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Detection of electron showers in Dual-Readout crystal calorimeters

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ABSTRACT

First attempts to use electromagnetic calorimeter prototypes made of either Mo-doped $PbWO_4$ crystals or by BGO crystals, in view of the possible application of such a detector in Dual-Readout hybrid calorimetry are presented. We have tested matrices of these crystals as electromagnetic calorimeters and studied the properties of the Cherenkov and scintillation components of the signals generated by high-energy electrons showering in these detectors. In these proceedings we investigate to which extent the promise of improved calorimeter performance can be realized with such crystal matrices.

1. Introduction

The Dual REAdout Method (DREAM) allows to improve the performances of hadronic calorimeters by measuring event-by-event the electromagnetic fraction of the hadronic cascade, thus reducing its fluctuation and reaching a better resolution and linearity. The method is based on the separation of the scintillation light due to ionization from Cherenkov light produced almost exclusively by relativistic particles, i.e. the electromagnetic component of the hadronic shower.

The DREAM method has been applied to both fiber calorimeters and homogeneous media (crystals). We have tested matrices of BGO and $PbWO_4$ crystals as electromagnetic calorimeters and studied the properties of the Cherenkov (C) and scintillation (S) components of the signals generated by high energy electrons showering in these detectors.

These studies have been accomplished within the DREAM program, which was recently accepted by CERN as the RD52 project.

2. Dual-Readout calorimetry with crystals

In the last few years, part of the experimental program was devoted to the study of the application of the Dual-Readout method to high-Z crystal. So far, we have tested $PbWO_4$ (undoped and doped varying the concentrations of impurities of both Praseodymium (Pr) and Molybdenum (Mo)) [1,2], BSO, and BGO crystals [3].

In order to separate the scintillation and Cherenkov components, we have used different characteristics of the two types of light, summarized in Table 1. In the studies presented here, we exploit only the first two characteristics, using optical filters and reading out the pulse shape of each signal (see Fig. 1, left).

In order to use crystals in Dual-Readout calorimeters, and to have a better separation between the C and S components, an optimal crystal should have an emission wavelength far from the bulk of Cherenkov radiation, a scintillation decay time of tenths of nanoseconds, and it should not be too bright to make Cherenkov light detection masked by the scintillation one. Pure $PbWO_4$ crystals do not satisfy these requirements: S light is predominantly blue and thus separating it from C by means of optical filters is not efficient since their spectral region is too close. Moreover the decay time of S light is very fast ($\tau < 10$ ns) and it is thus hard to distinguish it from the prompt light by exploiting the different time structure. Some studies [4–6] have shown that adding some doping elements can achieve a shift of the scintillation spectrum to longer wavelengths, and a longer decay time, as needed for the Dual-Readout.

Table 1
Different properties of C and S light.

Properties	*Cherenkov*	*Scintillation*
Time structure	Prompt	Exponential decay
Light spectrum	$1/\lambda^2$	Peak
Directionality	Cone: $\cos\theta_C = 1/\beta n$	Isotropic
Polarization	Polarised	Not polarised

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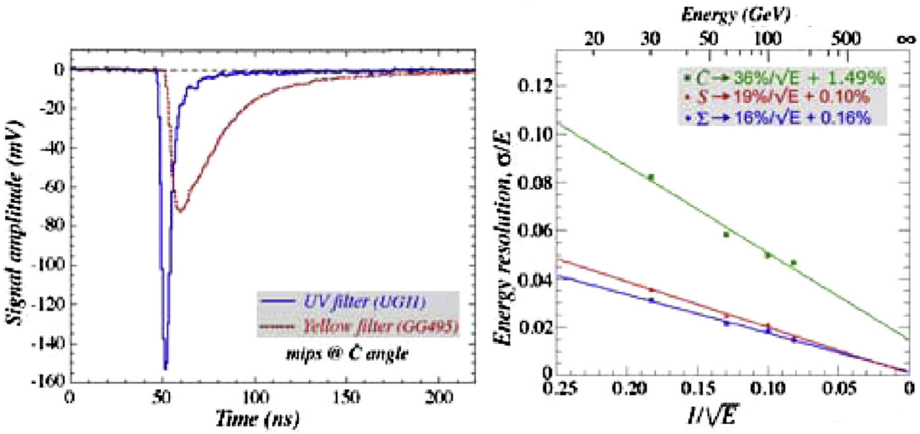

Fig. 1. Left: time distributions for UV filtered signals (blue line) and yellow filtered one (red line). The UV filtered light show the characteristic C time structure, while the other has the typical shape of the scintillation pulse. Right: energy resolution of BGO matrix for C, S, and Σ, the sum of the two components. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

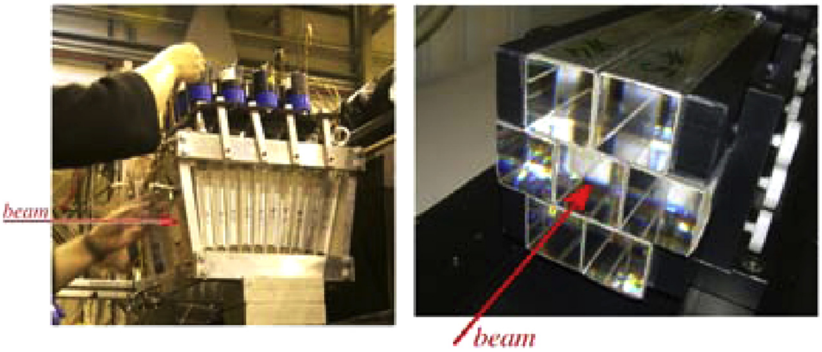

Fig. 2. The two crystal matrices: BGO on the left, $PbWO_4$ on the right.

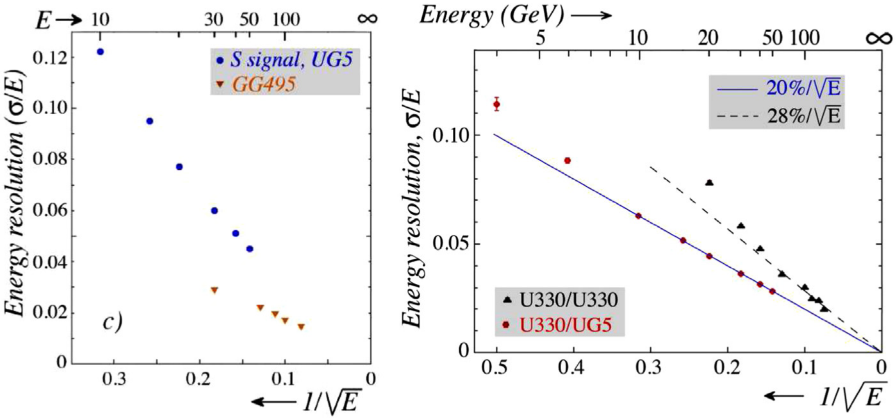

Fig. 3. Energy resolution for electrons showering in the $PbWO_4$ crystal matrix, as a function of energy for different filter combinations (see text for details). Right: the S signal is obtained using a yellow (GG495) filter (triangles) and blue (UG5) ones (circles). Left: the C signal is derived from UV (U330) filter on both sides (triangles) and from a combination of UV (U330) and blue (UG5) filters at the two ends of the crystals (circles).

3. Test beam setup

Our crystal matrices were tested in 2010 and 2011 at the H8 SPS test line at CERN with electron beams of different energies [7]. Our testbeam setup consisted of two Delay Wire Chambers for beam position measurement, two small trigger scintillators, and a “veto” counter, with a central hole, used to suppress beam halo, a preshower detector, a tail catcher scintillator, and a muon counter for beam cleaning. The trigger signals, as well as the veto signal, and information on the SPS beam structure are processed by an FPGA chip that implements the trigger logic. The time structure of each calorimeter channel was sampled with a CAEN V1742 board based on the Domino Ring Sampler (DRS) chip that allows time structure measurements with a sampling rate between 2.5 and 5 GHz [8].

4. BGO and $PbWO_4$ matrices

The BGO matrix consists of 100 $Bi_4Ge_3O_{12}$ crystals from a projective tower of the L3 experiment (end faces: $2.4 \times 2.4\ cm^2$

and $3.2 \times 3.2\ \text{cm}^2$, respectively, length 28 cm corresponding to $25X_0$, see Fig. 2, left). The matrix is readout by 16 PMTs (Hamamatsu R1355) coupled with a UV filter (Schott UG11: $\lambda < 400$ nm). Each PMT collects light produced by clusters of nine adjacent crystals. The signal was integrated over different time windows in order to extract C (fast component) and S (tail of the pulse shape).

The $PbWO_4$ matrix consists of seven custom made crystals [4] ($3 \times 3 \times 20\ \text{cm}^3$, $22.5X_0$, see Fig. 2, right). Each crystal was wrapped with mylar and read out at both sides by Hamamatsu 8900 PMTs. Different filter combinations were used, each optimizing one aspect of the readout. In a first attempt, a yellow filter (Schott GG495, $\lambda > 495$ nm) and an UV filter (Hoya U330, $\lambda < 410$ nm), coupled to the crystal and to the PMT by means of elastocil "cookies", were used in order to extract pure, respectively, S and C lights.

We obtained a good scintillation resolution but observed a strong light attenuation effect in the C side, leading to a large nonlinearity. In order to overcome this problem, we tested several configurations in which UV/UV and blu/UV filters were mounted upstream/downstream of the crystals. This configurations forced us to extract the S contribution using the difference in time structure of the two signals. We extract the S signal integrating the tail of the obtained pulse shape. Due to the strong reduction of the scintillation light caused both by the optical filter and reduced gate integration, we observed a severe worsening of the S resolution.

5. Results and conclusion

The energy resolution measured for the C and S components is shown in Fig. 1, right for the BGO matrix and in Fig. 3 for the $PbWO_4$ matrix.

To use crystals for the Dual-Readout calorimetry they cannot be read out in a conventional way, leading to not optimal results in terms of energy resolution of C and S components, respectively. In fact, extracting sufficiently pure C signals from these scintillating crystals implies a severe restrictions to short wavelengths. A large fraction of the potentially available C photons needs to be sacrificed. Furthermore, the surviving light is strongly attenuated due to UV self absorption. Our results show that the stochastic fluctuations in the C channel are at best $20\%/\sqrt{E}$ in the case of our Mo-doped $PbWO_4$ crystal matrix. Assuming that these fluctuations are completely determined by photoelectron (p.e.) statistics, this would mean that the C light yield for the electron showers was 25 p.e./GeV deposited energy. Hence this solution does not seem to offer a benefit in terms of the C light yield in Dual-Readout calorimeters. We recently measured a light yield in excess of 50 C p.e./GeV in our new Dual-Readout fiber calorimeter; for these reasons, the fiber option has now a higher priority in the RD52 project.

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