Optimization of trapezoidal double sided silicon strip sensors by evaluation of different p-stop patterns

Thomas Bergauer, M. Dragicevic, M. Friedl, I. Gfall, E. Huemer, C. Irmler, M. Valentan[1)]
(HEPHY Vienna, Austria)

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Abstract

Material reduction is a crucial point for inner tracking systems of all high energy physics experiments, especially for those located at lepton colliders. Silicon strip sensors with double sided readout are best suited to reduce the material budget of a tracking detector. We tested a trapezoidal 6” sensor, which can be used in a non-cylindrical part of a tracking detector

The strips on the n-side have to be electrically separated, in our case by the p-stop implant method. We have designed silicon strip sensors which feature different patterns of these implants, and different geometries for each pattern. Among others, these sensors have been tested at a beam test at CERN to determine the performance of the different patterns and geometries. Results from this test are shown in this report.

[1] Corresponding author: valentan@hephy.oeaw.ac.at, Nikolsdorfer Gasse 18, 1050 Wien, Austria

1. Introduction

The SiLC collaboration is pursuing research towards a new generation of silicon tracking devices for possible use in future projects like the International Linear Collider (ILC). The core activities include new developments in silicon sensors, readout chips, mechanics and system integration, complemented by simulation.
For any ILC experiment, material budget is a crucial point for its inner detectors. Therefore, different approaches to minimize the material budget are under investigation by the SiLC collaboration. One possibility of material reduction is to use double sided silicon sensors instead of single sided ones. These double sided sensors can give two-dimensional information about a particle's position, whereas single-sided sensors only measure the position in one dimension. Thus, two of the single-sided ones have to be combined to give the same information as one double-sided sensor.
The production of a double-sided sensor introduces the need to implant highly n-doped readout strips on the backside of an n-type silicon substrate. These strips would be shorted and useless without further efforts to ensure electrical strip separation. One way of strip separation is the so called p-stop blocking technique, which features highly p-doped regions between the strips for electrical insulation. Sensors with different patterns and geometries of these p-stop implant regions were designed and have been fabricated by Micron Semicondctor Ltd., Sussex, England.
Moreover, we designed and tested a trapezoidal double sided sensor, which could be used in conical parts of a tracking detector. For that application a conventional rectangular sensor would not be suitable.

2. Sensor Design and Production

The new silicon sensors are compiled such that all of them fit onto a single 6" wafer, which reduces the mask and setup costs to a minimum. A drawing of the full wafer is shown in figure 1. The wafer consists of the large trapezoidal sensor, a rectangular test sensor to the right and three square sensors implementing the different p-stop patterns to the left. The sensors are surrounded by different sets of test structures.

Quadratic baby sensors

The three quadratic baby sensors (called "baby2" to "baby4") on the left side of the wafer were designed especially to test different p-stop patterns. All of them have the exact same layout, except for the p-stop implants. On the p-side they have 512 strips with a pitch of 50 microns, and one intermediate strip between two readout strips. On the n-side they have 256 strips with a pitch of 100 microns. There is no intermediate strip on the n-side to see the effect of the p-stop pattern only.
The strips on the n-side are grouped into four zones. Each zone features a different geometric implementation of the p-stop pattern, i.e. different space between strip implant and p-stop implant.

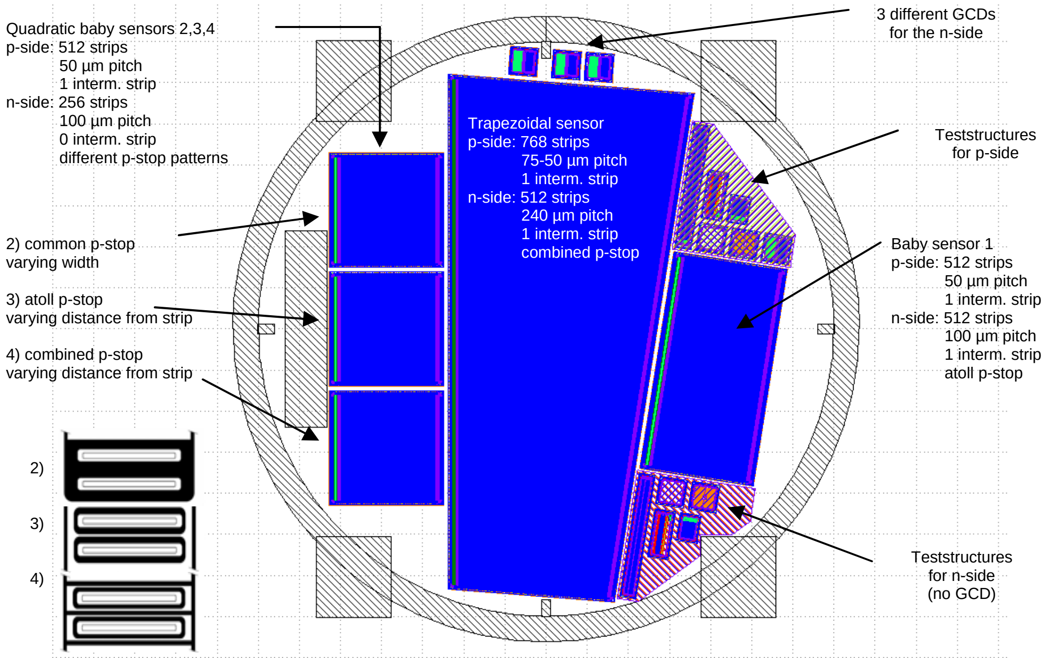
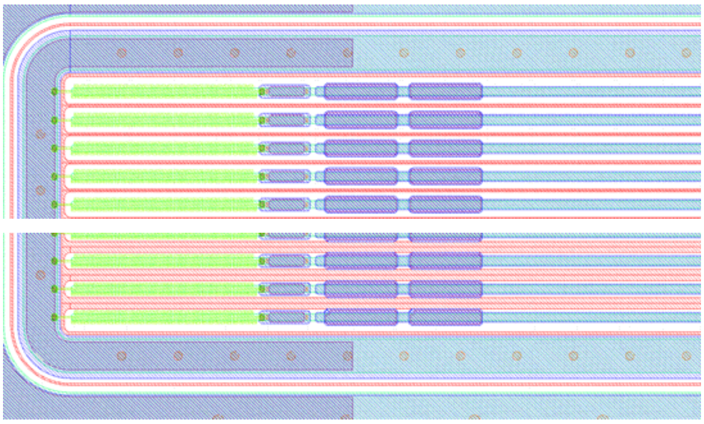


Figure 1: Layout of the full silicon wafer, as it was processed at Micron Semiconductor Ltd., Sussex, England.

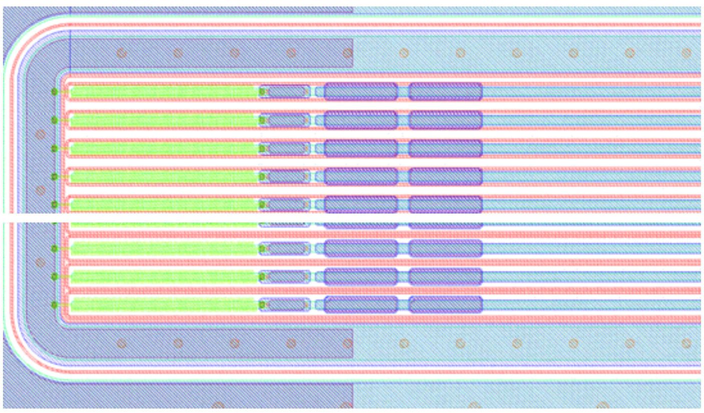
Baby sensor 2

The uppermost quadratic baby sensor features the so called common (or conventional) p-stop pattern. The strips on the n-side are embedded in a common p-implanted area. The picture to the right shows the zones 1 (bottom) and 4 (top). The implanted region between the strips is wide for zone 1, and gets narrower until it is just a small bar in zone 4.



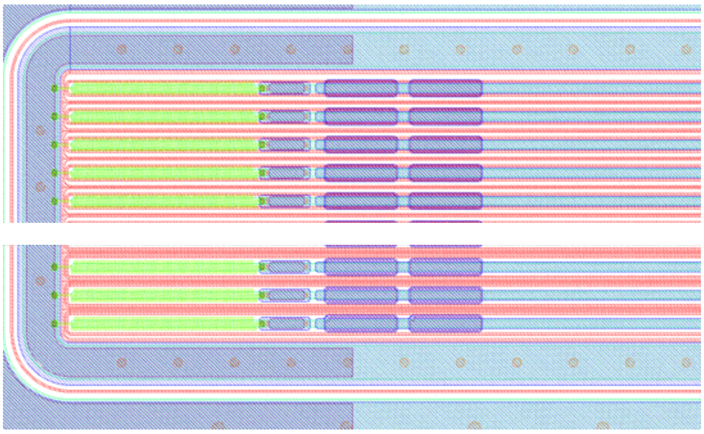
Baby sensor 3

The middle quadratic baby sensor features the so called atoll p-stop pattern. Each strip on the n-side is enclosed in an individual p-implanted area formed as a "ring" - the p-stop atoll. The picture to the right shows the zones 1 (bottom) and 4 (top). The atoll is far away from the strip for zone 1, and gets closer until it surrounds the strip implant very closely in zone 4. Moreover, there is a large ring surrounding all strips.



Baby sensor 4

The bottom quadratic baby sensor features the so called combined p-stop pattern. The strips on the n-side are embedded in a common p-implanted area and, in addition to that, enclosed with individual p-stop atolls. The picture to the right shows the zones 1 (bottom) and 4 (top). While the common part of the p-stop pattern remains the same in all zones, the atoll is far away from the strip for zone 1, and gets closer until it surrounds the strip implant very closely in zone 4.



Trapezoidal sensor

The middle sensor on the wafer is a large scale trapezoidal sensor, which can be used for non-cylindrical parts of a tracking detector. The 768 strips on the p-side follow the trapezoidal shape, which results in a varying strip pitch of 50...75 microns. The 512 strips on the n-side are parallel with a pitch of 240 microns. There is an intermediate strip between two strips, which is not read out. This intermediate strip improves the charge sharing and thus the resolution. The strip separation on the n-side is done using the combined p-stop pattern.

3. Module Assembly

Mechanical frames have been designed and manufactured using Vetronit (FR4), onto which the front-end hybrid and the different DUT sensors have been glued. The hybrid board hosts APV25 chips for readout, as used in the CMS experiment at CERN. In total, eleven modules have been built, two with trapezoidal sensors, and nine with quadratic baby sensors, three of each type. Examples of those modules are shown in figures 2 and 3.

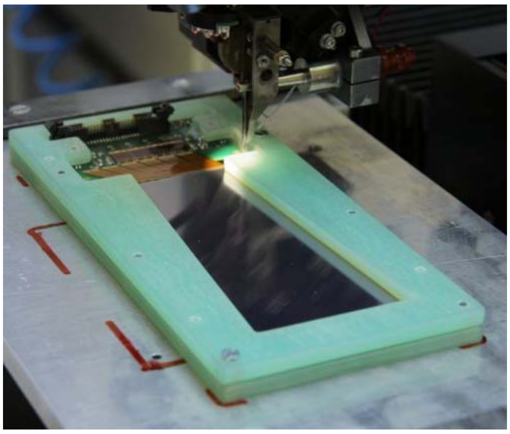


Figure 2: Trapezoidal sensor, p-side up, while wire-bonding the strips to the pitch adapter.

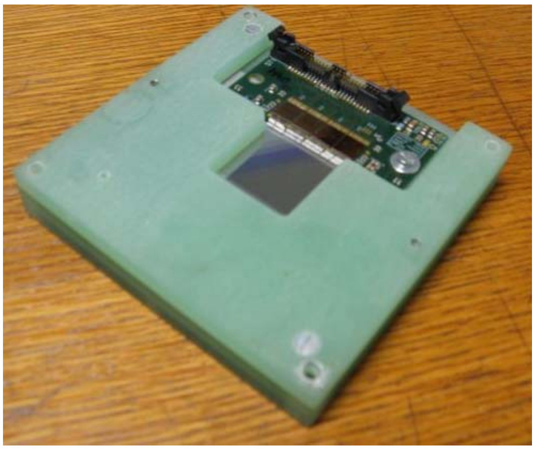


Figure 3: Quadratic baby sensor, p-side up.

4. Data Acquisition System and Beam Test

The DAQ and readout system, as sketched in figure 4 and shown in figure 5, is called APVDAQ, since it has been built to read out APV25 readout chips. It contains a 9U VME crate with a single controller (NECO) and a fan-out unit (SVD3_Buffer) as well as several FADC modules with built-in processing capabilities. The readout is done via the VME crate to a PC connected via NI VME controller.
On the front-end side, which can be located up to 30m away, there are repeater boxes (DOCK) which connect to the front-end hybrids housing the APV readout chips. The system has been adapted to be compatible with the EUDET pixel telescope, which means that the trigger information (including time-stamps) from the TLU is directly included into our VME hardware.

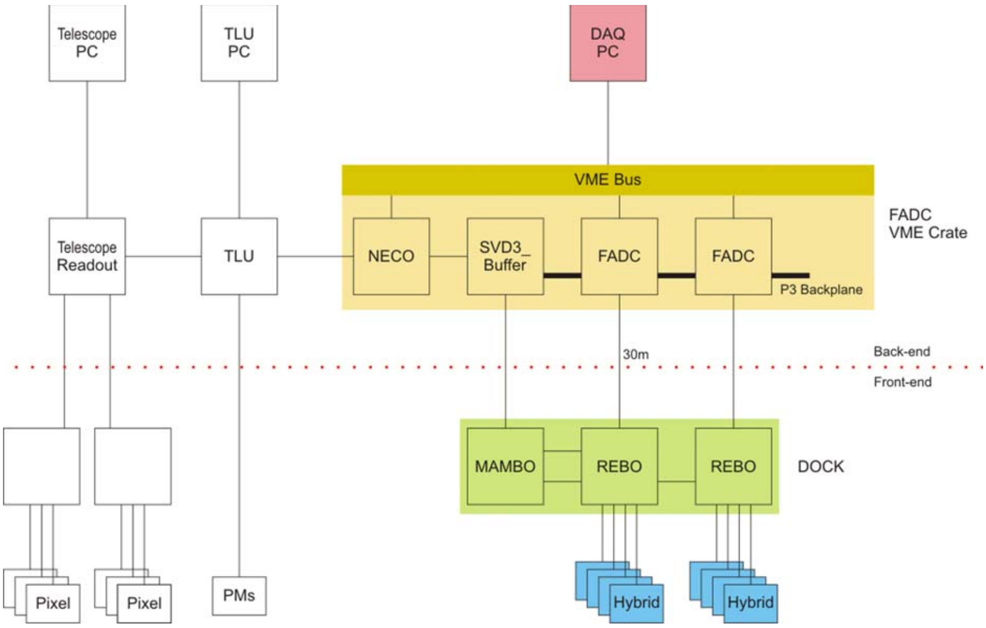


Figure 4: Schematics of the DAQ system.

The online DAQ software is implemented in LabWindows/CVI. The software has already been used for various beam tests before and is therefore very stable. The graph shown in figure 6 corresponds to a scope picture (raw data) of six consecutive readout frames of a single APV chip with 128 strip values multiplexed in each frame, where frames are spaced by 25ns. The shaper output waveform (50ns peaking time) of a strip with a particle hit is clearly visible. Multiple samples around the peak have been used to determine the particle timing with an accuracy of a few nanoseconds.

Figure 5: Picture of the VME crate housing the DAQ boards: NECO, Buffer and two FADC boards.

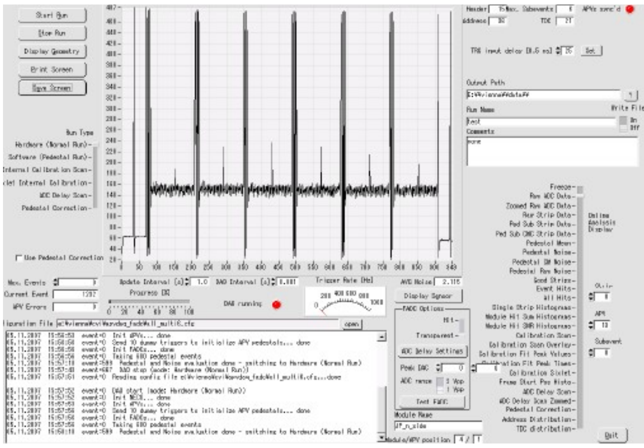


Figure 6: Screenshot of the DAQ software. The graph in the center shows the raw APV data of a single chip.

During our assigned two weeks (between 27th September and 11st October 2010) of beam time in the CERN north area beam zone H6b of the SPS accelerator, we have received hadrons, mainly pions, with an energy of 120 GeV to simulate minimum ionizing particles. The settings file from last years run has been applied (*H6b.802 (FM HAD (P0 off, H8=+180) PARLALLEL IN H6B SILC 2008*). The DUT sensors have been installed in the center of the EUDET telescope as shown in figure 7.

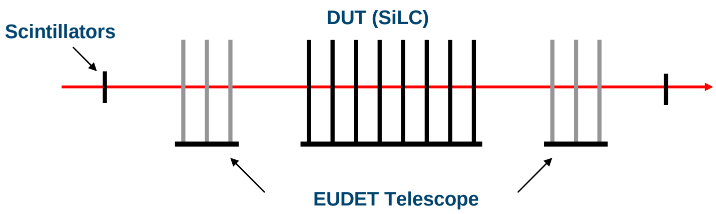


Figure 7: Scheme of the setup with DUT, Telescope and scintillators.

The scintillators, used for triggering, were connected to the TLU box, which provided trigger information to both the EUDET telescope and the APVDAQ system.

5. Results

The offline analysis software is based on several parts: The first stage is using LabWindows/CVI to read the raw data files from the APVDAQ system (binary files with extension*.*dat* and several text files with the extensions **.pro,*.sig,*.txt,*.cfg*) to perform cluster finding, pedestal subtraction and common mode correction. It writes the zero-suppressed data into binary files with the extensions *.*hit* and *.*eta* and a text file with the extension *.*mod*.

Since the online DAQ is storing six samples of the signal of each triggered event, another program is used to perform hit-time finding. This is done with a compiled ROOT-program called *hitfitgui* and the corresponding output files are called *.*hit.fit* (plus some plots in *eps*-format). The last stage is a ROOT-macro called *AnaRun*, which finally produces *eps*-files with plots containing Gaussian convoluted Landau fits of the signals.

The data analysis is still ongoing, so all results below are preliminary and tentative. We show here first results of a position scan performed with the trapezoidal sensor, and a preliminary comparison of the different p-stop patterns using the quadratic baby sensors. So far, no tracking information from the telescope has been used in the analysis.

Position scan of the trapezoidal sensor

We aimed the beam at three different positions on the trapezoidal sensor, one in the center, and one each at the narrow and wide sides. Figure 8 shows a sketch of the beam positions on the sensor. In this setup, the strips of the p-side are horizontal, while the strips of the n-side are vertical.

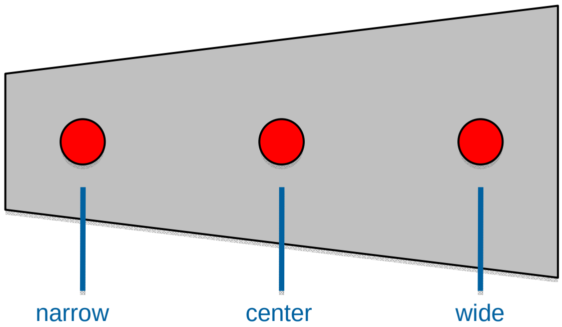


Figure 8: Beam positions on the trapezoidal sensor.

We found the signal-to-noise ratio (SNR) to behave as expected. On the p-side (long horizontal strips) the SNR shows no position dependence, whereas on the n-side (vertical strips with varying length) it drops on the wide side due to increased noise.
However, when looking at the signal itself, we found interesting effects. Figure 9 shows the signal distribution histograms of n-side signals for the three beam positions. The red line is the signal distribution of events with cluster width 1, i.e. the deposited charge is collected by one strip only. The blue line is the signal distribution of events with cluster width 2, i.e. the deposited charge is shared between two neighbouring strips.

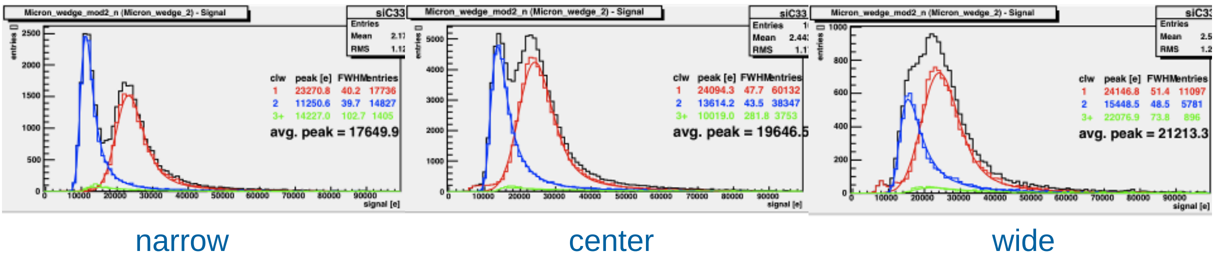


Figure 9: Signal distribution histograms of the trapezoidal sensor.

One can clearly see a double peak in the signal distribution histograms. Events with cluster width 2 (blue) have a significantly lower mean signal, which means that signal is lost when it comes to charge sharing between neighbouring strips. This is certainly an effect of the sensor itself and does not have its origin in the trapezoidal form. But the shape of the double peak is sensitive to the beam position! The double peak is very pronounced at the narrow side of the sensor, while it almost vanishes at the wide side. This implies that the charge sharing between neighbouring strips is sensitive to the strip length, which at the moment is not plausible. We think that the combination of the combined p-stop pattern and the intermediate strip may be the reason. In any case, we will investigate this effect further.

Comparison of different p-stop patterns

To test the performance of the different p-stop patterns we built a stack of eight modules consisting of quadratic baby sensors. One sensor of each p-stop type is located in the center of the stack as devices under test (DUTs), enclosed by two modules each in front and behind. The DUTs are read out on the n-side only, while the other sensors are read out on the p-side only. Figure 10 shows a photo of the stack.

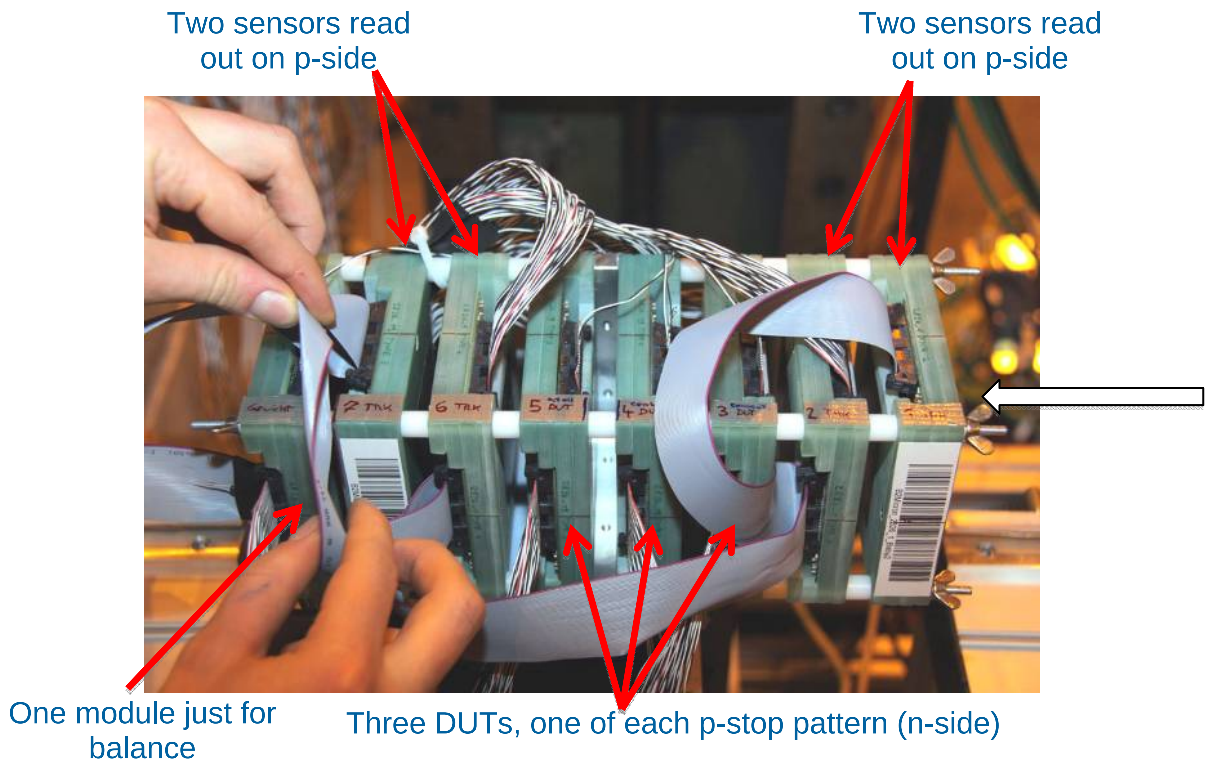


Figure 10: Stack setup of the quadratic baby sensors for testing the different p-stop patterns

After initial measurements at CERN, the sensors have been irradiated with a ^{60}CO gamma source in Mol, Belgium. During one night we accumulated a dose of 70 MRad. Back at CERN, we performed the same tests as before, to see the difference between the unirradiated and the irradiated state.

Figure 11 shows a comparison of the p-stop patterns in terms of signal-to-noise ratio. We found that the atoll p-stop perfoms best in the unirradiated state, while after irradiation the atoll pattern and the common (or conventional) p-stop are tied for best performance. In any case the combined p-stop pattern showed notably lowered performance. This was surprising, since two papers [1,2] favour the compined p-stop pattern, saying that it is the best tradeoff between charge collection efficiency and interstrip capacitance.

Note that this first analysis does not take into account the different zones on the sensors yet. We plan to do the same analysis broken down to the four zones to see differences in the geometric layout of each pattern. This needs tracking information obtained from the EUDET telescope.

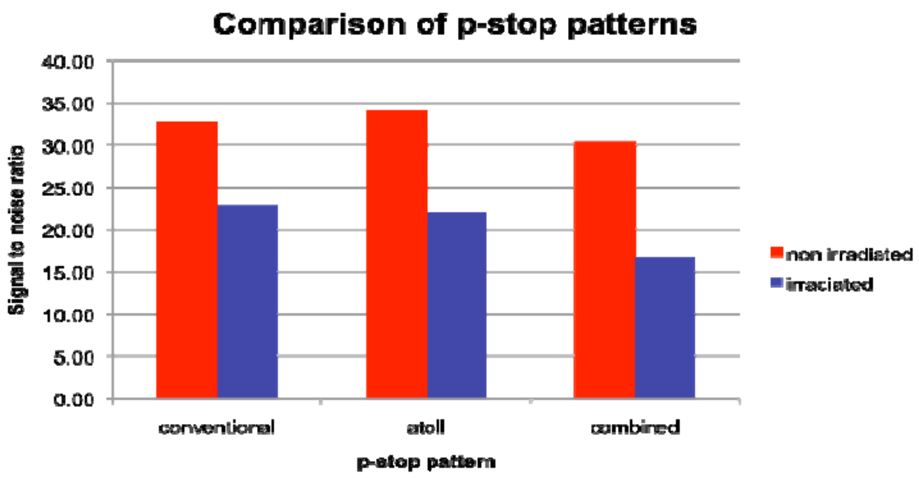


Figure 11: Comparison of p-stop patterns, before and after irradiation.

6. Conclusions

Within one year, a full cycle containing sensor design, sensor production, module design and assembly and a beam test have been performed. Two types of sensors have been developed: a trapezoidal 6" sensor suited to be used in a non-cylindric part of a tracking detector, and small quadratic test sensors to investigate the performance of different p-stop patterns.
For both we found unexpected effects. In the case of the trapezoidal sensor the charge sharing shows a dependence on the beam position. The results of the comparison of p-stop patterns contradict the conclusions of two scientific papers.
In any case, data analysis is continuing to get more meaningful and significant plots. Some discussion started already to re-test the sensors again in an upcoming beam test, as well as testing specialized modules in-house with a radioactive source.

Acknowledgement

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References

[1] IEEE Transactions On Nuclear Science 45 (1998) 303-309 - Iwata et.al. - Optimal P-Stop Pattern for the N-Side Strip Isolation of Silicon Microstrip Detectors
[2] IEEE Transactions On Nuclear Science 45 (1998) 401-405 - Unno et.al. - Evaluation of P-stop Structures in the N-side of N-on-N Silicon Strip Detector