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Evaluation report of habilitation thesis

To the Faculty of Nuclear Sciences and Physical Engineering, CTU in Prague,

Candidate Ing. Jan Čepila, PhD

Thesis title *Study of parton saturation effects on protons and nuclei*

The habilitation thesis deals with the field of Quantum Chromodynamics, the fundamental theory of the strong nuclear interaction. In particular the focus is on understanding collider scattering experiments at high energies. Experimentally this area of physics is studied at the LHC at CERN, and in the future at the planned Electron-Ion Collider in the US. These high collision energies are expected to reach the so called saturation regime, where nonlinear interactions between gluons play an important role in maintaining the unitarity of the scattering amplitude. One important class of high energy processes studied in this thesis are exclusive reactions, where the colliding proton or nucleus stays intact, or breaks up into only nucleonic fragments. Such exclusive processes are more sensitive to high gluon densities and thus to saturation than total cross sections. They also allow one to experimentally access the gluonic structure of the target proton or nucleus as a function of the transverse coordinate, known in this context as the "impact parameter".

The research work in the habilitation thesis is roughly divided into three related projects, each consisting of several published original research articles.

One of the central tools of studying QCD in the high energy regime is the perturbatively derived Balitsky-Kovchegov (BK) equation, which predicts the collision energy dependence of scattering amplitudes. Applications of the BK equation to phenomenology have commonly solved this equation by assuming an infinite, translationally invariant target, and superimposing an impact parameter dependence ex post facto. Most previous studies have therefore have not really been able to address the full consequences of the BK equation for exclusive reactions. The first topic of the work in this thesis is to solve the BK equation in a finite size system, and apply the solution to phenomenology. Here Dr. Čepila has, with his collaborators and his student M. Matas, realized that a recently developed collinear resummation procedure also enables a stable and realistic impact parameter dependent solution to the BK equation. They have followed up this, somewhat unexpected, discovery with a series of systematical calculations of exclusive, inclusive and diffractive cross sections with proton and nuclear targets.

It has in recent years become clear, from both deep inelastic scattering and heavy ion collision data, that the internal geometrical structure of the small-x gluons in a nucleon is very uneven and fluctuating event-by-event. The second topic addressed in the thesis work is to develop a model for this fluctuating geometry, in terms of a "hot spot" structure of the nucleon. This simple, well motivated model is able to describe existing experimental data. Strikingly, it also predicts a qualitative change of behavior at higher collision energies, with the dissociative cross section reaching a maximum and starting to decline, a clear sign of gluon saturation taking over and starting to suppress the fluctuations in the gluon density.

Exclusive heavy vector meson production has been widely identified as a good probe of small-x dynamics. This has led to a variety of parametrizations for the ingredients needed to calculate the cross section: the dipole amplitude and the vector meson wave function, and of other correction terms that need to be included. The third topic of the research work reported here has been a systematical comparison study of these ingredients, in particular focusing on the vector meson

wave functions. Given the variety of such models in the market, this study is a very welocme asessment of the field.

The habilitation thesis itself is clearly structured. It starts with a brief introduction to QCD and a description of the structure of the thesis. The next chapter describes the basics of gluon saturation. One then moves to the BK equation, describing different versions and solutions known in the literature and used in this work, followed by an exhibition of the cross sections and comparisons to experimental data. The following chapter starts with the basic idea of coherent and incoherent diffraction in the Good-Walker picture and a description of the hot-spot model developed by the author and collaborators, followed by a comparison to experimental data. Chapter 4 presents a systematical exposition of the effect of different meson wavefunctions, dipole amplitude parametrizations and other correction factors used in the literature, which are then compared quantitatively and confronted with experimental data. The text is followed by a list of references and 12 reprinted publications presenting the original research work of the candidate.

This is a phenomenologically focused work, where an important role is played by comparisons to existing experimental results and predictions for future ones. The theoretical methods used, especially in the case of the BK equation, are quite novel. The hot spot model development is also a novel and innovative idea. Thus the work reported here is at the forefront of active research in this field worldwide. Not surprisingly the results have been published in good journals, and have had a significant international impact.

A clear distinction is made between fundamental theory results, approximations needed for purposes of explicit calculations, and phenomenological models, all of which are necessary ingredients in a successfull phenomenological work. The interpretation of the results obtained and the outlook for future research show the perspective of a mature and independent researcher in the field. The thesis is written in a fully appropriate clear and explicit scientific style, in correct English, and laid out in a professional manner.

If time permits during the defence, I suggest that the candidate be asked the following questions:

1. In the hot spot model discussed in Chapter 3, the energy dependence mainly comes from the dependence of the number of hot spots on Bjorken x. Have you considered an alternative scenario where, instead, the parameters describing the sizes of the proton and of an individual hot spot would depend on x?
2. The study presented in Chapter 4 shows that existing HERA data can already differentiate between models of the dipole cross section and meson wave functions. What future Electron-Ion collider measurements would bring the most significant new constraints for these models?

Overall, I find that the habilitation thesis "Study of parton saturation effects on protons and nuclei" by Ing. Jan Čepila, PhD, makes several important contributions to knowledge in its field, and demonstrates the status of the candidate as an independent and established researcher. Thus I recommend that the habilitation be accepted and the candidate be given the title of docent.

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