Deeply Virtual Compton Scattering with CLAS and CLAS12

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Two very effective means of accessing Generalised Parton Distributions of the nucleon are Deeply Virtual Compton Scattering (DVCS) and Meson Production (DVMP). Jefferson Laboratory, USA, previously operational with a 6 GeV electron beam and currently undergoing an upgrade to 12 GeV, is ideally suited for measuring these processes. This paper focuses on a selection of recent results from the very active DVCS experimental programme with the large angle spectrometer CLAS, and introduces the exciting programme planned for its successor suite of detectors, CLAS12, in the vast, as yet unprobed kinematic region opening up to experiment.

1 Introduction

Studying the nucleon via the scattering of a high energy electron reveals different facets of its structure depending on the reaction observed. A three-dimensional image of the nucleon can be produced from measurements in deep exclusive reactions, which, for example, give access to Generalised Parton Distributions (GPDs), functions relating the transverse position of quarks to their longitudinal momentum.

Two powerful experimental methods for accessing GPDs are via Deeply Virtual Compton Scattering (DVCS) and Meson Production (DVMP), where a high energy electron scatters from a single quark in the nucleon and a high energy real photon or meson is produced as a result. The process is determined by the variables Q^2 (the virtuality of the photon exchanged between the scattered electron and the quark), x (the fractional longitudinal momentum of the struck quark), ξ (the fractional change in the longitudinal momentum of the struck quark) and t (the squared momentum change of the nucleon). In the kinematic regime of high Q^2 and low t, DVCS and DVMP give access to four GPDs: H, $\tilde{H}$, E and $\tilde{E}$ for each quark flavour.

In DVCS, the sensitivity of the experiment to different GPDs can be vastly increased if — in addition to measuring cross-sections — the polarisation of either beam or target (or both) is a controlled parameter: by measuring spin asymmetries (differences of cross-sections for opposite polarisation states divided by their sum). By applying fits to the measured asymmetries, it is possible to extract, in a model-independent way, Compton Form Factors (CFFs), which form the real and imaginary parts of combinations of GPD functions at certain x-values or their integrals along x. Since x is not an experimentally-accessible parameter in DVCS, model-application is then required to extract GPDs from the CFFs. The contributions of certain GPDs to some spin asymmetries are kinematically suppressed, depending on which polarisation states and nucleon target are used. Thus, for example, the beam-spin asymmetry on the proton is dominated by

GPD H, while on the neutron by GPD E. To enable a full extraction of GPDs it is therefore necessary to measure a wide range of observables, on both the proton and the neutron, and across maximally wide regions of phase space.

A significant advantage of meson production is that it gives additional access to quark-flavour decomposition, although the extraction of GPDs is made more complicated than in the case of DVCS by the stronger higher-twist contributions. Cross-sections for the production of vector mesons are sensitive to GPDs H and E, while those for pseudo-scalar mesons have high sensitivity to $\tilde{H}$ and $\tilde{E}$. Due to length constraints, we do not discuss DVMP results in the section below.

2 DVCS experiments with CLAS at Jefferson Lab — 6 GeV era

A very rich experimental programme in measurements of DVCS has been underway at Jefferson Laboratory, using its high intensity electron beam accelerator, which has just come to the end of its 6 GeV era, and the large angle spectrometer CLAS positioned in Hall B. In the past years, following a number of first measurements from early electroproduction experiments [1, 2], two dedicated experiments — both using polarised electron beams — have been carried out using CLAS. The first of these had an unpolarised H_2 target and allowed measurements of cross-sections and beam-spin asymmetries to be extracted on the proton (Figure 1), the second used a polarised H_2 target and also took a small pilot data sample with a liquid D_2 target. These data are currently under analysis for the extraction of cross-sections, beam-spin (Figure 2(a)), target-spin (Figure 2(b)) and double-spin asymmetries in DVCS on the proton and neutron, and for cross-section measurements of DVMP on the proton.

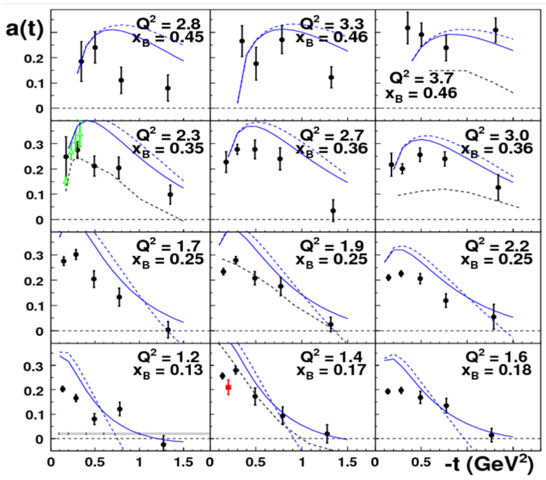
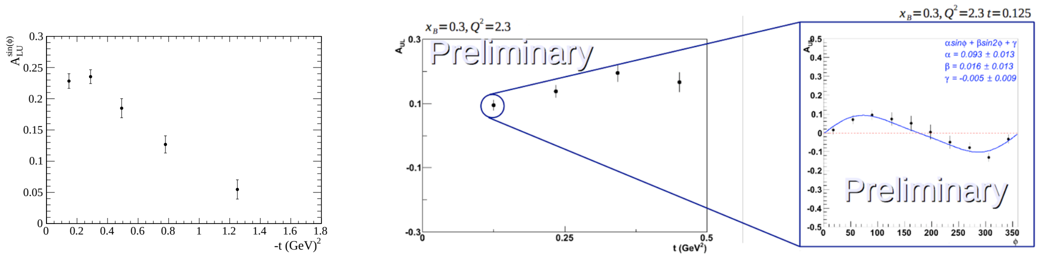


Figure 1: Beam-spin asymmetry (a(t)) in $ep \to e'p'\gamma$ [3] (round points), compared to model predictions: the solid line in each plot is VGG twist-2 [4], the dashed line above it is VGG twist-3, the darker dashed line below the solid one is the Regge model prediction. Points — square: previous CLAS result, triangle: Jefferson Lab Hall A result.



(a) (b)

Figure 2: Preliminary extraction of beam-spin, A_{LU} (left) and target-spin, A_{UL} (right) asymmetry in $ep \to e'p'\gamma$, uncorrected for background, from the recent CLAS experiment "eg1-dvcs" (*E. Seder, G. Smith, private communication 2012.*) The graph on the right shows how a single value of A_{UL} is determined from a fit to the ϕ-asymmetry.

The published beam-spin and target-spin asymmetries from CLAS have been analysed, in an almost model-independent way, for the extraction of the $\mathfrak{Im}H$ and $\mathfrak{Im}\tilde{H}$ CFFs (Figure 3). One of the resulting conclusions of their observed slopes in the dependence on t suggests that the axial charge may be more concentrated in the proton than the electromagnetic charge.

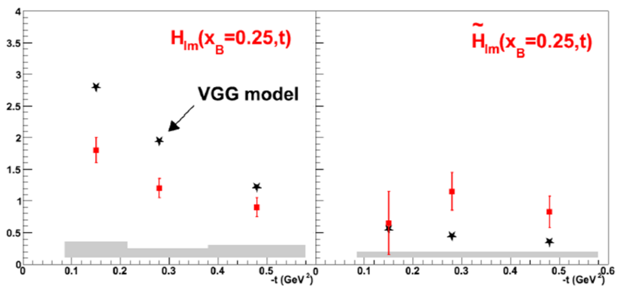


Figure 3: Comparison of CFF extracted with the technique of ref. [4] from data measured by CLAS (square) and predicted by the VGG model (star) as a function of t.

3 CLAS12 at Jefferson Lab — 12 GeV era

The Jefferson Lab accelerator is currently undergoing an upgrade to double its maximum energy of operation to 12 GeV, with 11 GeV deliverable to Hall B, where the design and construction of CLAS12 — a new set of detectors optimised for reconstruction of electroproduction events in the vast new region of phase space being opened to experiment (Figure 4) — is underway. The rich experimental programme proposed for CLAS12 includes, amongst others, experiments to measure DVCS and DVMP in the totally new kinematic region.

Specifically, the experimental DVCS programme approved includes 85 days with a polarised beam (expected degree of polarisation ≈ 85%) and an unpolarised H_2 target and 120 days with

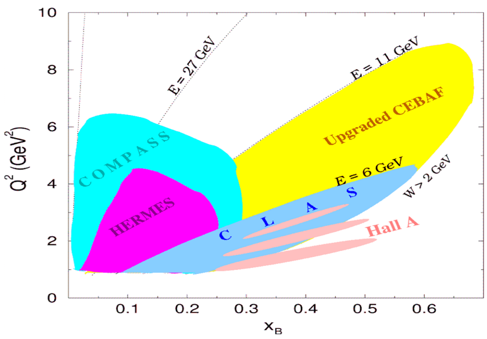


Figure 4: Regions of phase space covered by the existing facilities for electroproduction experiments, showing the vast new kinematic region covered by CLAS12.

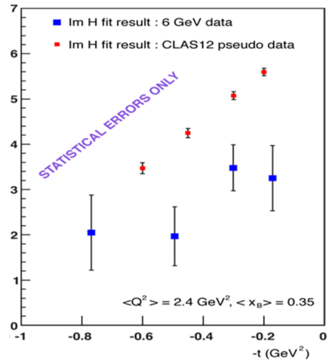


Figure 5: Comparison of the statistical error-bars on $\mathfrak{Im}H$ extracted from fits to CLAS data (big squares) and expected from the proposed CLAS12 experiment (H. Moutarde).

a longitudinally polarised H_2 target to measure beam- and target-spin asymmetries in DVCS on the proton, covering the kinematic regions $1 < Q^2 < 10$ GeV^2, $0.1 < x_B < 0.65$ and $t < 2.5$ GeV^2. As an example, the projected effect on the model-dependent extraction of $\mathfrak{Im}H$ can be seen in Figure 5, where the great reduction in the error-bars on the CFF is evident. Additionally, a proposal to measure exclusive DVCS on the neutron has been accepted last year [5], which will be the first extensive measurement of this reaction. The experiment has been accorded 80 days of beam-time on an unpolarised deuterium target. In this kinematic regime, neutron DVCS is extremely sensitive to GPD E, which is the least known and least constrained of the four GPDs. It is particularly important, however, as it features prominently in Ji's so-called "Sum Rule", which relates the total angular momentum of the quarks to the GPDs E and H. A measurement of E, therefore, has the potential to shed important light on the puzzle of nucleon spin. To enable exclusive measurements of neutron DVCS, a neutron detector optimised for the DVCS kinematics at 11 GeV and for the space and technical constraints of CLAS12 has been designed – and is currently under construction – at IPN Orsay.

Other opportunities at CLAS12 for 11 GeV include DVCS with a transversely polarised proton target, which would allow measurement of the transverse-spin asymmetries highly sensitive to the GPD E (and as a result to the up-quark contributions to proton spin), as well as measurements of the polarised and unpolarised DVCS cross-sections and both vector and pseudo-scalar meson production. CLAS12 will be the world's only full acceptance, general purpose detector for high luminosity electron scattering experiments, and will be perfectly suited for the GPD programme.

References

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