

OPEN ACCESS

Readout cross-talk for alpha-particle measurements in a pixelated sensor system

To cite this article: B. Norlin *et al* 2015 *JINST* **10** C05025

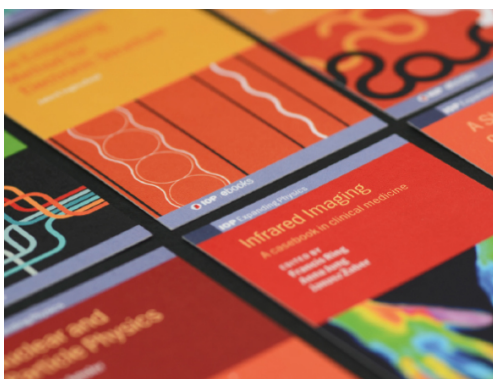
View the [article online](#) for updates and enhancements.

Related content

- [Study of a GaAs:Cr-based Timepix detector using synchrotron facility](#)
P. Smolyanskiy, D. Kozhevnikov, O. Bakina *et al*.
- [A Geant4 based framework for pixel detector simulation](#)
A. Schübel, D. Krapohl, E. Fröjdh *et al*.
- [Looking at single photons using hybrid detectors](#)
A. Bergamaschi, S. Cartier, R. Dinapoli *et al*.

Recent citations

- [Heteroepitaxial passivation of Cs₂AgBiBr₆ wafers with suppressed ionic migration for X-ray imaging](#)
Bo Yang *et al*
- [Validation of Geant4 Pixel Detector Simulation Framework by Measurements With the Medipix Family Detectors](#)
David Krapohl *et al*



IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

16th INTERNATIONAL WORKSHOP ON RADIATION IMAGING DETECTORS
22–26 JUNE 2014,
TRIESTE, ITALY

Readout cross-talk for alpha-particle measurements in a pixelated sensor system

B. Norlin,^{a,1} S. Reza,^a D. Krapohl,^a E. Fröjdh^{a,b} and G. Thungström^a

^a*STC Research Centre, Mid Sweden University,
Sundsvall, Sweden*

^b*Medipix Consortium, CERN,
Geneva, Switzerland*

E-mail: Borje.Norlin@miun.se

ABSTRACT: Simulations in Medici are performed to quantify crosstalk and charge sharing in a hybrid pixelated silicon detector. Crosstalk and charge sharing degrades the spatial and spectral resolution of single photon processing X-ray imaging systems. For typical medical X-ray imaging applications, the process is dominated by charge sharing between the pixels in the sensor. For heavier particles each impact generates a large amount of charge and the simulation seems to over predict the charge collection efficiency. This indicates that some type of non modelled degradation of the charge transport efficiency exists, like the plasma effect where the plasma might shield the generated charges from the electric field and hence distorts the charge transport process. Based on the simulations it can be reasoned that saturation of the amplifiers in the Timepix system might generate crosstalk that increases the charge spread measured from ion impact on the sensor.

KEYWORDS: Charge transport and multiplication in solid media; Hybrid detectors; X-ray detectors; Imaging spectroscopy

¹Corresponding author.

Contents

1	Background	1
2	Simulations and measurements	2
2.1	Model and geometry	2
2.1.1	Model variations	2
2.1.2	Contact size	2
2.2	Measurements	3
2.2.1	Detector depletion measurements	4
2.2.2	Cluster size measurements	5
2.3	Simulations	5
2.3.1	Charge pulses	5
2.3.2	Main results of impact area with different biases	6
2.3.3	Back contact doping influence	7
2.3.4	Scattering model	8
3	Discussion	8

1 Background

As the development of X-ray imaging detectors aims for higher resolution and denser readout electronics, the degradation of spatial and spectral resolution due to crosstalk and charge sharing becomes an increasing problem. Main detector categories are strip detectors systems and hybrid pixelated detector systems. A single photon processing X-ray imaging system is generally designed with a sensor chip bonded to a CMOS readout chip. This study deals with considerations relevant for pixelated design down to $50\ \mu\text{m}$, which concerns the design of MEDIPIX2 [1], TIMEPIX [2] and MEDIPIX3 [3] readout chips. The readout architecture of the Medipix system is based on the Krummenacher scheme [4, 5].

It is common to make a distinction between crosstalk and charge sharing. The former originates from interpixel coupling capacitances [6] or from capacitive couplings in the readout, mainly between the digital and analogue sections of the pixel readout [7]. Charge sharing usually refers to the physical absorption and charge collecting process in the sensor [8]. Both processes result in degradation of spatial and spectral resolution of the imaging system; however note that the distinction between the two processes is not always used systematically in literature.

For typical medical imaging applications, the photon energy is below 70 keV, and then the degradation process is dominated by charge sharing between the pixels in the sensor. This process depends on the bias voltage and the ratio between pixel size and detector thickness. In general it means that a photon absorbed in the centre of a pixel generates signal in only one pixel, while

photons absorbed close to the border between two pixels give signal in both pixels if the discriminating threshold is set to a value lower than half the photon energy. For heavier particles like alpha particles, each impact generates a larger and denser charge cloud compared to photons. In the resultant image, each alpha particle impact results in a cluster of pixels, where the size of the cluster depends on the particle energy and the detector bias [9]. For heavy particle impacts, there is a possibility that the big amount of charge can saturate the analogue amplifier [10], and influence charge transport mechanisms in the sensor or cross talk mechanisms in the readout circuitry [11]. These types of effects are indicated in [9], where measurements of ions with energy close to 100 MeV generate “volcano-like” absorption profiles with low charge collection in the impact pixel. One of the questions addressed in this study is if such “volcano-profiles” can be achieved in a simulation of a pure sensor without readout circuitry attached.

2 Simulations and measurements

2.1 Model and geometry

Simulations are performed with Taurus Medici [12], which is a device simulation tool included in the Synopsys TCAD software suite. The geometry modelled is a cylinder with radius $300\ \mu\text{m}$ from a $300\ \mu\text{m}$ thick silicon detector. This is a straightforward way to model the radius of the charge cloud, by extracting the current on the circular contacts. The charge drift is varied by increasing the bias voltage from 0 V and 100 Volt.

The sensor is modelled as n on p with two values of the n-type background doping, $5 \cdot 10^{11}\ \text{cm}^{-3}$ alternatively $1.2 \cdot 10^{11}\ \text{cm}^{-3}$. The p-type contact doping is modelled as a Gaussian profile reaching $1 \cdot 10^{20}\ \text{cm}^{-3}$, with junction depth of $2\ \mu\text{m}$. The back contact is modelled as a $2\ \mu\text{m}$ profile reaching $1 \cdot 10^{20}\ \text{cm}^{-3}$ n-type doping.

The model is cylindrical, which will give another weighting potential at the contacts, compared to the square geometry of a pixel detector. The influence of the result in the centre pixel due to the geometry is assumed to be negligible, but for the outer rings this geometrical influence might be of importance. However, for the validity of the conclusions, the precision of the charge in the center pixel is more important than the precision in the periphery.

2.1.1 Model variations

There are several simulation choices that can be considered when using a tool like Medici. Normally in sensors, a doping profile is added to the back contact. This will cause the charge drift cone to be narrowed. The simulation is done both with and without back contact. If the back doping is omitted the leakage current is expected to increase which is a drawback for the charge collection efficiency. Ageing of the detector can cause the back contact doping to decrease.

The simulation is further varied by turning on and off the Carrier-Carrier Scattering Mobility in Medici (CCSMOB) [13]. This model influences high densities of electron and holes, which might be relevant for this simulation.

2.1.2 Contact size

Since the cluster size seen for a $55\ \mu\text{m}$ pixelated detector was the main target for the cylindrical model, a first intention was to use circle segments with $55\ \mu\text{m}$ radius as in figure 1. However,

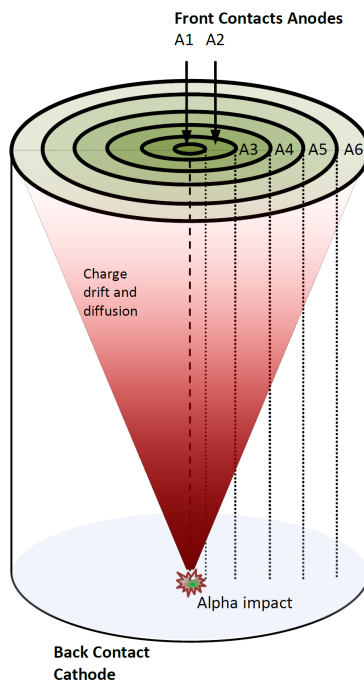


Figure 1. Illustration of circular geometry used in the Medici simulation. Geometries with 6 or 10 circular readout contacts are used. The simulated structure radius of $300\ \mu\text{m}$ corresponds to the area of 93 Medipix pixels.



Figure 2. Circular geometry from Medici. 10 contacts in the radial direction to provide enough resolution for cluster area estimation. (Both radius and thickness is $300\ \mu\text{m}$, no depletion region is showed.)

this geometry will be rough when it comes to interpret cluster area. Hence, the smaller contact geometry of figure 2 was used in most of the simulations.

2.2 Measurements

Measurements of alpha particles impact from Americium-241 ($5.5\ \text{MeV}$) are taken with a $300\ \mu\text{m}$ thick silicon sensor bounded on a TIMEPIX chip. The bias voltage is varied between $0.0\ \text{V}$ and $90.0\ \text{V}$. The detector is operated in time over threshold mode (ToT) and the low threshold is set close to the value of the noise floor. The ToT mode measures the charge pulse duration using clock pulses, these times are proportional to the charge of the pulses [2]. The clock frequency is set to $48\ \text{MHz}$, so a ToT value of 1 corresponds to $\sim 21\ \text{ns}$ charge pulse duration. Since the charge of an alpha particle is spread over several pixels, the measurements give a two dimensional charge collection profile for each impact. An example of such a profile is showed in figure 3.

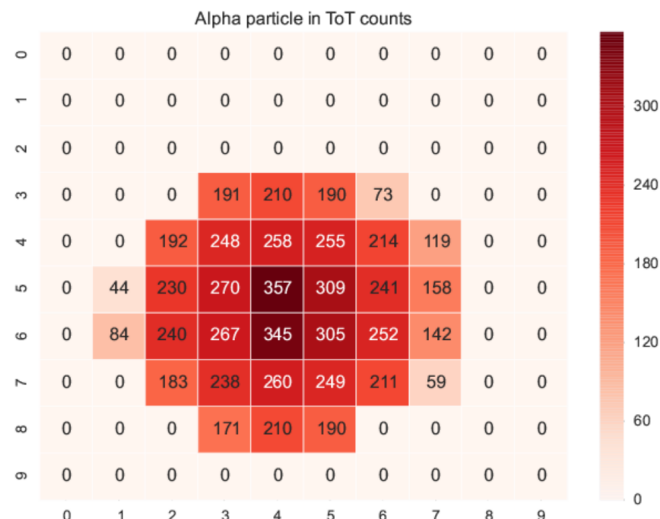


Figure 3. Charge profile after alpha particle impact generating signal in 33 pixels. The detector bias voltage is 10 V.

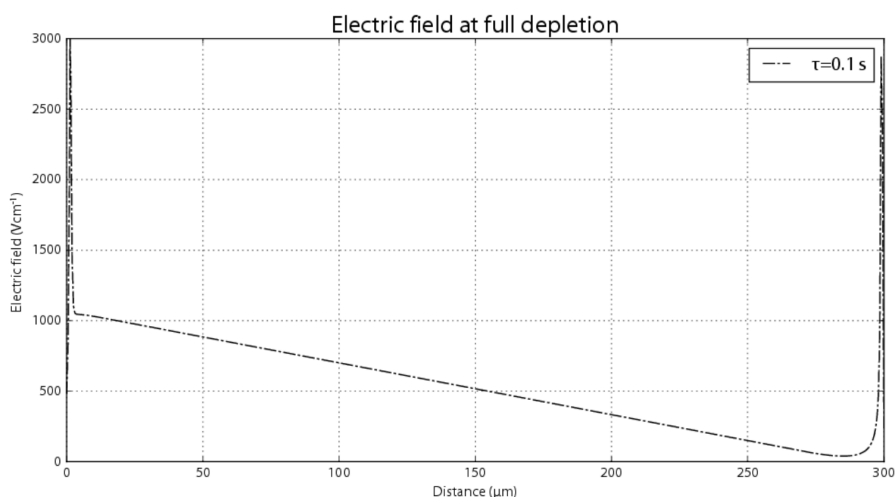


Figure 4. Simulated electric field profile at 10 V external bias when using $1.2 \cdot 10^{11} \text{ cm}^{-3}$ background doping. The sensor is depleted from the pixel contact at $0 \mu\text{m}$ to the back contact at $300 \mu\text{m}$. The alpha particle reaches the detector at the back contact. The lifetime τ is assumed to be 0.1 s.

2.2.1 Detector depletion measurements

To suppress charge sharing between the pixels, it is common to over deplete the sensors of the Medipix system. The sensor used has a breakdown voltage larger than 100 V, and is normally operated at 90 V.

A common value of detector background doping is $5 \cdot 10^{11} \text{ cm}^{-3}$, corresponding to a depletion voltage of 40 V. The depletion voltage varies between different Medipix sensors from different silicon vendors, but the depletion voltage for most of our Medipix sensors are in this range. However, measurements on the sensors actually used, showed a depletion voltage of 10 V, which corresponds to a background doping of $1.2 \cdot 10^{11} \text{ cm}^{-3}$.

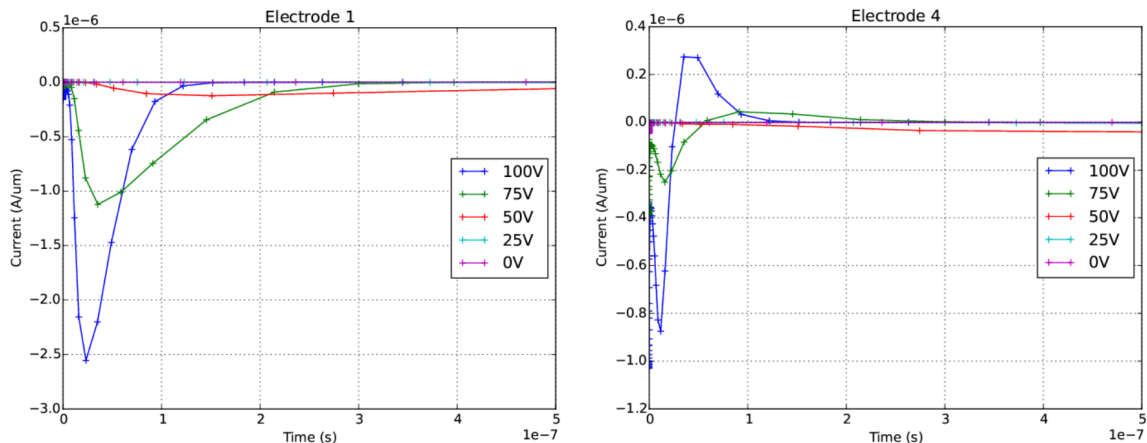


Figure 5. Current transients for the center electrode (left) and for electrode 4 (right) for an absorption of the 5.5 MeV alpha particle in the center (or at position 1). Five different bias voltages are plotted. The displayed current is normalized to correspond to the contact current of a $55\ \mu\text{m}$ pixel. The background doping is $5 \cdot 10^{11}\ \text{cm}^{-3}$.

The incident radiation is absorbed close to the surface at the backside of the sensor and it is this side that first will be undepleted when the bias is lowered. Hence for a not fully depleted sensor, the charge cloud generated will first be subjected to diffusion before the positive charges becomes subjected to the depletion field drifting them to the pixel contacts.

2.2.2 Cluster size measurements

Two series of cluster size measurements versus bias voltage are presented in the result sections 2.3.2 and 2.3.3. The cluster sizes are extracted from time over threshold measurements done with two different chips where the settings are intended to be similar between the two measurements (except for I_{krum}). Measurement 1 (with larger cluster sizes) has $I_{\text{krum}} = 1$ while measurement 2 uses $I_{\text{krum}} = 5$. The I_{krum} setting changes the leakage current compensation and a lower value gives a longer charge pulse fall time [1].

2.3 Simulations

Medici produces a steady state leakage current solution and a transient current after the charge impact of a 5.5 MeV alpha particle from Americium-241. This current is integrated to a charge pulse with leakage compensation considered. The maximum readout time of the circuit is estimated to $2\ \mu\text{s}$. For comparison, impact of heavy ions is also simulated, with an injected energy of 550 MeV.

2.3.1 Charge pulses

Medici generates current transient profiles, which are further processed to reveal the charge collection profile of the detector. In figure 5 such current profiles are shown, with significant charge contribution for the central pixel and a positive oscillation for the periphery pixel in the right figure. The profiles agree with their expected behavior.

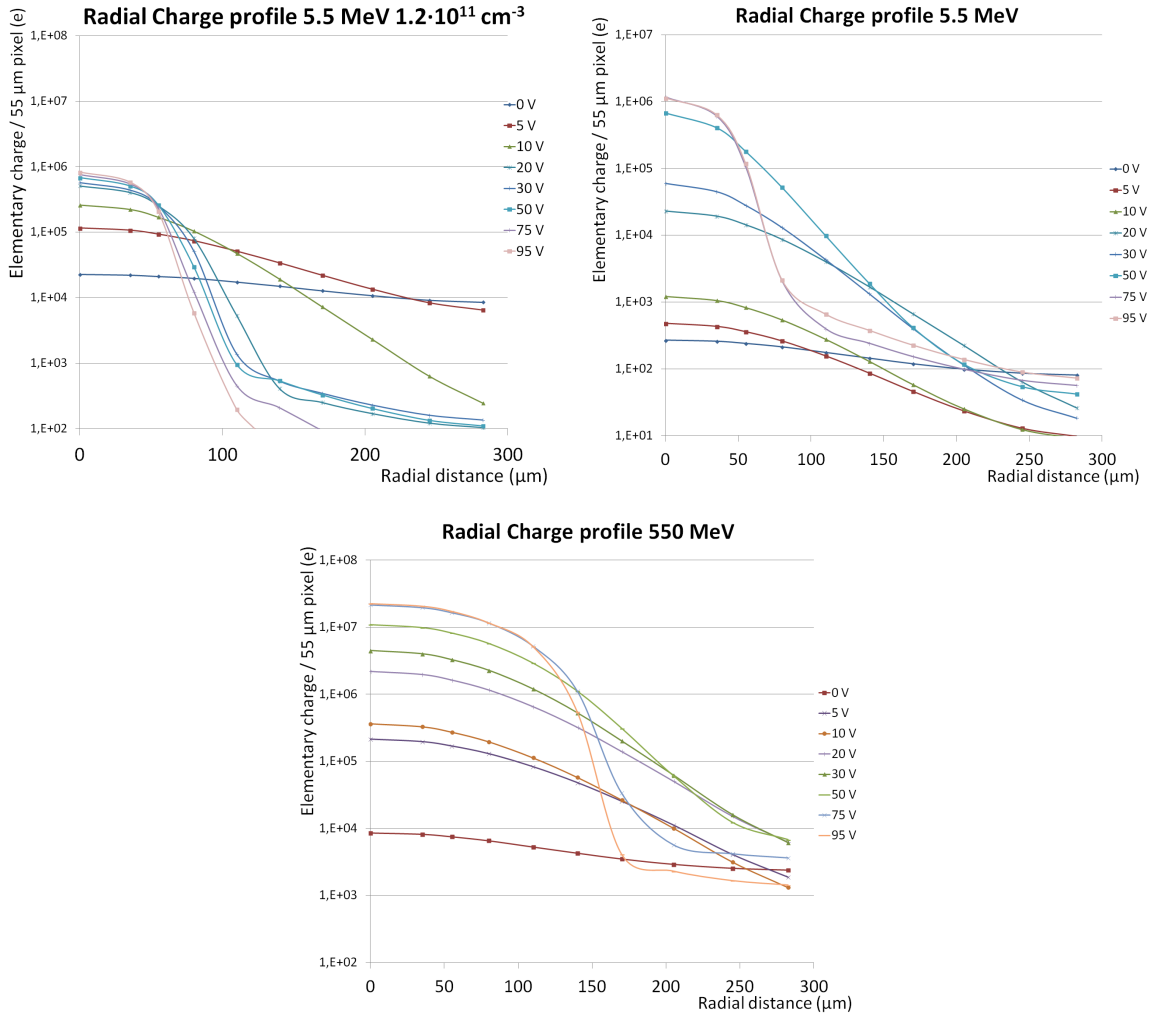


Figure 6. Radial charge collection profiles for detector biases between 0 V and 100 V. Simulation assuming back contact doping profile. Upper left and right is an alpha particle impact with different background doping in the detector. The lower figure is a heavy ion impact.

2.3.2 Main results of impact area with different biases

When lowering the bias, the collected charge profile is expected to be wider due to more transverse diffusion [9]. The charge transport time can be increased due to creation of plasma after impact [14, 15]. The radial charge collection profiles in the simulated detector structure for different biases are shown in figure 6, both for an alpha particle of 5.5 MeV and for a heavy ion impact of 550 MeV.

If the background doping is changed, the charge collection at low bias is strongly affected, about three orders of magnitude increase of charge collection in the centre pixel. When the bias is increased to 95 V, the charge collection of the centre pixel gets independent of the background doping. The charge cloud size is “small” as long as the sensor is overdepleted, with small meaning about $100\ \mu\text{m}$ radius ($\sim 3 \times 3$ pixels). To be detected, the charge must be above $650\ e^-$ which corresponds to the minimal noise floor of the Timepix system.

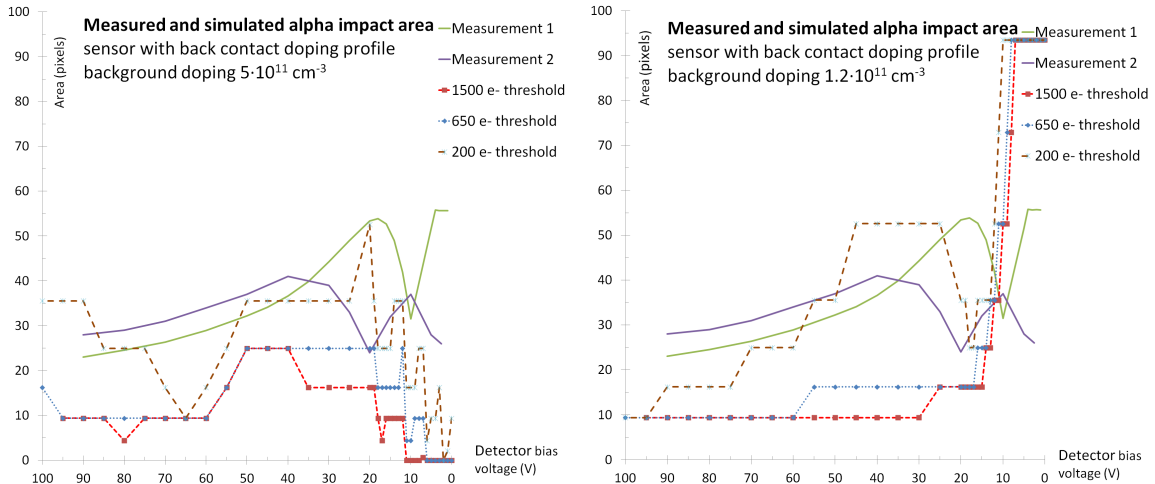


Figure 7. Cluster size for three simulated thresholds, compared to measurements. Simulation assuming back contact doping profile. The left and right shows different background doping.

When simulating high energy ions, we assume that their kinetic energy is fully absorbed in the sensor and not backscattered. The absorption profile assumed corresponds to a higher mass particle, comparable with the profile of Zr ions measured in [9]. The simulations gives no indication of the “volcano-like” charge profile measured in [9]; instead it shows that an increase of bias from 20 V to 95 V is expected to increase the collected charge at the impact pixel by one order of magnitude. The charge cloud of the heavy ion affects a larger area (about $170 \mu\text{m}$ radius or roughly 6×5 pixels) of the detector compared to the alpha particle; hence the charge increase at the impact pixel is only around one order of magnitude, although the assumed energy increase when going from alpha to a heavy particle is two orders of magnitude.

The charge profiles are related to the cluster size depending on the actual threshold value of the readout. Applying the threshold gives cluster size dependence as in figure 7. Three thresholds are used; $650 e^-$ which is the minimal detectable charge for Timepix [2], one higher threshold at $1500 e^-$ and for comparison also one unrealistic threshold at $200 e^-$ which is within the noise floor of the Timepix chip.

The comparison in figure 7 shows that both simulations and measurements follow a similar trend. The area drop at higher biases (50 V–100 V) due to the charge acceleration of the electric field is clearly visible. At lower voltage the area dip at 10–15 V is seen in the measurements and is indicated in the simulations in the left figure. However the comparison indicates that the simulation under predicts the charge spread, since only the unrealistic $200 e^-$ threshold reaches the same area values as the measured profiles. The agreement with measurement is better in the left figure, although it is the background doping concentration of the right figure that is measured for the sensor.

2.3.3 Back contact doping influence

If the back contact doping is omitted, the leakage current will increase between 10 and 100 times for background doping $5 \cdot 10^{11} \text{ cm}^{-3}$. In general the charge collection will be less efficient and the achieved cluster size will increase without back contact doping. Removing it is a way to modify the

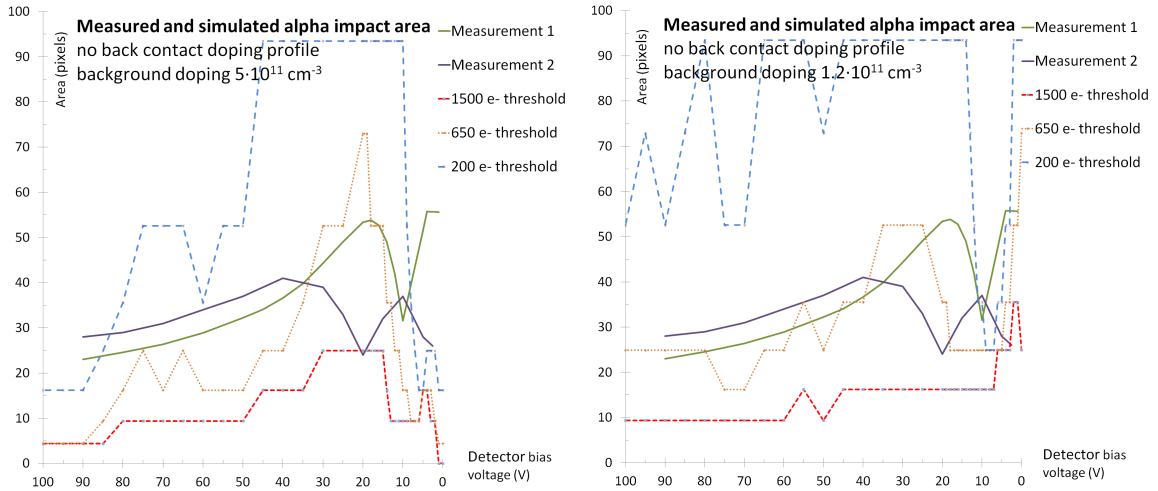


Figure 8. Cluster size for three simulated thresholds, compared to measurements. Simulation without back contact doping profile. The left and right shows different background doping.

simulation to compensate for the under prediction discussed in the previous section. The simulated cluster sizes are shown in figure 8. It can be noted that the expected dip in area at 10–15 V bias is now seen clearly in all, except one, simulation. In figure 7 this area dip is also indicated, but not as clear as in the measurements. The exception in figure 8 is the highest threshold with the low background doping.

It is interesting that the most realistic model in figure 7 under predicts the impact area, while if the simulation model is degraded by removing the back contact doping, the simulation results agree better with measurements, as in figure 8. If the threshold value is set below the noise floor in this case, the impact area is strongly over predicted.

2.3.4 Scattering model

The Carrier-Carrier Scattering mobility model in Medici is intended to model high concentration effects on a local level. For 5.5 MeV alpha particles, no significant influence is noticed when the Carrier-Carrier Scattering mobility model is disabled. For 550 MeV ions, the charge collection is affected for low bias cases only. This is exemplified in figure 9.

3 Discussion

The Medici model is able to predict the electric field dependence of the charge transport so its behaviour agrees with measurements. But it can also be seen from the results that the Medici model under predicts the absolute values of impact area, hence it over predicts the charge transport efficiency of the detector. If degradation like removing the back contact doping is introduced to the structure, the simulation agrees with measurements. This result indicates that some type of non modelled degradation of the charge transport efficiency exists in the actual detector. One explanation would be the plasma effect discussed in [15], where the plasma shields the generated charges from the electric field and hence distorts the charge transport process. The plasma effect is essentially a delay process which might delay the charges longer than the readout window.

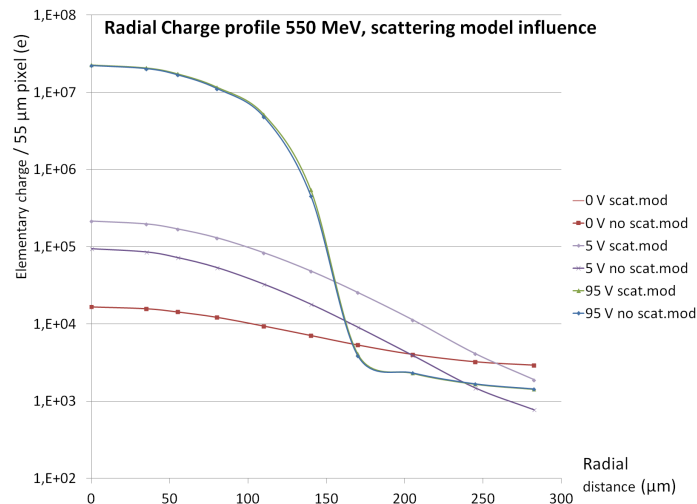


Figure 9. Radial charge collection profiles for a heavy ion impact for a few detector biases. Comparison between simulations with and without scattering model at background doping $5 \cdot 10^{11} \text{ cm}^{-3}$.

The simulation does not reveal the “volcano-profile” from [9] for high energy impact. It is therefore likely that these profiles are due to crosstalk after saturation processes in the readout [10] rather than due to charge transport in the sensor. The general simulation result (figure 6) is that, for bias voltages above the depletion voltage, a significant part of the high energy ion impact charge is collected in a relatively low numbers of pixels.

Acknowledgments

The measurements in this work were performed using detectors, software and readout system developed within the MEDIPIX collaboration, hosted by CERN.

References

- [1] X. Llopart, M. Campbell, R. Dinapoli, D. San Segundo and E. Pernigotti, *Medipix2: a 64k pixel readout chip with 55 μm square elements working in single photon counting mode*, *IEEE Trans. Nucl. Sci.* **49** (2002) 2279.
- [2] X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos and W. Wong, *Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements*, *Nucl. Instrum. Meth. A* **581** (2007) 485 [Erratum *ibid.* **A 585** (2008) 106].
- [3] R. Ballabriga et al., *The Medipix3RX: a high resolution, zero dead-time pixel detector readout chip allowing spectroscopic imaging*, 2013 *JINST* **8** C02016.
- [4] F. Krummenacher, *Pixel detectors with local intelligence: an IC designer point of view*, *Nucl. Instrum. Meth. A* **305** (1991) 527.
- [5] V. Barzdėnas and R. Navickas, *Leakage current compensation for the 0.13 μm CMOS charge sensitive preamplifier*, *Elektron. Elektrotech.* **77** (2007) 33.
- [6] L. Rossi, P. Fischer, T. Rohe and N. Wermes, *Pixel detectors*, Springer-Verlag, Berlin Heidelberg (2006).

- [7] J. Lundgren, S. Abdalla, M. O’Nils and B. Oelmann, *Evaluation of mixed-signal noise effects in photon-counting X-ray image sensor readout circuits*, *Nucl. Instrum. Meth. A* **563** (2006) 88.
- [8] H.-E. Nilsson, E. Dubarić, M. Hjelm and K. Bertilsson, *Simulation of photon and charge transport in X-ray imaging semiconductor sensors*, *Nucl. Instrum. Meth. A* **487** (2002) 151.
- [9] C. Granja, J. Jakubek, U. Köster, M. Platkevic and S. Pospisil, *Response of the pixel detector Timepix to heavy ions*, *Nucl. Instrum. Meth. A* **633** (2011) S198.
- [10] M. Kroupa et al., *Energy resolution and power consumption of Timepix detector for different detector settings and saturation of front-end electronics*, 2014 JINST **9** C05008.
- [11] G. Thungström et al., *Fabrication, characterization and simulation of channel stop for n in p-substrate silicon pixel detectors*, 2014 JINST **9** C07013.
- [12] SYNOPSYS, *Taurus Medici — a 2D device simulator*, <http://www.synopsys.com/Tools/TCAD/DeviceSimulation/Pages/TaurusMedici.aspx>.
- [13] SYNOPSYS, *Taurus Medici — Medici user guide*, Version 1 2013.12 (2013).
- [14] J. Becker, K. Gärtner, R. Klanner and R. Richter, *Simulation and experimental study of plasma effects in planar silicon sensors*, *Nucl. Instrum. Meth. A* **624** (2010) 716 [[arXiv:1007.4433](https://arxiv.org/abs/1007.4433)].
- [15] M. Campbell et al., *Study of the charge sharing in a silicon pixel detector by means of α -particles interacting with a Medipix2 device*, *Nucl. Instrum. Meth. A* **591** (2008) 38.