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Subject: Evaluation report - habilitation thesis in Physics - Jan Nemchik
Title: Diffractive electroproduction of vector mesons off nuclei: selected topics

The habilitation thesis is based in the following 8 published papers

1. J. Nemchik, N. N. Nikolaev and B. G. Zakharov, *Scanning the BFKL pomeron in elastic production of vector mesons at HERA,* Phys. Lett. **B341** (1994) 228 — hep-ph/9405355
2. J. Nemchik, N. N. Nikolaev, E. Predazzi and B. G. Zakharov, *Color dipole systematics of diffractive photoproduction and electroproduction of vector mesons*, Phys. Lett. **B374** (1996) 199 — hep-ph/9604419
3. J. Nemchik, N. N. Nikolaev, E. Predazzi and B. G. Zakharov, *Color dipole phenomenology of diffractive electroproduction of light vector mesons at HERA*, Z. Phys. **C75** (1997) 71 — hep-ph/9605231
4. J. Nemchik, *Anomalous t dependence in diffractive electroproduction of 2S radially excited light vector mesons at HERA,* Eur. Phys. J. **C18** (2001) 711 — hep-ph/0003244
5. J. Nemchik, N. N. Nikolaev and B. G. Zakharov, *Anomalous A-dependence of diffractive leptoproduction of radial excitation rho-prime (2s),* Phys. Lett. **B339** (1994) 194 — hep-ph/0003244
6. J. Nemchik, *Incoherent production of charmonia off nuclei as a good tool for study of color transparency*, Phys. Rev. **C66** (2002) 045204 — hep-ph/0205276
7. B. Z. Kopeliovich, J. Nemchik and I. Schmidt, *Production of Polarized Vector Mesons off Nuclei,* Phys. Rev. **C76** (2007) 025210 — hep-ph/0703118
8. B. Z. Kopeliovich, J. Nemchik, I. K. Potashnikova and I. Schmidt, *Gluon Shadowing in DIS off Nuclei*, J. Phys. **G35** (2008) 115010 — arXiv:0805.4613

High energy collisions involving nuclei are excellent tools to study the space-time structure of extended processes as jet production or hadronization. The author of this thesis is an expert on this type of analyses. The thesis focus on the production of vector mesons, especially in experiments of lepton-nucleus and lepton-proton collisions. Lepton-proton collisions were extensively studied at HERA in the 90's where the works originating this thesis started. There is at present several proposals for electron-nucleus and electron-proton colliders (EIC in the USA and LHeC in Europe) and this type of processes are of relevance for their physics cases. So, it is expected that measurements of vector mesons in electron-nucleus colliders will be available in the mid-term future with kinematics and statistics never probed before. In this sense, the studies presented in the thesis, although produced in the period 1994-2008 will be relevant for the new machines. Moreover, the techniques developed in the thesis can also be used for the so-called *Ultra-Peripheral Collisions* (UPCs) being measured in heavy-ion collisions at the LHC. UPCs use the intense Weizsacker-Williams quasi-real photon flux, created by the huge electromagnetic fields of the colliding heavy-ions, to study photon-nucleus or photon-photon collisions. Vector meson production, especially J/Ψ, has been one of the main interests as it is easy to identify and has been proposed to be sensitive to the square of the gluon parton distribution function (PDF), similar to other diffractive processes.

The calculations in the thesis are performed in the (light-cone) dipole formalism in which the virtual photon from the electron fluctuates into a $q\bar{q}$ pair (or higher Fock states with the same quantum numbers) and then interacts with the target. The lifetime of this fluctuation is usually called coherence time (t_c defined in eq. (1.3) in the manuscript), while the time for the dipole to reach the typical size of the vector meson is called a formation time (t_f defined in eq. (1.2)). For large coherence lengths (large energies) the fluctuation lives much longer than the typical separation between two nucleons in the nucleus and, according to Quantum Mechanics, the collisions cannot be independent. The effect is a suppression of the cross section known as *shadowing*. In the opposite limit, at smaller energies, the suppression of the production is due to incoherent scatterings, also known as *absorption*. Studying the different relative relevance of one and the other is one of the objects of the thesis.

The thesis has two sets of contributions, in the first set of papers (1. to 4. above, reported in Chapter 2) the dipole formalism for vector meson production is presented. The first paper shows that the BFKL pomeron can be written in terms of the dipole cross section and, hence, that the elastic production of vector mesons can probe the BFKL dynamics. This was a very important result in 1994, as HERA was starting to release the data that showed a strong increase of the structure functions at small-x, qualitatively in agreement with BFKL resummation. Constraining this dynamics in different observables was of utmost importance. Papers 2. and 3. improve the description of vector mesons and the dipole cross sections and, for the first time (in paper 2. above) the case of the excited states. Paper 4. above points out about an anomaly of the excited vector meson production when compared with the ground state due to interferences of wave functions. These sets of papers, written in the last years of the 90's had a strong impact in the field of DIS and small-x physics. They also helped to establish the formalism of (light-cone) path integrals, dipole picture, etc.

The second set of contributions concern scattering with nuclei and, in contrast with the first four, a more limited amount of experimenta data was available. It is worth emphasizing that this is largely still the situation nowadays, except for the data from HERMES, UPCs at the LHC and a few others.

The situation is expected to improve in the mid-term with the EIC in the USA and (possibly also) the LHeC in Europe.

For the case of nuclei, the coherence and formation times explained above are relevant and the space-time picture of hadronization accessible. The main physics motivation of these studies is studying this space-time picture. This motivation is also included in the documents reviewing the electron-ion collider physics cases. In this sense, the papers in this thesis are relevant for the planning of the future facilities.

In papers 5. the *anomaly* for excited states identified in paper 4. is generalized for the case of the nuclei, where the additional presence of color transparency translates into a non-trivial dependence on the nuclear size (A). As a result, the production of the excited ρ' is enhanced with respect to the ρ. Papers 6. and 7. study further effects of color transparency in nuclear collisions. Finally, paper 8. is a computation of gluon shadowing in the same formalism. Here, including higher Fock states as well as a numerical evaluation of the Green functions, and not only the eikonal approximation, have been essential for a correct implementation and comparison with data. These second group of papers, where nuclear collisions are studied, gathered a smaller number of citations than the first four. The main reason is most probably that the amount of experimental data and the experimental activity itself (no DIS experiments running in the period, besides HERMES, but with kinematics where the applicability of this formalism is questionable) was much smaller.

In summary, the contributions including in this thesis have been important for the understanding of vector meson production in lepton-proton and lepton-nucleus collisions. HERA data boosted the relevance of the first four papers under consideration, that indeed helped to support the dipole picture and the computational framework. Some of the papers of the author are references in the field. The applicability to the nuclear case opens the possibility to study the space-time picture of hadronization and other extended processes. The author, together with his collaborators are world-reference in this type os studies. I find the habilitation thesis of good quality also in terms of clarity and presentation.

Please, do not hesitate to contact me should you need any further clarification

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