Hard Exclusive Measurements with a Polarised Target at HERMES

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Abstract. Hard exclusive measurements at HERMES provide access to the information framework of Generalised Parton Distributions. This framework has the potential to provide a thorough, phenomenological description of the nucleon and aspects of it can be constrained by recent measurements made at the HERMES experiment at DESY. Consideration of meson production allows access to some GPDs, whilst observables from the deeply virtual Compton scattering process can allow a constraint on model parameters which are directly connected to the total angular momentum contribution of up and down quarks to the nucleon’s spin.

1. Introduction
The analysis of hard exclusive processes can be used to investigate Generalised Parton Distributions (GPDs). GPDs embody regular parton distribution functions and elastic form factors as kinematic limits and $x$-moments respectively. They provide at present the most complete phenomenological description of the nucleon [1]. Thorough understanding of the GPD framework could be used to reveal several previously-unknown quantities of the structure of the nucleon, from the transverse momentum distribution of individual quarks [2] to the total angular momentum of quarks of different flavour [3]. GPDs are currently poorly-understood, with few experiments able to provide data that can be usefully interpreted to aid the understanding of the framework. HERMES is such an experiment, however, and has recently released results on meson production and deeply virtual Compton scattering (DVCS) that disfavour certain models of GPDs.

HERMES makes measurements of exclusive processes from polarised and unpolarised proton targets with a positron or electron beam. As the HERMES forward spectrometer has a limited acceptance, it cannot measure the recoiling target nucleon, and so uses a missing-mass technique to ensure exclusivity. This means that background subtraction at HERMES is not always simple, and must be accounted for on a process-by-process basis.

2. Exclusive Meson Production
GPDs can be constrained by considering exclusive meson production, specifically cross-sections or azimuthal cross-section asymmetries. HERMES has recently published results on $\pi^+$ cross-sections and released preliminary results on $\rho^0$ meson production that are interpretable in terms of GPDs.
2.1. Hard Exclusive $\rho^0$ Meson Production

Longitudinally polarised $\rho^0$ mesons are produced at HERMES by scattering a positron or electron beam off a transversely polarised target. Such production results in an azimuthal asymmetry that can be predicted by a GPD model which has the total angular momentum of up-flavour quarks within the nucleon as a free parameter. Such an event is detected at HERMES by detecting unambiguously the scattered beam lepton and two oppositely charged hadrons, i.e. by detecting the process $e^+p \rightarrow e'^+p'\rho^0 \rightarrow e'^+p'\pi^+\pi^-$ and assuming that the two detected hadrons are pions with the requirement $0.6 \text{ GeV/c}^2 < m_{\pi\pi}^2 < 2.0 \text{ GeV/c}^2$ where $m_{\pi\pi}$ is the invariant mass of the hadronic system. A missing mass cut ensures that the undetected recoiling target particle is a proton. Due to limited missing-mass resolution, semi-inclusive background cannot be subtracted from the channel of interest experimentally. Instead, the data are corrected for semi-inclusive background using a PYTHIA Monte Carlo (MC) simulation. Non-resonant exclusive pion background is estimated at a few percent, and the data are not corrected for it.

2.2. Hard Exclusive $\pi^+$ Cross-Sections

The GPD $\tilde{E}$, dominated by the pion-pole contribution, is accessible through measurements of $\pi^+$ cross section measurements in the $t$ region measured by the HERMES experiment. This GPD is not easily accessible through DVCS at HERMES and so a measurement of $\pi^+$ cross sections is considered to be the best method of accessing it at HERMES. However, cross sections are difficult to measure at HERMES as the spectrometer was originally designed to measure asymmetries. Acceptance effects are assigned a systematic uncertainty, which is based upon Monte Carlo studies using GEANT to determine the percentage probability of detecting a generated event within the HERMES spectrometer.

The results shown in figure 1 show four model calculations which arise from different models of $\pi^+$ production. The figure is taken from reference [4]. The data at low $t$, where longitudinal production is expected to dominate, support a published GPD model [6] which features a Regge-type $t$-dependence and has had power corrections applied, and otherwise the data support well a Regge-type model [7] that includes both the longitudinal and transverse $\pi^+$ production mechanisms.

![Fig. 1: $\pi^+$ cross sections as a function of $t$ in four $Q^2$ bins. Also shown are four theory curves, two from a GPD model with a Regge-style $t$-dependence (dash-dot lines) and with power corrections applied (solid line) [5] and two from a Regge model describing longitudinal cross sections (dot lines) and total cross sections (dash lines) [6].](image)

Deeply virtual Compton scattering (DVCS) is the simplest process that provides access to GPDs at HERMES. Consideration of DVCS requires no knowledge of complicated meson distribution amplitudes, and the reaction channel $ep \rightarrow e'p'\gamma$ requires knowledge of only three particles in the final state to make an exclusive measurement. However, this seeming-simplicity is tempered by the fact that there is, at HERMES kinematics, a competing process – Bethe-Heitler (BH) scattering. BH is
indistinguishable in its initial and final states from DVCS, the difference between the two processes being that in BH scattering, the lepton scatters from the nucleon as a whole, rather than probing the constituent quarks. Bethe-Heitler scattering dominates DVCS by an order of magnitude at HERMES kinematics so background subtraction to isolate DVCS information cannot be done to sufficient accuracy to make such a process useful [7]. Instead, information on GPDs is gleaned from consideration of the interference term, which has azimuthal asymmetries which have a definite dependence on GPDs. These asymmetries have different dependences on GPDs depending upon whether the target or beams are polarised, and upon the beam charge.

DVCS events are determined through the use of a missing mass cut at HERMES, with events being selected for the correct kinematic regime ($Q^2 > 1$ GeV$^2$; $-t > 0.7$ GeV$^2$; $0.03 < x_B < 0.3$) and such that the missing mass of the reaction is consistent with the proton mass within detector smearing effects (-1.5 GeV/c$^2 < M_x < 1.7$ GeV/c$^2$). This choice of missing mass helps to remove background processes and results in a background contamination of the event sample on the 10% level. The most recently released DVCS result from HERMES concerns the transverse target spin asymmetries in DVCS, which features two angles, $\phi$ and $(\phi-\phi_s)$ where $\phi$ is the angle between the lepton production plane and the photon production plane and $\phi_s$ is the angle between the target polarisation direction and the lepton production plane. There are two asymmetries, $A^\sin(\phi-\phi_s)\cos(\phi) \propto A_1\sin(\phi-\phi_s)\cos(\phi)$ and $A^\cos(\phi-\phi_s)\sin(\phi) \propto A_2\cos(\phi-\phi_s)\sin(\phi)$ which are proportional to different combinations of GPDs and $A_2$ is suppressed by an order of magnitude compared to $A_1$. $A_1$ is plotted in various kinematic bins in figure 2 [8].

![Fig. 2: The least suppressed transverse target spin asymmetry from HERMES data from 2002-2004 shown over three kinematic variables. Also shown are predictions from a VGG model which takes $J_u$ as a free parameter, where the blue line has $J_u=0$, black line has $J_u=0.2$ and the red line has $J_u=0.4$ and $J_d=0$ in all three cases.](Fig. 2.png)

By combining information taken from data gathered by the HERMES experiment on a transversely polarised target and an unpolarised beam, a model-dependent constraint on the total angular momentum of up- and down-flavour quarks in the nucleon ($J_u$, $J_d$) has been achieved. This model-dependent constraint was achieved by generating asymmetry observables from a GPD model within a grid of $J_u$ and $J_d$ values adhering to the constraints $-1 < J_d < 1$ and $0 < J_u < 1$ and finding the closest approach of such a surface to the measured asymmetry integrated over all kinematics at the HERMES experiment. This constraint is shown in figure 3 [8].

3. Summary and Outlook
Recent results from HERMES provide the possibility to differentiate between various models of nucleonic structure, with particular reference towards the models that are a part of the GPD framework. Currently HERMES recreates the recoiling target nucleon kinematics using missing mass techniques, but in future will present results from data taken with the newly-installed recoil detector which allows truly exclusive measurements to be taken for the first time [9].

References
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