HARD DIFFRACTIVE PHENOMENA WITH NUCLEI - FROM DGLAP TO BLACK DISK LIMIT AND HOW THEY WILL BE STUDIED IN ULTRAPERIPHERAL COLLISIONS AT LHC

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We summarize the QCD expectations for hard diffraction in DGLAP and Black Disk Limits and argue that LHC will provide unique new oportunities for studing of these phenomena using ultraperipheral heavy ion (proton-ion) collisions at the LHC.

1. Introduction

Theoretical analyses of the HERA data find several indications of the onset of the regime of the maximal strength of interaction (Black Disk Limit -BDL) of color octet dipoles of transverse size ~ 0.3fm for the maximal HERA energies: (i) The impact factor for the interaction of such dipoles with nucleons is found to be close to one, (ii) probability of the gluon induced diffraction for $Q^2 \sim 4\text{GeV}^2$ reaches values $\sim 0.3 \div 0.4$, (iii) For $Q^2 \leq 4\text{GeV}^2$ the DGLAP fits to the HERA data appear to produce puzzling x- dependence of the gluon densities, see summary in [1]. Also the data on the leading pion production in the central deuteron-gold collisions at RHIC require large energy losses for the leading quarks and gluons which is possible only if the data correspond to the kinematics of the onset of the BDL in the interaction with nuclei (these data probe interactions at larger x than at HERA and mostly for quarks, however the nuclear enhancement factor $\sim 0.5A^{1/3}$ compensates for a weaker quark interaction.) [2].

After the HERA shutdown the next step in the studies of BDL using diffraction could be taken in the ultraperiperal collisions (UPC) of ions (protons and ions) at LHC, for the recent review see [3].

2. Theoretical expectations for diffraction at small x off nuclei.

Combining Gribov theory of shadowing and pQCD factorization theorem for diffraction in DIS allows to calculate LT shadowing for all parton densities [4] and also calculate the diffractive parton densities [5]. One finds that probability of diffraction is close to the maximal possible (1/2) corresponding to BDL for $x \sim 10^{-4}$ and $Q^2 \sim 4\mathrm{GeV}^2$ and it remains very significant: $\sim$ 0.2 up to Q=100 GeV. One also finds that the β-dependence of the parton diffractive pdfs changes with decrease of $x_{I\!P}$.

In the case of exclusive onium production we predict large shadowing effects even for the case of the Υ production since the shadowing for these processes is proportional to the square of the gluon shadowing for the gluon pdfs, which is expected to be significant even for $Q^2_{eff} \sim 40\mathrm{GeV}^2$ characteristic for the Υ photoproduction.

In the BDL we predict [6] several effects which are qualitatively different from the DGLAP case. The most relevant for the UPC case is the disappearance of the suppression of the exclusive diffractive production of two jets induced by light-quark component of the photon wave function.

3. UPC observables

The study of the feasibility of the study of the gluon pdfs in UPC at LHC was performed in [7]. We calculated photoproduction rates for several hard processes in ultraperipheral proton-lead and lead-lead collisions at the LHC with $\sqrt{s_{NN}}$ = 8.8 and 5.5 TeV respectively which could be triggered in large LHC detectors using ATLAS as an example. The lead ion is treated as a source of (coherently produced) photons with energies and intensities greater than those of equivalent ep collisions at HERA. We find very large rates for both inclusive and diffractive production which will extend the HERA x range by nearly an order of magnitude for similar virtualities. Nonlinear effects on the parton densities will thus be more important in these collisions than at HERA. In AA scattering it will be possible to measure gluon nuclear diffractive pdfs (or at least rapidity gap probabilities) in most of the small x kinematic range where measurements of nuclear gluon pdfs will be feasible. The key element is the possibility to use the direct photon mechanism to determine which of the nuclei has emitted the photon.

In the case of pA UPC collisions it would be possible to measure also the proton diffractive pdfs. However in this case the situation is more complicated than in the case of AA scattering. as we need to study jet production in the direct photon proton interactions $x_\gamma \sim 1$, and compare it to contribution due to nuclear diffractive pdfs at $\beta \sim 1$. Photon couples well to quarks (in particular heavy quarks), while in the inclusive dijet production gluon- gluon mechanism is strongly enhanced. Net result is that for heavy quarks photon contribution wins, while for dijet production nuclear Pomeron contribution may win [8]. Hence the studies of the gluon diffractive pdfs will be feasible.

We find that it will be feasible to investigate suppression of the coherent onium production in nucleus-nucleus collisions down to $x \sim m_{onium}/2(E_A/A)$ corresponding to production at the central rapidities[9]. At rapidities away from zero photons of smaller energies dominate making it very difficult to probe smaller x. However use of the incoherent diffractive onium production appears to solve this problem as one can use production of the soft neutrons to determine which of the nuclei emitted a photon and which was involved in the strong interaction [10].

Recently, we also evaluated the cross sections for the production of vector mesons in exclusive ultraperipheral proton-ion collisions at LHC[11]. We find that the rates are high enough to study the energy and momentum transfer dependence of vector mesons - ρ, ϕ, J/ψ, Υ photoproduction in γp scattering in a wide energy range (at least up to W = 1 TeV) extending the measurements which were performed at HERA, providing new information about interplay of soft and hard physics in diffraction. Also, we calculate the contributions to the vector meson yield due to production of vector mesons off nuclear target by photons emitted by proton. We find, that least in the case of Υ production it is feasible to observe simultaneously both these processes. Such measurements would increase the precision with which the A-dependence of exclusive onium production can be determined. This would also enable one to estimate the amount of nuclear gluon shadowing of generalized gluon distributions at much smaller x than that is possible in AA collisions and to measure the cross sections for photoproduction processes in a significantly wider energy range than that achieved in experiments with fixed nuclear targets.

Also, it will be possible to study at LHC a novel process of vector meson production at large t with a rapidity gap in $\gamma - nucleus$ scattering[11]. We find that by an appropriate choice of the rapidity gap interval it will be possible to study regimes of color transparency and opacity as well as the regime of the leading twist shadowing. In particular, it will be possible to investigate the pQCD prediction that for sufficiently large t this process is dominated by interaction of the photon in a small size $q\bar{q}$ configuration, which would lead to a color transparency regime, or by interaction in an average configuration, leading to suppression of the cross section by a factor of the order ten.

4. Conclusions

Studies of UPC at LHC will address many (though not all) of the benchmark issues of HERA III proposal including (i) Small x physics with protons and nuclei in a factor of ten larger energy range though at higher virtualities both in inclusive and diffractive channels, (ii) Interaction of small dipoles at ultrahigh energies - approach to regime of black disk limit, color opacity. However the physics of intermediate virtualities $Q \leq 5GeV$ will be missed for most of the processes. This would require a dedicated electron - nucleus collider.

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