Origin of Nuclear Shadowing and Antishadowing

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Our collaboration's goal is to develop a comprehensive approach to evaluate nuclear structure functions in the low Bjorken x regime. The longstanding issue of tracing the origin of the various patterns of shadowing and antishadowing (and/or lack thereof) in high energy data will be at reach through a combined analysis of data from the LHC, the neutrino-nucleus scattering program and the upcoming EIC.

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Nuclear parton distribution functions (PDFs) can be extracted from global analyses of available nuclear data using a variety of probes and targets, from electron, muon and neutrino scattering to Drell Yan (DY) processes. In particular, defining the ratio of the charged lepton deep inelastic scattering (DIS) nuclear structure functions to the nucleon ones, $R = F_2^A/AF_2^N$, one has that $R < 1$ for $x \lesssim 0.1$ – in the shadowing region – and that $R > 1$ for $0.1 \lesssim x \lesssim 0.3$ – in the so-called antishadowing region (see *e.g.* [1] for a review). Different observables, from neutrino scattering and DY processes, however, display different modifications patterns resulting *i.e.* in the absence of antishadowing [2, 3]. Although the present kinematic range covered by experiment does not allow us to fully quantitatively constrain the nuclear PDFs in the low Bjorken x regime, this goal will soon be at reach by combining information from the future EIC to the LHC. It is therefore mandatory to understand the physical origin of the modifications of the DIS structure function in nuclei: are these described in terms of intrinsically modified parton distributions, or are the nuclear modification patterns due to a form of quantum mechanical interference?

Nuclear shadowing can be described in terms of an initial state interaction where the virtual photon splits into a quark-antiquark pair which interacts strongly with other nucleons in the target. In this regime the lepton-nuclear cross section involves the interference between the standard lepton-quark scattering amplitude for the deep inelastic process on a single nucleon and a two-step process where diffractive scattering on a first nucleon combines with the amplitude for deep inelastic scattering on a second nucleon. The phases associated with the Pomeron and Reggeon exchange contributions to the diffractive amplitude determines whether one has destructive or constructive interference of the one-step and two-step amplitudes, leading to the flavor-independent shadowing suppression or the flavor-dependent anti-shadowing enhancement of the leading-twist deep inelastic scattering cross section at low x_{bj} [4–6]. As a result of the two-step/one-step interference, the standard leading-twist operator product and handbag diagram analyses of the forward virtual Compton amplitude on the nucleus is inapplicable, and the conventional momentum and spin sum rules are broken for nuclear structure functions [4]. The quantum-mechanical interference between the two-step and one-step amplitudes, which generates shadowing and flavor-dependent anti-shadowing, also bars the probabilistic interpretation of nuclear structure functions (see also

[7]).

This picture raises a fundamental question: even at leading twist, are structure functions the same as parton distributions? Here we consider parton distributions as parton densities in the nuclear state. In principle, these are defined through light-cone wave functions of the nucleon or nucleus. Imagine a hypothetical calculation, where the light-cone wave functions describing the Fock components of the quark-gluon wave function of the nucleon/nucleus are all included, would the suppression of nuclear PDFs at small x emerge from a modification of the light-cone wave functions at small x or are nuclear light-cone wave functions an incomplete description?

This question is fundamental as it calls into question the operator product expansion and QCD factorization at leading twist. Further investigations beyond the analyses in [4] will involve multi-loop model calculations [8]. One important aspect in this context is to ensure gauge invariant states, for example by starting from spectator models or using models that contain an explicit gauge link to ensure that non-local states are gauge invariant. This is particularly important for states that are transversely non-local because in that case choosing the light-cone gauge does not automatically eliminate gauge links and initial/final state interactions potentially become an issue even at leading twist.

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