TPA - TCT
Two Photon Absorption - Transient Current Technique

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supervised by M.Moll and U.Parzefall

Measurements performed at CERN
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Work performed in close collaboration with
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CERN
Universität Freiburg
Universidad del Pais Vasco (UPV-EHU)
Universidad de Sevilla (US)
Instituto de Física de Cantabria (CSIC-UC)

CERN, 24th October 2019

Silicon Detector Development

Detector Performance Requirements
- Radiation hardness
- Timing resolution
- Spatial resolution

Device Engineering
- p-type silicon
- thin detectors

...

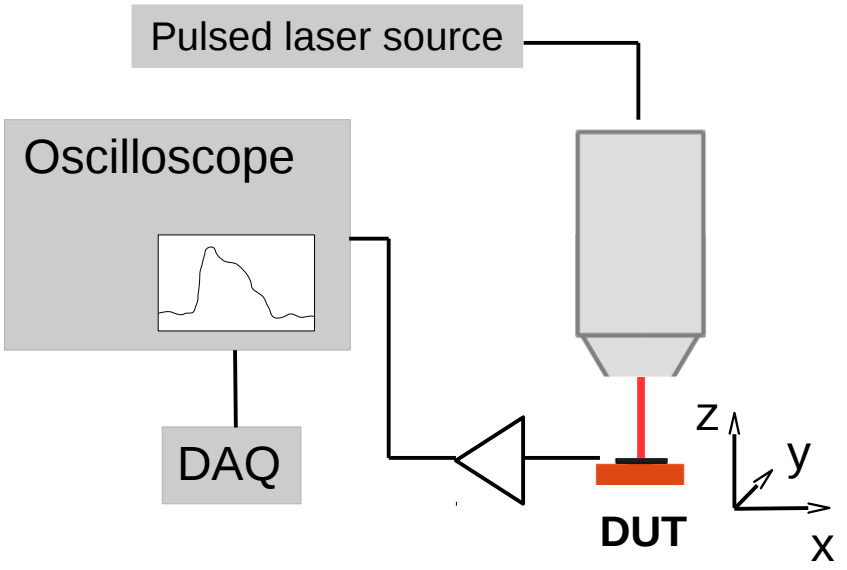
Material Engineering
- doping with foreign atoms
- new materials

...

Device- / Defect Characterization Tools

IV / CV,
Thermally Stimulated Currents,
Deep Level Transient Spectroscopy,
Transient Current Technique (TCT),
Two Photon Absorption TCT
…..

Transient Current Technique

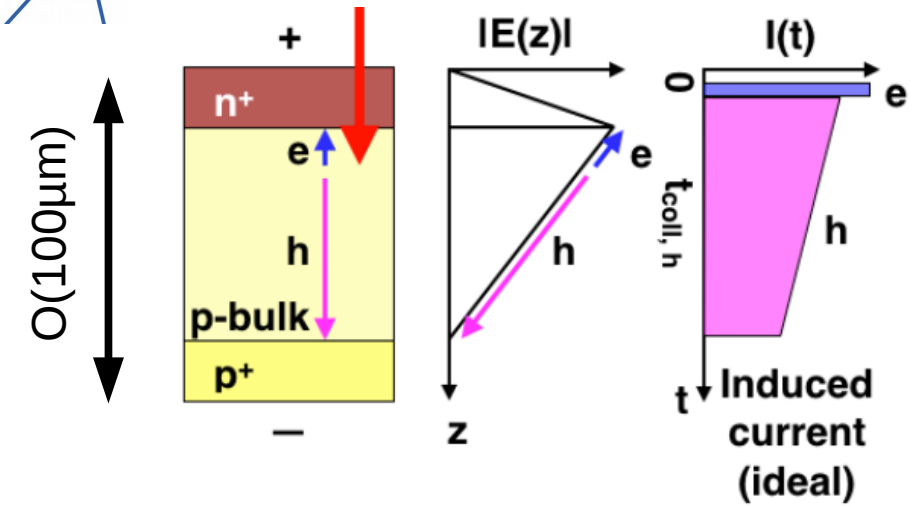


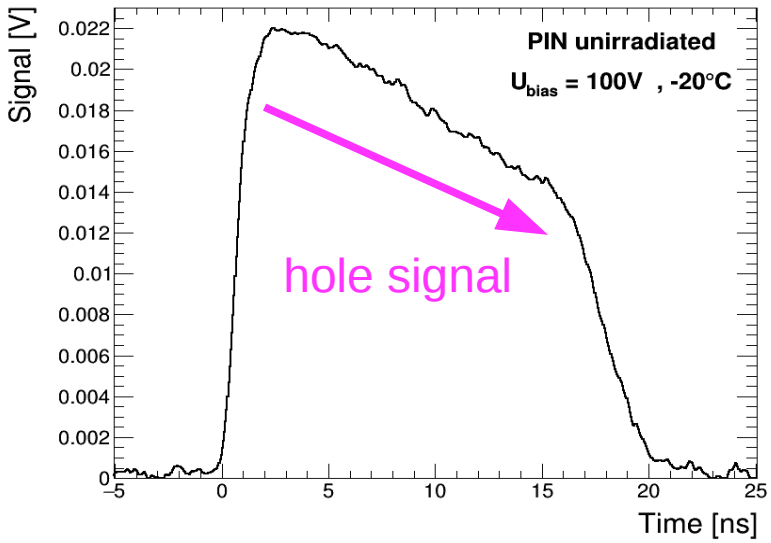
Measure:
electron/hole signal (top/bottom injection)
sensor bulk properties (edge injection)

- signal / noise
- charge collection time
- charge collection homogeneity
- electric field profile
- effective doping concentration
- ...

available at CERN – SSD TCT+ (B186)
Christian Gallrapp, “The TCT+ setup - a system for TCT, eTCT and timing measurements”, 1st TCT Workshop DESY

TCT - Transient Current Technique

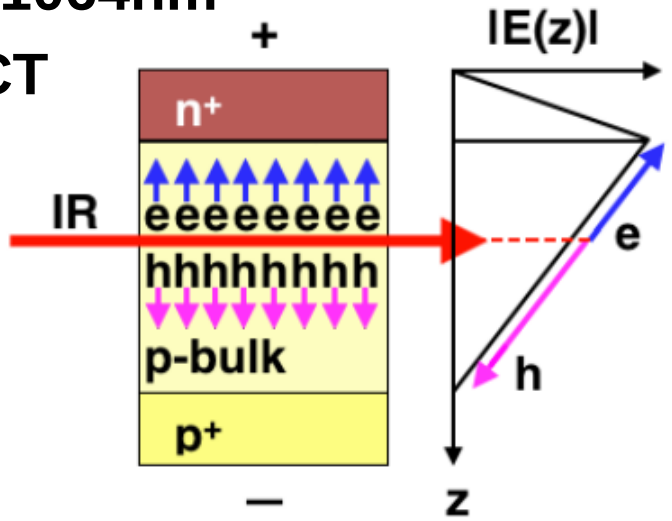


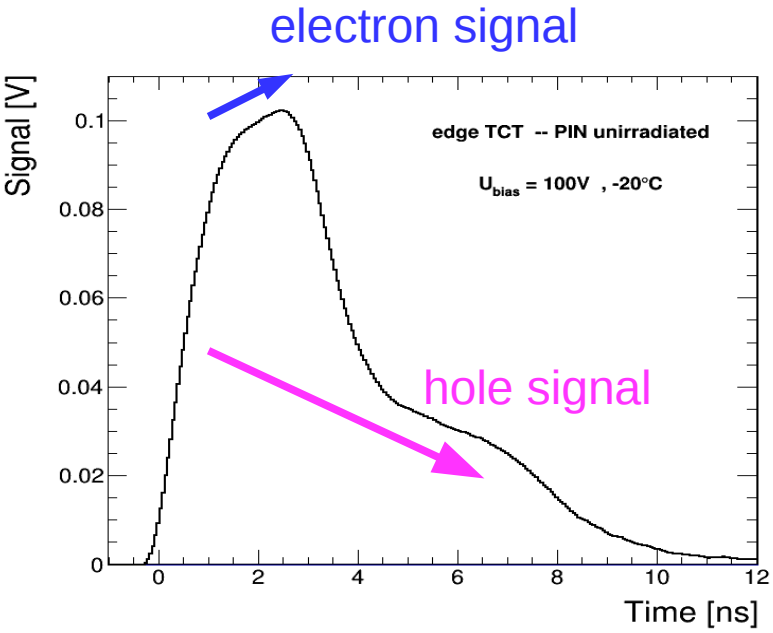


Red 660nm

Near IR 1064nm

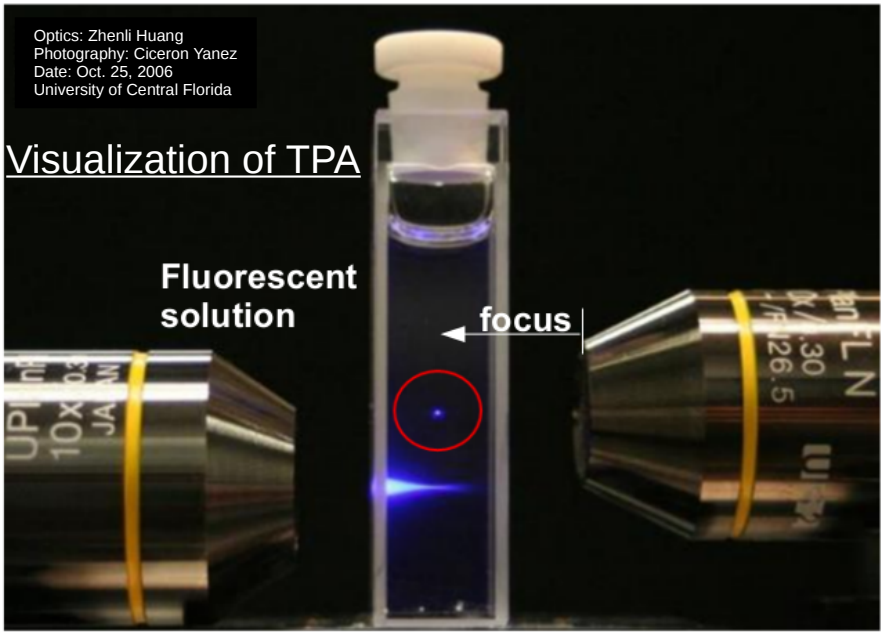
edge-TCT





Two Photon Absorption - TCT

Single Photon Absorption
Continuous energy deposition along beam direction



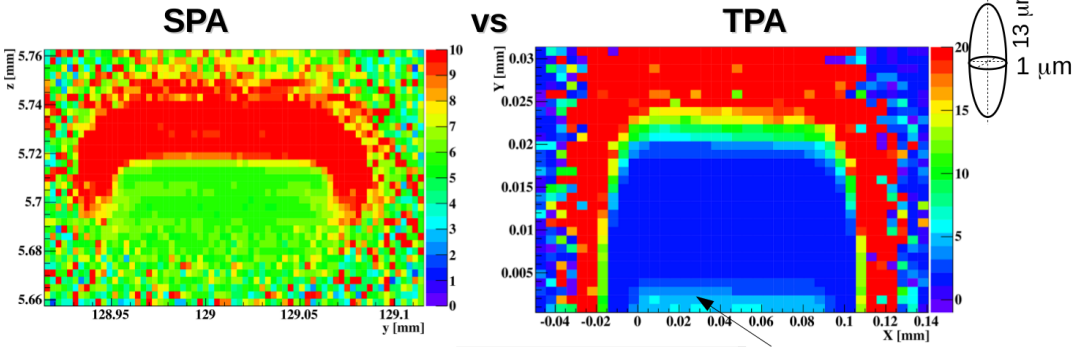
Two Photon Absorption

Absorption only at focal point

Confine photons in **time (femto-second laser)** and in **space (microfocusing)** for Two Photon Absorption

- 12th of March 2013, first TPA-TCT measurement at SGIker facility of UPV, Bilbao
- November 2014: Presentation of TPA-TCT at 25th CERN RD50 workshop
- 2013 – 2017: TPA-TCT measurements at UPV, Bilbao

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



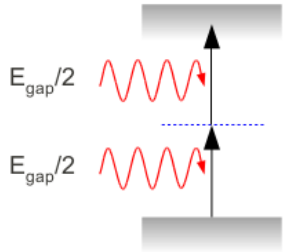
deep n-well in HVCMOS
Not resolved in SPA-TCT

Two Photon Absorption - TCT

Requirements for TPA-TCT:
- Sub band-gap energy laser
  $\lambda > 1100nm$ ($E < 1.12eV$)
- **large enough intensity**

TPA

TPA: Conventionally, no excitation if $E_{photon} < E_{gap} \sim 1$ eV. But, if **TWO** photons arrive in ~100 attoseconds:

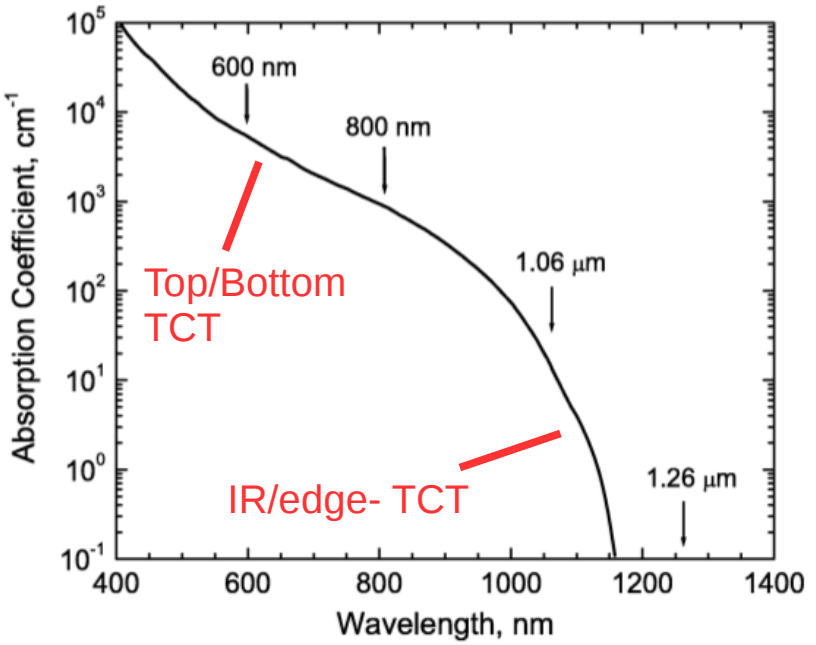


Virtual state

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

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

Carrier Generation equation



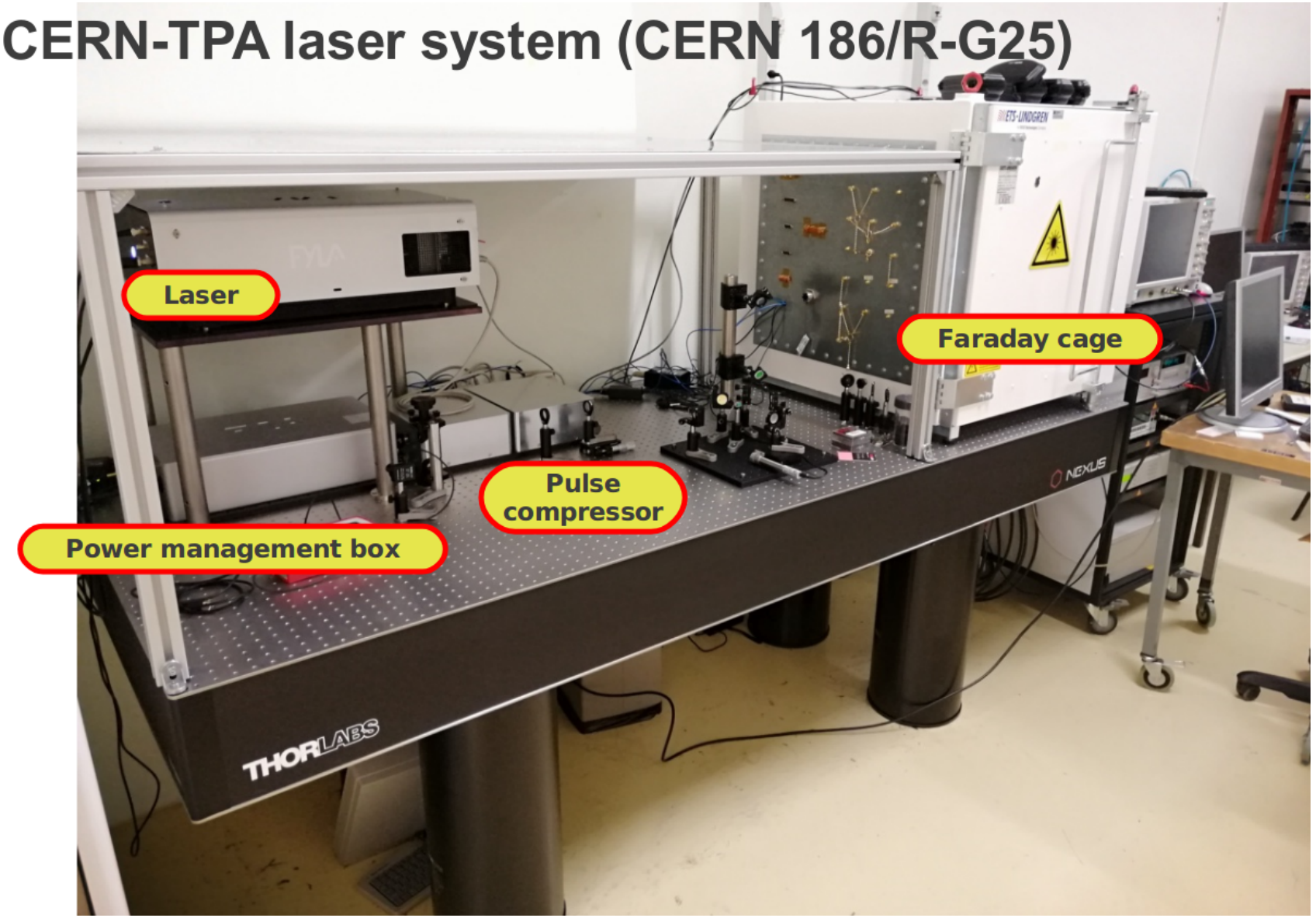
TPA-TCT
1550nm

Subbandgap Laser-Induced Single Event Effects: Carrier Generation via Two-Photon Absorption, D. McMorrow et al. 2002

2016: Presentation of TPA-TCT at CERN
to CERN KT Fund Selection Committee
→ Funding to build a compact TPA-TCT setup at CERN SSD lab

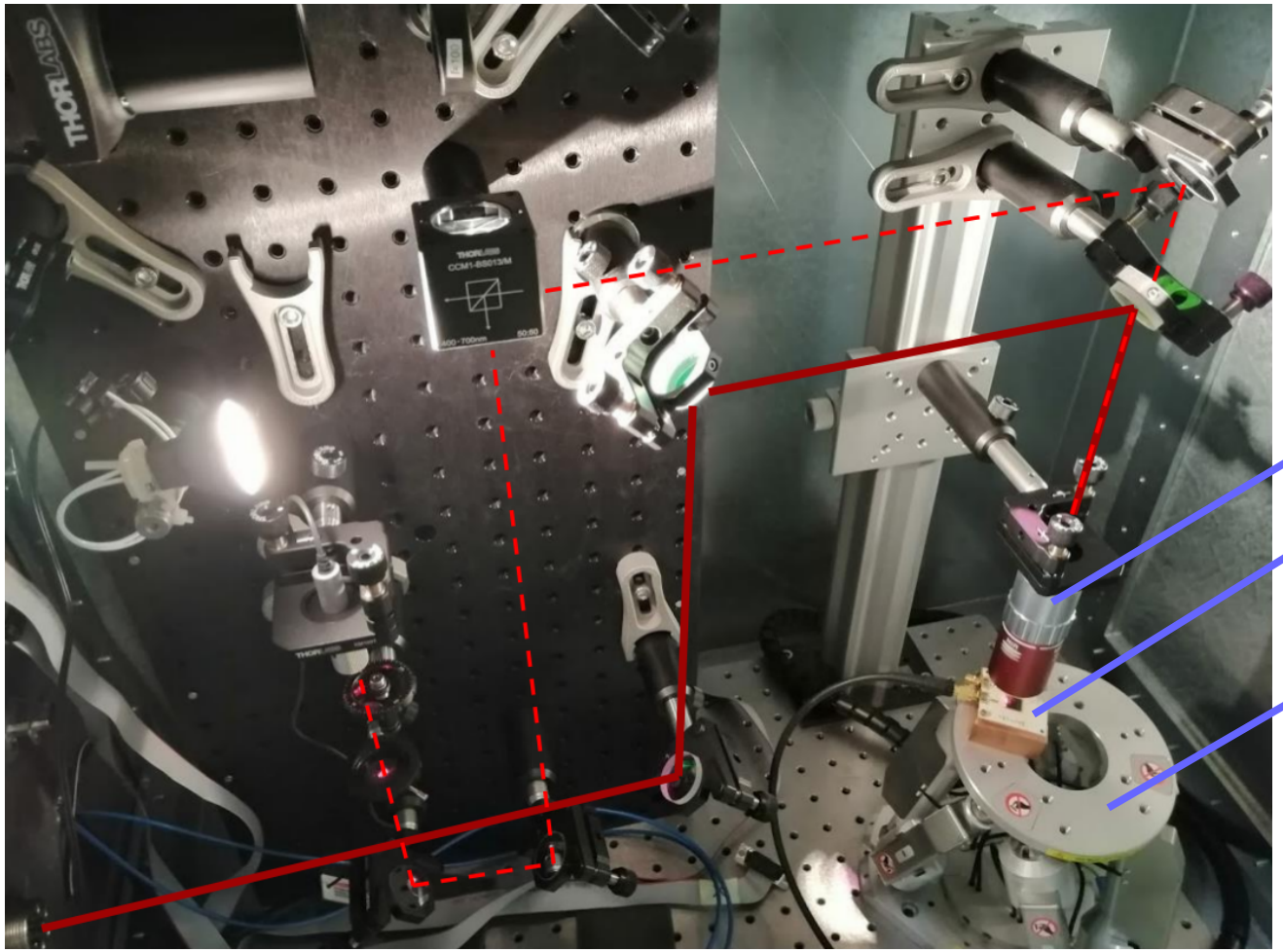
2nd of July 2019: First TPA-TCT signal at CERN

TPA – TCT at CERN



TPA – TCT at CERN

Vertical breadboard with microscope setup:
CMOS camera + red laser diode
→ imaging the detector for alignment



Mitutoyo microscope objective
100x NIR

PCB with sample

Hexapod HXP50
3 translation + 3 rotation axis
50-100 nm step size
1-2 cm travel range

Proof of TPA

Signal ~ Irradiance²

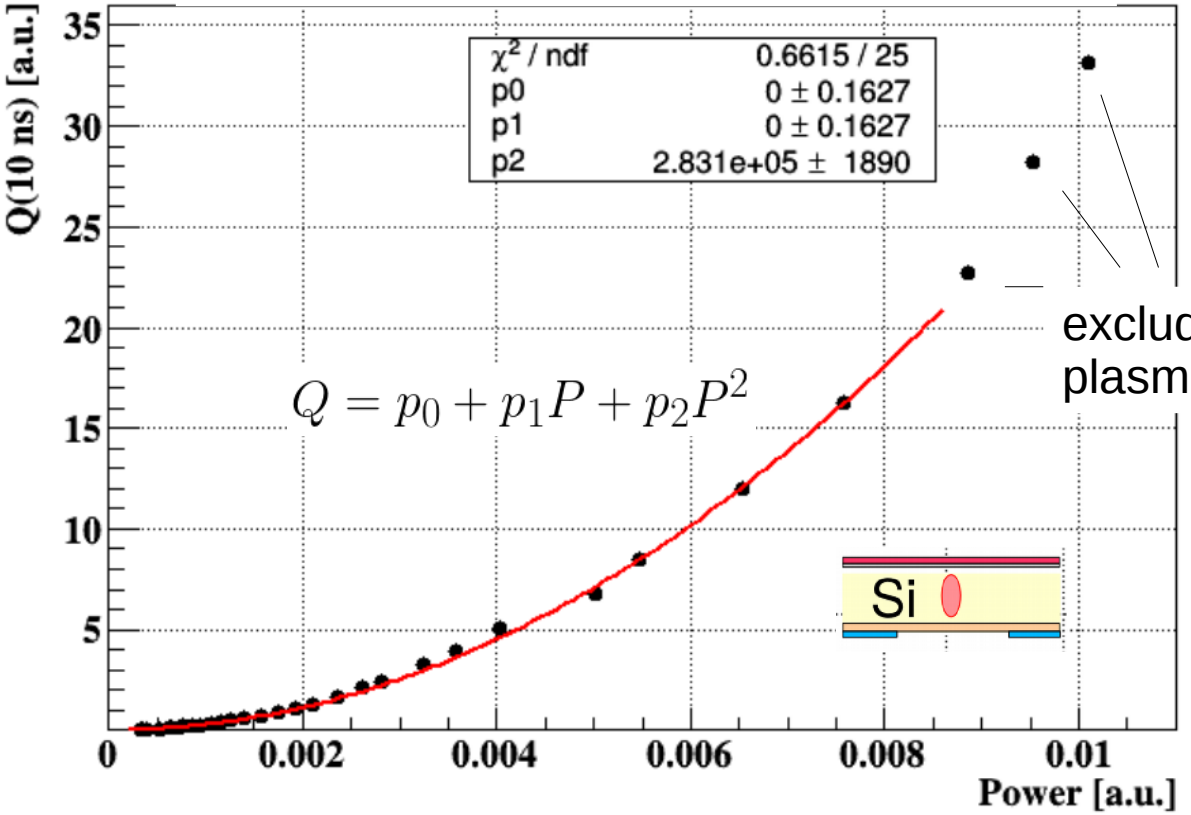
- Variable laser power
- Fixed focus inside detector
- Constant bias voltage

2nd order absorption (TPA)

→ quadratic dependence of signal on laser power

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

Carrier Generation equation

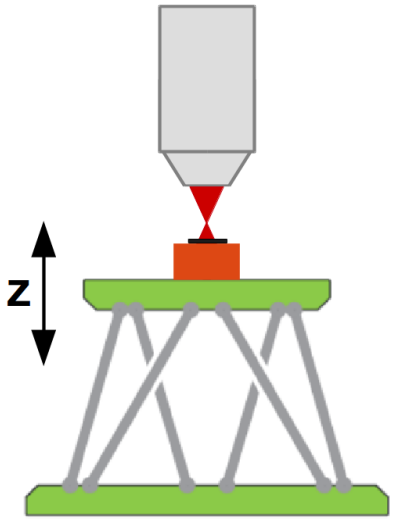


excluded due to plasma effect

HPK FZ200P-05-DiodeL-9
- unirradiated
- 200V bias voltage

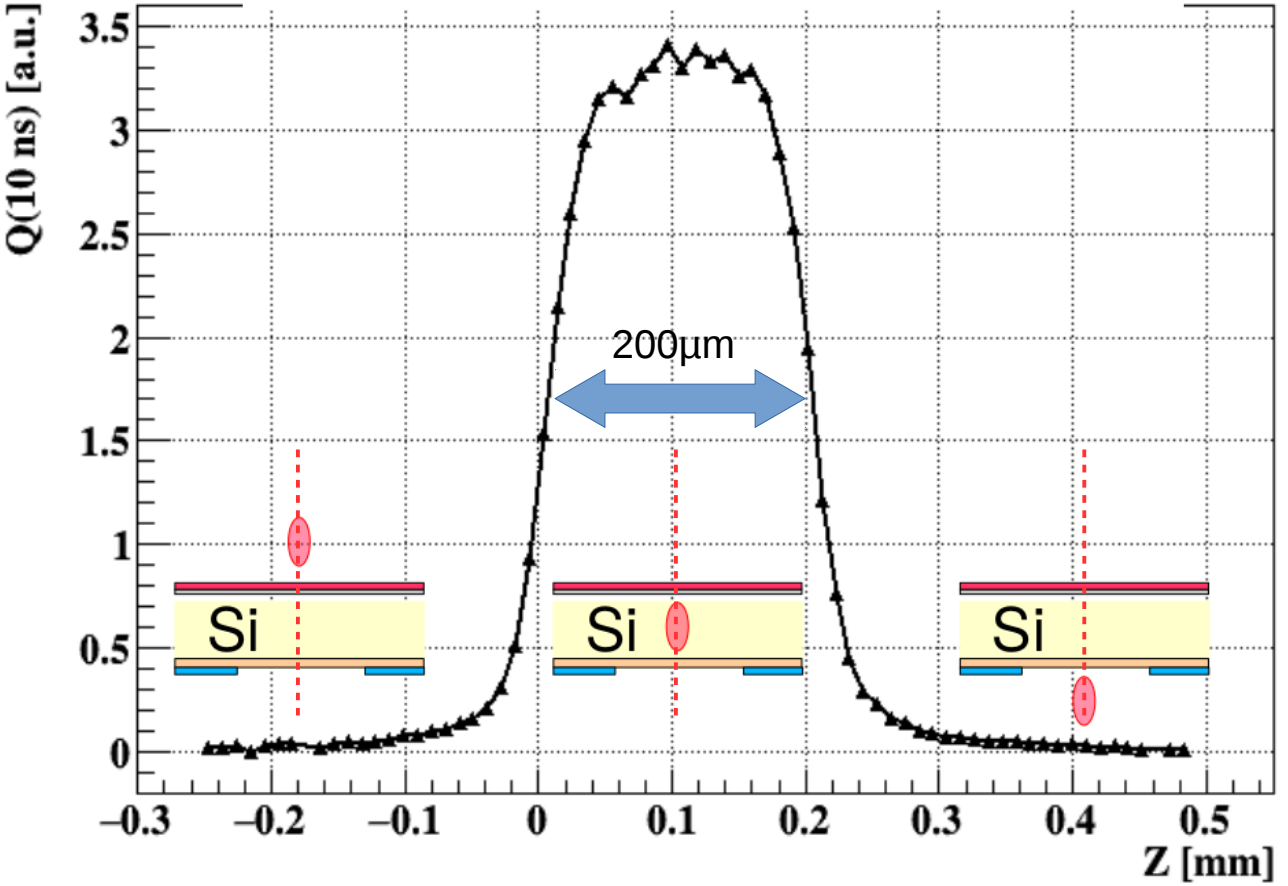
Proof of TPA

z-scan



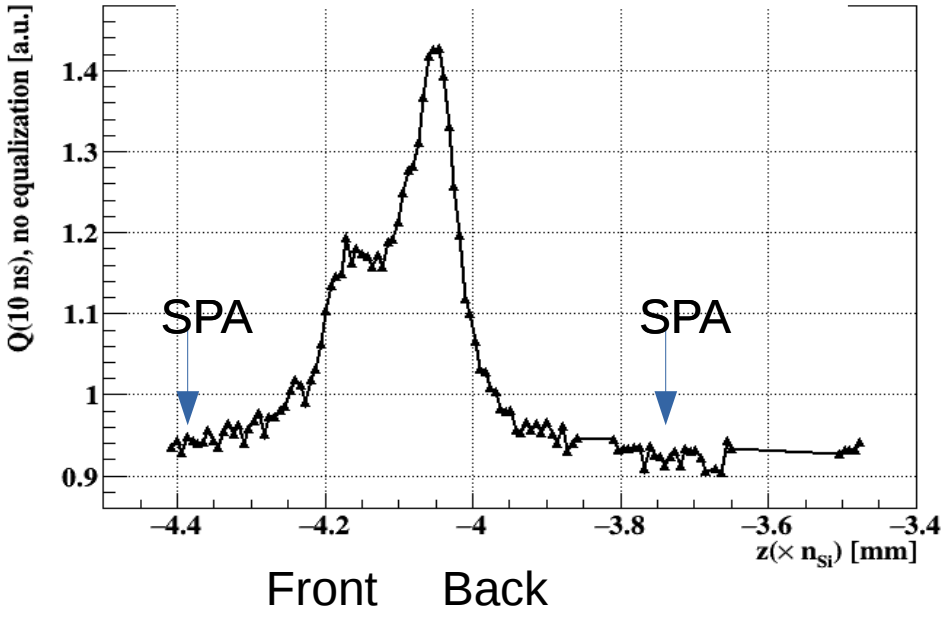
SPA: Light absorption anywhere along beam

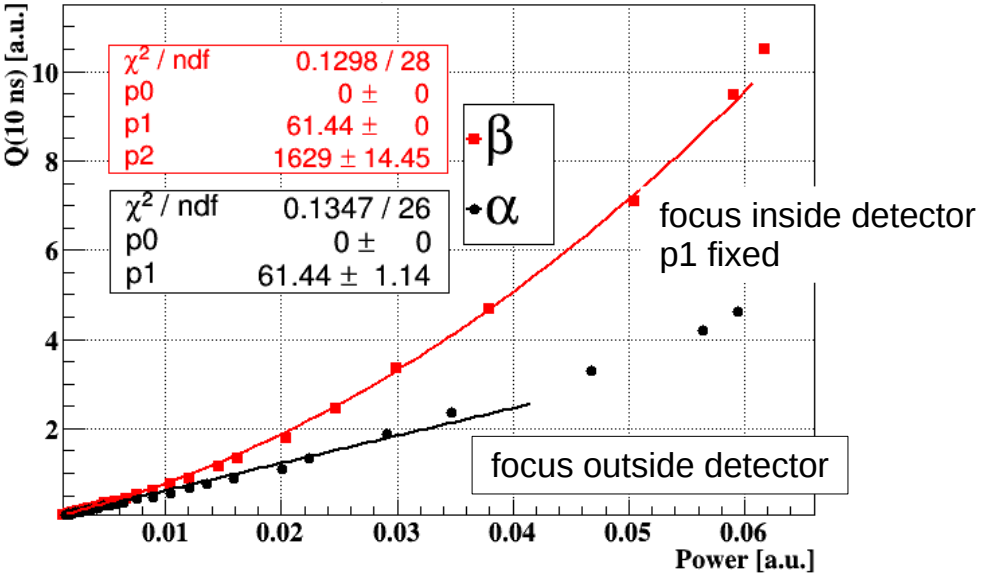
TPA: No signal, if focal point not inside detector



HPK FZ200P-05-DiodeL-9
- unirradiated
- 200V bias voltage

Irradiated Detector Test





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

Carrier Generation equation

- Irradiated with 1.6e16 n_{eq}/cm^2 (neutrons, Ljubljana)
20 V, no cooling, I=0.23 mA

- Main junction has shifted to backside after irradiation

- Not SPA corrected

Irradiation introduces defects in band gap

→ single photon absorption possible
→ TPA measurements need to be corrected

Summary

- TPA-TCT proved to be a powerful tool for sensor characterization with high spatial resolution
- First, very successful tests on compact CERN TPA-TCT setup
- Commissioning just started…

  ...many things to do, to finalize setup

  (cooling, DAQ, laser stability, optical setup...)

Many thanks to the CERN SSD team!

Gefördert durch DFG Deutsche Forschungsgemeinschaft

SPONSORED BY THE Federal Ministry of Education and Research

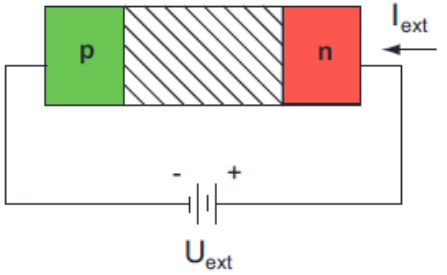
Silicon Detectors

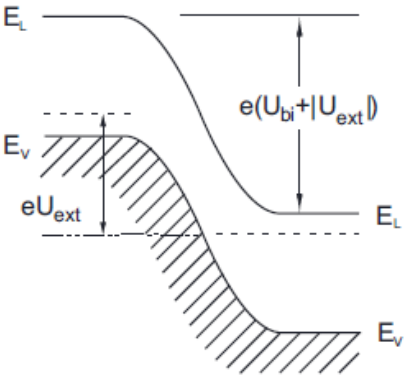
→ Deplete sensor by applying **reverse bias voltage**

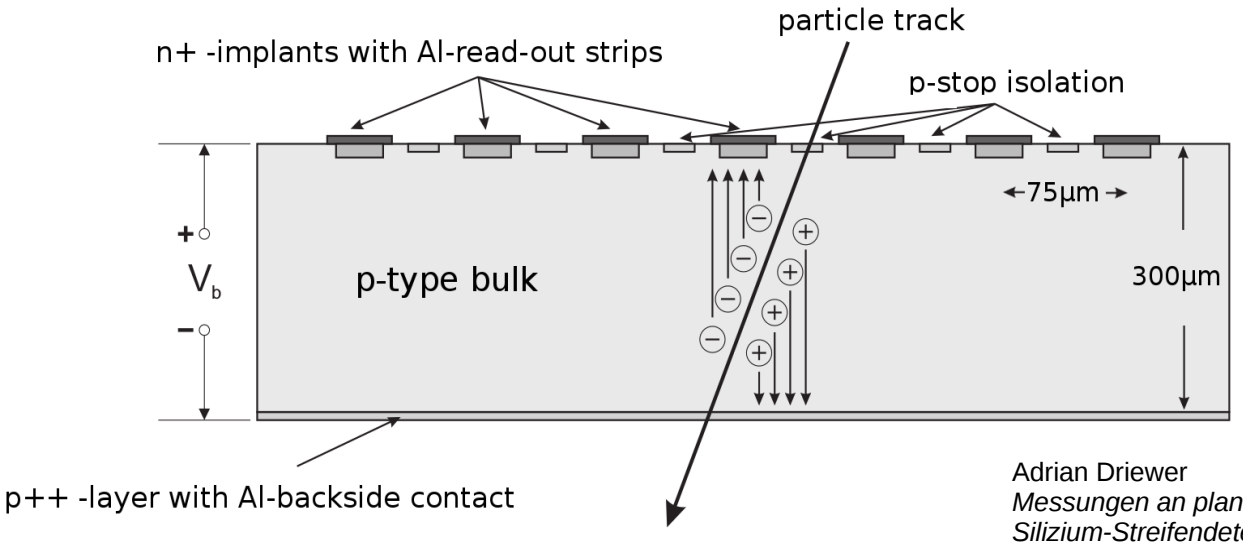
Charged particles lose energy in material by ionization and excitation of electrons in atomic shell
→ **Create electron-hole-pair** by lifting electrons into the conduction band

→ Charge drifts to read-out electrode
Drift current creates signal (Ramo-Theorem)

Intrinsic carrier density in Silicon:
145 x 10^8 cm^{-3} (room temperature)
e/h-pairs created by MIP in 300µm silicon:
~ 23,000

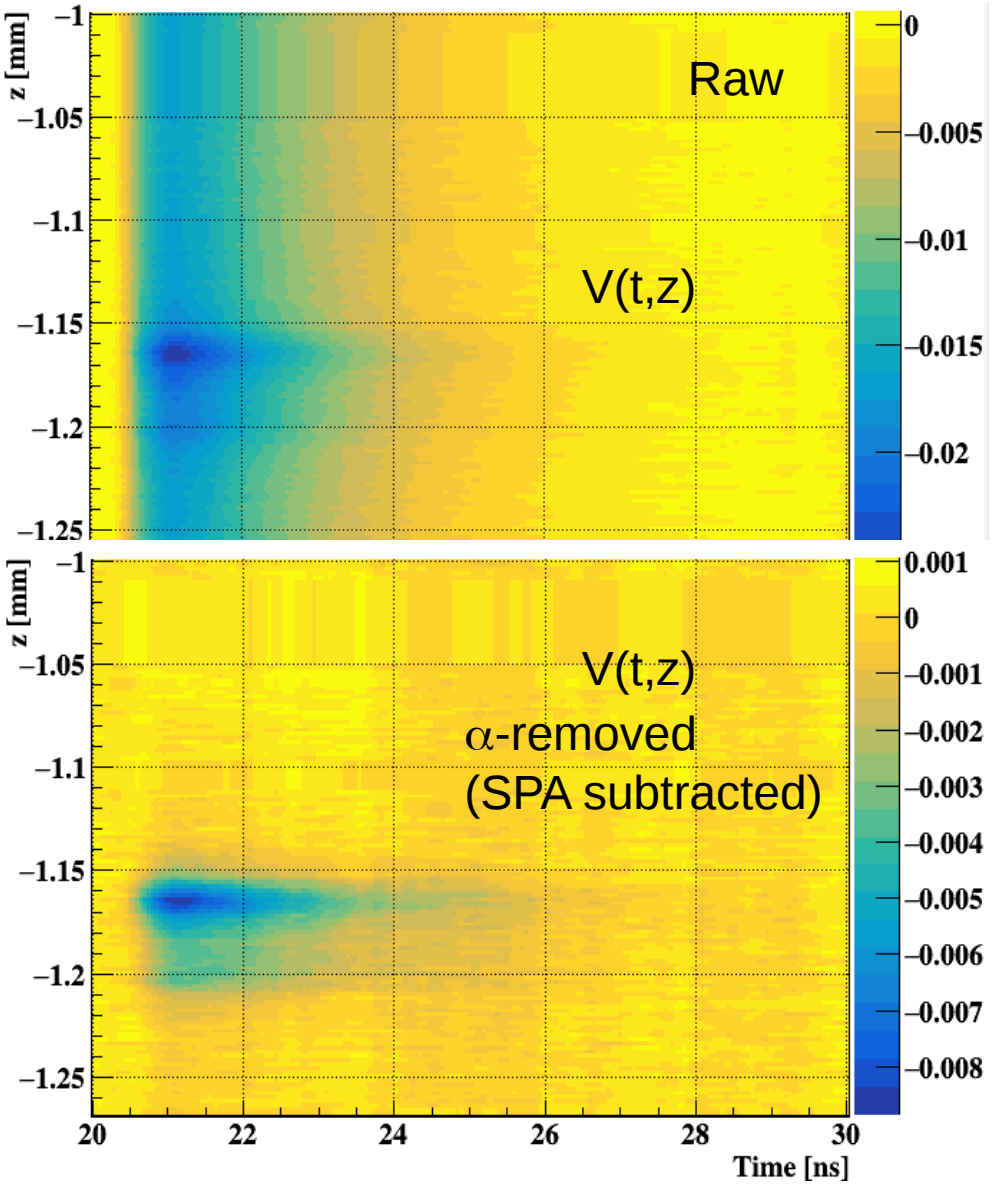






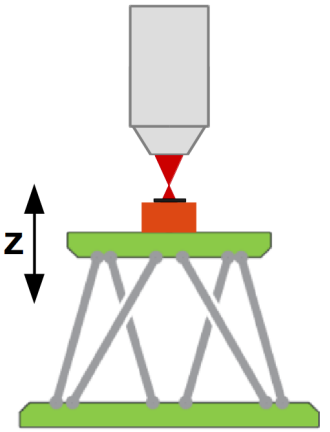
Adrian Driewer
Messungen an planaren, bestrahlten Silizium-Streifendetektoren für den HL-LHC

SPA – Correction

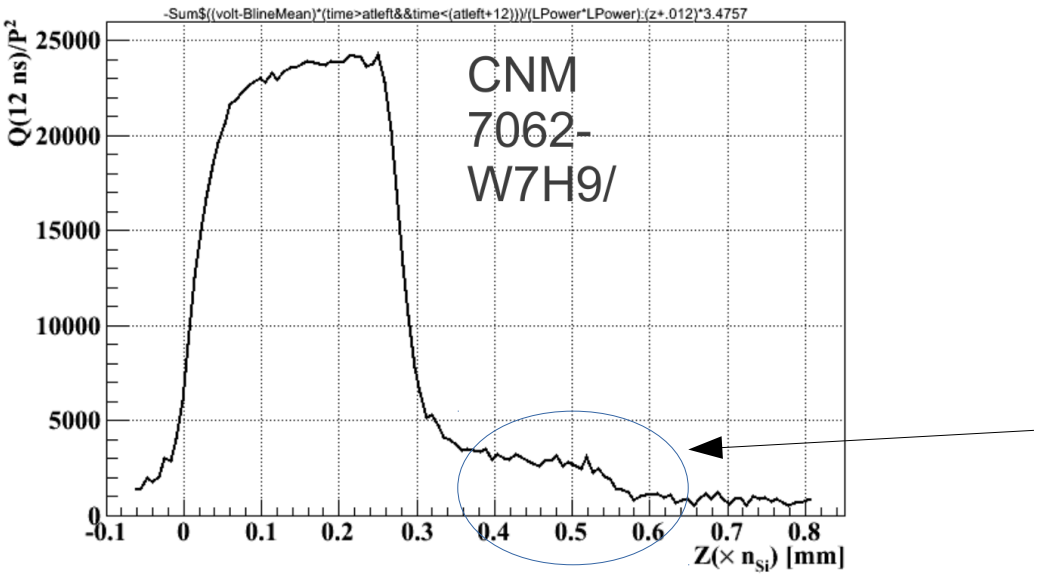


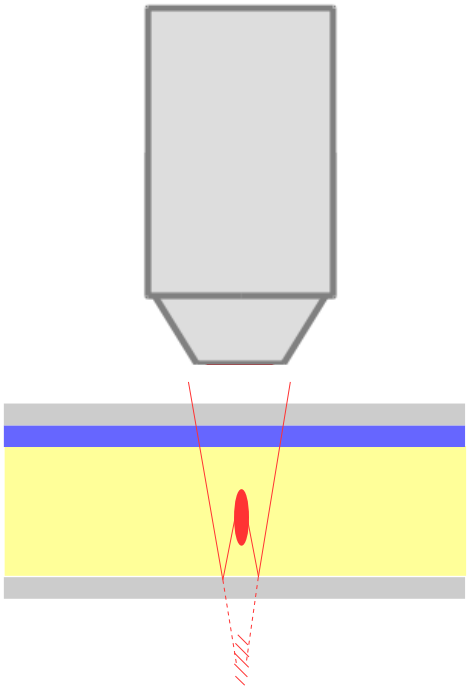
Irradiation increases SPA contribution
SPA is independent of laser focus position

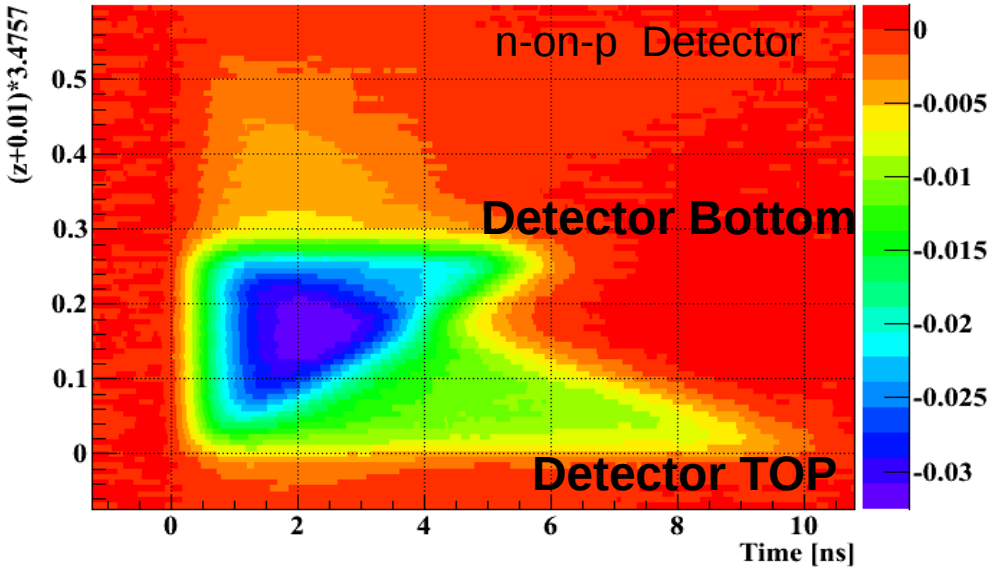
→ measure SPA contribution (focus outside of detector)
→ possibility to correct TPA measurement



Backside Reflection





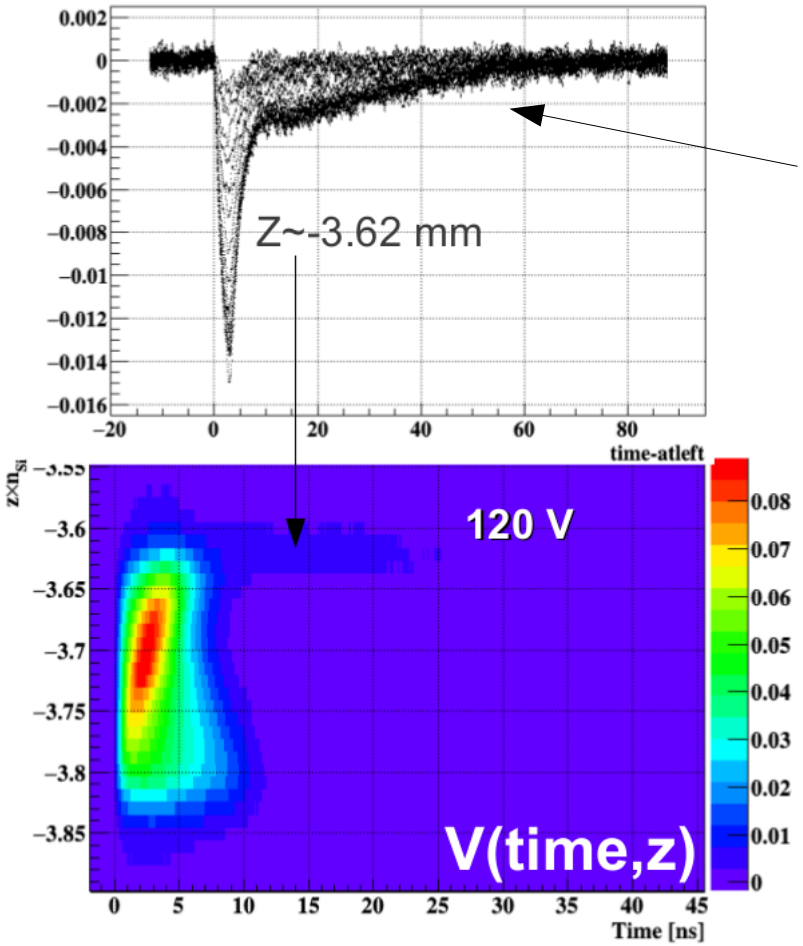


Reflections are less problematic for TPA-TCT than for conventional TCT:

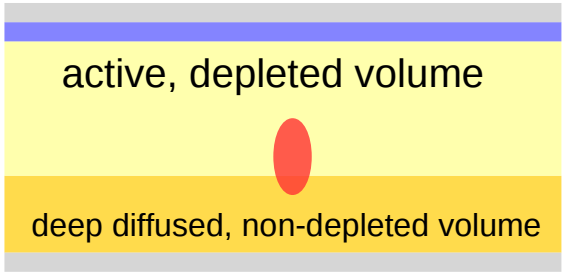
No charge generation
→ for diffuse scattering
→ or reflection of diverging beam

Deep Diffused Detector

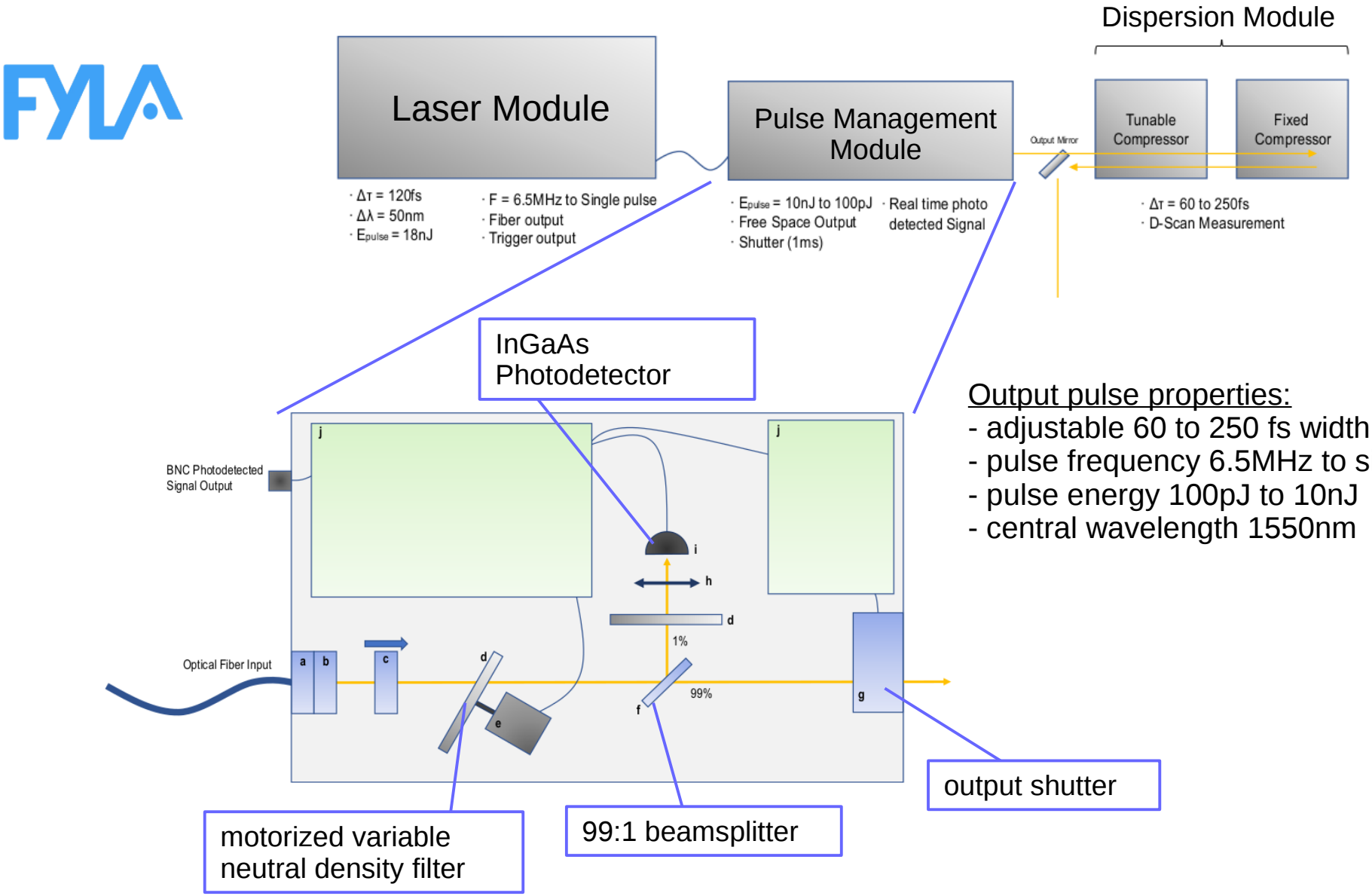
HPK deep diffused (200 um thick)
Aluminum contact is 120 away from end of depleted region
Observed drift+diffusion when beam is partially inside non-depleted region



signal from non-depleted volume only by diffusion
→ very slow signal (~60ns)



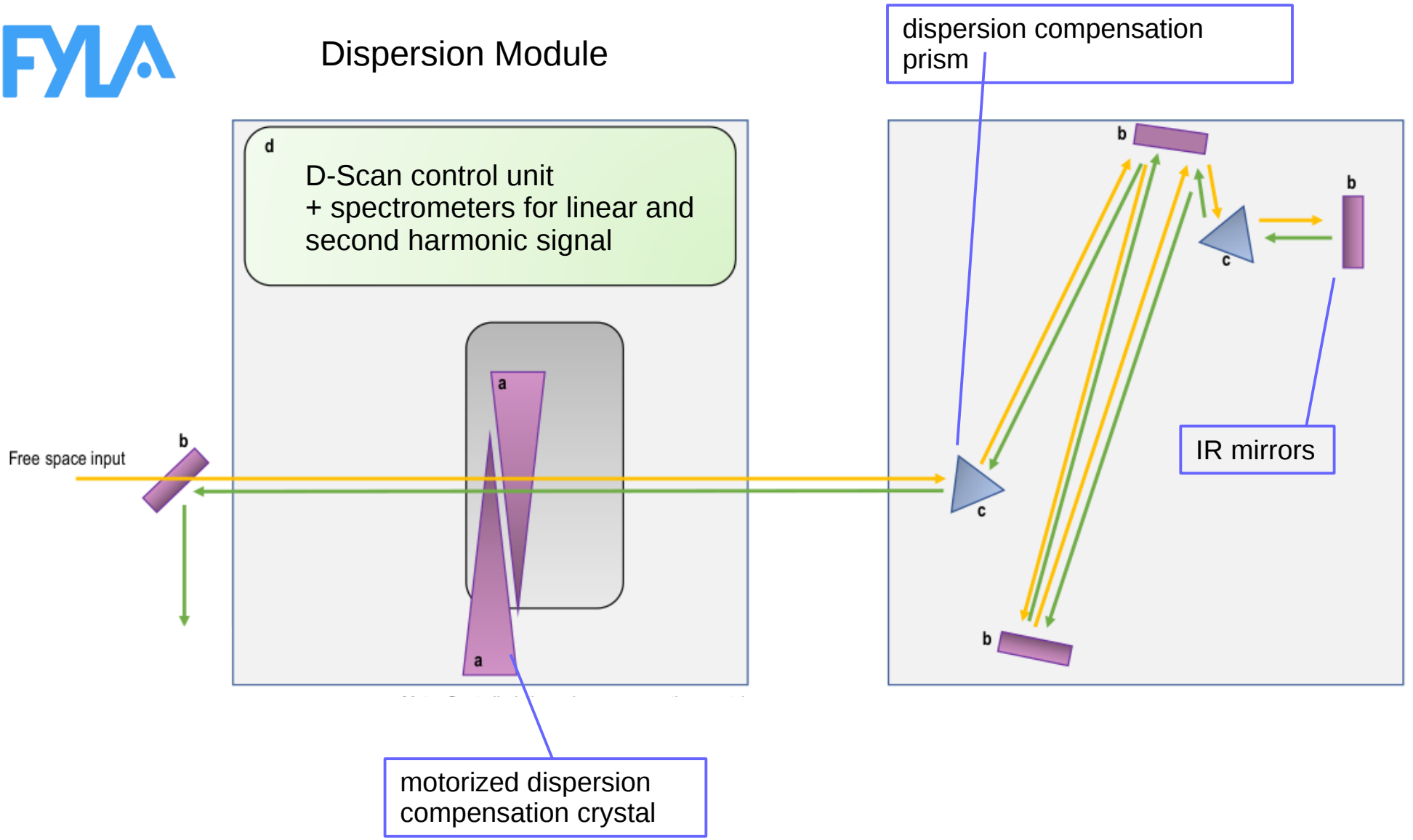
TPA - Laser



Output pulse properties:
- adjustable 60 to 250 fs width
- pulse frequency 6.5MHz to single pulse
- pulse energy 100pJ to 10nJ
- central wavelength 1550nm

TPA - Laser

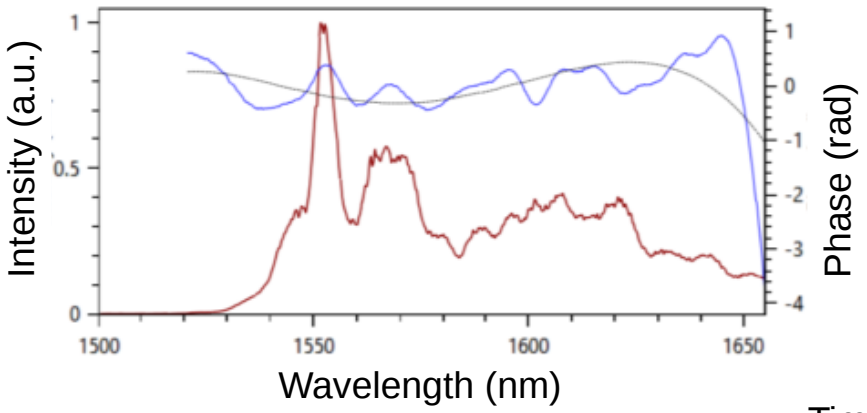
Dispersion Module



Pulse Characterization – D-Scan

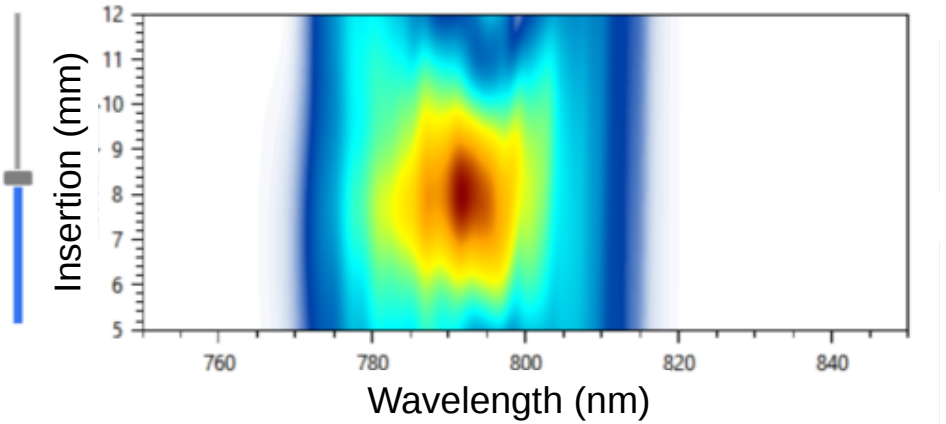
1) Measure **linear** and **second harmonic** power spectrum for different compressor insertions

Spectral Domain

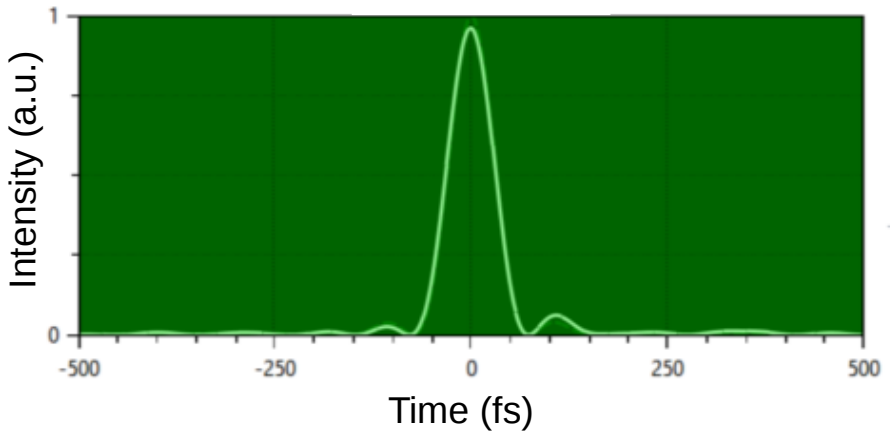


2) Compare measured **dispersion scan** to simulation to obtain phase curve

Retrieved D-Scan



Time Domain



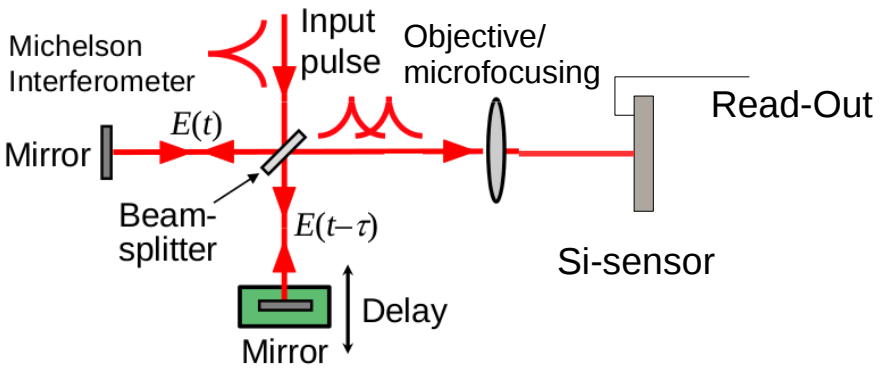
3) Calculate **pulse properties** in time domain

Pulse width	**66.18 fs**
Relative Peak Power	**96.1 %**

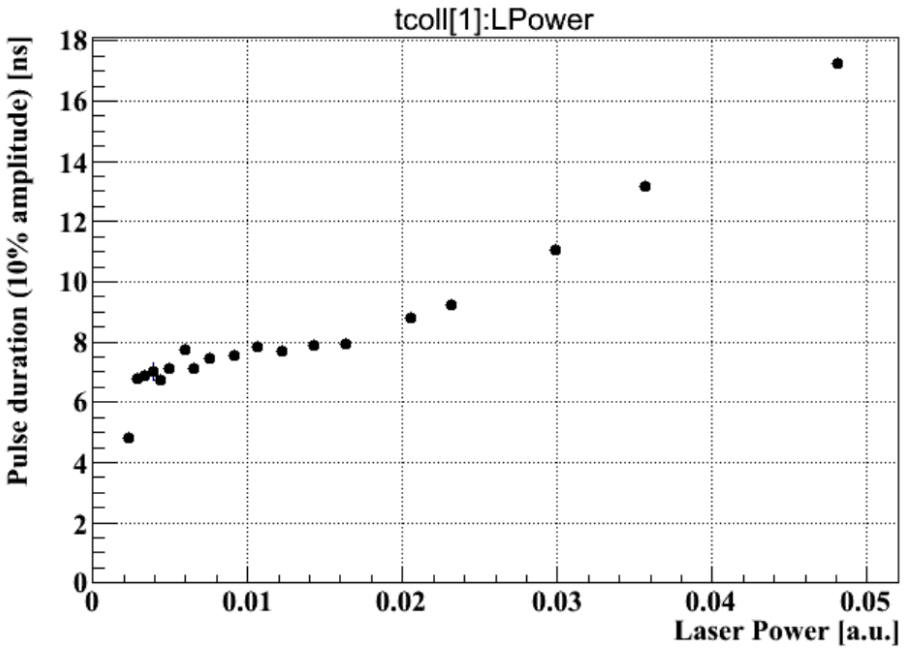
Miguel Miranda, Thomas Fordell, Cord Arnold, Anne L'Huillier, and Helder Crespo, "Simultaneous compression and characterization of ultrashort laser pulses using chirped mirrors and glass wedges," Opt. Express 20, 688-697 (2012)

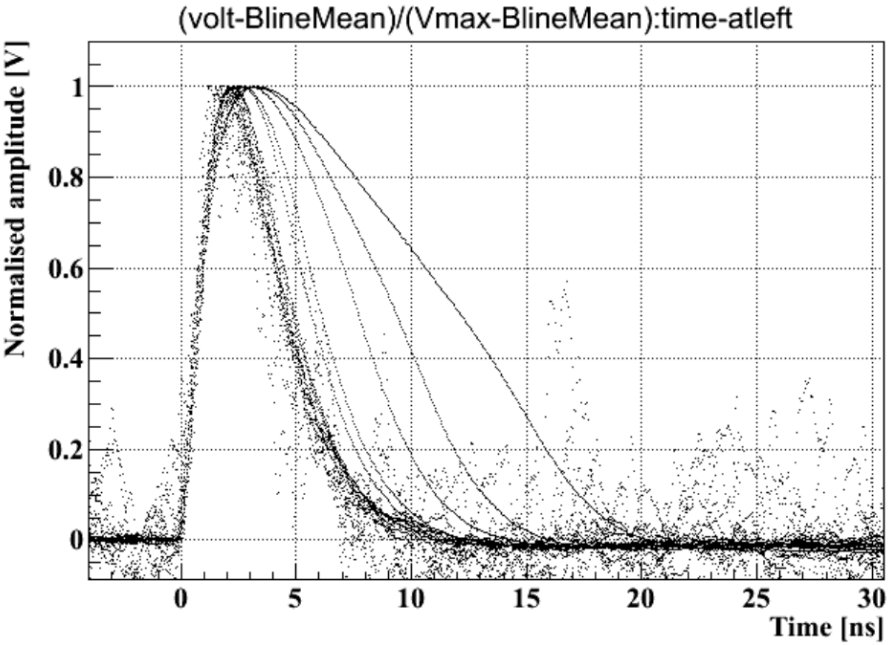
Things to do

- Automated measurement and data acquisition
- Cooling for measurements of irradiated devices
- Implement possibility for edge-TPA-TCT
- Microscope setup
- Intensity Autocorrelation for independent pulse length measurement



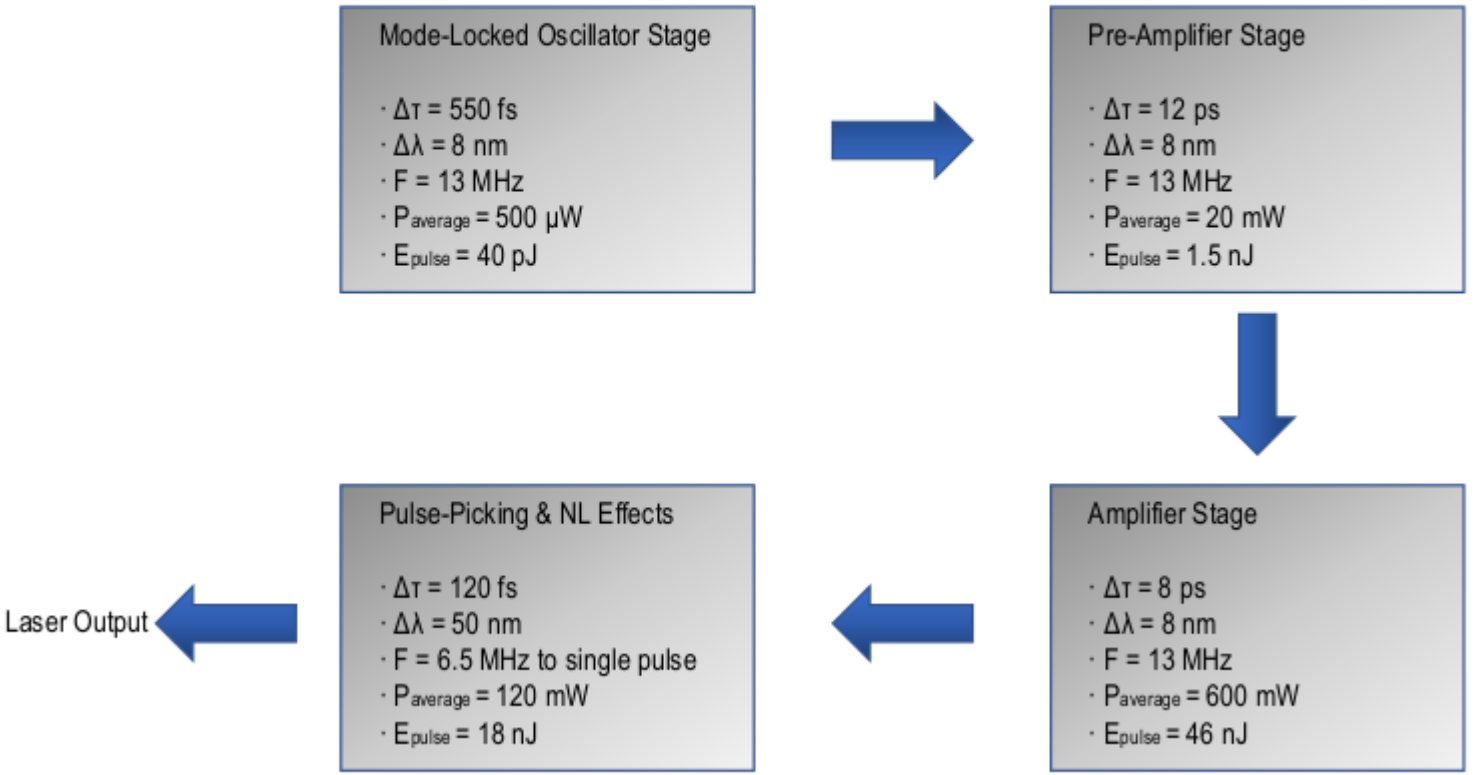
Plasma


tcoll[1]:LPower
Pulse duration (10% amplitude) [ns]
Laser Power [a.u.]
0
2
4
6
8
10
12
14
16
18
0
0.01
0.02
0.03
0.04
0.05

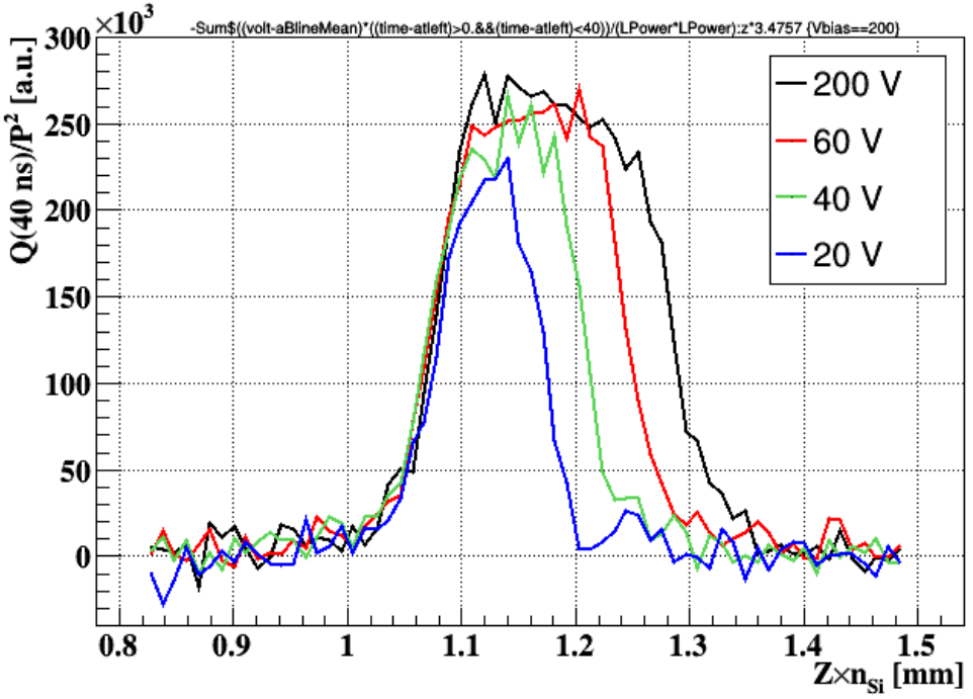

(volt-BlineMean)/(Vmax-BlineMean):time-atleft
Normalised amplitude [V]
Time [ns]
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30

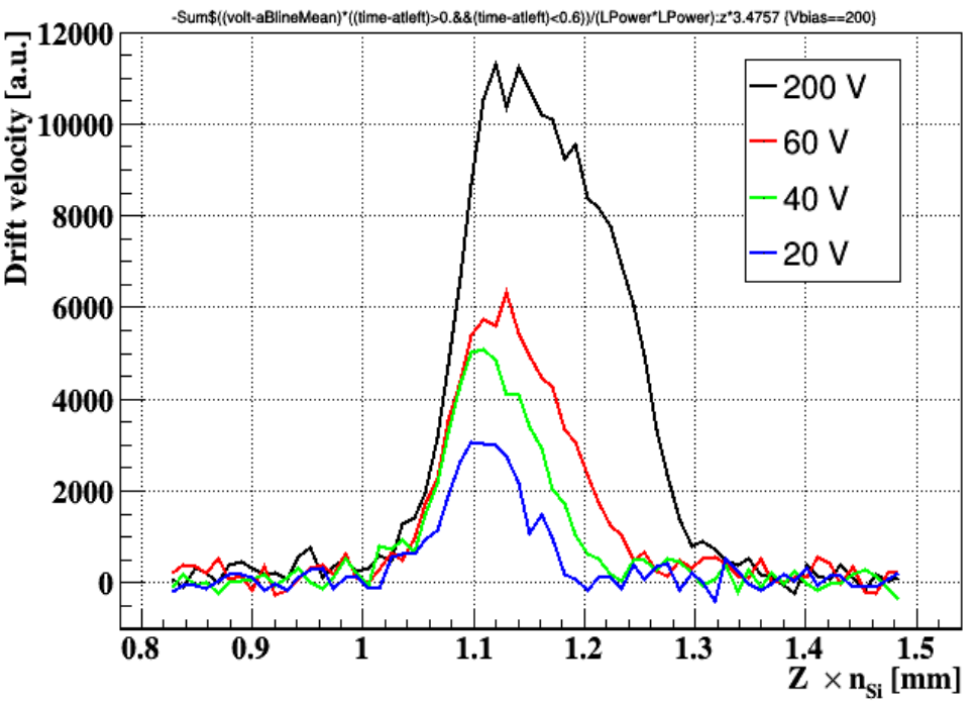
TPA - Laser

Laser Module (LM)



z-scan


-Sum$((volt-aBlineMean)*((time-atleft)>0.&&(time-atleft)<40))/(LPower*LPower):z*3.4757 (Vbias==200)
×10^3
Q(40 ns)/P² [a.u.]
Z×n_Si [mm]
200 V
60 V
40 V
20 V


-Sum$((volt-aBlineMean)*((time-atleft)>0.&&(time-atleft)<0.6))/(LPower*LPower):z*3.4757 (Vbias==200)
Drift velocity [a.u.]
Z × n_Si [mm]
200 V
60 V
40 V
20 V