A HIGHLY COMPACT ELECTROMAGNETIC CALORIMETER FOR THE VLQ SPECTROMETER IN H1 AT HERA

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The VLQ spectrometer[1] (VLQ=Very Low Momentum(Q) Transfer) is a new device dedicated to measure electrons scattered off protons under very low angles in the H1 experiment at the HERA e-p collider at DESY in Hamburg. It consists of a GaAs tracking detector a calorimeter and a time of flight system. In this article the calorimeter part will be discussed. The challenge of this project was to achieve the required energy and spatial resolution in a longitudinal space of only 16 cm. For this reason the calorimeter was built as a tungsten scintillator sandwich with a projective readout structure to obtain spatial resolution. In addition a very compact low noise readout electronics employing photodiodes and custom made integrated preamplifiers was developed.

1 Physics

The main goal of the VLQ spectrometer is to measure the inclusive photon-proton cross section :

$$\gamma^* + p \rightarrow X$$

in the Q^2 region between 10^{-2} and 2 GeV^2. Here Q^2 describes the momentum transfer from the incoming HERA electron beam to the virtual Photon γ^*. This region of Q^2 is up to now not explored by the H1 experiment due to the lack of detectors with acceptance in this kinematical region.

In addition further physics topics as exclusive meson production and diffractive physics can be examined.

2 Calorimeter Requirements

Due to the Q^2 range which should be examined by the VLQ it is clear that the detectors have to be placed under very small angles close to the beam pipe. The spectrometer consists of two identical modules one below and one above the beampipe. To put the VLQ acceptance in the desired region it is required to install the entire VLQ in a gap of approximately 50 cm length between the iron yoke and a superconducting compensation solenoid for beam optics in the existing H1 detector.

This puts severe constraints on the longitudinal extension of the spectrometer components. A tradeoff between the performance requirements of the different detectors yielded a total calorimeter length of 16 cm including the active volume as well as the readout electronics. From this limitation it is clear that no photomultipliers can be used for the readout since they would be too large. Thus photodiodes are chosen as active devices sensing the light output of the calorimeter. It is also clear that a very dense absorber has to be used to keep energy losses small. For this reason tungsten is used as absorber.

The photodiode readout requires low noise charge sensitive preamplifiers to measure the small charge generated by photons in the photodiodes. This demand is intensified by the high readout granularity required to obtain spatial resolution. Due to this the signal in single channels is lowered and noise behavior becomes more important.

The preamplifiers are developed as integrated circuits in the AMS (Austria Micro Systems) 1.2 μm CMOS process to satisfy the demand for compactness.

The design goals concerning spatial and energy resolution are a spatial resolution of better than 1 mm for energies higher than 5 GeV. This is required to accomplish track cluster matching between tracker and calorimeter and to correct the energy scale at the edge of the calorimeter. The energy resolution should be at the level of 3-4 % at an energy of 30 GeV.

3 Calorimeter Structure

The active calorimeter volume is composed of alternating layers of 2.5 mm thick tungsten plates and 3 mm thick scintillator planes. The whole volume consists of 24 scintillator planes and 23 tungsten plates. This amounts to a total length of the active volume of 129.5 mm. The calorimeter depth expressed in radiation length is 16.7 X_0. The Molière radius is 1.25 cm.

To achieve spatial resolution the scintillator planes are segmented in slabs of 5 mm width. These slabs are alternately arranged in x and y direction. This can be seen in figure 1.

Since the active area of the calorimeter has a lateral extension of 124x94 mm 24 slabs are used for the vertical planes and 18 the for horizontal planes. The slabs are wrapped with white paper to prevent crosstalk and to maintain total reflection at the surface of the slabs. A certain fraction of the light produced by the electron shower is thus forced to travel along the slabs by total reflection and emitted at both ends of the slab. At both ends of each scintillator slab there are wavelength shifters absorbing the light emitted from the scintillator slabs. The wavelength shifter absorbs the light emitted by all slabs at the same x or y position of all scintillator planes of the same slab orienta-

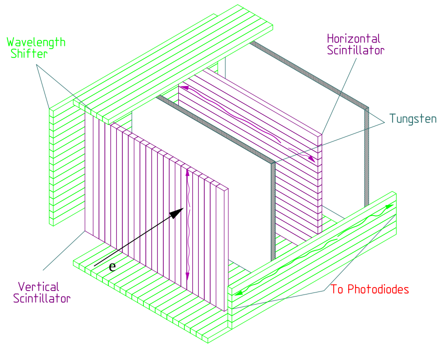

Figure 1: Readout structure of the calorimeter.

tion. This yields the integration of all the light in longitudinal direction. The wavelength shifters are glued directly to custom made photodiode arrays with 18 or 24 photodiodes on both ends respectively. Because every slab row is read out at both ends the number of photodiodes amounts to 168 per calorimeter module.

Behind the photodiodes PCB boards carrying the preamplifier chips are mounted on both ends of the active volume of the calorimeter. The longitudinal extension of this readout electronics adds approximately 10 mm on each side to the length of the calorimeter. The housing of the calorimeter adds another 5 mm on each side yielding a total calorimeter length of 160 mm.

The signals of both ends of one wavelength shifter are summed electronically so that the number of electronic readout channels is half the number of photodiodes reading out the calorimeter. This yields 84 electronics channels per module.

This readout structure is able to measure the x and y projection of the shower profile from which the impact point can be reconstructed by calculating the energy weighted center of gravity. The energy of the incident electron is represented by the sum of all readout channels showing a signal above the noise level. Due to the redundancy in the readout the so called single diode or nuclear counter effect can be easily suppressed. This can be done in the spatial as well as in the energy reconstruction.

4 Readout Electronics

Due to the severe space limitation imposed by the environment the preamplifiers are designed as integrated circuits. The chips have been developed in the AMS 1.2 μm CMOS process. Each chip contains 6 preamplifiers consisting of a charge sensitive amplifier followed by a shaper and output buffer. The shaping time is 200 ns. In addition an on chip calibration is provided. To be able to trigger with the calorimeter the chip can also provide the sum of the signals of all 6 channels. The summing of individual channels is programmable. The summed signal is shaped faster with a shaping time of 90 ns to obtain the time resolution needed to identify the bunch crossing to which the event belongs. The bunch crossing time at HERA is 96 ns.

The preamplifier features affecting the calorimeter performance most are linearity and noise. The linearity was found to be better than 1 %. The noise of the preamplifier is a function of the capacitance connected to its input. The measurement of the noise in dependence of the input capacitance can be seen in figure 2.

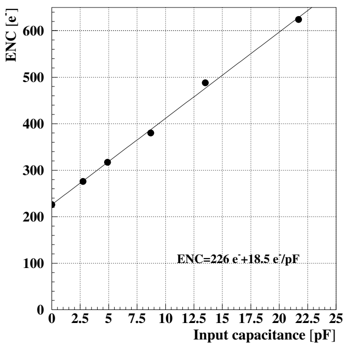

Figure 2: Preamplifier noise as function of the input capacitance.

The actual capacitance connected to the preamplifier input is the photodiode capacitance which is approximately 10 pF. This results in a preamplifier noise of 420 electrons.

5 Simulation Results

The calorimeter was simulated using the GEANT simulation tool. The energy resolution was found to be:

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{12.9\,\%}{\sqrt{E\,[GeV]}}\right)^2 \;+\; (3.1\,\%)^2 \;+\; el.\,noise \tag{1}$$

The relatively large constant term is caused by the short calorimeter length of only 16.7 radiation length.

The spatial resolution was found to be better than 1 mm for energies greater than 7 GeV.

An important feature of the calorimeter is that it should be possible to measure electrons close to the edge of the active area. For this reason the lateral energy containment should be very high. From the simulation it was found that at a distance of 2 mm apart from the calorimeter edge still 80 % of the shower energy are in the calorimeter. Due to this the energy resolution becomes only slightly worse at the calorimeter edge.

6 Testbeam Results

The device was tested in October 97 in an electron testbeam at the DESY synchrotron. The electron energy was adjustable from 1-5 GeV.

6.1 Energy resolution

The measured energy resolution in dependence of the beam energy can be seen in figure 3.

The line which can be seen in figure 3 is the parameterized energy resolution formula of equation 1. For the fit the sampling term was fixed to the result from the simulation of 12.9 %. Only the noise and constant term are fitted as free varying parameters. The large error bars of the measured points at 1 and 2 GeV originate from large systematic errors at these energies. These are caused by the different efficiencies of noise cuts applied to the data. The result of the fit is:

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{12.9\,\%}{\sqrt{E\,[GeV]}}\right)^2 \;+\; (9\,\%)^2 \;+\; \left(\frac{260\;MeV}{E}\right)^2 \tag{2}$$

The noise term of 260 MeV is due to the low noise of the preamplifiers which were already discussed. This is in agreement with the expectation. The

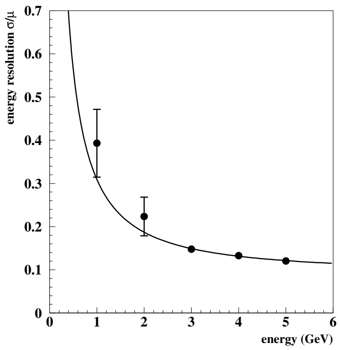

Figure 3: Energy resolution in dependence of the energy.

large constant term of 9 % is in disagreement with the result from the simulation where it was 3.1 %. This is due to the fact that so far no intercalibration has been applied to the single readout channels. For the energy reconstruction the contents of 20 readout channels are summed. The area in which the electrons hit is 2x2 cm defined by the size of the trigger scintillators in the testbeam. Thus about 30-35 readout channels are involved in the energy reconstuction. All these channels may have different response to the same electron they see. This originates from the channel to channel variations of the optical couplings in the optical components (e.g scintillator-wavelength shifter, wavelength shifter- photodiode). From the difference between the constant term determined by the simulation and by the measurement this inhomogeneity can by quantified by subtracting both numbers in quadrature. This yields to an intercalibration error of the channels of about 8 %. The intercalibration constants have been figured out recently. The result agrees exactly with the value figured out above.

The deviation from linearity of the energy response is found to be less than 1 %.

6.2 Spatial resolution

The measured spatial resolution in horizontal direction in dependence of the energy can be seen in figure 4.

The spatial resolution gets better than 1 mm for energies greater than 4 GeV. At 5 GeV the resolution is 772 μm. In vertical direction the resolution is slightly worse. At 5 GeV a resolution of 1 mm is obtained. The reason for this

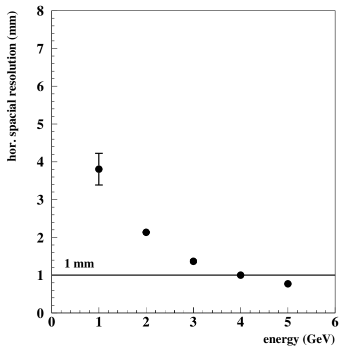

Figure 4: Energy resolution in dependence of the energy.

is larger noise in the channels involved in the vertical spatial reconstruction. In addition there seems to be less light output from the horizontal aligned scintillator slabs which are used for the reconstruction in vertical direction. The reason for this may be that these slabs are 3 cm longer than in the other direction and thus have higher attenuation. This point has still to be confirmed.

7 Conclusion

A highly compact electromagnetic calorimeter of 16 cm length was built. The calorimeter features a tungsten scintillator sandwich structure with projective readout and a highly advanced and compact low noise readout electronics which is crucial to meet the desired performance.

To obtain the final energy resolution from the recent testbeam measurements the channel intercalibration has to be applied to the energy resolution measurement. So far this can not be presented here.

The spatial resolution was found to be better than 1 mm for energies greater than 5GeV.

The calorimeter will go into operation in the H1 experiment in May 1998.

References

1. H1 Collaboration, Technical Proposal to build a Special Spectrometer covering Very Small Momentum Transfers, 1996