Investigation on observed charge multiplication when illuminating no-gain multiped LGAD region within plasma conditions and under low and high intensity injection using a femtosecond laser beam at ELI ERIC, ELI Beamlines

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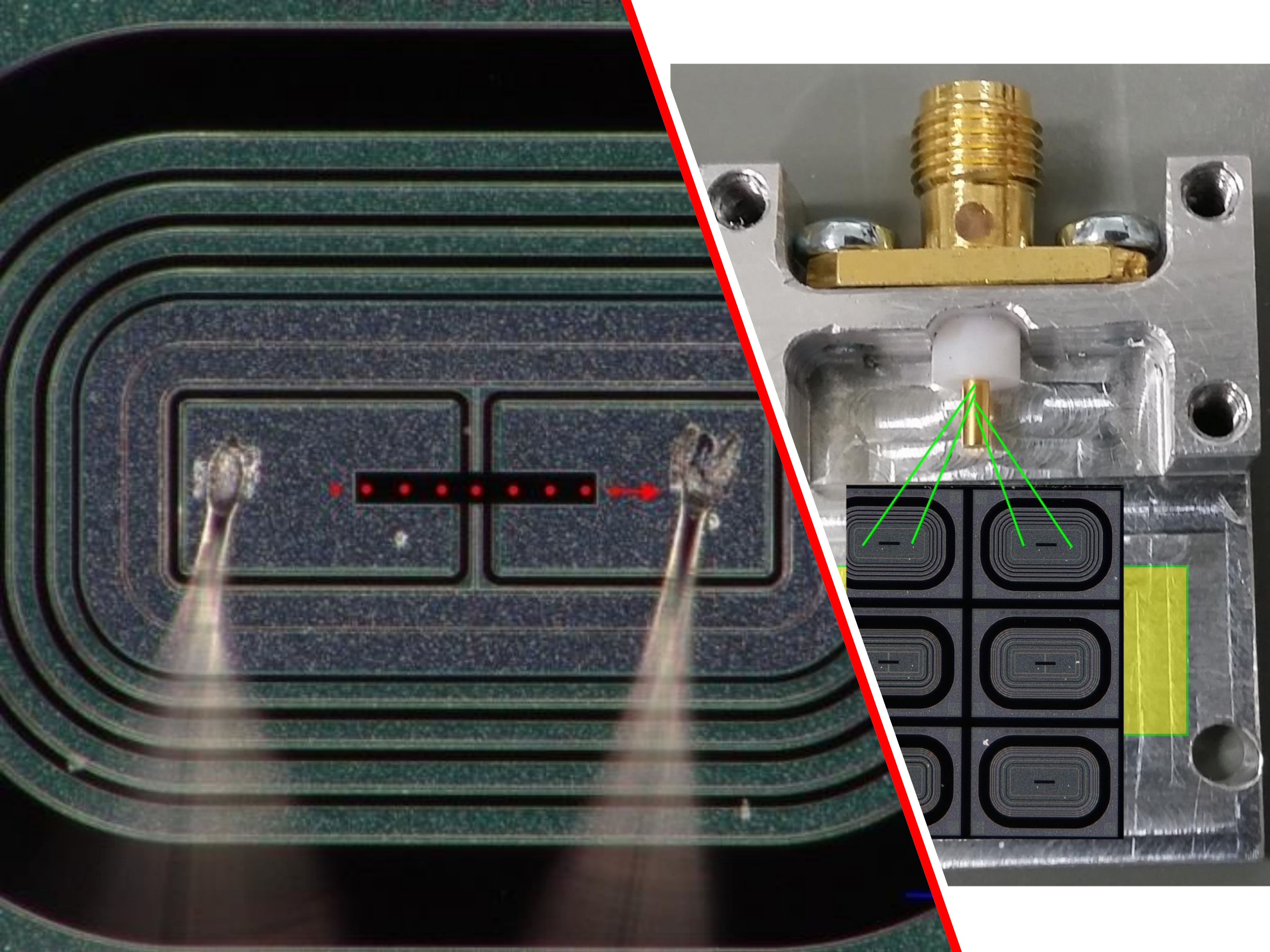
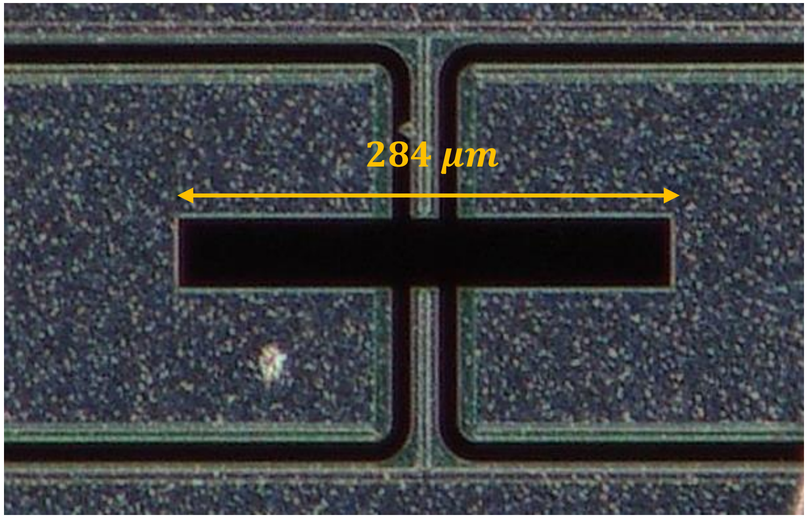


Opening window

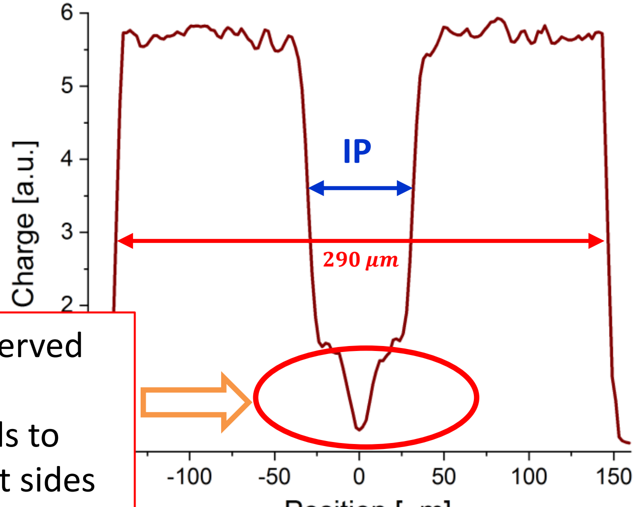
Opening window width measured under microscope is ≈284 um.



The width of the scan by SPA exhibits slightly bigger value 290 um (TPA exhibits better spatial resolution giving 285 +/- 1). Here we only present the research using TCT-SPA.

Since this value does not change and the study focuses on IP distance the shorter X-scans were performed for the most of experiments to save time. The region of interest was -60 to 60 μm where position 0 was defined as the center of the window.

Example X profile by SPA



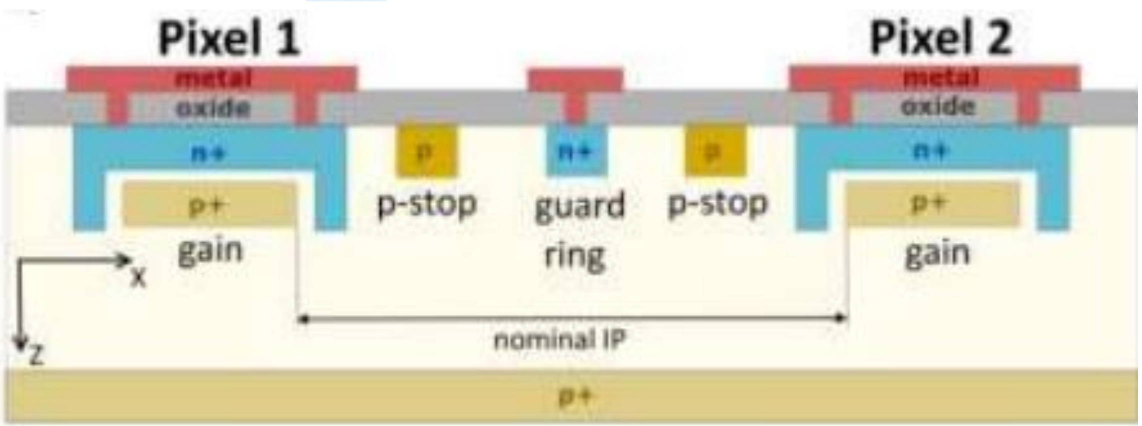
- This structure was not observed in HPK sample.
- Geometrically it corresponds to bias ring. From left and right sides

Device Under Test (DUT):
Not typical UFSD Type 10 (CMS reference)
&
Not trenched LGAD
(even produced in Ti-LGAD RD50 batch)

Explanation of a certain "Type"

Type	Inter-pad design
1	grid + extra grid
2	grid
4	grid
5	grid
7	grid + extra grid
8	grid + extra grid
9	2 p-stop
10	2 p-stop + bias grid
11	grid

Type 10:



The nominal inter-gap distance for this type 10 is a bit different wrt the same structures produced in the batches UFSD 4 or UFSD 3.2.

- **The nominal IP width (gain-gain distance) is 49 um.**
- epi layer is 45 um instead of the typical 55um used in UFSD 3.2 and UFSD 4.0

Device Under Test (DUT):
Not typical UFSD Type 10 (CMS reference)
&
Not trenched LGAD
(even produced in Ti-LGAD RD50 batch)

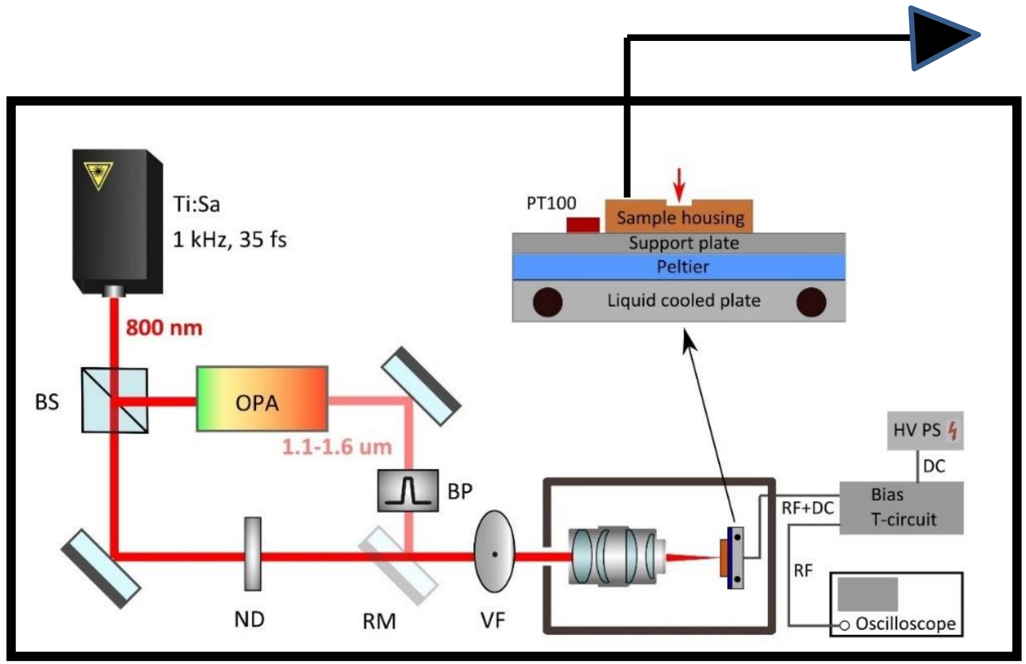
- The “UFSD type 10” was included in trenched structures production in the layout just for the purpose of a direct comparison between TI-LGAD structures and standard UFSD ones. Only for this reason.

- As the UFSD structures are on the same wafers of TI-LGAD, they have the same implants, oxides, thermal budget, metals, passivation.

- The only change is that on TI-LGAD, the termination structure - JTE and the isolation structure – P-stop for pixel isolation were replaced with a structure based on tranches.

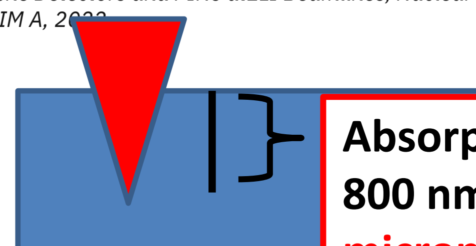
Experimental Technique: TCT

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)

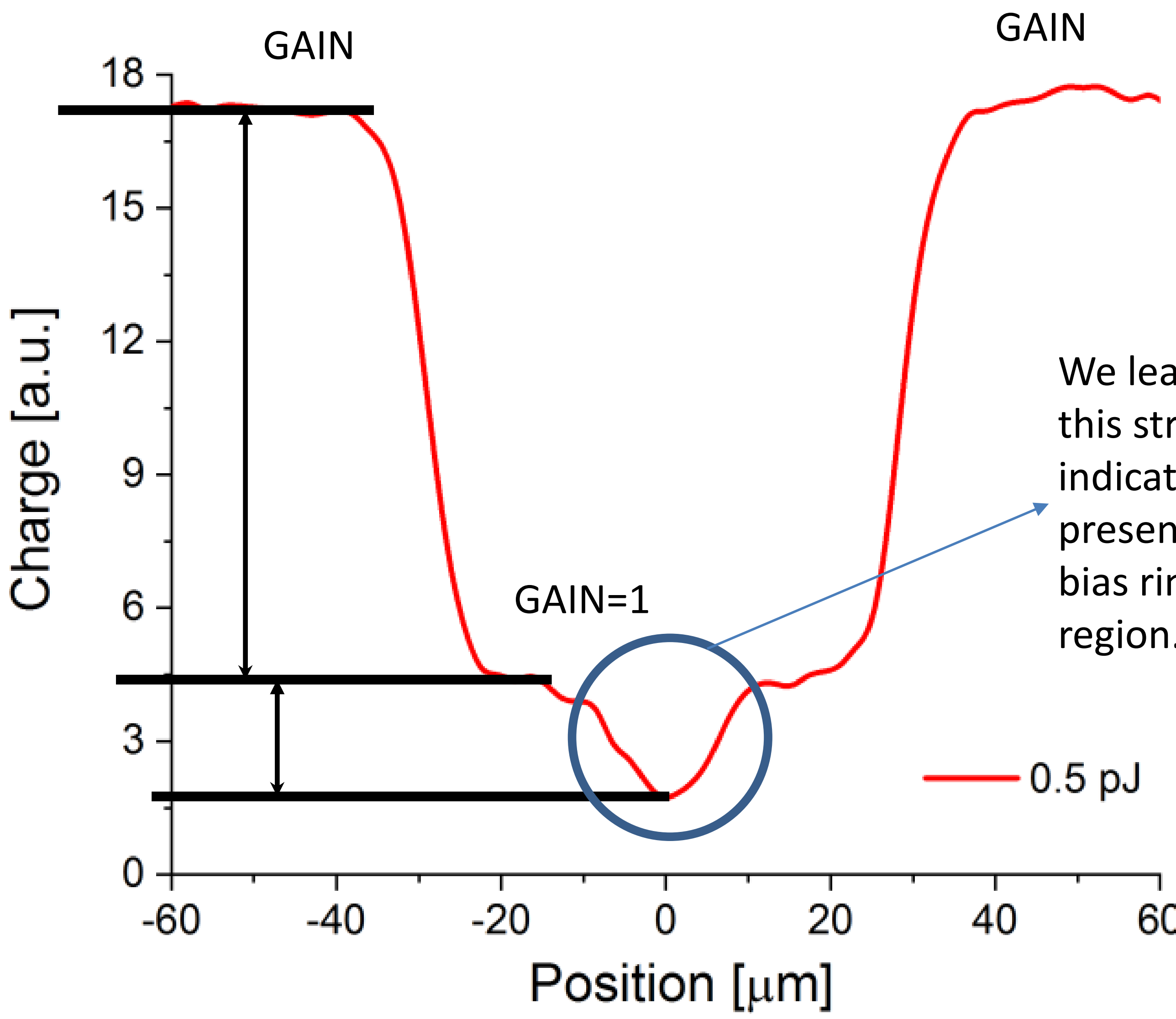
Ref: G. Lastovicka-Medin et al, Femtosecond laser studies of the Single Event Effects in Low Gain Avalanche Detectors and PINs atELI Beamlines, Nuclear Inst. and Methods in Physics Research, NIM A, 20



Absorption length for 800 nm – at around 20 microns in silicon

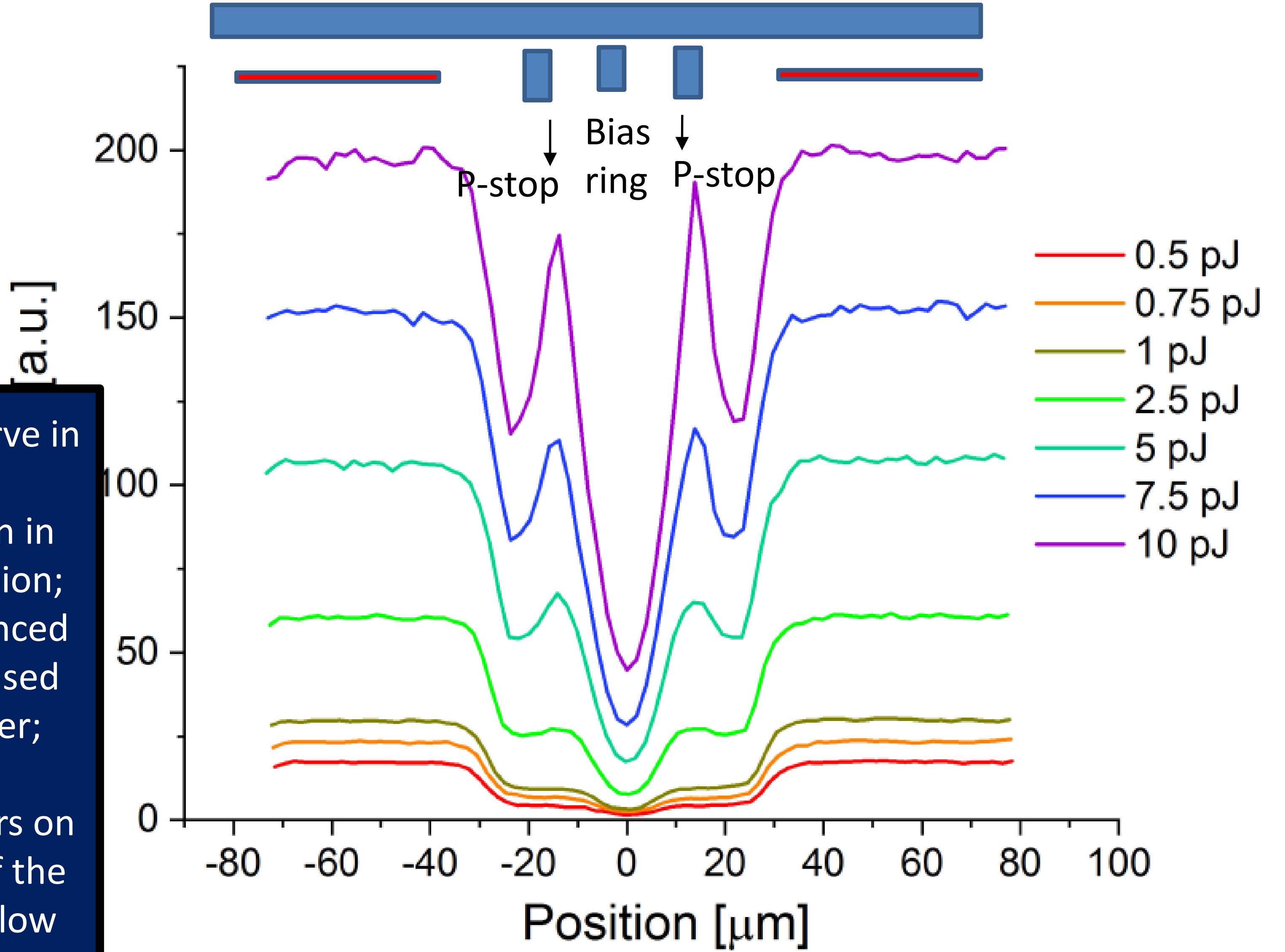
- Only **SPA** data are shown in this talk

X-profile shape



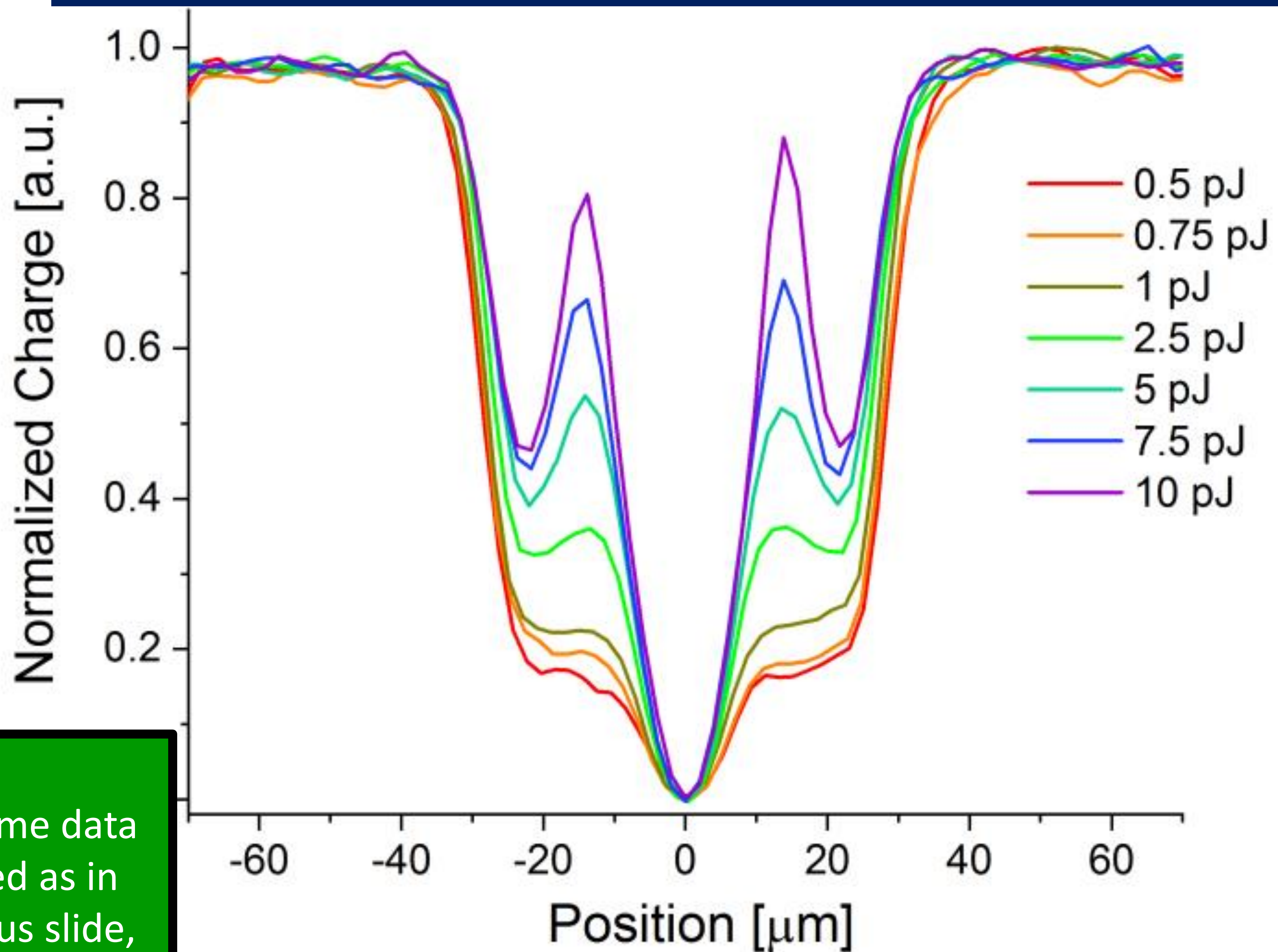
We learnt that this structure indicates the presence of bias ring in IP region.

IP vs Power (laser pulse energy)



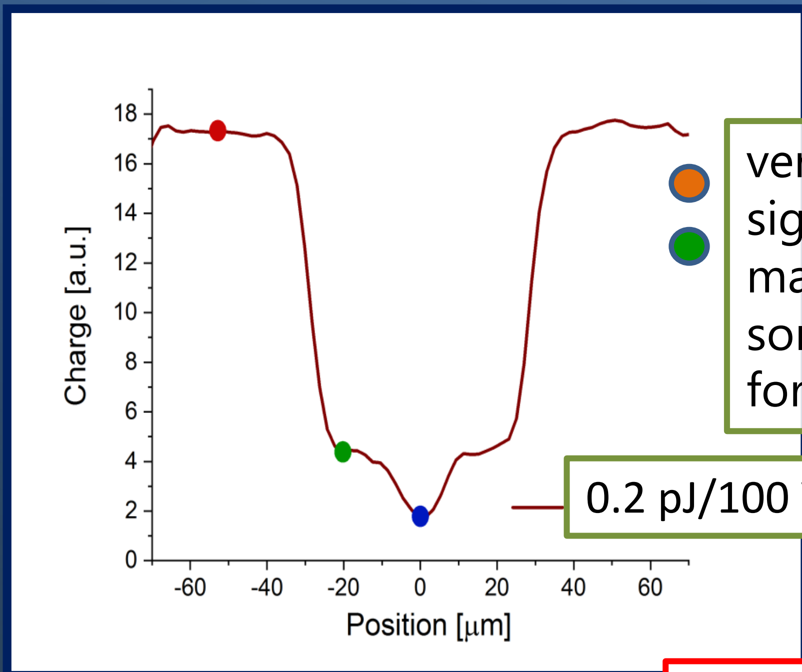
- ❑ Spikes observe in charge distribution in no-gain region; more enhanced with increased laser power;
- ❑ They appears on the sides of the central hollow (more or less at +/- 15 μm).

IP vs Power (laser pulse energy)

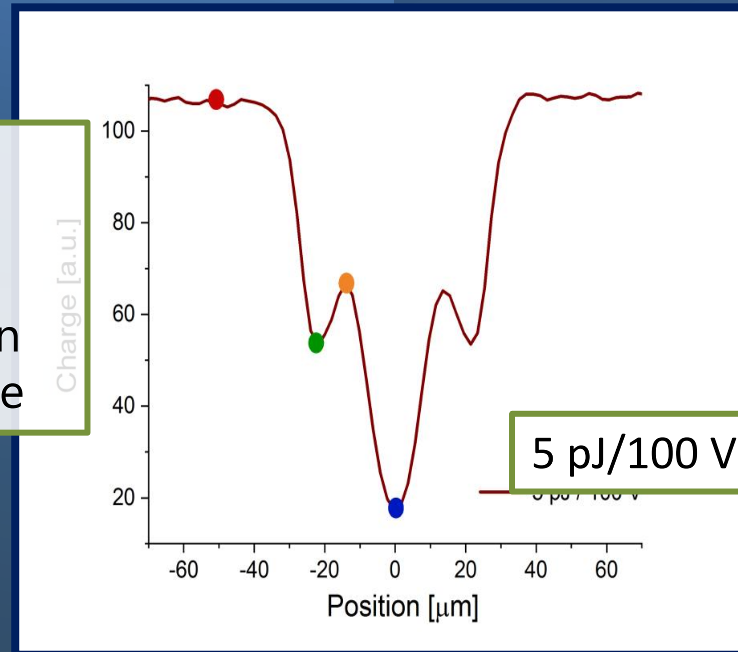


- The same data plotted as in previous slide, but distributions are normalized

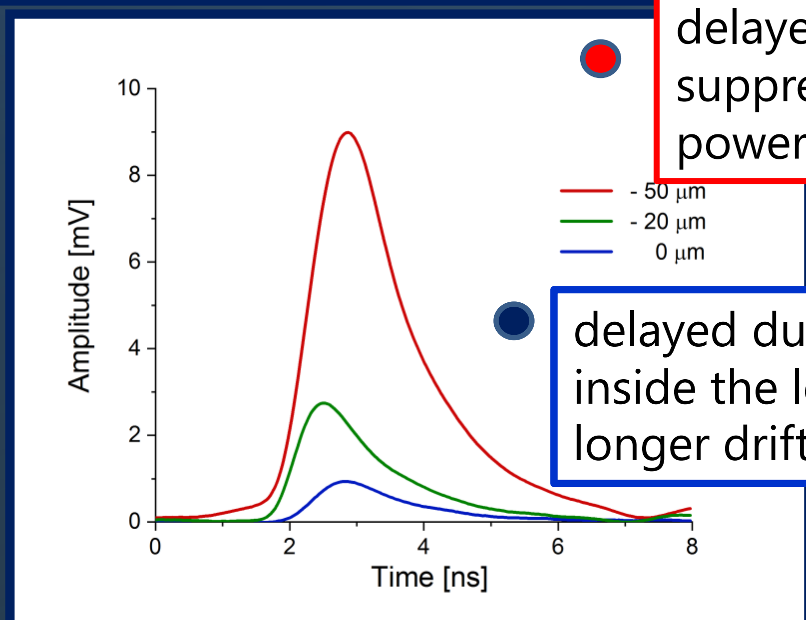
Waveform vs X-position and power



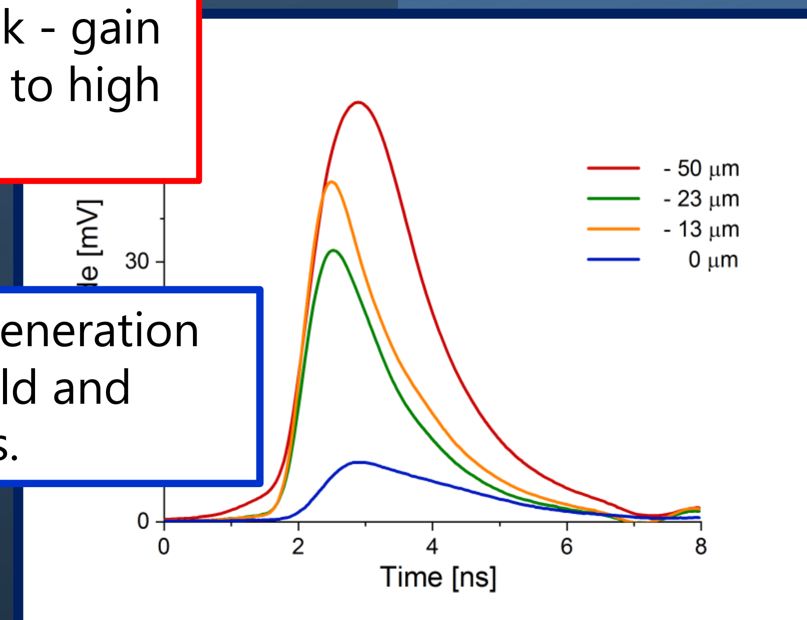
very fast signal; maybe some gain for orange



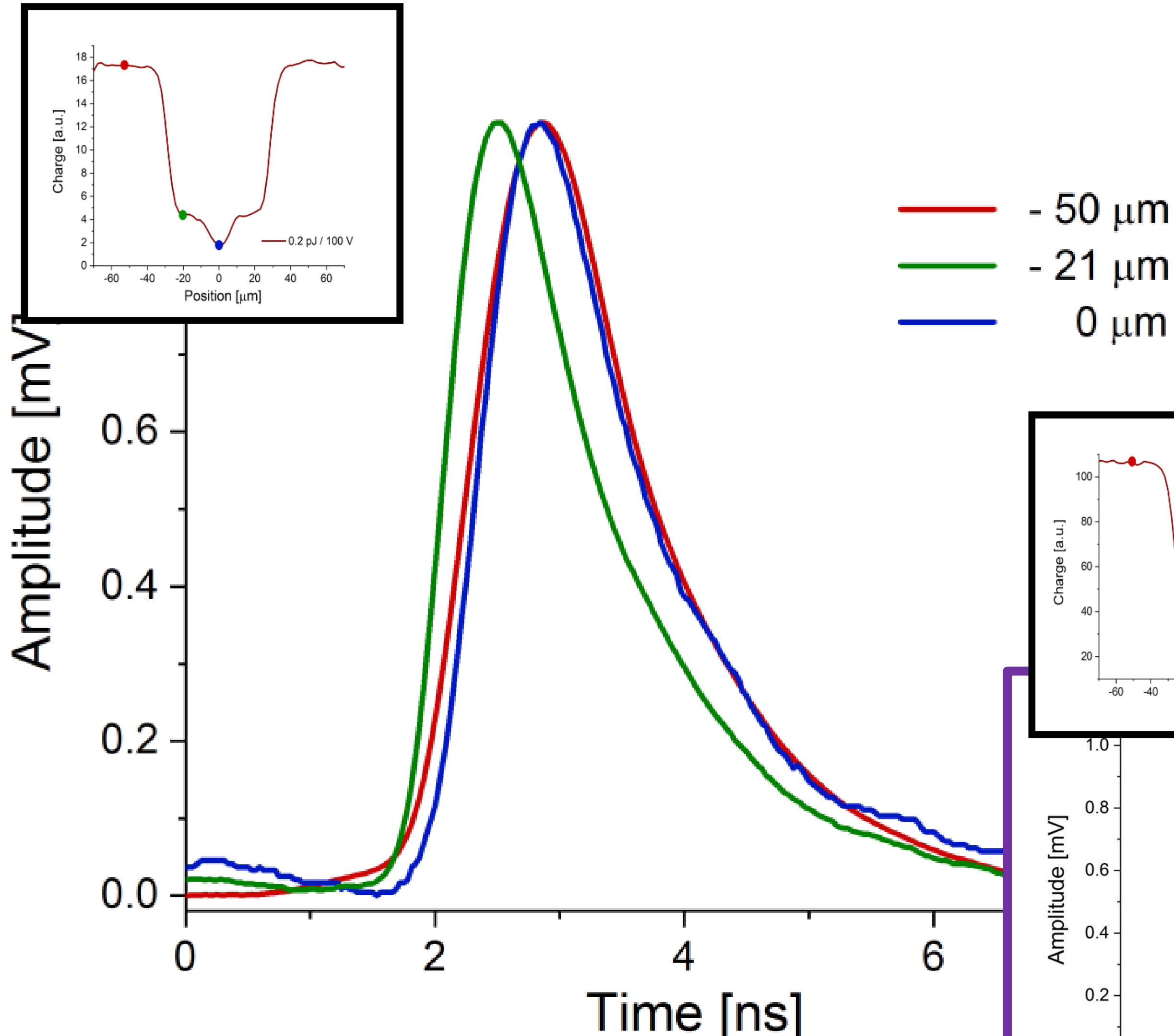
delayed peak - gain suppressing to high power

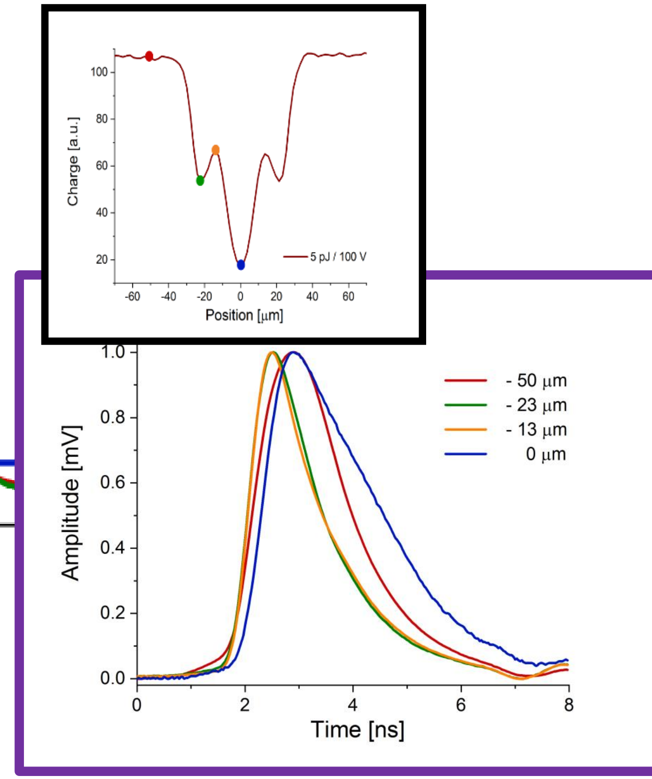


delayed due to generation inside the low field and longer drift paths.



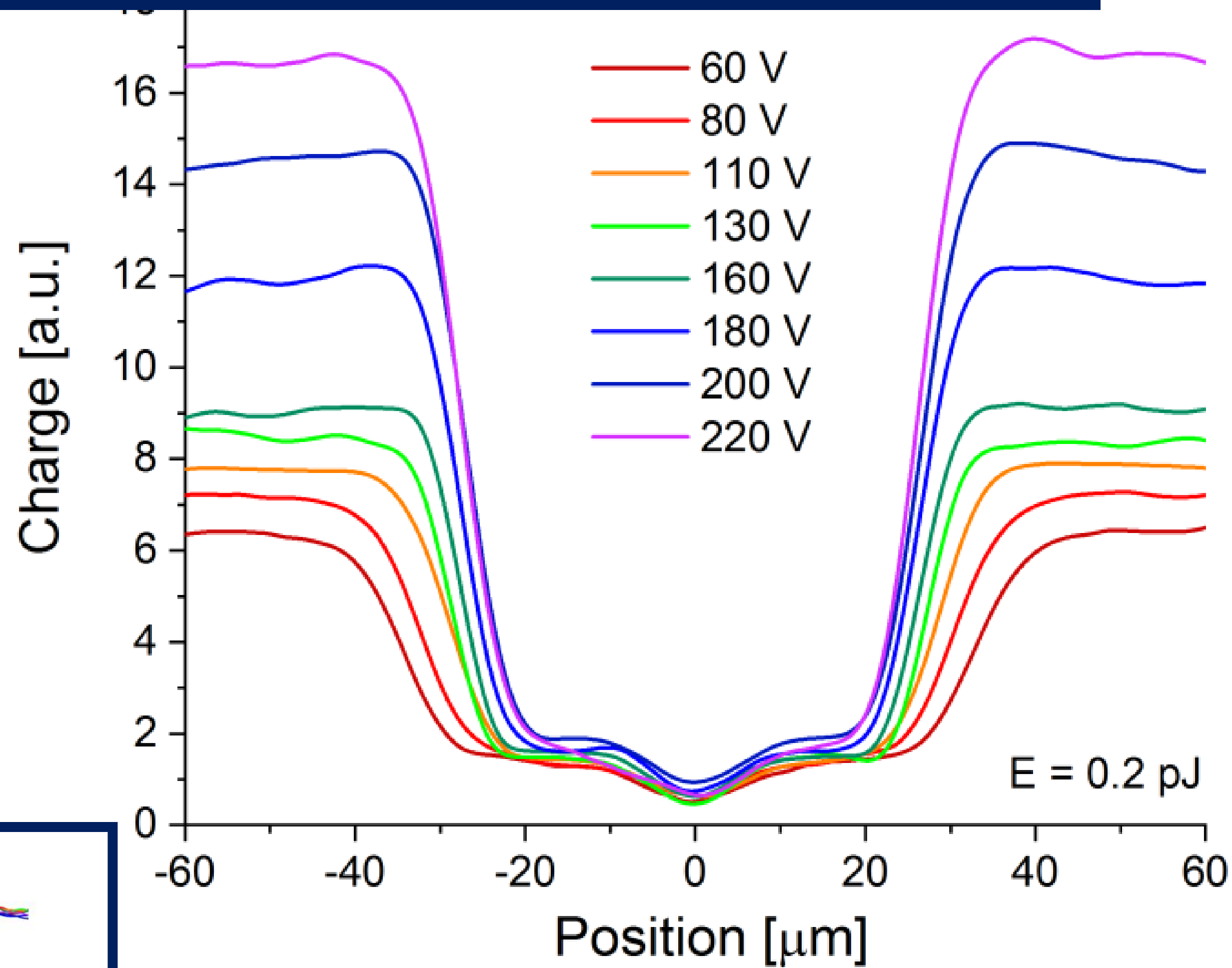
The same waveforms as in previous slide but normalized to better compare the shapes



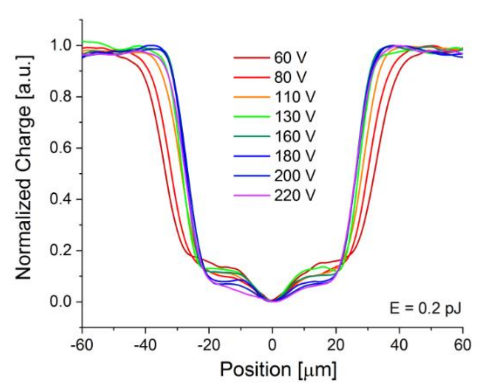


IP vs Bias at low power

At medium laser power (1 pJ) the side bands around the central hollow appears at higher bias

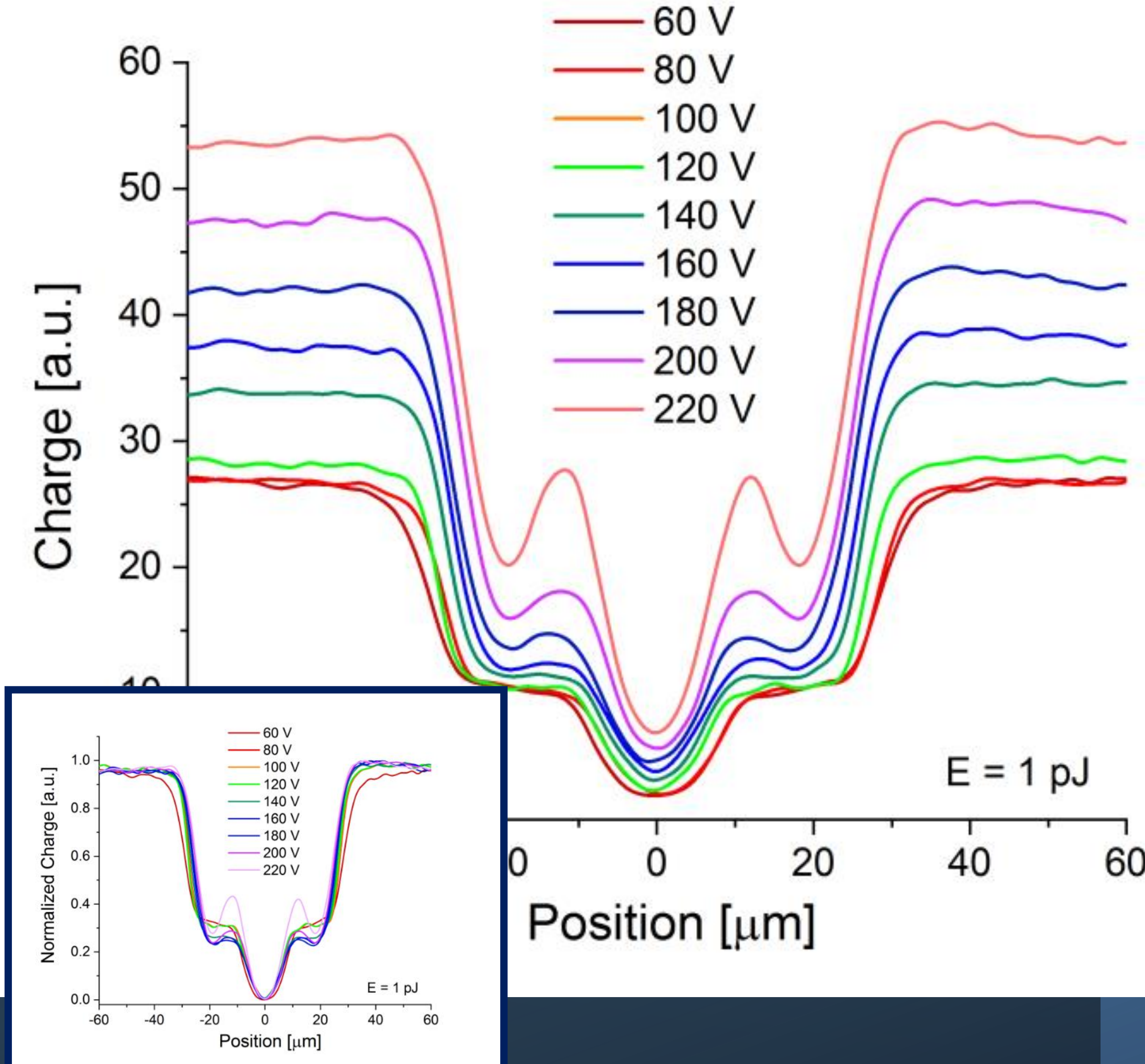


Same data as above but normalized for better comparison



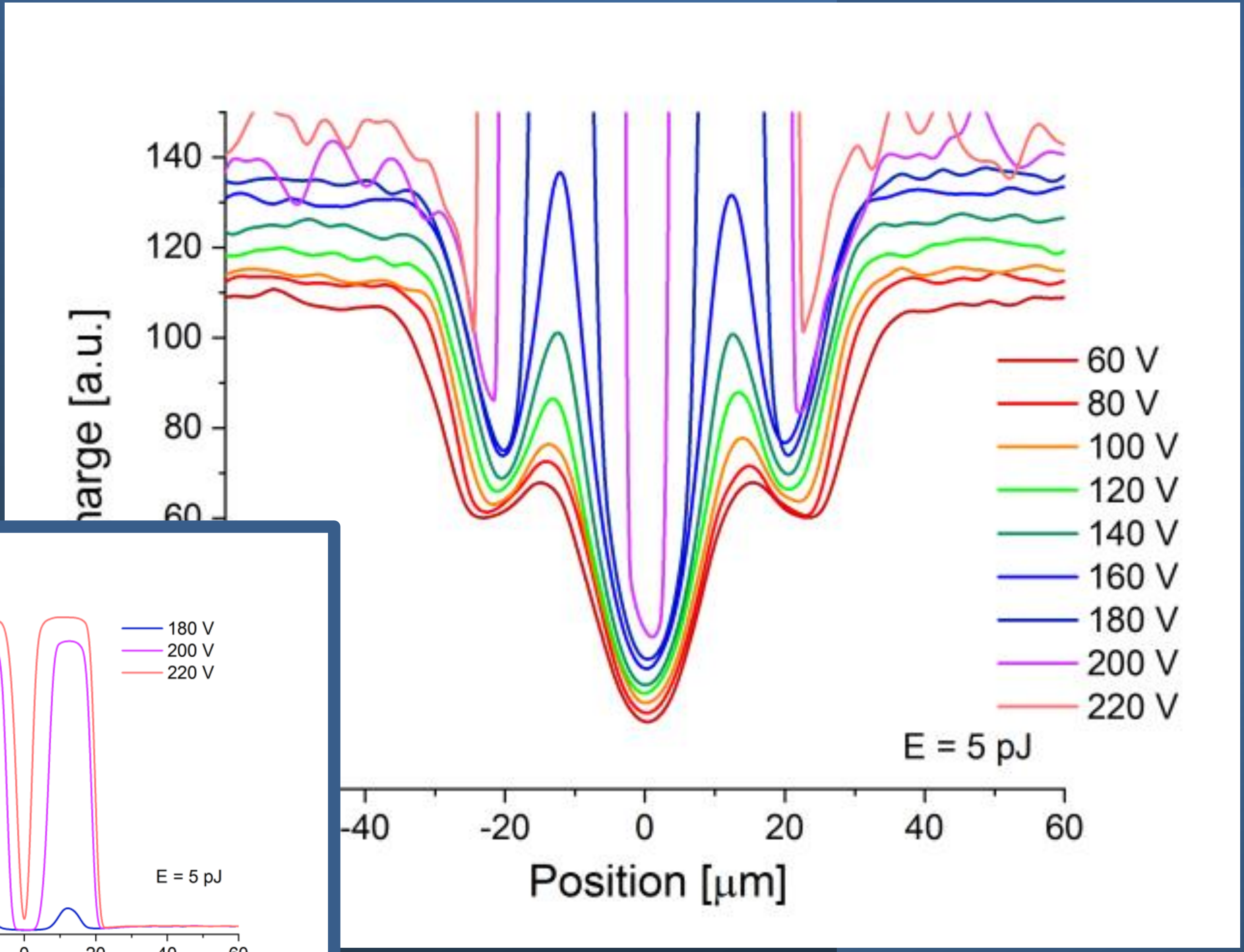
There is a clear general trend that IP distance decreases with increasing bias.

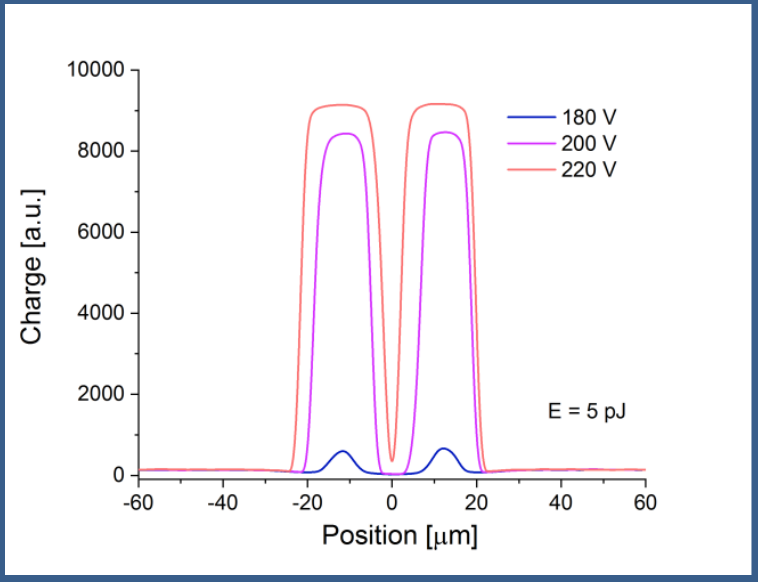
IP vs Bias at medium power



IP vs Bias at high power

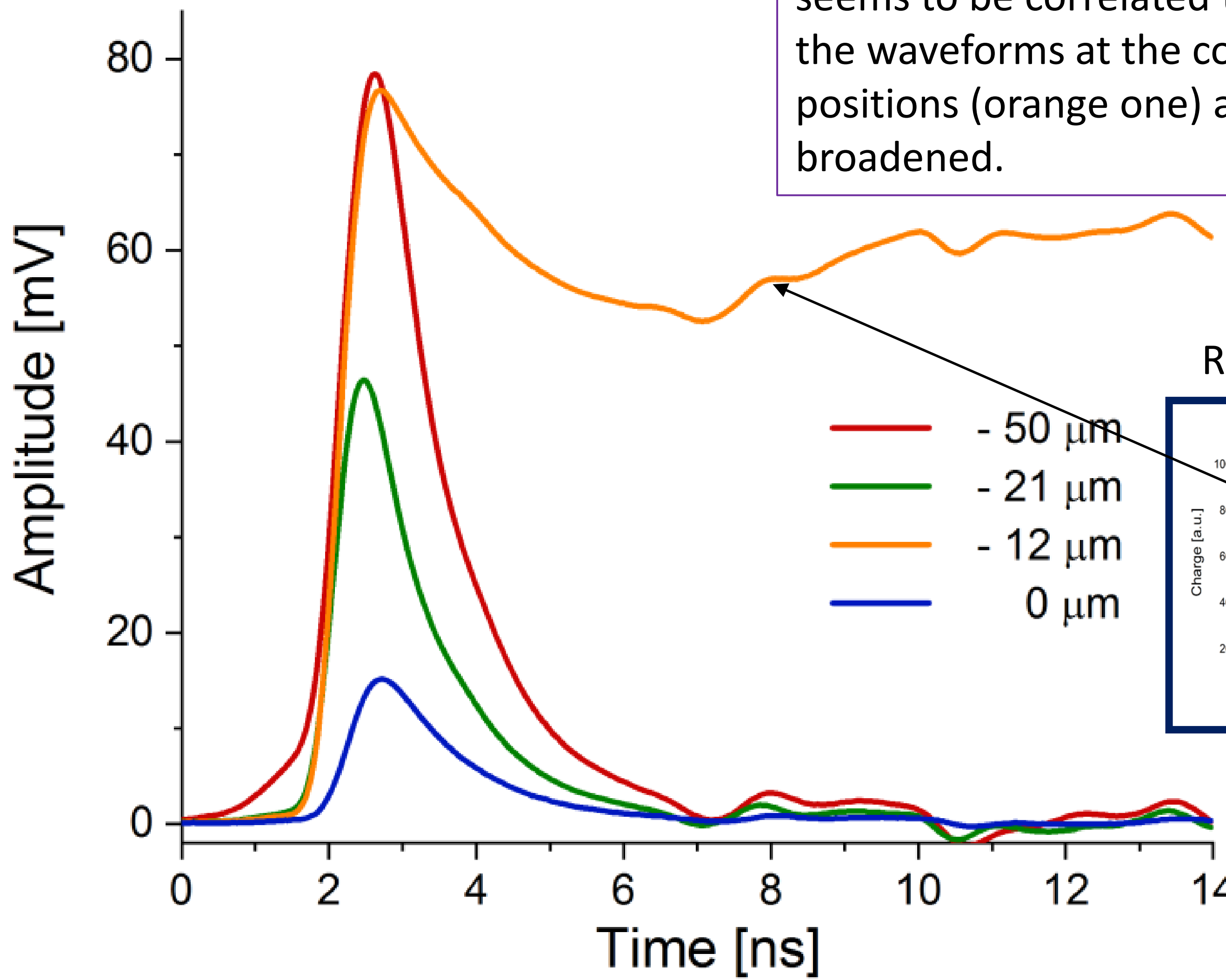
At high laser power (5 pJ) extremely strong side bands appear around the central hollow.



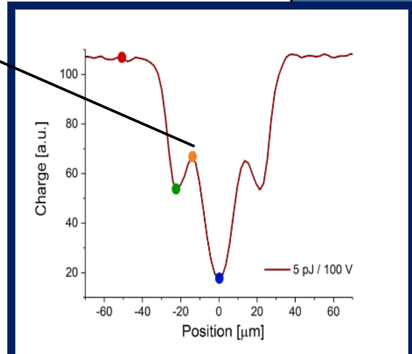


Waveforms recorded at high power and bias (5 pJ/180 V) at selected positions

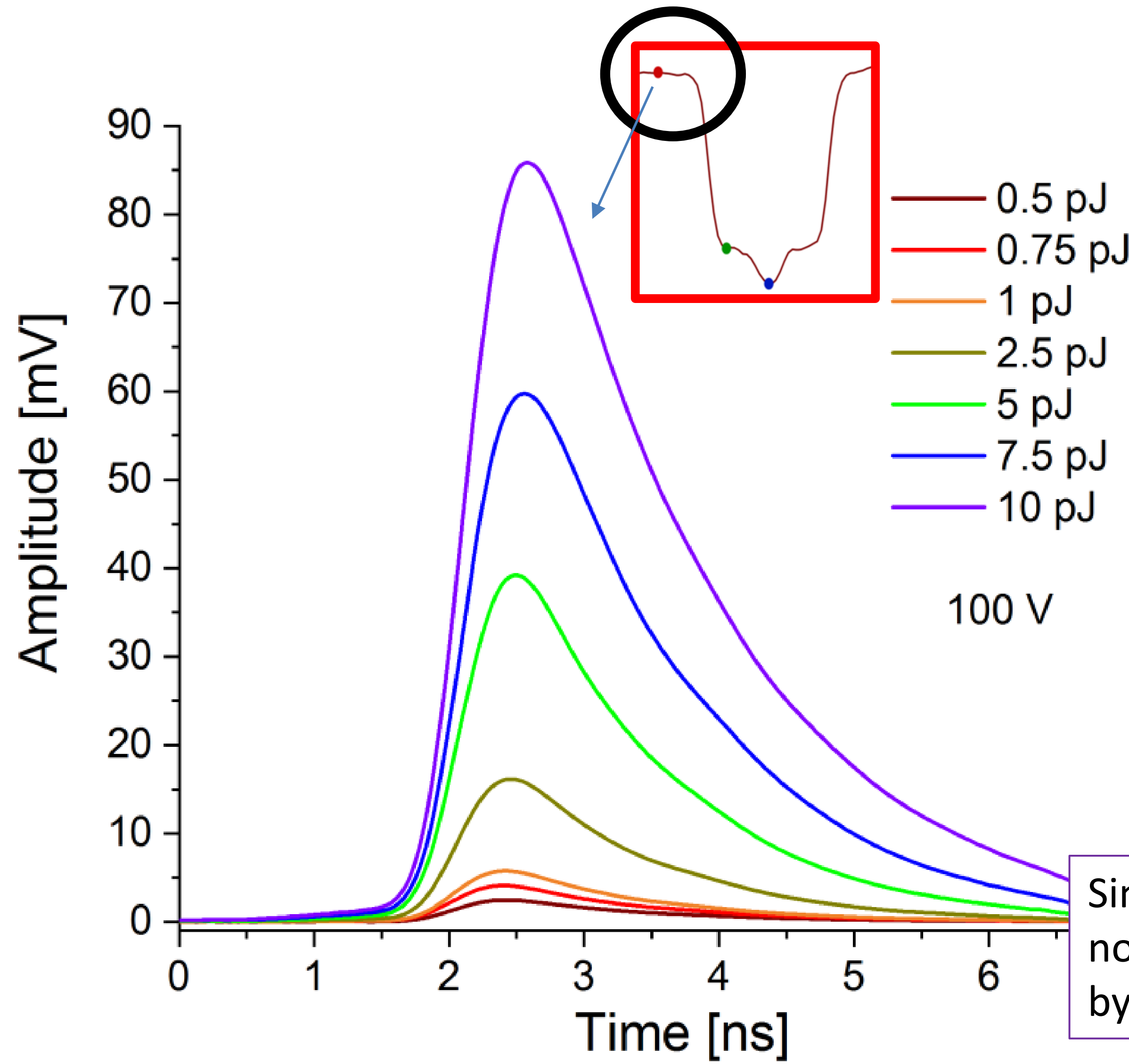
When we look at the waveforms it is visible that the very strong side bands seems to be correlated to the fact that the waveforms at the corresponding positions (orange one) are extremely broadened.

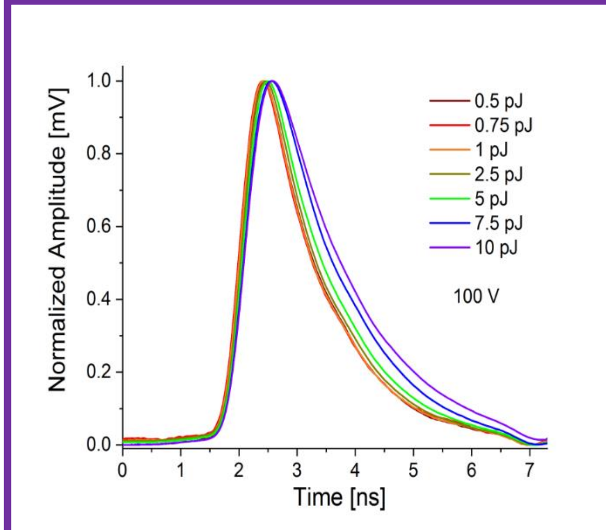


Reminder:



Waveform vs X-position and power

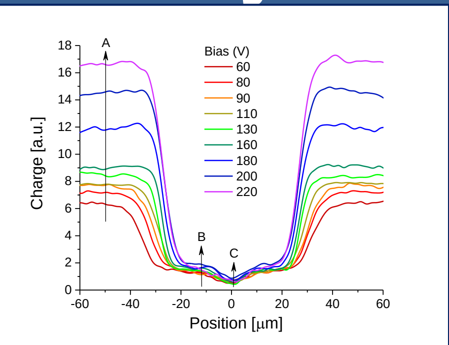




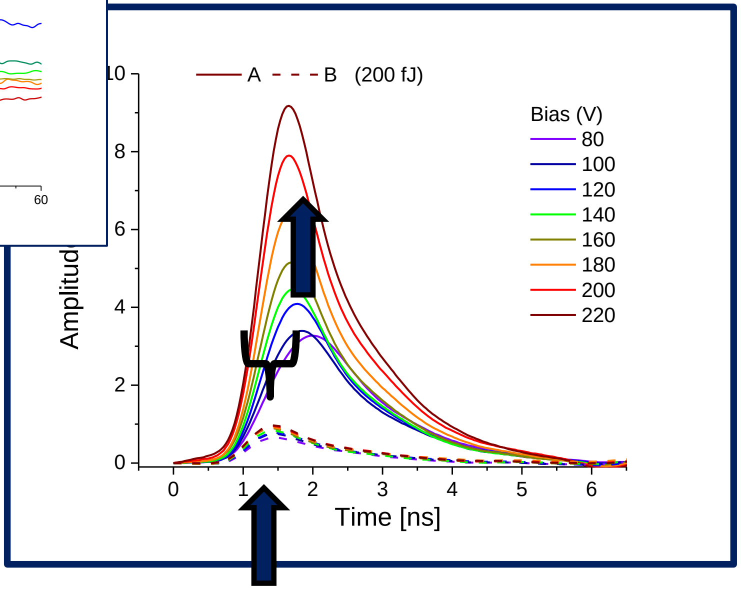
Single waveforms (original and normalized) (position indicated by red vertical line on X-profile)

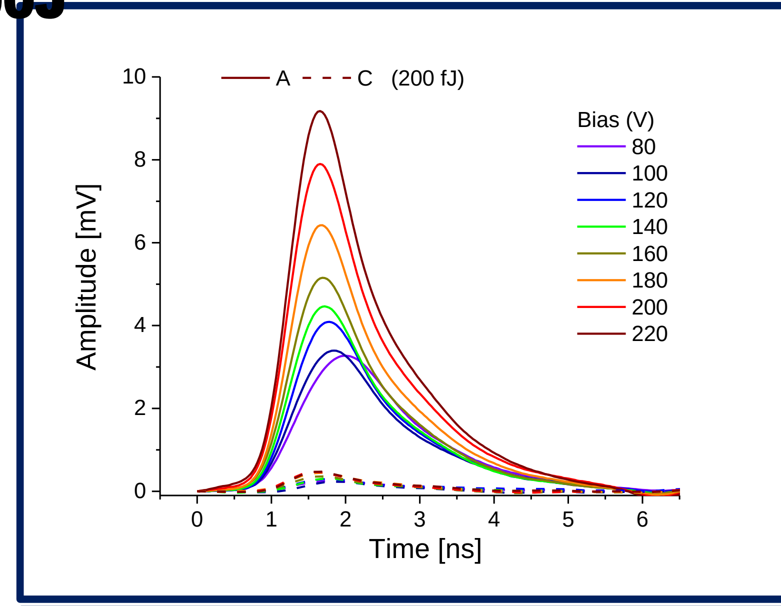
- **INSPECTION OF “SPIKES”**
  - **- BEHAVIOURAL PATTERN**
    - **- CRITICAL POINT SUGGESTING ONSET OF “ANOMALOUS” BEHAVIOUR**

We look how waveform are evolving at a certain laser intensity when scanned over HV bias

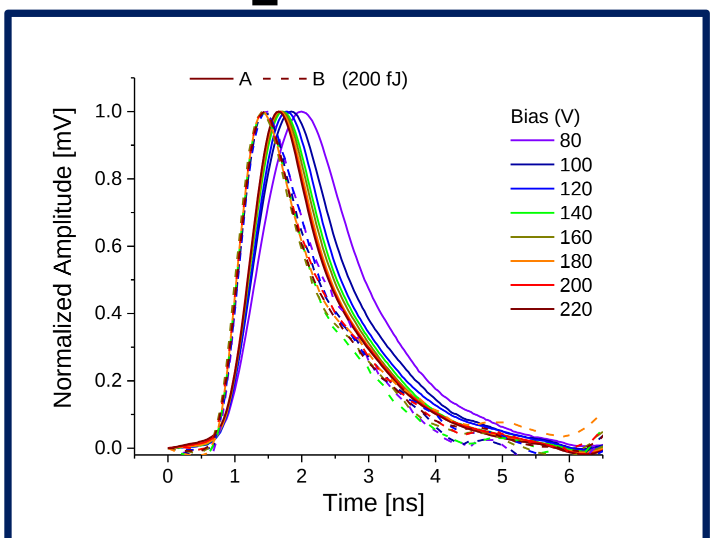


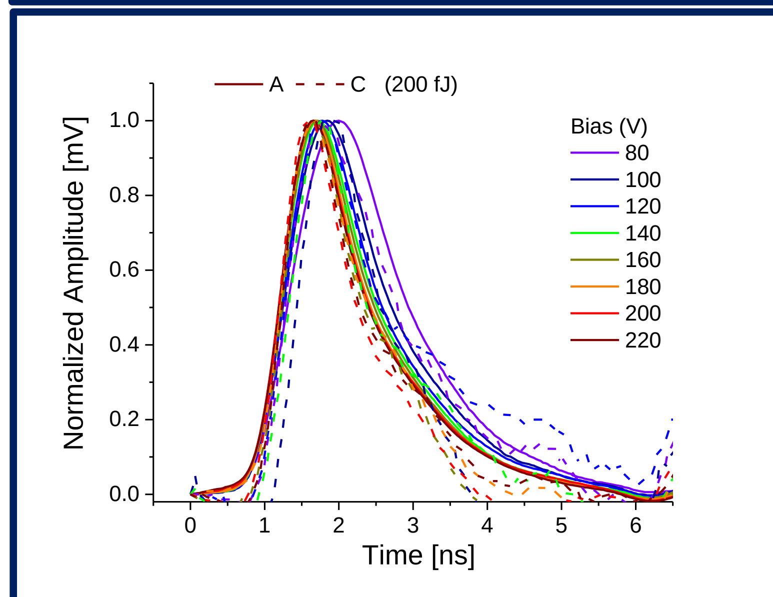
Waveforms vs bias at 200J



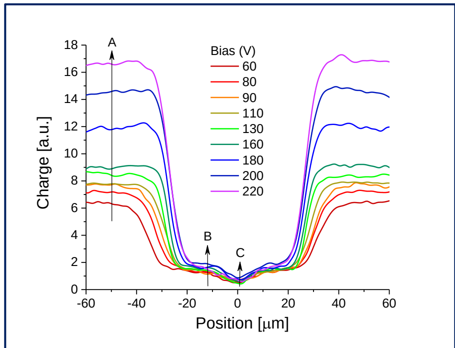


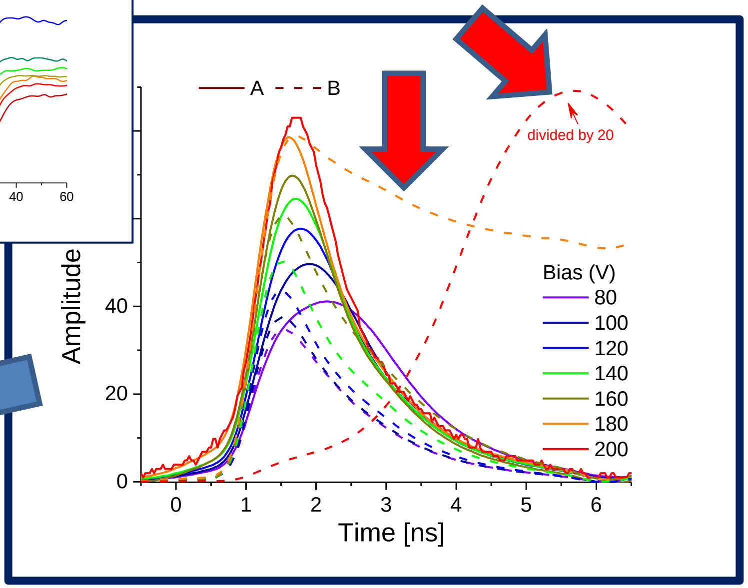
- At lower laser power the peak appeared faster then for pad region

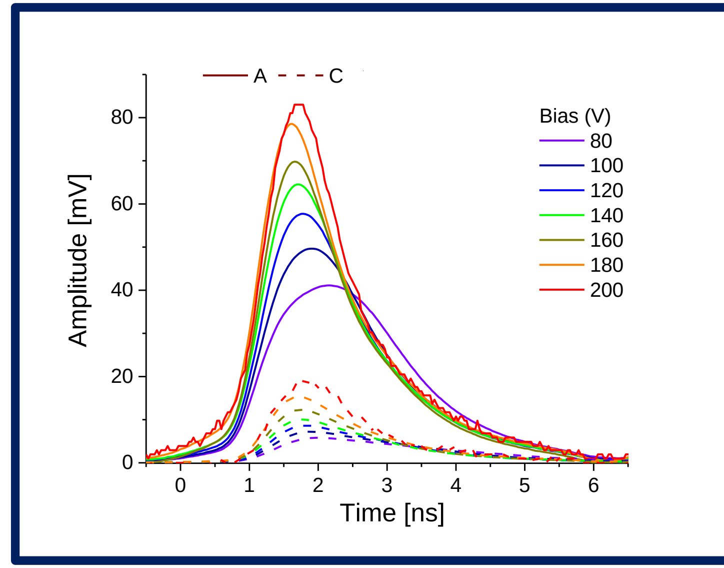




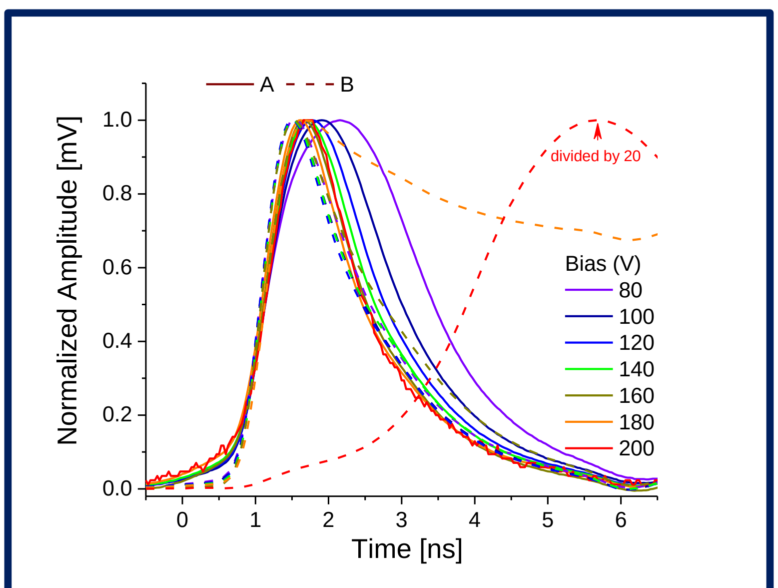
Waveforms vs bias at 5 pJ

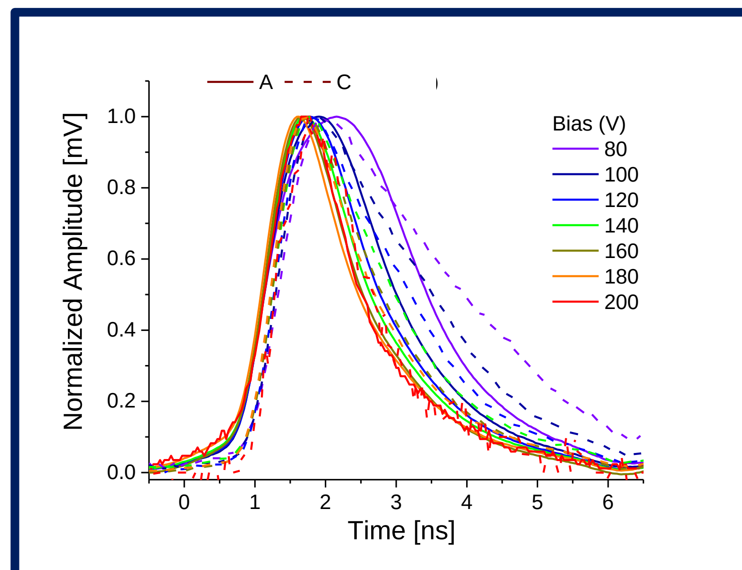




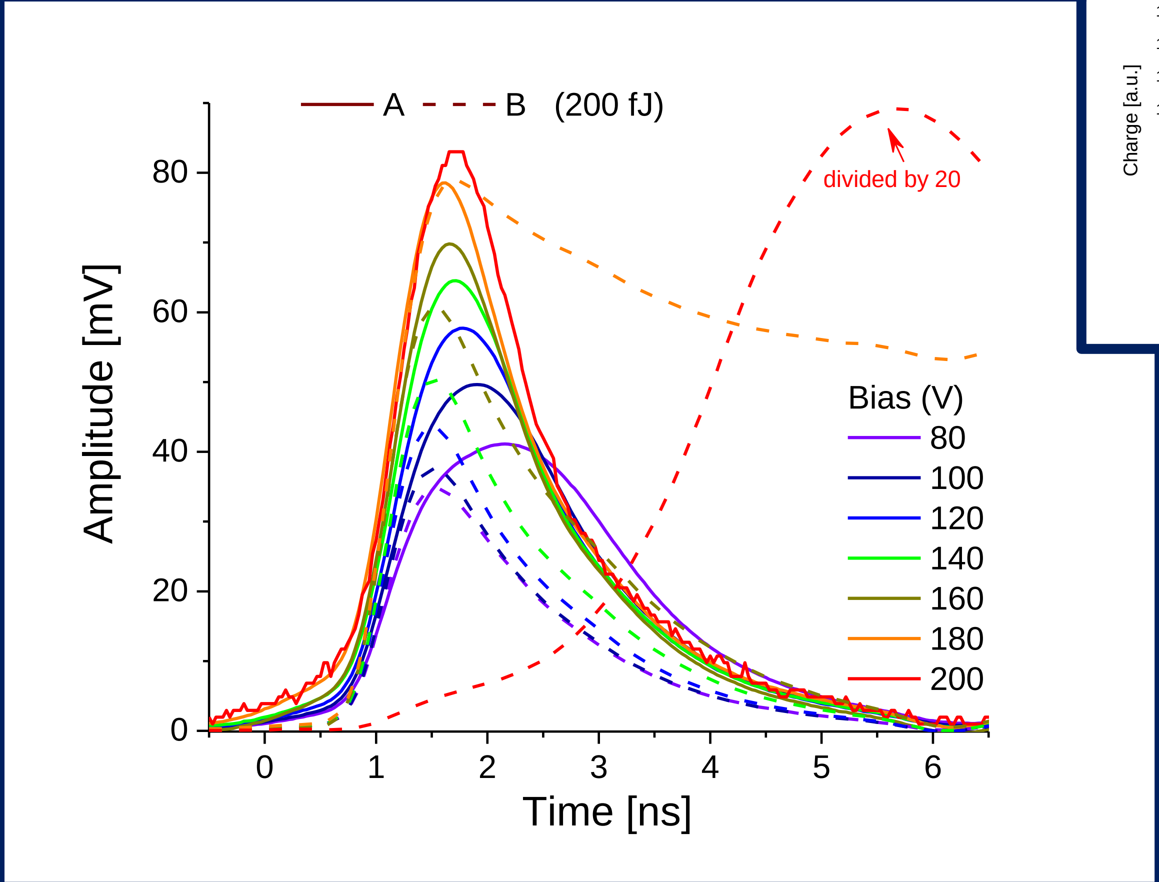


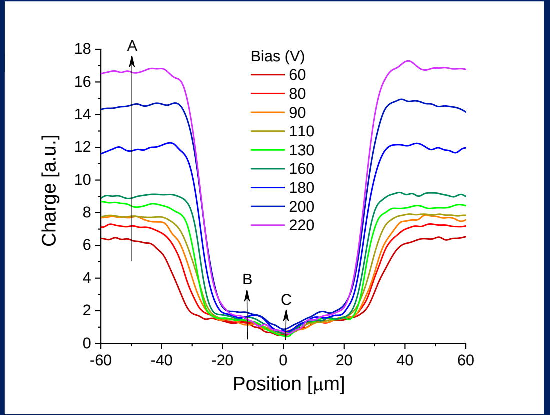
Discussion given in next page





Waveforms vs bias at 5 pJ

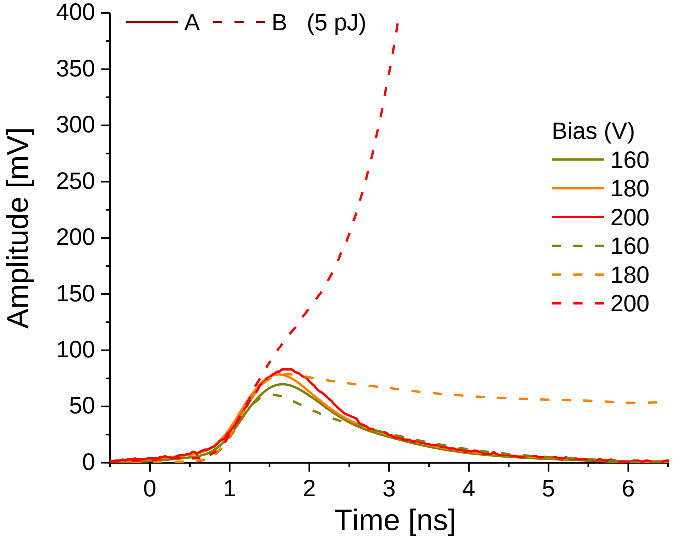


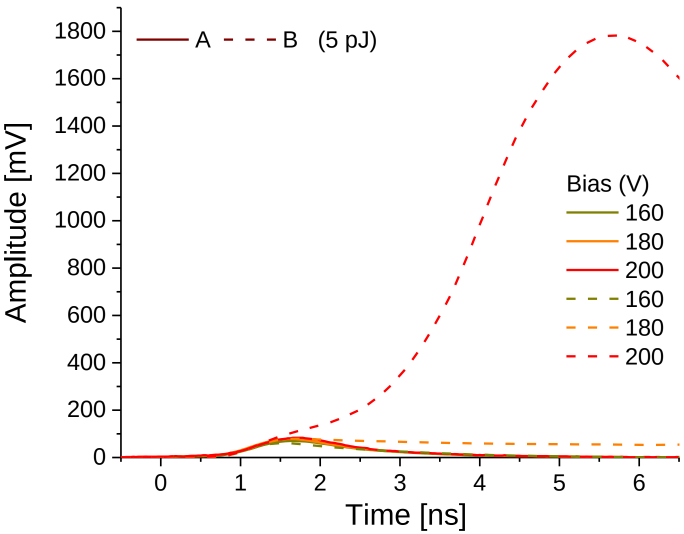


A few words about the waveform in spike area at 200 V.
We realized that the figure can be a bit misleading. For this bias there is huge increase in the signal (jump in amplitude of factor 20) so to show it together with other waveforms we had to rescale it (it's marked in figure that this waveform is divided by 20).

However it can make false impression that the rising of waveform is much slower and shifted whereas in the first phase this waveform rises like others but later instead of falling we have a second slower rise to the huge amplitude. We added two extra figures in the next page in different scales to show it better. In these new scales the waveform has original amplitude (not divided). The reasons for the noisy("jittery") waveforms at the highest bias are explained in the next page as well.

Waveforms vs bias at 5 pJ and high bias in different scale





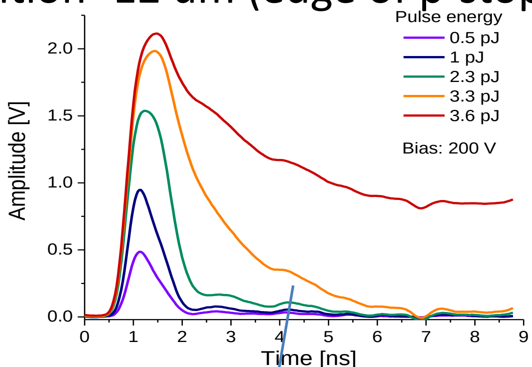
Explanation for the noisy waveforms

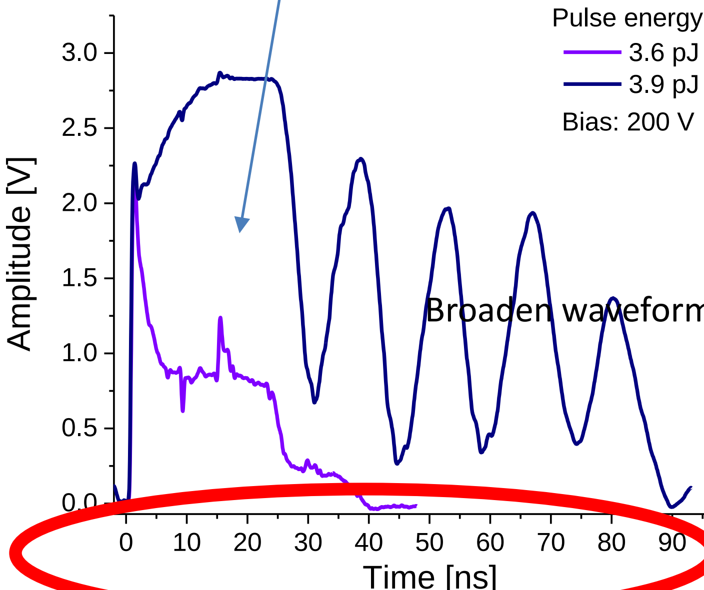
- The noisy waveforms for this bias is an effect of oscilloscope setting.
- The scope uses different vertical resolution to measure signals with low or high amplitude. To measure high amplitude (almost 2 V) the scope sets a vertical resolution which is poor for low signals, therefore it doesn’t reproduces nicely small changes and waveforms have this step-like noise structure.

Then we look more closely at waveforms in region B with 50 dB amplifier

To get more insight in spikes effect the waveforms were recorded for different power in spike area (-12 um). For comparison two other area were inspected in identical conditions (normal pixel area -50 um and central guard ring 0 um.

Position -12 um (edge of p-stop)

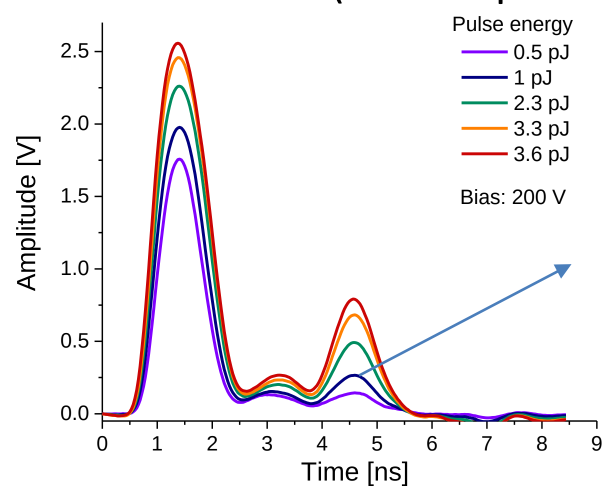




Broaden waveforms are unstable

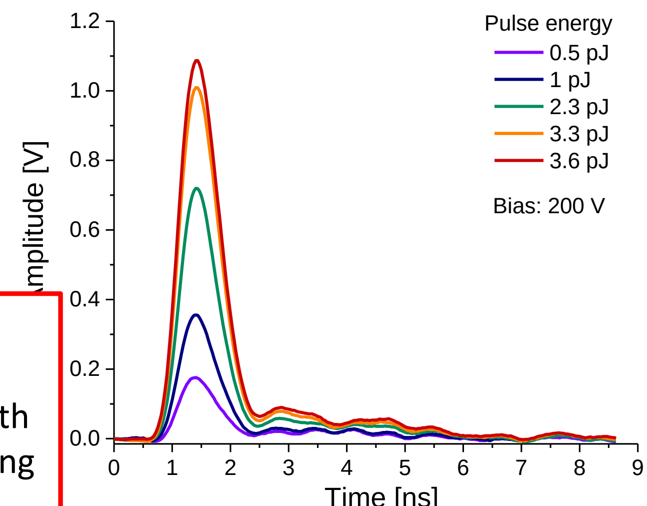
!!! Extremely Long decay of falling edge with extended ringing behaviour!

Position -50 um (normal pixel area)



Some artefacts (electronic reflection)

Position 0 um (central GR)

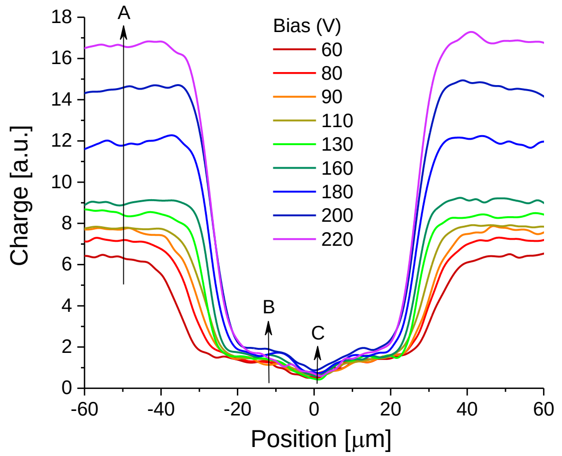


Possible explanation

What we see when we look at the A and B waveforms:

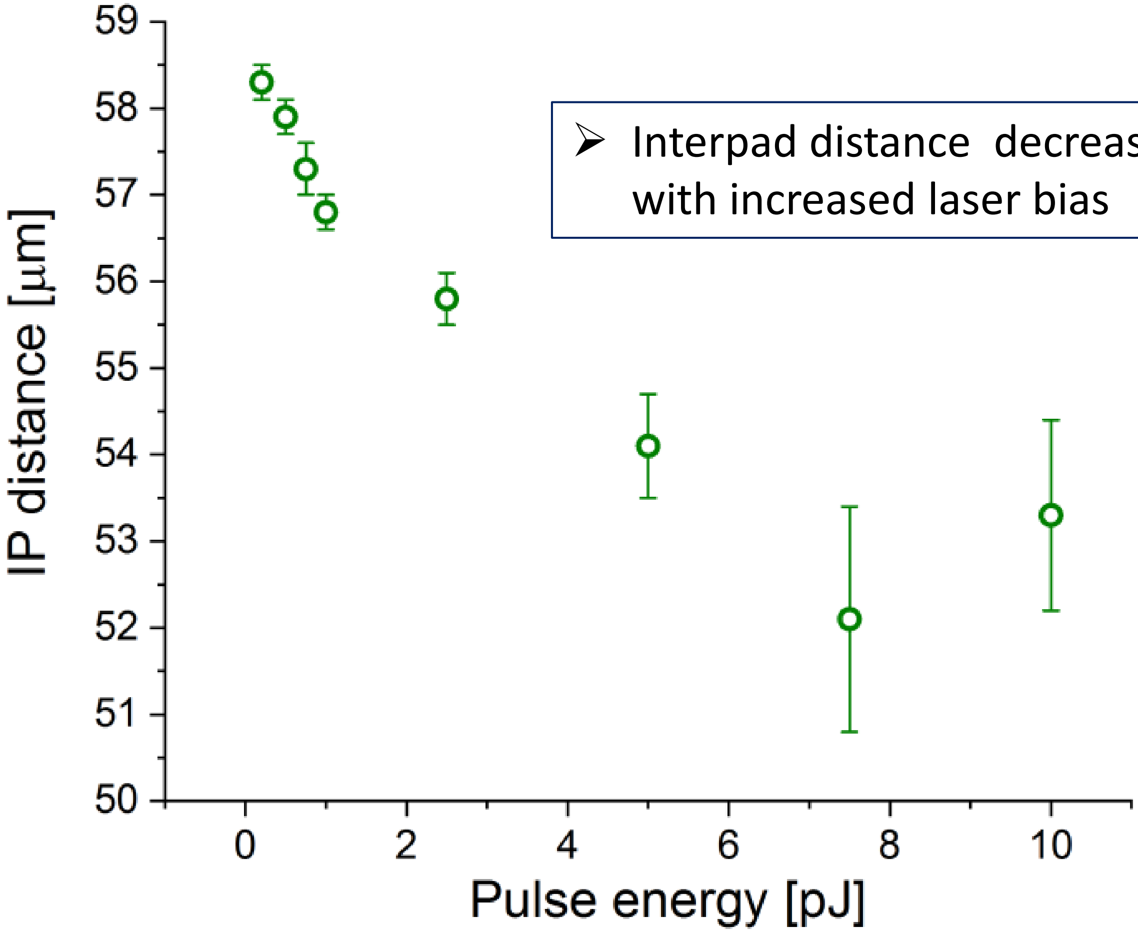
- with increasing the bias , the rise peak is shifted to the lower values, also falling edge is more steep and width of waveforms becomes narrower. ---> this means that with increased bias, the signal becomes faster --> this is logic reasoning since the charge previously glued in plasma in a small volume, gets more repulsed and with higher speed is reaching electrodes.

- BUT, at the place of spikes, the rate of change of leading edge seems to have two slopes: firstly it increases relatively "faster", and then by reaching the peak position similar to one recorded for pads, the leading edge does not go to decay but has another wave of "slower "avalanche", with slower rate of change (also exponential), then it undergoes the turning point where the waveform does not grow further but rather stay flat keeping for the prolonged time the reached height, then at some point, it starts to decay with ringing that slows down the vanishing of waveform as it look like each time "ringing" adds some boost to the charge collection and then again decay, and so on, .., finally reaching the zero value.



When we plot x-profile, we do not see spatial and temporal dynamics/evolution of charge collection, so much more we can learn from waveforms.

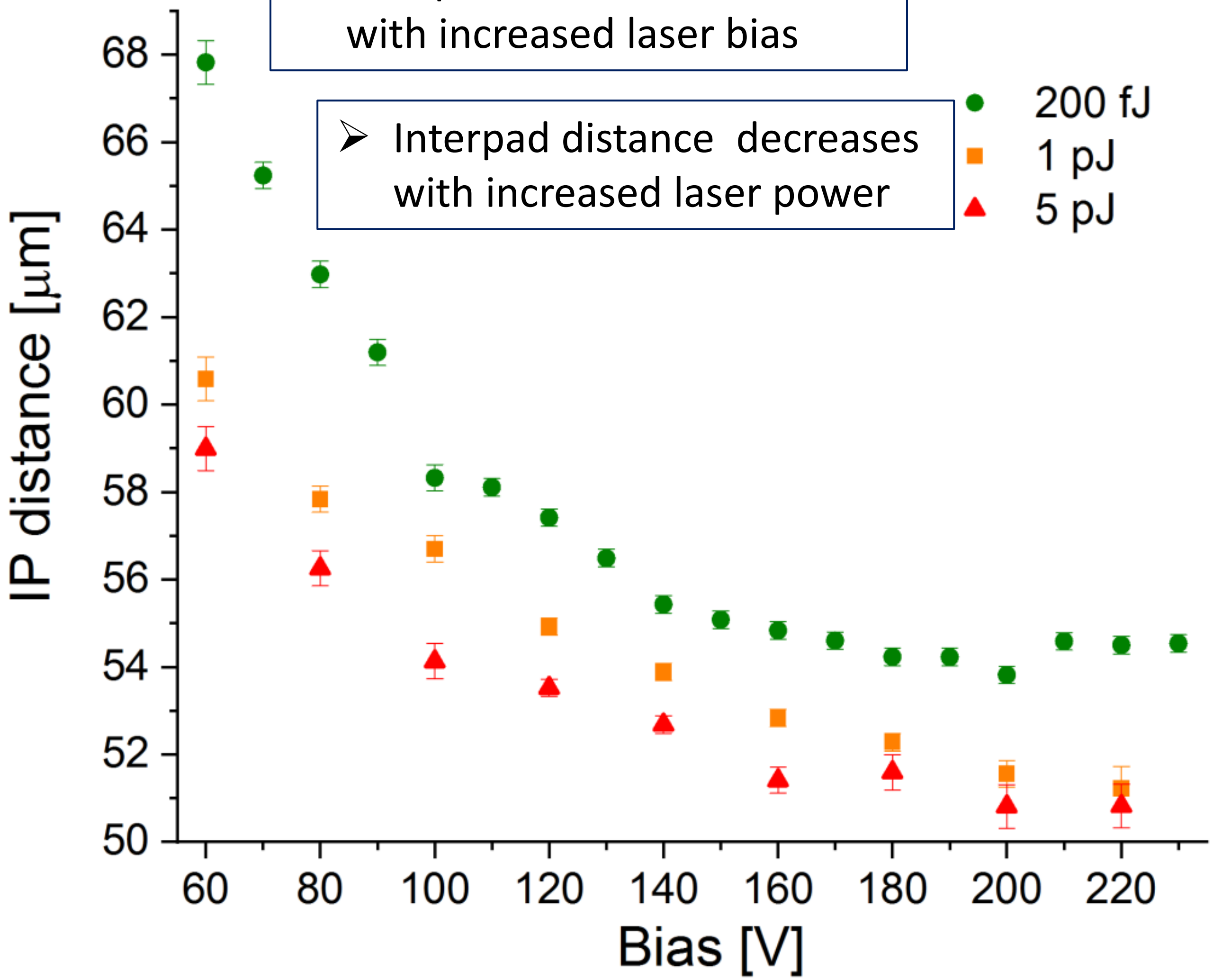
IP distance vs Power (laser pulse energy)



- Interpad distance decreases with increased laser bias

IP distance vs Bias

- Interpad distance decreases with increased laser bias
- Interpad distance decreases with increased laser power



CONCLUSIONS

UFSD Type 10 (from Tii-LGAD RD50 batch) has been investigated

- ✓ All the X-profiles have a characteristic hollow in the center : where is ring placed
- ✓ At higher laser power the strong side bands around the central hollow appear in the X-profiles (waveforms are highly broadened)
  - ✓ the position of spike correspond to the position of p-stops where high electric field exist
  - ✓ indicating charge multiplication in two "waves"
- ✓ IP distance decreases with increasing power (pulse energy)
- ✓ IP distance decreases with increasing bias

Inspection of spikes

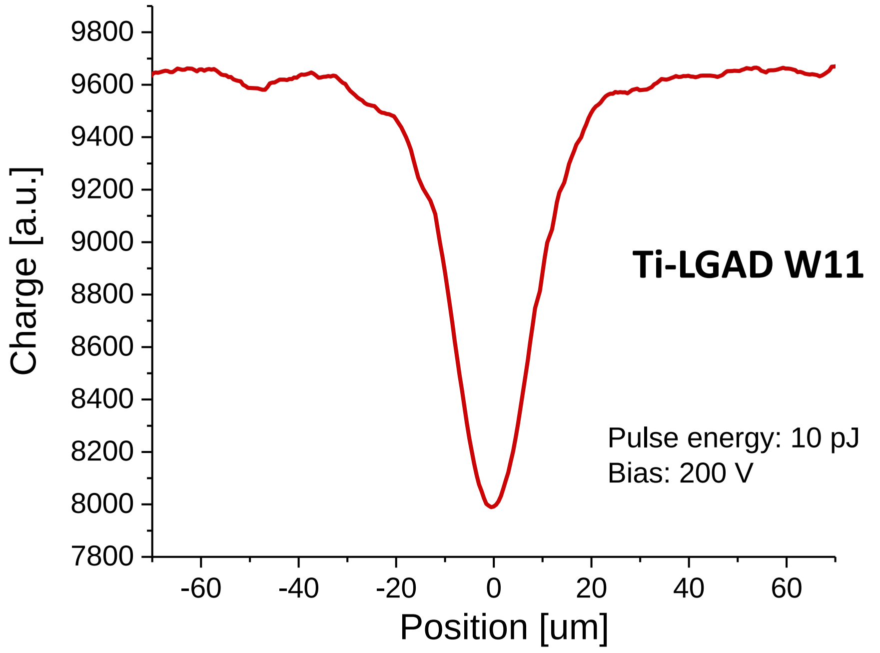
- ➢ At bias close to the breakdown HV, the time for peak to reach maximal value becomes extremely enlarged (like coming in two "waves" : two rate of change in leading edge are recorded), reaching finally the amplitude that is almost 20 times larger only by an change ((increase) of 20V (from 180V to 200V).
- ➢ At the HV bias close to the breakdown voltage, the ringing in the falling edge of the waveform becomes very enhanced and the signal is decaying over very extended period, indicating very long relaxation time of sensor.

Are spikes are observed in IP region of TI-LGADs?

No spikes observed in TI-LGADs

- We investigated also TI-LGADs (applying the same methodology for data analyses and the same data taking procedure), huge data base is recorded, but still needs to be fully processed so we are not able to present the results here (look at the 42nd RD50 Workshop in Montenegro in June);

However, we prepared one plot of X-profile over interpad area for trenched FBK sensor: W11-A2 4,2
at high power (10 pJ) and high bias (200V). We increased quite high laser intensity, so we see if any sign of spikes are there.



Thank you ☺