Effects of temperature dependence of the signals from Lead Tungstate

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Abstract. In recent papers [1] it has been demonstrated that Lead Tungstate signals contain both scintillation and Cherenkov components. In order to further assess and evaluate the relative contribution of the Cherenkov component, we performed measurements at different temperatures, ranging from 13°C to 45°C being only the scintillation component affected by the temperature change. Over this temperature range, the total light yield was measured to decrease by a factor of 2, while the relative Cherenkov contribution to the signals increased by the same factor. We also studied the decay time of the scintillation process and observed it to decrease as well.

1. Introduction
The results described in the following come from beam tests performed in 2007 as part of the DREAM project. It is well known that one of the main limitations to hadronic calorimetry is due to different response to electromagnetic and non-electromagnetic shower components, which led to non linearity and poor hadronic resolution. A possible solution to overcome this limitation is to measure the electromagnetic fraction ($f_{em}$) on event-by-event basis, for example, by separating the scintillation and the Cherenkov contributions, being the latter sensible only to the electromagnetic part of the shower. The capability of such a separation using different media [2] or crystals have been already proved. The measurement of the temperature dependence, of course, is not a technique to analyze data in an experiment, but allows us to evaluate the amount of Cherenkov contribution with respect to the scintillation one. More detail on the analysis can be found in [3]. Section 2 describes the experimental setup, Sections 3 and 4 are dedicated to the experimental results for both charge and time information analysis, respectively, while conclusions are drawn in Section 5.

2. Experimental setup
The beam tests took place in the H4 beam line of the Super Proton Synchrotron at CERN. We used a $PbWO_4$ crystal with a length of 18 cm and a cross-section of $2.2 \times 2.2$ cm$^2$. The transverse dimension, relevant for our measurements, corresponds to 2.5 radiation lengths. For the measurement described in this paper we used a 50 GeV electron beam. The light produced by particles traversing this crystal was read out by two PMTs, called in the following left (L) and right (R), located at opposite ends and coupled to the crystal by means of silicone cookies. This

1 The crystal was provided by the Alice collaboration
Figure 1. Sketch of the experimental setup. When $\theta > 0$ the PMT R is located downstream, while for $\theta < 0$ PMT L is downstream, as in the case shown here.

crystal was positioned on a rotating platform in order to perform angular scans, as shown in Fig. 1. The angle increases when the crystal is rotated such that the crystal axis LR approaches the direction of the traveling beam particles. The signal coming from the PMT are read with both an high sampling rate (2.5 GHz) oscilloscope and a 12-bit ADC module (100 fC(counts)), in order to study the time structure and the charge distribution, respectively. Typical signal can be seen in Fig. 2 and Fig. 3.

2.1. Temperature measurement and control

The temperature of the crystal was changed by means of a thermoelectric system, based on the Peltier effect, remotely controlled by a computer, which allows to achieve a temperature stability of about $\pm 0.3^\circ$C within a single run (100000 events acquired in about 5 minutes) and $\pm 1^\circ$C within a complete angular scan, lasting about 3-5 hours, as shown in Fig. 4. In both case only oscillation around the mean value can be observed. Therefore we can use in the following the

Figure 2. Typical time structure of the signal.

Figure 3. Typical ADC distribution for a PMT signal.
average temperature measured in each run. The dataset relevant for the work described in this paper consists of 13 angular scans performed at different temperatures, ranging from 13°C to 45°C. Almost all angular scans consist of quick scan at relevant angles, i.e. 0°, ±25° and ±30°, while 4 scans were performed in step of 5°, between −60° and +60°, shown as red full circles in Fig. 5.

3. Charge distribution analysis
The ADC charge distribution gives information on the energy deposit of electrons traversing the crystal. The signal shows a pedestal, the electromagnetic shower deposit and a MIP peak, probably due to beam contamination. The pedestal subtraction is performed using the mean value obtained from distributions of dedicated pedestal run taken for each data run.

3.1. Systematic studies
The contribution of the MIP peak has been evaluated to be constant on all the runs at about 1%, therefore we decided not to perform any selection to eliminate it. We also considered different parameterization of the ADC signal, and due to only 5% variation in peak/mean ratio we decide to use the mean of the distribution as parameter to characterize the ADC distribution. Moreover we studied the presence of long tails, which could bias the mean value, and it only appear in less than 0.5% of the events. A selection on beam position, as determined by Beam Chambers positioned just upstream our setup, is applied to reduce events in which the beam is not hitting the crystal.

3.2. Results on ADC signal analysis
From observation of the ADC signal at different temperature it can be deduced that the light yield of the PbWO₄ decreases as temperature grows. This effect is due to the decrease in the amount of scintillation light produced by the crystal as can be demonstrated by Fig. 6. This picture shows the average signals measured in PMT L (a) and PMT R (b) for rotation angle of the crystal of 0° and ±30° as a function of the temperature. The fact that the light yield at ±30° is larger than at 0° is due to the longer path traveled by electrons in the rotated crystal;
Figure 6. Average signal of left (a) and right (b) photomultipliers as function of the temperature at angles 0° and ±30°. The lines represent the results of least-squares exponential fits to the experimental data. Error bars are due to statistical uncertainties.

Table 1. Temperature dependence of the light yield measured in the two PMTs reading out the PbWO₄ crystal, for three different orientation.

| Angle θ  | Slope PMT L (%/°C) | Slope PMT R (%/°C) |
|----------|---------------------|---------------------|
| −30°     | 2.61 ± 0.02         | 2.99 ± 0.02         |
| 0°       | 2.81 ± 0.02         | 2.80 ± 0.02         |
| +30°     | 2.95 ± 0.02         | 2.66 ± 0.02         |

the difference observed between the light yields measured at +30° and −30° is the result of different contributions of Cherenkov light to the signals. In fact the Cherenkov light is emitted at fixed angle, and therefore is collected by the PMT positioned downstream at proper rotation angle. The results indicate in all cases an exponential decrease in the light yield as a function of temperature, but the slope of the fitted exponential clearly depends on the angle. The temperature dependence of the light yield, expressed in terms of this coefficient, is summarized in Table 1. It turns out that the decrease in the light yield for increasing temperatures is considerably steeper when the signals contain no (or very little) Cherenkov light, i.e., at 30° for PMT L and at −30° for PMT R. In those cases, the light yield decreases by 2.97%, compared with 2.64% for angles at which the Cherenkov content of the signals is largest. For 0°, a value of 2.80% was measured, indicating that there was at least some Cherenkov light contributing to the signals. This angular dependent pattern of the slope coefficients is consistent for the two PMTs, i.e., the measured slopes for the two PMTs at opposite angles are the same within experimental errors.

Due to different characteristic of isotropy of both scintillation and Cherenkov, being the latter emitted only at defined angles, it is possible to define a quantity, called anisotropy, ξ,
The response anisotropy $\xi$ as a function of the angle of incidence of the beam, measured at the temperature of $13^\circ$C to $45^\circ$C.

The response anisotropy $\xi$ as a function of the temperature at angles $25^\circ$, $30^\circ$ and $35^\circ$.

which depends on the angular position and which allows to measure the fraction of Cherenkov component in the signal:

$$\xi(\theta) = \frac{|R_\theta - R_{-\theta} - L_\theta + L_{-\theta}|}{|R_\theta + R_{-\theta} + L_\theta - L_{-\theta}|}$$

A non-zero value of $\xi$ means presence of non-isotropic component, i.e. Cherenkov signal. Since we normalized signal at $0^\circ$, by definition the anisotropy is null at this angle. Data show that the maximum of the anisotropy is seen at Cherenkov angle, as demonstrated by Fig. 7. Moreover, as discussed before, since at higher temperature the Cherenkov fraction is higher, due to reduction in scintillation light produced, the anisotropy increases as well as function of temperature, as shown in Fig. 8.

4. Time structure analysis

The Cherenkov and scintillation signals can be distinguished also on a timing base, since the former is prompt, while the latter has usually a larger decay time. As a consequence the Cherenkov contributes only to the leading edge of the signal, while the trailing edge is only due to scintillation light. Many characteristic features of the time structure of the signal can be derived by Fig. 9. The top plots show the time structure of the signal for the PMT R at $\pm30^\circ$ at $13^\circ$C (left) and $45^\circ$C (right), respectively. The red line corresponds at an an angle of $+30^\circ$, for which the PMT R is downstream and collects almost all the Cherenkov light. It can be noted that the amplitude of the red curve is larger and steeper in the leading edge. The trailing edge, on the contrary, shows the same shape and amplitude for both angles, due to isotropy emission of the scintillation light. As a confirmation of the light yield analysis described in Section 3.2 a difference in amplitude for data at $13^\circ$C (left) and $45^\circ$C can be observed. The difference of the signals at $\pm30^\circ$ is shown in the bottom plots of Fig. 9. Both left and right bottom plots show the same amplitude, further confirming the independence of the Cherenkov signal from the temperature.

2 Analogous plot can be produced for PMT L, with swapped angles
Figure 9. Average time structure of the signal for the PMT R at angles ±30° (top) and difference of the two signals (bottom) at 13°C (left) and 45°C (right).

Figure 10. Temperature dependence of the Cherenkov/scintillation signal ratio measured in one of the PMTs. This ratio is derived from the response anisotropy, or from the relative contribution of the prompt component to the signals (averaged over the two PMTs) for Cherenkov angle.
Figure 11. Fraction of the total signal represented by the prompt component as function of the angle of incidence measured at $45^\circ C$ (left) and $13^\circ C$ (right). The curves are shown for both PMT L (blue full circle) and PMT R (red triangle).

4.1. Results on time structure analysis
The fraction of Cherenkov component present in the signal can be evaluated by integrating the difference of the signal obtained at $\pm 30^\circ$ (the curves in bottom plots of Fig. 9), normalized with respect of the total signal obtained at angle opposite to the Cherenkov emission angle. The relative contribution of Cherenkov and scintillation signal thus obtained is shown as function of the temperature in Fig. 10. For comparison the analogous quantity evaluated from anisotropy is reported in the same figure. In both cases an increase by a factor of two in about $30^\circ C$ of temperature variation is observed, the absolute values is slightly different, anyway, due to the different definitions and normalization points used in the two analysis. If the fraction of Cherenkov component is evaluated as described before but for every angle with respect to the signal at angle opposite to the Cherenkov one, which is mostly a pure scintillation signal, plots as those shown in Fig. 11 can be obtained. The maximum of the curves, which correspond to the larger fraction of Cherenkov component in the signal, is reached at $+30^\circ$ for PMT R and $-30^\circ$ for PMT L, as expected. By definition, the curves reach a null value at angle opposite to the Cherenkov one ($-30^\circ$ for PMT R and $+30^\circ$ for PMT L).

4.2. Scintillation decay time study
As discussed before, the trailing edge of the time structure of the signal is dominated by scintillation light, which is sensible to the temperature variation. It can be observed (Fig. 12) that at higher temperature the trailing edge become steeper. A study of the decay time constant as function of the temperature has been performed and results are shown in Fig. 13. A decrease of about 30-40% in $30^\circ C$ temperature variation is observed.

5. Conclusions
A detailed study of the response of a single crystal of $PbWO_4$ has been performed as function of the temperature variation. This technique allows to determine the relative contribution of Cherenkov and scintillation lights in the signal, due to the fact that Cherenkov light is independent from temperature. Using the already assessed technique of Cherenkov and
scintillation separation, it has demonstrated that the Cherenkov contribution increases by a factor of two, passing from \(13^\circ C\) (left) to \(45^\circ C\), and in the same range also the decay time of the scintillation light decay by 30-40%.

References
[1] Ackurin at al., 2007 *Nucl. Instr. and Meth. A* 582 474
[2] Ackurin at al., 2005 *Nucl. Instr. and Meth. A* 537 537
[3] Ackurin at al., 2008 *Nucl. Instr. and Meth. A* 593 530