Center for European Nuclear Research - CERN.

California Institute of Technology - CMS Group

A Summer Student Project Report

Analysis of Time Resolution in HGCAL Testbeam

Author:
Jonas Steentoft

Supervisor:
Dr. Adi Bornheim

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Abstract

Using data from a 250 GeV electron run during the November 2016 HGCAL testbeam, the time resolution of the High Granularity hadronic endcap Calorimeter, HGCAL, was investigated, looking at the seven innermost Si cells, and using them as reference timers for each other. Cuts in the data was applied based on signal amplitude,$0.05\ V < A < 0.45\ V$, position of incoming beam particle,$0\ mm < TDCx < 22\ mm$ and $-7\ mm < TDCy < 11\ mm$ and size of the time difference between two cells, $|t_1 - t_2| < 200\ ps$. Timewalk corrections, wrt in-cell amplitude, were applied to the cut data, with the Photek as reference.
Gaussian functions were fitted to the corrected Δt distributions, and a time resolution of $15-50$ ps was obtained, depending on which two cells were compared, and how the low-statistics cut were placed. We also confirmed a slight correlation between time resolution and distance between the two cells compared.

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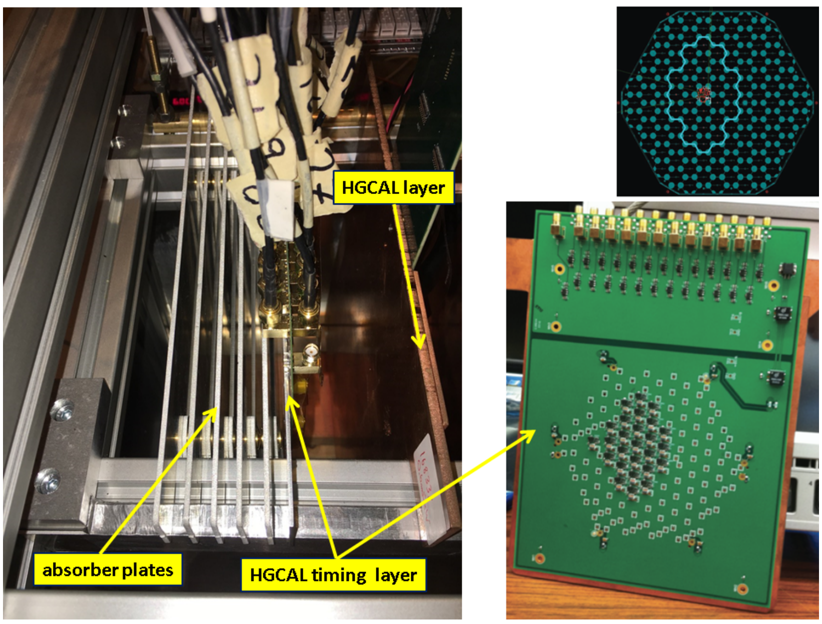

Figure 1: Photos of the November 16 testbeam setup, which generated the data used in this analysis

1 Introduction

The High Granularity hadronic endcap Calorimeter, HGCAL, is part of the high luminosity (HL) upgrade of the CMS detector. It is an inhomogeneous silicon calorimeter divided into $1x1\ mm^2$ hexagonal cells, with separate readout channels for each cell [1].

The purpose of this project was, to investigate the timing resolution of the device, by looking at distributions of timestamp differences between a cell and some reference timer. In the idealized case, particles moving at the same speed, with a timestamp recorded in two separated devices would give a singular value for difference between these two timestamps. This is obviously not the case in reality, therefore looking at the spread of the time difference (Δt) distribution gives a good estimate for the actual time resolution of the device.

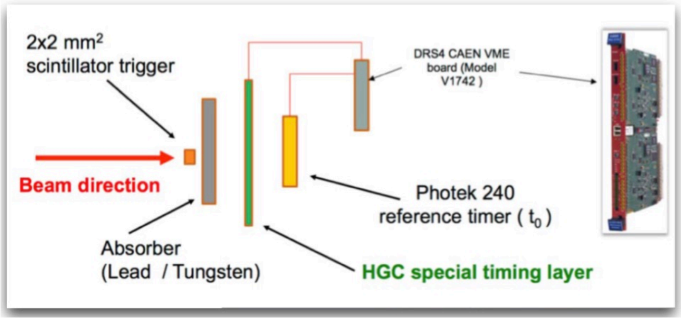

Figure 2: Illustration showing the TB setup used for generation the data analysed in this report.

The data for the project was provided by the November 2016 testbeam (TB) run, which included a 2D wire chamber in front of the absorbers and a high accuracy reference timer behind the HGCAL, the Photek. This can be seen on Figure 2. The Photek was placed a meter or so away from the HGCAL, which gives a hard limit on the time resolution, when the Photek is used as the reference, of about 20 ps. Therefore, the results presented here will focus on using a combination of the Photek, and a different Si cell, as the reference timer for a given Si cell. The layout and naming scheme of the Si cells used in study can be seen on Figure 3

The project was carried out using PyRoot as the analysis and plotting tool, and can be split up into three different parts:

1. Choosing some initial cuts to apply to the data.
2. performing the actual analysis on the selected data.
3. evaluating the results and figuring what to change in the initial cuts or analysis, in order to improve the results, then repeat until satisfaction or end of summer.

The reason for emphasising the actual working process, is provide clarity between the initial project description, and what was actually done, during the summer.

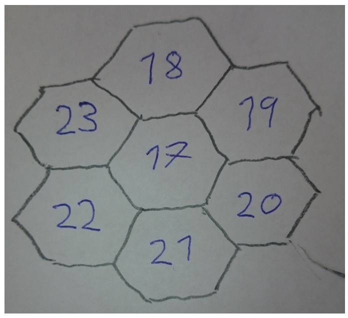

Figure 3: Layout of hexagonal cells which the HGCAL consist of, and their naming scheme.

2 Methods

For the sake of brevity, only the cuts and methodology used in the final analysis will be included in this report.

For cutting the data, the following variables were used:
Signal amplitude, position of incoming beam particle and magnitude of the difference between the two timestamps being compared.

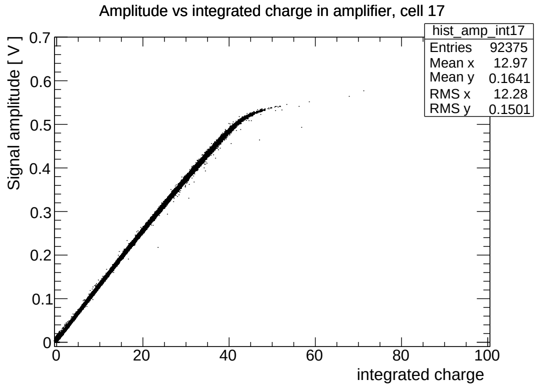

Figure 4: The relation between signal amplitude and integrated charge in the amplifier is shown here. The high amplitude limit of the amplifiers dynamic range can clearly be seen.

2.1 Amplitude cut.

As can be seen on Figure 4, the amplifier attached to each Si cell quenches above some high signal threshold, and this obviously needs to be cut out of the data. Initially this cut was placed at 0.48 V, but doing the implementation of timewalk corrections, 0.45 V turned out to be a more beneficial cut.

In the low amplitude limit, the response of the system becomes erratic, something we therefore want to cut away. One such erratic behaviour, which can be corrected to some degree, is the timewalk. This term means, that a low energy particle, ie a low amplitude signal, leads to a slower response of the Si cell, compared to a high amplitude signal. Other features of the low signal responses were not well understood, and therefore cut away.

The final amplitude cut used were

$$0.05\,V < A < 0.45\,V.$$

2.2 Δt cuts

We used the timing variable linearTime45 as the time stamp of both the Si cells and the Photek. This variable comes from fitting a straight line to part of the raw signal Gaussians.

In order to be reasonably sure, that the energy depositions in different cells were actually from the same event, something that is rather important when one wants to compare the measurements of an event in different cells, we required that

$$|t_1 - t_2| < 200\,ps.$$

2.3 TDCx and TDCy cuts

The TDCx and TDCy variables, from the front wirechamber, gives us access to the position of the individual beam particles before they interact with absorbers and create a shower. Due to the high longitudinal momentum of the beam particles, it is reasonable to assume that they will diverge minimally from where they were measured in the wirechambers, and where they hit the HGCAL.
Two differents methods of cutting on the x,y variables were investigated. Initially, the two variables were rescaled to have (0,0) at the center of cell 17, defining the center as the (x,y) of the event with the largest amplitude in cell 17. Then after rescaling, a geometric model of the HGCAL was drawn up, and events were required to be located in either of the two Si cells used for building a given Δt distribution. This effectively cut away all non primary beam particles, and let to problems with too low statistics. In the end this method was scrapped in favour of just cutting away the low event density tails of the (x,y) distribution.

$$0\,mm < TDCx < 22\,mm \qquad \text{and} \qquad -7\,mm < TDCy < 11\,mm$$

The (x,y) distribution of the raw data, and the effect of all the cuts, can be seen of Figure 5 and 6.

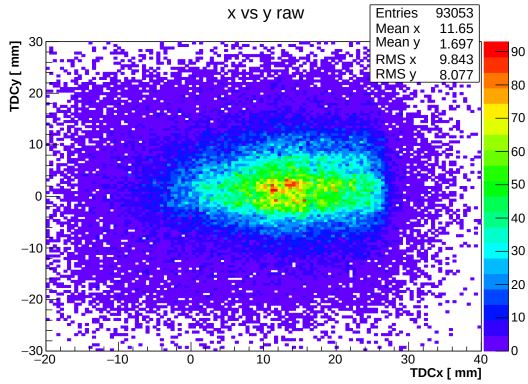

Figure 5: TDCy vs TDCx distribution of uncut data.

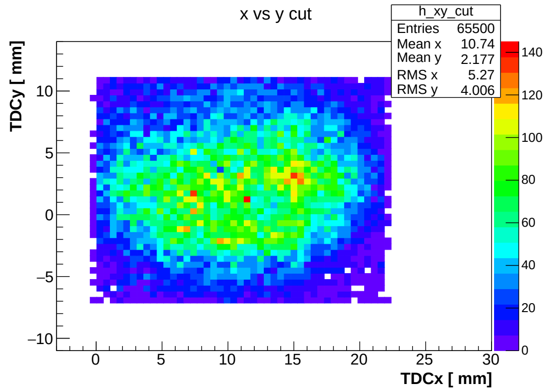

Figure 6: TDCy vs TDCx distribution, all cuts implemented.

3 Timewalk corrections

As mentioned earlier, there is an extra slowness in the response of the Si cells for low amplitude events, this can be visualised by plotting the time difference between a Si cell and the Photek, versus the amplitude of the event in that cell. To correct this feature of the data, which worsens the time resolution, we fit a function to the data that includes a flat line term, which is what we expect at high amplitudes, and some other term that dominates at low amplitude. the non-linearity is then corrected, and we then create a Δt distribution based on corrected timestamps in cell n and k.

$$F(A) = p_0 \cdot e^{p_1 A + p_2} + p_3 \tag{1}$$

$$\Delta t^{corr}_{pho,n,k} = \Delta t_{pho,n,k} - \left(F_{pho,n,k(A)} - p_{3\ pho,n,k}\right) \tag{2}$$

$$\Delta t^{corr}_{n,k} = \Delta t^{corr}_{pho,n,k} - \Delta t^{corr}_{pho,k,n} \tag{3}$$

Where $\Delta t_{pho,n,k}$ is the time differences between cell n and the Photek, selected such that all the events also had acceptable amplitude in cell k. Eq. 3 is what we then fit a Gaussian to. Timewalk correction plots for the cell 17 vs 19 comparison can be seen on Figure 7 and 8.

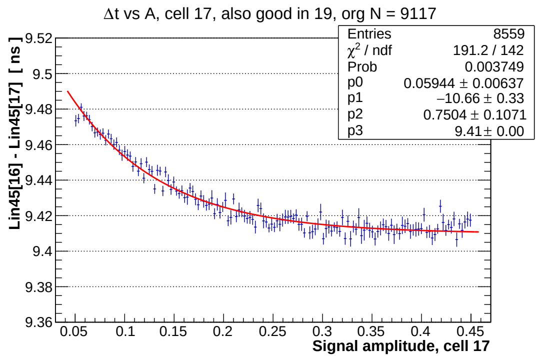

Figure 7: Timewalk for cell 17 data, also good in cell 19.

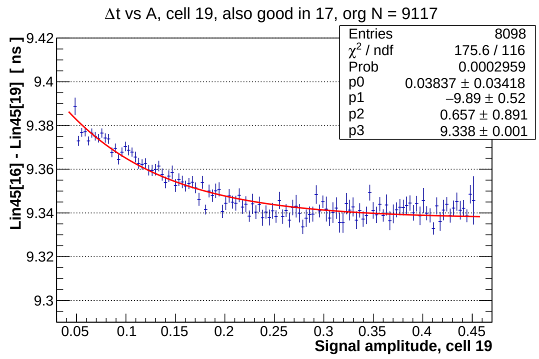

Figure 8: Timewalk for cell 19 data, also good in cell 17.

3.1 Evaluting the effectiveness of timewalk corrections

To evaluate the effectiveness of our timewalk corrections, we recreate the plots shown on Figure 7 and 8, but now with the corrected data from Eq. 2. an example of this can be seen on Figure 9 and 10, showing two out of the 42 plots generated in total. In general we observed that

- Before timewalk corrections, non-linearity was around 60-100 ps.
- After timewalk corrections, non-linearity is around 10-50 ps.

This means, that the timewalk correction decreased the spread of the Δt distributions with a factor 2 to 5.

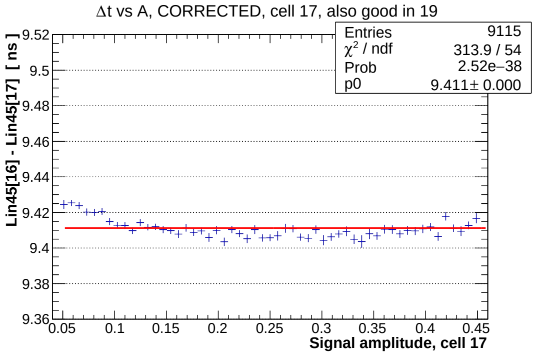

Figure 9: Effectiveness of TW for cell 17 data, also good in cell 19.

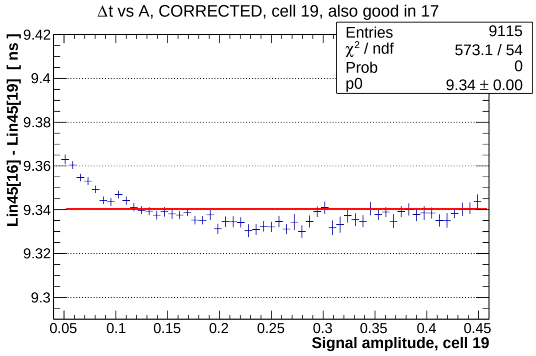

Figure 10: Effectiveness of TW for cell 19 data, also good in cell 17.

4 Gauss fitting

Now that we have corrected the 21 Δt distributions, 21 being the amount of possible unique combinations for the seven innermost cells, we can fit a Gaussian to each and extract the spread as the time resolution, two examples of this are shown on Figure 11 and 12.

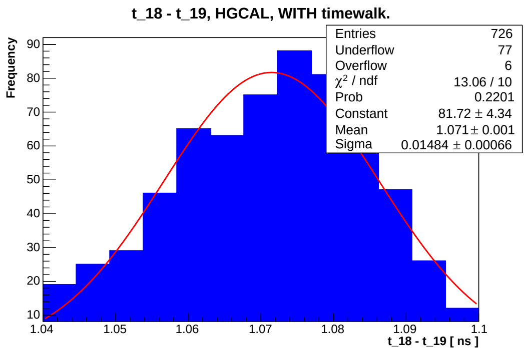

Figure 11: Gauss fit for Δt cell 17vs18.

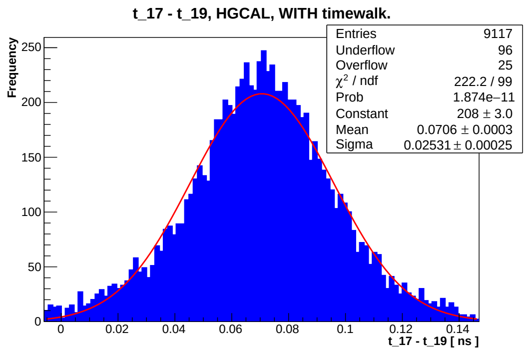

Figure 12: Gauss fit for Δt cell 17vs19.

5 Final results

We can now plot the time resolution of the different cell combinations, looking at Figure 13 and 14, we see that requiring a large number of events, results in excluding the cell-cell combinations with a larger spread in time. There is one exception to this, which is cell 18 vs 19, which has the best resolution of any combination, 14.8ps but is excluded when the requirement of 4k events or above is implemented. Looking at Figure 16 we see no correlation between the average Δt and the distance between the two cells being compared, which is good, because it is one less thing to worry about. On Figure 15 we see a slight dependence between the size of $\sigma_{n,k}$ and the distance between centers of cell n and k, which makes sense, since the propagation of the signal, from point of impact, is not instantaneous.

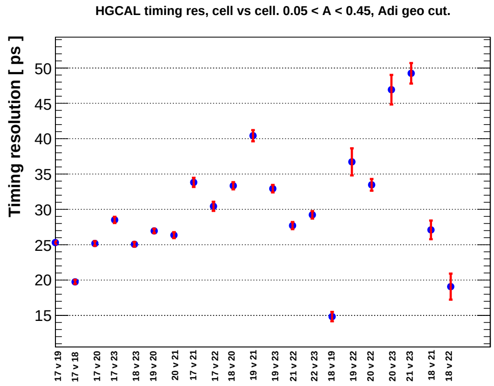

Figure 13: Time resolution for all 21 cell-cell combinations.

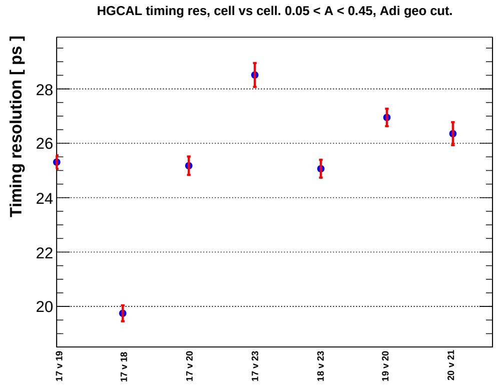

Figure 14: Time resolution with a hard cut on number of required events.

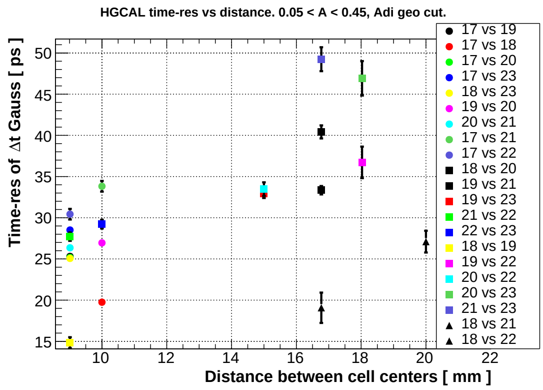

Figure 15: Time resolution vs distance between the two cells compared.

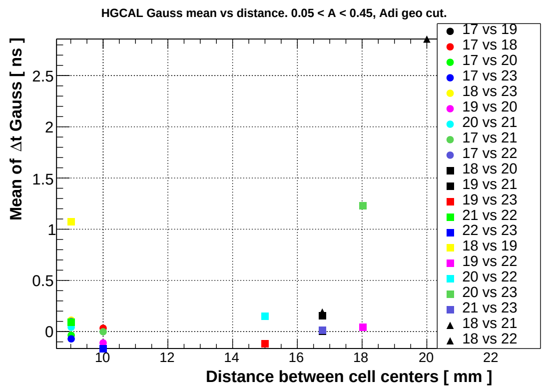

Figure 16: Mean time difference vs distance between the two cells compared. Should be ideally zero.

6 To-do list

Here we list the obvious next steps, if we were to continue the work of this project:

- Improve timewalk corrections:
  1. Customize profile plot to use most-probable value instead of mean, for the asymmetric δT distributions.
  2. Do timewalk wrt. TDCx and TDCy.
  3. change timewalk correction altogether from parametrisation to bin-by-bin corrections.
- Repeat analysis for different energies, all results shown in this report are from one 250 GeV electron run.

7 conclusion

Using data from a 250 GeV electron run during the November 16 HGCAL testbeam, we looked into the time resolution of the HGCAL, using one Si cell as a reference timer for another Si cell. We applied cuts to the data based on signal amplitude, position of primary particle and size of the time difference between two cells. After implementing timewalk corrections, wrt. amplitude, where the Photek was used as a reference, we managed to obtain a time resolution of $15 - 50\ ps$, depending on which two cells we compared, and our definition of to low statistics.

References

[1] A. Ahmad et al. - *The silicon microstrip sensors of the ATLAS semiconductor tracker*. page 102 and 112
Nuclear Instruments and Methods in Physics Research A 825 (July 2016) 62-68