Saturation: what do we need

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Abstract

A discussion session was organized during the ISMD in Hamburg. This note describes a summary of open questions that were brought up to introduce this discussion session.

1 Introduction

Parton saturation has been a topic of considerable scientific interest since many years. It would allow to access a new QCD region where apart from simple parton branching diagrams also parton recombination will contribute. Thus one can probe a region of large parton densities, where one can still use a perturbative expansion to describe the system, due to the α_s value that remains small. Saturation has been predicted to occur at HERA in the bare proton for values of low-x but, while there is circumstantial evidence for it, the situation is still not clear.

In 2009 the LHC will turn on and will allow in principle for measurements to reach regions of lower x values than before, at high enough scales. It will be important to analyse data at the LHC with the objective of searching for saturation effects. This will require equiping the present detectors with better instrumentation in the forward regions, i.e. the regions at high pseudo-rapidity $\eta = -\ln\tan\theta/2$. Both ATLAS and CMS have studies ongoing to extend forward region instrumentation, and some of it is already being installed [1].

This short note reports on a few questions that served as an introduction for the discussion session at the symposium, and were in part already presented in [2].

2 Discussion

The program to investigate non-linear effects at HERA further, and to constrain the validity of linear evolution equations, is essential for any proper interpretation of small-x effects at LHC. HERA is the main place where these effects can systematically be studied in a clean and controllable environment, i.e. where precision measurements of these subtle QCD effects are possible. The results of such a program will have direct impact on measurements at RHIC and even more so at the LHC, where deviations from linear dynamics (saturation and multi-parton interactions) are expected to affect even the high p_t processes [3].

The following questions were put forward:

- What is a good and at the same time indisputable signature for parton saturation? There are definitely a number of hints in the HERA data, eg the observation of diffractive events and their interpretation in terms of the dipole picture. A strong signal for the onset of a dense region (or black disk limit) are the measured diffractive gluon PDFs, which indicate [4] that for $x \sim 10^{-4}$ and $Q^2 \sim 4$ GeV^2 the probability of diffraction in gluon induced processes reaches $\sim 40\%$ which is close to the black disk limit of 50%. Now, the theoretical understanding of the dense region has received much support from measurements at RHIC, and new evolution equations (like the Balitsky-Kovchegov equation [5,6] (BK)), which include non-linear terms, are available. However, the BK equation is derived for a large nucleus and only approximately applicable to ep and pp. Although saturation is theoretically well motivated, a clear, clean and indisputable experimental signature for it is still missing. To decide if and where nonlinear dynamical effects become important at HERA is difficult, especially since some signatures of saturation can be mimicked approximately within the linear DGLAP or BFKL descriptions.

- What can HERA still contribute to clarify the situation on saturation? The k_t-dependence of the unintegrated PDF as a function of x could provide important information. In a linear scenario (BFKL) the parton density (for fixed k_t) is expected to increase with deceasing x, while in the case of saturation this density will first increase, then flatten for smaller and smaller x and will eventually decrease. As a function of k_t the parton density is expected to decrease for k_t below the saturation scale and the x-dependence of the saturation scale can thus be studied directly. High-precision data in a wide kinematic region for dedicated observables will certainly help. Are there other signatures? Proposals are to study F_L, $F^{2D}/F_2, F_2 - F_2^C$ (in terms of geometrical scaling), as also discussed in [7].
- Can the potential larger x-range of the LHC be used for saturation studies? The LHC offers the opportunity to reach smaller x values, perhaps even down to 10^{-7}. What are the most useful processes/variables to study to search for saturation effects? In the CMS/TOTEM common physics program LOI [8] the Drell-Yan process was proposed to study saturation. Are all theoretical tools for saturation analyses at the LHC in place?
- Nuclei versus protons studies? Nuclei are expected to amplify the saturation effect as a result of the overlap in the transverse projection of the nucleons, by an enhancement factor $A^{1/3}$ which is about 6 for heavy nuclei. The HERA collider program has been terminated and thus HERA will never run with heavy nuclei instead of protons, but future machines where this is an option are under study like EIC [9] and LHeC [10]. The kinematic reach of these facilities is shown in Fig. 1a. Still naively one could ask if the effects seen in nuclei can be interpreted directly for the dynamics of the single proton case.
- What is the Q^2, x region where non-linear effects become important ? A typical "saturation plane" is shown in Fig. 1b with the transition from dilute to dense systems. Where that transition exactly happens is however somewhat vague (see also below).

Clearly continuing and specific analyses of present data from e.g. HERA and future data at the LHC can shed more light on this topic. On the other hand on the theoretical side progress would be desirable on:

- the calculation of the evolution of unintegrated PDFs in the presence of saturation,
- the factorization and factorization breaking in the presence of saturation,
- the calculation of the change of the leading pion spectrum expected due to the onset of the saturation regime compared to the factorization prediction.

Furthermore, besides investigations on saturation, the range of validity of the linear evolution equations is not yet fully understood:

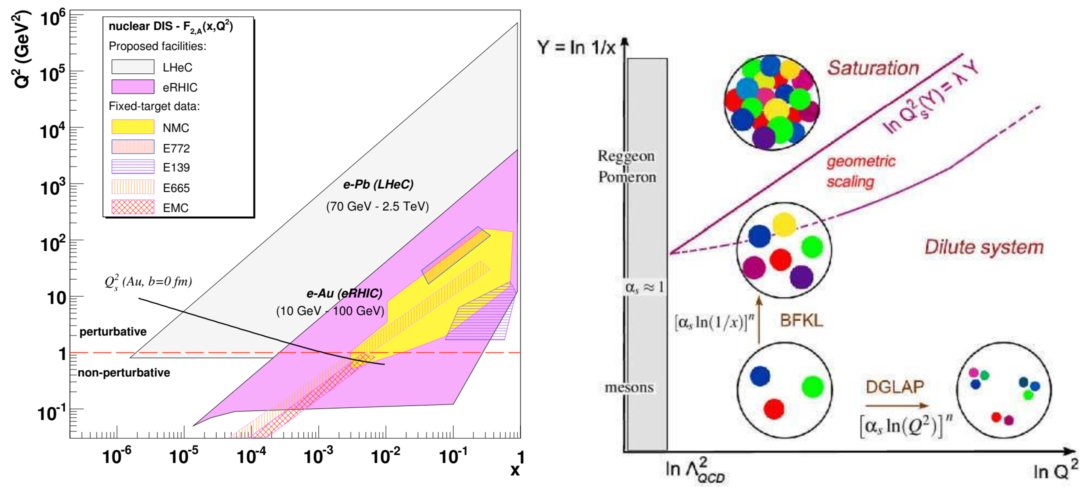

Fig. 1: (a) new proposed nuclear DIS facilities (right): LHeC and EIC/eRHIC (adapted from [11]; (b) saturation QCD "phase diagram" in the $1/x, Q^2$ plane (each dot represents a parton with transverse area $\sim 1/Q^2$ and fraction x of the hadron momentum). The different evolution regimes (DGLAP, BFKL, saturation) as well as the "saturation scale" and "geometric scaling" curves between the dense and dilute domains are indicated. Adapted from [12]

- in the moderate Q^2 region contributions from higher twist effects (multi-parton exchange processes) are expected. However they are suppressed by additional powers of $1/Q^2$ and therefore typically have only a small effect. At small x this contribution is increased by large $\log(1/x)$ terms. A systematic investigation of the higher-twist region would require measurements at the same Q^2 but with x varying over a larger range than available up to now. This can be achieved with F_2 measurements recorded at lower center-of-mass energies.
- in the large x region a breakdown of the collinear factorization ansatz is expected due to the transverse momentum as well as energy momentum conservation as advocated in [13].

3 Conclusion

Saturation in the proton is an important effect which still awaits to be established unambiguously in data. Here a number of questions and suggestions have been collected for further progress and developments on this interesting topic.

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