021.
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