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Routing of the fibers in module 0

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Abstract

We report on the method used in the design of the routing of the fibers in Module 0.

Contents

1 Introduction

The routing of fibers in Tilecal imposes a delicate compromise between optical requirements and mechanical and geometrical constraints. Light budget calculations aimed to find the best uniformity of the calorimeter without loss of signal. Then, maquette instrumentation with fibers, allowed to find the best path for the fibers and the method for insertion, if the configuration was compatible with the mechanical and geometrical constraints.

We begin with the presentation of the guidelines to the light budget. Parametrizations of tile and fiber light output have been used in order to make light budget calculations. We present these parametrizations and the main results of the measurements that led to the parameters we used. The readout cell geometry has already been described in an Atlas internal note [1], and we present here a summary of the points that were needed for this work. The routing of fibers and readout configurations followed an evolution that was dependent on the results of light budget calculations. This evolution is described, therefore justifying the proposed solution. Finally, this solution is presented, with the light output and uniformity foreseen.

2 Light budget requirements

The light output of a cell depends of many parameters, mainly on the tile and fiber response. The Tilecal cells group several tile sizes and several fiber lengths in the same cell [1], leading to non-uniformities of light output inside a cell, and different light outputs for the several cells.

The goal of the light budget calculations was to get a fiber routing configuration respecting the following conditions:

- non-uniformity inside the cells should be small (prototype values of about $\pm 5\%$ used as guiding numbers)
- the light output should be the maximum possible, to keep prototype photostatistics
- the fiber length should be the minimum, to minimize fiber direct response in the girder region, and minimize the cost

- the spread of light output from cell to cell should be small, to allow PMT's to work at similar gains

To allow the estimation of the relative light output for the studied solutions of the routing, a very simple optical model similar to that presented in [2] was used. In a rough aproximation the light output that is read by the PMT for each tile depends multiplicatively on the light output of the tile and on the light output of the fiber that reads that tile,

$$I_{PMT}(t, f) = I_t \times I_f \tag{1}$$

where the tile and fiber light outputs, I_t and I_f, are both obtained from parametrizations.

3 Parametrization of the tile light output

It was shown in previous works [2] that the tile light output, in a rough approximation, is inversely proportional to the tile area A_t, and directly proportional to the tile-fiber coupling length L:

$$I_t = a + b \times \frac{L}{A_t} \tag{2}$$

The Tilecal tiles are produced by injection molding technique, and the parameters obtained with different production sets of tiles may change by non-negligible amounts. In particular, the tiles for module 0 are the first tiles produced with areas up to twice the areas of the largest tiles of the prototypes. By the time this study was proceding, only a set of 11 tiles, one of each size, was available. They were measured, to get a representative parametrization, and the results are shown in Fig. 1.

The results show a good agreement with the linear dependence on L/A_t of eq. 2 and the parameters of the fit to the experimental points are a = -25.4 and b = 3574.

4 Parametrization of the fiber light output

The fiber light output has been parametrized as the sum of two exponentials with reflection in the aluminized end,

$$I_f(x,L) = I_{fI}(x,L) + I_{fR}(x,L) \tag{3}$$

$$I_{fI}(x,L) = I_0^{short} \times e^{\left(-\frac{x}{L_{att}^{short}}\right)} + I_0^{long} \times e^{\left(-\frac{x}{L_{att}^{long}}\right)} \tag{4}$$

$$I_{fR}(x,L) = R \times \left(I_0^{short} \times e^{\left(-\frac{2L-x}{L_{att}^{short}}\right)} + I_0^{long} \times e^{\left(-\frac{2L-x}{L_{att}^{long}}\right)} \right) \tag{5}$$

L_{att}^{short} is the short attenuation length, L_{att}^{long} is the long attenuation length, $I_0^{total} = I_0^{short} + I_0^{long}$ is the light yield, R is the reflection coeficient, x is the distance from the PMT to the point in the fiber were the light is colected and L is the fiber length. The parametrization with the sum of two exponentials has already been used with fibers of this type [3] and the generalization for the case with reflection is straightforward, assuming light from short attenuation length and long attenuation length propagations reflect the same way in the aluminized end.

The values used for the attenuation lengths and light yield were based on the measurement of 1995 fibers (Kuraray Y11(200)MS, with 600 ppm of UV absorber), for 1.5 and 2 m long fibers (table 1). These were the fibers available at the time our study was going on and are of the same type of the ones used in module 0. The reflection coeficient was estimated from the preliminary measurements of 1996 fibers, with a value of 70%.

Length (cm)	I_0^{short} (a.u.)	L_{att}^{short} (cm)	I_0^{long} (a.u)	L_{att}^{long} (cm)
200	3.08	20.8	4.72	303
150	3.06	20.8	4.82	315
100	3.17	19.3	5.02	260
used	3.1	20.	4.8	310.

Table 1: Fiber parameters.

The results for the 1995 fibers are shown in Fig. 2. The plotted values are the ones obtained with the aluminized fibers, and the lines correspond to the parametrizations obtained for each length, using the reflection coeficients measured for those fibers (50% for 2 and 1.5 m long and about 45% for the 1 m long fibers).

In each point of the fiber, the light output deviation of the parametrized value may reach $\pm 5\%$. Measurement of shorter fibers (1 m long, also in table 1) showed slightly different parameters, and this behavior should be taken into account in future calculations.

5 Readout configurations

A small computer program was implemented to simulate the light output and uniformity, as a function of fiber and tile parameters and the options adopted for the routing. Routines describing the necessary aspects of geometry of the calorimeter and the tile and fiber parametrizations were built, and the uniformity in each cell was obtained as a function of cells-PMT configuration - *readout configuration*, in this note - and of the criterium used to define the fiber lengths within each cell.

5.1 Geometry

The first instrumentation of barrel MODULE 0 has been done in the half module corresponding to the negative η region. The readout cell geometry has been fully described in [1] and we summarize here the information that was needed for this work.

The Tile calorimeter is radially segmented into 3 layers [4] that correspond to 3 longitudinal samplings. There are 11 tiles in radius, distributed in a non uniform radial structure - 3 tiles of 10 cm , 3 tiles of 13 cm, 3 tiles of 15 cm and 2 tiles of 19 cm, tiles 1 to 11, respectively - and divided into the 3 longitudinal samplings. Each of this samplings is segmented, by grouping in the same PMT bundle fibers from different scintillators, in a way that grants an η (pseudo) projectivity.

In the barrel region, the first two of these samplings have a 0.1 segmentation and the third 0.2. The first sampling - A - is made with the 3 tiles of 10 cm radial depth and the third - D - with the two 19 cm tiles. The second sampling - BC is internally divided into 2 subsamplings - B and C - made with the 3 tiles of 13 cm and the 3 tiles of 15 cm radial depth, respectively, in order to provide more (pseudo) projectivity.

In Figs. 3 and 4 this cell geometry is shown, as it is viewed from side 1.

The tiles are read by fibers that run radially from the first one to be read to the girder. In the girder region they are routed to the PMTs. Each fiber can read either one or two tiles: if it reads the second tile of (sub)sampling is called *short* fiber, in this note, if it reads the first and third tile of (sub)sampling is called *long* fiber (with the exception of sampling D, where there are only two tiles and each fiber reads only one tile).

5.2 Fiber length calculations

The fiber length is a key parameter for the light budget. For its determination a constant compromise between what is mechanicaly feasible, simple to implement and respects light budget requirements has been kept.

it was taken into account that fibers loose signal when curved to certain values [5]. A limit ray of 5 cm was used as a guiding value.

The length of fibers can be divided into two components:

- one, of the part of the fiber that runs radially to the girder; it is defined by the (sub)sampling and tile number read by the fiber;
- the other, of the part of fiber that is routed to the PMT in the girder; it depends on the criterium used to define the fiber lengths, and on the readout configuration.

We refer to the first component as *geometric* component, and to the second as *routing* component.

The geometric component is obtained by summing:

- the lengths of the tiles from the first one to be read by the fiber till tile 11;
- an extra length of 1 cm for all the fibers but the long fibers of sample A, to allow the aluminized end to stay out of the readout edge of the tile by 1 cm;
- an extra length of 12.4 cm for the fiber to pass into the girder.

In table 2 we present the values of the geometric component.

(sub)Sampling	Tiles read	Type	Length (cm)
A	1,3	long	164.4
A	2	short	156.4
B	4,6	long	136.4
B	5	short	123.4
C	7,9	long	97.4
C	8	short	82.4
D	10	long	52.4
D	11	short	33.4

Table 2: Geometric components of fiber length.

Two criteria for defining the fiber lengths within a cell were tested:

- one in which each fiber within a cell has the length required by mechanical and geometrical constraints;
- the other in which all fibers within a cell have only one of two lengths, short or long, that is required for the tile that belongs to the layer most far away from the PMT to be read; this lowers non-uniformity inside the cell, and makes it depend essentially on the readout configuration.

Light budget calculations excluded the first criterium: light output variations go far above the envisaged values of $\pm 5\%$, with typical values for tile and fiber parameters. The other criterium, on the other hand, seemed feasible in mechanical terms: the extra length of each fiber has medium values of the order of 11 cm, 18 cm, 15 cm and 34 cm, for samplings A, B, C and D, respectively, which can be set within the girder with no major difficulties. Our experience with the maquette confirmed this assumption and this was the adopted criterium. This criterium is the most robust in what concerns uniformity (there where uncertainties on tile and fiber parameters). On the other hand, it is the most simple, therefore adequate for fiber insertion automation in future Tilecal.

The routing component of the fiber length within a cell was obtained by summing:

- the straight distance from the layer of tiles that is most far away from the PMT that reads the cell to the PMT position in the girder;

- a length of 7 cm for the fibers to bundle inside the bundle tubes;
- an extra length of 5.5 cm to allow the fibers to have curvature rays greater than 5 cm;
- an extra length, depending of the cell, ranging between 1 and 3 cm, to allow the sub-bundles of fibers winding smoothly between them;
- an extra length of 10 cm for fibers of cells C1, C2 and C6 (for reasons presented in section 5.3).

5.3 Readout configuration in MODULE 0

The configuration that allows the maximum light output/minimum fibre length should have the PMT of each cell located in the girder in a Z position coincident with the geometrical center of the cell, for cells of samplings A and D. For cells of sampling BC there are 2 sub-samplings with different fibre lengths and different tile light output, making the uniformity worst inside the cell. Thus, the respective PMT positions should be eventually displaced to the B or C side, to balance tile/fibre light output for the tiles of the two sub-samplings. The ideal scenario is not possible because there is a limited number of PMT holes in the girder and the cells have to be distributed by those holes. To sart, the PMT's of the BC cells are centered as much as possible, and A and D cells are shifted as less as possible, filling the remaining holes. Global light budget is calculated for this configuration, and the PMT's of BC cells are displaced to positions that allow a better uniformity inside BC cells, followed by displacements of A and D PMT's. This procedure is repeated until the best uniformity inside BC cells is achieved. In situations of similar uniformity the chosen configuration is the one that gives more light output to A cells.

Several configurations were tested, following the evolution of the dimensions of the modules and the tile and fiber parametrizations (Clermont-Ferrand,Lisbon/IST), [6].

The faster than expected drop of light with tile size forced the PMTs of BC cells to be moved towards the center of C. Furthermore, the length of fibers in cells C1, C2 and C6 was artificially increased by 10 cm, in order to grant the uniformity in BC1, BC2 and BC6 cells, without compromising the uniformity/light output in the other cells.

The location of the PMT's of each cell of the proposed configuration, the lengths of fibers that correspond to this configuration and their quantity are shown in fig. 5 for side 1 and in fig. 6 for side 2.

6 Light budget

Light budget calculations were made using parametrizations for the tile light output (eq. 2) and for the fiber light output (eq.3). This last one depends on the fiber length and the values presented in figs. 5 and 6 were used.

The light budget for the side 1 and side 2 of Module 0 cells is summarized in figs. 7 and 8, where the values of tile light output were normalized to tile number 1. In figs. 9 and 10 the same values are shown but with a normalization for the smaller tile in each cell. With the exeption of cells BC6, BC7 and BC8, where the maximum fluctuation may reach $\pm 7.5\%$ the non-uniformity in all the cells is within the required range of $\pm 5\%$.

7 Summary

The routing of fibers in Module 0 is summarized in figs. 5 and 6 where the cells-PMT configuration and the fiber lengths are shown.

The light budget for these configurations is summarized in figs. 7, 8, 9 and 10, where it can be seen that the imposed requirements have been satisfied.

References

[1] A. Gomes et al., *Barrel Readout Cell Geometry*, submitted to publication as TILECAL internal note

[2] J. Proudfoot, R. Stanek, *An Optical Model for the Prototype Module Performance from Bench Measurements of Components and the Test Module Response to Muons*, Atlas internal note, TILECAL-NO-066 (1995)

[3] M. David et al., *Comparative Measurements of WLS Fibers*, Atlas internal note, TILECAL-NO-034 (1994)

[4] *ATLAS Technical Proposal*, CERN/LHCC/94-43 LHCC/P2

[5] M David, *Low dose rate effects in scintillating and WLS fibers by ionizing radiation,* Master thesis, Lisbon (1996)

[6] A. Gomes, presentation in Tilecal Optics Meeting, Lisbon (1/1996) and in Tilecal General Meeting, CERN (3/1996)

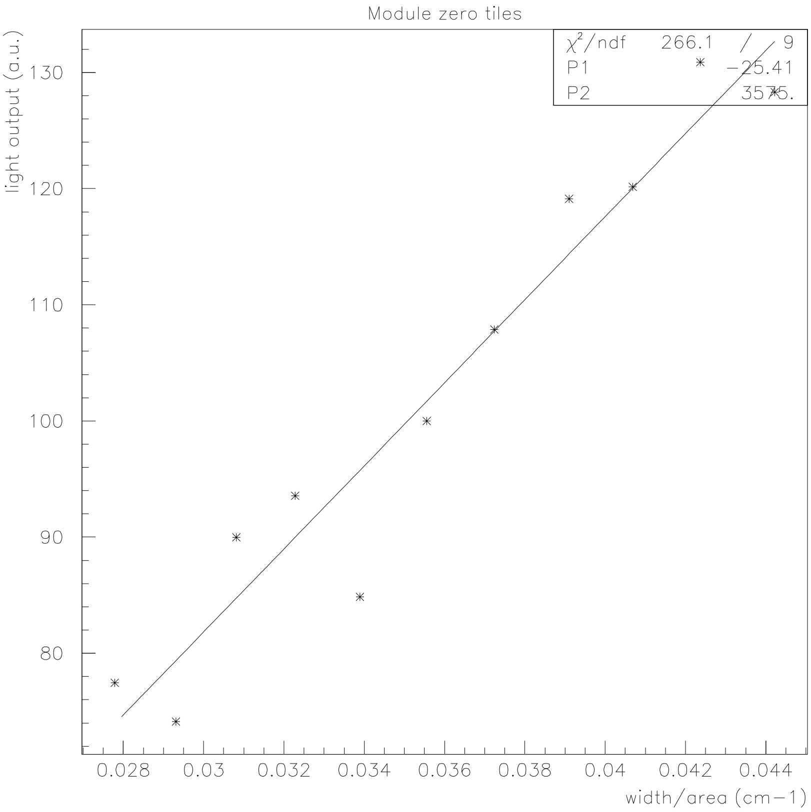

Figure 1: Light output in the center of the tile as a function of L/A_t (width/area). One wrapped tile (unmasked) of each size was measured.

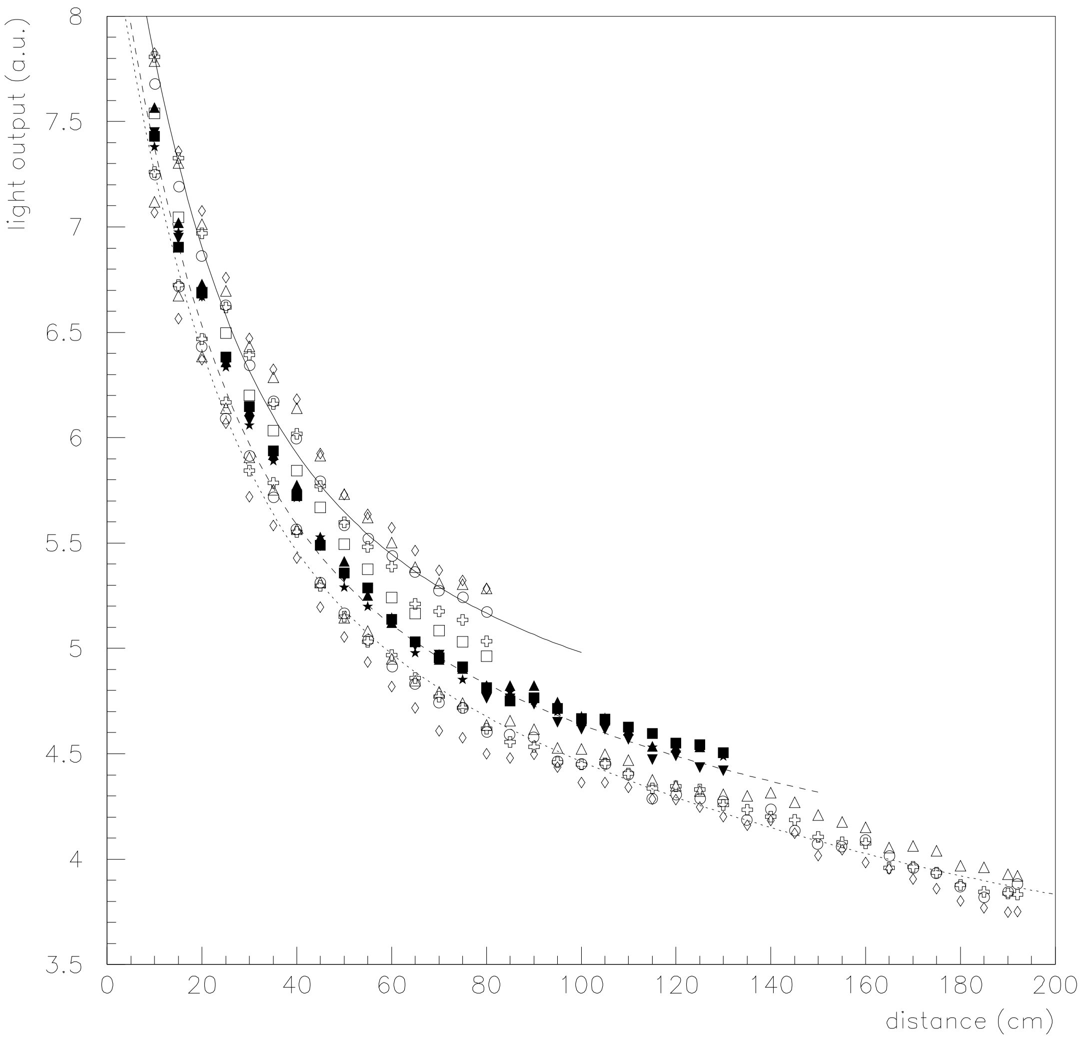

Figure 2: Light output for 2, 1.5 and 1 m long aluminized fibers used in the 1995 prototypes. The lines correspond to the parametrization obtained for each fiber length, using the average reflection coefficient.

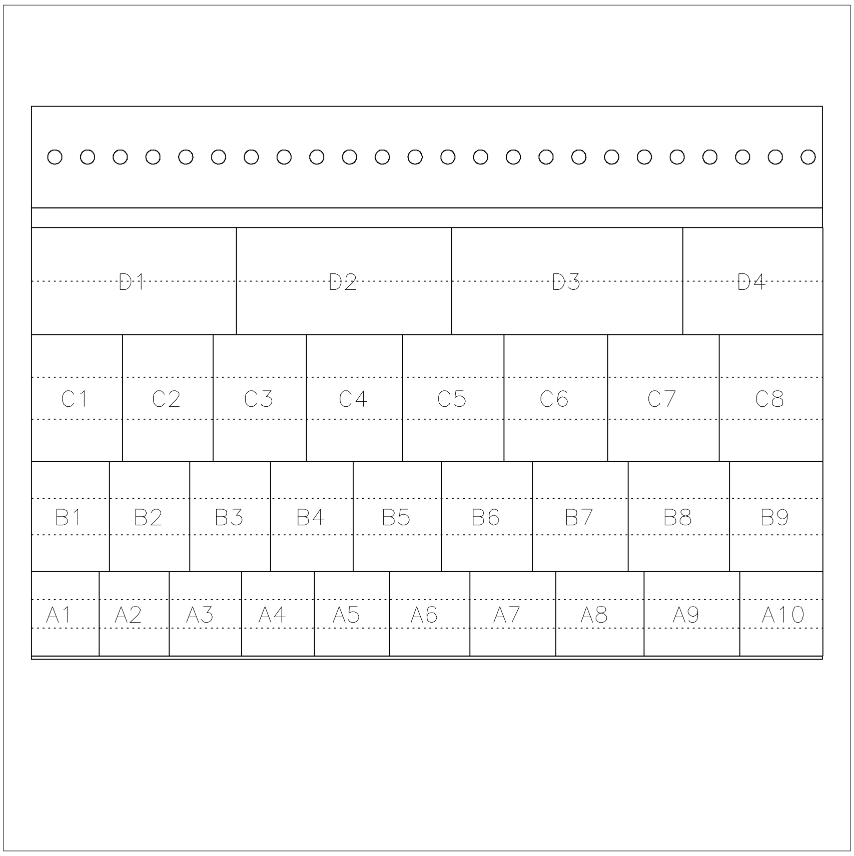

Figure 3: Cell geometry as viewed from side 1 in half of a barrel module. The full horizontal lines that border the labeled boxes correspond to the longitudinal sampling and subsampling division; dashed lines correspond to the radial cell division within the subsamples (11 tiles). The center of the module is at the left side of the figure. The circles in the top are the PMT holes in the girder.

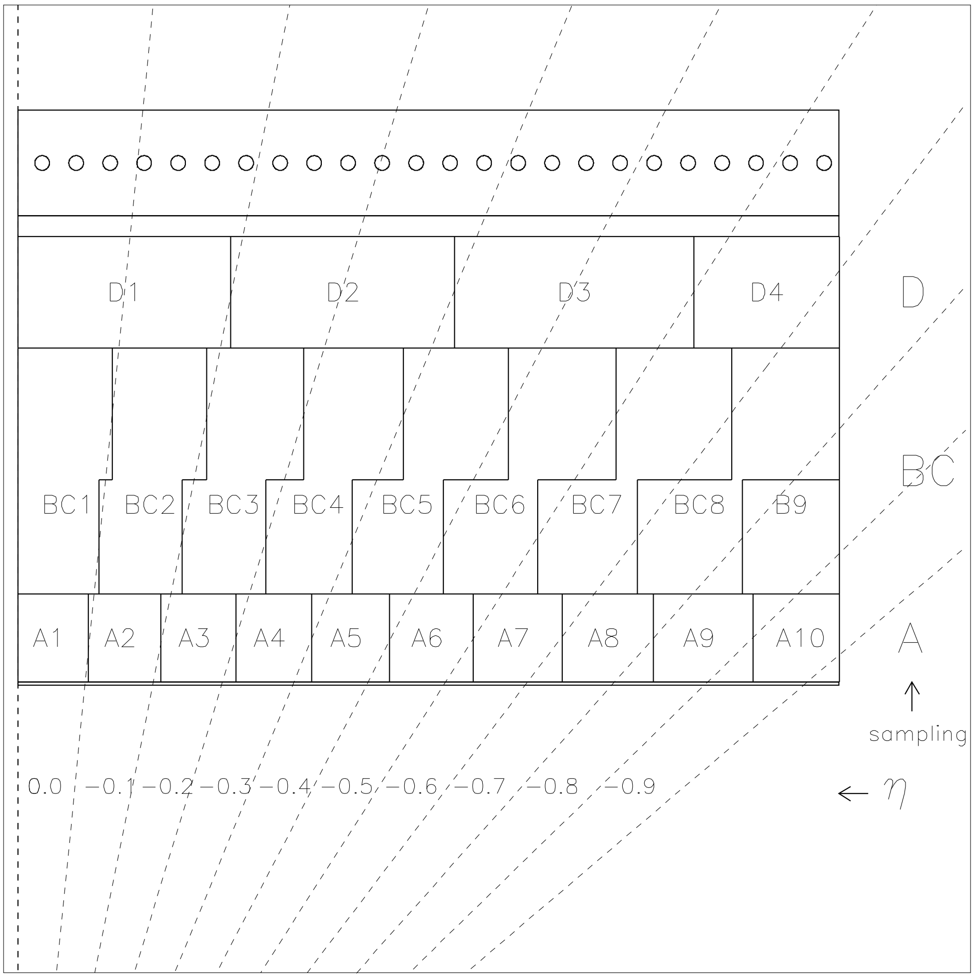

Figure 4: Cell geometry as viewed from side 1 in half of a barrel module. Longitudinal sampling segmentation and η segmentation is shown. The center of the module is at the left side of the figure. The circles in the top are the PMT holes in the girder.

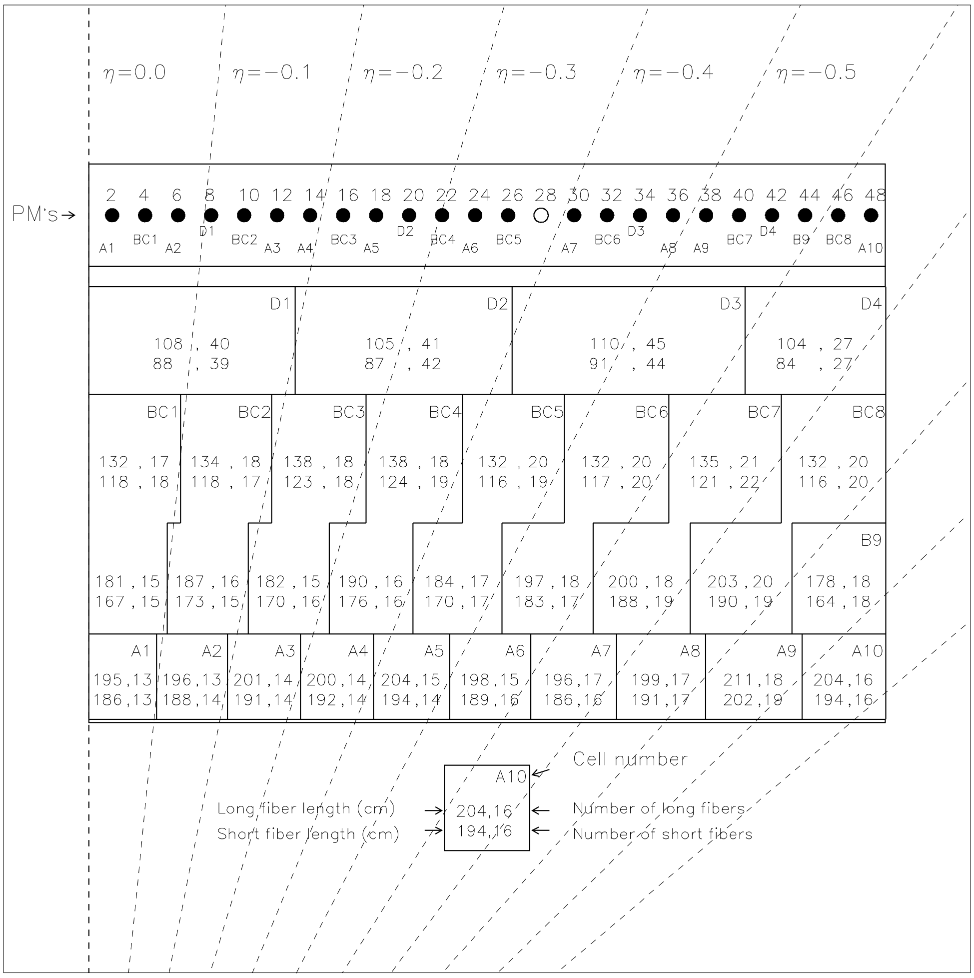

Figure 5: Configuration and fiber lengths for side 1 of MODULE 0: PMT's with corresponding cell numbers, cells with coresponding long and short fiber lengths, and respective quantity.

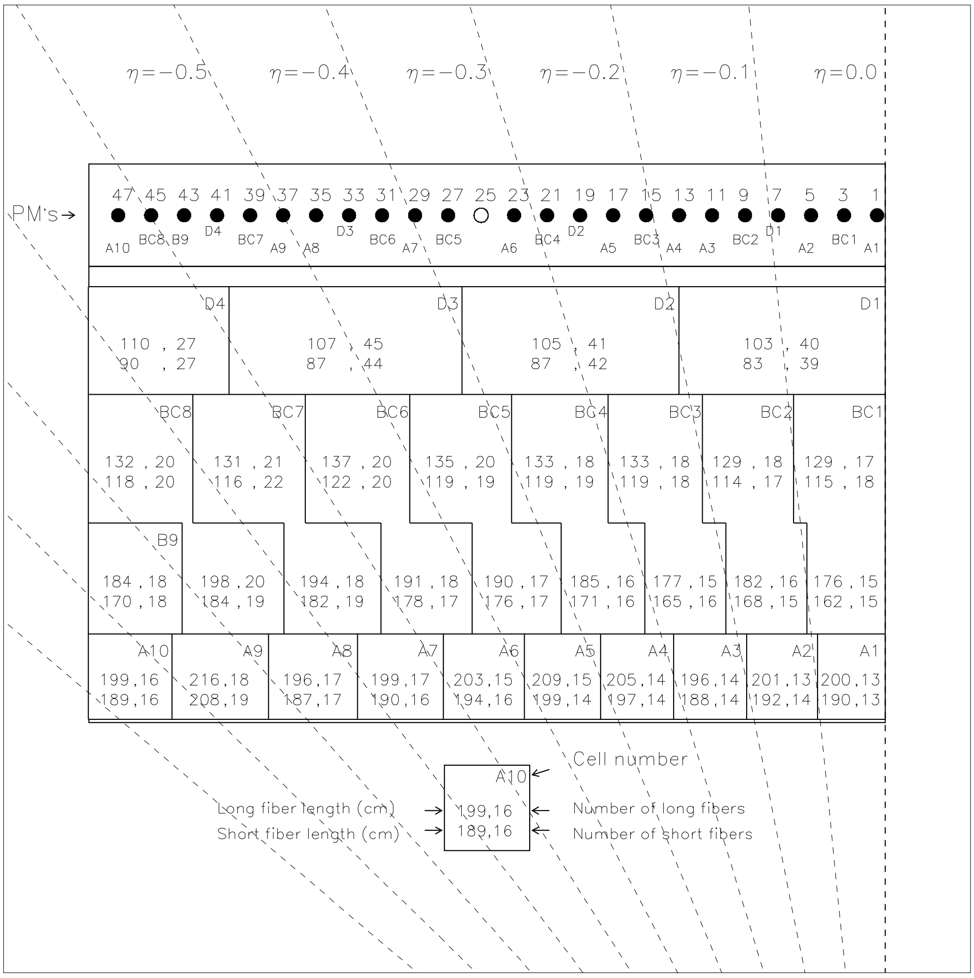

Figure 6: Configuration and fiber lengths for side 2 of MODULE 0: PMT's with corresponding cell numbers, cells with coresponding long and short fiber lengths, and respective quantity.

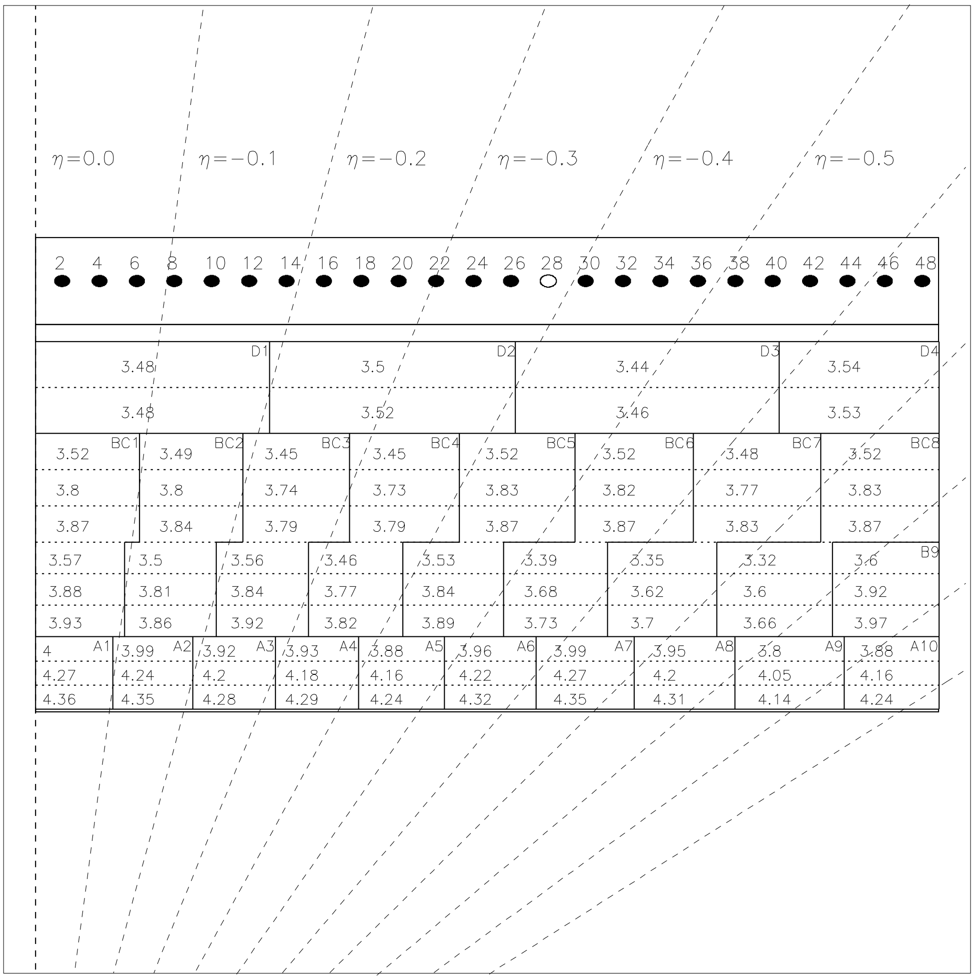

Figure 7: Light budget for side 1 of MODULE 0. Inside each cell, in the position corresponding to each tile, is shown the value obtained with parametrizations for that tile and the fiber that reads it. Values of tile light output have been normalized to tile number 1.

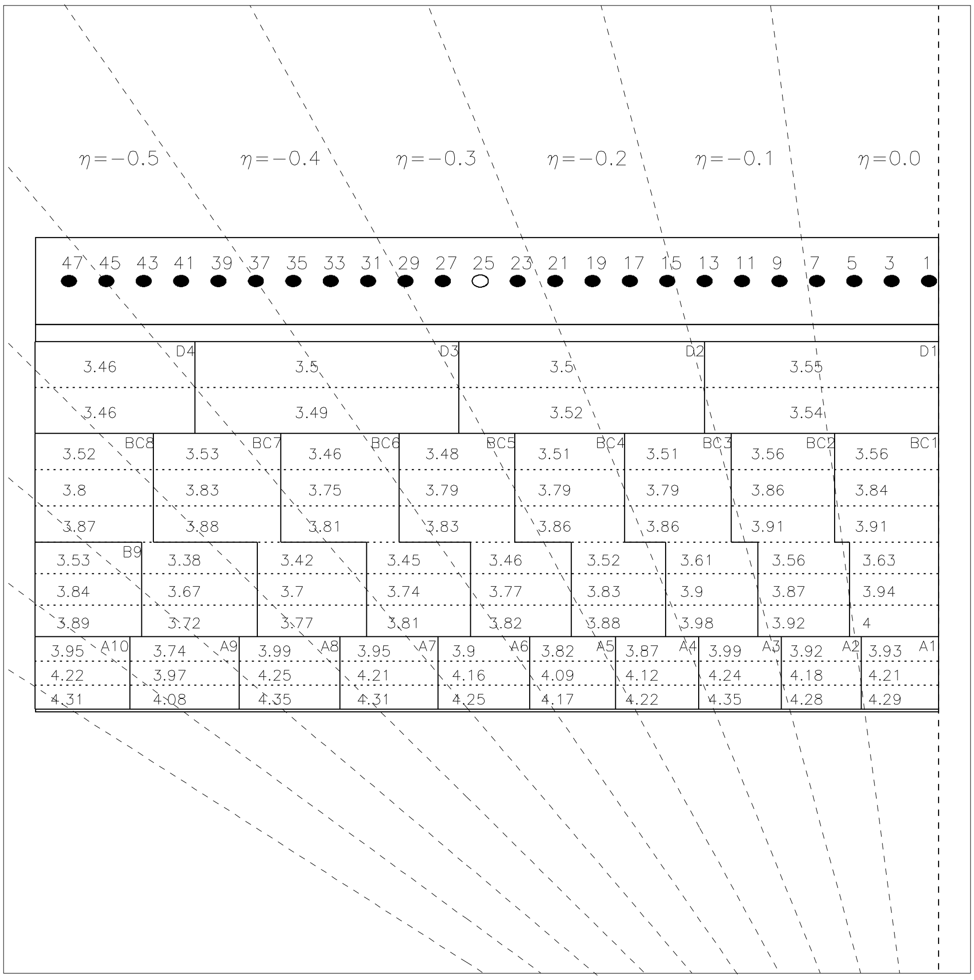

Figure 8: Light budget for side 2 of MODULE 0. Inside each cell, in the position corresponding to each tile, is shown the value obtained with parametrizations for that tile and the fiber that reads it. Values of tile light output have been normalized to tile number 1.

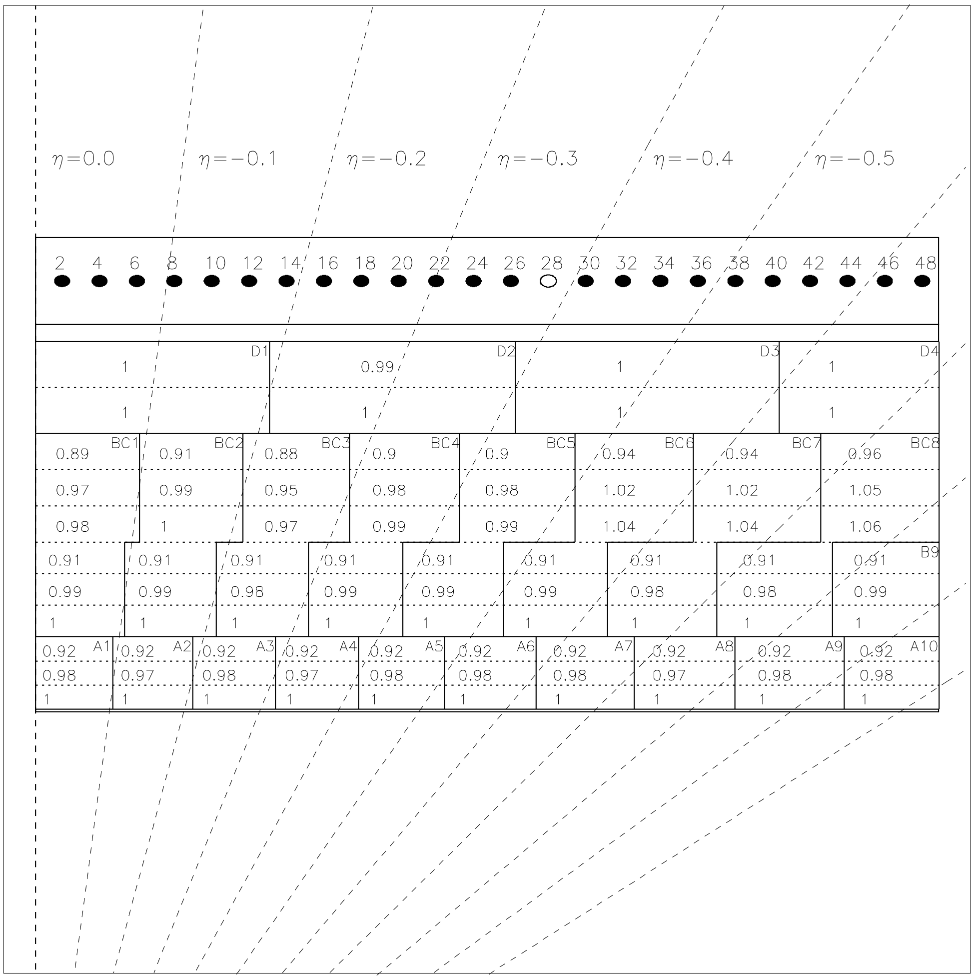

Figure 9: Light budget for side 1 of MODULE 0. Inside each cell, in the position corresponding to each tile, is shown the value obtained with parametrizations for that tile and the fiber that reads it, normalized to the smaller tile of a cell (tile 1 for A cells, tile 4 for B and C cells, and tile 10 for D cells).

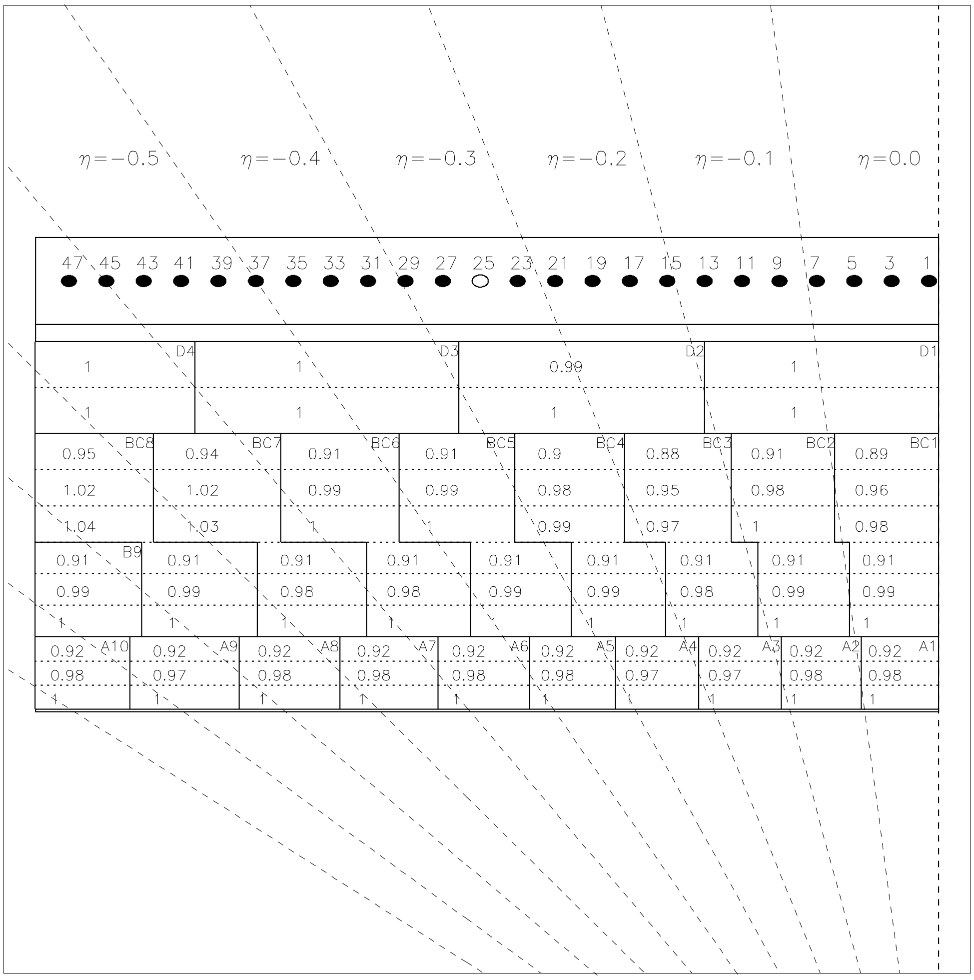

Figure 10: Light budget for side 2 of MODULE 0. Inside each cell, in the position corresponding to each tile, is shown the value obtained with parametrizations for that tile and the fiber that reads it, normalized to the smaller tile of a cell (tile 1 for A cells, tile 4 for B and C cells, and tile 10 for D cells).