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The HERMES Recoil detector: commissioning status and analyses prospects

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In order to allow for the detection of low momentum particles, originating from the scattering of a 27.6 GeV electron beam off hydrogen and deuterium at the HERMES experiment at DESY, a dedicated Recoil detector was installed. It consisted of a silicon strip detector, located inside the beam vacuum, a scintillating fiber tracker and a photon detector. The full detector assembly is mounted inside a 1 T super-conducting solenoid and is able to detect pions and protons with momentum from 0.090 GeV/c up to 1.40 GeV/c in a large azimuthal acceptance. The Recoil detector will allow the measurement of exclusive reactions in HERMES like deeply virtual compton scatttering, and exclusive meson productions with minimal background levels and excellent precision. Furthermore, tagged neutron structure function can be measured via the detection of spectator protons in electron scattering off deuterium.

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1. Introduction

Generalized Parton Distributions (GPDs) provide a unified three-dimensional picture of nucleon structure. They deliver a simultaneous description of transverse position and longitudinal momentum distributions of partons, subsuming both elastic form factors and forward parton distribution functions [1]. Moreover, GPDs offer a way to access the total angular momentum carried by partons in the nucleon [2]. The behavior of GPDs can be constrained by measurements of hard exclusive leptoproduction of a real photon (Deeply Virtual Compton Scattering, DVCS) or a meson in processes that leave the target intact. Deeply virtual Compton scattering has been analyzed at the HERMES experiment at DESY in Hamburg. There a 27.6 GeV electron or positron beam was scattered off a fixed gaseous hydrogen, deuteron or heavier target. Initially, due to the forward geometry of the spectrometer, it was not possible to detect the low-momentum recoiling protons, but only the scattered electron and the photon. The DVCS processes were then selected by reconstructing the missing mass of the proton. That method suffered from sizable background contributions, which can be reduced now down to $\sim 1\%$ using the Recoil detector to directly measure the recoiling protons.

It is well-known that the structure functions of the nucleons are altered when these nucleons are embedded in a nuclear environment. For high values of x (the fraction of the nucleon's momentum carried by the struck quark), this difference is known as the EMC effect [3]. No unambiguous explanation for the origin of the EMC effect is available today [4], although there are various theoretical models [5] that are capable to describe it. The validity of such models can be studied by means of the measurement of tagged structure functions of deuterium in semi-inclusive reactions [6]: $e+D \to e+p+X$. This kind of reactions are accessed via detecting or tagging the spectator proton and the scattered electron. In addition, one of the most interesting open questions about the behavior of the structure functions is what happens at the extreme kinematic limit $x \to 1$, where nearly all of the nucleon momentum is carried by a single quark. This limit is dominated by the relative contributions of the u and d valence quarks. Again, there are several models of quark dynamics in nuclei which can be studied by means of the behavior of the ratio of the neutron and proton structure functions F_2^n/F_2^p at high x. Although F_2^p is well-known, F_2^n can only be deduced using nuclear targets which for inclusive experiments requires models for the nuclear physics and a subtraction of the F_2^p background. Provided that the Recoil detector is able to detect spectator protons in electron scattering off deuterium, HERMES will be able to measure the neutron structure function in an almost model-independent way [7].

2. The HERMES Recoil detector

The experimental setup of HERMES with Recoil detector (years 2006-2007) consisted of a longitudinally polarized 27.6 GeV electron beam (HERA) to scatter off unpolarized hydrogen and deuterium targets. The Recoil detector was compounded of several layers of tracking devices around the target cell and surrounded by a superconducting solenoidal magnet providing an integrated field strength of 1 Tesla (Fig. 1).

The innermost component, the Silicon Strip Detector (SSD), is compounded of 16 double-sided sensors arranged in two parallel layers around the target cell. The whole system is located inside the accelerator vacuum five centimeters close to the electron beam, in such a way that the amount of material between the interaction point and the first active sensor is minimized and protons with a momentum down to 0.090 GeV/c can be detected. 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°. The purpose of both SSD and SFT is to provide space-points for the reconstruction of tracks from charged particles, in case of the SSD down to momentum as low as 90 MeV/c. The SFT covers a momentum range of 250-1400 MeV/c for protons. The azimuthal ϕ-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 $\pm 45°$. The purpose of the PD is the detection of photons from resonance decays (like $\Delta^+ \to p\pi^0 \to p\gamma\gamma$) and PID for momentum higher than 600 MeV/c.

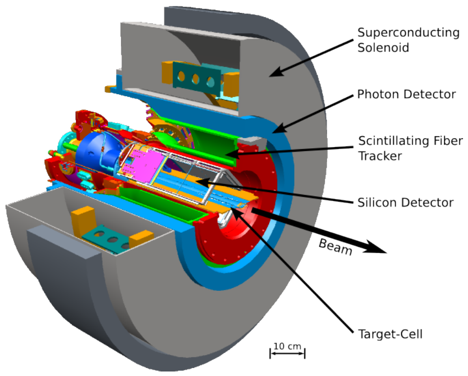

Figure 1: Schematic drawing of the HERMES Recoil detector.

Space-points in the SSD or the SSD+SFT are combined in order to form tracks. The momentum of the low-energy protons (90-145 MeV/c) that are stopped in the SSD are determined via the sum of their energy deposits. Momentum of charged particles that reach the SFT are reconstructed by bending in the magnetic field using SSD and SFT space-points, taking energy losses and multiple scattering into account. For protons, the energy deposition ΔE in the SSD is included in the momentum reconstruction in addition to the coordinate information from space-points in the SSD, or SSD+SFT. In this procedure, the dependence of ΔE 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. 2).

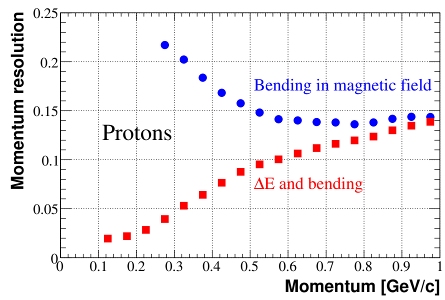

Figure 2: Momentum resolution vs. momentum for protons.

Energy depositions in different sub-detectors are combined together (using a logarithmic likelihood formalism) to provide PID. The pion contamination in the proton sample is about 1% with a proton efficiency of more than 99% for momentum smaller than 450 MeV/c, slowly rising till 10% for momentum 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. [8] and [9].

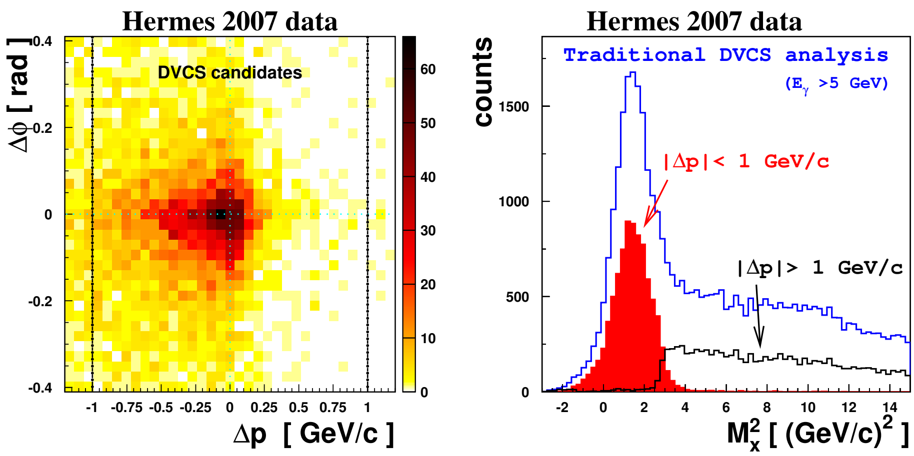

Figure 3: PRELIMINARY 2007 HERMES data of DVCS event candidates, including Recoil detector information. Left: missing azimuthal angle vs. missing momentum. Right: M_X^2 from the 'traditional' DVCS analysis (in blue) and with a cut in missing momentum (red).

3. Analyses prospects

3.1 Exclusive reactions

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 electron, a single neutral cluster in the calorimeter without an associated track and an energy deposition greater than 5 GeV, and $Q^2 > 1$ GeV^2. From the kinematics of the electron 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 Δp is displayed in Fig. 3 (left), where the bump at zero reveals a clear correlation of spectrometer and Recoil information.

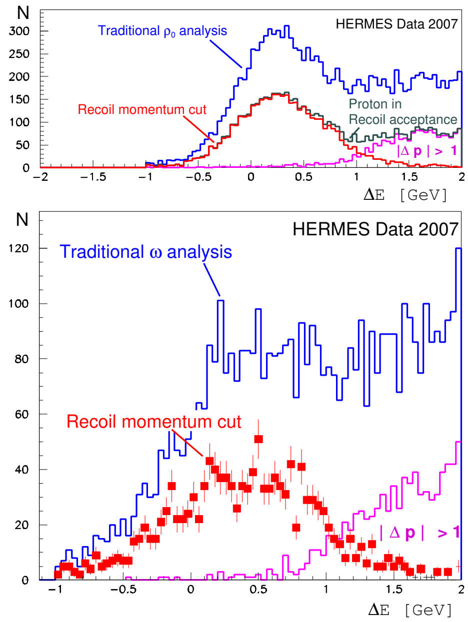

Figure 4: PRELIMINARY 2007 HERMES data of hard exclusive vector meson production with Recoil detector cut. Top: exclusive ρ^0. Bottom: exclusive ω.

Figure 3 (right) also displays the squared missing mass distribution M_X^2 from the 'traditional' DVCS analysis without Recoil detector [10]. This 'traditional' method suffers from background contributions. A small contribution, $\sim 3\%$, originates from semi-inclusive processes, while a larger contribution, $\sim 12\%$, is due to associated production, where the proton is excited to a Δ^+-resonance. This last one decays into a proton and a π^0 or a neutron and a π^+. With the help of

Recoil detector the total background contribution can be reduced down to $\sim$1% simply by imposing a cut in missing momentum of $|\Delta p| < 1$ GeV/c (Fig. 3).

A first analysis with Recoil detector data was also performed for exclusive vector mesons. The scattered beam electron was detected in coincidence with two or three pions in the spectrometer ($\pi^+\pi^-$ in case of the ρ^0-meson or $\pi^+\pi^-\pi^0$ in case of the ω-meson). The respective missing momentum were calculated. Fig. 4 shows the 'traditional' missing energy distribution $\Delta E = (M_X^2 - M_p^2)/(2M_p)$ [11], 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 momentum greater than 1 GeV/c selects background. The selection of genuine exclusive events is expected to improve in particular in case of exclusive ω-production, which comes along with large background contributions.

3.2 Tagged neutron structure function

The extraction of tagged structure function of the neutron involves the detection of the spectator proton in coincidence with the scattered electron off deuterium. The idea is to 'tag' DIS interactions which actually occurred in the neutron by means of an efficient selection of these spectator protons.

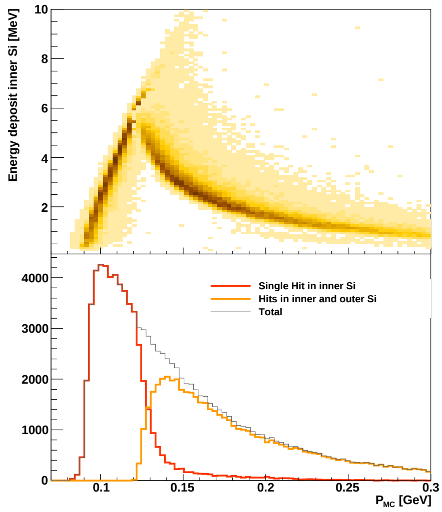

Figure 5: Spectator protons in the Recoil detector. Top: Energy deposition in inner SSD as a function of momentum. Bottom: Accessible spectator spectrum with Recoil detector (30%).

According to the model proposed in Ref. [12] about the deuterium spectral function, the spectator spectrum is expected to be at low-energy and isotropically distributed. Based on a MC simulation of this simple spectator model, feasibility studies are on going by the collaboration: Provided that the Recoil detector is able to measure protons with momentum above 90 MeV/c, approximately 30% of the spectator spectrum will be accessible (Fig. 5). In regards with the selection of spectator events, it has been already addressed in several theoretical works [6, 7] and other experimental proposals for JLAB (BoNuS [13] and CLAS [14]), that it is possible to select a clean spectator sample by constraining the proton to low momentum and very backward scattering angles. It is argued there that any possible background contribution from target fragmentation would be strongly suppressed. The approach adopted here for the event selection can be thought as a generalization of the previous method. The idea is to study and exploit different kinematics of spectator protons with respect to any possible background. Assuming the simple spectator model quoted above, a full simulation of the DIS process on deuterium has been developed with the addition of these spectators every time that the interactions happen in the neutron. In such a way, kinematic distributions of spectator and non-spectator events have been obtained, suitable to perform a signal recognition analysis. In addition to proton momentum and scattering angle, other kinematic variables which involve correlations with the scattered electron have been used. Using the facilities provided by the toolkit for multivariate data analysis in ROOT (TMVA [15]), advanced pattern recognition algorithms have been applied to our particular problem of signal selection. We remark here the performance achieved using a Multi-layer Perceptron (MLP). Fig. 6 shows normalized distributions for spectator (blue histogram) and background (red hatched histogram) events. A selection cut of MLP>0 reduces the background levels below 3%, while keeping signal efficiency around 75%. An estimate of the actual size of the background contribution can also be made by measuring the rate of protons produced from a hydrogen target and wrongly tagged as 'spectators' by our selection criteria.

4. Summary and outlook

In 2006/07, HERMES collected data with the Recoil detector on unpolarized hydrogen and deuterium targets. 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. This will reduce systematic uncertainties due to background corrections. The Recoil detector will allow the tagging of spectator protons from DIS off deuterium. The study of this reaction will provide important insights into the neutron structure function.

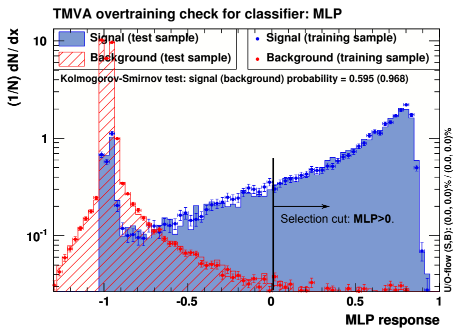

Figure 6: Response of a MLP in spectator selection. Signal events are drawn in blue, while background events are in hatched red. Both distributions are normalized to the same quantity.

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