FPIX0 Test Stand Studies of Chip Characteristics

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1 Introduction

We have organized a computer test stand to evaluate all channels of an FPIX0 readout chip. The UNIX system uses CAMAC modules to produce drive and control voltages under program control and a waveform digitizer and memory module to record address and 8-bit pulseheight information from the chip. We have built a custom interface board to link the FPIX0 chip into the readout system. Signal timing and widths are controlled by external NIM or CAMAC modules. The system layout is shown in figure 1.

The test injects charge into selected cells by applying a known voltage level to the input of the test capacitor. As will be discussed below, operating considerations require the input pulse to be short. With our present test generator, this means that both negative and positive edge transitions occur within the integration window of the FPIX0 chip. This may lead to a ballistic deficit; the injected charge is proportional to the injection voltage through some unknown constant factor. However, we have studied the output level as a function of input width at constant V_{inj}. The output is constant for widths $> 120ns$. Without measuring a calibrated chip whose charge response and threshold settings are known, we cannot set an absolute charge scale from these measurements. If one ignores the ballistic deficit, the approximate scale is 30 electrons/mV.

There is a speed mismatch between the CAMAC waveform digitizer module, with a minimum sampling rate of 8 MHz, and the analog response time of the FPIX0 system and the associated external buffer/driver on the interface card. In our system we take 16 samples of the waveform for each injection pulse and store the information from a suitably-stable region of the response function. This limits the output data size to 40 active pixels per scan. In practice, we generally make one complete row or quarter of a given column active per DAQ run.

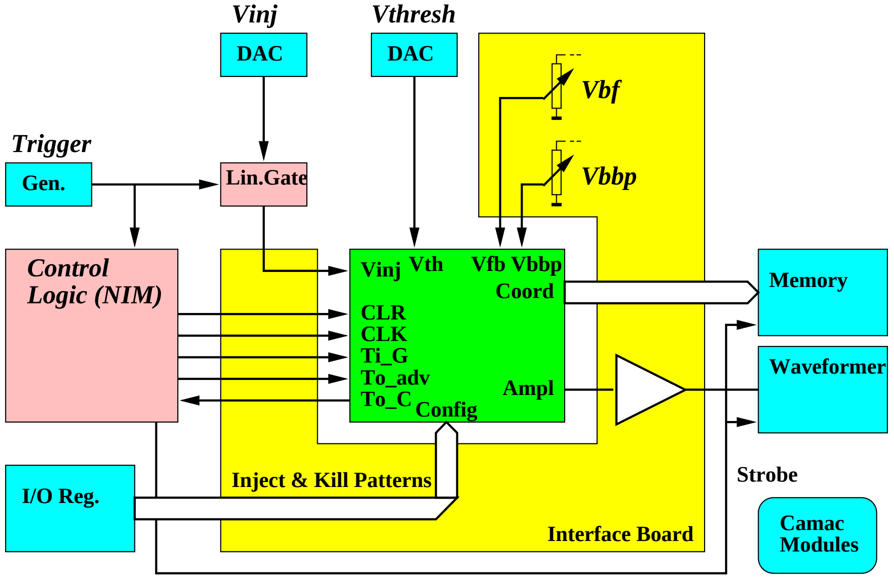

Figure 1: Block Diagram of Test Setup

2 Calibrating Test System Intrinsic Resolution

We have used a Tektronix 820 Digital Storage Scope to compare measurements with the computer system. Measuring the FPIX0 output response for many repetitions of the same input signal gives an rms error of $\leq$ 0.4% of the output signal for a wide range of voltages seen by the waveform digitizer. This agrees with the spread of voltage levels seen on the scope. This is adequate to make gain and linearity studies of FPIX0 to better than 6-bit accuracy.

3 Test System Operation

3.1 Setting Operating Conditions

The operating sequence for data collection has the following steps:

1. set FPIX0 chip parameters I_{bias}, I_{fb}, V_{ee} by hand
2. download inject and kill pattern to define active cells
3. select $V_{threshold}$ and sequence of injection voltages and number of points per voltage in script
4. initiate DAQ script to inject charge, read output and store data
5. at completion of sequence, make ntuple for output analysis.

3.2 Test sequence

A typical test sequence checks the 768 cells of the chip for output response over a range of input signals at a given threshold. The threshold is then changed and another set of data taken. The voltage range of the input and number of events sampled per input voltage and the threshold setting range are adjustable in the control script. The output data are available on disk in a ntuple format to be analyzed by offline analysis. Data are recorded for every hit. The record consists of the event number, hit number in the event, injection voltage, pixel coordinates and the associated waveform digitizer output.

4 Test Results

We have measured the following FPIX0 parameters for one bare chip and one chip bonded to an Atlas-style sensor:

1. active channel distribution for chip
2. channel gain distribution
3. channel offset distribution
4. threshold behaviour versus $V_{threshold}$
5. threshold width distribution

4.1 Bare chip study

The map in figure 4 shows channels for which there was a measureable threshold. In the figure, the width of the box is proportional to the threshold value in that channel. One sees that within a column the thresholds are quite uniform. For this chip a group of 16 channels in column 4 fail to respond. (Dave Christian confirmed that this group of preamps has no charge-injection connection in the chip layout. The channels are presumed to be alive for the sensor connection.)

The script varies V_{inj} over a range from threshold to approximately 1 MIP, using a scale factor of 1 mV = 30e for the injection signal and ignoring the ballistic deficit mentioned above. For each channel one can develop a gain curve. In FPIX0 columns 1 and 9 are designed with higher-gain channels than the rest of the chip. One can see those two different slopes in figure 2. The nonlinearity is significant in the interesting charge region, but it is stable. A stable, nonlinear response can be remapped by the calibration procedure, so that one can make a cubic spline fit and invert the function to give the charge input that produces an observed response.

4.1.1 gain and offset characteristics

If one limits the fit region to the linear part of the V_{inj} curve, then one can fit all channels and compare gains and offsets. The data shown in these figures has $V_{th} = 2.05$V. The approximate linear range for V_{inj} can be seen in figure 2. The resulting distribution of gains for all active channels is shown in figure 6. The two groups of gain, normal and high, are associated with their respective columns. In figure 6(c) and (d) one sees that the normal-gain peak in fact has two contributions: columns 0,2,4,8 and columns 3,5,7,11. This even-odd effect shows a difference in gain of 7% between the two groups. Gain uniformity within each group is good; the spread about the mean is gaussian with a 1% σ . The extrapolation of the straight-line fit to 0 is an indication of the offset of the peak-detector output. Again, good coherence for all channels is observed in figure 5. Different column groupings shows no particular variation.

4.1.2 threshold variations and noise characteristics

A major question we wanted to address was the level and uniformity of noise in the charge threshold. The threshold variation for $V_{th} = 2.05$V is illustrated in figure 3. The 10-90% firing probability slope is quite steep, indicating very low noise. The actual threshold charge level varies somewhat from channel to channel, as expected. There are structural regularities, perhaps related to voltage drops within the chip. Figure 7 shows the distribution of thresholds within the chip, again for all channels and then for the three groups of columns which have different gains. Again, three groups, related to different columns, can be identified. We define the width of the distribution to be the 50-90% injection voltage change (mV). The widths, related to the internal noise, are rather sharp and independent of column, as shown in figure 8. These threshold and width data were taken at a threshold setting of 2.05V.

We have determined that chip operation is stable for V_{th} settings up to 2.05V. Threshold widths do not appear to depend on V_{th}. The channel gains in the linear region are reduced as V_{th} is increased (increased sensitivity). The effect is about 4% per 100 mV change in V_{th} and is linear. The threshold variation itself is also linear in V_{th} and is shown in figure 9. The bars on the points are the σ values for the gaussian distributions of thresholds for the normal gain or high gain columns and illustrate the range of thresholds within the chip at a given V_{th} setting. The measurement is made in terms of V_{inj}, as shown on the left-hand scale. The right-hand scale uses the conversion factor 30e/mV to quote the threshold in electrons. Recall that we have not firmly established this conversion by comparing our results to a charged-particle measurement.

4.2 Bonded chip study

We studied a second chip, bonded to a 300 μm-thick Si pixel sensor with 50μm x 400 μm pads. The second chip had not been characterized before bonding, so these results reflect both chip-to-chip variations and the effect of having additional input capacitance. Because of the bonding pad layout of FPIX0 there were external connections to test features of Row 0 of the chip which had to be left unconnected. On the bare chip test these had been terminated in 50Ω resistors. These open pads led to instability in the chip if the 12 channels in Row 0 were allowed to be active. We loaded a KILL pattern to turn off this row, and the instability disappeared. [N.B. The kill pattern load process is quite sensitive to slewing in the transition times between the $ckAn$ and $ckbAn$ signals. These should be complementary signals generated at the same time within a few nanoseconds.]

The sensor had a depletion voltage of 45V. We made the tests using a bias voltage of 58V.

4.2.1 gain and offset characteristics

The distribution of gains for all active channels at $V_{th} = 2.05$V is shown in figure 10. The two groups of gain, normal and high, are associated with their respective columns. The even-odd variation in the normal-gain channels is reversed for this chip; odd columns have on average 3% higher gain than the even columns. Gain uniformity within each group is somewhat worse; the distributions are not as nearly gaussian as for the bare chip. The spreads, estimated from a gaussian fit, have 2% σ . In practical operation, these variations will not be important, but more work will be needed to decide if these are chip-to-chip variations or detector-induced changes.

4.2.2 threshold variations and noise characteristics

The threshold variation for the bonded chip at V_{th}=2.05V is illustrated in figure 11. Compared to the unbonded chip, there is a significant shift toward lower threshold: 110 mV (unbonded)/ 72 mV (bonded). The width of the threshold curve shows only a 10% increase due to the increased input capacitance. This change in the threshold level is the only significant difference we have observed between the two chips. We cannot say if it is chip-dependent or sensor-dependent. The change in threshold with V_{th} is shown in figure 12. The change in channel gain with V_{th} is the same as reported for the bare chip.

5 Summary

The CMU test stand has been used to characterize two FPIX0 chips, one bonded to a test board, the other attached to a Si pixel sensor. Both chips are fully operational and show relatively good uniformity at the 10% or better level. Noise is low. The charge threshold of the chip, set by the external V_{th} voltage, has an operational limit (maximum sensitivity) at 2.05 V. At this voltage we measured rather different charge-equivalent thresholds for the bonded and unbonded chips. The chip having the sensor showed a much lower charge threshold. From only these two measurements, we cannot tell if this is a chip-dependent variation or a sensor-dependent variation.

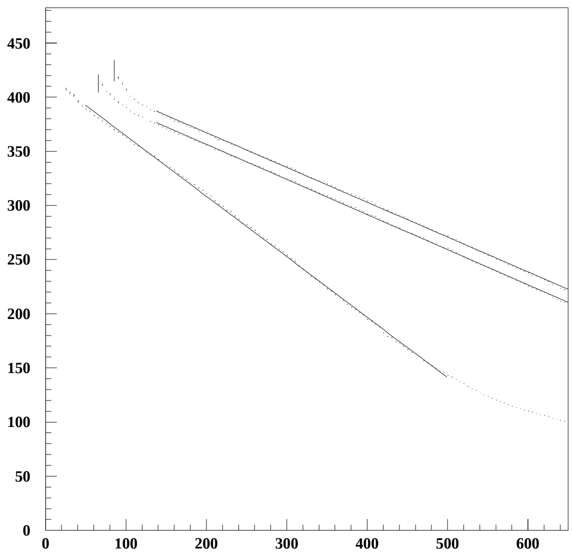

Figure 2: Channel Response (counts) vs Injection Signal (mV) for Row=0 Col=3,5,1 (top to bottom) for Bonded Chip When Vth=2.05

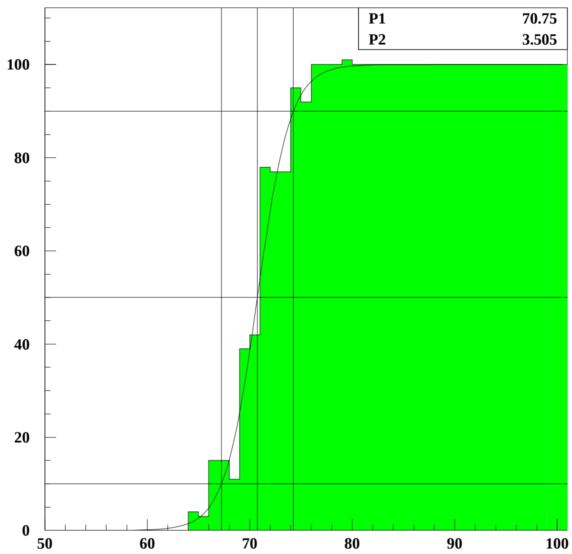

Figure 3: Threshold Curve in the Cell Col=5 Row=16 Fitted by $f(x) = 2.197*N_{ev}/(1+exp^{\frac{-(x-p(1))}{p(2)}})$. Threshold width is a half width for 10%-90% transition.

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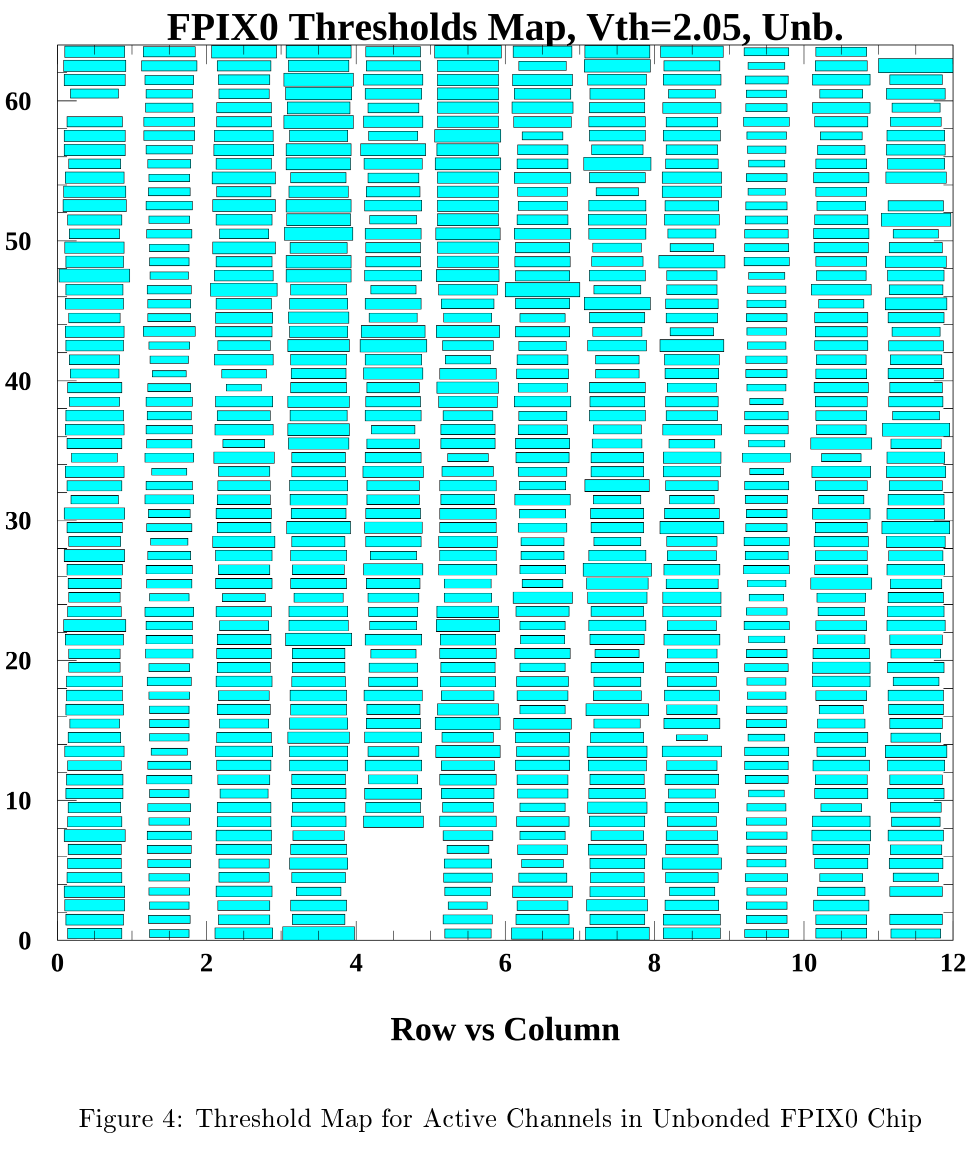

Figure 4: Threshold Map for Active Channels in Unbonded FPIX0 Chip

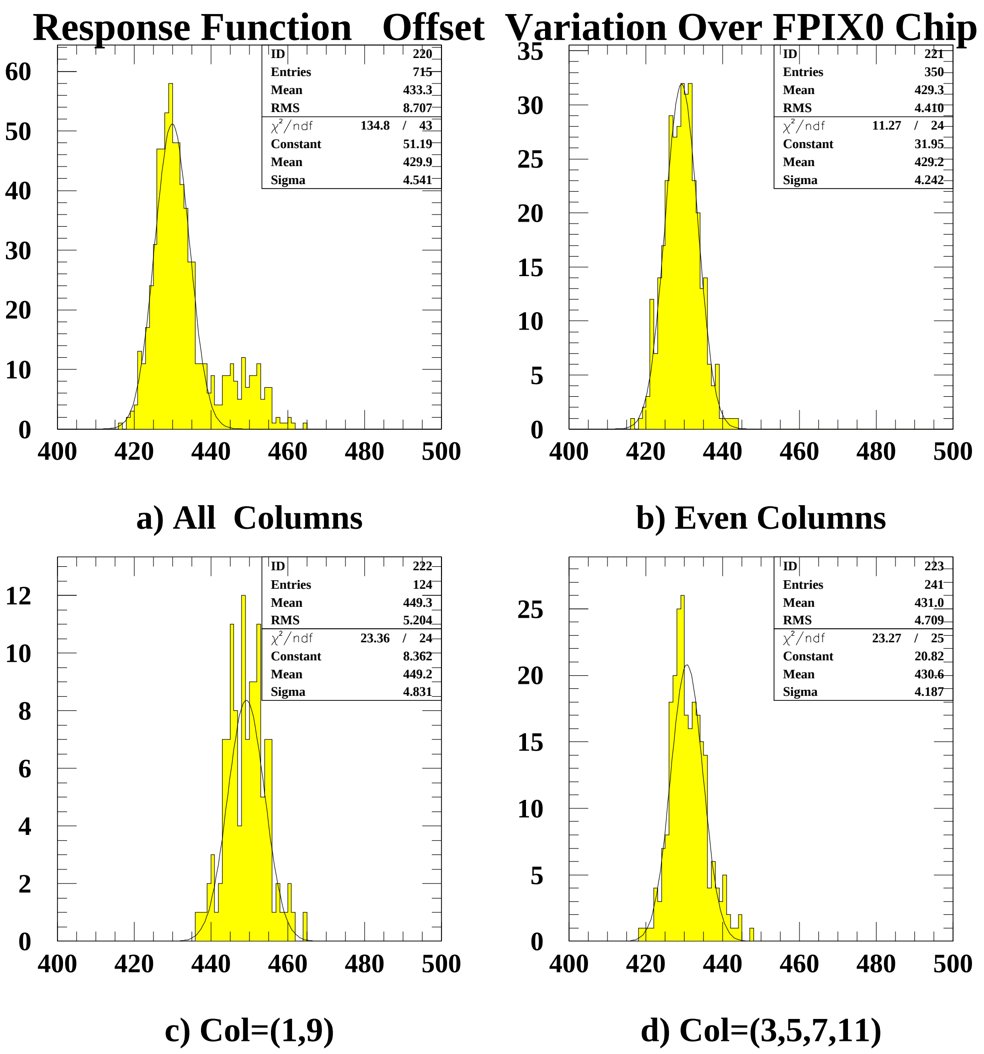

Figure 5: Channel Offsets in Unbonded FPIX0 Chip

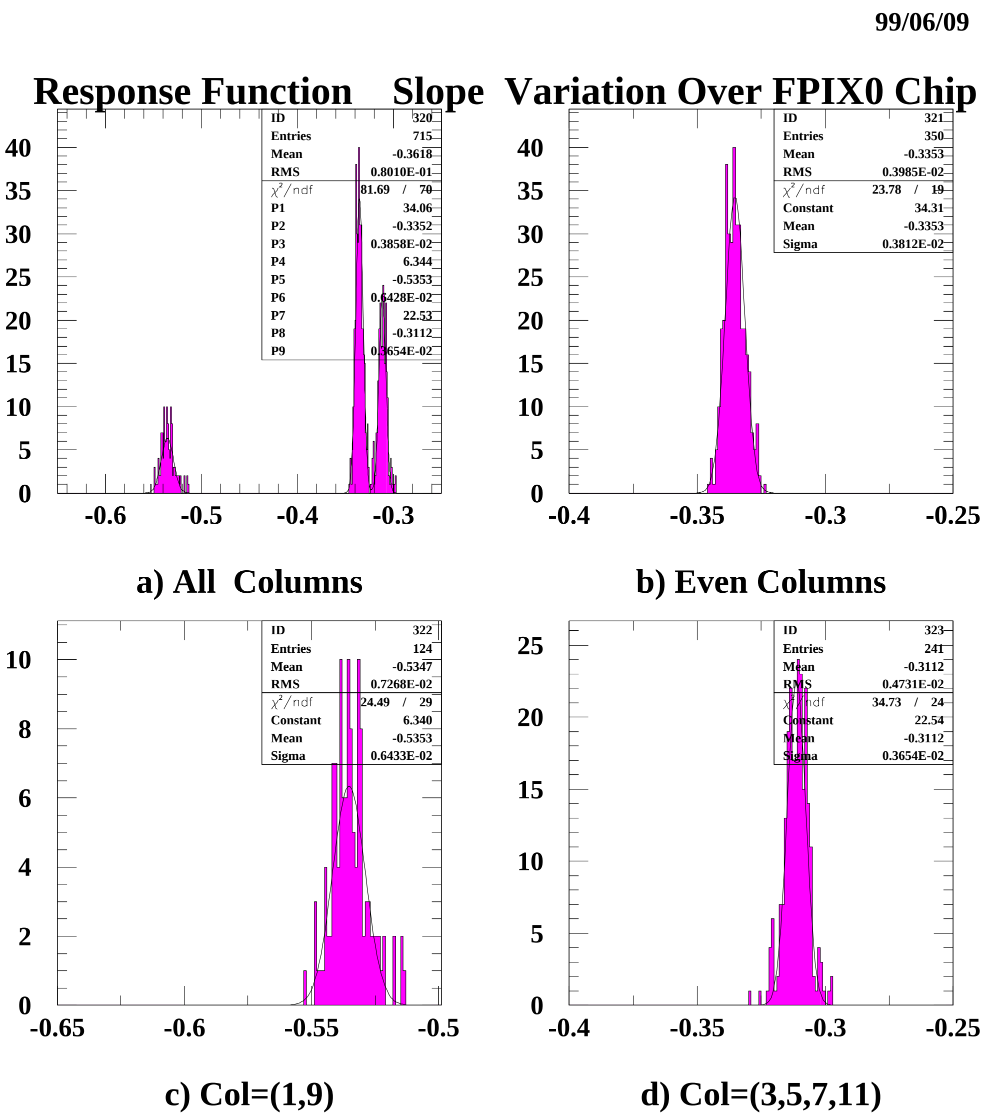

Figure 6: Channel Gains in Unbonded FPIX0 Chip

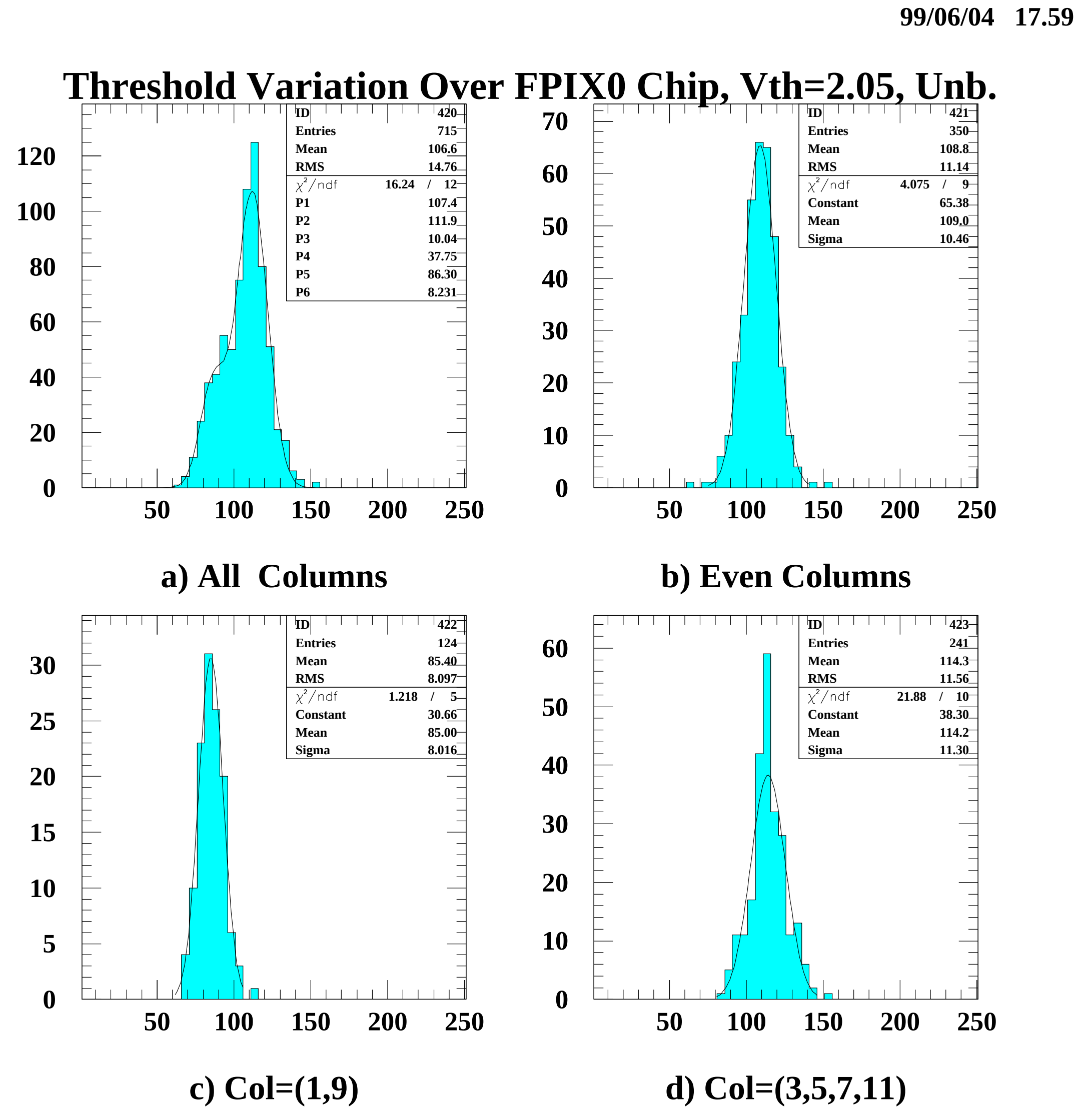

Figure 7: Threshold Distribution at 2.05V in Unbonded FPIX0 Chip

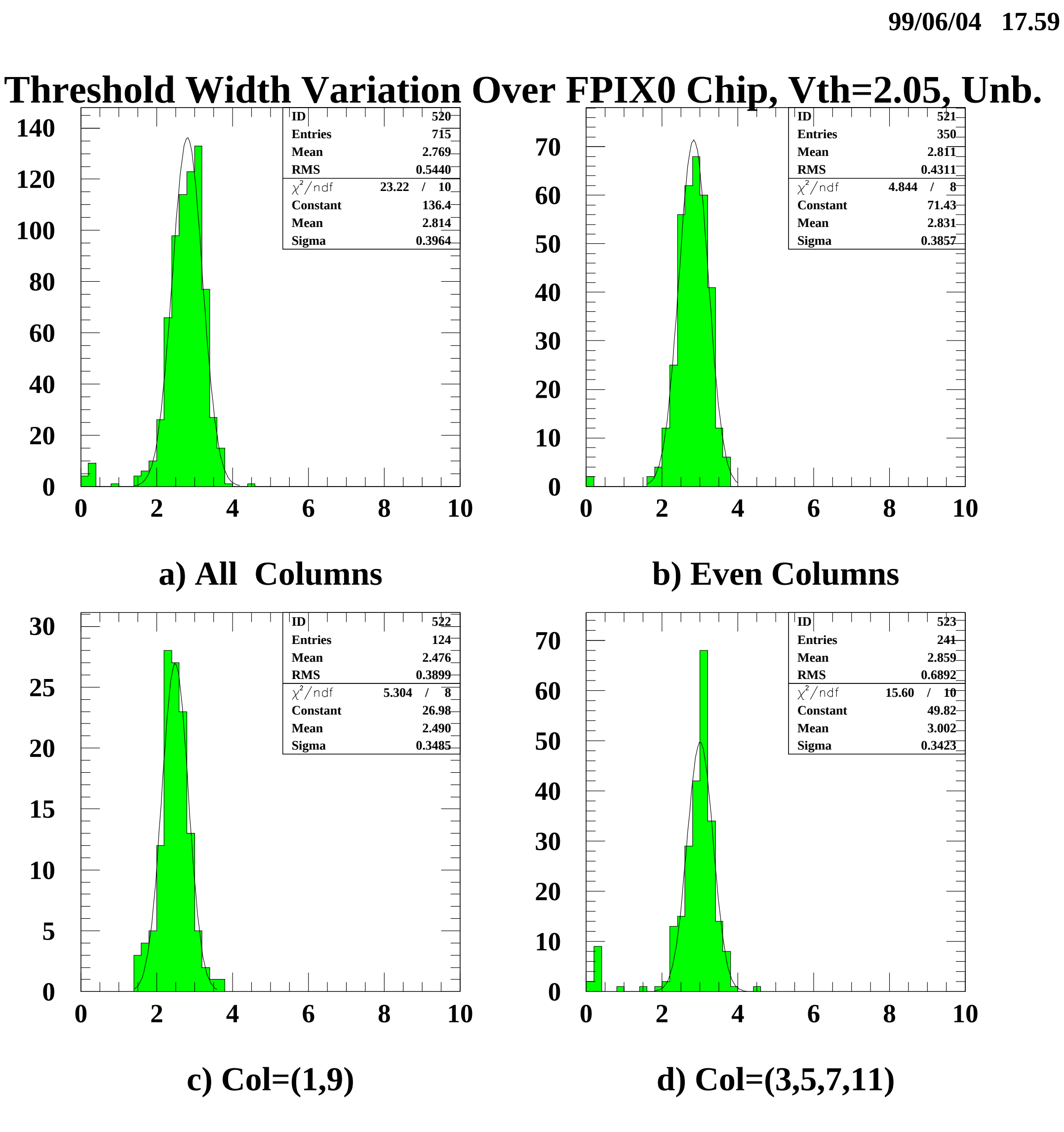

Figure 8: Threshold Width Distribution at 2.05V in Unbonded FPIX0 Chip

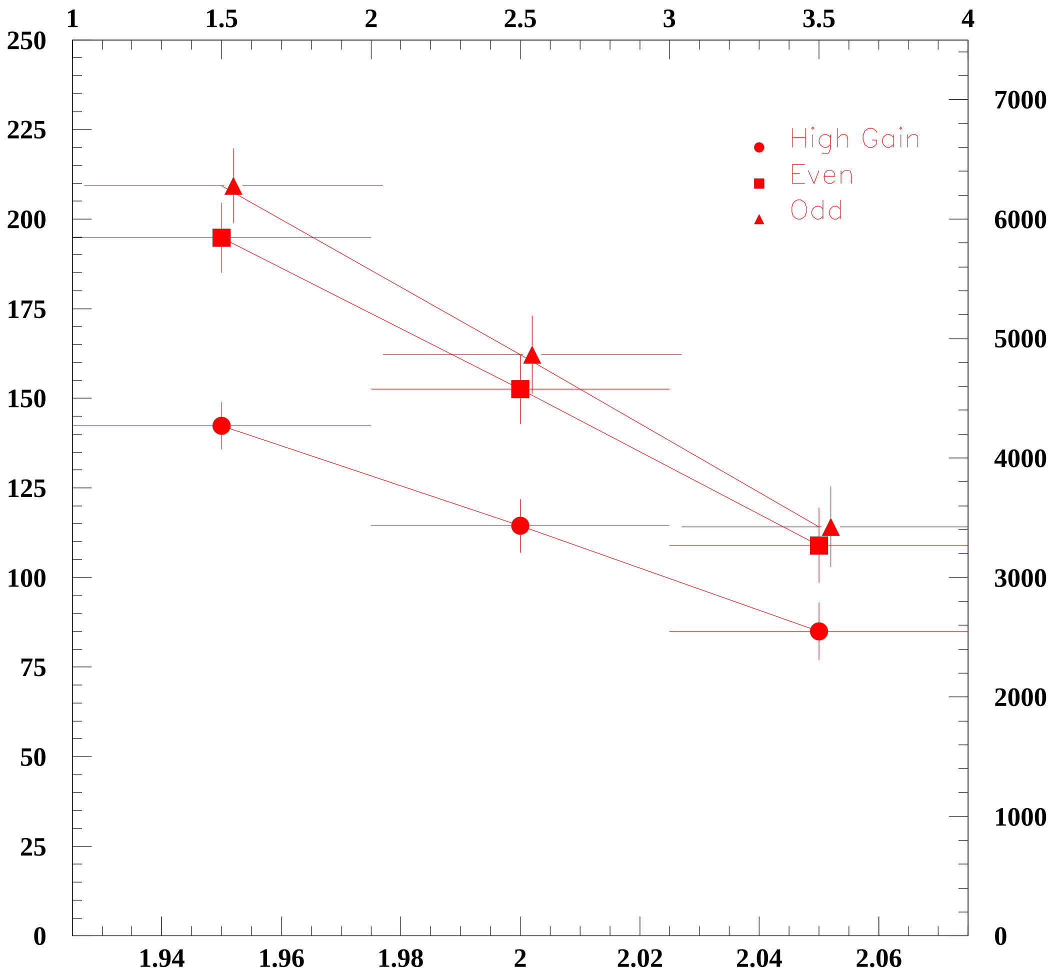

Figure 9: Threshold Variation with V_{th} (Volts) for 3 groups of cells in Unbonded FPIX0 chip. Cell threshold is in mV (Left) or Electrons (right). Error bars represent thresholds variation in group of cells.

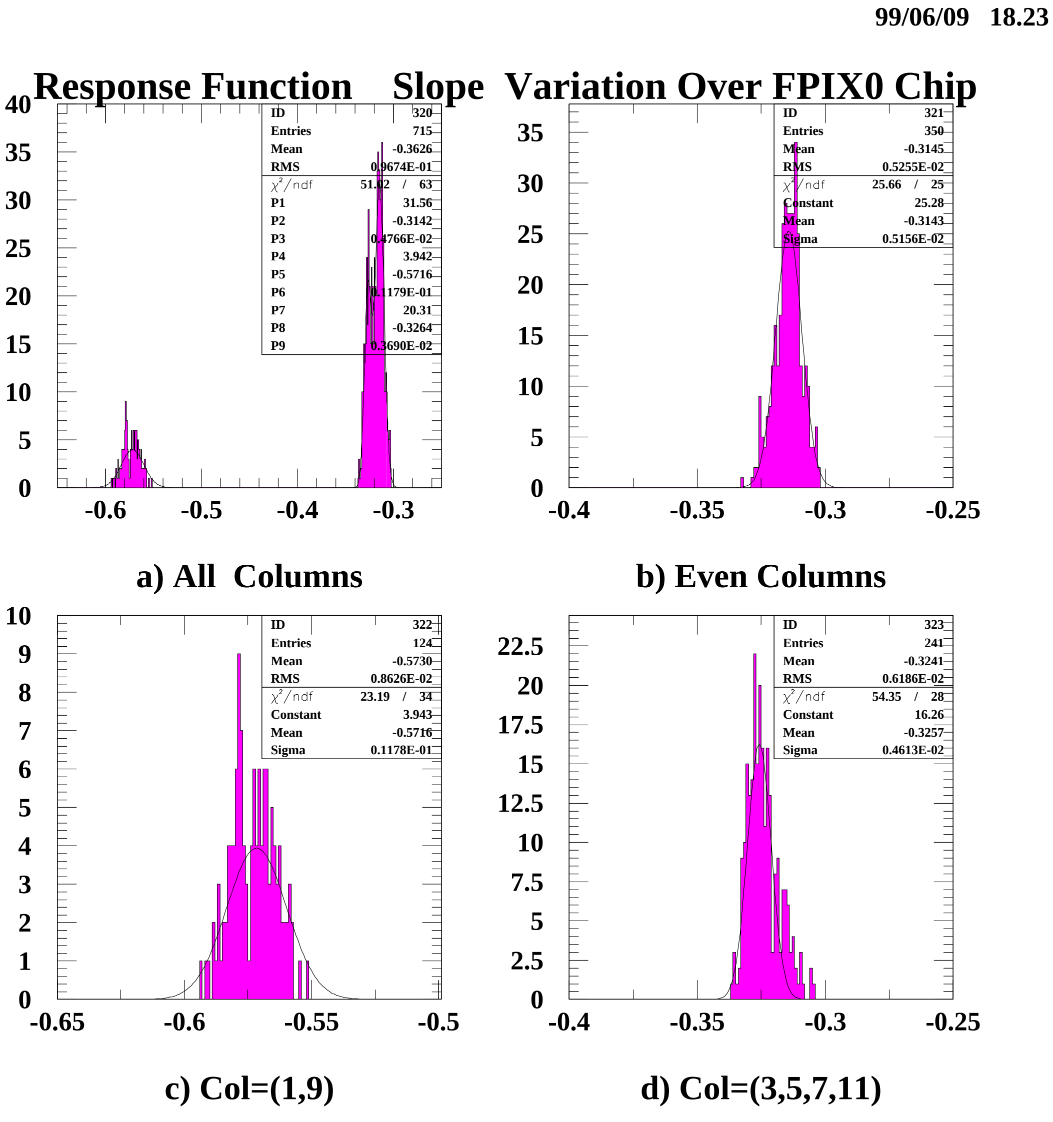

Figure 10: Channel Gains for Bonded FPIX0 Chip

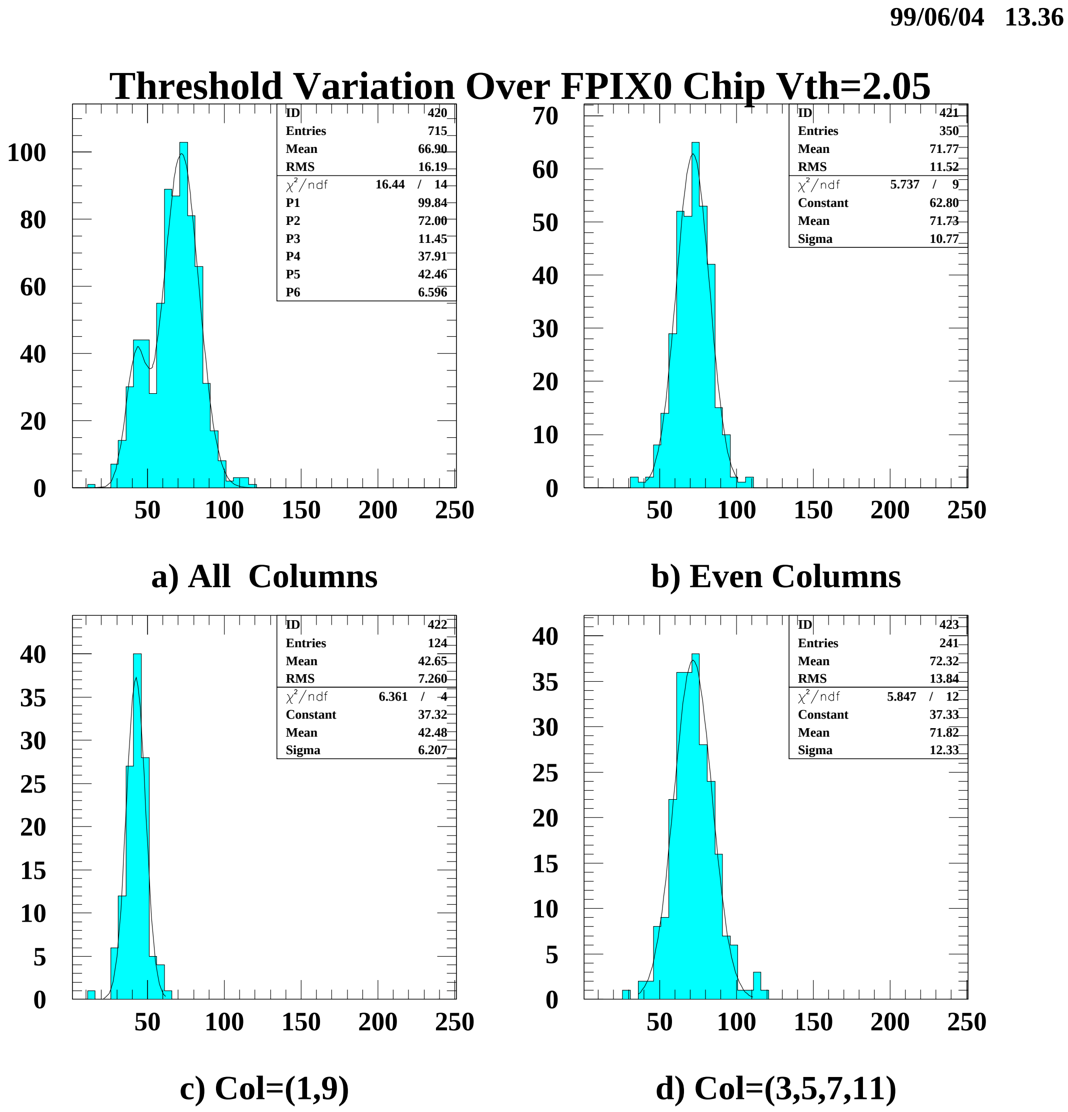

Figure 11: Threshold Distribution at 2.05V for Bonded FPIX0 Chip

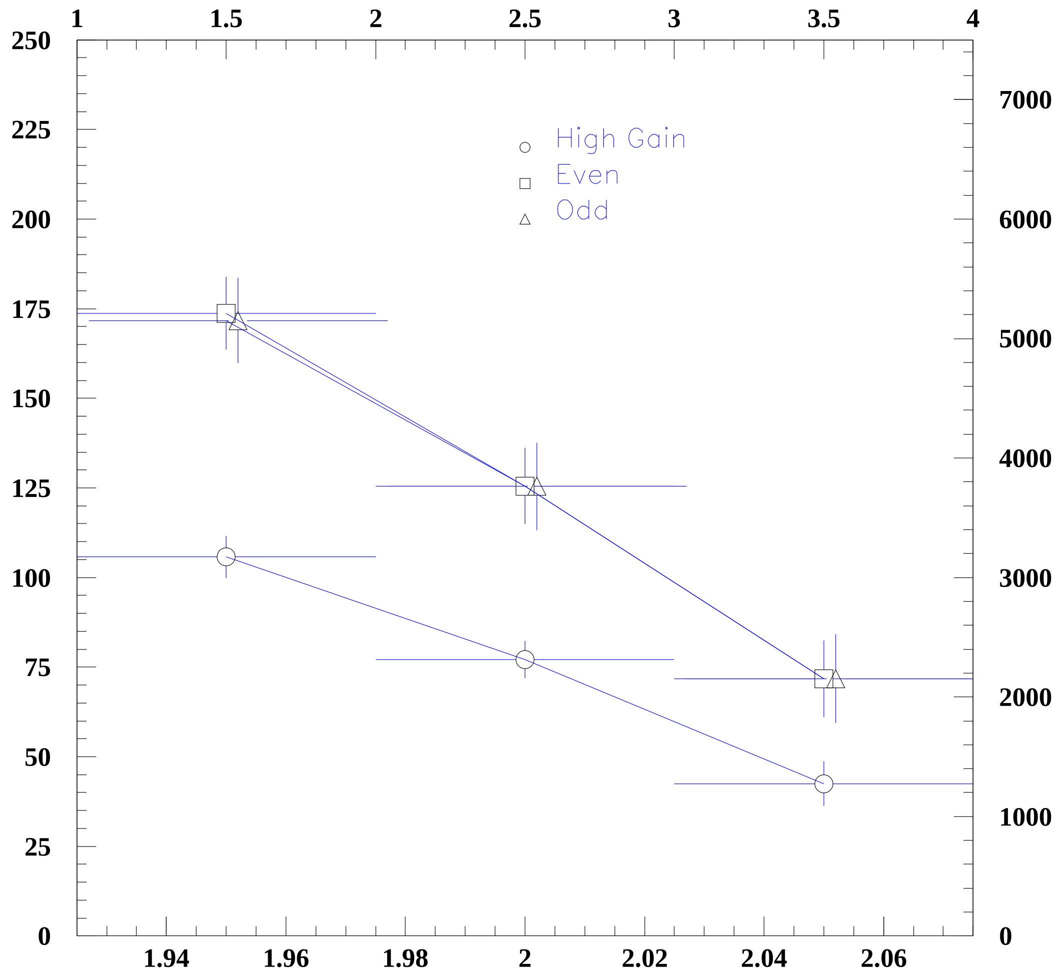

Figure 12: Threshold Variation with V_{th} (Volts) for 3 groups of cells in Bonded FPIX0 Chip. Cell threshold is in mV (Left) or Electrons (right). Error bars represent thresholds variation in group of cells.