PERFORMANCE OF THE H1 LEAD/SCINTILLATING-FIBRE CALORIMETER

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The H1 detector has been upgraded in the backward region with the insertion of a lead/scintillating-fibre calorimeter (SpaCal). The purpose of the calorimeter is to provide a precise measurement of the energy and polar angle of the scattered electron in ep collisions at HERA. In addition to an excellent energy, position and time resolution, the calorimeter measures the hadronic energy flow in the backward region and provides sophisticated trigger information. In particular, a large suppression of the abundant beam related background is obtained by exploiting the different timing of genuine electron-proton collisions compared to proton beam induced background. The performance of this calorimeter is described.

1 Introduction

The backward region of the H1 detector at the ep storage ring HERA has been equipped with a high resolution lead/scintillating-fibre calorimeter (SpaCal) [1]. The main physics motivation for the construction of this calorimeter is the measurement of the energy and position of the scattered electron in deep inelastic scattering events. High precision for the reconstruction of the event kinematics is required for the measurement of the proton structure function and for QCD tests. SpaCal gives access to Q^2 values between 0.35 and 100 GeV^2 for x values down to 10^{-6}. The electromagnetic calorimeter section of SpaCal provides an excellent measurement of the energy and polar angle of the scattered electron. The existence of distinct electromagnetic and hadronic sections and the fine granularity of SpaCal result in a good separation capability between showers originating from electrons and hadrons and provide a good e/π separation and hadronic energy measurement.
The technical parameters of the calorimeter are summarized in Table 1.

2 Time measurement and Trigger function

The calorimeter electronics [3] consists of three parallel branches for the energy, time and trigger information as shown in Fig. 1. At the energy readout branch the calorimeter cell information is produced which forms the input to the event reconstruction. The noise level reached in the readout branch is < 3 MeV.

Table 1: Technical specifications of the SpaCal.

	electromagnetic	hadronic
Lead/Fibre Ratio	2.27:1	3.4:1
Fibre Type	BICRON BCF-12	BICRON BCF-12
Fibre Diameter	0.5 mm	1.0 mm
Active Length	25 cm	25 cm
Cell size	4.05×4.05 cm^2	12.0×12.0 cm^2
Number of Cells	1192	136
Radiation Length	0.90 cm	0.85 cm
Moliere Radius	2.55 cm	2.45 cm
Interaction Length	25 cm	25 cm
fine mesh PMT [2]	Hamamatsu R5505	R2490-06
PMT gain at $\sim$ 1T	$\sim 10^4$	$\sim 2 \times 10^4$

For the time measurement for each individual cell the signals are fed into constant fraction discriminators (CFD). The CFD output signals are in turn fed into the TDC system [3,4] – providing time information for all SpaCal channels at a precision of $\leq$ 1 ns – and into the Time-of-Flight sensitive trigger. On line monitoring of the rates is performed by producing various histograms according to different trigger selections.
The Time-of-Flight information allows to distinguish between good ep interactions and proton induced background at the first trigger level. The time difference between genuine positron-proton collisions and proton beam induced background is 10 ns. The Time-of-Flight is used at the first trigger level where positive coincidence is required between the time signal and an adjustable gate (TOF window) which defines the time interval of in-time ep physics events (TOF).
In the trigger branch analog energy sums are produced and compared with adjustable trigger thresholds. In case of coincidence the cell energy trigger signal is fed into the TOF trigger branch otherwise it is fed into the ATOF branch. The TOF branch mainly comprises the inclusive electron trigger (IET) [5]. The IET is segmented in 320 arrays of 4×4 neighbouring cells. In order to avoid inefficiencies at the boarder of these windows the arrays overlap using the sliding window technique.
The analog energy sums are compared to three different thresholds adjustable in the range between $\sim$ 100 MeV and $\sim$ 20 GeV. The thresholds may also

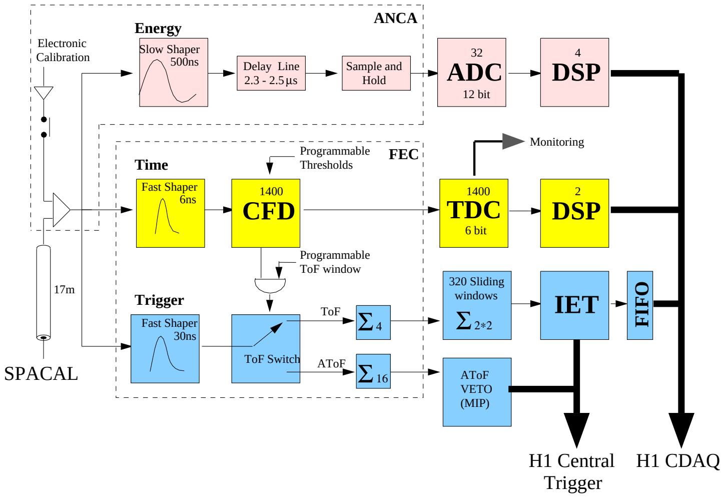

Figure 1: Diagram of the SpaCal electronics chain.

vary over the detector area. The SpaCal trigger reaches 100% efficiency with a short rise time. The importance of Time-of-Flight sensitivity for the SpaCal trigger can be evaluated from the fact that the physics events amount only for a small fraction of the total rate. Fig. 2 shows the time distribution of events with a given trigger selection. Before first trigger level selection the background peak contains 100 times more events than the ep interactions peak. The first peak is due to background energy deposits, while the second peak corresponds to ep interactions events. The time resolution of the SpaCal calorimeter and the electronics is $\sigma \simeq 0.4$ ns.

3 Energy calibration

In order to achieve a homogeneous detector response and optimum energy resolution, the relative equalization of the response of the calorimeter cells is of major importance. The relative calibration of SpaCal is based on three methods. High energy electrons in deep inelastic scattering events [6,7], cosmic muons [8] and muons from the proton beam halo [9] are used. The first method which is based on the characteristic maximum, close to the electron beam energy, shown at the energy distribution of scattered electrons at ep collisions is only used for the calibration of the electromagnetic section. In Fig. 3 the excellent agreement of the calibrated data with the simulation is displayed for

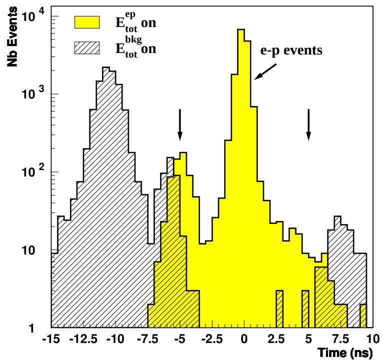

Figure 2: Time distribution at the 1st trigger level output. The peaks are due to background energy deposits (first), and to ep interactions events (second). The Time-of-Flight window is also indicated (arrows). The small peak at $\sim$ -5 ns is due to the proton beam structure.

regions of the calorimeter with different radial distance to the beam line.
For the determination of the absolute energy scale, independent checks are performed using only the polar scattering angles of the electron and the hadronic final state to calculate the expected electron energy [10]. Comparison of the expectated with the measured energy in the calorimeter provides a determination of the absolute energy scale. Other means to extract the absolute energy scale are the study of elastic QED Compton processes [11], where the scattered electron and the radiated photon energies must add to the beam energy, and the invariant mass reconstruction of π^0 mesons [12].
The electromagnetic SpaCal energy resolution is found to be:

$$\frac{\sigma}{E} = \frac{7.5\%}{\sqrt{E(GeV)}} \oplus 1\%.$$

Detailed investigations have demonstrated that the calibration delivers an uncertainty of the absolute energy scale of less than 0.7% for energies of the order of 27 GeV. The analysis of ep data has demonstrated that combining information from the SpaCal calorimeter and from the backward drift chamber which is situated in front of the calorimeter, an angular resolution of 0.6 mrad is achieved.

4 Calorimeter performance

In Fig. 4 the two-photon invariant mass spectrum in tagged photoproduction events is shown.

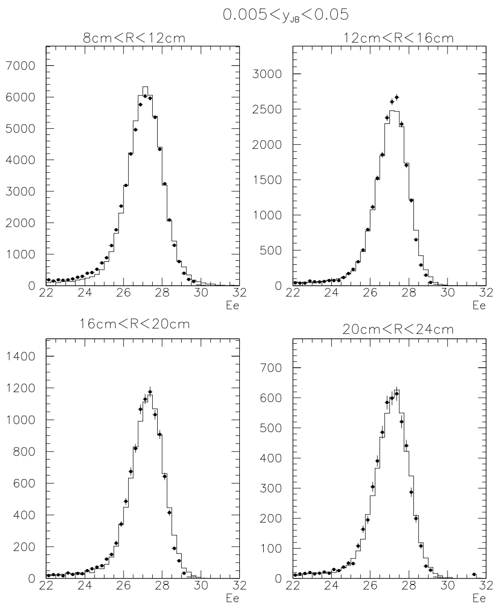

Figure 3: Energy spectra of the scattered electrons for calibrated data (points with error bars) compared to the simulation (histogram). The plots are ordered in increasing values of the radial distance to the beam line. The y_{JB} cut is made in order to select events where the electron is scattered at beam energy.

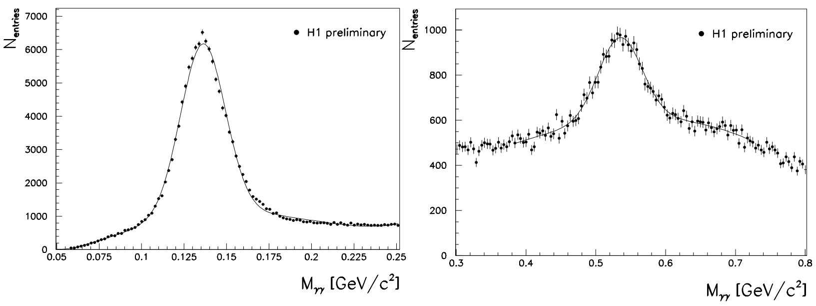

Figure 4: Two-photon invariant mass spectrum. A clear signal due to the π^0 and η mesons can be seen.

Table 2: Mass and width of the π^0 and η mesons reconstructed in SpaCal.

SPACAL	π^0	η
E_{γ_i}	> 1 GeV	> 1.5 GeV
$\mu(M_{\gamma\gamma})$	136 MeV / c^2	535 MeV / c^2
$\sigma(M_{\gamma\gamma})$	13MeV / c^2	31 MeV / c^2

In these events the scattered electron is detected in a small angle electron tagger detector and the photon candidates are detected in the SpaCal calorimeter. The spectra are shown for the π^0- and the η- meson invariant mass regions. The photon energy cuts applied as well as the values for the reconstructed mass and width of the two resonances are shown in Table 2. The π^0 and η invariant mass distributions reflect both the excellent energy and angular resolution of the calorimeter and the quality of the relative energy calibration.

5 Summary

A high granularity lead/scintillating fibre detector with distinct electromagnetic and hadronic sections has been successfully built and operated. It combines calorimetric, Time-of-Flight and trigger functions. A low noise level and an excellent time resolution are achieved. Due to its high granularity and to the existence of different threshold levels the trigger can easily be adapted to different experimental requirements. The difference in Time-of-Flight between genuine electron-proton collisions and proton beam induced background is used to positively identify and suppress this background at the 1st trigger level.
The calorimeter provides high precision measurement of the energy ($\sigma/E = 7.5\%/\sqrt{E(GeV)} \oplus 1\%$ with energy scale uncertainty 0.7% at 27.5 GeV) and angle of the scattered electron (angular resolution 0.6 mrad) and is successfully used for high precision physics analyses [13,14].

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