

# The LHeC and its low $x$ Physics Potential

*J. B. Dainton*<sup>1†</sup>, *M. Klein*<sup>2</sup>, *P. R. Newman*<sup>3</sup>

<sup>1</sup> Cockcroft Institute of Accelerator Science and Technology,

<sup>2</sup> University of Liverpool

<sup>3</sup> University of Birmingham

## Abstract

This contribution briefly recounts a talk given by one of us at the workshop on the potential and prospects for colliding electrons with protons or heavy ions at the LHC, as currently considered in the framework of the LHeC. Particular emphasis is placed on the opportunities which the LHeC offers for exploring low  $x$  physics.

## 1 The Large Hadron Electron Collider

Plans are being developed to build a Large Hadron Electron Collider (LHeC) as a complement to the LHC. The LHeC makes possible deep-inelastic lepton-hadron ( $ep$ ,  $eD$  and  $eA$ ) scattering for 4-momentum transfers squared  $Q^2$  beyond  $10^6$  GeV<sup>2</sup> and for Bjorken- $x$  down to  $10^{-6}$ , see Figure 1. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense Quantum Chromodynamics, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure and of parton dynamics at the LHC energy scale.

Currently two versions of the LHeC are under consideration, a ring-ring collider [1], with high luminosity of the order of  $10^{33}$  cm<sup>-2</sup>s<sup>-1</sup> and electron beam energies up to typically 70 GeV, and a linac-ring collider [2,3], with luminosity of the order of  $5 \cdot 10^{31}$  cm<sup>-2</sup>s<sup>-1</sup> but possibly much increased electron beam energies (up to perhaps 140 GeV). In the coming years the accelerator, the physics and the detector will be further investigated and, under the auspices of CERN and ECFA, a Conceptual Design Report is being worked out [3]. The LHeC could be operated simultaneously with  $pp$  collisions in a late phase of the LHC and would thus expand significantly the physics programme carried out at CERN in the future. Much more detailed information can be found at [4].

## 2 Low $x$ Physics

The energies at the LHeC are so high that one expects parton densities at low  $x$  to reach the limits at which dynamical changes must occur in order to satisfy unitarity. This implies that definitive answers may be obtained to the questions raised by HERA as perhaps its most enduring legacy: namely its pioneering contribution to low  $x$  physics, stimulated by the strong rise of the proton quark ( $\sim F_2$ ) and gluon ( $\sim \partial F_2 / \partial \ln Q^2$ ) densities with decreasing  $x$ . These observations have established a new field in Quantum Chromodynamics, its high density, low coupling limit, in which matter in a new state may be explored. Other striking HERA discoveries associated with

---

<sup>†</sup> speaker

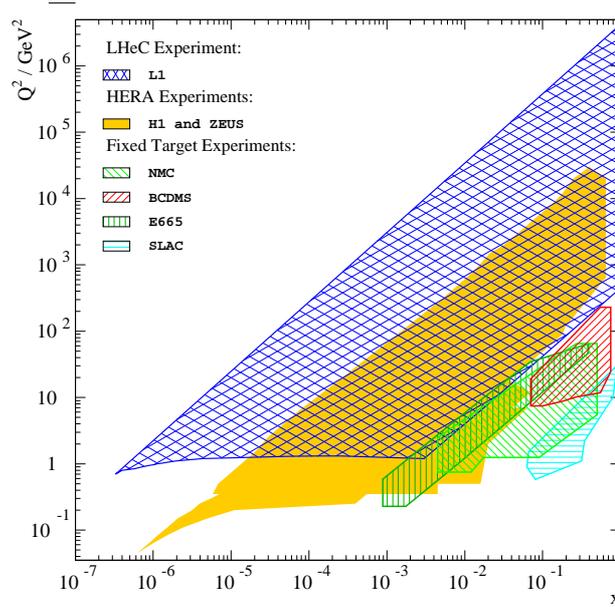


Fig. 1: Kinematic coverage of fixed target, HERA and LHeC deep inelastic lepton-proton scattering experiments (DIS). The LHeC, here assumed to be a  $140 \times 7000 \text{ GeV}^2$  collider, is equivalent to a fixed target experiment with PeV beam energy and thus represents a huge extension of the kinematic range compared to the first DIS experiments. In the course of the work on the CDR, a detector, here called L1, will be designed and its measurement accuracy and kinematic coverage will be studied.

low  $x$  physics have been the process of hard diffraction in DIS and the Deeply Virtual Compton Scattering process (DVCS,  $ep \rightarrow e\gamma p$ ), both of which have been now been investigated in some detail. The LHeC will allow these fields to be developed in much greater depth, both in electron-proton scattering, as can only be sketched below, and in electron-ion scattering. In the  $eA$  case the gain in kinematic coverage is astonishing, since the DIS  $lA$  experimental coverage is extended by 4 orders of magnitude in  $Q^2$  and  $x$  and, moreover, since parton densities are expected to be amplified  $\propto A^{1/3}$ .

• **Inclusive Cross Sections and Parton Saturation:** It is expected that parton saturation effects could be conclusively established at the LHeC through the observation of deviations from expectations for one or more observable in the framework of perturbative QCD. In such studies at HERA, models based on colour dipole scattering [5–7] have been used in order to access the necessary very low  $Q^2$  values.

In one example dipole study of HERA data [6], the inclusive structure function  $F_2(x, Q^2)$  is subjected to fits in which the dipole cross section either does not exhibit saturation properties, or saturates as expected in two rather different models [6, 7]. All three dipole fits are able to describe the HERA data adequately in the perturbative region  $Q^2 \geq 2 \text{ GeV}^2$ , whereas a clear preference for the models containing saturation effects becomes evident when data from the range  $0.045 < Q^2 < 1 \text{ GeV}^2$  are added [6]. Due to the non-perturbative nature of this kinematic

region, there is no clear interpretation in terms of parton dynamics (for example recombination effects,  $gg \rightarrow g$ ). Similar conclusions are drawn when the same dipole cross sections are applied to various final state observables [8].

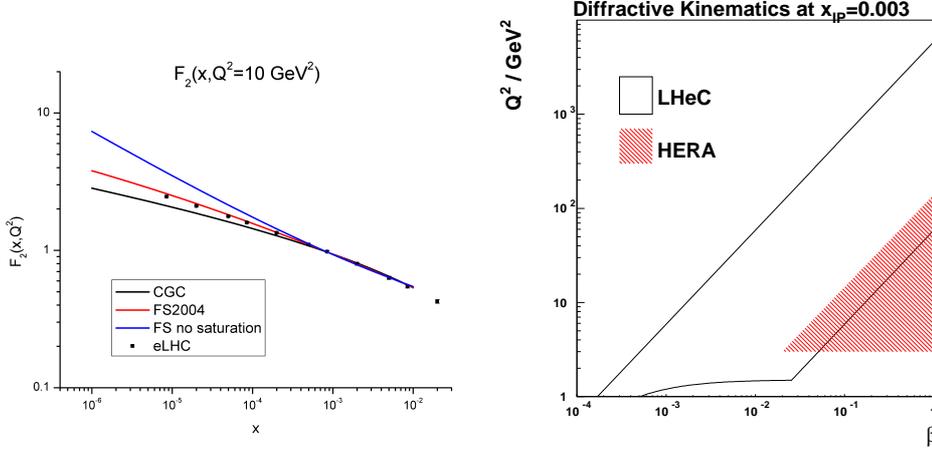


Fig. 2: Left: Example results from fits to HERA  $F_2$  data with  $10^{-4} \lesssim x < 10^{-2}$  using three different dipole models. The curves are extrapolated to lower  $x$  values [9] and compared with simulated LHeC data. Right: The  $\beta - Q^2$  kinematic plane for diffractive DIS at HERA and the LHeC for an example  $x_p = 0.003$ .

Figure 2 shows an extrapolation of the three dipole models [6] into the LHeC kinematic range at an example  $Q^2 = 10 \text{ GeV}^2$ . The extrapolations are compared with a simulated LHeC measurement with  $1 \text{ fb}^{-1}$ , where statistical errors are negligible and reasonable estimates of systematic errors are at the 1–3% level. The LHeC data clearly distinguish between the extrapolated fits to HERA data without resorting to a region where perturbative methods are inapplicable. It remains to be shown whether this continues to be the case when the LHeC data are also included in the fits.

• **Diffractive DIS:** Statistical uncertainties should be insignificant for the measurement of a diffractive DIS cross section with  $1 \text{ fb}^{-1}$  at the LHeC. Systematic errors are estimated to be in the region of 5–10%, depending strongly on the design of the forward region of the detector. At an example  $Q^2 = 10 \text{ GeV}^2$ ,  $x_p$  values below  $10^{-5}$  are accessible, allowing a very clean separation of the diffractive exchange from sub-leading contributions. The  $\beta = x/x_p$  and  $Q^2$  kinematic plane at HERA and the LHeC is illustrated in Figure 2, for an example  $x_p = 0.003$ . Accessing higher  $Q^2$  at fixed  $\beta$  and  $x_p$  will test the factorisation properties of diffraction [10] in detail and will allow more precise constraints on diffractive parton distribution functions (DPDFs), including sensitivity to their flavour decomposition through  $W$  and  $Z$  exchange contributions. The low  $\beta$  region of the DPDFs, which, through the basic exchange of a pair of gluons, is particularly sensitive to parton saturation effects or other novel QCD dynamics, will be investigated for the first time.

• **Deeply Virtual Compton Scattering** As at HERA, measurements of DVCS could be made at the LHeC through the inclusive selection of  $ep \rightarrow ep\gamma$  events and the statistical subtraction of the Bethe-Heitler background. A first simulation [11] has been performed assuming that final state photons with  $p_{\perp} > 5$  GeV can be efficiently selected. With  $10 \text{ fb}^{-1}$ , a precision measurement becomes possible over an unprecedented range with, e.g. seven bins of  $W$  between 150 GeV and 750 GeV at  $Q^2 = 30 \text{ GeV}^2$ , with 1 – 4% statistical uncertainty. With the huge luminosity possible compared with HERA and the much extended kinematic range, the LHeC is likely to provide unique information on Generalised Parton Densities.

**To summarize**, with the LHeC the physics of deep inelastic scattering has a fascinating future, based on the powerful  $p$  and also  $A$  beams at the LHC. DIS physics will be led to new horizons at large scales, with sensitivity to  $eq$  masses up to 2 TeV. Correspondingly very low  $x$  values may be accessed in the DIS region, where a host of new and exciting measurements are possible, of which this report has barely scratched the surface. QCD is the richest theory of fundamental interactions and much is still to be done for its deep exploration!

### Acknowledgement

We would like to thank Hannes Jung for his encouragement to submit this summary and his efforts to let the community share the excitements of QCD.

### References

- [1] J. Dainton et al., JINST 1 (2006) P10001.
- [2] S. Chattopadhyay and F. Zimmermann, private communication.
- [3] ECFA talk of M. Klein, November 2007, in [4].
- [4] For more detailed information on the LHeC project, see <http://www.lhec.org.uk>.
- [5] K. Golec-Biernat, M. Wüsthoff, Phys. Rev. D59 (1999) 014017.
- [6] J. Forshaw, G. Shaw, JHEP 0412 (2004) 052.
- [7] E. Iancu, K. Itakura, S. Munier, Phys. Lett. B590 (2004) 199; H. Kowalski, L. Motyka, G. Watt, Phys.Rev. D74 (2006) 074016.
- [8] J. Forshaw, R. Sandapen, G. Shaw, JHEP 0611 (2006) 025.
- [9] J. Forshaw, private communication.
- [10] For a HERA investigation, see e.g. H1 Collaboration, Eur. Phys. J. C48 (2006) 715, *ibid* 749.
- [11] L. Favart, private communication.