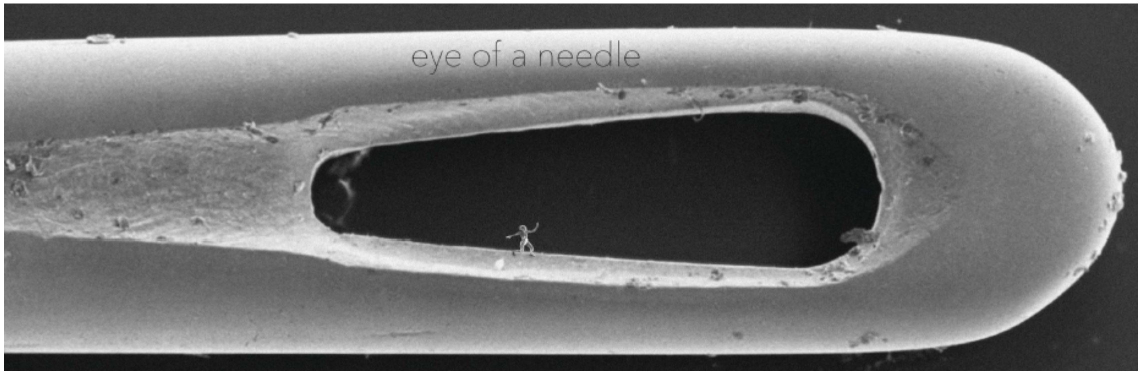
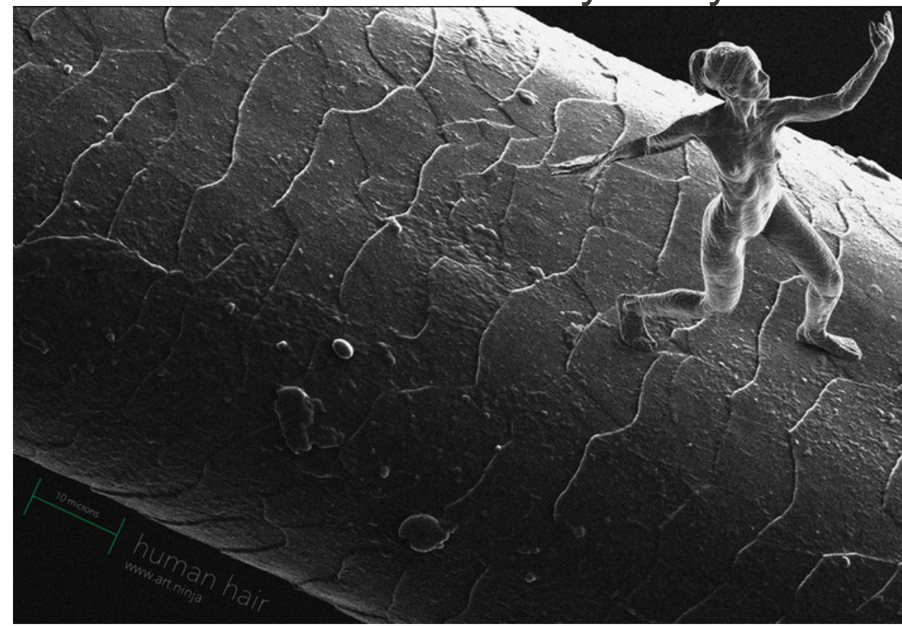
15TH VIENNA CONFERENCE ON INSTRUMENTATION

Art by Jonty Hurwitz





High resolution 3D characterization of silicon detectors using a **Two Photon Absorption** Transient Current Technique

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Universidad de Sevilla
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Outline

What is TCT and TPA?

The setup(**s**)

Examples of application in Si:

- Diodes
- HVCMOS

} Irradiated and non-irradiated

Summary

Two Photon Absorption-Transient Current Technique (**TPA-TCT**) is a **new technique** to characterize semiconductors detectors using a **point-like** laser **probe**, so called “**voxel**”. A voxel can be **scanned in the three coordinates**, thus obtaining true **3D spatial resolution**.

Transient Current Technique

R&D on radiation hardness of Si sensors

CERN — IFCA Instituto de Física de Cantabria

+

Two Photon Absorption

Test of Single Event Effects on electronics — Universidad de Sevilla

Ultrafast molecular spectroscopy — eman ta zabal zazu UPV EHU

TPA-TCT

This mixture has been possible via RD50 collaboration

What is TCT?

Technique to characterize a material via the transport of **excess carriers** generated typically using a **laser** beam.
E-field profile, **space charge**, charge collection efficiency, trapping.. can be reached.

Induced current pulse is **time resolved**, measured, and analyzed.

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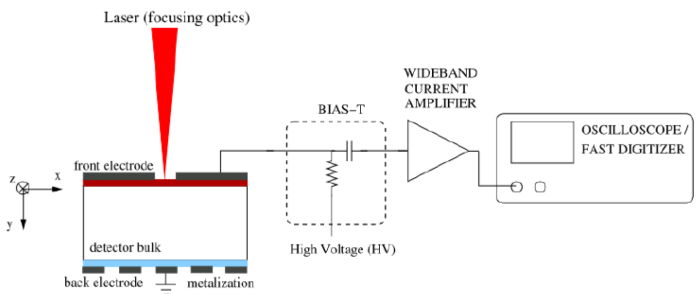
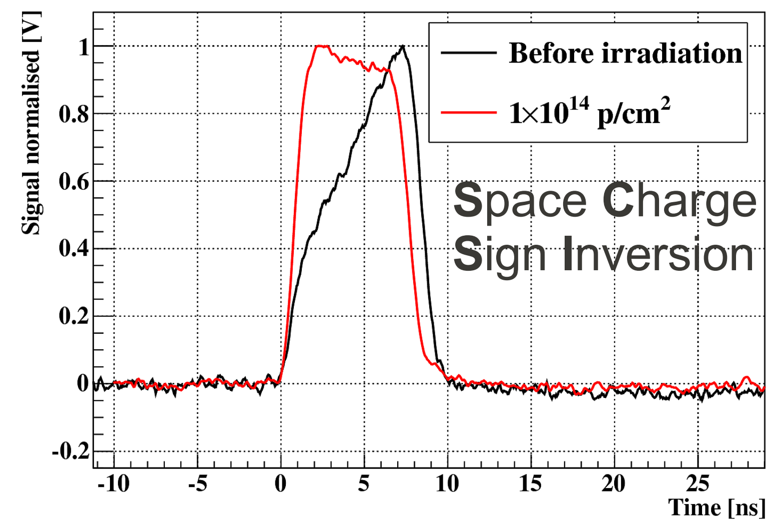


Induced current pulse is **time resolved**, measured, and analyzed.



From **early 1990s** widely used for measurements of radiation effects in semiconductors.
Workhorse for **ROSE** and **RD50** collaborations.

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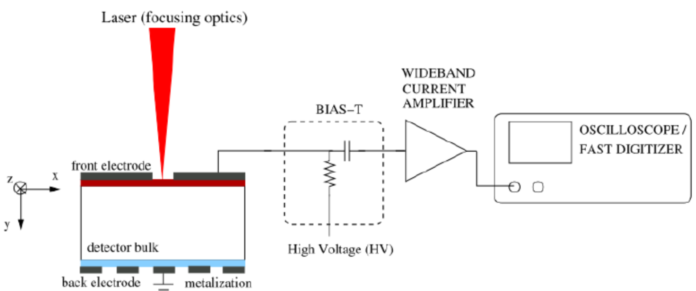

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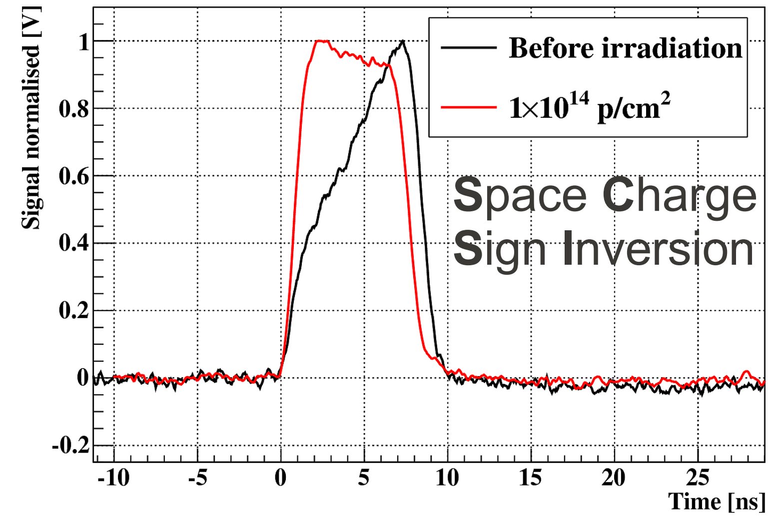
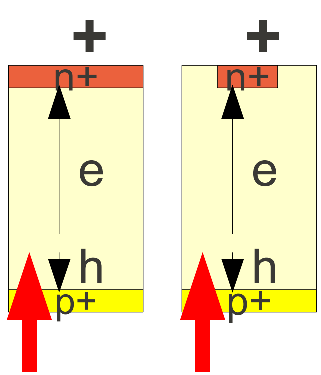
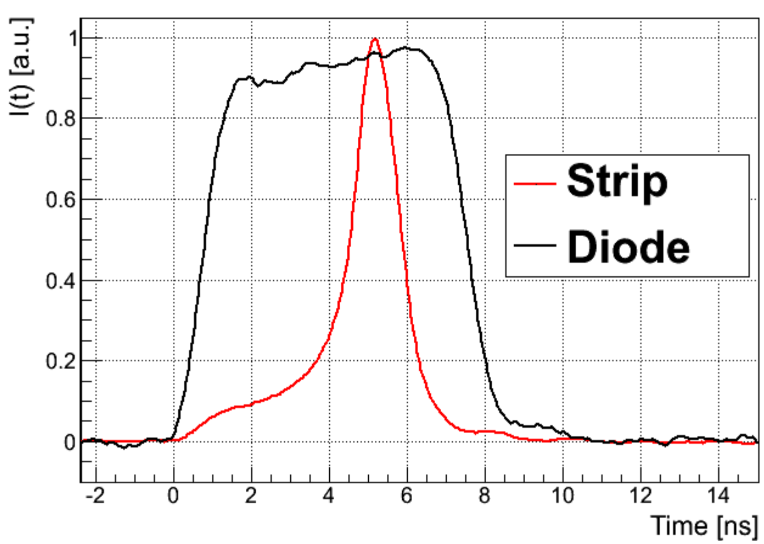
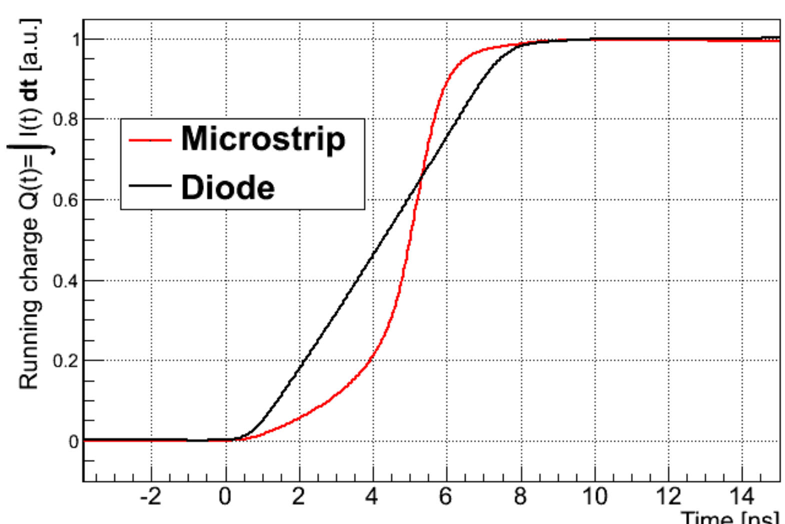


From **early 1990s** widely used for measurements of radiation effects in semiconductors.
Workhorse for **ROSE** and **RD50** collaborations.

Sensitive to product of **drift** and **weighting field**







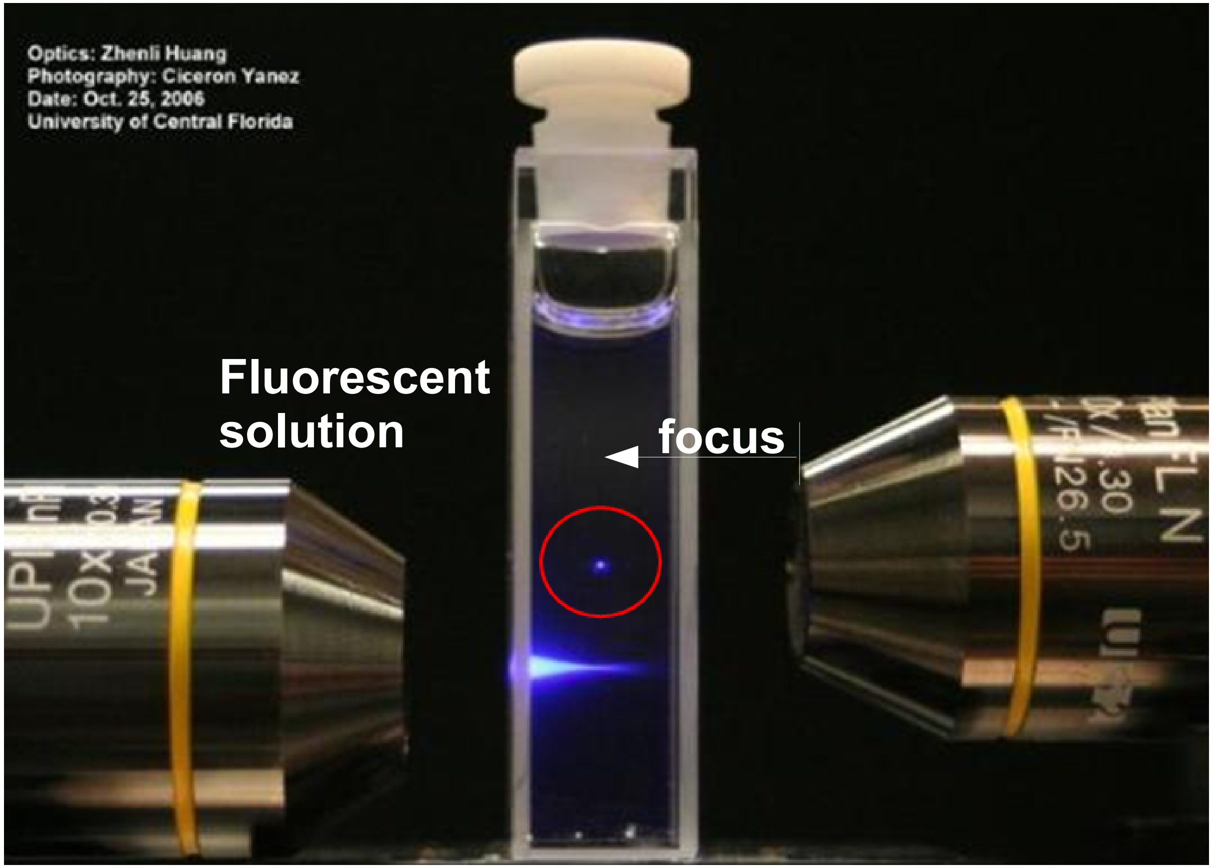
What is TPA?

- TPA is a **non-linear effect** shown by any material when illuminated with a **high intensity** source (for instance, a laser). For certain wavelengths, light absorption (=signal) only happens **at the focus** of the beam. No photons are absorbed “out of focus”. The more light is focused, the better “point-like” signal generation volume.
- The physical phenomena exploited is the **simultaneous absorption of 2 photons** in the material

OLD

Single Photon Absorption

Continuous energy deposition (no spatial resolution along beam prop. dir.)



NEW

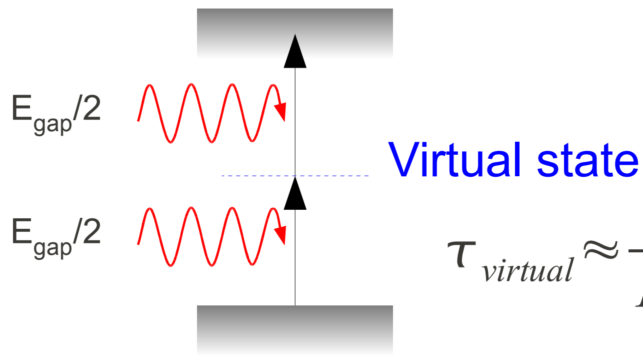
Two Photon Absorption

Energy confinement

Two photons from one laser !!

Two Photon Absorption

TPA: Conventionally, no excitation if $E_{photon}<E_{gap}\sim1$ eV.
But, if **TWO** photons arrive in ~100 attoseconds:

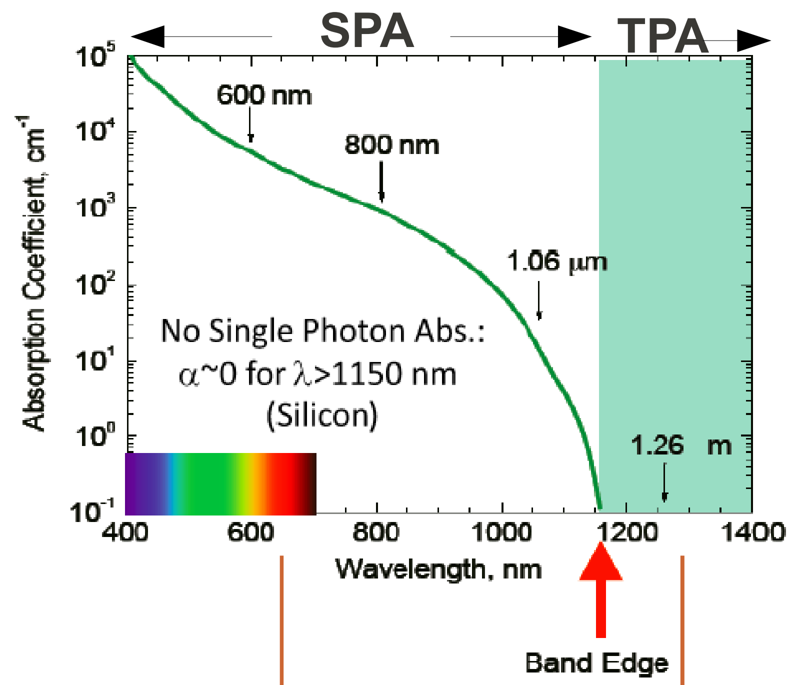


$$\tau_{virtual} \approx \frac{\hbar}{E_{gap}/2} \approx 0.1\ fs$$

Two Photons ($E>E_{gap}/2$) must be:

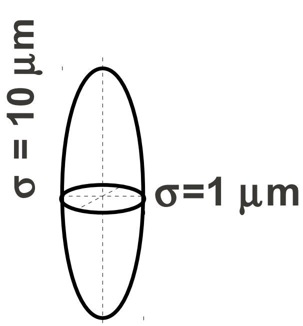
1) coincident in time (pulsed **mode-locked fs-lasers**)
2) and in **space** (**microfocusing**)

Absorption in Si



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

Spot size



×100 objective

Measured using knife edge technique.

This is the **3D probe** we scan across the volume of the detector

SPA

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

Negligible $\lambda \geq 1100$ nm

TPA

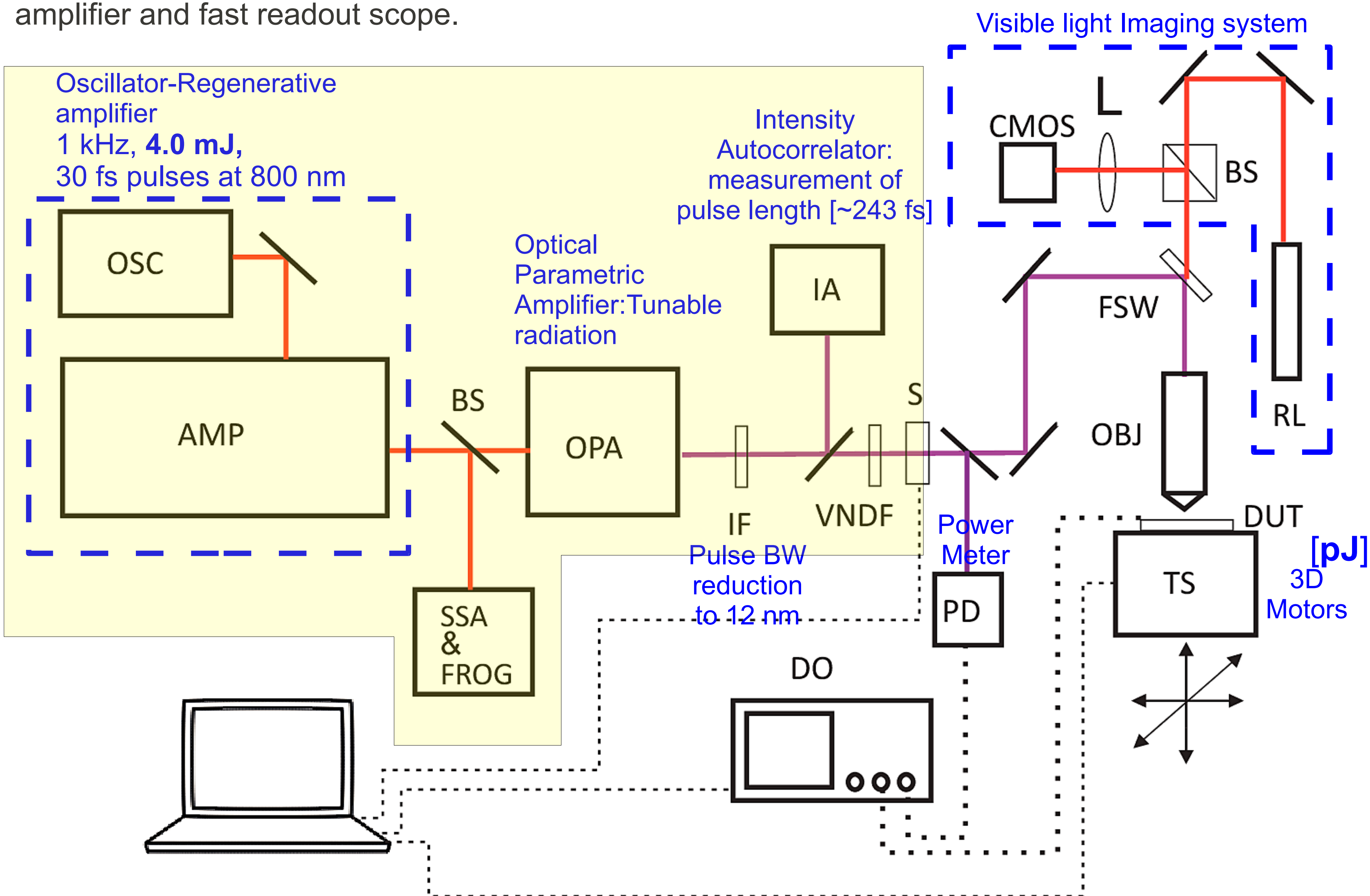
Two **P**hoton **A**bsorption
Point-like resolution

Boosted by using short pulsed fs lasers, where $I^2>>I$ for the same average power laser.

TPA-TCT in UPV laser facility

RD50 · sgiker Ikerkuntzarako Zerbitzu Orokorrak · Servicios Generales de Investigación · UPV EHU

- **Tunable** wavelength, energy for the sensor (after attenuation) [~pJ]. Then typical **TCT readout**: top/side injection, 3D system, current amplifier and fast readout scope.



New CERN TPA-TCT

TPA-TCT presented at 2016 CERN EP-**Knowledge Transfer** innovation day
→ It was selected for funding: Proposed Project on non-destructive QC of semiconductors

Status:

- The core of this system is a **custom fibered laser** working at 1.5 μm. It is being delivered this March 2019 after ~1 year development by Laser company.

- Rest of the system is based in our already existing SPA-TCT at CERN-SSD lab (known as TCT+).

- Some key differences / improvements:

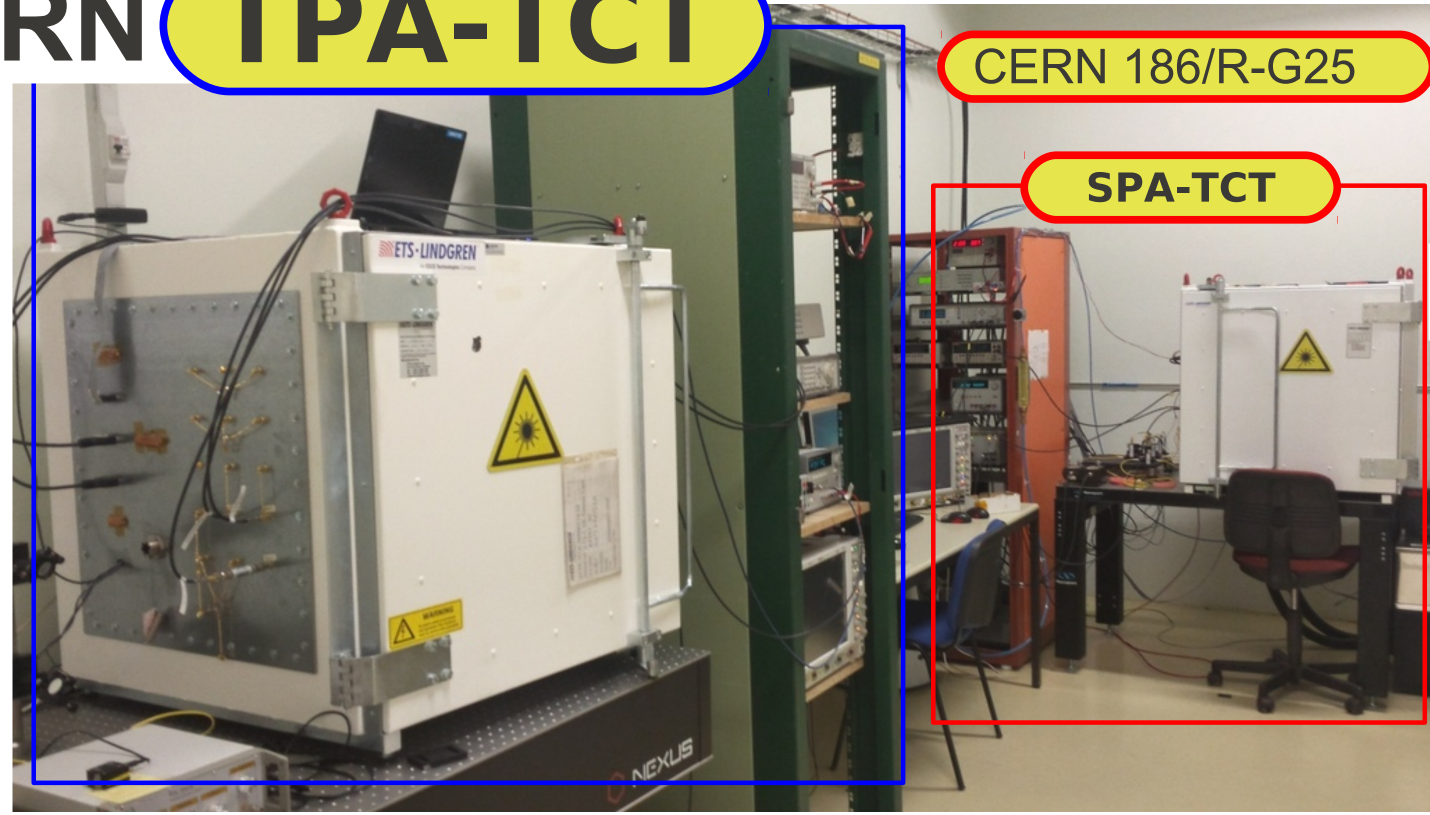
  - **Improved positioning system** (6 degrees of freedom hexapod system)
  - **Optimal cooling and sample support**. It can be rotated for edge-side injection

- German Doctoral Student (M.W., Gentner Program) responsible for construction of this demonstrator.

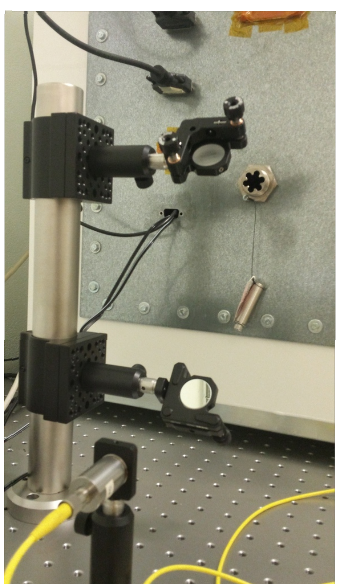
- Upon completion of the project access to this laser via RD50 collaboration.

New CERN TPA-TCT

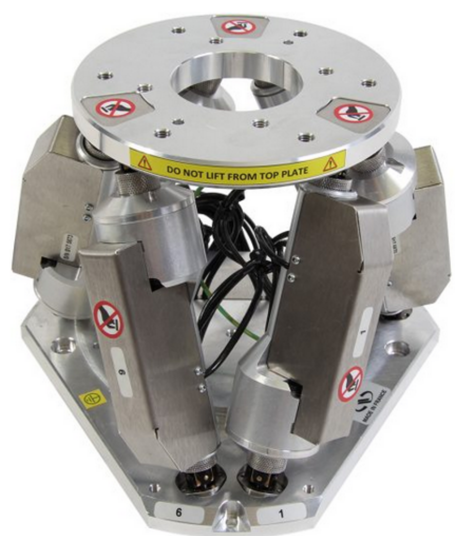
Status as of Feb 15th, 2019



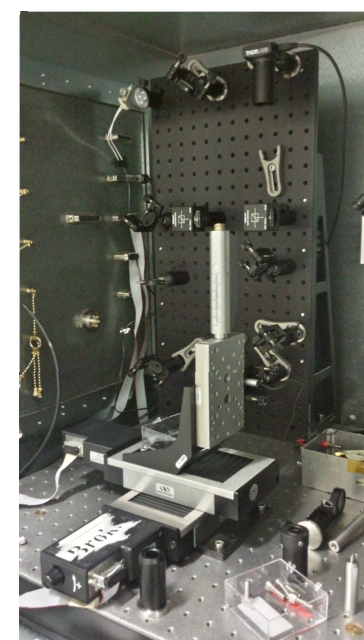
Light injection system



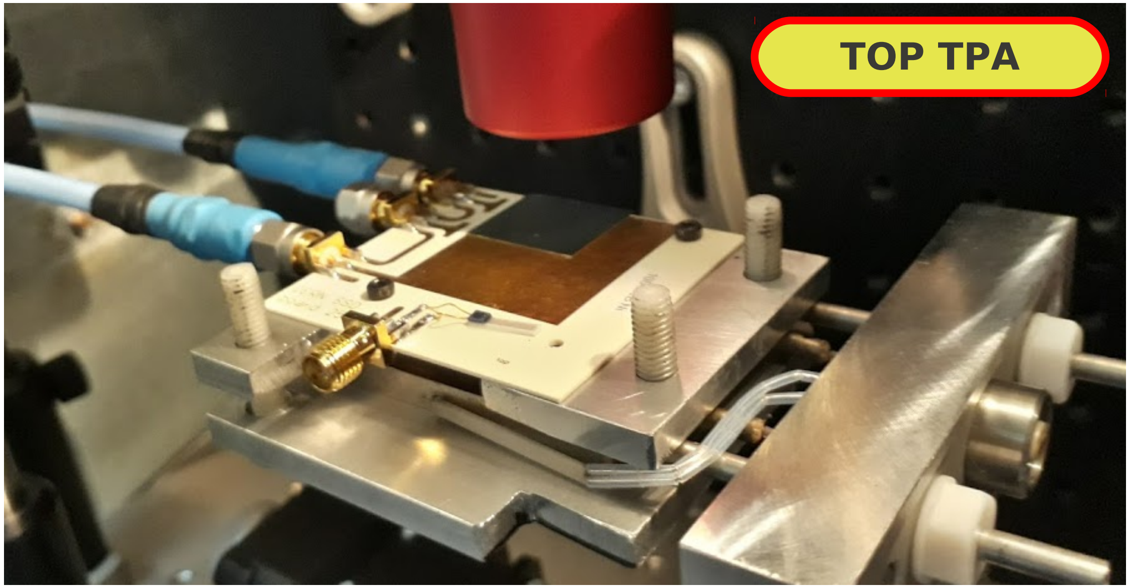
6 degrees of freedom, high load capacity motion system



Laser routing, microfocusing, visible laser imaging system, cooling, stage system inside Faraday Cage.

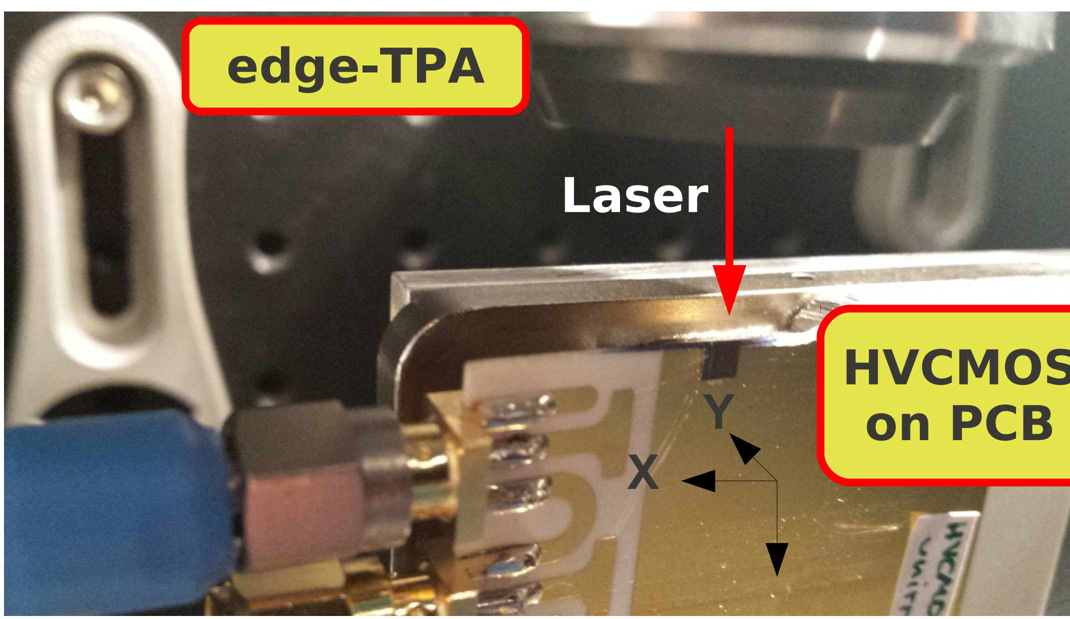


TPA-TCT light injection



In both illumination configurations, the focus is fixed and the detector is moved

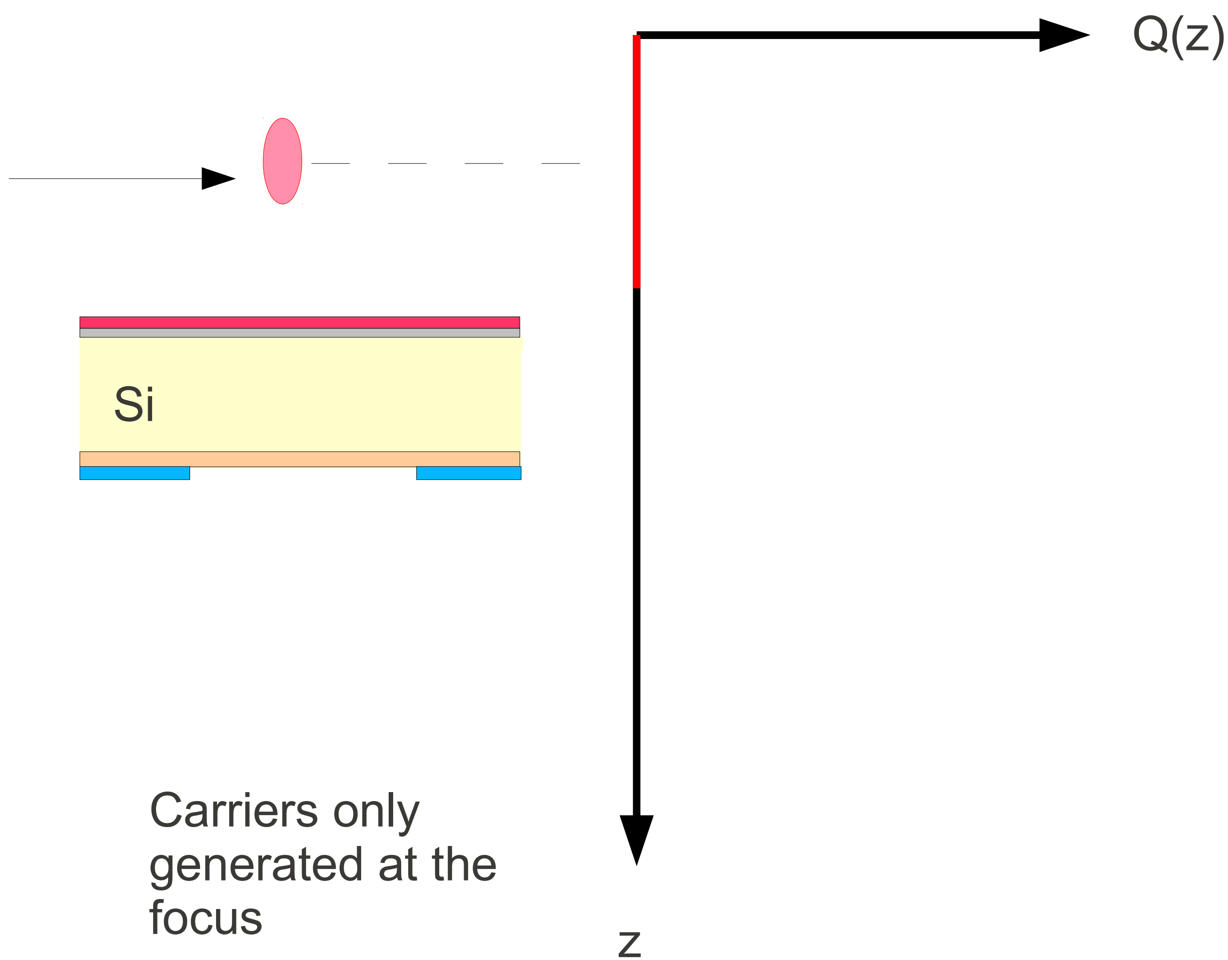
Top-TPA: detector is scanned in vertical → depth scan (10 μm resol.)



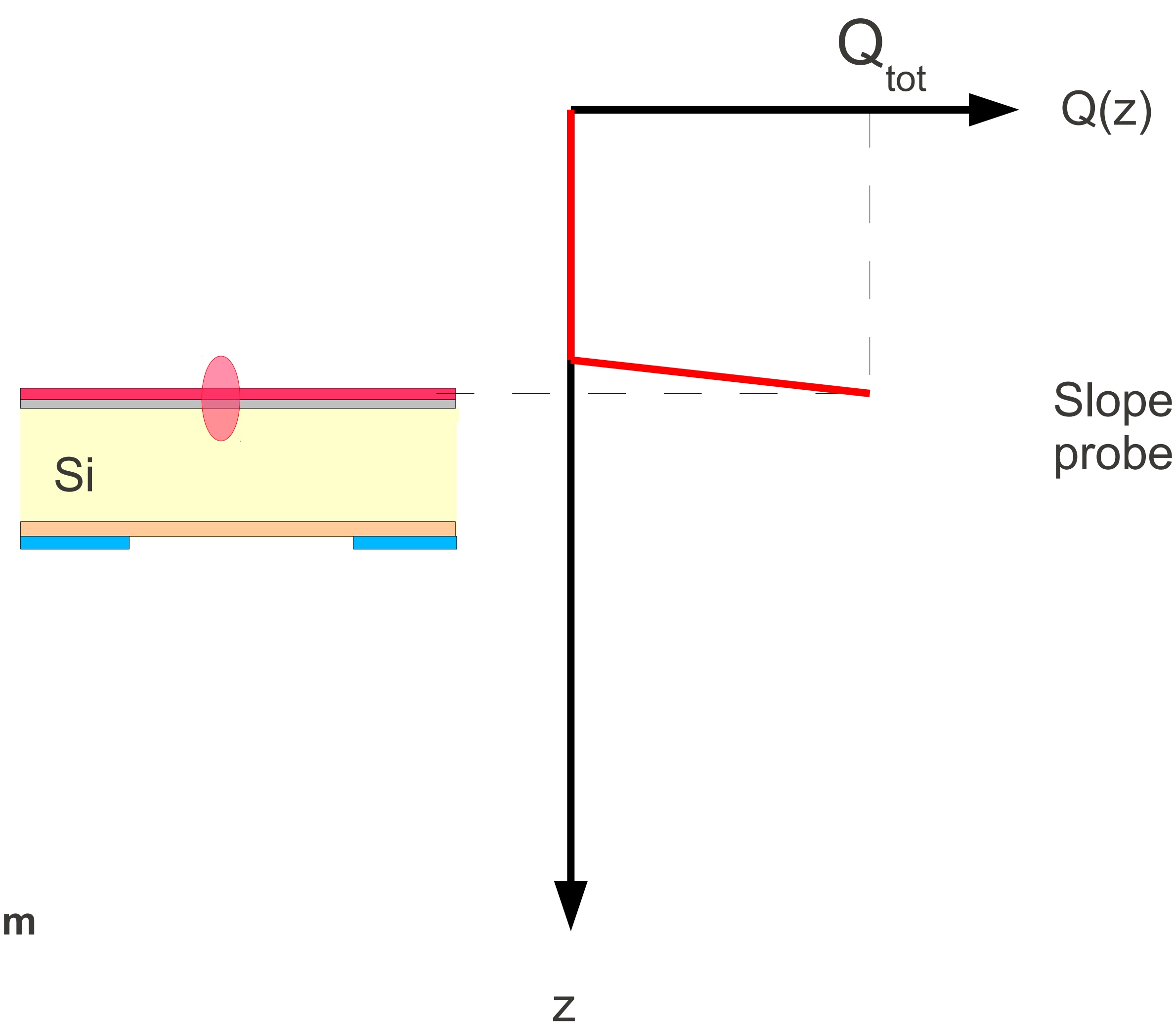
Rotating the detector by 90 degress, we can, for instance, map the depletion region with 1 μm resolution: **edge-TPA**

TPA top injection

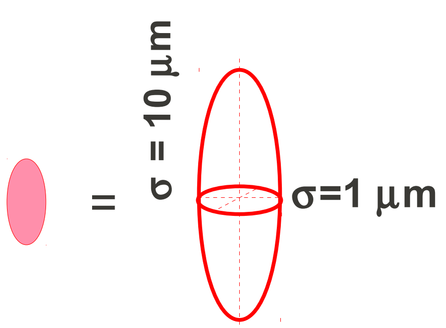
▪ **TPA:** For simplicity, here moving the focus wrt the detector.
In real measurements, the detector moves.
▪ Assuming fully depleted detector
▪ Laser probe → Excess charge carriers → Induced Current → Showing integrated current vs position



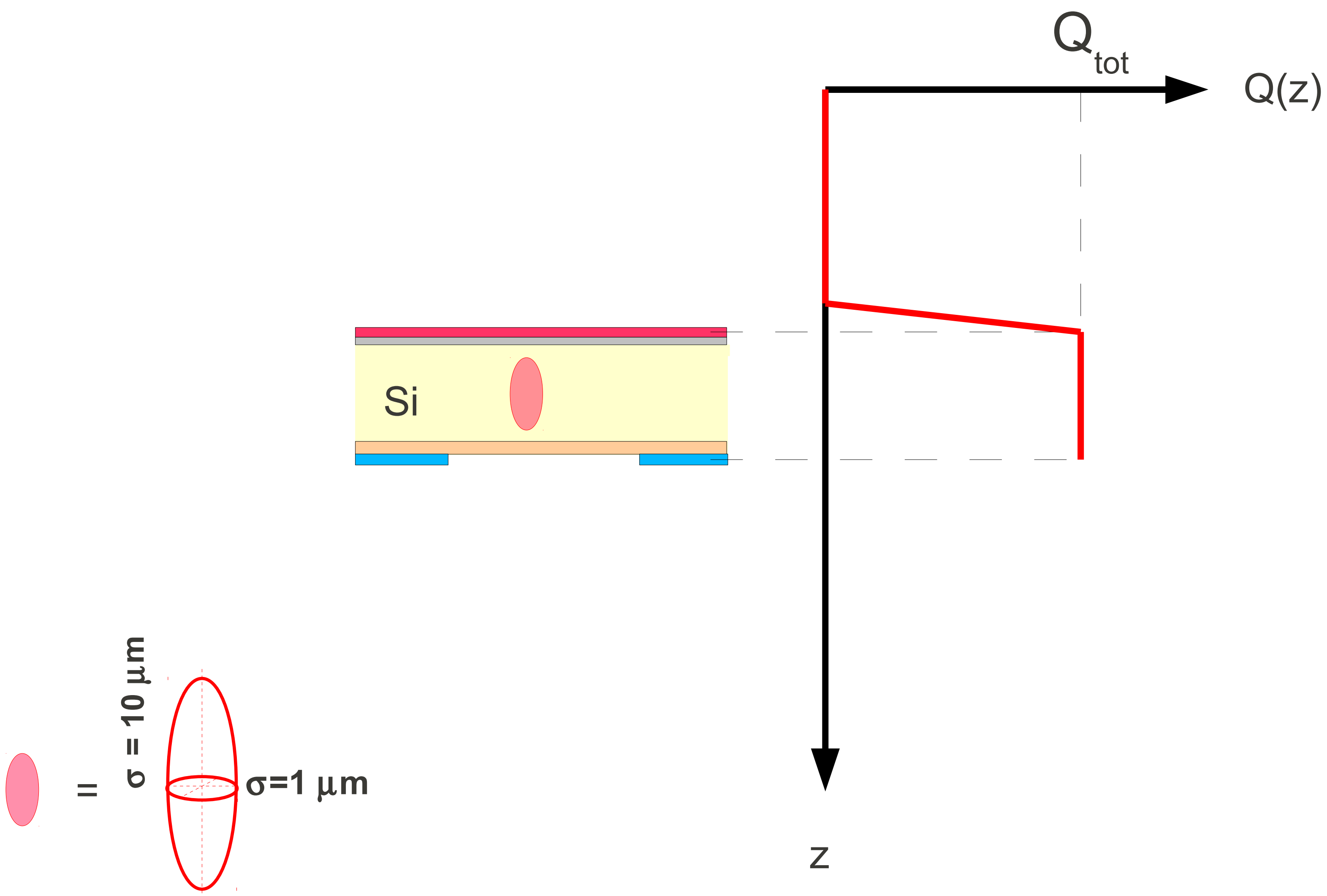
TPA top injection



Slope proportional to probe length

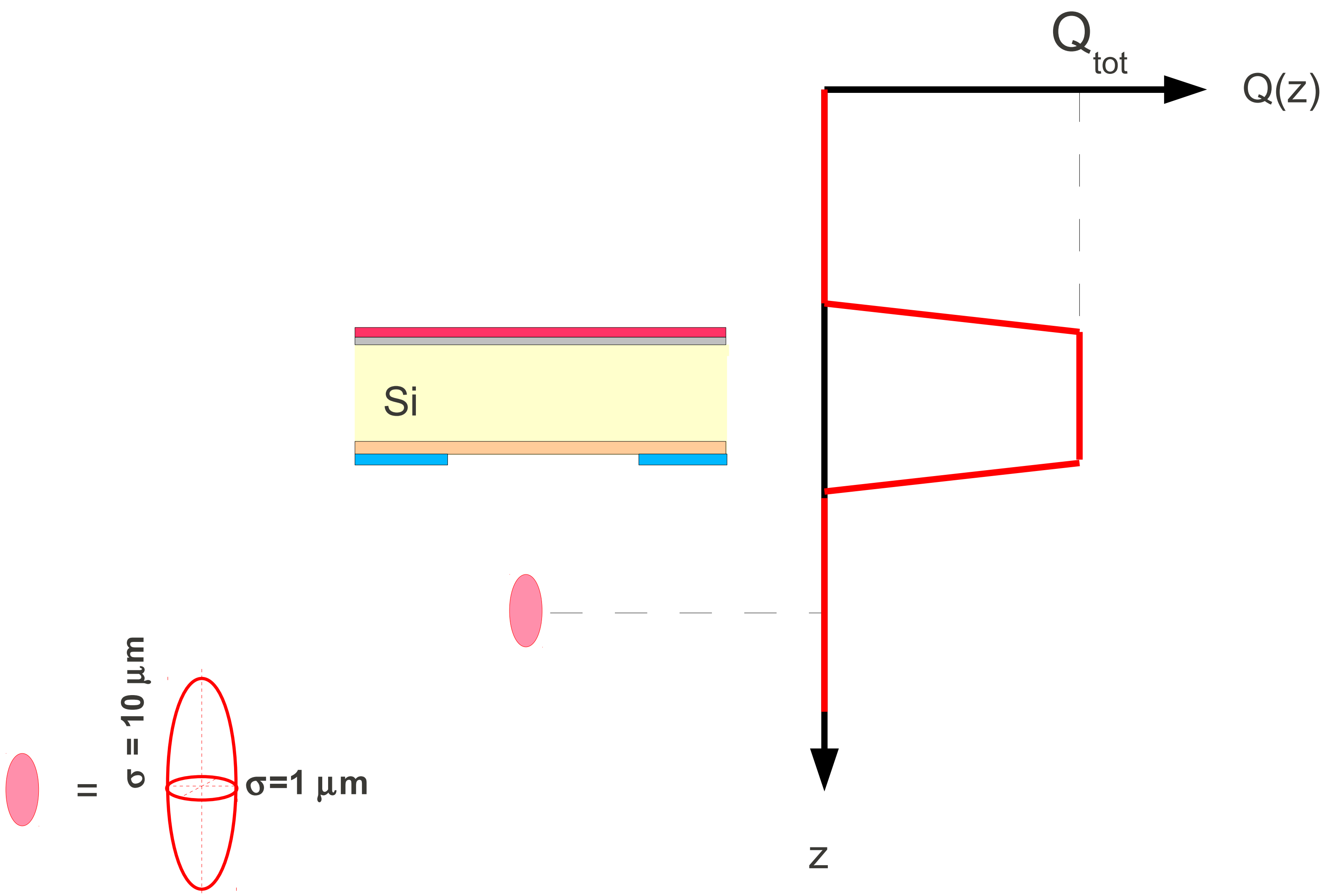


TPA top injection

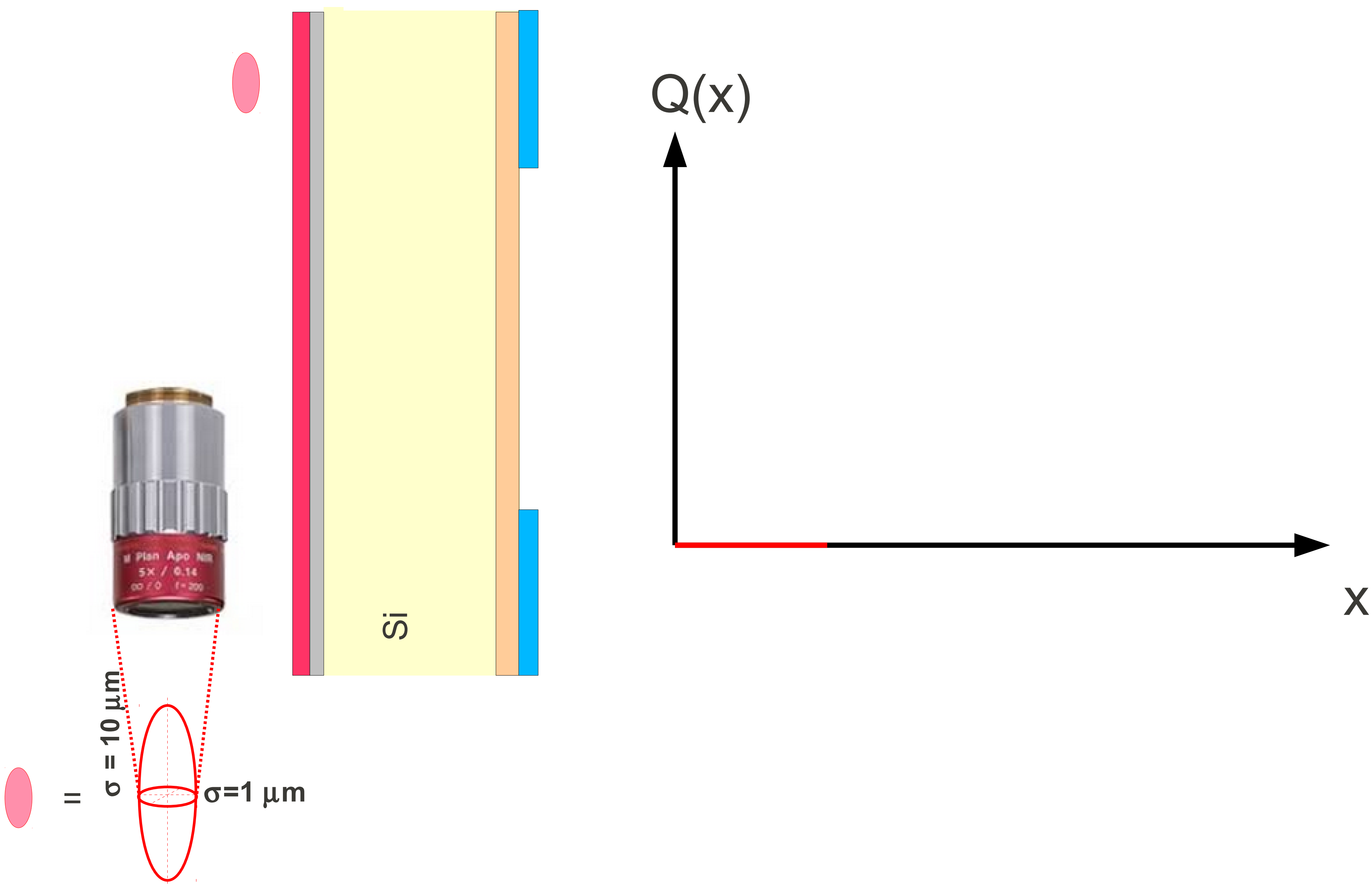


TPA top injection

No light absorbed before/after the focus
A depth scan of the detector is done from the top!
Measurements not affected by side effects, guard rings...



TPA edge injection



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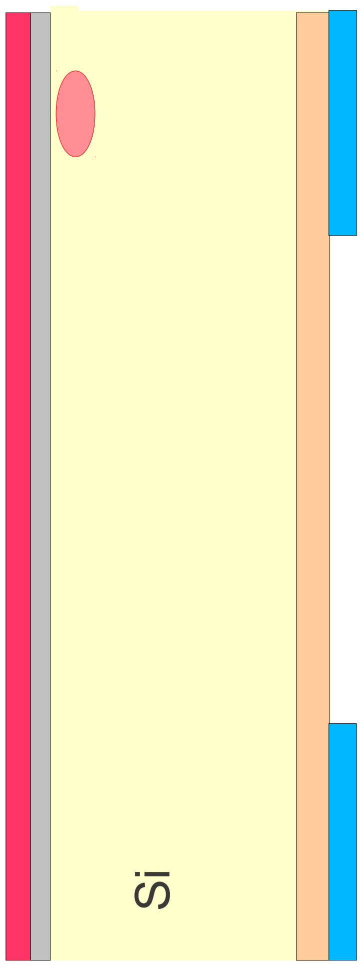
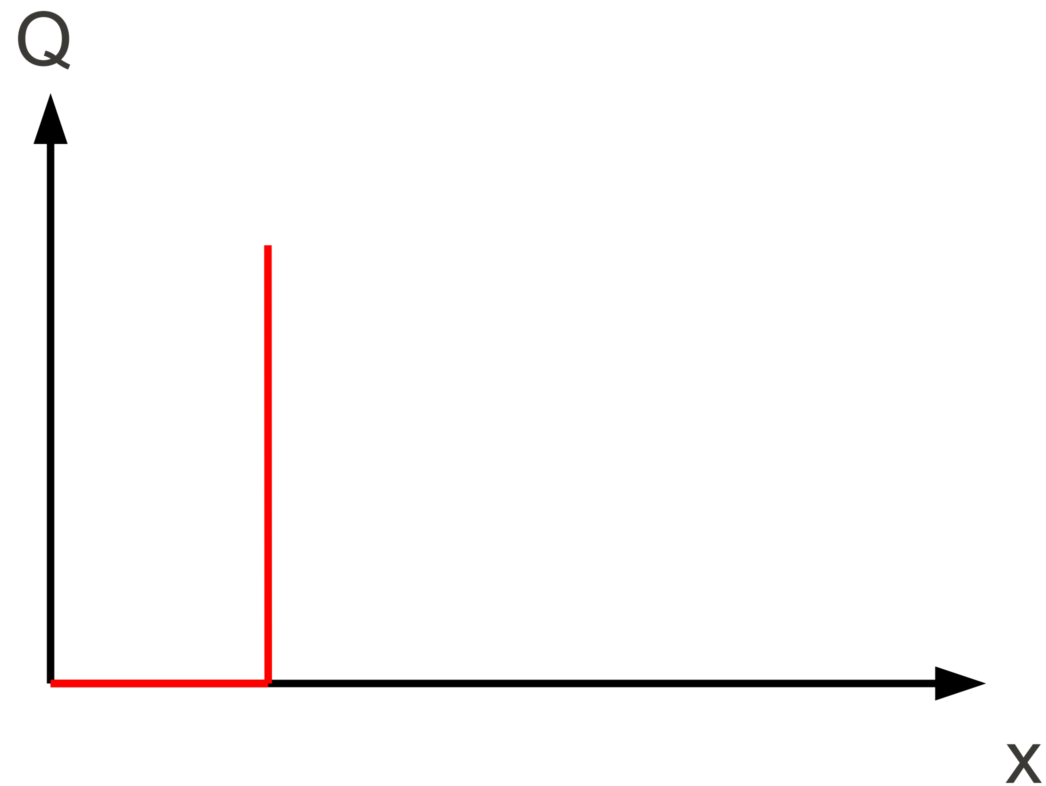
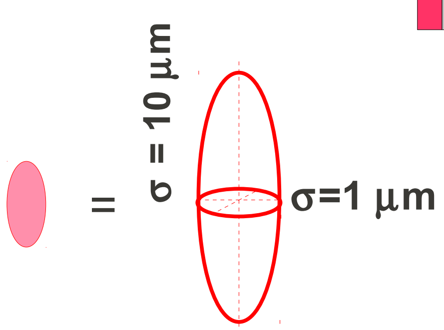
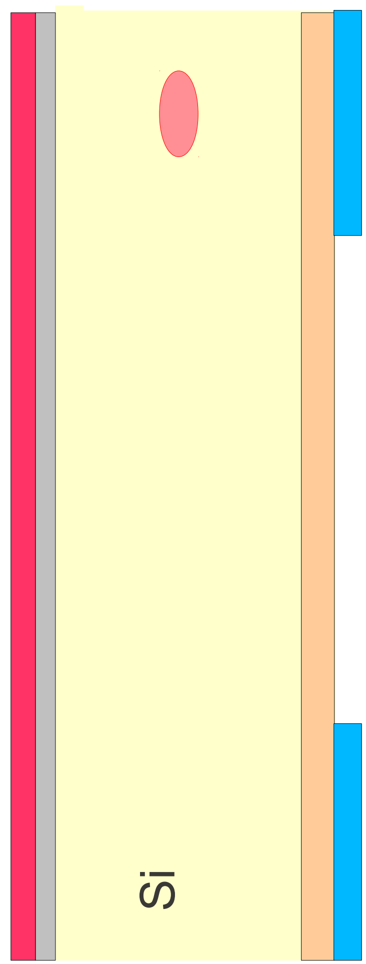


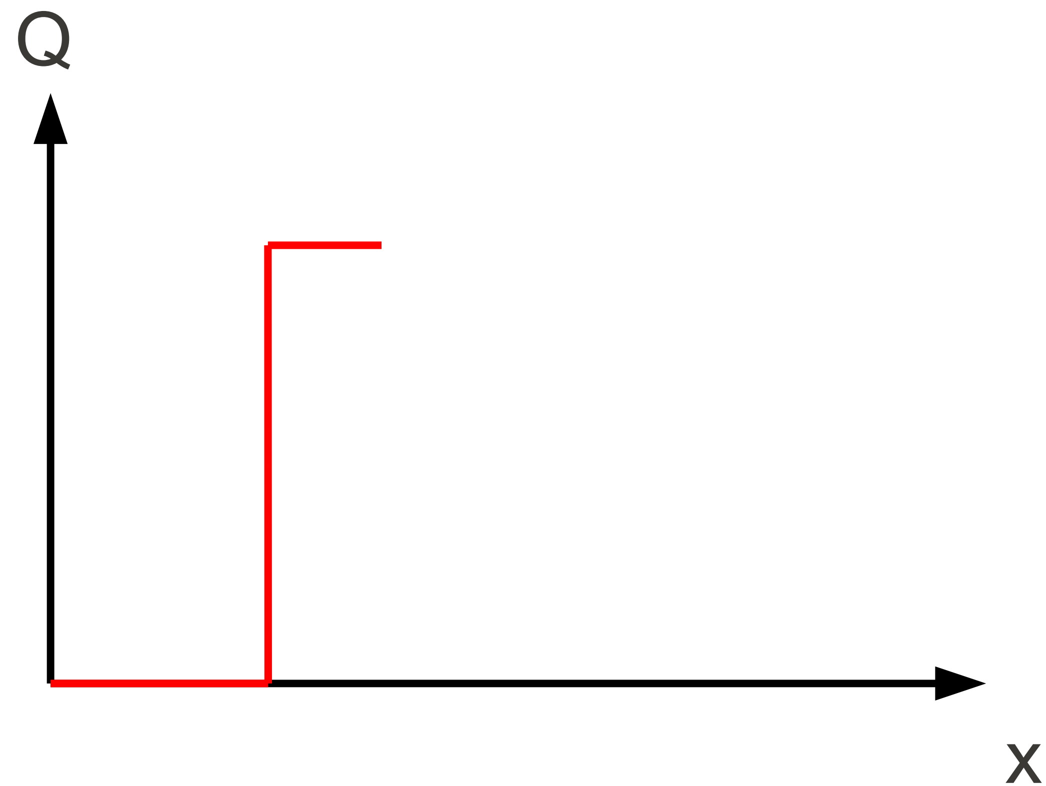


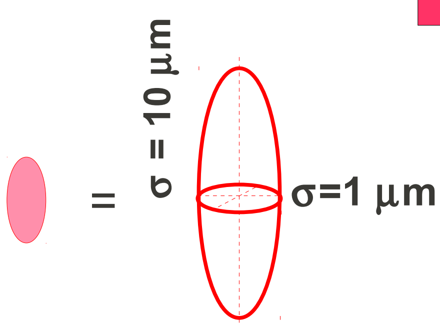
Very sharp transition because of 1 µm beam waist



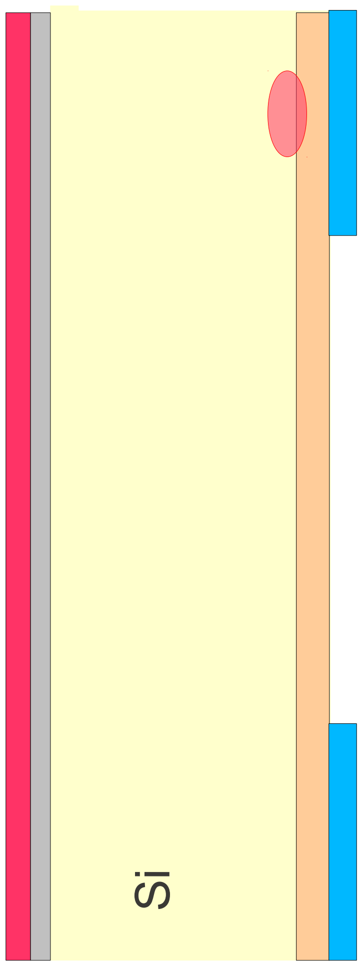
TPA edge injection

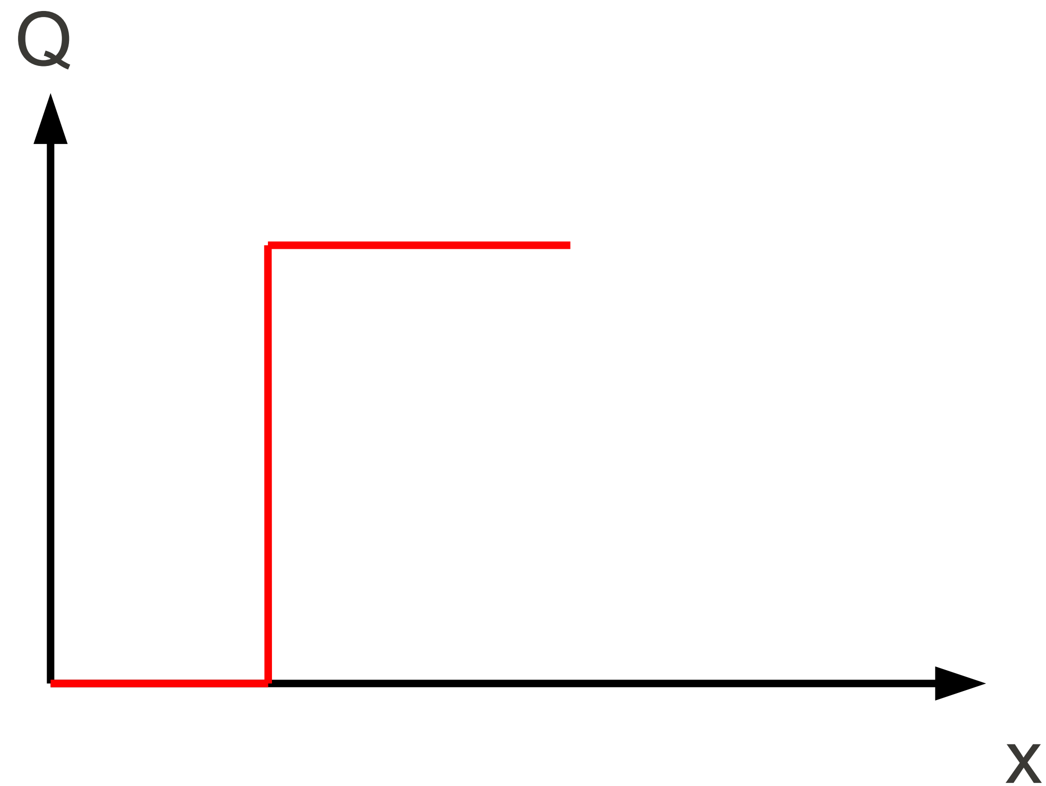


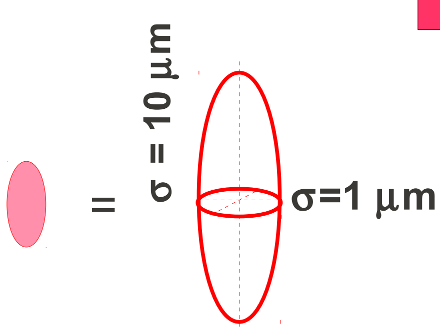




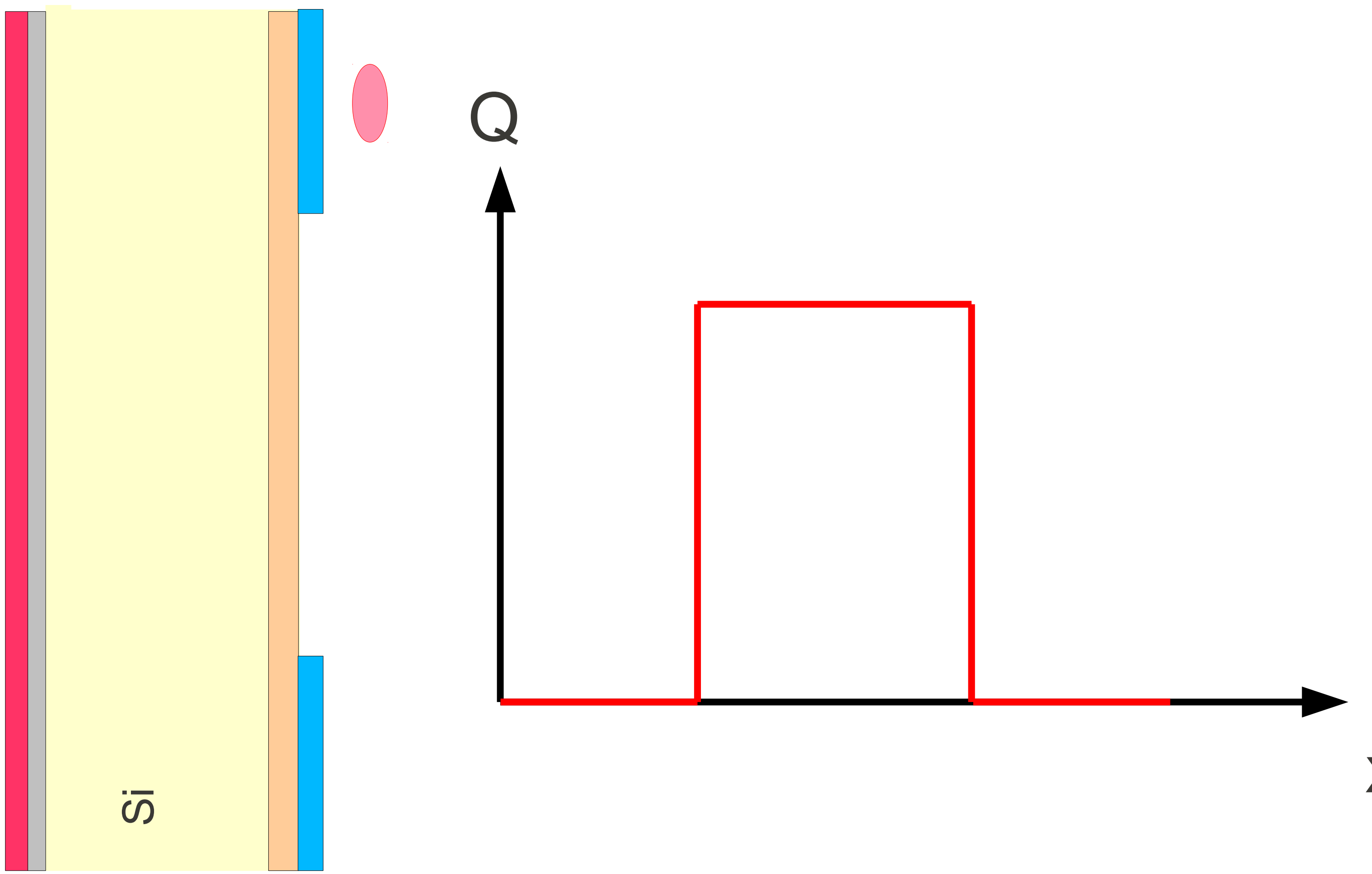
TPA edge injection

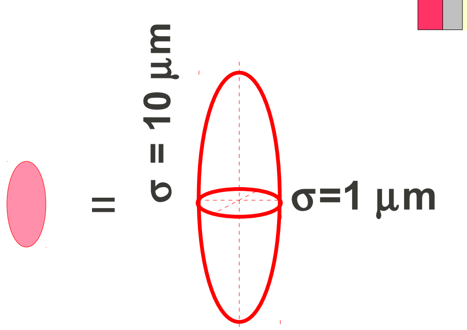






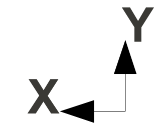
TPA-TCT edge injection



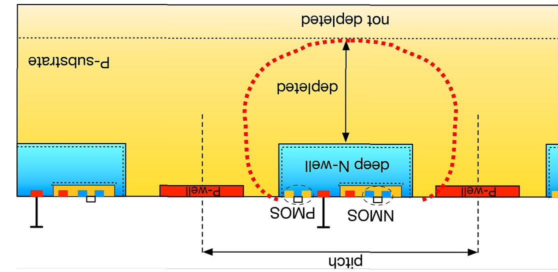


Depth scan of the detector is done from the side with the best resolution achievable in this method

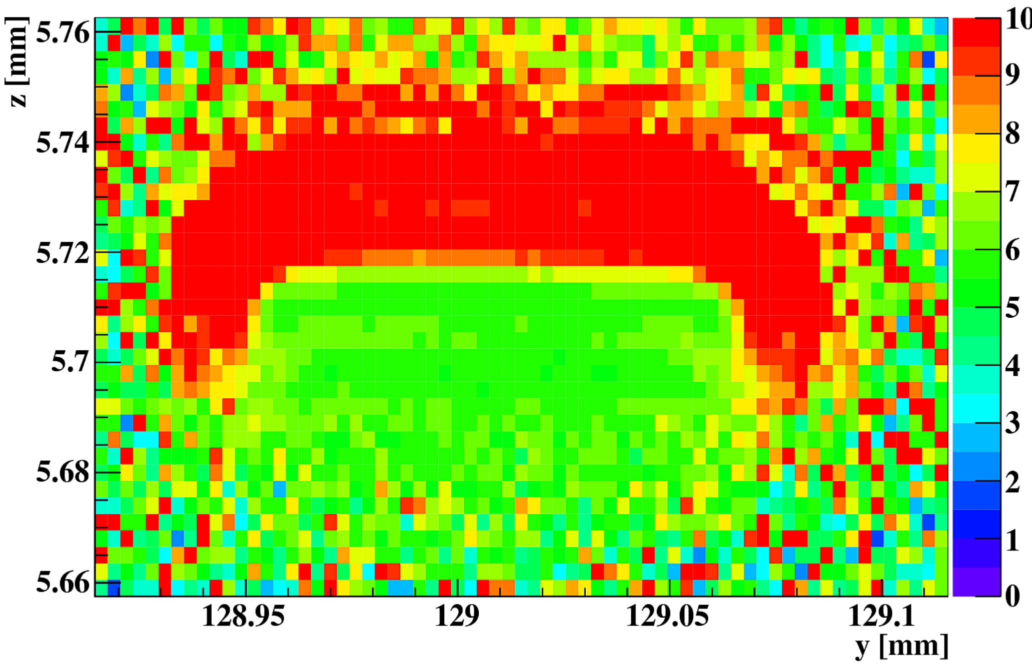
Edge-TPA: unirradiated HVCMOS



- HVCMOS is a partially depleted sensor, built on commercial CMOS technology.
Substrate of **very low resistivity** → very narrow depletion width (~**10 μm at 100 V**). **Challenging detector for SPA-TCT**



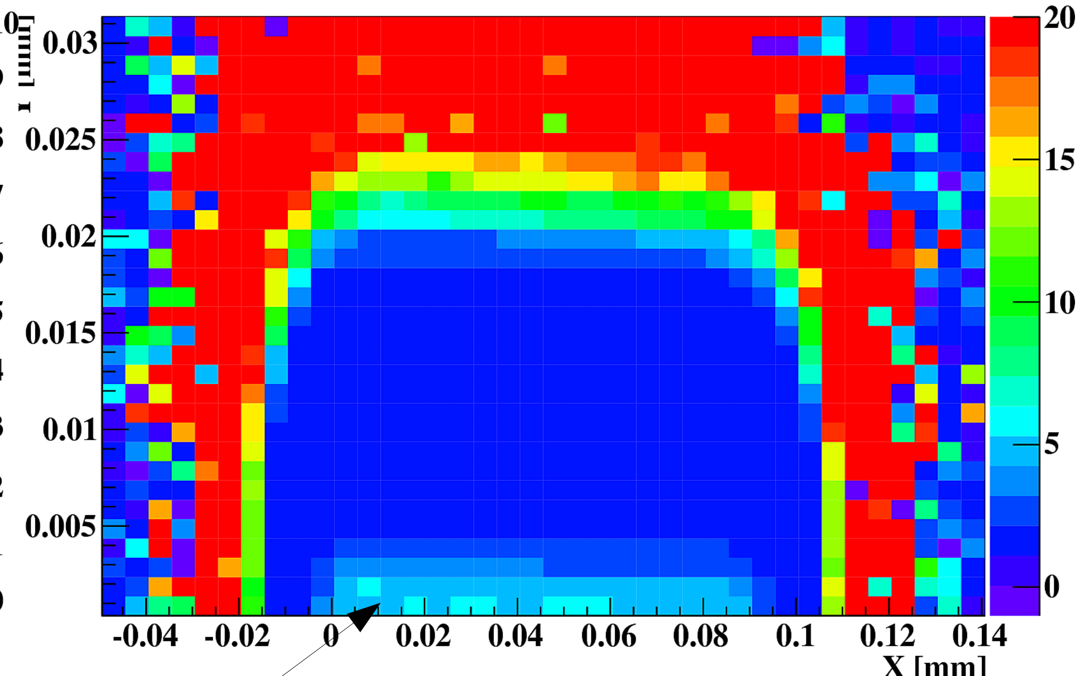
Standard SPA-TCT



Spatially continuous laser source, ps pulses

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

TPA-TCT



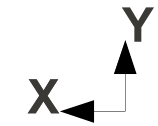
Point-like laser source, fs pulses

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

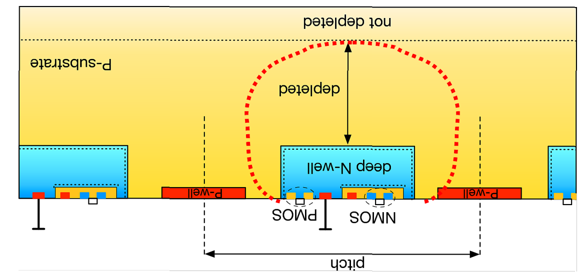
- Showing 2D map of the **collection time** of charge carriers (time lapse till 98% charge is collected). Very sensitive to creation point of carriers.

Substructures resolved with TPA-TCT

Edge-TPA: unirradiated HVCMOS



- HVCMOS is a partially depleted sensor, built on commercial CMOS technology.
  Substrate of **very low resistivity** → very narrow depletion width (**~10 μm at 100 V**). **Challenging detector for SPA-TCT**



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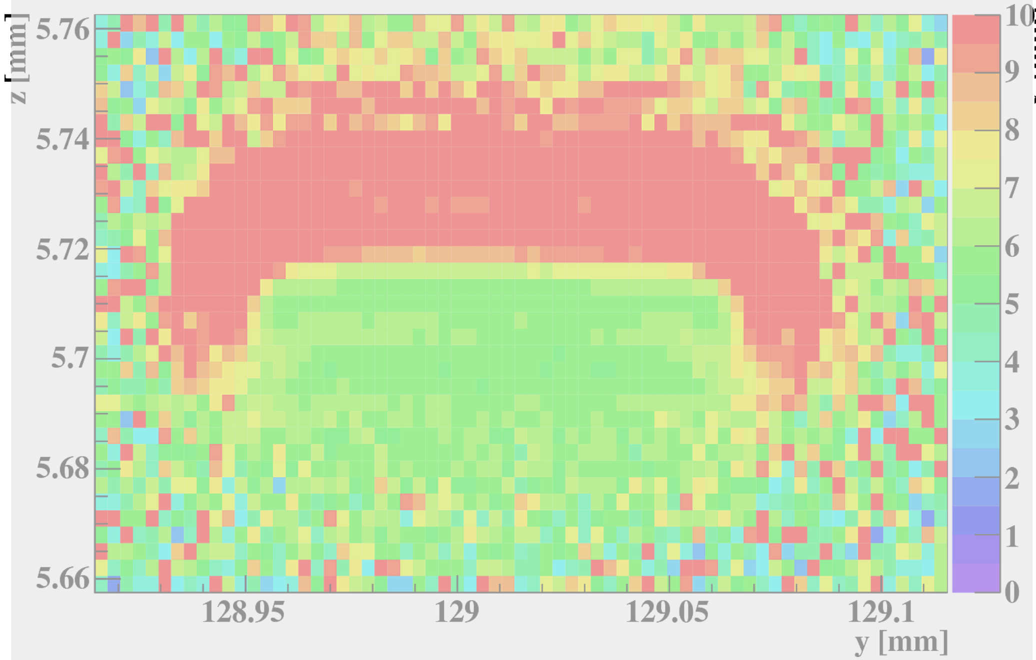

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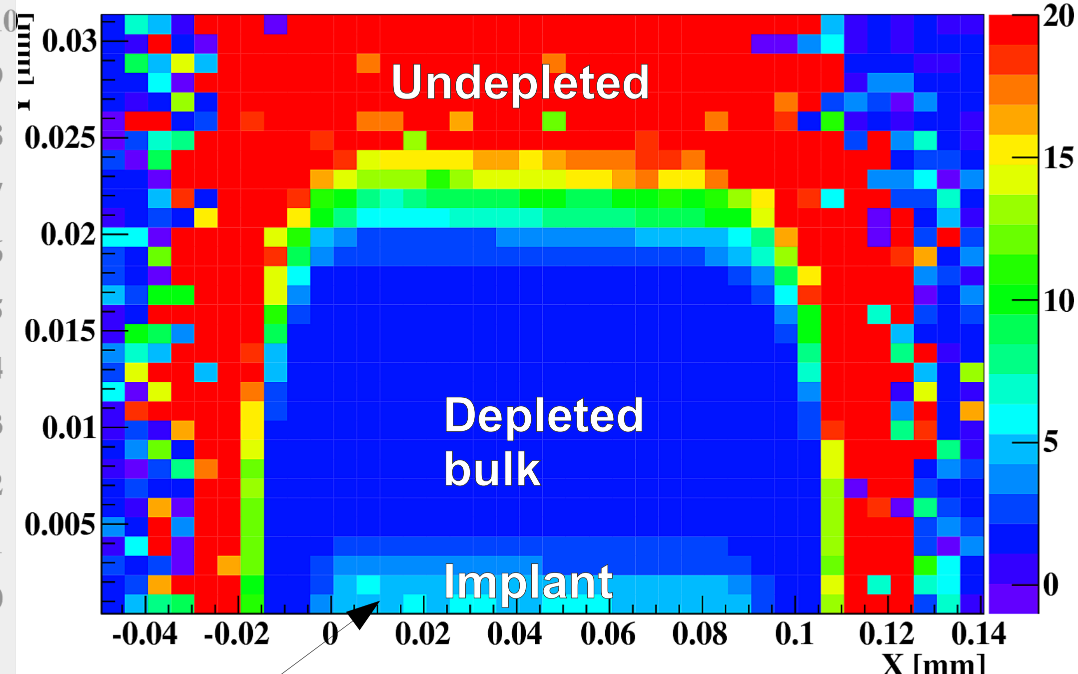
TPA-TCT



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

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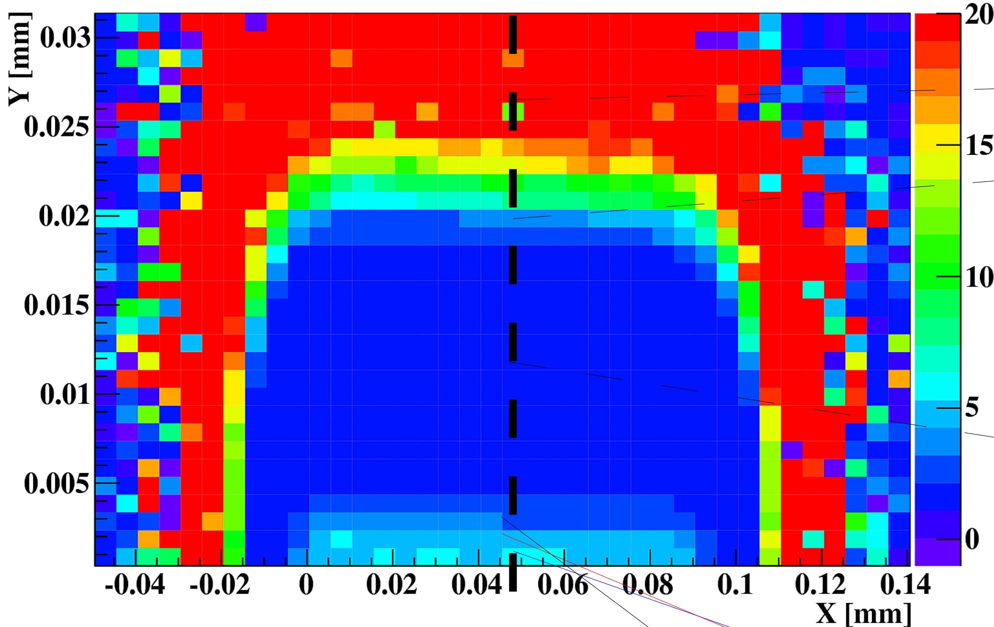
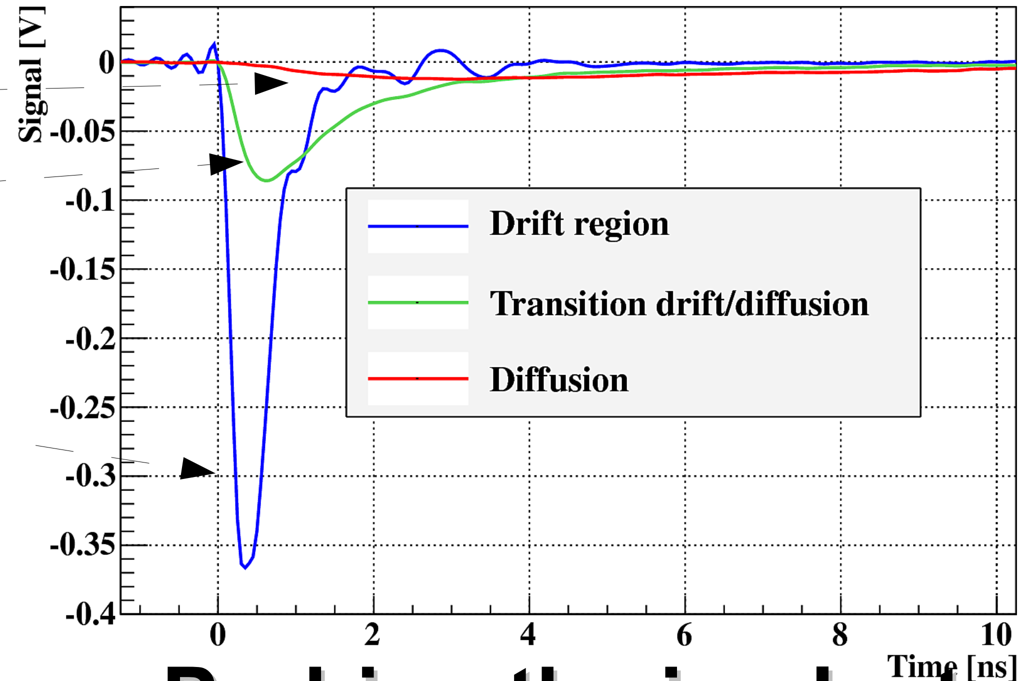
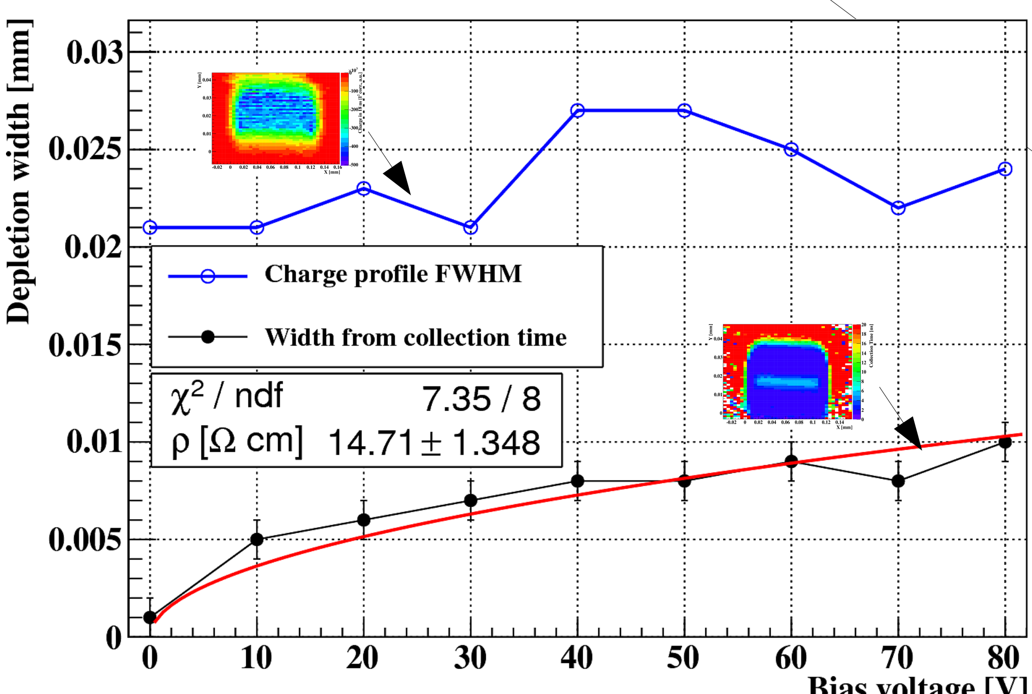
Substructures resolved with TPA-TCT

Drift/diffusion discrimination

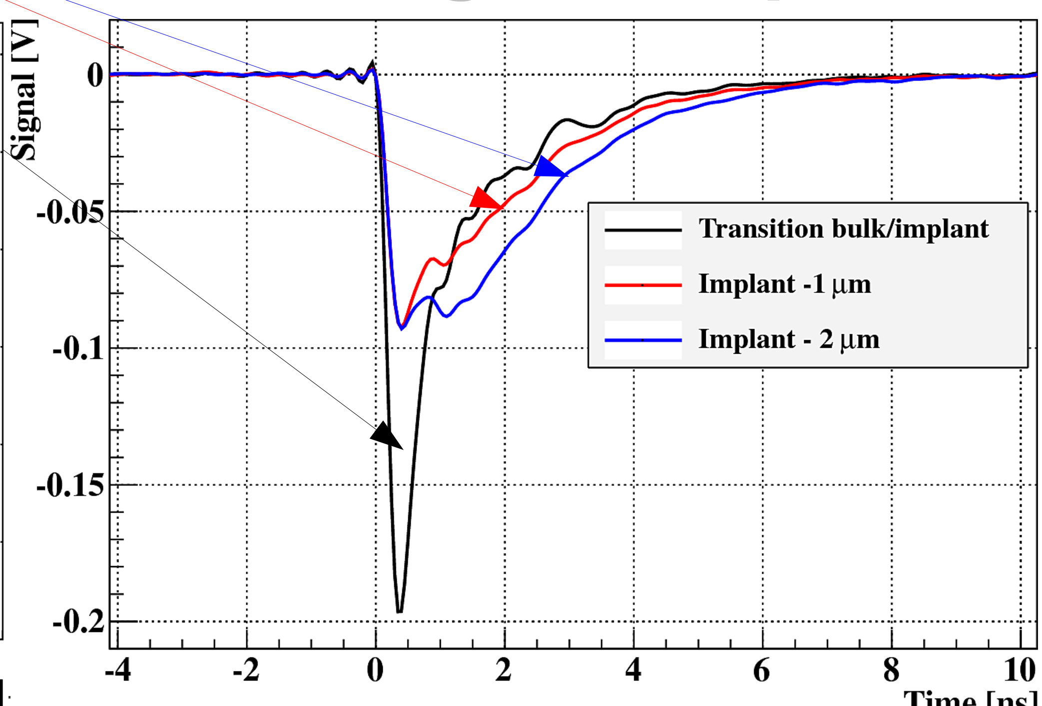




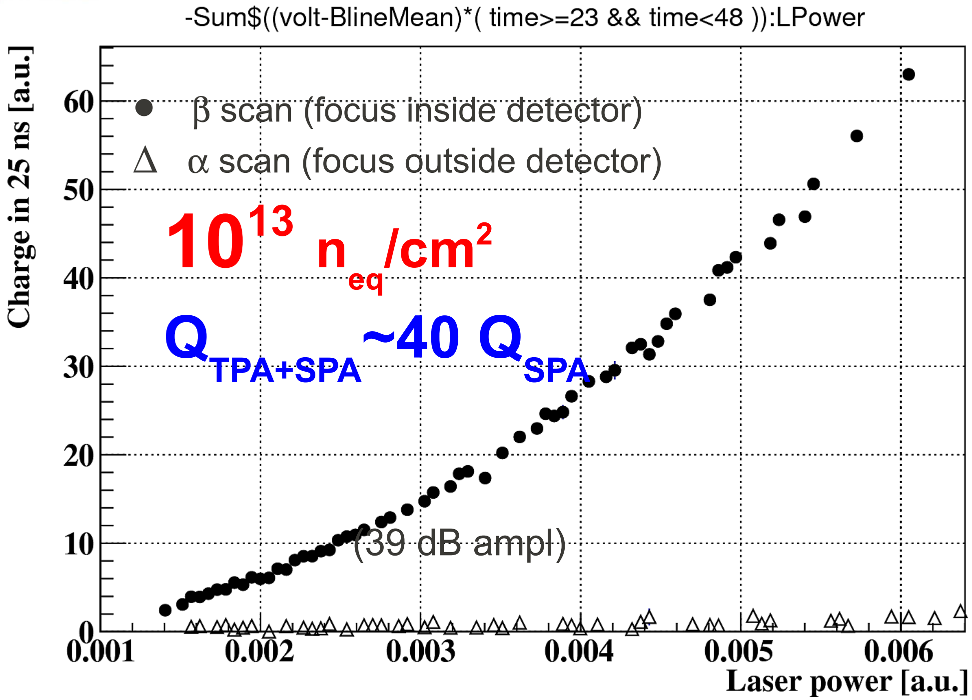
Doping concentration



Probing the implant



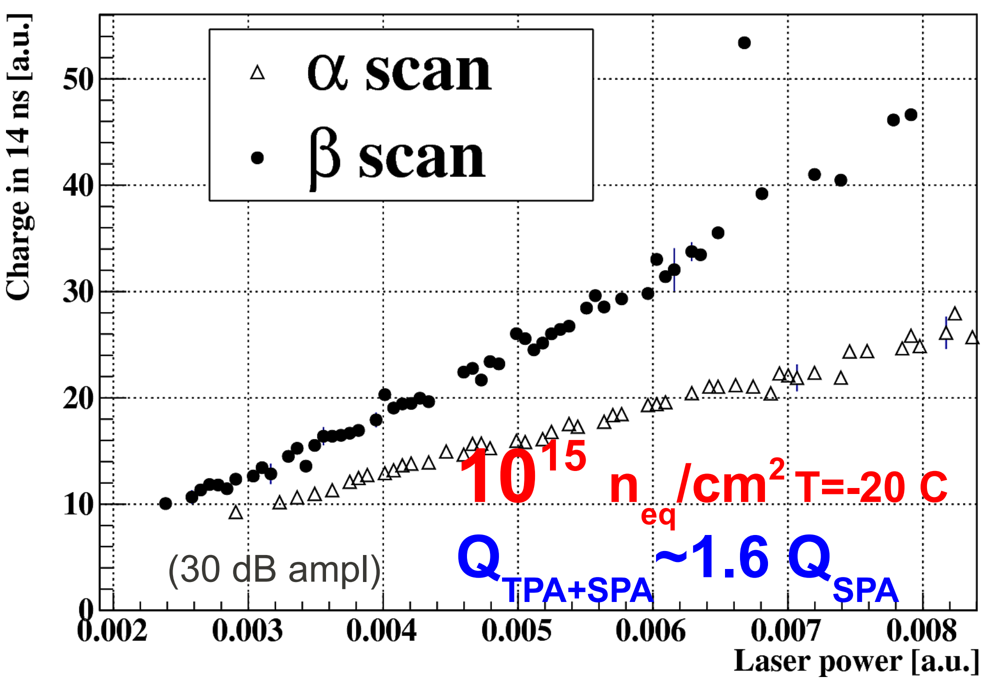
TPA in irradiated Silicon

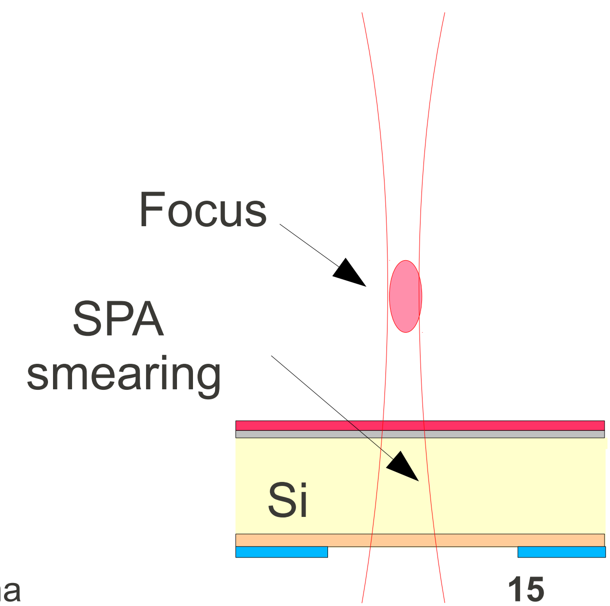


- In Silicon, ionizing radiation creates **Deep** Energy **Levels** within the bandgap, that **increase** Single Photon **Linear Absorption**. More free charge carriers but less photons for TPA
- Linear absorption **smears** spatial resolution along the beam propagation direction.
- Clear signature:

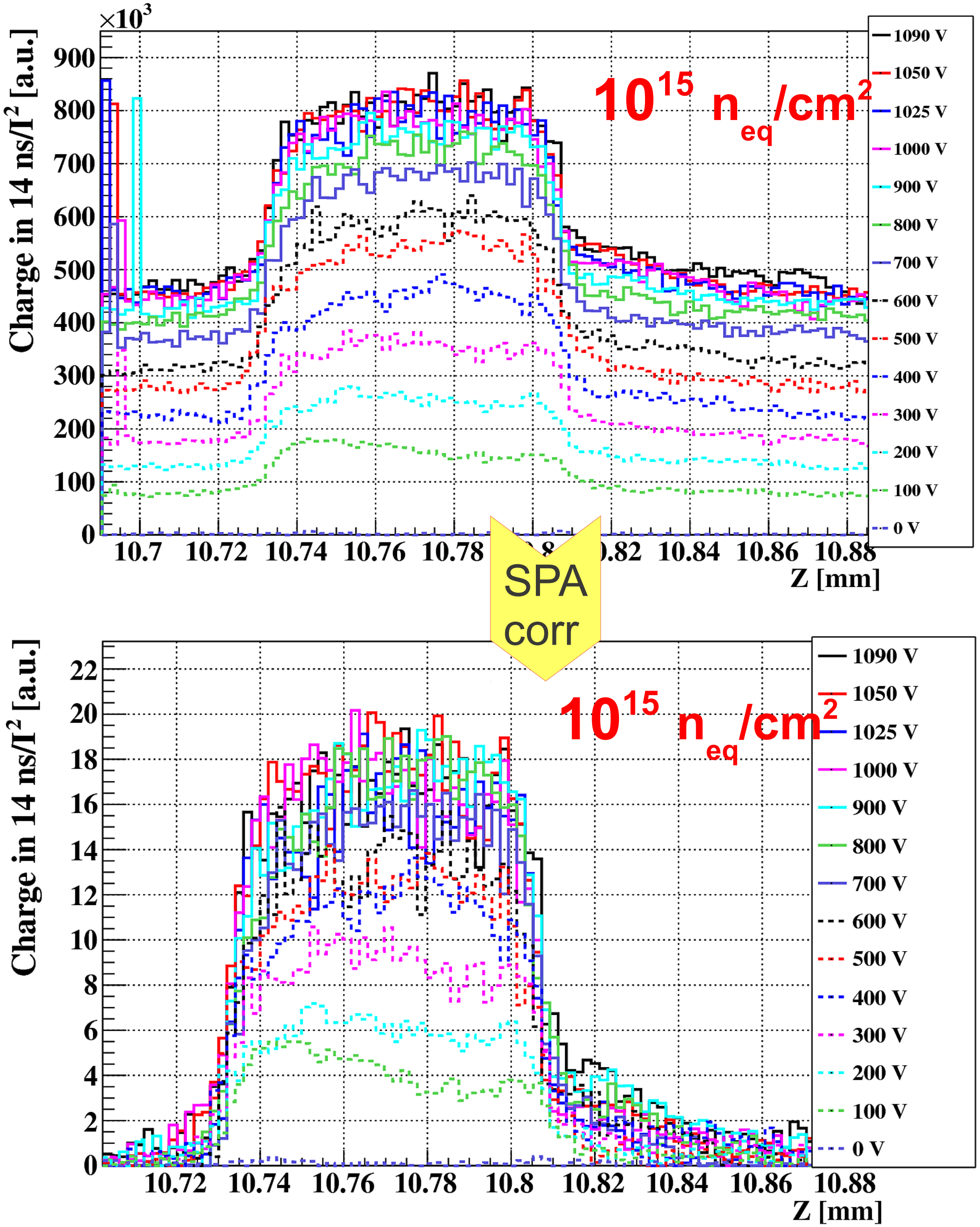
1) carriers collected even when focus is outside the detector.
2) Linear increase of signal as power increases

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

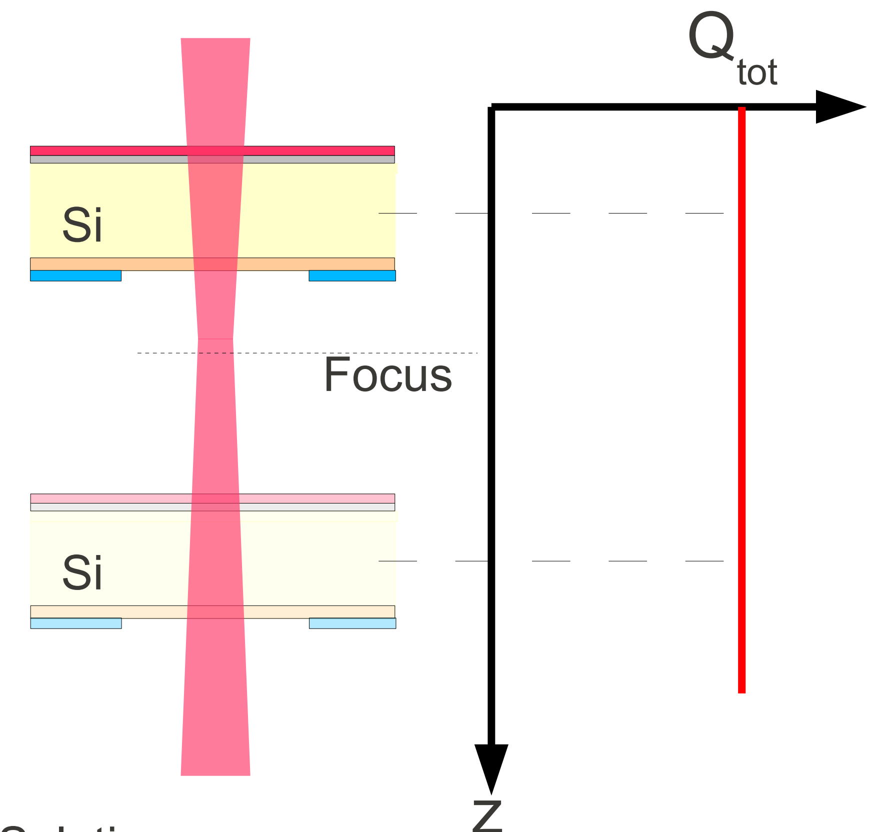




TPA in irradiated diodes



In TPA, the increase of linear absorption can be subtracted exploiting the fact that it is Z-invariant

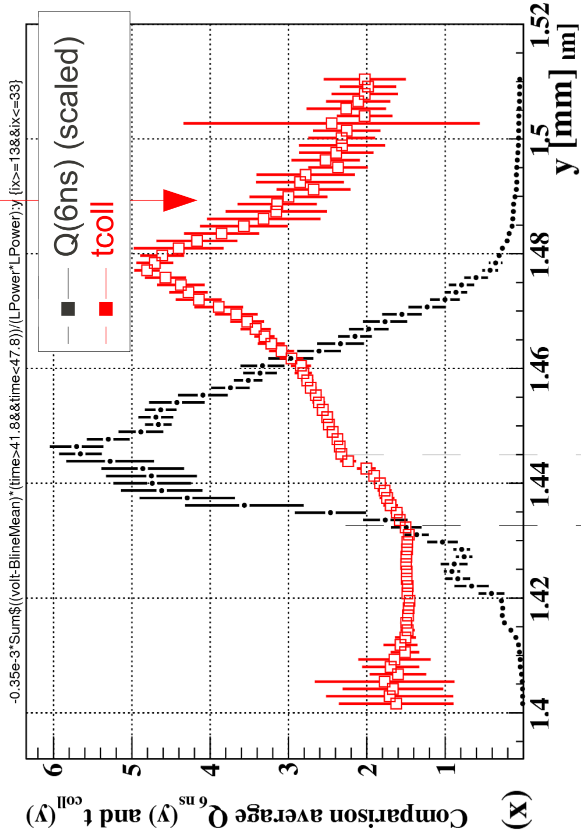


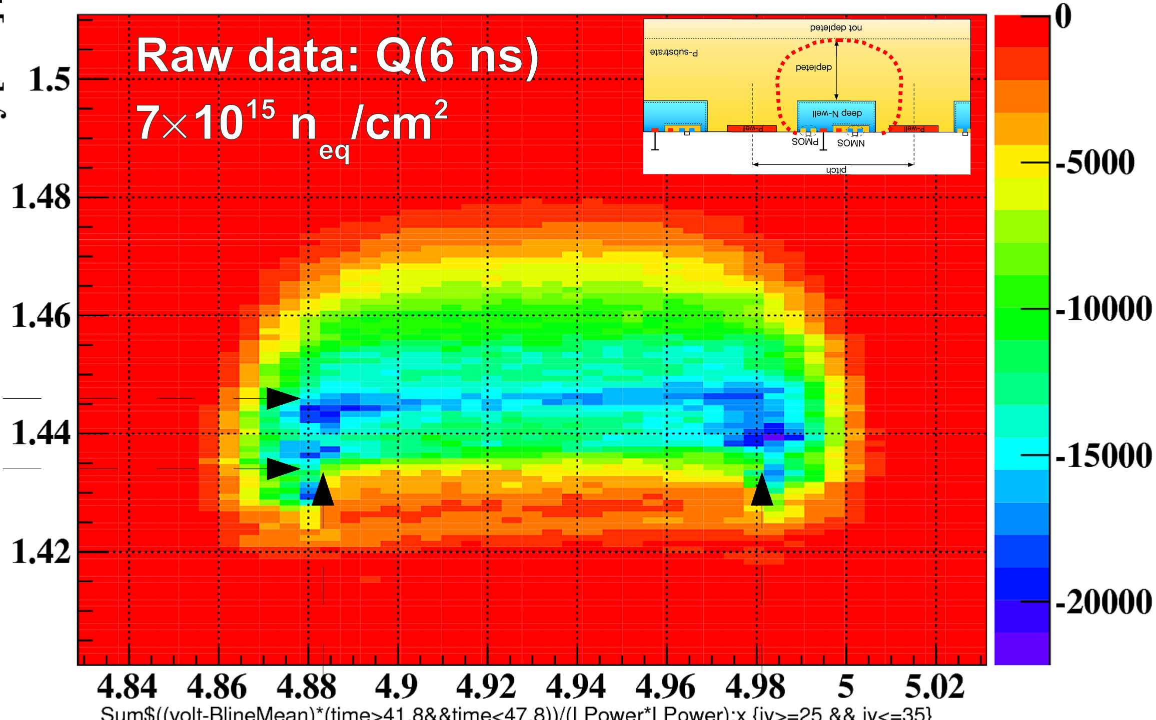
Solution:

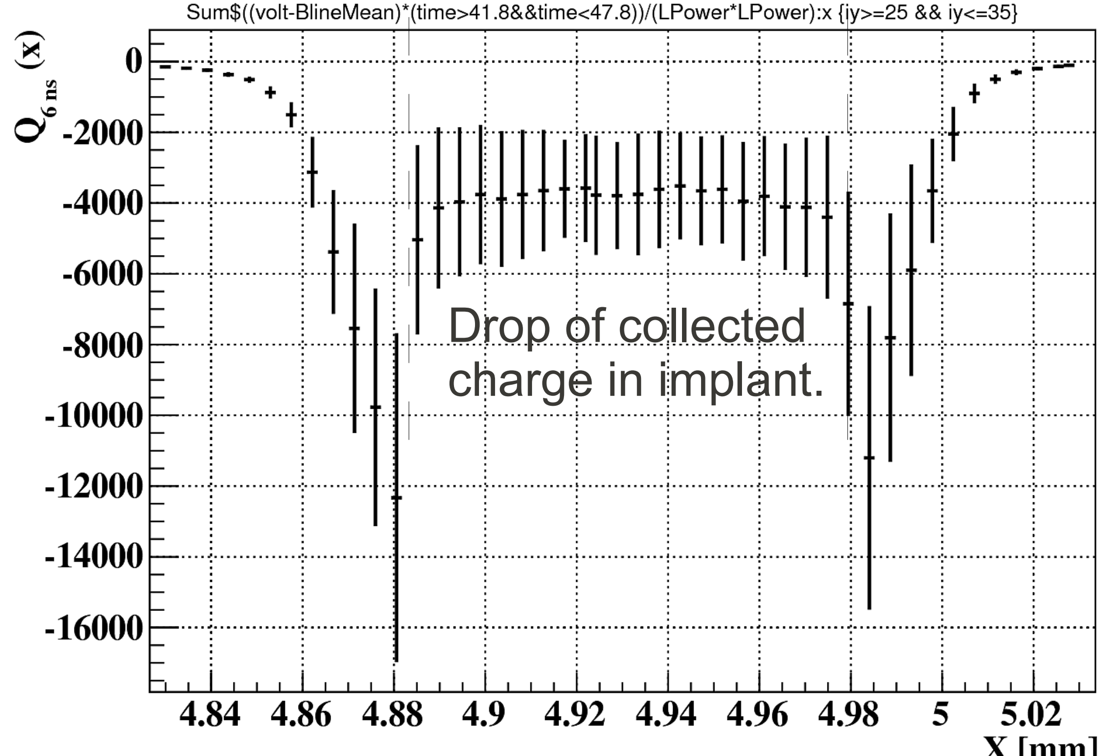
1) place focus outside the detector → measure α-induced signal: $I(t,\alpha)$

2) Subtract $I(t,\alpha)$ (waveform-by-waveform) to measurements with focus inside the detector

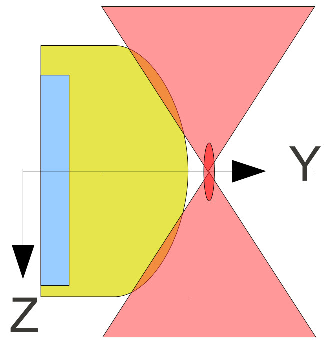
TPA in irradiated HVCMOS







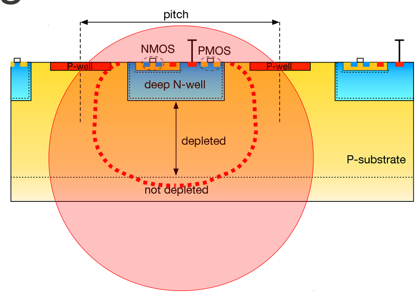
- No sharp decrease of Q(y) or collection time, due to α-contamination.

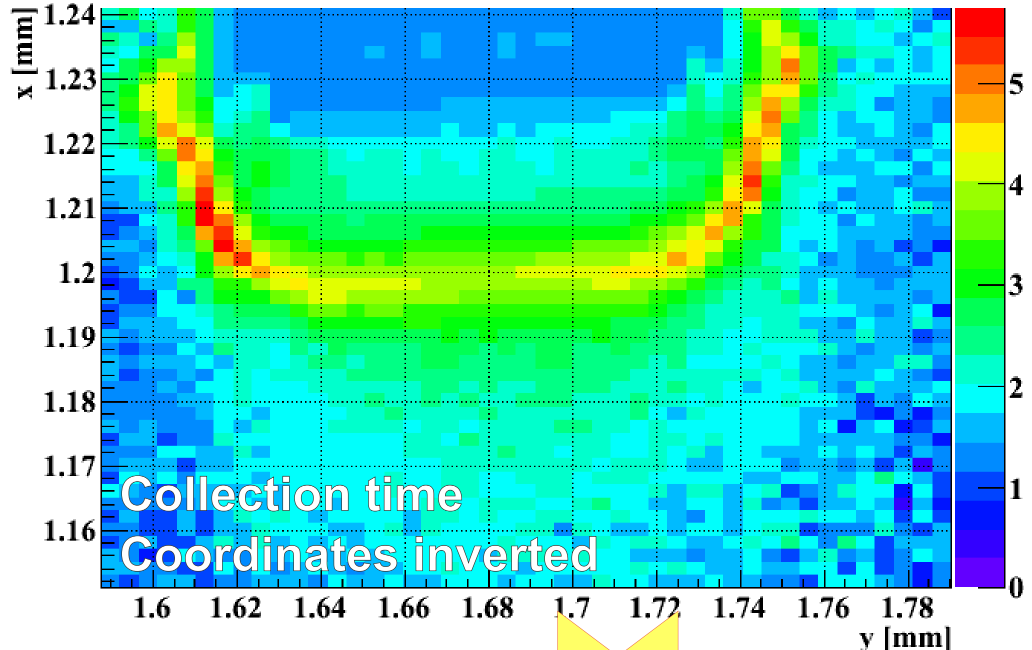


- edge-TPA can overestimate depletion width in irradiated devices if this effect is not accounted for.

TPA in irradiated HVCMOS

Due to strong beam focusing/divergence, the α-contribution can overflow the depleted region:

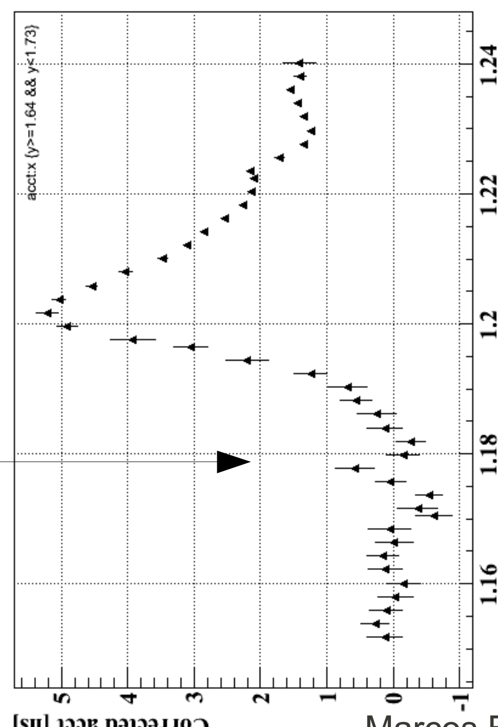


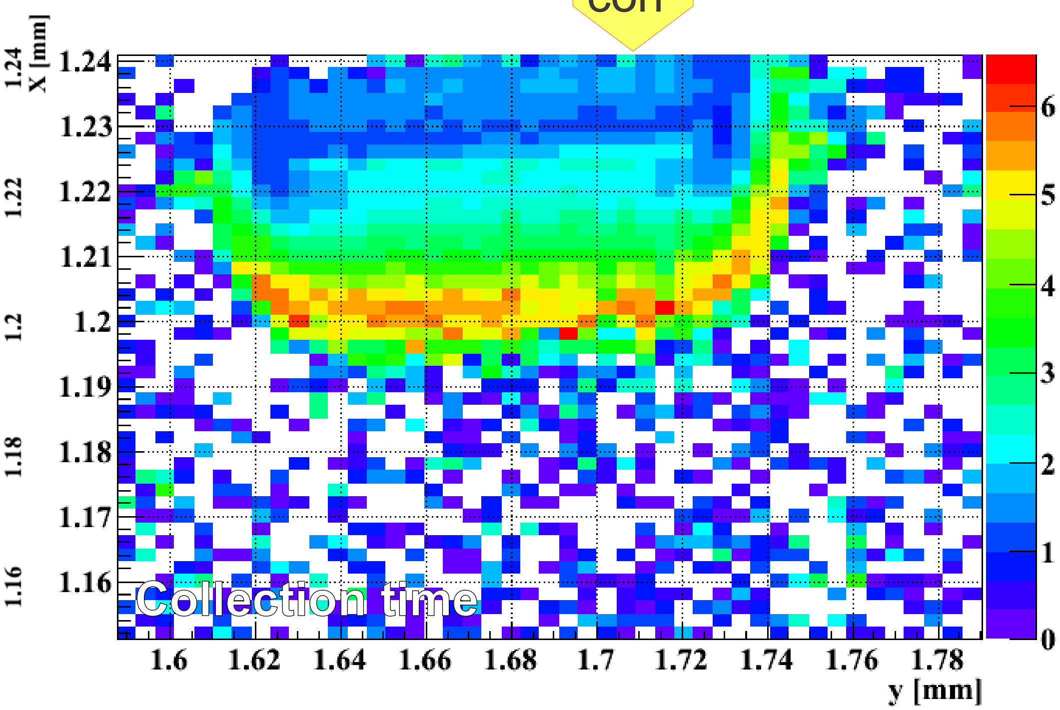


Diode-like correction method not applicable ⇨ Developed a different one (see backup) based on 2 consecutive scans of the same region at different powers

SPA corr

Because of α correction, collection time drops to zero behind depleted region





Summary

- TPA-TCT is a new material characterization technique providing 1 μm resolution in 2D and up to 10 μm along the beam direction → Optimal configuration for edge injection
- Physical phenomena exploited is the simultaneous absorption of two photons at the focus of a fs-laser beam.
- Demonstrated performance on a low resistivity HVCMOS with 15 um depletion depth
- Increase of linear absorption with irradiation in Si (intrinsic to Si) reduces TPA contrast. This smearing can be corrected either by moving the focus outside of the sample (diodes) or by dual scan at different power (devices with very small depletion width).
- From the experience gained on the demonstrator system in Bilbao, we are building an optimized setup for Silicon measurements at CERN. Laser delivery this next month. Project funded by 2016 CERN Knowledge Transfer Program.
- All these activities have been carried out in the framework of CERN-RD50 collaboration

TPA -TCT extra information

1) NIMA Vol 845, 11 February 2017, Pages 69-71
https://doi.org/10.1016/j.nima.2016.05.070

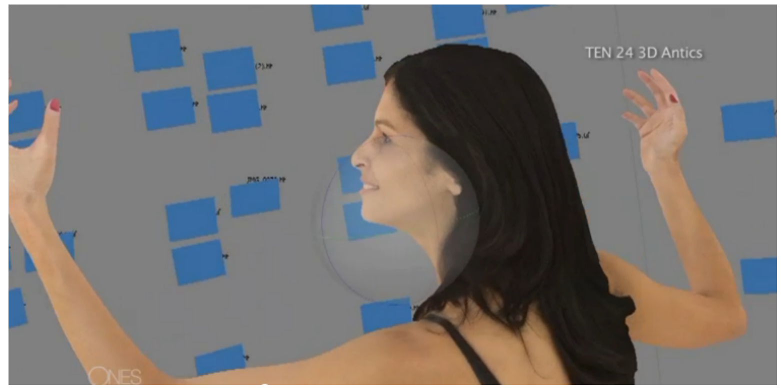
2) Journal of Instrumentation, Volume 12, January 2017
http://iopscience.iop.org/article/10.1088/1748-0221/12/01/C01038

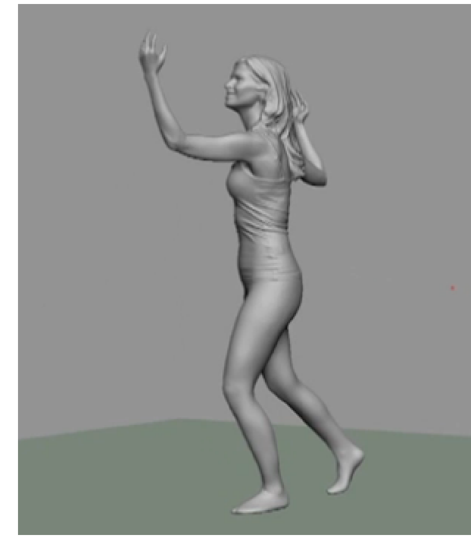
3) I. Vila, CERN Detector Seminar, 26th January 2018
https://indico.cern.ch/event/697958/

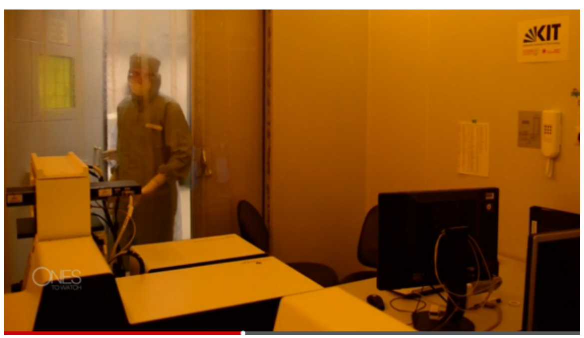
4) M. Fernandez, Seminaire de physique corpusculaire, University of Generva, 30th Nov 2016
http://dpnc.unige.ch/seminaire/talks/fernandez.pdf

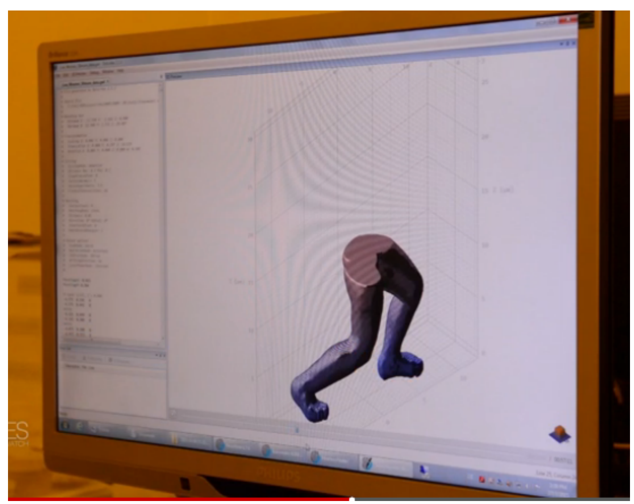
BACKUPS

3D microfabrication: using **focused ultrashort laser pulses** on the volume of a **photoresist**, the pulses initiate **polymerization**. After illumination of the structure and **development** (washing out the non-illuminated regions) the **polymerized** material remains in the prescribed **3D** form.









Screenshots from “**Is this the world's smallest sculpture?**” CNN “Ones to watch”

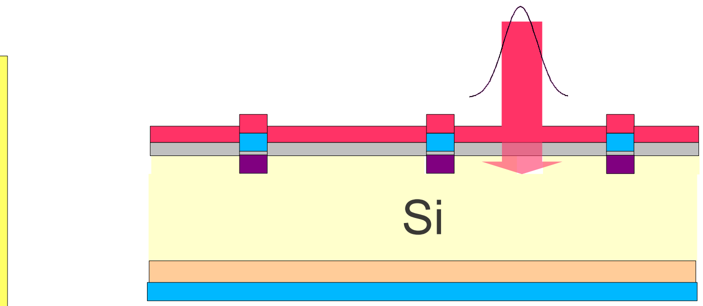
Further reading: **Two Photon Polymerization: a New Approach to Micromachining**, Photonics spectra, October 2006

Common characterization techniques of semiconductor radiation detectors

Technique	Type	Spatial resolution	Efficiency	Reach	Requirements
IV/CV	Electrical	Not applicable	No	I_{leak}, $V_{dep}(\propto N_{eff})$, V_{br}, C_{end}	Needle system Cold chuck pA-meter, LCR meter...
TCT (Transient Current Technique)	Optical	2D	Yes	N_{eff}, $\tau_{e,h}$ (low Φ_{eq}) uniformity	ps-pulsed laser stepper motors Amplifier, scope
Radioactive source	Source	None	Yes	V_{dep}, CCE	Radioactive source, trigger system
IBIC	Source	2D	Yes	2D CCE	Accelerator
Test beam	Source	2D	Yes	Setup/sensor dependent: 2D CCE,...	Accelerator, beam time, telescope, trigger,

MIP capabilities: Test beam, infrared TCT

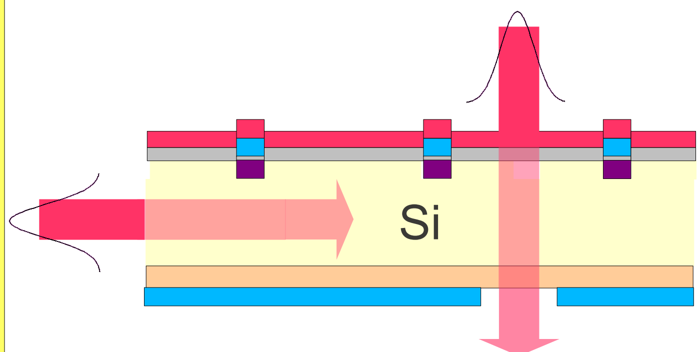
Laser characterization techniques



SPA-TCT Red

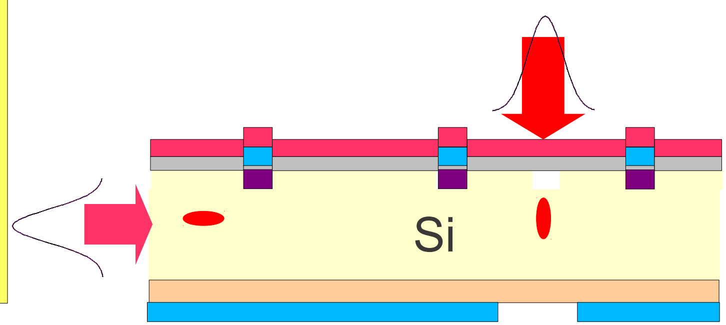
Employing short absorption length laser (red for Si), all carriers deposited in few μm from surface.
Allows to study drift of one kind of carriers.
No spatial resolution along beam direction.
1 photon=1 e-h pair

SPA: Single Photon Absorption
TCT: Transient Current Technique



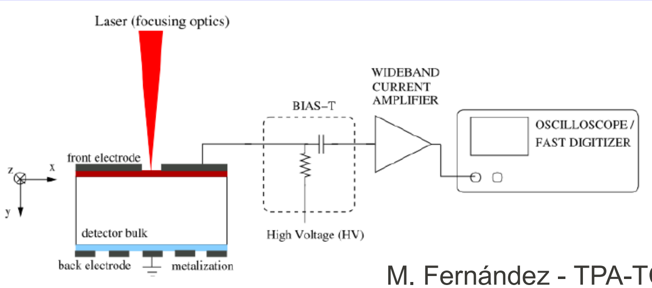
SPA-TCT Infrared

Using long absorption length laser (infrared for Si).
Homogeneous distribution along “Rayleigh length”.
Similar to MIPs, though different dE/dx.
Incidence can be from **top, bottom** or **edge.**
Edge: lateral spatial resolution.
1 photon=1 e-h pair



Two Photon Absorption (TPA-TCT)

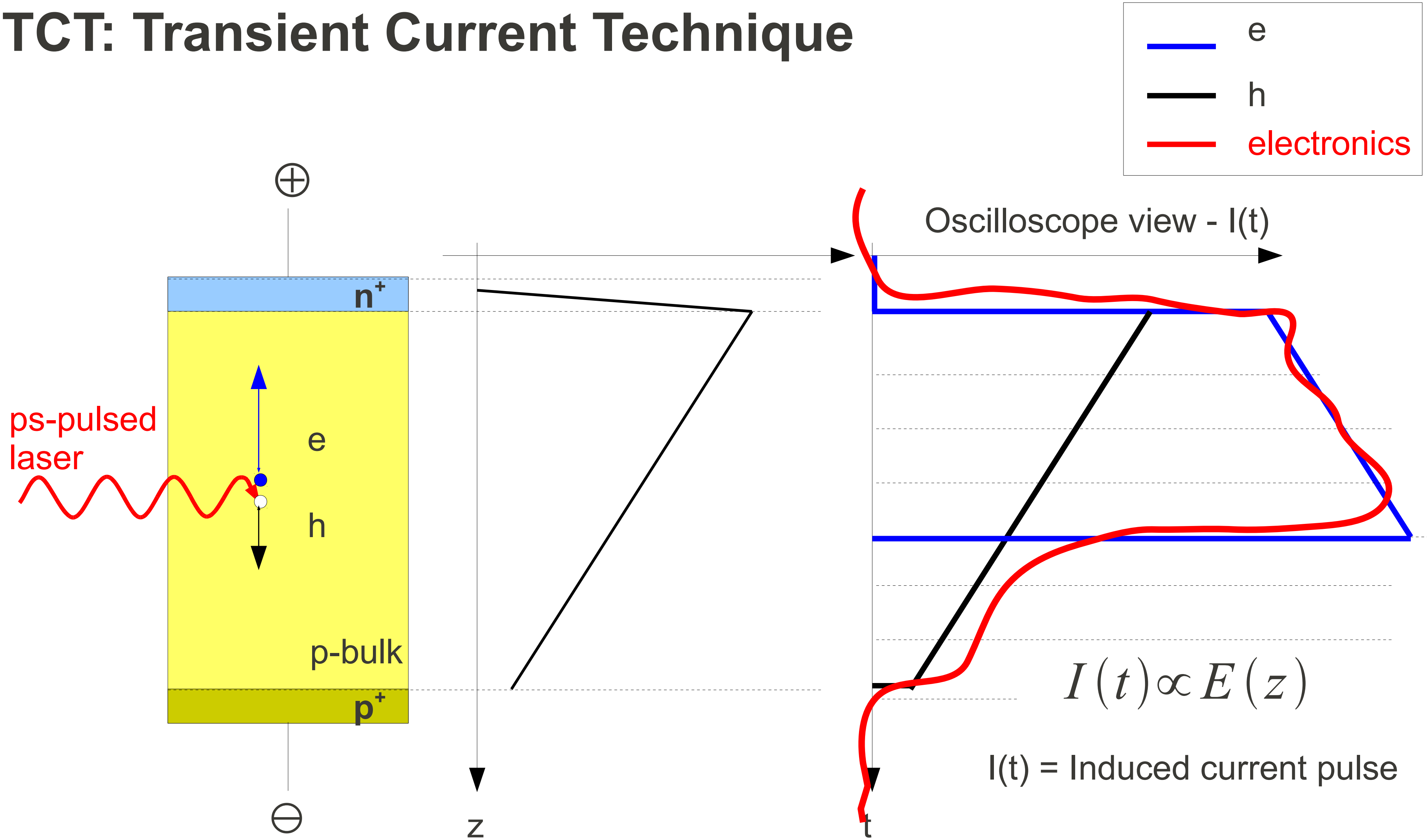
Point-like energy deposition → 3D spatial resolution
Novel technique developed by **IFCA, CERN, US, UPV**
2 photons=1 e-h pair



Transient Current Techniques

Applicable to both pad/segmented detectors
Simple readout
DAQ directly on digital scope

TCT: Transient Current Technique



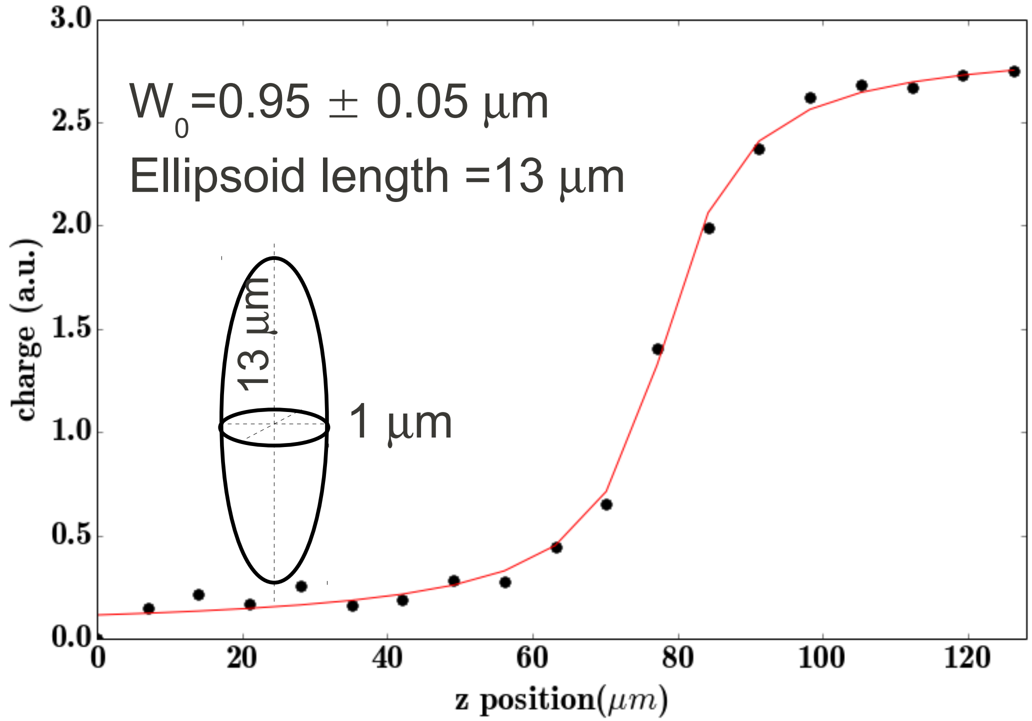
$$I(t) = N_{eh} A q_e v_{drift} E_W \propto v_{drift} = \mu(E) E \Rightarrow I(t) \propto E(z)$$

Assumption: 1D, overdepleted, non-irradiated diode

Evidences for TPA process

1) Collected charge varies quadratically with power
2) Z-scan is not Z-invariant.

Then characterize the excitation volume:



Ellipsoid is completely described by waist (w_0), λ and β.

$$w(z) = w_0 \sqrt{\frac{\lambda z}{\pi w_0^2 n}}$$

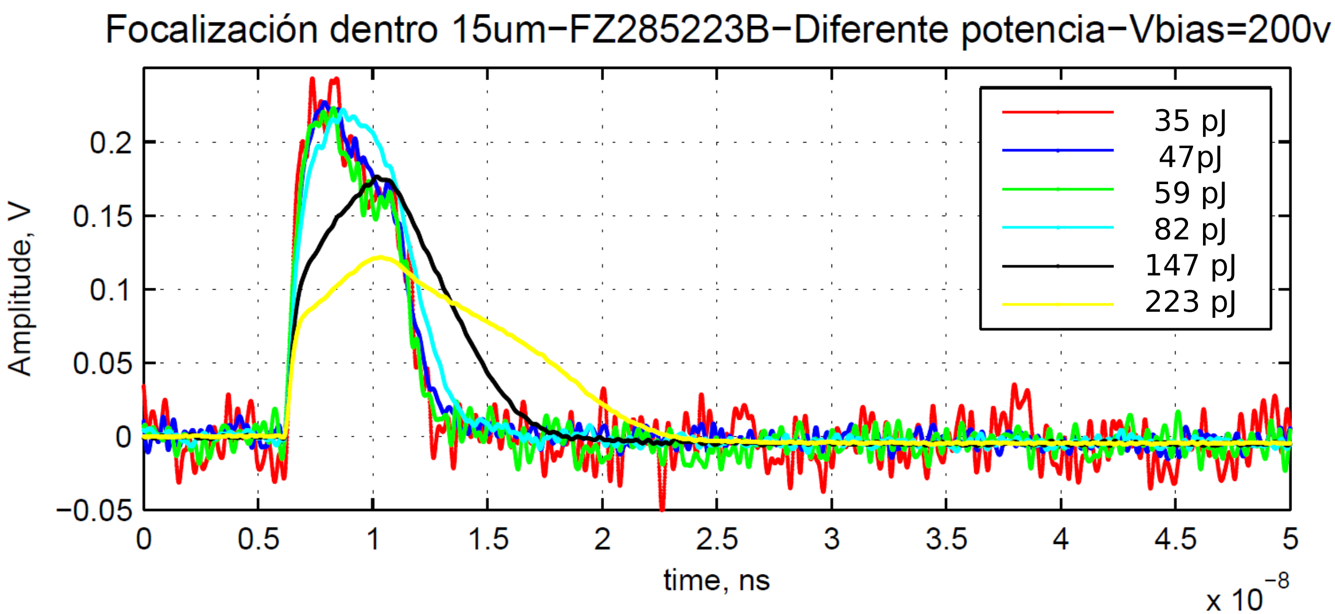
$$I(z) = \frac{2P}{\pi w^2(z)} e^{\frac{-2r^2}{w^2(z)}}$$

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

$$t \sim t_p \rightarrow N(z) = \int_{-\infty}^{\infty} 2\pi r \cdot t_p \cdot N(r,z)\, dr$$

An **edge-TPA** scan is optimum, because spatial resolution is **~1 μm**
Try to scan **pads from the edge** → Get active area very close to the border

⇒ Work in a power regime where **β>>α** but **without** producing **plasma**.



- For this detector. Laser power<80 pJ ⇒ no plasma effect

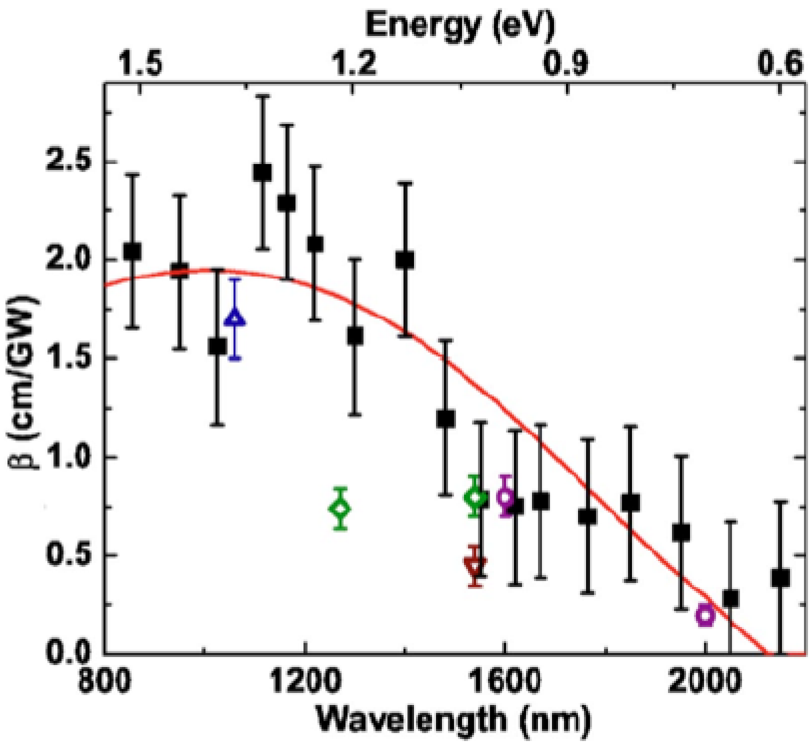
The primary equations governing pulse propagation and carrier generation in a semiconductor material are [15], [16]

$$\frac{dI(r,z)}{dz} = -\alpha I(r,z) - \beta_2 I^2(r,z) - \sigma_{ex} N I(r,z) \quad (1)$$

$$\frac{d\Phi(r,z)}{dz} = \beta_1 I(r,z) - \gamma_1 N(r,z) \quad (2)$$

$$\frac{dN(r,z)}{dt} = \frac{\alpha I(r,z)}{\hbar\omega} + \frac{\beta_2 I^2(r,z)}{2\hbar\omega} \quad (3)$$

where I is pulse irradiance, N is the density of free carriers, and Φ is the phase. α is the linear absorption coefficient, β_2 is the two-photon absorption coefficient that is proportional to the imaginary part of $\chi^{(3)}$ (the third-order nonlinear-optical susceptibility), σ_{ex} is the absorptivity of laser-generated free carriers, β_1 is proportional to the real part of $\chi^{(3)}$, γ_1 describes the refraction due to free carriers, and z is the depth in the material.



Applied Physics Letters, vol. 90, no. 19, p. 191104, 2007.

$$N_{1P}(z) = \frac{\alpha}{\hbar\omega}\exp(-\alpha z)\int_{-\infty}^{\infty} I_o(z,t)\,dt$$

$$N_{2P}(z) = \frac{\beta_2}{2\hbar\omega}\int_{-\infty}^{\infty} I^2(z,t)\,dt$$

the longitudinal dependence of the beam radius $w(z)$ is

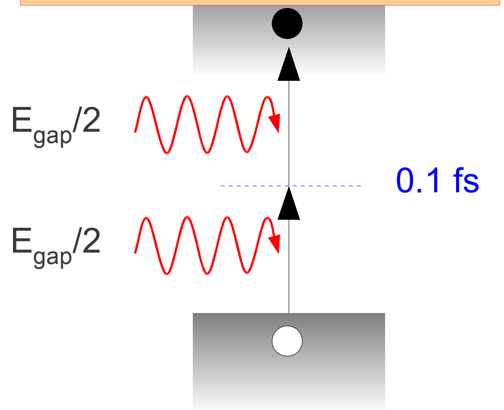
$$w(z) = w_o\left[1 + \left(\frac{\lambda z}{\pi w_o^2 n}\right)^2\right]^{1/2}. \qquad z_o = \pm\frac{\pi n w_o^2}{\lambda}.$$

ered carefully. When nonlinear absorption is the only loss mechanism in a material, the irradiance as a function of depth is given by

$$I(z) = \frac{I_o}{1+\beta_2 I_o z}. \quad (9)$$

The parameter $2z_o$ defines the propagation distance over which the beam is reasonably well collimated in the vicinity of w_o. In silicon ($n \approx 3.51$), for 1.26 μm light and 0.8 μm beam radius (that of the present study), $2z_o$ is ~11.2 μm.

Non irradiated



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

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

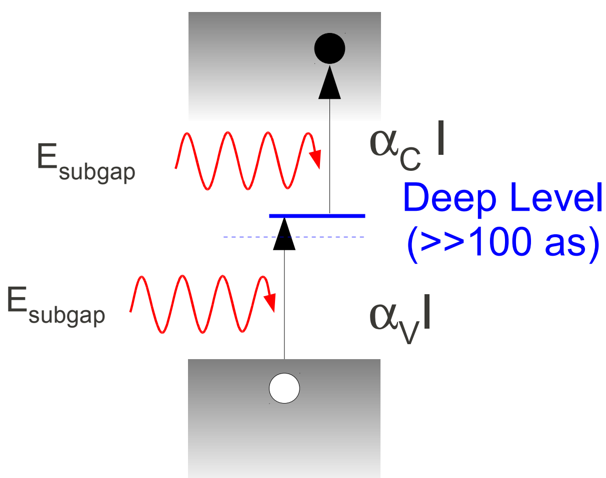
TPA: Needed two (simultaneous) photons to produce 1 e-h pair. Mediated by virtual state

Resonant TPA: Two (sequential) photons to produce 1 e-h pair. Mediated by Deep Level (DL)

Two SPA: Unpaired holes (in BV) or electrons (BC). Generation is proportional to number of DLs (it grows with fluence) and laser intensity (more photons available for transition).

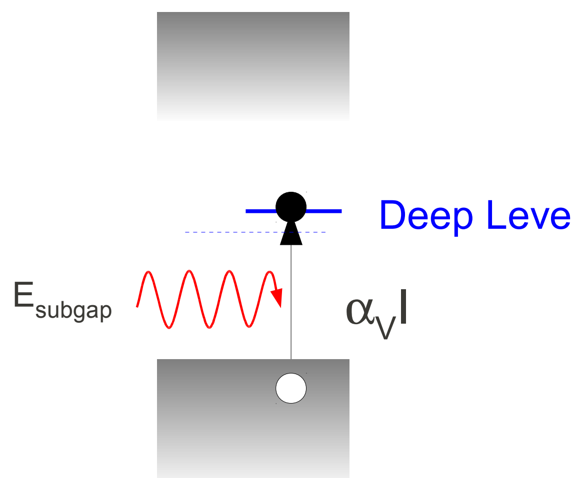
Irradiated

Resonant (sequential) **TPA**

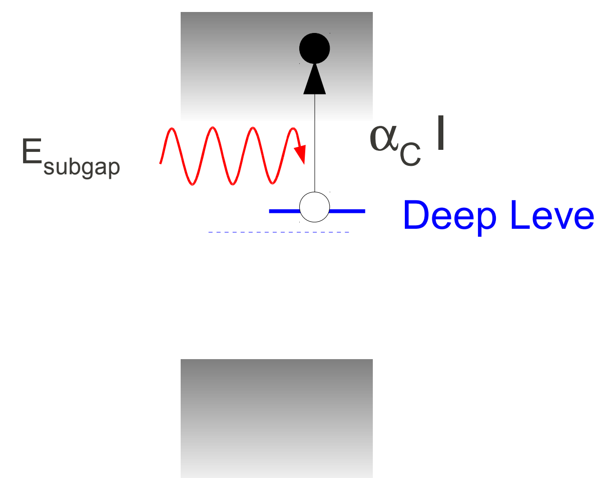


$$\frac{dN(r,z)}{dt} \propto \frac{\alpha_V \cdot \alpha_C I^2}{2\hbar\omega}$$

Two **S**ingle **P**hoton **A**bsorption



$$\frac{dN(r,z)}{dt} \propto \frac{\alpha_V(\Phi) I}{\hbar\omega}$$



$$\frac{dN(r,z)}{dt} \propto \frac{\alpha_C(\Phi) I}{\hbar\omega}$$

HVCMOS: correction of radiation induced SPA signal

Generation rate of e-h pairs per unit volume:

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

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

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)*

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

Then:

$$Q_{DUT} = q_e \int_r \int_z N(r,z;i)\ dr\,dz = q_e N(i)$$

This is the charge measured in the detector (easy to calculate)

HVCMOS: correction of radiation induced SPA signal

Assuming a "rectangular" laser pulse of duration t_p (~30 fs)

$$\int \alpha \frac{I(r,z;i)}{\hbar\omega} dt + \int \frac{\beta_2 I^2(r,z;i)}{2\hbar\omega} dt = \alpha \frac{P t_p}{\hbar\omega} + \frac{\beta_2 t_p P^2}{2\hbar\omega}$$

So finally:

$$Q_{DUT} = \frac{q_e \alpha t_p}{\hbar\omega} P + \frac{q_e \beta_2 t_p}{2\hbar\omega} P^2 \quad \left\{ \begin{array}{l} Q_\alpha = \dfrac{q_e \alpha t_p}{\hbar\omega} \\ Q_\beta = \dfrac{q_e \beta_2 t_p}{2\hbar\omega} \end{array} \right.$$

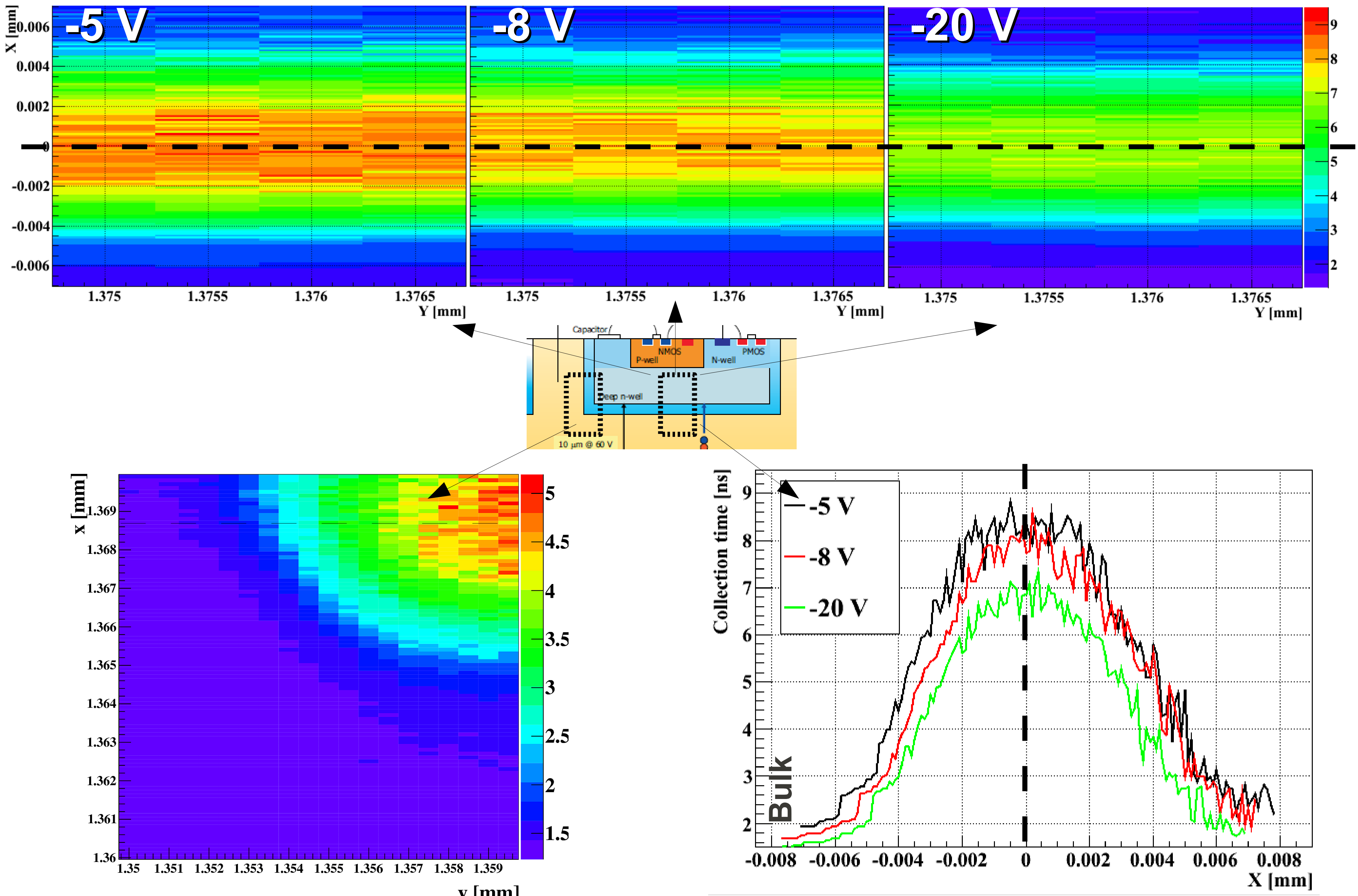
With Q_α and Q_β the SPA and TPA contributions to the signal (they should be constants)

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

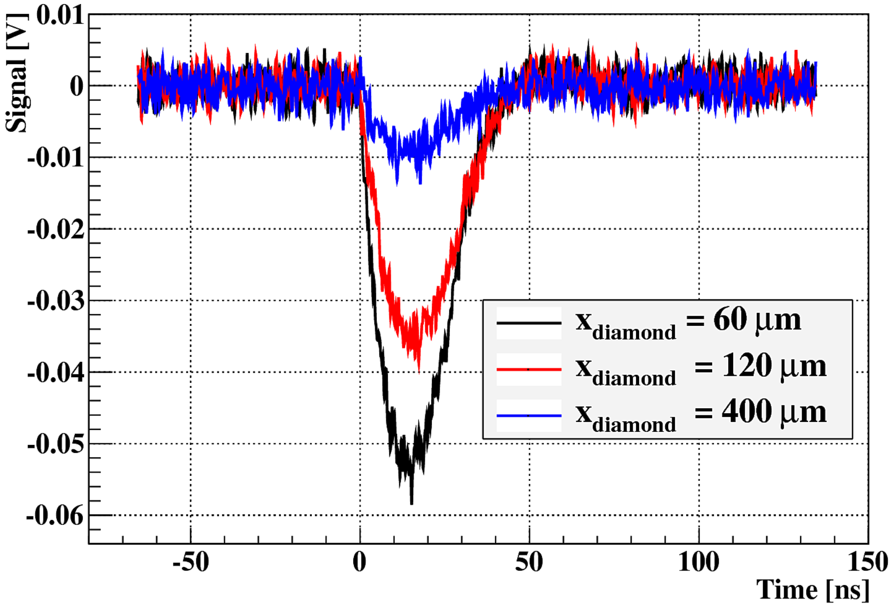
$$\left. \begin{array}{l} Q_1 = Q_\beta P_1^2 + Q_\alpha P_1 \\ Q_2 = Q_\beta P_2^2 + Q_\alpha P_2 \end{array} \right\} \quad Q_\beta = \frac{\frac{Q_1}{P_1} - \frac{Q_2}{P_2}}{P_1 - P_2} \quad Q_\alpha = \frac{\frac{Q_1}{P_1^2} - \frac{Q_2}{P_2^2}}{\frac{1}{P_1} - \frac{1}{P_2}}$$

The α corrected signal is: $Q_\beta P_1^2 = Q_1 - Q_\alpha P_1$

Fun: High Resolution imaging inside implant



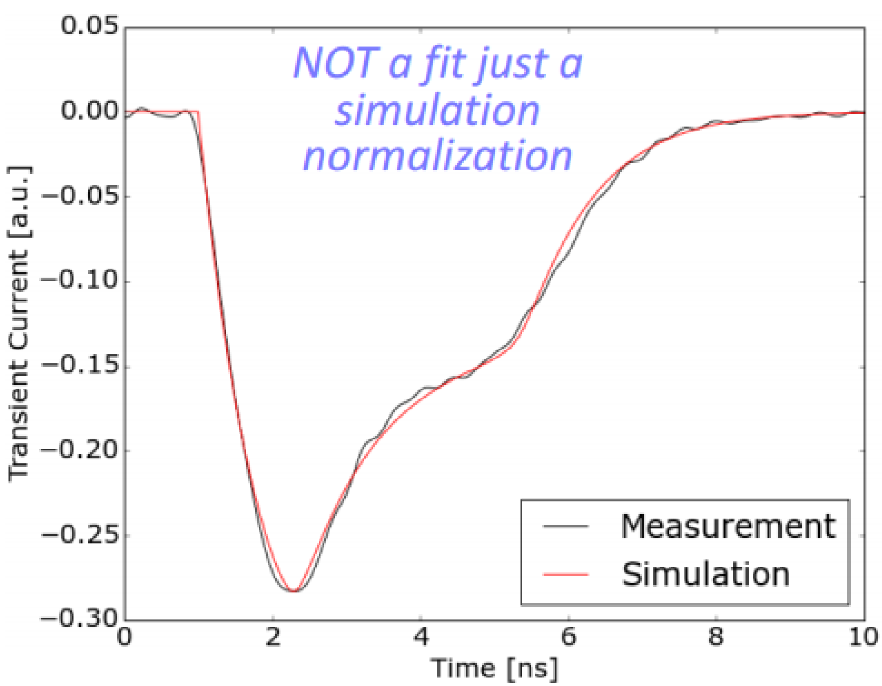
TPA in diamond



- Applying standard TCT to diamond because would require a **UV laser.**
- Using λ_{TPA}= 400 nm we did TPA-TCT in diamond
- Picture to the left is just a proof of principle: we got a signal in a diamond device.

That's a first laser TCT in diamond ever !

DAQ, simulation and analysis packages



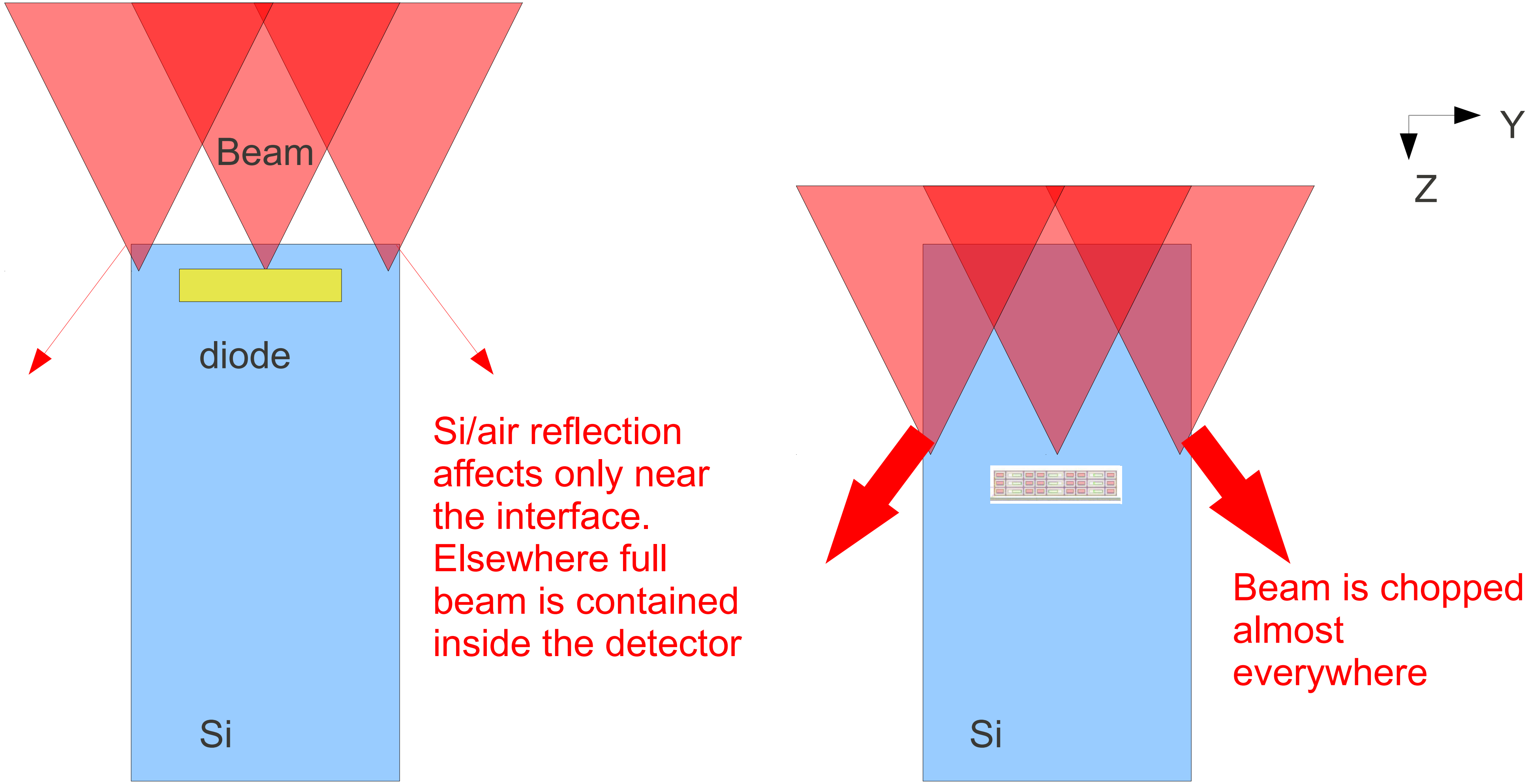
- We have **developed** a simulation package called **TRACS**:

  https://github.com/JulesDoc/Tracs

  that simulates any TCT, including TPA-TCT.

- We also have a complete **ROOT-based** software package to do **3D analysis** of TPA data.

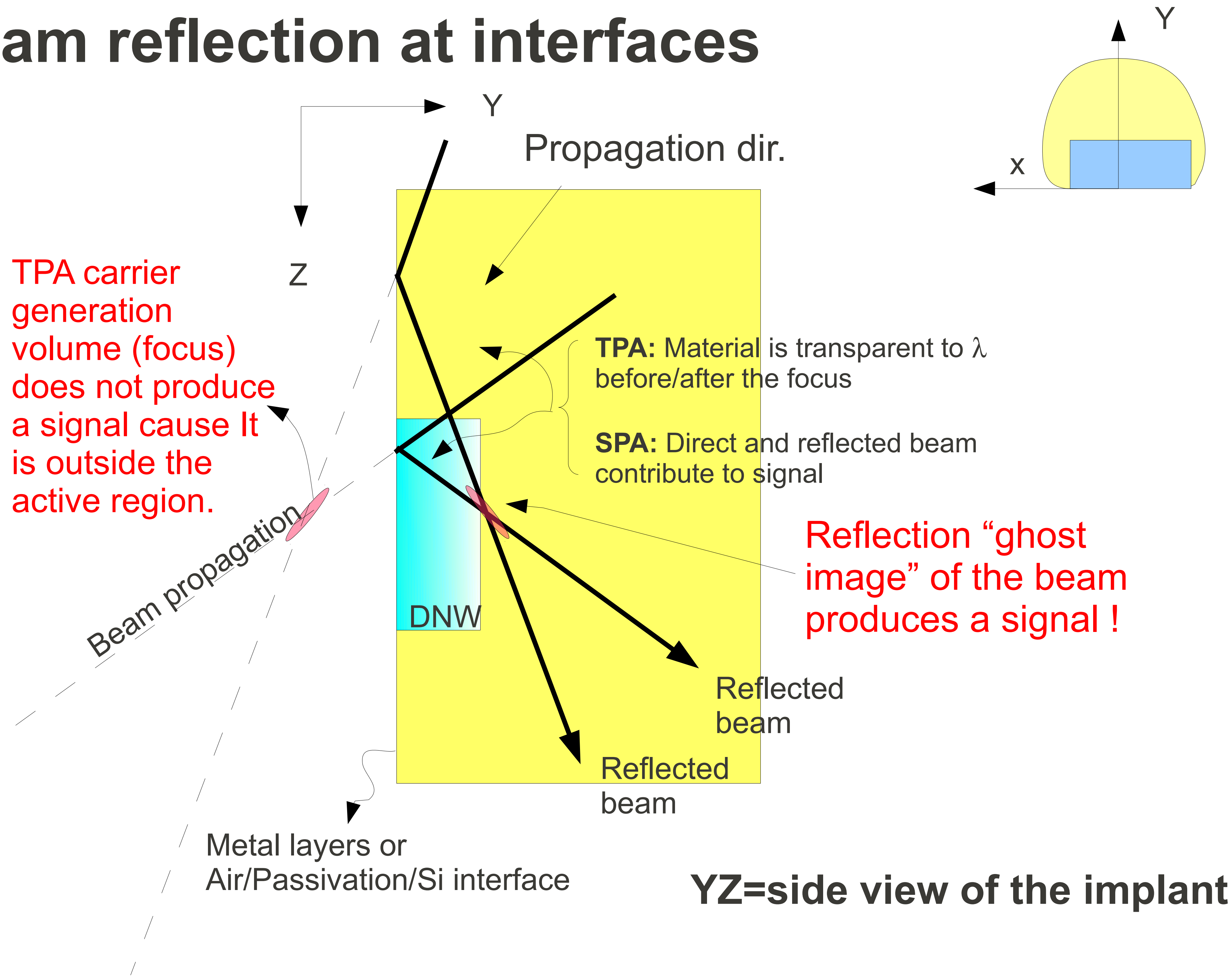
Beam coupling to deep motifs



Shallow motif to scan
Small loss due to reflection at the borders
Approximately constant coupling of energy to focus.
Good layout for TPA measurement

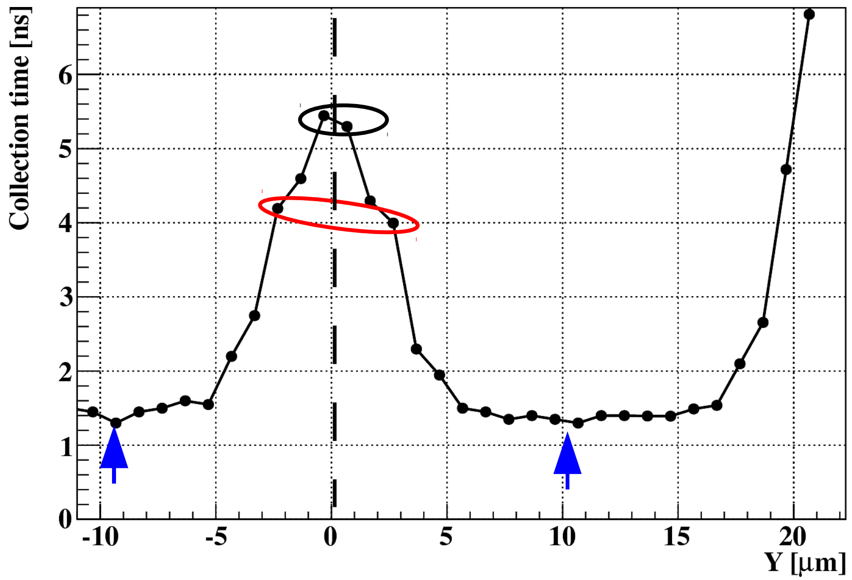
Deep motif to scan
Very asymmetric coupling to the focus
Bad layout for TPA measurement

Beam reflection at interfaces



YZ=side view of the implant

Comparison of direct and ghost signals



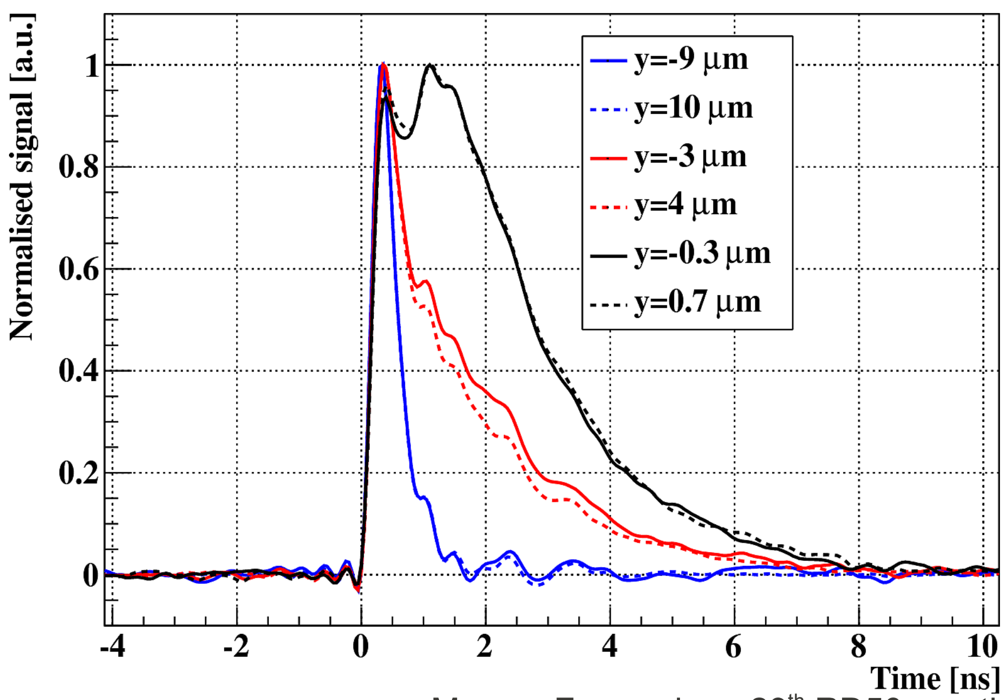
Choosing pairs of waveforms:

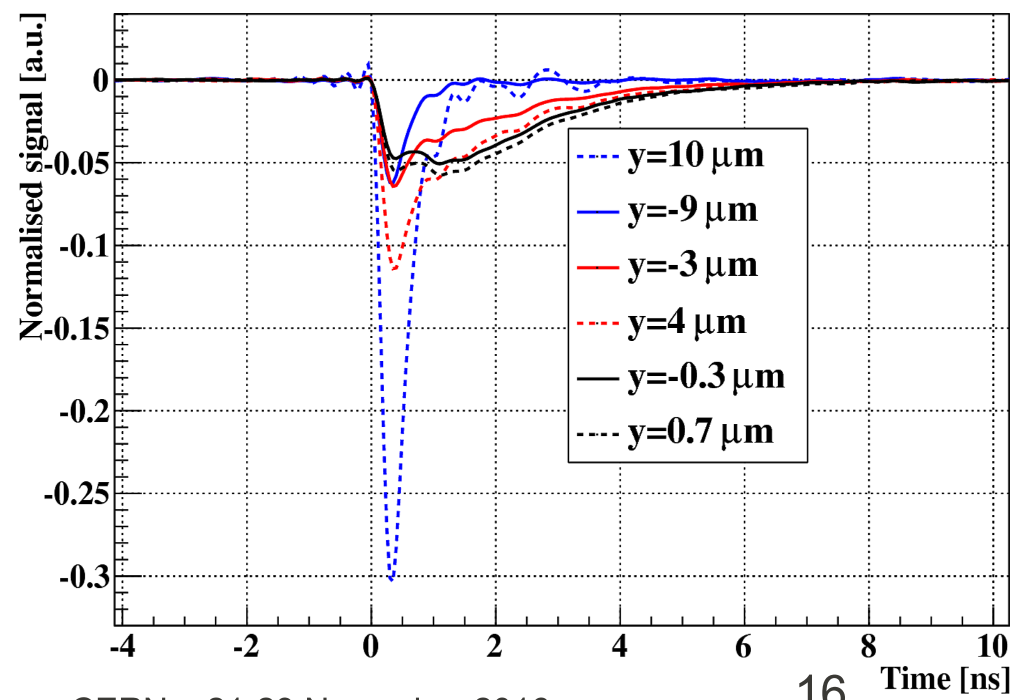
1) at the interface
2) ±2 μm away
3) ±10 μm away

Seen reflection of pulses well inside the bulk.

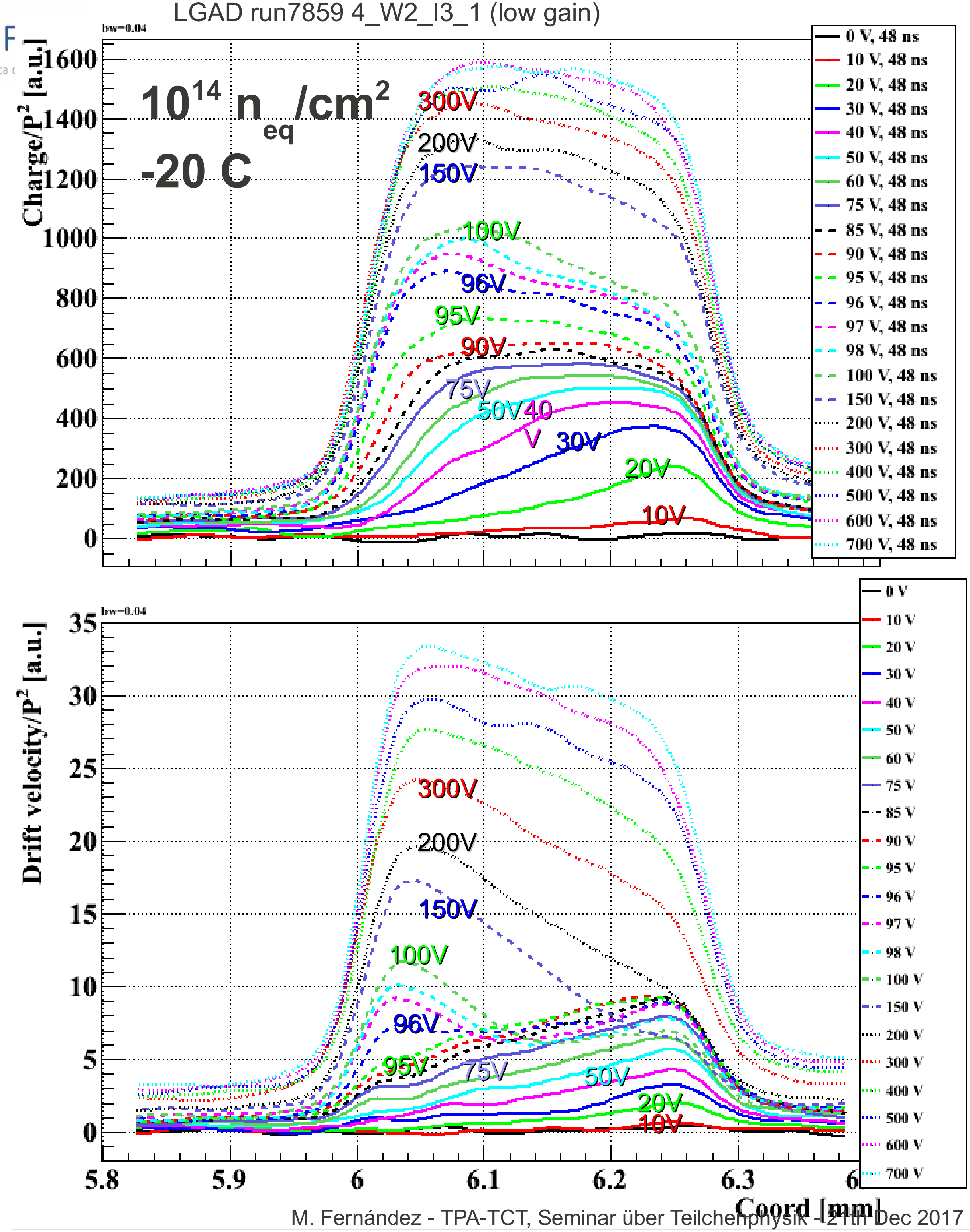
In SPA-edge-TCT this reflection can not be easily resolved because the beam is continuous.

I. Vila, proceedings Pixel 2016, Sept. 2016

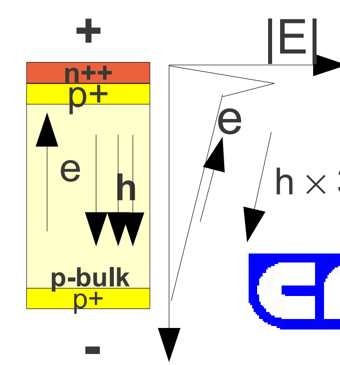




Top-TPA on LGADs



- Top TPA on LGAD
  PS protons: 10^{14} n_{eq}/cm^2



0-95 V: Charge collection starts from the back.
SCSI: p → n
Inverted p-type device

96-200V: Front junction develops and overcomes back junction

>200V: Overdepletion

- Proofs existance of double junction mechanism in LGADs. Impact on Acceptor Removal interpretation

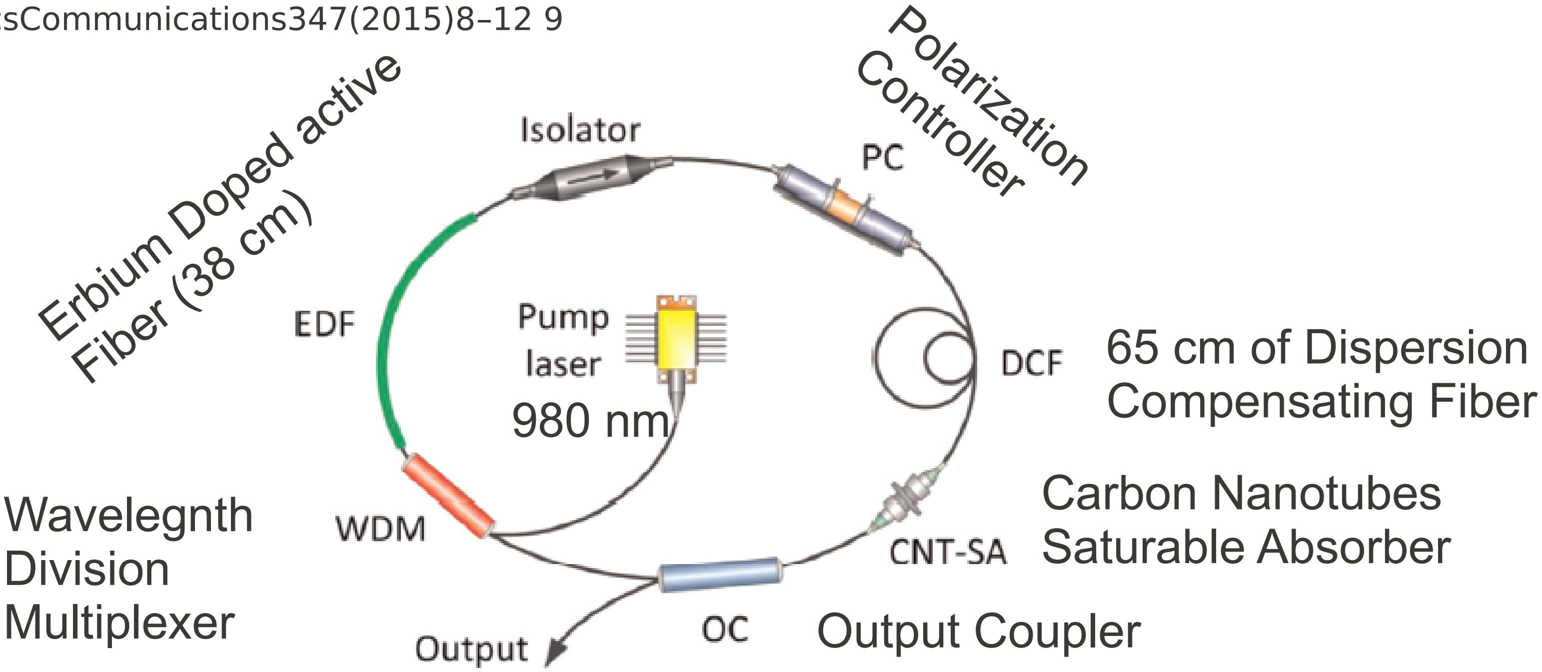


Fig. 1. Setup of the dispersion-managed, Er-doped seed laser.

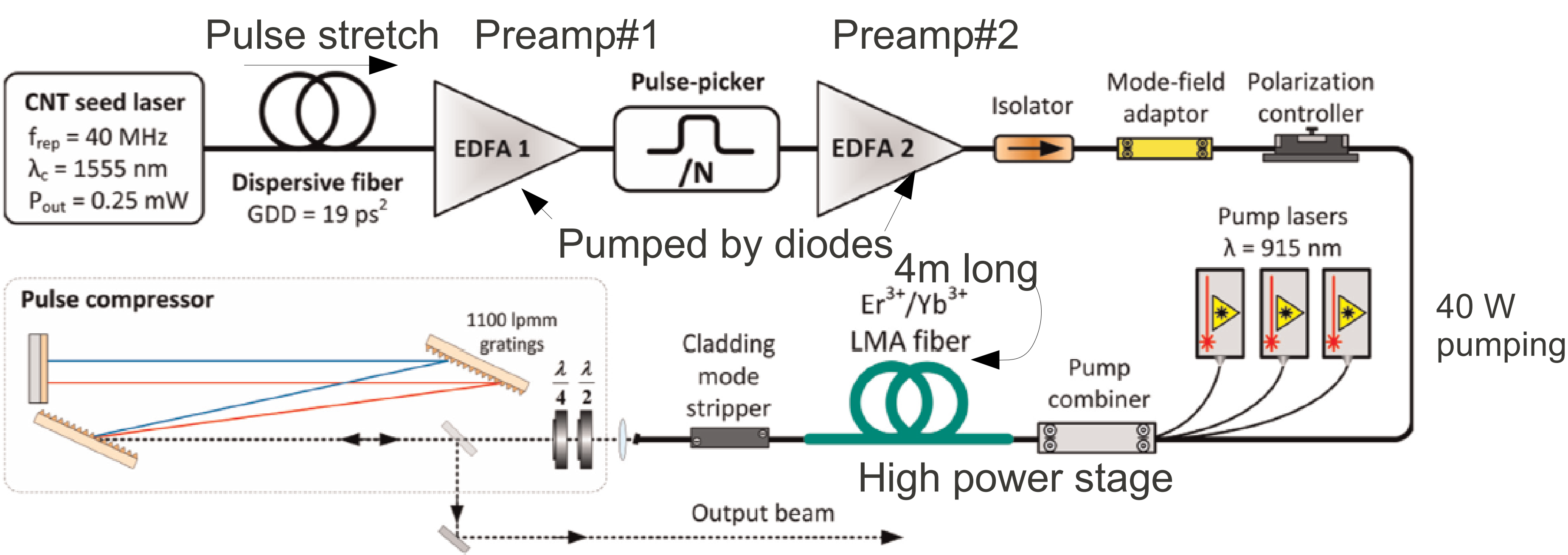


Fig. 3. Schematic of the complete CPA setup.

Z scan Technique
Funny and Useful!

SubSurface Laser Engraving (SSLE)

Tipically in BK7 Glass (Borosilicate doped with potassium)

<u>Also with pure quartz (SiO_2)</u>

Pico or FemtoSecond Laser, 1064 nm (SiO_2), 532 nm (BK7)

Multi-Photon Absorption

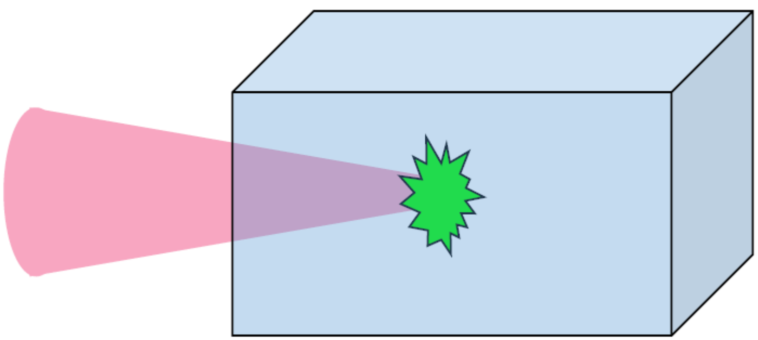
Free electron creation in the focus point

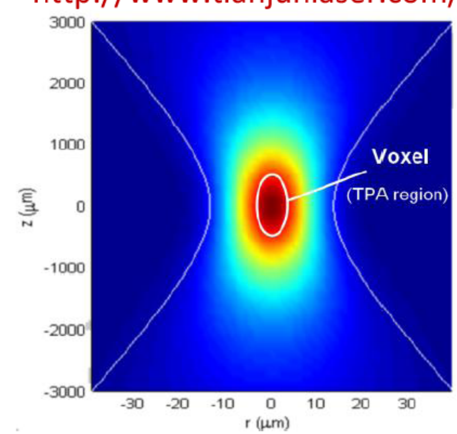
FotoChemistry in Solids:

<u>Index of refraction changes</u>,

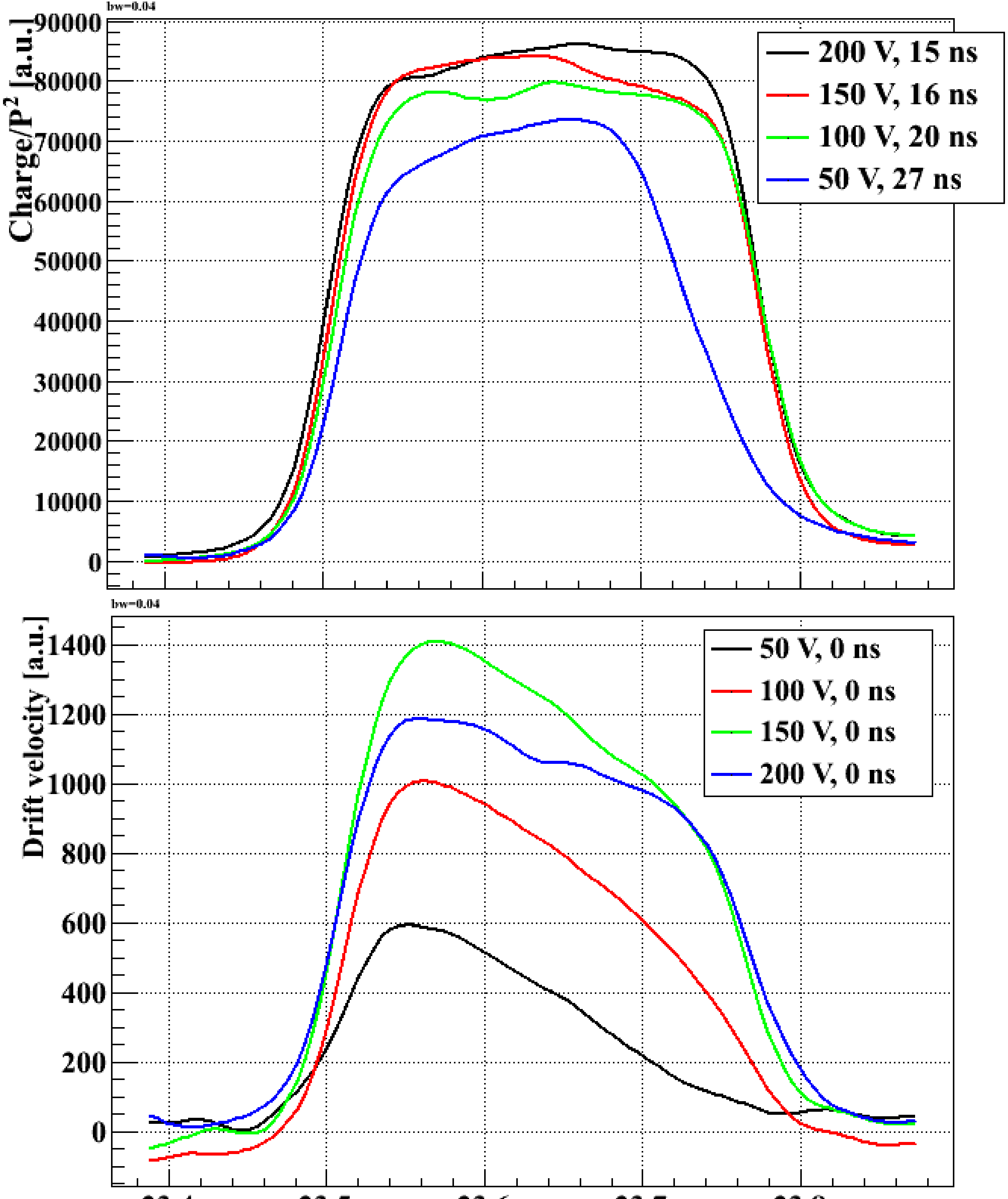
<u>Color centers</u>

TJDP-532K Machine (532 nm, BK7 crown glass)
http://www.tianjunlaser.com/

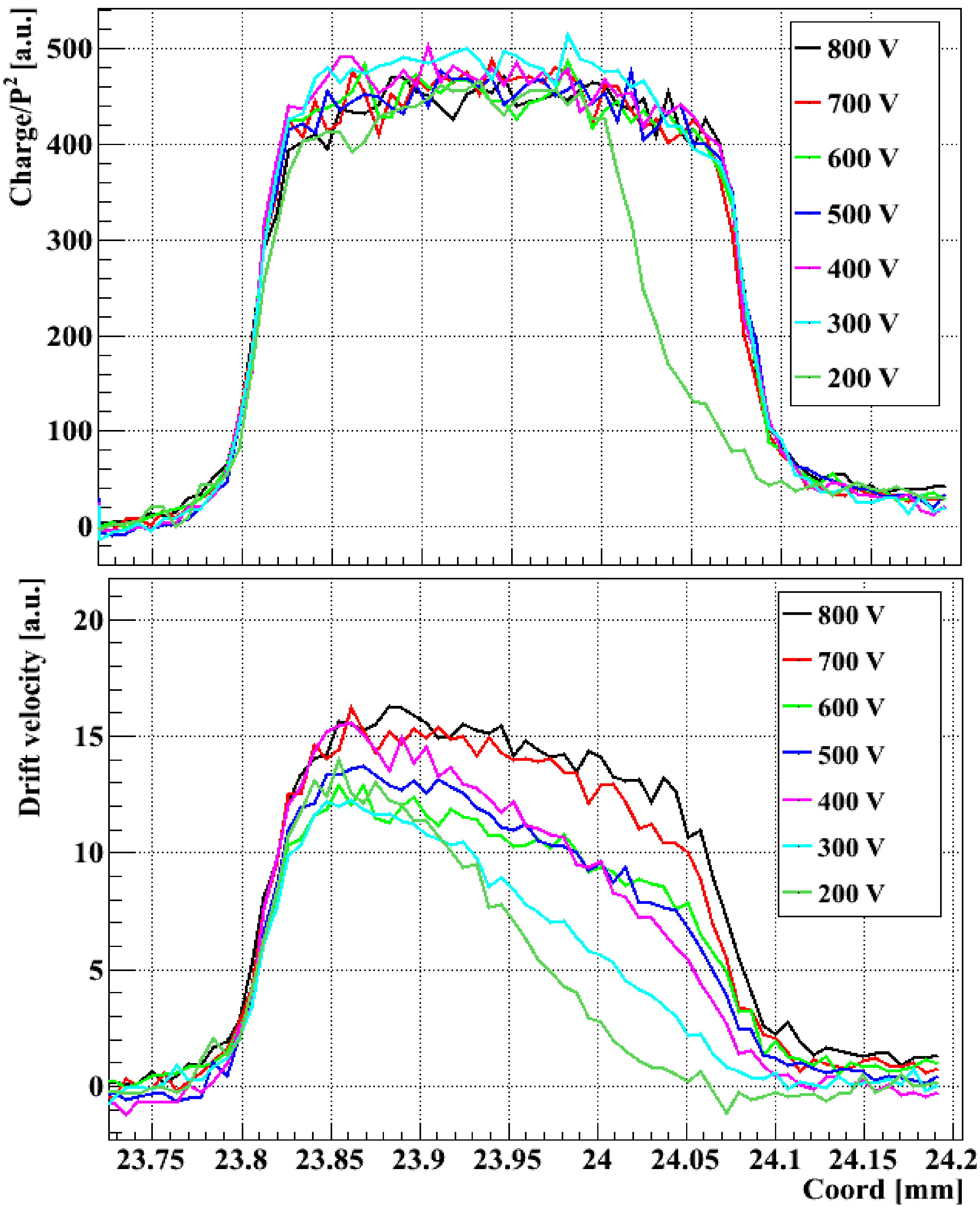




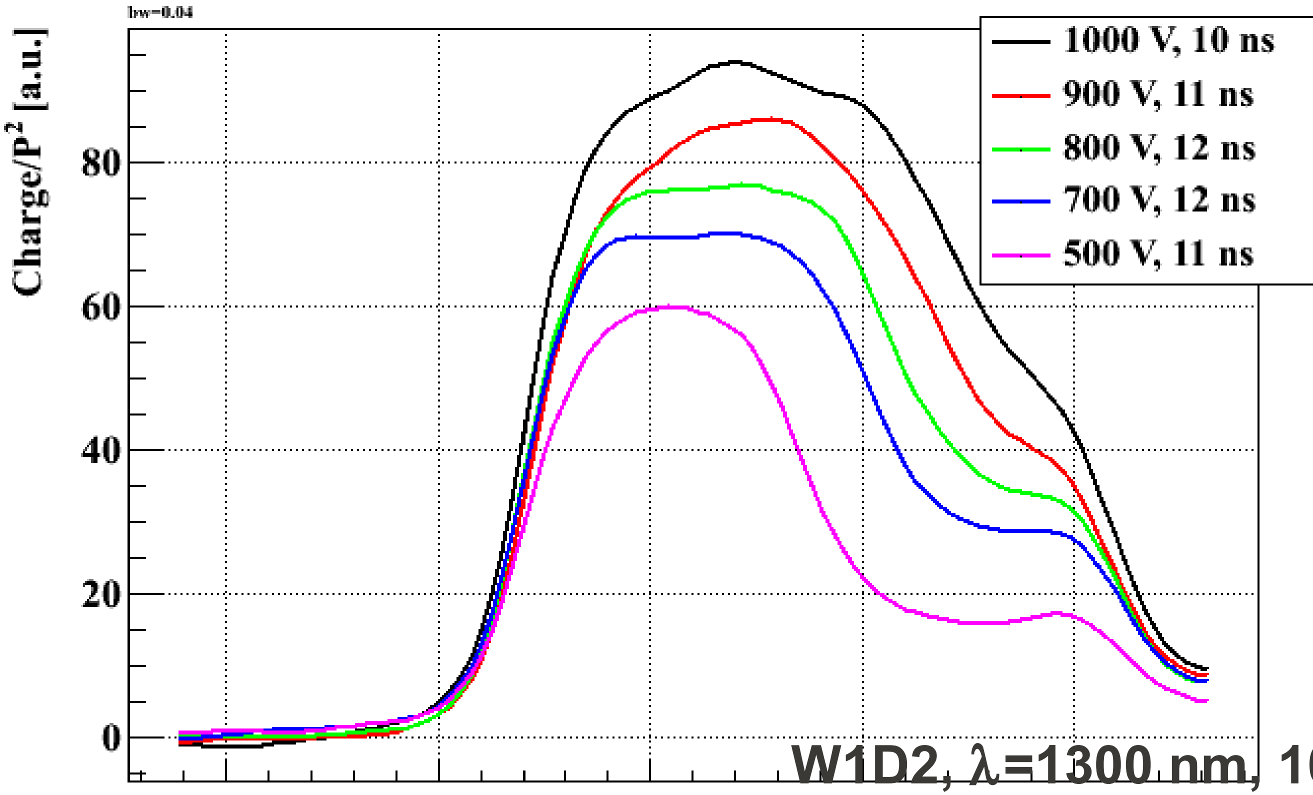
Two-Photon Photopolymerization and 3D Litographic Microfabrication. H.B.Sun and S.Kawata. APS (2004) 170 pp 169-273, Springer-Verlag.
Femtosecond Laser Litography in Organic and Non-Organic Materials, F.Jipa et al., Chap.3, Nanotechnology and Nanomaterials, "Updates in Advanced Litography", ed. by S.Hosaka, INTECH, 2013.



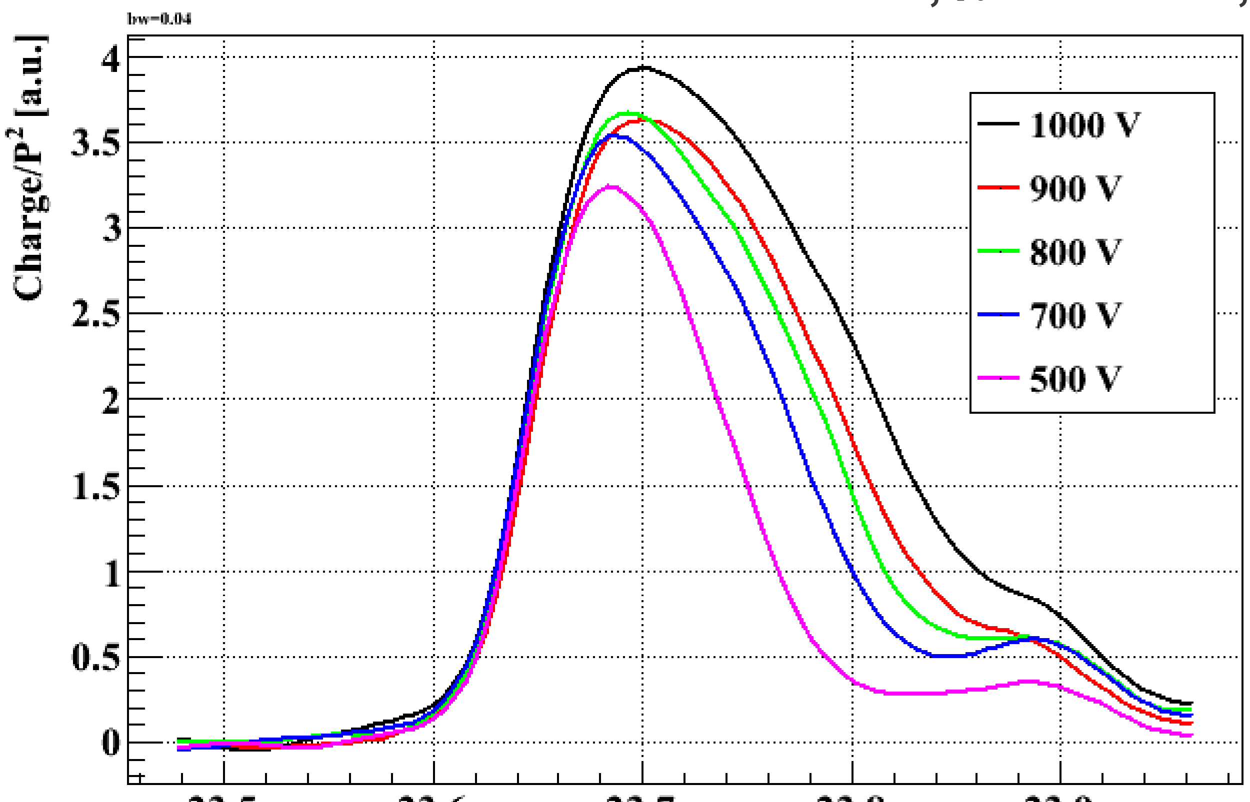
bw=0.04
Charge/P^2 [a.u.]
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
200 V, 15 ns
150 V, 16 ns
100 V, 20 ns
50 V, 27 ns
bw=0.04
Drift velocity [a.u.]
1400
1200
1000
800
600
400
200
0
50 V, 0 ns
100 V, 0 ns
150 V, 0 ns
200 V, 0 ns

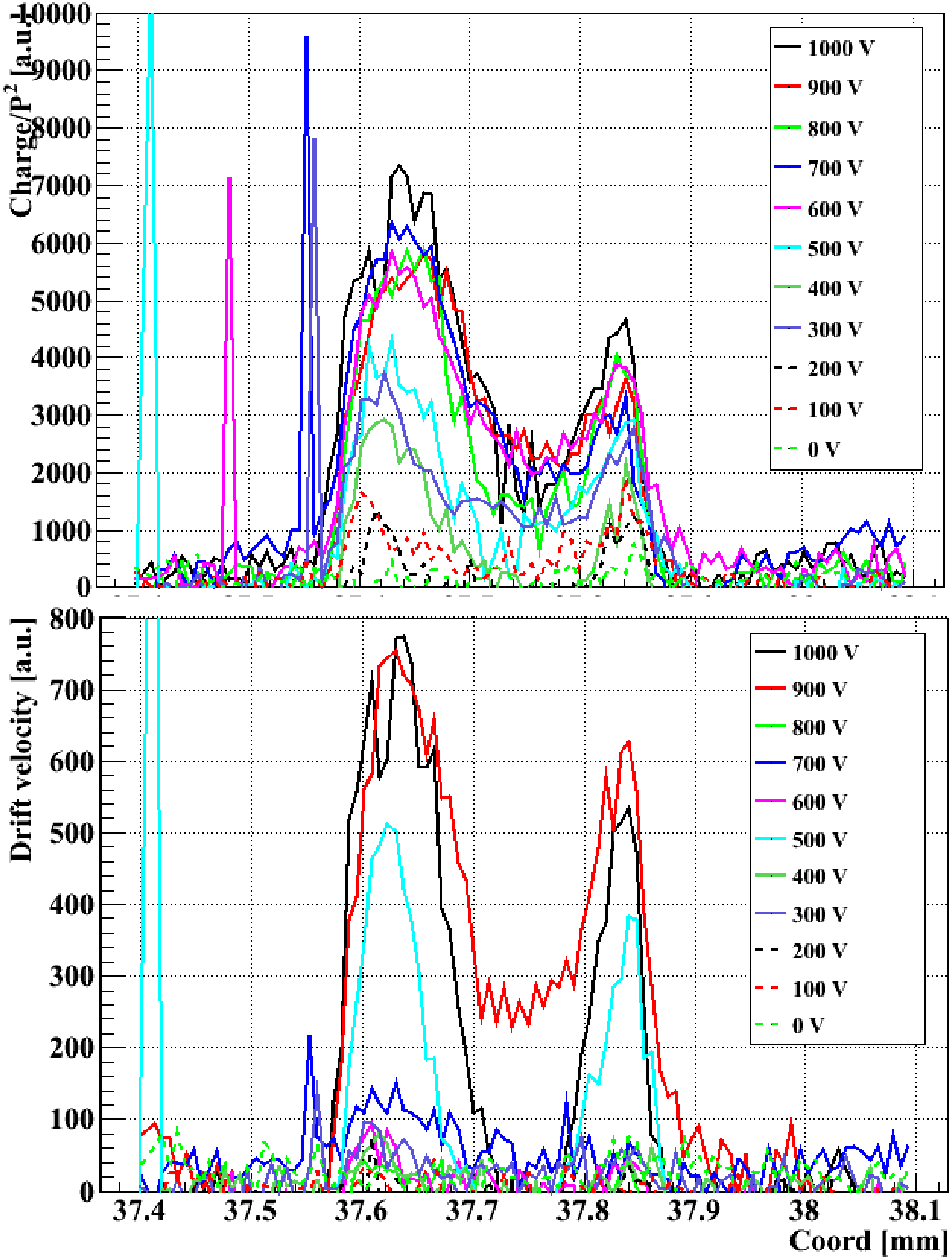


w1f8, 1.3 um, 1e14, -20C



W1D2, λ=1300 nm, 10^{15} n_{eq}/cm^2,-20 °C (SPA correc

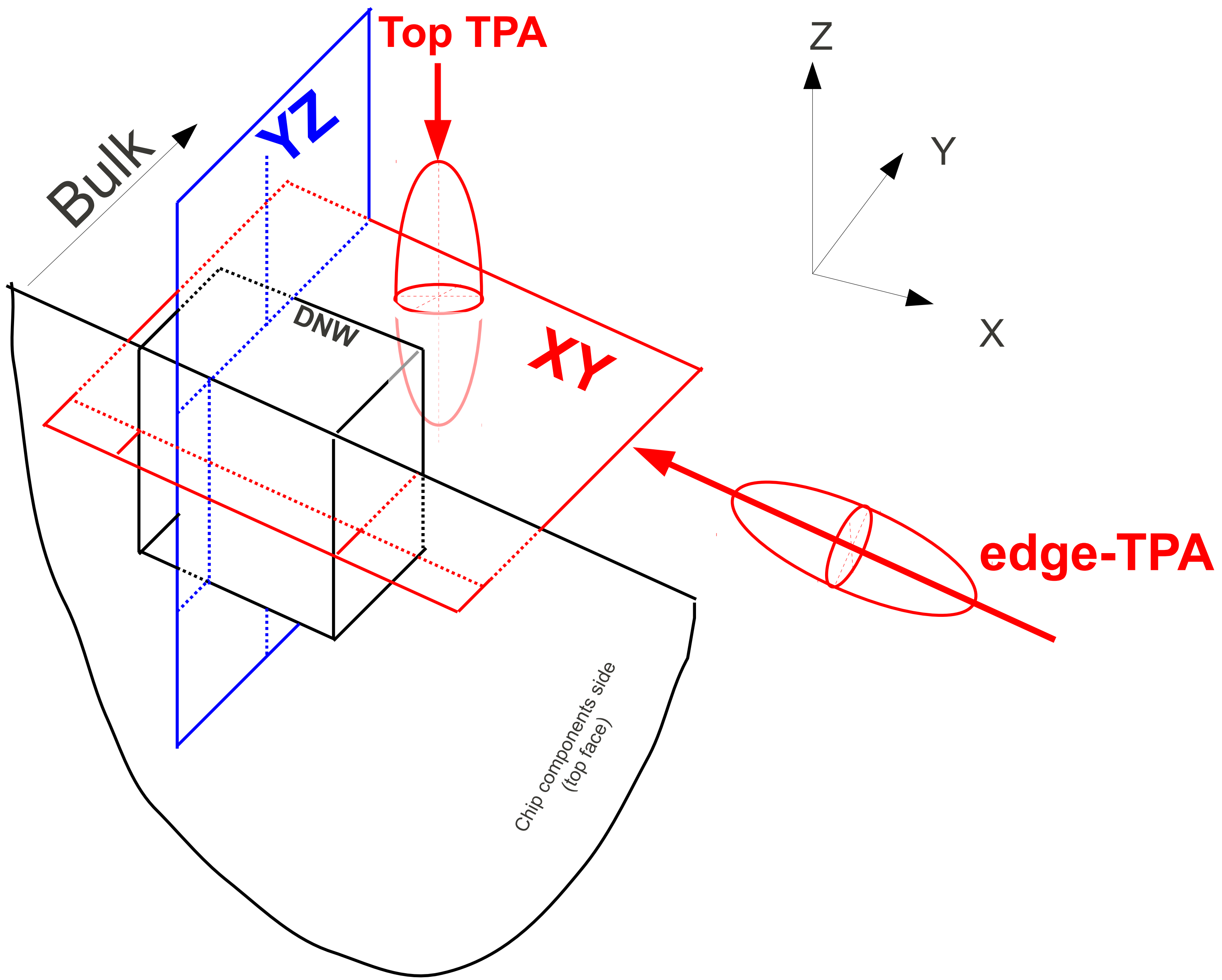




tleft = 26.8 ;
tright = 40.0 ;

Some values missing!
Go file by file

Check 200,400 V


Top TPA
YZ
Bulk
DNW
XY
Z
Y
X
edge-TPA
Chip components side
(top face)