Charge Protection Characterisation and Drift Time Resolution Improvement for GridPix

W.J.C. Koppert[1], M. Fransen[1], N. van Bakel[1], H. van der Graaf[1], F. Hartjes[1], J. Timmermans[1], J. Visser[1], R. Kluit[1], V. Gromov[1], F. Zappon[1], V. Blanco Carballo[2], J. Schmitz[2], Y. Bilevych[3]

***Abstract*—A GridPix detector is a gaseous detector capable of detecting single primary electrons from ionising particles. Such a detector consists of a pixel chip as active anode covered with a thin layer of silicon rich silicon nitride (SiRN) for protection against discharges. A layer of 8 μm SiRN, and according recent tests even 4 μm, is sufficient to protect against discharges. The effect of the thickness of the SiRN layer on the operation of a detector has been determined.**
Time walk effects due to pixel electronics response time and gas gain statistics cause errors in drift time measurements thereby worsening the resolution in the drift direction. Simulations and measurements have been performed to determine how much time walk can be compensated for.
GridPix detectors are high resolution low mass detectors that measures track segments in 3D. Very recently we performed first tests in a 250 MeV proton beam, in order to investigate the application of GridPix in Proton therapy and results are promising.

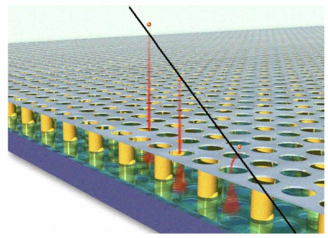
***Index Terms*—GridPix, Time walk, MPGD, TPC, Proton Therapy**

I. Introduction

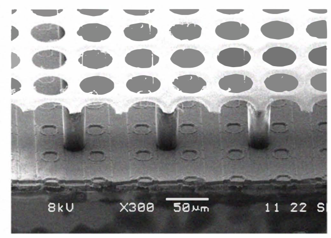
GridPix detectors are micro Time Projection Chambers (μTPCs) with a pixel chip as readout anode. It measures the 3D positions of single electrons created by ionising particles, see Fig. 1(a). The TimePix readout chip was developed at CERN and is based on the Medipix2 [3] design. It has 256×256 square pixels with a 55 μm pitch. Each individual element of the pixel matrix is connected to a preamplifier, discriminator and digital counter integrated on the pixel. The digital counter can either be set to measure the drift time in Time to Threshold (TtoT) or the Time over Threshold (ToT) of the signal.

Since the bare TimePix chip is not able to measure single electrons, an amplification grid is placed on 50 μm tall spacers, see Fig. 1(b). The grid is a layer of 1 μm thick aluminum with holes etched in it. Between the grid and the chip the electric field (∼ 100 kV/cm) is large enough to create avalanches and hence to generate enough charge to be measured by the chip. A SiRN protection layer is deposited on the pixels to avoid damage from discharges. The individual ionisation electrons are focused into the grid-holes. The electron drift time is measured by an internal counter in the pixel started by an external trigger to obtain an absolute time measurement.

Manuscript received November 22, 2011.
Email: wkoppert@nikhef.nl
[1] Nikhef, Amsterdam, The Netherlands
[2] Twente University, Enschede, The Netherlands
[3] Bonn University, Bonn, Germany



(a)



(b)

Fig. 1. a) Schematic of a GridPix detector, the black line indicates a particle track, the drifting electrons are indicated in red. b) SEM image of a GridPix chip.

II. Time Walk Correction

The time to threshold resolution is dominated by time walk effects. Fig. 2 shows that the simulated spectrum for electrons with zero drift distance has an average delay of about 25 ns [4]. For comparison the drift velocity in Argon/Isobutane (80:20) is 50 μm/ns. The next generation TimePix3 (currently under development) is capable of measuring both TtoT and ToT simultaneously, which allows doing a correction on the time to treshold.

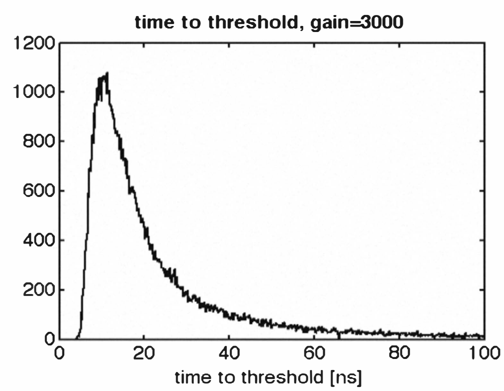


Fig. 2. Simulated TtoT spectrum without correction, σ=22 ns

The simulated Time to Threshold as function of Time over Threshold is shown by Fig. 3 for two signal shapes (RC feedback and Constant Current feedback), this relation is used for correction of the TtoT. Fig. 2 shows the TtoT spectrum without correction. Fig. 4 shows the TtoT spectrum after correction; the spread reduces by a factor 3.

Gossipo3 is a single pixel prototype chip with a 560 MHz oscillator developed by Nikhef and Bonn University to test the most important structures for doing high resolution time

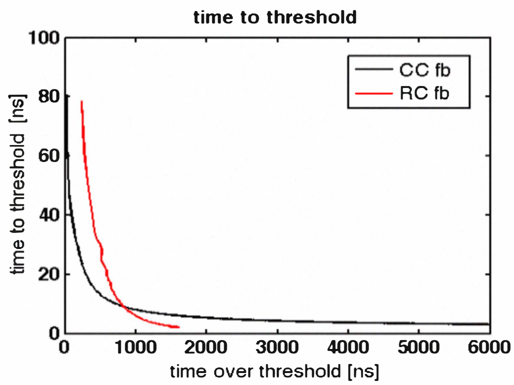


Fig. 3. Simulated Time to Threshold as function of Time over Threshold.

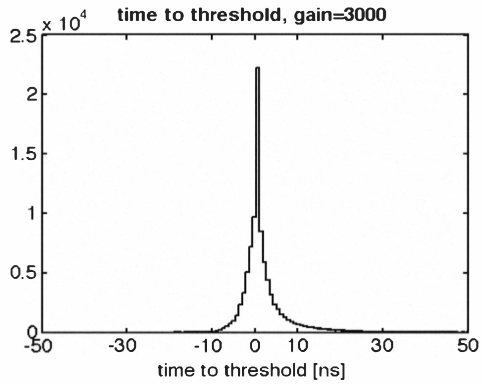


Fig. 4. Simulated TtoT spectrum without correction after correction σ=7.5 ns, the error reduces by a factor 3.

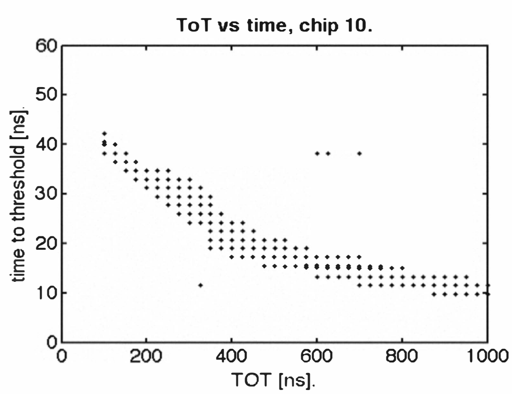


Fig. 5. Time to Threshold as function of Time over Threshold as measured by Gossipo3

measurements. It is able to measure both TtoT and ToT simultaneously. Gossipo3 is used to verify the time walk correction principle. The Time to Threshold as function of time over threshold measured with Gossipo3 is shown by Fig. 5. Fig. 6 shows the TtoT spectrum without correction. Fig. 7 shows the TtoT spectrum after correction, the error reduces by a factor 7. The difference with respect to the simulated error reduction can be explained by less electronic noise, e.g. 70 electrons in simulations compared to 25 electrons in Gossipo3. In addition Gossipo3 failed to record small signals and hence the tail of the spectrum is missing.

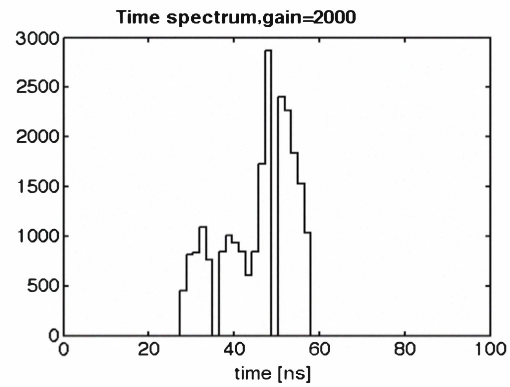


Fig. 6. Time to threshold spectrum measured by Gossipo3 without correction σ=8.5 ns.

III. SiRN Protection Layer

A Silicon Nitride (SiRN) protection layer (see Fig. 8) quenches lethal discharges, resulting in a limited charge on each pixel. The SiRN layer should be slightly conductive in order to reduce charge up effects. The resistance of the SiRN layer is measured by determining the gain reduction as function of the grid voltage for different Fe-55 conversion event rates [4]. From Fig. 9 the resistance of the SiRN layer is calculated to be $\mathcal{O}(10^{13})$ Ω cm.

IV. False Hit Identification

GridPix beam telescope (see Fig. 10) measurements performed in the SPS beam at CERN gave insight into time walk at different amplification fields. The measured timespectra for Grid voltages from 500 to 620 Volts are shown by Fig. 11. Time walk is the dominant error in time measurements with small signals with TimePix. Small signals occur either when the charge in the avalanche is small at low amplification fields or at high amplification fields ($\sim$ 124 kV/cm) when a large avalanche induces a small signal on an adjacent pixel. The latter is referred to as false hits (Fig. 12).

False hits are studied in more detail by exposing a GridPix detector with a 4 μm thick protection layer to Fe-55 quanta at 8 cm distance in Helium/Isobutane (80:20) (Fig. 12) [4]. In time over threshold mode they are identified by a signal

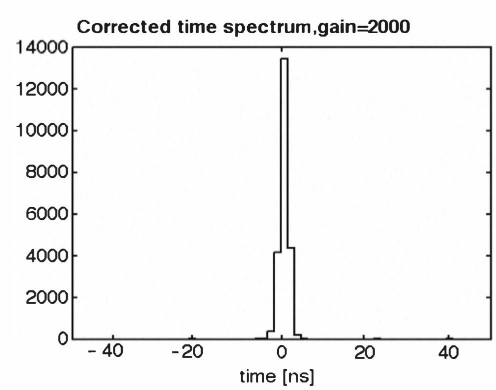


Fig. 7. Time to threshold spectrum with correction as measured by Gossipo3 σ=1.1 ns, the error reduces by a factor 7.

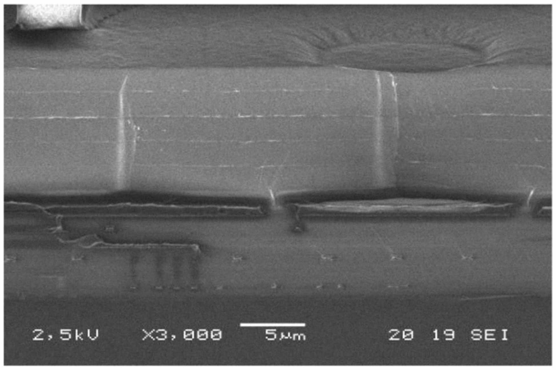


Fig. 8. A SEM image of a 8 μm thick SiRN layer on top of a pixel.

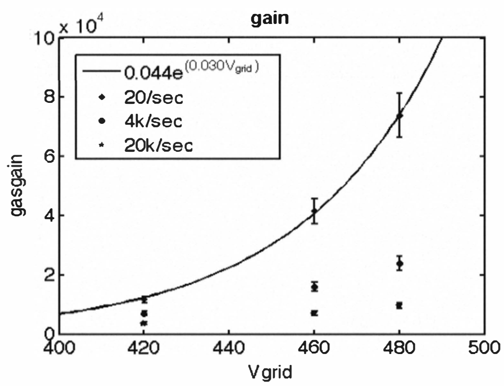


Fig. 9. Gain as function of the grid voltage for different event rates.

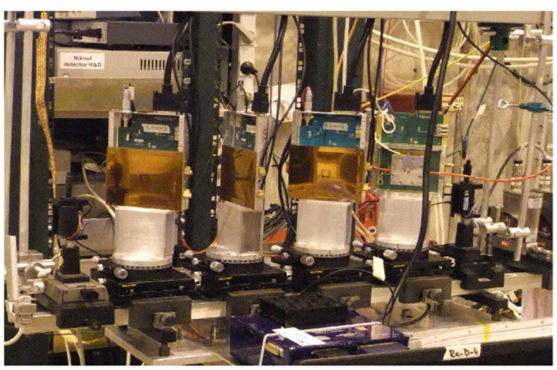


Fig. 10. GridPix beam telescope, with three Gossips (1 mm driftgaps) and one DICE (1.9 cm driftgap) at the SPS, CERN

with a low ToT combined with an adjacent pixel with a high ToT. The probability that a pixel gives a false hit as function of the charge in an avalanche on an adjacent pixel is shown by Fig. 13. It turns out that in measurements with an 8 μm thick protection layer the false hit probability is larger. The average charge in an avalanche is obtained by measuring the average ToT and the induced signal on the grid under the same conditions for Fe-55 conversions as shown by Fig. 14 for Helium/Isobutane (80:20) [4].

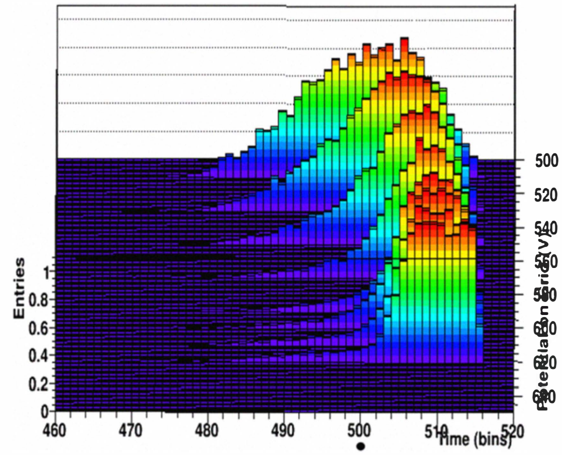


Fig. 11. The normalised time spectra for increasing amplification fields in clock cycles of 10 ns for 45° muon tracks.

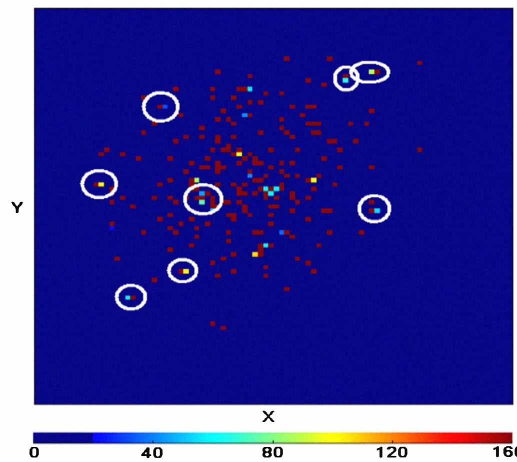


Fig. 12. An Fe-55 conversion in Helium/Isobutane (80:20), the colours indicate the Time over Threshold, false hits are indicated with a circle.

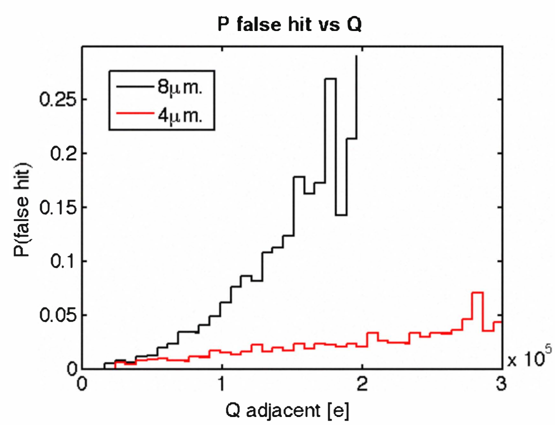


Fig. 13. The probability that a pixel gives a false hit as function of the charge in an avalanche on an adjacent pixel for 4 μm and 8 μm thick protection layers.

V. An Application: GridPix for Proton Therapy

An application for the use GridPix detectors for tracking protons in proton therapy is currently under study. In external beam radiotherapy it is of crucial importance that most of

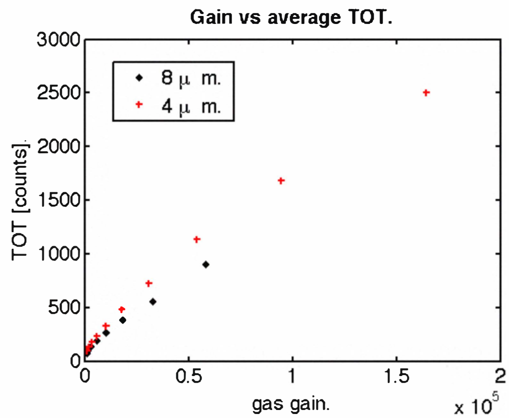


Fig. 14. The average ToT as function of the average induced signal per hit pixel.

the energy of the incident particle is absorbed in the tumour. Monoenergetic protons lose most of the energy in the last few millimeters of their trajectory, the so called Bragg peak. However, the absolute position of the Bragg peak depends on the density of the matter along the proton path and the proton energy. Densities along the proton path might be calculated with X-ray CT information. The combination of this information and proton beam transmission data is under study. Fig. 15 represents a setup [6] with two GridPix detectors that are used to reconstruct 3D tracks of the passing protons and a calorimeter that measures the remaining energy of the passing protons. Because of the low mass, GridPix detectors hardly influence the proton path. The first GridPix detector will serve as a beam monitor during irradiation.

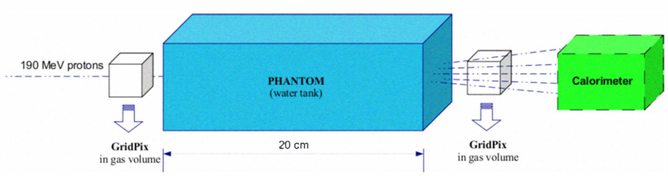


Fig. 15. Proton therapy setup, the PHANTOM water tank represents a human body. Two GridPixes are used for tracking and a calorimeter measures the energy for calibration.

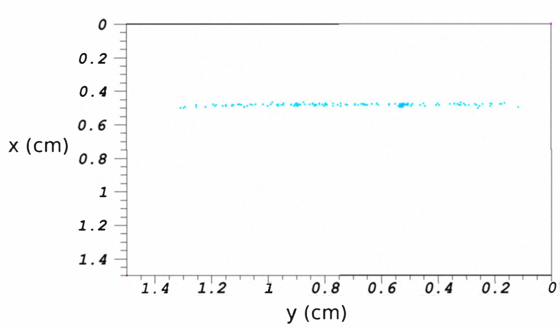


Fig. 16. Typical track of a proton in a GridPix detector at KVI projected on the xy plane from raw data [7].

Recently we performed tests in a 190 MeV proton beam at KVI in Groningen as a proof of principle. One GridPix

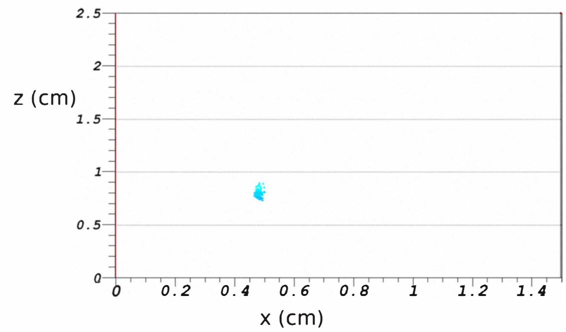


Fig. 17. Typical track of a proton in a GridPix detector at KVI projected on the xz plane from raw data [7].

detector with a 16 mm driftgap was flushed with CO2/DME (50:50). The drift field was 1.5 kV/cm. The GridPix was oriented parallel to the beam in order to avoid interaction of the beam with the readout chip. Fig. 16 and Fig. 17 show the projection of a triggered proton track on the xy and xz plane, the chip was located at z=0. The risetime of the signal of the current TimePix is slong, therefore timewalk is dominant in the z resolution as can be seen in Fig. 17. The first results are promising and the analysis of the data in ongoing.

VI. Acknowledgements

We would like to thank our promising master students P. Tsopelas and B. Huisman for supplying data from their experiments at KVI. We would like to thank KVI, Groningen, The Netherlands for sharing their facilities and knowledge to perform the GridPix tests.

References

[1] X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos, W. Wong, NIM A 581 (2007) 285-494.
[2] Z. Vykydal et al., NIM A 563 (2006) 254-258.
[3] X. Llopart et al., IEEE Trans. Nucl. Sci. 49 (2002) 2279.
[4] M. Fransen, PhD Thesis, to be finished, 2012.
[5] J. Melai, PhD thesis, 2010.
[6] P. Tsopelas and J. Visser (Nikhef), private communication.
[7] P. Tsopelas and B. Huisman (Nikhef), private communication.