A Spaghetti Calorimeter for the H1–Detector

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ABSTRACT

The H1–collaboration is upgrading the backward region of the H1 detector to probe the parton structure of the proton down to very low values of x (10^{-4}). The centerpiece of the upgrade project will be a high resolution spaghetti calorimeter. The new calorimeter is divided in an electromagnetic and a hadronic section. The electromagnetic section consists of scintillating fibers with a diameter of 0.5 mm embedded in a lead matrix. This small radius ensures in combination with a lead to fiber ratio of 2:1 an excellent energy resolution which has been measured to $7.2\ \%/\sqrt{E} \oplus 1.0\ \%$. The electromagnetic calorimeter is designed to measure scattered electrons down to angles of 177°, with respect to the proton direction, giving the opportunity to cover a wide range in Q^2. To measure the hadronic energy flow the second calorimeter section is built with fibers of 1 mm diameter and a lead to fiber ratio of 4:1.

1. Introduction

The electron–proton collider HERA at DESY provides the unique possibility to probe the parton structure of the nucleon up to kinematical regions which have not been accessible to fixed target experiments. Recently new theoretical approaches have stimulated experimental interest in the low–x regime[1].

Events originating from low–x processes are characterized by boosts in the backward (electron) direction, Both the electron and the hadronic final state need to be detected in the backward region. As the H1 detector was designed originally to explore the largest momentum transfers available it was therefore proposed to upgrade the instrumentation in the backward region[2] the centerpiece of which will be a high resolution electromagnetic calorimeter.

The current H1 detector is equipped in the backward region with an electromagnetic lead scintillator sandwich type calorimeter with photodiode readout allowing electron reconstruction up to polar angles of 173° relative to the proton direction. Whereas the new calorimeter is designed to measure electrons up to angles of 177° thus giving access to a wide range of Q^2 for very low values of x.

2. Design and Construction of the Calorimeter

The design of the new calorimeter was guided by the following criteria:

- Access to large electron angles up to 177° to cover a wide range in Q^2,
- Excellent energy resolution, less than 2% at 30 GeV,

- Good time resolution and a high granularity to suppress proton beam background,
- Small radiation length and Molière radius to achieve a compact calorimeter,
- Good electron identification to suppress hadrons from photoproduction background
- Measurement of the hadronic energy flow,
- Operation in a 1.0 Tesla magnetic field.
- Radiation hardness,

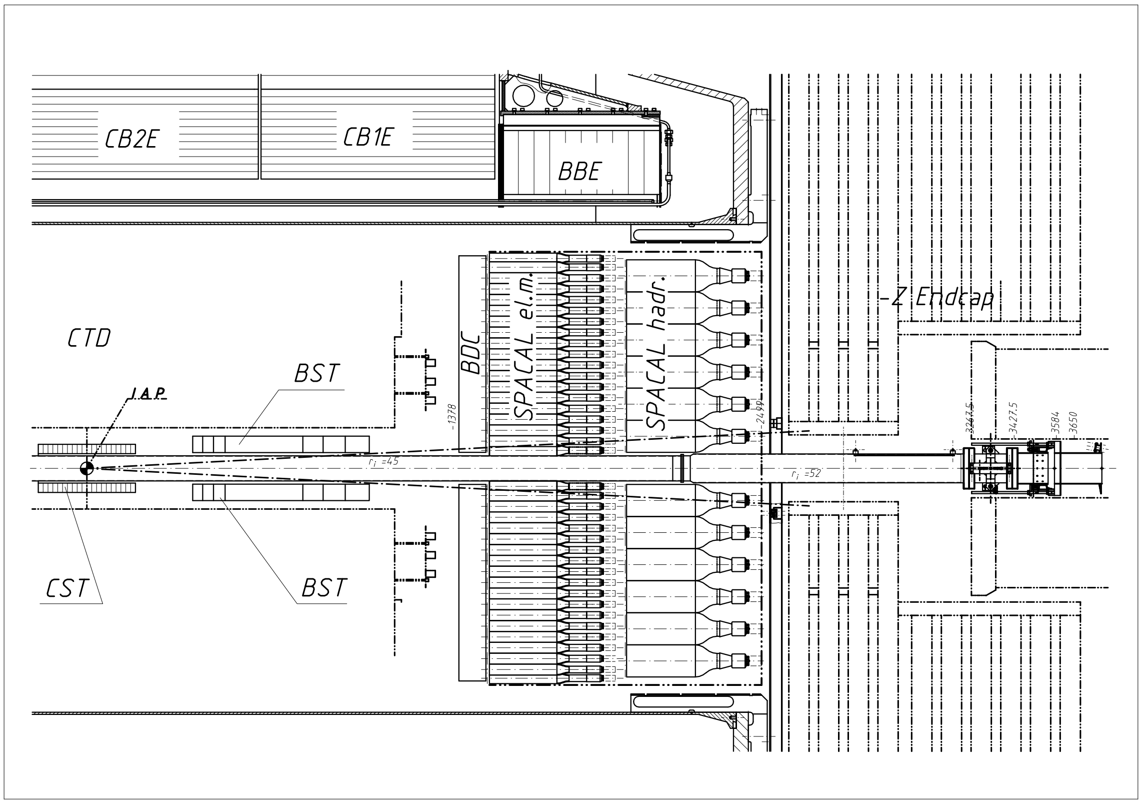

Figure 1: View of the backward scattering region of the H1 detector with the spaghetti calorimeter.

To meet these requirements a spaghetti calorimeter consisting of an electromagnetic and a hadronic section was chosen with a fiber diameter of 0.5 mm and 1.0 mm and a lead to fiber ratio of 2:1 and 4:1, respectively[3]. The detailed design parameters are given in table 1. The overall layout is shown in figure 1.

Table 1: Design parameters of the new calorimeter

Parameter	Electromagnetic Section	Hadronic Section
Pb/Fiber Ratio	2:1	4:1
Fiber Type	Bicron BCF–12	Bicron BCF–12
Fiber Diameter	0.5 mm	1.0 mm
Active Length	25 cm	25 cm
Cell Size	40.5×40.5 mm^2	120×120 mm^2
Number of Cells	1192	136
Angular Coverage	$\leq 177.5°$	$\leq 178°$
Radiation Length	0.91 cm	–
Molière Radius	2.55 cm	–
Interaction Length	25 cm	20 cm
Energy Resolution(elm)	$7\%/\sqrt{E}\oplus 1\%$	$13\%/\sqrt{E}$
Angular Resolution	≤ 2 mrad	–
Time Resolution	≤ 1 ns	≤ 1 ns

The basic unit of the electromagnetic section is called a submodule consisting of two cells each $40.5 \times 40.5 \times 250$ mm^3. The fibers are bundeled over a length of 85 mm and held in a bundeling frame. The fiber bundels are glued with black glue over a length of 2 cm to kill the cladding light. It has been observed in the R&D phase that mechanical pressure on fibers at the cell boundaries causes inhomogeneities. Therefore precautions have been taken to avoid high pressure in the bundeling frame which was dimensioned big enough to allow a complete relaxation of all fibers. The submodules were only prepressed with 1.5 tons horizontally and vertically which corresponds to the maximum pressure in the assembled calorimeter due to its own weight. The fiber bundel is coupled via an air gap to a light mixer which in addition concentrates the light on the photocathode of a 1" photomultiplier. The photomultiplier is glued to the light mixer. As the readout needs to be operated in a magnetic field of 1.0 Tesla mesh dynode photomultipliers were chosen [4] (Hamamatsu R–5505). The spectral sensitivity of the bialkali photocathode matches the emission spectrum of blue fibers (Bicron BCF–12) which have been selected for both the electromagnetic and the hadronic section after an intensive R&D program had been carried through[5]. The fibers are mirrored at the front end.

Eight submodules are combined to form a supermodule. Each supermodule has a common housing for light mixers, photomultipliers and bases. It is equipped with a high voltage distribution board and a calibration module which monitors the gain by coupling light of a LED via fibers into the light mixers. The electromagnetic calorimeter consists of 60 regular supermodules plus a combination of four differnt types of edge modules to approximate the round surface of the enclosing cylinder. Figure 2 shows a photo of an assembly 4 supermodules, i.e. 64 cells.

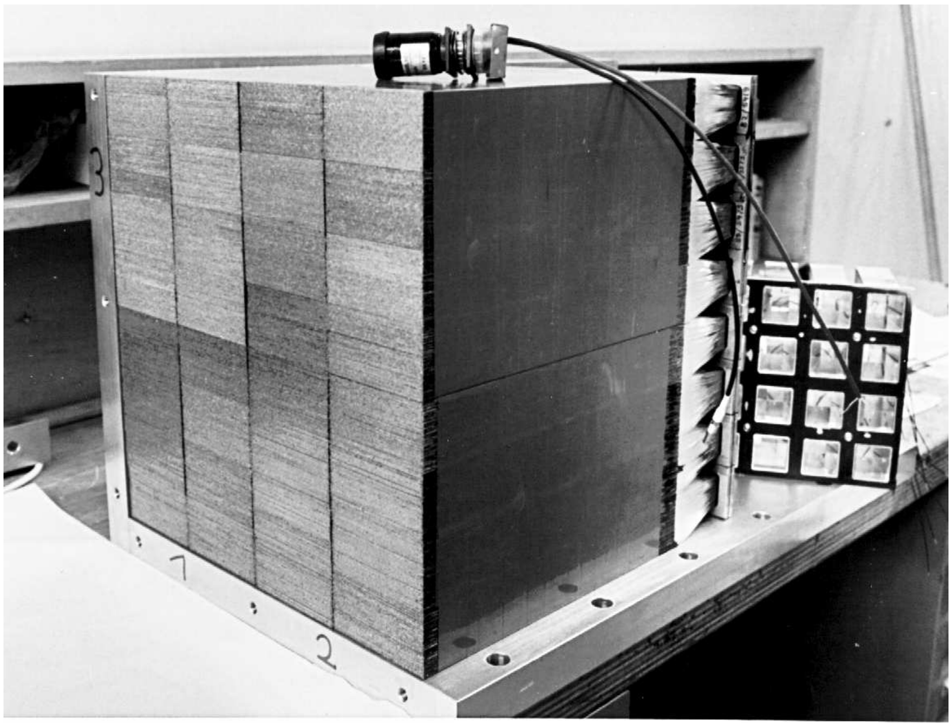

Figure 2: Photo of an array of 4 Supermodules (64 cells).

To avoid channeling effects which have been observed in all SPACAL calorimeters the lead fiber matrix is always orientated in such a way that no main symmetry axis is parallel to a particle trajectory.

The innermost module contains a 2 mm tantalum shield around the beampipe against synchrotron radiation. The fibers closest to this shield are bundeled seperately to act as a veto layer for shower leakage.

The hadronic section is built of single modules which measure 120 $\times$ 120 $\times$ 250 mm^3. The readout is done by 2" Hamamatsu R–2490-06 photomultipliers.

3. Performance of the Calorimeter

A number of the modules produced were submitted to test beam measurements at DESY and at the CERN SPS and PS. An energy scan was performed at an angle of 5° in the horizontal and 3° in the vertical direction to avoid channeling. Linearity was maintained up to 80 GeV to better than 1%. A common fit for the DESY and CERN data, taken with the 64 cell matrix shown in figure 2, yields a sampling term of $7.2\%/\sqrt{E}$ and a constant term of 1% (figure 3) giving a resolution of well below 2% at 30 GeV. For the DESY measurement 100 MeV have been subtracted in quadrature in order to account for the finite momentum resolution of the beam. Simulations have shown that fiber to fiber variations in light output, which are observed in the order of 5%, contribute with 0.5% to the constant term.

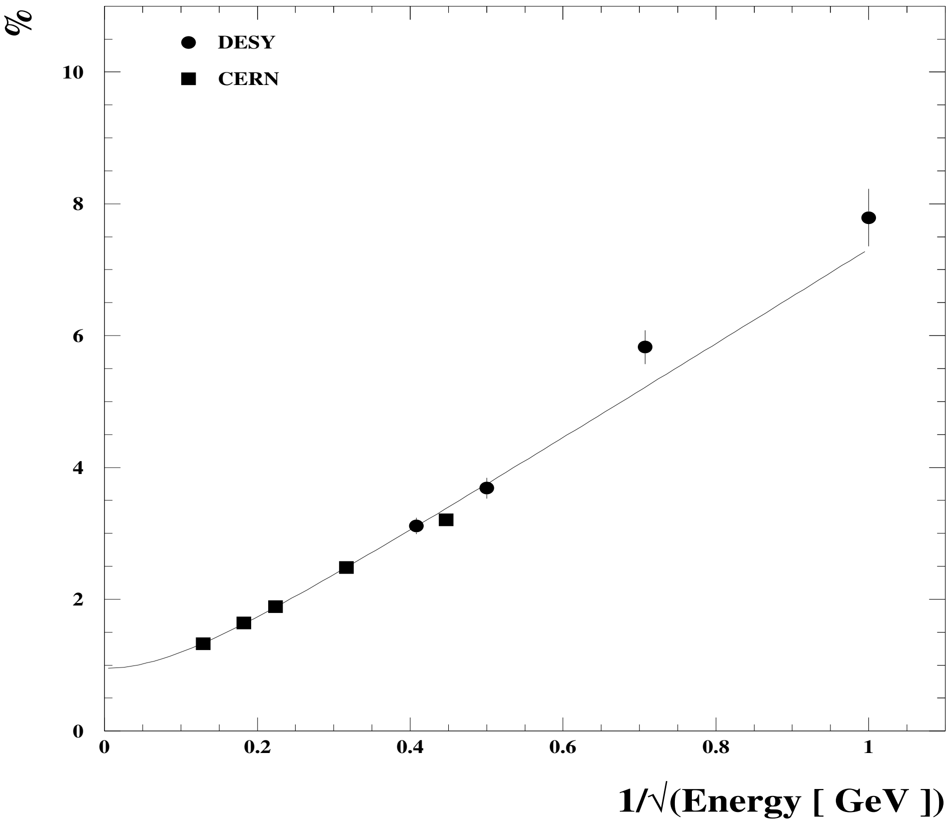

Figure 3: Energy resolution, measured with the modules shown in figure 2.

The light yield has been determined by comparison with a LED to be 2.8 ± 0.3 photo electrons per MeV. For minimum ionizing particles an energy deposition of 400 MeV has been observed. The time resolution was measured to be below 0.5 ns. The calorimeter shows a spatial resolution of 2.8 mm $/\sqrt{E} \oplus 0.4$ mm which translates to 1.9 mrad.

All produced modules were scanned from the front face with a beta source to determine the homogeneity of the supermodules[6]. The modules were scanned with variable step size between 1 and 2 mm in both directions using a ^{90}Sr source with a collimator of 1.5 mm. Within the submodules the response varied only with an RMS of 3 – 4% corresponding to the light yield fluctuations of the individual fibers. The scanning of the final modules revealed a decrease in the response at the cell boundaries of 5% over a width of approximately 2.5 mm. The different orientaions of the lead fiber matrix, to avoid channeling, change the lead fiber ratio at cell boundaries, showing a very localized decrease or increase in response of 10% as observed in the beta–scan. Inhomogeneities are seen in the beam measurements too.

For the hadronic section first test measurements at ITEP give an energy resolution for electrons of $13.3\%/\sqrt{E} \oplus 3.6\%$ and for hadrons of $71\%/\sqrt{E} \oplus 20\%$ for non leaking hadron showers (1Λ only!). The timing resolution is 0.9 ns and the light yield has been determined to 0.7 photo electrons per MeV. Recently a combined measurement of electromagnetic and hadronic modules has been carried out at CERN. The analysis is under way.

4. Summary

The design criteria for a new calorimeter to upgrade the backward region of the H1 detector have been presented. These goals led to the design and realization of a spaghetti calorimeter. The production for both the electromagnetic and the hadronic section will be completed in November 1994. The calorimeter will be installed in the H1 detector during the shut down 1994/1995.

Test measurements on the final modules show that the design goals for energy and time resolution have been met. Local inhomogeneities at cell boundaries in the order of 5%, measured with a beta scan bench, have been observed. As all modules were scanned carefully we plan a software correction for these inhomogeneities.

We are looking forward to taking the first physics data with our new calorimeter in 1995!

5. Acknowledgements

I wish to thank the backward upgrade group for their permanent support and stimulating interest in this project. Without the outstanding effort of the technical staff of DESY and the collaborating institutes this calorimeter would not be possible. Thanks to the organizers for a very enjoyable and interesting conference in Brookhaven.

6. References

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