Investigation of neutron, proton, and gamma irradiated planar sensors using the Two Photon Absorption – Transient Current Technique

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[4]Universidad de Sevilla
[5]TU Dortmund University

https://indico.cern.ch/event/1270076

20.06.2023

42nd RD50 workshop – S. Pape in Tivat

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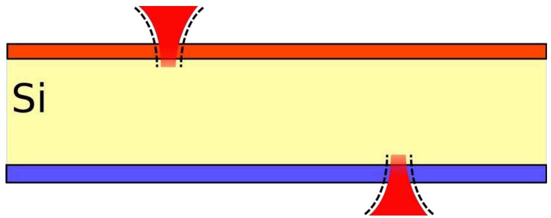
Single Photon Absorption-TCT

λ ≈ 700 nm



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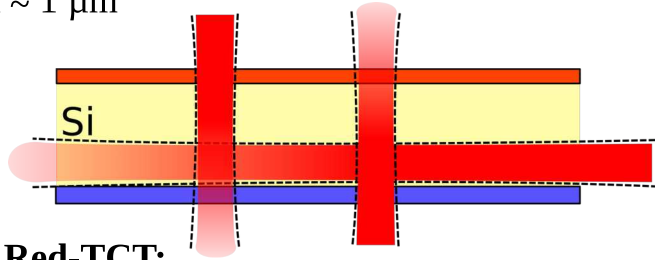

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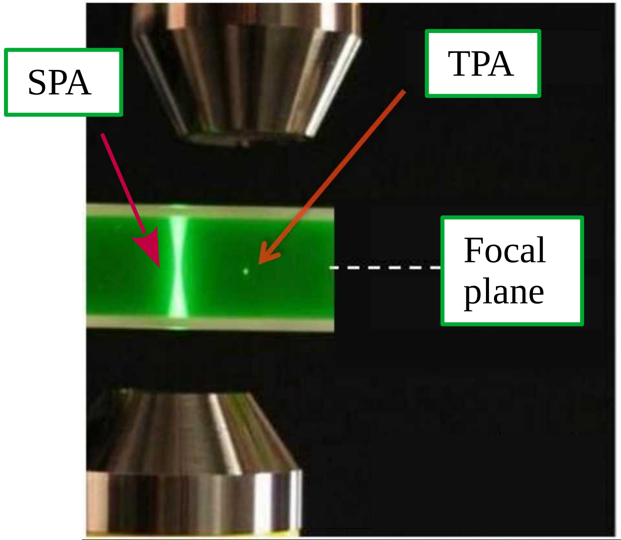
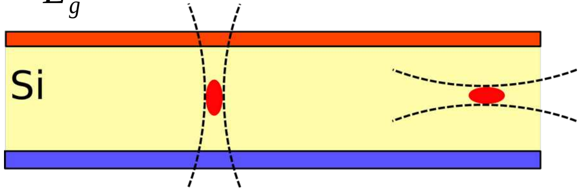


Photography: **Ciceron Yanez**, University of Central Florida

Two Photon Absorption-TCT

$$\lambda > \frac{hc}{E_g}$$



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- Non-linear effect, depends quadratic on the intensity

→ main excitation around focal point

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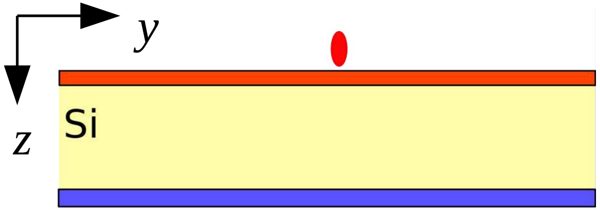

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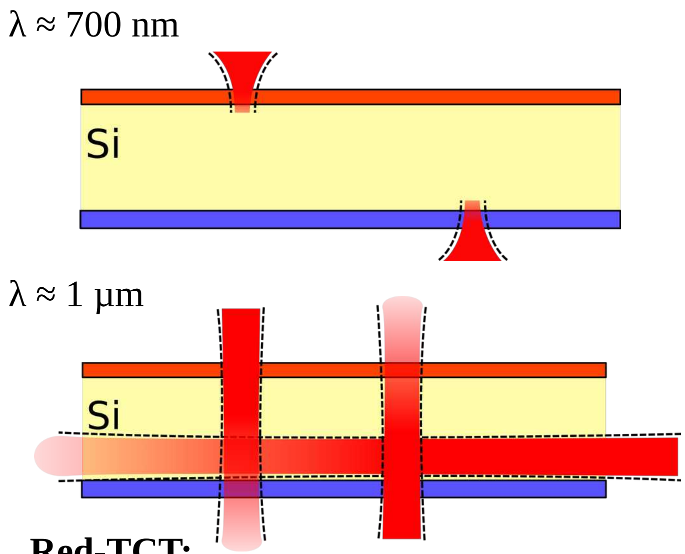

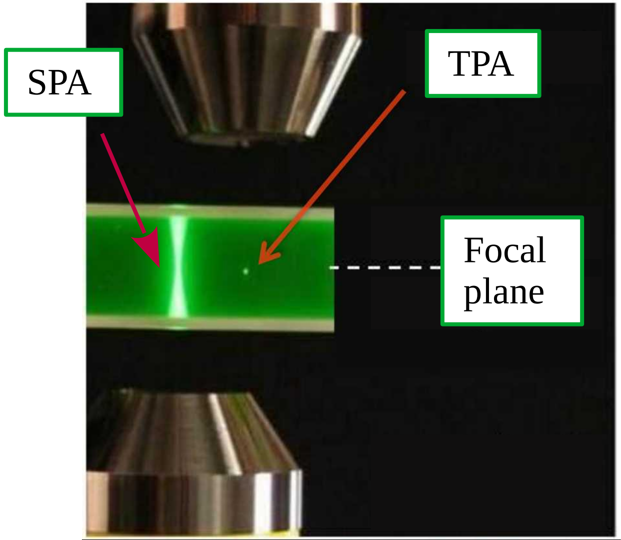

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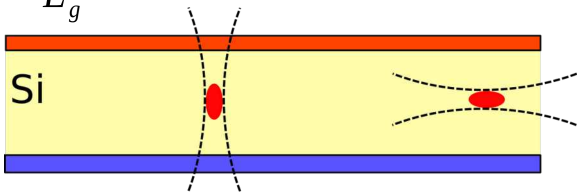

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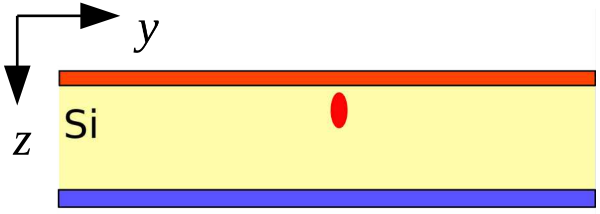
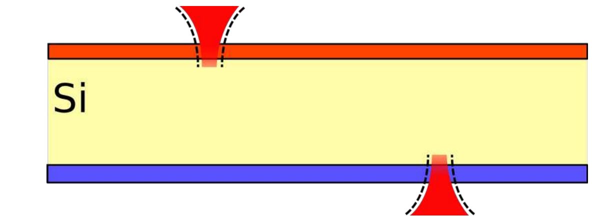


Single Photon Absorption-TCT

$\lambda \approx 700$ nm



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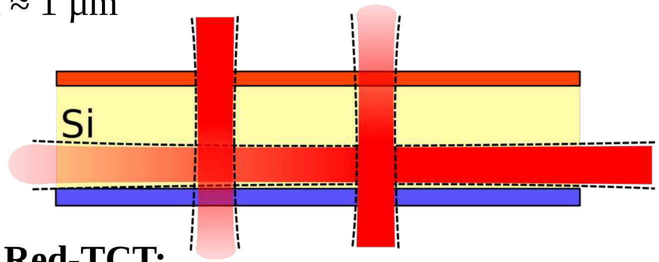

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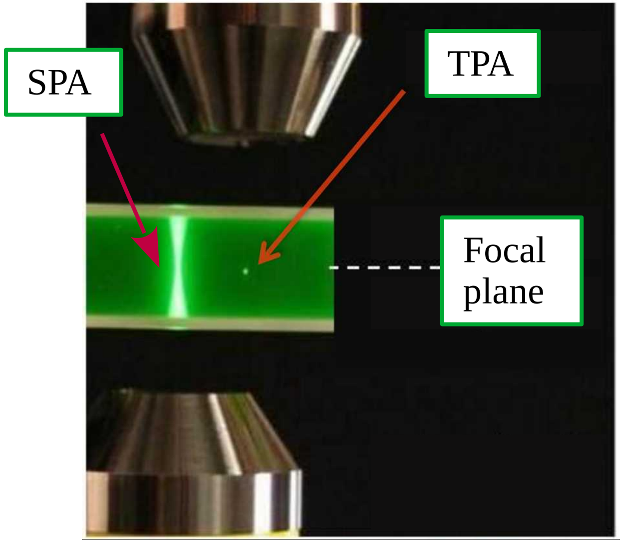

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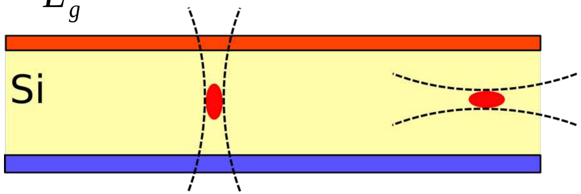

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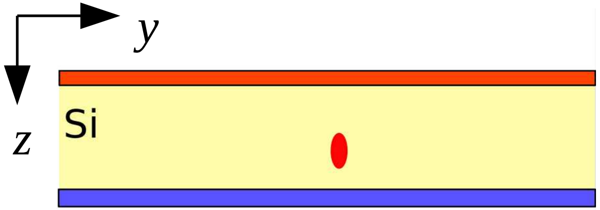

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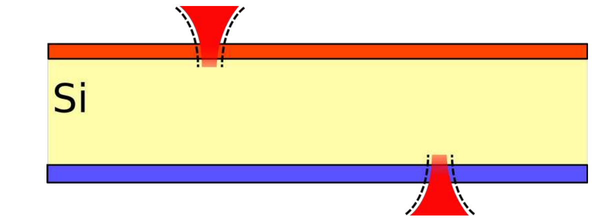

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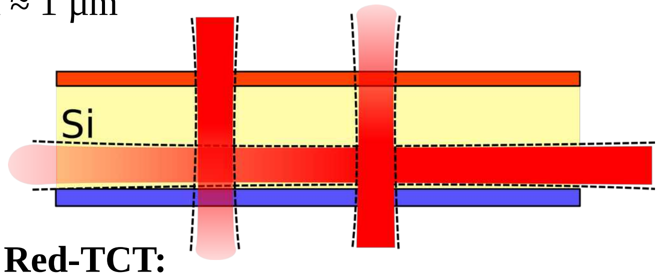

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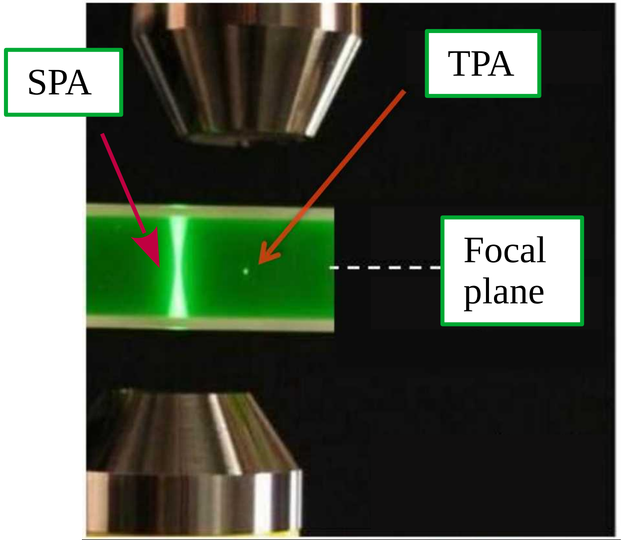

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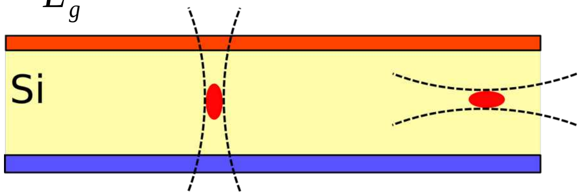

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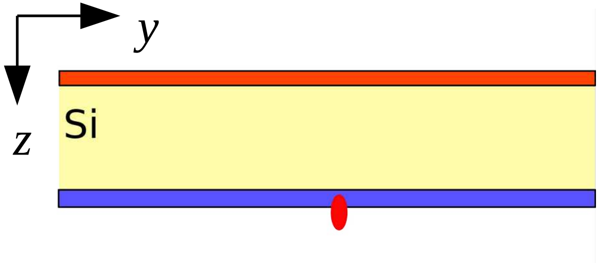
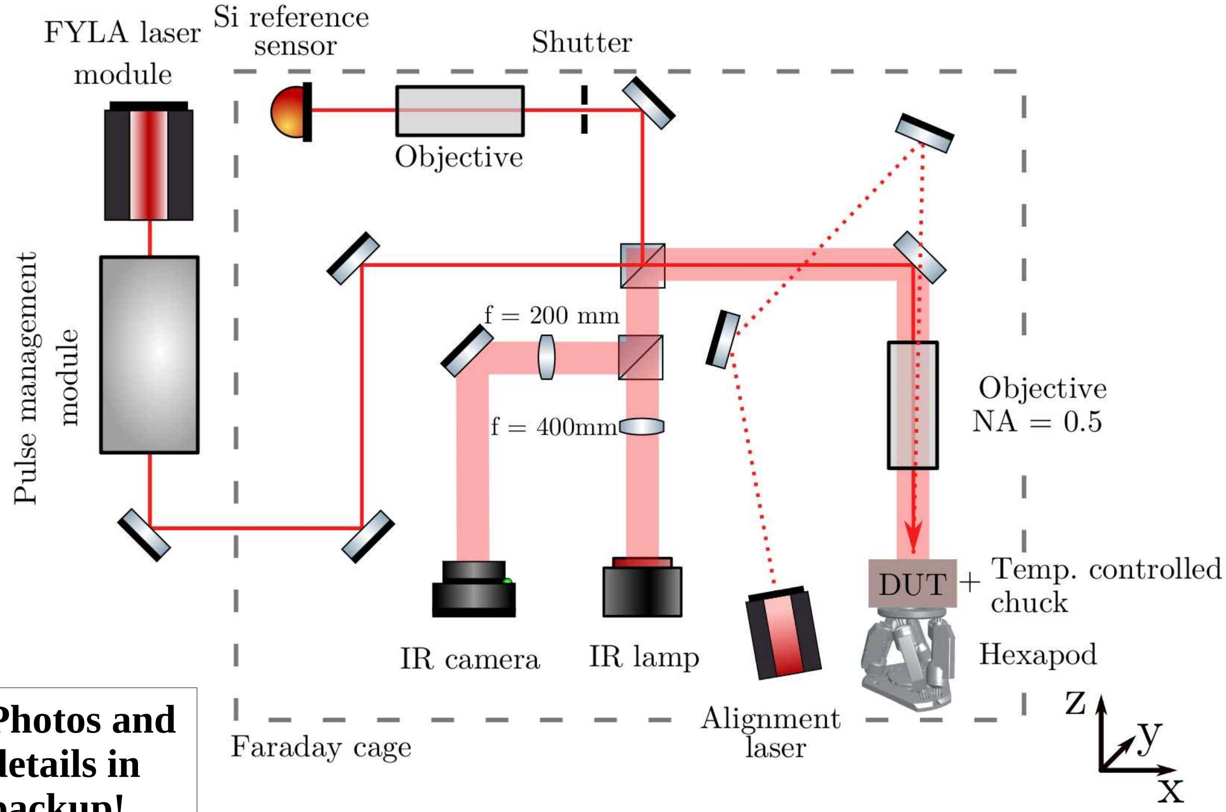


TPA-TCT: Setup & Calibration

Sketch of the TPA-TCT setup at CERN SSD:

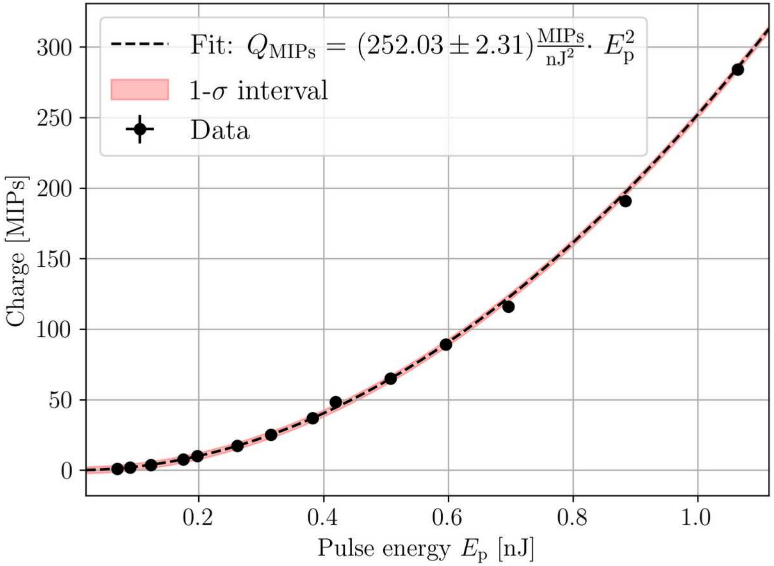


Photos and details in backup!

M. Wiehe et al.:
Development of a Tabletop Setup for the Transient Current Technique Using Two-Photon Absorption in Silicon Particle Detectors

Calibration:

Pulse energy against generated charge (in a 285 µm PIN; NA = 0.5 at 20°C and 0% humidity):



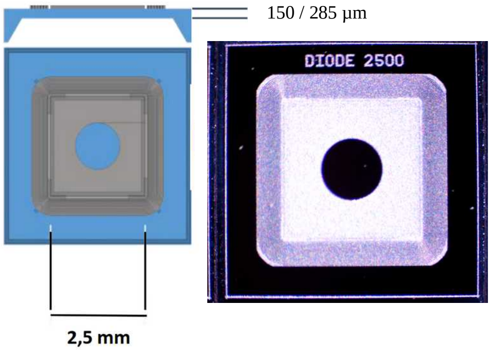
The pulse energy is measured with a S401C thermal power sensor from Thorlabs.

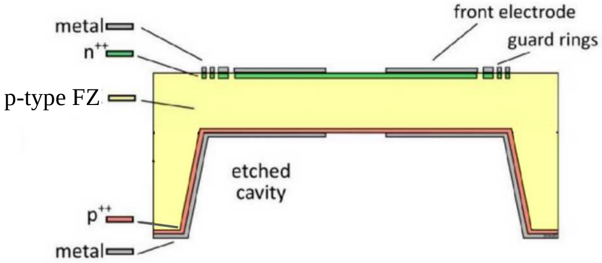
$Q = \alpha I + \beta_2 I^2$ → pure quadratic behavior shows absence of SPA

Details about the used samples

Design of the planar sensors:

CiS Forschungsinstitut für Mikrosensorik GmbH

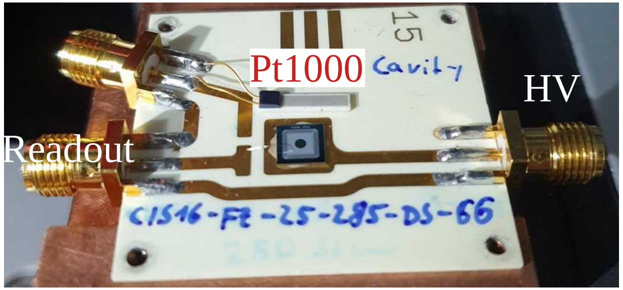




CIS16 FZ planar diodes, p-type, >10kΩ·cm, 2.632×2.632mm² active area

Thickness [µm]	Type of irradiation	Facility	Fluence	Annealing
285	Neutron	TRIGA JSI	≤ 7.02×10^{15} n / cm2	10min @ 60C 6600min @ 20C
150	Neutron	TRIGA JSI	≤ 7.02×10^{15} n / cm2	10min @ 60C 6600min @ 20C
150	Proton	CERN PS (23GeV)	≤ 1.17×10^{16} p / cm2	10min @ 60C 6600min @ 20C
150	Gamma	IRB Zagreb (^{60}Co)	< 200 Mrad	None

Measurement temperature: (-20±0.1)°C
Humidity: flushed with dry air (~0%)



Radiation damage

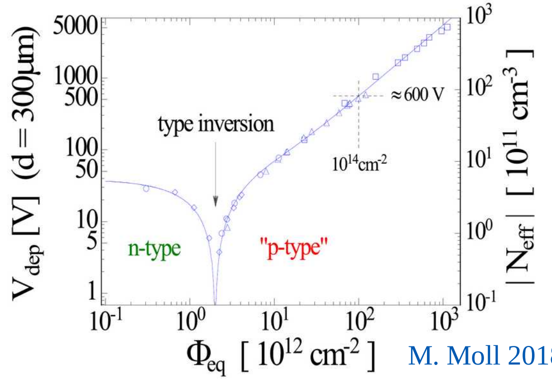
Radiation introduces damage due to non-ionising energy loss (NIEL) in form of point and cluster defects.

Defects can introduce energy states within the band gap and:

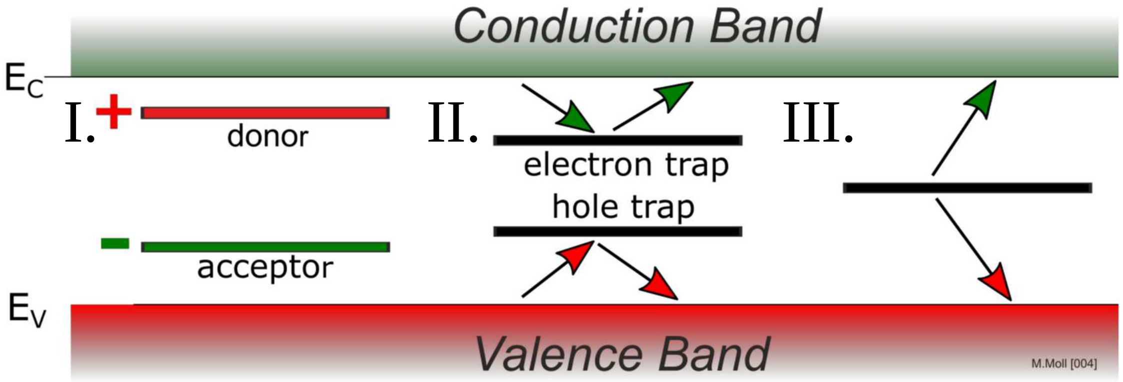
I. act as acceptor and donor levels → change in the effective doping

II. trap charge carriers → loss in collected charge

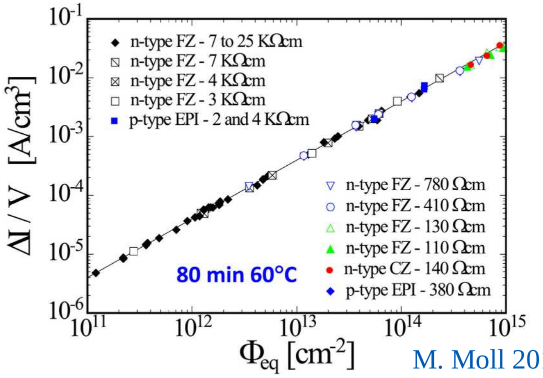
III. function as current generation centers → increasing leakage current



M. Moll 2018



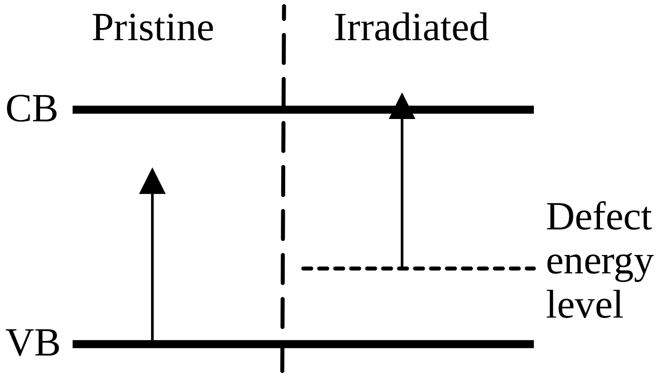
M. Moll 2021



M. Moll 2018

Influence of radiation damage on the TPA-TCT

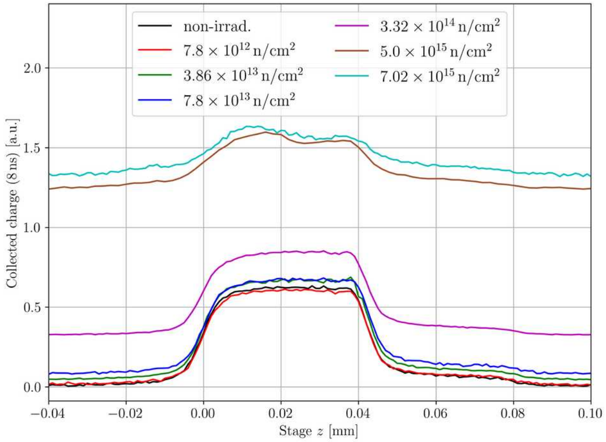
Radiation damage can introduce new energy levels in the band gap that trap charge carriers



→ Trapped charge carriers can be excited by a single 1550nm photon

→ This enables a parasitic single photon absorption component to the TPA-TCT measurement

In depth measurements of neutron irradiated PINs:



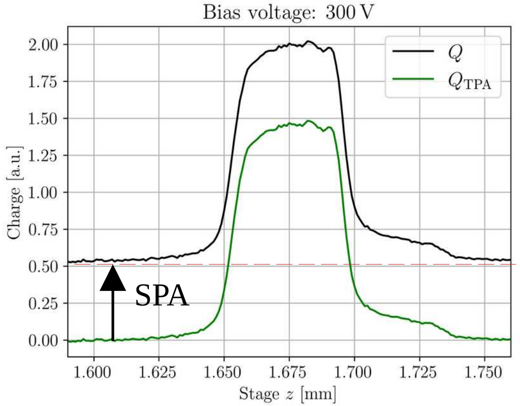
→ Parasitic SPA component is found as a offset, as it is not depth dependent $Q_{SPA}(z)$ = const

→ Different methods to correct this SPA component were developed

Methods for the SPA correction

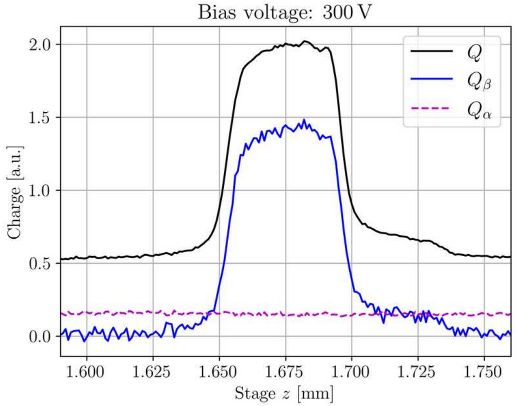
SPA correction: Removal of the parasitic single photon absorption contribution in irradiated detectors

I. Subtraction of constant



- Simplest method
  → Simple subtraction of constant offset
- Can be used to correct the SPA offset
- Does not correct for SPA on waveform level
  → shape of the waveforms are still impacted by SPA

II. Correction by intensity



- Most sophisticated method
  → required two measurements at different laser intensities
- SPA offset correction
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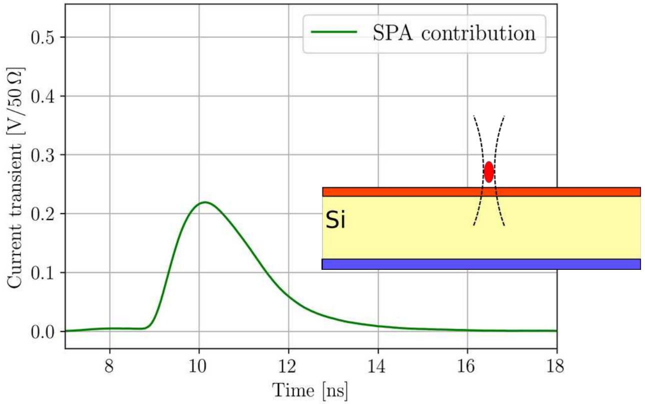
- see M. Fernández García et al. for details
  → **Can be applied if laser intensity varies over scan (e.g. by clipping)**

III. Subtraction on waveform level



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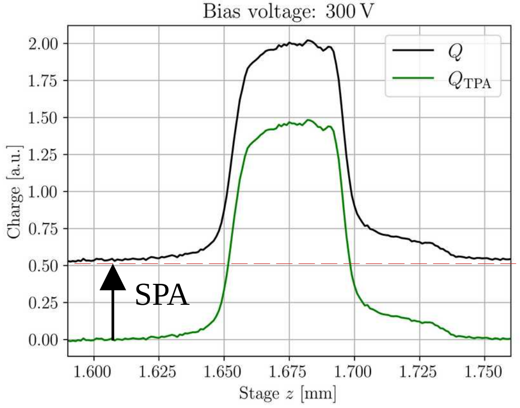

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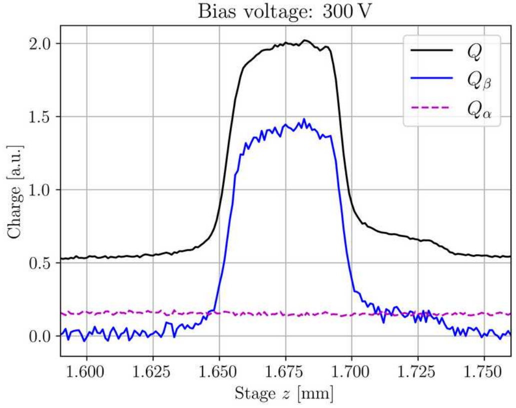

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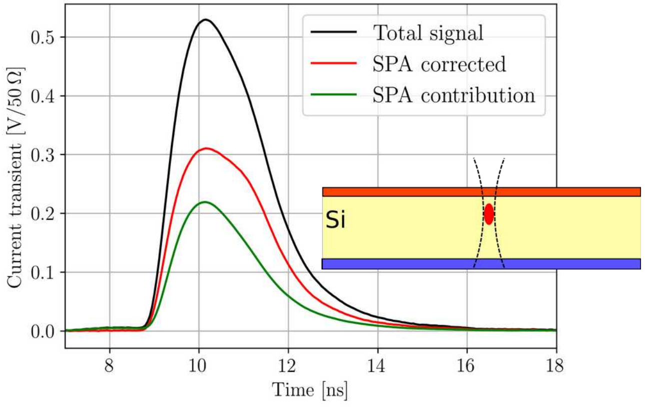

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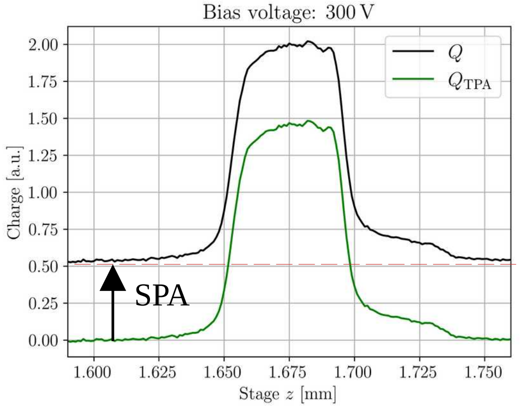

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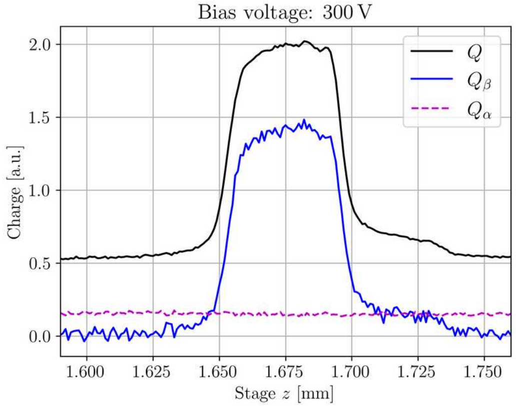

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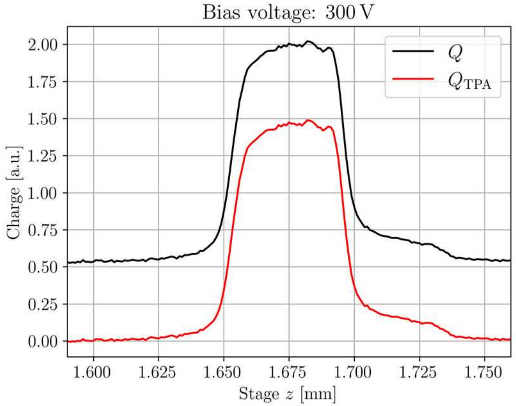

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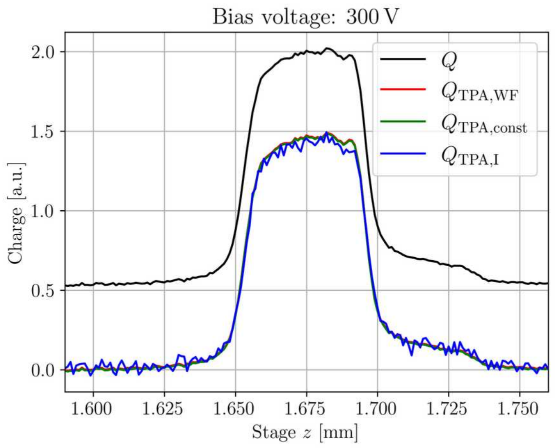
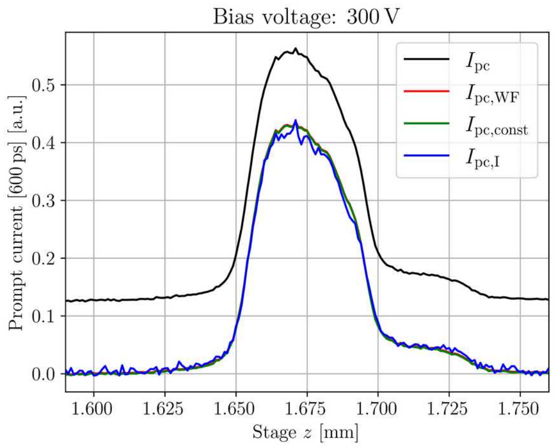
Comparison between the methods

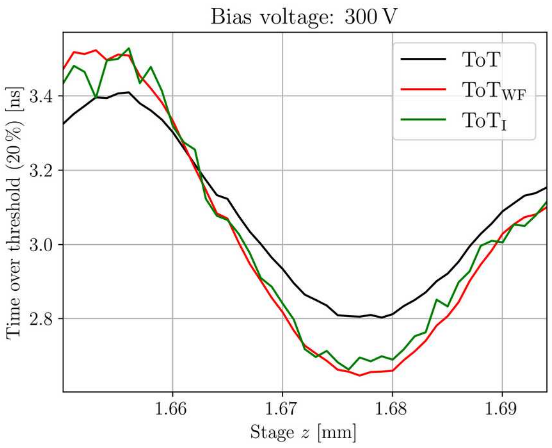
Collected charge:



Prompt current:



Time over threshold:

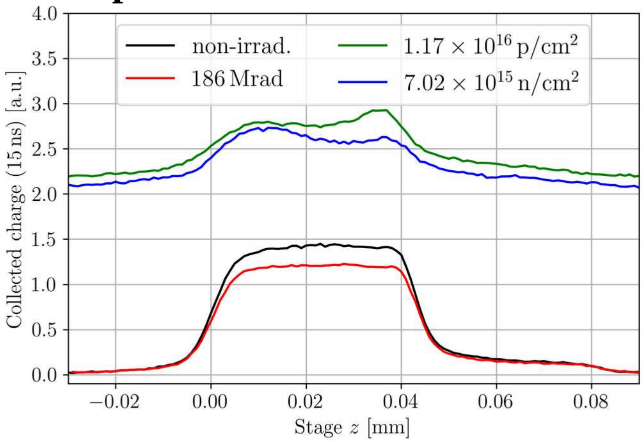


- All methods correct the SPA contribution in the CC and prompt current
- Correction by intensity is more noisy, because the lower SNR of the low intensity measurement propagates

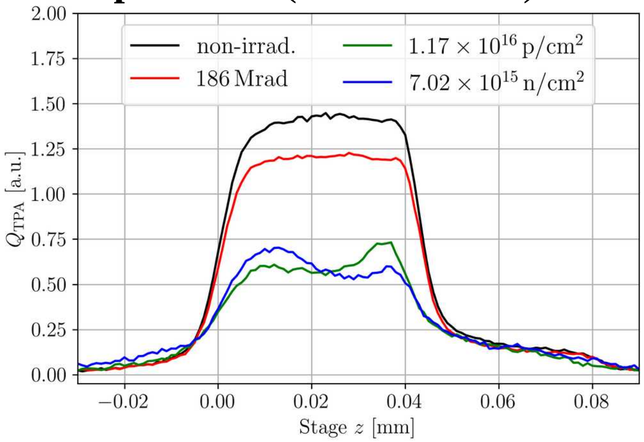
- Method II. & III. correct the SPA contribution to the WF's shape
- Method I. can not be applied to correct the ToT profile

Comparison between neutron, proton, and gamma irradiated samples

Depth scans:



Depth scans (SPA corrected):



Neutron & proton irradiation:

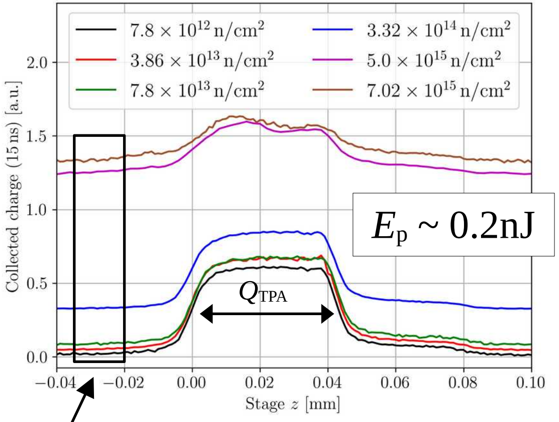
→ Both lead to a SPA offset
→ Charge loss depends on depth position of charge deposition
→ for the picked fluence they both show a double junction (see prompt current plots in the backup)

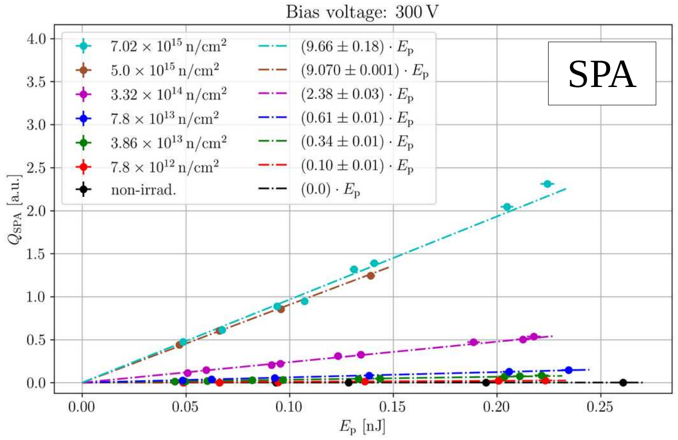
Gamma irradiation:

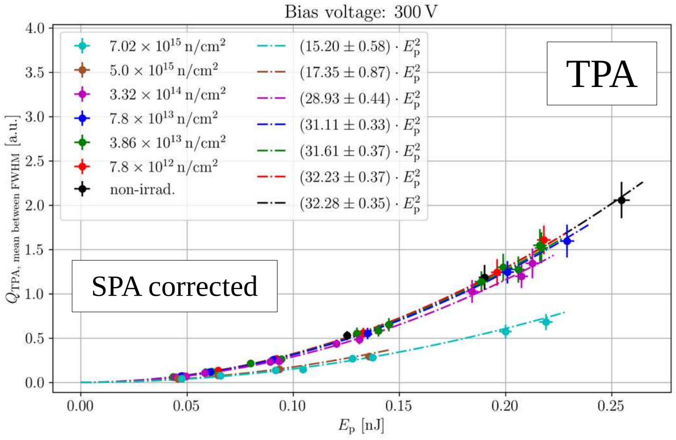
→ **No SPA offset visible!**
→ Charge loss is constant throughout the device depth

Analysis procedure on the example of the neutron irradiated samples

Extraction of Q_{SPA} & Q_{TPA}:







Q_{SPA} : Average of the collected charge of the first 10 waveforms

Q_{TPA} : Mean of the collected charge between FWHM (SPA corrected)

Q(z) measurements are performed for various intensities and fitted:

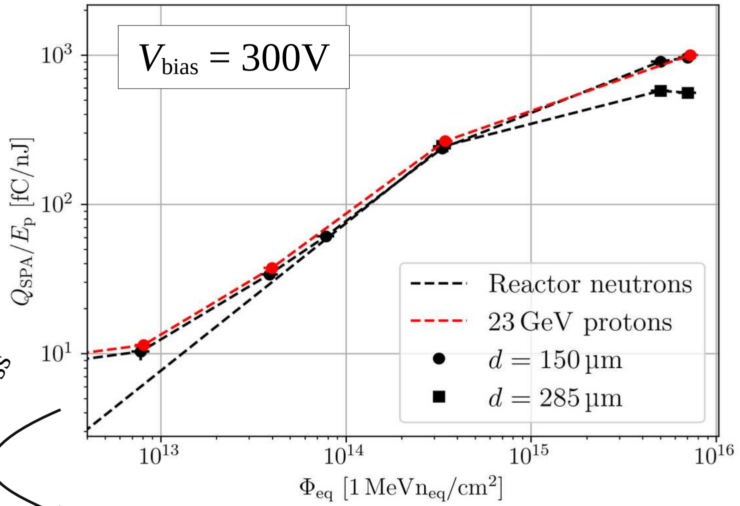
$Q_{SPA}(E_p) = m \times E_p$
$Q_{TPA}(E_p) = x_1 \times E_p^2$

Observation:

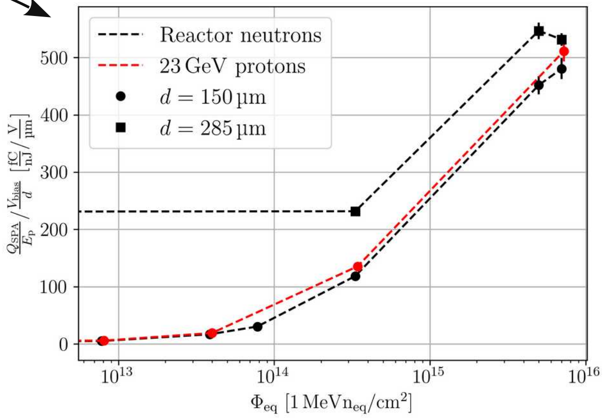
- SPA background follows linear function
- SPA increases steadily with fluence

- TPA follows purely quadratic function
- Collected charge decreases steadily with fluence

Fluence scaling of the SPA contribution



Normalised by V_{bias} / thickness



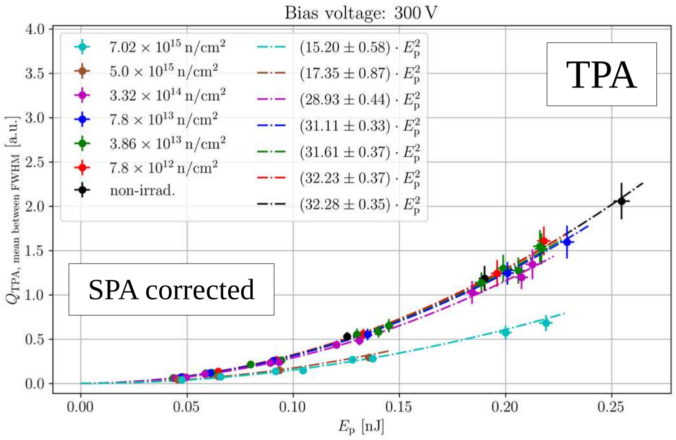
Observation:

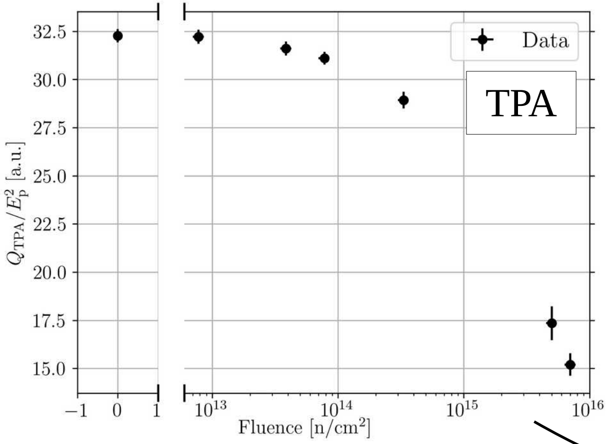
- Higher fluence ↔ higher SPA background for proton & neutron irrad.
- Scaling with equivalent fluence is similar for **proton** and **neutron** irradiation
- Approx. linear in log-log plot for <$10^{15} n_{eq}/cm^2$ (function: $C \cdot \Phi^m$)
- Different thickness ↔ different electric field
  → needs to be considered to compare different thicknesses

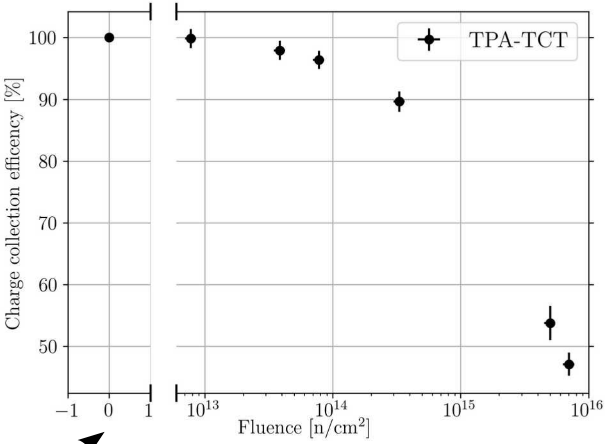
Conclusion:

- **Protons** & **neutrons** create damage that leads to similar influence on TPA measurements
- Thicker samples generate more SPA (as SPA depends on the thickness) ↔ also have higher trapping due to longer drift time

Neutron irradiation: TPA contribution







Normalise by Q_{unirrad}

Observation:

- Q_{TPA} / E_p decreases with fluence
- Fitting parameter can be used for to express the average charge over the device thickness

Remarks:

- Direct conclusion of CCE is not possible, because the TPA coefficient could be affected by irradiation → charge generation could be changed by irradiation

Neutron irradiation: Crosscheck CCE measurements with a ^{90}Sr setup

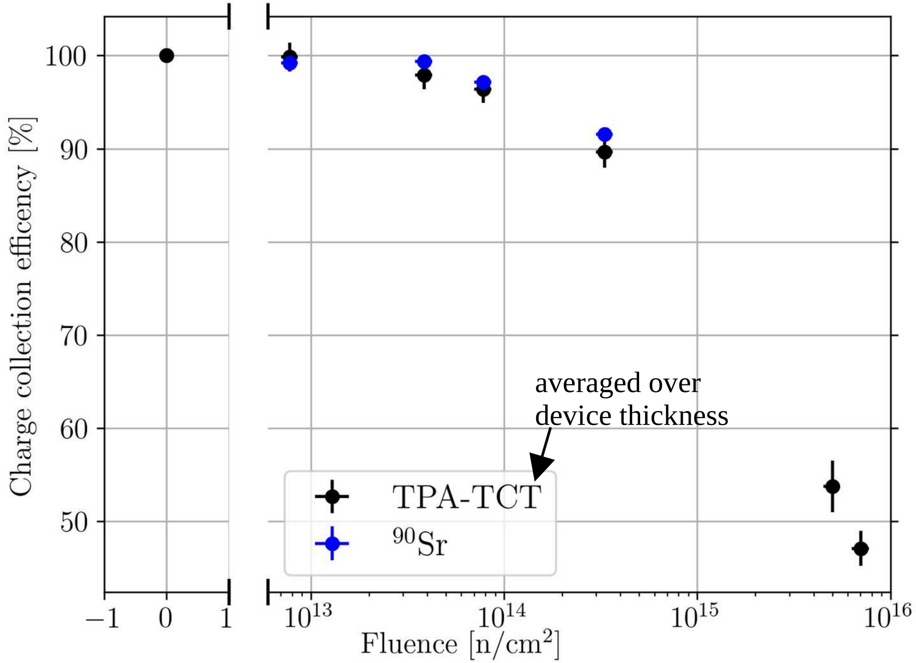
TPA-TCT:

- Extracted the TPA contribution of a $Q(z)$ measurement at different laser intensities
- Quadratic fit to $Q_{\mathrm{TPA}}(E_{\mathrm{p}})$
- Normalised the fit parameter with the one of a pristine detector → CCE

^{90}Sr:

- CC measurements for all fluences
- Normalised to the CC of a pristine detector → CCE

Details on the ^{90}Sr measurements are in the backup!



Observation:

- CCE is equally measured with the ^{90}Sr setup and the **TPA-TCT**
- TPA-TCT can be used for higher fluences, as there is no noise problem
  → amount of deposited charge can be chosen & possibility to average waveforms

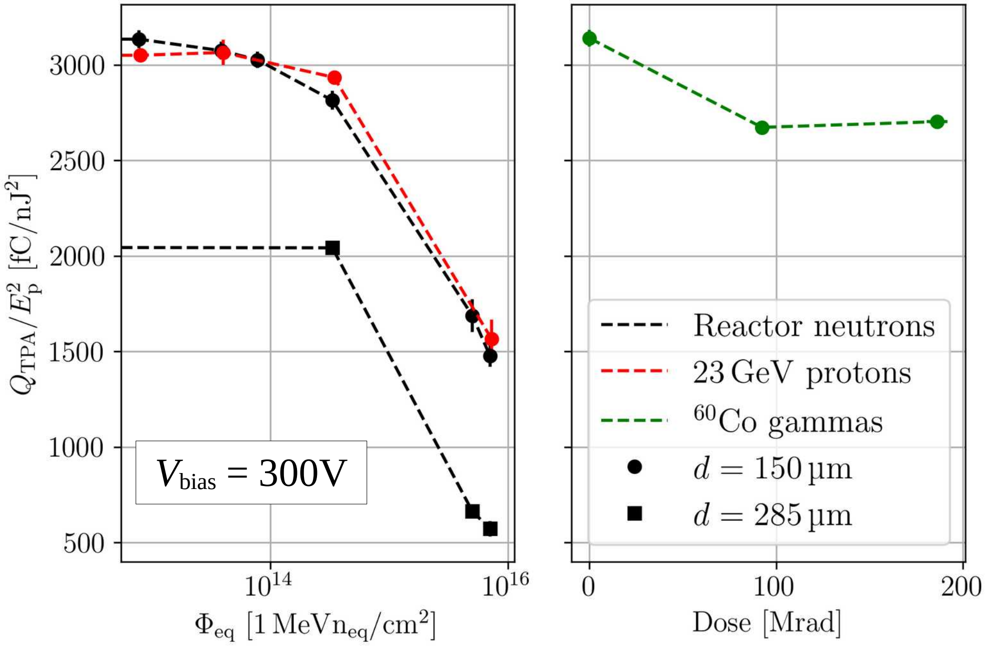
Conclusion:

- Charge loss mechanism is scaling in the same way for both techniques
- Strongly hints that:

→ charge generation mechanism of **TPA** is not influenced or at least similarly influenced as **^{90}Sr**

→ β_2 (TPA absorption coefficient) probably does not change with fluence

Loss in charge collection with irradiation



Observations:

- All irradiations lead to a decrease in charge collection
- **Protons** and **neutrons** damage lead to a similar charge loss
- Thicker devices have a higher charge loss
- **Gamma** irradiation: charge loss for 100Mrad and 200Mrad is about the same

Summary

- Influence of radiation on the TPA-TCT was investigated
  → Charge loss and change in the absorption behaviour (SPA background) observed
- Three different methods to correct the parasitic SPA background were reviewed
  → Waveform correction (method III.) was recommended
- Influence of gamma, proton & neutron irradiation was investigated:
  - Gamma irradiation showed no SPA background, but a decrease in the collected charge
  - Proton and neutron irradiation leads to comparable SPA background and charge loss
- CCE measurements with a ^{90}Sr setup & TPA-TCT lead to the same result
  → hints that the charge generation does not change with irradiation ($\beta_2(\Phi)$ = const)

Thank you!

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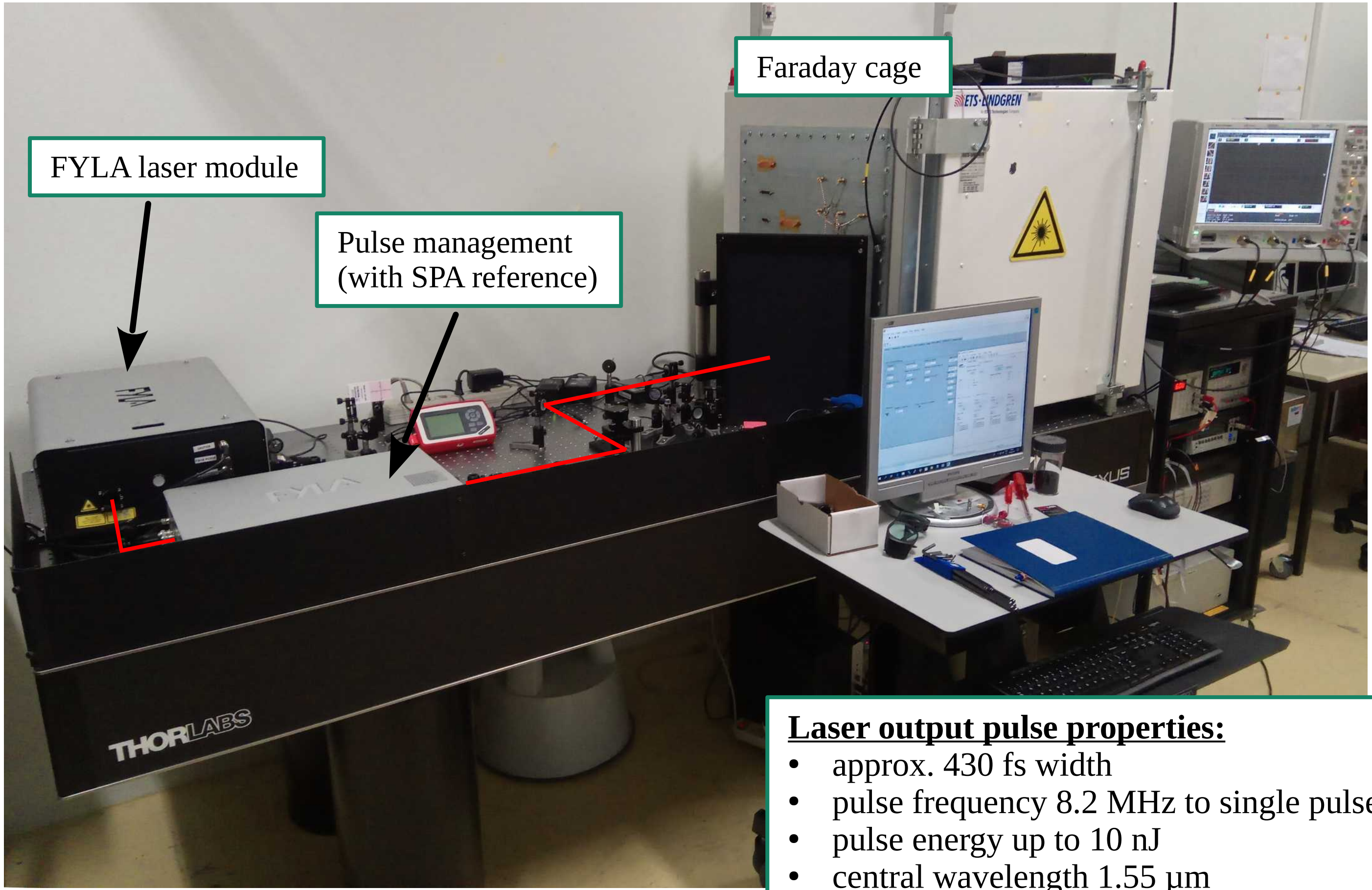
BACKUP

TPA-TCT setup at CERN SSD

M. Wiehe et al.: *Development of a Tabletop Setup for the Transient Current Technique Using Two-Photon Absorption in Silicon Particle Detectors*

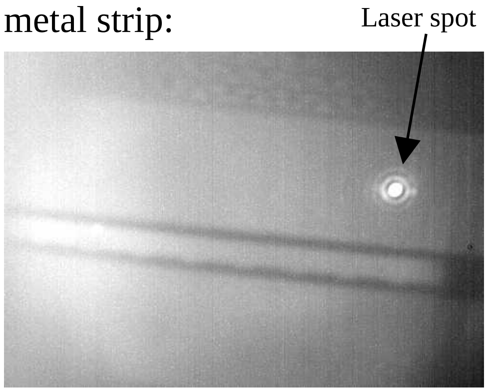


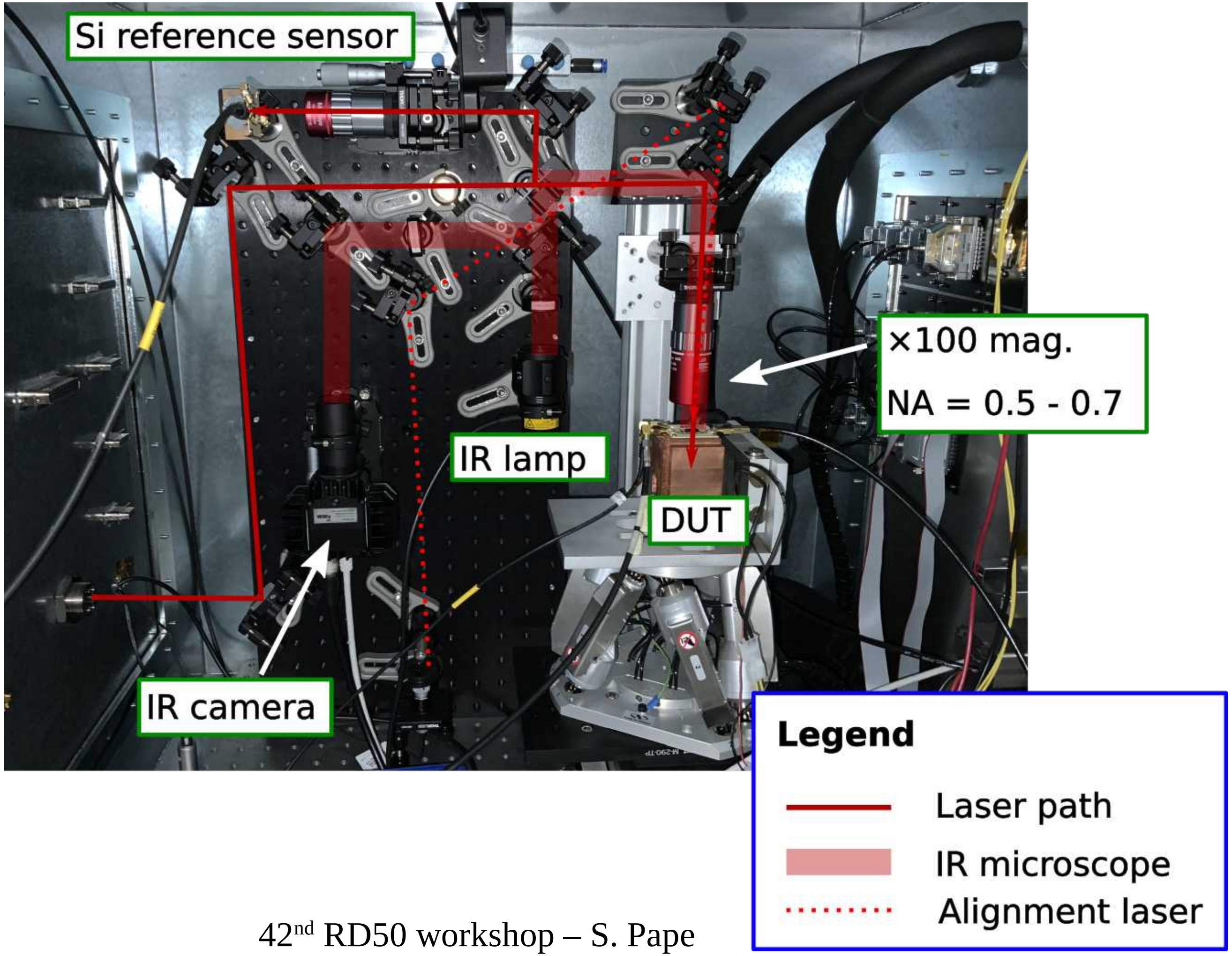
Laser output pulse properties:

- approx. 430 fs width
- pulse frequency 8.2 MHz to single pulse
- pulse energy up to 10 nJ
- central wavelength 1.55 µm

TPA-TCT setup: Inside of the Faraday cage

IR microscope picture of a metal strip:





CCE measurements with a ^{90}Sr setup

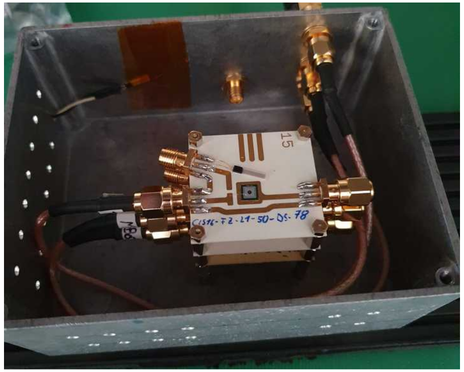
^{90}Sr setup

Ref (CH0)

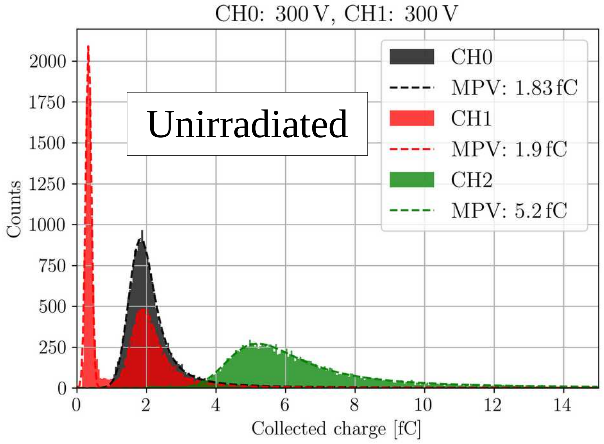
DUT(CH1)

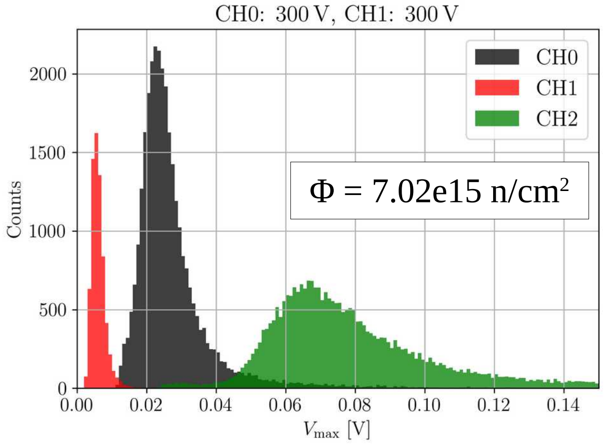
Ref (CH2)

Two reference diodes are used as a trigger, to lower the acceptance and increase the SNR.



Charge sensitive CIVIDEC amplifiers are used to improve the SNR.

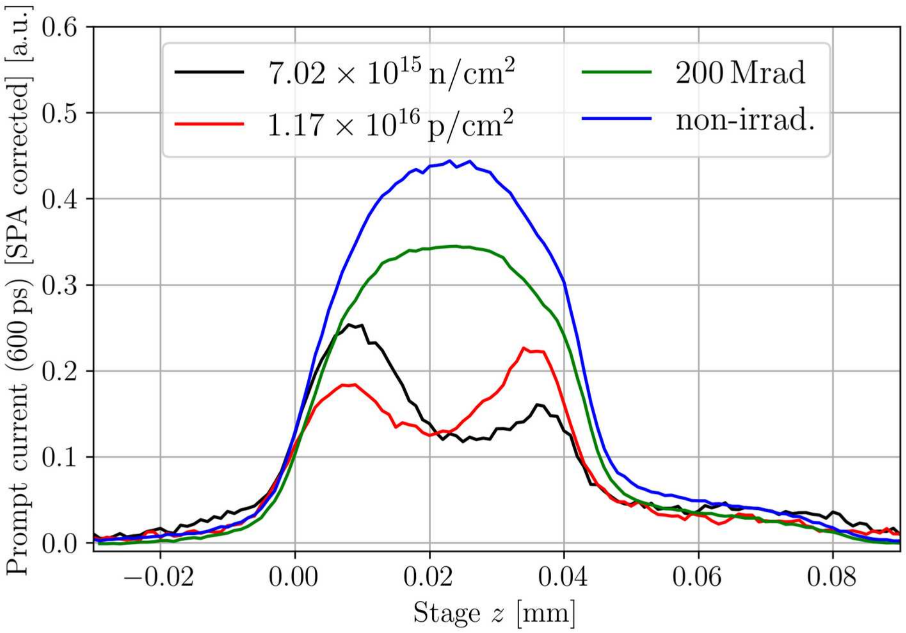




- Record 25k events
- Landau-Gauss distribution for the signal → MPV used as CC
- Gaussian distribution for the noise
- Signal and noise are well separated by the amplitude height

- SNR decreases with fluence
- Separation by signal height not possible → also separate the peaking time of the signal
- Separation between signal and noise not possible at fluences $\geq$ 5e15n/cm^2

Prompt current of neutron, proton, and gamma irradiated samples



- Double junction in neutron and proton irradiated samples is clearly visible
- Gamma irradiated samples shows no difference in shape, but in amplitude
- Electric field is decreased in all irradiated samples compared to the non-irradiated sample