TPA-TCT

A novel Transient-Current-Technique based on the Two Photon Absorption process

25th RD50 Workshop @ CERN

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Scope of this talk

- Here, this talk focused on the experimental results from the first proof-of-concept measurement to study the TCT currents induced by TPA in an RD50-like non-irradiated standard PiN diode.

- More details on the basics of the TPA process can be found in this talk by F.R. Palomo (link)

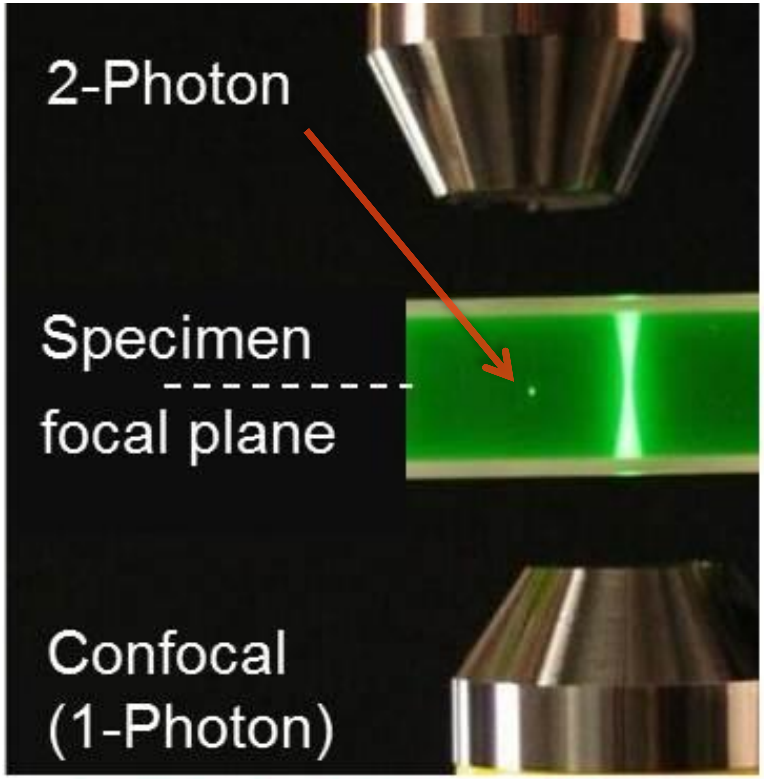
- More details on the code TRACS (TRansient Current Simulator) used to compute the theoretical current waveforms in P. de Castro talk (link)

Outline

- Motivation and challenges for a TCT technique based on the Two- Photon- Absorption (TPA) process.
- Femto-second laser setup:
  - Signal size and shape vs. laser power.
  - Determining the charge carriers generation volume.
- Experimental data vs. simulation for a z-scan in a PiN diode.
- Conclusions and outlook

Motivation for a TPA-based TCT technique

"A picture is worth a thousand words"



Photography: Ciceron Yanez, University of Central Florida

TPA-TCT is a way to **generate very localized electron-hole pairs** in semiconductor devices (microscale volume).

TPA-TCT **simplifies the arrangement to inject light into the device and the unfolding** of the device internal Electric field and other relevant parameters of the theoretical model.

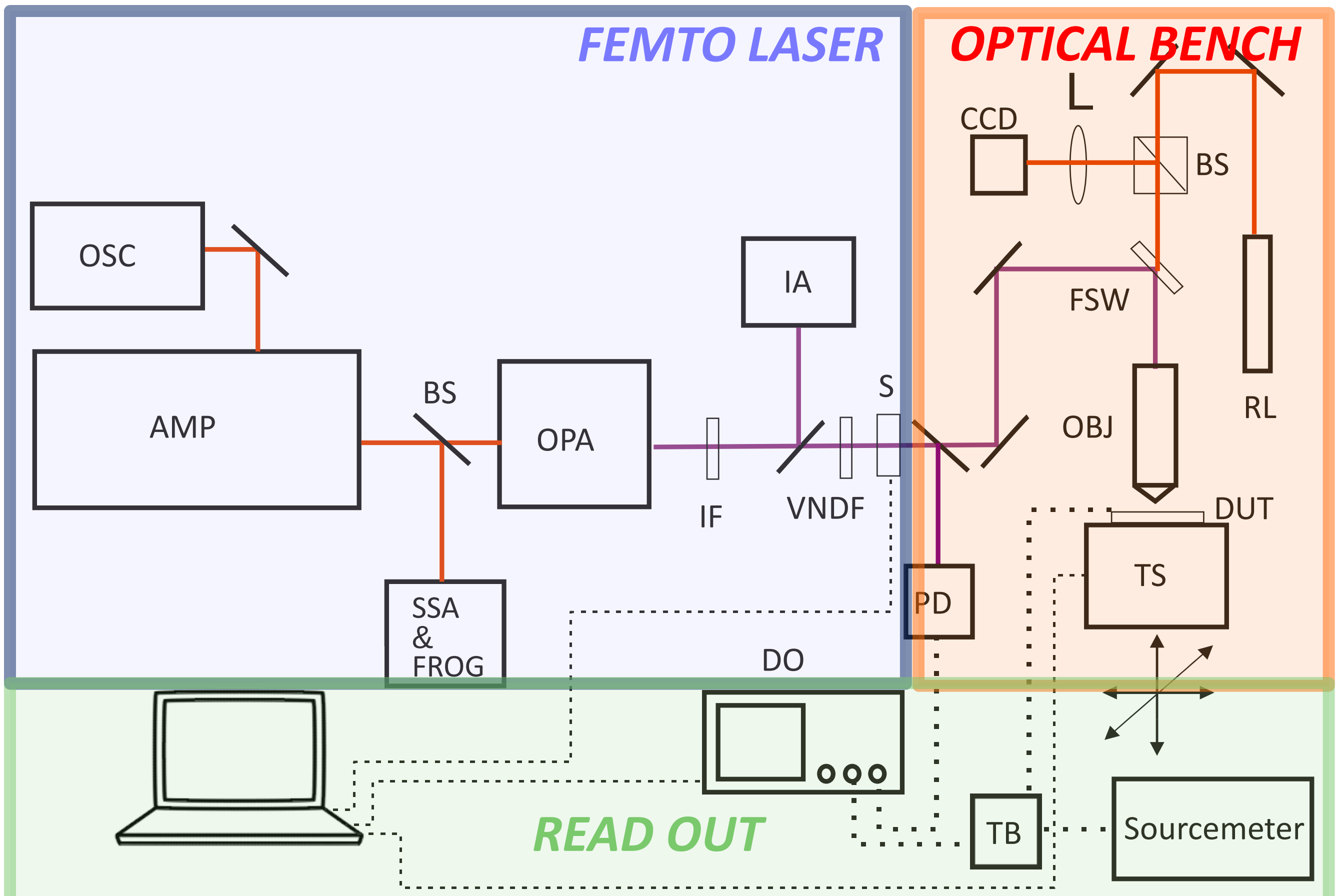
TPA-TCT could provide a novel experimental tool for studying the currently under development small pixel size detectors.

TPA-TCT Proof-of-concept Challenges

1. Confirm the generation of TPA induced current in a silicon diode with the appropriate laser power.
2. Determine the dimensions of the charge-carrier's generation volume.
3. Compare the experimental TCT current waveforms against the theoretical simulated current waveforms (access its potential as experimental tool to discriminate between different theoretical models).

Experimental arrangement (1)

Pulsed femto laser (at normal incidence) entering the diode junction side (conventional top-TCT configuration)



Laser

λ ~ 1300 nm

P ~ 50-100 pJ

ΔT ~ 240 fs

Rate ~ 1 kHz

Δf ~ 11 nm

Microfocus

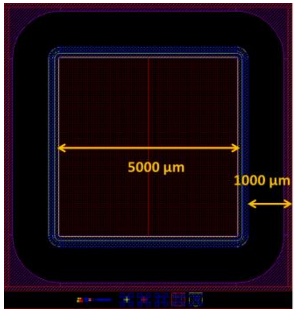
X100 Objective

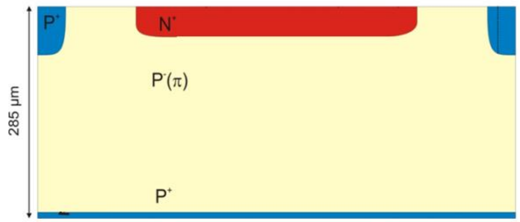
f 100 mm lens

2.5 GHz DSO

Experimental Arrangement (2)

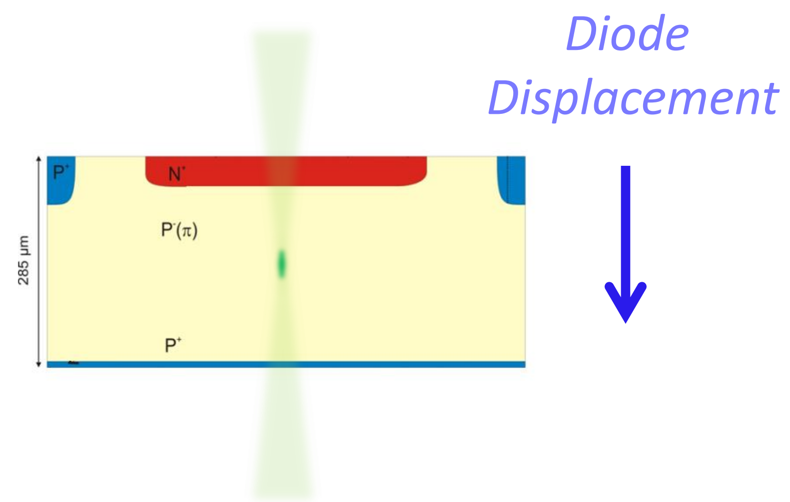
DUT CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9

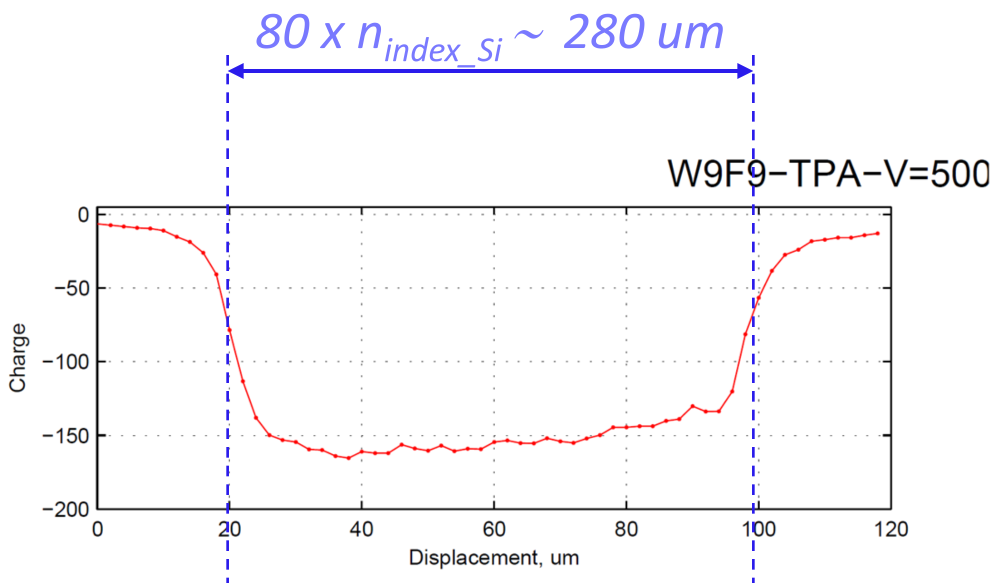




Evidence of TPA-TCT (1)

– Z-Scan: vertical displacement of the DIODE perpendicularly to the laser beam (z axis)



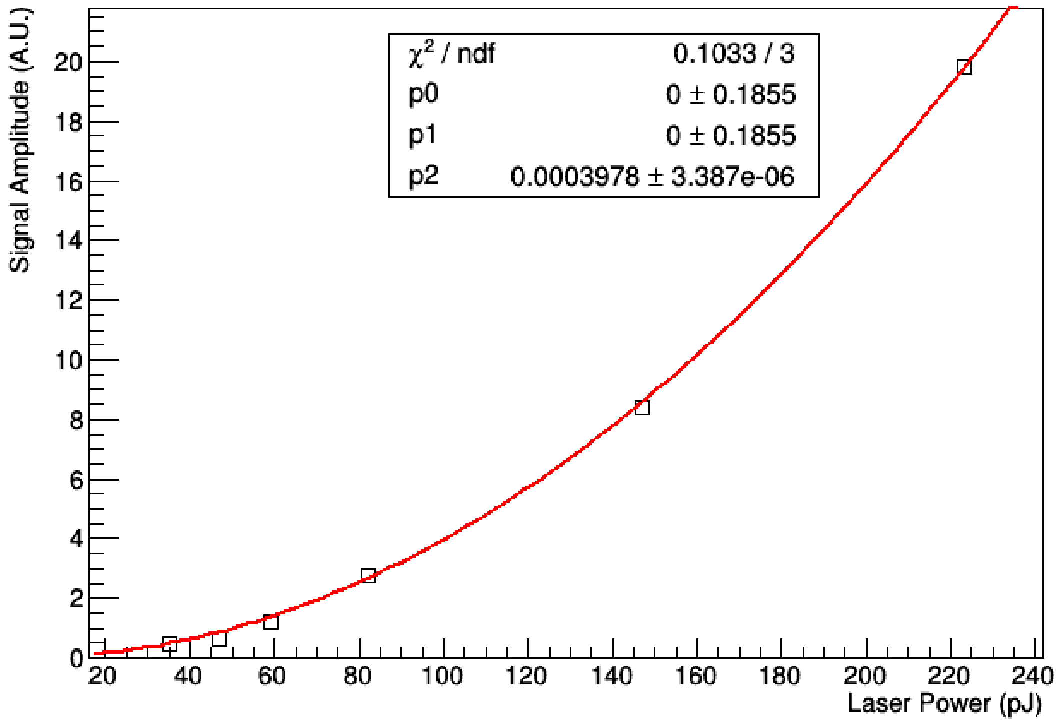


– TPA -> Charge vs z -> plateau (Observed behavior)

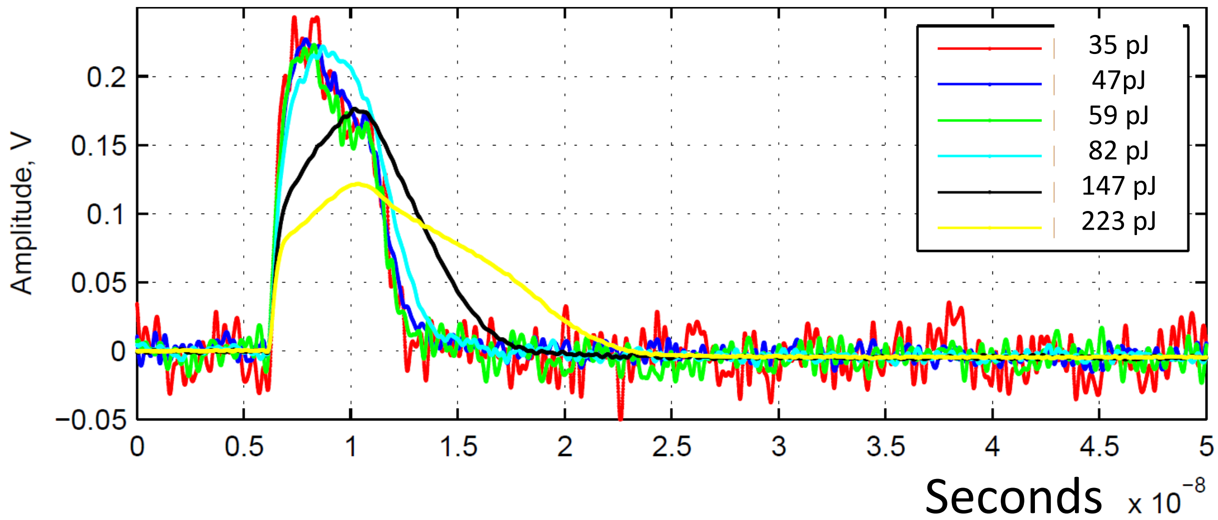
– SPA (Standard TCT) -> Charge vs z -> no z dependence.

Evidence of TPA-TCT (2)

– Pure quadratic dependence between the Signal Charge and the laser power.



Which is the adequate laser power ?



– Similar pulse shapes for laser pulses up to a power of 60-80 pJ, for higher power values TCT waveform gets wider and wider (likely due to plasma effects).

TPA-TCT Proof-of-concept Challenges

1. Confirm the generation of TPA induced current in a silicon diode with the appropriate laser power.
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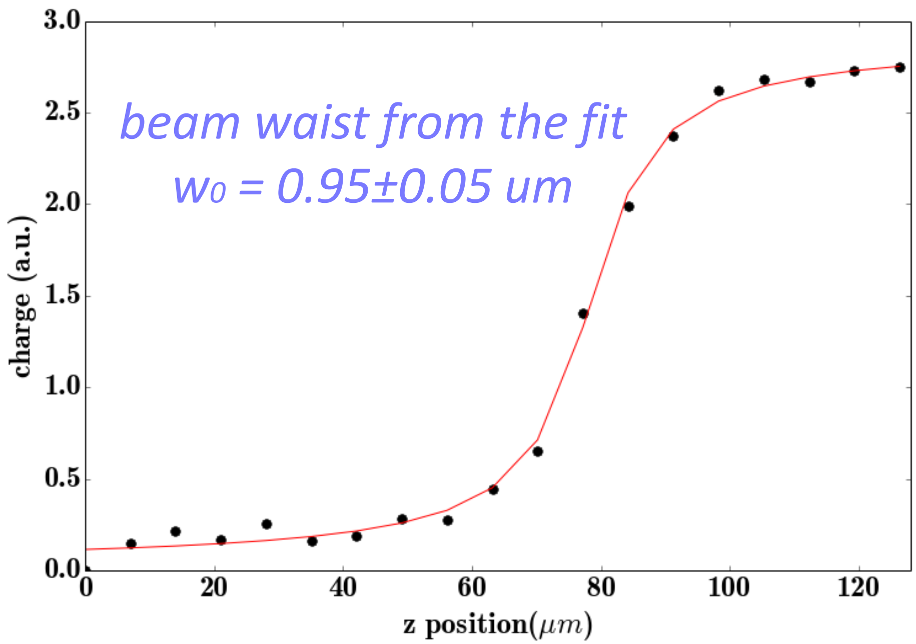
TPA-Induced charge-carriers volume

- The laser's volume of excitation (e-h pair creation) is fully determined by the laser parameters (λ and W_0) and the TPA cross-section in Silicon (β)
- In our case, λ and β are known, a fit of the raising edge of the charge z-scan profile determines W_0



Gaussian Intensity Profile

$$w(z)^2 = w_o^2\left[1 + \left(\frac{\lambda z}{\pi w_o^2 n}\right)^2\right]$$

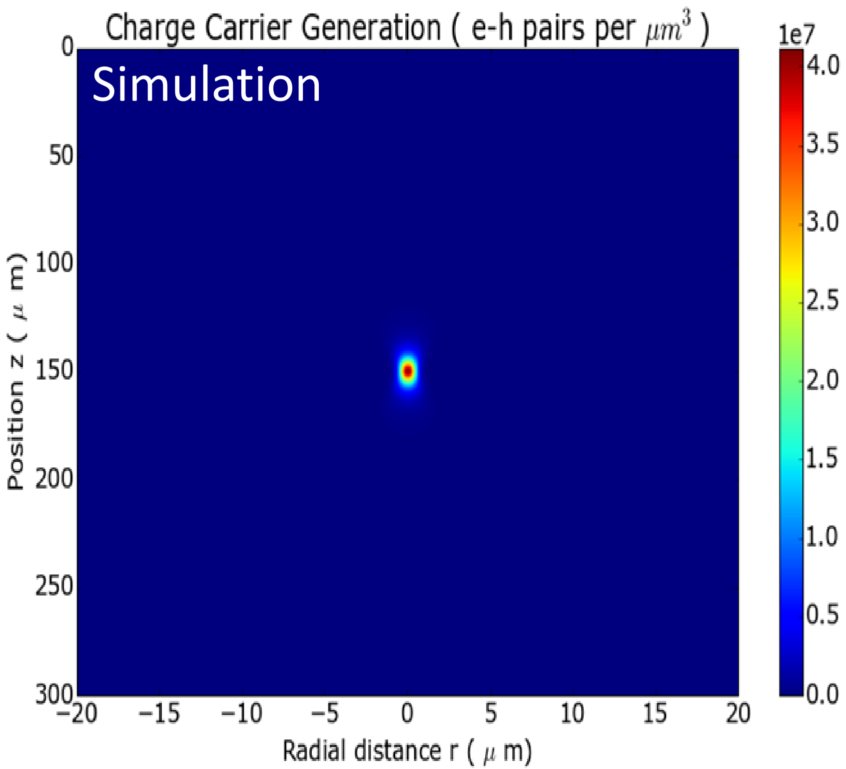
$$I(r,z) = \frac{2P}{\pi w(z)^2}\exp\frac{-2r^2}{w(z)^2}$$

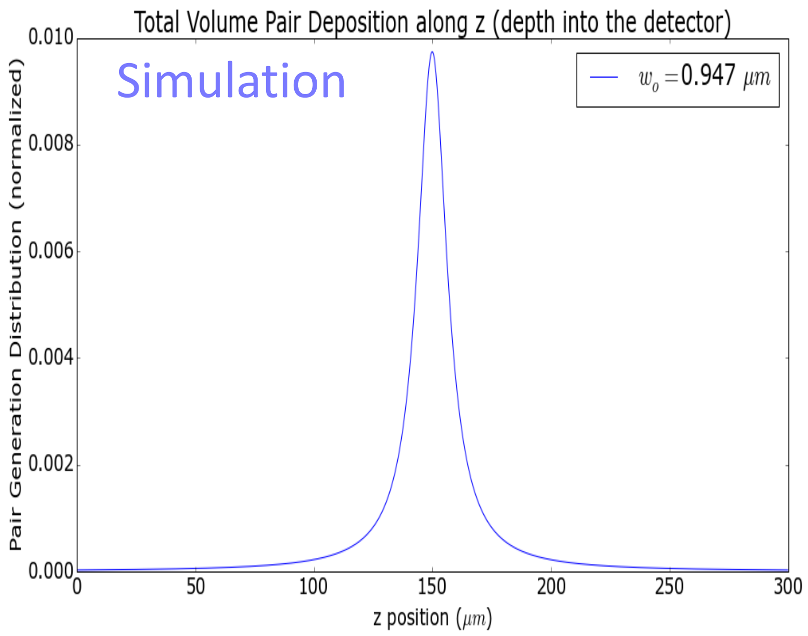
TPA absorption (negligible attenuation)

$$n_{TPA}(z) = \frac{\beta\tau}{2\hbar\omega} I(r,z)^2$$

TPA-Induced Charge-carriers volume (2)

- **r spot size** → 1σ~0.8 μm & 2σ~3.4 μm
- **z spot size** → 1σ~13 μm & 2σ~60 μm



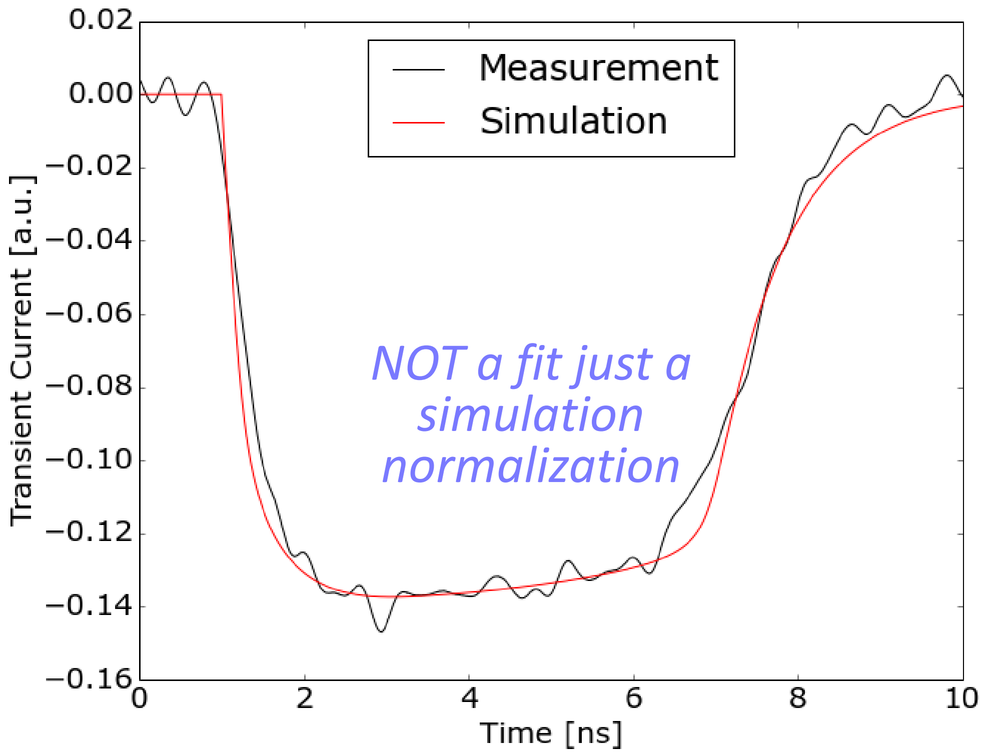


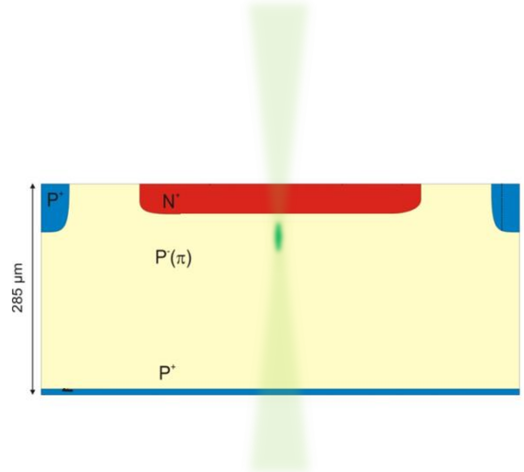
TPA-TCT Proof-of-concept Challenges

- Confirm the generation of TPA induced current in a silicon diode with the appropriate laser power.
- Determine the dimensions of the charge-carrier's generation volume.

3. Compare the experimental TCT current waveforms against the theoretical simulated current waveforms (assess its potential as experimental tool to discriminate between different theoretical models).

TCT Waveforms: 20um focus depth

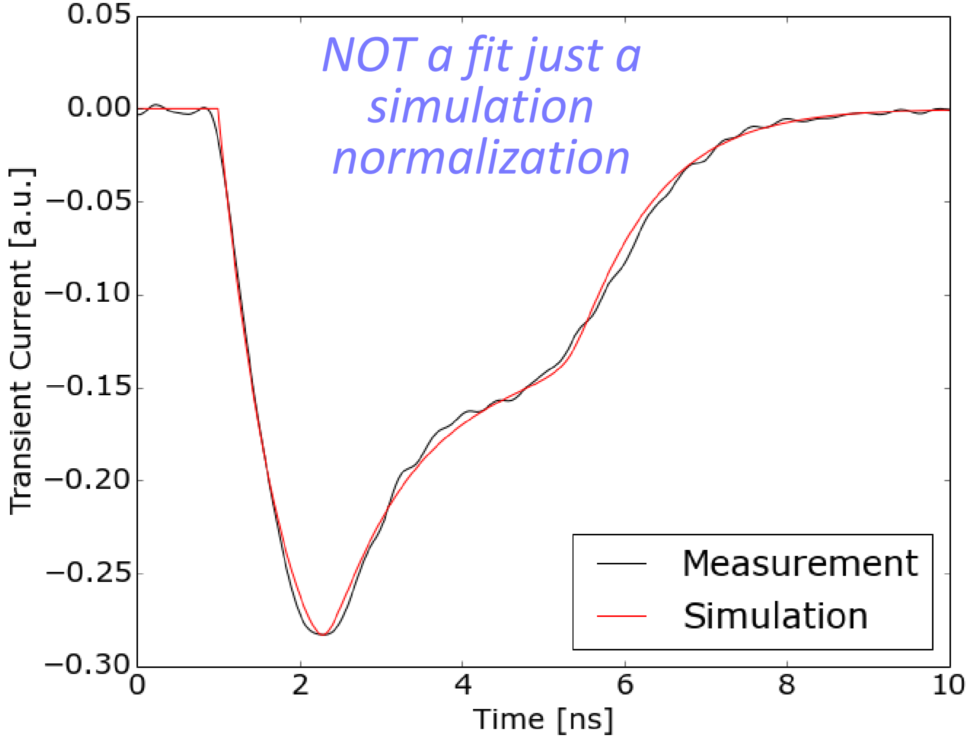


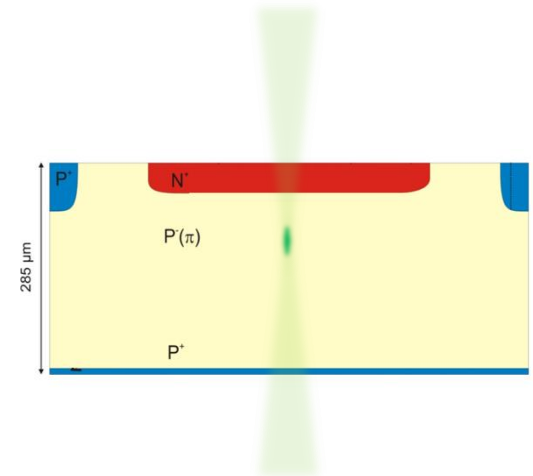


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

Single Photon Absorption red laser TOP-TCT (hole injection)

TCT Waveform: 97 um focus depth

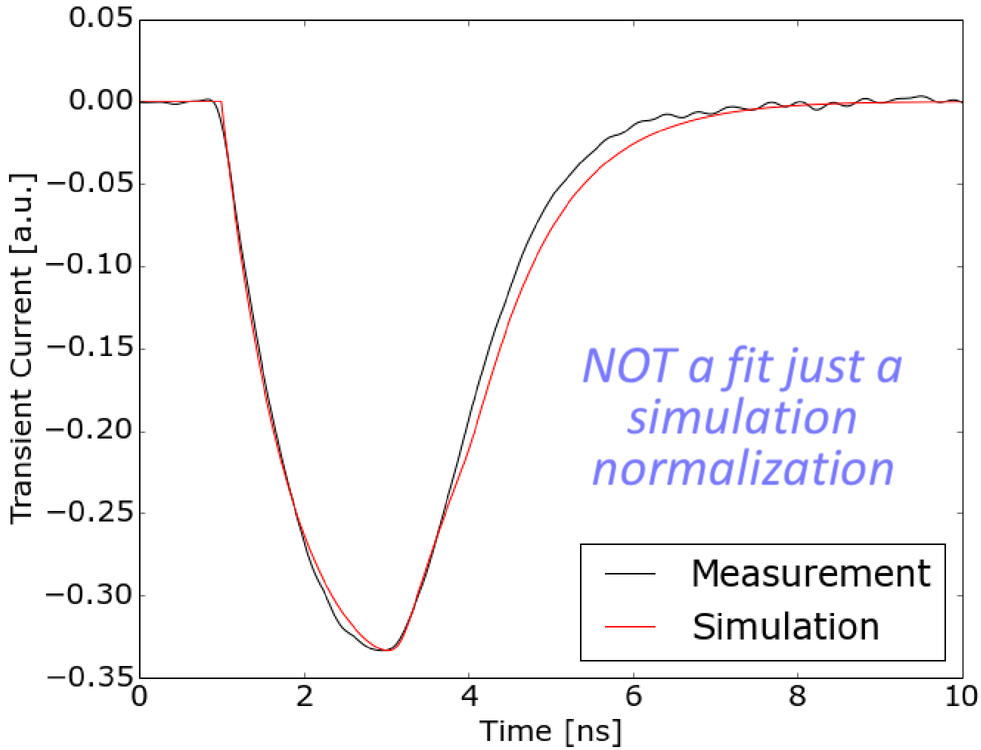


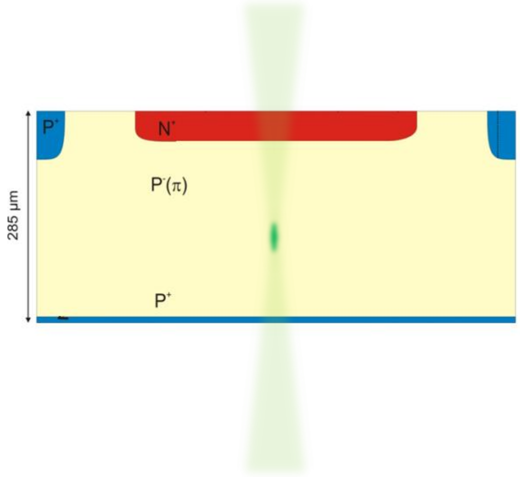


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

– Electrons and holes TCT current contribution distinct from the TCT current shape.

TCT Waveform: focus depth 160um

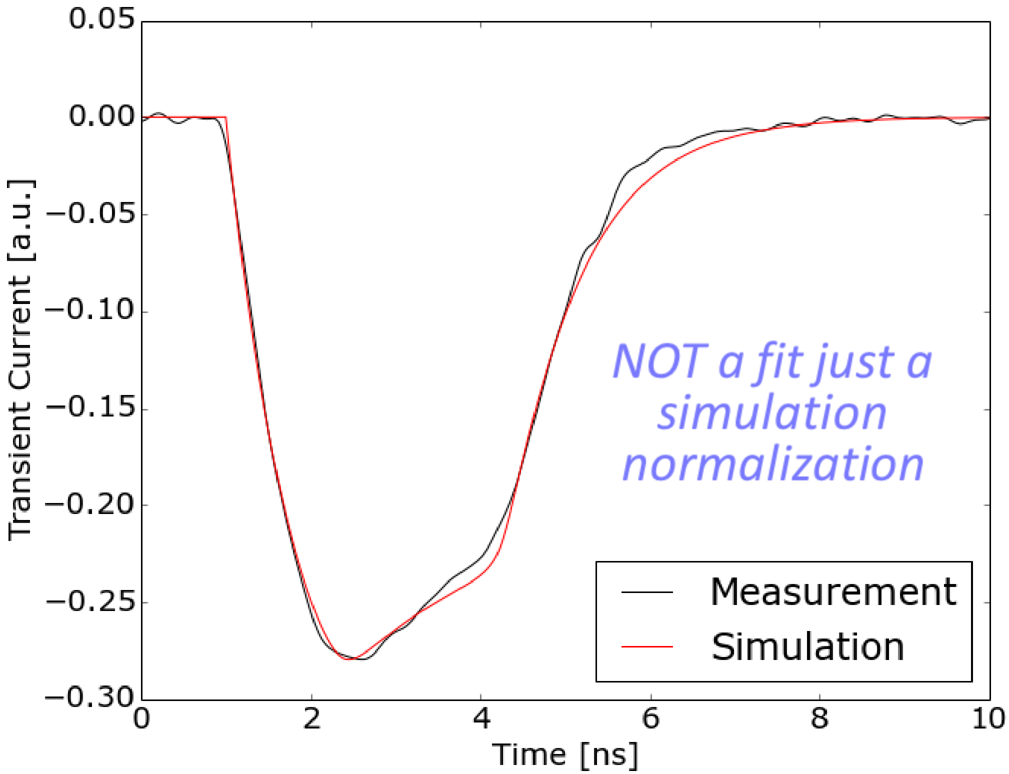


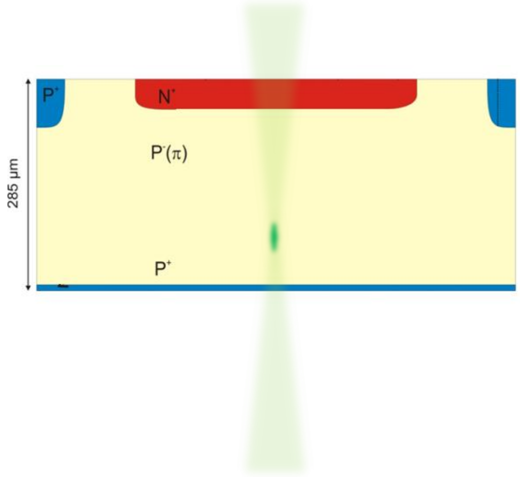


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

– Around the minimal pulse width, similar arrival times for electrons and holes

TCT Waveform: focus depth 237um

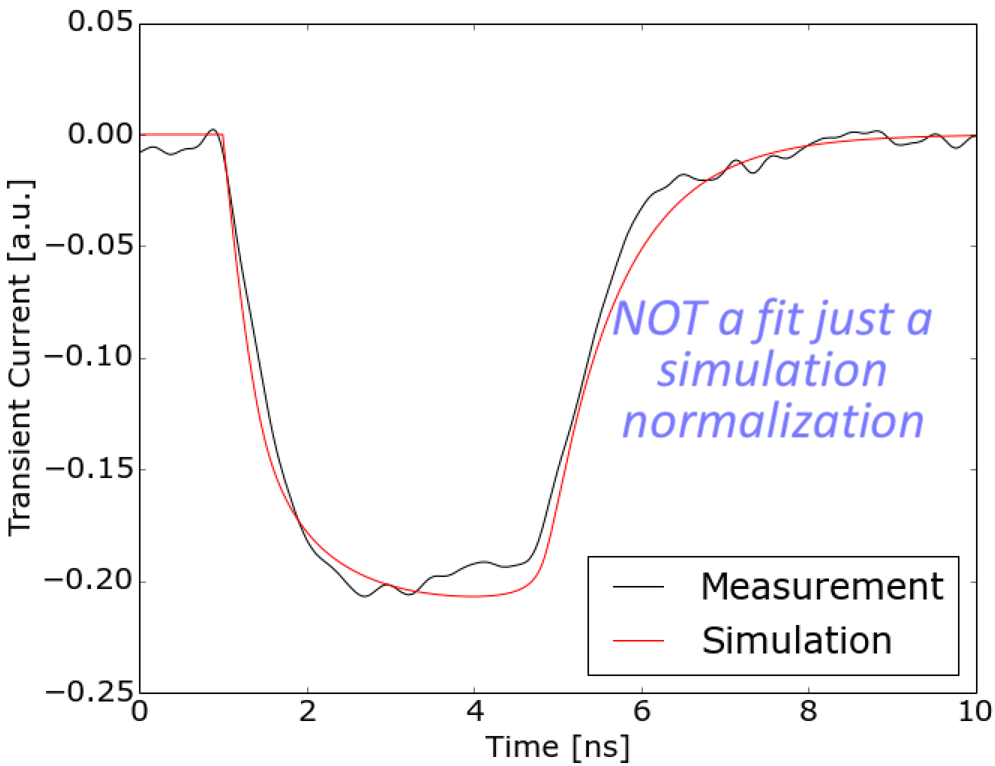


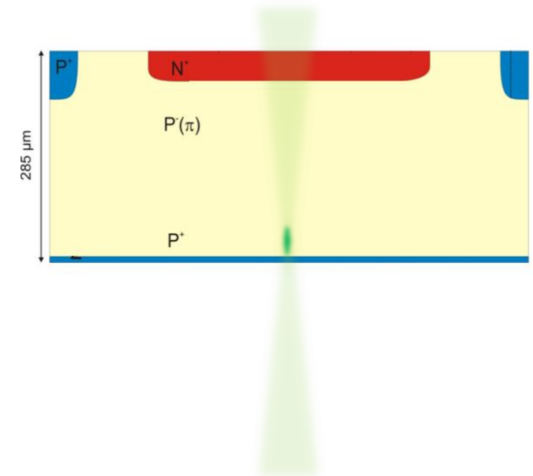


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

– TCT wavefrom gets wider again, trailing edge dominated by electrons now.

TCT Waveform: focus depth 278um

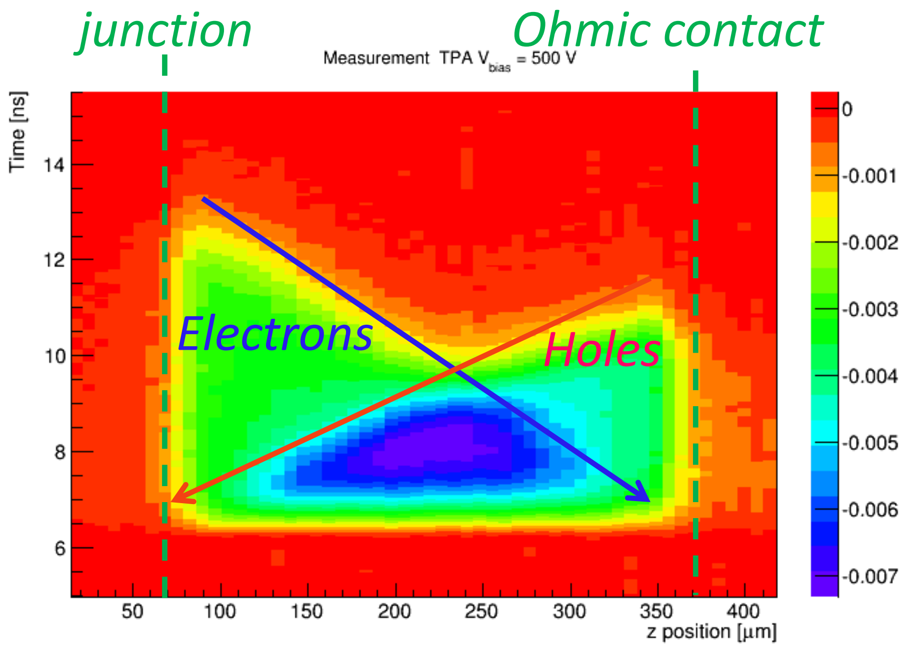


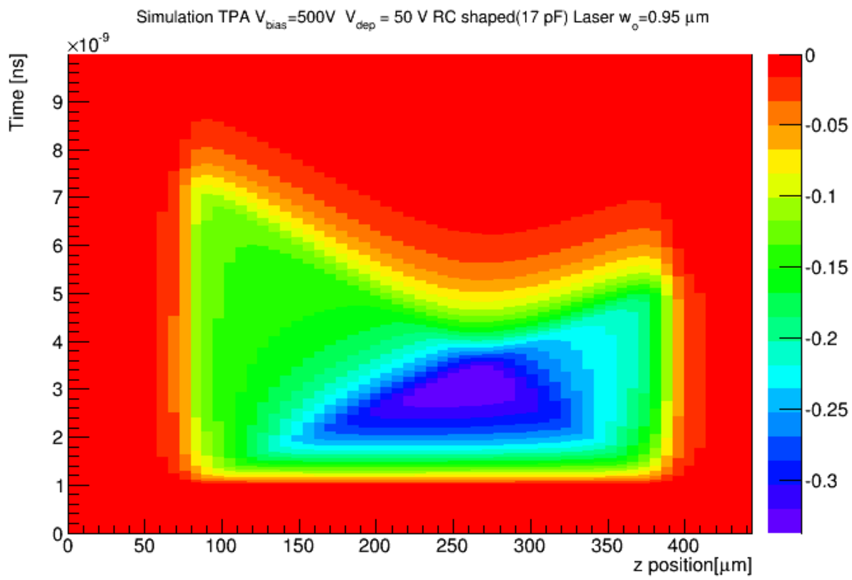


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

SPA - red laser bottom-TCT like signal (electron injection)

TPA-TCT: Distinct Electron & Hole dynamics





- Out of the box simulation (no fit): 500 V, RC 17pC, Laser waist 0.95 um, Vdep 50 Volts
- Excellent agreement between data (left) and TRACS simulation.

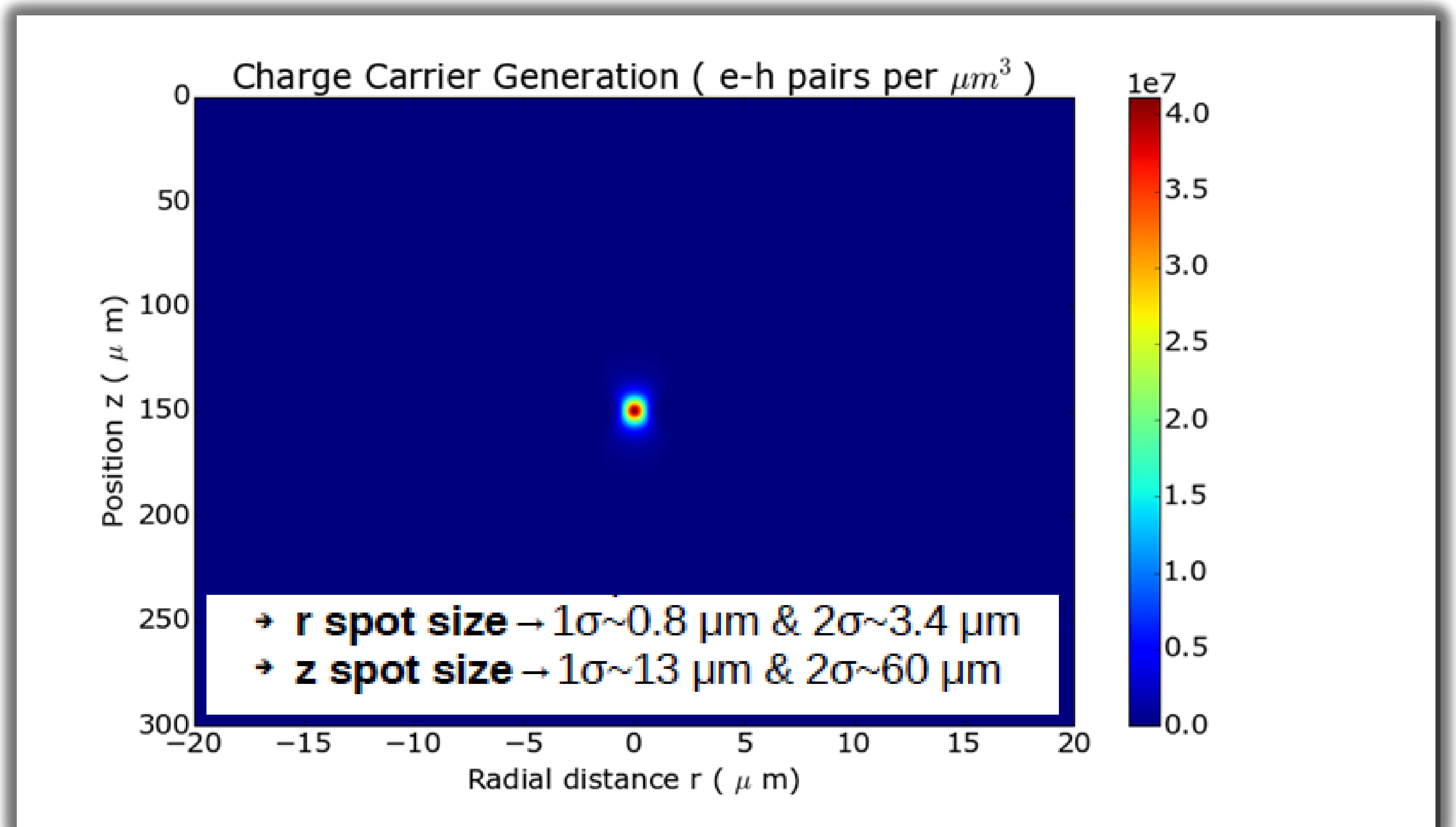
TPA-TCT Proof-of-concept Challenges

- ✓ Confirm the generation of TPA induced current in a silicon diode with the appropriate laser power.
- ✓ Determine the dimensions of the charge-carrier's generation volume.
- ✓ Compare the experimental TCT current waveforms against the theoretical simulated current waveforms (assess its potential as experimental tool to discriminate between different theoretical models).

Conclusions and Outlook

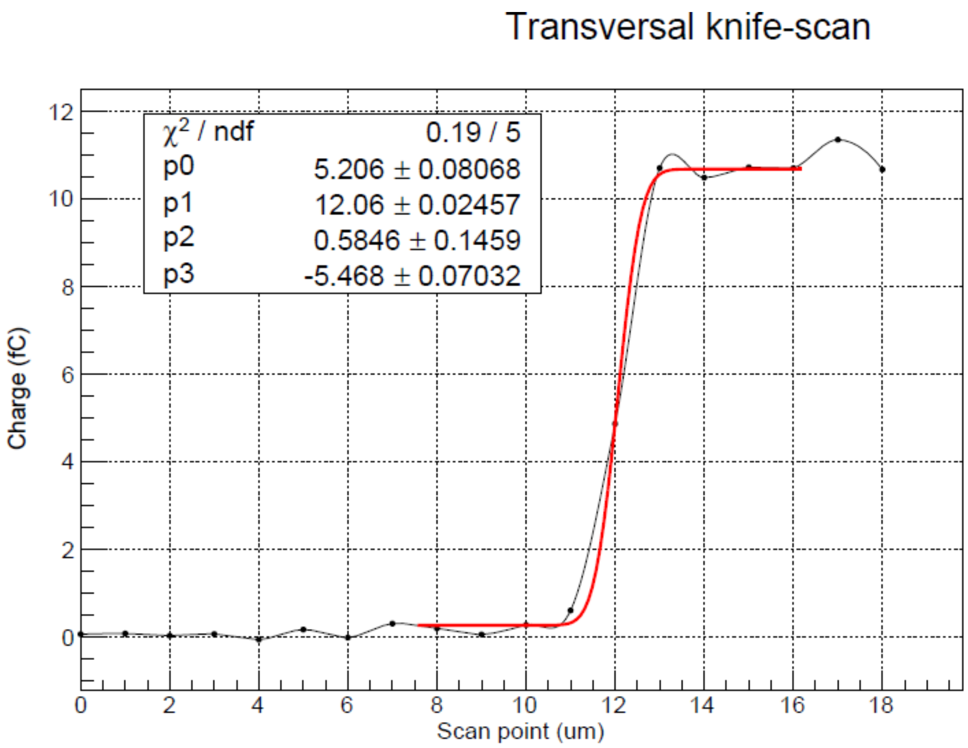
- We have completed the successful proof-of-concept of a novel Transient-Current-Technique based on the Two-Photon-Absortion (TPA) process
- Excellent agreement between the experimental data and the simulation points to its potential as tool for disentangling different theoretical models.
- Opens up the possibility of a new range of opportunities for boosting the scope of TCT techniques:
  - More accurate 3D mapping of E_{field}.
  - Simpler unfolding methods.
  - More accurate study of pixelated sensors.
  - Less relevance of metal-induced beam reflections.
- But, still a lot of work and challenges ahead to make it a reliable, accessible and practical diagnostic tool.

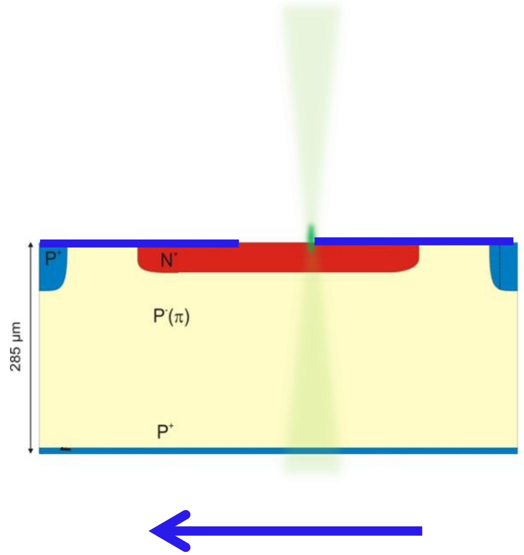
THANK YOU !



Charge Carrier Generation (e-h pairs per μm^3)
1e7
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Position z (μ m)
−20
−15
−10
−5
0
5
10
15
20
Radial distance r (μ m)
r spot size → 1σ~0.8 μm & 2σ~3.4 μm
z spot size → 1σ~13 μm & 2σ~60 μm

Generation Volume (knife-scan)





Diode Displacement

Laser waist < than 1 um (accuracy limited by motor displacement resolution)