LEAD TUNGSTATE CRYSTALS FOR THE CMS ELECTROMAGNETIC CALORIMETER AT THE LHC

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With its over 80,000 scintillating lead tungstate $PbWO_4$ (PWO) crystals the CMS electromagnetic calorimeter (ECAL) will be the largest one ever constructed. It was designed to work in the demanding LHC environment and give a resolution of 0.5% for photon energies above 50 GeV/c. An important R & D effort was necessary in order to guarantee the production of PWO crystals able to satisfy such challenging constraints. The performance of the pre-production crystal batches (about 6000 barrel crystals) is consistent with the very strict quality parameters defined by the ECAL Collaboration. The meaning of quality controls as well as the main characteristics of these crystals are discussed. More, recent developments in the PWO crystal growth technology may speedup the crystal supplying for the ECAL construction.

1 Introduction

The operating conditions of the LHC (10^{34} $cm^{-2}s^{-1}$ luminosity and 24.95 ns bunch separation) and costs limitations imposed for the construction of the CMS electromagnetic calorimeter the choice of a radiation hard, fast and high density scintillator [1]. Following an important R&D effort [2] the lead tungstate was retained to be the best candidate for the ECAL construction. A dedicated R&D activity had to be continued up to 1998 and was followed by a pre-production phase aimed at tuning the large scale production PWO parameters to the ECAL-CMS constraints. All this was necessary because PWO is a very special scintillator. The co-existence of several scintillation centres allows for a tuning of the emission peak and decay time which is an advantage for the one who is looking for new applications of PWO scintillators. It is instead a drawback for who wants to freeze these properties once the application was chosen. More, the quenched character of PWO luminescence at room temperature results in a poor light yield (LY) with a relatively high temperature coefficient which add supplementary complications to the definition and further check of PWO scintillator qualification parameters.

2 PWO crystals for the Electromagnetic Calorimetry

Besides the CMS ECAL construction, PWO massive use is foreseen for ALICE experiment at LHC, for ANKE spectrometer at COSY (KFA Jülich) and for ZEUS experiment at the electron(positron)/proton collider HERA (see respective articles in present proceedings). This PWO success is mainly due to its high density (8.26 g/cm^3) and high atomic number which turns into a small radiation length (0.89 cm) and small Molière radius (2.2 cm). For high energy applications the relatively low LY (2% of its forerunner, the BGO) is balanced by the use of APDs (AvalanchePhotoDiodes) available now at industrial scale. The emission spectrum of PWO consists of two components, the blue one peaking around 420 nm ascribed to the regular lattice centre $(WO_4)^{2-}$ and the green one peaking around 480 to 520 nm ascribed to different defects depending on the nature and history of the samples [3]. The blue component is fast (15 ns) while the green emission components may be slow, of the order of 10^2 ns and more. PWO crystal is intrinsically radiation hard and it was further improved by stoichiometry tunning [4], thermal treatments [5] and doping with trivalent [6, 7] and/or pentavalent [2, 4] elements.

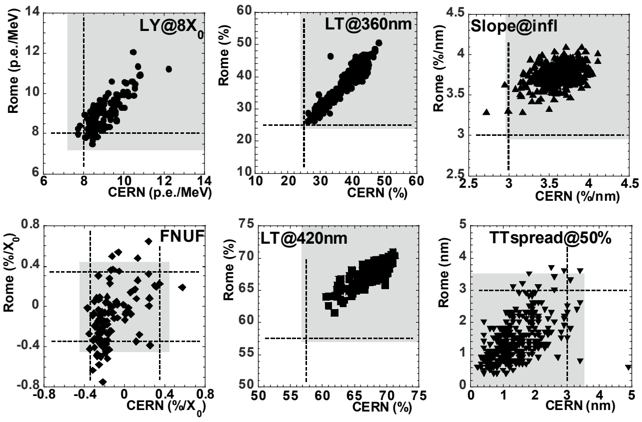

Figure 1. Correlation between qualification parameters as measured in two Regional Centres by different ACCOS machines. The gray marked regions define the acceptance limits for each parameter.

At the end of the R&D phase, three domains for the specifications defining the acceptance tests to be performed on PWO crystals were considered: geometry, optical properties and radiation tolerance. For each of these domains one or several qualification parameters were defined and based on ECAL performance goals and working conditions, acceptance conditions were fixed. Automatic crystal control systems (ACCOS) were built in ECAL Regional Centres (INFN Rome, Italy and CERN Geneva, Switzerland) able to give complete information on dimensions, transparency and LY characteristics of the 34 types of ECAL standard geometry PWO crystals [8, 9]. Given the differences in construction and measuring principle between the two ACCOS machines (only dimensions are measured with similar subunits), several hundreds of crystals were measured in both RC in order to fix the inter-calibration between the two crystal control systems. Fig. 1 gives the correlation between qualification parameters as measured in the two Regional Centres. At the end of the pre-production phase, the acceptance conditions were updated taking into account the properties of the PWO crystals produced at industrial scale and the inter-calibration errors.

3 Preproduction crystal properties

Starting with 1998 till 2000 during the pre-production phase were produced more than 6000 PWO crystals of standard ECAL-CMS characteristics at Bogoroditsk Techno-Chemical Plant (BTCP) in Russia and several hundreds at Shanghai Institute of Ceramics (SIC) in China. Grown by Czochralski method, PWO crystals produced at BTCP constantly improved both in quality and uniformity of their properties. Fig. 2 gives the trend in the quality of the pre-production crystals at BTCP. The improvement of the longitudinal transmission at 420 nm is to be noticed (fig. 2a). The relative decrease of the LY values is due to the modification of the mechanical processing of lateral surfaces aimed at improving the LY uniformity along the PWO scintillator (fig. 2b).

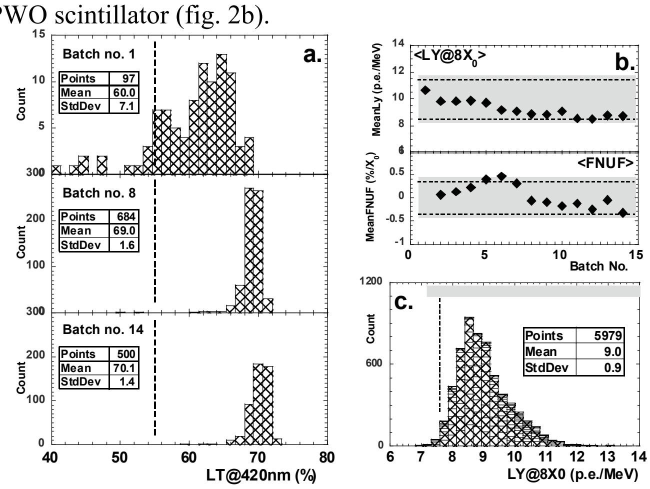

Figure 2. General trend in the quality of pre-production crystals at BTCP.

Crystals produced at SIC are grown by Bridgman method. The dimension requirements as well as transparency, scintillation decay and LY characteristics are well satisfied by SIC pre-production crystals (fig. 3). Nevertheless there are still large variations among SIC made crystals as for their behavior under irradiation conditions, more than 50% of them showing a LY increase with irradiation at LHC dose rates [10]. They are also sensitive to small temperature changes, thus still unsatisfactory from the point of view of stability.

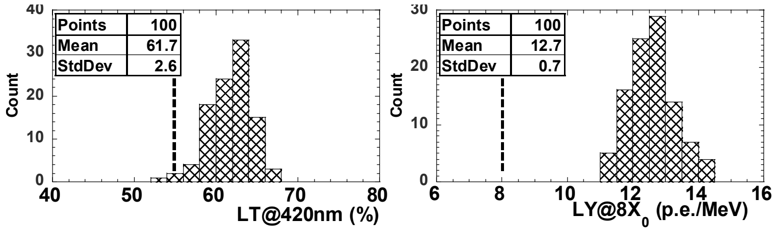

Figure 3. China made PWO crystals. Distribution of LT@420nm and LY@8X0. Note the relatively large values of the LY partially due to the fact that China made crystals have all lateral faces optically polished.

Measurements performed on ACCOS were acompanied by accurate beam tests in order to assess the performance of PWO crystals in true to life exploitation conditions [11, 12]. The measured light yield values, the excellent energy resolution found in sub-matrices of 9 crystals, the values of intrinsic and correlated noise, the agreement between simulation and measured data for the reconstructed energy as well as the results of dedicated radiation hardness test [13] are as many arguments for the choice of PWO crystals and the soundness of the ECAL project.

4 Recent developments in PWO crystal growth technology

56000 crystals for barrel and 16000 crystal for endcaps are still to be produced till the end of 2004. This is an important challenge rising huge technological problems for the PWO crystals producers. Using the experience reached in large diameter crystal growth for endcap (44 mm as grown ingots) the BTCP recently succeeded the growth of PWO ingots of 65 mm in diameter from which two barrel crystals may be obtained. The 65 mm diameter ingots are grown with modified furnaces and crystal holders in the same pulling machines which thus almost double their productivity [14]. Careful test were performed on 65 mm dimeter PWO crystals aimed at verifying the radial and axial uniformity of their properties, mainly scintillation characteristics and radiation hardness. As for the radial uniformity, a rise of the order of 5% in the induced absorption coefficient is noticed from the rim to the axis at the bottom side of as grown ingots while a rise of tipically 10% is measured at the top (seed) side. The larger nonuniformity (typically 20% rising from top to bottom) measured in axial direction may be compensated by optimal crystal cut and further improved by a better control of the raw material quality, crucible loading and growth conditions. Anyway the measured values of typically $0.3m^{-1}$ for the induced absorption coefficient at 420nm (μ_{420}) are well below the acceptance limit imposed by the ECAL-CMS specifications ($\mu_{420}<1.5m^{-1}$ at saturation dose). More, recently made [15] ACCOS measurements performed on a batch of 300 PWO barrel crystals showed that the characteristics of the crystals produced with the new technology (13.3% of the batch) are statistically speaking the same as those of crystals produced with the old technology.

5 Conclusions

Given the CMS goals, LHC working conditions and budget constraints, PWO crystal was the best choice among other possible candidates for the construction of the ECAL. The R&D activity aimed at tuning PWO properties to the ECAL-CMS constraints was doubled by a technological effort in order to create the means to qualify PWO crystals in industrial quantities. The performance of the pre-production crystal batches (over 6000 barrel crystals) is consistent with the very strict quality parameters defined by the ECAL Collaboration. The production of PWO crystals with uniform optical properties at industrial scale is attainable. More, PWO growth technology for ingots up to 65mm in diameter is now well under control. Further increase of the diameter and application of this technology to endcap crystals, are feasible.

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