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Non-uniformity measurements of $PbWO_4$ crystals

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Abstract

Two independent methods have been used to measure the longitudinal non-uniformity scintillation response of 3 different (23-cm long) $PbWO_4$ crystals. The first one is the classical ^{60}Co source method. The source is collimated along the crystal, each 1,5-cm, and the scintillation signal is measured with a photomultiplier (a hybrid photomultiplier in our case). The second one is the use of cosmic particles (Minimum Ionizing Particles). A cosmic bench allows reconstructing the track of the MIP's and thus the energy deposit with the help of a full GEANT simulation of the setup. Variations of E along the crystal artificially cut in 1,5-cm divisions, leads to determine the non-uniformity. The conclusion is that both methods agree quite well. Furthermore, a good estimation of crystal light yield can be obtained.

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1 Introduction

The energy resolution of an electromagnetic calorimeter based on long crystals is very dependent not only on the quality of the crystal (scintillation efficiency) but also the way it is wrapped, uniformized (i.e. the light collected is independent of portion along crystal axis) and coupled to the photosensor.

Simulations [1] have shown that a poor uniformity of the response along its axis leads to a considerable degradation of the energy resolution of crystal matrices. This degradation is enhanced by the crystal prism shape. Many efforts have been done in the aim of uniformizing the crystals, unfortunately reducing the light yield.

To obtain the non-uniformity profile of these crystals, the classical method consists of putting a ^{60}Co collimated source near the crystal, and measuring the scintillation quantity with a PM when moving the source along the crystal axis. The disadvantage of this method is the decrease of energy deposition versus the crystal thickness (as can be seen with GEANT simulation, the decrease is relatively linear, except a peak in the first millimeter). So the crystal response could be suspected to be non homogeneous enough. Nevertheless, the source method is relatively easy and fast.

To confirm this source method we propose to compare the results of the ^{60}Co method with a cosmic ray method: the scintillation is induced by cosmic particles crossing the crystal. One measures the thickness crossed and deduces the theoretical energy deposited. A comparison with a HPMT signal proportional to the energy really deposited leads to the non-uniformity curve [2].

2 Experimental setup and method

2.1 The crystals

The crystals in test are lead tungstate ($PbWO_4$) trapezoidal in shape, 23-cm long (exact dimensions can be found in crystal database at CERN). The rear face 2.4 x 2.4 cm2 is in contact with the hybrid photomultiplier via optical grease (Rhodorsil V 500000). Matching factor is around 0,4. The crystal is wrapped with Tyvek (figure 1).

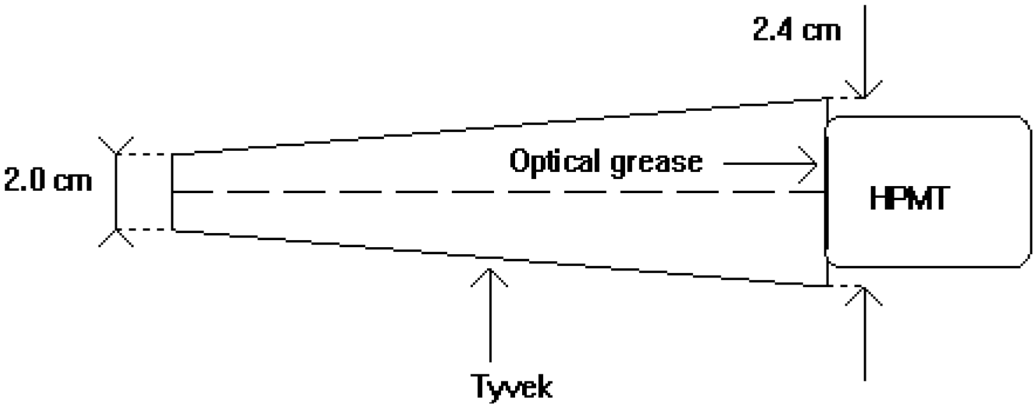

Figure 1. $PbWO_4$ crystal and the hybrid photomultiplier

2.2 The hybrid photomultiplier

The E18 (figure 2) model electrostatically focused HPMT from Delft Electronische Producten [3] has an 18-mm photocathode on a spherically symmetric shaped window. The model we use is UV sensitive (Model PP0270K). The photoelectrons that are generated by the incoming photons are focused on a small PIN diode. Two electrodes, each on a negative high voltage, provide the focusing on the diode. The accelerated photoelectrons bombard the backside of the PIN diode and create electron-holes pairs. When the diode is biased in reverse, these electron-holes pairs cause a charge variation. A built-in charges amplifier (2,1 V/pC) converts this charge into a voltage.

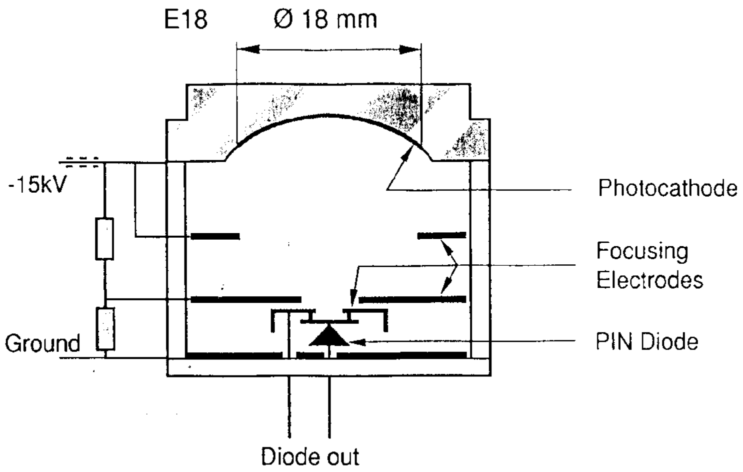

Figure 2. HPMT architecture, from DEP [3]

The greatest advantage of this type of photomultiplier is the resolution of the photoelectron peaks. A classical PM can resolve up to three photoelectron peaks whereas the HPMT can easily resolve up to 10 peaks (see figure 3 where the first peak corresponds to the single photoelectron). The HPMT driven at – 15 kV has a typical gain of 3500 (much lower than a classical PM). The HPMT is well suitable to few photon detection applications.

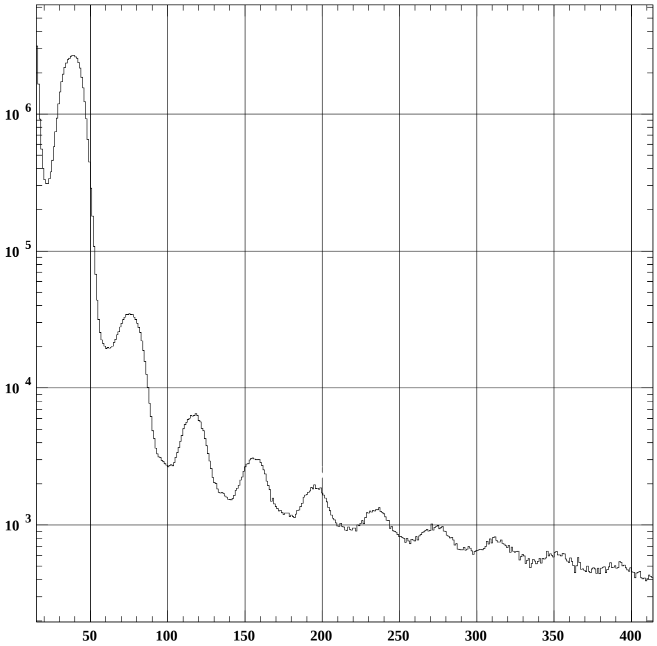

Figure 3. A typical photoelectron spectrum provided by the HPMT (first peak corresponds to the single photoelectron signal)

The voltage signal the preamplifier delivers is amplified and sent to a peak-sensing analog-to-digital converter (ORTEC AD811, 0-2 V, 2048 channels). The home made shaping amplifier gives a trigger signal, which allows using HPMT in a self-triggering mode, which is used in the ^{60}Co source measurements.

2.3 The cosmic bench

We have developed and built a device, which is able to detect cosmic particles and reconstruct their track. Figure 4 shows the complete setup that is around 2 meters high.

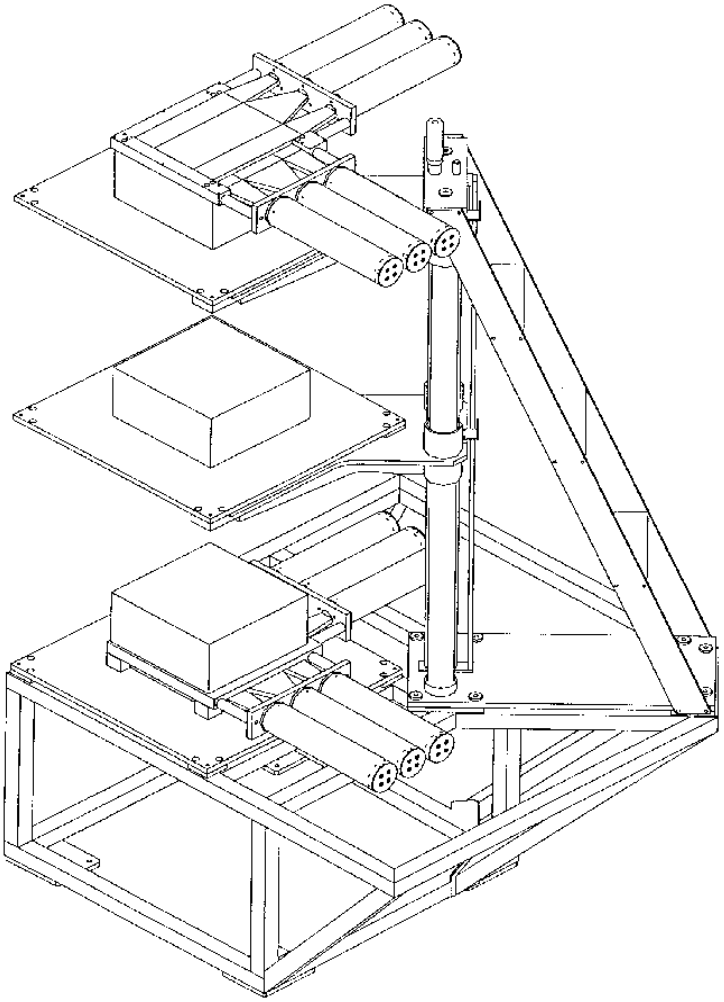

Figure 4. Global view of the cosmic bench

Three X-Y drift chambers can slide along a vertical axis. The Z-coordinate of each chamber is thus fixed and each chamber gives the X and Y coordinates of the particle crossing it.

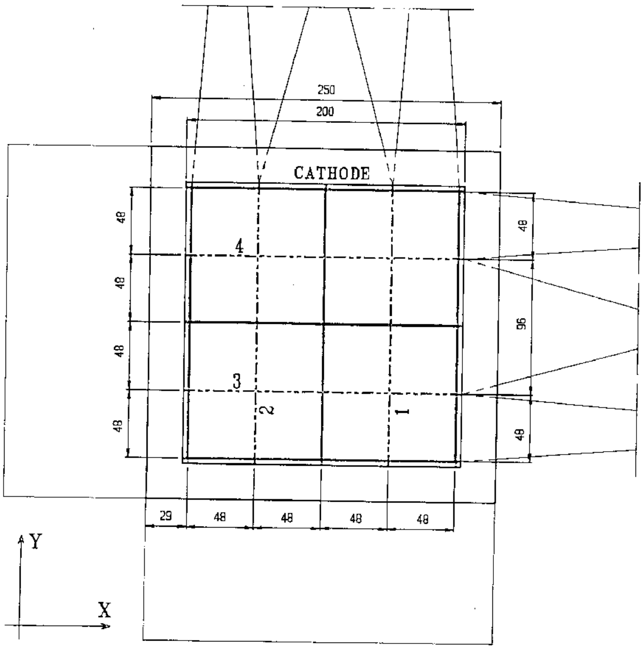

Figure 5. Details of one X-Y drift chamber block

Figure 5 presents an X-Y drift block. Dimensions are in mm. In fact we have 4 drift chambers, 2 for X-axis (wires 1 and 2) and 2 for Y-axis (wires 3 and 4). The X and Y chambers are superimposed. Each chamber has a unique wire (anode) at +1750 V, which concentrates the electrons produced by ionization of the gas inside (2/3 Argon, 1/3 Isobutane). The electron drift speed was measured to be 49 mm/µs [4]. The electrons are driven by an electric field built on a negative drift plan put at –4100 V.

Scintillators at the top and the bottom give the trigger signal. Photomultiplier converts scintillation in electric signal and a pattern unit reads the scintillator number. The geometry is chosen (see figure 5) so that the region indetermination (left-right) from the drift information can be removed. The stop is given by the detection of drift electrons on the anode wire and a TDC (1-ns/channel) measures the start-stop time (leading to a 50 microns precision in X-Y position). We are able to reconstruct the tracks of the MIP particles and calculate their path in the crystal.

2.4 Method

First we completely simulate the cosmic bench experiment by mean of GEANT program [5], with the real geometry (figure 6) : two scintillators for the trigger and the crystal.

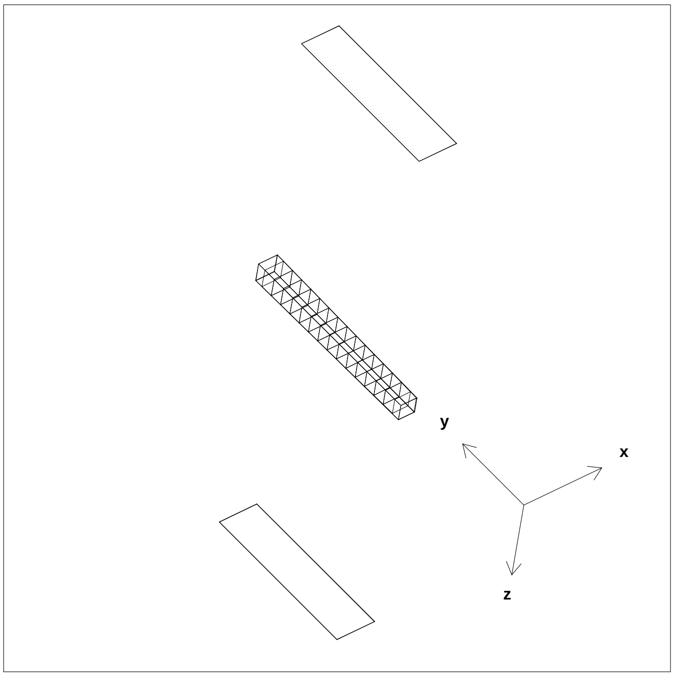

Figure 6. GEANT geometry

We artificially cut the 23-cm long crystal in 14x1,5-cm slices. As in the real experiment we neglect 1 cm at both sides of the crystal. The crystal is supposed to be homogeneous.

At ground level, cosmic particles are mainly muons. Their energy distribution simulated by GEANT (with standard cuts except for photons and electrons : 10 keV) is shown in figure 7 [6]. Peak energy is around 2 GeV. There are almost no particles below 1 GeV. Between 1 and 10 GeV, a Landau curve can approximate the law. The decrease law is in E-2,7 beyond 10 GeV. The angular distribution is in cos2 θ , θ being the angle between the track and vertical.

We have generated one million of cosmic tracks uniformly issued from scintillator 1, with the energy and angular distribution shown in figure 7. We keep those reaching scintillator 2 and hitting the crystal.

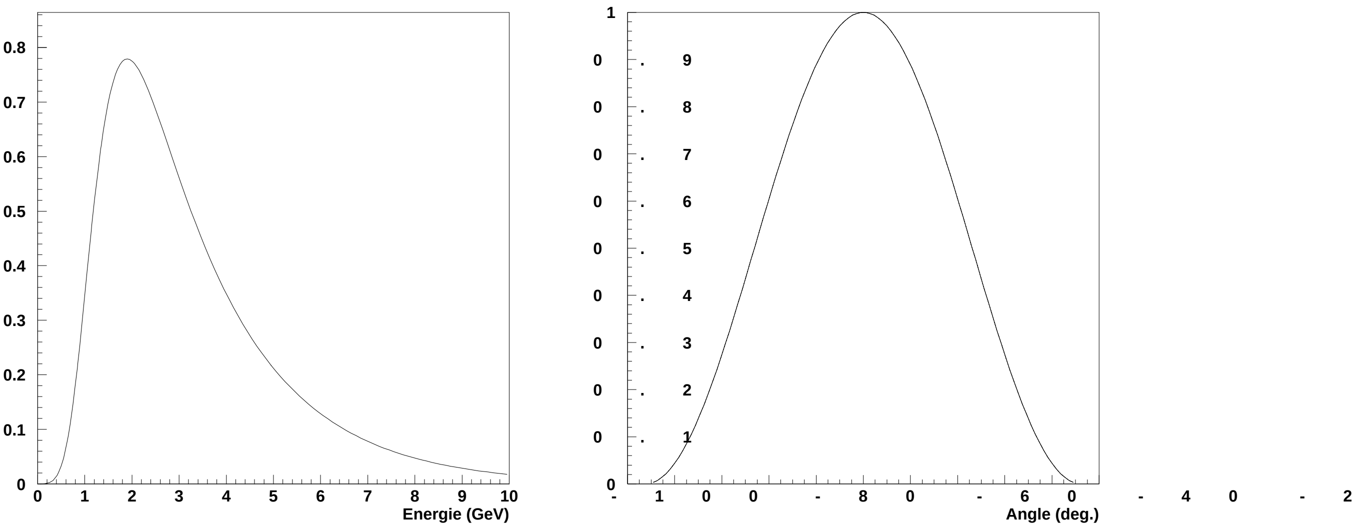

Figure 7. Simulated energy and angular distribution of cosmic particles at ground level

We obtain the global deposited energy (figure 8-left), with a peak value around 22 MeV (so we can estimate the average peak dE/dx value to be around 10 MeV/cm). GEANT also gives the energy spectrum of each 1,5-cm division (figure 8-right). The variation of energy deposited in each division is essentially due to geometrical effect (the crystal is trapezoidal, so the thickness varies from one division to another).

We thus obtain the theoretical law of variation of energy deposited in a uniform crystal. We will compare this law with the bench data. The ratio between these two laws gives the non-uniformity of the crystal.

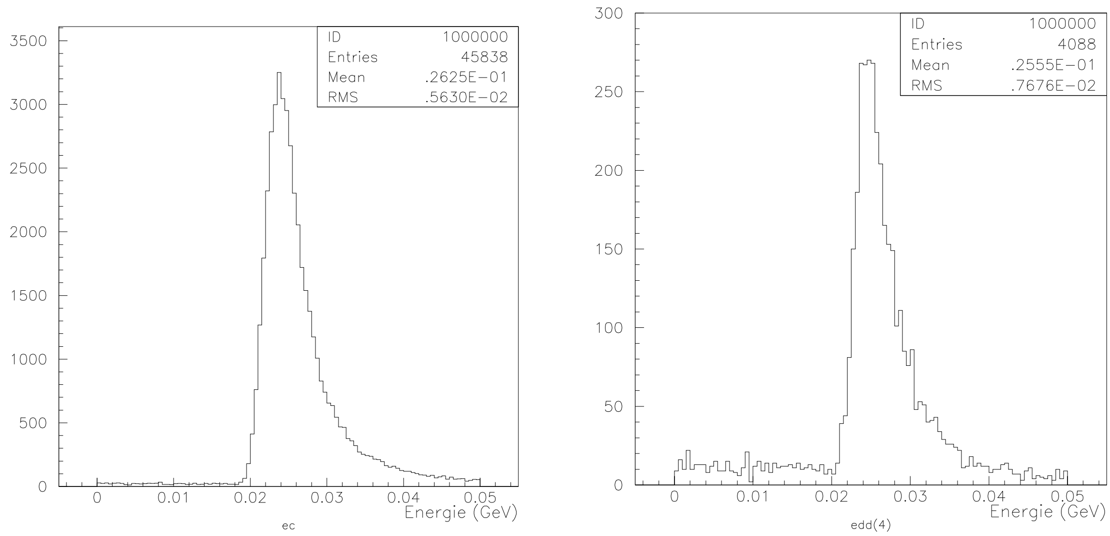

Figure 8. GEANT simulated spectra of energy deposited in $PbWO_4$ crystal (left : global, right : one 1,5 cm division)

3 Measurements

3.1 Cosmic bench

For each crystal, two weeks of data taking were necessary to record approximately 6000 correct events. Figure 9-left shows the global HPMT information. The pedestal events correspond to particles correctly triggering the cosmic bench but not hitting the crystal. Figure 9-right shows the same information for one 1,5-cm crystal division (obtained after track reconstruction and localization in crystal). The energy information of each division is the mean ADC value (pedestal subtracted) of all events beyond pedestal (all events beyond channel 250 in our case).

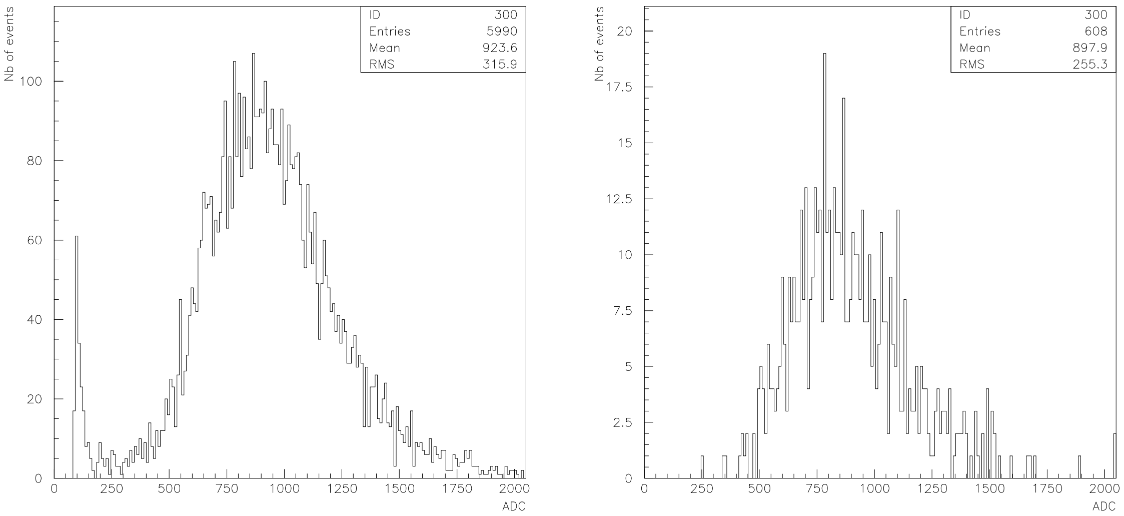

Figure 9. Global HPMT spectrum (left) and energy spectrum for one division (right).

We obtain this information for each of the 14 predefined division. Dividing these values by the GEANT ones (and normalizing to the maximum) gives the non-uniformity of the crystal, as shown in figures 11 to 13.

As the photoelectron spectrum allows us to obtain a good and precise absolute calibration (23,5 channels /photoelectron in this experiment), we can give the average light yield of each crystal : around 40 photoelectrons in the spectrum above in regard to 22 MeV energy deposited. Taking into account matching factor (0,4), quantum efficiency (20 % for HPMT around 420 nm) and temperature effect (we worked near 22 Celsius degrees), we are in good agreement with the 9 photoelectrons/MeV values obtained by CERN [7] (matching factor 1, quantum efficiency 13 %, 18 Celsius degrees).

3.2 ^{60}Co source

The crystal completely absorbs the 1,2 MeV γ emitted by the collimated ^{60}Co source. We can obtain the non-uniformity curve of the crystal by moving the source along its axis. Figure 10 shows the HPMT spectrum. We can see the pedestal around channel 50, the first photoelectron peak around channel 100 and the second around channel 150.

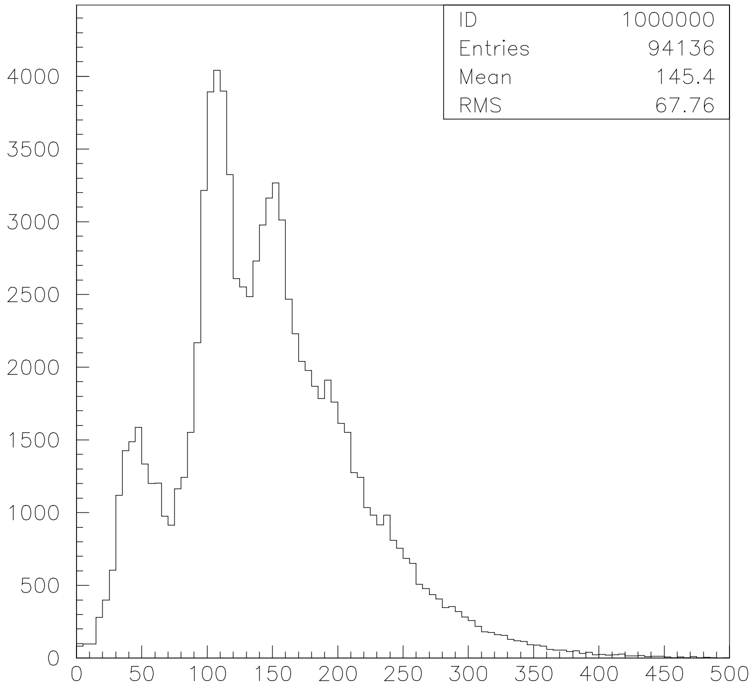

Figure 10. ^{60}Co HPMT spectrum.

We only keep information beyond pedestal (above channel 84 in our case).

As we are in self-triggering mode, this spectrum is the superposition of the scintillation phenomenon induced by ^{60}Co and the natural HPMT spectrum (noise). We suppose both phenomena yield to a Poisson Law. So the resulting spectrum is a Poisson law too and the mean value of the resulting spectrum is the sum of the means of each phenomenon. We record a HPMT noise spectrum (without any scintillation phenomenon), giving us the mean noise. We record all the source spectra corresponding to each 1,5-cm division of the crystal. We subtract the noise mean from each source spectrum mean. We finally obtain the mean corresponding to the scintillation phenomenon alone.

As in the cosmic bench measurement, we normalize these values to those obtained by GEANT and the result is the non-uniformity curve seen in figures 11 to 13.

4 Final results

Figures 11 to 13 show the comparison between both methods. As can be seen, for three crystals coming from completely different batches, the two sets of results are compatible.

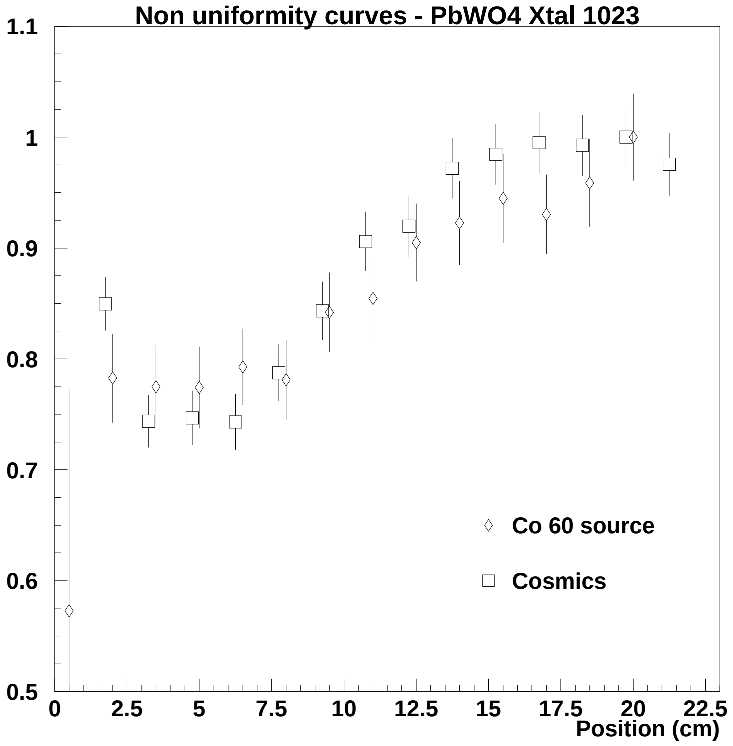

Figure 11. Non-uniformity curves for both measurements methods (first crystal). Curves are normalized to 100 % (1 on Y-axis), corresponding to the maximum signal observed.

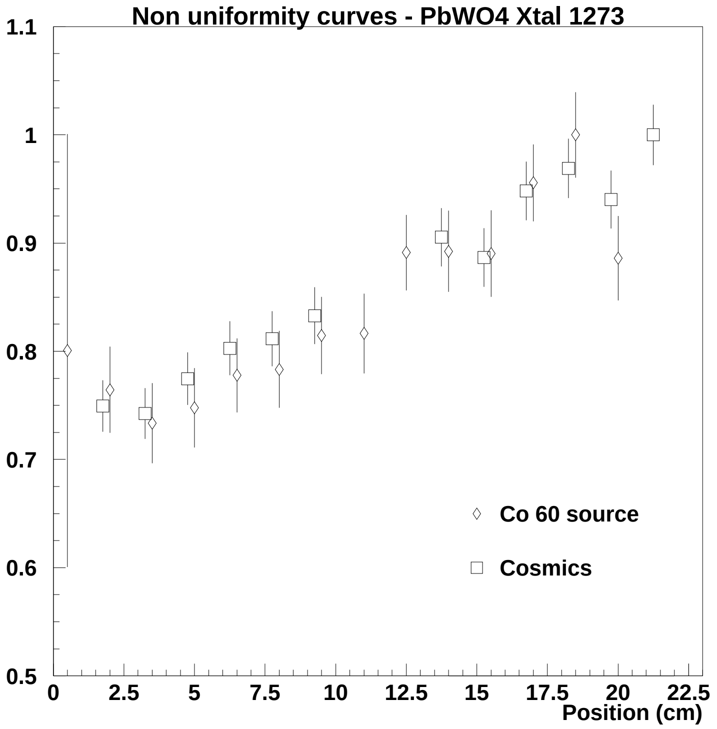

Figure 12. Non-uniformity curves for both measurements methods (second crystal)

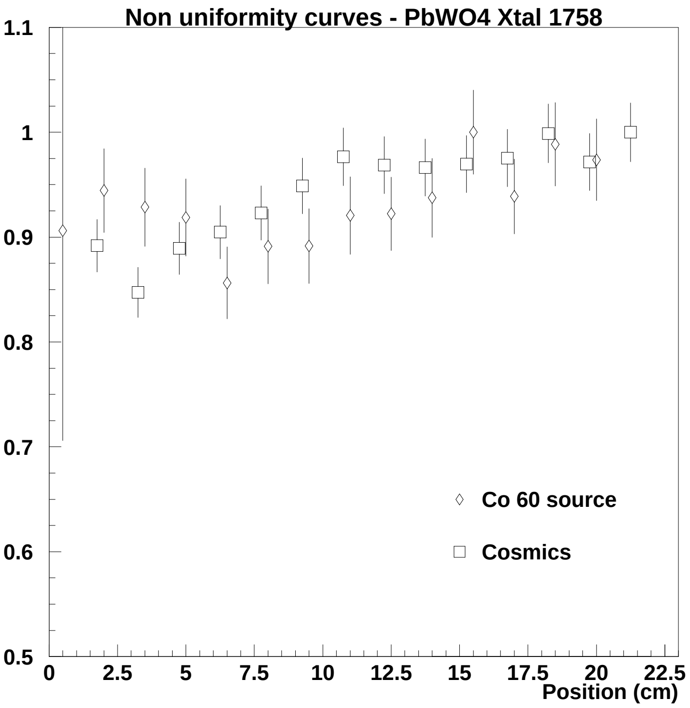

Figure 13. Non-uniformity curves for both measurements methods (third crystal)

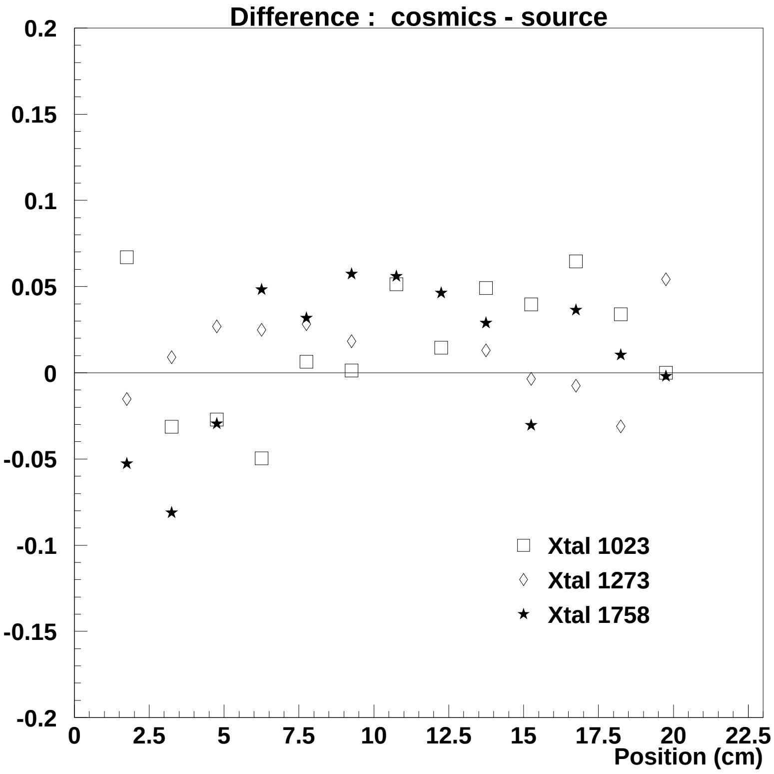

Figure 14. Differences between both methods

The difference between the cosmic and the source methods (figure 14) shows a systematic small excess of the cosmic one in the central area of the crystal whereas the situation is more confused at the extremities. This small effect might be explained by the attenuation/focalization curves that govern the non-uniformity response of such crystals. The cosmic method has a more uniform interaction with the crystal than the source one.

5 Conclusion

The cosmic bench method uses MIP particles that crossed the entire crystal whereas source method has a more local (not uniform in thickness) investigation. Nevertheless, from our measurements, we conclude that both methods give similar results.

Acknowledgments

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