Pulse Shape Extraction and Measurement of Pedestal and Noise

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Abstract

This report elaborates on the two projects I worked on, during the summer student program. Namely extraction of the shape of the test pulse provided to the prototype silicon detectors and implementation of a new algorithm for the measurement of the pedestal and the noise in the channels of the detectors.

1 Introduction

In 2022 the LHC will be upgraded to reach a peak luminosity of 10 times its original design. Correspondingly the detectors will need to be improved to fully utilize the potential created by this upgrade. For this purpose the first prototypes of the silicon detectors have been created and a framework has already been implemented which controls the data acquisition system. My work involved implementation of new features in the already existent framework.

2 Pulse Shape Extraction

2.1 Background

Due to exposure to radiation, the sensors, in the detector, are slowly damaged. This occurs in two ways, Surface damage which is due to charge accumulation and Bulk damage which is due to charge and trapping[1]. Over time this damage builds up and measures have to be taken to compensate for this damage. The correct depletion voltage can be applied to the detector if the damage can be accurately known. One way of estimating this damage is to provide a test pulse to the detector, extract it using the DAQ and notice how the characteristics of the extracted pulse change with exposure to radiation.
2.2 Method

To extract the test pulse, the value of the potential provided is calculated at each point in time. The \textit{time delay} of the test pulse is iterated over with step sizes of nano seconds and a \textit{voltage threshold scan} is done for each value. The resultant plot is fitted with a defined function which is then stored.

2.2.1 Iteration Over Time Delay

The value of time delay is set using two registers which change the \textit{coarse delay} and the \textit{fine delay}. The coarse delay refers to time at which the test pulse is injected, changing it by 1 unit varies the time by 25ns. The fine delay indicates the time at which the measurement is made, it can be varied in steps of 1ns and can have a maximum value of 25ns.

\[
TimeDelay = 25 \times (CoarseDelay + 1) - FineDelay
\]  

(1)

Using equation (1) the values for coarse delay and fine delay are calculated and written to the registers.

2.2.2 Voltage Threshold Scan

For each time step, a voltage scan is done in which the voltage is varied from 0V to the maximum. The number of events at each value of the voltage are filled into a histogram creating a step function. This histogram is then normalized and the last point, before the step function falls below 0.5, is extracted from the histogram. This value of voltage along with the value of time delay, over which the scan was performed, provides a single point of the pulse shape plot. This scan, when done for each value of time delay, gives the shape of the whole pulse.

2.3 Result and Analysis

Using the obtained points a curve similar to Figure 1 is obtained.

A fit is performed on this curve using equation 2. The derived parameters can serve as indicators of the damage to the detector.

\[
\theta(t) = \frac{t}{\tau} e^{-\frac{t}{\tau}}
\]  

(2)
Figure 1: Pulse obtained before fitting

Figure 2: Pulse obtained after fitting
3 Pedestal and Noise Measurement

3.1 Background

The measurement of the pedestal and noise, in a channel, are necessary to be able to discriminate the signal from the background. In the implemented framework, this is done by performing a threshold scan which takes the number of events at each voltage and creates a histograms which can be approximated by a step function. This step function is then fitted with an S-curve.

![Histogram obtained through threshold scan](image)

Figure 3: Histogram obtained through threshold scan

3.2 S-curve Fitting - Implemented Method

The acquired histogram is fitted with an S-curve. The shape of the S-curve depends on the probability distribution function of the noise in the channel. In the detector a gaussian distribution is assumed for the noise and therefore the histogram is fitted with the adjusted form of the gaussian error function given in equation (2). The fitting function is shifted by the mean, $\bar{x}$, and the spread is controlled by the standard deviation, $\sigma$, which results in equation (3).

\[
\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_{0}^{x} \exp^{-t^2} dt
\]  (3)
\[ Fit = \frac{\text{erf} \left( \frac{x - \bar{x}}{\sigma \sqrt{2}} \right)}{2} + 0.5 \]  

(4)

Figure 4: Fit of the histogram given in Figure 2

The mean and standard deviation of the obtained S-curve represent the pedestal and the noise respectively.

3.3 Numerical Derivative - New Algorithm

As the name suggests, the change in value is calculated at each point of the step function. As such a histogram is created of the differences and the mean and RMS are obtained. The pedestal corresponds to the mean and the noise corresponds to the RMS.
This method offers the advantage of making the calculation, of pedestal and noise, independent of the noise distribution. No approximations have to be made for the probability distribution function of the noise in the channel. It can have a gaussian distribution or a triangular distribution and the method would remain the same. Furthermore this method involves considerably less computation as compared to the fit method, which is recursive in nature.

3.4 Results

Pedestal and noise measurements were performed for every channel, using both methods, and the following results were generated. 10 events were taken for each channel.
Figure 6: Distribution of pedestals calculated through the fit method (red) and the numerical derivative method (blue).

Figure 7: Distribution of noise calculated through the fit method (red) and the numerical derivative method (blue).
4 Conclusion

This summer student program has been a wonderful experience for me. I feel that the projects I was given were perfectly suited for someone with my educational background, they allowed me to directly contribute to something substantial and to develop my skills at the same time. The lectures were well organized and introduced us to research happening at the fore-front of particle physics. Furthermore, this program allowed me to interact and make friends with people from extremely diverse backgrounds which significantly improved the overall experience.

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6 Bibliography

References