Two Photon Absorption – Transient Current Technique: Recent results on segmented sensors and improved measurement methods

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

18th Trento workshop – S. Pape
in Trento

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- Method for the investigation of segmented devices
  - Extraction of the device thickness
  - The weighted prompt current method
  - Application: Passive CMOS strip detector, HV-CMOS & Strip detector
- The mirror technique: Exploiting back side reflections

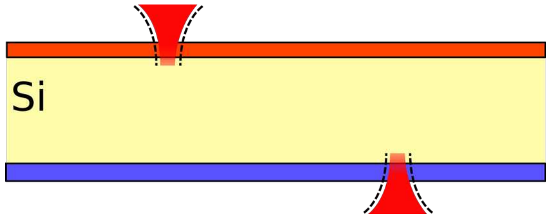
Introduction

Methods for segmented devices

- **Backup:**
  - Photos of the TPA-TCT setup @ CERN SSD
  - The passive CMOS strip detector (Low dose 55 µm)
  - Methods for the extraction of the Time over threshold, the prompt current & the coll

Single Photon Absorption-TCT

λ ≈ 700 nm



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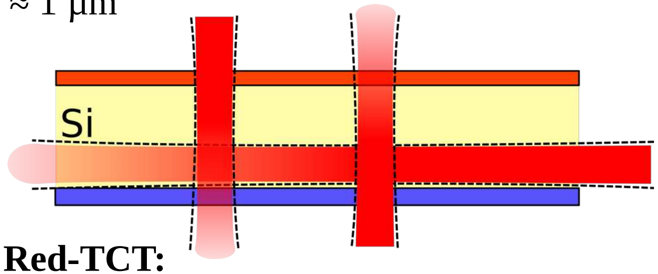
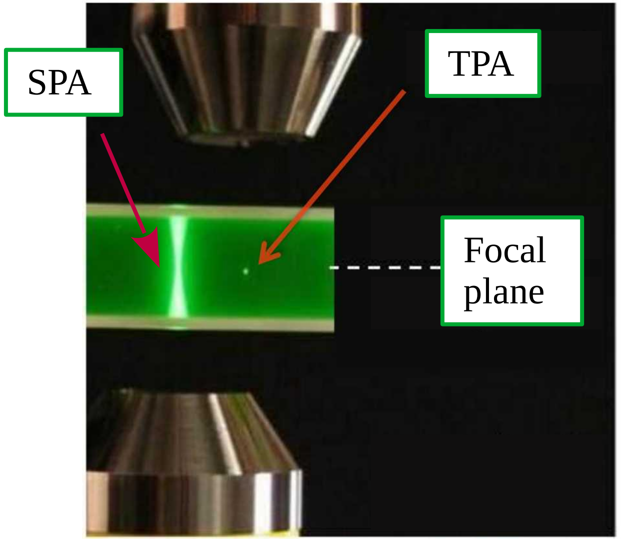


- **Red-TCT:**
  - Full light absorption in ~3-10 µm depth
  - optimal for e/h separation
  - Laser can be micro focused to < 5 µm: **2D resolution**

- **IR-TCT:**
  - To mimic MIPs (continuous laser absorption)
  - Normally 6-10 µm **2D resolution**
  - Edge injection in thick devices allows a depth study



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

Two Photon Absorption-TCT

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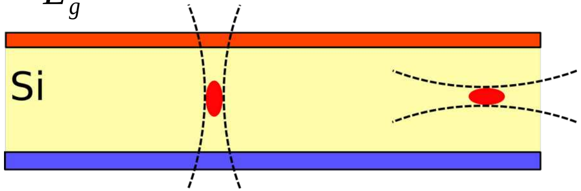
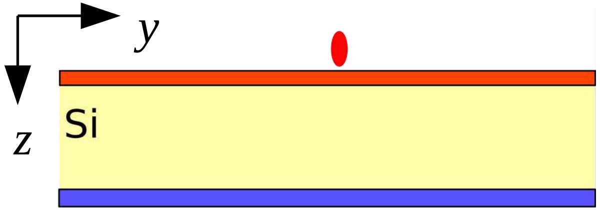


- **TPA** excites charge carriers into the CB
- Non-linear effect, depends quadratic on the intensity

→ main excitation around focal point

- **3D resolution** tool for the detector characterisation:



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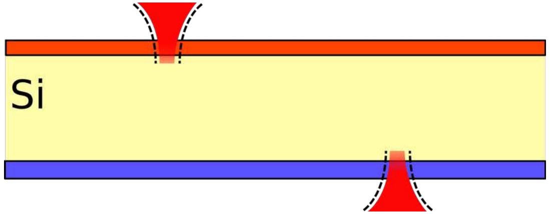

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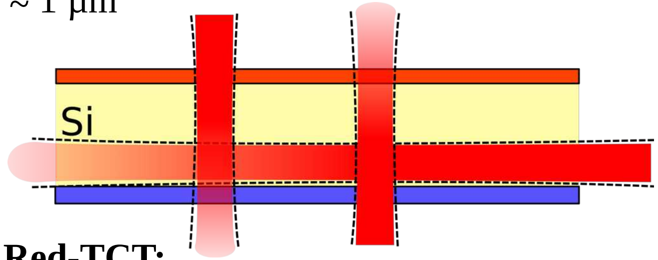

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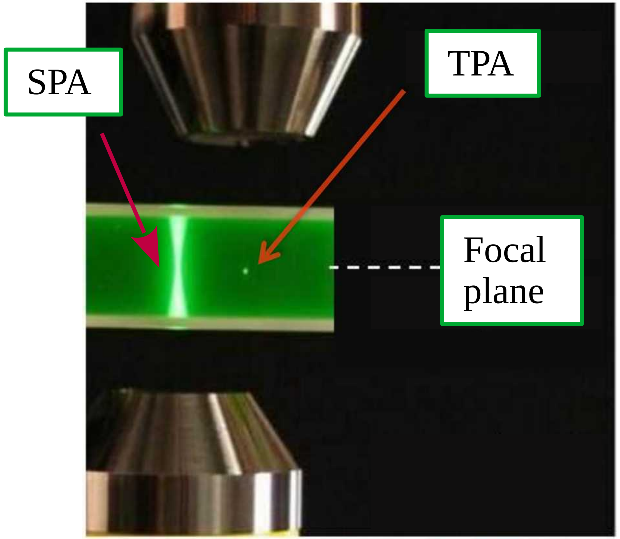

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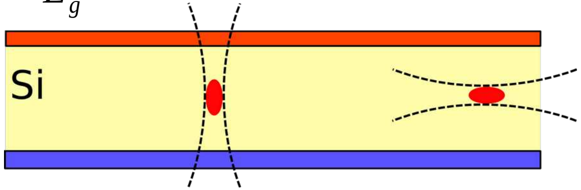

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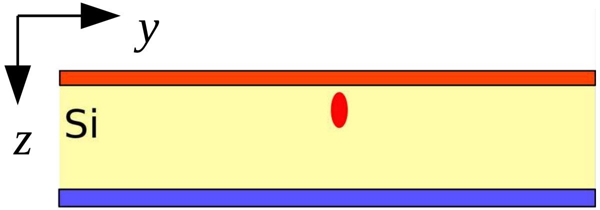

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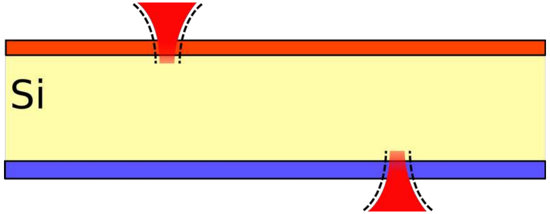

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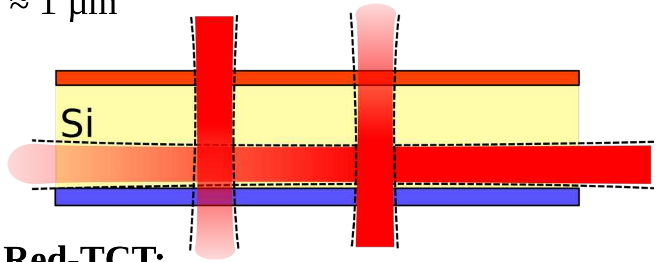

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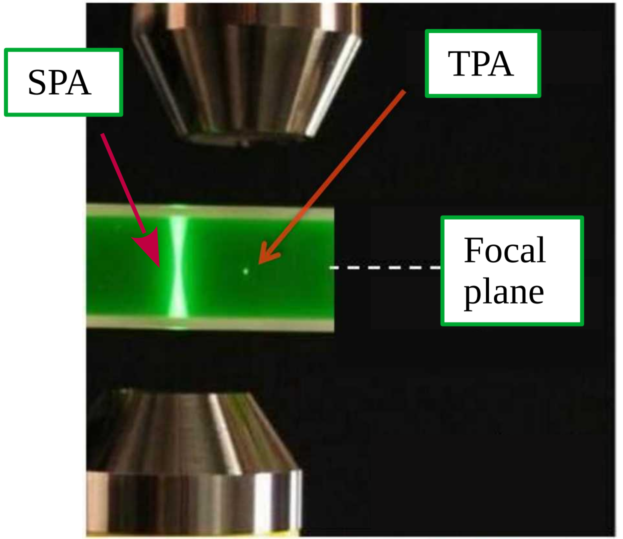

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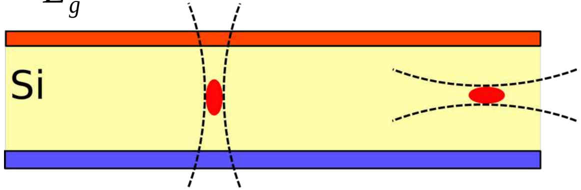

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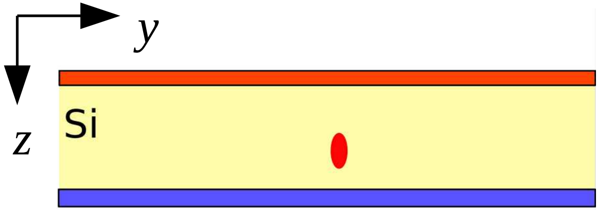

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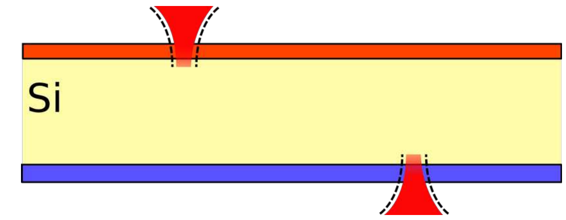

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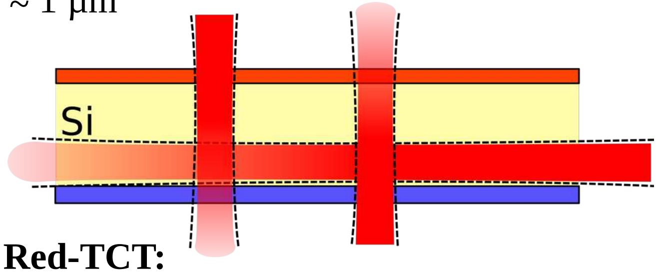

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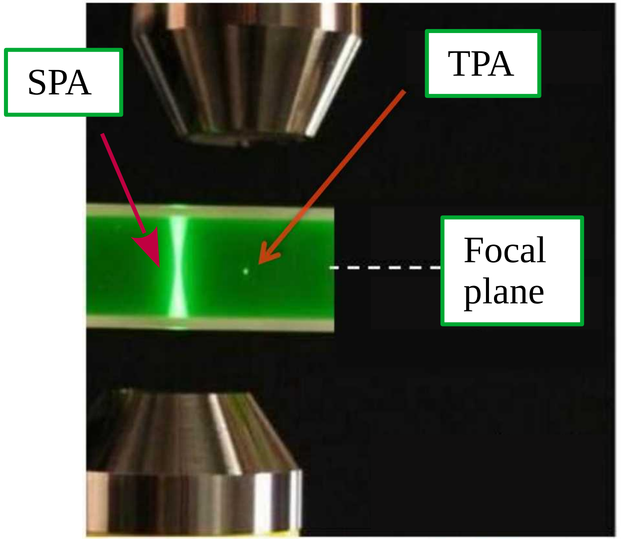

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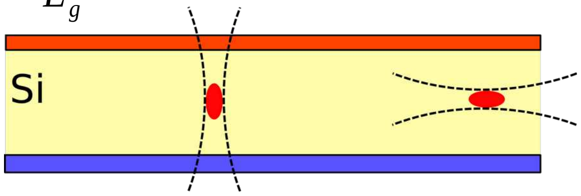

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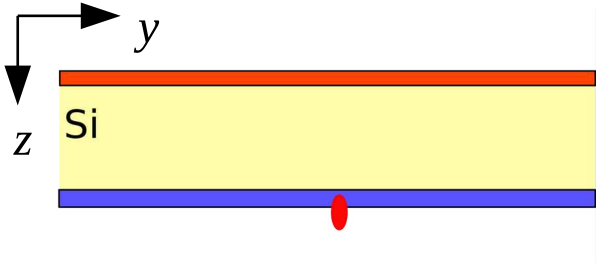
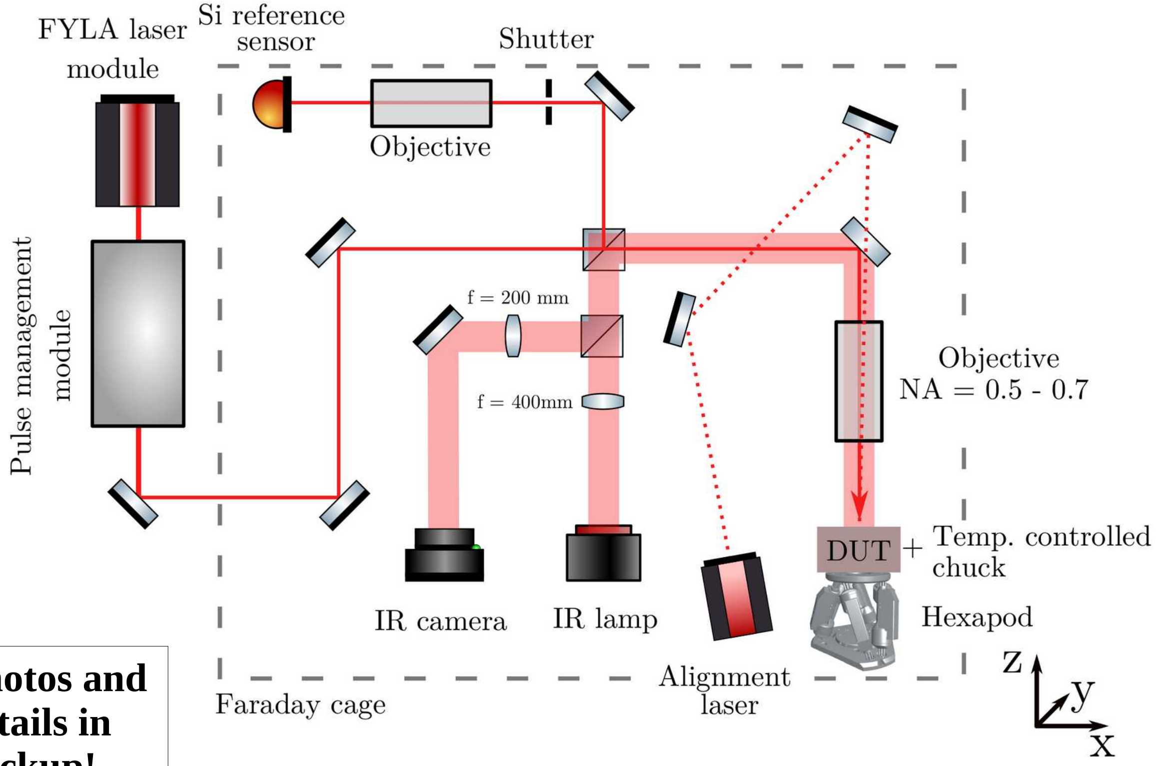


TPA-TCT: Setup & Calibration

Sketch of the TPA-TCT setup at CERN SSD:

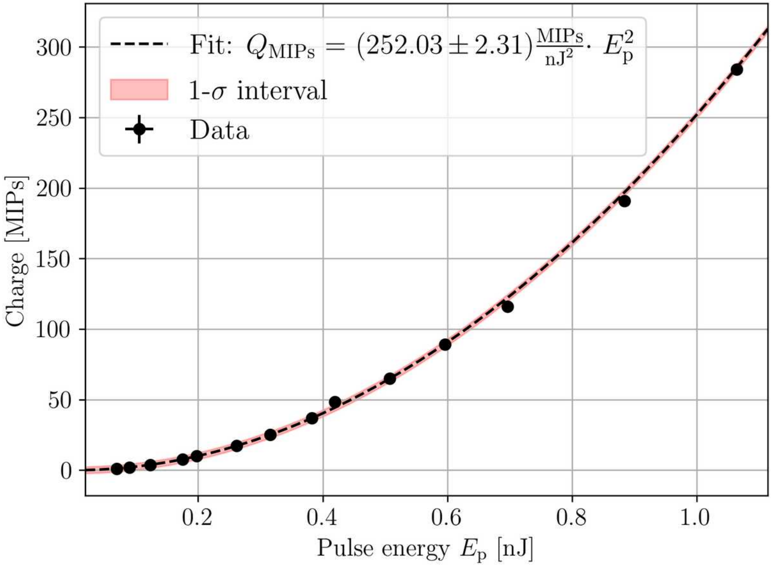


Photos and details in backup!

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.

$$Q = \cancel{\alpha} I + \beta_2 I^2$$

→ pure quadratic behavior shows absence of SPA

Method for the investigation of segmented devices: Motivation

TPA-TCT requires high focusing optics, with large opening angles (up to 45°)

→ can lead to laser beam clipping at metallisations or geometry of the DUT

→ laser intensity, i.e. charge generation can be position dependent

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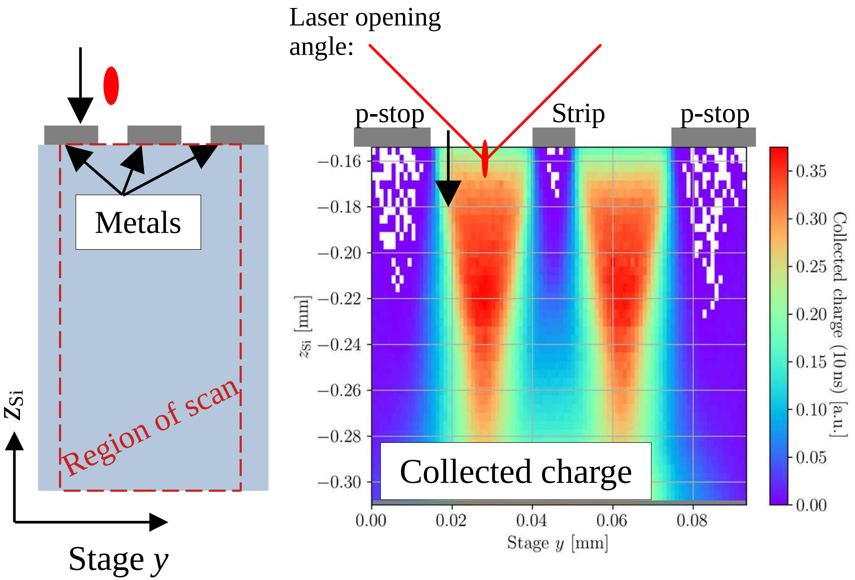
→ can lead to artefacts in the measurement of the collected charge

DUT: Passive strip CMOS detector



Details on the DUT in the backup

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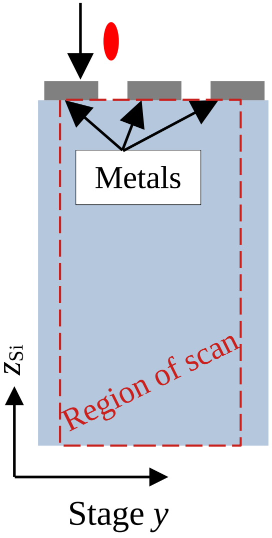
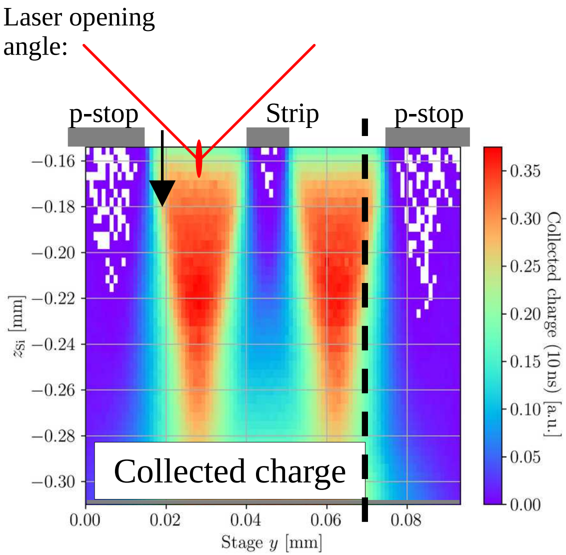
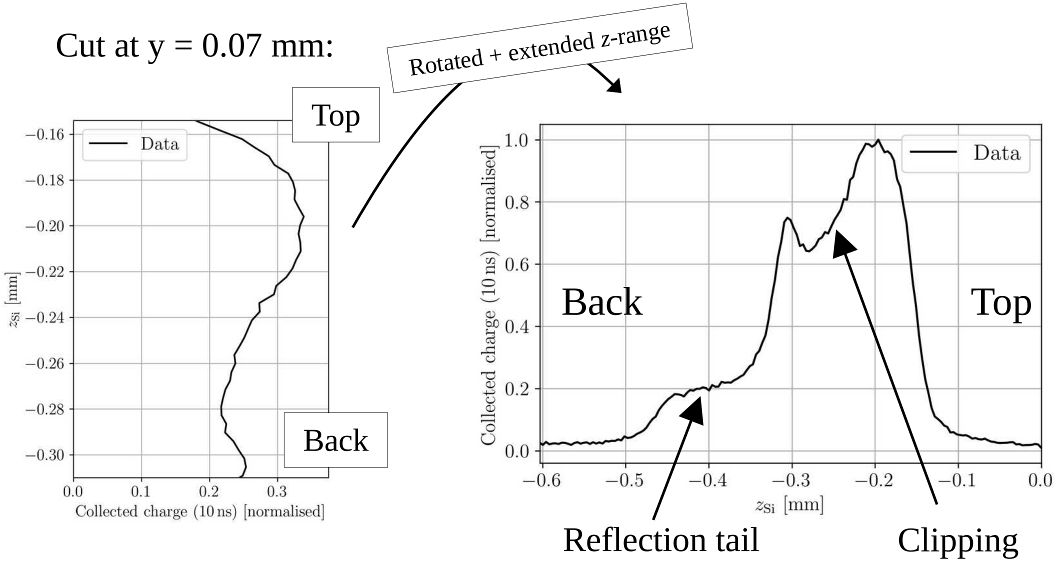




Details on the DUT in the backup

- Charge collection profile is distorted by laser beam clipping at the top side metallisations

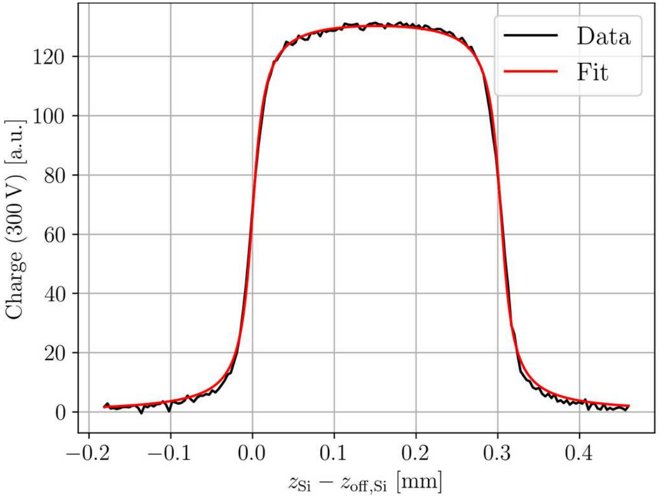
Cut at y = 0.07 mm:



Extracting the device thickness

For **constant intensity** → Fit of the charge collection profile

DUT: ~300µm thick PIN device



Fit function for constant intensity:

$$C \times [\arctan(\frac{d-z}{z_0}) + \arctan(\frac{z}{z_0})]$$

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Varying intensity → more complex charge collection profile

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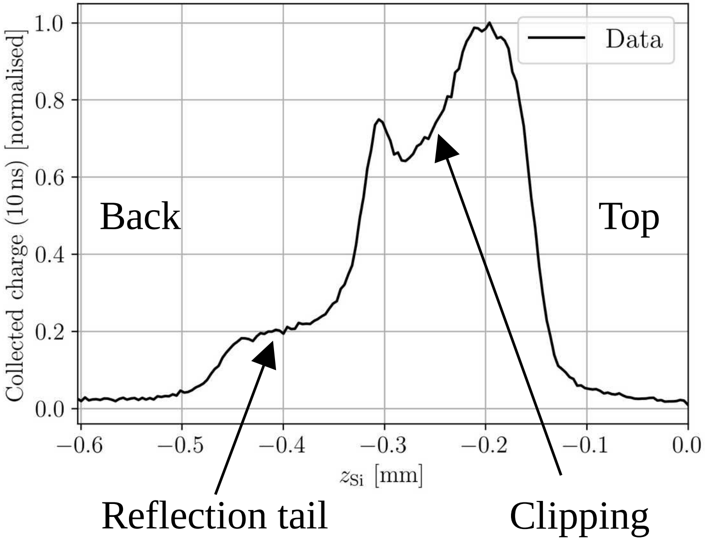


→ **new method needed to extract the depletion depth**

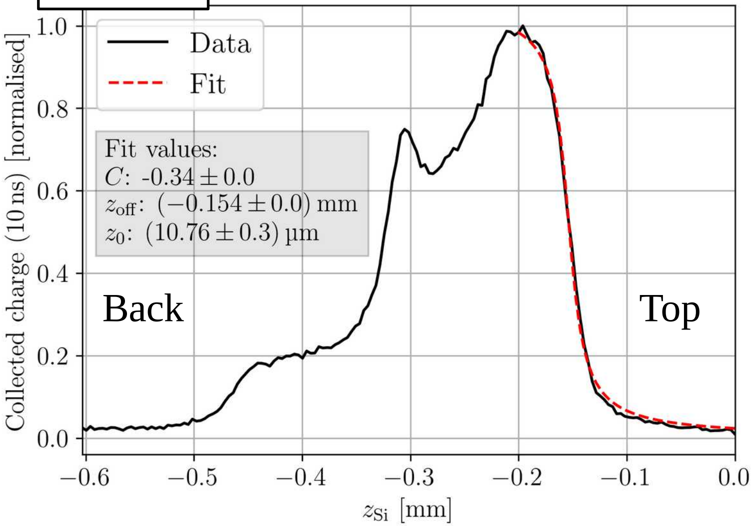
New method to extract the device thickness

Depletion device thickness in two steps:

DUT: Passive strip CMOS detector

1. Extraction of top side position
2. Extraction of the rear side position (requires metallised back side)

Step 1:



Fit only towards the top surface:

$$Q_{Top} = C \times \left(\arctan\left(\frac{z - z_{off}}{z_0}\right) - \frac{\pi}{2}\right)$$

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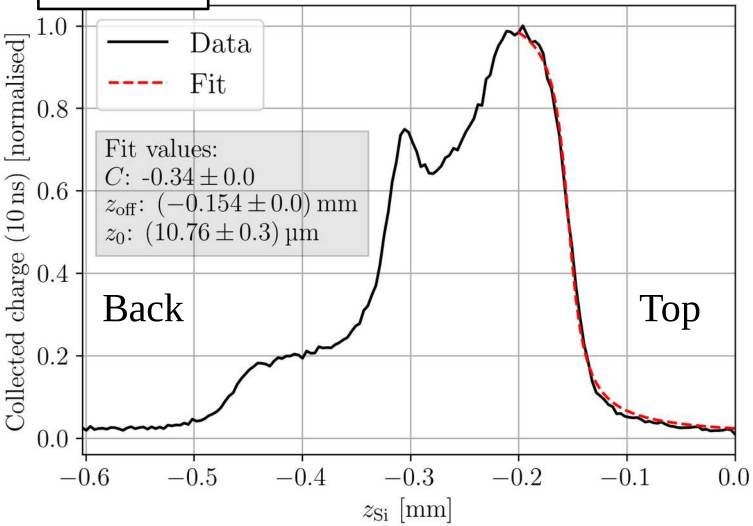

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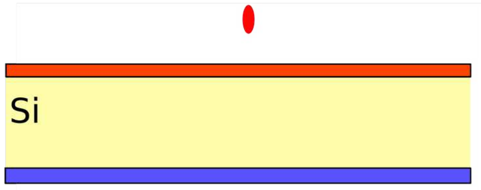

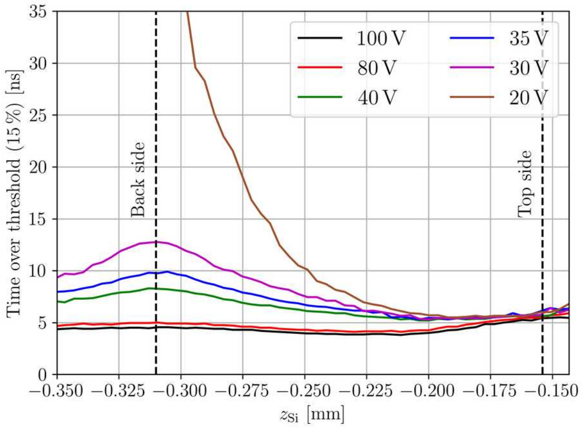

More details about the ToT in backup

As the focal point is reflected at the backside, the Time over threshold (ToT) profile is symmetrical at the back side

→ position of the back surface is found as a peak

The ToT strongly increases for diffusion
→ Gives a hint for the depleted region

ToT ≙ Time over constant fraction of 15 %

New method to extract the device thickness

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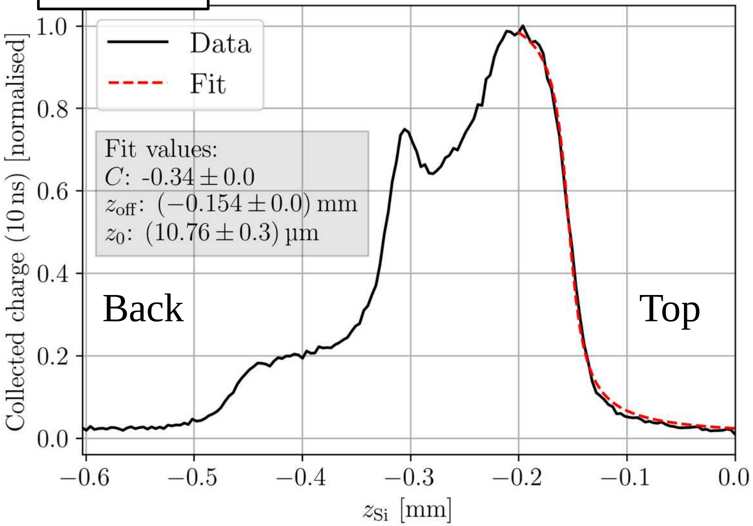

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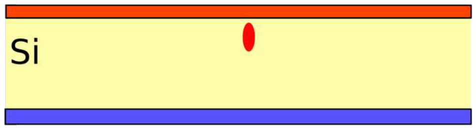

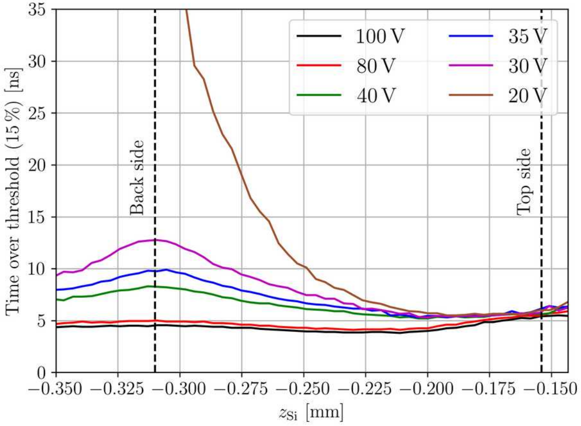

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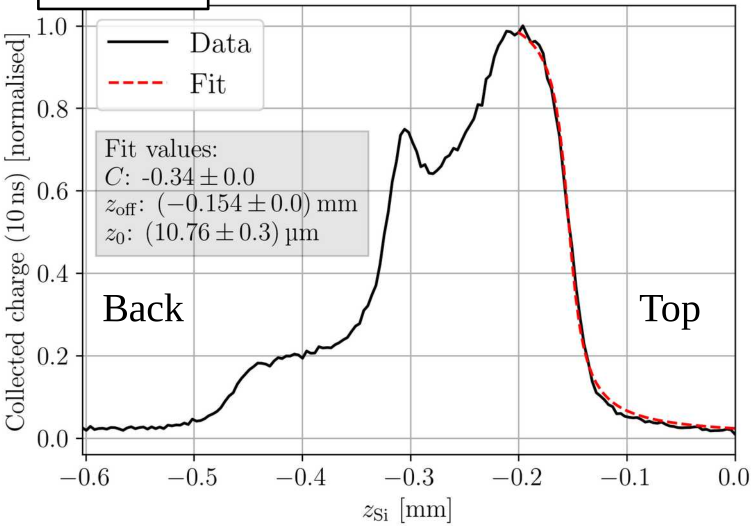

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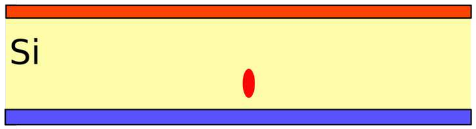

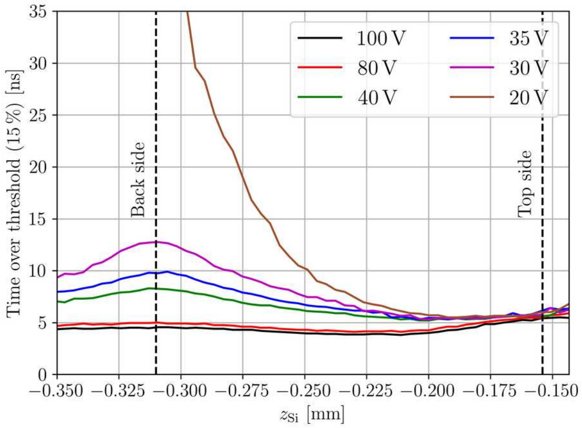

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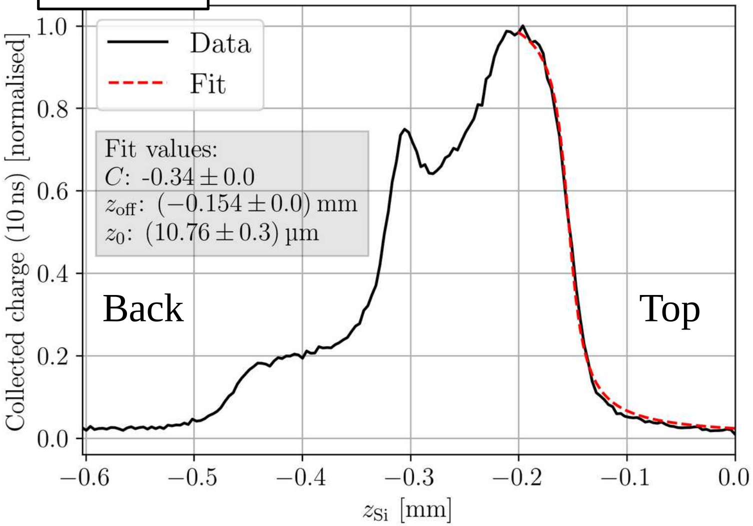

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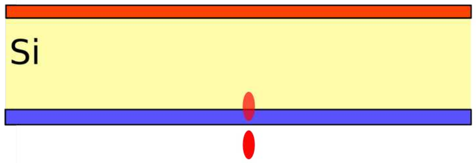

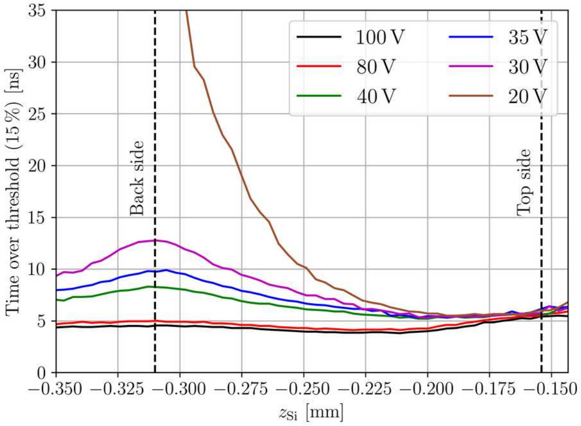

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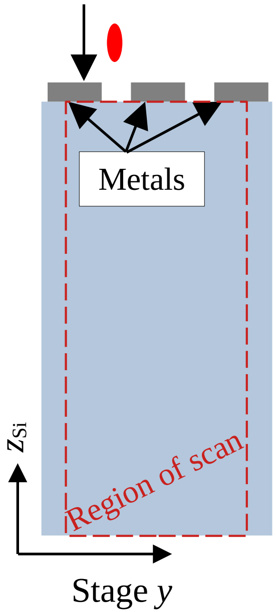
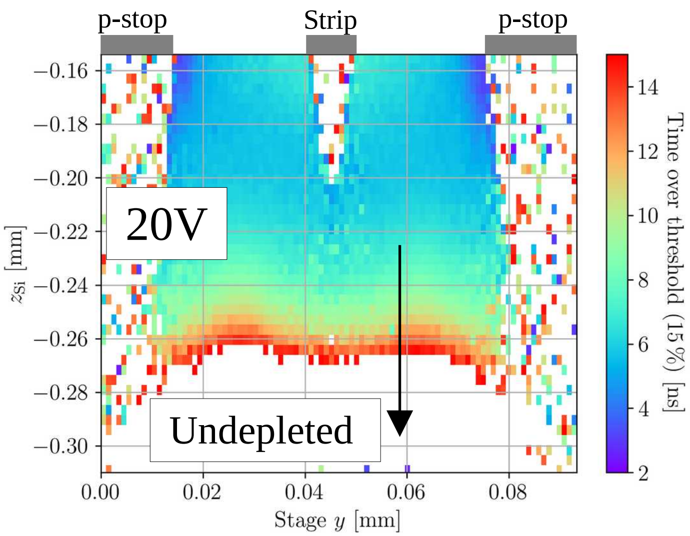
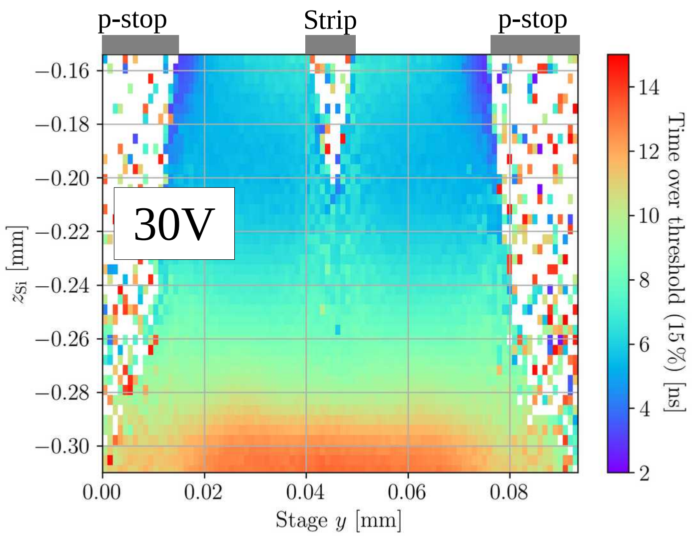
3D scanning of the depletion behavior

DUT: Passive strip CMOS detector

As TPA-TCT allows 3D probing, the ToT can be used to investigate the depletion behavior:







All quantities that can be extracted from the drift current can be probed with 3D resolution!

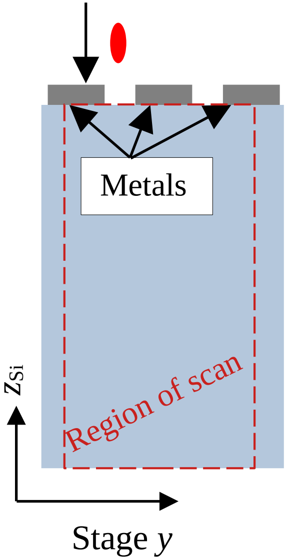
Details on the DUT in the backup

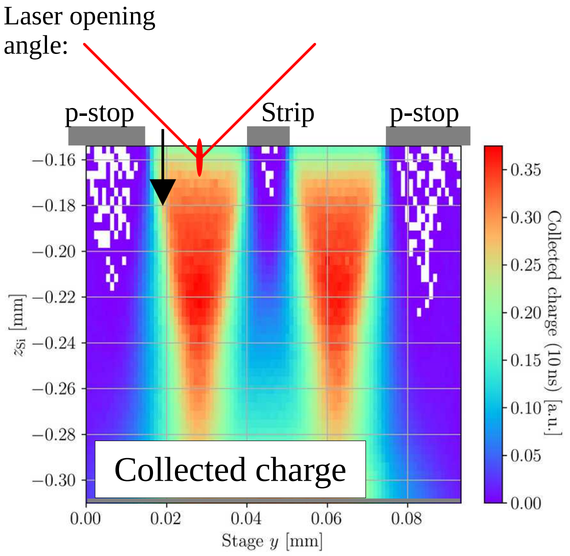
Investigation of the electric field

Usually the electric field is investigated using the prompt current method: $I_{pc} \approx Q \vec{E}_w (\mu_e + \mu_h) \vec{E}$

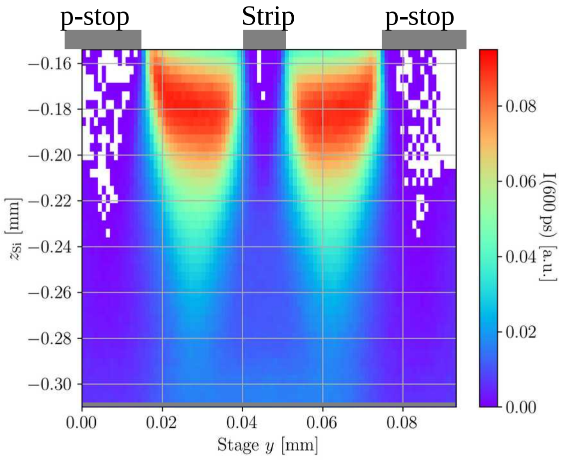
→ A varying intensity heavily influences the prompt current.

Example: Passive strip CMOS detector





Prompt current:



More details on the prompt current method:
G. Kramberger et al.
Investigation of Irradiated Silicon Detectors by Edge-TCT

The weighted prompt current method

To mitigate the dependence on the laser intensity, the prompt current can be weighted with the collected charge:

Prompt current

$$I_{pc} \approx Q \vec{E}_w (\mu_e + \mu_h) \vec{E}$$

➡

Weighted prompt current

$$\frac{I_{pc}}{Q_{coll}} \approx \vec{E}_w (\mu_e + \mu_h) \vec{E}$$

S. Pape et al.

Techniques for the Investigation of Segmented Sensors Using the Two Photon Absorption-Transient Current Technique

The weighted prompt current method

To mitigate the dependence on the laser intensity, the prompt current can be weighted with the collected charge:

Prompt current → Weighted prompt current

$$I_{pc} \approx Q\,\vec{E}_w(\mu_e+\mu_h)\,\vec{E} \qquad \frac{I_{pc}}{Q_{coll}} \approx \vec{E}_w(\mu_e+\mu_h)\,\vec{E}$$

Generated charge

Collected charge

Both methods are designed to investigate the electric field / drift velocity ($\vec{v}_d=\mu_{e/h}\vec{E}$).

S. Pape et al.

Techniques for the Investigation of Segmented Sensors Using the Two Photon Absorption-Transient Current Technique

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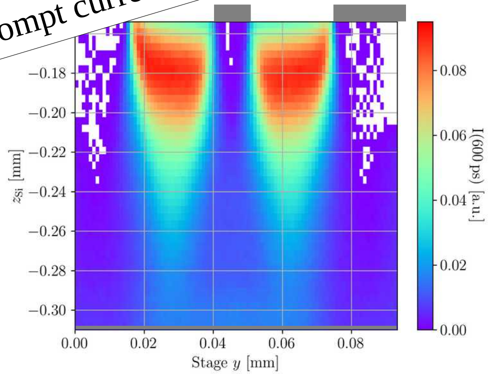
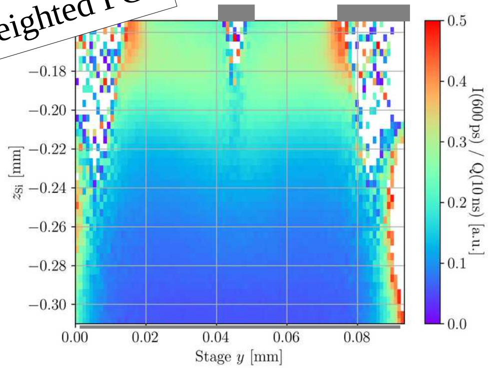
Weighted prompt current is independent of the generated charge!

Prompt current:



Weighted PC:



Example: Passive strip CMOS detector

S. Pape et al.
Techniques for the Investigation of Segmented Sensors Using the Two Photon Absorption-Transient Current Technique

The weighted prompt current method

To mitigate the dependence on the laser intensity, the prompt current can be weighted with the collected charge:

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Generated charge

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Collected charge

Both methods are designed to investigate the electric field / drift velocity ($\vec{v}_d = \mu_{e/h} \vec{E}$).

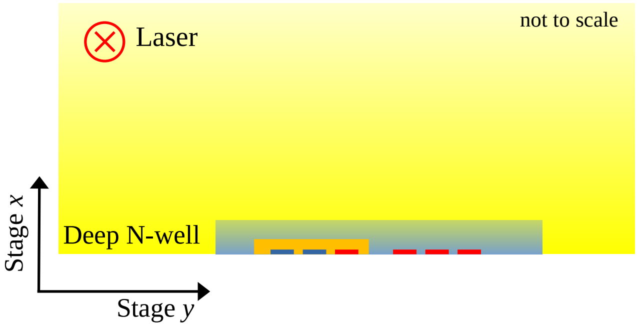
Comments on the weighted prompt current:

- Weighting requires that all generated charge is collected: $Q = Q_{coll}$
  → not applicable if meaningful trapping or charge loss is present
- Weighted prompt current yields the drift velocity times the weighting field → $\vec{E}_w$ is accessible with TCAD
- More sensitive towards the SNR than the prompt current method and small signals → "0 / 0"

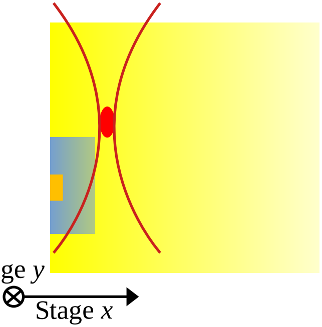
Weighted prompt current is independent of the generated charge!

S. Pape et al.
Techniques for the Investigation of Segmented Sensors Using the Two Photon Absorption-Transient Current Technique

Example: HV-CMOS (CCPDv3)



Side view:



M. Fernández García et al.:
High-resolution three-dimensional imaging of a depleted CMOS sensor using an edge Transient Current Technique based on the Two Photon Absorption process (TPA-eTCT)

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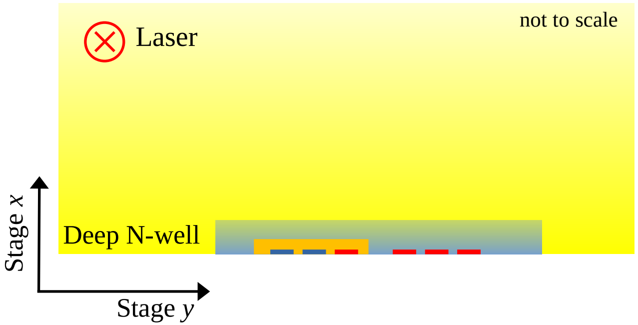
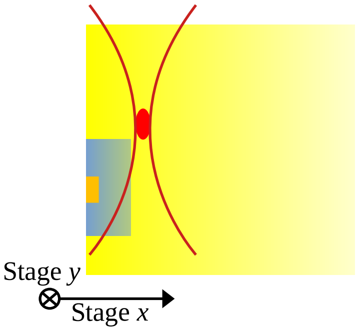
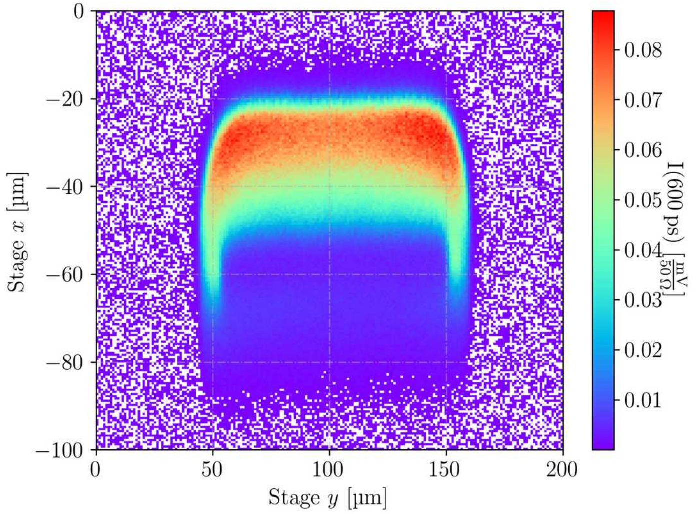
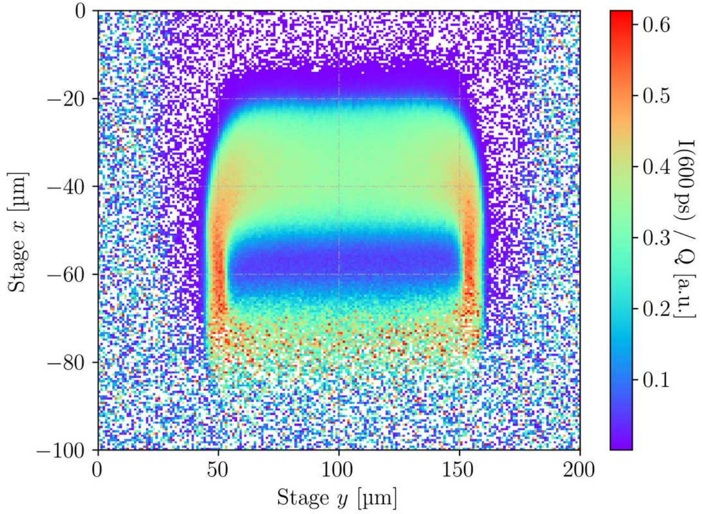


Side view:




Prompt current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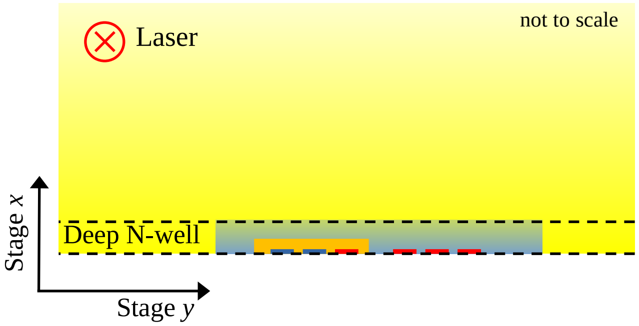
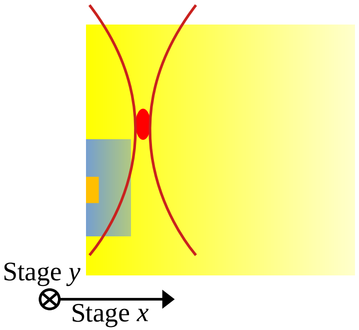
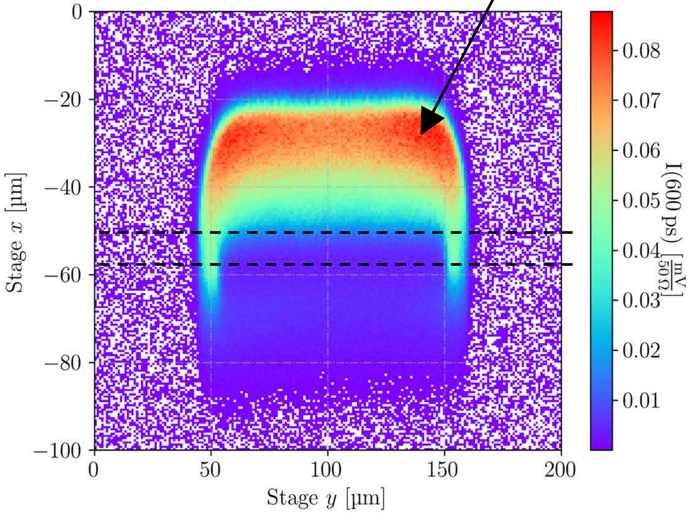


Side view:

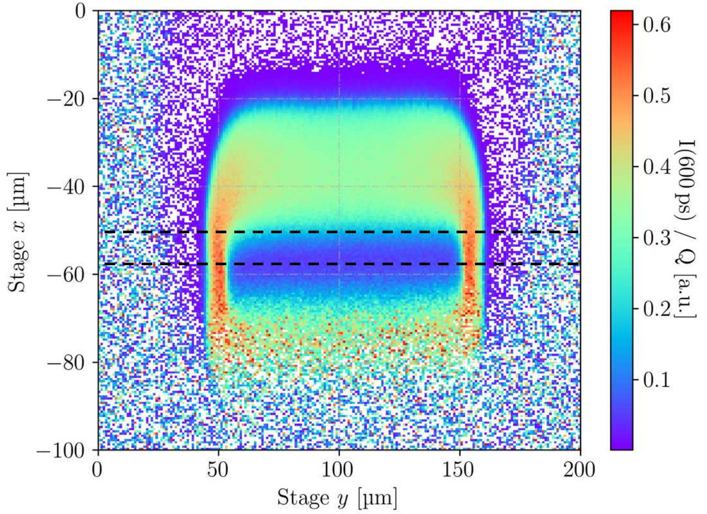


Artefact due to clipping!

Prompt current



Weighted prompt current



Extensive clipping close to the surface and reflection at the Si-air interface

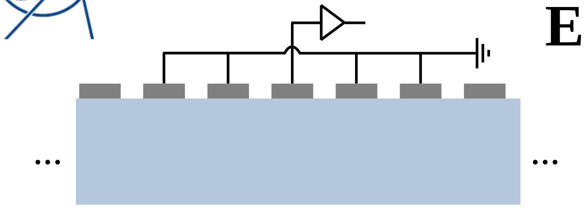
Artefact not present in the weighted prompt current!

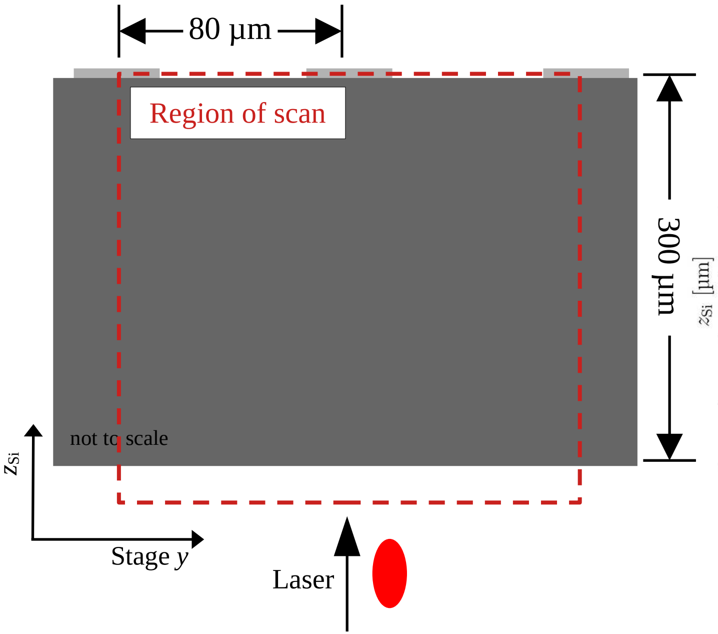
Highest $\vec{E}_w(\vec{v}_e+\vec{v}_h)$ found at the junction.

M. Fernández García et al.:
High-resolution three-dimensional imaging of a depleted CMOS sensor using an edge Transient Current Technique based on the Two Photon Absorption process (TPA-eTCT)

Example: Strip detector (FZ Micron)

Readout scheme:





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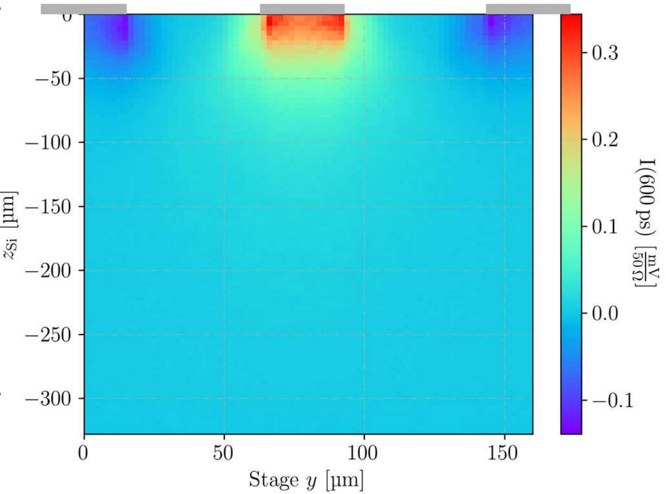
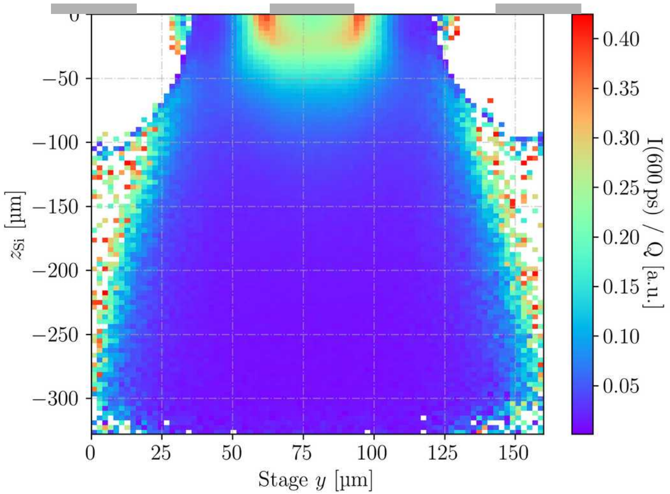


Weighted prompt current



Details of the strip detector:
38th RD50 workshop CERN (virtual):
S. Pape: *A table-top Two Photon Absorption – TCT system: experimental results*

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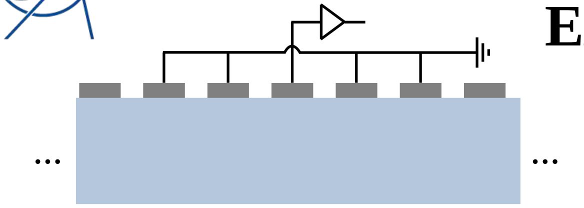
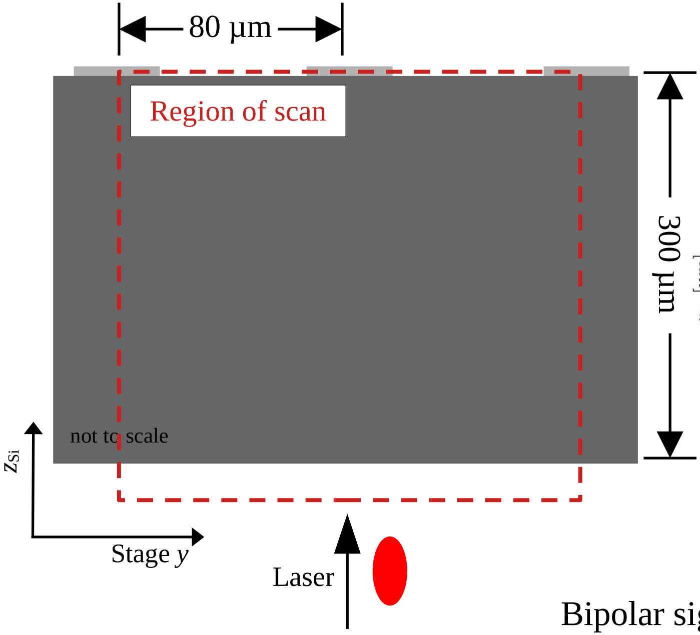
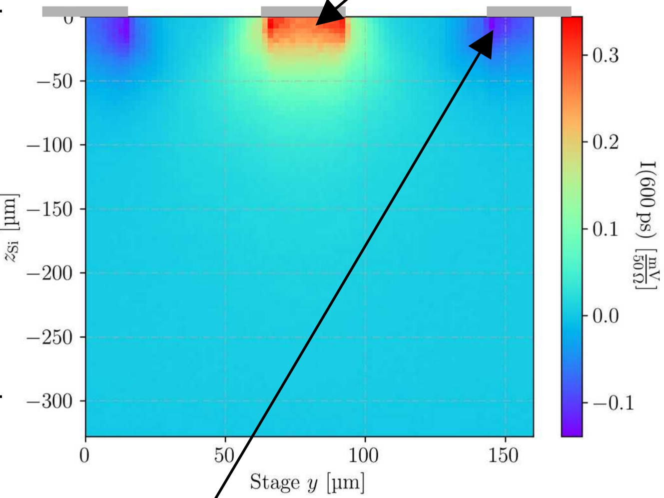




Reflection at top side metal increase the generated charge and lead to an artefact

Prompt current



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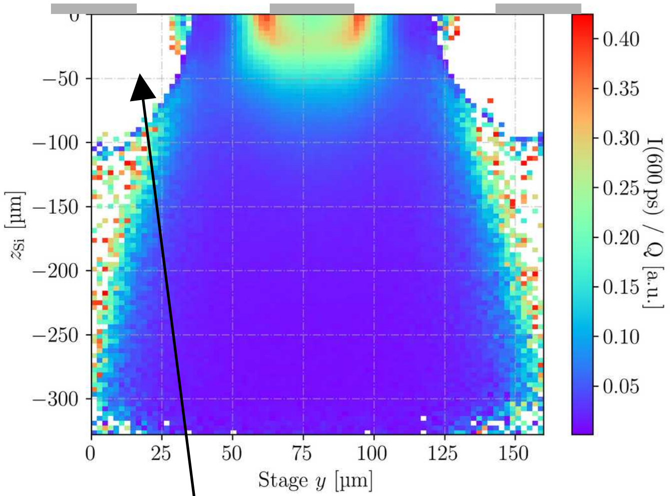
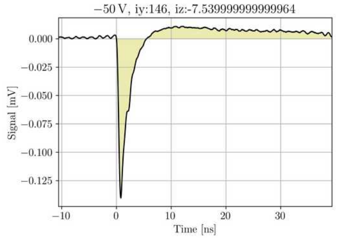


Bipolar signals lead to a negative prompt current as the charge is collected by the neighboring strip



$Q_{coll} \approx 0$ → leads to “-∞”

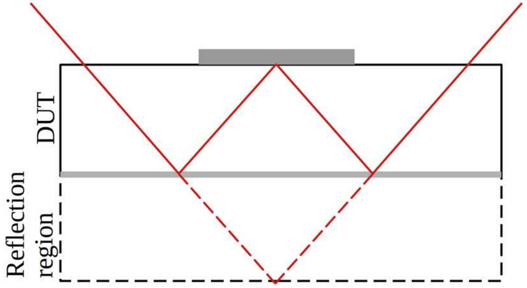
Details of the strip detector:

38th RD50 workshop CERN (virtual):

S. Pape: *A table-top Two Photon Absorption – TCT system: experimental results*

The mirror technique

Reflection at a metallised back side can be exploited to probe below the top side metallisations with illumination from the top:



All intensity independent quantities can be probed in this way.

This technique is only available with the TPA-TCT, as it requires 3D resolution!

S. Pape et al.
Techniques for the Investigation of Segmented Sensors Using the Two Photon Absorption-Transient Current Technique

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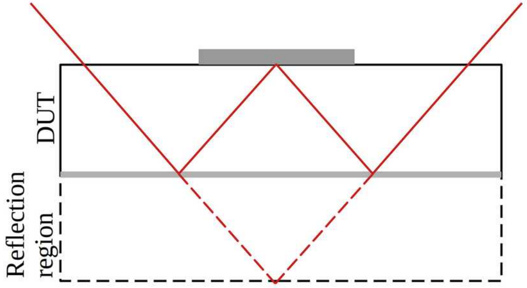

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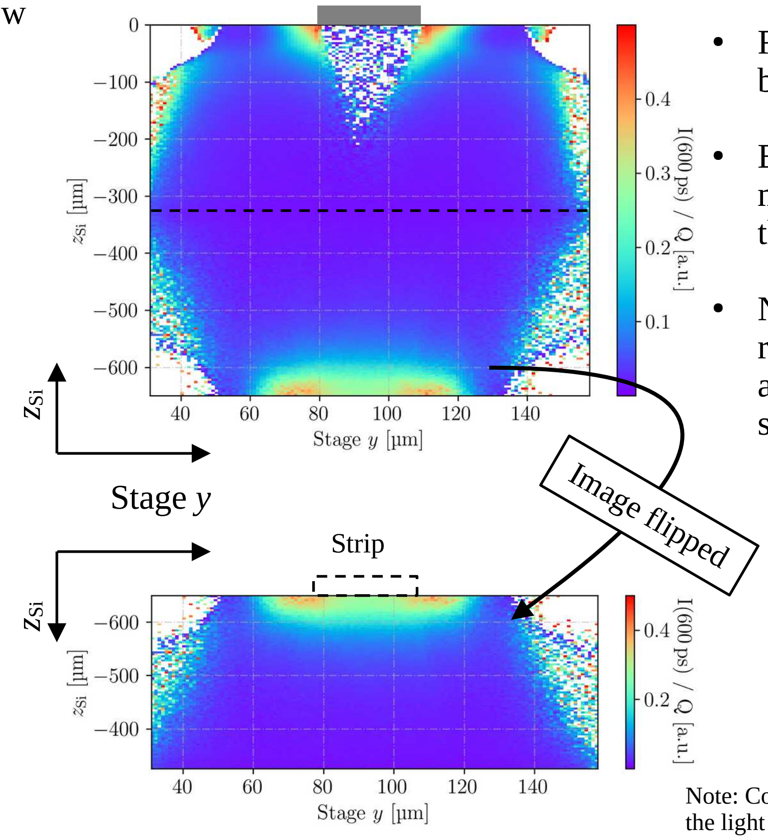
Standard strip detector as an example:



- Requires a metallised back side
- Enables a “clean” measurement below the top side metals
- Note that clipping can reduce the numerical aperture and hence the spatial resolution

Note: Compared to slides 21 – 22, here the light is injected from the top side

DUT: Strip detector (FZ Micron)

S. Pape et al.
Techniques for the Investigation of Segmented Sensors Using the Two Photon Absorption-Transient Current Technique

Summary

- Extraction of the **device thickness**: Top side position from fit towards charge collection profile & back side position from a peak in the time over threshold profile

- **Weighted prompt current method** presented on various segmented detectors

  → Not affected by a varying excess charge carrier generation → corrects for clipping, reflection, and potential fluctuations in the laser intensity

- Yields the drift velocity times the weighting field with a 3D resolution → **accessible with TCAD!**

- The technique can also be applied to SPA-TCT measurements

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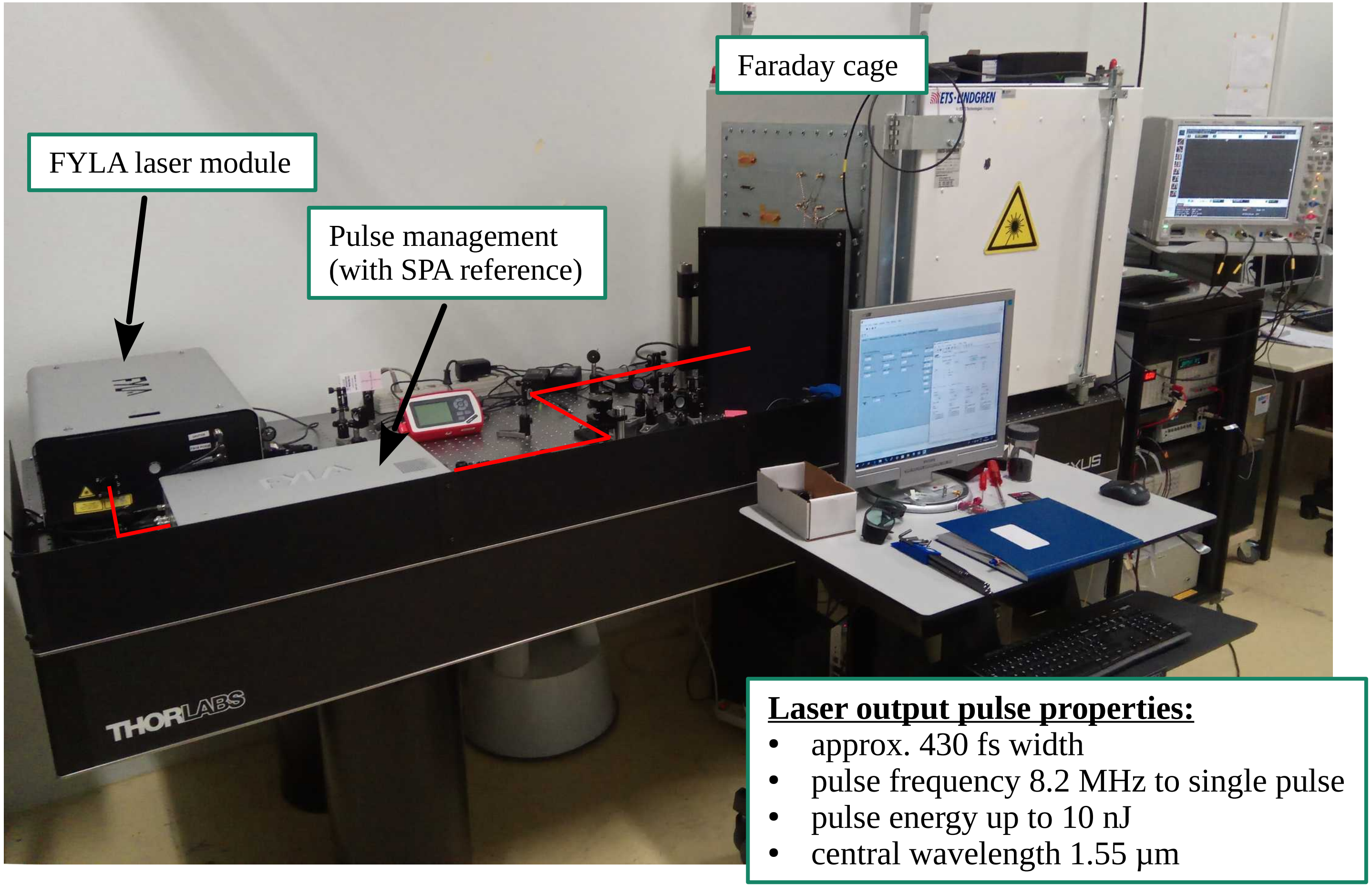
Thank you!

BACKUP

TPA-TCT setup at CERN SSD



FYLA laser module

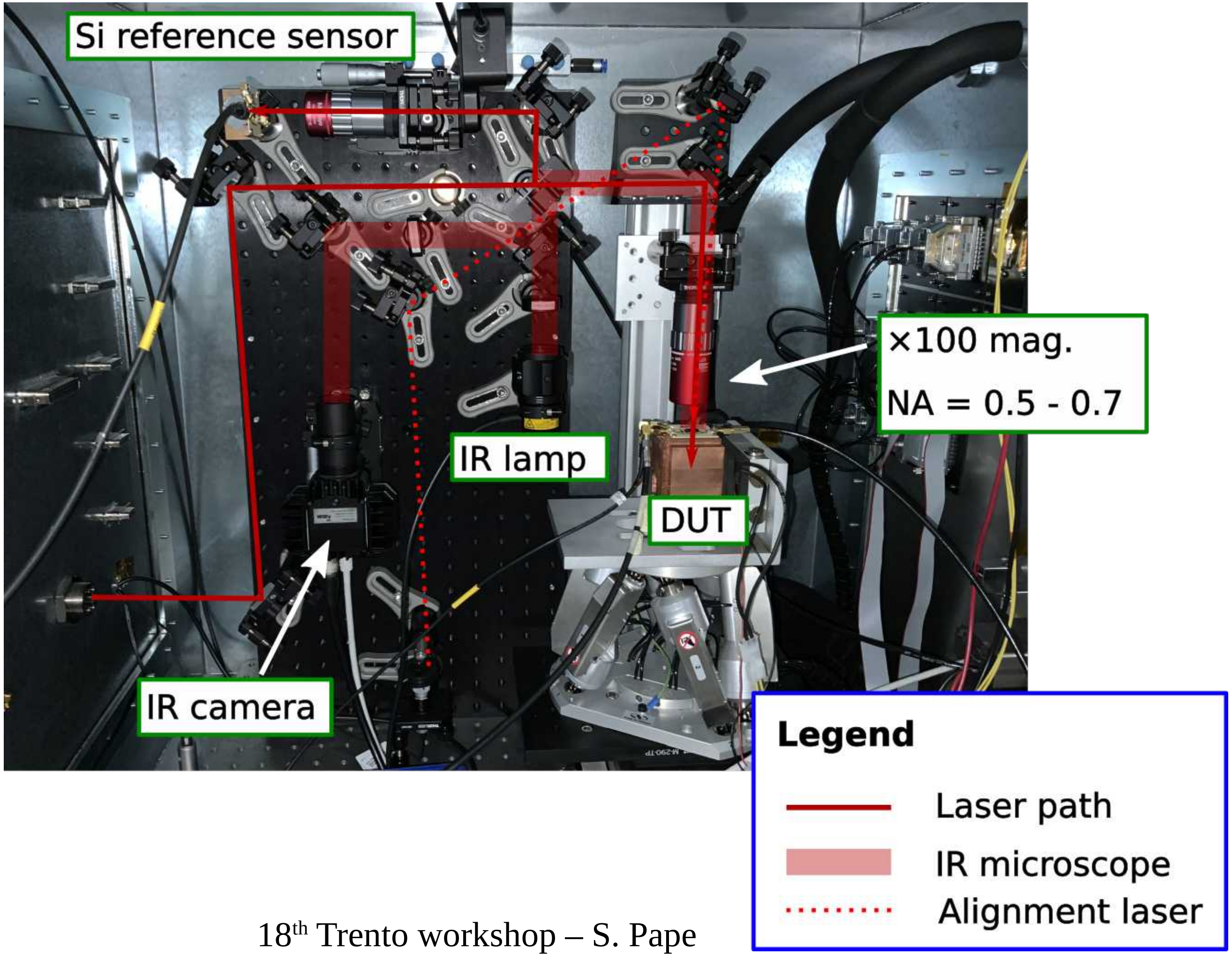
Pulse management
(with SPA reference)

Faraday cage

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

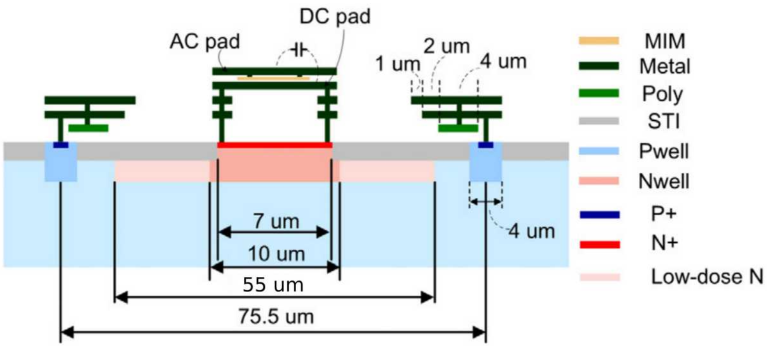
M. Wiehe et al.: *Development of a Tabletop Setup for the Transient Current Technique Using Two-Photon Absorption in Silicon Particle Detectors*

TPA-TCT setup: Inside of the Faraday cage



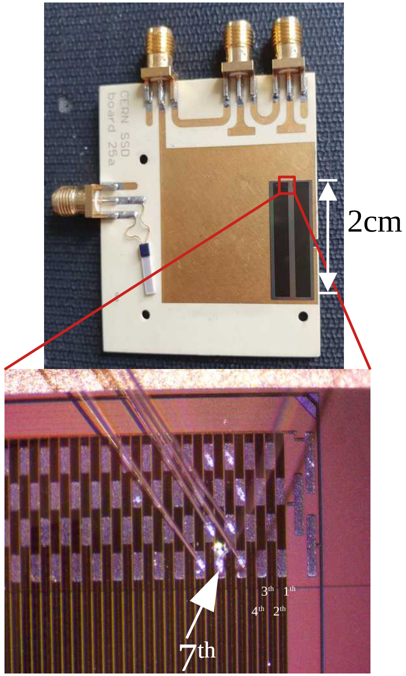
The passive CMOS strip detector (Low dose 55 µm)

Implantation design:



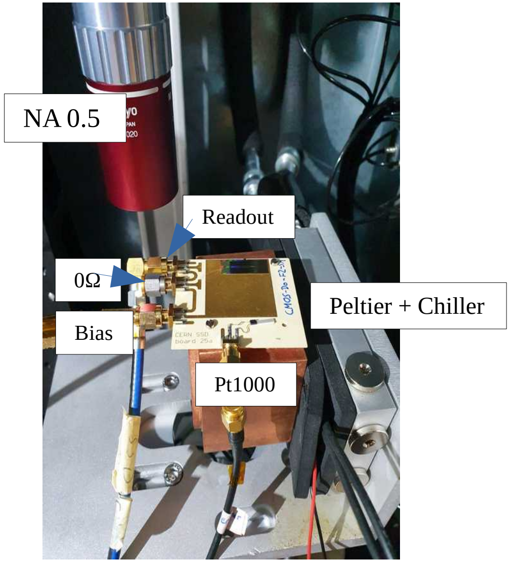
- p-type strip detector, 3 – 5 kΩcm
- Pitch: 75.5 µm
- 150µm thick wafer produced by LFoundry in a CMOS procedure
  - → 1cm^2 reticles stitched together

Sample preparation:



7th strip readout (in regular notation: 33th strip of low dose); bias ring, first, and second neighbours grounded

DUT mounted in setup:



HV is applied from the back side
AC pad of the 7th strip is read out
→ CIVIDEC current amplifier used

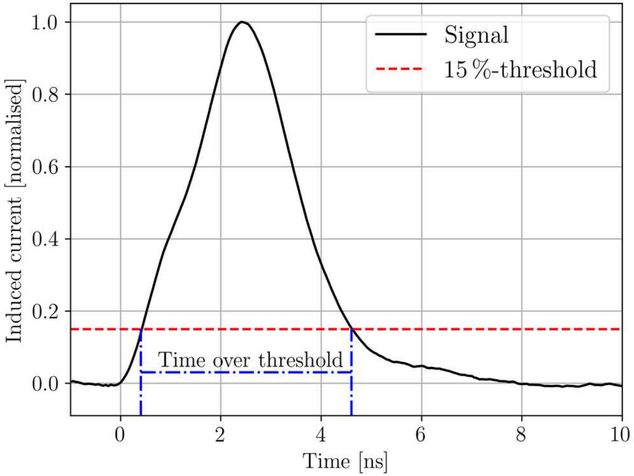
More details:
L. Diehl et al.:
Characterization of passive CMOS strip sensors

Project of:

Time over threshold

Here "Time over threshold" means the time the normalised signal is above 15 % of its maximum amplitude.

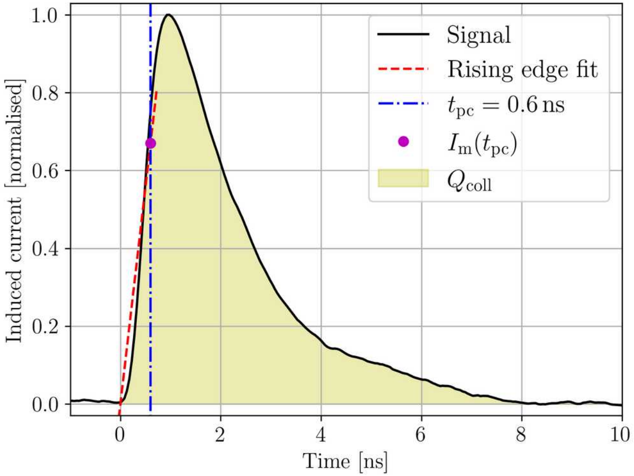
This is done for each waveform independently.



Prompt current & Collected charge

The prompt current is extracted as the current at a given time t_{pc} after illumination. The illumination time is extracted as the starting time of signal, which is found with a fit towards the rising edge. This is done for all waveforms individually and the average starting time is than used.

The collected charge is found by integrating the current signal from the start time to the defined collection time t_{coll} (here 10 ns).



More details in:
S. Pape et al.
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