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BEAM TEST RESULTS OF LIQUID SCINTILLATOR CALORIMETER PROTOTYPE MODULES

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Abstract

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

Introduction

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

1 The module

1.1 The design

The module has parallelepiped shape with a cross-section of 66x66 mm^2 and 2380 mm length including a 380 mm long photodetector housing (Fig. 1).

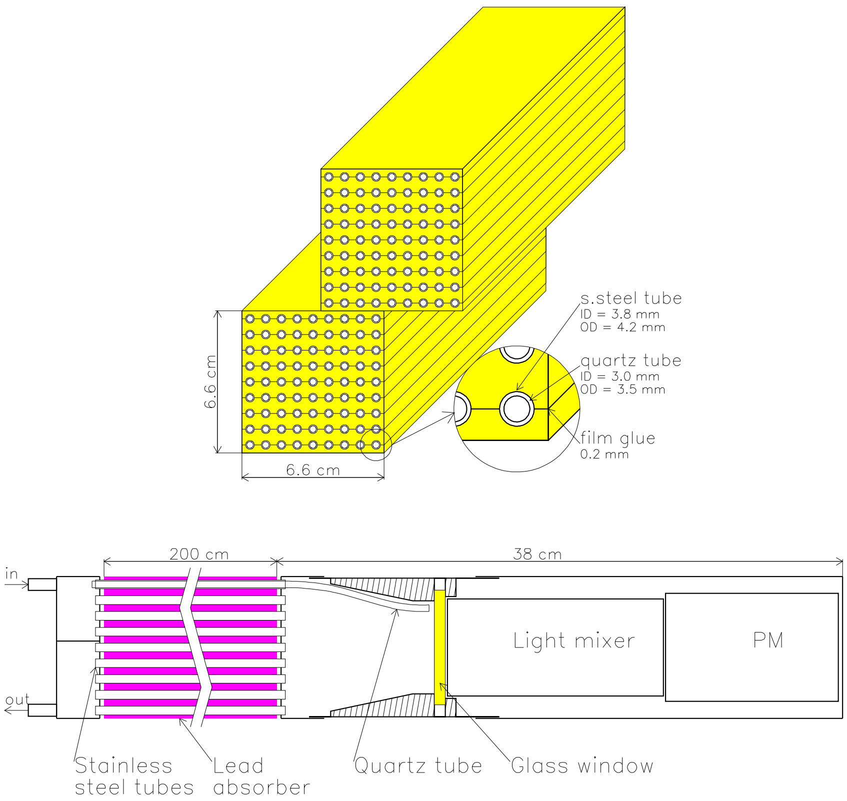


Figure 1: *Calorimeter module design*

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

1.2 The construction

The modules were constructed from grooved lead plates produced with casting technology. The 2010 mm long stainless steel tubes with inner diameter of 3.8 mm and wall thickness of 200μm were placed in the grooves. The lead plates were glued together using special 100μm thick tape. The tape was put under and above the tubes. The assembly underwent some compression and high temperature effects. The compression was released after glue hardening.

The stainless steel tubes coming out at both the 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 within a few hours and dried with air. The 2100 mm long quartz tubes were inserted from the back module end. The last 10 cm of the tubes' far end are bent to form a bundle of a 42x42 mm^2 cross section.

1.3 Filling with a liquid scintillator

To study the issues of the module filling with liquid scintillator, and the liquid circulation through the tubes, a 1.5 m long model made of glass tubes and manifolds was built. Liquid flows in the individual tubes were watched by adding a dye in a transparent liquid and pumping it through the system. Tests showed that a laminar flow without stagnation can be obtained provided the front manifold has a membrane placed in the middle. The membrane separates the module in two halves with the liquid flowing in the opposite directions in them.

It's worth mentioning that the high irradiation doses expected at the LHC are delivered to a small volume of a few per cent with of the entire volume of the forward calorimeter. Calculations show that at a flow speed of 20 cm/hour the liquid scintillator in the "hottest" modules (D^{year}_{peak} = 100 Mrad) will be exposed in a single pass to 0.1 Mrad before being stirred up in the recycling system.

1.4 Liquid scintillators

We performed a series of light yield and light transmission measurements with single tubes filled with different scintillators and exposed to ^{106}Ru source. Results of three promising candidates are shown in Fig. 2.

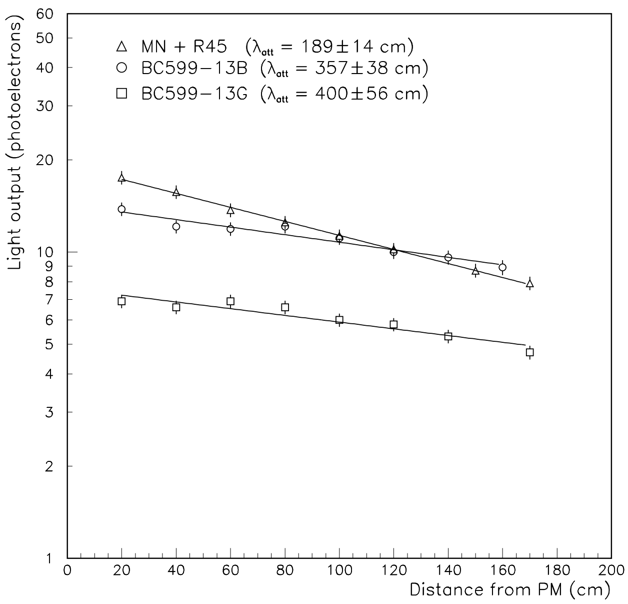


Figure 2: *Light yield for different scintillators as a function of the distance from PM*

They all are hydrocarbons with high refraction indicies. The two MN+R45 (methylnaphtalene based) and BC599-13G (BICRON product) are green emitters. BC599-13B emits in the blue.

Light attenuation contributes to the constant term in the hadronic resolution due to large fluctuations in the shower development. In this respect, the BICRON scintillators are more perspective. Anyhow, this contribution to the electromagnetic resolution reported in this paper is negligible.

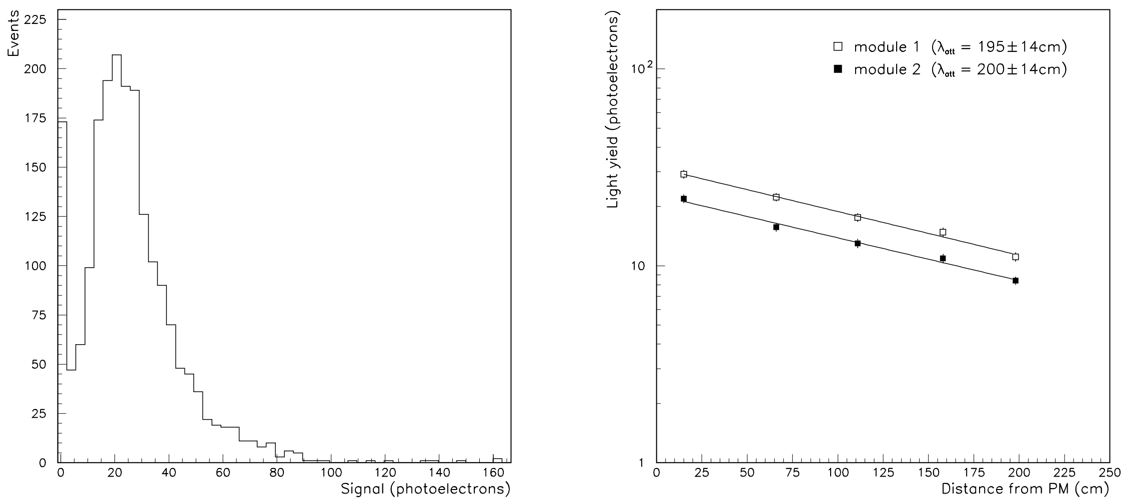
The modules were filled with the MN+R45 scintillator which was available in the required quantity (about 4 liters). Prior to filling with the liquid scintillator the modules were blown with nitrogen. After filling the liquid was circulated by a pump to remove bubbles. Then the outlet pipe was connected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

1.5 Light collection and read-out

In order to distribute the light delivered by the quartz tubes to the exit glass window over the PM photocathode a 15 cm long plexiglass 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” PM photocathode. A green LED was fixed in a tiny pit on the side surface of the light guide. The signal from the PM (type 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 using 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.

2 Cosmic tests

The light yield produced by a minimum ionizing particle (MIP) and the attenuation length was measured with cosmic muons hitting the module perpendiculaly to the tube axis. Results are given in Fig. 3.



(a) (b)

Figure 3: *The results of measurements with cosmic muons: (a) pulse height distribution measured at 15 cm from the exit window, (b) module light yield vs the distance from the exit window*

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 the 90 days' period.

3 Beam tests

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

3.1 Beam line and experimental set-up

The modules were tested in the H2 beam of the SPS at CERN. 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 composed of 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 5x5 mm^2. DWCs provided an 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 at energies 20, 40, 80 and 150 GeV.

3.2 Signal uniformity

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. 4.

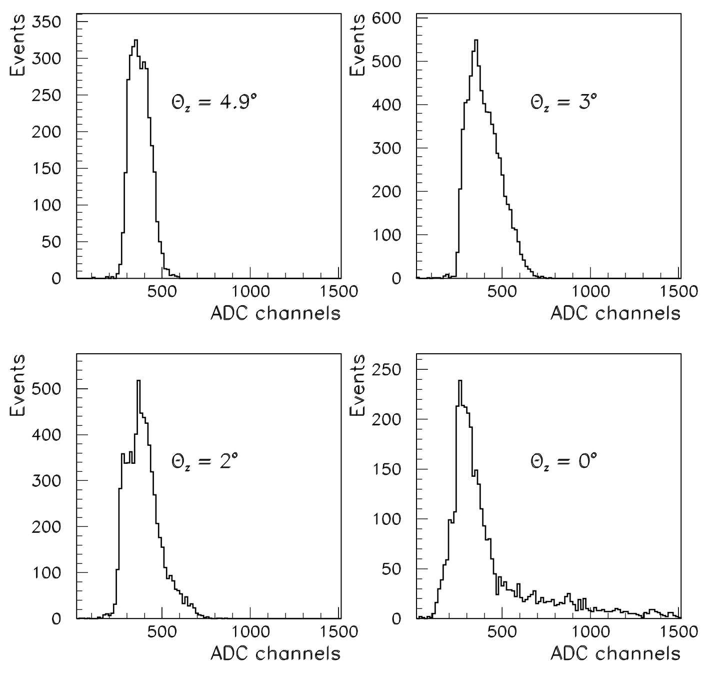


Figure 4: *Signal distribution for 80 GeV electrons at different angles*

The asymmetric, non-gaussian shape of the distributions should be attributed 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 peaks can be disentangled selecting particles according to the distance from the centre of the tube. This is illustrated in Fig. 5 for $\theta_z = 1^o$ and 80 GeV energy.

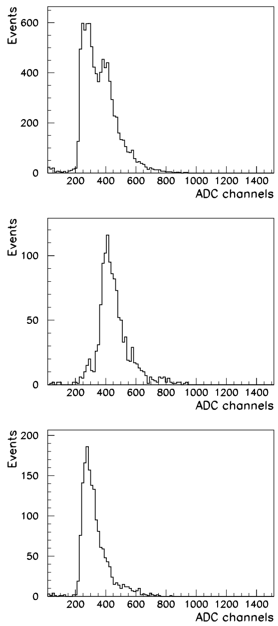


Figure 5: *Signal distributions for 80 GeV electrons entering the module at $\theta_z = 1^o$. Top - all events, middle - events with the impact point within 2.4 mm distance from the center of the tube, bottom - events with the impact point distance between 3.4 and 4.8 mm from the center of the tube*

The scan across the boundary of the two adjacent modules was made at an incidence angle of 3^o in the vertical plane. The modules were moved in the horizontal direction in steps of 5 mm. Fig. 6 shows the response to 80 GeV electrons as a function of the X impact point. X = 0 comply 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 a nonperfect shape of one of the modules.

3.3 Angular dependence of the energy resolution

The enregy resolution discussed in this section is defined as r.m.s./mean of the corresponding distributions.

Fig. 7 presents 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 $\theta_z = 5^o$ but it deteriorates significantly towards zero. Fig. 8 shows the energy dependence of the resolution at angles 2^o and 4.9^o relevant for the forward calorimeter at the LHC. The quadratic fit exhibits a slightly better agreement with the data than the linear one. From Fig. 7 and 8 one can conclude that the constant term for electrons is likely to be within $10 \div 20$ % range.

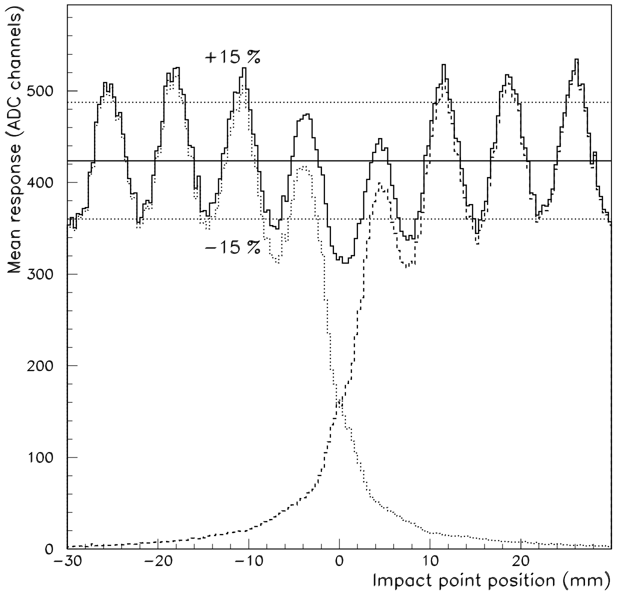


Figure 6: *Response to 80 GeV electrons as a function of X impact point position.* $\theta_z = \theta_y = 2.9^o$

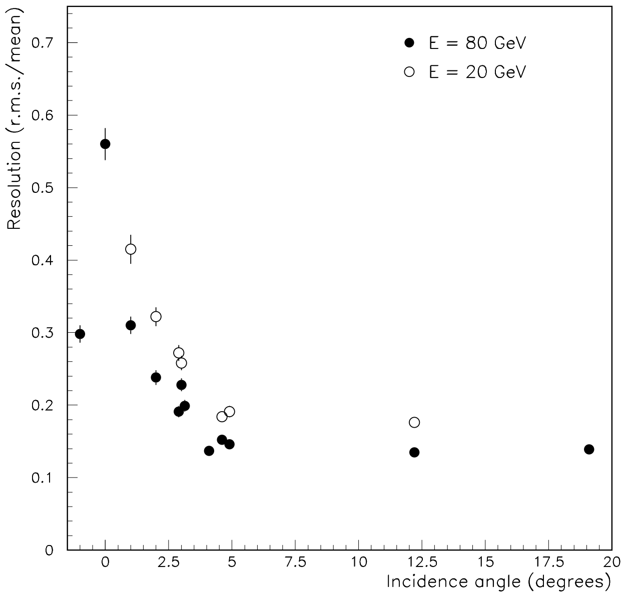


Figure 7: *The resolution as a function of the incidence angle*

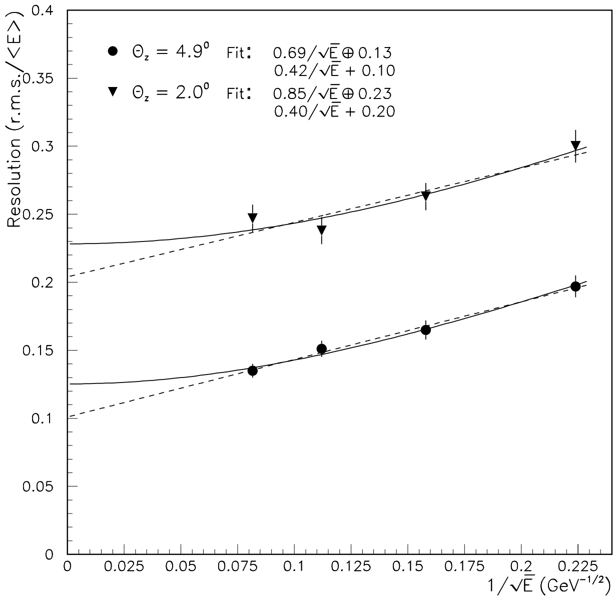


Figure 8: *The resolution for electrons as a function of energy*

3.4 Signal linearity

The linearity of the response to electrons was studied at different angles. The results are given in Fig. 9. The signals at a fixed angle are found to be linear over the energy range 20 ÷ 150 GeV. It turns out that the signal per GeV at $\theta_z = 2^o$ is 6 % higher that the one at 4.9^o. Similar measurements with pions are required before driving to a conclusion about its effect on the absolute energy scale for jet measurements.

3.5 Effect of material in front of the module

The electromagnetic resolution would be improved 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. Fig. 10 shows that the response becomes narrower and almost symmetric when the preradiator is far upstream. The effect in terms of energy resolution is given in Fig. 11. At 4 X_0 the resolution improves by factor of $\sim$ 1.5. At a short distances the effect is marginal as we expected since secondaries are not spread in space.

3.6 Response to π^0's

The simulation of π^0 response was based of the following assumptions:

- no correlation between decay gamma responses
- response shape to decay gamma was approximated by the measured response to electron of nearest energy (20, 40, 80 or 150 GeV).

Fig. 12 shows the simulated signal to π^0 of 80 GeV in comparison with the observed signal to 80 GeV electron. The π^0 signal shape is more smooth and symmetric, the resolution improves for a few per cent.

Conclusion

We have constructed and tested in high energy electron beams two liquid scintillator full scale modules designed for the Forward Calorimeter at the LHC.

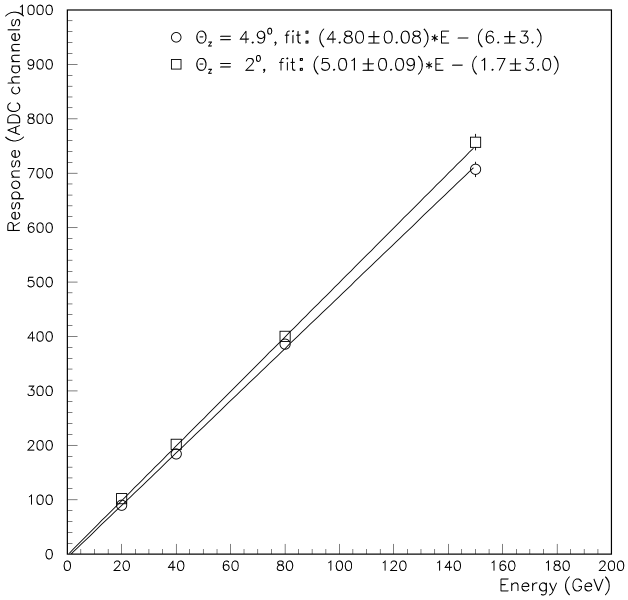


Figure 9: *Signal linearity for electrons at different* θ_z

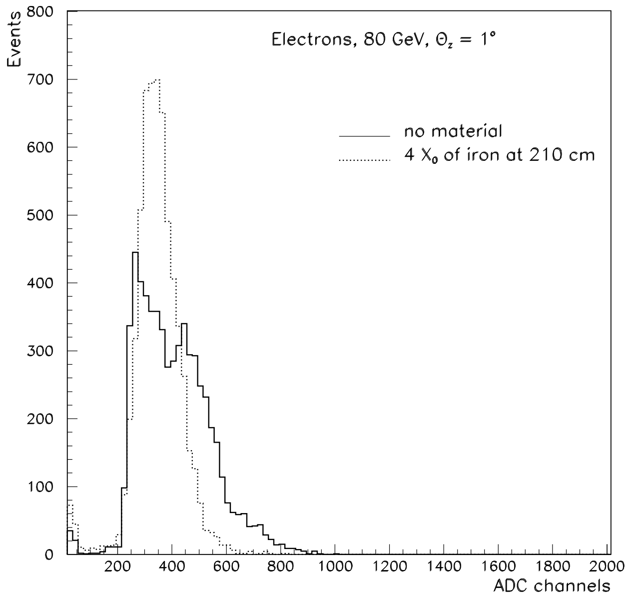


Figure 10: *Effect of material in front of the module*

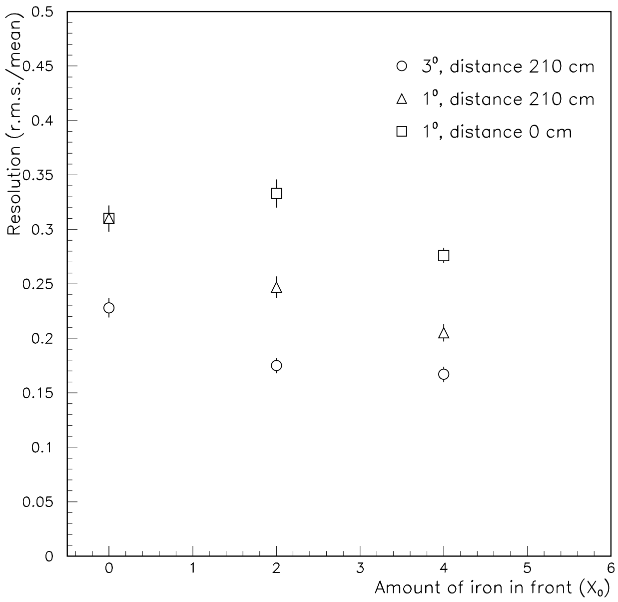


Figure 11: *The resolution as a function of amount of the material in front installed at two different distances*

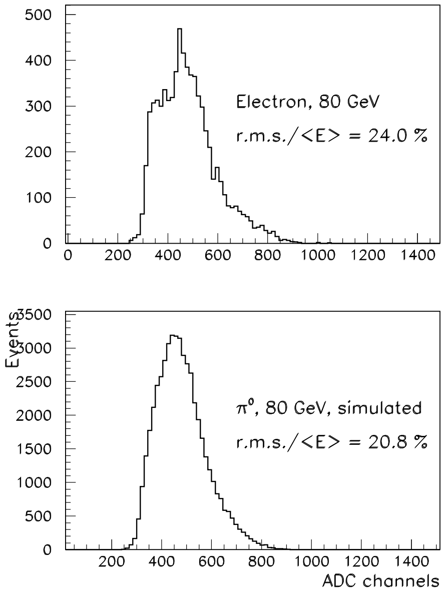


Figure 12: *Observed response to 80 GeV electron hitting the module at θ_z = 2^o (top) and the simulated response to π^o of the same energy (bottom)*

Response to electrons was studied at different incidence angles. The resolution constant term depends strongly on the incidence angle. The quadratical fit yields an increase of the constant term from 13 % at $\theta_z = 5^o$ up to 23 % at $\theta_z = 2^o$. The origin of such a constant term is well understood from the lateral scan data: the coarse structure of the module produces a nonuniformity with a regular pattern of about ± 15 % at $\theta_z = 3^o$.

The resolution improves when a preradiator was located upstream of the module.

The signals at a fixed angle were 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^o down to 2^o.

Acknowledgements

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References

[1] A. Artamonov et al., in Proc. II Int. Conf. on Calorimetry in High Energy Physics, October 1991, Capri (Italy)

[2] A.Artamonov et al., in Proc. III int. Conf. on Calorimetry in High Energy Physics, September-October 1992, Corpus Christi, Texas (USA)

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