Deeply Virtual Compton Scattering on Spin-1 Nuclei\footnote{1\textsuperscript{to be published in the Proceedings of the XVIth International Conference on Particles and Nuclei (PANIC02), Osaka, Japan, 30 September 4 October 2002}}

F. Cano\footnote{1} and B. Pire\footnote{2},
\begin{itemize}
  \item[1] DAPNIA/SPbN, CEA-Saclay, F91191 Gif-sur-Yvette Cedex, France
  \item[2] CPhT, École Polytechnique, F-91128 Palaiseau, France\footnote{2 Unité mixte C7644 du CNRS.}
\end{itemize}

Abstract:

We consider the Generalized Parton Distributions for spin-1 nuclei in general and on the deuteron in particular. We use the impulse approximation to obtain a convolution model for them. Sum rules are used to check the validity of the approach and to estimate the importance of higher Fock-space states in the deuteron. Numerical predictions for the Beam Spin Asymmetry in deeply virtual Compton scattering are presented.
Figure 1: Contributions to the deuteron GPDs in the impulse approximation for the lowest $|pn\rangle$ Fock-space state of the deuteron. The figure (c) corresponds to higher components that we have neglected.

1 Introduction

Hard exclusive processes, such as deeply virtual Compton scattering (DVCS) and deeply exclusive meson production (DEMP), have been recently demonstrated to open the possibility of obtaining a quite complete picture of the hadronic structure. The information which can be accessed through these experiments is encoded by the Generalized Parton Distributions, GPDs [1] (for recent reviews see [2]). The physical interpretation of the GPDs has been elucidated by some authors [3]. Recent measurements of the azimuthal dependence of the beam spin asymmetry in DVCS [4] have provided experimental evidence to support the validity of the formalism of GPDs and the underlying QCD factorization theorems.

The formalism of GPDs can be applied to the deuteron as well [6]. From the theoretical viewpoint, it is the simplest and best known nuclear system and represents the most appropriate starting point to investigate hard exclusive processes off nuclei [7]. Moreover, hard exclusive processes could offer a new source of information about the partonic degrees of freedom in nuclei, complementary to the existing one from deep inelastic scattering.

A parameterization of the non-perturbative matrix elements which determine the amplitudes in DVCS and DEMP on a spin-one target were given in terms of nine GPDs for the quark sector [6] (five coming from the vector operator and four from the axial vector one). Due to the spin-one character of the target, there are more GPD’s than in the nucleon case, but at the same time the set of polarization observables which in principle could be measured is also richer.

2 Deuteron GPD’s in the impulse approximation

The simplest way to model deuteron GPDs is to use the impulse approximation where the interaction with photons occurs in a single nucleon the other being a spectator (see fig. 1). For the sake of simplicity we will focus in the following on the helicity independent GPD’s but analogous relations can be found for the helicity dependent ones. Since the deuteron is an isoscalar target we have:

$$H_i^a(x, \xi, t) = H_i^d(x, \xi, t) = H_i^g(x, \xi, t)$$ (1)
The relationship between deuteron GPDs and the helicity matrix elements of the non-local quark vector operator is given by:

\[ H^q_i(x, \xi, t) = C^\lambda_i V^q_{\lambda\lambda} \]  

where \( C^\lambda_i \) are coefficients which depends on the polarization vectors of the deuteron and on the chosen kinematics and \( V^q_{\lambda\lambda} \) is given in the impulse approximation by a convolution between deuteron wave functions and the isoscalar combination of nucleon GPDs:

\[
V^q_{\lambda\lambda} = \frac{2}{(16\pi^3)} \int d\alpha d\vec{k}_\perp \sqrt{1 + \xi \frac{1}{1 - \xi \alpha'}} \sum_{\lambda_1, \lambda_2} \chi^\dagger_{\lambda'}(\alpha', \vec{k}'_\perp, \lambda_1, \lambda_2) \chi(\alpha, \vec{k}_\perp, \lambda_1, \lambda_2) \]

where \( \alpha' \) refers to the fraction of plus momentum carried by the active nucleon in the initial deuteron and \( \vec{k}_\perp \) to its transverse momentum in a frame where \( \vec{P}_\perp = 0 \). The kinematics of the process imposes that \( \alpha' = \frac{\alpha(1 + \xi - 2\xi)}{1 - \xi} \) and \( \vec{k}'_\perp = \vec{k}_\perp - \frac{1 - \xi}{1 + \xi} \vec{\Delta}_\perp \). The integral over \( \alpha \) is appropriately bounded from below to ensure the positivity of plus momentum involved in the problem.

The combinations of nucleon GPDs which appear are the isoscalar ones:

\[ H^\text{IS}(x_N, \xi_N, t) = \frac{1}{2}(H^u(x_N, \xi_N, t) + H^d(x_N, \xi_N, t)) \]

with \( \xi_N = \frac{\xi}{\alpha(1 + \xi)} \), \( x_N = \frac{\xi}{\xi_N} \). The minimal value of the momentum transfer is \( t_0 = -\frac{4M_N^2\xi^2 + \vec{\Delta}_\perp^2}{1 - \xi^2} \) and \( \eta_\lambda \) is a phase.

It is clear that for most cases the dominant contribution will be the one proportional to \( H^\text{IS} \). Numerically, the term that goes with \( E^\text{IS} \) has little effect on the cross sections.

In the impulse approximation we have discarded higher Fock-space states in the deuteron (see fig. 1). An important check of our model is the \( \xi \)-independence of the integrated quantities \( \int_{-1}^1 H_i(x, \xi, t) \) at fixed \( t \). These sum rules relate the \( x \)-integrated GPD’s to the form factors of local vector and axial currents. They read:

\[ \int_{-1}^1 H_i(x, \xi, t) = G_i(t) \quad (i = 1, 2, 3) \quad ; \quad \int_{-1}^1 H_i(x, \xi, t) = 0 \quad (i = 4, 5) \]  

We see on fig. 2, where we have plotted \( I(\xi) \equiv \int_{-1}^1 H_i(x, \xi, t = -0.5\text{GeV}^2) \), that these sum rules are quite well verified by our model. The variation of \( I_i(\xi) \) with \( \xi \) gives a measure of the physical ingredients which are missing in the impulse approximation.

### 3 Beam spin asymmetry in DVCS

Let us now present one observable calculated with our modelized deuteron GPD’s, namely the beam spin asymmetry in DVCS. It is defined as
Figure 2: $\xi$ dependence of the first moments of vector GPDs $H_i$. Lines correspond to the theoretical ($\xi$-independent) expected value according to the sum rules and points are the actual values obtained with the impulse approximation for the GPDs.
Figure 3: Azimuthal dependence of the Beam Spin Asymmetry as defined in the text. Left: $x_{Bj} = 0.2$, $Q^2 = 2$ GeV$^2$ and $E_e = 6$ GeV. Right: $x_{Bj} = 0.1$, $Q^2 = 4$ GeV$^2$ and $E_{e^+} = 27$ GeV. In both cases $t$ is fixed to $-0.3$ GeV$^2$.

$A_{LU}(\phi) = \frac{d\sigma^\uparrow(\phi) - d\sigma^\downarrow(\phi)}{d\sigma^\uparrow(\phi) + d\sigma^\downarrow(\phi)}$  \hfill (5)

where $\phi$ is the angle between the lepton and hadron scattering planes. The numerator is proportional to the interference between the Bethe-Heitler and the DVCS amplitudes. A very rough approximation, in the case of the dominance of the Bethe-Heitler process, leads to an asymmetry proportional to $\sin(\phi)$.

Our predictions are shown on Fig. 3 for JLab and Hermes energies. The sign of the asymmetry is reversed for a positron beam. Such a sizable asymmetry should be quite easily measured. It will constitute a crucial test of the validity of our model.

Acknowledgements
This work has been supported by the EC–IHP Network ESOP, Contract HPRN-CT-2000-00130.

References
[1] D. Müller et al., Fortsch. Phys. 42 (1994) 101; X. Ji, Phys. Rev. Lett. 78 (1997) 610; A. V. Radyushkin, Phys. Rev. D56 (1997) 5524; M. Diehl et al, Phys. Lett. B411 (1997) 193; J. Blümlein et al. Nucl. Phys. B560, 283 (1999).
[2] P. A. Guichon and M. Vanderhaeghen, Prog. Part. Nucl. Phys. 41, 125 (1998); A. V. Radyushkin, arXiv:hep-ph/0101225; X. D. Ji, J. Phys. G 24 (1998) 1181; K. Goeke et al, Prog. Part. Nucl. Phys. 47 (2001) 401.

[3] M. Burkardt, Phys. Rev. D 62 (2000) 071503; J.P. Ralston and B. Pire, hep-ph/0110075; M. Diehl, Eur. Phys. J. C 25 (2002) 223; A.V. Belitsky, D. Müller, hep-ph/0206306.

[4] S. Stepanyan et al. [CLAS Collaboration], Phys. Rev. Lett. 87 (2001) 182002; A. Airapetian et al. [HERMES Collaboration], Phys. Rev. Lett. 87 (2001) 182001.

[5] J.C. Collins, L. Frankfurt and M. Strikman, Phys. Rev. D56, 2982 (1997); J. C. Collins and A. Freund, Phys. Rev. D59, 074009 (1999).

[6] E.R. Berger et al. Phys. Rev. Lett. 87 (2001) 142302.

[7] A. Kirchner and D. Müller, hep-ph/0202273; F. Cano and B. Pire, Nucl. Phys. A711 133 (2002).

[8] M. Garçon and J.W. Van Orden, Adv. Nucl. Phys. 26 (2001) 294.