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Performances of the CsI(Tl) detector element of the GLAST calorimeter

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Abstract

The CsI(Tl) Detector Element (CDE) is the unit of detection of the calorimeter subsystem of the Large Area Telescope (LAT) of the GLAST satellite (IEEE Nuclear Science Symposium, 2002), which will be launched in September 2006. The LAT consists of 4×4 identical towers, each one including a strip silicon tracker on the top and a CsI(Tl) calorimeter on the bottom. A segmented plastic scintillator anticoincidence detector surrounds the 16 towers. The calorimeter modules, 8 layers of 12 CDEs each, have a hodoscope's shape to allow the measurement of the gamma-ray direction.

The CDE main characteristics are its Light Yield, the energy resolution and the tapering, ratio of left/right signals used for the determination of the crossing position of the particle in the crystal.

The CDE have to operate in space at about -10°C. We will describe the CDE, the optimization of its main parameter, the L.Y., and finally its variation with temperature.

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Keywords: Calorimeter; CsI(Tl); PIN photodiode; Light yield; Reflective material; VM2000

1. Introduction

The GLAST Large Area Telescope (LAT) Calorimeter [1] is characterized by its huge energy range from 20 MeV up to 300 GeV/c, and also by its tracking capability, especially for high-energy gamma. To cope with these requirements, the calorimeter is segmented into 16 identical modules forming a hodoscope of 1536 identical CsI(Tl) Detector Elements (CDEs). The scintillation light is detected at each end of the crystal by two PIN photodiodes with an active area ratio of about 6, the smaller (PIN A) for the highest energy deposition and the larger (PIN B) for the lowest. To increase position detection capability along the crystal, the left/right signal difference (named: tapering) is improved by depolishing 2 of the 4 long sides of the crystal.

2. CDE description and main parameters

The CDE is the element of detection of the calorimeter and it can be independently fully characterized. It is composed of a CsI(Tl) crystal ($326 \times 19.9 \times 26.7\,\text{mm}^3$, from Amcrys) with two custom dual PIN photodiodes (DPD, S8576 from

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Hamamatsu) bonded at each ends (0.7 mm of silicon glue, DowCorning DC93-500). It is wrapped in a very reflective material: VM2000, multilayer of Mylar of 2 different indices, total thickness 65 μm from 3 M Company, with a end capsule (Delrin endcap) at each ends.

The main parameter of the CDE is the Light Yield of each PIN diode, the number of collected electrons by deposited MeV in the crystal, the integration constant being 3 μs. Two other parameters also characterize the CDE: the tapering and the energy resolution. The tapering is the L.Y. of the PIN diode when particles cross the crystal at 2 cm from its opposite end over the L.Y. when they cross at 2 cm from its side. The energy resolution is calculated with particles crossing the crystal at its center, it is deduced from the normalized difference between the left and the right CDE PIN diodes.

The cosmic test bench uses cosmic muons depositing about 10.2 MeV in the 2 cm of CsI(Tl). Two plastic scintillator hodoscopes perpendicular to the CDE, up and down, give the muon crossing position. The coincidence between at least one plastic of the bottom and the top hodoscopes gives the trigger to the data acquisition system (NIM, CAMAC with Labview). The PIN diode signal is first pre-amplified (eV 5093, 3.6 mV/fC) then shaped (3 μs) and amplified and finally converted by a peak sensing ADC. All events are registered and analyzed with a C++ program base upon ROOT program (http://root.cern.ch/); Figs. 1–3 give typical curves or histogram from which we extract the main parameters.

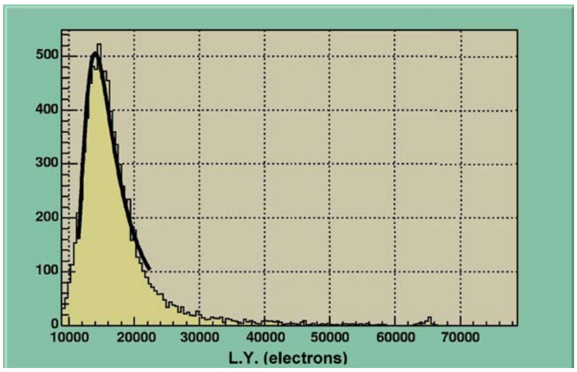

Fig. 1. Typical L.Y. spectrum obtained with cosmic muon crossing the CDE, with Landau fit.

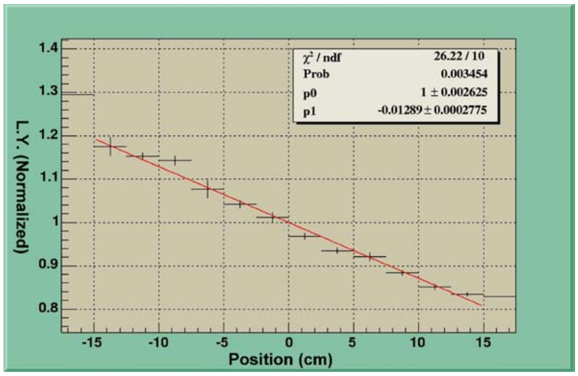

Fig. 2. Typical Tapering curve: normalized L.Y. vs muons crossing position along the CDE, with a linear fit.

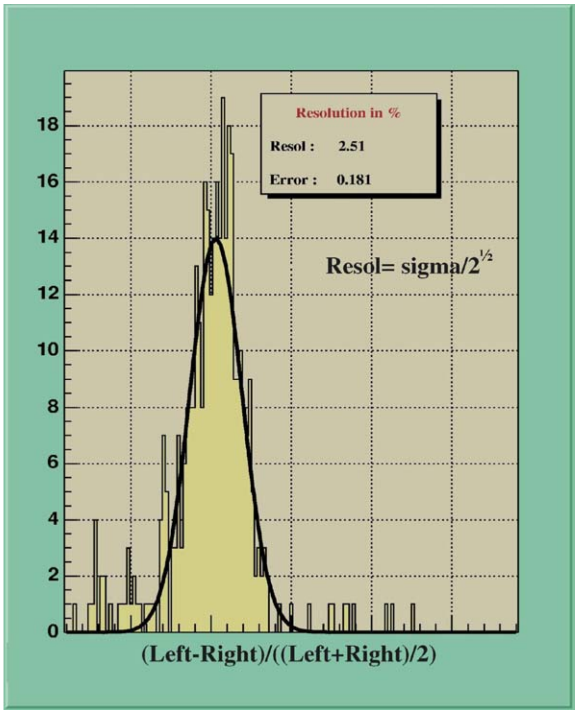

Fig. 3. Typical energy resolution spectrum, with Gaussian fit.

We have assembled and tested 14 CDEs for their insertion in the “engineer module” at the Naval Research Laboratory (NRL, USA); both for integration tests with the front-end electronic and

Table 1
CDE L.Y., energy resolution and tapering requirements and measurements of the first 14 elements delivered to NRL

Parameter	Unit	PIN A (25 mm^2)		PIN B (152 mm^2)	
		Requier.	Meas.	Requier.	Meas.
Light Yield	(e/MeV)	>1100	1170–1400	>7000	7700–8600
Energy resol.	(%)	No	3.6–5.3	<8	1.5–2.3
Tapering	(%)	60–80	69–82	60–80	65–80

environmental tests. Table 1 gives their required and measured performances.

3. Light yield optimization

The L.Y. is very dependent upon wrapping material, and the tapering is anti-correlated to it. First the base line material for the wrapping was Tyvek plus aluminum, which was used for the crystal characterizations and tests.

To increase the L.Y. different reflective materials have been tested and compared to a novel one: a multilayer of Mylar of different indices named VM2000 (Visual Mirror 2000 from 3 M). Table 2 summarizes the comparison of VM2000 with: Tyvek plus aluminum, Millipore plus aluminum, Aluminum and finally Tedlar, which is a black material giving the limit value when all the light coming out of the crystal is lost. It shows the very good performances of the VM2000 up to 40% better than Tyvek plus aluminum.

The VM2000 wrapping material covers only the four long sides of the crystal and the PIN photodiodes cover 335 mm^2 of the 472 mm^2 of the crystal end. An endcap cover about 68 mm^2 of the 137 mm^2 remaining area. We have tested four different configurations for the crystal end: with no endcap (137 mm^2 of bare crystal), with the Delrin endcap, with VM2000 on the endcap and finally with VM2000 covering the whole bare crystal area. Table 3 summarizes the results and shows an increase of the L.Y. of 15% with the endcap and up to 8% more when adding VM2000. Nevertheless, as our L.Y. CDE performance is well over the requirement, for practical reason, we decided to keep the Delrin endcap as our baseline.

Table 2
Wrapping material comparison performed with the largest PIN photodiode, normalized to VM2000

Material	Normalized L.Y.
VM2000	1.00
Tyvek + Alu.	0.71
Millipore + Alu.	0.62
Aluminum	0.33
Tedlar (black)	0.18

Table 3
End crystal wrapping study: comparison between different end crystal configurations of the L.Y. performance normalized to VM2000 and remaining bare crystal area

Material	Bare area (mm^2)	Normalized L.Y.
No endcap	137	0.87
Endcap	69	1.00
Endcap with VM2000	69	1.04
VM2000	0	1.08

4. CDE operation from −20°C to 30°C

All tests on the CDE are performed at room temperature (about 20°C) although the space operating one will be around −10°C. As the CsI(Tl) L.Y. decreases with the temperature, we have to measure this dependency.

We have used a climate test cabinet where we have put a CDE with its laboratory front-end electronic (eV 5093 preamplifier) and a reference PIN photodiode.

The L.Y. is mainly the convolution of: the crystal scintillation and transmission, the PIN diode photosensitivity and electron–hole collection, and the preamplifier gain.

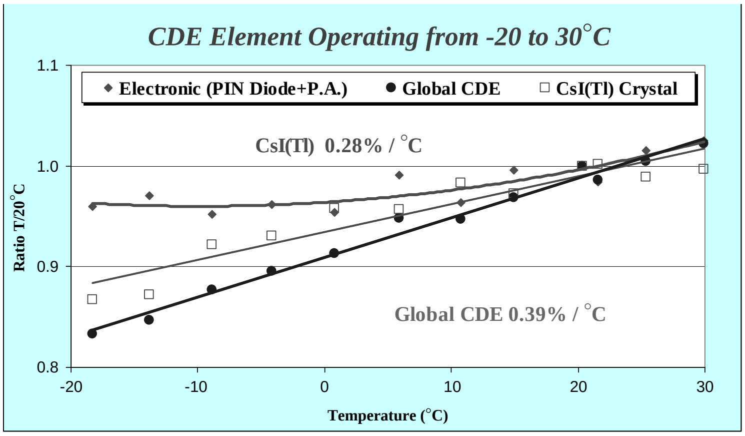

Fig. 4. Variation with temperature of the electronic, the global CDE and the CsI(Tl) crystal (de-convolution of the two formers).

To de-convolute these different contributions, we have used: a gamma-ray (AmBe, 4.43 MeV) source on the CDE, an optical fiber linked to a pulsed green LED and a X-ray source (Co57, 122 keV) on the reference PIN photodiode, and finally a pulse generator linked to the dedicated input of the eV 5093 pre-amplifier.

We have first decreased the temperature from 30°C to −20°C by step of 10°C, and then increased it from −15°C up to 25°C.

The normalized values with the pulse generator, the green LED and the X-ray source on the reference PIN diode show the same variation. So we could conclude that the dominant contribution is the pre-amplifier gain. On the graph Fig. 4, we have put the mean value of this curve (labeled "electronic"). The normalized value with the gamma-ray source on the CDE (labeled "global CDE") shows linear dependence with temperature with a slope of 0.39% per degree Celsius. If we de-convolute the electronic contribution we get the CsI(Tl) dependence with temperature (labeled "CsI(Tl) crystal"). The linear fit gives a slope of 0.28% per degree Celsius.

5. Conclusion

For the GLAST LAT calorimeter, we have chosen to use this very good reflective material, VM2000 and a white Delrin endcap closing each crystal ends. In this condition we get a L.Y. well over the requirements, about 8200 electron by MeV with the larger PIN diode covering 32% of the crystal end. We have confirmed the temperature dependency of the Light Yield. The L.Y. lost when the calorimeter will operate in space at about −10°C, will be of the order of 8%.

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[1] W.N. Johnson et al., The Construction and Performance of the CsI Hodoscopic Calorimeter for the GLAST Beam Test Engineering Module, IEEE Trans. Nucl. Sci. 48 (2001) 1182.