First characterization of TI-LGAD technology in a test beam setup

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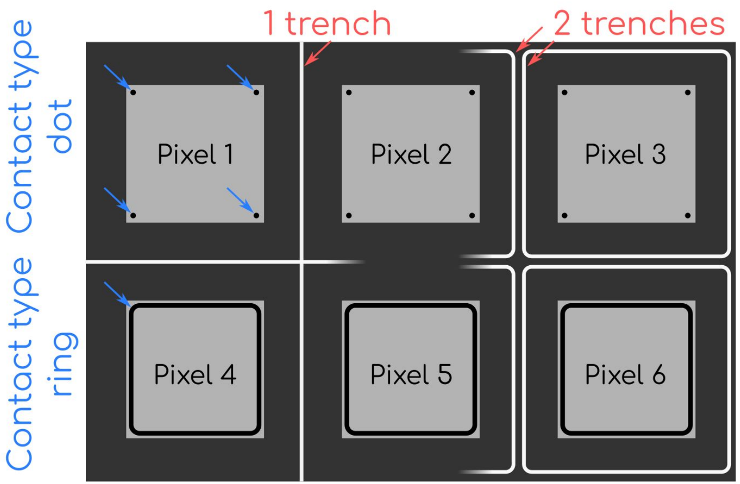
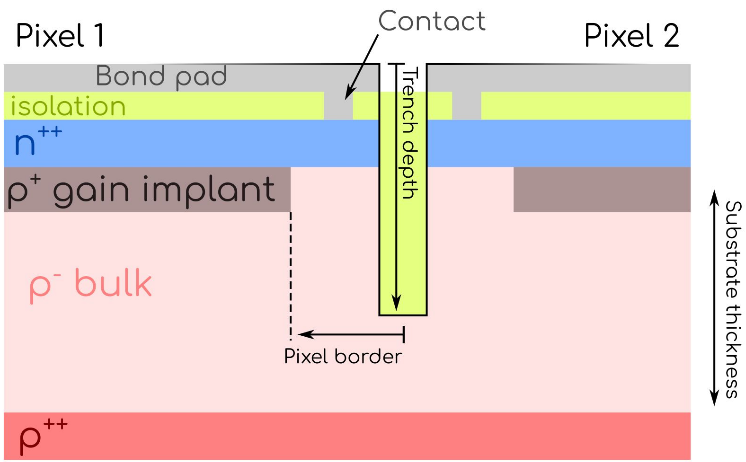
The TI-LGAD technology

Goal: Sensor with small pixels (<= 100 um) and high Fill Factor (> 80%).

TI-LGAD FBK RD50 production:

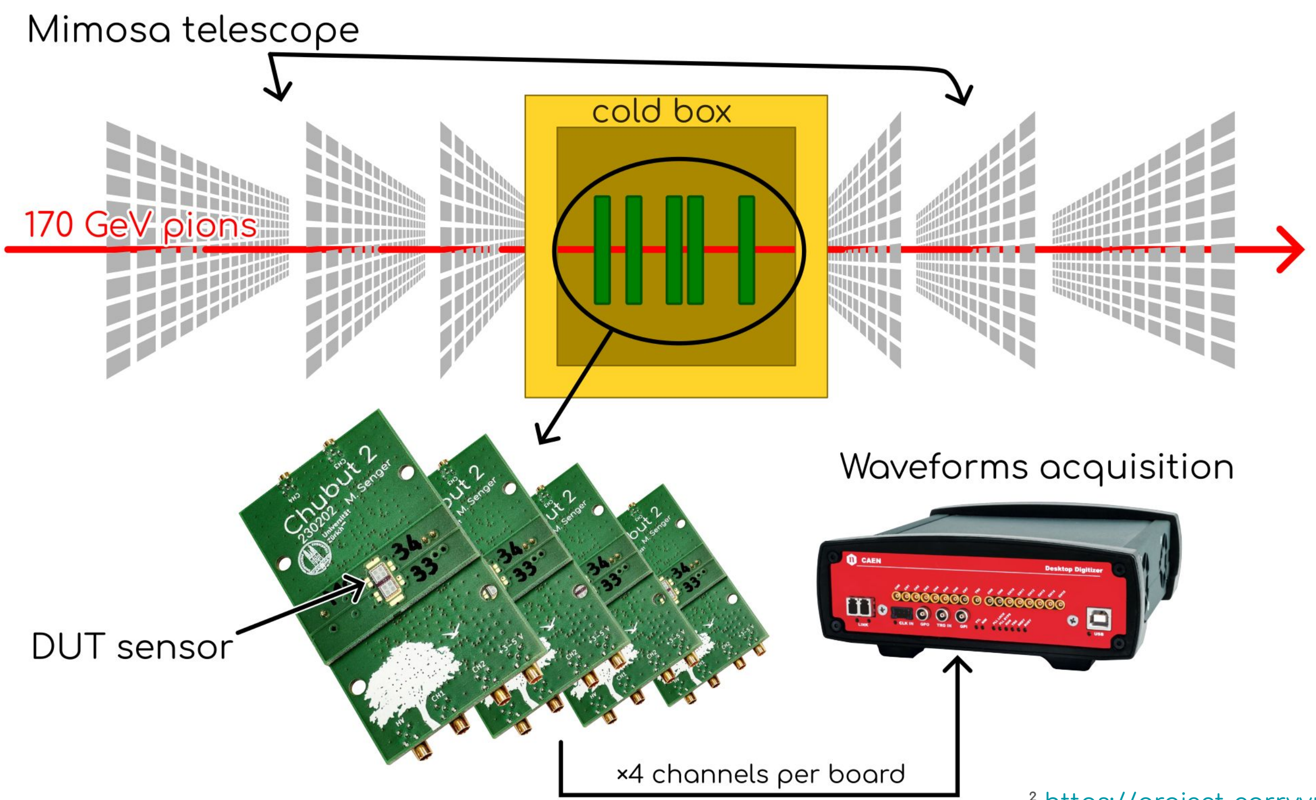
- Trenches: 1 or 2.
- Contact type: “Ring” or “dot”.
- Pixel border: “V1” < “V2” < “V3” < “V4”.
- Trench depth: “D1” < “D2” < “D3”.





Test beam setup

Simplified diagram:

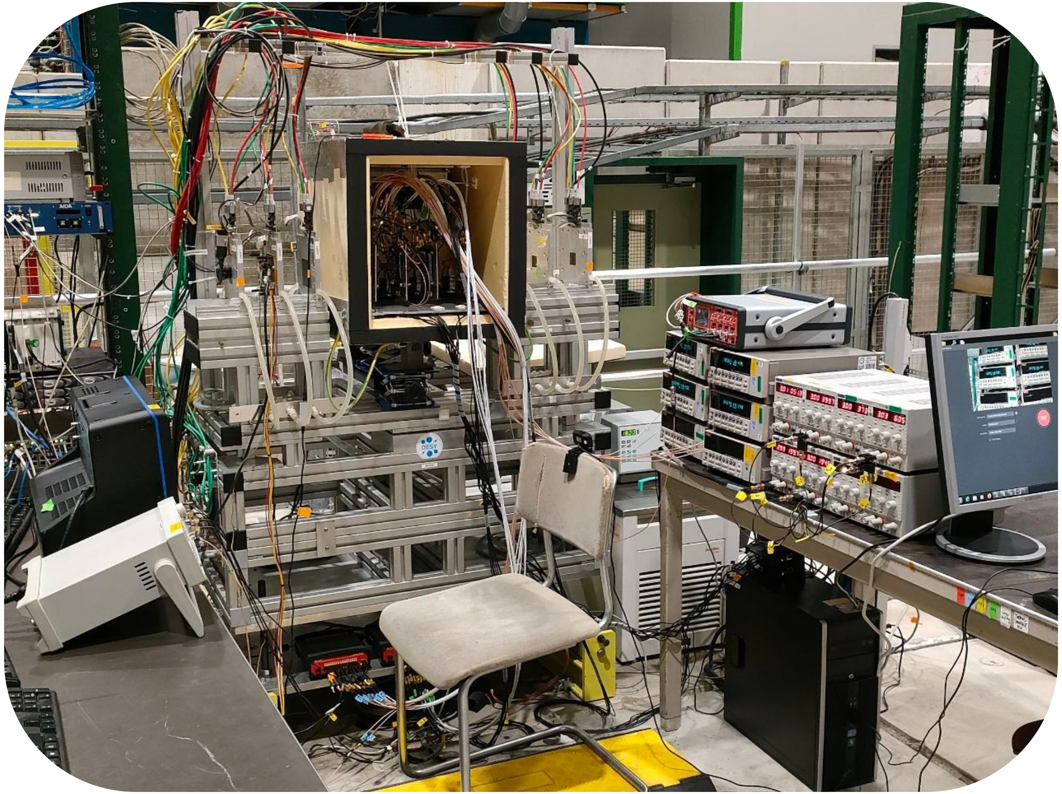


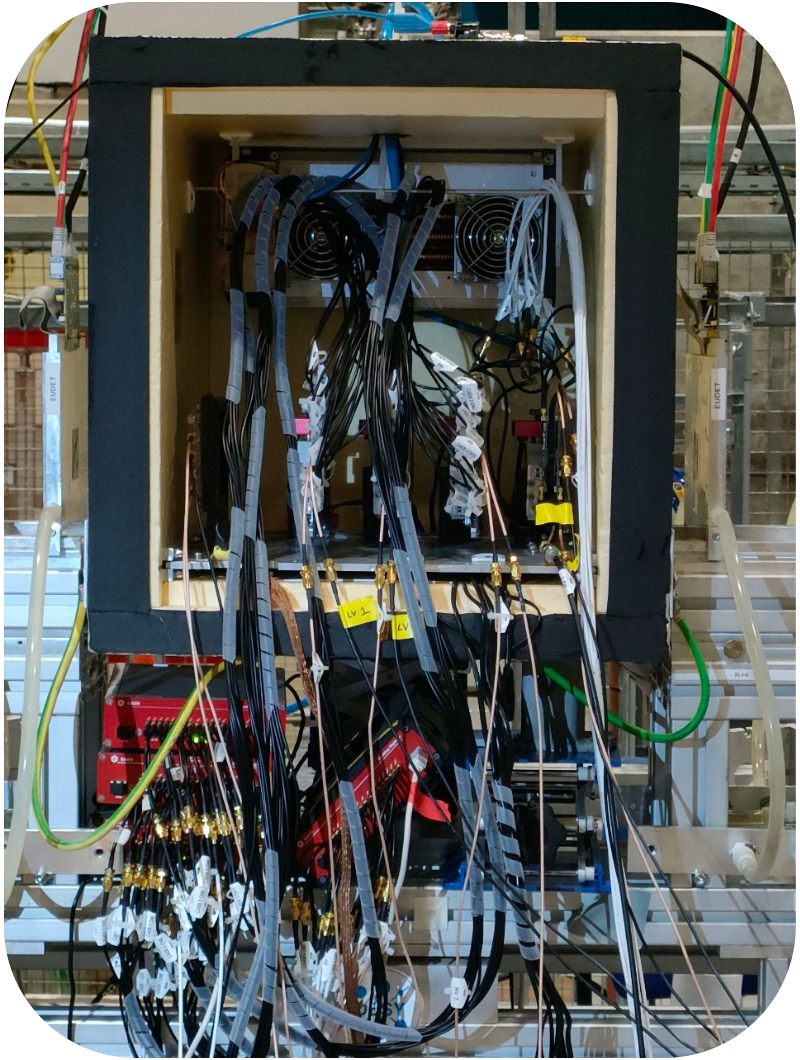
- CERN H6 beamline (120 GeV pions)
- Mimosa telescope
- Chubut 2, 4 channels readout board[1]
- CAEN DT5742 digitizer, 500 MHz @ 5 GS/s
- Cold box for irradiated DUTs, down to -12 °C
- Tracks reconstruction using Corryvreckan[2]

[1] https://github.com/SengerM/Chubut_2
[2] https://project-corryvreckan.web.cern.ch/project-corryvreckan/

Test beam setup

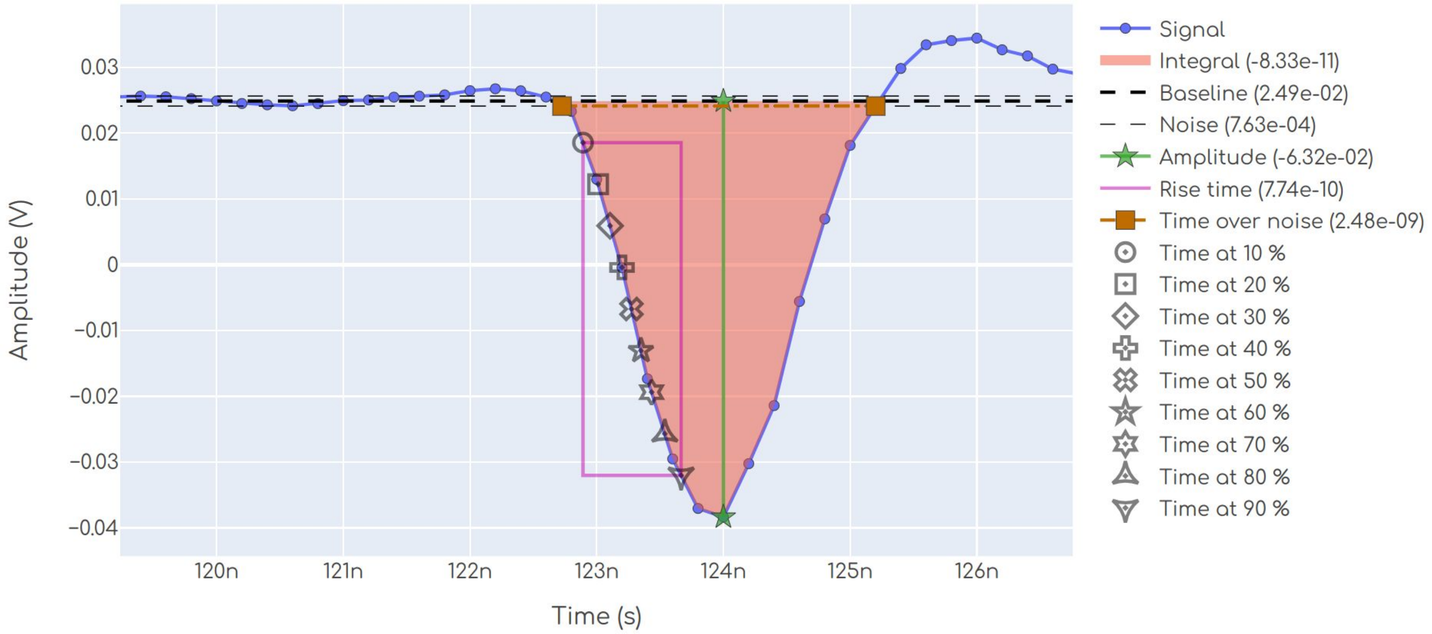
Some photos:





Waveforms analysis

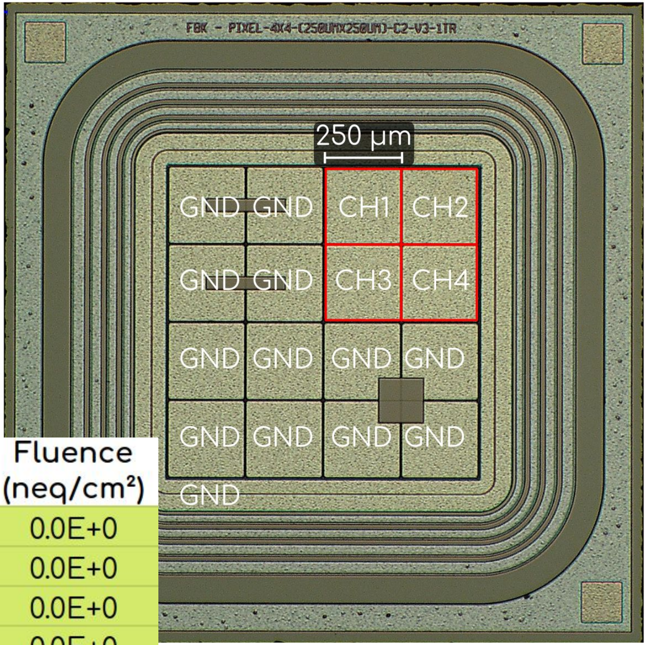
We record the waveforms, then process them offline*. Example:



* https://github.com/SengerM/signals

Tested devices

- All from FBK RD50 TI-LGAD production
- Same physical layout and connection →
- 8 DUTs, details in table below ↓

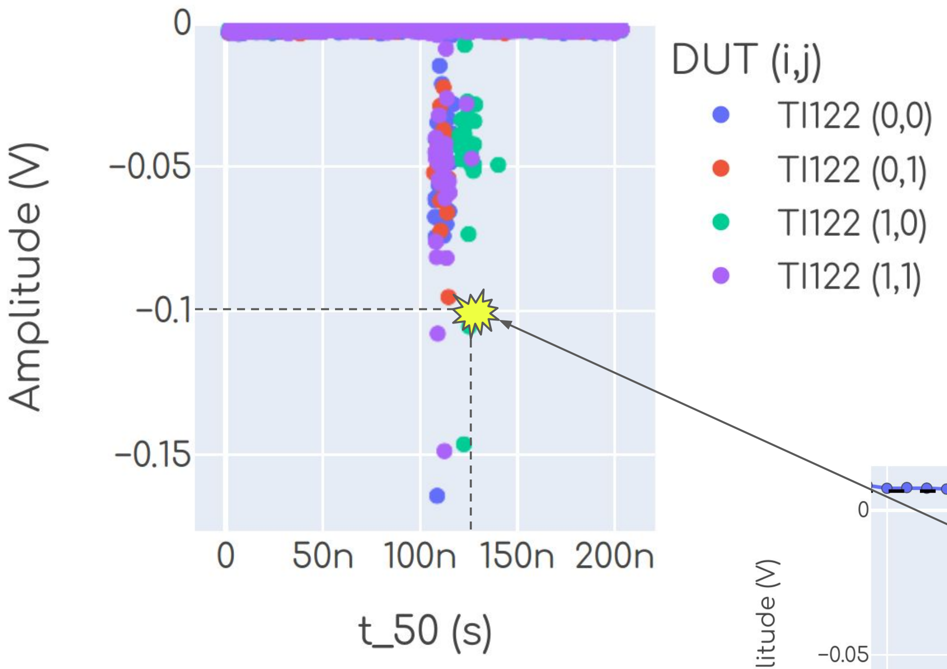


device_name	wafer	trench process	trench depth	trenches	pixel border	contact type	Fluence (neq/cm²)
TI116	16	P2	D3	1	V3	dot	0.0E+0
TI122	16	P2	D3	1	V3	ring	0.0E+0
TI123	16	P2	D3	1	V3	ring	0.0E+0
TI143	16	P2	D3	1	V2	ring	0.0E+0
TI145	16	P2	D3	1	V2	ring	1.0E+15
TI146	16	P2	D3	1	V2	ring	1.0E+15
TI229	7	P2	D2	1	V3	ring	1.0E+15
TI230	7	P2	D2	1	V3	ring	1.0E+15

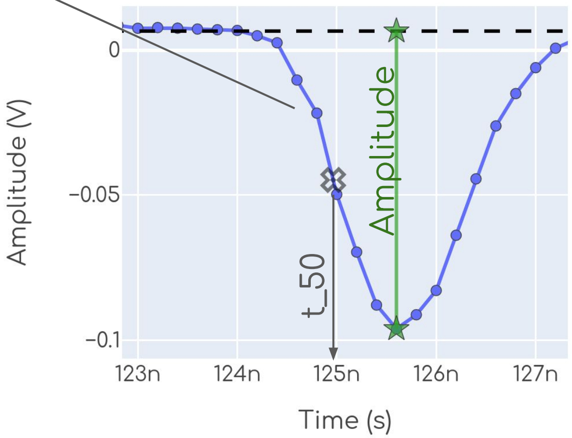
* Devices were irradiated with reactor neutrons at JSI, Ljubljana.
** "device_name" can be ignored, it is shown here for curious readers who may want to see details from the examples.

Results

Waveforms distribution and events selection



- Each dot is one waveform
- Color denotes channel

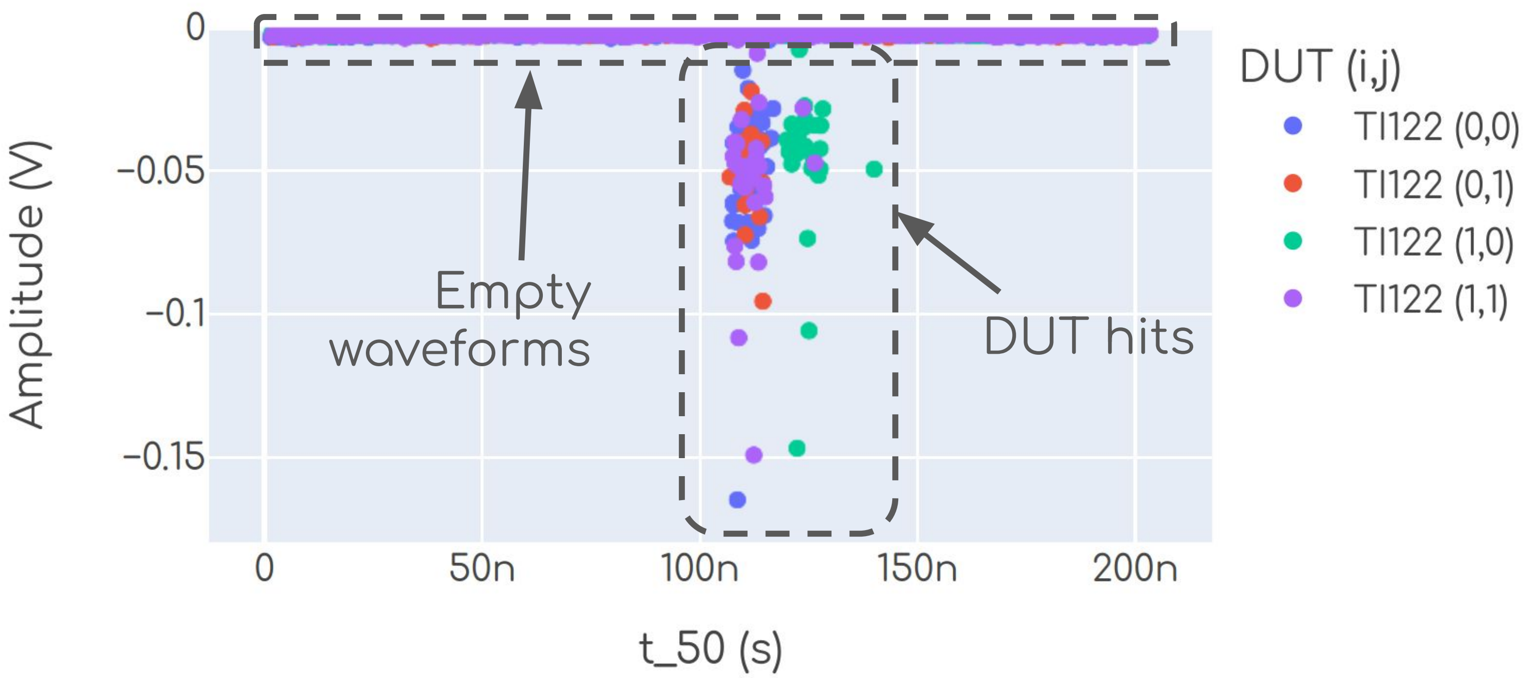


Example: This waveform has amplitude = 100 mV and t_50 = 125 ns

* This example is for one DUT, they all look similar.

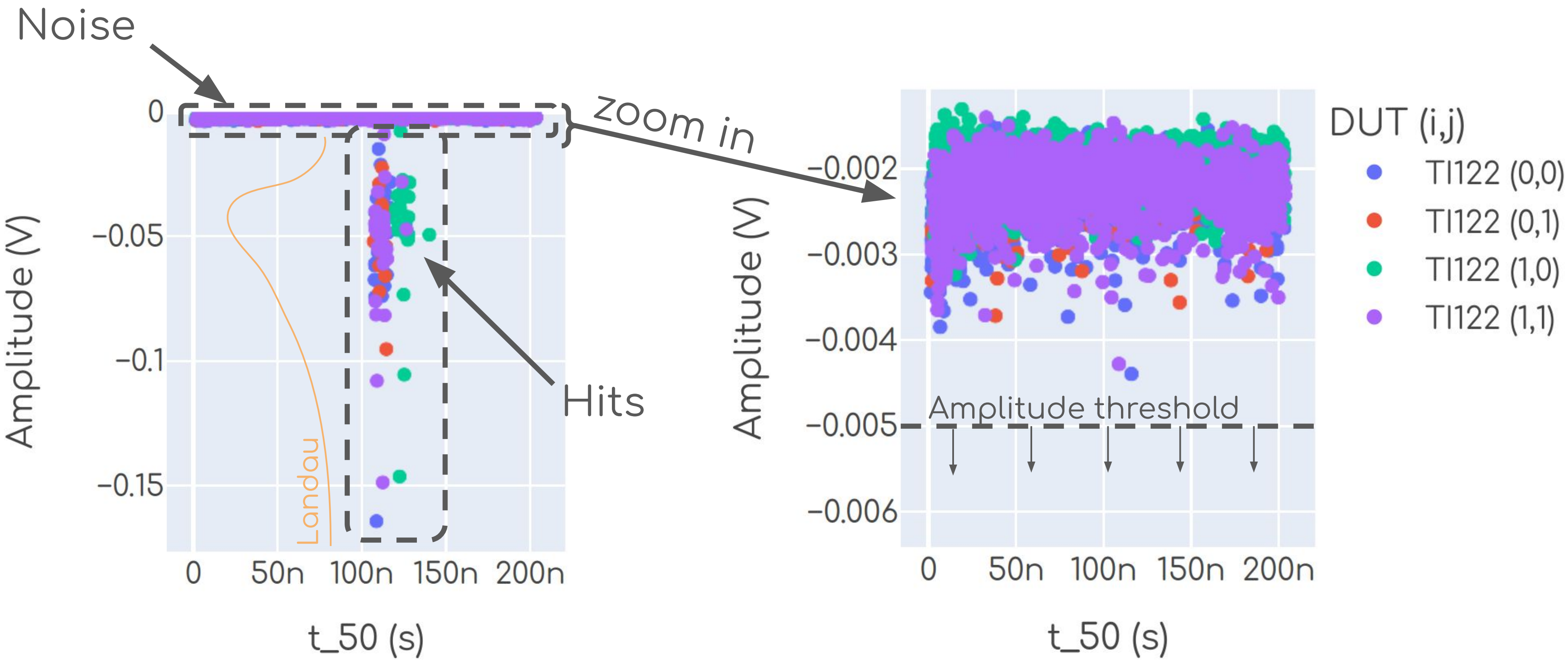
Waveforms distribution and events selection

- Hits have large amplitude and well defined time.
- Empty waveforms have small amplitude (noise) and random time.



Waveforms distribution and events selection

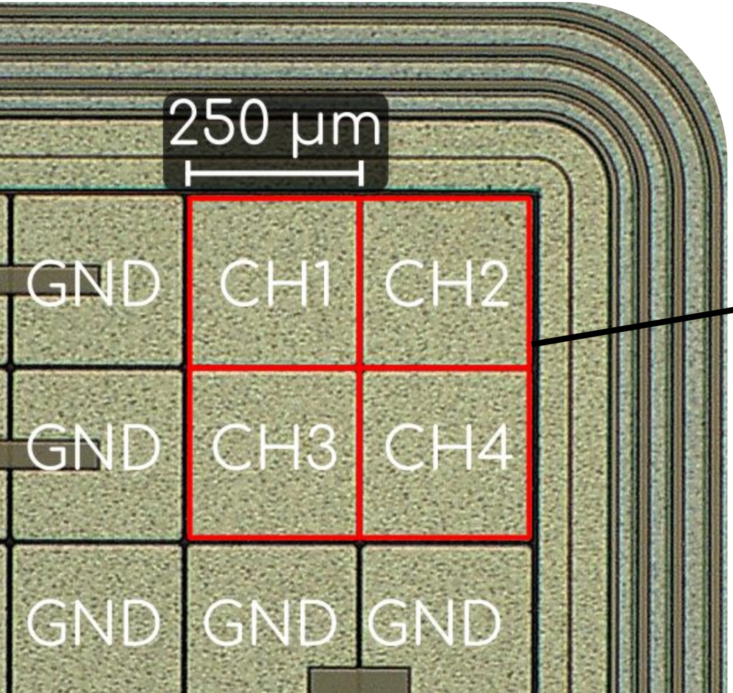
A threshold in amplitude defines what we consider a hit in a pixel:



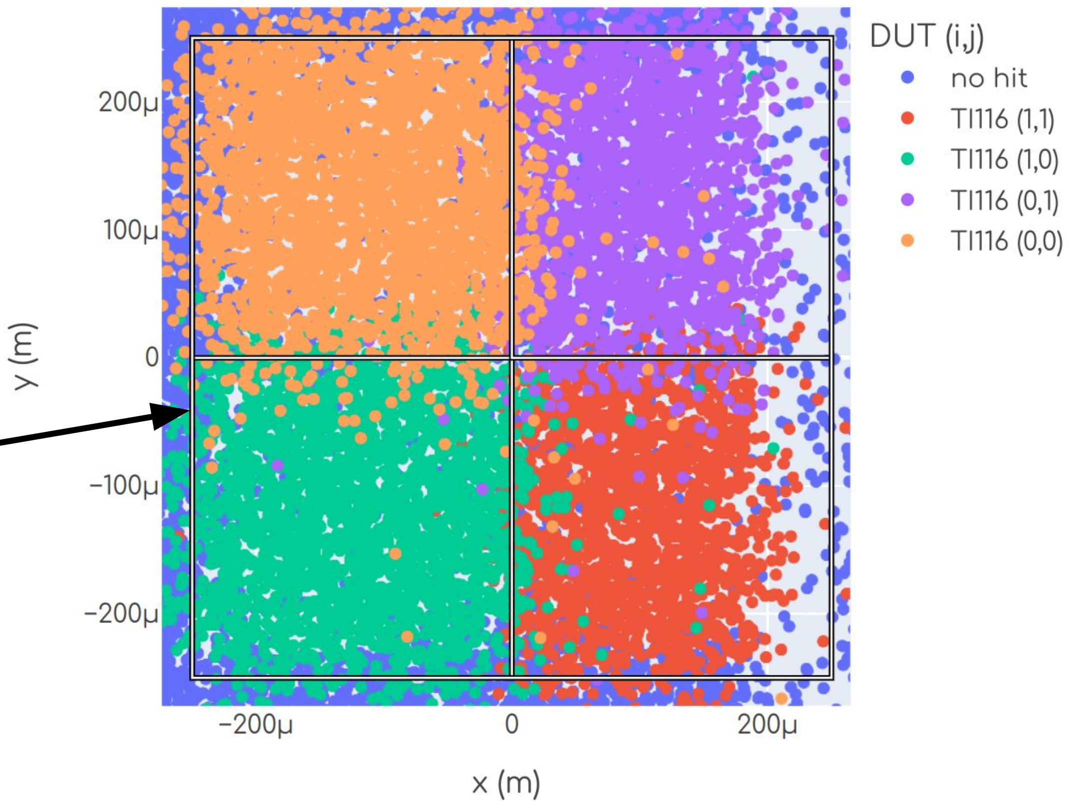
Tracks and hits on DUTs

* This example is for one DUT, they all look similar.
[1] Corryvreckan - CERN

- Each dot is a track
- Colored according to which channel was hit
- Tracks reconstruction using Corryvreckan[1]



This gap is due to the trigger device

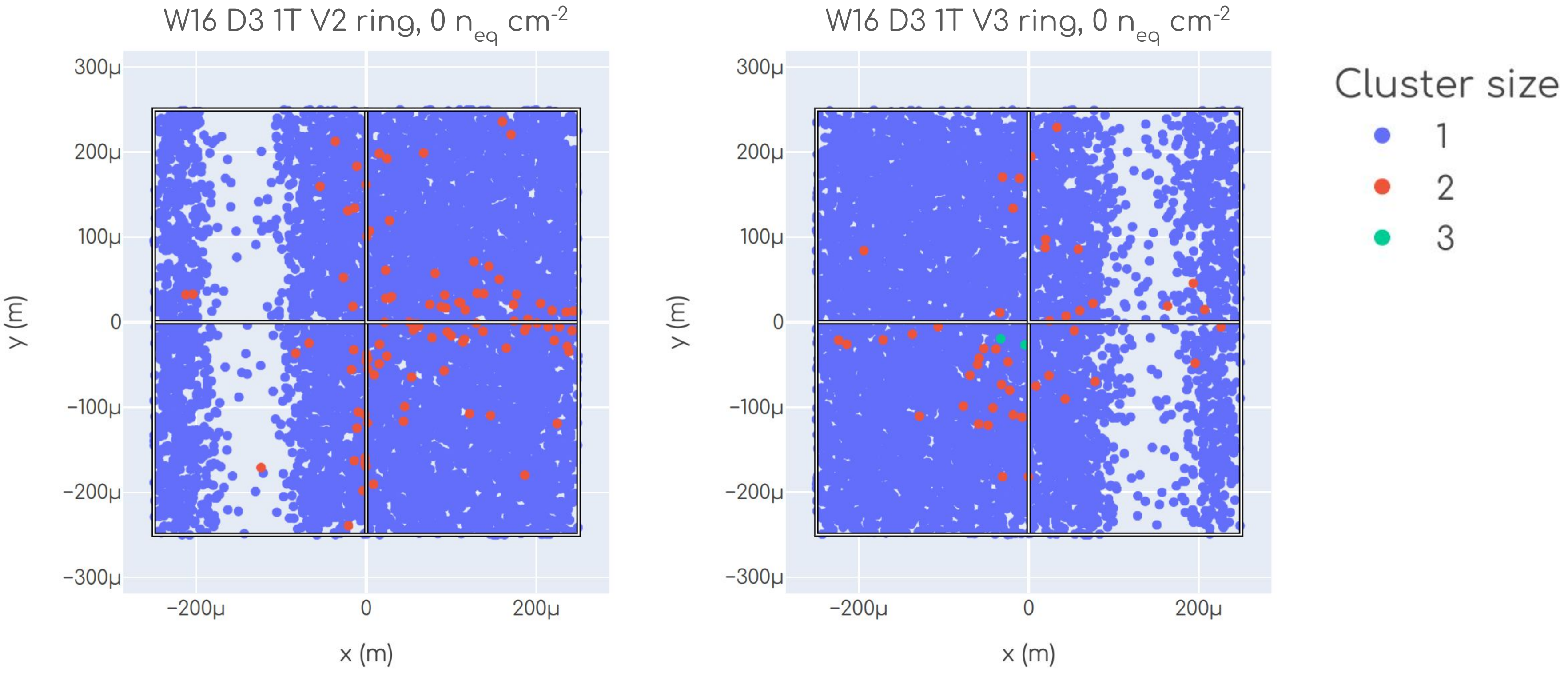


Charge sharing in TI-LGADs

* This example is for two DUTs, they all look similar.

We look at the cluster size, i.e. number of active pixels per hit.

Example for two DUTs:

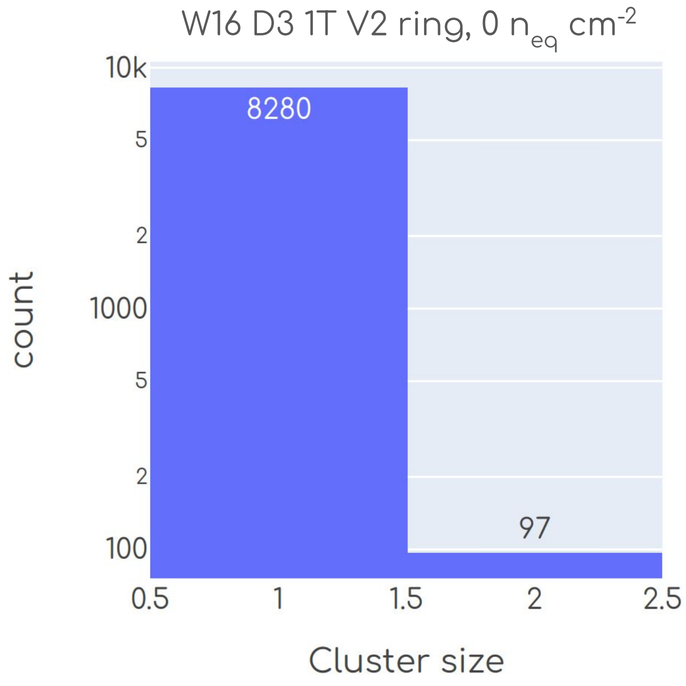


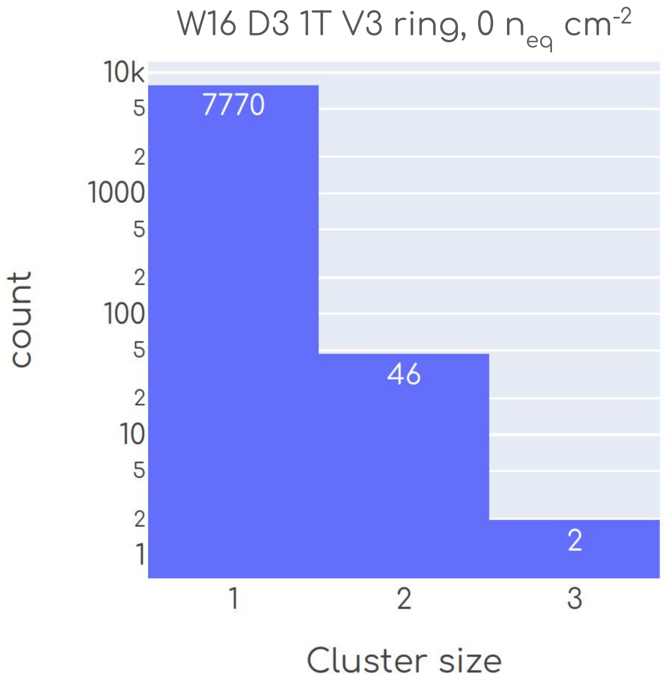
Charge sharing in TI-LGADs

* This example is for two DUTs, they all look similar.

Only ~1 % of events share charge, low value consistent with expectation ✅

Example for two DUTs (similar for all of them):



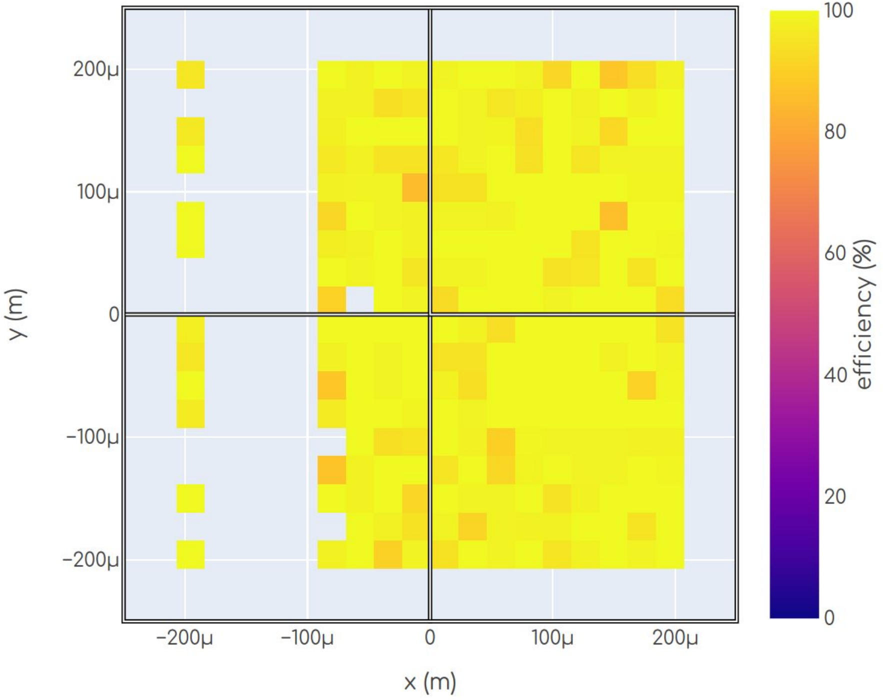


Efficiency vs position

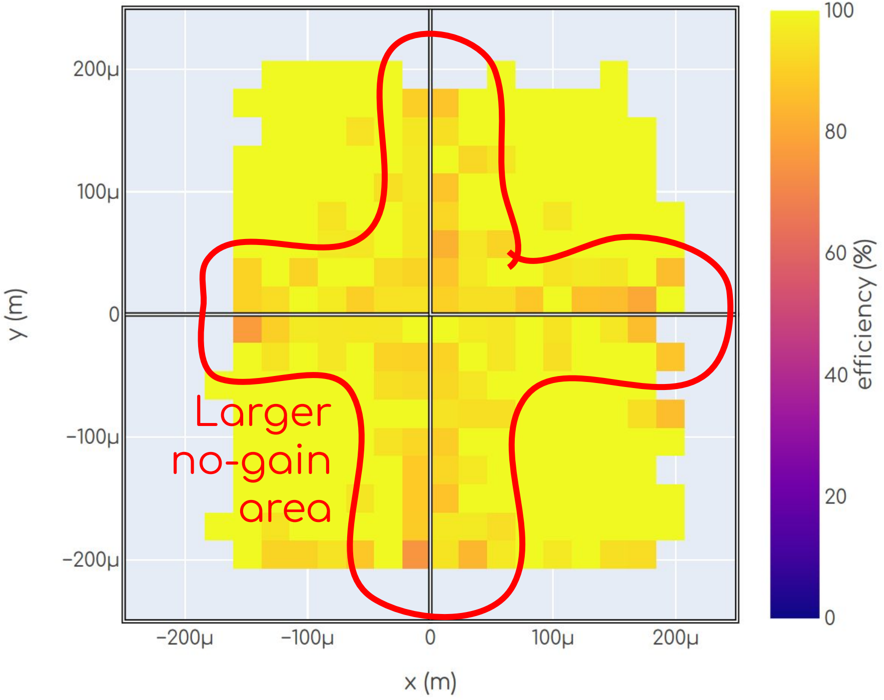
$$\text{Efficiency} = \frac{\text{Number of detected particles}}{\text{Number of particles that went through}}$$

This DUT was measured as a control DUT, knowing it has a larger inter-pixel distance. Here we can see it ✅

W16 D3 1T V2 ring, 0 n_{eq} cm^{-2}

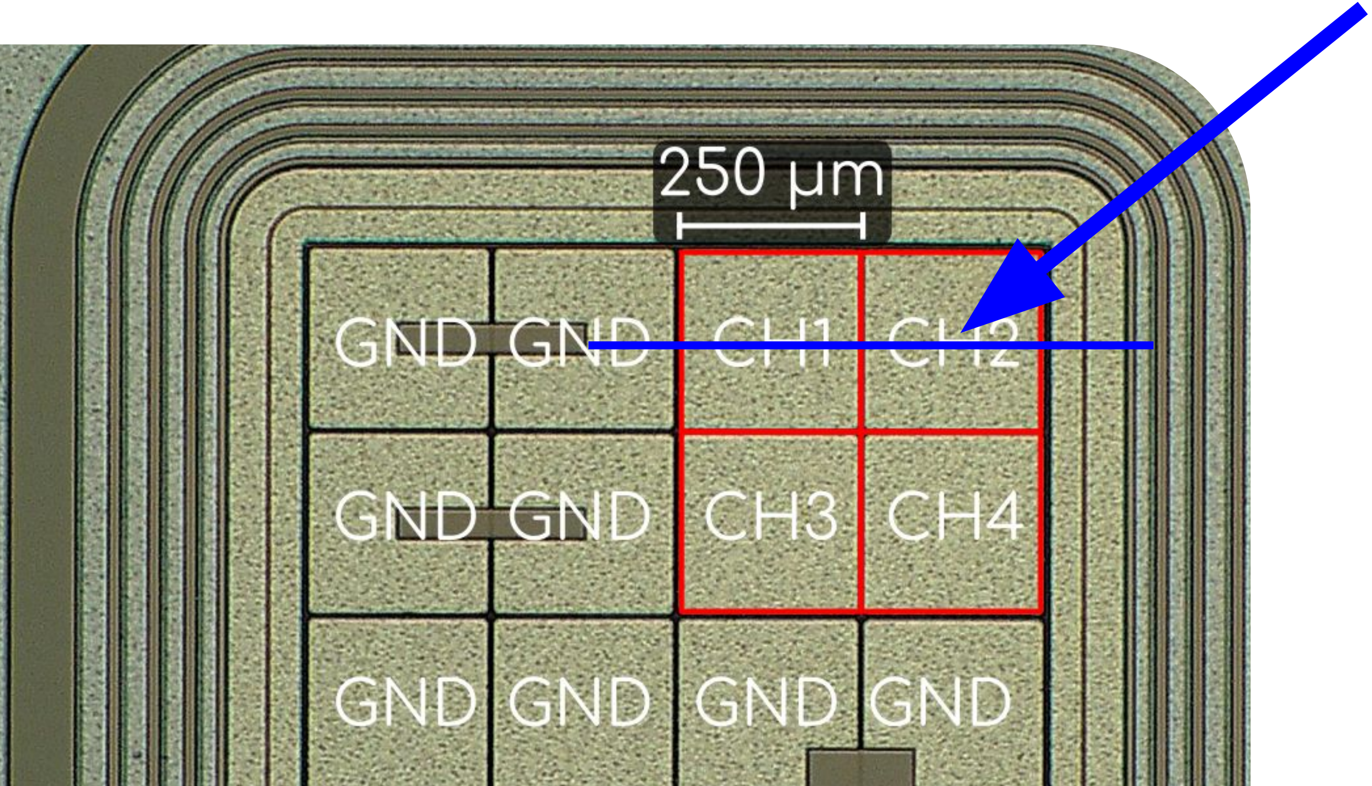


W16 D3 1T V3 ring, 0 n_{eq} cm^{-2}



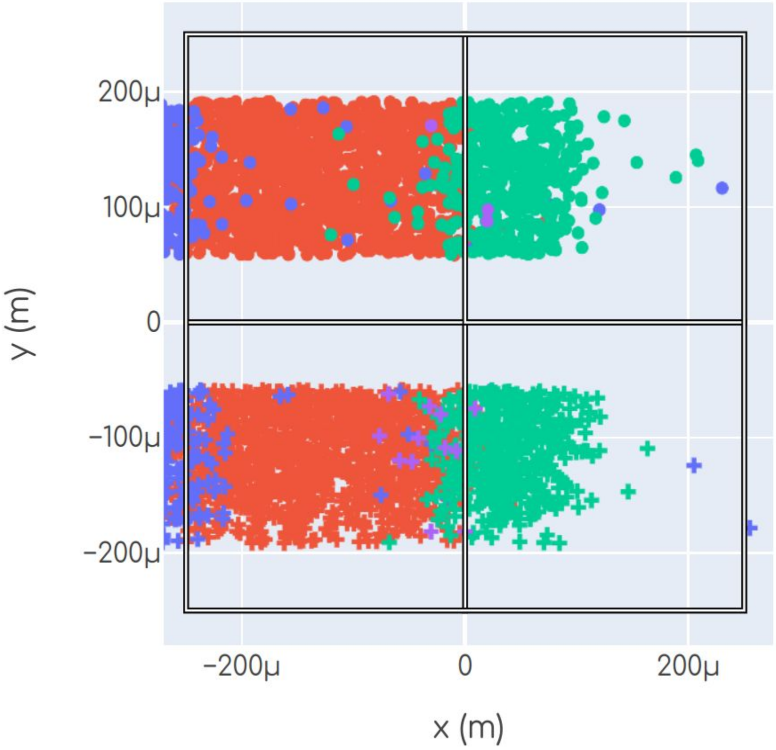
Efficiency profile

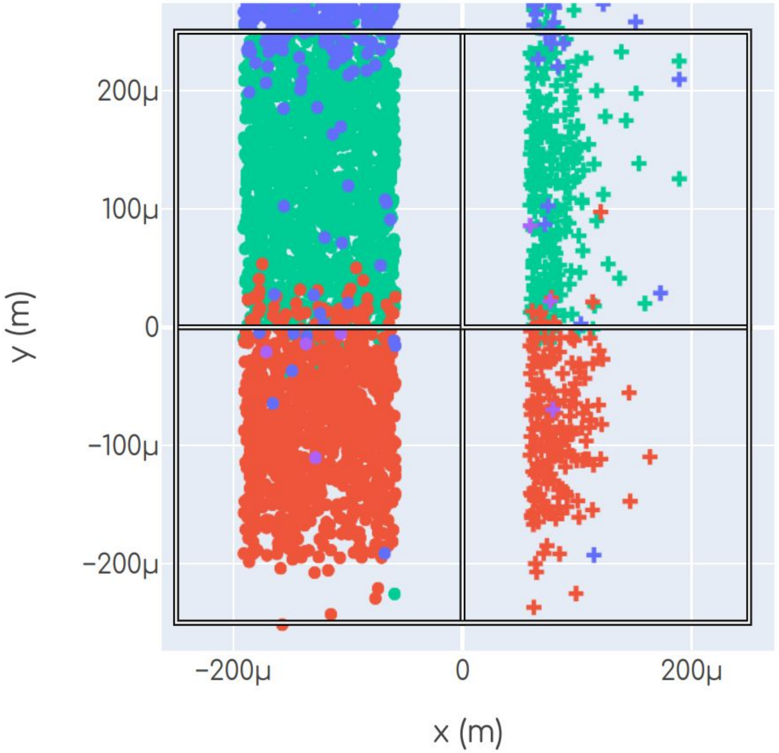
What's the efficiency profile along two pixels?



Efficiency profile

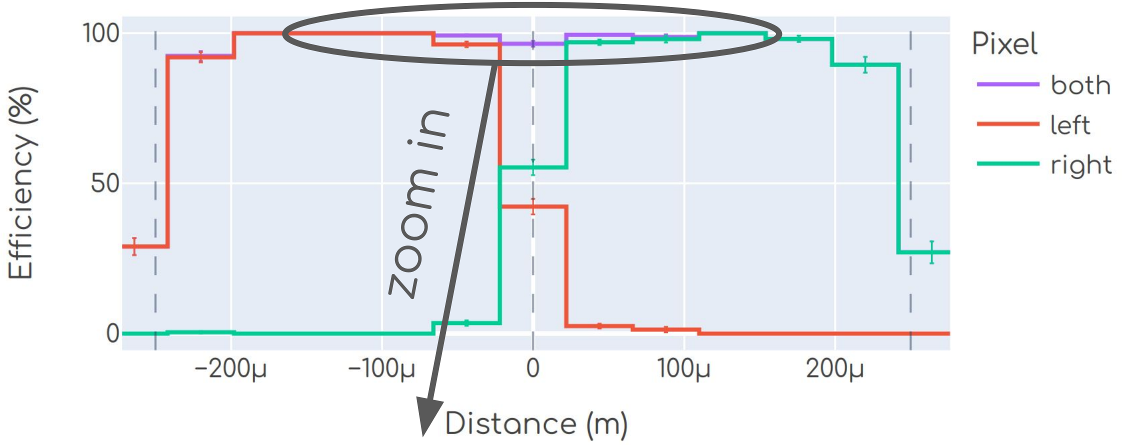
Select tracks within these strips and project along x and y

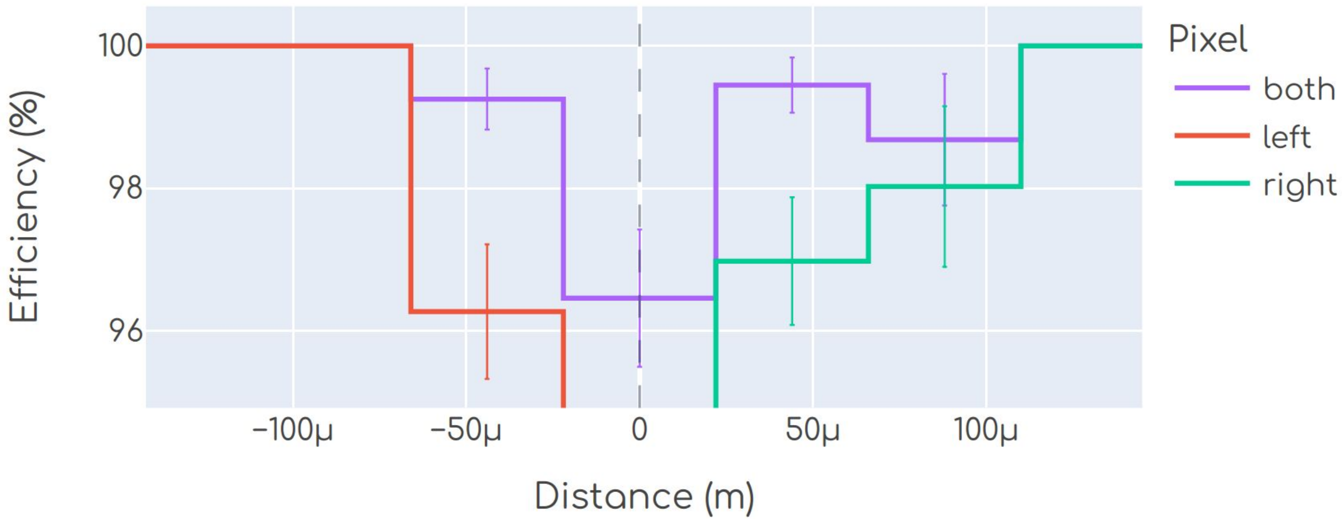




Efficiency profile

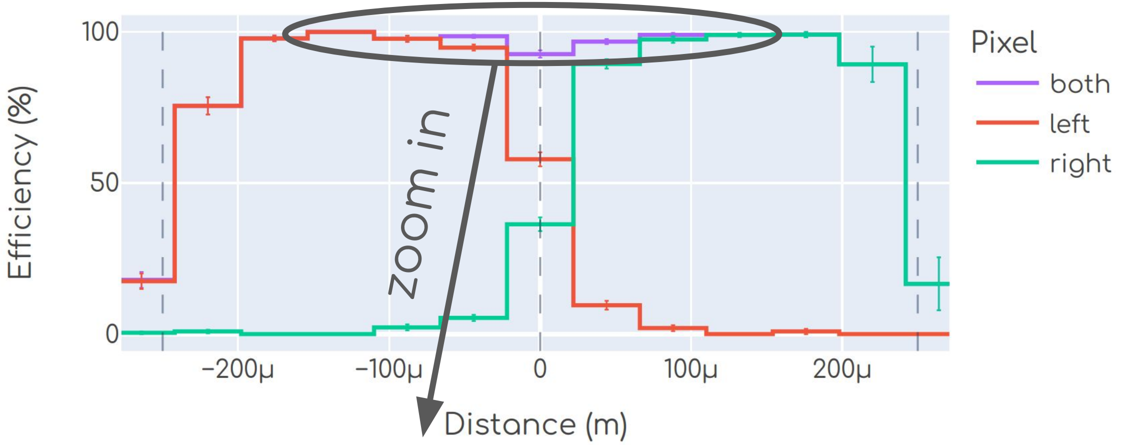
- W16 D3 1T V3 ring
- 0 n_{eq} cm^{-2}
- 230 V
- Room T

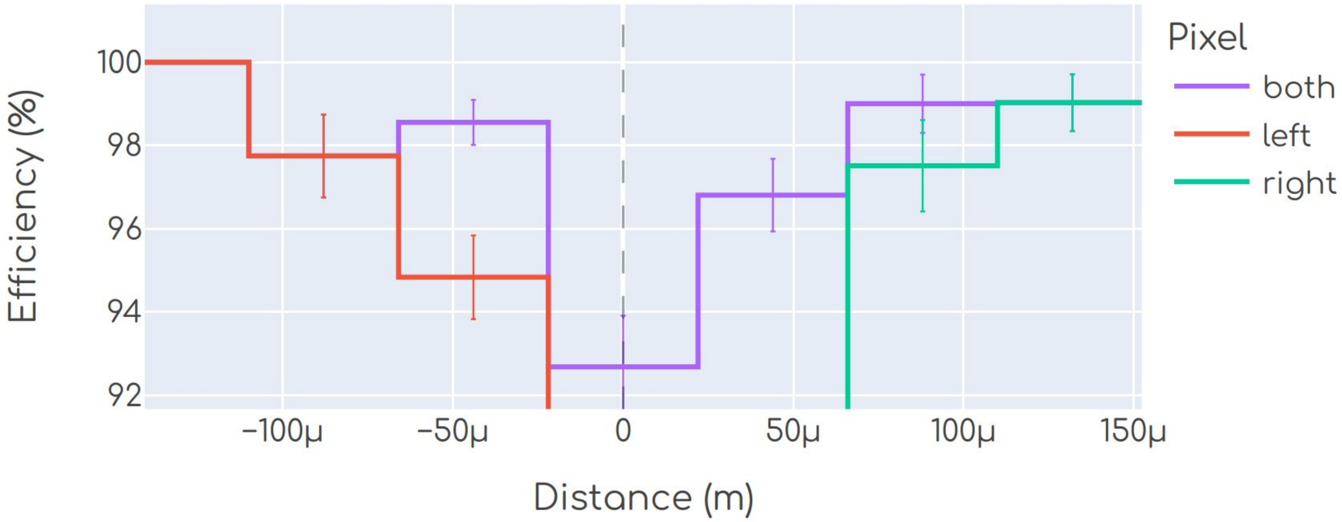




Efficiency profile

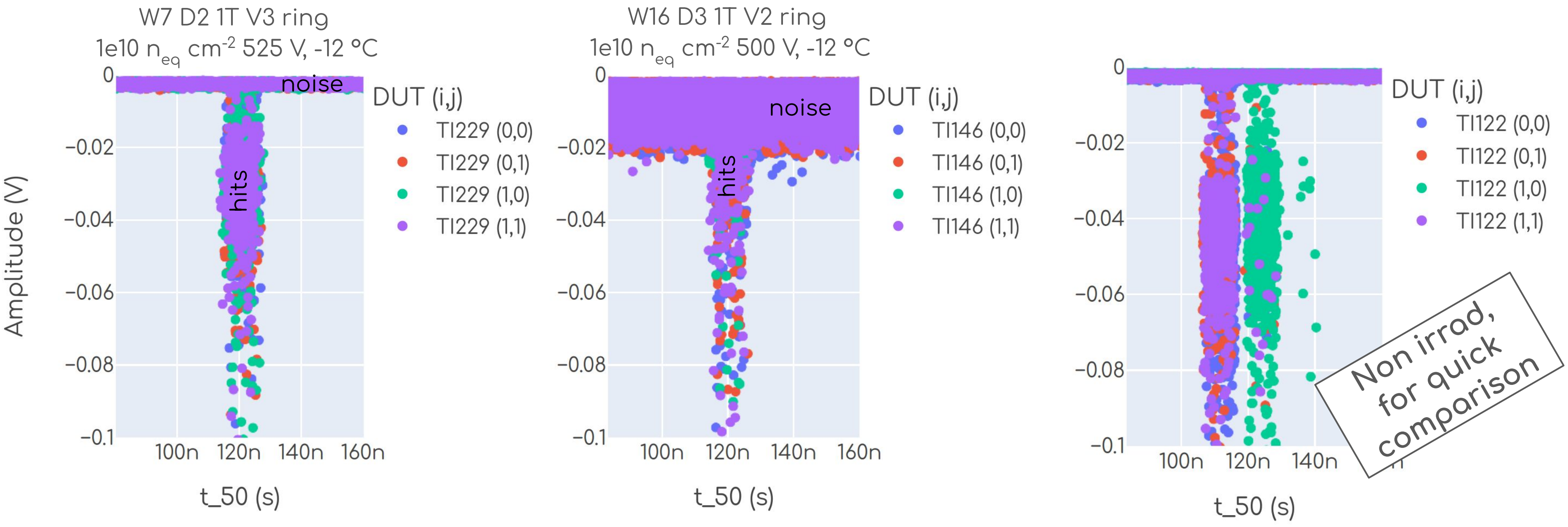
- W16 D3 1T V3 dot
- 0 n_{eq} cm^{-2}
- 230 V
- Room T





Irradiated TI-LGADs

Waveforms distribution for irradiated TI-LGAD

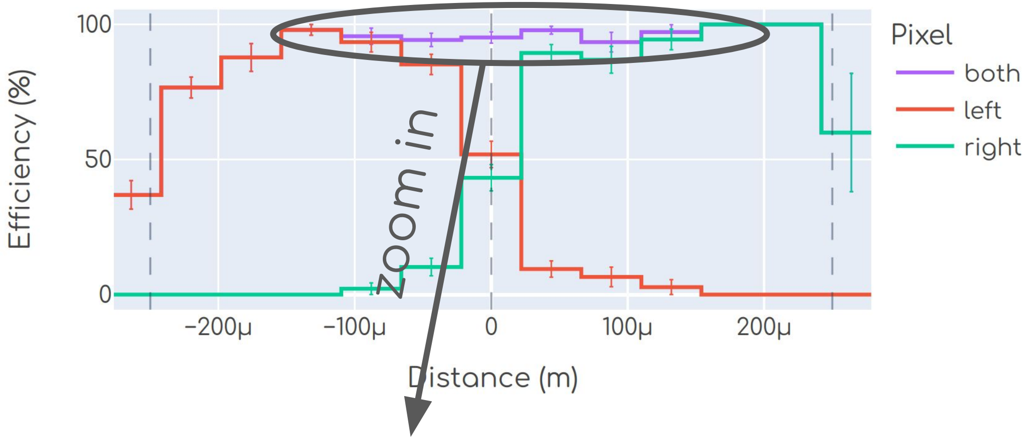


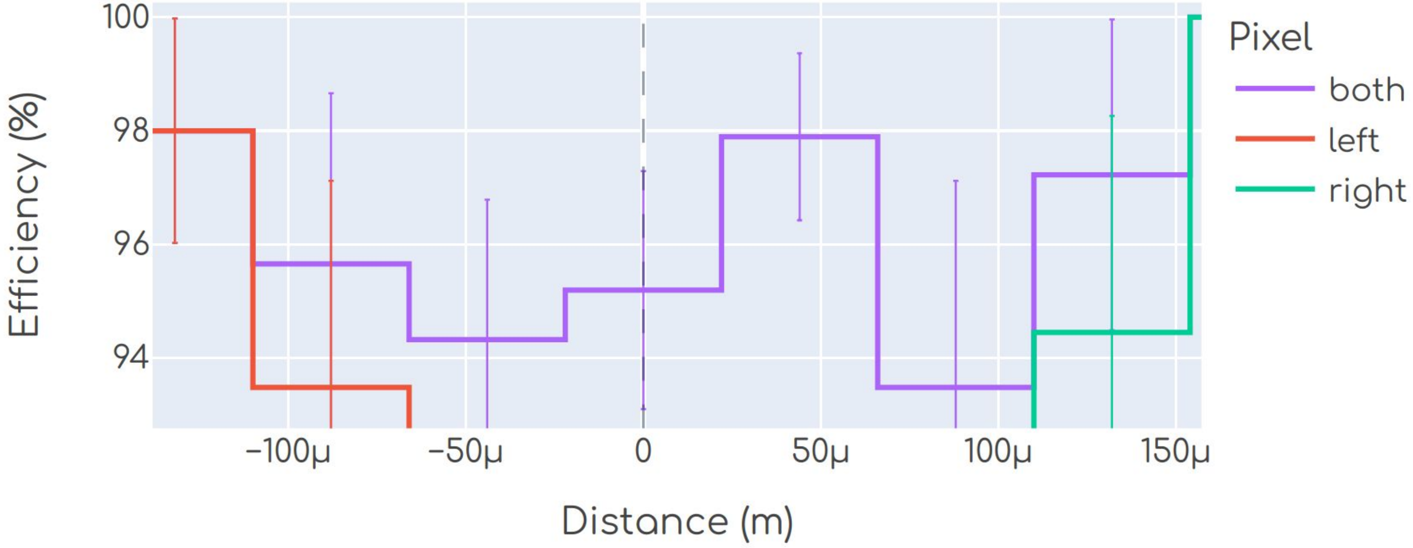
- W7 D2 1T V3 ring: Low noise, amplitude threshold at -5 mV ✅ (same as non irrad)
- W16 D3 1T V2 ring*: Noisier → higher amplitude threshold & less gain → lower efficiency 🙁

* During the test beam a single voltage point was taken, it is possible that if e.g. 490 V instead of 500 V would have been applied, the noise would be greatly reduced.

Efficiency profile

- W7 D2 1T V3 ring
- 1 n_{eq} cm^{-2}
- 525 V
- -12 °C

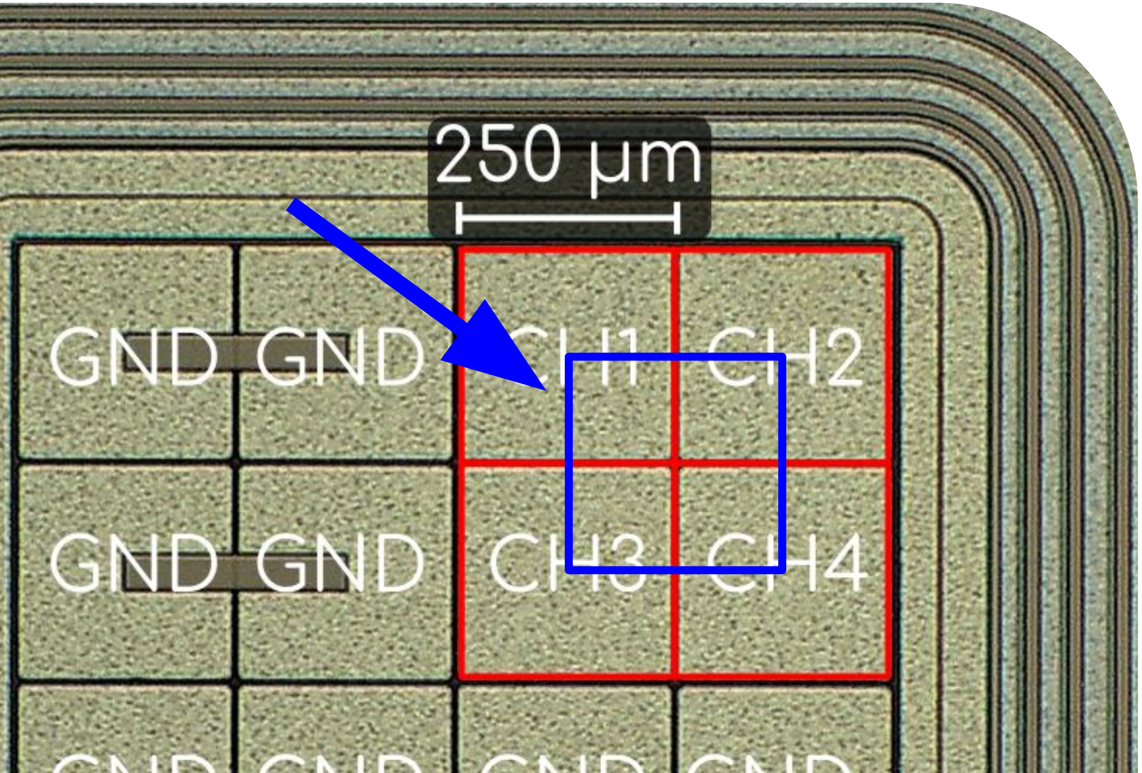




Effective efficiency

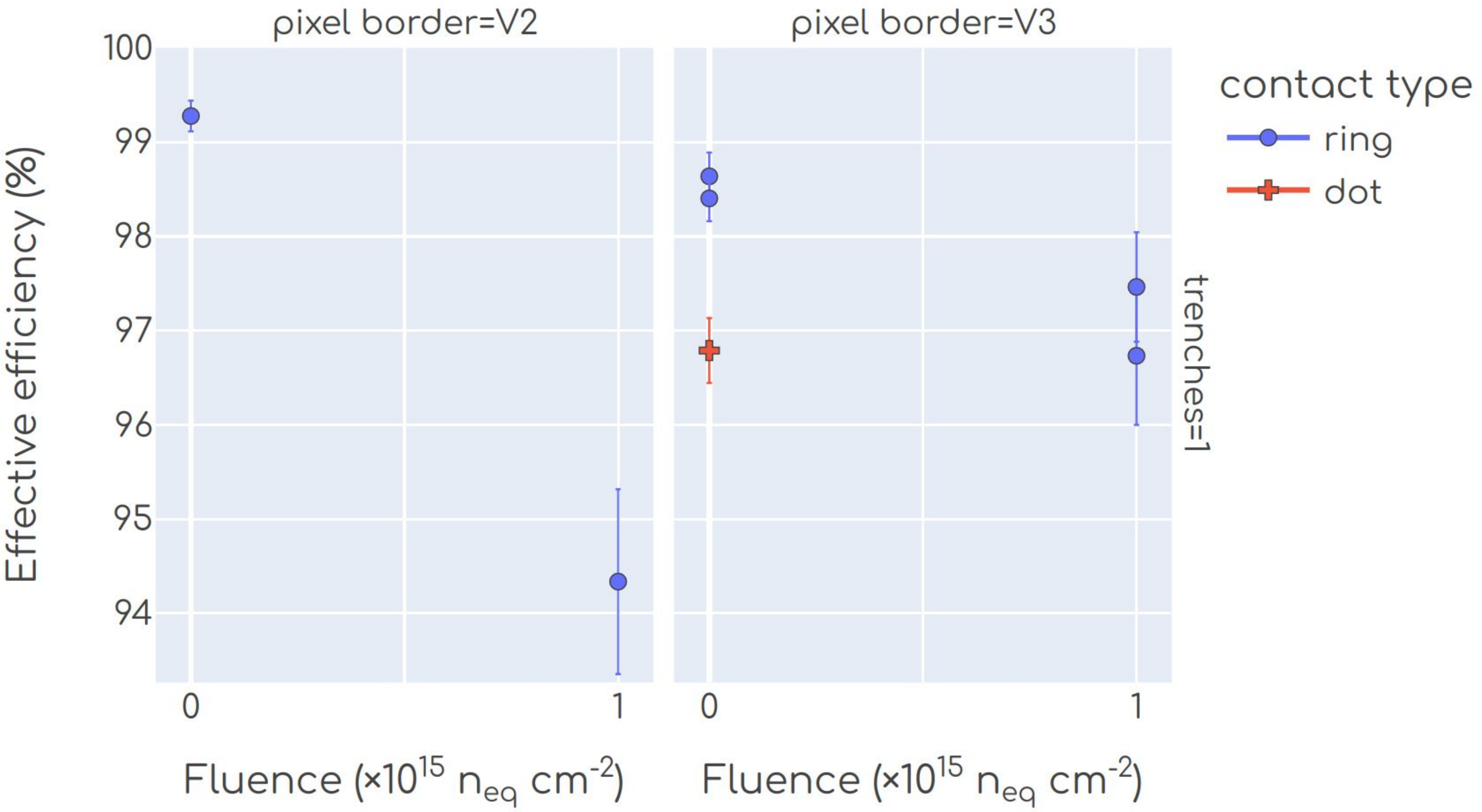
Effective efficiency

Efficiency measured in an area of the same size as a pixel. To avoid edge effects, take it close to the center:



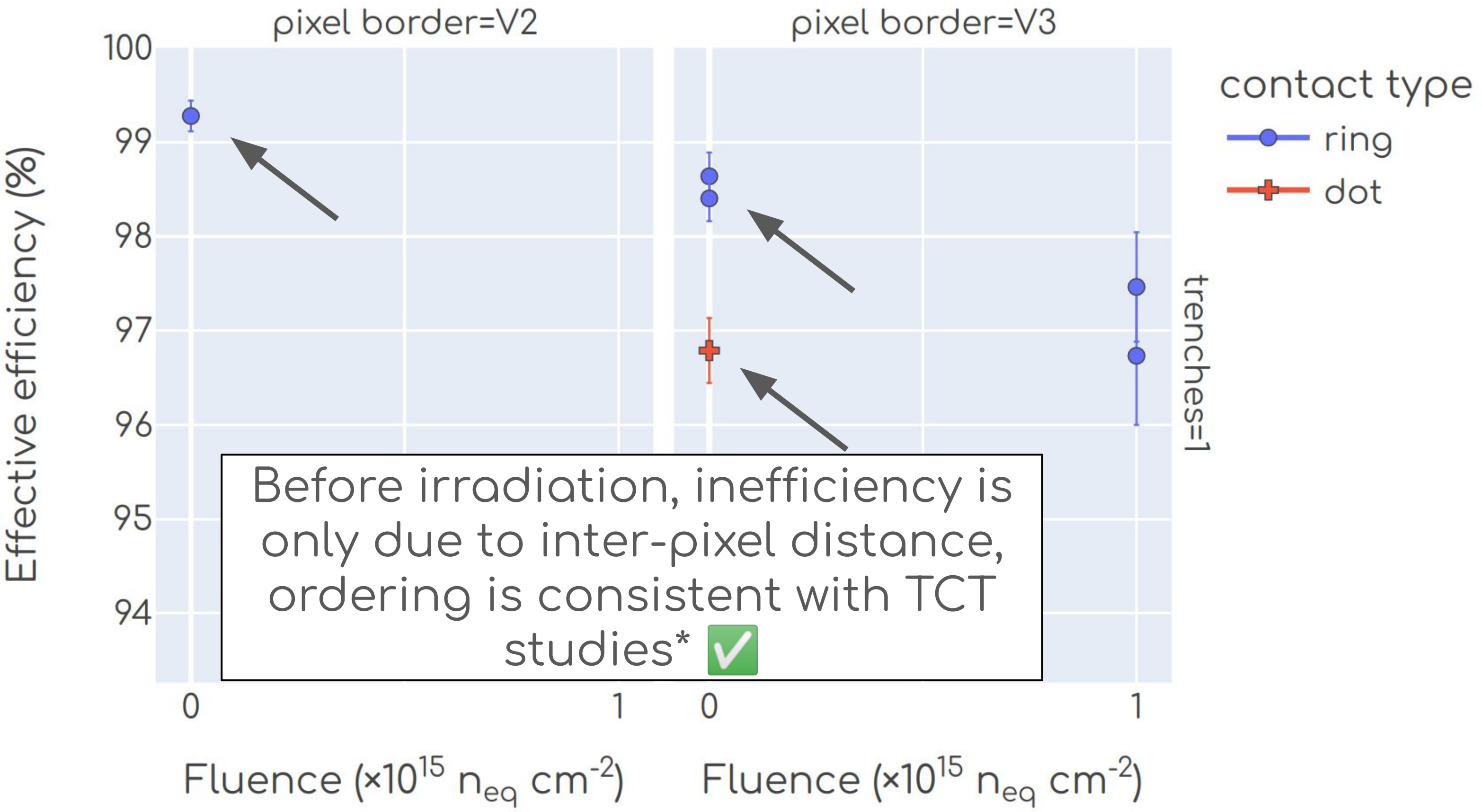
- Global efficiency that a large area sensor would have
- Thanks to DUT symmetry, it is translation invariant
- Higher statistics

Effective efficiency

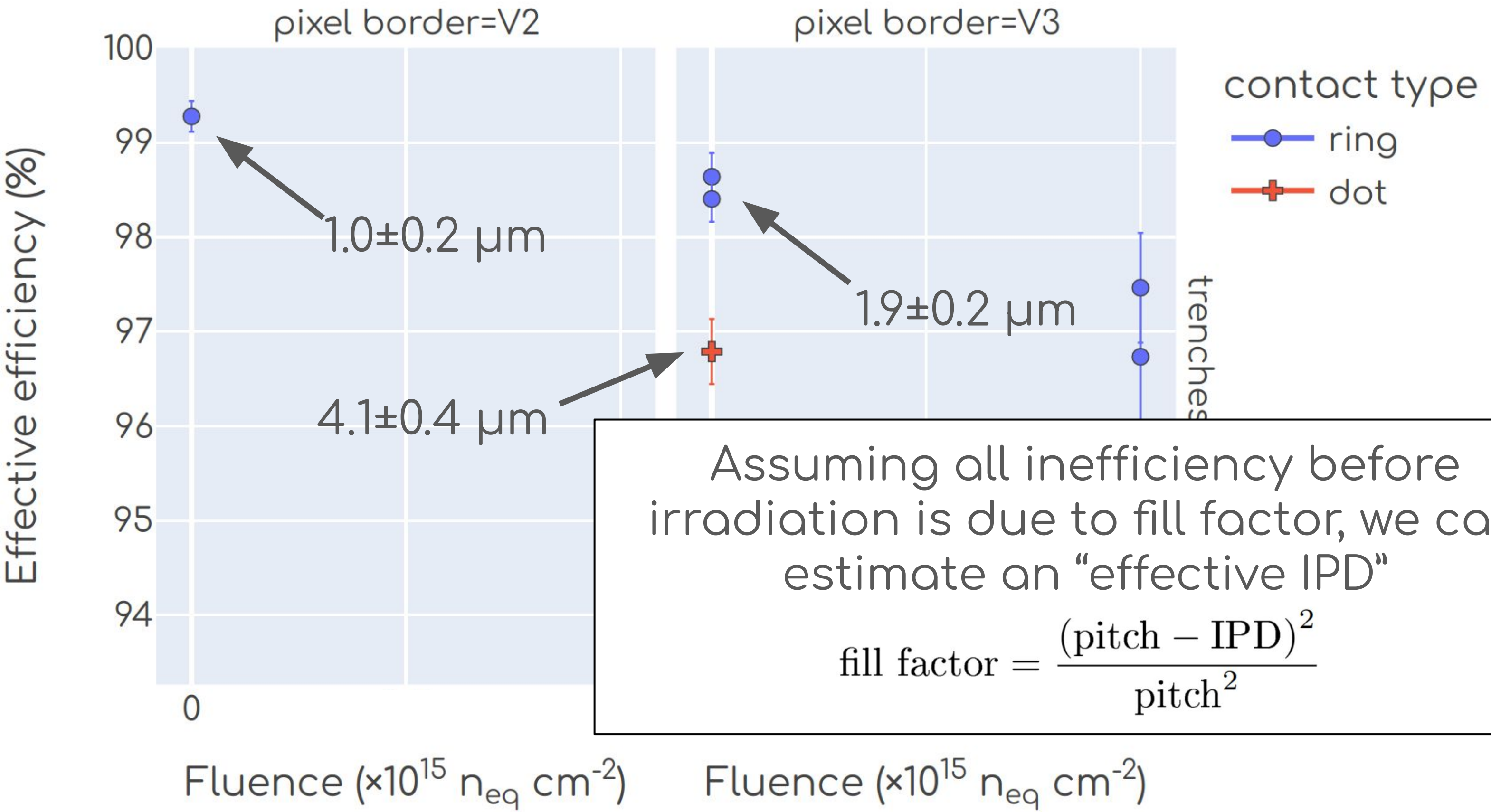


Effective efficiency

* Senger, M.; Macchiolo, A.; Kilminster, B.; Paternoster, G.; Centis Vignali, M.; Borghi, G. A Comprehensive Characterization of the TI-LGAD Technology. Sensors 2023, 23, 6225. https://doi.org/10.3390/s23136225



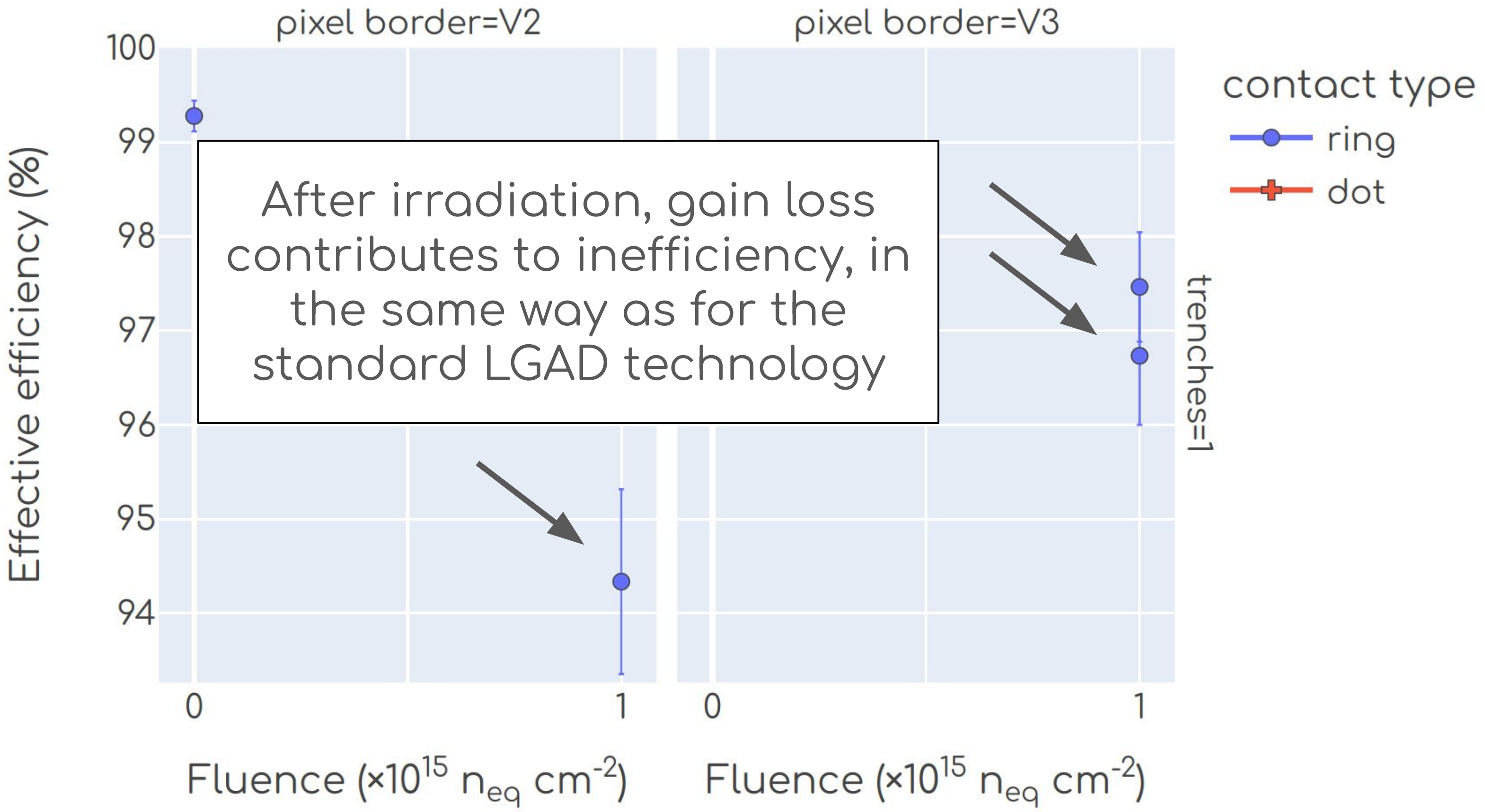
Inter-pixel distance (IPD)



Assuming all inefficiency before irradiation is due to fill factor, we can estimate an "effective IPD"

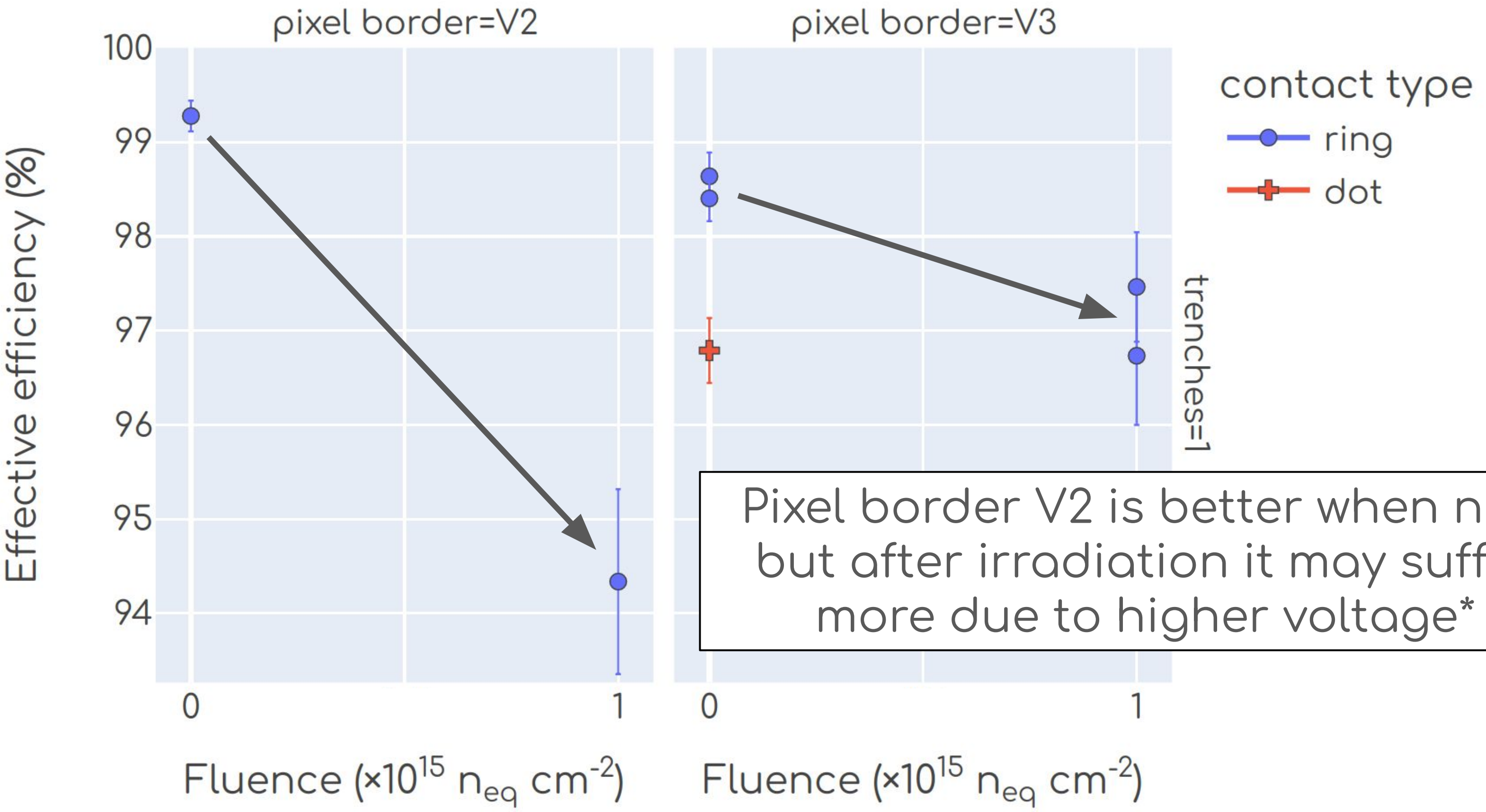
$$\text{fill factor} = \frac{(\text{pitch} - \text{IPD})^2}{\text{pitch}^2}$$

Effective efficiency



Effective efficiency

* Unfortunately only one voltage point was taken for V2, it may happen that reducing the voltage a bit fixes this issue and efficiency goes up again



Pixel border V2 is better when new, but after irradiation it may suffer more due to higher voltage*

Conclusions

- TI-LGAD samples were characterized in a test beam setup.
- Before irradiation, 99.2±0.2 % efficiency measured.
- After 1e15 n_{eq} cm^2 with reactor neutrons, 97.4±0.6 % efficiency measured.
- Charge sharing between neighboring pixels very small.

Future work

- FBK AIDAinnova TI-LGAD production: Addition of carbon co-implantation for enhanced radiation hardness.
  - Laboratory testing.
  - Test beam testing.

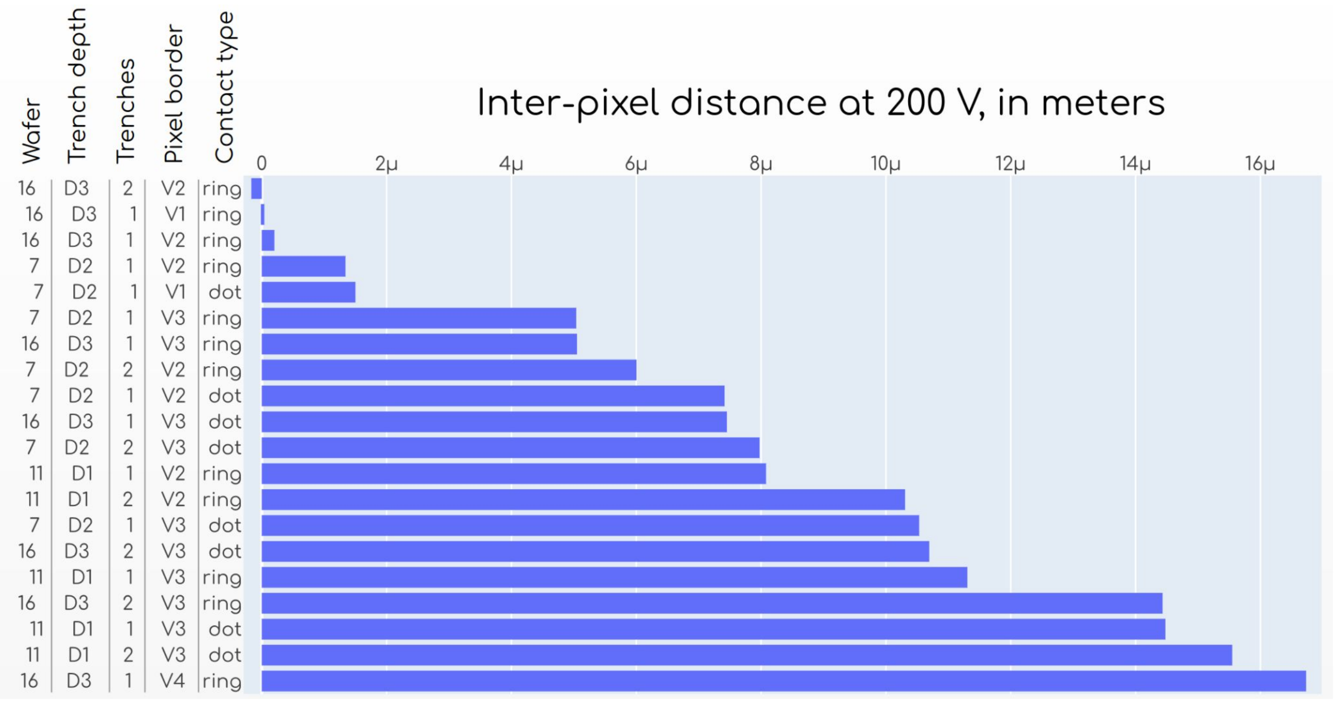
Acknowledgements

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004761.

Backup slides

TCT characterization

Almost all design patterns from the FBK RD50 TI-LGAD production were ranked according to their inter-pixel distance as measured with laser TCT, more details in https://doi.org/10.3390/s23136225.



Time resolution

Measured in laboratory beta source setup as well as in test beam setup, see https://doi.org/10.3390/s23136225 for more details.