Finding Bad Channels in ATLAS FCal from Delay Calibration Runs

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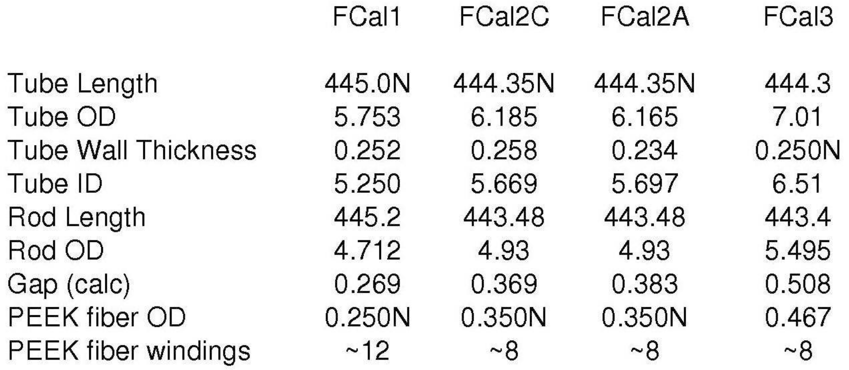
Table 1: Specifications of the Three FCal Modules [1]



	FCal1	FCal2C	FCal2A	FCal3
Tube Length	445.0N	444.35N	444.35N	444.3
Tube OD	5.753	6.185	6.165	7.01
Tube Wall Thickness	0.252	0.258	0.234	0.250N
Tube ID	5.250	5.669	5.697	6.51
Rod Length	445.2	443.48	443.48	443.4
Rod OD	4.712	4.93	4.93	5.495
Gap (calc)	0.269	0.369	0.383	0.508
PEEK fiber OD	0.250N	0.350N	0.350N	0.467
PEEK fiber windings	~12	~8	~8	~8

The ATLAS Experiment

The ATLAS (A Toroidal LHC AparatuS) is a detector based on CERN's Large Hadron Collider (LHC) straddling the border between the France and Switzerland. It is one of the four major experiments on the LHC ring and is one of two multipurpose detectors (the other being the Compact Muon Solenoid, CMS).

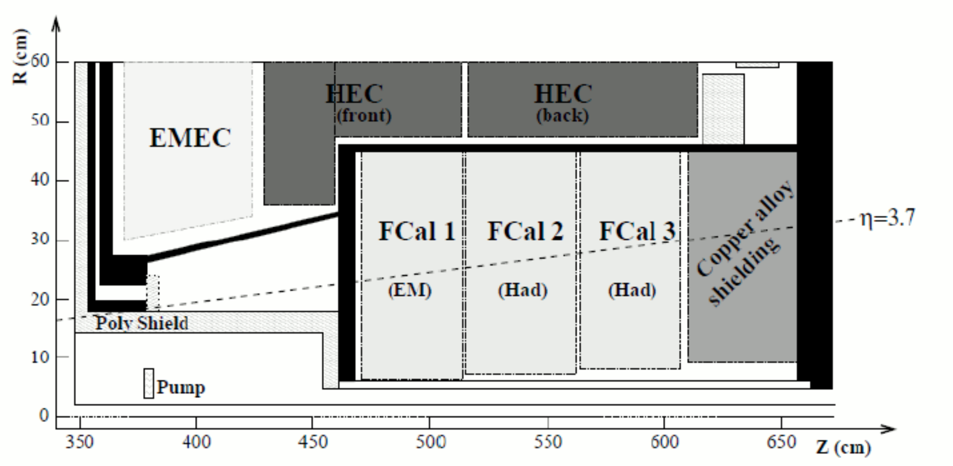
The Forward Calorimeters

The forward calorimeters are liquid argon (LAr) ionization sampling calorimeters located close to the beam pipe in the endcap region of the ATLAS detector ($3.1 < |\eta| < 4.9$). Effective calorimeter coverage is necessary in this region to ensure proper missing E_T signals, especially when considering minimum bias events.

The FCal is made up of three separately instrumented layers (FCal1, FCal2, FCal3). FCal1 is an electromagnetic calorimeter, while FCal2,3 are both hadronic calorimeters (see figure 1). There is a small (uninstrumented) copper plug placed behind the FCal to help stop any particles that punch through the FCal from damaging the muon systems behind. In all three modules the individual electrodes are made up of copper tubing and are inserted into liquid argon gaps ranging in thickness from 0.27-0.51 mm forming a hexagonal array. Because of the different purposes of these three modules, the construction of all three are slightly different (see table 1). The electrodes in FCal1 are inserted into a copper body, while both FCal2 and FCal3 has a body constructed out of mostly tungsten.

Each electrode is not read out as an individual channel. Rather, a collection of electrodes (called a tube group) is summed together (hardware sum), and a collection of tube groups are further summed together on a summing board to form a single channel. The number of electrodes the form a tube group, and the number of tube groups that form a channel varies from layer to layer (figure 2 gives a small cartoon of the electronics involved). However, near the extreme edges of the calorimeter, it is sometime necessary to form a channel with only a single tube group because of geometrical limitations.

Figure 1: FCal Layout [1]



Calibration Runs

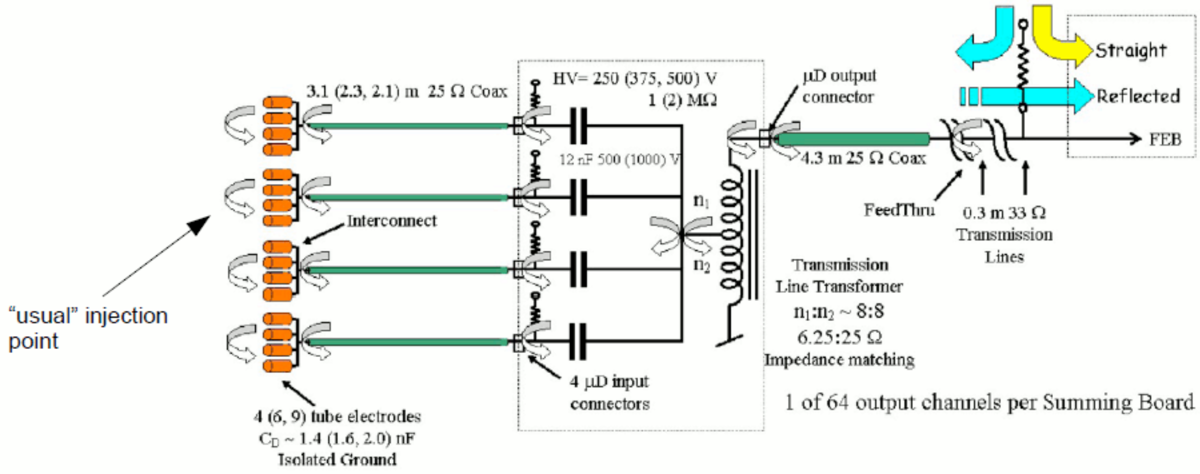
The calibration runs are taken in order to ensure that the channel's in ATLAS' calorimeter system are working correctly. And, in the case that some channels are misbehaving, they can be accounted for, and either a correction can be applied, they can be repaired, or discarded from analysis. Examples of problems in channels could be high noise, or distortions in the physics pulses, both of which can affect energy reconstruction. To determine whether or not a channel has a noise problem, one looks at the pedestal runs. While some major issues with the electronics readout chain can be found by looking for anomalous pedestal values, it is much more effective to find these by looking at distortions in the waveshapes coming from the delay runs.

Most of the calorimeters in ATLAS are designed so that the calibration lines inject a known pulse directly into the electrodes of the calorimeters (ie: from the same place where signals from 'real' physics events would come from). The FCal was built slightly differently in that the calibration lines actually inject the pulse near the front end boards (FEBs). As a result, about half of the pulse goes directly into the FEB, while the other half travels along the length of the electronics to the electrodes and back to the FEB. However, there are multiple different components, and interconnects along the path from the electrodes to the FEB. Because of impedance mismatching at these interconnects, there there is a partial reflection of the injected waveform at each of these points. Figure 2 gives a pictorial representation of this process.

Because of these reflections, the calibration waveform readout at the FEB looks much different than a normal physics pulse would (see figure 3). In fact, this can be used to our advantage, as the distortion in these pulses will not only give an indication of a problem with the channel, but the location of the distortion in the reflection may be able to point out which component is faulty.

By studying a sample high-gain delay run (with 768 samples in the waveform) taken on June 22, 2009, I was hoping to be able to develop an algorithm that picked out faulty channels efficiently, without too many 'false positives'. Additionally, it was hoped that by studying this run, it may be possible to diagnose faults in the electronics readout by looking for specific distortions. Figure 4 shows some of the common faults that can occur in a channel, and outline some possible variations that take place in the waveshape.

Figure 2: Schematic of Electronics Readout with Impedance Mismatches Labeled [2]



From J.Rutherfoord, A.Savine *Diagnostics using the Calibration Pulse* ATL-LARG-2004-010

Figure 3: Physics Wave Shape Vs Calibration Wave Shape [3]

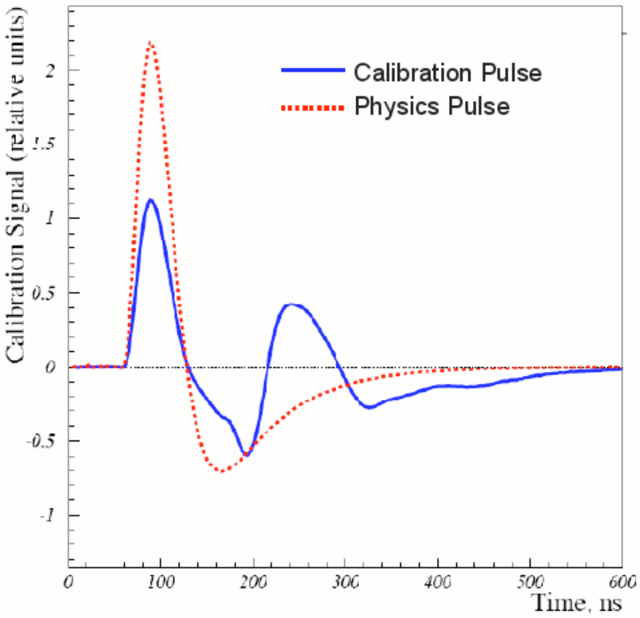
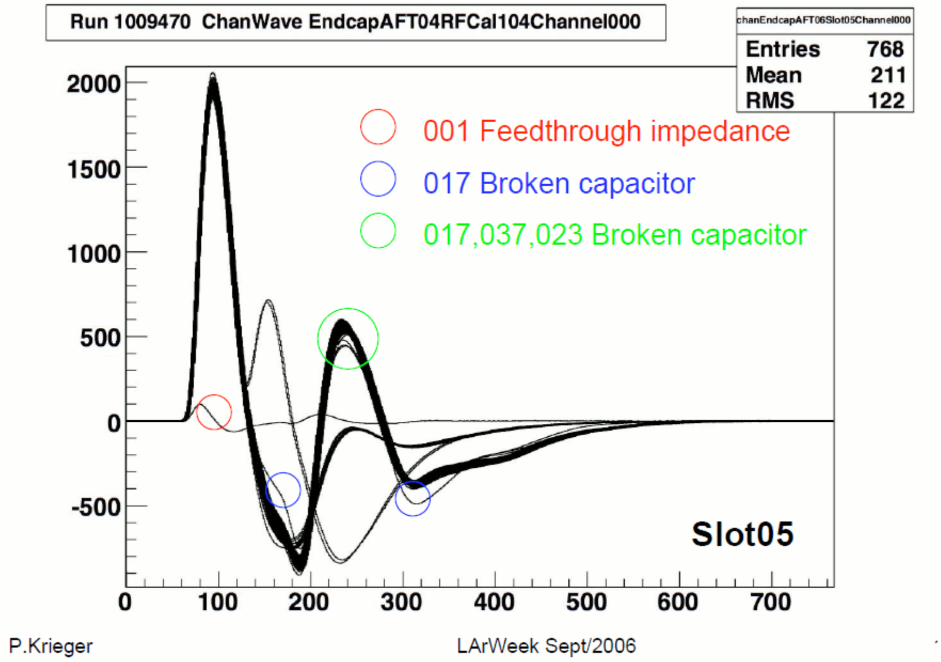


Figure 4: Sample Calibration Waveshapes with Faulty Channels Overlaid [3]



Code

Because of the many readout channels (> 3000) in the FCal it would be extremely inefficient to go through each pulse shape separately looking for outliers. Instead, a small piece of code (named Nero.C) runs through all channels picking out distortions in pulse shapes and labeling them as bad candidates. As the distorted waveshapes often look very similar to the good channels, some amount of subjectivity is involved, and it was not expected that 100% of the bad channels could be found with 100% purity (ie: no false positives). To evaluate the efficiency and purity of the code developed, the results were always compared back to the bad channel database for the FCal maintained by Manuella Vincter of Carleton University.

From looking at some of the distortion shown in the figures previous, it is easy to see that there are certain parts of the waveform that have more sensitivity to channel defects. The code was constructed to focus on these more sensitive parts of the waveform in order to sniff out the bad channel candidates. These sections of the waveform are the various peak/trough heights and widths, the overall integral of the waveform, and the tail section (see figure 5).

The method by which the code selects out these bad channels is fairly simple. For each channel, the peak heights and widths, integral, and average tail value are evaluated. These values are then compared back against average values for all of the other channels. If these two results differ more than a prescribed amount, the channel in question in labeled as a bad candidate. Making this allowed window too small decreases the purity, while making the window too large decreases efficiency. Making the allowed window $\pm 5\sigma$ from the mean of the distribution seems to offer the best trade off between efficiency and purity. Figure 6 gives a sample distribution for what is called the tail test. In this test the last 25 points of the waveform are averaged. The hope is that the average should be fairly close to zero if the channel is good. If the value differs greatly, there is likely an issue!

It should be noted that the three layers of the FCal are made with slightly different design

Figure 5: Sensitive Regions of the Calibration Waveform

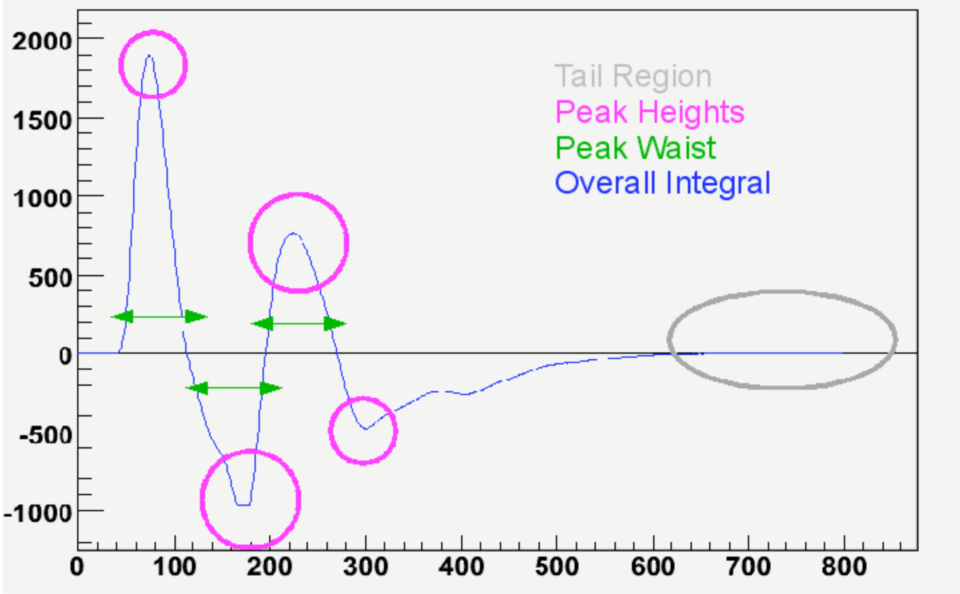


Figure 6: Sample Distribution for Tail Test (black bars are 5σ exclusion)

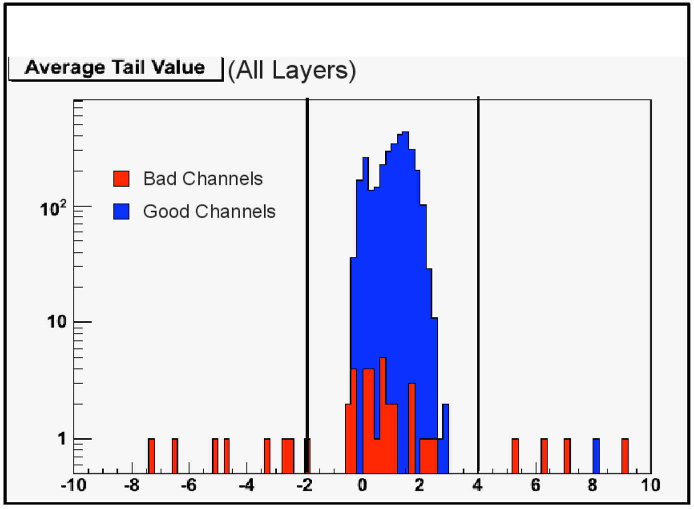
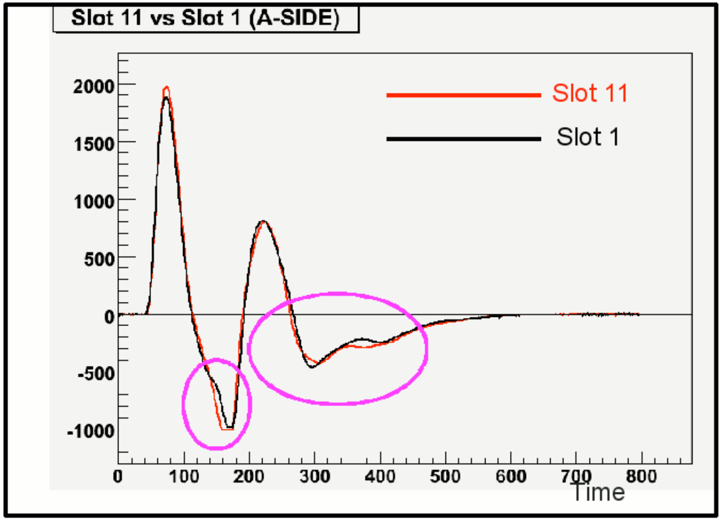


Figure 7: Variation of Waveshape between Two Different Slots



parameters. For example, the liquid argon gap is not constant throughout the three layers and the number of electrodes summed in each channel varies as well. Therefore, we expect that parts of each layer's characteristic waveshape may look slightly different as is illustrated by figure 7. Because of these variations, characteristics such as the waveshape integral can vary greatly between the three layers. Therefore, it is important that channels under scrutiny are only compared to channels *in the same layer*. That being said, there is one particular part of the waveform that should be independent of the layer number: the tail section. No matter what the design differences are, we expect that the tail section of the waveform should average to (approximately) zero. So while tests that compare the varies height/widths and integral values of the waveform are done on a per layer basis, the tail test compares against all channels.

While comparing on a per layer basis accounts for design variations between the different layers, there are still slight electrical variations in each of the slots that make up a layer. These slight differences do cause non-negligible variations in the waveform shapes even amongst good channels (figure 8). In order to get a higher efficiency (and purity), it is beneficial to not just compare channels on a per layer basis, not actually on a per slot basis. Just as discussed above, the tail section comparison can still be done with all channels, regardless of slot/layer.

Efficiency Statistics

At the writing of this document, the current statistics for the Nero.C software is as follows

- Efficiency: 59/65 (~92%)
- Purity: 59/72 (~82%)

Efficiency is defined as the number of correctly identified bad channels over the number of known bad channels. Purity is defined as the number of correctly identified bad channels divided by the total number of channels flagged as bad. These statistics also only correspond to finding distorted channels, not high noise channels (these are diagnosed from the pedestal runs).

Figure 8: Variation of 2nd Peak Width as a function of Slot Number

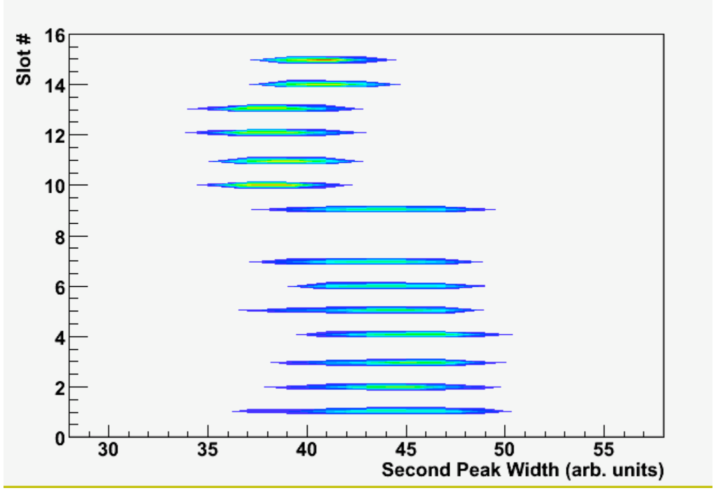


Table 2: Potential Bad Channels in FCal

A/C Side	Slot	Channel	Problem
C	11	32	Tail region average not zero (Fig. 9)
C	15	21	Final trough too deep (Fig. 10)
C	15	23	Final trough too deep (Fig. 10)
C	15	39	Final trough too deep (Fig. 10)
C	15	61	Final trough too deep (Fig. 10)

Potential (Additional) Bad Channels

Over the course of this study, I have identified a handful of potentially bad channels that are not currently on the bad channel data base. These channels should perhaps be monitored in the future as these faults may, or may not effect energy reconstruction for real physics pulses.

The first issue is with channel 32, slot 11, side C. This channel displays an anomalously high tail value ($> 5\sigma$ away from mean value) as can be seen in figure 9. As the rest of the waveform matches the shape of a good channel, it may be that this fault will not effect energy reconstruction.

The rest of the potential bad channels share a common distortion as seen in figure 10. There is no obvious reason as to why these four channels all share a very similar distortion (except that they are all in the same slot). They are not located on the same calibration line, are not geometric neighbors, and are not FEB neighbors. This points to the fact that it could be a legitimate common problem with the electronics chain in all four channels.

Acknowledgments

I would like to first and foremost thank the Institute of Particle Physics (IPP) for providing the funding that allowed me to study at CERN and attend the CERN summer school. I would also like to thank my two co-supervisors this summer: Dr. Manuella Vincter and Dr. Alain Bellerive (Carleton University). Last but not least, CERN for putting on such a fantastic opportunity and program.

Figure 9: First Defect (tail region)

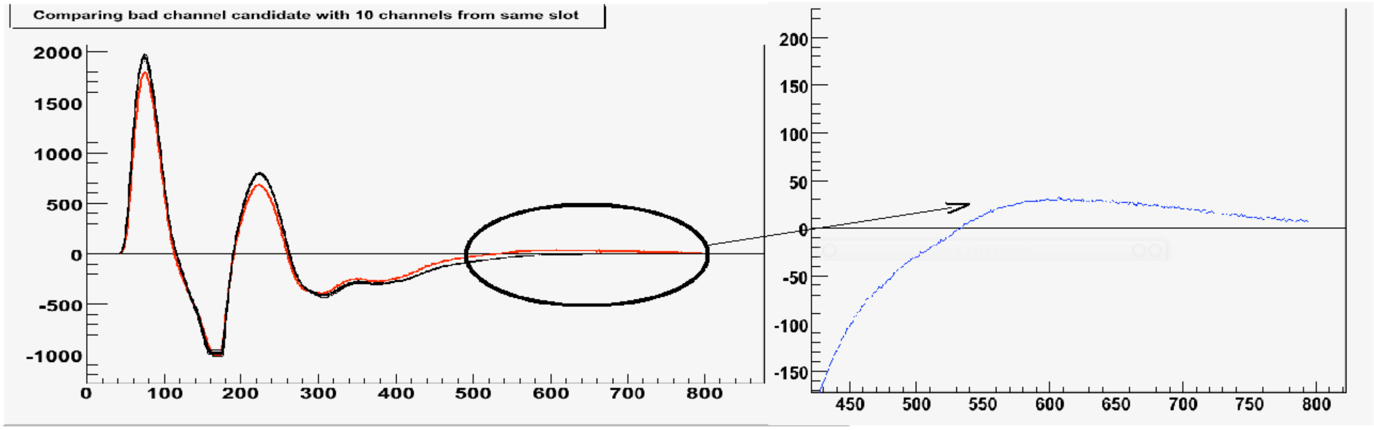
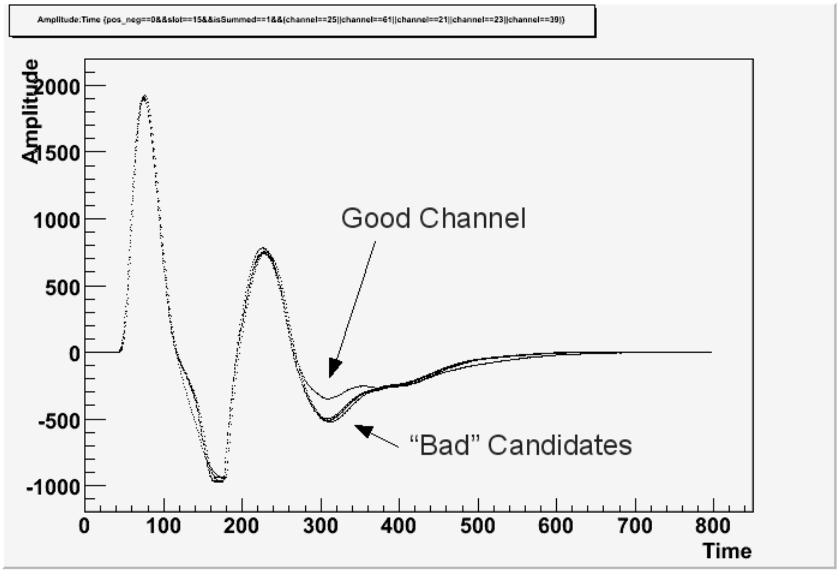


Figure 10: Second Defect (last trough)



References

1. “The ATLAS Forward Calorimeters”, 2008 Jinst 3 P02002.
2. “ATLAS FCal Diagnostics using the Calibration Pulse”, ATL-LARG-2004-010.
3. Krieger, Peter. FCal Commissioning, LAr Week, September 2006 (Slides).