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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Liquid scintillator calorimetry for the LHC

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Abstract

We report on the beam tests of full scale liquid scintillator modules designed for a very forward calorimeter for an experiment at the CERN Large Hadron Collider (LHC). Tests were performed in the electron beams of the SPS at CERN within the 20 and 150 GeV energy range. The response as a function of the beam impact point and incidence angle was measured.

1. Introduction

The liquid scintillator technique for the very forward calorimetry at an LHC experiment has known advantages related to high speed, low noise and radiation hardness. The proposed solution is a SPACAL-like calorimeter with liquid scintillator circulating in hollow light guides [1]. An R&D study is being performed as a collaboration between two Russian groups (one of them involved in the ATLAS project) and INFN Naples [2]. In this paper we report on the design, construction and test of two full scale prototype modules.

2. Module design and construction

The module has a parallelepiped shape with a cross-section of 66 × 66 mm^2 and 2380 mm length including a 380 mm long photodetector housing (Fig. 1).

It consists of a lead matrix confining 81 quartz tubes. Their inner diameter is 3 mm and the wall thickness is 250 μm. All tubes run parallel to one another along the module and parallel to the beam direction. The tubes are arranged in a square transverse pattern. The spacing (center-to-center) is 7.3 mm which provides the 6 : 1 volume ratio between lead and liquid scintillator.

The modules were constructed from grooved lead plates produced by casting. 2010 mm long stainless steel tubes with inner diameter of 3.8 mm and wall thickness of 200 μm were placed in the grooves. The lead plates were glued together using special 100 μm thick tape. The tape was put under and above the tubes. The assembly underwent some compression and high temperature. The compression was released after glue hardening. The stainless steel tubes coming out at both ends of the module were inserted into holes drilled in the stainless steel manifolds and then tin soldered. The front manifold has inlet and outlet pipes separated by a membrane. The back manifold is provided with a frame with a glass window to transmit the scintillation light.

The modules were washed with a purified alcohol flow circulated by a pump during a few hours and dried with air. The quartz tubes were inserted from the back of the modules. The last 10 cm of the tubes' far end were bent to form a bundle of a 42 × 42 mm^2 cross section.

The modules were filled with the MN + R45 scintillator which was available in the required quantity (about 4 l). Prior to filling with the liquid scintillator the modules were blown with nitrogen. After filling the liquid was circulated by a pump to remove bubbles. Then the outlet pipe was connected to the buffer volume filled up to $\frac{1}{3}$ with the scintillator and with nitrogen ($\frac{2}{3}$).

3. The test set up

In order to distribute the light delivered by the quartz tubes to the exit glass window the PM photocathode a 15 cm long Plexiglas light mixer was placed between the window and the PM. It also serves to translate the square light image at the exit window into a round one, so matching the 2 in. PM photocathode. A green LED was

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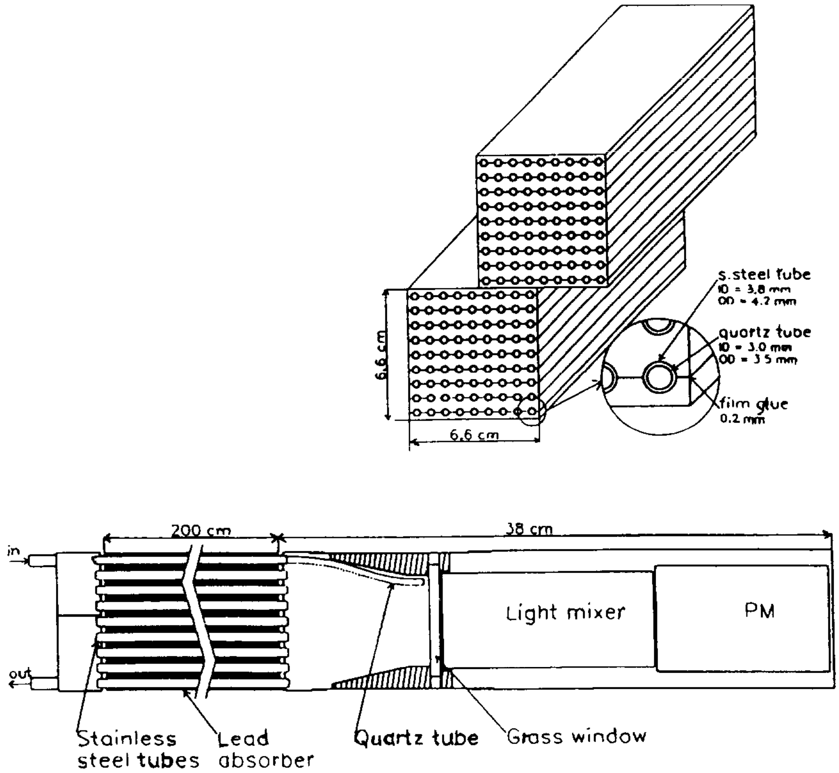

Fig. 1. Calorimeter module design.

fixed in a tiny pit on the side surface of the light guide. The signal from the PM (EMI 9839A) was amplified and digitized by a charge sensitive ADC LeCroy 2249W. The integration time was 200 ns. The absolute calibration (conversion of the ADC counts into a number of photoelectrons) was done by means of the LED. In order to be able to detect the signal from a single photoelectron the PM gain was increased with respect to the nominal low setting used during the beam tests to provide linearity. Relative normalization at different gain settings was done by means of a reference LED light pulse.

The light yield produced by a minimum ionizing particle (MIP) and the attenuation length were measured with cosmic muons hitting the module perpendicularly to the tube axis. The observed light yield corresponds to about 20 photoelectrons. The effective attenuation length is about 200 cm in agreement with single tube measurements. No degradation of the attenuation length was observed over a 90 days period.

The energy resolution of a very forward calorimeter for the LHC is largely dominated by the constant term. A 10% constant term for single hadrons seems to be adequate to achieve the physics goals [3]. Since neutral pions carry on average one third of the jet energy an electromagnetic constant term as large as 15% is sufficient.

The modules were tested in the H2 beam of the SPS. They were installed side by side on a movable support. Particles were sent onto the detector at various angles in the horizontal and vertical plane (θ_x, θ_y). Upstream of the modules, 5 scintillating counters and 2 Delay Wire Chambers (DWC) were installed. The trigger signal was produced by the coincidence of either of the 5 counters or only 3 of them. In the first case the beam spot was round with a 20 mm diameter, in the second case it was a square of 5×5 mm^2. DWCs allowed to determine the impact point position on the front face of the modules with an accuracy better than 0.5 mm. The modules were exposed to beams of electrons of 20, 40, 80 and 150 GeV.

4. Experimental results

Examples of the response to 80 GeV electrons hitting the centre of the module at different angles with the module axis (θ_z) are given in Fig. 2.

The asymmetric, non-Gaussian shape of the distributions has to attribute to the coarse structure of the module, i.e. the response depends on the particle impact point. Using the position information provided by the beam chambers we found that for particles hitting the module in the tube or nearby, the response is higher compared to that of particles hitting the absorber. The less the incidence angle and the higher the energy, the more distinct becomes the two-peak structure of the response distribution. The

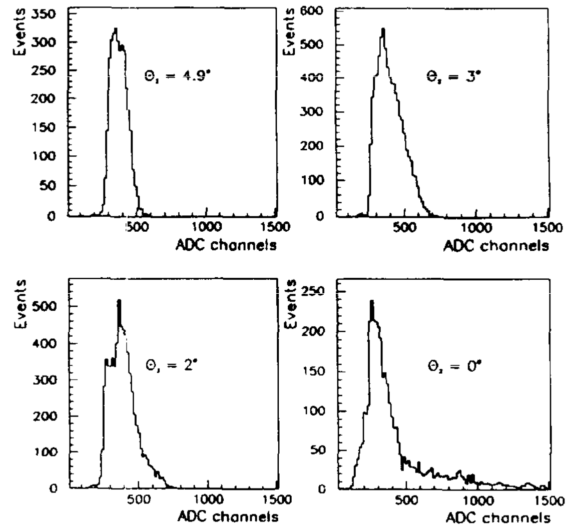

Fig. 2. Signal distribution for 80 GeV electrons at different angles.

peaks can be disentangled selecting particles according to the distance from the centre of the tube. This is illustrated in Fig. 3 for $\theta_z = 1°$ and 80 GeV energy.

A scan across the boundary of the two adjacent mod-

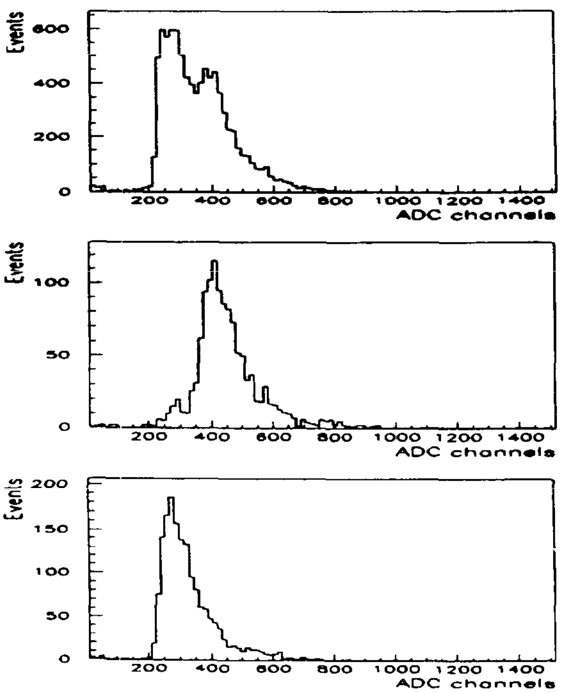

Fig. 3. Signal distributions for 80 GeV electrons entering the module at $\theta_z = 1°$. Top – all events, middle – events with the impact point within 2.4 mm distance from the center of the tube, bottom – events with the impact point distance between 3.4 and 4.8 mm from the center of the tube.

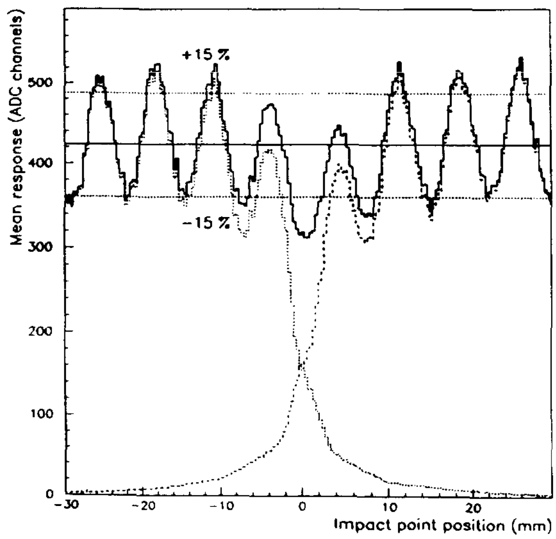

Fig. 4. Response to 80 GeV electrons as a function of the impact point position. $\theta_z = \theta_y = 2.9°$.

ules was performed at an incident angle of 3° in the vertical plane. Modules were moved in the horizontal direction in steps of 5 mm. Fig. 4 shows the response to 80 GeV electrons as a function of the X impact point. $X = 0$ complies with the boundary between the modules. Alternating minima and maxima correspond to the 7.3 mm center-to center distance between the tubes. The 10% drop around the boundary could be attributed to the 1 mm crack between the modules along the first 50 cm caused by the imperfect shape of one of the modules.

The energy resolution discussed in this section is defined as the rms/mean of the corresponding distributions.

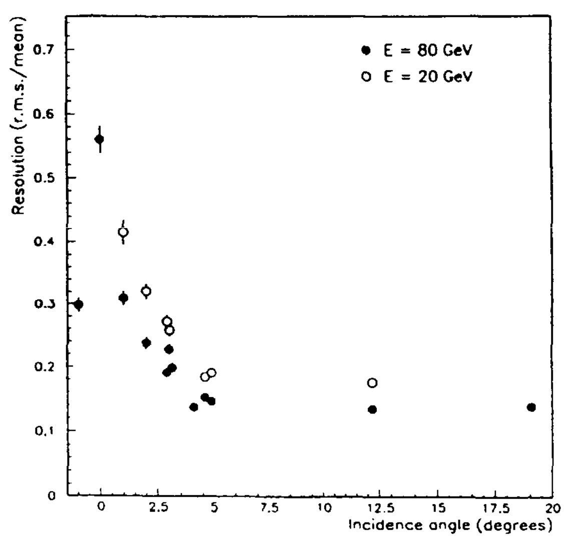

Fig. 5. The energy resolution as a function of the incidence angle.

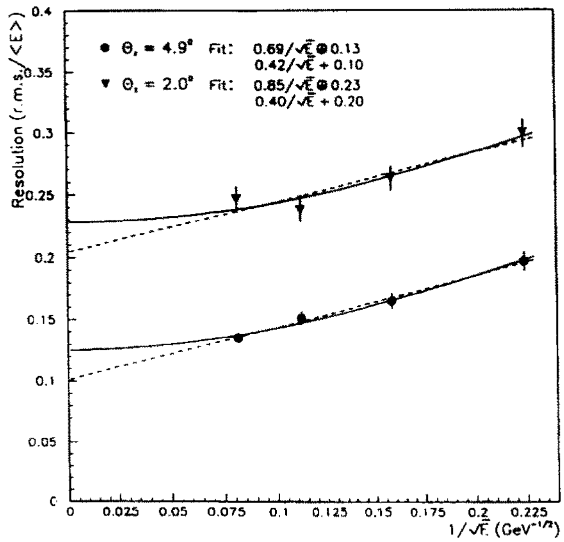

Fig. 6. The energy resolution for electrons as a function of energy.

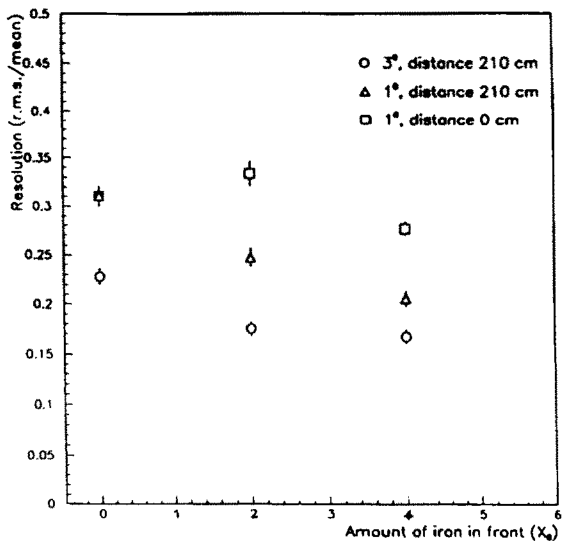

Fig. 8. The resolution as a function of the amount of material in front of the module for different distances.

Fig. 5 shows the resolution as a function of the particle incidence angle θ_z at 20 and 80 GeV. The points with close values of θ_z were obtained at different θ_x, θ_y. The resolution is almost flat above $\theta_z = 5°$ but it deteriorates significantly towards zero. Fig. 6 shows the energy dependence of the resolution at angles of 2° and 4.9°, relevant for a very forward calorimeter in an LHC experiment. The quadratic fit exhibits a slightly better agreement with the data than the linear one. One can conclude that the constant term for electrons is likely to be within the 10–20% range.

The linearity of the response to electrons was studied at different angles. Results are given in Fig. 7. The response at a given angle is linear over the energy range 20–150 GeV. The output signal per GeV at $\theta_z = 5°$ is 6% higher that the one at 4.9°. Similar measurements with pions are required before driving to a conclusion about its effect on the absolute energy scale for jet measurements.

The electromagnetic resolution is expected to improve by placing a preradiator in front of the module. Tests were done with an iron preradiator of 2 and 4 X_0 located at distances of 0 and 210 cm. In Fig. 8 one sees that with 4 X_0 the resolution improves by factor of ~1.5. At short distances the effect is marginal as we expected since secondaries are not enough spread in space.

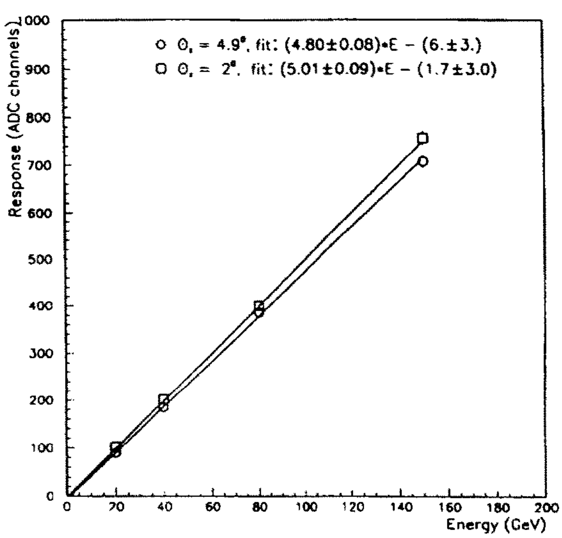

Fig. 7. Signal linearity for electrons at different θ_z.

5. Conclusions

We have constructed and tested with high energy electron beams two lead/liquid scintillator full scale modules designed for a very forward calorimeter to be used in a LHC experiment.

The response to electrons was studied for different incidence angles. The constant term in the energy resolution strongly depends on the incidence angle. A quadratic fit yields an increase of the constant term from 13% at $\theta_z = 5°$ up to 23% at $\theta_z = 2°$. The origin of such a term is well understood performing a transverse scan of the modules: the coarse structure of the module produces a nonuniformity with a regular pattern of about ±15% at $\theta_z = 3°$. The resolution improved with a preradiator located upstream of the module. The response at a fixed angle was found to be linear over the energy range 20–150 GeV. It turns out that the signal per GeV increases by 6% when the angle decreases from 5° down to 2°.

References

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[3] ATLAS, Letter of Intent for a General-Purpose pp Experiment at the LHC at CERN, CERN/LHCC/92-4, LHCC/I 2.