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The CMS Electromagnetic Calorimeter: Results on Crystal Measurements, Quality Control and Data Management in the Rome Regional Center

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Abstract

The barrel of the CMS electromagnetic calorimeter is currently under construction and will contain 61200 PbWO_4 crystals. Half of them are being fully characterized for dimensions, optical properties and light yield in the INFN-ENEA Regional Center near Rome. We describe the setup of an automatic quality control system for the crystal measurements and the present results on their qualification, as well as the REDACLE project, which has been developed to control and ease the production process. As it will not be possible to precalibrate the whole calorimeter, the crystal measurements and quality checks performed at the Regional Center will be crucial to provide a basis for fast in-situ calibration with particles. REDACLE is at the same time a fast database and a data management system, where the database and the workflow structures are decoupled, in order to obtain the best flexibility.

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1 Introduction

The barrel of the CMS [1] electromagnetic calorimeter [2] is currently under construction and will contain 61200 PbWO_4 crystals. Given the large amount of involved components (crystals, APD [3] photodetectors, different mechanical support parts), the calorimeter construction is a distributed process, which several countries take part in. The common use of a workflow [4] and a data management system allows this coordinated effort to happen and ensures each construction step is fulfilled in the proper way.

The Rome Regional Center is responsible for half of the barrel construction. Crystals undergo the following chain: they are received from the producer [5] and registered in the Center. In the registration procedure each crystal gets a barcode number, which will allow its unique identification in the database and in the further assembly steps, and undergoes a visual inspection by the Center operators, aiming at rejecting crystals with impurities or damaged crystals, if present. Crystals are then measured in the automatic control machine ACCOR [6]: measurement results are stored in the REDACLE [7] database, which has been developed by the Rome group in order to cope with the complexity of the construction process. Crystals passing the specification requirements are coupled with APD capsules, characterized in the Lyon Regional Center. Two APDs mounted in a capsule are glued onto the crystal rear face and will detect and enhance the crystal light signal. Crystal and capsule form a so-called subunit. Ten subunits are assembled together, using an alveolar structure, to form a submodule. Forty submodules, corresponding to 400 crystals, are finally mounted on an aluminum support structure to assemble a module. The modules are shipped to the CERN Regional Center, where other module types are produced and where sets of four modules are further assembled into so-called supermodules, of 1700 crystals each. There will be in total 36 supermodules, of which about one third are already produced. Not more than a few will be precalibrated with particle beams of known energies [8] before being installed in the detector. For the other supermodules an intercalibration procedure will be used, i.e. they will be calibrated by means of the laboratory data taken during assembly in the Rome and CERN Regional Centers. Thus crystal measurements are important not only to check the crystal quality, but also to provide an initial, startup, intercalibration of the complete calorimeter. It is therefore clear that high precision measurements are mandatory, so that the intercalibration can successfully take place. It has finally to be noticed that, for the first time, “industry-like” methodologies are used in the construction of a particle physics detector, whose design key-point is the very good energy resolution, i.e. the automatized procedures are joined together with high precision.

2 The ACCOR measurement system

The ACCOR system, described in detail in [6], consists of three measuring stations and allows the automatic measurement of crystal dimensions, optical transmission and light output. Up to 70 crystals per day can be fully characterized in two runs, feeding in turn the machine with seven trays of five crystals each. Moving belts set the trays under each measurement station.

Dimensions are reconstructed with a commercial 3D machine, by measuring five points on both the front and rear faces and eight points each on the lateral ones. The measurement reproducibility is $\pm 2\mu\text{m}$.

The transmission is measured with a single-beam array spectrometer, directly coupled to an integrating sphere, and by using a collimated Xenon lamp as light source in the range 300-700 nm. The array spectrometer allows to take in one single shot all data in the desired spectral range. In total twelve transmission spectra are collected for each crystal: one longitudinal (LT) and eleven transverse (TT) ones, taken every 2 cm along the crystal. The stability of the reference measurements over two minutes is better than 1% in most of the spectral range of interest (320-700 nm) and it is never worse than 2% near the edge of the UV region, where the signal intensity is lower.

Afterwards we measure the uniformity of the light output as well as the light yield (LY) at eight radiation lengths ($8 X_0$) from the crystal front face, distance corresponding to the shower maximum. The LY is evaluated by detecting the photo-peak in the scintillation spectrum of a γ -emitting Co^{60} source. The source is moved along the crystal and 21 spectra are collected with 1 cm step, in order to check the light collection front non-uniformity (FNUF). The light yield measurement and calibration procedure are discussed in detail in [9] and [10]. The ACCOR results are calibrated with reference measurements on a classical bench, where the crystals are in optical contact with the photomultiplier and wrapped in a Tyvek sheet on the lateral faces, in order to reproduce as closely as possible the actual configuration of the CMS experiment, where the crystals will be glued to the APDs and inserted in reflective

alveola. Furthermore, the same five reference crystals are measured every day to check the stability of the machine. The total time needed to measure five crystals on a tray is about 55 minutes: 15 for the dimension, 20 for the transmission and 20 for the light yield measurement, respectively.

3 REDACLE

REDACLE (a Relational Ecal DATABASE for Construction LEvel) has replaced the previous data management system, CRISTAL [11], which was in use in the Center until end 2002, but did not meet our requirements of having a fast and low resource demanding tool, which should be easy to use for the operators, in order not to slow down the construction process with software issues. The design strategy has been to use Open Source software only, in particular MySQL [12] for the database structure, and to keep the software as modular as possible, also by decoupling the database and the workflow functionality. Different methods and languages access it:

- web interfaces with PHP scripts for the assembly,
- c++ programs for the interaction with ACCOR,
- Java programs for computing crystal characteristics and quality checks,
- Labview programs for photodetector quality checks,
- perl scripts for queries and data export.

The data are stored in tables and the relationships between tables are provided by internal pointers and identifiers. As an example, the table “activity” contains all activities performed with parts, where each part is uniquely identified by its barcode, and is stored in the “part” table. Crystals, subunits, submodules, etc., are parts. Activities have to be performed in the proper sequence, i.e. capsules for instance cannot be glued to crystals, if the crystals have not yet been fully characterized. An activity is for example: “measure LY”. It has a pointer to the “characteristic” table, which joins together the pointers to the part barcode, to the list of performed measurements (in this example: light yield values along the crystal length, light yield at eight X_0 , non-uniformity), as well as to the real data. The data are stored either as single numeric fields (table “value”), three numeric values (table “multiValue”), or as a single string field (table “charValue”). Some examples are given in Table 1.

The interaction between ACCOR and REDACLE is fully automatic. Unlike what happened with the previous database, even big amounts of data (for instance all measurements belonging to several modules) can be extracted from REDACLE in a negligible time. This provides us with a powerful tool for offline data analysis and long term quality checks.

The use of REDACLE has greatly increased the production capability of our Center, allowing us to reach the rate of two modules per month, foreseen for 2004 by the CMS-ECAL production schedule.

4 Results

4.1 Crystal Quality Checks

Crystal quality checks are performed at the end of each tray measurement set, during the measurement of the next tray. Crystals not satisfying the quality requirements are then remeasured. The total rejection factor is about 0.3%. Some important results are summarized in the following.

The tolerance on crystal dimensions is $(-120, +20) \mu\text{m}$ from nominal values, in order to minimize the dead space in the calorimeter and to avoid mechanical stress between crystals. This requirement is met by almost 100% of the crystals.

The longitudinal and transverse transmission spectra are related to the crystal quality, in particular to the presence of absorption bands and to the crystal radiation hardness. Typical LT and TT spectra, with 100 data points between

Table 1: Top: “characteristic definition” table, which defines as an example the measurements number 33 and 34, their nicknames, their units and the activity type they belong to (here number 6, which means Light Yield measurement). Middle: two entries of the “characteristic” table, showing the pointers to two measurements (33 and 34, as described above) for the crystal with barcode 33101000020910. The “characteristic” Id is automatically incrementing, and is used to relate this table to the “value” one below. Bottom: two entries of the “value” table, with the real data corresponding to the two measurements discussed above: light yield at eight X_0 (9.3 pe/MeV) and front non-uniformity ($-0.23 \text{ \%}/X_0$).

Id	description	name	unit	actDefId
33	light yield at eight X_0	LY8X0	pe/MeV	6
34	LY front non-uniformity	FNUF	$\%/X_0$	6

Id	charId	partId	activityId
235895	33	33101000020910	40275
235896	34	33101000020910	40275

Id	x	characteristicId
104995	9.2720	235895
104996	-0.2262	235896

300 and 700 nm for each spectrum, are shown in Figure 1. The curves show a steep rise up to 400-420 nm, and a plateau at longer wavelengths. This steep rise is characteristic of radiation-hard crystals and is used as selection requirement for the longitudinal transmission. The LT has to be above 25%, 55% and 65% at 360 nm, 420 nm and 620 nm, respectively. The slope at the inflection point of the curve has to be greater than 3%/nm. The crystal homogeneity is ensured by the TT dispersion requirement. The wavelength at which the transmission is 50% is calculated for all eleven TT spectra, and its dispersion has to be less than 3nm. Less than 0.2% of the crystals have been rejected because of the LT thresholds.

The LY is required to be above 7.2 pe/MeV, so that the stochastic term in the energy resolution is small enough. This threshold value takes into account the global calibration, i.e. the actual raw measurements are about 4-5 pe/MeV. The FNUF has to be less than $0.45\%/X_0$, in order to ensure the contribution to the constant term in the energy resolution to be less than 0.4%. In total about 0.2% of the crystals have been rejected by our center because of either the LY at eight X_0 or the FNUF.

4.2 Light Yield Stability

The stability of the LY measurements is checked every day in the Center by measuring the same five reference crystals. Over almost two years we have observed no degradation in the crystal light output and good reproducibility of the measurements. The crystal behaviour over a long time scale had not yet been investigated before this analysis.

An example is given in Figure 2, showing the light yield distribution of one of those crystals. The resolution is between 3.4% and 4.1% for the individual crystal, while it is 3.6% for their average, pointing out that the measurements are correlated. The correlation depends on the calibration procedure, as discussed in detail in [10], and can be reduced by rescaling the LY measurements by the LY average of the reference crystal measurements taken in the same day.

Figure 3 shows the measurement behaviour of the five reference crystals as a function of time, before and after rescaling. All crystals but one manifest a constant light output with no signal degradation. The remaining crystal shows an apparent LY decrease of $-0.3 \pm 0.2 \text{ (pe/MeV)/year}$, whose reason is under investigation and is probably due to instrumental effects. After rescaling, the LY relative precision considerably improves to 0.5%.

Figure 1: Typical transmission spectra, normalized to unity, as a function of the wavelength, in nm. The figure shows the longitudinal and the transverse transmission spectra, taken at different distances (in cm) from the crystal front face.

Figure 2: Light Yield distribution of one reference crystal. The data are collected over almost one year. The resolution for a single crystal is about 3.6%.

Figure 3: Light Yield measurements (in pe/MeV) as a function of time (in days) for the five reference crystals, labelled with the last three digits (084 – 088) of their barcode. The top Figure presents the measurements before rescaling, together with a superimposed linear fit showing the constant light output over the considered timescale. The bottom one shows the same measurements after rescaling, pointing out the improved resolution.

4.3 Light Yield and Longitudinal Transmission Correlation

We have observed [13] a strong correlation between the crystal light yield and its longitudinal transmission T_{360} at $\lambda = 360$ nm, as shown in Figure 4, for about 3200 production crystals measured in the Regional Center in 2003, corresponding to eight modules of type 2 and 3. For a variation of T_{360} in the interval 25-50% the light yield increases by about 40%. This result cannot be explained by models where the emission spectra are assumed to be identical for all crystals, such that the maximum LY variation is expected to be below 10%. This variation indicates a correlation between the amount of light produced and the transmission curve edge and might be due [13] to a variation of absorption and emission center concentration from one crystal to another, with subsequent different positions of the crystal transmission band-edge and correspondingly different amount of produced light.

A linear fit to the (approximately linear) correlation of Fig. 4 yields the relation between light yield and longitudinal transmission at $\lambda = 360$:

$$LY = 4.62 + 0.129 \cdot T_{360} \quad (1)$$

The overall residual distribution between the measured LY and the calculated one is shown in Figure 5.

The measurement of T_{360} can therefore be used to detect and correct instabilities during the direct LY measurement. It could also be used as an independent LY measurement and combined with the direct measurement in order to improve the crystal intercalibration achievable with laboratory measurements, which is currently 4.5% [14]. A statistically significant comparison with test beam data will definitely tell whether this procedure can help determining the crystal intercalibration constants.

4.4 Cross-calibration

The cross-calibration with the CERN machine, where the other half barrel is measured and assembled, is also constantly monitored [15]. As an example, Figure 6 shows the LY and the FNUF difference for a few hundred crystals measured in both centers. Both differences are compatible with zero within the resolutions. The mean value of the LY difference is 0.1 pe/MeV, with a resolution of 0.7 pe/MeV. For the FNUF the difference between the two laboratories is 0.08 %/ X_0 with a sigma of 0.18 %/ X_0 .

5 Conclusions and Outlook

A panoramic view of the Rome Regional Center activities is presented, focusing on the crystal measurement results and on the development of a new database and workflow management system.

A strong effort for improving the LY determination precision is currently taking place. In the near future, a statistically significant comparison between laboratory and test beam data will be of utmost importance to determine the actual amount of the possible improvements on the crystal intercalibration.

6 Acknowledgements

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Figure 4: Top: correlation between the Light Yield (LY, in pe/MeV) and the longitudinal transmission T_{360} (in %), for 3200 production crystals measured in the INFN-ENEA Regional Center. The superimposed solid line shows the linear fit result: $LY = 4.62 + 0.129 \cdot T_{360}$. Bottom: histogram profile of the previous plot, with the performed linear fit. The resulting fit parameters are: $P_0 = 4.62 \pm 0.14$ pe/MeV and $P_1 = 0.129 \pm 0.003$ pe/MeV.

Figure 5: $\text{LY}_{\text{CALC}} - \text{LY}_{\text{MEAS}}$ distribution, where $\text{LY}_{\text{CALC}} = 4.62 + 0.129 \cdot T_{360}$ for all crystals, according to the global fit described in the text.

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Figure 6: Difference distributions between the Rome and CERN measurements for the LY (in pe/MeV, top) and the FNUF (in %/ X_0 , bottom). Details are given in the text.

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CMS Notes and Rapid Notes are available on <http://cmsdoc.cern.ch/docnotes.shtml>