DESY CMS group

Analysis of the pulse shapes of CMS Castor Calorimeter channels

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Contents

Abstract

CASTOR is a small (56 cm diameter) quartz-tungsten Cerenkov calorimeter covering the small angles 0.2-0.6 degrees corresponding to $-6.6 \leq \eta \leq 5.2$ in CMS, one of the biggest experiment at LHC. It's divided in 14 longitudinal modules and 16 azimuthal sectors that allow identification of particles from their energy-loss profile. They are read by a QIE chip that divides the input signal into multiple ranges, with each range integrating a scaled fraction of the signal. An analysis of the pulse shapes of each channel was conducted using data from LED timing scans and real data from LHC and it provided a parametrization of the functions of the pulse shapes themselves after having isolated the channels without a signal and the ones without a converging fit. This analysis is very important to treat the pile-up of the signals when LHC has a higher luminosity and to extract for every event the whole signal. It was also analysed the best delay for each channel looking at the ADC spectrum and considered some corrections because of LED jitter effect and the dependence of the pulse shape on the amplitude of the signal.

Introduction

Castor calorimeter is one of the detectors of the CMS experiment at LHC. It's important for forward QCD studies (diffractive, low-x) and cosmic-rays-related physics in both proton-proton and heavy-ion collisions. It's a Cerenkov quartz-tungsten sampling calorimeter, installed at 14.4 metres from the interaction point. The calorimeter is constructed from layers of tungsten alloy plates as absorber and silica quartz plates as active medium. The segmentation is organized with 16 semi-octants (sectors) and longitudinally with 14 channels per sector (see fig.1). Each sector is divided longitudinally in 2 electromagnetic layers and 14 hadronic ones. The Cerenkov light emitted by the quartz plates is collected and transmitted to light-sensitive devices through air-core light guides and finally to PMTs. The electrical readout for the CASTOR calorimeter uses frontend cards, with circuits around the ASIC, called QIE (charge Integrator and Encoder). This chip integrates the charge for every bunch crossing and digitizes it with a dynamic range of 10^4 and with a quantization error below 3%. This is very important because it can digitize wide dynamic range charge signals at high rate to a very good precision. This is due to the fact that a QIE chip divides the input signal into multiple ranges, with each range integrating a scaled fraction of the signal. The range capacitors are offset, so that for any given signal magnitude, only one range will be selected as valid. The QIE module works using four identical sets of capacitors so that one bank of them can be integrating, a second settling, a third being digitized and a fourth being read out, resulting in a continuous digital output every 25 nanoseconds. The range is achieved by charge integration simultaneously on four scales having relative sensitivities of 2.6, 13, 65 and 325 fC per least count. There is one QIE module for every 6 read-out channels.

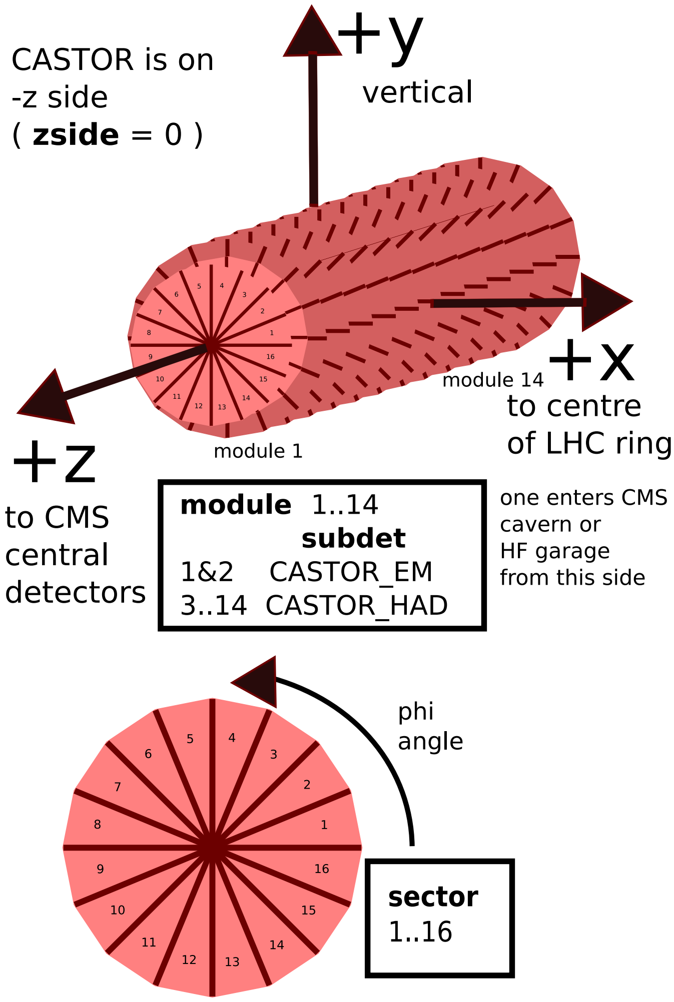

Figure 1: Structure of the CMS Castor calorimeter

Chapter 1

Analysis of the signal

A study of the signal from the channels of the calorimeter is necessary to calibrate and know the behaviour of the detector. To do that, an analysis was conducted with both data from LED timing scans and real data from LHC. For both of them, 13 different delays were set between 0 ns and 24 ns with about a quite good statistic of 20000 events each. For every event of these, it's been recorded 25-ns-wide 10 time slices in the readout. The data come from these ranges of runs:

- 132631 - 132632 - 1632633 - 132634 - 132635 - 132636 - 132637 - 132638 - 132762 - 132764 - 132768 - 132770 - 132772 for LED data
- 132442 - 132476 - 132477 for real data

It has to be remarked the fact that the magnetic field was on during these runs. The high voltage for the channels was of the type "near/far equalise first 3.8 T+(m1s5,6=0V)+(m1s11,12=1200/70V)"; this means that some channels have to be set at reduced voltages to prevent HV trips.

1.1 LED timing scan: mapping of the calorimeter

The first analysis was conducted with calibration data from LED (Light Emission Diode) connected by fibers to the photocathode of the phototube. Every octant has a different LED with the same intensity and fibers of different lenghts. For these data, LEDs give the signal to the phototubes producing a pulse shape, as it can be seen from fig.1.1, that goes through the QIE chip that integrates the charge. The starting time is given by a programmable delay in respect from the LHC global clock. The ADC spectrum generally has a peak in one of the central time slices and a tail in the next ones. Figure 1.2 represents the average amplitudes in 20000 events for each time slice for a random channel, chosen for instance module 5 sector 15 for 0 ns delay, while fig.1.3 is the same plot for 24 ns delay: as it can be seen, there is a shift of the signal towards lower time slices because, in fact, changing the delay from 0 ns to 24 ns, the pulse moves from one bunch crossing to the previous one. The bin where the maximum is, is for 0 ns delay the 5th time slice while for 24 ns delay this corresponds to the 4th one. For a dead channel, chosen for instance module 7 sector 13 in the fig.1.4 and 1.5, the expected pulse shape doesn't appear, the signal has no maximum and generally the maximum amplitude is quite small. For all the channels the pedestal has been subtracted.

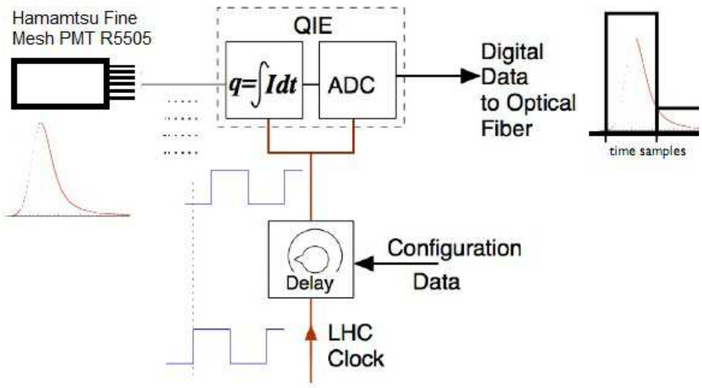

Figure 1.1: Timing scan for LED data

First of all, the analysis needs a selection of "good channels", that are those having a proper signal inside. This was done with two types of criteria:

- maximum signal in one of the time slices in the channels more than 3

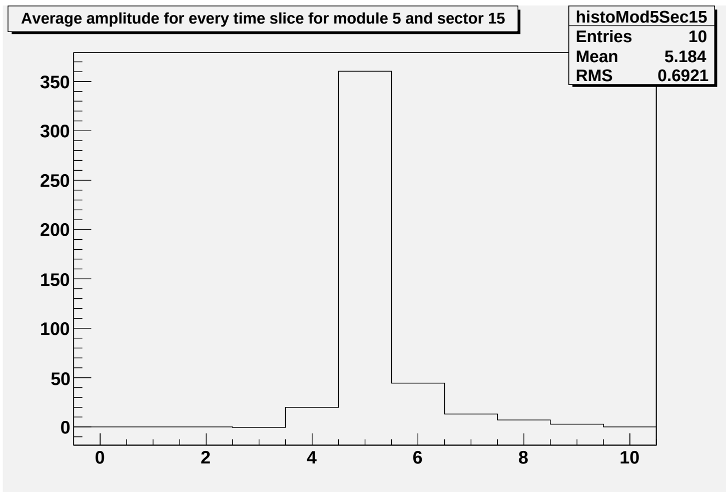

Figure 1.2: ADC spectrum for a good channel for 0 ns delay

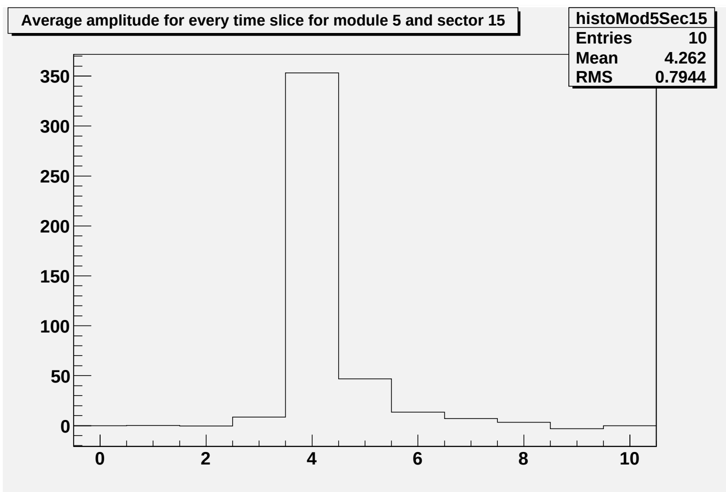

Figure 1.3: ADC spectrum for a good channel for 24 ns delay

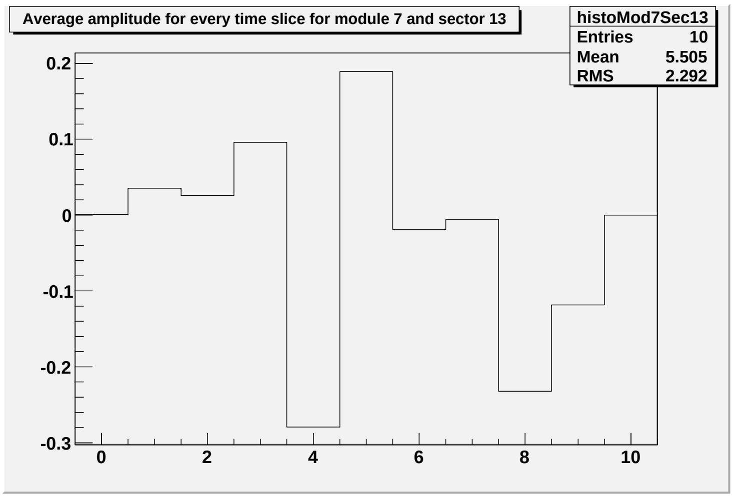

Figure 1.4: ADC spectrum for a dead channel for 0 ns delay

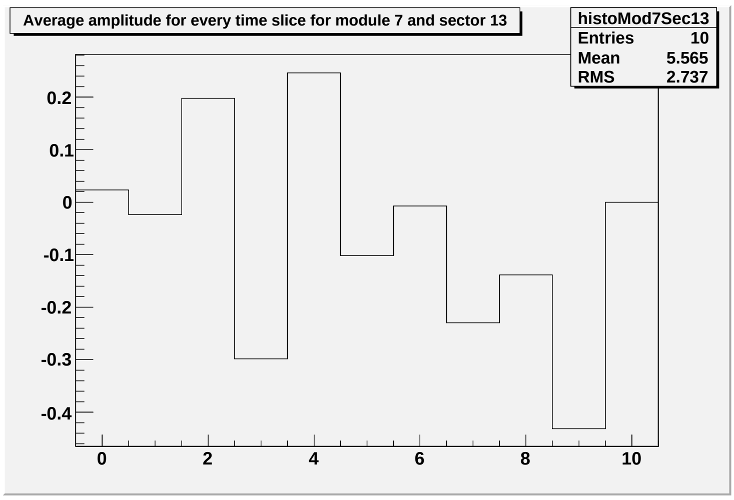

Figure 1.5: ADC spectrum for a dead channel for 24 ns delay

fC (fig.1.6 and fig.1.8);

- sum of the signals in the time slice where there is the maximum and in the next ones more than 3 times RMS of the pedestal (fig.1.7 and fig.1.9)

The first selection is quite rough because it's simply a cut in the signal and it removes all the channels with a small amplitude; the second one is more accurate.

It was important to check the "dead" channels (that don't work properly) for the first run and the last one to verify the stability of the signal during the data taking. These runs correspond to 0 ns and 24 ns delay and the plots for the dead channels are compatible to each other: this means that the signal is stable.

As it can be seen from all the previous figures, the "dead channels", represented in white, are especially in the central region of the calorimeter and this is due to the magnetic field effect because in the module 7 and 8, the shielding is not perfect. Then, other dead channels correspond to module 1 sector 5, 6 that have no high voltage and to module 1 sector 14, 15 that have broken fibers. Therefore, pattern of Castor calorimeter, from these two selections, is quite well known and the analysis of the pulse shapes can go on, considering only the "good" channels.

1.2 Parametrization of the pulse shape

The next step for the analysis is the parametrization of the pulse shape for each channel. In fig.1.10, it can be seen the signal for the previous channel in all the delays; it's clear the progressive migration of the peak from the fifth time slice to the forth, while the delay increases.

To obtain the parametrization of the pulse shape of the signal, the procedure can be:

1. to find the time slice which the maximum signal is in, for 24 ns delay data, because this set corresponds to the smallest bin, as it's clear from the fig.1.10;

2. to evaluate for each delay the following ratio:

$$r = \frac{\text{maximum amplitude}}{\text{amplitude of the whole signal}}$$

   that is simply the maximum amplitude normalized to the amplitude of the signal;

3. in order to increase the phase shifts, to evaluate the same ratio for the sum of two and three bins corresponding to the maximum signal and

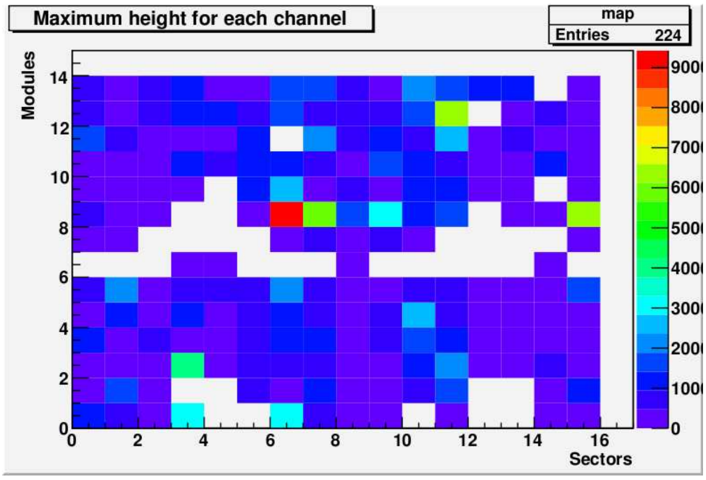

Figure 1.6: Mapping of the calorimeter with the first selection for 0 ns delay

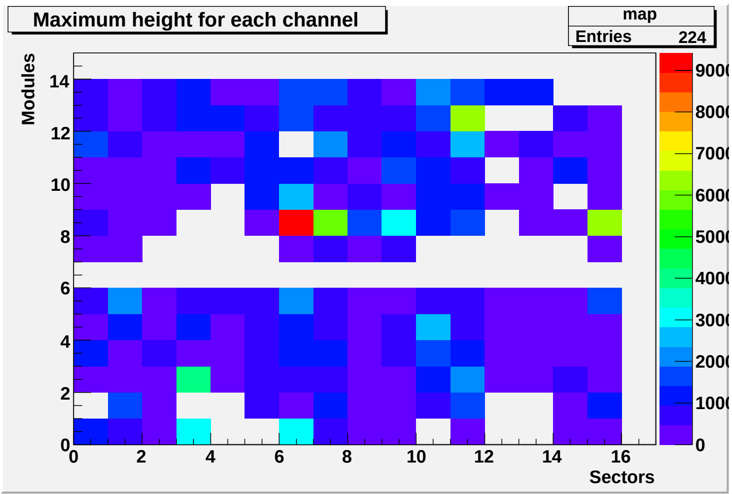

Figure 1.7: Mapping of the calorimeter with the second selection for 24 ns delay

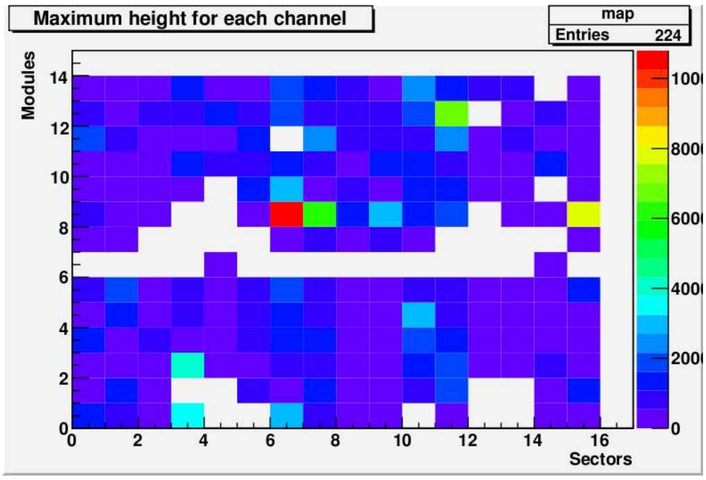

Figure 1.8: Mapping of the calorimeter with the first selection for 24 ns delay

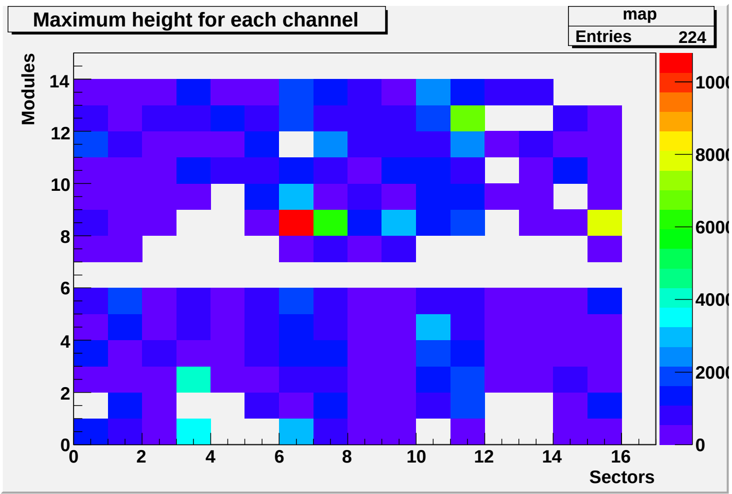

Figure 1.9: Mapping of the calorimeter with the second selection for 24 ns delay

the next time slices, normalized to the whole signal; the new phase shift is the delay plus, respectively for the sum of two or three bins, 25 ns and 50 ns;

4. to fit the resulting slope (13 delays · 3 times procedure at the point (3) = 39 points to be fitted) with the function:

$$integral = \frac{par4}{1 + par0 \cdot e^{par1 \cdot x} + par2 \cdot e^{par3 \cdot x}}$$

with 5 parameters and x phase shift from different delays; this function is the integral function of the pulse shape for each channel;

5. to take the derivative of this function in order to obtain the pulse shape.

1.2.1 Plots

In this section, results of the fit procedure, explained before, are reported:

- plots of the integral function and the pulse shape for module 5 sector 15: fig.1.11 and fig.1.12;
- plot of the integral function for a dead channel (module 7 sector 13): fig.1.13;
- plots of the best delay for each good channel, the bin that has the maximum signal for all the good channels: fig.1.14 and 1.15;
- plots of the ratio for the amplitude in the bin next forward to the bin with the maximum signal: fig.1.16
- plots of the ratio for the amplitude in the bin next backward to the bin with the maximum signal: fig.1.17

The fit for the chosen channel is good and the signal has the expected pulse shape. The fit for a dead channel is a constant close to 0. The values of the parameters aren't always good because some fits don't converge.
The best delay for each channel was chosen by taking the delay with the highest amplitude in the peak independently on the time slice where it is. From this choice, dead channels according to the first criterium were removed.

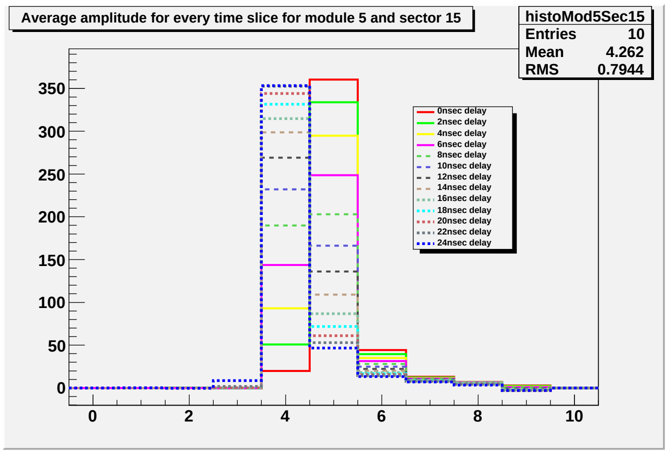

Figure 1.10: Average amplitudes for module 5 sector 15 for all the delays

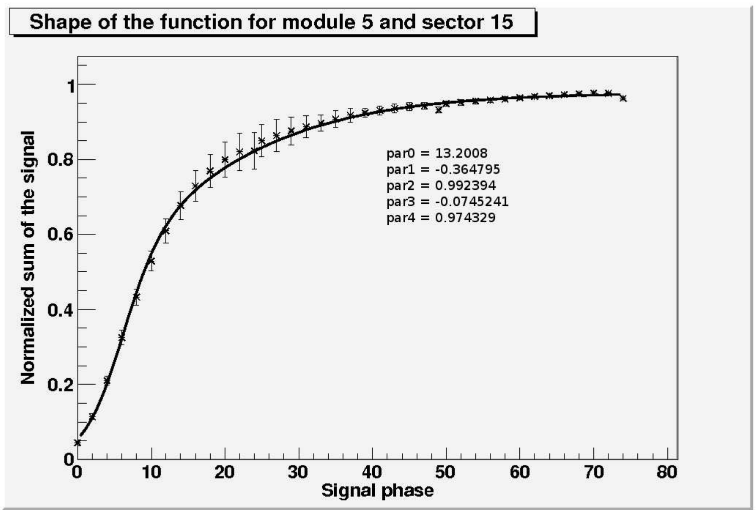

Figure 1.11: Integral function for module 5 sector 15

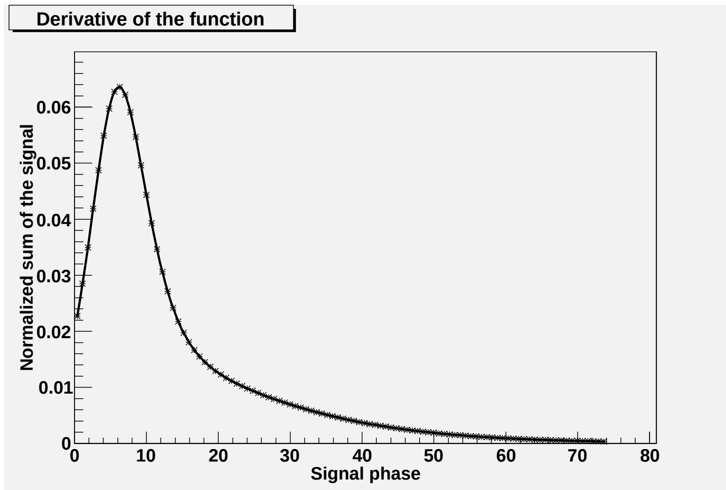

Figure 1.12: Pulse shape for module 5 sector 15

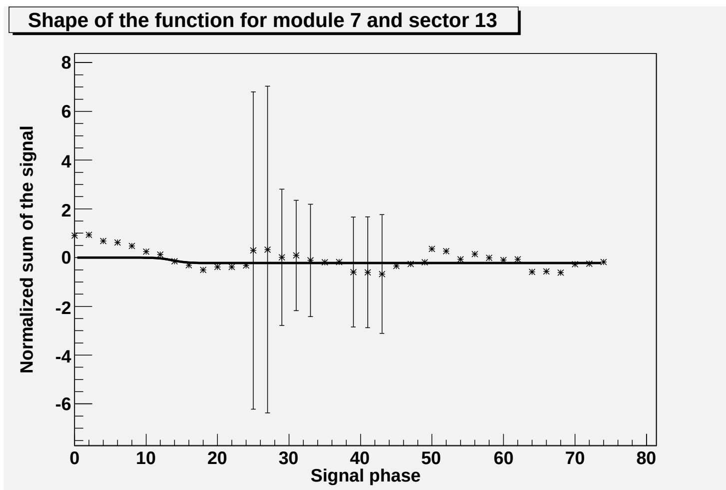

Figure 1.13: Integral function for the pulse shape for module 7 sector 13

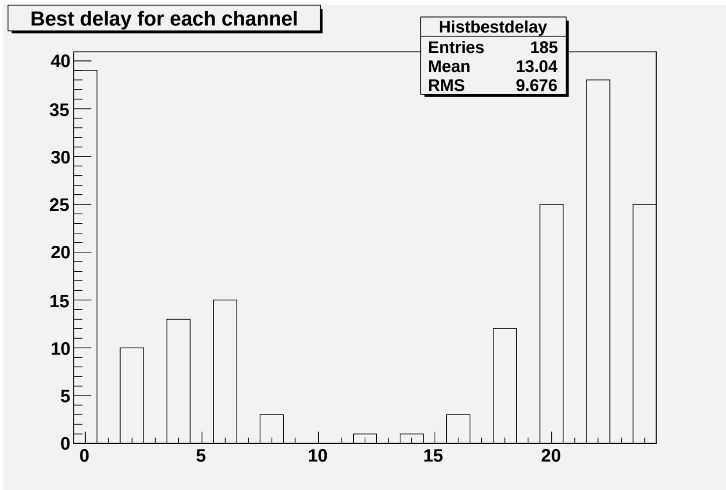

Figure 1.14: Best delay for all the channels for LED timing scan

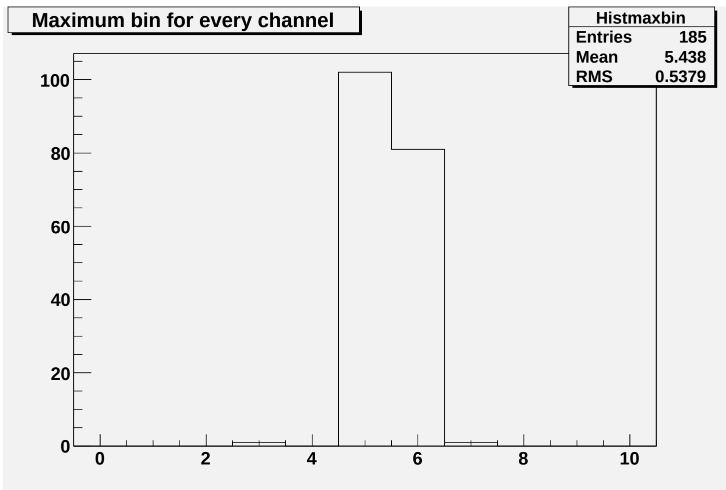

Figure 1.15: Time slice where the maximum signal is for all the channels

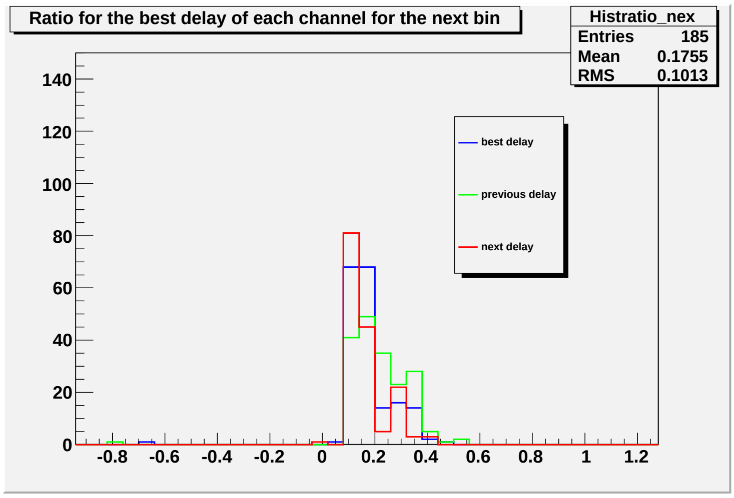

Figure 1.16: Value of the ratio of the amplitude in the next forward bin and the amplitude in the bin with the maximum signal for the best delay and for the next ones

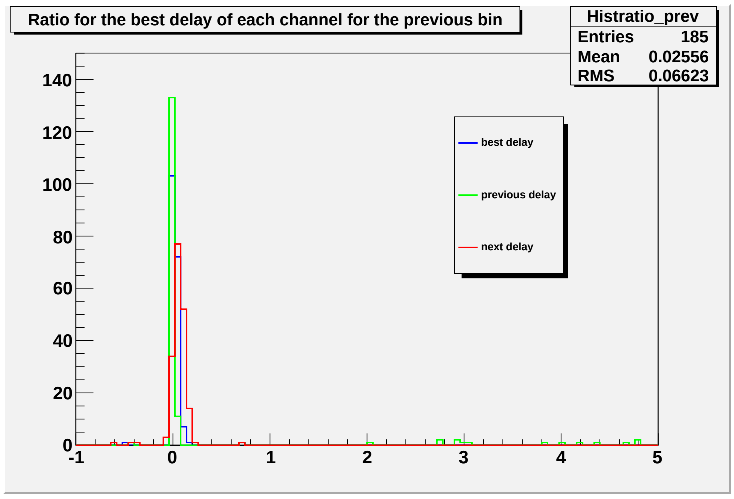

Figure 1.17: Value of the ratio of the amplitude in the next backward bin and the amplitude in the bin with the maximum signal for the best delay and for the next ones

Chapter 2

Analysis of real data

This chapter reports the same analysis, done for the previous set of data, for the real data from LHC. The pulse shapes were obtained in the same way of the previous analysis.

2.1 Plots

The shape of the signal is quite the same but now the time slice where the maximum signal is, is the first one or the second one, dependently on the settings, as it can be seen in the fig.2.1 for module 5 sector 15. It's also clear the progressive migration of the signal from a time slice to the previous one. For a dead channel, the difference of the shape is very clear (see fig.2.2). In fig.2.3 and 2.4, the integral function of the pulse shape and the pulse shape itself for the usual channel are represented, obtained by the same procedure. The fit isn't as good as the LED one but it can be accepted. As before, finally, it's important to choose the best delay, as the one that has highest peak, to see in which time slice it is, and to evaluate and to plot the ratio between the signal in the peak and the signal in the previous bin and the same ratio for the next bin. These are represented respectively in fig.2.5, fig.2.6, fig.2.7 and fig.2.8.

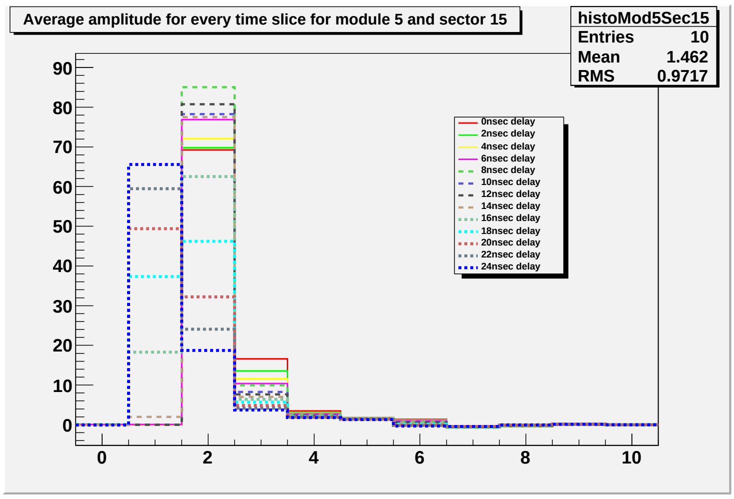

Figure 2.1: ADC spectrum for all the delays for module 5 sector 15

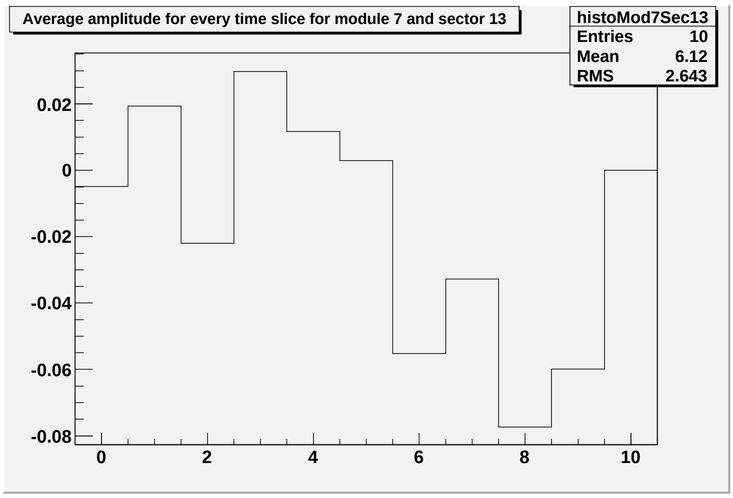

Figure 2.2: Signal in a dead channel, chosen module 7 sector 13

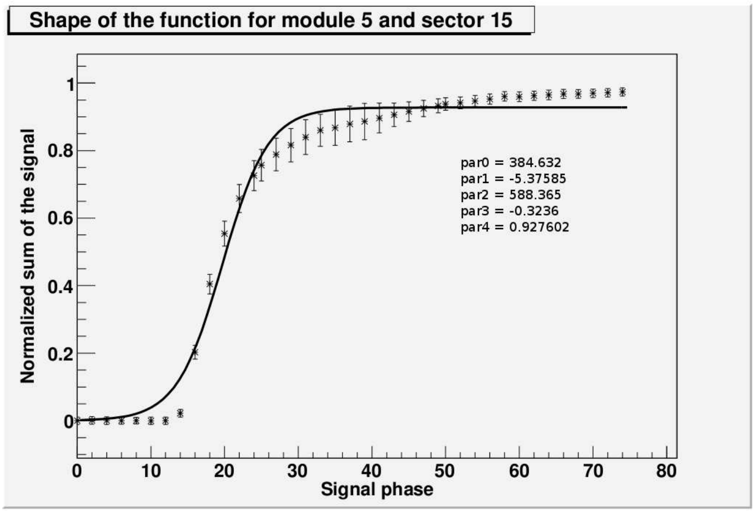

Figure 2.3: Integral function of the pulse shape for module 7 sector 13

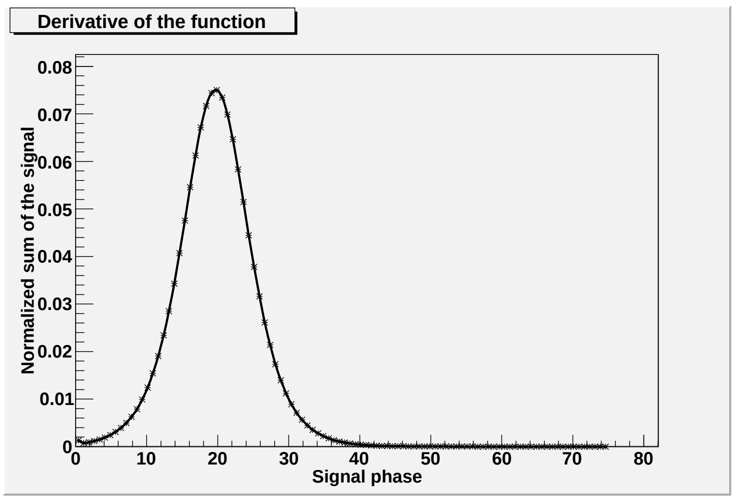

Figure 2.4: Pulse shape of the signal in module 7 sector 13

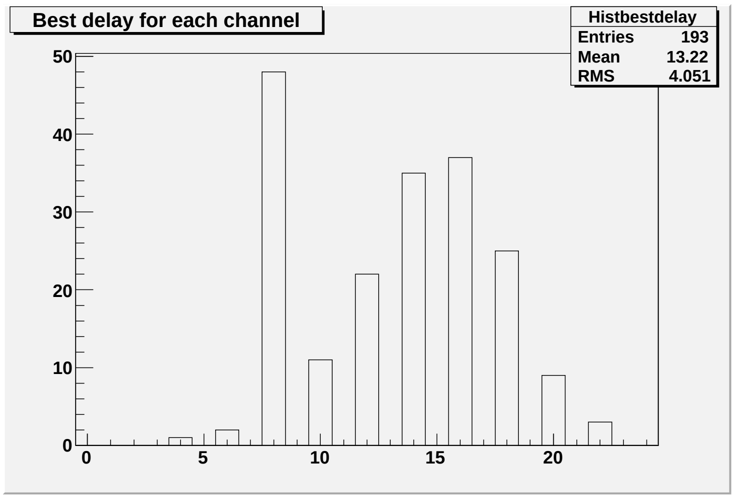

Figure 2.5: Best delay for all the channels for real data

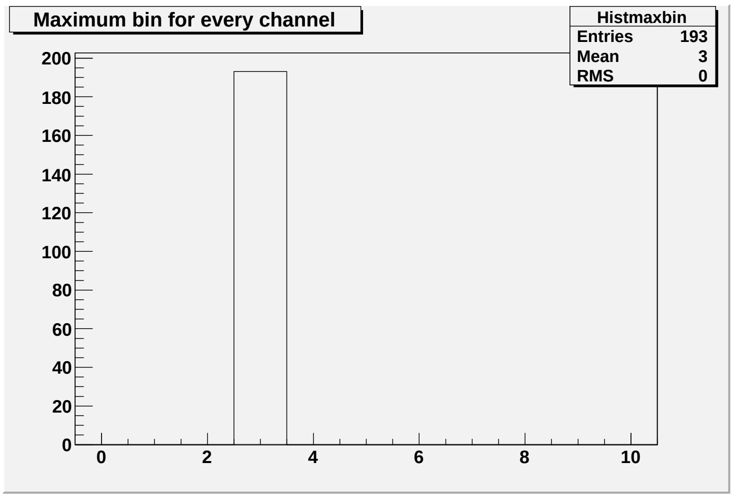

Figure 2.6: Time slice for the absolute maximum signal for real data

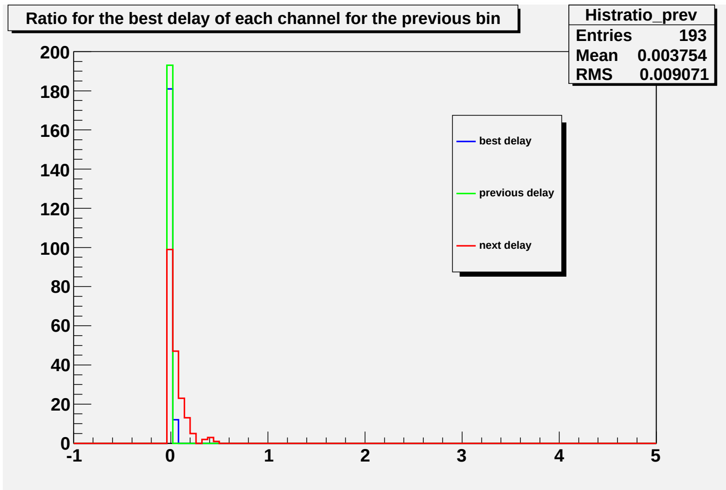

Figure 2.7: Ratios for the signal in the time slice before the peak and the peak itself for real data and module 5 sector 15

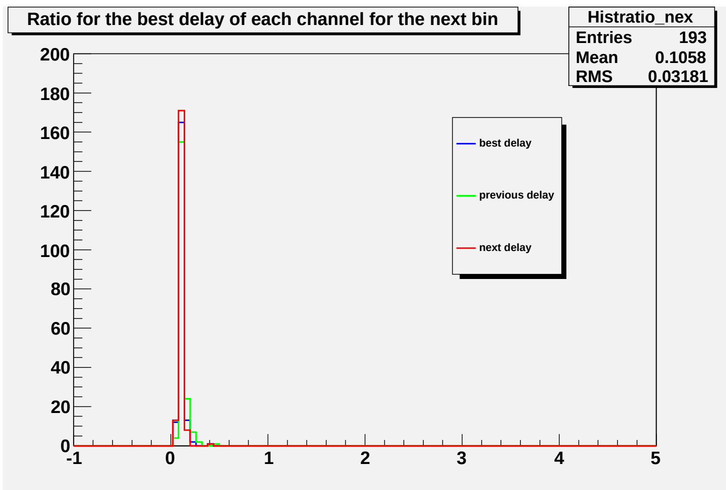

Figure 2.8: Ratios for the signal in the time slice after the peak and the peak itself for real data and module 5 sector 15

Chapter 3

Conclusions

This project brought an analysis of signals in Castor calorimeter channels, coming from two different sources. LED timing scans have obtained good results and they can be used as calibration data. From each channel best delay and a parametrization for the pulse shape were found for both LED data and real data. The project has also analysed the dependence of the pulse shape from the amplitude of the signal and a possible correction to improve LED data pulse shape because of jitter effect; these topics aren't treated in this report. It could be important going farther this analysis by:

- studying one by one the pulse shape of the channels which don't have a converging fit;
- after this operation, compare the fit parameters from the two sources of data;

Finally, this is the reference directory of every plot inside the report for every channel:
/afs/desy.de/user/g/gunnep/public/useful/

In this location there are also text files with all the obtained results for each channel.