Study on 50 75 and 150μm thick p-type Epitaxial silicon pad detectors irradiated with protons and neutrons

Pad detector Characterization

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Outline

- Studied samples and irradiations
- CV/IV measurements
  - Tools
  - Results
- TCT measurements
  - Tools
  - Results
- CCE measurements
  - Tools
  - Results
- Conclusions

Studied samples and irradiations

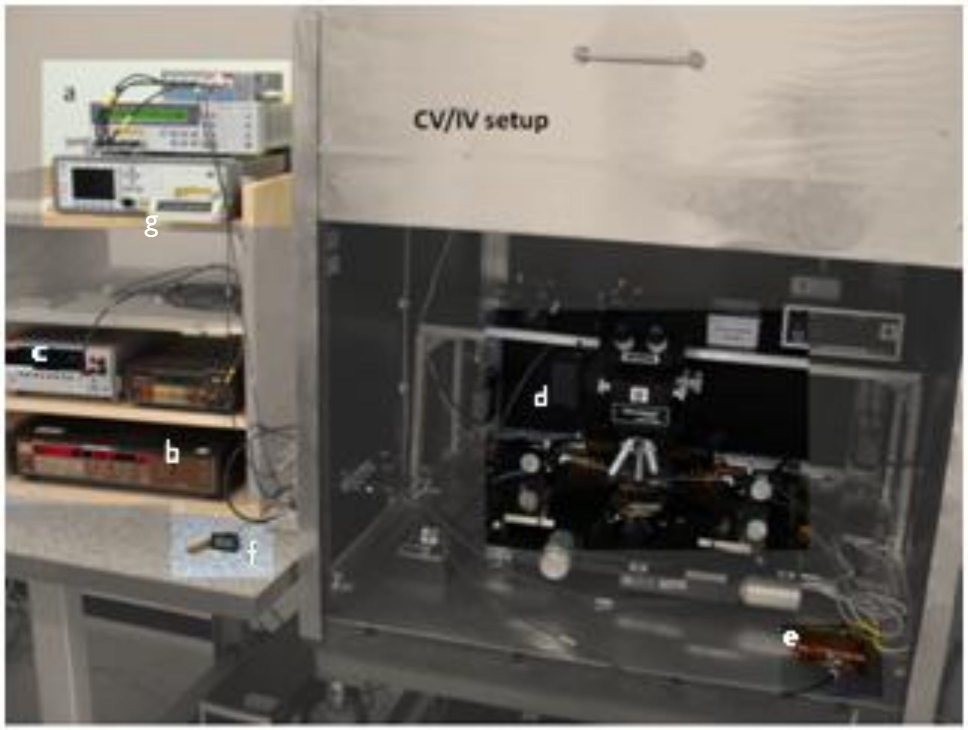
- The material used in this study was produced by ITME
- Epitaxial layers are grown on a highly B doped ($\rho = 0.02\ \Omega$cm) CZ substrate

Producer	d [um]	ρ [Ωcm]	Producer (sensor)	Device labels	Size [mm²]	V_{dep} [V]	$\|N_{eff}\|$ [10^{12}cm^{-3}]
ITME	50	220	CiS	W3/W4/W5	2. 5 x 2.5	113.1 ± 2.1	59.5 ± 1.11
ITME	75	350	CiS	W9/W10	2.5 x 2.5	187.5 ± 12.5	43.88 ± 2.93
ITME	150	1000	CNM	CNM22	5 x 5	211.4 ± 21.3	12.37 ± 1.25

- 24GeV/c proton irradiation (CERN PS), ϕ_{eq}= 8 x 10^{11} – 5 x 10^{15} cm^{-2}
- Some CNM-22 samples irradiated with reactor neutrons (TRIGA reactor, Ljubljana) ϕ_{eq}= 7 x 10^{12} – 3 x 10^{15} cm^{-2}
- Hardness factor of 0.62 used to convert 24 GeV/c protons to equivalent fluences
- All samples were annealed to 4min 80°C

CV/IV measurements

❑ Tools



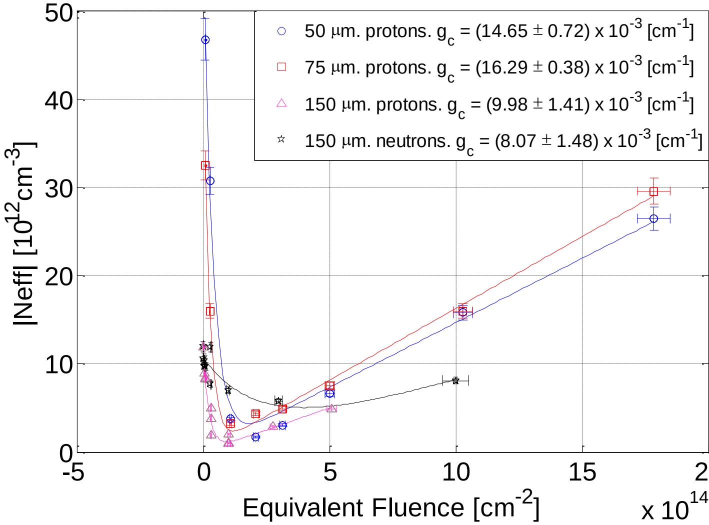
- Sample connections in two ways
  - Using the probe station
  - Through SMA connectors on PCB boards over which samples can be mounted
- CV / IV Switch
- Temperature control
  - Sensor close to sample under test (e)
  - Monitored by user in a LCD screen (f)
- CV measurement
  - Keithley 237 used as Voltage Source (b)
  - Agilent 4263B LCR meter operating at 10 KHz in parallel mode (a)
- IV measurement
  - Keithley 2410 source meter (c)
  - Keithley 485 current meter were used (g)

- Measurements at room temperature
- In all diodes, guard ring is connected to ground and biasing is applied from the back
- LabView software for interfacing the setup and postprocessing the data

CV/IV measurements

❑ Results. N_{eff} vs fluence

Curves extracted from CV measurements

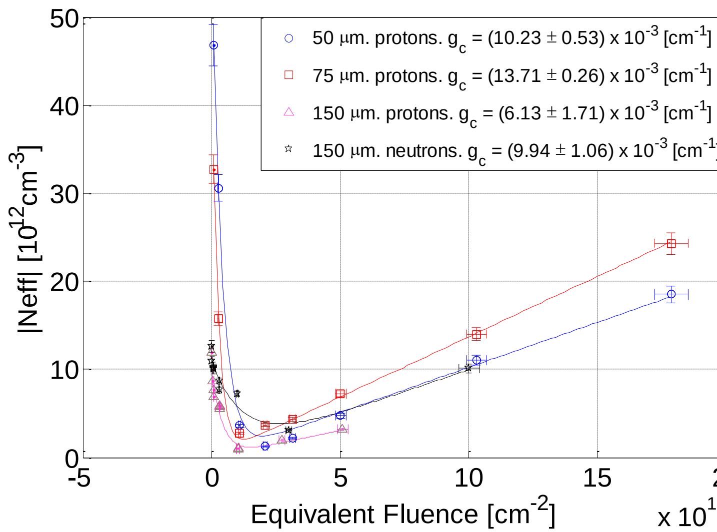


[Data measured by K.Kaska and presented in the 15th RD50 Workshop]

Fitting model

$$\left|N_{eff}\right| = N_0 \cdot e^{-c \cdot \phi_{eq}} + g_c \cdot \phi_{eq}$$

Curve extracted from IV measurements



Comparing with data in n-type from Hamburg group

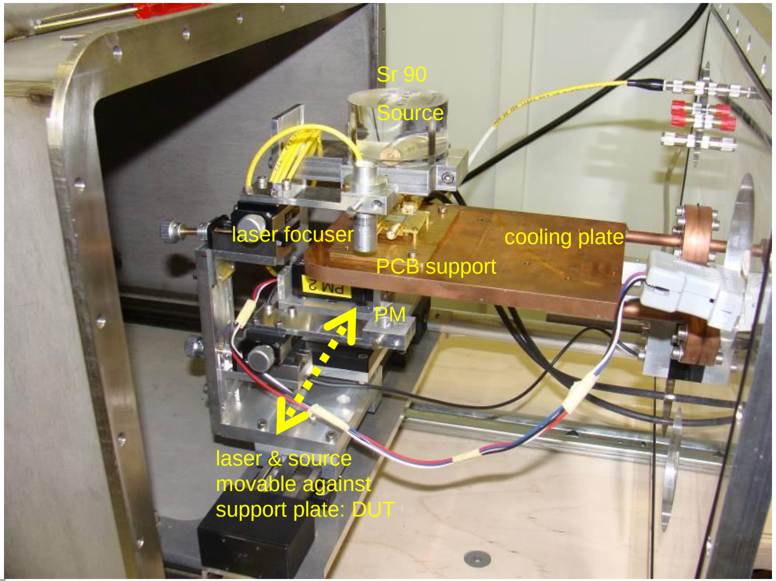
Thickness [µm]	50	75	150
g_c (n-type) [$10^{-3}cm^{-1}$]	-23	-12	-6
g_c (p-type) [$10^{-3}cm^{-1}$]	15	16	10

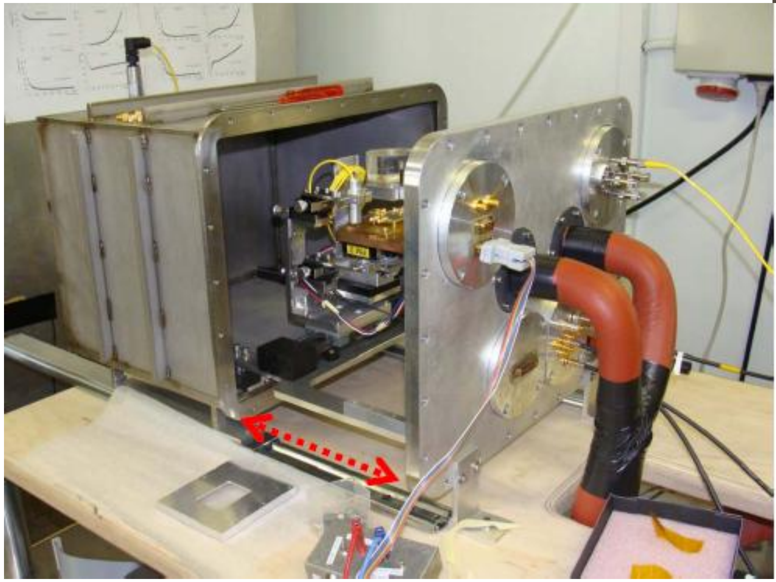
[Data extracted from " Microscopic study of proton irradiated epitaxial Silicon Detectors " talk, in the 15th RD50 Workshop]

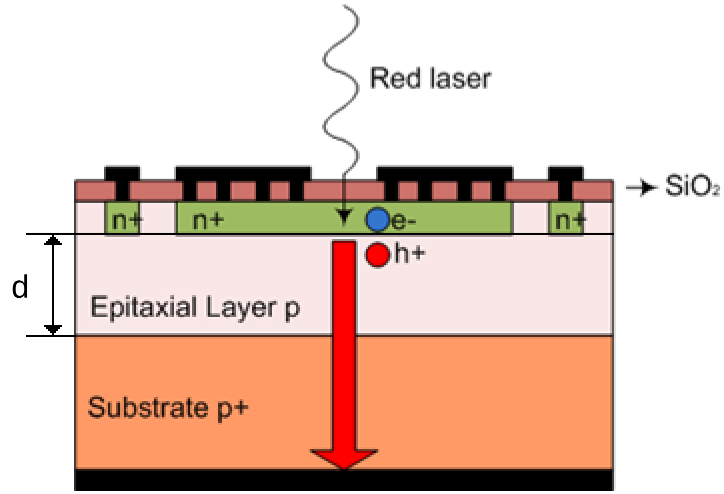
TCT measurements

❑ Tools

- Laser wavelength 660 nm (ps pulses)
- Cooled with silicon oil (down to -25° C)
- Dry air atmosphere (humidity less than 5%)
- Laser can be scanned over DUT with linear motor stage and X-Y screws
- Laser illumination only in the front of the sample due to the thickness of the CZ substrate
- Sample boards (support PCB)
- Diodes are biased from the front
- Measurements at 5° C

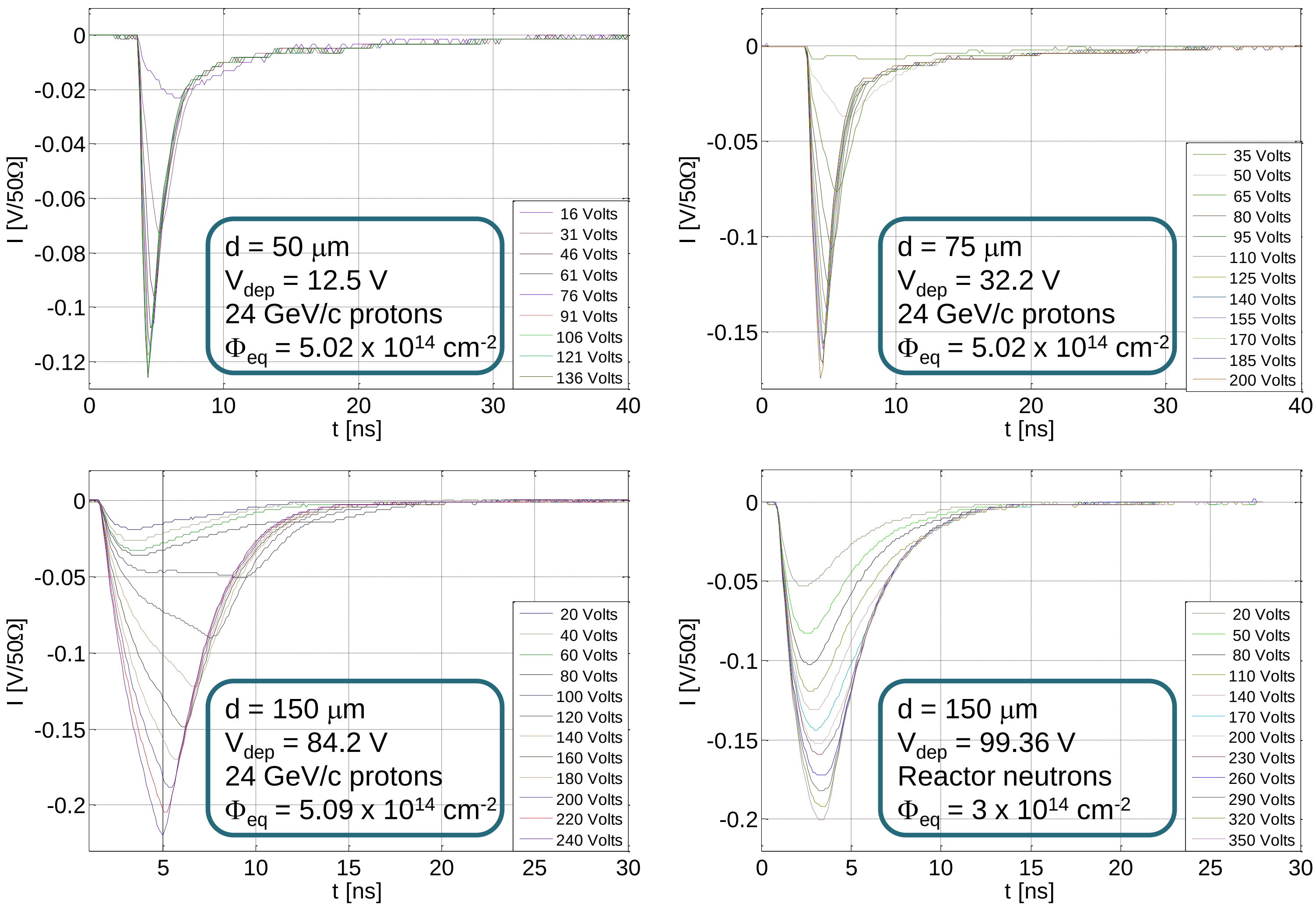






TCT measurements

❑ Results. Current pulses (not corrected)



TCT measurements

❑ Results. Trapping time estimation

- For proton-irradiation we have type inversion in the bulk
- Now is possible the estimation of the trapping times for holes with the charge correction method [Gregor Kramberger´s doctoral thesis]
- The amount of drifting charge decreases with time due to trapping as

$$N_{e,h}(t) = N_{e,h}(0) \cdot e^{-\frac{t}{\tau_{eff_{e,h}}}}$$

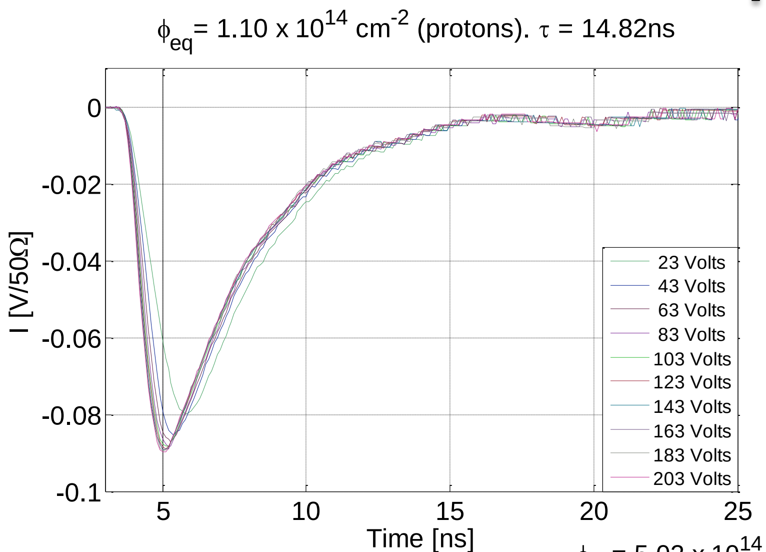
- Effective trapping time can be got from the current integral at voltages above full depletion
- Correcting measured current with an exponential can compensate for trapping

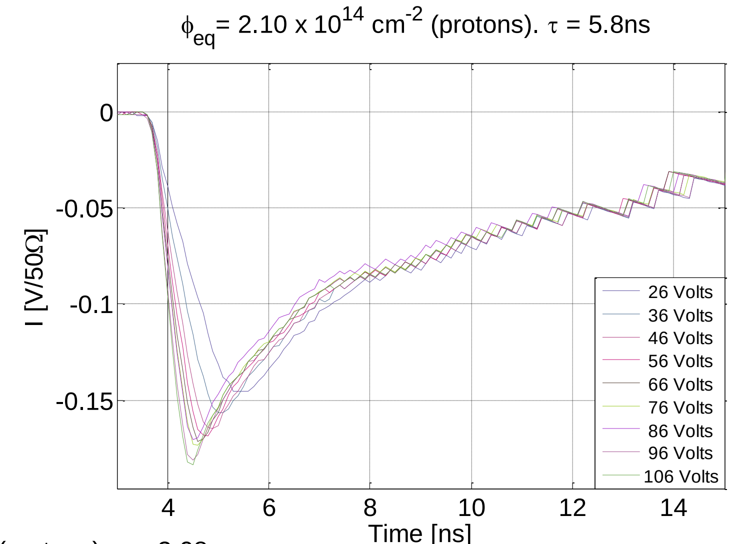
$$I_c(t) = I_m(t) \cdot e^{\frac{t - t_0}{\tau_{tr}}}$$

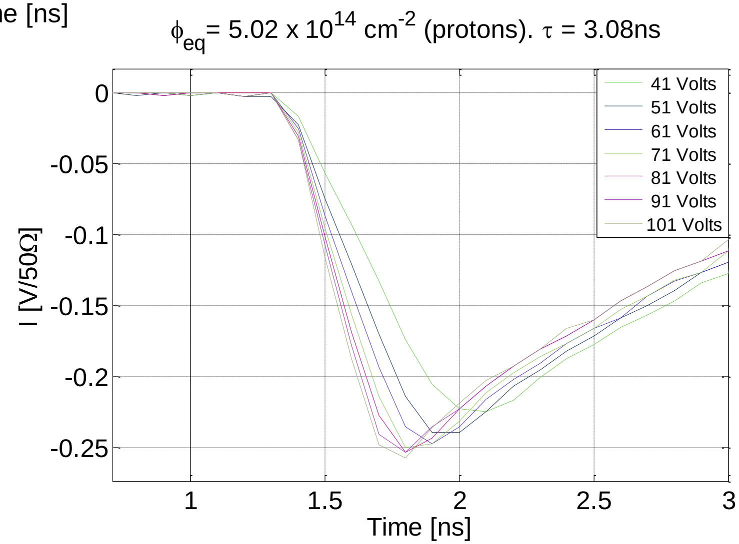
- The integral of I_c over time is equal for all voltages above depletion

TCT measurements

❑ Results. Current pulses corrected (d = 50 μm)

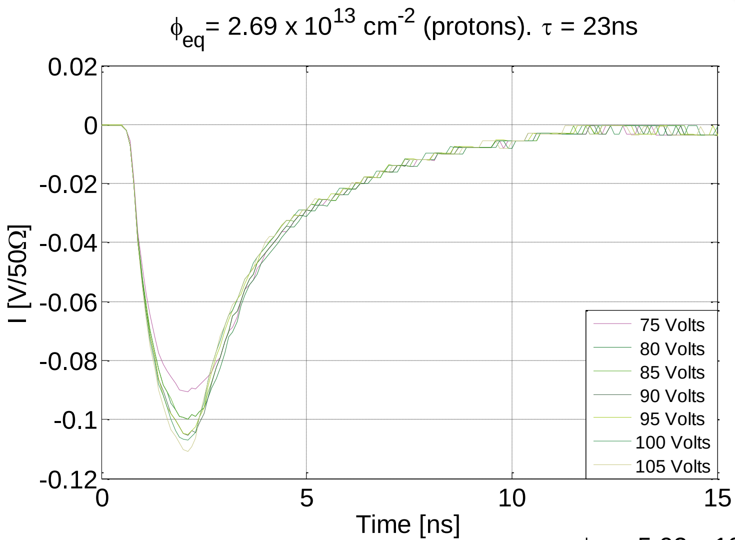


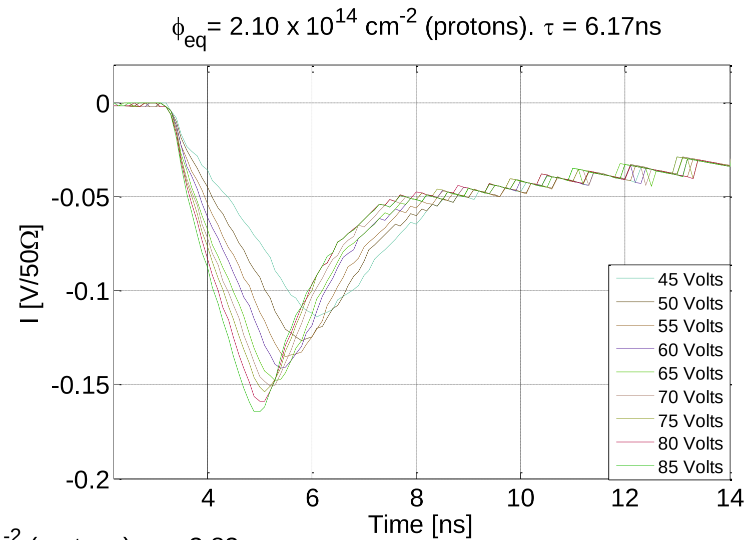


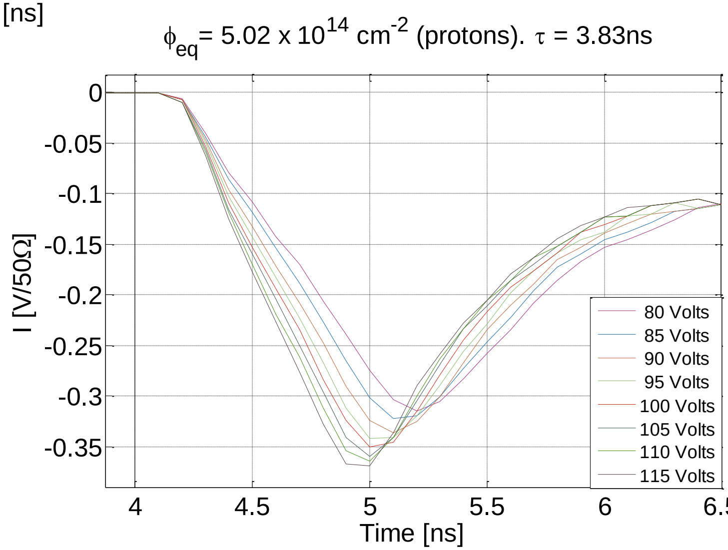


TCT measurements

❑ Results. Current pulses corrected (d = 75 μm)

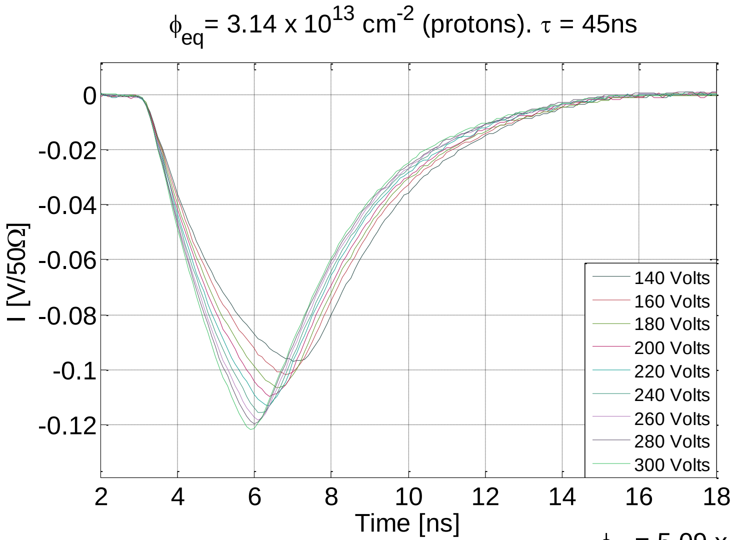


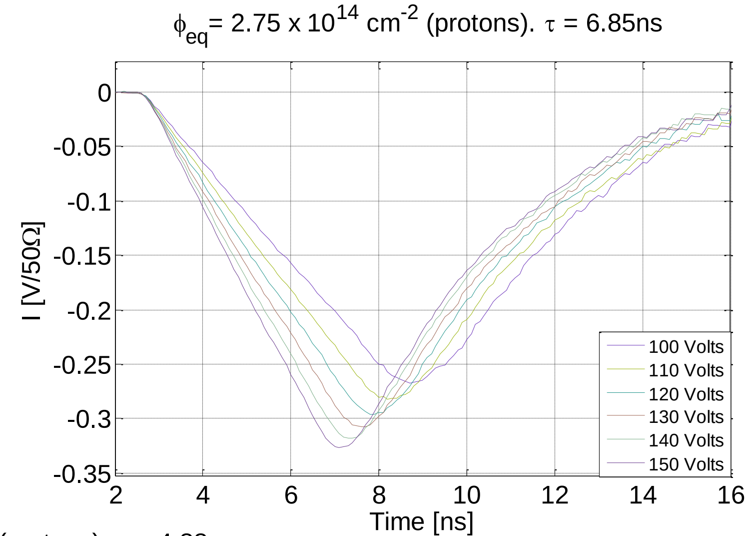


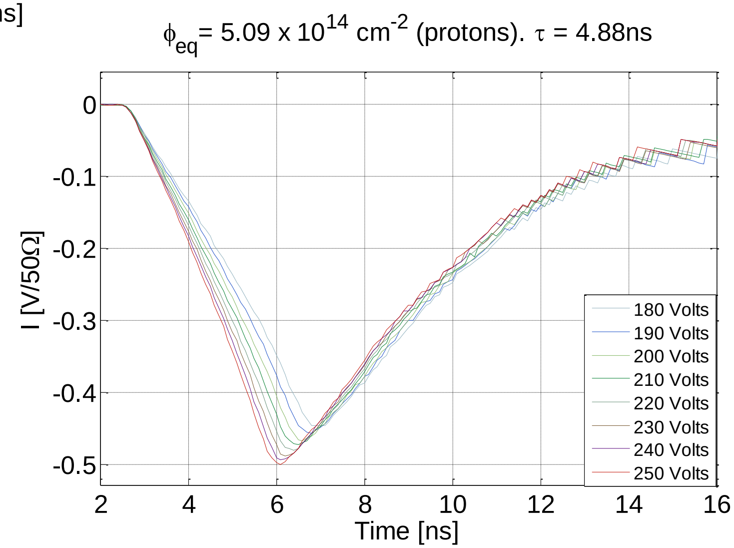


TCT measurements

❑ Results. Current pulses corrected (d = 150 μm)



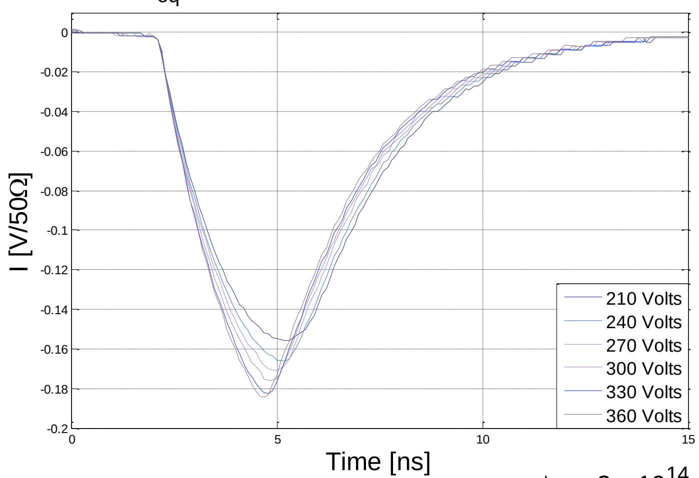




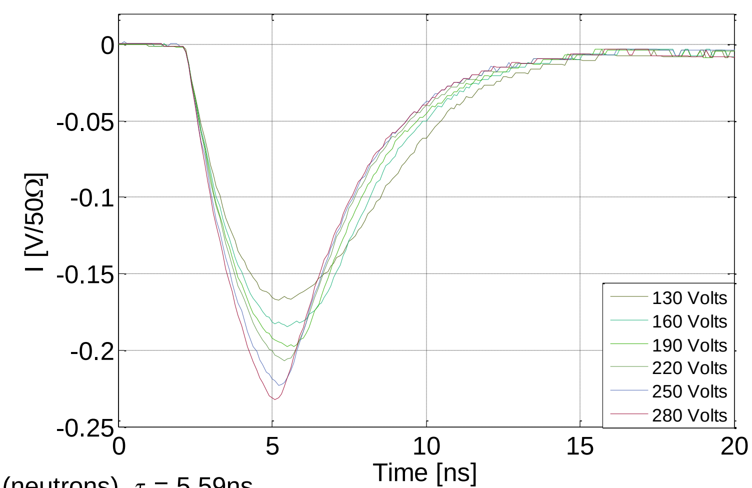
TCT measurements

❑ Results. Current pulses corrected (d = 150 μm)

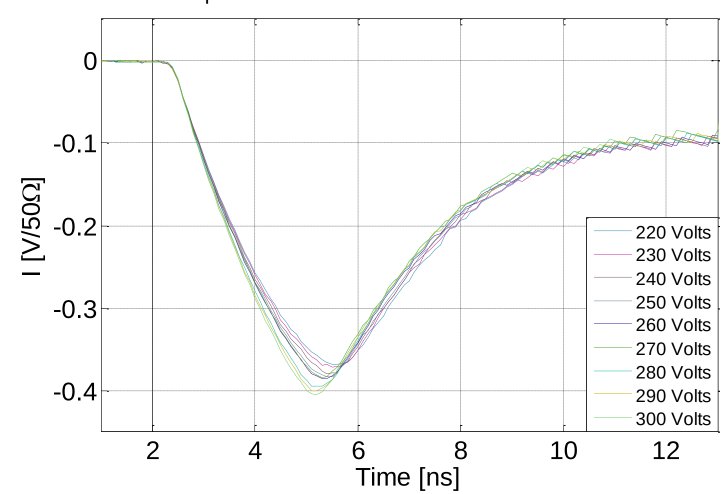
ϕ_{eq} = 3 x 10^{13} cm^{-2} (neutrons). τ = 42.8ns



ϕ_{eq} = 10^{14} cm^{-2} (neutrons). τ = 18.56ns



ϕ_{eq} = 3 x 10^{14} cm^{-2} (neutrons). τ = 5.59ns

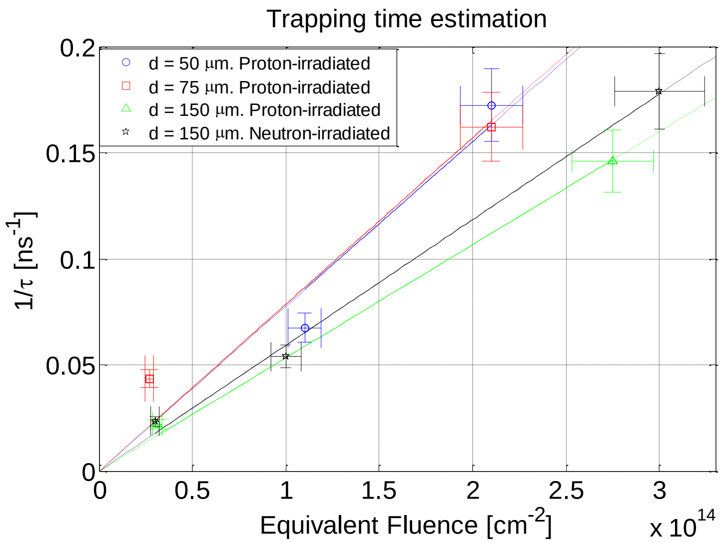


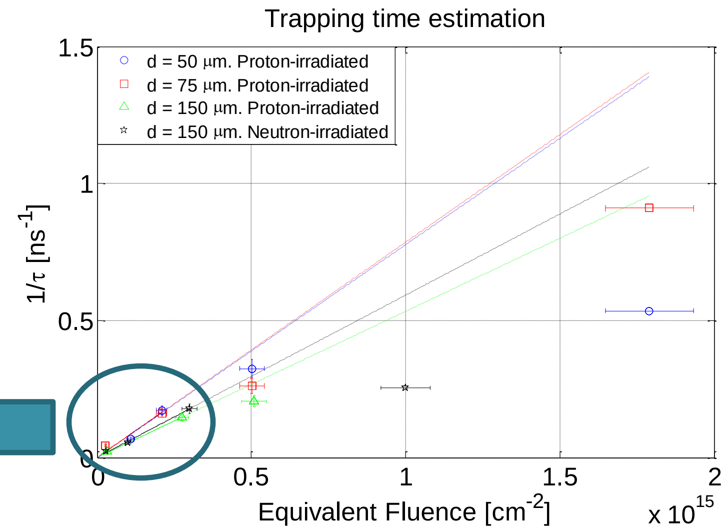
TCT measurements

❑ Results. Hole trapping time estimation

- We only take those samples until ϕ_{eq} = 3 x 10^{14} cm^{-2}

- Fitting model : $\frac{1}{\tau} = \beta \cdot \phi_{eq}$





- For proton irradiation :

  $\beta_{50\mu m}$ = (7.76 ± 1.55) x 10^{-16} [cm^2ns^{-1}]
  $\beta_{150\mu m}$ = (7.85 ± 1.93) x 10^{-16} [cm^2ns^{-1}]
  $\beta_{150\mu m}$ = (5.33 ± 0.36) x 10^{-16} [cm^2ns^{-1}]

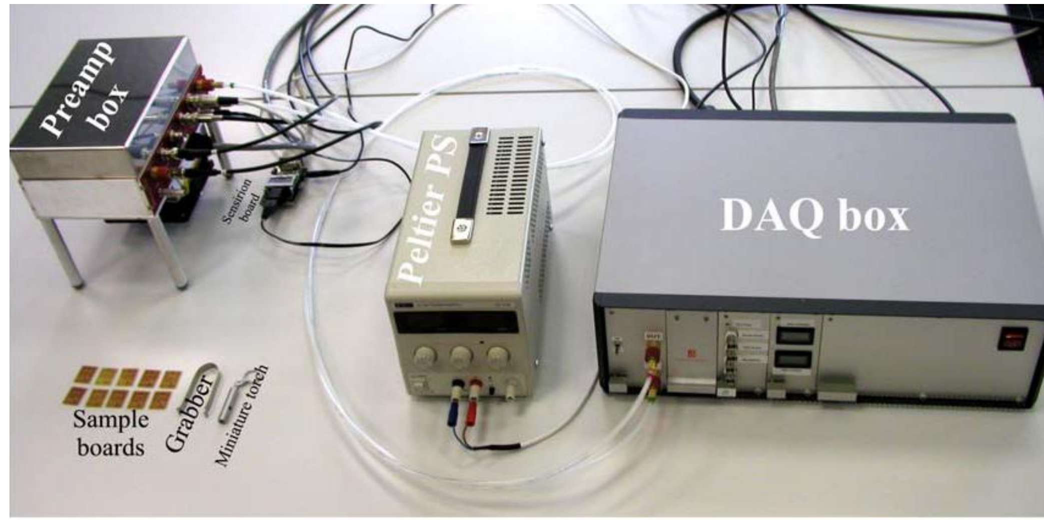
- For neutron irradiation :

  $\beta_{150\mu m}$ = (5.92 ± 0.23) x 10^{-16} [cm^2ns^{-1}]

CCE measurements

❑ Tools

Fred Hartjes
NIKHEF



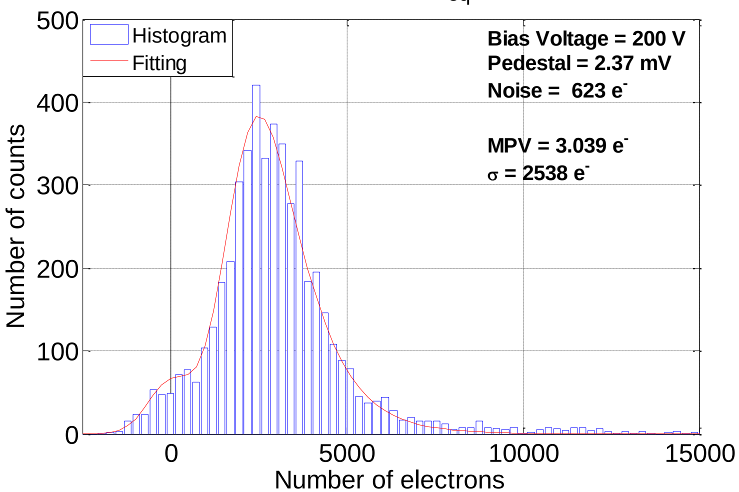
- Charge amplification
  - Sensitivity of 0.75 V/pF
- Shaping and base line stabilization
  - Rise time of 1us and fall time of 0.85us
  - Adjustable Gain between 40 and 100
- ADC sampling
  - 12 bit ADC in the range of ±5 V
  - Preamplifier before digitising for higher or lower ranges
- Radiactive source Sr 90
- Gain of 243 e^-/mV at -20 °C
- Biasing from the back and guard ring to ground

- Collimation and Scintillation
  - W/Cu 72/18 alloy collimator with aperture width 0.6 mm^2
  - Plastic scintillator 3 mm wide and long at 9.5 mm under the collimator
  - Scintillator coupled to a photomultiplier through a long light guide
- XY and Z screws to adjust collimator and scintillator position
- Temperature control
  - Air temperature block on a Peltier cooler
  - Two thermistors upstream and downstream in the airflow along the sample
  - Sensirion SHT75 sensor for temperature and humidity in the air temperature block

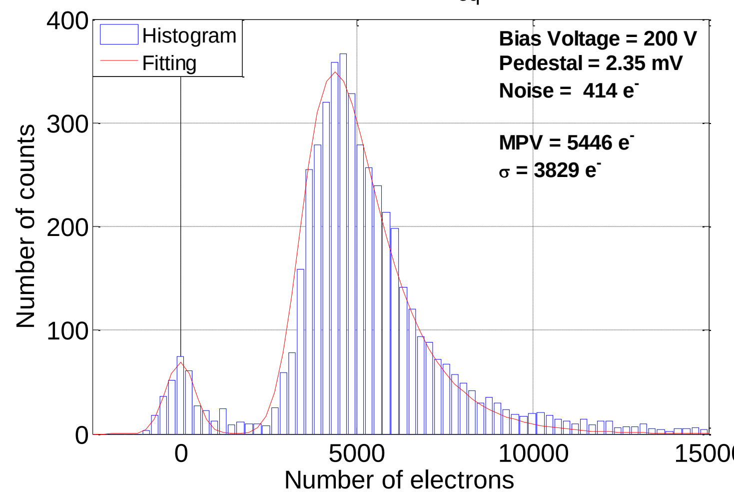
CCE measurements

❑ Results. Histograms

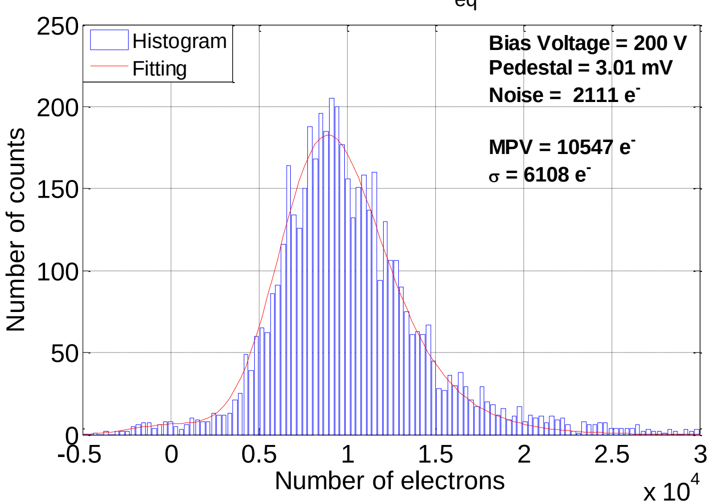
d = 50 μm, proton-irradiated. ϕ_{eq} = 2.10 x 10^{14}cm^{-2}



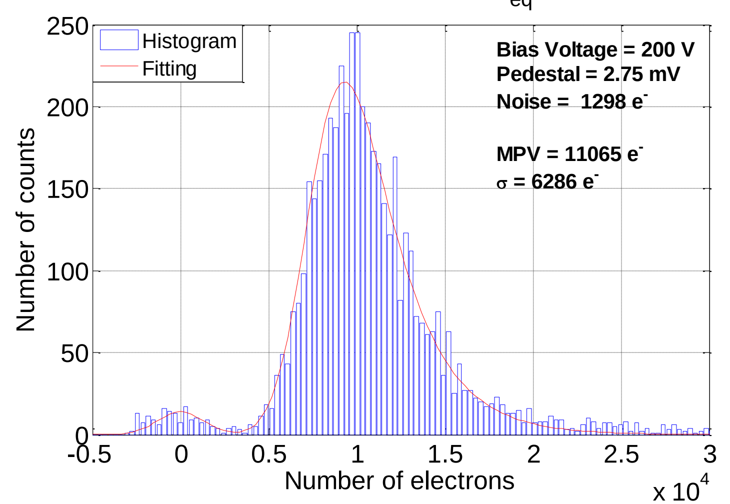
d = 75 μm, proton-irradiated. ϕ_{eq} = 2.10 x 10^{14}cm^{-2}



d = 150 μm, proton-irradiated. ϕ_{eq} = 2.75 x 10^{14}cm^{-2}

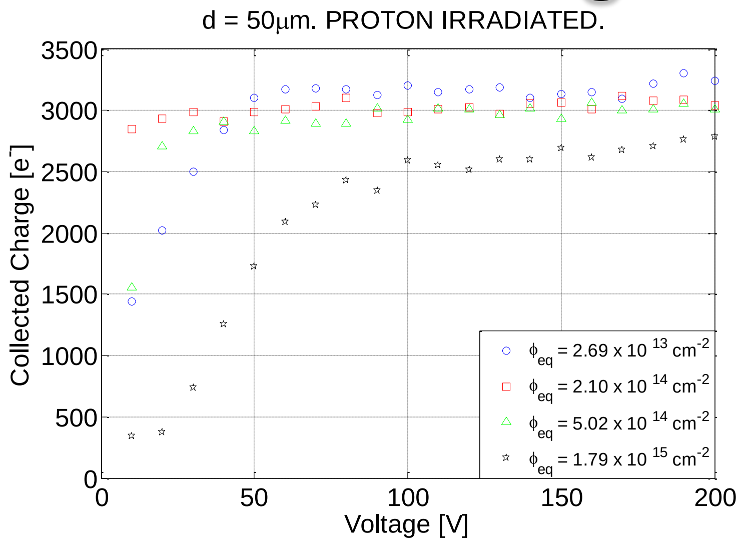


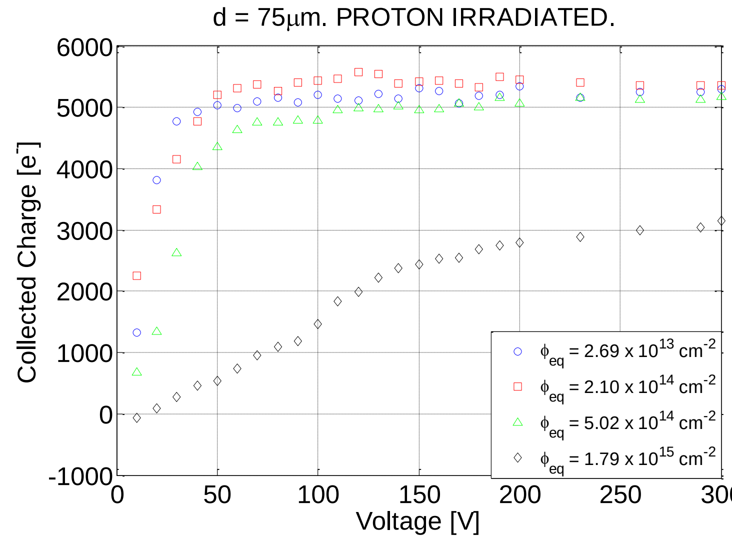
d = 150 μm, neutron-irradiated. ϕ_{eq} = 10^{14}cm^{-2}

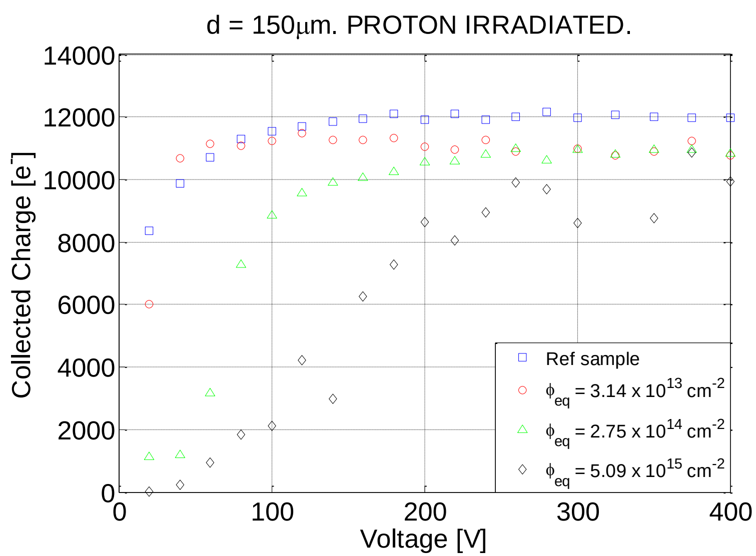


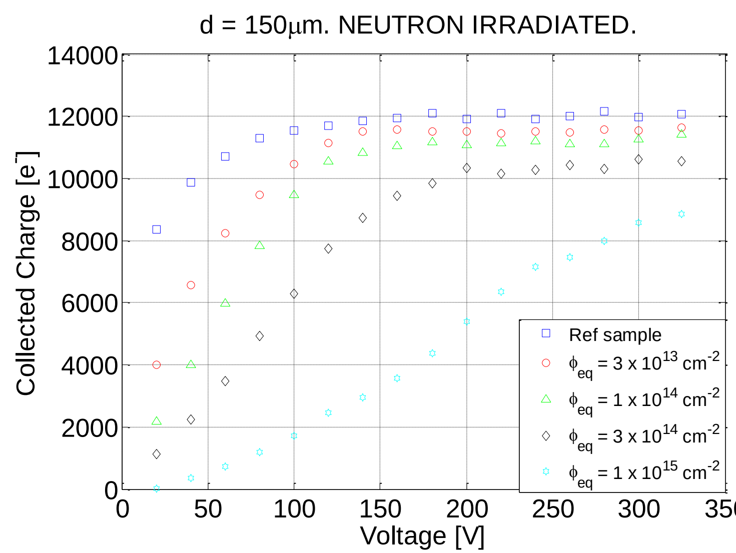
CCE measurements

❑ Results. Charge collected curves



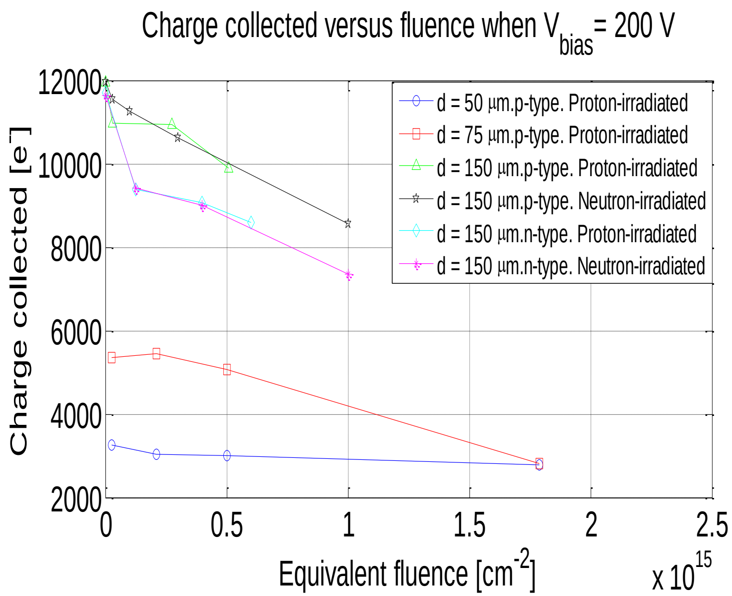


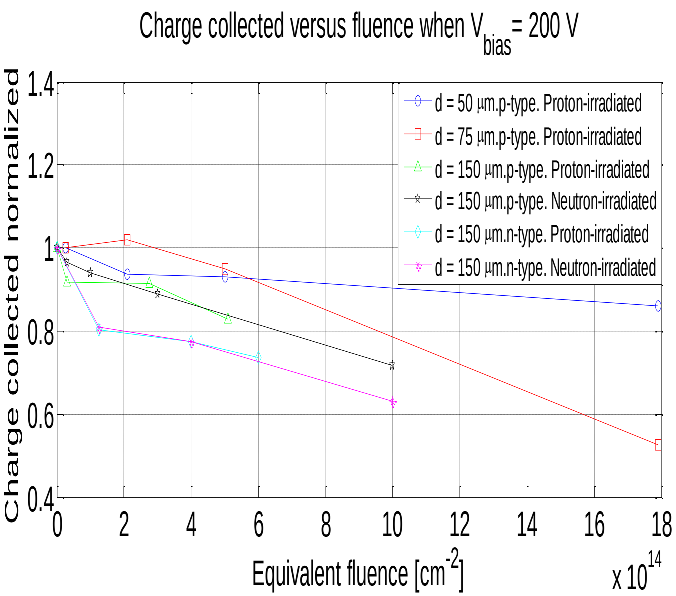




CCE measurements

❑ Results. Comparison





- We can see a not expected behavior in the curve for thickness 75 µm
- Coherence among the different geometries at low fluences.
- For 150 µm, we can see a drop in CCE for n-type in comparison with p-type

[K. Kaska,"Study on 150 um thick n- and p-type epitaxial silicon sensors irradiated with 24GeV/c protons and 1 MeV neutrons" Nucl. Instr. and Meth. A 612 (2010) 482-487]

Conclusions

- CV/IV, TCT and CCE measurements has been performed over a set of p-type epitaxial diodes of thicknesses 50, 75 and 150 μm irradiated with protons and neutrons
- It was observed that the variation of the dependence with fluence of N_{eff} , as function of thickness, is slighter in p-type than in n-type detectors
- In p-type pad detectors, space charge sign inversion from negative to positive takes place after proton irradiation but not after neutron irradiation
- Hole trapping time estimation was performed for all the thicknesses, getting values for 50 and 75 um proton-irradiated devices, in agreement with [1], as well as for 150 um neutron-irradiated.
- For 150 um, the charge collected in p-type detectors, for low fluences, doesn´t drop with fluence so fast than for n-type.

[1] J. Lange," Charge collection studies of proton-irradiated n- and p-type epitaxial silicon detectors" Nucl. Instr. and Meth. A (2010)

END