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The HERMES Recoil Detector

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Abstract. The HERMES Collaboration installed a new Recoil Detector to upgrade the existing spectrometer to study hard exclusive processes which provide access to generalised parton distributions (GPDs) and hence to the orbital angular momentum of quarks. The HERMES Recoil Detector mainly consists of three components: a silicon detector surrounding the target cell inside the beam vacuum, a scintillating fibre tracker and a photon detector with three layers of tungsten and scintillator bars in three different orientations. All three detectors are located inside a solenoidal magnet which provides a 1 T longitudinal magnetic field. The Recoil Detector was installed in January 2006 and data taking will last until July of 2007.

PACS. 29.30.Aj Charged-particle spectrometers: electric and magnetic – 14.20.Dh Protons and neutrons – 29.40.Wk Solid-state detectors – 29.40.Mc Scintillation detectors

1 Introduction

HERMES is one of the three experiments at HERA, and uses the 27.5 GeV longitudinal polarised electron/positron beam and a polarised or unpolarised gas target internal to the storage ring to explore and disentangle the different contributions to the spin of the nucleon. The HERMES spectrometer [1] is a forward-angle instrument with a dipole magnet providing an integrated field of 1.3 Tm. The spectrometer consists of two identical halves located above and below the electron/positron beam pipe, and has an angular acceptance of ±170 mrad horizontally, and ±(40–140) mrad vertically. Three drift chambers in the front region, three multi-wire-proportional chambers (MCs) inside the magnet and four drift chambers in the backward region compose the tracking system of the spectrometer. The track reconstruction is based on a pattern-matching algorithm and momentum look-up method [1]. The average angular resolution is better than 0.6 mrad and the average momentum resolution is better than 2%. These resolutions degraded somewhat after the insertion of the ring imaging Cherenkov detector (RICH) in 1998 with more materials in the path of the particles. Particle identification (PID) is provided by a lead-glass calorimeter, a pre-shower detector, a transition radiation detector, and a RICH. The PID system provides electron/positron identification with an average efficiency of 98–99% and a hadron contamination of less than 1%. The trigger for the scattered electron/positron is formed by requiring hits in three scintillator hodoscopes together with energy deposited in two adjacent columns of the calorimeter.

Due to the limited acceptance and energy and momentum resolutions of the HERMES spectrometer, the HERMES Collaboration installed a new Recoil Detector in January 2006, whose main purpose is to study hard exclusive processes by detecting the recoiling particles. These hard exclusive processes provide access to the generalised parton distributions (GPDs) [2]. GPDs offer a possibility to determine the orbital angular momentum of quarks, and can be accessed by studying deeply virtual Compton scattering (DVCS) [3]. In the reaction $ep \rightarrow e'\gamma p$, the DVCS process interferes with the Bethe-Heitler process where the incoming or outgoing electron/positron radiates a hard real photon in the Coulomb field of the nucleon. This interference leads to measurable beam spin and beam charge asymmetries around the virtual photon direction.

2 The Recoil Detector

The energy resolution for the electrons/positrons and photons of the existing HERMES spetrometer is not sufficient to select a clean sample of the exclusive DVCS process, and it has no acceptance to detect recoiling particles under large angles. The Recoil Detector [4] has been designed to upgrade the HERMES spectrometer to mainly study this exclusive DVCS process. Its objectives are positive identification of recoiling protons, measuring the momenta of these particles to improve the resolution of the transverse momentum and rejecting non-exclusive background events.

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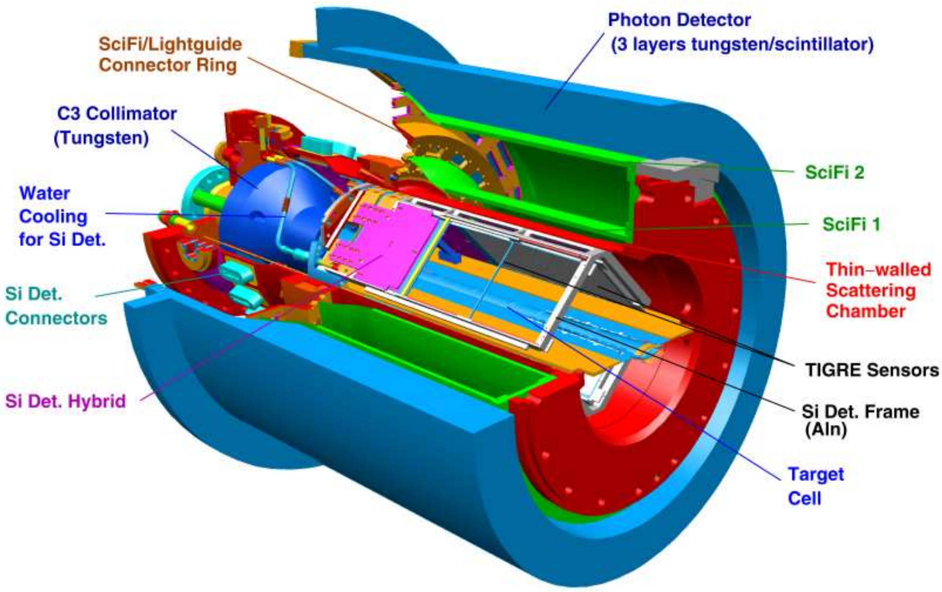

Fig. 1. Schematic overview of the HERMES Recoil Detector.

The Recoil Detector shown in fig. 1 consists of three main components: a silicon strip detector surrounding the target cell inside the beam vacuum, a scintillating fibre tracker and a photon detector consisting of three layers of tungsten and scintillator bars. All three detectors are placed in a longitudinal magnetic field of 1 T generated by a solenoidal magnet. An additional collimator (C3) was installed in the front part of the target chamber to suppress the beam-related background in the Recoil Detector. The fibre tracker and the silicon detectors are optimized to detect recoiling protons from hard exclusive processes. They cover a momentum range around $0.1\,\mathrm{GeV}/c$ to $1.4\,\mathrm{GeV}/c$ and provide the particle identification properties to discriminate protons from pions. The photon detector is used for particle identification of high-momentum particles and for background rejection of neutral particles. All three detectors provide a measurement of the deposited energy of the traversing particles. Momentum determination for low-momenta particles stopping inside the silicon detector is performed using the total energy deposition in both layers of silicon in combination with the reconstructed track direction. The momentum of fast particles is determined by their bending in the longitudinal magnetic field.

2.1 The silicon strip detector

The silicon strip detector (SSD) measures the momentum of recoiling protons in the range 135–400 MeV/c via their energy deposition and also provides space points for the tracking of minimum ionising particles (MIPs). It consists of 16 double-sided silicon sensors based on the TTT [5] design of Micron Semiconductors, with 128 strips per side and a strip width of $758\,\mu$m. The sensors measure $99 \times 99\,\mathrm{mm}^2$ with a thickness of $300\,\mu$m and are arranged around the target cell in two layers of four modules, each containing two sensors. The necessary high dynamic range of up to 70 MIPs is established by a charge division readout where the signal is split into a high-gain and a low-gain path. Both signals are read out by Helix 3.0 readout chips. A signal-to-noise ratio of 6.5 for a minimum ionising particle could be reached at test beams with an efficiency of close to 99%. The sensors have been calibrated with low-energy protons at the Erlangen tandem accelerator to better than 2%.

2.2 The scintillating-fibre tracker

The scintillating-fibre tracker (SFT) measures the particles of higher momenta above 250 MeV/c using two barrels consisting of 4 layers of 1 mm Kuraray SCSF-78 scintillating fibres each. A stereo angle of 10° between each two adjacent layers of each barrel allows space point reconstruction. Each layer was assembled in modules such that single modules with defects could have been discarded. The diameters of the barrels are 220 mm and 370 mm, respectively. The signals of the fibres are read out via 3.5 m long light guides of Kuraray clear fibres coupled to Hamamatsu H-7548 64-channel PMTs. The readout of the SFT is based on front-end cards using GASSIPLEX chips which are hold-and-sample chips. Due to this fact, the readout integrates over 6 adjacent HERA bunches, which would increase the random background by the same factor. In order to avoid this, the dynode 12 signals of the PMTs are used to extract additional fast-timing information to discriminate between different HERA bunches. The cylinders are built from 72 SciFi strips as self-supporting structures to minimize the material transversed by the particles. A gain monitoring system (GMS) was built to monitor changes in the response of the PMTs. The momenta of particles are measured through the deflection of the tracks in the solenoidal 1 T longitudinal magnetic field. From a GSI test experiment with a mixed proton and pion beam at GSI/Darmstadt, the detection efficiency of the SFT modules for a minimum ionising particle using a threshold of 1 photon electron has been determined to be $\approx 99\%$, efficiencies for protons even exceed this value. In addition to the tracking information the energy deposition in the fibres will be used to obtain pion/proton particle identification up to about $800\,\mathrm{MeV}/c$.

2.3 The photon detector

The photon detector consists of 3 layers of scintillator bars with tungsten as a converter. The scintillators are 1.1 cm thick and are read out using wavelength shifting fibres. The innermost scintillators are parallel to the beam, the two further layers have stereo angles of $\pm 45°$, respectively so that charged-particle tracks can be reconstructed in space. The detection of photons, especially those from the Δ^+ decays, will allow the further reduction of non-exclusive background events. The photon detector also provides a cosmic-ray trigger for test and alignment measurements, and provides additional pion/proton particle identification at higher momenta.

3 The commissioning of the Recoil Detector

Before the installation of the Recoil Detector in January 2006, the completely assembled detector was tested in 2005 using cosmic particles with the magnetic field turned on at a test site in the HERMES experimental hall. This test not only provided the chance to commission the whole hardware and the data acquisition system, but also gave the opportunity to accumulate cosmic data, to develop the required software, and to take data for the internal alignment of the detector.

After a rough alignment, the residuals from cosmic tracks were measured to be 0.27 mm for the silicon detector and 0.35 mm for the SFT, about 20% higher than what would be expected for a perfectly aligned detector. Efficiencies for the SFT and the photon detector were in agreement with the test experiments, but the MIP detection efficiency for the silicon strip detector was with 80–90% significantly lower due to high common mode noise present in the cosmic test. The electrical set-up of the detector was revised and the noise level was reduced to the level known from the previous test measurements.

The Recoil Detector was installed in January 2006 and started data taking in February. Data taking using the HERA electron beam has been successfully carried out for the scintillating-fibre tracker and the photon detector. The target cell was damaged by accidental beam loss in March, which caused problems for the silicon detector due to radio frequency noise introduced by the beam bunches. At the end of June 2006 the HERA beam polarity was changed from electrons to positrons. The data taking was continued with the fully installed Recoil Detector after the repair of the target in July 2006.

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