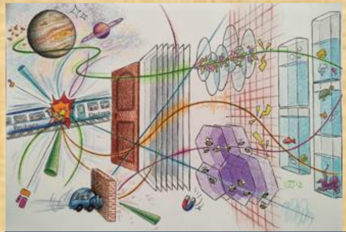

DRD3

3D SILICON PIXEL SENSOR WITH FS-LASER BASED SPA AND TPA-TCT AT ELI

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[3] ELI ERIC, ELI Beamlines, Prague, Czech Republic

UCG Univerzitet Crne Gore

Jožef Stefan Institute

eli

Motivation

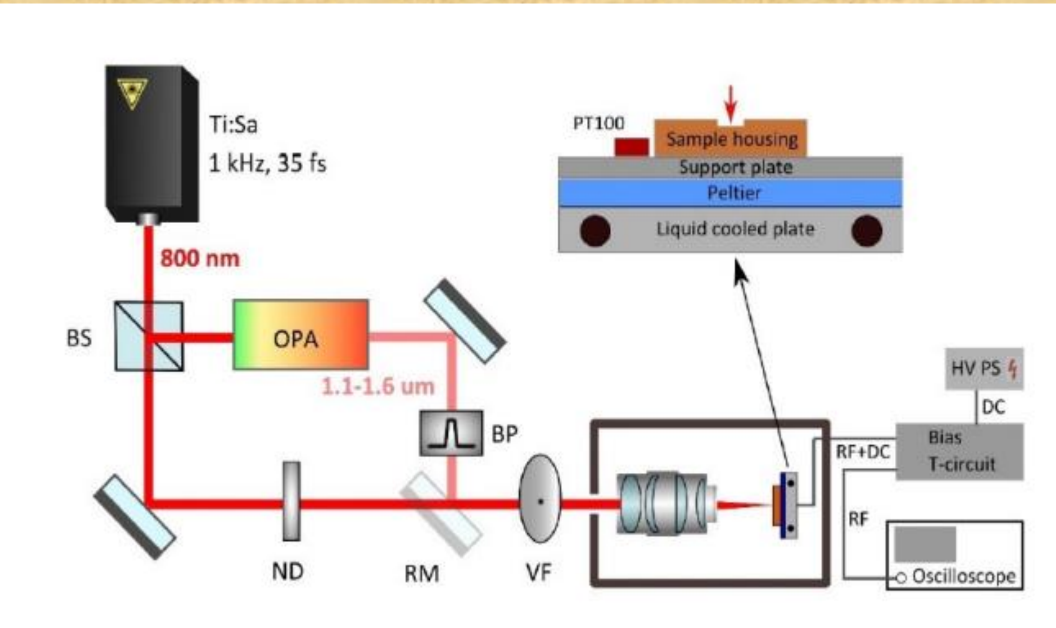
- To demonstrate that ELI fs-laser beam is an excellent probing tool for studying the 3D detectors.

OUTLINE

- ❑Materials and Methods
  - ➢ Investigated 3D silicon columnar samples
    - ✓ CNM Quadratic
    - ✓ Hexagon 3D structures (RD50 Common production project)
- ❑Results from three approaches
  - ➢ 3D scanning (only TPA data at 35 µm depth analyzed
  - ➢ Laser shooting along the X and Y direction crossing the central electrode
  - ➢ N+ and P+ are precisely shooted with SPA
- ❑Conclusions & Future steps

2D SPA scans, along the X and Y direction, with fs-laser of 800 nm, in steps of 1µ, are fully completed by not analyzed yet.

TCT at ELI



G. Laštovička-Medin et al. "Femtosecond laser studies of the single event effects in low gain avalanche detectors and PINs at ELI beamlines." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1041 (2022): 167321.

✓ originally installed for SEB verification in LGADs

Transient Current Technique (TCT)

- Operational modes: Single and Two photon absorption (SPA and TPA)
- Wavelength: 800 nm (SPA), 1550 nm (TPA)
- Pulse energy on sample: Variable by ND filters (accuracy: 0.2 pJ)
- Focus waist radius: 0.85 um (SPA), 1.5 um (TPA)
- Rayleigh length: 3.31 um (SPA), 7.74 um (TPA)
- Sample cooling: Down to -25 deg. C
- Sample movement: X, Y, Z
- Bias voltage: variable, up to >720 V
- Detection: 6 GHz (20 GSa) oscilloscope and leakage current measurement (accuracy: 0.1 uA)

Jitter on Triggering Signal

In our TCT Timing experiment at ELI we do not use an electronic signal from the main laser SDG unit (synchronization and delay generator). This is possible but in that case jitter would be >50 ps. In classical TCT a small laser diodes is used and there is a special output providing the electronic synchronization signal.

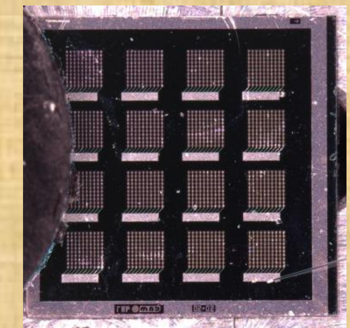
In our measurements performed at ELI we split the laser pulse: one part to fast InGaAs photodiode (as trigger), second part to investigated detector. Then, only one source of jitter is. It comes from the InGaAs photodiode and it is it's internal jitter which is much better than laser SDG signal.

We used fast InGaAs photodiode (ET-3000 from Eotech) as trigger. Manufacturer (Eotech) doesn't provide information on the jitter **but the rising edge we use for triggering has rise time < 17 ps so the jitter should be significantly better than this value.**

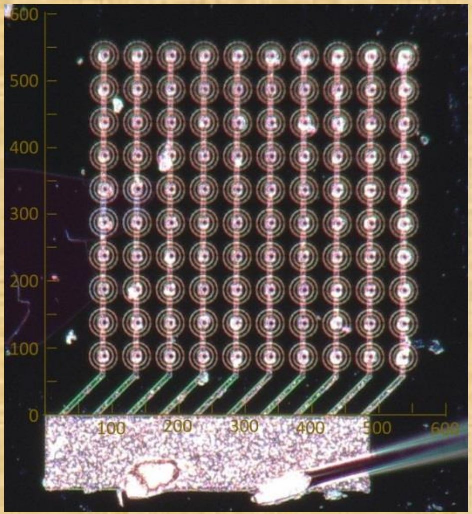
However, to obtain exact value, we will try to measure the jitter for trigger pulse during next campaign at ELI.

Investigated 3D column (CMN) sensors

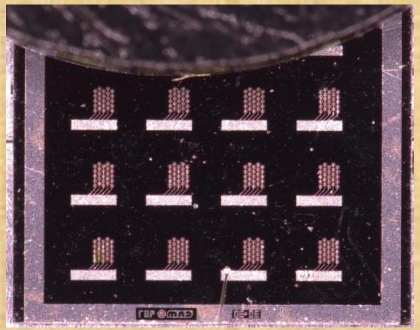
6-x SQUARE



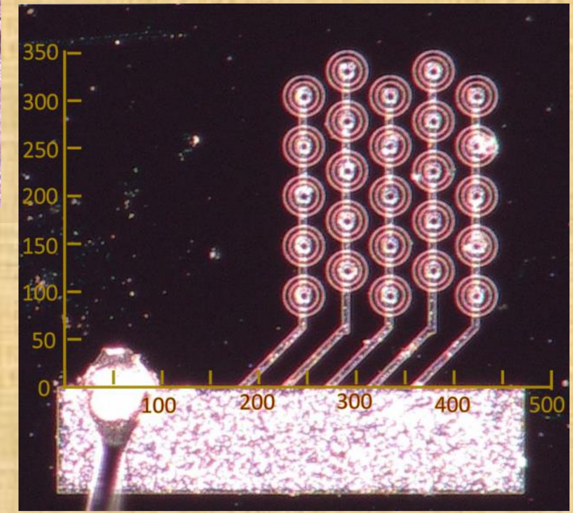
Zoom of wirebonded sensor (with scale in µm)



4-x HEX

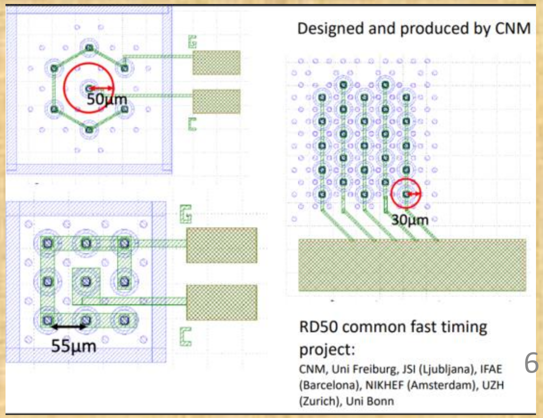


Zoom of wirebonded sensor (with scale in µm)

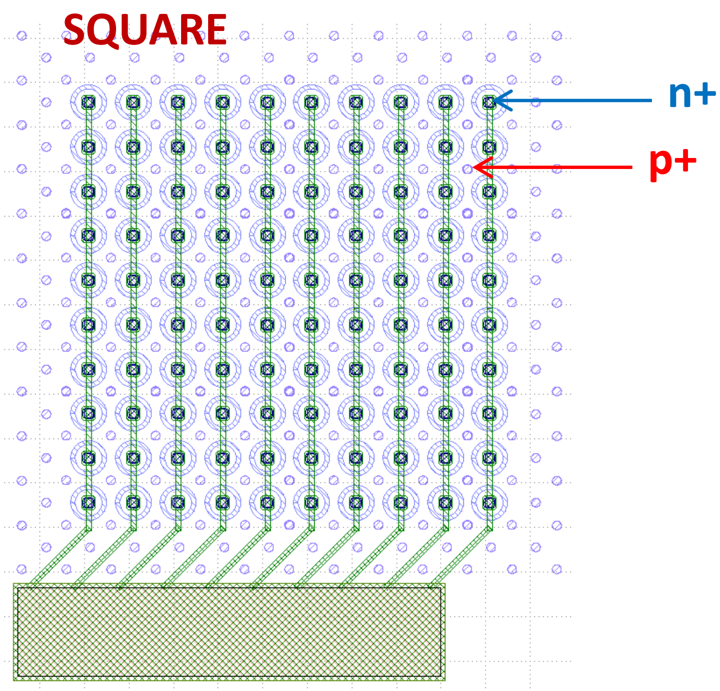


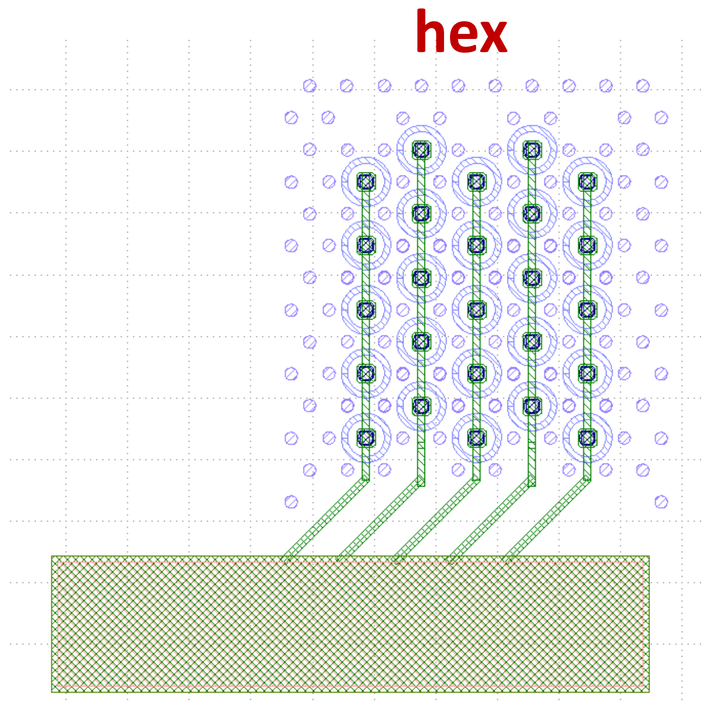
Main goal: to investigate differences in signal parameters in different areas in the sensor

- Charge collection
- Rise time (10-90%)
- Time of arrival (25%)



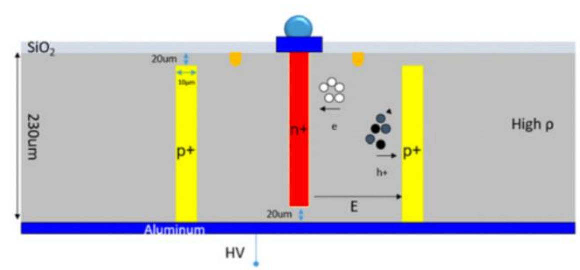
Sensors layout



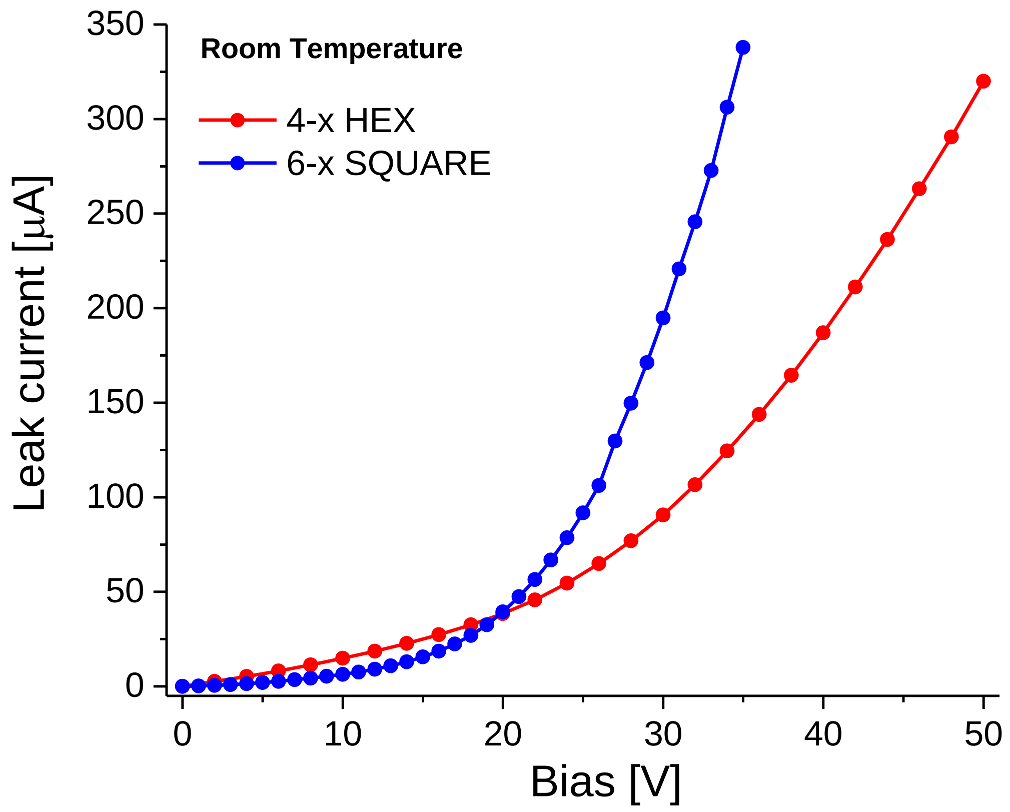


Green circles are metal rings with holes corresponding to **n+** columns and blue circles are **p+** columns.

CNN 3D Double side
double type silicon sensor



Leak current & bias limit



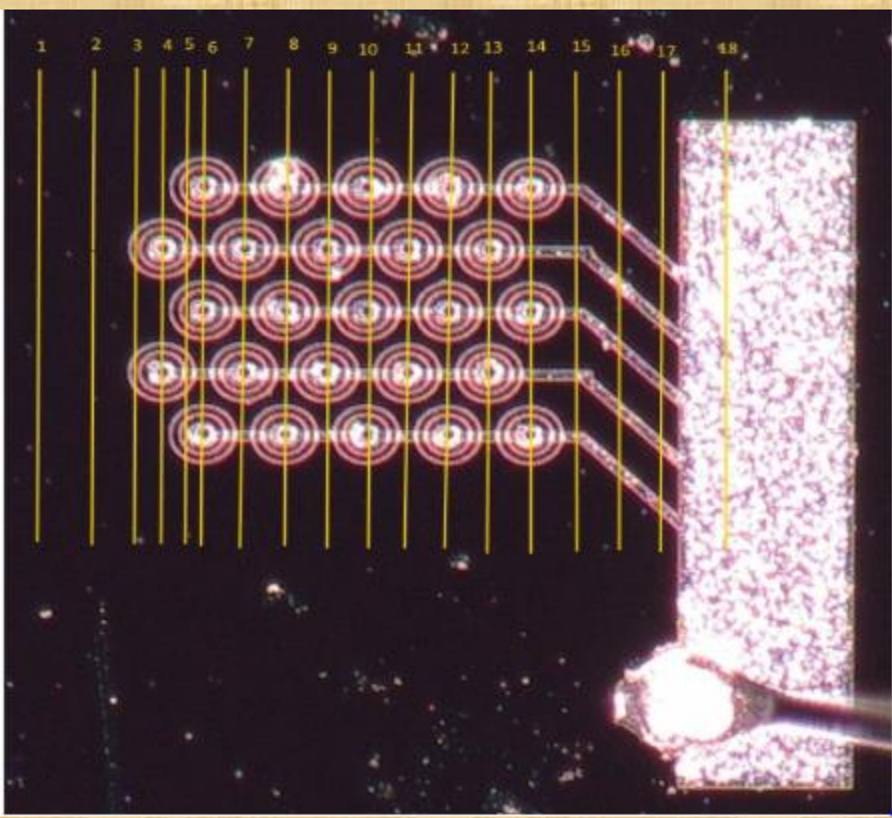
Both sensors exhibit high leak current.
Maximal bias to keep current below 0.5 mA (our hardware limit) is 55 V for HEX and 40 V for SQUARE. All measurements were performed with max bias 5V lower for safety (50 V and 35 V).

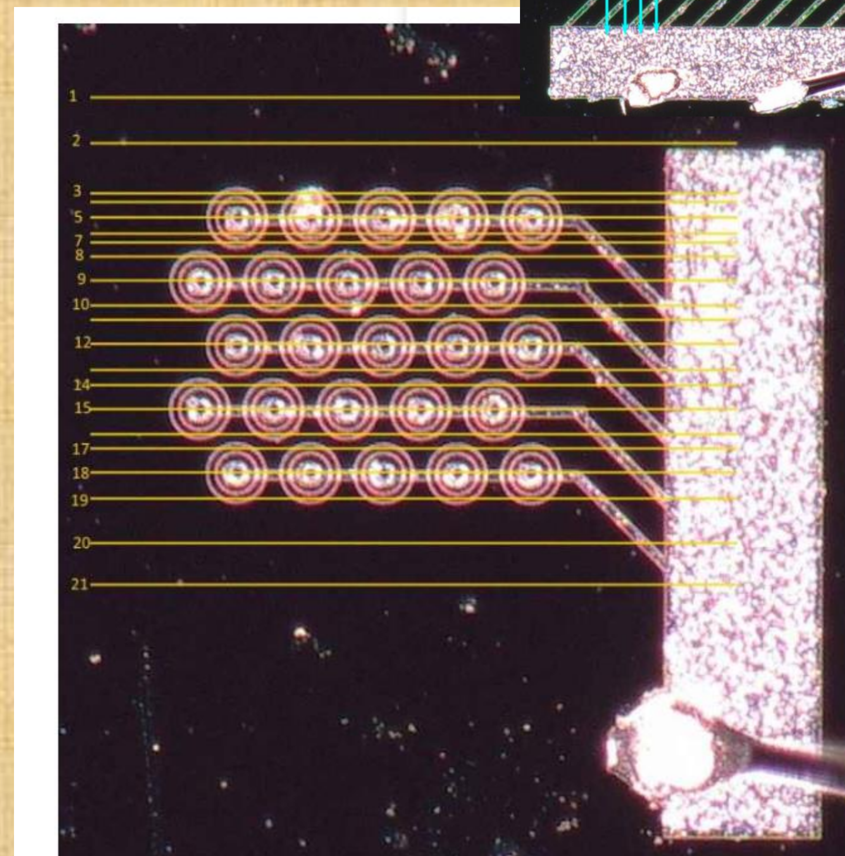
Experiment parameters

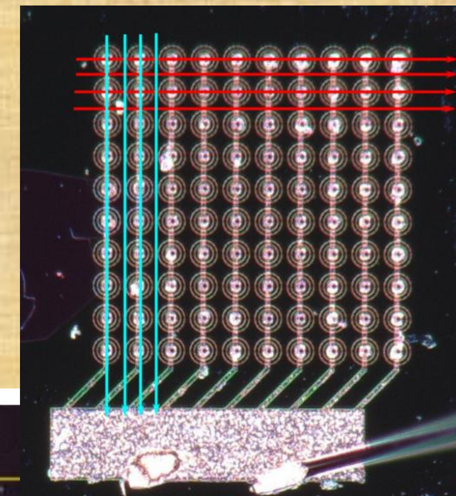
- Bias: 35V for SQUARE and 50V for HEX
- Pulse energy: 1-5 pJ (1 pJ = 10 MIPs)
- SPA: 800 nm, TPA (1550 nm)
- Room temperature
- Amplifier: no (some tests have been performed but without any improvement of S/N**).**
- **A very accurate oscilloscope is used so signals of few mV were recorded. The density of carriers is kept small enough not to see plasma effects.**

1st approach

- ➢ **2D Scanning with SPA**
- ➢ **3D scanning with TPA**

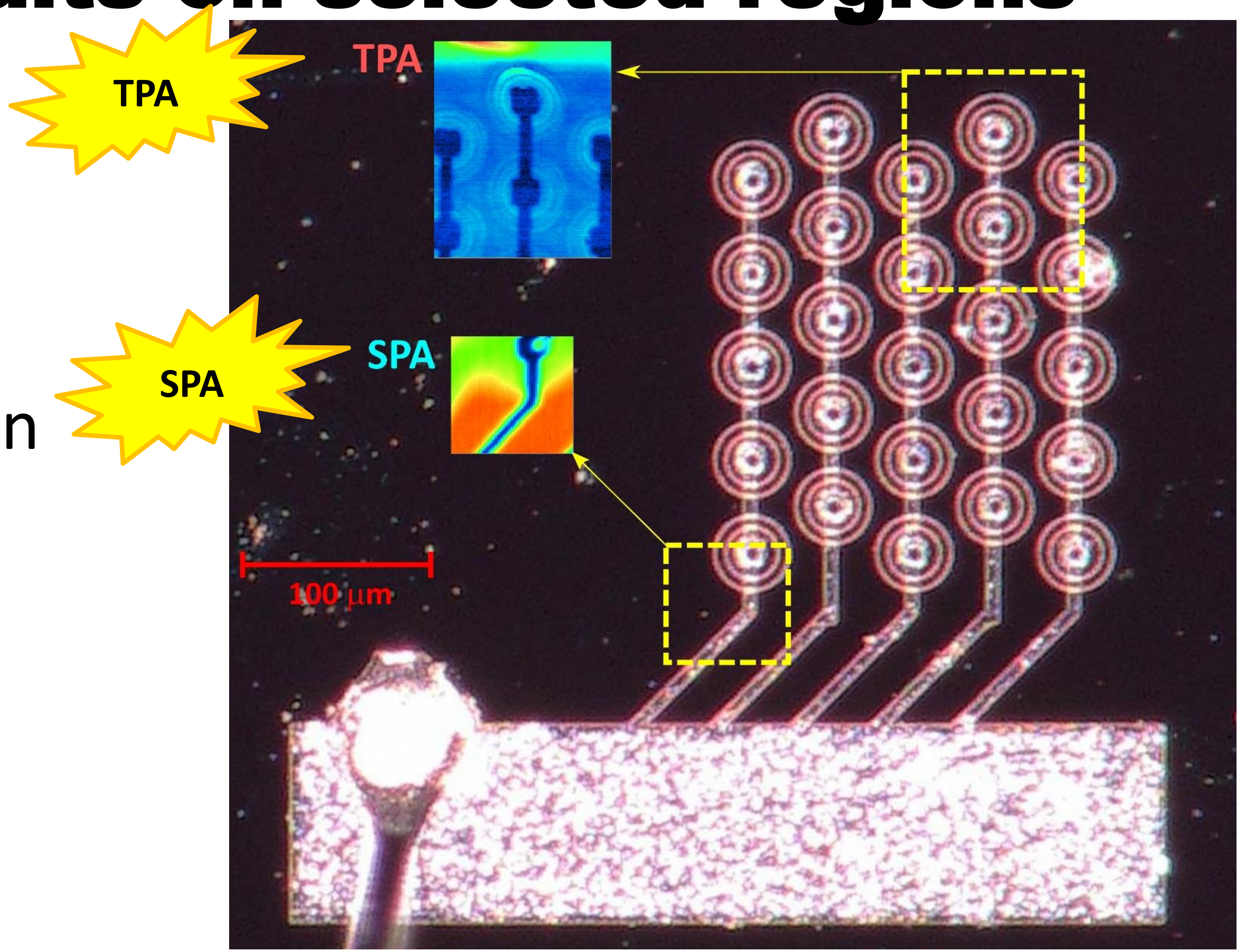






Results on selected regions

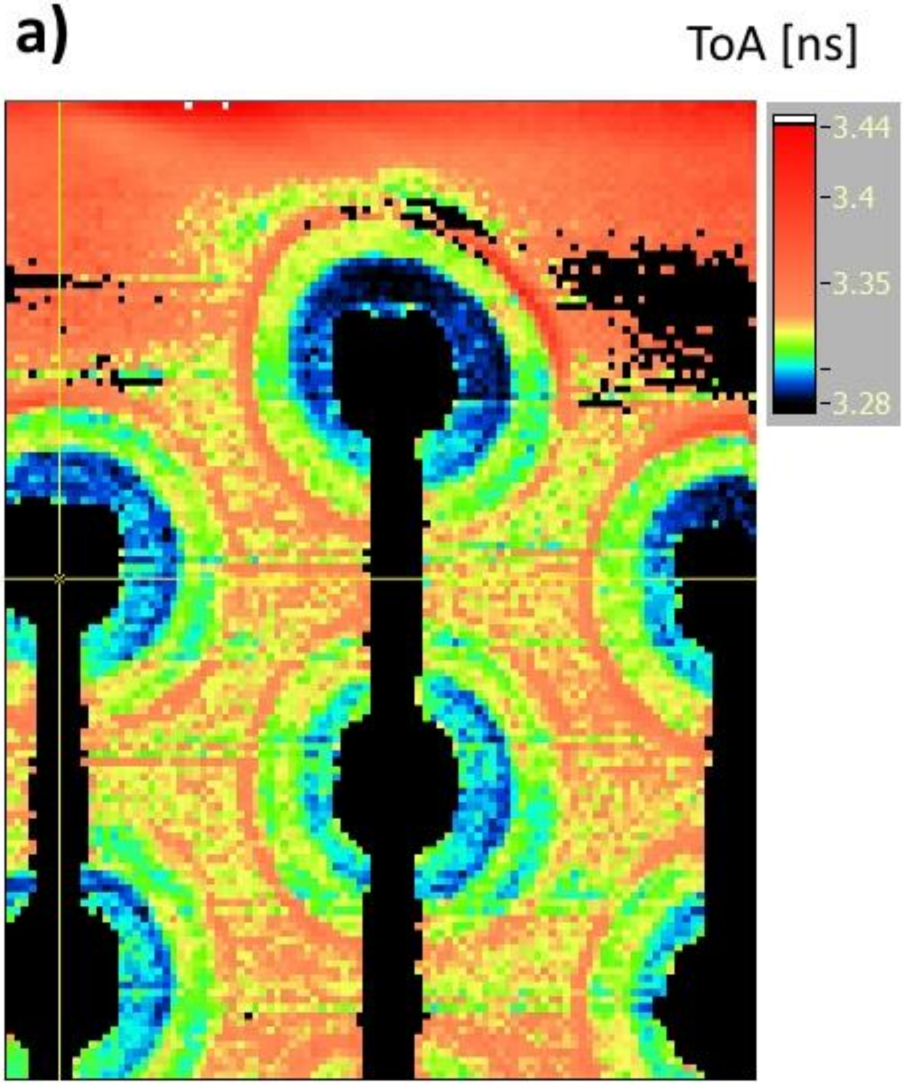
Charge Distribution

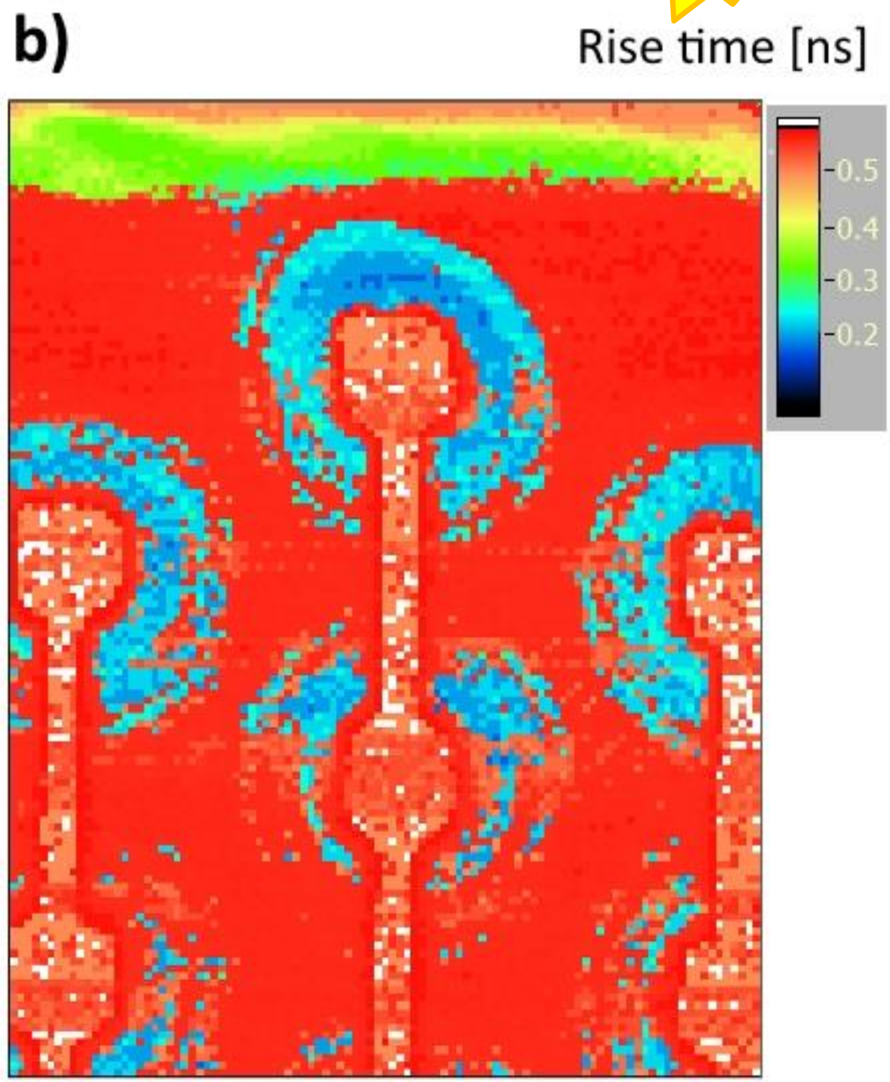


TPA data will be shown in detail on the next slides

TOA & Rise time

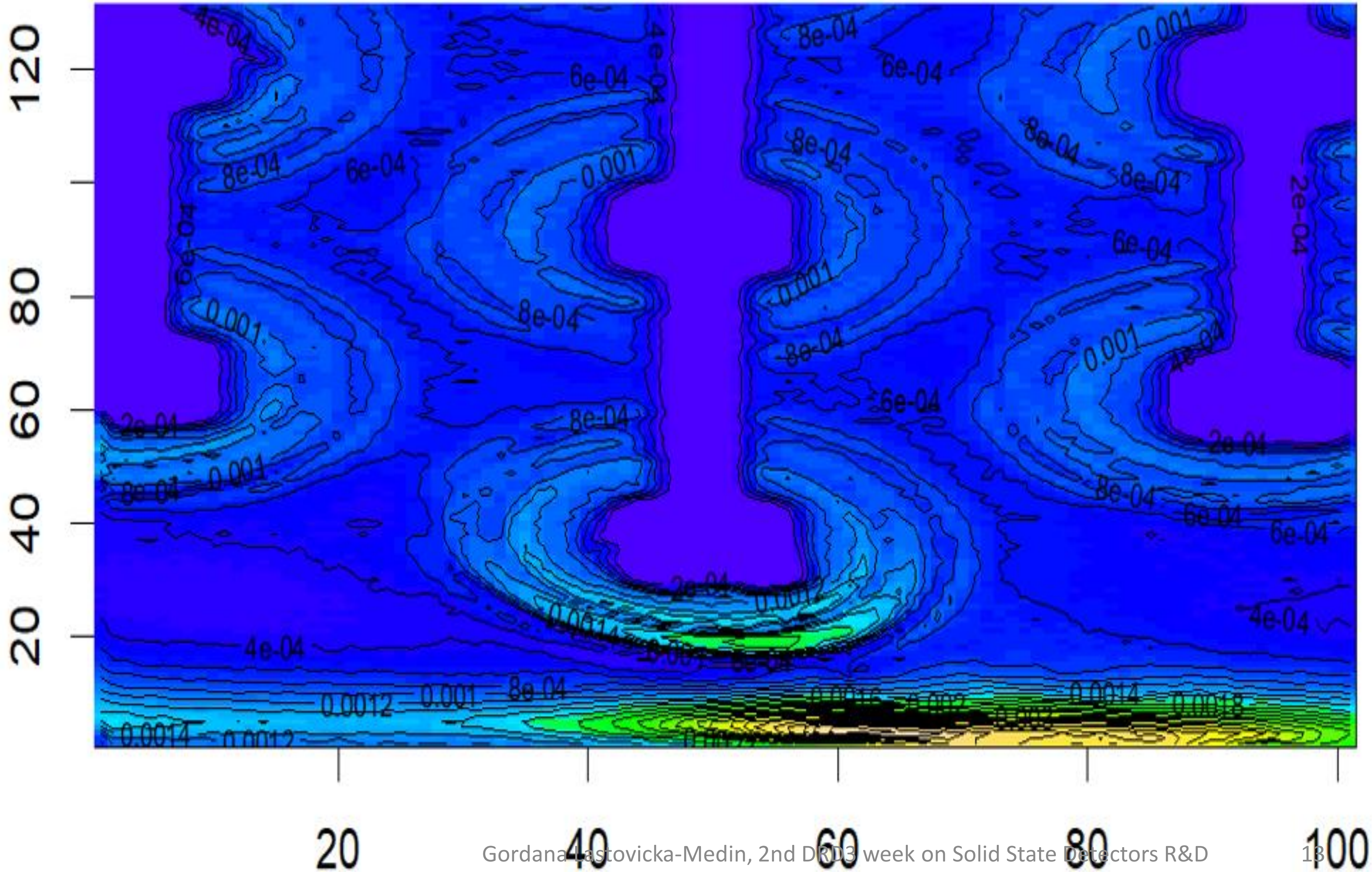
TPA





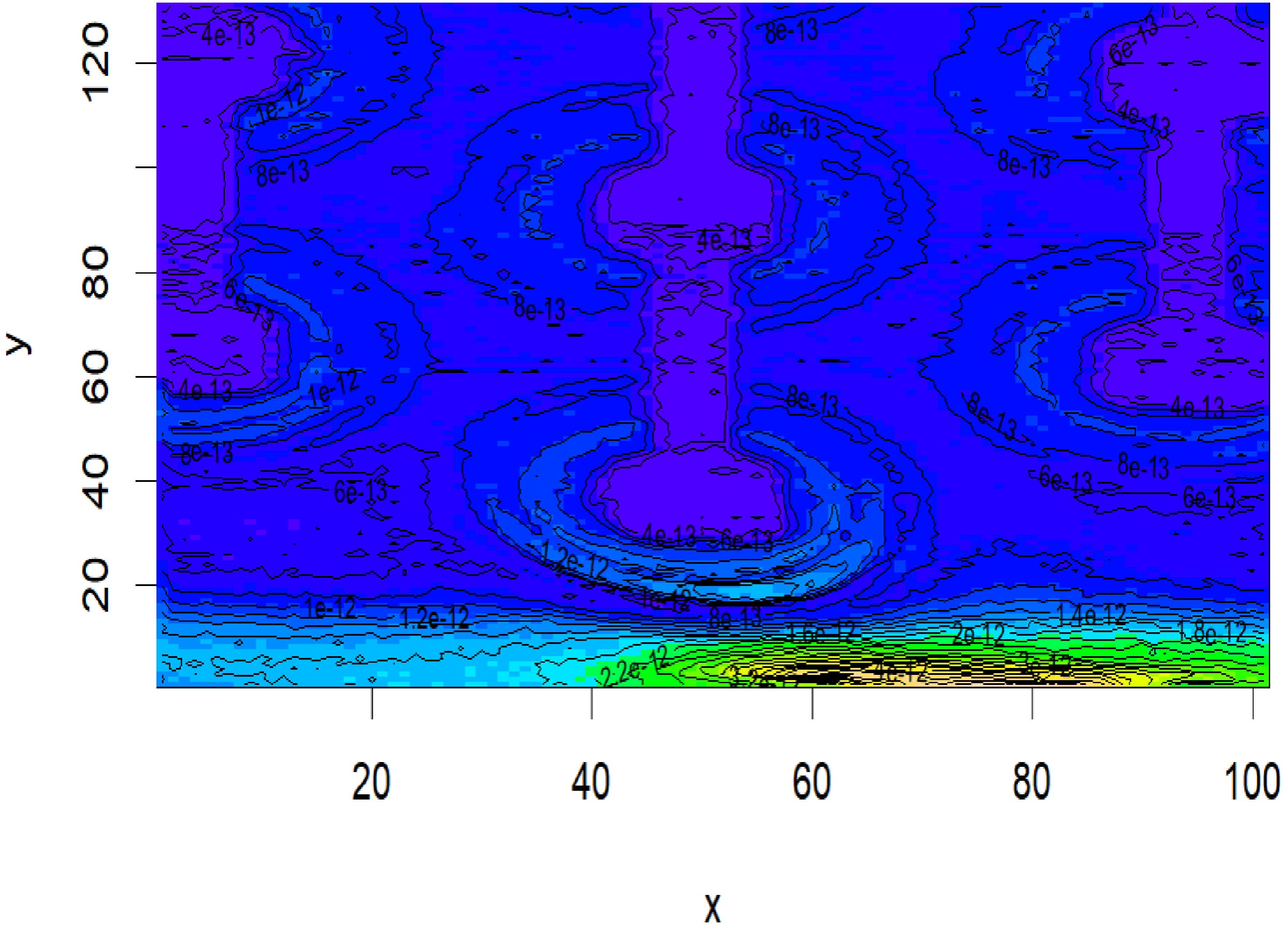
Amplitude Contour Plots
(regions of low and high CCE)

TPA



Charge (arbitrary unit) Contour Plots

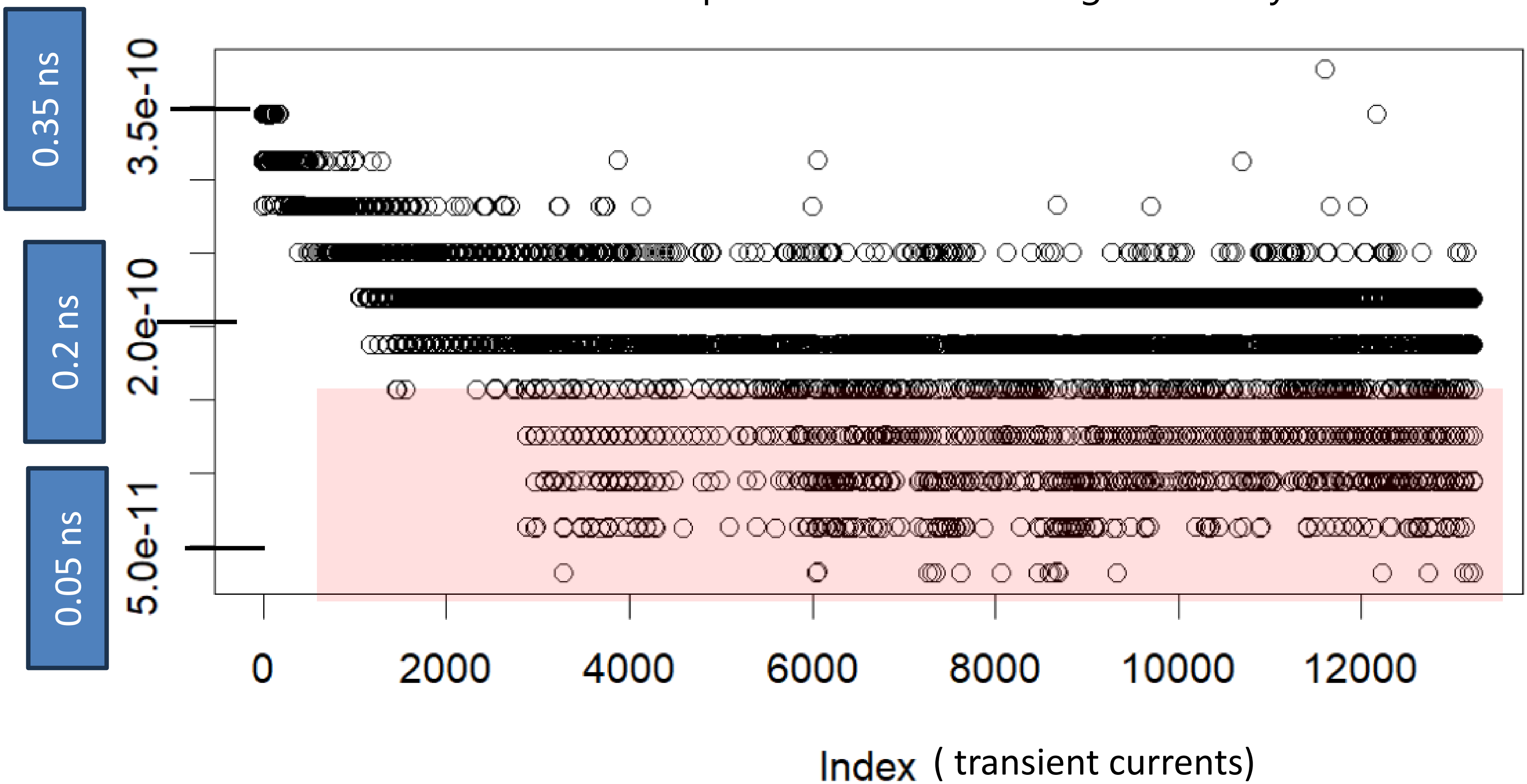
TPA



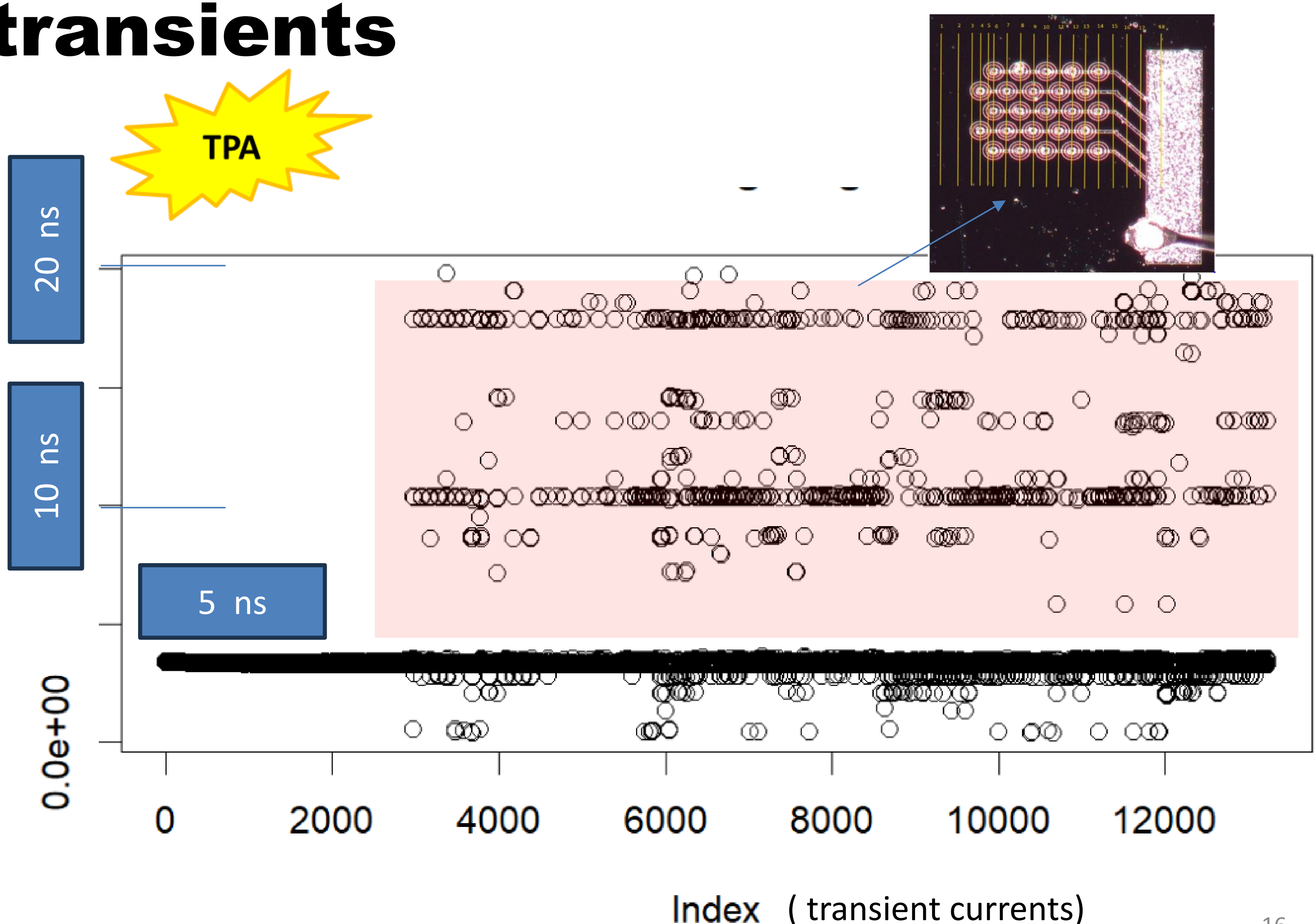
Rising time vs all measured transients

TPA

This plot simply shows that rising time is between 0.35 ns and 50 ps. This plot is important to show how good the system is.



ToA estimated from all measured transients

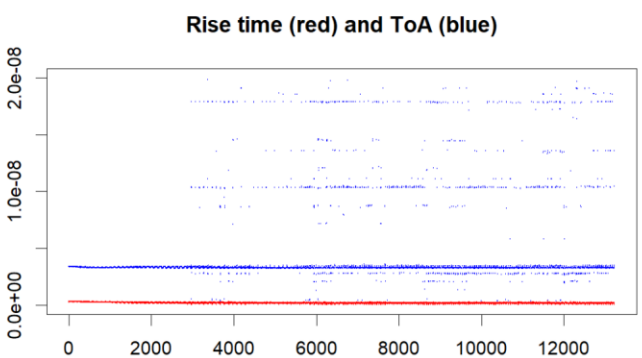


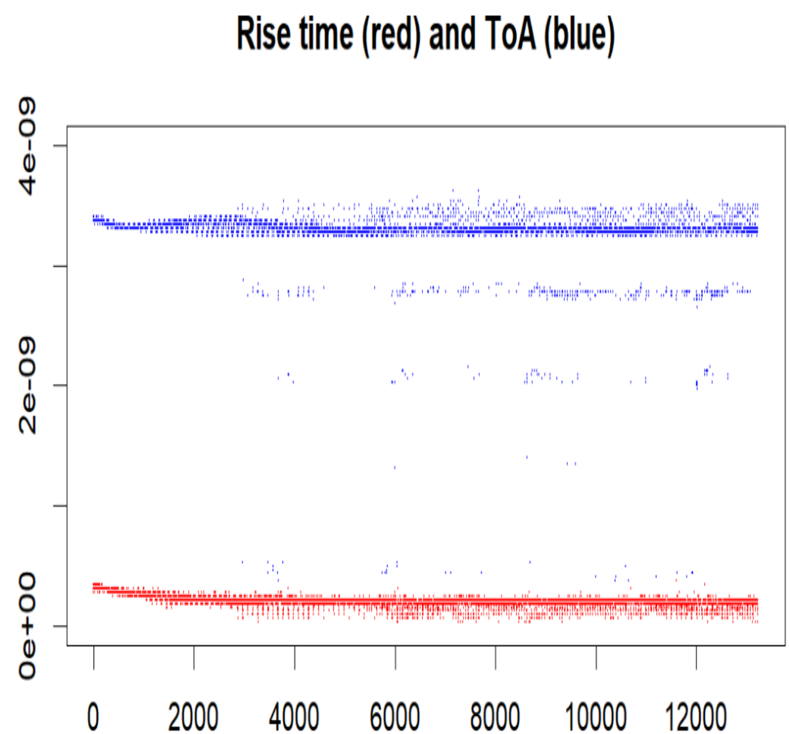
ToA & Rise time comparison for all measured transients

TPA

Mean, Max and Min calculated

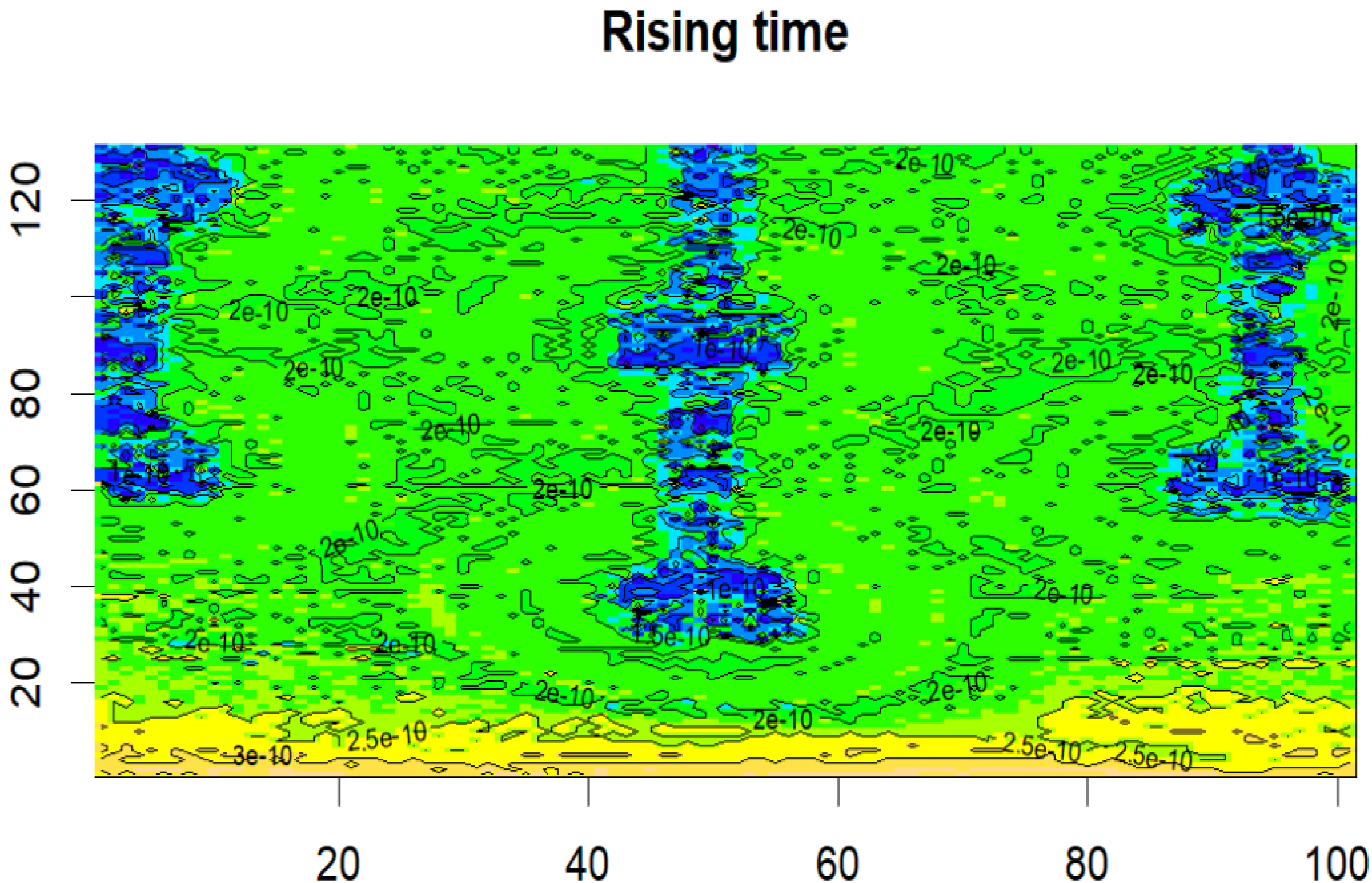
	Min	Median	Mean	Max
Rising time	0.04ns	0.218ns	0.219ns	0.375ns
ToA	0.375ns	3.31ns	4.02ns	19.8ns





Rising time contour plot

TPA

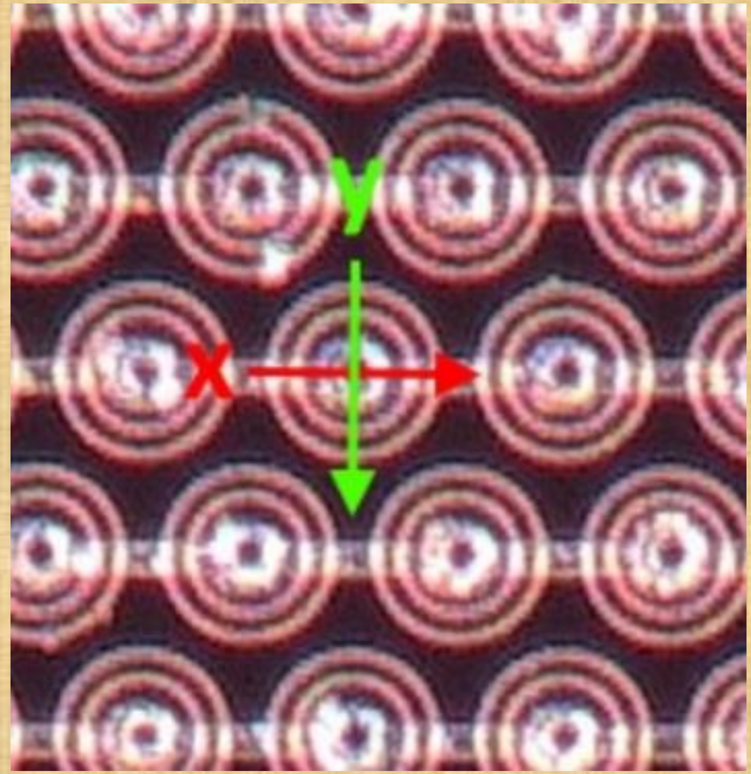


SPA

2nd approach

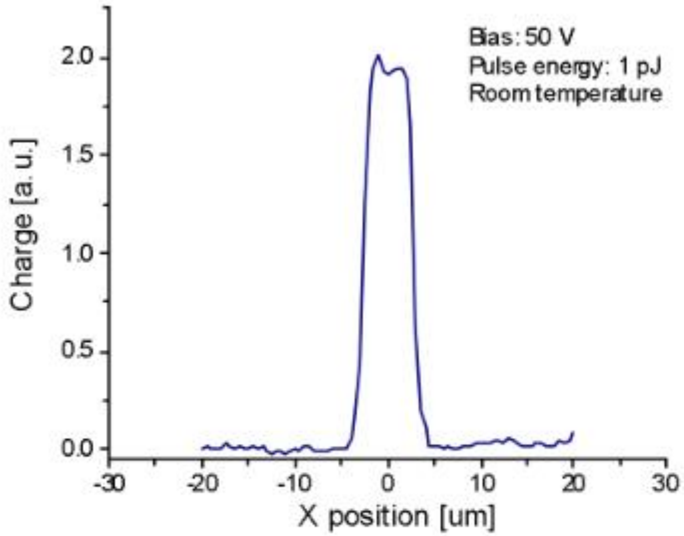
X and Y scanning along n+ electrode

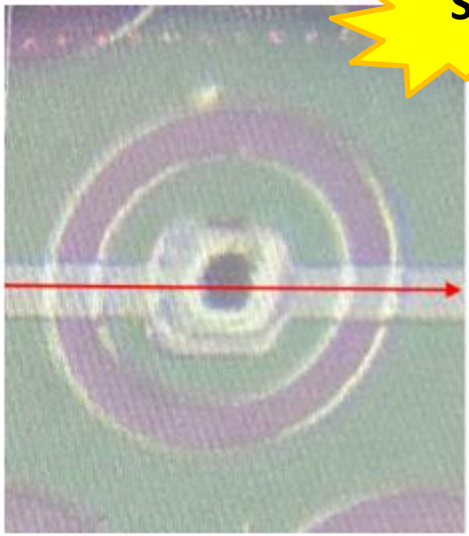
We applied this approach to test and verified the sensitivity of our research tool on small changes in electric field (not known to us if the electrodes are filled with poly si or not)

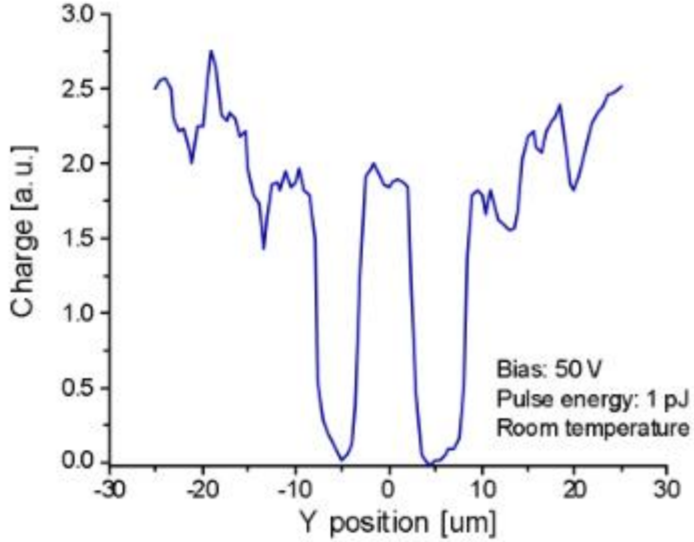


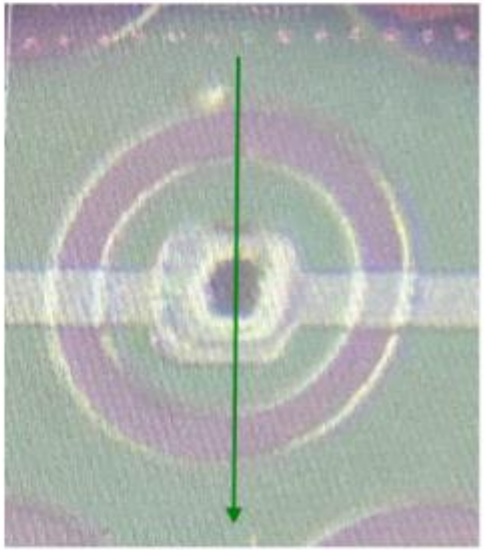
X & Y Profile through Central Rode

SPA



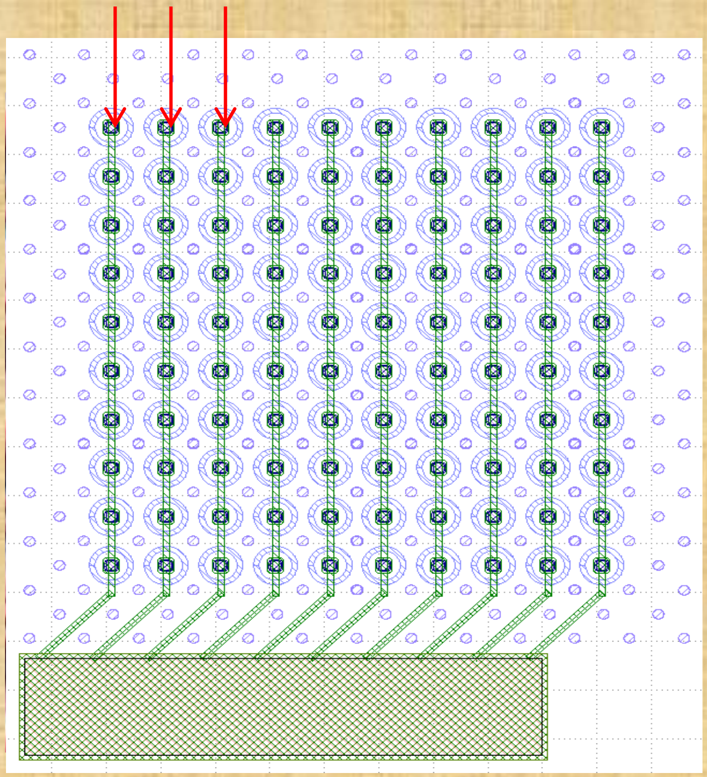






SPA

3rd approach



N+ and P+ are precisely shooted by laser at certain positions using SPA

We wanted to see how charge is collected in a small field above the column, and how efficient the columns are.

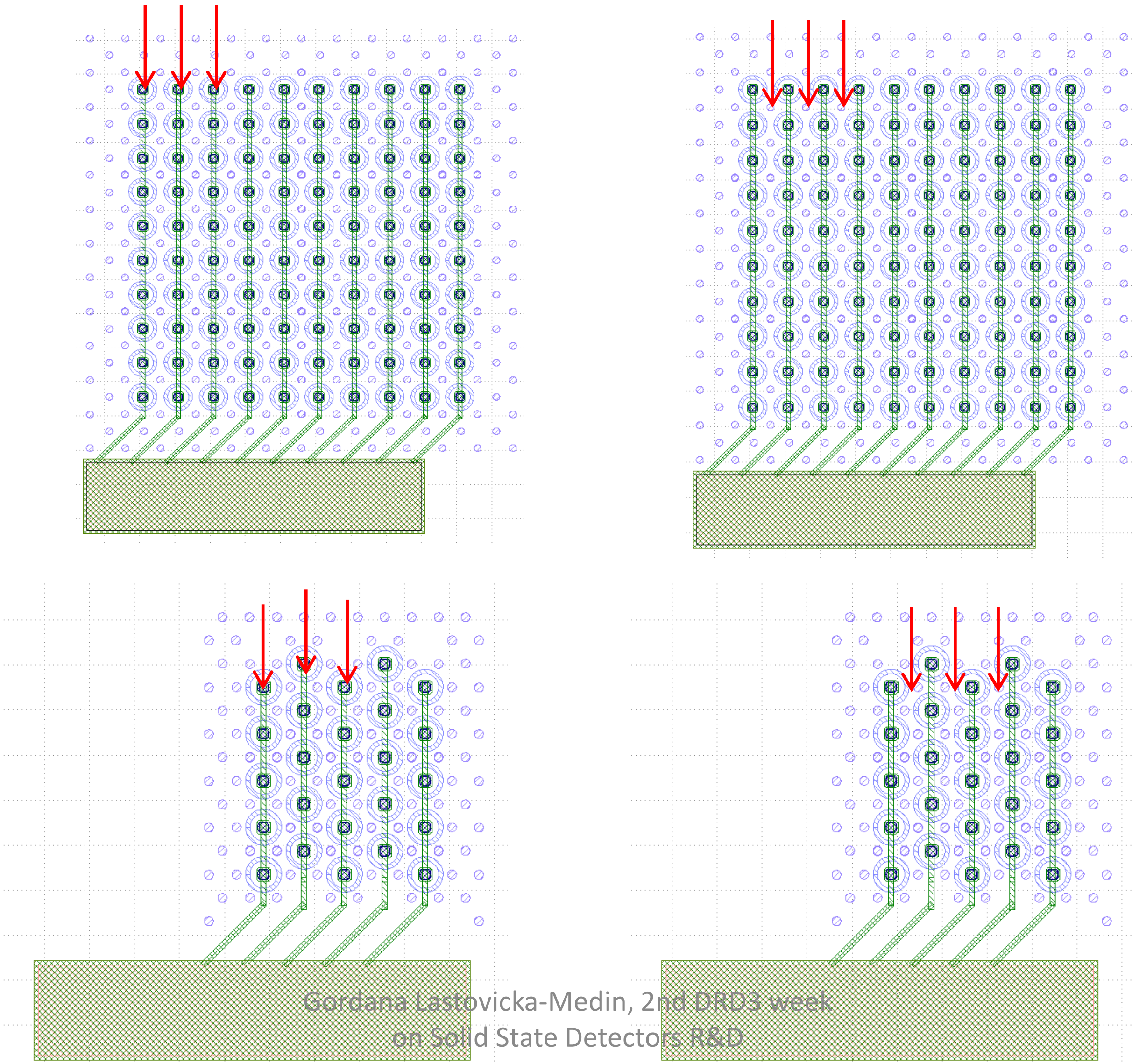
SPA with fs-laser beam of 800 nm wavelength seems to be excellent tool for studying the low field region (where no overlapping region between n+ and p+ ex9st or if exists it is a very small, few microns.

To get fully comparable data from different cells the set of single cell measurements was performed. One bunch of data was recorded for N+ columns where the laser was focused exactly on the center of metallic ring. The second set was recorded for P+ columns, exactly in the middle between N+ columns (as depicted below).

N+ columns | **P+ columns**

SQUARE

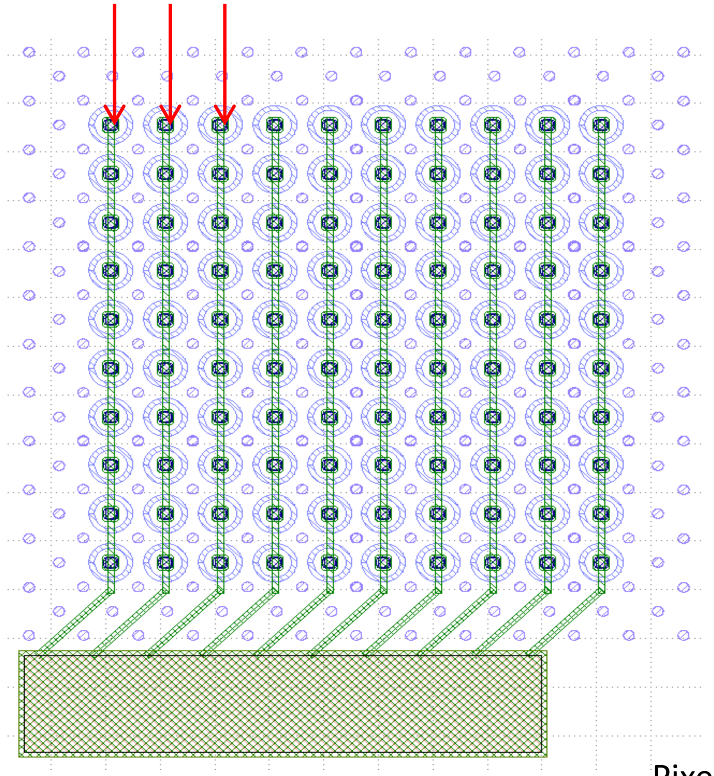
HEX

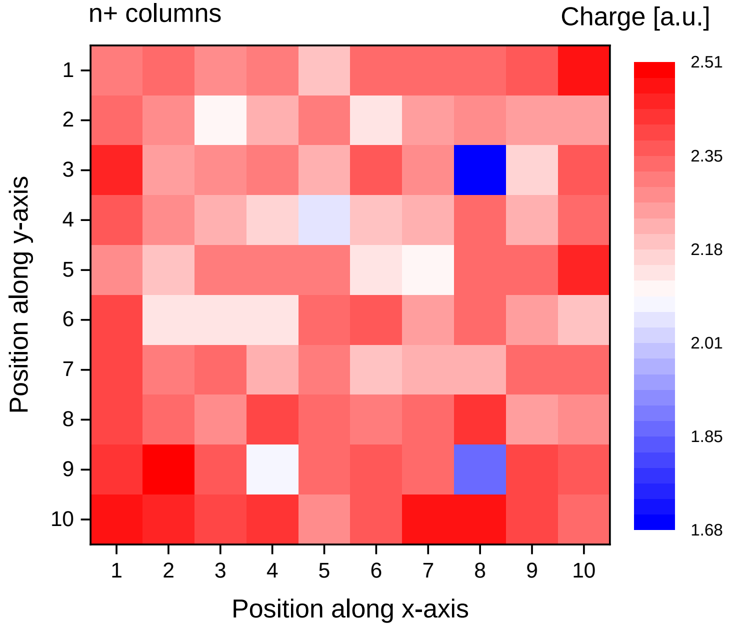


N+ columns (Charge) SQUARE 3D

SPA

Laser focused exactly on the center of every n+ column (hole in metallic structure)

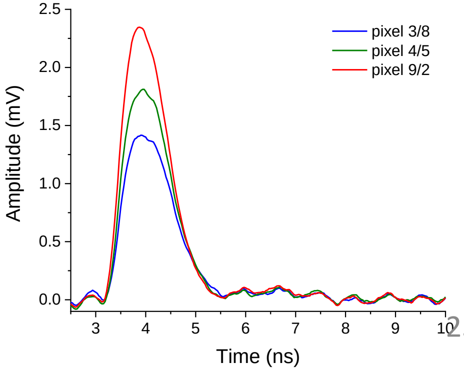




49%

Pixels correspond to individual n+ columns in 10 x 10 array

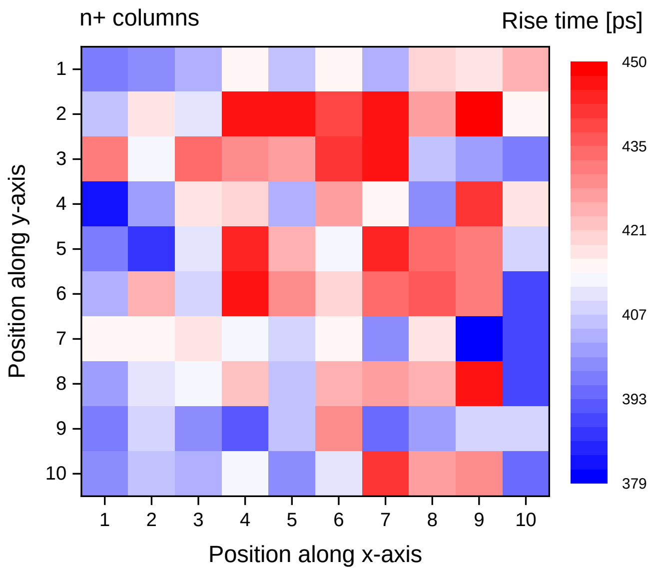
Charge is not completely homogenous over all the columns but it doesn't create any specific pattern. In some cases the metallic structure is not very nice and obscure the hole what can result in reduced signal like in pixel 3/8 (it means electrode in 3rd row and 8th columns)



N+ columns (RiseTime) SQUARE

SPA

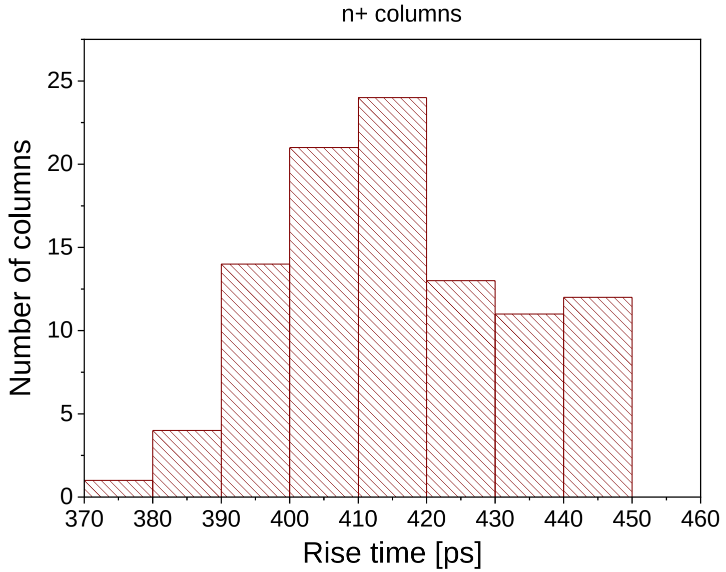
Rise time calculated as time between the moments when signal reaches 10% and 90% of amplitude



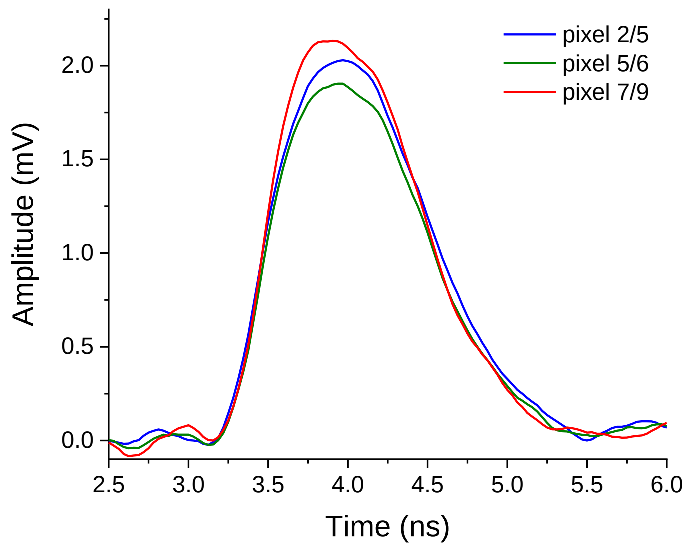
Rise time varies from column to column but it's random variation and doesn't create any specific pattern across the array

19%

Statistical distribution of rise time over all n+ columns of the sensor



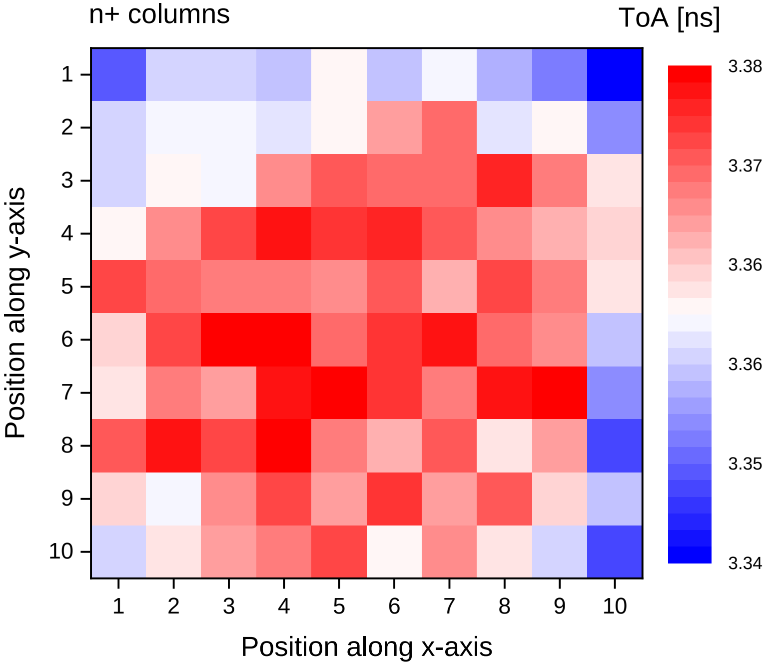
Example waveforms corresponding to the pixels exhibiting different rise time



N+ columns (TOA)

SQUARE

SPA

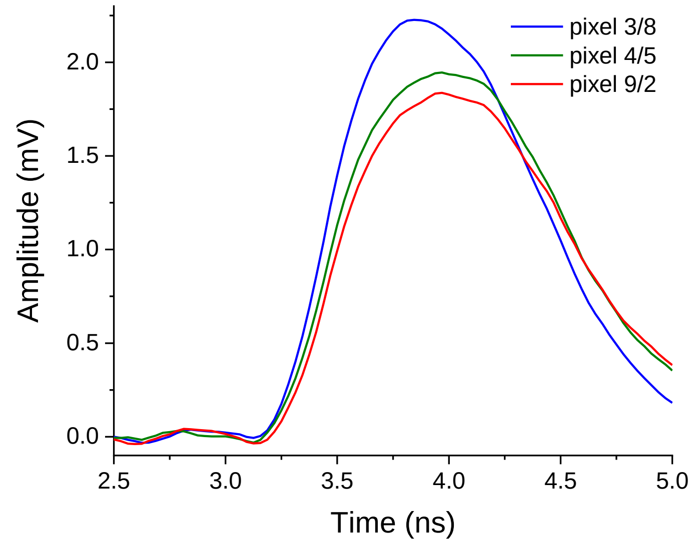


3.38 ns

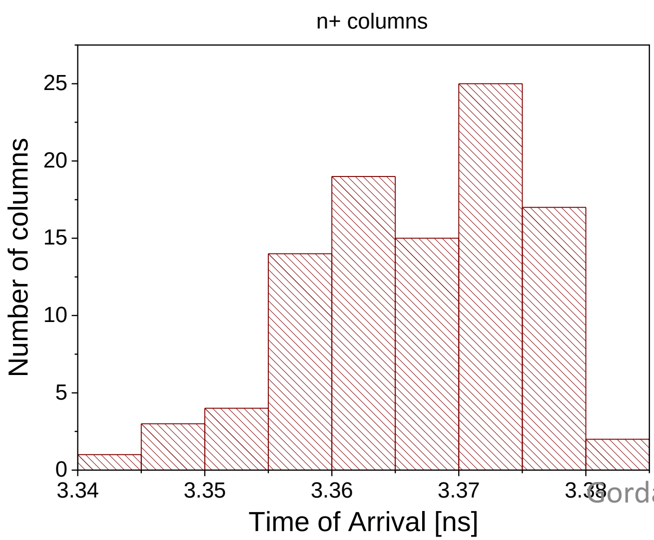
3.34 ns

Maybe it's only coincidence but ToA seem to create a certain pattern. In the central pixels the signal arrives later than in the outer ones.

Example waveforms corresponding to the pixels exhibiting different ToA

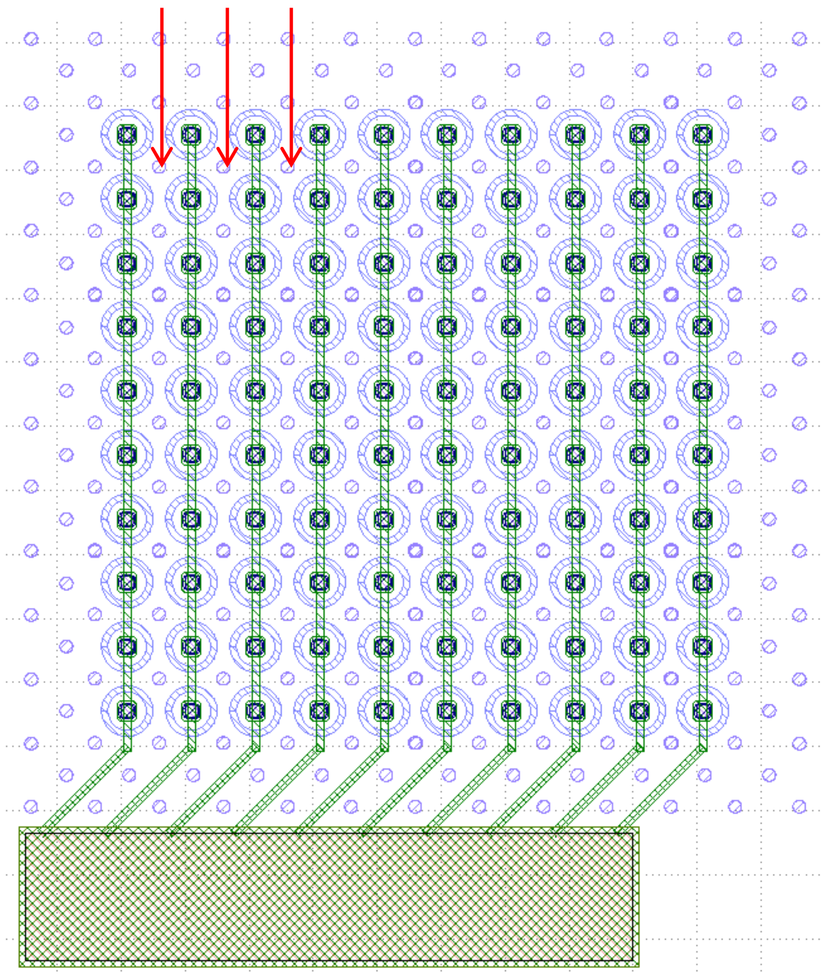


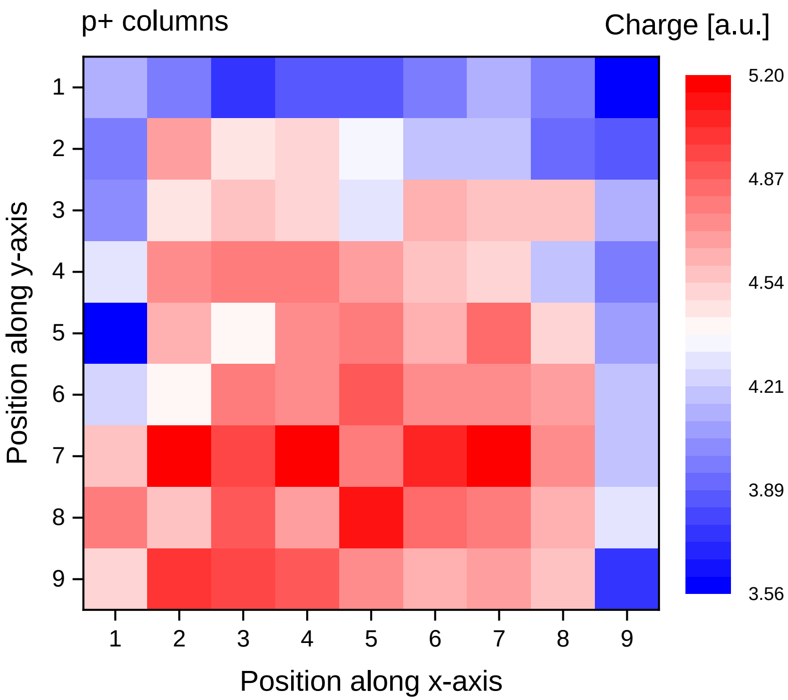
Statistical distribution of ToA over all n+ columns of the sensor



P+ columns (Charge)

Laser focused exactly on p+ electrodes (between neighbor n+ electrodes)

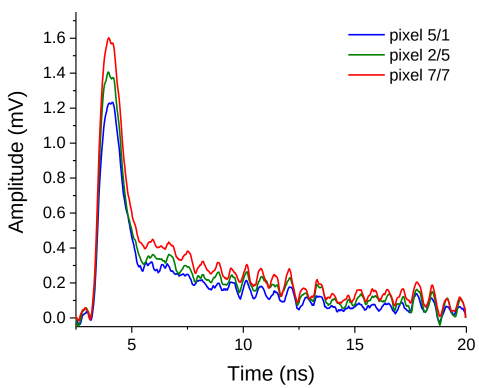




46%

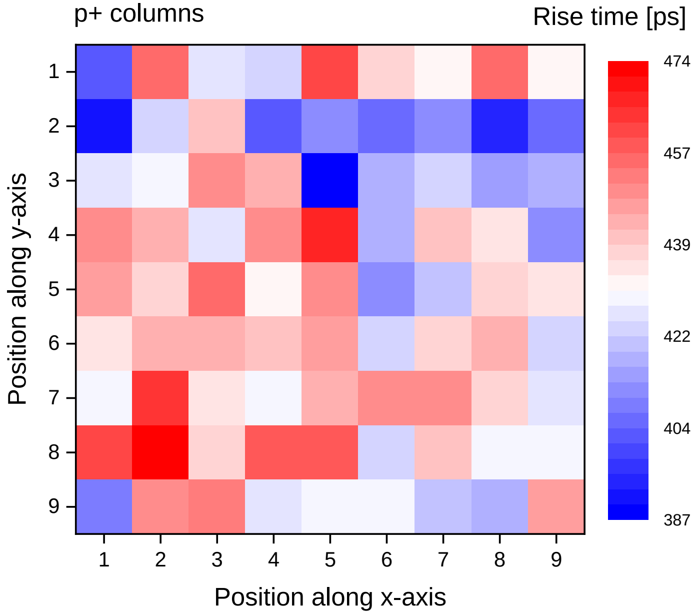
Pixels correspond to individual p+ columns in 9 x 9 array

Here it seems that more charge is generated in lower part of the layout (closer to connector bar)



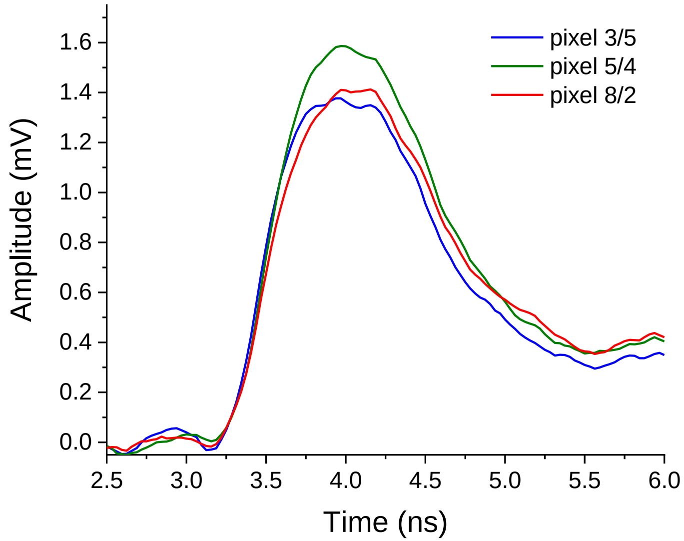
P+ columns (Peak Rise Time) SQUARE

SPA

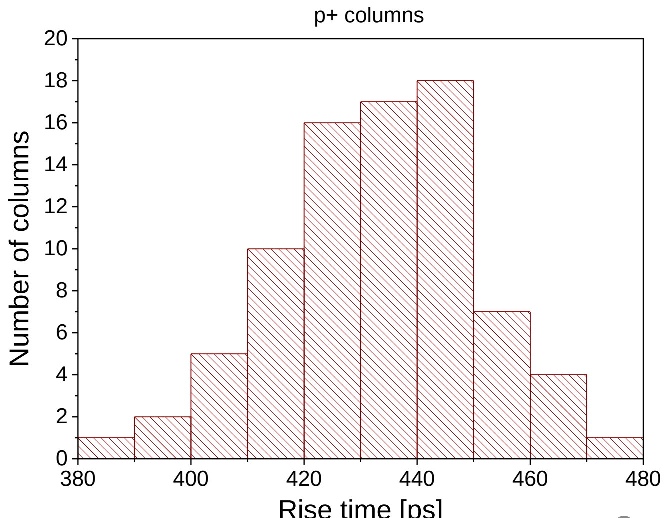


Rise time here is completely random over the p+ columns layout

Example waveforms corresponding to the pixels exhibiting different rise time

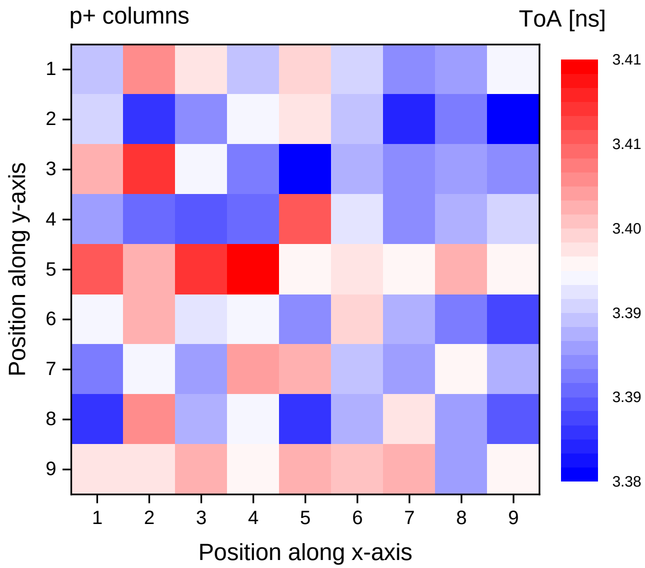


Statistical distribution of rise time over allp+ columns of the sensor



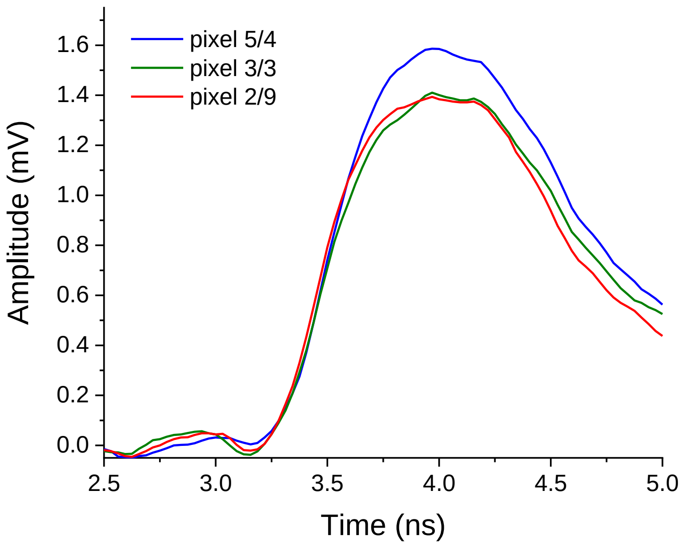
P+ columns (Arrival Time)

SQUARE

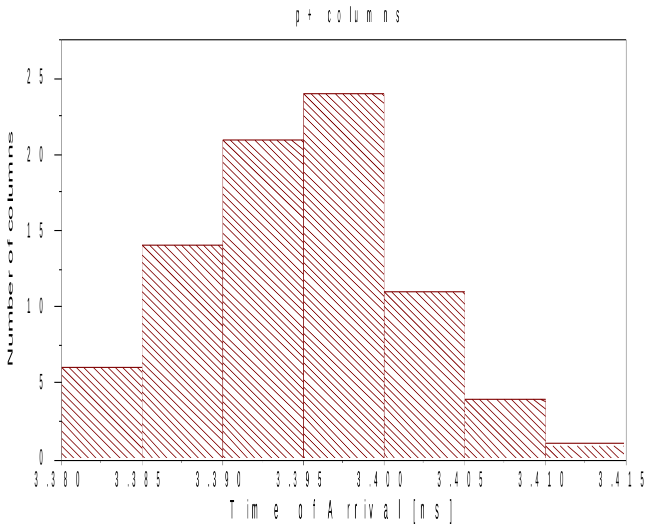


ToA is also random over p+ columns not giving any pattern.

Example waveforms corresponding to the pixels exhibiting different ToA



Statistical distribution of ToA over all p+ columns of the sensor

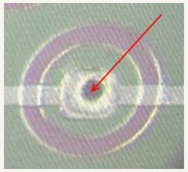


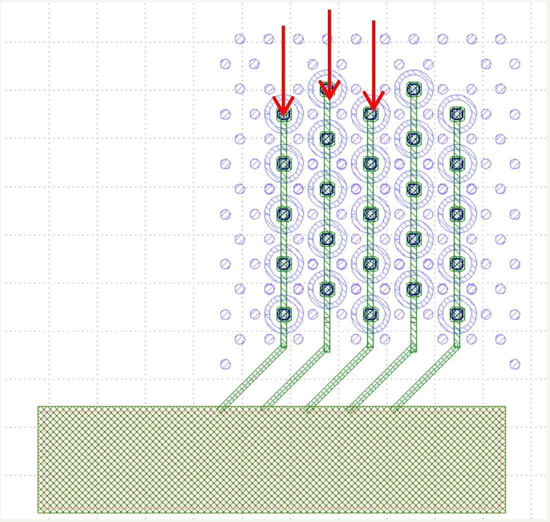
N+ columns (Charge)

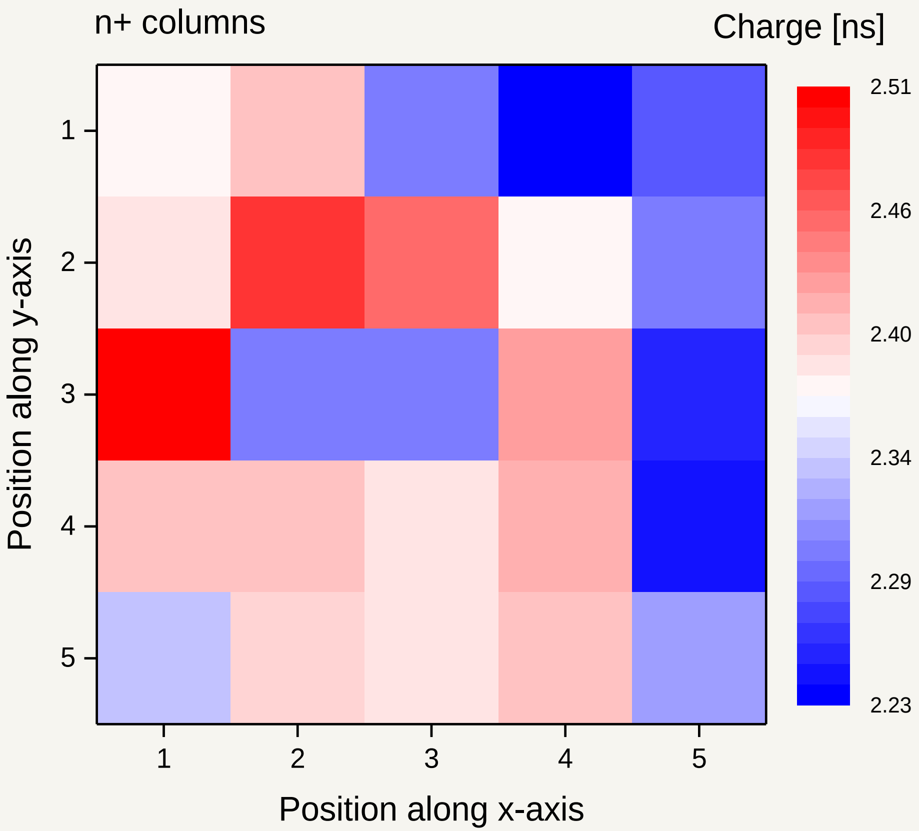
HEX

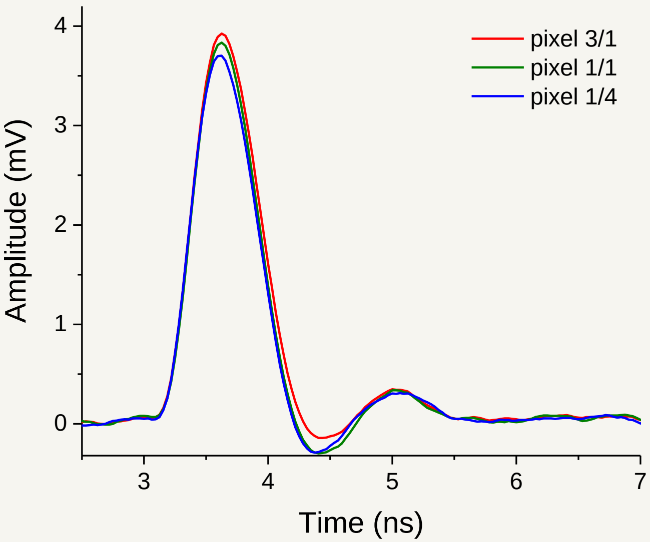
SPA

Laser focused exactly on the center of every n+ column (hole in metallic structure)





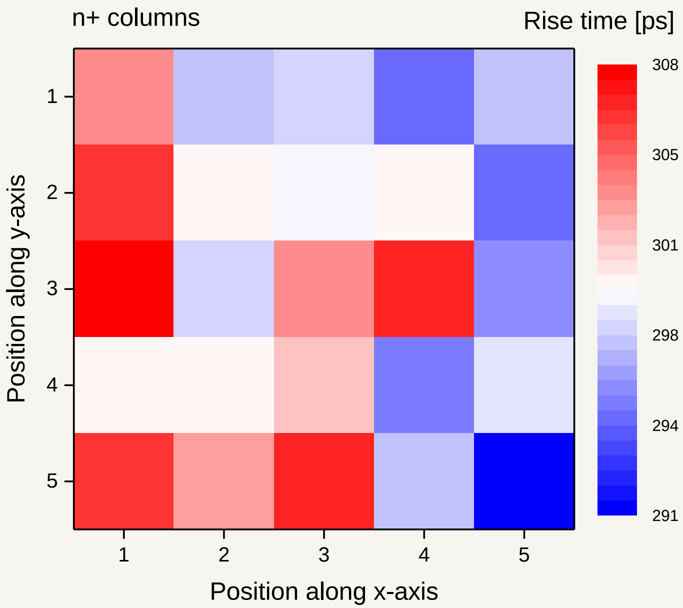




N+ columns (Rise Time)

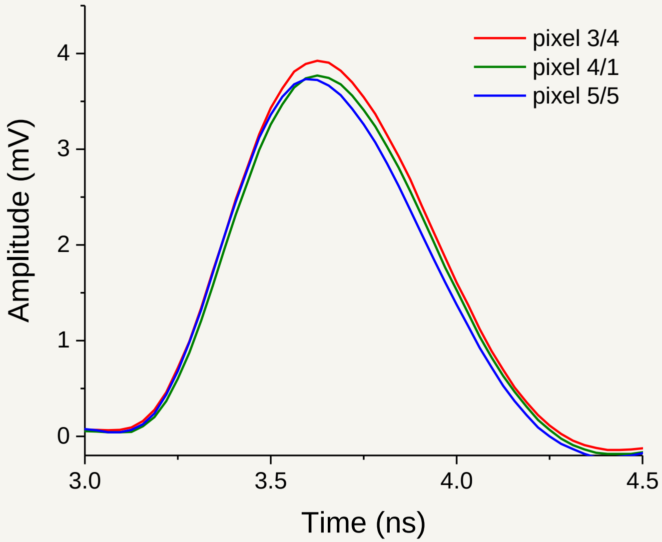
HEX

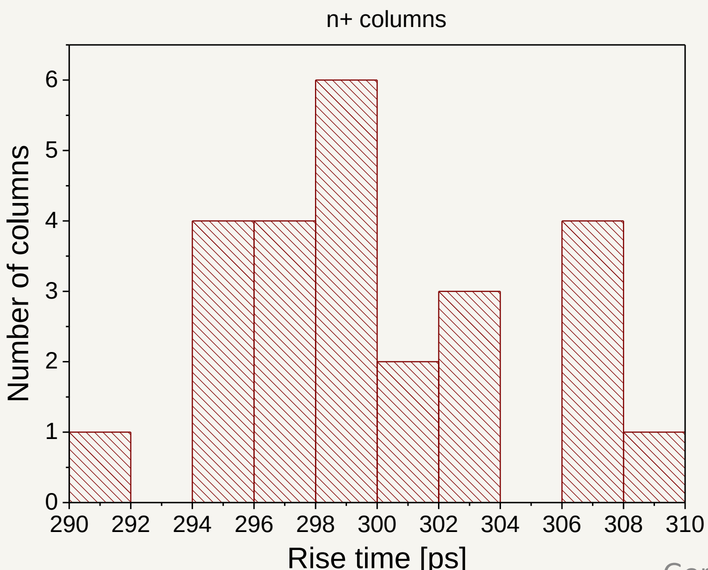
Rise time calculated as time between the moments when signal reaches 10% and 90% of amplitude



308 ns

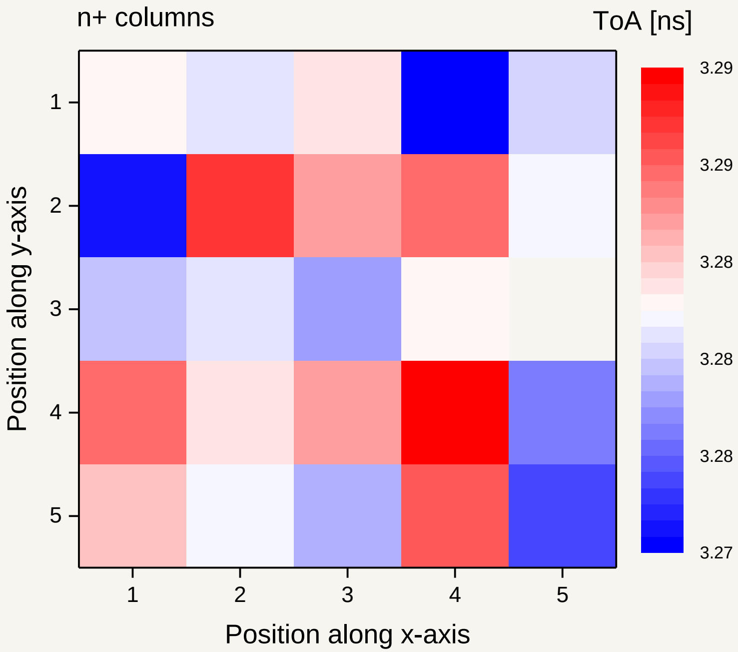
291 ns





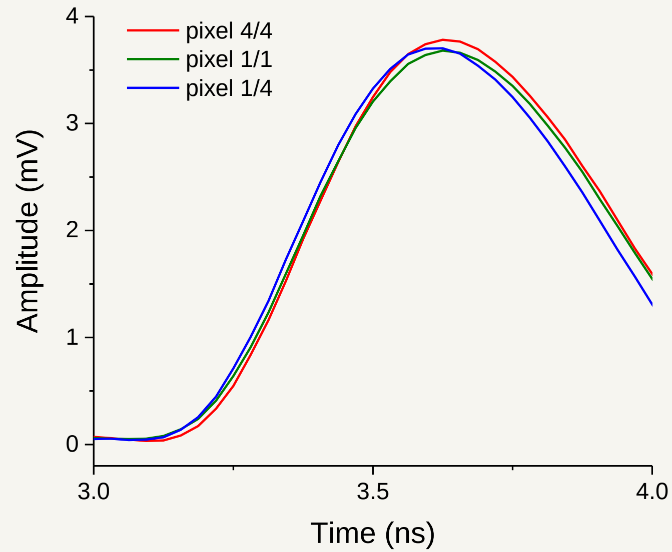
N+ columns (TOA)

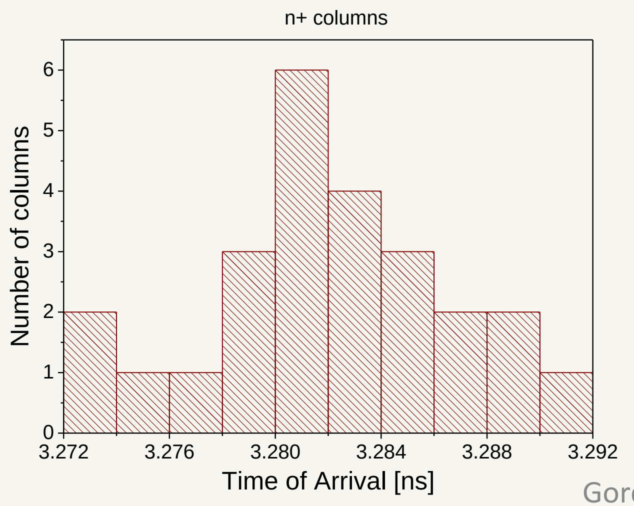
HEX SPA



3.29 ns

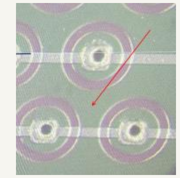
3.27 ns





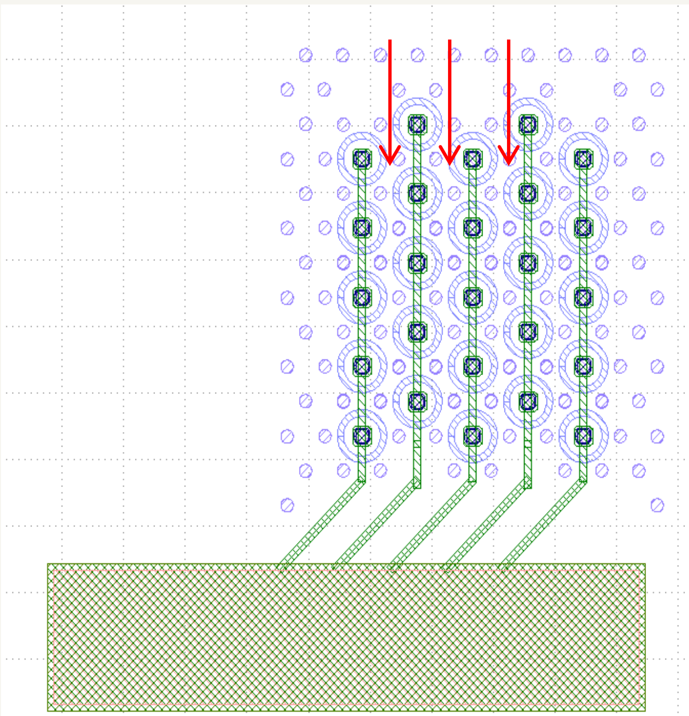
P+ columns (Charge)

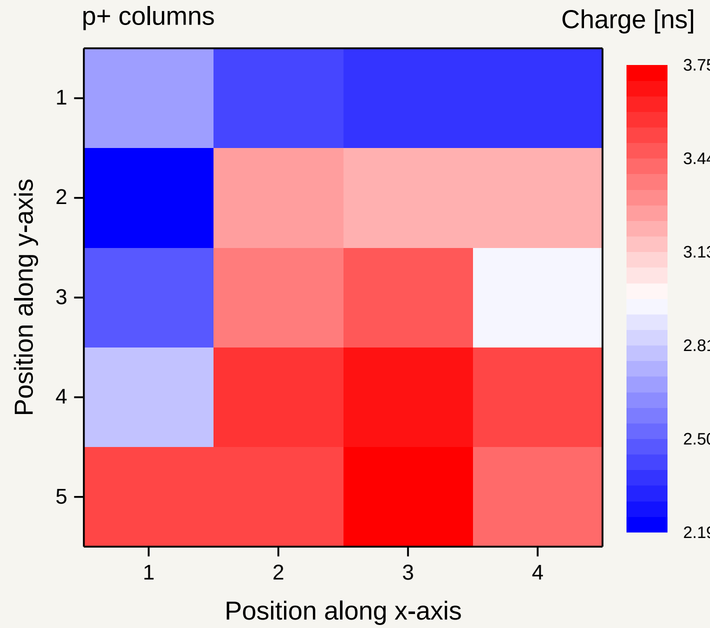
HEX

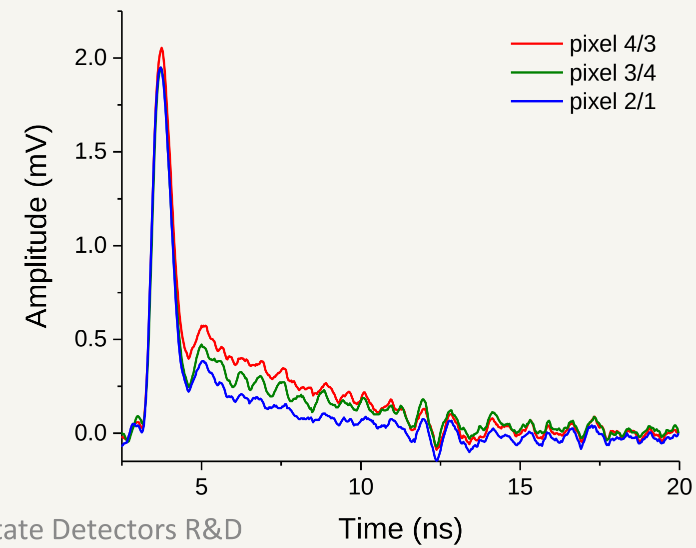


SPA

Laser focused exactly on p+ electrodes. Only electrodes laying between neighbor n+ electrodes were measured (therefore array is 4x5)

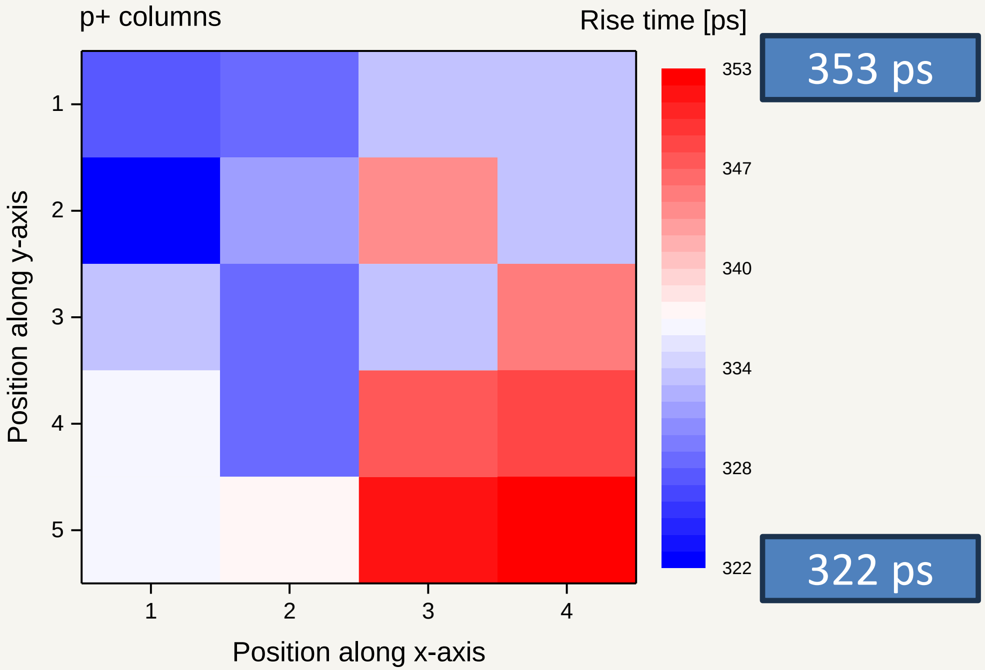


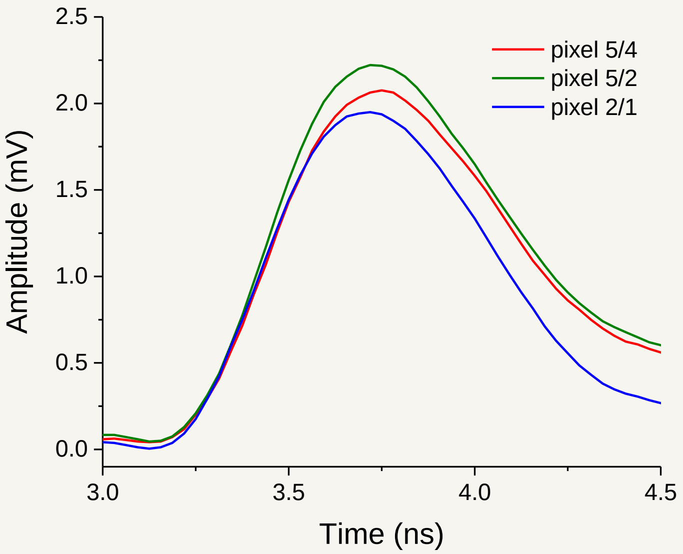


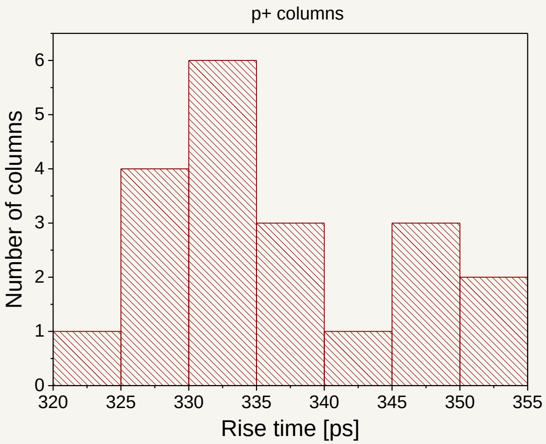


P+ columns (Rise Time)

HEX SPA

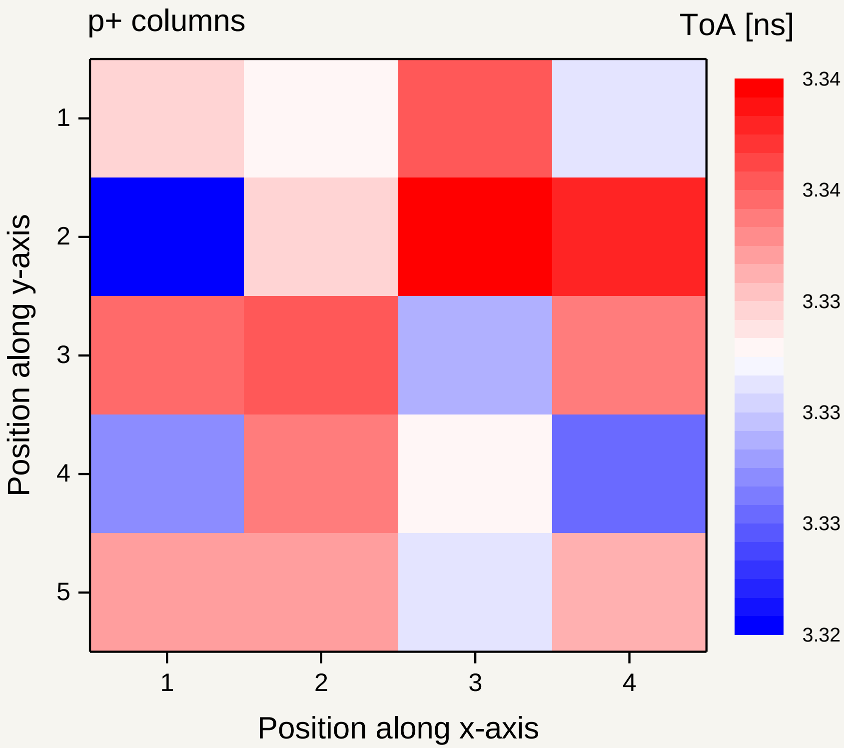






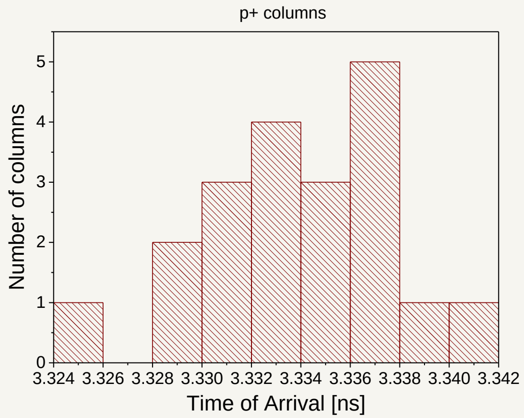
P+ columns (TOA)

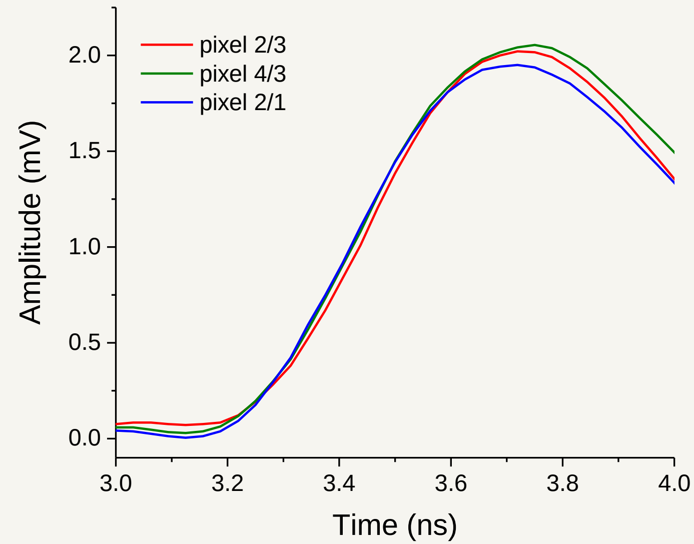
HEX SPA



3.34 ns

3.32 ns





Conclusions & Future Steps

- ELI beam (and ELI TCT) has been demonstrated to be the excellent tool for studying the 3D detectors, due to its 50 fs pulses, high intensity (TPA option) and super focusing performance.
- The first experimental run showed the rise times comparable to the expected ones and pulses of 1 ns were precisely measured.
- Both TPA and SPA were successfully used to probe ToA, rise time and charge collection efficiency over the RD50 3D cells.
- The signals will be simulated with the KDetSim to compare the measurements and results.
- 3D scans (TPA) over full depth of 3D sensors are ready completed; we presented only TPA data at the senot's depth of 35 microns. Full data analysis will be completed soon.
- We plan do perform wavelength scans exploiting SPA at ELI (this is possible based on the Optical Parameter Amplification), including 1065 nm. This will be compared with the TPA data measured at the different depths. This will help us to understand effect of clipping as well.
- SPA in lab with 1064 nm will be also tried.

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Thank you ☺