Resolution studies on silicon strip sensors with fine pitch

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Abstract

In this project we investigated the spatial resolution of different strip geometries on a silicon strip sensor (SSD) with 50 microns read-out pitch. For this purpose a custom multi geometry sensor was designed and tested in a 120 GeV Pion beam at the SPS. In this memo we summarize the whole process form sensor procurement to the data analysis.

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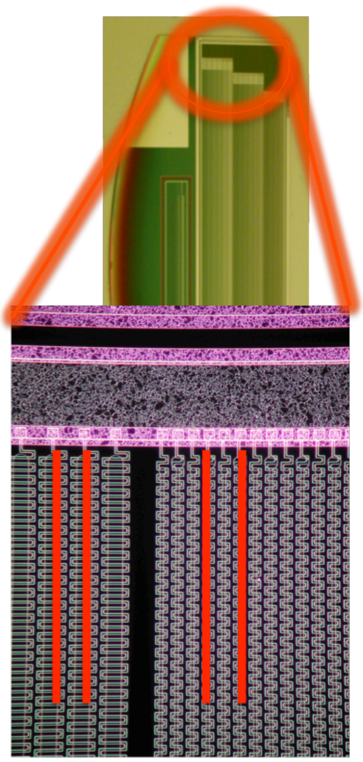
1 Introduction

In order to build a high resolution silicon strip sensors the strip geometry is of crucial importance. The geometry influences the strip capacity and the charge sharing ability of the strips, both basic properties that contribute to the spatial resolution. Therefore the aim of the project was to evaluate the best strip geometry of silicon strip sensors with 50 microns pitch to achieve the highest possible spatial resolution.
For this purpose a custom multi geometry sensor was designed by the SiLC collaboration. Over the 16 zones of this sensor we varied the strip width from 5 to 25 microns. The number of intermediate strips varied between zero and two.
As part of a SiLC order 30 of those sensors were manufactured by Hamamatsu Photonics in Japan. They were tested in Vienna and Karlsruhe to assure their quality and eight were selected to build modules, which form our test detectors.
The readout electronics and data acquisition software required for operating the detector were developed in Vienna and had been steadily improved in previous test beams. Therefore the whole setup was working reliable and stable.
In June 2008 the detector was tested using a 120 GeV Pion beam at the SPS beam line at CERN.
The detector, consisting of eight multi geometry sensors plus readout electronics will be referred to as device under test (DUT) in this report.
Furthermore the EUDET Telescope, a 2D pixel detector provided by DESY, was used to obtain high precision tracks which will serve as a reference and will be matched to tracks measured by the DUT. Although preliminary results were obtained by analysing the DUT data alone this will provide an additional way to determine residuals for all the zones.

2 Sensor Layout

The sensor order at HPK consisted of 30 single-sided AC-coupled silicon strip sensors.
The wafer was approximately 320 μm thick and a resistivity of 6.7 kΩcm of the bulk material was chosen such that the full depletion voltage of the sensor fell between 50 and 100V.
The strips were connected to the bias line using poly-silicon resistors with a resistance of 20MΩ (±5MΩ).
Each sensor had 256 AC-coupled readout strips with a pitch of 50 μm, which were read out. These strips were grouped into 16 zones. Within a zone (16 strips) the layout was constant. A missing strip separated the zones.
For each zone we varied the strip width and the number of intermediate strips. The intermediate strips are capacitively coupled to the readout strips and improve the resolution by charge sharing. The first six zones had no intermediate strips and strip widths between 5 and 25 μm. Zone 7 to 12 had a single intermediate strip,



TESTAC:

strip width [μm]	intermediate strips
5	no
10	no
12.5	no
15	no
20	no
25	no
5	single
7.5	single
10	single
12.5	single
15	single
17.5	single
5	double
7.5	double
10	double
12.5	double

Figure 1: Microscopic image of the poly-silicon resistors at the transition for zone 6 to 7. The red lines indicate the p+ strips underneath the resistors

with a strip width varying between 5 and 17.25 µm. Zone 13 to 16 had 2 intermediate strips. Due to spatial limitations the strip width could only be varied between 5 and 12.5 µm in the last region.

3 Sensor Testing:

Overall 30 multi geometry test structures were produced whereof 28 were tested in Vienna. Ten of these 28 sensors went to Karlsruhe later on, to undergo further testing.

3.1 I-V Curves:

I-V curves of all sensors were measured up to 800V. All sensors were stable up to and beyond the full depletion voltage of around 60V. Some showed early breakdown below 400V but most of them were stable up to 800V bias voltage.

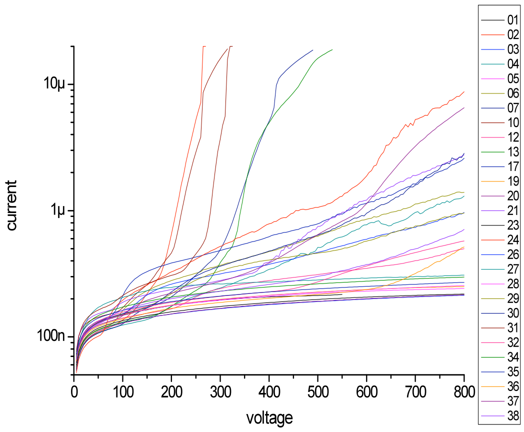


Figure 2: I-V curves for all 28 sensors.

3.2 C-V Curves:

C-V curves were measured to determine the full depletion voltage, which turned out to be around 50 to 60V for all sensors. This basically agrees with the measurements done by HPK, which were approximately 5V higher due to different measurement methods.
The sensor met our specifications, which demanded a full depletion voltage between 50V and 100V

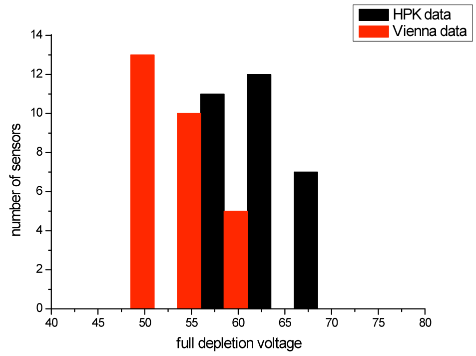


Figure 3: Distribution of the full depletion voltage of all 28 sensors.

3.3 Inter Strip Capacitance:

As expected the inter strip capacitance was rising with increasing strip width as the distance between strips gets smaller. We also found a varying offset for zones with zero, one or two intermediate strips. Surprisingly, zones with one intermediate strip had a slightly larger offset, instead of zones with 2 intermediate strips.

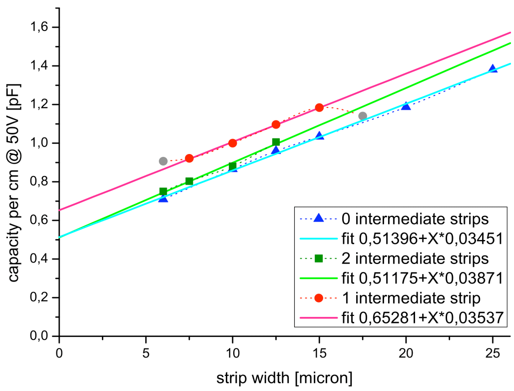


Figure 4: Measured inter strip capacitance fitted for 0, 1 and 2 intermediate strips.

4 Construction of the modules and the DUT:

The modules containing the sensor and the front end of the readout electronics (hybrid) were developed and assembled in Vienna. In total 9 modules have been built, 8 were used for the DUT.
The hybrid, based on the APV25 readout chips, was also developed at our institute. The material chosen for the support structure, to carry sensor and hybrid, is Vetronit.

The modules where assembled to a module pack consisting of 8 modules as seen in figure 5. The black foil and the Vetronit were not sufficient to protect the sensors from ambient light. Therefore the DUT had to be wrapped in a light proof blanket during operation.

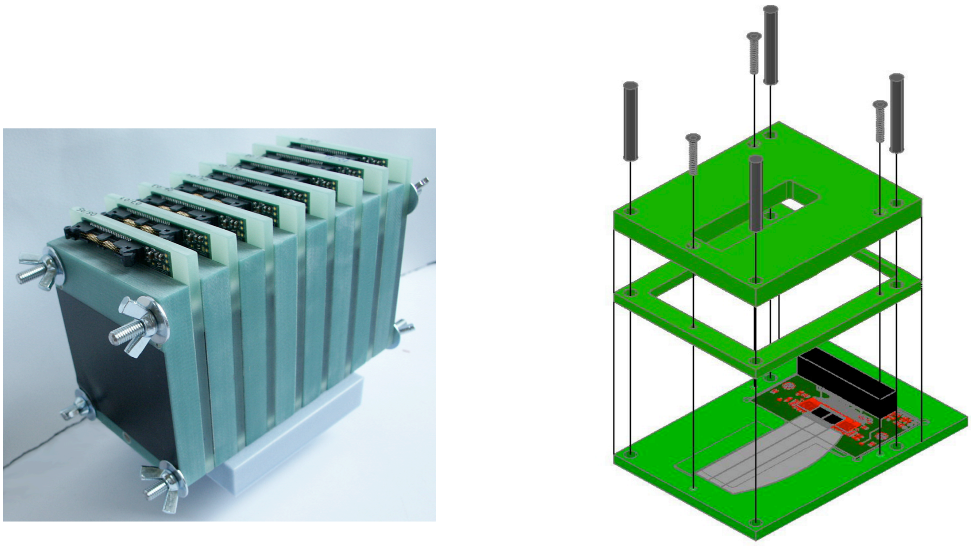


Figure 5: The module pack (DUT, left) and a schematic view of a single module (right).

5 Testbeam Setup:

The testbeam took place from 30.05 – 5.06.08 at the H6B area at CERN (SPS beamline).
The DUT was mounted on an XYZ-rotation-stage between the detector planes of the EUDET Telescope and the scintillators. This rotation stage should have served as a tool to adjust the the DUT's orientation exactly to the beam and the telescope. Additionally it was planned to performe angle scans with a single module. This would have been easy with the remotely controlled rotation stage as no beam interruptions would have been required to readjust the DUT. Unfortunately the stage didn't work properly so the DUT had to be moved by hand.

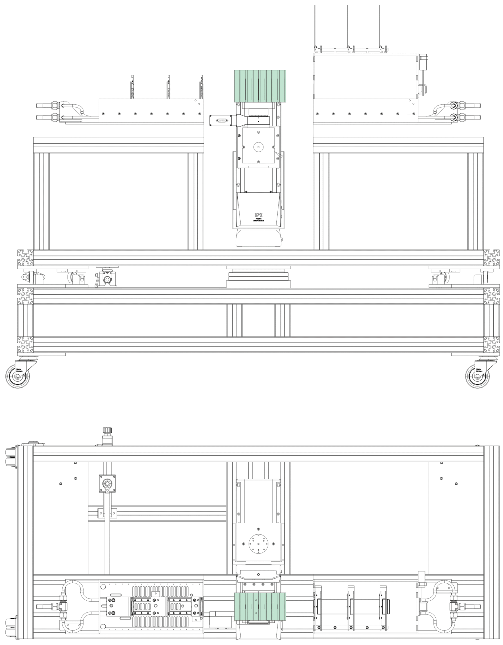


Figure 6: Side and top view of the DUT and the telescope in the test beam setup.

Scintillators were necessary to trigger on incomming particles. The Trigger Logic Unit (TLU), receiving the scintillators signal, enables the DUT and the telescope to synchronize the data takeing, thus the same tracks will be recorded by the two systems.

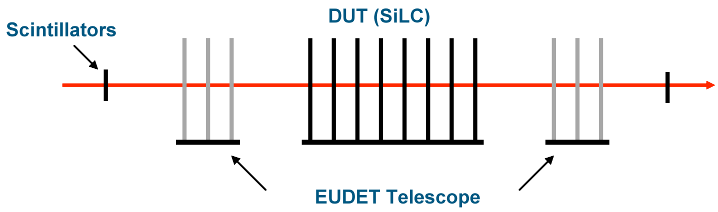


Figure 7: Scheme of the setup with DUT, Telescope and scintillators.

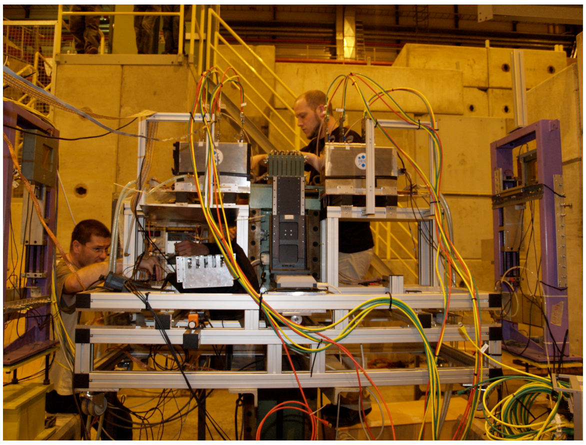


Figure 8: Test beam setup at the SPS beam line.

6 Measurements:

The main goal of the test beam was to record data that allows us to estimate the resolution for different detector geometries with the help of the EUDET Telescope. Unfortunately the Telescope's sensitive area, which is 7x7 mm^2 didn't cover the full sensor width of the DUT, so it was necessary to split each measurement into three runs. Each of this resolution runs had 10^5 events. The different areas on the sensor, covered during the runs, can be seen in the picture on the left.

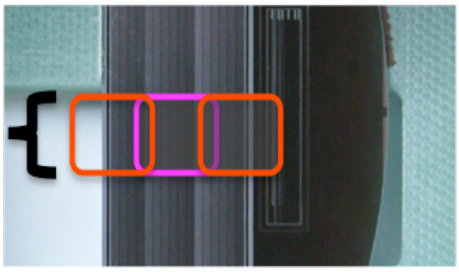


Figure 9: Area of the sensor covered by the Telescope's active area.

The readout electronics of the DUT (APVDAQ) offered two modes, raw mode and zero suppressed mode. Resolution tests together with the Telescope were only recorded in raw mode, which was more reliable compared to zero suppressed mode. The latter mode was tested separately at this test beam.

We also wanted to examine the dependence of the detector signal on the depletion voltage. Therefore we did 9 Voltage Scans (10^4 events each), varying the voltage between 10V and 100V.

Furthermore we investigated the dependence of the resolution on the angle between the beam axis and the detector planes. The angle scan was done in 10˚ steps between 0˚ and 60˚ tilt of the detector planes, taking 10^4 events in each run.

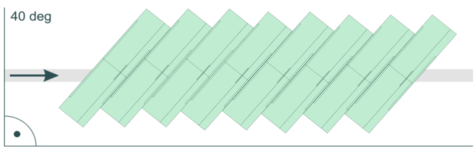


Figure 10: Angle Scan Setup for 40˚

7 Preliminary Results:

The correlation plot between the Telescope and the DUT shows that the two detectors were synchronized well.
Also the modules within the DUT show positive correlations. Figure 11 shows the correlations between the two detectors and also between the first and the last plane

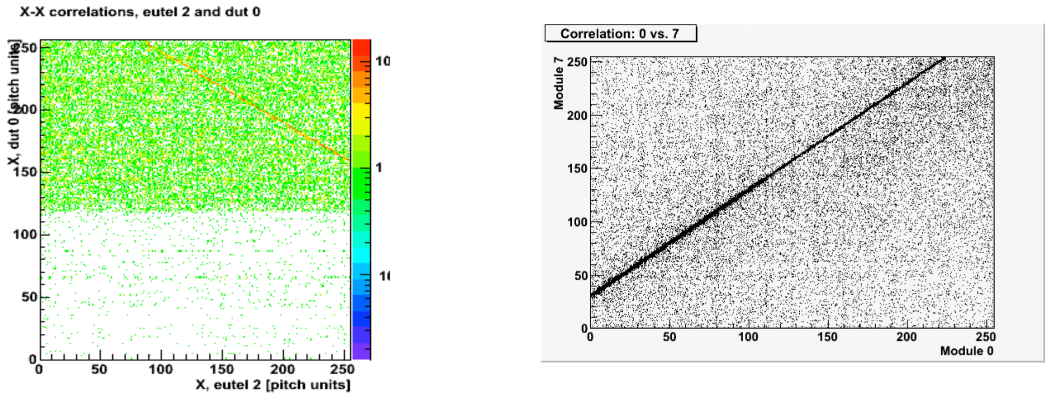


Figure 11: Correlation plots. Telescope plane vs DUT module (left): the red line indicates correlation, DUT module 0 vs moldule 7.(right)

Calculations of the resolution that were available at the time of writing were done in Prague and don't make use of the EUDET Telescope data yet. The resolutions were calculated by estimating the residuals of a single plane in the center of the module pack iteratively, using the rest of the modules as "telescope".
In the first iteration, the tracks are fitted assuming equal resolution on all detector planes for all zones, zone 3 is omitted from the fit. The estimated residuals for zones on plane 3 then are applied to the other detector planes for the second iteration.
Only tracks with hits on all detector planes were considered, so their number was to small to achieve reliable statistics for the edge zones (1, 15, 16). Therefore these are not included in figure 12.
There is a significant increase of resolution for the region with one intermediate strip compared to none. Two intermediate strips only seem to provide a small improvement compared to one strip. The achievable resolution is about 5 µm.
A slight influence of the strip width is also visible in the middle region but further investigation exploiting the full amount of data is necessary to obtain more detailed results.

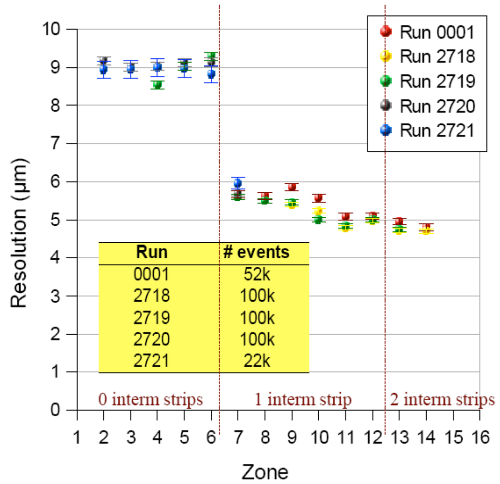


Figure 12: Plot of the first results.

Acknowledgement

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