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LG, XMS, MS, JS

Report on the analysis of the Ultimate sensor telescope used in the CERN test beam

Introduction

The PXL detector upgrade for STAR will use MAPS sensors developed by IPHC in Strasbourg. There are two phases in the development process. A prototype detector is planned to be installed in STAR for run 13. This detector was originally intended to use an earlier generation of sensors, Phase-2 which are a column parallel discriminator output sensor with a 640 us integration time. The first submission of the final sensor, Ultimate, which includes a zero suppression scheme and a 186 us integration time were tested and found to be functional and the decision was made to build the prototype detector using these first submission run sensors. A telescope composed of 3 Ultimate sensors was quickly constructed to be available for the already scheduled beam testing time at the CERN SPS. The goal of these tests was to measure the sensor performance for efficiency versus noise rate for various bias settings and verify the sensor characteristics before their use in the prototype detector. We report on the results of the beam test with 120 GeV/c pions at the CERN SPS test beam line. A telescope composed of Phase-1 sensors was also tested in the same light box. This data is not presented in this report as the goal is to show the characterization of the production sensors.

Tested apparatus

We constructed a telescope composed of three full thickness (700um) Ultimate sensors mounted onto individual sensor testing boards. There is an additional 0.062” of FR-4 PCB under each sensor in the beam direction. A schematic representation of the testing apparatus can be seen in Figure 1. A photograph of the testing box showing some sensors may be seen in Figure 2. Sensor data is taken through prototype hardware from the expected STAR PXL RDO chain (i.e. through a Mass Termination Board for buffering and into a FPGA based RDO board for event formation and then over a fiber optic connection into a RDO PC). The trigger was a coincidence of the two scintillator paddles shown. The scintillator size was ~0.5cm larger than the sensors in both directions.

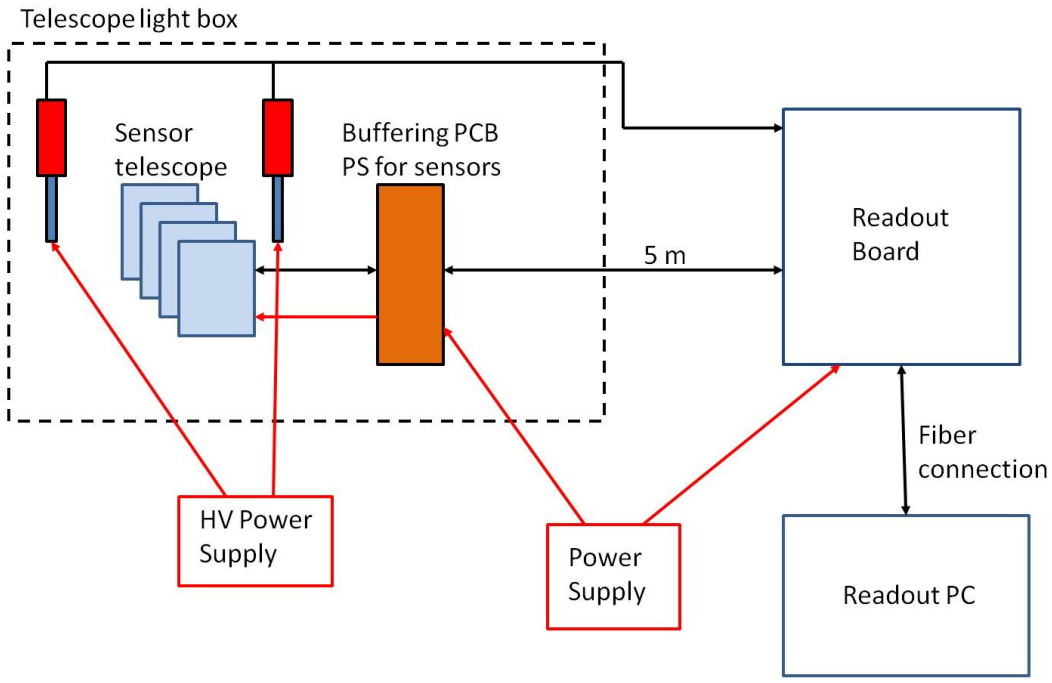


Figure 1 Schematic of the testing apparatus.

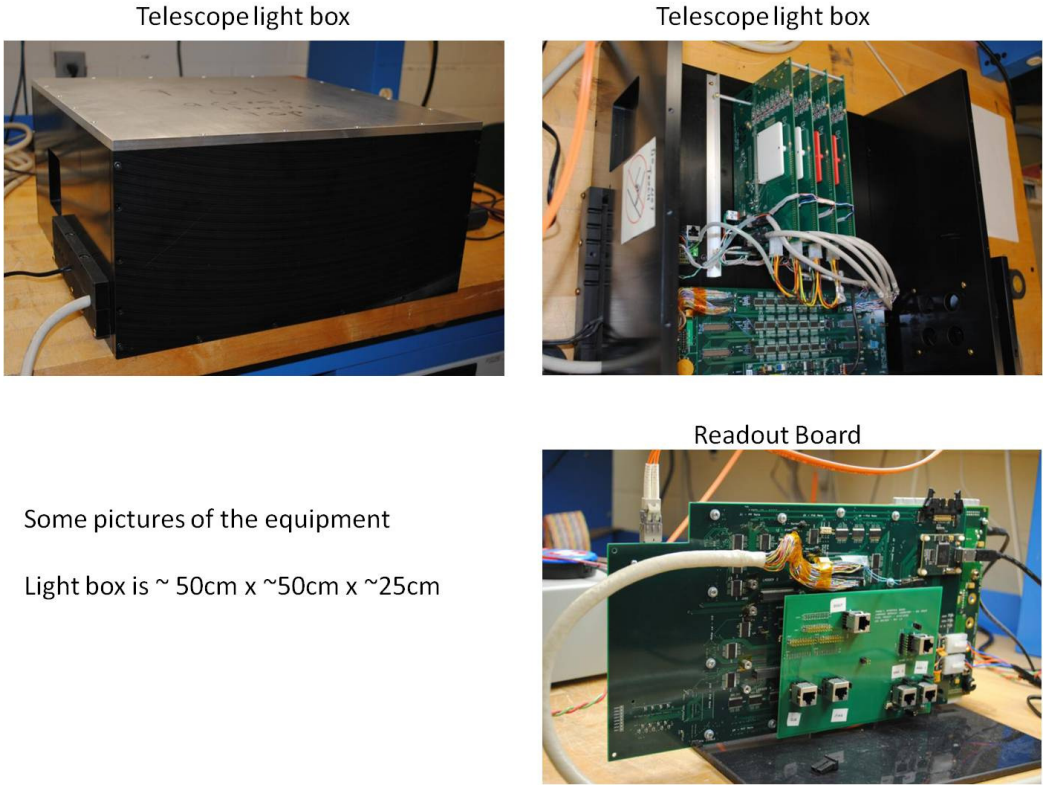


Figure 2 Photographs of the testing system components.

Figure 3 Telescope box in beamline at CERN SPS test Beam.

We took data at the CERN SPS test beam line during the week of October 14-22, 2011. A plot showing the distribution of hits on the first sensor is shown in Figure 4.

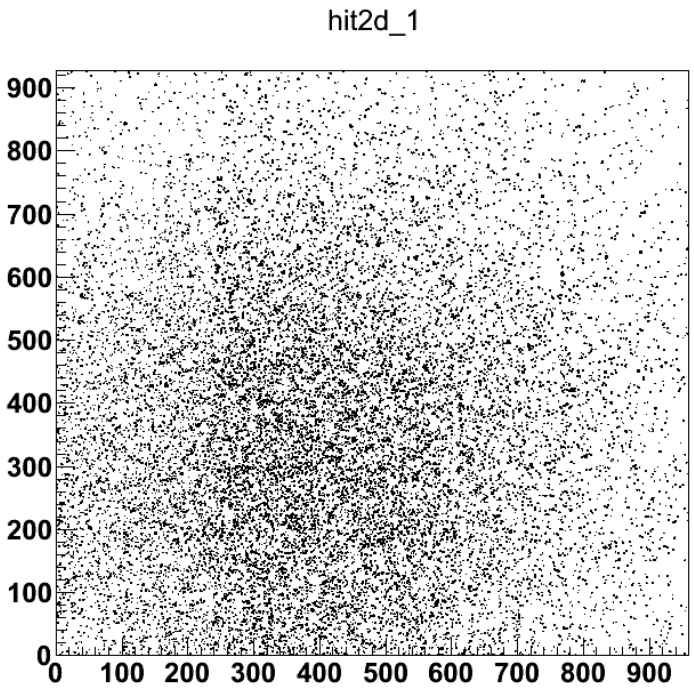


Figure 4 Hit pattern on the first sensor. This image is integrated over 20k frames.

Analysis technique

Clustering

We start by forming clusters from the hits on the sensors. The sensors are numbered (in the order of the impinging beam particles) plane _0, plane_ 1 and plane_2. Plane_1 is the Device Under Test (DUT) and all efficiencies are calculated for this sensor. Single particle can fire multiple hits because of charge diffusion. Usually hits fired by the same particle are adjacent. Hits which are connected are referred as cluster.

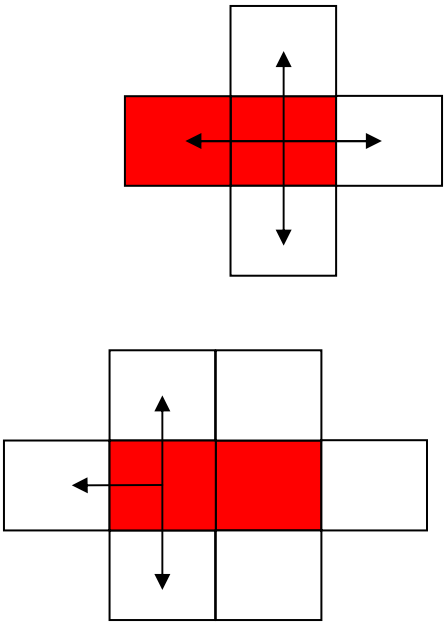


Figure 5 Cluster finding algorithm

Figure 5 shows how the clusters are constructed. We start from an individual hit and search for its direct neighbor to see if any neighbor is hit. If the neighbor is hit, we start a new search using the neighbor as the seed hit. This is iterated until all connected hits are grouped to one cluster. The coordinates of a cluster is the weighted center of all hits belonging to this cluster.

Figure 6 shows the number of hits per cluster in an average run.

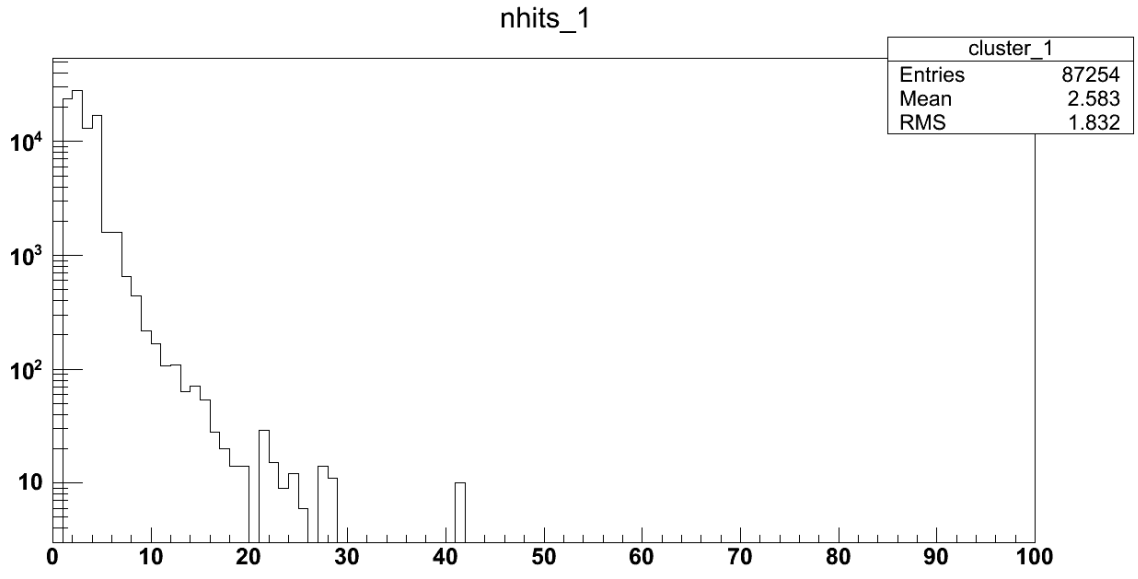


Figure 6 Hits per cluster histogram for plane_0

Alignment

After we have formed the clusters, we use the clusters to align the sensors. The sensors in the telescope need to be aligned before measuring the efficiency. We use plane_0 as reference. We also assume that all sensors are parallel. To align another plane with the reference plane, there are three parameters to be determined; dx dy and dsita. Dx and dy are the offsets in the x and y axis. Dsita is the rotation angle between two planes. These three parameters are extracted from correlation plots. The correlation plot for the x-axis for plane_1 is defined in the following way. Using plane_0 as reference, hits in plane_0 have coordinates X_i, Y_i, where 0<=i<nhit in plane_0. For any hit p in plane_1(x_k,y_k), put (X_i-x_k) in a histogram to get the raw (uncorrected) x correlation plot shown below.

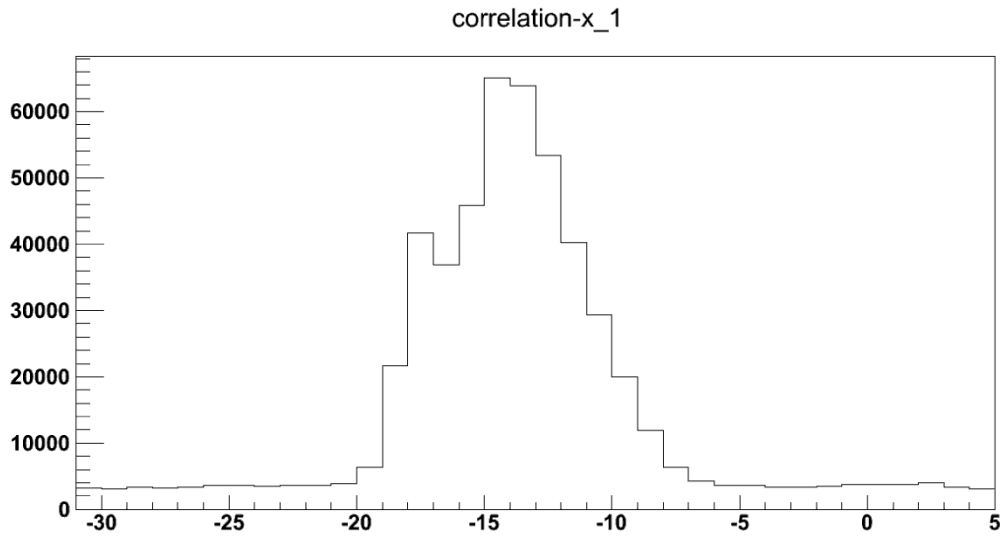


Figure 7 Uncorrected (raw) correlation plot for plane_0, Plane_2

From x correlation plot, we can get dx by the center of the peak. Dy can be found in a similar way. To calculate dsita, we divide the sensor into two parts, the upper part and lower part. We calculate the x correlation plot and extract the dx for each part. Dsita is the difference between dx of upper and lower half of the sensor divided by the distance between the hit gravity centers of upper and lower halves of the sensor. These are shown in Figure 8.

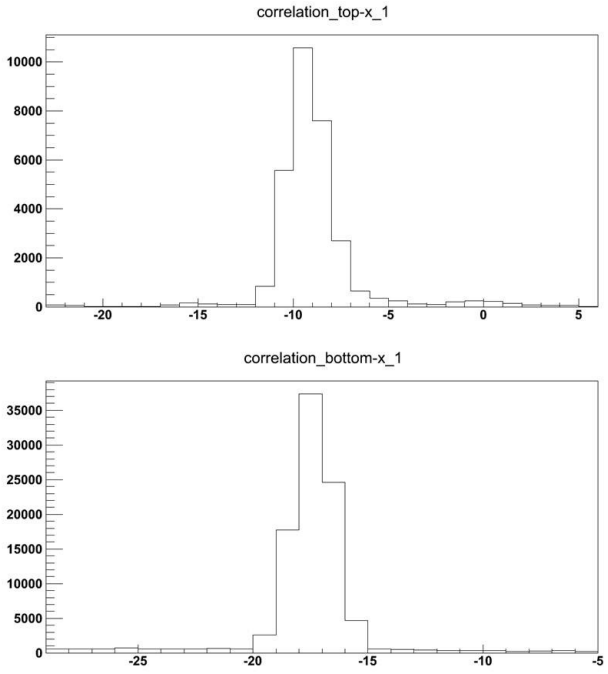


Figure 8 Upper and lower Correlation plots used to calculate dsita.

Once these corrections have been applied, we obtain the final aligned correlation plots shown below.

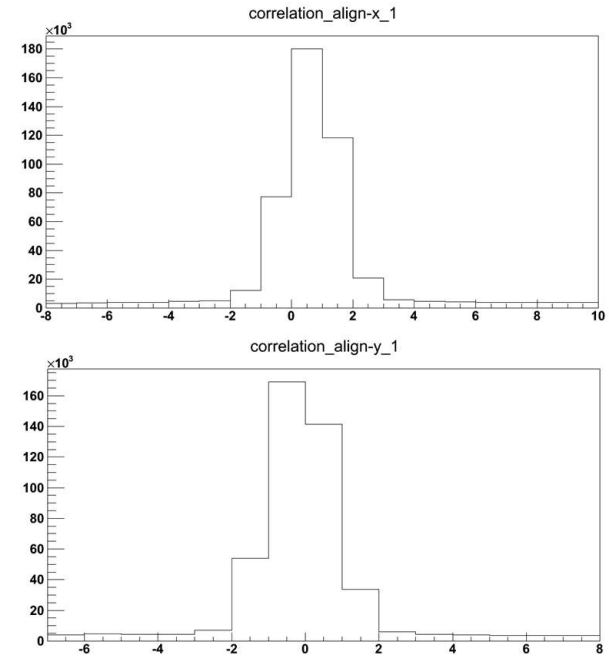
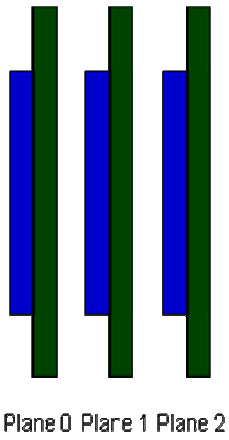


Figure 9 Final correlation plots after corrections are applied.

Efficiency

We arrive at our efficiency in the by the following method;



1. Find a cluster in plane_0 at point P
2. Open a search window of radius R around P on plane_2, if we find a (closest) cluster in plane_2 within search window radius R, we increase the counter CAND by 1.
3. Open a search window around P on plane_1. If we find a (closest) cluster in plane 1 within search window radius R, we increase the counter MATC by 1.
4. Search over all the clusters in plane_0
5. Measured efficiency = MATC/CAND

Cuts

The efficiency is a function of search window radius R and JTAG bias and threshold settings. The relation between search window radius and efficiency is shown in the plot below for the standard configuration.

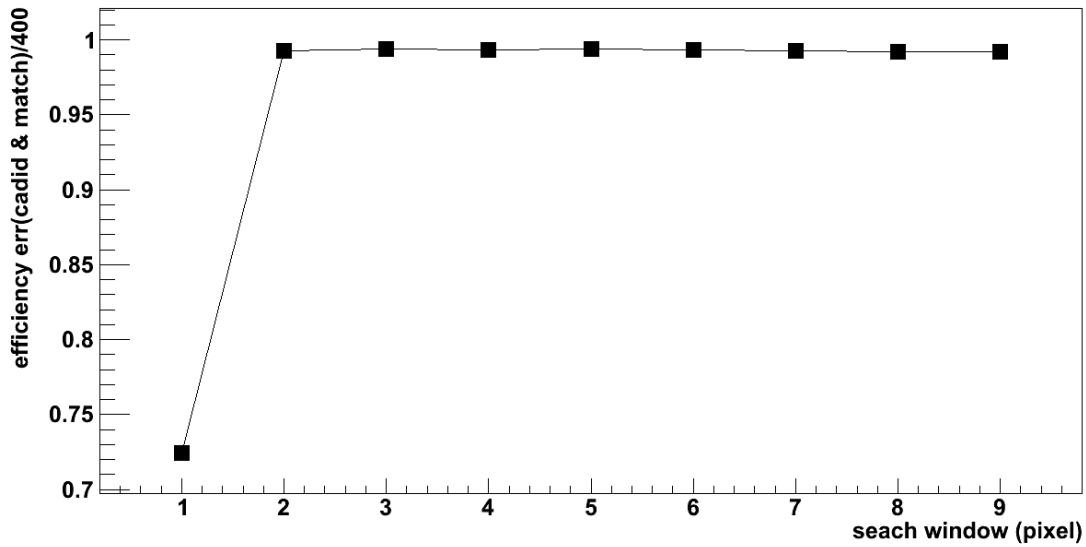


Figure 10 Efficiency vs. Search window size.

We cut on the edge for plane_0 and plane_2 for 10 pixels removing a 10 pixel band around the edge of the sensors. As the telescope was constructed quickly just before the beam test, we did not have a good set of sensors to use in the telescope. Thus, the sensor in position plane_0 was not one we would have chosen for ladder assembly and showed some anomalous behaviors. A set of rows in plane_0 were found to be very noisy in plane 0, so we also removed this region from the data analysis. The hit map in plane 0 after our cuts is shown in Figure 11.

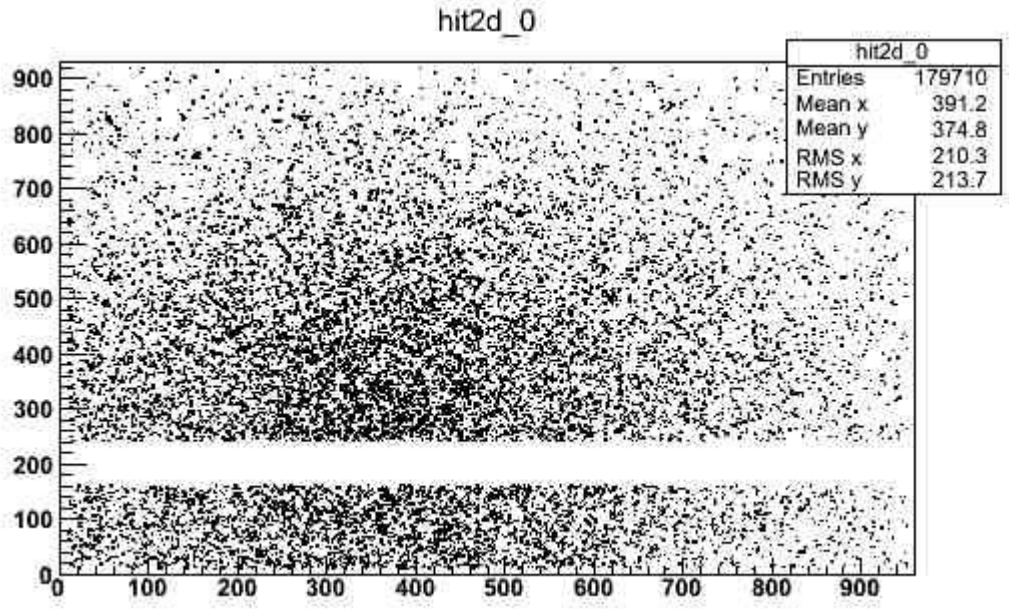
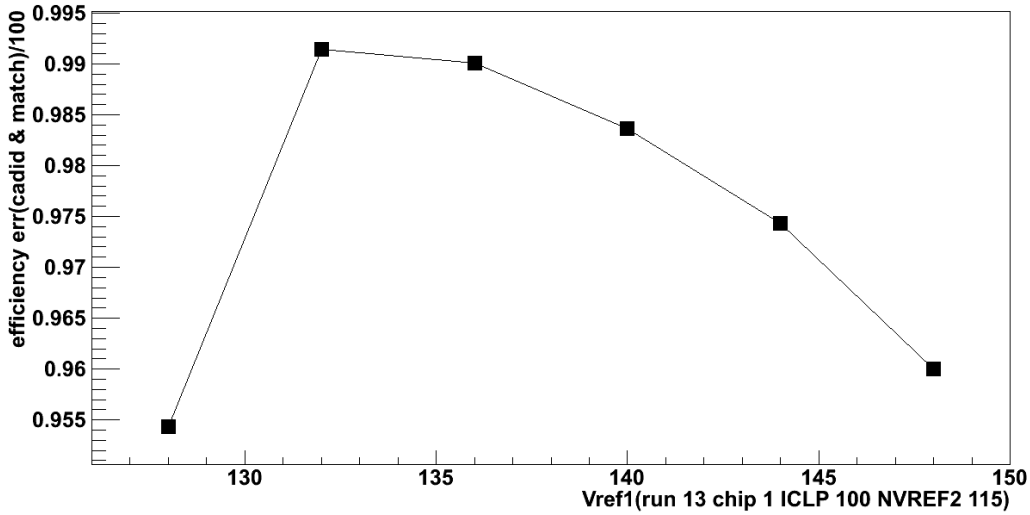
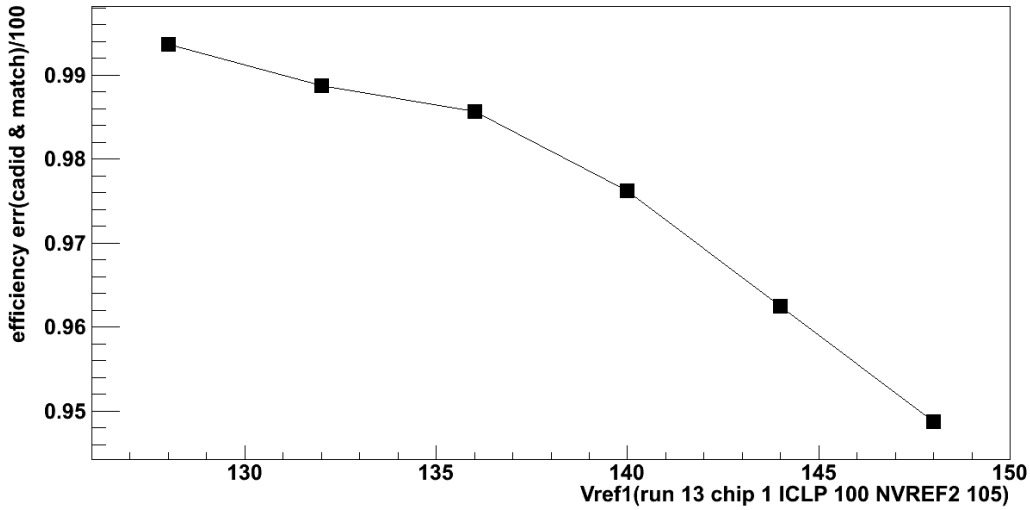


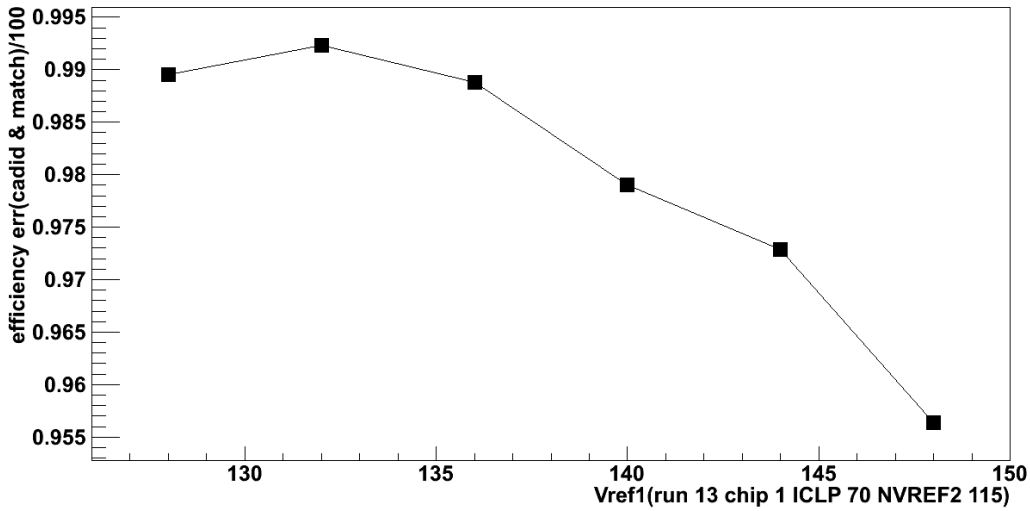
Figure 11 Hit pattern after all geometric cuts have been applied.

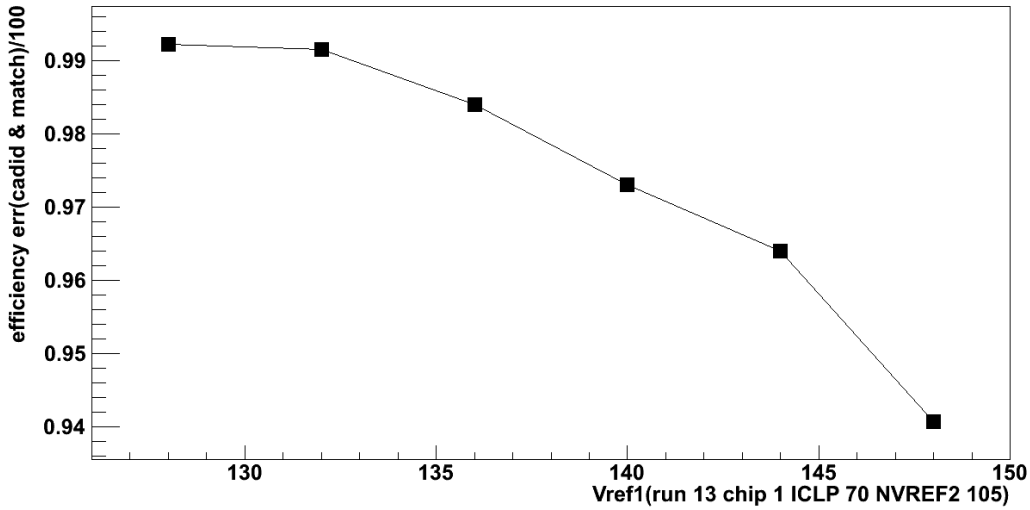
Results

We took data for a range of bias settings. We used two NVREF2 settings of DAC = 105 and 115 and two VCLP settings of DAC = 70 and 100. At each of these settings we took a range of Vref1 (threshold) settings. More information about the internal sensor function may be found in the user manual at http://rnc.lbl.gov/hft/hardware/docs/ultimate/Ultimate_UserManual.pdf. Noise runs were taken during beam off periods in the beam line to provide the corresponding accidental hit rates. The results are shown below;

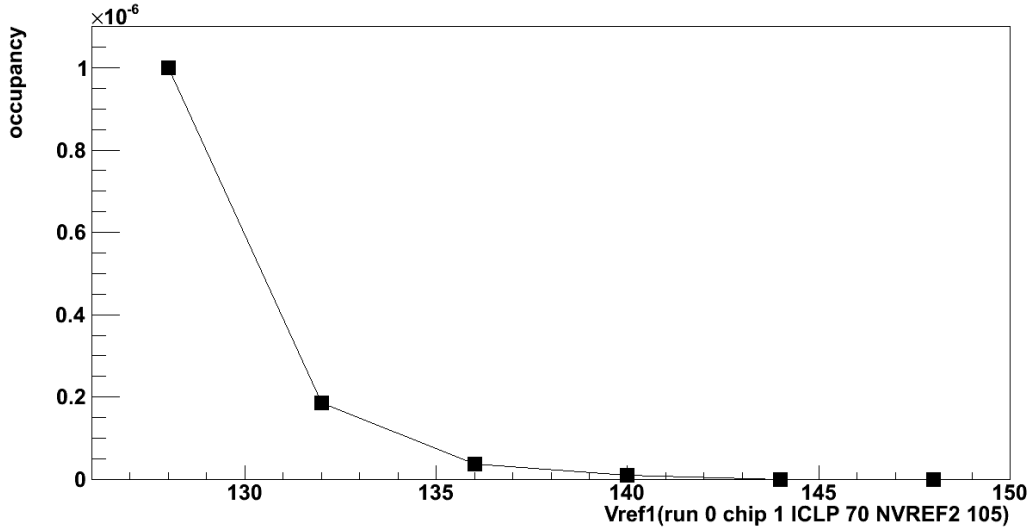

efficiency err(cadid & match)/100
0.995
0.99
0.985
0.98
0.975
0.97
0.965
0.96
0.955
130
135
140
145
150
Vref1(run 13 chip 1 ICLP 100 NVREF2 115)

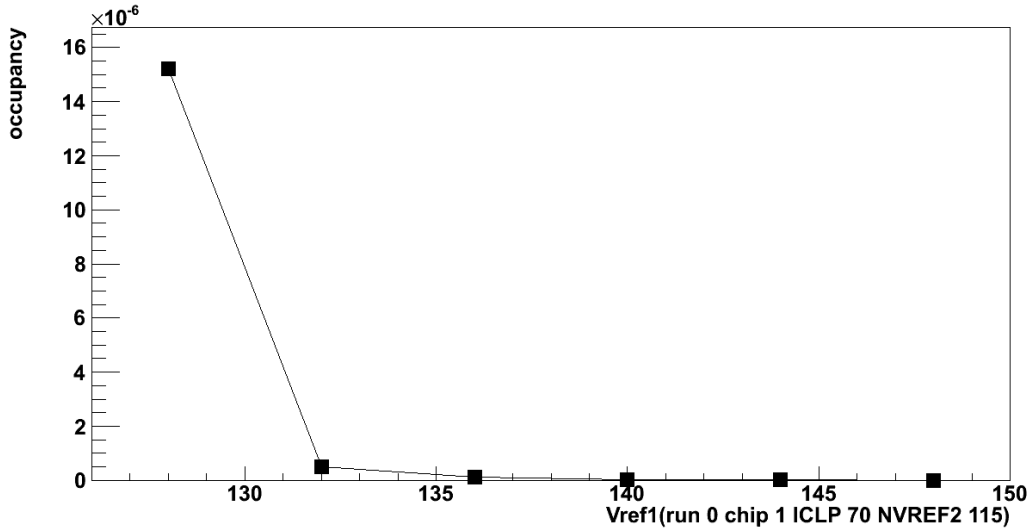

efficiency err(cadid & match)/100
0.99
0.98
0.97
0.96
0.95
130
135
140
145
150
Vref1(run 13 chip 1 ICLP 100 NVREF2 105)

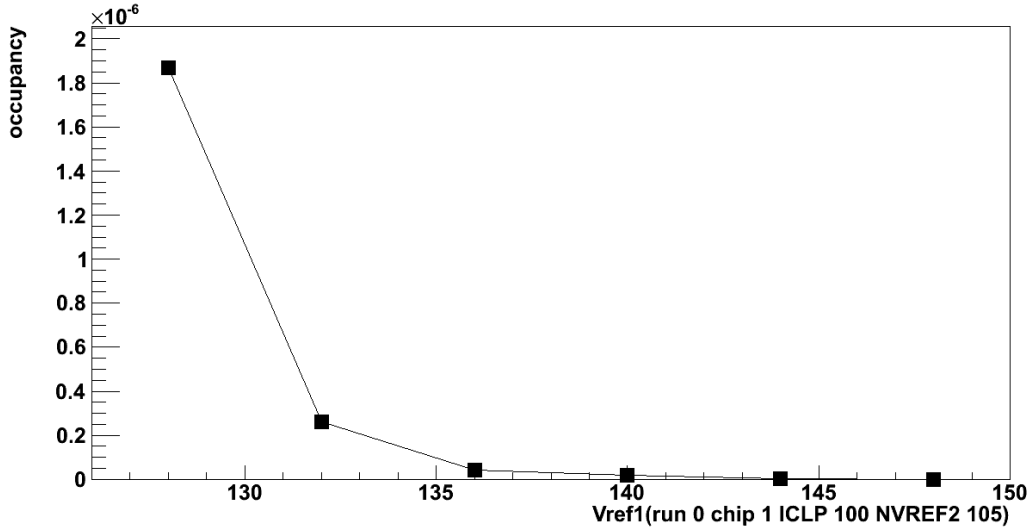


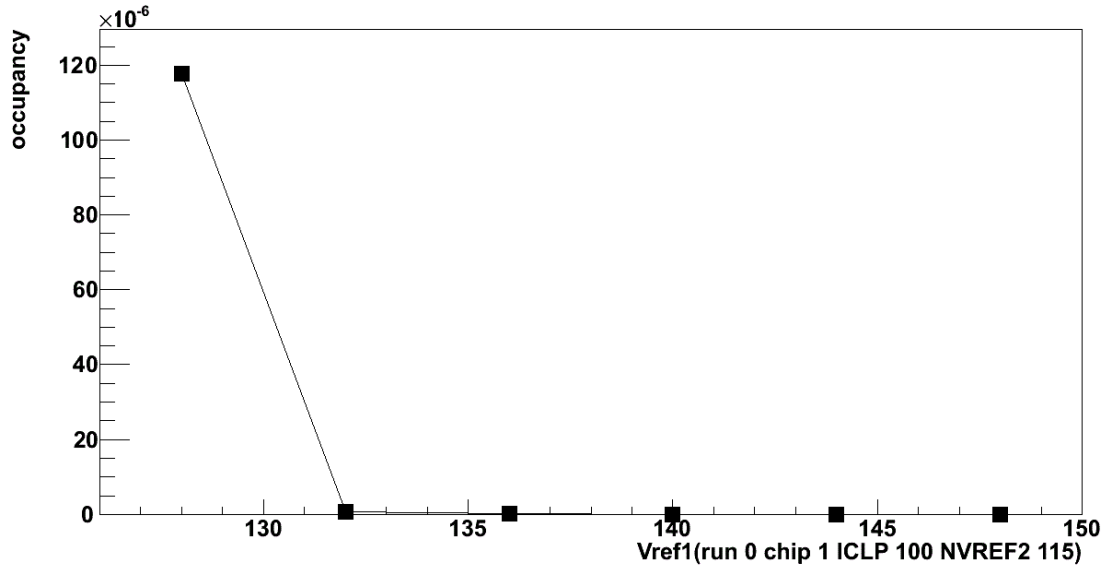


The corresponding accidental hit rates are shown below:


occupancy
×10-6
1
0.8
0.6
0.4
0.2
0
130
135
140
145
150
Vref1(run 0 chip 1 ICLP 70 NVREF2 105)


occupancy
×10-6
16
14
12
10
8
6
4
2
0
130
135
140
145
150
Vref1(run 0 chip 1 ICLP 70 NVREF2 115)





The best efficiency measured in this data set is shown below:

voltage	efficiency	Accidental hit rate	ICLP	NVREF2	VREF1
3.3v	99.36%	1.87×10^{-6}	100	105	128

We took data at a supply voltage of 3.0 volts to the sensors, but were not able to properly adjust and scale the biases on the beam line, so this data is not presented.