

# Status of Commissioning and Analysis with the HERMES Recoil Detector

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For the final running period of HERMES at DESY (Hamburg, Germany) in 2006 and 2007, a Recoil detector was installed to improve measurements of hard exclusive processes. Data were collected from scattering the longitudinally polarized positron or electron beams of the HERA storage ring off pure unpolarized hydrogen or deuterium targets. The commissioning status and first analysis results including Recoil detector information are presented.

## 1 Generalized Parton Distributions and hard exclusive processes

In the past decade, Generalized Parton Distributions (GPDs) have emerged as a unified three-dimensional picture of nucleon structure [2]. They deliver a simultaneous description of transverse position and longitudinal momentum distributions of partons, subsuming both elastic form factors and forward parton distribution functions [3]. Moreover, GPDs offer a way to access the total angular momentum carried by partons in the nucleon [4]. The behavior of GPDs can be constrained by measurements of hard exclusive leptonproduction of a real photon (Deeply Virtual Compton Scattering, DVCS) or a meson in processes that leave the target intact (Fig. 1). Presently the experimentally mostly accessible GPDs are the chirality-conserving quark GPDs  $F^f(x, \xi, t)$  with  $F = H, E, \tilde{H}, \tilde{E}$  and parton species  $f = (u, d)$ -quark.

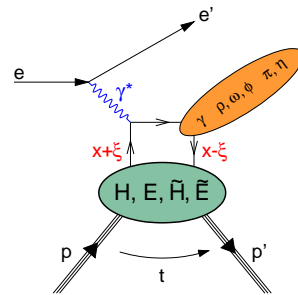


Figure 1: Hard exclusive leptonproduction of a real photon or a meson.

## 2 The HERMES Recoil detector

HERMES [5] was a fixed-target experiment employing the longitudinally polarized 27.6 GeV lepton beam of the HERA storage ring to scatter off targets of pure gases. In the end of 2005, the setup for the transversely polarized hydrogen gas target was removed and a Recoil detector was installed in the front region of the HERMES experiment. After the detector upgrade, data were taken in 2006 and 2007 on unpolarized  $^1\text{H}$  and  $^2\text{H}$  targets in a high luminosity run. The detector consists of several layers of tracking detectors around the target cell and is surrounded by a superconducting solenoidal magnet providing an integrated field strength of 1 Tesla (Fig. 2).

The innermost component is the Silicon Strip Detector (SSD). It consists of 16 double-sided sensors located inside the accelerator vacuum five centimeters close to the lepton beam. The sensors are arranged in two layers around the target cell. The Scintillating Fiber Tracker (SFT) surrounds the SSD. It consists of two barrels hosting each four layers of scintillating fibers, two of which are aligned parallel to the beam and two under a stereo angle of  $10^\circ$ . The purpose of both SSD and SFT is to provide spacepoints for the reconstruction of tracks from charged particles, in case of the SSD down to momenta as low as 125 MeV/c. The SFT covers a momentum range of 250-1400 MeV/c

for protons. The azimuthal  $\phi$ -angle coverage of the detector is 76%. The SSD and the SFT allow for Particle IDentification (PID) through the different characteristic responses caused by charged pions and protons traversing the detector materials. The outermost component is the Photon Detector (PD). It consists of three layers of a tungsten/scintillator sandwich, one layer being oriented parallel to the beam and the other two under stereo angles of  $\pm 45^\circ$ . The purpose of the PD is the detection of photons from resonance decays (like  $\Delta^+ \rightarrow p\pi^0 \rightarrow p\gamma\gamma$ ) and PID for momenta higher than 600 MeV/c.

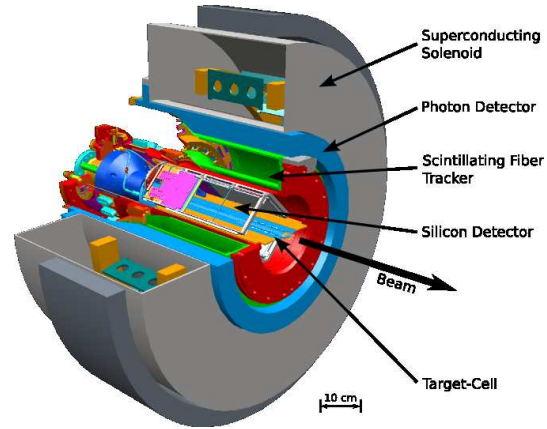


Figure 2: Schematic drawing of the HERMES Recoil detector.

### 3 Commissioning of the Recoil detector

Spacepoints in the SSD or the SSD+SFT are combined in order to form tracks. The momenta of the low-energy protons (125-145 MeV/c) that are stopped in the outer SSD layer are determined via the sum of their energy deposits. Momenta of charged particles that reach the SFT are reconstructed by bending in the magnetic field using SSD and SFT spacepoints, taking energy losses and multiple scattering into account.

For protons, the energy deposition  $\Delta E$  in the SSD is included in the momentum reconstruction in addition to the coordinate information from spacepoints in the SSD, or SSD+SFT. In this procedure, the dependence of  $\Delta E$  in the SSD layers on the proton three-momentum obtained from a detailed Monte-Carlo (MC) simulation is used. This significantly improves the momentum resolution, in particular at low values of momentum (Fig. 3).

The energy deposition of tracks in the Recoil detector vs. their reconstructed momenta is considered separately for up to nine layers. Such a PID-plane of one of the SFT-layers is

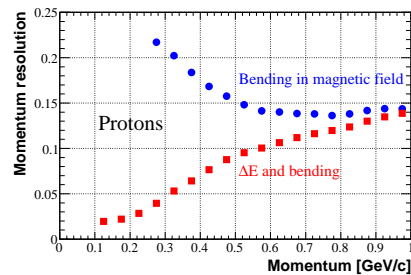


Figure 3: Momentum resolution vs. momentum for protons.

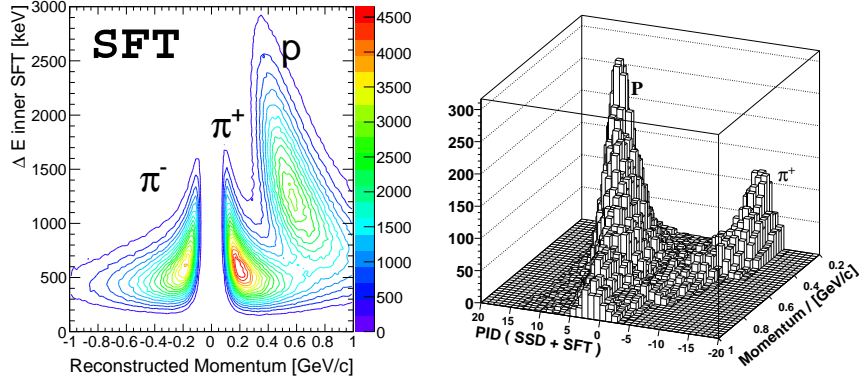


Figure 4: Left: PID-plane for one of the SFT layers. Right: SSD+SFT-combined PID values vs. momentum of tracks. A clean proton/pion separation is observed.

shown in Fig. 4. A clean separation between positively charged pions and protons is observed for momenta up to 600 MeV/c. The PID-planes of the other layers look very similar. The PD PID-planes show a pion/proton separation also for momenta greater than 600 MeV/c.

In an advanced PID-scheme, the different layers are combined and overall PID-values are calculated for each track in a logarithmic likelihood formalism. The distribution of PID-values vs. momentum obtained from combining SSD and SFT information is displayed in Fig. 4. With a PID-cut at 0, the pion contamination in the proton sample is about 0.1% with a proton efficiency of more than 99% for momenta smaller than 450 MeV/c. The pion contamination slowly rises to not more than 10% for momenta up to 1 GeV/c, where a proton efficiency of 50% can still be reached. More details about the detector performance are given in Refs. [6] and [7], in the latter in particular about the SSD calibration.

#### 4 First data analysis with the Recoil detector

The purpose of the Recoil detector is the tagging of exclusive events by identifying the recoiling target proton and particles from competing background channels. DVCS event candidates were selected by requiring a single track in the HERMES spectrometer that is the scattered beam lepton, a single neutral cluster in the calorimeter without an associated track and an energy deposition greater than 5 GeV, and  $Q^2 > 1 \text{ GeV}^2$ . From the kinematics of the lepton and the photon, the expected kinematics of the recoiling target proton in the DVCS process were calculated and compared to the kinematics measured by the Recoil detector. The result of the missing azimuthal angle  $\Delta\phi$  vs. missing momentum  $\Delta p$  is displayed in Fig. 5, where the bump at zero reveals a clear correlation of spectrometer and Recoil information.

Figure 5 also displays the squared missing mass distribution  $M_X^2$  from the 'traditional' DVCS analysis without Recoil detector [8]. The  $M_X^2$  distribution shows the expected elastic peak at around the squared proton mass. Mostly at higher values of  $M_X^2$ , processes in which the target proton is excited to a resonant state (e. g.  $\Delta^+$ ), and semi-inclusive processes contribute to the yield. The latter were estimated in a MC simulation to account for about

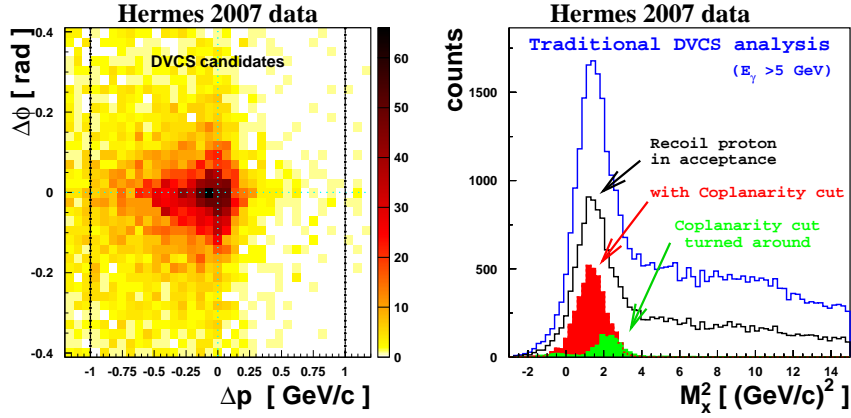


Figure 5: PRELIMINARY 2007 HERMES data of DVCS event candidates, including Recoil detector information. Left: missing azimuthal angle vs. missing momentum. Right: A first attempt to separate the elastic and resonant contributions.

3% in the traditional exclusive region  $-2.25 \text{ GeV}^2 < M_X^2 < 2.89 \text{ GeV}^2$  and were corrected for. The contribution from resonant processes was estimated from MC to be about 12%. As the underlying spin and charge asymmetries are unknown, the resonant contributions were considered part of the signal.

With data from the Recoil detector, there is a handle to separate the elastic and resonant contributions. The branching ratio of the  $\Delta^+$ -decay is  $1/3$  for  $\Delta^+ \rightarrow n\pi^+$  and  $2/3$  for  $\Delta^+ \rightarrow p\pi^0$ . In the presence of the  $\pi^0$ -meson, the proton from the  $\Delta^+$ -decay will fail a coplanarity cut. In Fig. 5, the filled dark gray (red) histogram displays the elastic DVCS contribution selected by imposing an upper cut on the missing azimuthal angle and in addition a cut on the ratio of calculated to measured transverse momenta of the recoiling proton. The filled light gray (green) histogram shows the selected resonant contribution that fails the coplanarity cut, with additional upper and lower cuts on the missing momentum. These results are very preliminary and the imposed cuts require further tuning on MC. Moreover, the PD will serve as  $\pi^0$  veto and will therefore be of significant importance for the separation of elastic and resonant processes.

A first analysis with Recoil detector data was also performed for exclusive vector mesons. The scattered beam lepton was detected in coincidence with two or three pions in the spectrometer ( $\pi^+\pi^-$  in case of the  $\rho^0$ -meson or  $\pi^+\pi^-\pi^0$  in case of the  $\omega$ -meson). The respective missing momenta were calculated. Figure 6 shows the 'traditional' missing energy distribution  $\Delta E = (M_X^2 - M_p^2)/(2M_p)$  [9], with  $M_p$  being the proton mass. An upper cut on the missing momentum selects the exclusive region at  $\Delta E \equiv 0$ . Requiring missing momenta greater than  $1 \text{ GeV}/c$  selects background. The selection of genuine exclusive events is expected to improve in particular in case of exclusive  $\omega$ -production, which comes along with large background contributions.

The 'one-dimensional' approach described above requires cuts on missing kinematic variables that were determined independently of each other. In the refined analysis, all kinematic parameters of all particles in a given event will be considered simultaneously in a fit, including their covariances.

## 5 Summary and outlook

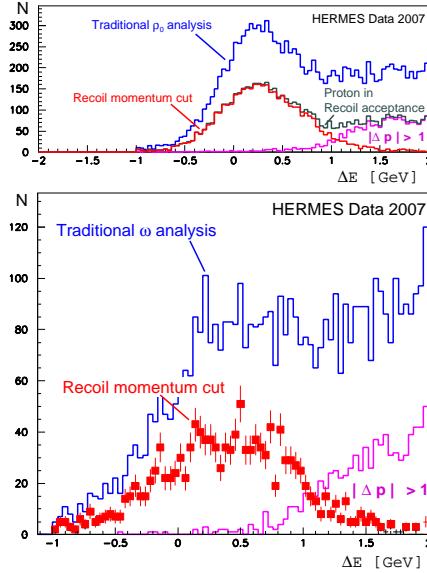


Figure 6: PRELIMINARY 2007 HERMES data of hard exclusive vector meson production with Recoil detector cut. Top: exclusive  $\rho^0$ . Bottom: exclusive  $\omega$ .

not detected. The tagging of spectator protons from deep-inelastic scattering on a deuterium target promises insight into the 'tagged structure function' ratio  $F_2^n/F_2^p(x_B)$  and DVCS on the neutron.

## References

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In 2006/07, HERMES collected data with the Recoil detector on unpolarized  $^1\text{H}$  and  $^2\text{H}$  targets. The statistics exceeds the one of the data taken between 1996 and 2005 [10]. The commissioning of the Recoil detector has reached the final stage and first analyses of DVCS and exclusive vector meson production including the new detector information have been carried out. The recoiling target proton and the particles of accompanying background processes can be detected, instead of having to rely on simulations. This will reduce systematic uncertainties due to background corrections.

Beam-helicity asymmetries for exclusive photon and meson production will be extracted. Of great interest is in particular the separation of the elastic and resonant azimuthal asymmetry amplitudes in DVCS, which was impossible prior to the detector upgrade. The extraction of beam-charge asymmetries will require more technical effort as the SSD was only operational for the HERA positron run.

Considering Recoil detector information will significantly improve the analysis of exclusive neutral pions, which suffers from large non-exclusive background if the recoiling proton is