First Results of ATLASPix3.1 Testbeam

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Introduction

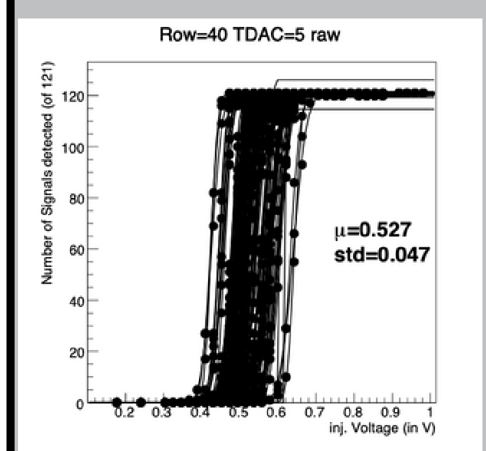
The ATLAS Pix sensor has been developed as the monolithic High Voltage CMOS sensor candidate for the ATLAS inner tracker upgrade. The ATLASPix3 is the third version, and is the first full reticle-sized sensor developed for multi-module compatibility. The detector is operational, and has been tested as a single chip, as 4- and 8-layer telescopes and as a quad module in an electron testbeam at DESY, with energies up to 6GeV. First results of the testbeam data analysis are presented here.

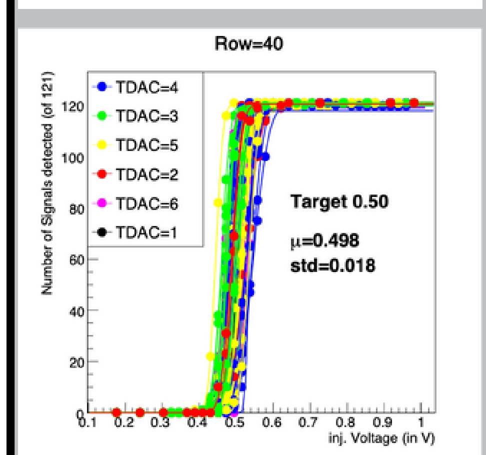
Technical Setup

- The sensors were produced by AMS/TSI and consist of 180 nm technology on 200 Ωcm wafers with large fill-factor charge collection wells.
- The reticle size is 20.2×21 mm², consisting of 132 columns × 372 rows of pixels, with pixel size of 150×50 µm².
- 3-bit threshold TDAC, 8-bit ToT, 10-bit time stamp.
- Readout can be both triggered or trigger-less via two separate readout structures.
- Column-drain readout.
- Can be configured through serial, SPI bus or command line.
- Chip is RD53 compatible
  - Data is encoded with Aurora protocol (triggerless: 8/10b, triggered: 64/66b)
  - Command decoder
  - Data link up to 1.28 Gbit/s
- Chip is low power, and so requires less cooling (160 mW/cm², 120 mW/cm² of which is analog), low threshold (400 e) and low material budget (150 µm)
- Version 3.1 has added changes to the metal layers
  - Pixel biasing structure has been improved.
  - Amplifier input capacitance has been reduced by ~0.5 to reduce time walk.
  - Capacitance has been added to the voltage regulators to avoid oscillations
  - Shielding of the test signal injection has been traded-off, introducing crosstalk.
- Readout is done using GECCO (GEneric Configuration and COntrol) system for all chip configurations.

Single Chip Characterisation

The ATLASPix has been thoroughly tested and characterised. Presented here is the single chip characterisation for the ATLASPix3.1 version.





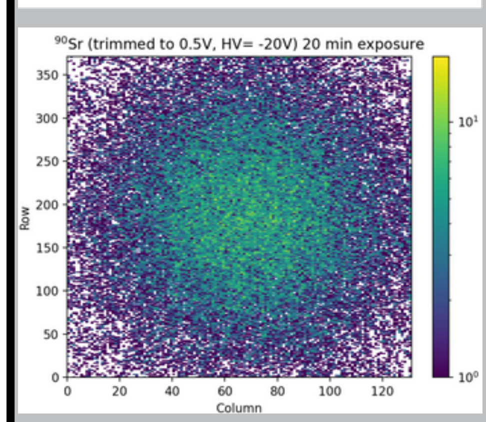


Figure 1.a shows the S-curves for every pixel in row 40, when given an injection voltage of 0.5V. *Figure 1.b* shows the same S-curves after tuning each pixel. Each colour in *figure 1.b* corresponds to the tuned TDAC value. The standard deviation decreases from 47 mV in *figure 1.a* to 18mV in *figure 1.b*, showing successful tuning. Early lab tests were performed with a number of sources, one of which is shown in *figure 1.c*.

Figure 1.a. (left)
Untuned S-curves at TDAC = 5 for row 40, σ = 47 mV.

Figure 1.b. (left)
Tuned S-curves for row 40, σ = 18 mV.

Figure 1.c. (right)
Map of Strontium-90 source. The source profile can be clearly seen.

References:

ATLASPix3 Manual, available at *https://adl.ipe.kit.edu/downloads/ATLASPIX3_um_v3.pdf*

R. Schimassek, *Test results of ATLASPIX3 A reticle size HVCMOS pixel sensor designed for construction of multi chip modules*

Corryvreckan, available at *https://project-corryvreckan.web.cern.ch/project-corryvreckan/*

Testbeam Reconstruction

In April 2022, the ATLASPix3 was tested at DESY using an electron testbeam with a range of energies (up to 6 GeV), run in various configurations. These included a quad module, a 4 layer telescope, two interleaved telescopes, different voltages, etc. The data was taken over a period of a week using hit-driven readout. Synchronisation between the two arms was provided by the primary system sending a synchronisation signal to the secondary system.

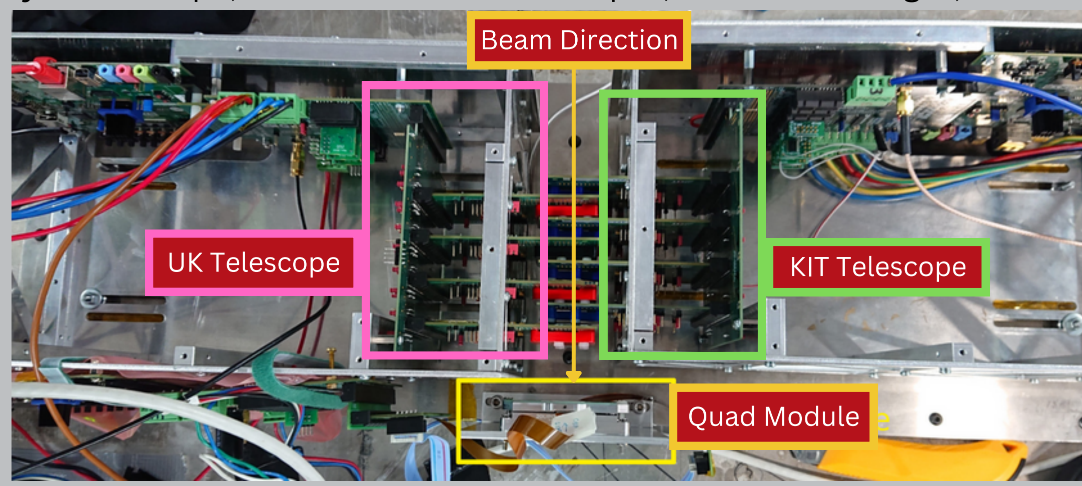
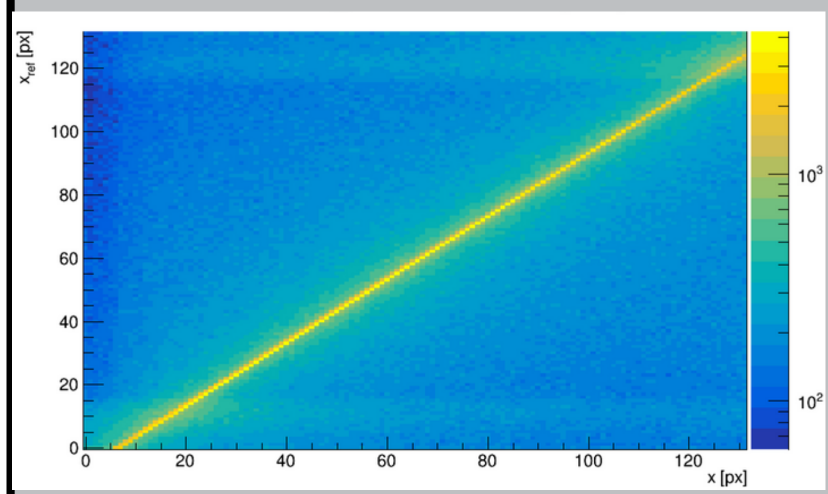
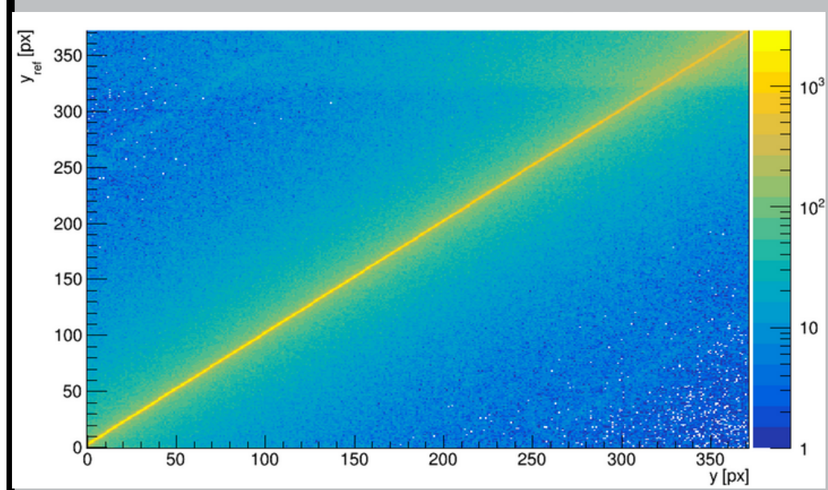
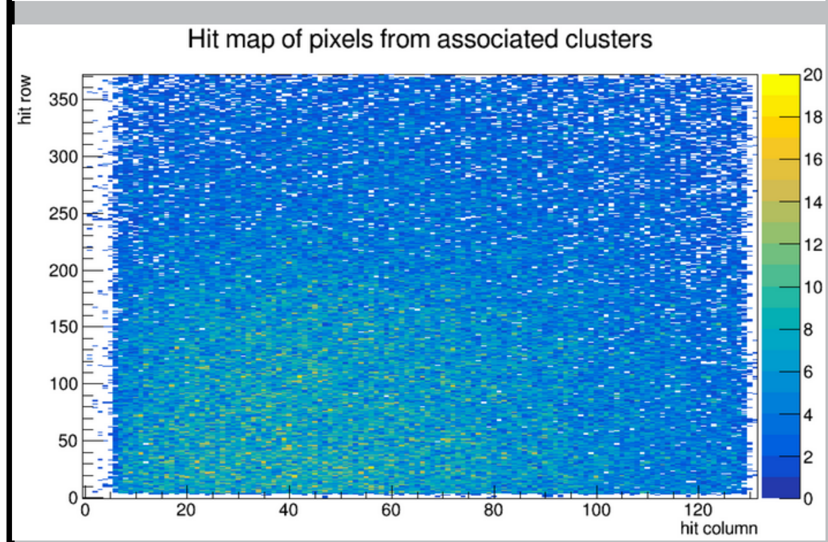
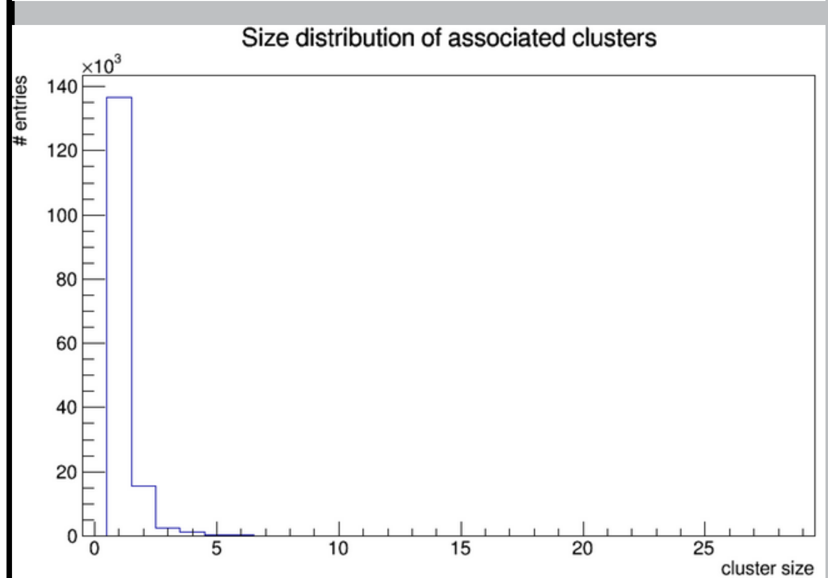


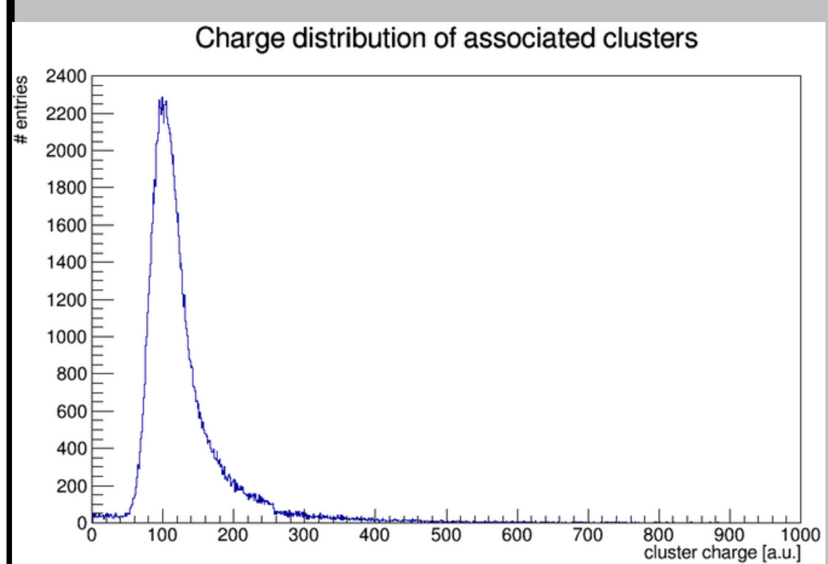
Figure 2.a (Right)
This image shows the 2 interleaved telescope arms, the left from the UK, the right from KIT, and the quad module from INFN. There is a separation distance of 1.27cm between the planes of the interleaved modules.







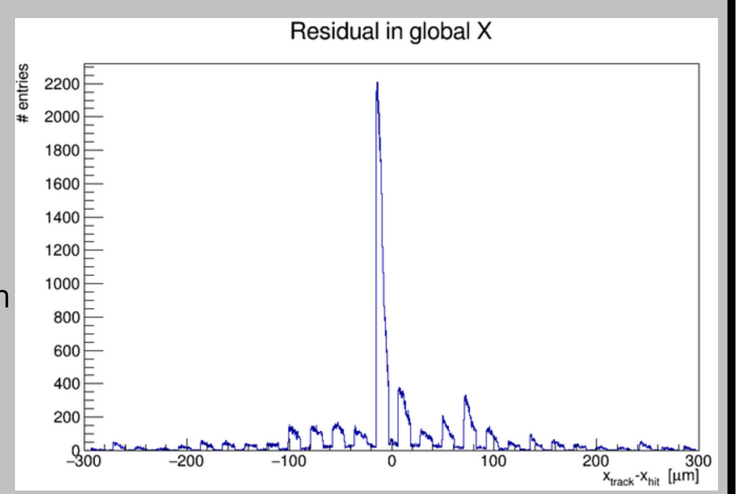


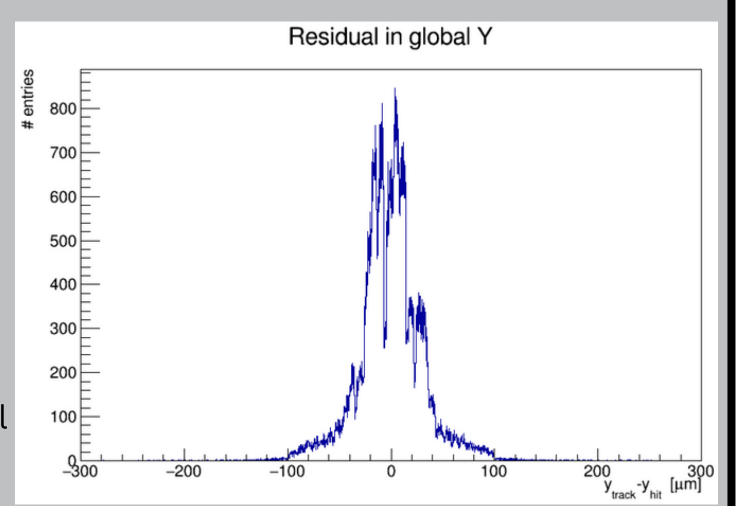


Currently, the analysis focuses on the 4-plane telescope configuration. The sensors were operated in zero-suppressed, triggerless mode. For each hit, a time stamp, location and time over threshold were registered. Tracks are reconstructed using the Corryvreckan package. *Figures 2.b & 2.c* show the correlation plots between the reconstructed x (y) position of the track on the DUT and the x (y) position of the track. The strong correlations demonstrate that we see tracks.

Figure 2.d shows a map of the clusters associated with tracks. Since the pixels are large with respect to the size of the charge cloud, there is little charge sharing as can be seen in *figure 2.e* where the cluster size distribution is shown. By far most clusters consist of a single pixel, with a small fraction of larger clusters. The total cluster charge in ToT units is shown in *figure 2.f*. The distribution follows the well-known Landau distribution well. *Figures 2.g & 2.h* show the spatial resolution in x and y for the DUT.

The spiky nature of the distribution is well understood. This is due to the quantisation of the reconstructed hit position in the telescope module. The principle is illustrated in *figure 2.i*. Since the beam is almost parallel and a lot of the clusters are single pixel, tracks are reconstructed using the centre locations of pixels. Hence, an example track might hit in the x-direction the four layers in respectively pixels 12, 12, 12 & 12, as shown with the red line. If layer 3 is the DUT, the recorded hit position is 12 and the reconstructed position for that layer is 12. Hence, the residual in this case is 0. If the track is instead at a small angle, the four layers will register hits in pixels 12, 12, 12 & 13, as shown with the yellow line. yielding a predicted track position of 12.57 for layer 3 and thus a residual of 0.57. This quantised nature of reconstructed hit positions results in the spikes.





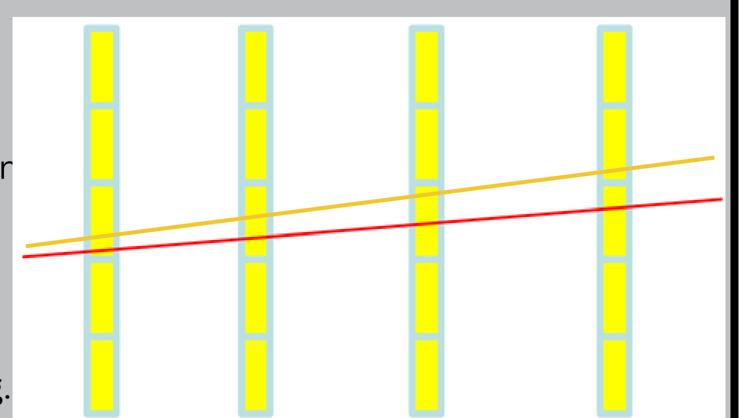


Figure 2.b.(c) (left)
Correlation plot in x (y) of Device Under Test (DUT) between pixel predicted by the track and pixel measured by the DUT. A sharp diagonal line as shown here shows hit correlation.

Figure 2.d. (left)
Map of clusters associated with tracks.

Figure 2.e. (left)
Size distribution of clusters associated with tracks.

Figure 2.f. (left)
Charge distribution of the same clusters as figure 2.d.

Figure 2.g.(h) (right)
After alignment procedure, reconstructed global position in x (y) minus actual global position in x (y). Shown here is an unusually distinct multiple peak structure, which is found in both telescope and DUT residuals. This is explained in the text above.

Figure 2.i. (right)
Illustration of the principle leading to the distribution pattern in figures 2.f and 2.g.

Conclusions

The ATLASPix3 was successfully operated in the testbeam at DESY. The reconstruction and analysis are still ongoing, but first results show that the sensor functions well. The single chip has been thoroughly characterised, and multi-chip setups and a quad module have been shown to be working well. The ATLASPix3 is a working, matured full reticle-size chip. More measurements are planned for understanding and further characterisation of the chip. However, the ATLASPix chip has been shown to be a good candidate for a large area tracker for Higgs factories and other future experiments.