Simulation of Irradiated Silicon Pixel Detectors for Future High Energy Physics Experiments

Devis Contarato, University of Hamburg
Gregor Kramberger, DESY

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Outline

- Introduction & motivation
- Basics of device simulation
- Charge collection in irradiated segmented devices
- Simulation of thin pixel detectors
- Summary & Conclusions

Introduction & Motivation

Position sensitive silicon detectors will be widely used in future HEP experiments. At high particle fluences (up to 10^{16} cm^{-2} at SLHC) trapping times become comparable with charge collection times: loss of drifting charge – trapping.

Thin pixel detectors: a way to cope with high fluences?

Advantages

- $V_{fd} \propto D^2$: at high N_{eff} detectors can be fully depleted
- Short collection distance i.e. collection times
- Low mass, small radiation length X_0
- Finer detector granularity to cope with higher occupancy

Disadvantages

- Small signal: need for radiation hard low noise read-out electronics

Questions

• Can thin pixel detectors be successfully operated at fluences around 10^{16} cm^{-2}?

• How does the geometry of the electrodes influence the detector performances?

• What is the impact of trapping on the sensor charge collection properties?

Basics of simulations

Current induced at the electrodes by a point charge q drifting in the electric field of a reversely biased silicon detector:

$$I_{e,h}(t) = \underbrace{q \exp\left(-\frac{t}{\tau_{eff,e,h}}\right)}_{\text{trapping}} \underbrace{\vec{E}_w(\vec{r}_{e,h}(t))}_{\text{weighting field}} \underbrace{\mu_{e,h}\,\vec{E}(\vec{r}_{e,h}(t))}_{\text{electric field}}$$

trapping

$$\frac{1}{\tau_{eff,e,h}} = \beta_{e,h}\ \Phi_{eq}$$

$\beta_e = 5.7\cdot10^{-16}\ \mathrm{cm^2/ns}$

$\beta_h = 7.7\cdot10^{-16}\ \mathrm{cm^2/ns}$

weighting field

Constant *1/D* (diode-like) if <u>pad or pixel pitch>>*D*</u>

In general complex - highest close to collecting electrodes

electric field

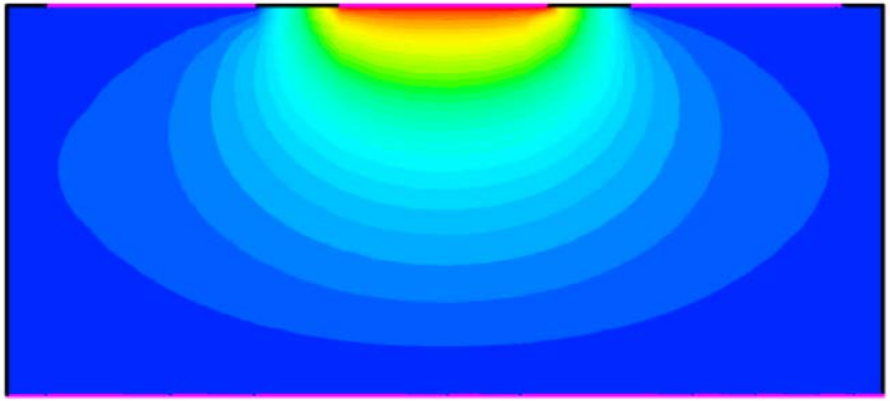
Irradiation: $N_{eff} = -g\cdot\Phi_{eq}$

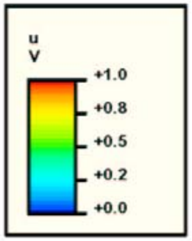
$g = 0.0071\ \mathrm{cm^{-1}}$ (DOFZ)

$$\nabla^2 U = -\frac{e_0\, N_{eff}}{\varepsilon\varepsilon_0} \quad \Rightarrow \nabla U = -\vec{E}$$

The Ramo field describes the electrostatic coupling between the drifting charge and the sensing electrode

Basics of simulations (2)



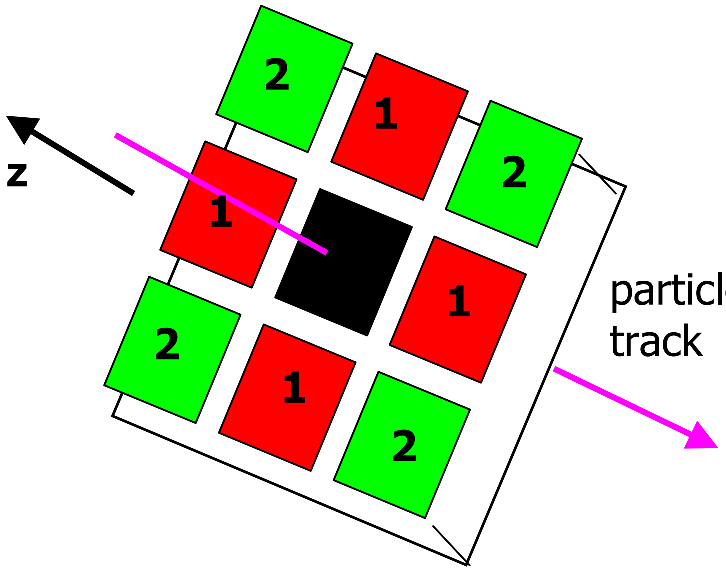


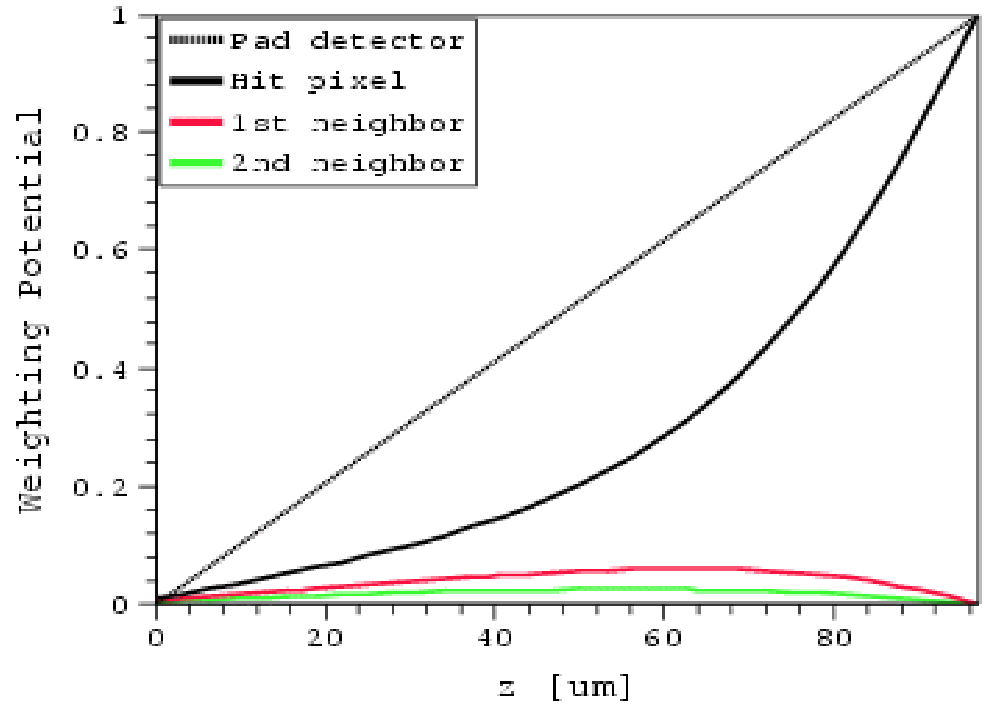
- potentials were calculated with custom-made software and ISE-TCAD package
- *n*-type bulk, $N_{eff}=10^{12}$ cm^{-3}
- all simulations performed at T=263 K

What is not considered in the simulation:

- a uniform charge generation along the track is assumed (no GEANT simulation)
- $N_{eff}(\mathbf{r})$=const: a homogeneous effective dopant concentration is assumed (double-junction effect is not taken into account)
- no further electronic processing of the induced current

Charge collection in irradiated segmented detectors





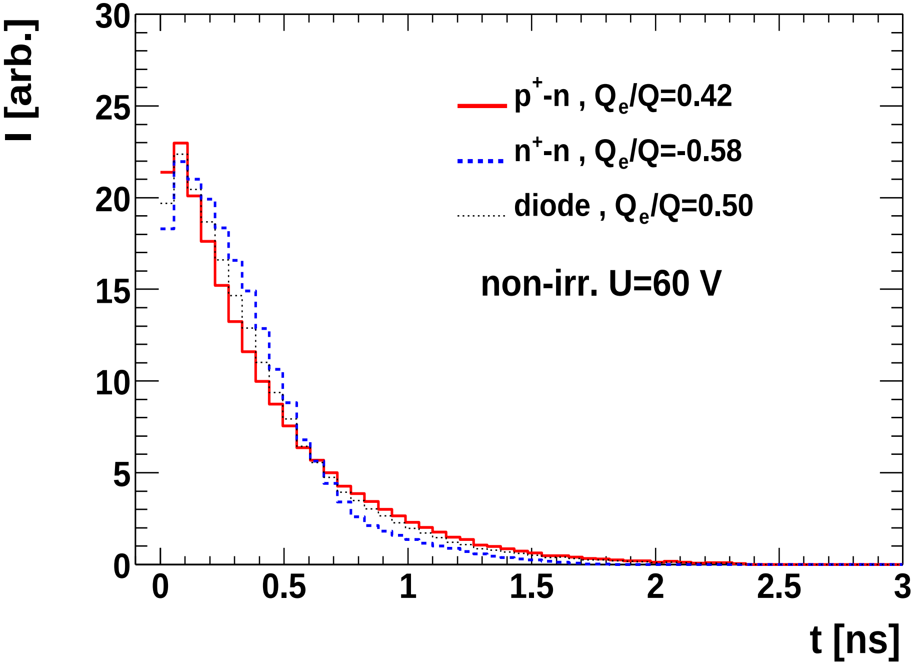
D=100 µm, Pixel Pitch=70 µm,
Implant Width=50 µm

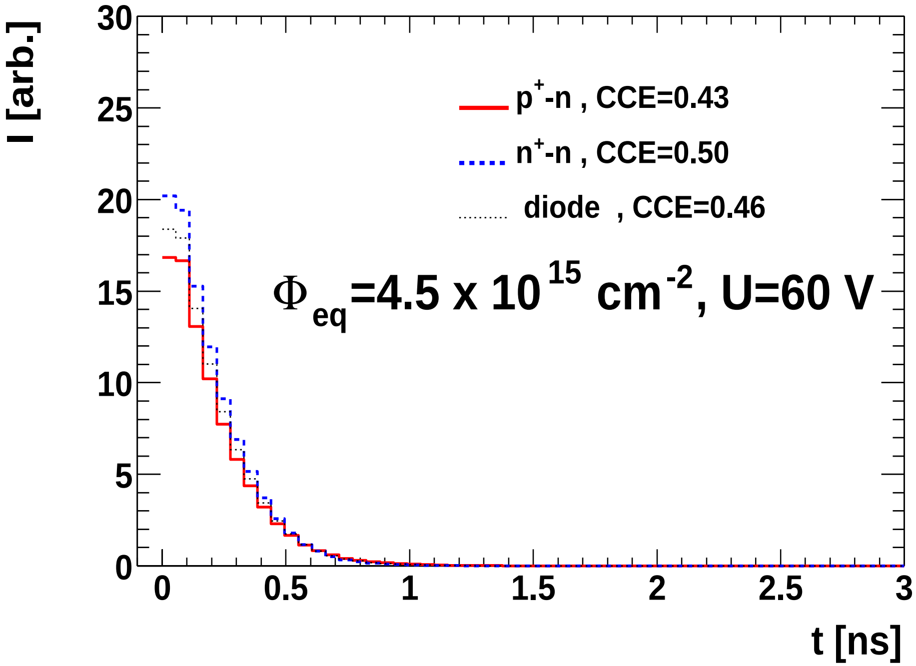
Diode: electrons and holes drifting to opposite directions in the diode contribute equally to the induced charge

Pixel detector: carriers drifting to the pixel side contribute to the larger part of the induced charge

Charge collection in irradiated segmented detectors (2)

D=50 μm, Pixel Pitch=70 μm, Implant Width=50 μm





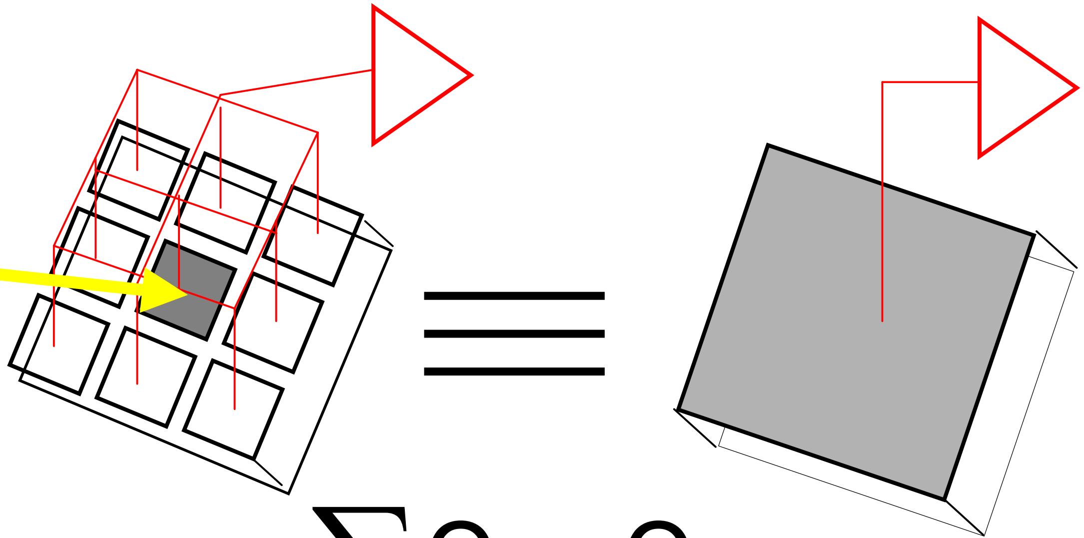
Currents before irradiation

Currents after irradiation

Irradiated detectors: smaller CCE in p^+-n detector compared with n^+-n detector with CCE of the diode in between

Induced charge in segmented detectors

electrode hit by ionizing particle



Constant weighting field 1/D

equal charge measured in the front and in the back electrode

$$\sum_{\text{all electrodes}} Q_i \equiv Q_{diode}$$

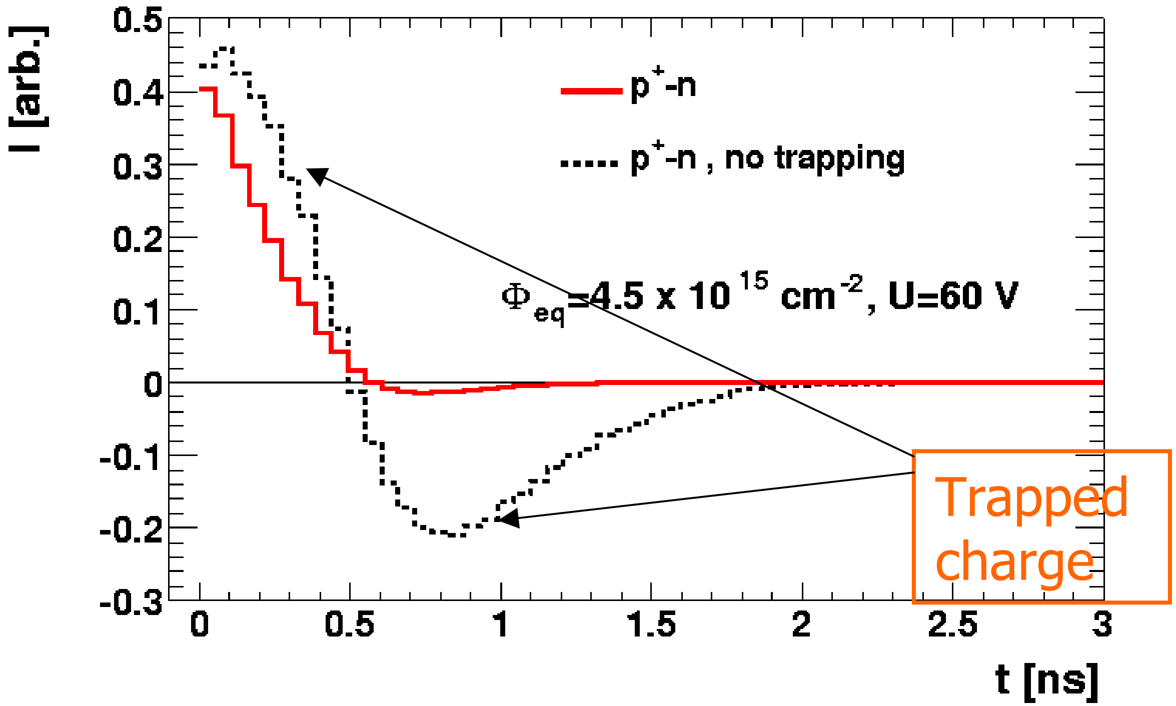
p^+ - induced charge on neighboring electrodes has the same polarity as for the hit electrode

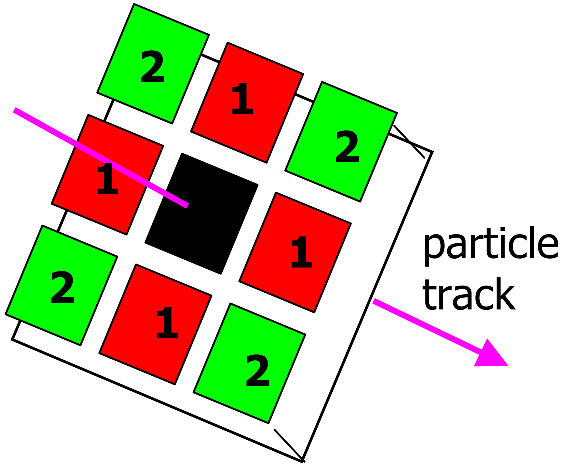
n^+- induced charge on neighboring electrodes has the opposite polarity as for the hit electrode

n^+ - higher signal in hit electrode p^+ - wider clusters

Induced charge in segmented detectors (2)

Current induced in the first neighbors





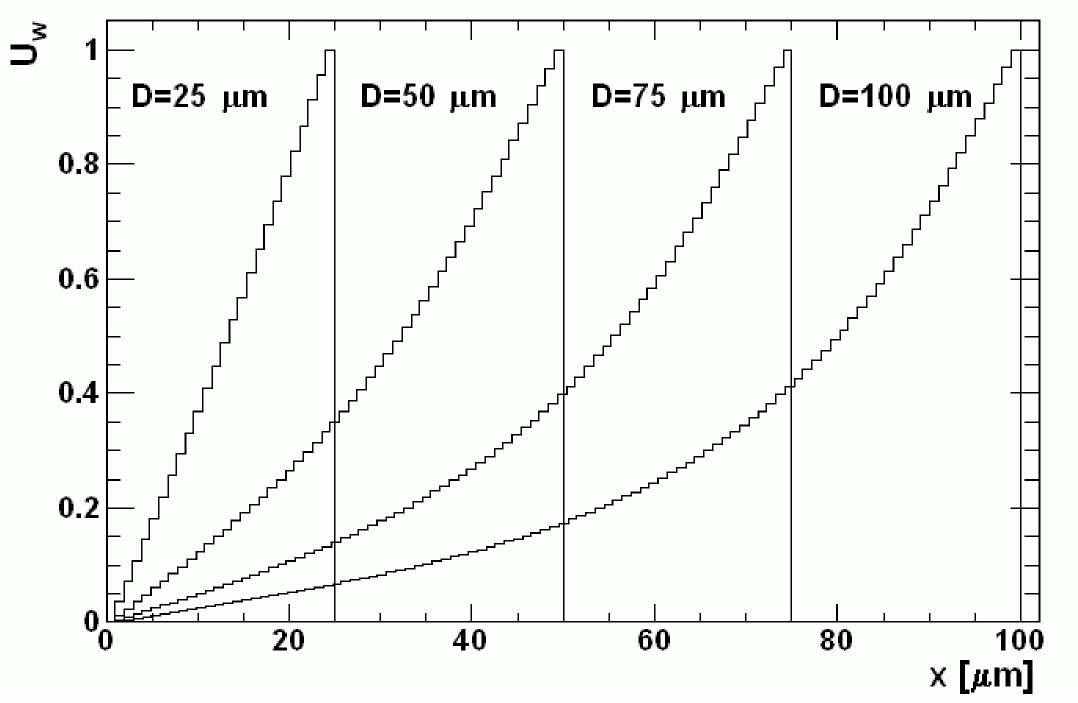
Absence of trapping $\int I(t)\,dt = 0 \xrightarrow{\text{trapping}} \int I(t)\,dt \neq 0$

This effect is far more important in irradiated detectors with **p$^+$** pixel due to the much larger hole trapping

Incomplete charge collection due to trapping →Charge sharing mechanism

Simulation of thin pixel detectors

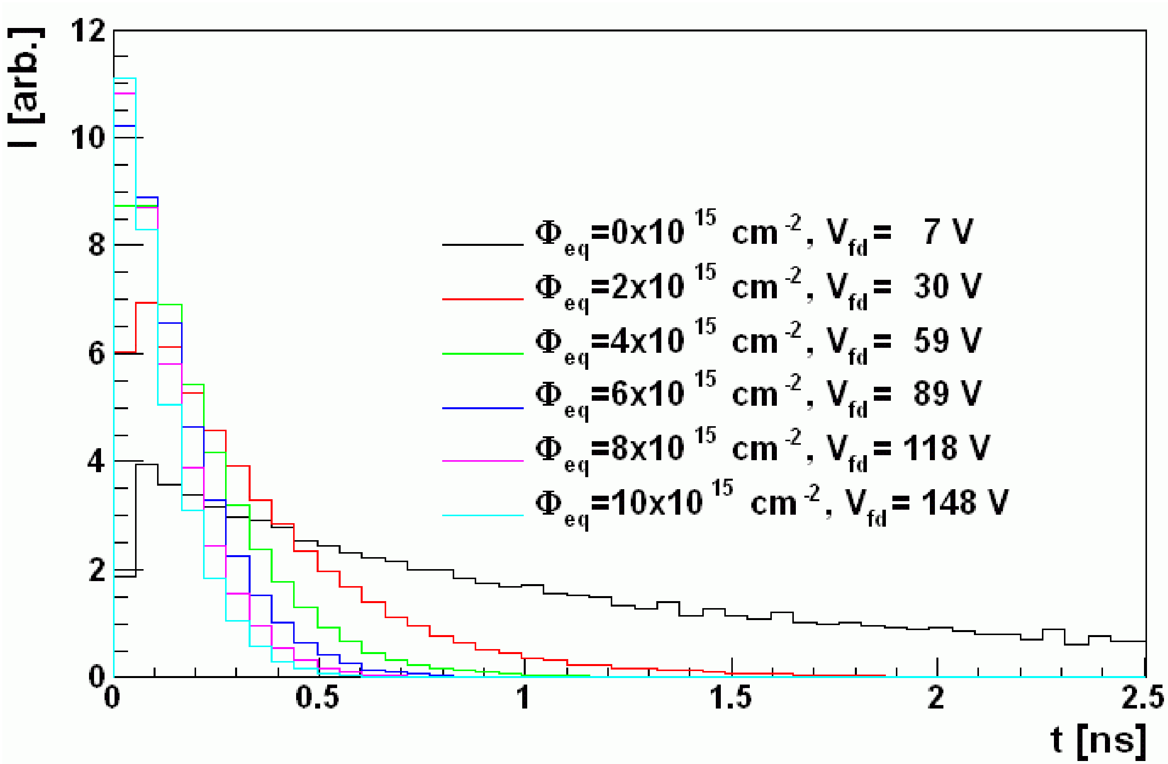
Simulated geometry: 3x3 arrays; pixel pitch 70x70 μm, implant width 50 μm
Thicknesses: 25, 50, 75, 100 μm. Central hits only considered.



Weighting potential along central pixel: no difference between n^+ and p^+ pixels is expected for Implant Width/Thickness>1: diode-like case!

Thin pixels: induced currents

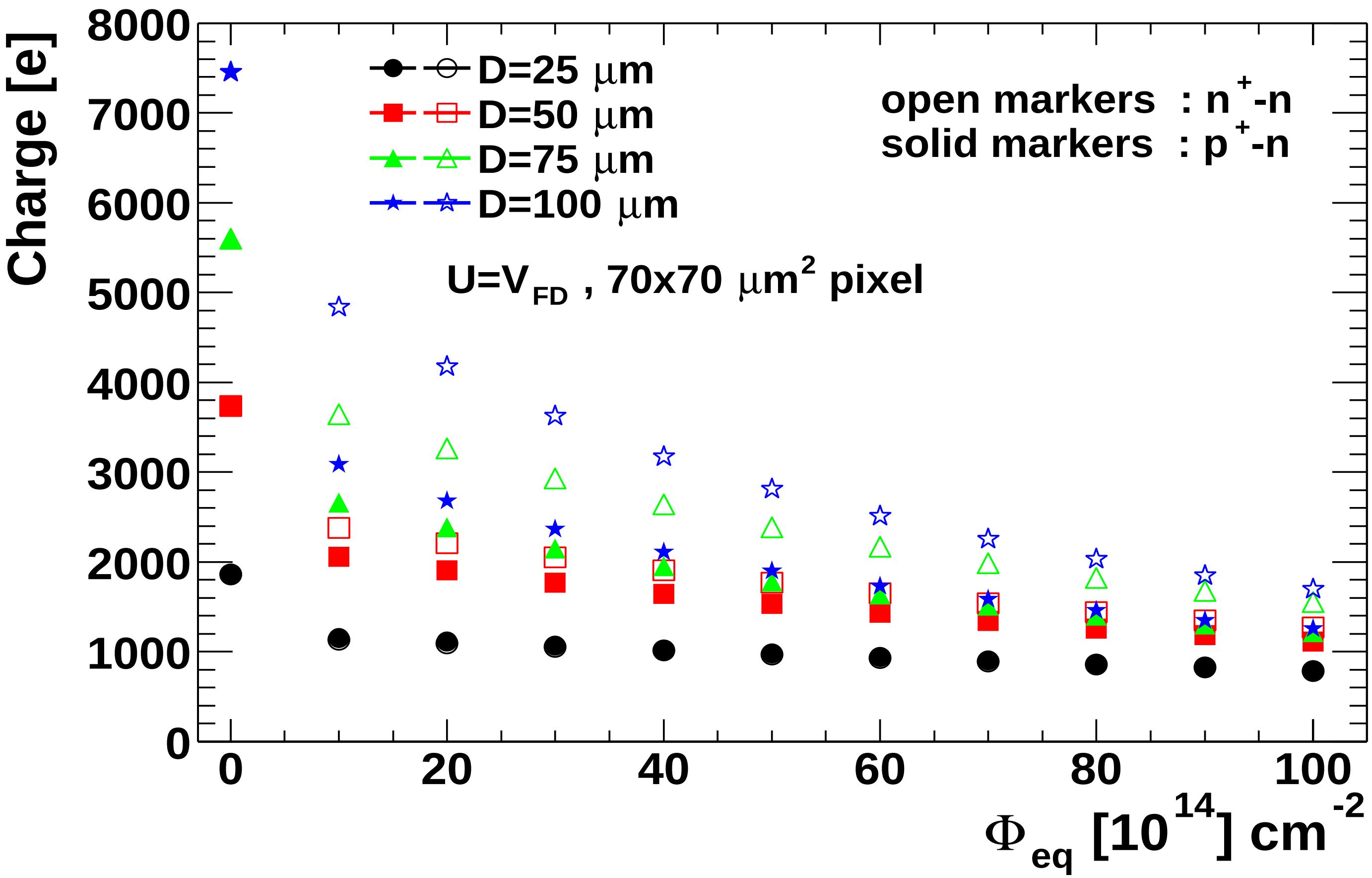
D=50 µm, N_{eff} = 0.0071 cm^{-1}x Φ_{eq} (DOFZ), operated at V_{fd}.



Simulated charge collection times are short (at Φ_{eq} =10^{16} cm^{-2} of order 0.15 ns for 50 µm thick detector).

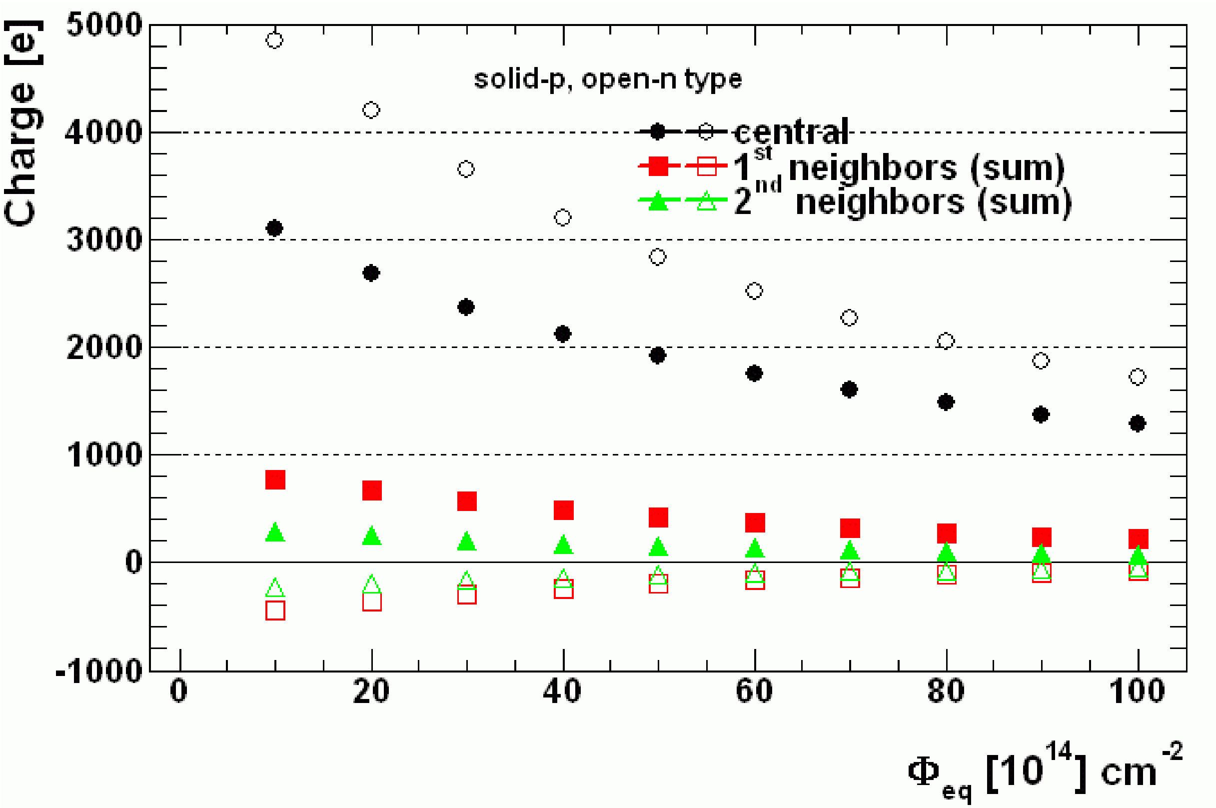
What are the consequences?

Thin pixels: collected charge

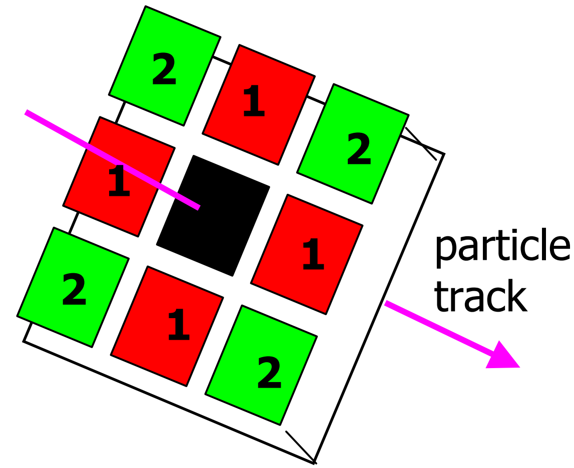


- At best only 1000-2000 e at high fluences
- Small difference between different pixel thicknesses at 10^{16} cm^{-2}
- Much better performance of n-type pixels for IW/D<1

Thin pixels: trapping-induced charge sharing

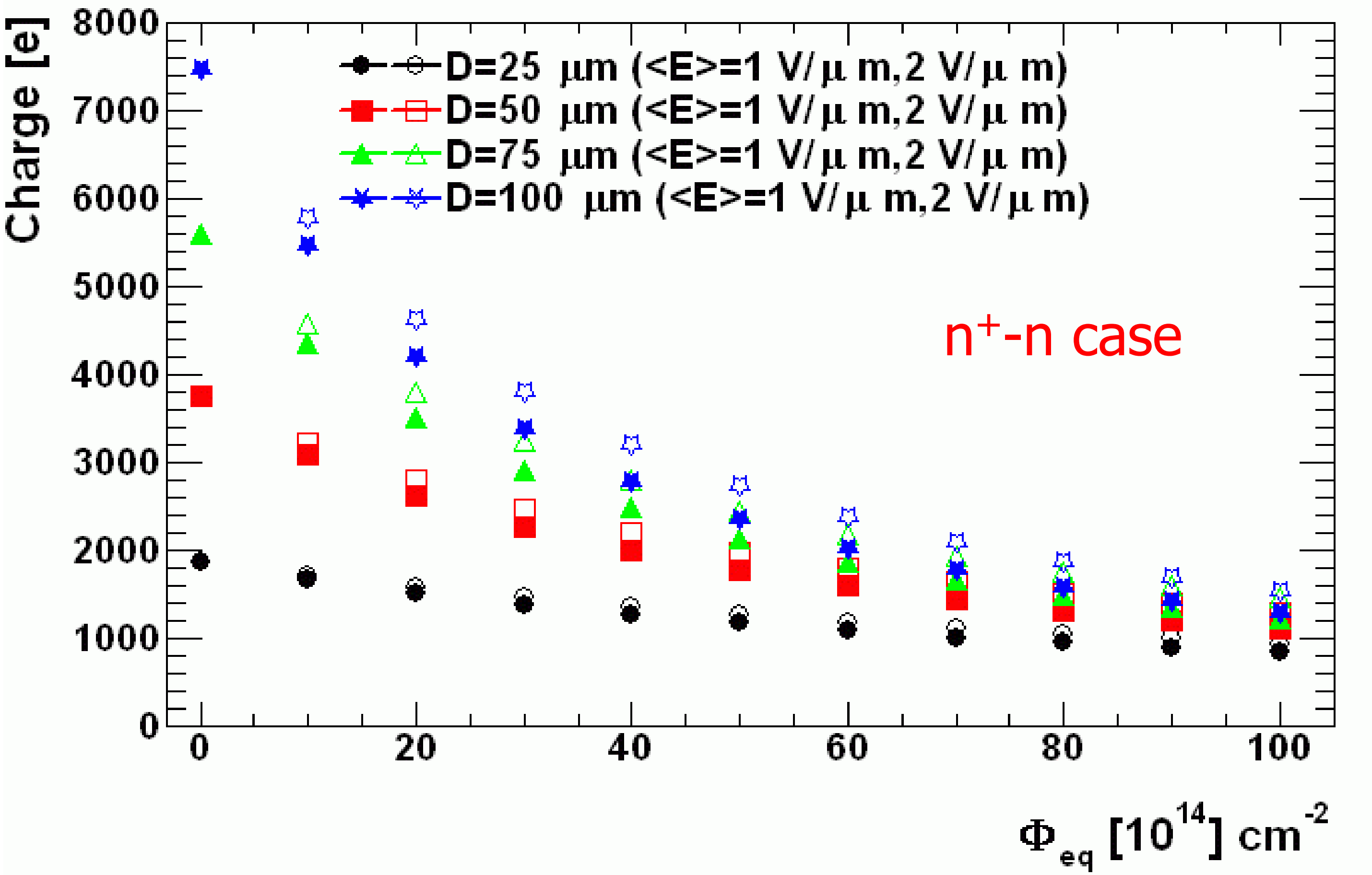


D=100 µm,
Pixel Pitch=70 µm,
Implant Width=50 µm,
operated at V_{FD}



- The charge induced in the neighboring pixels can be significant if Implant Width/Thickness<1
- Diffusion is negligible due to the short collection times
- Very beneficial n-type pixels (possible use of signals of opposite polarity to enhance S/N)

What if we make a device that has ideal N_{eff}~0?



- the signals don't differ much from the case of large N_{eff}
- higher electric field doesn't improve the induced charge significantly (saturation of the drift velocity)

Summary & Conclusions

Charge collection in segmented detectors:

• "Segmentation" in terms of charge collection means how much weighting field deviates from constant (diode)
• In irradiated segmented detectors it is beneficial to collect electrons (n^+-n pixels). Incomplete charge collection due to trapping leads to a charge sharing mechanism

Thin pixel detectors:

• Expected signals are ~1000-2000 e after $\Phi_{eq}=1\text{x}10^{16}\ \text{cm}^{-2}$: may be large enough, but put higher requirements on the read-out electronics

• IW/D>1: no differences between n^+ and p^+-type pixels (diode-like case)

• IW/D<1: better performance of n^+-type pixels

• even if detectors are operated at N_{eff}~0 expected signals are ~1000-1600 e after $\Phi_{eq}=1\text{x}10^{16}\ \text{cm}^{-2}$