EP R&D Day 2022, 20 June 2022

WP1.4. Silicon Detectors **TPA-TCT** (Two-Photon Absorption Transient Current Technique)

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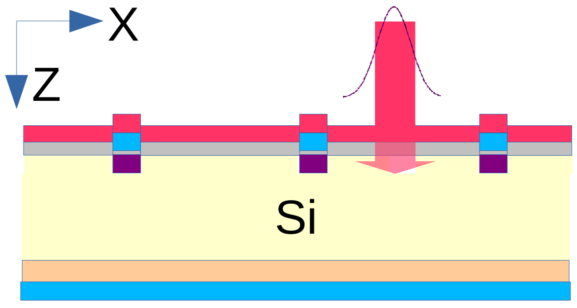
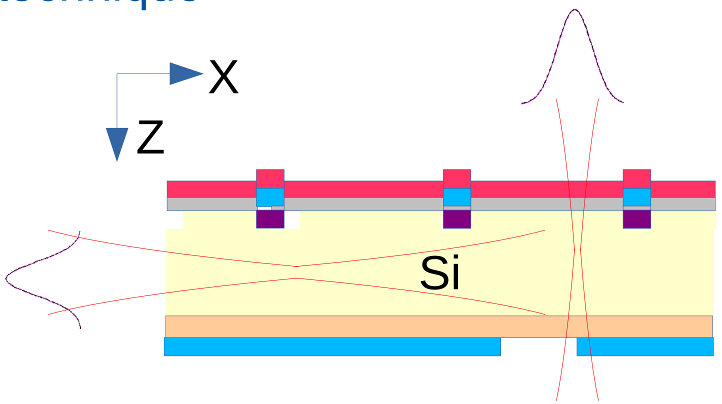
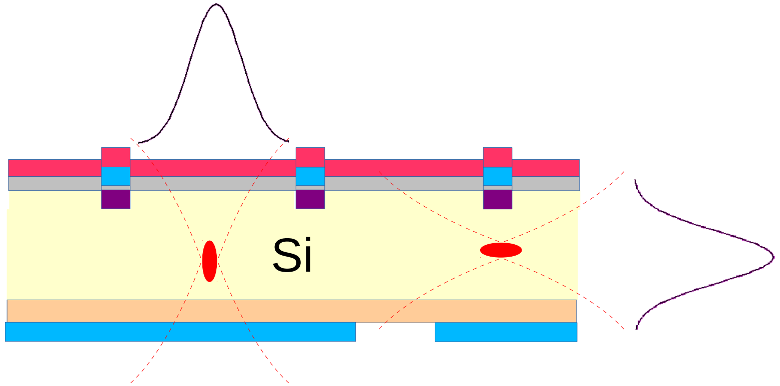
Transient Current Technique

TCT is a technique to study the current induced by charges moving in detectors.
Excess carriers injected using laser, ions (IBIC), or α's from source.

TPA is an illumination technique







Single **P**hoton **A**bsorption **SPA-TCT Top/Bottom**

Using short penetration depth laser (red for Si)
All carriers deposited in few μm from surface
Allows to study one kind of carriers (e/h) at a time
1 photon=1 e-h pair
2D (XY) resolution
No Z resolution

SPA-TCT Infrared

Using long penetration laser (infrared for Si)
Uniform carrier **generation** along beam path
Similar to MIPs, power can be tuned to 1 MiP
1 photon=1 e-h pair
Top, bottom:
2D (XY) resolution, no Z resolution
Edge:
Z resolution at the expense of X resolution

Two Photon Absorption-TCT

2 photons from the same laser **= 1 e-h pair**
Incidence can be from top, bottom or edge
Carriers only **generated at the focus** of laser
3D resolution:
Very narrow beam perpendicular to laser path
Along the beam direction~Rayleigh Length

$$w_0 = \frac{\lambda_0}{\pi NA} \qquad z_R = \frac{\lambda_0 n}{\pi NA^2}$$

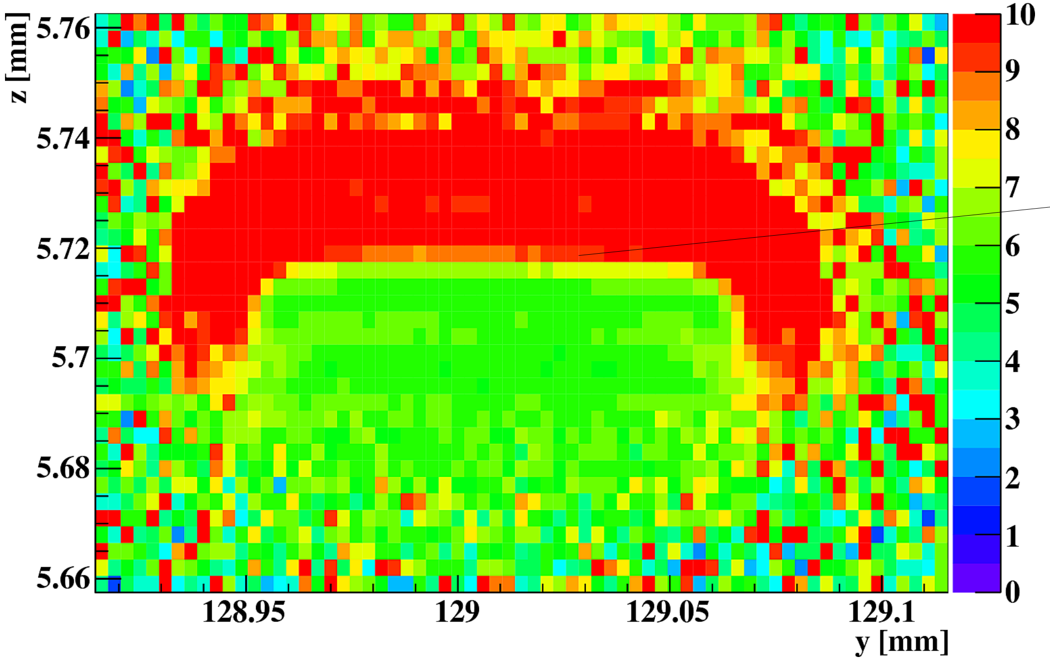
Already demonstrated in Si, diamond and SiC

← No 3D resolution →

TCT: Transient Current Technique
SPA: Single Photon Absorption

SPA vs TPA, under edge incidence

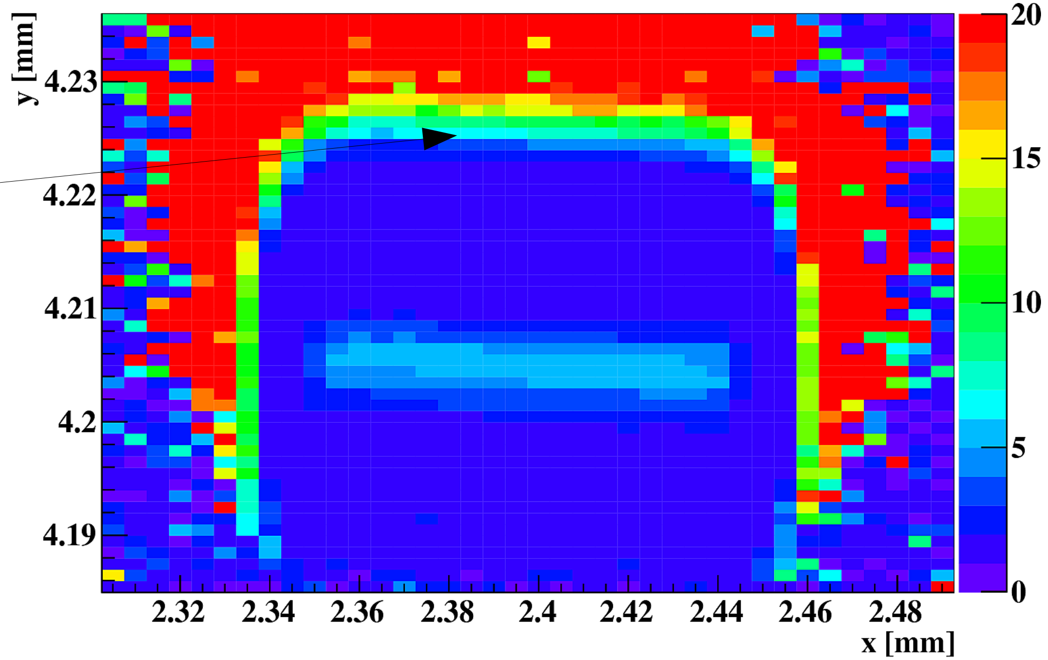
Standard TCT



Spatially continuous laser source, time pulsed

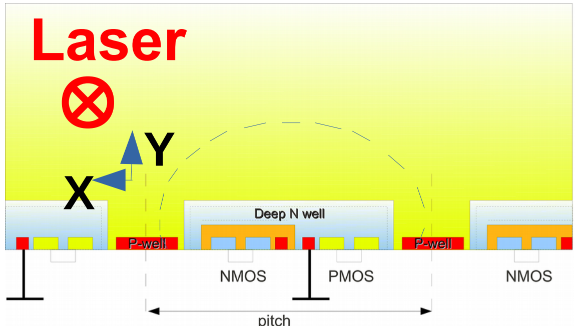
λ=1064 nm, σ=10 μm, **200 ps**-pulsed laser

TPA-TCT



Point-like laser source, time pulsed

λ=1300 nm, σ=1 μm, **200 fs**-pulsed laser



Substructures resolved

Historical overview

TCT "invented": **1996**

edge-TCT invented within RD50: **2010**

TCT commercialized: **2013**

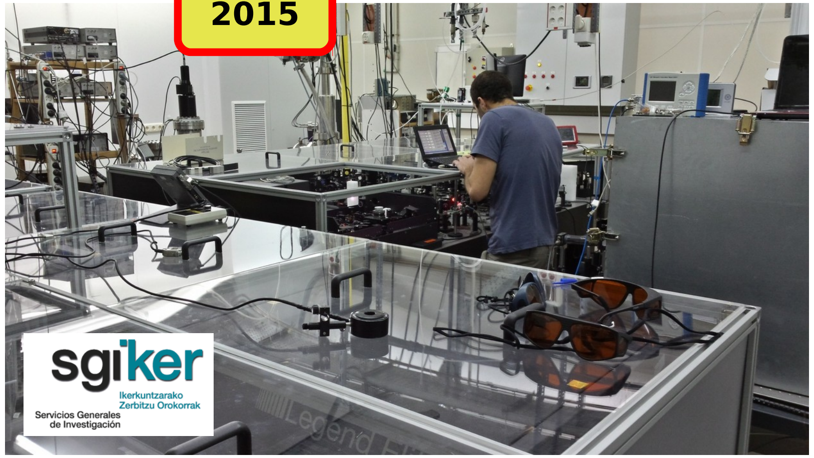
TPA-TCT: Proof of concept presented by RD50 in **2015**

Table-top TPA-TCT laser commercialized: **2020/21**

Table-top TPA-TCT system

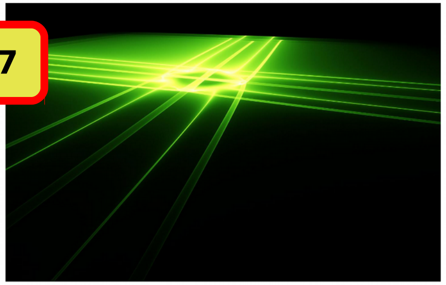
AIDAinnova

2015



Ultra-Short Laser facility: 40 fs, 2mJ, Tunable: 240-2100 nm
Access granted via RD50 collaboration

2017



A non-destructive laser application for quality control & radiation studies in semiconductor devices

The project aims to develop a method and platform to extract doping and electric field profiles within semiconductor devices by non-destructive femtosecond laser induced Two-Photon Absorption. Several fields could benefit from this development, amongst them Quality Control & Assurance of semiconductor devices, E-Field and Charge Collection Efficiency mapping of photosensors, and radiation damage studies for high-energy physics detectors.

This project is a collaboration between CERN and the Instituto de Física de Cantabria (CSIC-UC).

KEY FACTS

A non-destructive laser application for quality control & radiation studies in semiconductor devices

Submission Year
2017

Budget
120 kCHF

Timeline
2017 -

Funding Opportunities
CERN Knowledge Transfer fund

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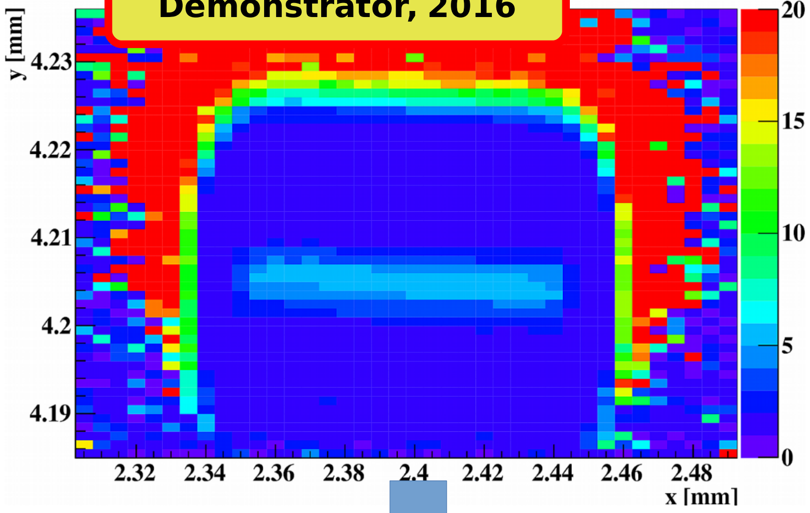
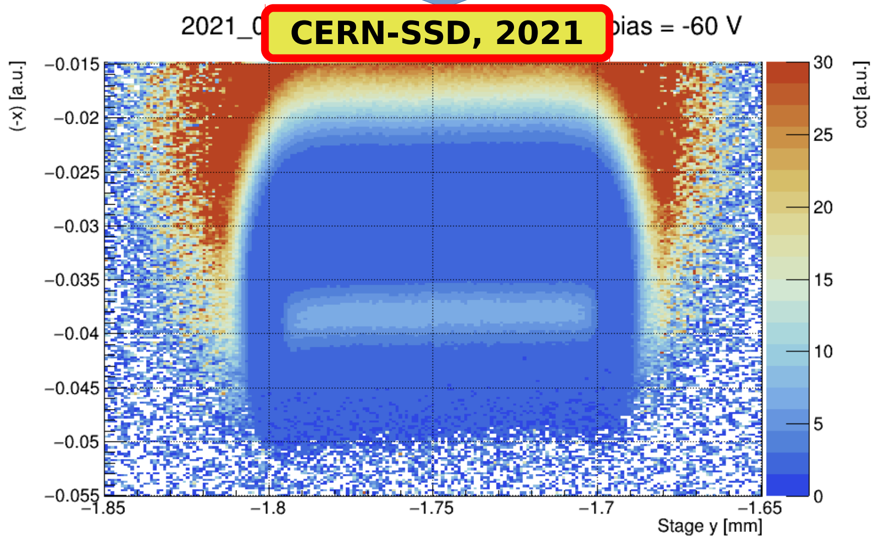
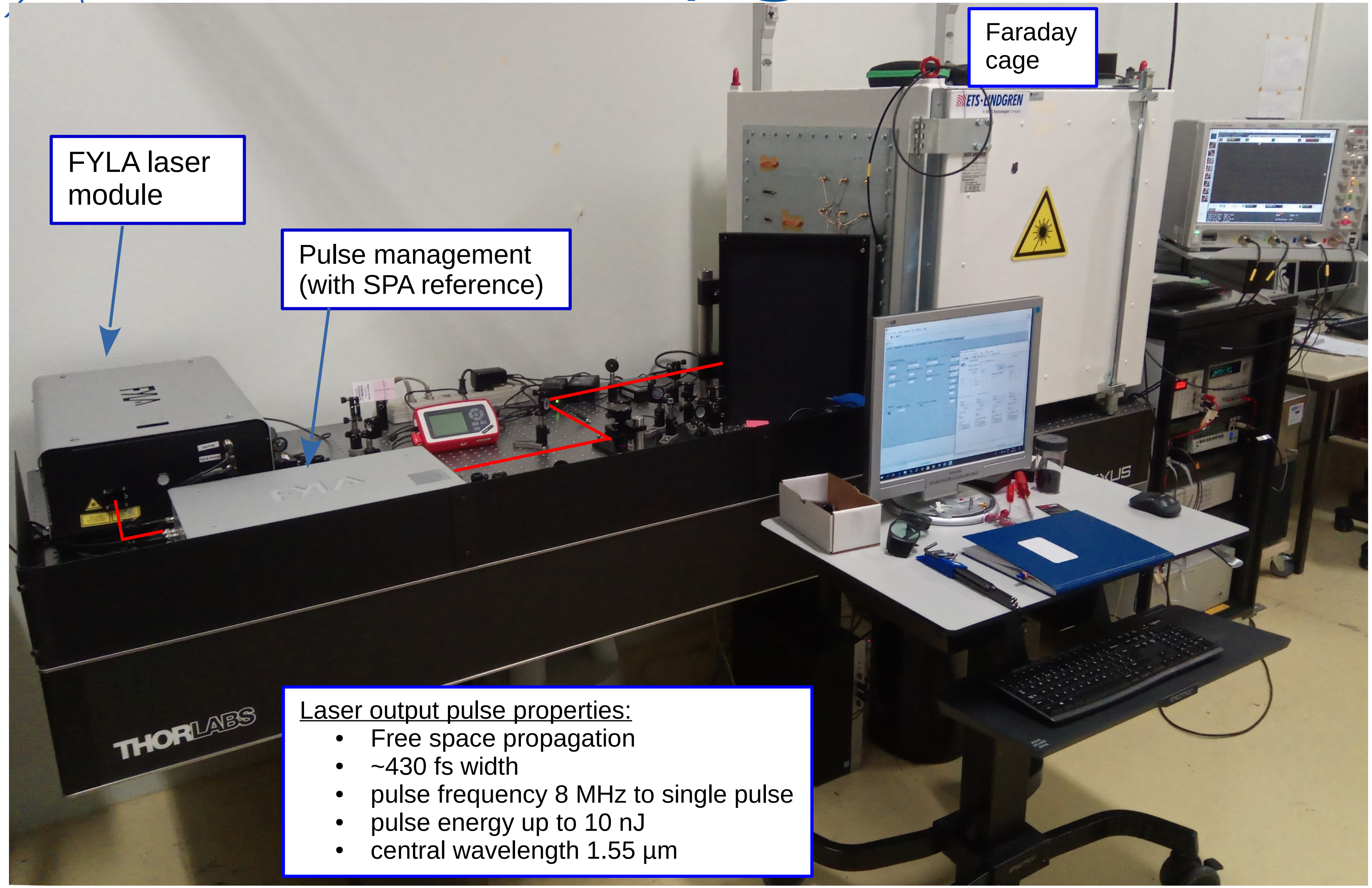
Demonstrator, 2016



CERN-SSD, 2021



TPA-TCT setup@CERN-SSD



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

IEEE Transactions on Nuclear Science (Volume: 68, Issue: 2, Feb. 2021)

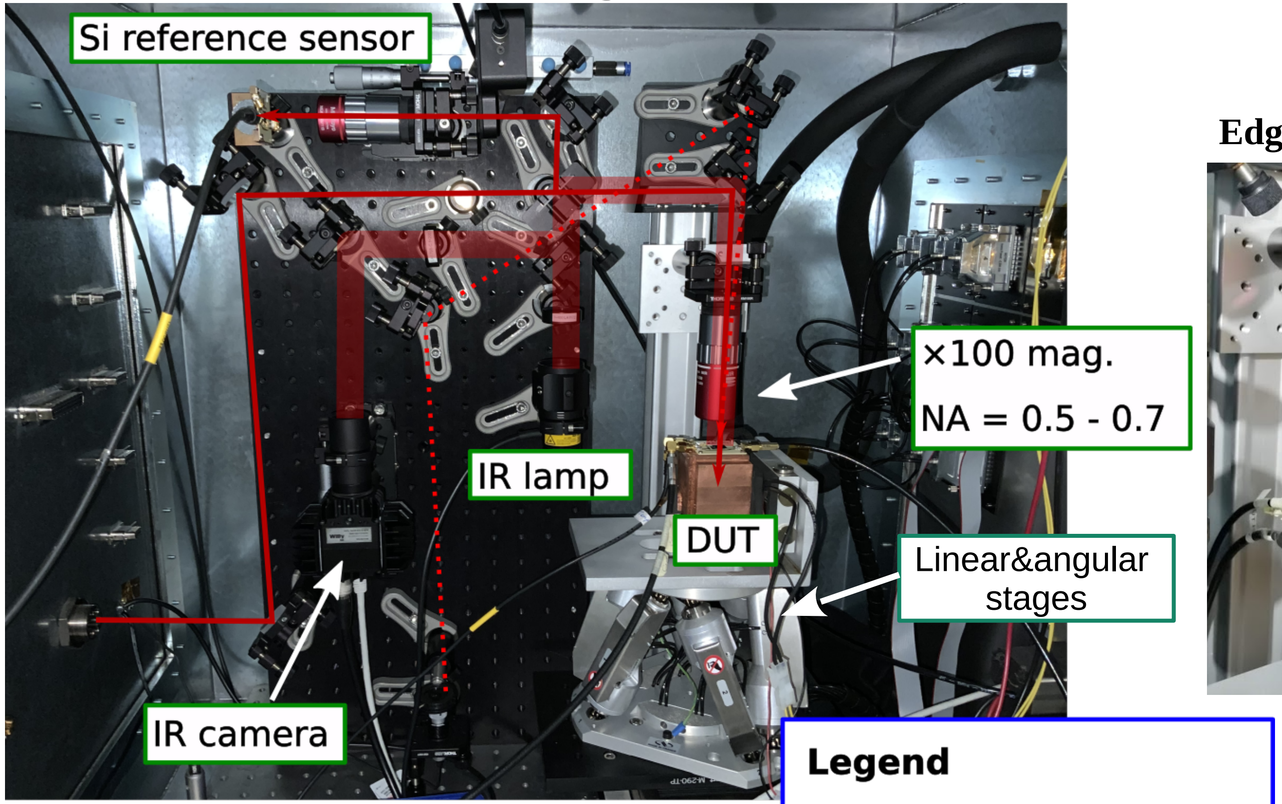
I. Mateu (former CERN fellow):
DAQ system

You are welcome to visit the lab!

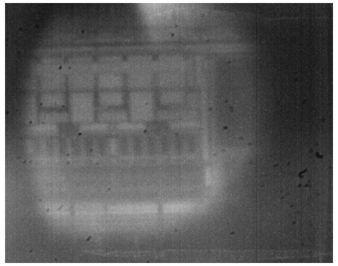
CERN 186/RG25

TPA-TCT setup@CERN-SSD

Inside the Faraday cage:



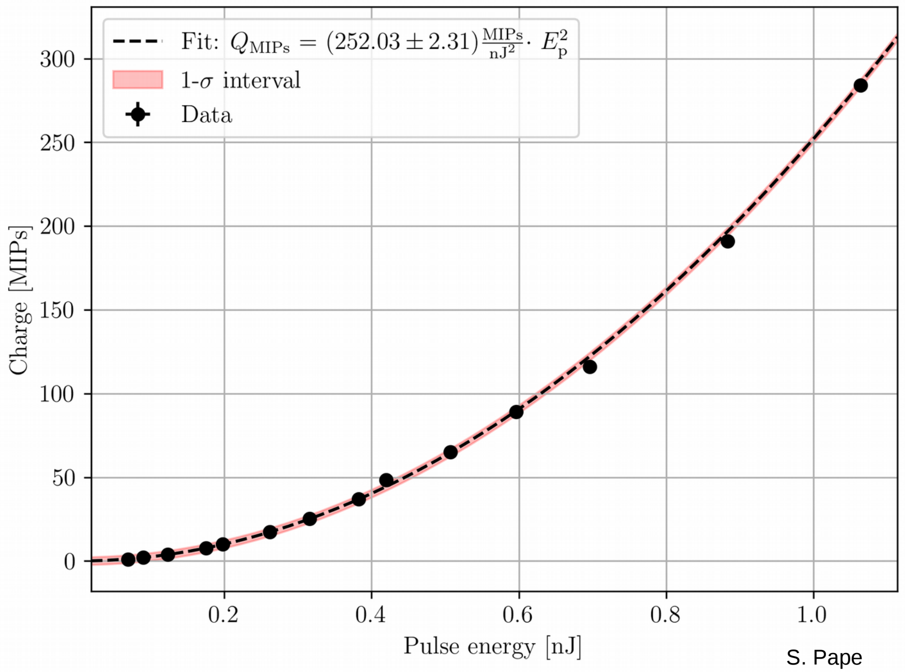
IR camera picture of a structured device through its back side



Edge-illumination

Laser Calibration

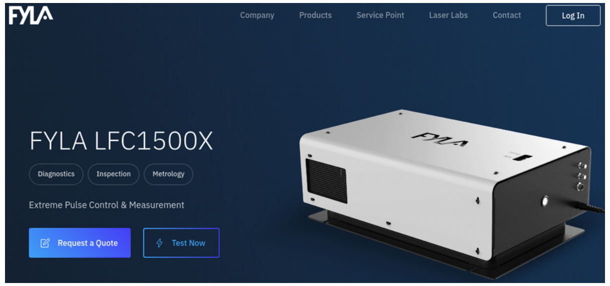
Pulse energy against generated charge (in a 285µm PIN; NA = 0.5 at 20°C and 0% humidity):



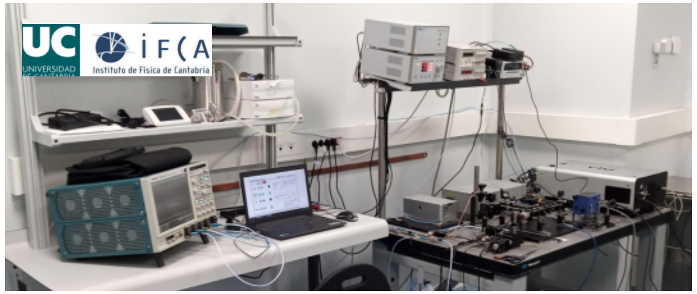
The pulse energy is measured with a S401C thermal power sensor from Thorlabs

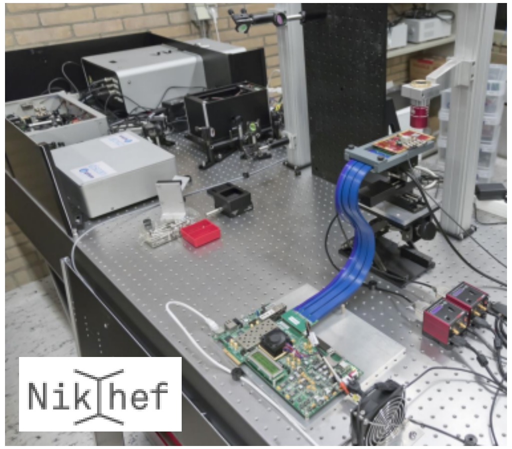
From R&D to a commercial product

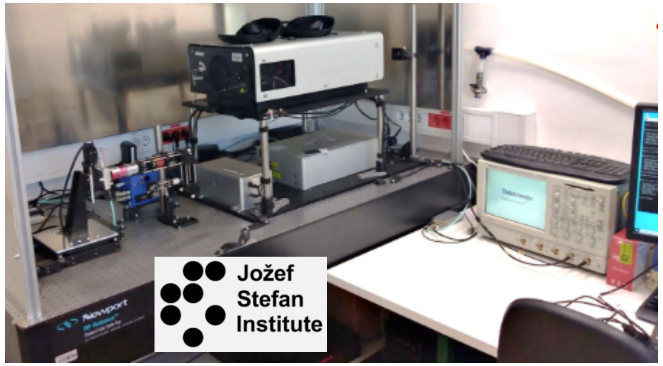
2019-2020: prototype construction and testing of laser@CERN
Since 2021: Laser commercialized by FYLA

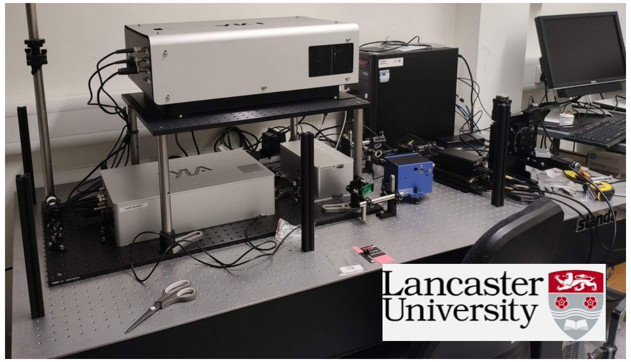


All-fiber CPA femtosecond pulses generation
Pulse rep rate selection. **Single shot to 8 MHz**
Pulse energy modulation: **<10 pJ to > 10 nJ**
Synchronized shutter**. rise/fall time < 1 us**
Fixed pulse duration**~400 fs**





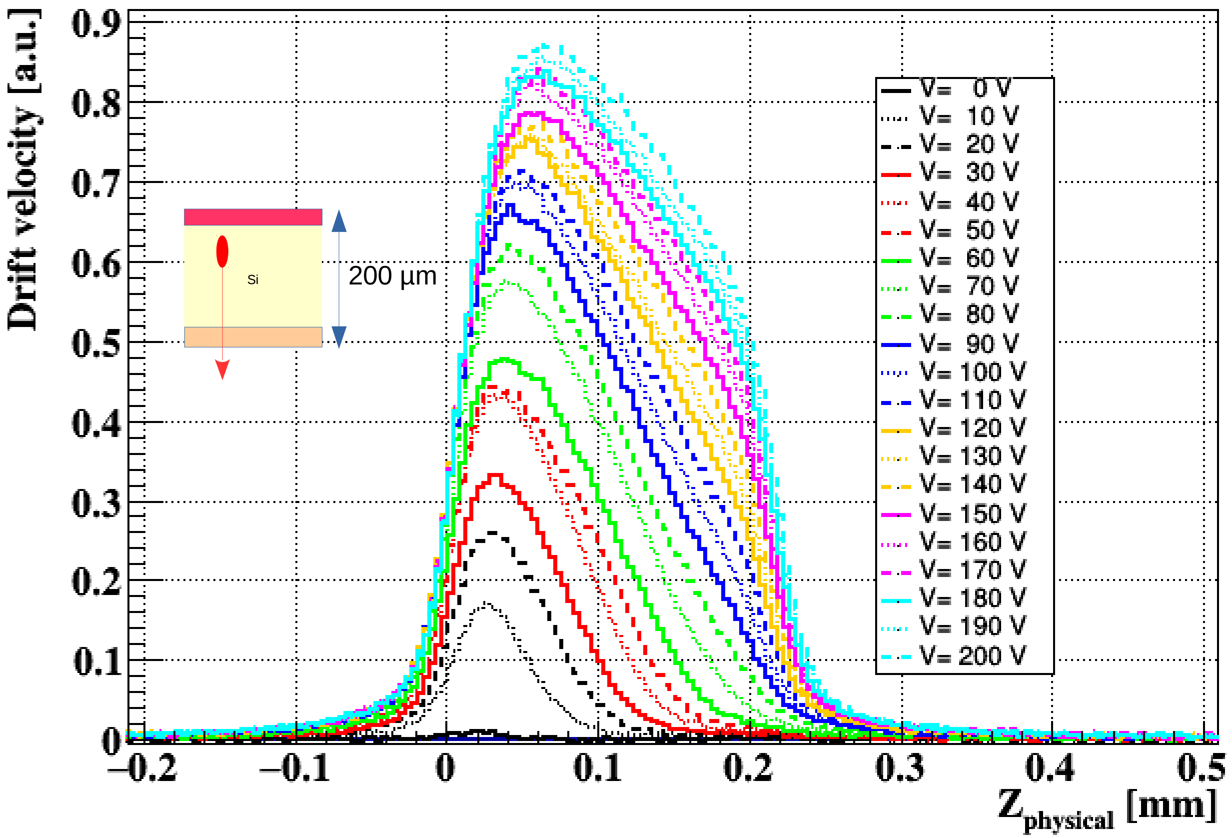




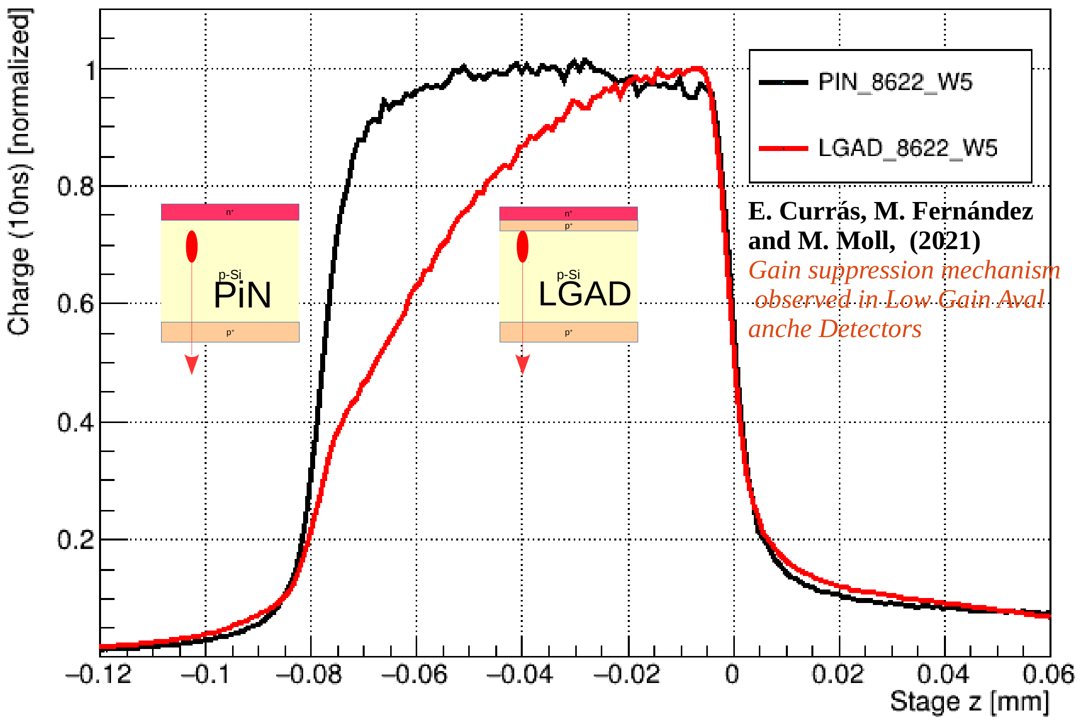
Work in progress
AIDA INNOVA
Single box all-fiber

- **LPS + LPM + D-SCAN** in single box fully all-fiber
  - Pulse duration goal < 100 fs
  - Fiber-based tunable dispersion compensation: < 100 fs to 1 ps
  - Fiber-pigtailed AOM functionalites:
    - Energy modulation
    - Pulse rep rate selection
    - Sync shutter
  - Dispersion-less fiber output delivery to TPA-TCT optical subsystem

Use cases: thick detectors



Top TPA Si diode: Example of **3D resolution** along the beam path
Top-TPA: very simple light injection scheme
Drift velocity as expected “by-the-book”
Here ~200 µm non-irradiated Si diode

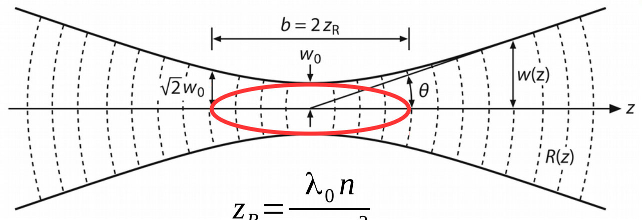


Top TPA Si diode vs LGAD
LGAD: device with internal gain
At high power, the excess carriers shield multiplication field at the front→ **gain reduction**
Effect clearly seen in TPA top illumination at high power

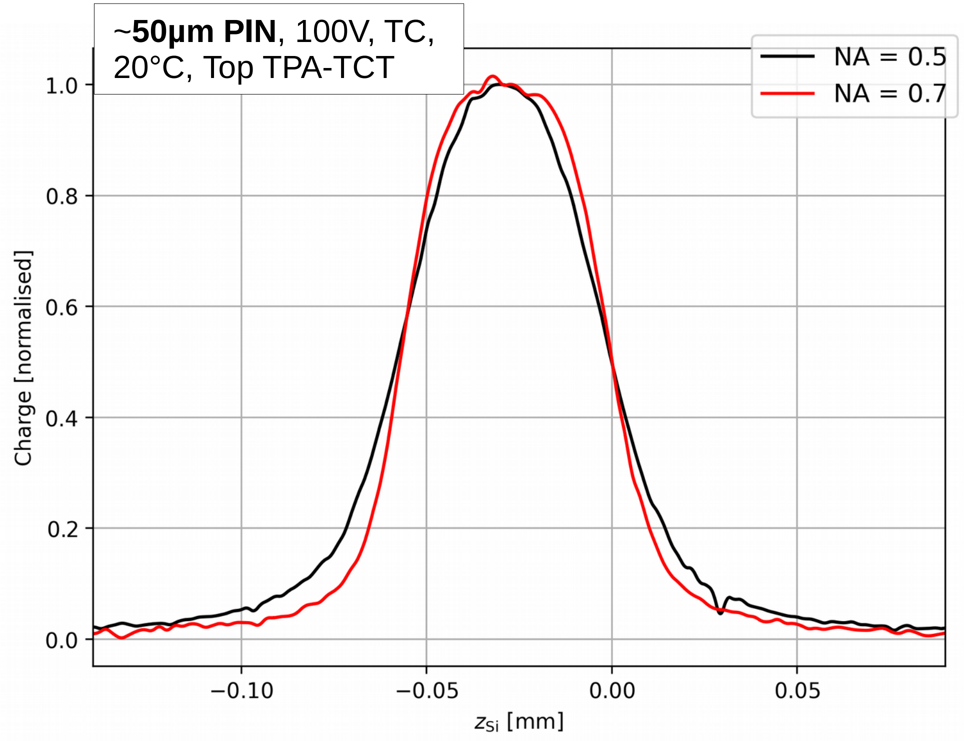
Use cases: thin detectors

LHC: “thick” detectors to obtain more signal (300 µm thick was the standard)
HL-LHC: thinner detectors to reduce trapping
Timing optimized detectors are 35-50 m thick!

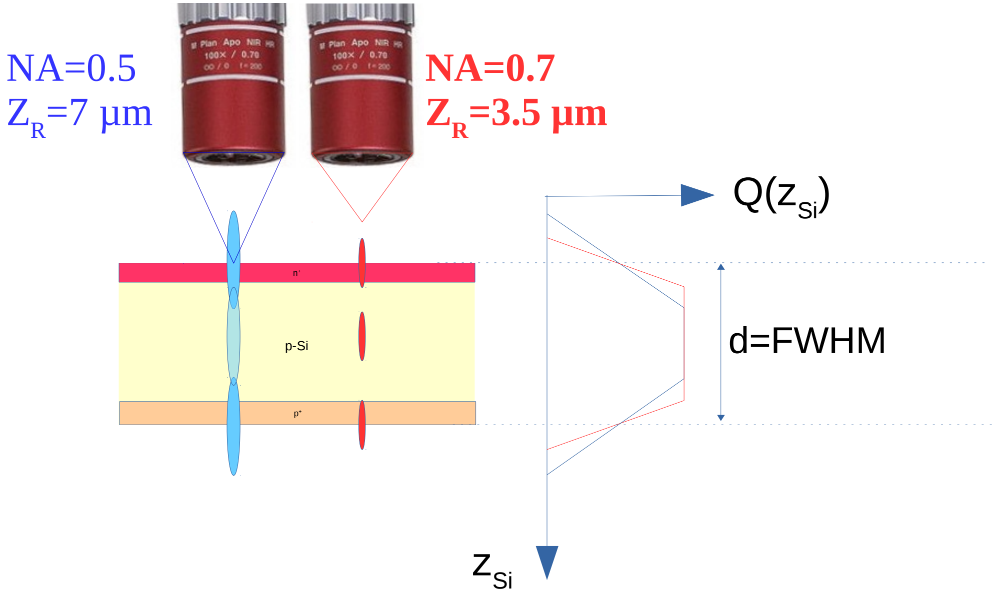
TPA-TCT system upgraded to measure thin/very thin detectors.
Using NA=0.7 objective.
Ellipsoid is a factor 2 smaller



$$z_R = \frac{\lambda_0 n}{\pi NA^2}$$



Higher NA leads to “sharper edges” and better SNR for the same laser power

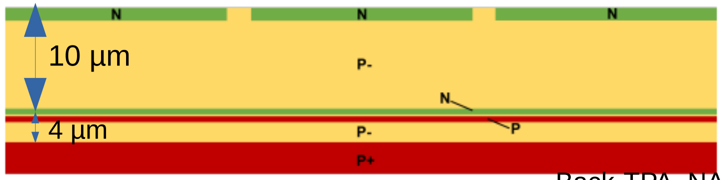


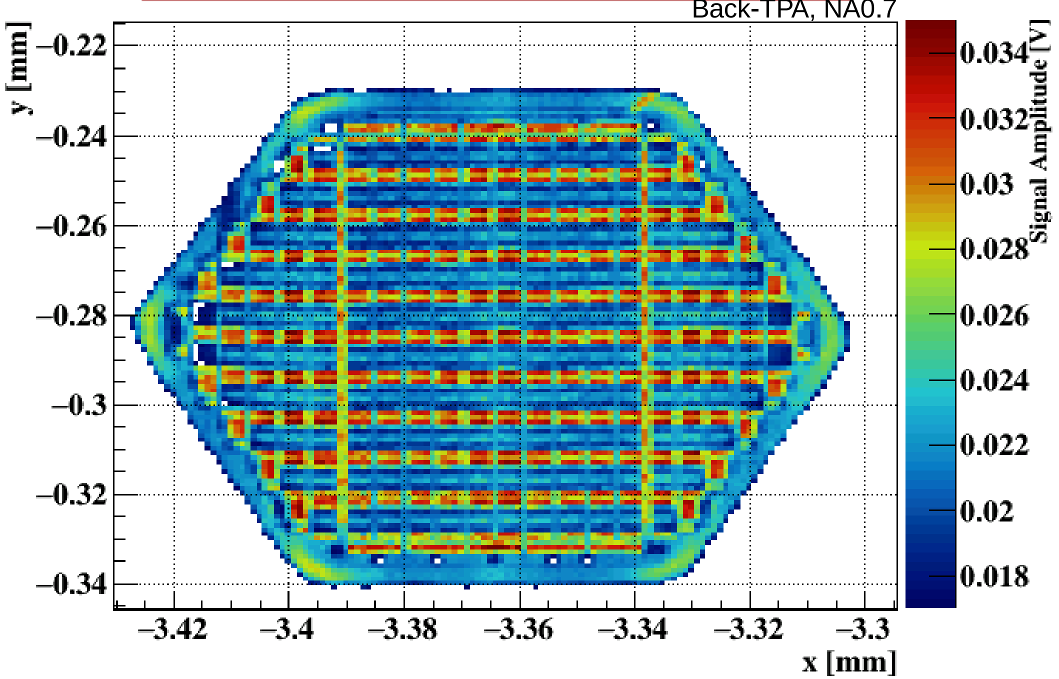
Use cases: very thin detectors

Such as those where the depletion region is ≤ beam Rayleigh length (z_R)

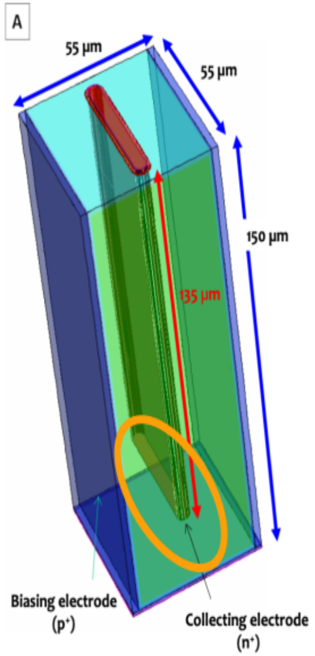
PicoAD (UniGe) Device characterization
Study of gain and mapping of response

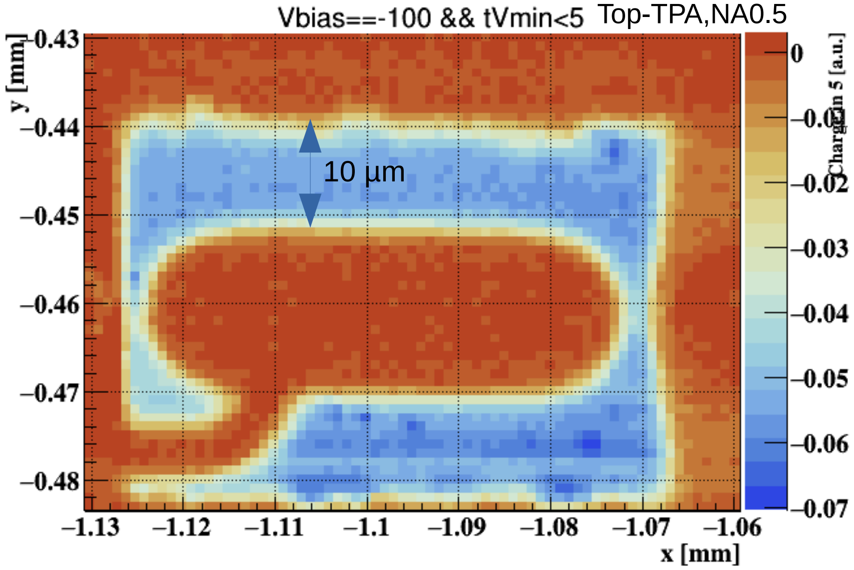
See: arXiv:2206.07952v1





TimeSpot
Study of time resolution and mapping of response
L. Anderlini et al 2020 JINST 15 P09029



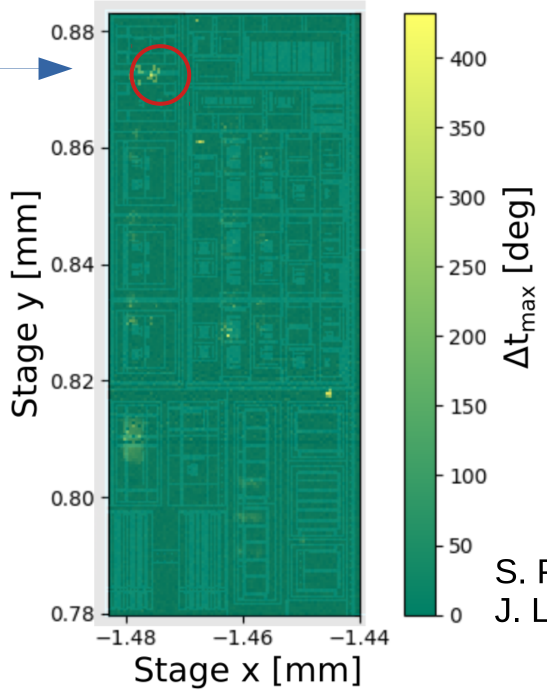


Use cases: SEE studies

TPA-TCT idea came from SEE studies in electronics: combine TPA carrier generation with TCT bulk studies
Despite being designed for silicon bulk measurements, our system dynamic range can also address SEE studies!

RD53B: Single **E**vent **E**ffects found during heavy-ion testing on specific transistors
Use TPA-TCT to access chip from the back side.
→ TPA-TCT resolution is high enough to scan chip components individually
→ find sensitive components to determine the origin of the SEE

Sensitive part of the Clock&Data Recovery Circuit



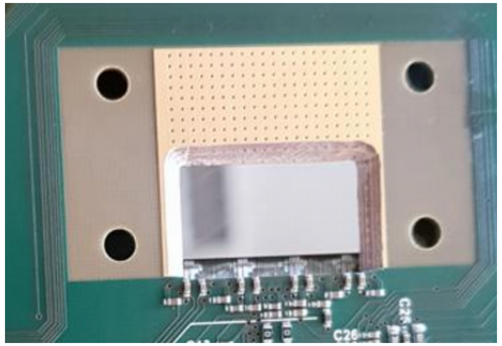
Laser settings:
Pulse energy 1.2nJ
Repetition rate 10Hz
Spatial resolution: 1 µm

Multiple SEE were found.
They were unproblematic fast events
No destructive events were provoked

The **RD53B** design is already revised and the problem is **fixed.**

Work to be presented at TWEPP22

S. Pape
J. Lalic (CERN EP-ESE)



Backside TPA on the RD50B chip

Conclusions & outlook

CERN KT funded project TPA-TCT concluded with the development of a commercial laser by FYLA
Since end of 2020 setup operational at CERN-SSD

Setup designed by M. Wiehe, former PhD student at CERN-SSD
Upgrades and measurements by Sebastian Pape, current PhD student at CERN

Within AIDA-INNOVA, FYLA is producing a new all-fibered version of the laser
FYLA is also working on a complete TPA-TCT system ”turn-key”

During 2021-2022, CERN TPA-TCT is serving a wide user community:

- **RD50**: Study of Gain reduction mechanism
- **RD53**: SEE mapping
- **CMS-ETL**: HPK and CNM LGAD characterizations
- **picoAD**: Field and gain mappings
- **TimeSpot**: time resolution