DVCS *vs* GPDs: WHAT DOES DVCS TELL US ABOUT GPDs?*

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As recent studies have shown, the most popular models for generalized parton distributions cannot describe the new data from the H1, ZEUS, HERMES and CLAS experiments on Deeply Virtual Compton Scattering (DVCS) if a full QCD analysis including evolution is performed. In this note, we will discuss why this is the case and how the problem can be cured thereby producing a very good description of the H1 data.

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1. Introduction

Generalized Parton Distributions (GPDs) have enjoyed a tremendous interest in the last few years [1–3]. This was spurred by the realization that these distributions are not only the basic, non-perturbative ingredient in hard processes such as deeply virtual Compton scattering (DVCS) but that they are generalizations of the well known parton distributions (PDFs) from inclusive reactions, incorporating both a partonic and distributional

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amplitude behavior. Therefore, they encode within their structure more information about the hadronic degrees of freedom than PDFs. Unfortunately, the modeling of GPDs has not yet produced very satisfactory results when comparing to recent data both from H1 and ZEUS [3] on the DVCS photon level cross section, $\sigma(\gamma^* + p \to \gamma + p)$, [4,5] and from HERMES and CLAS [3] on the DVCS single spin asymmetry (SSA) [4,5] or charge asymmetry (CA) in both leading (LO) and next-to-leading order (NLO). On the one hand, the currently most viable models, phenomenologically speaking, rely on an appealingly simple structure, on the other hand, one of the ingredients of this simple structure is at the heart of the problem. Thus, the question to answer is "How can one modify this Ansatz without destroying its simple, and thus appealing, structure ?". To do this, let us first discuss GPDs in more detail.

2. GPDs: definition, models, problems and cure

In general, matrix elements of twist-2, bi-local, renormalized operators sandwiched between *unequal* proton momenta P_1, P_2 appearing in the description of hard, exclusive reactions can be expressed through a two dimensional spectral representation, parameterized through functions called double distributions (DDs) [1,6]. The GPDs are obtained through a reduction from the two dimensional to a one dimensional spectral representation which relates the DDs to the GPDs via

$$H(x,\xi) = \int_{-1}^{1} dx' \int_{-1+|x'|}^{1-|x'|} d\alpha \; \delta\left(x' + \xi\alpha - x\right) \; F_{\rm DD}(x',\alpha) \,, \tag{1}$$

where x' and α are in general independent of one another, but are now related in Eq. (1) via a δ function. The GPD, H, is defined on the interval $[-1,1]$ with x a parton momentum fraction defined with respect to the average of P_1, P_2 and $\xi = -(q_1+q_2)^2/(q_1+q_2)\,(P_1+P_2) = \frac{x_{\rm bj}}{2-x_{\rm bj}}$, a generalized Bjorken variable, with q_1, q_2 being the momenta of the incoming photon and the outgoing particle. The GPD has two regions in which its behavior is qualitatively different: the ERBL region $-\xi \le x \le \xi$ where the GPD behaves like a distribution amplitude and the DGLAP region $\xi \le |x| \le 1$ where the GPD has a partonic interpretation akin to the standard PDFs. The most popular model used for $F_{\rm DD}$ has a factorized t-dependence [1]:

$$F_{\rm DD}^{Q/g}(x',\alpha,\mu^2,t) = \pi^{Q,g}(x',\alpha)\, f^{Q/g}(x',\mu^2)\, r^{Q/g}(t)\,, \tag{2}$$

where $\pi^{Q,g}(x',\alpha)$ are the profile functions [1] for quarks and gluons. Having defined the model for the double distribution one may then perform the

α-integration. This modifies the limits on the x' integration according to the region concerned: for the DGLAP region $x > |\xi|$ one has

$$H^{Q,a}(x,\xi) = \frac{1}{\xi} \int_{\frac{x-\xi}{1-\xi}}^{\frac{x+\xi}{1+\xi}} dx' \pi^Q \left(x', \frac{x-x'}{\xi}\right) Q^a(x') \,, \tag{3}$$

with similar expressions for $\bar{q}$ and for q and $\bar{q}$ in the ERBL region. Note that the gluon is formed analogously to the quark and that $Q^a(x) = q^a(x)/x$. Let us now turn to DVCS. The photon level cross section is defined in terms of DVCS, amplitudes, $T_{\rm DVCS}$, as

$$\sigma_{\rm DVCS}(\gamma^* p \to \gamma p) = \frac{\alpha^2 x_{\rm bj}^2 \pi}{Q^4 B} |T_{\rm DVCS}|^2|_{t=0} \,, \tag{4}$$

where B stems from the t-integration. For simplicity, we have assumed a global t dependence, e^{Bt}, with the slope, B, of the t dependence fixed at an average value of 6.5 GeV^2 for convenience. How to compute $T_{\rm DVCS}$ through H can be found in great detail in [4, 5]. It was shown in [4] that at both a high and low input scale one cannot describe the H1 data with the above DD model. The problem was traced to the imaginary part of the amplitude and thus, in LO, directly to the quark-singlet GPD at ξ, $\sigma \propto |\mathrm{Im}\, T_{\rm DVCS}|^2 \propto |H^{\rm singlet}(\xi,\xi)|^2$. The reason for the enhancements in the GPDs using the DD model can be readily understood if one inspects the lower limit of integration in Eq. (3). There one notices that it probes the region $x' \to 0$ for the limiting case of $x \to \xi$, analogous statements are true for the ERBL region. This limit requires to extrapolate any "off-the-shelf" inclusive distribution beyond the point where it is constrained by data. Since the relevant forward PDFs, in this case the quark sea, are all strongly divergent for $x' \to 0$, one is dealing with a DD at the input scale with a large contribution from a region which should not contribute strongly at all, leading to a quark GPD which is too large. This problem does not occur for the gluon due to a much milder divergence in the forward PDF. How can the problem with the quark GPD be remedied? In the last reference of [2] a successful description of DVCS, in terms of agreement with both ZEUS and H1 data, was achieved within QCD by modeling the imaginary part of the DVCS amplitude at the input scale using the aligned jet model (AJM) [7]. Using the AJM result and perturbative QCD in LO one obtains:

$$\frac{\mathrm{Im}\, T_{\rm DVCS}}{\mathrm{Im}\, T_{\rm DIS}} = \frac{H^{\rm singlet}(\xi,\xi)}{Q^{\rm singlet}(x_{\rm bj})} \simeq 2 \;\Rightarrow H^{\rm singlet}(\xi,\xi) = 2\, Q^{\rm singlet}(x_{\rm bj}) \tag{5}$$

for small $x_{\rm bj}$. Note that the same relationship between GPD and PDF can be obtained in a model where the bounds of the integrals in the reduction formula (3) are modified for $x \sim \xi$ through a constraint on the invariant mass of the intermediate state in this region [8]. The AJM constraint can

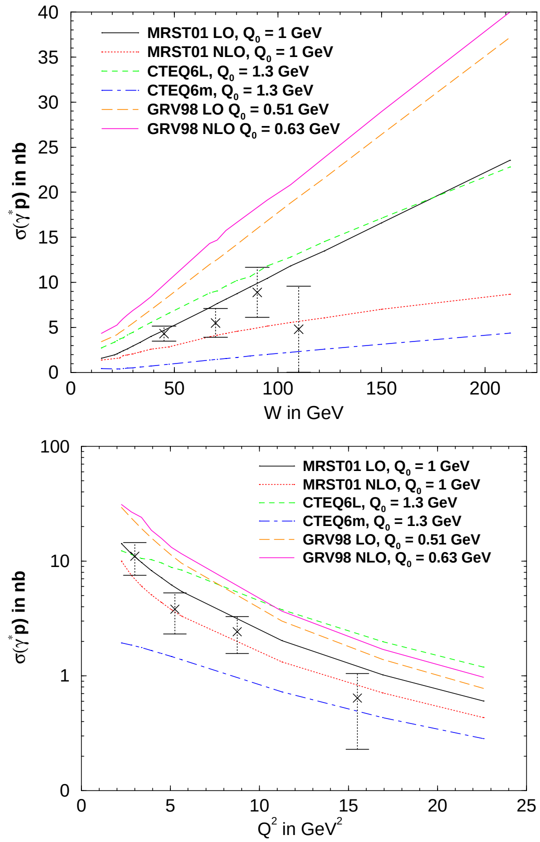

Fig. 1. Photon level cross section $\sigma(\gamma^* P)$, at $Q^2 = 4.5$ GeV^2 in W (upper plot) and at $W = 75$ GeV in Q^2 (lower plot) using the AJM Ansatz.

be theoretically implemented within the DD Ansatz, however, a numerical implementation is not possible within reasonable computing time. Thus we assume $H^{\rm singlet}(x,\xi) = Q^{\rm singlet}(x)$ for small ξ, which corresponds to the profile functions being a δ-function in the DD Ansatz. Also we know that $\frac{H^{\rm singlet}(x,\xi)}{Q^{\rm singlet}(x)} \simeq 1$ for $x \simeq 2-3\,\xi$ so this model is close the AJM one. We assume the same for the gluon, giving us a viable input model for the GPD $H^{q,\rm singlet}$ and H^g in the DGLAP and the ERBL region. Note that after just a short evolution step $Q_0 \sim 1 \to 2-3$ GeV^2 the AJM constraint (Eq. (5)) is already reached and at a value of Q^2 which is in the region of validity of the AJM model. Using this model and three different LO and NLO input distributions we find the following DVCS cross section in very good agreement, at least for the MRST01 input, with the H1 data in LO and NLO, Fig. 1. Computing DVCS asymmetries at large $x_{\rm bj}$, we find the following values for the SSA and CA for average HERMES kinematics of $\langle x\rangle = 0.11, \langle Q^2\rangle = 2.56$ GeV$^2, \langle t\rangle = -0.265$ GeV^2: SSA $= -0.19$ (LO), -0.17 (NLO) with the experimental value being -0.21 ± 0.08 [9] and CA $= 0.03$ (LO), 0.05 (NLO) with the experimental value being 0.055 ± 0.04 [9]. For average CLAS kinematics $\langle x\rangle = 0.19, \langle Q^2\rangle = 1.31$ GeV$^2, \langle t\rangle = -0.15$ GeV^2 we find: SSA $= 0.14$ (LO) and the experimental value is 0.202 ± 0.041. This demonstrates that our model Ansatz works surprisingly well even at large $x_{\rm bj}$ and provides a good starting point to make fits to the available data.

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