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Simulation of light collection in the CMS lead tungstate crystals with the program Litrani: coating and surface effects

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Abstract

The accuracy of the lead tungstate electromagnetic calorimeter of the CMS experiment under construction at CERN relies, among other things, on the correction of the calibration parameter from variations due to crystal ageing. This ageing will be measured by a so-called monitoring system, but the relation between monitoring and calibration parameter variations is not so trivial, and depends much on the overall optical characteristics of crystal and photodetector. We present here simulations done with the program Litrani based on real ageing data for a realistic CMS crystal with a defined surface quality (optically polished, with or without one lateral face slightly depolished), covered by coatings of various characteristics, from totally absorbing to nominal aluminum or diffusing medium. The correlation coefficient between monitoring and scintillation signals depends greatly on these characteristics, and varies between about 1.3 and more than 10 (the optimum being one).

Keywords : Scintillator detector; light yield; ageing; ray tracing

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1. Introduction

The lead tungstate scintillating crystals of the CMS [1] electromagnetic calorimeter [2] will be exposed to an intense radiation throughout the accelerator operation, broken by quiet periods. The optical transmission of crystals will fluctuate [3], and consequently their light collection efficiency. In order to preserve the calibration precision of the instrument, both calibration with physical events, at a time scale of a few weeks, and continuous monitoring of the optical characteristics of the crystals are required [4]. It has been shown in previous papers that the correlation between variations of collection efficiencies for scintillation light (directly related to the calibration parameters) and monitoring light is dominated, for crystals of good optical quality, by the quality of light containment in crystals, that is by the properties of their surfaces and coating [5]. We report here more quantitative simulations performed with the program Litran [6] and based for the crystal optical absorption on physical data [7].

Various surface state and coating conditions are investigated, in order to clarify their influence on this correlation.

2. Simulations

2.1. Input

For the calculations reported here, the optical absorption data stem from the optical absorption measurements performed previously on a PbWO_4 crystal (n° 1854 of CMS database) exposed to cycles of gamma-ray or neutron irradiation and thermal annealing [7]. Its behaviour is representative of CMS recent crystals. Fig. 1 represents the initial and extreme (lowest and highest) absorption lengths measured.

The optical indices published in [7] were used for PbWO_4 . The scintillation spectrum is shown in Fig. 1. The crystal geometrical shape used was CMS shape n° 6 (see [2] p 54). APD was simulated by a 0.25 cm^2 square detector with usual APD quantum efficiency.

Five different coatings were simulated: – no coating (bare crystal from which all escaping light is lost);

– nominal aluminum using optical characteristics reviewed in [9], reflection entirely specular; – partly absorbing aluminum, with 20% absorption probability for the reflected light; – same with a 50% probability; – diffusive aluminum, same properties as nominal aluminum but entirely diffuse reflection.

Monitoring light was simulated by injection of a light beam with a 11° angular aperture from 1 mm out of the crystal at the center of the front end (smallest end, corresponding to the monitoring geometry of the barrel in CMS), or of the back end (largest end, end-cap geometry). The wavelength ranges from 375 to 600 nm. We have also simulated UV injection by generating scintillation light inside the crystal at 1 mm from its front end.

2.2. Comparison between anisotropic simulations and isotropic simulations

In a preliminary work, a fully anisotropic crystal is simulated, using the anisotropic absorption lengths Λ_{ord} and Λ_{ext} measured in [7] and the optical indices n_{ord} and n_{ext} of birefringent lead tungstate. In order to reduce computation time and to introduce depolished surfaces (Litran did not handle depolished surfaces of anisotropic materials at that time), the results are compared to those obtained with the version of Litran for isotropic materials. For effective isotropic parameters $\Lambda_{iso}^{-1} = 2(\Lambda_{ord}^{-1} + \Lambda_{ext}^{-1})$ and $n_{iso}^2 = (2n_{ord}^2 + n_{ext}^2)/3$ the light yield agreed within 2% over the full range of absorption. All following calculations are done with these effective isotropic parameters.

Fig. 1: Effective absorption length of PbWO_4 crystal $n^\circ 1854$ (see § 2 and [7]) and scintillation spectrum (linear arbitrary unit) used for simulation.

2.3. Lateral face depolishing, light yield uniformisation

CMS crystals have one face depolished in order to suppress the light yield non-uniformity due to the so-called focusing effect induced by the tapered shape of crystals [10]. Depolishing is simulated in Litrani by a random orientation of the transition plane using an angular parameter θ_{max} , which can be varied between 0° and 90° . It was found that $\theta_{max} = 50^\circ$ gives a good uniformity for any coating or surface, as shown in Fig. 2 for a bare crystal. This angle is used afterwards for simulation of uniformised crystals.

Fig. 2: Light collection efficiency versus position of emission for a crystal with one longitudinal face depolished; simulation for different Litrani's depolishing parameters $\theta_{\max}$ (0 (polished), 10, 20, 30, 50, 90°). For clarity data are shown only for $\theta_{\max} = 0$ and 50°. Lines are exponential fits to data.

2.4. Variation with optical absorption: correlation between monitoring and scintillating light variations for various crystal coatings

Simulations have been performed for both types of crystal (polished, uniformised), the 12 optical absorption data sets and the five coatings. Scintillation light and monitoring light had the same characteristics as previously.

They confirm, as shown in Fig. 3, that the light collection uniformity is not affected by the ageing, except for the worst and unrealistic case of a bare uniformised crystal.

Fig. 3: Variation of the light collection uniformity for uniformised crystals with no coating (bare crystal) and aluminum wrapping for different absorption. Lines are exponential fits to data. Data are shown only for the best and the worst crystal transparencies. The shadowed line indicates the 50 GeV electron shower density (in linear arbitrary unit) [11].

The electron shower efficiency is calculated by convolution of the light collection efficiencies and a 50 GeV electron shower profile [11] along axial position z . The shower efficiency as function of the monitoring efficiency for each simulation condition (type of crystal, coating and monitoring) is plotted. As foreseen in [5] the data can be fitted by a power law $y = ax^b$. The monitoring correction coefficient called S/R in [4] and R in [12] is equal to b (and to the slope of the curve in a log/log plot as in Fig. 4).

Fig. 4: Correlation between light collection efficiency for a 50 GeV electron shower and collection efficiency for monitoring light (at 450 nm), computed for the same crystal conditions with different coating conditions. Lines are fits to a power law and give the correlation slope.

Fig. 5: Variation of the correlation slope S/R as function of the monitoring light wavelength for the different coating conditions, for polished and uniformised crystals, monitoring from the front.

Fig. 5 summarizes the results for the standard monitoring geometry, i.e. front monitoring and Fig. 6 for the back monitoring geometry. One finds again the same parameter already discussed in [5]: a highly efficient light confinement is essential to increase the amount of multireflected monitoring light, and thus to reduce S/R . This is particularly evident for polished crystals, where lateral coating acts only for monitoring light. In a crystal uniformised by depolishing, a lateral coating is essential to preserve light collection.

Fig. 6: Variation of the correlation slope S/R as function of the monitoring light wavelength for the different coating conditions, for polished and uniformised crystals, monitoring from the back.

Fig. 7: Ratio of the correlation slope S/R between front and back monitoring as function of the monitoring light wavelength for the different coating conditions, for polished and uniformised crystals.

Monitoring light injection by the back increases obviously the path length of the monitoring light. However the S/R reduction is equal to 2 only for bare crystal or low efficiency coating. In other cases multiple reflections reduce this factor to 1.5 or even less (see Fig. 7).

It should be noted that the simulations, despite of a rough description of the optical characteristics of the crystal ends, agree with the slopes measured experimentally [12]. One can conclude that most of the dispersion or non-repeatability observed experimentally is related to a poor or insufficient control of the coating optical characteristics, especially at the ends of the crystals.

2.5. UV excitation

As expected, monitoring by UV injection inducing fluorescence would be a good mean to obtain a direct correspondence between monitoring and scintillation, thus $S/R = 1$.

3. Conclusion

The simulation described here confirms that the monitoring correction parameter, i.e. the so-called S/R

coefficient is strongly dependent not only on the proximity of scintillation and monitoring wavelength, but above all, as soon as crystals have a high transparency, on the optical properties of their coatings. A great attention should be given to the optical properties of the crystal ends, to their stability and characterisation.

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5. References

- [1] CMS collaboration, CERN/LHCC 94–38, LHCC/P1 (1994).
- [2] CMS collaboration, CERN/LHCC 97–33, CMS TDR 4 (1997).
- [3] N. Annenkov et al., Rad. Measurements 29 (1998) 27.
- [4] P. Verrecchia, Nuclear Phys. B (Proc. Suppl.) 61B (1998) 71; P. Bonamy et al., CMS Note 1998/013 (1998).
- [5] R. Chipaux and M. Géléoc, Nucl. Instrum. Methods. A451 (2000) 610; R. Chipaux, in: V. Mikhailin (Ed.), Proc. 5th Int. Conf. on Inorganic Scintillators and their Applications. SCINT 99, M.V. Lomonosov Moscow State University, Moscow, 2000, pp. 639.
- [6] F.-X. Gentit, “Litrani, a general purpose Monte-Carlo program simulating light propagation in isotropic or anisotropic media”, this conference.
- [7] R. Chipaux and M. Géléoc, in: V. Mikhailin (Ed.), Proc. 5th Int. Conf. on Inorganic Scintillators and their Applications. SCINT 99, M.V. Lomonosov Moscow State University, Moscow, 2000, pp. 629.
- [8] S. Baccaro et al., Nucl. Instrum. Methods A385 (1997) 209. See also [7].
- [9] D.Y. Smith, E. Shiles, M. Inokuti, in: E.D. Palik (Ed.), Handbook of Optical Constants of Solids, vol. 1, Academic Press, Orlando, 1985, pp 369.
- [10] E. Auffray et al., CMS Note 2001/004 (2001).
- [11] A. Givernaud, personal communication.
- [12] G. Davies, J.-P. Peigneux, A. Singovski, C. Seez, CMS Note 2000/020 (2000).