Uniformisation of Lead Tungstate Crystals for the CMS Electromagnetic Calorimeter Endcaps

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Abstract

Electromagnetic calorimeters based on dense, scintillating crystals have the potential to achieve extremely good energy resolution. However, care must be taken to minimise systematic effects such as variation of light collection efficiency with depth in the crystal. A HPMT has been used to accurately measure the non-uniformity of light collection in lead tungstate crystals for the CMS detector. It is found that the non-uniformity of crystals measured in the detector configuration is not much larger than the maximum tolerable limit. Shading the chamfered edges of the crystals with a pencil can reduce the non-uniformity by approximately $0.1\%/X_0$. Roughening the chamfers achieves a similar reduction.

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1 Introduction

A key feature of the CMS experiment at the LHC is a high precision electromagnetic calorimeter (ECAL) [1]. The ECAL will consist of some 80000 scintillating lead tungstate ($PbWO_4$) crystals arranged in a barrel section and two endcap sections. Stringent demands are placed upon the ECAL performance. The energy resolution is paramaterised as follows:

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c \tag{1}$$

where a is a stochastic term, b the electronics noise term and c is a constant term. Calorimeters employing fully active media can usually achieve very good stochastic terms; the energy resolution, particularly at high energy, is then dominated by the constant term. A major factor in the constant term in non-uniformity of light collection in the crystals.

The CMS ECAL crystals are tapered in shape to obtain a pseudo-pointing geometry. This shape focuses light produced at the small, tapered end of the crystal onto the photodetector mounted at the rear giving a non-uniform light response along the length of the crystal. Simulation studies have shown that to limit the constant term to a value of 0.55% then the maximum tolerable change in detected light in the shower maximum region (hereafter referred to as the front non-uniformity, or FNUF) is $0.35\%/X_0$[2].

2 Experimental Techniques

The technique for measuring non-uniformity involves scanning a ^{60}Co source along the length of a crystal in 1cm intervals and the output recorded with a HPMT [3], which can detect low numbers of photons with impressive accuracy. The light yield at each point is extracted by fitting the data with a custom-written function [4] as shown in Figure 2. The light yield is plotted as a function of distance from the HPMT and the FNUF is calculated from the slope in the shower maximum region.

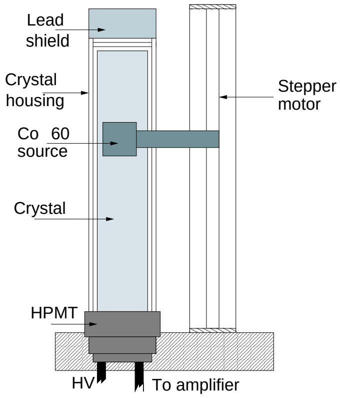

Figure 1: Schematic diagram of HPMT setup

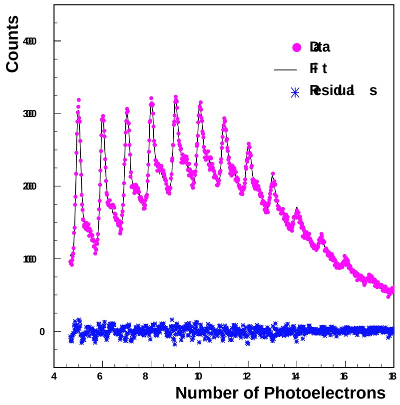

Figure 2: A fitted HPMT spectrum.

3 Studies of Uniformity

A sample of 52 endcap crystals have been measured in a carbon fibre alveolar, similar to the final detector configuration. One crystal could not be fitted due to low light yield. The results are presented in Figure 3 and it can be seen that the mean FNUF is only slightly above the limit. The fraction of crystals above the tolerable limit is 35%. The distribution of Figure 3 contains the FNUFs of so called 'anomalous crystals'. These are crystals that have abnormally large values of FNUF and it is hoped that such crystals will not appear during mass production. If these crystals are ignored, the fraction above the tolerable limit falls to 21%.

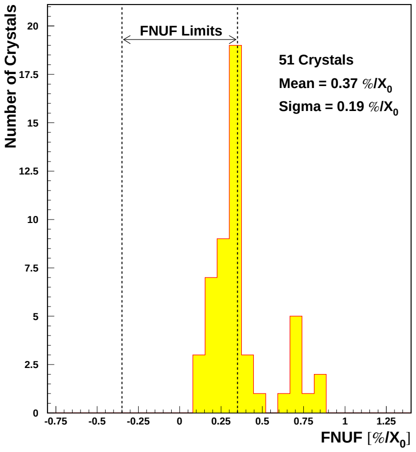

Figure 3: Distribution of FNUFs of crystals measured in a carbon fibre alveolar

4 Uniformisation Techniques

4.1 Crystal Chamfers

The CMS crystals have chamfered edges to relieve stresses on the polished faces that represent about 2% of the total crystal surface area. Simulations have shown that the chamfers can have a noticeable effect on the crystal light collection uniformity because many photons undergo a high number of reflections before detection [5]. Two methods of manipulating the chamfers to achieve the desired uniformity have been investigated. The first was to shade the chamfers using a HB pencil and the second involved de-polishing the chamfers. These two procedures are further described below.

4.2 Graphite Shading

The optimum shading length was first determined by shading the chamfers in 1cm steps from the small end and measuring the FNUF after each step. The optimum shading length seems to be about 6cm as this is where the reduction in FNUF appears to have saturated but the amount of light lost is still small. The 6cm shading was applied to all 52 crystals which were then measured in the alveolar with a tyvek endpiece. The results are shown in Figure 4. Six crystals could not be fitted due to low light yield.

We measure an average FNUF of $0.28\%/X_0$ for crystals with 6 cm shading inside the alveolar, a reduction of about $0.1\%/X_0$ when compared to unshaded crystals. Shading also causes a reduction in light yield of about 4%. The fraction of crystals above the $0.35\%/X_0$ limit after shading has been applied is 21%. However, if the anomalous crystals are ignored the fraction above the limit after shading is 5%.

4.3 De-polishing Chamfers

The technique for uniformising barrel crystals involves de-polishing a face [6]; we suspected that the FNUF could be altered by changing the roughness of the lapping process used to machine the chamfers. The two faces adjacent to the chamfer being de-polished were first masked off to prevent damage. Grade FF emery cloth was used to roughen the entire length of the chamfer. This procedure was applied to four crystals.

Although four crystals is not a large statistical sample we observe results which are consistent with the results we have obtained for shaded crystals, namely an average reduction in FNUF of about $0.1\%/X_0$ and an average reduction in light yield of 4%.

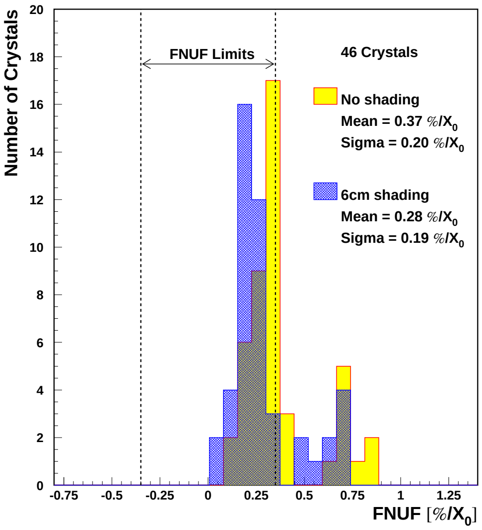

Figure 4: Distribution of FNUFs before and after 6 cm shading has been applied.

5 Conclusions

The non-uniformity of $PbWO_4$ endcap crystals can be measured with high precision using a HPMT. Studies of crystals in the alveolar have revealed that the average FNUF of 0.37 %/X_0 is only slightly above the requirement of $0.35\%/X_0$ for the sample of crystals investigated.

The FNUF of crystals can be reduced on average by about $0.1\%/X_0$ if the chamfered edges are shaded with pencil 6cm from the small end. This causes a reduction in light yield of 4% on average when compared to unshaded crystals. It was speculated that adjusting the roughness of the chamfers could have a similar effect. This appears to be confirmed, albeit with limited statistics, by measurements of crystals with de-polished chamfers. De-polishing the entire length of all 4 chamfers with grade FF emery cloth causes an average reduction in FNUF of $0.1\%/X_0$ and a 4% loss of light yield.

References

[1] The CMS Collaboration, *"The Electromagnetic Calorimeter Project Technical Design Report"*, **CERN/LHCC 97-33**.

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[3] R. DeSalvo, *"Why People Like the Hybrid Photodiode"*, Nucl. Inst. Meth. **A387** (1997) p.92-96.

[4] D. Britton *et al.*, *"Precision fitting function for HPMT spectra"*, Nucl. Inst. Meth. **A504** (2003) p.298-300.

[5] D. Britton *et al.*, *" Simulation of the HPMT/VPT Light Collection Ratio"*, **CMS Note 2003/011**.

[6] G.J. Davies *et al.*, *"Development of a Uniformisation Procedure for the* $PbWO_4$ *Crystals of the CMS Electromagnetic Calorimeter"*, **CMS Note 2001/004**.