Two Photon Absorption – Transient Current Technique: Techniques for the investigation of segmented sensors and the influence of temperature

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41st RD50 workshop – S. Pape in Seville

30.11.2022

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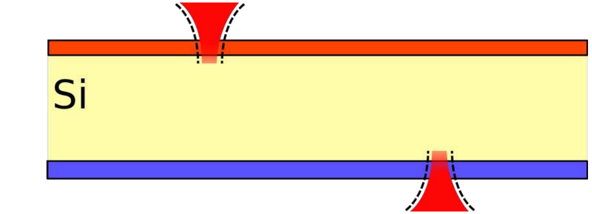
Introduction

Methods for segmented devices

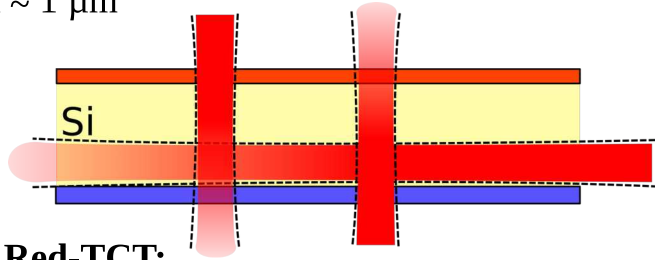
Temperature study

Single Photon Absorption-TCT

λ ≈ 700 nm

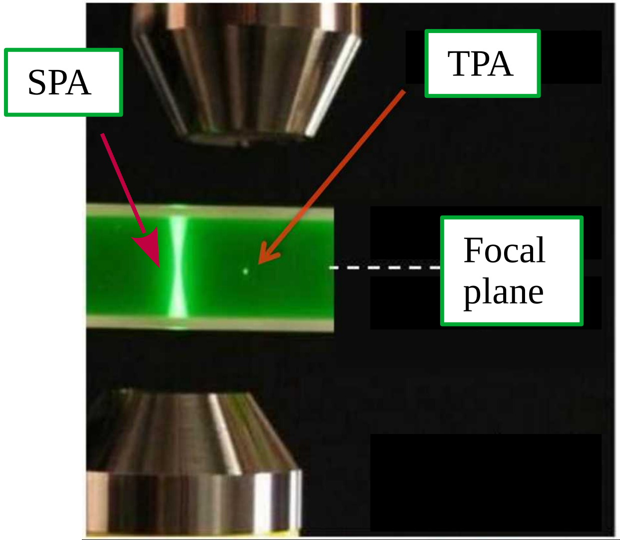


λ ≈ 1 µm



- **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**

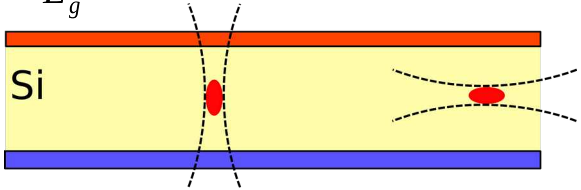
- **IR-TCT:**
  - To mimic MIPs (continuous laser absorption)
  - Normally 6-10 µm **2D resolution**
  - Edge injection in thick devices allows a depth study



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

Two Photon Absorption-TCT

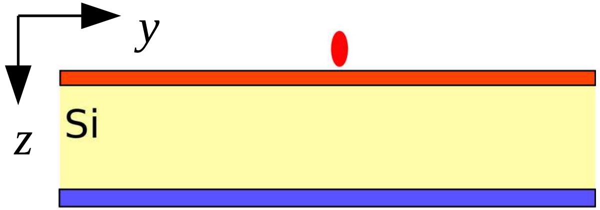
$$\lambda > \frac{hc}{E_g}$$



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

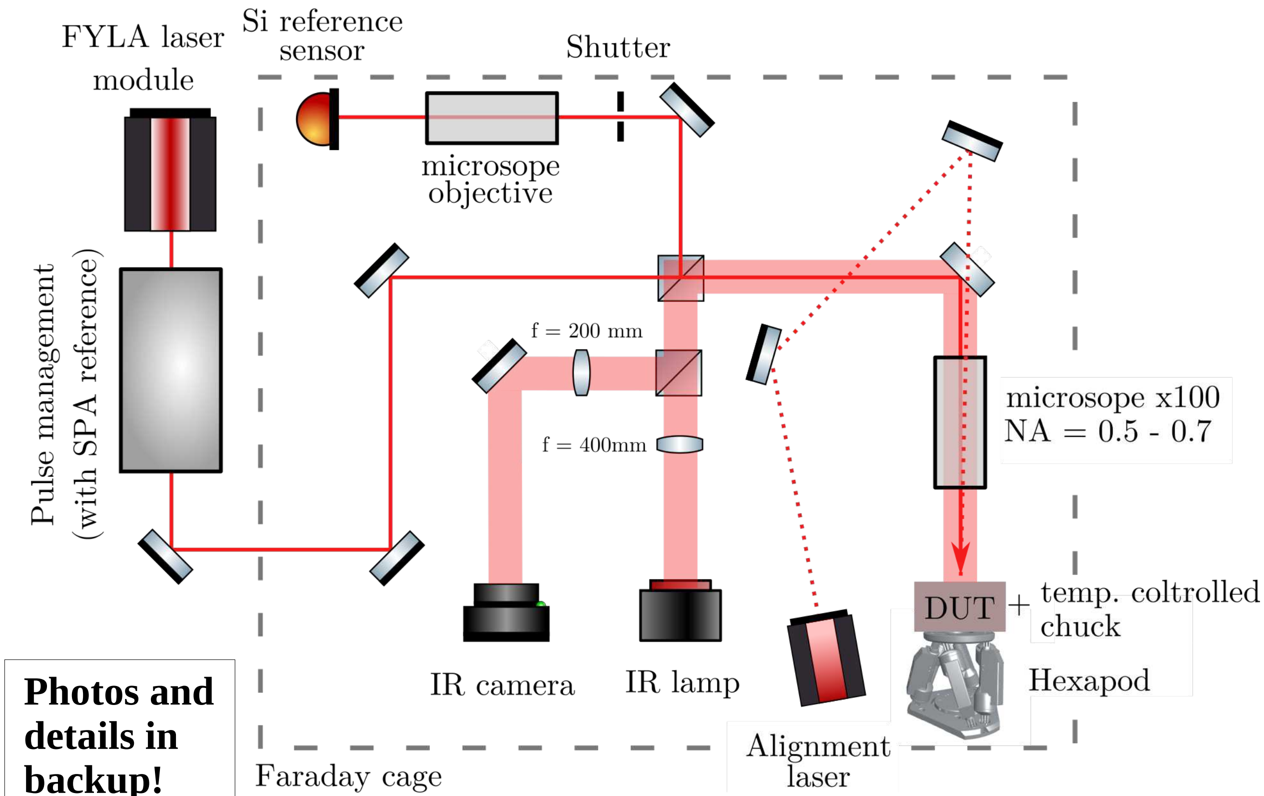
→ main excitation around focal point

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



TPA-TCT: Setup & Calibration

Sketch of the TPA-TCT setup at CERN SSD:

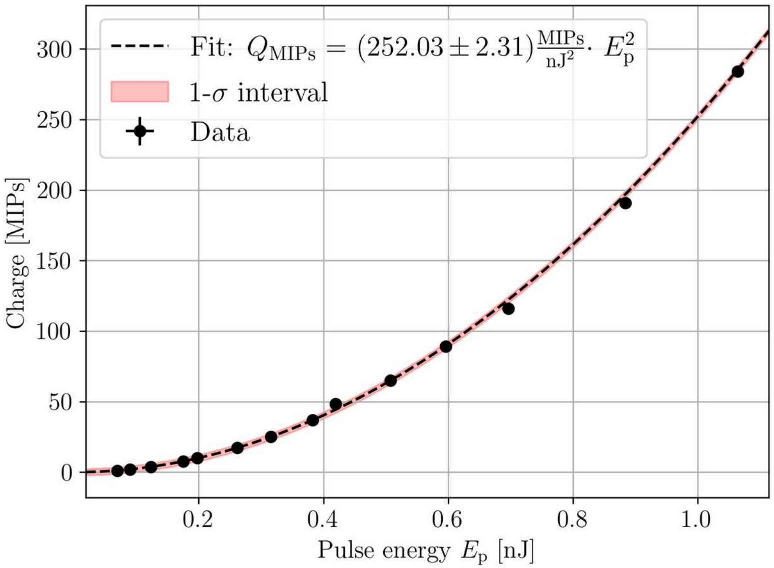


Photos and details in backup!

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 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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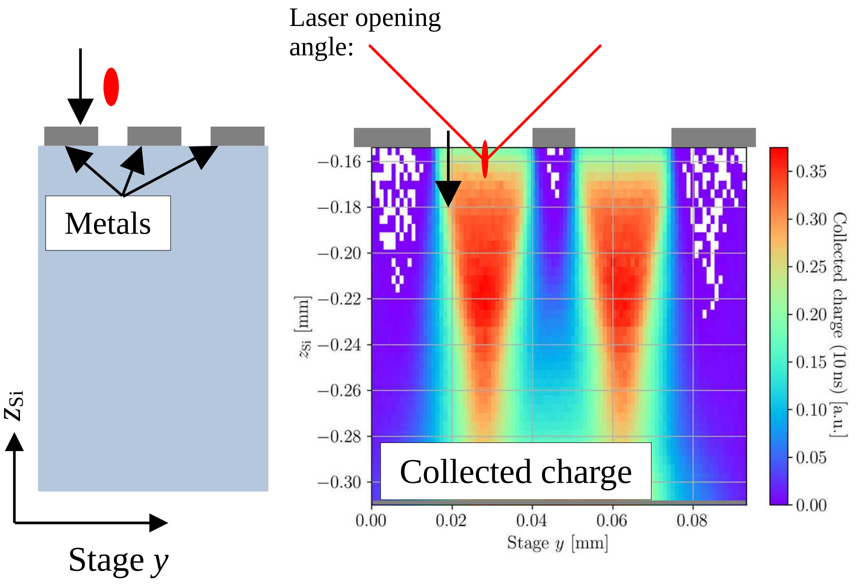
Example: Passive strip CMOS detector



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

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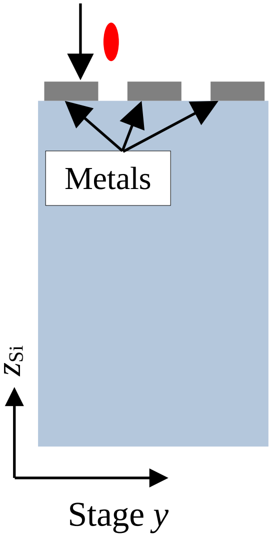
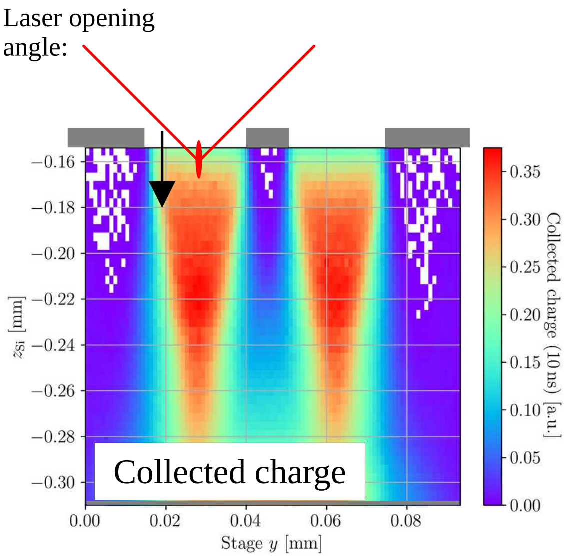
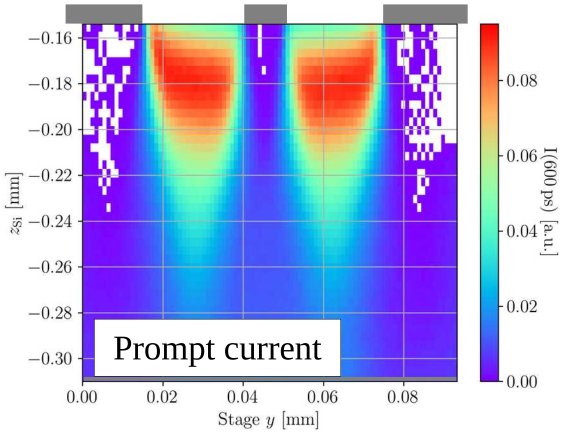




- Charge collection profile is distorted by laser beam clipping at the top side metallisations
- The collected charge propagates to the **prompt current**:



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

The prompt current method is widely used for studies of the **electric field / drift velocity**

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

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

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

S. Pape et al. [arXiv:2211.10339]
Techniques for the investigation of segmented sensors using the Two Photon Absorption – Transient Current Technique

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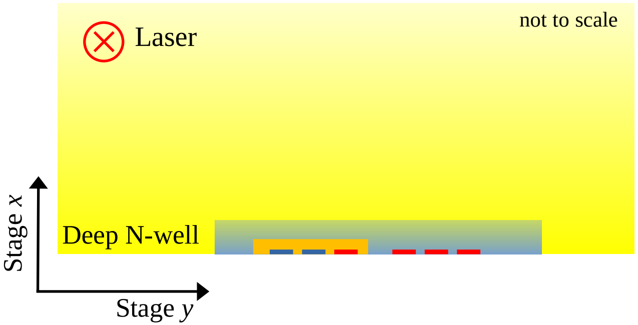
Comments on the weighted prompt current:

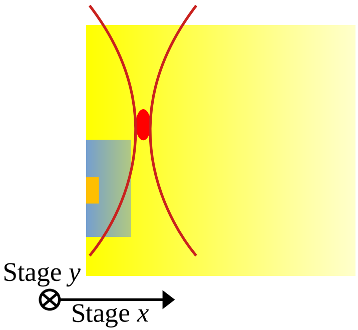
- Weighting requires that all generated charge is collected: $Q = Q_{coll}$
  → not applicable if meaningful trapping or charge loss is present
- More sensitive towards the SNR than the prompt current method and small signals → “0 / 0”
- Not affected by intensity varying effects (reflection, clipping, etc.)

S. Pape et al. [arXiv:2211.10339]
Techniques for the investigation of segmented sensors using the Two Photon Absorption – Transient Current Technique

Application: 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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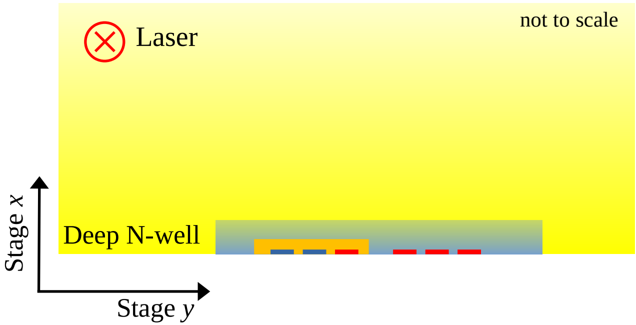

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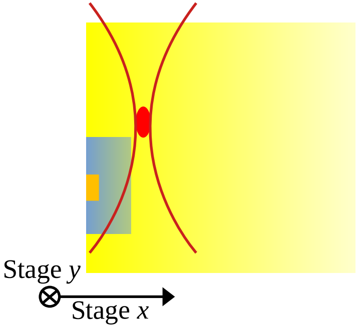
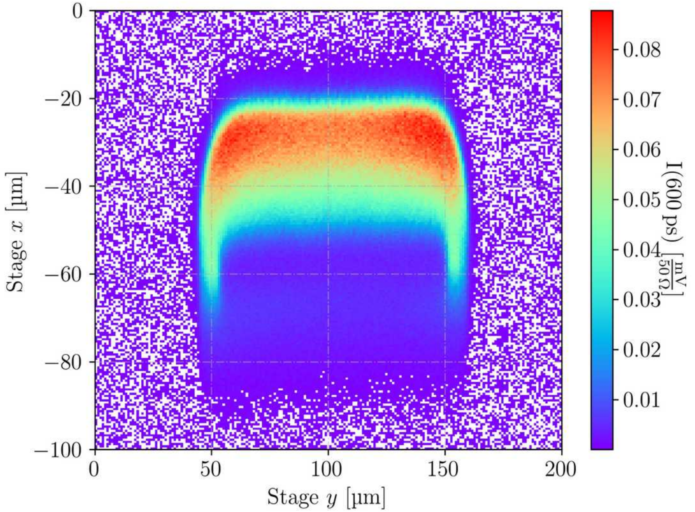
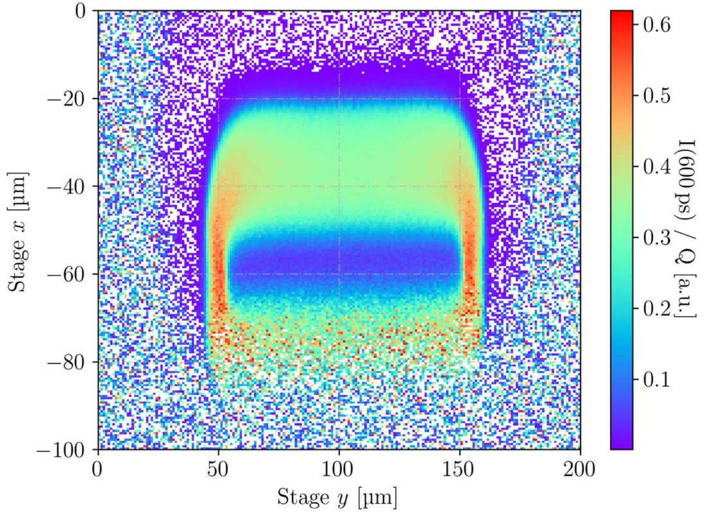


Prompt current



Weighted prompt current



Region of the maximum changed!

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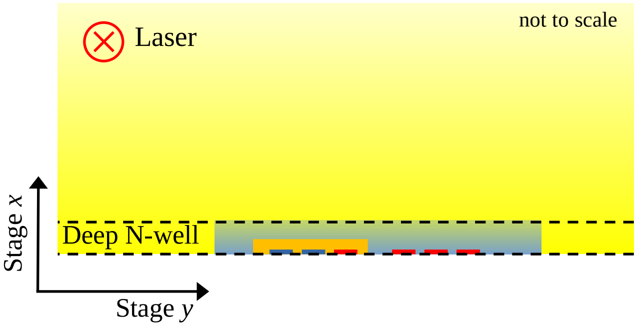

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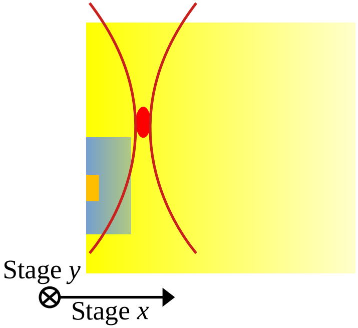

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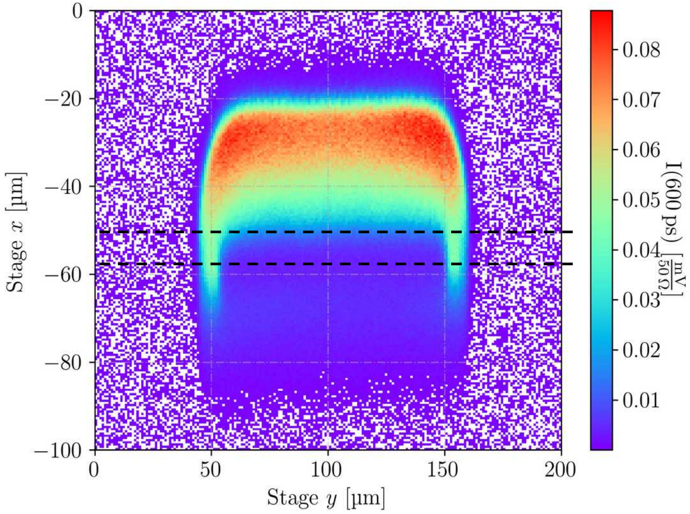

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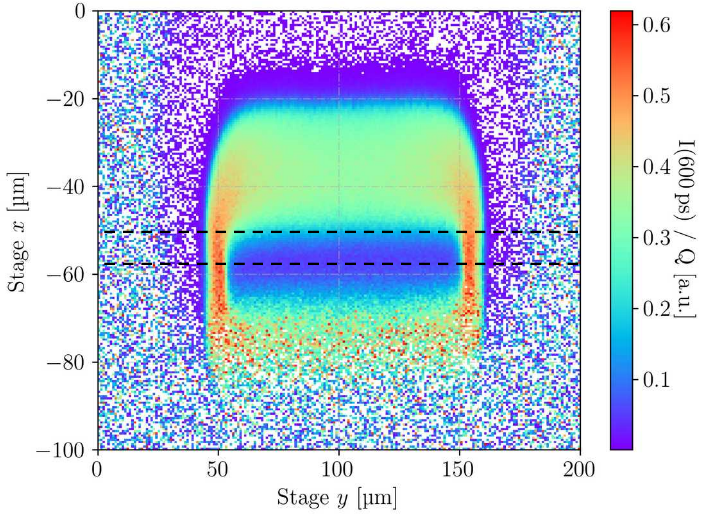

Extensive clipping close to the surface and reflection at the Si-air interface

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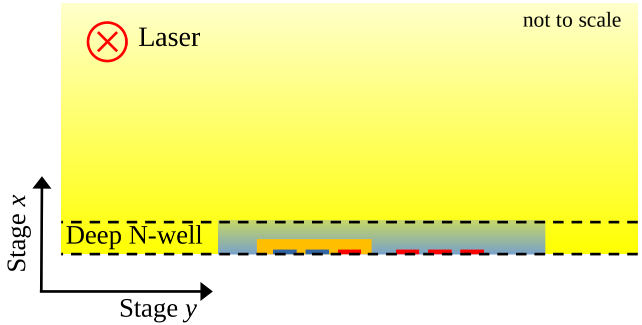
Application: HV-CMOS (CCPDv3)

Higher signals in the back, because laser beam is less clipped!



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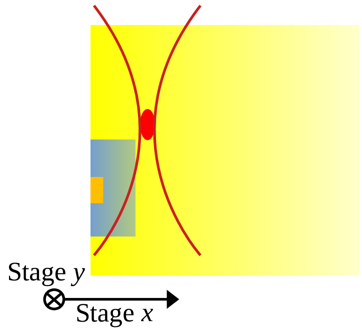
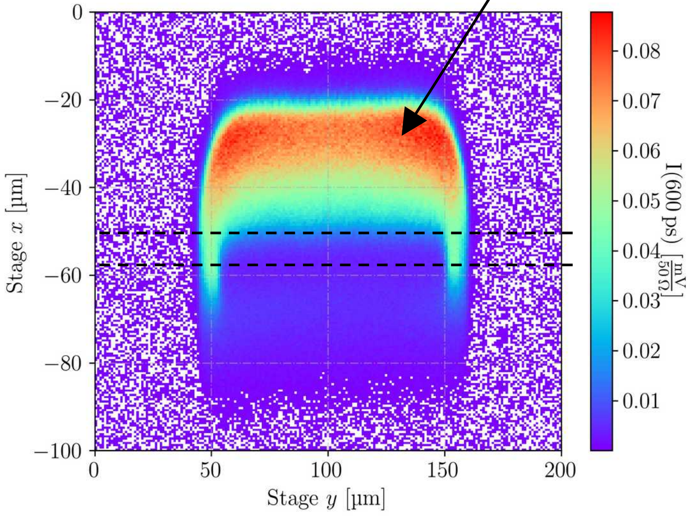
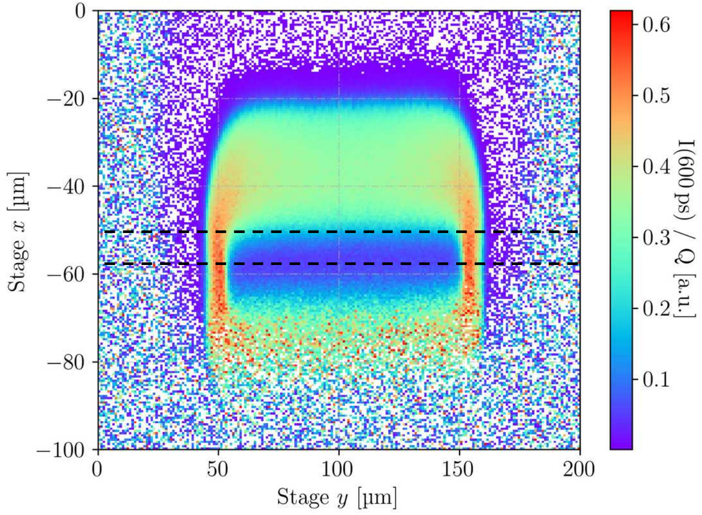


Prompt current



Weighted prompt current



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

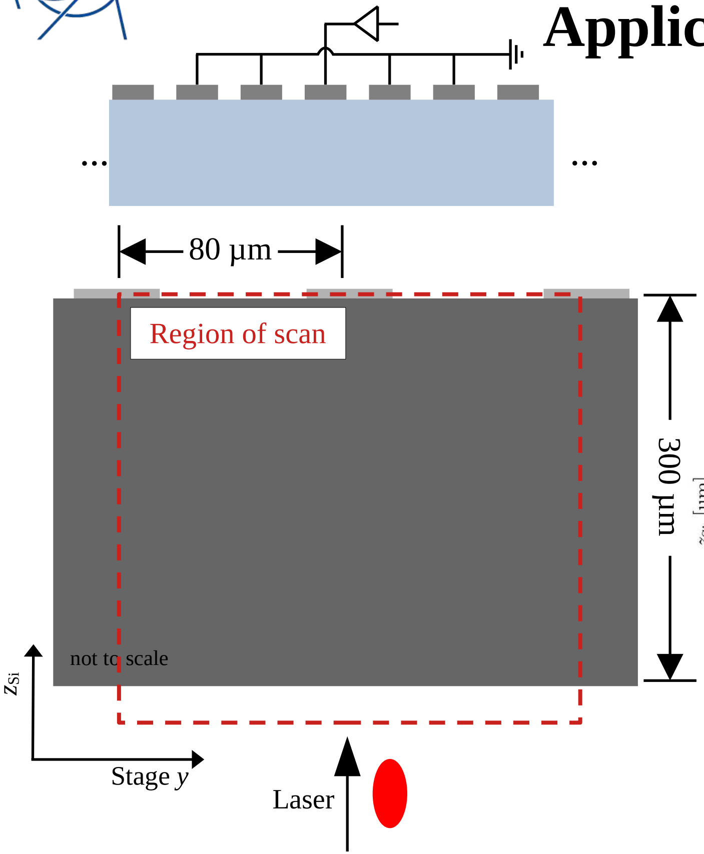
Region of the maximum changed!

Clipping is not affecting the weighted prompt current!

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)*

Application: Strip detector (FZ Micron)

Readout scheme:



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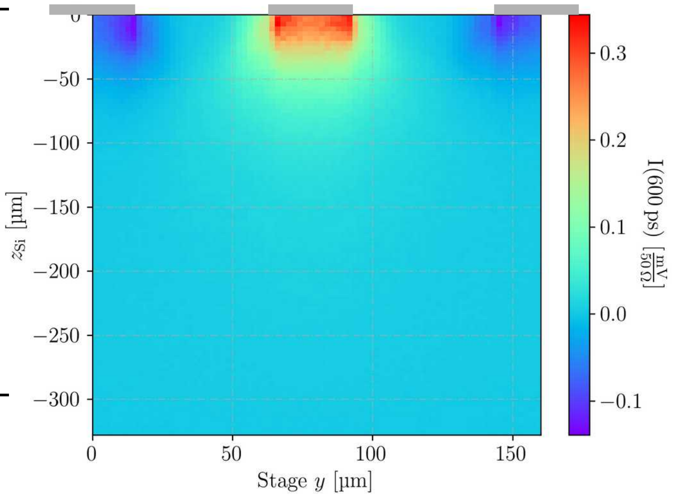

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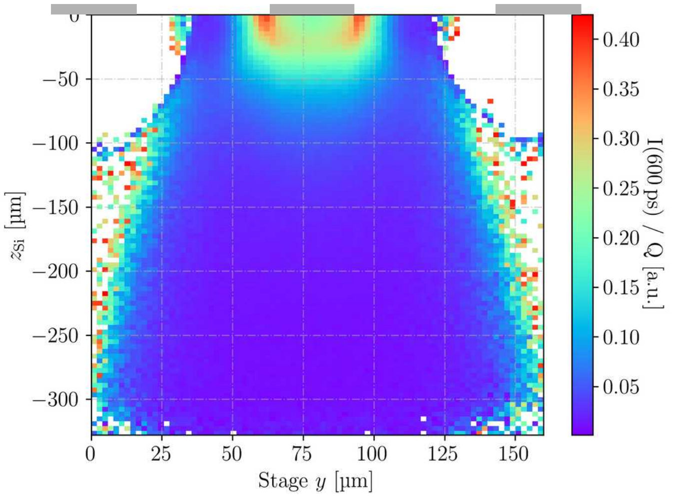


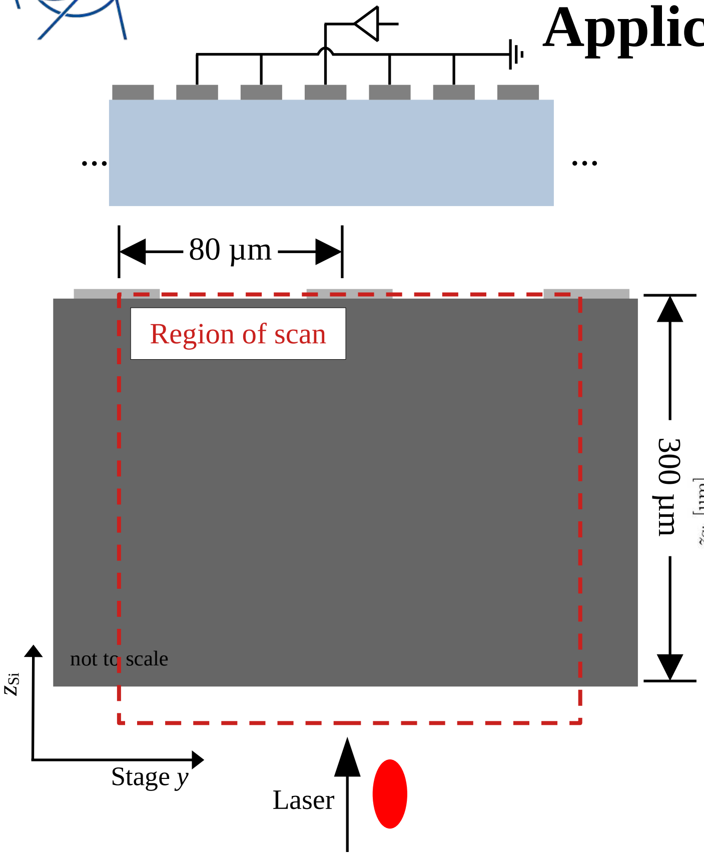
Details of the strip detector:

38th RD50 workshop CERN (virtual):

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

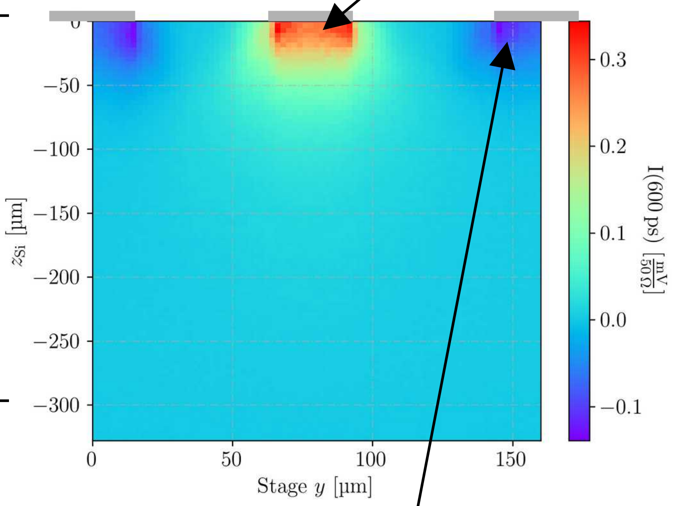
Application: Strip detector (FZ Micron)

Readout scheme:

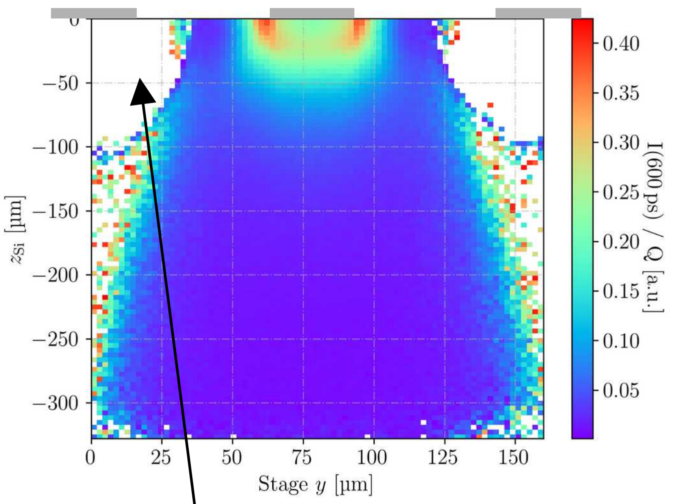


Reflection at top side metal leads to
an increased generated charge i.e. prompt current

Prompt current



Weighted prompt current



Negative prompt current as signals are bipolar and the charge is collected by the neighbor

$Q_{coll} \approx 0 \rightarrow$ leads to "-∞"

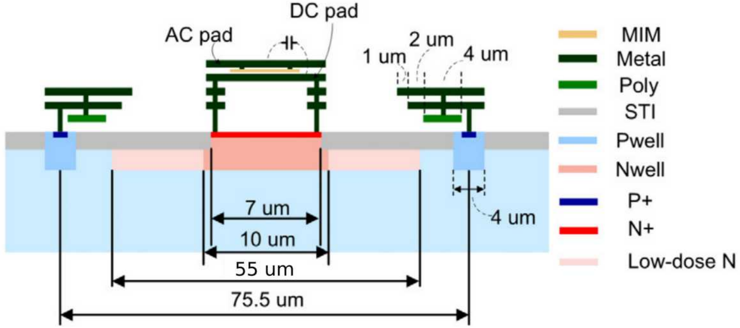
Details of the strip detector:
38th RD50 workshop CERN (virtual):
S. Pape: *A table-top Two Photon Absorption – TCT system: experimental results*

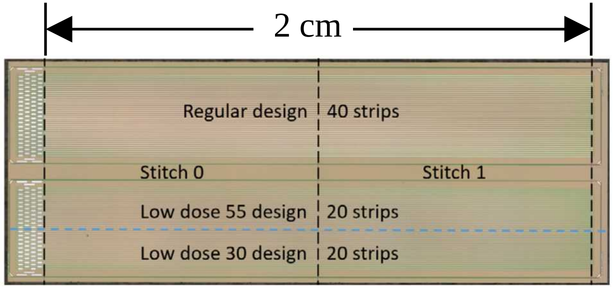
Passive strip CMOS detector

Common project of:

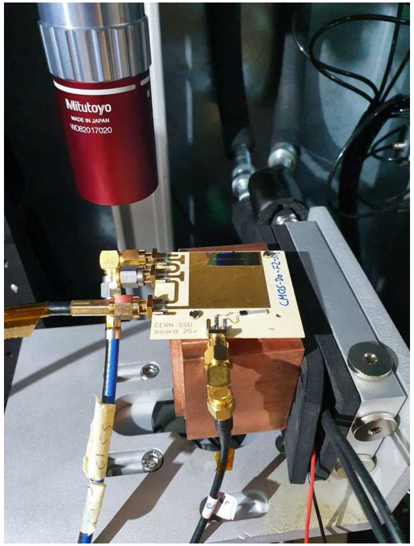
- Cost efficient device for large detector application
- Produced by LFoundry, using a 150 nm process
- Stitching of 1 cm² reticles
- p-type bulk
- Multiple implantation designs available → here tested: low dose 55 µm

Implantation of the low dose 55 µm design:





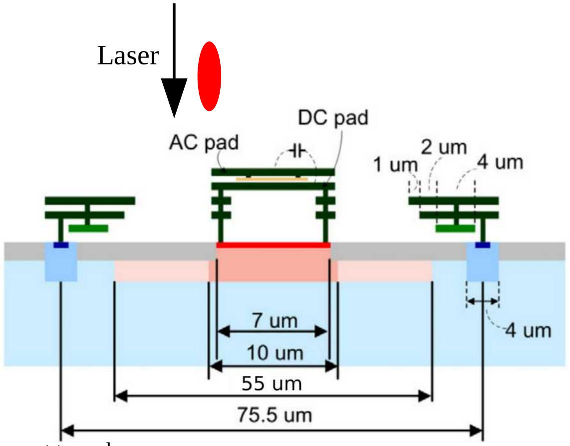
Mounted in the TPA-TCT setup at CERN:



More details on the device and project:
L. Diehl et al.
Characterization of passive CMOS strip sensors

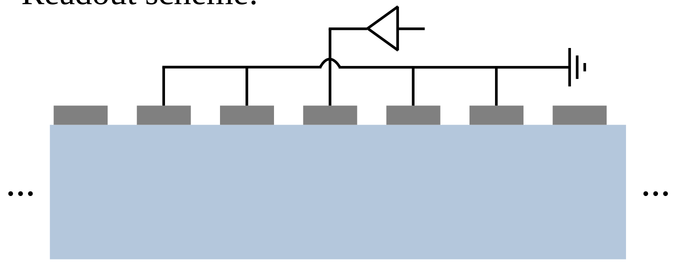
Also see M. Baselga's talk on Fri. 9⁰⁰

Application: Passive strip CMOS detector (low dose 55 µm design)



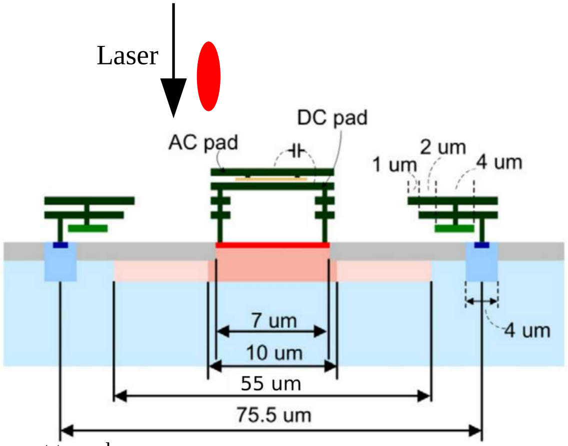
not to scale

Readout scheme:



AC pad is read out.
All DC pads are GND via the bias ring.

Application: Passive strip CMOS detector (low dose 55 µm design)



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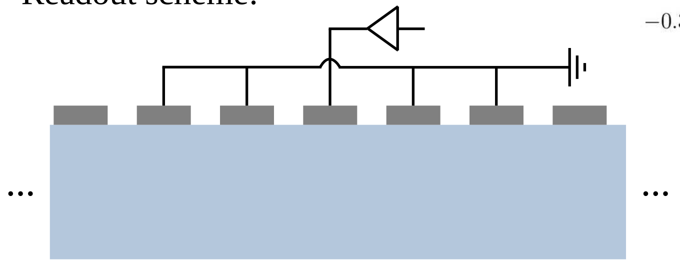

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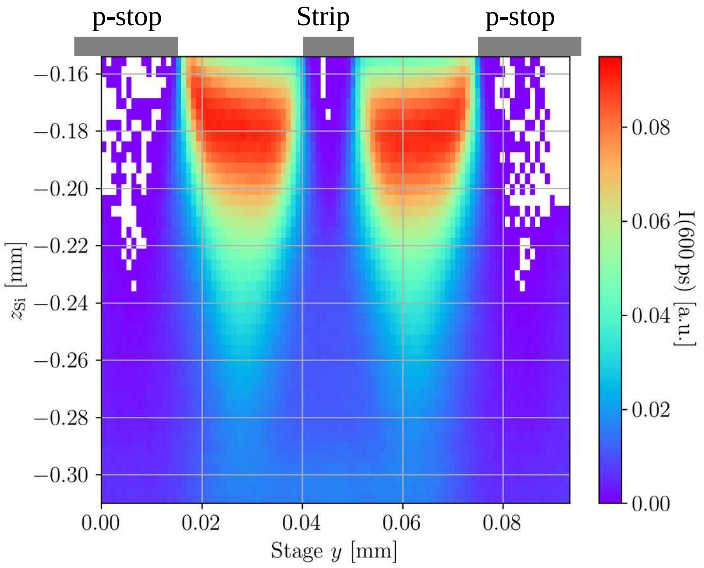
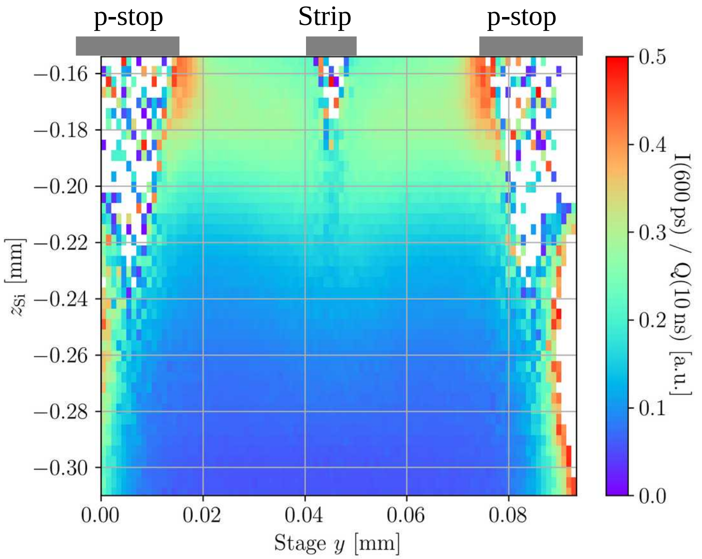
Prompt current



Weighted prompt current



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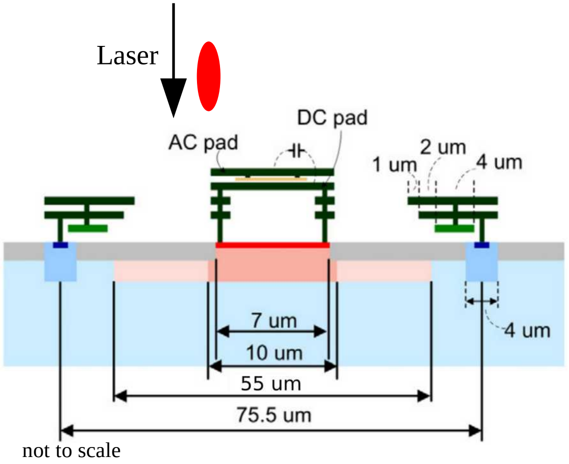

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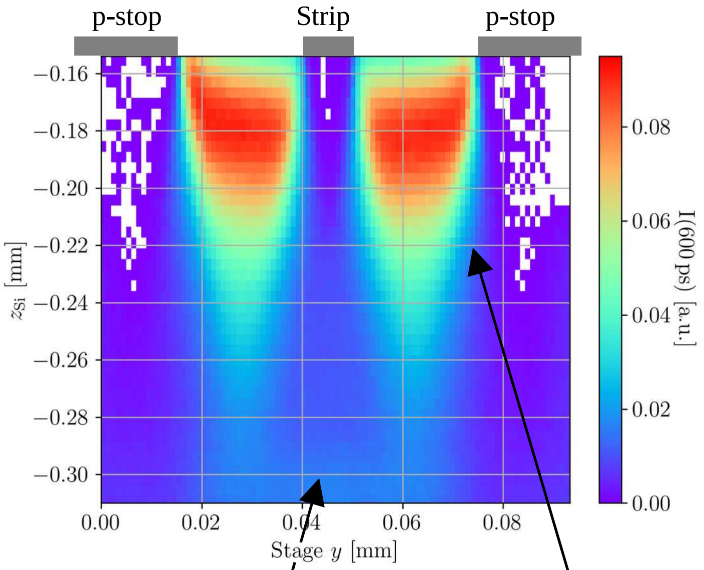

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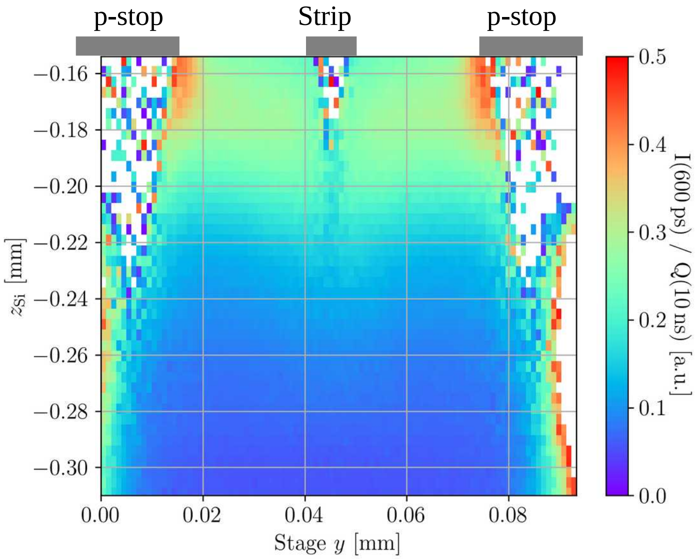
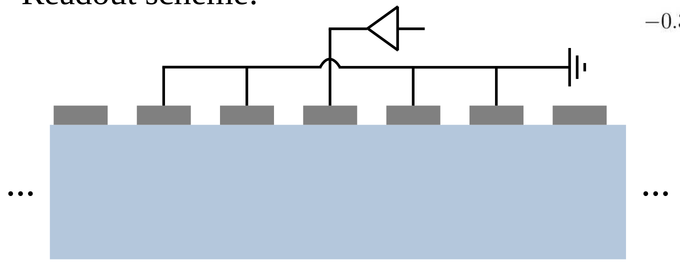


Shaped by the amount of clipping

Increased prompt current due to reflection at the back side metallisation

Shape not visible in the weighted prompt current.

Readout scheme:



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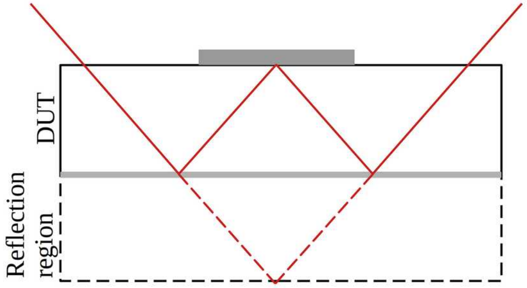
All DC pads are GND via the bias ring.

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. [arXiv:2211.10339]
Techniques for the investigation of segmented sensors using the Two Photon Absorption – Transient Current Technique

The mirror technique

Again using the passive strip CMOS detector as an example:

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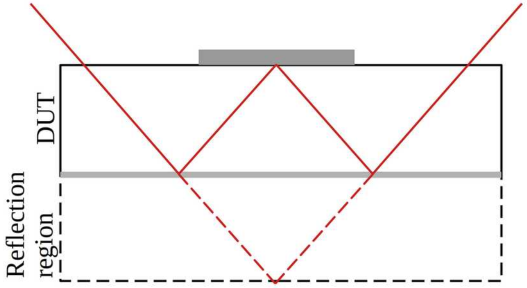

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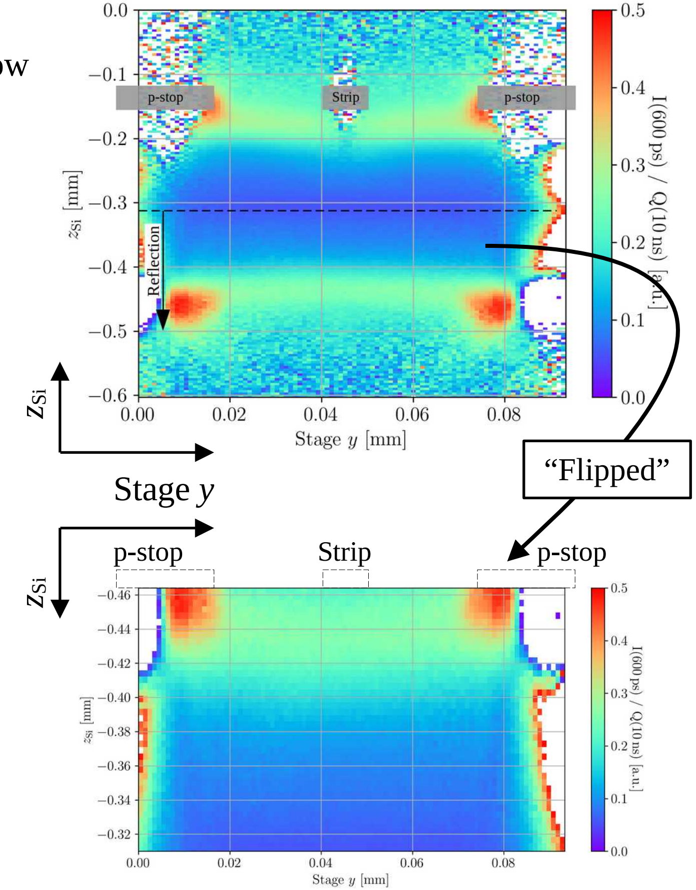


- Requires a metallised back side
- Enables a "clean" measurement in the reflection
  → probing below the top side metals is possible

S. Pape et al. [arXiv:2211.10339]
Techniques for the investigation of segmented sensors using the Two Photon Absorption – Transient Current Technique

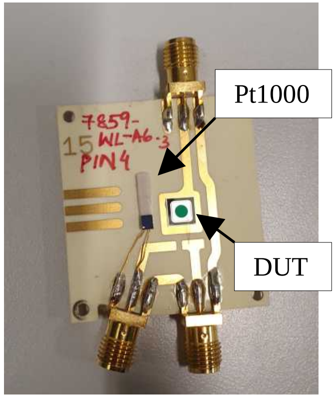
Influence of the temperature on the Two Photon Absorption – Transient Current Technique

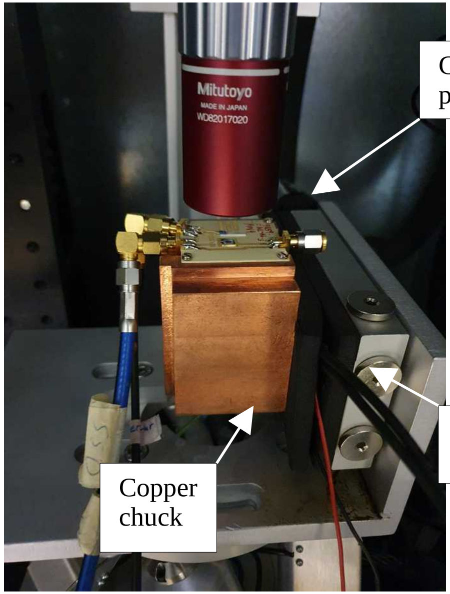
Motivation

- Preparing study for later measurements of irradiated devices
- Profound understanding needed to disentangle temperature related effects from irradiation related ones

Device under test:

Type	Nominal thickness [µm]	Depletion voltage [V]
p-type PIN	285 µm	27 V

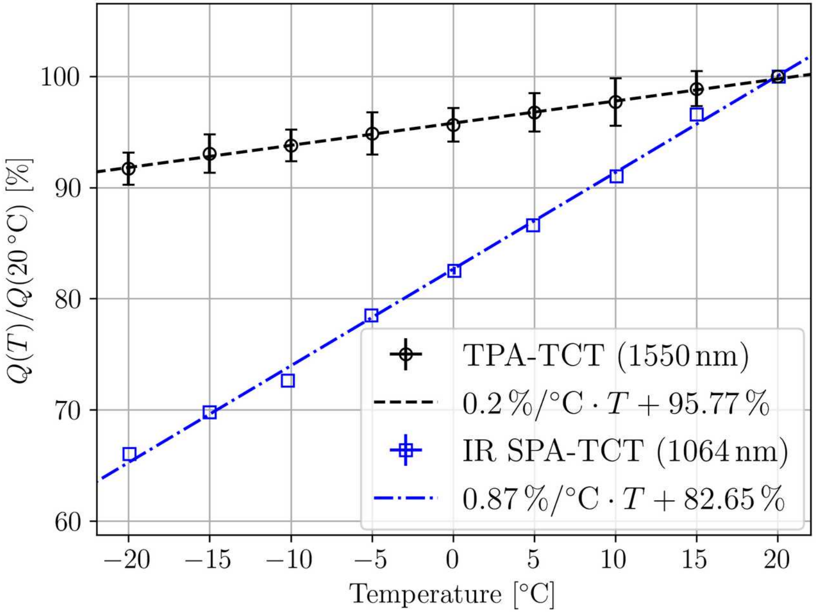




All shown measurements are performed at 100 V and 0% humidity.

DUT temperature fluctuation < 0.1 K

Charge collection



DUT thickness 285 µm

- Measured the charge collection of TPA- and SPA-TCT at different temperatures
- Charge collection decreases with temperature: less phonons available, increasing band gap (here < 1 meV)
  → for the used temperature the the dependence is linear
- Linear absorption decreases by 35 % and quadratic absorption by 8 %
- Charge generation is given by:

$$Q_{TPA}(T) \sim n(T)\beta_2(T)$$
$$Q_{SPA}(T) \sim n(T)\alpha(T)$$

- Refractive index: n(-23°C) / n(20°C) = 99.8 % → negligible

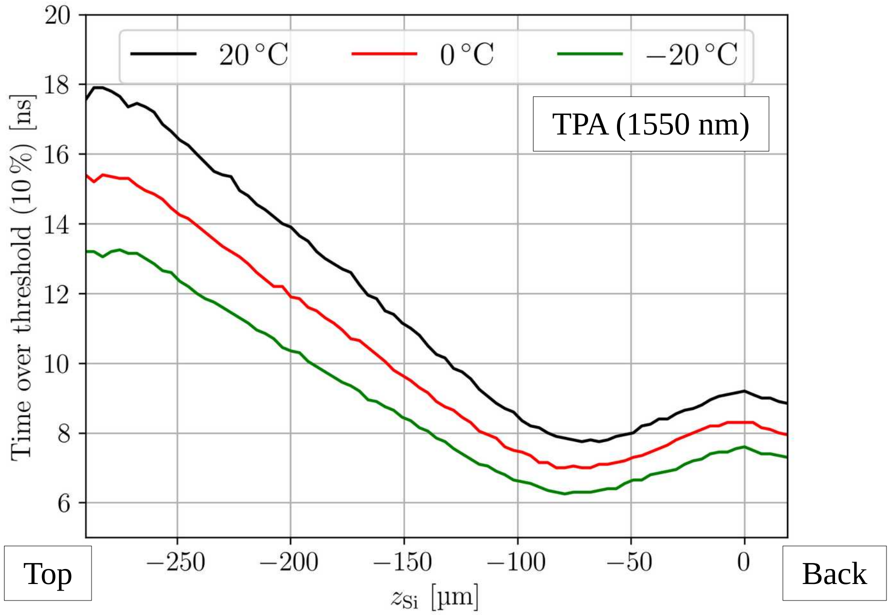
→ absorption coefficients dominate the loss in charge generation

Literature: β_2(-23°C) / β_2(17°C) = (88 ± 2.6) %

→ in agreement with our measurement

Sinclair et al.:
Temperature Dependence of the Kerr Nonlinearity and Two-Photon Absorption in a Silicon Waveguide at 1.55 µm

Charge collection time

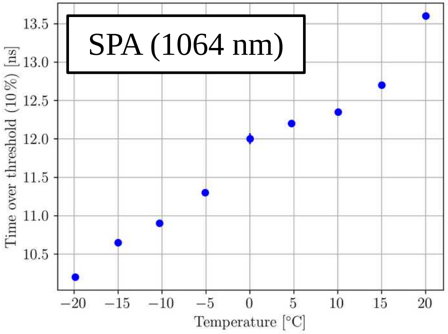


- Time over threshold decreases with temperature from 20 °C to -20 °C by about 17 % to 27 % depending on the deposition depth

  → Decreased phonon population

  → Less scattering of the charge carriers

  → Increasing charge carrier mobility



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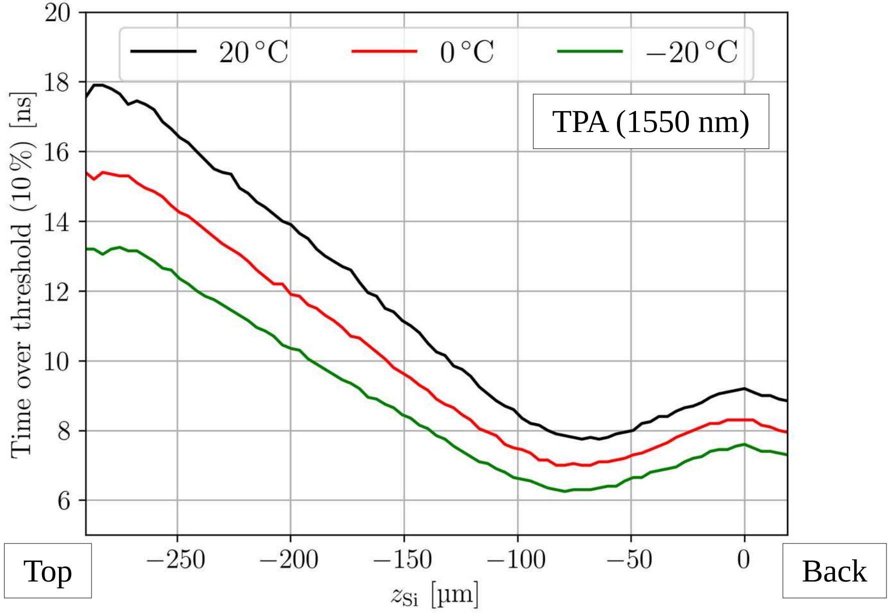

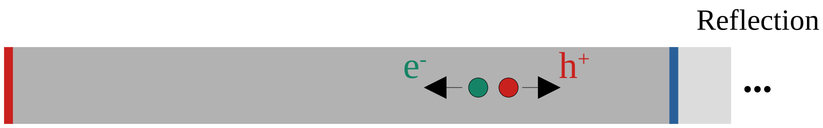

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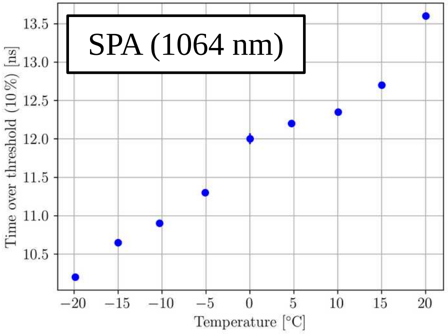

- Minimum in the Tot plot is reached, when electrons and holes need the same collection time

  → Closer to the back side, because holes have a lower mobility than electrons

Summary

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

  → Not affected by a varying excess charge carrier generation → corrects for clipping, reflection, and 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

- **Mirror technique:** Exploiting a reflection at a metallised back side, to measure below the top side metallisation

- **Charge collection and temperature:** Q_{TPA} (-20 °C) is 8% lower than Q_{TPA} (20 °C) → less drastic than for SPA

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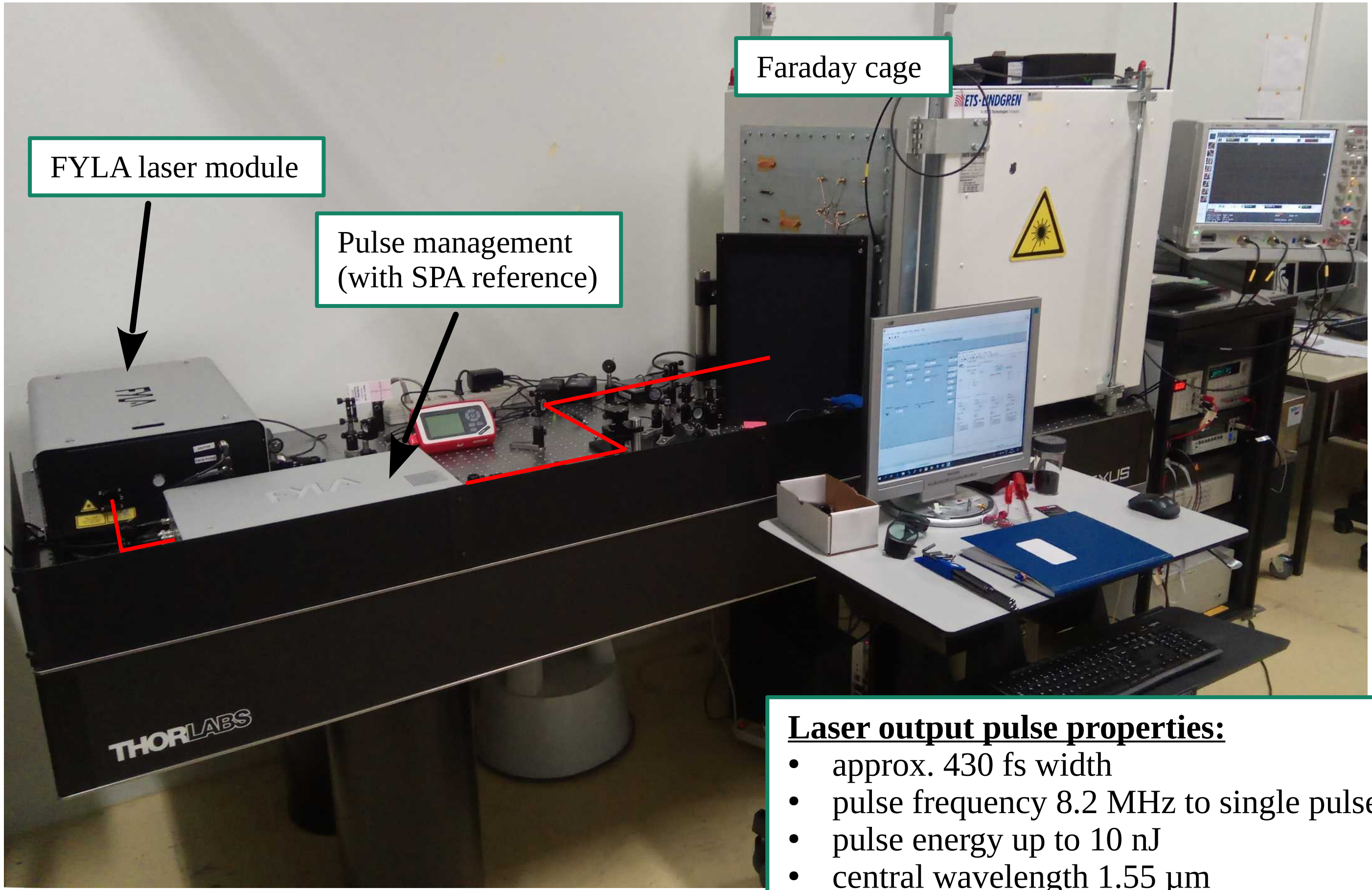
Thank you!

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

WE LASER THE NEW INDUSTRY

TPA-TCT setup: Inside of the Faraday cage