studies of radiation hardness of ECAL modules

Iradiation tests of ECAL modules

A. Make use of the LHC radiation field. Two Inner type modules were placed in the LHC tunnel at the opposite side from the LHCb interaction point.

- testing same type modules as in present ECAL;
- same composition of the radiation field as in ECAL itself

→ reliable estimation of rad. damage;

- the dose rate is several times faster than at ECAL central modules;
- modules installed in September 2010, equipped with passive and active dosimeters;
- the test will last several years, with measurements with ^{137}Cs source scanner during shutdowns
  - first scan performed 15-Feb-2012
  - second scan 18-Apr-2013

B. Irradiate an Outer type module at the PS IRRAD facility, 24 GeV protons (Maurice Glaser)

– different composition of the radiation field

– different dose rate and longitudinal profile – different effect on the resolution

– different module type (Outer)

\+ but quick answer; and

\+ light yield degradation measurement is robust

19-Nov-2010 – irradiated to ~2 Mrad

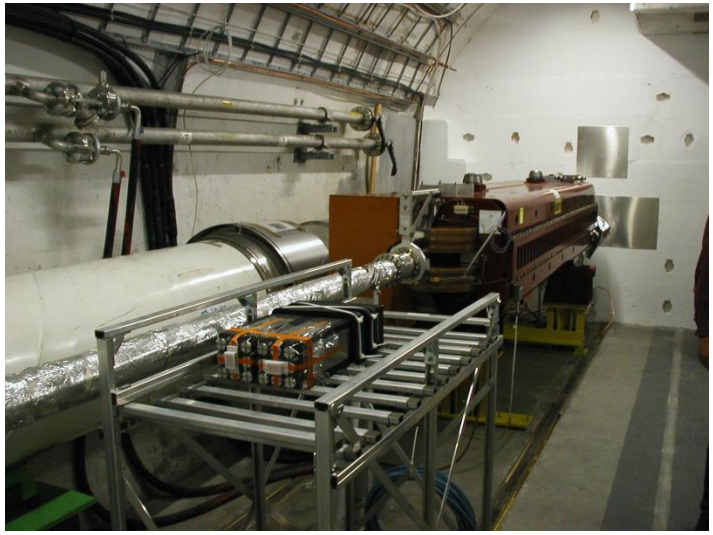
02-Aug-2011 – tested at the SPS electron beam

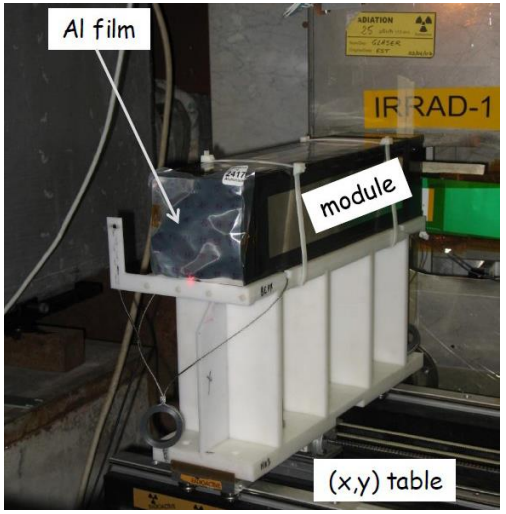
15-Feb-2012 – scan with ^{137}Cs source

07-Jun-2012 – irradiated again to 2 Mrad, 2+2=4

16-Aug-2012 – beam tests

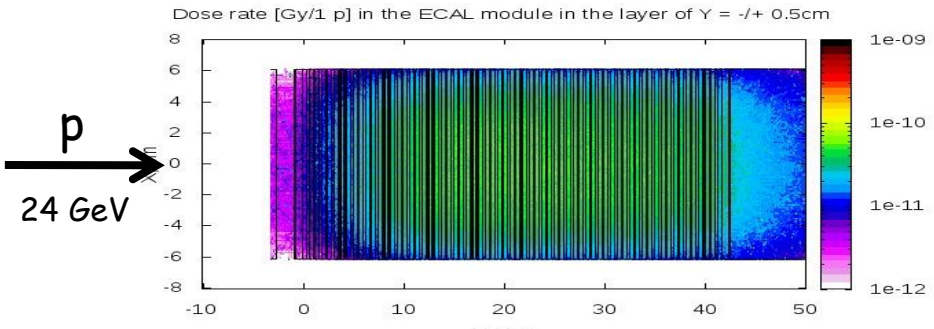
18-Apr-2013 – scan with ^{137}Cs source



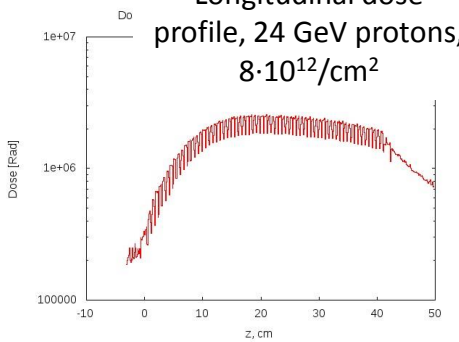


irradiations at PS in 2010 and 2012

The dose profiles and induced activity level were calculated using FLUKA (V. Talanov). It was found that in order to obtain ~ 2 Mrad inside the module we need ~$8 \cdot 10^{12}$ protons/cm^2.



Longitudinal dose profile, 24 GeV protons, $8 \cdot 10^{12}$/cm^2



The list of tests with an Outer type module is given below; results at the next slide.

19-Nov-2010: the 10x10 cm^2 central area of an Outer type (1 large cell) module's 12x12 cm^2 was uniformly irradiated, using the (x,y)-movable table. The irradiation took ~36 hours. The input proton flux was measured with Al film. It showed good dose uniformity (controlled with Al film); the input flux ~$9 \cdot 10^{12}$ p/cm^2 (requested $8 \cdot 10^{12}$, to have ~2 Mrad).

02-Aug-2011: tested at the SPS electron beam, along with a non irradiated module. The module performance was found still satisfactory, however significant light yield degradation (factor of 5.5) was observed.

15-Feb-2012: the longitudinal scan with ^{137}Cs source was undertaken. It confirmed (within the precision of the method) the light yield loss seen in the beam test.

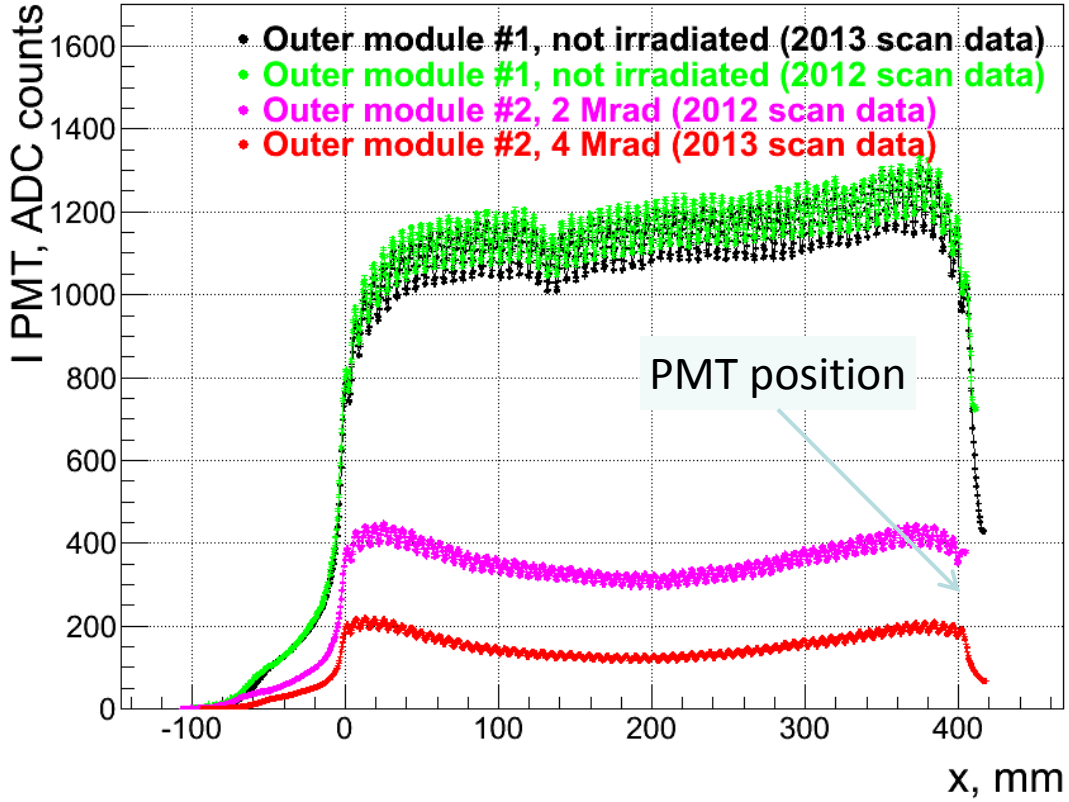
07-Jun-2012: another irradiation of this already irradiated module was performed in 2012, in the same conditions and to the same dose as in 2010. The flux was again verified with Al film: ~$9 \cdot 10^{12}$ p/cm^2 on average, with good uniformity. The total dose received by this module is 4 Mrad.

16-Aug-2012: test at the SPS electron beam. Further performance degradation was observed: light yield reduced further by other factor of ~2.5, resolution also degraded. The module performance is not good any more.

18-Apr-2013: the longitudinal scan with ^{137}Cs source. It confirmed the light yield loss seen in the beam test in August 2012.

irradiations at PS in 2010 and 2012

E beam, GeV	module #2, not irradiated		module #1, 2 Mrad		module #1, 4 Mrad	
	light yield, ph.el./GeV	resolution, %	light yield ph.el./GeV	resolution, %	light yield ph.el./GeV	resolution, %
50	2598±52	1.37±0.04	583±12	2.16±0.04	223±10	2.74±0.04
100	2611±52	1.01±0.03	576±12	1.57±0.03	221±10	2.26±0.05
120	2604±52	0.98±0.03	571±12	1.36±0.03		
125					220±10	2.06±0.05
150					219±10	1.77±0.05

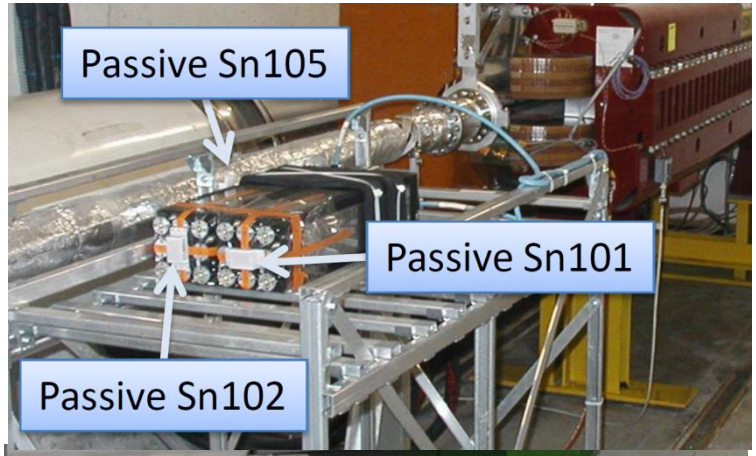


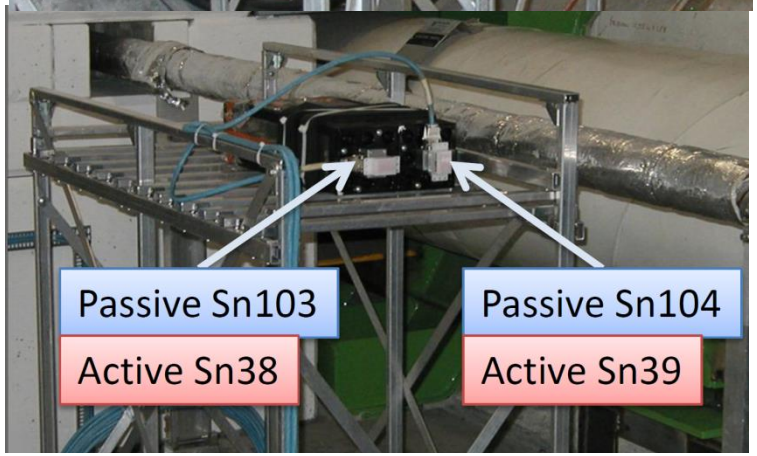
The module performance is satisfactory with 2 Mrad; not any more with 4 Mrad. Expected to be better for Inner modules: higher fiber density. We believe therefore that the ECAL modules will remain operational till ~2.5 Mrad (20 fb^{-1}) at least.

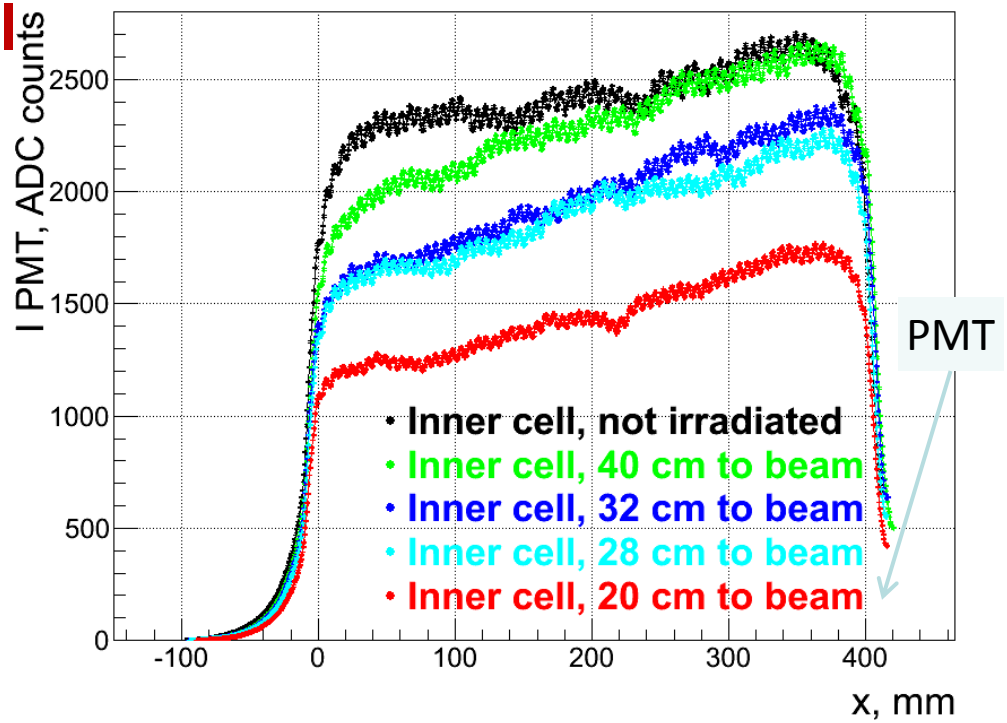
irradiation at the LHC tunnel

The 2011 dose measurements: Matthias, 13-Jun-2012. The 2011+2012 dose is ~ 3x of this (~1 Mrad at the cell closest to the beam).

ECAL Tunnel	Coordinates					
ITEM_ID	X	Y	Z	Alanine results [Gy]	FLUKA [Gy] 1.22fb-1	Sim/Alanine
4CRCERPW000101	-264	0	-8820	235	2.91E+02	1.24
4CRCERPW000102	-132	0	-8820	762	2.89E+03	3.79
4CRCERPW000103	-264	0	-8380	642	1.17E+03	1.82
4CRCERPW000104	-132	0	-8380	1137	4.18E+03	3.68
4CRCERPW000105	-70	60	-8660	3130	3.01E+03	0.96





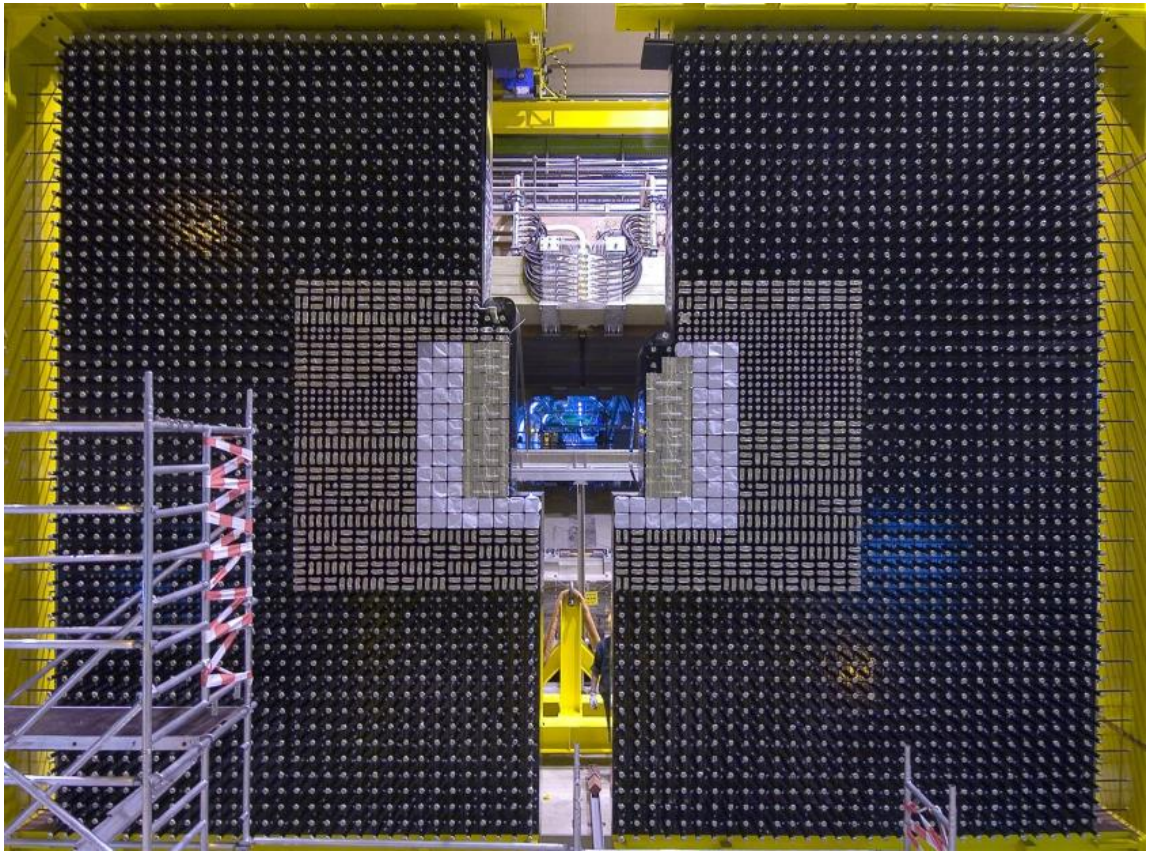


Results of the ^{137}Cs scan 18-Apr-2013, modules spent 2011+ 2012 in the tunnel. These tests done with same PMTs at same HV. Scanned were: the cell closest to beam pipe in the module #1 (20 cm from beam, max dose), opposite cell of module #1 (28 cm from beam, intermediate dose), cell closest to beam pipe in the module #2 (32 cm from beam, intermediate dose), opposite cell of module #2 (40 cm from beam, minimum dose) . For comparison, a cell of a reference (not irradiated) module was scanned.

The degradation of the "20 cm" cell is moderate; we can expect that it will remain operational till ~2.5 Mrad (20 fb^{-1}).

The "32 cm" light yield is slightly higher than that of "28 cm" – this represents the method's precision.

module replacement



Year	Energy	Int. Lumi.
2010	7 TeV	37 pb^{-1}
2011	2.76TeV	71 pb^{-1}
2011	7 TeV	1.0 fb^{-1}
2012	8 TeV	2.2 fb^{-1}
2013	LHC splice repair	
2014		
2015	13 TeV 25 ns bunch crossing	>5 fb^{-1}
2016		
2017		
2018	LHCb upgrade	
2019		
2020	5-10 fb^{-1}/year	
2021		
2022	LHC lumi upgrade	
2023		
2024		

The performance of ECAL central modules is expected to remain satisfactory till 20 (30?) fb^{-1}.
The module replacement at LS2 will be too early.
We may consider replacement of central modules during LS3 (2022) – so what about 30 fb^{-1}?

further plans

- ❑ All the irradiated ECAL modules are now stored at the LHCb RP lab. What are we going to do with them?
- ➢ The proposal is (to be discussed) :
  - re-install the Inner module #1 (the one which was closer to the beam pipe) into the tunnel for further irradiation
  - keep the Inner module #2 in the RP lab till LS3, when it may be used for replacement
  - the Outer module irradiated at PS can go to radioactive waste. Before this, one can perform various annealing/repair tests on it (do we think it is necessary?).

- ❑ Revision of spare ECAL Inner modules.
- ➢ There are 31 modules, in many of which 1 or 2 cells are marked as bad according to the 2004 cosmic tests results. This is to be verified.
  - We can start with ^{137}Cs scan of all of them.
  - 4 scans per module ➔ 4-5 days of work.
  - can be done this year.