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The HERMES Recoil Detector

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ABSTRACT: For the final running period of HERA, a recoil detector was installed at the HERMES experiment to improve measurements of hard exclusive processes in charged-lepton nucleon scattering. Here, deeply virtual Compton scattering is of particular interest as this process provides constraints on generalised parton distributions that give access to the total angular momenta of quarks within the nucleon.
The HERMES recoil detector was designed to improve the selection of exclusive events by a direct measurement of the four-momentum of the recoiling particle. It consisted of three components: two layers of double-sided silicon strip sensors inside the HERA beam vacuum, a two-barrel scintillating fibre tracker, and a photon detector. All sub-detectors were located inside a solenoidal magnetic field with a field strength of 1 T.
The recoil detector was installed in late 2005. After the commissioning of all components was finished in September 2006, it operated stably until the end of data taking at HERA end of June 2007. The present paper gives a brief overview of the physics processes of interest and the general detector design. The recoil detector components, their calibration, the momentum reconstruction of charged particles, and the event selection are described in detail. The paper closes with a summary of the performance of the detection system.

KEYWORDS: dE/dx detectors; Gamma detectors (scintillators, CZT, HPG, HgI etc); Particle tracking detectors; Particle tracking detectors (Solid-state detectors); Detector alignment and calibration methods; Particle identification methods; Data acquisition concepts; Front-end electronics for detector readout.

Contents

1. Introduction

In the winter shutdown of 2005/2006 the HERMES spectrometer [1] was upgraded in the target region with a Recoil Detector (RD). The detector surrounded the HERMES target cell and comprised, in a coaxial structure, a set of Silicon Strip Detectors (SSD) situated inside the HERA lepton beam vacuum, a Scintillating-Fibre Tracker (SFT) and a Photon Detector (PD), all surrounded by a superconducting magnet with a field strength of 1 T in the center of the bore. The RD was commissioned during the 2006 data taking and operated in conjunction with the HERMES forward spectrometer until the end of HERA data taking in the middle of 2007.

The purpose of the RD was to improve access to hard exclusive electroproduction of real photons (γ) or mesons (m) off nucleons (N), $e+N \rightarrow e+N+\gamma/m$, at HERMES. Hard exclusive processes have come to the forefront of nucleon structure physics because they provide information on Generalised Parton Distributions (GPDs) [2, 3, 4]. GPDs can be considered the natural complement to transverse-momentum-dependent parton distributions, as both are derived from the same parent Wigner distributions [5, 6]. In particular, GPDs have quickly risen in importance in hadron physics since it was shown that they may provide access to the total angular momentum carried by quarks (and gluons) in the nucleon [7] and they provide a multi-dimensional picture of the nucleon structure [8].

Deeply Virtual Compton Scattering (DVCS), i.e., the hard exclusive electroproduction of a real photon, presently provides the cleanest access to GPDs. GPDs depend on four kinematic variables: t, x, ξ, and Q^2. The Mandelstam variable $t=(p-p')^2$ is the squared four-momentum transfer to the target nucleon, with p (p') its initial (final) four-momentum. In the 'infinite'-target-momentum frame, x and ξ are related to the longitudinal momentum of the struck parton, as a fraction of the target momentum. The variable x is the average of the initial and final momentum fractions carried by the parton, and the variable ξ, known as the skewness, is half of their difference. The evolution of GPDs with $Q^2 \equiv -q^2$, where $q=k-k'$ is the difference between the four-momenta of the incident (k) and scattered (k') lepton, can be calculated in the context of perturbative quantum chromodynamics as in the case of parton distribution functions. There exist several GPDs to describe the various possible helicity transitions of the struck quark and of the nucleon as a whole. The DVCS process on an unpolarised proton is very well suited to access the GPD H, which describes the dominant transition that conserves the helicities of both the struck quark and the nucleon.

The DVCS process contributes to the reaction channel $eN \rightarrow eN\gamma$, which is dominated at HERMES kinematics by the Bethe-Heitler (BH) process, i.e., elastic eN scattering with a bremsstrahlung photon in the initial or final state. The two processes are experimentally indistinguishable and therefore interfere. The differential cross section is given by

$$\frac{d\sigma}{dQ^2\, dx_\mathrm{B}\, d|t|\, d\phi} = \frac{x_\mathrm{B} e^6}{32(2\pi)^4 Q^4 \sqrt{1+\varepsilon^2}} |\tau_\mathrm{Total}|^2, \tag{1.1}$$

where

$$|\tau_\mathrm{Total}|^2 = |\tau_\mathrm{BH}|^2 + |\tau_\mathrm{DVCS}|^2 + \underbrace{\tau_\mathrm{BH}\tau^*_\mathrm{DVCS} + \tau_\mathrm{DVCS}\tau^*_\mathrm{BH}}_{I}. \tag{1.2}$$

In equation 1.1, e is the elementary charge of the electron, x_B is the Bjorken scaling variable $x_B = Q^2/(2pq)$ and $\varepsilon = 2x_B \frac{M}{Q}$ with M the proton mass. The angle ϕ denotes the azimuthal orientation of the photon production plane with respect to the lepton scattering plane. In equation 1.2, the square of the scattering amplitude consists of three parts: one due to the BH contribution, one due to the DVCS contribution and one due to the interference between the two, denoted I. Although the DVCS contribution to the cross section is small at the kinematic conditions of HERMES, it is 'amplified' in the interference term I by the (much) larger BH contribution. Experimentally, the preferred way to study DVCS is the measurement of cross-section asymmetries. For an unpolarised hydrogen target, the beam-helicity asymmetry $\mathscr{A}_{LU}$, where L denotes the longitudinally polarised beam and U the unpolarised target, and the beam-charge asymmetry $\mathscr{A}_C$ can be accessed. These are constructed as

$$\mathscr{A}_{LU}(\phi) = \frac{d\sigma^{\rightarrow}(\phi) - d\sigma^{\leftarrow}(\phi)}{d\sigma^{\rightarrow}(\phi) + d\sigma^{\leftarrow}(\phi)}, \tag{1.3}$$

$$\mathscr{A}_{C}(\phi) = \frac{d\sigma^{+}(\phi) - d\sigma^{-}(\phi)}{d\sigma^{+}(\phi) + d\sigma^{-}(\phi)}, \tag{1.4}$$

where $d\sigma^{\rightarrow}(\phi)$, $d\sigma^{\leftarrow}(\phi)$, $d\sigma^{+}(\phi)$ and $d\sigma^{-}(\phi)$ represent cross-sections from positive and negative beam helicity and positive and negative beam charges, respectively. Various experimental results on these asymmetries have been published so far by the HERMES collaboration [9, 10, 11, 12]. In these measurements an enriched sample of exclusive events was selected using a missing-mass technique. An event-by-event selection was not possible as the recoiling proton was outside the acceptance and the existing spectrometer did not have sufficient resolution. Monte Carlo (MC) calculations showed that the contribution of events from "associated" production ($ep \rightarrow eN\pi\gamma$, including the resonant production $ep \rightarrow e\Delta^+\gamma$) was expected to be in average 13%, while 3% were expected from semi-inclusive processes. The contribution from the decay products of neutral pions from exclusive reactions that are misidentified as single-photon events was found to be negligible.

The analysis related to the study of DVCS and HERMES employing the RD involves two major motivations. The first is the selection of a DVCS (in the following DVCS corresponds to DVCS and BH) event sample with a background contamination below 1%, and the extraction of a beam-helicity asymmetry from it. This allows a cleaner comparison to predictions from the ongoing theoretical efforts to fit GPD models to HERMES data. The second motivation is the potential to extract an asymmetry in associated production in the Δ-resonance region.

The present paper is structured as follows. Chapters two and three give an overview of the general detector design and the individual detector components. The data acquisition system and the data taking performance are described in chapter four. The energy calibration and the energy measurement in general are outlined in chapter five, and chapter six explains the momentum reconstruction. The performance of the RD is summarized in chapter seven. The event selection with the RD is described in chapter eight. The paper is summarized in chapter nine.