Perspectives on DIS and the LHeC

Max Klein[1]

[1]University of Liverpool, Department of Physics, United Kingdom

DOI: http://indico.cern.ch/contributionDisplay.py?contribId=xy&confId=153252

This paper is a brief summary of a plenary talk held to conclude DIS12 with considerations on the future of deep inelastic scattering. It is primarily based on the perspectives which have been obtained in a few years of study on the physics and the design concepts of a second energy frontier *ep* and a first *eA* collider, the Large Hadron Electron Collider (LHeC), which following HERA may commence operation at CERN in the early twenties.

1 Introduction

This writeup is on a concluding plenary talk [1] held at the 2012 conference on Deep Inelastic Scattering (DIS) at Bonn. The talk was devoted to perspectives in DIS as arise newly from the prospect for a TeV energy scale electron-proton and electron-ion collider, the LHeC, which relies on the unique hadron beams of the LHC. The talk was delivered at the eve of the discovery of the Higgs boson by the ATLAS and CMS experiments, which have excluded much of the expected new physics, as from SUSY, in the about $0.5-1$ TeV mass region. The three colliders, the Tevatron, LEP/SLC and HERA, which dominated particle physics for recent decades, have now all terminated operation and their data analyses are approaching completion. It had thus for various reasons been a special moment to examine perspectives of the physics of deep inelastic scattering, which has been part of the development of modern particle physics so successfully, not only by discovering quarks but also, for example, by providing the gluon distribution without which there would be no understanding of the Higgs cross section in *pp* at the LHC.

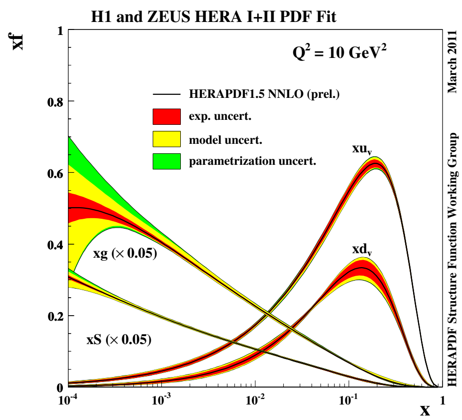

Figure 1: A determination of parton distributions at NNLO based on the HERA data.

If there was one figure to illustrate the current legacy of DIS, perhaps it is close to Fig. 1. It reveals that the proton structure at momentum fractions larger than $x \sim 0.2$ is determined by the up and down valence quarks, pointlike constituents of the proton which where discovered at SLAC in the first deep inelastic electron-proton scattering experiment, back in 1969. It then illustrates, note the downscaling factor of 0.05, that at lower fractions of $x \lesssim 0.1$ the momentum is carried by gluons dominantly and also by sea quarks while the valence quark distributions, albeit not directly measured yet at low x, vanish. Based on the rise of F_2 and of $\partial F_2/\partial \log Q^2$, as discovered at HERA, the sea and the gluon distributions increase towards low x, with the uncertainty of the xg determination below $x \simeq 3 \cdot 10^{-4}$ becoming too large for any meaningful distinction between a steady and a tamed rise. This and similar PDF determinations from a number of well known and cooperating groups are indeed major achievements of particle physics of eminent importance, particularly when combined with the assumption of universality of PDFs which relies on the factorisation theorem. The different bands hint to the highly developed techniques of distinguishing various sources of uncertainty. And finally, the theory is now available and used to N^2LO, which is as remarkable as the range and precision of the DIS data, mostly but not exclusively from HERA. The DIS12 workshop was yet another vivid demonstration of the richness of DIS physics, with remarkable new measurements obtained as on heavy quarks, diffraction or jets, for example. And yet, HERA is reaching its completion and thus, independently of the Higgs discovery, of the LHC physics or the termination of the Tevatron, there are intrinsic DIS reasons to newly examine its perspectives and their possible realisation.

Just at about the time of the Bonn workshop the comprehensive LHeC design report (CDR) approached completion, which is now published [2]. The talk was thus invited to coherently describe the status and development of the LHeC and its role for the future of deep inelastic scattering, as well as for particle physics from the perspective of DIS. At the workshop it was again well demonstrated that the field is not short of important initiatives and ideas to develop DIS also at medium and low energies, as with precision, with polarised and lower energy eA measurements and the development of the $3D$ view on the nucleon, for example. While an attempt had been made to include in the presentation [1] also the designs and a sketch of the physics programme of the EIC projects, under development at BNL and Jlab, this is not included in the current short writeup. Instead, reference is made to other workshop contributions and their summaries [3], and also to the extended summary of the EIC science case from a recent workshop [4]. An instructive overview on current ep collider projects, including lower energy machines, is given in the very recent issue of the ICFA Beam Newsletter [5].

The importance of the LHeC for DIS and particle physics cannot be underestimated. It exceeds the luminosity of HERA by a factor of 100 and reaches a maximum Q^2 of above $1\,\mathrm{TeV}^2$ as compared with a maximum of $0.03\,\mathrm{TeV}^2$ at HERA. Correspondingly the lowest Bjorken x covered in the DIS region with the LHeC is about 10^{-6}, where gluon saturation is expected to exist. This coverage allows a multitude of crucial DIS measurements to be performed, to complement and extend the search potential for new physics at the LHC, and it also makes the LHeC a testing ground for the Higgs boson cleanly produced in WW and ZZ fusion in ep. The extension of the kinematic coverage in DIS lepton-ion collisions amounts to nearly 4 orders of magnitude and can be expected to completely change the understanding of quark-gluon interactions in nuclei, tightly constraining the initial conditions of the formation of the quark-gluon plasma (QGP). The LHeC project represents a unique possibility to take forward the field of DIS physics as an integral part of the future high energy physics programme. It enhances the exploration of the accelerator energy frontier with the LHC. Naturally it is linked to the LHC time schedule and lifetime, which is estimated to continue for two decades hence. Therefore, a design concept has been presented which uses available, yet challenging, technology, both for the accelerator and for the detector, and time schedules are considered for realising the LHeC within about the next decade.

The following presents a brief summary of the physics, a detector and the accelerator design of the LHeC. Following the Bonn DIS workshop, at an LHeC workshop in June 2012 [6], the project had been examined in detail, a mandate been given by CERN to prototype the most crucial technical elements, and a decision has been taken, in agreement with the CERN directorate, to pursue the linac option of the LHeC in the coming years, considering the ring option as a backup, in case new technical or physics developments were suggesting to revisit that configuration.

2 Physics Perspectives with the LHeC

Basic Programme

The LHeC, with a multi-purpose detector, has a unique physics programme of deep inelastic scattering, which can be pursued with unprecedented precision over a hugely extended kinematic range. This comprises a per mille level accuracy measurement of α_s, accompanied by ultra-precise charm and beauty density measurements, the accurate mapping of the gluon field over five orders of magnitude in Bjorken x, from $x \simeq 3 \cdot 10^{-6}$ up to x close to 1, the unbiased resolution of the complete quark content of the nucleon, including first direct measurements of the Q^2 and x dependences of the strange and top quark distributions, and the resolution of the partonic structure of the photon. Neutron and nuclear structure can be explored in a vast new kinematic region, as these were uncovered by HERA, and high precision electroweak measurements can be made, for example of the scale dependence of the weak mixing angle $\sin^2\Theta_W$ and of the light-quark weak neutral current couplings. These and more exclusive measurements of e.g. jets and diffraction at high energy and mass scales, represent new challenges for the development of Quantum Chromodynamics to a new level of precision. By accessing very low x values, down to 10^{-6} at $Q^2 \simeq 1\,\mathrm{GeV}^2$, the LHeC is expected to resolve the question of whether and how partons exhibit non-linear interaction dynamics where their density is particularly high, and whether indeed there is a damping of the rise of the parton densities towards low x, a question also related to ultra-high energy neutrino physics, which probes very small x values.

Relation to QCD: Developments and Discoveries

The ultra-high precision measurements with the LHeC challenge perturbative QCD to be further developed, by preparing for a consistent DIS analysis to N^3LO. Precision measurements of generalised parton distributions in DVCS are necessary for the development of a parton model theory based on scattering amplitudes and the development of a 3-dimensional view of the proton. Analysis in the extended phase space will pin down the mechanism of parton emission and will determine unintegrated, transverse momentum dependent parton distributions for the description of ep as well as pp final states. The coverage of extremely low x regions at $Q^2 \geq 1\,\mathrm{GeV}^2$, both in ep and in eA, will establish the basis for the theoretical development of non-linear parton evolution physics. High energy ep scattering may be important for constructing a non-perturbative approach to QCD based on effective string theory in higher dimensions. Instantons are a basic aspect of non-perturbative QCD, which also predicts the existence of the Odderon, a dressed three-gluon state, and both are yet to be discovered. A new chapter in eA scattering will be opened with measurements of unprecedented kinematic range and precision, allowing huge progress in the understanding of partonic interactions in nuclei, which is still in its infancy. It will also probe the difference between hadronisation phenomena inside and outside the nuclear medium. The establishment of an ultra-high parton density, "black-body" limit in DIS would change the scaling behaviour of the structure functions and the rates with which diffraction and exclusive vector meson production occur. QCD is a subtle theory which is far from being mastered and many of its areas call for a renewed and extended experimental basis.

Relations to LHC Physics

Deep inelastic scattering is the ideal process for the determination of the quark and gluon distributions in the proton. Studies of the parton substructure of the nucleon are of great interest for the development of strong interaction theory, but they are also a necessary input for new physics searches and studies at the LHC, whose potential will be correspondingly enhanced. With the increasingly apparent need to cover higher and higher new particle masses in this endeavour, it becomes ever more important to pin down the parton behaviour at large x, which governs both signal and background rates near to the LHC kinematic limit. An example is the prediction of gluino pair production cross sections from gluon-gluon fusion, which are currently not well known at masses beyond a few TeV, and for which a new level of precision on the gluon distribution will be critical. Similar situations are expected to arise in future studies of electroweak and other new physics, where large x parton distributions will play a crucial role. QCD predicts factorisation as well as resummation phenomena which can be tested with much enhanced sensitivity by combining LHC and LHeC results in inclusive and also in diffractive scattering. Certain parton distribution constraints, e.g. for the strange quark, are also derived from Drell-Yan measurements of W and Z production at the LHC, which will be verified with much extended range, accuracy and completeness at the LHeC. The eA measurements determine the parton densities and interaction dynamics in nuclei and are therefore a natural and necessary complement to the AA and pA investigations made with the LHC.

Depending on what new phenomena are found at the LHC, which has a superior cms energy compared to the LHeC (and to any of the proposed e^+e^- colliders), there are various scenarios where the cleaner ep initial state can help substantially to clarify and to investigate new physics. Key examples are the spectroscopy of leptoquarks, R-parity violating SUSY states, substructure and contact interaction phenomena, as well as the search for excited electron or neutrino states.

The Higgs particle is produced in WW and ZZ fusion in ep collisions at the LHeC. These production modes can be uniquely identified by the nature of the charged or neutral current process, and decays can be studied with low background, including the dominant decay to $b\bar{b}$ to about 4 % precision. From the WW production the contributions from CP even (SM) or odd (non-SM) Higgs quantum numbers can be unfolded.

3 LHeC Accelerator

Electron Beam Layout and Civil Engineering

The default electron beam energy is set to 60 GeV, see [2]. Two suitable configurations have been considered in the design report: a storage ring mounted on top of the LHC magnets, the ring-ring configuration (RR), and a separate linac, the linac-ring configuration (LR). In the RR case, bypasses of 1.3 km length each are considered around the existing LHC experiments, also housing the RF. This option is now treated as backup only, mainly because of its strong interference with the LHC. For the LR case, based on available cavity technology and accepting

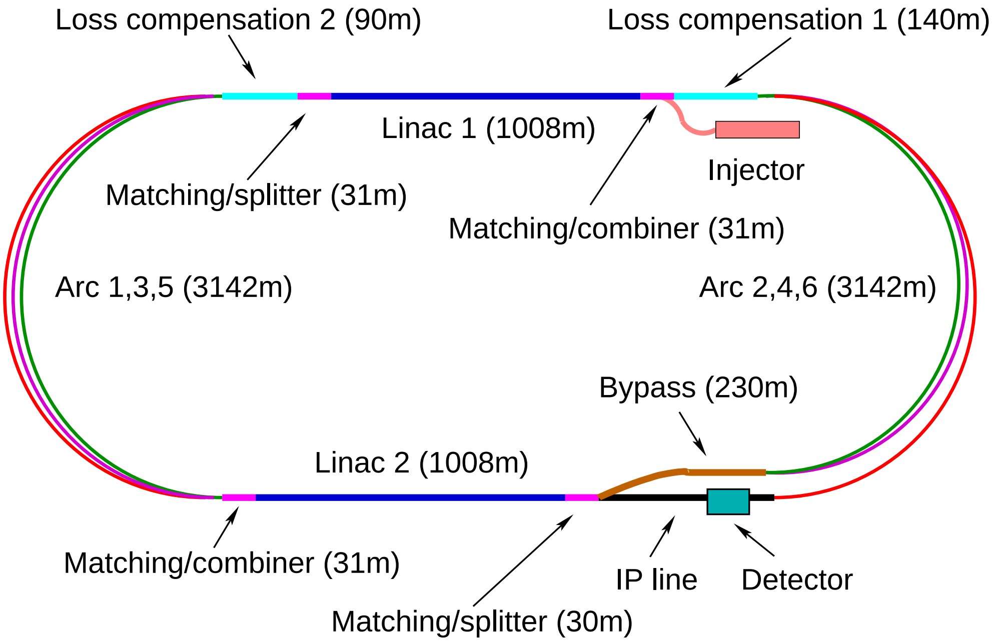

Figure 2: Schematic view on the LHeC racetrack configuration. Each linac accelerates the beam to 10 GeV, which leads to a 60 GeV electron energy at the collision point with three passes through the opposite linear structures of 60 cavity-cryo modules each. The arc radius is about 1 km, mainly determined by the synchrotron radiation loss of the 60 GeV beam which is returned from the IP and decelerated for recovering the beam power. Comprehensive design studies of the lattice, optics, beam (beam) dynamics, dump, IR and return arc magnets, as well as auxiliary systems such as RF, cryogenics or spin rotators are contained in the CDR [2], which as for physics and detector had been reviewed by referees appointed by CERN.

a synchrotron energy loss of about 1 % in the arcs, a new tunnel of racetrack shape and a length of 9 km is required, not much larger than HERA or the SPS at CERN, see Fig. 2. The tunnel is arranged tangential to IP2 (see below) and is best positioned inside the LHC, which avoids a clash with the LHC injection line TI2 and allows access shafts at the Prevessin and Meyrin sites of CERN, or in close proximity, to be erected. The civil engineering (CE) concepts were evaluated externally and no principal problem has been observed which would prevent completion of a tunnel within a few years time. For the project to begin in the early twenties, the CE efforts are considered to be strengthened by 2013/14.

Components

Designs of the magnets, RF, cryogenic and further components have been considered in some detail. Some major parameters for both the RR and the LR configurations are summarised in Tab. 1. The total number of magnets (dipoles and quadrupoles excluding the few special IR magnets) and cavities is 4160 for the ring and 5978 for the linac case. The majority are the 3080 (3504) normal conducting dipole magnets of 5.4 (4) m length for the ring (linac return arcs), for which short model prototypes have already been successfully built, testing different magnet concepts, at BINP Novosibirsk and at CERN. The number of high quality cavities for the two linacs is 960, grouped in 120 cavity-cryo modules. The cavities of 1.04 m length are operated at a currently preferred frequency of 721 MHz, at a gradient of about 20 MV/m in CW mode, as is required for energy recovery. The cryogenics system of the ring accelerator is of modest demand. For the linac it critically depends on the cooling power per cavity, which for the draft design is assumed to be 32 W at a temperature of 2 K. This leads to a cryogenics system with a total electric grid power of 21 MW. The projected development of a cavity-cryo module for the LHeC is directed to achieve a high Q_0 value and to reduce the dissipated heat per cavity, which will reduce the dimension of the cryogenics system.

	Ring	Linac
magnets		
number of dipoles	3080	3504
dipole field [T]	$0.013 - 0.076$	$0.046 - 0.264$
number of quadrupoles	968	1514
RF and cryogenics		
number of cavities	112	960
gradient [MV/m]	11.9	20
linac grid power [MW]	–	24
synchrotron loss compensation [MW]	49	23
cavity voltage [MV]	5	20.8
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5\ 10^{10}$
cooling power [kW]	5.4@4.2 K	30@2 K

Table 1: Selected components and parameters of the electron accelerators for the 60 GeV e beam energy.

Interaction Region and Choice of IP

Special attention is devoted to the interaction region design, which comprises beam bending, direct and secondary synchrotron radiation, vacuum and beam pipe demands. Detailed simulations are presented in [2] of synchrotron radiation effects, which will have to be pursued further. Stress simulations, geometry and material development considerations are presented for the detector beam pipe, which in the LR case is very asymmetric in order to accommodate the synchrotron radiation fan. The LR configuration requires a long dipole, currently of ± 9 m length in both directions from the interaction point, to achieve head-on ep collisions. The dipole has been integrated in the LR detector concept. The IR requires a number of focusing magnets with apertures for the two proton beams and field-free regions through which to pass the electron beam. The field requirements for the RR option (gradient of 127 T/m, beam stay-clear of 13 mm ($12\,\sigma$), aperture radius of 21 (30) mm for the p (e) beam) allow a number of different magnet designs using proven $NbTi$ superconductor technology and make use of cable (MQY) developments for the LHC. The requirements for the linac are more demanding in terms of field gradient (approximately twice as large) and tighter aperture constraints which may be better realised with Nb_3Sn superconductor technology, requiring prototyping.

The detector requires an interaction point for ep collisions while the LHC runs. There are eight points with adjacent long straight tunnel sections, called IP1-IP8, that could in principle be used for an experimental apparatus. Four of these (IP1, IP2, IP5 and IP8) house the current LHC experiments. There is no experimental cavern at IP3 nor IP7, and it is not feasible to consider excavating a new cavern while the LHC operates. Since IP6 houses the beam extraction (dumps) and IP4 is occupied with RF equipment, the LHeC project can only be realised according to the present understanding if it uses one of the current experimental halls. The nature of the *ep* collider operation is to run synchronously with *pp* in the high luminosity phase of the LHC, which is determined primarily by the searches for ultra-rare phenomena by ATLAS (IP1) and CMS (IP5). A 9 km tunnel excavation and surface installations close to an international airport, as would be required at IP8, is considered not to be feasible. Therefore, IP2 has been used as the reference site for the CDR. IP2 appears to be well suited as it has an experimental surface hall for detector pre-assembly and with the LHeC inside the LHC ring, access to the linacs will be possible with shafts and surface installations placed on, or very close to existing CERN territory. It therefore has to be tentatively recognised that IP2 is in practice the only option for housing the LHeC detector. This would require a transition from the ALICE to the LHeC detector, for which consultations between ALICE and LHeC have recently been initiated.

The LHeC design report considers only one detector. This could possibly be built by two analysis collaborations, cooperating in its operation but otherwise ensuring independent and competing software and analysis approaches, as a "push-pull" detector philosophy is not feasible.

4 Detector Principles

The physics programme depends on a high level of precision, required for example for the measurement of α_s, and on the reconstruction of complex final states, as appear in charged current single top events or in Higgs production and decay into b final states. The detector acceptance has to extend as close as possible to the beam axis because of the interest in the physics at small and 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, down to about 1° and 179° for forward going final state particles and backward scattered electrons at low Q^2, respectively. A cross section of the central, baseline detector is given in Fig. 3. In the central barrel, the following detector components are currently considered: a central silicon pixel detector surrounded by silicon tracking detectors of strip or possibly strixel technology; an electromagnetic LAr calorimeter inside a 3.5 T solenoid and a dipole magnet required to achieve head-on collisions; a hadronic tile calorimeter serving also for the solenoid flux return and a muon detector, so far for muon identification only relying on the precise inner tracking for momentum measurements. The electron at low Q^2 is scattered into the backward silicon tracker and its energy is measured in backward calorimeters. In the forward region, components are placed for tracking and for calorimetry to precisely reconstruct jets over a wide energy range up to O(TeV). Simulations of tracking and calorimeter performance are used to verify the design, although a complete simulation is not yet available. The report also contains designs for forward and backward tagging devices for diffractive and neutron physics and for photoproduction and luminosity determinations, respectively. The time schedule of the LHeC project demands a detector to be ready within about ten years. The radiation level at the LHeC is lower than in *pp*, and the *ep* cross section is 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 for the HL-LHC. 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

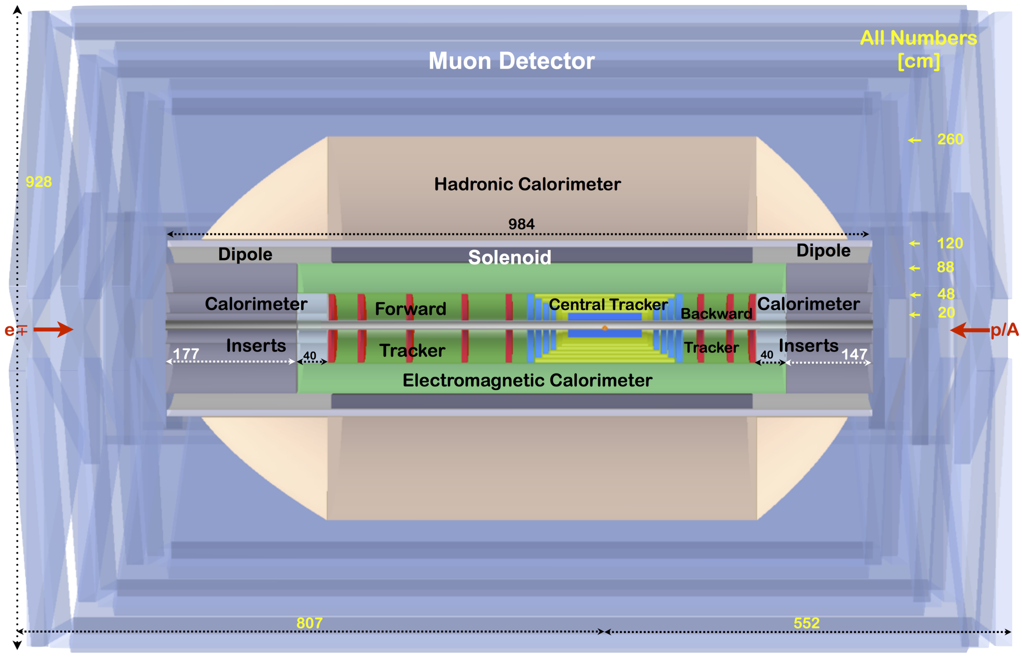

Figure 3: An rz cross section of the LHeC detector in its baseline design with the magnet configuration for LR, with the solenoid and dipoles placed between the electromagnetic and the hadronic calorimeters. The proton beam, from the right, collides with the electron beam, from the left, at the IP which is surrounded by a central tracker system, complemented by large forward and backward tracker telescopes, and followed by sets of calorimeters. The detector dimensions are ≈ 13.6 m in z and a diameter of ≈ 9.3 m, which fits in the L3 magnet structure considered for supporting the LHeC apparatus [2].

prototyping, may yet proceed without an extended R&D program.

A first study is made about the principles of pre-mounting the detector at the surface, lowering and installing it at IP2. The detector is small enough to fit into the L3 magnet structure of 11.2 m diameter, which is still resident in IP2 and is available as mechanical support. Based on the design, as detailed in the CDR, it is estimated that the whole installation can be done in 30 months, which is compliant with the operations currently foreseen in the LS3 shutdown, during which ATLAS intends to replace its complete inner tracking system.

Time Schedule and Mode of Operation

Following a CERN decision, for the next few years the LHeC design will be further pursued and collaborations are being extended or established for this purpose. The electron accelerator and new detector require a period of about a decade to be realised, based on experience from previous particle physics experiments. This duration fits with the industrialisation and production schedules, mainly determined by the required ~ 3500 approximately 5 m long warm arc dipoles and the 960 cavities for the Linac. The current lifetime estimates for the LHC predict two more decades of operation. An integrated luminosity for the LHeC of O(100) fb^{-1} may be collected in about one decade. This and the current shutdown planning of the LHC define the basic time schedule for the LHeC project: it has to be installed during the long shutdown LS3 of the LHC, currently scheduled for 2022 and a period of about 2 years. The connection of the electron and proton beams and the detector installation can be realised in a period not significantly exceeding this tentative time window. The considerations of beam-beam tune shifts show that the *ep* operation may proceed synchronously with *pp*. Therefore with the electron beam, the LHC will be turned into a three beam facility. In the design considerations [2] it has been excluded to operate *ep* after the *pp* programme is finished, a) because this would make the LHeC as part of the LHC much more expensive by adding an extra decade of LHC operation requiring also substantial efforts to first consolidate the LHC, when the high radiation *pp* programme is over, and b) since one would loose the intimate and possibly crucial connection between the ep/pp and the eA/AA physics programmes, as sketched in this note.

5 Relation of the LHeC to other Projects

The LHeC represents a natural extension to the LHC, offering maximum exploitation of the existing LHC infrastructure at CERN. Physics-wise it is part of the exploration of the high energy frontier and as such linked to the LHC and the lepton-lepton colliders under consideration, a relation which resembles the intimate connection of HERA to the physics at Tevatron and LEP for the investigation of physics at the Fermi scale. As an *ep* and *eA* machine, the LHeC unites parts of the particle and nuclear physics communities for a common big project. It has a characteristic electroweak, QCD and nucleon structure physics programme which is related primarily to the LHC but also to lower energy fixed target DIS experiments operating at CERN and Jlab, and also to plans for realising lower energy electron-ion colliders at BNL and at Jlab. The superconducting (SC) IR magnets resemble HL-LHC superconducting magnet developments by the USLARP and SC magnet developments elsewhere. The LHeC linac is relevant to a variety of facilities such as the XFEL at DESY, ESS, the CEBAF upgrade at Jlab, also to the SPL at CERN and other projects for high quality cavity developments. Through the development of its high energy ERL application to particle physics, the LHeC is related to about ten lower energy projects worldwide, which are developing the energy recovery concept. The detector technology is linked mainly to the LHC experiments and some of their upgrades. It is thus evident that there are very good prospects for realising the LHeC within dedicated international collaborations at a global scale where mutual benefits can be expected at many levels.

6 Summary

The LHeC represents a new laboratory for exploring a hugely extended region of phase space with an unprecedented high luminosity in high energy DIS. It builds the link to the LHC and a future pure lepton collider, similar to the complementarity between HERA and the Tevatron and LEP, yet with much higher precision in an extended energy range. Its physics is fundamentally new, and it also is complementary especially to the LHC, for which the electron beam is an upgrade. Given the broad range of physics questions, there are various ways to classify these, partially overlapping. An attempt for a schematic overview on the LHeC physics programme as seen from today is presented in Tab. 2. The conquest of new regions of phase space and intensity has often lead to surprises, which tend to be difficult to tabulate.

QCD Discoveries Higgs Substructure New and BSM Physics Top Quark	$\alpha_s < 0.12$, $q_{sea} \neq \overline{q}$, instanton, odderon, low x: (n0) saturation, $\overline{u} \neq \overline{d}$ WW and ZZ production, $H \to b\overline{b}$, $H \to 4l$, CP eigenstate electromagnetic quark radius, e^*, ν^*, W?, Z?, top?, H? leptoquarks, RPV SUSY, Higgs CP, contact interactions, GUT through α_s top PDF, $xt = x\overline{t}$?, single top in DIS, anomalous top
Relations to LHC	SUSY, high x partons and high mass SUSY, Higgs, LQs, QCD, precision PDFs
Gluon Distribution Precision DIS	saturation, $x \approx 1$, J/ψ, Υ, Pomeron, local spots?, F_L, F_2^c $\delta\alpha_s \simeq 0.1\,\%$, $\delta M_c \simeq 3\,\mathrm{MeV}$, $v_{u,d}$, $a_{u,d}$ to $2-3\,\%$, $\sin^2\Theta(\mu)$, F_L, F_2^b
Parton Structure Quark Distributions QCD	Proton, Deuteron, Neutron, Ions, Photon valence $10^{-4} \lesssim x \lesssim 1$, light sea, d/u, $s = \overline{s}$?, charm, beauty, top $\mathrm{N^3LO}$, factorisation, resummation, emission, AdS/CFT, BFKL evolution
Deuteron Heavy Ions Modified Partons	singlet evolution, light sea, hidden colour, neutron, diffraction-shadowing initial QGP, nPDFs, hadronization inside media, black limit, saturation PDFs "independent" of fits, unintegrated, generalised, photonic, diffractive
HERA continuation	F_L, xF_3, $F_2^{\gamma Z}$, high x partons, α_s, nuclear structure, ..

Table 2: Schematic overview on key physics topics for investigation with the LHeC.

With its unique and precise QCD measurements the LHeC will be the necessary precision complement to ATLAS and CMS, when these run at maximum luminosity for searching at high masses, corresponding to large x. It also has its own possibilities for new physics to be observed, both in QCD and beyond the current model of particle physics. Combined with precision fixed target and medium or low energy collider measurements, the LHeC can lead the physics of DIS much beyond HERA and to its renaissance, as part of the movement of particle collider physics to smaller dimensions and higher mass scales and for the development of QCD.

Acknowledgments

The LHeC design report, on which the presentation relied, has been worked out by a large group of physicists and engineers in much of their free time. It is for that effort that one can now realistically consider a future of DIS as part of the exploration of the energy frontier. Special thanks are due to my colleagues Nestor Armesto, Armen Bunyatian, Olaf Behnke, Rohini Godbole, Paul Newman, Alessandro Polini, Daniel Schulte, Anna Stasto and RogelioTomas, who delivered detailed presentations on various aspects of the LHeC design to this workshop. DIS12 was a pleasure to attend for which I would like to express sincere thanks to the organizers.

References

[1] Slides:
`http://indico.cern.ch/contributionDisplay.py?contribId=364&sessionId=0&confId=153252`

[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, see also `http://cern.ch/lhec`

[3] E. Aschenauer and P. Newman, Summary talks on the future of DIS session, this workshop.

[4] D. Boer, M. Diehl, R. Milner, R. Venugopalan, W. Vogelsang, D. Kaplan, H. Montgomery and S. Vigdor *et al.*, arXiv:1108.1713 [nucl-th].

[5] ICFA Beam Newsletter No 58, August 2012, to appear.

[6] CERN-ECFA-NuPECC Workshop on the LHeC, Chavannes, Switzerland, 2012, see `http://cern.ch/lhec`.