The H1 VLQ-Spectrometer: Track-Cluster Matching in the sub-mm Region

A. Stellberger for the H1 Collaboration
Institut für Hochenergiephysik
Universität Heidelberg
Schröderstraße 90, D-69120 Heidelberg

The VLQ spectrometer[1] (VLQ=Very Low Momentum(Q) Transfer) is a new device dedicated to measure electrons scattered off protons by very low angles in the H1 experiment at the HERA e-p collider at DESY in Hamburg. It consists of a Si-strip tracking detector, an electromagnetic calorimeter, and a time-of-flight measuring system. In this article the interplay of the tracking system with the electromagnetic calorimeter is discussed. The most important parameter describing this interplay is the track-cluster matching between these two components. This parameter is purely dominated by the alignment of the detectors and the spatial resolution of the calorimeter. The spatial resolution of the calorimeter was measured in a test beam as well as in the H1 operation. In the test beam the spatial resolution was determind to be better than 1 mm for energies bigger than 4 GeV. In the H1 data taking this parameter was measured to be 700 μm without alignment. With alignment this value is expected to become as low as 500 μm.

1 Introduction

The VLQ spectrometer was designed to extend the acceptance of the H1 detector at the HERA storage ring in Hamburg to lower values of the kinematic variable Q^2. The acceptance in Q^2 of this spectrometer ranges from 0.02 to 1 GeV^2. In this Q^2 range the electron scattering angle is very small, and therefore the spectrometer must be mounted very close to the beampipe in the electron downstream direction. To measure the relevant kinematical variables, the energy and the scattering angle of the scattered electron have to be determined. Thus the VLQ spectrometer consists of a silicon-strip tracking detector to measure the scattering angle and an electromagnetic calorimeter to measure the energy of the scattered electron. In additon, a time-of-flight measurement system is included to reject proton induced background. The two modules the system consists of are mounted on a moving mechanics in order to retract the detectors during the injection of the beams. All this can be seen in figure 1. To cover the Q^2 range desired the beampipe narrows at the position of the spectrometer. The diameter of the beampipe at the VLQ spectrometer position is 6 cm. Therefore the detectors are located only at a distance of 3 cm from the beams. Due to the mounting location of the spectrometer in the H1 detector between the compensating magnet seen on the right side in figure

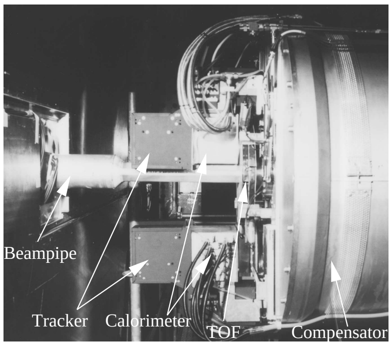

Figure 1: The VLQ spectrometer mounted in the H1 Experiment. The two modules consisting of silicon tracker and calorimeter respectively are mounted above and below the modified beam pipe in the middle. The upper module is in measuring position whereas the lower module is moved out. The electrons come from the left and the protos from the right side. The whole spectrometer has a length of only 50 cm.

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2 Calorimeter Structure

The electromagnetic calorimeter is built as a tungsten-scintillator sandwich calorimeter. Tungsten was chosen as absorber to reach the compactness required. The compactness is necessary to reduce energy losses due to shower leakage. The dense structure of the calorimeter allows to measure electrons hitting very close to the calorimeter edge on the bottom side with correspondingly very low Q^2. To obtain the spatial resolution required the scintillator layers are alternatingly segmented in x- and y-direction in strips of 5 mm width. These strips are read out by wavelength shifter strips on both ends. The wavelength shifter strips are then read out by photodiodes at the front and at the back side. The basic structure of the calorimeter is sketched in figure 2. A whole calorimeter module consists of 23 tungsten layers of 2.5 mm thickness and 24 scintillator layers of 3 mm thickness. Twelve scintillator layers are segmented in x- and twelve in y-direction. There are 18 channels in the horizontal and 24 channels in the vertical direction. The length of the whole active structure is only 13.3 cm which corresponds to a depth of 16.7 radiation lengths. The Molière radius is 1.25 cm. This low value corresponds to the fact that energy leakage is small even if the electron hits close to the calorimeter edge. The size of the active area covered is 9x12 cm^2. This calorimeter structure features a twofold redundancy in the x- and y-projection. This redundancy is needed

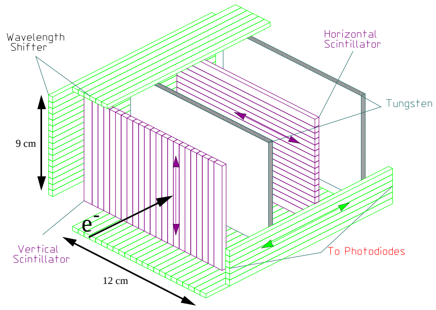

Figure 2: The basic structure of the VLQ calorimeter. The scintillator planes are alternatingly segmented into slabs in x- and y-direction. The slabs are read out at both ends by wavelength shifters which are read out at both ends also by photodiodes.

to kill the so called single diode or nuclear counter effect. This effect is the occurrence of huge signals in single channels caused by charged particles going directly through the silicon photodiodes and depositing charge. This effect is easy to recognize with the help of the redundancy because the photodiode on the opposite side of the scintillator strip will not show a signal if there was no real light (energy) in the calorimeter.

3 Tracker Structure

A module of the silicon-tracker consists of ten silicon detectors of 34x59 mm^2 size. These ten detectors are arranged in two planes with 13 cm distance. Each plane is built up of three vertically oriented detectors for the x-measurement and two horizontally oriented detectors for the y-measurement. The pitch of the silicon strips is 50 μm yielding 640 channels per detector and therefore 6400 channels per module. The signal-to-noise ratio of the detectors measured in a testbeam was determined to be 22. The spatial resolution of a detector is 15 μm.

From the experience gained in the first four months of HERA running it is known that there are about 50 hits per event detected in both modules of the silicon tracker. This corresponds to about 12-13 hits per plane. These hits are mostly due to synchrotron radiation photons hitting the tracker. From simulations before installation roughly the same number of fake hits was expected. Since a normal electron track should leave only one hit per plane it is very difficult to find the real track within all these fake hits from the information of the silicon tracker alone. Therefore the spatial information from the calorimeter is used to select the hits in a cylinder around a straight line from the calorimeter cluster to the interaction vertex. This procedure normally rejects the fake hits because the synchrotron photons are not seen by the calorimeter. To make the rejection efficiency as good as possible the spatial resolution of the calorimeter must be very good to be able to make the radius of the selection cylinder as small as possible. This means that a good track-cluster matching between calorimeter and tracker is absolutely essential for a proper functioning of the spectrometer.

4 An Event Display of a QED-Compton Event

In figure 3 the eventdisplay of a QED-Compton event measured with the VLQ spectrometer is shown. Due to energy and momentum conservation the en-

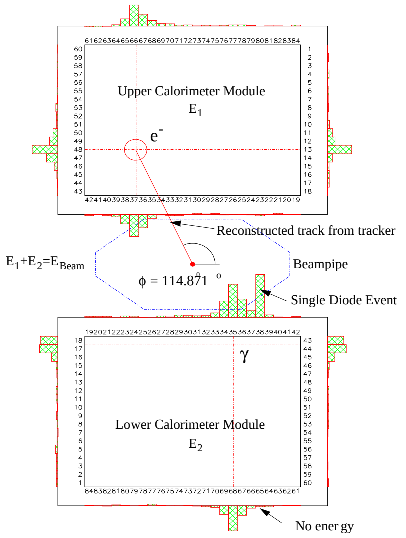

Figure 3: A QED-Compton event measured with the VLQ-Spectrometer. The cluster in the upper calorimeter module is that from the electron because a corresponding track is detected. The photon detected by the lower module hit only 5 mm away from the calorimeter edge.

ergies of the electron and the radiated photon have to sum up to the beam energy and have to be back-to-back (excluding higher order processes). The display shows the upper and lower calorimeter module and the four measured projections of the showers. The heights of the hatched rectangles correspond to the energy in the channel. It can be clearly seen that the noise is very low compared to the clusters. In the event display the reconstructed track is also drawn. This track matches almost perfectly the cluster position in the calorimeter. For the cluster in the lower module no track was found which means that this was the photon. The impact point of the photon is only about 5 mm away from the calorimeter edge. This demonstrates the enormous compactness of this device. In the upper projection of the lower module a single diode event shows up. This can be recognized very easily because there is no energy on the opposite side. Even if the single diode event had been in the cluster it is recognizable by comparing the shower projections measured at opposite sides.

5 The Track-Cluster Matching

The track-cluster matching of the tracker and the calorimeter that corresponds mainly to the spatial resolution of the calorimeter was measured in a test beam from 1-6 GeV. The energy resolution and linearity of the calorimeter were also extracted from the data. The measured energy resolution was in agreement with the expectation from simulations, and the linearity was at the 1% level. A further result from the test beam was that the shower of an electron with 4 GeV energy is fully contained in the calorimeter if it hits the calorimeter more than 2 cm away from the edge. This demonstrates again the compactness of the device. All these measurements except the last one described were carried out with electrons hitting the middle of the active area [2].

The spatial resolution of the calorimeter was measured to be 1 mm for electrons with 4 GeV energy. The energy dependence of the spatial resolution was found as follows (eq 1):

$$\Delta x = \frac{2 \text{ mm}}{\sqrt{E/\text{GeV}}} \qquad (1)$$

Extrapolating this formula to energies of about 20 GeV yields an expected spatial resolution of about 500 μm. In figure 4 the difference of the y-coordinate measured by the silicon-tracker and the calorimeter is plotted from the data taken during HERA operation. The width of the distribution is 700 μm. The behaviour for the x-direction is similar. This value is not yet as good as expected from the test beam data. The reason for this is that the detectors have not yet been aligned for the HERA operation, and that most of the events considered are close to the calorimeter edge, and therefore information is missing. After applying corrections for the energy leakage and the alignment it is expected to reach the expected value of 500 μm.

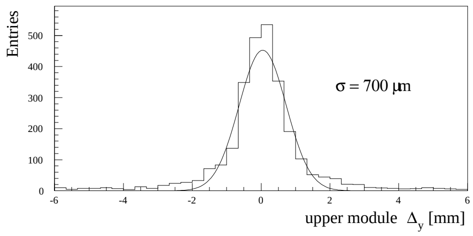

Figure 4: The difference of the y-coordinate measured by the silicon-tracker and the calorimeter in the HERA operation. The track-cluster matching is at the level of 700 μm.

6 Conclusion

A very compact spectrometer consisting of a silicon-tracker and an electromagnetic calorimeter was built and installed in the H1 detector to measure events with very low momentum transfer Q^2. In test beam results the predicted performance expected from simulations was reached. The most outstanding feature of this spectrometer is its excellent ability to match clusters in the calorimeter to tracks in the tracking detector at a level of a few hundred microns.

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