Low-x Physics in ep and eA Scattering at the LHeC: Inclusive and Final State Observables

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The opportunities for low-x physics studies at the proposed Large Hadron-electron Collider at CERN will be examined. After a brief introduction, the kinematical reach of the machine will be presented. Then I will focus on inclusive and final state observables, with special attention to the improvements on the determination of parton densities both in ep and eA and to the possibilities for establishing novel aspects of the dynamics at small-x.

1 Introduction

From our present experimental knowledge of DIS, it is widely accepted that inclusive and diffractive data at small-x can be described by several alternatives: non-perturbative models and, within perturbative QCD, different realizations of evolution equations - fixed-order perturbation theory (DGLAP), resummation schemes and non-linear approaches. Concerning the last item, saturation of partonic densities should occur at high energies or small Bjorken-x. The present discussion focuses on the relevant kinematical regime for such phenomena and the possibilities offered by existing or future experiments to discriminate between different schemes.

On a more practical level, our knowledge of partons distributions (PDFs) at small x in protons and nuclei does not suffice for the required predictive precision within collinear factorization at hadron colliders. Besides, in lepton-nucleus and in the semihard region for particle production, collinear factorization is not expected to work and other factorization schemes have been proposed. Both aspects are key for the study of hadronic and nuclear collisions.

The Large Hadron-electron Collider (LHeC [1, 2, 3]) is an electron-proton/ion collider currently under design, that will collide $20 \div 140$ GeV $e^{\pm}$ against the LHC beams. Besides EW and new physics investigations, this machine will perform precision QCD studies and should allow an unambiguous access to the novel regime of QCD in which non-linear effects are dominant - the dense region in Fig. 1. With the transition between the dilute linear region and the new phase characterized by high density, a two-pronged approach will be pursued: either decreasing x at fixed mass number A and negative photon virtuality Q^2, or increasing A at fixed x and Q^2. The LHeC will explore a completely new region of the Q^2-x plane, see Fig. 2. In this contribution I will mention some aspects: inclusive and final state observables, of the small-x studies that may be performed at the LHeC (for other aspects, see the contribution by A. Stasto [3]). Full information can be found in [2] to which I refer the reader for details and references, and in related work concerning the proposed Electron-Ion Collider in the USA [4, 5], see also [6].

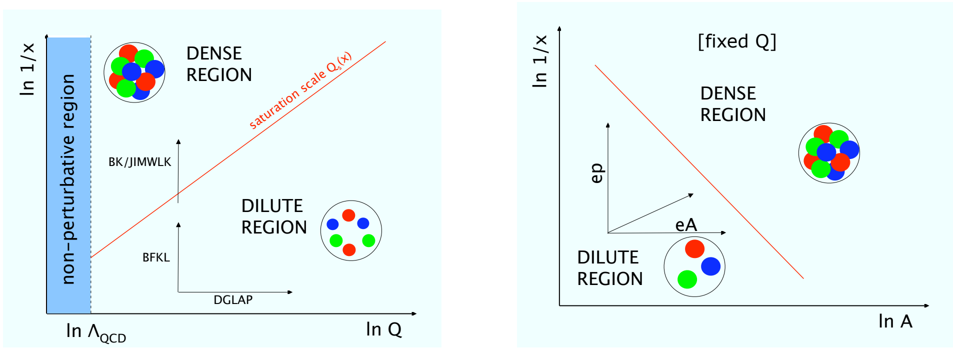

Figure 1: Sketch of the access to the dense partonic region where unitarity effects are essential, from the dilute one where linear evolution is valid. (From [2].)

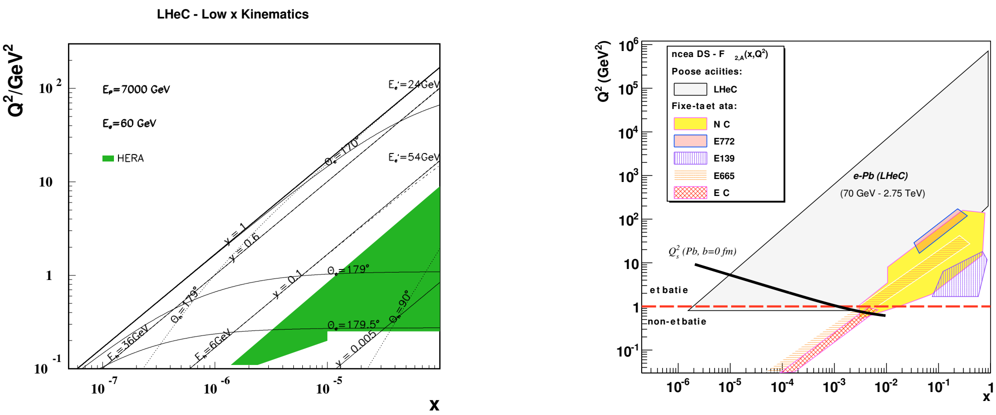

Figure 2: Left: kinematics of ep scattering at the LHeC at low x. Solid (dotted) curves correspond to constant polar angles θ_e (θ_h) of the scattered electron (hadronic final state). The polar angle is defined with respect to the proton beam direction. Dashed (dashed-dotted) curves correspond to constant energies E'_e (E_h) of the scattered electron (hadronic final state). The shaded (green) area illustrates the region of kinematic coverage in neutral current scattering at HERA. Right: region of the Q^2-x plane that will be explored with the LHeC in ePb, compared to those achievable at existing eA experiments. An estimation of the saturation scale indicating the dilute-dense transition is shown. (From [2].)

2 Inclusive observables at small x

With its huge kinematical lever arm and the possibility to measure not only the total structure function, F_2, but also its flavor decomposition and the longitudinal one, F_L (see Figs. 3 and 4 for examples of pseudodata for F_2 and F_L in ep and eA respectively), the LHeC offers rich possibilities for:

(a) Constraining PDFs in DGLAP analysis, both in ep and eA, particularly for sea quarks and gluons. For this purpose, the combination of F_2, F_L and $F_{2c,b}$ appears to be very promising. As shown in Figs. 3 and 4 for F_2 and F_L, the expected uncertainty of data is much smaller than the

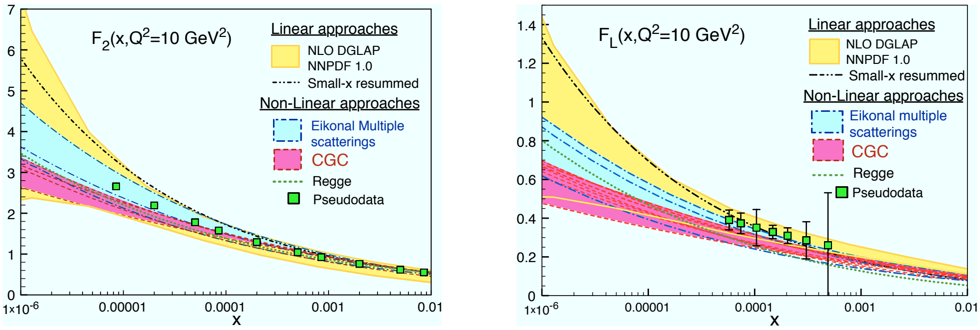

Figure 3: Predictions from different models for $F_2(x, Q^2 = 10\ \mathrm{GeV}^2)$ (plot on the left) and $F_L(x, Q^2 = 10\ \mathrm{GeV}^2)$ (plot on the right) versus x, together with LHeC pseudodata. (From [2].)

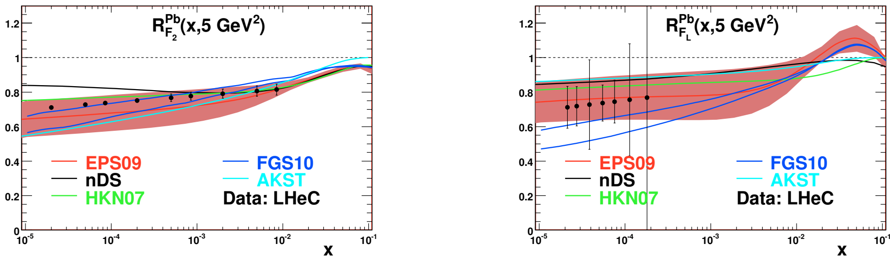

Figure 4: Predictions from different models for the nuclear ratio $R^{\mathrm{Pb}}_{F_i} = F_i^{\mathrm{Pb}}/(208\, F_i^{\mathrm{p}})$, $i = 2, L$, at small x, see the legend on the plots. Circles with error bars are LHeC pseudodata. (From [2].)

spread of existing models. This will have strong implications on the search of ultra-high-energy neutrinos in cosmic ray experiments.
(b) Disentangling fixed-order evolution schemes from resummation or non-linear ones. In this respect, the combination of data on F_2 and F_L is required.

As an additional aspect, the measurement of the γp cross section will help to constrain models for the high-energy behavior of hadronic cross sections.

3 Final states

The LHeC will offer huge possibilities for clarifying the dynamics of QCD radiation and hadronization. For example:
(a) The dynamics of QCD radiation at small x will be studied through forward jet and particle production, which will be abundant, see Fig. 5.
(b) The parton/hadron energy loss mechanism in semi-inclusive DIS will be tested by introducing a nucleus which would modify the hadronization pattern. 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 will be studied. As an example of the large yields, inclusive jet rates for $Q^2 = 0$ around 10^3 jets per GeV per year are expected with $E_{Tjet} \sim 95$ (80) GeV in ep (ePb).

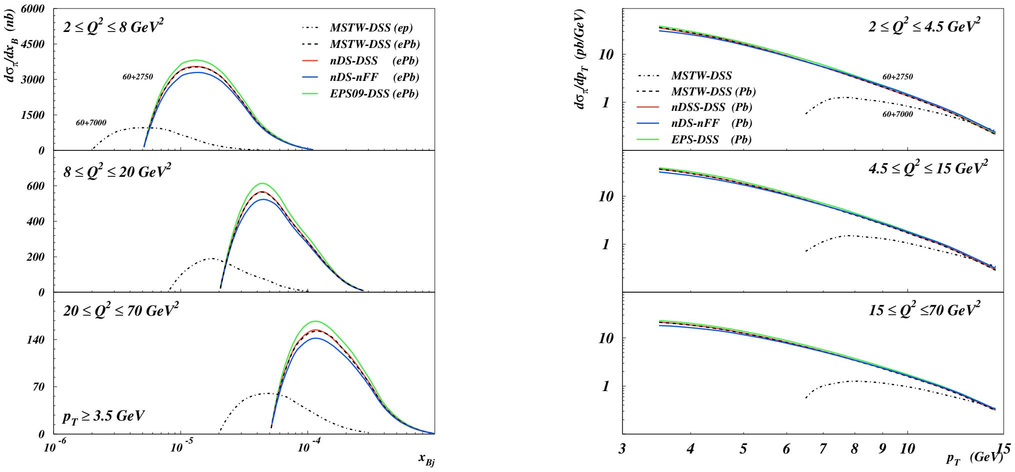

Figure 5: Cross section per nucleon for inclusive π^0 production versus $x_{Bj} = x$ for $p_T > 3.5$ GeV/c (left) and versus p_T (right), computed in NLO QCD. Dashed-dotted black lines refer to ep collisions. All other line types refer to ePb collisions: dashed black ones to standard nucleon PDFs and fragmentation functions (FFs), solid red and green ones to nuclear PDFs and nucleon FFs, and solid blue ones to nuclear PDFs and nuclear FFs. Cuts: $\theta_\pi \in [5°, 25°]$, $x_\pi = E_\pi/E_p > 0.01$, have been applied. (From [2].)

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