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Small-x physics at the Large Hadron-electron Collider

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I review the aspects of small-x dynamics that can be addressed at the proposed Large Hadron-electron Collider (LHeC) at CERN, both in lepton-proton and in lepton-nucleus collisions. After a brief introduction, I discuss results illustrating the capabilities of such machine to provide information on structure functions, inclusive and exclusive diffraction, and other observables of interest for constraining the high-energy dynamics of QCD.

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PoS(DIS 2010)255

1. Introduction

Inclusive and diffractive data at small-x from HERA and fixed-target experiments, can be described by different realizations of evolution equations within perturbative QCD (see e.g. [1]): fixed-order perturbation theory (DGLAP), resummation schemes (BFKL/CCFM/CCSS/ABF) and non-linear evolution (BK). While the unitarity of QCD implies that non-linear phenomena are unavoidable, existing data do not allow to distinguish among the different available schemes.

The Large Hadron-electron Collider (LHeC, [2, 3]) is an electron-proton/ion collider currently under design at CERN, which will collide $50 \div 150$ GeV $e^{\pm}$ against the LHC beams, with a goal luminosity 10^{33} cm^{-2}s^{-1}. Besides precision QCD and electro-weak studies, and searches for new physics, this machine should allow an unambiguous access to the novel regime of QCD in which unitarity constraints are at work - the dense region shown in Fig. 1. With the transition between the dilute region and the new phase being a density effect, a two-pronged approach will be pursued: either increasing x at fixed mass number A and Q^2, or increasing A at fixed x and Q^2.

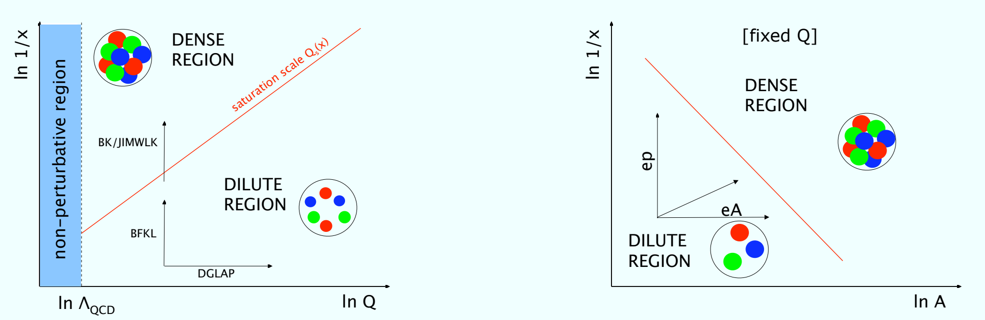

Figure 1: Sketch of the access to the dense partonic region where unitarity effects are essential, from the dilute one where linear evolution is valid. See the text for explanations.

From a more practical point of view, our knowledge of the gluon distribution at small x both in proton and nuclei does not suffice for the required precision in predictions within collinear factorization at hadron colliders. In this contribution I will review some aspects of small-x physics which can be addressed with the LHeC. Due to the lack of space, I will focus on the possibilities with nuclear targets, and on inclusive observables. More information can be found in [4, 5, 6]), and in related work concerning the proposed Electron-Ion Collider at the US [7, 8].

2. Inclusive observables

The LHeC will give access to a completely new region of the Q^2-x plane, see Fig. 2. With this huge kinematical lever arm and the possibility to measure not only F_2 but also its flavor decomposition and F_L (see Figs. 3 and 4 for examples of LHeC pseudodata on nuclear ratios of F_2, F_L and F_{2c}), the LHeC offers huge possibilities for:

• Constraining the parton densities in DGLAP analysis, both in ep (see Rojo in [3]) and eA (see [4] and Fig. 4). For this purpose, the combination of F_2, F_L and $F_{2c,b}$ appears to be very promising. As shown in Fig. 3 for F_2 and F_L in the nuclear case, the expected accuracy of data is much smaller than the spread of existing models.

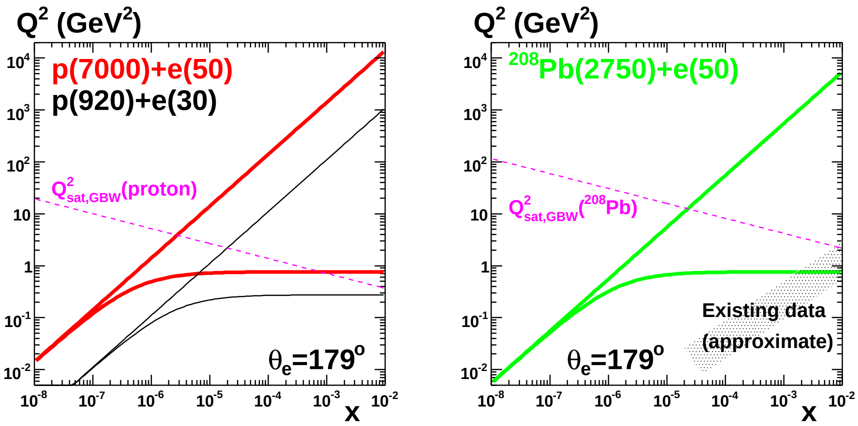

Figure 2: Region of the Q^2-x plane that will be explored with the LHeC in ep (left) and ePb (right), red lines, compared to those achievable at HERA (black lines on the left plot) and existing eA experiments (shaded region on the right plot). The lines have been drawn for a 1-179 degree acceptance. An estimation of the saturation scale indicating the dilute-dense transition in both cases is shown (pink lines).

• Disentangling fixed-order evolution schemes from resummation or non-linear ones, see [1] and [10]. For this purpose, the combination of data on F_2 and F_L is required.

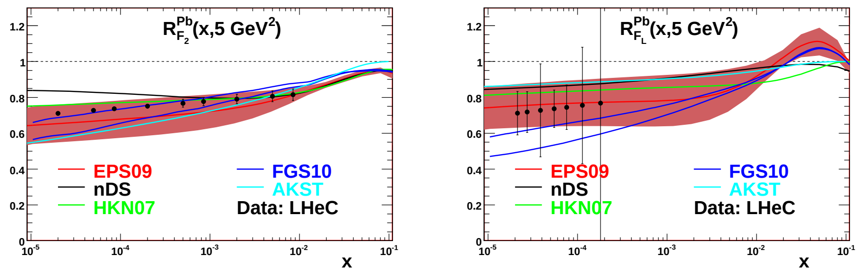

Figure 3: Predictions from different models [9] for the nuclear ratio $R^{\rm Pb}_{F_i} = F_i^{\rm Pb}/(208\,F_i^{\rm p})$, $i = 2, L$, at small x, see the legend on the plots. Circles with error bars are LHeC pseudodata.

Work on including flavor decomposition in DGLAP analysis of ep LHeC pseudodata, and F_L and flavor decomposition in eA, is under progress. Note that the nuclear effects on F_L at small x are unknown, which makes the extraction of F_2 at the smallest x problematic in the nuclear case [6].

3. Diffractive observables

On diffraction in ep collisions [4, 5], the LHeC will explore a new domain of very low β (e.g. down to a few times 10^{-4} for $Q^2 \sim 4$ GeV^2 at $x_P = 0.003$, two orders of magnitude smaller than at HERA). Several aspects can be highlighted:

• It will give access with enough statistics to diffractive masses as large as 200 GeV, providing data to check models describing the transition from low to high masses, and to improve the determination of diffractive parton densities in DGLAP analysis.

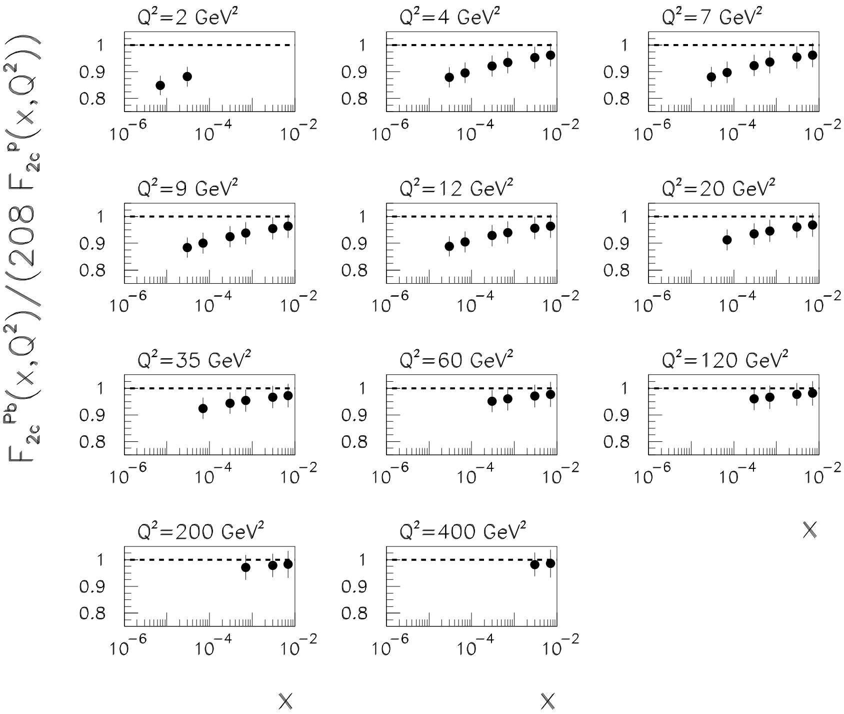

Figure 4: LHeC pseudodata for the nuclear ratio $R^{\rm Pb}_{F_{2c}} = F^{\rm Pb}_{2c}/(208 F^{\rm p}_{2c})$ at small x.

• For elastic vector meson production or DVCS, a huge lever arm in W will be explored (e.g. upto ≈ 1.2 TeV for $E_e = 50$ GeV) with enough precision to disentangle linear evolution schemes from non-linear ones. The differential spectrum in t will also be accessible up to $t \sim -2$ GeV^2.
• Gribov's relation between diffraction in ep and nuclear shadowing will be checked in a single experimental setup (see e.g. the FGS and AKST models in [9] and Fig. 3).

In eA, the perspectives for the reach in kinematics are very similar to those in ep - with the difference that for nuclei information on diffraction at small x [5, 6] does not exist at all. The experimental challenge in separating inclusive diffraction ($e + {\rm A} \to e + X + X'$ with a rapidity gap) from coherent ($e + {\rm A} \to e + X + {\rm A}$) and incoherent ($e + {\rm A} \to e + X + Z{\rm p} + [A - Z]{\rm n}$) is under study.

4. Final states

Besides the study of jets for the determination of α_s (see [1] and Behnke in [3]), the LHeC will offer huge possibilities for:
• Clarifying the dynamics of hadronization, through testing the parton/hadron energy loss mechanism in SIDIS by introducing a piece of colored material - the nucleus - which would modify its pattern (length/nuclear size, chemical composition; see Brooks in [8]). Energies as high as 10^5 GeV in the rest frame of the nucleus will be accessible and the transition from low to high energies (with hadronization expected to occur inside or outside the nucleus respectively) could be studied.

• Establishing the dynamics of QCD radiation though the measurement of forward jets in DIS (see Kutak in [3]).

Studies of hadronic final states through Monte Carlo simulation using DPMJET-III [11] for the purpose of detector design, are under way [5].

Summarizing, I have presented some of the observables and opportunities at small x, whose measurement at the LHeC will offer most valuable information to clarify the high-energy behavior of the strong interaction. Work on all these aspects is in progress, with the aim of producing a Conceptual Design Report before the end of 2010.

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