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Hadron Calorimetry using scintillator Tiles and WLS fibers: the Tilecal/ATLAS

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Abstract. Scintillator Tiles read out by WLS optical fibers are the active medium of the Tilecal, the barrel hadron calorimeter of the ATLAS detector. The scintillator tiles are oriented perpendicularly to the beam axis and light is detected by photomultiplier tubes.

Several optical components have been tested in the laboratory and in calorimeter prototypes. The first real scale prototype of a barrel module was built and tested by the first time in 1996. The response to beams of muons and pions allows to study the performance of the calorimeter, namely its uniformity. Preliminary results are presented.

INTRODUCTION

The Tilecal, the barrel part of the hadron calorimeter of the ATLAS detector, is a sampling calorimeter using 3mm thick scintillator tiles read out by 1mm diameter WaveLength Shifting (WLS) fibers as active medium and iron as absorber [1]. The barrel part is subdivided in 64 modules, each one made of stacks of repeating elements, with 18 mm thickness (periods). Each period is a stack of four layers: the first and third layers are formed by large trapezoidal steel plates (masters), the second and fourth layers are formed by small trapezoidal steel plates alternating with scintillator tiles (figure 1). An innovative feature of the design is the orientation of the tiles which lie in the r-ϕ plane, perpendicularly to the beam axis [2].

The first real scale module (the barrel module 0) was tested by the first time in 1996. The barrel module 0 has a front face area of $560 \times 22 cm^2$ spanning $\frac{2\pi}{64}$ in the azimuthal angle with a radial depth of 7.6λ at $\eta=0$. Three depth segmentations are defined with thicknesses equal to 1.5λ for the first sampling, 4.2λ for the second sampling and 1.9λ for the third one at $\eta=0$. The barrel module 0 has a projective tower read out with a granularity in $\Delta\eta \times \Delta\phi$ equal to 0.1×0.1 for the first two samplings and 0.2×0.1 for the third sampling. There are 11 tile sizes in the radial depth. The transversal segmentation within the calorimeter is achieved by grouping fibers reading out different tiles in one photomultiplier. Two photomultiplier tubes (PMT) are required to read out each cell: one to the right side and the other to the left side of the tiles. The PMT's are housed in the drawer inside the girder structure located in the outer face of the modules.

In this paper the optical components of the calorimeter are described and the results on the light yield uniformity and response of the barrel module 0 to pions and muons are presented. Other aspects on the performance of the calorimeter are described in ref [3].

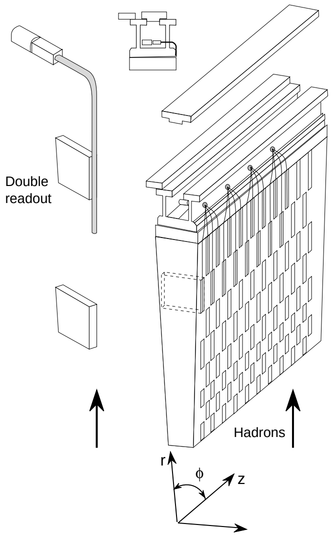

FIGURE 1. The periodic structure of the Tilecal.

THE OPTICAL COMPONENTS

The scintillator tiles for the Tilecal are produced by injection molding technique, using polystyrene as scintillator matrix base, and PTP and POPOP as dopants. The ionizing particles crossing the tiles induce the production of light in the base material of the tiles, with wavelength in the UV range which subsequently is converted to visible light by the scintillator dyes. The wavelength shifting process is assured by the combination of 1.5% PTP and 0.05% POPOP dopants. The light generated by ionizing particles is internally reflected between the tile surfaces and transmitted to the WLS fibers. The uniformity of the light output of a tile depends on the local light yield uniformity and on the tile transparency. The optical parameters are sensitive to the base material quality, to the injection conditions, to the homogeneity of the dopants distribution in the tile and to the tile thickness.

Central scans with a ^{90}Sr source in the tiles show non-uniformities exceeding the design requirement of 5% near the read out fibers (figure 2). The tiles are wrapped with Tyvek, a diffuser material with an opacity of 97% and a reflectivity of 95%.

To reduce the non-uniformities, a mask was applied on the tyvek wrapper to absorb part of the light which would otherwise be reflected back into the tile [4]. The ideal mask should cover a complex surface constituted by regions where the light output is more than 5% above the tile average. For the barrel module 0 only a trapezoidal black strip was used and it was decided that no masking was required on the 5 smallest tiles, because their uniformity was acceptable [5].

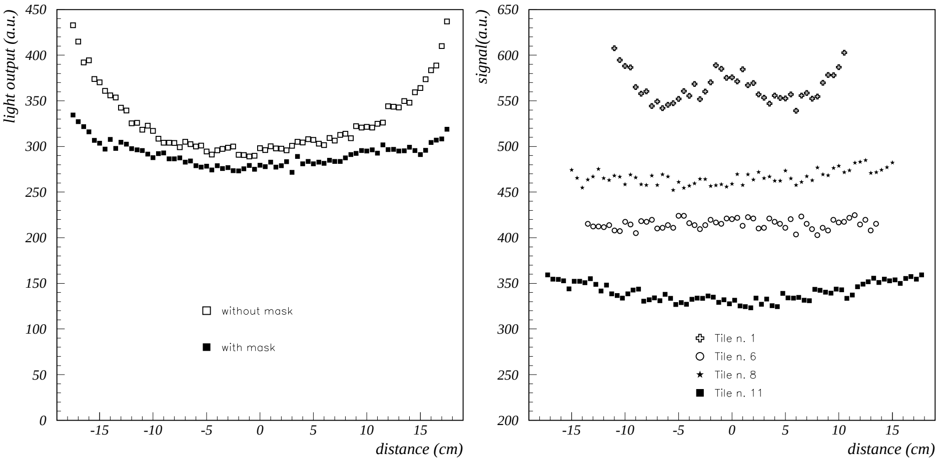

FIGURE 2. Central scan for some tiles of the barrel module 0. On the left, a scan for tile size #11 with and without mask; on the right, only the three largest tiles are masked.

The WLS fibers collect the scintillation light from each side of the tiles and transmit it to a PMT. Each fiber collects light from one or two tiles and this is accomplished by the fluor in the fiber which absorbs the blue light from scintillator and re-emits it to longer wavelengths. The light propagated through the fiber is read out by a PMT in one of the fiber end. The other fiber end is aluminized in order to increase the light collection in the PMT. The light collection should be efficient, fast, with low attenuation along the fiber length and the fibers should be radiation hard.

Sample fibers from three producers (Bicron, Kuraray and Pol.Hi.Tech) have been (and are still being) studied in laboratory in a comparative way. These fibers are characterized in what concerns to light output, attenuation length, radiation hardness and mechanical flexibility. By their quality, the double clad Kuraray fibers Y11(200) doped with 600ppm UV Absorber were chosen to equip the module 0.

Many factors contribute to fiber-to-fiber response fluctuations. These include fiber diameter, fiber light yield, attenuation length and aluminization quality.

The light yield measured (I), when fibers are excited at different distances (x) from the PMT (figure 3), can be parameterized by a sum of two exponentials with reflection (R) at the aluminized end, given by the following equation [6]:

$$I = I_{o,s} e^{\frac{-X}{L_{short}}} + I_{o,l} e^{\frac{-X}{L_{long}}} + R\{I_{o,s} e^{\frac{-(2L-X)}{L_{short}}} + I_{o,l} e^{\frac{-(2L-X)}{L_{long}}}\} \qquad (1)$$

The flexibility of the WLS fibers for the Tilecal is essential because the routing of

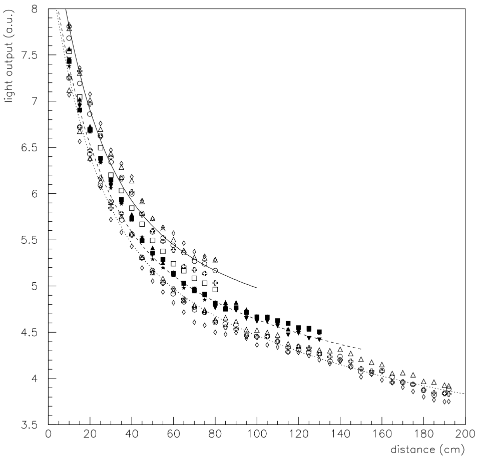

FIGURE 3. Light output produced by 1m, 1.5m and 2m long aluminized fibers. The fibers are excited with light produced by a Tilecal scintillator.

the fibers to the PMTs requires that they are bent with curvature radii larger or equal to ~5cm causing some mechanical stress. The bending can affect the optical properties of the fibers, since it introduces mechanical damage to the fiber surface, namely small micro-cracks in the cladding [1].

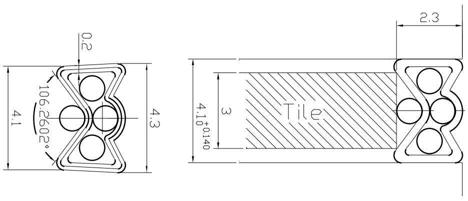

FIGURE 4. Boxing of the profiles into the grooves of the module.

To allow the optical coupling between the fiber and the tile, profiles made of high impact white polystyrene doped with TiO_2 to provide a good diffuser reflectivity have been designed and prototypes have been constructed (figure 4). The elasticity of the plastic material allows an easy insertion of the profiles into the grooves of the calorimeter. The profiles box into the grooves of the module by a simple pressure action. The dimensions of the profiles should cope with the grooves dimensions and tolerances. Each profile gives support to four fibers, but only one of the fibers is in optical contact with the tile, collecting the light that is produced in the tile. The profiles are in development phase.

THE LIGHT YIELD UNIFORMITY

The light output of a Tilecal cell depends on many parameters among which the most important are the tile and the fiber response. To get the cell geometry of the module 0, tiles of several sizes and fibers of several lengths are grouped in the same photomultiplier, leading to non-uniformities within cells and different light outputs for different cells. Light budget calculations (the product of the tile response by the fiber response) were done to design the fiber routing configuration. The minimization of the non-uniformities within a cell and the maximization of the total light output are the most important conditions used to design the fiber routing. The uniformity response of the light yield of the barrel module 0 was studied using two sources of information:

- the light yield produced by the ^{137}Cs source passing through the tiles of the module;
- the light yield produced in the cells by 180 GeV muons impinging the barrel module 0 at $\theta = 90^o$;

The ^{137}Cs data was taken passing the source through all the tiles during the calibration of the barrel module 0. In the following analysis the integral of the calibration curves normalized to the width of the cell was used. This quantity is proportional to the amount of light produced by the source and collected in the PMT, and to the gain of the PMT [1,7].

To estimate the energy loss by muons in each cell for each tile size, a fit with a Moyal function was done to the total energy deposited in each cell and the most probable value (MOP) was taken from the fit (fig. 5, left). The signal produced by muons in each cell was normalized to the size of the cell (18mm×number of tiles in the cell).

The light yield studied with the ^{137}Cs source shows non-uniformities with a rms value of the order of 8% while the non-uniformities on the light yield measured with muons have a rms value of the order of 10% (preliminary results). A study of the correlation between the Cesium and the muon data shows a correlation with a rms value of the order of 7%.

RESPONSE OF THE BARREL MODULE ZERO TO MUONS AND PIONS

The Tilecal can identify muons with energies above 2 GeV [8]. These muons lose in average about 2 GeV in the whole calorimeter. The energy loss spectrum approximately follows a Landau distribution with high energy tails due to energetic δ rays as well as radiative losses. Figure 5 shows the most probable value of the energy losses which increase with the energy of the beam due to the increasing probability of radiative processes. The most probable value varies from ~2.4GeV to ~2.8GeV for incident muon energies between 10 and 180GeV, which represents a variation of ~ 15% over the whole range studied.

The η uniformity of the barrel module 0 response to 180 GeV muons and 100 GeV pions has been studied as a function of the pseudo-rapidity η and impact

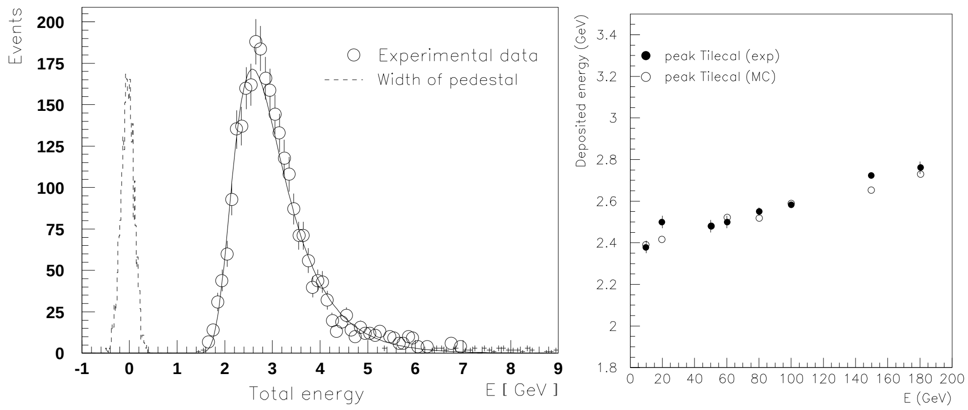

FIGURE 5. Detection of muons in the Tilecal: Left: Muon energy loss spectrum for 100GeV muons at η=0.55, a fit with a Moyal function is superimposed; Right: Most probable value in module 0 as a function of the muon beam energy.

point in the front face of the module [9]. For polar angles close to zero there is a modulation on the signal produced by 180 GeV muons which is a consequence of the structural periodicity of the module and the correspondent oscillation in the scintillator sampling fraction. Muons that crossed the module traversing almost only iron produce small signals (figure 6) while muons that cross mainly scintillator produce large signals. This is very clear for η near zero, where the amplitude of the modulation represents about 60% of the mean energy loss by muons in the module. The modulation has periodicity of ~9mm, which is one half period of the barrel module 0, and the respective period increases with η.

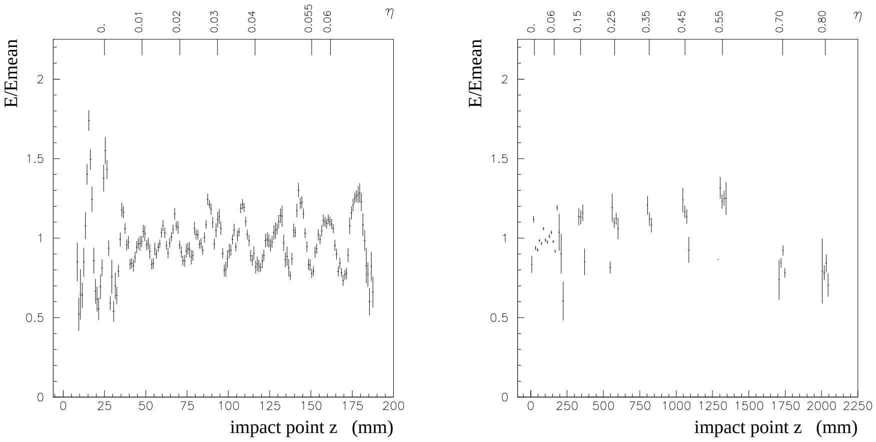

FIGURE 6. η response of the barrel module 0 to 180 GeV muons (test beam data). (a) small η values; (b) whole η range.

For 100 GeV pions a modulation on the signal for small η values can be seen (figure 7). This effect is expected to be strongly suppressed in the ATLAS environment because the electromagnetic compartment is in front of the Tilecal. The pion shower will start in the electromagnetic calorimeter and than the response will be less sensitive to the variations in the sampling fraction.

The non-uniformities measured over the whole η range of the barrel module 0 present a rms value of the order of 2%. The decrease in the signal for η <0.09 and η >0.85 is due to the lateral and longitudinal leakage. Note that only one half of the barrel module 0 is instrumented with optics and electronics, and for small η values the shower enters the non-instrumented part of the module.

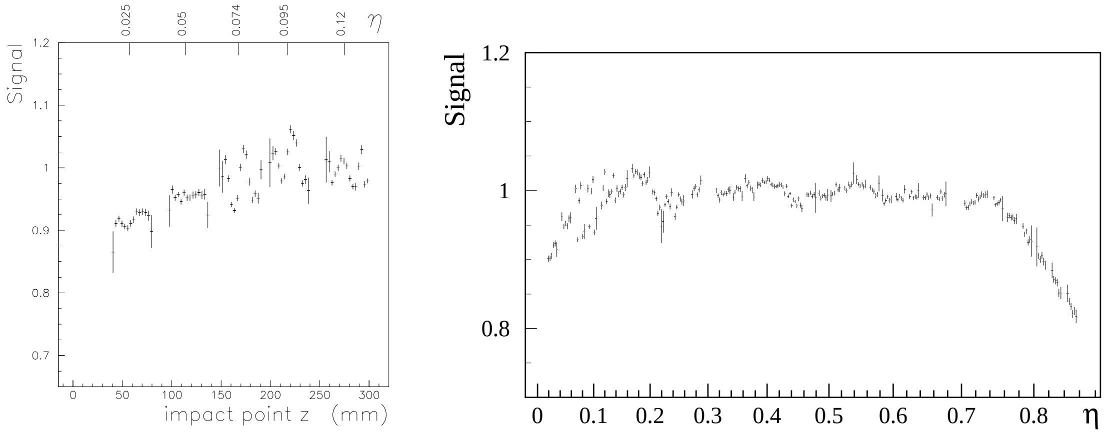

FIGURE 7. η response of the barrel module 0 to 100 GeV pions (test beam data- preliminary results). Left: small η values; right: whole η range.

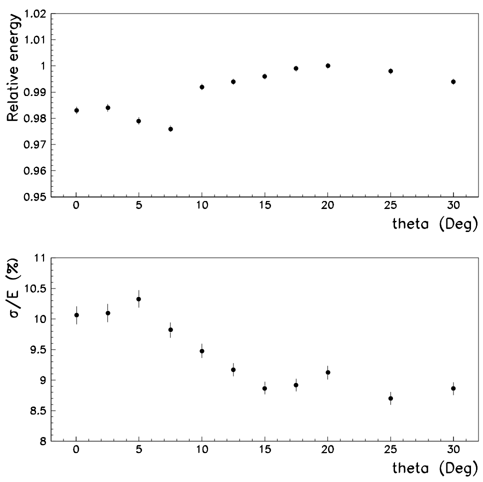

FIGURE 8. Top: Mean energy of 50 GeV pions in module 0 as a function of θ. Bottom: The corresponding relative resolution $\frac{\sigma}{E}$. The values are normalized to the value at 20^o.

Figure 8 shows the variation of the energy deposited by 50 GeV pions in the module 0 normalized to the 20^o point. The response is uniform except in the range from 0^o to 8^o where the response of the calorimeter is 2% smaller, because in this range the pions showers enter the non-instrumented part of the module. The bottom figure shows the corresponding resolution which is about 9% in the range above 15° and slightly worst bellow 8° ($\sim 10\%$), due to the large variations in the sampling fraction for small η values and to the lateral leakage [1].

CONCLUSIONS

The Tilecal barrel module 0 was instrumented with optics and electronics and was tested during 1996. Preliminary results for the response to muons and pions are in agreement with the expectations. The most probable value of the muon energy loss in module 0 increases with the energy of the beam showing an increase of about ~15% for muon energies between 10 and 180GeV. The η response of the barrel module 0 to muons shows a modulation for small η values that is a consequence of the structural periodicity of the module. The response of the barrel module 0 to pions is uniform over almost the whole θ range, except in the zone where the shower enter the non-instrumented part of the module. The resolution of the barrel module 0 for 50GeV pions is about 9%.

ACKNOWLEDGEMENTS

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