UNIVERSITY of CALIFORNIA

SANTA CRUZ

EFFECT OF CHANNEL-TO-CHANNEL VARIATIONS ON PULSE EFFICIENCY AND NOISE OCCUPANCY FOR THE USE OF KPIX ASIC FOR READOUT OF SILICON μ-STRIP SENSORS

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Sheena C. Schier

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The thesis of Sheena C Schier is approved by

Professor Bruce Schumm
Technical Advisor

Professor Adriane Steinacker
Thesis Advisor

Professor David P Belanger
Chair, Department of Physics

ABSTRACT

Effect of Channel-to-Channel Variations on Pulse Efficiency and Noise Occupancy for the Use of KPix ASIC for Readout of Silicon μ-Strip Sensors

by

Sheena C. Schier

KPix7 is a 64 channel electronic readout chip designed by SLAC and is competing for use in the ILC tracker. It is currently the only detector readout chip that aims to fulfill both tracking and calorimetry needs for an ILC detector. The front end amplification has an average gain over all channels of -40.83mV/fC with an RMS spread of 1.565mV/fC, and an average offset from zero of -103.6mV with an RMS spread of 8.237mV. The range of comparator thresholds that were found to comply with the 99.9% efficiency and 0.1% occupancy requirements lies between 0.705fC and 0.950fC before considering 2% loss to ground and 10% loss due to charge sharing between nearest neighbor detector strips. This range decreased slightly after charge loss was examined, and is too narrow to provide confidence in KPix as a tracking chip at this stage of development. Three new versions of the chip have been fabricated since completing this study, and SCIPP is making efforts to repeat efficiency/occupancy studies for KPix9, while awaiting the arrival of the newest version, KPixA, once it is ready for testing.

Contents

1 Introduction

In 1930, at the Cavendish Laboratory in Cambridge, England, the world's first official particle accelerator went online to allow two physicists a high-powered expedition into the nucleus. John D. Cockcroft and E.T.S. Walton designed their machine to use a 500kV potential to accelerate a proton through an eight foot long vacuum tube to collide with lithium nuclei (Steere, pg 2). Since then, particle accelerators have become more and more powerful, providing an increasingly deeper perception of the sub-atomic realm. The most recent accelerator built, The Large Hadron Collider (LHC), achieved energies 10^7 times larger than did Cockcroft and Walton at the Cavendish Laboratory, and it has a long list of hopeful discoveries that will result from its extreme energy collisions.

On this list are supersymmetric heavy super-partners, evidence of dark matter, extra spacial dimensions, and, at the forefront of attention, the particle responsible for all particle masses, the Higgs Boson. Physicists hope not only to detect the Higgs, but to measure its mass to an accuracy of 1% or better, and to observe at least one of its decay modes. There are three possible outcomes for LHC experiments involving the Higgs Boson: the Higgs is observed, and its measured properties, like mass and decay mode, are consistent with the Standard Model; the Higgs is observed with properties inconsistent with the Standard Model; the Higgs Boson is not observed. Whichever of these possibilities comes true, and whatever else is observed, further experimentation will be necessary to complete our understanding of the Higgs mechanism, super-symmetry, dark matter, and other unexpected properties of the universe.

The International Linear Collider (ILC) is one such place where these extended experiments could happen. Although still in its design phase, international collaborators propose that this e^+e^- collider, with energies of 500GeV, and 1TeV after upgrade, will be able to contribute unambiguous answers about whether the heavy particles found in LHC experiments are actually super-partners with spin and coupling ratios that support super-symmetry theory. Collaborators also expect the ILC to expand on LHC observations with ultra-precise measurements of the plethora of super-partners and Higgs particles, which would in turn answer questions about symmetry breaking, the Big Bang, and the role of super-symmetry in the unification of the fundamental forces.

The precision of measurements needed to achieve these goals puts strict constraints on the performance of the detector system and readout electronics placed in the ILC. For tracking purposes, exceptionally precise hit position measurements are needed to obtain specific particle momenta.
The minimum detectable signal must be small enough to support this precision. Noise and channel-to-channel variations in the electronic readout play a vital role in the accuracy of the tracker, which can be quantified through pulse efficiency and noise occupancy analysis of the chip. In my research, I studied the effects of channel-to-channel variations on the pulse efficiency and noise occupancy on KPix as a tracking chip.

2 Background & Motivation

2.1 Beam Spill & Silicon Detector System

The projected ILC beam is made of 1ms long bunch trains that repeat continually at 5Hz. In every bunch train there are 3000 bunch crossings spaced 300ns apart [4]. Bunch crossings create numerous particle collisions that could give birth to exotic particles and their eventual decay products. Surrounding every bunch-crossing in the ILC will be a Silicon Detector System (SiD system), an intricate 3-dimensional web of silicon made from concentric cylinders that are spaced approximately 25cm apart, and lined with a total of ten thousand 10cm^2 sensors. A quadrant view of the cylindrical tracking system, which is rotationally symmetric along the Z- coordinate axis, is shown in Figure 1. Particles from ILC collisions emerge from the origin at some angle with respect to the Z-axis, and a 5T magnetic field directed along the Z-axis causes the particles to travel in a helical path through the layers of silicon barrels that make up the tracking system.

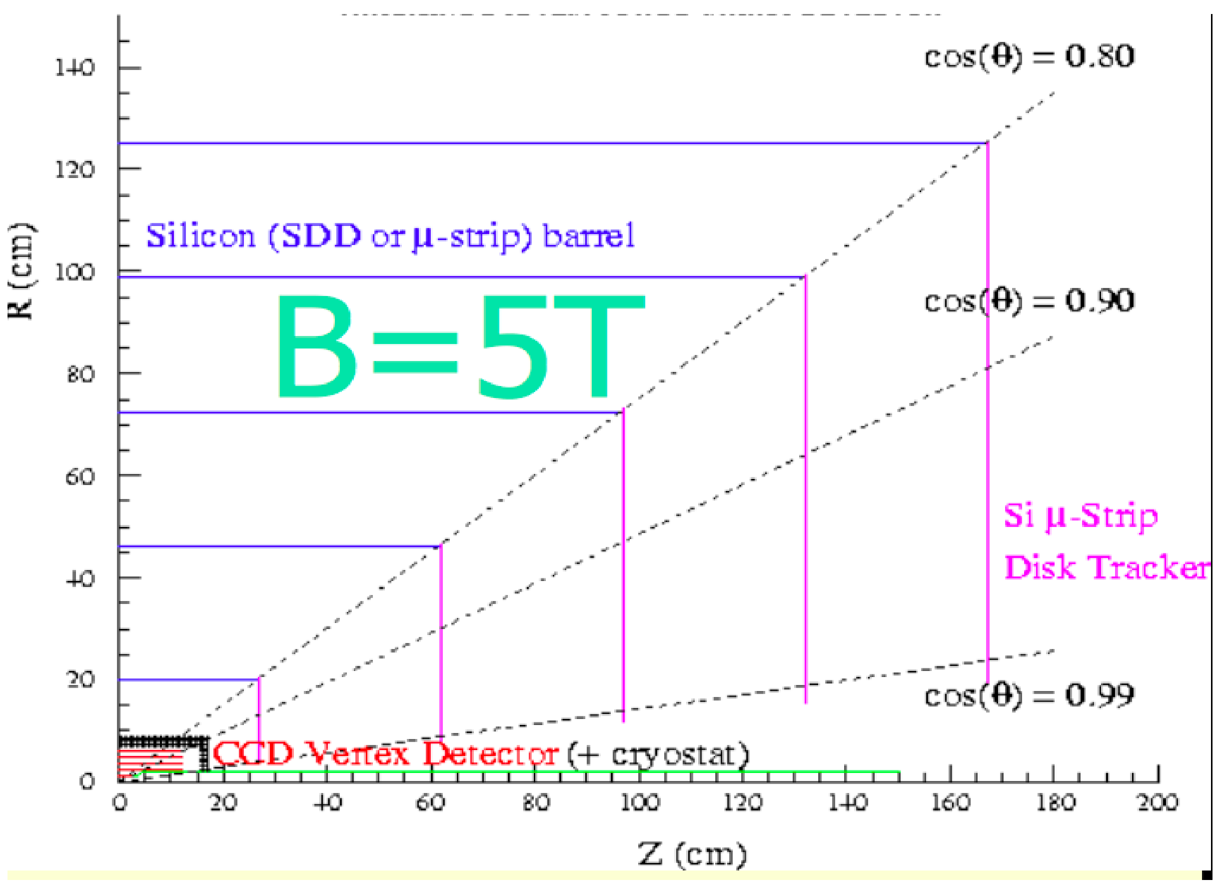

Figure 1: Quadrant view of tracking system that

As seen in Figure 2, each detector is made from an n-type bulk of silicon with evenly spaced p-type strips embedded in the surface at a 50μm pitch [5]. On top of each p-type strip, with an insulating silicon oxide passivation layer in between, is a aluminum electrode that is read out by a nearby electronic readout chip. A particle will pass through the detector at some angle to the detector surface, and as it interacts with the silicon it frees electrons from the crystal lattice creating electron-hole pairs. The detector is back biased with a negative voltage at the p-side, generating an electric field that sweeps the positively charged holes to the strips. The radius of curvature of the particle's path is proportional to the particle's momentum, given by

$$r = \frac{p \cdot c}{300\mathrm{B}} \frac{MeV}{T}$$

where r is the radius of curvature in meters, p is the particle's momentum, c is the speed of light, and B is the magnitude of the magnetic field. Each sensor needs to measure the particle's position to within 5μm in order to accurately measure the radius of curvature. This accuracy in hit position measurements can be met by taking a weighted average of charge deposited across multiple strips.

Each $10\mathrm{cm}^2$ sensor contains 2000 readout strips, which means there are 20 million chip channels that can potentially store information from each particle collision. Most of the channels will actually contain no information about an event at any given time; therefore, it is important that each channel has a noise occupancy of less than 0.1% so that only strips that contain information are read out. The purpose of this study is to explore whether KPix electronics can detect signals from passing particles without recording noise hits in more than 0.1% of all channels.

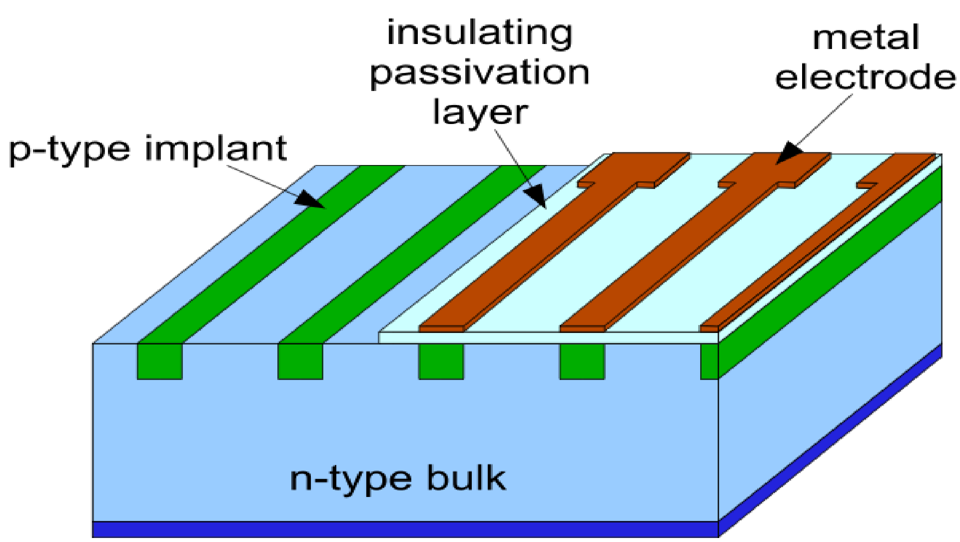

Figure 2: Silicon strip sensor cross section. Silicon sensors are back biased with voltage -V on the p-side, and ground voltage on the n-side of the sensor.

2.2 Readout Electronics

The typical amount of charge deposited on a tracking detector strip from a minimum ionizing particle is about 4fC, which is small enough to require low-noise amplification before being shaped and analyzed. KPix makes use of a feedback-type charge-sensitive front end amplifier, which offers better control of KPix amplifier gain and also gives the amplifier a larger dynamic range by allowing the feedback path to switch between three different capacitor circuits, depending on the signal size.

The transistors that make up the amplifier do not provide a perfectly linear response; therefore, the amplifier relies on the linear behavior of the capacitor in the feedback loop to control the overall gain of the system. This kind of feedback network creates what is known as a "charge-sensitive amplifier" (Spieler [7], pg 93).

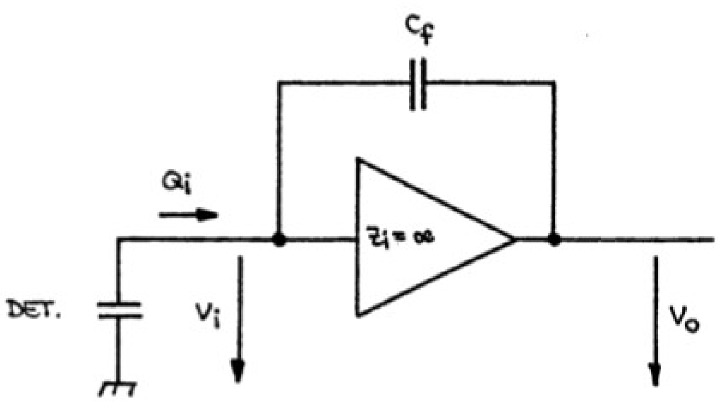

Figure 3: Example “charge-sensitive amplifier” circuit (Spieler [6], Pg 81).

A charge-sensitive amplifier, as shown in Figure 3, is an inverting amplifier with high input impedance that has both input and output nodes connected through a feedback capacitor (marked as C_f in the figure). The voltage output of the amplifier per input charge is represented by

$$A_Q = v_0/Q_i \qquad (eq\ 1)$$

The output voltage is just the inverted and amplified input voltage,

$$v_0 = -Av_i \qquad (eq\ 2)$$

in which -A is the amplification coefficient of the amplifier. Using the definition of capacitance, C = Q/V, the input charge is represented by

$$Q_i = C_i v_i \qquad (eq\ 3)$$

where C_i is the detector capacitance. Applying equations 2 and 3 to equation 1 gives,

$$A_Q = -Av_i/C_i v_i = -A/C_i \qquad (eq\ 4)$$

The voltage difference across the feedback capacitor is equal to the difference between the input voltage (v_i) and the output voltage ($-Av_i$),

$$\Delta V = v_i - (-Av_i) = (A+1)v_i = v_f \qquad (eq5)$$

If we assume the ideal case in which the amplifier input has infinite resistance, then all the input charge gets stored on the feedback capacitor so that

$$Q_i = Q_f \qquad (eq\ 5)$$

From this it is easy to see that

$$C_i = Q_f / v_i = C_f(A+1) \qquad (eq\ 6)$$

Inserting this expression of C_i into (eq 3) and assuming that A >> 1 yields the expected result

$$A_Q = A/(A+1)C_f = 1/C_f \qquad (eq\ 7)$$

Thus, the charge gain is set by the charge on the feedback capacitor.

Once amplified, the signal is shaped by frequency filters that change its frequency response; consequently, its time response also changes. Since signal and noise frequencies are different, a low-pass filter can improve the signal-to-noise ratio by filtering out noise frequencies, but also has the adverse effect of increasing the length of the pulse. Shaping the pulse to be too wide can cause problems when successive particles are detected and need to be analyzed, as they will pile on top of each other. This problem is mitigated by subjecting the pulse to a high-pass filter that shortens its decay time, allowing the initial pulse to relax back down to the baseline before another pulse gets thrown in on top of it. A simple example of the effects of these types of filtering is shown in Figure 4.

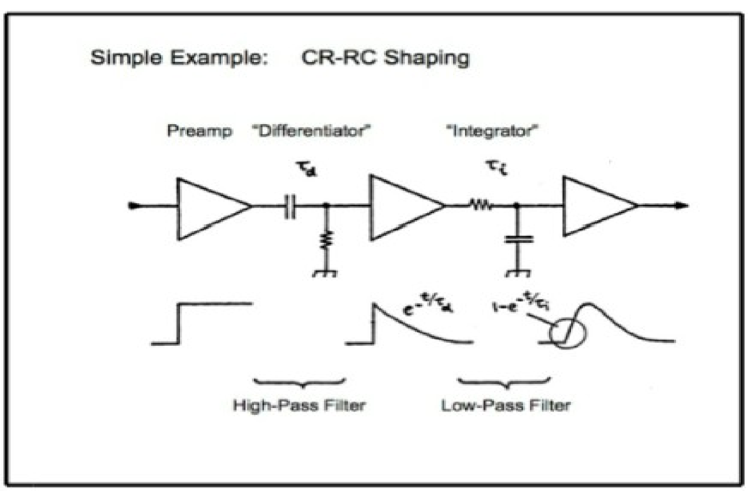

Figure 4: Simple example of pulse shaping due to high-pass and low-pass filtering (Spieler, Radiation Detectors and Signal Processing, pg 32)

After being properly shaped, each individual pulse is fed into a signal discriminator that has a preset voltage standard by which each pulse height is judged. Whenever the threshold is crossed, the discriminator "fires", triggering a circuit that causes the charge to be passed to a storage capacitor. The comparator threshold is responsible for determining the minimum detectable charge, and should optimize pulse efficiency measurements. The comparator response is converted to a digital response that goes high when the pulse is above the comparator threshold. These transitions are recorded and used to tell when a channel contains information about a particle collision. If the signal is not above the preset threshold, it will not be seen by the comparator, lowering that channel's efficiency.

An analog to digital converter (ADC) is a device that takes a continuous quantity such as an amount of electrical charge, and converts it into a digital value that represents the magnitude of that quantity. In general, ADCs work by comparing an input voltage to the voltage produced on a charging capacitor. Once the capacitor has charged completely so that the voltage across it is equal to the input voltage determined

by the comparator, it is isolated from the system. Since the digitization process introduces large amounts of electronic noise into the system, the chip waits until the beam spill is over, then discharges the capacitor through the ADC at a linear rate. The amount of time it takes the capacitor to deplete fully is measured by a discrete number of a predefined time intervals, which represent the analog signal and converts it into a digital signal. This process is useful for finding the centroid but is not important to the efficiency and occupancy studies that are the main focus of this thesis.

2.3 Pulse Efficiency and Noise Occupancy

Although the shaper improves the signal-to-noise ratio by filtering out some of the noise frequencies, there is still noise present in the system that causes the amplifier output to fluctuate randomly. These noise fluctuations play an unavoidable role in determining the minimum threshold that can be set in the comparator in order to avoid too high a percentage of noise saturation. The probability of noise occurring at a certain voltage is governed by a gaussian distribution centered at zero volts, as in Figure 5. In the absence of a signal pulse, the probability that the noise is above the discriminating amplitude at any given time is called the noise occupancy. Similarly, the probability that a signal pulse of a certain voltage will be created from a particle incident on the detector is governed by a Landau distribution, also shown in Figure 5, with its peak at minimum ionizing energy of about 3.7fC, which can be converted into a voltage by multiplying by the amplifier gain and adding a correction due to the voltage offset. The probability that a signal pulse will cross the comparator threshold at any given time is called the pulse efficiency. The SiD design specifies that a threshold be set that suppresses the noise to less than 0.1% probability of occupancy, and allows for at least 99.9% efficiency in pulse detection.

If this criterion can be maintained for all channels of KPix for a reasonable range of thresholds, then one major requirement for being considered as an ILC tracking chip has been fulfilled. Figure 5 roughly depicts this idea and shows, according to this portrayal, where along the x-axis (signal height) the comparator threshold should lie in order to suppress 99.9% of the noise and retain 99.9% of the signal pulse. The width of the Gaussian modifies the threshold(s) that fit this criteria; for instance, the Gaussian can be wide enough so that no threshold will retain 99.9% of the signal pulse while suppressing 99.9% of the noise, which would be problematic. Conversely, the Gaussian can be thin enough so that a broad range of thresholds will suppress 99.9% of the noise while still retaining 99.9% of the signal.

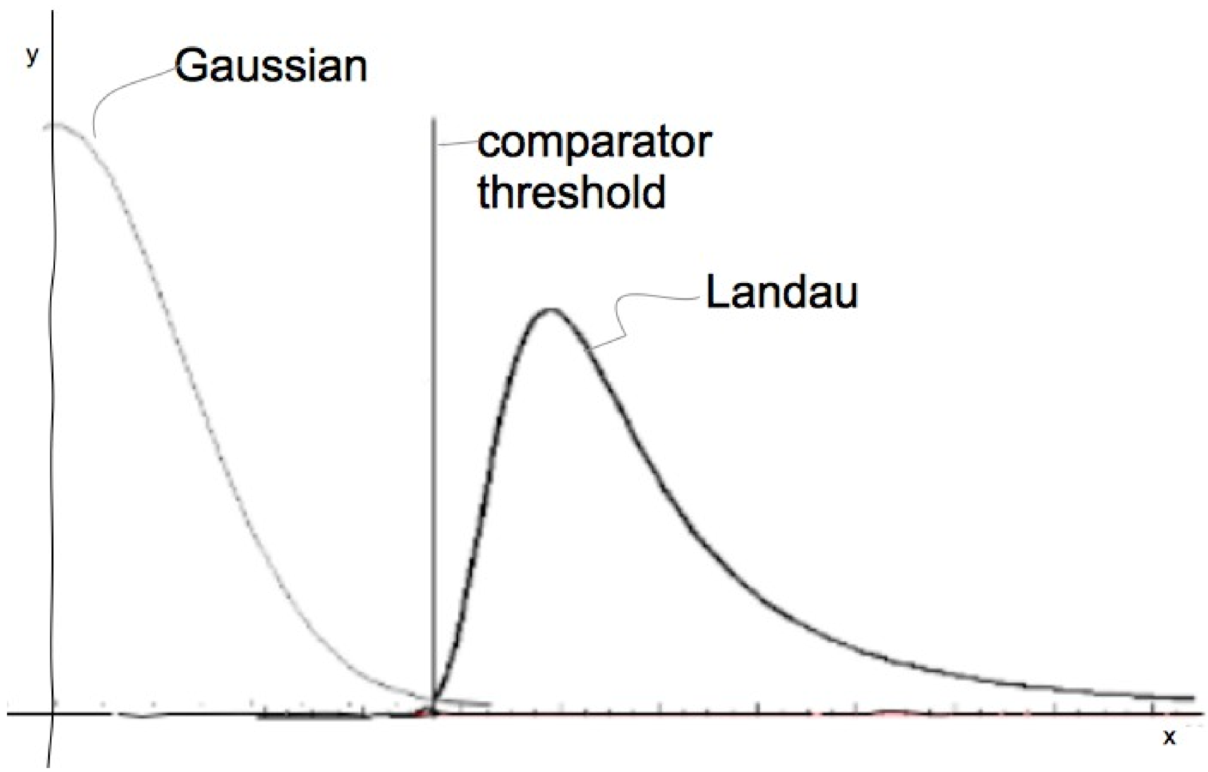

Figure 5: A Gaussian distribution for noise (left) centered at 0V, and a Landau distribution for signal pulse (right) with its peak at Min-I energy (~3.7fC). The y-axis is the number of occurrences and x-axis is the pulse height.

While the noise distribution is expected to be similar for all chip channels, the amplifier gain and voltage offset that forms the linear relationship between input charge and threshold voltage are not. The amplifier gain is measured by injecting a series of increasing charge pulses at the input and determining the threshold in volts for which the signal surpasses the comparator 50% of the time. A linear fit of these voltage points as a function of input charge for any given channel will establish a slope, which is the amplifier gain for that channel, and a y-intercept, which is the voltage offset for that channel. Since this relationship varies channel to channel, the efficiency and occupancy will also vary channel to channel if a single comparator threshold is applied uniformly to all channels. The goal is to see whether these efficiency and occupancy thresholds are stable enough over all channels such that there exists a single threshold which, when set, is high enough to suppress 99.9% of the noise, but low enough to see 99.9% of signals, for all channels. There is no method of testing this directly for high energy charged particles passing through a sensor; therefore, the charge development simulation developed at UC Santa Cruz is needed to simulate charge deposition onto readout strips coupled to readout electronics.

3 Materials & Procedure

3.1 KPix Chip

KPix version 7 has 64 readout channels, four of which are non-operable for the chip that has been tested. Each channel is composed of three major circuit blocks in sequence: the analog block, the digital block, and the address register. Inside the analog block, the incoming signal is amplified, shaped, discriminated, and stored before continuing on to the digital block. Inside the digital block, a Wilkinson ADC digitizes the signal (Carman, pg 3). Both the analog and digital segments communicate with the outside world through the address register block.

As shown in Figure 6, the KPix chip is mounted onto a small test board 2 square inches in area, which is connected to a daughter board through a 60 pin MEC1 connector. The daughter board is then linked to an FPGA board through 5 separate fiber optic connections for the command, trigger, reset, clock, and data out differential voltages, and controlled through a graphical user interface that is linked to the FPGA board through a USB connection. An Agilent E3646A Dual Output DC Power Supply dispenses 7V each to the daughter board and the FPGA board, and the daughter board then provides the 2.5V to the test board needed to bias the KPix chip.

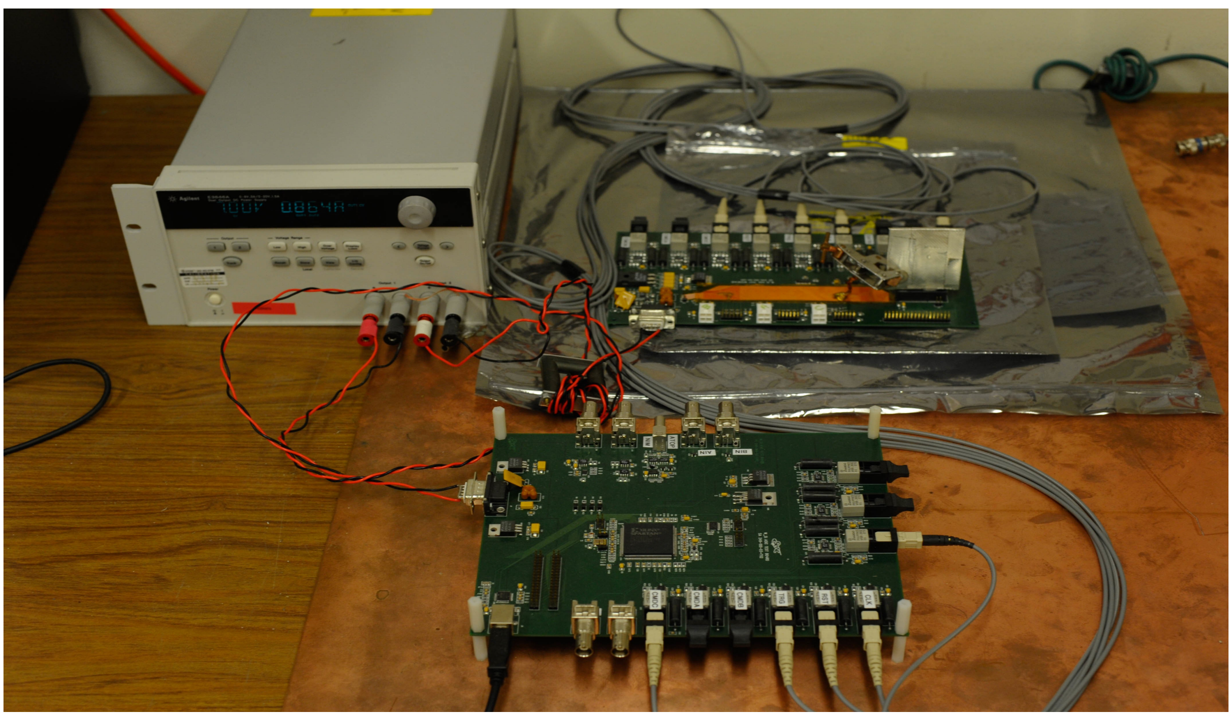

Figure 6: KPix setup has a power supply in the top left corner, with the daughter board next to it on the right, and the FPGA board in the front. The KPix test board, wrapped in aluminum tape, is visible standing upright on the daughter board

3.2 Taking Data from the KPix Chip

In order to take data directly from the KPix chip, software was provided by Ryan Herbst, an engineer at SLAC. Included in the KPix software package is the program thresh_scan that scans through a range of trigger thresholds for a specific injected charge, and when the amplified signal from the calibration capacitor exceeds the trigger threshold in the comparator it gets placed on a storage capacitor then released for digitization. To acquire the amplifier gain and voltage offset for a given channel, a charge is injected with low set threshold for which the comparator fires 100% of the time, then that threshold is slowly raised, causing the comparator to fire less often, until at some point it becomes too high to see any of the pulses. The percentage of hits seen by the comparator is then plotted as a function of set threshold. If no noise is present, this curve will make an immediate jump from 0 to 100 percent at the threshold voltage that corresponds to the amplitude of the injected signal.

Figure 7 shows that this transition is not instantaneous; but rather, occurs over a voltage interval. Since the noise that gets added to the signal has a Gaussian distribution, the comparator response, measured over a range of trigger thresholds and plotted as comparator hit-fraction versus threshold, has the shape of an error function, also referred to in this context as an S-curve. The width of the S-curve, fit statistically to an error function, is the Gaussian variance of noise, and the mean is the voltage threshold for which the comparator fires 50 percent of the time, known as the mean threshold.

The mean threshold represents the true voltage amplitude associated with the injected charge. If a series of charges is injected for a given channel, as in Figure 7, a linear fit of the mean thresholds, plotted as a function of the corresponding injected charge, supplies both the gain measurement and offset measurement for that channel (see Figure 8). The measured gains and offsets vary from channel to channel, reducing the accuracy of the application of a single threshold that is applied across the chip. For each of the 60 working channels, a range of charges between 4fC and 10fC is injected in 1fC intervals using the thresh_scan routine. For each injected charge, a range of comparator thresholds from 0mV to 1220mV is scanned through in 10mV intervals, and for every threshold set in the comparator, the specified charge is injected 1000 times to obtain good statistical accuracy in the gain, offset, and noise calculations. At the end of every data acquisition run, thresh_scan automatically uses ROOT[1] software to plot the corresponding S-curves and gain curves.

1 An object oriented library developed at CERN for particle physics data analysis.

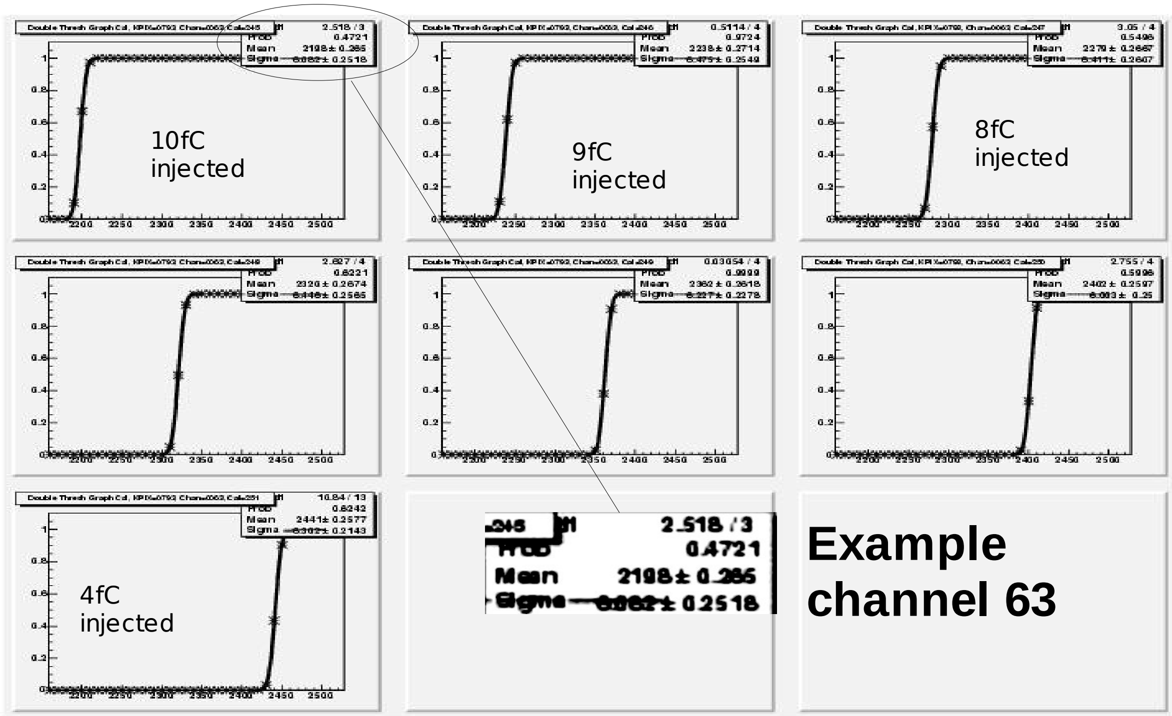

Figure 7: Sample S-curves for KPix7 channel 63 for a typical series of injected charge. The fit parameters can be found in the top right corner of each graph. The two most important parameters are "Mean", representing mean threshold, and "Sigma", representing the noise.

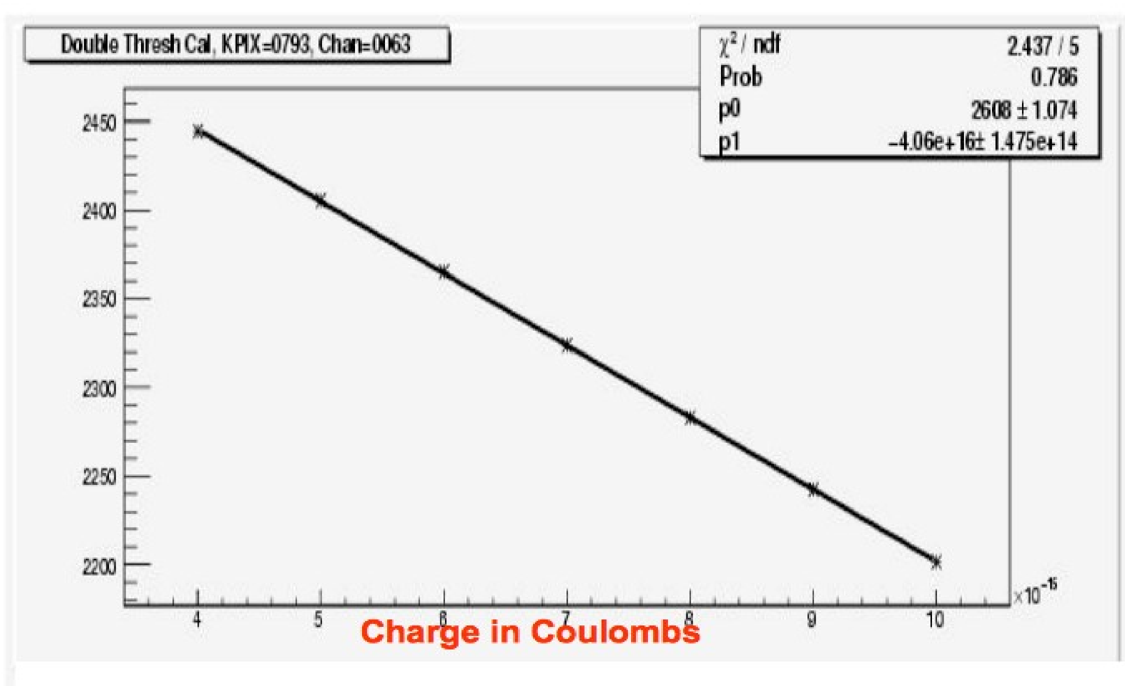

Figure 8: Sample gain curve generated from mean thresholds for injected charges in Figure 5. Note that the y-axis is inverted due to inverted amplification. Zero offset in mV is 2500.

3.3 Pulse Development Simulation

3.3a Simulating Particle Detection

The UCSC charge-development simulation software is a collection of c++ modules that simulate the sensor physics and electronic readout for high-energy particles that pass through the detector. The software assumes an n-type bulk silicon detector, as shown in Figure 2, with 9 embedded p-type strips and associated metal electrodes. The simulation makes use of positively charged pions with an energy of 5Gev then enter the silicon detector at normal incidence. When energetic particles from ILC collisions enter a silicon detector they are hardly affected by the material medium, allowing them to race through to the next layer of detectors; their passage through the medium creates a large number of electron-hole pairs. In the charge development simulation, a routine written by Gerry Lynch, SimSIdE, divides the bulk material into 20 layers, and, as the simulated pion moves through each layer, a number of electron-hole pairs are created in each layer according to a Landau distribution. Summing over all 20 layers, the overall most likely deposition is 3.7fC, which corresponds to about 24,000 e/h pairs.

The electric field, due to the back-biasing of the sensor, forces the positive charges to drift upward towards the electrodes. They drift at an angle of 180 milliradians with respect to the original particle trajectory due to the Lorentz force associated with the 5T magnetic field (refer back to Figure 1), causing an average 50μm spread of charge across the surface, depending on the layer from which it originates. An additional spreading of 5 – 10μm also occurs due to the natural diffusion of charge over the time it takes to travel to the electrode. This effective spreading causes the charge to deposit across two or three electrodes, as opposed to all being concentrated on the one strip aligned with the particle track, resulting in multiple strips with net charge deposited on them.

3.3b Calculating Efficiency and Occupancy

As mentioned in the Background & Motivation section, pulse efficiency is the probability that a signal pulse will cross the comparator threshold, and noise occupancy is the probability that the noise alone will be above the comparator threshold at any given instant in time. As part of the particle development simulation described in the previous section, I added a routine that simulates the comparator function of the KPix chip and allows for efficiency and occupancy calculations. The comparator routine compares a deposited strip charge to a pre-defined threshold and reports whether the input went above that threshold for each of the nine simulated strips; a counter is incremented each time the threshold is crossed. The total number of threshold crossings is divided by the number of simulated particle passages in order to calculate the probability that a deposited charge will be seen. This probability is known as the efficiency.

Using this comparator simulation in concert with the charge development simulation, I scan through a range of thresholds from -0.15fC to 2.54fC, simulating the passage of 100,000 particles through the nine-strip sensor per threshold, which gives the comparator 900,000 chances to fire at each set threshold. For efficiency calculations, the simulated strips are stimulated by interacting particles; for occupancy calculations, the simulated strips have no stimulus so that only noise is measured. To meet the requirements of seeing 99.9% of all signals, the comparator must fire on at least 99,900 of the 100,000 pulse signals. To suppress 99.9% of the noise for a certain threshold, since there are nine strips containing noise for each signal pulse, the comparator must fire on no more that 900 of the 900,000 noise pulses. This is repeated for every one of the 60 working KPix channels, making use of the individual channel's measured amplification

The applied comparator threshold corresponds to an average over all channels, but because of channel-to-channel variations in the measured gains and offsets, the threshold seen by each individual channel is not necessarily the average threshold, but will be distributed over some range of thresholds, the average of which is equal to the uniformly applied threshold. Therefore, the gain and offset of each channel must be used to shift the applied threshold to the threshold each channel actually sees.

4 Results

Data is taken for each KPix channel as described in the Taking Data section, and a gain curve is generated, such as the one in Figure 8, for each channel. A linear fit of each gain curve supplies the relationship between amplified charge (x) and voltage threshold (y) as y = mx + b, where the fit parameter m is the gain in mV/fC, and the parameter b is the voltage offset in mV. Note that this expression can be inverted, allowing a channel's input charge (x) to be calculated if the amplified signal magnitude (y) is given.

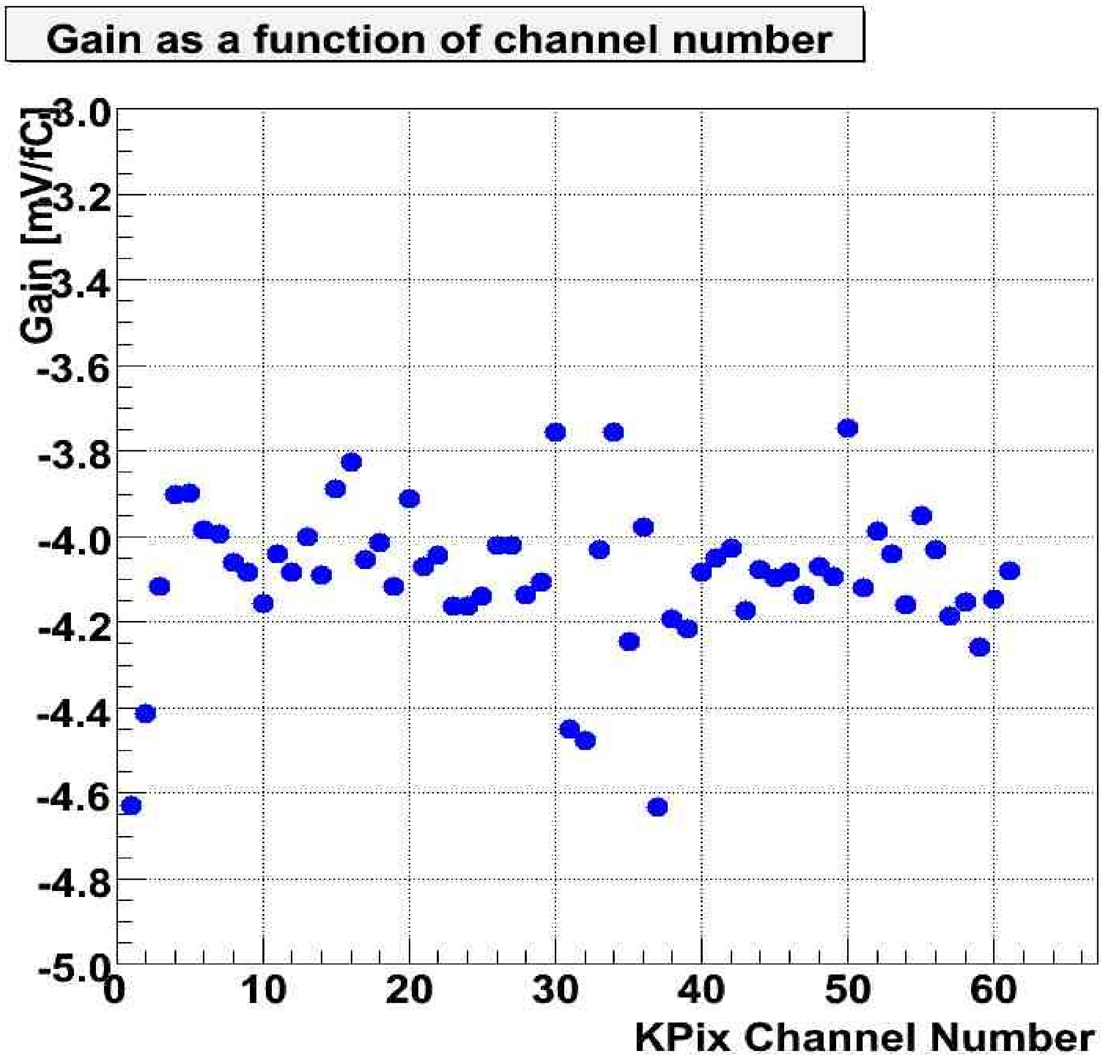

Figure 9: Measured gain as a function of KPix channel. Note that gain is plotted in units of 10mV/fC.

Figure 9 shows that the gain is tightly distributed around -40.5mV/fC. The average gain over all channels is -40.83mV/fC and the RMS spread is 1.565mV/fC.

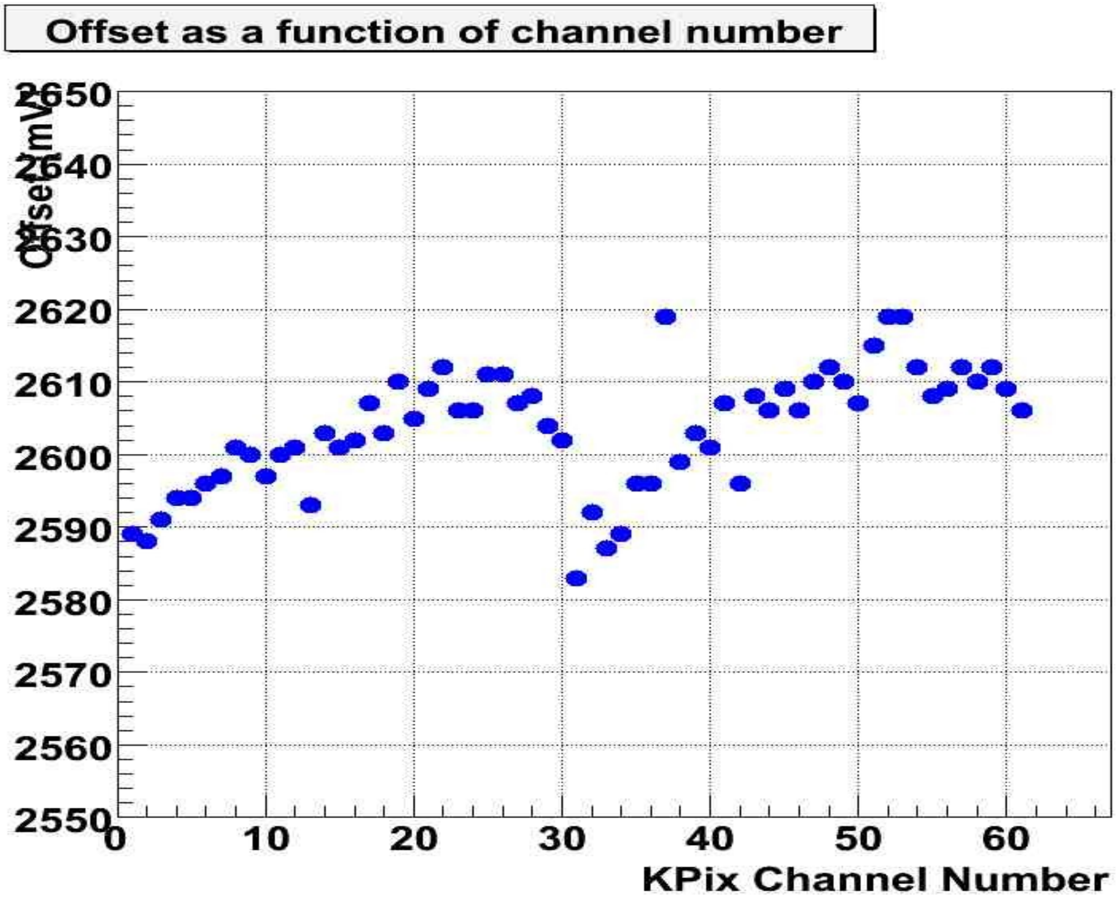

Figure 10: Measured offset as a function of KPix channel. Note that the y-axis is inverted due to inverted amplification. Zero offset in mV is 2500. 2620mV corresponds a to zero offset of -120mV, and 2580mV corresponds to a zero offset of -80mV.

In Figures 9 and 10, the gains and offsets are plotted as a function of KPix channel number, displaying graphically the channel-to-channel variations. The chip operates by applying a single voltage threshold equally to all the chip channels. Since the amplifier gains and offsets vary from channel-to-channel, different amounts of input charge are required to surpass the comparator threshold. It is interesting to look at the distribution of charges that will trigger a 1.2fC threshold, which is expected to be a threshold that would sufficiently suppress the noise while still allowing the comparator to trigger on greater than 99.9% of the pulse (illustrated in Figure 5). For all the channels, the average amplified signal voltage for 1.2fC is measured to be 2554.8mV. Applying this voltage to the inverted response function (gain and offset) for each channel generates a distribution of charge at the average 1.2fC threshold that has a peak at 1.35fC and an RMS spread of .1957fC (Figure 11). This means that the applied threshold will be different from the intended 1.2fC by some tenths of a fC or more.

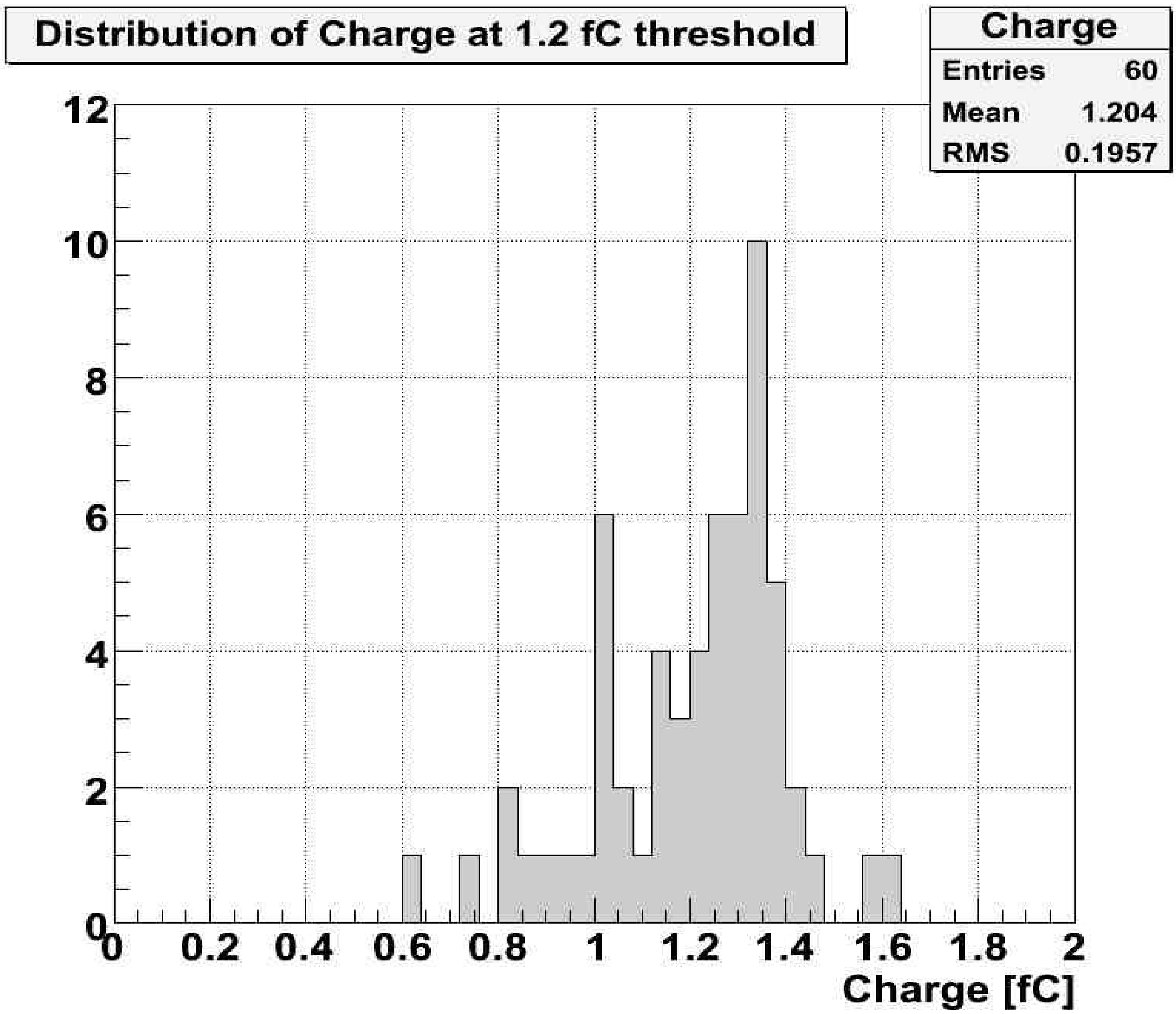

Figure 11: Histogram of charge value over all channels at the average 1.2fC threshold

Figure 11 shows how the channel-to-channel variations in amplifier gain and voltage offset from Figures 9 and 10 causes a variation in the effective threshold values interpreted by each channel for a single threshold applied uniformly to all channels. Referring to Figure 11, one channel interprets the applied 1.2fC to be 0.6fC, which is a difference of 0.6fC. Another channel interprets the applied 1.2fC to be 1.6fC, which is a difference of four 0.4fC. Modifications need to be made to the comparator routine to account for these variations, which is done by inverting the response function for a given channel and applying it to the discriminating voltage before comparing it to the strip charges. This is what causes KPix to have different efficiency and occupancy characteristics for each channel in the simulation.

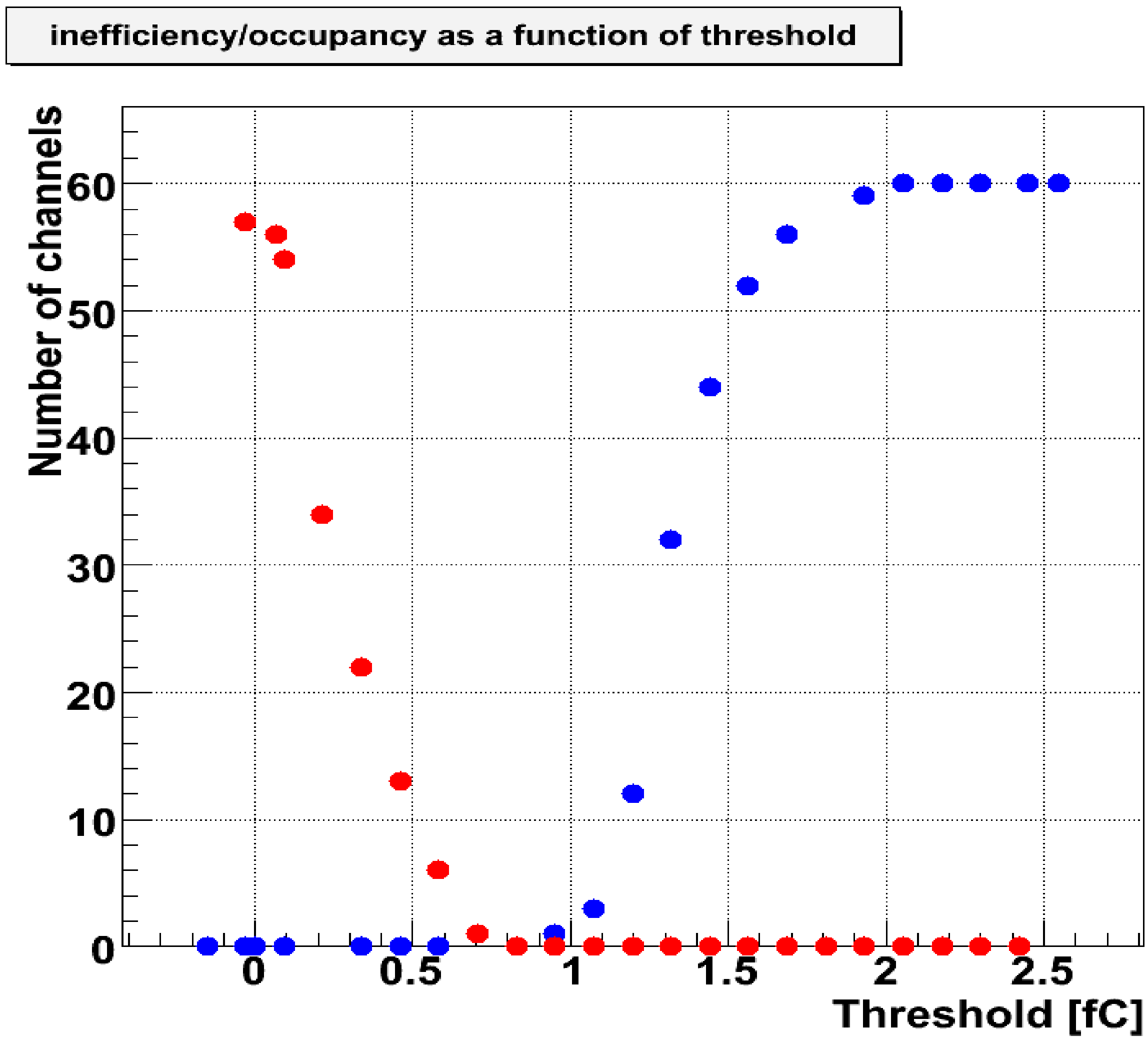

Figure 12: Plot of inefficient (blue) and occupied (red) channels as a function of comparator threshold before strip charges are modified to include ground-loss and charge sharing

With this done, the pulse development simulation can be used to determine the number of channels with efficiency less than 99.9% and occupancy greater than 0.1%; so for any given applied threshold, the number of KPix channels with efficiency less than 99.9% (inefficient channels) and occupancy greater than 0.1% (occupied channels) can be plotted as a function of this applied threshold. The operable threshold range occurs where both the inefficiency and occupancy curves are at zero on the channel number axis. The results of this calculation are shown in Figure 12. The range of comparator thresholds that meet the required 99.9% efficiency and 0.1% occupancy lies between, but does not include, 0.705fC and 0.950fC. At the 0.705fC threshold, all channels are more than 99.9% efficient, but one channel remains occupied above the 0.1% standard. At the 0.950fC threshold, all channels are occupied less than 0.1%, but one channel is below the 99.9% efficiency standard.

However, these results were generated under the assumption that all the charge deposited on a single strip from a particle track gets amplified and discriminated; but in reality, some charge is lost from each strip to the ground plane, and also each strip shares some of its charge with its nearest neighbors. Separate sub-routines are written to modify the strip charges by subtracting 2% of the charge from each strip for ground-loss, and another 10% from each strip to be split and shared with its nearest neighbors. With these modifications in place, the simulation is re-run. The results are plotted in Figure 13 below.

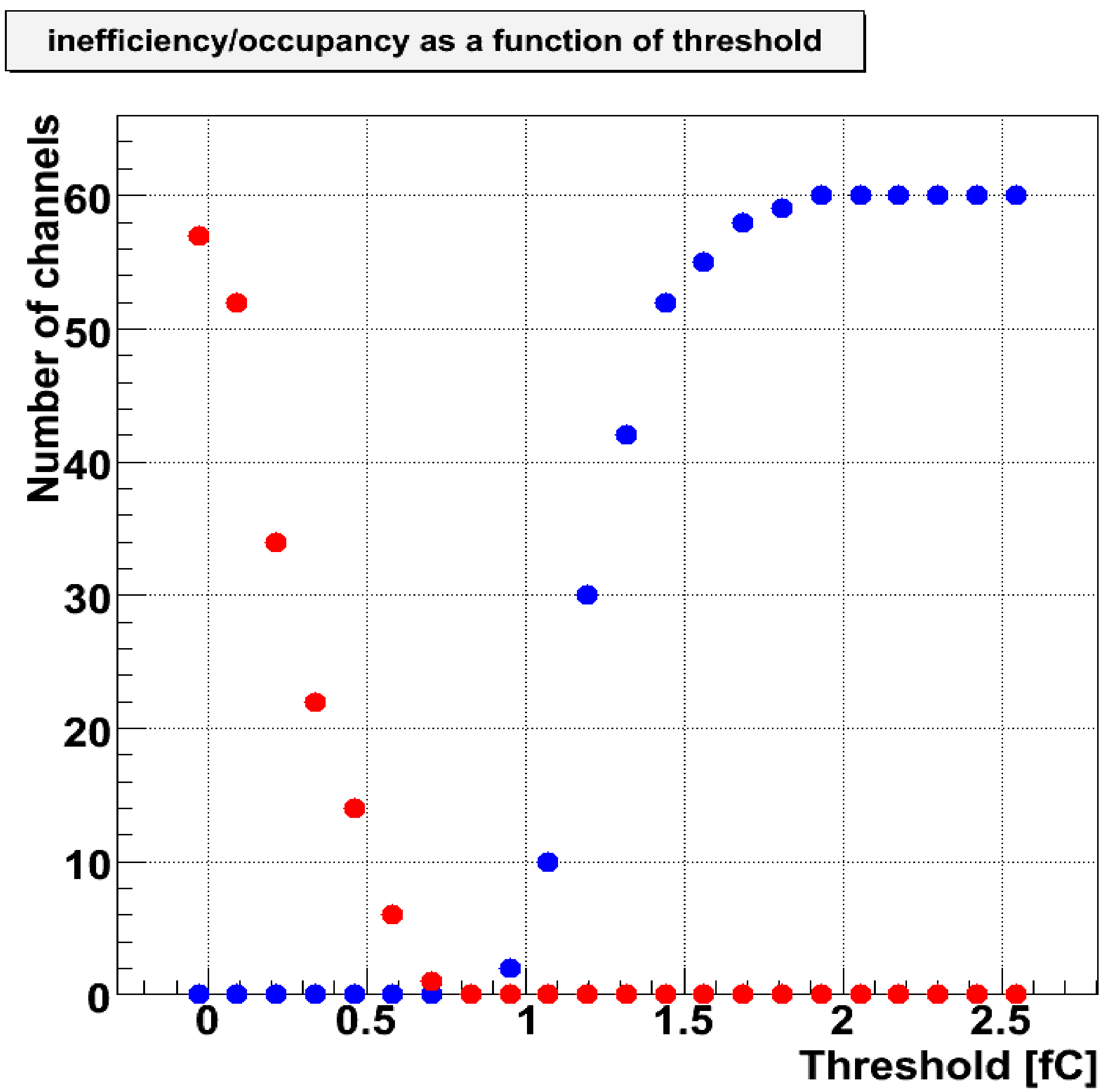

Figure 13: Plot of inefficient (blue) and occupied (red) channels as a function of comparator threshold after strip charges are modified to include ground-loss and charge sharing

The range of comparator thresholds that meet the 99.9% efficiency and 0.1% occupancy requirements still lies between 0.705fC and 0.950fC, but it is important to note that changes in the number of inefficient and occupied channels occurs for thresholds at the upper and lower boundaries. The number of occupied channels at 0.46fC threshold decreases by 1 after ground-loss and charge sharing modifications were made; yet, the number of inefficient channels increases by 18 at 1.2fC threshold, by 8 at 1.07fC threshold, and by 1 at 0.95fC threshold, effectively narrowing the operable threshold range to a width of about 0.1fC. The results in Figure 13 are considered to be the final results and are reported to the design engineer, Dieter Freytag. Who commented that the range is too narrow and is making changes in the KPix design to widen that range.

5 Summary & Conclusion

The KPix ASIC is a low-noise electronic readout chip that aims at performing both tracking and calorimetry readout in the ILC. The efficiency and occupancy of the KPix chip for low thresholds (up to ~2.5fC) is important to study because it determines how efficiently particle interactions with silicon strip sensors can be detected for ILC particle tracking. It also determines the rate at which data must be transferred from the detector onto storage disks. Position measurements need to have an accuracy to within 5μm so that accurate momentum measurements are possible; therefore, the minimum detectable threshold must be low enough to detect the charge on strips to either side of the centriod.

Channel-to-channel variations in the gain and offset were measured and used in the charge development simulation that simulated KPix readout of charged detector strips from ILC particle collisions. The average gain over all channels was measured at -40.83mV/fC with an RMS spread of 1.565mV/fC, and the average offset from zero was measured at -103mV with an RMS spread of 8.237mV . The gain and offset for each channel were used in the charge development simulation to calculate the effective threshold value seen by each channel when a single threshold was applied uniformly to all channels, which allowed for an efficiency and occupancy estimation for each individual channel as a function of applied threshold.

The range of comparator thresholds that meet the requirements of 99.9% efficiency and 0.1% occupancy was discovered to lie somewhere between 0.705fC and 0.950fC with an approximate width of about 0.1fC. This result was reported to the chip design engineer at SLAC who proclaimed it to be unsatisfactory for ILC tracking standards. Thresholds between 0.705fC to 0.950fC were considered low enough to detect signals on strips to either side of the centroid. Since this study was completed, refinements have been made to the KPix design to ensure a broader range of thresholds. The newest version, KpixA, will be arriving at SCIPP in the near future, and the efficiency and occupancy study will be repeated.

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