PROCEEDINGS OF SCIENCE

Low-x Physics at the LHeC

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The huge possibilities for enlarging our knowledge about the small-x, high-energy dynamics of QCD offered by the Large Hadron-electron Collider will be shown, with the main focus on $e^{\pm}$p collisions. Inclusive, diffractive and final state observables will be reviewed. The LHeC will unambiguously answer the question of the existence of a novel, non-linear regime of QCD in its accessible kinematical region.

XXI International Workshop on Deep-Inelastic Scattering and Related Subject -DIS2013,
22-26 April 2013
Marseilles,France

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[†]The work of NA is supported by European Research Council grant HotLHC ERC-201-StG-279579; by Ministerio de Ciencia e Innovación of Spain under projects FPA2009-06867-E and FPA2011-22776; by Xunta de Galicia (Consellería de Educación and Consellería de Innovación e Industria - Programa Incite); by the Spanish Consolider-Ingenio 2010 Programme CPAN and by FEDER.

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1. Introduction

Low-x physics constitutes one of the most important fields of study within QCD. The present situation can be summarised as follows: inclusive and diffractive data at small-x from fixed-target experiments and HERA can be described by non-perturbative models and, more interestingly, by different realisations of evolution equations within perturbative QCD - the standard explanation within fixed-order perturbation theory (DGLAP evolution equations), resummation schemes, and non-linear approaches. On the theory side, unitarity of QCD as a quantum field theory implies that non-linear phenomena are unavoidable and saturation of parton densities is expected to occur at high energies or small Bjorken-x. A non-perturbative but weak coupling realisation of saturation ideas is provided by the Colour Glass Condensate, see [1] and references therein. At present, the discussion centres on the relevant kinematical regime for such phenomena and on the possibilities offered by existing or future experimental data to distinguish among the different available schemes.

On a less fundamental level, our knowledge of the gluon distribution at small x both in protons and nuclei is not precise enough for predictions within collinear factorisation at hadron colliders. Besides, both in the lepton-nucleus case and in the semihard region for particle production, collinear factorisation is expected to fail and other factorisation schemes are under scrutiny. Both aspects are of great importance for the study of hadronic and nuclear collisions.

The Large Hadron-electron Collider (LHeC, see the Conceptual Design Report in [2] and contributions to the European Strategy Update in [3]) is an electron-proton/ion collider currently under design at CERN, which will collide $20 \div 140$ GeV $e^{\pm}$ against the LHC beams, with a nominal luminosity of 10^{33} cm^{-2}s^{-1}, although more recent studies indicate that 10^{34} cm^{-2}s^{-1} and integrated luminosities of order 1 ab^{-1} are within reach (see [4, 5]). The machine is subject, apart from several requirements on detector performance and power consumption, to the constraints of creating minimal disturbance during construction and working simultaneously to the LHC. Besides Higgs and electro-weak studies and searches for new physics, this machine will perform precision QCD studies and it should allow unambiguous access to the novel regime of QCD in which unitarity constraints are at work - the dense region shown in Fig. 1. As the transition between the dilute and the dense regions is a density effect, a two-pronged approach must be pursued: decreasing x at fixed mass number A and Q^2, and also increasing A at fixed x and Q^2. The LHeC will give access to a completely new region of the Q^2-x plane for protons and, more prominently, for nuclei.

In this contribution I will focus on small-x possibilities at the LHeC, mainly in $e^{\pm}$p collisions. More information on these and other aspects can be found in [2, 3] and in the different contributions to this conference [5]. I will start with inclusive measurements, then focus on diffraction and, subsequently, on final state observables. Finally, I will present some brief conclusions and outlook.

2. Inclusive measurements at small x

The LHeC will increase the studied region in the Q^2-x plane towards smaller values of x by a factor $\sim$20 in $e^{\pm}$p and by four orders of magnitude in $e^{\pm}$A, see [2], and [3] for a comparison with the expected kinematical reach at the LHC. With its huge lever arm in x and Q^2 and with the

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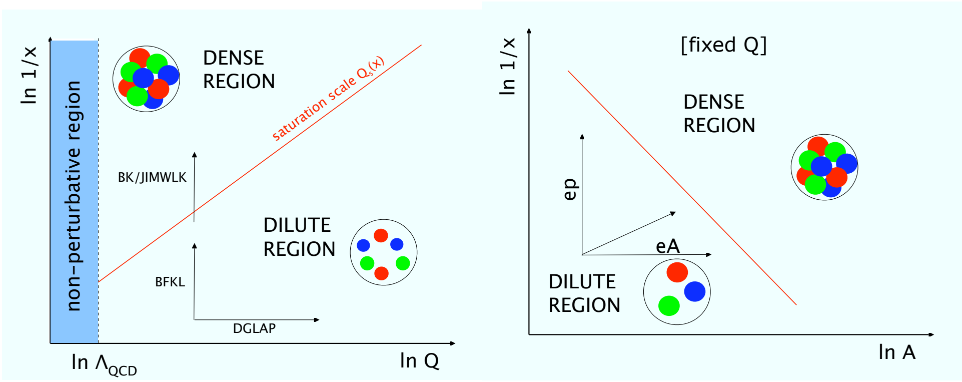

Figure 1: Sketch of the access to the dense partonic region where unitarity effects are essential, from the dilute one where linear evolution is valid. See the text for explanations. (From [2].)

expected precision in the measurements of cross sections and structure functions, the LHeC will be able to:

- Improve the existing constraints on parton densities, particularly on gluons, at small x. For that, the combination of F_2, $F_{2c,b}$ and F_L is expected to be particularly powerful, see Fig. 2.
- Establish the existence of physics beyond standard DGLAP fixed-order linear evolution through the appearance of tensions in the description of different observables, particularly F_2 and F_L, in the framework of global analysis of parton densities.
- Constrain extrapolations of parton densities to extremely low values of $x \sim 10^{-10} \sim 10^{-8}$ relevant for detection of ultrahigh-energy neutrinos in cosmic ray experiments.

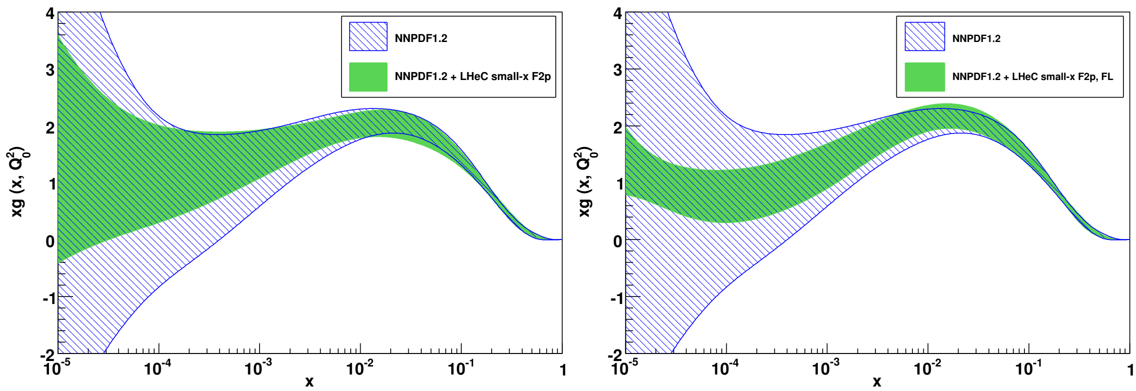

Figure 2: The results for the gluon distribution in the standard NNPDF1.2 DGLAP fit [6], together with the results when additionally including LHeC pseudodata for F_2 (left) and for both F_2 and F_L (right). The results are shown at the starting scale for DGLAP evolution, $Q_0^2 = 2$ GeV^2. (From [2].)

3. Diffraction

The LHeC will give access to a new region of the Q^2-β plane at moderate and, above all, at

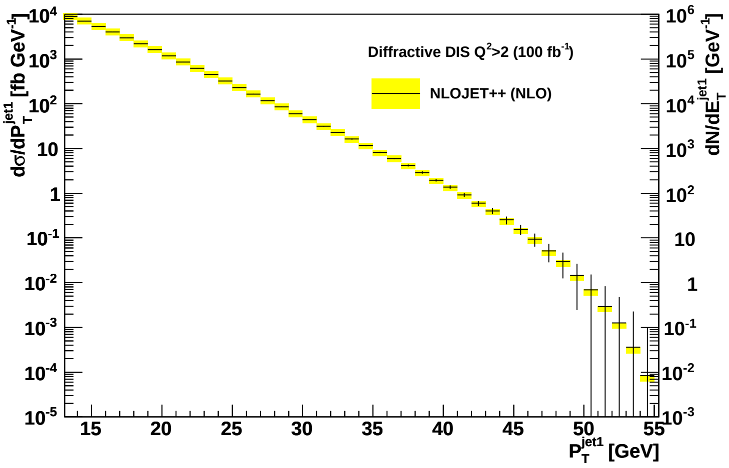

Figure 3: Simulated transverse momentum distribution of the jets in diffractive dijet production in DIS ($Q^2 > 2$ GeV^2). The simulation was performed using NLOJET++, assuming an integrated luminosity of 100 fb^{-1} and high acceptance for the scattered electron (1°). Scale uncertainties are illustrated by varying the factorisation scale in the range $(0.25\mu^2, 4\mu^2)$. (From [2].)

low ξ, with respect to existing measurements at HERA[1]. The extension towards small β will be enlarged by $2 \div 3$ orders of magnitude, and diffractive masses in excess of 200 GeV/c^2 will be studied, with new possibilities for producing high-mass objects, even exotics, and studying CC diffractive events. The possibility of using both the rapidity gap method and the identification of leading protons is under study. Considering all this, the LHeC offers huge possibilities for:

- Extracting diffractive parton densities through DGLAP analysis, and clarifying the status of factorisation in diffractive events by accurate measurements of jet and dijet diffractive production, see Fig. 3. Nuclear diffractive parton densities would be experimentally studied for the first time.

- Establishing the relevance of non-linear phenomena at small x through the energy and t dependences of quarkonium production, with J/ψ looking particularly promising both in photoproduction in $e^{\pm}$p, see Fig. 4, and in $e^{\pm}$A.

- Extracting gluon and quark GPDs through the t-differential study of vector meson production, and through the DVCS process that will be accessible in an unprecedented range of x and Q^2.

- Confirming the relation, through Gribov inelastic shadowing, of diffraction in $e^{\pm}$p and nuclear shadowing, for which lepton-deuteron collisions would be of particular interest.

[1] ξ is the momentum fraction of the proton taken by the colourless object that is exchanged in diffractive scattering, β the momentum fraction of the struck parton with respect to this colourless object, and t the squared four-momentum exchanged in the scattering.

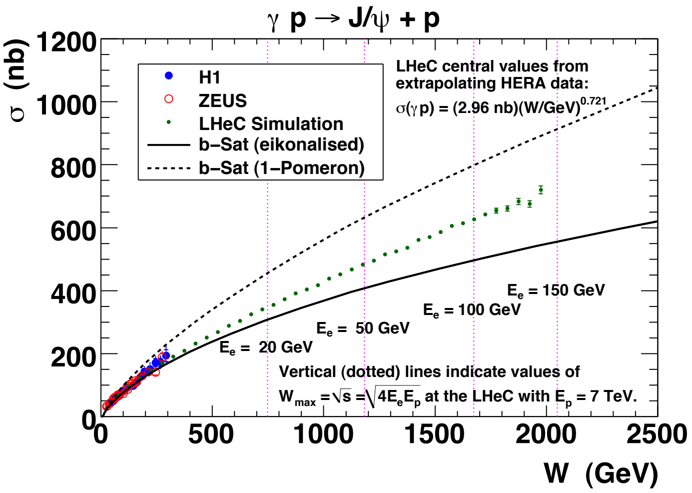

Figure 4: LHeC exclusive J/ψ photoproduction pseudodata, as a function of the γp centre-of-mass energy W, plotted on a linear–linear scale. The difference between the solid and dashed curves indicates the size of unitarity corrections according to the b-Sat dipole model. (From [2].)

4. Final state observables

Concerning final state observables, the LHeC will be able, among other unexplored possibilities, to:

- Study dihadron azimuthal decorrelation at small-x in $e^{\pm}$A collisions, an observable that in dAu collisions at RHIC has been considered as one of the most suggestive signals of saturation.
- Measure dijet azimuthal decorrelation or forward jets ($p_\perp \sim Q$) to disentangle the mechanism of QCD radiation: ordered in transverse momentum as in DGLAP, disordered in transverse momentum like in BFKL, and possible saturation effects. These studies can also be performed imposing a rapidity gap.
- Perform studies of the dynamics of QCD radiation and hadronization through semi-inclusive measurements in $e^{\pm}$A collisions, in regions complementary to those already examined in fixed-target experiments.

In conclusion, the LHeC offers huge possibilities for enlarging our knowledge about the small-x or high-energy dynamics of QCD. Specifically, it will unambiguously answer the question of the existence of a novel, non-linear, regime of QCD in its accessible kinematical region. With a CERN mandate to proceed towards a technical design in three years, a comparison of the capabilities of the LHeC to those of the LHC will be performed, and the physics case refined.

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