Timelike Compton Scattering - A First Look

P. Nadel-Turonski[1], T. Horn[1,2], Y. Ilieva[3], F.J. Klein[1],
R. Paremuzyan[2,4], S. Stepanyan[2]

Catholic University of America, Washington, DC 20064
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
University of South Carolina, Columbia, SC 29208
Yerevan Physics Institute, 375036 Yerevan, Armenia

Abstract. A major goal of the 12 GeV upgrade at Jefferson Lab is to map out the Generalized Parton Distributions (GPDs) in the valence region. This is primarily done through Deeply Virtual Compton Scattering (DVCS), which provides the simplest and cleanest way of accessing the GPDs. However, the "inverse" process, Timelike Compton Scattering (TCS), can provide an important complement, in particular for measuring the real part of the amplitude and understanding corrections at finite Q^2. The first measurements of TCS have recently been carried out in Hall B at Jefferson Lab, using both tagged and untagged photon beams.

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Generalized Parton Distributions (GPDs) provide a framework that encompasses both the traditional measurements of elastic nucleon form factors, and collinear Parton Distribution Functions (PDFs) obtained from Deep Inelastc Scattering (DIS). Relying on the dominance of the handbag diagram, where the initial and final momenta of the struck quark are different, exclusive processes can be used to create a tomographic image of the nucleon.

The simplest and cleanest way to perform such imaging of the valence quarks is through Deeply Virtual Compton Scattering (DVCS), making it a cornerstone of the 12 GeV program at Jefferson Lab (JLab). But DVCS is only one limit of the general Compton process, $\gamma^* p \rightarrow \gamma^* p$, where the final-state photon is real. Timelike Compton Scattering (TCS), which is the "inverse" reaction where the incoming photon is real

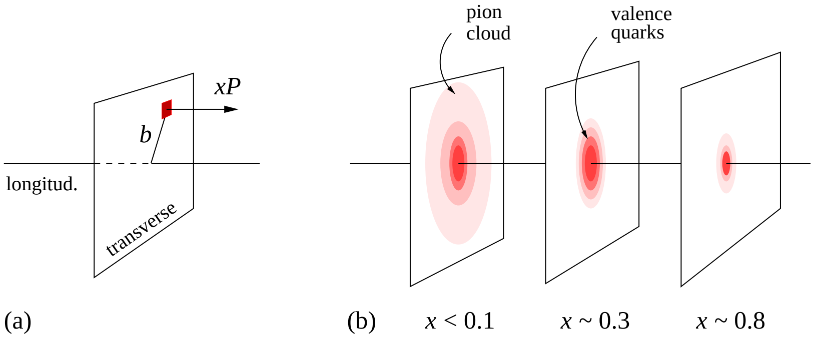

FIGURE 1. GPDs can provide a tomograhic image of the nucleon. *Courtesy of C. Weiss.*

and the final-state photon has a large timelike virtuality (providing the hard scale), may offer a complementary way of probing GPDs. TCS has recently drawn considerable theoretical interest, both in ep scattering [1], as well as ultraperipheral pp [2] collisions, and even e^+e^- radiative annihilation [3].

The main advantages of TCS are threefold:

1) It provides a straightforward way of measuring the real part of the amplitude with small systematic uncertainties.

2) Since the TCS and DVCS amplitudes are equivalent only to leading order, a combination of data will provide a better understanding of the corrections at finite Q^2.

3) TCS asymmetries are easy to compare direcly with GPD models even with limited experimental statistics.

On the other hand, there are also limitations to TCS. For instance, resonances restrict the range in Q'^2 (the virtuality of the final state photon, measured as the invariant mass squared of the produced lepton pair). At JLab this falls between the ϕ and J/Ψ. The cross section for TCS is also smaller than for DVCS, and more importantly, smaller than Bethe-Heitler (B-H) for all kinematics. The TCS cross section can thus not be measured directly. But the interference term, enhanced by the strong B-H, can be easily isolated due to a crucial feature of the TCS phenomenology. The reason is that the TCS and B-H contributions are even under the exchange of lepton momenta, but the interference term is odd. Any observable that does change sign will therefore project out *only* the interference term. The angular distribution of the lepton pair (with respect to the angle φ between the reaction plane and lepton decay plane) is such an observable. The corresponding DVCS observable is the beam charge asymmetry, a measurement of which requires very good control of systematics.

When the photon beam is (on the average) unpolarized, only the real part of the TCS amplitude contributes to the interference term [1]. In contrast, accessing the real part of the DVCS amplitude through a direct cross section measurement is only possible in some kinematics, and requires a good understanding of the B-H and π^0 backgrounds. Circular photon polarization adds the imaginary part to the TCS-BH interference term, but this is also relatively easy to study through DVCS beam spin asymmetries. However, since all helicity amplitudes enter the expression for the TCS-BH interference term with different trigonometric dependencies on the angle φ, it is possible to form asymmetries that project out only one specific contribution. These asymmetries can also be calculated from various GPD models, and are easy to compare with data, as illustrated in Figure 2.

Actual extraction of GPDs is a rather complex process, as the observables are convolution integrals over x of the GPDs. In fact, the imaginary part of DVCS or TCS probes the GPD along the the line where the skewness ξ is equal to x, while the real part probes at a fixed ξ for all values of x. Advanced schemes are being developed to deconvolute the underlying GPDs [4], and theoretical efforts are made to reduce the number of fit parameters, for instance by applying dispersion relations. But having reliable measurements of both the real and imaginary parts of the Compton amplitude remains essential.

It should also be noted that another theoretically appealing, but experimentally difficult, possibility is opened by considering the most general Compton process, Double-DVCS, where both the initial- and final-state photons are virtual. Such a measurement would avoid the need for deconvolution by sampling individual points at any $x < |\xi|$.

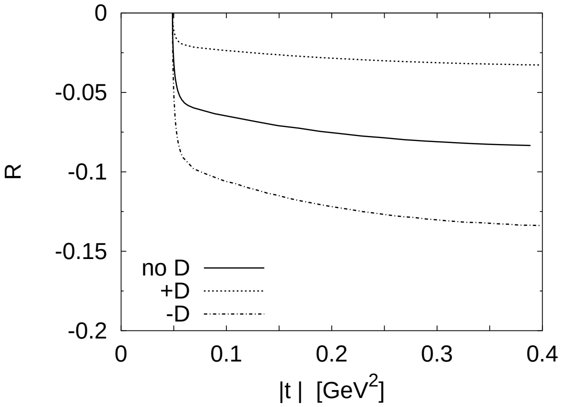

FIGURE 2. Asymmetry related to helicity amplitude $\tilde{M}^{--}$ calculated for E_γ = 13 GeV and Q'^2 = 5 GeV^2 with two model assumptions for the Polyakov-Weiss D-term, as well as without it [1].

EXPERIMENTS

The first dedicated effort ever to study TCS with tagged real photons was made during the CLAS g12 run period, using the CLAS detector system [6], a 40 cm long LH_2 target, and a photon tagger [7]. The latter tagged all photons with energies between 20% and 95% of the electron beam energy of 5.7 GeV. In order to increase the luminosity, only photons with energies between 3.6 and 5.4 GeV were included in the trigger, which was of a new FPGA-based design developed for this run period, allowing efficient operation with parallel hadronic, leptonic, neutral, and mixed triggers. Data were acquired at rates of up to 10 kHz, and consisted mainly of events requiring at least two charged tracks in addition to the tagged photon. Between March 29 and June 8, 2008, about 25 billion events were collected in total. The large hadronic statistics make it possible to investigate potential resonances above the ϕ mass through their hadronic decays, to check if they could significantly contribute to the e^+e^- final state. As the only high-energy photoproduction experiment at JLab to date, g12 featured the full set of CLAS Cerenkov detectors in addition to the electromagnetic calorimeter. Based on the earlier g7 data, this allows pion rejection of 10^{-4} with one detected lepton and 10^{-7} with both detected. The photon beam was circularly polarized, although the level of polarization varied during the experiment. The calibrations for this experiment are almost finished, and the data will be available for analysis in the fall of 2009. The results can be used as a basis for the development of program for the new experiment Hall D after the 12 GeV upgrade, where one would have access to linearly polarized tagged photons.

There are also several CLAS data sets using electron beams between 5 and 6 GeV that can be used for TCS analyses. The ongoing analysis focuses on e1-6 and e1f, but could be expanded to include, for instance, e1-DVCS. All these data sets have circularly polarized photons. Looking for TCS in the process $e^- p \rightarrow e'^- p e^+ e^-$ presents a complication in that the beam electron is scattered at a very small angle and is not detected. However, detection of the other three final-state particles makes it possible to require the missing momentum to be aligned with the beam direction (95% of selected events had electrons scattered within 0.5°), and the missing mass to be very small. When

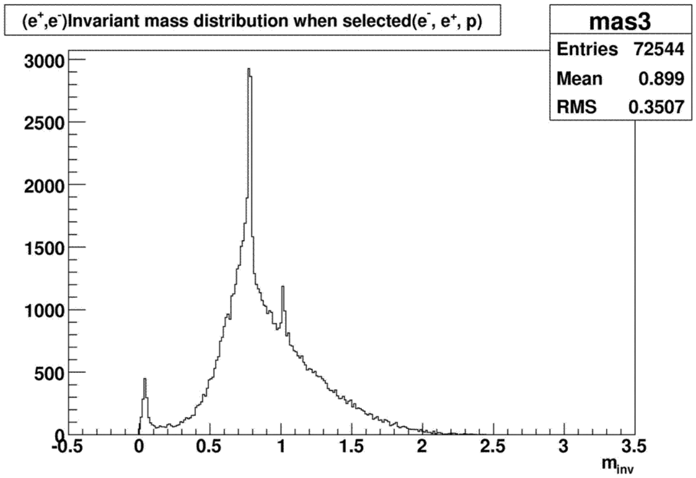

FIGURE 3. e^+e^- invatiant mass (Q') spectrum from the CLAS 6 GeV e1-6 data set showing the vector mesons (ω on top of the ρ), and the statistics for TCS candidates above the ϕ peak.

$Q^2 \sim 0$ and Q'^2 is large enough to be of interest for TCS analysis, the electron from the produced lepton pair will usually go out at a much larger angle. This makes an unambiguous electron assignment possible, and is nicely illustrated by the clear vector meson peaks in the mass spectrum shown in Figure 3. When both Q^2 and Q'^2 become significant, however, this is no longer the case, making attempts to measure Double-DVCS much more challenging [5]. Figure 3 also illustrates the statistics in the e1-6 data set for lepton pairs above the ϕ mass. First asymmetries from this analysis are expected this fall. The results will lay the foundation for a 12 GeV program in Hall B after the 12 GeV upgrade. Since the TCS measurements would not require any special configuration or hardware, the experiments could in principle run in parallel with other parts of the CLAS12 program. With a luminosity of 10^{35} cm^{-2}s^{-1} and several years of beam time, a sizeable data set could be collected.

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