The total angular momentum of quarks is linked to two Generalized Parton Distributions (GPDs) via the Ji relation. Theoretically, the cleanest way to access these GPDs is provided through the analysis of Deeply Virtual Compton Scattering (DVCS). In this process, a lepton interacts with a quark in the nucleon via the exchange of a virtual photon. After the absorption of this virtual photon a real photon is emitted, leaving the nucleon intact. The HERMES experiment has been analyzing DVCS, detecting the scattered lepton and the photon in the forward spectrometer and reconstructing the recoil nucleon via its missing mass. The obtained DVCS sample, contains 16% background. In 2006 a new detector, the recoil detector, was installed around the target region allowing for the detection of the recoil proton. The analysis of DVCS with the recoil detector will reduce the background contribution to ∼1%.

1 Introduction

To understand the different contributions to the spin of the nucleon, the intrinsic spin and orbital angular momentum of the quarks and gluons have to be taken into account. Measurements of inclusive Deep-Inelastic Scattering (DIS) have taught us that the quark spin is responsible for ∼30% [2] of the nucleon spin. The contribution of the quark orbital angular momentum remains unknown so far. A possibility to access this contribution is provided through the Ji relation [3], which relates the total angular momentum of a quark $J^q$ to two quark Generalized Parton Distributions (GPDs) $H^q$ and $E^q$:

$$J^q = \lim_{t \to 0} \frac{1}{2} \int_{-1}^{1} dx x [H^q(x, \xi, t) + E^q(x, \xi, t)],$$

with $t$ being the momentum transfer to the nucleon, $x$ the average longitudinal momentum fraction of the struck quark and $2\xi$ the longitudinal momentum fraction transfer to that quark. The GPD $H^q(x, \xi, t)$ represents the unpolarized nucleon helicity non-flip GPD, while $E^q(x, \xi, t)$ represents the unpolarized nucleon helicity flip GPD. Generalized parton distributions are the probability amplitude for emitting a quark with longitudinal momentum fraction $x + \xi$ and absorbing a quark with longitudinal momentum fraction $x - \xi$. These distributions are a generalization of the known parton distributions. Integrating them over $x$, one obtains the elastic form factors. As such, GPDs describe the longitudinal momentum distribution of the quarks inside the nucleon and the distribution of their position transverse to the nucleon momentum [4].

Theoretically, the cleanest way to gain knowledge about GPDs is provided through the study of Deeply-Virtual Compton Scattering (DVCS). In this process, a lepton interacts with a quark inside the nucleon through the exchange of a virtual photon. After absorption of the photon by the quark, this emits a real photon, leaving the nucleon intact. At HERMES,
the cross section for DVCS is around 2 orders of magnitude smaller than that for Bethe-Heitler (BH), which has exactly the same initial and final state as DVCS, but where the real photon is emitted by the incoming or scattered lepton and not by the quark. It is through the interference term of these two processes, by determining azimuthal asymmetries, that HERMES has the possibility to access GPDs.

In the HERMES experiment a 27.6 GeV/c longitudinally polarized electron or positron beam is scattered off a fixed transversely or longitudinally polarized or unpolarized gaseous hydrogen or deuterium target or unpolarized heavier target. For the reconstruction of DVCS events, the scattered lepton and the emitted photon are detected by the forward spectrometer. Due to the low momentum and angular distribution of the recoiling nucleon, it cannot be detected but is reconstructed via its missing mass. The obtained DVCS sample, contains a 4% background contribution from semi-inclusive deep-inelastic scattering and a 12% contribution from associated Bethe-Heitler, in which the nucleon does not stay in its ground state but is excited to a $\Delta$-resonance [5]. The asymmetries are corrected for the first background contribution but not for the second. To reduce the contribution from the background processes a new detector, the recoil detector, was installed in the beginning of 2006 around the target region, allowing for a reduction of the background to $\sim 1\%$. Data taking with this detector was ongoing until June 30th 2007, using an unpolarized hydrogen and deuterium target and a longitudinally polarized electron and positron beam.

2 The recoil detector

To satisfy the Ji relation one has to take the limit of the momentum transfer to the nucleon to zero, meaning that one wants to detect protons as low as possible in momentum. As about two-thirds of $\Delta^+$-resonances decay into a proton and a neutral pion (which then decays into two photons), while one-third decays into a neutron and a positive pion, the identification of pions and photons, in addition to the proton, is sufficient to identify associated Bethe-Heitler events and improve the exclusivity of the measurement. These requirements lead to the construction of the recoil detector as consisting of a Silicon Strip Detector (SSD), Scintillating Fiber Tracker (SFT) and a Photon Detector (PD) located around a 150 mm long target cell made out of a 75 $\mu$m thick aluminum tube, as can be seen in Figure 1. The whole is mounted inside a 1 Tesla superconducting solenoid.

The silicon strip detector is located within the beam vacuum, to allow for the detection of very low momentum particles. It consists of 8 modules, placed in diamond shape around the target cell. A module is made out of 2 double-sided silicon sensors, containing each $2 \times 128$ strips, with a thickness of 300 $\mu$m. The strips have a pitch of 758 $\mu$m and are placed perpendicular to each other on each side of the sensor to allow for a 3-dimensional space point reconstruction. Applying capacitive charge division, each strip is read out twice: once via a low gain readout channel, allowing for the detection of low momentum protons, and once via a high gain readout channel, allowing for the detection of higher momentum protons and pions. In this way a dynamic range from 1 to 70 MIPs is covered. The readout chips and on-board electronics are mounted on the circuit board (see Figure 1 hybrid), located inside the vacuum chamber and actively cooled with -8°C ethanol. From the energy deposition in the silicon strip detector, protons with momenta between 135 and 450 MeV/c can be reconstructed.

The scintillating fiber tracker is formed of 2 concentric cylinders, each containing 2 layers of scintillating fibers parallel to the beam direction and 2 layers under an angle of 10°,
providing two space points coordinates for tracking. The fibers are 1 mm in diameter and read out by multi-anode PMTs. They allow for a pion and proton momentum reconstruction between 250 and 1200 MeV/c using the bending of the charged particles in the magnetic field.

The third active detector component is the photon detector. Its main purpose is the detection of photons and, if both decay photons are detected, the reconstruction of neutral pions. It consists of three sandwich layers of tungsten-scintillator material. The inner layer has its scintillating strips parallel to the beam pipe, while the two outer layers have their strips under an angle of +45/-45° with respect to the beam pipe. The strips are 2 cm wide, making a rough space point reconstruction possible. The scintillating light is transported over wave-length shifters and clear light guides to multi-anode PMTs.

Proton/pion separation is provided by the silicon strip detector and the scintillating fiber tracker for proton momenta below 700 MeV/c. Starting from momenta of 650 MeV/c, the photon detector also contributes to the charged particle identification.

3 Detector performance

The first physics channel seen by the recoil detector was elastic lepton-proton scattering. Requiring exactly one lepton in the forward spectrometer with momentum greater than 25 GeV/c, a clear signal originating from the elastic protons was visible in the 3 detector components. These elastic events will be used to align the recoil detector as a whole with the forward spectrometer.

After testing the internal alignment of the scintillating fiber tracker, as obtained in a test beam prior to the detector installation, the silicon strip detector and photon detector were aligned with respect to the scintillating fiber tracker. The residuals for the SFT are 280 µm, compared to 220 µm for a perfectly aligned Monte Carlo simulation, while for the SSD residuals of 0.26 strip units are obtained. Also, the beam position as reconstructed by the recoil detector and by the beam position monitors installed at HERMES were compared with each other. The values obtained from both measurements are in agreement with each other [1].

As mentioned above, the momentum reconstruction of charged particles is performed by
the silicon strip detector and/or the scintillating fiber tracker, depending on the momentum range and type of the particles.

For protons stopped in the silicon strip detector, the sum of the energy depositions in each layer allows for the momentum reconstruction. The momentum of faster protons, punching through all of the SSD layers but not reaching the SFT, is reconstructed from the energy loss versus path length. For particles reaching the SFT, the momentum reconstruction is obtained from the bending in the magnetic field. In Figure 2 the momentum resolution is shown as a function of the momentum generated in Monte Carlo. The red circles represent the momentum resolution for pions. The green squares correspond to reconstructed protons taking energy deposits in the SSD into account, while the blue triangles are for proton momenta reconstructed from the bending in the magnetic field.

After the alignment and a preliminary calibration of the detector components, the energy deposition in the SSD and SFT versus momentum allow for a first proton/pion separation. This is shown in Figure 3 for the SFT, where on the left side one distinguishes negative pions and on the right, a clear separation between protons and positive pions is visible.

First data taking with the recoil detector started in February 2006, using an electron beam. During this period the SFT was completely operational. From July 2006 on, the electron beam was replaced by a positron beam and starting from September of that year, all recoil detector components were operational. Data taking was stopped on June 30th 2007. In total 3 (0.8) million DIS events on hydrogen (deuterium) with electron beam and 28 (7) million DIS events on hydrogen (deuterium) with positron beam and a fully operational recoil detector were collected. This large amount of data taken with the recoil detector will allow the suppression of the background contribution to the DVCS sample down to ~1% and the refinement of the DVCS results obtained from data taken prior to the recoil detector installation.

References

[1] Slides: [link to slides]


