

# Pixel Telescope to test pixel Phase II ROCs and sensors

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A silicon-strip sensor based particle telescope is being developed to aid in the characterization of next-generation silicon-pixel detectors for the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC). This telescope is expected to enable sub-micron feature studies of prototype detectors by combining 25- $\mu$ m pitch strip detectors with a very low noise readout system. Additionally, this telescope improves upon previous iterations by deploying a parallel readout scheme to increase the maximum trigger rate by a factor of 16.

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## 1. Introduction

The innermost layer of the CMS Detector at the LHC is the silicon pixel tracker. The current version of the detector has performed well and been critical to the physics program of CMS. The High Luminosity LHC upgrade of CMS will replace the entire silicon tracking system. As part of this upgrade, a proposed new section of the pixel tracker will be added in the so-called “very-forward” ( $\eta \sim 4$ ) region of the detector. Because the particles in this region are traveling almost parallel to the magnetic field of the detector, enhanced  $\phi$  sensitivity is required to accurately measure track curvature, a critical measurement for finding particle momentum and charge. Therefore, the proposed detector will reshape the standard  $100 \times 150\mu\text{m}$  pixels to be more sensitive in  $\phi$ , sacrificing precision in  $\rho$ . A telescope is being developed for the express purpose of characterizing different pixel geometries. The telescope operates by using eight layers of silicon-strip sensors, with the prototype pixel detector placed with four layers on each side. A beam of minimum-ionizing charged particles is directed to pass through both the strip sensors and the prototype pixel sensors. Measurements from the telescope are taken to reconstruct individual particle tracks. These tracks are then compared to data collected from the pixel sensor to characterize its performance.

## 2. Technical Overview

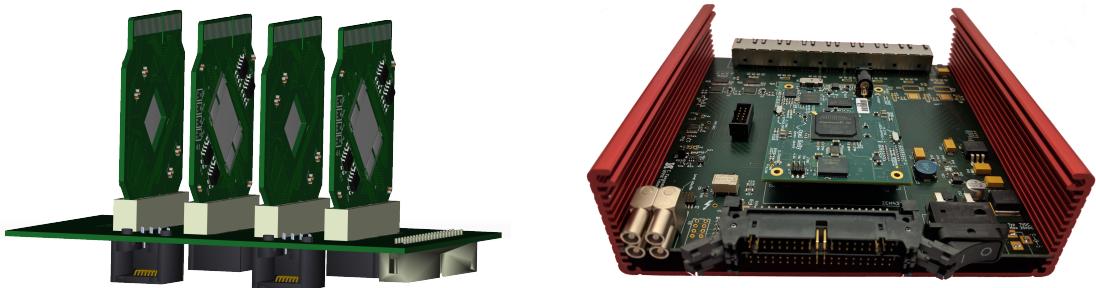
What follows is a description of the hardware of the telescope and a high-level overview of the readout scheme.

### 2.1 Hardware

The telescope has been built up around a silicon-strip sensor and accompanying readout chip, both of which were originally developed for the H1 vertex detector at HERA[1]. The strip sensor contains 512 strips with  $25\mu\text{m}$  strip-width. The readout chip is the **Analog Pipeline Chip - 128** (APC). Each APC can read 128 strips so four are required to read a single strip sensor. The APC operates an integrating pre-amplifier that collects charge from a single sensor strip and keeps a 32 sample history of the output of that pre-amplifier. When a trigger is received from, for example, a scintillation detector indicating a particle has passed through the telescope, the appropriate sample is chosen from the 32-sample history based on the calibrated trigger latency and the selected samples from all 128 channels of the APC are serialized to its output. An illustration of what the signal coming from a single APC may look like is shown in Figure 2.

The strip-sensor and four APC are mounted onto a sensor-card along with four buffer amplifiers that compensate for the relatively weak output of the APC and generate a more robust differential signal with the proper output impedance for driving CAT-5 cables ( $100\Omega$ ). Four sensor-cards are plugged into a motherboard which provides mechanical support for the sensor-cards and routes electrical signals between the sensor cards and the I/O ports.

The signals from the two motherboards that constitute the telescope are routed to the data acquisition (DAQ) board. The DAQ board contains eight 40MHz 10-bit ADCs with four channels each, giving a total of 32 digitization channels. The DAQ board also contains circuitry for supplying the bias voltage for the strip detectors, and LEMO connectors for supplying an external trigger and



(a) A rendering of the telescope “motherboard” showing four “sensor-cards” each of which holds a single strip-sensor. The control signals needed by the readout chip are supplied by a 40-pin header (bottom-right). The data readout happens over four RJ-45 connectors, into which CAT-5 cables are plugged to transmit the signals to the DAQ board.

(b) An image of the DAQ board featuring an 8xRJ-45 connector (back) to receive data from two connected motherboards, a 2x40-pin header (front) for supplying control signals to the motherboards, and an Opal-Kelly FPGA integration module (center) to orchestrate the operation of the telescope.

Figure 1: The main hardware components of the telescope are the motherboard with associated sensor-cards (a) and the data acquisition board (b)

clock signal. Digital logic is implemented via an Opal Kelly FPGA integration module which features an Altera Cyclone IV FPGA, 128MB of RAM, and a Super-Speed USB link for data transfer.

## 2.2 Readout Scheme

The readout scheme has been designed to maximize the data throughput in terms of analog strip-sample values per second. This has been done in an effort to minimize downtime since the APC cannot take data during readout. Therefore, any data from beam that passes through the telescope during readout is lost. Figure 2 illustrates the readout scheme. Roughly speaking, the readout happens in three stages. The first stage is handled by the electronics in and in the immediate vicinity of the beam. It is there that the passage of a charged particle is converted to an electronic pulse by the strip-sensor and the height of that pulse is recorded by the APC. The APC then serializes pulse heights from many channels to the cables exiting the beam region.

The signals from the telescope are then routed to the DAQ board where they are digitized and fed into an FPGA. The FPGA contains firmware that is responsible for dropping strip readings with pulse-heights below the set threshold and grouping the remaining strips into “hit” objects. These hit objects, along with their associated trigger id, are then pushed to a connected PC via a USB link to be saved to disk.

Offline analysis software then uses this data to identify the individual tracks of particles passing through the telescope. Detector alignment studies will also be critical to measuring the position of the strip sensors to micron precision. Finally, the tracks can be interpolated to the impact point with the prototype pixel detector and used to measure its properties.

## 3. Projected Telescope Performance

The performance of the telescope can be quantified in two ways. First, the precision with which individual particle trajectories can be measured, and second, the rate at which data can be

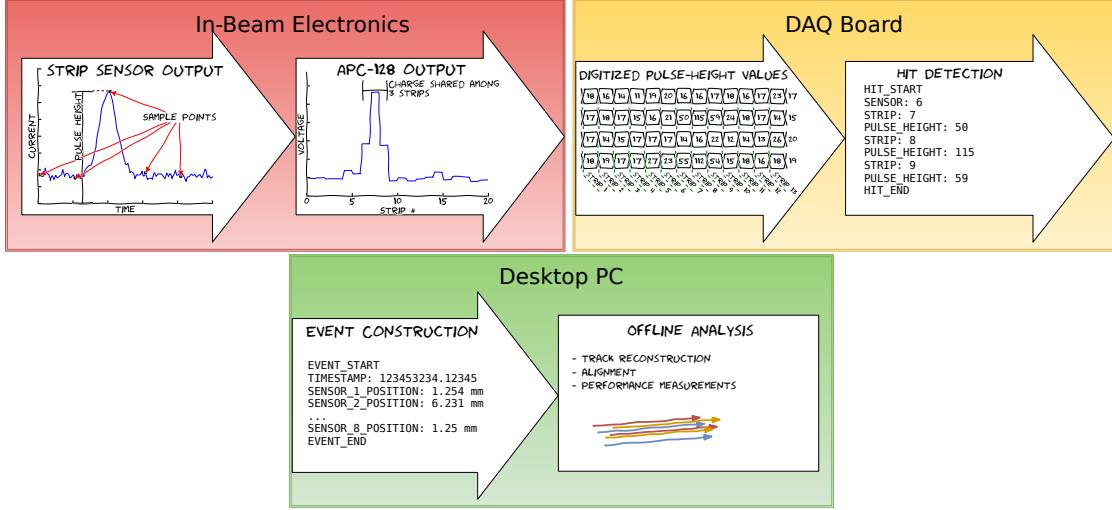


Figure 2: Illustration of the readout scheme of the telescope.

collected.

The measurement precision of particle tracks depends on the number of detector layers and the single hit precision. The telescope consists of eight silicon-strip sensor layers with strip-widths of  $25\mu\text{m}$ . For strip-sensors with charge sharing the single hit precision can be approximated by the strip-width divided by the signal-to-noise ratio (SNR) of the readout system. The expected SNR of the telescope is 25[2]. This yields a single-hit precision of  $\approx 1\mu\text{m}$ . This single-hit precision combined with two measurements in each dimension on each side of the prototype sensor should give sub-micron track localization at the point of impact with the prototype sensor.

The data collection rate for the telescope is primarily limited by the speed sample data can be transferred from the APC to the data acquisition board. This is because many typical test-beam facilities have beam rates on the order of MHz while the telescope can only be triggered at  $\approx 15\text{kHz}$ . The trigger rate can be improved somewhat by optimizing the readout electronics using well established techniques such as the placement of buffer amplifiers near the APC to reduce the rise-time of signals as they propagate along the cables to the DAQ board, as well as the use of differential signaling on these same cables to reduce electro-magnetic interference. It is because of this limitation that the decision was made to readout every APC in parallel, in contrast with previous incarnations of this telescope which serialized sixteen APC[3]. This alone will yield a 16-fold decrease in readout time.

## References

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- [2] A. Ryser, *Semesterarbeit - Pixel Telescope*, 2013, unpublished
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