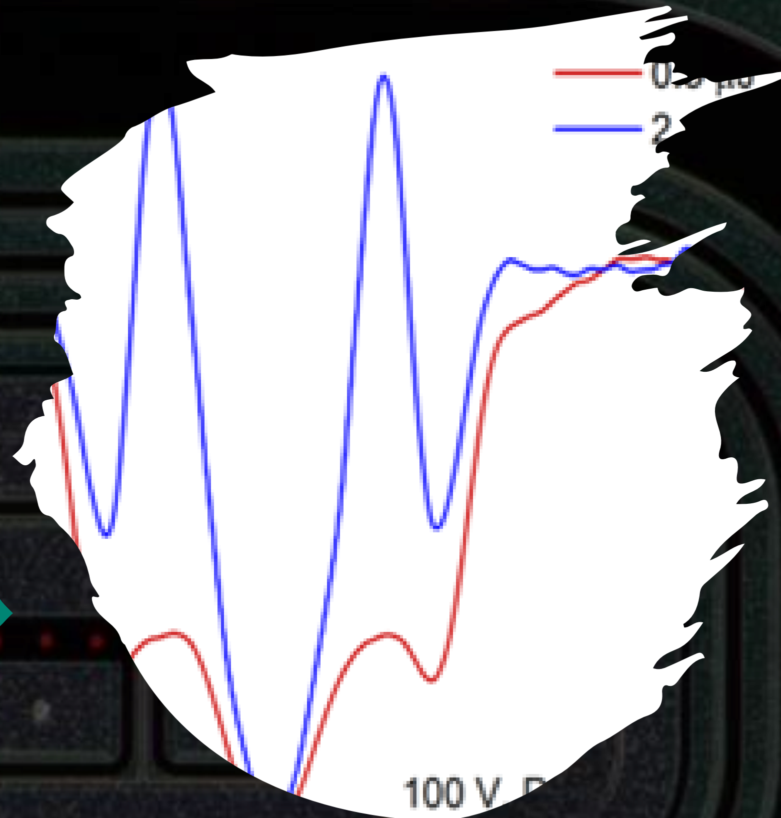

43rd RD50 Workshop, CERN, 27th of November – 1st of December 2023

INVESTIGATING ANOMALOUSLY STRONG CURRENT IN IP REGION OF DOBLE TRENCHED TI-LGADS & DISCOVERING DIFFERENT IP SIGNALS

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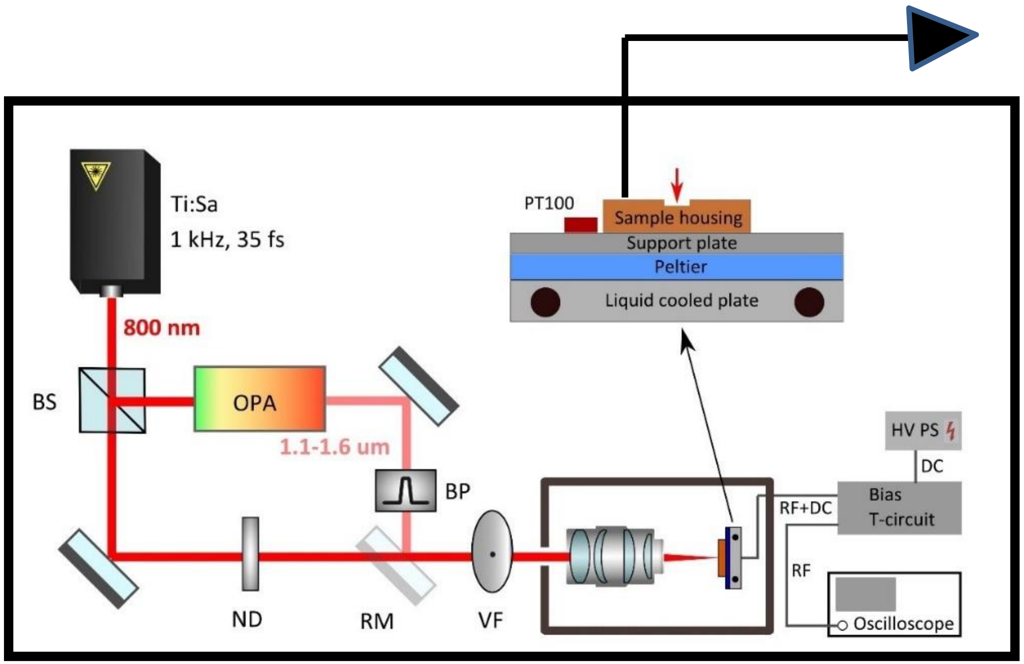
OUTLINE

- Introduction (Motivation)
  - Study on Ti-LGAD Type 10
- Study on UFSD4
- Study on Single Trench LGAD
- Study on Double Trenched Ti-LGAD
- Summary

Experimental Technique: fs-laser based TCT at ELI

Place	ELI Beamlines
Operational modes	Single and two photon absorption (SPA and TPA)
Pulse energy on sample	Variable by ND filters (accuracy: 0.2 pJ)
Wavelength	800 nm (SPA), 1550 nm (TPA)
Pulse width in sensor	1550 nm, ~ 150 fs 800 nm, ~ 50 fs
Focus waist radius	0.85 µm (SPA), 1.5 µm (TPA)
Rayleigh length	3.31 µm (SPA), 7.74 µm (TPA)
Sample cooling	Down to -25 deg. C
Sample movement	X, Y, Z
Bias voltage	up to or > 720 V
Detection	6 GHz (20 GSa) oscilloscope and leakage current measurement (accuracy: 0.1 µA)

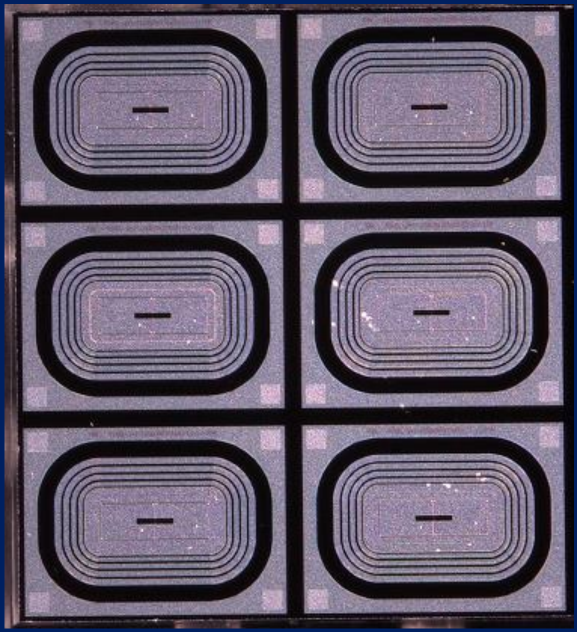


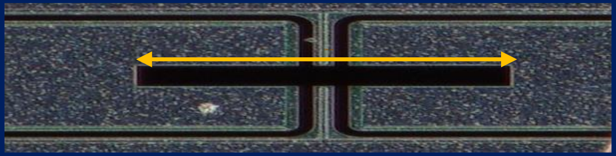
Schematic view of the setup for TCT-SPA and TCT-TPA measurements at ELI Beamlines (BS – beam splitter, OPA - optical parametric amplifier, BP - bandpass filter, ND - neutral density filter, RM - removable mirror, VF - variable filter)

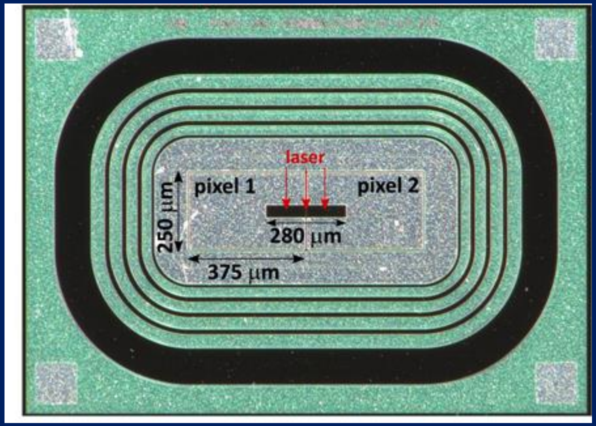
In study presented here we did not use amplifier.

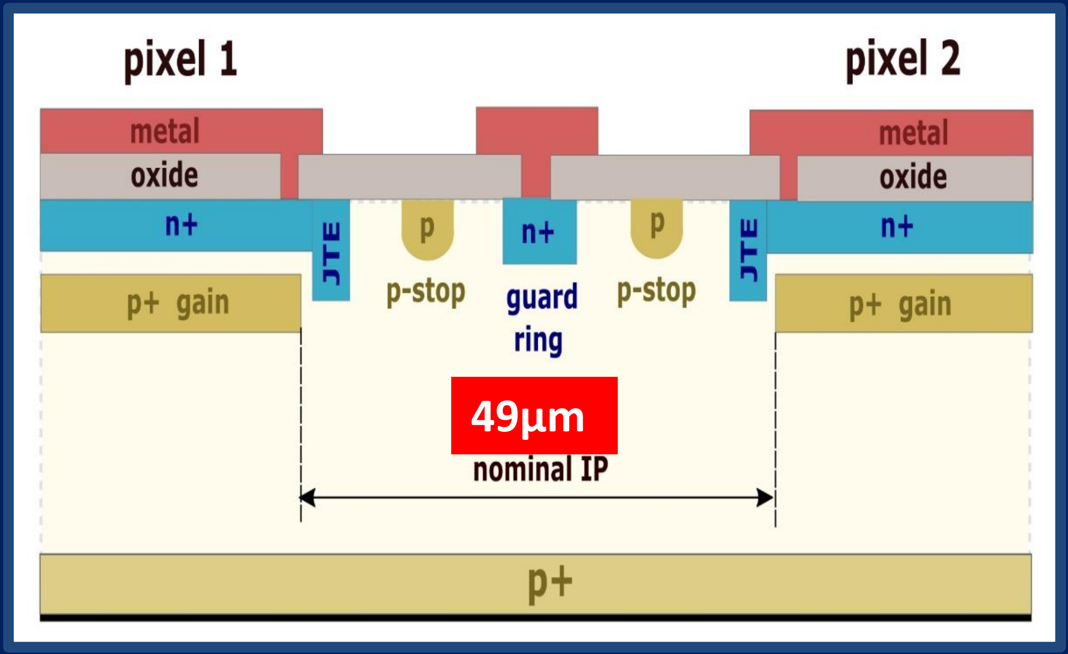
Ref: G. Lastovicka-Medin et al, Femtosecond laser studies of the Single Event Effects in Low Gain Avalanche Detectors and PINs atELI Beamlines, Nuclear Inst. and Methods in Physics Research, NIM A, 2022

Motivation:







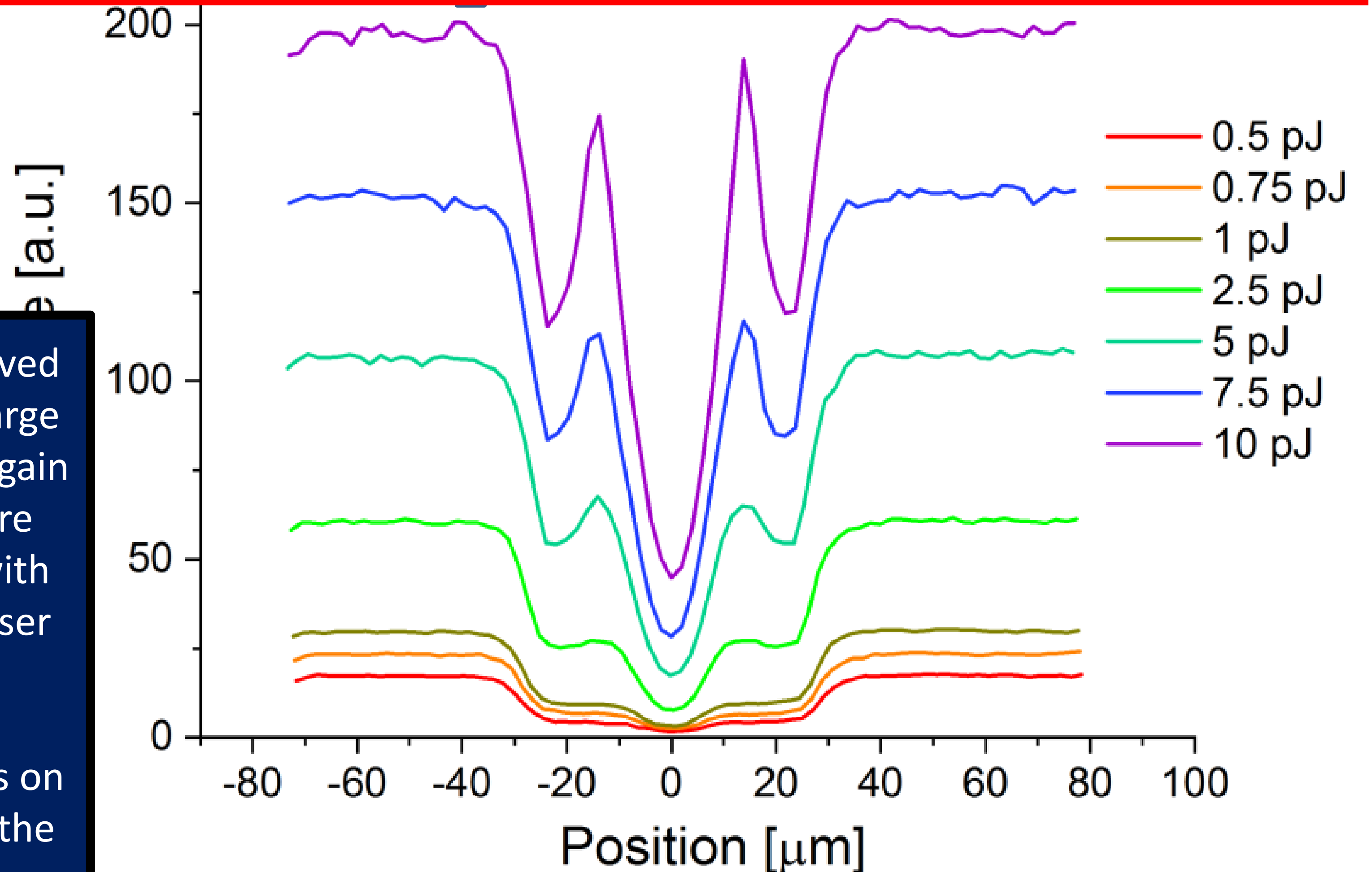


Ti-LGAD Type 10

2 p-stops + bias ring in IP region

Reminder

Strong enhancement in IP region

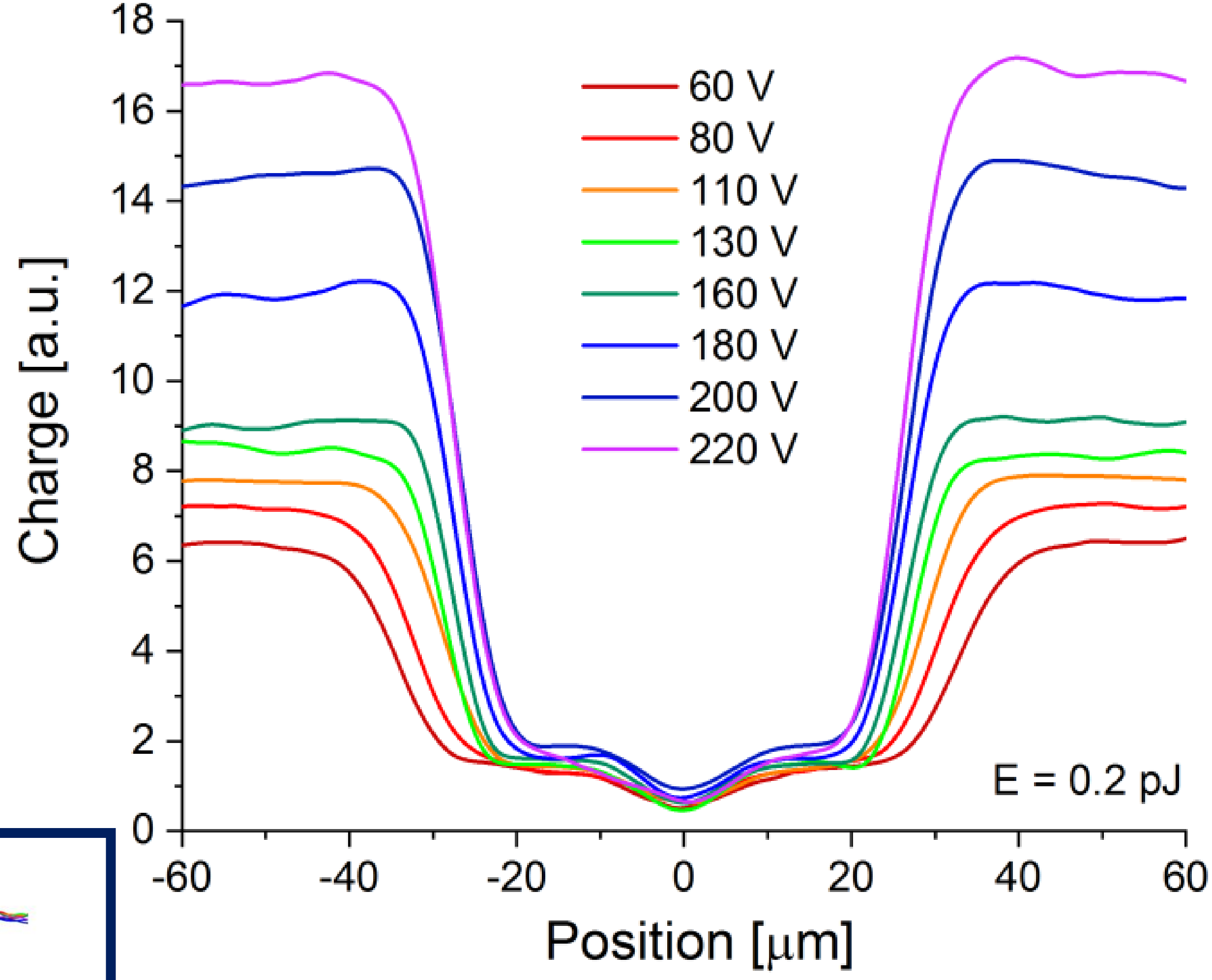


Space-charge profile vs laser pulse energy)

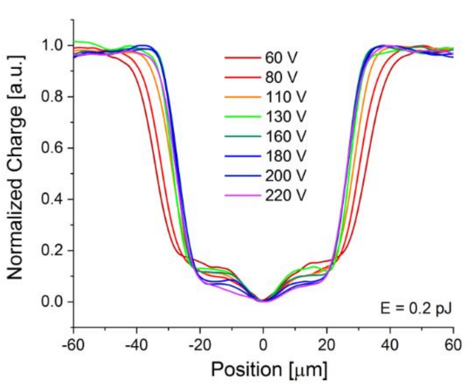
- Spikes observed in space charge profile in no-gain region; more enhanced with increased laser power.
- They appears on the sides of the central hollow (more or less at +/- 15 μm).

at low laser power

Reminder



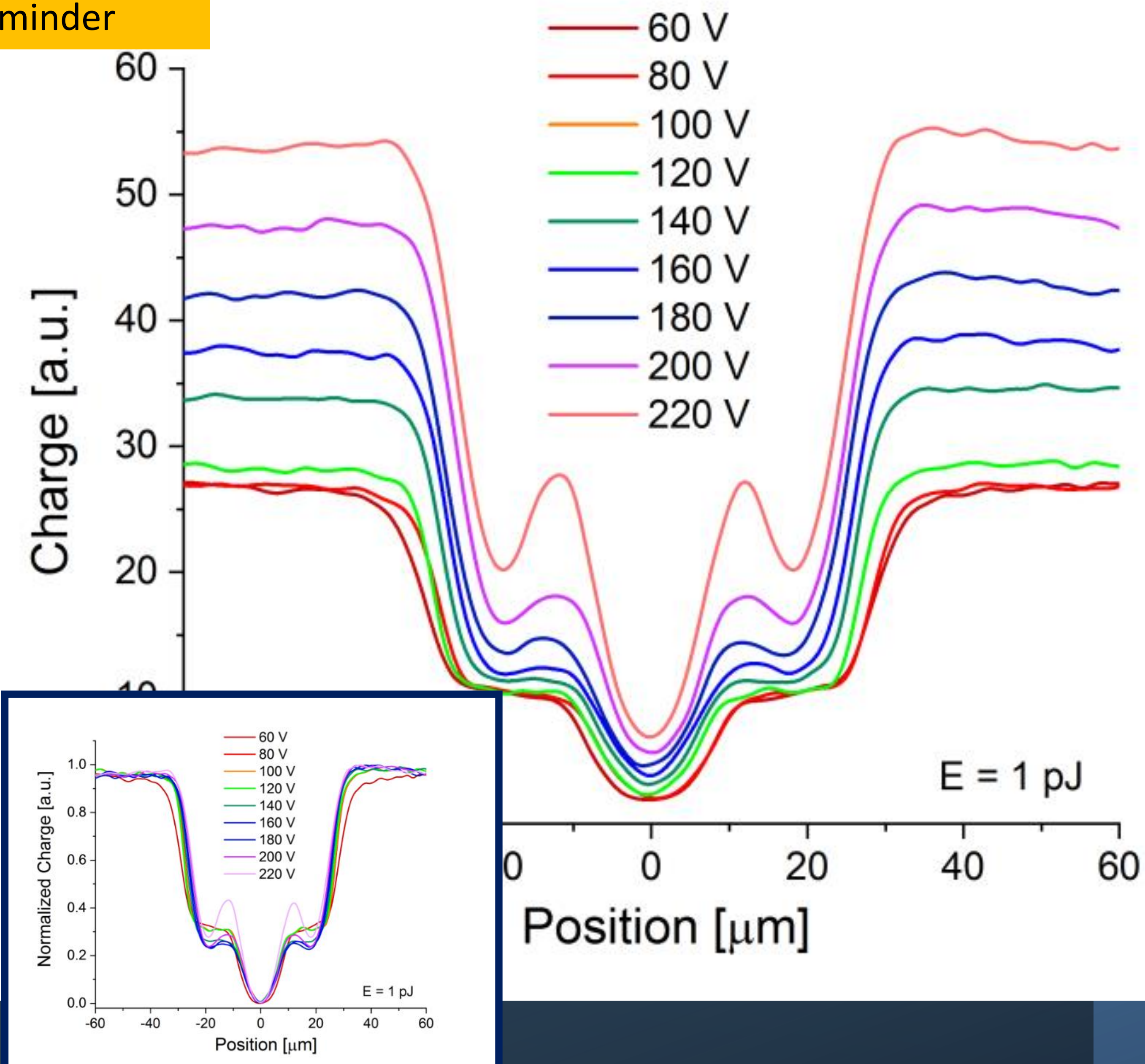
Same data as above but normalized for better comparison



IP distance decreases with increasing bias.

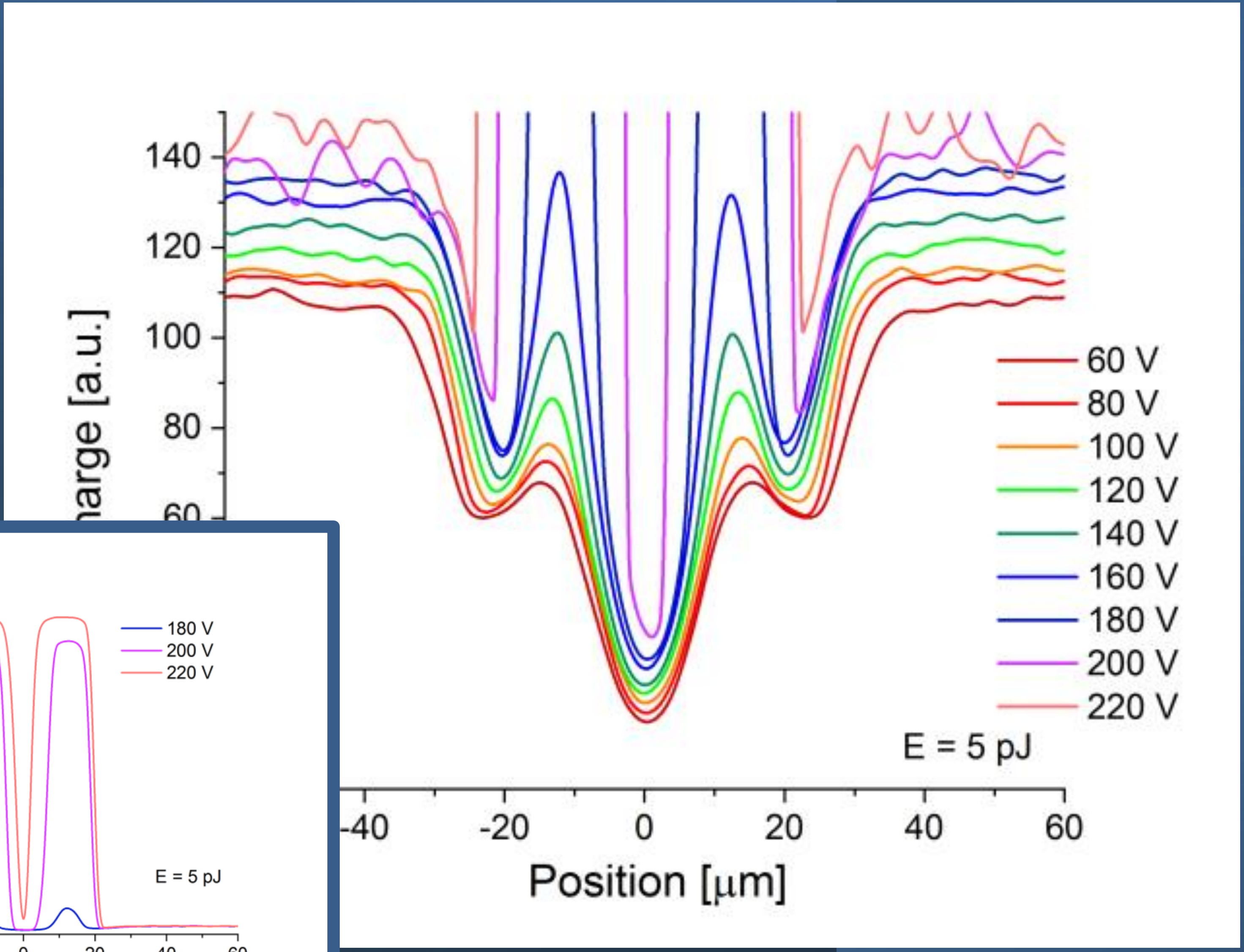
at medium laser power

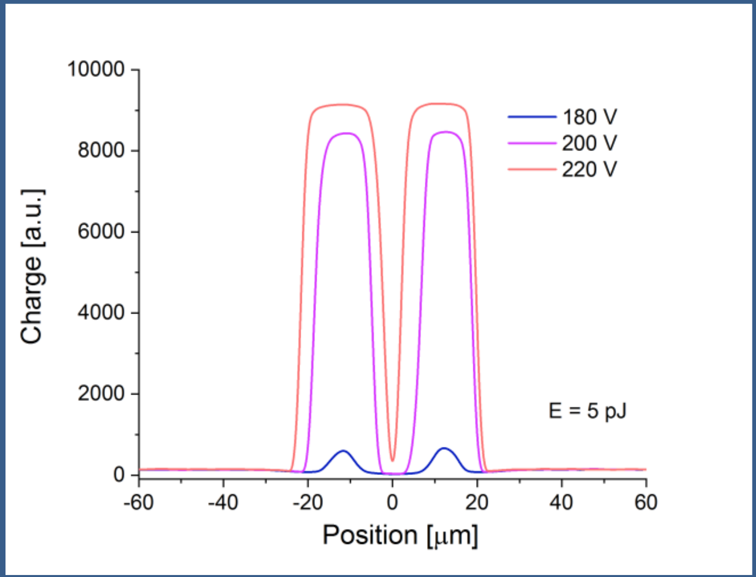
Reminder



at high laser power

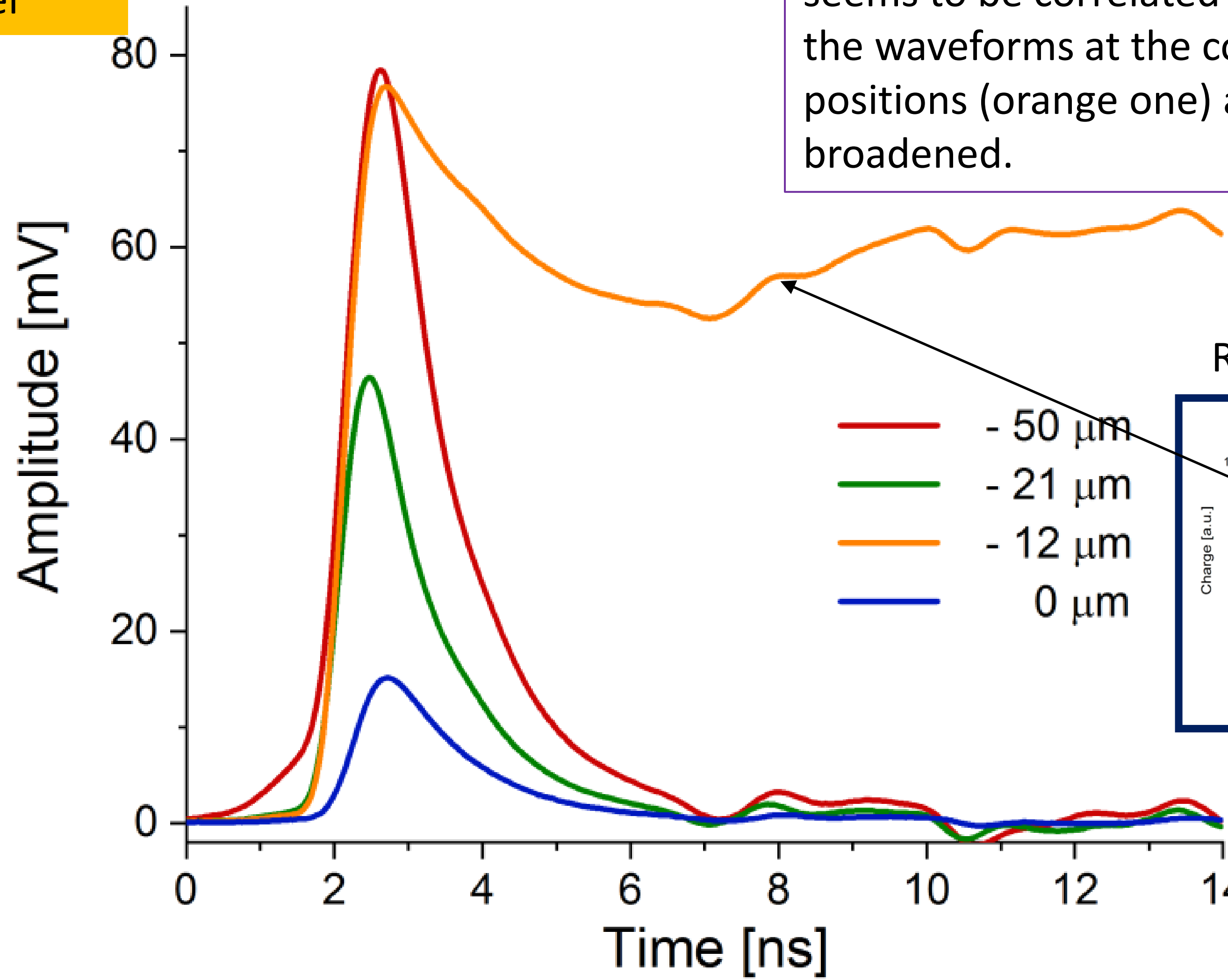
At high laser power (5 pJ) extremely strong side bands appear around the central hollow.





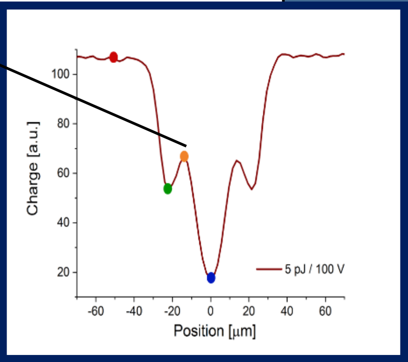
Waveforms recorded at high power and bias (5 pJ/180 V) at selected positions

Reminder



When we look at the waveforms it is visible that the very strong side bands seems to be correlated to the fact that the waveforms at the corresponding positions (orange one) are extremely broadened.

Reminder:



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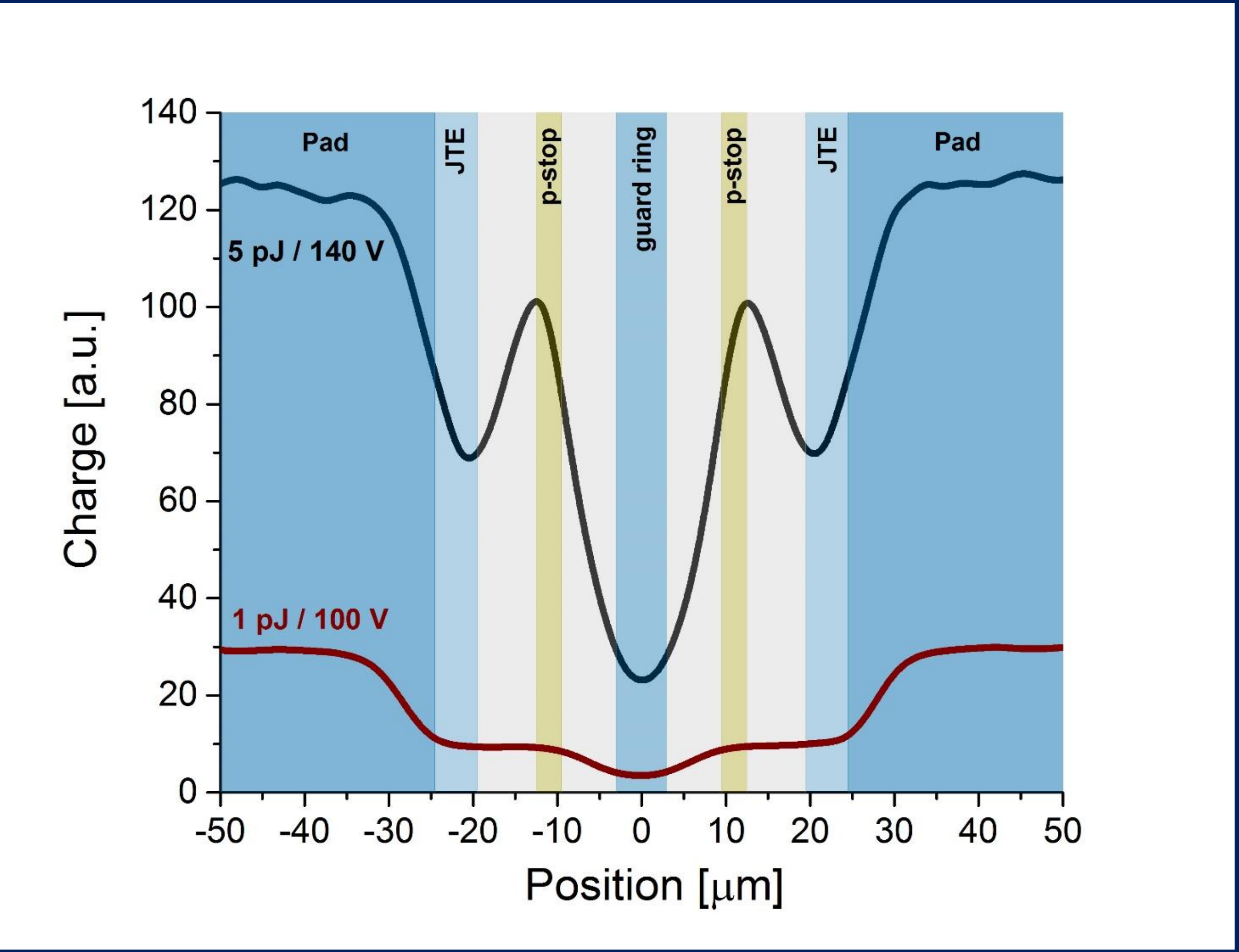
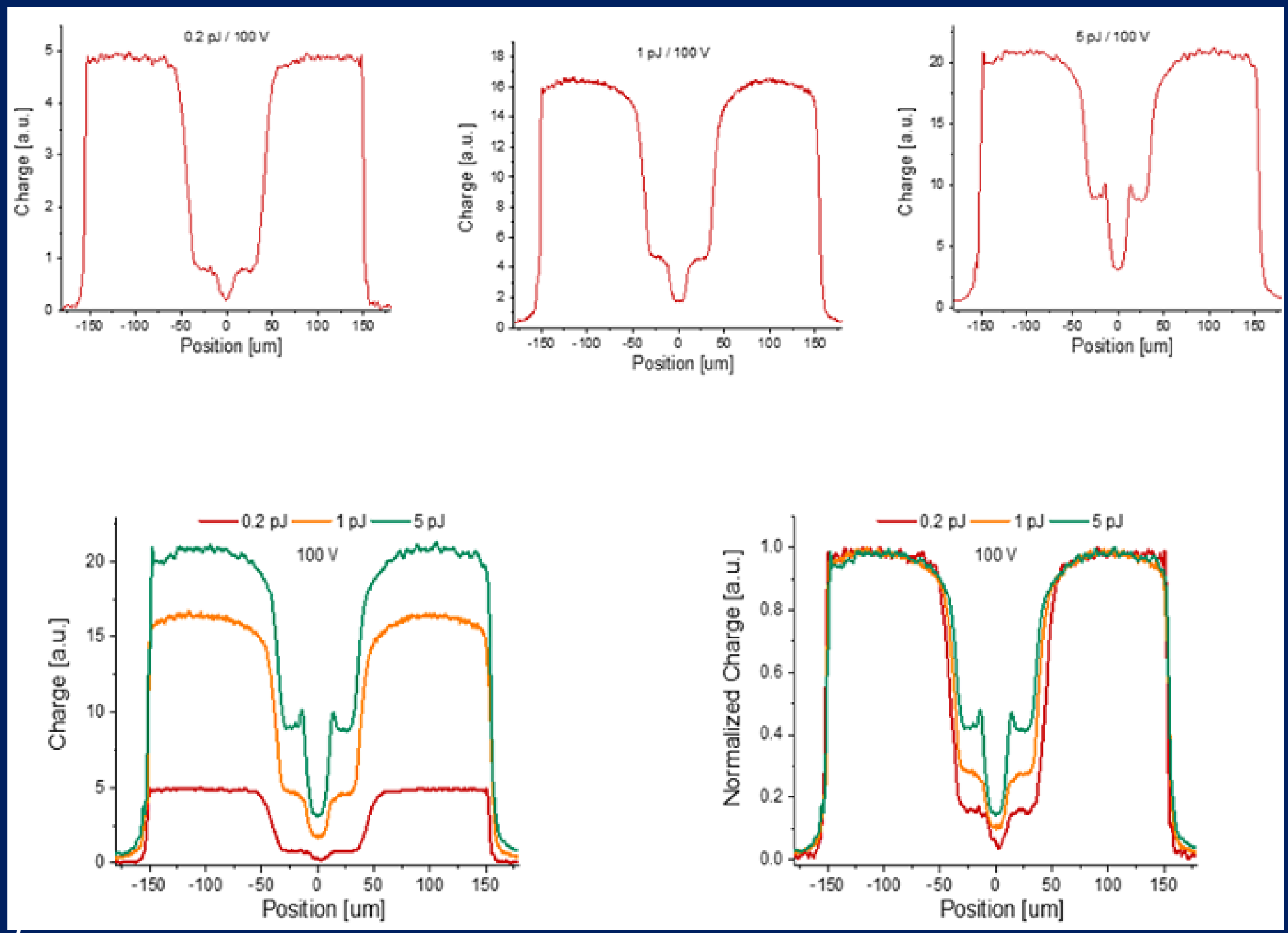


Published in Sensor:

G. Laštovička-Medin et al., Exploring the Interpad Gap Region in Ultra-Fast Silicon Detectors: Insights into Isolation Structure and Electric Field Effects on Charge Multiplication, Sensors 23, No. 15 (2023) 6746.

UfSD4, IPD = 61µm

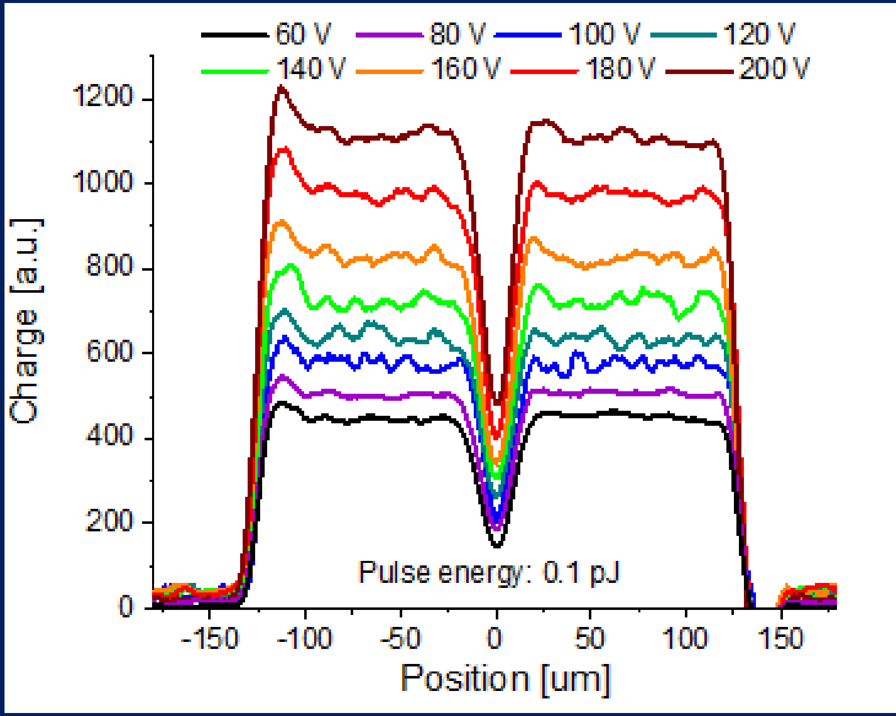


Submitted to Radiation protection and Isotopes (RAP 2023 conf)

No enhancement has been seen in IP region.

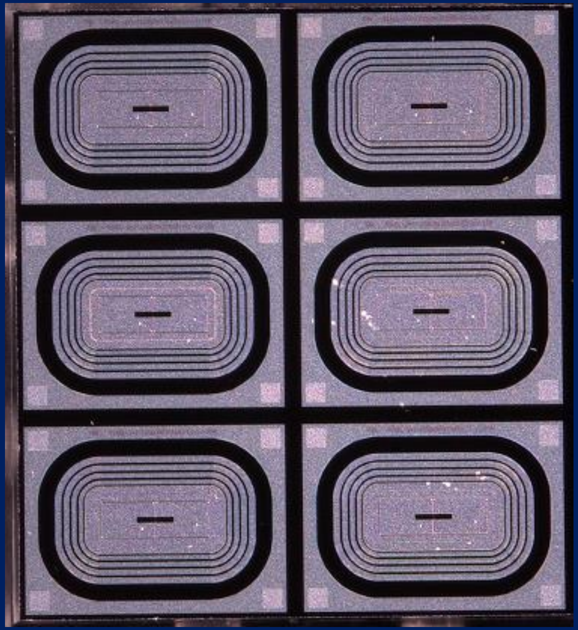
Single Trenched LGAD

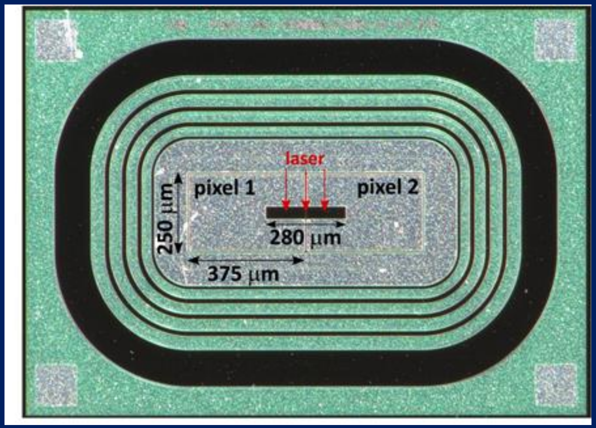
1TR W11 (A1 54 C1V3)



No enhancement has been seen in IP region.

Double Trenched LGAD : Main topic

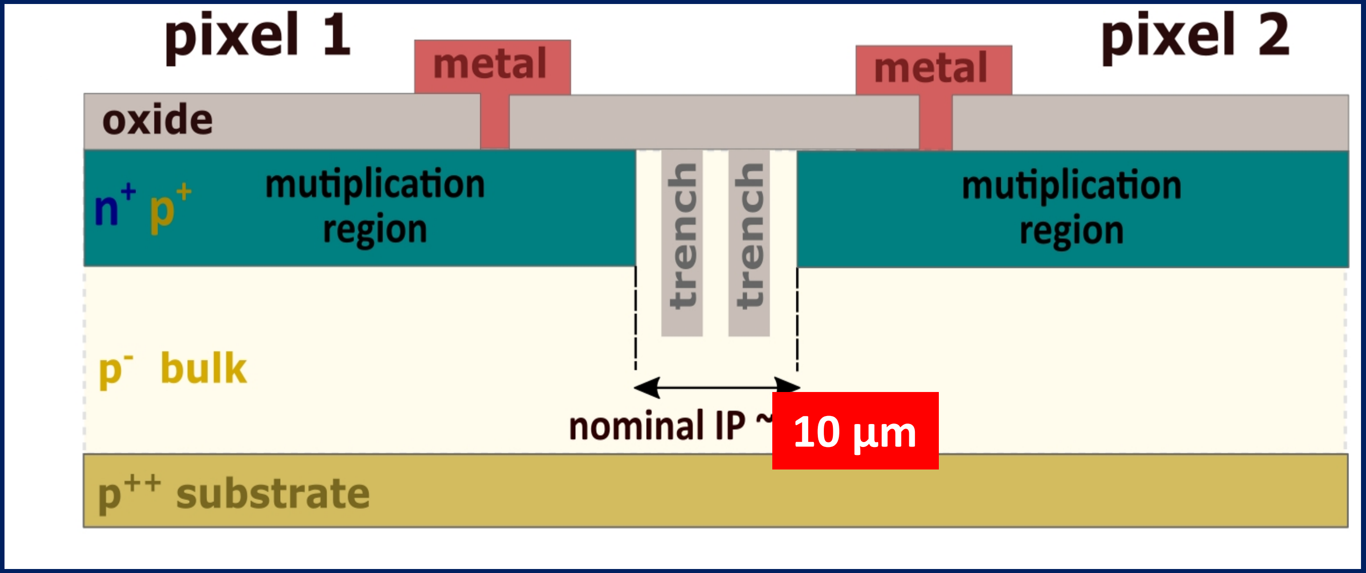




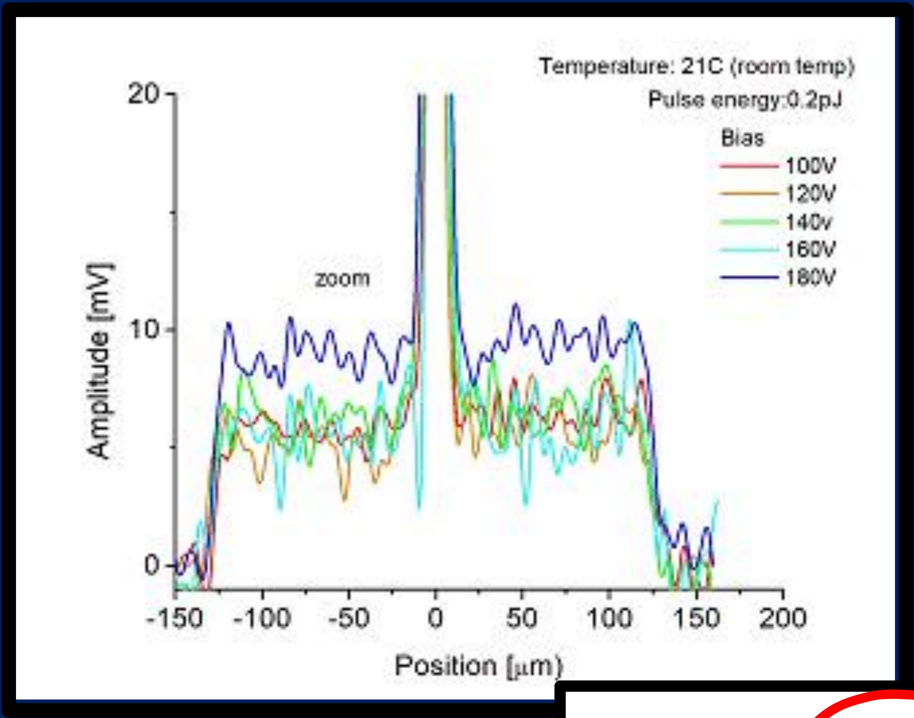
- W7: C2-V3-2TR-GRT2
- W11: C1-V2-2TR
- W16: C1-V4-2TR and C2-V2-2TR

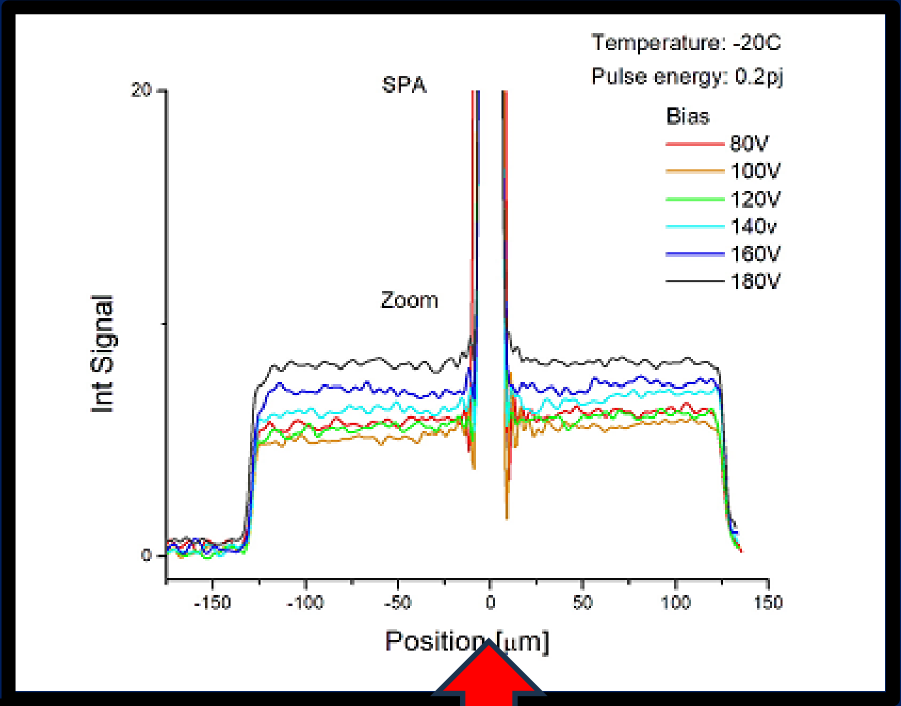
W7, lower gain, higher leakage current
W11: shallower trench
W16: deepest trench

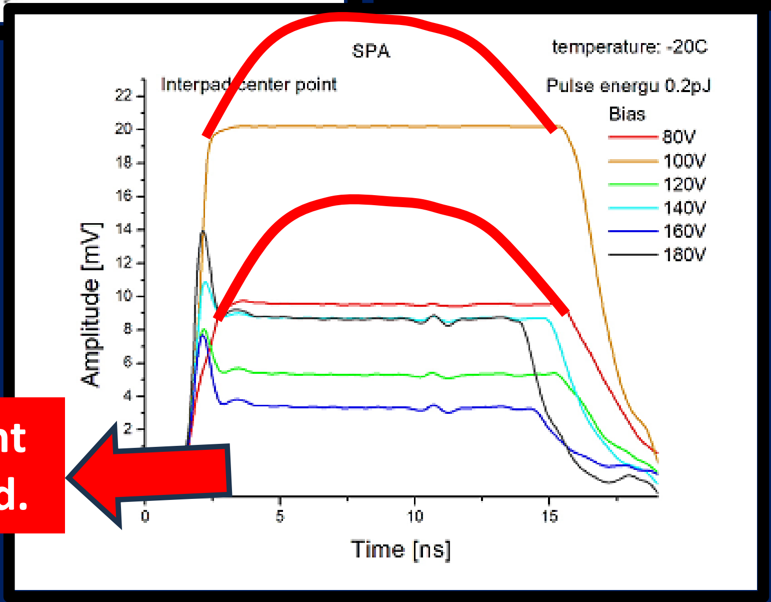
(V_{GL}=25 V, V_{FD} =30 - 35 V, G = 5-10



Space-Charge profile







Strong current in IP region was measured.

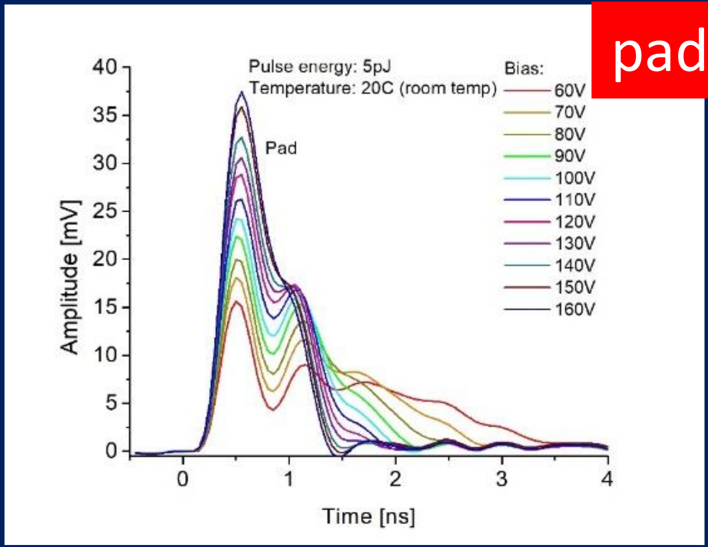
Extremely prolonged TCT waveform /averaged over 64 shots.

The most probable different IP signals are superimposed.

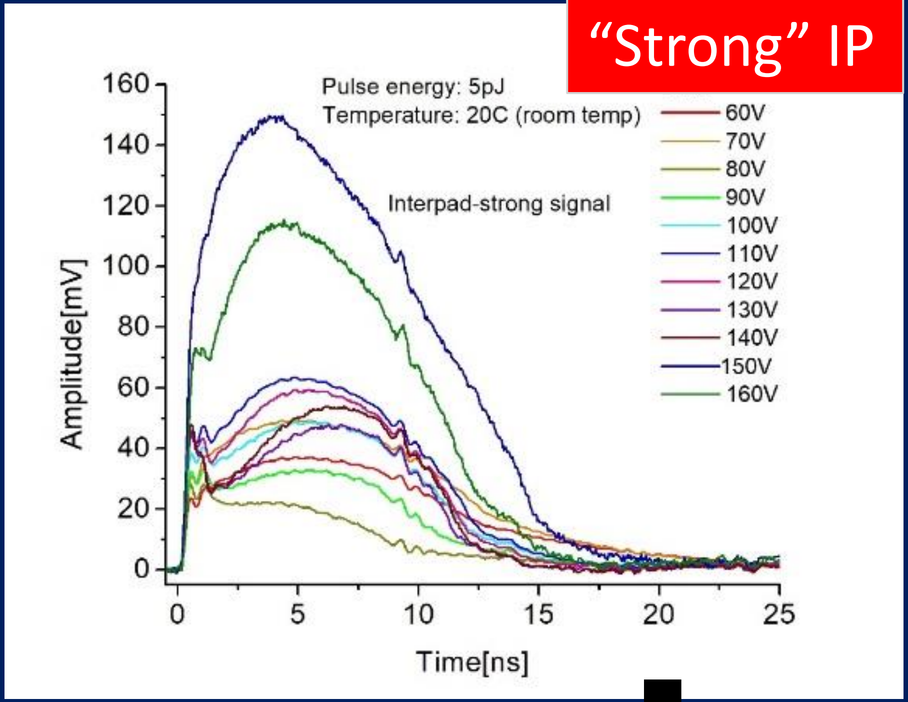
TCT Waveforms

Sample from W7, T=20^0C

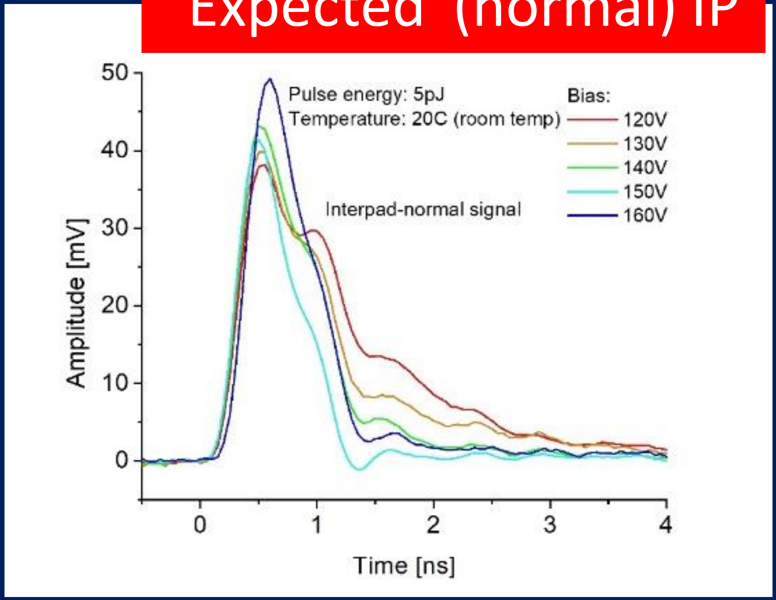
pad

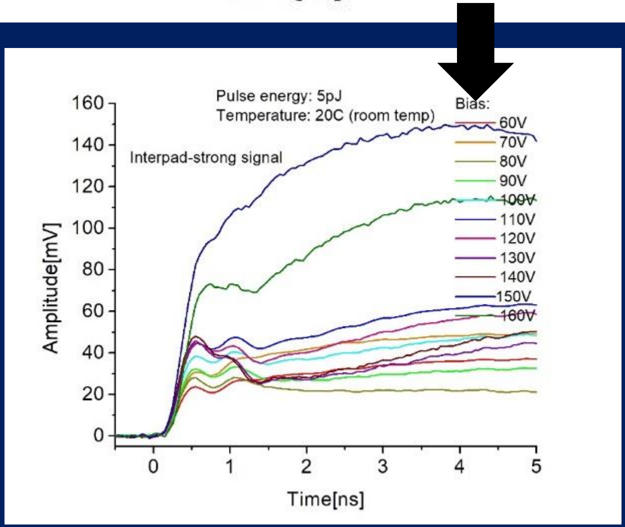


“Strong” IP



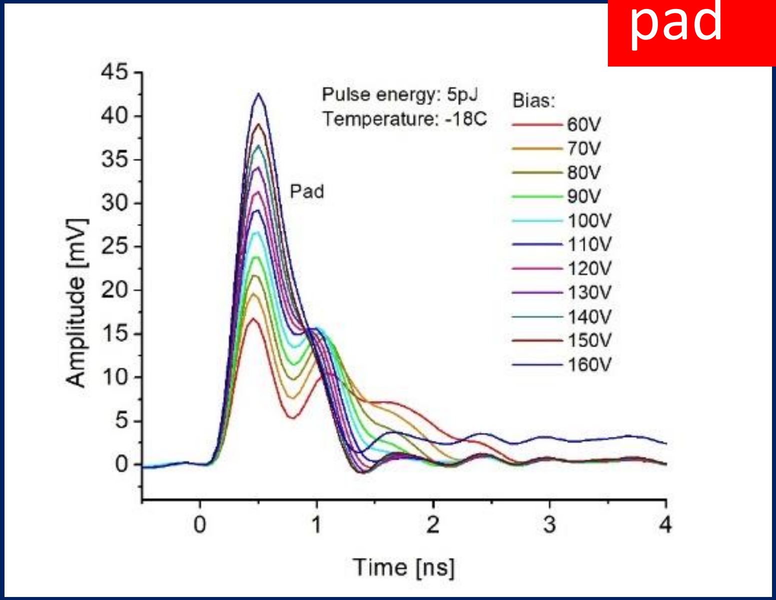
“Expected”(normal) IP



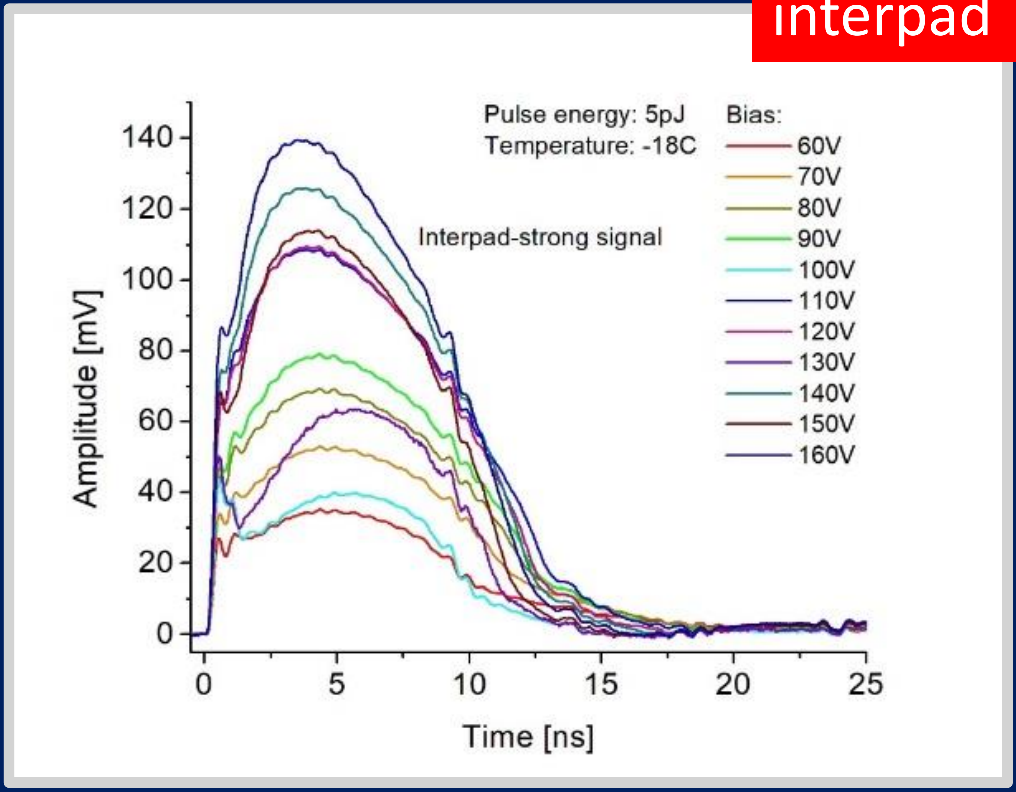


W7, T=-20^{0}C

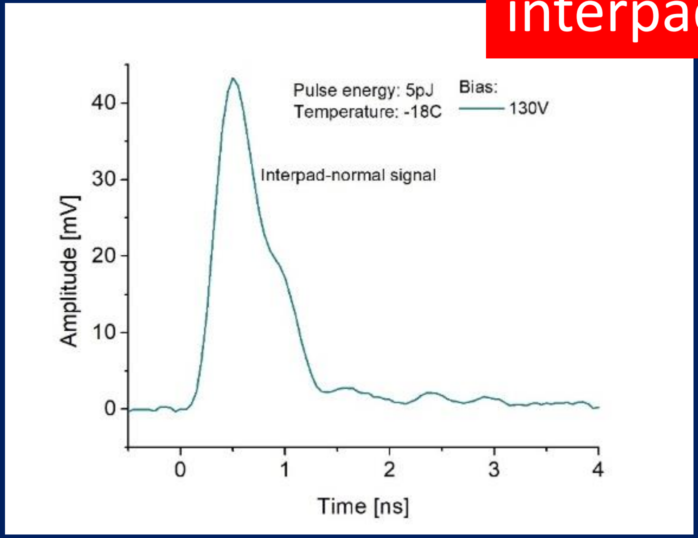
pad



interpad

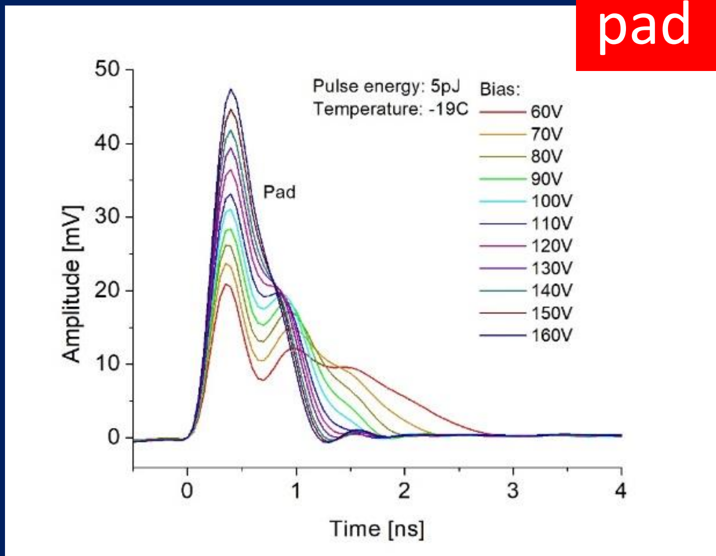


interpad

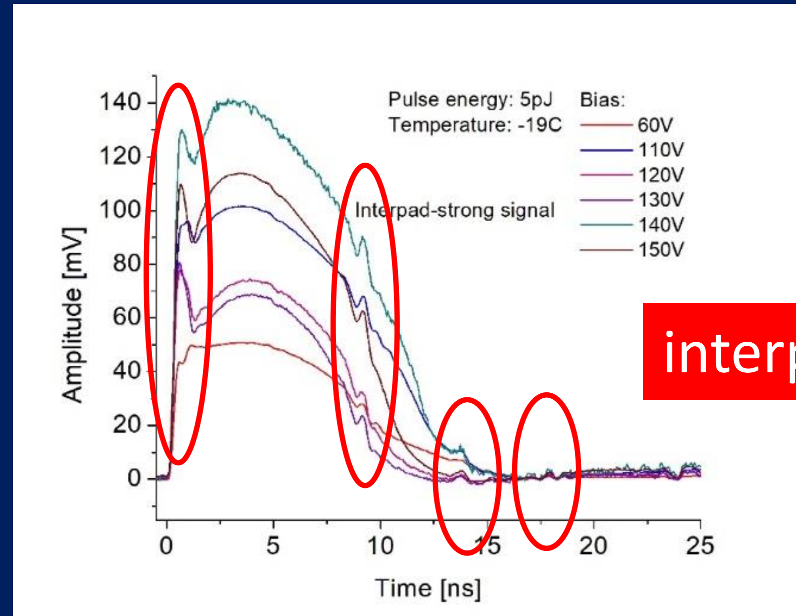


W11,T=-20^{0}C

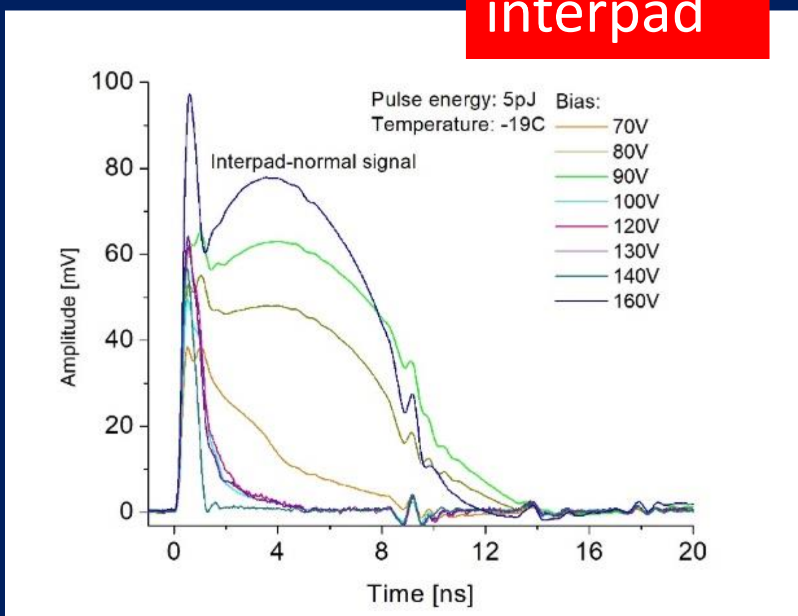
pad

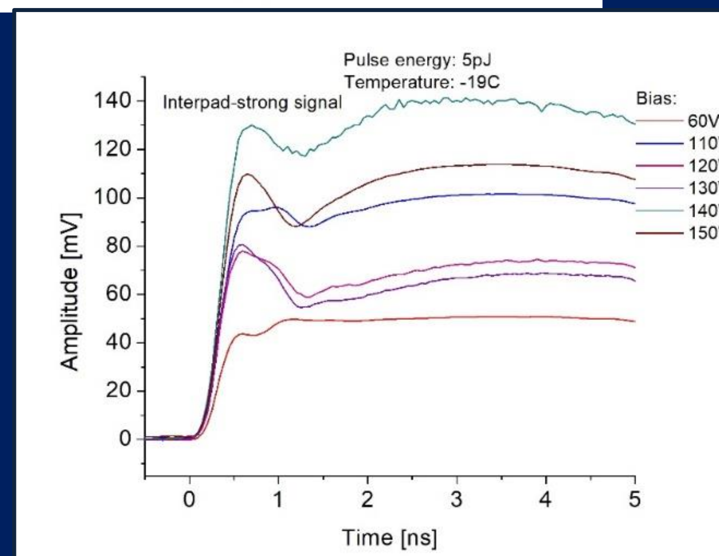


interpad

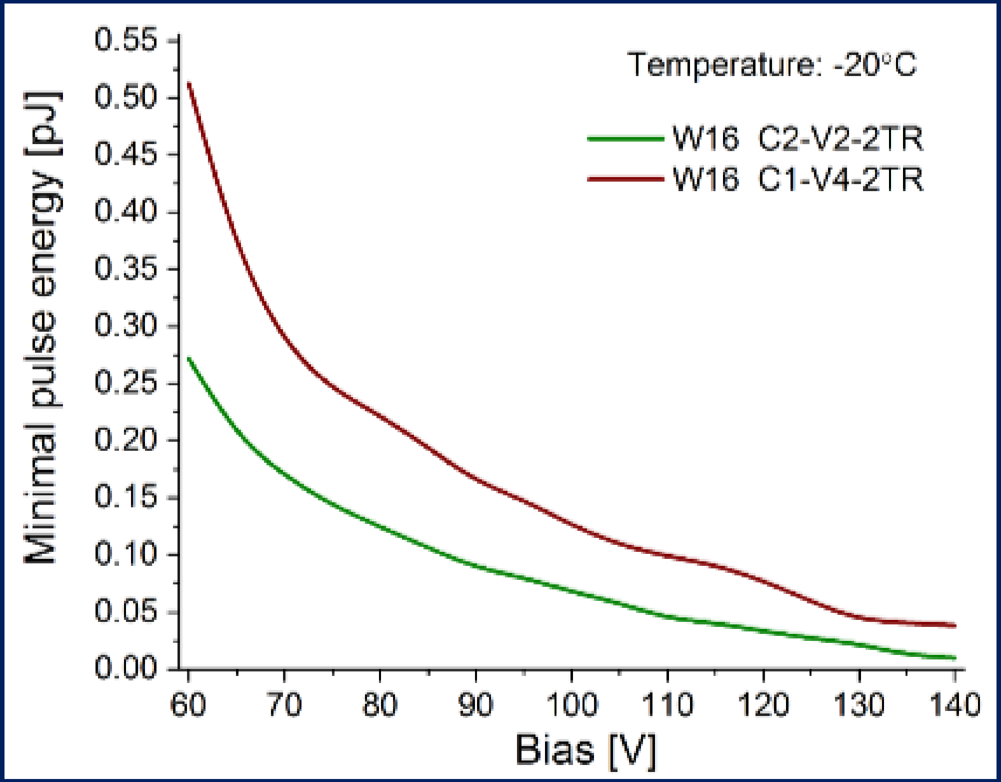


interpad





Threshold conditions for strong IP signals



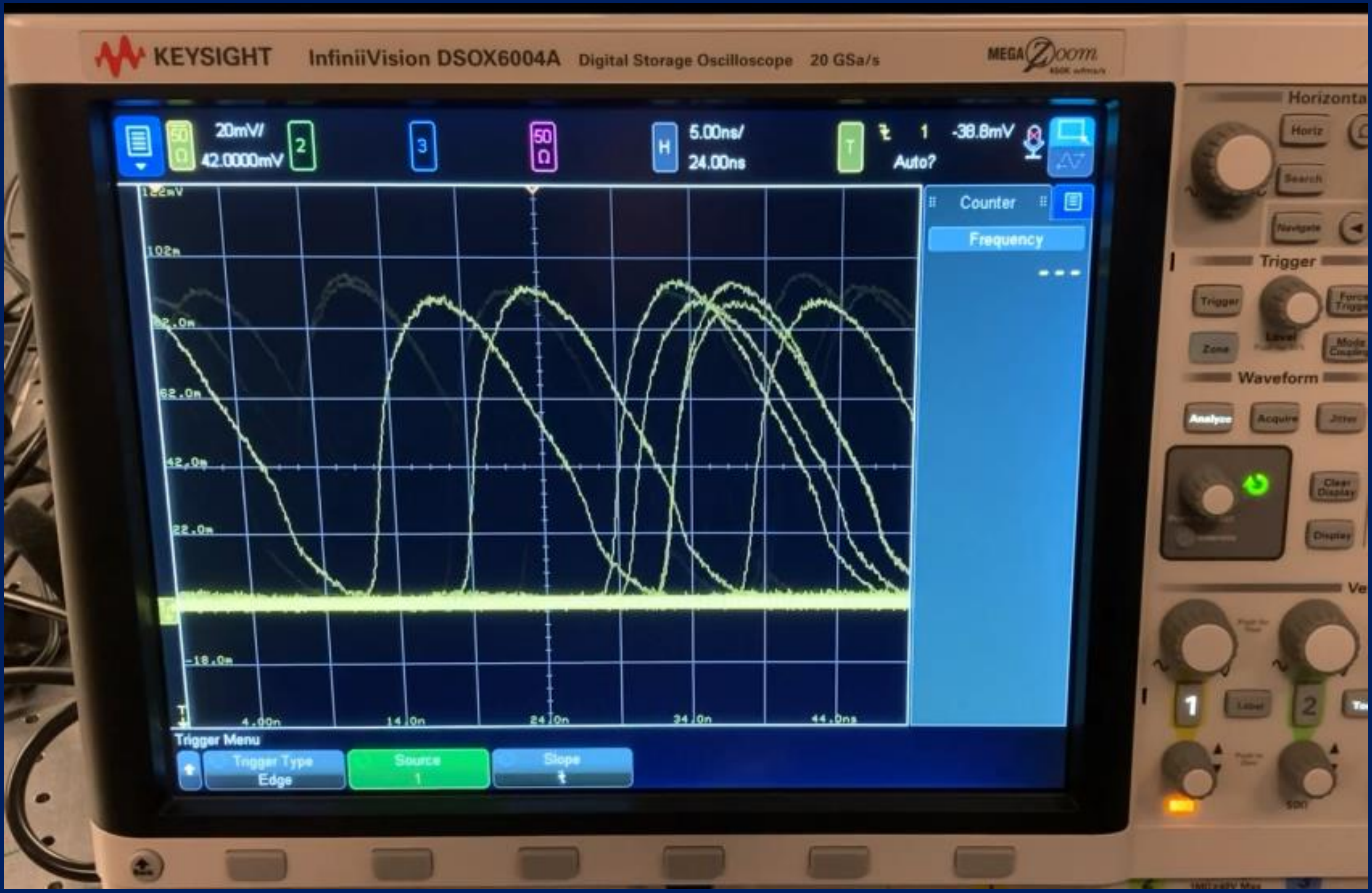
The "threshold plots: The Minimal laser pulse energy vs bias for strong signal in IP region for W16 sample obtained at -20C temperature.

Broad strong signal induced by laser illumination appears when some threshold conditions (laser power/bias) are achieved as illustrated in Figure.

For example, at high bias (140 V) even very weak 0.01 pJ laser pulse induces strong signal. To achieve this regime at 60V pulses with energy about 0.5 pJ are needed.

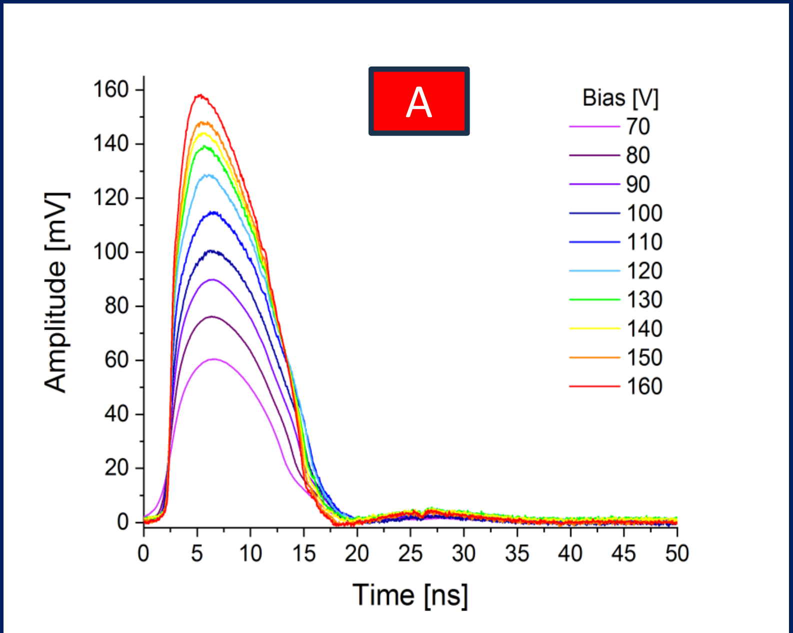
Ghosts

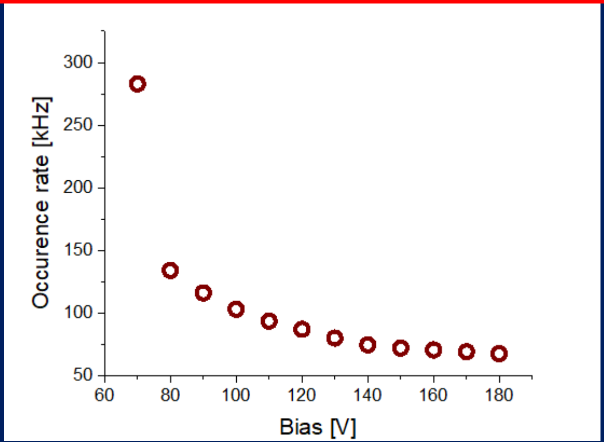
Without laser induced charge in Ti-LGAD

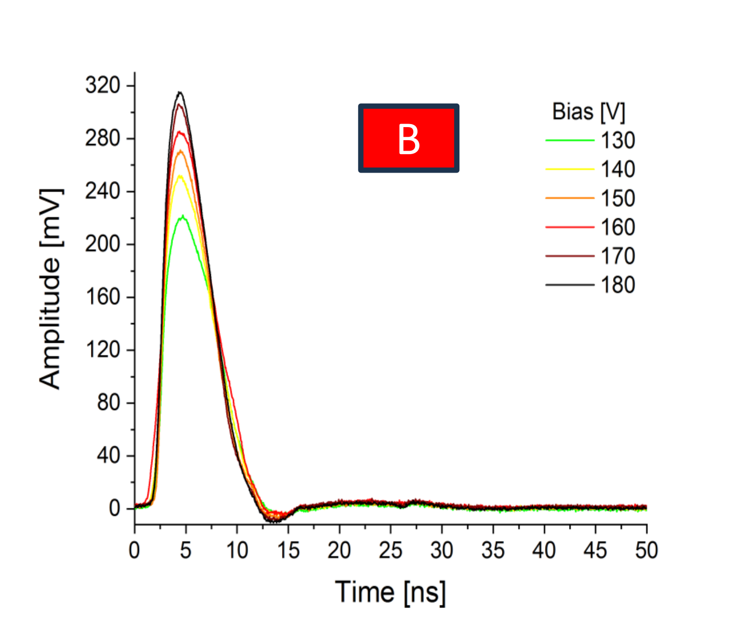


T=20^{0}C;W11: C2-V2-2TR

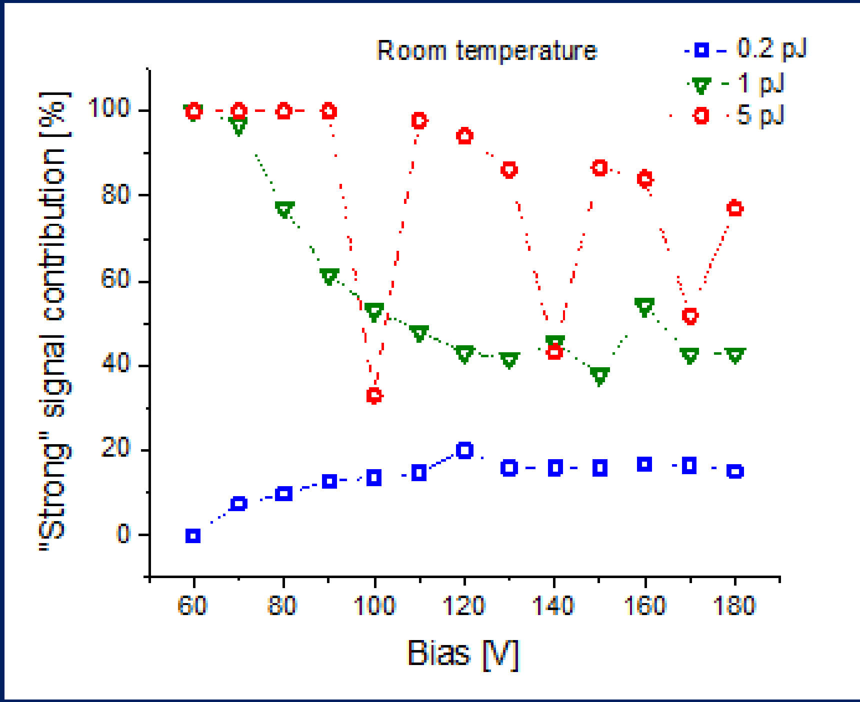
Example of waveforms in IP region

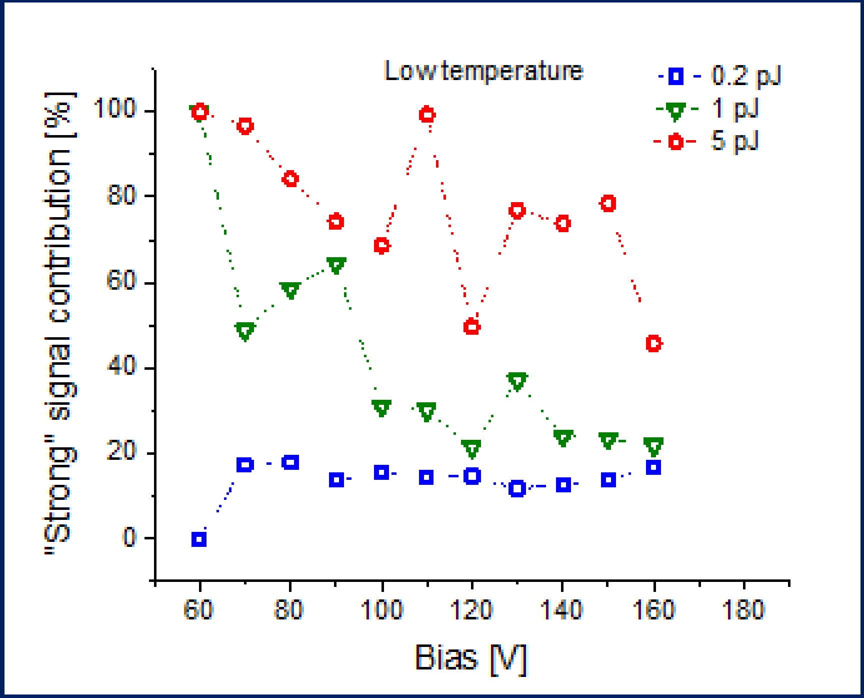






- ❑ Two types of ghost waveforms are observed
- ❑ Waveforms A appears at threshold 67 V and waveforms B at 130 V
- ❑ Amplitude of both types increases with bias in entire range
- ❑ Width of waveforms A is about 11 ns and slightly decreases with bias from 100 to 180 V
- ❑ Waveforms B are stronger and narrower (width about 5 ns)
- ❑ Rising of waveforms A becomes faster with bias
- ❑ Occurrence rate of waveforms A decreases with bias; occurrence of waveforms B was not stable and varies between 1 and 3 kH





Ratio of "normal" to "strong" signal represented as contribution of "strong" signal in percent

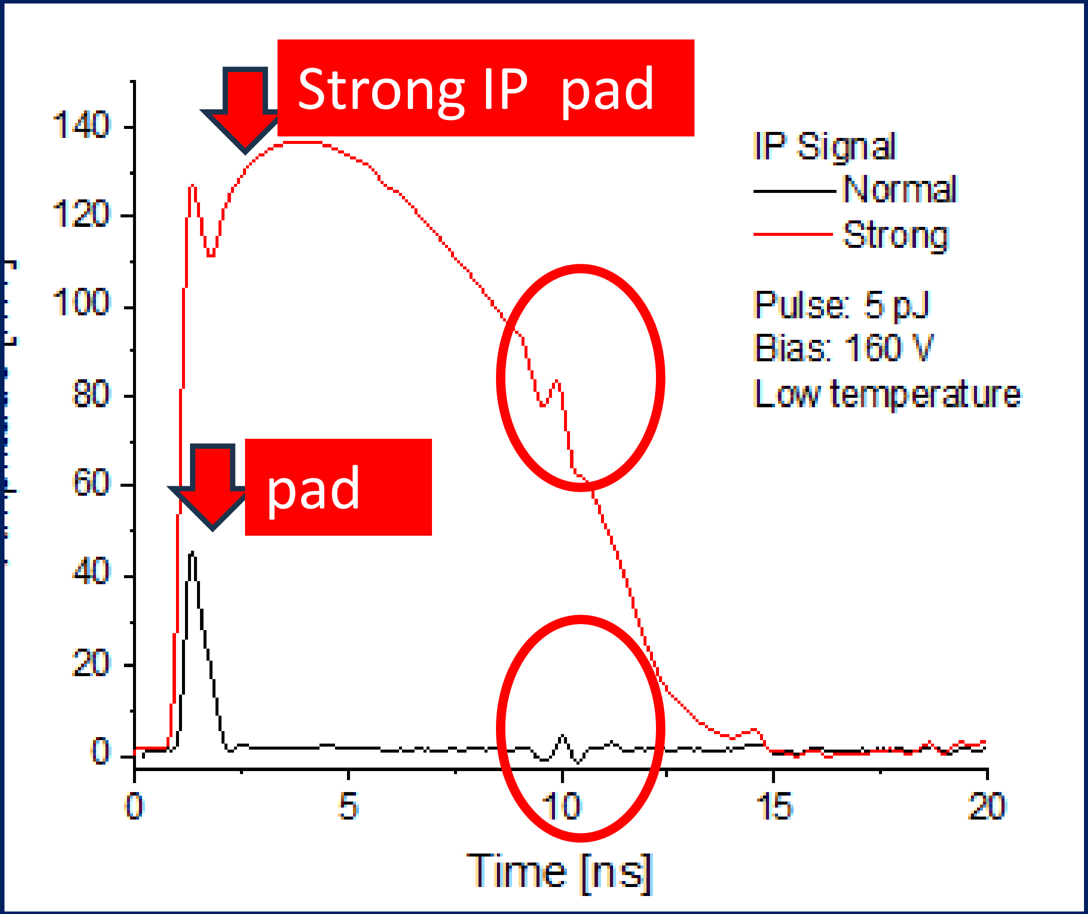
- 10,000 shots were recorded at every power/bias combination (center of IP region illuminated by laser)
- At low power (0.2 pJ) "strong" signal appears above certain threshold (about 70 V) and its contribution first increases vs bias to about 15% and stays more or less constant for bias > 100 V.
- At high power (5 pJ) we observe only "strong" signal (100% contribution). Above 100 V this contribution start slowly decreasing (suppression of "strong" signal)
- Aside of general slow decreasing trend we also see some rapid drops for some bias values (for example 100, 140 and 170 V). Interestingly this effect is relatively reproducible. The measurements were repeated twice and this drop of "strong" signal contribution was always observed at the same bias (+/- 5 V)
- Data at low temperature were measured only once so we don't know how reproducible they are. Nevertheless they show generally similar trends to those at room temperature, and follow trend of ghosts.

Little spike at the 10th s

Small replica
in pad
waveform

- To check small peak we observed for higher power we compared “strong” IP signal with pad signal at the same condition. We can see the same artifact in pad signal so this effect is not related to IP region.

- We checked also the same signal for two different cables: 100 cm length vs 50 cm and this small peak is still in exactly the same place.

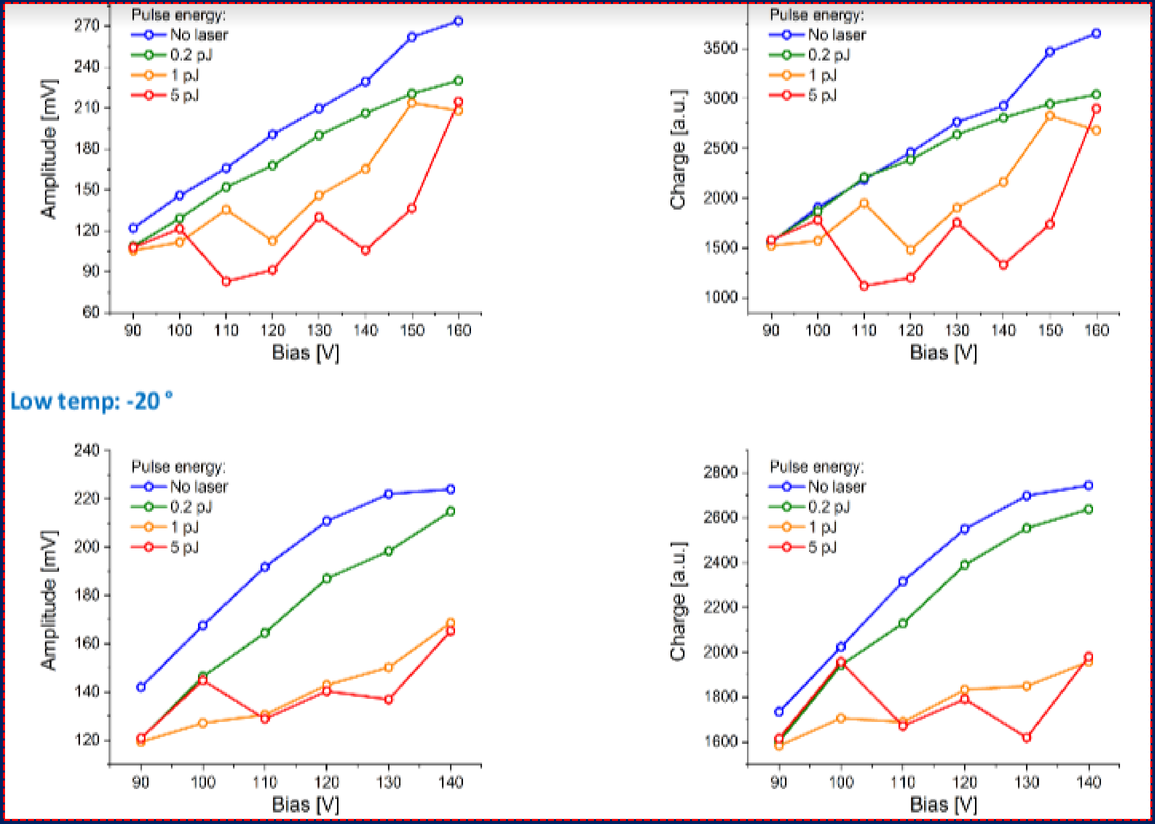


Increase in space charge supressing the ghost

W16: C1-V4-2TR

- By increasing the bias voltage, the amplitude of the transient current signal increased in all cases, nevertheless whether LGAD was illuminated by fs-laser or laser was not used.

- Signal amplitude decreased with increasing the laser power (more charge is generated more gain was suppressed)



- Noticeably, in all studied cases, the measured IP signal was lower when LGAD IP region was illuminated by lase.

Study on irradiated sample

- The strong signal disappeared.
- Ghosts vanished.

Summary

- The 2 Tr Ti-LGAD samples, produced from different wafers W7, W11 and W16, are studied.
- We found that the examined 2Tr sample showed different induced current signals in the IP region compared to previously studied sensors with different isolation structures.
- We identified two types of laser pulse induced signals in the IP region: “normal” signal, and “strong” signal represented by significantly broader waveforms with several times higher amplitude.
- In addition, randomly occurring “ghost” signal appearing in biased but not laser-illuminated sensors were identified.
- All three types of signals were explored in terms of the influence of bias voltage and laser power at different temperatures.
- Experimental data indicates the presence of bias threshold for enhanced signal.

- Comparison of “ghost” waveforms with laser-induced “strong” signal shows the laser quenching effect. Laser induced signal was lower in amplitude then ghost signal and it decreased with increasing laser power.

- Temperature influence on the “ghost” signal is small, with a moderate amplitude increase after cooling.

- However, the thermal effects become pronounced in the laser-induced signal. especially at high laser power. In addition, the shape of the laser-induced signal also changes in this case. For instance, the waveforms recorded at 5 pJ exhibit sharp features resembling the contribution of the “normal” fast IP signal.

- The disappearance of both sensor self-induced and strong IP signals (laser linked) signals, after irradiation, indicates that strong IP (laser linked) signal is built from normal (relatively fast) IP signal (laser linked) and high-rate sensor self-induced signals (extremely broaden in time and extremely enlarged in amplitude due to second hole multiplication) whose multiplication goes much faster than multiplication of by laser solely induced signal.