A table-top Two Photon Absorption – TCT system: experimental results

Marcos Fernández García[1,2], Michael Moll[1], Raúl Montero Santos[3], Rogelio Palomo Pinto[4], Sebastian Pape[1,5], Ivan Vila Alvarez[2], Moritz Wiehe[1,6]

[1]CERN
[2]Instituto de Física de Cantabria
[3]Universidad del Pais Vasco (UPV-EHU)
[4]Universidad de Sevilla
[5]TU Dortmund University
[6]Universität Freiburg

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of Education
and Research

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38th RD50 Workshop

Outline

- TPA-TCT employed on different devices:
  - ➔ HV-CMOS
  - ➔ Inter-pad region LGAD
  - ➔ Strip detector
  - ➔ Unirradiated and Irradiated PIN’s

- Comparison:
  Objectives NA0.5 & NA0.7

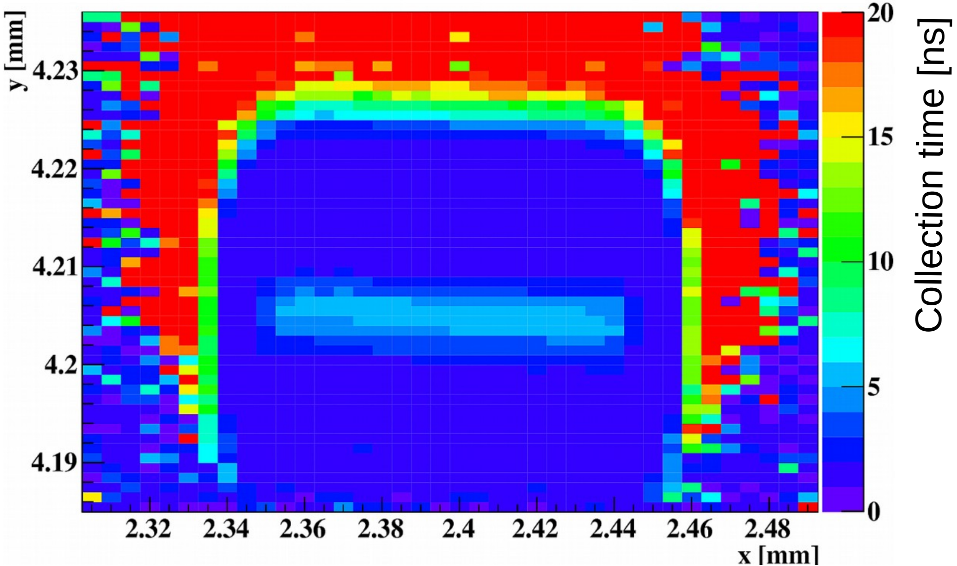
HV-CMOS

HV-CMOS

Measurements performed in edge TPA-TCT configuration (see Backup)

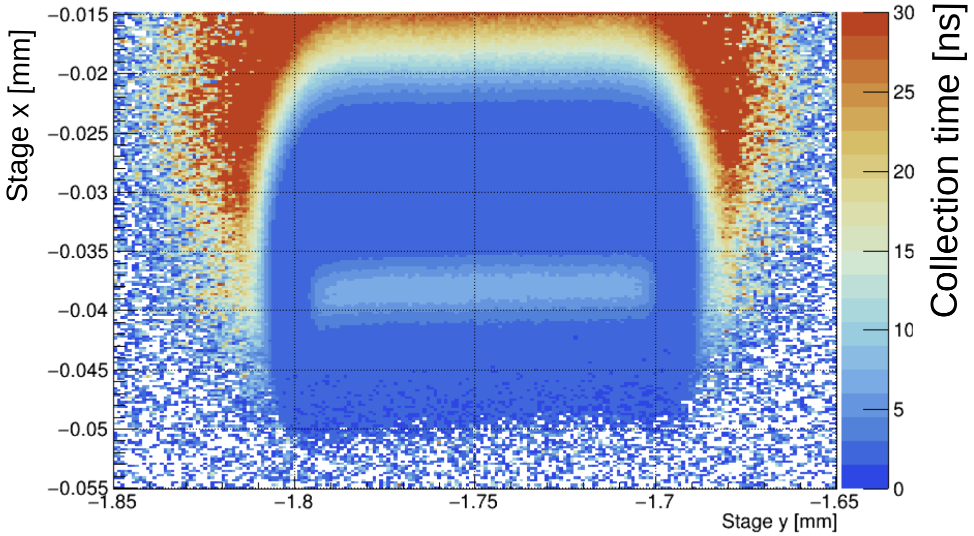
Demonstrator
Bilbao SGIKER

Source



Bias voltage: 80 V

CERN setup

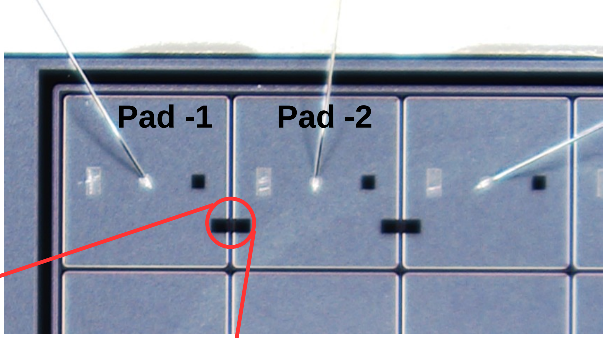


Bias voltage: 60 V

Result from Bilbao could be reproduced at CERN

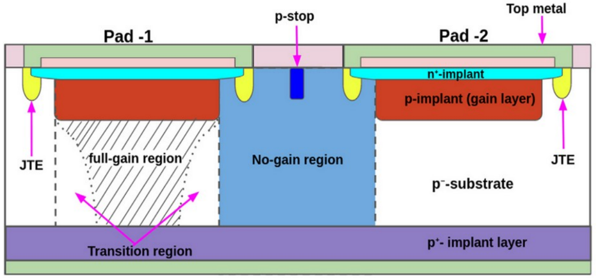
Inter-pad region LGAD

Inter-pad region: HPK2 5x5 LGAD

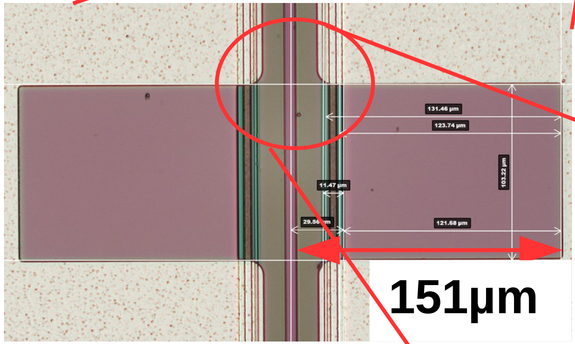


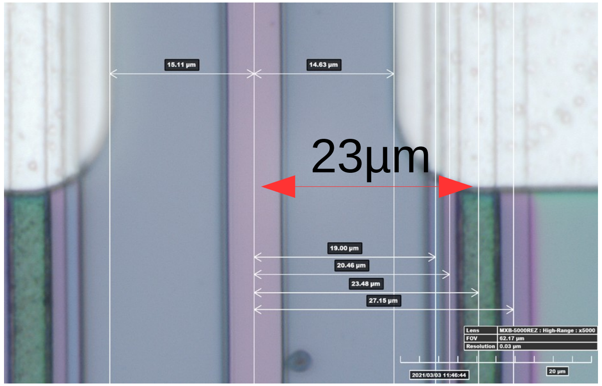
Neighbors floating

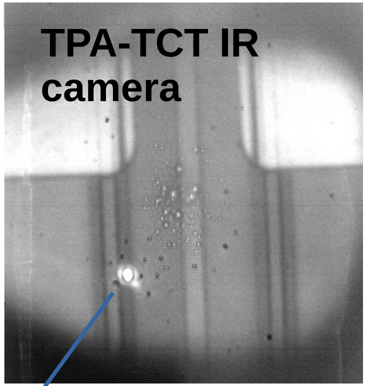
HPK2-W28-S1-LGAD-P14
LG 5x5-SE3-IP5-UBM



S. Bharthuar et.al.
https://doi.org/10.1016/j.nima.2020.164494



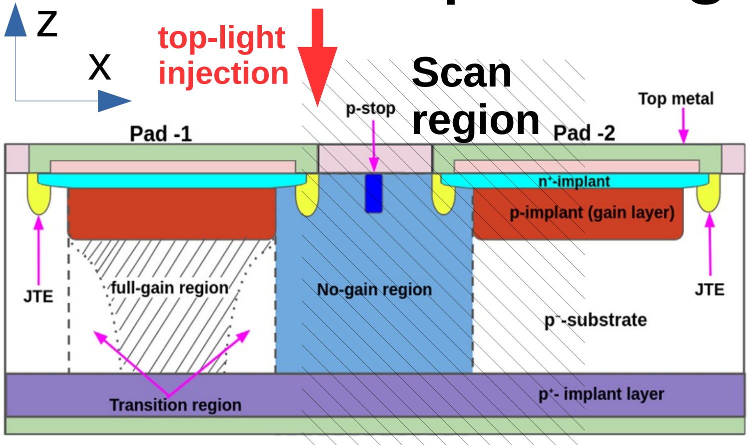




laser beam spot

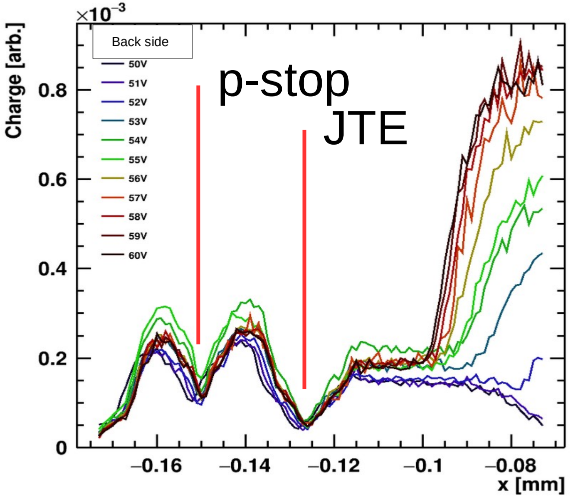
Images with Hirox microscope
CERN EP-DT QART lab

Inter-pad region: HPK2 5x5 LGAD

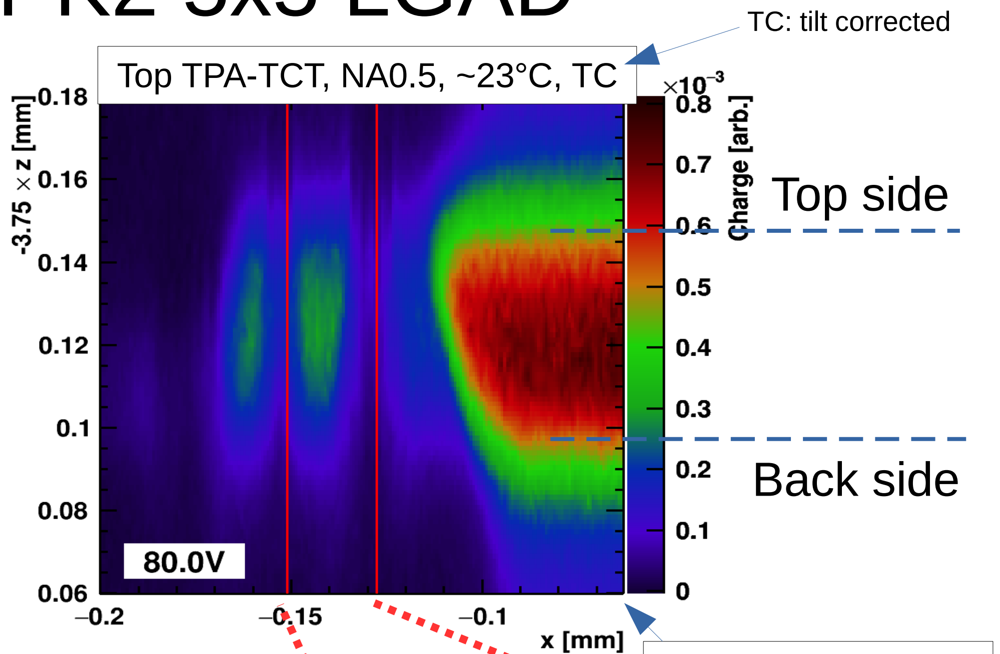


S. Bharthuar et.al.
https://doi.org/10.1016/j.nima.2020.164494

(not to scale)



TC: tilt corrected



1.3µm beam waist
12µm Rayleigh length

HPK2-W28-S1-LGAD-P14

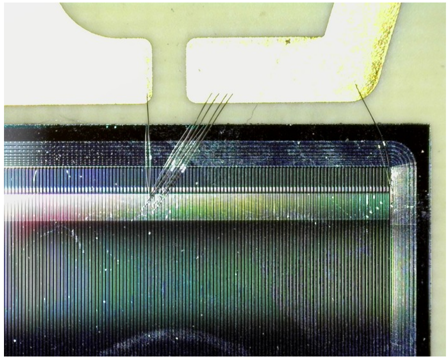
LG 5x5-SE3-IP5-UBM

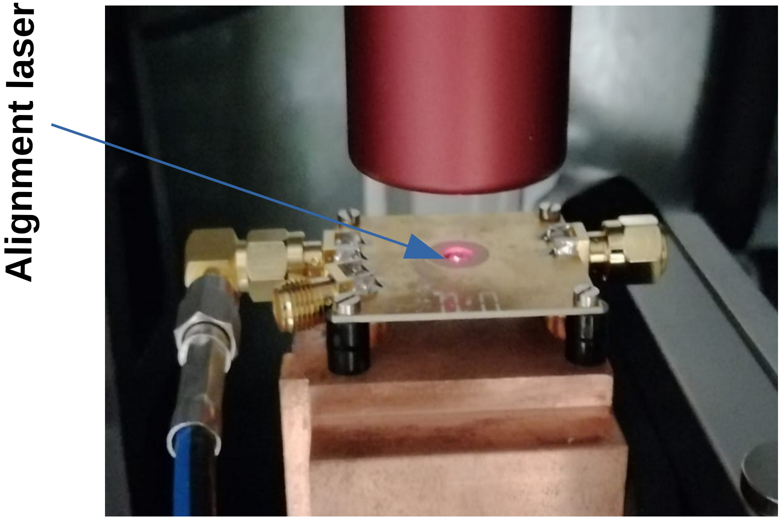
Strip detector

Strip detector

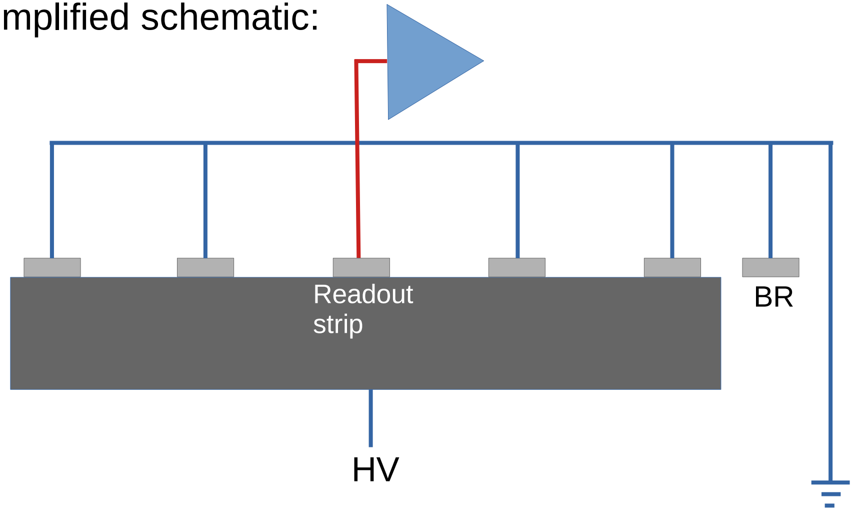
- Micron strip detector → *p*-type, 80µm pitch, 30µm strip metalization width, 300µm thick and **unirradiated**
- Back side biased; bias ring (BR), 1. & 2. neighbor strip grounded

  → AC and DC pads of neighboring strips grounded
- Back side mounted (to avoid clipping at strip metalization):





Simplified schematic:



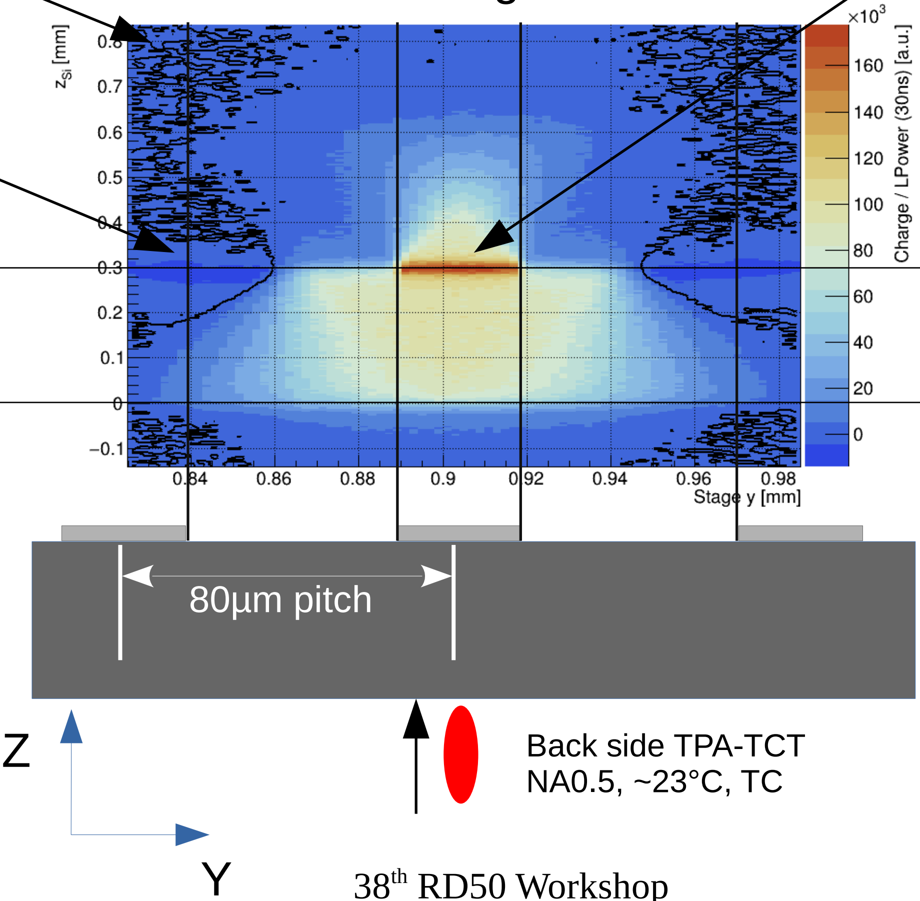
Strip detector

Bias voltage: -50V

Contour line at 0

Negative Charge:
Ballistic deficit
Capacitive coupling

≈ 300µm

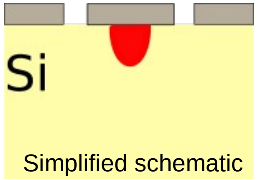


Top side

Back side

Back side TPA-TCT
NA0.5, ~23°C, TC

Reflection at strip metalization:



Simplified schematic

Charge highest: **Q~I²**

DUT:

- 300µm Micron strip detector
- **unirradiated**
- 80µm pitch

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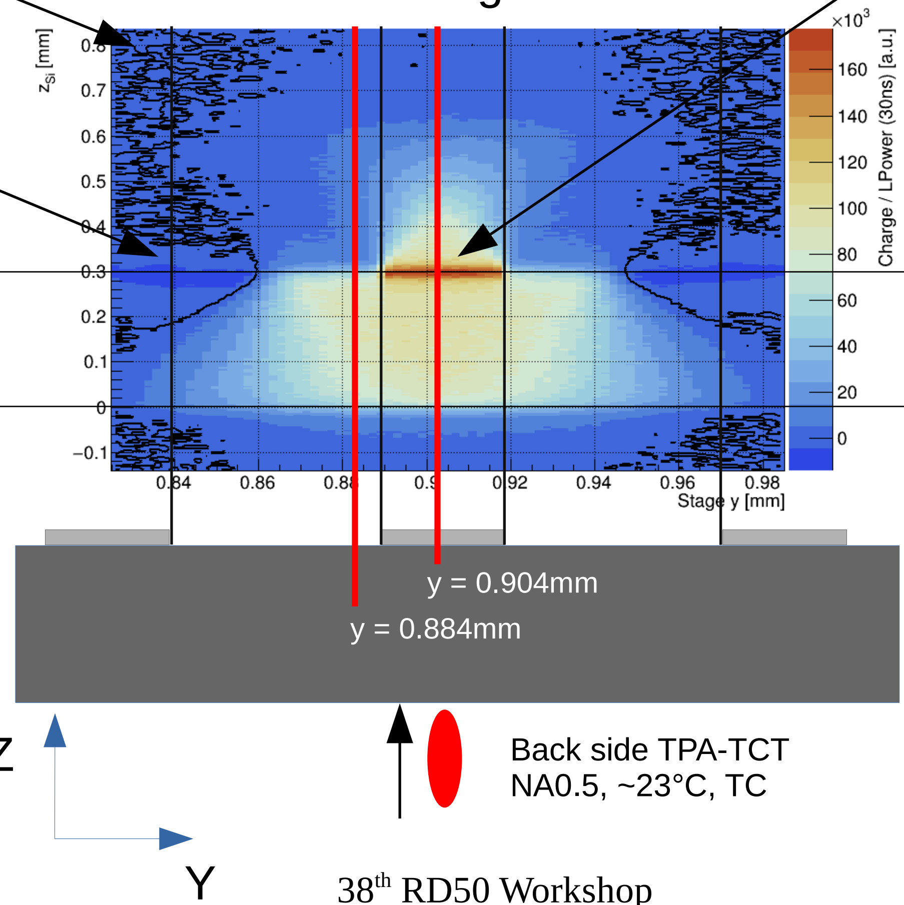
Bias voltage: -50V

Contour line at 0

Negative Charge:
Ballistic deficit
Capacitive coupling

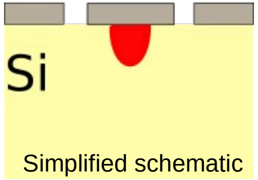
≈ 300µm



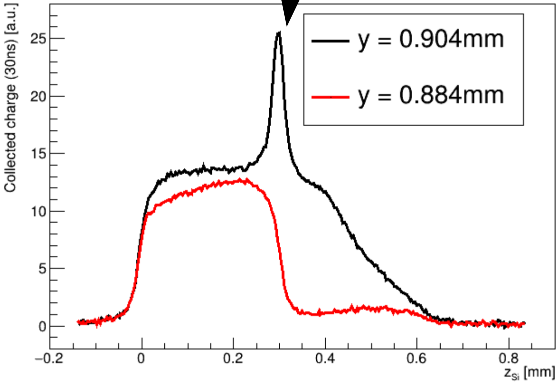
Top side

Back side

Reflection at strip metalization:



Charge highest: **$Q \sim I^2$**



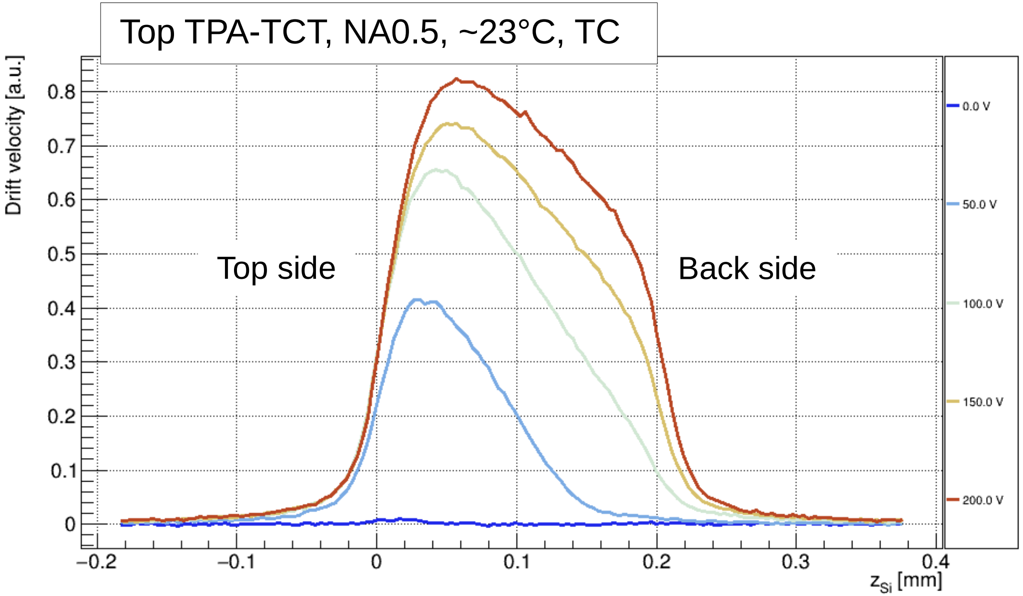
Back side TPA-TCT
NA0.5, ~23°C, TC

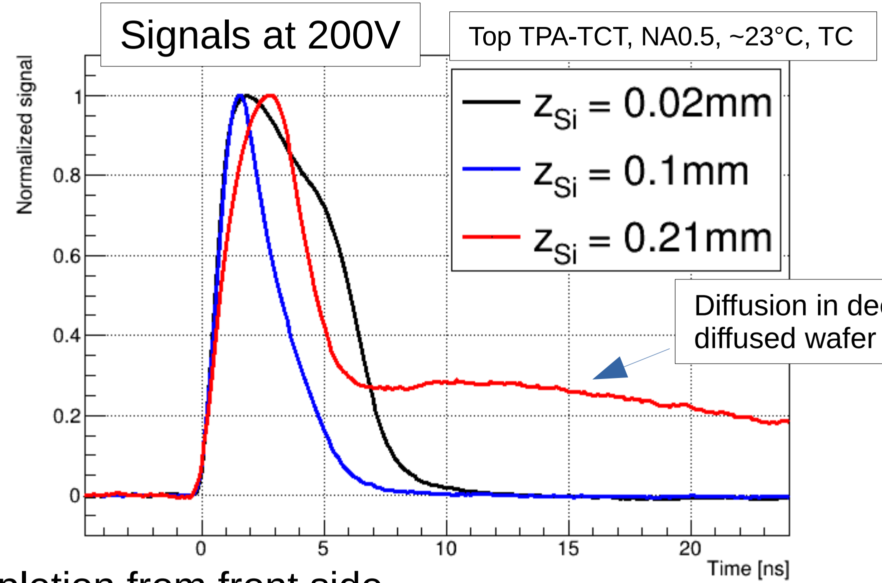
DUT:

- 300µm Micron strip detector
- **unirradiated**
- 80µm pitch

Unirradiated PIN detectors

FZ200: drift velocity


Top TPA-TCT, NA0.5, ~23°C, TC

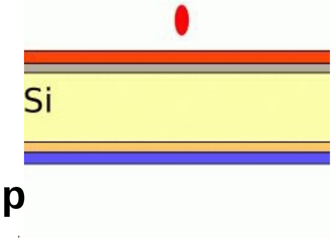

Signals at 200V

Top TPA-TCT, NA0.5, ~23°C, TC

Diffusion in deep diffused wafer

DUT:
- HPK deep diffused campaign
- 200µm FZ, p-type
- **unirradiated**
- Deep diffused wafer

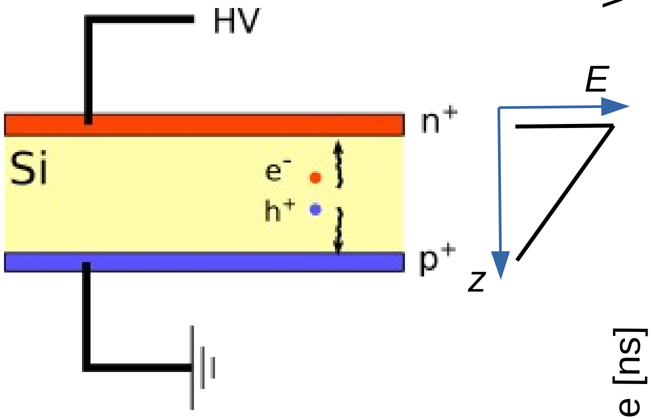
- Depletion from front side
  - **3D resolution:**
- Signal length higher at back side → **transition to undepleted deep diffused wafer observed**

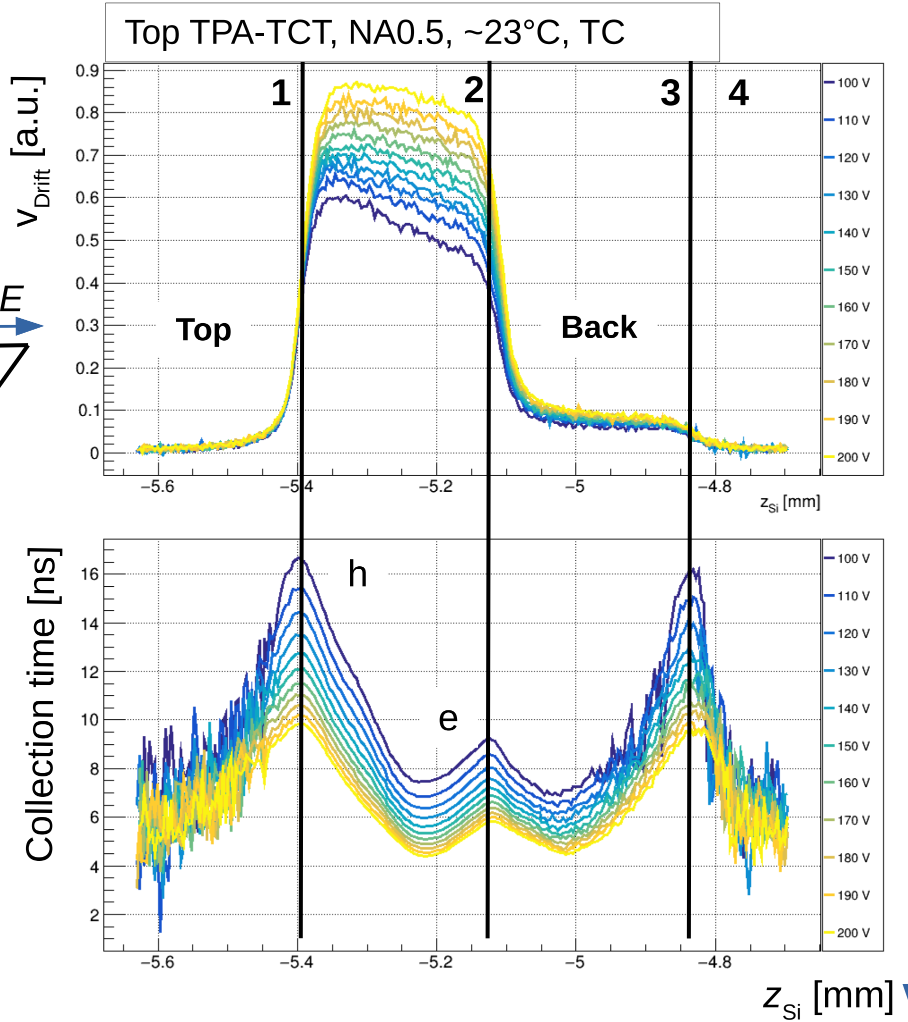


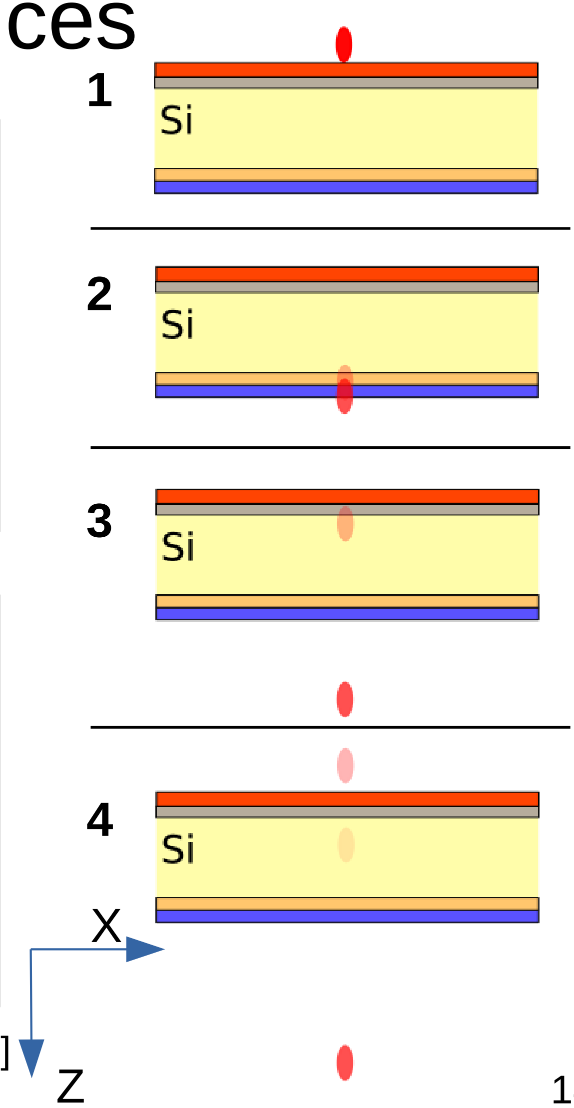
Further information about the collection time in backup

Reflection: unirradiated devices

Unirradiated,
285µm physical thickness,
CNM p-type PIN:





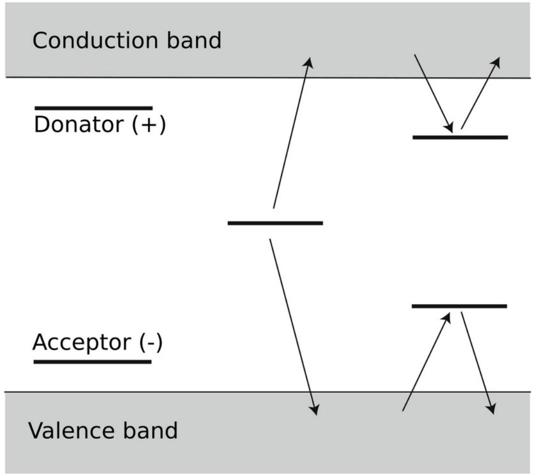


→ Reflections useful to detect surfaces

Irradiated PIN detectors

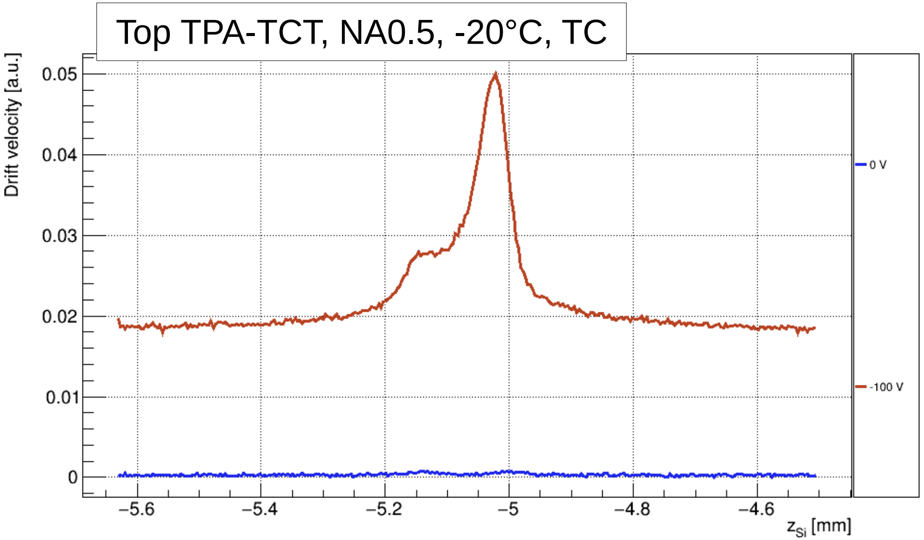
TPA-TCT in irradiated detectors

Irradiation introduces extra energy levels in the band gap region:



Picture (modified) taken from:
H. Kolanoski, N. Wermes - Teilchendetektoren

- Intermediate levels trap carriers inside the band gap
- ➔ λ = 1550 nm can directly excite those charge carriers
- ➔ Single photon absorption (SPA) grows
- ➔ SPA only depends on the intensity, not on the *z* position of focal point → **constant background in *z*-scans**
- ➔ **SPA can be corrected**

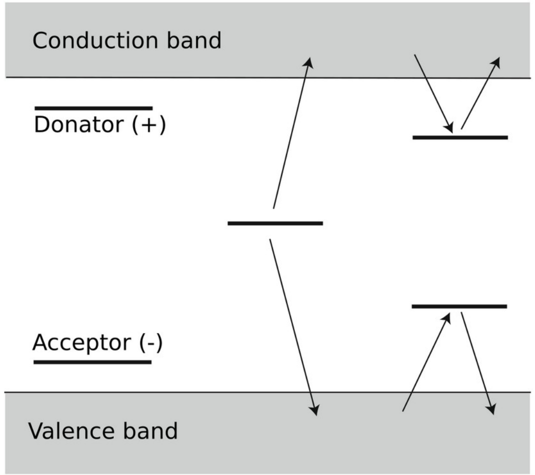


Above: FZ n-type detector

- 120 µm thick
- Irradiated: 6.25E+15 n_{eq}/cm^2
- HPK deep diffused campaign

TPA-TCT in irradiated detectors

Irradiation introduces extra energy levels in the band gap region:



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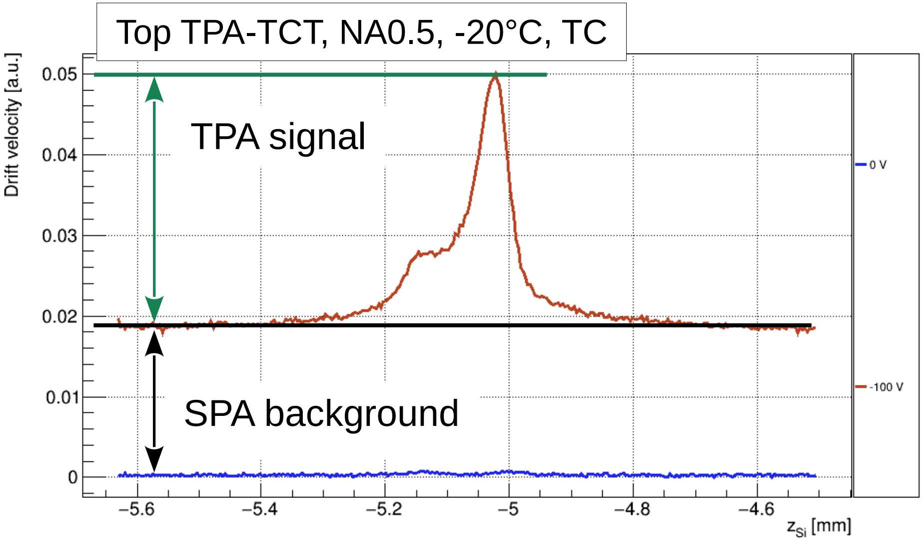

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- 120 µm thick
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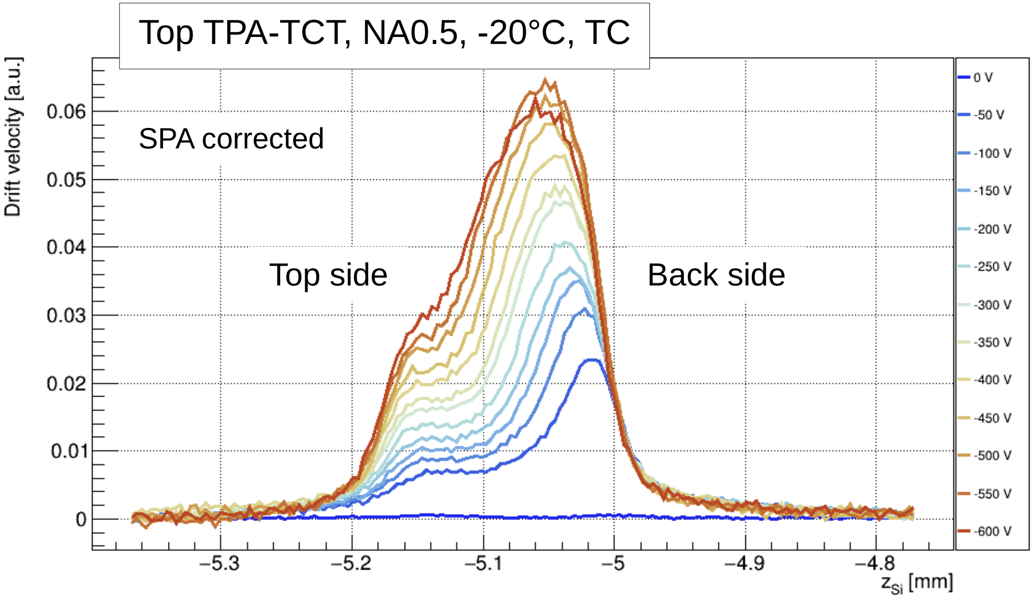
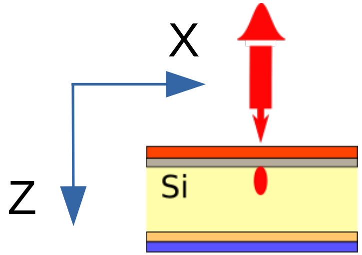
- HPK deep diffused campaign

FZ120N: drift velocity



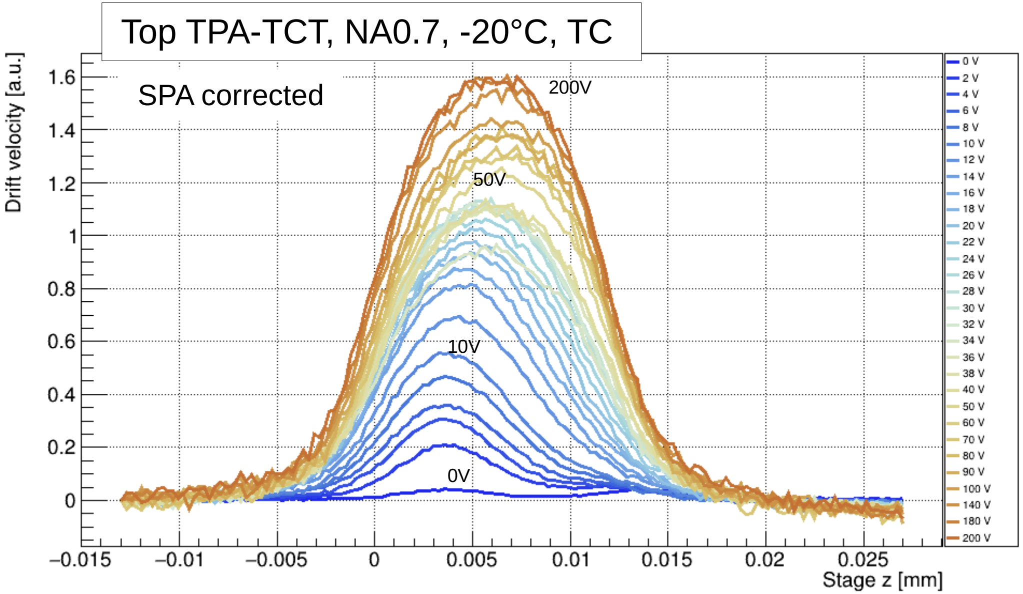
Top injection:

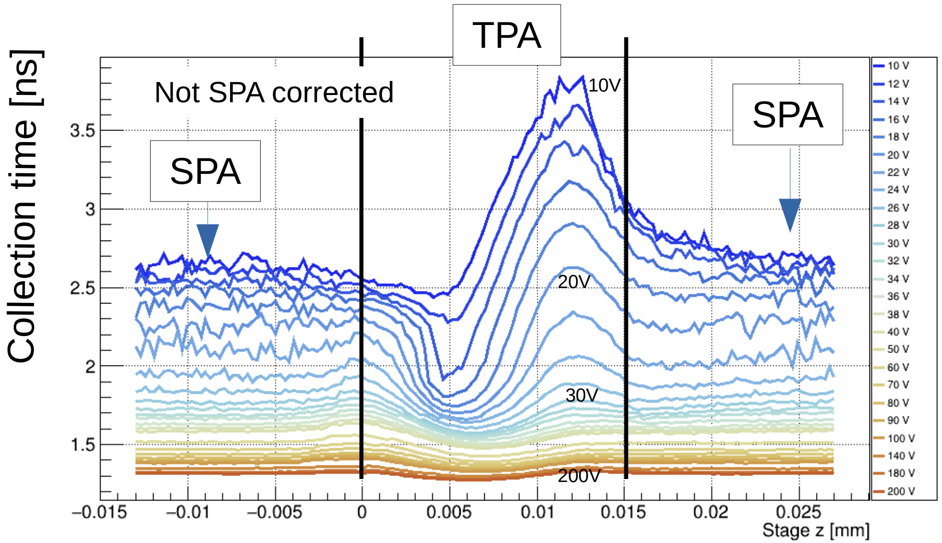


- HPK deep diffused campaign
- n-type FZ device → junction at top side
- Irradiated: **6.25E+15 neq/cm^2**
- Highest electric field at back side
  - ➔ Space charge sign inversion

HPK2-PIN: drift velocity

Top TPA-TCT is able to resolve depletion of thin devices (50 µm)



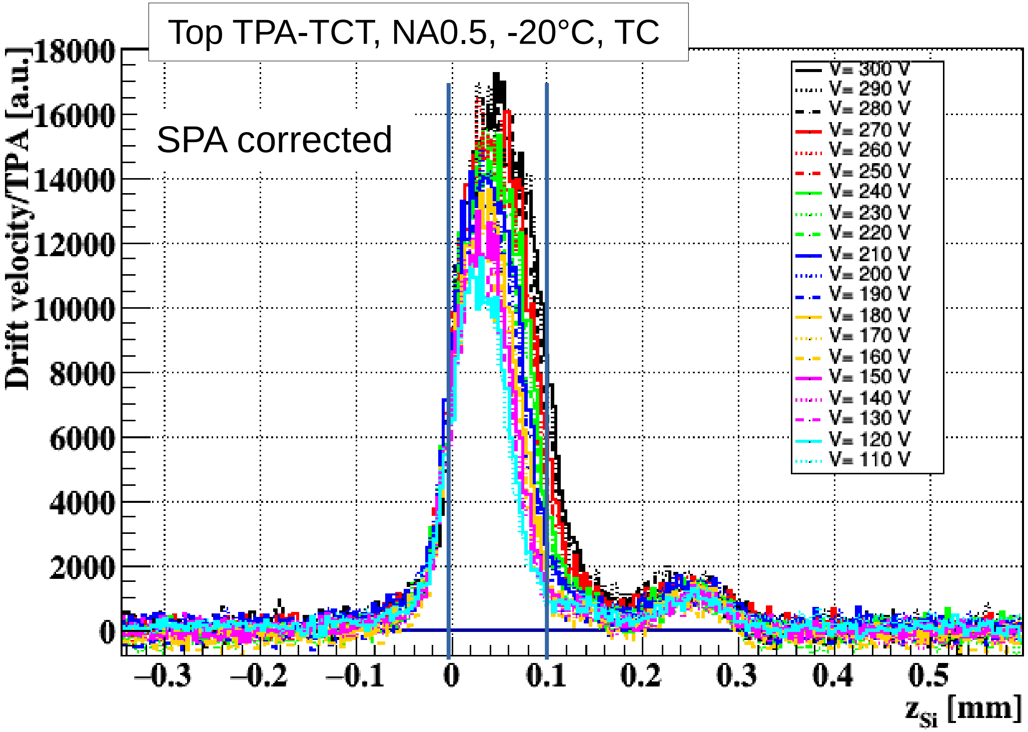


- Depletion from top side
- Collection time smaller in depleted region
- Depletion behavior can be studied
- Full depletion around 30V

DUT:

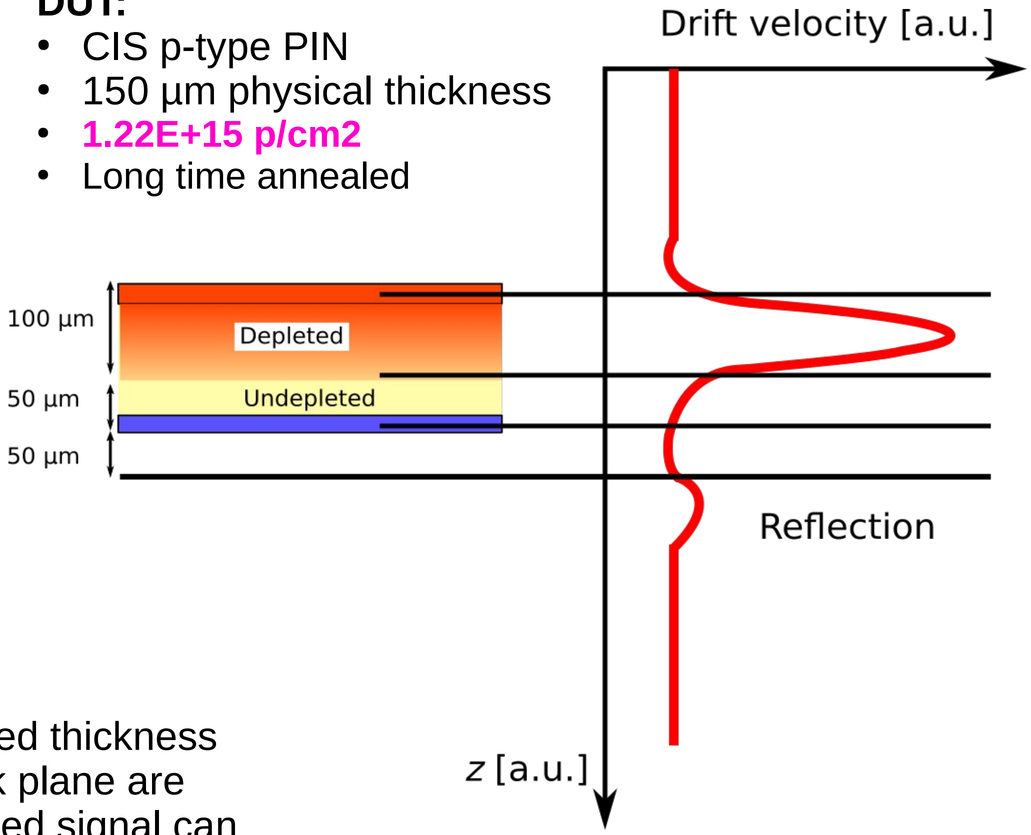
- 50µm p-type HPK2-PIN
- **4.00E+14 neq/cm2**
- 150µm support wafer

Reflection: irradiated devices



DUT:

- CIS p-type PIN
- 150 µm physical thickness
- **1.22E+15 p/cm2**
- Long time annealed



The position of the reflection informs us about the depleted thickness (FWHM~100µm at 300V). The last 50µm before the back plane are undepleted (or very low E-field). Neither direct nor reflected signal can be measured there. First reflection appears 100µm after depletion.

→ Reflections useful to detect surfaces

Comparison: Objectives NA0.5 and NA0.7

Numerical aperture

Numerical aperture:
Correlates with the objective’s resolving power

Connected with the beam parameters:

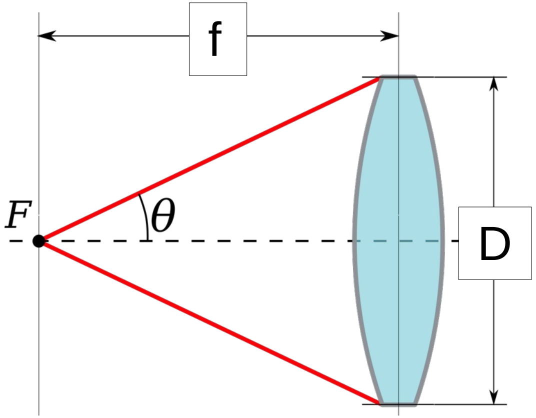
$$w_0 \approx \lambda/(\pi\times NA)$$

$$z_0 \approx \lambda\times n/(\pi\times NA^2)$$

Majority of charge is generated within the first Rayleigh length

➔ higher NA ↔ smaller volume of charge generation

$$NA = n\times\sin(\theta) \approx n\times D/(2f)$$



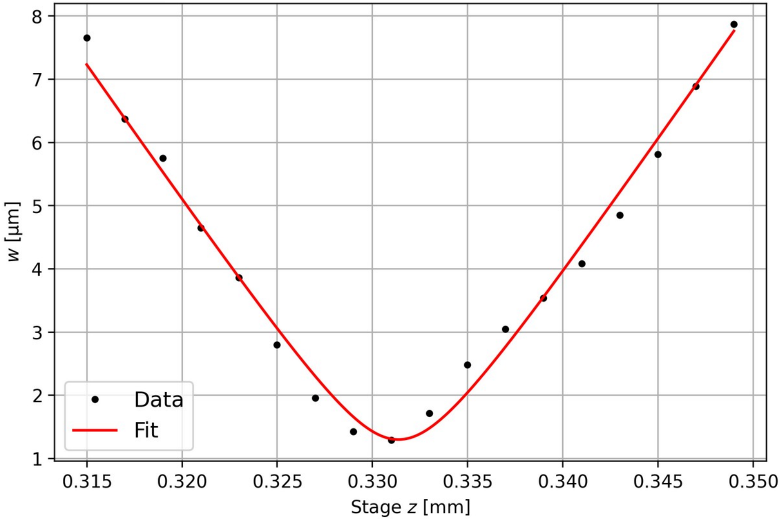
Source edmundoptics.com

100X Mitutoyo Plan Apo
NIR HR Infinity Corrected Objective

Knife edge scans: NA0.5 and NA0.7

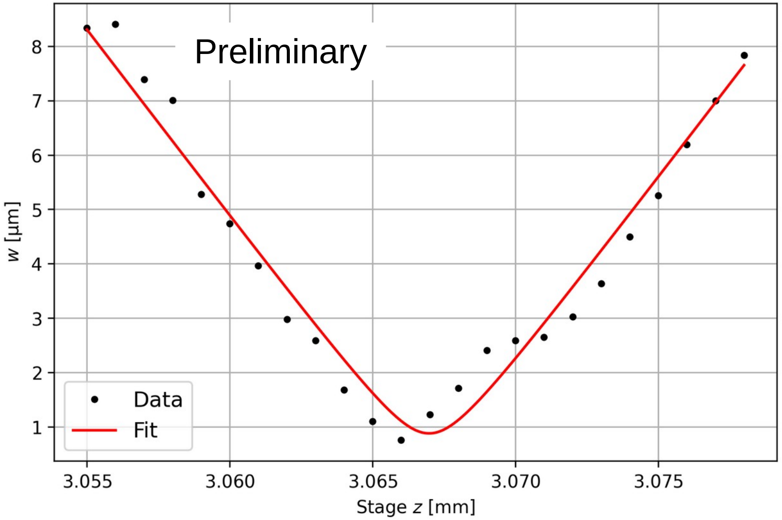
NA0.5

W_0 = 1.3 µm, $z_{0,Si}$ ≈ 12 µm



NA0.7

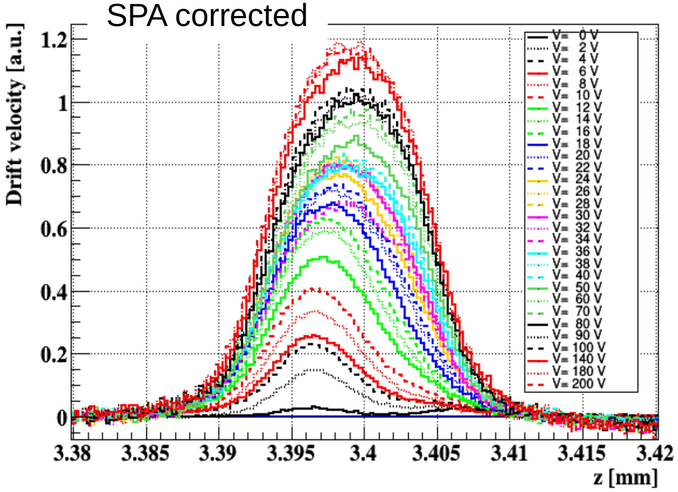
W_0 = 0.9 µm, $z_{0,Si}$ ≈ 6 µm

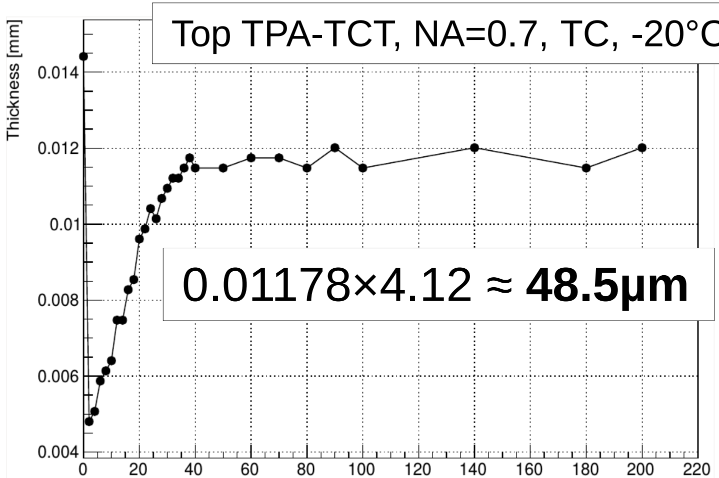


Rayleigh length for NA0.7 is approx. two times smaller
→ Resolution along the beam axis improves by a factor of two

Depletion depth of a thin device

Thickness from drift velocity inflection points

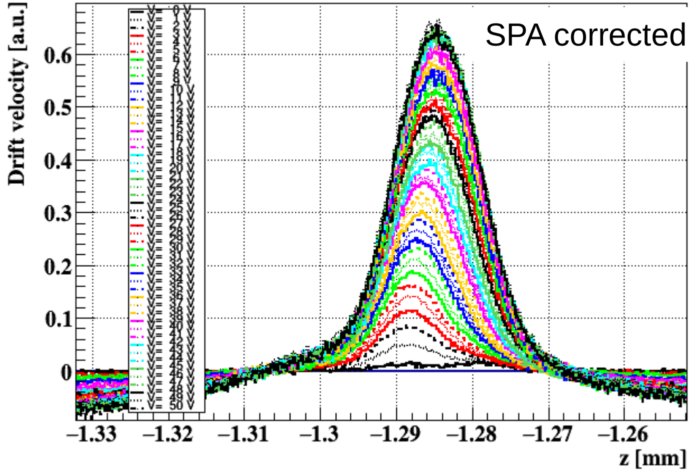


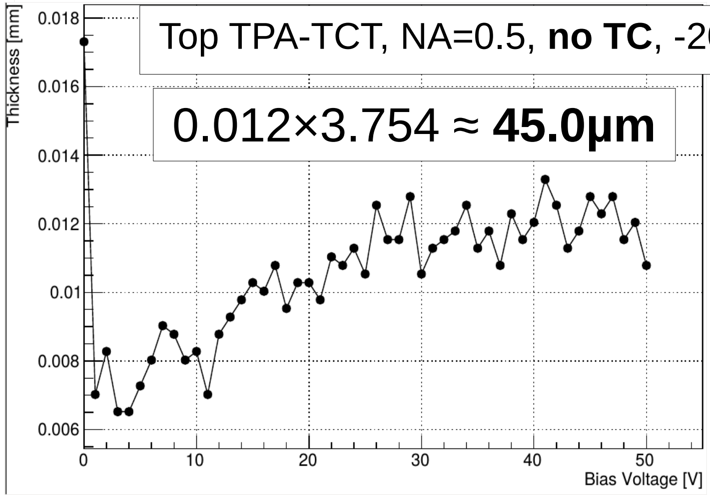


Top TPA-TCT, NA=0.7, TC, -20°C

0.01178×4.12 ≈ **48.5μm**

CV measurement:
47.8μm thickness





Top TPA-TCT, NA=0.5, **no TC**, -20°C

0.012×3.754 ≈ **45.0μm**

DUT:

- 50 μm HPK2-PIN
- **4.00E+14 neq/cm2**
- 150μm support wafer

Summary

Summary

- Table top system validated against demonstrator from Bilbao using HV-CMOS
- Top TPA-TCT provides 3D resolution to resolve depletion depth of thin (50µm) and thick devices
- One micrometer resolution (perpendicular to beam) used for imaging the inter-pad region of a multipad LGAD
- Reflections useful to determine the device’s boundaries
- TPA-TCT employment in SEE studies is currently discussed (see Backup)

Thank you for your attention!

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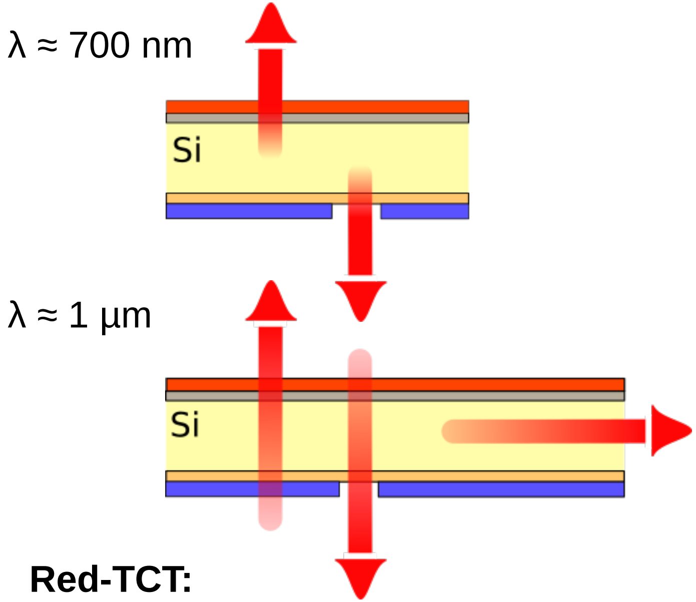
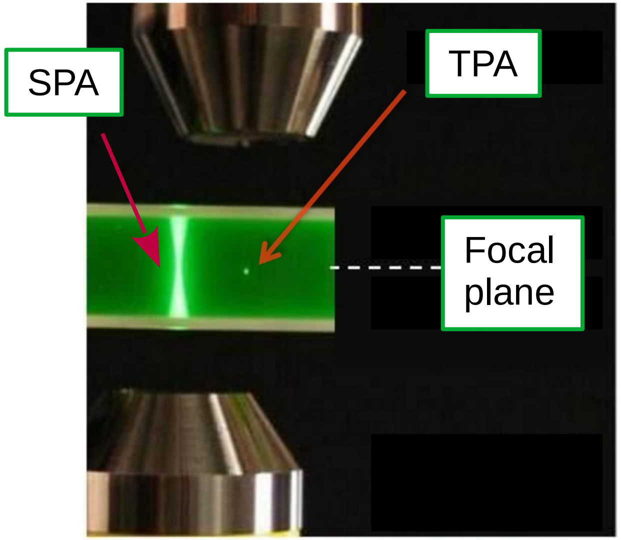
Backup

Single Photon Absorption-TCT



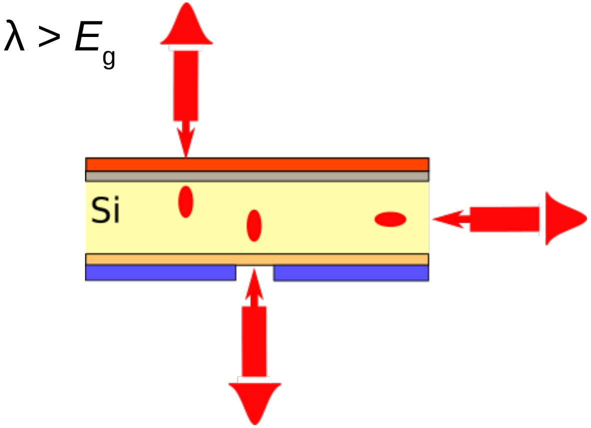
- **Red-TCT:**
  - Full light absorption in ~3-10 µm depth
  - optimal for e/h separation
  - Laser can be microfocused to < 5 µm: **2D resolution**

- **IR-TCT:**
  - Mimics MiP (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

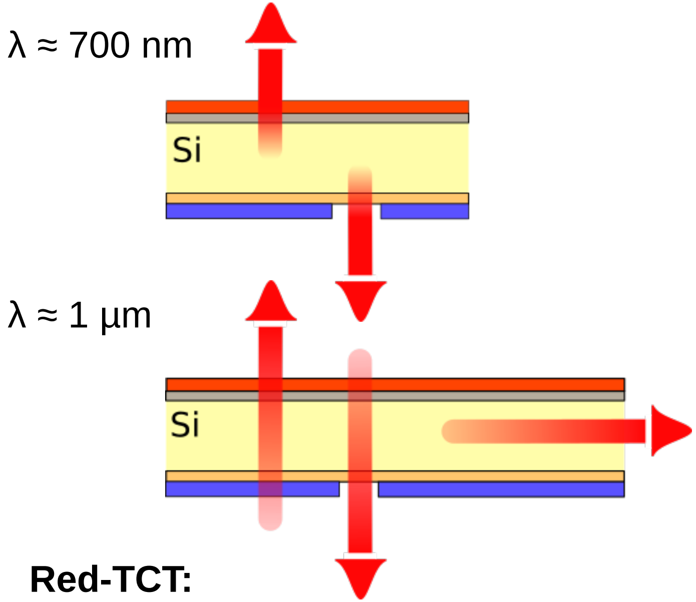


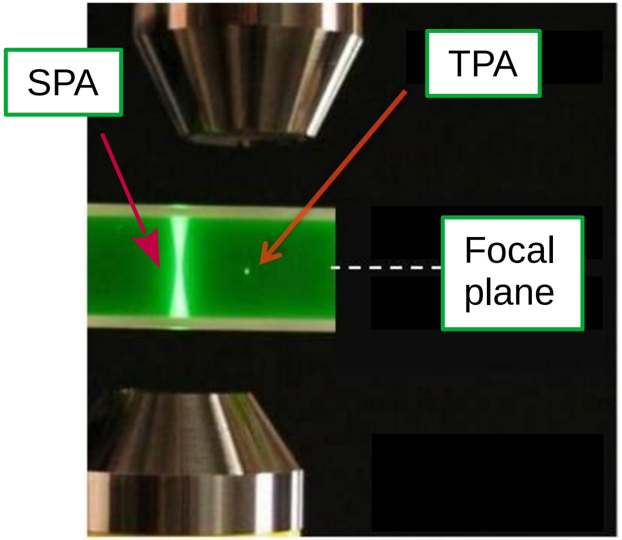
- **TPA** excites charge carriers into the CB
- Non-linear effect, strongly depends on intensity
- Coincidence in time and space needed

⟶ only excitation around focal point

- **3D resolution** tool to scan silicon devices

Single Photon Absorption-TCT





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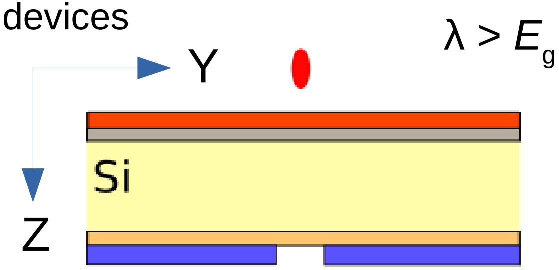
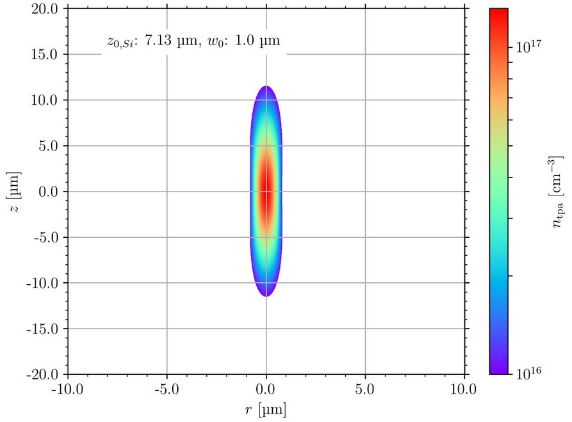
Two Photon Absorption-TCT

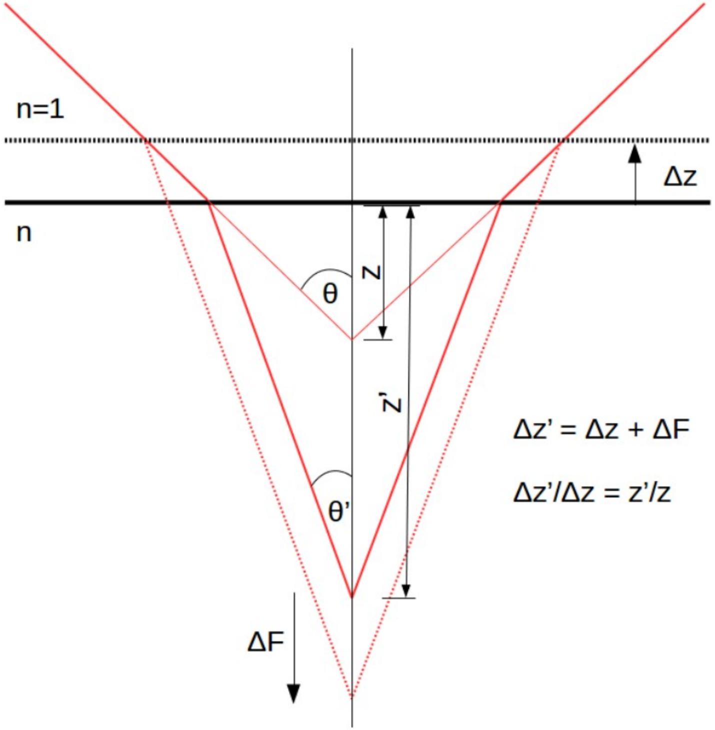
- **3D resolution** tool to scan silicon devices



TPA excited **charge carrier density** in silicon:



Refraction in silicon



Δz' = Δz + ΔF

Δz'/Δz = z'/z

Moritz 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, VOL. 68, NO. 2

Beam moves different in Si than in Air, due to refraction!

$n_{Si} = 3.4757$

Conversion of movement in air to movement in silicon depends on the focusing:

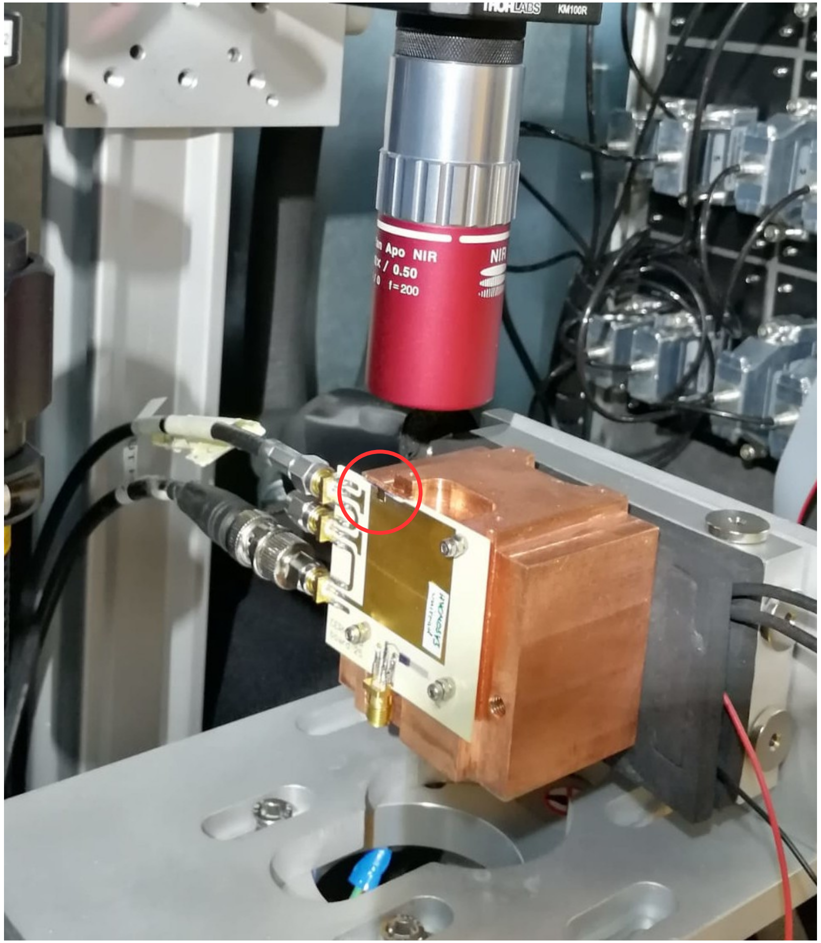
$$z' = z\sqrt{\frac{n^2 - NA^2}{1 - NA^2}}$$

$$z' = z\sqrt{\frac{z_0 \pi n^3}{z_0 \pi n - \lambda n^2 + \lambda}}$$

Measured: NA = 0.5 → z'/z = 3.754
NA = 0.7 → z'/z = 4.12

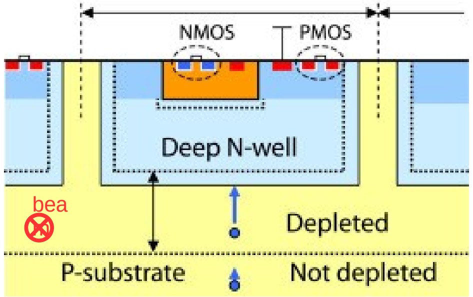
HV-CMOS

Edge TPA-TCT configuration



Finding the device and the active volume under the objective is challenging.

The active volume has a size of approx. 120 × 25 µm and is buried 50µm deep under the surface (in the direction of the beam).



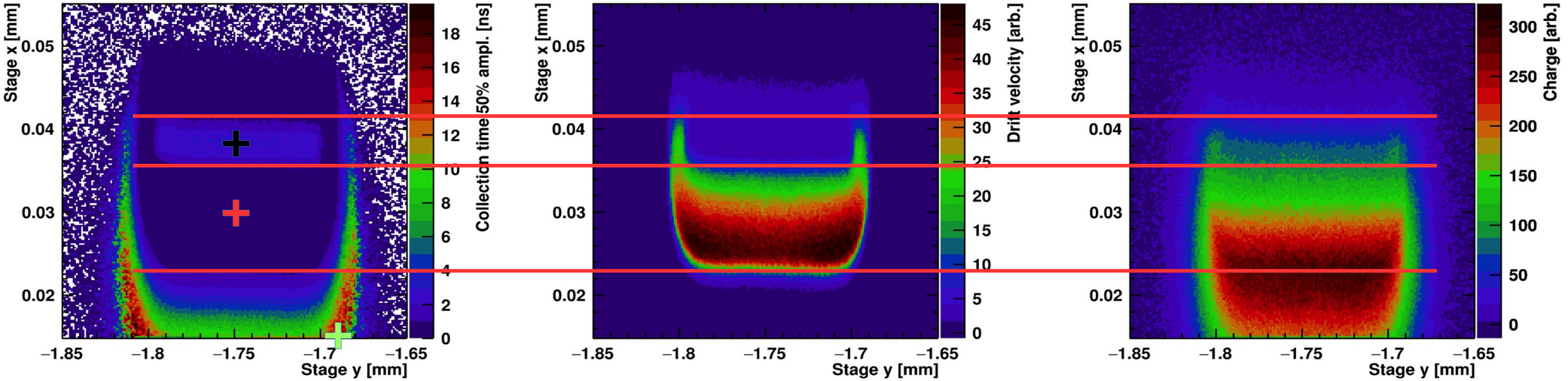
https://doi.org/10.1016/j.nima.2016.06.001

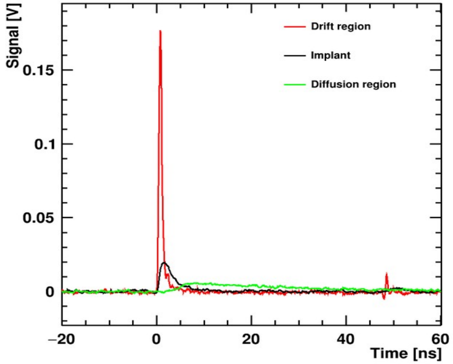
HV-CMOS

Three signal regions are identified.
Implant, low amplitude, slower signals
Drift region, high amplitude, fast signals
Diffusion region, very long signals, charge carriers diffuse into depleted region

charge integration time 25ns

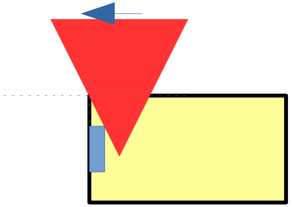
drift velocity integrated 600ps
same distribution for lower
integration times (100-600ps)

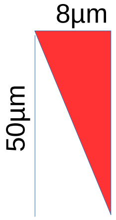




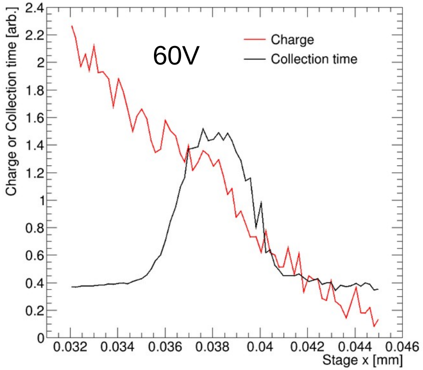
DNW can not be identified in collected charge.

Focal point is ~50µm below the surface.
Gradient of collected charge (and drift velocity)
likely due to clipped beam.





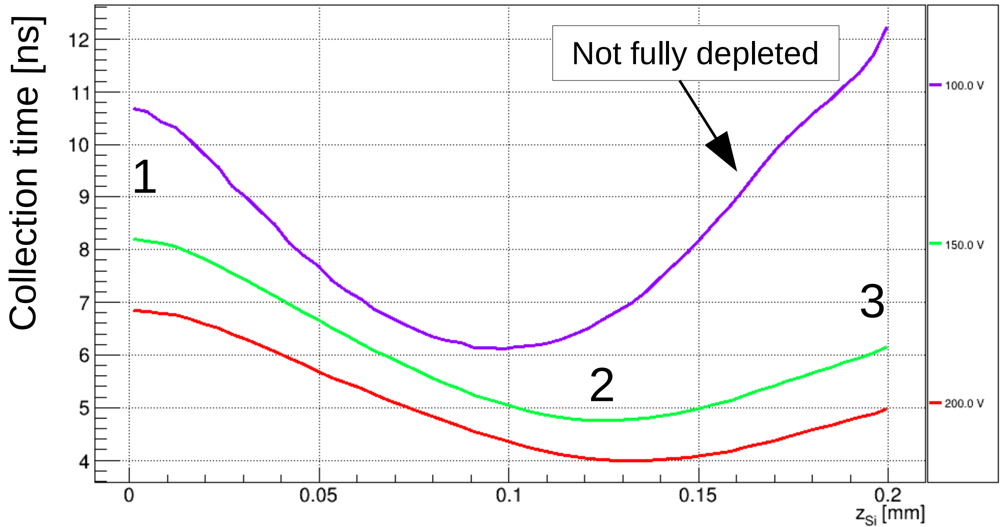
NA=n·sin(θ)



FZ200: collection time

Top TPA-TCT, NA0.5, ~23°C, TC

Zoom-in -0.05 to 0.2 mm z_{Si} region:

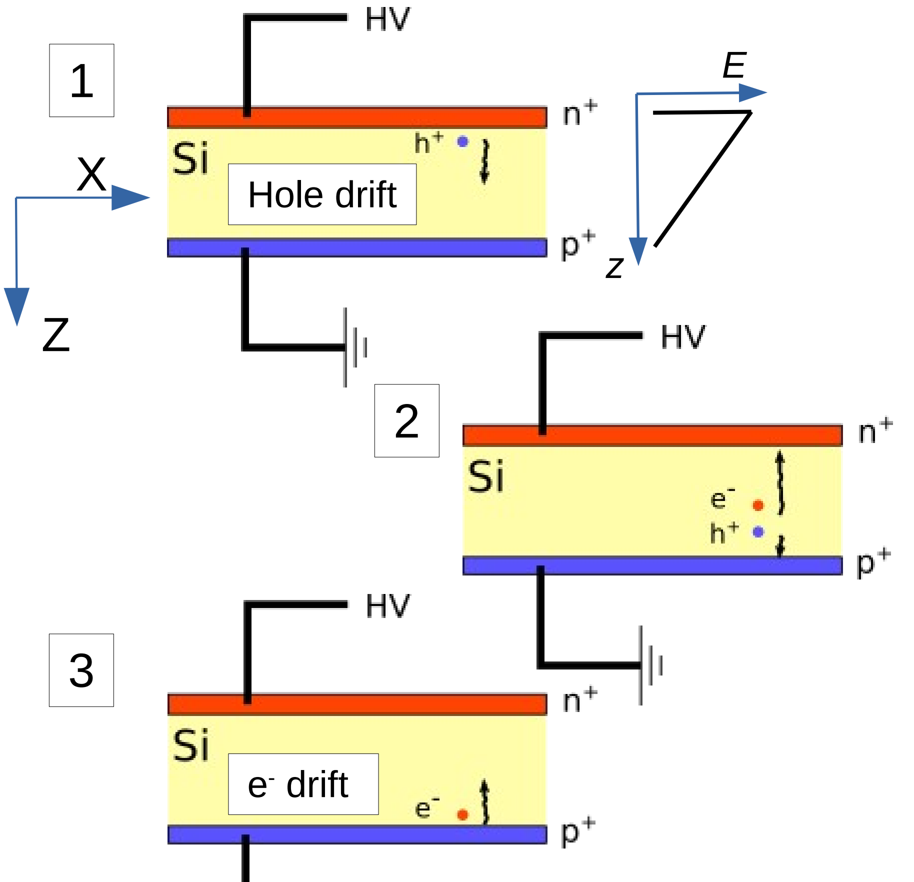


Top side

Back side

DUT:

- HPK deep diffused campaign
- 200µm FZ, p-type
- **unirradiated**
- Deep diffused wafer

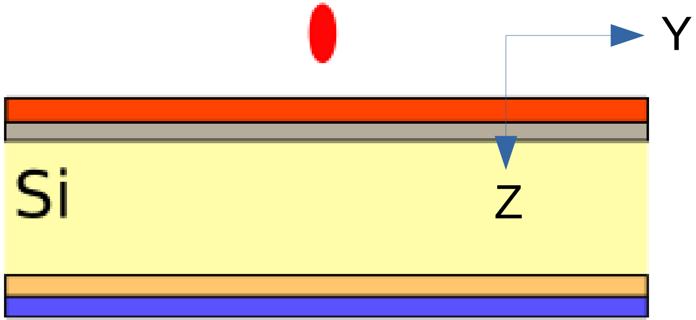


- Transition into undepleted region visible

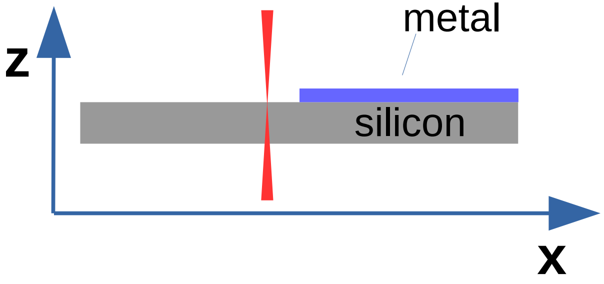
Reflection in TPA-TCT

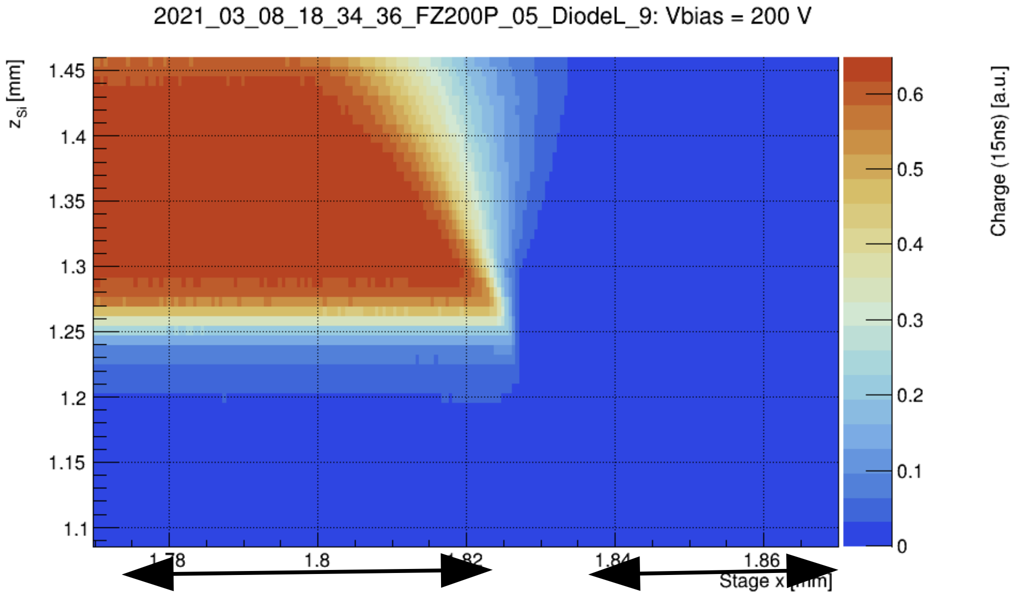
- Occurs when the focal point crosses a boundary layer with different refractive indices
- $R_0 = \left| \frac{n_1 - n_2}{n_1 + n_2} \right|^2,$ $T_0 = 1 - R_0$
  - ➔ For silicon-air $R_0 \approx 0.3$ ($n_{Si} \approx 3.48$)
  - ➔ Due to $Q \sim I^2$ the reflection signal is ≈10% of the original signal
- Multiple reflections possible

Schematic animation of reflections in a DUT
(initial reflection on top surface not considered)



Knife edge scan



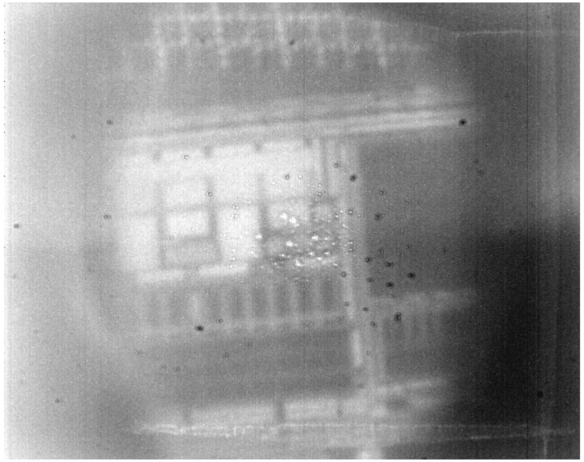


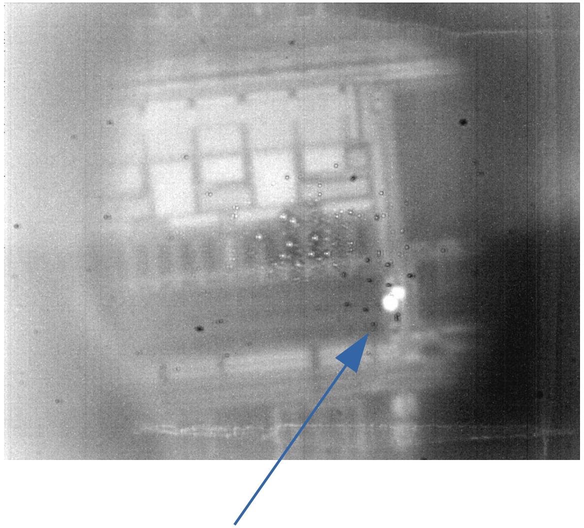
1. no metal
fit z-scans
→ obtain z0

2. metal: knife-edge
fit x-scans
→ obtain w(z)

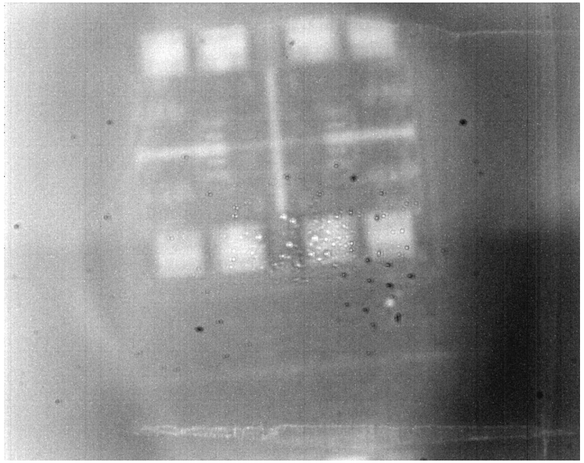
Backside imaging of RD53 chip

Chip fixed to dummy PCB, backside illuminated (λ = 1.550 µm) through the ×100 objective and imaged using an IR camera





TPA beam spot (for comparison)



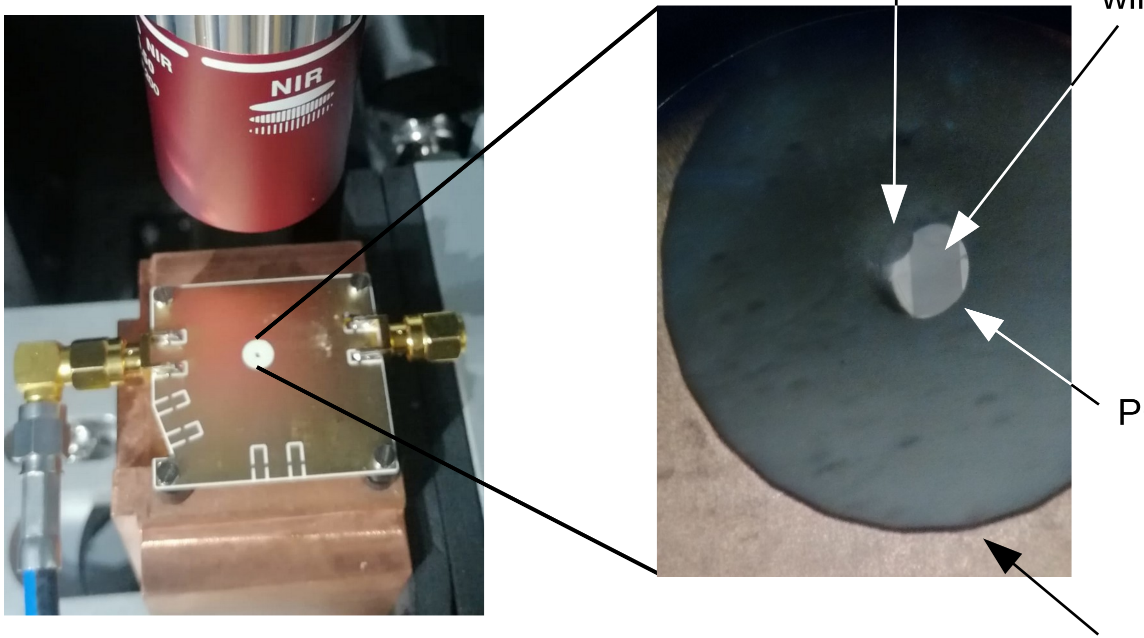
Analog island

TPA-TCT could be used to study SEE

Clipping study

- Unirradiated 50 µm thick *p*-type PIN

Back side mounted:



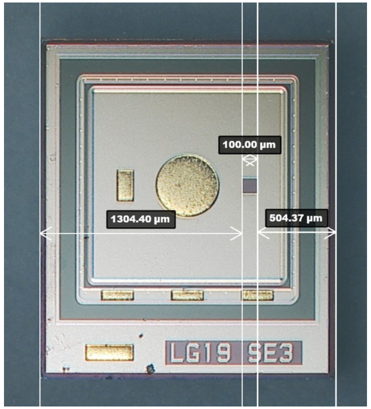
Glue

DUT’s opening window

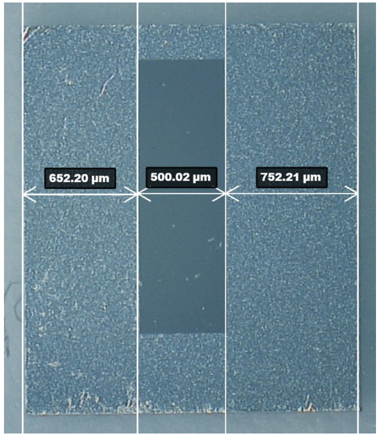
PCB opening

PCB metallization

DUT’s top side:

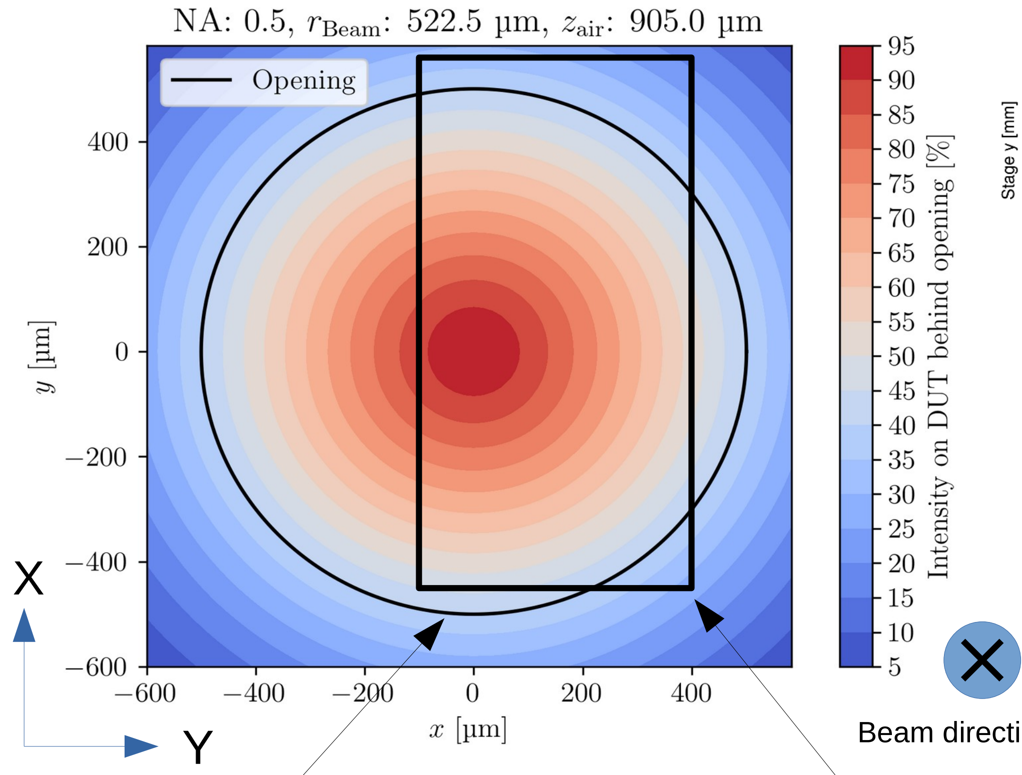


DUT’s back side:

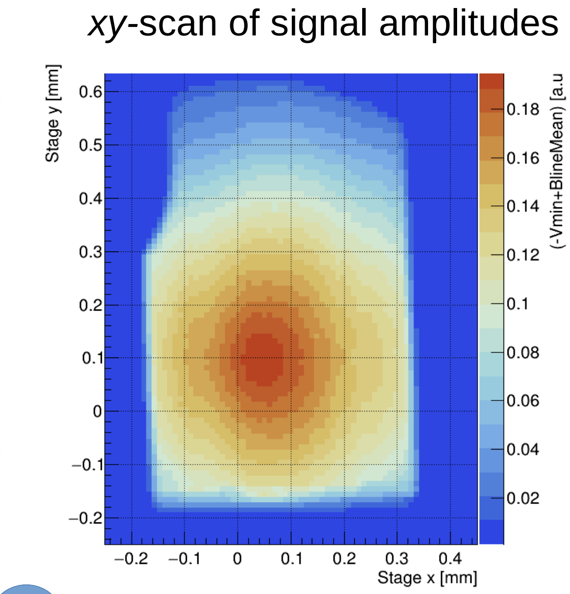


Simulated clipping (just considering geometrical effects)

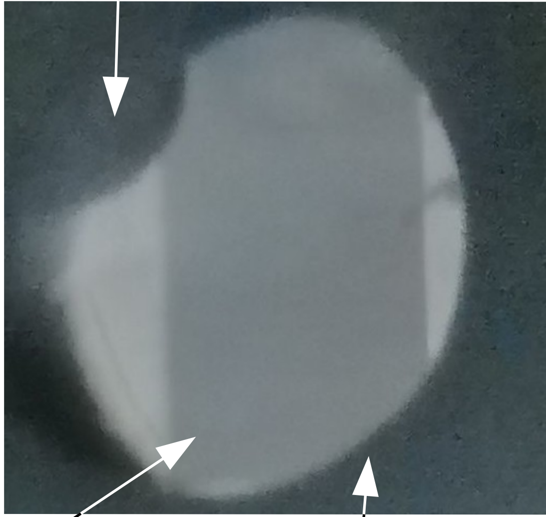
z_{air} = 905µm ≈ PCB thickness (850µm) + inside detector (55µm)



Beam direction



Glue



PCB opening

Back side opening of the DUT

PCB opening

Inhomogeneities in the *xy*-scan are most likely due to clipping at the PCB opening.

Clipping in TPA-TCT

- Clipping is an well understood **geometrical effect**
- Can be the reason for inhomogenities in the measured intensity across a DUT
- Limits maximum depth (along beam) in edge-TPA
- Only a problem if a homogeneous laser intensity is important (e.g. collected charge)
  - ➔ Other quantities are not influenced (e.g. collection time)