TREDI 2023, FBK, Trento, 28th Feb – 2nd March, 2023

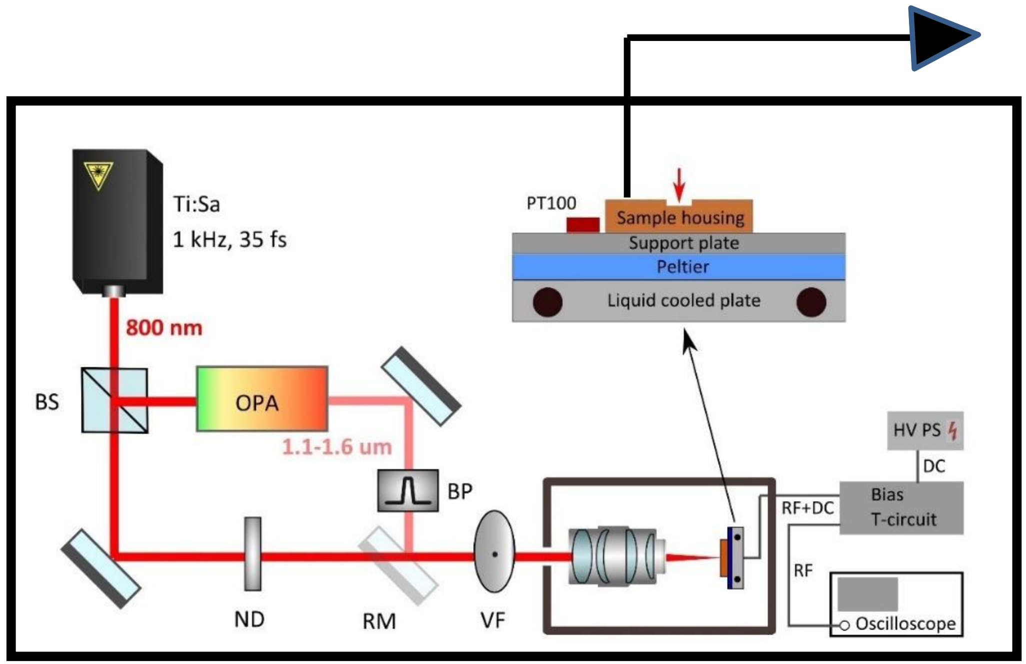
The observed effect of plasma expansion on spatio-temporal dynamics of the charge collection in LGAD

Gordana Lastovicka-Medin[1] & Mateusz Rebarz[2]
in collaboration with
Gregor Kramberger[3] and Jakob Andersson[2]

[1]University of Montenegro, [2]ELI ERIC, Eli Beamlines, [3]Jozef Stefan Institute

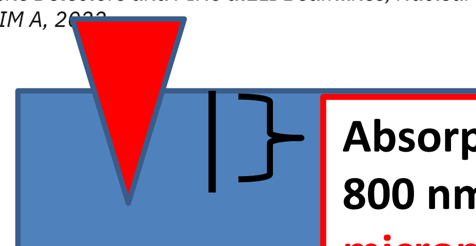
Experimental Technique: TCT

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

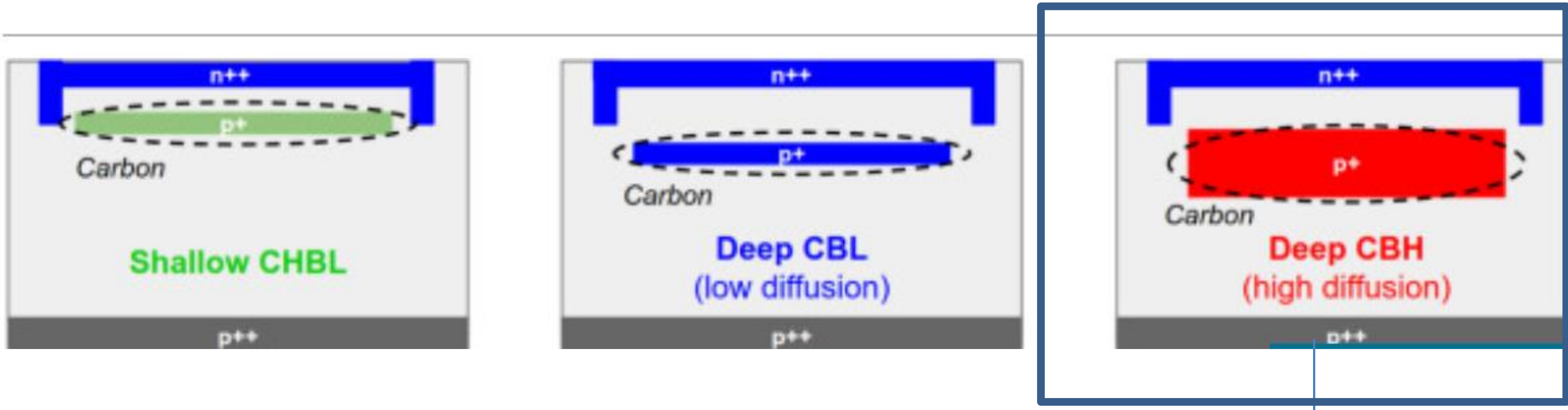
➢ Only **SPA** data are shown in this talk

Gain/plasma study on multipad array

Comparison of signal obtained by illumination of different areas of multipad array.

This study is similar to the one performed in February 2022 when irradiated sample (1.5e15) FBK UFSD3.2 W18 2x2 array was used.

Prior to UFSD3.2, FBK only used shallow gain implants: in this geometry, the high electric field region is narrower than 1 µm; whereas, for the deep implants, the high-field region extends for about 1.5–2 µm



FBK UFSD3.2 W18 + C -enriched

What was observed before

- Contrary to the expectations, it was observed that the transient signal in LGAD becomes faster and shorter if plasma is denser.
- Moreover, the ratio between the amplitudes of signals from the pad and the inter-pad region has been increasing with the decreased plasma density.

- The observed behaviour can only be explained by additional underlying mechanism that is more dominant then plasma induced screening of local electric field; the charge screening of local field would slow down the charge velocity.

- Instead of observing the slower signal with the increased plasma density as it would be if only charge screening of local el field dominates the dynamics of charge collection, we observed the opposite effect: the faster signal.

- The wavelength of fs-laser is 800 nm, and this corresponds to 20 microns of absorption depth in silicon(far away from the bottom electrodes in LGAD). Also, only Single Photon Absorption of TCT technique was used. Therefore, the reflection of the laser beam from the bottom electrode can not be the reason.

- We think that the thermal effect is responsible for faster plasma expansion in denser plasma, broadening the plasma charge cloud; as result the induced signal becomes faster in denser plasma. The repulsion effect of the same sign charge clouds may also contribute.
- However, more data and larger pool of LGAD prototypes are needed

Gain/plasma study on multipad array

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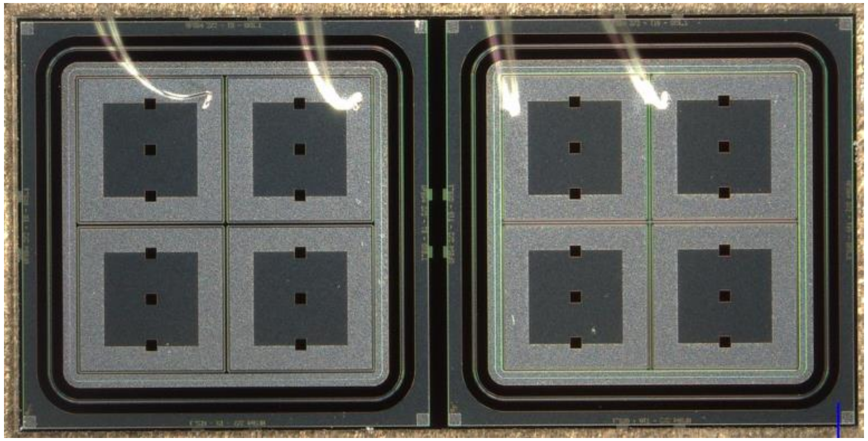
Here, in this presentation, we use non-irradiated **FBK UFSD4 W9 (C-1) LGAD 2x2** array
(there are actually two identical 2x2 arrays and one of them is studied)



W9 has shallow GL and it is C-enriched LGAD

Not the same type design as for FBK3.2

- **Type9 – 49µm nominal inter-pad distance, individual p-stop**
- Type10 – 61µm nominal inter-pad distance, indivudal p-stop + bias ring
- Effective IPD is smaller for W9 than W18 since it has a shallow GL and less bending of field lines.

Technique: TCT (SPA), 800 nm, 50 fs, 1kHz, pulse energy 50 fJ to 5 pJ
Method: shooting at pad, interpad, ring region
by varying the laser power, we varied the density of initially generated charge
Amplifier: 50 dB

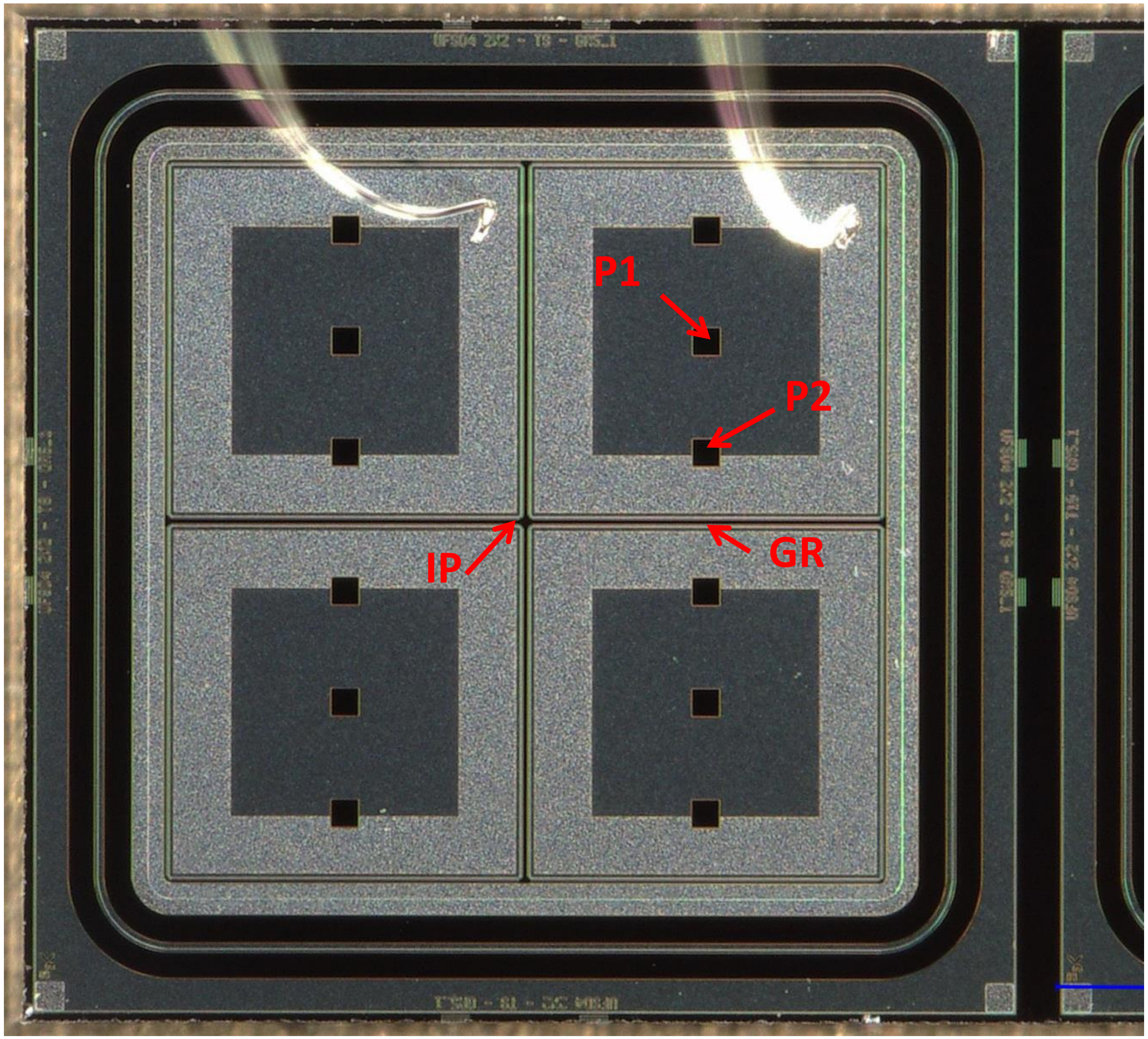
4 different areas were inspected:

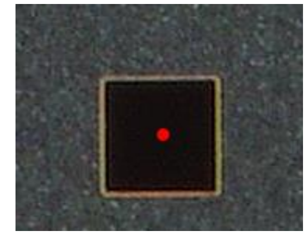
P1 – pad 1

P2 – pad 2 (for crosschecking)

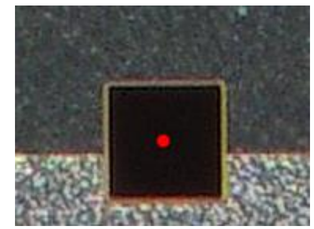
IP – central interpad region

GR – guard ring between neighbor pixels (actually I don’t know architecture this sensor so maybe guard ring is not correct term, this is area between two adjacent pixels so also interpad in some sense)

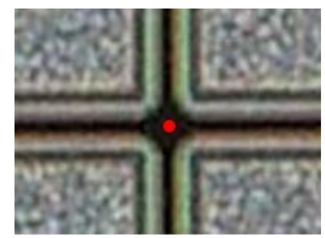




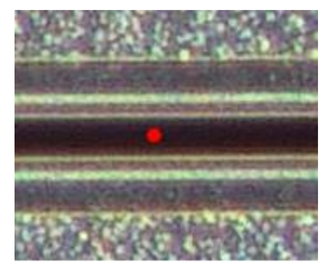
P1



P2



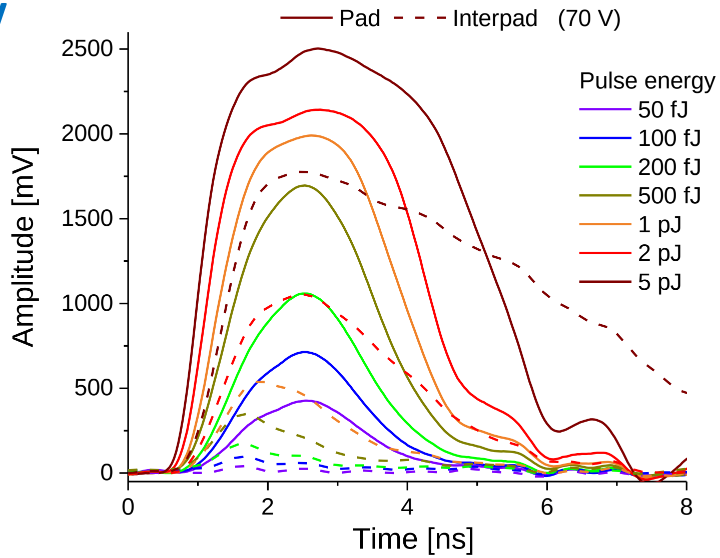
IP



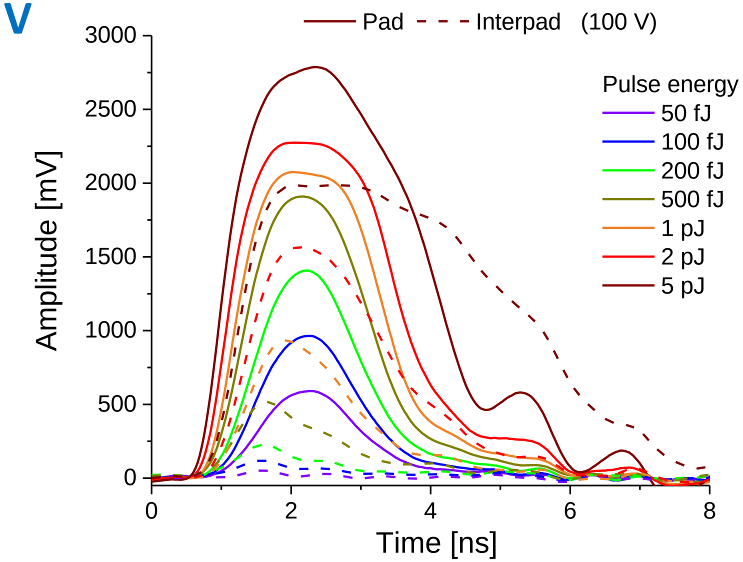
GR

Waveforms at P1 and IP vs pulse energy

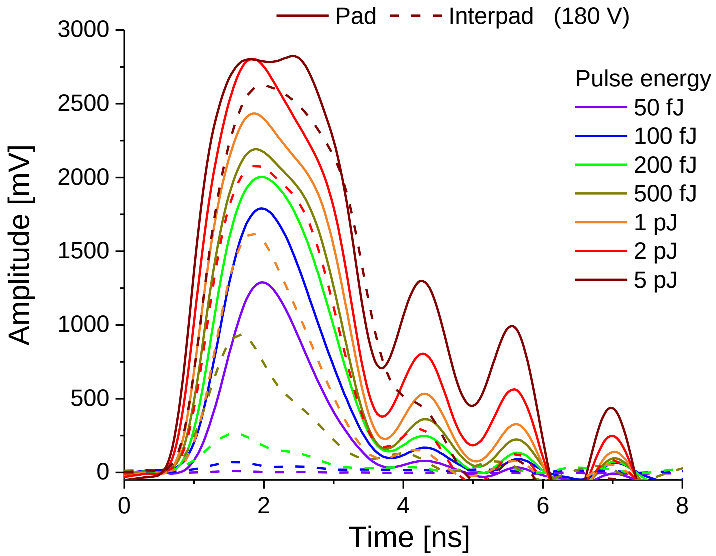
70 V



100 V

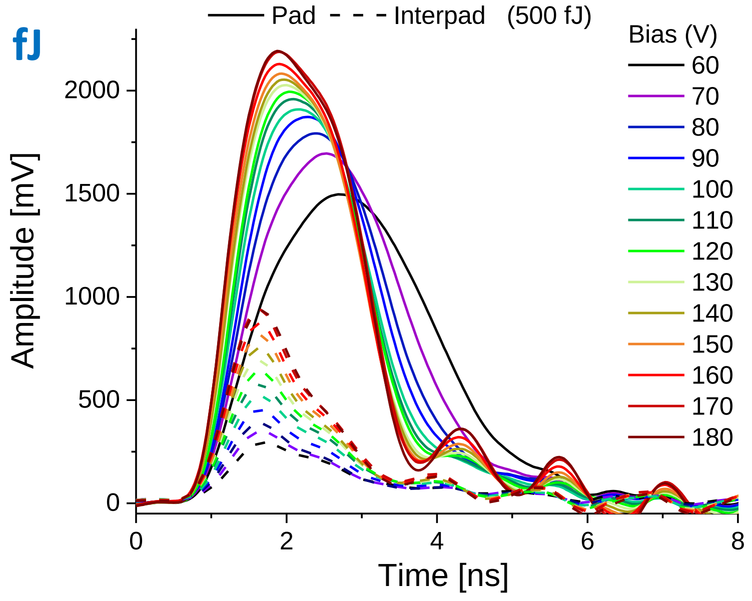


180 V

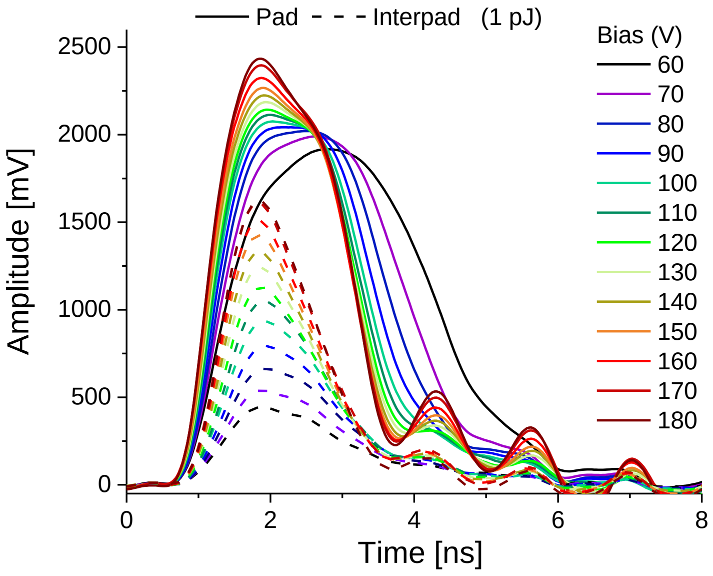


RESULTS: Waveforms at P1 and IP vs bias

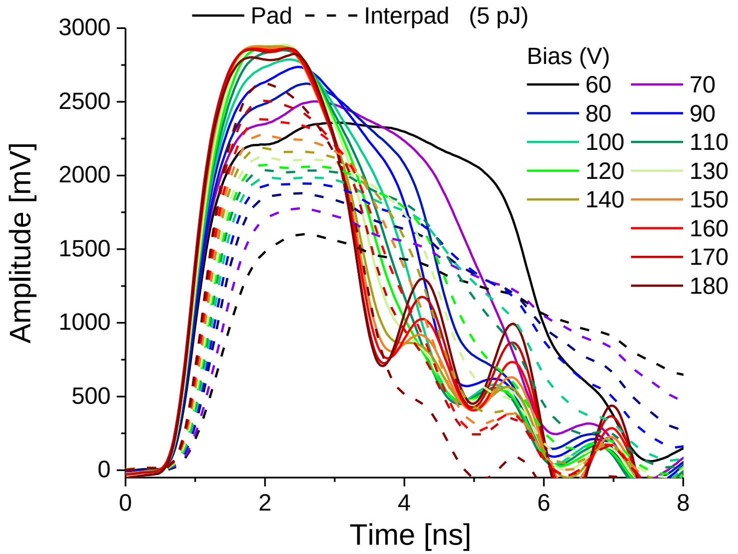
500 fJ



1 pJ

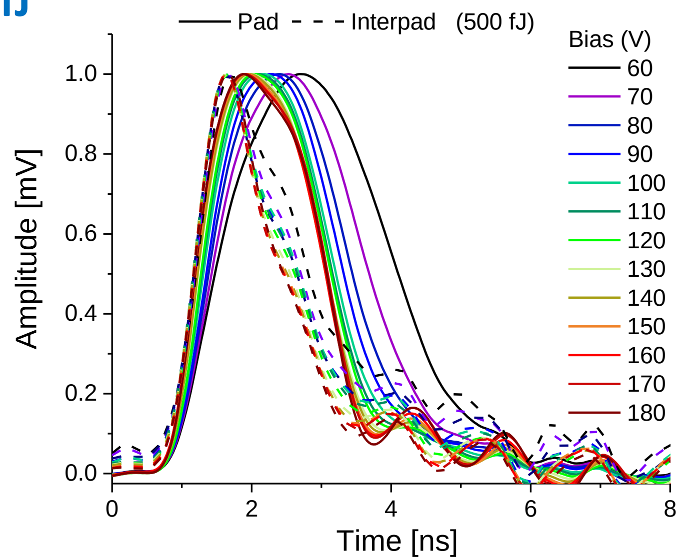


5 pJ

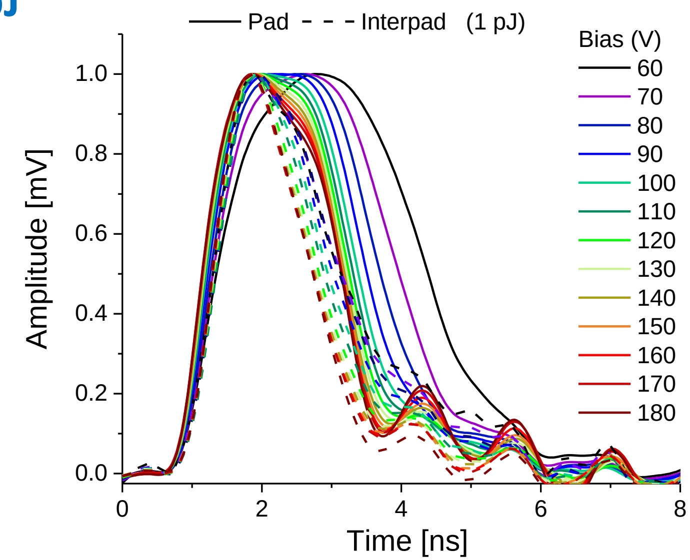


Normalized Waveforms at P1 and IP vs bias

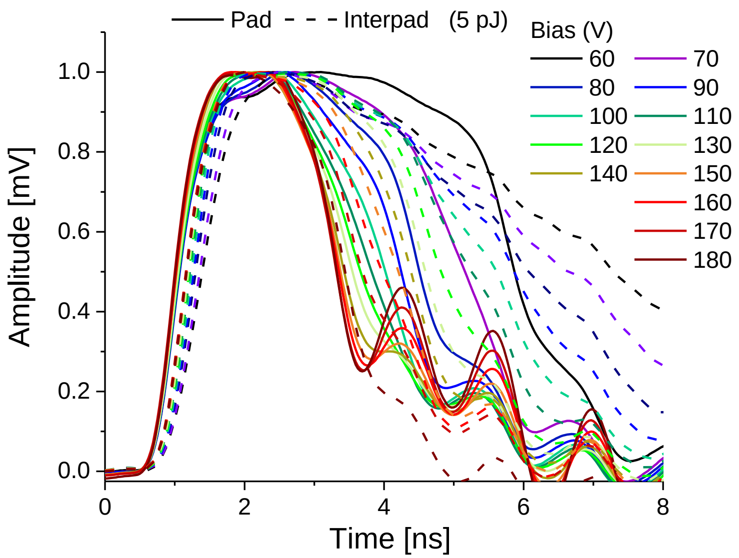
500 fJ



1 pJ



5 pJ

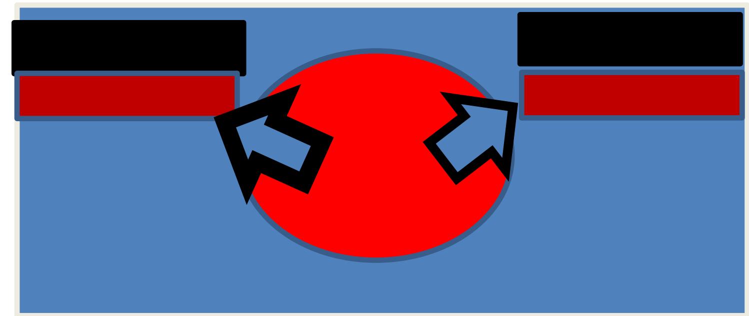


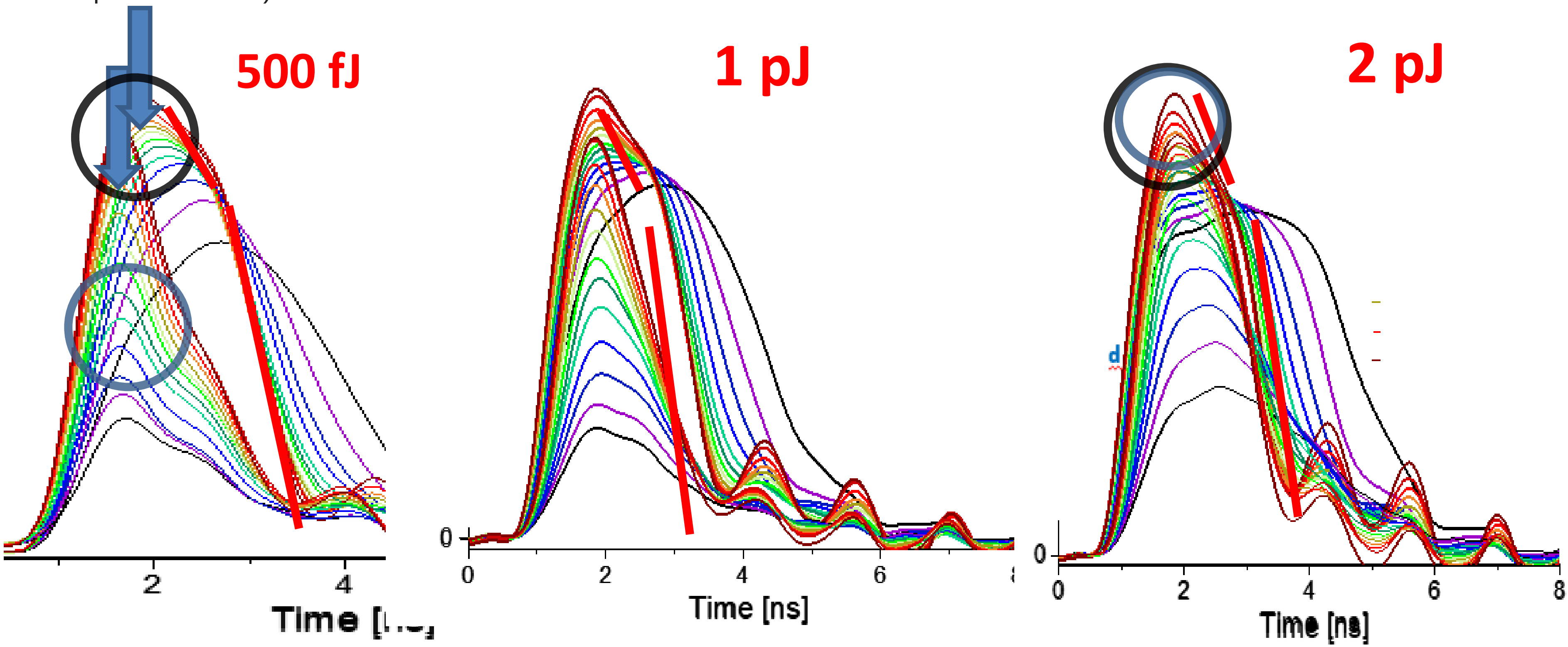
At high laser power the inter-pad region starts to behave like pad (at least the left part of entire waveform).

- For discussion see the next page.

DISCUSSION:

- By Increasing the laser power (in particular at the highest bias) the waveforms recorded for Interpad regions become almost identical to those from the pad.
- Possible explanation can be that at some critical point, the volume of plasma in IP becomes so enlarged that with further increase in bias the charge is significantly spread laterally and can reach the gain layer where undergoes the impact ionisation)





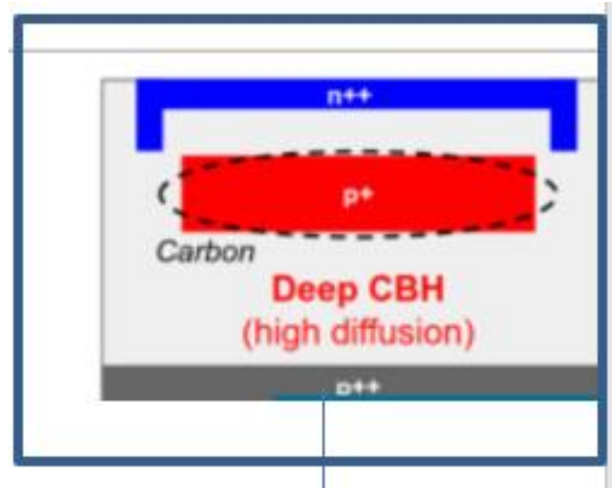
At the same time, charge from plasma in pad when plasma is dispersed (due to increased bias) is coming in large amount (large charge density) in gain layer --> producing this way effect of gain suppression.

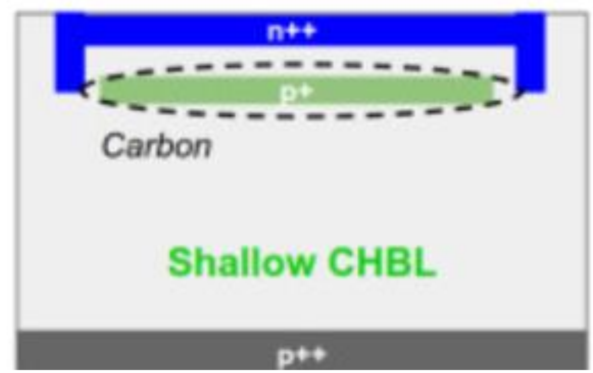
---> So somewhere, at some point, limits by design make that both pad and intrepad have similar waveforms

Conclusion

- The study shown here is similar to the one we performed in February 2022 when irradiated sample (1.5e15) FBK UFSD3.2 W18 2x2 array was used (presented at the 41st RD50 Workshop). The FBK UFSD3.2 W18 is C -enriched and Deep CBH (high diffusion) sample (see the top image on the right side)

- Opposite, the sample UFSD 4.0 W9, investigated in this study is UFSD with shallow gain (see the bottom image on the right side)



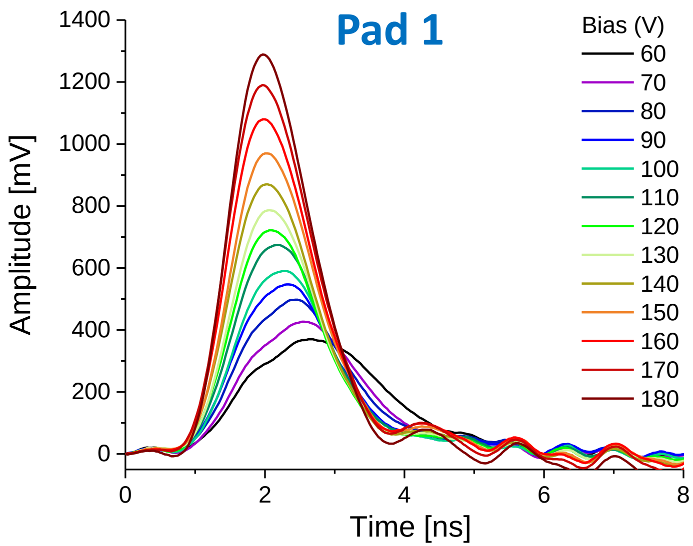


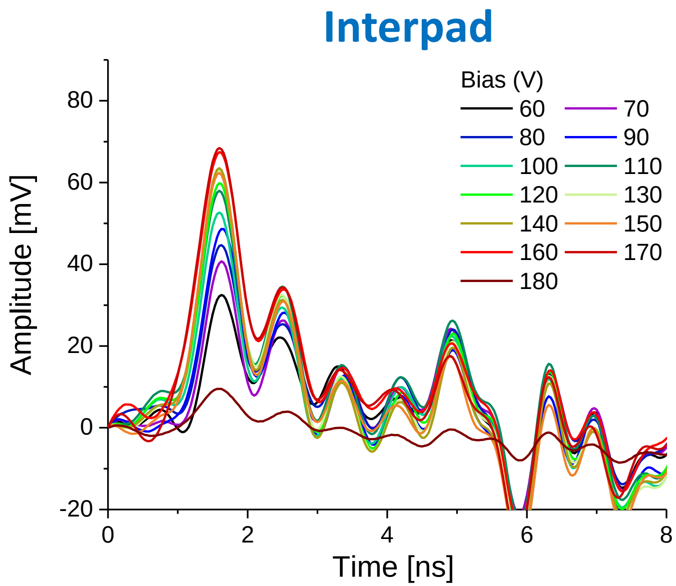
- Contrary to the expectations, in the study performed on the “Deep CBH” UFSD, it was observed that the transient signal in LGAD becomes faster and shorter if plasma is denser. Thermal expansion enhanced in dense plasma was assumed as possible reason. We should also remind that investigated sample was irradiated.

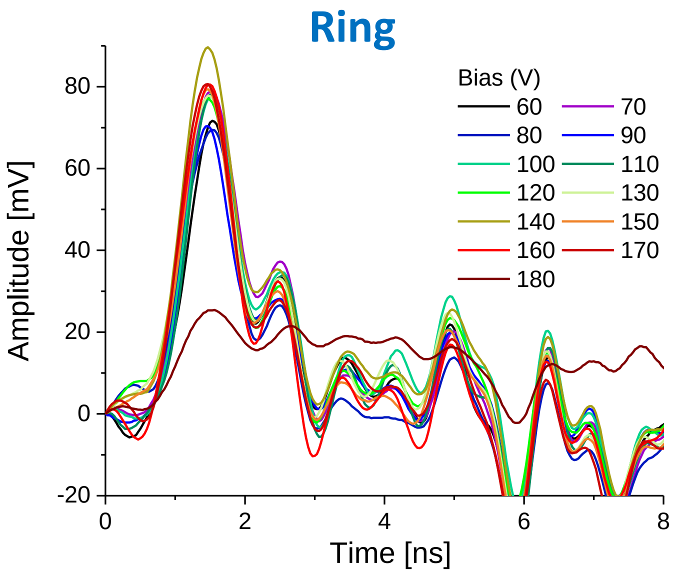
- Analysis, performed on “Shallow CHBL” (non-irradiated) did not show above stated observation so explicitly. However, in both cases, the radio of Pad/Interpad signal amplitude increased with decrease in laser power.
- What is observed in this analysis is the following: at some critical point (right condition of fs-laser power and high HV bias), the interpad behaves as pad. This condition was also found in previous analysis.
- The possible explanations is that at some critical point the plasma cloud becomes quickly enlarged and charge initially generated in IP region (when laterally spread) reaches the gain layer were it is then multiplied. At the same time the charge generated in pad is collected within conditions of gain suppression, so at some point sort of “equilibrium” in the whole segmented LGAD is reached.
- The stated observations are in line with what was observed in SEB study: close to breakdown point both. Pad and interpad shown almost the equal distribution.
- The results also show that LGADs behaviour is extremely sensitive on it processing parameters, and geometry arrangements. Straightforward comparison is not possible. Certainly, some differences come out from the fact that one sample was irradiated, while another was not.

BACKUP SLIDES

Waveforms at 50 fJ

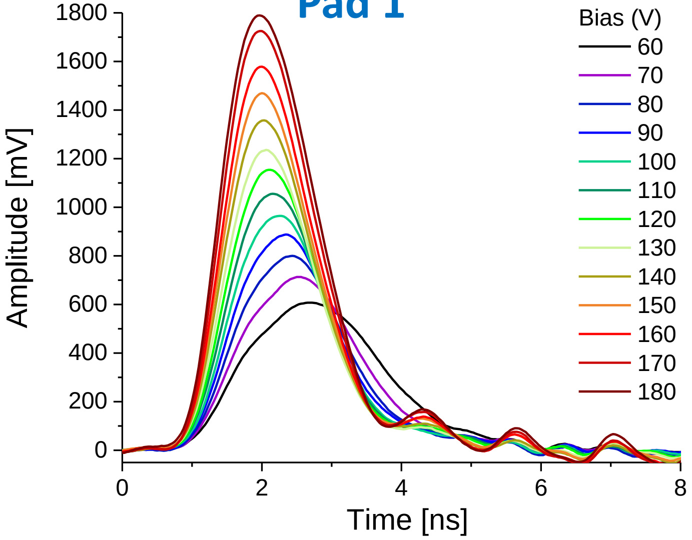




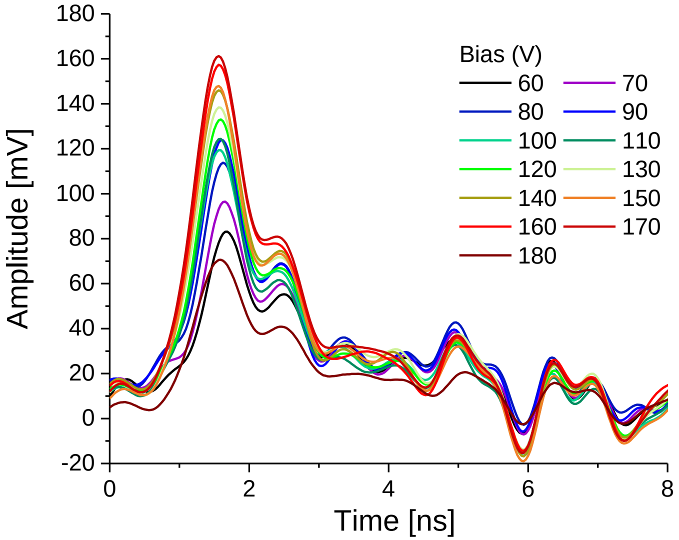


Waveforms at 100 fJ

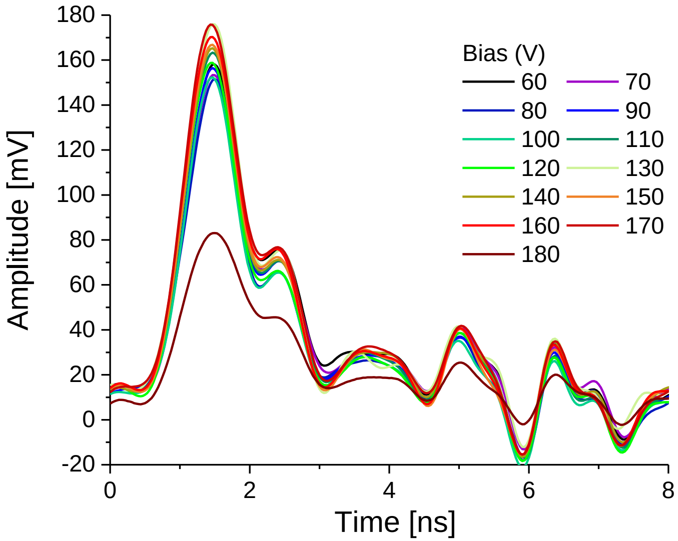
Pad 1



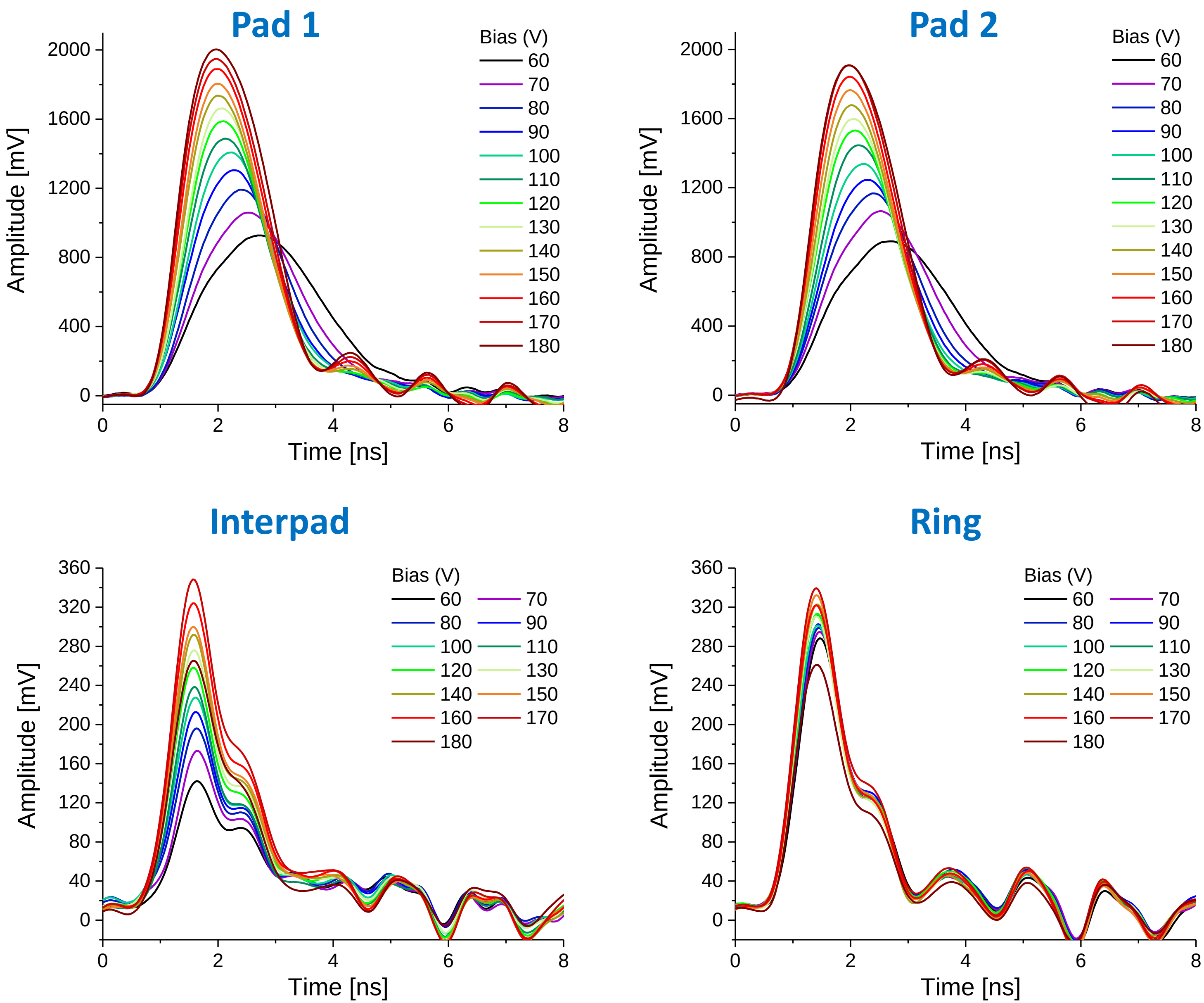
Interpad



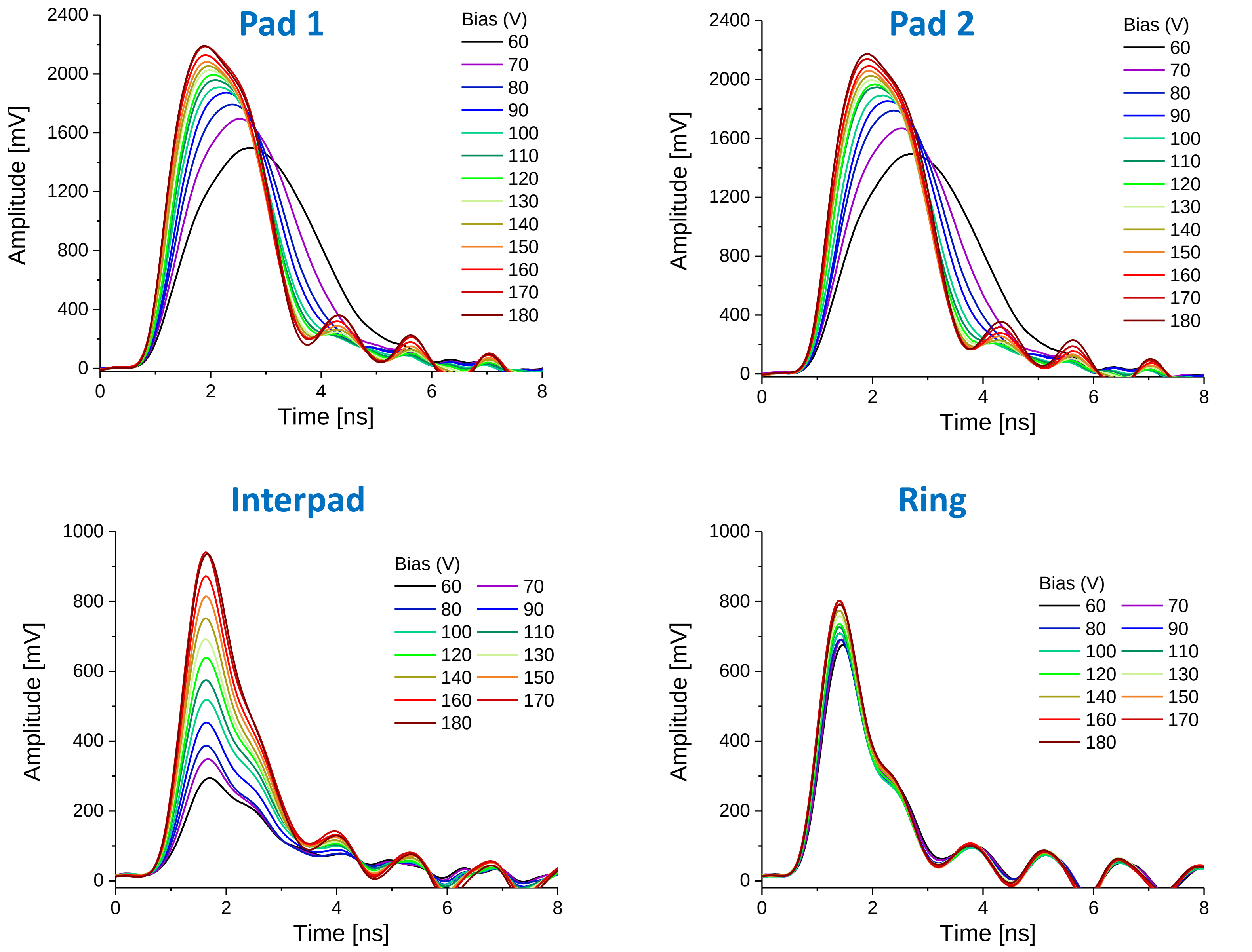
Ring



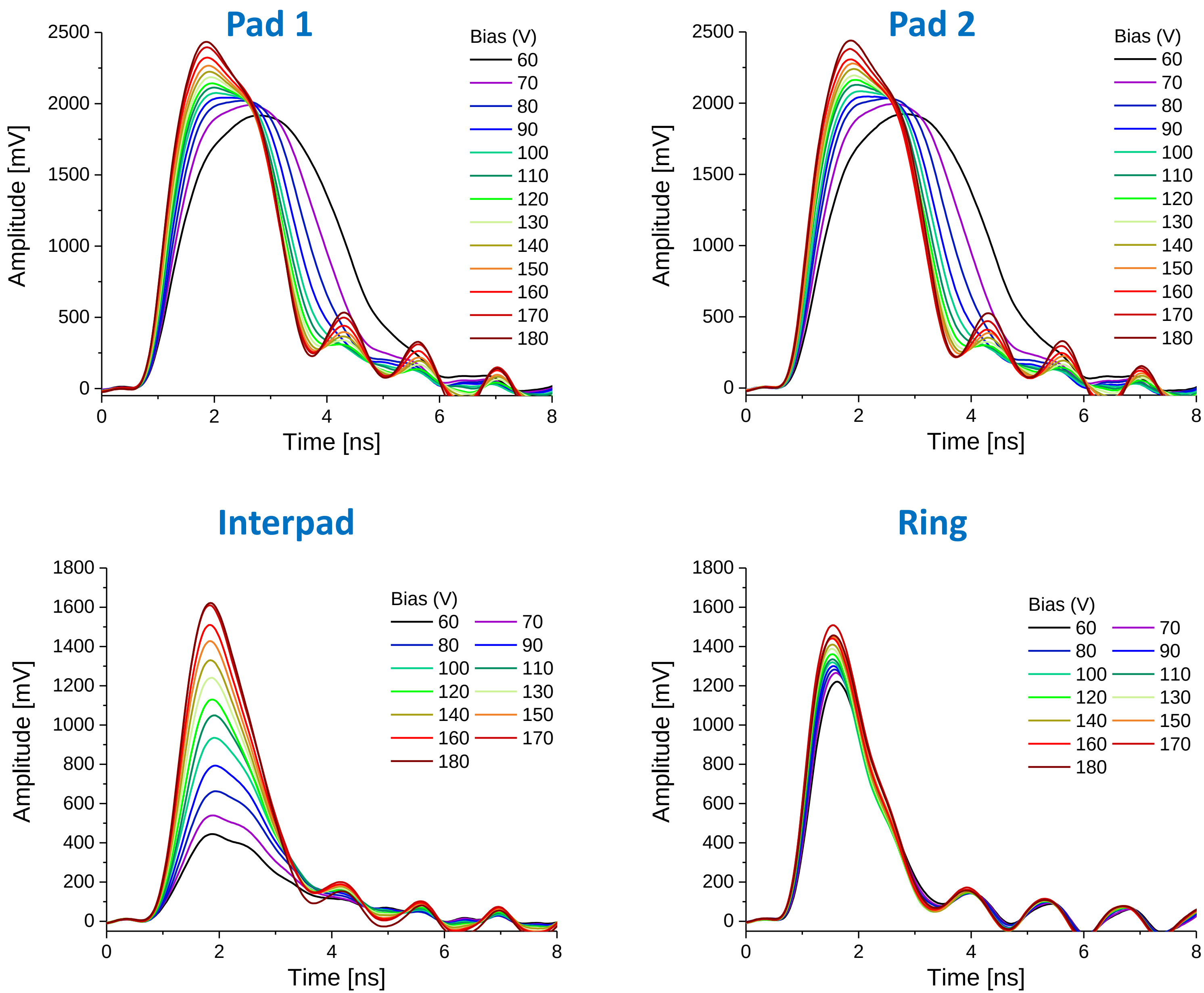
Waveforms at 200 fJ



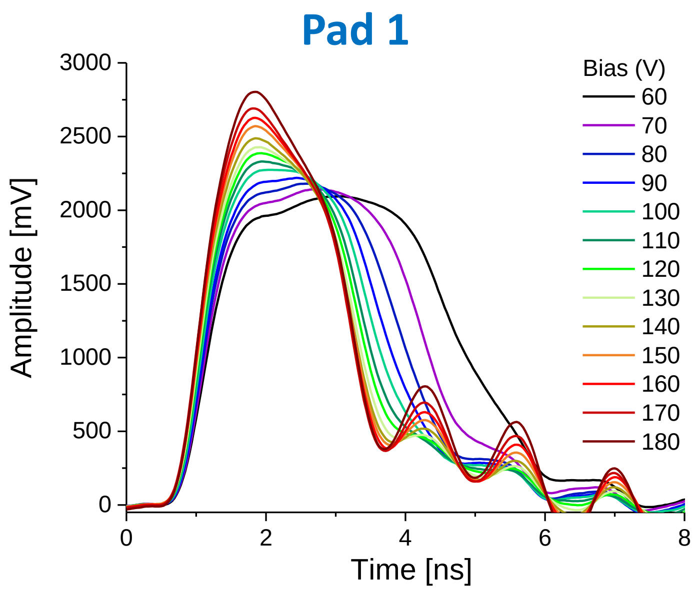
Waveforms at 500 fJ

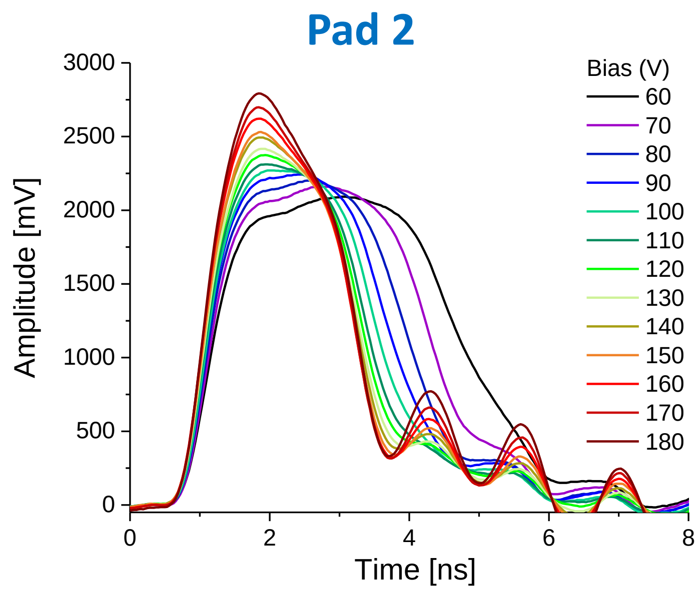


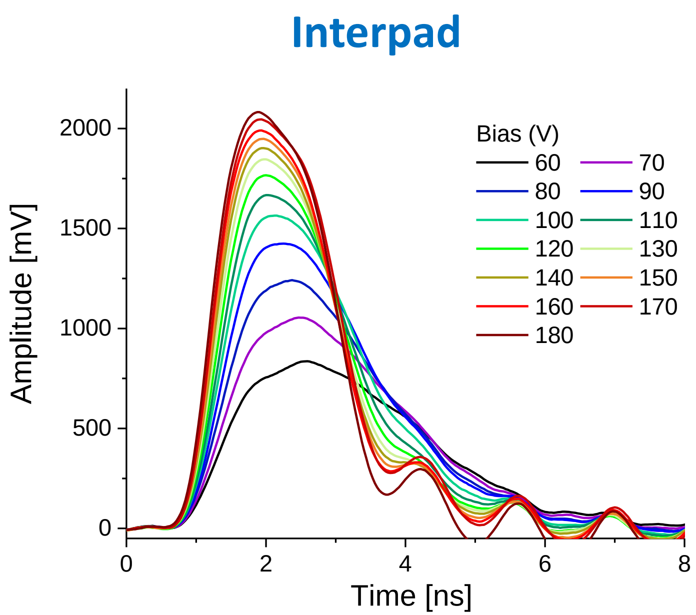
Waveforms at 1 pJ

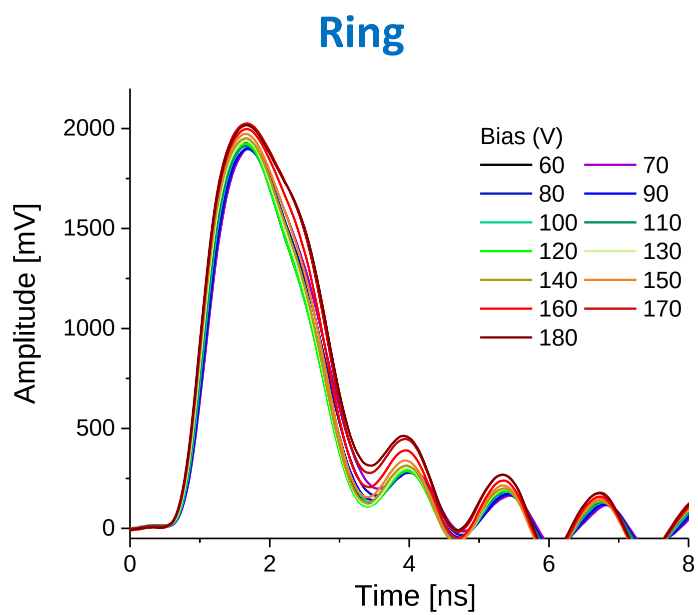


Waveforms at 2 pJ



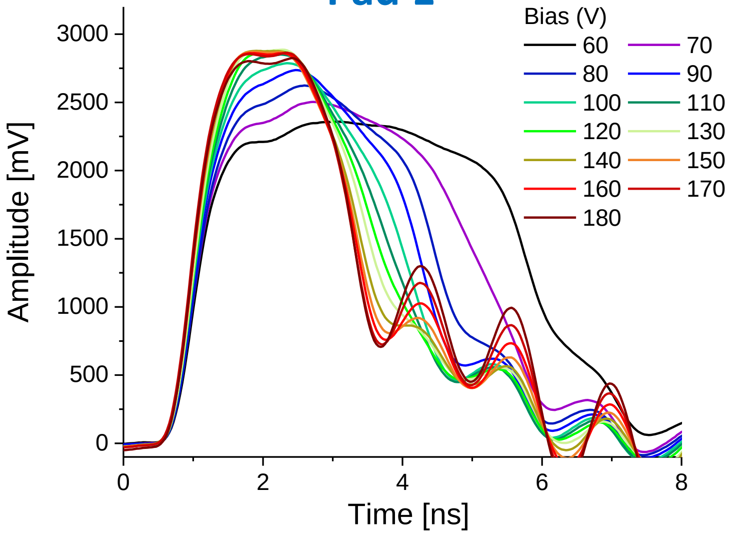




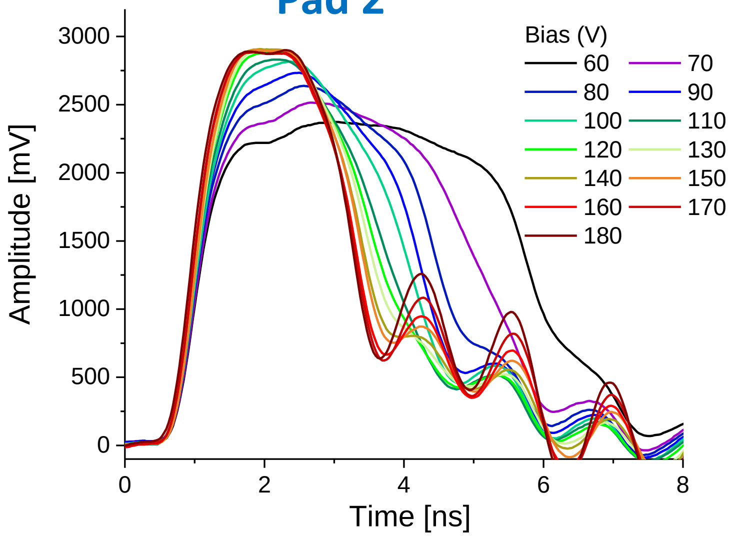


Waveforms at 5 pJ

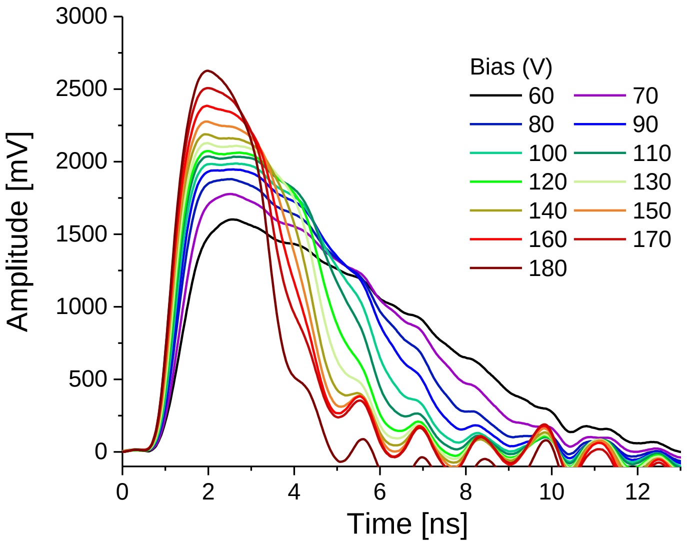
Pad 1



Pad 2



Interpad



Ring