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The HCAL Optics Radiation Damage Study

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ABSTRACT

The radiation damage of the optical components of the LHCb Hadron Calorimeter have been studied. The scintillating tiles and fibers were irradiated in the vicinity of the internal target station of the Serpukhov 70 GeV proton accelerator. The irradiation has been done with a wide energy range and a natural mixture of the charged particles with gammas and neutrons.

Several set-ups have been assembled for this study. The X-Y coordinate beta-source scanner operated by a PC computer have been developed for precise tile response measurements. Moving along the fiber a blue LED has been used for attenuation length studies. The modified SF-46 spectra-photometer was used to measure fiber emission spectra.

A typical degradation of 20% in light yield have been seen in scintillating tile up to dose of ∼0.5 Mrad. This increases to 50% for 1.5 Mrad. The tile response non-uniformity has been measured.

The fibers of type Y11(S200) and Pol.Hi.Tech.(S250) have almost the same behaviour but BCF-92 show stronger degradation in attenuation length after irradiation. The measurement of the emitting light spectra for BCF-92 fibers shows that most of transparency losses are concentrated below 550 nm of the wave length range.

1 Introduction

The central region of the Hadron Calorimeter in the LHCb experiment [1, 2] will operate in a hostile radiation environment. The expected annual dose absorbed in vicinity of the LHC beam pipe achieves 50 Krad per year. The performance of that region eventually will degrade, and we have to estimate in advance the consequences to the calorimeter performance.

The optical components expected to be used in HCAL have to be checked for degradation caused by irradiation under conditions close to reality in LHCb. Many efforts during last decade have been devoted to this subject. Most of the measurements have been performed in gamma irradiation facilities with an energy range of several MeV. But recently [3] it was mentioned that large differences exists in scintillator damage caused by neutrons and gammas.

The use of a proton accelerator as a source should give a more realistic picture of damages caused in the calorimeters during LHC operation. The IHEP 70 GeV proton synchrotron gives a good opportunity for such studies with hadronic showers originating in the vicinity of the target stations. Here we present results on radiation damage of optical components measured separately. These results have been used for Monte-Carlo study of the HCAL performance with irradiated components [4]. The final aim of this study is to insert irradiated tiles and fibers inside HCAL Prototype [5] to make direct measurement of the HCAL performance degradation.

2 Radiation damage of scintillating tiles

In our measurements 16 spare scintillating tiles produced for the HCAL Prototype assembly have been irradiated at the IHEP 70 GeV proton synchrotron in December 1998 run with a dose range from 81 krad to 1560 krad during 25 day exposition with an average dose rate of 70 Krad/day.

Tile samples were produced by injection moulding technique and wrapped in a Tyvek envelope. The components used for their production were granulated polystyrene PSM-115 as a base, 1.5% of paraterphenyl (PTP) and 0.03% of POPOP as primary and secondary WLS dyes.

The total light yield and light attenuation have been measured for samples before and after irradiation, and in addition 8 non-irradiated samples were used for reference.

The dimension of samples was 78×156mm^2. The setup used for the measurements is shown in Fig. 1.

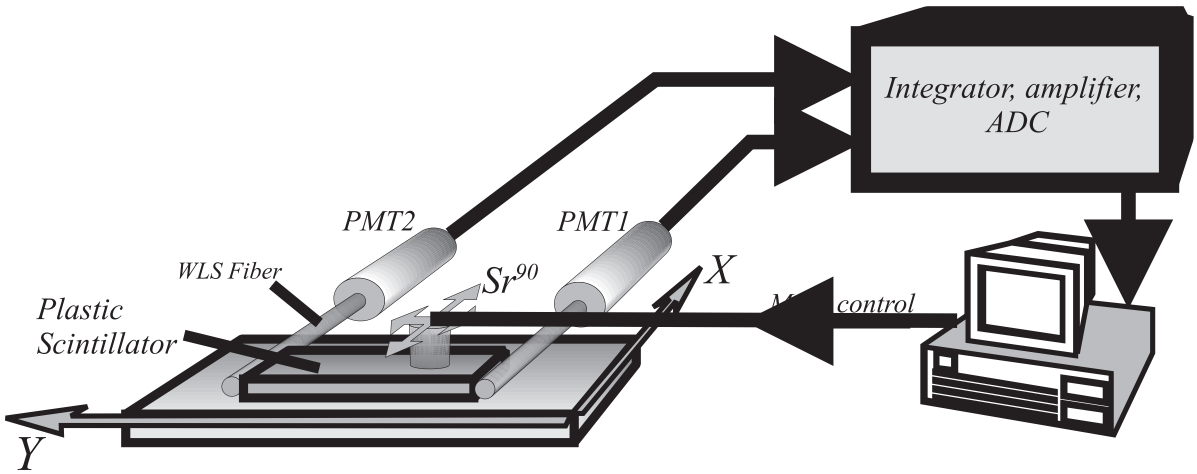

Figure 1: The schematics of the setup to record the X-Y coordinate dependence of the tile light yield. Two WLS fibers were attached to the wrapped tile. The fibers were fed through small holes in the Tyvek envelope at the edges of the tile. The light have been collected from it's short side.

The experimental setup consists of a radioactive source(Sr^{90}), a scanning system and two photodetectors. Scintillation light was excited by a collimated radioactive source and then collected by two Pol.Hi.Tech.(S250) WLS fibers. The plastic scintillator and fibers are covered by Tyvek (not shown on the figure). The fibers are connected to two PMT FEU-84-3 with green extended photocathode. After amplification and integration of the PMT current, the output level was digitized by a 12-bit ADC. The scanning system allows to move radioactive source along X and Y directions with accuracy of 0.1 mm. During this measurement the source was moved along X and Y coordinates with a grid spacing 2.0×2.0 cm.

The relative light yield has been determined by:

$$R_{LY} = \frac{(L_{after}/L_{before})}{(LREF_{after}/LREF_{before})}$$

where:
L_{before} is light yield of the sample before irradiation,
L_{after} is light yield of the sample after irradiation,
$LREF_{after}$ is light yield of the reference sample, measured in the same run with L_{after} and
$LREF_{before}$ is light yield of the reference sample, measured in the same run with L_{before}.

To exclude a systematics in the measurements during several months, each scan of the tile have been performed both for irradiated sample and non-irradiated one used as a reference. To calculate the total relative light yield we sum over the tile surface the measurements made by each PMT separately and normalize them with the reference measurement before irradiation, divided by the same ratio for the reference sample. Afterwards the two PMT data were added.

The results of the average light yield on absorbed dose is seen in Fig. 2.

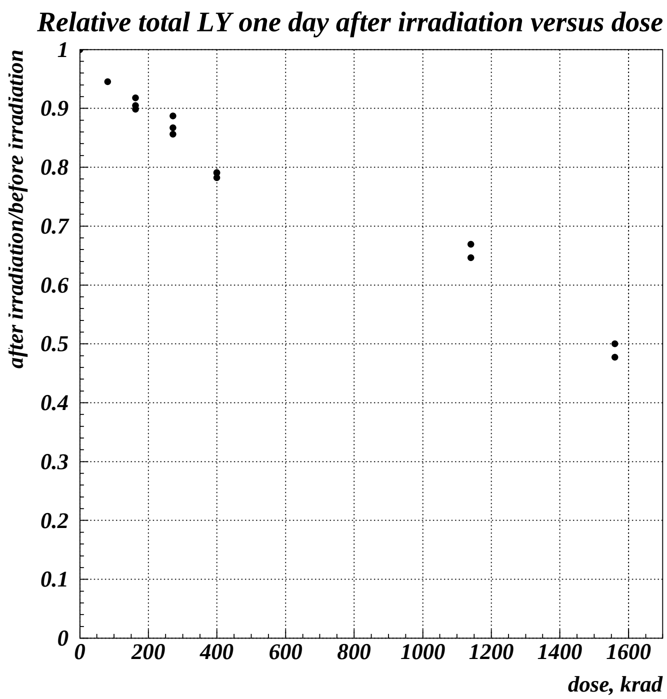

Figure 2: The average light yield of irradiated tile for different accumulated doses. Each point corresponds to a different tile sample.

A decrease of $\sim 20\,\%$ is seen below 0.5 Mrad and of up to $50\,\%$ for an accumulated dose around 1.5 Mrad. The dose range in our measurement covers the expected 0.5 Mrad of the accumulated dose in the HCAL central region after 10 years of operation.

Along with the decrease in light yield, the tile response non-uniformity is also an important issue for the HCAL performance. We estimate this value as the difference in measured PMT current for the minimal and maximal distance to the fiber, divided by the average over the whole tile surface.

We observe a moderate light yield non-uniformity of $\pm 5\%$ (see Fig. 3) after irradiation up to 0.5 Mrad.

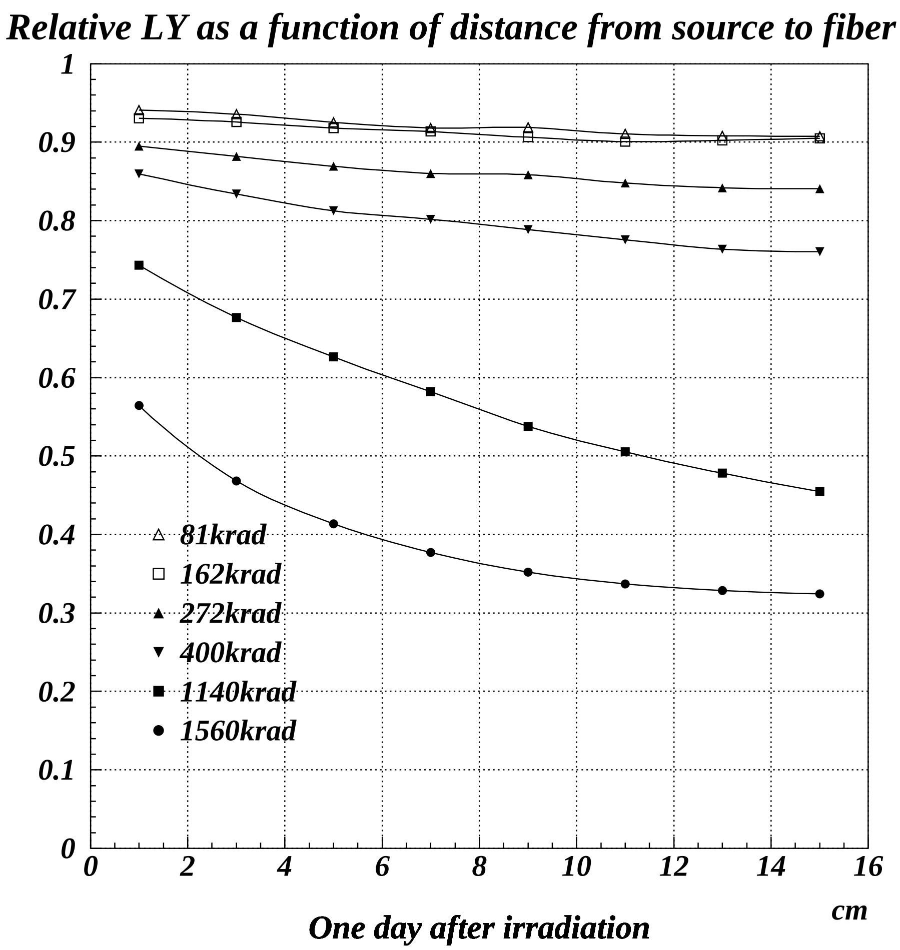

Figure 3: The relative light yield after irradiation to one before irradiation for different accumulated doses.

At larger doses (1 Mrad and more) the difference in light yield increases up to $\pm$ 20 %.

The light yield measurements have been repeated many times with a maximal interval between the measurements of more than 3 month. To avoid a long term instability of ADC's, PMT's e.t.c. one sample was permanently used as reference, i.e. after a series of measurements with irradiated samples one measurement of non-irradiated reference sample has been done. We estimate that the systematic error of our measurements lies within a few percent.

No visible annealing has been observed during several months of measurements (see Fig. 4). This coincides with results of gamma-irradiation [6], where they observe large annealing within first $7-30$ hours after irradiation and a weak dependence after.

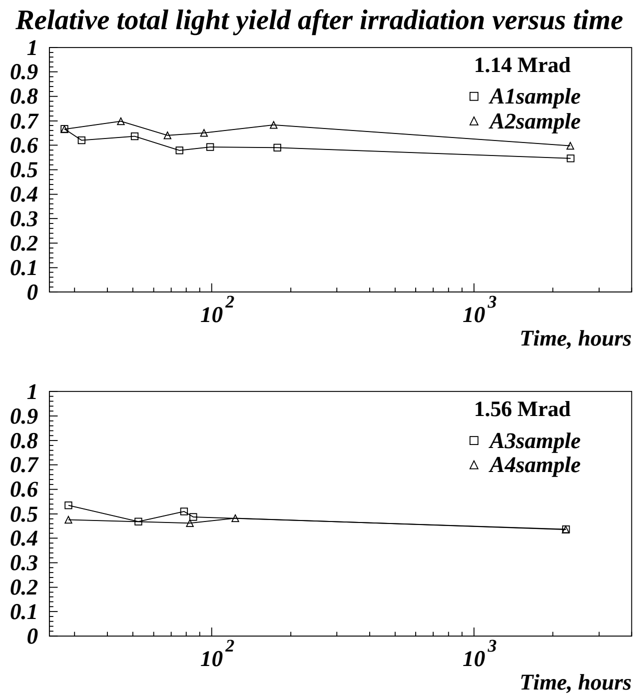

Figure 4: The time dependence of light yield for four samples with maximal irradiation. No annealing is observed.

In conclusion of this section, we can expect decrease in light output by 20 % in the worst situation at the central cells of HCAL and a tile response non-uniformity of 5 % within the tile height.

3 Radiation damage of WLS fiber

The second component in optics of HCAL are WLS fibers. If loosing in transparency they cause a longitudinal non-uniformity in the detected light and increase the constant term in the calorimeter resolution due to hadronic shower fluctuations in depth.

Several types of fibers have been irradiated at the accelerator in vicinity of the internal target. The accumulated dose on fibers on December 1998 run have been reached to 1.55 Mrad and limited within 0.7 Mrad in a three weeks exposition on December 1999 run.

During the first run fiber of type Y11(S200) have been studied and during the second run three fibers of type Pol.Hi.Tech(S250) and two fibers of type Bicron BCF-92 have been irradiated and measured for attenuation length degradation. One fiber of each type was used as a non-irradiated reference.

The measurements have been performed on a set-up that consists of a vertical black box of 1.7 m height with a PMT attached on the top. The fiber under study was fixed at the high end between teflon lips that kept it in touch with the PMT window. Three stainless steel strings drawn up along the fiber guide a white plastic disk. The fiber is fed through the central hole in the disk and was activated by a bright-blue LED pulses. The PMT response has been gated by a 200 ns ADC and stored by a 4K channel analyzer. The average of 4000 pulses have been calculated and recorded. The accuracy including systematics was checked by repeated measurements with the same fiber hanged in the box and is within a few percent.

All measurements have been performed 35 days after the run was stopped. The results for fibers Y11(S200) and Pol.Hi.Tech.(S250) are shown in Fig. 5.

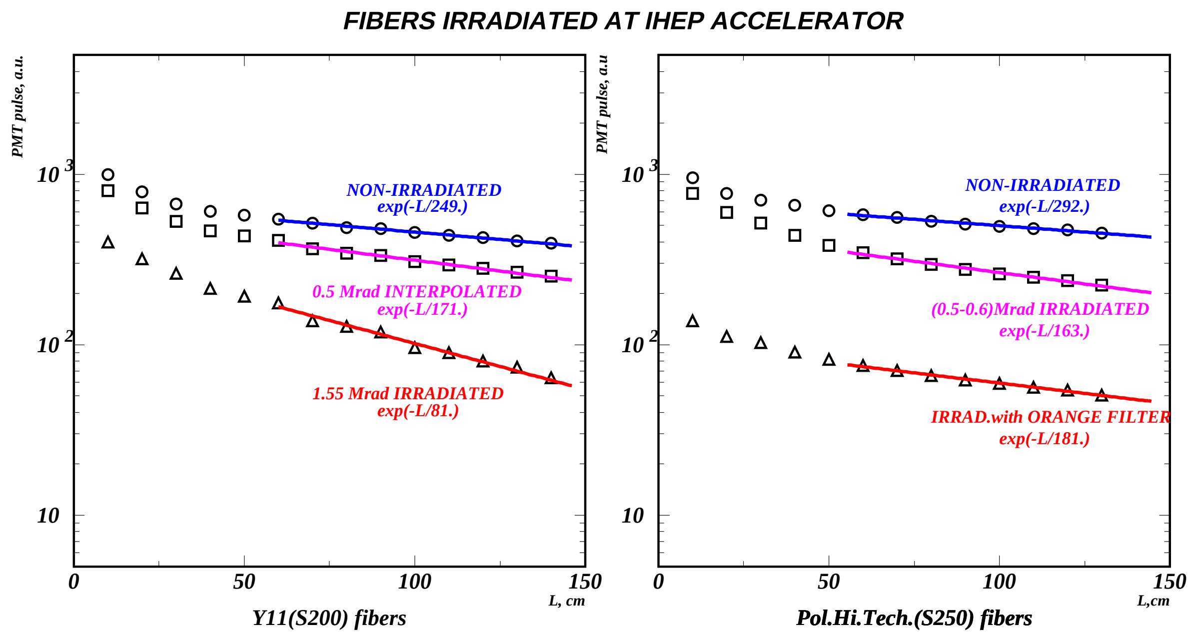

Figure 5: The fiber transparency measurement for Y11(S200) and Pol.Hi.Tech.(S250) samples. Both fiber types show almost the same behavier. X-axis is the LED-PMT distance

The irradiation dose for Y11 appear to be slightly larger than expectation for the LHCb HCAL central region environment. For that reason we interpolate Y11 fiber responce to dose 0.5 Mrad (shown in squares in Fig. 5).

The attenuation length degrade from $\sim 2.5-3\,\mathrm{m}$ to $1.6\,\mathrm{m}$ after 0.5 Mrad irradiation. A small $10\,\%$ improvement is seen if an orange filter is used. The re-emitted light yield decreases within a range of $30 \div 50\,\%$ compared to non-irradiated sample at the same distance to PMT.

The results for the fiber of type BCF-92 are shown in Fig. 6.

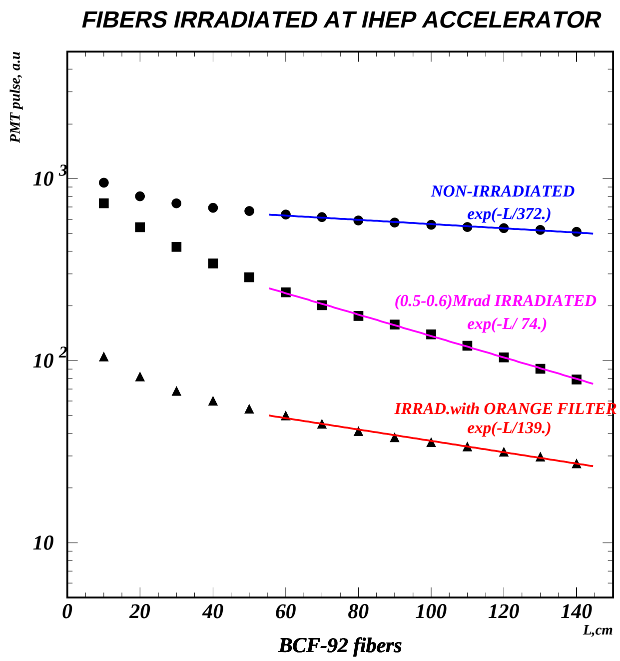

Figure 6: The fiber transparency measurement for BICRON BCF-92 sample. Circles — non-irradiated sample, squares — irradiated up to (0.5-0.6) Mrad. Triangles — the same with orange filter between fiber and PMT window.

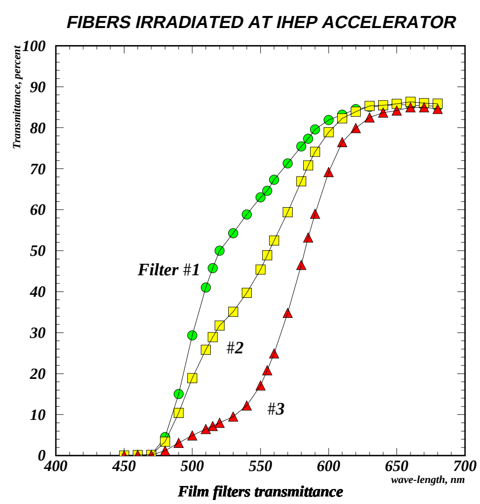

Figure 7: The film filter transmittance on the light wave length. We use in measurements filter No.3 with cut off around 580 nm.

Here the attenuation length decreases almost 5 times from 3.7 m to 0.75 m for distances to PMT above 50 cm. But in orange-red light the attenuation length is being recover to 1.4 m. The film filters used have not a sharp enough cut off in wave length, as shown in Fig. 7.

To get more understanding of this phenomena we measure the light emission spectra both for irradiated and non-irradiated samples of 30 cm long BCF-92 fiber. For that we use SF-46 semi-automated spectra-photometer with a tungsten lamp activated fiber as a light source. The results are shown in Fig. 8.

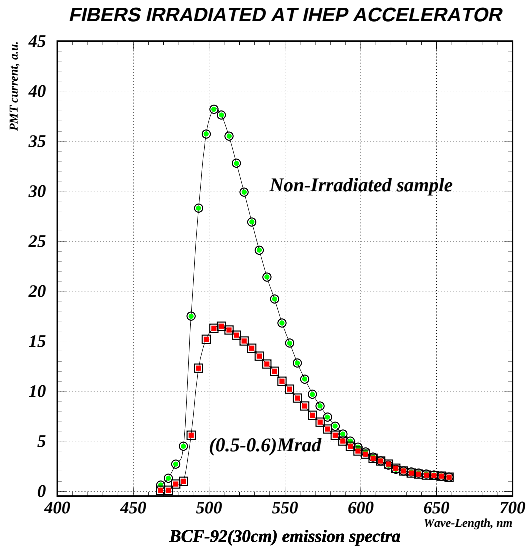

Figure 8: The emission spectra for 30 cm long BCF-92 fiber samples as measured with SF-46 spectra-photometer. The minor difference in light output above 550 nm is clearly seen.

One can see that the light output degradation is non-proportional for different vawe length. Above 550 nm the irradiation damage apear to be less drastic compared to shorter vawe-length range. This feature could be exploit to increase HCAL performance in the inner region by using the orange light filters between the fiber and the PMT, and therefore reducing the variation of light yield in time. The design of the HCAL includes a special calibration subsystem [7] with stable Cs^{137} radiactive source to monitor any decrease in attenuation length of each fiber during the LHCb operation for meny years.

4 Summary

In summary radiation damage of scintillating tile and two type of WLS fibers have been studied.

The light yield in tiles degrade within 20% for accumulated dose up to 0.5 Mrad and groth to 50% for 1.5 Mrad. The expected tile non-uniformity stay within acceptable range of $\pm 5\%$ up to 0.5 Mrad and rise up to $\pm$ 20% with dose of $1 \div 1.5$ Mrad. Those values are within acceptable limit taking in to account that accumulated dose in the HCAL central cells is evaluated as 0.5 Mrad after 10 years of operation.

The fibers degrade more rapidly. At the doses $0.5 - 0.6$ Mrad the attenuation length of both Y11(S200) and Pol.Hi.Tech(S250) decrease from 2.9 m to 1.6 m. For the BCF-92 the degradation is substantially higher: from 3.7 m to 0.7 m. Most of the loss is in the green range of the wave length. The measured emission spectra shows a relatively small difference at the wave-lengths above 550 nm.

References

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[7] HCAL Prototype beam-test results, LHCb 2000-036.