Two Photon Absorption-TCT of neutron irradiated pad detectors

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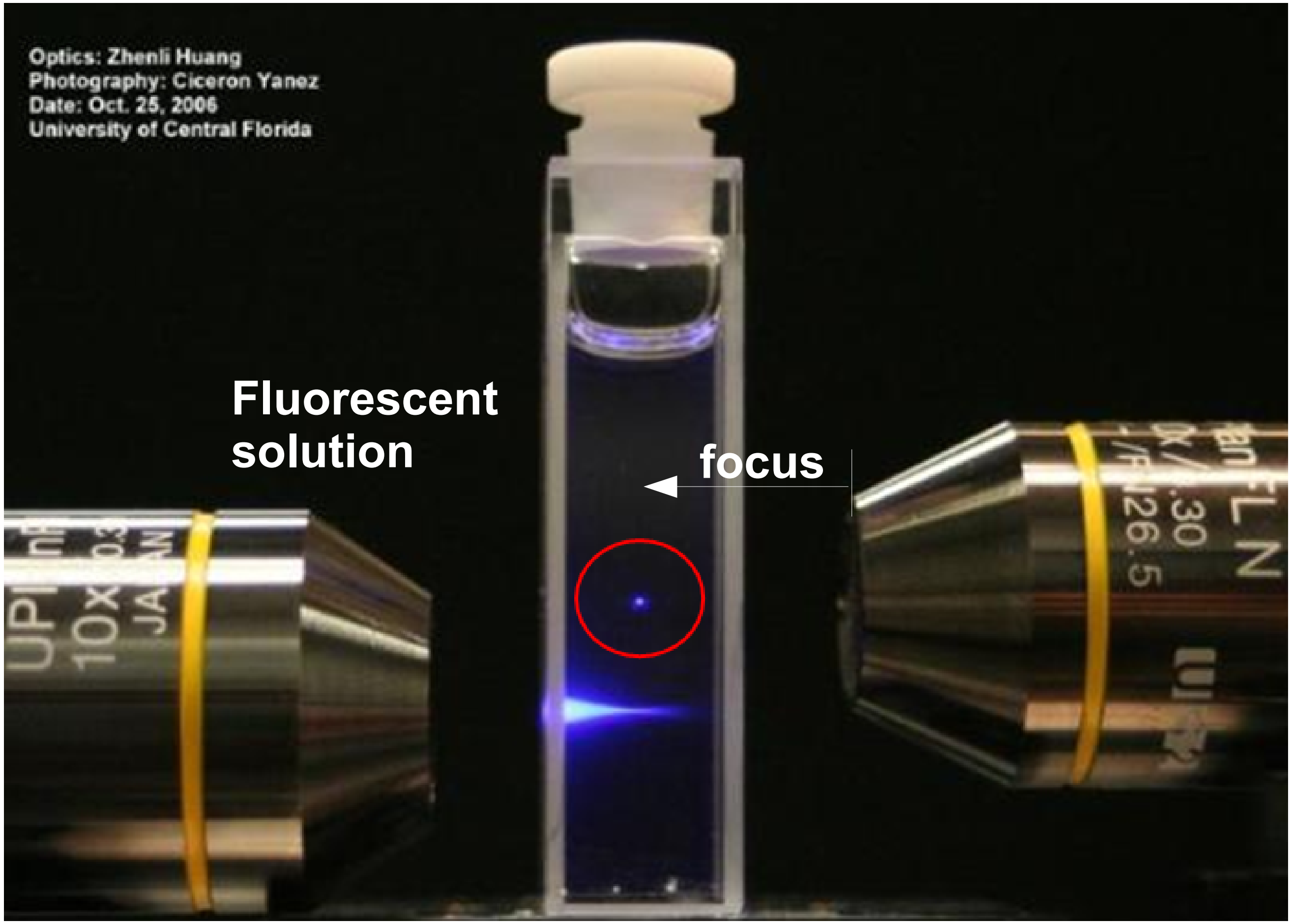
Two Photon Absorption

SPA

Single Photon Absorption

Continuous energy deposition



TPA

Two Photon Absorption

Energy confinement

Motivation

Ionizing radiation creates **deep energy levels** within the band gap that will enhance the **S**ingle **P**hoton **A**bsorption (increasing of the alpha parameter) in detriment of the **T**wo **P**hoton **A**bsorption signal.

Quantify the possible radiation-induced increment of the SPA process with respect to the TPA process

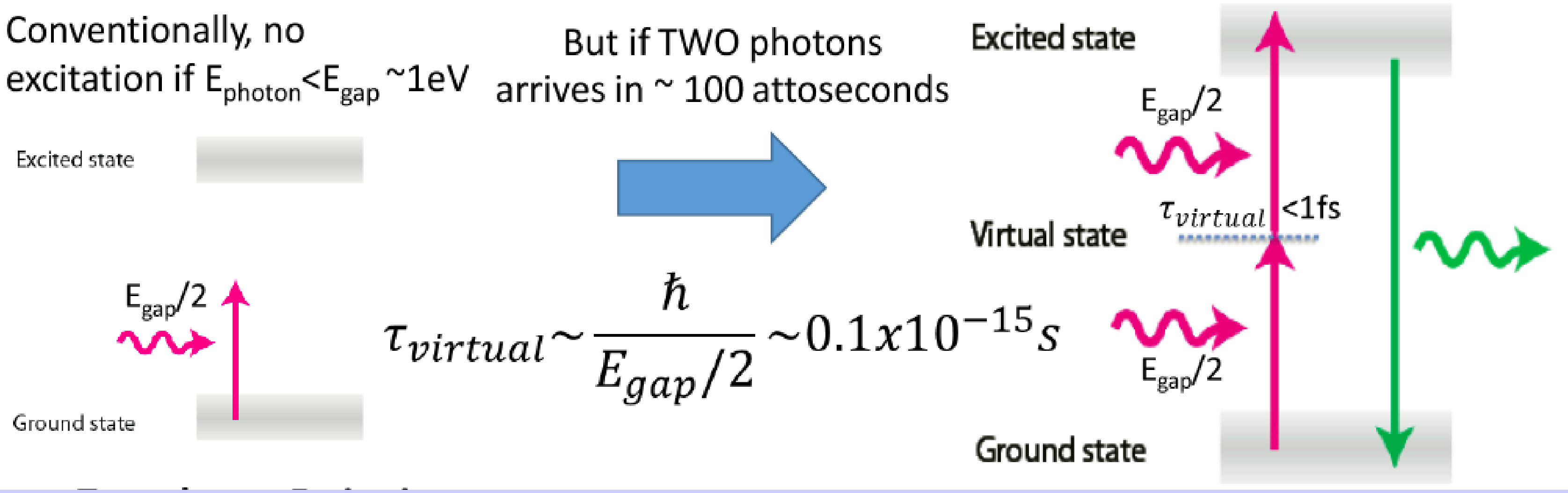
Outline

→ Two Photon Absorption and experimental setup

→ Results for n-irradiated **10^{13} , 10^{14} , 10^{15} , 10^{16} n_{eq}/cm^2**
Comparison of TPA at **1300 nm** (absorption maximum)
and **1500 nm (λ commercially available)**

RD50-2015-03 project
Evaluation of the potential of a Transient Current Technique based on Two-Photon-Absorption (TPA) process

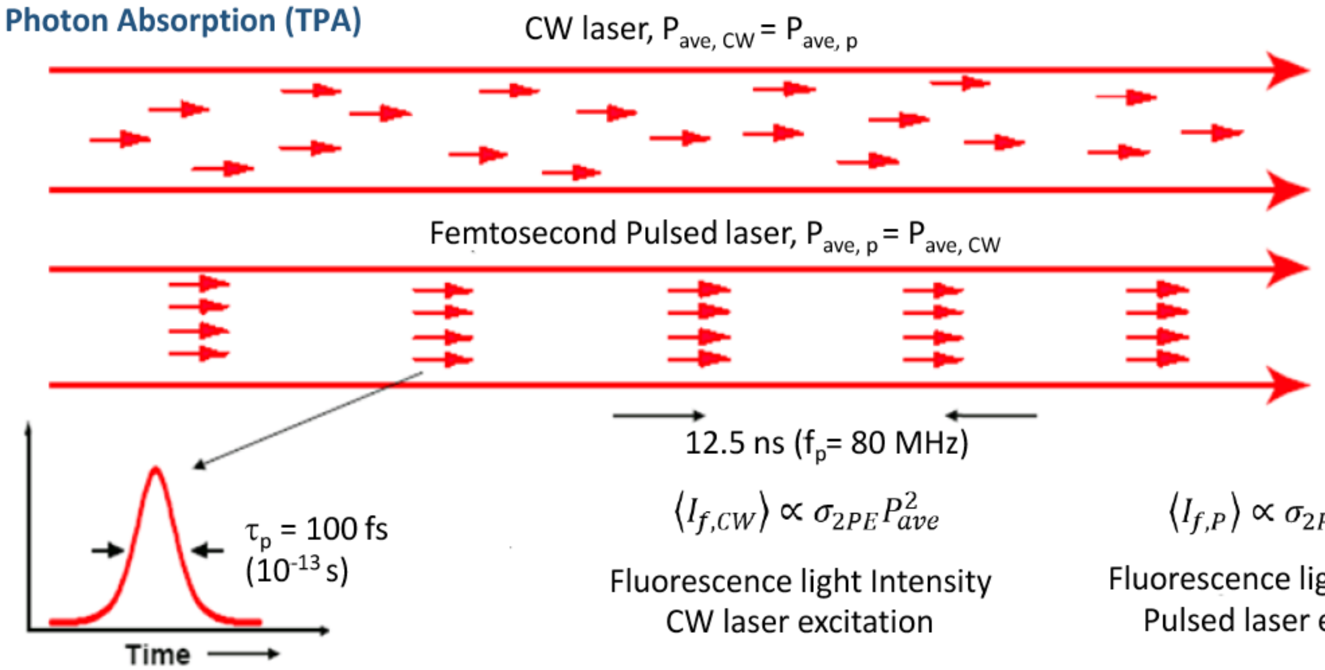
Two photon absorption basics (I)



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

But if TWO photons arrives in ~ 100 attoseconds

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



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

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

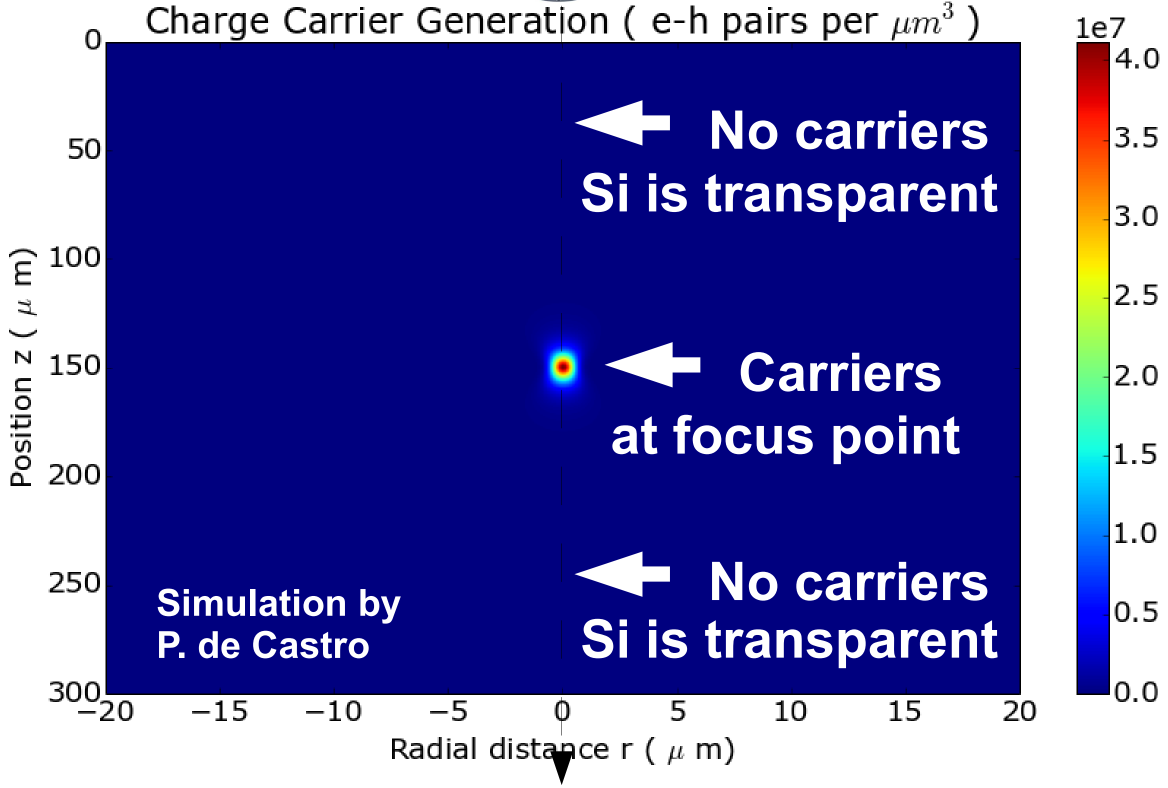
The probability of a two photon absorption is increased by $(1/t_p f_p)=10^5$ for the same average power by using a mode-locked pulsed laser

TPA basics (II)

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

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

λ=1300 nm (0.95 eV)

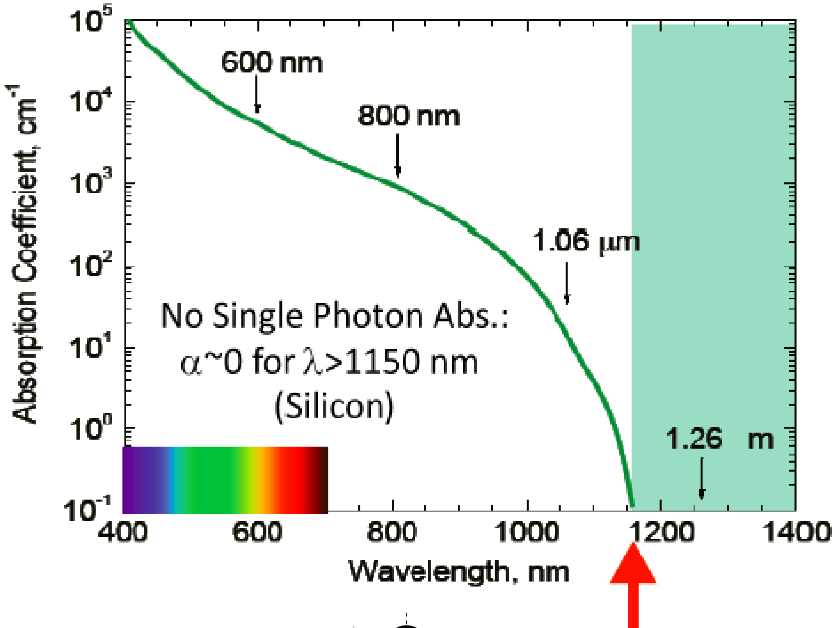


No carriers Si is transparent

Carriers at focus point

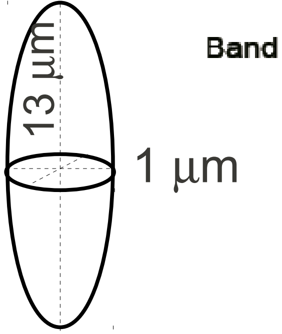
No carriers Si is transparent

Simulation by P. de Castro



No Single Photon Abs.: α~0 for λ>1150 nm (Silicon)

Band Edge



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

TPA laser facility

sgiker
Ikerkuntzarako
Zerbitzu Orokorrak
Servicios Generales
de Investigación

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

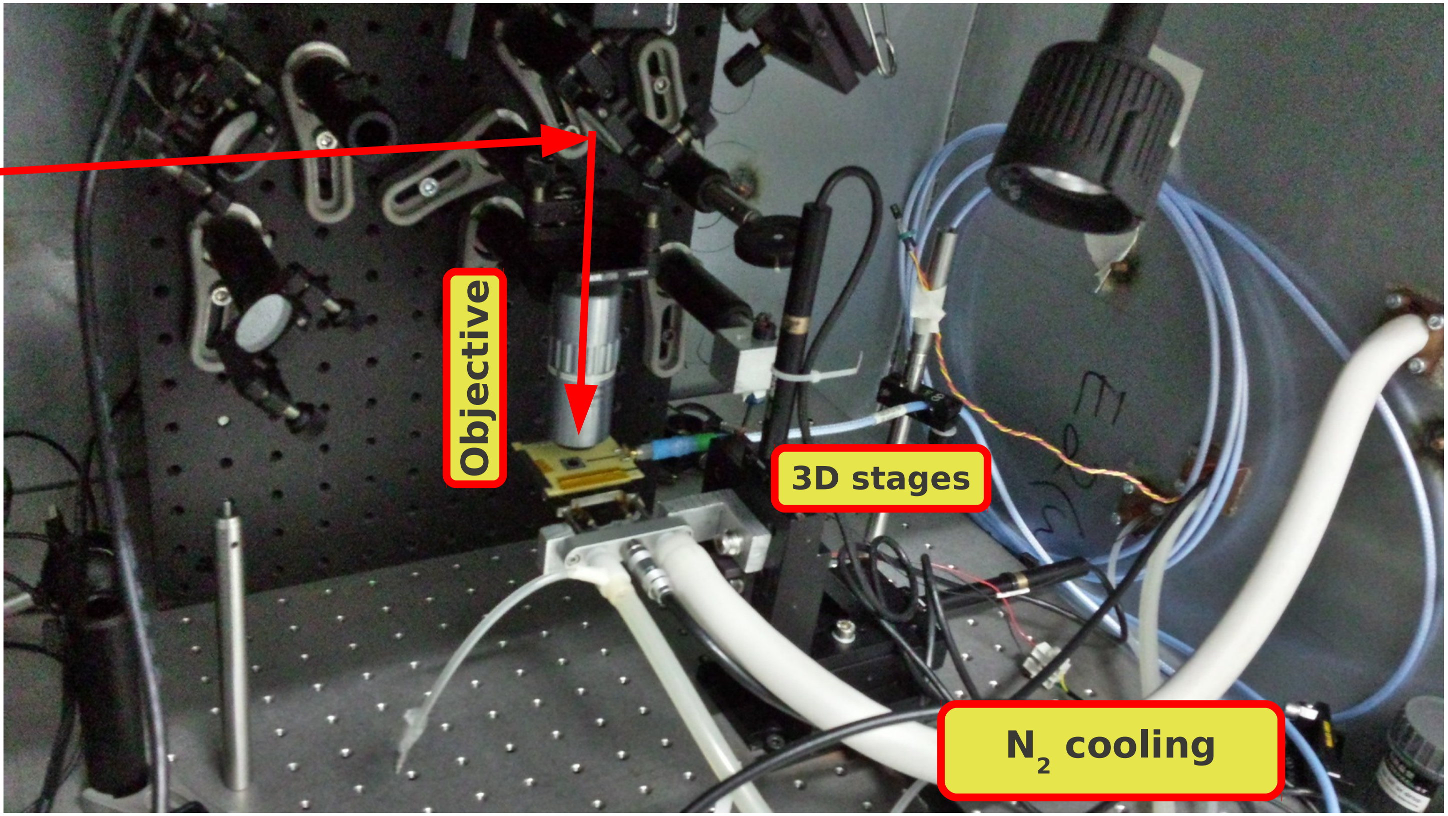
  http://www.ehu.es/SGIker/es/laser/

- ➜ Very flexible and tunable laser system (intensity, λ, pulse duration...)
- ➜ Access granted via RD50 collaboration.
- ➜ See backup for full specs

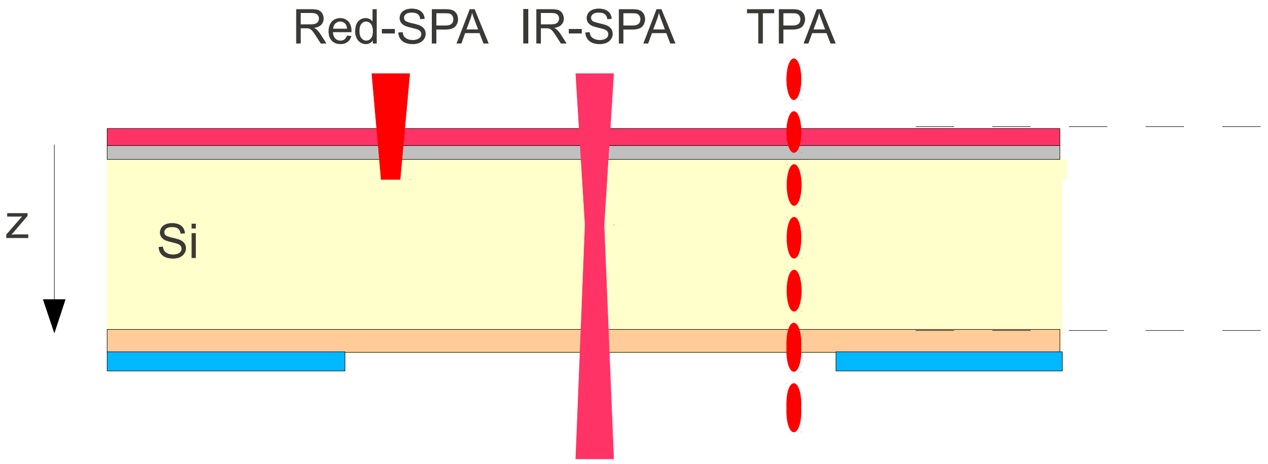
In this study

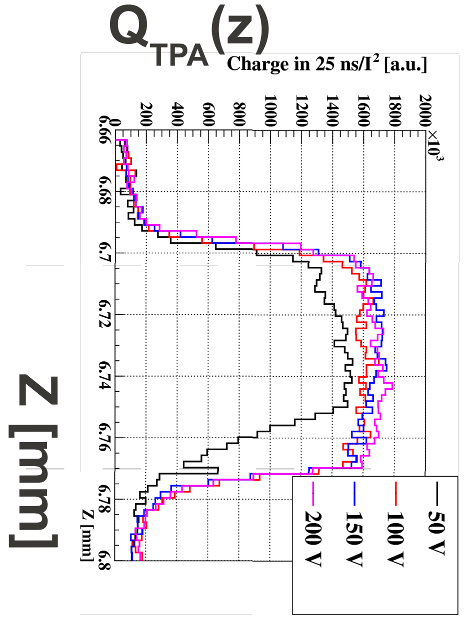
$(\lambda,\Delta t)=(1300\ \mathrm{nm},240\ \mathrm{fs})$
or
$(\lambda,\Delta t)=(1500\ \mathrm{nm},\ 40\ \mathrm{fs})$

Spectral resol.~10 nm



Differences SPA-TCT and TPA-TCT (I)



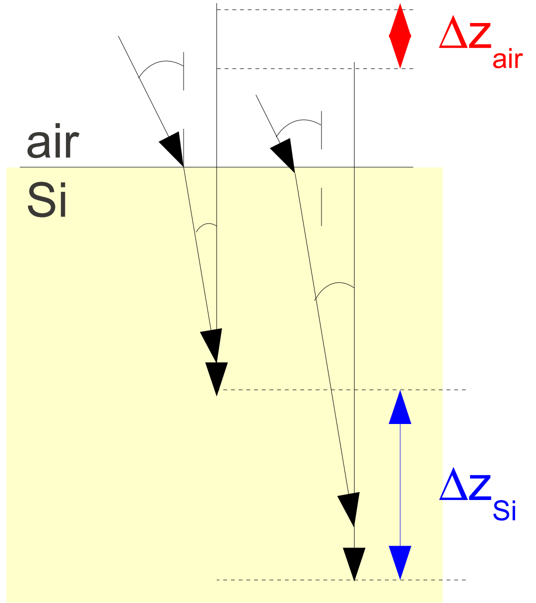


1) **TPA-TCT:** In a "*z-scan*" the beam is moved perpendicularly to the pad.
SPA-TCT: invariant in z coordinate.

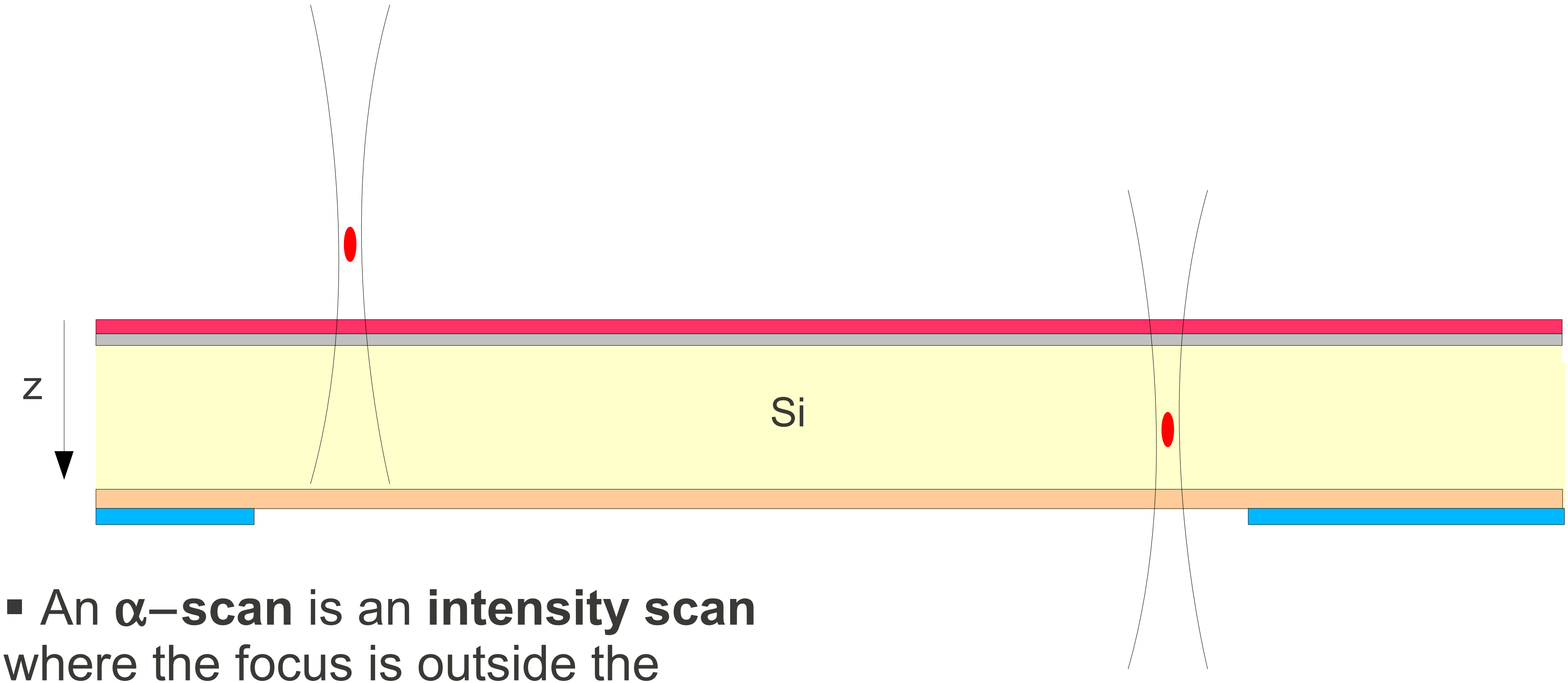
2) Top injection TPA-TCT: Because the spot is "point-like" we can induce current at different depths and study currents, depletion width... as a function of depth and voltage. It is like an edge-TCT scan.

3) Augmentation factor air-Si: Due to the different refraction index of Si w.r.t. air and the steep incidence of the focused beam a vertical movement of Δz_{air} corresponds to:

$$\Delta z_{Si} \sim n_{Si}(\lambda) \cdot \Delta z_{air}$$



Differences SPA-TCT and TPA-TCT (II): Intensity scans



- An α–**scan** is an **intensity scan** where the focus is outside the detector. No contribution of TPA. Since λ>>1100 nm no SPA signal should be measured.

An α–**scan** in an **irradiated detector** will tell us about the trapping assisted SPA charge carrier generation

- A β–**scan** is an **intensity scan** where the focus is inside the detector. Only TPA should be created.

An irradiated detector with α≠0 will exhibit a mixture of SPA and TPA

Samples

- FZ **diodes** from the **LGAD** run 7509 (reference diodes → no amplification). All from wafer 1. Sensor glued on PCB for TCT measurements. Fluences 10^{13}-10^{16} n_{eq}/cm^2 (**neutron** irradiation at **Ljubljana**).

- **No intentional annealing** of samples (transport, handling...). A systematic annealing study needs to be conducted soon.

- **Top** light **injection**
  All measurements at **T_{PCB}=-15 °C** (RH and T monitored) except 10^{15} n_{eq}/cm^2 at -20 C

- **Readout** chain

  Sensor → Bias Tee → attenuation (19-28 dB) → Amplifier 50 dB → Scope

  ↑
  HV

  Note: some measurements taken without amplifier

- Pulse duration is measured before entering the Faraday Cage. Pulse duration varies after each optical element, in particular the objective. We will measure it during the next access.

- Some measurements taken 2 weeks ago. Still digesting...

Neutron irradiated diodes
10^{13} , 10^{14} , 10^{15} , 10^{16} n_{eq}/cm^2
(1300 nm, 240 fs)[1]

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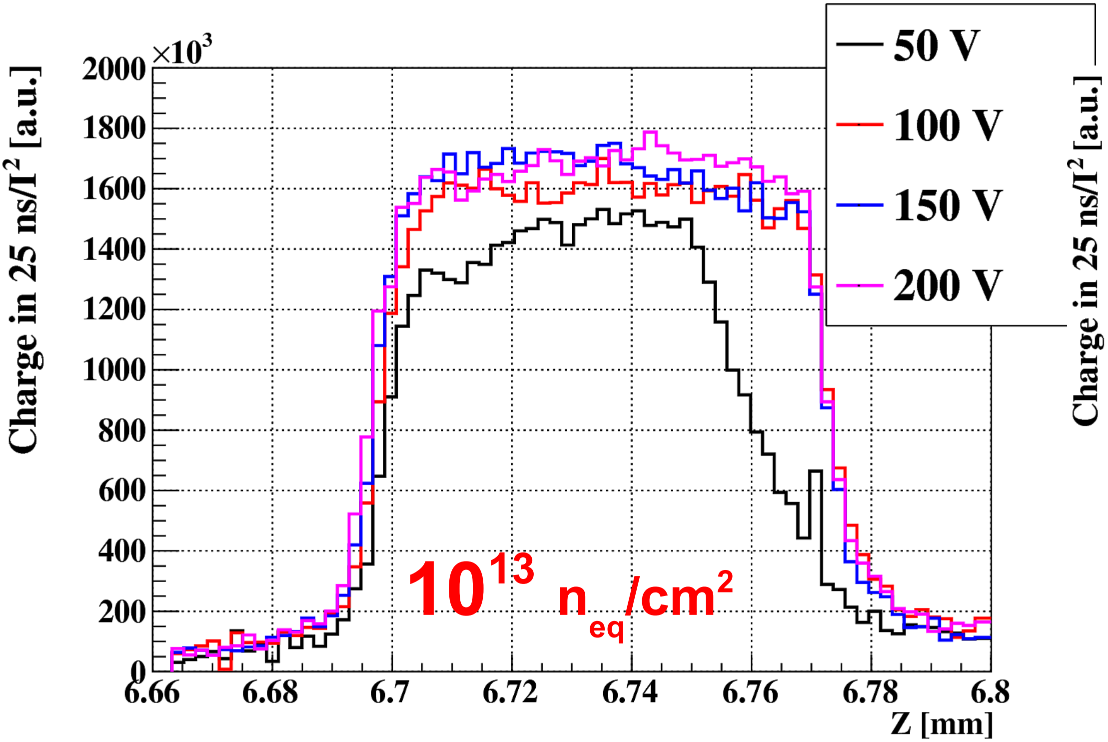
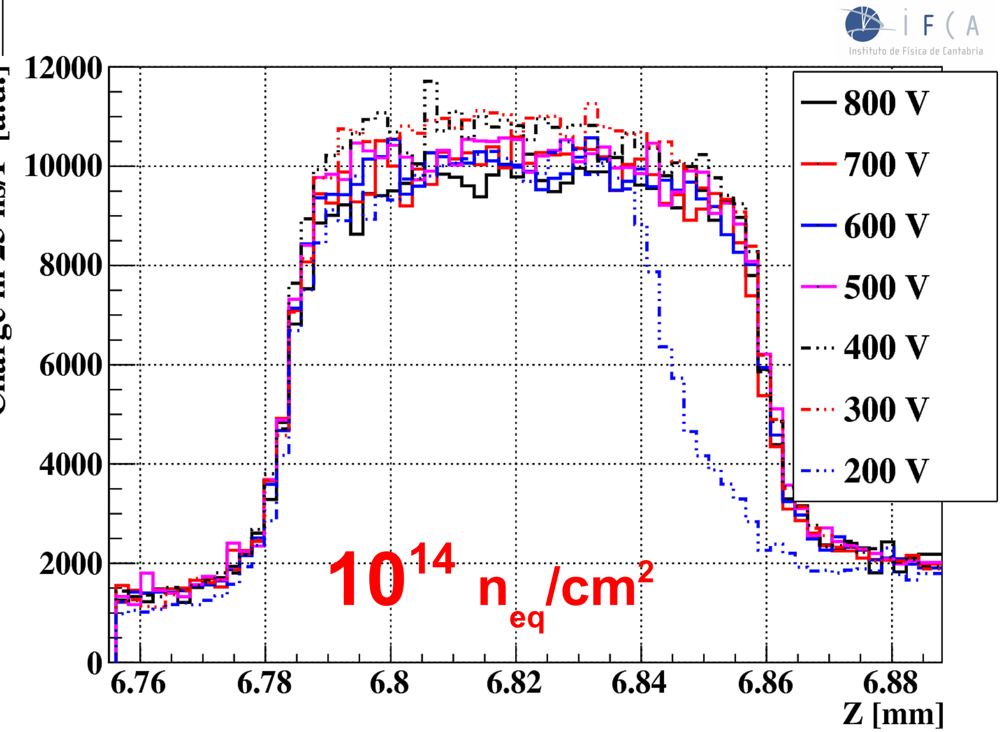
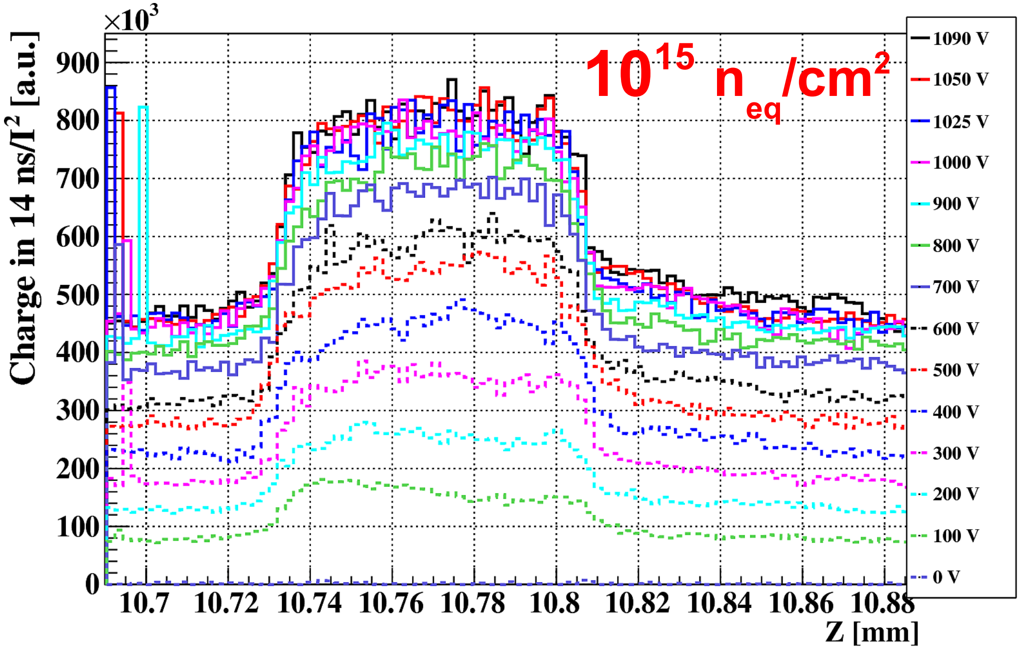
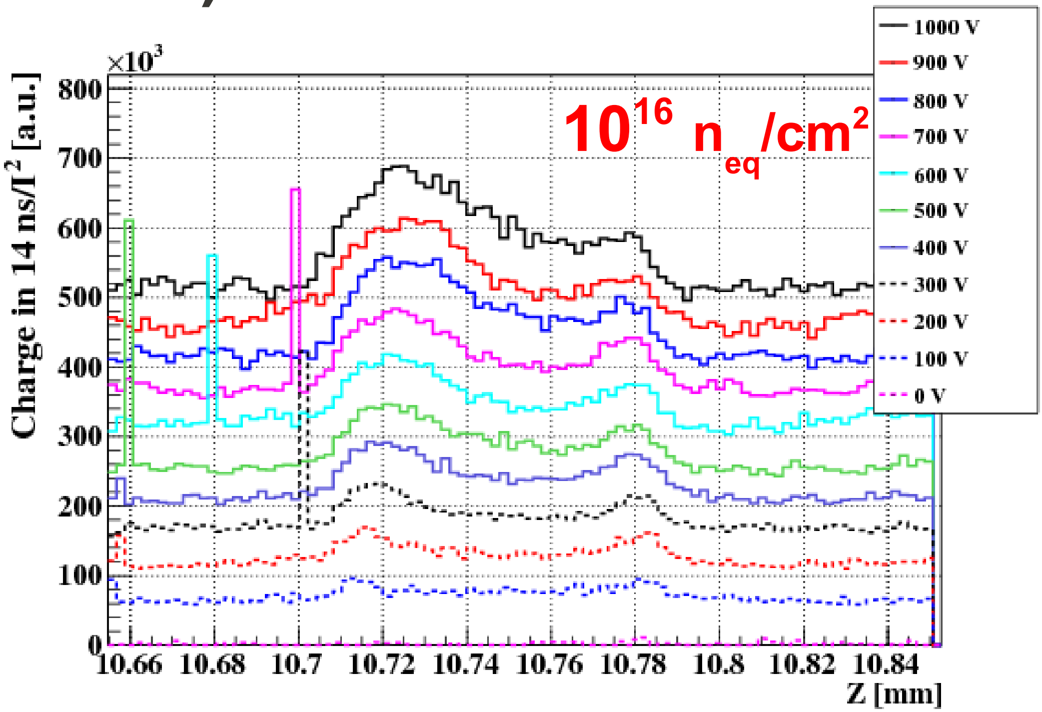
[1] Figures measured at the entrance of the Faraday cage, before the focusing optics



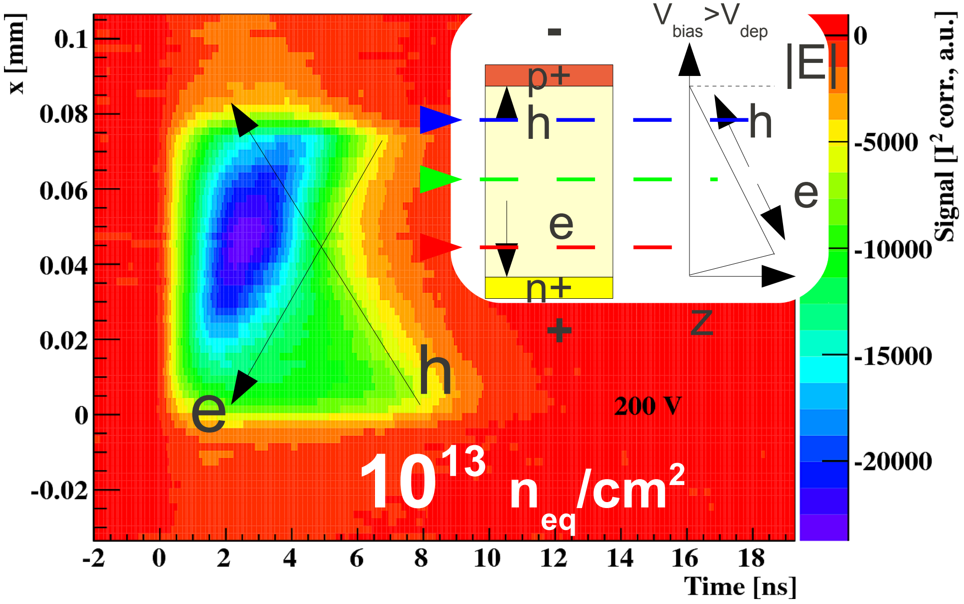


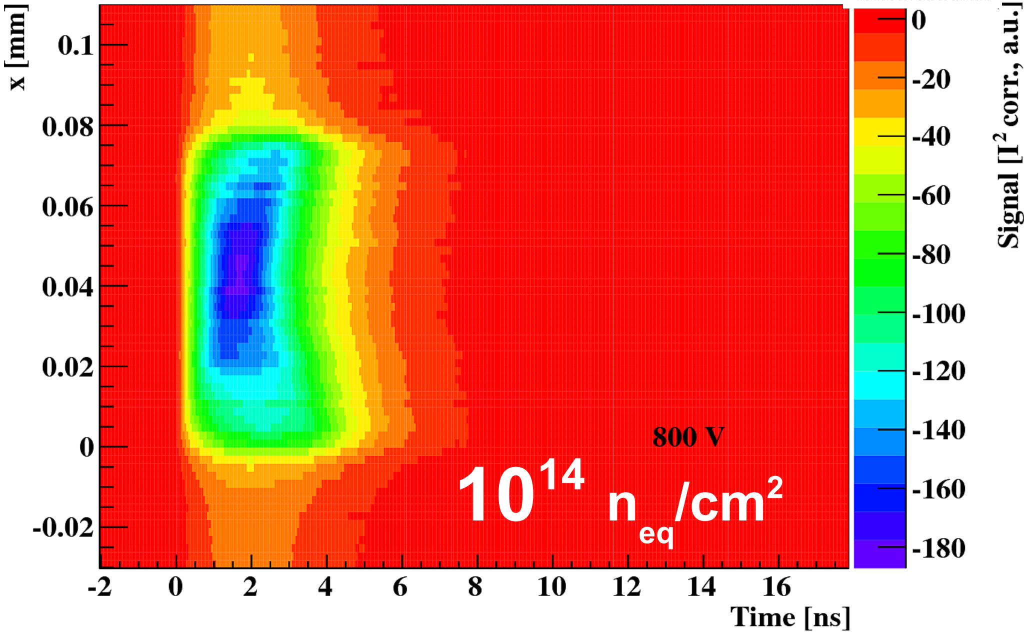
Charge profiles(z ; 14 ns) at λ=1300 nm

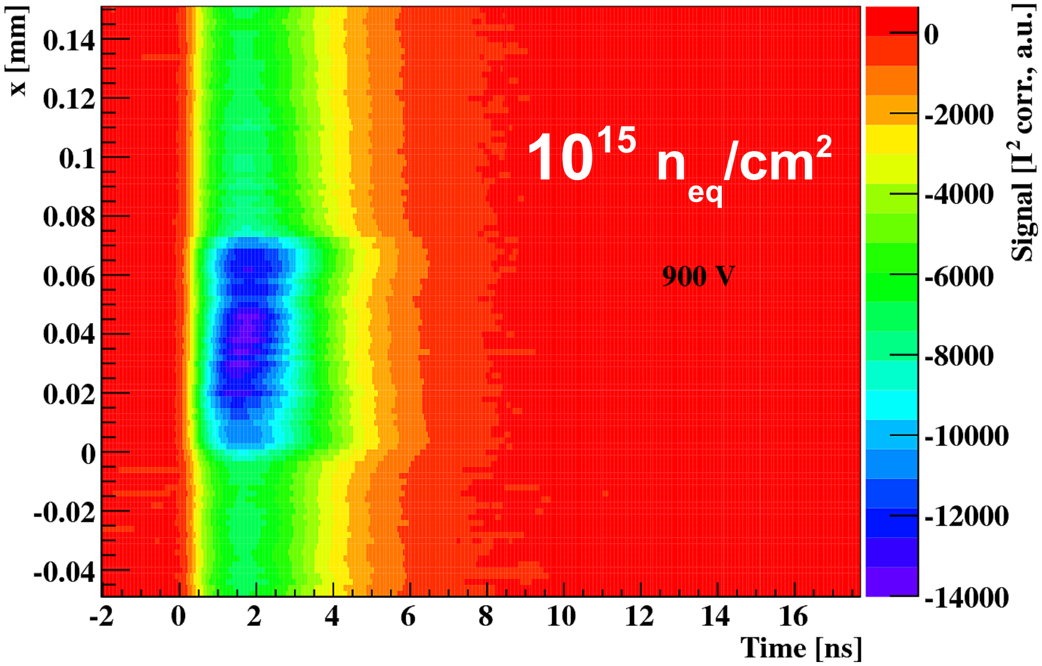


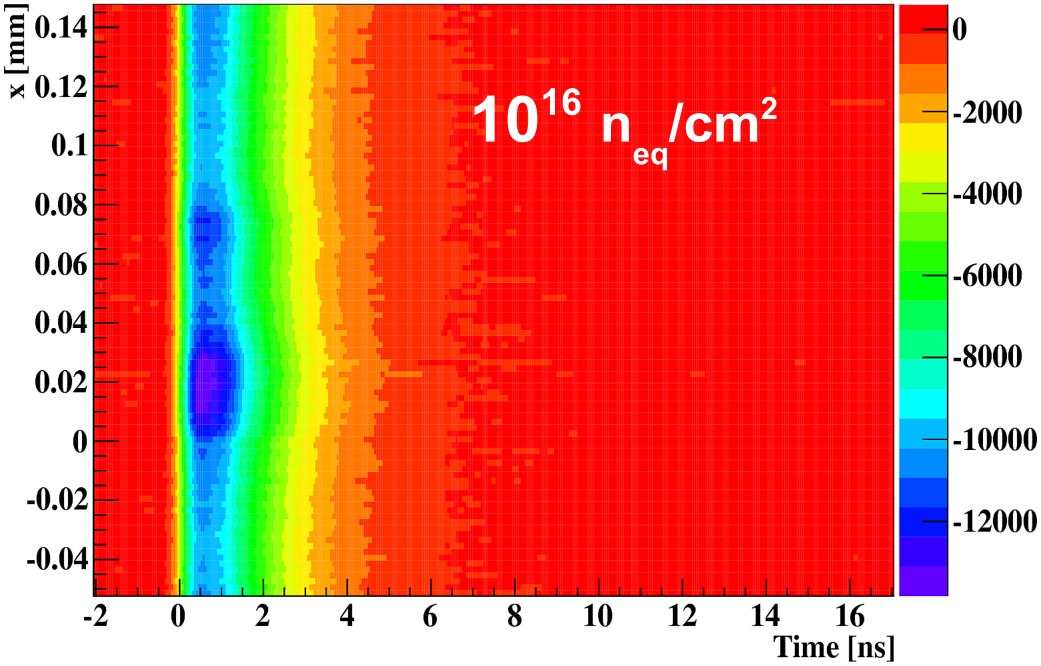


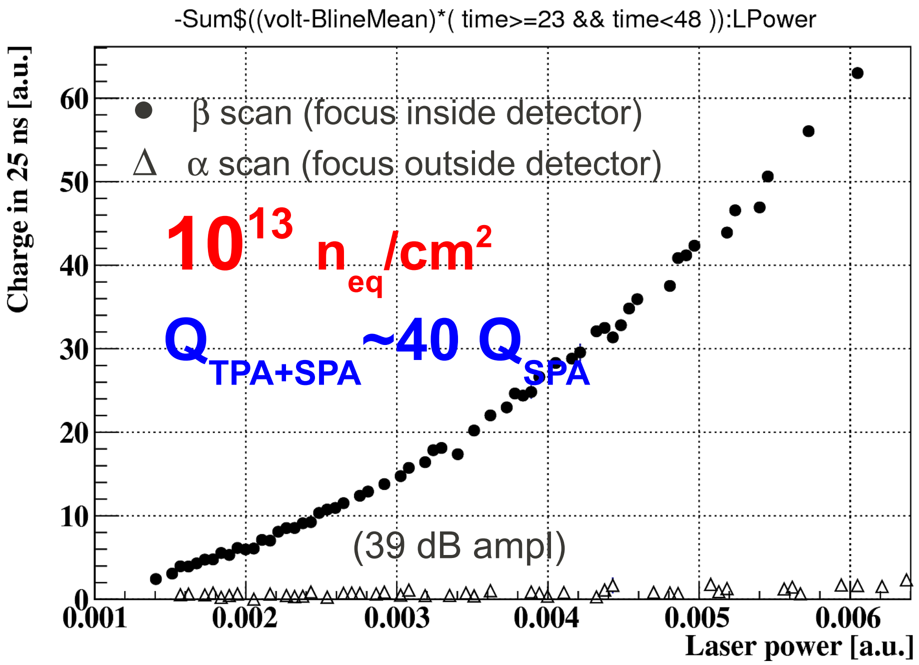
V(t,z ; fixed V_{bias}) maps at λ=1300 nm







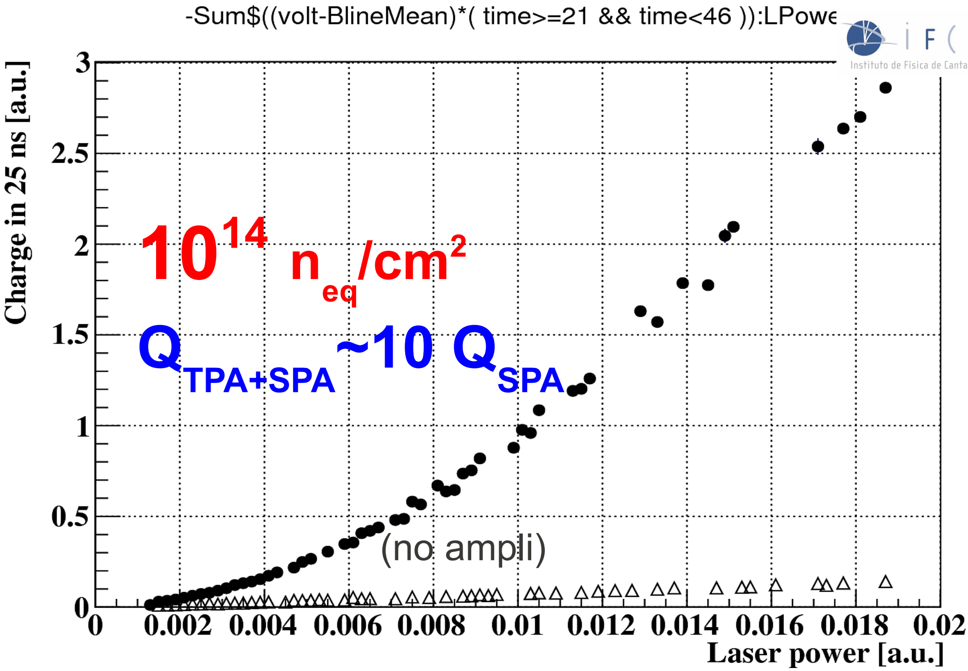




10^{13} n_{eq}/cm^2

$Q_{TPA+SPA}$ ~40 Q_{SPA}

(39 dB ampl)



10^{14} n_{eq}/cm^2

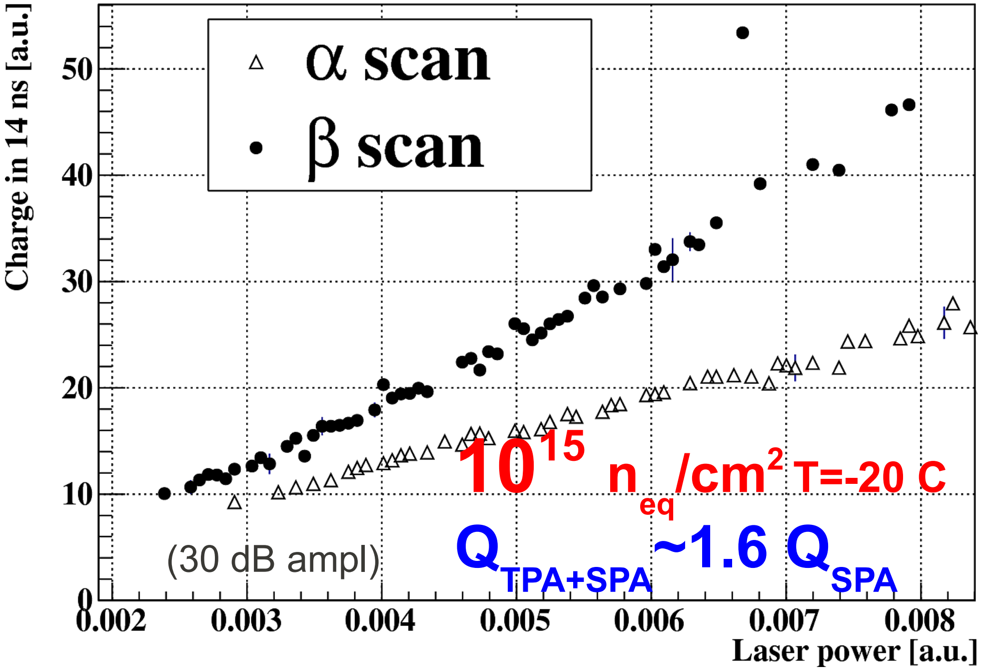
$Q_{TPA+SPA}$ ~10 Q_{SPA}

(no ampli)

Intensity scans at λ=1300 nm

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

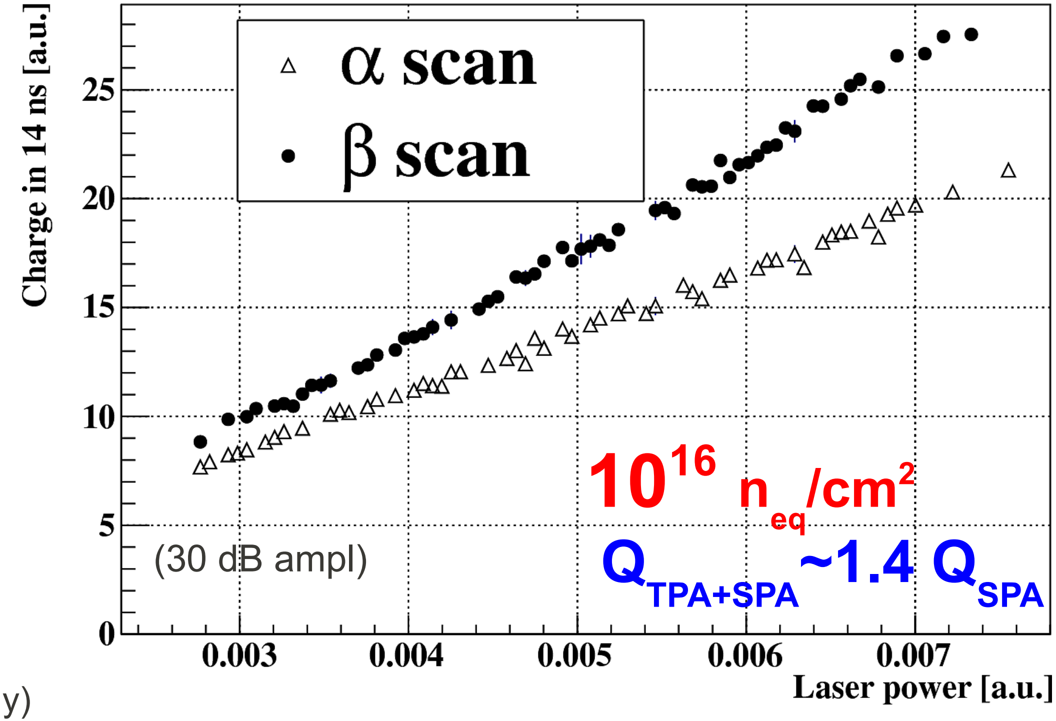
Ratios at Laser Power=0.06



10^{15} n_{eq}/cm^2 T=-20 C

$Q_{TPA+SPA}$ ~1.6 Q_{SPA}

(30 dB ampl)



10^{16} n_{eq}/cm^2

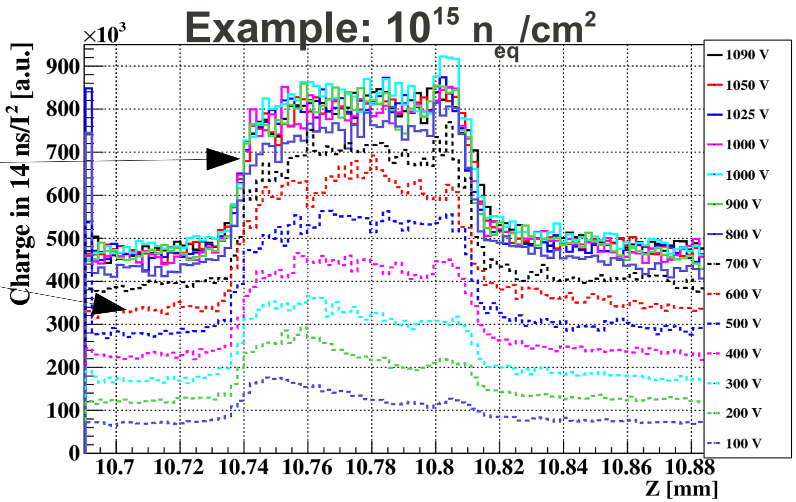
$Q_{TPA+SPA}$ ~1.4 Q_{SPA}

(30 dB ampl)

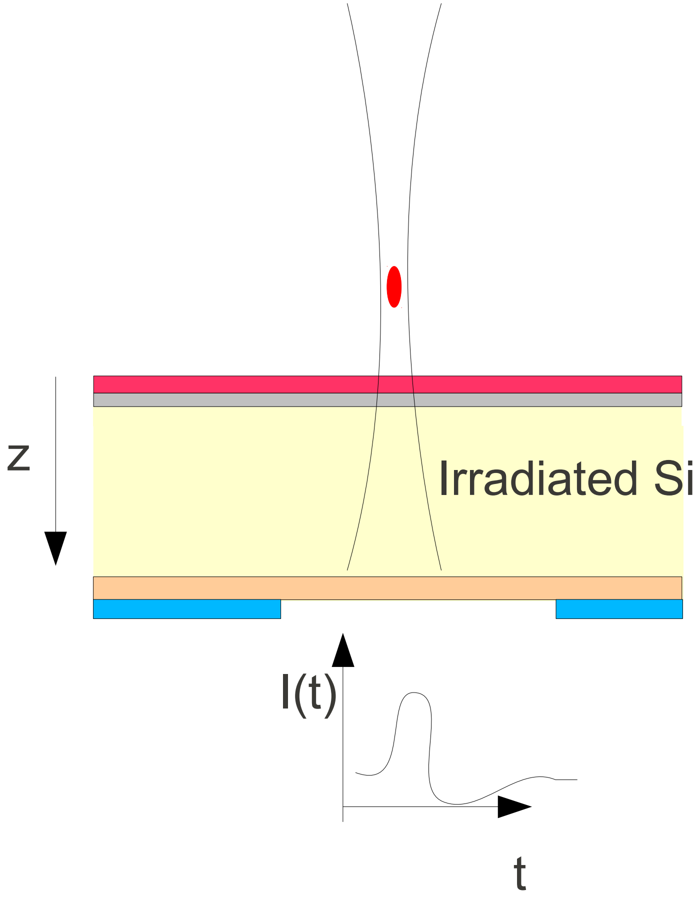
SPA subtraction (irradiated detector)

Irradiated detectors:

We observe a **TPA signal** on top of a **Z-invariant** charge “baseline”. This offset diminishes the TPA/SPA contrast.



Example: 10^{15} n_{eq}/cm^2

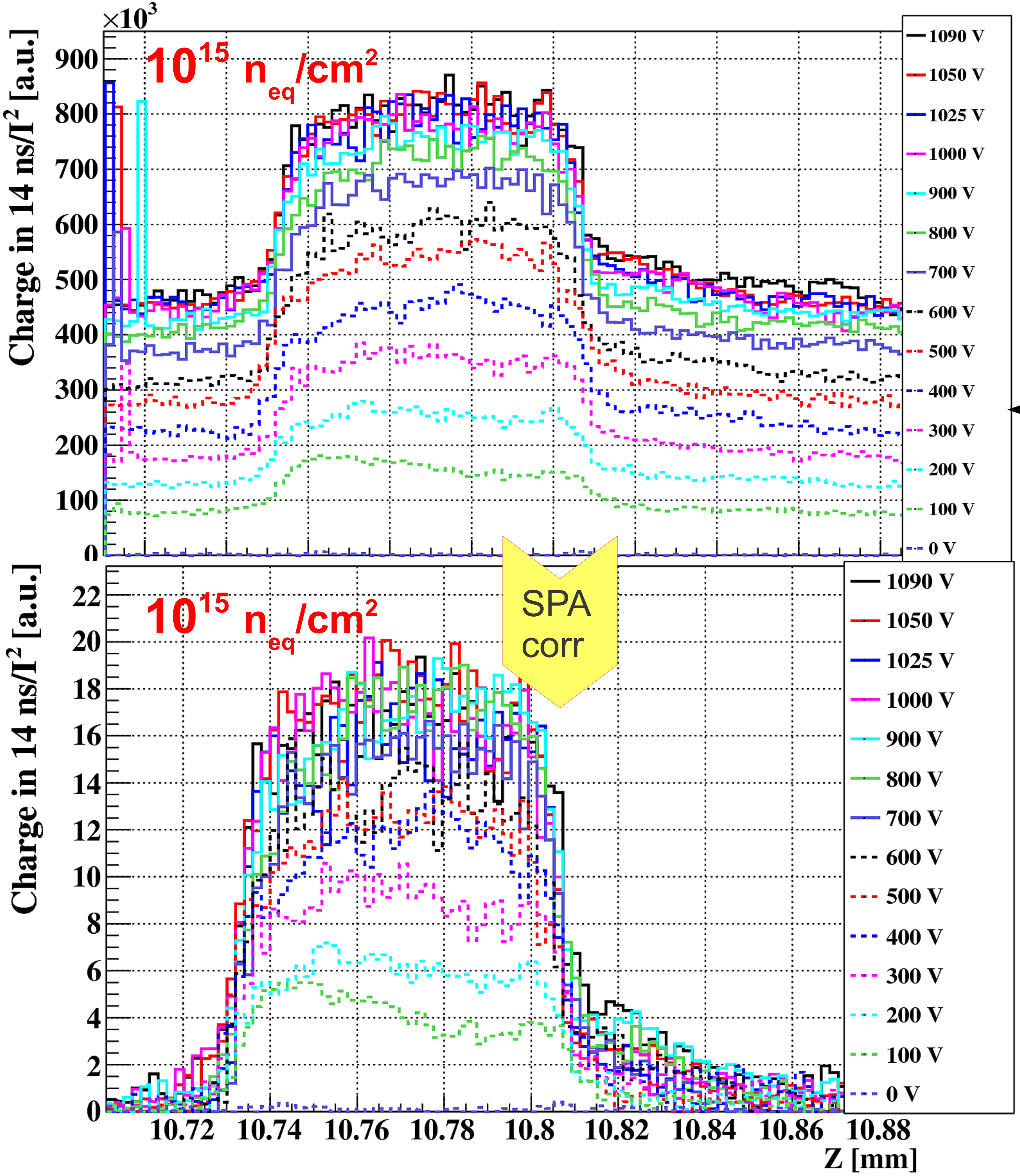


Before the focus enters the detector (no TPA contribution), the signal induced in the sensor can only be due to trap-assisted SPA.

Take the induced current **I(t)** when the focus is outside the detector as the SPA contribution and subtract it from the subsequent waveforms.

TPA profiles (SPA corrected) 1300 nm

T=-20 C

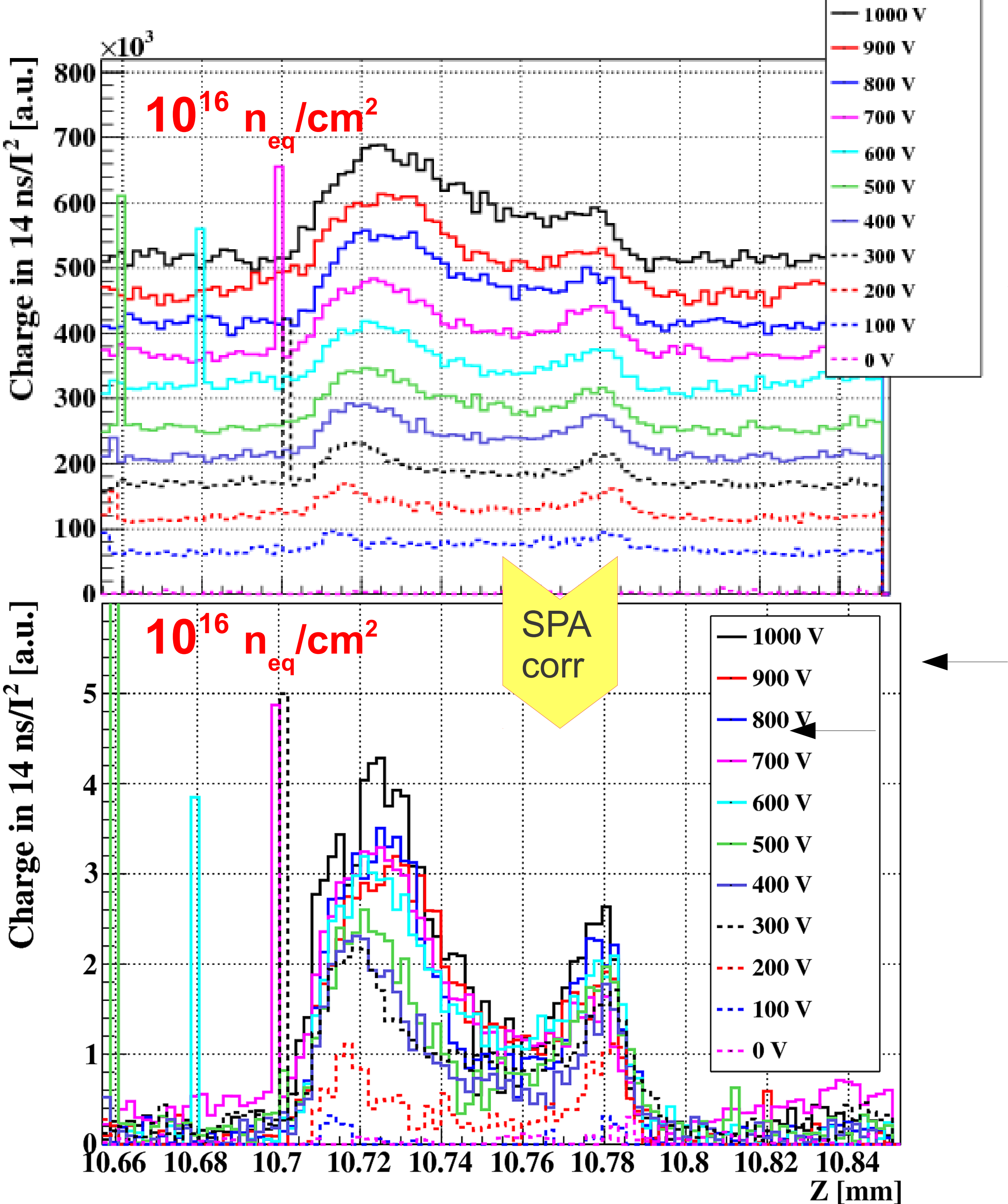


Charge profiles (raw)

Charge profiles after SPA correction.

Some surplus of collected charge after the detector: reflection in the interface Si/air. Looks like SPA (incoherent)

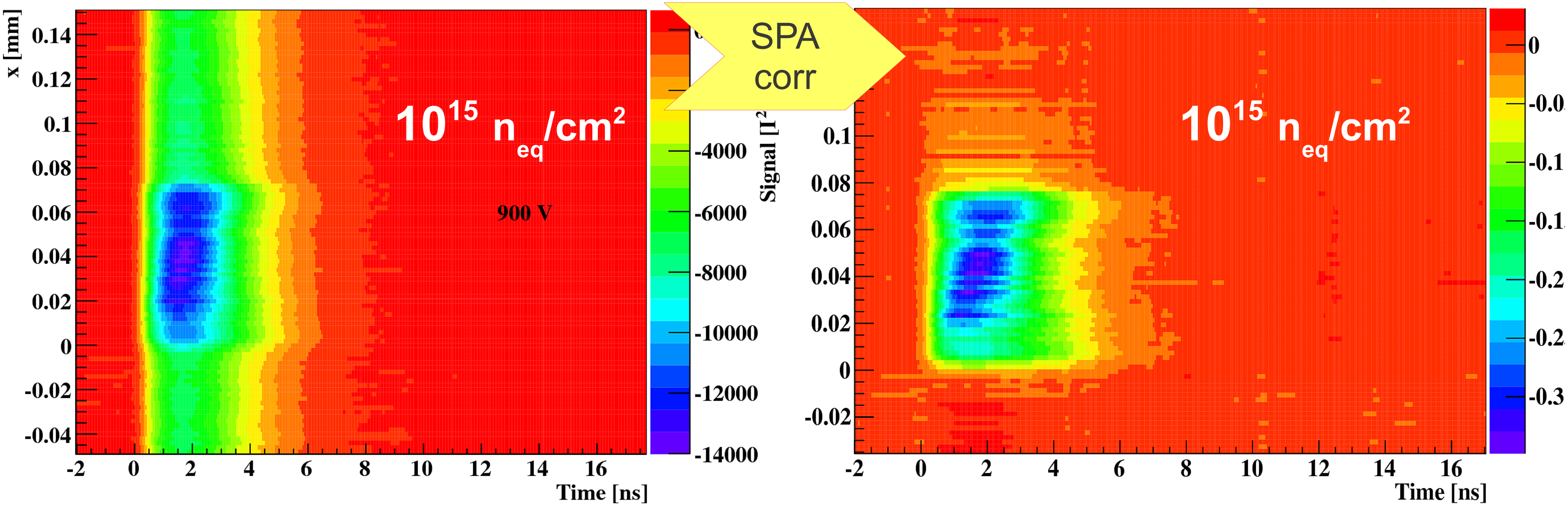
TPA profiles
(SPA corrected)
1300 nm



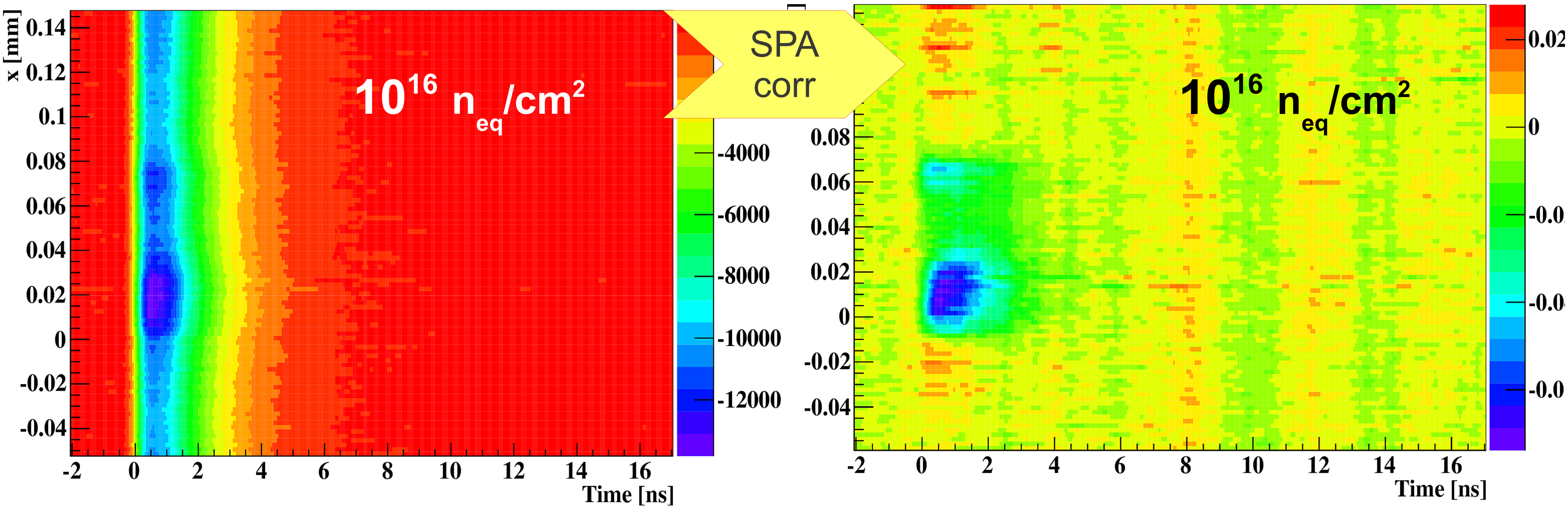
Charge profiles (raw)

Charge profiles after SPA correction.

Spikes are glitches in the reference photodiode (to be fixed)



SPA-corrected V(t,z ; fixed V_{bias}) maps at λ=1300 nm



10^{15} , 10^{16} n_{eq}/cm^2

(1500 nm, 40 fs)[1]

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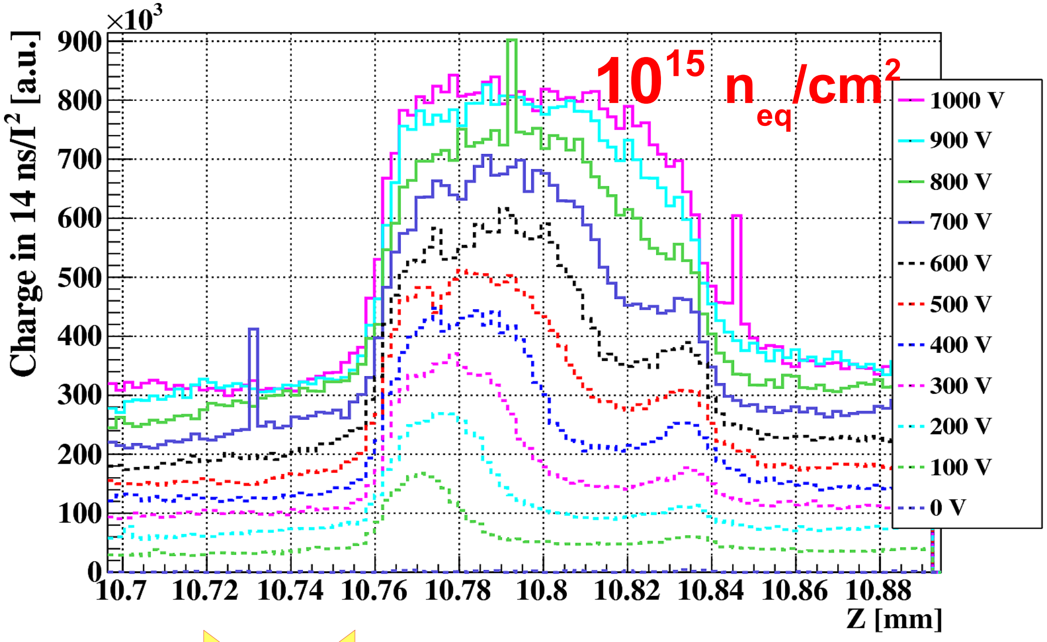
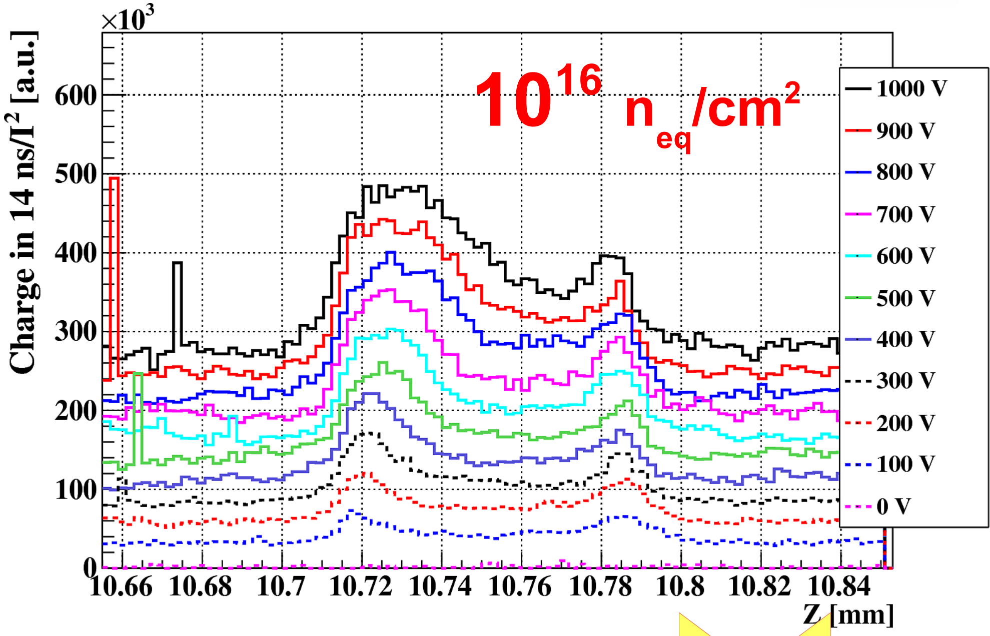
[1] Figures measured at the entrance of the Faraday cage, before the focusing optics

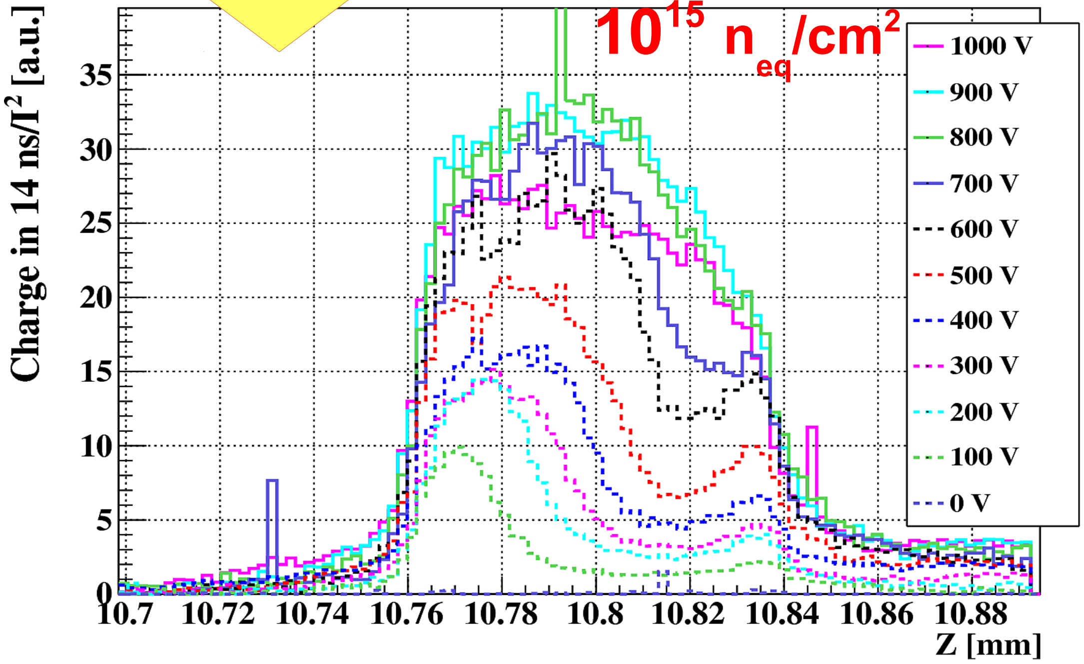


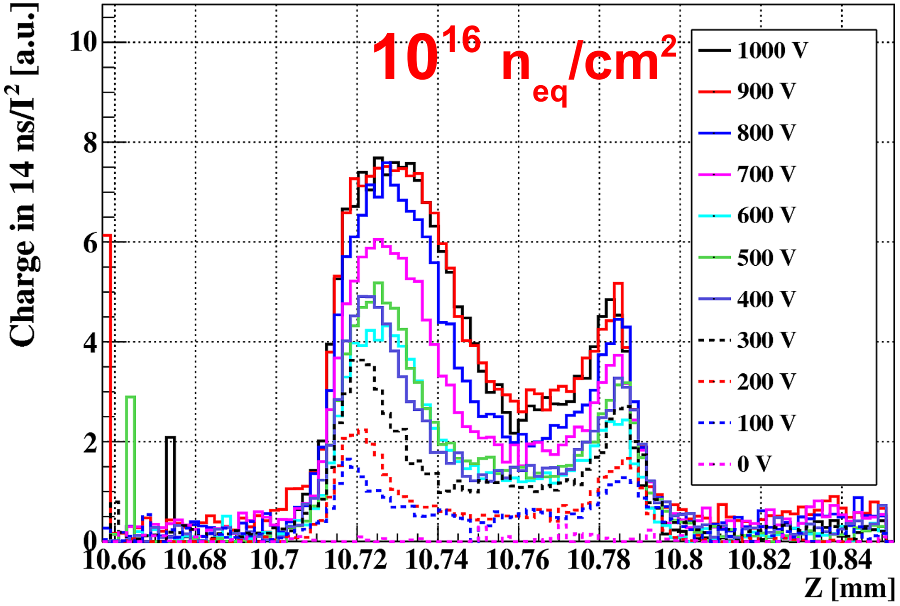


SPA
corr

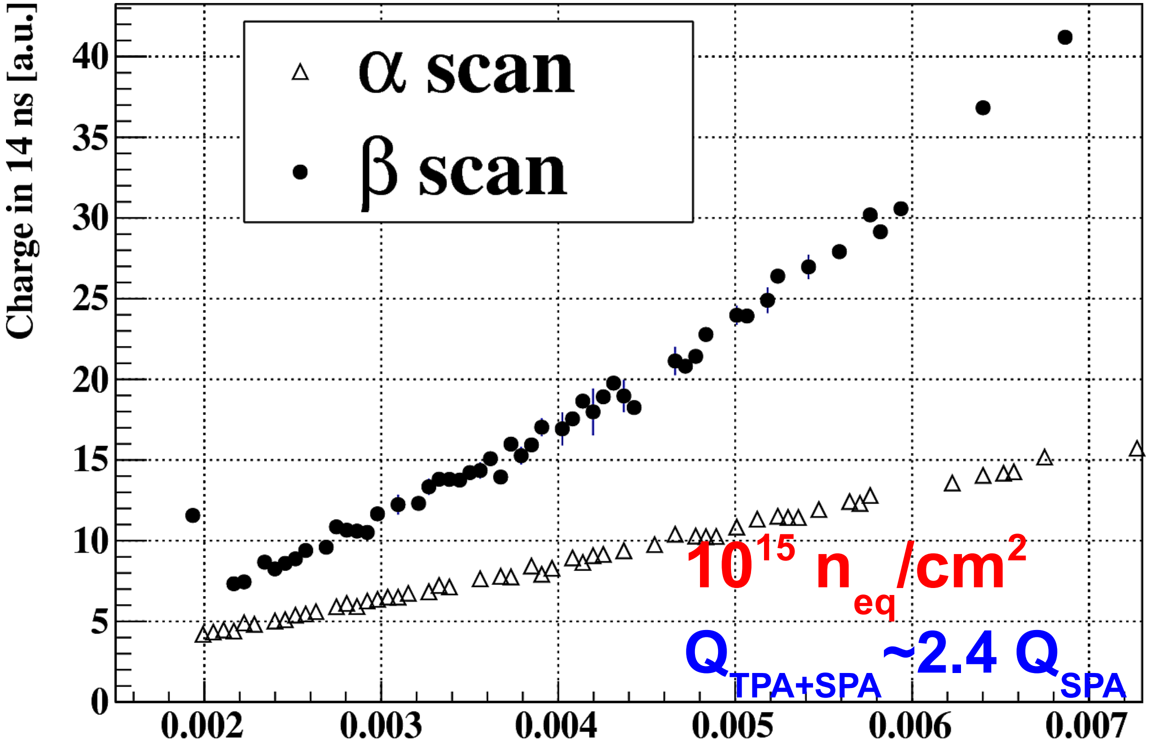
Charge profiles(z ; 14 ns) at λ=1500 nm

SPA
corr



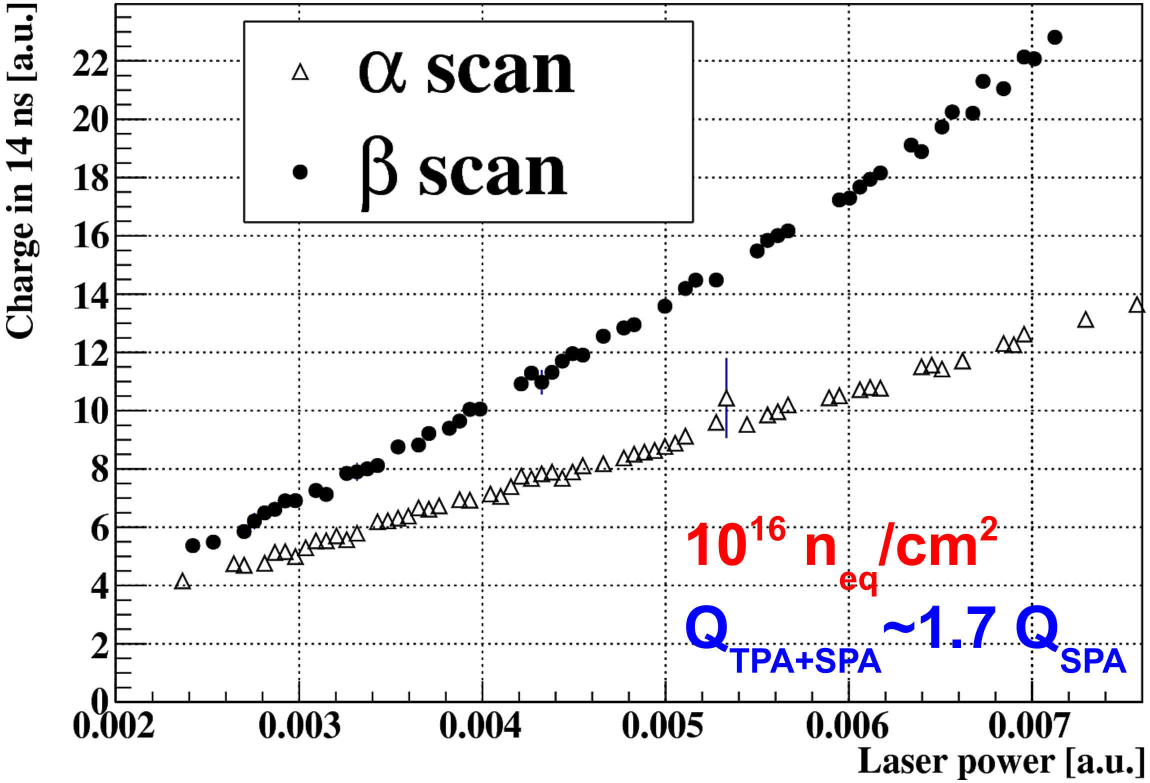


(1500 nm, 240 fs)



10^{15} n_{eq}/cm^2

$Q_{TPA+SPA}$ ~2.4 Q_{SPA}

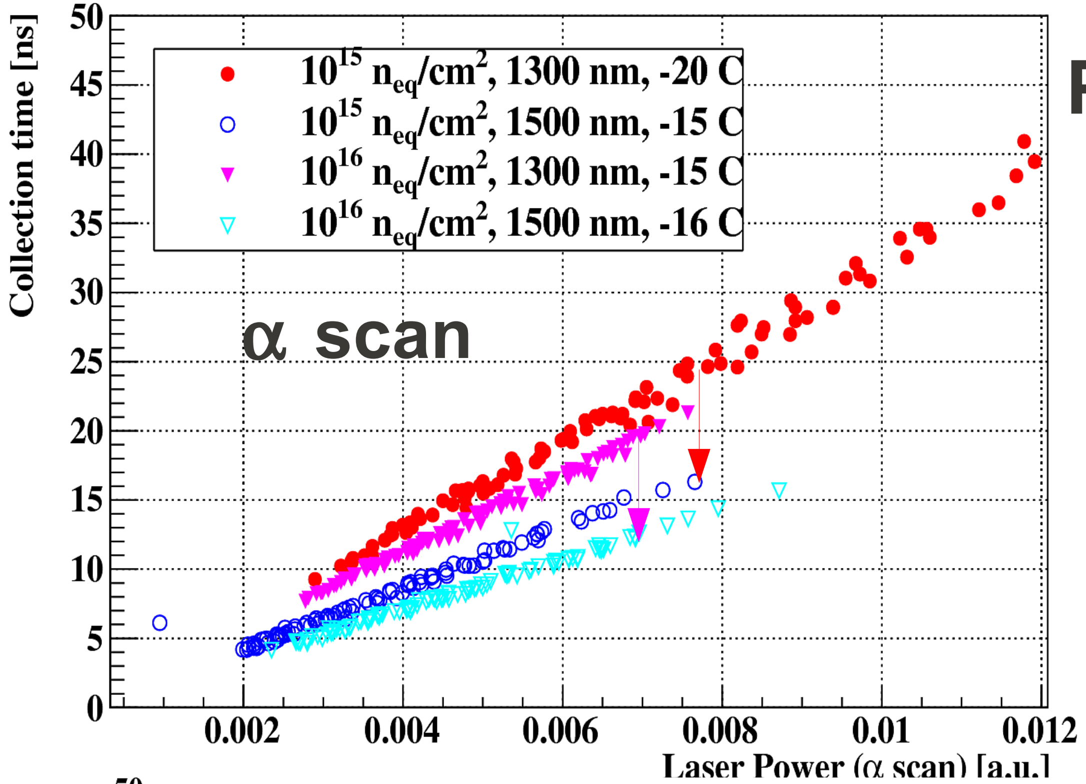


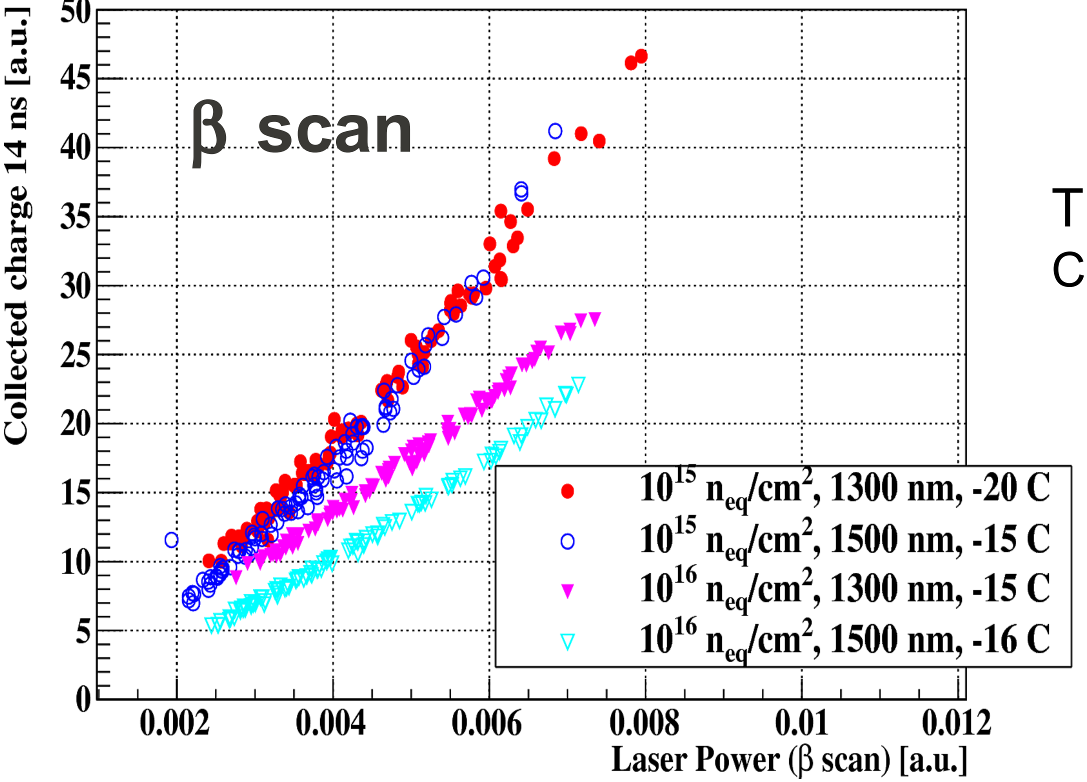
10^{16} n_{eq}/cm^2

$Q_{TPA+SPA}$ ~1.7 Q_{SPA}

Higher TPA to SPA **ratios** than at 1300 nm, 40 fs (it was 1.6 and 1.4 respectively)

Preliminary analysis on (α,β)





Higher α at 1300 nm

10^{15} n_{eq}/cm^2

α(●,1300 nm,-20 C) > α(ο,1500 nm,-15 C)
α decreases with wavelength
Also α decreases with T
The effect of λ in α is stronger than
the effect of T

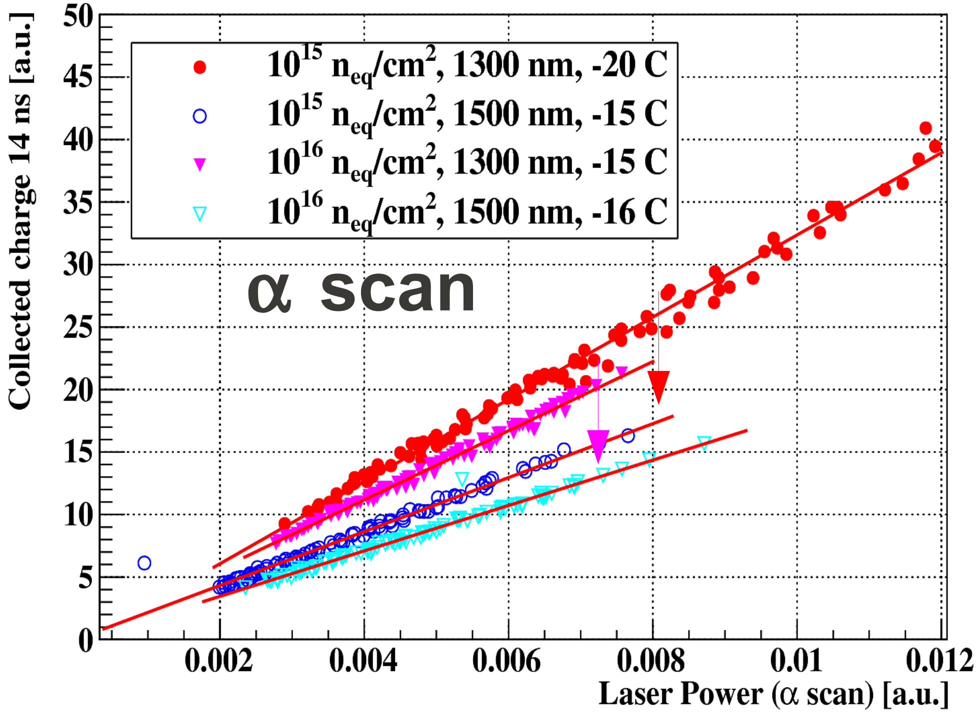
10^{16} n_{eq}/cm^2:

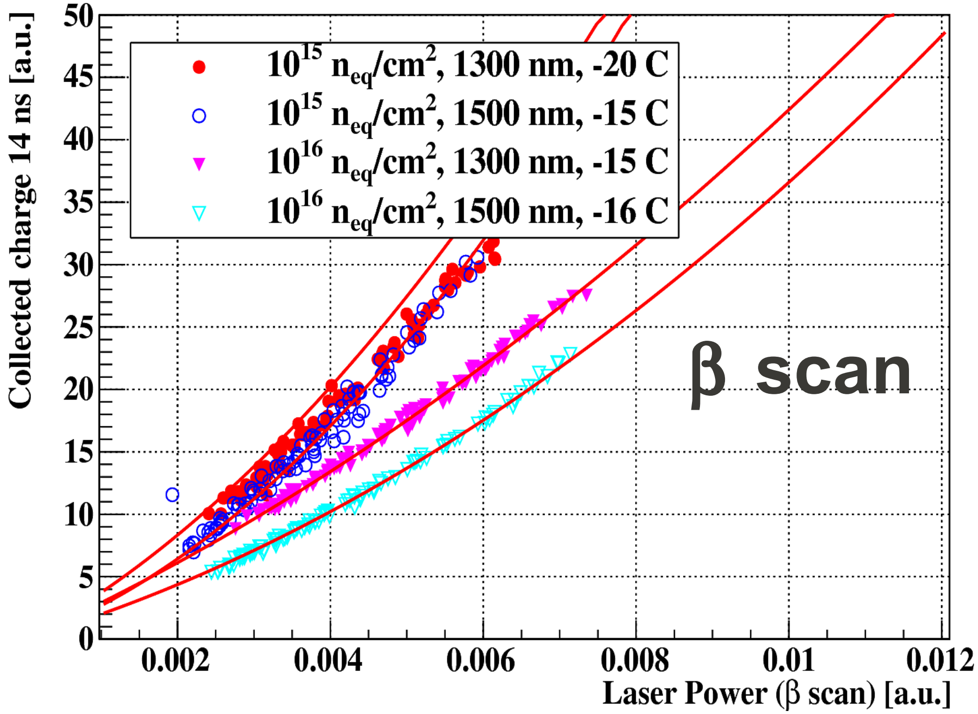
α(▼1300 nm)>α(▽1500 nm)
Lower SPA at higher wavelength

The β scan has both components: **α+β.**
Conclusions on **β** not direct (correlation)

1) Fit α-scan to $Q = \alpha I$
    1.1) Freeze α
3) Fit β-scan to $Q=\alpha I+\beta I^2$

Effect of different pulse durations?





@P=0.007	α(1500)/α(1300)	β(1500)/β(1300)
D2 1e15	0.7	1.2
C6 1e16	0.6	1.3

	β/α
1e15, 1300 nm, -14 C (no amplification)	294
1e15, 1300 nm, -20 C	268
1e16, 1300 nm, -16 C	107
1e15, 1500 nm, -15 C	490
1e16, 1500 nm, -16 C	203

λ=1500 nm is a **good** choice for irradiated detectors

Conclusions

Ionizing radiation creates deep energy levels within the band gap that enhance the Single Photo Absorption process (increasing linear absorption α).

A method to remove the additional SPA absorption and improve the TPA signal has been successfully applied.

For irradiated detectors, TPA-TCT at (λ=1500 nm, 40 fs) exhibits lower linear absorption (α) and higher non-linear TPA probability (β) than TPA(1300 nm, 240 fs)

Preliminary data but clear conclusion: TPA-TCT is validated for both irradiated and non-irradiated sensors.

Note 1: TPA(1300 nm,40 fs) was tested but objective seems to stretch this pulse. Pulse duration after the focusing optics will be measured during next access.

Note 2: TPA-TCT already done for unirradiated LGAD and diamond

Extra information

W1D2 10^{15} n_{eq}/cm^{2}, Laser: **1300 nm, 240 fs,** T_{linkam} = - 20 C , T_{PCB} = - 14 C

W1D2 10^{15} n_{eq}/cm^{2}, Laser: **1300 nm, 240 fs,** T_{linkam} = - 27 C , T_{PCB} = - 20 C

W1D2 10^{15} n_{eq}/cm^{2}, Laser: **1500 nm, 40 fs,** T_{linkam} = - 20 C , T_{PCB} = - 15 C

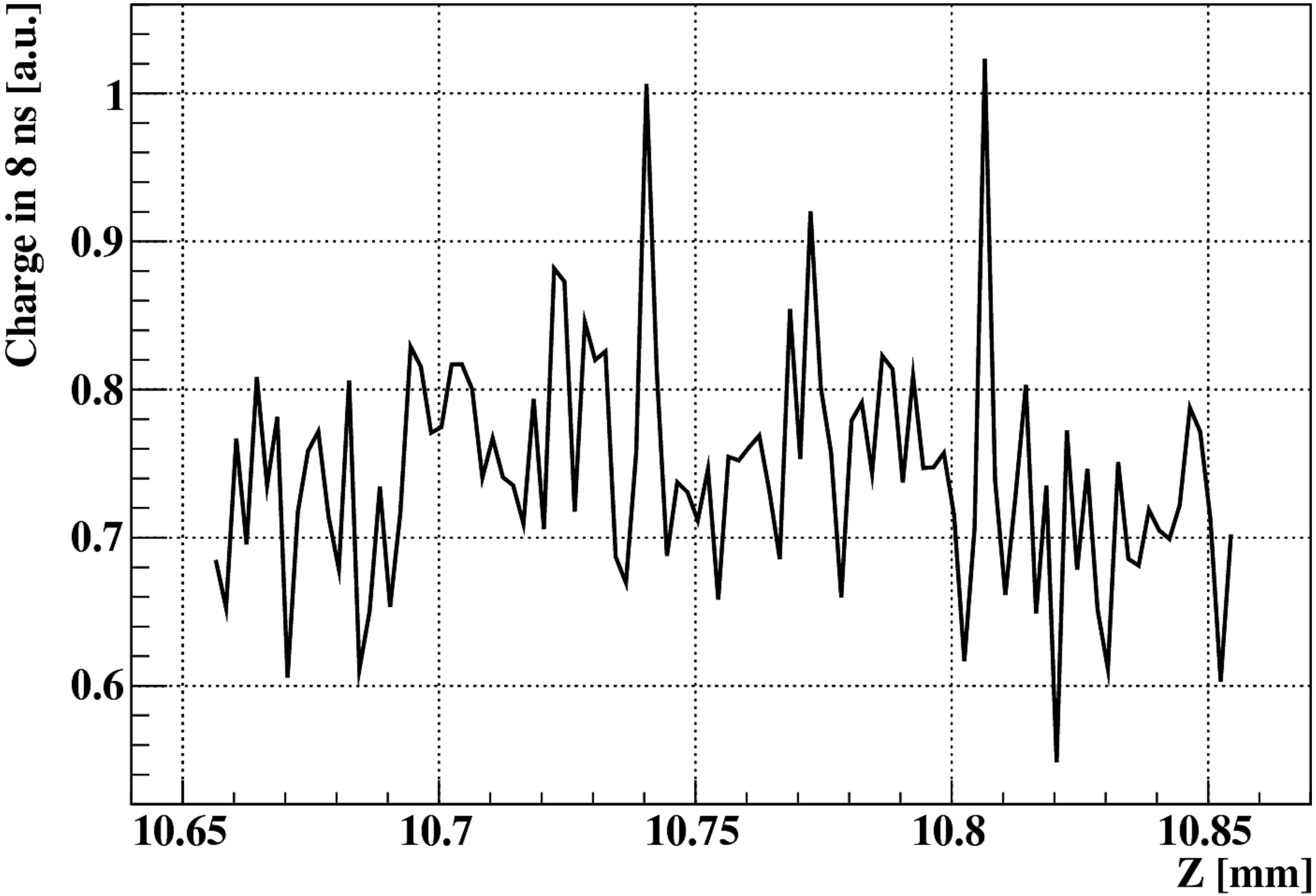
W1C6 10^{16} n_{eq}/cm^{2}, Laser: **1300 nm, 240 fs,** T_{linkam} = - 23 C , T_{PCB} = - 16 C

W1C6 10^{16} n_{eq}/cm^{2}, Laser: **1500 nm, 40 fs,** T_{linkam} = - 23 C , T_{PCB} = - 16 C

LGAD w6H11, not irradiated, Laser: **1500 nm, 40 fs,** Room T

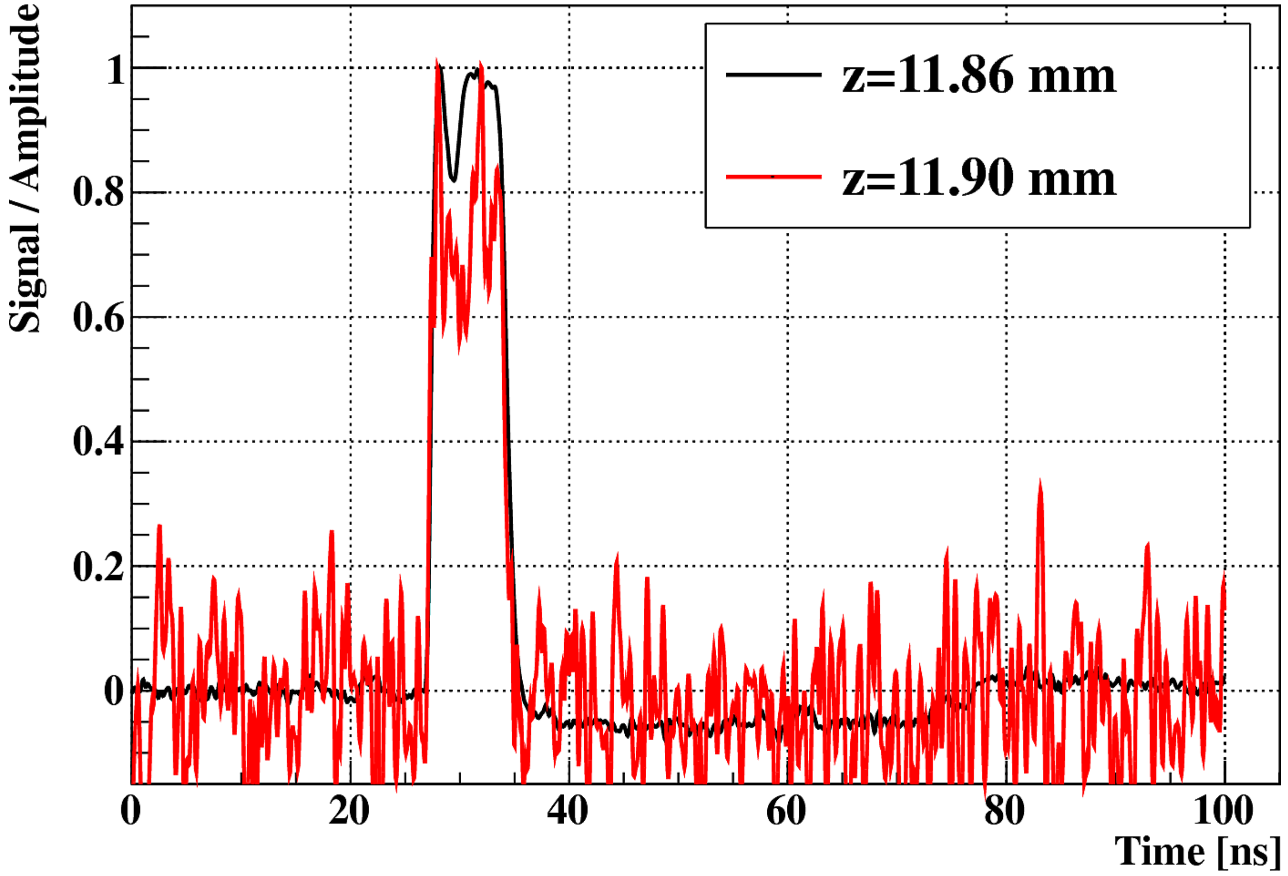
Detector → Bias Tee → 28 dB att → Ampli → Scope
28 dB attenuation (otherwise saturation of amplifier at 1000V)

Low energy scan



At low energy alpha dominates. Parabola below the straight line

20160525_1045_W1D2_1000V_M20C_33uA_1300nm_low_energy_baseline_substrated



Reflected light has same collection time as the **direct signal**

Maybe focus is reflected back into the detector