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CMS NOTE 1999/022

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

April 12, 1999

Initial Tests on First Full-size ECAL Endcap Crystals

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ECAL

Abstract

At the end of last year the first full size ECAL endcap crystals were delivered to CERN.Thirty in number, they were produced to the final geometrical specifications; 220mm long with a rear square face of 30mm and a front square face of 28.6mm. All were delivered polished. The visual inspection, dimension, transmission, light yield and light yield uniformity tests carried out since are discussed, with particular emphasis on the light yield uniformity. The results are very encouraging. suggesting that the endcap crystals will not need uniformisation.

1 Introduction

All crystals were visually inspected and had their transmissions measured, 10 had their dimensions verified and 27 had their light yield and light yield uniformity measured. Several crystals were also irradiated to study their radiation hardness. Each type of measurement is described in the following sections, 2 through 6 respectively and conclusions are given in section 7.

2 Visual Inspection

All crystals were visually inspected and any chips, core defects or other abnormalities noted. Approximately 1/3rd of the crystals were clear and fully transparent to the eye, 1/3rd had core defects of varying size, ~1/6th were slightly yellow in colour due to absorption at 420nm and several had strong colouration, possibly due to doping inversion. These results were confirmed by the transmission measurements (section 3). The chamfers were larger than on the barrel pre-production crystals as one is now reaching the limit on the size of the ingot.

3 Dimension

Ten crystals were measured in the metrology department at CERN. The distribution of the back and front faces are shown in fig. 1.

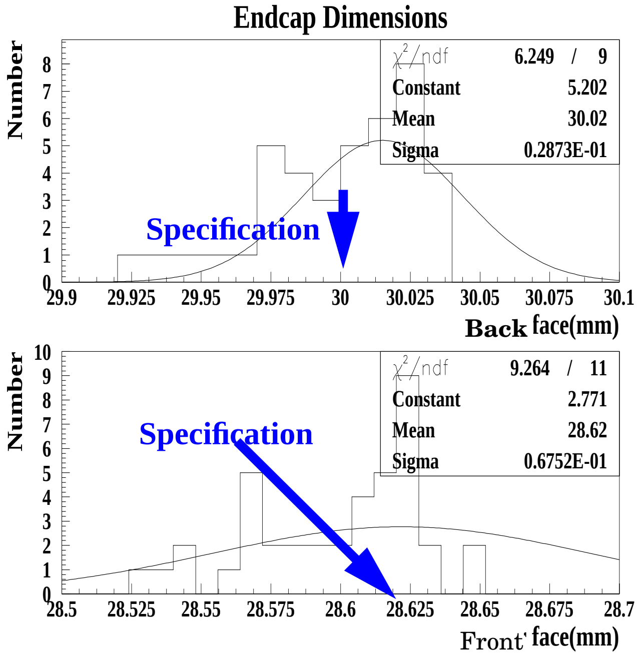

Figure 1: Distribution of back and front faces.

All are within 0.1mm of the specification, thus falling very close to the barrel crystal pre-production criteria of + 0 -0.10mm.The distributions in length and planarity are shown in fig. 2. The planarity value shown is the maximum deviation from the mean. Here the variations are somewhat larger - the barrel pre-production tolerance on the planarity is 0.20mm.

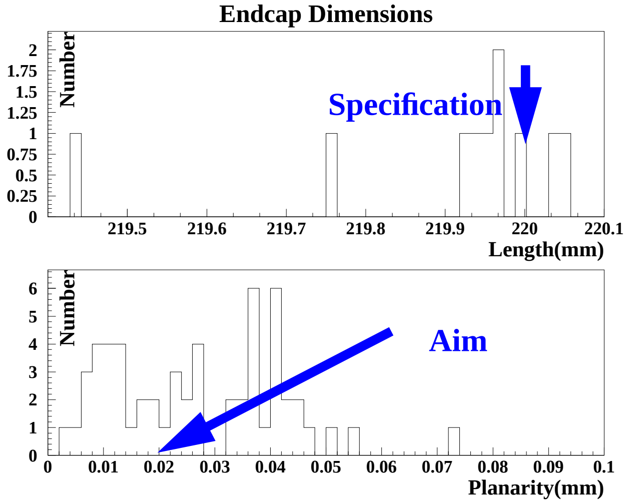

Figure 2: Distribution in length and planarity.

4 Transmission

The transmission of all crystals was measured between 300 and 700nm both longitudinally and transversally (at 6 points along the crystal) using the standard building 27 spectrophotometer. About 1/3rd of the crystals had excellent transmission, a typical crystal is shown in fig. 3.

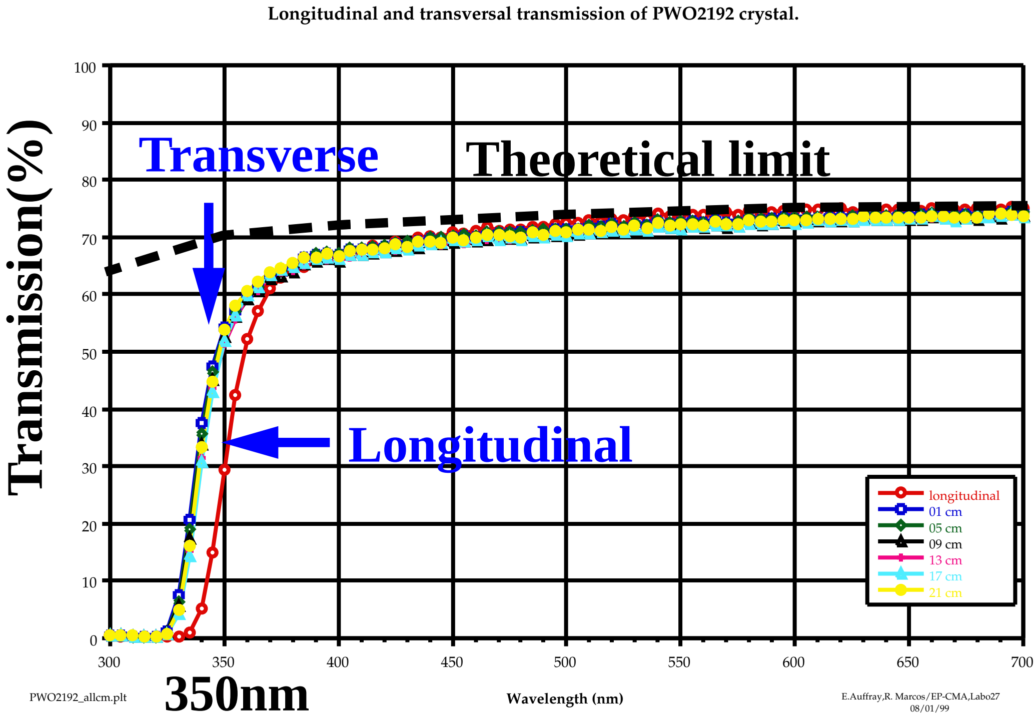

Figure 3: Longitudinal and transversal transmission of crystal 2192.

Note the very sharp turn-on at short wavelengths and that the theoretical limit from surface reflections is reached above 500nm, as for good quality barrel crystals. Figs. 4a and b illustrate cases where slight aborption at 420 nm (a) (giving a yellow tint) and core defects (b) are present. About 1/3rd of the crystals displayed core defects and

~1/6th slight aborption at 420nm. This absorption is however slight and did not affect the light uniformity measurements - section 4. The transmission curves for the three crystals with strong colouration confirmed the hypothesis of doping inversion.

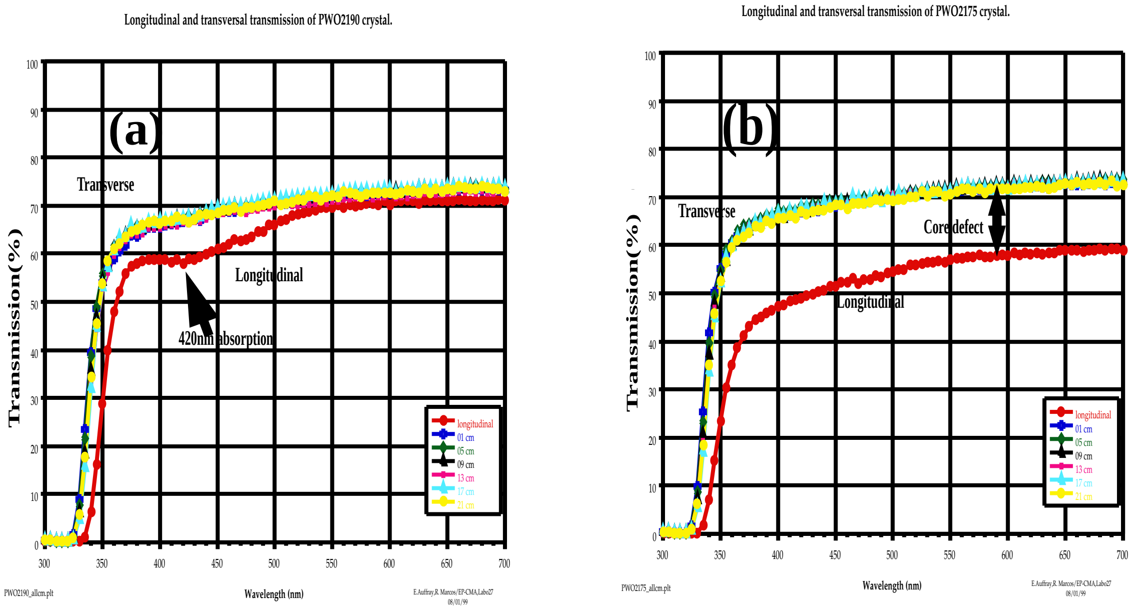

Figure 4: Transverse and longitudinal transmission of crystals, 2190 and 2175, showing 420nm absorption and a core defect respectively.

The longitudinal transmission at 420nm (close to the scintillation emission peak) for all crystals is shown in fig. 5. The barrel pre-production specification is > 55% at 420nm, about 80% of these crystals pass this requirement.

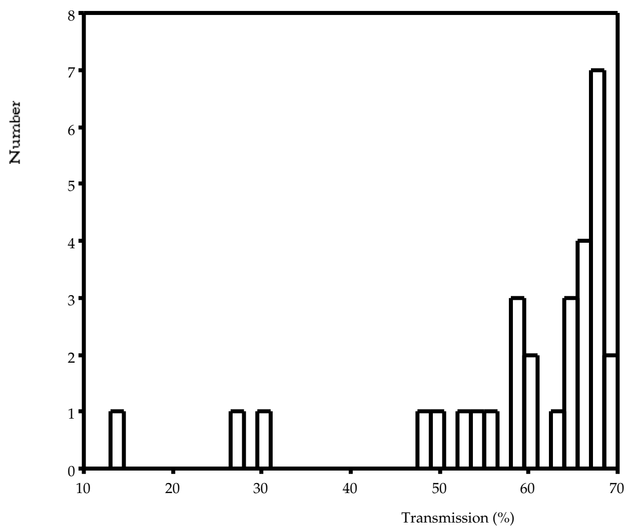

Figure 5: Longitudinal transmission at 420nm of the full 30 crystals.

5 Light yield and light yield uniformity.

Tests were performed in a temperature stabilized, light tight environment similar to that described in [1]. The crystal is coupled vertically (large face at bottom) via optical grease to a large area (40mm active diameter) Hybrid Photomultiplier (HPMT). A ^{60}Co source is scanned in 1cm steps up the crystal and the scintillation signal at each point recorded. Straight line fits are performed between 3.5 and 11.5 cm from the front face and 11.5 and 19.5cm to obtain the front (FNUF) and rear uniformity (RNUF) respectively. The light yield (LY) is also measured at the reference point 6.5cm from the front of the crystal. All crystals (27), except those with doping problems were measured.

The design goal of the CMS ECAL is a constant term in the energy resolution of <0.5%, allowing effective and rapid exploitation of the H->γγ decay channel. Any non-uniformity in light collection along the length of the crystal contributes significantly to this constant term. The slope in the shower maximum region (where the FNUF is measured) has the greatest effect. Previous studies [2,3,4] have shown that the ideal slope here is flat, with a small increase, ~10% over the rear of the crystal (corresponding to where the RNUF is measured); the slope in the shower maximum region must be less than $\pm 0.35\%/X_0$ to keep the effect on the energy resolution to a tolerable level.

The barrel crystals have a relatively large taper, ~3mm, from the front, non detector end towards the larger, rear detector end. The effect of this taper is to 'focus' the light from the front so that the light collected from this region is greater than that from the back, thus inducing a natural non-uniformity. To compensate for this it is necessary to depolish one of the lateral faces and so randomise the direction of the light reflected from it. The extent to which the surface is roughened must be carefully controlled, this optimisation, coupled with its mass application to the full 60,000 barrel crystals is non-trivial. Furthermore depolishing one surface greatly increases the dependence of the light yield on the surrounding wrapping, making the use of a dedicated reflector necessary.

The endcap crystals are less tapered and so the natural non-uniformity should be reduced. These tests represent the first, preliminary evaluation of whether uniformisation (and hence wrapping[a)]) is necessary for actual, full size endcap crystals - the avoidance of such procedures being of very great significance.

In the final detector the crystals will be inserted in a 'black' non reflecting alveolar structure, with a diffuse reflecting tyvek insert at the small, non-detector end (the latter is easily inserted and can form part of the mechanical support). If a reflector is used on the lateral faces in the final detector it will most probably be a form of specular reflector, such as aluminised mylar. All crystals were measured unwrapped ('naked') as this is close to a possible final scenario and was most easily achieved with the existing set-up. Cross checks on a limited number of crystals were also performed with only a tyvek insert on the front end, mylar on the lateral faces and the front end and mylar on the lateral faces with tyvek on the front end to represent the other possible scenarios.

a. A small increase in light yield is observed with a good quality reflector, even for a non-depolished crystal.

The expected shape, as given by a ray-tracing program[a], developed at Imperial College is shown in fig.6 for the

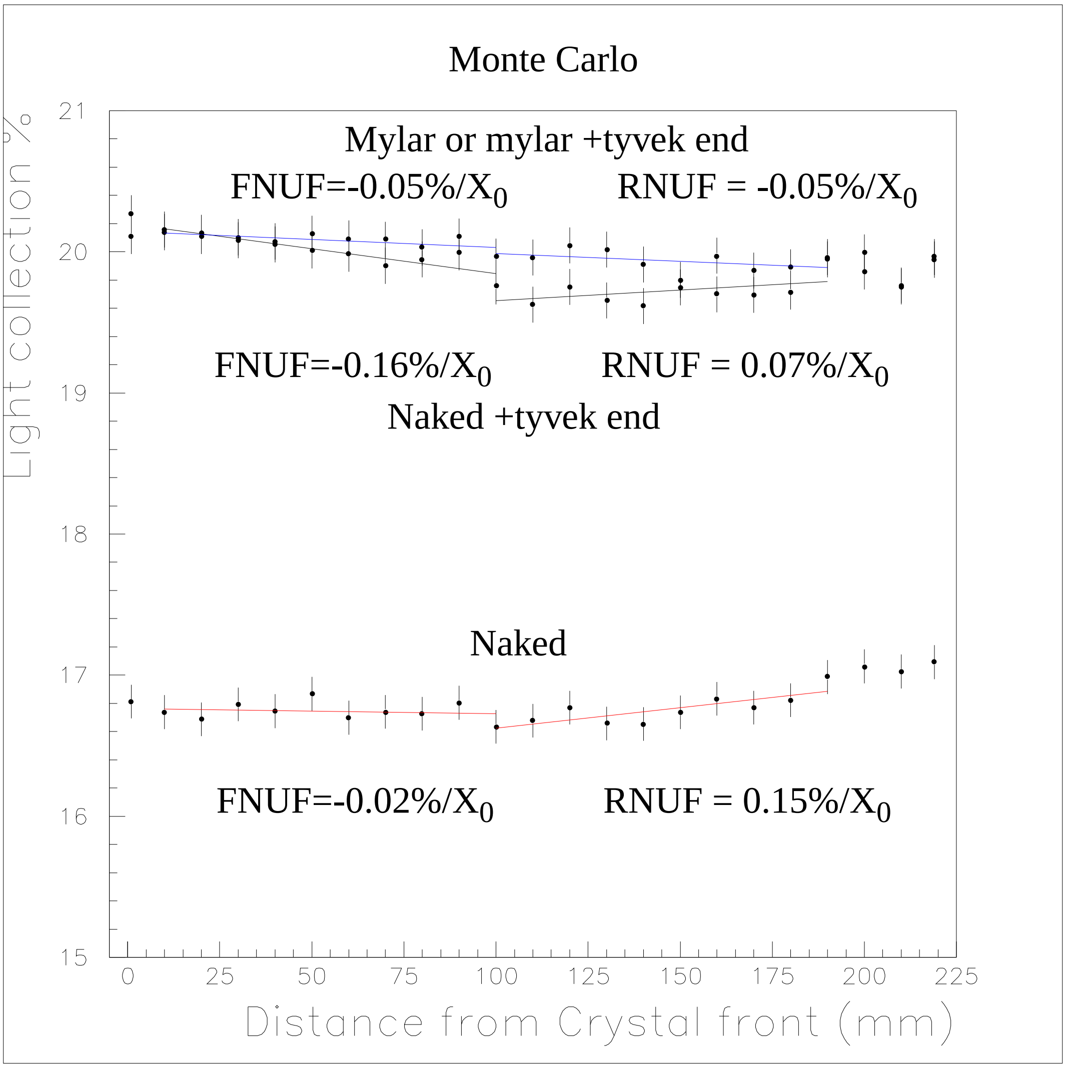

Figure 6: Monte Carlo prediction for the light yield uniformity in full size endcap crystals.

various wrapping scenarios. Crystal emission and transmission spectra typical of a good quality barrel pre-production crystal were used; the former should be the same and the latter was measured to be. No detector angular acceptance or re-scattering within the crystal were included. As can be seen the expected uniformity is close to ideal, particularly in the 'naked' case. The error on each slope is ~0.1%/X_0, so there is really no significant difference between the wrappings in terms of the uniformity. The light yield from all cases involving wrappings is the same, at ~1.19 times the naked case. This suggests that, as found previously, the small end has the greatest effect on the light yield, whilst the lateral faces have little effect.

The measured result for a 'naked' crystal with good transmission is shown in fig. 7. The error on either slope, estimated from repeated measurement/past experience with the system is ~ 0.15%/X_0.

a. This program has previously been cross-checked against measurement and other light collection simulations, in particular that of ref. [5].

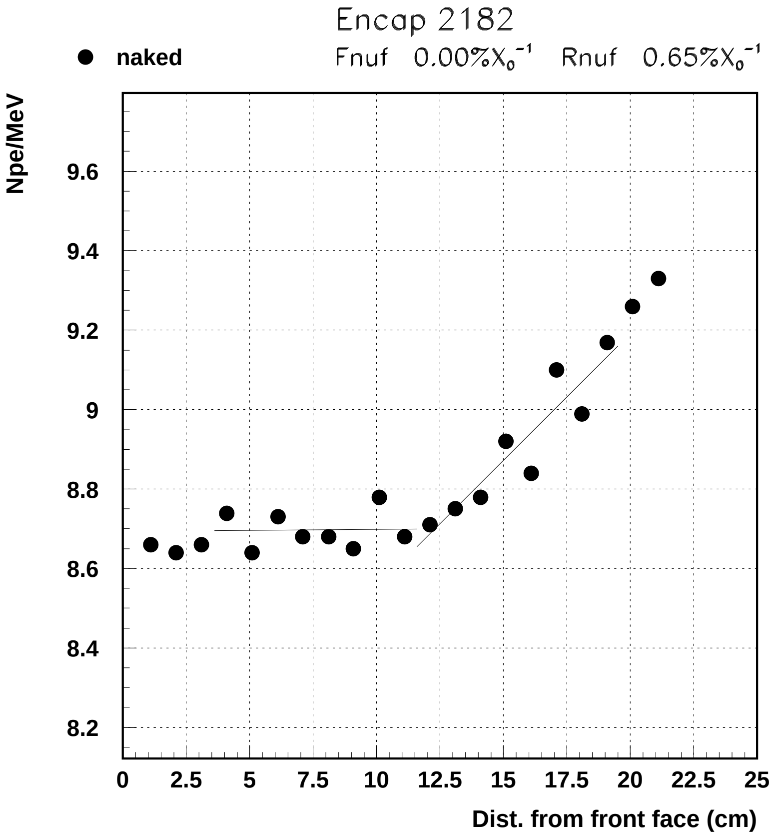

Figure 7: Light yield uniformity of endcap crystal 2182.

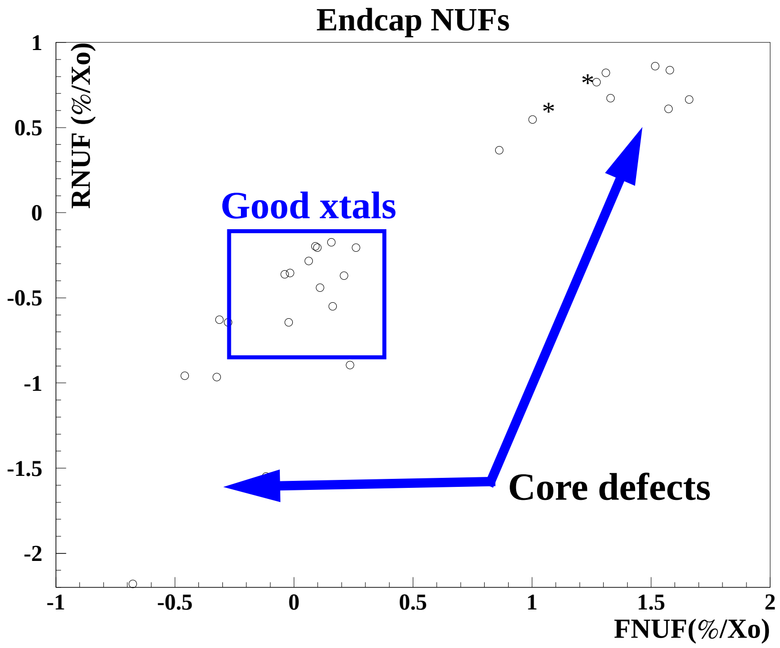

Figure 8: FNUF vs. RNUF for the 27 crystals measured.

Fig.8 shows the FNUF and RNUF values for all crystals measured. Those crystals with good optical transmission or only slight absorption at 420nm have been boxed and labelled ‘Good xtals’. Those crystals with abnormal uniformities correspond to those with core defects; the presence of such defects will modify significantly the expected uniformity. There are however two crystals with good transmission which appear to give abnormal uniformities - marked by * in fig. 8.This abnormal behaviour is currently under investigation.

As mentioned previously, other wrapping were also investigated. The effect of these, including masking the HPMT to use only a 25mm diameter active area, closer to that of the photo-detectors proposed for the endcaps, is illustrated in fig. 9 for crystal 2179. A number after the wrapping type in the figure legend indicates a repeated measurement i.e. Naked 1 and Naked 2 are repeated measurements made under the same conditions. The measurements were repeated on other crystals and, as the individual measurements were in agreement, combined. See table 1. The error on the light yield is a few percent.

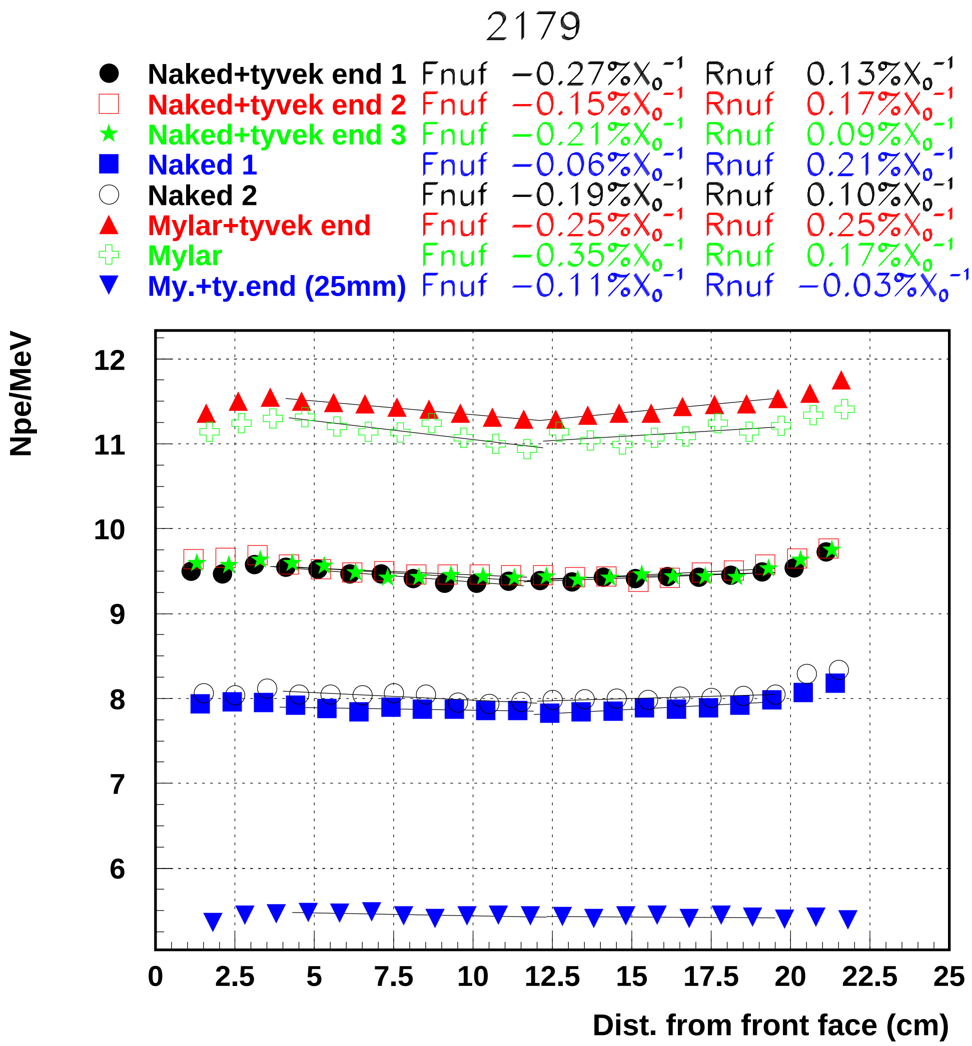

Figure 9: Light yield uniformity for endcap crystal 2179 with various wrappings.

Tab. 1. Comparison between different wrappings/detection area.

Comparison between	Change in FNUF (%/X0)	Change in RNUF (%/X0)	LY wrt naked
Naked and mylar	-0.18	-0.02	1.39
Naked and tyvek end	-0.07	0.05	1.21
Mylar and mylar + tyvek	0.11	0.05	1.45 (mylar+tyvek)
Full area and 25mm area for mylar + tyvek end	0.03	-0.24	0.53 - direct ratio

As can be seen there is no significant change in uniformity with wrapping or with the reduction in the active photo-detection area - in agreement with the Monte Carlo predictions. There is however a clear disagreement with the observed increase in light yield with wrapping. Though the increase with tyvek on the small end is, within errors, as predicted the increase with wrapping the lateral faces is in complete contrast to the prediction. It is believed that this is due to re-scattering within the crystal. Initial studies in which re-scattering was including in the ray tracing program indicate that indeed this greatly increases the sensitivity to wrapping the lateral faces. The effect of the re-scattering on the uniformity should be to slightly reduce the effect of the taper. The initial tests indeed show that the uniformity is somewhat improved. The FNUF is moved slightly by ~+0.1%, closer to 0 and the RNUF is more significantly increased by ~+0.5%. Here the scattering length was tuned to match the increase in light yield observed between the wrapped and unwrapped cases (~ 80cm). Such effects are being investigated in more detail with colleagues at Imperial College.

To strengthen the extrapolation of the uniformity results towards the final size endcap photo-detector the ray tracing program was re-run with a 25mm diameter detector for all the previously considered cases. Within the errors the results for uniformity and relative light yield were as found for the large area detector case. The LY ratio between the 25 mm and large area detector for the mylar with tyvek end was 0.72, in contrast with the observed value of 0.53. Initial tests also indicate that this is due to re-scattering within the crystal.

5 Radiation Hardness.

As a first test two crystals, one with very poor (fig. 10a) and one with good transmission (fig. 10b) were irradiated from the **front** with gammas, at a dose **rate** and **level** comparable to that expected in the **barre**l ECAL, using the facility decribed in ref [1].

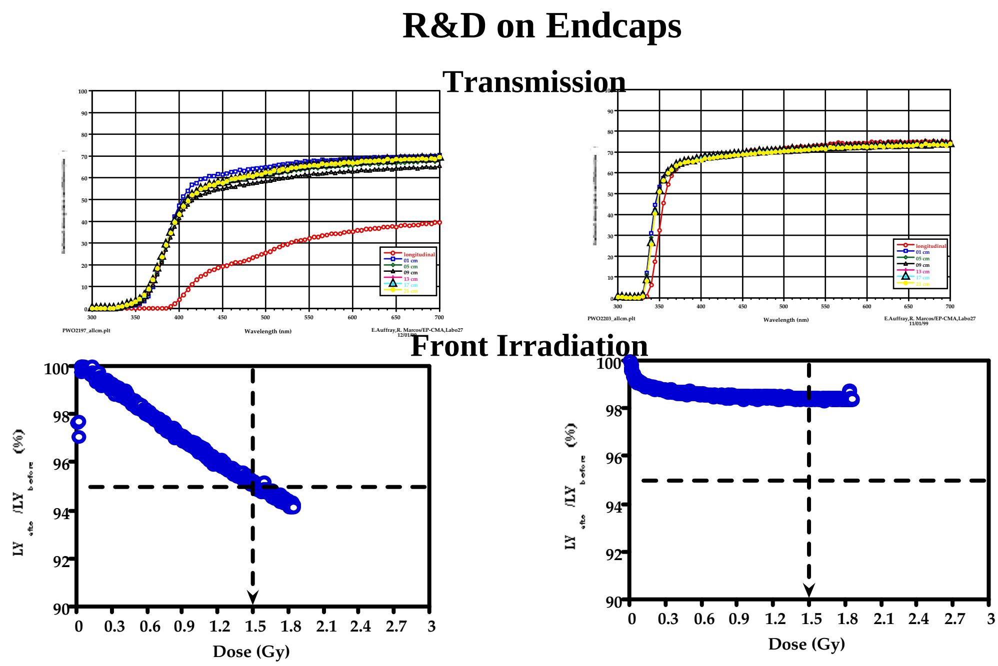

Figure 10: Preliminary irradiation of two endcap crystals.

Previous studies [6] have shown that for barrel crystals the turn-on (340-370nm) in the longitudinal transmission can be used to predict radiation hardness - crystals with a slope greater than 1.5%/nm suffer less than 6% light yield loss after 1.5Gy. Thus one would expect poor radiation tolerance for the crystal in fig. 10a but good radiation tolerance for 10b - this is what is observed. Thus endcap crystals behave like barrel crystals as one would hope. The next stage is to irradiate to dose levels, at dose rates, comparable with those expected in the endcap - such tests are underway.

6 Conclusion.

The results obtained with these first full size endcap crystals are extremely promising; whilst there is still room for improvement our congratulations go to the Producers.

The light yield uniformity tests suggest that it may well not be necessary to uniformise the endcap crystals. Indeed simulations carried out by colleagues at Imperial College based on these crystals show that grinding a lateral face does not improve the FNUF. The measured uniformities are in agreement with the Monte Carlo predictions. The effect of re-scattering within the crystal is significant, particularly in terms of the total light collection. If the re-scattering within the crystals is significantly reduced, the sensitivity to wrapping the lateral faces will be reduced and it will not be necessary to incorporate a reflector within the alveolar structure. If significant re-scattering remains the potential increase in light collection may well prove too tempting to ignore, despite the increased complexity of construction. The final decison will clearly be affected by the gain and noise performance of the endcap VPTs which are still under optimisation. Uniformity tests with actual VPT readout are planned in the ISIS test beam at RAL and using similar techniques to those described here at Imperial College.

We look forward to receiving more, improved, crystals during the year.

Acknowledgments

It is a great pleasure to thank the crystal Producers, the Metrology Department at CERN and the TIS teams without whom this work would not have been possible.

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