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Deep Inelastic Electron-Nucleon Scattering at the LHC*

J. B. Dainton[1], M. Klein[2], P. Newman[3], E. Perez[4], F. Willeke[2]

[1] Cockcroft Institute of Accelerator Science and Technology,
Daresbury International Science Park, UK
[2] DESY, Hamburg and Zeuthen, Germany
[3] School of Physics and Astronomy, University of Birmingham, UK
[4] CE Saclay, DSM/DAPNIA/Spp, Gif-sur-Yvette, France

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http://www-zeuthen.desy.de/lhec/LHeCprop.pdf

Abstract

The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, $10^{33}\text{cm}^{-2}\text{s}^{-1}$, and high energy, $\sqrt{s} = 1.4\,\text{TeV}$, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (ep, eD and eA) scattering for momentum transfers Q^2 beyond $10^6\,\text{GeV}^2$ and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense partonic systems, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure, as described in Quantum Chromodynamics, and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

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The physics and the design of a Large Hadron Electron Collider (LHeC) are sketched. It is illustrated that a unique and important programme of physics is possible with a 70 GeV electron/positron beam in collision with the 7 TeV LHC proton (and ion) beam at a luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$. Experiments at such a collider probe electron-quark and positron-quark physics in an unparalleled manner, thereby enabling a substantial extension of the discovery potential at the LHC and making possible measurements of a precision characteristic of lepton-hadron measurements. Highlights include

- Observation and precision measurement of new physics in the lepton-quark spectrum at the TeV scale, which could reveal unexpected and new leptoquark phenomena. The LHeC will provide precision measurements which are important to the interpretation and quantification of this new physics.
- Discovery and precision measurement of new physics in proton structure at very low Bjorken-x, which will be crucial to superhigh energy neutrino physics, to forward physics at the LHC and basically to the development of our understanding of QCD in the high parton density, low coupling limit, and thereby the phase equilibria of chromodynamics in a variety of hadronic systems at the TeV energy scale.
- A new level of precision measurements and precision tests of the validity of QCD at a new distance scale, corresponding to substructure dimensions of 10^{-19} m, which promise to have a direct bearing on the overall consistency of the Standard Model and its underlying physics as one moves towards the unification scale.
- Measurements which will make possible the determination of parton distribution functions of nucleons and nuclei over a hitherto inaccessible kinematic range in probe scale (Q^2) and longitudinal momentum fraction (Bjorken-x), and which are essential if the sensitivity at the LHC to new and rare physics in both pp and ep physics is to be optimised.
- The energy densities achieved in an AA interaction at the LHC are immense, and to fully explore the nature of the interactions will require comparable data in pA, pp, and eA collisions. LHeC and the LHC will thus constitute an experimental tool unparalleled in the history of hadron physics in that nowhere else has there ever been such a range of possible measurements at such an energy scale.

A conceptual design of a high luminosity Large Hadron Electron Collider, the LHeC, is presented. The approach takes advantage of developments in technology which are now well advanced, and which are necessary for future electron/positron linear accelerators, to achieve an electron/positron storage ring of for example 70 GeV energy in the LHC tunnel. It is shown how, with the careful design of the RF structure and the interaction region, it is possible to achieve a luminosity of $10^{33}\,\text{cm}^{-2}\text{s}^{-1}$ in collisions with one of the LHC hadron beams. The solution is based on 25 ns bunch spacing with a small crossing angle of 0.5 mrad which requires crab-crossing for the proton beam. The concept is aimed at the simultaneous operation of LHC and LHeC and first considerations of how this can be achieved are stated. Wherever possible, realistic constraints are included based on past operation of electron storage rings and on the operation of the HERA electron and proton storage rings at DESY Hamburg. Further work is needed to address a number of issues which have yet to be resolved concerning the feasibility of such a concept. Nevertheless, to date it appears not unreasonable to continue to contemplate a major and important ep physics programme at the TeV scale as part of the physics programme of the LHC.