DVCS off He nuclei with positron beams

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The relevance of using (polarized) positron beams in DVCS off ^{4}He and ^{3}He is addressed. The way the so-called $d-$term could be extracted from the real part of the relevant Compton form factor, using as an example coherent DVCS on ^{4}He, is summarized. The importance and novelty of such a measurement is presented. The role of ^{3}He targets, of incoherent (tagged) DVCS processes, and the unique possibility offered by positron beams for the investigation of Compton form factors of higher twist, are also briefly addressed.

In the last few years, there has been a growing interest on nuclear DVCS, thanks essentially to two reasons. The first being the possibility to shed light on the EMC effect, i.e., the nuclear modifications of the nucleon parton structure (1, 2), while the second reason is being the possibility to distinguish coherent and incoherent channels of nuclear DVCS, which is experimentally demonstrated recently by the CLAS collaboration at JLab using a ^{4}He gaseous target (3, 4).
To fix the ideas on how positron beams could help in this field, let us think to coherent DVCS off ^{4}He. We recall that ^{4}He has only one chiral even Compton Form Factor (CFF) at leading twist. In the EG6 experiment the crucial measured observable was the single-spin asymmetry A_{LU}, which can be extracted from the reaction yields for the two electron helicities ($N^{\pm}$):

$$A_{LU} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}, \tag{1}$$

where P_B is the degree of longitudinal polarization of the incident electron beam. In EG6 kinematics, the cross section of real photon electroproduction is dominated by the BH contribution, while the DVCS contribution is very small. However, the DVCS contribution is enhanced in the observables sensitive to the interference term, *e.g.* A_{LU}, which depends on the azimuthal angle ϕ between the (e, e') and $(\gamma^*, ^4\text{He}')$ planes. The asymmetry A_{LU} for a spin-zero target can be approximated at leading-twist as

$$A_{LU}(\phi) = \frac{\alpha_0(\phi)\,\Im m(\mathcal{H}_A)}{den(\phi)}, \tag{2}$$

$$\begin{aligned} den(\phi) &= \alpha_1(\phi) + \alpha_2(\phi)\,\Re e(\mathcal{H}_A) \\ &+ \alpha_3(\phi)\left(\Re e(\mathcal{H}_A)^2 + \Im m(\mathcal{H}_A)^2\right). \end{aligned} \tag{3}$$

The kinematic factors α_i are known (see, e.g., Ref. (5, 6)). Using the different $\sin(\phi)$ and $\cos(\phi)$ contributions, in the experimental analysis, both the real and imaginary part of the so-called Compton Form Factor $\mathcal{H}_A$, $\Re e(\mathcal{H}_A)$ and $\Im m(\mathcal{H}_A)$, respectively, have been extracted by fitting the $A_{LU}(\phi)$ distribution. Theoretical calculations from Ref. (7) are shown together with the data of Ref. (3) in Figs. 1 and 2. Big statistical errors are seen everywhere but they are bigger for $\Re e(\mathcal{H}_A)$ than for $\Im m(\mathcal{H}_A)$, due to the small coefficient α_2.

Realistic theoretical calculations are possible for light nuclei and could help to unveil an exotic behavior of the real part of $\mathcal{H}_A$. Forth-coming data form JLab 12 with electrons, using also the detector system developed by the ALERT run-group (8), will obtain smaller errors; anyway $\Re e(\mathcal{H}_A)$ will be always less precise than $\Im m(\mathcal{H}_A)$, intrinsically, due to that small coefficient. The knowledge of $\Re e(\mathcal{H}_A)$ would be instead crucial. Positrons would guarantee it, because combining data for asymmetries measured using electrons and positrons the role of $\Re e\mathcal{H}_A$ would be directly accessed. Let us recall how it is possible.
One should notice that, between the quantities appearing in the above equations and the cross sections defining the generic photo-$e^{\pm}$production cross section in the following schematic general expression, previously given in this White Paper,

$$\begin{aligned} \sigma^e_{\lambda 0} &= \sigma_{BH} + \sigma_{DVCS} + \lambda\tilde{\sigma}_{DVCS} \\ &+ e\sigma_{INT} + e\lambda\tilde{\sigma}_{INT}, \end{aligned} \tag{4}$$

The following relations hold:

$$\begin{aligned} \sigma_{BH} &\propto \alpha_1(\phi), \\ \sigma_{DVCS} &\propto \alpha_3(\phi)\left(\Re e(\mathcal{H}_A)^2 + \Im m(\mathcal{H}_A)^2\right), \\ \sigma_{INT} &\propto \alpha_2(\phi)\,\Re e(\mathcal{H}_A), \\ \tilde{\sigma}_{INT} &\propto \alpha_0(\phi)\,\Im m(\mathcal{H}_A), \end{aligned} \tag{5}$$

while $\tilde{\sigma}_{DVCS}$ is proportional to a term kinematically suppressed at JLab kinematics, dependent on higher twist CFFs. From a combined analysis of data taken with polarized electrons and/or positrons, one could access all the five cross sections in Eq. (4). In particular, using only unpolarized electrons and positrons, $\Re e(\mathcal{H}_A)$ would be directly accessed. In particular, let us briefly analyze why the knowledge of $\Re e\mathcal{H}_A$ would be very important for nuclei. From a theoretical point of view, one can write, for the quantities $\Re e(\mathcal{H}_A)$ and $\Im m\mathcal{H}_A$ shown in Figs. 2 and 1 respectively (9):

$$\Re e\mathcal{H}_A(\xi,t) \equiv \mathcal{P}\int_0^1 dx H_+(x,\xi,t)C_+(x,\xi), \tag{6}$$

and

$$\Im m\mathcal{H}_A = H_+(\xi,\xi,t), \tag{7}$$

with:

$$H_+ = H(x,\xi,t) - H(x,-\xi,t), \tag{8}$$

amd

$$C_+(x,\xi) = \frac{1}{x+\xi} + \frac{1}{x-\xi}. \tag{9}$$

Besides, it is also known that $\Re e(\mathcal{H}_A)$ satisfies a once subtracted dispersion relation at fixed t and can be therefore related to $\Im m\mathcal{H}_A$, leading to (10–13)

$$\Re e\mathcal{H}_A(\xi,t) \equiv \mathcal{P}\int_0^1 dx H_+(x,x,t)C_+(x,\xi) - \Delta(t) \tag{10}$$

One notices that, in contrast to the convolution integral entering the real part of the CFF in Eq. (6), where the GPD enters for unequal values of its first and second argument, the integrand in the DR (spectral function) corresponds to the GPD where its first and second arguments are equal. The subtraction term $\Delta(t)$ can be related to the so called $d-$term and accurate measurements and precise calculations would allow to access therefore the nuclear $d-$term. This quantity, introduced initially to recover polinomiality in DDs approaches to GPDs modelling (14), can be related to the form factor of the QCD EMT (see e.g. Ref. (15)). It encodes information on the distribution of forces and pressure between elementary QCD degrees of freedom in the nucleus. For nuclei, it has been predicted to behave as $A^{7/3}$ in a mean field scheme, either in the liquid drop model of nuclear structure (16) or in the Walecka model (17). None of these approaches makes much sense for light nuclei. Accurate realistic calculations are possible in the latter case. Using light nuclei one would therefore explore, at the parton level, the onset and evolution of the mean field behavior across the periodic table, from deuteron to finite nuclei.

In this sense, the ^{3}He target acquires an important role: an intermediate behavior is expected between that of the almost unbound deuteron system and that of the deeply bound alpha particle. The formalism would follow that already presented for the proton, a spin one-half target, in terms of CFFs defining proper spin dependent asymmetries. Realistic theoretical calculations are available for GPDs (18–21) and are in progress for the relevanto CFFS, cross sections and asymmetries.

Needless to say, incoherent DVCS off He nuclei at JLab 12, in particular tagged using the detector developed by the ALERT run group (22), performed with electron and positron beams, would allow the measurement of the $D-$term for the bound nucleon, either proton (tagging 2H from DVCS on ^{3}He or ^{3}H from DVCS on ^{4}He) or neutron (tagging ^{3}He from DVCS on ^{4}He). Modifications of the $D-$term of the nucleon in the nuclear medium, studied e.g. in (17), would be at hand, as well as a glimpse at the transverse structure of the neutron, complementary to that obtained with deuteron targets.

We note on passing that, in principle, from the measurement of $\tilde{\sigma}_{DVCS}$ using electron and positron beams in coherent DVCS on ^{4}He, for the first time higher twist CFFs would be studied for a spin-less target... To be developed????????????

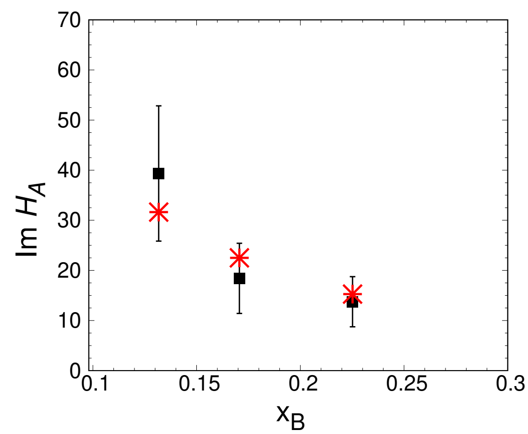

Fig. 1. The imaginary part of the CFF measured in coherent DVCS off ^{4}He. Data from Ref. (3); calculations (red crosses) from Ref. (7)

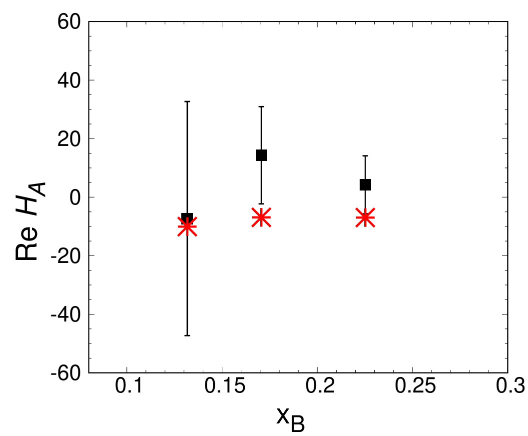

Fig. 2. The imaginary part of the CFF measured in coherent DVCS off ^{4}He. Data from Ref. (3); calculations (red crosses) from Ref. (7)

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