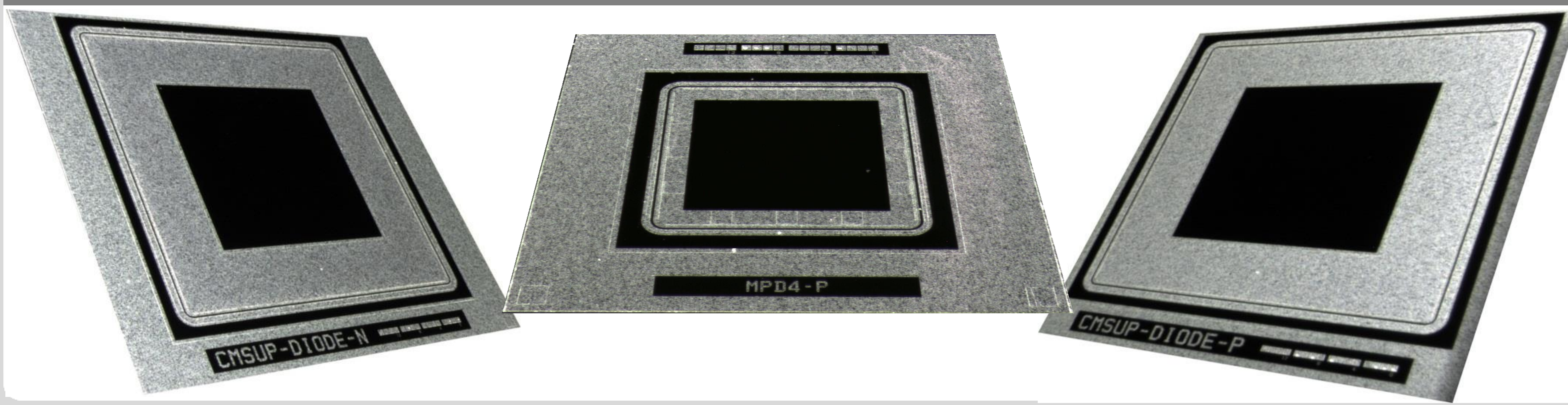
Simulation of CV, TCT and CCE with an effective 2-defect model

3-5 June 2013 in Albuquerque

Robert Eber

22nd RD50 Workshop

Institut für Experimentelle Kernphysik

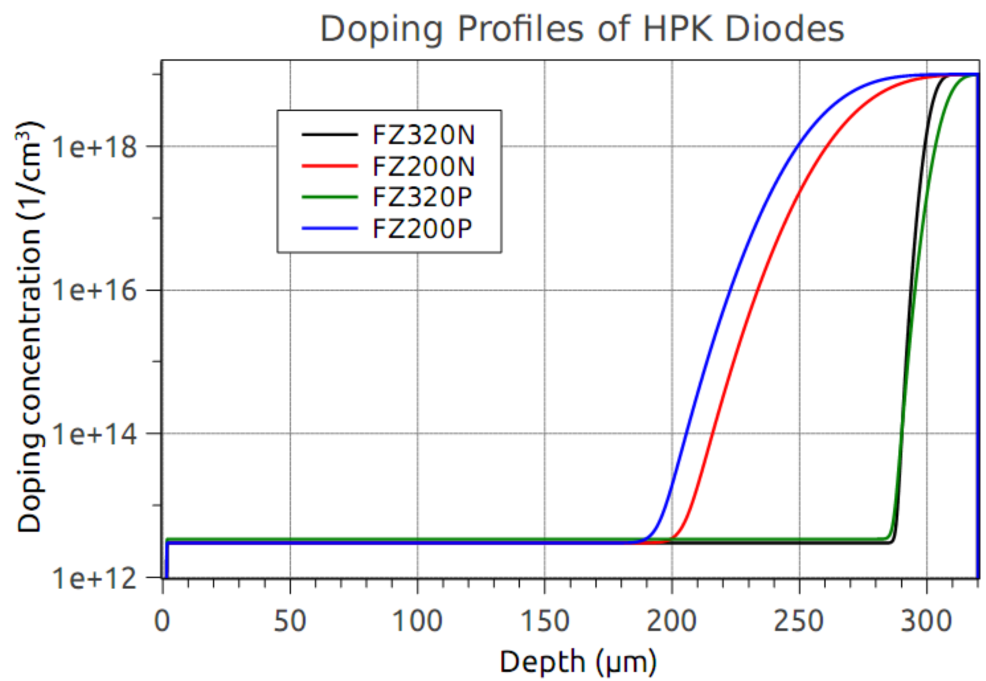


Contents

Introduction

Simulation Device

- HPK like diodes: FZ material; thickness: 200µm, 320µm; p-bulk / n-bulk
- Junction at front side: 1.5µm depth gaussian shape
- Junction at back side: deep diffusion depending on thickness
- Very simple device 1µm (x 1µm) x 320µm
- Irradiate device → 2 Modify 2-defect model



Original Trap Model (EVL)

Trap	Energy	Cross section (e/h)	Intro rate
Donor	EV+0.48eV	1e-15/cm^2	1
Acceptor	EC-0.525eV	1e-15/cm^2	1

Matches unirradiated measurements (IV, CV)

Motivation for correct electric field

- Current in irradiated devices
  - Only dependent on particle fluence
  - Independent of particle type
- Increase of bulk current well described by α

$$\Delta I = \alpha \times V \times F$$

- Correct current has to be established in the simulation
  - Filling of traps / space charge dependent on current
  - Filling of traps determines eletric field shape
- HPK diodes: 1st annealing step 10min@60°C
  - α = 8.9e-19 A/cm
- How to determine current according to simulation parameters?

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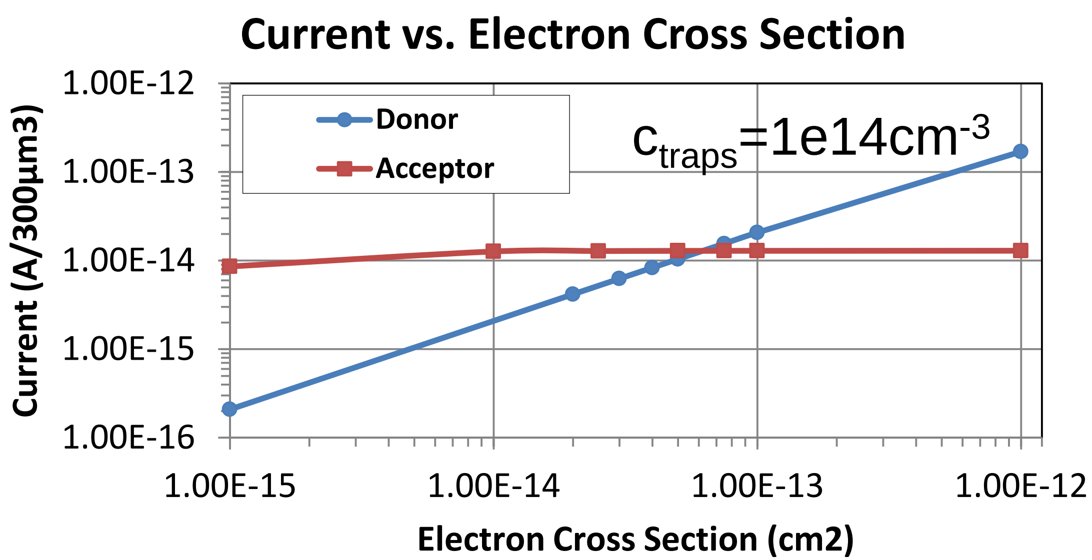
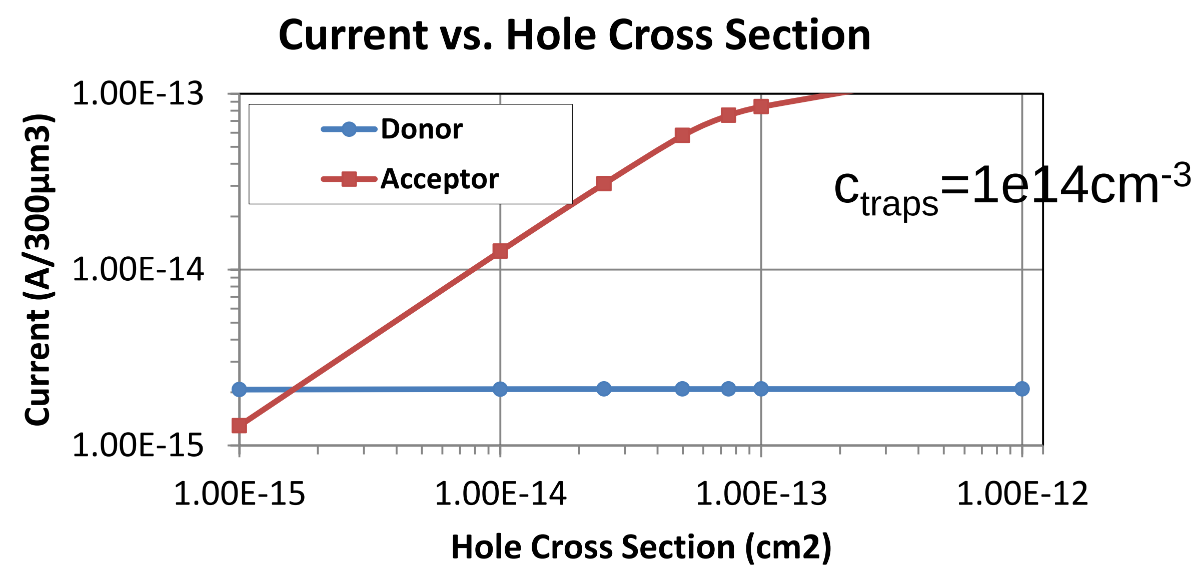
Parameterisation of generated Current





- Current mainly produced by the cross section of one charge carrier
- Current also dependent on concentration of traps
- Calculate concentration of traps dependent on c, σ and α

$$\Delta I = \alpha \times V \times F$$

$$X = \frac{I}{\sigma_{test} \times c_{test}}$$

$$c_{Acc} = \frac{\alpha \times Vol. \times F}{r \times (X_{e,Don} \times \sigma_{e,Don} + X_{h,Don} \times \sigma_{h,Don}) + (X_{e,Acc} \times \sigma_{e,Acc} + X_{h,Acc} \times \sigma_{h,Acc})}$$

$$c_{Don} = r \times c_{Acc}$$

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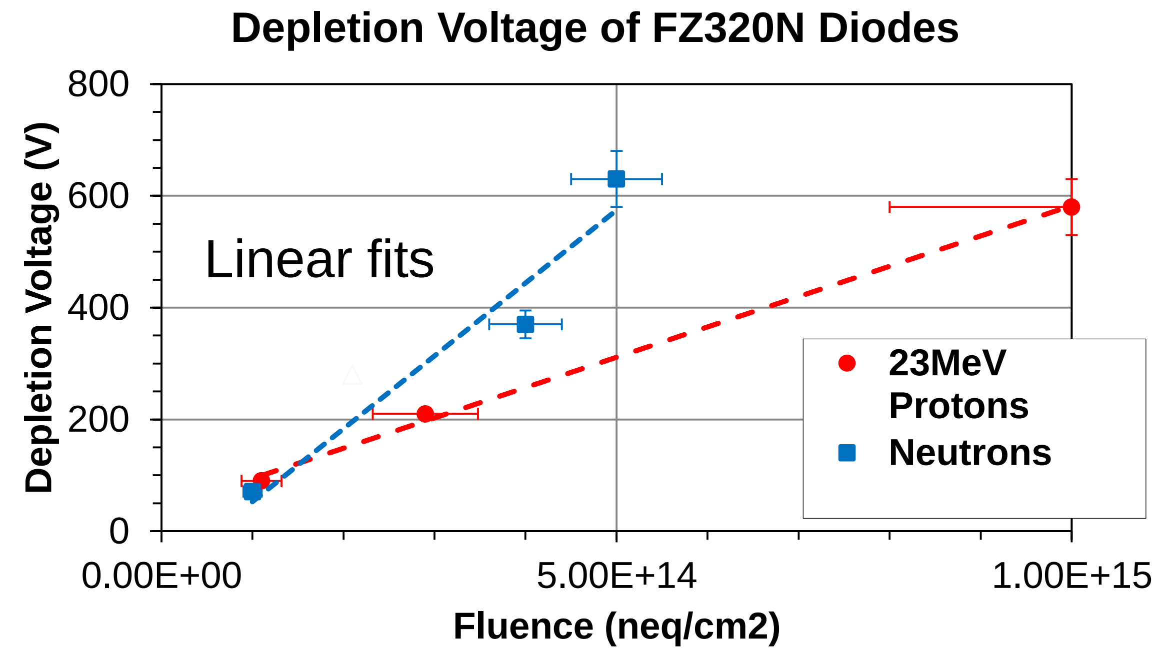
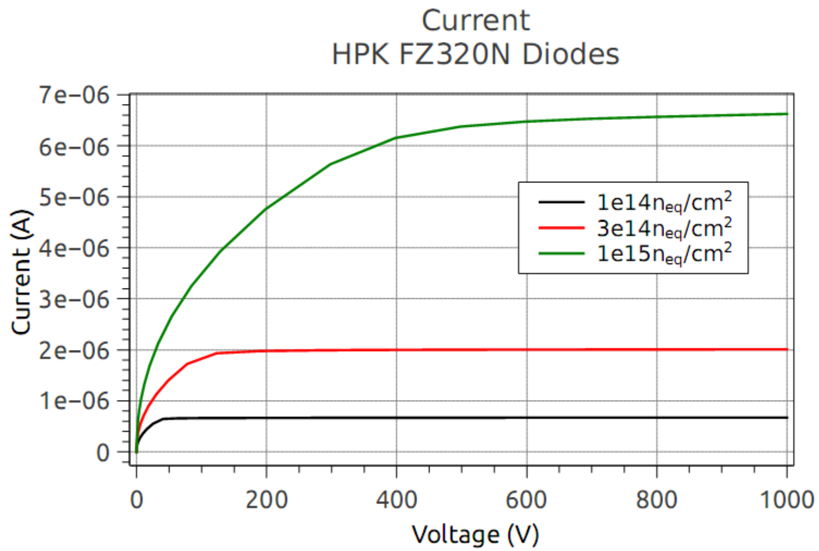
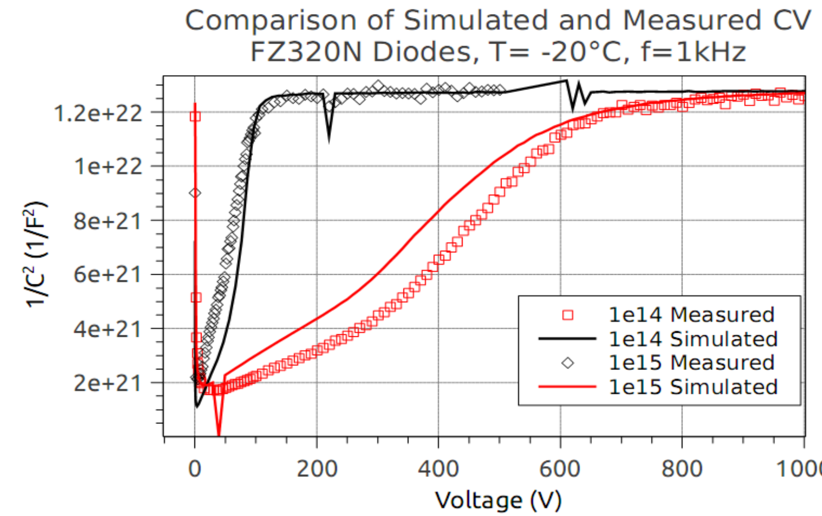
Depletion Voltage

- Different depletion voltage observed at -20°C, 1kHz Annealing 10min@60°C
  - For 23MeV protons
  - For neutrons
- Linear approximation feasible
- Derive Models





Proton irradiation



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Radiation Damage Models

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- Neutron Irradiation

- Donor
  - c = 0.9 * c(Acc) = 1.395 * **F**
  - X(e) = X(h) = 1.2e-14cm2

- Acceptor
  - c = 1.55 * **F**
  - X(e) = X(h) = 1.2e-14cm2

- Proton Irradiation

- Donor
  - c = 5.598 * **F** – 3.959e14
  - X(e) = X(h) = 1.0e-14cm2

- Acceptor
  - c = 1.189 * **F** + 0.645e14
  - X(e) = X(h) = 1.0e-14cm2

- Donor removal = 50% in n-bulk

Valid for 1e14 – 1e15neq/cm2

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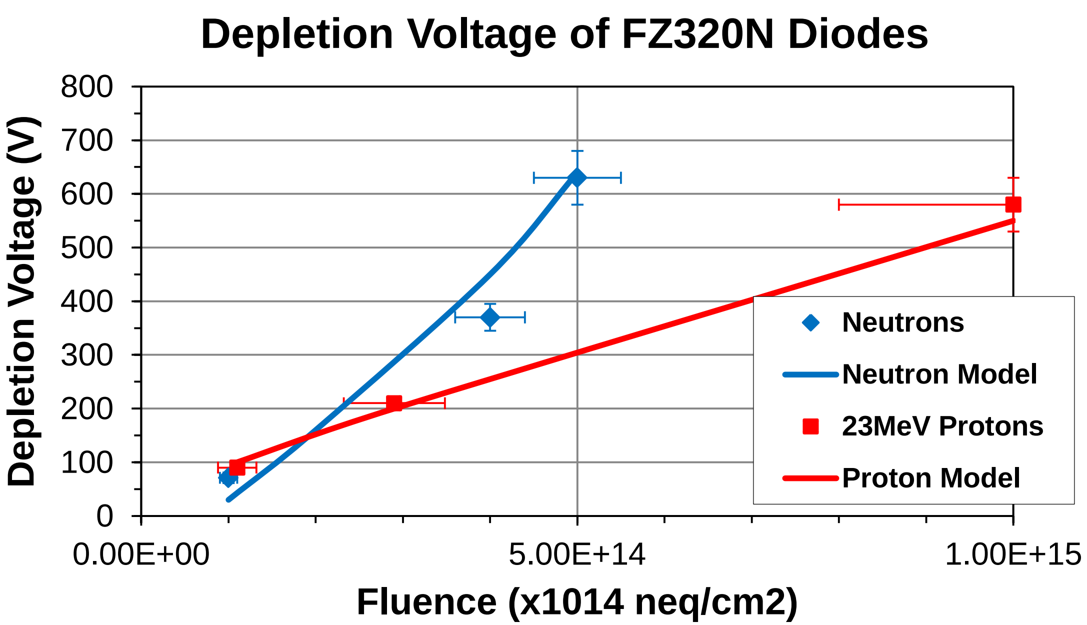
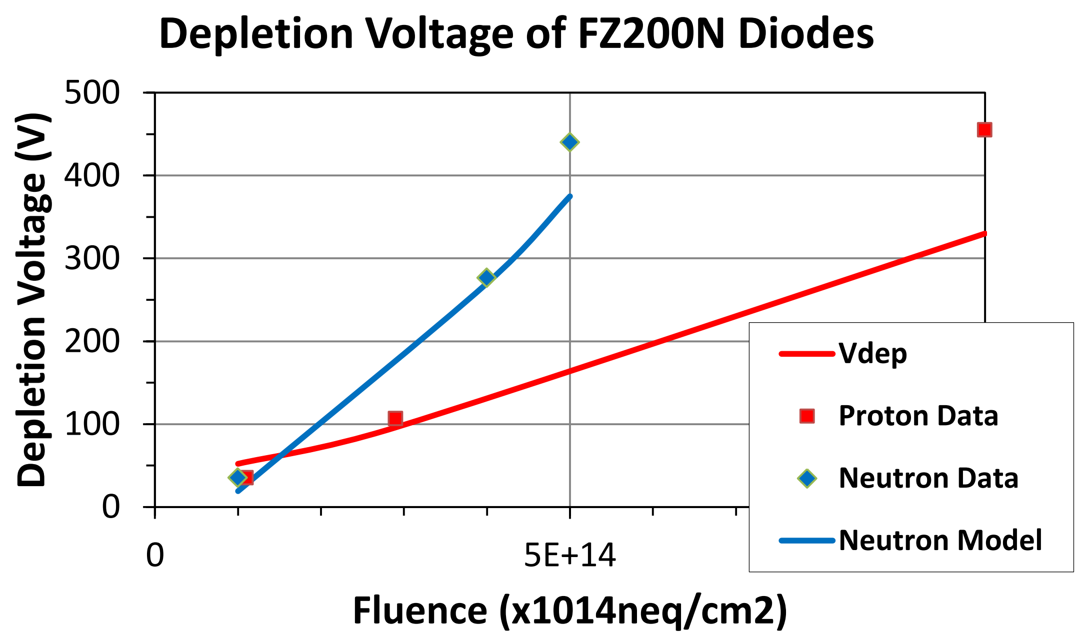
Overview of Depletion Voltage (n-bulk)





- Models describe the depletion voltage of all n-bulk diodes quite well
- Most problems experienced describing higher fluences for protons

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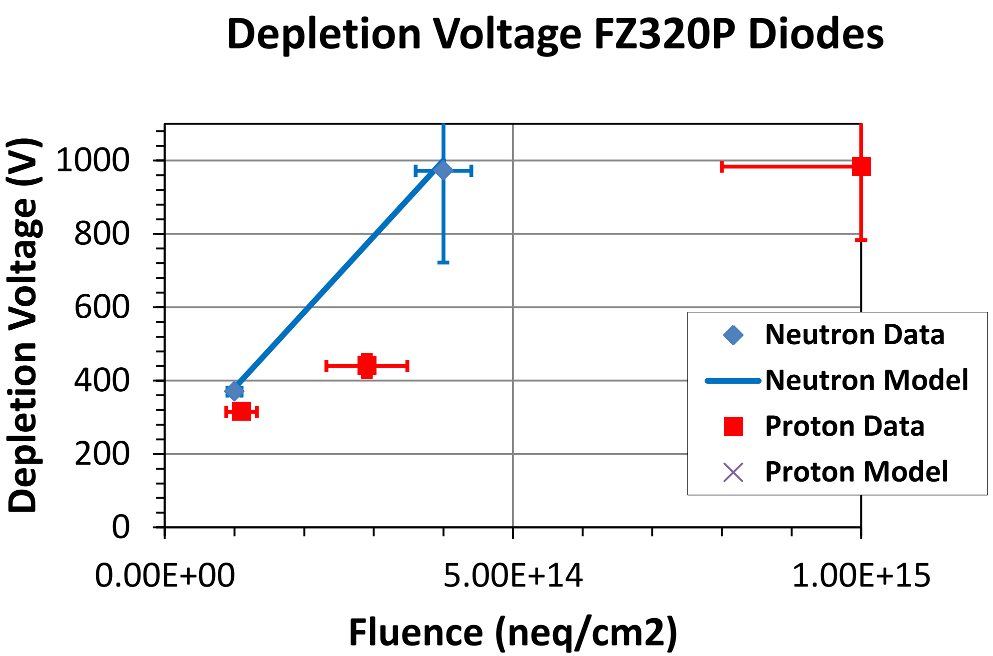
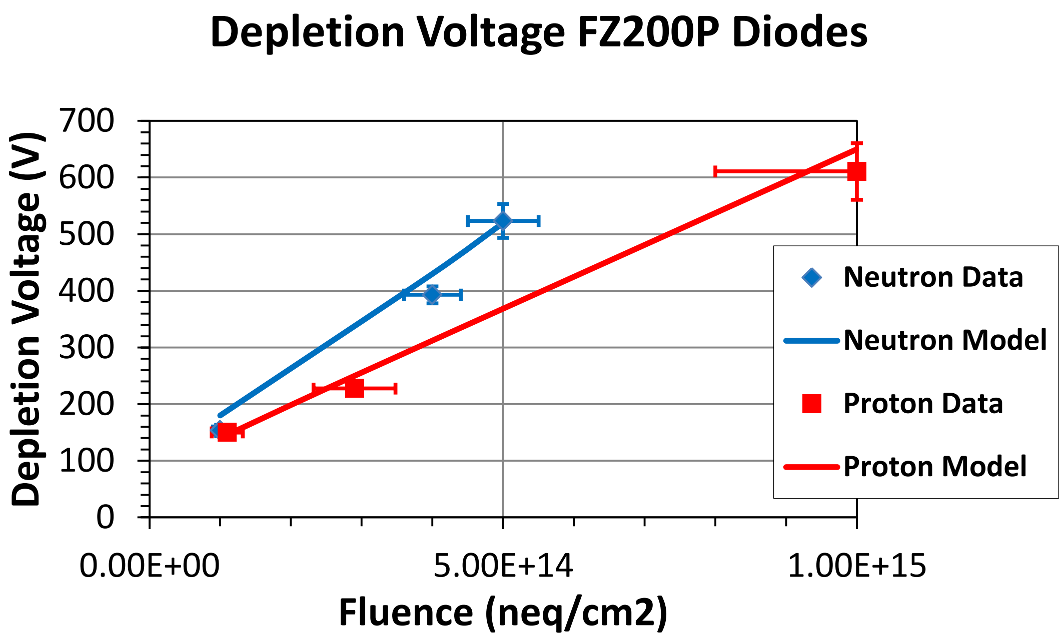
Overview of Depletion Voltage (p-bulk)





- Take same models – and plug them in for p-bulk diodes (320µm, 200µm)
- Neutron model fits again all points very well
- Proton model cannot be used for FZ320P – under investigation

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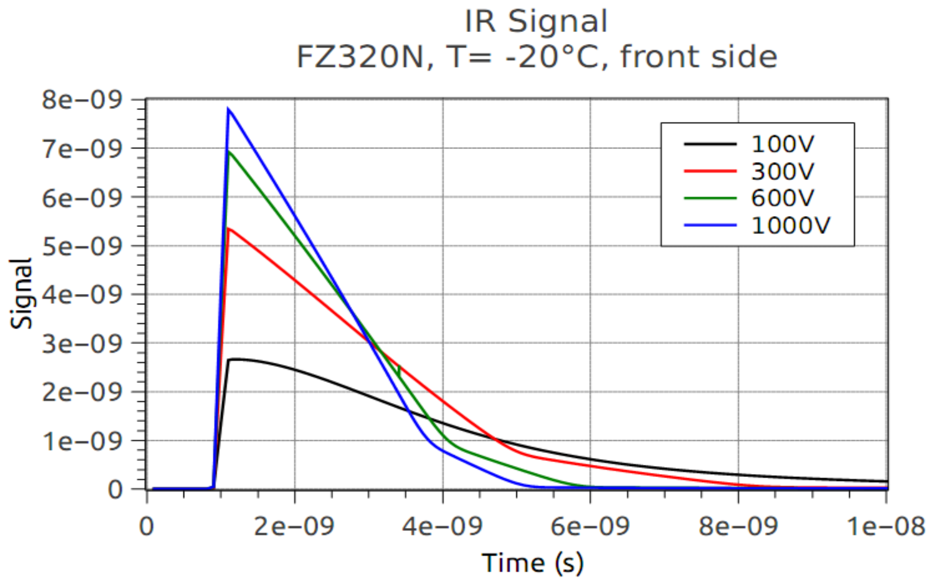
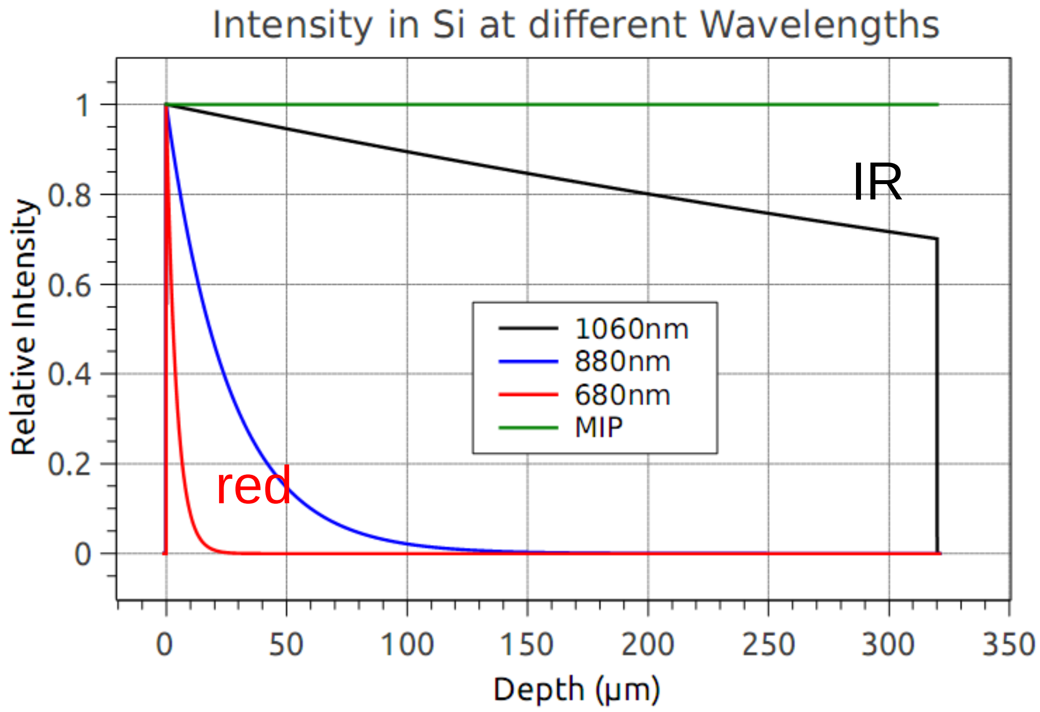
Transient Simulation

- Shoot Laser at front side of the diode
  - Generate e/h-pairs
- Look at time evolution of current
- Convolute current with readout network
- CCE: Integrate IR pulses and normalize to unirradiated charge





Focus on FZ320 n-bulk diodes

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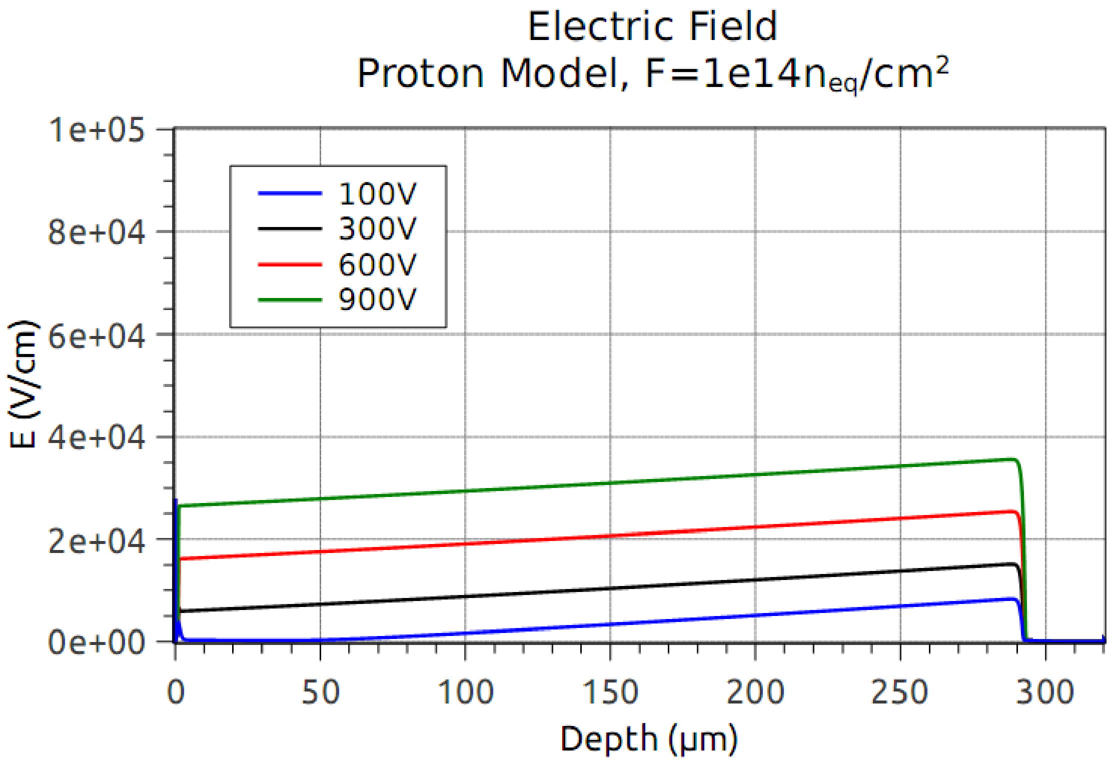
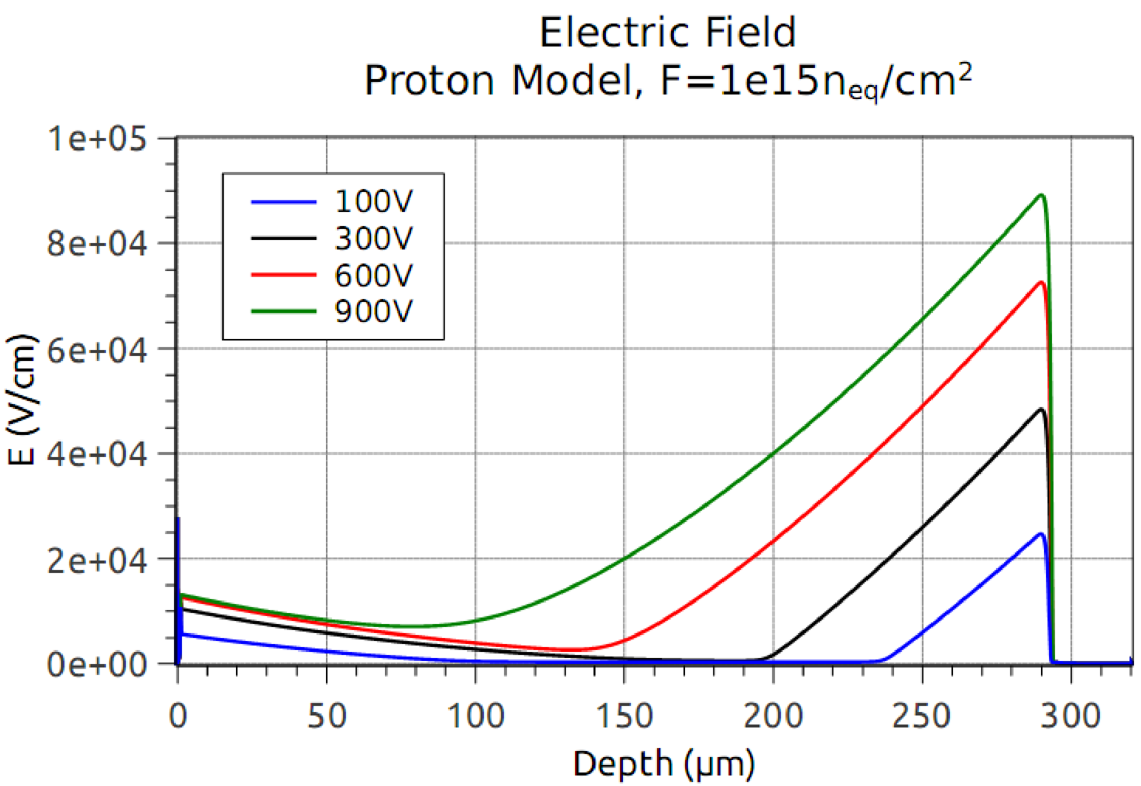
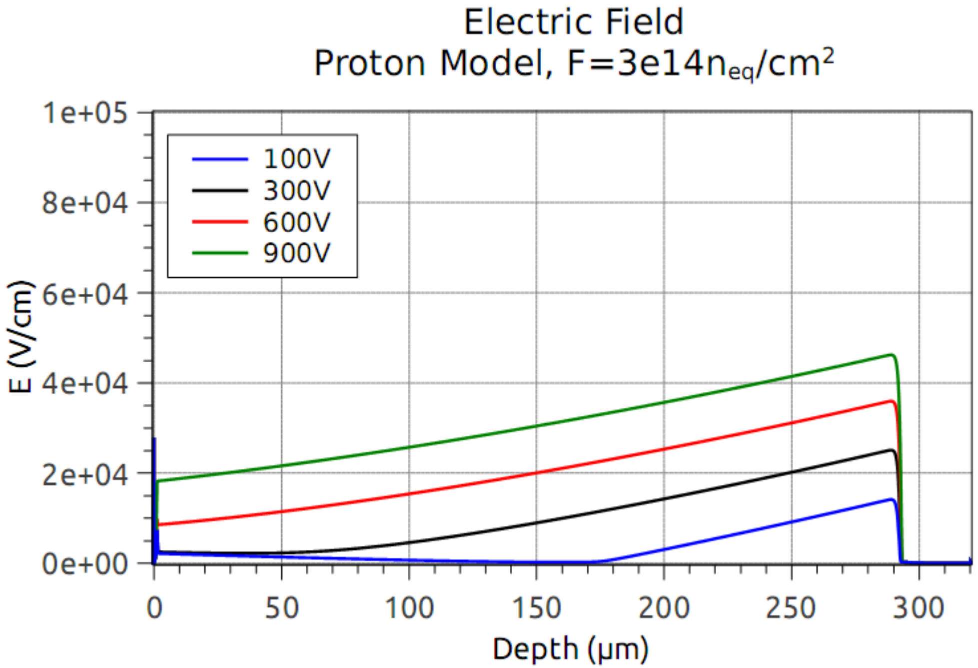
Electric Field – FZ320N

- Device "type inverted", start depletion from the back
- Double peak E-field visible







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Results of the TCT Simulation

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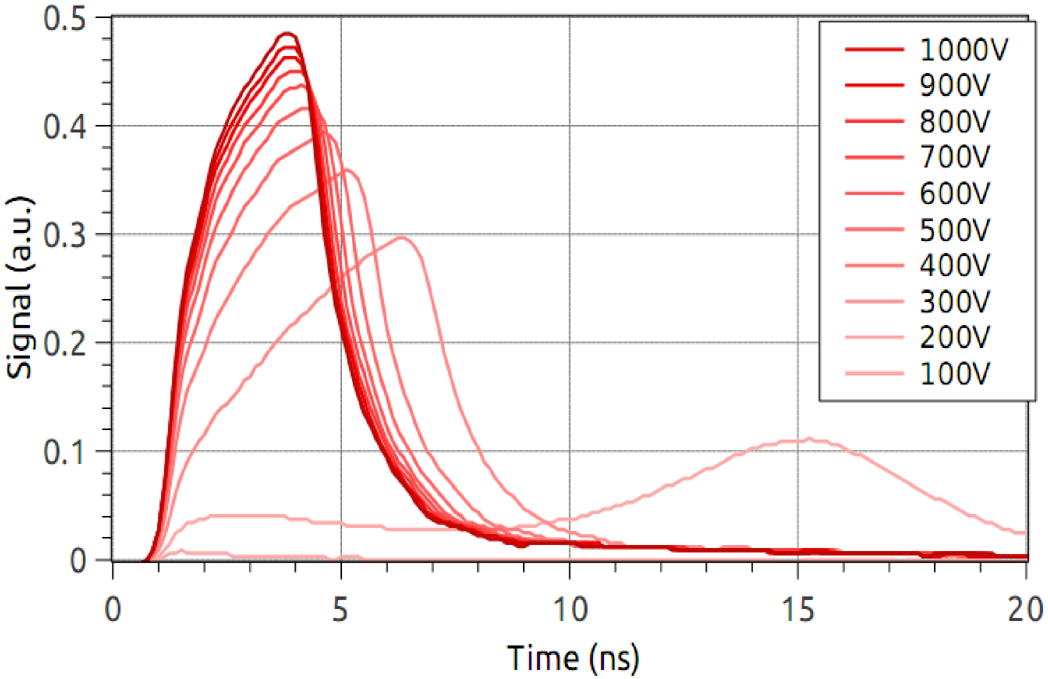
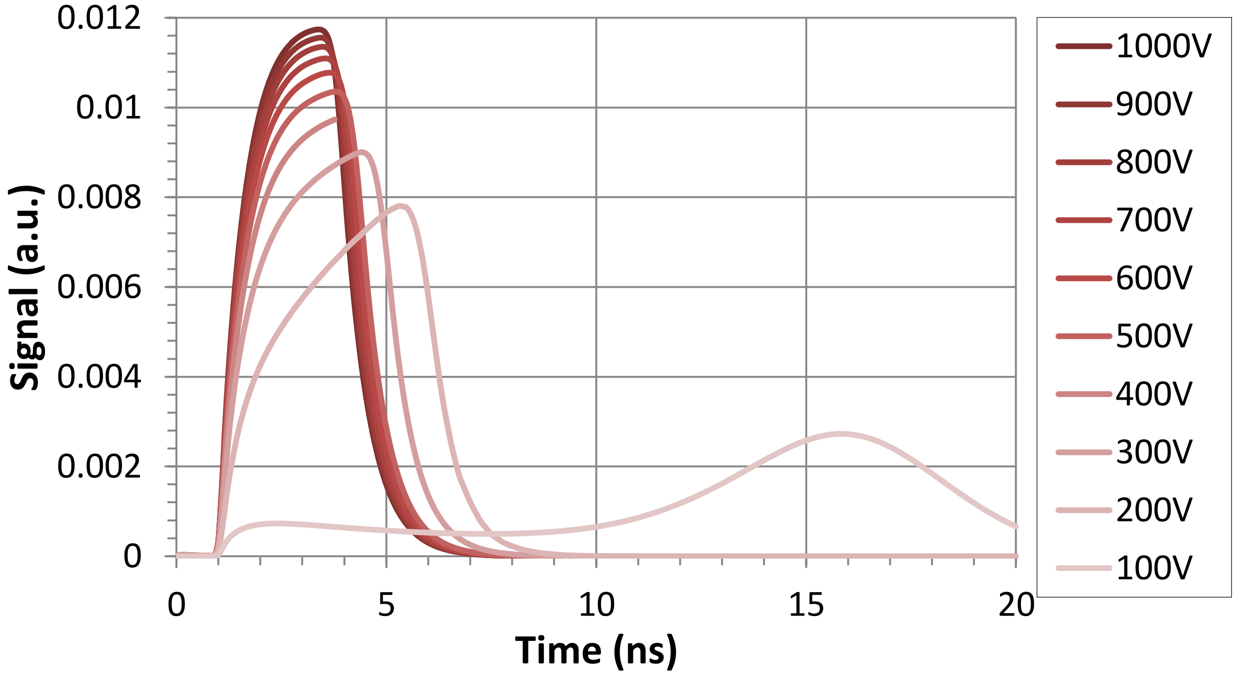
- 100V fits very good
- Peak heights well reproduced
- Shape and peak position at high voltages difficult – need to modify mobility / v_{sat}

Measurement

F=1.1e14neq/cm2 (protons), T= -20°C

Simulation





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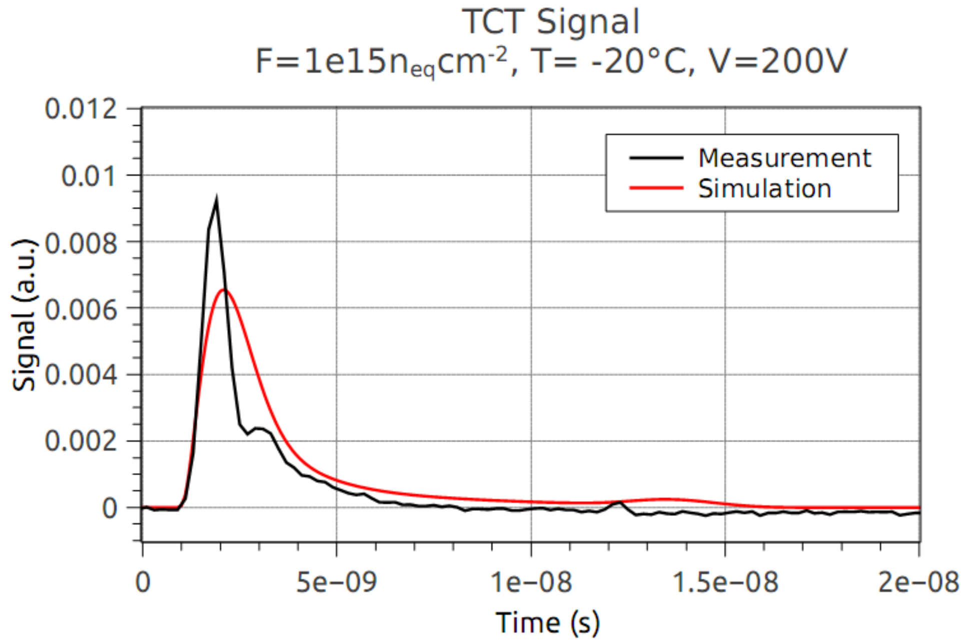
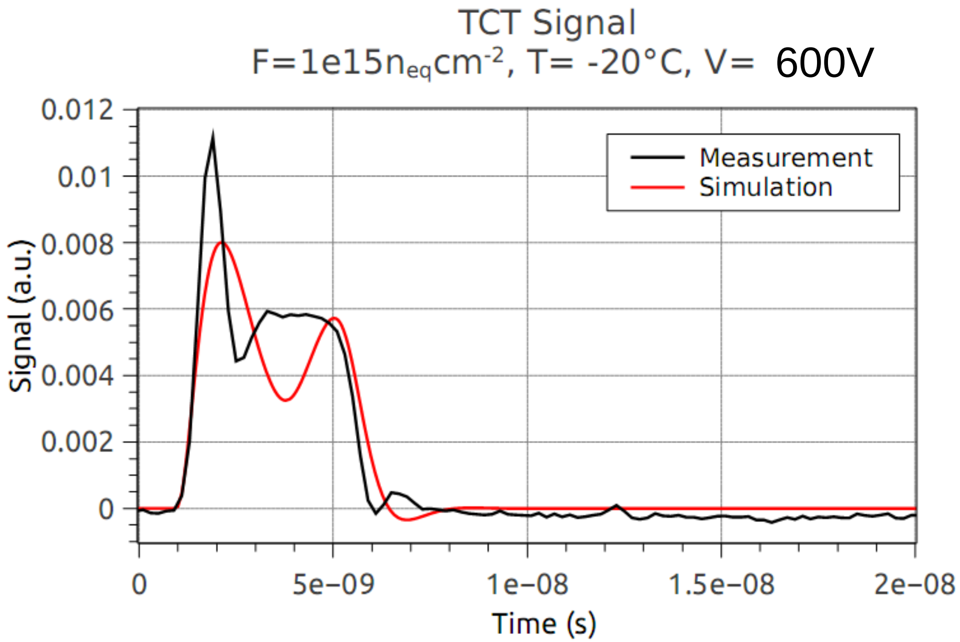
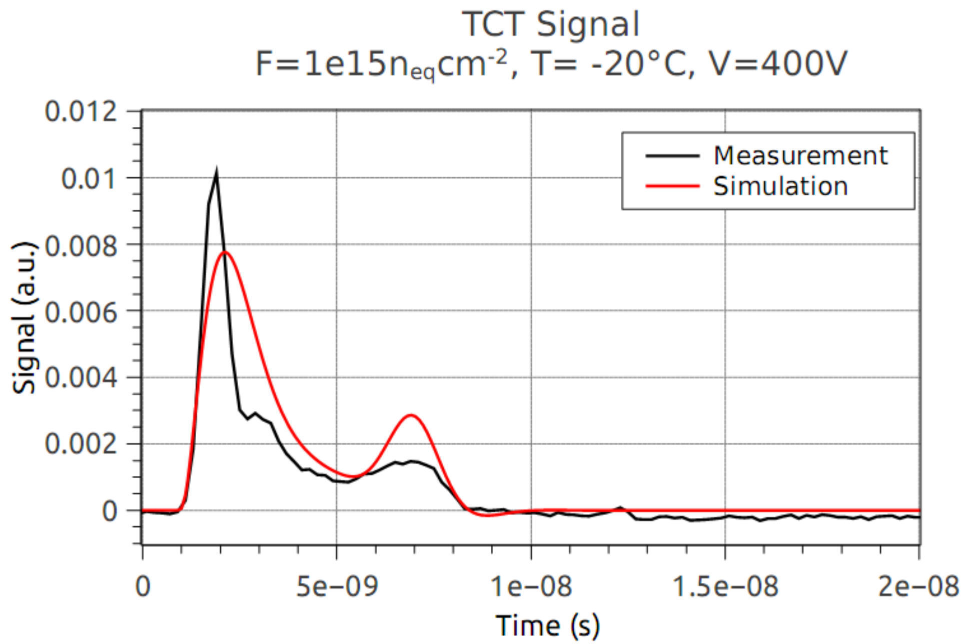
Results of the TCT Simulation

- TCT pulse is quite well reproduced by the simulation
- Second peak too high (?) – Trapping time too low?







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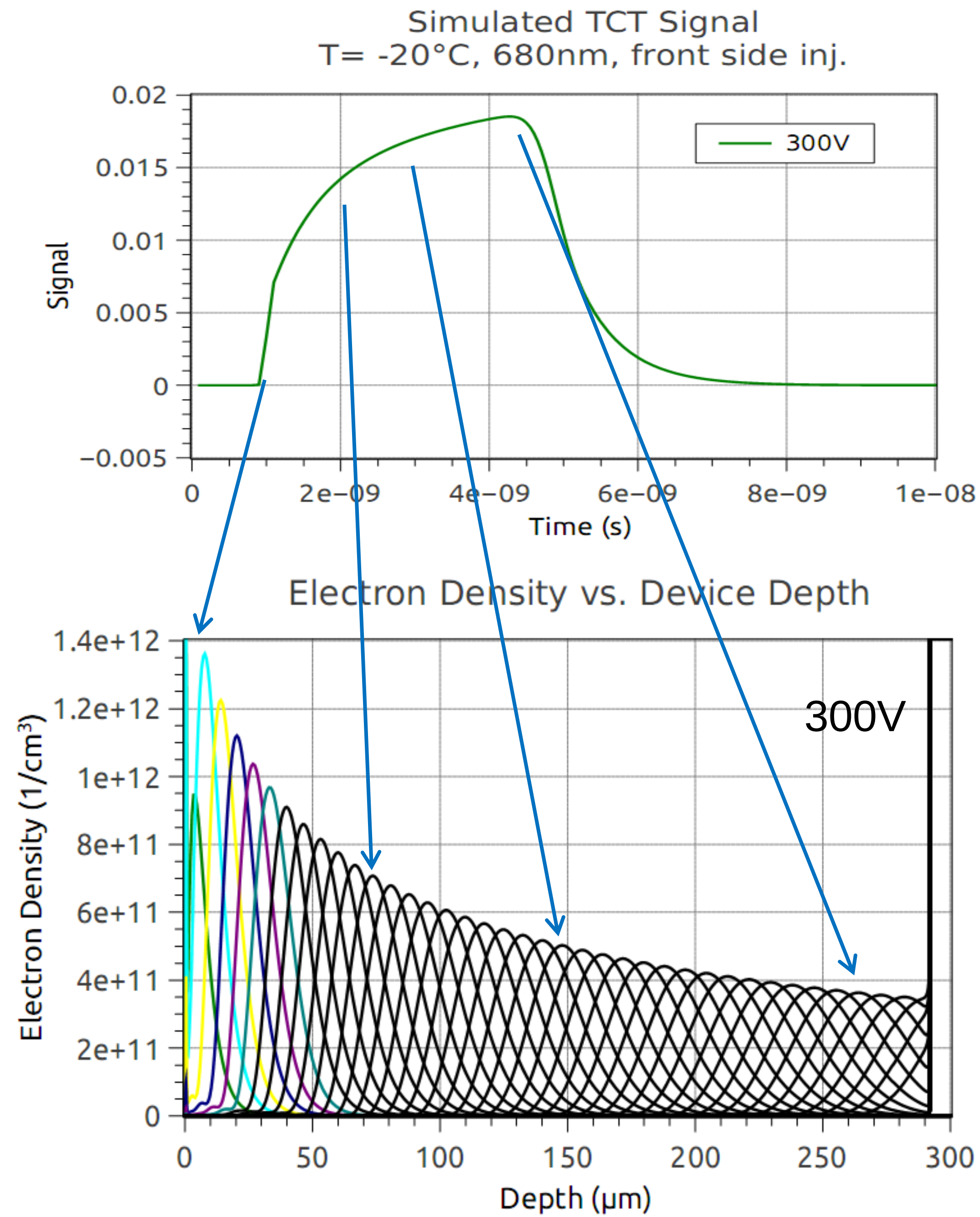
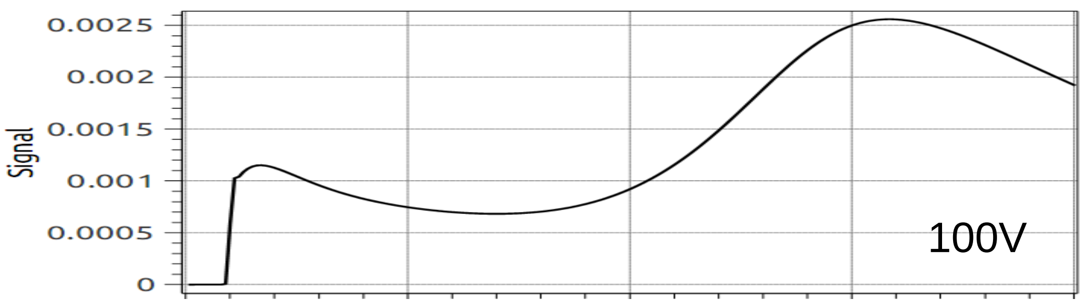
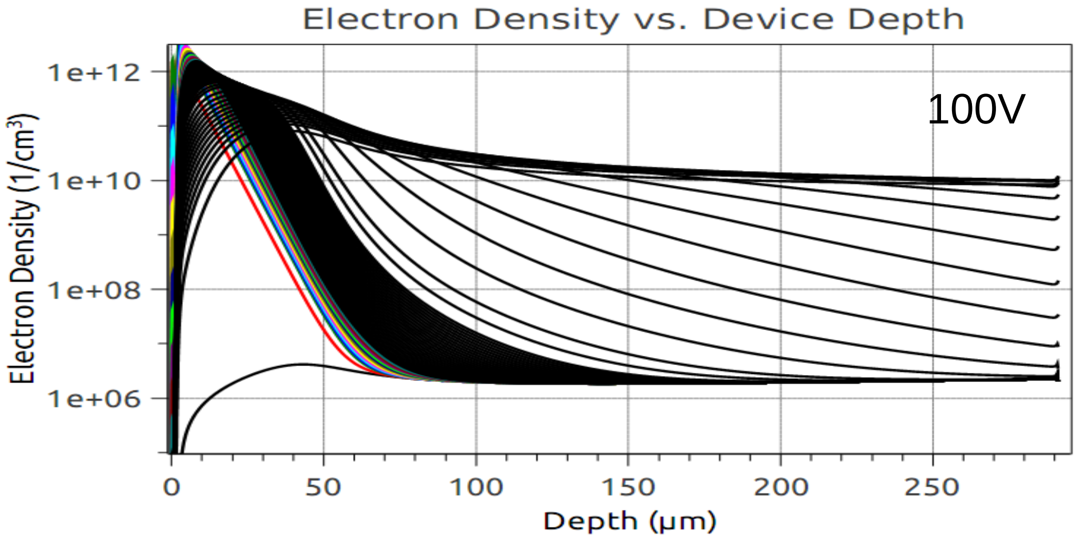
Investigation of Trapping F=1e14neq/cm2

- Electron density in the device is known
- Very fine simulation in time
- Investigate trapping of electrons during transport in the device



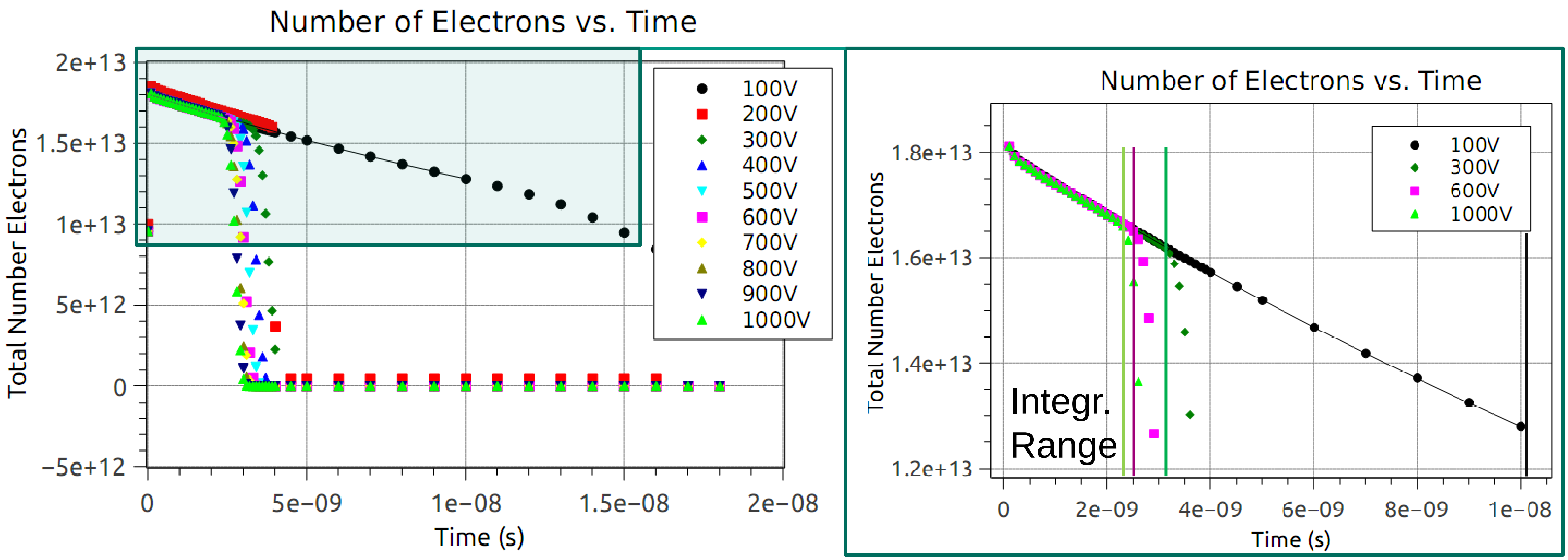




Electrons in the device

- Integration of the electron density at each time → total number of electrons
- Simple Approach: fit linear decay with trapping time
- Averaged trapping time: **28.5ns**

$$e = e_0 \times \exp\left(-\frac{t - t_0}{\tau}\right)$$



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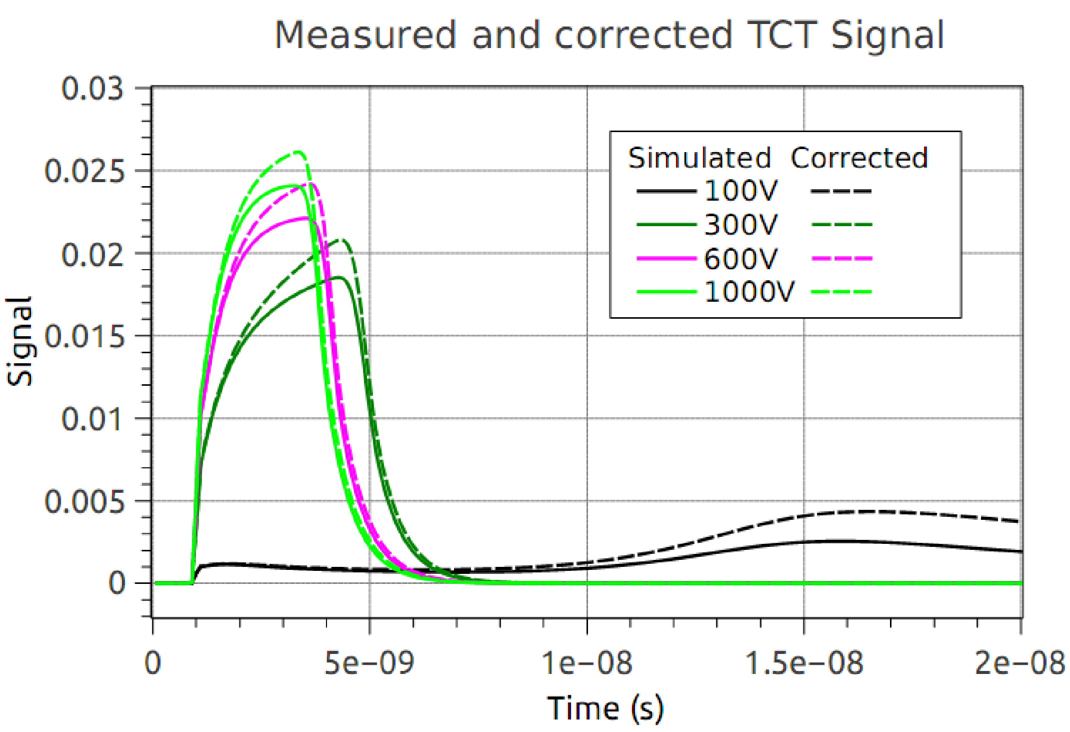
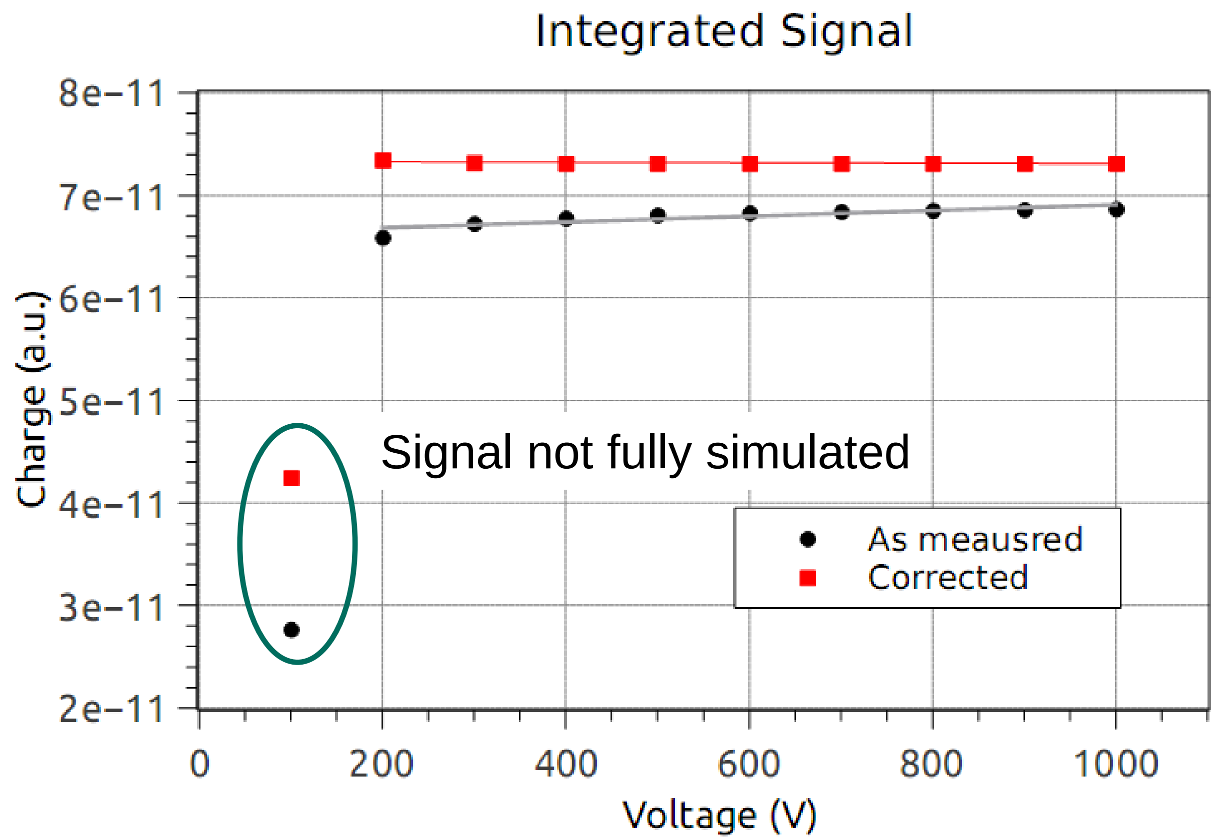
Integrated Signal

- Signal corrected by trapping time
- 28.5ns is in the range also found in the literature (~25ns @ 1e14neq/cm2 e.g. by G.Kramberger et al., NIMA 476, 645 and NIMA 481, 297)





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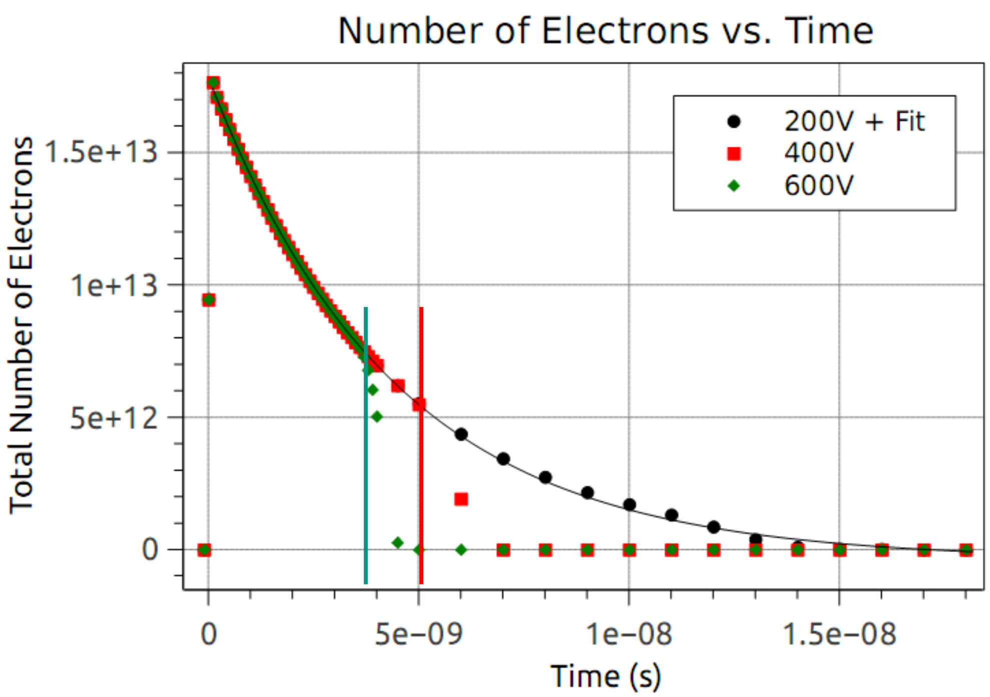
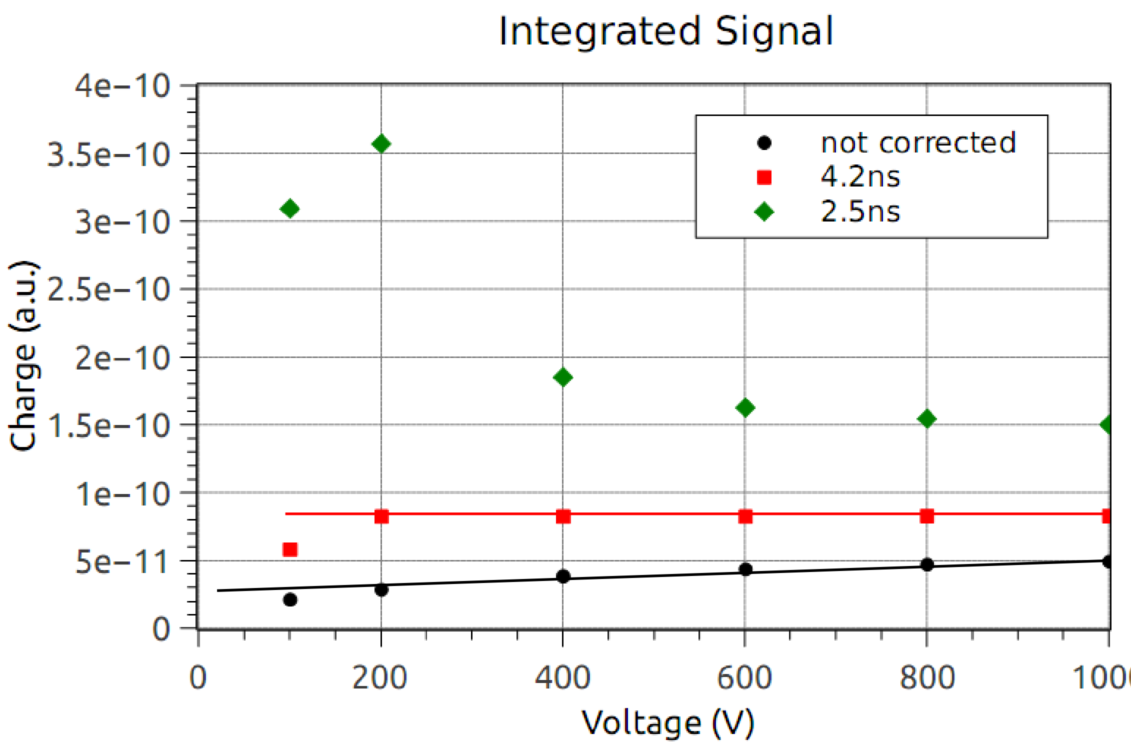
Investigation of Trapping F=1e15neq/cm2

- Averaged trapping time: 4.2ns > 2.5ns (expected trapping time @1e15n_{eq}/cm^2)
- Correction with 2.5ns leads to over-correction of collected charge





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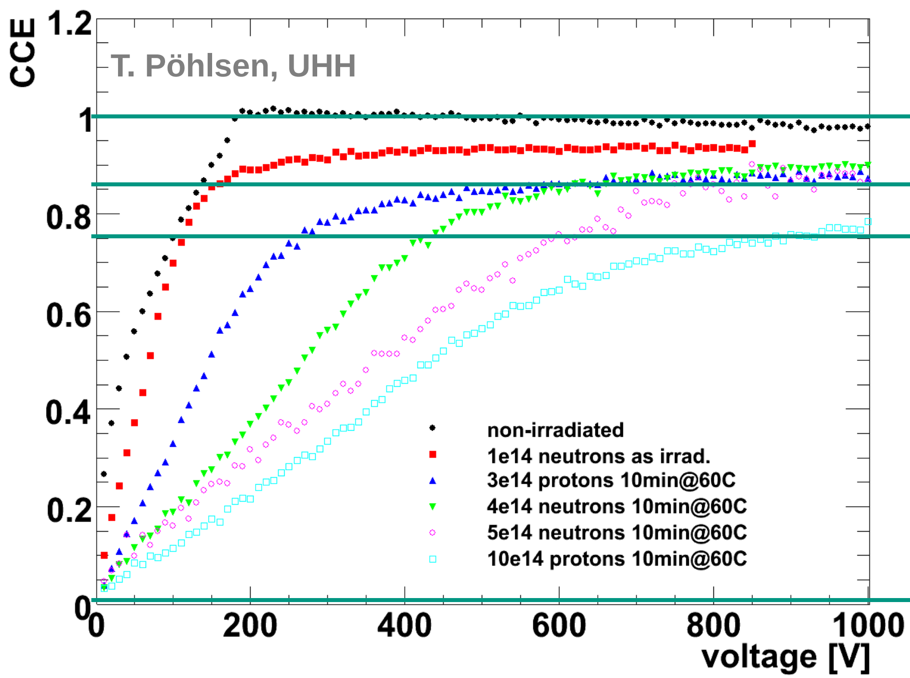
Results of the CCE Simulation

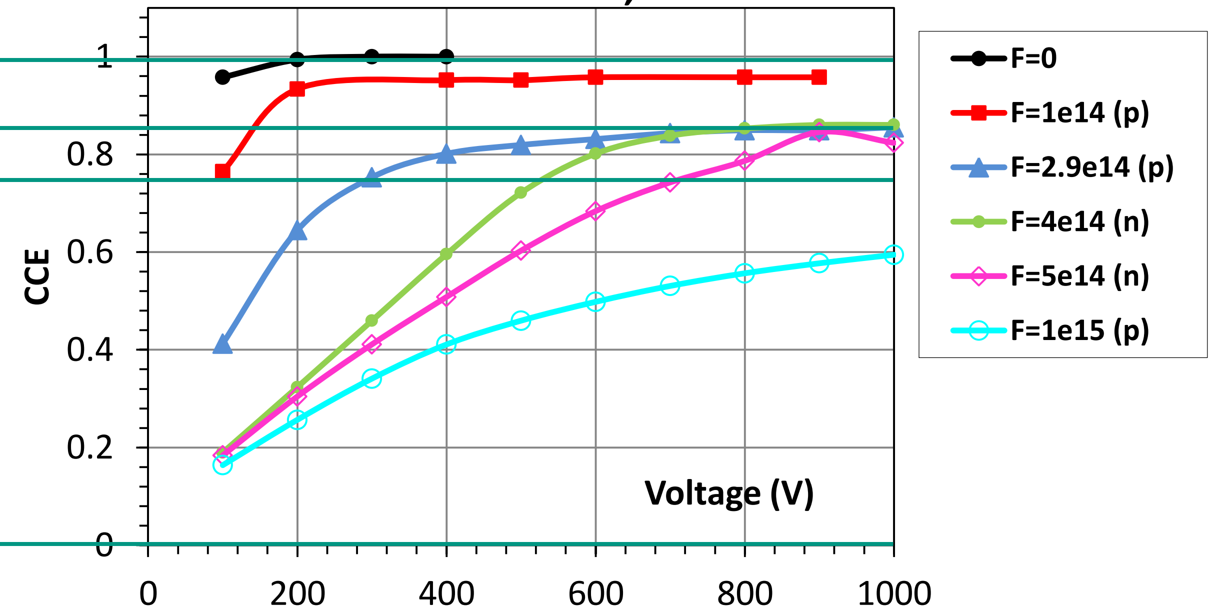
- Charge Collection Efficiency
  - Simulated with IR laser
- Agreement between Measurement and Simulation quite good
  - Although trapping time is larger at $1e15 n_{eq}/cm^2$ – simulated CCE is lower

Measurement



FZ320N

Charge Collection Efficiency: IR-Laser Simulation, T= -20°C



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Summary

- Starting from the EVL model, a two-defect model has been tuned to describe diodes from the HPK campaign
- Linear fits for the defect concentrations matching
  - Leakage current
  - Depletion voltage
- Simulation of TCT pulses possible
  - Matching not perfect – tuning of mobility, saturation velocity may be needed
- Trapping time implemented in the simulator
  - Agreement with measured values at $1e14 n_{eq}/cm^2$
  - At $1e15 n_{eq}/cm^2$ trapping time is larger – but also V_{dep} is quite low
  - Simulation may be a way to determine trapping times
- Agreement of the CCE simulation with measurements (except $1e15 n_{eq}/cm^2$)

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Last Words

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- Simulations are a mighty tool for description of irradiated silicon detectors

- Converging to **a coherent overall picture** including
  - Leakage current
  - Depletion Voltage
  - TCT
  - CCE

- Still a long way to go to include **all effects**:
  Temperature, Annealing, mixed Irradiation (p+n)

Thanks for your attention!

ADDITIONAL INFORMATION

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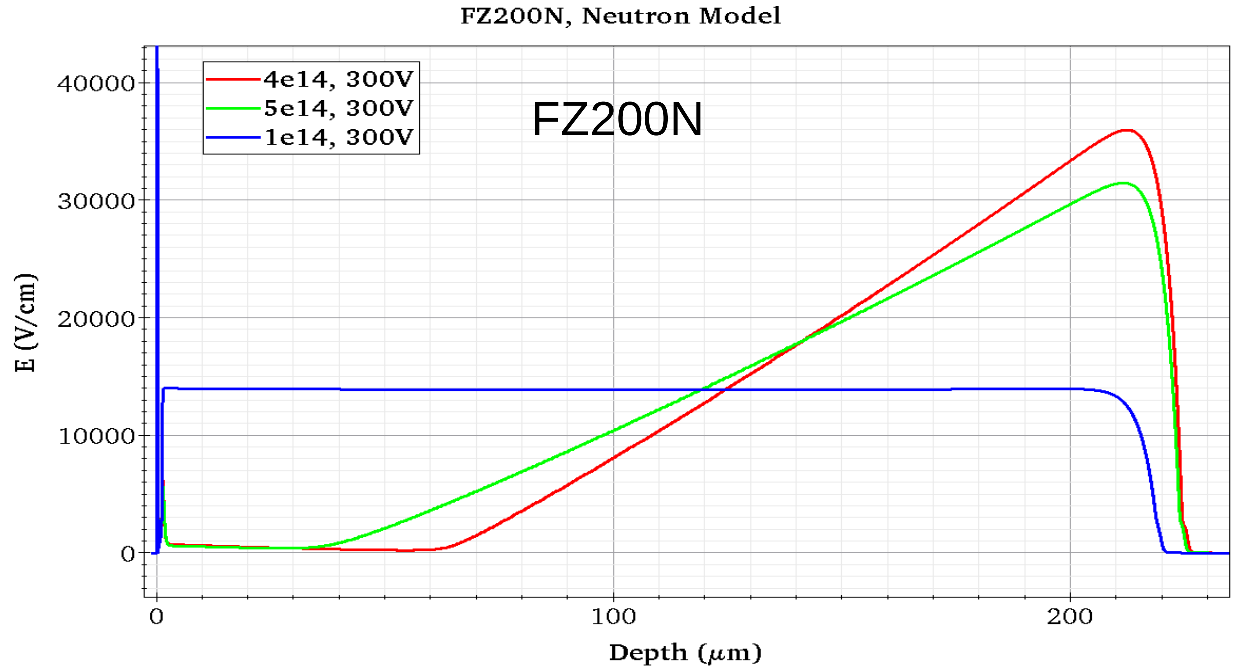
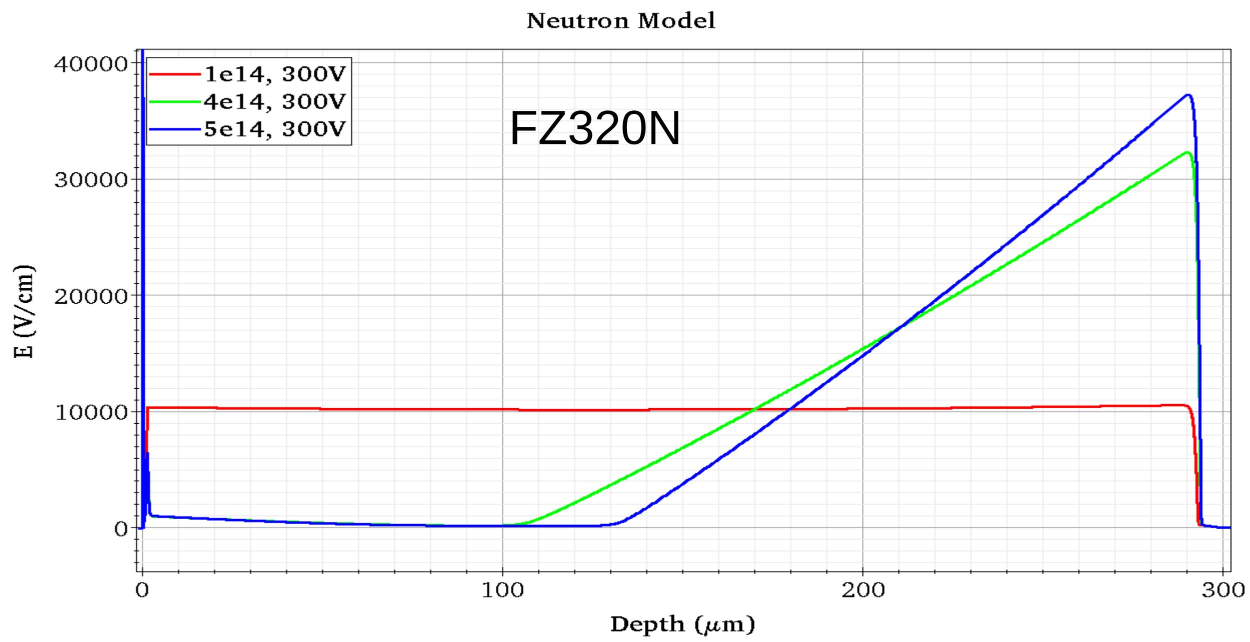
Electric field for n-type detectors

- 1e14neq/cm2 is just at "type inversion"
- Higher fluences clearly deplete from the backside





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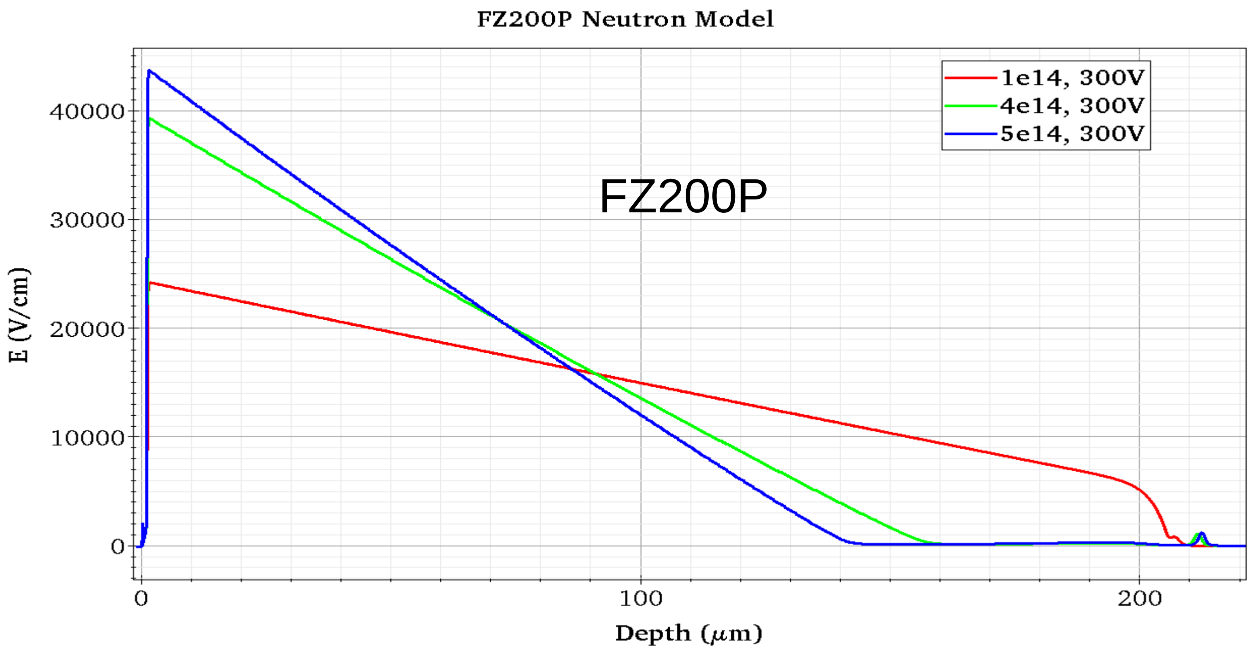
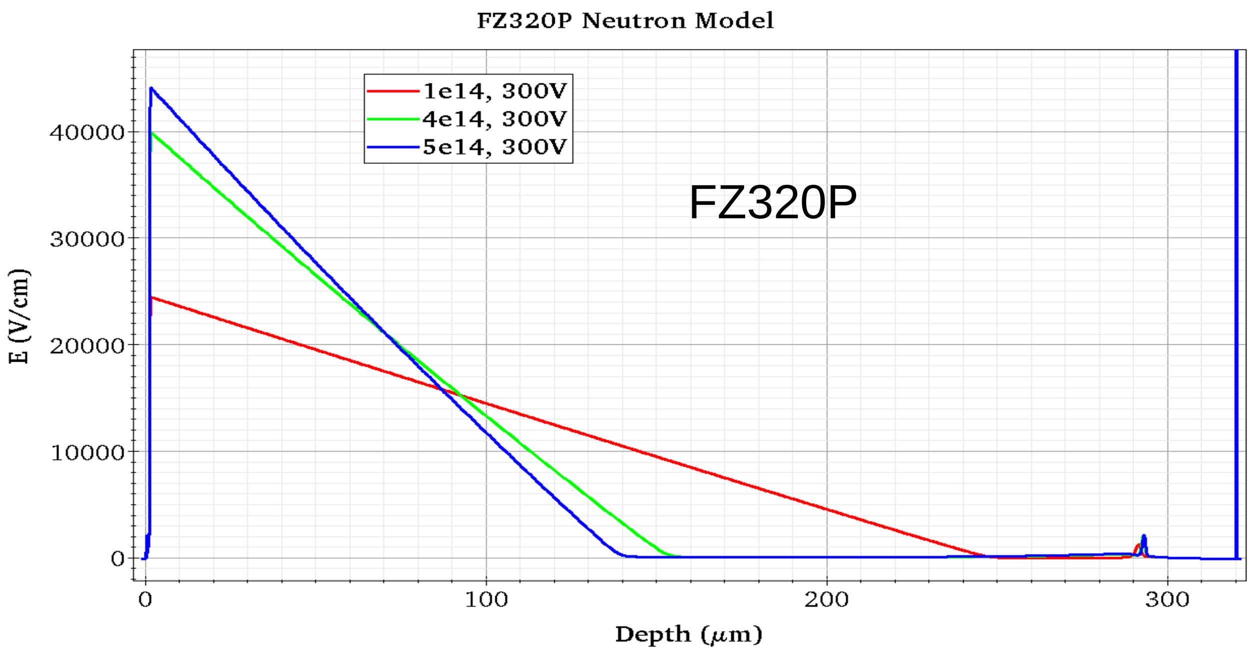
Electric field for p-type detectors

- P-type clearly depletes from the front
  (not "type inverted")





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Proton irradiation

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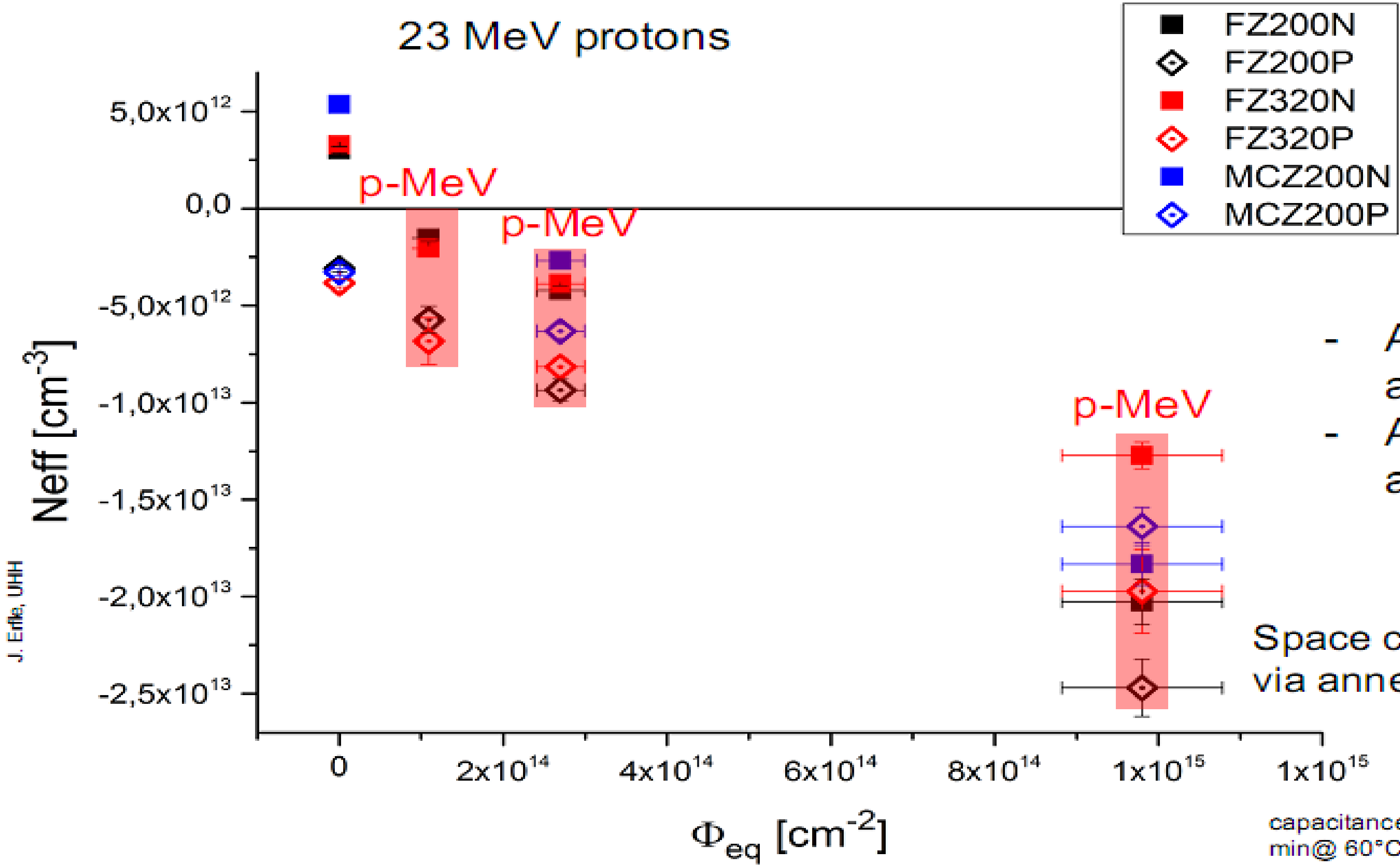
$$|N_{eff}| = \frac{2\epsilon\epsilon_0}{q_0}\frac{V_{dep}}{d^2}$$



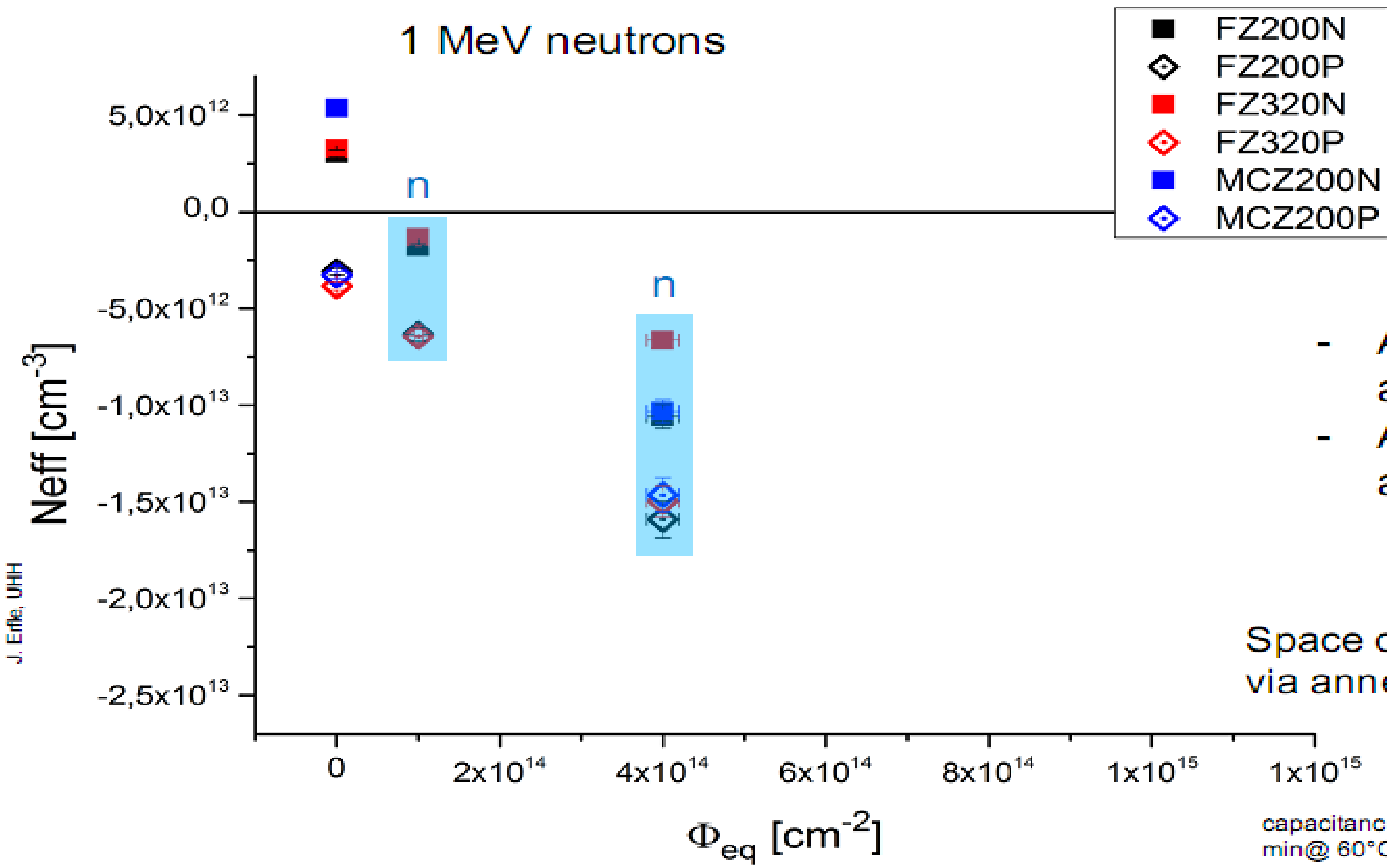
- All n-type materials are type inverted
- All p-type materials are not type inverted

Space charge sign determined via annealing and TCT.

capacitances are measured after annealing of 10 min@ 60°C at 0°C, 1kHz, guard ring grounded

Neutron irradiation

$$|N_{eff}| = \frac{2\epsilon\epsilon_0}{q_0}\frac{V_{dep}}{d^2}$$



- All n-type materials are type inverted
- All p-type materials are not type inverted

Space charge sign determined via annealing and TCT.

capacitances are measured after annealing of 10 min@ 60°C at 0°C, 1kHz, guard ring grounded

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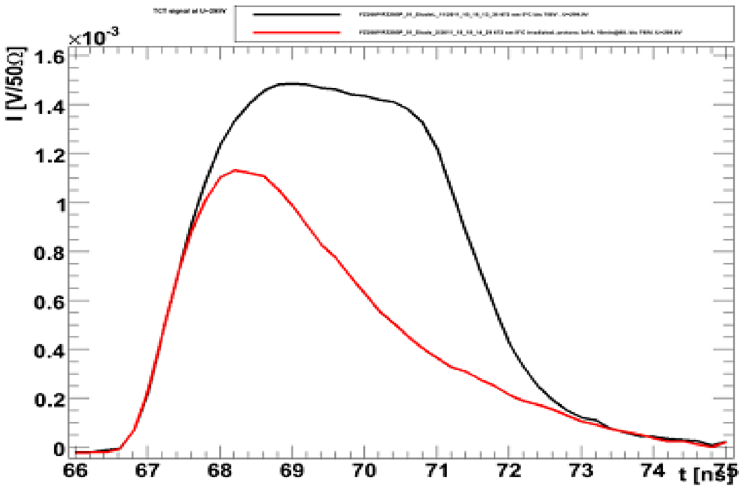
The experimental situation for FZ P-type

- TCT Signals of FZ P-type
- **Unirradiated**
- **Proton irradiation: 3e14neq/cm2**

Not type inverted: Depletion from the front

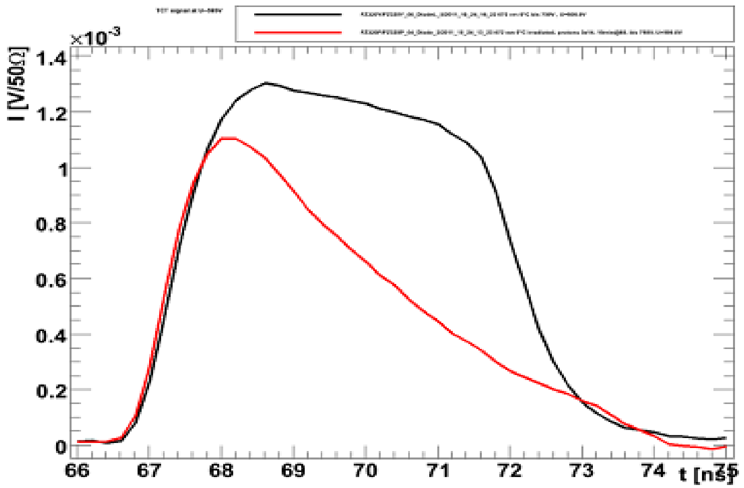
FZ200P



courtesy of T. Pöhlsen

300V

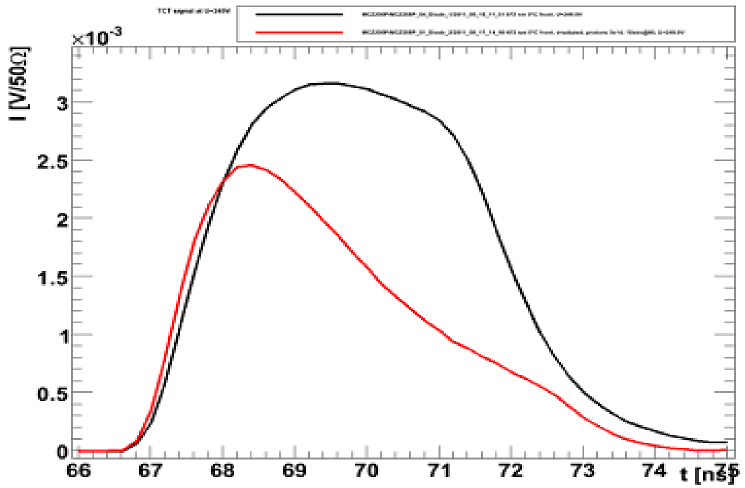
FZ320P



courtesy of T. Pöhlsen

600V

MCZ200P



courtesy of T. Pöhlsen

250V

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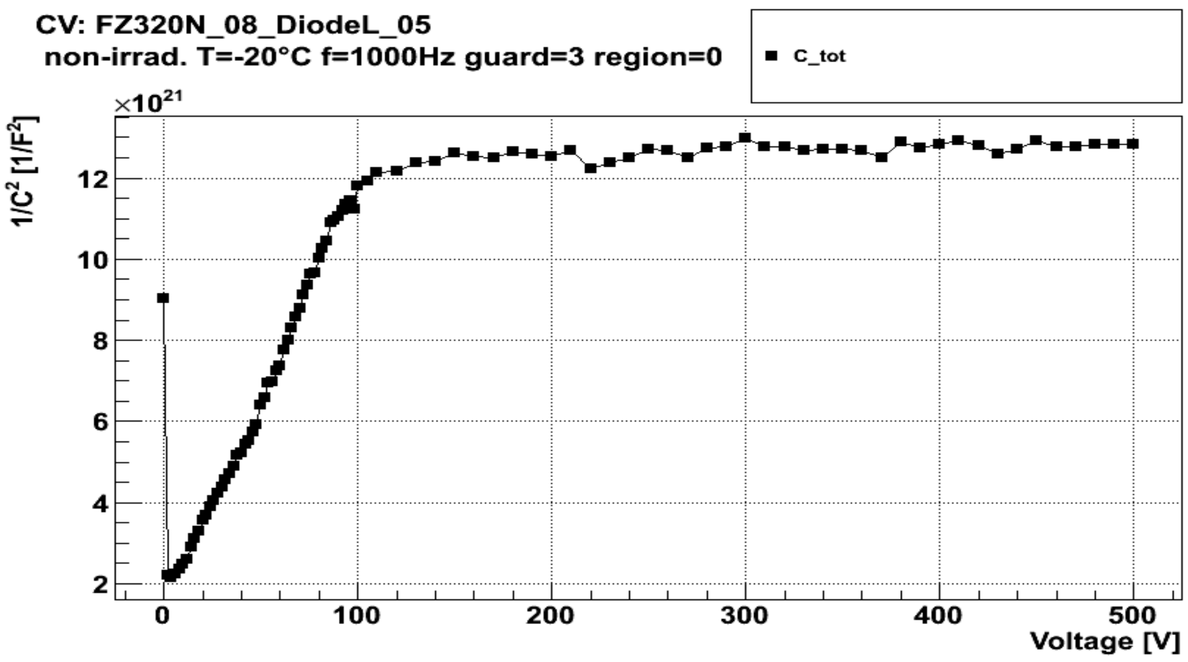
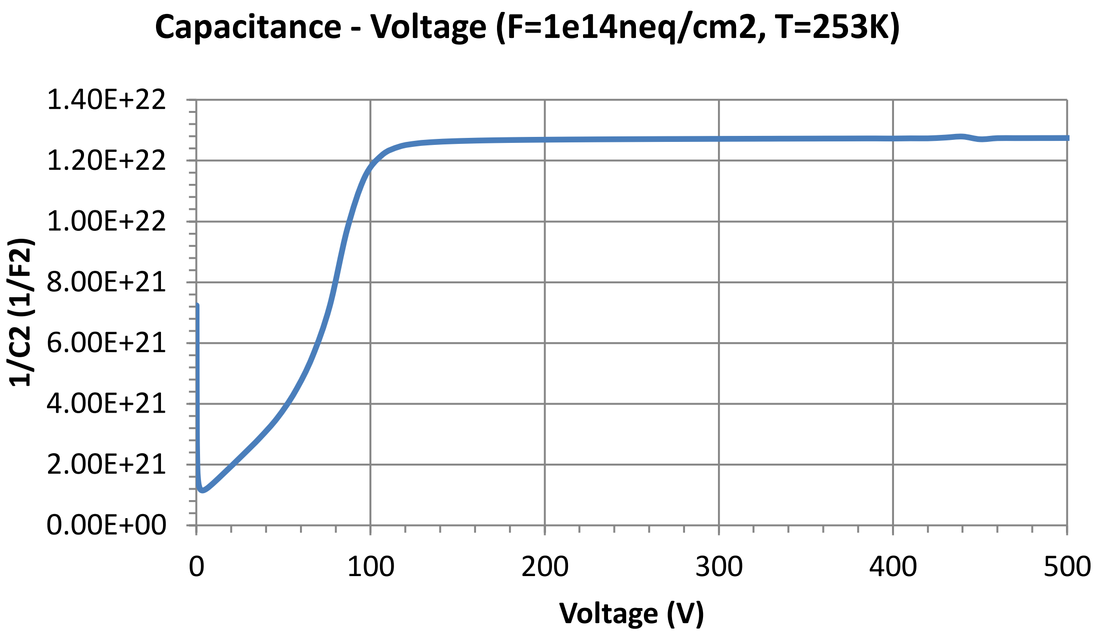
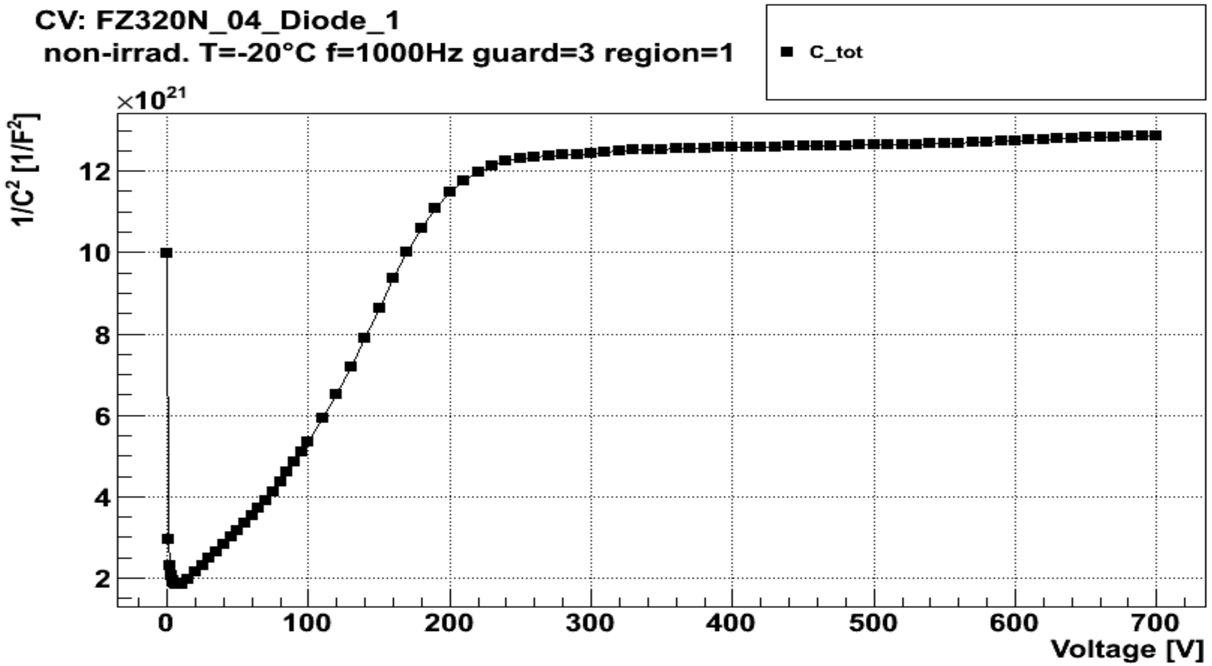
1e14neq/cm2, -20°C, 1kHz

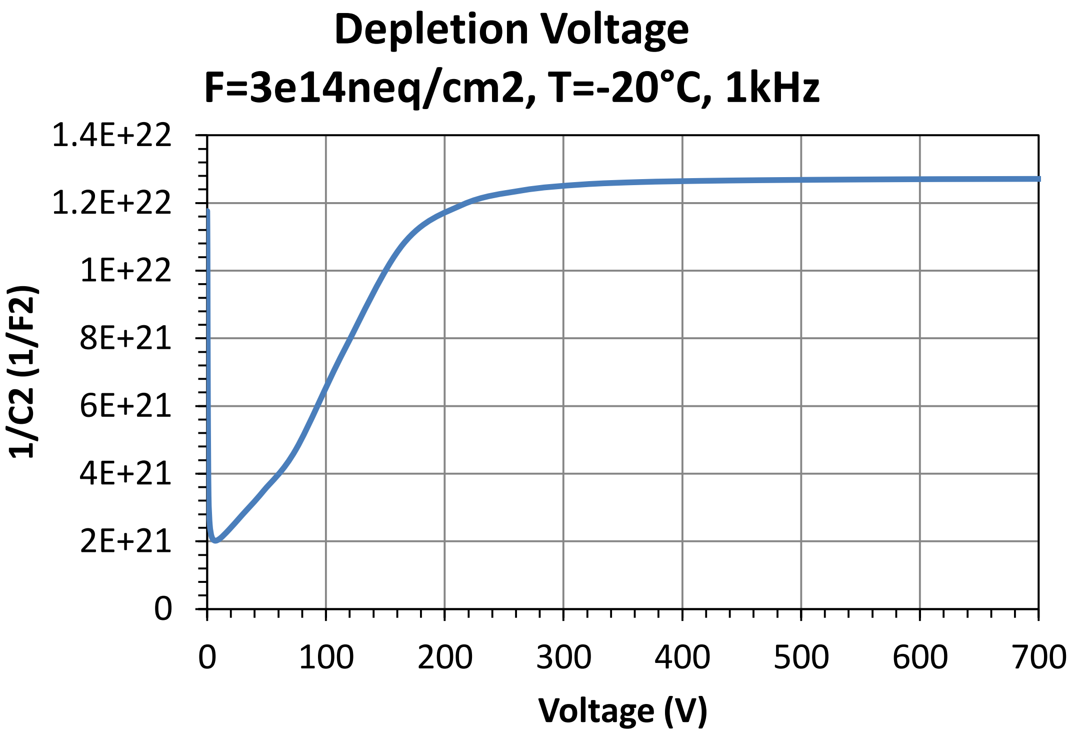




- Very good agreement
- Correct end capacitance
- Kink in the low voltage region
  - Maybe tunable by the cross sections of holes (for donor) or electrons (for acceptor)

2.9e14, -20°C, 1kHz





- Very good agreement
- Slight slope before depletion also visible in measurement
- Correct end capacitance

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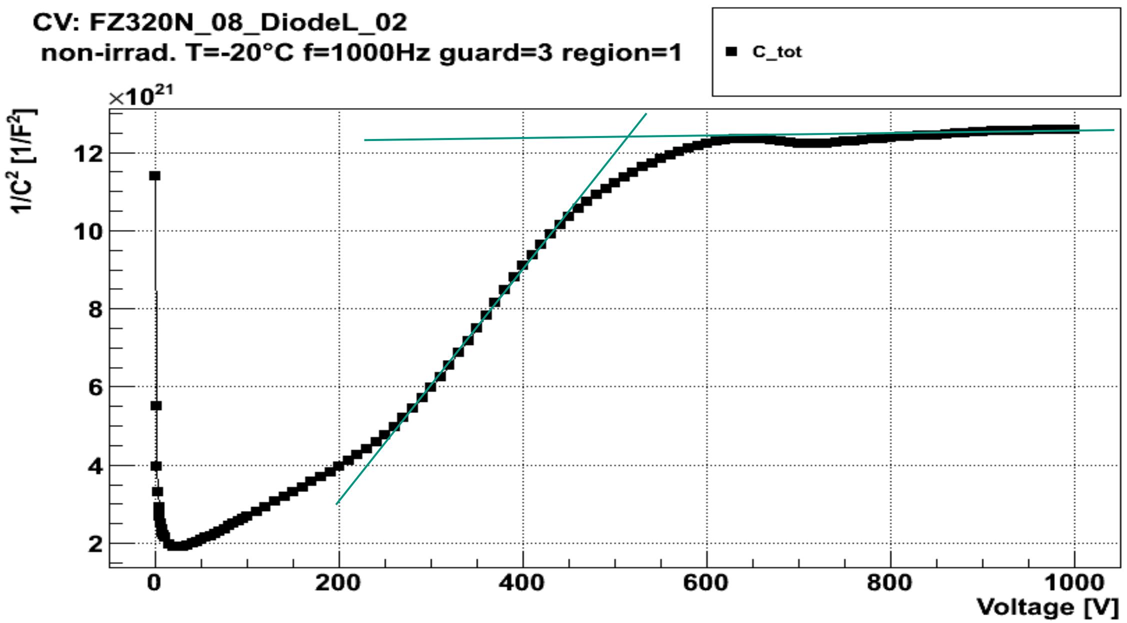
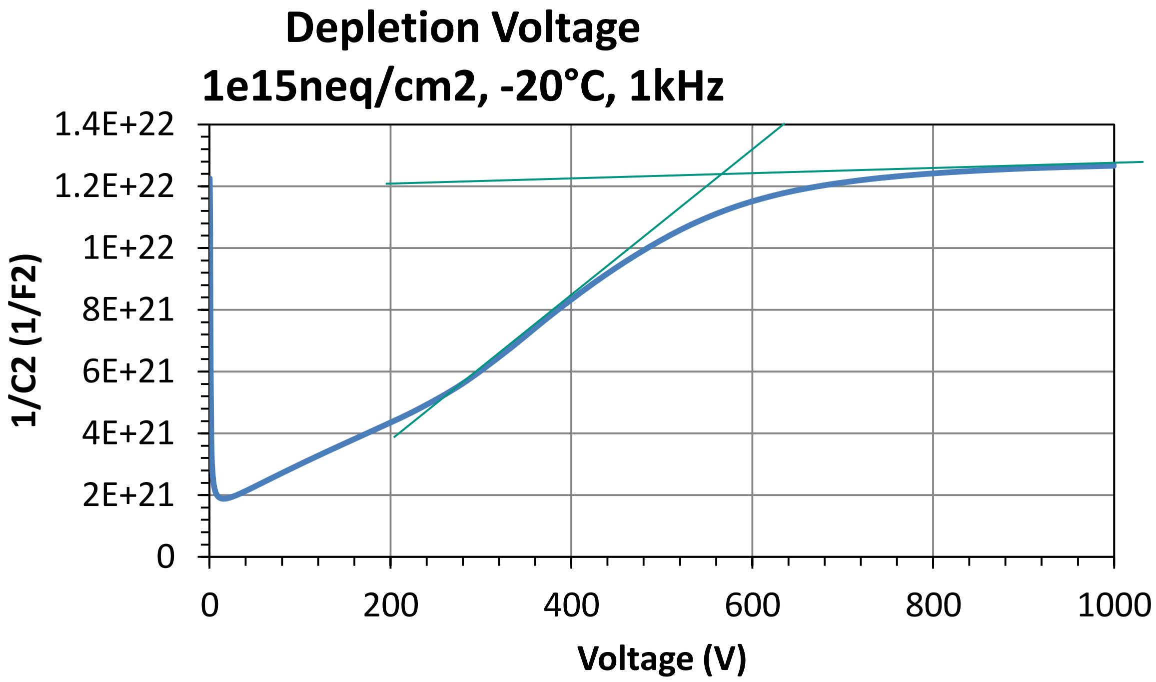
1e15neq/cm2, -20°C, 1kHz





- Kink at 300V correct
- Depletion Voltage (linear fits) about the same
- Slight disagreement around depletion voltage

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