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HFT prototype telescope: full chain readout tests

We describe a set of tests that were performed recently with our telescope system. The primary goal of these tests was to validate the complete data readout chain and to demonstrate that the readout and data taking parts of the system work together. The results of these tests show that we will shortly be ready to advance to the next stage of testing which involves testing the assembled system and MIMOSTAR2 telescope at the Advanced Light Source.

Three complementary tests are described in this write-up. They were performed to validate the following components of the readout chain:

1. Pixel alignment in the normal readout mode
2. CDS block and mapping of hot pixels.
3. Full readout path.

The prototype telescope

A picture of the HFT prototype telescope is shown in Figure 1. The readout system composed of the motherboard, daughter card, Stratix development board and a Detector Data Link module is presented in the left picture. This system allows for the reading of data from MimoStar2 sensors that are a small prototype of the sensors to be used in the STAR detector upgrade. The architecture of the sensor readout chain is presented in Figure 2. A detailed description of this system can be found in the presentation given at Detector Advisory Committee on 30 Jan 2007[1] and on Leo's webpage.[2]

The hardware and firmware parts of the readout system are ready. At present, we have only two chips working in parallel that can be read out with this system. We are still working on the graphical user interface that will facilitate the system control. For the purpose of the tests described below, we used simple programs developed in the LabView environment that provides for simple visualization of the acquired data.

[1]Progress on Monolithic APS & associated electronics @ http://rnc.lbl.gov/~jhthomas/public/review
[2] http://www.lbnl.leog.org/rdo/index.html

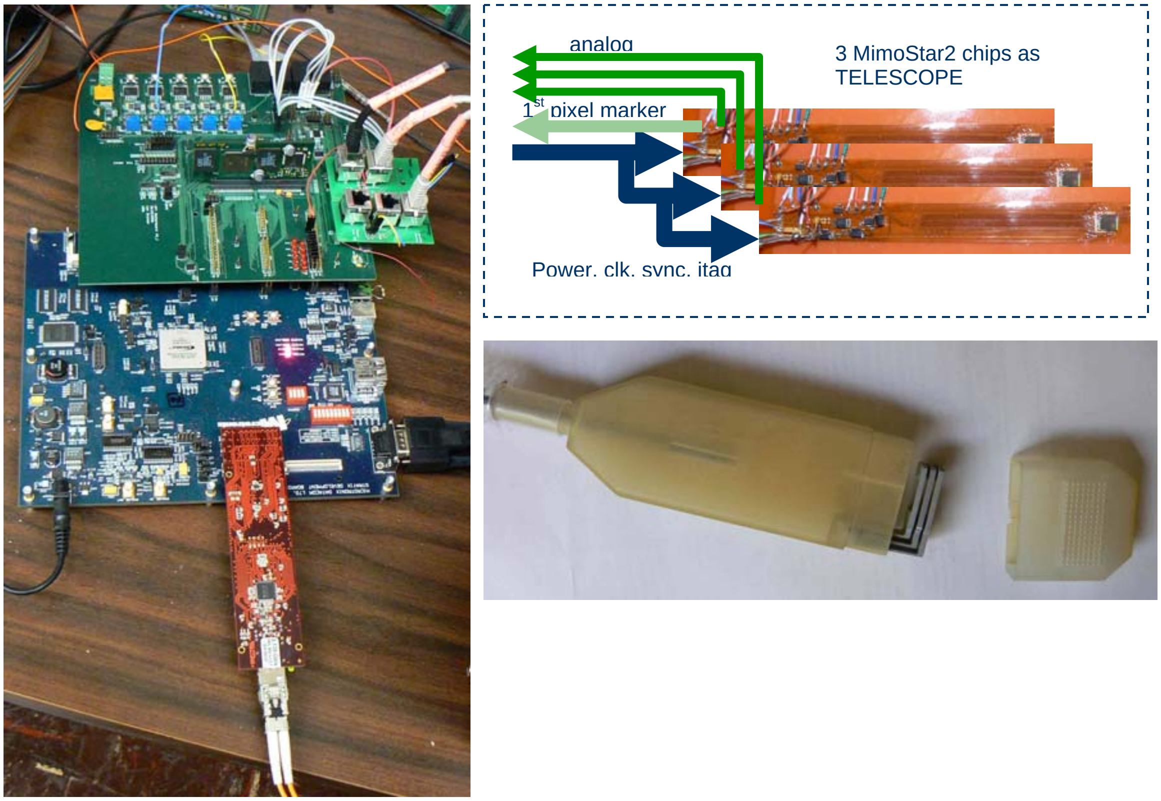

Figure 1 The HFT prototype telescope system. To the left is the assembled readout system. To the right is the schematic view of our telescope that will be build from 3 MimoStar2 chips (top). The telescope will be placed in a plastic head that will allow stacking 3 chips (bottom).

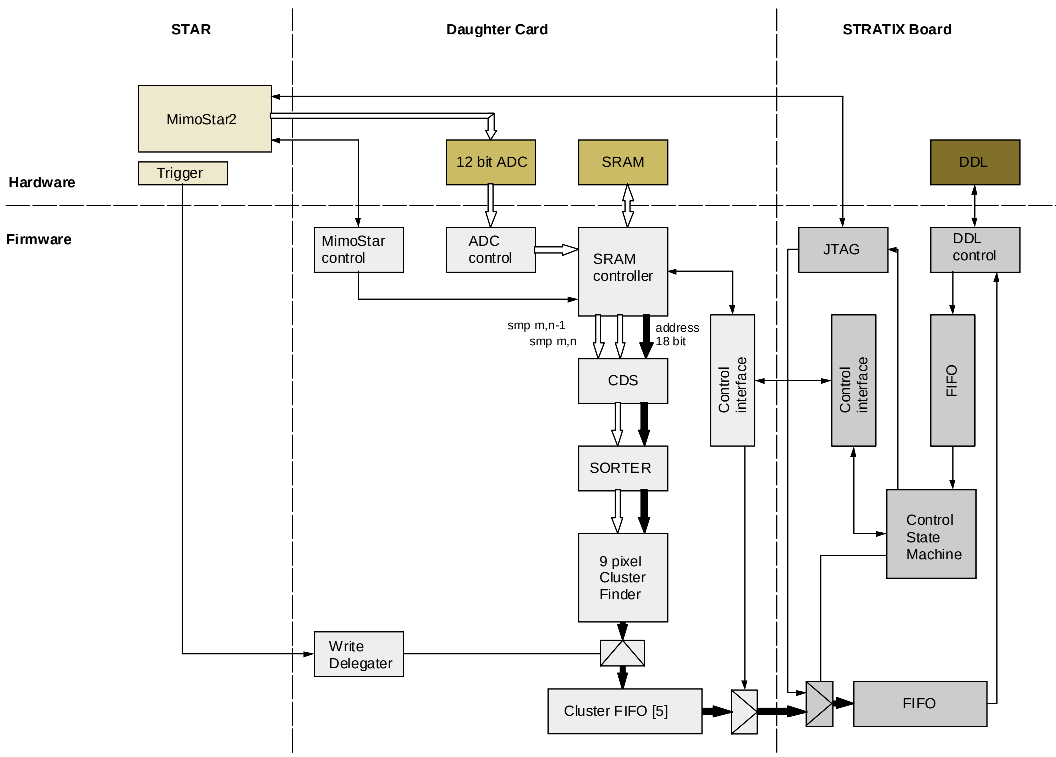

Figure 2 The architecture of the readout system for the telescope prototype. The same architecture, but scaled up to full detector size, will be used for the 4ms HFT.

Glossary

A short explanation of terms used in the test descriptions.

Cluster finder – The input to our cluster finder is a square nine-pixel box. In the current implementation, signal clusters are located based on two thresholds: on the central pixel, and on one of the 8 closest neighbors. The output of the module is the address of the central pixel in a cluster.

Cluster FIFO – a FIFO where addresses coming form the cluster finder module are stored. In response to the trigger, the FIFO is active for the time equal to the complete readout time of the sensor (4ms). After this time the collected data are sent to the acquisition PC. The depth of the FIFO is adjusted to allow approximately the same number of entries for each sensor as it is foreseen for working in the STAR environment. Some safety margin is included. The FIFO can not store data for a large number of pixels due to limited resources in the FPGA

Full frame readout – In this readout mode most of the readout chain is bypassed. The modules of the CDS, sorter, cluster finder and cluster FIFO are not used. The 12-bit data from ADCs goes trough the DDL to the acquisition PC resulting in a large and continuous data flow. This mode allows calibrating the MimoStar2 sensors with an iron-55 source. Data acquired in this mode is analyzed offline. The full frame readout mode is also a very good debugging tool.

Normal readout – This is the default readout mode for our system. The whole readout path presented in Figure 2 is used. This is a triggered mode which means that data is sent to the acquisition PC only in response to an external trigger. Data sent to the PC consists of (18-bit) addresses of pixels that contained signals high enough to pass thresholds set in the cluster finder module.

Hot pixel map – a pixel is considered hot when it exhibits a very high signal fluctuation resulting in noise much higher than for other pixels. Even if initially the sensor is free of hot pixels they can appear as a result or radiation damage. High noise of these pixels may result in fake hits not associated with impinging particles. The hot pixel map allows masking hot pixels based on the noise criteria so that the signal going into the cluster finder is set to zero.

Test 1

Goals: Demonstrate that the telescope system is capable of readout of more than one chip at the same time. Verify that the alignment of pixel addresses in all parts of the readout chain is correct.

Testing procedure: We took raw, full frame data for both chips (one chip at a time). Visualization of the data was performed with a LabView based program that is dedicated to chip calibrations and allows us to see the DC levels of all pixels. Based on this, we found DC level thresholds that allowed us to cut off a limited number of pixels that had DC levels significantly different from majority of pixels. These thresholds were then implemented in the cluster finder module. The CDS block was disabled (we have previously tested this block and know that it works) to allow the passing of raw data into the cluster finder. In the normal readout mode a single event was triggered. The image reconstructed form pixel addresses was compared to images obtained in the full frame readout mode.
Two limitations of this test are that the CDS block was not tested and that only one (central pixel) threshold was used in the cluster finder.

Results: Full frame data (12-bit values) collected for both chips are displayed in the left column in Figure 3. Only a small fraction of the pixel array is presented for clarity. Pictures in the right column present data collected in normal readout mode. The position of pixels that passed the threshold set in the cluster finder was reconstructed based on the acquired addresses.

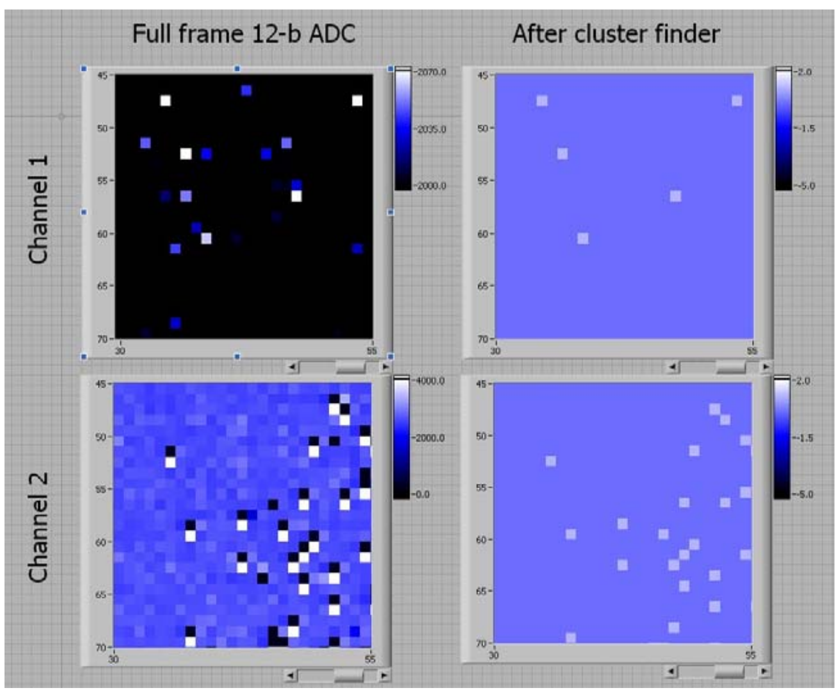

Figure 3. Successful readout of two chips in the telescope system. Left column shows DC levels of pixels in a small subsection of the pixel array. Pixels that are related to the distortions seen in the middle of the frame are clearly visible. The right column presents reconstructed images of pixels that passed high threshold in the cluster finder module. Data is correctly aligned throughout the whole readout chain.

Conclusions: We successfully readout out two chips and reconstructed correctly the addresses of pixels that passed the threshold set in a cluster finder module. The location of each pixel corresponds exactly to what we see in the full-frame data set.

Test 2

Goals: Test the readout chain including the CDS block. Validate the functionality of the hot pixel map.

Testing procedure: We used LEDs placed above chips to induce signals in the pixels not masked by the hot pixel map. The time that LEDs were switched on correlated with the trigger signal that is required by the normal readout mode. To limit the number of pixels that would generate high signals and lead to overflow of the cluster FIFOs we masked certain areas of the chips. This was accomplished using the hot pixel mask. This way we set the number of pixels that could pass the cluster finder module using the technique where only the threshold on the center pixel was set. The same mask was used for both chips. The addresses seen correspond to unmasked pixels that were illuminated by the LED and thus selected by the cluster finding algorithm after successful CDS.
A limitation of this test is that uncalibrated LEDs were used to induce signals in the MimoStar2 chips. In addition, only one threshold in the cluster finder was used.

Conclusions: Based on addresses registered by the telescope system we reconstructed the unmasked image. The images of both chips acquired at the same time are presented in Figure 4. Each row corresponds to one chip. The first plot in a row is the image reconstructed for the whole detector. The next two images show the first two sub arrays of the chip. In MimoStar2 these two sub arrays correspond to real pixels. The other eight sub arrays are virtual and allow emulating behavior of a larger chip. Notice that two lines in the letter S are missing. This is due to marker pixels which correspond to constant voltage only. However, at this time, this voltage level is still quite noisy in our system. This allowed one marker pixel to show up in the first line of the second sub array of chip1. This shows successful operation of the CDS block and the hot pixel map.

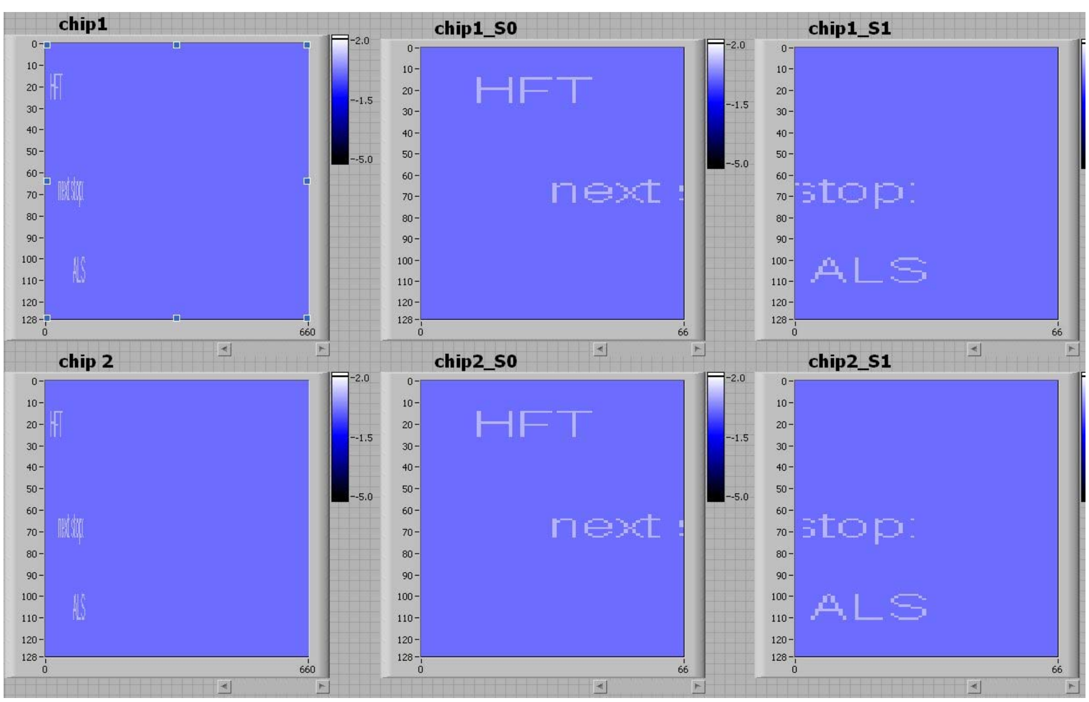

Figure 4. Readout of the telescope system when pixel arrays were masked in such a way to reveal only a pattern with the following text "HFT next stop: ALS".

Test 3

Goals: Test the complete readout system including two thresholds in the cluster finder. Compare results of raw data analysis (LabView software) with data coming form the telescope system.

Procedure: The test was performed with a ^{55}Fe source. Only one chip was tested. Probably the best and certainly the easiest way to compare results from the full frame data analysis and from the full readout chain is to look at them statistically. The assumption was that if we can get similar ratio of clusters in both cases then it would be a proof that the system and cluster finding algorithm work.
Data:

- 1000 events of full frame data were taken and analyzed with the LabView analysis software.
- 100 events were acquired in the normal readout mode.

Conclusions: The results are summarized in Table 1, where average number of hits per frame is presented. The results are very similar. The complete telescope system seems to work as expected.
Slightly higher number of hits per frame, in case of the LabView analysis, results probably from a weaker condition on the second cut – the sum of 8 surrounding pixels should exceed the threshold. In case of the telescope, one single pixel among these 8 has to have signal passing the second cut. It is possible to implement either algorithm in any of these systems but it would require more development effort than was foreseen for these simple tests.
An example of a single event is presented in Figure 5. The left picture shows a frame from the full frame data analysis and the second picture is from the normal readout mode.

Table 1. Average number of hits per frame

System; thresholds used	Sub array0	Sub array 1
LabView; center>37, summed ring>11	2.2	1.6
Telescope; center>37; one on the ring>11	1.8	1.5

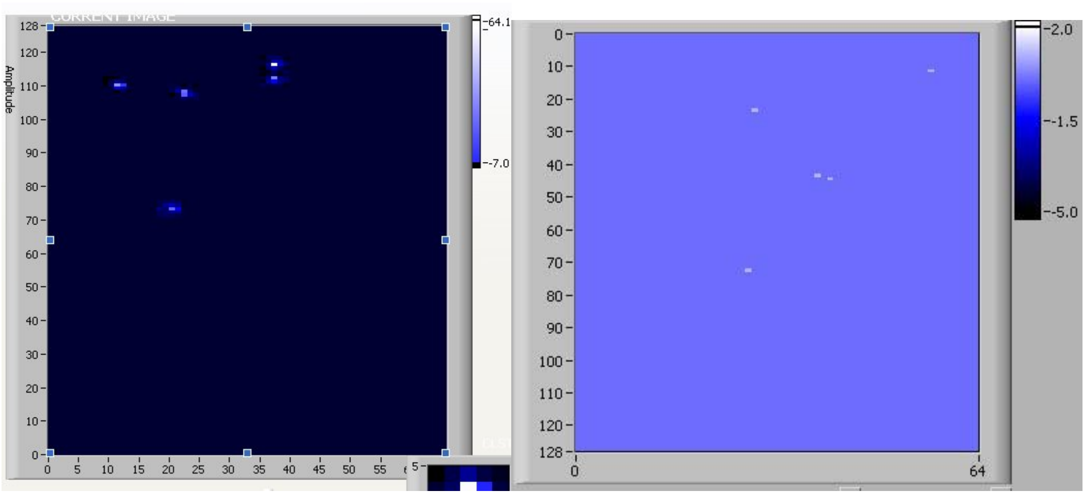

Figure 5. Images of iron source after full frame data analysis (left) and reconstructed based on pixel addresses (right). In both cases similar statistics are observed. In the second case only 64 columns are visible because the marker pixels (originally the first two columns) were removed.

Note: In the right plot in Figure 5 marker columns were removed due to the fact that on both sub arrays they were generating some entries at a rate of about 94 hits per 100 frames. This behavior can be easily explained if we look at the noise distribution of these pixels (Figure 6).

94 entries in 100 frames per 512 marker pixels (2 columns of 128 pixels in 2 sub arrays) result in probability of a hit at about 0.18% level.

On the other hand, assuming close to Gaussian distribution of the noise of marker pixels, the chance that the signal passes the first cut (37 ADC counts) that is close to 3 sigma (~40 ADC counts) is higher than 0.1%. The second cut on a neighboring pixel (>11 ADC counts) is below the mean noise level. This is a strong indication that the test was performed correctly.

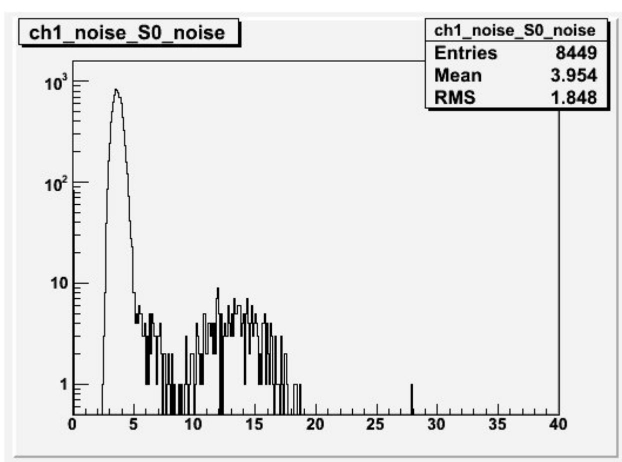

Figure 6 Distribution of noise for all pixels in one sub array of the MimoStar2 chip mounted on a kapton cable. There are 256 marker pixels and 8192 regular pixels in one sub array. The first peak corresponds to mean value of the standard deviation on regular pixels (mean ~3.7). The second, much lower peak corresponds to the standard deviation of signal from marker pixels (mean ~13.3).