

## Extraction of Compton Form Factors from DVCS data

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We present the results of a fitter code which aims at extracting Compton Form Factors (CFFs) from DVCS (Deep Virtual Compton Scattering) experimental data, in a largely model-independent way. CFFs are linked to GPDs (Generalized parton Distributions) and are the quantities which are directly measurable. The data that we have analyzed are from JLab and HERMES experiments. We obtain some first important constraints on the  $H$  and  $\tilde{H}$  CFFs. The kinematical dependences ( $x_B, t$ ) of these CFFs provide some new insights on nucleon structure.

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Generalized Parton Distributions allow us to describe the structure of the nucleon in a very rich and unprecedented way. Among other things, they contain the correlations between the (transverse) position and (longitudinal) momentum distributions of the partons in the nucleon, they allow us to derive the orbital momentum contribution of partons to the nucleon's spin and they provide an access to the nucleon's ( $q\bar{q}$ ) content. Experimentally, GPDs are the most simply accessed through the exclusive leptonproduction of a photon (DVCS :  $ep \rightarrow e'p'\gamma$ ) or of a meson. We refer the reader to Refs. [1, 2, 3, 4, 5, 6, 7] for the original theoretical articles and recent comprehensive reviews on GPDs and for details on the theoretical formalism.

At QCD leading twist and leading order approximation, there are four independent nucleon GPDs which can be accessed in the DVCS process:  $H$ ,  $E$ ,  $\tilde{H}$  and  $\tilde{E}$ . These four GPDs depend on three variables  $x$ ,  $\xi$  and  $t$ , of which only two are experimentally accessible:  $t$  and  $\xi$ , where  $\xi$  is related to the standard Deep Inelastic Bjorken variable  $x_B$  through the formula:  $\xi = \frac{x_B}{2-x_B}$ . This is why only CFFs, which are weighted integrals of GPDs over  $x$  or combinations of GPDs at the line  $x = \xi$ , can in general be extracted from DVCS experiments. In our notation which was introduced and used in Refs. [8, 9, 10, 11], there are eight CFFs which are:

$$H_{Re} = P \int_0^1 dx [H(x, \xi, t) - H(-x, \xi, t)] C^+(x, \xi), \quad (1)$$

$$E_{Re} = P \int_0^1 dx [E(x, \xi, t) - E(-x, \xi, t)] C^+(x, \xi), \quad (2)$$

$$\tilde{H}_{Re} = P \int_0^1 dx [\tilde{H}(x, \xi, t) + \tilde{H}(-x, \xi, t)] C^-(x, \xi), \quad (3)$$

$$\tilde{E}_{Re} = P \int_0^1 dx [\tilde{E}(x, \xi, t) + \tilde{E}(-x, \xi, t)] C^-(x, \xi), \quad (4)$$

$$H_{Im} = H(\xi, \xi, t) - H(-\xi, \xi, t), \quad (5)$$

$$E_{Im} = E(\xi, \xi, t) - E(-\xi, \xi, t), \quad (6)$$

$$\tilde{H}_{Im} = \tilde{H}(\xi, \xi, t) + \tilde{H}(-\xi, \xi, t) \quad (7)$$

$$\tilde{E}_{Im} = \tilde{E}(\xi, \xi, t) + \tilde{E}(-\xi, \xi, t) \quad (8)$$

with

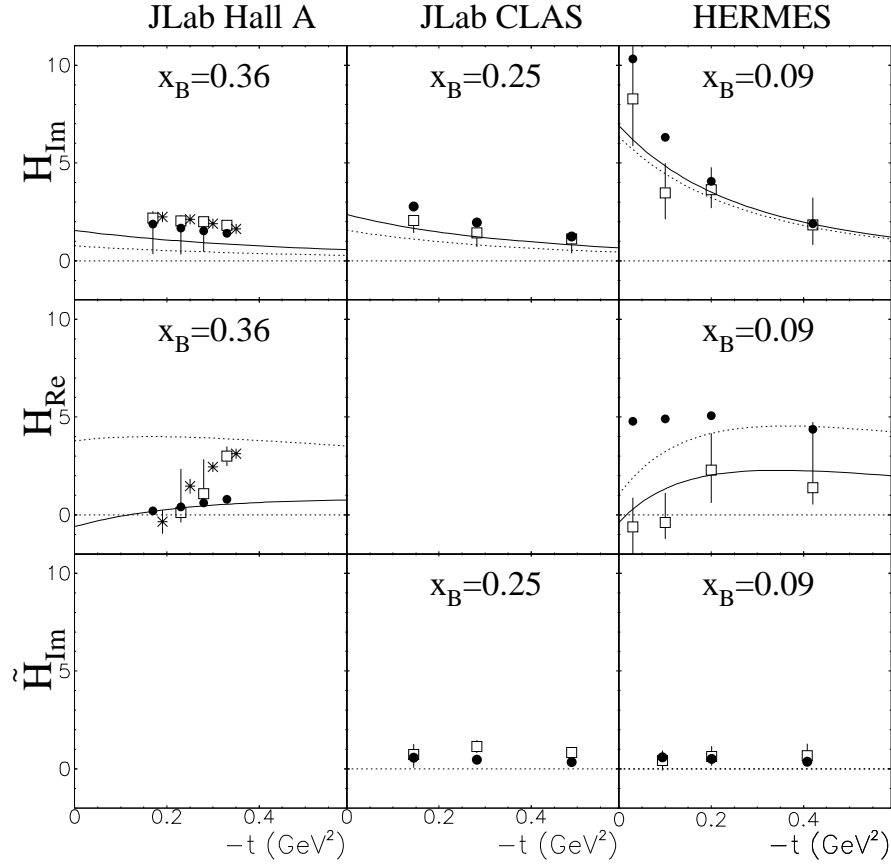
$$C^\pm(x, \xi) = \frac{1}{x-\xi} \pm \frac{1}{x+\xi}. \quad (9)$$

In Refs. [8, 9, 10, 11], we have developed a largely model-independent fitting procedure which, at a given experimental ( $\xi$ ,  $-t$ ) kinematic point, takes the CFFs as free parameters and extracts them from DVCS experimental observables using the well established DVCS theoretical amplitude [12, 13]. This task is not trivial. Firstly, one has to fit seven <sup>1</sup> parameters from a limited set of data and observables, which leads in general to an under-constrained problem. However, as some observables are in general dominated by a few particular CFFs, one can extract a few specific CFFs. Secondly, in addition to the particular DVCS process of direct interest, there is another mechanism which contributes to the  $ep \rightarrow e'p'\gamma$  process and whose amplitude interferes with the DVCS amplitude. This is the Bethe-Heitler (BH) process where the final state photon is radiated by the incoming or scattered electron and not by the nucleon itself. However, it is precisely known and calculable given the nucleon form factors.

<sup>1</sup>Guided by theory considerations, we actually neglect  $\tilde{E}_{Im}$  in our work.

With our fitting algorithm, we have managed to determine in previous works :

- the  $H_{\text{Im}}$  and  $H_{\text{Re}}$  CFFs, at  $\langle x_B \rangle \approx 0.36$ , and for several  $t$  values, by fitting [8] the JLab Hall A proton DVCS beam-polarized and unpolarized cross sections [14],
- the  $H_{\text{Im}}$  and  $\tilde{H}_{\text{Im}}$  CFFs, at  $\langle x_B \rangle \approx 0.35$  and  $\langle x_B \rangle \approx 0.25$ , and for several  $t$  values, by fitting [10] the JLab CLAS proton DVCS beam-polarized and longitudinally polarized target spin asymmetries [15, 16],
- the  $H_{\text{Im}}$ ,  $H_{\text{Re}}$  and  $\tilde{H}_{\text{Im}}$  CFFs, at  $\langle x_B \rangle \approx 0.09$ , and for several  $t$  values, by fitting [9, 11] a series of HERMES beam-charge, beam-polarized, transversely and longitudinally polarized target spin asymmetry moments [17, 18, 19, 20].



**Figure 1:** The  $H_{\text{Im}}$ ,  $H_{\text{Re}}$  and  $\tilde{H}_{\text{Im}}$  CFFs, as defined in Eqs.1, 5 and 7, as a function of  $-t$ . The empty squares show the results of our works, the stars the result of the CFF fit of Ref. [22], the curves the results of the model-based fit of Ref. [23] and the solid points show the predictions of the VGG model [13, 4, 21].

In Fig. 1, we compile all our results, each panel having the same scales for ease of comparison. The empty squares show the results of our works, the stars the result of the CFF fit of Ref. [22], the curves the result of the model-based fit of Ref. [23] (solid: without the Hall A data of Ref. [14] and dashed: including the Hall A data in the fit) and the solid points show the predictions of the

VGG model [4, 13, 21]. Except for  $H_{\text{Re}}$  where there are marked differences between the different approaches, it seems that all these works show the same trends within error bars.

Our results have average uncertainties of the order of 30%. This is due to the limited precision of the data and/or the limited number of experimental observables to be fitted. Obviously, having more observables to fit simultaneously and more precise data (which can be foreseen in the near future) can only reduce these uncertainties. Also, one has to keep in mind that we keep in our fits all seven CFFs as free parameters<sup>2</sup>. If, guided by some theoretical considerations, one can remove some of the CFFs from the fit and thus reduce the number of free parameters, error bars on the results will obviously diminish. For instance, in Ref. [22] (stars on Fig. 1), all GPDs but  $H$  have been neglected resulting in smaller uncertainties (an additional error has then to be introduced in order to take into account the neglect of the other GPDs; an attempt of the estimation of such additional error has been done in Ref. [22]). For the present time, in our approach, our uncertainties reflect all our ignorance on all GPDs other than the ones which come out from our fits and their full potential influence. In particular, we found in Ref. [10] that the central value on the fitted  $H_{\text{Im}}$  CFF would vary by a factor of  $\approx 3$  whether one would fit the JLab Hall A proton DVCS cross sections [14] by taking into account only the  $H$  GPD or by taking into account all four GPDs.

In Fig. 1, some general features and trends can be distinguished. We comment them briefly in the following:

- Concerning  $H_{\text{Im}}$ , it seems that, at fixed  $-t$ , this CFF increases as  $x_B$  decreases (i.e. going from JLab to HERMES kinematics). This is reminiscent of the  $x$ -dependence of the standard proton unpolarized parton distribution as measured in DIS, to which  $H_{\text{Im}}$  reduces in forward kinematics ( $\xi = t = 0$ ). Another feature is that the  $t$ -slope of  $H_{\text{Im}}$  seems to increase with  $x_B$  decreasing. This could then suggest that low- $x$  quarks (the “sea”) would extend to the periphery of the nucleon while the high- $x$  (the “valence”) would tend to remain in the center of the nucleon. Indeed, the  $t$ -dependence of GPDs can be interpreted as a reflection of the spatial distribution of some charge in some specific frame [24, 25, 26].
- $H_{\text{Re}}$  has a very different  $t$ -dependence than  $H_{\text{Im}}$  both at JLab and at HERMES energies: while  $H_{\text{Im}}$  decreases with  $-t$  increasing,  $H_{\text{Re}}$  increases (at least up to  $-t \approx 0.3 \text{ GeV}^2$ ) and may change its sign, starting negative at small  $-t$  and reaching positive values at larger  $-t$ : all four approaches (empty squares, stars, solid points and solid curves) show this “zero-crossing” at JLab kinematics while only our CFF fitting work tends to show it for HERMES kinematics. We also notice that both VGG and the dashed curve of the model-based fit of Ref. [23] overestimate our fitted values for  $H_{\text{Re}}$ .
- Concerning  $\tilde{H}_{\text{Im}}$ , we notice that it is in general smaller than  $H_{\text{Im}}$ , which can be expected for a polarized quantity compared to an unpolarized one. There is very little  $x_B$  dependence. The  $t$ -dependence is also rather flat. The weaker  $t$ -dependence of  $\tilde{H}_{\text{Im}}$  compared to  $H_{\text{Im}}$  suggests that the axial charge (to which the  $\tilde{H}$  GPD is related) has a narrower distribution in the nucleon than the electromagnetic charge.

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<sup>2</sup>To be precise, in our work, the CFFs are actually bound to vary in a space  $\pm 5$  times some reference model values which should be a priori a very conservative hypothesis.

To summarize, in this short report, we have presented the results of our fitting code, based on the leading twist and leading order QCD DVCS handbag diagram amplitude (and BH), which aims at extracting CFFs from DVCS data (in the quark sector). We have extracted in a largely model-independent way some numerical constraints on three CFFs :  $H_{\text{Im}}$ ,  $H_{\text{Re}}$  and  $\tilde{H}_{\text{Im}}$ , which hint at some original features of the nucleon structure. Where applicable, we have compared our results with other approaches which in general show the same trends as the ones we found.

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