ATLAS Internal Note
TILECAL-NO-002
13 December 1993

Study of the effect of the radiation on the TILECAL Barrel hadron calorimeter to be used in ATLAS

(Presented by Ana Henriques-In the framework of the RD34 collaboration)

A. Amorim[1,2], M. David[1,2], A. Gomes[1,2], A.Henriques[3], A. Maio[1,2]

1- LIP/Lisbon ; 2- University of Lisbon ; 3- CERN

Abstract

The effects of radiation damage induced by neutrons and charged particles on the performance of a TILECAL Barrel hadron calorimeter are studied. For an integrated luminosity of $10^6 pb^{-1}$ (10 years running at a peak luminosity of $1.6 \times 10^{34} cm^{-2} s^{-1}$) the degradation on the jet energy resolution and the total light reduction are marginal, even when the 4 longitudinal sectors of the calorimeter are not periodically recalibrated. The largest effect is observed in the light reduction on the first tile, starting at 1.95λ, and it is is 6.2% at η = 1.5 and 4.8% at η = 0. In the most exposed Barrel region (η = 1.5) the increase on the jet energy resolution of 300 GeV incident jets is 0.24% without longitudinal calibration and 0.16% when the calibration is applied. The total signal is reduced by 1.51% without calibration and 0.14% after calibration.

1. Dose Levels Expected in the Barrel Hadron Calorimeter in ATLAS.

The expected annual peak dose in the ATLAS barrel hadron calorimeter coming from charged particles and neutron fluxes (E_n > 100 keV) is 36 Gy/y[1,2,3], considering a 5 cm polyethylene moderator in front of the LAr/Pb e.m. calorimeter and followed by a iron/plastic scintillator hadron calorimeter.

This dose has been obtained from a more general ATLAS setup: a mean medium in the calorimeters (LAr/Pb in the e.m. calorimeter and LAr/Iron in the had. calorimeter)[2,3]. In the case of a iron/plastic scintillator calorimeter with a ratio of 4.5 to 1 (TILECAL), the dose induced by neutrons and charged particles in the plastic scintillator is higher and has been corrected for.

1.1- Corrections applied to the doses induced by neutrons

Neutrons produced in the hadronic shower will have a large $\sigma_{elast.}$ to elastically scatter off the protons in the plastic scintillator of the TILECAL calorimeter. The neutron capture in Hydrogen is negligible with respect to the elastic scattering in the full energy range[5].

A relation between an integrated neutron fluence F_n (n/cm^2) and the induced dose deposited in the plastic (Gy) considering only elastic processes (σ_{elast} in cm^2) is given by [6]:

$$(Dose)_n = F_n \frac{N_0 \, \sigma_{elast}}{A} \frac{<E>}{2} \qquad (1)$$

where $N_0 = 5.2 \times 10^{25}$ protons.kg^{-1}, A = 1 and <E>/2 is the mean energy (in J) of the proton recoil after elastic scattering. In the case of a mean medium of Fe/LAr (A>> 1) there is a negligible neutron contribution to the total dose.

The contribution of neutrons to the doses deposited in the plastic scintillator will be calculated directly from the neutron fluxes expected in the barrel hadron calorimeter . Only the fast (E_n > 100 keV) fluxes with a 5 cm polyethylene moderator in front of the LAr e.m. calorimeters, e.g. 1.0×10^{12} n/cm^2 were considered. This value is reduced 14% when the LAr is

2. Radiation Hardness of a Tile/WLS fibre calorimeter considering the SDC and TILECAL configurations.

Due to the absence of complete experimental results concerning irradiation in the exact TILECAL configuration, the SDC experimental radiation damage results were used to evaluate the light reduction as a function of the dose, since this is the closest configuration to the TILECAL calorimeter. In fig. 2 is shown the light ratio (before/after irradiation) as a function of the dose in Mrad (1 Gy = 100 rad) at the maximum of the shower induced by 2.5 GeV electrons in a SDC module[7]. The data from 3 different modules fit well with a 2 exponential curve:

$$I/I_0 = 0.824\, e^{-D/\gamma_1} + 0.157\, e^{-D/\gamma_2} \quad \text{with } \gamma_1 = 43000\,\text{Gy} \; ; \; \gamma_2 = 1350\,\text{Gy} \qquad (2)$$

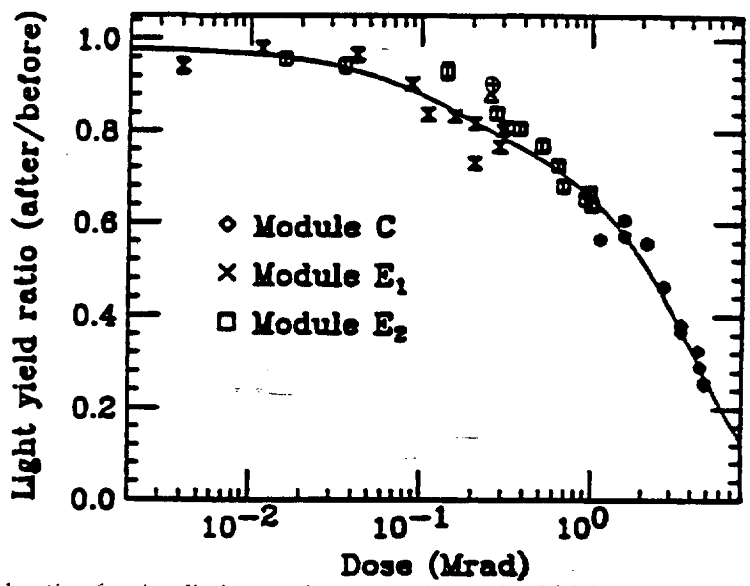

Fig. 2 Light yield ratio after irradiation at shower maximum for SCSN81(tiles)/Y7(WLS fibres) modules as a function of the dose at the shower maximum[7]. The ♦, x and ▥ points correspond to 3 different modules.

Preliminary results obtained by irradiating in a γ-^{60}Co source several tile/WLS fibre assemblies* in the exact TILECAL configuration[2] show very encouraging results, which we describe next: PSM-115 tiles of 200x100x3 mm^3 and 350x100x3 mm^3 have been irradiated to a dose of 2.75 kGy with a maximum dose non uniformity of 10%. The fibres (1.5 m long) were irradiated with a constant dose of 2.2 kGy in the last 1 meter[9]. The first 0.5 m length received a nigligible dose**. This is a pessimistic situation since we expect a logarithmic decrease of the dose as a function of the fibre depth (fig. 1). The dose rate was 16 Gy/hour.

The light output of each tile/fibre assembly was measured with a ^{90}Sr source before and after irradiation, doing a scan with the source in the middle of the tile along the longest dimension. Two fibres of the same quality placed in the grooves made in the two far oposite extremities of the tile[2] are used in the measurements. The light output of 2 tile/fibre assembly types (PSM-115/BCF91A and PSM-115/Y11(200ppm)M) is shown in fig. 3a and 3b respectively.

**Tile type: PSM-115 (granulated polystyrene base doped with 1.5% PTP and 0.03% POPOP). They are processed by injection molding technology in Protvino laboratory.*
Fibres types: BCF91A from Bicron and Y7(150ppm), Y7(150ppm)N (new cladding), Y11(200ppm), Y11(200ppm)M (double cladding), Y11(100ppm)M (double cladding) from Kuraray.

*** Considering the origine the end of the fibre that will be read out by the PMT.*

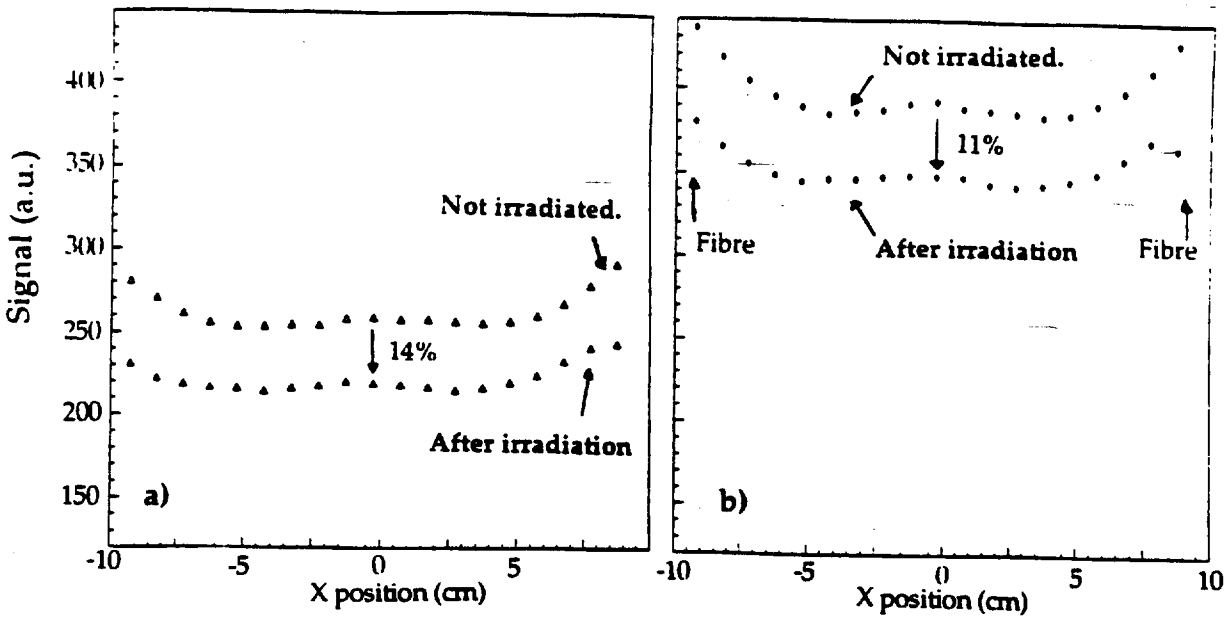

Fig. 3- Light output as a function of the x position for 2 tile/fibre assembly types a) PSM-115/BCF91A and b)PSM-115/Y11(200ppm)M), before and after irradiation in a ^{60}Co source at a dose of 2.75 kGy.

We observe that before irradiation the light output using the Y11(200ppm)M fibre pair is higher by about a factor of 1.5 with respect to the BCF91A fibre pair. This is mainly because the Y11(200ppm)M fibre has a double cladding (index of refraction n_{core} = 1.59, $n_{clad\ 1}$ = 1.49, $n_{clad\ 2}$ = 1.42) which improves the light reflection in the core-cladding surface and increases the numerical aperture[10]. The light reduction after irradiation is about the same in both cases within the experimental errors. When the BCF91A fibres are used we observe a light reduction after irradiation of 14%, and 11% for the Y11(200ppm)M fibres.

The Δ and ⊕ points in fig. 2 for a dose of 2.75 kGy (0.275 Mrad~100 years working at LHC) correspond to the two TILECAL tile/fibre configuration assemblies (fig. 3), showing good agreement with the SDC results. The light reduction in the fibres is the major contribution to the global light reduction of the tile/fibre assemblies due to the non realistic fibre dose profile applied, mentioned before. This was confirmed redoing the scan of fig. 3a using the same tile but non irradiated BCF91A fibres. In this case a light reduction of 3.5% is observed.

The light attenuation curve of each individual fibre was also measured before and after irradiation. The light output ratio of each individual fibre type measured at a distance of 130 cm from the PMT over the signal measured at a distance of 40 cm from the PMT is shown in table 3 after normalizing to the respective ratio before irradiation.

Using the parametrized curve of the results shown in fig. 2 (eq. 2) we estimated the light yield ratio expected on the hadron calorimeter for $\eta = 0$ and $\eta = 1.5$ after an integrated luminosity of $10^6\,pb^{-1}$. Before recalibrating longitudinally each of the 4 cells the light reduction in the first tile (the worst case) is 6.2% for $\eta = 1.5$ and 4.8% for $\eta = 0$. Assuming that it is possible to know the longitudinal profile of the damage, each of the four longitudinal sectors can be calibrated. In this case the light ratio in the first tile deviates by 1.1% and 1.8% from the calibration constant in the first sector (mean of 3 first tiles) for $\eta = 0$ and for $\eta = 1.5$ respectively.

Table 3- Light output ratio of each individual fibre type measured at a distance of 130 cm from the PMT over the signal measured at a distance of 40 cm from the PMT. The values given are normalized to the respective ratio before irradiation. See text for details.

Fibre Type	Y11(100)M	Y11(200)M	Y11(200)	Y7(150)	Y7(150)N	BCF91A
Ratio	0.88	0.89	0.88	0.83	0.89	0.85

3. Effect of Radiation Damage on the Performance of the TILECAL hadron calorimeter in the Barrel region.

To evaluate the effect of the radiation on the performance of the calorimeter jets of 300 GeV have been generated using GEANT and FLUKA in the ATLAS configuration (Accordion Lar/Pb e.m. and TILECAL had. calorimeter), at $\eta = 0$. An adequate weight was given to each cell in order to reproduce the light ratio of each tile after $10^6 pb^{-1}$, either at $\eta = 0$ or $\eta = 1.5$. In the e.m. calorimeter no degradation due to radiation was considered. Fig. 4 shows the signal distribution for 300 GeV jets at $\eta = 1.5$. We observe that even at $\eta = 1.5$ and without longitudinal calibration the effect of radiation on the jet energy resolution is marginal, as well as in the total light reduction. In table 4 are given the values of the increase of the jet energy resolution and total light reduction both at $\eta = 0$ and $\eta = 1.5$.

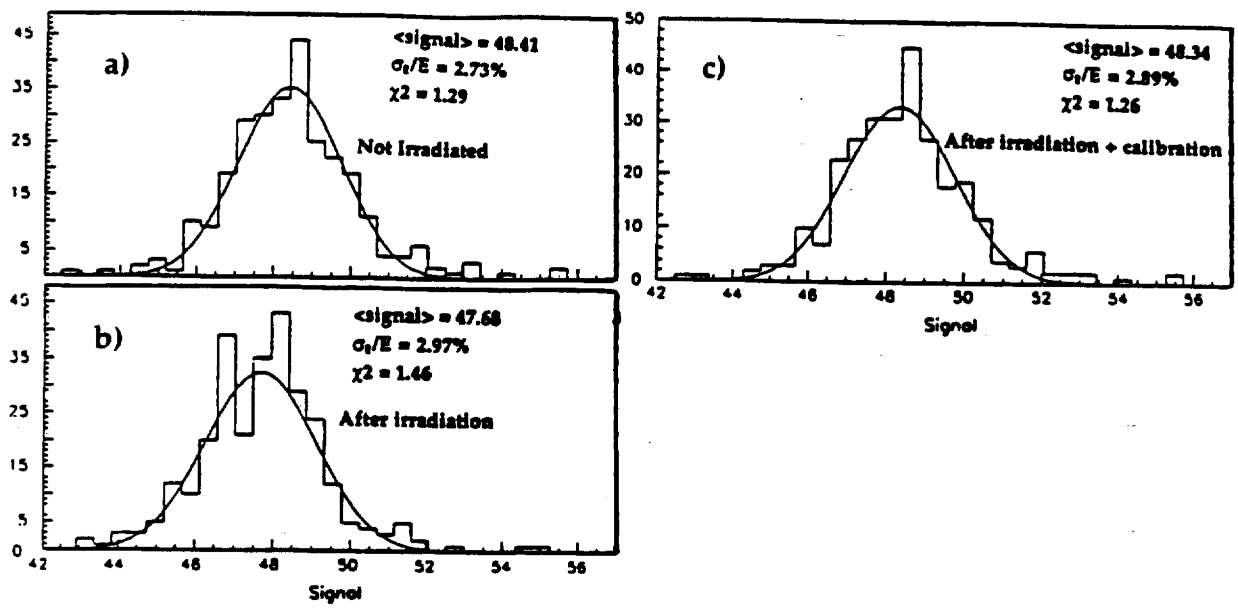

Fig. 4- The signal distribution for 300 GeV jets generated at $\eta = 1.5$ (a), after irradiation with the doses expected at $\eta = 1.5$ but without longitudinal calibration (b), after longitudinal calibration (c). It was considered the effect of irradiation after $10^6 pb^{-1}$.

Table 4- Expected degradation of the TILECAL hadron calorimeter performance in ATLAS for 300 GeV jets generated with GEANT and FLUKA. The values given are for an integrated luminosity of $10^6 pb^{-1}$.

	$\Delta(\sigma_E/E)_{\eta=0}$ (%)	Δ Sig.$_{\eta=0}$ (%)	$\Delta(\sigma_E/E)_{\eta=1.5}$ (%)	Δ Sig.$_{\eta=1.5}$ (%)
without calibration	+ 0.18	- 1.28	+ 0.24	- 1.51
after calibration	+ 0.10	- 0.10	+ 0.16	- 0.14

References:

1- A. Amorim, A. Henriques and A. Maio, Atlas Internal Note, CAL-NO-021, and ref. there in.
2- ATLAS Lettter of Intent, CERN/LHCC/92-4, LHCC/I2 (1992).
3- A. Ferrari et al., Atlas Internal Note, CAL-NO-005.
4- Johns K. at II International Conference On Calorimetry in High Energy Physics at TEXAS 1992.
5- Neutron cross section curves, Academic Press, Inc. Harcourt Brace Jovanovich, Publishers.
6-D. Green, FERMILAB Internal Note FERMILAB-FN-597.
8- SDC Technical Proposal, SDC-92-201, pag. 6-367.
9-A. Gomes et al., Radiat. Phys. Chem., Vol 41, No 1/2, pag. 185, 1993.
10- A. Byon-Wagner, ICFA Instrumentation Bulletin, No 9, pag. 23, April 1993.