Progress report on the validation of a Two-Photon Absorption based Transient-Current-Technique on irradiated silicon

26th RD50 Workshop @ Santander

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Motivation & Scope

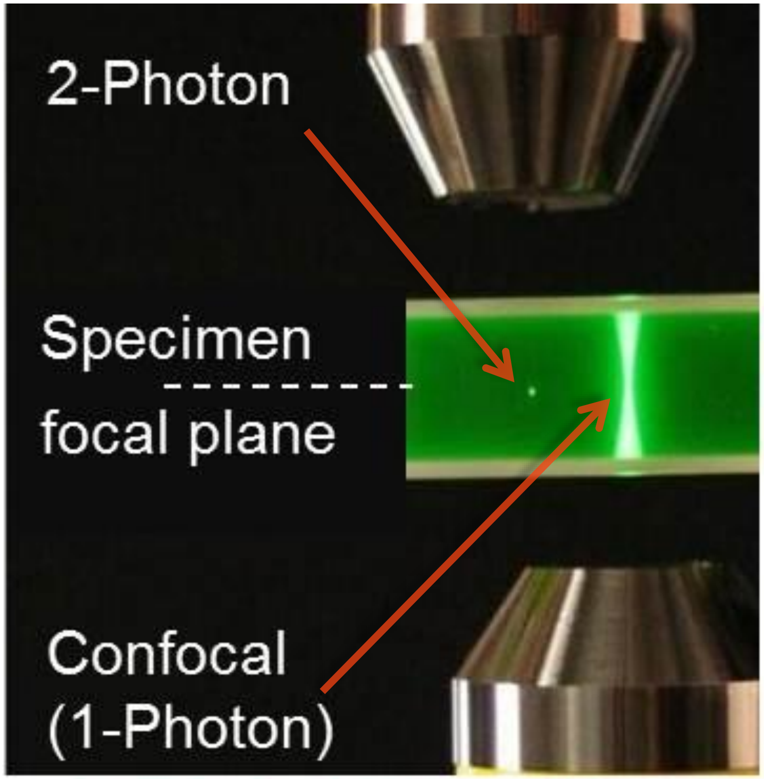
- After the first proof-of-concept measurement to study the TCT currents induced by Two-Photo-Absortion proccess in an non-irradiated standard silicon PiN diode move to study the TPA-TCT on irradiated devices.
- New RD50 internal project to estimate the possible radiation induced changes on TPA and SPA process cross-sections.
- In this talk: progress report, lessons learned and a few results

Outline

- Brief recall on the TPA-TCT technique: motivation, simulation and experimental results on irradiated samples.
- Experimental arrangement to determine the TPA and SPA cross-section against the irradiation fluence (neutrons).
- Conclusions and outlook

Motivation for a TPA-based TCT technique

"A picture is worth a thousand words"



Photography: Ciceron Yanez, University of Central Florida

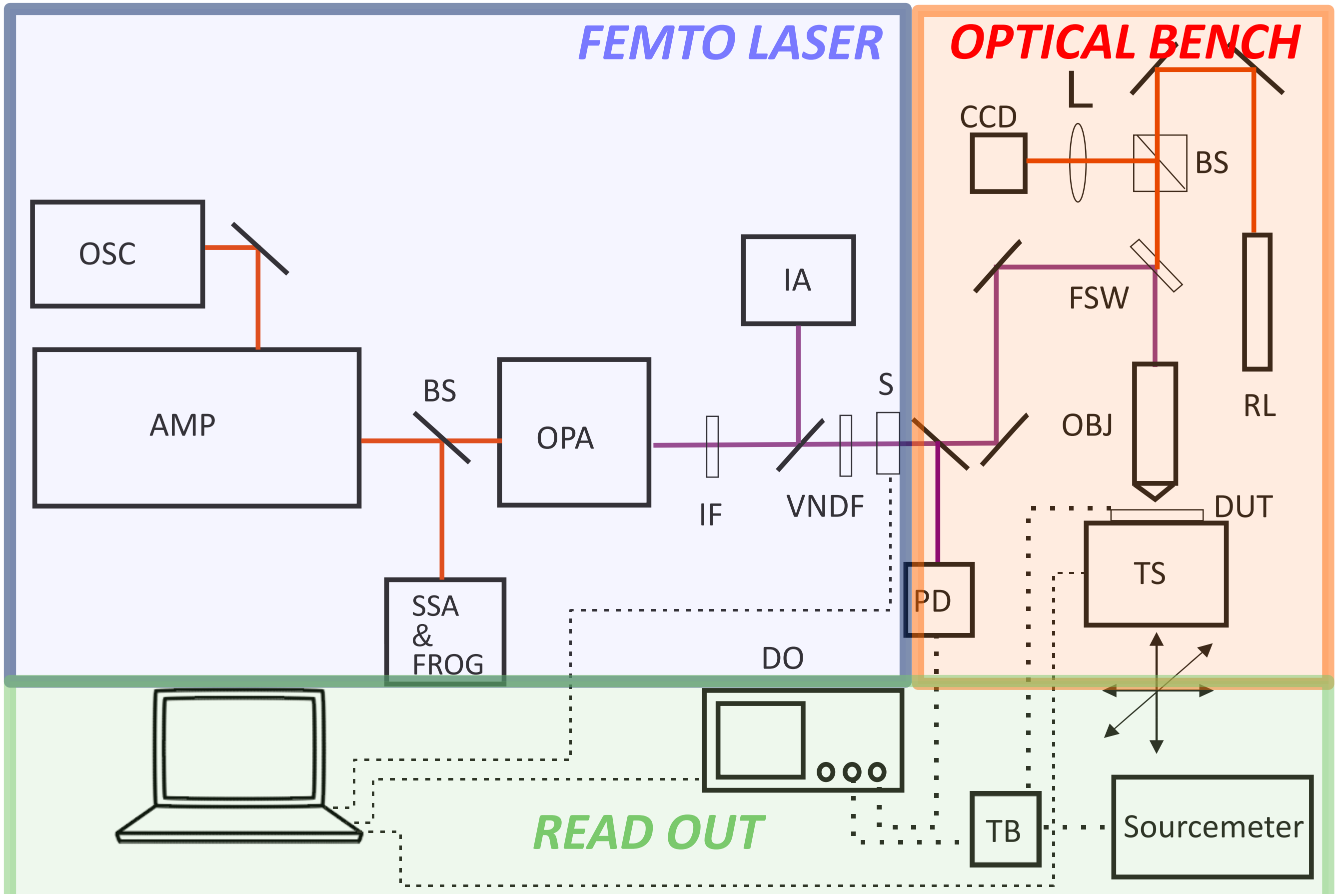
TPA-TCT is a way to **generate very localized electron-hole pairs** in semiconductor devices (microscale volume).

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.

Experimental arrangement (1)

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



Laser

$\lambda \sim 1300$ nm

P ~ 50-100 pJ

$\Delta T \sim 240$ fs

Rate ~ 1 kHz

$\Delta f \sim 11$ nm

Microfocus

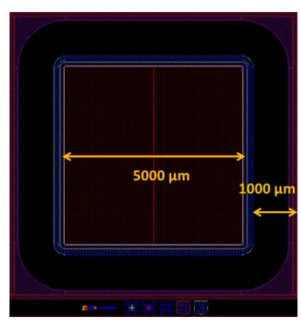
X100 Objective

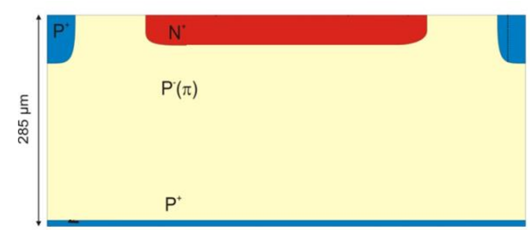
f 100 mm lens

2.5 GHz DSO

Experimental Arrangement (2)

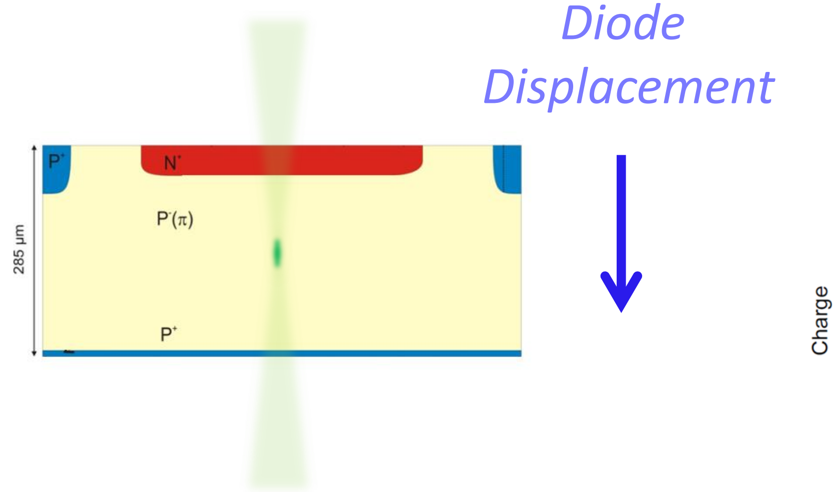
DUT CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9

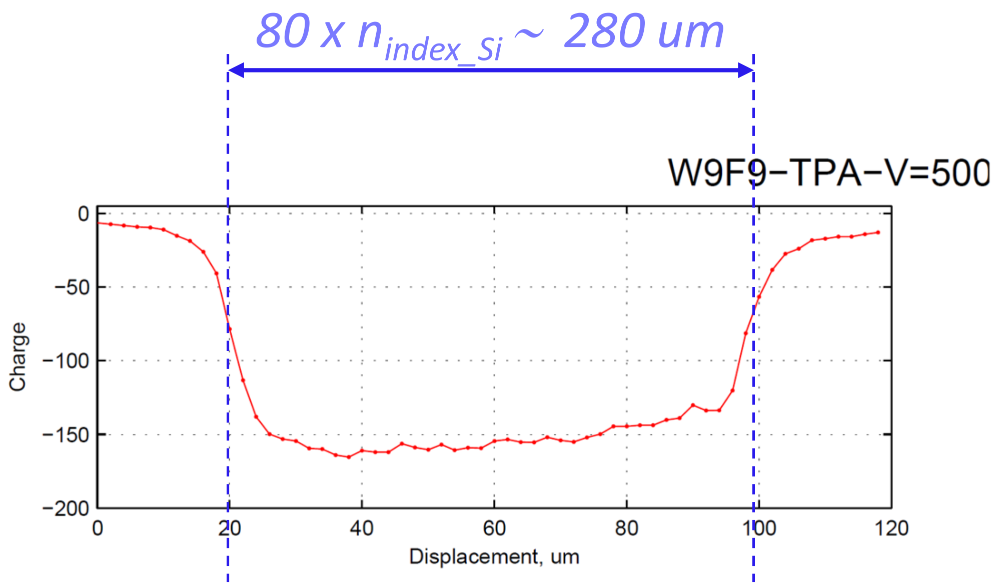




Evidence of TPA-TCT

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



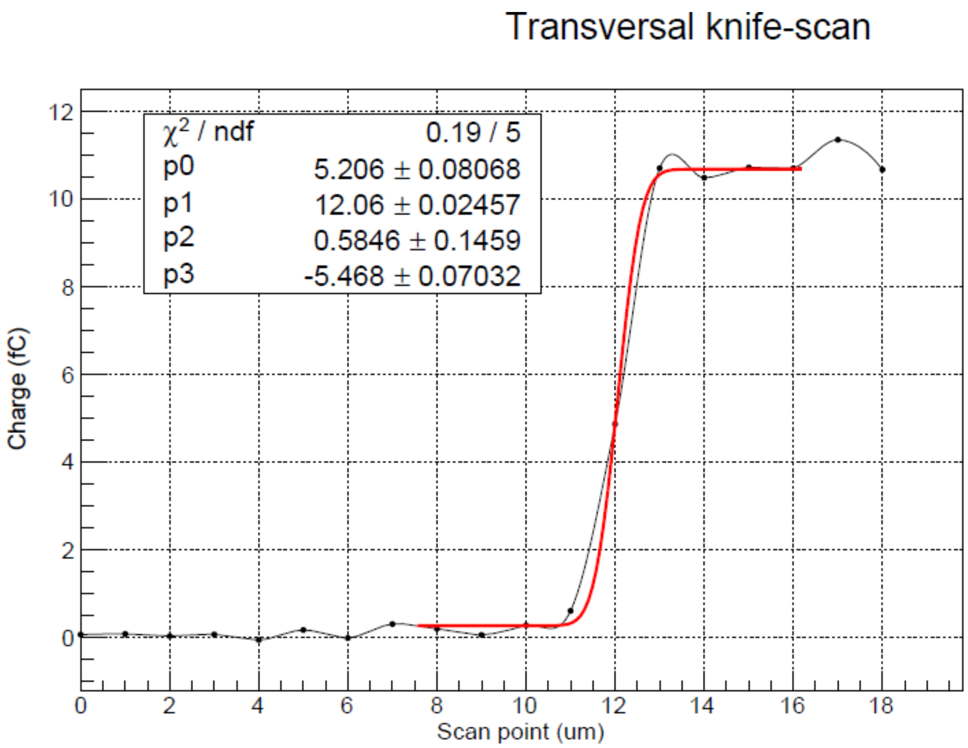


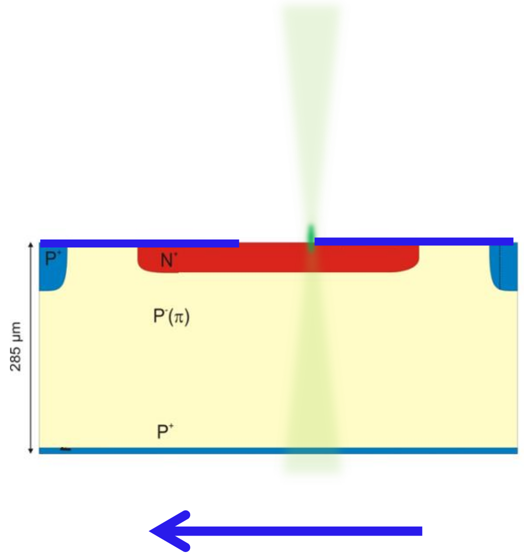
– TPA -> Charge vs z -> plateau (Observed behavior)

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

CAVEAT -> The validity of the method relies on SPA signal<<TPA Signal

Generation Volume (knife-scan)

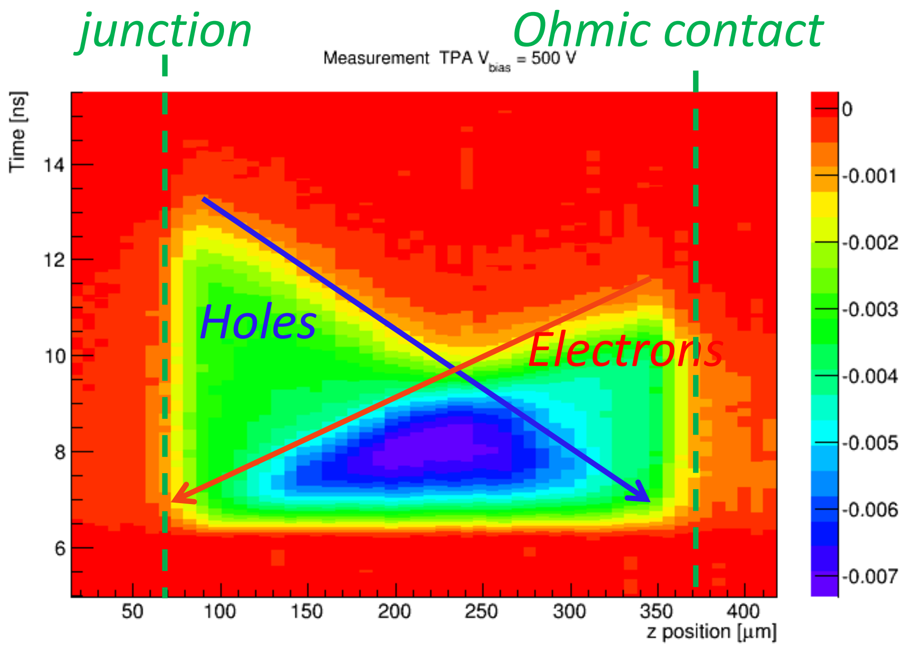


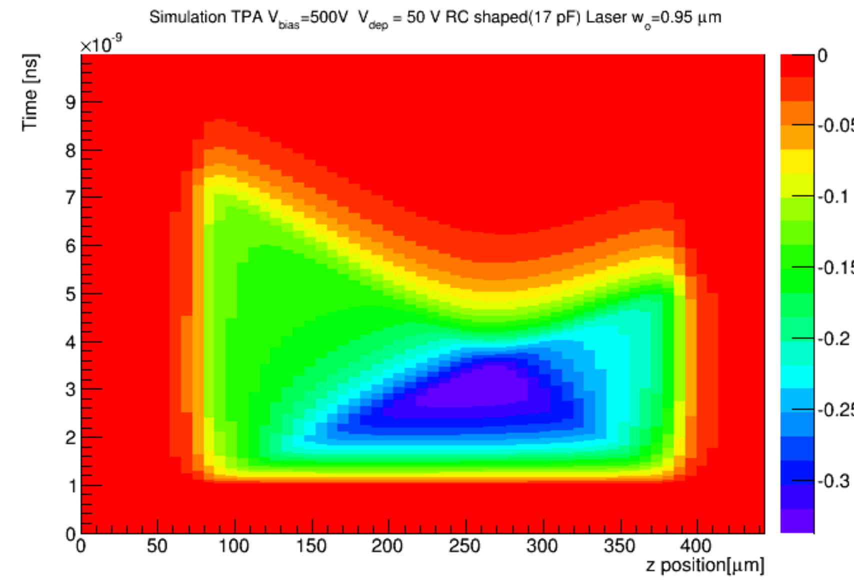


Diode Displacement

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

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 feasiblity RD50 project: goals

- The goal of the this project is to **quantify the relative contribution to the TCT current** of the radiation-induced Single-Photon-Absorption and Two-Step-Single-Photon-Absorption processes with respect to the TPA process
- In addition, study the feasibility of using a femtosecond laser tuned in the C-band (1530-1570 nm) a more suitable band due the higher availability of off-the-shelf photonics components

TPA-TCT feasiblity RD50 project: Method

$$-\frac{dI}{dz} = \alpha I + \beta I^2$$

– "Z-scan" measurement on the diodes under test. During the Z-scan, in addition to the measurement of the transient photocurrent, the transmitted light will be measured (Ge photodiode).

– From this measurement we will extract the β Two-Photon-Absorption and α SPA parameter

Samples and upgraded experimental arrangement

– 12 identical (almost) PiN diodes from LGAD runs.

Run 7509	20150324	
Laboratory	**Device**	**W1**
Ivan (Ifca+Cern)	PiN1	C5, D2, F7, G6
	PiN2	C6, D3, E5, F8
	PiN3	C7, D4, E6, G8

– Three fluences (neutrons): 1E13, 1E14 and 1E15

– Ge diode to measure the transmitted light during the z-scan.

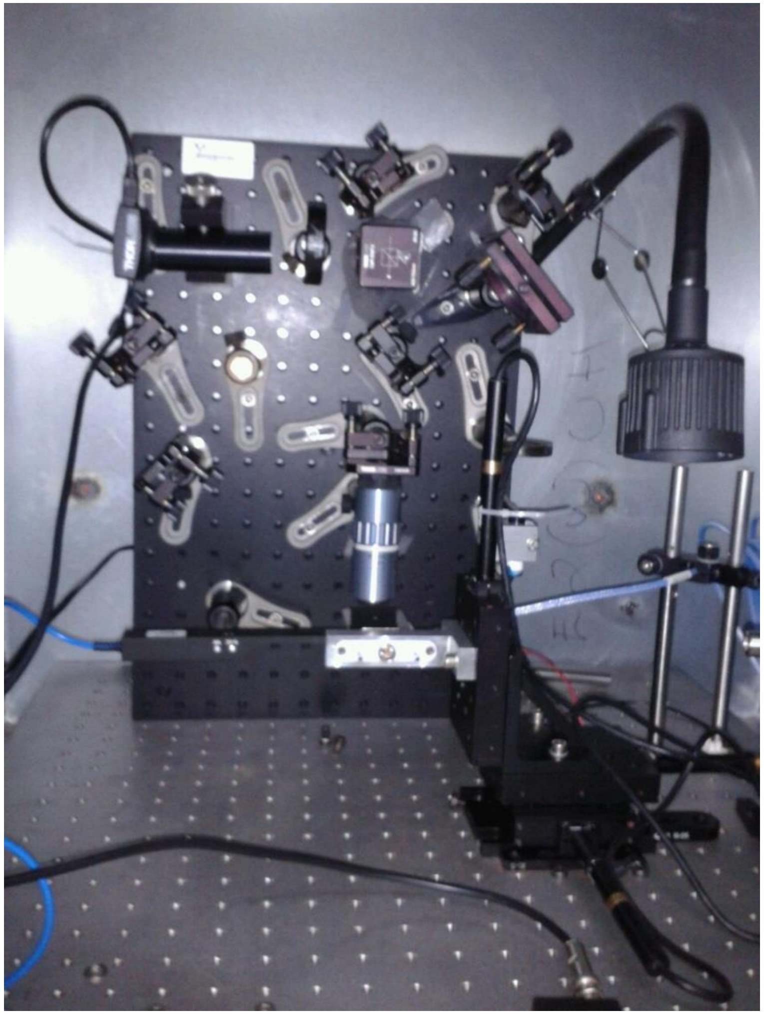
– Thermal chuck to reach -20 Celsius degrees.

– Light tight enclosure: dry box and Faraday cage.

Experimental arrangement (2)

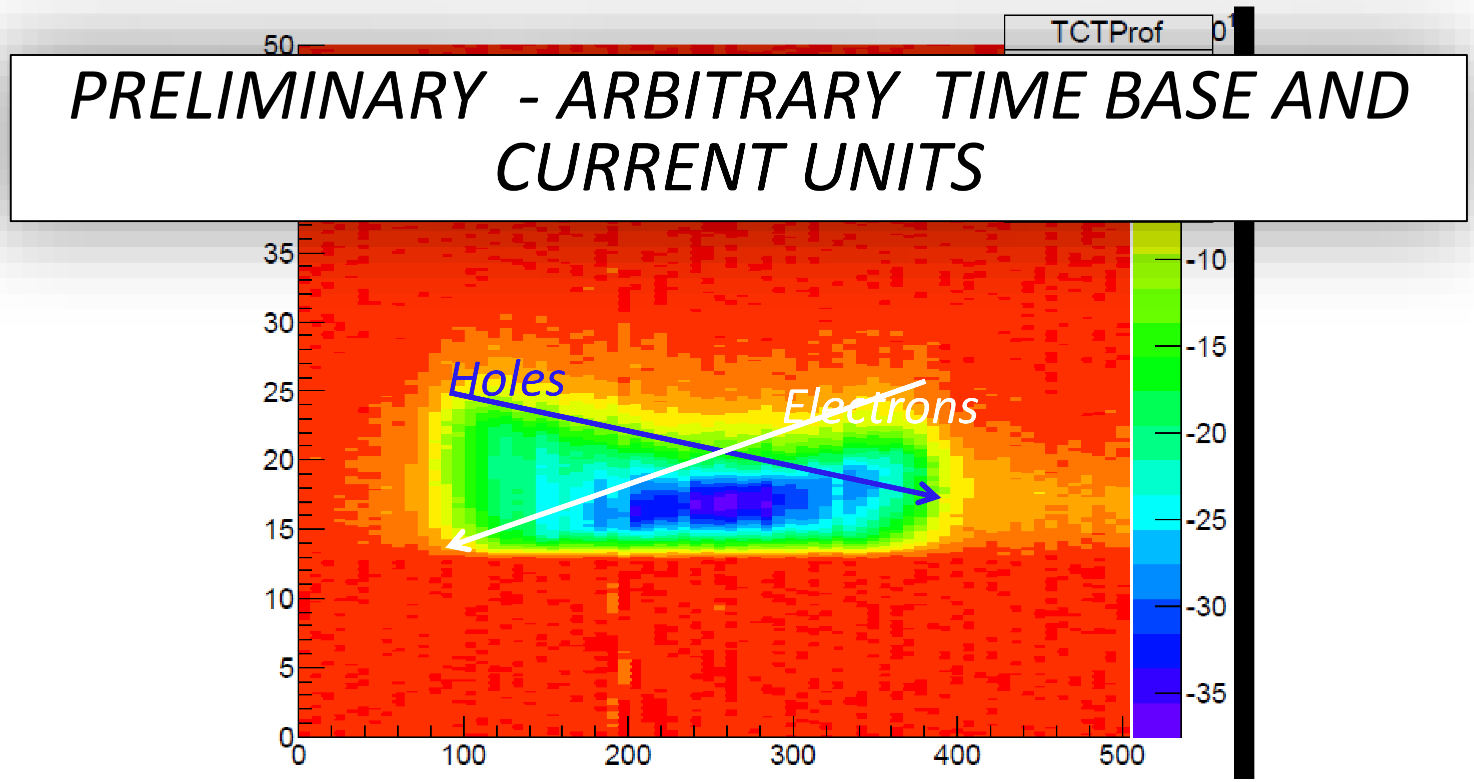
Experimental arrangement (2)

- Performed several "Z-scan" measurement on a diode at three different temperatures.
- First conclusion: not enough sensitivity to measure a change in the transmitted light
- need to increase the excitation volume keeping the same irradiation (to increase signal x 1E3)



First commissioning measurements:

– C5 diode; distinct holes and electron dynamics.



Conclusions and short term plans

- New TPA-TCT arrangement completed capable of of temperature control and able to measure the transmitted laser light.
- Initial commissioning measurement shows not enough sensitivity for transmission measurement, alternative plan in development.
- 2nd week of July, complete the full TPA-TC characterization of non irradiated diodes, then start with the irradiation.
- September/October characterization of irradiated samples.

References

- 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)
- Details on the first proof-of-concept measurements (link)

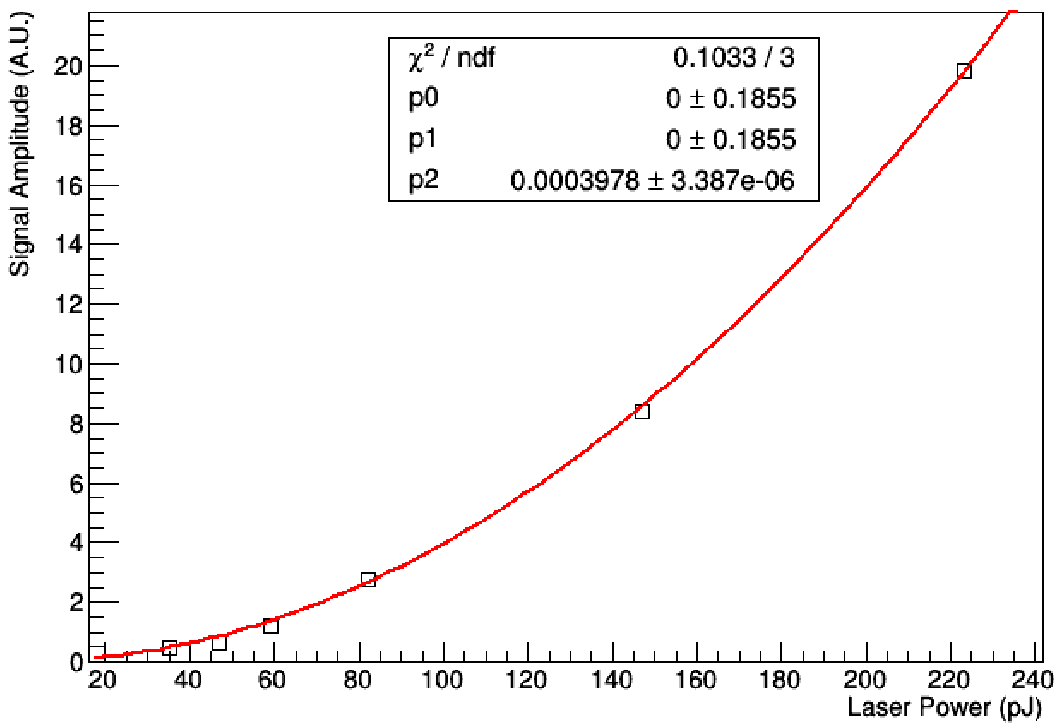
BACK-UP

TPA-TCT Proof-of-concept Challenges

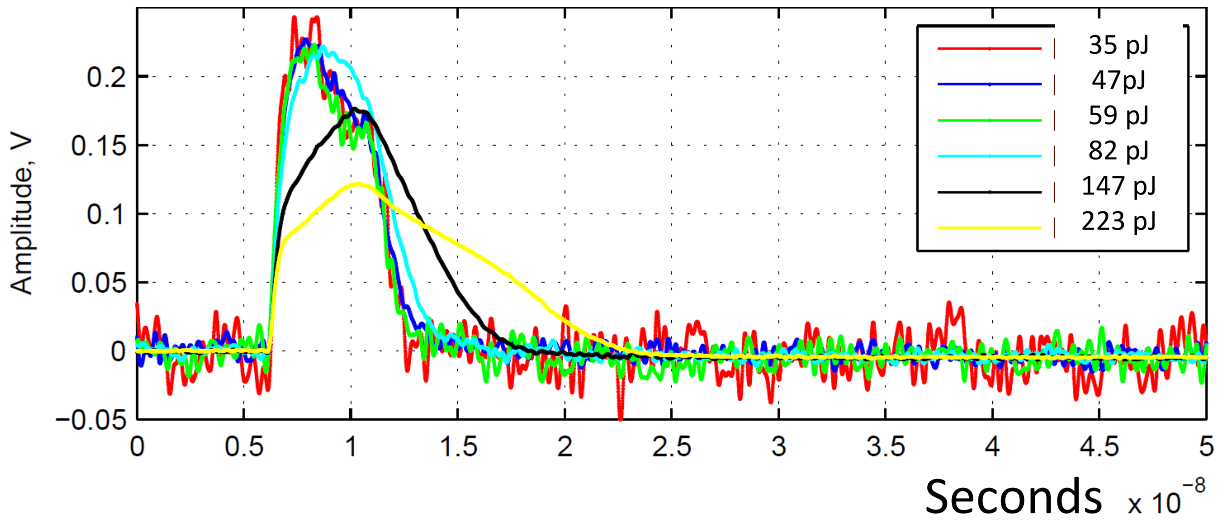
- Confirm the generation of TPA induced current in a silicon diode with the appropriate laser power.
- Determine the dimensions of the charge-carrier's generation volume.
- Compare the experimental TCT current waveforms against the theoretical simulated current waveforms (assess its potential as experimental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

Evidence of TPA-TCT (2)

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



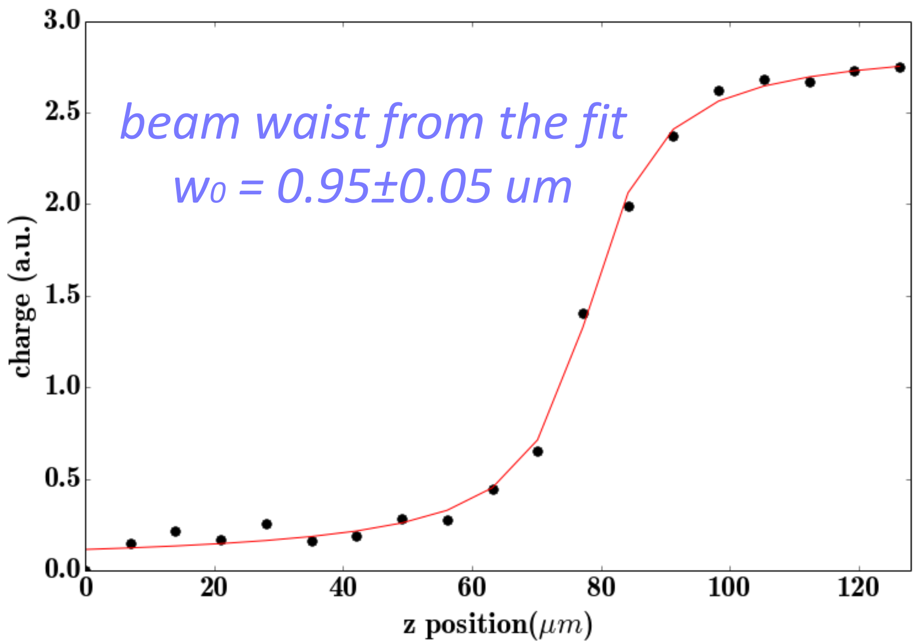
Which is the adequate laser power ?



– 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-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

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

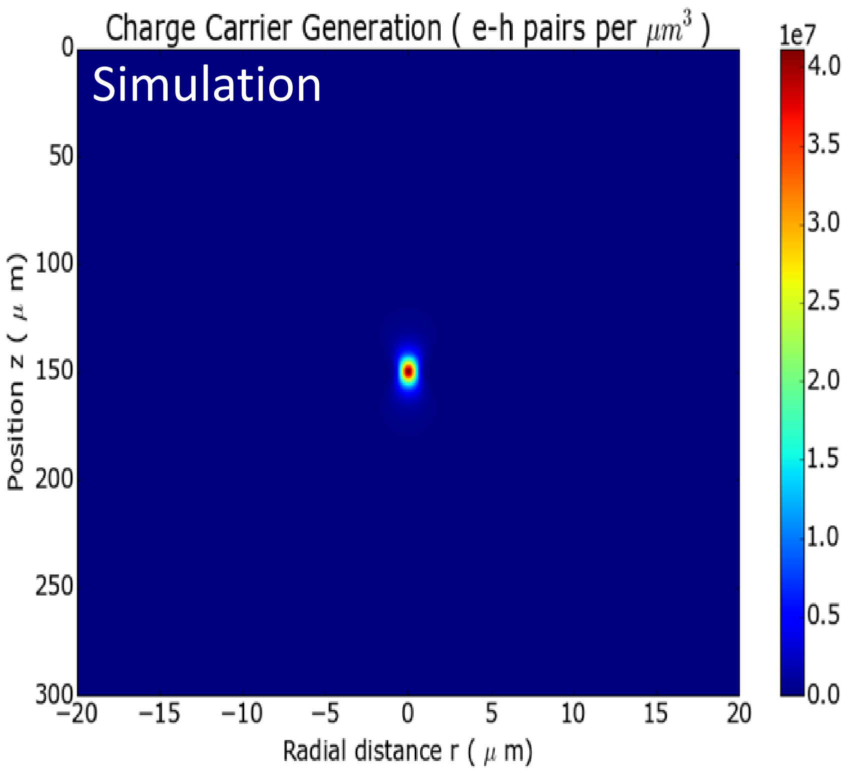
$$I(r,z) = \frac{2P}{\pi w(z)^2} \exp \frac{-2r^2}{w(z)^2}$$

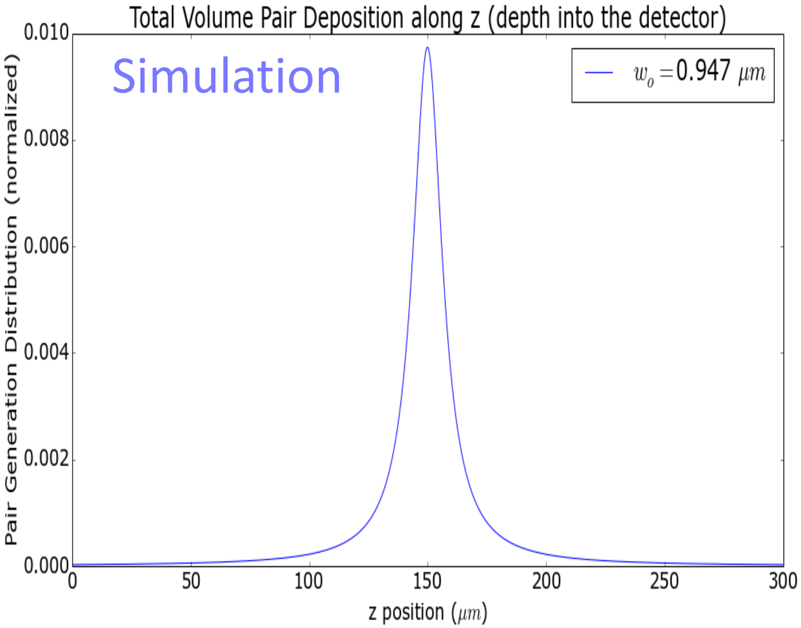
TPA absorption (negligible attenuation)

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

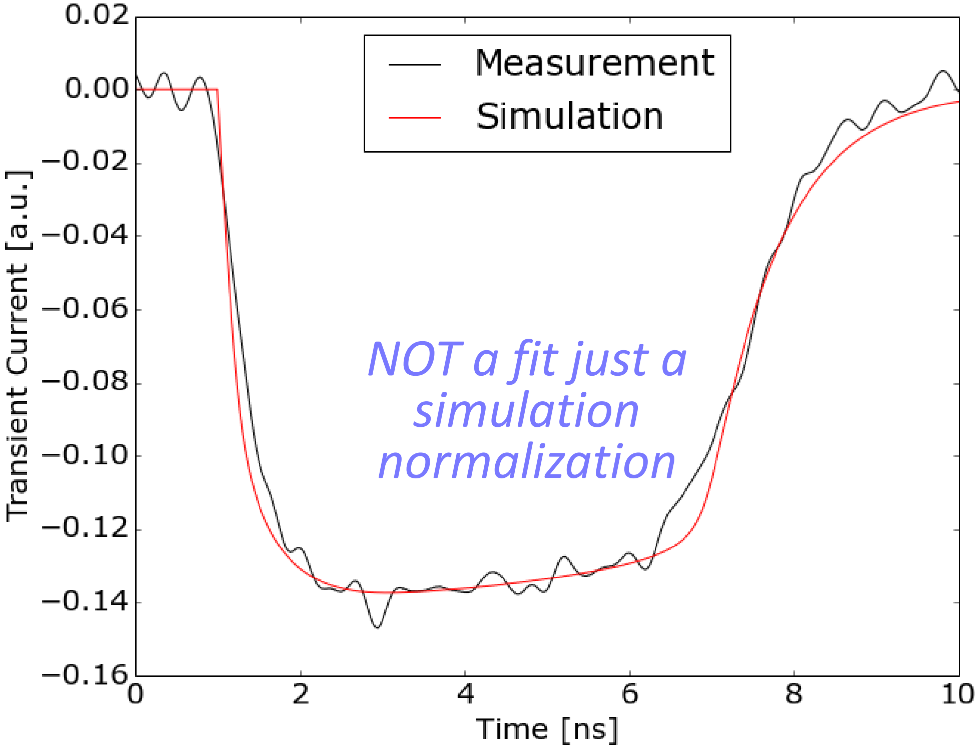
TPA-Induced Charge-carriers volume (2)

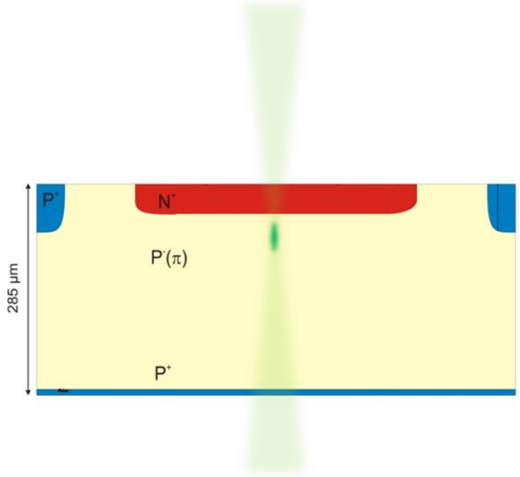
- **r spot size** → 1σ~0.8 μm & 2σ~3.4 μm
- **z spot size** → 1σ~13 μm & 2σ~60 μm





TCT Waveforms: 20um focus depth

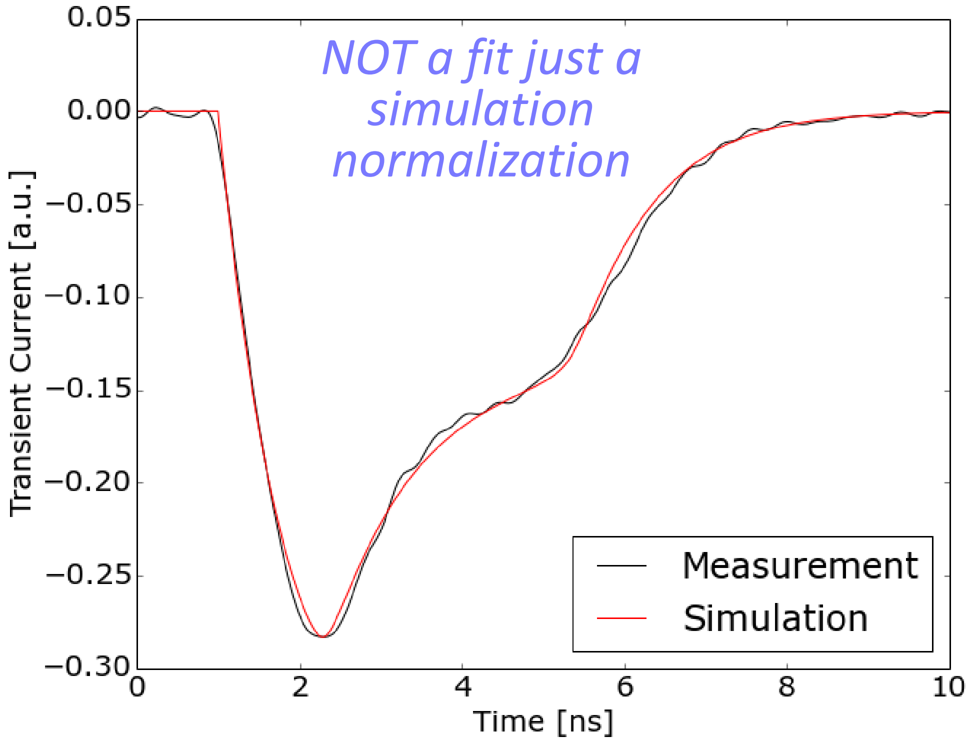


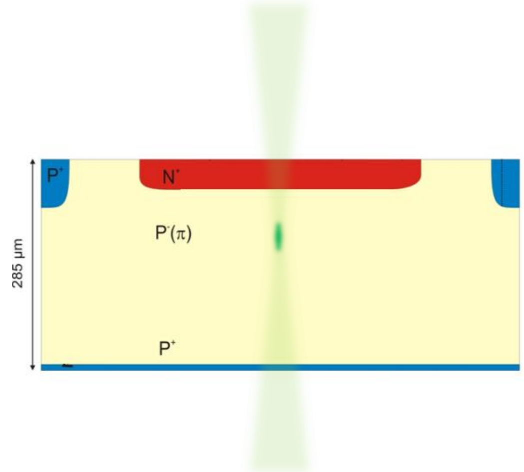


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

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

TCT Waveform: 97 um focus depth

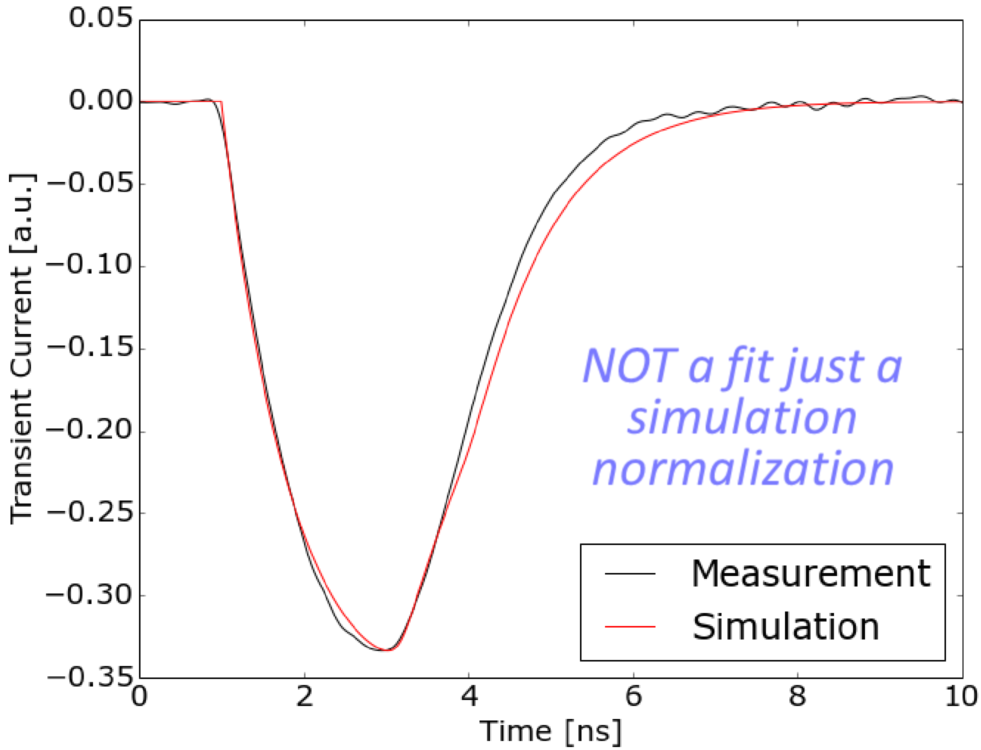


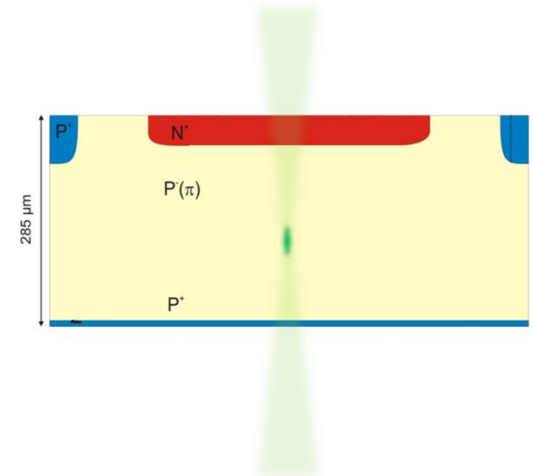


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

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

TCT Waveform: focus depth 160um

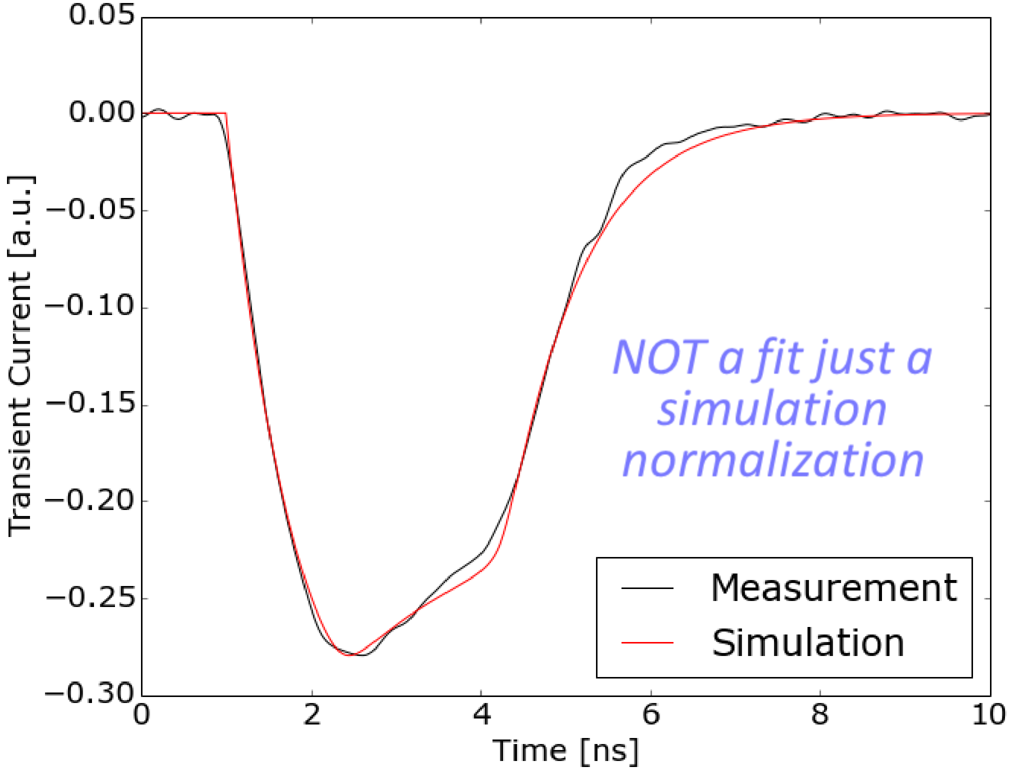


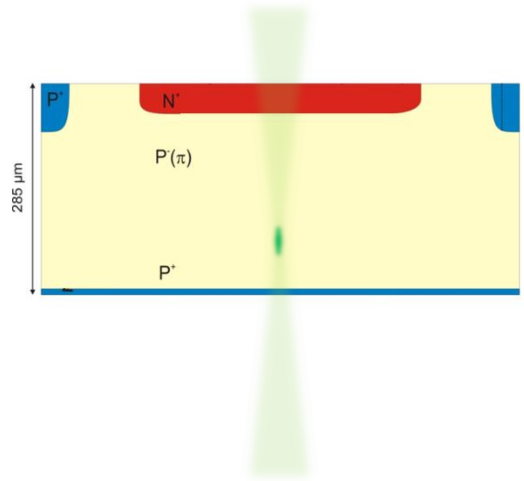


CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

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

TCT Waveform: focus depth 237um

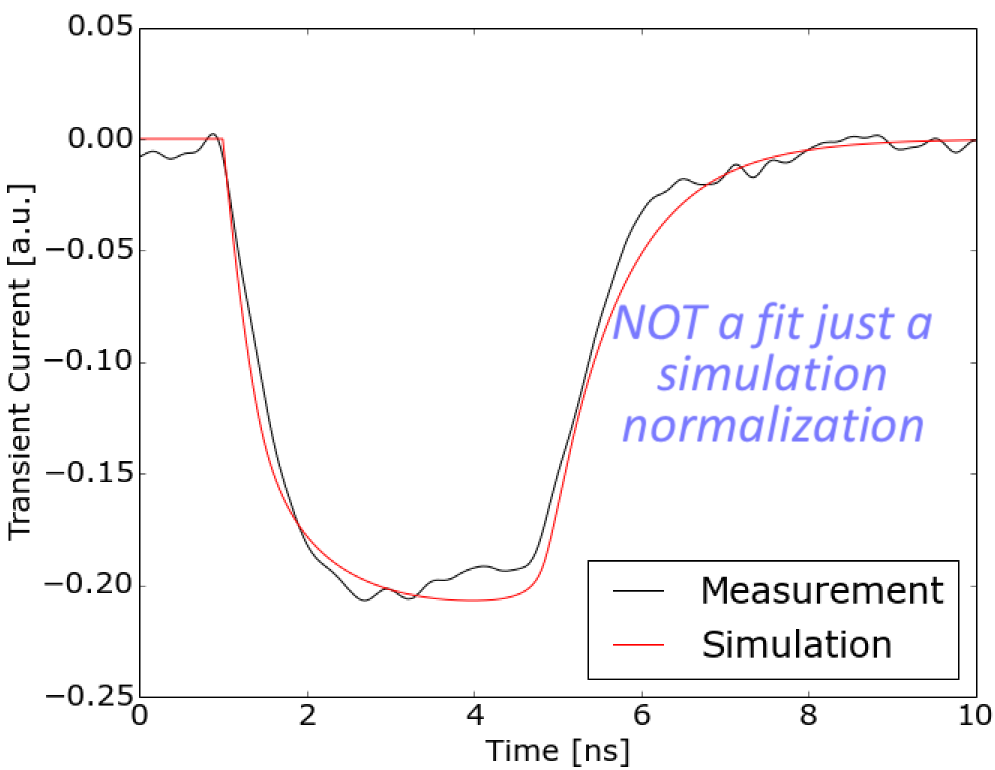




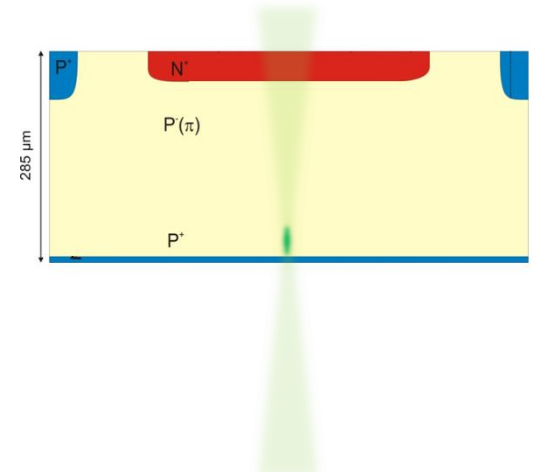
CNM N-IN-P DIODE
LGAD PIN REFERENCE DIODE
Ref - W9F9 (500 V bias)

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

TCT Waveform: focus depth 278um

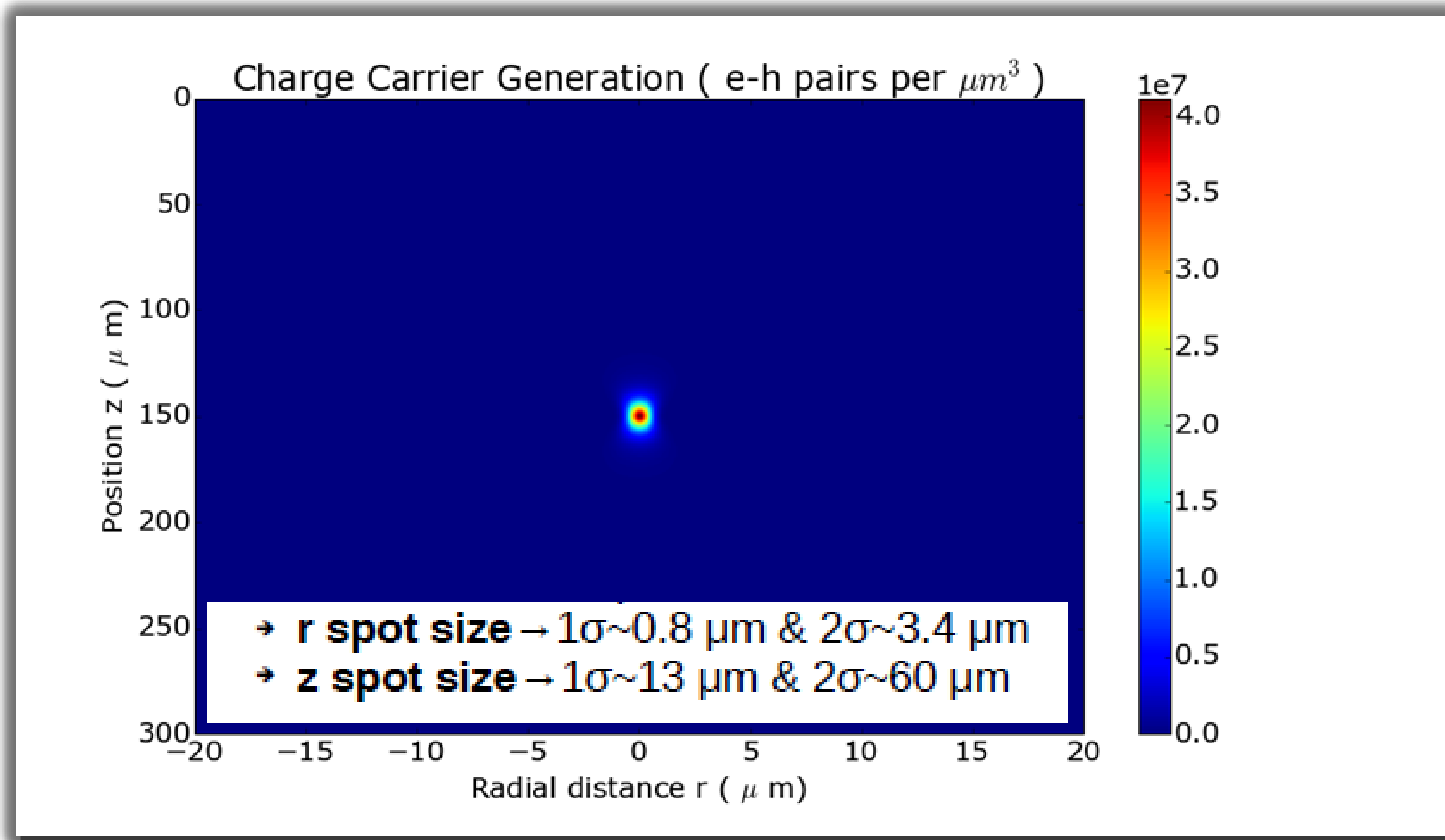


NOT a fit just a simulation normalization



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

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


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

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.