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TIME OVER THRESHOLD MEASUREMENTS ON THE LONG SHAPING TIME FRONT END SILICON SECOND PROTOTYPE DETECTOR CHIP

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ABSTRACT

TIME OVER THRESHOLD MEASUREMENTS ON THE LONG SHAPING TIME FRONT END SILICON SECOND PROTOTYPE DETECTOR CHIP

By London Chappellet-Volpini

The LSTFE 2 is a silicon readout detector chip designed for use in the ILC. It is using a unique time over threshold method to measure input charge amplitude. The use of a comparitor makes it important to take time over threshold data at 1.2fC and .6fC. The ratio of time over threshold to input charge for a 1.2fC threshold is approximately 1.5 microseconds per femtocoulomb for low input charge between 1.2fC-20fC and about .7fC for high input charge between 20fC-400fC. The correlation of time over threshold to input charge for .6fC threshold has been approximated to 3.4 microsecons per fC between .6fC-2fC, 2.6 microseconds per fC between 2fC-3fC, and 2 microseconds per fC between 3fC-5fC. This behavior of time over threshold versus input charge is in agreement with the expected behavior for the LSTFE 2 chip.

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1. INTRODUCTION

The goal of my project has been to explore the shaper output of the LSTFE 2 in order to see weather the amount of time its amplified signal is over a given threshold has the designed dependence on the input charge. This is a unique factor of the LSTFE 2, which converts pulse height into signal duration and thus allows a measurement of pulse height in real time by measuring the signal's duration. During a collision spill from a particle accelerator most readout chips charge a storage capacitor when the detector signal amplitude is greater than the threshold voltage. Then they convert the capacitor charge into a digital signal after a collision spill has ended. The number of charge deposits stored is limited by the amount of capacitors there are to store them. This is very different for the LSTFE 2, which converts pulse height into signal duration and thus allows a measurement of pulse height in real time by measuring the signal's duration. Therefore this real time conversion of input charge to a digital bits representing the length of the pulse will allow the LSTFE 2 to measure many more charge signals than the common readout chip in a collision spill.

The LSTFE 2 chip is designed to help measure the properties of the Higgs boson at the proposed International Linear Collider. The Higgs boson is associated with the Higgs field, which accounts for the creation of fundamental particle mass in the Standard Model. The Higgs is also the only component of the Standard Model that has not been discovered. For this reason scientists are greatly invested in discovering the Higgs and studying the properties.

In order to discover that the Higgs particle exists, scientist worldwide have gotten together in Geneva, Switzerland to build the Large Hadron Collider. The LHC project began in 1995. It was completed by September 2008 and has been running since November 2, 2009. The LHC is producing proton collisions that should produce a Higgs, so it is thought that the Higgs will be found soon.

The LHC has reached 7 TeV in the center of mass frame, but collisions of quarks, the particles that make up protons, are at much lower energies for all but a few rare collisions. Also the center of mass frame of the colliding quarks cannot be calculated due to the uncertainty in how much energy is carried by each of the quarks within an accelerated proton. Therefore it is impossible to discern which quarks colliding will produce the Higgs. For this reason scientists will have to assume that the Higgs produces either a bottom quark anti-bottom quark, or a pair of photons. When either of these pairs is detected with right invariant mass the LHC will have found the Higgs.

If the Higgs particle is found by the LHC it will be desirable to study its properties with higher precision. Thus scientists have proposed to create the International Linear Collider. The ILC will accelerate electrons and positrons instead of protons like the LHC. This simplifies the measurement of the Higgs because when a positron collides with an electron the collisions full energy goes into the final state. Occasionally a few of these states contain a Higgs, such as a electron positron collision creating a Z boson and a Higgs. It is best to detect the Higgs by measuring the Z boson, instead of measuring the decay properties of the Higgs by making assumptions as to what particles it decays into. The Z Boson is known to decay into two leptons. The mass and energy of the Z boson can be reconstructed by measuring the momentum of these leptons. From this Z boson the mass of the state recoiling against the Z is estimated. Then by creating Histograms of the recoil masses, all the detected Z bosons associated with the Higgs can be identified. Figure 1 shows a histogram of the massive object recoiling from the Z boson, for different quality of the measurement of the lepton's momenta, the recoil mass reconstruction improves or degrades. When a Higgs is produced it can be identified simply by noting that the event's recoil mass is that which is expected for a Higgs.

To get accurate data on lepton energies, the momentum must be found precisely. By looking at Figure1 below it can be that the normal momentum accuracy relates to pt*1 the light blue line. If the accuracy of momentum measurement is worse than that of the light blue line then the Higgs recoil mass will be very difficult to accurately calculate, as shown for example by the dark blue line. Hence it is very important that the LSTFE 2 time over threshold is accurate enough to give a momentum of pt*1 or greater such as pt*.5 the yellow line. Obtaining the nominal mass resolution requires detectors that can measure position to an accuracy of 7 micrometers. Thus when the peak narrows the accuracy of the lepton momentum is increased and the Higgs will be detected.

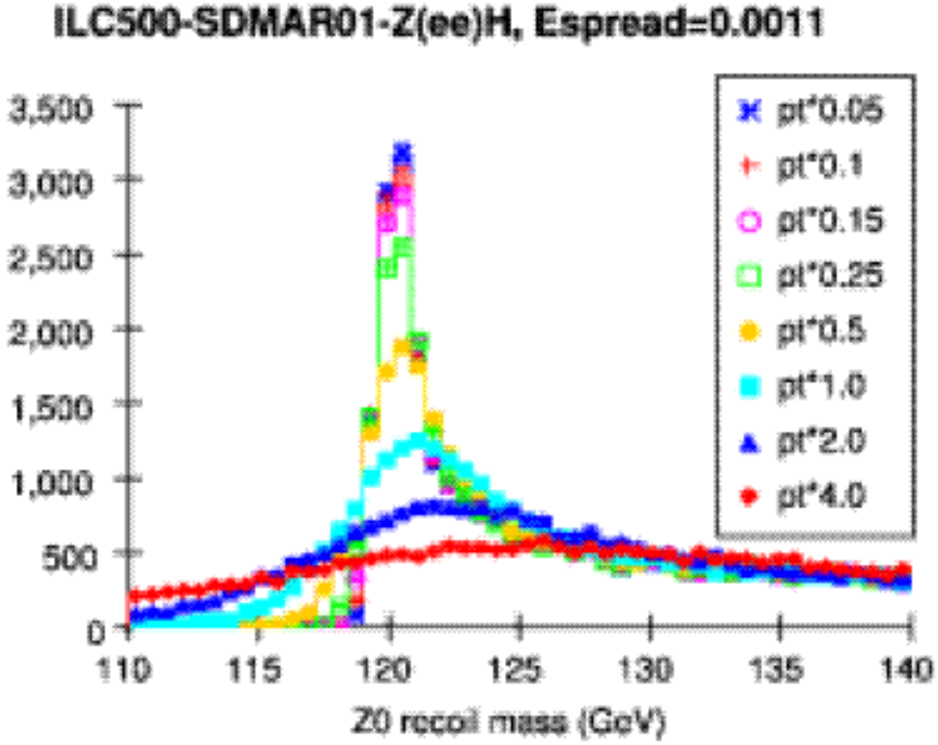

Figure 1: A Historgram of recoil mass in GeV. The light blue line represents an accuracy of 7micrometers. The more prominent the peak the better the accuracy in micrometers. By Haijun Yang, Michigan. [2]

2 **Momentum Measurement and Silicon Strip Detectors**

Several groups have proposed using silicon strip detectors to measure the trajectories of charged particles that arise from the collisions that could make the Higgs boson. Silicon strip detectors work at high speeds and are very accurate which makes them perfect for detecting new particles like the Higgs. The silicon strips as seen below in Figure 2.1 are composed of n-type silicon with uniformly spaced p-type silicon strips on the surface. Covering this structure is an insulation layer, which has a aluminum readout strip that sends detection signals to the readout chip. The signals arise on the strip through the capacitive coupling between the p-type and the aluminum strip. The n-type bulk has a metal layer underneath it that creates a positive bias voltage.

The silicon strip is then ready to detect particles by utilizing its p and n-type components. When the p-type is grounded it creates a drop in voltage across the n-type bulk that depletes the n bulk of electric free charges. When an ionizing particle excites electron-hole pairs the electrons are attracted to the positive plate. The holes/positive charges move toward the p type implant inducing a signal on p type implant and capacitively; coupled aluminum strip. The return path through ground for this signal is routed through the amplifier and amplified.

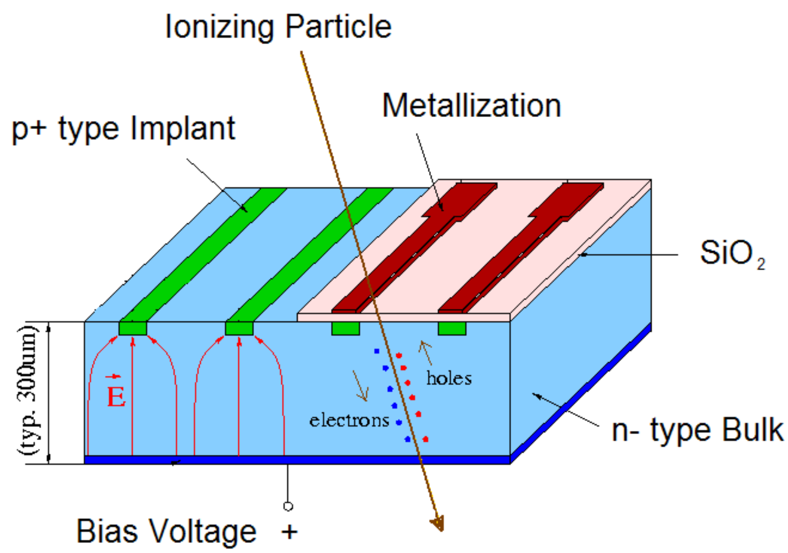

Figure 2: Illustration of an AC-based silicon detector.[3]

Figure 3 below is a tracking system for a detector that will be used in the ILC. The 5T magnetic field is directed along the Z-axis. Depending on the momentum of the particle flying through the magnetic field they will have different helical radii. The radius is directly related to the momentum and the magnetic field through the equation below.

$$r[m] = \frac{p * c}{300B}\left[\frac{MeV}{Tesla}\right]$$

Here r is radius, the p is momentum, the c is light speed, and B is the magnetic field strength. The radius of curvature is determined by measuring the trajectory of the particle through the five tracking layers seen in Figure 3 below.   As noted in the introduction, to measure momentum accurately enough the particle's path though the detector on each tracking layer must be measured to within 7 micrometers when the silicon strips are placed 50um apart. The unique LSTFE 2 time over threshold method uses signal width to measure measures the charge of neighboring strips. Then a 7 micrometer accuracy can be achieved by taking a weighted average of charge signal on each neighboring strip. It is crucial to the accuracy of the momentum measurement that we determine the relationship between deposited charge and time over threshold so we can be confident of obtaining 7 micrometer accuracy.

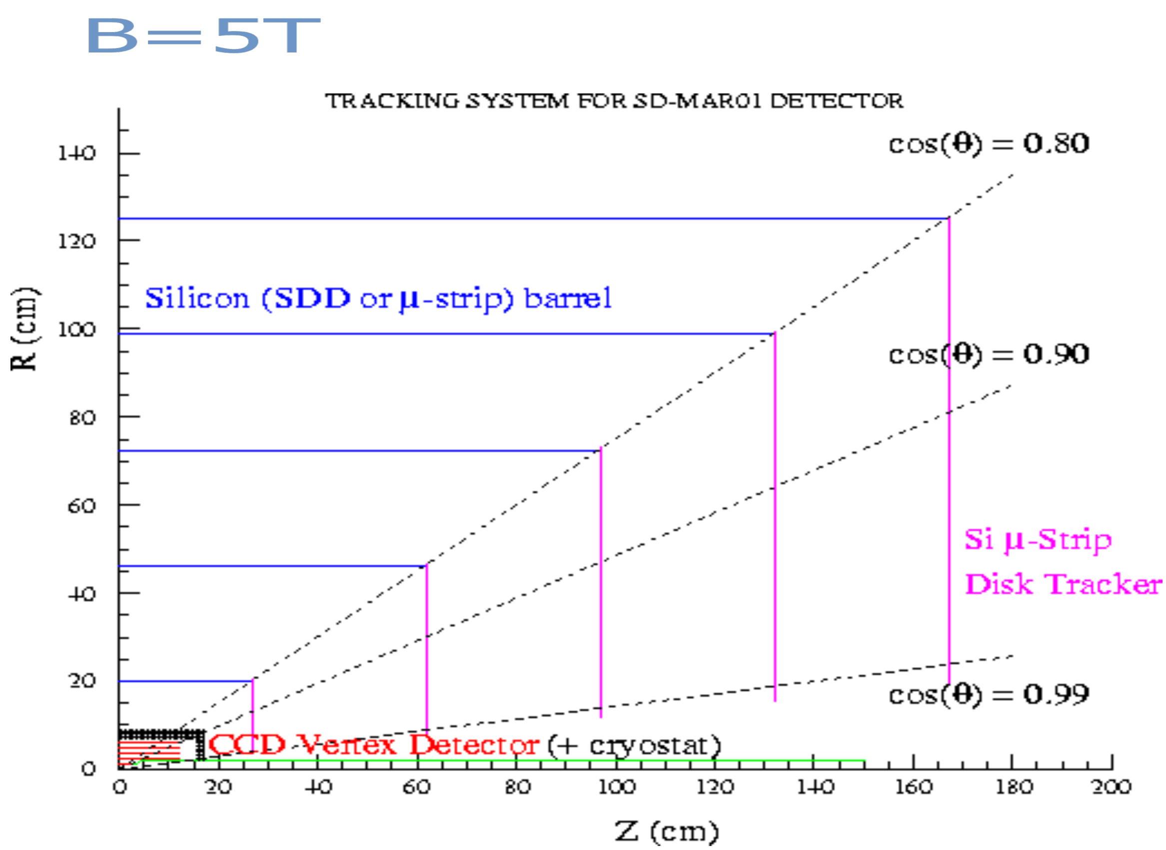

Figure 3: A tracking system for the ILC that is concentrating on Barrel for which silicon strip detectors are proposed. The detectors will be mounted on the five barrel layers with their strips oriented to the Z axis. [2]

LSTFE 2

The LSTFE 2 is the second prototype version of the LSTFE chip. It has 128 channels which will be connected to the silicon detector strips. When a charge signal comes into the LSTFE 2 it gets amplified by the Pre-Amplifier. The Pre-Amplifier amplifies the charge producing a signal of 5mv per fempto-coulomb of charge. The signal then passes to the shaper stage where it again gets further amplified to a gain of 100mv per femto-coulomb. The shaper also acts as a band-width filter to stop noise contributions with frequencies above approximately 1Mhz. From the shaper stage the signal get sent to the comparitor. If the signal is above a preset comparitor threshold the comparitor goes high. The time during which the comparitor is above threshold is called the time over threshold. The chip is designed so that the time over threshold is directly related to the amplitude of the charge input to the LSTFE 2. Measuring the relationship of the charge input to the LSTFE 2 versus the time over threshold is the motivation of this thesis. Simulation studies done several years ago suggest that a comparitor threshold of 1.2fC is appropriate for separating the signal from the noise, while a threshold of .6fC is better for precise measurements of the input charge amplitude. Thus in what follows we study both of these thresholds.

3. **MATERIALS AND PROCEDURE**

3.1 LSTFE 2 chip setup

The LSTFE setup can be seen in Figure 4. The chip is mounted on a printed circuit board. The printed circuit board attaches to a parameter analyzer, power supplies, and a pulser. The parameter analyzer sets currents for the pre amp and the shaper. The power supplies sets the low and high threshold for the comparitor. The pulser is used to send a calibration signal to replicate an input from a silicon detector strip.

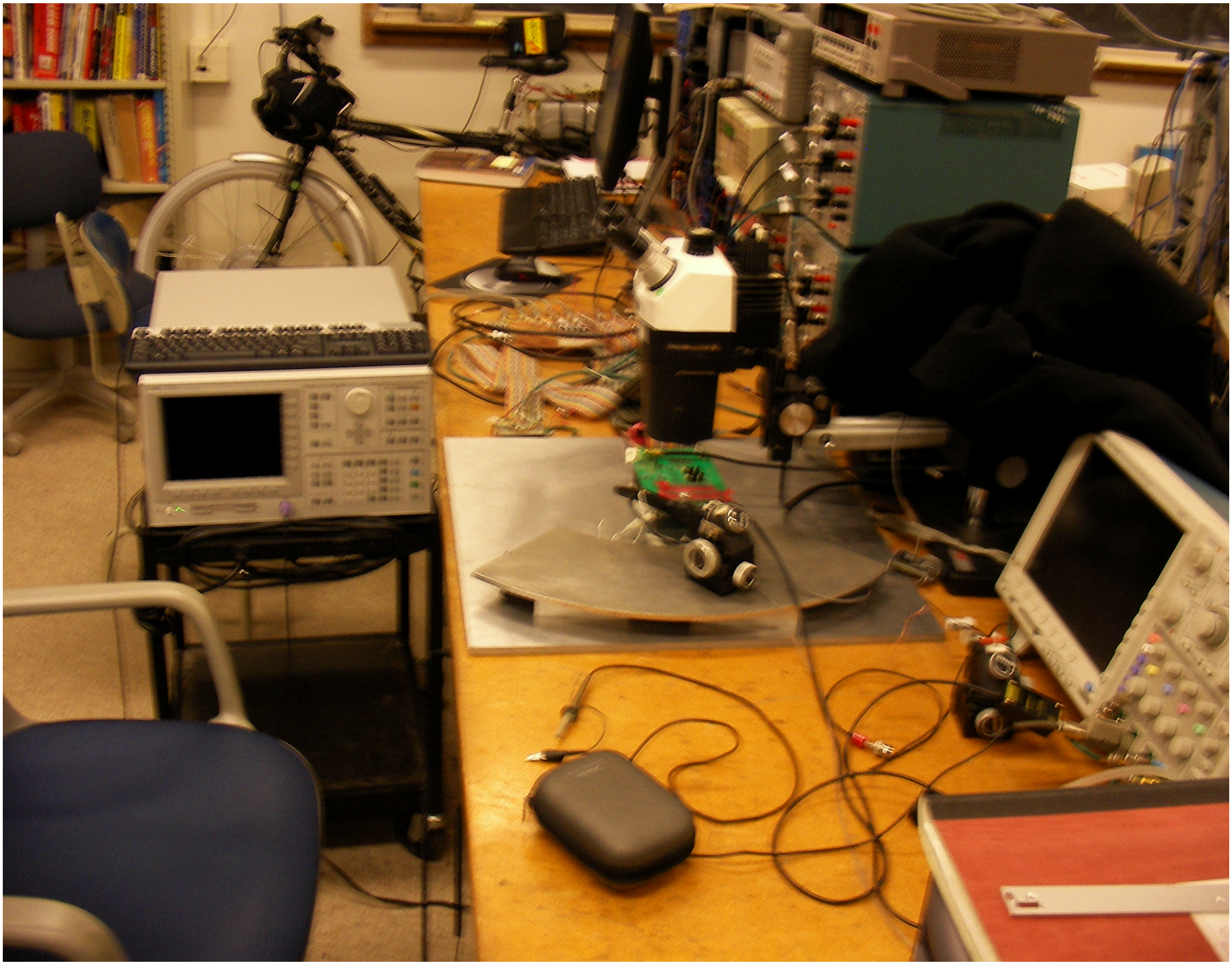

Figure 4: The LSTFE 2 station with pulser underneath table, parameter analyser on the left, pico-probe next to the LSTFE 2 board, microscope over the LSTFE 2 chip, power suplies in the back behind the microscope, and oscilloscope on the right.

3.2 Taking data from LSTFE 2

Everything begins with the voltage step sent by the calibration system so that a charge is input on the chip. We then place the tip of a pico-probe on a chip pad connected directly to the output of the shaper stage and display this output on an oscilloscope. Instead of looking at the comparitor we directly measure on the oscilloscope when the charge is above threshold. Due to the noise fluctuations of the amplified signal it is important to use oscilloscope averaging to get an average pulse and measurement of time over threshold.

To measure time over threshold as a function of input charge, it is important to know the magnitude of the calibration charge input on the chip. We deliver charge by inducing a voltage step with the pulser across a known value capacitance that is mounted near the input to the LSTFE 2 chip:

$$Q=CV,$$

where Q is charge, C is capacitance and V is voltage. To have a 1fc input charge there must be a 1mv step used across the 1 pico-farad input capacitor. For our research we want to start at inputs as low as .6fC and go all the way to 400fC. Such a small beginning input charge is not possible with our pulser so it is necessary to attenuate the signal.

The calibration of the attenuation is also very important to our understanding of the time over threshold response. The attenuation can be measured by taking the voltage at the input capacitor before it is converted into charge and comparing it to the initial pulser voltage step for a series of pulser steps. These points can be plotted as seen in the Figure 5 below. The slope of the line provides the conversion from the pulser voltage step to the input charge value. This makes it possible to compare the time over threshold width with the actual input charge on the chip and see its accuracy. We find an attenuation factor of .0042fC per mv of height of the pulser step function.

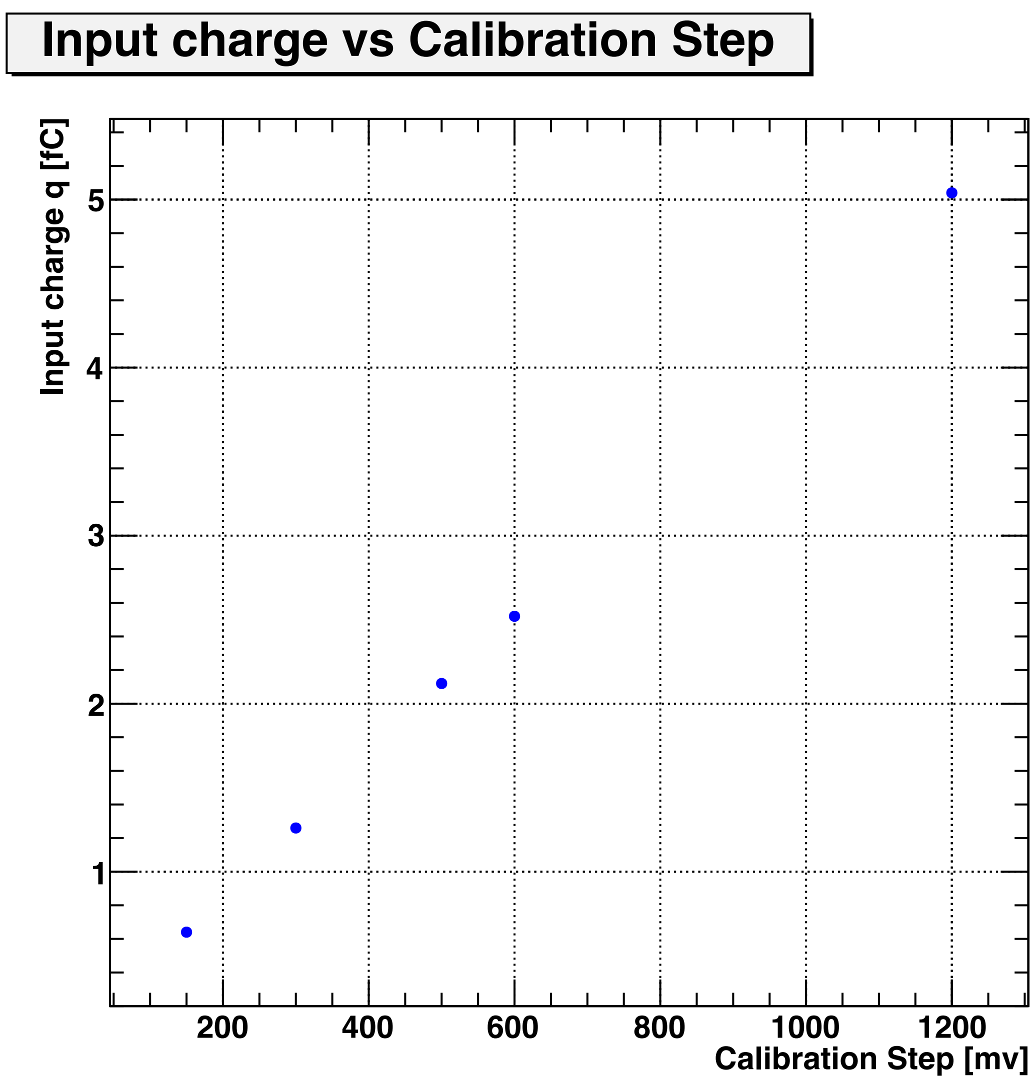

Figure 5: The plot above is of input charge values with different calibration steps.

Once the ratio of calibration voltage step to input charge is found we can take measurements of the time over threshold. For time over threshold measurements the width of the pulse is measured when it is above the 1.2fc threshold amplitude. This is set high at 1.2 fc to suppress noise fluctuations. Time over threshold measurements are also taken at a threshold of .6fc. At .6fc there is more noise but it is very important because the measurement of input charge is more accurate. The LSTFE 2 has both these thresholds for high and low comparators so that the time over threshold can be compared for both cases. We take measurements of the time over threshold for a range of increasing input charge from .6fc-400fc. Then our data are plotted in ROOT[4] to see how accurately the time over threshold measures the different input charge values.

4. **Results and Analysis**

Figure 6 shows time over threshold for 1.2 femptocoulomb. When looked at closely the data in Figure 6 shows us that the first few femtocoulomb of charge have a larger slope. Thus there is more accurate measurement of charge because with any small variation in width the charge measurement will change. This is very important because the majority of charge detected will be in the small range from 1-4fc. Then as we approach the higher charge region, the data become less steeply sloped and thus less accurate in measuring the charge for small variations in signal width. The less accurate measurements in the large femptocoulomb range is acceptable because of the infrequent detection of charge at that range. These data are very useful because it tells us how the chip will take data when given input charge from detectors. It is crucial that in the beginning femtocoulomb range it is sloped more steeply for small charges than for larger charges.

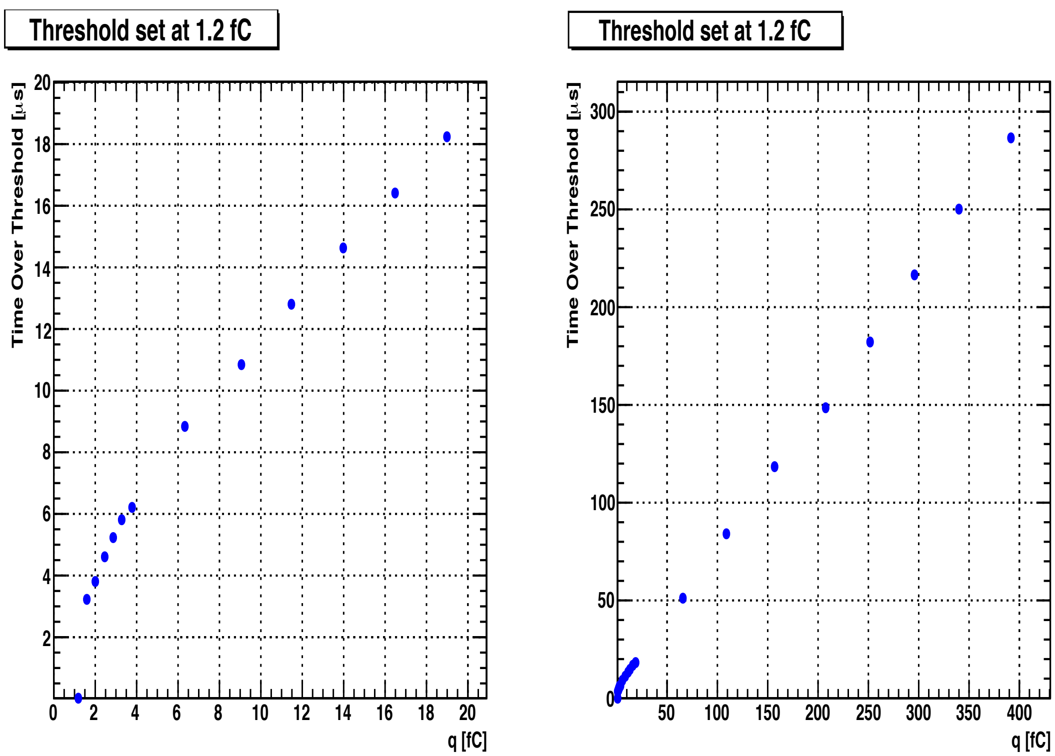

Figure 3: the graph on the left is a blown up version from 1.2-20fC of the graph on the right.

The slope in the lower fC range from 1.2-4fc is approximately 1.5 microsecond per fC. In the larger region from 4fc-400fc the slope is approximately .7 microsecond per fC. The difference in these slopes is expected from the design of the LSTFE 2.

Figure 7 shows time over threshold for .6fC. When analyzed it can be seen that at lower femptocoulomb values the slope is larger. Thus the accuracy is even greator at the lower fC range between approximatley .6fC and 2.0fC.

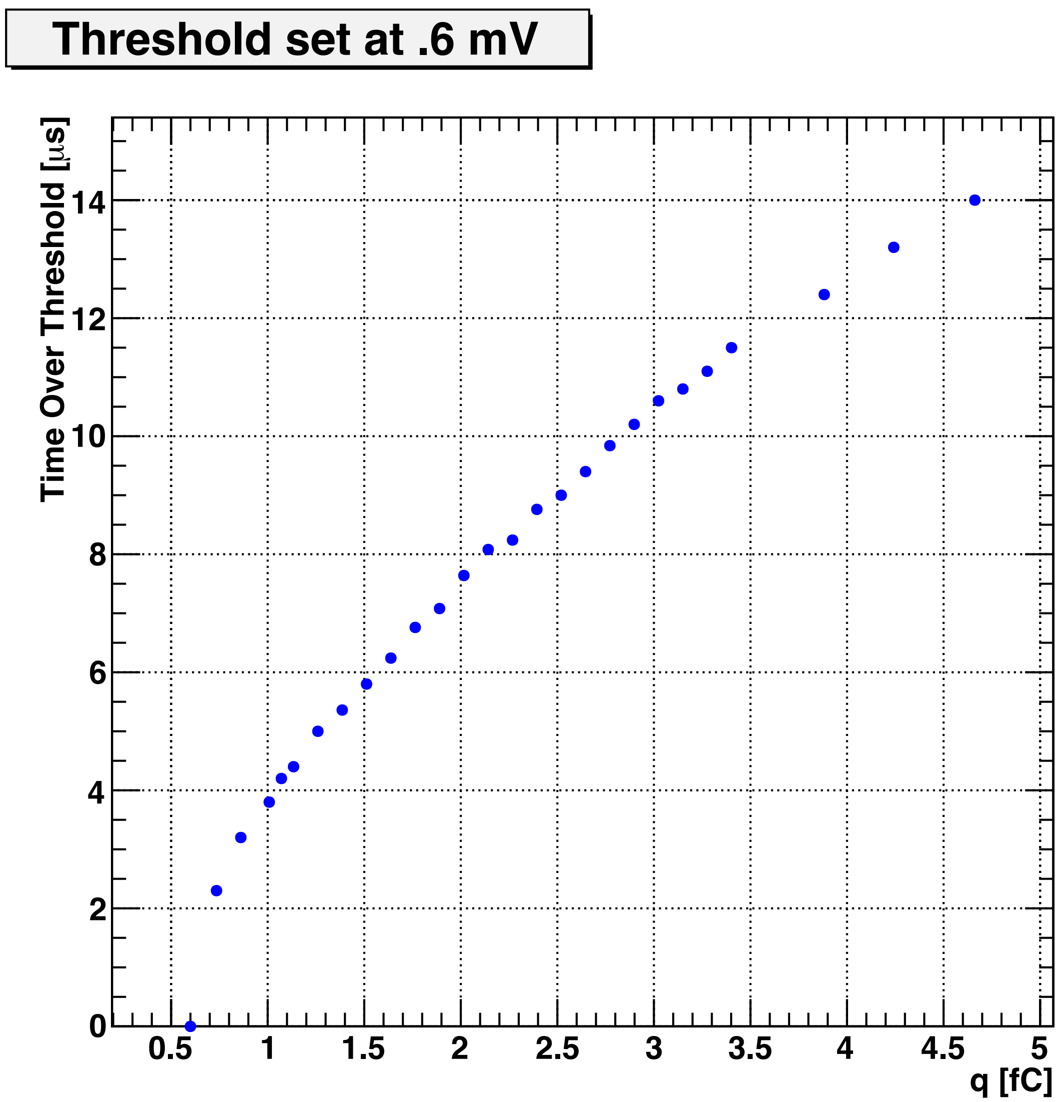

Figure 7: The graph above is the .6fC threshold analysis of time over threshold to input charge.

In the graph above the slope in the first range of .6fC-2.0fC is approximately 3.4 microseconds per femtocoulomb. The middle range of 2.0fC-3fC is sloped approximately 2.6 microsecond per fC. Then at the higher charge range of 3fC-5fC the slope is approximately 2 microsecond per fC. Therefore as seen from the slopes the LSTFE 2 is working as designed and correctly being more accurate for lower fC input charges.

5.**Conclusion**

The data we took was a good indicator that the LSTFE chip is in working condition and ready to test real detector inputs. The LSTFE is the most suited silicon chip for detecting the momentum of the Higgs boson due to its long shaping time and effective time over threshold feature. In future experiments I plan to create an analysis that gives us an understanding of time over threshold noise resolution.

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