Nuclear Effects on Generalized Parton Distributions of $^3$He

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Abstract. The relevance of measuring generalized parton distributions (GPDs) of nuclei is stressed and the unique possibilities offered by nuclear few body systems are emphasized. A realistic microscopic calculation of the unpolarized quark GPD $H_3^q$ of the $^3$He nucleus is reviewed. Nuclear effects are found to be larger than in inclusive deep inelastic scattering, flavor dependent, increasing with the momentum transfer and the asymmetry of the process. They also depend on the realistic nuclear potential chosen to estimate them. Besides, it is found that nuclear GPDs cannot be factorized into a $\Delta^2$-dependent and a $\Delta^2$-independent term, as suggested in prescriptions proposed for finite nuclei.

Generalized Parton Distributions (GPDs) parametrize the non-perturbative hadron structure in hard exclusive processes (for a recent review, see, e.g., [2]), entering the long-distance dominated part of exclusive lepton Deep Inelastic Scattering (DIS) off hadrons. In particular, Deeply Virtual Compton Scattering (DVCS), i.e. the process $eH \rightarrow e'H'\gamma$ when $Q^2 \gg m_H^2$, is one of the the most promising to access GPDs. Here and in the following, $Q^2$ is the momentum transfer between the leptons $e$ and $e'$, and $\Delta^2 = (P' - P)^2$ the one between the hadrons $H$ and $H'$, which have momenta $P$ and $P'$, respectively. GPDs depend on $\Delta^2$, on the so called skewness parameter, given by $\xi = \Delta^2/(P + P')^+$, and on the fraction of light cone momentum $x$. The dependence on the scale $Q^2$ will not be discussed here.

Recently, the issue of measuring GPDs for nuclei has been addressed. In the first paper on this subject [3], concerning the deuteron, it has been observed that the knowledge of GPDs would permit the investigation of the short light-like distance structure of nuclei, and thus the interplay of nucleon and parton degrees of freedom in the nuclear wave function. In standard DIS off a nucleus with four-momentum $P_A$ and $A$ nucleons of mass $M$, this information can be accessed in the region where $Ax_{Bj} \simeq Q^2/(2M \nu) > 1$, being $x_{Bj} = Q^2/(2P_A \cdot q)$ and $\nu$ the energy transfer in the laboratory system. In this region measurements are very difficult, because of vanishing cross-sections. As explained in [3], the same physics can be accessed in DVCS at much lower values of $x_{Bj}$. The usefulness of nuclear GPDs has been stressed also for finite nuclei in Refs. [4].

The study of GPDs for $^3$He is interesting for many aspects. In fact, $^3$He is a well known nucleus, for which realistic studies are possible, so that conventional nuclear effects can be safely calculated. Strong deviations from the predicted behavior could be therefore ascribed to exotic effects, such as the ones of non-nucleonic degrees of freedom, not included in a realistic wave function. Besides, $^3$He is extensively used...
as an effective neutron target. In fact, the properties of the free neutron are being investigated through experiments with nuclei, whose data are analyzed taking nuclear effects properly into account. Recently, it has been shown that unpolarized DIS off three body systems can provide relevant information on PDFs at large $x_{Bj}$, while it is known since a long time that its particular spin structure suggests the use of $^3$He as an effective polarized neutron target [5]. Polarized $^3$He will be therefore the first candidate for experiments aimed at the study of spin-dependent GPDs in the free neutron, to unveil details of its angular momentum content.

In this talk, an Impulse Approximation (IA) calculation of the quark unpolarized GPD $H_3^{q}$ of $^3$He is reviewed. The calculation is fully described in [6], where the reader can find all the formalism, skipped here. In [7], for any spin $1/2$ hadron target made of three spin $1/2$ constituents, a convolution formula is obtained for $H_3^{q}$, in terms of $H_N^{q}$, the GPD of the internal particle, and a non diagonal spectral function $P_3^{N}(\vec{p},\vec{p}+\vec{\Delta})$:

$$H_3^{q}(x,\xi,\Delta^2) = \sum_N \int_1 x \frac{dz}{z} h_N^3(z,\xi,\Delta^2) H_N^{q}\left(\frac{x}{z},\frac{\xi}{z},\Delta^2\right),$$

where

$$h_N^3(z,\xi,\Delta^2) = \int dE \int d\bar{p} P_3^N(\bar{p},\bar{p}+\bar{\Delta}) \delta \left(\bar{z} + \frac{2p^+}{(P+P')^+}\right).$$

Formally the above equation fulfills the theoretical constraints of GPDs [7] and it has been numerically evaluated for $^3$He in [3], using a realistic $P_3^N(\bar{p},\bar{p}+\bar{\Delta})$, so that Fermi motion and binding effects are rigorously estimated. In particular, for its evaluation use has been made of wave functions overlaps evaluated in [8] by means of the AV18 NN interaction. The proposed scheme is valid for $\Delta^2 \ll Q^2, M^2$ and despite of this it permits to calculate GPDs in the kinematical range relevant to the coherent, no break-up channel of deep exclusive processes off $^3$He. In fact, the latter channel is the most interesting one for its theoretical implications, but it can be hardly observed at large $\Delta^2$, due to the vanishing cross section. The nuclear GPDs obtained here are a prerequisite for any calculation of observables in coherent DVCS off $^3$He, although they cannot be compared with existing data. Thus, the main result of this investigation is not the size and shape of the obtained $H_3^{q}$ for $^3$He, but the size and nature of nuclear effects on it. This will permit to test directly, for the $^3$He target at least, the accuracy of prescriptions which have been proposed to estimate nuclear GPDs [4], providing a useful tool for the planning of future experiments and for their correct interpretation.

Nuclear effects are found to be larger than in the forward case ($\Delta^2 = 0, \xi = 0$) and increasing with $\Delta^2$ and $\xi$. They are also flavor dependent, being more important for the flavor $d$ than for the flavor $u$. They also depend on the used realistic nuclear potential. Besides, it is found that nuclear GPDs cannot be factorized into a $\Delta^2$-dependent and a $\Delta^2$-independent term, as suggested in prescriptions proposed for finite nuclei.

An illustration of the size and relevance of nuclear effects is given in Fig. 1, where it is shown the ratio $R^{(0)}$ (see [3] for a detailed definition) of the nuclear to nucleon GPDs $H_3^{q}$, corresponding to the flavor $d$. Such a ratio would be one if there were no nuclear effects. It is clearly seen from the figure that nuclear effects increase with $\xi, \Delta^2$ and that
they depend on the choice of the NN potential, at variance with what happens in the forward case.

A detailed analysis of DVCS off $^3$He, with estimates of observables, such as cross-sections or spin asymmetries, is in progress.

FIGURE 1. Left panel: the ratio $R^{(0)}$, for the $d$ flavor, in the forward limit $\Delta^2 = 0, \xi = 0$, calculated by means of the AV18 (full line) and AV14 (dashed line) interactions, as a function of $x_3 = 3x$. The results obtained with the different potentials are not distinguishable. Right panel: the same as in the left panel, but at $\Delta^2 = -0.25$ GeV$^2$ and $\xi_3 = 3\xi = 0.2$. The results are now clearly distinguishable.

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