Abstract

In order to allow for the detection of low momentum particles, originating from the scattering of a 27.6 GeV lepton beam off a fixed gaseous target at the HERMES experiment at DESY in Hamburg (Germany), a dedicated recoil detector was installed. It consists of a silicon strip detector, located inside the beam vacuum, a scintillating fiber tracker and a photon detector, around a 150 mm long target cell made out of a 75 µm thick aluminum tube. The full detector assembly is mounted inside a 1 T super-conducting solenoid and is able to detect protons and pions with momenta up to 1.40 GeV/c and photons in the region surrounding the target cell. The detector has been operational from February 2006 until June 2007. The commissioning and performance of the detector are presented in this paper.

Key words: silicon strip detector in beam vacuum, scintillating fiber tracker, momentum reconstruction, particle identification

1. Introduction

The nucleon spin can be decomposed into a contribution from the total angular momentum of the gluons, the orbital angular momentum of the quarks and the spin of the quarks [1]. This last quantity amounts to \( \sim 30\% \) [2], while the two other contributions so far remain unknown. A possibility to access the orbital angular momentum of quarks is provided by the Ji relation [1], which relates two so-called generalized parton distributions (GPDs) of a certain quark flavor with the total angular momentum of that quark. Such GPDs are a generalization of the usual parton distributions: not only do they describe the distribution of the quark longitudinal momentum, but in addition they provide information about the transverse position of the partons [3]. Experimentally, knowledge about these GPDs can be obtained by analyzing deeply virtual Compton scattering. In this process a quark in the nucleon interacts with a beam lepton through the exchange of a virtual photon. After the absorption of this photon, the quark emits a real photon and returns back to the nucleon, leaving it intact, yet with a different momentum.

Deeply virtual Compton scattering has been analyzed at the HERMES experiment at DESY in Hamburg. Here a 27.6 GeV electron or positron beam was scattered off a fixed gaseous hydrogen, deuterium or heavier target. The forward geometry of the spectrometer did not allow to detect the low-momentum recoil protons. Initially, only the scattered lepton and the photon were detected. The deeply virtual Compton process was then selected by reconstructing the missing mass of the proton. This 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 \( \Delta^+ \)-resonance. This last one decays into a proton and a \( \pi^0 \) or a neutron and a \( \pi^+ \). The total background contribution can be reduced down to \( \sim 1\% \) by detecting the recoiling protons directly, as well as charged pions and photons. This was made possible in 2006 by the installation of a recoil detector around the target region. The detector was placed as close as possible to the target as the above mentioned Ji relation is valid in the limit of momentum transfer to the nucleon going to zero.

2. The recoil detector

The recoil detector consists of three active detector components: a silicon strip detector (SSD) and a scintillating fiber tracker (SFT) to detect protons within a momentum range of 0.125 to 1.40 GeV/c and a photon detector (PD) to detect the photons originating from the \( \Delta^+ \)-resonance. The SSD and SFT are able to distinguish protons from positive pions with momenta lower than 0.6 GeV/c. For higher momenta, the PD will contribute to the particle identification. All of these detectors are surrounded by a 1 T superconducting solenoid. A schematic drawing of the recoil detector is given in Fig. 1.
2.1. The silicon strip detector

The inner component, the silicon strip detector, is located inside the beam vacuum, around the 75 µm thick aluminum target cell. In this way, the amount of material between the interaction point and the first active sensor is minimized and protons with a momentum down to 0.125 GeV/c can be detected. The SSD is composed of four modules, each consisting of two layers of silicon sensors, placed in diamond-shape around the target. One layer is formed out of two 300 µm thick double-sided silicon micro-strip sensors, placed next to each other and each covering an area of 99x99 mm$^2$. The strip pitch is 758 µm and the strips on each side of the sensor are placed perpendicular with respect one to another to allow for a three-dimensional space point reconstruction.

The strips are read out by HELIX chips which have a dynamic range of 1-10 MIPs. The dynamic range needed to detect minimum ionizing pions, as well as very low momentum protons ranges up to 70 MIPs. This increase in dynamic range is made possible by integrating a charge division network to the readout of the strips. Each strip is connected to two HELIX chips: to one directly and to the other through a 10 pF capacitor. This coupling ensures that the chip directly coupled to the strip collects 10 times more charge than the one connected via the coupling capacitor. After additional adjustment of some timing related chip parameters, a total dynamic range of 1-70 MIPs is covered. The readout chips and on-board electronics are mounted on the circuit board (see Fig. 1 hybrid), also located inside the vacuum chamber and actively cooled with -8° C ethanol.

2.2. The scintillating fiber tracker

The scintillating fiber tracker is located around the SSD, outside the beam vacuum. It consists of two concentric cylinders of each four layers of scintillating fibers. The first two layers have their fibers parallel to the beam line, while the outer two layers are positioned under a 10° stereo angle. The fibers are 1 mm in diameter, 25 cm long and read out by multi-anode PMTs.

2.3. The photon detector

The photon detector is formed out of three layers of tungsten-scintillator. The inner layer has its scintillating strips parallel to the beam pipe, while the outer two layers have their strips under an angle of ±45°. The strips are 2 cm wide, 1 cm thick and 28 cm long. The tungsten covers 3.4 radiation lengths, providing a 85% probability for the photons to shower. Wave-length-shifters, glued along both sides of each strip, bring the scintillating light to clear light guides, which are read out by multi-anode PMTs.

3. Performance of the recoil detector

Data taking with the recoil detector started in February 2006, with an e$^-$-beam and only the SFT being operational. A month later, problems with the target cell forced the dismantling and repair of the SSD. In September 2006, data taking with an e$^+$-beam and all detector components operational could start and went on with a 95% efficiency until the shutdown of the storage ring in June 2007. During these 10 months, a total of 28 M deep-inelastic scattering events were collected with a hydrogen target and 7 M with a deuteron target.

3.1. Alignment

The first physics channel observed by the recoil detector, even before any calibration, were protons originating from elastic e-p scattering. Requiring exactly one lepton with a momentum above 25 GeV/c in the forward spectrometer, made the signal from the scattered proton visible in each of the recoil detector components. This process was later used for the alignment of the recoil detector as a whole with respect to the forward spectrometer.

The relative alignment of the individual components was performed using signals from cosmic particles and from tracks originating from the interaction of the lepton beam with the proton target. Also the beam position reconstructed by the recoil detector and by beam position monitors installed at HERMES were checked to be in agreement with each other.

3.2. Calibration

The calibration of the SFT and PD was straightforward, using signals from minimum-ionizing pions. For the SSD a more elaborate procedure was necessary.

First of all, a correction for drifting pedestals was needed. Certain strips suffered from a strong RF coupling with the beam and showed a pedestal increasing with decreasing beam current. To correct for this, pedestal measurements were collected every two hours during data taking.

After pedestal subtraction and common mode noise correction, which is based on the signal of the 32 first channels of a chip, an increase of pedestal width with chip channel number was still visible. The reason for this
broadening could not be traced down with certainty but it is believed that the explanation lies in the coupling to the output cables inside the beam vacuum. To correct for this behavior, every eight strip was read out in so-called unsparsified mode, meaning that no threshold was applied for the readout of this strip. In a next step, these data were then used in a spline fit applied event by event. Finally, a correction for cross talk which amounts to up to \( \approx 16\% \) made the data ready for calibration.

The actual calibration of the SSD took place in two steps. The first one consists of the calibration of the high gain readout channel, which covers energy depositions lower than 1 MeV. Taking into account for each strip individually the correct momentum and path length distribution, ADC spectra from data were compared with energy distributions from a GEANT4 simulation for signals originating from negative pions with a momentum between 0.2 and 0.5 GeV/c. This method allows each strip to be calibrated individually. When extrapolating the obtained calibration to signals with a higher energy deposition, it became clear that the response is not linear. In addition, a non-linearity of the different sensor sides was observed. Based on the high-gain calibration results, the energy deposition in one sensor side, versus the energy depositions in all the other sensor sides belonging to the same quadrant half, were then simultaneously fit to a curve obtained from a GEANT4 simulation. This procedure does not allow for an individual calibration of each strip due to the limited statistics. Previous test measurements show that the variation in gain from one channel to another does not exceed 5\%, thus making this method of calibration adequate for the analysis of deeply virtual Compton scattering.

### 3.3. Momentum reconstruction

The momentum reconstruction of protons varies with the proton momentum. For very low momentum protons, stopped in a SSD layer, the total energy deposition in the SSD layer(s) is used to determine their momentum. For higher momentum protons, punching through the outer SSD layer, the energy loss is located in the \( 1/\beta^2 \) region of the Bethe-Bloch curve. This strong dependence of energy loss with momentum, provides an accurate determination of the momentum of protons from their energy deposition. For even higher momentum protons, above 500 MeV/c, and pions in all momentum ranges, a reliable momentum reconstruction is provided by the bending in the magnetic field, as determined from the up to four space points in the SSD and SFT. The momentum resolution versus momentum for protons and pions is given in Fig. 2. The circles represent the momentum resolution for pions, the triangles show the resolution for proton momenta reconstructed from the bending in the magnetic field, and the squares represent the resolution when including the information from the energy deposition in the SSD.

### 3.4. Particle identification

After alignment and calibration, it is then possible to extract particle identification information from the energy deposition versus momentum in each of the three detector components. This can be seen in Fig. 3 for one layer in the SSD (left), SFT (middle) and PD (right). The negative momentum represents negatively charged particles, mostly negative pions, while on the right side, one can clearly distinguish protons from positively charged pions for momenta up to 600 MeV/c in the SSD and SFT and for higher momenta in the PD.

**Figure 3:** Energy deposition versus momentum as obtained from data.

### Conclusion

The three detector components of the recoil detector have been aligned and calibrated. The momentum reconstruction is successfully performed based on the energy deposition in the silicon strip detector and the bending of the charged protons and pions in the magnetic field. The energy distribution versus momentum allows then to distinguish protons from pions. A large amount of data has been collected on a hydrogen and deuteron target.

A further fine tuning of particle identification and event selection criteria will then allow for the analysis of deeply virtual Compton scattering with a background contribution reduced down to \( \sim 1\% \).

**References**

