Acceptor removal in silicon pad diodes with different resistivities

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Outline

- Introduction to acceptor removal
- Motivation
- Materials, devices and irradiation plan
- Annealing study of a subset of irradiated sensors (CV/IV and TCT)
- Space charge and TCT charge collection
- Implications on acceptor removal
- Summary
- TSC - acceptor removal from a microscopic perspective (Upcoming talk)

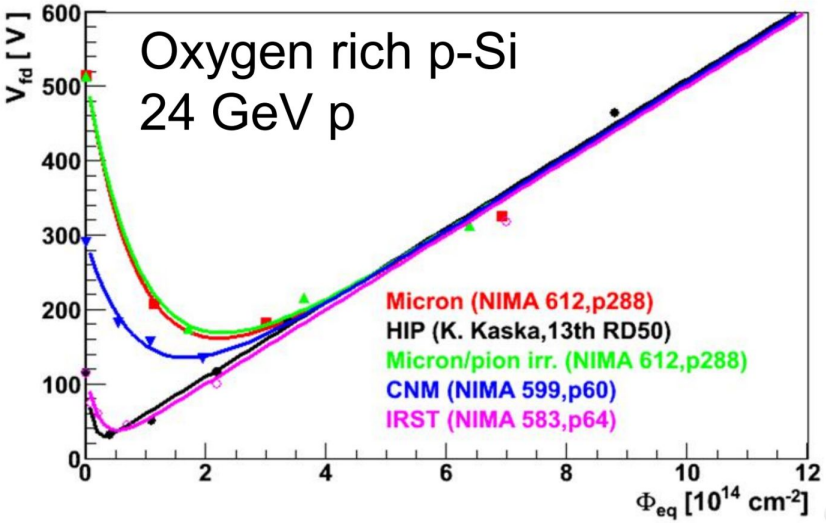
Acceptor removal

- Usually described as:

$$N_{eff}(\Phi) = N_{eff0}.e^{-c\cdot\Phi} + g_c\Phi$$

- The acceptor removal coefficient (*c*) is poorly studied, i.e. only few results as function of acceptor concentration exist

G. Kramberger, 23rd RD50 Workshop



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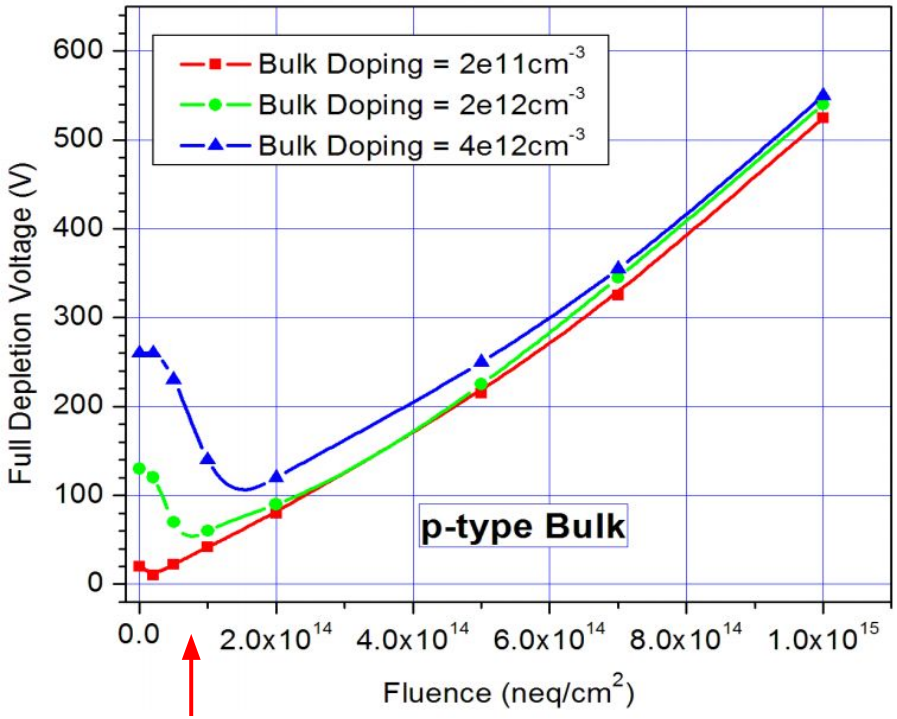
Ranjeet Dalal et al, 25th RD50 Workshop

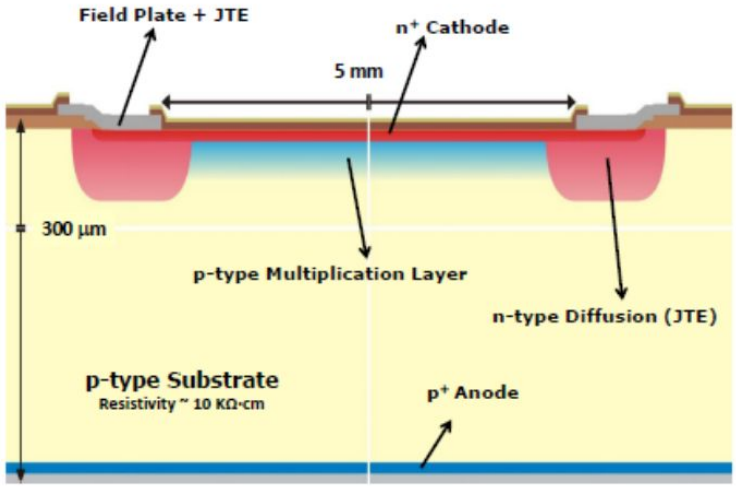


Simulation can qualitatively reproduce this behaviour **without** Boron removal

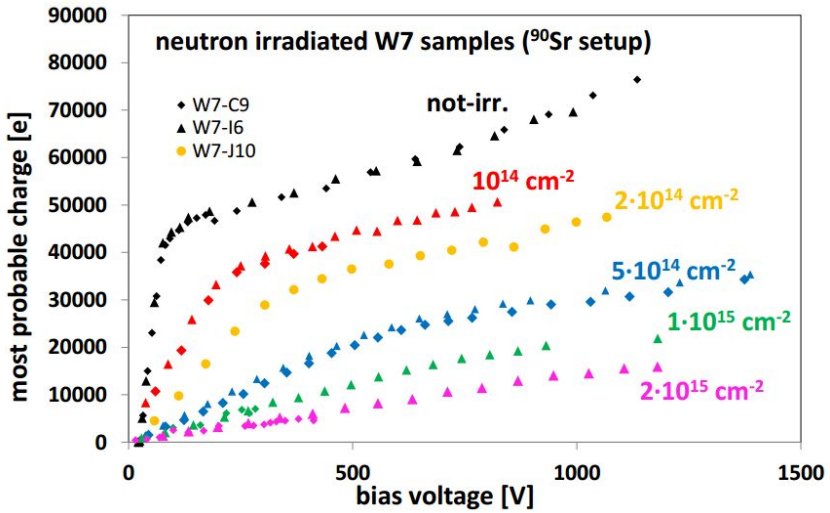
Motivation

Example: Low Gain Avalanche Detectors (LGADs)

- LGADs have a highly doped layer to achieve gain
- Interesting for their timing capabilities
- However, the gain decreases when exposed to radiation due to ‘acceptor removal’

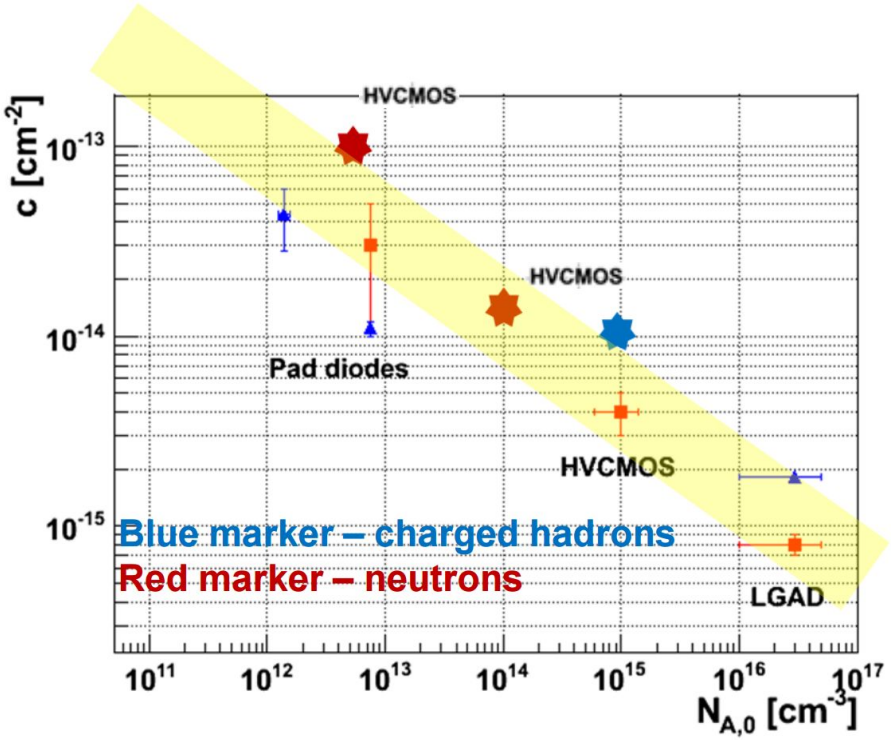


G. Kramberger et al, JINST (2015)



Motivation

No systematic study, hard to compare results from literature:



- Different devices
- Different oxygen content
- Different material types
- Different measurement techniques

G. Kramberger, VERTEX (2016)

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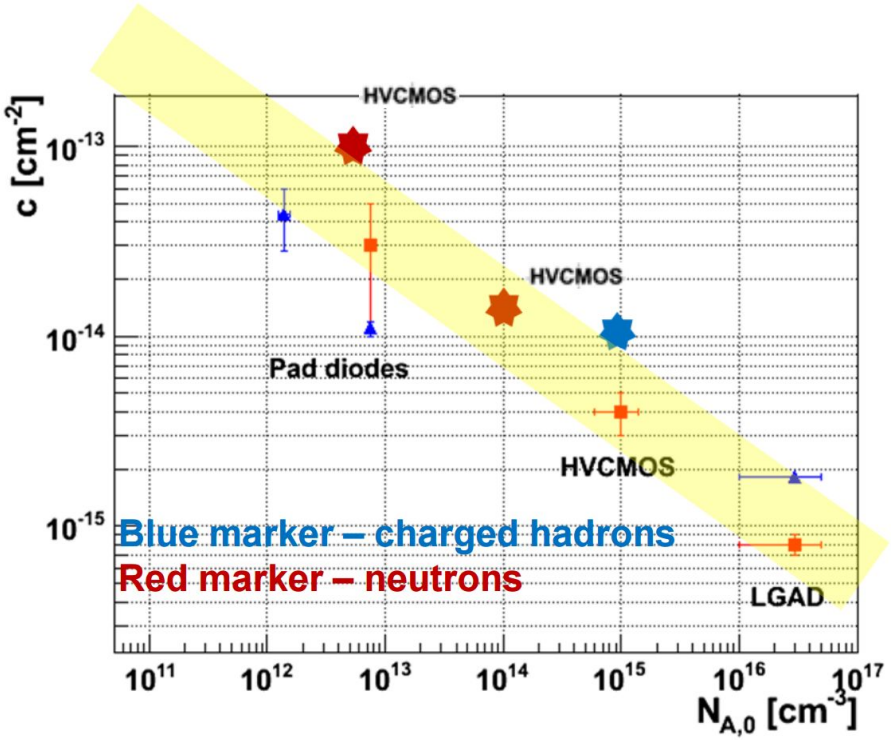

- Different devices
- Different oxygen content
- Different material types
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G. Kramberger, VERTEX (2016)

Solution: dedicated characterization experiment

A large number of sensors with the same structure with varying thicknesses, resistivities and material types

Materials and Devices

Simple p-type pad diodes

Epitaxial (50 µm)
- 10 Ω·cm
- 50 Ω·cm
- 250 Ω·cm
- 1000 Ω·cm

Float zone (>10 000 Ω·cm)
- 100 µm
- 150 µm
- 200 µm
- 285 µm

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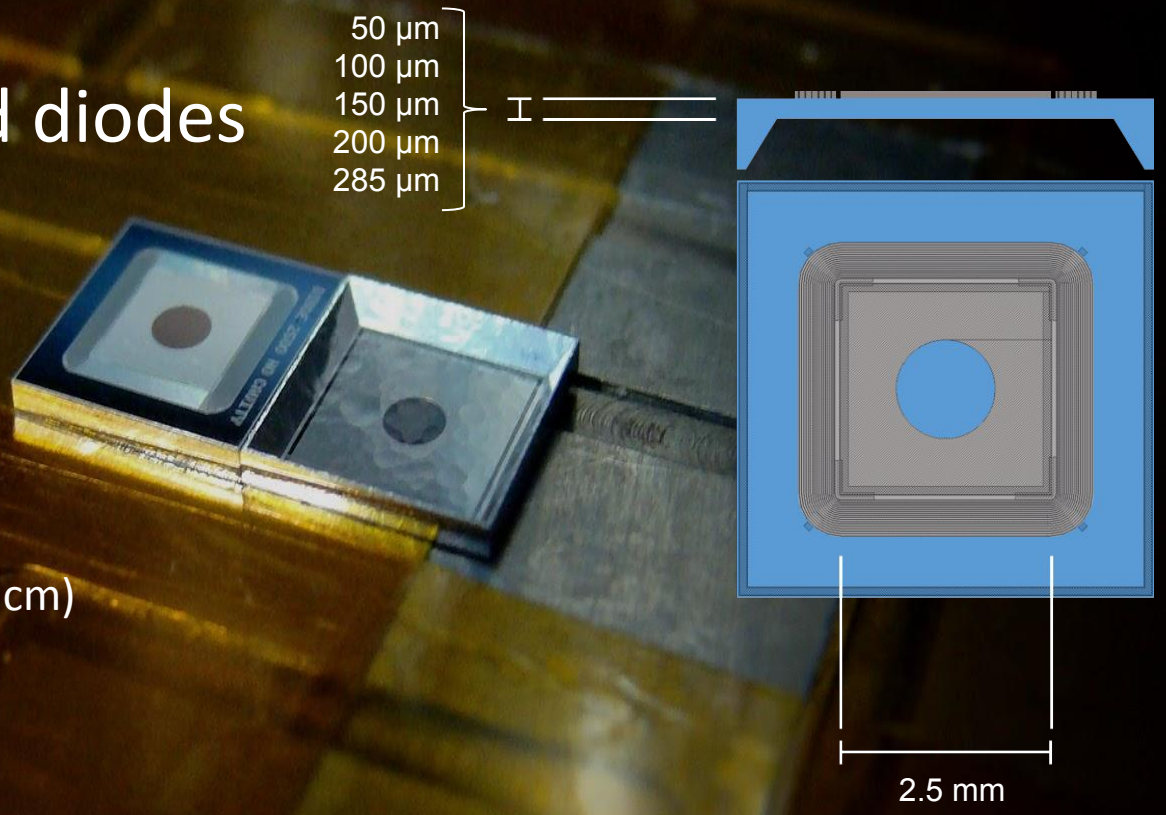


Irradiation

Proton and neutron irradiation

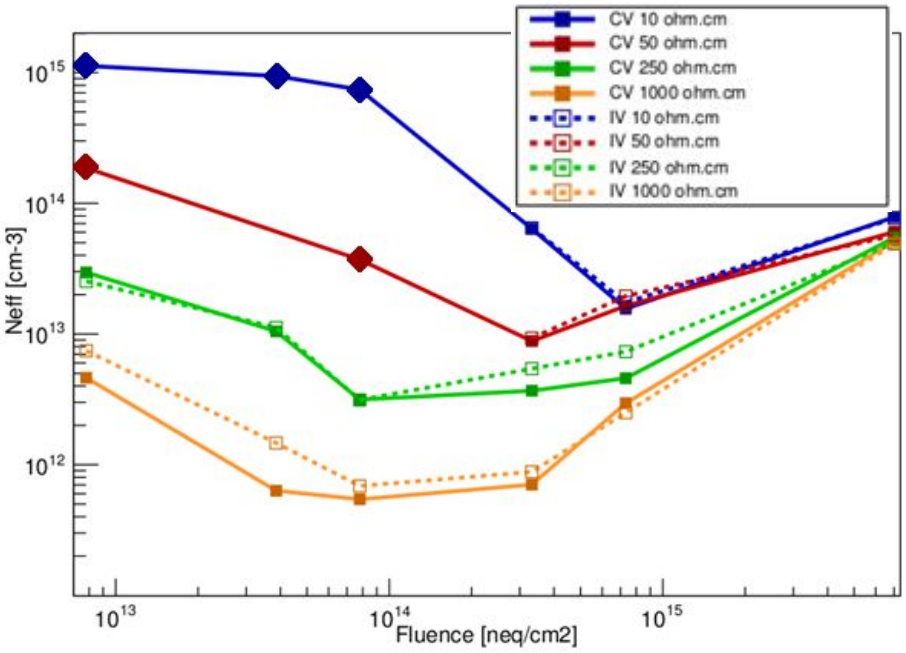
From ~ $7x10^{13}$ to $7x10^{15}$ $n_{eq}cm^{-2}$

CERN | IRRAD Proton Facility

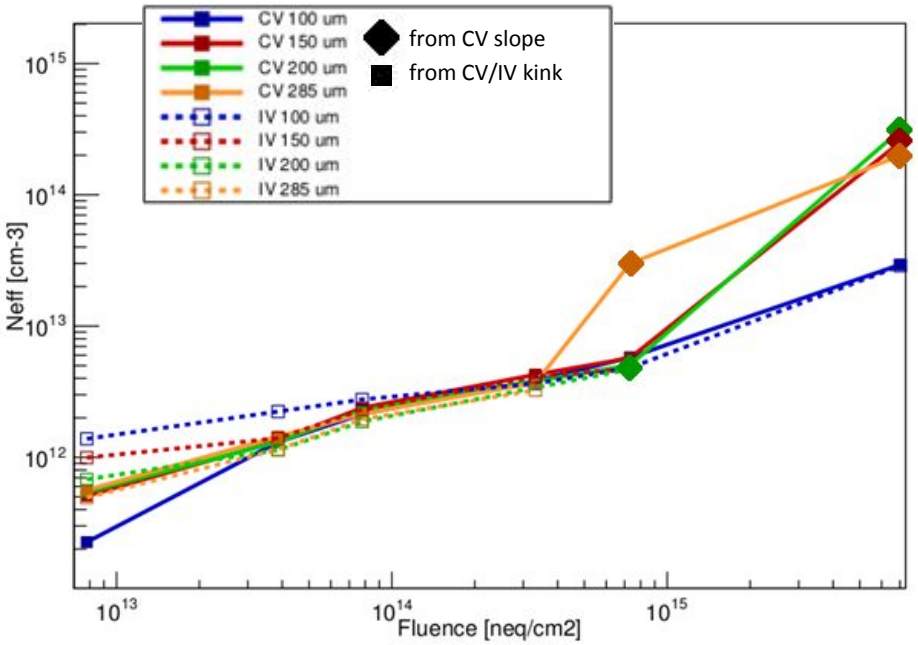
Institut "Jožef Stefan" 50 let REAKTORJA TRIGA

Acceptor Removal by Proton Irradiation

Epitaxial



Floatzone



P. Almeida et al, 30th RD50 (2017)

Acceptor Removal by Proton Irradiation

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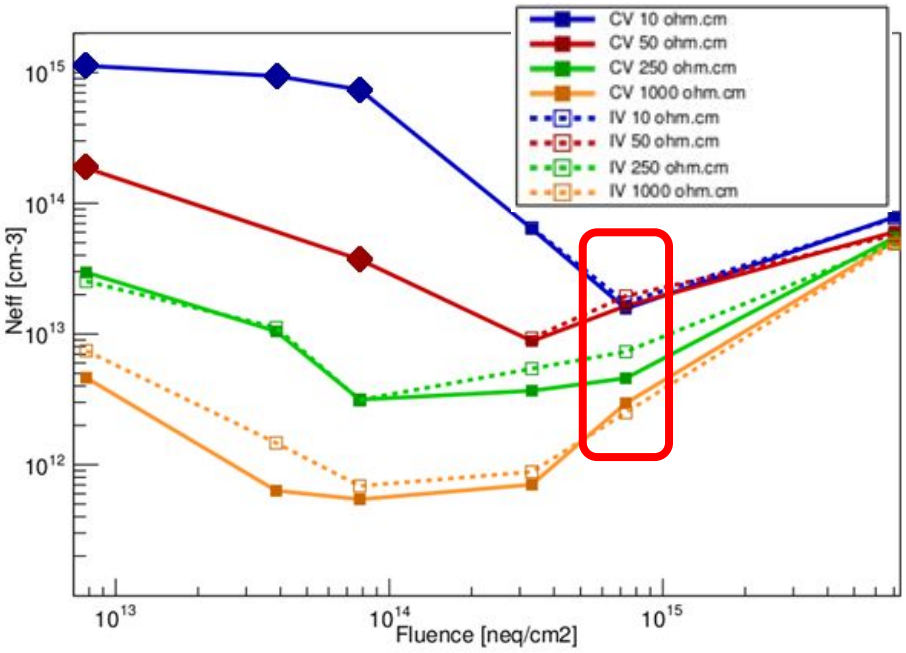
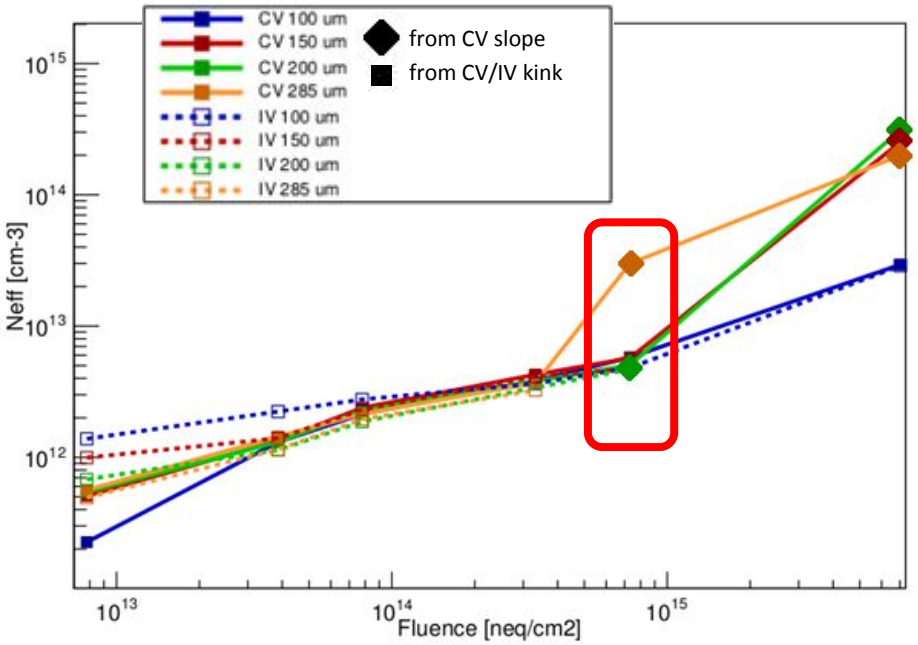


Floatzone

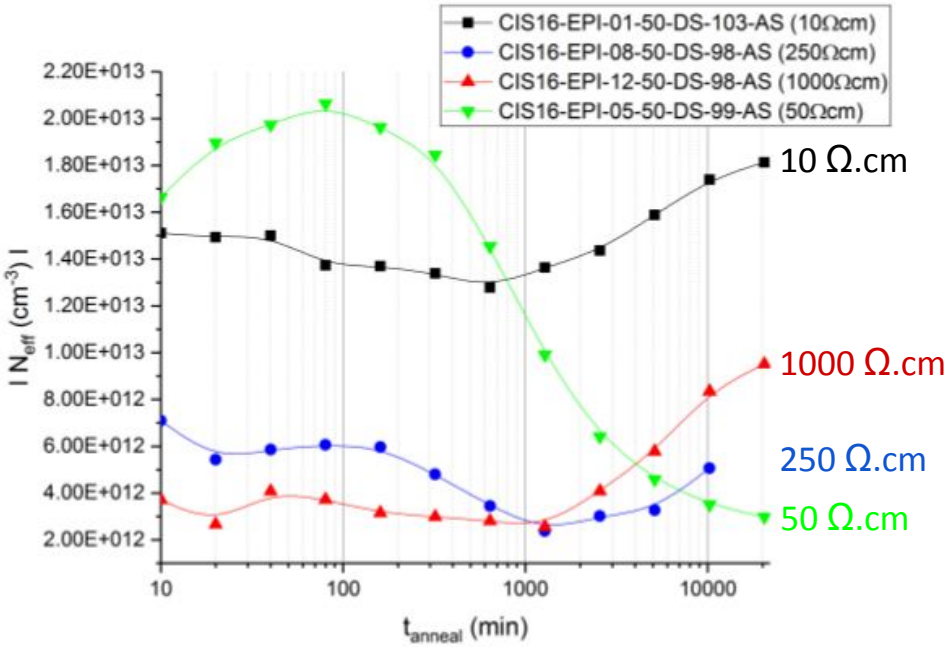


P. Almeida et al, 30th RD50 (2017)

- Annealing study with a subset of 8 sensors irradiated to 7.32×10^{14} $n_{eq}cm^{-2}$

Annealing Study Measured |Neff|

Epitaxial



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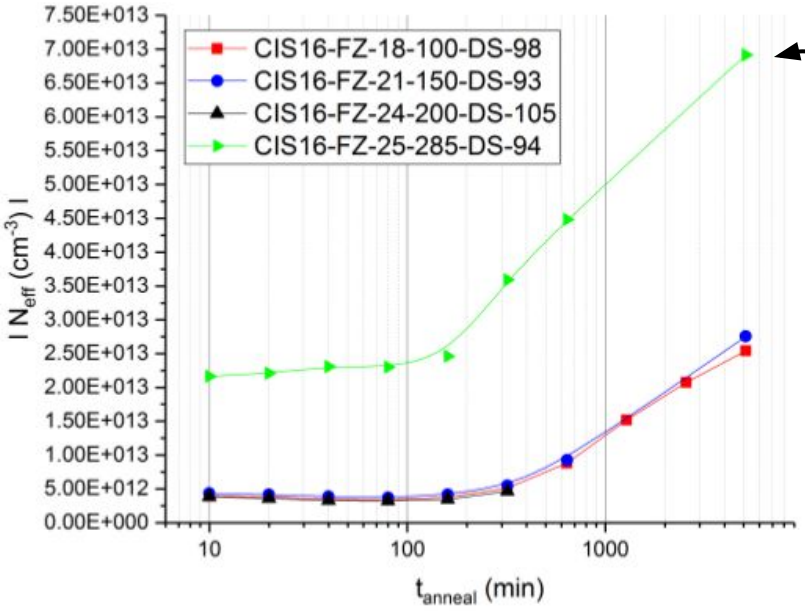
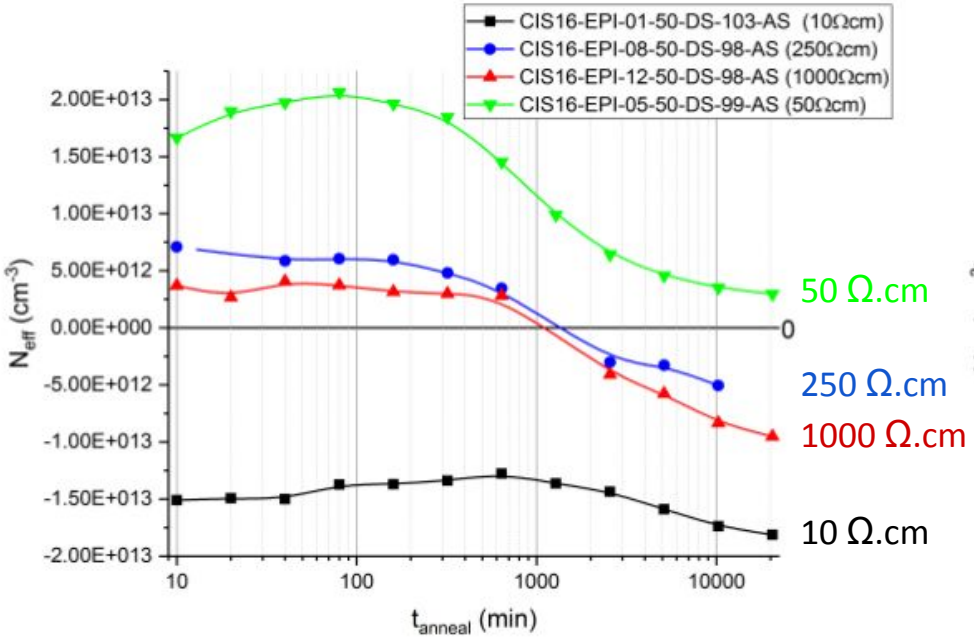


Neff offset caused by usage of different method
(Neff taken from slope of CV instead of kink)

- Annealing at 60ºC
- Up to 20480 min or ~14 days of accumulated annealing
- Neff calculated from CV measurements

Annealing Study Interpretation of Neff

Epitaxial



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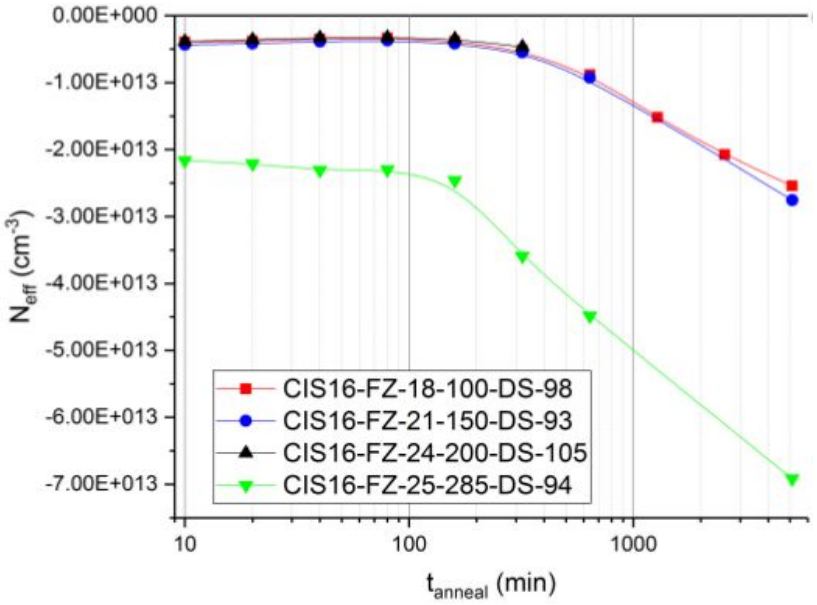

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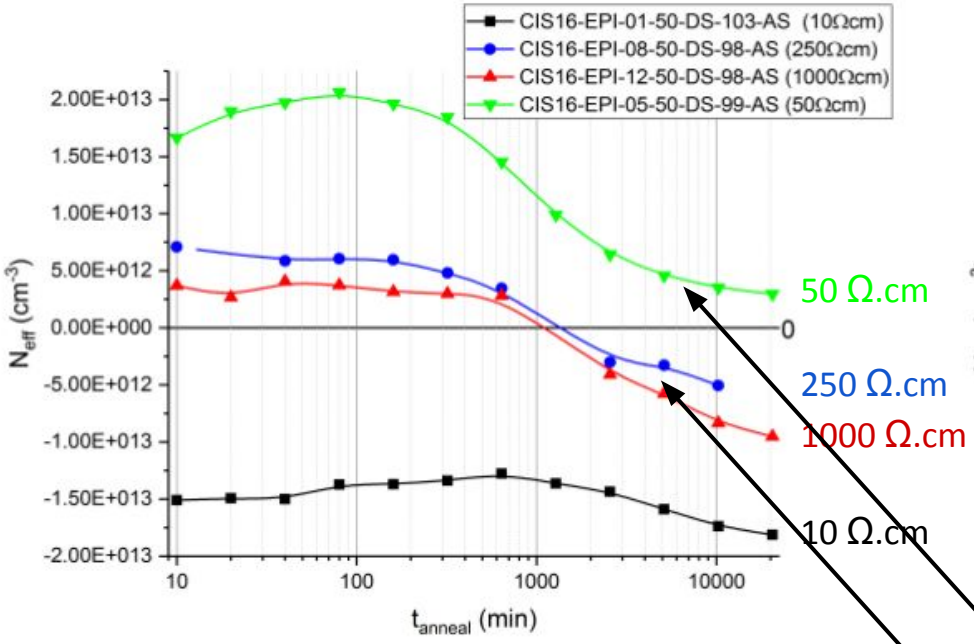


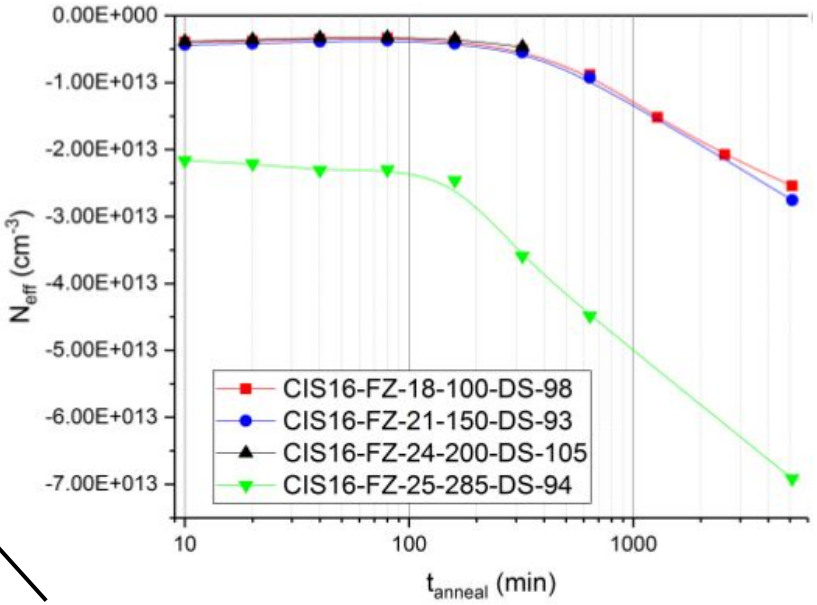
50 Ω.cm

250 Ω.cm

1000 Ω.cm

10 Ω.cm

Floatzone

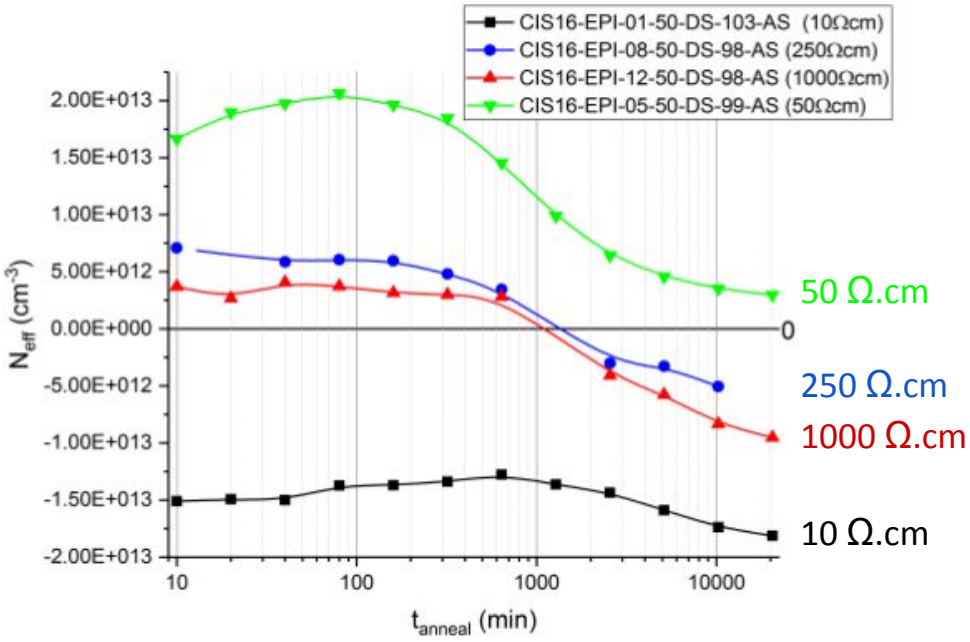


Sensor type inverted by Irradiation

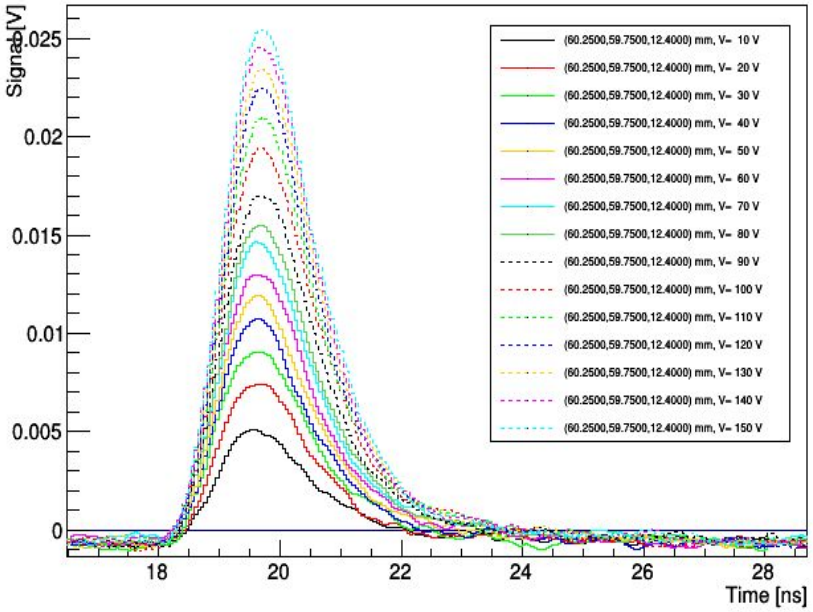
Sensors type inverted by Irradiation and inverted back by the annealing!

Annealing Study TCT confirmation

Epitaxial



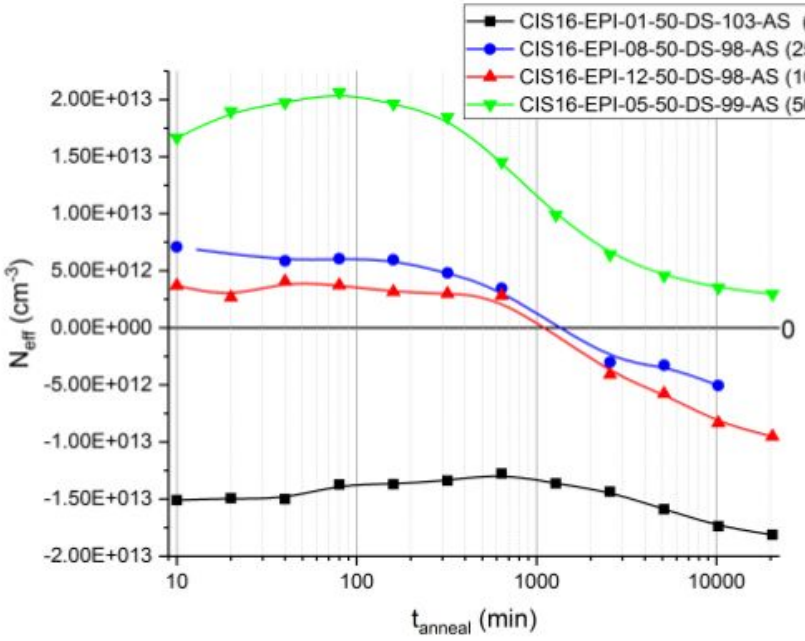
Example of a TCT voltage scan

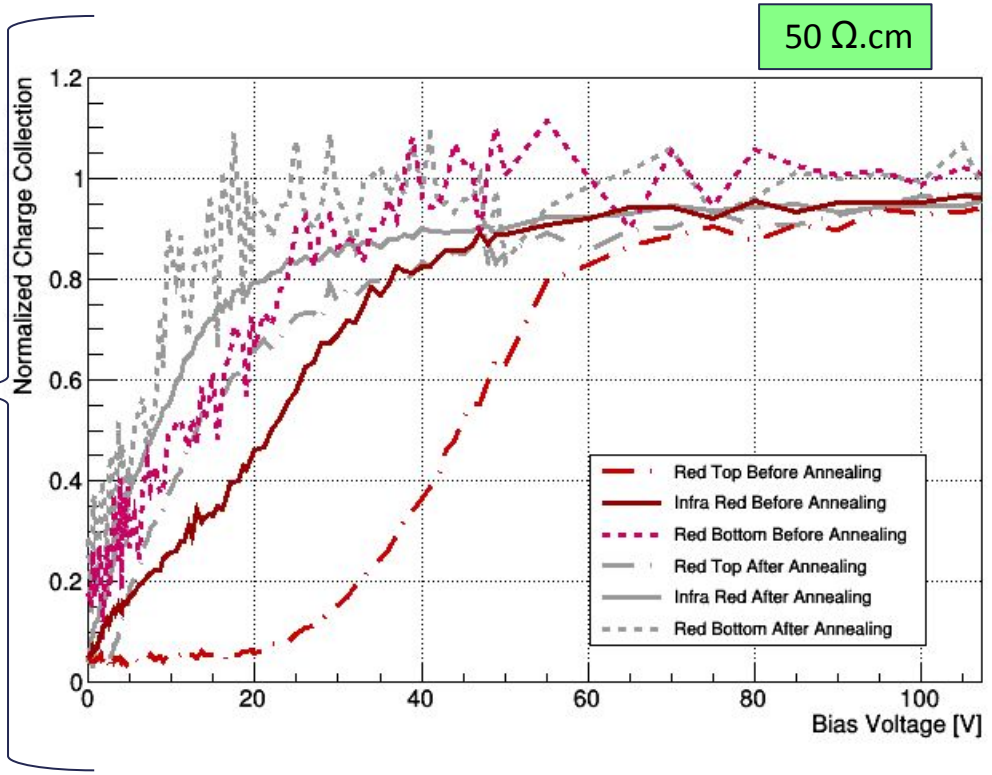


Since the Epitaxial sensors are so thin (50 µm), the TCT pulse shape is hard to analyse

Annealing Study TCT confirmation

Epitaxial

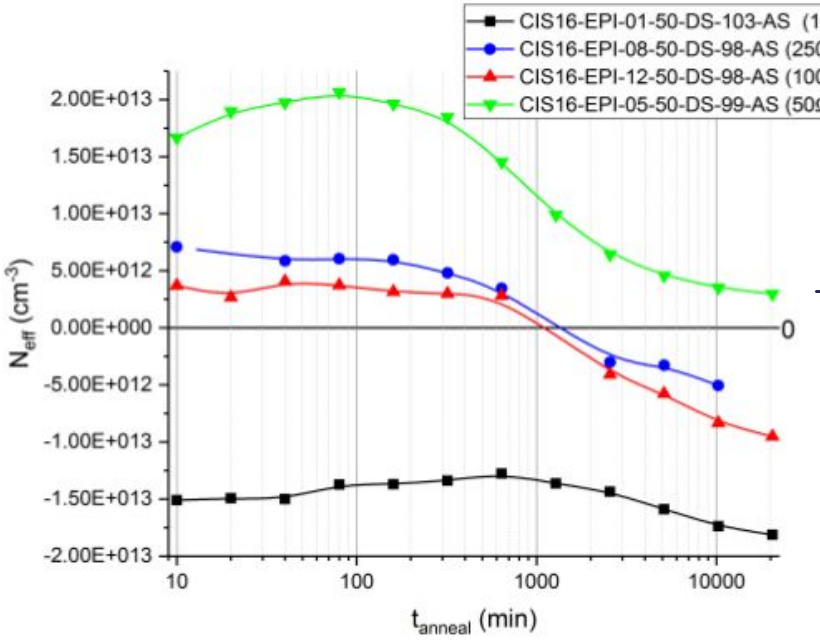




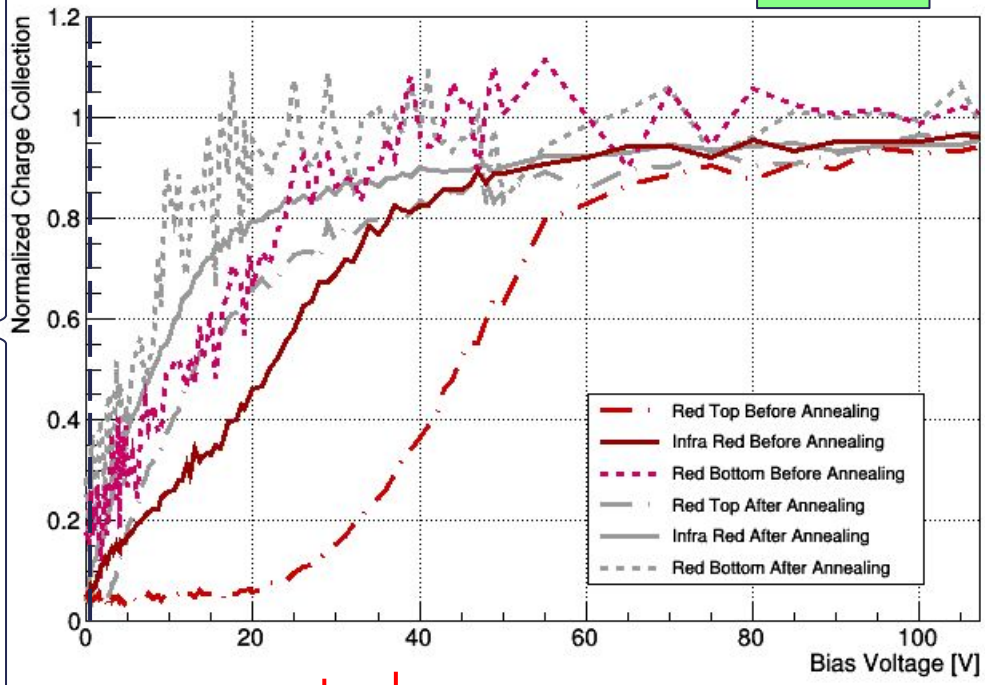
However, a comparison between the charge collection of red top, red bottom and infra-red TCT can be used to confirm the type inversions

Annealing Study TCT confirmation

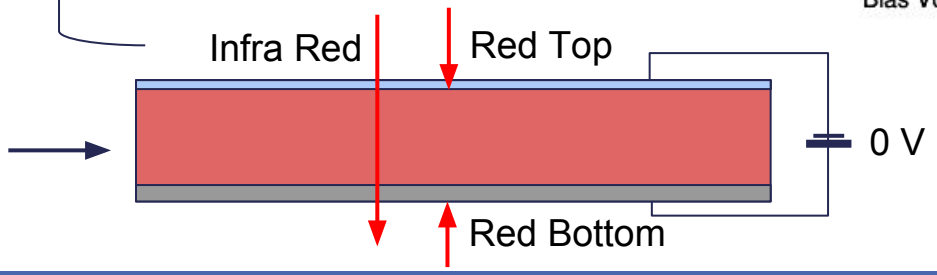
Epitaxial



50 Ω.cm



The 50 Ω.cm sensor is depleting from the back before annealing



Annealing Study TCT confirmation

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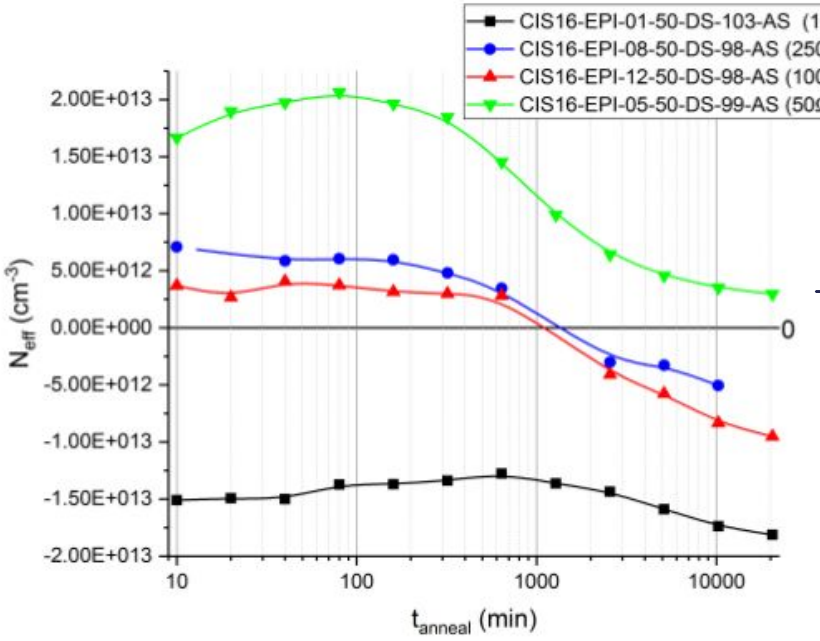

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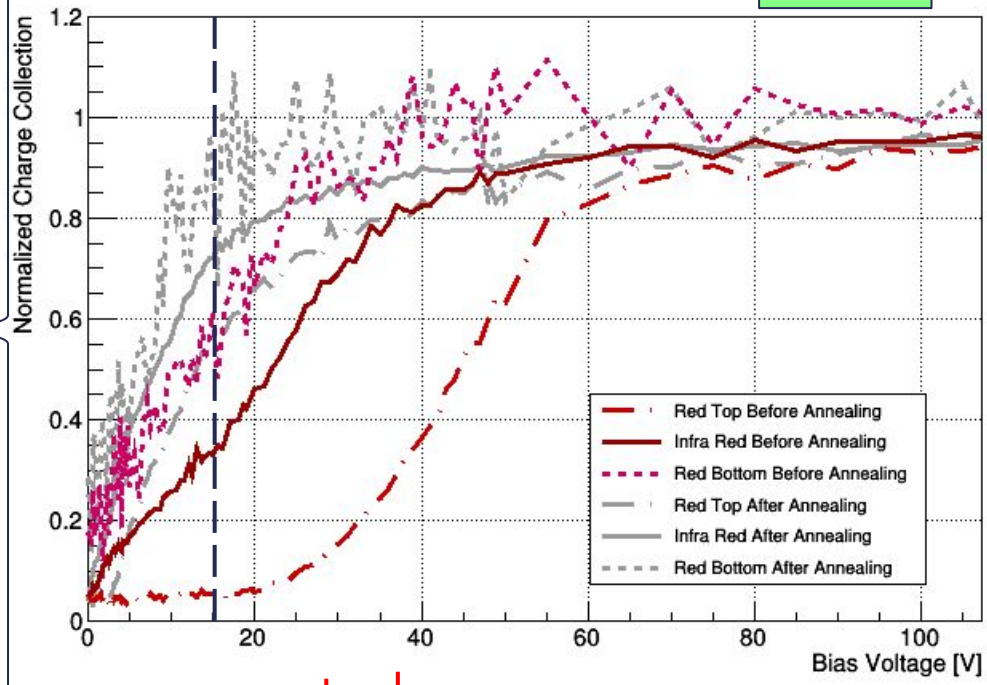

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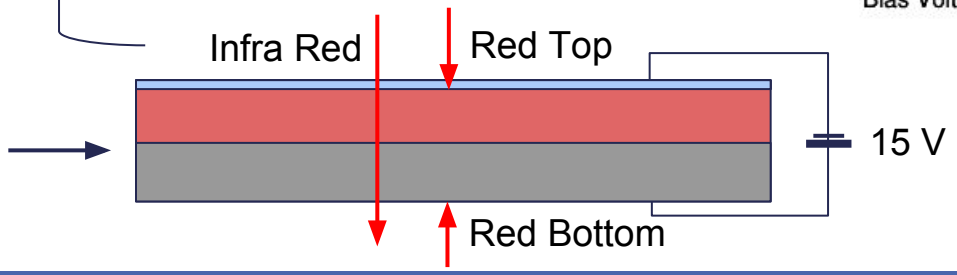

Annealing Study TCT confirmation

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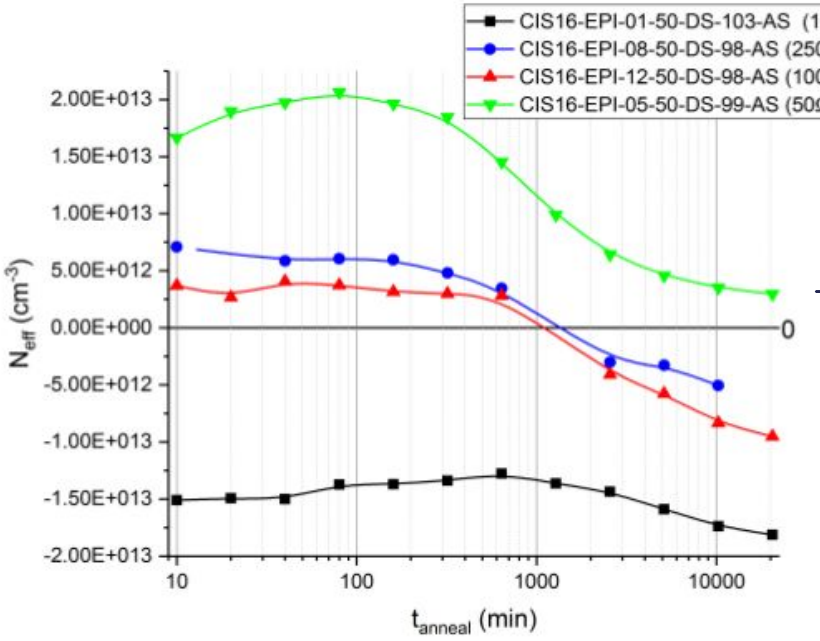

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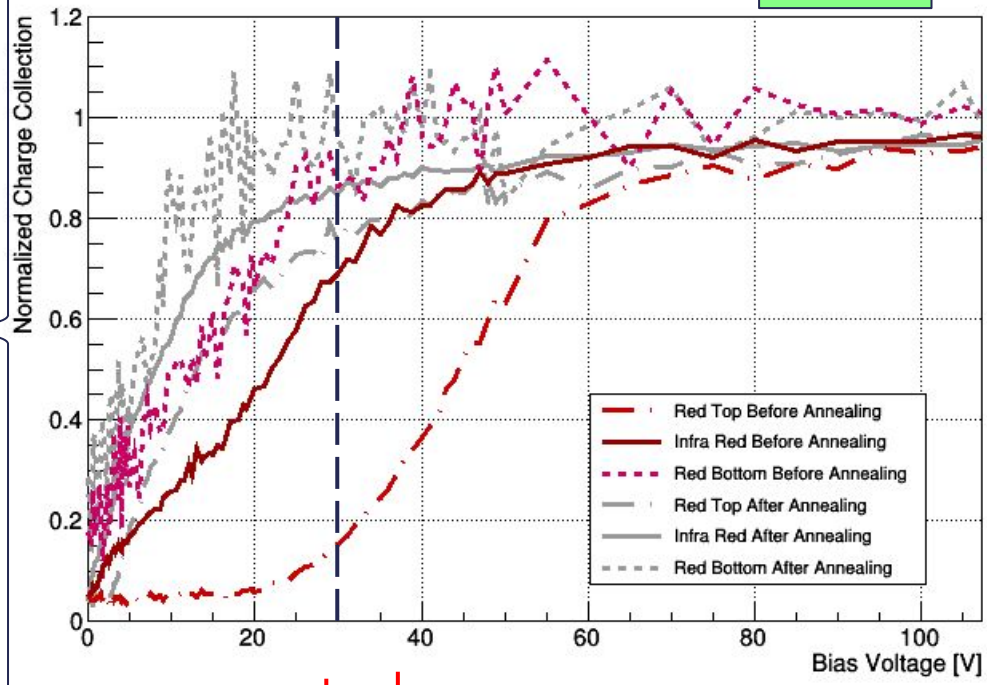

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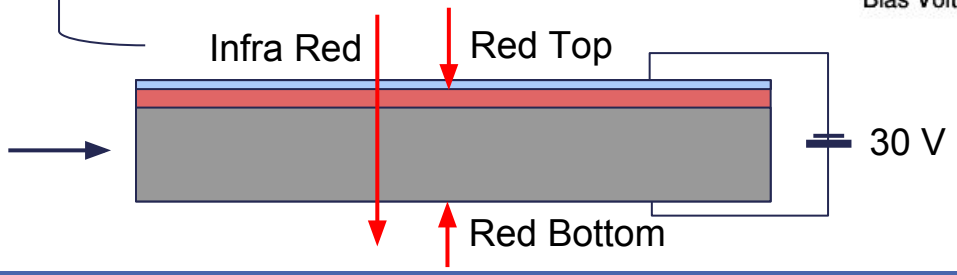

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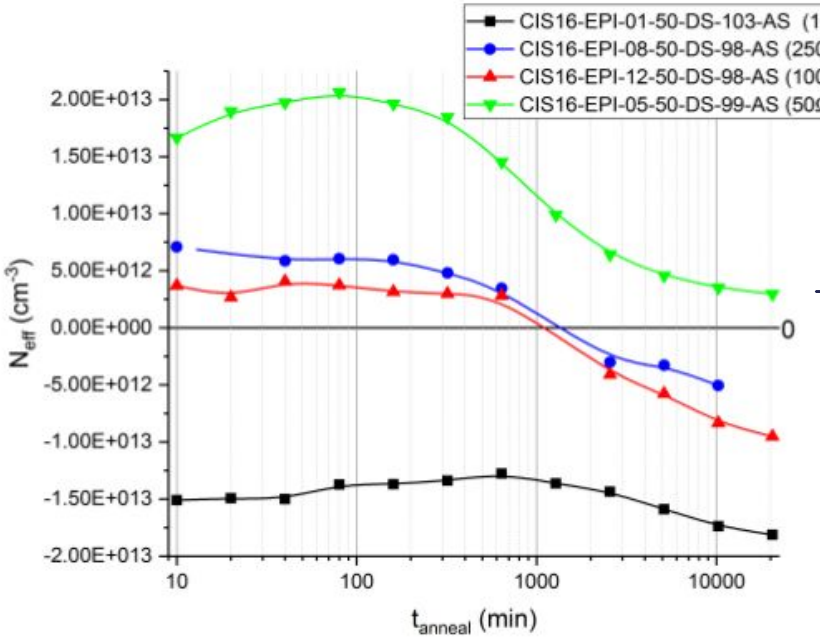

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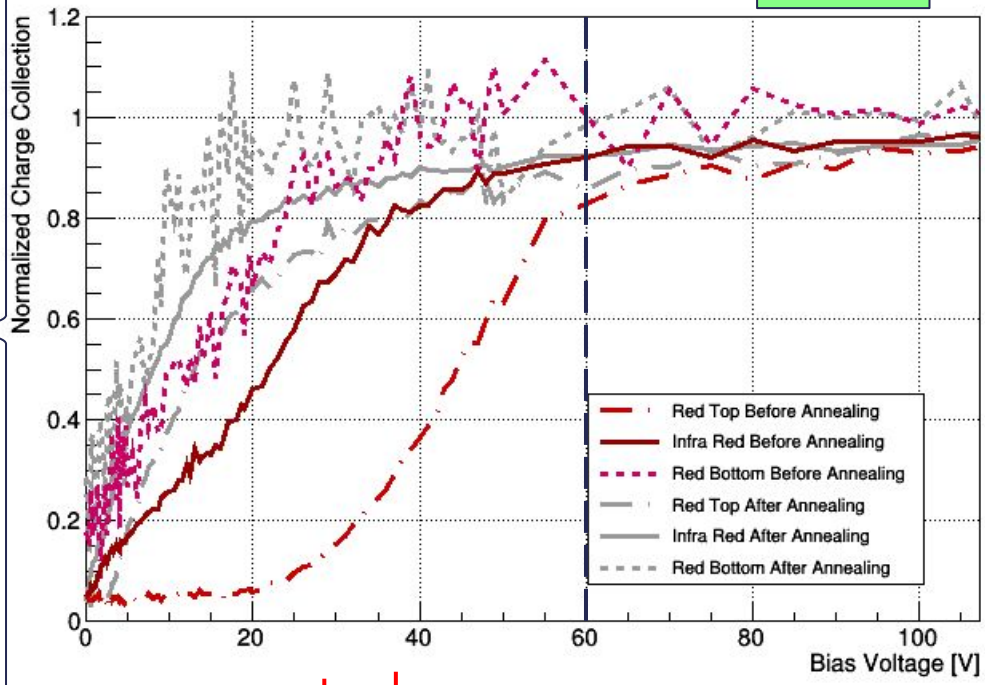

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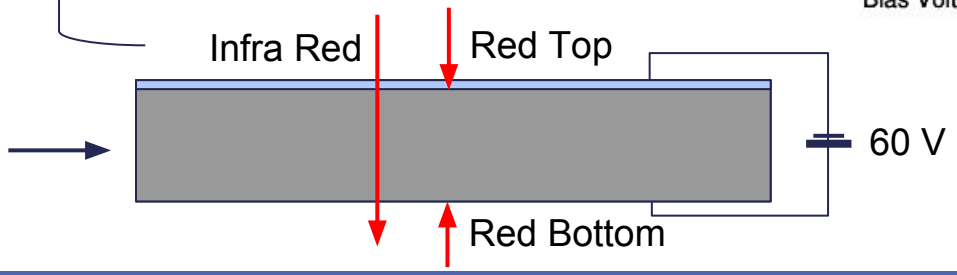

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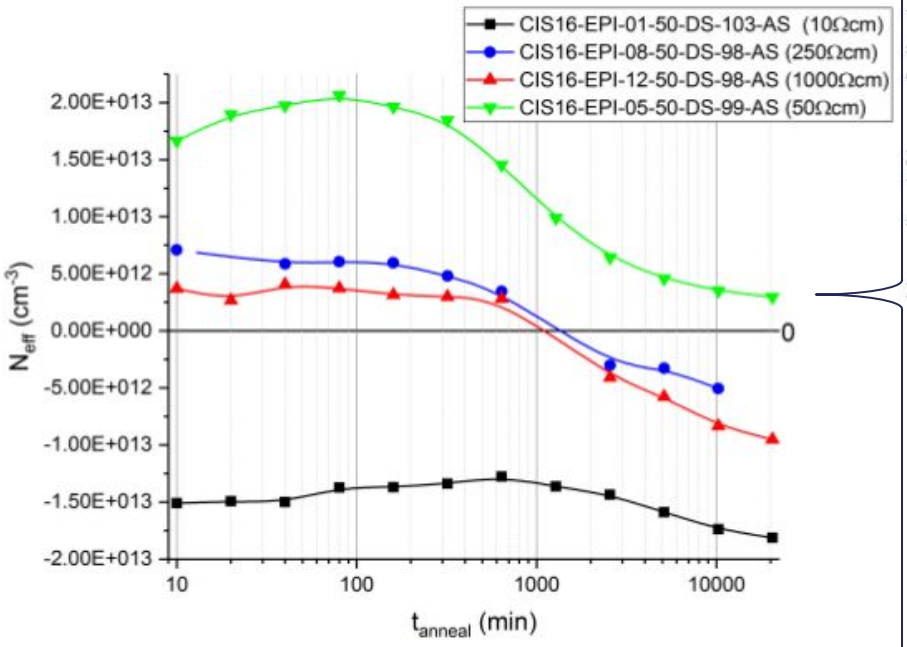
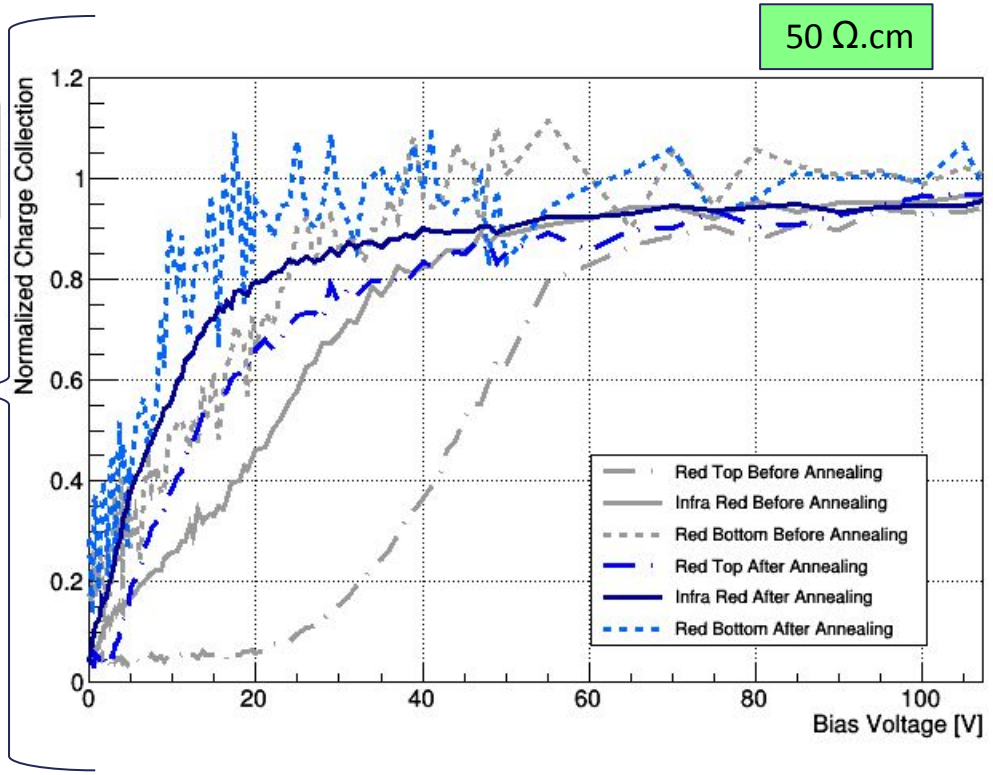
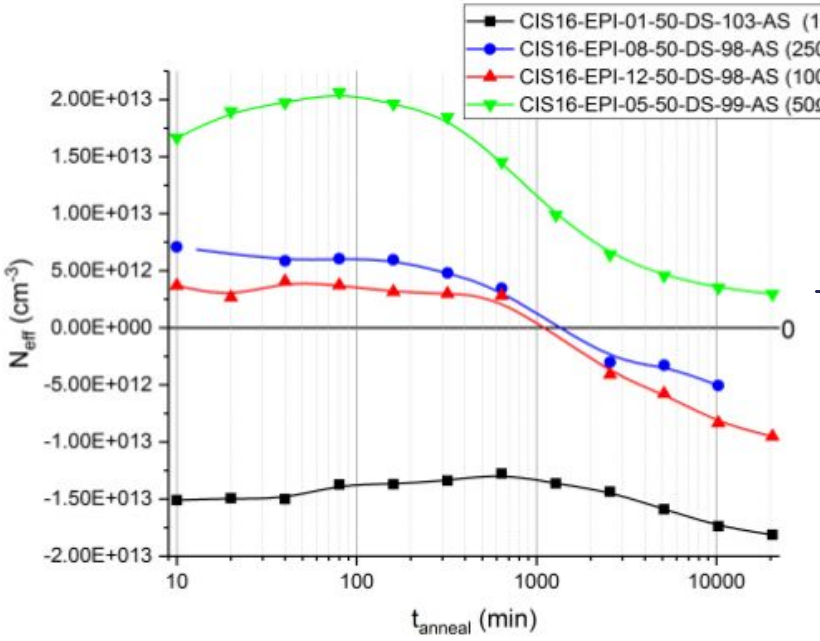


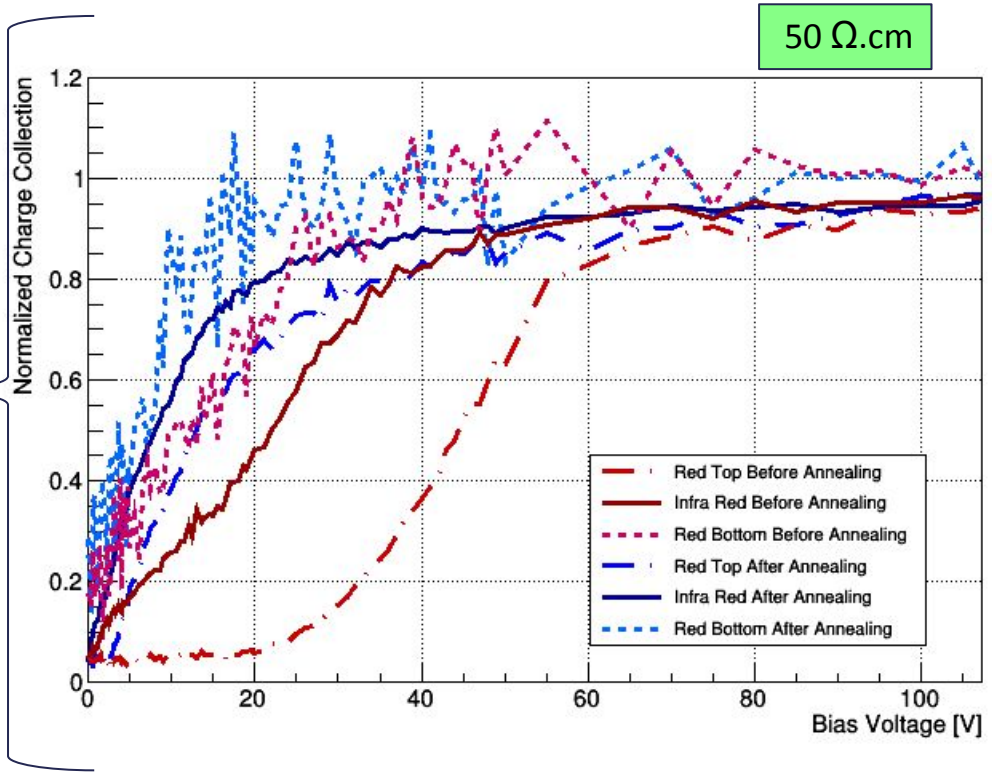


After annealing the behaviour is still similar, so the annealing didn't cause type inversion

Annealing Study TCT confirmation

Epitaxial





Annealing Study TCT confirmation

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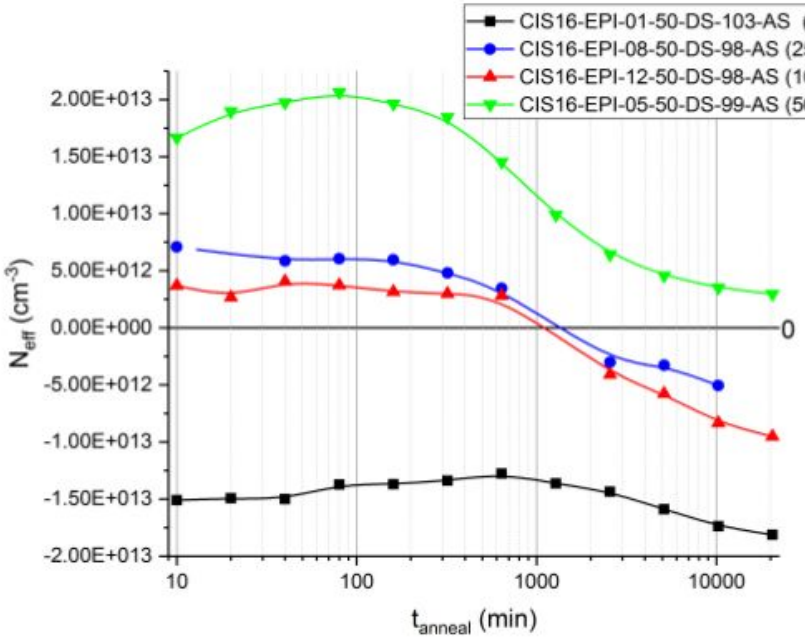

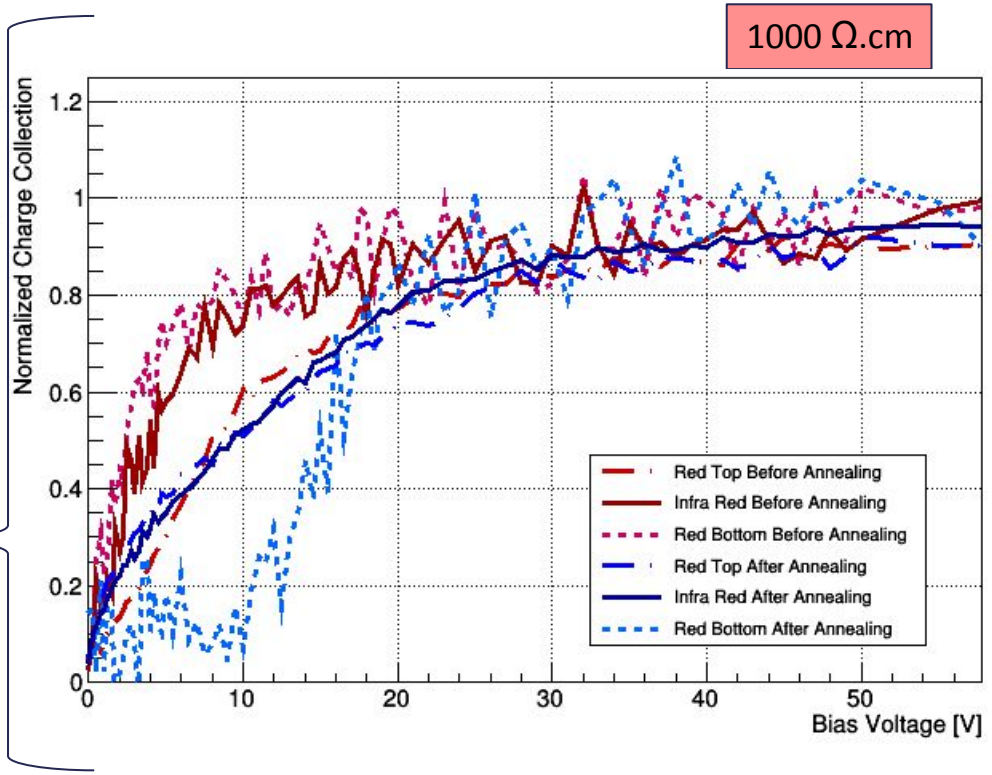

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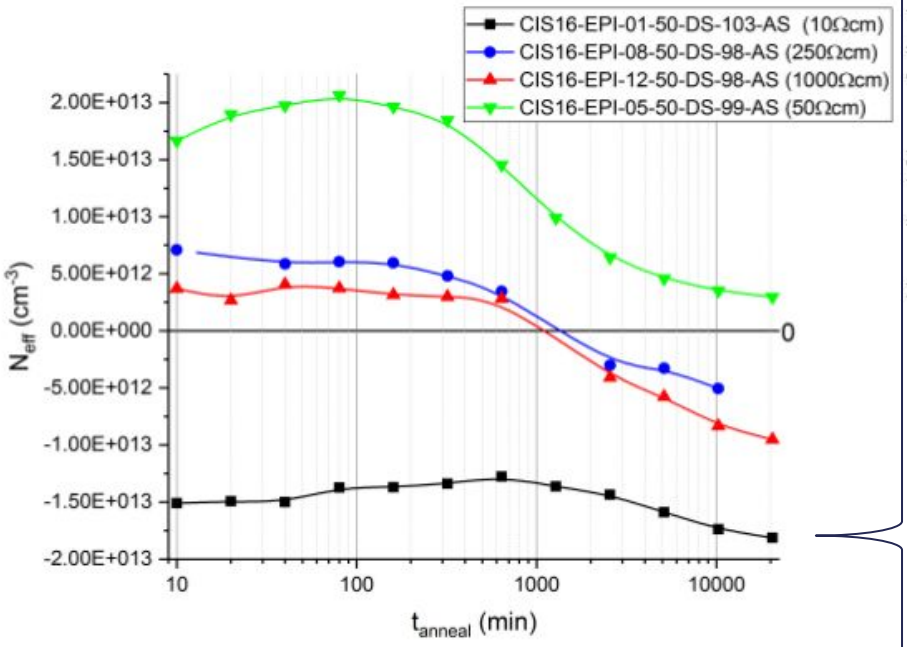
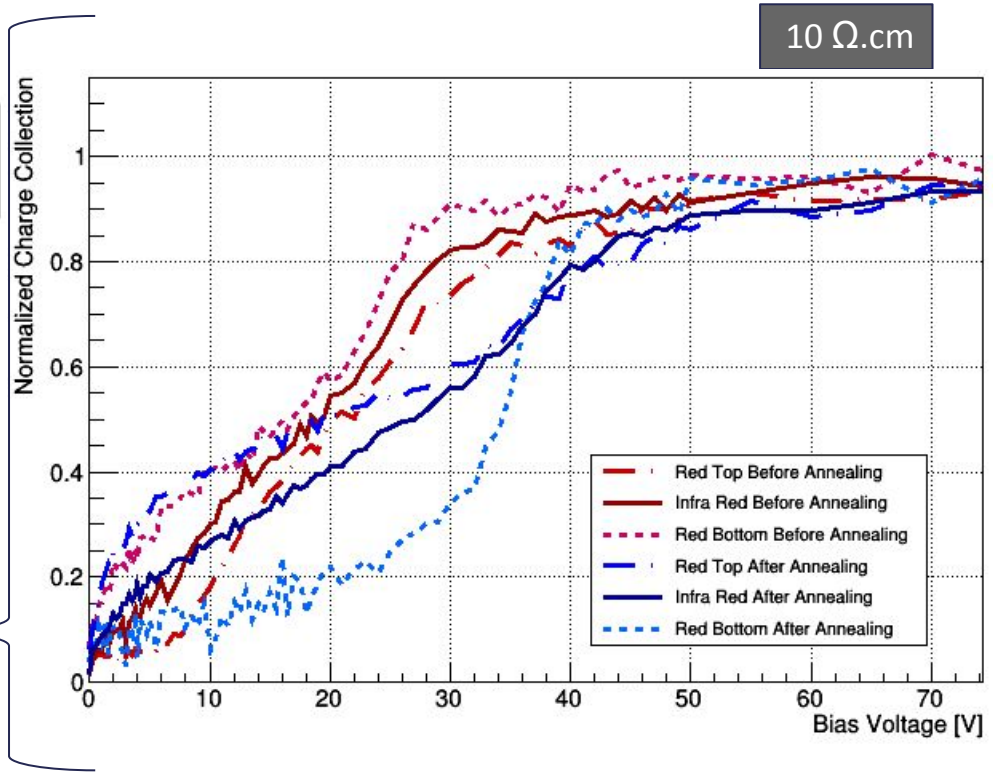
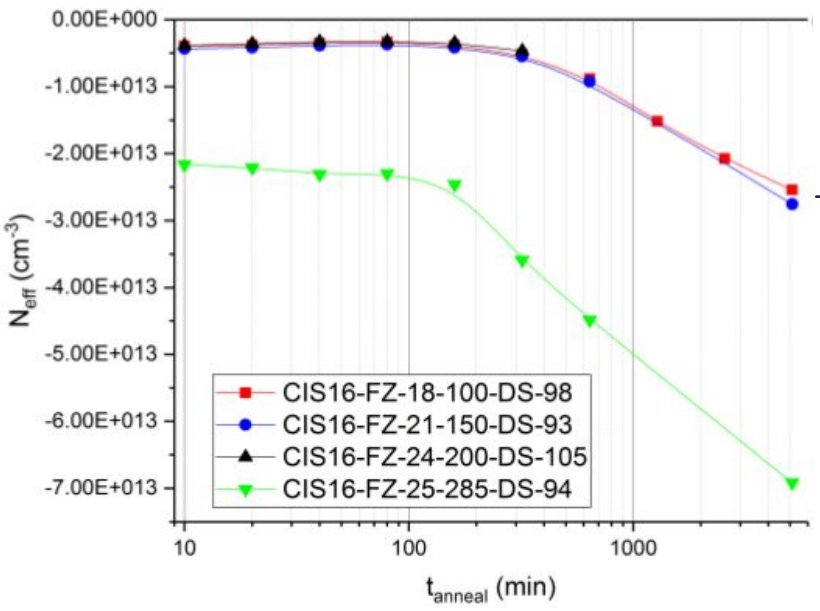


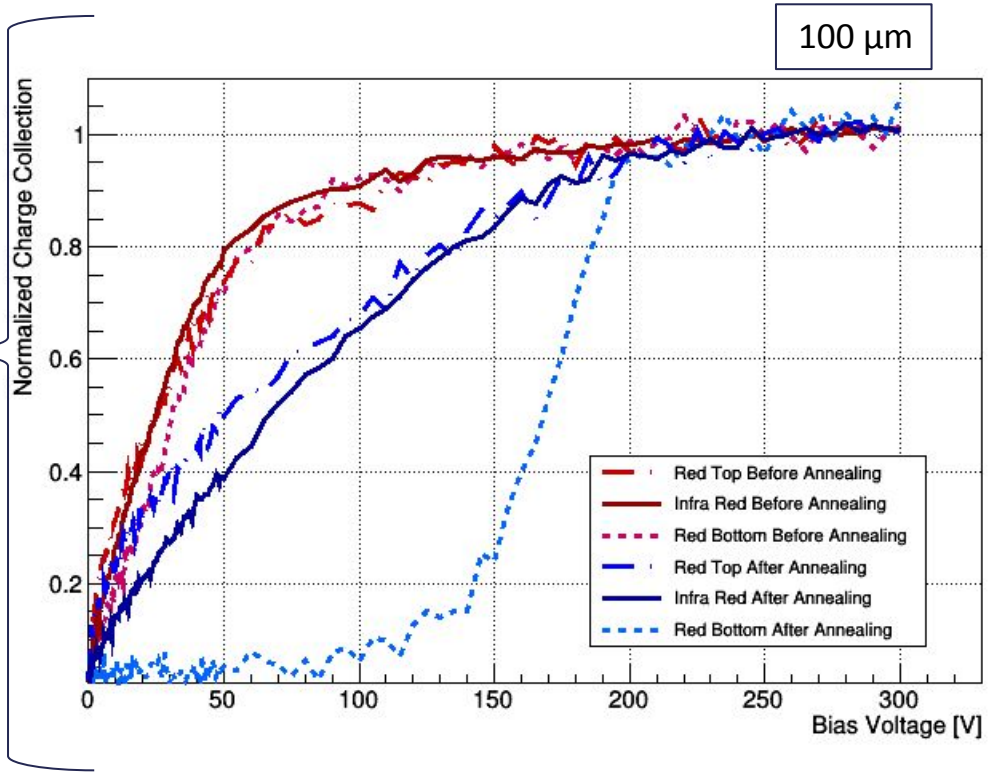


Strange sensor not yet understood

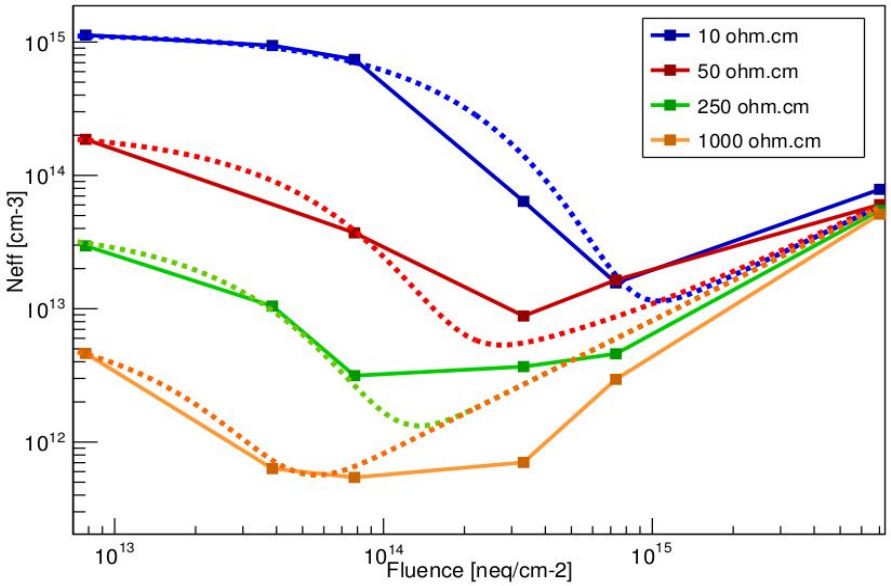
Annealing Study TCT confirmation

Epitaxial



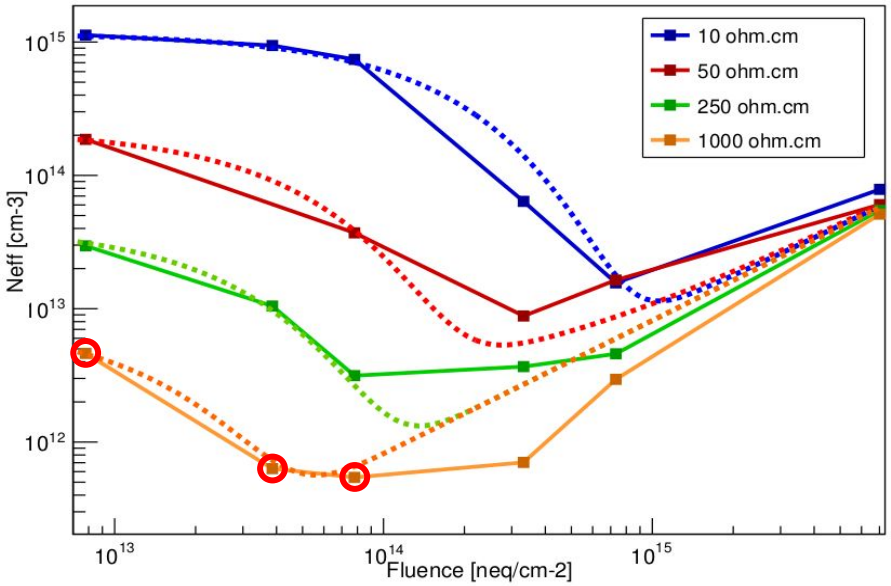


Acceptor Removal

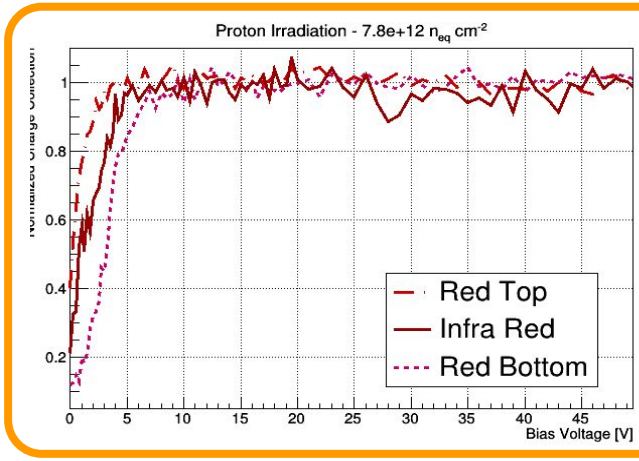


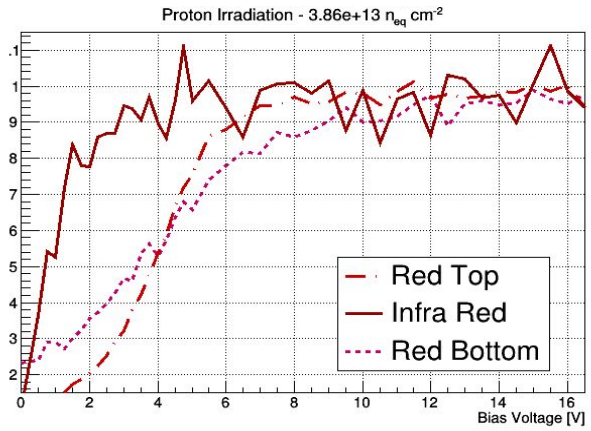
How does the acceptor removal parametrization change if we take type inversion into account?

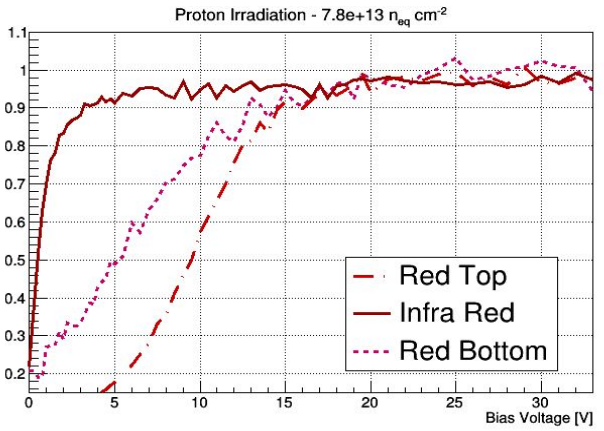
Acceptor Removal



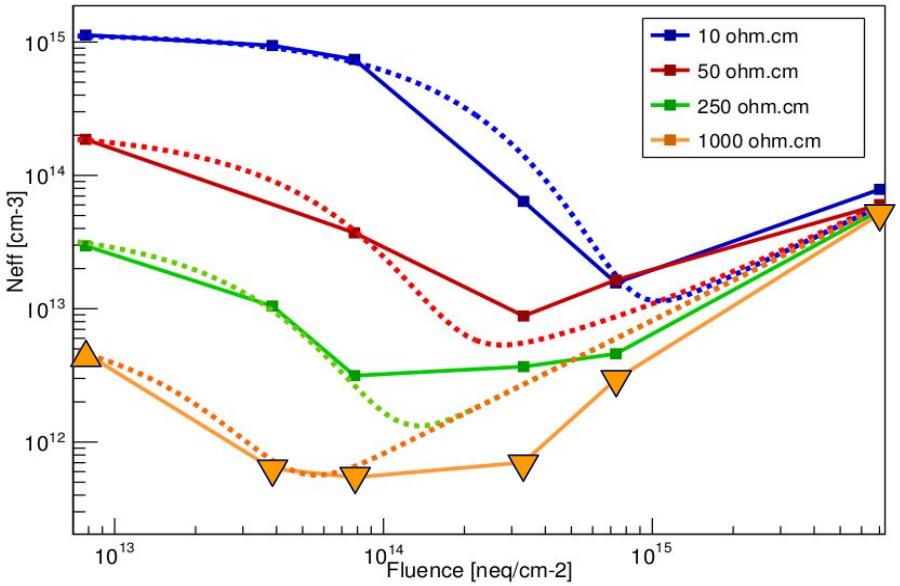
1000 Ω.cm





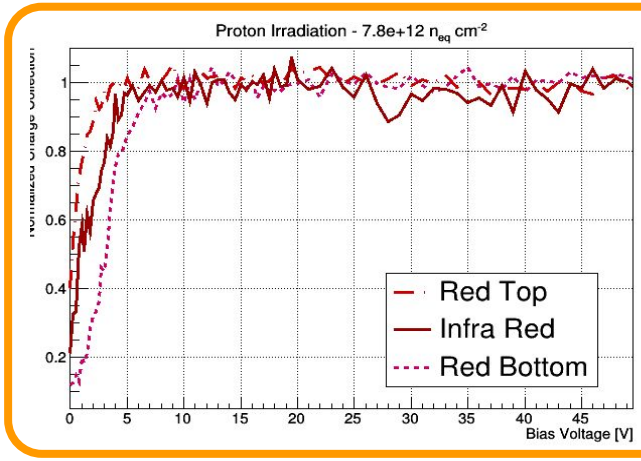


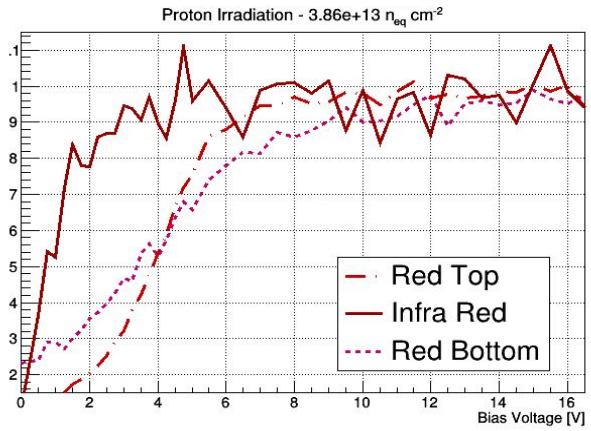
Acceptor Removal

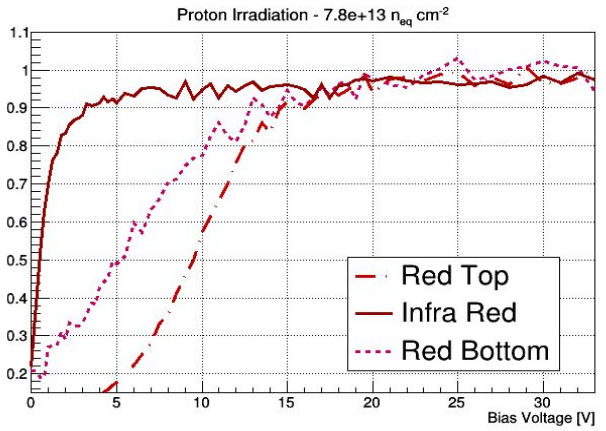


△ Depletes from the top
▽ Depletes from the bottom

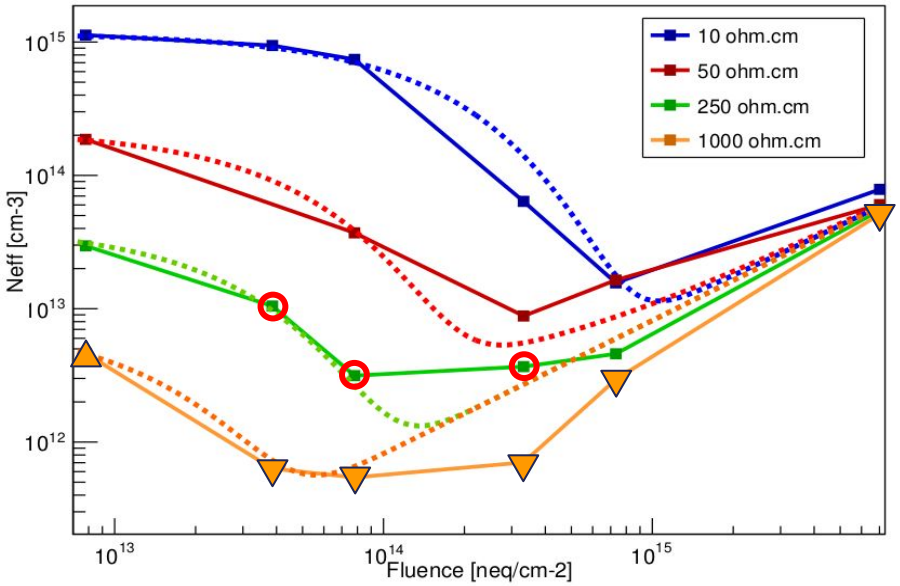
1000 Ω.cm







Acceptor Removal



△ Depletes from the top
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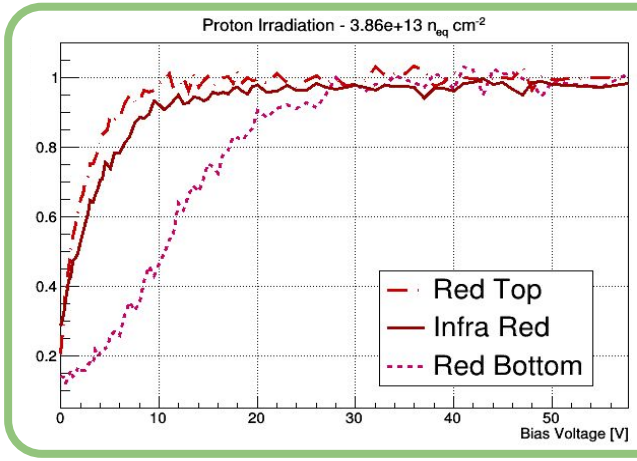
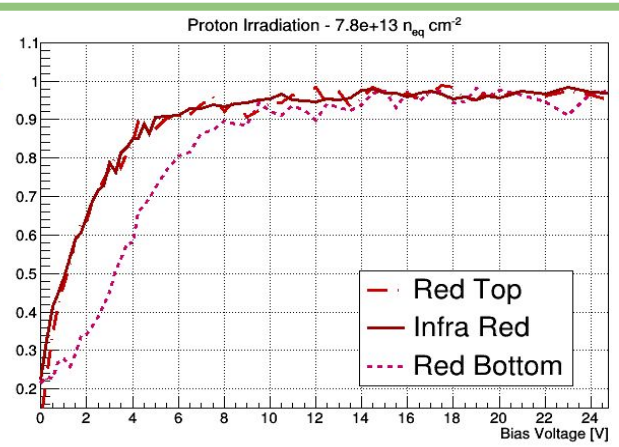
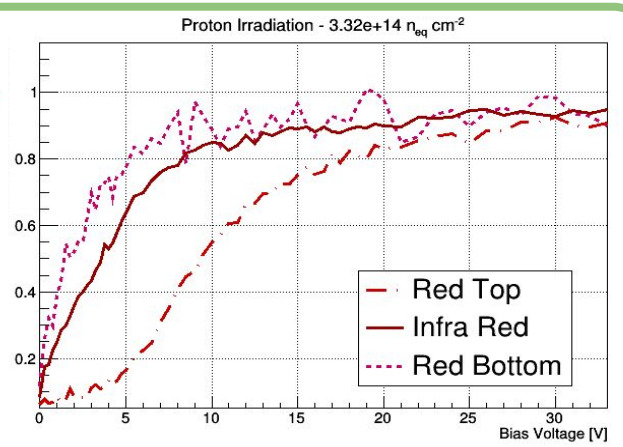
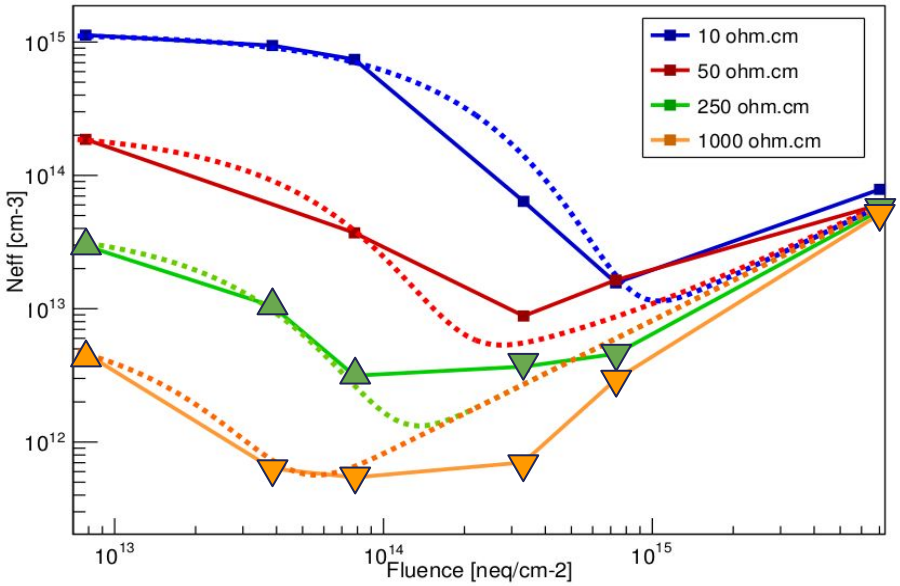
250 Ω.cm







Acceptor Removal



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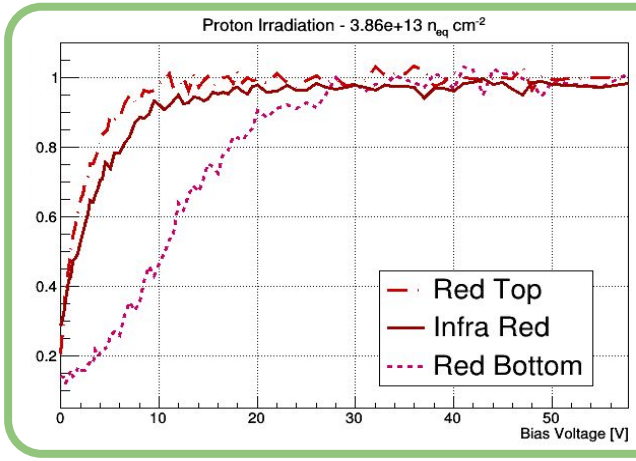
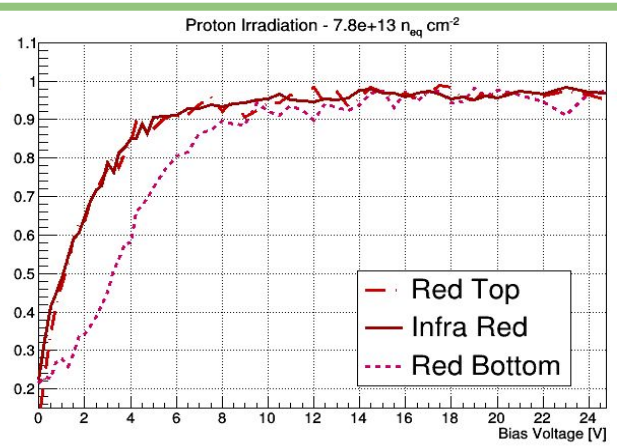
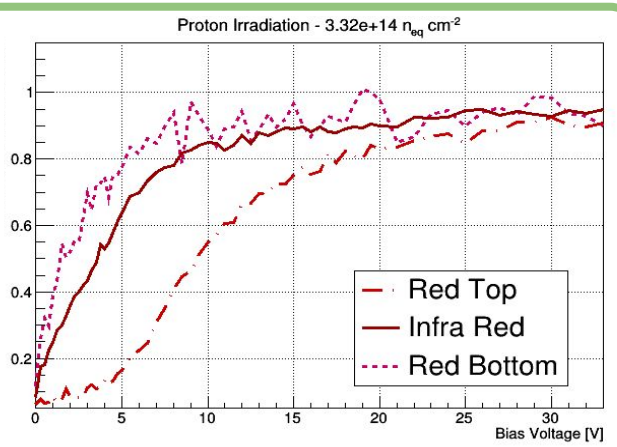
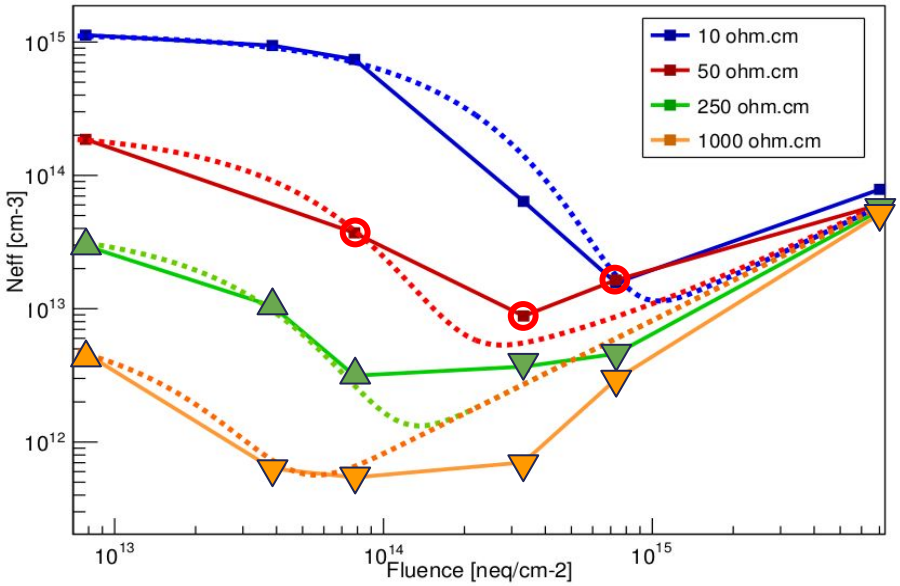
250 Ω.cm







Acceptor Removal



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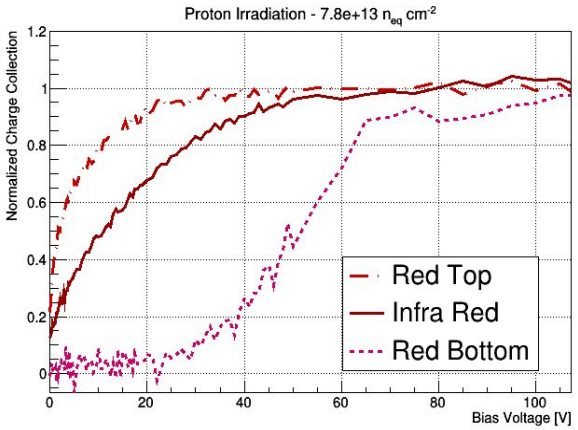
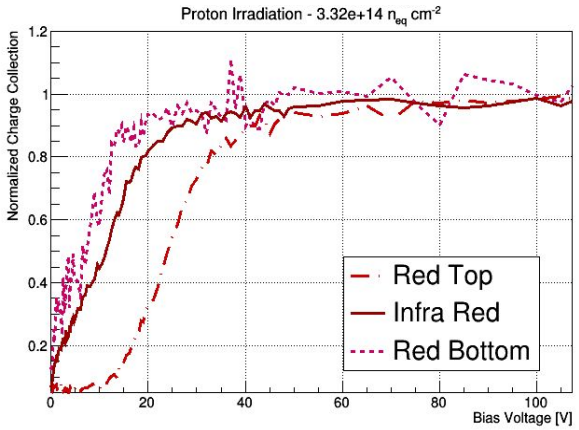
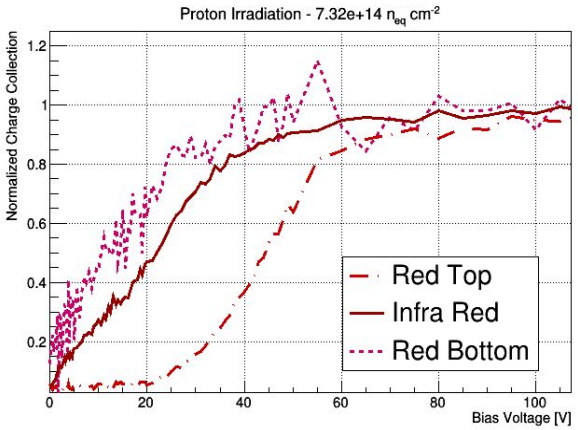
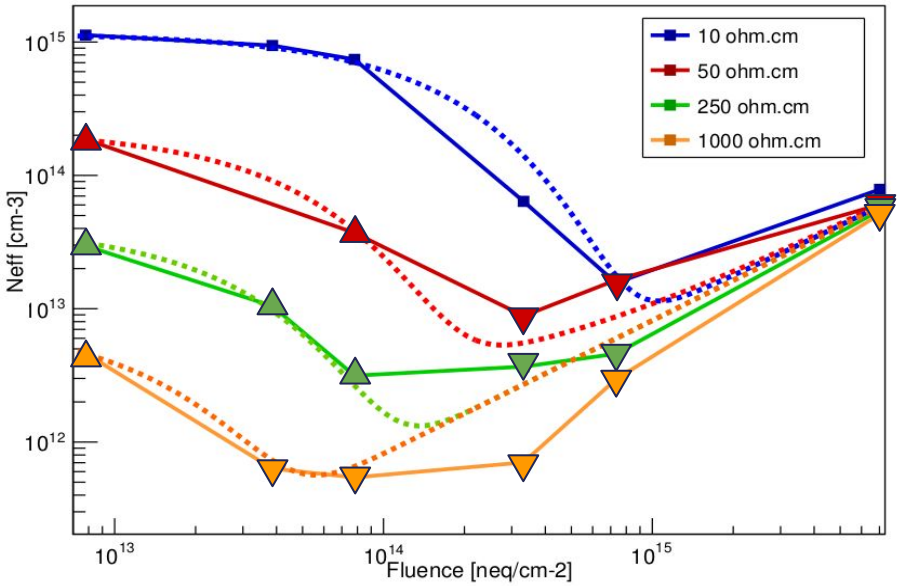
50 Ω.cm







Acceptor Removal



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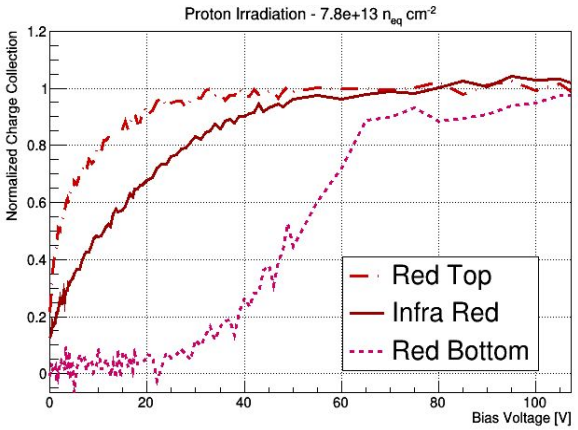
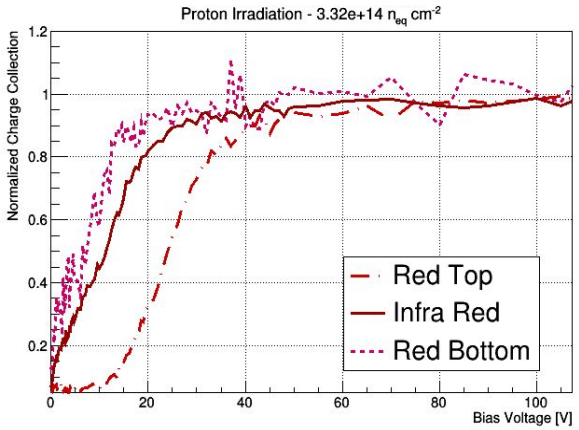
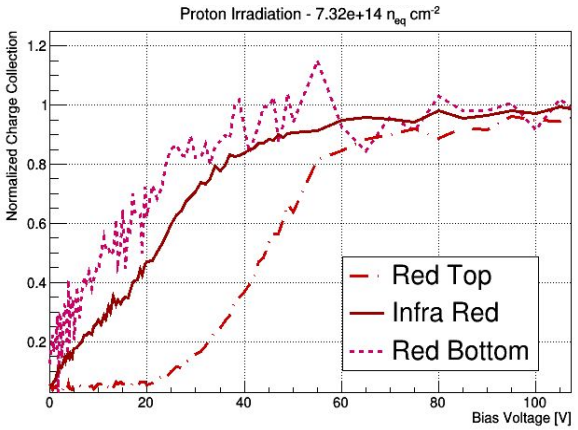
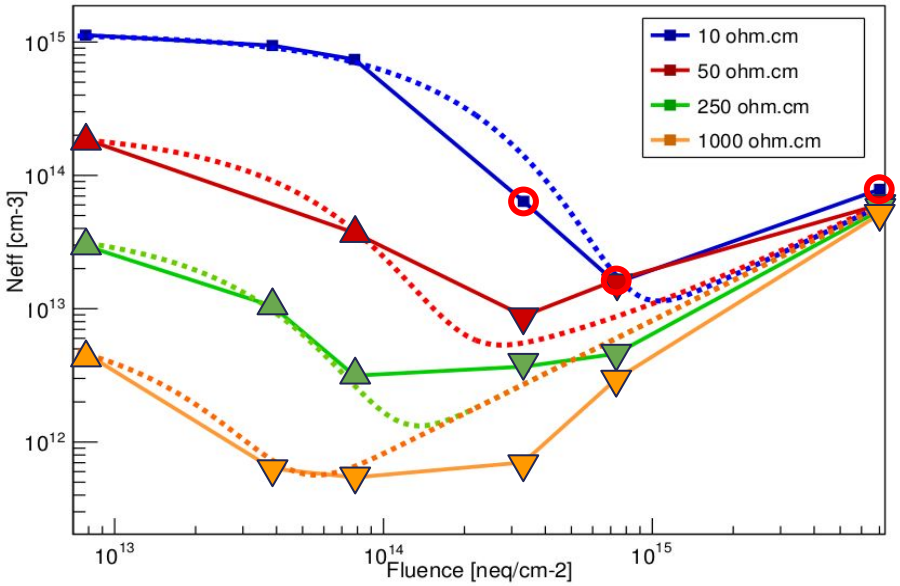
50 Ω.cm





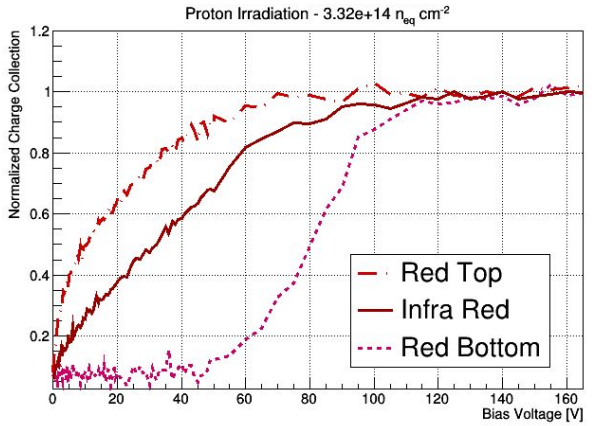


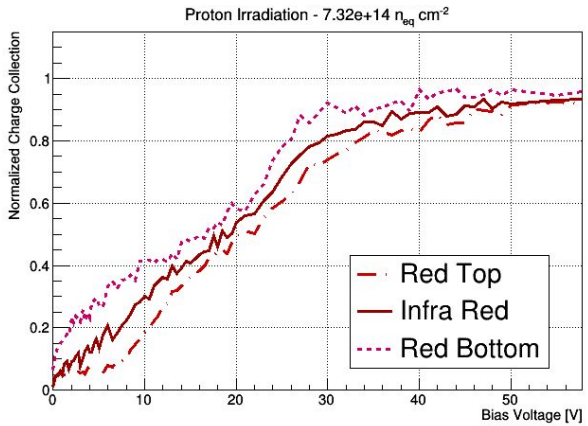
Acceptor Removal

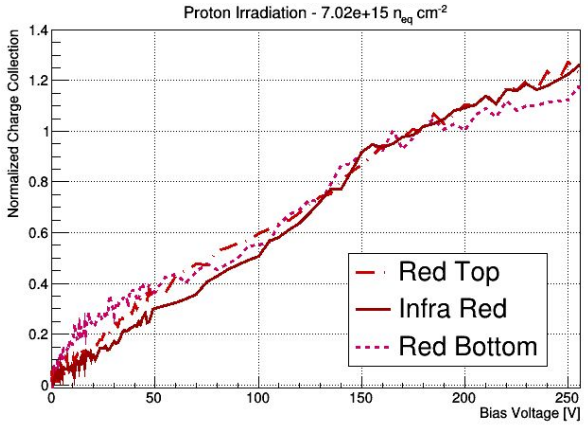


How does the acceptor removal parametrization change if we take type inversion into account?

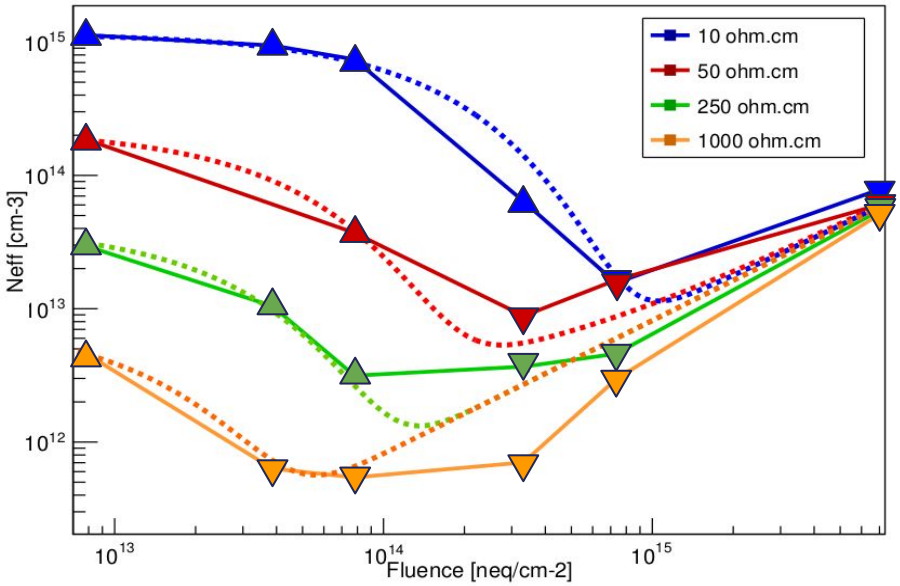
10 Ω.cm







Acceptor Removal



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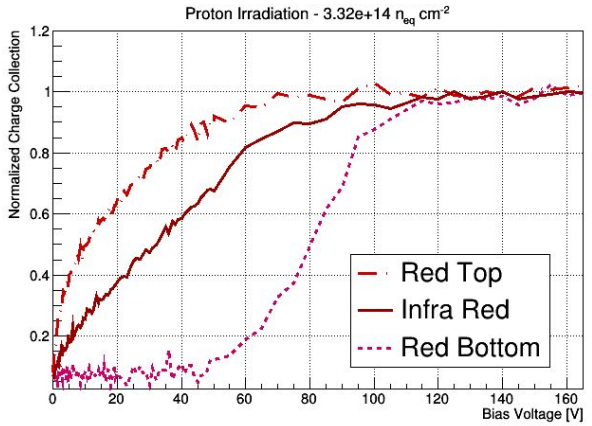
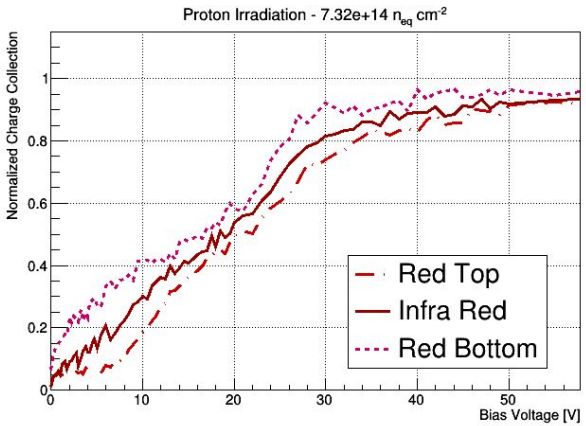
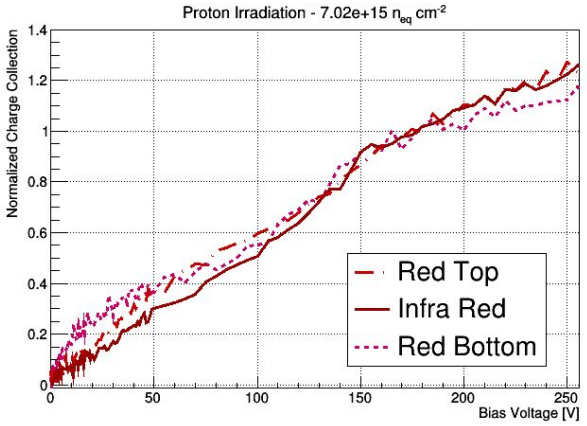
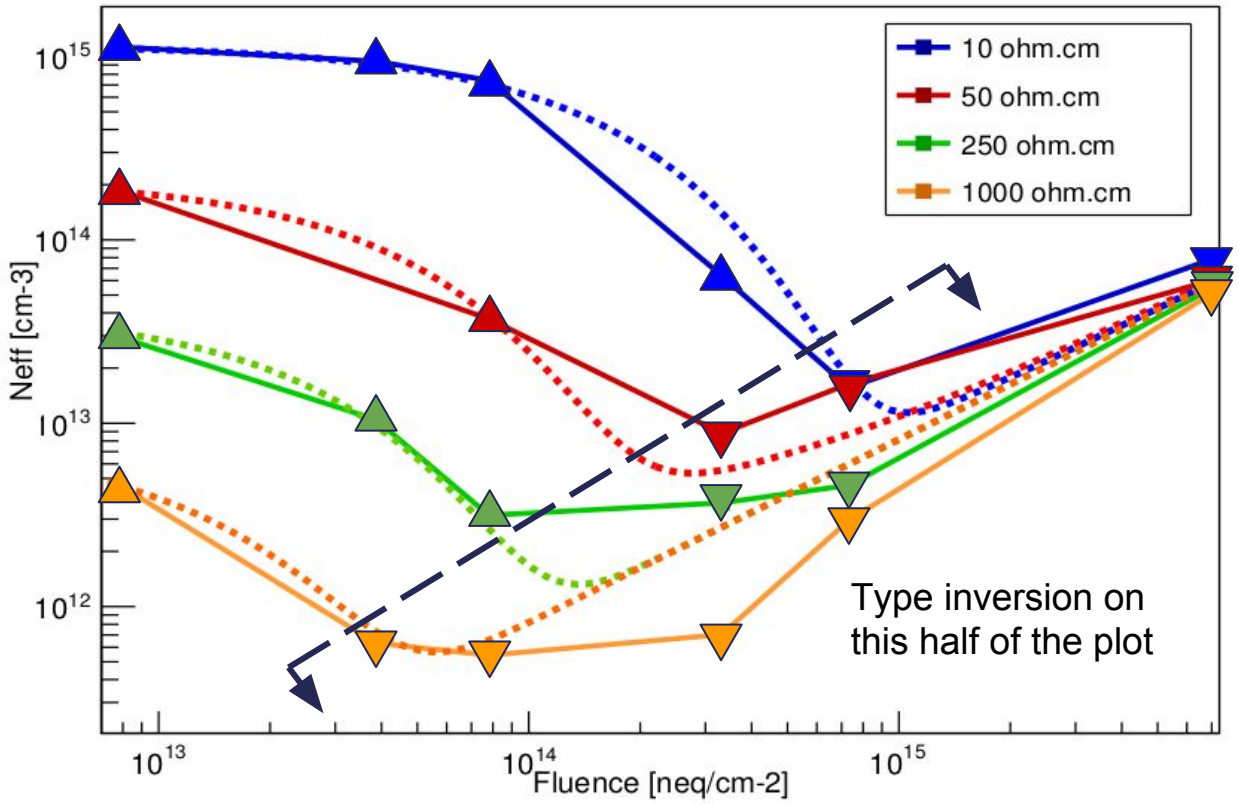
10 Ω.cm







Acceptor Removal



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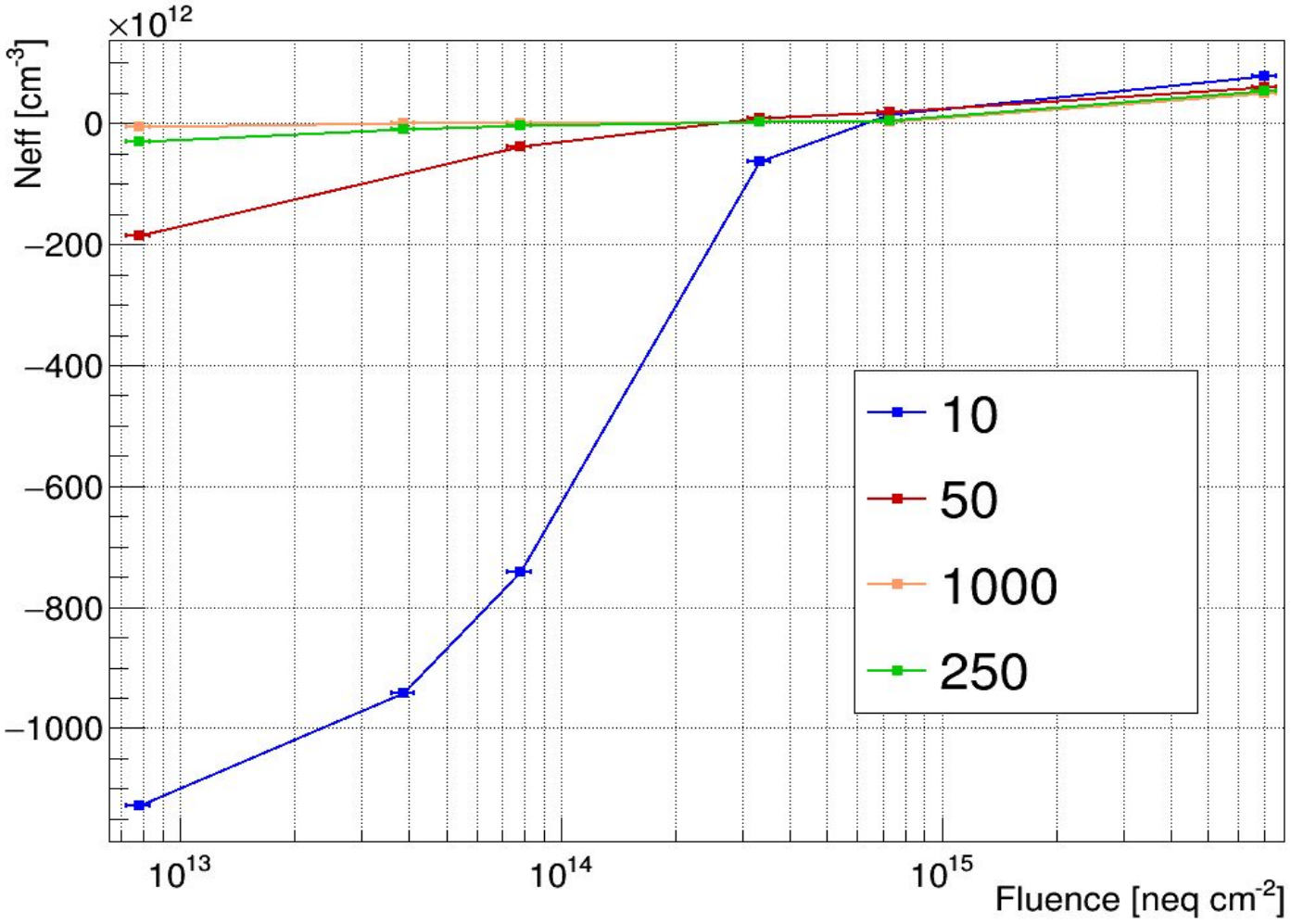
Acceptor Removal



Summary and Outlook

- Work in progress to study acceptor removal
- Annealing study of one fluence with very interesting results:
  - One fully type inverted detector (50 Ω.cm)
  - Two type inverted detectors returned to normal after annealing (250 and 1000 Ω.cm)
  - One stayed with negative space charge (10 Ω.cm)
- Using charge collection vs bias of different TCT illuminations it was possible to confirm type inversion
- The same method was used in rest of samples to determine the space charge and throughout the acceptor removal process

Upcoming

- Annealing study with neutron irradiated samples
- New c parameters from fitting
- What is the microscopic origin of positive space charge?