Characterization of the FORTIS 4T MAPS sensor

Application for Transnational Access to the CERN Testbeam and usage of the

EUDET telescope

J.J. Velthuis[1] (project leader), D. Cussans[1], P. Dauncey[2],
J. Goldstein[1], M. Stanitzki[3], M. Tyndel[3]

[1] *University of Bristol*
[2] *Imperial College London*
[3] *Rutherford Appleton Laboratory*

The Cherwell program is a focused R&D program aimed at the development of pixel sensors for future particle physics vertexing and tracking with in-pixel data processing with emphasis on Linear Colliders. The goal is to implement the full data processing for an array of pixels onto the monolithic active pixel itself. Here one can think of: hit finding, digitization, clustering and hit position reconstruction. The first step towards this is the study of the FORTIS. The FORTIS is the first 4T monolithic active pixel sensor developed for particle physics.
After a successful week of beam tests using the EUDET telescope at DESY in March 2010 we have been granted a week of beam time at CERN. We request travel support for 5 people for 9 days to come to CERN and take data.

1 Scientific Background

As particle physics colliders reach higher energies and luminosities, finely segmented pixel detectors will be needed for vertexing and tracking.

1.1 Vertexing

The function of a vertex detector is to provide precision spatial measurements of tracks close to the primary interaction vertex without introducing too much material. The innermost layer is placed as close as possible to

the interaction vertex (typically $\sim$1 cm). To distinguish the tracks from displaced vertices the resolution needs to be a few microns, implying a pixel size of 20 μm or smaller and analogue readout. Some form of time-stamping is required to get the occupancy per time-slice below $\sim$1% as required for pattern recognition. The material per measurement layer is a crucial parameter if multiple scattering is not to spoil the measurement of track angles. Thin layers of silicon plus supports can be realised with a material budget of $\sim$0.1% radiation lengths (X_0) provided the required power can be restricted to sufficiently low levels so that liquid cooling is not required.
Monolithic silicon technology is one of the few proven techniques for realising thin, low power consumption sensors with the small pixel sizes required.

1.2 Tracking

The function of a tracking detector is to provide sufficient granularity and measurement precision to be able to find and reconstruct all charged particles, again without introducing too much material and to provide a precise measurement of the curvature. Achieving the required momentum resolution requires an rϕ precision of $\sim$15 μm. Pattern recognition for track reconstruction demands the detector occupancy to be less than 1%.

1.3 Cherwell sensor

The first Cherwell sensor is currently being designed. It will be realised using the 4T imaging technology which has recently become available to us and will provide better noise performance than previous 3T architectures. It provides efficient charge collection and storage with low power. The readout will be realised as a conventional rolling shutter, with the columns subdivided to give the required time slicing. It is an important question for our R&D programme to determine whether this approach using a pinned photodiode will provide full detection efficiency for minimum-ionising particles (MIPs) with compact clusters and adequate precision. This could be more challenging with the larger pixels ($\sim$25-50 μm) needed for tracking. The readout and memory buffers will be distributed over the pixel area with no dead space using the deep p-well INMAPS technology. These sensors will be known as the Cherwell family. A schematic picture of the Cherwell concept can be found in figure 1. The time-stamp resolution will be adjustable from the full 1 ms in the barrel down to 0.1 ms in the very forward region. Power dissipation even in the forward region is expected to be compatible with gas cooling.

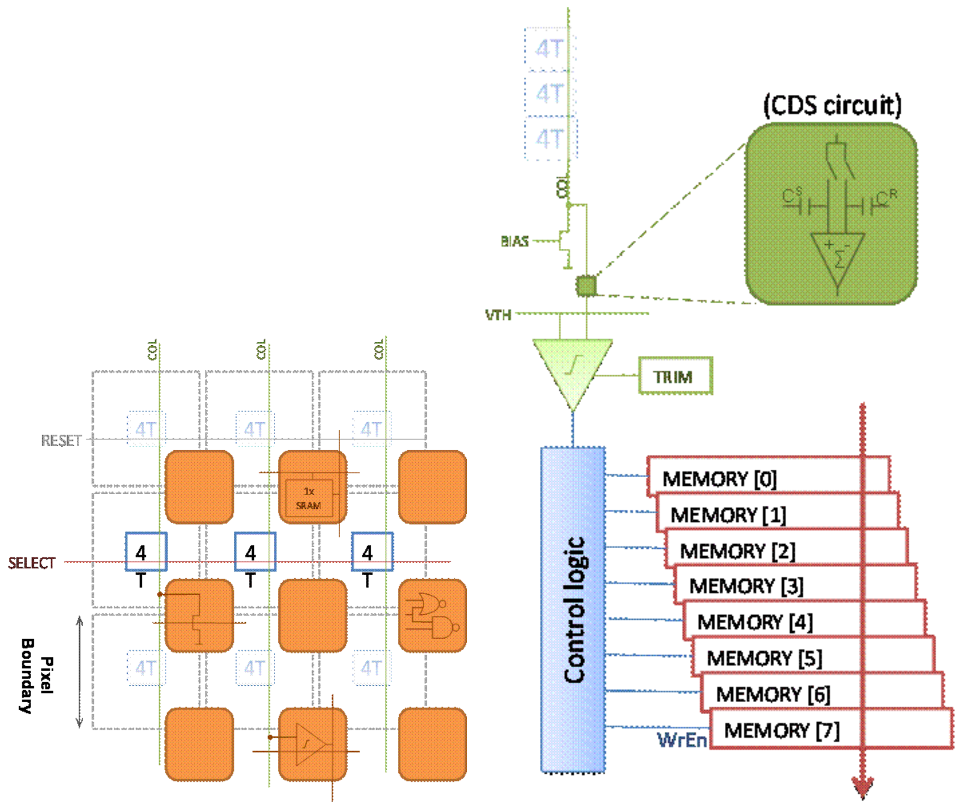

Figure 1: *Schematic drawing of the Cherwell concept.*

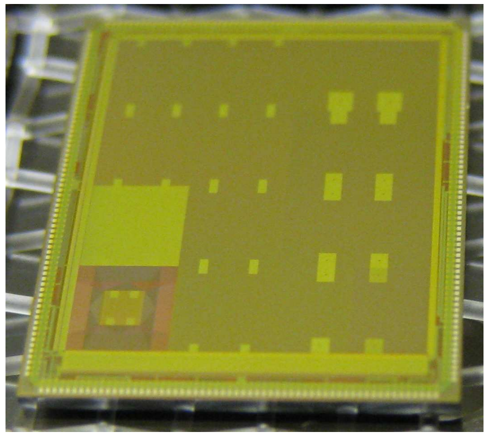

Figure 2: *Photograph of the FORTIS.*

2 FORTIS

At the moment we have the first 4T sensor, the FORTIS, in hand. This is a technical study sensor for the 4T architecture performance. The FORTIS' sensor area of 512×448 pixels was divided into twelve different sections. These differ in pixel size, diode size, in-pixel active area shape and in-pixel source follower transistor size.

By varying the diode area, the effects of a larger diode could be observed. Larger diodes have a larger diode capacitance, which means that more charge can be collected. The size of the diode also affects the cross talk between pixels in an array. The larger the diode, the less the amount of cross talk as the diode area to pixel area ratio is greater. The experimental shape of the active area which contains the four transistors present in the 4T pixel should reduce the capacitance and hence increase the conversion gain of the pixel. The in-pixel transistor size determines the noise. Therefore multiple transistors were implemented.
The FORTIS was produced in three variations. All three have a 4T read out structure. Besides the reference FORTIS, some have a high resistivity epitaxial layer and some deep p-well islands. A high resistivity epitaxial layer should result in faster and more complete charge collection. The deep p-well islands might change the charge collection properties of the sensor. This needs to be studied in detail as the readout electronics for Cherwell will be implemented in these deep p-well islands. A picture of the FORTIS can be found in figure 2.

2.1 DESY beam test results

As the beam test is only just completed data analysis is still in an early phase. At the moment the analysis is limited to only one substructure. However, in figure 3 some preliminary results are shown. In the top left corner one can see the signal-to-noise ratio for every pixel in every event after pedestal subtraction. This clearly shows that the there are hits found in all three the FORTIS types. The noise for all three is more or less similar. The use of a high resistivity epitaxial layer makes a difference for the cluster size. Also shown are the cluster signals for the three types. Here the signal-to-nosie ratios are listed.

	Signal (ADC)	Noise (ADC)	S/N
Standard	1840±10	16.7± 0.1	110.2±0.9
High res	1210±10	14.2±0.1	85.2±0.9
Deep p-well	1733±14	16.1±0.1	108±1

Indeed the 4T structure results in a very high signal-to-noise as expected.

In figure 4 the correlation between predicted telescope hits and actual FORTIS hits are shown. Currently, alignment of FORTIS is not yet optimised. The hit reconstruction at the moment is just the seed position. Still a position resolution of 22 μm is obtained. This also includes the telescope error of around 10 μm.

3 CERN aims

One of the issues with the data taken at DESY is the limited precision of the telescope due to multiple scattering. The error on the predicted position is estimated to be around 10 μm. One of the essential measurements is to study the effect that the deep p-wells have on the charge collection. For this we need to make a detailed study of the in-pixel variations in charge collection. As most substructures have a 15 μm pitch this is not possible in the DESY data. The uncertainty on the predicted position will be reduced to $\sim$2.5 μm enabling these studies.

4 Beam test request

FORTIS has been granted 1 week of beam time at the CERN SPS test beam facility starting the 7th of June 2010. We request usage of the EUDET telescope. The telescope is needed to provide precision tracks.

We also request travel support to come to CERN and take the data. We will send our TLU expert, David Cussans, earlier so he can help debugging

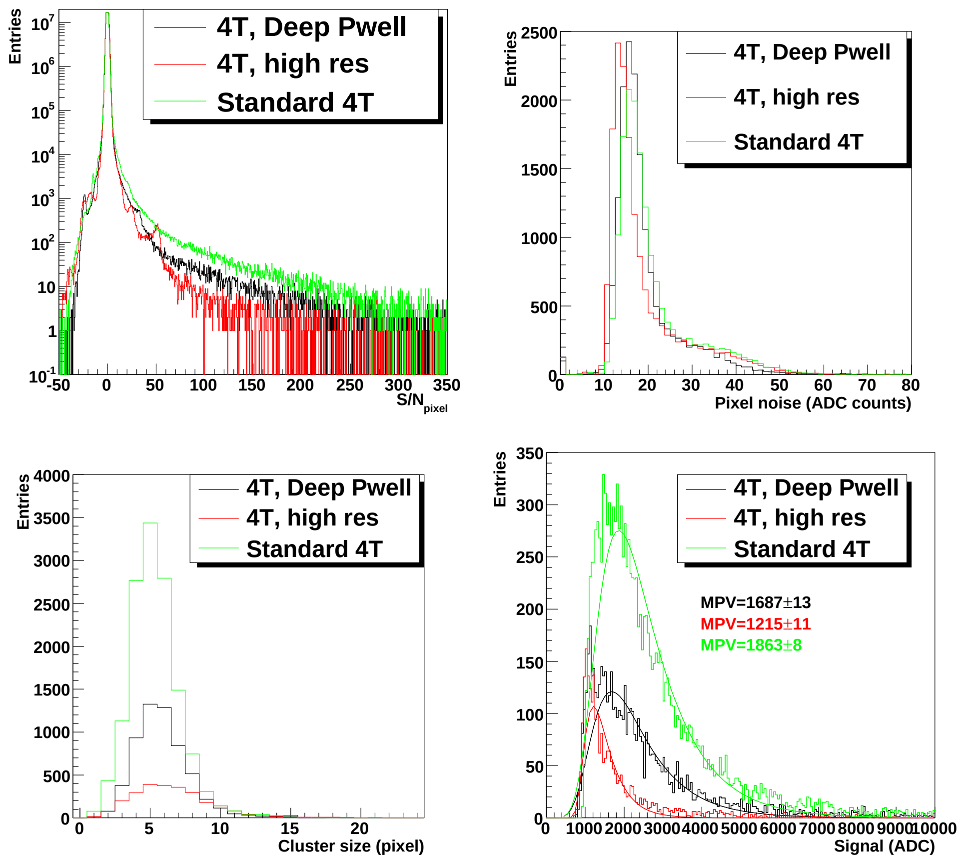

Figure 3: *Signal-to-noise ratio for every pixel in every event after pedestal subtraction, pixel noise, cluster size and cluster signal for the three types of FORTIS.*

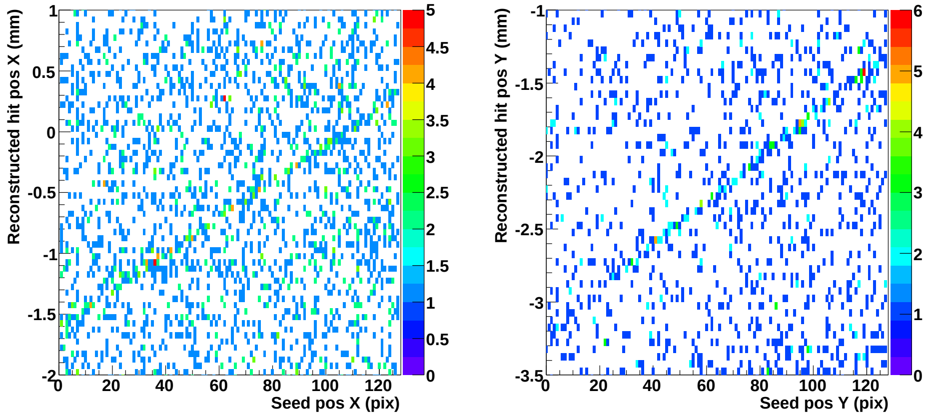

Figure 4: *Correlation between telescope predicted and actual FORTIS hits.*

running with 2 DUTs. He will have to travel by rental car in order to transport our equipment. Dr Goldstein and Dr Wilson will be present only for the beamtest and travel by plane. While Dr Velthuis is already at CERN and wil return in the rental car. The rental car is much cheaper than flying ourselves and sending over our equipment. The total costs are estimated to be 5000 Euros.