PROCEEDINGS OF SCIENCE

First Results of ATLASPix3.1 Testbeam

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Abstract: The ATLASPix sensor has been developed as a 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, and as a 4-layer telescopes in an electron testbeam, with energies up to 6 GeV at DESY. First results of the testbeam data analysis are presented here.

10th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging (Pixel2022)
12-16 December 2022
Santa Fe, New Mexico, USA

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1. Technical Setup

The ATLASPix sensor has been developed as a monolithic High Voltage CMOS sensor candidate for the ATLAS inner tracker upgrade [1, 2]. The sensors were produced by AMS/TSI in 180 nm technology on 200 Ωcm wafers with the deep n-well as charge collecting diode with large fill factor. The reticle size is 20.2×21 mm^2, consisting of 132 columns × 372 rows of pixels, with a pixel size of $150 \times 50\ \mu$m^2.

The sensor can be configured through a serial bus, an SPI bus or a command line interface. The sensor supports zero suppressed readout. The chip can be configured as both triggered or trigger-less column-drain readout via two separate structures. Each pixel has its own threshold offset, which is set via a 3-bit TDAC. For each signal hit an 8-bit time over threshold (ToT) and a 10-bit timestamp of the crossing of the threshold are recorded. The hit information is transmitted with up to 1.28 Gbit/s through a serial link. Readout of a single sensor and a multi-layer telescope with up to four layers is achieved using the GECCO (GEneric Configuration and COntrol) system [3].

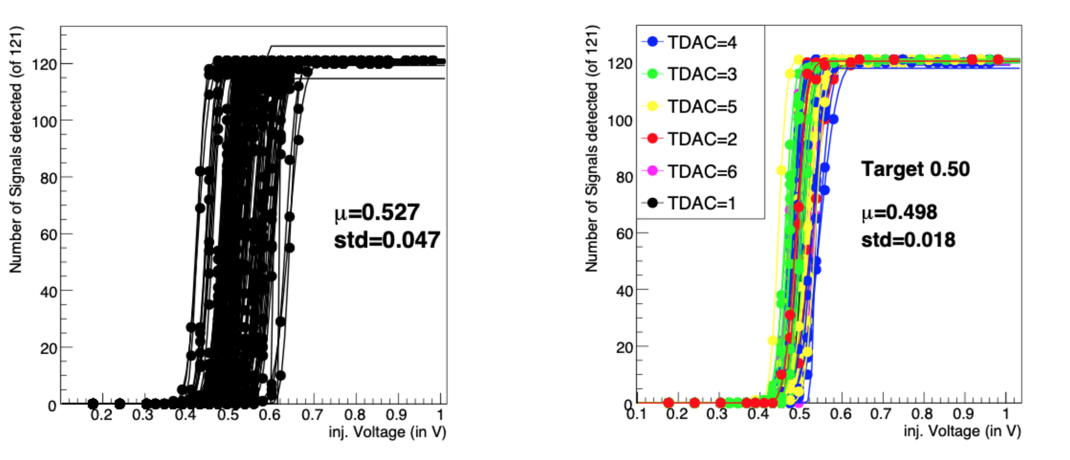
The chip is generally low power (160 mW/cm^2, 120 mW/cm^2 of which is analog), although specific power requirements will depend on the number of hits and the readout mode. The chip can be operated with a threshold as low as 400 e, and a material budget as low as 50 μm [4].

The version of the chip used in the testbeam was the ATLASPix3.1. Version 3.1 has added various changes. The pixel biasing structure has been improved, and the capacitance has been decreased to half of the original value in order to reduce time walk. Capcitance has also been added to the voltage regulators in order to avoid oscillations, at the cost of limiting the shielding of the test signal injection, introducing some crosstalk.

2. Single Chip Characterisation

The ATLASPix has been characterised in the lab. Presented here is the single chip characterisation for the ATLASPix3 version.

Every pixel has a separate offset with respect to the global threshold setting to compensate for pedestal variations. The desired setting for each pixel is obtained by varying the voltage used for the charge injection and measuring the pixel hit efficiency, resulting in S-curves. Figure 1a shows the pre-tuned S-curves for a particular row, and Figure 1b shows the same S-curves after tuning each pixel. Early lab tests were performed with a number of sources, with Strontium-90 shown in Figure 2. The source signal is clearly observed.



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

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

Figure 1: Figure 1a shows the S-curves before each pixel is tuned to its optimal value, and Figure 1b shows the S-curves for the same row after tuning.

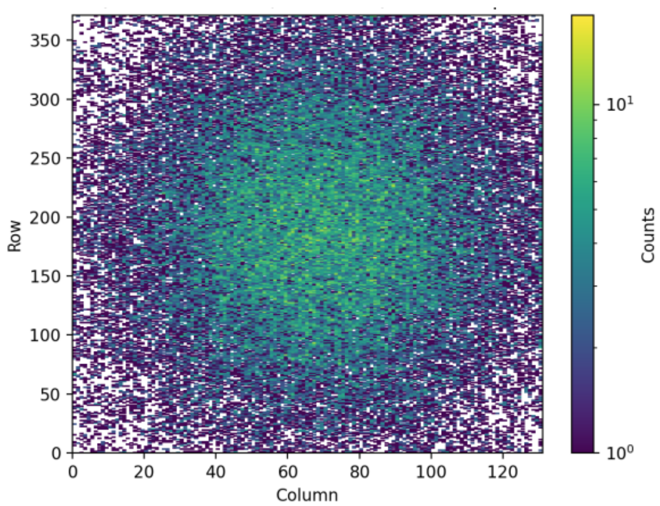


Figure 2: Hitmap obtained using a Strontium-90 source. The source profile can be clearly seen.

3. Testbeam Reconstruction

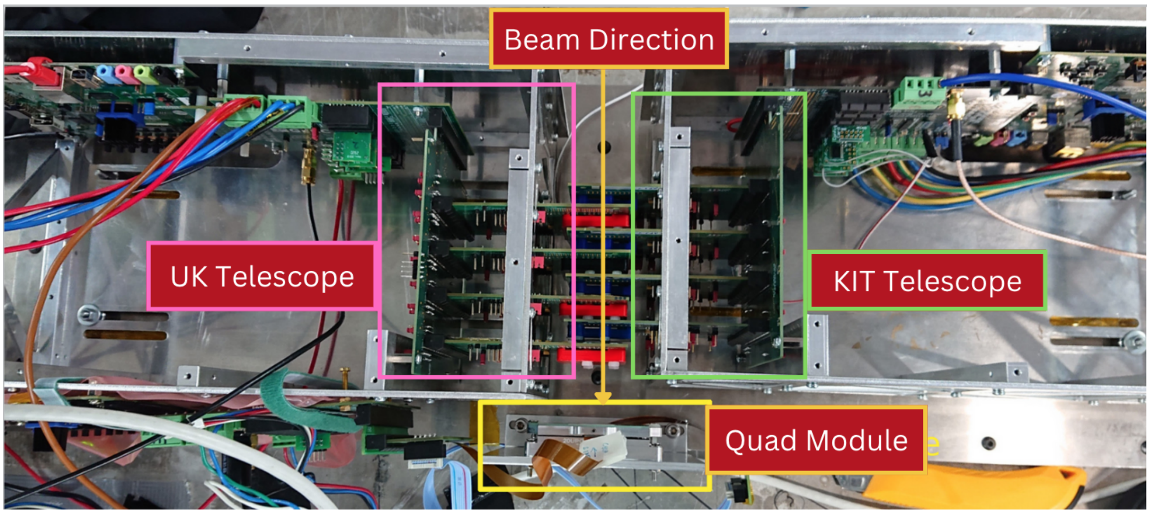
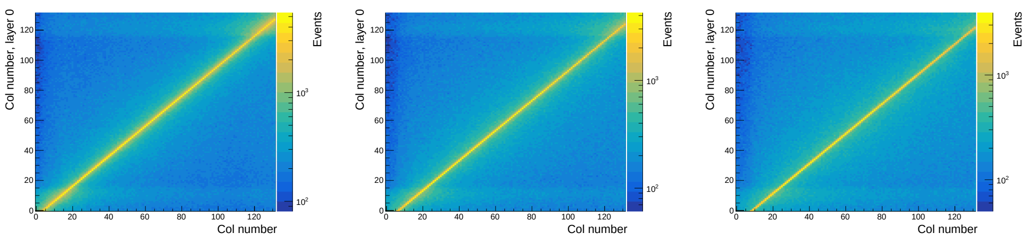


Figure 3: This image shows the 2 interleaved telescope arms, the left from the UK, the right from KIT, and the quad module from INFN. There is a separation distance of 1.27cm between the planes of the interleaved modules.

In April 2022, the ATLASPix3 was tested at DESY using an electron testbeam with a range of energies (up to 6 GeV). Various configurations were tested, including a 4-layer telescope and two interleaved telescopes. The data were taken over a period of a week. Figure 3 shows the experimental layout.

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 ToT were registered. Tracks are reconstructed using the Corryvreckan package [5]. Figure 4 shows the correlation between the column number on a given plane against that of the reference plane (plane 0). As part of analysis process, the Corryvreckan package aligns the planes to ensure that tracking and track reconstruction is accurate. We see strong diagonal lines in Figure 4, showing that both the Corryvreckan package and the 4-layer telescope are functioning as intended.



(a) Layer one against layer zero. **(b)** Layer two against layer zero. **(c)** Layer three against layer zero.

Figure 4: Correlation in x (columns) of layer n against layer zero.

During the analysis process, a Device Under Test (DUT) layer can be designated after the alignment process. The DUT, layer two here, is not used in track reconstruction. Figure 5 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 6a 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 6b, with the distribution following the well-known Landau distribution.

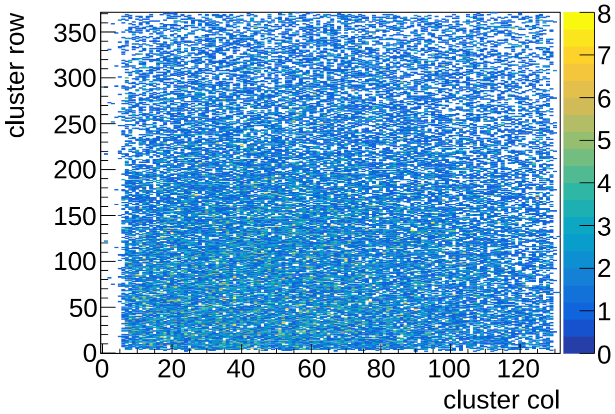
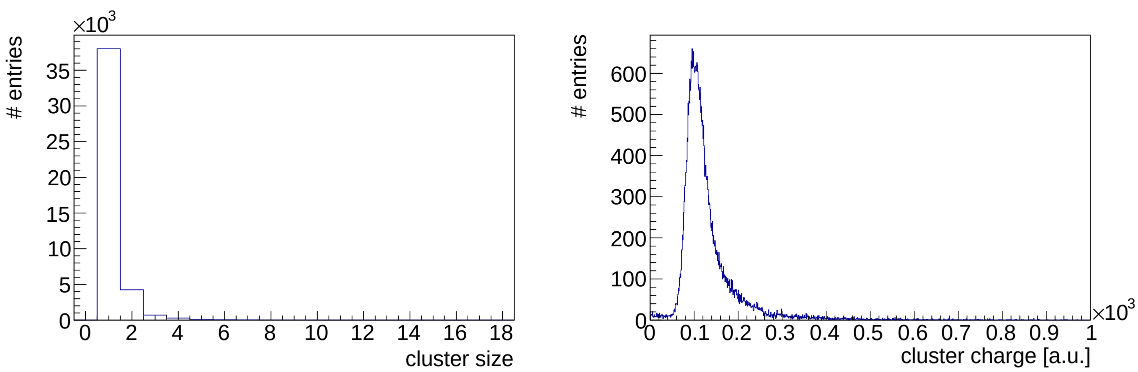


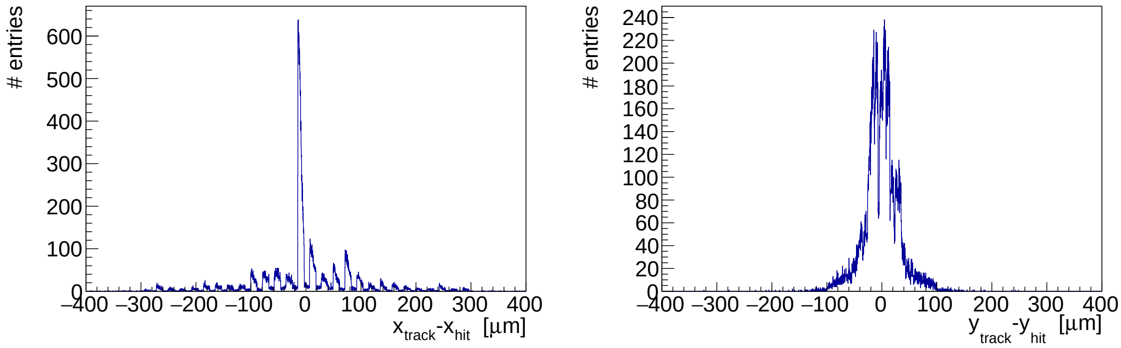
Figure 5: Map of clusters associated with tracks.



(a) Size distribution.

(b) Charge distribution.

Figure 6: Distributions of size and charge of clusters associated with tracks.

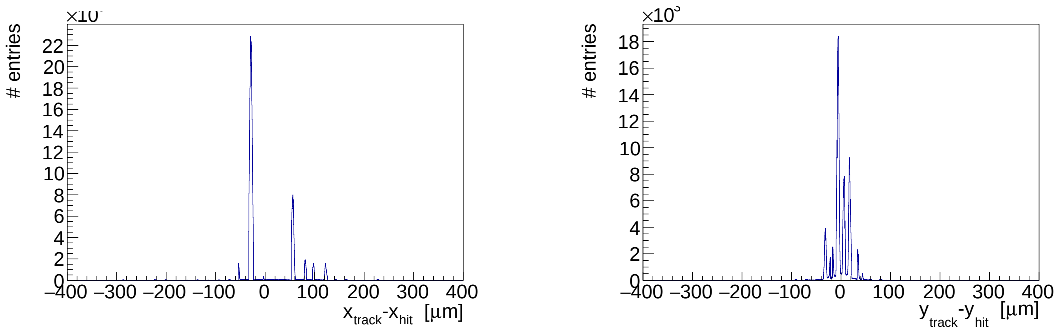


(a) Global residual in x **(b)** Global residual in y

Figure 7: 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 telescopes and DUT residuals. This is explained in the text, and confirmed in simulation.

Figures 7a and 7b show the spatial resolution in x and y for the DUT. The spiky nature of the distribution is well understood. Since the beam is almost perpendicular to the detector planes and a majority of the clusters consist of a single pixel, tracks are reconstructed using the centre locations of pixels. The result of this is that track angles and thus extrapolated track positions are quantized, resulting in the spikes. This pattern was reproduced using the AllPix^2 simulation software [6], in Figure 8.

The results show that the sensor is performing well in the lab and in testbeam. Further studies are underway.



(a) Residual in global x **(b)** Residual in global y

Figure 8: Simulation of global residuals in x and y done in AllPix^2 to confirm the quantised peak structure.

4. Conclusion

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 characterised in the lab, and a multi-chip setup has 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. The ATLASPix chip has been shown to be a good candidate for a large area tracker for Higgs factories and other future experiments. Design and tests of multi-chip modules built out of ATLASPix3 sensors and designs for a light-weight support and cooling structure for multi-module chains are discussed in a separate contribution to this conference [7].

Acknowledgements

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

References

[1] I. Perić, "*A novel monolithic pixelated particle detector implemented in high-voltage CMOS technology*," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 582, no. 3, pp. 876–885, 2007. VERTEX 2006.

[2] I. Perić, M. Prathapan, H. Augustin, M. Benoit, R. C. Mohr, D. Dannheim, F. Ehrler, F. G. Messaoud, M. Kiehn, A. Nürnberg, R. Schimassek, M. V. Barreto, E. V. Figueras, A. Weber, W. Wong, and H. Zhang, "*A high-voltage pixel sensor for the ATLAS upgrade*," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 924, pp. 99–103, 2019. 11th International Hiroshima Symposium on Development and Application of Semiconductor Tracking Detectors.

[3] R. Schimassek, "*Description of the GECCO Test System*." Published online, 16 February 2022. Accessible at https://git.scc.kit.edu/adl_documents/gecco_documentation/-/raw/main/gecco_description.pdf.

[4] R. Schimassek, A. Andreazza, H. Augustin, M. Barbero, M. Benoit, F. Ehrler, G. Iacobucci, A. Meneses, P. Pangaud, M. Prathapan, A. Schöning, E. Vilella, A. Weber, M. Weber, W. Wong, H. Zhang, and I. Perić, "*Test results of ATLASPIX3 — A reticle size HVCMOS pixel sensor designed for construction of multi chip modules*," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 986, p. 164812, 2021.

[5] D. Dannheim, K. Dort, L. Huth, D. Hynds, I. Kremastiotis, J. Kröger, M. Munker, F. Pitters, P. Schütze, S. Spannagel, T. Vanat, and M. Williams, "*Corryvreckan: a modular 4D track reconstruction and analysis software for test beam data*," *Journal of Instrumentation*, vol. 16, p. P03008, March 2021.

[6] S. Spannagel, K. Wolters, D. Hynds, N. Alipour Tehrani, M. Benoit, D. Dannheim, N. Gauvin, A. Nürnberg, P. Schütze, and M. Vicente, "*Allpix2: A modular simulation framework for silicon detectors*," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 901, pp. 164–172, 2018.

[7] R. Zanzottera, "*ATLASPIX3 modules for experiments at* e^+e^- *colliders*," in *10th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging (Pixel2022)*, (Santa Fe, New Mexico, USA), 12-16 December 2022.