Diffractive and exclusive processes at small x at the Large Hadron-electron Collider

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In this talk, I will discuss the opportunities for the exploration of physics phenomena at low values of Bjorken x at the Large Hadron-electron Collider. In particular, the prospects for the measurements of the diffractive and exclusive processes will be outlined.

Small x physics at the LHeC. Large Hadron-electron Collider (LHeC) is a proposed facility for the electron - hadron and nucleus scattering at CERN which would utilize existing high energy beams from the LHC. The projected energy for the electron beam is in the range of $60 - 140$ GeV. In addition to the deep inelastic electron-proton scattering, the LHeC proposal includes also collisions of electrons with lead nuclei. This machine would greatly expand the kinematic range previously explored by the HERA collider thus allowing to probe the details of strong and electroweak interactions.

Of particular interest is the huge physics potential of the LHeC of exploring the region of small values of Bjorken x. Large center-of-mass energy, of the order of $\sqrt{s} \sim 1 - 2$ TeV, would allow to extend the range in x by at least an order of magnitude compared to the HERA collider. In this regime novel phenomena are expected which are related to the occurrence of the high parton density. An alternative way of probing the high parton density is through the collisions of electrons with heavy nuclei thus providing a unique insight into the structure of nuclei at high energies, and furnishing valuable input for the heavy ion collisions probed at the LHC. The LHeC would be characterized by the large instantaneous luminosity, of the order of $10^{33}\ \text{cm}^{-2}\text{s}^{-1}$, which would allow for the high precision measurements.

Wide range of physics possibilities at the LHeC have been discussed in other talks in this workshop. In particular, prospects for the precision QCD and Electroweak measurements have been reviewed by O. Behnke [1] and the inclusive measurements essential for the exploration of the small x physics have been discussed by N. Armesto [2] including the DIS off nuclei. This talk focuses on the diffractive and exclusive processes at small x which could be explored at the LHeC. All the material presented in this talk can be found in the Conceptual Design Report for the LHeC [3].

Inclusive diffraction. It was discovered at HERA that a large fraction, i.e. about 10%, of DIS interactions are diffractive events. These events are of type $ep \to eXp$, where the interacting proton stays intact. It emerges in the final state well separated from the rest of the hadronic final state X by a rapidity gap. From a variety of theoretical studies it has become clear that the diffraction is closely linked with the partonic saturation. The phenomenological studies based on dipole models at small x suggest that the diffractive DIS events involve significantly softer scales as compared with the non-diffractive events at the same values of Q^2. Thus a study of diffraction offers a unique opportunity to investigate the transition between perturbative and non-perturbative dynamics and the onset of non-linear effects in parton density.

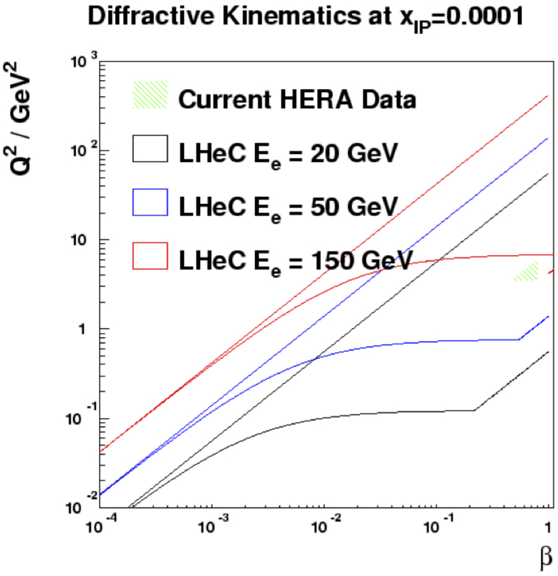

Figure 1: Diffractive DIS ranges in Q^2 and β of HERA and of the LHeC for electron energies $E_e = 20, 50, 150$ GeV and $x_{I\!P} = 0.0001$. Scattered electron acceptance is taken to be 1°.

The LHeC will offer ample opportunities to perform the measurements of the diffractive DIS in an unprecedented kinematic range. The diffractive kinematic plane is shown in Fig. 1 for a value of the Pomeron momentum fraction $x_{I\!P} = 0.0001$. The accessible kinematic ranges are shown for three electron energies, $E_e = 20, 50, 150$ GeV. The kinematic coverage of HERA is superimposed in this plot. It is clear that the LHeC will have a much increased reach for the diffractive events compared with HERA towards low values of both $x_{I\!P}$ and β. The kinematic range of diffractive DIS measurements at the LHeC is also illustrated in Fig. 2 (left plot) for the example of a 150 GeV electron beam compared with an estimation of the final HERA performance. The pseudodata for F_2^D diffractive structure function are simulated for the LHeC together with the range accessible at HERA. The dependence of the kinematical ranges on the backward acceptance cuts of 1° and 10° of the detector is also illustrated.

The diffractive DIS region of very low β is of particular interest since the diffractively produced systems will be created with very large invariant masses. This is clearly illustrated in Fig.2 (right plot). This figure compares the expected M_X distributions for one year of running at three LHeC electron beam energy choices. LHeC will enable to experimentally access the region of very large diffractive masses, up to several hundred GeV. Therefore it will be possible to study diffractive final states involving beauty quarks and W and Z bosons. If existing, the exotic states with 1^- quantum numbers, could be produced.

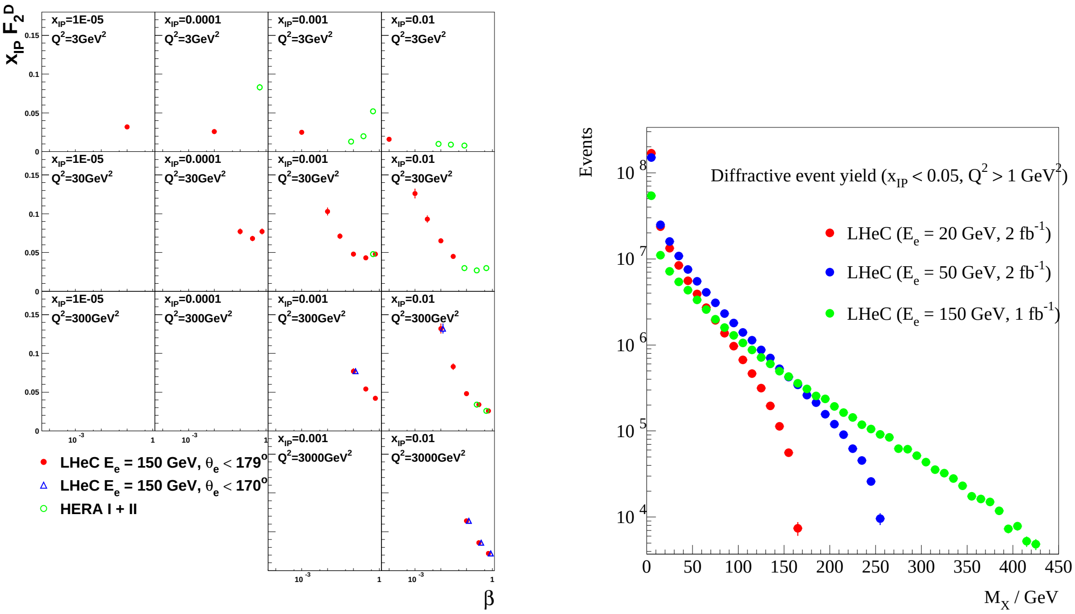

Figure 2: Left: simulation of an LHeC measurement of the diffractive structure function, F_2^D using a 2 fb^{-1} sample, compared with an estimate of the results achievable at HERA. Luminosity for an experiment is taken to be 500 pb^{-1}. The loss of kinematic region if the LHeC scattered electron acceptance extends to within 10° of the beam-pipe, rather than 1° is also illustrated. Right: simulated distributions in the invariant mass M_X from the RAPGAP Monte Carlo for $x_{I\!P} < 0.05$.

Measurements of the inclusive diffraction at the LHeC will allow large improvements in extraction and constraining of the diffractive PDFs. In addition, the assumption about the proton vertex factorisation can be tested precisely by comparing the β and Q^2 dependences at different small $x_{I\!P}$ values in their considerable regions of overlap. Furthermore, the ample production of dijets or heavy quarks as components of the diffractive system X will allow for the precision tests of QCD collinear factorisation in diffraction.

Inclusive diffraction can also be explored in electron-ion scattering, where it is expected to be enhanced over the proton case. In the nuclear case two types of processes can occur, the fully coherent diffraction, where the nucleus stays intact ($eA \to eXA$) and incoherent diffraction, where the nucleons within the nucleus are resolved and the nucleus breaks up. Dedicated forward instrumentation will be implemented to distinguish between these two scenarios.

Exclusive processes. Exclusive processes such as the electroproduction of vector mesons and photons or photoproduction of heavy quarkonia provide a valuable information on nucleon structure and small-x dynamics. Diffractive channels are of particular interest since the underlying exchange is dominated by the gluons, and the cross section for this process is proportional to the square of the gluon density (unlike the inclusive non-diffractive case). Thus, the study of these processes could provide us with the better understanding of the gluon saturation. The same exclusive processes can be measured in electron scattering off nuclei, where the gluon density is modified by nuclear effects.

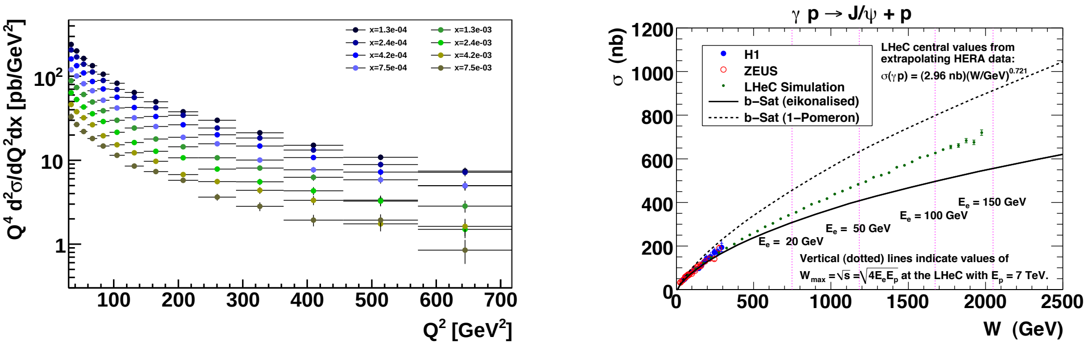

Figure 3: Left: Simulated LHeC measurement of the DVCS cross section multiplied by Q^4 for different x values for a luminosity of 100 fb^{-1}, with $E_e = 50$ GeV, and electron and photon acceptance extending to within 10° of the beampipe with a cut at $P_T^{\gamma} = 5$ GeV. Right: LHeC exclusive diffractive J/ψ photoproduction pseudodata, as a function of the γp centre-of-mass energy W. The difference between the solid and dashed curves indicates the size of unitarity corrections.

The exclusive processes give access to the spatial distribution of the gluon density, parametrized by the impact parameter of the collision. They can be used to extract the Generalised Parton Densities (GPDs) which encode the information on the three-dimensional structure of the hadron. At the LHeC the Q^2-dependence of these processes can be studied and different channels compared in order to test the universality of GPDs. Vector meson production probes the gluon GPD of the target, while the Deeply Virtual Compton Scattering (DVCS) involves also the singlet quark GPD.

A simulation of the DVCS process at the LHeC is shown in Fig. 3 (left plot). Precise measurements extending to $Q^2 > 500$ GeV^2 are possible, well beyond the range previously explored for DVCS or other GPD-sensitive processes. The right plot in Fig. 3 shows the predictions for exclusive J/ψ photoproduction obtained within the dipole model which includes parton saturation effects. Comparison between the single-Pomeron exchange contribution and the calculation which includes non-linear effects is shown. It is clear from Fig. 3 that the errors on the LHeC pseudodata are much smaller than the difference between the two predictions. Therefore, exclusive J/ψ photoproduction at the LHeC may be an ideal observable for investigating unitarity corrections at small x.

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[3] *A Large Hadron-electron Collider at CERN*, Report on Physics and Design. Concepts for Machine and Detector (*to be published*).