Cross Sections for the Exclusive Photon Electroproduction on the Proton and Generalized Parton Distributions

Citation for published version:

Digital Object Identifier (DOI):
10.1103/PhysRevLett.115.212003
10.1103/PhysRevLett.115.212003

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published in:
Physical Review Letters

General rights
Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 05. Dec. 2018
Cross Sections for the Exclusive Photon Electroproduction on the Proton and Generalized Parton Distributions

Unpolarized and beam-polarized fourfold cross sections $(d^4\sigma/dQ^2dx_Bdt\eta\phi)$ for the $ep\rightarrow e'p'\gamma$ reaction were measured using the CLAS detector and the 5.75-GeV polarized electron beam of the Jefferson Lab accelerator, for $110 (Q^2,x_B,t)$ bins over the widest phase space ever explored in the valence-quark region. Several models of generalized parton distributions (GPDs) describe the data well at most of our kinematics. This increases our confidence that we understand the GPD $H$, expected to be the dominant contributor to these observables. Through a leading-twist extraction of Compton form factors, these results support the model predictions of a larger nucleon size at lower quark-momentum fraction $x_B$.

DOI: 10.1103/PhysRevLett.115.212003

The internal structure and dynamics of the proton, the nucleus of the most abundant chemical element in the visible Universe, still remain a mystery in many respects, more than 40 years after the evidence for its quark and gluon substructure. How are the spatial and momentum distributions of the quarks and gluons (i.e., the partons) correlated inside the nucleon? How do the partons contribute to the bulk properties of the proton (mass, spin, charge, etc.)? These are some fundamental questions at the intersection of nuclear and particle physics which are still to be resolved.

In order to tackle these essential issues, a large experimental program was launched worldwide at Jefferson Lab (JLab), COMPASS and HERA, facilities using multi-GeV electromagnetic probes, to study deeply virtual Compton scattering (DVCS). In the valence-quark region, this corresponds to Compton scattering at the quark level, with the incoming photon radiated from the lepton beam. As in the study of atomic or nuclear structure, the energy and angular distributions of the scattered photon reflect the distribution in momentum and/or space of the targets, which in our case are the quarks inside the proton. At JLab, electron beams are used and the reaction to study proton structure is $ep\rightarrow e'p'\gamma$. It was shown [1–5] that this process, at sufficiently large squared electron momentum transfer $Q^2 = -(e - e')^2$ and small squared proton momentum transfer $t = (p - p')^2$ (in terms of the electron and proton four-vectors), could be interpreted in the framework of quantum chromodynamics (QCD), the fundamental theory governing the interaction of quarks and gluons, as the product of the elementary Compton scattering at the quark level $\gamma'q\rightarrow \gamma q$ with factorizable structure functions called generalized parton distributions (GPDs).

Figure 1 (left) illustrates the GPD QCD factorization for the DVCS process. In a frame where the nucleon moves at the speed of light in a given direction, a quark with longitudinal momentum fraction $x + \xi$ along that direction absorbs the virtual photon, and, after radiating the final-state photon, the same quark returns into the nucleon with a longitudinal momentum fraction $x - \xi$, plus some transverse kick included in $t$. The GPDs are functions of $x$, $\xi$, and $t$ and represent the probability amplitude of such a process. The variable $\xi$ is related to the Bjorken variable $x_B$: $\xi \approx x_B/(2 - x_B)$, where $x_B = Q^2/(2M_\nu)$ with the proton mass $M$ and $\nu = E_e - E_{e'}$. Thus, it is determined by the scattered-electron kinematics. The quantity $x$ is not measurable in the DVCS process. At leading-order QCD, GPDs do not depend on $Q^2$. At leading-twist QCD (i.e., when quark-gluon interactions and higher-order quark loops are neglected), four GPDs enter the description of the DVCS process: $H, \tilde{H}, E, \tilde{E}$, representing the four independent helicity-spin transitions of the quark-nucleon system between the initial and final states. The GPDs are QCD matrix elements that project on a few variables the full complexity of the quarks’ and gluons’ dynamics within the nucleon.

FIG. 1 (color online). Left: The dominant mechanism for the DVCS process at large $Q^2$ and small $|t|$, as predicted by the QCD factorization theorem. Right: The Bethe-Heitler (BH) process.
The GPDs embody the longitudinal momentum distribution of the quarks in the nucleon, their transverse spatial distribution, and the correlation between these two distributions. One uses the term *nucleon tomography* as one can probe the transverse size of the nucleon for different quark longitudinal-momentum slices. For details on the GPD formalism, see the reviews [6–11].

In the $ep \rightarrow e'p'\gamma$ reaction, the DVCS process interferes with the well-known BH process (Fig. 1, right), where the final-state photon is radiated by the incoming or scattered electron.

Extracting the GPDs from the DVCS process requires measuring a series of observables for the $ep \rightarrow e'p'\gamma$ reaction over the broadest kinematic domain possible. Several observables, such as the unpolarized cross section and polarized beam or/and target asymmetries, are necessary to separate the four GPDs. Each observable is sensitive to a particular combination of GPDs.

This Letter presents a major contribution to this global and long-term endeavour: the extraction of the $ep \rightarrow e'p'\gamma$ (i.e., DVCS + BH) unpolarized and beam-polarized cross sections over the widest phase space ever explored in the valence-quark region, with $110 (Q^2, x_B, t)$ bins covering $1.0 < Q^2 < 4.6$ GeV$^2$, $0.10 < x_B < 0.58$, and $0.09 < -t < 0.52$ GeV$^2$. In this kinematic domain, our results strongly enhance the existing set of measurements of the $ep \rightarrow e'p'\gamma$ reaction which consists of four $(Q^2, x_B, t)$ bins of unpolarized cross sections and 12 bins of beam-polarized cross sections measured by the JLab Hall A Collaboration [12] and 57 bins of beam-spin asymmetries [13] and 18 bins of longitudinal target- and beam-target double-spin asymmetries [14,15] measured by the CLAS Collaboration (in addition to the handful of CLAS pioneering data points from Refs. [16–18]).

The experiment took place at JLab during three months in 2005, using the 5.75-GeV polarized electron beam (79.4% polarization), a 2.5-cm-long liquid-hydrogen target, in 2005, using the 5.75-GeV polarized electron beam [13] and 18 bins of longitudinal target- and beam-target cross sections over the widest phase space ever explored in the deep virtual regime. As an example, Fig. 2 shows the effect of two of the four exclusivity cuts.

Under these conditions, we ended up with about 300 000 events. Figure 3 shows the resulting $(Q^2, x_B)$ and $(-t, x_B)$ kinematic coverages of the data and the adopted binning [21 $(Q^2,x_B)$ bins and six $t$ bins], which is finer than the one used in Ref. [13]. Note that the bins and results presented here are limited to the $|t|$ region below 0.52 GeV$^2$, while the actual coverage of the data goes beyond 1 GeV$^2$. The $ep \rightarrow e'p'\gamma$ cross sections vary very rapidly with kinematics, primarily due to the BH process. In order to minimize the uncertainties related to the knowledge of the kinematics, we minimized the size of our bins, while keeping comparable statistics in each bin.

Because of the azimuthal symmetry when using an unpolarized target, the $ep \rightarrow e'p'\gamma$ reaction depends on four independent variables. For the study of GPDs, the
most appropriate ones are $Q^2$, $x_B$, $t$, and $\phi$, where $\phi$ is the azimuthal angle between the $(e,e')$ and $(p',p)$ planes around the virtual photon direction. We have thus extracted fourfold cross sections as follows:

$$\frac{d^4\sigma_{ep\rightarrow e'p'\gamma}}{dQ^2dx_Bdt\,d\phi} = \frac{N_{ep\rightarrow e'p'\gamma}}{L_{\text{int}}\Delta Q^2\Delta x_B\Delta t\Delta \phi\,\text{Acc}\,F_{\text{rad}}}.$$  \hspace{1cm} \text{(1)}

In Eq. (1), $N_{ep\rightarrow e'p'\gamma}$ is the number of $e p \rightarrow e' p' \gamma$ events in the $(Q^2, x_B, t, \phi)$ bin. We evaluated the contamination from the $e p \rightarrow e' p' \pi^0$ channel where one photon of the $\pi^0$ decay can escape detection, using a combination of $e p \rightarrow e' p' \pi^0$ measurements and Monte Carlo simulations. On average, this contamination is less than 9% and was subtracted on a bin-by-bin basis. The four-dimensional acceptance or efficiency of the CLAS detector, Acc, for the $e p \rightarrow e' p' \gamma$ reaction was determined for each $(Q^2, x_B, t, \phi)$ bin by generating more than $200 \times 10^6$ DVCS + BH events, using a realistic Monte Carlo generator adapted from Ref. [20].

The events were processed through the Geant simulation of the CLAS detector and the same reconstruction and analysis codes that were used for the data. The event generator includes radiative effects so that Acc also corrects for a part of the real internal radiative effects. $F_{\text{rad}}$ corrects, for each $(Q^2, x_B, t, \phi)$ bin, for the virtual and the remainder of the real internal radiative effects, which can both be calculated theoretically [21]. The product $(\Delta Q^2\Delta x_B\Delta t\Delta \phi)$ is the effective hypervolume of each bin. Finally, $L_{\text{int}}$ is the integrated luminosity, corrected for the data acquisition dead time, which was deduced from the integrated charge of the beam measured by a Faraday cup. In addition, we applied a global renormalization factor of 12.3%, determined from the analysis of the elastic scattering $e p \rightarrow e' p'$, by comparing the experimental cross section to the well-known theoretical one. This factor compensates for various kinematic-independent inefficiencies, such as those from the CLAS time-of-flight scintillators and trigger, not well reproduced by the simulations.

Figure 4 shows, for two selected $(Q^2, x_B)$ bins in different parts of the phase space, the $\phi$ dependence of the $e p \rightarrow e' p' \gamma$ unpolarized cross section and beam-polarized cross-section difference. The latter of these two observables is defined as follows:

$$\Delta(d^4\sigma) = \frac{1}{2} \left[ \frac{d^4\sigma_{ep\rightarrow e'p'\gamma}}{dQ^2dx_Bdt\,d\phi} - \frac{d^4\sigma_{ep\rightarrow e'p'\gamma}}{dQ^2dx_Bdt\,d\phi} \right].$$  \hspace{1cm} \text{(2)}

where the arrows correspond to beam helicity states $+$ and $-$. For each of these $(Q^2, x_B)$ bins, three selected $t$ bins are shown. Note that the data do not always provide a full coverage in $\phi$ for each of the 110 $(Q^2, x_B, t)$ bins. In Fig. 4, the black error bars show the statistical uncertainties of the data [13.9% on the unpolarized cross section on average], over the 110 $(Q^2, x_B, t)$ bins, and the blue bands show the systematic uncertainties [14% on the unpolarized cross section on average]. The contributions to the latter include the uncertainties on the beam energy and therefore the kinematics and associated corrections (5.7% on average, using a different beam energy value in the analysis), the acceptance correction (5.3%, with an alternate event generator), the global renormalization factor (5%), the exclusivity cuts (3.5%, from variations of the cuts), the radiative corrections (2.2%, including next-to-leading-order effects), the particle selection (1.6%, from variations of the cuts), and the $d^0$ background subtraction (1%, with an alternate event generator).

The unpolarized cross sections peak towards $\phi = 0^\circ$ due to the BH process (green long-dashed curves in Fig. 4) for which the final-state photon is predominantly emitted in the direction of the initial or scattered electron. The difference between the BH curves and the data can thus be attributed to the DVCS process. We display in Fig. 4 calculations of
four GPD models. The modeling of the GPDs in the VGG and KMS models is based on the double-distribution representation [1,27,28]. The VGG calculations in Fig. 4 include only the contribution of the GPD $H$ as the inclusion of the other GPDs barely changes the results. The KM model is based on the Mellin-Barnes representation [25,29]. The KM10 version of the model includes contributions from all four GPDs for which the free parameters were fitted to the JLab [12,13], HERMES [30], and ZEUS/H1 [31,32] data. In that work, it was found that it is possible to fit the JLab Hall A unpolarized cross sections only at the price of introducing a very strong $H$ contribution [33]. The KM10a version is based on a fit which excludes the JLab Hall A unpolarized cross sections [12] and sets $H$ to zero. Note that none of these four models has been tuned to our data.

Figure 4 shows that the predictions of standard GPD models like VGG, KMS, and KM10a, whose compatibility is remarkable despite their different approaches, are in good agreement with our unpolarized cross-section data. In contrast, the KM10 version, which includes the strong $H$ contribution, tends to overestimate our data. Over our 110 $(Q^2, x_B, t)$ bins, the average $\chi^2$ per degree of freedom [34] is the smallest for KM10a (1.46), followed by KMS (1.85), VGG (1.91), and KM10 (3.94). We can therefore conclude that standard GPD models with a dominant contribution of the GPD $H$ to the unpolarized cross section, i.e., without the introduction of a strong $H$ contribution, describe the data well. Moreover, the disagreement between our data and the KM10 model is based on the Mellin-Barnes representation [25,29].

The KM10 version of the model includes contributions from all four GPDs for which the free parameters were fitted to the JLab [12,13], HERMES [30], and ZEUS/H1 [31,32] data. In that work, it was found that it is possible to fit the JLab Hall A unpolarized cross sections only at the price of introducing a very strong $H$ contribution [33]. The KM10a version is based on a fit which excludes the JLab Hall A unpolarized cross sections [12] and sets $H$ to zero. Note that none of these four models has been tuned to our data.

Figure 4 shows that the predictions of standard GPD models like VGG, KMS, and KM10a, whose compatibility is remarkable despite their different approaches, are in good agreement with our unpolarized cross-section data. In contrast, the KM10 version, which includes the strong $H$ contribution, tends to overestimate our data. Over our 110 $(Q^2, x_B, t)$ bins, the average $\chi^2$ per degree of freedom [34] is the smallest for KM10a (1.46), followed by KMS (1.85), VGG (1.91), and KM10 (3.94). We can therefore conclude that standard GPD models with a dominant contribution of the GPD $H$ to the unpolarized cross section, i.e., without the introduction of a strong $H$ contribution, describe the data well. Moreover, the disagreement between our data and the KM10 model, which instead matches the Hall A results, might reveal an inconsistency between the two sets of data. As a check, we performed a dedicated data analysis using the exact same $(Q^2, x_B, t)$ bin limits as those used for the Hall A analysis $(Q^2 = 2.3$ GeV$^2, x_B = 0.36$, and $-t = 0.17, 0.23, 0.28$, and 0.33 GeV$^2$). However, in this limited and particular $(Q^2, x_B, t)$ region, the comparison is hampered by our large statistical uncertainties and lack of $\phi$ coverage around $\phi = 180^\circ$. Thus, no conclusion can be drawn from this comparison. The Hall A experiment was run at a luminosity almost 3 orders of magnitude larger than ours but in a much more limited phase space.

Overall, the four models, including KM10, give a good description of the beam-polarized cross-section difference, and the data barely allow one to distinguish one model from another. Over our 110 $(Q^2, x_B, t)$ bins, the average $\chi^2$ per degree of freedom [34] is the smallest for KM10a (1.06), followed by KM10 (1.20), VGG (1.40), and KMS (1.84).

Finally, we attempted to extract some GPD information from these two sets of observables. We used a simplified version of the local-fitting procedure developed in Refs. [35–38]. At leading twist and leading order, this procedure uses well-established DVCS and BH amplitudes and fits simultaneously the $\phi$ distributions of our unpolarized and beam-polarized cross sections at a given $(Q^2, x_B, t)$ kinematic point by the (real) quantities:

$$F_{Re}(\xi, t) = \mathcal{P} \int_{-1}^{1} dx \left[ \frac{1}{x - \xi} + \frac{1}{x + \xi} \right] F(x, \xi, t),$$

$$F_{Im}(\xi, t) = F(\xi, \xi, t) \mp F(-\xi, \xi, t),$$

where $F = H, \tilde{H}, E, \tilde{E}$, the top and bottom signs apply to the unpolarized $(H, E)$ and polarized $(\tilde{H}, \tilde{E})$ GPDs, respectively, and $\mathcal{P}$ is the principal value integral. These quantities are called Compton form factors (CFFs) [39] in Refs. [35–38] and “sub-CFFs” in Ref. [40].

Here, we considered fits with only $H_{Re}, H_{Im}, \tilde{H}_{Re},$ and $\tilde{H}_{Im}$, which are the dominant CFFs, neglecting the contributions from $E$ and $\tilde{E}$. Despite the underconstrained nature of the problem, i.e., fitting two observables with four free parameters, the algorithm generally manages to find, when the range of variation of the CFFs is limited, minimum $\chi^2$ values for $H_{Im}$ and $H_{Re}$ as the two fitted observables are dominated by the contribution of the GPD $H$. Figure 5 shows, for a selection of three of our 21 $(Q^2, x_B)$ bins, the $t$ distribution of the fitted $H_{Im}$ and $H_{Re}$. Contrary to these two, $\tilde{H}_{Im}$ and $\tilde{H}_{Re}$ do not come out of the fit with finite error bars within the allowed range of variation, for most kinematics. Nonetheless, they must be included in the fit because of their impact on the errors of $H_{Im}$ and $H_{Re}$. Figure 5 also shows the VGG predictions, which overestimate the fitted $H_{Im}$ at the smallest values of $x_B$.

We have fitted, in Fig. 5, the $t$ dependence of $H_{Im}$ by the function $Ae^{bt}$ with $A$ and $b$ as free parameters. Keeping in mind that the $Q^2$ values are different for the three $x_B$ bins, the results of these fits show that $A$ and $b$ increase, in a systematic way, with decreasing $x_B$. Under the hypothesis of neglecting $Q^2$ higher-twist and evolution effects as well as deskewing effects [41], these behaviors might reveal tomographic features of the quark content of the nucleon. Under the mentioned conditions, $b$ is related to the transverse size of the nucleon. Our data therefore suggest that

$$Q^2 = 1.11 \mathrm{GeV}^2, x_B = 0.126; \quad Q^2 = 1.63 \mathrm{GeV}^2, x_B = 0.185; \quad Q^2 = 2.10 \mathrm{GeV}^2, x_B = 0.304$$

$$A = 5.30 \pm 0.95, b = 4.25 \pm 0.98; \quad A = 4.08 \pm 0.56, b = 3.03 \pm 0.55; \quad A = 1.81 \pm 1.72, b = 1.18 \pm 2.26$$

FIG. 5 (color online). Results of the CFF fit of our data for $H_{Im}$ and $H_{Re}$, for three $(Q^2, x_B)$ bins, as a function of $t$. The blue solid curves are the VGG predictions. The black dashed curves show the fit of the results by the function $Ae^{bt}$. 

212003-5
the size of the nucleon increases as lower momentum fractions (proportional to \( x_B \)) are probed. The rising of \( A \) reflects the increase of the partonic content of the nucleon as lower \( x_B \) values are probed. \( H_{R\phi} \) does not lend itself easily to a simple interpretation, as it involves a weighted integration of the GPD \( H \) over \( x \). Nevertheless, its extraction is of great use to constrain models.

In conclusion, we have measured the unpolarized and beam-polarized fourfold cross sections \((d^4\sigma/dQ^2dx_Bdt\phi)\) for the \( e^+e^- \rightarrow e^+e^-\gamma^* \) reaction over the widest phase space ever covered in the valence-quark region. The full data set, available at Ref. [42], will provide stringent constraints on GPD models. We have shown that three well-known GPD models describe the data well without additional inputs. The model interpretation of the present results favors a smaller deviation from the pure BH process around \( x_B \). Nevertheless, its extraction is of great use to constrain models.

We thank the staff of the Accelerator and Physics Divisions at Jefferson Lab for making this experiment possible. We also thank I. Akushevich, K. Kumerički, and D. Mueller for informative discussions and making available their calculations. This work was supported in part by the U.S. National Science Foundation, the Chilean Comisión Nacional de Investigación Científica y Tecnológica (CONICYT), the French Centre National de la Recherche Scientifique (CNRS), the French Commissariat à l’Energie Atomique (CEA), the French-American Cultural Exchange (FACE), the Italian Istituto Nazionale di Fisica Nucleare (INFN), the National Research Foundation of Korea (NRF), the Scottish Universities Physics Alliance (SUPA), and the United Kingdom’s Science and Technology Facilities Council (STFC). This work benefited from the support of the French Agence Nationale de la Recherche (Contract No. ANR-12-MONU-0008-01 PARTONS) and the Joint Research Activity GP Dex of the European program Hadron Physics 3 under the Seventh Framework Programme of the European Community. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Contract No. DE-AC05-06OR23177.

1Corresponding author.
jo@ipno.in2p3.fr
2Present address: Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA.
3Present address: Mississippi State University, Mississippi State, MS 39762, USA.

\[ x_B \]

\[ H_{R\phi} \]

\[ A \]

\[ d^4\sigma/dQ^2dx_Bdt\phi \]

\[ e^+e^- \rightarrow e^+e^-\gamma^* \]

\[ x_B \]

\[ H_{R\phi} \]

\[ x \]

\[ A \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]

\[ x_B \]
[33] The introduced $\tilde{H}$ contribution is about a factor of 3 larger than values given by standard parametrizations, such as in VGG, or inferred from simple relations to polarized parton distribution functions.
[34] The $\chi^2$ values, integrated over all the bins, give a general indication, but the level of agreement or disagreement between each GPD model’s predictions and the data varies as a function of the kinematics.

[39] The CFFs are alternatively defined as four complex quantities whose real and imaginary parts are, respectively, as $\text{Re}F(\xi,t) = F_{\text{Re}}(\xi,t)$ and $\text{Im}F(\xi,t) = -\pi F_{\text{Im}}(\xi,t)$.
[41] The transition $H(\xi,\xi,t) \rightarrow H(\xi,0,t)$ was estimated in a model-dependent fashion to be of the order of 20% in Ref. [11].