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The LHeC Detector Design Concept

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The Conceptual Design Report for the Large Hadron Electron Collider has recently been released. This contribution summarises the part of the report covering design concepts for a new detector, which combines the demands of very high precision with those of large acceptance into a novel device for electron-proton physics at TeV energies. The physics and technical requirements, the choices of detector techniques and the integration of the detector with the 3 beam interaction region including its magnet designs are presented.

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1. Introduction

At the LHeC [1], electrons of energy from 60 GeV and up to 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 physics program is devoted to an exploration of the TeV 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 continuing and extending the unique analysis of DIS lepton-hadron scattering by a factor of twenty in the four-momentum squared, Q^2, and in the inverse Bjorken x. A huge physics potential is opened also by the $(Q^2,\ 1/x)$ region accessible in electron-ion (eA) scatterings which at the LHeC is by four orders of magnitude larger compared to previous lepton-nucleus DIS experiments.

The LHeC Conceptual Design Report has recently been released [2]. This writeup presents the main aspects of detector design. Section 2 summarizes the overall requirements coming from the physics and the constraints from the accelerating machine. The detector layout along with a description of the main detector components are discussed in Section 3. An outlook on the project is given in 4.

2. Requirements and Constraints

The new ep/A detector at the LHeC has to be a precision instrument of maximum acceptance. The physics program depends on a high level of precision, as for the measurement of α_s, and in the reconstruction of complex final states, like the charged-current single-top production and decay or the precision measurement of the b-quark density.

Fig.1 shows the kinematics of scattered electron and of the interacting hadronic final state detection as a function of Bjorken x, and the fourmomentum trasfer squared Q^2. The acceptance has to extend as close as possible to the beam axis because of the interest in the physics at low and at large Bjorken x. The dimensions of the detector are constrained by the radial extension of the beam pipe in combination with maximum polar angle coverage desirably down to about 1° and 179° for forward (i.e. along the proton outgoing direction) final state particles and backward scattered electrons at low Q^2, respectively.

The LHeC interaction region poses additional constraints coming from a complex optics which includes 3 beams (the interacting protons and electrons and the second spectator proton beam). Two options for providing the electron beam are presently being discussed. In the Ring-Ring design (RR), an electron ring is installed on top of the existing LHC requiring for high luminosity running additional strong focusing magnets located at 1.2 meters from the interaction point. In the Linac-Ring (LR) option an Energy Recovery Linac provides the electron beam. Special arrangement has to be done in order to avoid parasitic interactions which for the LHC bunch spacing of 25 ns requires either a non null crossing angle (RR) or an extra dipole field (LR) along the whole length of the central detector and beyond. A sketch of the interaction region for this second and more complex case is shown in Fig.2-a. Synchrotron radiation coming from the deflection of the electron beam will need an asymmetric beampipe to accomodate for the synchrotron fan which needs to pass the central detector area as depicted in Fig.2-b.

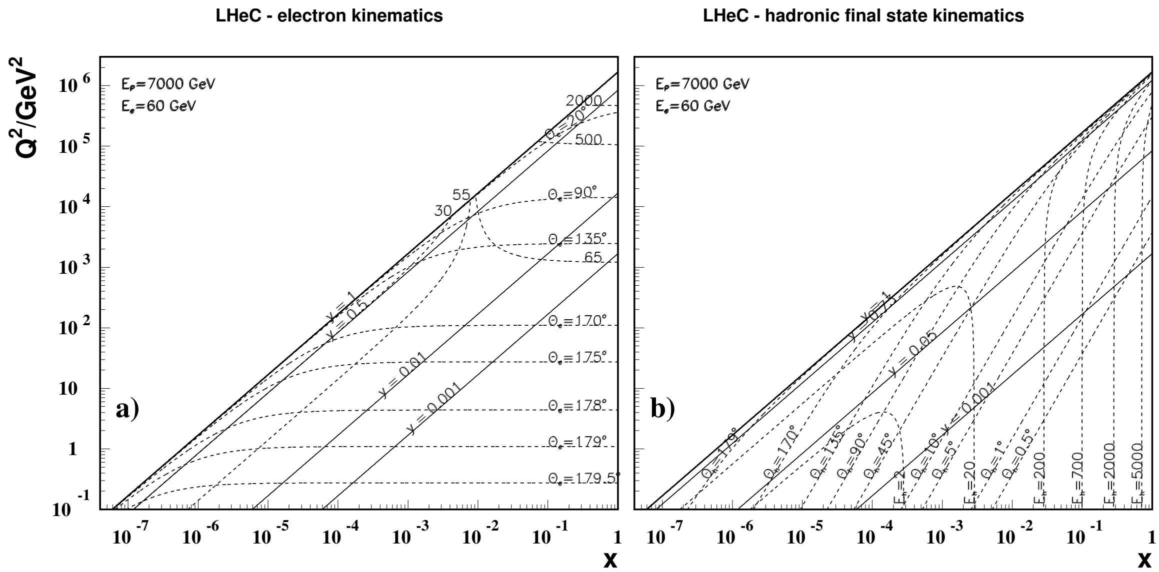

Figure 1: **a)** Kinematics of electron detection at the LHeC. Lines of constant scattering angle θ_e and energy, in GeV, are drawn. The region of low Q^2 ($\leq 10\,\mathrm{GeV}^2$), comprising the lowest x region, requires to precisely measure electrons scattered backwards with energies not exceeding E_e. **b)** Kinematics of hadronic final state detection at the LHeC. Lines of constant energy and angle of the hadronic final state are drawn, as represented by simple kinematics of the struck quark. One easily recognizes that the most demanding region is the large x domain, where very high energetic final state particles are scattered close to the (forward) direction of the proton beam.

A further general requirement to the detector is a high modularity to enable the bulk of the construction phase to be performed above ground and therefore keep the installation time at a minimum, and allow to access inner detector parts within reasonable shutdown times. The time schedule of the project demands to have the detector ready within about ten years from now, for the LHC Phase II running (around year 2023). This prevents any significant R&D program to be performed although the project can still rely on the vast experience from HERA, the LHC, including its detector upgrades to come, and the ILC. Compared to the LHC pp program, the expected radiation level at the LHeC appear to be lower, and the ep cross section low enough for the experiment not to suffer from pile-up, which are the two most demanding constraints for the ATLAS and CMS detector upgrades.

3. Detector Design

The LHeC detector has to be hermetic in order to maximize coverage especially in the forward and backward regions and provide precise energy and missing energy, the latter being the signature for charge-current processes where the incoming electron is converted into an outgoing neutrino. The LHeC detector is asymmetric in design, reflecting the beam energy asymmetry. Moving from the interaction region outwards, a light beampipe surrounded by a precision tracking detector with extended forward and backward parts is required before reaching the electromagnetic calorimetry. A strong solenoid (3.5 Tesla) is needed for momenta separation and long dipoles of 0.3 Tesla are required in the LR configuration along the whole interaction region from $z = -9m$ to $z = +9m$ pro-

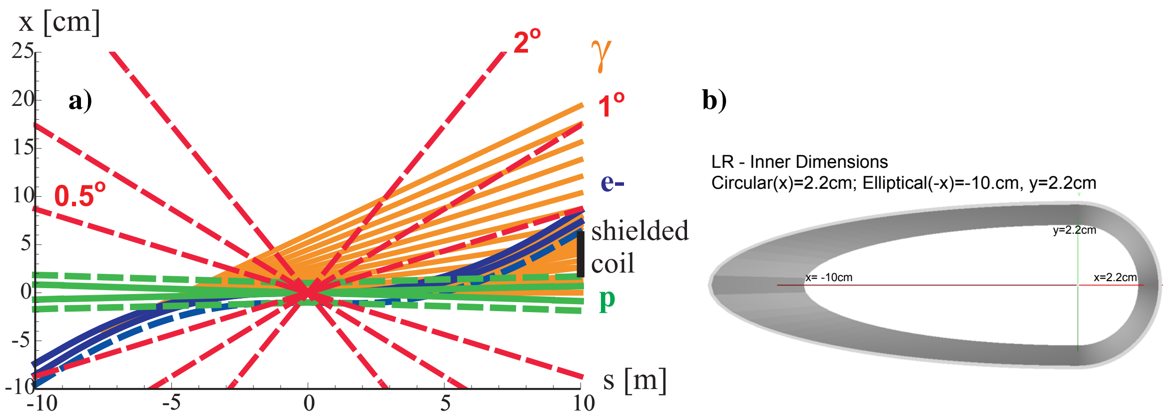

Figure 2: a) LR interaction-region layout. Shown are the beam enevelopes of 10σ (electrons) [solid blue] or 11σ (protons) [solid green], the same envelopes with an additional constant margin of 10 mm [dashed], the synchroton-radiation fan [orange], the approximate location of the magnet coil between incoming protons and outpgoing electron beam [black], and a 1° line. **b)** Perspective drawing of the beam pipe and its dimensions in the LR configuration. The dimensions consider a 1 cm safety margin around the synchrotron radiation envelope.

viding a field in a region not too extended in radius. The requirement of a precise electron energy measurement and not too large beam-steering magnets, suggest to have the solenoid and the dipoles integrated in a single structure placed immediately outside of the electromagnetic calorimetry. The hadron calorimeter surrounds therefore the magnet system and is enclosed in a muon tracker system. The described detector layout is shown in Fig. 3. The inner detector dimensions along the beamline are constrained by the radial extension of the beam pipe in combination with maximum polar angle coverage (1° and 179°) for forward going final state particles and backward scattered electrons at low Q^2, respectively. The outer radial size is mainly determined by the requirement of full energy containment of hadronic showers in the calorimeter. The main detector is complemented by hadron tagging detectors (not shown) in the forward direction and a polarimeter and luminosity measurement system backwards. Below some details for the different subdetectors are given.

3.1 Tracking System

The constraints given by the magnet system (solenoid/dipoles) force the tracking detectors to be kept small in radius. The baseline layout is an all-Silicon detector, for high momentum resolution[1] and secondary vertices tagging extending over the pseudorapidity range of $-4.8 < \eta < 5.5$. Pixels are used in the inner layers while strips or strixels are used in the external layers summing up to a total area of about 34 m^2 of Silicon sensors including also the forward and backwards tracker discs. All of the components need power and cooling, influencing the material budget of the tracker system which should be kept as low as possible. The technology used must be advanced at the industrial level, radiation hard and relatively cheap.

[1]Momentum resolution: $\delta p_t/p_t^2 \simeq 0.001\ c/\mathrm{GeV}$ for $p_t = 100$ GeV and $4°\theta \leq 90°$; impact parameter resolution $\delta ip \simeq 10\mu m$ for $4°\theta \leq 90°$. Data obtained using the LicToy simulation program.

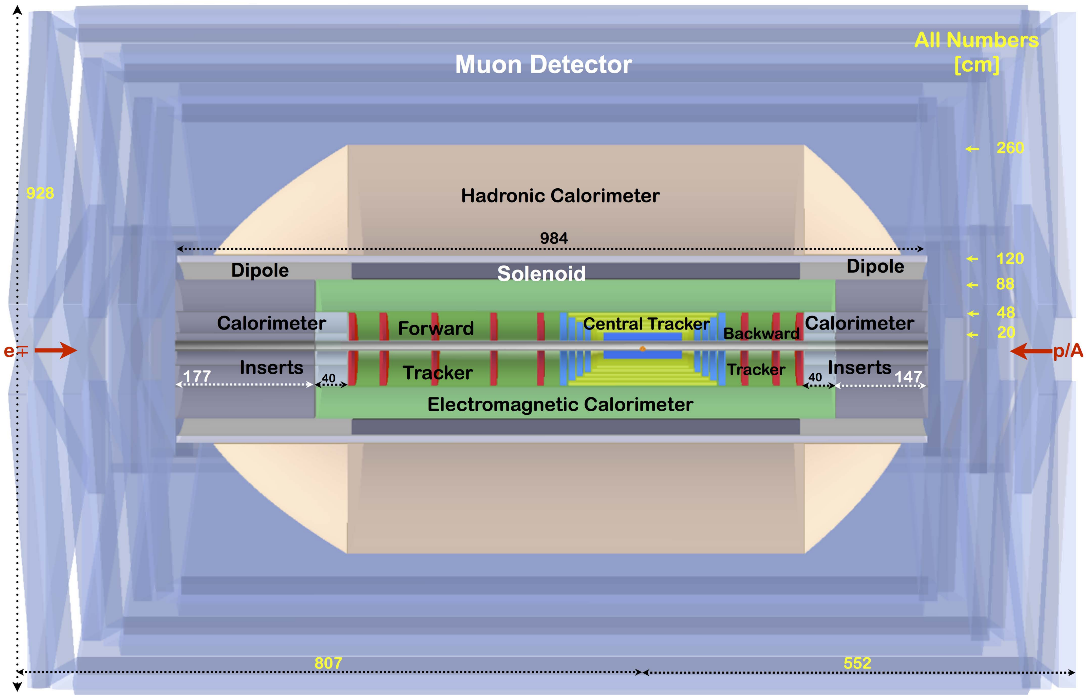

Figure 3: An *rz* cross section of the LHeC detector in its baseline configuration with the magnet configuration for LR with the solenoid and dipoles placement between the electromagnetic and the hadronic calorimeters. The proton beam, from the right, collides with the electron beam, from the left, at the IP which is surrounded by a central tracker system complemented by large forward and backward tracker telescopes followed by sets of calorimeters.

3.2 Calorimetry

A modular structure of independent electromagnetic (EMC) and hadronic (HAC) calorimeter components is foreseen. The design of the EMC modules differs for the very forward region, where energies up to few TeV are expected and the barrel and backward regions where lower energies and a precise measurement of the scattered electron are paramount. Based on experience with H1 and ATLAS the EMC the default choice is a Liquid Argon (LAr) Calorimeter. The superconducting dipoles are placed in a common cryostat with the detector solenoid and the LAr EMC. The HAC is an iron-scintillator tile calorimeter which provides the required mechanical stability for the inner LAr and Magnet cryostat and guides the return flux of the magnetic field, as in ATLAS. The restrictive geometry of the forward/backward insert calorimeters requires a non-conventional and challenging design using silicon readout in conjunction with tungsten as the absorber material, in particular for the forward inserts. For the hadronic absorber, also copper might be considered as an alternative. The choice of the sampling calorimetry for all calorimeter parts is motivated by the good experience from past experiments along with considerations on the available technologies, and cost, although other approaches (dual readout or fully active calorimetry, etc.) could be considered. Preliminary simulations on all calorimeters parts including the dead material of the magnet system have been done using the GEANT4 and FLUKA programs and support a satisfactory performance.

3.3 Muon Detection

Muon detection is an important aspect of the LHeC physics program as it can improve the scope and the spectrum of many measurements, like Higgs decay, leptoquarks, lepton flavor violation, PDF fits from semileptonic decay of hadrons and heavy favors, vector meson production. The two LHC general purpose detectors, ATLAS and CMS, combine Drift Tubes and Cathode Strip Chambers for precision measurements along with Resistive Plates Chambers and Thin Gap Chambers for Trigger and second coordinate measurements. A similar approach can also be considered for the LHeC although, for the baseline design, the muon detectors will not provide an independent momentum measurement since no strong magnetic field is present. Other technologies along with further developments of the existing ones, might also be considered for the LHeC. The use of a forward toroid to improve the momentum measurement in the forward region where high energy muons are expected is beeing evaluated. Of particular interest is also the option where, by means of a second larger active return shielding solenoid surrounding the muon detector, an iron free area with almost constant field (1.5T) provides a precise muon tracking as was first proposed by the 4th concept detector collaboration for the ILC.

3.4 Forward and Backward Detectors

The central detector is complemented by forward and backward detectors to extend the coverage in the regions at very small angles both in the proton and electron direction and aiming at the measurement of very forward diffractive nucleons, the electron or positron beam polarisation and the instantaneous luminosity. The placement of dedicated taggers both forward and backward along the beam pipe will also provide additional means to trigger and select data for specific diffractive and photoproduction analyses. Studies and simulations confirm the feasibility and compatibility of these elements to the LHC beam optics.

4. Conclusions and Outlook

The LHeC is a project with an ambitious physics program which complements the measurements of present and future *pp* and lepton collider experiments. A baseline design and some extensions for the LHeC detector have been presented. Further developments are ongoing, aiming at a precise simulation of the interaction region first and a framework for a full detector simulation later. The LHeC detector will undergo changes and optimizations when new groups will join its development. The choice of components for the LHeC detector can rely on the experience obtained at HERA, at the LHC, including its detector upgrades currently being developed, and also on detector development studies for the ILC. The detector development, while requiring prototyping, may yet proceed without an extended R&D program. A roadmap with an LHeC taking data concurrently with the other experiments during the LHC high luminosity program appears feasible.

References

[1] M. Klein, “The LHeC Project”, ICHEP 2012, Melbourne 2012, these proceedings.

[2] J. L. Abelleira Fernandez *et al.* [LHeC Study Group], “A Large Hadron Electron Collider at CERN" J.Phys.G. **39**(2012)075001, arXiv:1206.2913.

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