New Physics: Sae Mulli,
Vol. 69, No. 4, April 2019, pp. 376∼379
http://dx.doi.org/10.3938/NPSM.69.376

Cross Section Results for Deeply Virtual Compton Scattering with CLAS

Hyon-Suk Jo*
Department of Physics, Kyungpook National University, Daegu 41566, Korea

(Received 13 December 2018 : accepted 28 December 2018)

The internal structure of the nucleon still presents fundamental questions, regarding the spatial and momentum distributions of the quarks and gluons, *i.e.* the partons, correlated inside the nucleon, that remain to be resolved. Generalized parton distributions (GPDs) are functions describing the complex internal structure of the nucleon and can be accessed through the study of hard exclusive processes. A measurement of unpolarized and beam-polarized four-fold cross sections for the electroproduction of a real photon, $ep \to e'p'\gamma$, was performed with the CEBAF large acceptance spectrometer (CLAS) and the 5.75-GeV polarized electron beam of the Jefferson Lab accelerator, for 110 (Q^2, x_{B}, t) bins over the largest kinematic domain ever explored in the valence-quark region. Several GPD models present good agreement with the cross section data at most of the measured kinematics. These experimental results show promising elements of a first tomographic image of the nucleon.

PACS numbers: 12.38.−t, 13.40.Gp, 13.60.Fz, 13.60.Hb, 14.20.Dh, 24.85.+p
Keywords: Hadronic physics, Nucleon structure, Electron accelerator, Quarks, Electroproduction

I. Introduction

The nucleon's internal structure still has many unresolved questions several decades after the discovery of its quark and gluon substructure. The way the spatial and momentum distributions of the quarks and gluons, *i.e.* the partons, are correlated inside the nucleon remains unknown, as well as the way those partons contribute to basic properties of the proton, such as its mass, spin, and charge. Thus, the proton spin crisis is still to be resolved.

The study of hard exclusive processes during the past two decades has significantly increased our understanding of the structure of the nucleon in terms of the quarks and gluons. Deeply virtual exclusive reactions with high photon virtuality Q^2 proved to be an essential tool to probe the nucleon's internal structure at the level of the partons. These reactions include the electroproduction of a real photon, known as deeply virtual Compton scattering (DVCS), and deeply virtual meson production (DVMP). The study of these reactions give access to generalized parton distributions (GPDs) which are universal functions describing the complex internal structure of the nucleon. The GPDs extend the information provided by the form factors and parton distributions by giving access to the correlation between the spatial distributions of the partons and their longitudinal momentum fraction inside the nucleon. As the GPDs reveal the position distribution of the partons inside the nucleon for each interval of longitudinal momentum, one often refers to a 3D image of the nucleon or *nucleon tomography*. Another major interest of the GPDs is that they also provide a unique access to the total angular momentum of the quarks in the nucleon, essential to finally solve the proton spin crisis.

Facilities with multi-GeV lepton beams, such as Jefferson Lab, COMPASS (CERN) and HERA (DESY), set large experimental programs to study the DVCS and DVMP processes using their lepton beams as electromagnetic probes. DVCS corresponds to Compton scattering at the parton level, with the incoming photon radiated from the lepton beam. The energy and angular distributions of the outgoing photon provide information on the

*E-mail: hyonsuk@knu.ac.kr

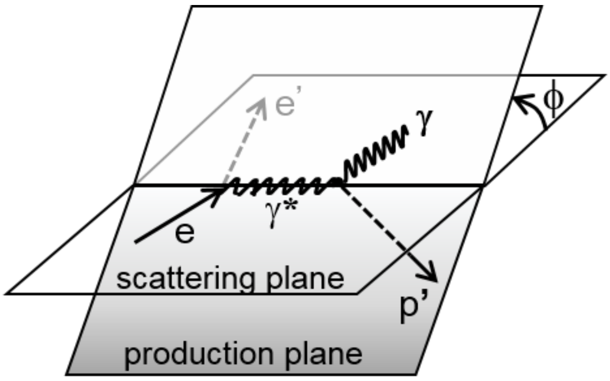

Fig. 1. The electroproduction of a real photon, known as deeply virtual Compton Scattering (DVCS), is the key reaction giving access to the generalized parton distributions (GPDs).

distribution in momentum and/or space of the partons inside the proton. In the framework of Quantum Chromodynamics (QCD), it was shown [1–5] that one needs to study the DVCS process at sufficiently large squared electron momentum transfer Q^2 and small squared proton momentum transfer t in order to reach the validity domain of the GPD formalism. At leading-order, leading-twist QCD, GPDs do not depend on the Q^2 variable and the DVCS process can be described using four GPDs: H, $\tilde{H}$, E and $\tilde{E}$, corresponding to four independent helicity-spin transitions of the quark-nucleon system from the initial state to the final state of the process. DVCS is the key process providing access to GPDs as it offers a straightforward interpretation in terms of GPDs, with the DVMP processes presenting a more complex case. Details on the GPD formalism can be found in reviews [6–11].

Fig. 1 shows the DVCS reaction for a proton, with the incoming electron (from the beam), the scattered electron, a virtual photon exchanged between the electron and one of the partons from the nucleon, the recoil proton, and the produced real photon. The incoming and scattered electrons form the scattering plane while the recoil proton and the produced photon form the production plane. To achieve the extraction of the four GPDs from the DVCS process, one needs to perform the measurements of a series of observables for the electroproduction of a real photon, *i.e.* the $ep \to e'p'\gamma$ reaction, with the measured kinematic domain as large as possible to provide stronger constraints to GPD theoretical models. As each DVCS observable is sensitive to a specific combination of GPDs, the separation and extraction of the different GPDs needs the measurements of the different observables. Those include the unpolarized cross section, beam-polarized cross-section difference, and polarized beam or/and target asymmetries.

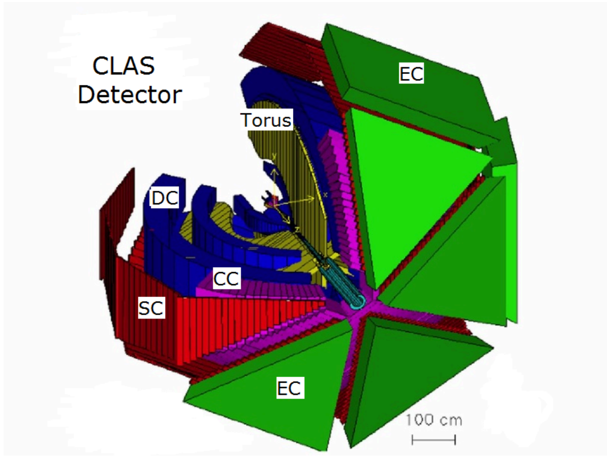

Fig. 2. (Color online) View of the CLAS detector and its numerous components. CLAS is built around a toroidal magnet and includes three regions of drift chambers (DC), Cherenkov counters (CC), scintillation counters (SC), and electromagnetic calorimeters (EC).

Jefferson Lab (located in Newport News, Virginia, USA), with the CEBAF electron accelerator, is one of the very few facilities in the world allowing experiments dedicated to the study of GPDs. Various measurements of hard exclusive reactions (DVCS, exclusive electroproduction of mesons) were performed over the past several years with the 6 GeV electron beam and the large acceptance CLAS detector of Hall B and led to very promising results. In this article, we briefly present the recent results on the unpolarized cross section and beam-polarized cross-section difference measured with the CLAS detector in the Hall B of Jefferson Lab [12].

II. Experiment

Fig. 2 shows a view of the CLAS (CEBAF Large Acceptance Spectrometer) detector [13] and its various and numerous components. The CLAS detector is built around a toroidal magnet providing a magnetic field changing the trajectories of charged particles. The subdetectors of CLAS include three regions of drift chambers (DC), Cherenkov counters (CC), scintillation counters

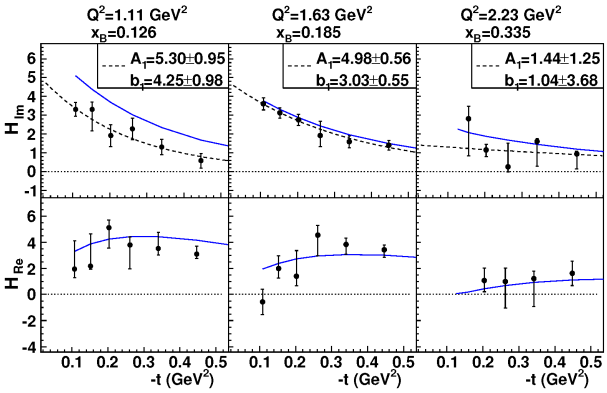

Fig. 3. (Color online) Figure extracted from [12]. Results of the fits of the cross section data, for three kinematic values, as a function of t. The blue solid curves are the predictions of a GPD model. The black dashed curves show the fit of the results by the function Ae^{bt}.

(SC), and electromagnetic calorimeters (EC). As seen in the figure, the CLAS detector consists of six sectors distributed around the beamline.

The experiment which led to the recent cross section results presented in [12] used the 5.75-GeV polarized electron beam, with a beam polarization of about 79.4% and a luminosity of 2×10^{34} cm^{-2}s^{-1}. The electron beam interacted with a 2.5-cm-long liquid-hydrogen target to produce the studied reaction. A specially designed DVCS inner calorimeter [14] was added to the CLAS detector in order to detect the photons emitted at the forward angles. In addition, a solenoid magnet around the target was used to shield the inner calorimeter from the numerous low-energy Møller electrons coming from the target.

III. Results

The extraction of unpolarized cross section and the beam-polarized cross-section difference was performed over the widest kinematic domain ever explored in the valence-quark region, with 110 $(Q^2, x_{\rm B}, t)$ bins covering: $1.0 < Q^2 < 4.6$ GeV^2, $0.10 < x_{\rm B} < 0.58$, and $0.09 < -t < 0.52$ GeV^2, with $x_{\rm B}$ as the Bjorken variable. The data analysis started with the selection of events with at least one electron, one proton, and one photon in the final state. Those events then went through 3σ cuts on several kinematic variables to ensure the exclusivity of the $ep \to e'p'\gamma$ reaction. Contamination from the $ep \to e'p'\pi^0$ reaction in the case where one photon of the π^0 decay escapes detection was estimated and rejected for each kinematic bin, by using a combination of Monte-Carlo simulations. One critical factor in the normalization of the measured cross section was the determination of the four-dimensional acceptance, *i.e.* geometrical efficiency, of the CLAS detector for each kinematic bin by simulating more than 200 million Monte-Carlo events. Indeed, the acceptance of the CLAS detector is particularly complex due to numerous small inactive areas and also inoperative detector parts at the time of data taking. Other cross section normalization factors include the radiative effects, the effective hypervolume of each bin, and the effective integrated luminosity. Details of the data analysis can be found in [12]. Overall, the statistical uncertainties of the data are of 13.9% on the unpolarized cross section on average, over the 110 $(Q^2, x_{\rm B}, t)$ bins, and the systematic uncertainties are of 14% on the unpolarized cross section on average. The predictions of several GPD theoretical models were compared to the data. Overall, the GPD models show a good agreement with the cross section data.

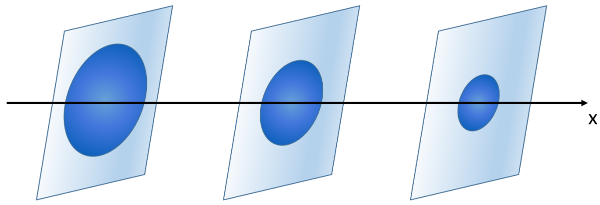

Fig. 4. (Color online) The experimental results from [12] seem to indicate that the size of the nucleon decreases with increasing longitudinal momentum fraction x, providing the first elements of a tomographic image of the nucleon.

The local-fitting procedure developed in Refs. [15–18] was used to interpret these cross section results. Fits using the function Ae^{bt} are presented in Fig. 3. Details can be found in [12].

While the Q^2 values are different for the three $x_{\rm B}$ bins, the results of the Ae^{bt} fits show that the values of A and b decrease with increasing $x_{\rm B}$. In an approximation neglecting several effects, the variable b is related to the transverse size of the nucleon, and these fit results suggest, over this limited $x_{\rm B}$ range, that the size of the nucleon seems to decrease at higher values of momentum fraction (which is proportional to $x_{\rm B}$). As discussed in [19] and illustrated in Fig. 4, the interpretation of these cross section results seems to indicate that the size of the nucleon decreases with increasing longitudinal momentum fraction x, with the valence quarks (higher momentum fractions) located at the center of the nucleon while the position of the sea quarks (lower momentum fractions) extends from the center of the nucleon to its periphery.

IV. Conclusions

The unpolarized and beam-polarized four-fold cross sections for the $ep \to e'p'\gamma$ reaction was measured for 110 (Q^2, x_B, t) bins, over the largest kinematic domain ever explored in the valence-quark region. These results provide strong constraints for GPD models over a wide kinematic range. The fit results of these cross section data seem to indicate that the nucleon size decreases at higher parton-momentum values, thus providing promising elements of a first tomographic image of the nucleon.

With the successful 12 GeV upgrade of the CEBAF electron accelerator of Jefferson Lab and the construction of the new CLAS12 detector in Hall B, a new era of exciting experiments has started. Several DVCS measurements, aiming to the extraction of several DVCS observables, will be performed over a much larger kinematic range with much higher statistics, and thus with a much higher precision.

ACKNOWLEDGEMENTS

This research was supported by Kyungpook National University Research Fund, 2018 (이 논문은 경북대학교의 2018학년도 신임교수정착연구비에 의하여 연구되었습니다).

REFERENCES

[1] D. Müller, D. Robaschik, B. Geyer, F.M. Dittes and J. Horejsi, Fortsch. Phys. **42**, 101 (1994).
[2] X. D. Ji, Phys. Rev. Lett. **78**, 610 (1997).
[3] X. D. Ji, Phys. Rev. D **55**, 7114 (1997).
[4] A. V. Radyushkin, Phys. Lett. B **380**, 417 (1996).
[5] A. V. Radyushkin, Phys. Rev. D **56**, 5524 (1997).
[6] K. Goeke, M.V. Polyakov and M. Vanderhaeghen, Prog. Part. Nucl. Phys. **47**, 401 (2001).
[7] M. Diehl, Phys. Rept. **388**, 41 (2003).
[8] X. D. Ji, Ann. Rev. Nucl. Part. Sci. **54**, 413 (2004).
[9] A. V. Belitsky, A. V. Radyushkin, Phys. Rept. **418**, 1 (2005).
[10] S. Boffi and B. Pasquini, Riv. Nuovo Cim. **30**, 387 (2007).
[11] M. Guidal, H. Moutarde and M. Vanderhaeghen, Rept. Prog. Phys. **76**, 066202 (2013).
[12] H. S. Jo *et al.* (CLAS Collaboration), Phys. Rev. Lett. **115**, 212003 (2015).
[13] B. A. Mecking *et al.*, Nucl. Instrum. Meth. A **503**, 513 (2003).
[14] F. X. Girod *et al.* (CLAS Collaboration), Phys. Rev. Lett. **100**, 162002 (2008).
[15] M. Guidal, Eur. Phys. J. A **37**, 319 (2008).
[16] M. Guidal, H. Moutarde, Eur. Phys. J. A **42**, 71 (2009).
[17] M. Guidal, Phys. Lett. B **689**, 156 (2010).
[18] M. Guidal, Phys. Lett. B **693**, 17 (2010).
[19] R. Dupré, M. Guidal, S. Niccolai, M. Vanderhaeghen, Eur. Phys. J. A **53**, 171 (2017).