F96 - Characterisation of Silicon Pixel Sensors for High-Energy Physics and beyond

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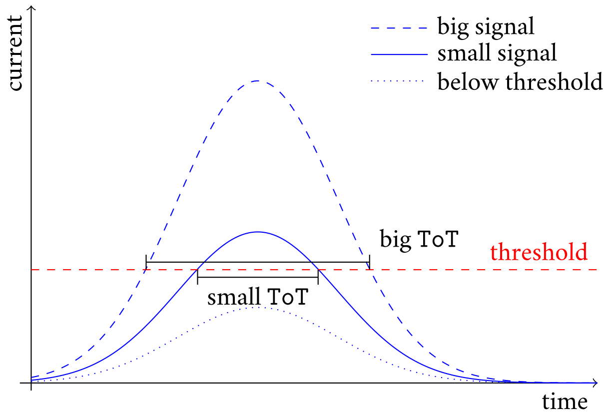

Figure 1: Time-over-threshold measurement illustration

1 Introduction

Silicon pixel sensors are widely used in particle physics to detect, track and analyse ionizing particles. They work by measuring the current pulse in a reverse biased diode that is produced by the charge carriers drifing to the electrodes when a ionizing particle hits the depletion region and produces new electron-hole pairs. The number fo charge carriers produced depends on on the energy of the ionizing particle so the energy of the ionizing particle can be measured by measuring the area of the current pulse. By placing many diodes in a 2D array, the location can be determined and by measuring the time the current pulse initially crosses the threshold (time of arrival - `ToA`) the time. In practice this is done by measuring the time the current is above a certain threshold, the time-over-threshold (`ToT`), see figure 1.

The classical design for silicon pixel sensors are **hybrid pixel sensors**. Here the diodes are on a seperate chip from the readout part. Usually they are connected by bump-bonding. The `Timepix3` sensors used in the reference telescope for this analysis are of this kind.

A alternative are monolythic active pixel sensors (`MAPS`), that combine detection diode and readout logic on the same chip. In the `HVMAPS` variant an additional high voltage on the order of 100 V is applied as reverse bias.

In the following we will analyse the spatial and temporal resolution and accuracy of the `ATLASpix1` sensor, a new `HVMAPS` sensor.

2 Setup

We analyse the `ATLASpix1` sensor using the test-beam facility at the Super-Proton Synchrotron (`SPS`) at `CERN`. It provides a beam of charged pions with a momentum of 120 GeV. The data we are analysing is from run 29 663 taken in November 2018. In this run, the bias voltage was set to -75 V, the threshold voltage to 750 mV and a clock period of 8 ns was used.

To analyse the `ATLASpix1` sensor a reference telescope of `Timepix3` sensors is used to determine the actual track of each particle, which is then compared to the data measured by the `ATLASpix1`. The `ATLASpix1` sensor (DUT) is placed inbetween the `Timepix3` sensors and the `Timepix3` sensors are tilted slightly to increase the chance of a particle hitting multiple pixels, which can be used to increase the spatial resolution. Figure 2 shows a schematic drawing of the measurement setup.

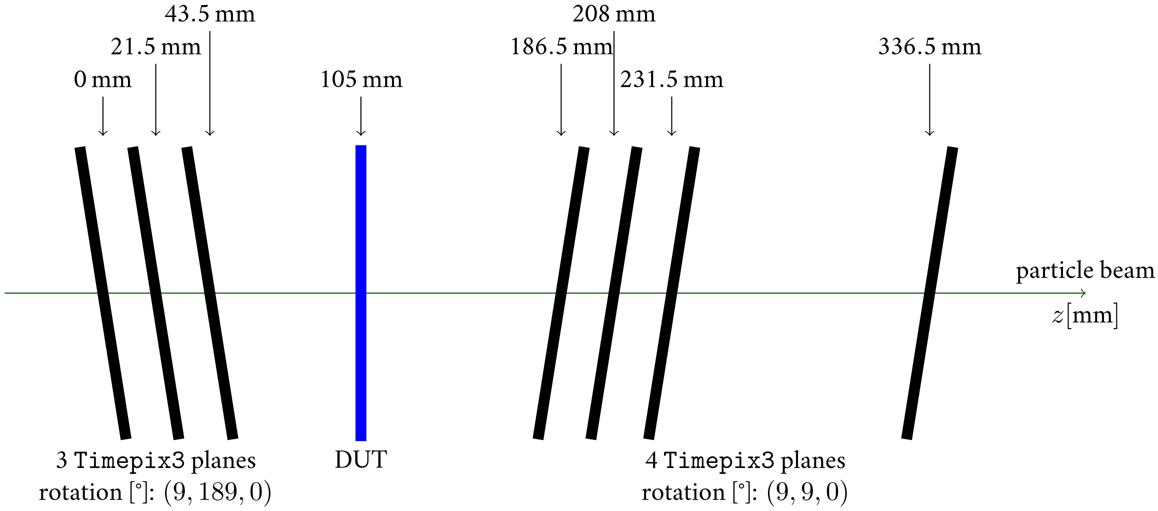

Figure 2: Schematic of detector setup

3 Analysis

To analyse the `ATLASpix1` the general idea is to first reconstruct the track taken by a particle using the reference `Timepix3` sensors and then compare the track with the position and time measured by the `ATLASpix1` sensor. These steps are carried out using [**corry**] and ROOT [**root**].

4 Data processing

The data is processed using the analysis program `Corryvreckan`. The used data was taken during the run 29663 in November 2018 by CLICdp. The data is analyzed in slices of 20 µs to reduce the requirements on the RAM.

In a first step the data is imported using the modules 'EventLoaderTimepix' and 'EventloaderATLASpix'. Subsequently the 'Clustering4D' module is applied to find cluster, which arise from on a particle hitting multiple pixels of a detector or from charge spilling over. These clusters are assigned the position of their ToT-weight center of gravity and in addition the pixel in the cluster with the highest ToT is named the seed pixel.

In the next step the module 'Corrrelations' is applied to receive plots of the spatial correlation of the detectors relative to the reference detector. This is used to do a first correction of the alignment. This is done by the module 'Prealignment', which determines the peak of the correlations and updates the geometry file in a way that the peaks are shifted to zero.

Then the module 'Tracking4D' is applied which reconstructs the trajectory of the particle by searching for hits on a ellipsoid on the planes along the estimated tracks. This allows then to group the signals one particle produces along his track. Based on this result a precise alignment for the telescope planes is calculated by the module 'AlignmentTrackChi2'. It iterative alters the position and rotation of the telescope planes and refits the tracks trying to minimize the χ^2 value.

Based on the telescope alignment the tracks on the DUT are reconstructed by the module 'DUT Association'. Using this results the DUT can finally be precisely aligned by the module 'AlignmentDUTResiduals', which iterative alters the DUTs translation and rotation trying the minimize the absolute of the Residuals.

The telescope and the DUT data is now sufficiently calibrated and the full data set analyzed. In addition the full analysis is run again for a grid of altering values of x and y spatial cuts in order to determine the dependence of the pixel efficiency from these factors. The spatial cuts give the distance which a hit can differ from the supposed position and is still considered belonging to the track.

To improve the time resolution of the sensor, the timewalk effect can be corrected by the module `AnalysisTimingATLASpix`. The timewalk effect refers to the dependence of the delay between hit and detection on the signals size.

5 Results

We used the aligned data set to investigate the properties of the `ATLASpix1` sensor with respect to the reference sensor.

We find the time resolution of the sensor by fitting a Gaussian function on the central parts of the time residual distribution shown in Fig. 3. For this we used the interval between -130 ns and -90 ns. The offset of the peak is depending on the system and not relevant for our analysis. We find the time resolution

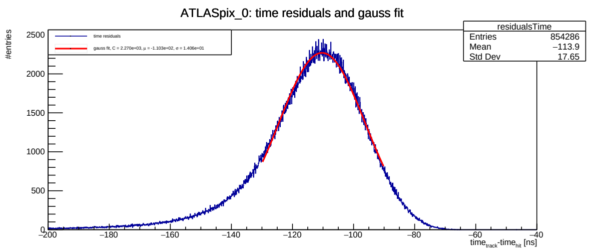

Figure 3: Time residual distribution

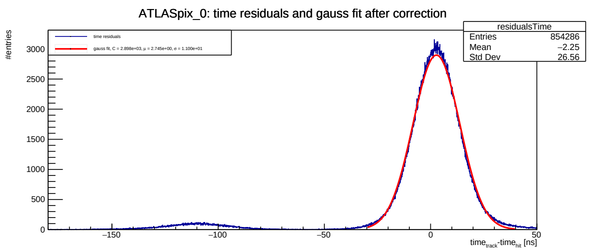

Figure 4: Time residual distribution corrected for timewalk

$$\Delta t = 14.06\,\text{ns} \tag{1}$$

After correcting our data for the timewalk effect, we repeated the analysis and received a time residual distribution cleared for the timewalk effect, which lacks the overshoot of low time residuals characteristic for the effect (see Fig. 4). After this correction, we achieved an improved time resolution

$$\Delta t = 11.00\,\text{ns} \tag{2}$$

By comparing the reference telescope and the `ATLASpix1`, the efficiency of each pixel was determined. That yielded the efficiency map shown in Fig. 5. As the `ATLASpix1` is larger than the reference telescope, data is not available for all pixel. The pixel for which data is available, achieve a mean efficiency of 0.96.

In a last step the influence of the spatial cuts where examined. For this the data analysis was repeated multiple times with varying spatial cuts in x- and y-direction. The result is shown in Fig. 6. The efficiency seems to vary only slightly spatial cuts larger than the respective pixel dimension, but

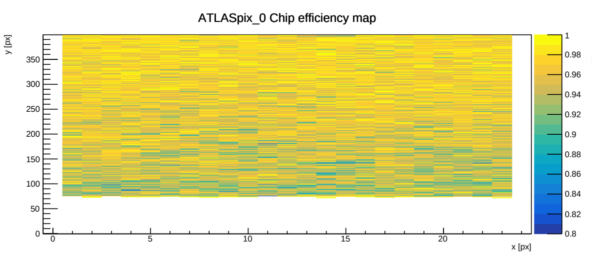

Figure 5: Efficiency map for the `ATLASpix1` detector

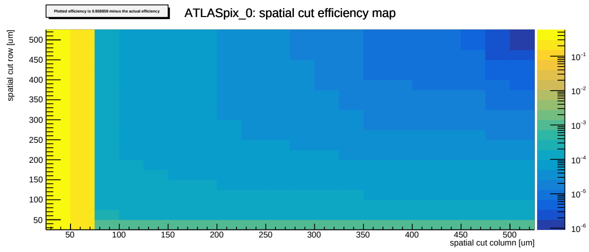

Figure 6: Difference in mean efficiency compared to the previous efficiency in dependence on the spatial cut

drops suddenly for spatial cuts smaller than the respective pixel pixel dimension.

6 Discussion

The measurement of the time resolution show that the detector is capable to measure processes on the nanosecond scale. The results could be further improved by optimizing the detectors setting, especially the threshold. The threshold was set at 950 mV, which is slightly inefficient. With improved settings even better time resolution are achievable. [] achieved a time resolution of 8.1 ns before time walk correction and 5.9 ns after timewalk correction. We also see that the timewalk correction helps to improve the resolution significantly and should therefore always be apllied if small timescales are involved.

The efficiency of the chip is in average quite high. But we see a trend of pixels near the edges to have a lower efficiency. That might be caused by an reduced depletion zone in this pixels, which increases the probability of recombination and lowers the efficiency.

We find meanwhile the spatial cut settings to have only a minor influence on the overall efficiency of the sensor as long as the spatial cut is above the respective pixel size. If it is below, single pixels would have to be divided, causing the efficiency to drop as an effective path reconstruction is no longer possible.

7 Conclusion

[1] [2]

References

[1] R Schimassek et al. “Test results of ATLASPIX3–A reticle size HVCMOS pixel sensor designed for construction of multi chip modules”. In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2020), p. 164812.

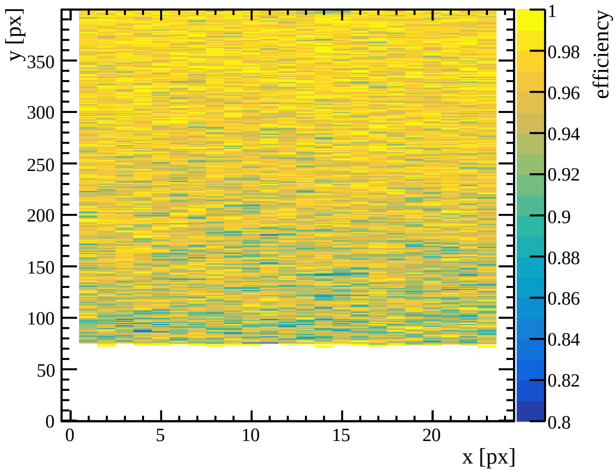

Figure 7: Chip efficiency map of `ATLASpix1` detector

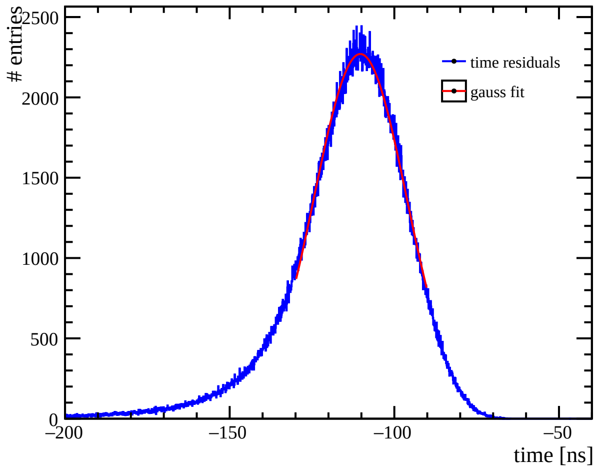

Figure 9: Distribution of time residuals for `ATLASpix1` detector

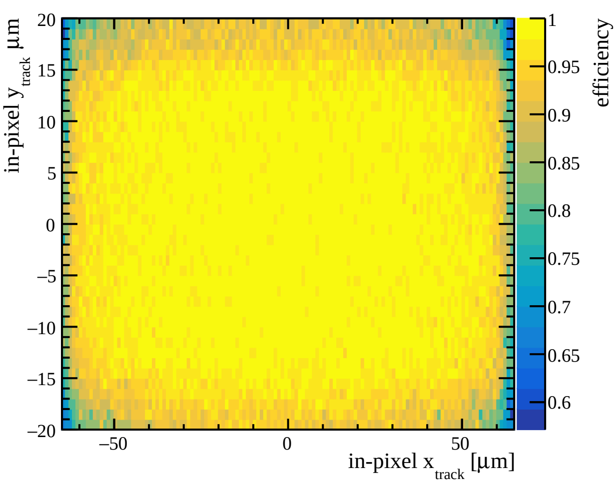

Figure 8: Pixel efficiency map of `ATLASpix1` detector

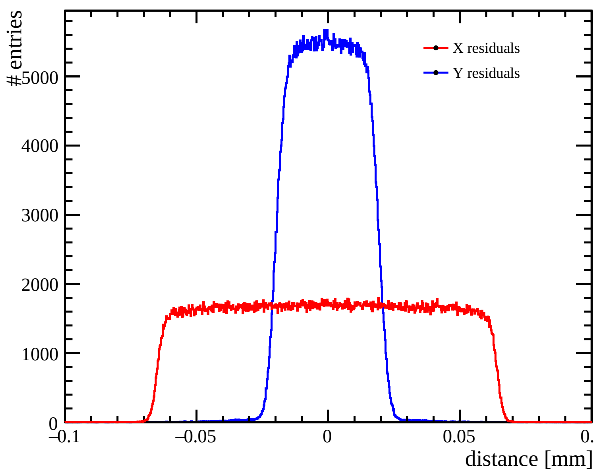

Figure 10: Distribution x and y time residuals for `ATLASpix1` detector

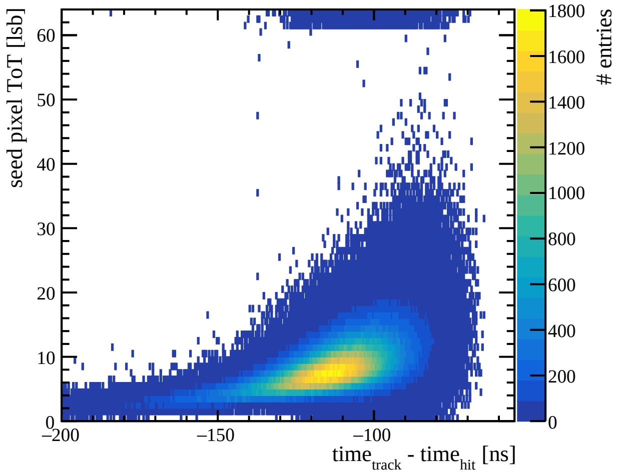

Figure 11: Time residuals in dependence of seed pixel ToT

[2] A Schöning et al. “MuPix and ATLASPix–Architectures and Results”. In: *arXiv preprint arXiv:2002.07253* (2020).