TI-LGAD characterization using TCT setup at UZH

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this is me

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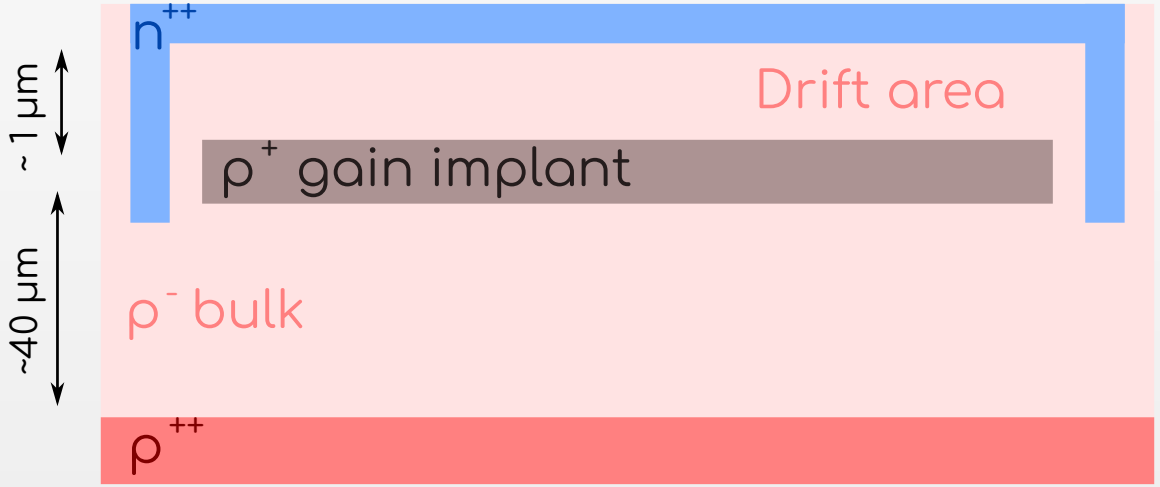
FONDAZIONE BRUNO KESSLER

University of Zurich[UZH]

RD50

LGAD

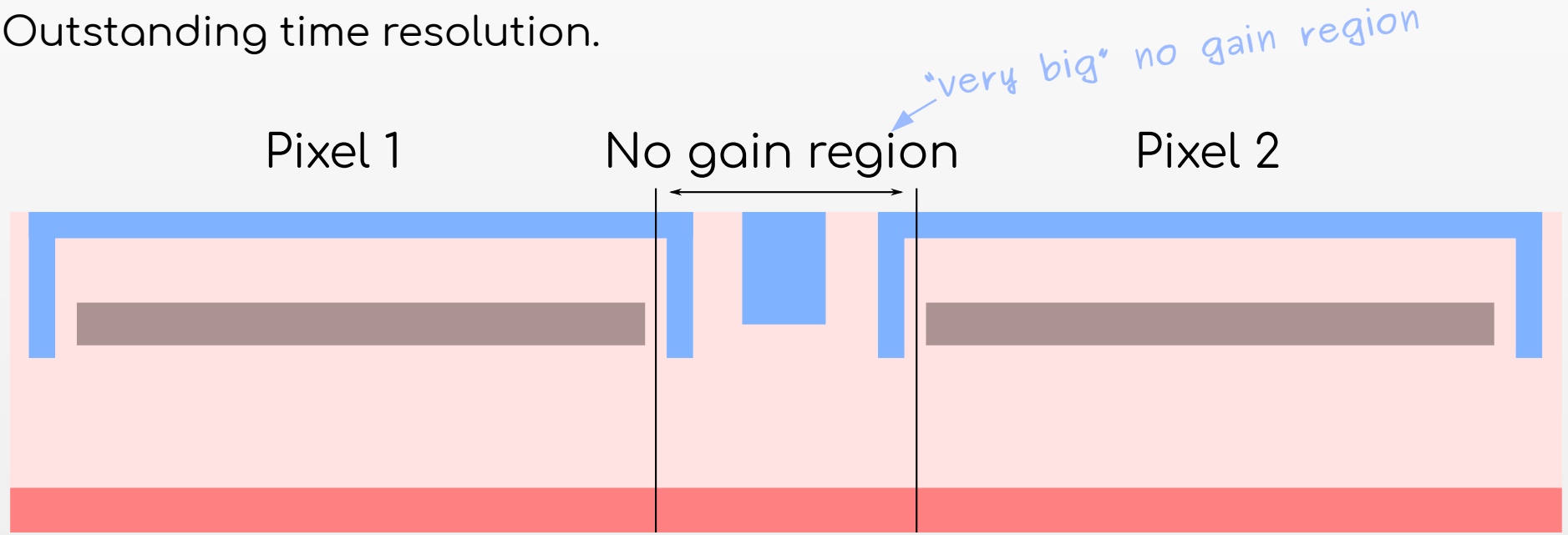
- Low Gain Avalanche Detector (LGAD)
- Solid state diode:
  - Very thin active thickness ~40 μm.
  - Gain layer provides gain ~10.
  - Time resolution for 1 MIP ~10-30 ps.



*Cartoon adapted from Ferrero, M., Arcidiacono, R., Mandurrino, M., Sola, V., Cartiglia, N., 2021. An Introduction to Ultra-Fast Silicon Detectors: Design, Tests, and Performances. CRC Press. https://doi.org/10.1201/9781003131946

LGAD technology and (x,y,z,t) tracking

- "Plain LGAD": mature technology.
  - CMS ETL
  - Atlas HGTD
- Outstanding time resolution.
- Issue: Fill factor
  - Inter-pixel distance (IPD) is on the order of 20-50 µm.[1]



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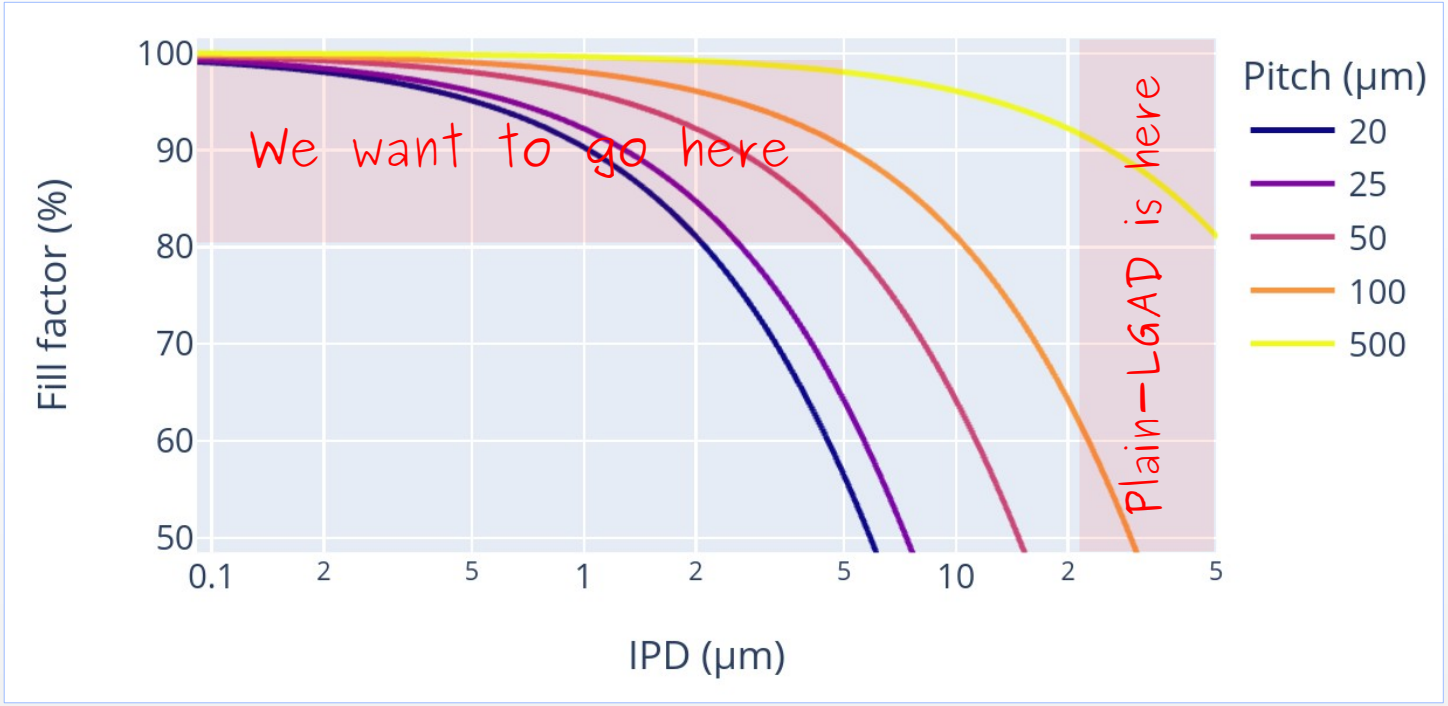
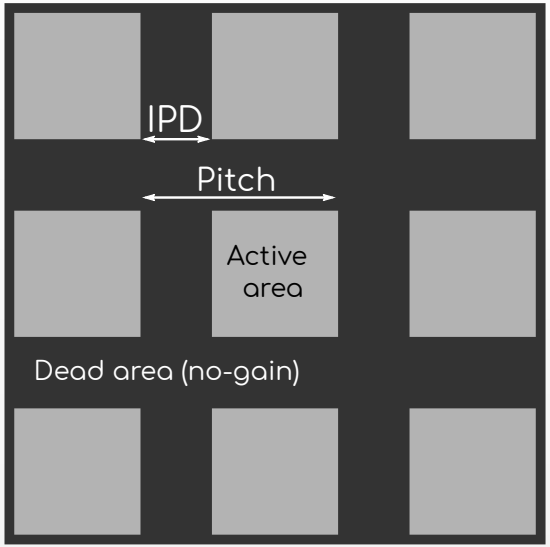


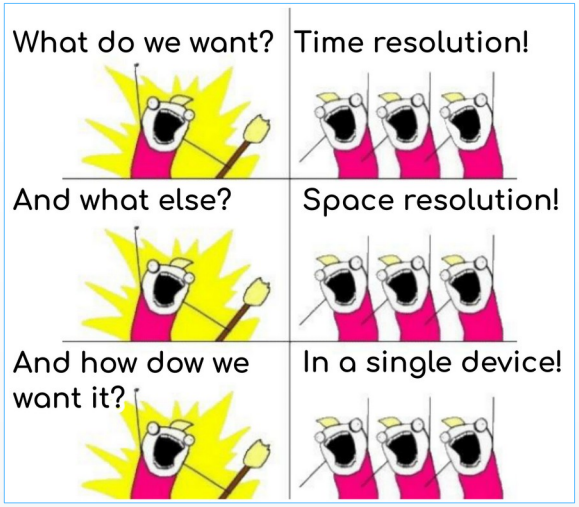


$$Fill\ factor = \frac{Active\ area}{Total\ area}$$

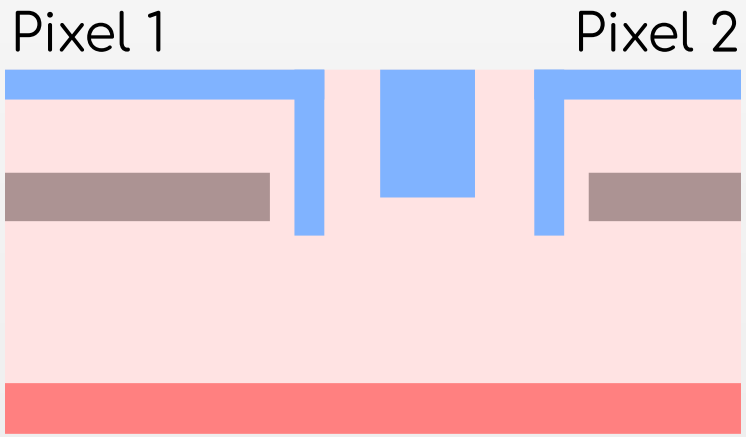
For small pixels (pitch~50 μm or less) smaller IPD values (~2 μm or less) are required to get a reasonable fill factor (~90 % or more).

High granularity LGAD technologies

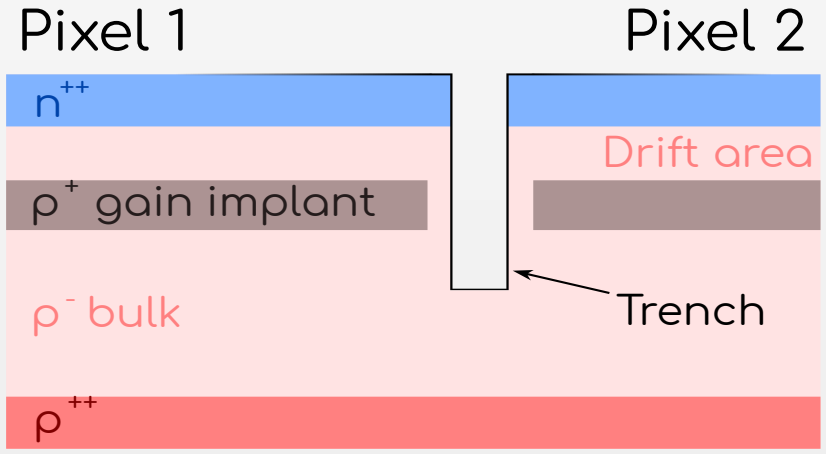
- Trench Isolated LGAD (TI-LGAD). ←this talk
- AC coupled LGAD (AC-LGAD).
- Inverse LGAD (iLGAD).
- Deep Junction LGAD (DJ-LGAD).
- Others (etc-LGAD).



Plain-LGAD



TI-LGAD



*These cartoons show a simplified/idealized picture and are meant for visualization purposes.

The "RD50 TI-LGAD Project"

- Goal: "Design and production of TI-LGAD with small pixels (<= 100 um) and high Fill Factor (> 80%)."[1]

[1] G. Paternoster. "Latest Developments on Trench-Isolated LGADs." Presented at the 35th RD50 Workshop, CERN, November 19, 2019. https://indico.cern.ch/event/855994/contributions/3637012/.

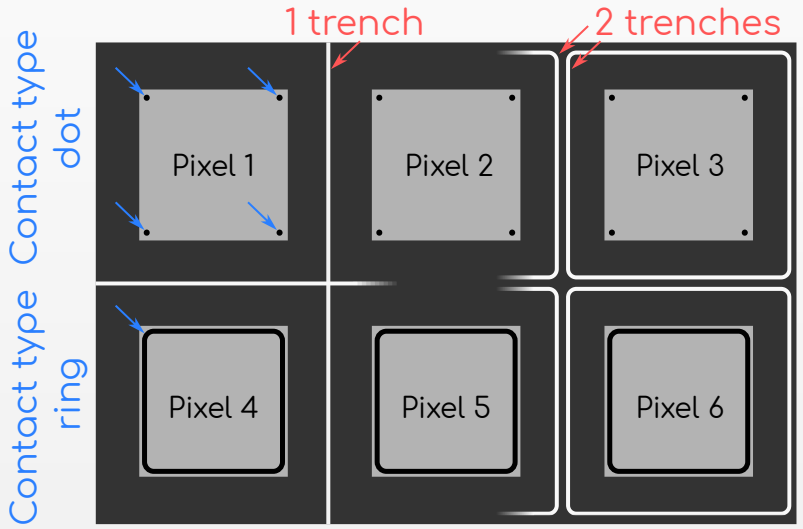
The "RD50 TI-LGAD Project"

- Goal: "Design and production of TI-LGAD with small pixels (<= 100 um) and high Fill Factor (> 80%)."[1]

Design patterns available at UZH:

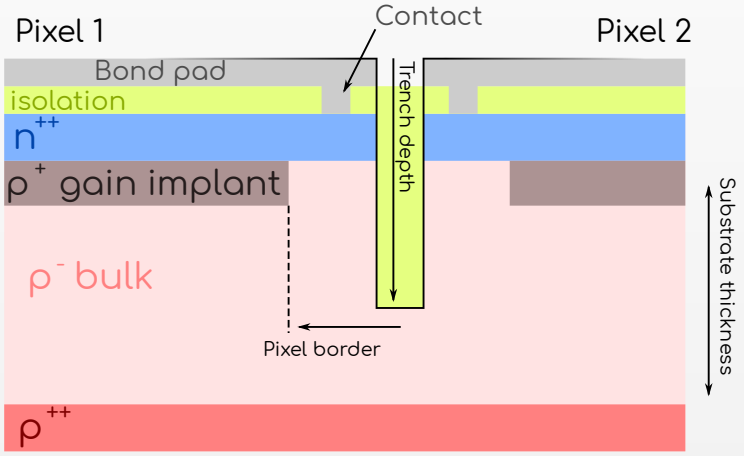
1) Trenches:
   - 1.
   - 2.
2) Contact type:
   - Ring.
   - Dot.
3) Pixel border:
   - trench-gain layer distance.
4) Trench depth.

Top view



*These design patterns are constant within each sample, here they are drawn all together as in a single sample just to illustrate.

Side view



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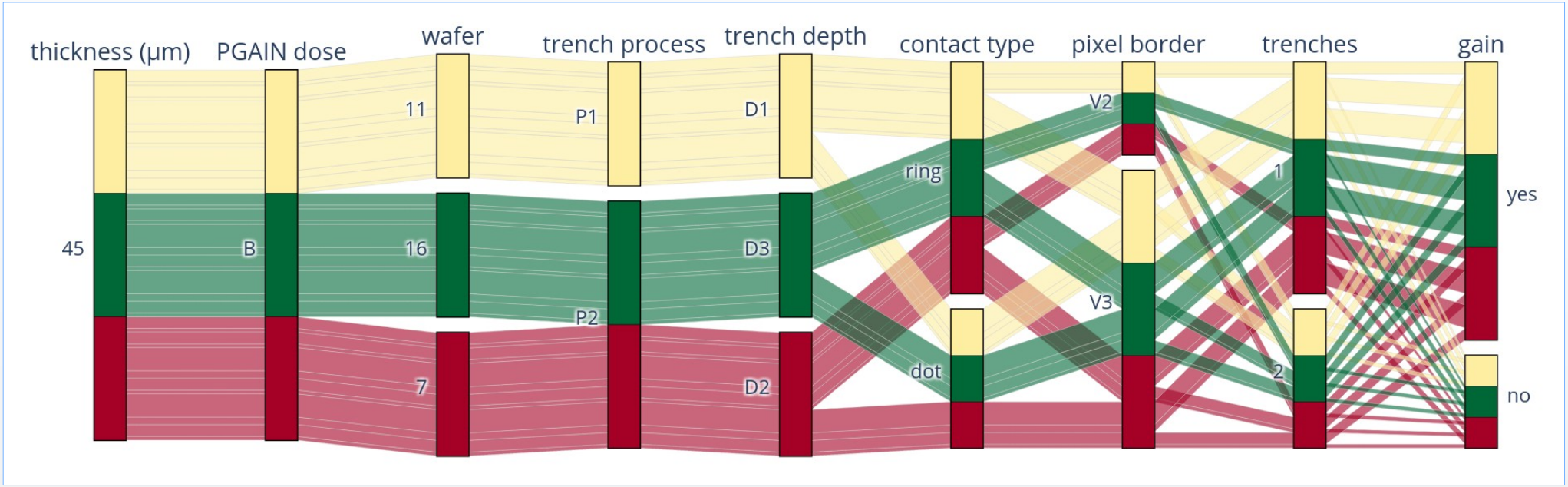
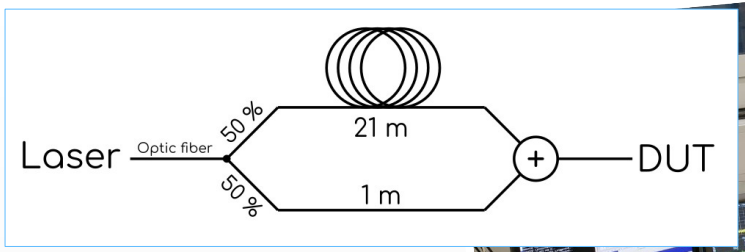
TI-LGAD samples @ UZH

A total of 96 devices distributed according to the following diagram:

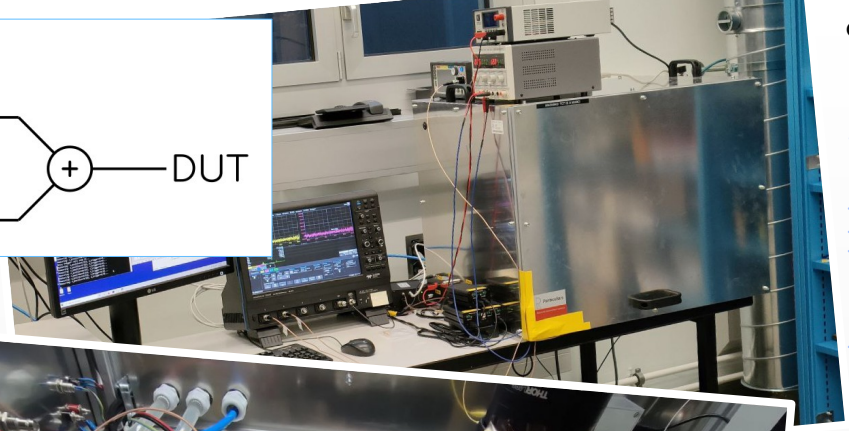


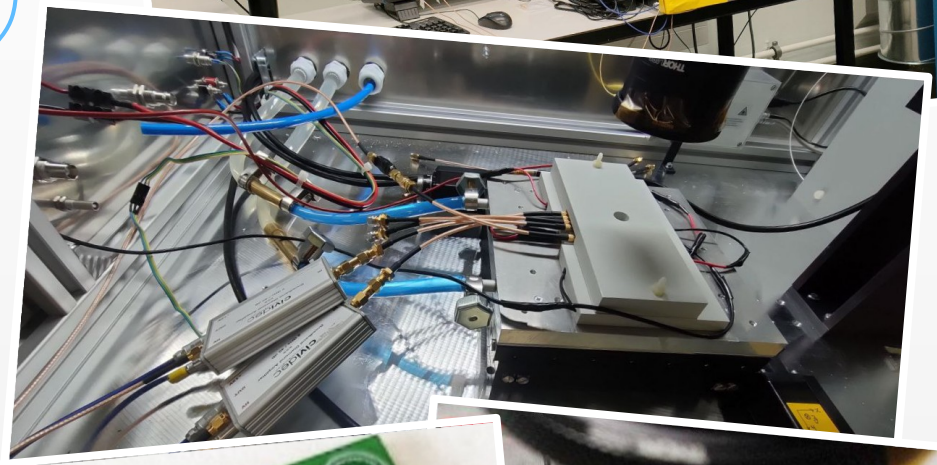
- 1 single thickness (45 µm).
- 1 single PGAIN dose (B).
- 3 wafers (7, 11 and 16).
- 2 trench processes (P1, P2).
- 3 trench depths (D1<D2<D3).
- 2 contact types (ring, dot).
- 2 pixel borders (V2<V3).
- Number of trenches (1, 2).

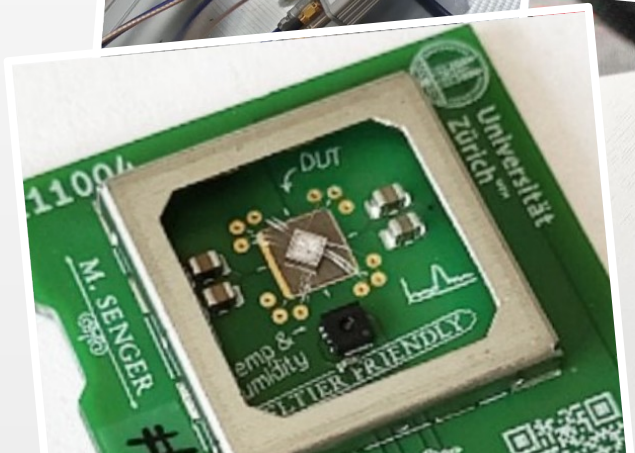
TCT setup @ UZH

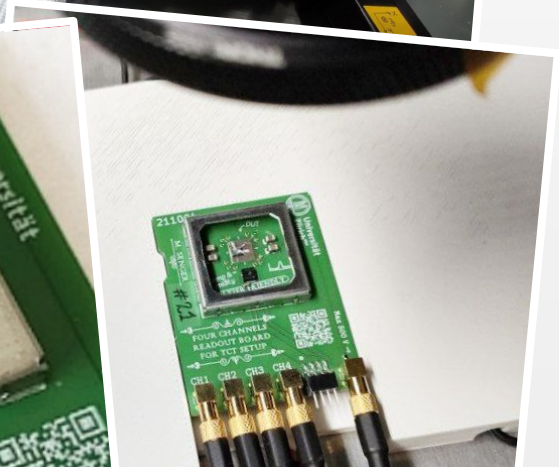


- Particulars Scanning TCT:
  - Infrared laser (1064 nm).
  - Laser spot Gaussian with σ ~ 9 μm.
  - Laser splitting+delay[1] with optic fiber for timing measurements provides two pulses separated by 100 ns.
- Custom made passive readout board.
- Cividec TCT amplifier.
  - 10 kHz - 2 GHz, 40 dB.
- Oscilloscope WaveRunner 9254M.
  - 4 GHz, 40 GS/s.
- Keithley 2470 bias voltage source.









[1] https://msenger.web.cern.ch/laser-delay-system-for-the-scanning-tct/

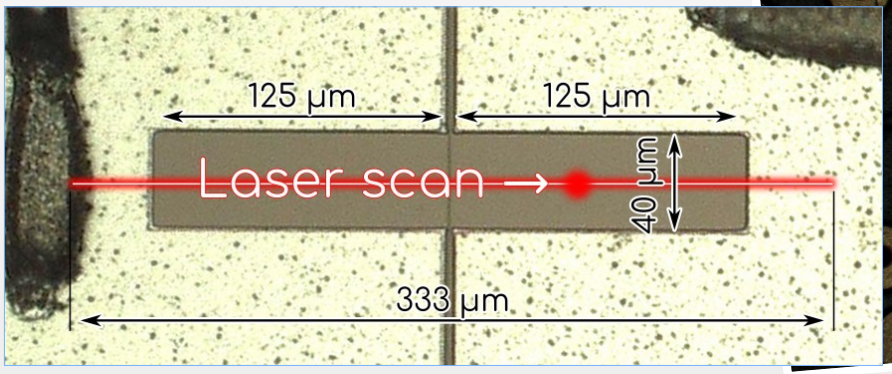
Samples geometry and laser scans

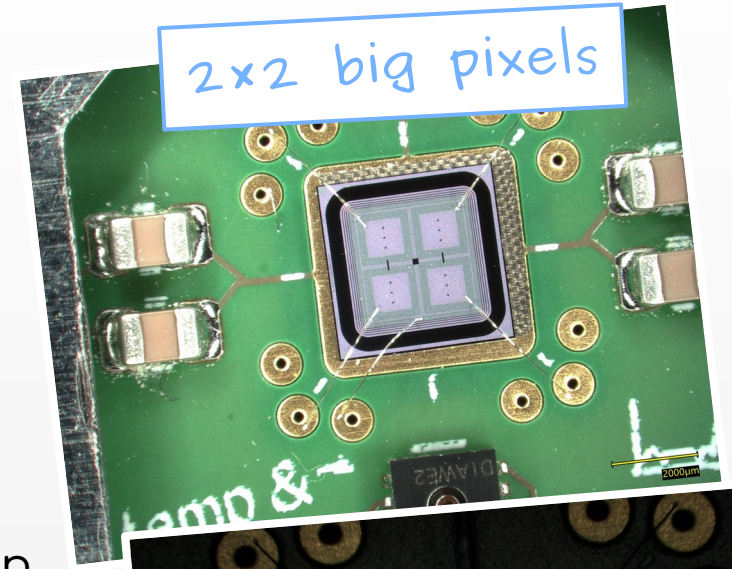
- 1D linear scan.
- From metal to metal crossing through the window.
- Two geometries:

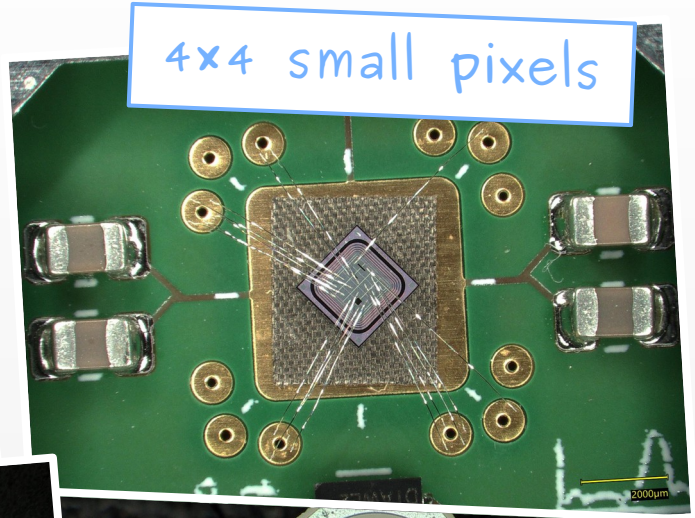
  1) 2×2 big pixels.

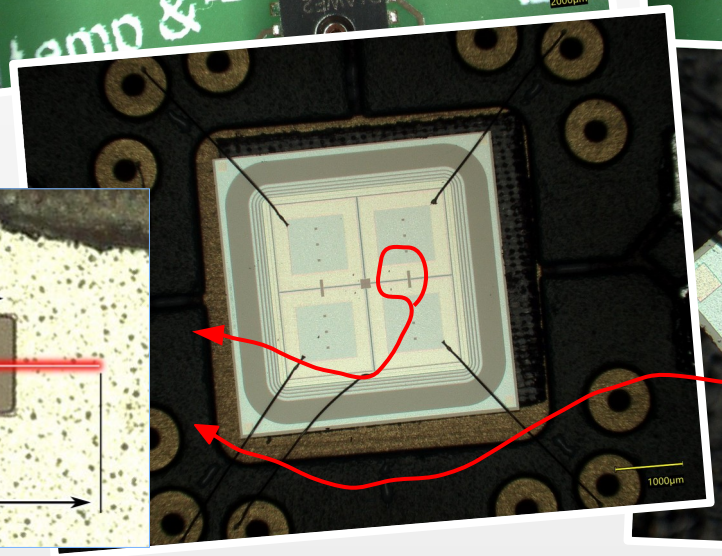
  2) 4×4 small pixels.

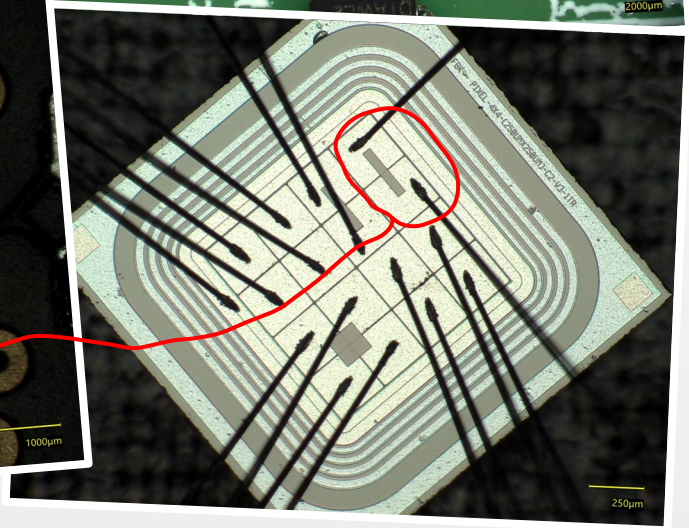
  - Window is identical in both.





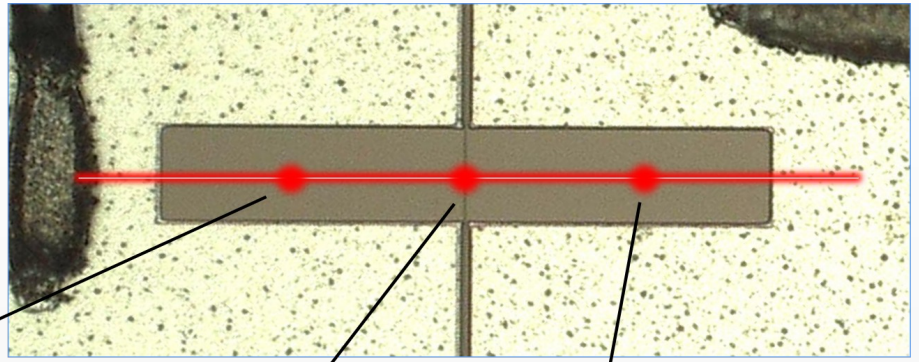


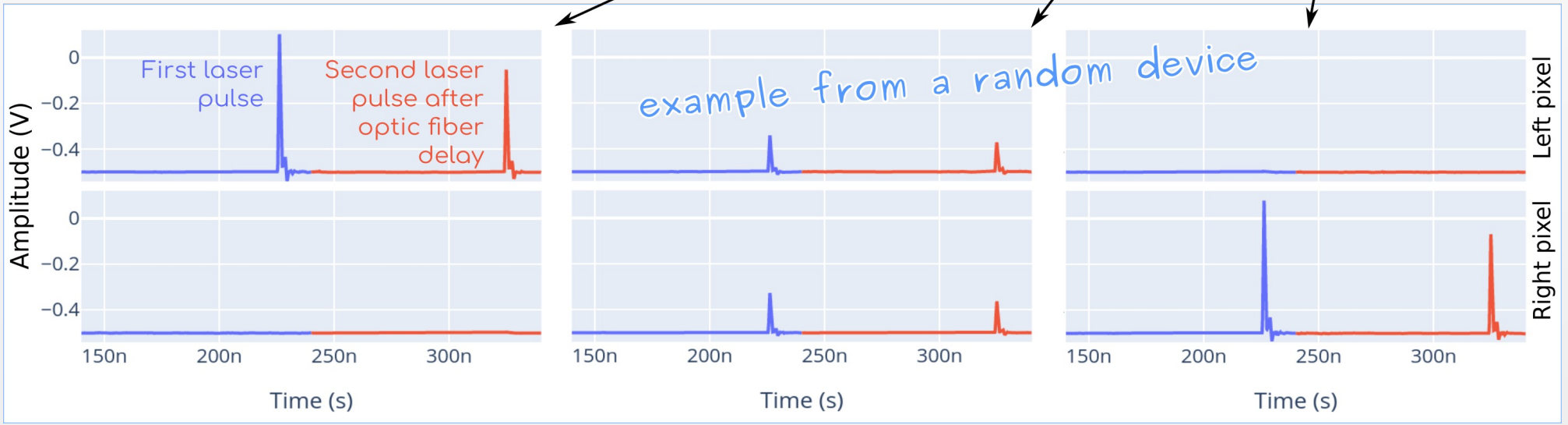




Laser scans

- Trenches provide good isolation.
- Shared signal in the middle is shared due to the size of the laser spot.
- Qualitative similar behavior for all devices.

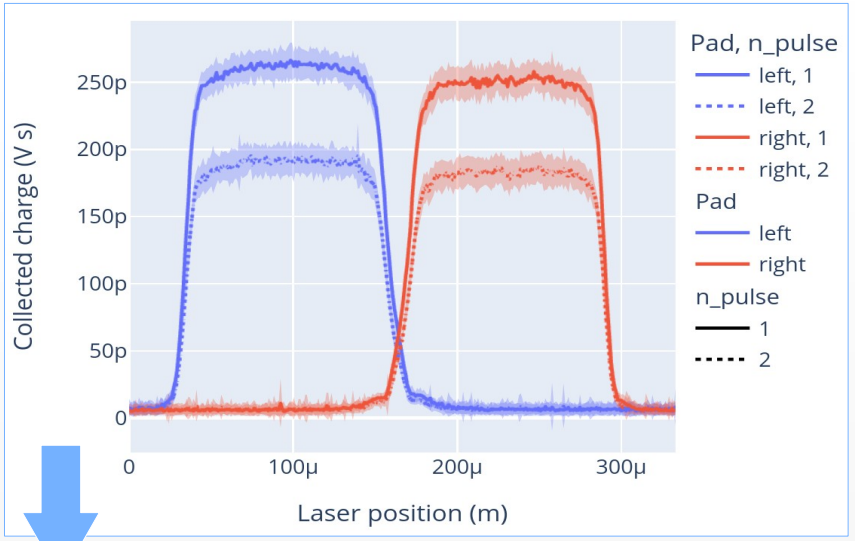


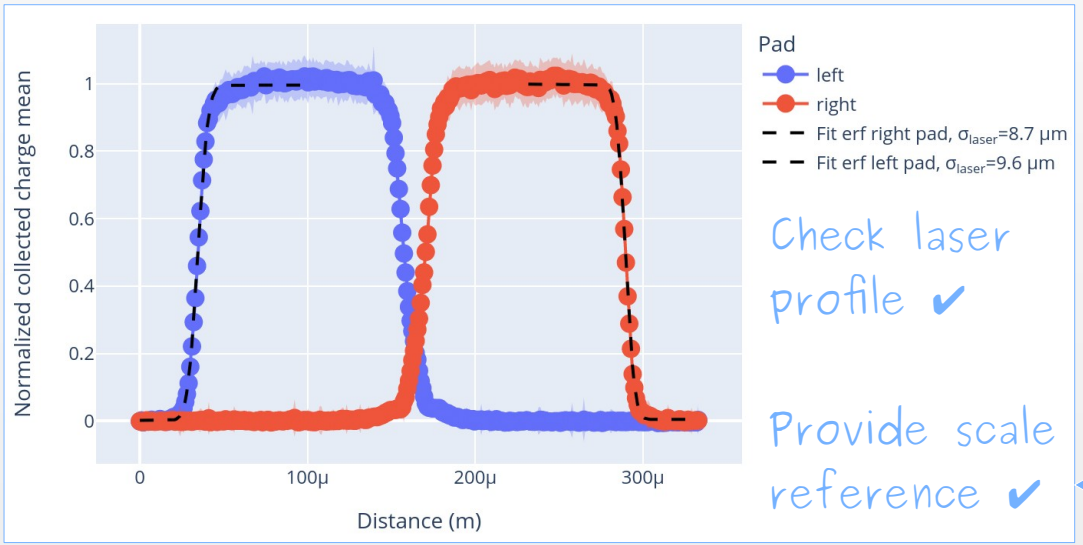


Laser scans

- Steps of 1 µm.
- ~ 50 events at each position.
- Metal-silicon interface as reference:
  - Check laser shape/size.
  - Distance scale correction (2-5 %).

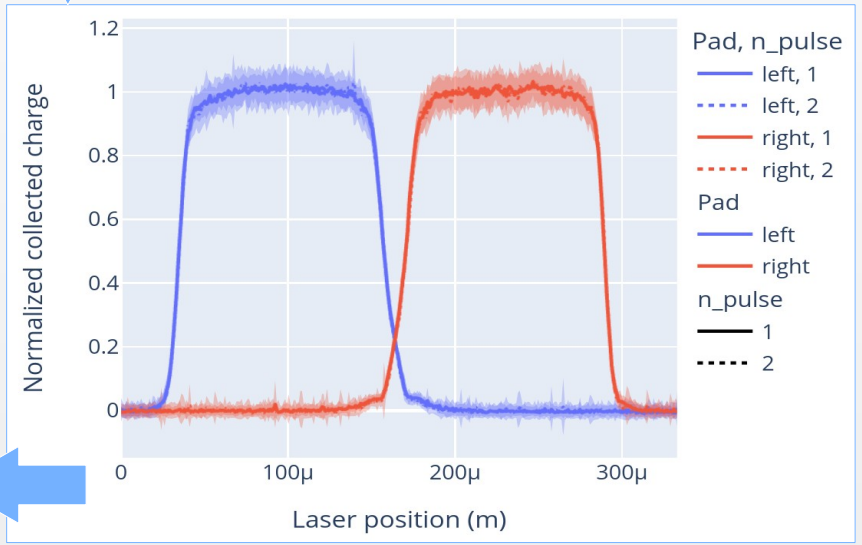
Example from a random scan





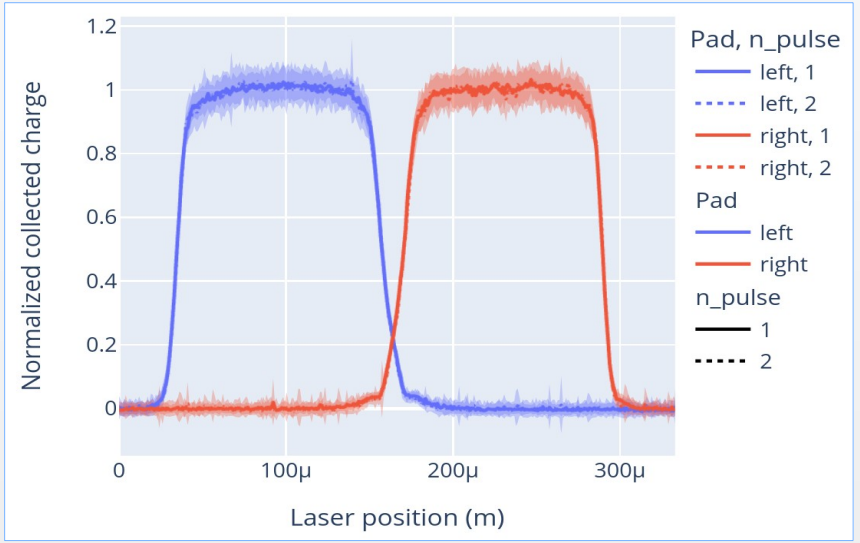
Check laser profile ✔

Provide scale reference ✔



Laser scans

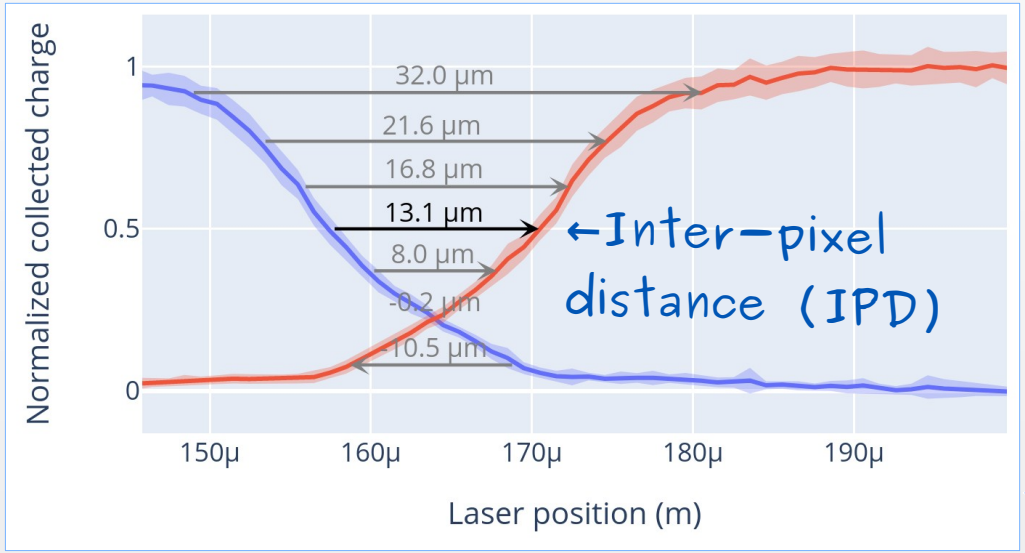
Go to next slide 😀

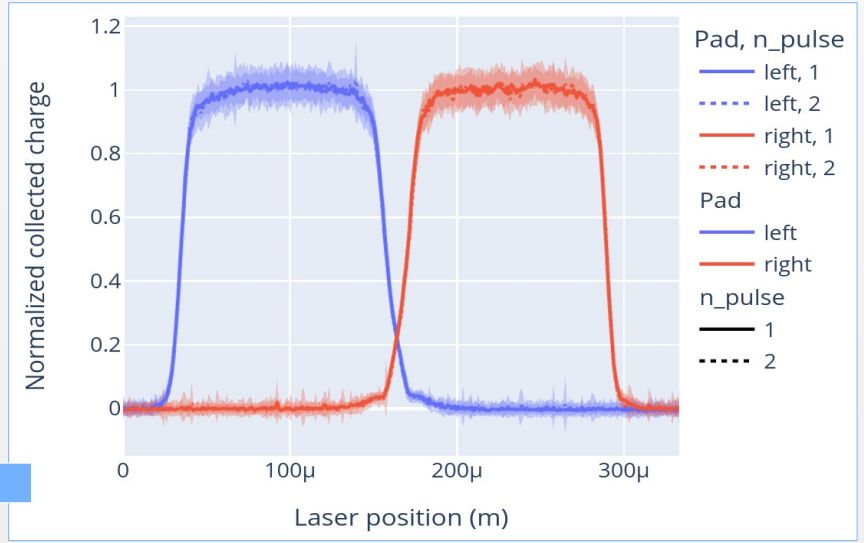


Inter-pixel distance (IPD)

- IPD: Distance between 50 % of normalized collected charge of each channel.
- Linear interpolation, not “S function”.
  - Observed deviations from “S”, different for each design pattern and dependent on the bias voltage.

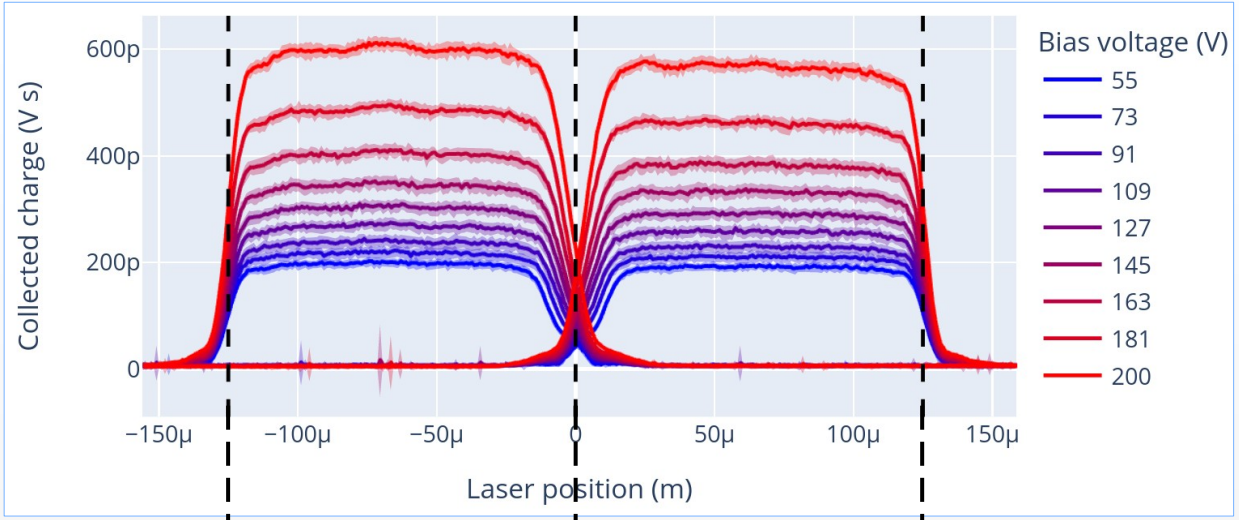
Example from a random scan

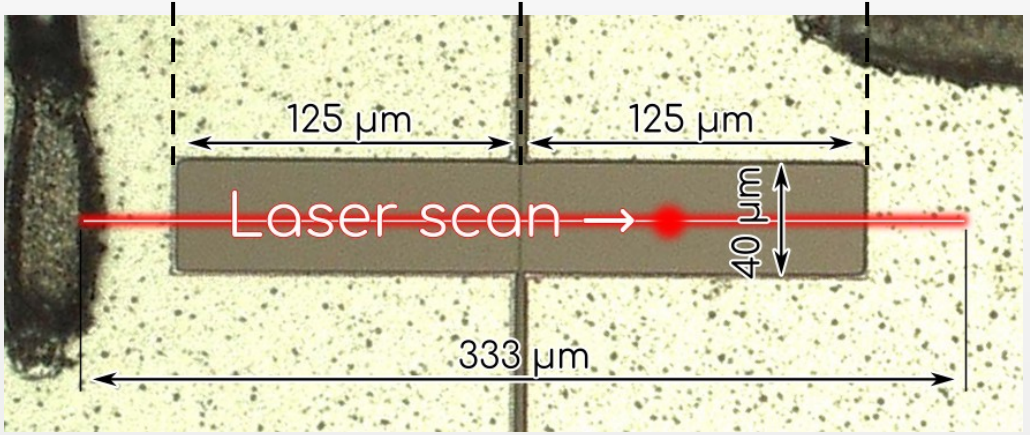




Scanning at different bias voltages

Example from a random scan





Scanning at different bias voltages

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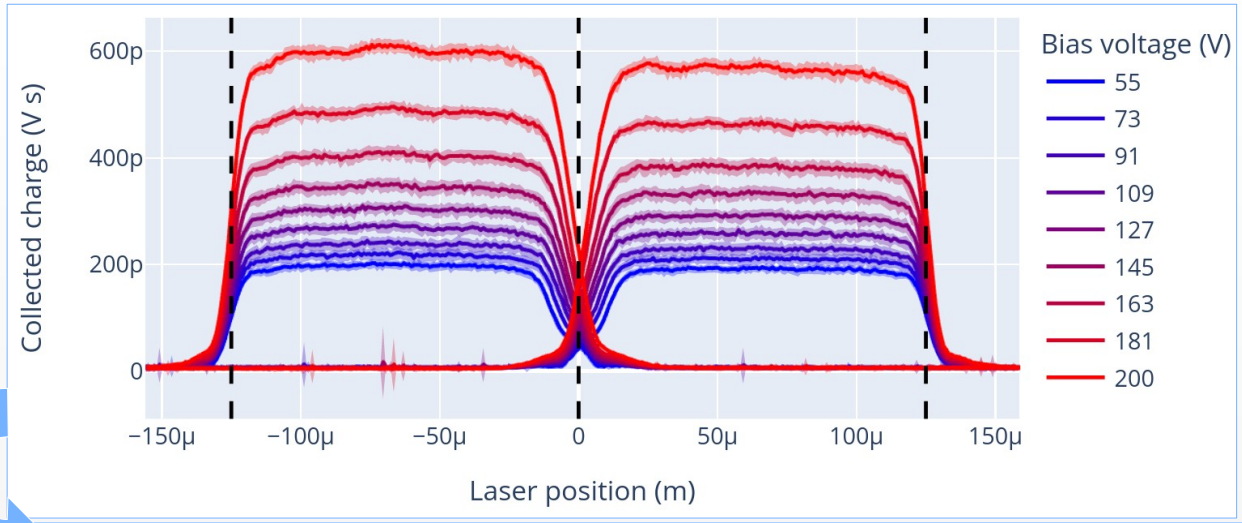
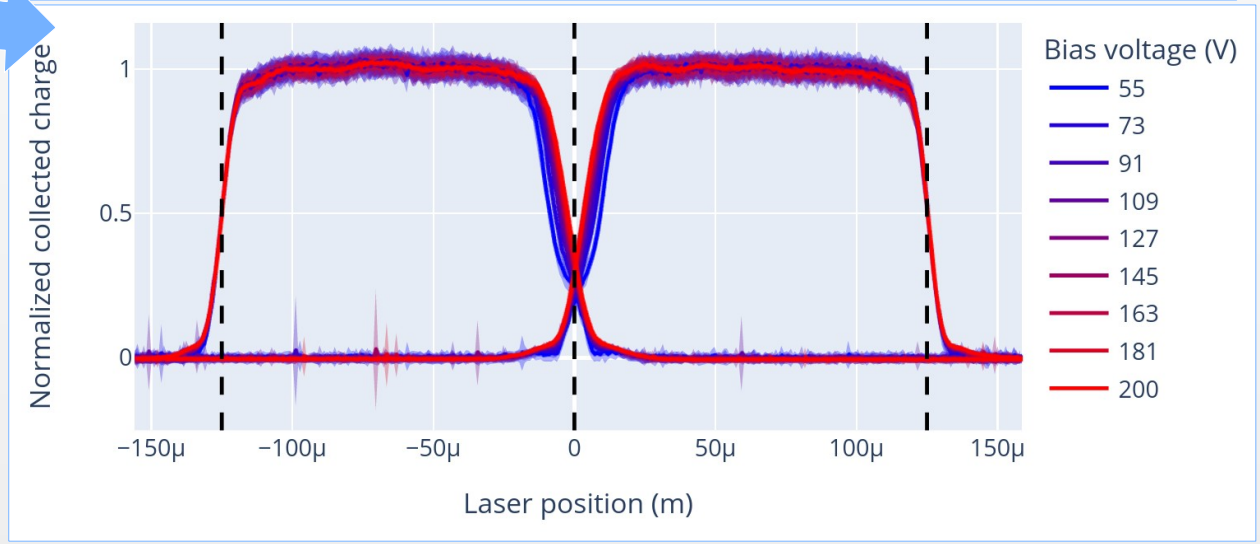
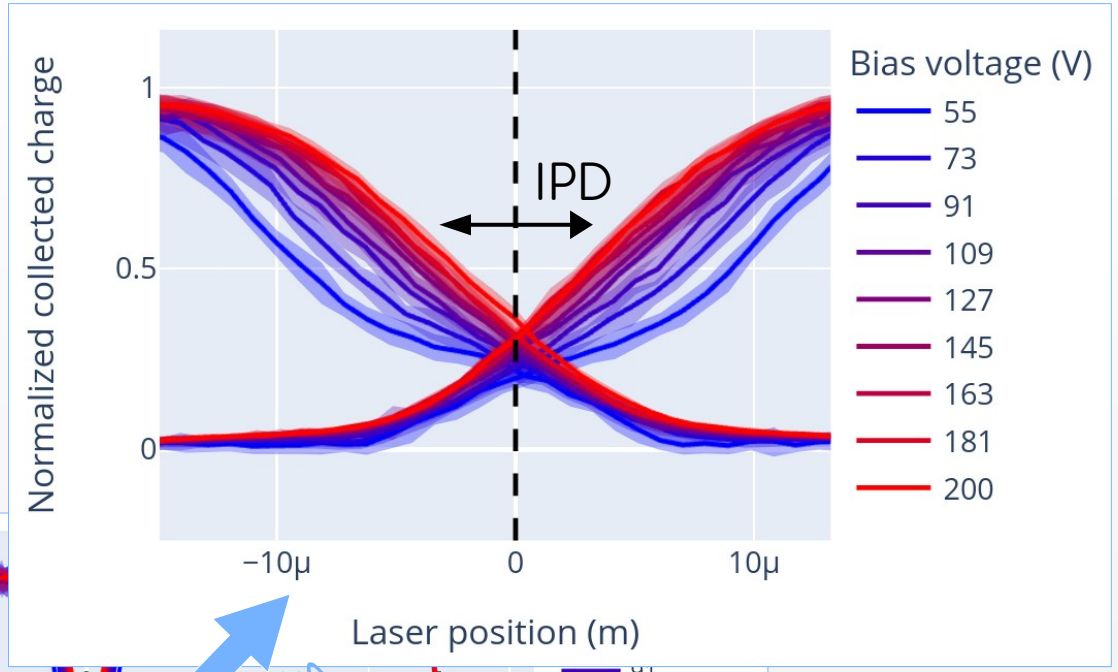


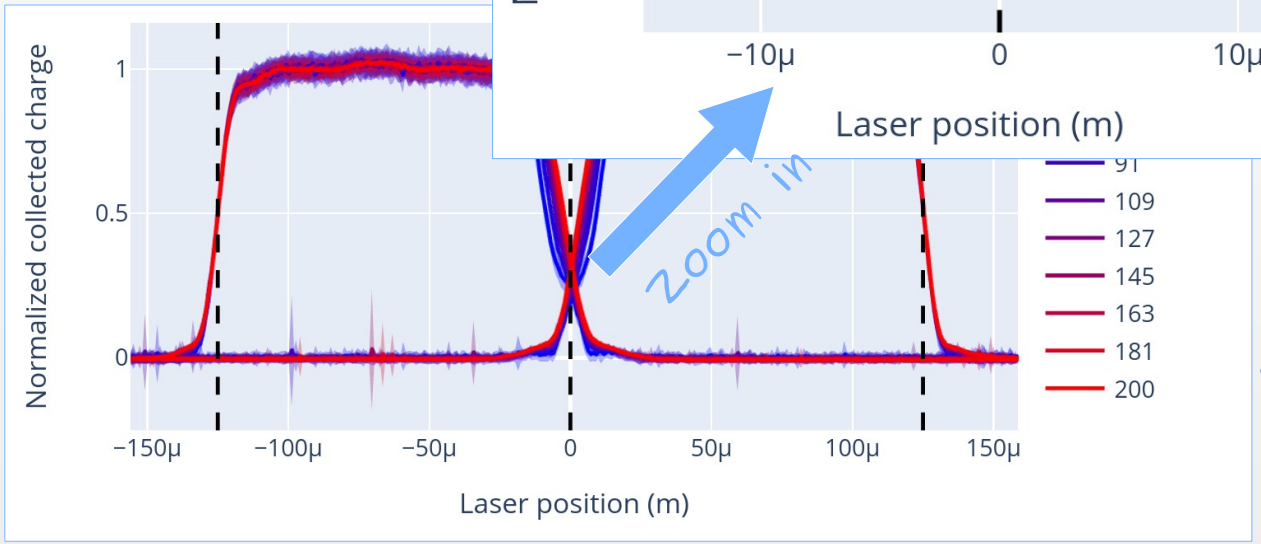
Normalize



Scanning at different bias voltages

Inter-pixel distance (IPD) depends on bias voltage[1].



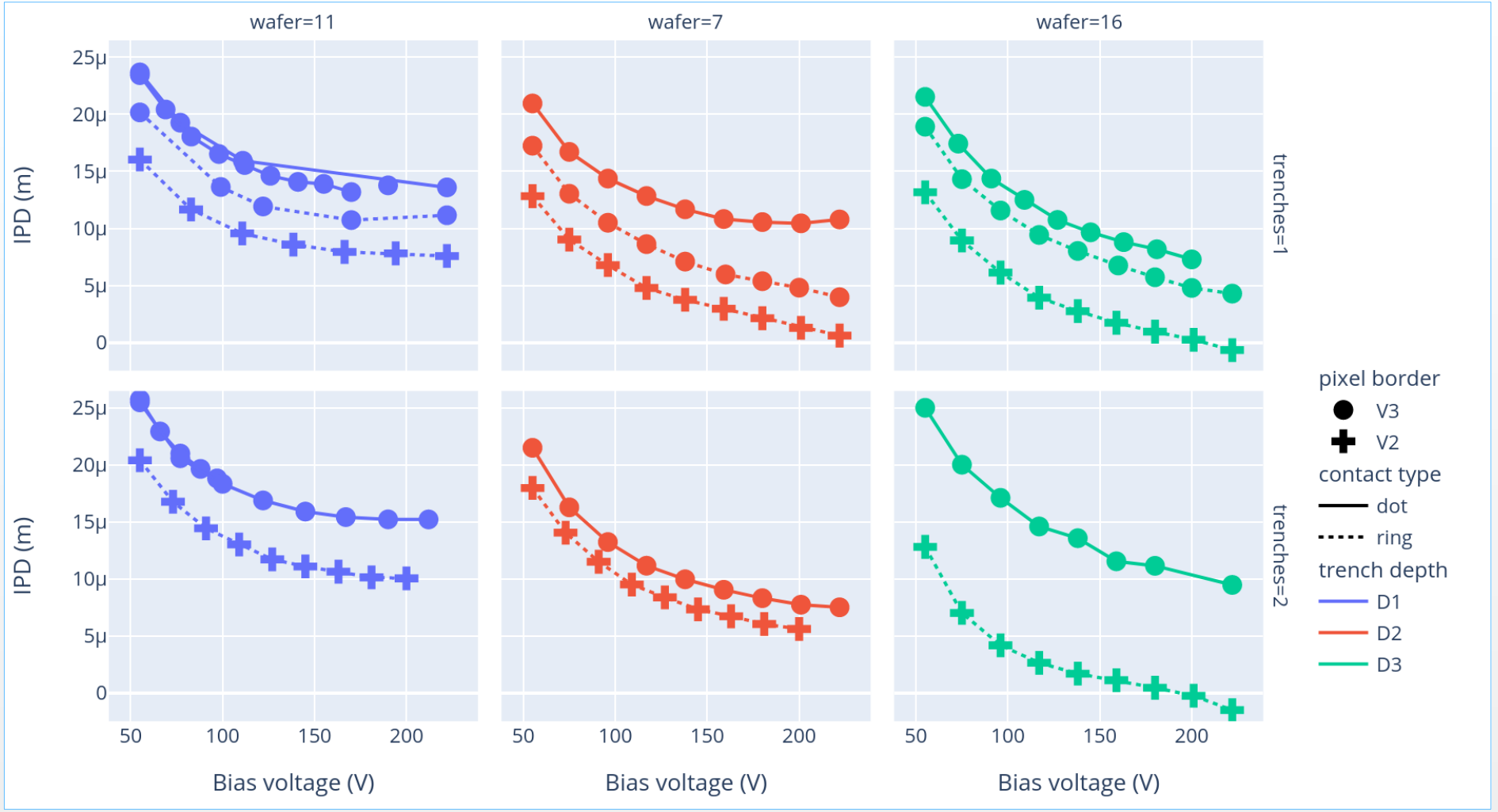


Zoom in

Example from a random scan

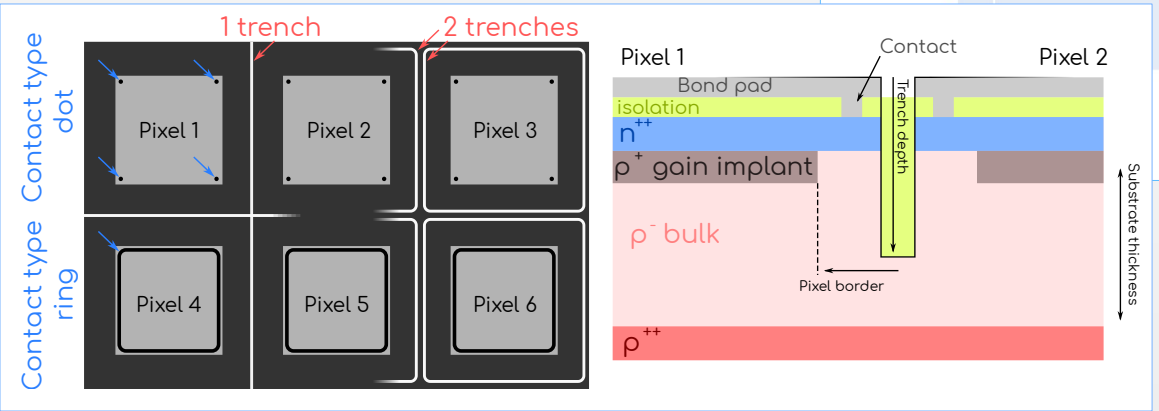
[1]Also reported by Ashish Bisht. 2021. "Characterization of Novel Trench-Isolated LGADs for 4D Tracking." Presented at the WORKSHOP ON PICO-SECOND TIMING DETECTORS FOR PHYSICS, Zurich, September 9. https://indico.cern.ch/event/861104/contributions/4514658/

Measured IPD for each design pattern



Measured IPD for each design pattern

- Wafer 16 and 7 are better than wafer 11:
  - Deeper trenches better than shallow. (Or "trench process" P2 is better than P1?)
- Pixel border V2 (smaller) is better than V3 (longer).
- Contact type "ring" better than "dot" (unexpected to me).



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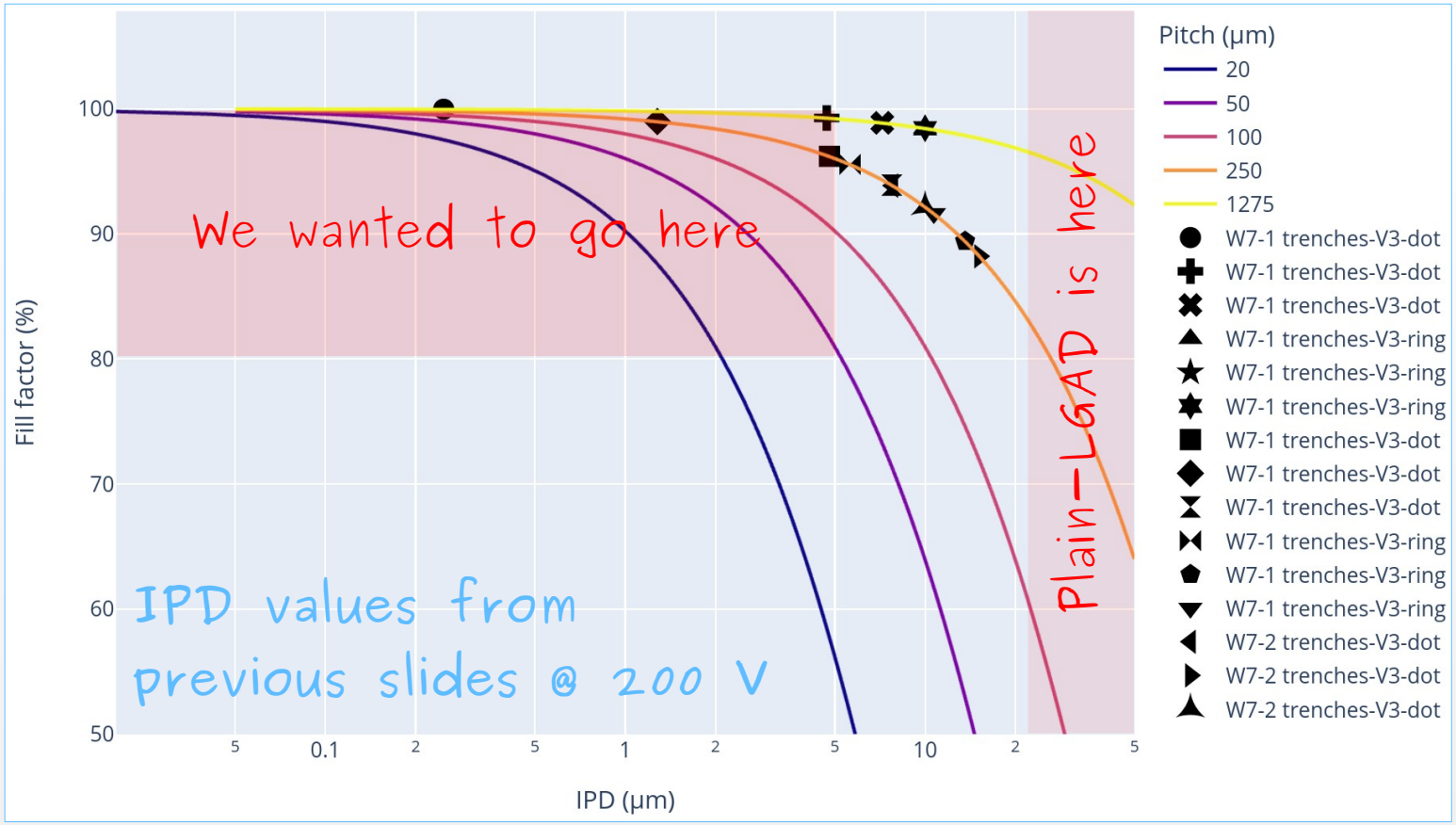
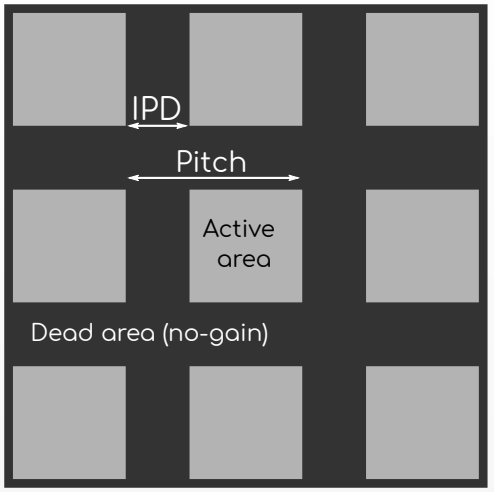
Where are TI-LGADs?



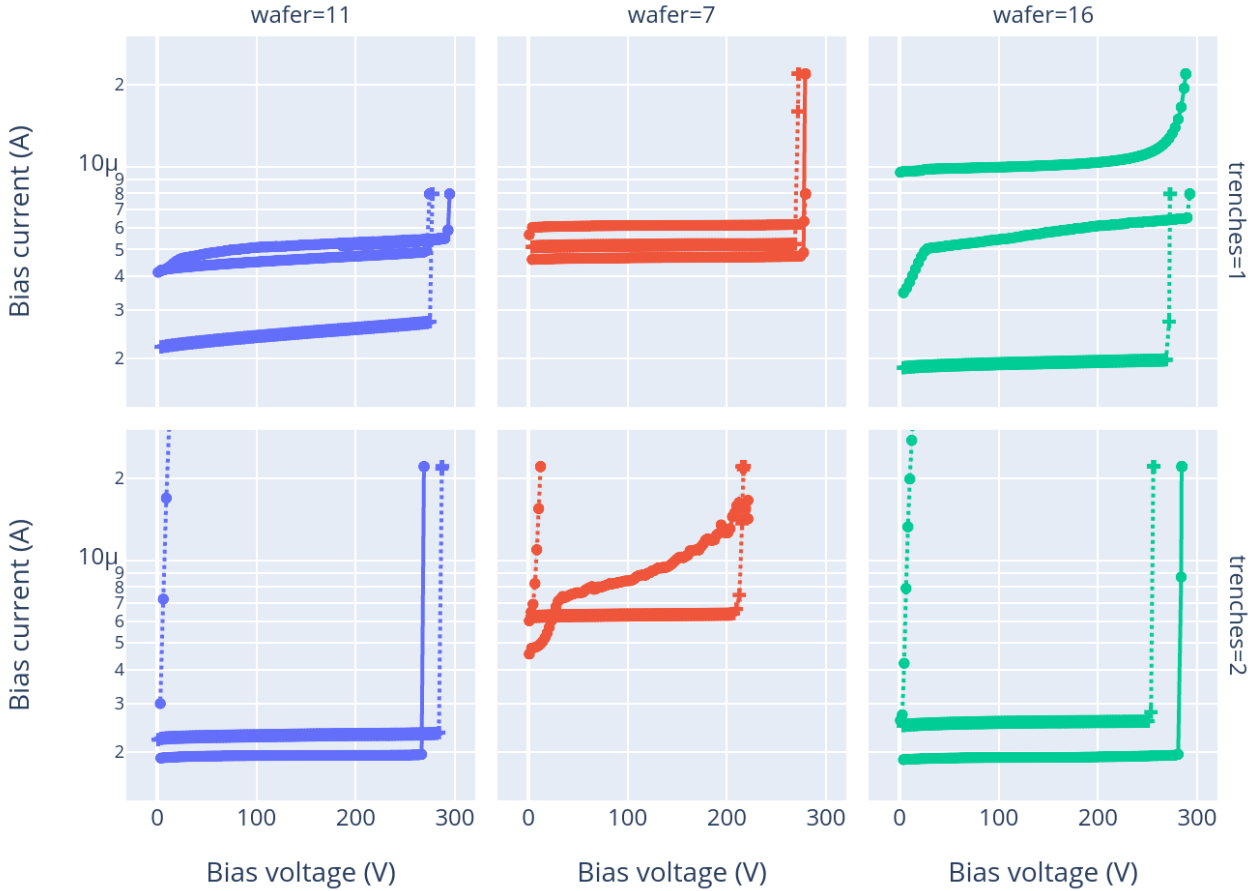


Pitch:

- 250 for "4x4 small" layout.
- 1275 for "2x2 big" layout.

Wafers 7 and 16 with pixel border V2 and contact type "ring" and both 1 and 2 trenches have IPD < 4 µm @ 200 V. ✔

IV curves



Measurement conditions:

- Devices installed in readout boards.
- All pixels grounded or 50Ω terminated.
- Room temperature (not controlled).
- Light/laser off.

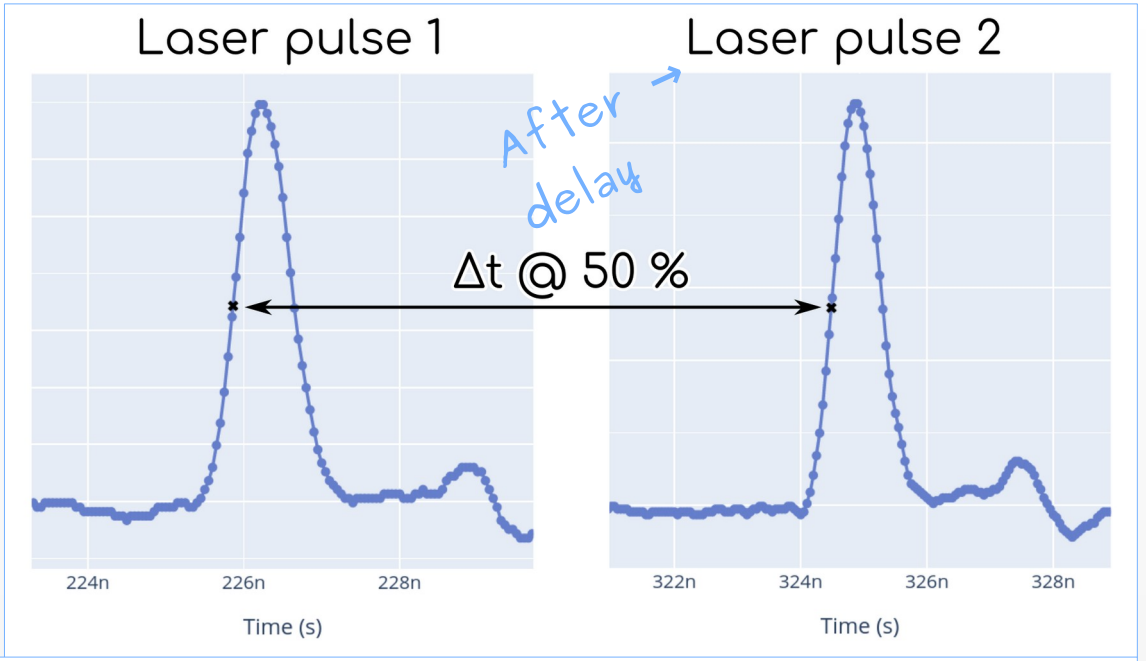
⇒ All devices with “2 trenches” & "pixel border V3" & “contact type ring” seem to go into breakdown at very low voltages (see plot).

Time resolution

Example from a random scan

- Constant fraction discriminator.
- Time resolution vs laser position.

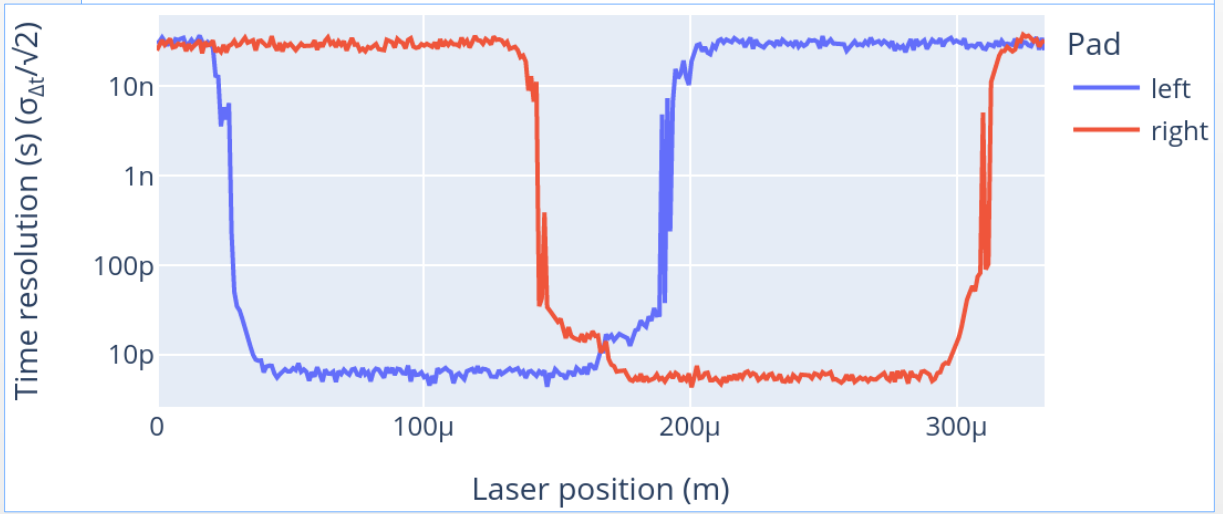
$$Time\,resolution = \frac{\sigma_{\Delta t}}{\sqrt{2}}$$



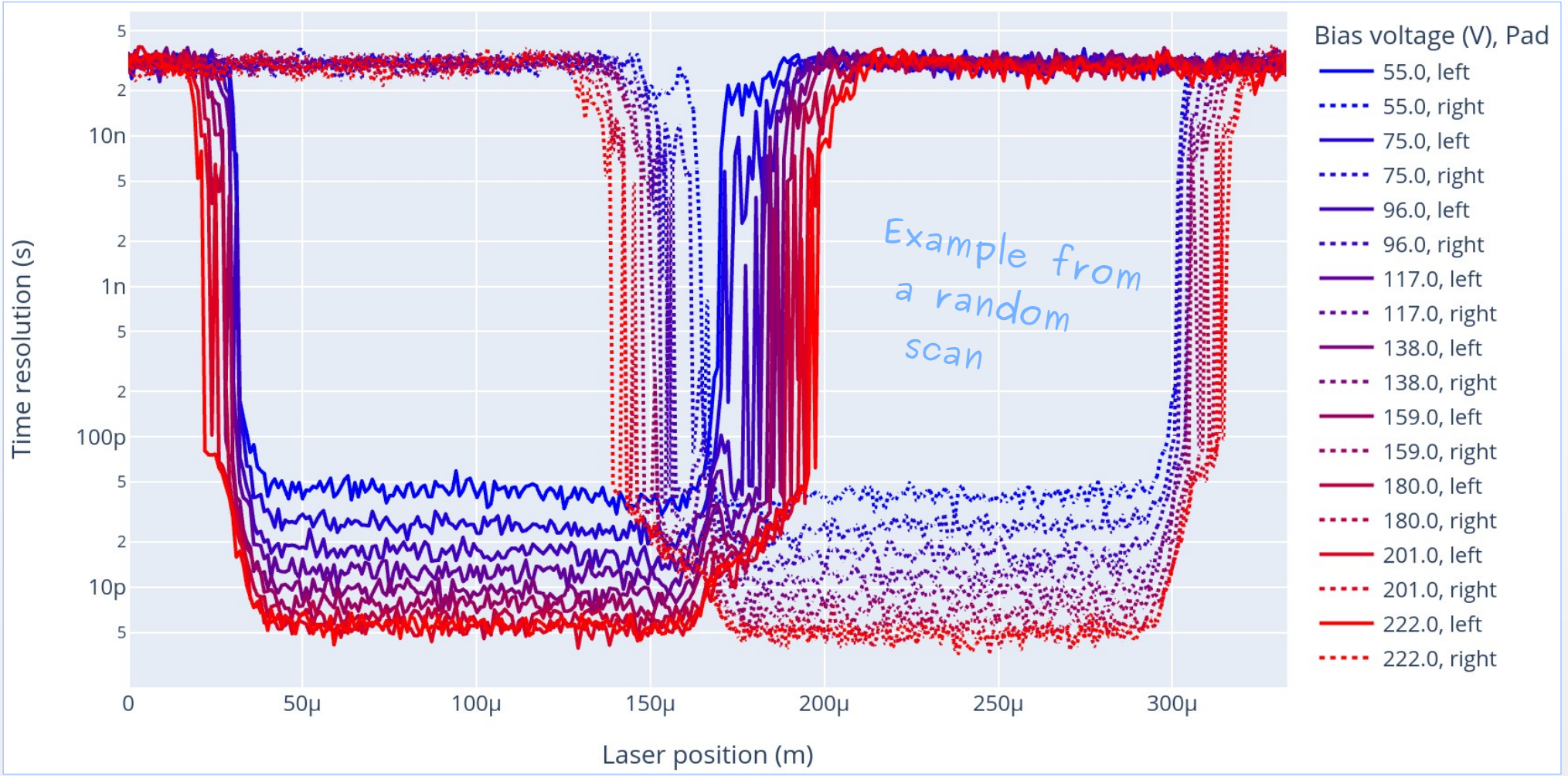
- Within window (laser in silicon):
  - ~ 10 ps ✔

Outside window (laser in metal):

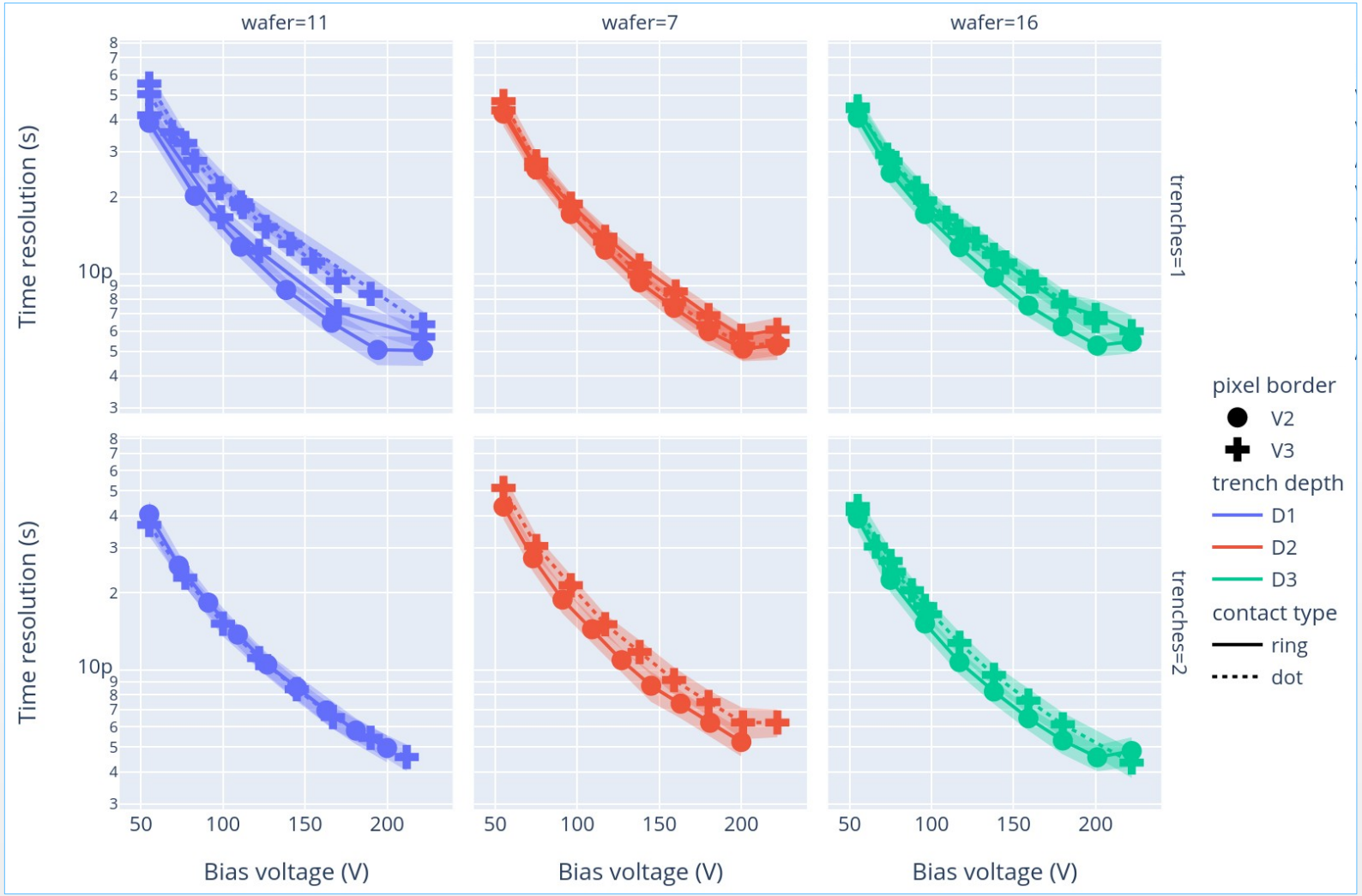
  - > 10 ns because the software is measuring noise ✔



Time resolution @ different bias voltages



Time resolution for each design pattern

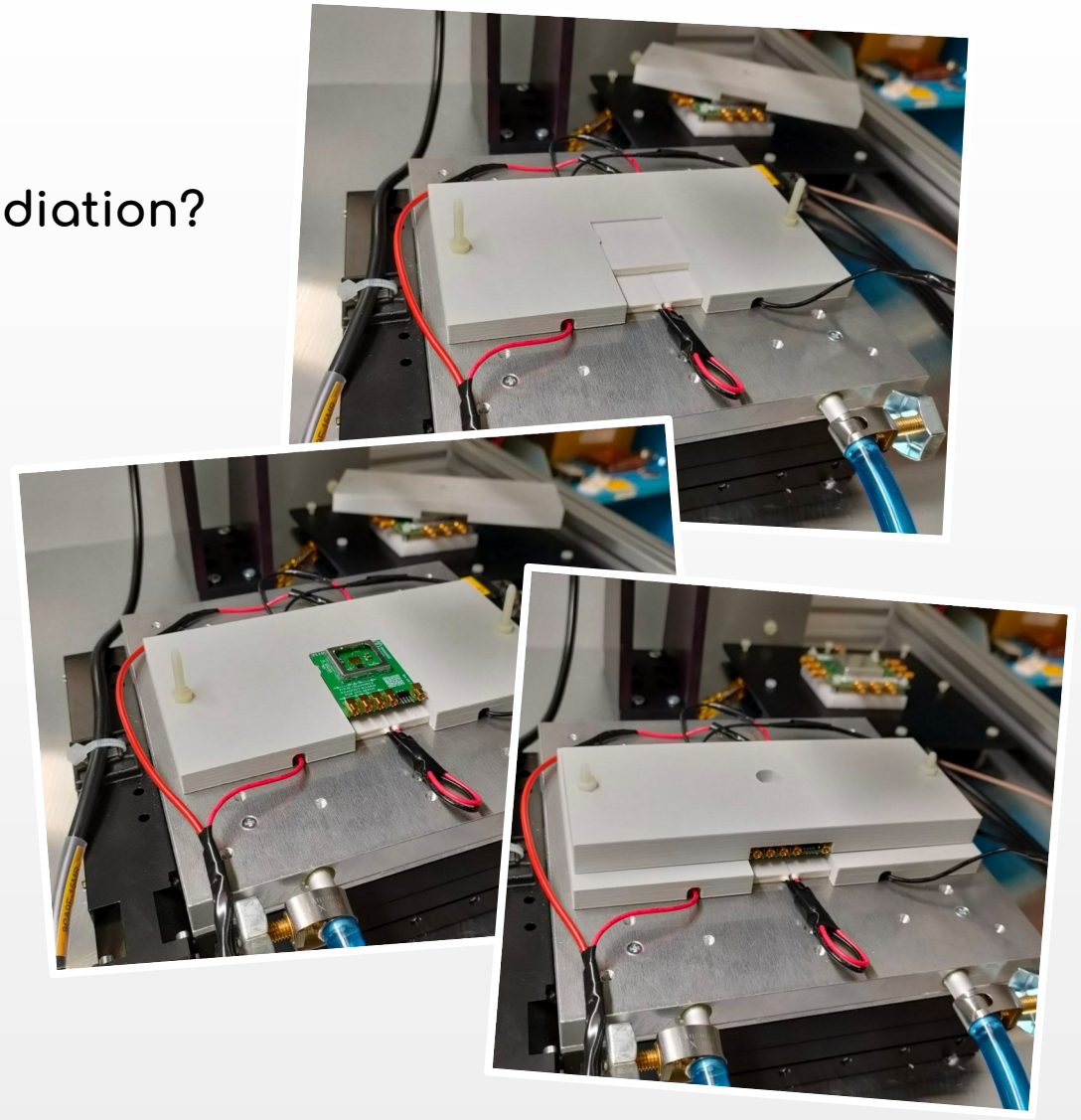


- Independent of trenches design patterns. ✔
- Measured with laser: no Landau contribution.
- Similar to “plain-LGAD”. ✔

Irradiation campaign

How do TI-LGADs behave after irradiation?

- Neutrons & protons:
  - $15 \times 10^{14} n_{eq}/cm^2$
  - $25 \times 10^{14} n_{eq}/cm^2$
  - $35 \times 10^{14} n_{eq}/cm^2$
- Re-measure IPD & time resolution with TCT setup.
- Setup has been adapted to reach low temperature (-25 °C).



Conclusions

- Systematic characterization of TI-LGAD devices using TCT setup was done:
  - Inter-pixel distance (IPD) measured according to “the 50 % of charge criterion”.
  - Time resolution was measured (without Landau contribution).
- Results look promising:
  - IPD < 4 μm for some of the design patterns allow for fine segmentation.
  - Time resolution similar to “plain-LGAD”.

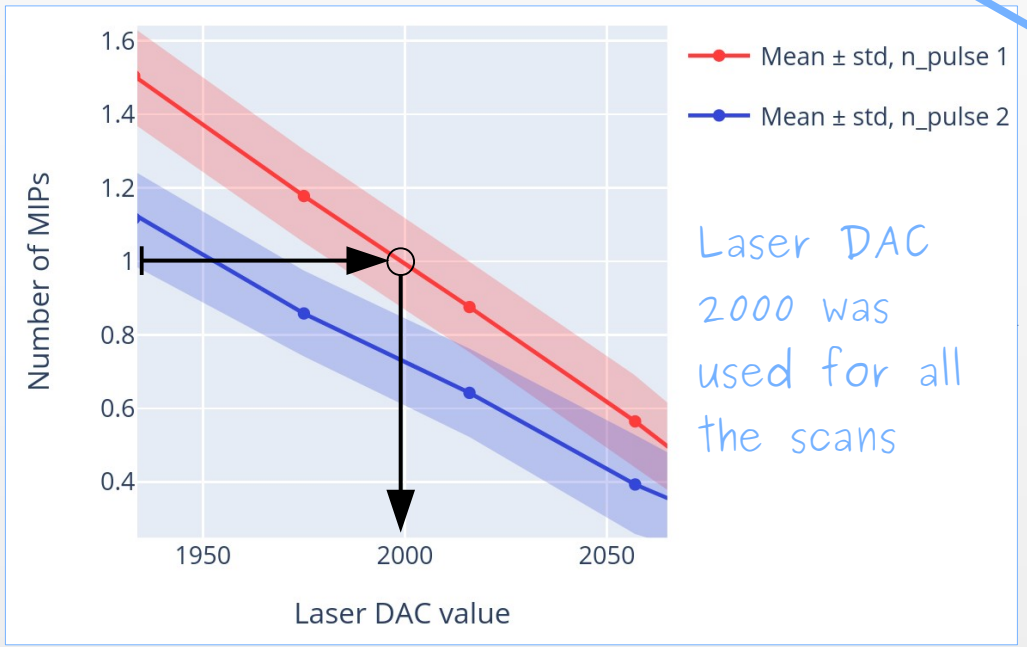
  ⇒ **TI-LGAD is a promising candidate towards 4D-pixels**.
- Irradiation campaign was presented:
  - Results will be shared soon, stay on tune!

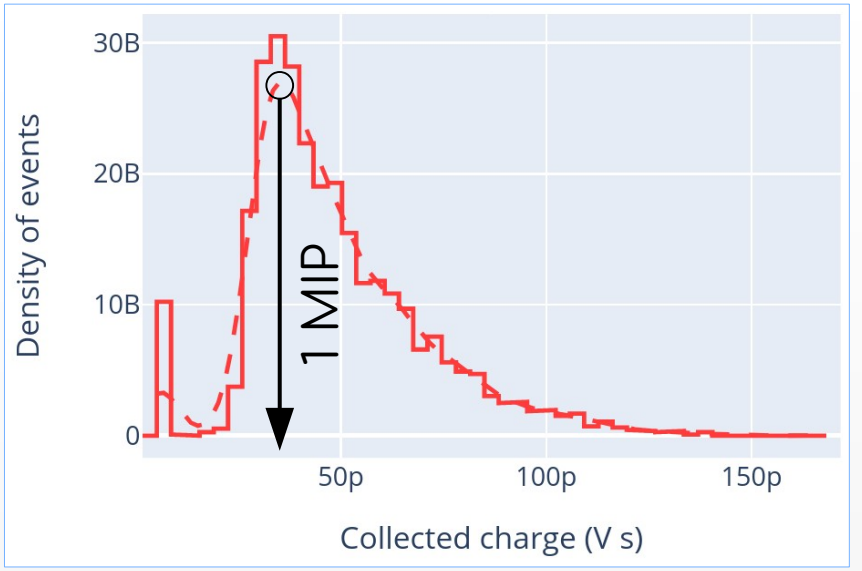

The
End

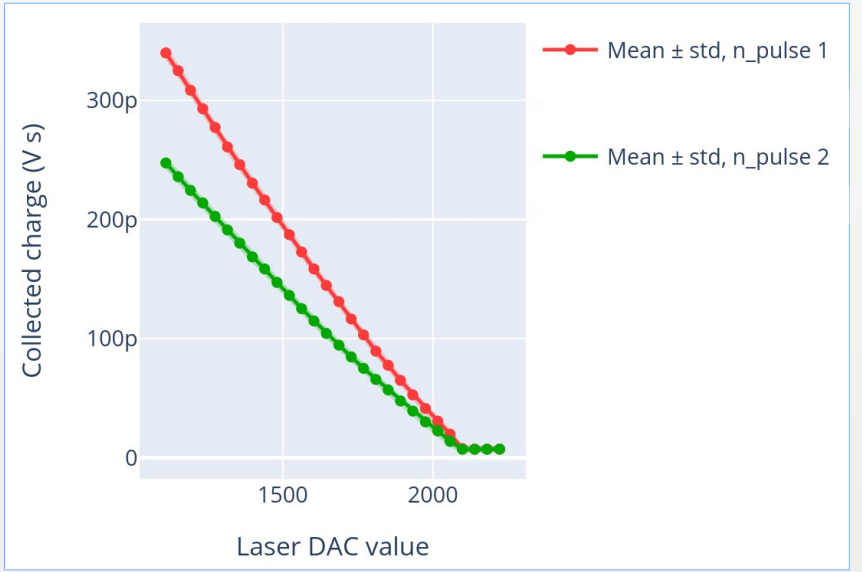

Backup
slides

Laser intensity calibration

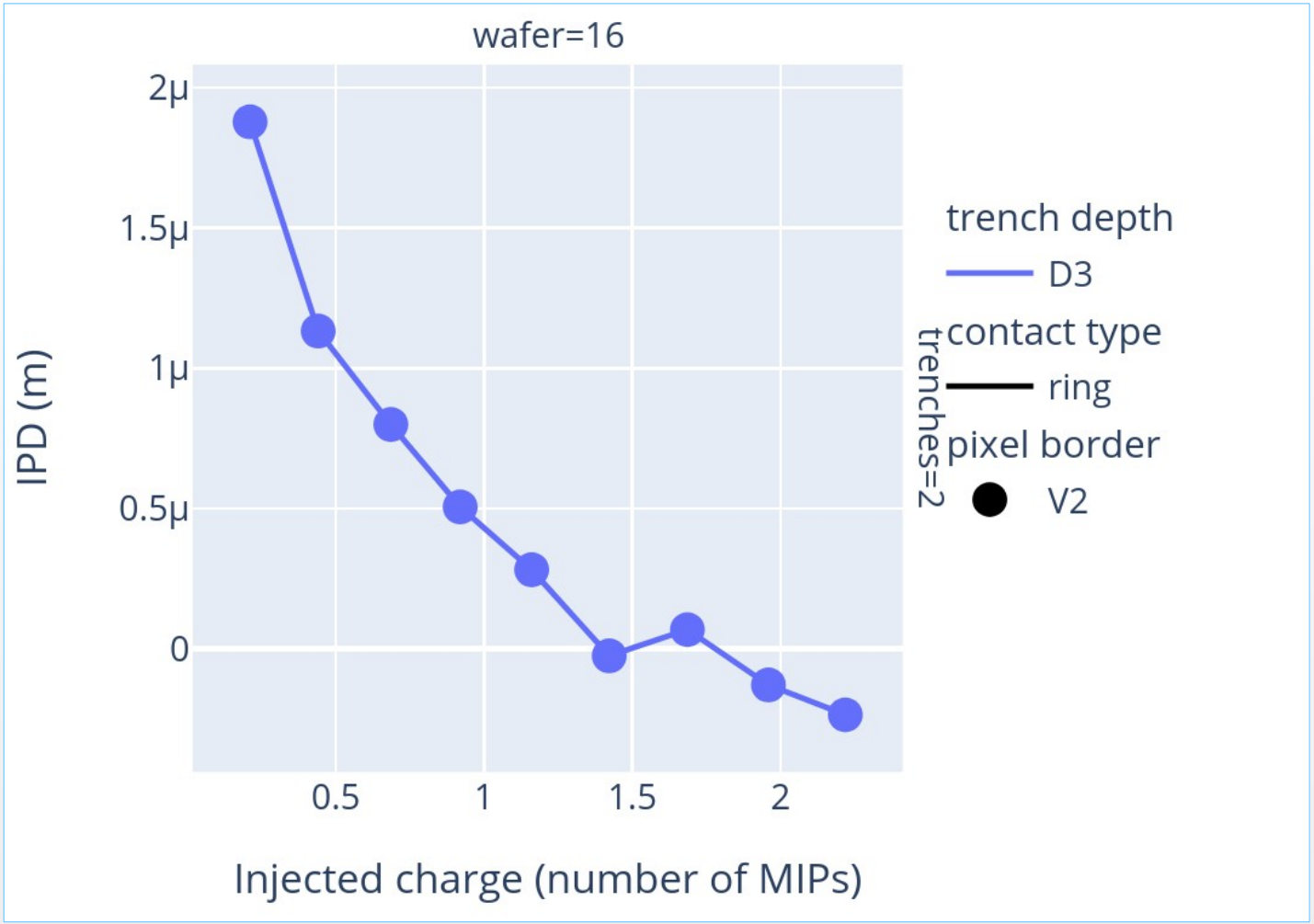
1) Beta scan with PIN diode.
2) Laser intensity scan for that same PIN diode.
3) Calibration scale.







IPD vs injected charge?

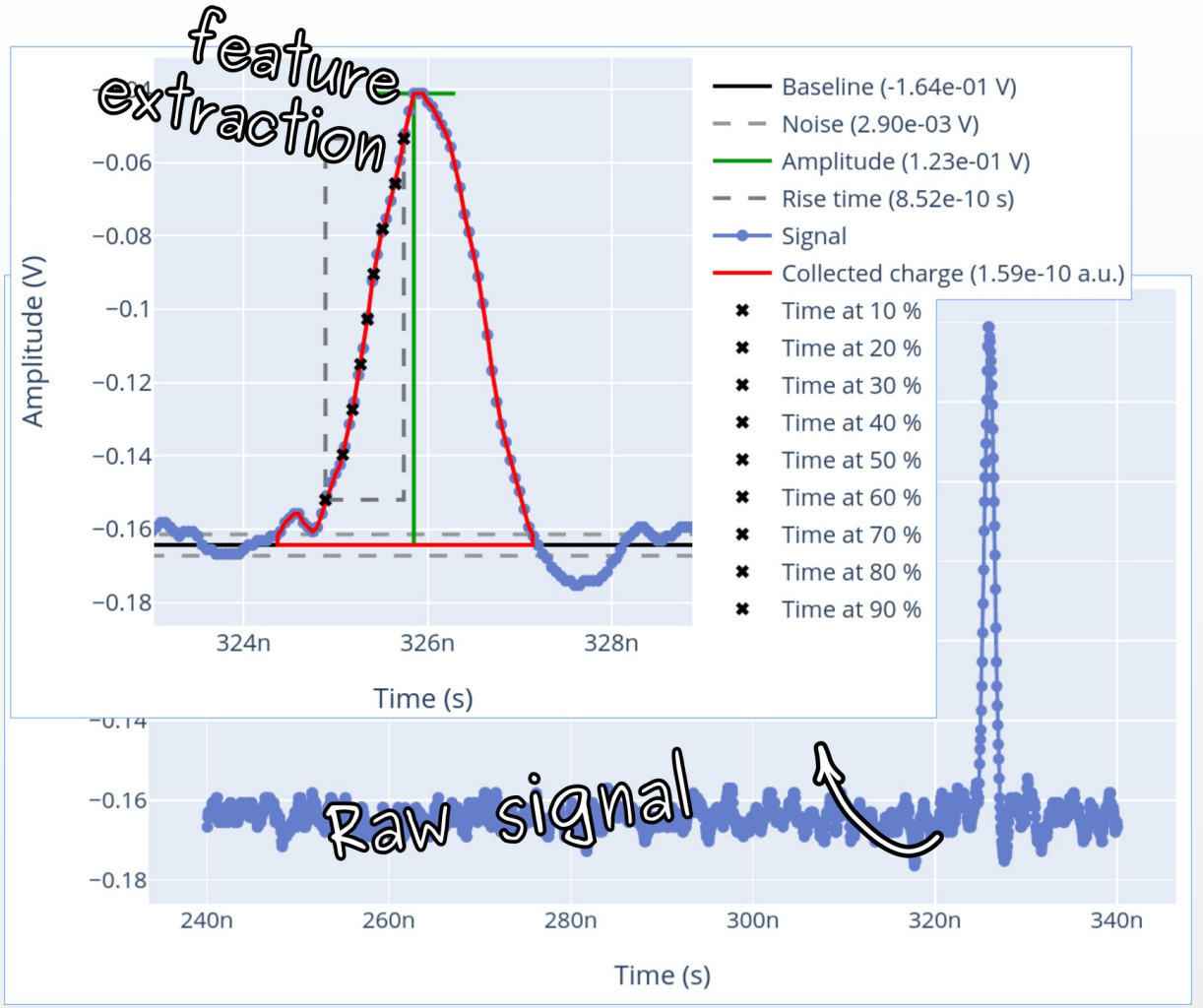


- V_{bias} = 170 V.
- Varied "Laser DAC" around 2000 (see previous slide).
- Measured only for this single device.

Signal acquiring and processing

- Events are processed individually.
- Signals processed online by custom made software[1].
- Only features (not waveform) of each event are recorded.
- Averaged waveform also recorded.

Example event →



[1] https://github.com/SengerM/lgadtools