| CERN | # IRRADIATION PERMIT<br>PERMIS D'IRRADIATION | Annex SC/RP PRP 17 |
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LHCb 26/08/2010

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|---|
| Short description of the material irradiation<br>A module of the LHCb electromagnetic calorimeter, of lead-scintillator sandwich structure.<br>About 120x120x520 $mm^3$, 26.5 kg. |

| Name | Inst / Dep-Grp | Phone | Signature |
|---|---|---|---|
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| LHCb: Yu. Guz | PH/ULB | 79488 | |
| Installation supervisor: M. Glaser | PH/DT2 | 72058 | M. Glaser |

**SIGNATURES OBLIGATORY BEFORE START OF IRRADIATION**

| | Date | Name | Signature* |
|---|---|---|---|
| SC / RP | | Markus WIDORSKI 163758 | |
| RSO (PH Department) | | | |
| RSO (AB Department) | | | |

*: accepted with reservations specified in the attached conditions:

| ✓ | Attachments (to be provided by the person responsible for the material irradiation) |
|---|---|
| | Justification of the material irradiation |
| | Detailed time schedule for the complete material irradiation<br>(installation, irradiation, storage/transport, tests, shipping/transport, disposal) |
| | Detailed description of the material irradiation |
| | Specification of the material to be irradiated |
| | Irradiation properties (beam properties, intensity, total dose, etc.) |
| | All aspects related to radiation and general safety |
| | Results of estimates of produced radionuclides, their activities and the dose rate. ** |
| | Request for storage space for radioactive waste. ** |

# Request for irradiation of LHCb ECAL modules with 24 GeV/c protons in 2010

## LHCb CALO project

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## 1. Introduction

The LHCb ECAL is a lead-scintillator shashlik type electromagnetic calorimeter. It is installed at the distance of 12.5 m from the beam interaction point and covers the area of ~7.8x6.3 m$^2$. The inner edges of the instrumented area of ECAL are at a distance of 32 and 24 cm from the beam line in X and Y directions, respectively [1]. The ECAL is subdivided into three zones, inner, middle and outer, with cell sizes of 4x4, 6x6 and 12x12 cm$^2$. Its energy resolution is approximately $\sigma_E / E = 10\% / \sqrt{E(GeV)} \oplus 0.8\%$

The LHCb ECAL is built from independent modules with transverse size of 12x12 cm$^2$ and length of ~50 cm. Internally, the modules represent a lead-scintillator sandwich structure (66 layers of 2 mm thick lead and 4 mm thick scintillator plates). The optical readout is performed by wavelength shifting (WLS) fibers running through the longitudinal holes in the lead-scintillator structure. The Outer type modules form single 12x12 cm$^2$ cell; the Middle and Inner ones are optically subdivided into 4 and 9 cells, respectively.


**Fig.1** *The ECAL module structure (Outer module shown).*

The performance of the LHCb Electromagnetic Calorimeter is of high importance for the LHCb physics programme. The light yield and energy resolution of ECAL degrade with radiation dose. During first several years of the LHC operation LHCb will take data at luminosity of $2\cdot10^{32}$ cm$^{-2}$s$^{-1}$. The calculations of the longitudinal dose profile for the innermost ECAL module after 1 year at $\mathcal{L}=2\cdot10^{32}$ cm$^{-2}$s$^{-1}$ is shown in Fig. 1 ([1]; see also

[2]). Then, after the upgrade Phase 1, four years of LHCb operation at $10^{33}$ $cm^{-2}s^{-1}$ are foreseen. At this luminosity, the radiation doses at the ECAL inner zone will be rather high, and it may happen that its performance will degrade significantly.

The possibility to replace the innermost modules is implemented into the mechanical design of the LHCb ECAL. The purpose of these tests is to measure the degradation of the ECAL module after irradiation corresponding to 2-4 years of operation at $10^{33}$ $cm^{-2}s^{-1}$, estimate our needs in spare modules, and take a decision to produce additional spares if it will be found necessary.

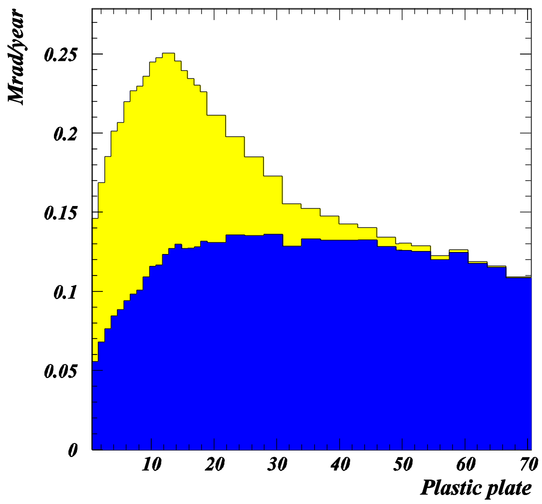


**Fig. 1** *The longitudinal dose profile for the innermost ECAL module. The dose corresponds to one year at* $\mathcal{L}=2\cdot10^{32}$ $cm^{-2}s^{-1}$*. The contributions from electromagnetic and hadronic components of the shower are shown separately. The horizontal axis represents the number of plastic plate counting from the front of the module. The period of the structure is 6 mm (4 mm scintillator + 2 mm lead).*

Previously, the ECAL irradiation tests were performed in components: the degradation of scintillator and WLS fibers, namely, loss of their light yield and transparency, were measured separately, and the predictions for performance of irradiated modules were done using simulation. Now we would like to irradiate whole module(s), and compare the performance before and after the irradiation by means of tests at SPS electron beam.

Another reason to perform the irradiation tests at the PS proton beam is that previous tests were carried out mainly with electron beam. The radiation damage in hadron beam may however differ from that in electron beam in both severity of the damage and degree of annealing. In total, the irradiation at PS will give us more reliable prediction concerning the lifetime of the modules. Of course the conditions at the PS beam will differ from those at LHCb in many aspects; our purpose is in fact to obtain a reliable lower limit for the radiation tolerance of the LHCb ECAL modules.

## 2. Outcome of the previous tests

The radiation resistance of LHCb ECAL modules was studied during the R&D phase of the project [3]. The most important test was carried out at LIL (LEP Injector Linac) in 2002. The results of irradiation tests of similar optical components can be found in [4].

Two modules were irradiated with 500 MeV electron beam up to ~5 Mrad dose at shower maximum, which, according to the simulation (Fig.1), corresponds to 20 years at

$\mathcal{L}=2\cdot10^{32}$ $cm^{-2}s^{-1}$ (or 4 years at $10^{33}$). Then the light yield of the modules, as a function of the longitudinal position, was measured my means of the radioactive source scan. These measurements were performed several times at 7—2000 hours after the irradiation. A significant annealing effect was observed.

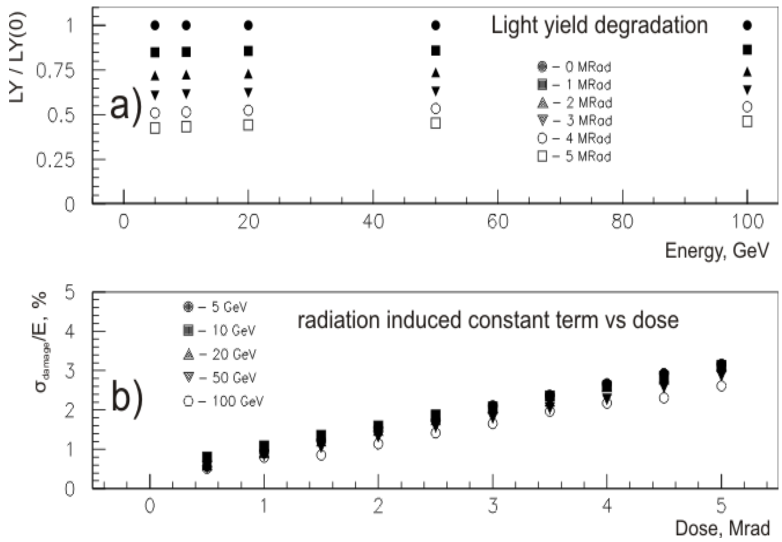


**Fig.2** *Results of simulation studies of radiation induced degradation of ECAL module at different values of accumulated dose at the shower maximum position:* **a)** *the relative light yield for doses (1—5) Mrad calculated at different beam energies;* **b)** *the resolution degradation in terms of increase of the constant term, as a function of dose.*

The data taken after 2000 h annealing were used as an input to the simulation of response to electromagnetic showers obtained with GEANT4. For the calculation of the light yield at intermediate doses, an exponential interpolation was used. The results are shown in Fig. 2. One can see that at 5 Mrad the predicted degradation is such that the light yield becomes 40% of that before irradiation, and the constant term becomes ~3% instead of 0.8%, which is at the margin of acceptable for the LHCb operation.

## 3. Justification for irradiation at PS in 2010

The major objective for the irradiation of LHCb ECAL modules in 2010 is evaluation of the performance (light yield and energy resolution) of LHCb ECAL modules after dose similar to that received by inner modules during 4 years at $\mathcal{L}=10^{33}$ $cm^{-1}s^{-1}$.

## 4. Request for irradiation at the PS in 2010

We would like to irradiate one or two LHCb ECAL modules of Outer type[1] to the dose of 1-3 Mrad at the PS IRRAD3 facility. The performance of the module(s) after the irradiation will be measured at the SPS electron beam; this means that we need at least a 8x8 $cm^2$ part of the whole 12x12 $cm^2$ module front face to be irradiated to this dose.

[1] Irradiation of an Outer type module may be preferable by two reasons. First, while we are short in spare Inner type modules, we have a number of spare Outer modules which will apparently not be needed for replacements. Second, the Outer type modules have lower fiber density than the Inner ones [1], and therefore more sensitive to the radiation damage of the scintillator tiles. The results obtained with Outer modules can be considered as a reliable lower limit for the radiation stability of the Inner modules.

The necessary proton flux and levels of induced activity after the irradiation were estimated using FLUKA.

In order to obtain the required dose, we need total of $\sim 5 \cdot 10^{14}$ protons uniformly distributed over the ~ 8 cm size area centered at the centre of the module front face. As the PS beam is rather narrow, we plan to irradiate this area step by step, remotely moving the irradiation table. The exact sequence of steps will depend on actual beam conditions.

We are considering an option to irradiate two identical modules, one with $\sim 5 \cdot 10^{14}$ protons, as above, and another one with $\sim 2 \cdot 10^{14}$ protons over the same area. This will give us information on the performance degradation as a function of dose. From mechanical point of view this looks feasible, the two modules can be installed on the same irradiation table, with a 5 cm space between them, and irradiated one after another. We have performed FLUKA calculations for the configurations with one and two modules. In the following, the expectations for the case of two modules are given.

We have no preference on the rate of irradiation, it can be chosen on the basis of beam time optimization.

## 5. Procedure

An LHCb ECAL module has: front face dimensions of 120x120 $mm^2$, length of 520 mm, and mass 26.5 kg. The two modules will be installed on the standard remotely controlled irradiation table at IRRAD3. For that, a dedicated Plexiglas support will be produced in cooperation with M. Glaser.

The module is a lead-scintillator sandwich with WLS fiber readout (see Fig.3). It contains following materials, in order of decreasing of quantity:

- Lead – 21.6 kg. The chemical composition of the ECAL lead is: 99.278% Pb, 0.260% Sn, 0.460% Sb, 0.002%Ag [6]
- Polystyrene – 4.5 kg. This comprises plastic scintillator (4.1 kg), WLS fibers (0.05 kg), front and back covers and support elements (0.35 kg). The composition of scintillator is: polystyrene ($[C_8H_8]_n$) + 2.5% p-Terphenyl ($C_{18}H_{14}$) + 0.01% POPOP ($C_{24}H_{16}N_2O_2$) [3]. The fibers are polystyrene-based KYRARAY Y11(250)MS.
- Stainless steel – 0.4 kg (Fe + 18% Cr + 9% Ni) – support elements

The dose rate and induced activity were evaluated from FLUKA simulation. We assumed quasi-uniform irradiation of the central 8x8 $cm^2$ area of each module: 22 spots with beam with Gaussian profile and diameter of 3 cm. The map of accumulated dose after the irradiation with $5 \cdot 10^{14}$ protons in module #1 and $2 \cdot 10^{14}$ in module #2 is shown in Fig. 3.

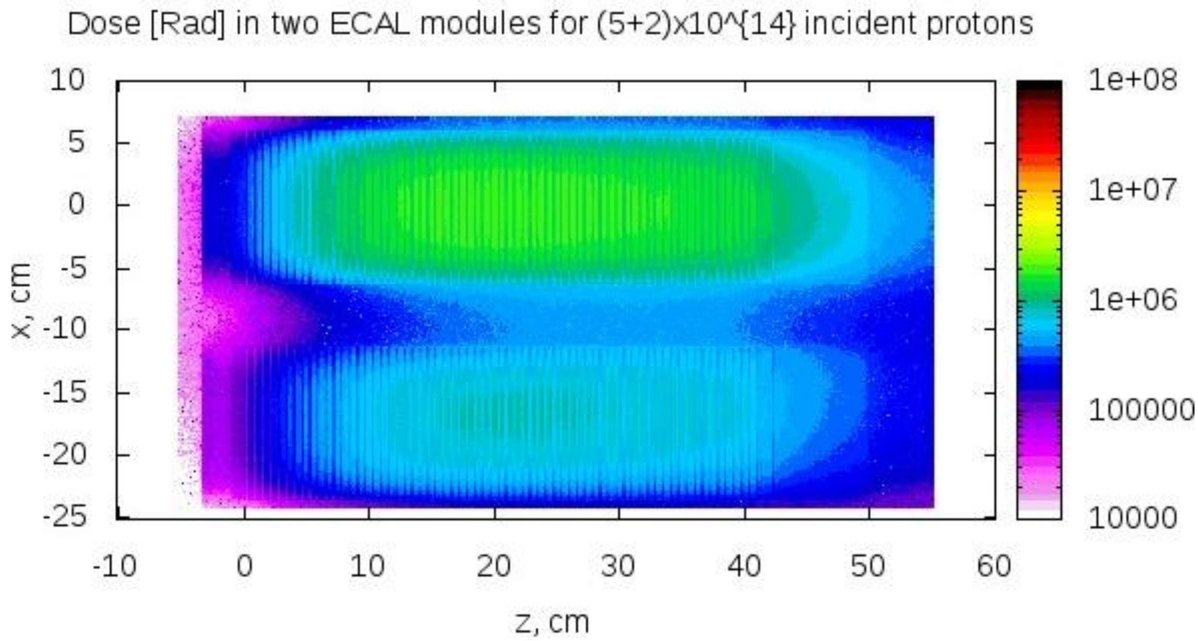


**Fig.3** *The dose profile for $5 \cdot 10^{14}$ protons in module #1 (up) and $2 \cdot 10^{14}$ in module #2 (down). The beam direction is along z axis, from left to right*

| Time, days after irradiation | Dose, in μSv/h, between the two modules, at z=30 cm | Dose, in μSv/h, at 10 cm above the surface of the module #1, at z=25 cm | Dose, in μSv/h, at 1 m above the surface of the module #1, at z=25 cm |
|---|---|---|---|
| 0 | $2.5 \cdot 10^4$ | $1 \cdot 10^4$ | $3 \cdot 10^2$ |
| 1 | $3 \cdot 10^3$ | $1.2 \cdot 10^3$ | 60 |
| 10 | $2.5 \cdot 10^2$ | $1.1 \cdot 10^2$ | 4 |
| 30 | 60 | 25 | 1.2 |
| 100 | 10 | 5 | 0.15 |

**Table 1.** *Expected induced activity after the irradiation.*

To make a reference point before the irradiation, in July 2010 the performance of the modules was studied at the SPS electron beam. The longitudinal scan with the $^{137}Cs$ source is foreseen in the LHCb CALO lab in bld. 156 for October 2010.

During the irradiation, the overall dose will be measured at the centre of the front and of the back of each module with passive dosimeters [5]. The expected dose at these points is estimated from the simulations.

We are applying for the irradiation period in November 2010. The expected necessary cooling time will be 50-60 days (see Table 1). After that, the modules will be stored in the radiation storage area in Bld. 157. The measurements of performance of the irradiated modules at the SPS electron beam (H4) are scheduled for July-August 2011. After the measurements, the modules will be sent to the waste.

The foreseen manipulations are listed in Table 2.

| Date | Location | Dose rate, μSv/h | At distance cm | Activity | Person | Time estimate, min | Dose, μSv |
|---|---|---|---|---|---|---|---|
| 15/11/2010 | B. 14 | 0 | | Training for the module installation and removal operations | M. Glaser<br>Yu. Guz<br>E. Chernov | 60<br>60<br>60 | 0<br>0<br>0 |
| 15/11/2010 | IRRAD3 | 200 | Local | Move IRRAD3 table from Pos1 to Pos2, install the module | M. Glaser<br>A.Guipet<br>Yu. Guz | 2<br>3<br>2 | 7<br>10<br>7 |
| 16/11/2010 | IRRAD3 | -NC- | | Start of irradiation | M. Glaser | | |
| 18/11/2010 | IRRAD3 | -NC- | | End of irradiation | M. Glaser | | |
| 18/11/2010 | IRRAD3 | -NC- | | Start cool down in IRRAD3 | | | |
| | | | | | | | |
| 07/03/2011 | IRRAD3 | -NC- | | End of cool down in IRRAD3 | | | |
| 07/03/2011 | IRRAD3 | 20 | 10 | Remove the irradiated module from IRRAD3. Move IRRAD3 table from Pos2 to Pos3 | M. Glaser<br>A. Guipet | 2<br>3 | 7<br>10 |
| 07/03/2011 | IRRAD3 | 20 | 10 | At Door 152.<br>Moving the modules inside the transport box | M. Glaser | 2 | 7 |
| 07/03/2011 | B157 | 20 | >100 | Transport from Door 152 to radiation storage inside building 157. | M. Glaser<br>Yu.Guz<br>M. Gutier | 5<br>5<br>10 | 0.1<br>0.1<br>0.1 |
| 20/07/2010 | ENH1 | <1 | 100 | Transport to H4 beam area | Yu.Guz | 20 | 0.1 |
| 21-22/07 | ENH1 | <1 | >100 | Measurements with beam at H4 | Yu.Guz<br>P. Shatalov | -NC- | 0<br>0 |
| 25/07/2010 | B157 | <1 | 100 | Transport to the storage | Yu. Guz | 30 | 0.1 |

Table 2. *Manipulations foreseen during the module irradiation and measurements*

# 6. References


1. S. Amato *et al*, "*LHCb Calorimeters Technical Design Report"*, CERN/LHCC/2000-0036, CERN, 06 September 2000
2. G. Cortri, L. Shekhtman, "*Radiation background in the LHCb experiment*", LHCB-2003-83, 22 September 2003
3. S. Barsuk *et al*, "*Radiation damage of LHCb electromagnetic calorimeter*", LHCb-2000-033
4. G. Britvich *et al*, "*The HCAL Optics Radiation Damage Study*", LHCb-2000-037
5. A.V. Antipov, G. Britvich *et al*, "*Precise densitometer for thin-film dosimeters*", NIM B 94 (1994), 338-340

6. G. Cortri, L. Shekhtman, "*Estimation of induced radioactivity in LHCb to determine the Reference Waste Zoning of the experiment*", LHCB-2007-097 and EDMS 850261, 15th June 2007