Physics at low x_{Bj} and in eA at the LHeC

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Abstract. I discuss the project of an electron-proton/ion collider at CERN using the LHC beams, the Large Hadron Electron Collider. After a brief introduction, I present the project. Then I summarize the possibilities for small-x studies and for electron-nucleus collisions. I also indicate the status of the project and future steps to be taken.

1. Introduction

From studies at fixed-target experiments and at the HERA accelerator at DESY, it has been concluded that inclusive and diffractive data at small-x can be described by non-perturbative models and, more interestingly, by different realizations of evolution equations within perturbative QCD: the standard explanation within fixed-order perturbation theory (DGLAP evolution equations), resummation schemes, and non-linear approaches. Concerning the last item, unitarity of QCD as a quantum field theory implies that non-linear phenomena are unavoidable and saturation of partonic densities is expected to occur at high energies or small Bjorken-x. The Color Glass Condensate offers a non-perturbative but weak coupling realization of saturation ideas, see [1] and references therein. The present discussion lies 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.

Even ignoring such fundamental considerations and focusing merely on practical purposes, our knowledge of the gluon distribution at small x both in protons and nuclei does not suffice for the required precision in predictions within collinear factorization at hadron colliders. Besides, in the lepton-nucleus case 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 of great importance for the study of hadronic and nuclear collisions.

The Large Hadron-electron Collider (LHeC [2]) 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 goal luminosity 10^{33} cm^{-2}s^{-1}. The machine is subject, apart from several requirements on detector performance, to the constraints of creating minimal disturbance during construction and working simultaneously to the LHC. Besides electro-weak studies and searches for new physics, this machine will perform precision QCD studies and it 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 decreasing x at fixed mass number A and Q^2, or increasing A at fixed x and Q^2. The LHeC will give access to a completely new region of the Q^2-x plane, see Fig. 2 for the eA case.
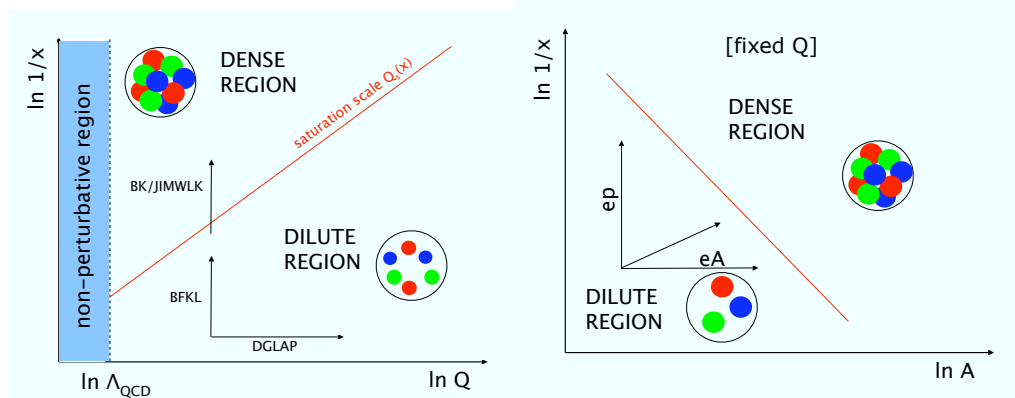
Figure 1. Sketch of the access to the dense partonic region where unitarity effects are essential, from the dilute one where linear evolution is valid. See the text for explanations. (From [2].)
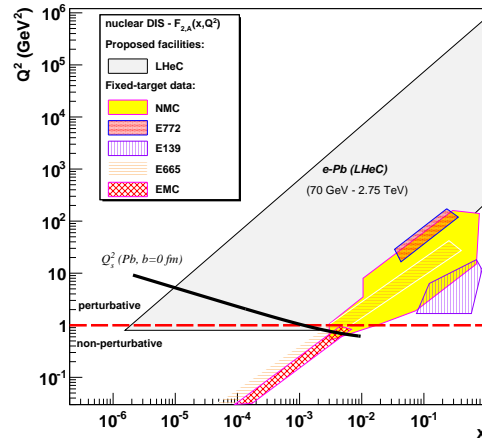

Figure 2. Region of the Q^2-x plane that will be explored with the LHeC in ePb, compared to those achievable at existing eA experiments. An estimation of the saturation scale indicating the dilute-dense transition is shown. (From [2].)

In this contribution I will mention some aspects of the QCD studies that may be performed at the LHeC. Due to the limitations of space, I will focus on small-x physics and nuclear targets, which can be addressed with the LHeC. More information can be found in [2], and in related work concerning the proposed Electron-Ion Collider in the USA [3]. After the completion of the Conceptual Design Report [2], the next steps are the submission for consideration in the European Strategy for Particle Physics [4], and a Technical Design Report for 2015.

2. Inclusive observables at small x

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 the total structure function, F_2, but also its flavor decomposition and the longitudinal one, F_L, (see Fig. 3 for examples of LHeC pseudodata on nuclear ratios of F_2 and F_L), the LHeC offers huge possibilities for:
• Constraining the parton density functions (PDFs) in DGLAP analysis, both in ep and eA (see [2]), particularly for sea quarks and gluons. For this purpose, the combination of F_2, F_L and
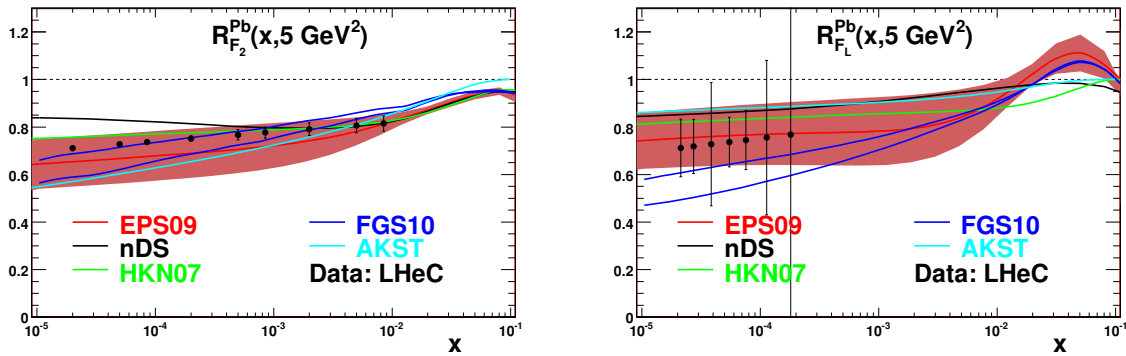
Figure 3. Predictions from different models for the nuclear ratio $R_{F_i}^{\mathrm{Pb}} = F_i^{\mathrm{Pb}}/(208\,F_i^{\mathrm{p}})$, $i = 2, L$, at small x, see the legend on the plots. Filled circles are LHeC pseudodata. (From [2].)

$F_{2c,b}$ appears to be very promising. As shown in Fig. 3 for F_2 and F_L in the nuclear case, the expected uncertainty of F_2 data is much smaller than the spread of existing models.

• Disentangling fixed-order evolution schemes from resummation or non-linear ones, see [5]. In this respect, the combination of data on F_2 and F_L is required.

3. Diffractive observables

On diffraction[1] [2], the LHeC will explore a new domain of very low β (e.g. down to a few 10^{-4} for $Q^2 \sim 4$ GeV^2 at $x_P = 0.003$, two orders of magnitude smaller than at HERA, for p; for nuclei, information on diffraction at small x does not exist). Several aspects can be highlighted:

• It will give access to diffractive masses as large as 200 GeV, providing data to check models describing the transition from low to high M_X, and to constrain nucleon and nuclear diffractive PDFs in DGLAP analyses.

• For elastic vector meson production or deeply virtual Compton scattering, a huge lever arm in W will be explored (e.g. up to ≈ 1.2 TeV for ep with $E_e = 50$ GeV) with enough precision to disentangle linear evolution schemes from non-linear ones. Besides, the differential spectrum in t will be accessible down to $t \sim -2$ GeV^2. All this will also constrain quark and gluon generalized parton densities (GPDs) at small x where they are presently unknown. Measurements of diffractive production of two vector mesons will allow the determination of helicity-flip GPDs.

• Gribov relation between diffraction in ep and nuclear shadowing will be checked in a single experimental setup (see e.g. the FGS10 and AKST models in Fig. 3, the others being NLO DGLAP analyses).

• Diffractive dijets will be measured in DIS with E_T as large as 25-30 GeV, providing a check of collinear factorization for diffractive processes.

The experimental challenge in separating inclusive diffraction ($e + \mathrm{A} \to e + X + X'$ with a rapidity gap) from coherent ($e + \mathrm{A} \to e + X + \mathrm{A}$) and incoherent ($e + \mathrm{A} \to e + X + Z\mathrm{p} + [A-Z]\mathrm{n}$) is under study.

4. Final states

The LHeC will offer huge possibilities for clarifying the dynamics of QCD radiation and hadronization. For example:

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[1] The diffractive kinematical variables are $x_P = (M_X^2 - t + Q^2)/(W^2 + Q^2)$ and $\beta = x/x_P$, with M_X the diffractive mass, t the transverse momentum squared and W the γ^*-hadron center-of-mass energy.
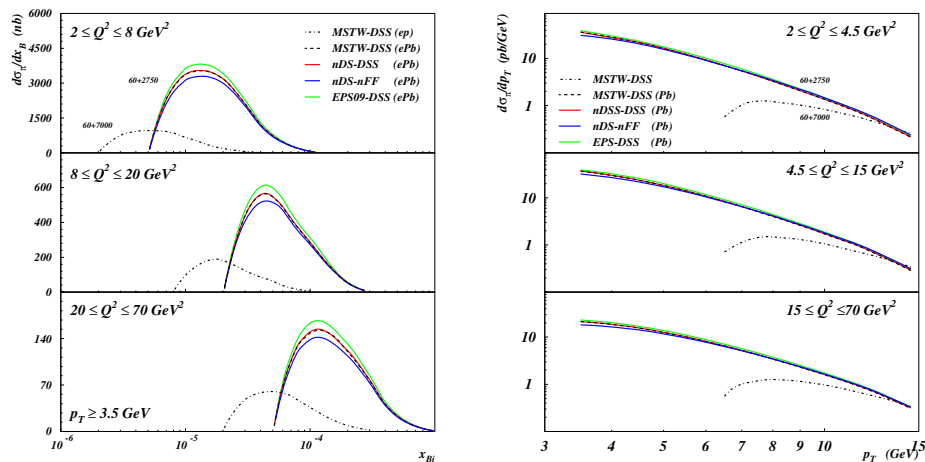
Figure 4. Cross section for inclusive π^0 production versus Bjorken x_{Bj} for $p_T > 3.5$ GeV/c (left) and versus p_T (right), computed in NLO QCD [6]. Dashed-dotted black lines refer to ep collisions. All other line types refer to ePb collisions: dashed black ones to standard nucleon PDFs and fragmentation functions, solid red and green ones to nuclear PDFs and nucleon fragmentations functions, and solid blue ones to nuclear PDFs and nuclear fragmentation functions. All cross sections are given per nucleon i.e. divided by 208 for Pb. Cuts: $\theta_\pi \in [5°, 25°]$, $x_\pi = E_\pi/E_p > 0.01$, have been applied. (From [2].)

- The dynamics of QCD radiation at small x will be studied through forward jet and particle production, which will be abundant, see Fig. 4.
- The parton/hadron energy loss mechanism in semi-inclusive DIS will be tested by introducing a piece of colored material - the nucleus - which would modify the hadronization pattern i.e. its dependence on the traversed length (by varying either the impact parameter or the nuclear size), its chemical composition,... Energies as high as 10^5 GeV in the rest frame of the nucleus will be accessible and the transition from moderate to high energies will be studied.

As an example of the abundant yield of high-energy probes, inclusive jet rates for $Q^2 = 0$ around 10^3 jets per GeV per year are expected [2] with $E_{Tjet} \sim 95$ (80) GeV in ep (ePb).

References
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