Timing resolution and CCE of irradiated n-on-n 3D silicon sensors with TCT

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  - Timing 2D map – 1e17n_{eq}/cm^2
- Small pixel array
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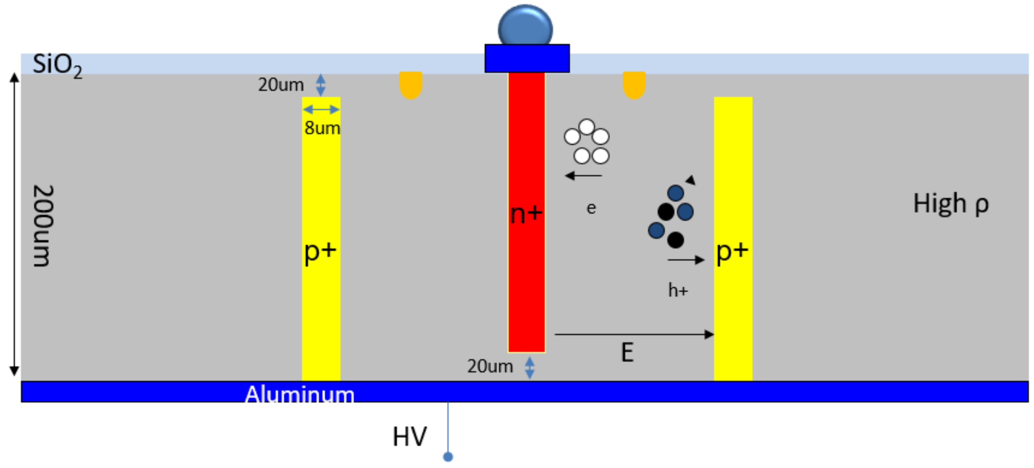
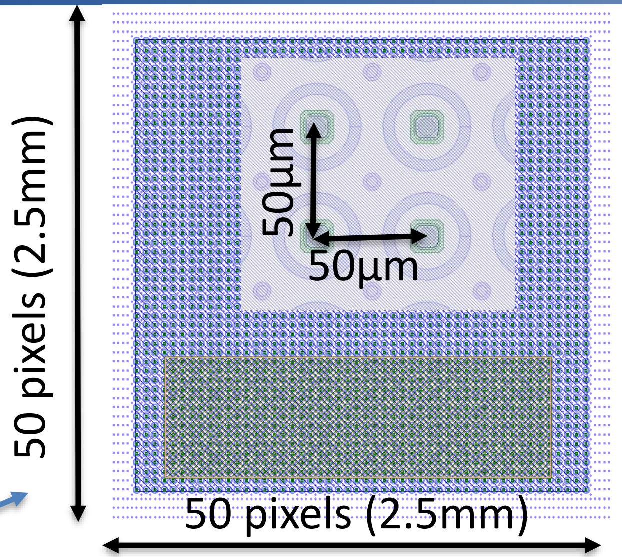
  - Timing resolution
- Conclusions and future work

DUTs

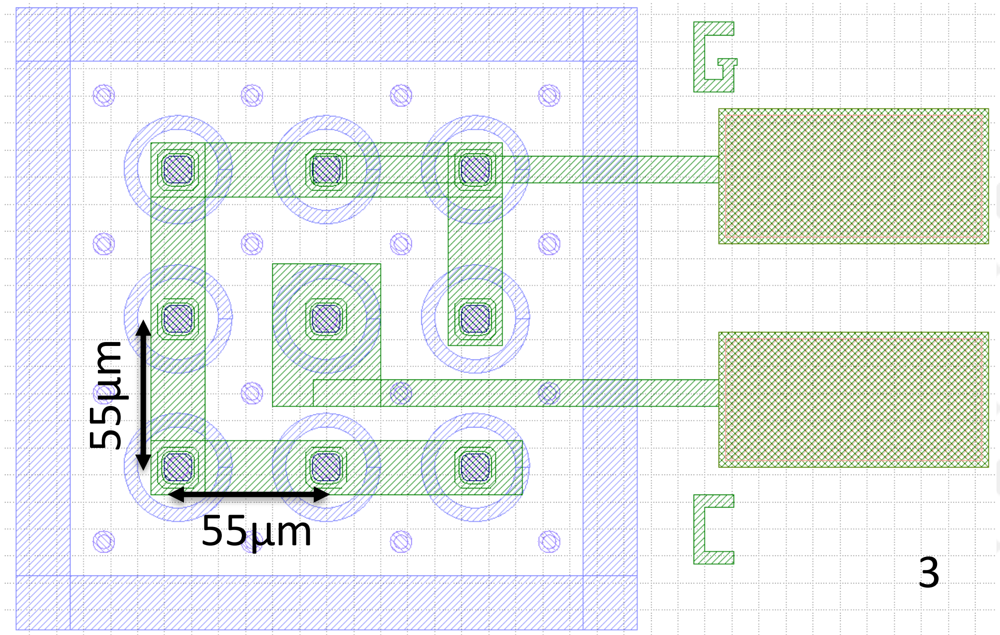




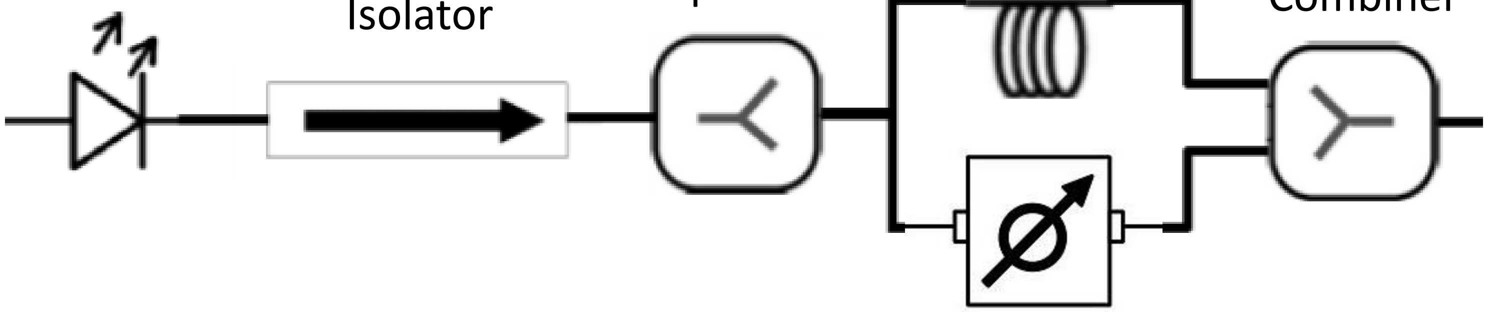
Timing limited by noise induced by large capacitance (~81pF for $1e14 n_{eq}/cm^2$)

Hi Resistivity (>5kOhmxcm), **n-type** -Fz Silicon
Wafer thickness: 200µm
Active thickness: 200µm
Double-sided process
Two types of sensors tested
Irradiation campaign – from both type, neutron irradiated at fluences:

- $1e14\ n_{eq}/cm^2$
- $1e15\ n_{eq}/cm^2$
- $5e15\ n_{eq}/cm^2$
- $1e16\ n_{eq}/cm^2$
- $5e16\ n_{eq}/cm^2$
- $1e17\ n_{eq}/cm^2$



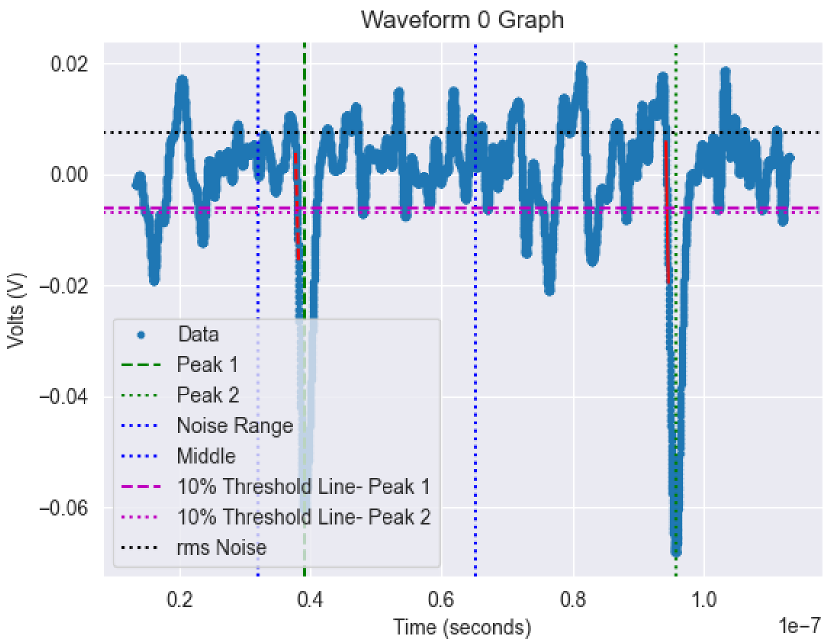
TCT Timing Setup



- IR laser Split into two paths.
- One path, delays the laser pulse roughly 56ns. This pulse is used as the reference signal.
- The second is attenuated to compensate the loss of light from the delaying cable.
- The two pulses are recombined and illuminates the DUT.
- Amplified with 40dB CIVIDEC amplifier.
- Signal processed at oscilloscope of 2.5GHz, with 16GSa/s.

Timing data analysis

- Script in python.
- Reads csv data, transforms into array.
- Finds every peak with a quadratic fit of 6 points, and removes outliers.
- At different CFD, gets the difference in time between both peaks using a linear fit to estimate the exact position of the CFD %, and makes the histogram to take the total time resolution.



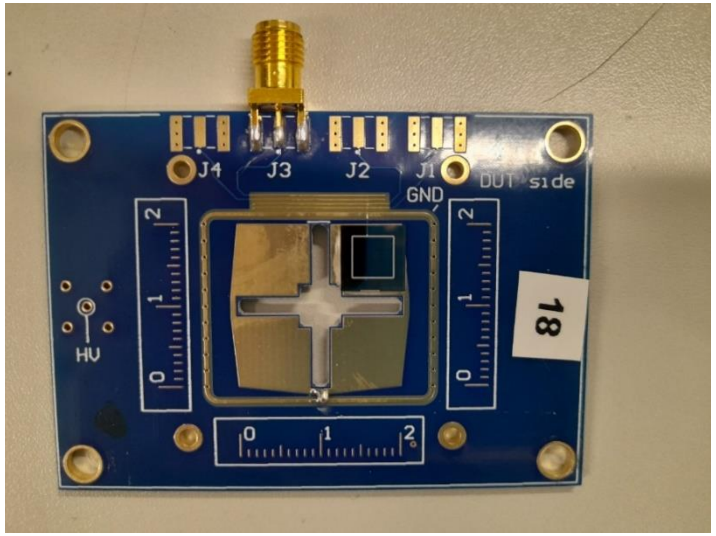
- The time resolution of the sensor is then:

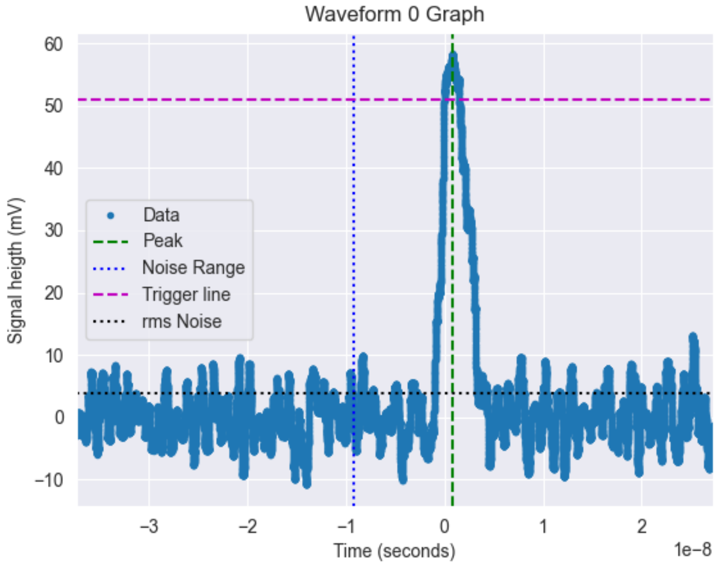
$$\sigma_{Total}^2 = \sigma_{DUT}^2 + \sigma_{Ref}^2 = \sigma_{3D}^2 + \sigma_{3D}^2 = 2\sigma_{3D}^2 \rightarrow \sigma_{3D} = \sigma_{total}/\sqrt{2}$$

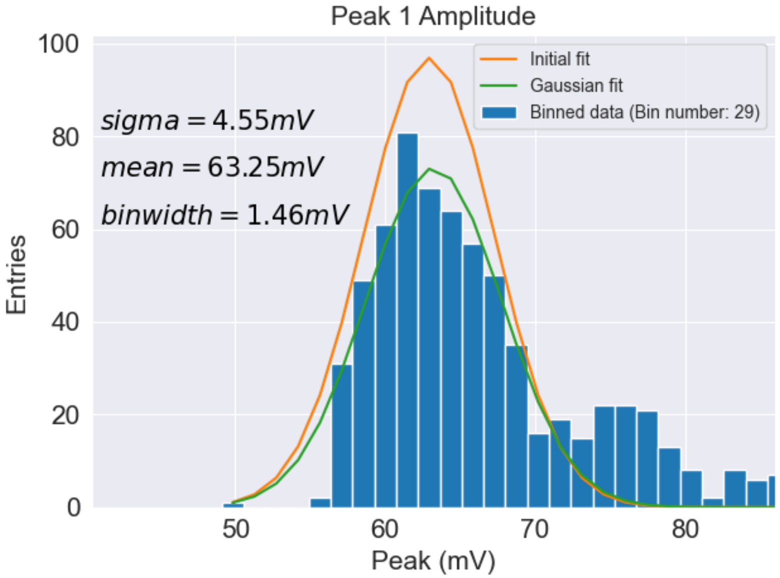
- Since the signal is fast, as an approximation the CCE is calculated from the relation from the peak amplitudes (working on integrating the actual charge).

Signal height calibration with beta source

- Measurements made with diode:
  - 6-4, W1, Run 14002
- PIN 300µm thick
- Self-triggering - trigger level = 51mV
- Room Temperature
- Bias Voltage: 300V
- Mean signal height = 63mV



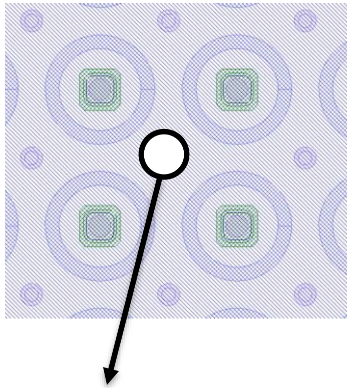


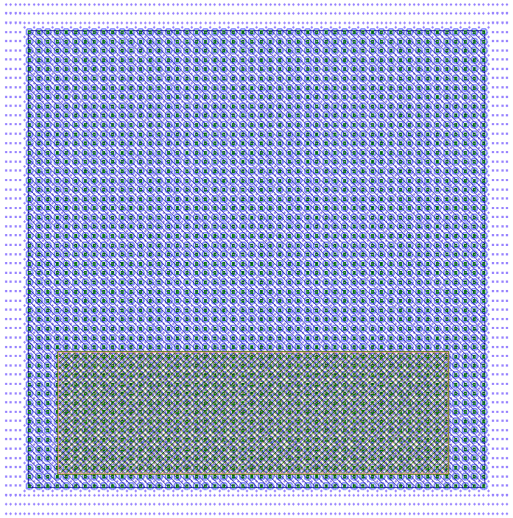


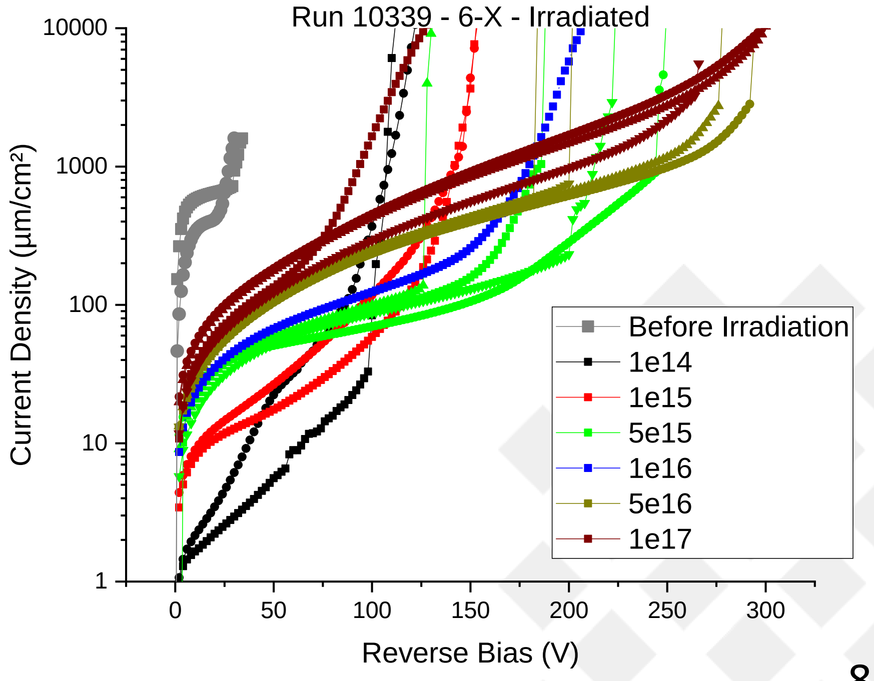
50x50 diode array

Big diode array sensors

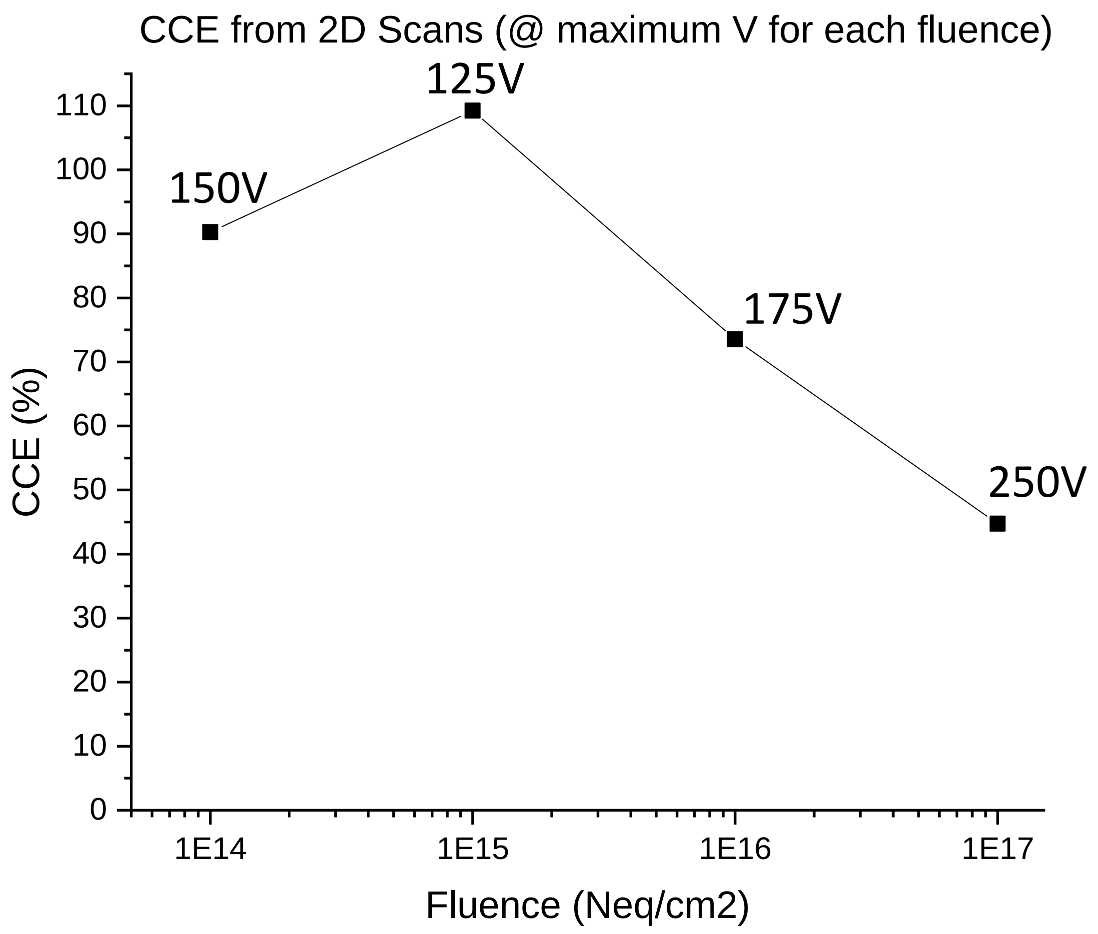
- Measurements performed with the TCT setup @ IFAE.
- 6-X pad diodes from 10339 run (50x50 array, 50µmx50µm pixel pitch), n-type wafer → leakage current decreases after irradiation due to substrate inversion
- Electrodes shorted with highly doped polysilicon to avoid reflection from metal
- Big arrays → high noise due to capacitance (time resolution limited by jitter)
- Measurements at low temperature ~ -18ºC
- Overall spot size of around 15-20µm
- Tested fluence levels:
  - 1e14 n_{eq}/cm^2
  - 1e15 n_{eq}/cm^2
  - 1e16 n_{eq}/cm^2
  - 1e17 n_{eq}/cm^2

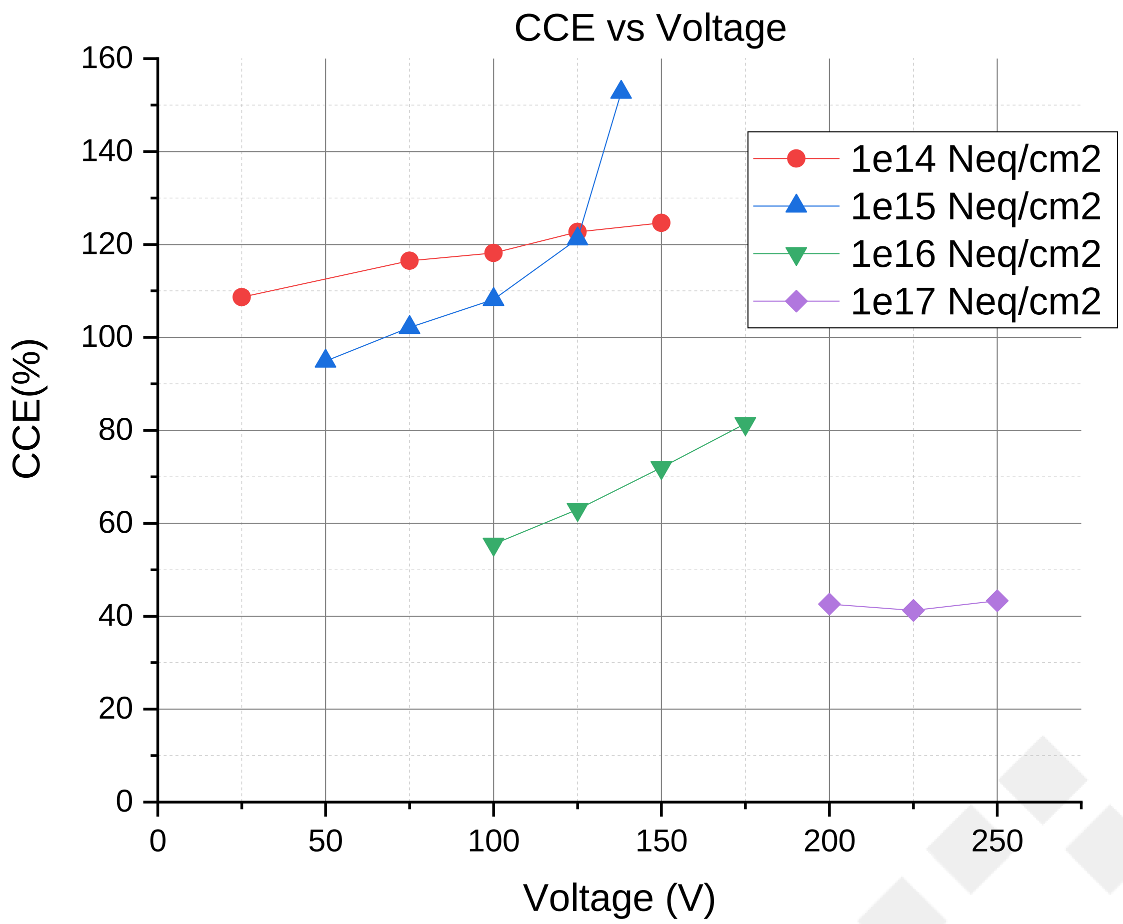






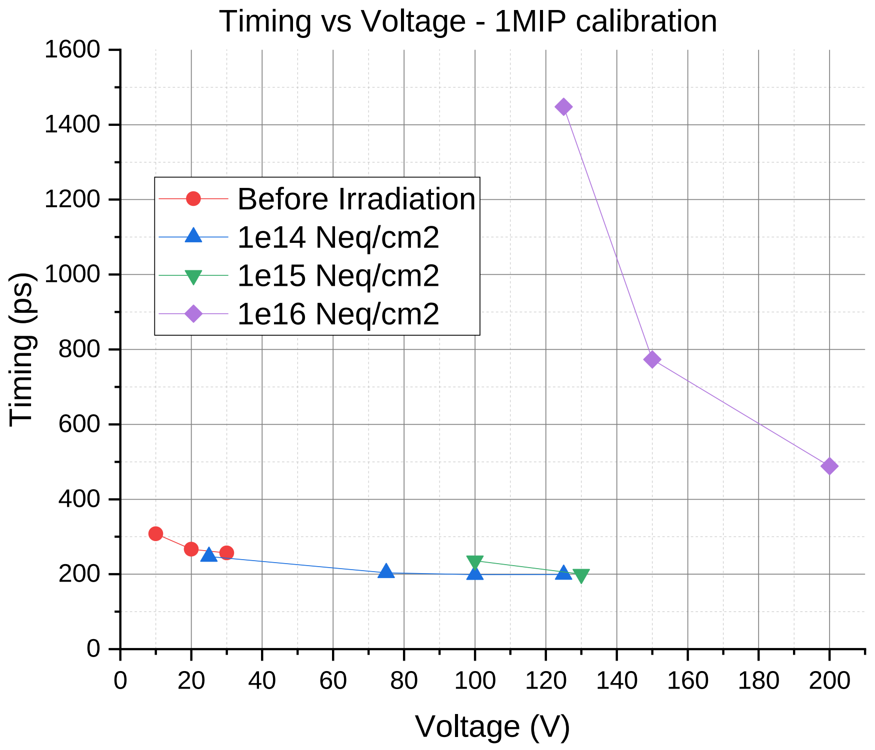
Charge collection efficiency

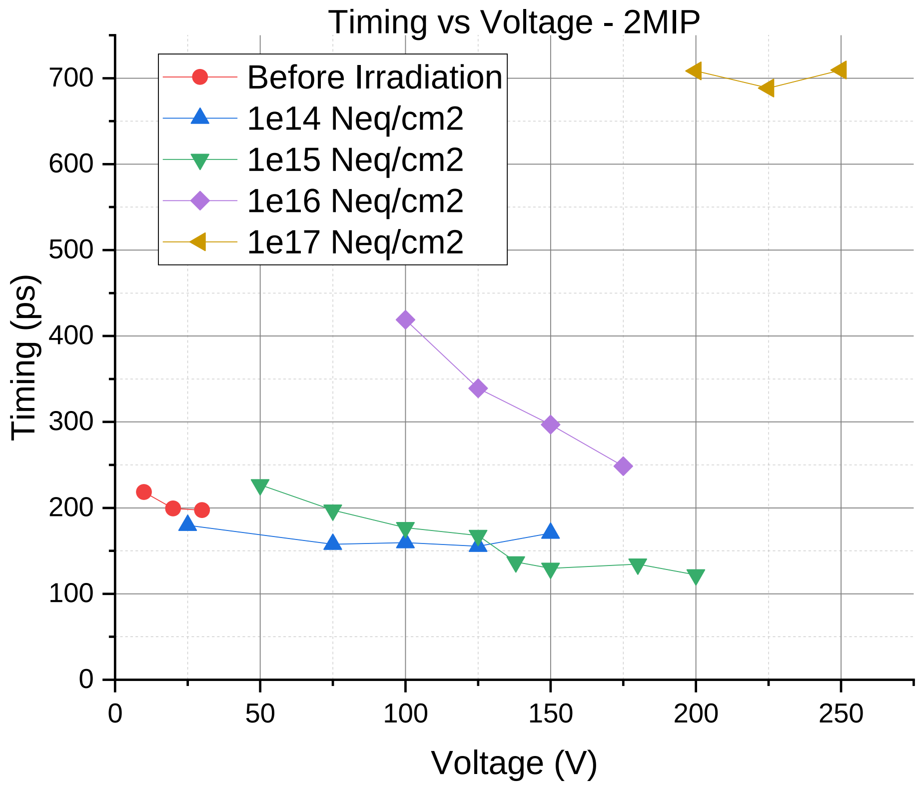




CCE ranging from >100% up to 1e15n_{eq}/cm^2 to 43% for 1e17n_{eq}/cm^2

Time resolution

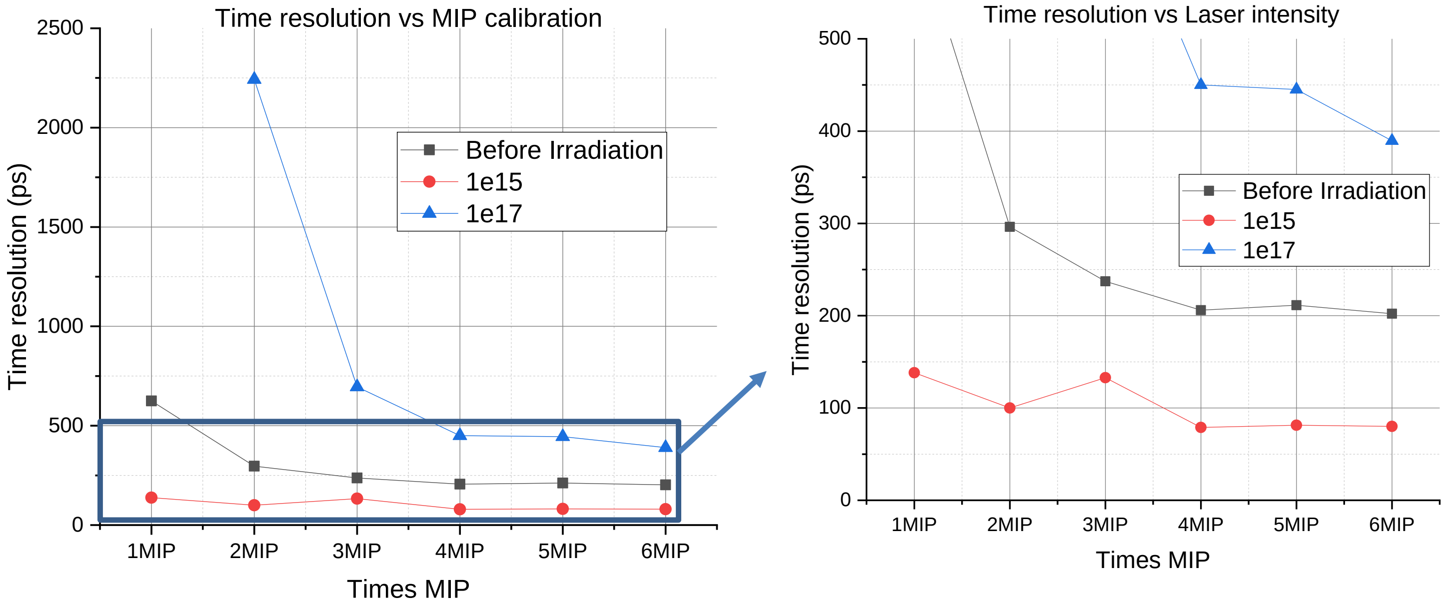




- Time resolution limited by noise due to large capacitance (~81pF for $1e14n_{eq}/cm^2$)
- Timing resolution of 200.16ps up to $1e15n_{eq}/cm^2$ and 488,47ps for $1e16n_{eq}/cm^2$.
- Time resolution of 675ps for $1e17n_{eq}/cm^2$ → SNR too low even for 2MIP calibration due to large pixel array

  → Necessary to measure with small pixel array

Effect of laser intensity on timing resolution

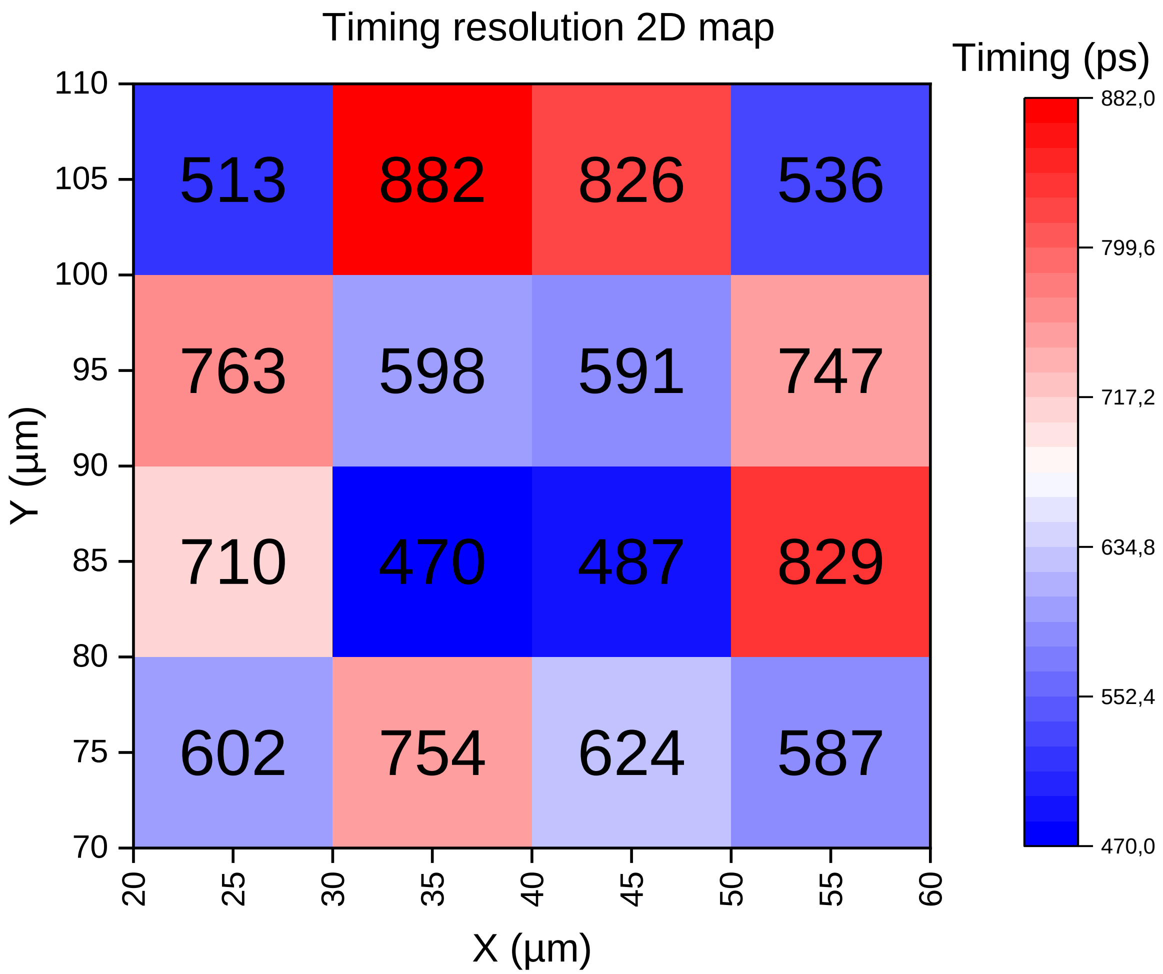


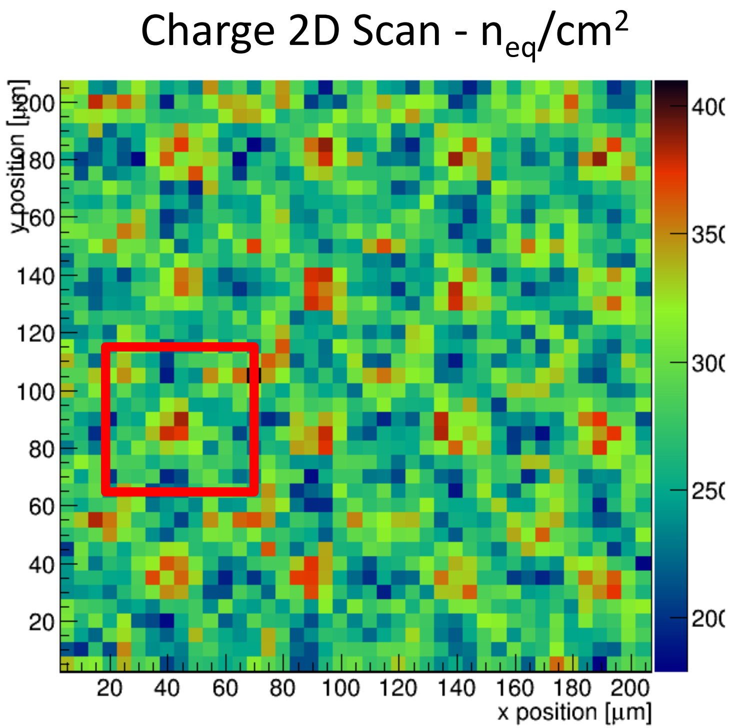
MIPs	Amplitude (mV)
1	62
2	124
3	186
4	248
5	310
6	372

Intensity laser intensity set at different % of laser width using PIN reference

- Higher effect on highly irradiated sensor, not so much on $1e15 n_{eq}/cm^2$
- With such high noise, jitter is predominant → the higher the laser intensity, the better time resolution

Timing 2D map – 1e17Neq/cm2



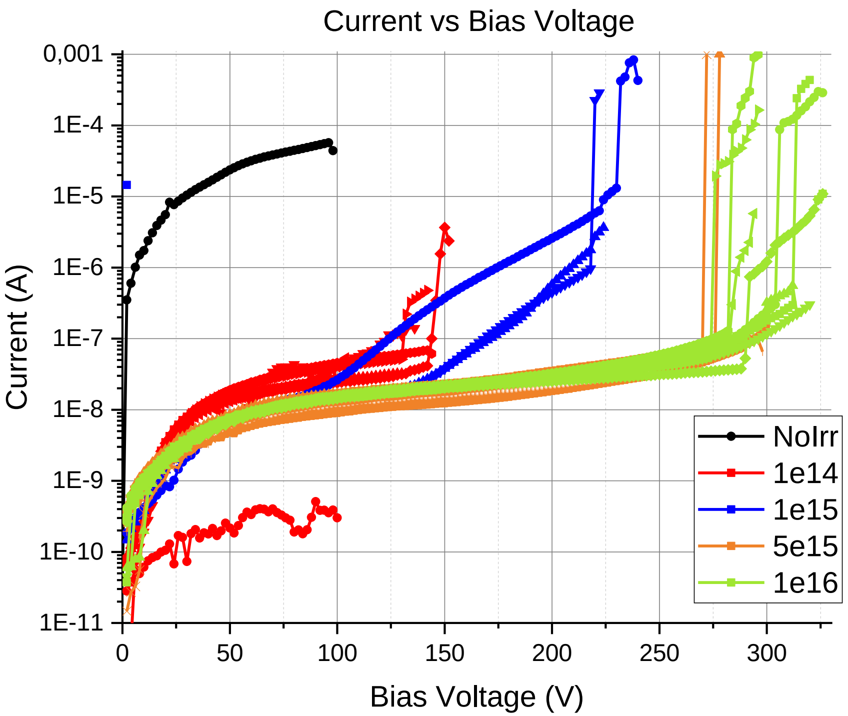


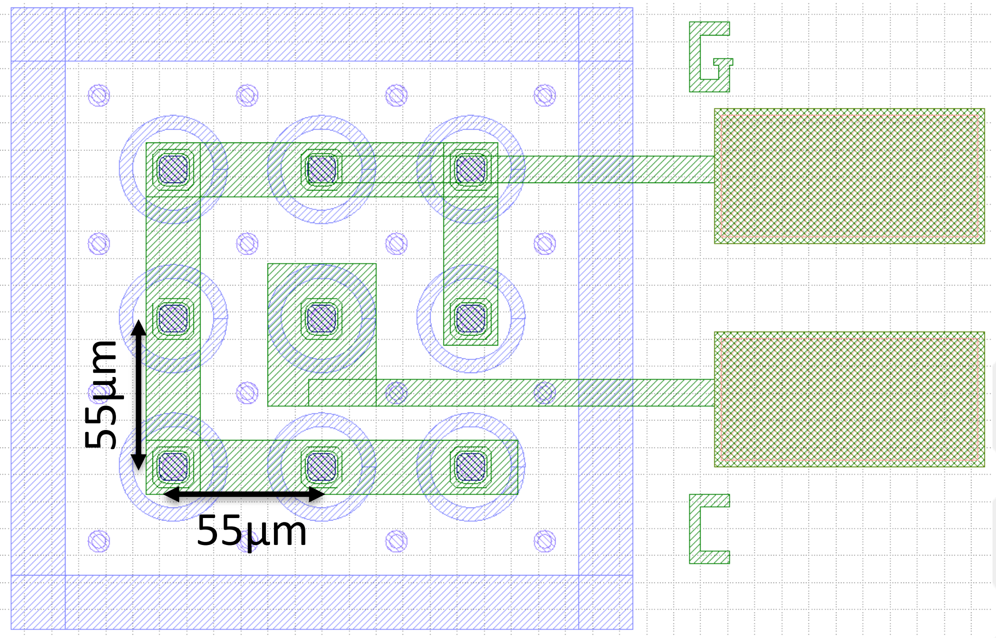
- Laser calibration ~ 6MIP
- Spot size ~40 µm
- Bias = 250 V
- Step size = 10 µm

Test structures

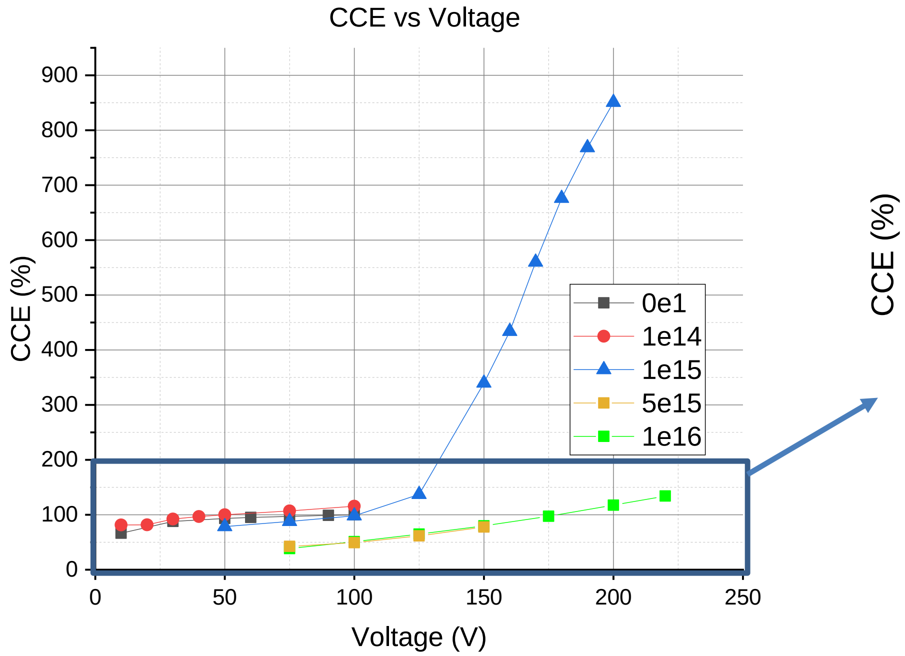
Test structure samples

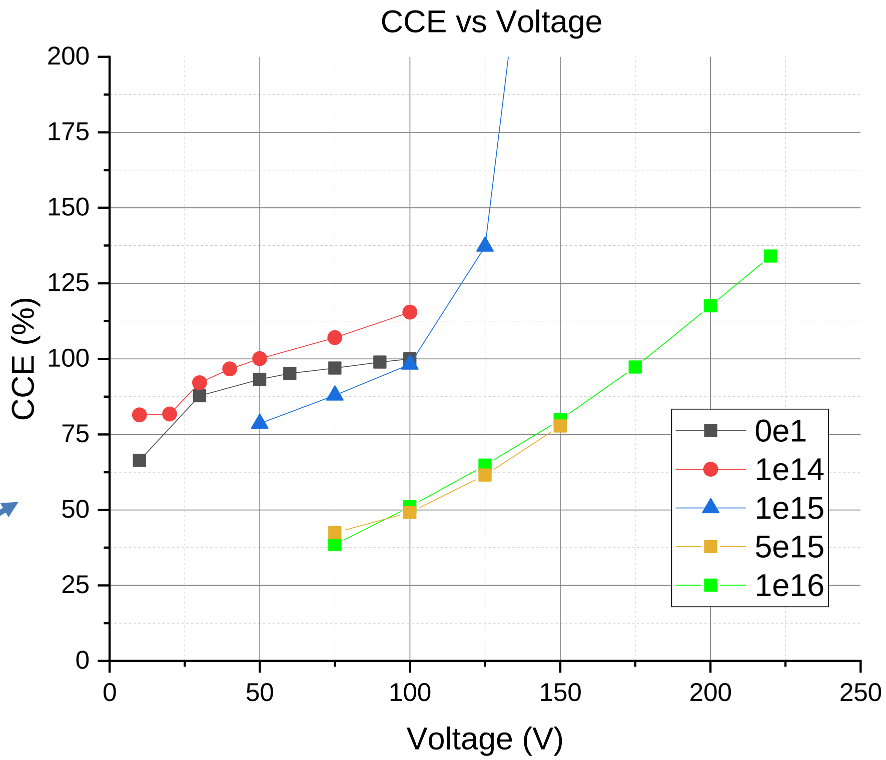
- Measurements done @ IFAE
- Low temperature (~ -18ºC)
- Small diode arrays → 3x3 pixels
- Ground and column pads are shorted towards channel line – ground from backside.
- Pixel geometry: 55µm x 55µm pixel pitch
- Spot size of laser ~ 15-20µm
- Samples for $5e16n_{eq}/cm^2$ and $1e17n_{eq}/cm^2$ are damaged → waiting for them to be repaired



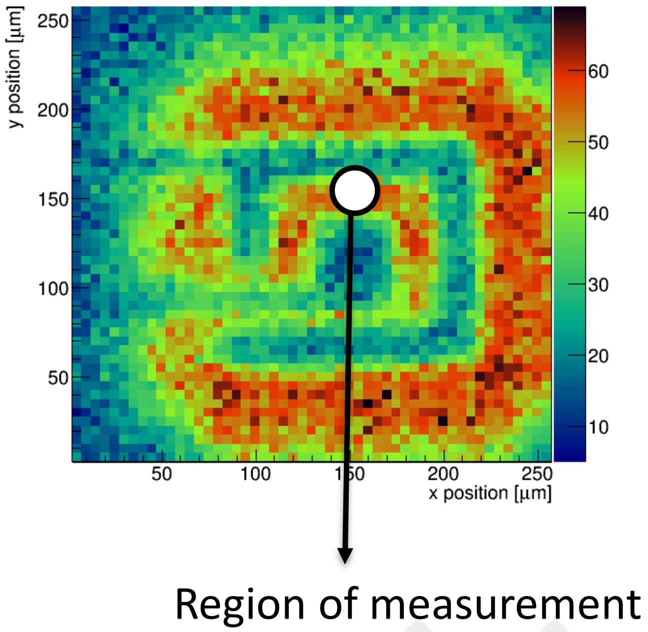


Charge collection efficiency



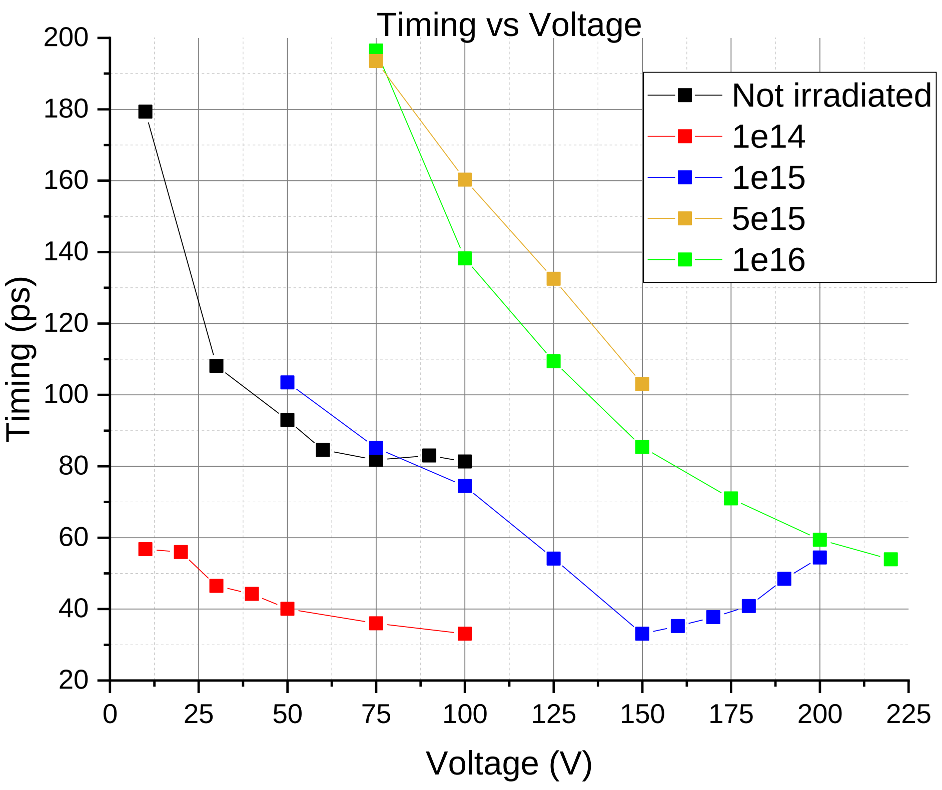


$1e14n_{eq}/cm^2$ @ 30V

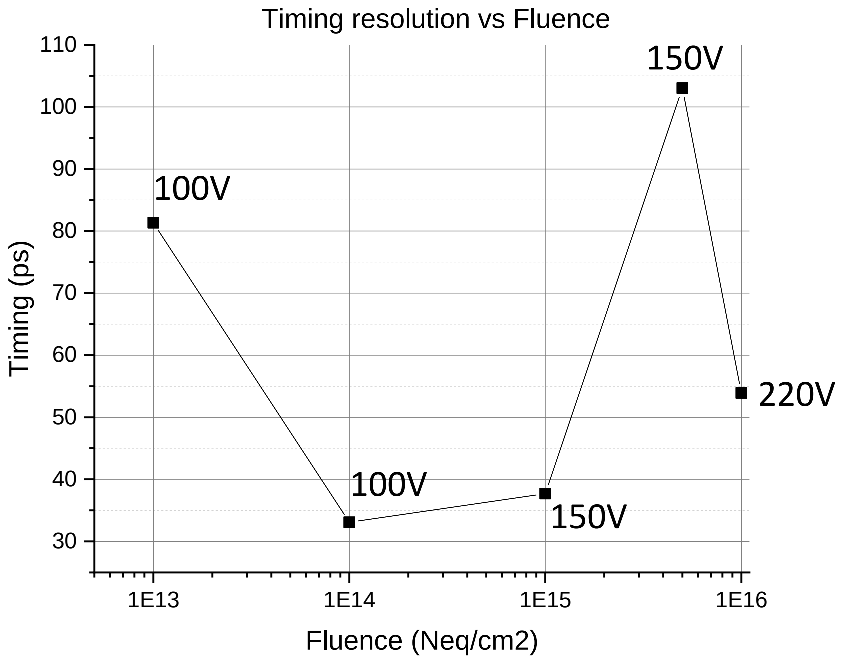


- At high voltages, there is charge multiplication in irradiated sensors → CCE >100%
- Fluence level $5e15n_{eq}/cm^2$ has a very similar behaviour as $1e16n_{eq}/cm^2$ with earlier breakdown → another device will be tested to double check.

Time resolution



Fluency (n_{eq}/cm^2)	Timing resolution (ps)	Voltage of minimum timing (V)
Before irradiation	81.33	100
1e14	33.07	100
1e15	37.7	150
5e15	103.03	150
1e16	53.9	220



Values for fluence level of $5e15 n_{eq}/cm^2$ again showing strange behaviour → will repeat measurements with another device

Conclusions and future work

- Timing and CCE have been measured and discussed on irradiated n-on-n 3D sensors using a TCT setup.
- 3D n-on-n silicon sensors have been proved to withstand high irradiation levels with CCE > 100% and time resolution of 55ps at 1E16neq/cm2 with small enough sensors
- Laser intensity proofs not to be a crucial part unless it is a highly limited time resolution due to noise
- Preliminary timing 2D map on the big diode array at $1E17n_{eq}/cm^2$ shows a highly position dependant time resolution.

Future work

- Double check behaviour of irradiated small sensor at fluence level of $5e15n_{eq}/cm^2$
- Repairing metal pads from small samples irradiated at fluence level of $5e16n_{eq}/cm^2$ and $1e17n_{eq}/cm^2$ and test them.
- Try and test them on a beta-source setup

Thank you for your attention

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Project references: RTI2018-094906-B-C22, PID2020-113705RB-C32

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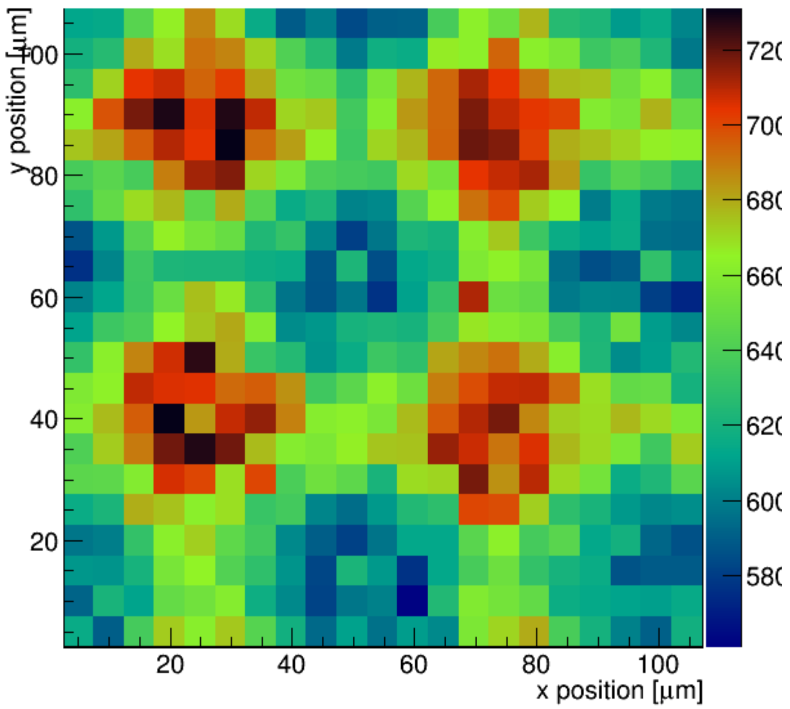
Backup slides

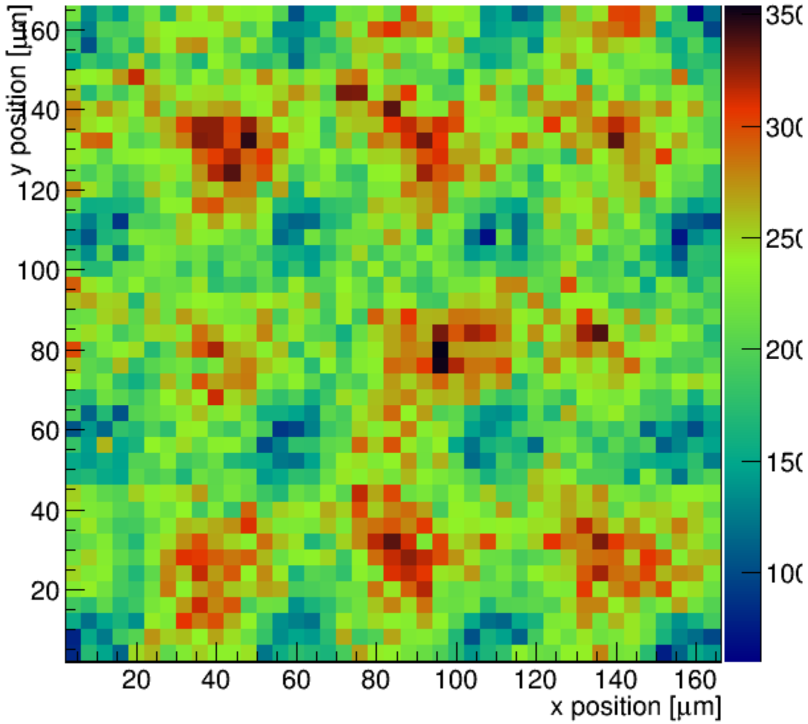
Charge 2D map – big diode arrays

Not irradiated



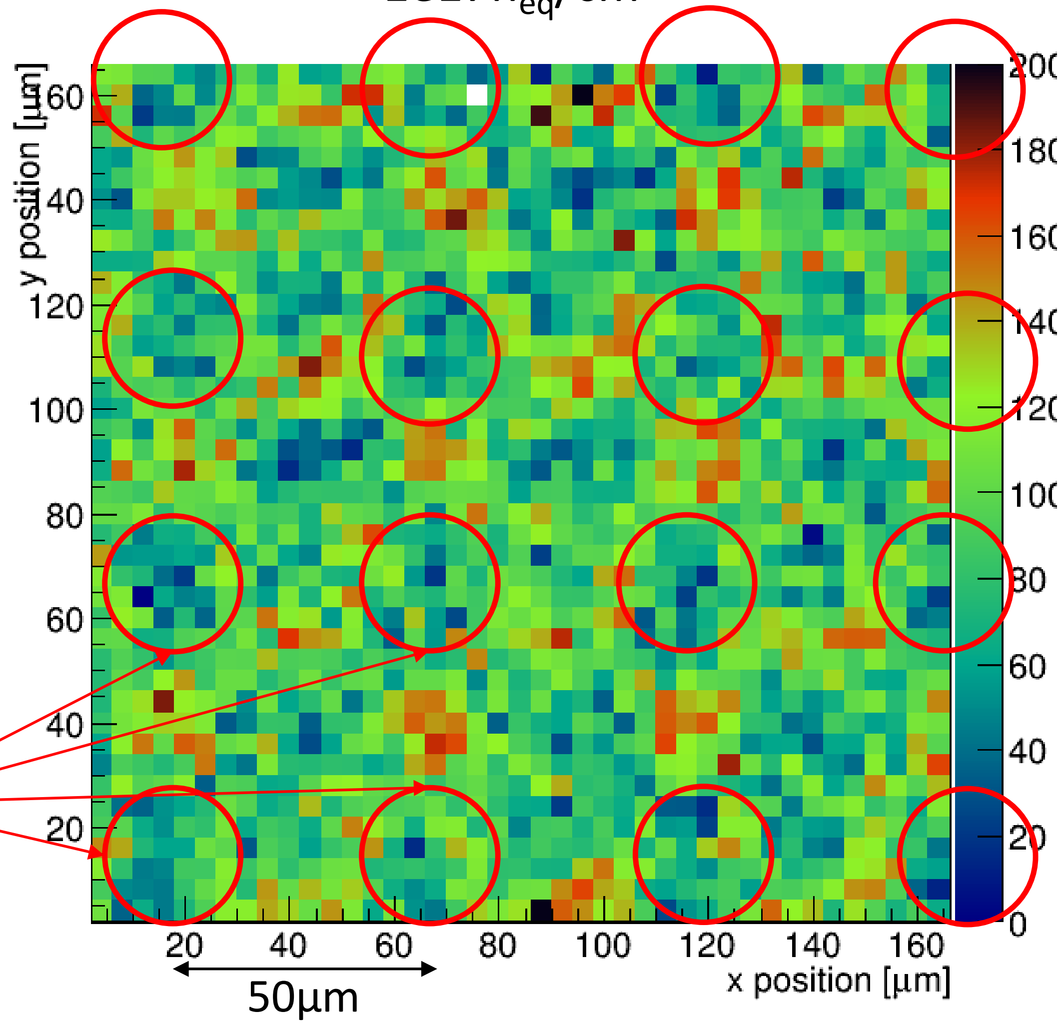
30V

$1e16\ n_{eq}/cm^2$



2D Charge Scans – 1e17 n_{eq}/cm^2

$1e17 n_{eq}/cm^2$



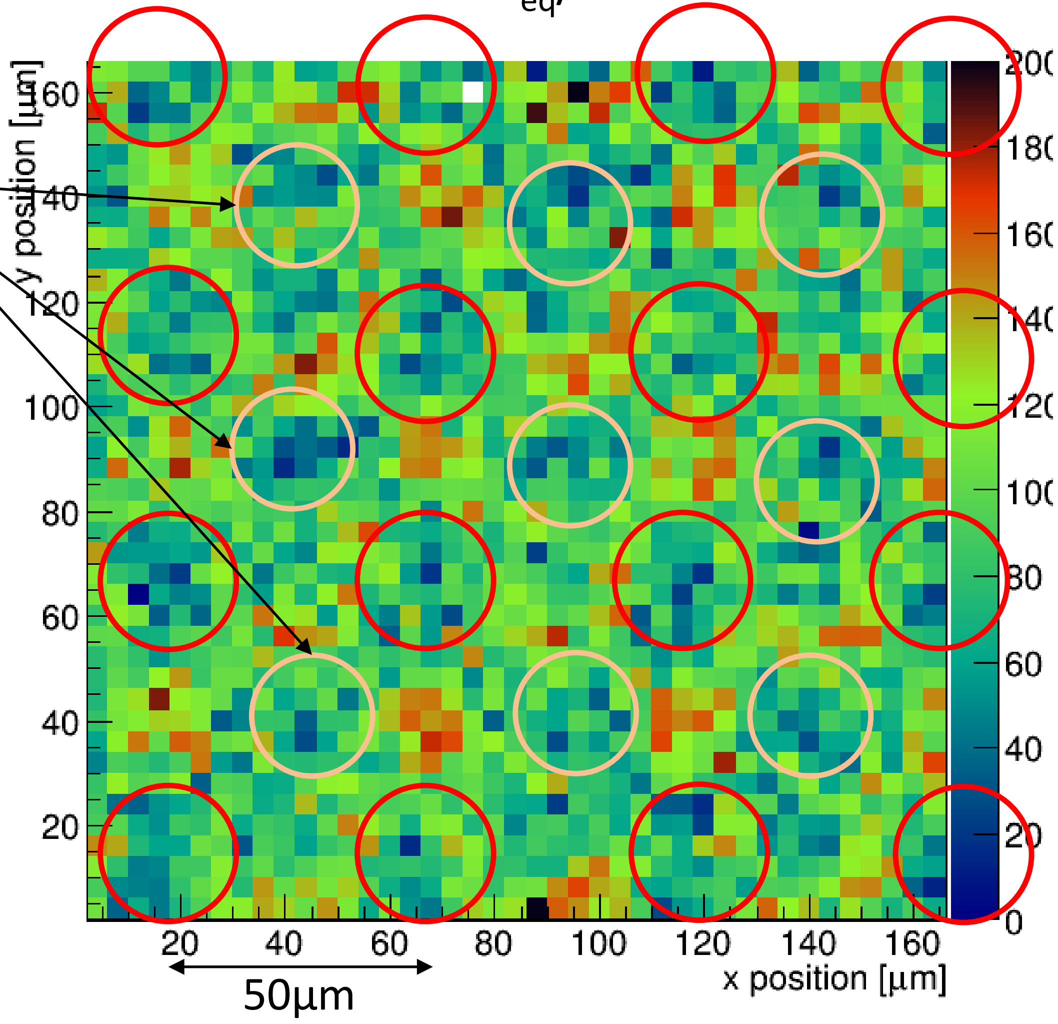
With some imagination….

N++ Columns
(50µm pitch)

2D Charge Scans – 1e17 n_{eq}/cm^2

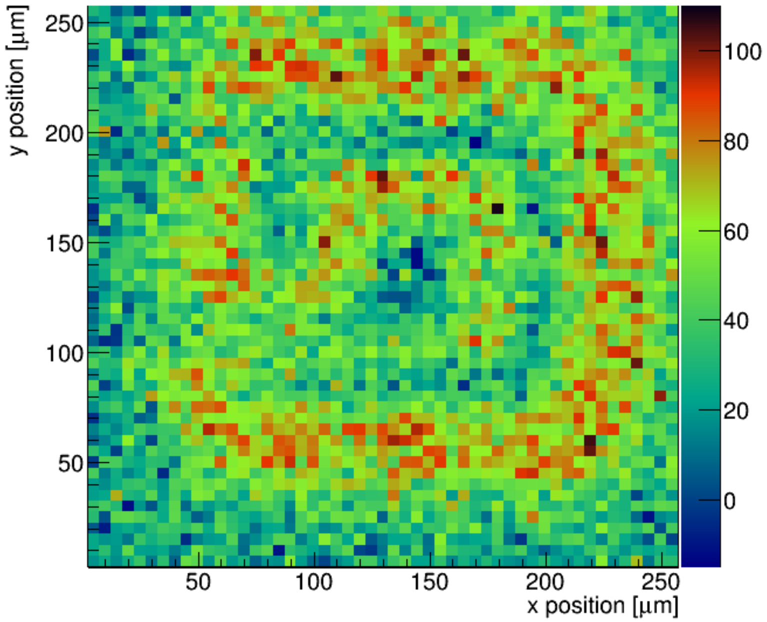
Regions also with lower charge collection → Low mean free path?

1e17 n_{eq}/cm^2

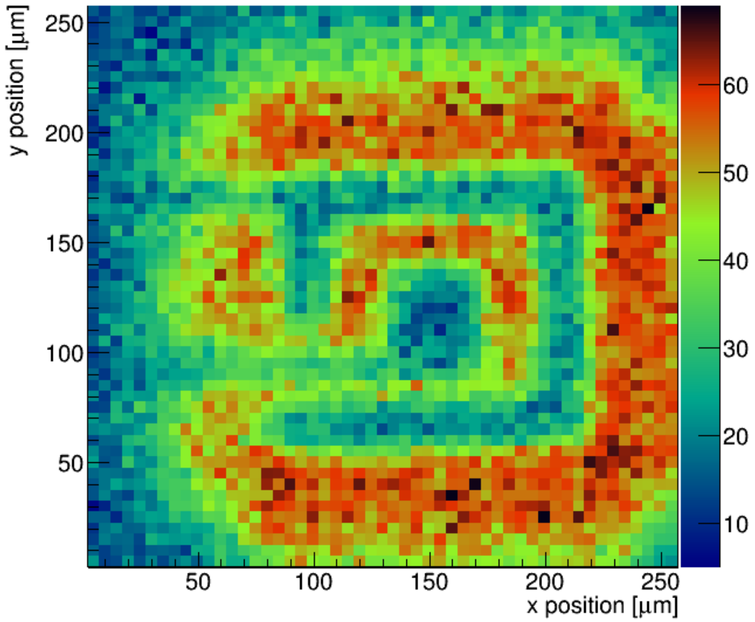


Charge 2D map – Small test structures

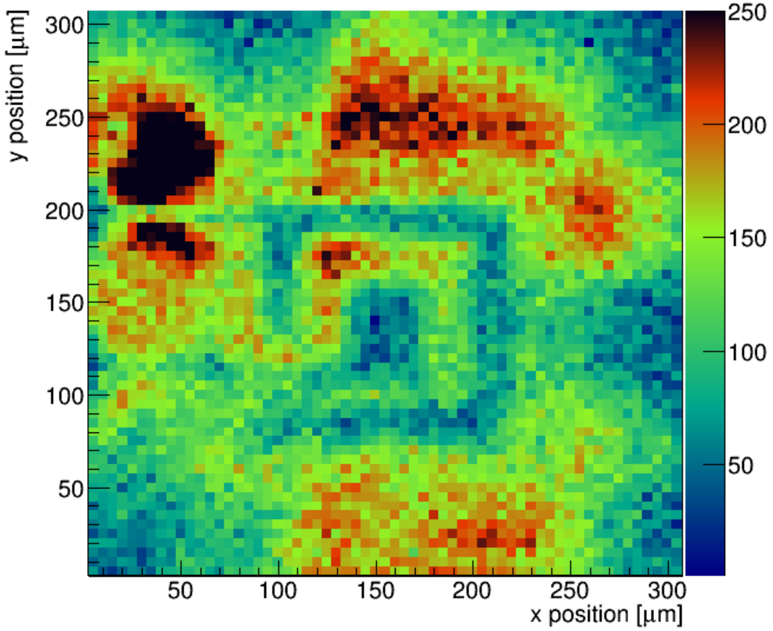
Before irradiation @ 30V



1e14n_{eq}/cm^2 @ 30V

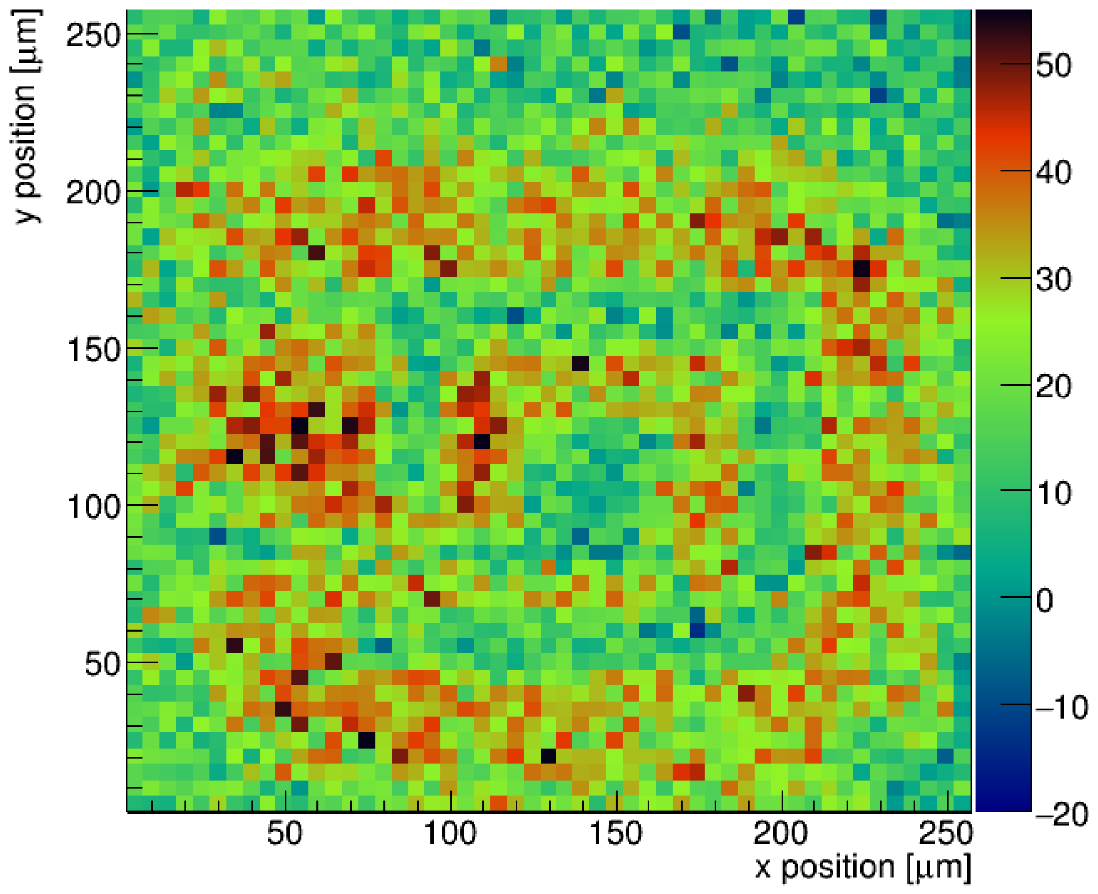


1e15n_{eq}/cm^2 @ 30V

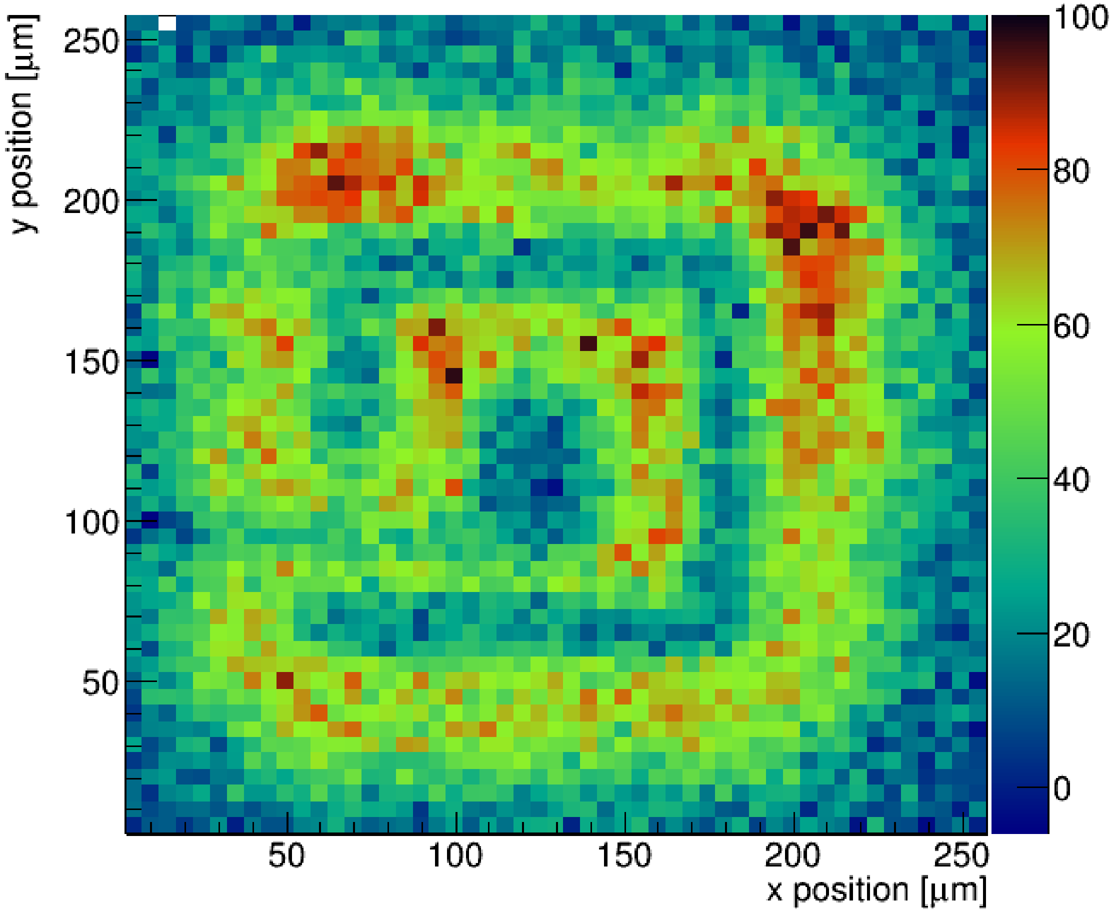


Charge 2D map – Small test structures

5e15n_{eq}/cm^2 @ 150V



1e16n_{eq}/cm^2 @ 220V



Noise and Risetime – Small test structures