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The HiRes FADC Data Acquisition System

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Abstract

The HiRes II detector located atop Camelsback Ridge at Dugway Proving Ground in Utah operates 42 optical telescopes instrumented with flash-analog-to-digital converters (FADC's). We describe the system and provide a status report on its performance.

1 Introduction

The 42 telescopes on Camelsback are housed in pairs in 21 mirror buildings, which shield the telescopes from sunlight or bad weather. Each telescope has a camera of 256 phototubes, each tube a pixel of one degree field of view. After minimal analog processing, phototube signals are continuously digitized at 10MHz and digitally delayed 819μsec to allow formation of a preliminary trigger for deadtimeless transfer of snapshots to a local buffer for further processing.

The system uses inexpensive, low-power, conventional modern commercial CMOS electronics, including 8-bit FADC's, programmable logic (PLD's) and small 16-bit digital signal processors (DSP's). Embedding digital logic in PLD's allows the logic to evolve without physical modification of initial board designs, in addition to providing flexible high-density inexpensive logic. The DSP provides signal processing, control and monitoring of the board functions and communication with other modules. To reduce noise sensitivity, most signal processing and triggering is digital. Communication between buildings uses optical fiber. The site may be operated remotely, with no nearby human operator.

2 Readout and Control Communications

The mirror buildings are operated remotely from a central facility building, which has a single VME crate linked to a commercial UNIX platform and containing an interface to a site-wide optical fiber communication system. Each mirror building has a single enclosed electronics rack housing the FADC electronics for two mirrors and a small control crate. The detector is operated in the dark, often in very cold weather, with no operator intervention. Extreme temperatures, lightning and rodents create a hostile environment for the detector electronics. The only signal connections between buildings are optical fiber. We monitor and control all functions remotely.

The raw data rates are high. The 42 telescopes have 10,752 phototubes and 13,440 FADC channels, including the row and column sums. A single 25μsec snapshot yields 3.36Mbyte of data. A steady flow of monitor data, control commands and trigger communications must be delivered promptly. Each building is linked to a building on either side with bi-directional 30 Mbyte/sec optical fibers that provide two independent unidirectional serial busses. A unidirectional fiber link, from the central facility, supplies the site-wide, equal-time, 10MHz measurement clock along with direct communications, including hardwired control and DSP code for the distributed system. The links to neighboring buildings provide both fast site-wide trigger communications and an independent path for data transfer.

3 Signal Processing

Preamplifiers in the phototube bases amplify and shape the tube outputs, which are transmitted differentially on twisted pair cables to the FADC modules housed in the single rack. Each **FADC module** receives signals from a vertical column of 16 phototubes. The incoming signals are shaped and amplified with separately variable computer-controlled gains and offsets, and digitized every 100ns by 8-bit FADC's.

The four-pole filter has an impulse response of 120ns and a final summed FADC measurement of 1 FADC count per photoelectron. The digitizations pass though an 8K ring buffer that provides a fixed delay of 819μsec to allow adequate time for first level trigger formation.

A first level trigger automatically transfers a block of data from the ring buffer to a 32K event buffer, for all FADC channels within the crate, for possible further processing. Since the second memory can hold 64 snapshots of 50μsec each, signal processing, selection and readout are all deadtimeless unless something fills up.

4 Trigger System

To form a first level trigger and to increase the dynamic range of signal measurement, we form 16-tube analog sums for each of the 16 horizontal and 16 vertical rows of tubes. Each FADC module digitizes one vertical and one horizontal sum with 16 times lower gain than the individual channels. The analog sums are also digitized with higher gains and a longer shaping time and digitally discriminated to provide horizontal and vertical trigger profiles to the Trigger/Host module.

The **Trigger/Host module** receives the horizontal and vertical trigger profiles: 32 threshold comparisons every 100ns. A shower signal appears as light sweeping across the cluster, appearing in one analog sum as it disappears from a neighboring sum, but moving with a direction and time scale that varies from shower to shower. To detect these space-time adjacencies, we first double the apparent pulse widths, using 7-bit counters that increment when the signal is above threshold, decrement otherwise, but never underflow or overflow. Requiring a counter and its immediately higher neighbor be nonzero provides a loose two-fold coincidence. Repeating the process with another layer of 7-bit counters provides a loose three-fold space-time coincidence.

The trigger hardware interrupts the module DSP whenever a three-fold coincidence has been followed by a programmed period without coincidence. The DSP then reads the times of the first and last coincidences and the coincidence pattern, with additional encoding to aid subsequent trigger processing. Triggers are passed to the Link module, which can broadcast triggers site-wide. A first level trigger transfers a snapshot, typically 50 microseconds, for each of the 320 FADC channels in the crate, to a second memory capable of storing multiple events for a total of 3.2msec. Each trigger is then confirmed or rejected by the crate that generated it, by having DSP's on the FADC modules scan with a digital filter matched to the trigger channel filter time, looking for a response above threshold in the individual channels at the trigger time. Confirmation or rejection is then broadcast to the original recipients of the first level trigger. A confirmed trigger starts a detailed scan of all snapshot windows associated with the trigger. This first level trigger requires three or four adjacent rows of tubes, each detecting at least 35 photoelectrons per microsecond and a minimum total of 50 photoelectrons per row.

In Figure 1, we show one of the first air showers observed by a telescope at Camelsback instrumented with FADC electronics. The image required more than 7μsec to sweep across about 15°. Individual tube profiles are presented for eight tubes in the center of the shower, in descending elevation. After the initial trigger, a snapshot window of nearly 50μsec was transferred to the second memory for all channels. After the successful confirming scan, the full window was rescanned. The raw data that was selected for readout is plotted in full for the eight tubes: 10μsec sequences centered on the maximum response of the digital filter. In Figure 2, we show an event display for a laser shot seen in three mirrors.

5 Monitoring and Calibration of Sensitivity

To establish and monitor the phototube sensitivity, or response to a given number of photons, we have a variety of calibration techniques. First of all, the gain and baseline of the FADC measurement is programmable and verifiable independent of the tube response. We have a variety of stable calibrated light sources, including light sources distributed by fixed fibers as well as lasers and flashers in the sky. We can also determine independently the single photoelectron response.

A small module within the control crate continuously monitors the low voltage power at each supply and at the load; temperatures in the crates, the power supplies, phototube bases and cluster; status of light switch and door limit switches; outside light level; and HV power supply voltage and current. The module controls power supplies; can open and close the door; operates a programmable 32-channel pulser in each cluster; and controls a heat exchanger in the rack and heaters in the clusters.

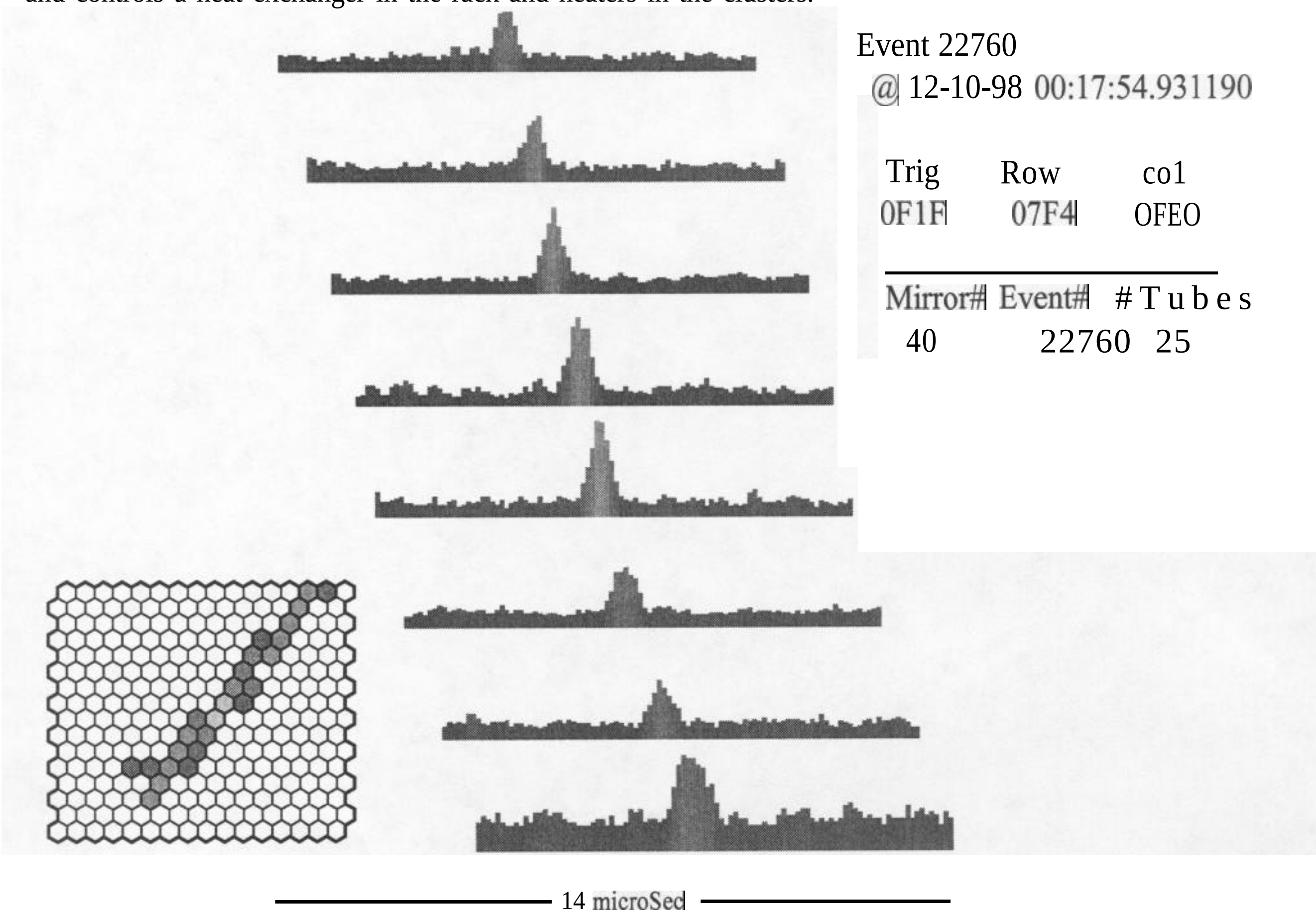

Figure 1: HiRes event display of a cosmic ray shower with FADC profiles for eight viewing channels.

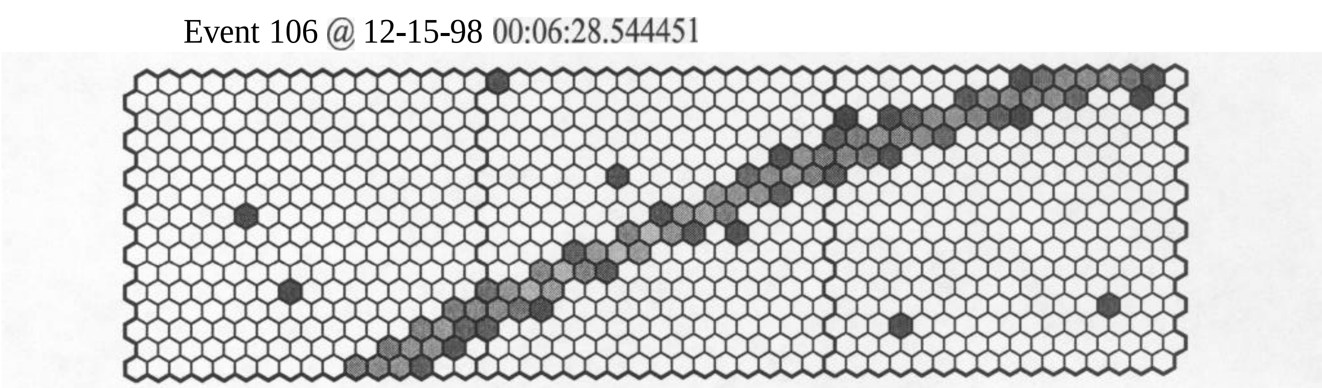

Figure 2: An event display for a laser shot seen in three mirrors.

For all 256 tubes, the FADC measurements of anode current are AC coupled, but provide a measurement of the DC light levels through statistical fluctuations in ambient light. This light measurement is useful for a variety of purposes. Tracking the images of stars across the array provides accurate geometrical calibration. Tracking the intensity of starlight provides cross checks on atmospheric attenuation and cloud cover. The FADC gain scale is set to one integrated FADC count per photoelectron. Under typical good viewing conditions, we have an average of 4 photoelectrons per 100ns measurement, which results in rms deviations from the mean equal to 2 FADC counts.

In Figures 3 and 4, we follow the progress of a pair of bright stars across the field of view of one telescope for one hour. Each separate plot shows the time dependence of the variance of an FADC channel. Each plotted point is the mean square deviation from the mean, averaged over ten measurements of 25.6 µsec in ten seconds. For the individual tubes, the variance is equal to the average number of photoelectrons in the 100ns sampling time. The stars are travelling diagonally up across the array, requiring about five minutes to cross the 1" pixel represented by each 4cm hexagonal tube. The light levels in the tubes are typically about 3 photoelectrons per 100ns, increasing to more than 20. The spot size on the cluster is more than a centimeter in diameter, with noticeable gaps between tubes. The last plots show the effect on the vertical trigger sums of 16 tubes, with different gain and longer filter time. Again the variance is linear in the total ambient light, with perhaps 500 photoelectrons per µsec increasing roughly two-fold as the bright stars cross the vertical column of tubes. The rms pedestal widths of these trigger channels increase roughly 40%.

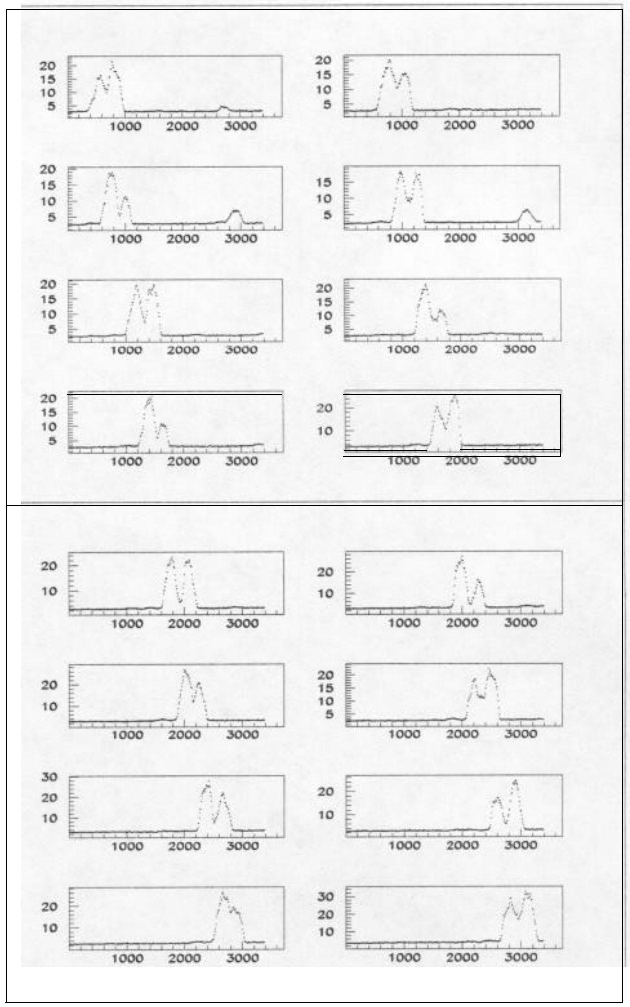

Figure 3 Variance measured for one hour by 16 phototubes along the track of two bright stars.

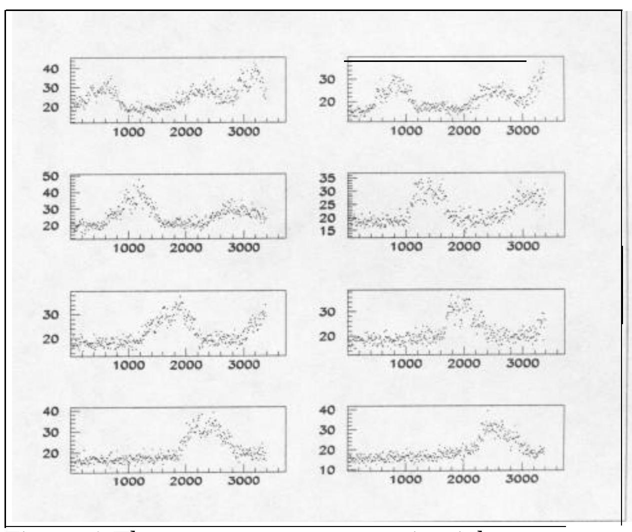

Figure 4 The same two stars seen in eight vertical trigger sums containing the phototubes.

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