CERN Physics Department PH-DT Detector Technologies

Characterization Methods for Silicon Detectors

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Outline

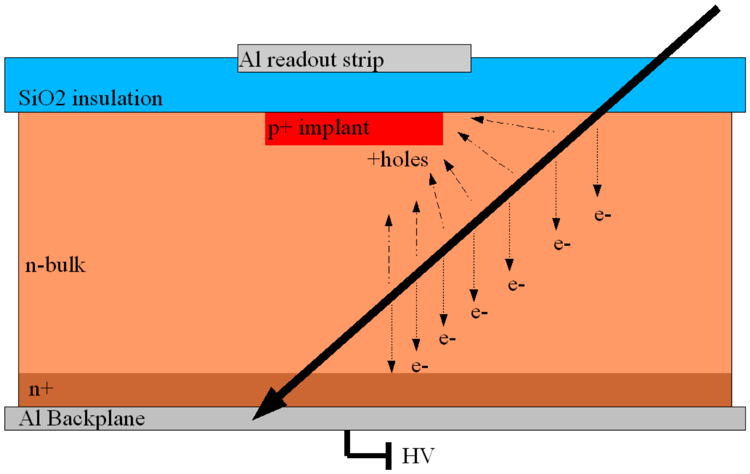
- Introduction
  - Silicon detectors at the LHC
  - Radiation damage in silicon detectors
  - Characterization of detectors at CERN
- C-V/I-V measurements
  - Set up, detectors, theory and results
- Edge Transient Current Technique (e-TCT)
  - Set up, detectors, theory and results
- Transient Current Technique (TCT)
  - Small Overview

http://www.hephy.at

Introduction

Silicon detectors at the LHC

- Silicon detectors are based on abrupt diodes of the type p+n or p+p
- Radiation creates electron-hole pairs
  - Holes are attracted to the p+ electrode
  - Electrons are attracted to the n+ electrode
- *Movement* of charge carriers induces a signal



Bergauer, Dragicevic, Krammer (2005)

Radiation damage in silicon detectors

The main macroscopic effects of radiation damage are

- **Increased leakage current**: Current that flows through the protective ground conductor to ground.
  - An increase in leakage current leads to an inaccurate signal and higher noise
- **Increased depletion voltage**: Bias voltage at which the junction is fully depleted. Important factor because operating detectors are supposed to be depleted.
  - An increase in the depletion voltage leads to higher noise and power consumption
- **Increased trapping**: Irregularities in the crystal of the semiconductor (defects) that have different energy levels causes mobile charges to get “trapped.”
  - An increased trapping interferes on the behavior of free charge carriers and the charge collection efficiency is reduced. It also causes smaller signal to noise ratio than in non-irradiated detectors

Characterization of detectors at CERN

- The HPK campaign is a characterization campaign to select materials and new sensor designs for he new upgrade of the CMS experiment
- SSD lab at CERN, under the supervision of Dr. Michael Moll, is in charge of characterizing diodes of different materials and thickness
  - Uses three different techniques
    - C-V/I-V measurements
    - Edge Transient Current Technique (e-TCT)
    - Transient Current Technique (TCT)
  - Compare detectors before and after they had been irradiated

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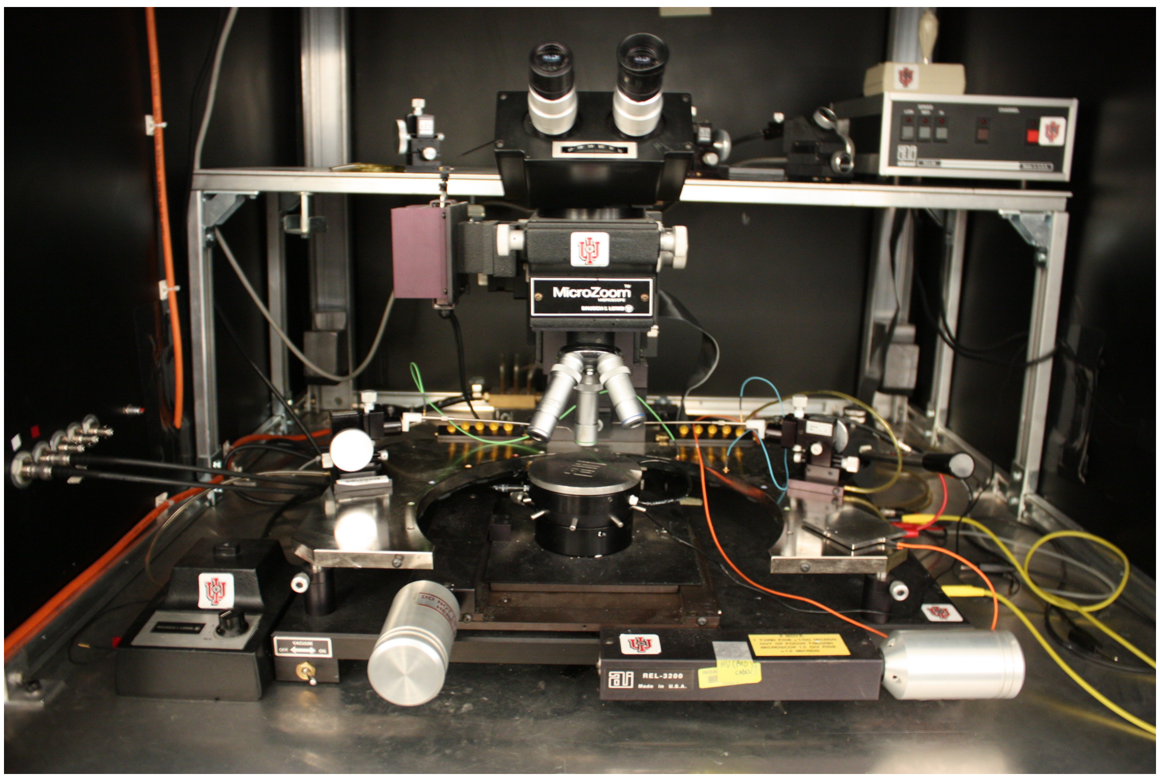
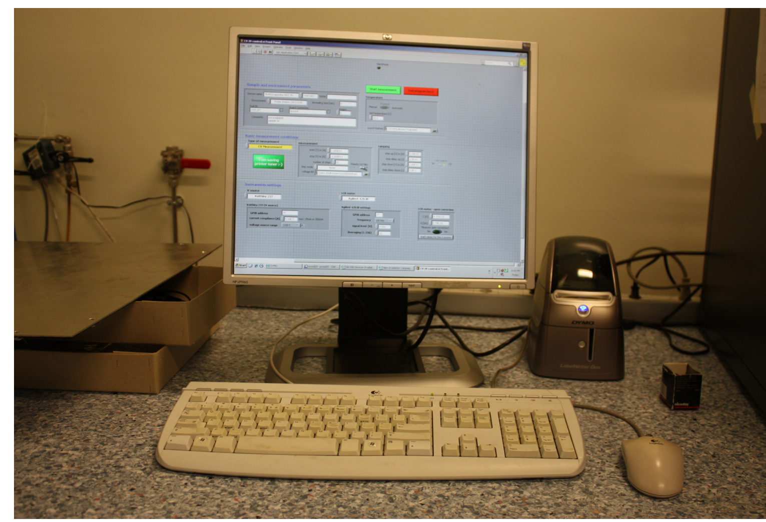
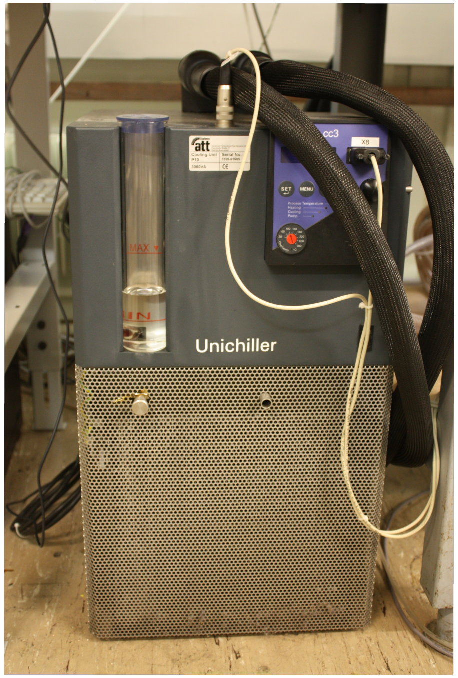
C-V/I-V Technique

Vacuum probe station





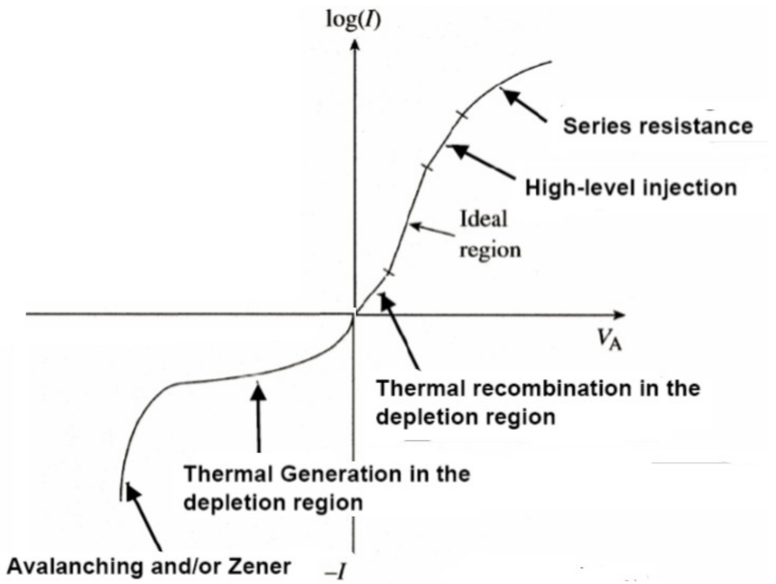
Vacuum Probe Station with temperature control



Theory: Behavior of a diode

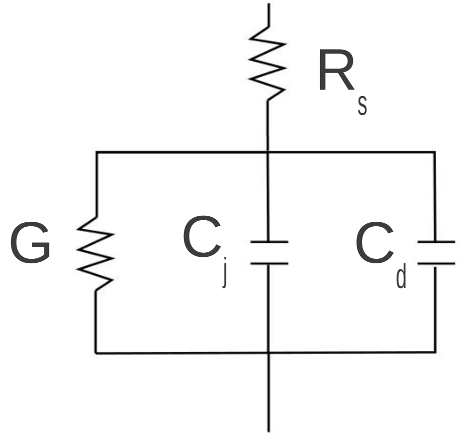
DC behavior

- A long list of assumptions are involved in deriving the ideal diode equation and a careful examination of experimental I-V characteristics will reveal discrepancies.

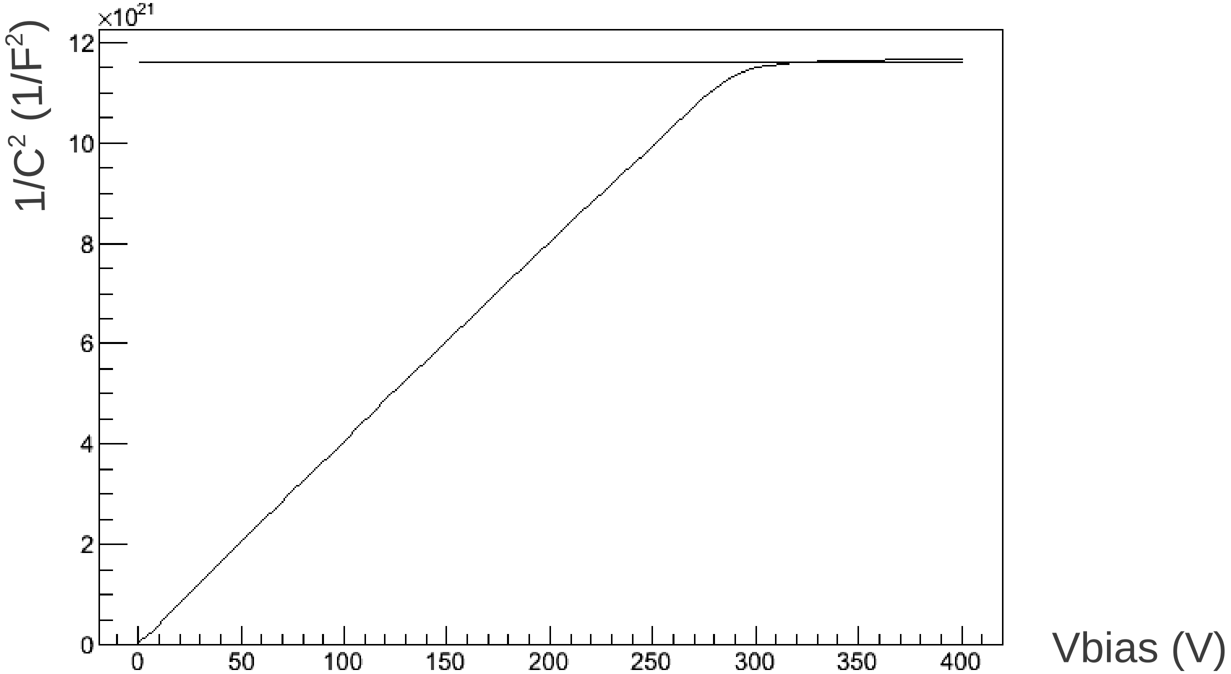


AC behavior

- When reverse-biased the junction diode becomes functionally equivalent to a capacitor.
- A small sinusoidal voltage is taken to be superimposed on the applied d.c. bias



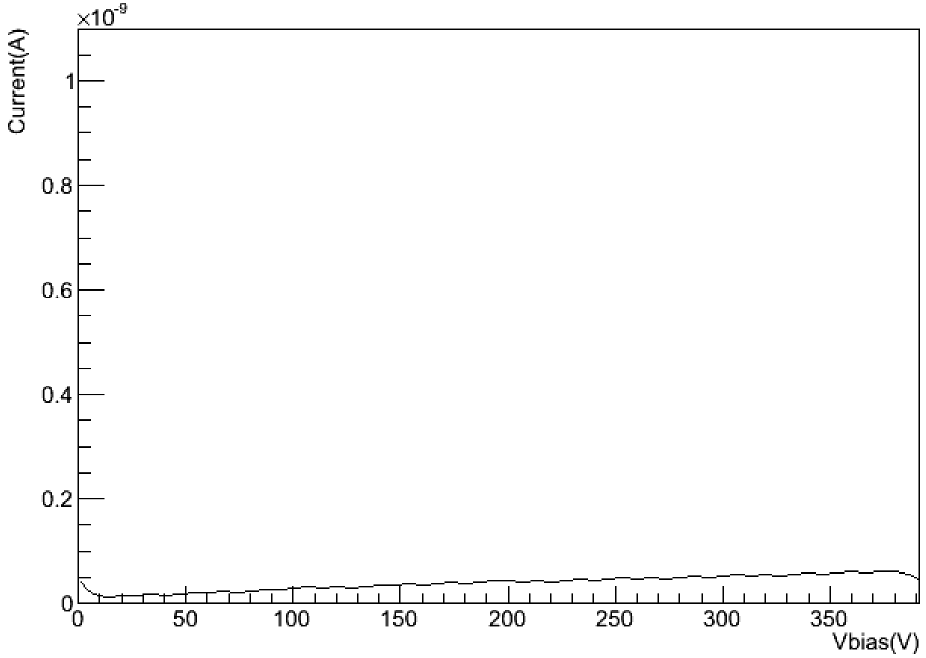
CV: Depletion Voltage and end capacitance



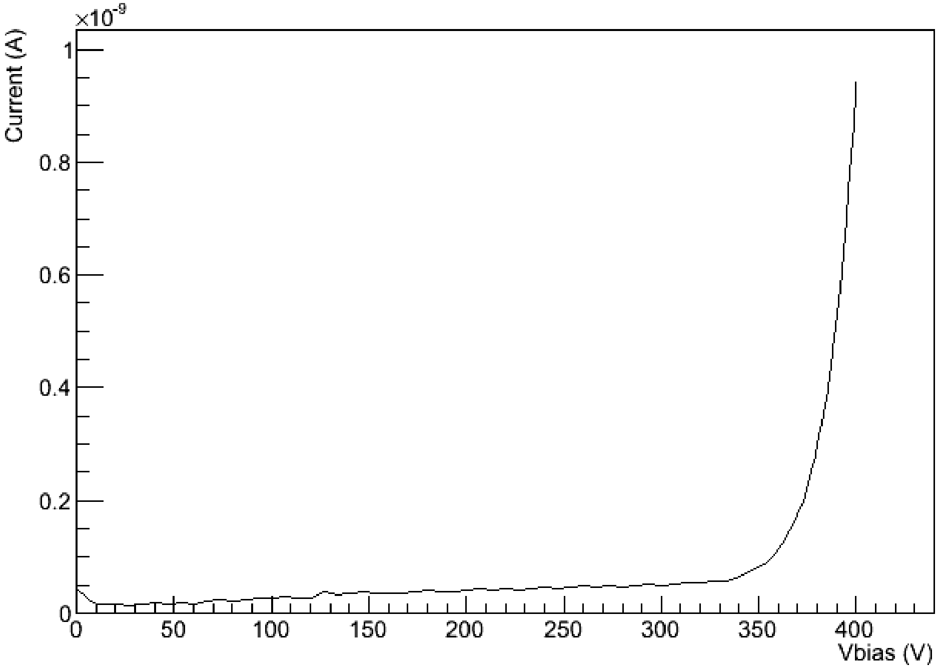
- The depletion region is the area of the doped semiconductor where the mobile charge carriers have diffused away, or have been forced away by the electric field. The only elements left on this region are donors or acceptors. Hence, detectors operate at a full depletion mode.
- In this case
  - V_{dep} = 300.25 V where V_{dep} depends on the properties of the semiconductor
  - C_{end} =9.27901e-12 F where C_{end} depends only on the geometry of the detector

IV: Break-down

No Break-down



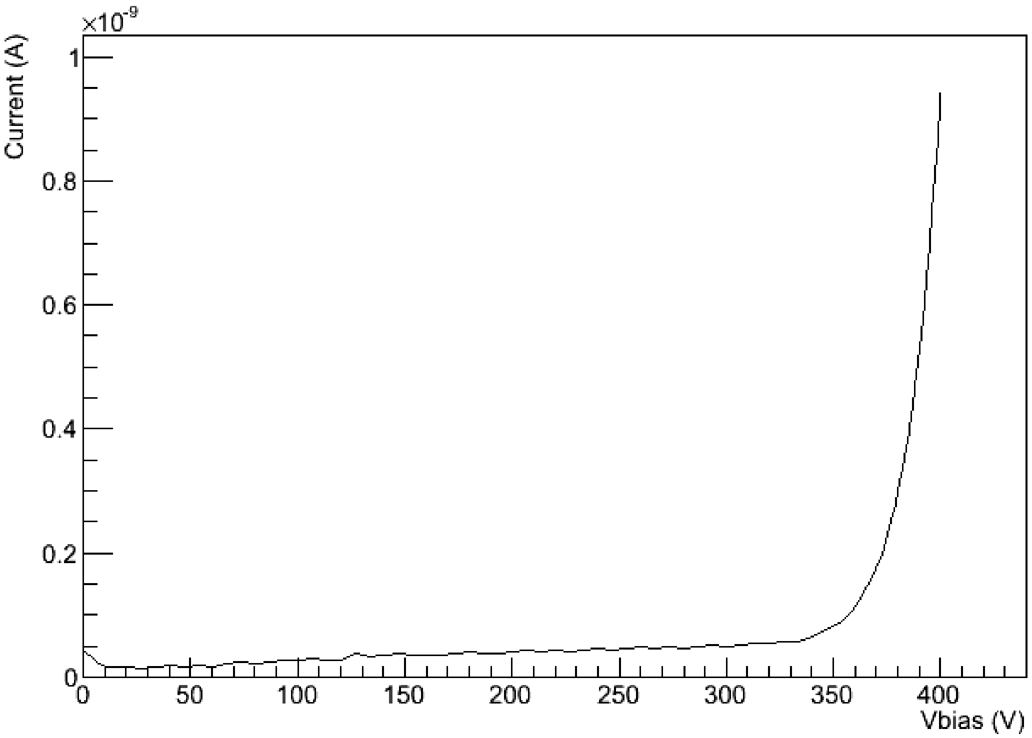
Break-down



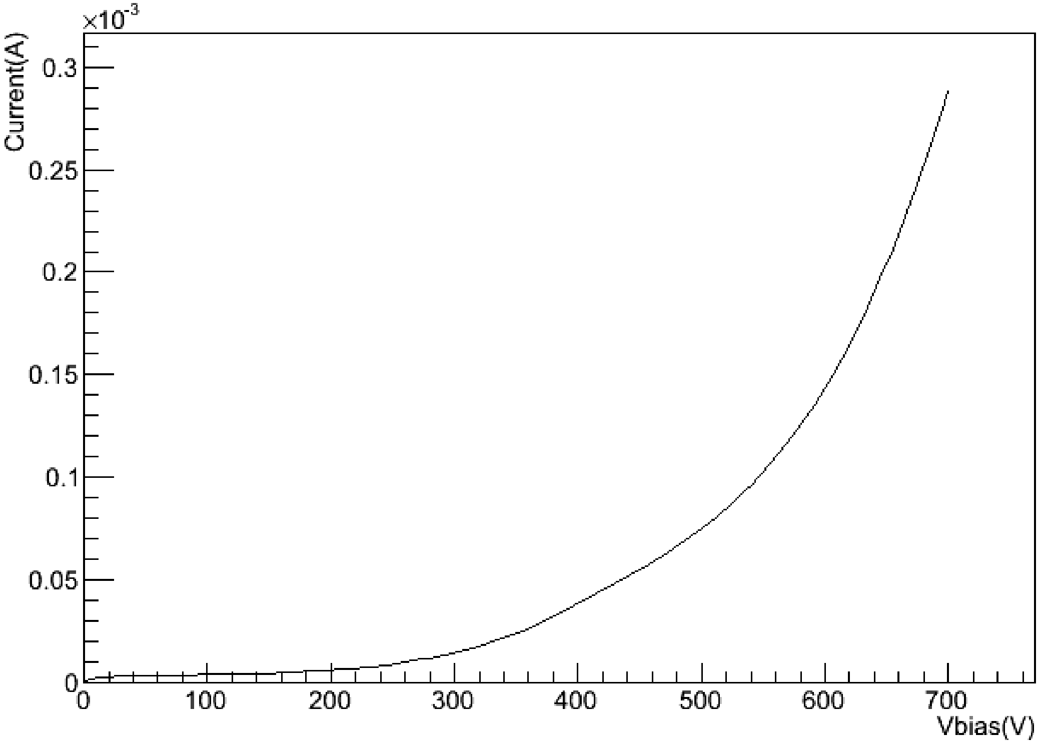
- The large reverse current that flows when the reverse voltage exceeds a certain value is a completely reversible process; breakdown does not damage the diode in any way
- Two different breakdown mechanism:
  - Avalanching breakdown
  - Zener (tunneling) breakdown

IV: Leakage current

Non irradiated detector

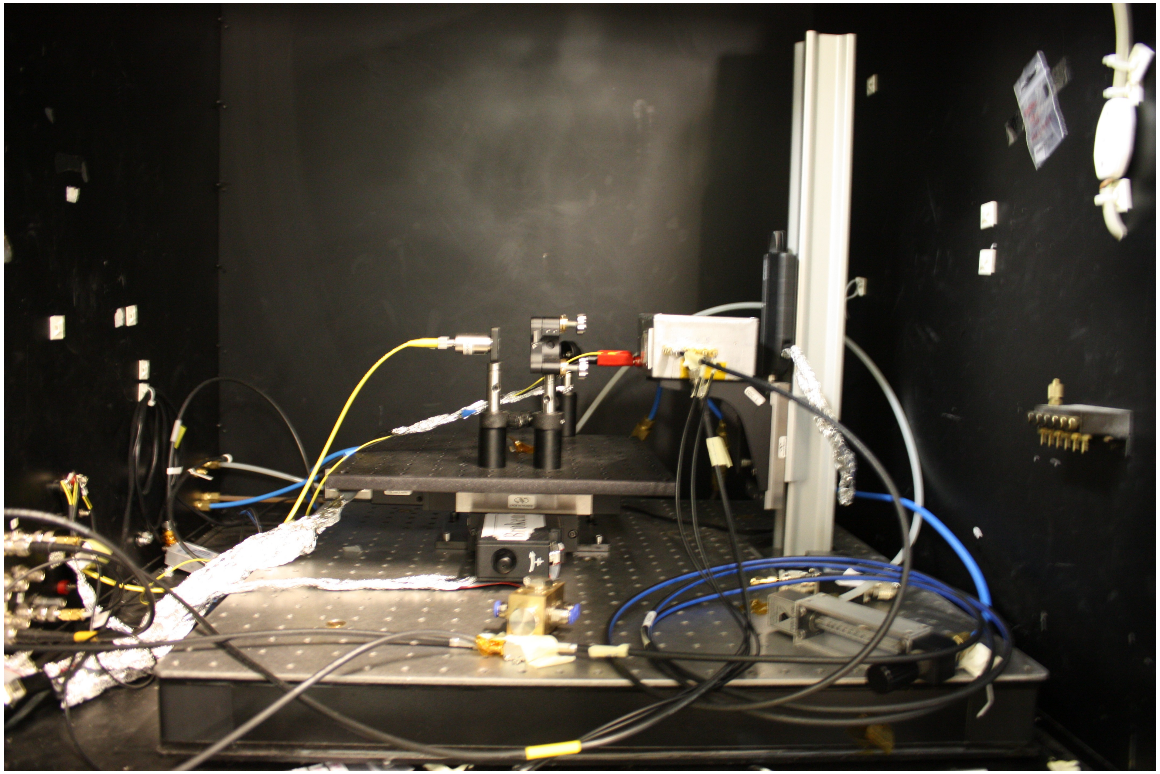


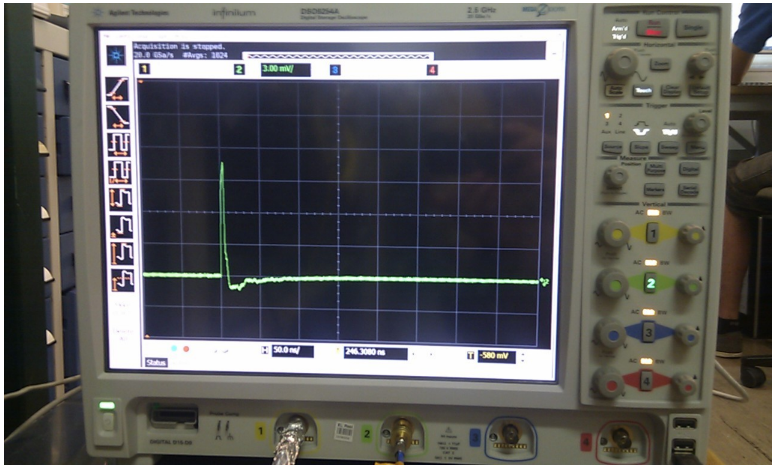
Irradiated detector

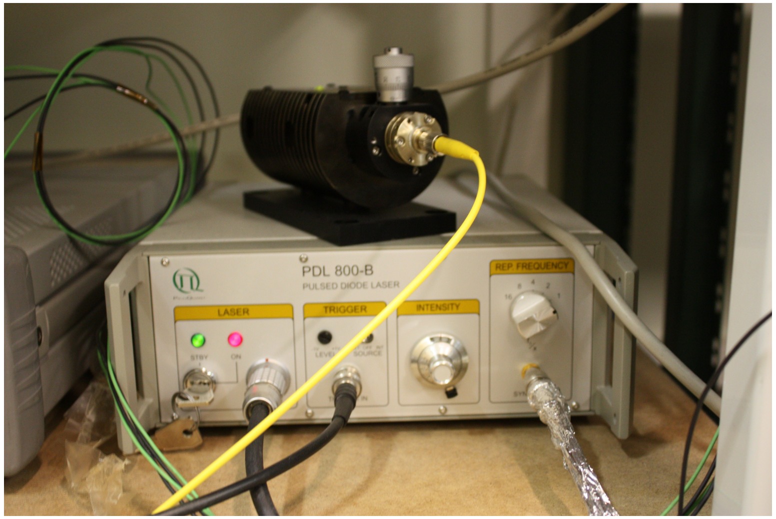


Edge Transient Current Technique (e-TCT)

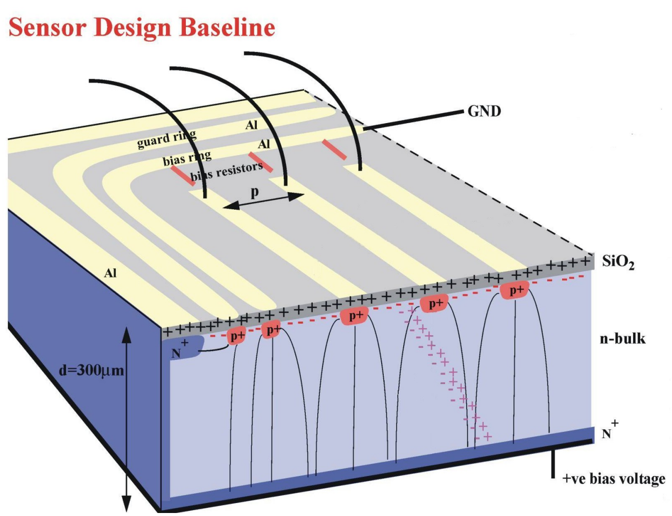
Edge-TCT set up







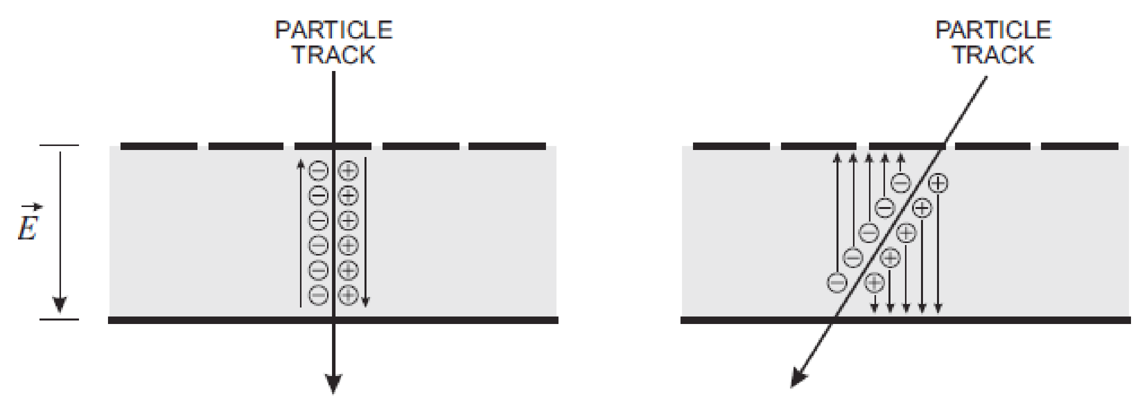
Strip detectors



Bergauer, Dragicevic, Krammer (2005)

- Very similar to diode detectors but with segmented electrodes
- The magnitude of the signal measured on a given electrode depends on its position relative to the sites of charge formation

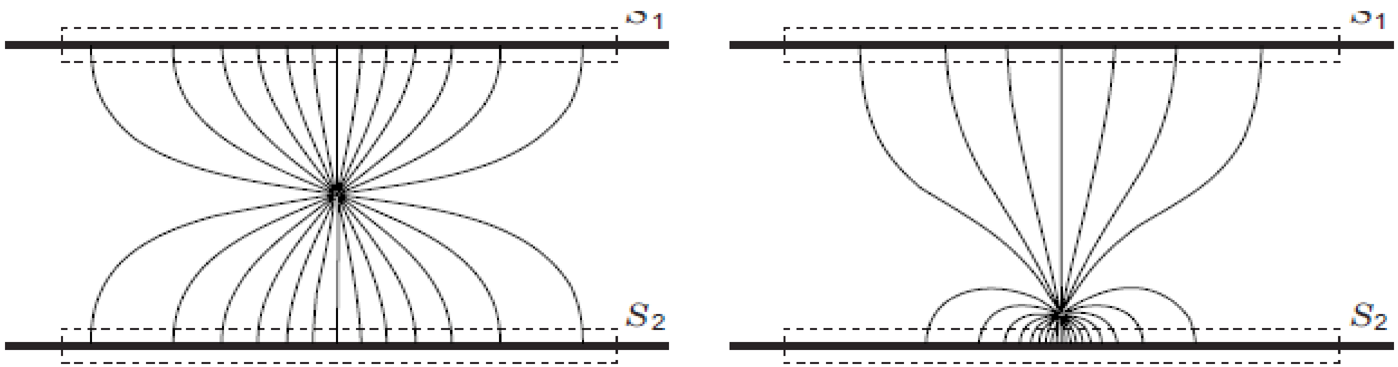
- Offers advantages compared to diode detectors:
  - Angled tracks deposits charge on two or more electrodes
  - Provides position information



Spieler (2005)

Theory: Ramo's theorem

- When the detector experiences an electromagnetic disturbance the current pulse begins when the charge q begins to move, not when the charge reaches the electrode.



Spieler (2005)

- The current induced at the electrode and the total charge are given by **Ramo's theorem**:

$$Q = -q\varphi_w(x)$$

$$i = q\mathbf{v}\mathcal{E}_w(x)$$

Theory: Profile extraction

- Potential profile.
  - Poisson's equation in one dimension

$$\frac{dV}{dx} = -\mathcal{E}$$

- Velocity profile
  - Obtained through a parametrization

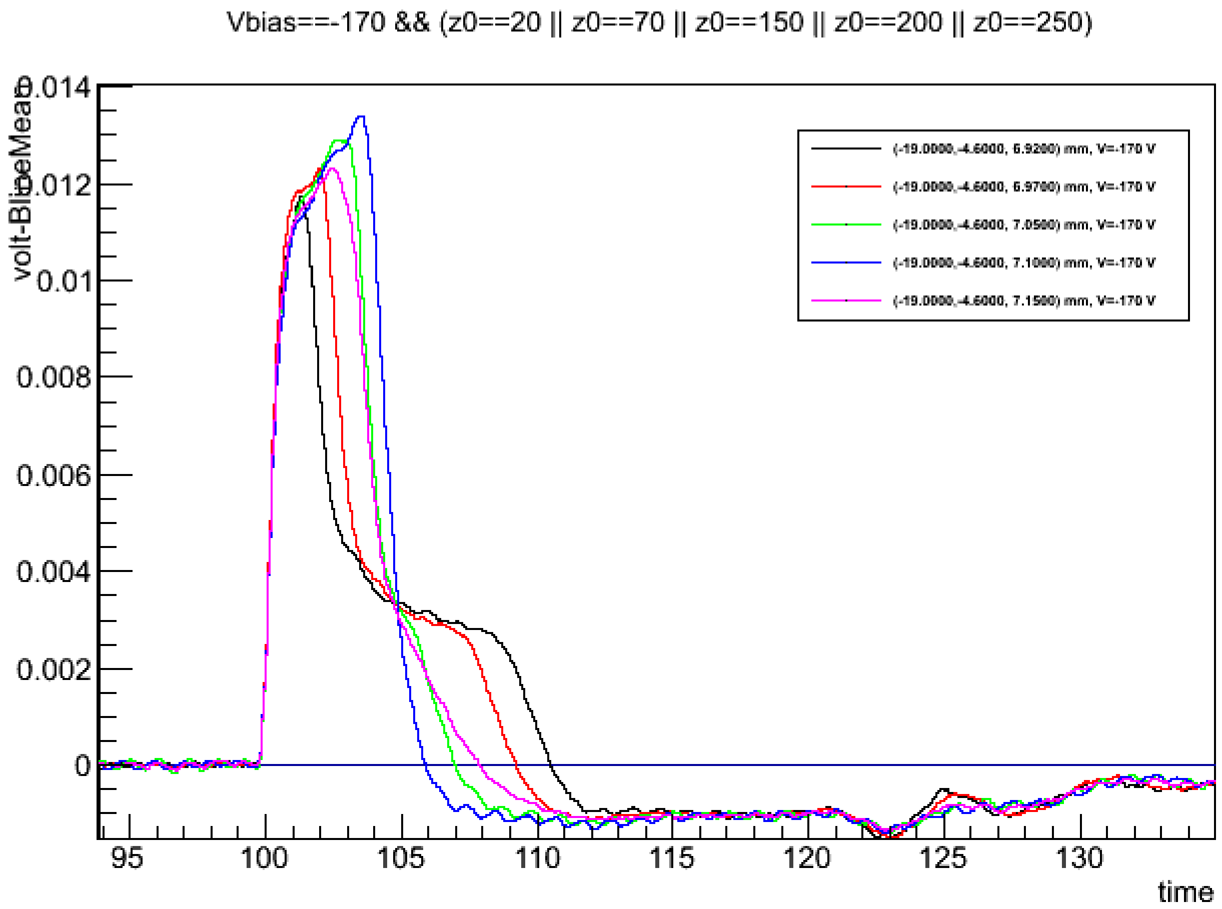
$$v_{d_{e,h}} = \frac{\mu_{0_{e,h}}\mathcal{E}}{\left[1 + \left(\frac{\mu_{0_{e,h}}\mathcal{E}}{v_{sat_{e,h}}}\right)^{\beta}\right]^{\frac{1}{\beta}}}$$

- Charge density profile

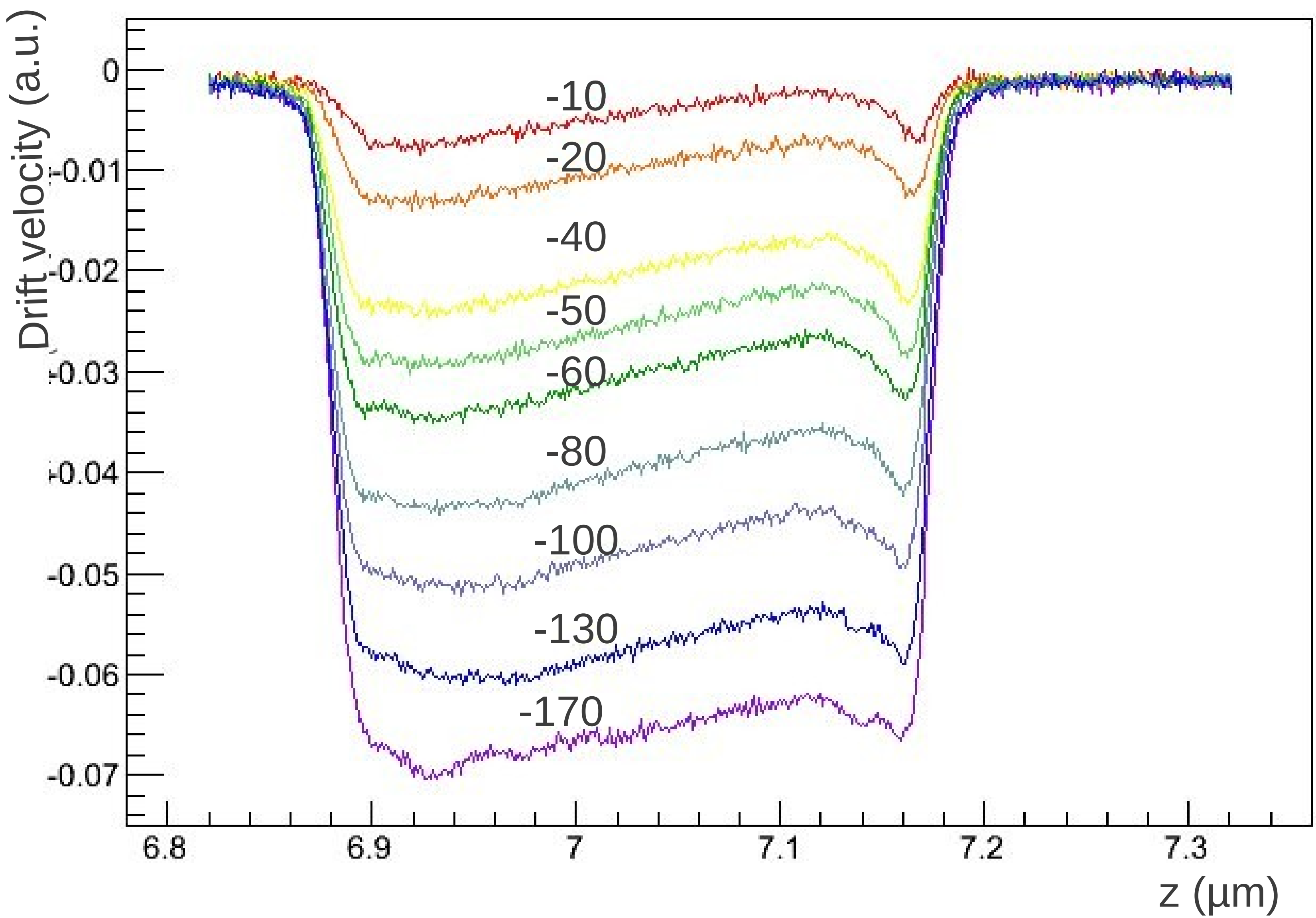
$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{\varepsilon} \qquad \varepsilon = K_s \varepsilon_0$$

If we have the Electric Field profile we can extract the other profiles easily. The electric field profile can be extracted from the induced current pulse received at the electrode, to do so we need to use Ramo's theorem.

Current pulse

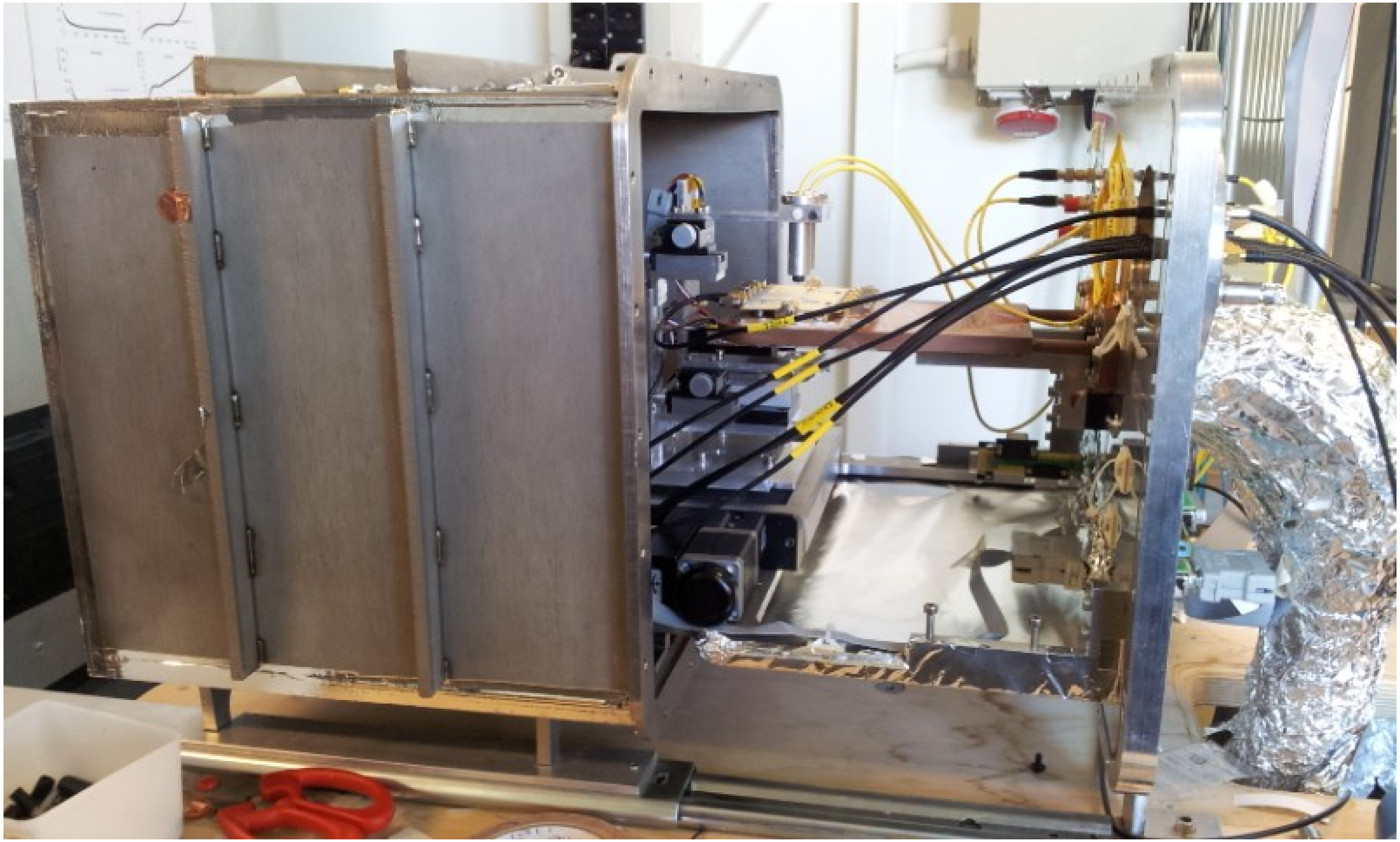


Velocity profile



Transient Current Technique (TCT)

TCT set up



TCT vs. e-TCT

TCT

- Shine the sample from the heavily doped extremes of the detector.
  - Observable transient currents is caused by just the contribution of electrons or just the contribution of holes
- Better to analyze global contribution of a particle passing through the detector
- Used to analyze diode detectors
- Good for detectors exposed to lower fluences of particles (current LHC)

e-TCT

- Shine the sample from one of its edges so that the laser penetrates in the bulk of the sample
  - The transient current measured shows the contribution of both electrons and holes
- Better for measurements that requires accurate spatial resolution
- Used to analyze strip detectors
- Good to analyze detector exposed to higher fluences of particles (future upgrade of the LHC)

Contributions to the project

- Measurement of CV/IV curves of different detectors
- Analysis of CV/IV curves using ROOT
- e-TCT analysis using ROOT
- Developed a way to extract the Electric Field profile using the induced current pulses at different positions and Ramo's theorem (under revision)
- Doping profile extraction from CV/IV measurements

References

- Hamel, L.A., and Julien, M., (December, 2008) *Generalized demonstration of Ramo's theorem with space charge and polarization effects*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 597, Issues 2–3, Pages 207–211

- He, Z. (2000) *Review of the Shockley–Ramo theorem and its application in semiconductor gamma-ray detectors*, Nuclear Instruments and Methods in Physics Research A 463 (2001) 250–267

- Knoll, G.F. (200)*Radiation Detection and Measurement*, third ed., Wiley, New York, ISBN 0-471-07338-5

- Kramberger, G. , Cindro, V. , Mandic?, I. , Miku˘z, M. , Milovanovic, M. , Zavrtanik, M. , and ˘ Zagar, K. (August, 2010), *Investigation of Irradiated Silicon Detectors by Edge-TCT*, IEEE Transactions On Nuclear Science, Vol. 57, No. 4

- Pierret, R. F. (March, 1996), *Semiconductor Device Fundamentals*, Addison Wesley Ed.

- Pöhlsen, T., (April, 2010), *Charge Collection and Space Charge Distribution in Neutron-Irradiated Epitaxial Silicon Detectors,* Doctoral Thesis, Universität Hamburg Institut für Experimentalphysik

- Riegler, W. (August, 2004), *Extended Theorems for Signal Induction in Particle Detectors*, Nuclear Instruments and Methods in Physics Research A 535 (2004) 287–293

- Spieler, H. (2005), *Semiconductor Detector Systems*, Oxford University Press

- Spieler, H. (1999), *Introduction to Radiation Detectors and Electronics,* IX.1 Semiconductor Detectors II – The Signal

Thank you for your attention!

Questions?