Two Photon Absorption-TCT on HV-CMOS, LGAD and diodes

Instituto de Física de Cantabria

Marcos Fernández[(1)], Richard Jaramillo, David Moya, Javier González Iván Vila

eman ta zabal zazu

UPV EHU

Raúl Montero

CERN

Michael Moll

Universidad de Sevilla

Rogelio Palomo

30th RD50 workshop – 5 - 7 June 2017, Krakow (Poland)

(1) Also visiting scientist at CERN

Outline

Two Photon Absorption (TPA) **introduction**

TPA **news**

TPA **setup** modifications

Edge-TPA on irradiated **HVCMOS**

Edge-TPA on **diodes**

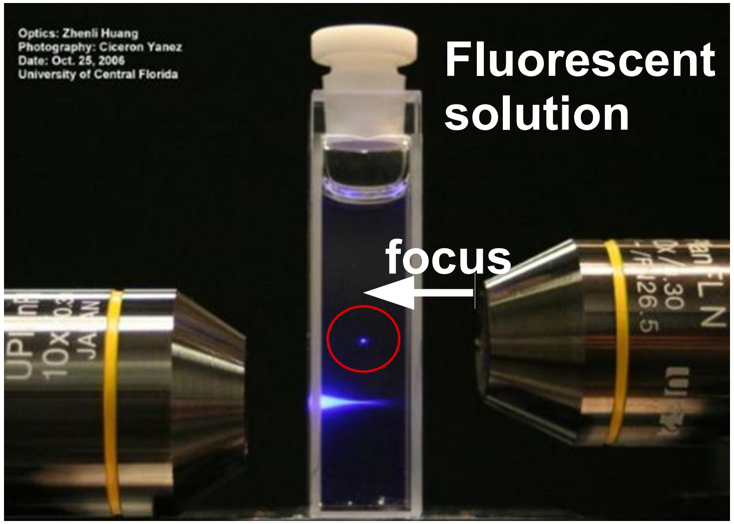
TPA on **LGADs**

Reminder I: TPA basics

SPA

Single Photon Absorption

Continuous energy deposition

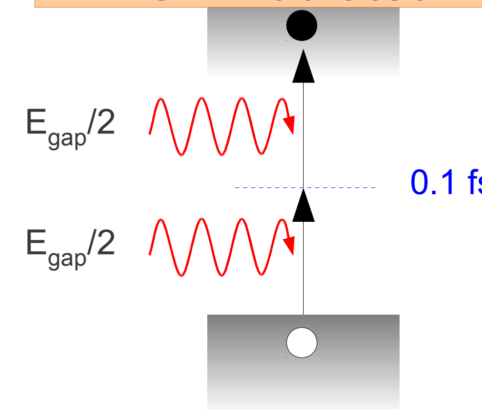


TPA

Two Photon Absorption

Energy confinement

Non irradiated

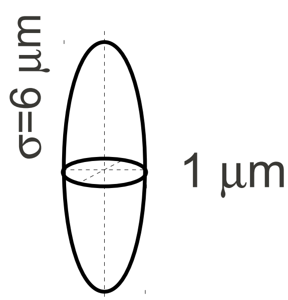


$$\frac{dN(r,z)}{dt} \propto \frac{\beta_2 I^2(r,z)}{2\hbar\omega}$$

Two Photon Absorption

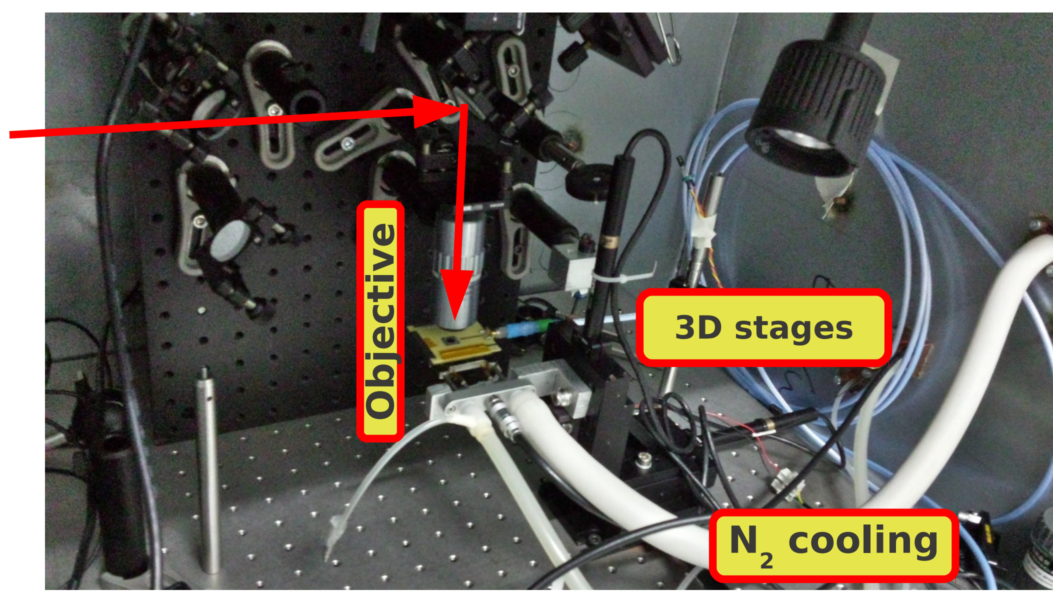
Spot size

Two Photons must be **coincident in time** (pulsed **mode-locked** lasers) and in **space** (**microfocusing**)



×**100** objective

Setup

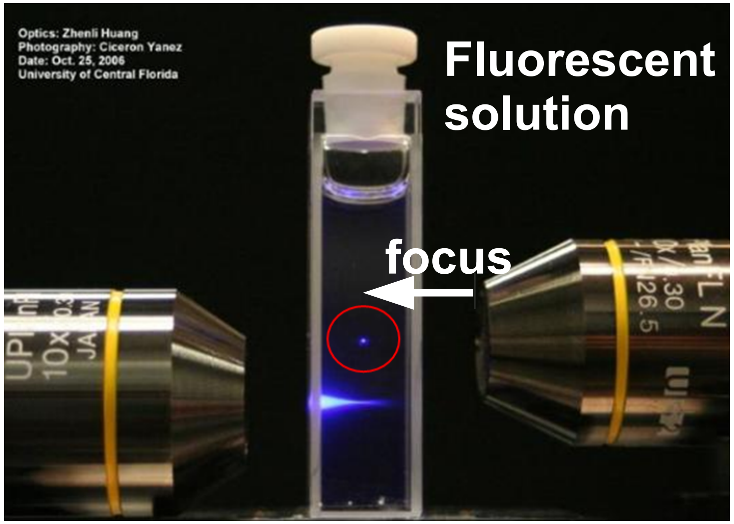


Reminder I: TPA basics

SPA

Single **P**hoton **A**bsorption

Continuous energy deposition

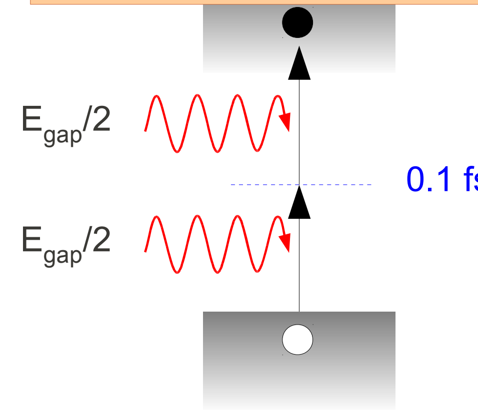


TPA

Two **P**hoton **A**bsorption

Energy confinement

Non irradiated



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

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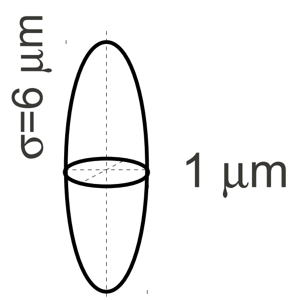
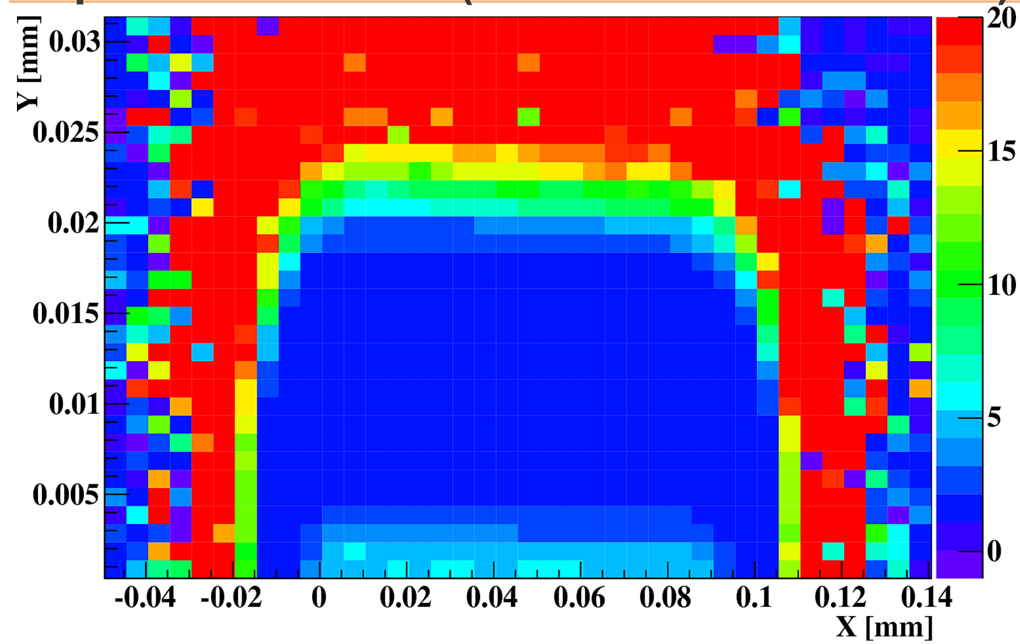


×**100** objective

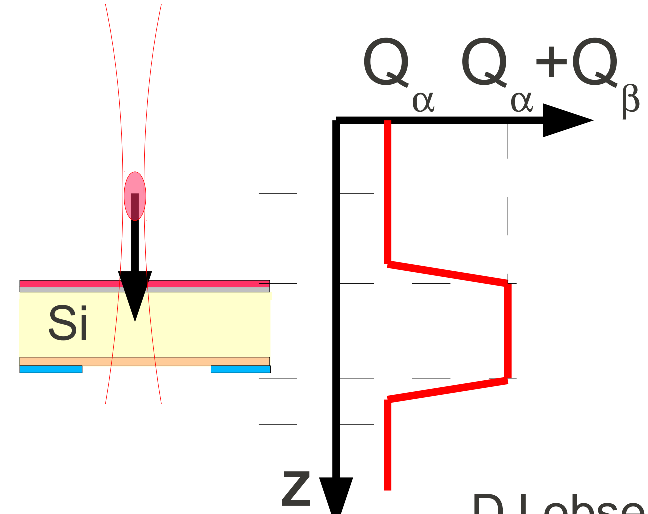
Spatial resolution (drift/diff discrimination)

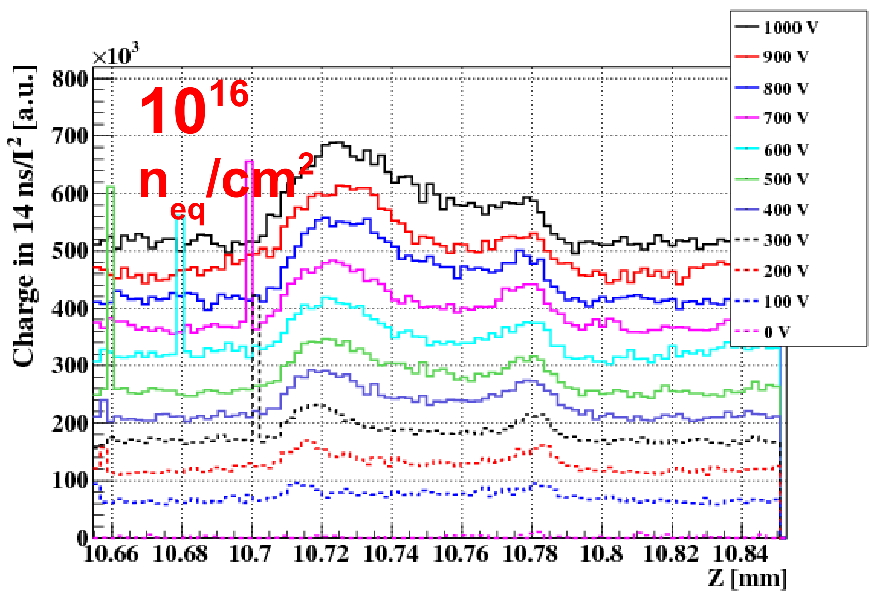


Reminder II: TPA of irradiated devices

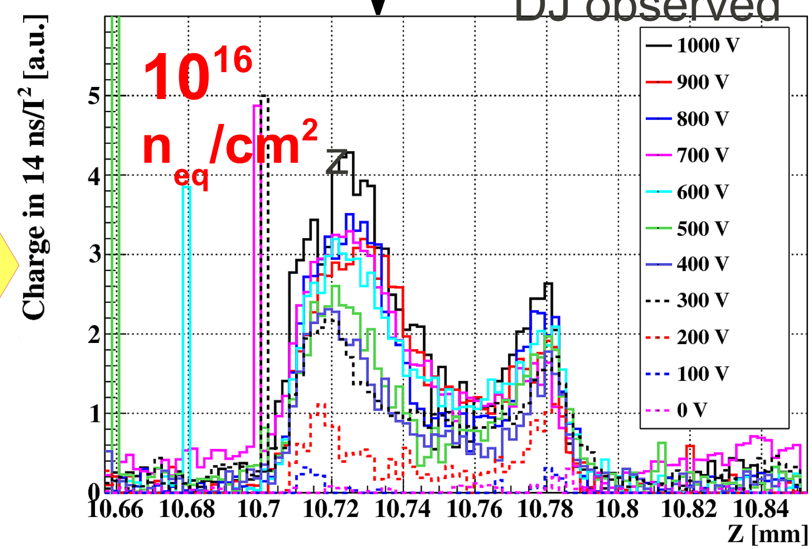
Radiation induced **Deep Levels enhance SPA** in detriment of TPA.
Consequence for TPA scans: signal out of the focal point → **Smeared 3D resolution**.

However, SPA signal is **independent** of the **focus** position: Z-invariant. We can measure the SPA background with the **focus outside** of the sensor and subtract it when the focus is inside.





SPA corr



Results from **RD50-2015-03:** article in preparation

News I: TPA projects

Two RD50-TPA projects **running** for the last 6 months:

- **RD50-2016-04**

"*Determination of the Electric Field across the electrodes of **planar pad-like diodes** using an **Edge TCT** technique based on a Two-Photon-Absorption (TPA) process*"

6 RD50 institutes: IFCA, CERN, IJS, MPI, IMB-CNM, INFN-To
Contact person: Iván Vila

- **RD50-2017-02**

*"3D imaging of irradiated and non-irradiated **HVCMOS** using Two Photon Absorption **edge** illumination"*

5 RD50 institutes: CERN, IFCA, IJS, IFAE, Liverpool
Contact person: Marcos Fernández

Status of these 2 projects reported in this talk

News II: TPA CERN KT fund

The project:

“***3D characterization*** *of* ***solid state devices*** *using a Two Photon Absorption Transient Current Technique*”

was **selected** for funding by **CERN Knowledge Transfer Fund**. Scope being:

1) Development of a **“table-top” proof-of-principle** system at CERN, integrating:
   - A **commercial** femtosecond laser
   - Focusing **optics**
   - Motorized **3D scanning** system
   - Faraday **cage**
   - **DAQ** and **analysis** software

   Common to CERN-SSD TCT+ (Faraday cage, DAQ and analysis software)
   (See C. Gallrapp at 1st TCT workshop@DESY)

2) **Application** of the **TPA-TCT** technique as:
   - Doping concentration **profiler**, instead of SIMS or Spreading Resistance systems
   - **Electric field** profiler (unique)
   - **Mobility** calculation

EP KT Innovation day: https://indico.cern.ch/event/575296/timetable/#20161014

TPA setup upgrade

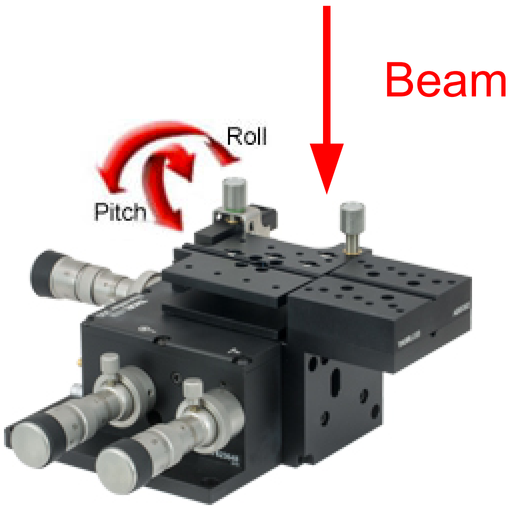
Optics:

Objective x100
Optimized for IR, highly focused (but divergent), motifs close to surface

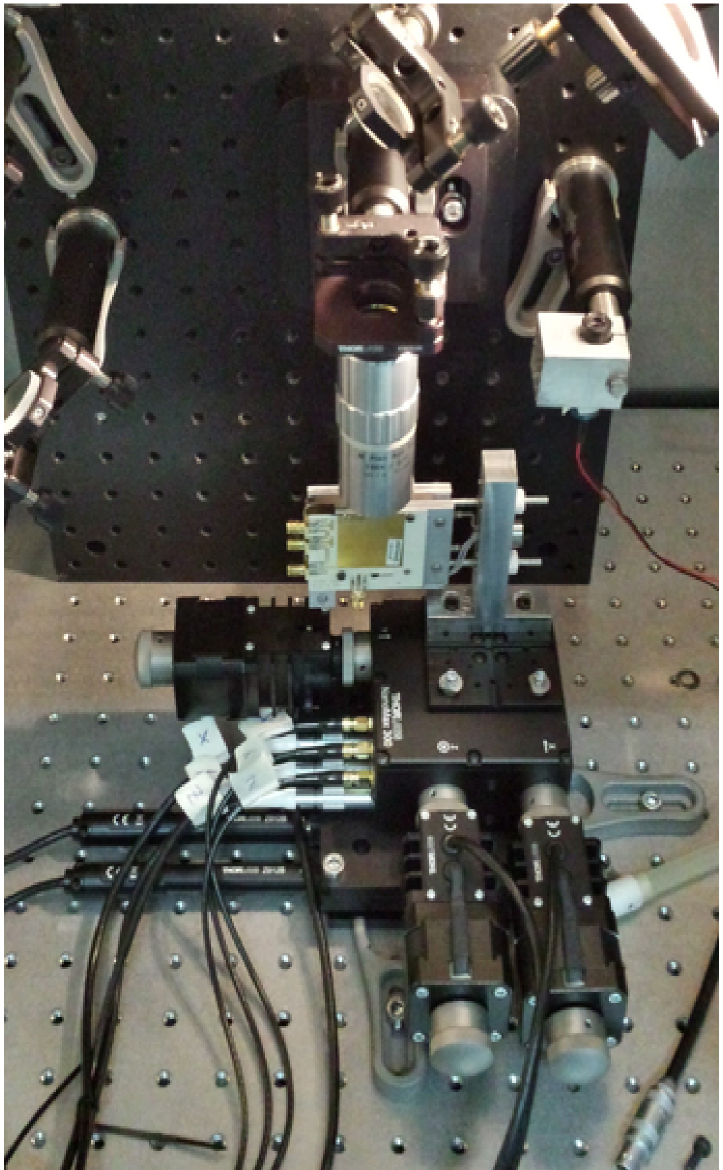
Objective x20
Optimized for IR, lower focusing and lower divergence, for deeper (along the beam) motifs

A motorized 6-linear axis system:
3 **steppers:** (X,Y, Z ; range 4 mm, 60 nm resolution)
3 **piezoelectric** (X,Y, Z ; range 20 μm, 5 nm resolution)

Sample angular orientation
Pitch & Roll (arrived late May'17)
Pitch & Jaw



TPA setup upgrade



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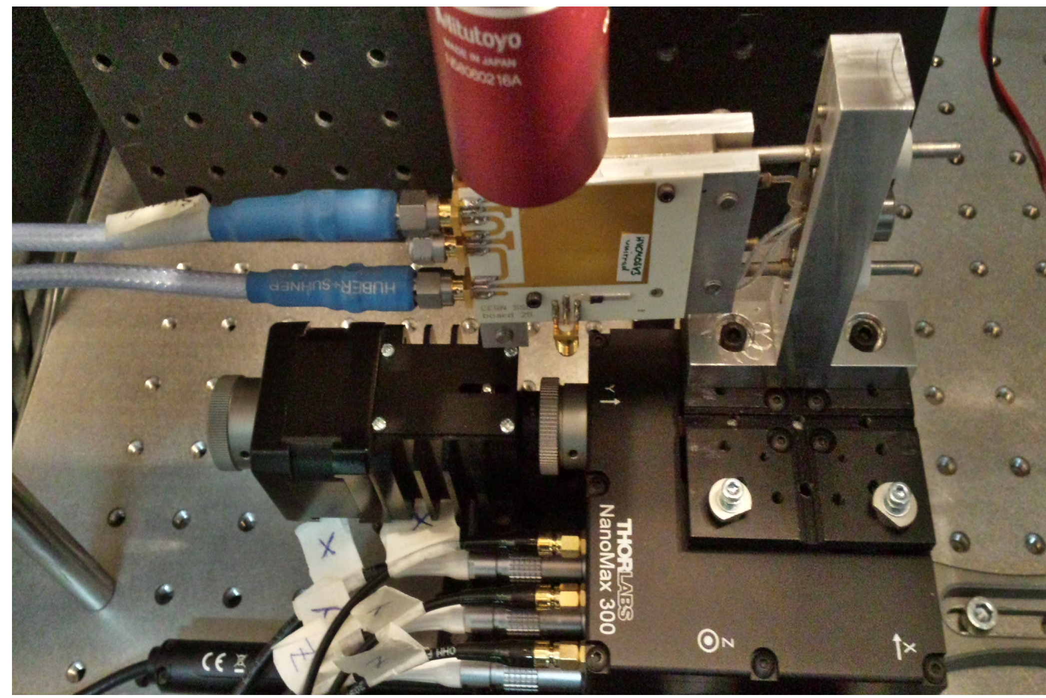
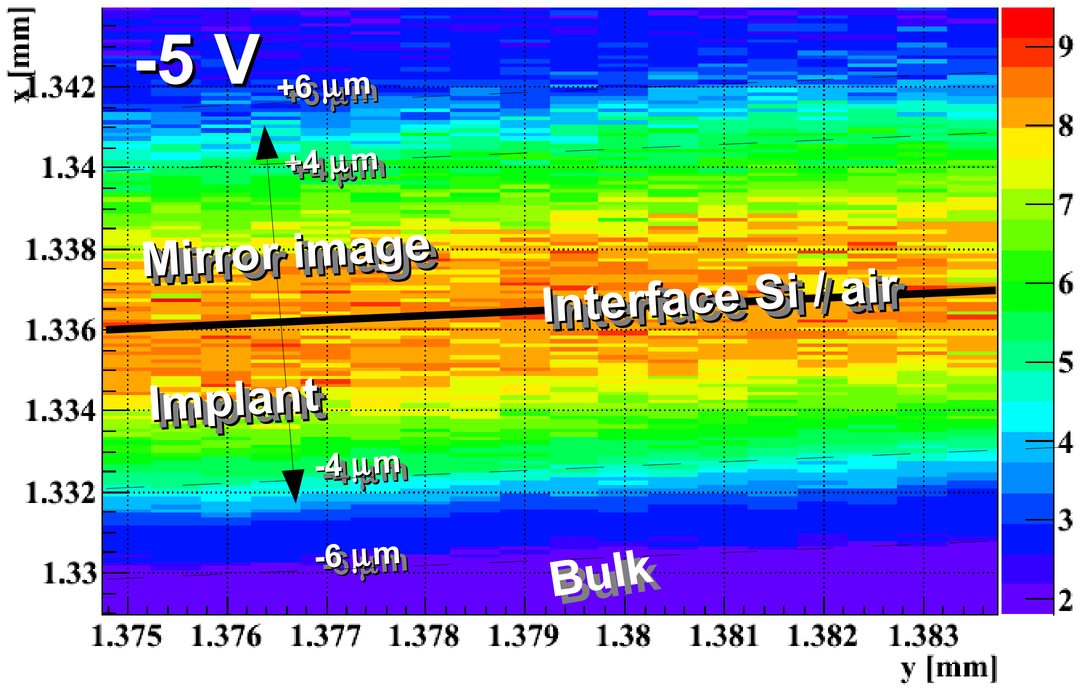
Servicios Generales de Investigación

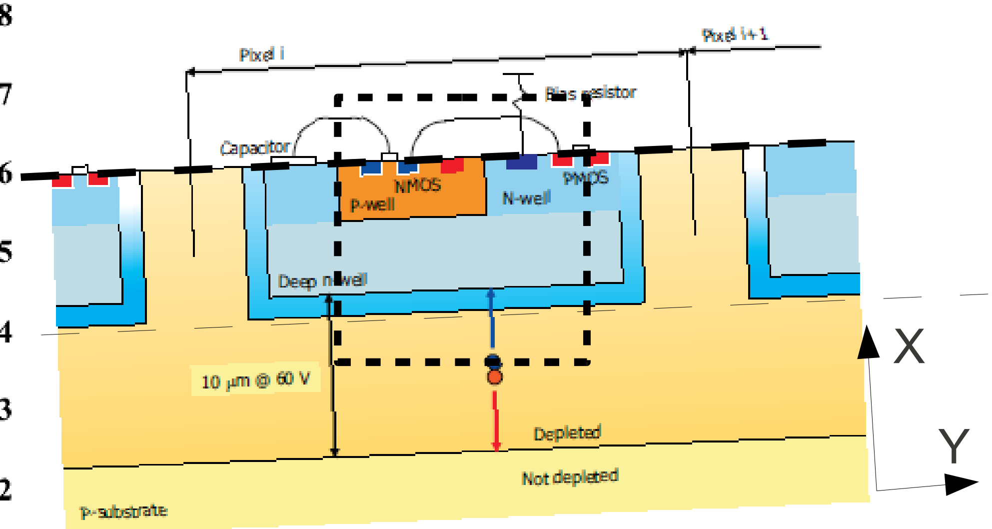


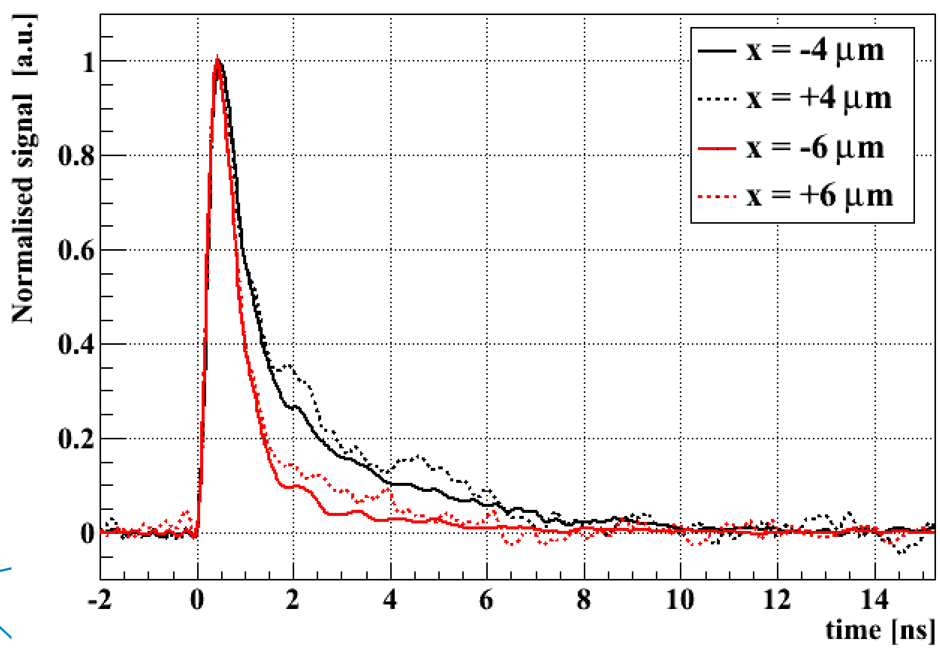
HVCMOS: resolving implant depletion & boundaries

Collection time [ns] = f(y,x)

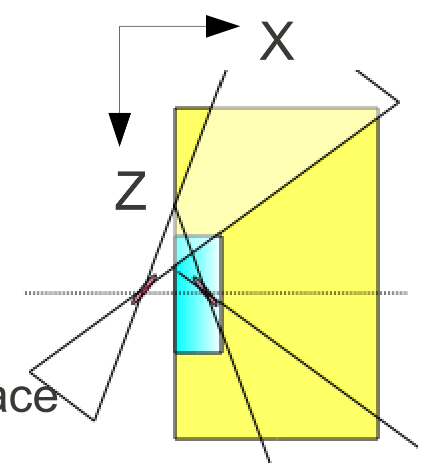


HVCMOSv3, fresh detector





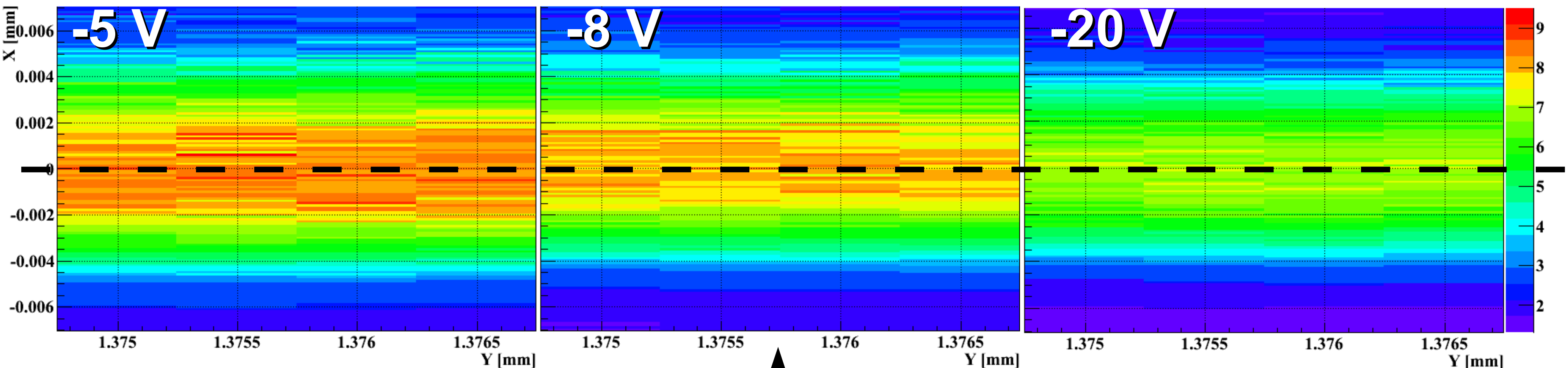
Due to **reflection** of the beam at the **air/Si** interface the **implant's apparent width is a factor 2 bigger** than expected.

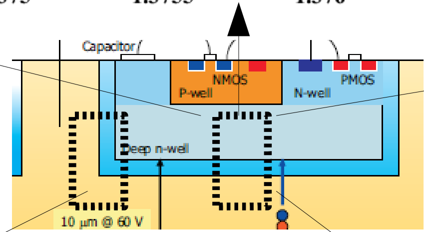


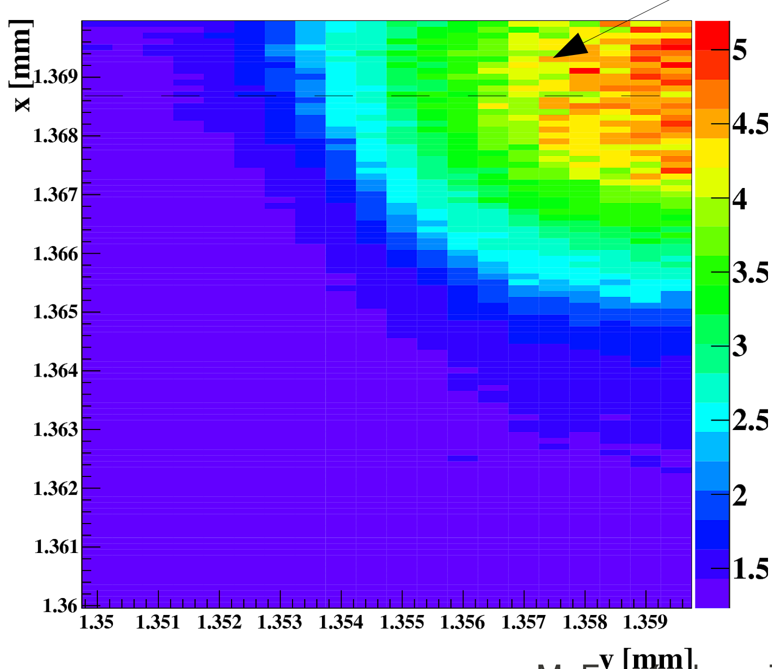
Present in all TCT techniques at the interface air-Si or air metal!!

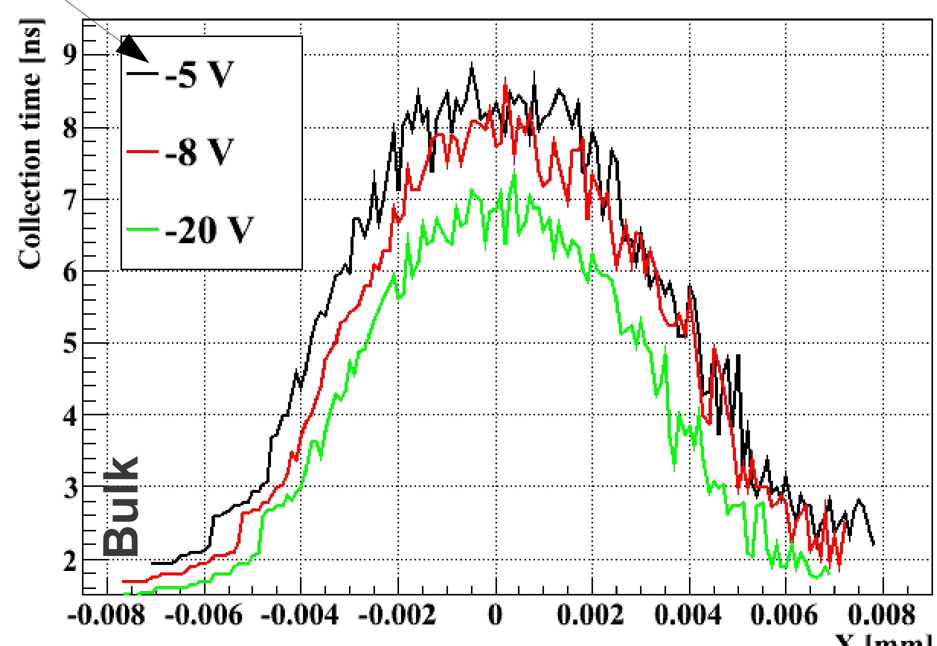
Waveforms identical around the interface line. This is a handle to locate detector boundaries!!

High resolution imaging inside implant









HVCMOS: correction of radiation induced SPA signal

For **top** TPA-TCT on **diodes**, **radiation** induced linear absorption (**α** contribution) was removed by **defocusing** the beam (β supression)

In HVCMOS, the defocused beam would not fit inside the narrow depleted region.

Instead, two identical measurements at **different power** are taken. The one at lower power (low β content) is used to correct a from the one at higher power. The more different the powers, the better.

$$\left. \begin{aligned} Q_1 &= Q_\beta P_1^2 + Q_\alpha P_1 \\ Q_2 &= Q_\beta P_2^2 + Q_\alpha P_2 \end{aligned} \right\}$$

Q_i=Charge mesured by the HVCMOS detector

P_i=Laser power measured by Ge photodiode

Q_α=Linear absorption component

Q_β=Non-linear TPA signal **(our goal)**

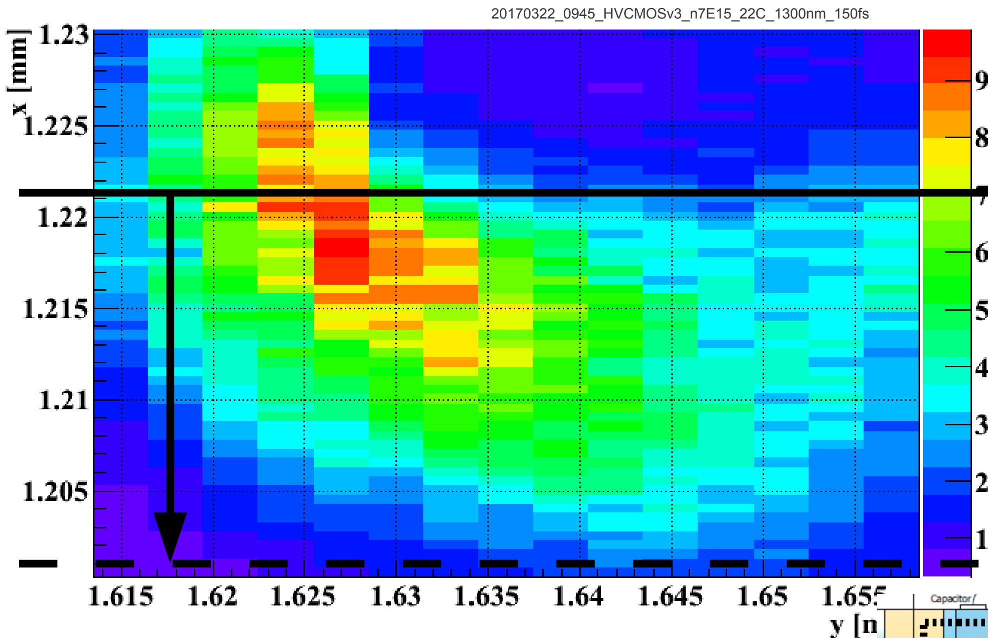
(See backup slides)

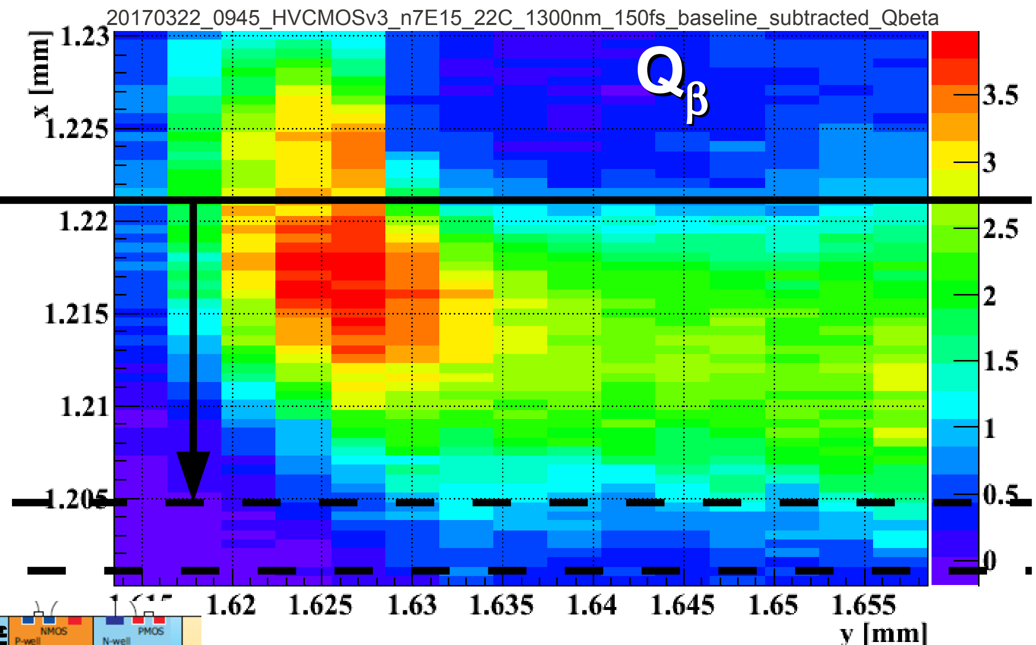
Solving for Qα and Qβ:

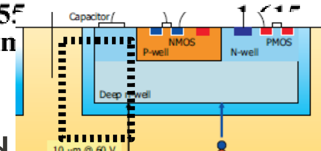
$$Q_\beta = \frac{\dfrac{Q_1}{P_1} - \dfrac{Q_2}{P_2}}{P_1 - P_2} \qquad Q_\alpha = \frac{\dfrac{Q_1}{P_1^2} - \dfrac{Q_2}{P_2^2}}{\dfrac{1}{P_1} - \dfrac{1}{P_2}}$$

HVCMOS_7×10^{15} n$_{eq}$/cm^2: SPA correction

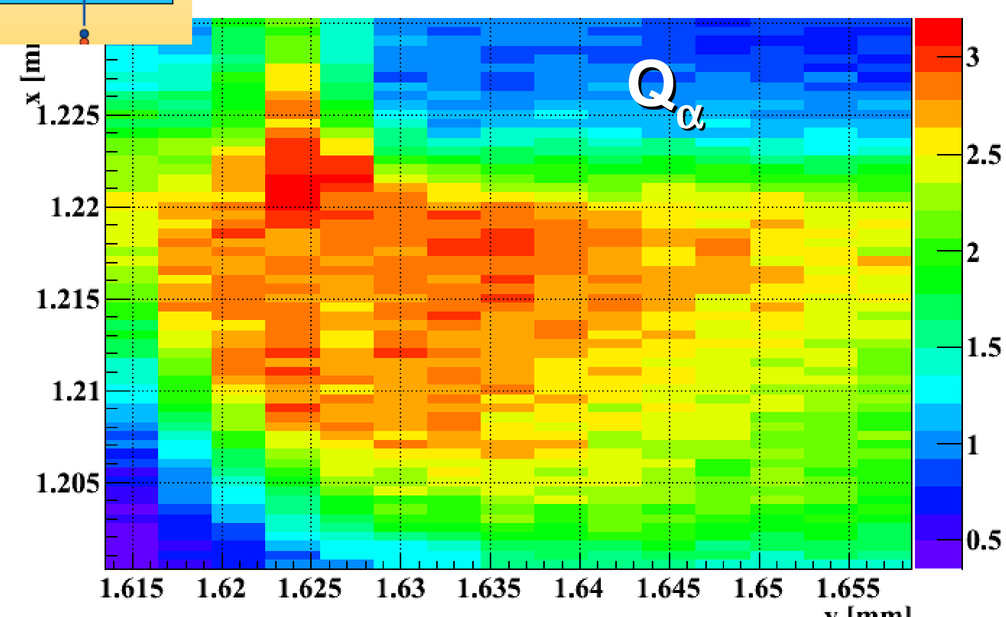
Vbias=-20V







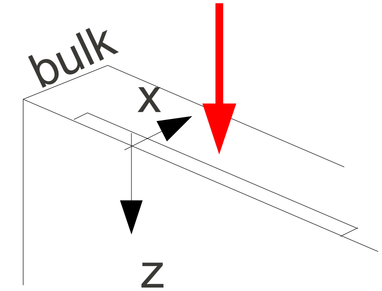
Top left: SPA + TPA uncorrected
Bottom right: SPA signal (e-TCT-like)
Top right: Corrected signal



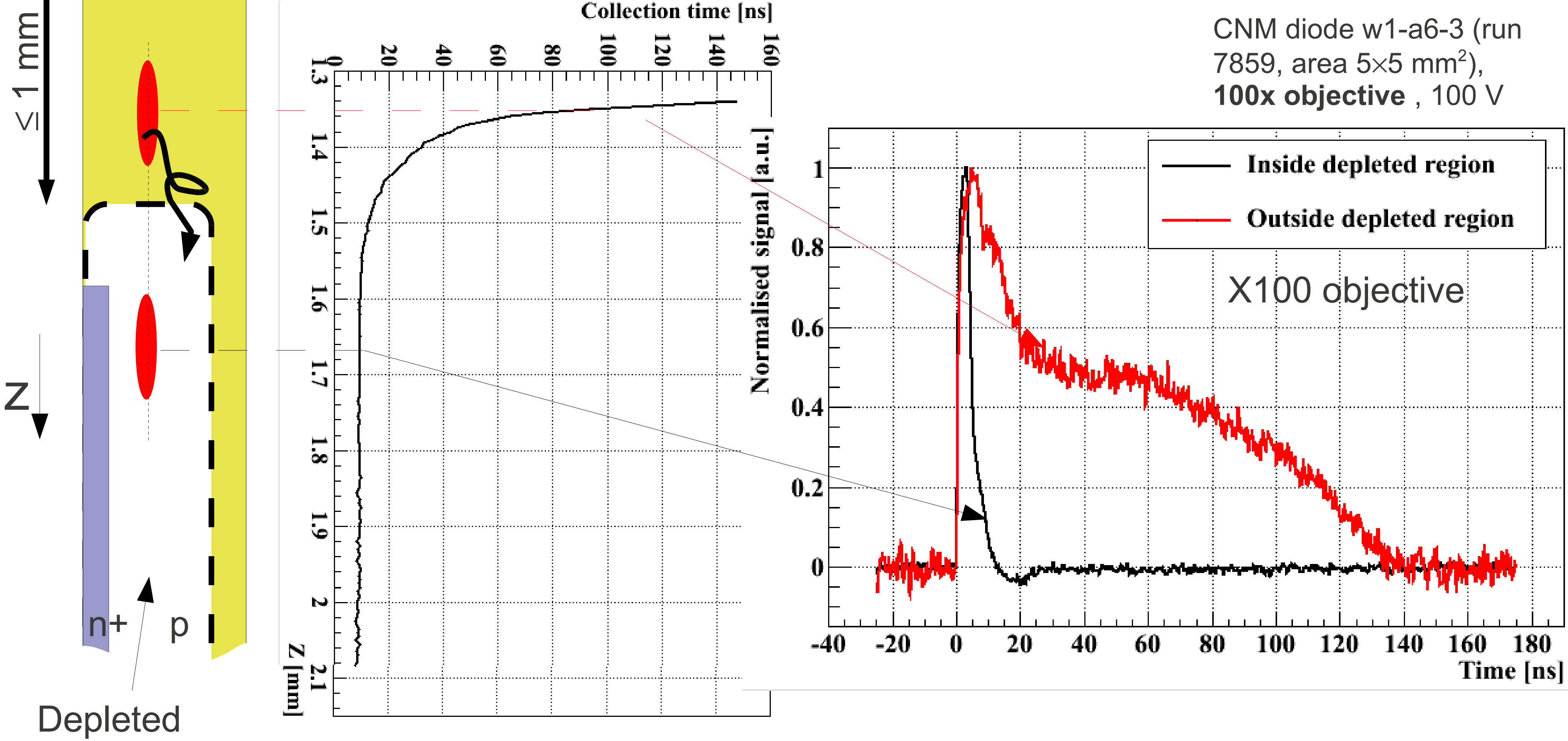
Corrected depletion thickness smaller than measured using standard edge-TCT.

This has **implications** in the calculation of the effective doping concentration (**acceptor removal**) !!

Edge-TPA of a diode (I)



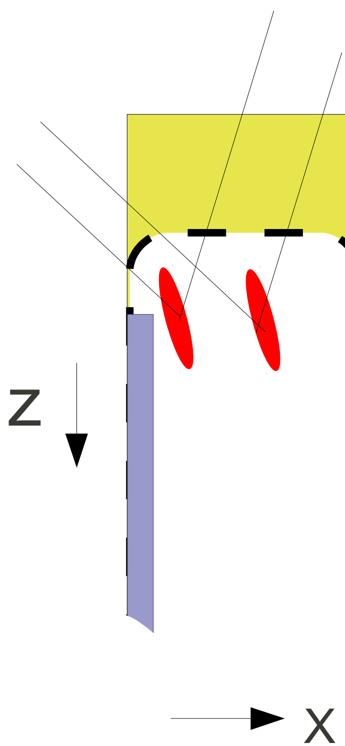
CNM diode w1-a6-3 (run 7859, area 5×5 mm^2), **100x objective** , 100 V

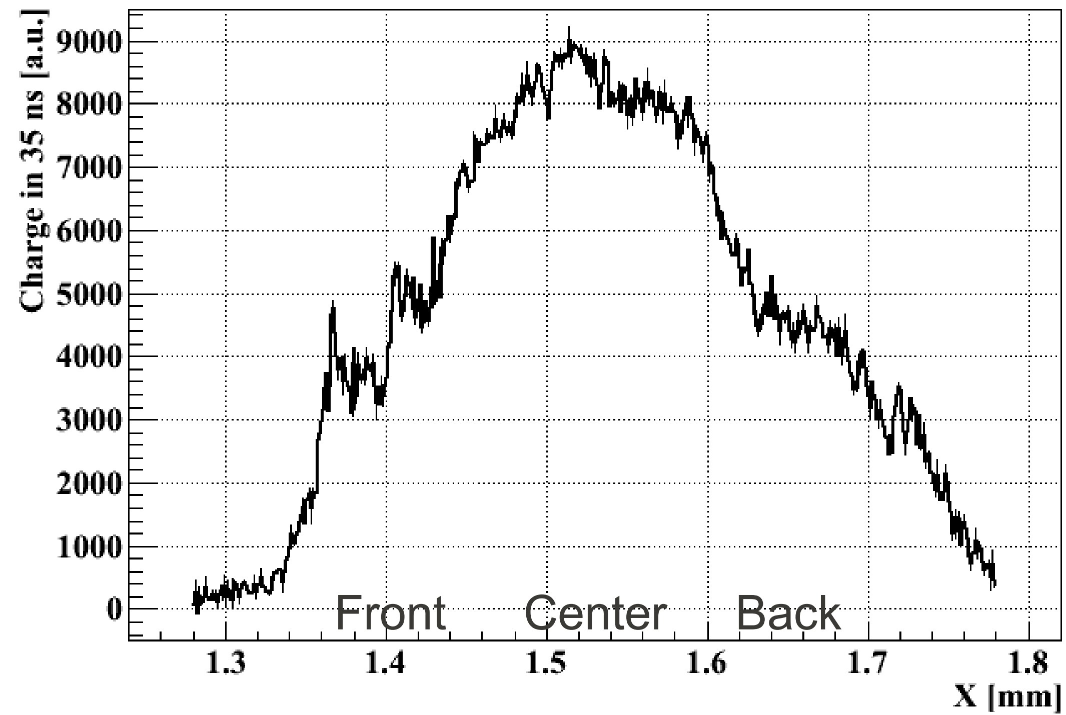


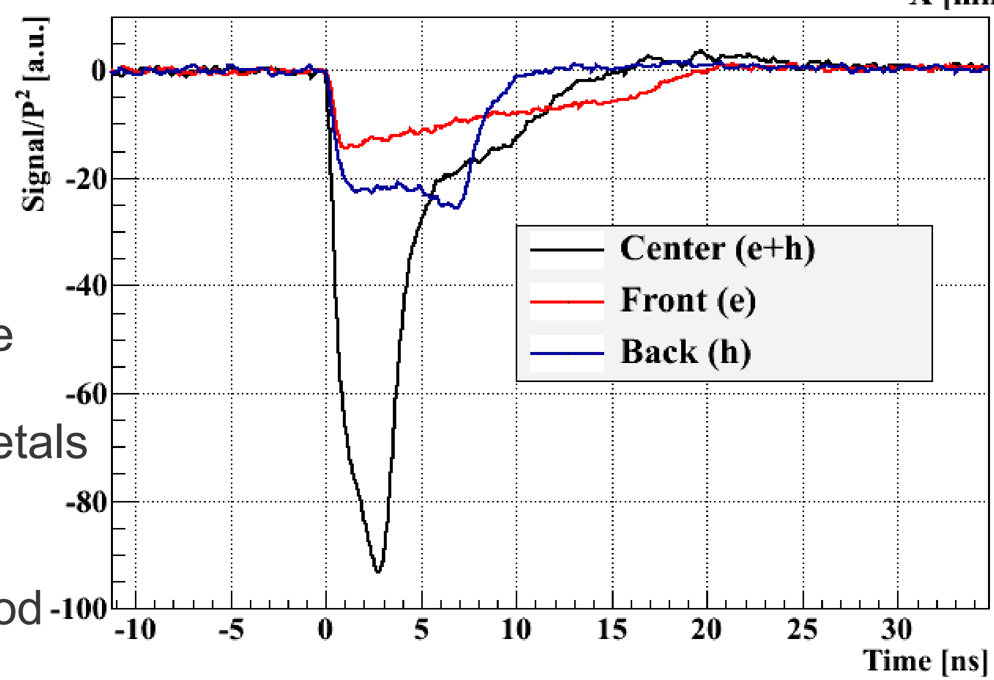
Z-scan (along the beam propagation direction), shows waveforms with very different collection times. Long pulses indicate that the beam is out of the depleted region (diffusion involved). For short pulses the beam is inside the depletion region. **Edge-TPA TCT shows resolution along the beam.**

Edge-TPA of a diode (II)

Due to the strong focusing (×100) and the misalignment, the beam is chopped by the detector sidewalls.



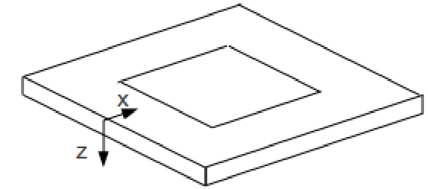




The charge collected at different depths in the bulk is not constant (different amount of light coupled into the detector, different surface metals on opposite sides, etc).

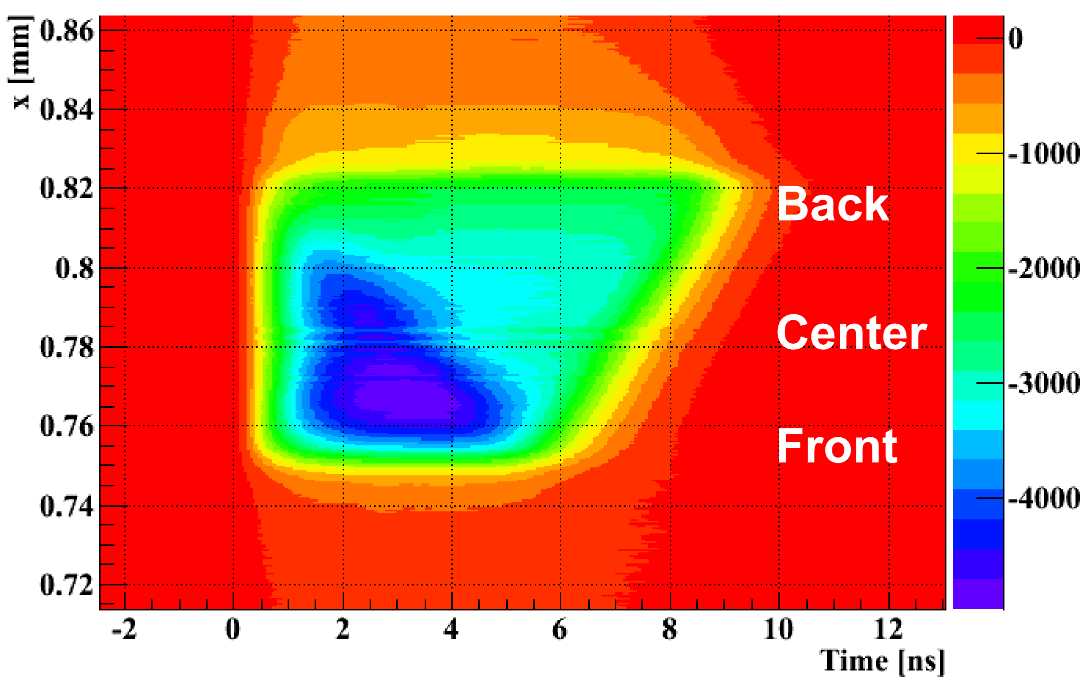
Measurements with ×20 amplification and good alignment need to be performed.

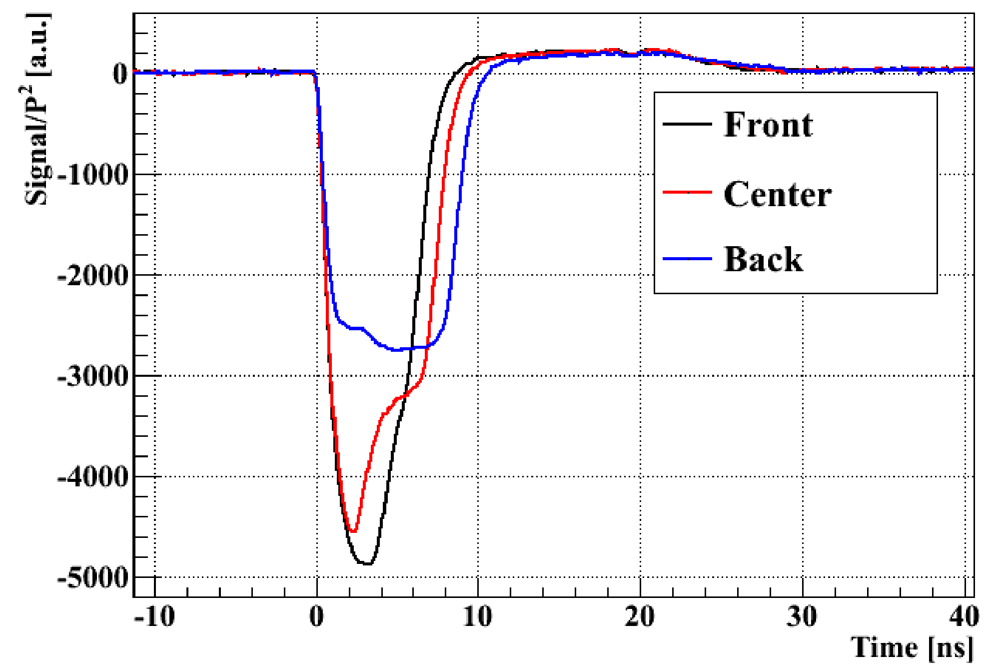
TPA-TCT of an LGAD



W1D8 (7062), LGAD diode (with amplification), Top TPAx100

Top incidence, edge-TCT-like plots, decoupling of h and e signals. Long pulses for 600V (due multiplied holes injection)





Summary

Two **RD50 projects** (edge-TPA on diodes and edge-TPA of HVCMOS) have started. Presented first results of a 1 week long access to Bilbao TPA facility

CERN **KT funding** awarded to a project that we are starting. As a byproduct, a TPA-test stand will be built at CERN.

Setup improved with high resolution piezoelectrics (nm-resolution profiling possible) and tilting platforms (tilts not yet tested).

High resolution scan of the **implant** showed (inwards) depletion of the DNW of an HVCMOS

Radiation induced **linear absorption corrections** now available for top/edge-TPA configurations Successfully tested on irradiated HVCMOS.

The TPA ellipsoid can be focused well beyond the edge of the detector using a x100 objective, though the total beam spot is chopped by the sidewalls.

Edge-TPA on diodes is possible!
Top-TPA-TCT of an LGAD demonstrated

Next: active-edges studies, objective x20, alignment systematics,...


Guggenheim museum in Bilbao

NEXT STOP: **Bilbao !!!!**

For those interested in the generation, manipulation and measurement of ultrashort laser pulses, the UPV (Bilbao) organizes a **5 days-intensive** course.

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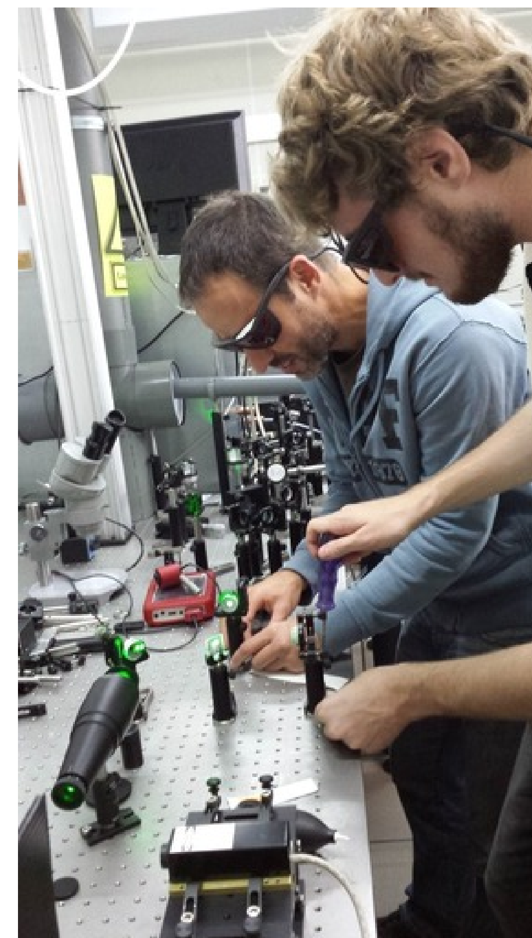
UPV EHU



The course is divided into morning lectures followed by hands-on training using the actual fs-laser.

25-29 September 2017 (flexible dates)

Very good for first time users

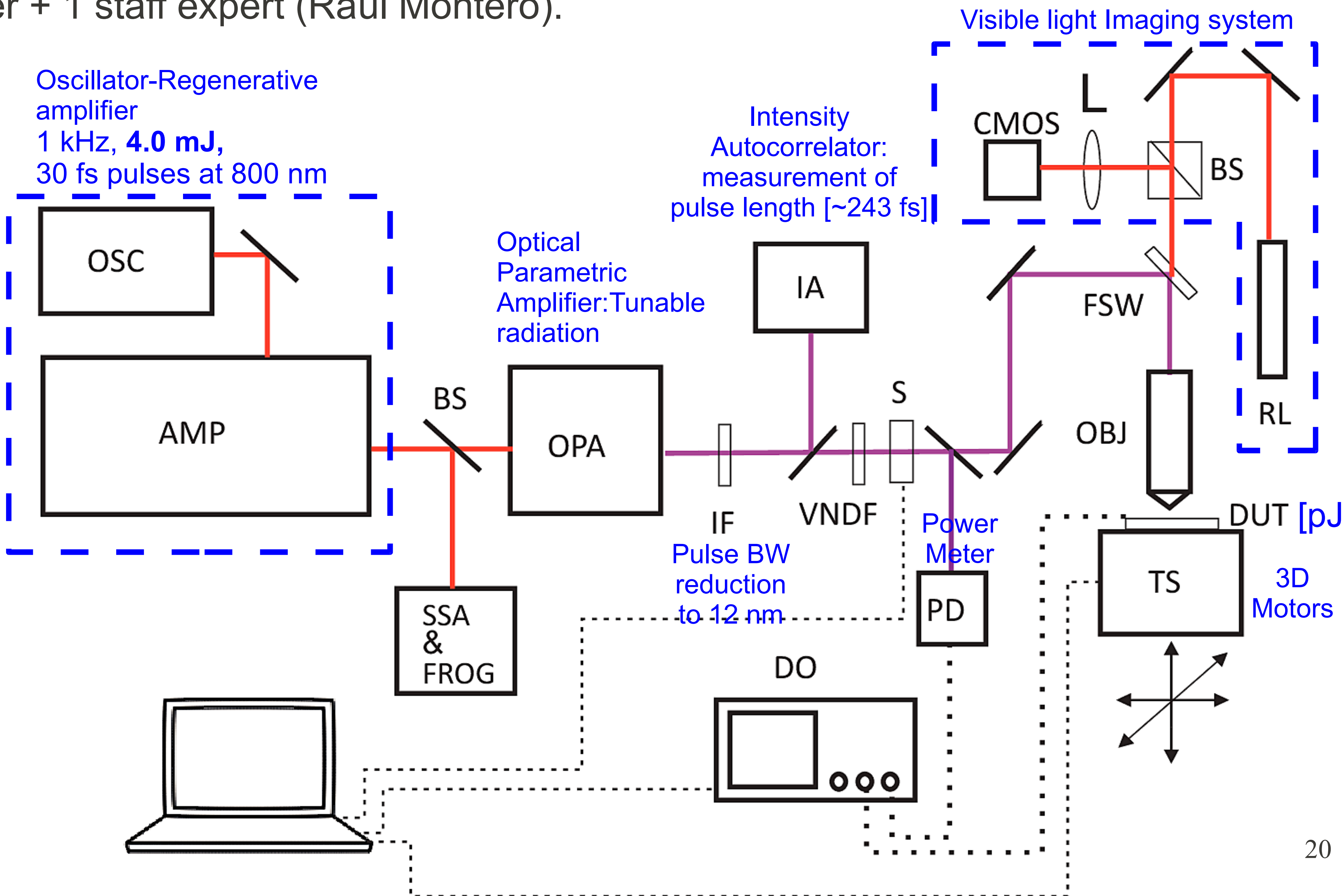
Course can be customized for particular applications, like TPA

Interested people, contact:
raul.montero@ehu.es

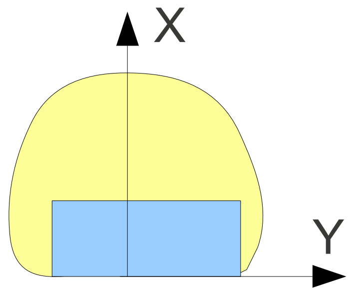
SP
AR
ES

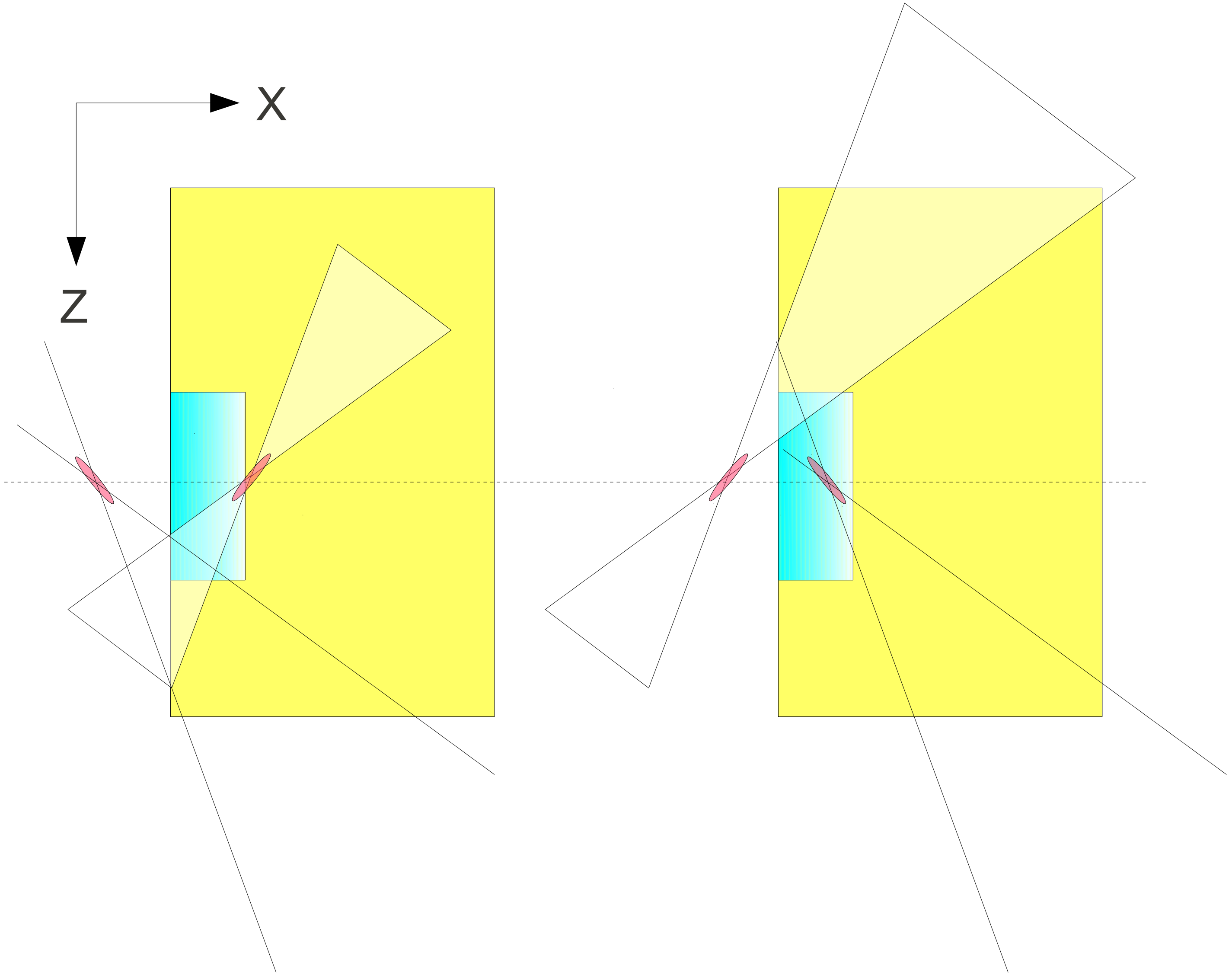
The SGIKER laser facility (I)

- SGIKER laser facility in Bilbao (Spain) is a service of the UPV for the academic community. Granted access via RD50 to the R&D laser + 1 staff expert (Raúl Montero).



Beam reflection at interfaces

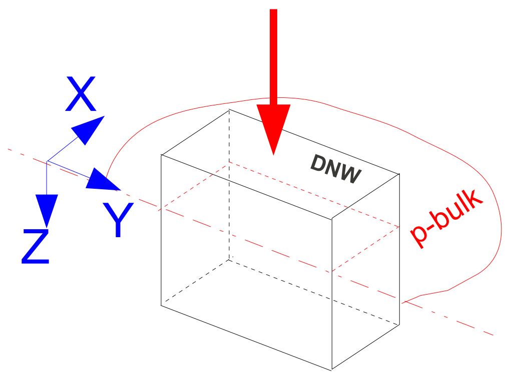




Once the focus exits the interface, we have a reflection inside the detector

TPA DUT rotations

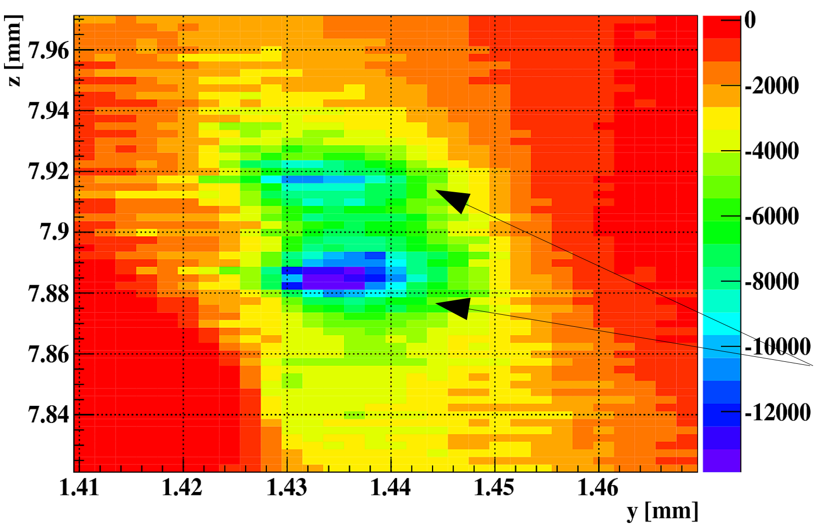
SPA has **2D** spatial **resolution**. It is quite **insensitive** to (small) rotations around X and/or Y axis. SPA is most **sensitive** to rotations around Z axis (beam propagation direction).



HVCMOS
XY=plane of junction (bulk)
XZ=perpendicular to junction

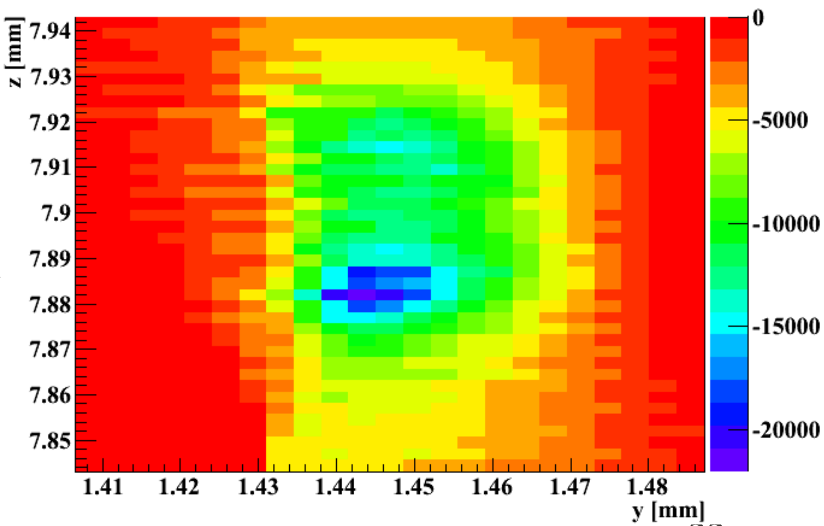
Similarly to SPA, a TPA XY scan is sensitive to rotations around Z axis. In a XZ scan, TPA is sensitive to Y-rotations.

Example: Edge-TPA YZ scan of HVCMOS bulk



Observed YZ tilt is a rotation around X axis. Manipulation by hand (time consuming)

Rotation around Y axis can be inferred as well



HVCMOS: correction of radiation induced SPA signal

Generation rate of e-h pairs per unit volume:

$$\frac{dN(r,t;i)}{dt} = \alpha \frac{I(r,t;i)}{\hbar\omega} + \frac{\beta_2 I^2(r,t;i)}{2\hbar\omega}$$

with $I(r,z)=\frac{2P}{\pi w(z)^2}\exp\frac{-2r^2}{w(z)^2}$ (assuming also Gaussian time dependence)

A Ge photodiode (linear response at 1300 nm) is used to measure laser power, which is proportional to the integral of the irradiance: *I(r, t ; i)*

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(r,z)\,drdz \;\propto\; P \qquad \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(r,z)^2\,drdz \;\propto\; P^2$$

Then:

$$Q_{DUT}=q_e N(i) \;=\; q_e\int_r\int_z\int_t N(r,t;i)\;dr\,dz\,dt \;=\; Q_\alpha(i)P \;+\; Q_{\beta_2}(i)P^2$$

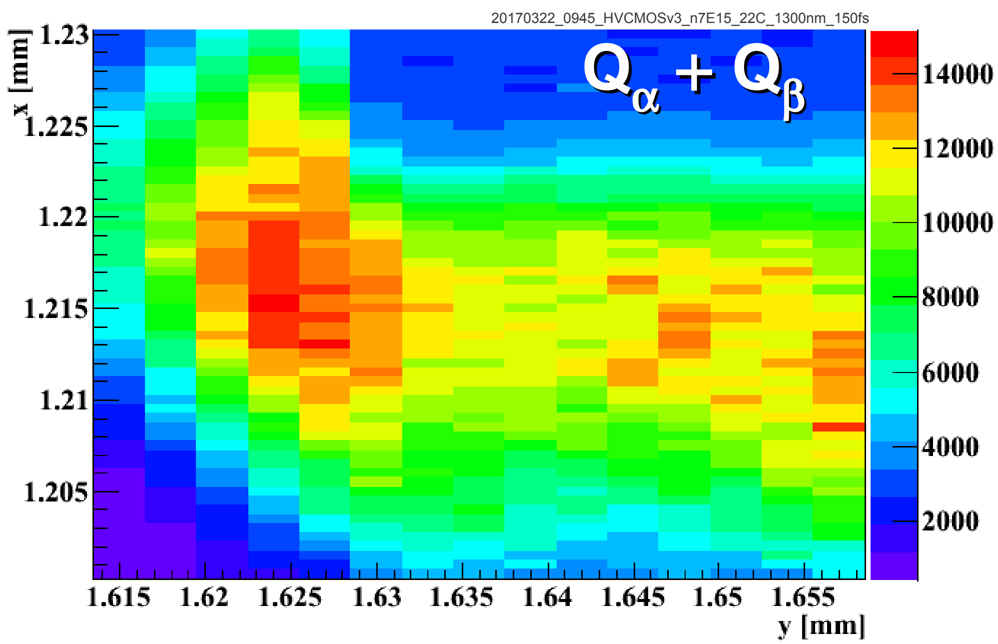
With Q_α and Q_β the SPA and TPA contributions to the signal.

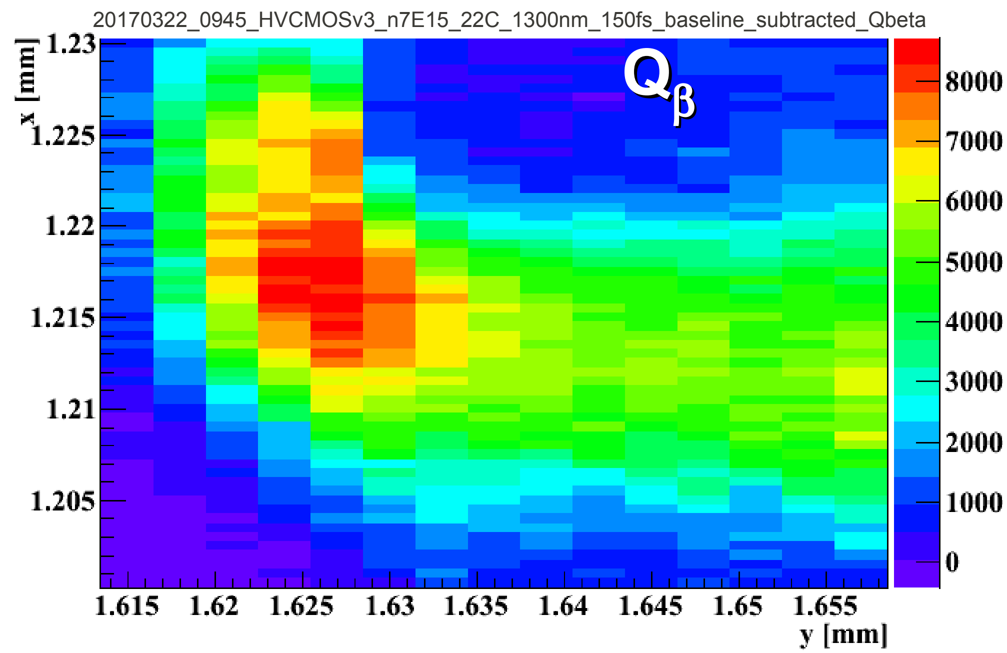
Now, we can take 2 identical measurements at 2 different intensities and calculate Q_β

$$\left.\begin{aligned} Q_1 &= Q_\beta P_1^2 + Q_\alpha P_1 \\ Q_2 &= Q_\beta P_2^2 + Q_\alpha P_2 \end{aligned}\right\} \qquad Q_\beta=\frac{\frac{Q_1}{P_1}-\frac{Q_2}{P_2}}{P_1-P_2} \qquad Q_\alpha=\frac{\frac{Q_1}{P_1^2}-\frac{Q_2}{P_2^2}}{\frac{1}{P_1}-\frac{1}{P_2}}$$

CERN RD50 IFCA Instituto de Física de Cantabria

HVCMOS_7×10^{15} n_{eq}/cm^2: SPA correction





Top left: SPA + TPA uncorrected
Bottom right: Typical Edge-TCT SPA signal
Top right: Corrected signal