3D imaging of an HVCMOS using Two Photon Absorption-TCT

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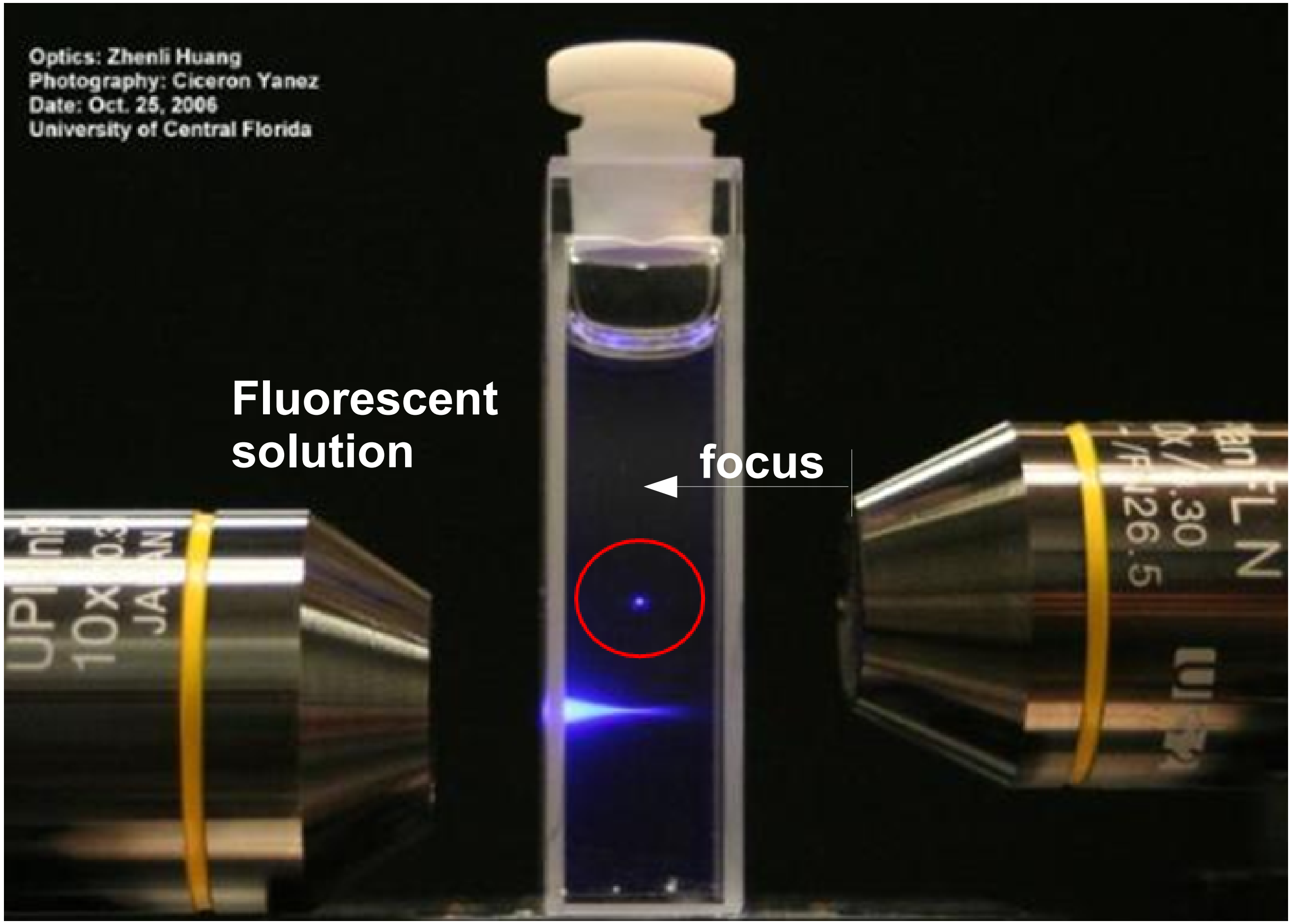
Two Photon Absorption



SPA

Single Photon Absorption

Continuous energy deposition

TPA

Two Photon Absorption

Energy confinement

Outline

→ Two Photon Absorption

→ Application to depleted MAPS (HVCMOSv3) characterization

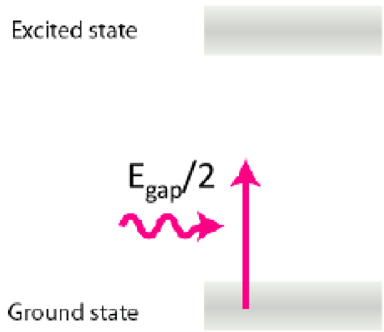
→ Preliminary: Irradiated (7×10^{15} n_{eq}/cm^2) detector

TPA-TCT is a characterization technique developed within the **RD50 collaboration**

Two photon absorption basics (I)

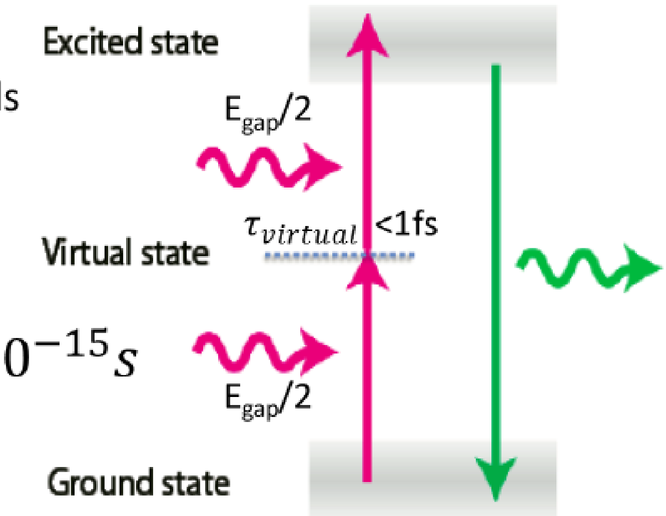
iFCA Instituto de Física de Cantabria

Conventionally, no excitation if $E_{photon}<E_{gap}$ ~1eV

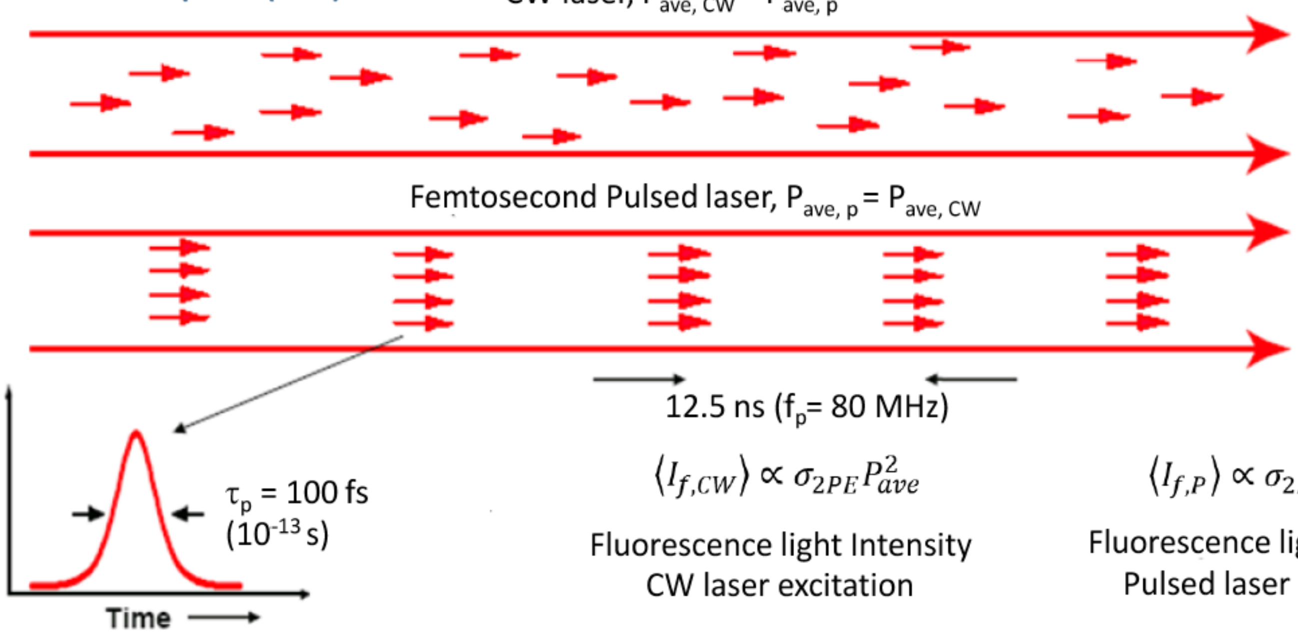


But if TWO photons arrives in ~ 100 attoseconds

$$\tau_{virtual} \sim \frac{\hbar}{E_{gap}/2} \sim 0.1x10^{-15}s$$



Photon Absorption (TPA)



$$\langle I_{f,CW} \rangle \propto \sigma_{2PE} P_{ave}^2$$

Fluorescence light Intensity CW laser excitation

$$\langle I_{f,P} \rangle \propto \sigma_{2PE} \frac{P_{ave}^2}{\tau_P\, f_p}$$

Fluorescence light Intensity Pulsed laser excitation

The probability of a two photon absorption is increased by $(1/t_p f_p)=10^5$ for the same average power by using a <u>mode-locked pulsed laser</u>

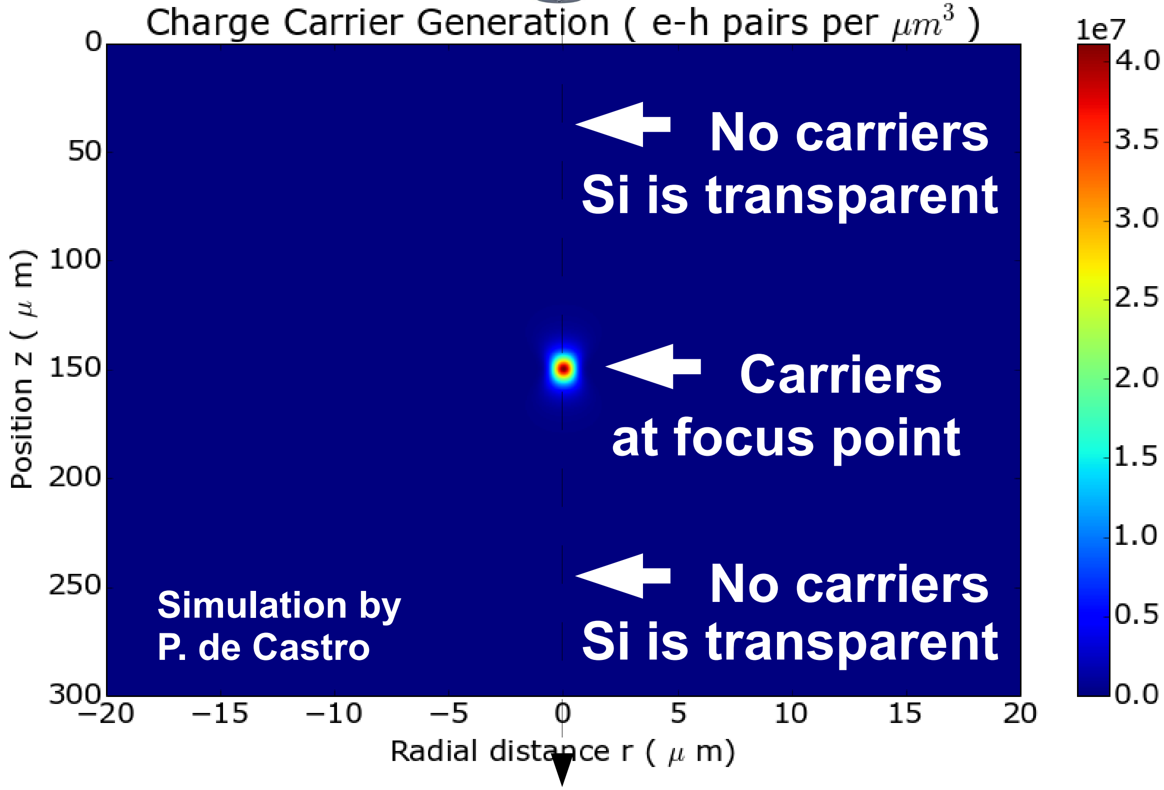
TPA basics (II)

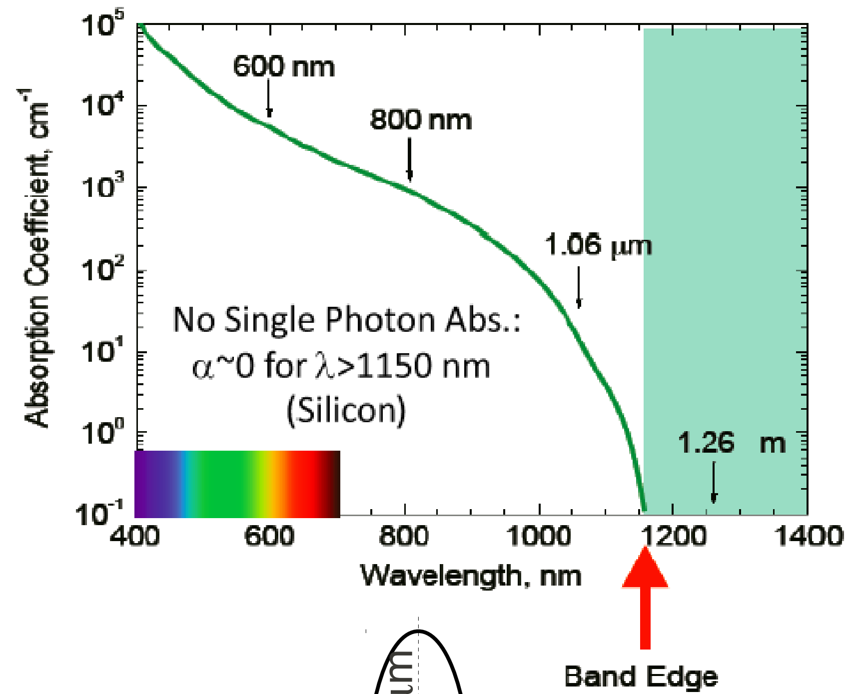
Carrier generation: $$\frac{dN(r,z)}{dt} = \alpha\frac{I(r,z)}{\hbar\omega} + \frac{\beta_2 I^2(r,z)}{2\hbar\omega}$$

SPA *TPA*

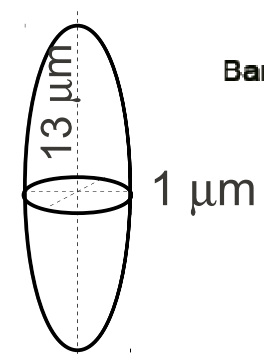
TPA$\propto$I^2 : Significant carrier generation occurs only at **high intensity focal region**

λ=1300 nm (0.95 eV)





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



TPA laser facility

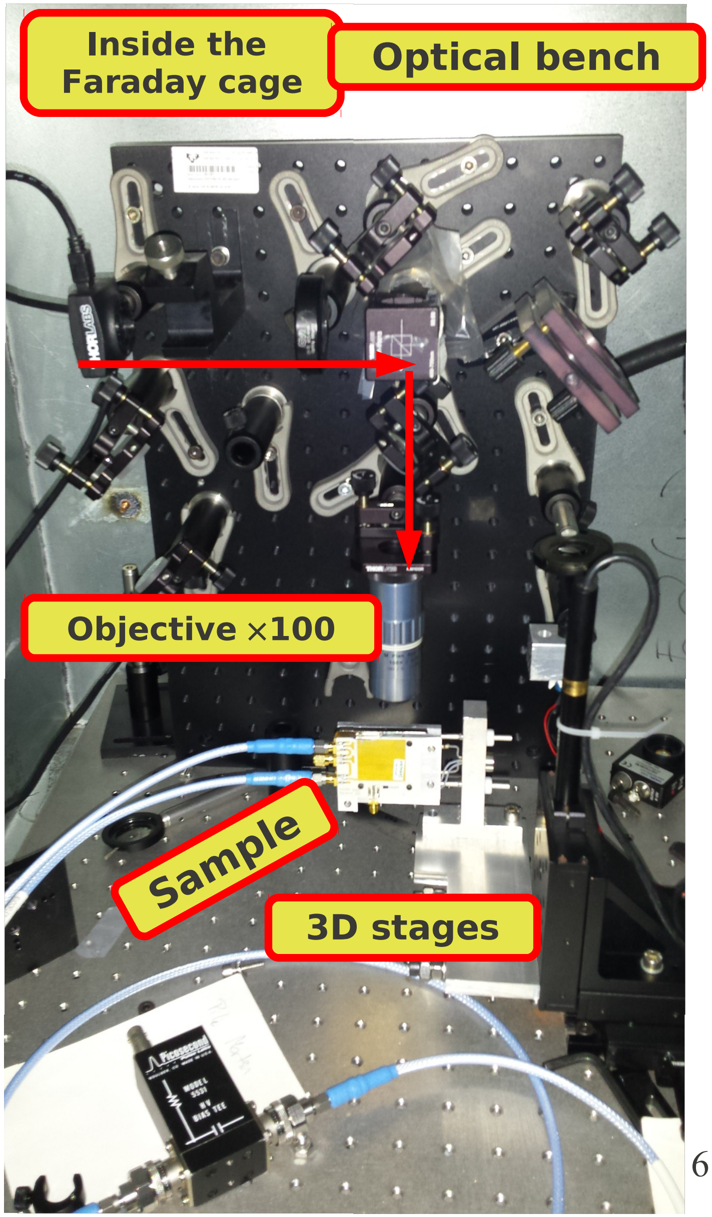
➜ Measurements conducted at the Singular Laser Facility of the UPV (Bilbao, Spain).

http://www.ehu.es/SGIker/es/laser/

➜ Very flexible and tunable laser system (intensity, λ, pulse duration...)

➜ Access granted via RD50 collaboration.

➜ See backup for full specs

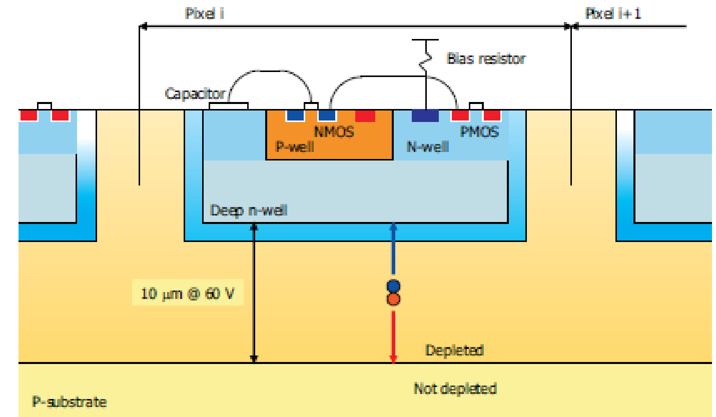


In this study:
λ=1300 nm, 12 nm bandwidth, Δt=240 fs

Introduction to HVCMOS

- HVCMOS sensors are partially depleted MAPS implemented in **low resistivity** CMOS technology, able to withstand voltages **up to 100 V**.

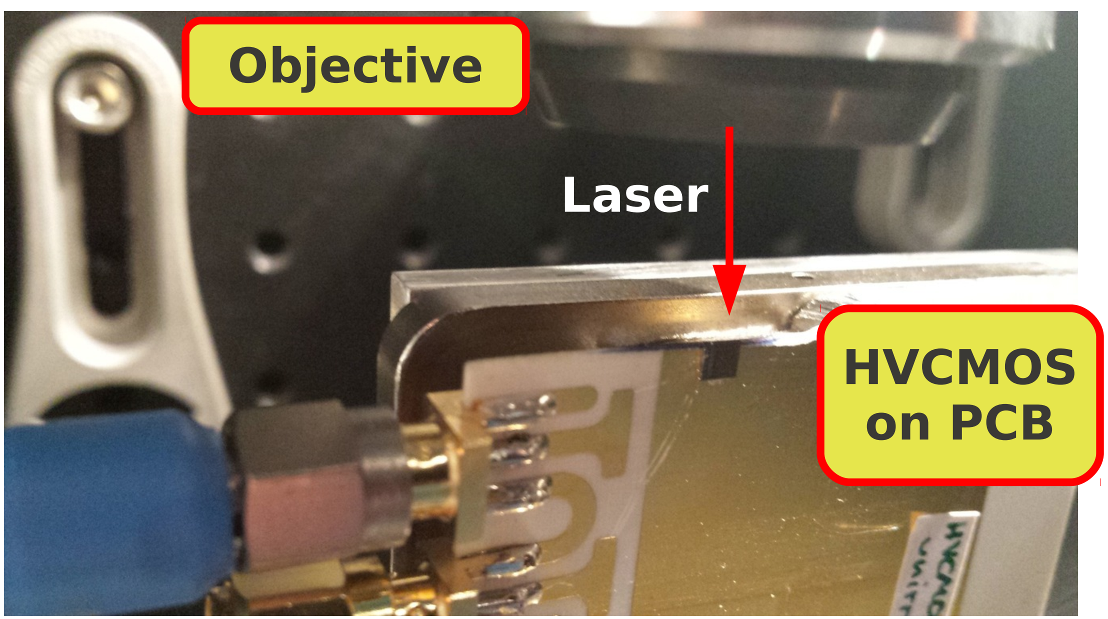
- The deep n-well (DNW) is both the substrate for shallow transistors and the collecting diode.

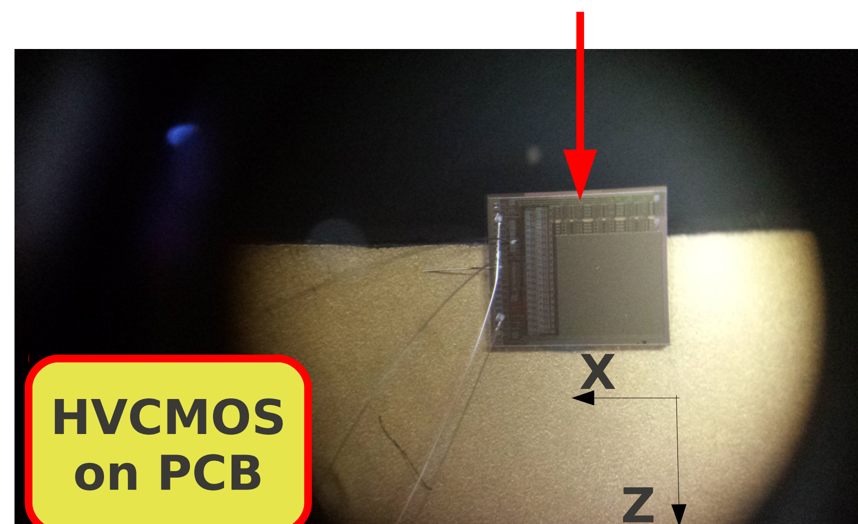


I. Peric doi:10.1088/1748-0221/7/08/c08002

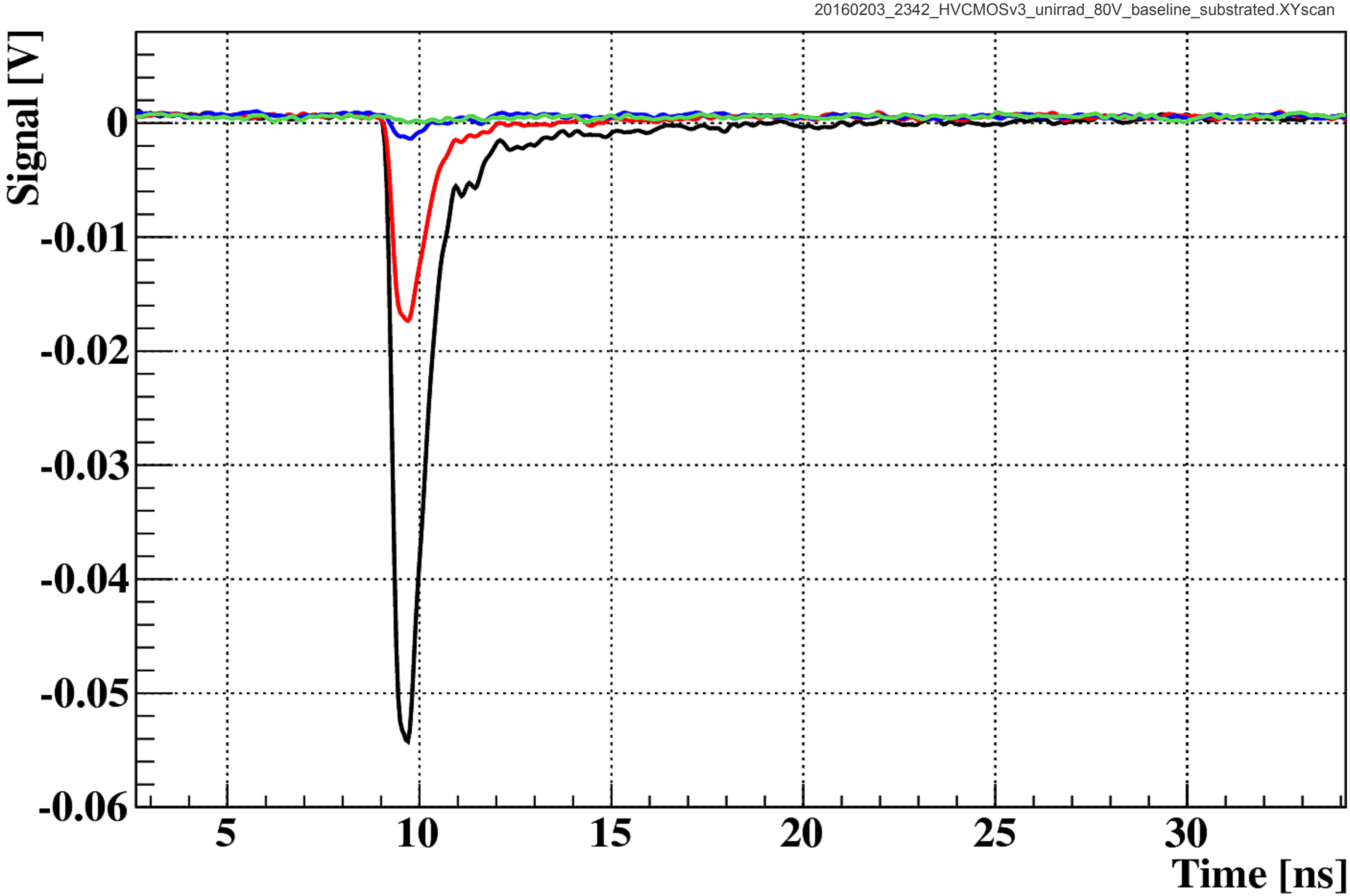
- Due to the low resistivity and maximum voltage granted by the technology, the maximum depletion depth is of the order of 10 µm ← **Tough for SPA methods**

- For this experiment, laser illumination from the **edge of the detector.**



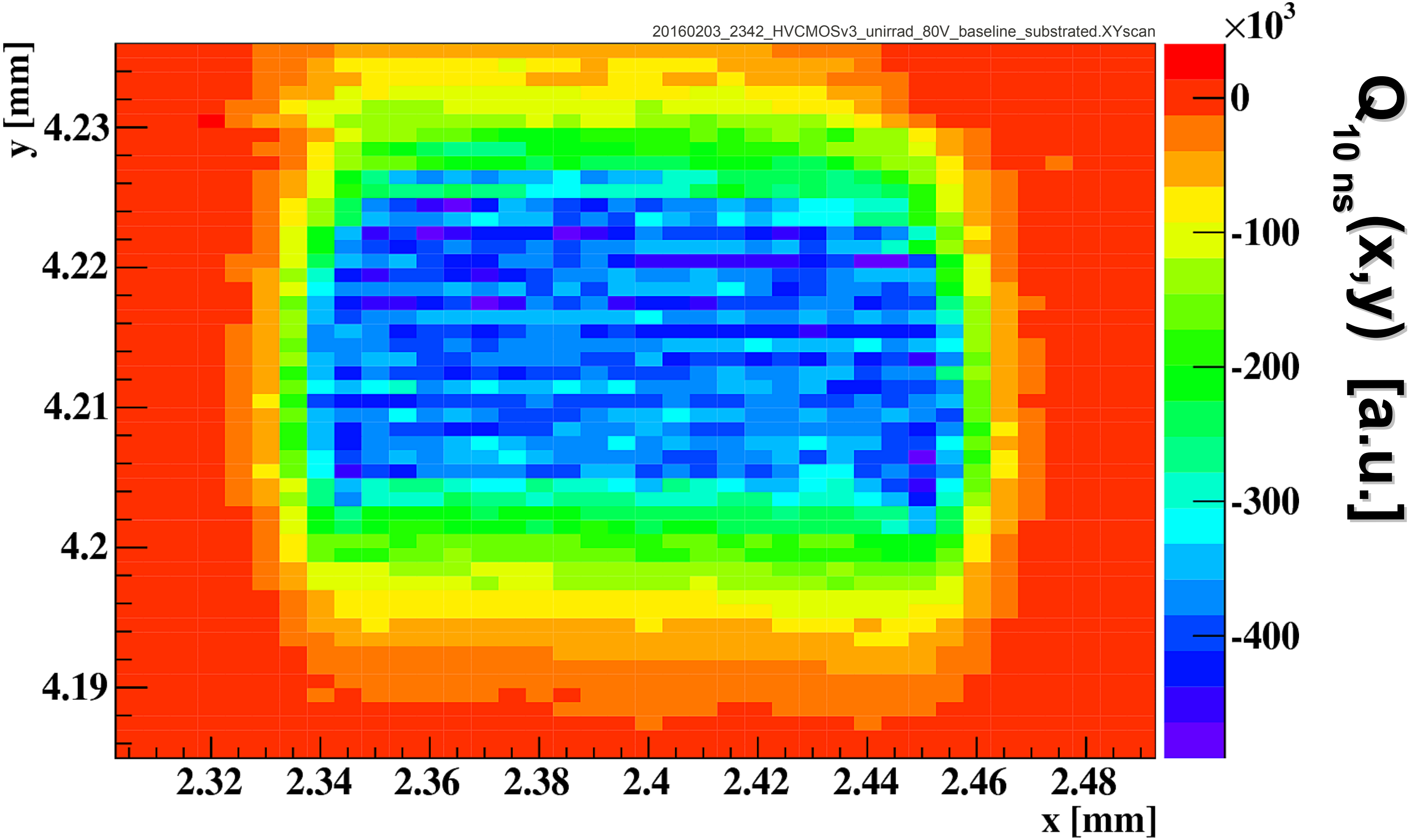


TPA-TCT: Subset of waveforms during edge scan



Few induced transient currents

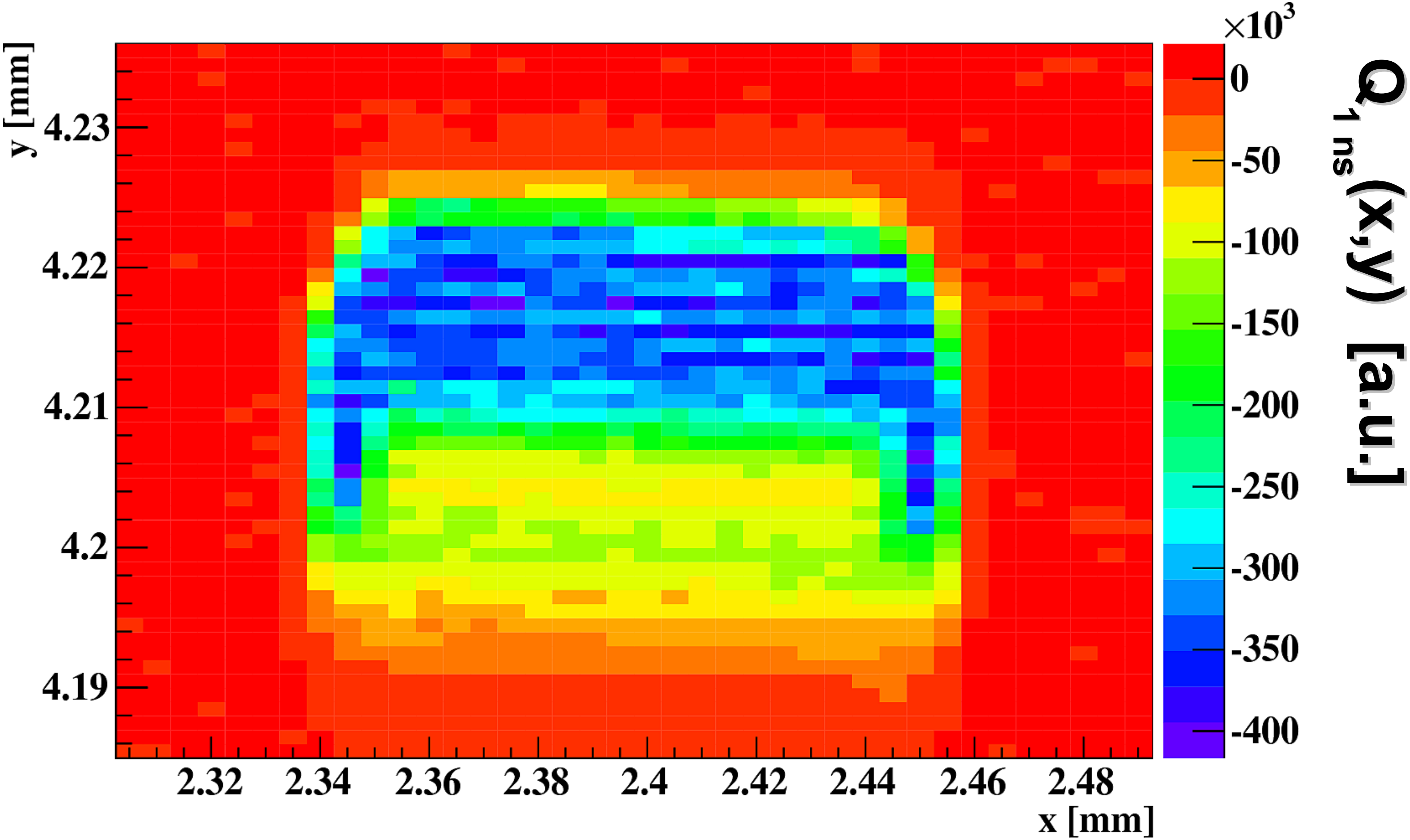
TPA-TCT: Charge in 10 ns, -80 V, unirradiated HVCMOSv3



FWHM=120 × 25 μm²

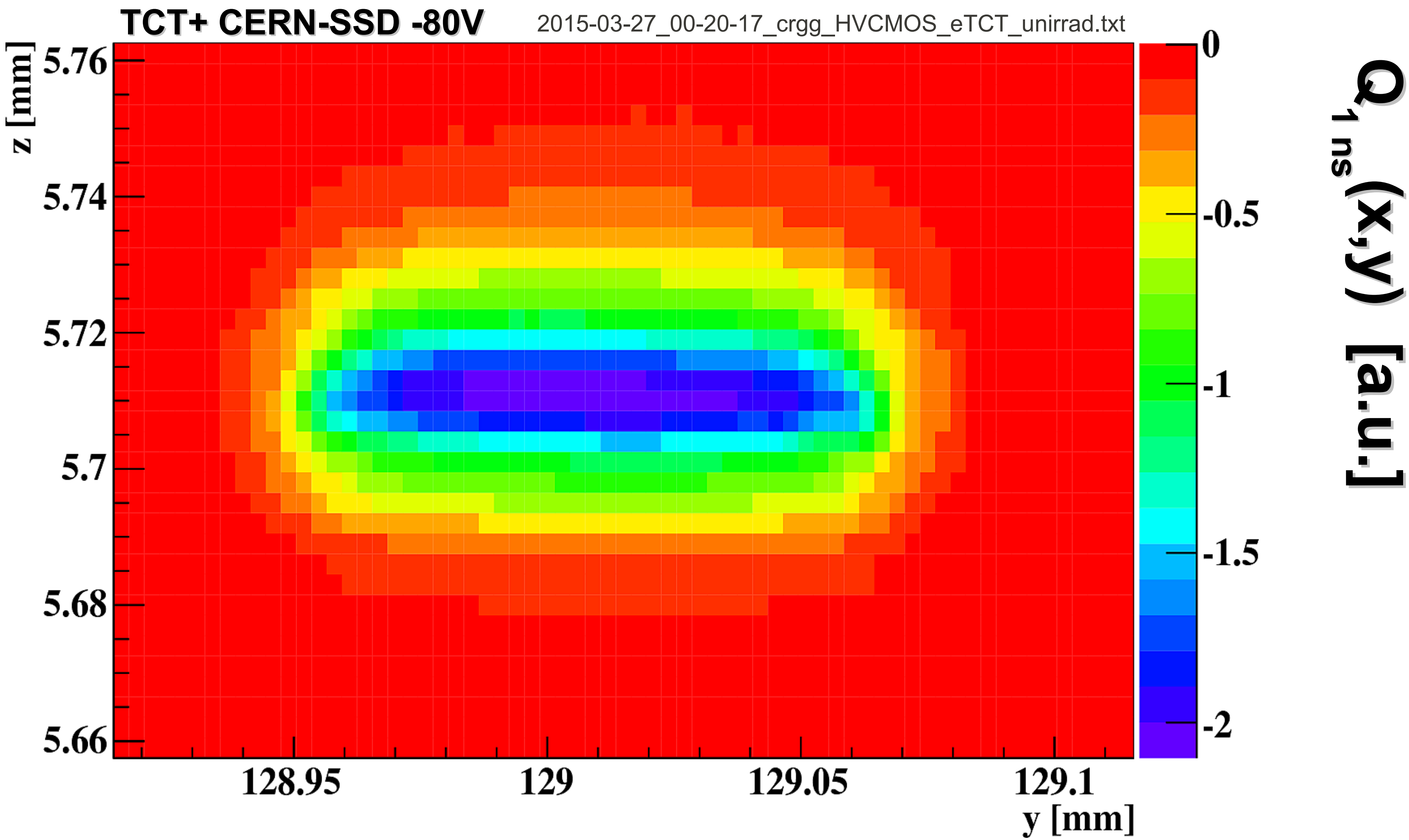
Meas. width>>expected (10 μm)

TPA-TCT: Charge in 1 ns, -80 V, unirradiated HVCMOSv3



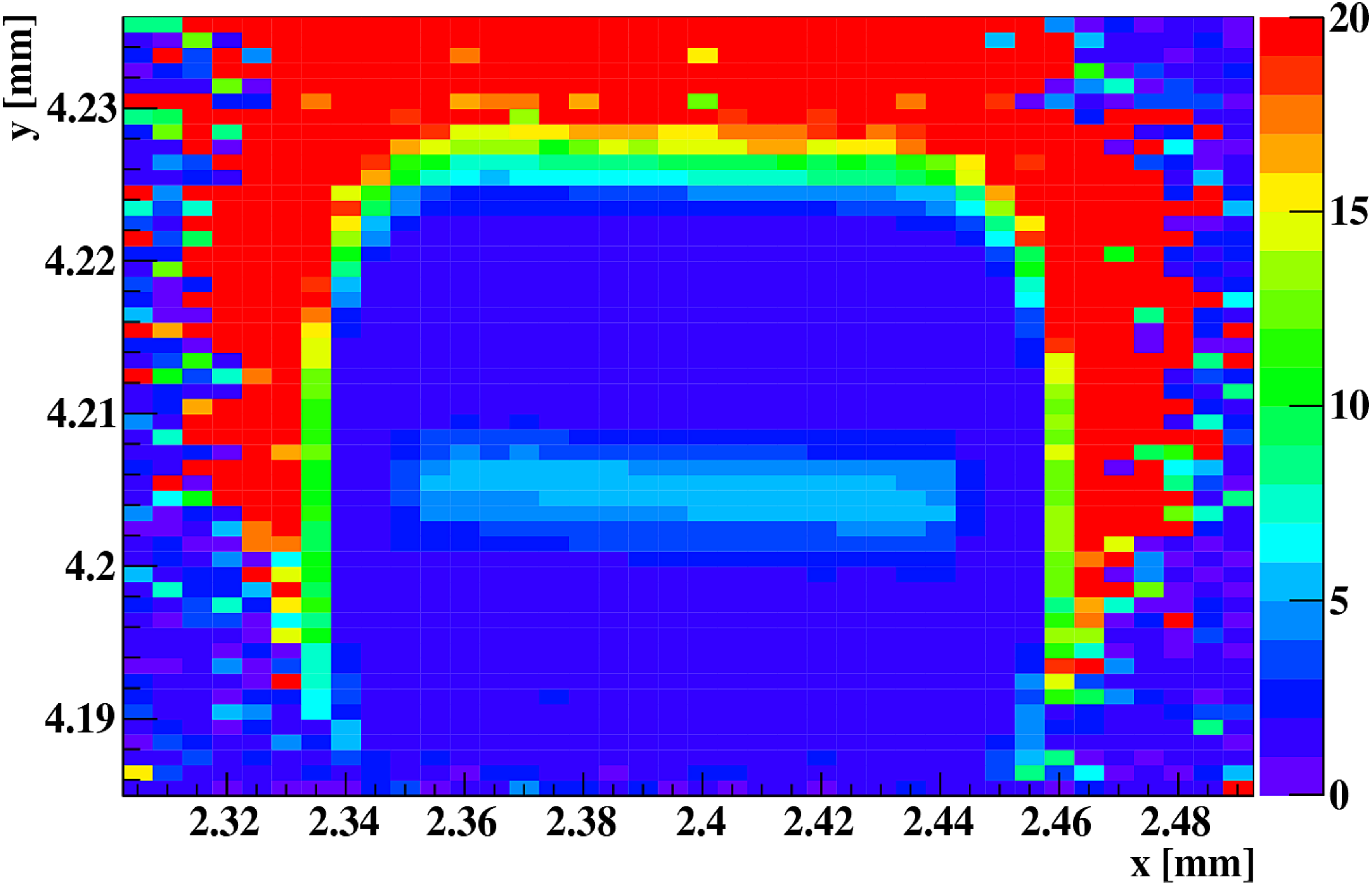
Rectangular structure showing up

SPA-TCT: Charge in 1 ns, -80 V, unirradiated HVCMOSv3



Substructure is not visible with Single Photon TCT

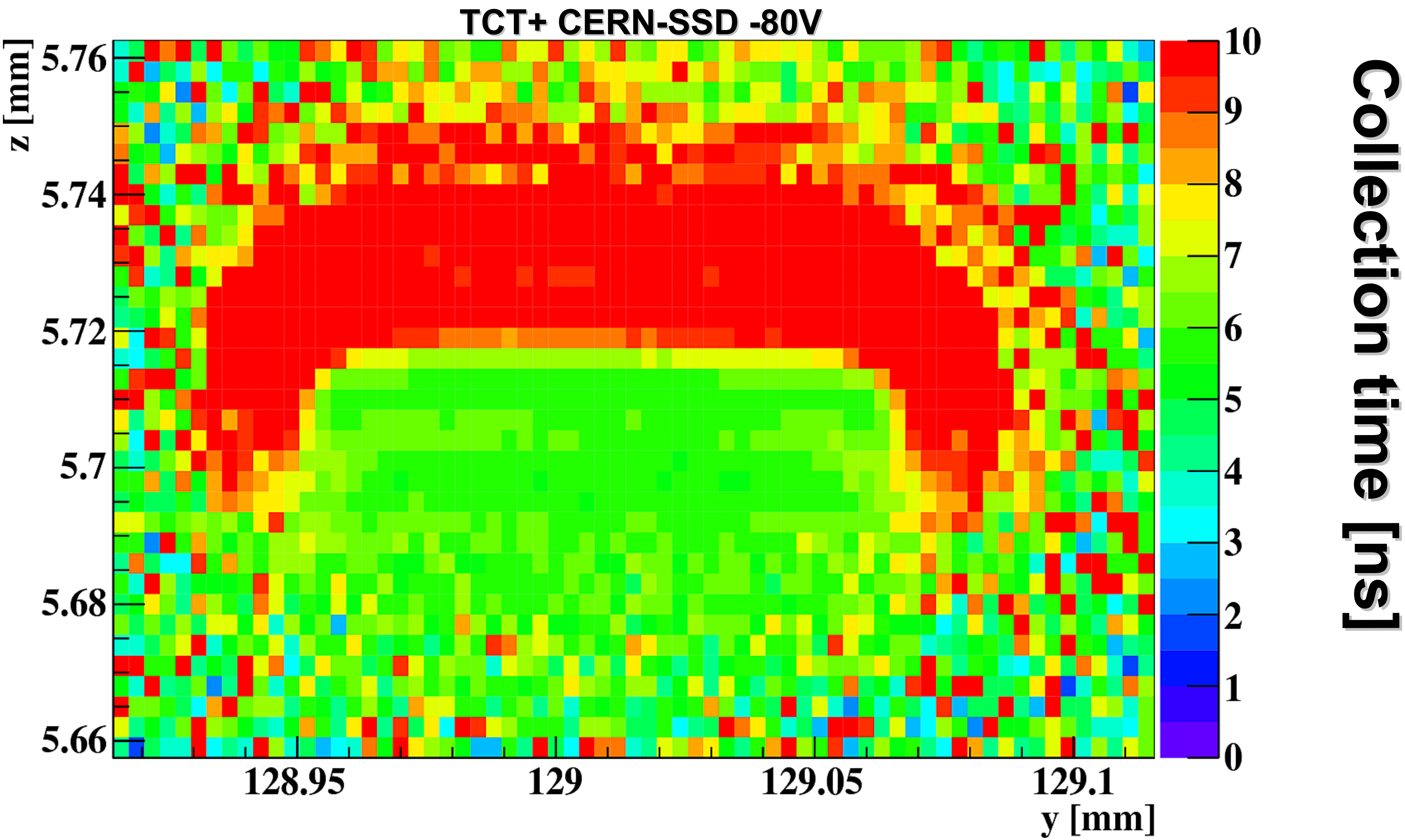
TPA-TCT: Collection time $t_{coll}(x,y)$



Time lapse between the beginning and end of the signal.

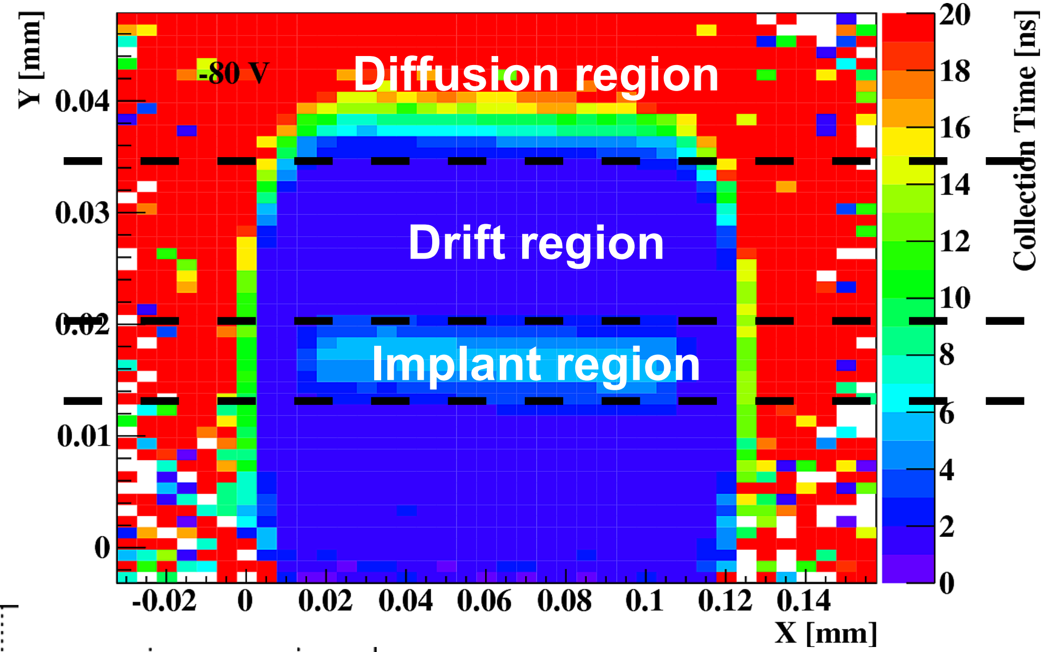
Collection time in this plot limited to 20 ns

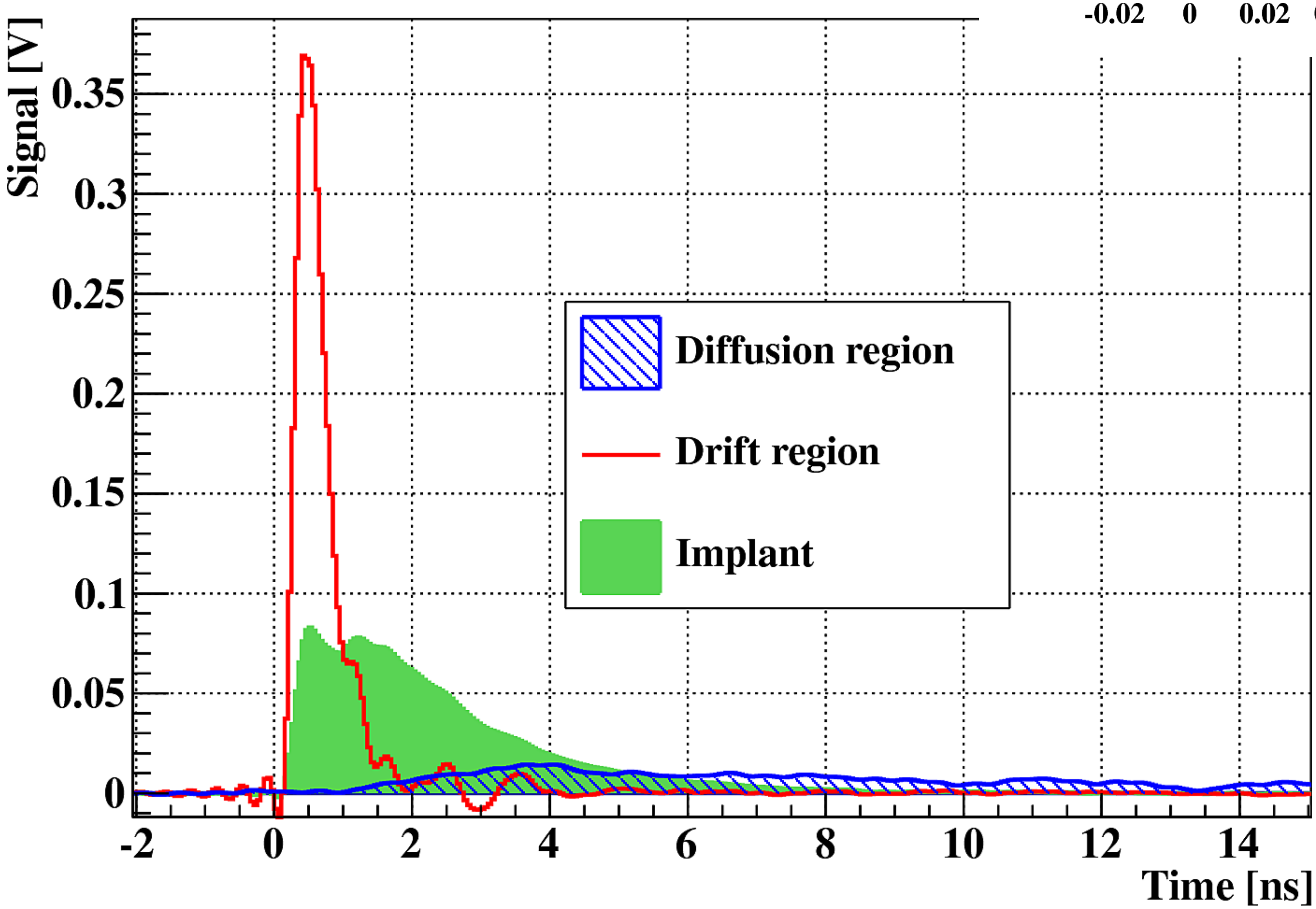
SPA-TCT: Collection time $t_{coll}(x,y)$



SPA-TCT spots a transition between drift and diffusion regions, not the implant

TPA-TCT: Drift/diffusion discrimination





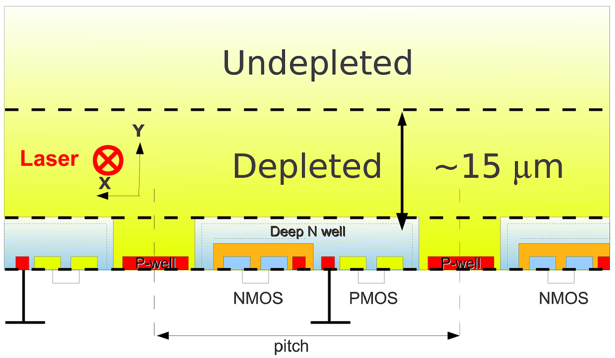
Distinct waveform shape depending on zone of illumination.

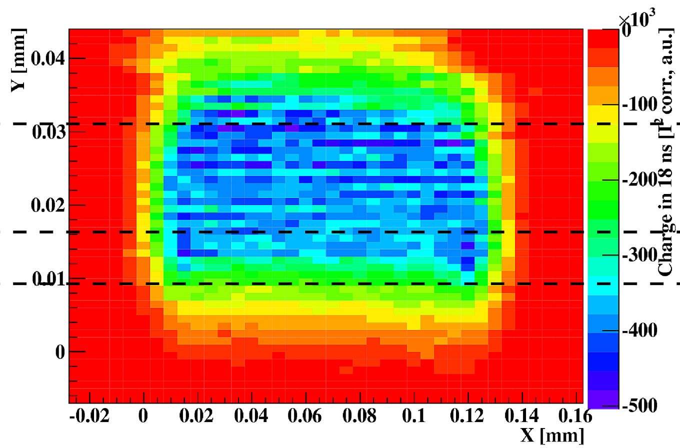
Drift: fast
Diffusion: slow

At the **implant** double peak observed in the waveform and lower E-field.

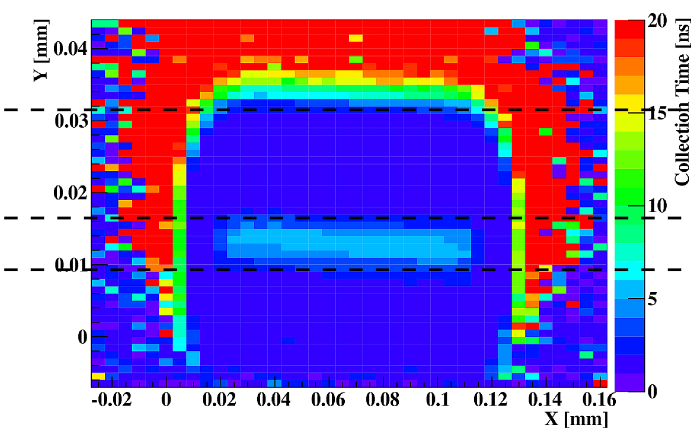
3D scan of HVCMOS detector using TPA-TCT

Laser at 1300 nm, 240 fs, pJ pulse energy
XY scan of sensor edge (Δx=5 μm,Δy=1 μm)





Collected charge map



Collection time map

- Test structure measured: DNW without embedded NMOS or PMOS wells.
- Intended for optical measurements

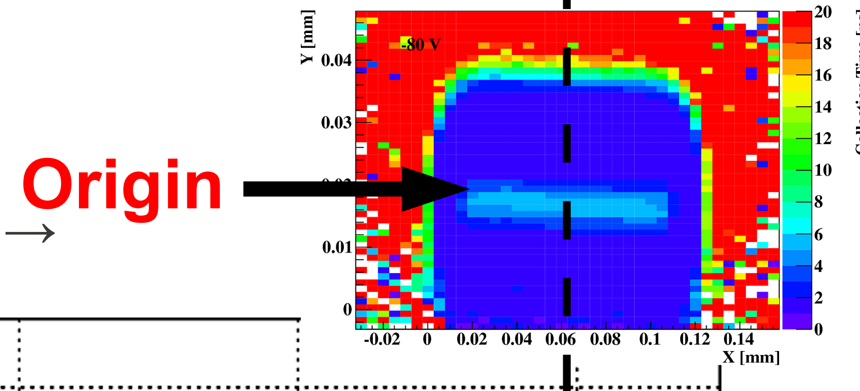
- An structure pops up in the charge collection map, FWHM=120 $\times$ 25 μm^2 Meas. width>>expected (10 μm)

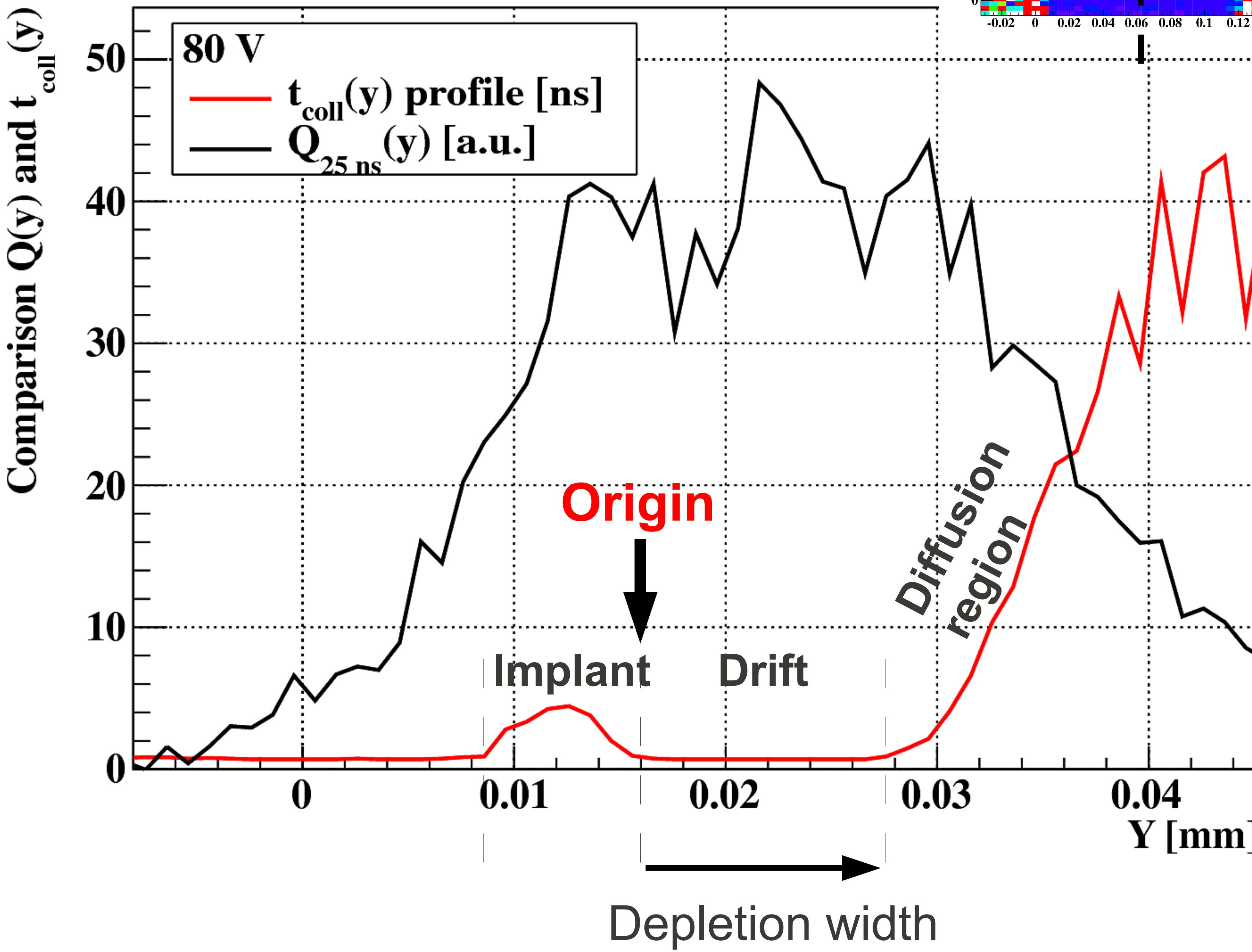
- Time lapse between the beginning and end of the signal.
- Rectangular structure with calculated FWHM 95$\times$7 μm^2 identified as DNW

Identification of the DNW boundaries allows to set a reference for the calculation of depths

Calculation of depletion depth

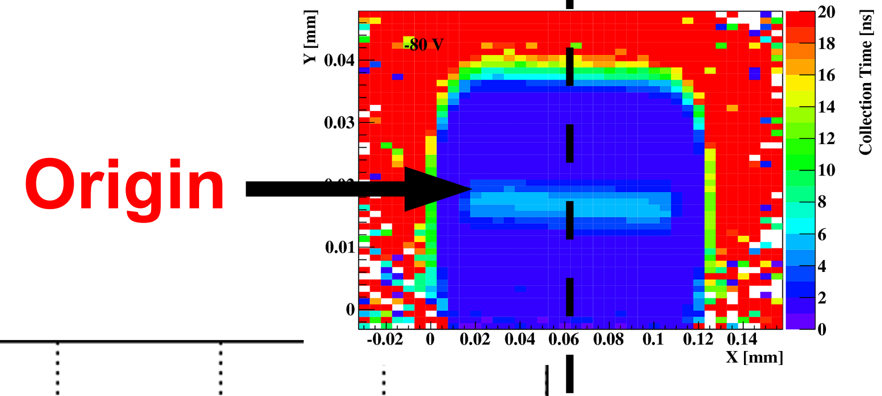
Showing projection along the dashed line →

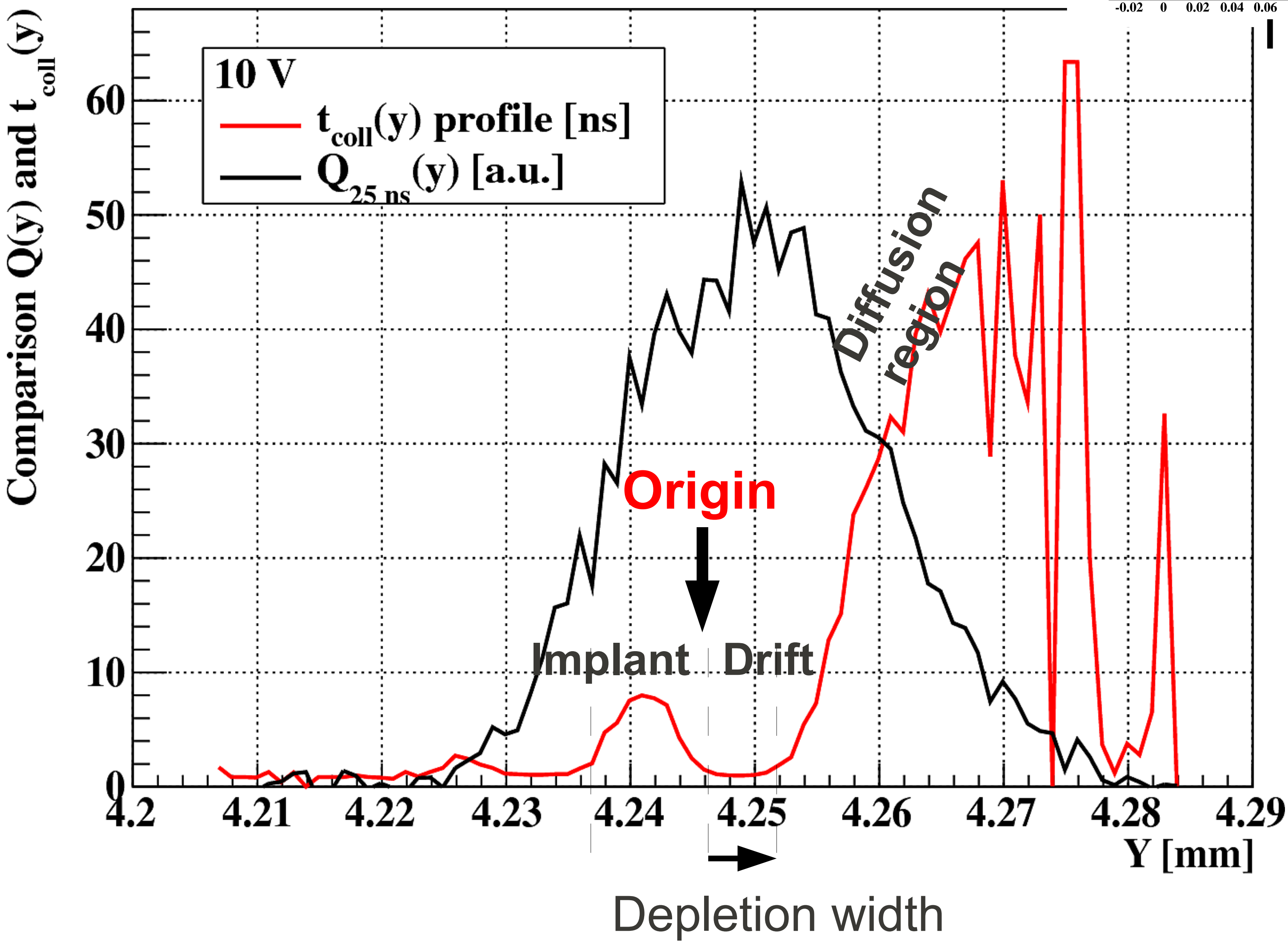




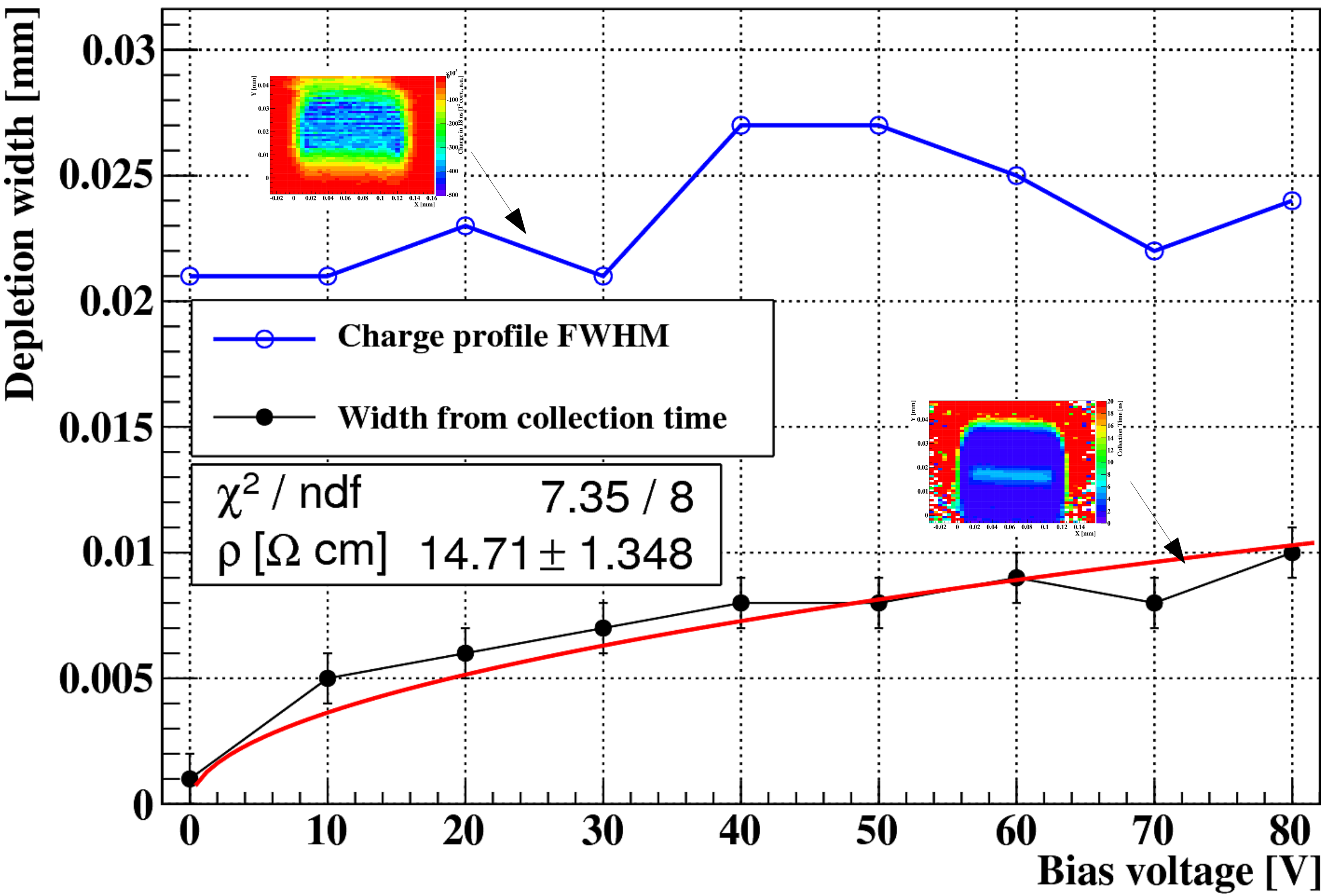
Calculation of depletion depth

Showing projection along the dashed line →





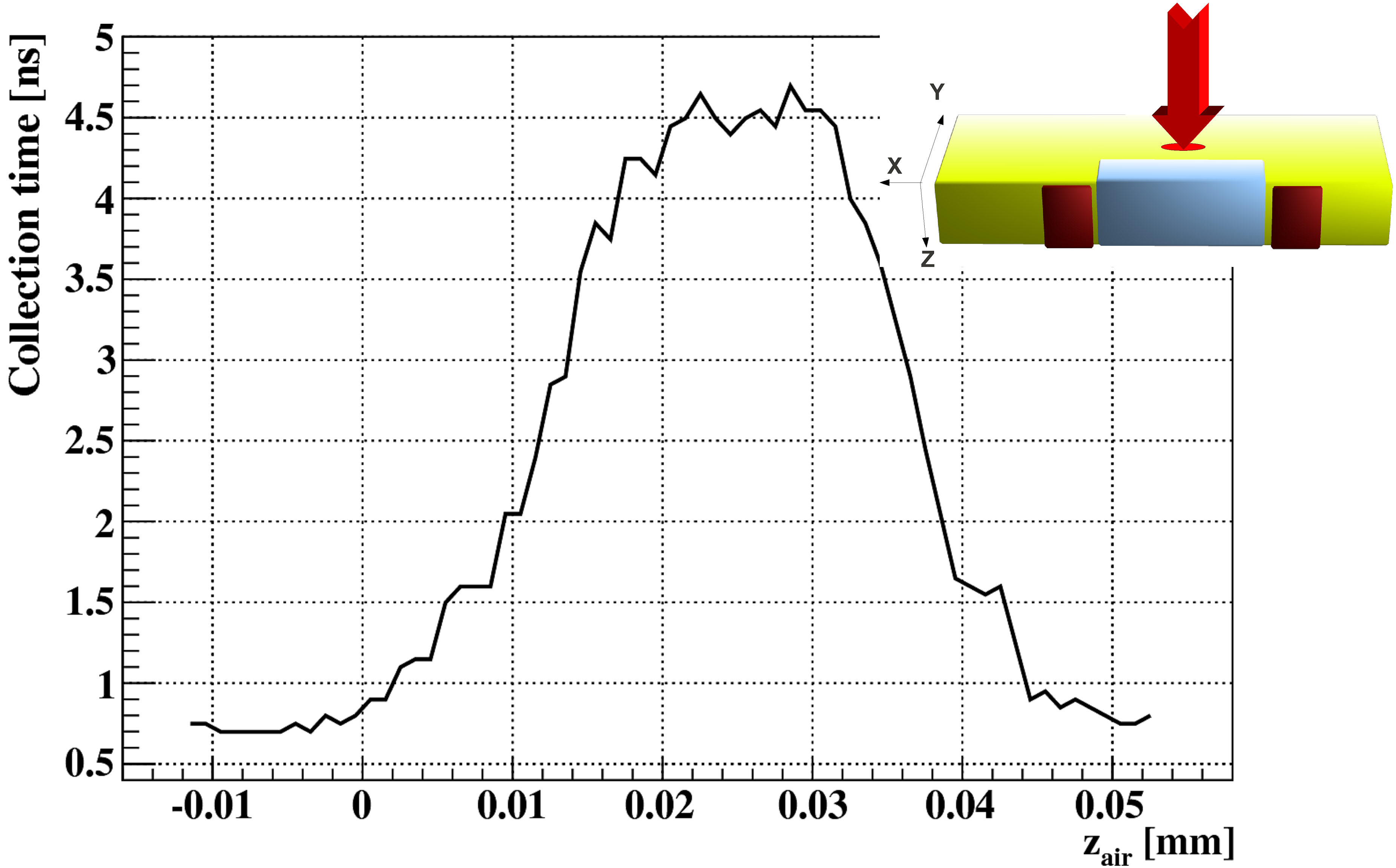
TPA-TCT: depletion width and resistivity



Coincides with expected depletion value

$$w_p[\mu m] = 0.3\sqrt{\rho[\Omega \cdot cm]V}$$ → Calculated resitivity 15 Ω.cm (10 Ω.cm nominal)

TPA-TCT: Implant depth (along Z)



Collection time of signals shows implant depth~100 μm

This measurement is not possible with Single Photon Absorption SPA-TCT

First look at TPA-TCT on $7 \times 10^{15}\ n_{eq}/cm^2$

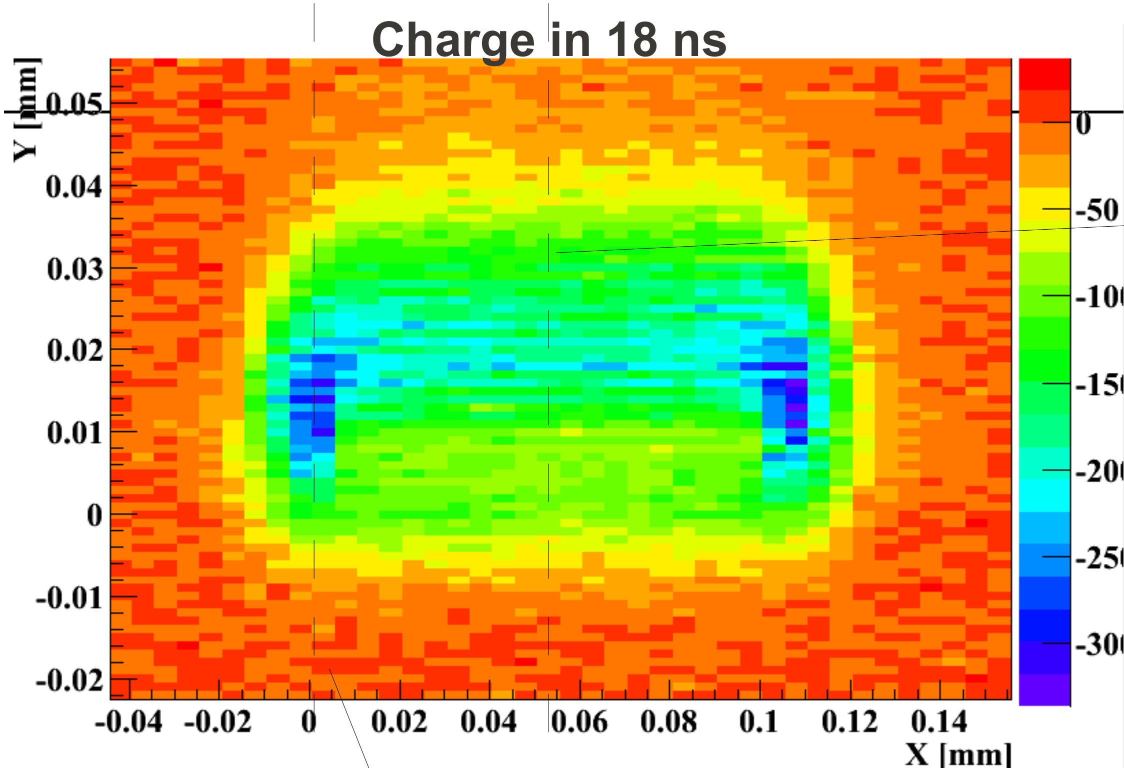
Unfortunately, during the installation of the PCB on the vertical platfrom, I touched the edge of the detector

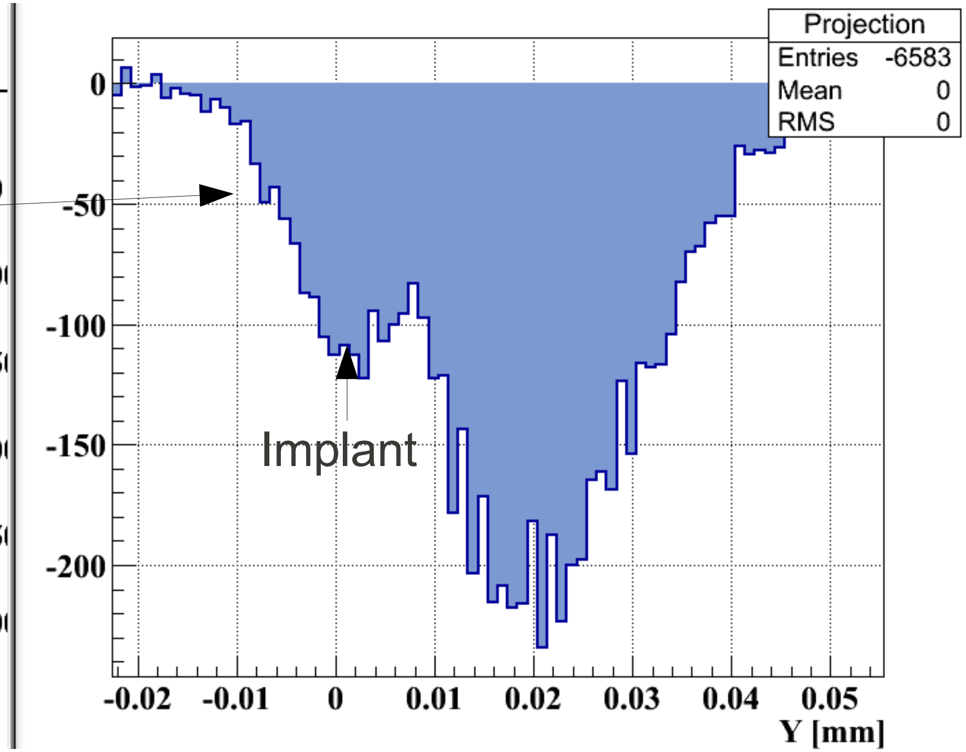
Leakage current increased from 80 μA (70V) to 620 μA (50 V)

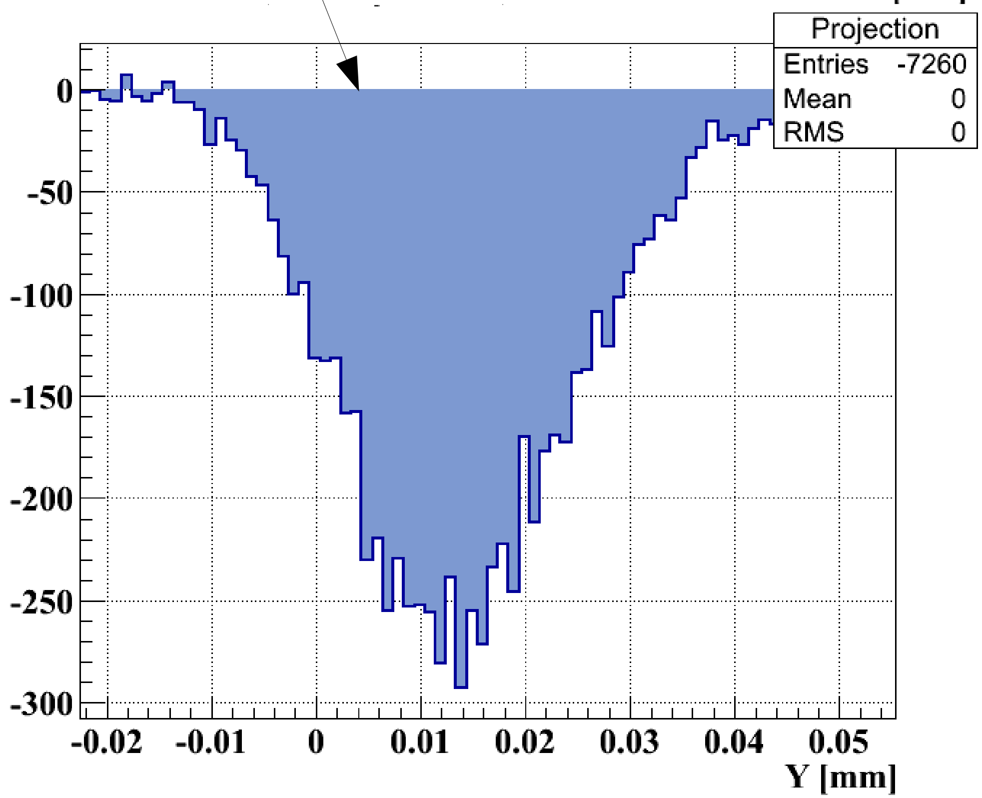
We measured anyway

The following slide should be considered as informative only

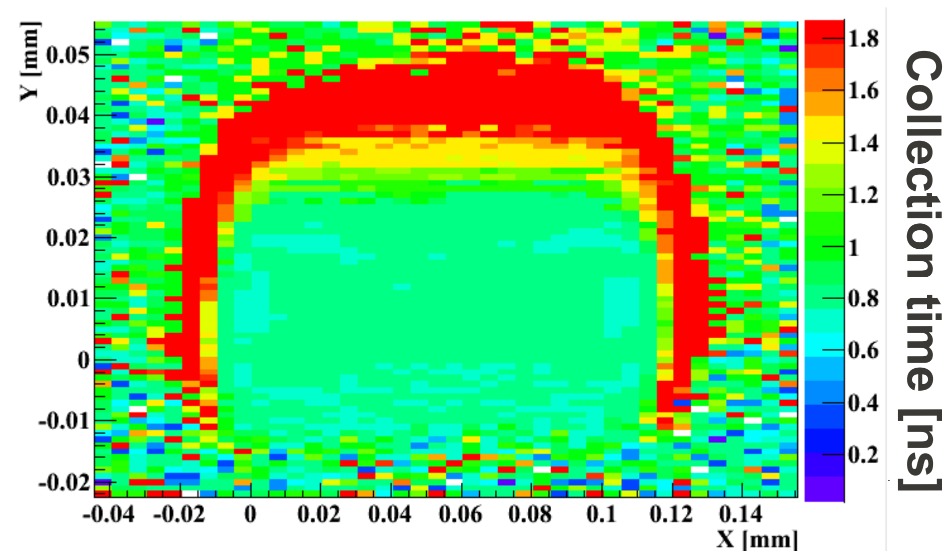
Measurements on irradiated HVCMOS will be performed during next access to TPA-facility in September







Increased charge at corners
Hints for DNW in collected charge map



Conclusions

➔ New technique TPA-TCT, developed within RD50 collaboration, benefits of 1 order magnitude better spatial resolution than SPA-TCT.

➔ Localized charge carrier generation: High-resolution 3D mapping of the charge collecting junction.

➔ First distinct determination of the deep n-well on HV-CMOS devices and precise determination of its sensitive volume.

➔TPA-TCT specially adapted for testing small size feature detectors.

➔ Strong focus leads to high divergence. Motifs close to surface are best for TPA-TCT

➔ HVCMOS results published as part of VCI 2016 proceedings:

http://www.sciencedirect.com/science/article/pii/S0168900216304569

➔ Request RD50 project coordinated with RD50's HVCMOS one to provide access to laser facility

Thanks to the CERN bondlab for (re-)wirebonding of some of the detectors presented in this work

Some other TPA-TCT presentations

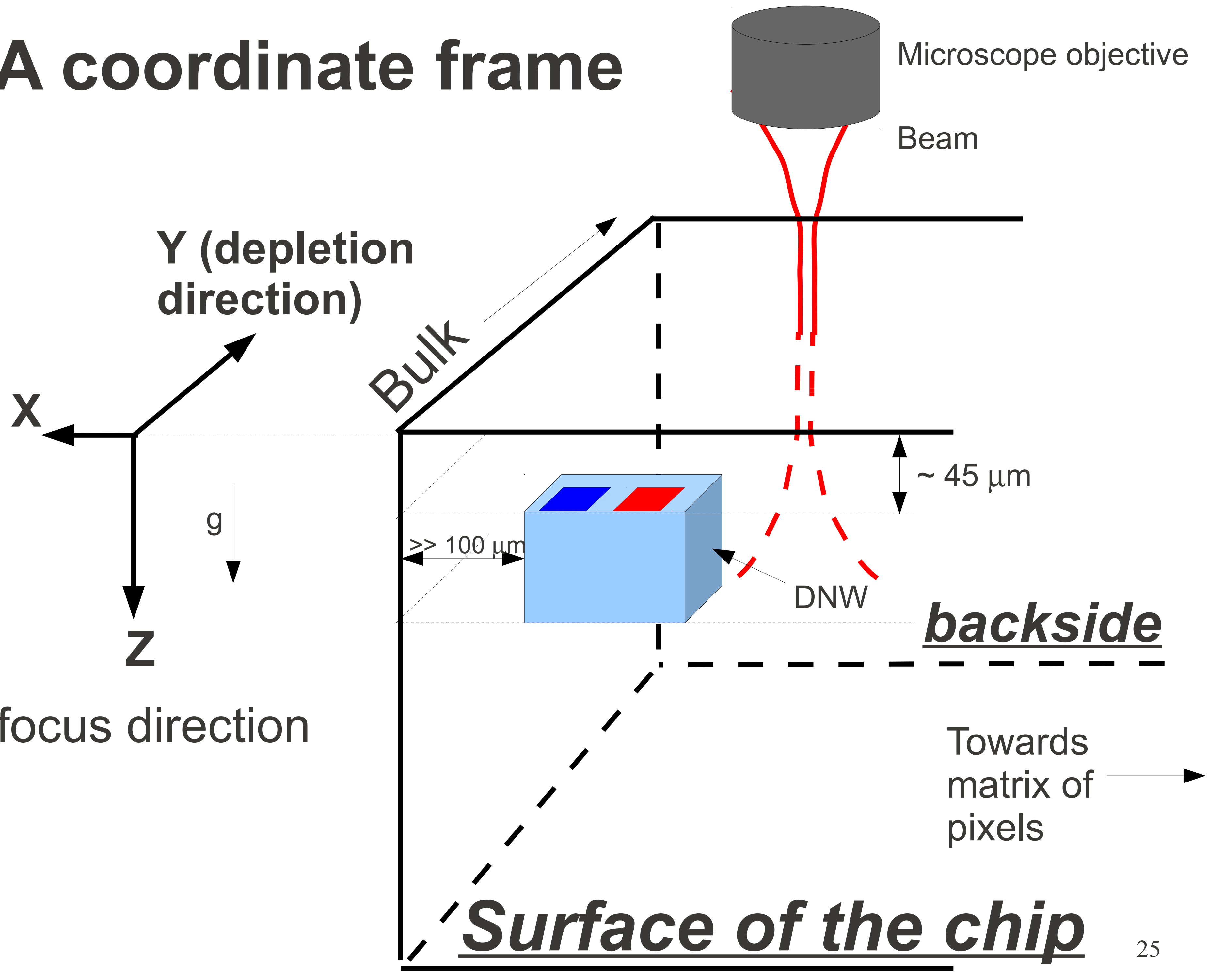
F. Rogelio et al, Two Photon Absorption and carrier generation in semiconductors
https://indico.cern.ch/event/334251/contributions/780784/

I. Vila et al, A novel Transient Current Technique based on the Two Photon Absorption (TPA) process
https://indico.cern.ch/event/334251/contributions/780782/

I. Vila et al, Investigation on the radiation resistance of HV-CMOS and pin diodes using a Transient Current Technique based on the Two-Photon-AbsortionProcess
https://indico.cern.ch/event/452766/contributions/1117347/

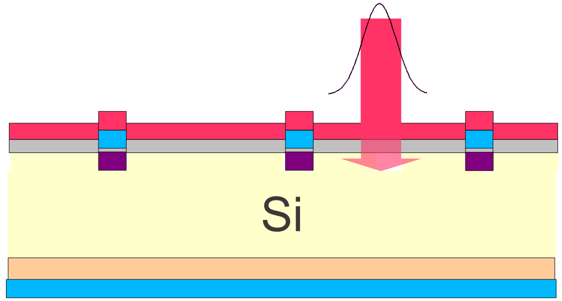
Extra information

TPA coordinate frame



Laser focus direction

Laser characterization techniques



SPA-TCT Red

Employing short penetration depth laser (red for Si), all carriers deposited in few μm from surface

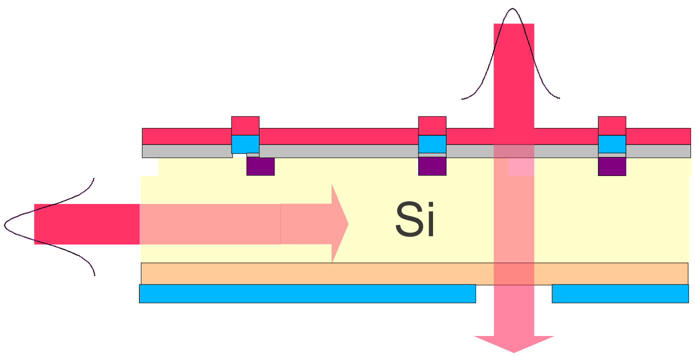
Allows to study drift of one kind of carriers

No “vertical” spatial resolution

1 photon=1 e-h pair

SPA: Single Photon Absorption

TCT: Transient Current Technique



SPA-TCT Infrared

Employing long penetration laser (infrared for Si)

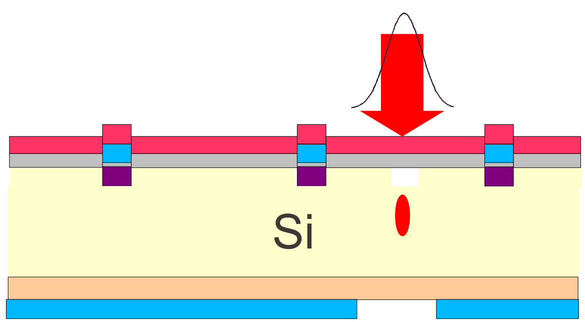
Homogeneous distribution along “Rayleigh length”

Similar to MIPs, though different dE/dx

Incidence can be from **top, bottom** or **edge**

Lateral spatial resolution

1 photon=1 e-h pair



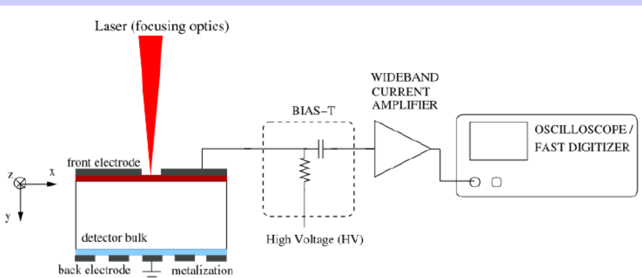
Two Photon Absorption (TPA-TCT)

It has been used to test SEE in chips,

First time used to test bulk radiation detectors

Point-like energy deposition → 3D spatial resolution

2 photons=1 e-h pain



Transient Current Techniques

Applicable to both pad/segmented detectors

Simple readout

DAQ directly on digital scope

2. Setup and facility description

Fig. 1 shows the schematic setup of the TPA-TCT experiment. Femtosecond laser pulses are generated by a commercial Ti:Sapphire oscillator-regenerative amplifier system (Coherent Mantis-Legend, 1 kHz, 4.0 mJ, 30 fs pulses at 800 nm). A fraction of the amplifier output is used to pump an optical parametric amplifier (OPA) producing tunable radiation. The experiments were carried out at a wavelength of 1300 nm. In order to avoid temporal stretching of the laser pulses due to the propagation inside the detector, the group delay dispersion is minimized using bandpass filter (Thorlabs, FB1300-12) reducing the bandwidth to 12 nm. The duration of the resultant pulses (243 fs, see Fig 2) was measured with a custom made second order intensity autocorrelator (IA). A variable neutral density filter is used to control the pulse energy at the detector in the range 10 pJ-1 nJ. Laser intensity is monitored and recorded with a Ge photodiode (PD: Thorlabs, Det50B) simultaneously with the detector signal. IR pulses are reflected in the surface of an uncoated fused silica window and focused onto the detector, which is mounted in a high precision three axis translation stage (Thorlabs, PT3-Z8), with a 100× objective (Mitutoyo, M Plan Apo SL) giving rise to a beam waist of 1 μm in linear regime. Location of the beam spot on the detector is achieved by imaging the sample surface on a CMOS camera together with the reflection of a cw 625nm reference laser (RL) spatially overlapped ultrashort pulse beam. The signals from the detec-

The laser facility

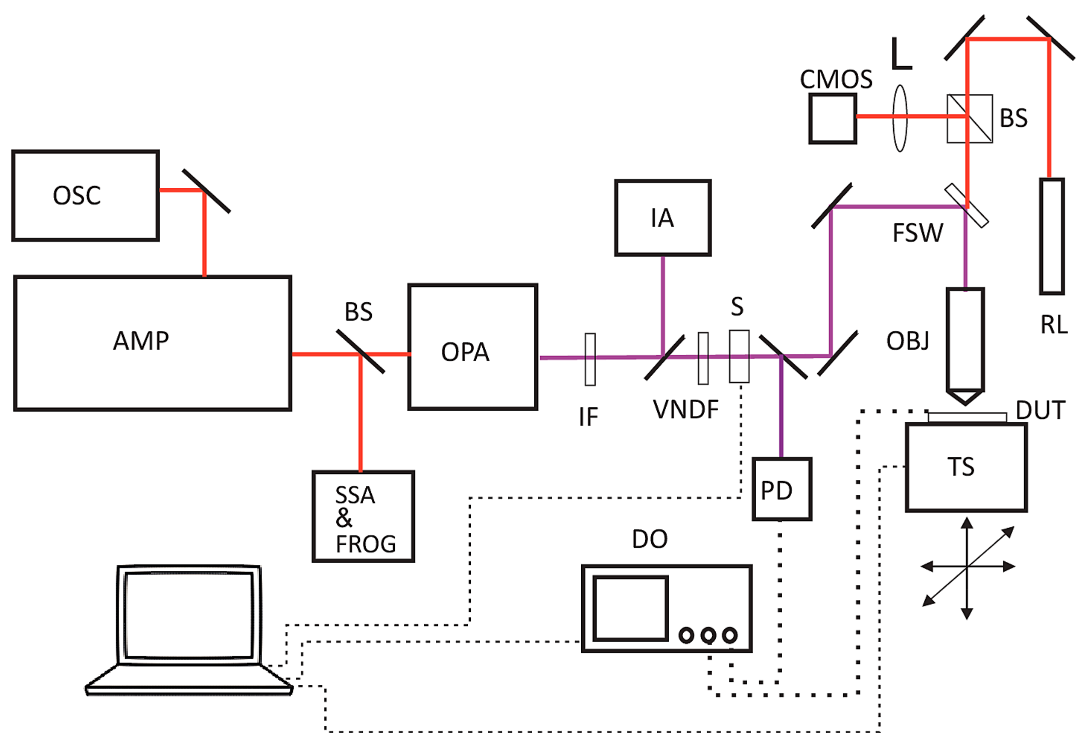
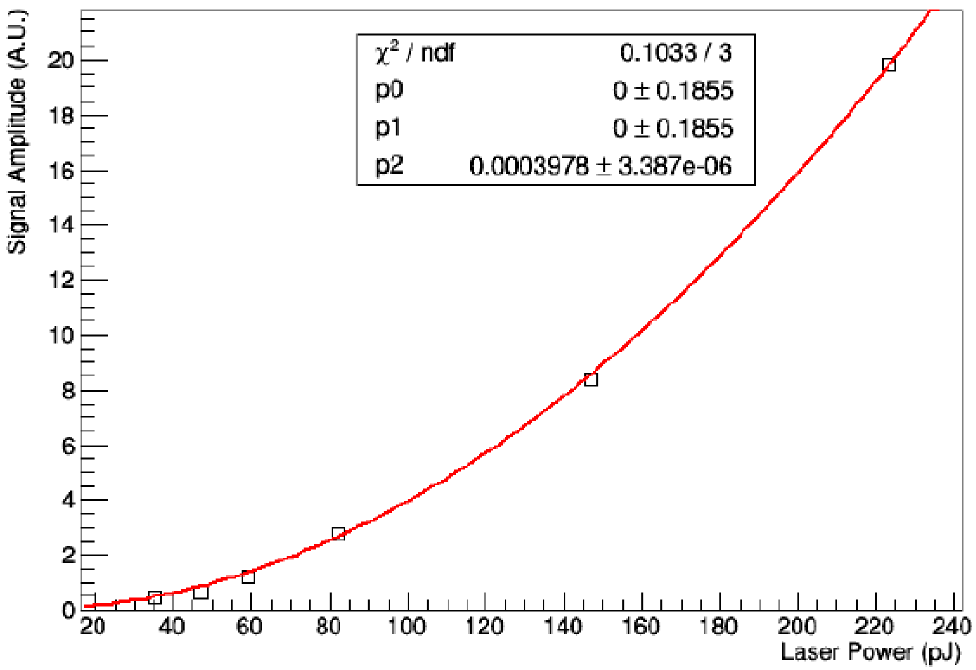
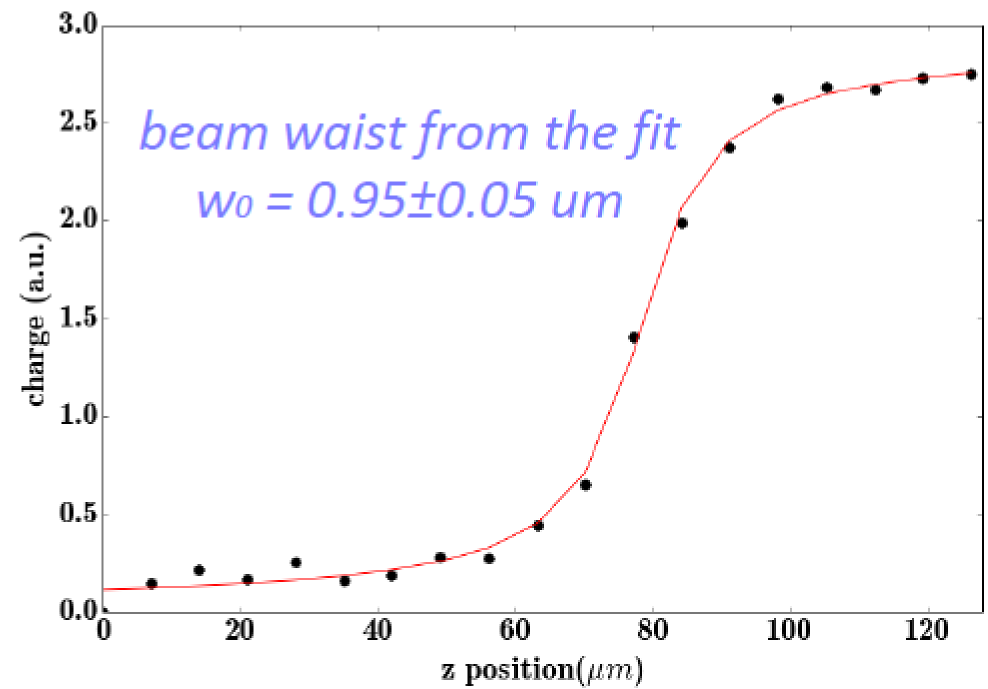


Figure 1: Schematic representation of the TPA-TCT setup. OSC: Ti:Sapphire oscillator; AMP: Ti:Sapphire regenerative amplifier; BS: beam splitter; OPA: Optical parametric amplifier; IF: Interferential filter; IA: Intensity autocorrelator; VNDF: Variable neutral density filter; S: Shutter; PD: Ge photodiode; FSW: Fused silica wedge; OBJ: X100 Objective; L: f 100 mm lens; CMOS: CMOS camera; RL: Reference laser; DUT: Device under test; TS: 3D translation stage; DO: Digital oscilloscope. Colored lines are the laser beams. Dotted lines are the signals from the detector and reference photodiode. Dashed lines are device controls.

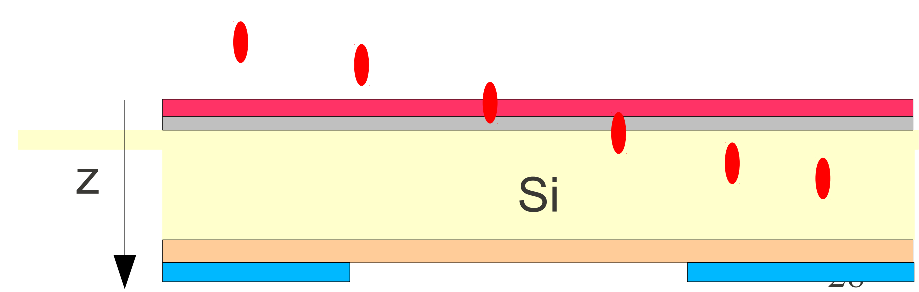
Two Photon Absorption signatures

Evidence of TPA: pure quadratic dependence between collected charge in a diode and laser power





$$\frac{dN(r,z)}{dt} = \frac{\beta_2 I^2(r,z)}{2\hbar\omega}$$



HVCMOS in harsh radiation environemnt

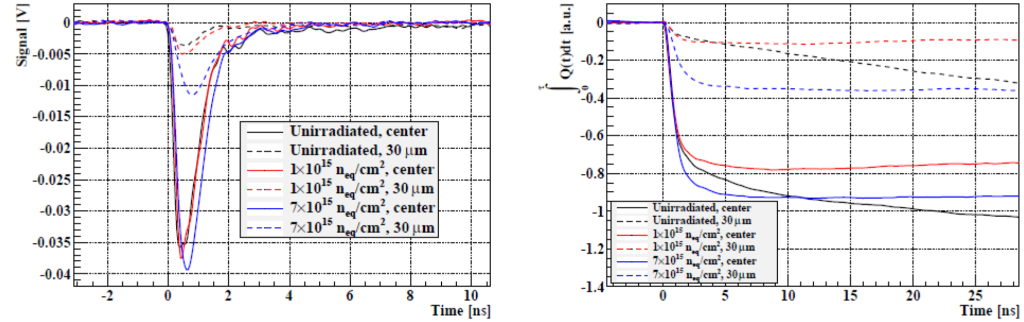


Figure 6. Left: Time resolved transient current in the center of the depletion width, and 30 μm below, shown for two different fluences. The beginning of the pulse has been artificially moved to t=0. Right: Running charge (accumulated charge as a function of integration time) for an unirradiated detector (black lines) and irradiated (red). After irradiation charge is accumulated only by drift. For both plots, detector bias was −80 V at T=−20 °C.

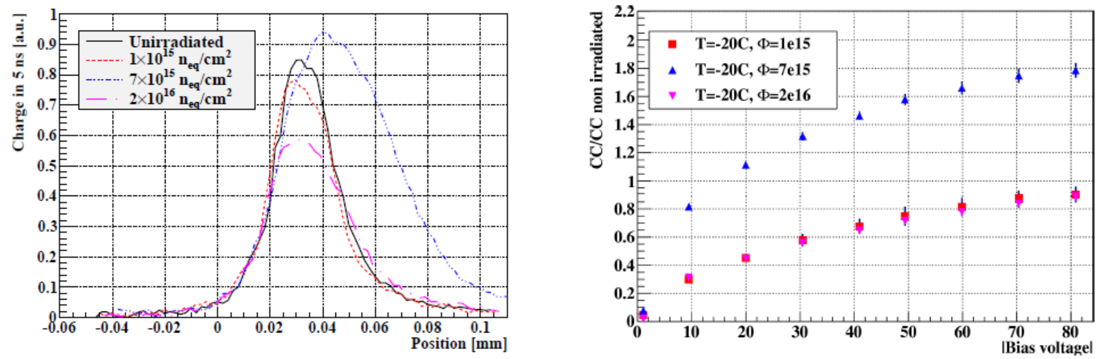


Figure 7. Left: collected charge (in 5 ns, T=-20 °C, −80 V bias) profiles for different fluences. Right: Collected charge (in 5 ns, integrated over 90 μm depth, T=−20 °C) of irradiated detectors versus bias voltage referred to the collected charge of the unirradiated sample. Note the overlap of the data for the 1×10^{15} and 2×10^{16} samples.

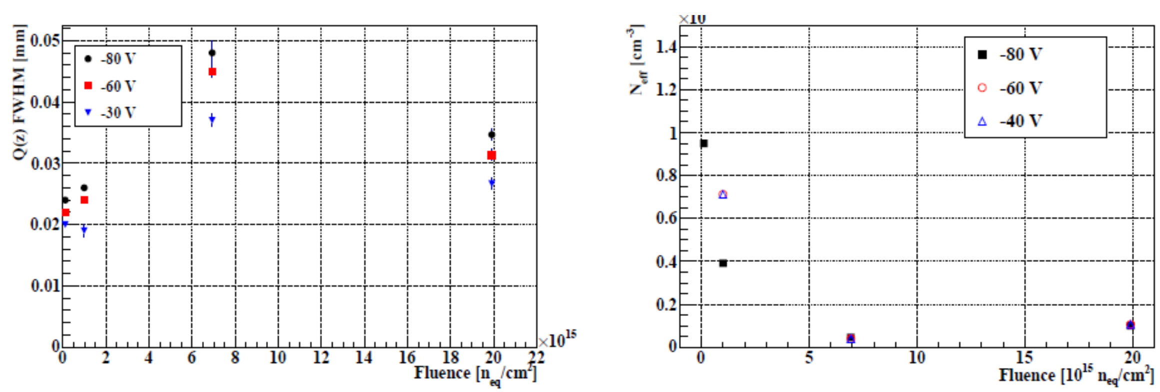


Figure 9. Left: Measured depletion depth calculated as FWHM of charge profiles. Right: calculated effective doping concentration versus fluence.