17th "Trento" Workshop on Advanced Radiation Silicon Detectors

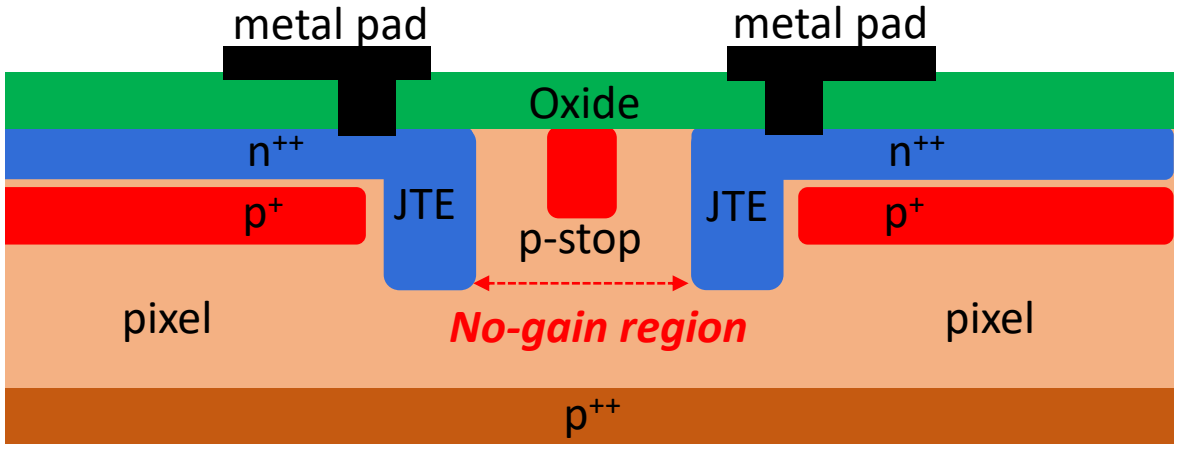
Characterization of Trench-Isolated LGADs before and after irradiation

M. Ferrero, R. Arcidiacono, A. Bisht, G. Borghi, M. Boscardin, N. Cartiglia, M. Centis Vignali, F. Ficorella, O. Hammad Ali, G. Gioachin, M. Mandurrino, L. Menzio, R. Mulargia, G. Paternoster, F. Siviero, V. Sola, M. Tornago

Part of this work has been performed in the framework of RD50 CERN collaboration

Motivation

Traditional LGAD

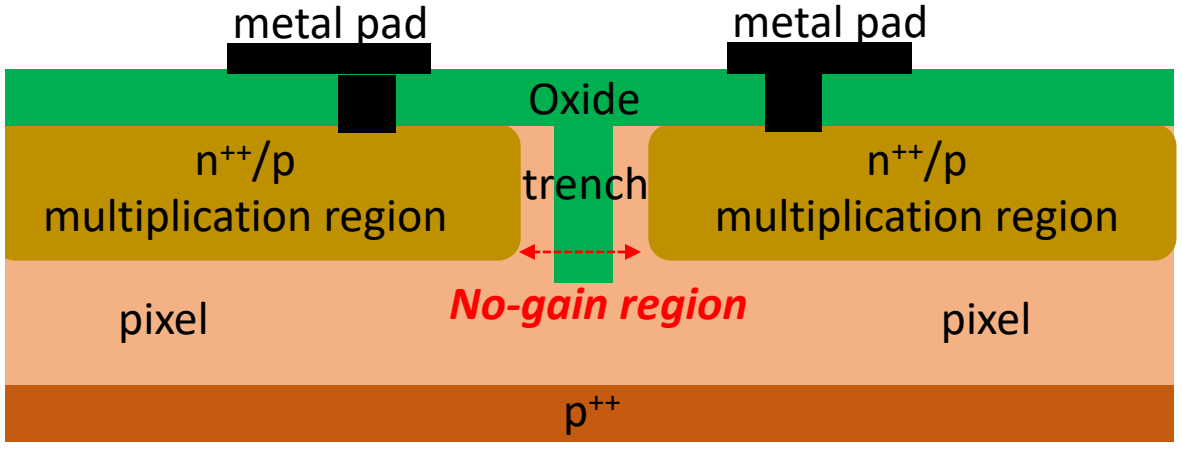


Standard segmentation based on:

- Junction Termination Extension (JTE)
- p-stop implant

No-gain region of 60-120 µm

Trench-Isolated LGAD (TI-LGAD)



Segmentation based on Depth Trenches filled with Oxide

No-gain region of ~10 µm (Fill Factor improvement)

TI-LGAD samples

Process parameters:

- Three trench depths: **D1 < D2 < D3**
- Three trench processes: **P1; P2; P3**

Additional Information:

- Active thickness of 45 µm
- p-bulk inverted (in new sensors)
- Boron High Diffusion gain implant
- No carbon co-implantation

Wafer	Trench depth	Trench process
1	D2	P1
7	D2	P2
9	D2	P3
11	D1	P1
16	D3	P2

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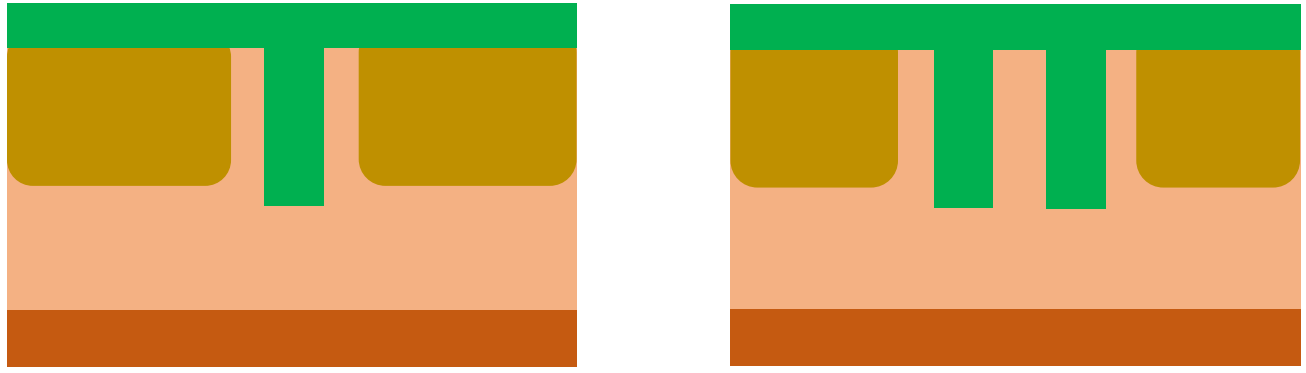
Inter-pixel layout:

- **One/Two trenches (1TR/2TR)** to separate pixels
- Four pixel borders: (most aggressive) **V1<V2<V3<V4** (least aggressive)

Wafer	Trench depth	Trench process
1	D2	P1
7	D2	P2
9	D2	P3
11	D1	P1
16	D3	P2

Pixel border Layout



1 trench (1TR) **2 trenches (1TR)**

TI-LGAD samples

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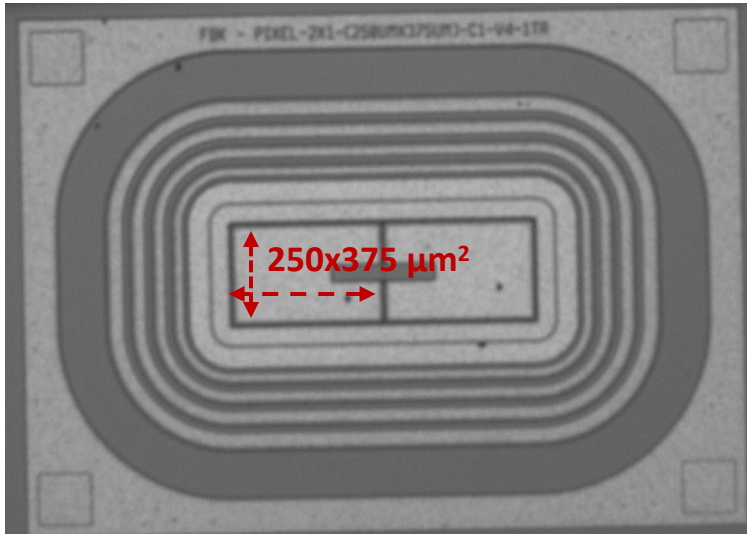
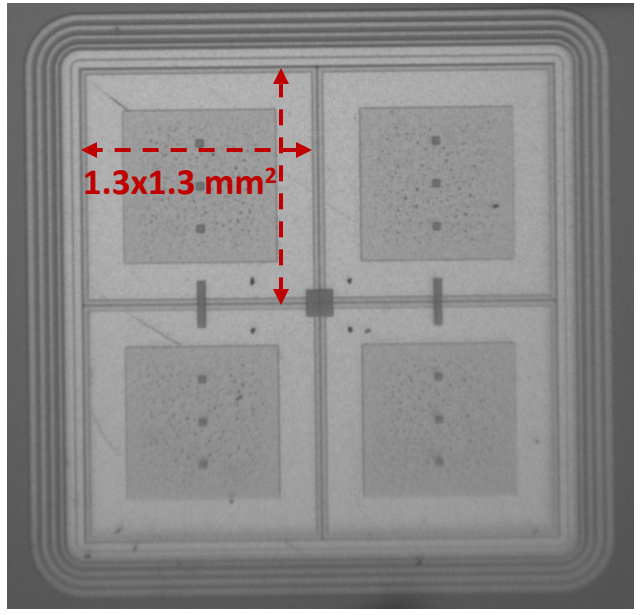
Sensors geometry:
- 1x2 array with several inter-pixel flavours
- 2x2 array, with pixel-border V3-1TR

Wafer	Trench depth	Trench process
1	D2	P1
7	D2	P2
9	D2	P3
11	D1	P1
16	D3	P2





TI-LGAD samples

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Sensors geometry:
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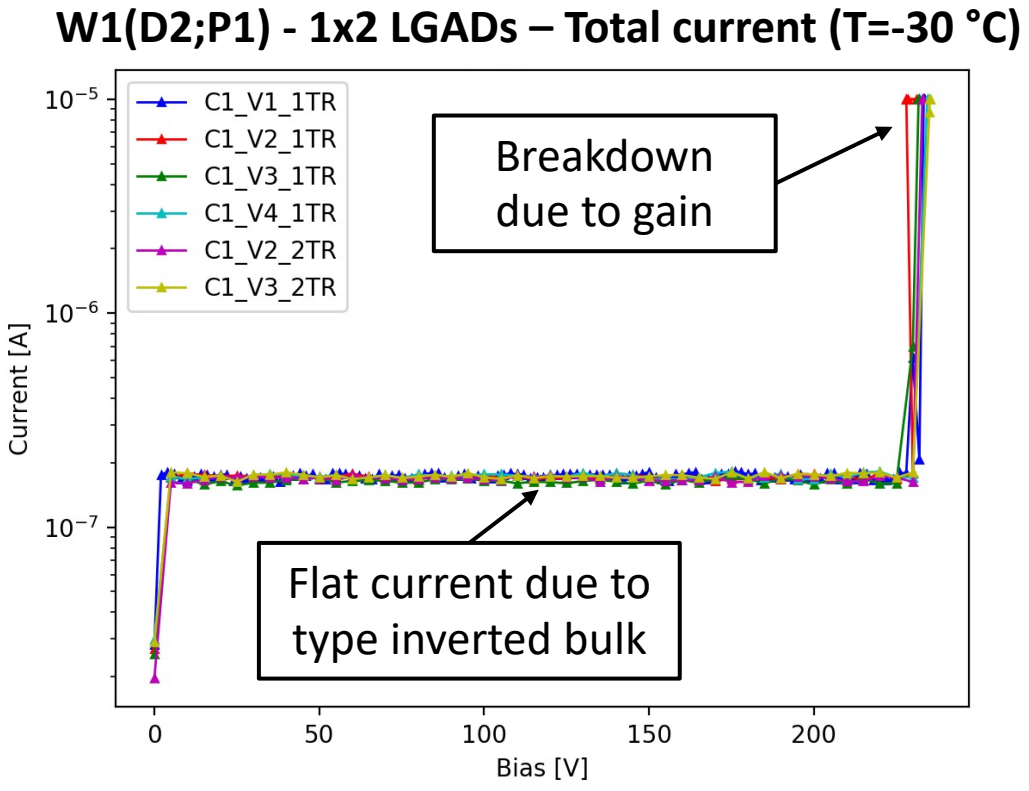
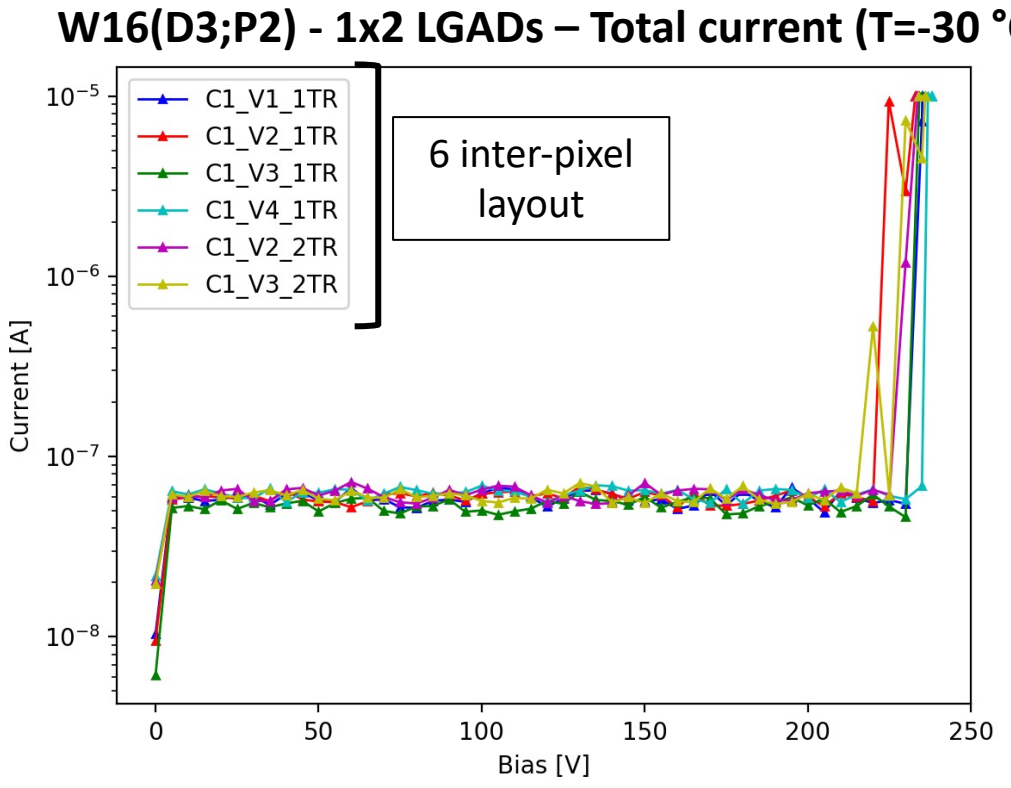
- 2x2 array, with pixel-border V3-1TR

Wafer	Trench depth	Trench process	Neutron Irradiation Fluence [10^{15} n_{eq}/cm^5]	X-Ray Irradiation Dose [Mrad]
1	D2	P1	0.4 – 0.8 – 1.5	1 – 5 – 10
7	D2	P2	0.4 – 0.8 – 1.5	
9	D2	P3	0.4 – 0.8 – 1.5	
11	D1	P1	0.4 – 0.8 – 1.5	1 – 5 – 10
16	D3	P2	0.4 – 0.8 – 1.5	

Irradiation campaign:
- Neutrons at JSI TRIGA reactor in Ljubljana
- X-Rays in Genova (E=40 kV; Dose rate=0.96 Mrad/h)

Breakdown in pair-LGADs (new)





Breakdown in LGADs is independent of:

Depth of trench

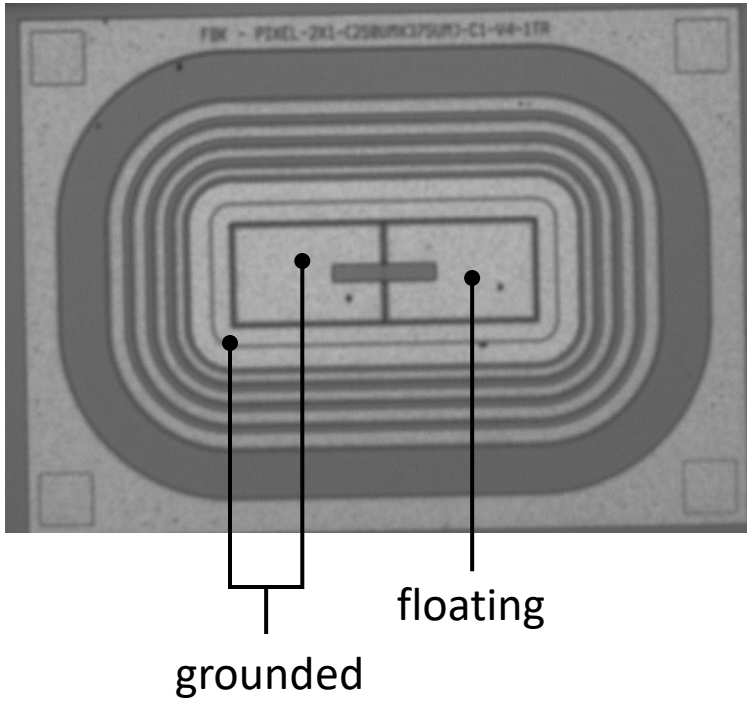
Trench process

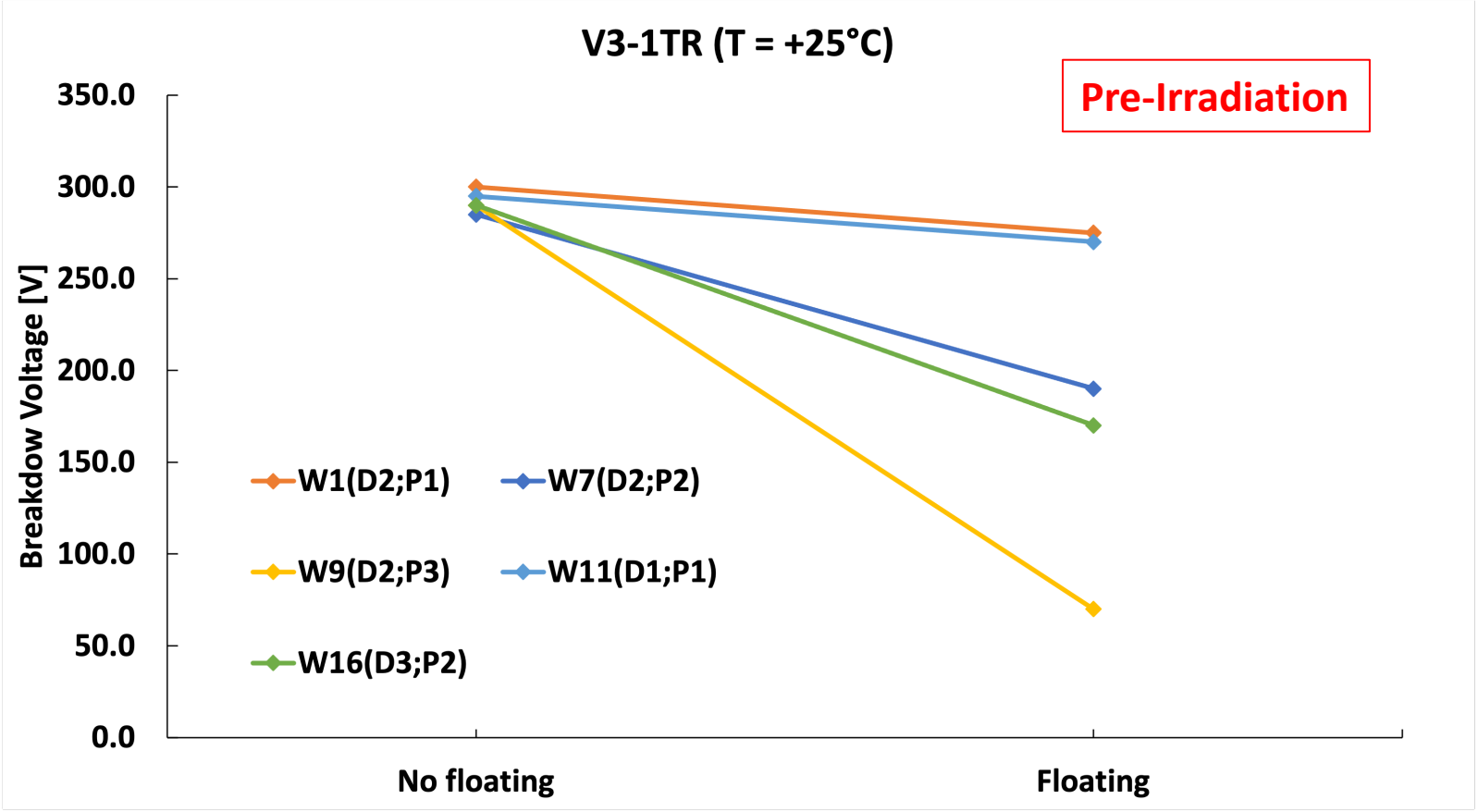
Number of trenches in inter-pixel region

Pixel border design

BD resilience to floating pixels

Connections:
Sensor biased from the back

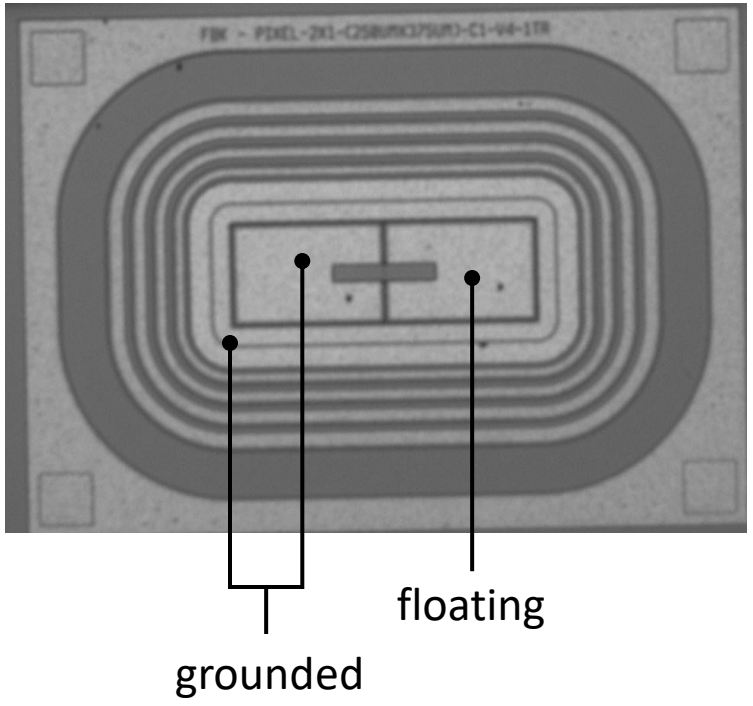


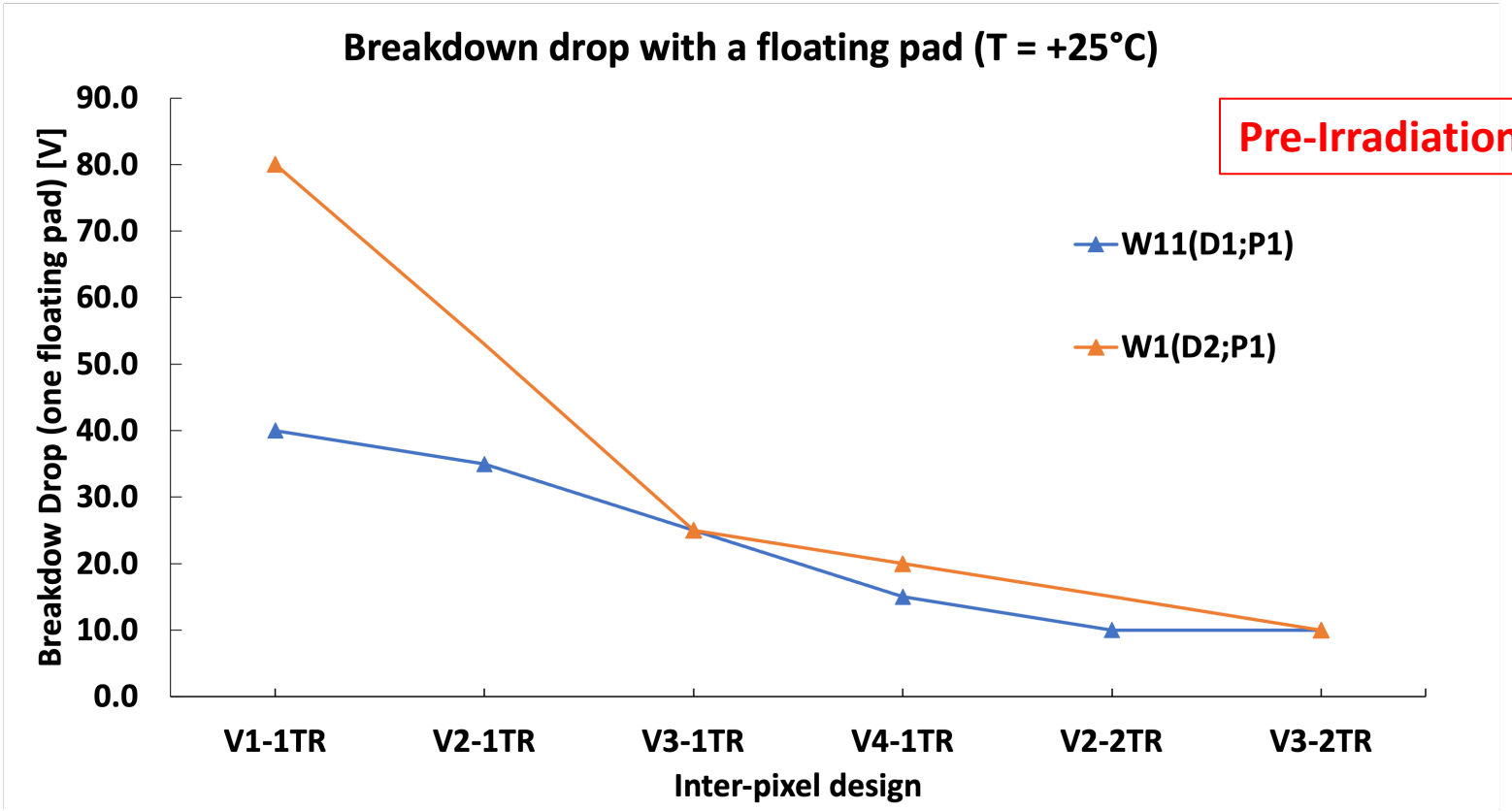


Clear correlation between BD Resilience to floating pads and trench process
Pre-Irradiation: almost unchanged breakdown in devices with **trench process P1**

BD resilience to floating pixels

Connections:
Sensor biased from the back



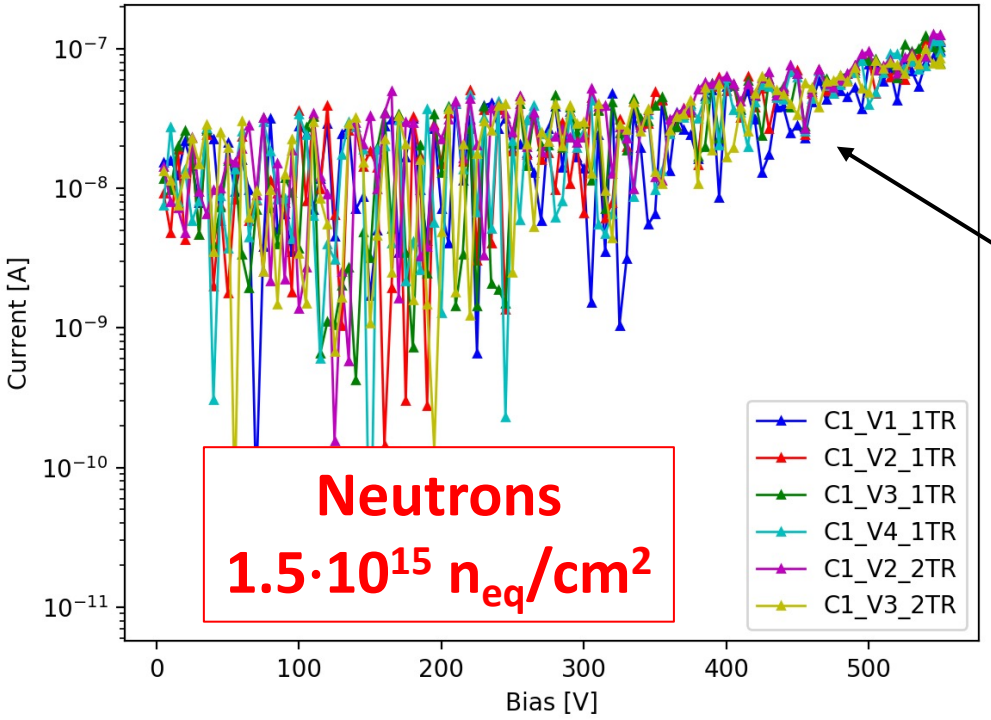


Weak correlation between BD Resilience to floating pads and pixel-border type

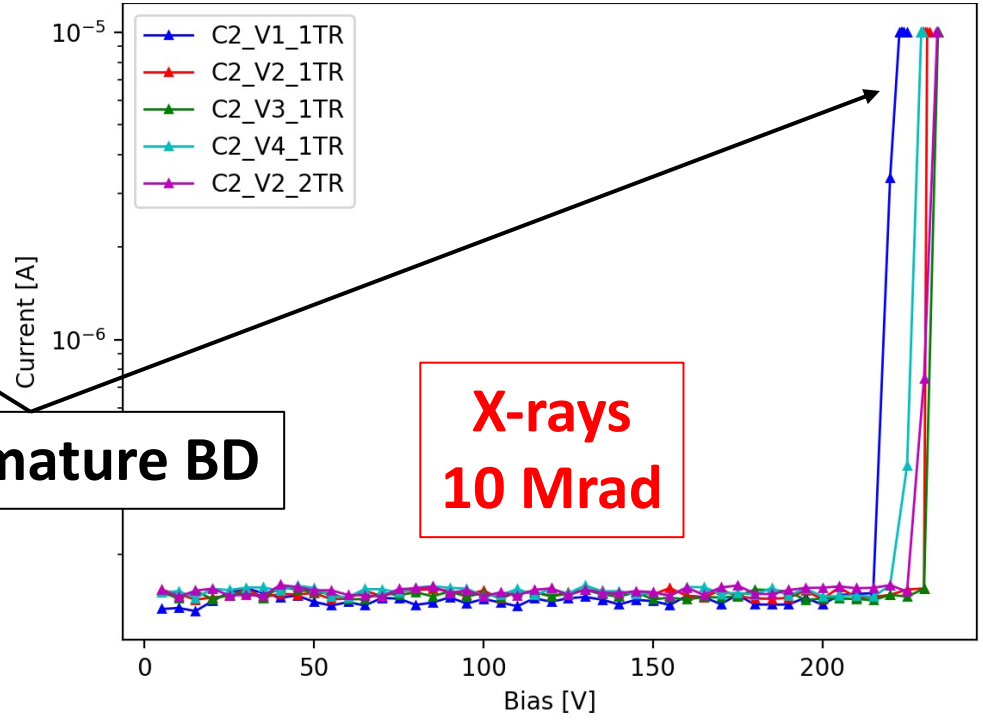
Current-Voltage in irradiated LGADs

Trench depths **D1-D2** and trench process **P1** selected for studies post irradiation

Neutron Irradiation at $1.5 \cdot 10^{15}$ n_{eq}/cm^2
W1(D2;P1) - 1x2 LGADs – Total current (T = -30 °C)



X-ray Irradiation at 10 Mrad
W1(D2;P1) - 1x2 LGADs – Total current (T = -30 °C)

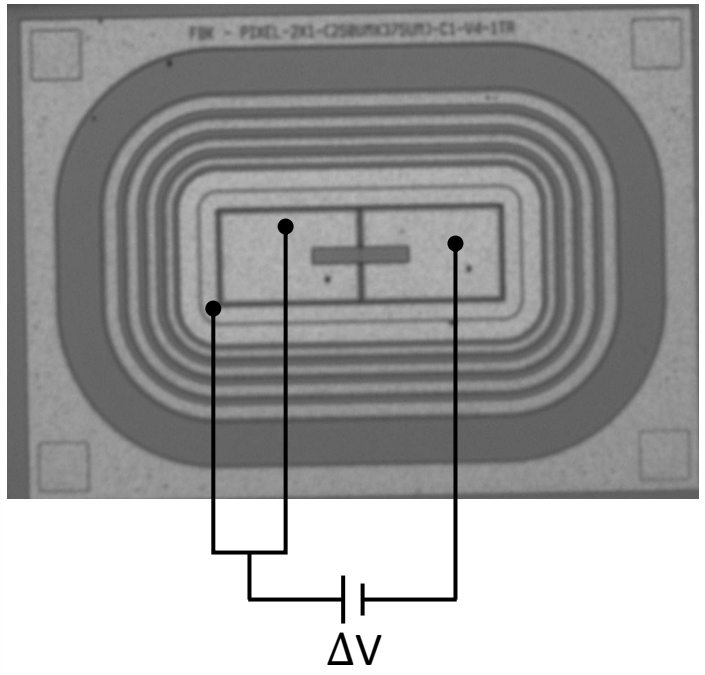


No premature BD

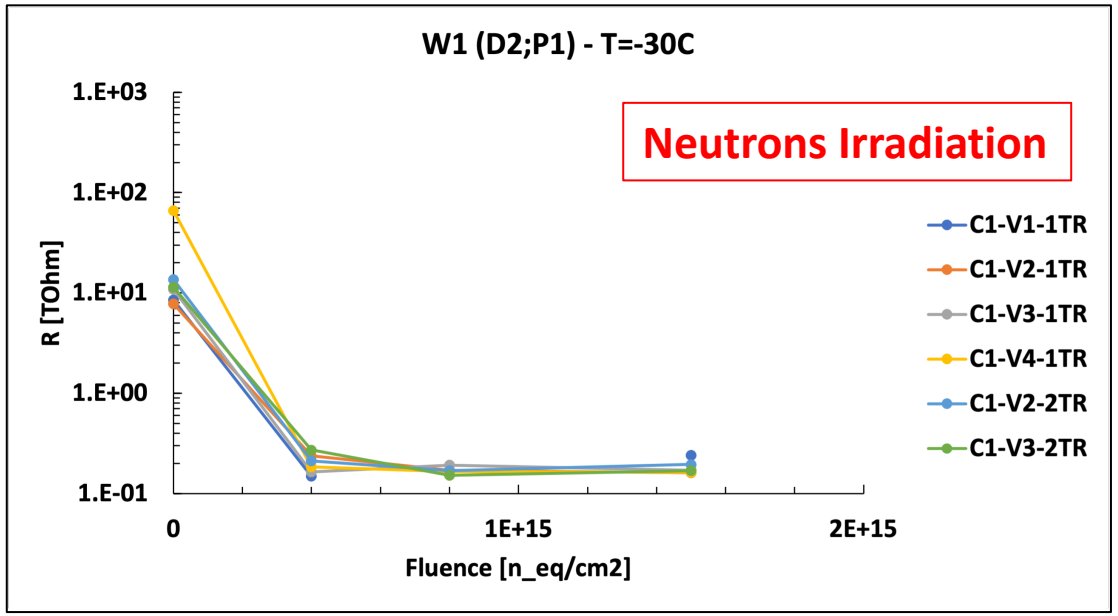
- **Trench isolation technology is radiation hard up to** neutrons fluence of **$1.5 \cdot 10^{15}$ n_{eq}/cm^2** and X-rays dose of **10 Mrad**
- BD Resilience to floating pad is maintained post neutrons and X-rays irradiation

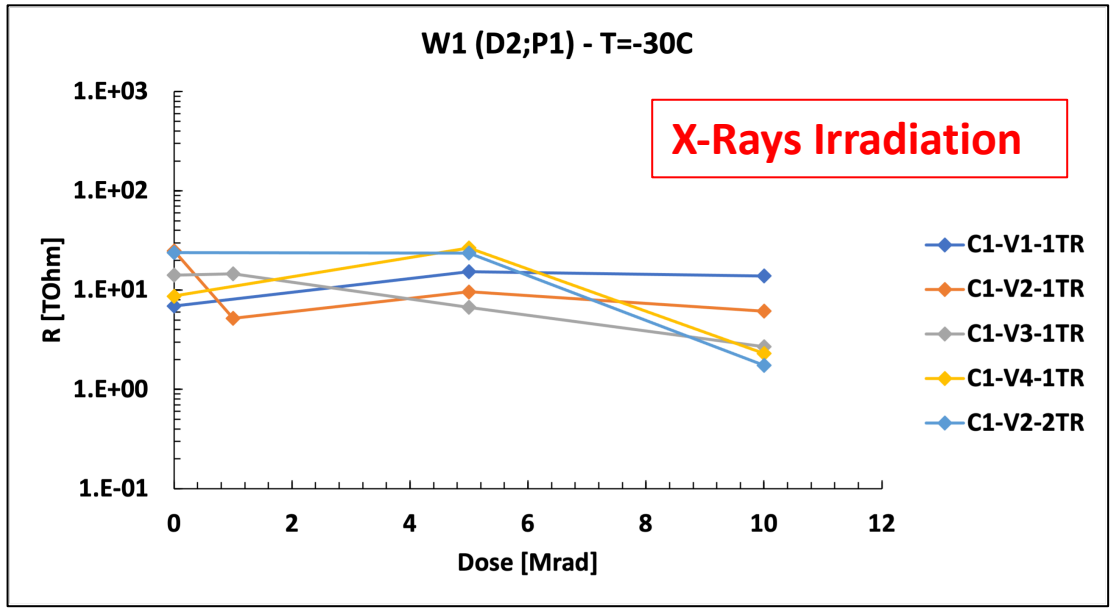
Pixel isolation: Inter-pixel resistance

Connections:
Sensor in full depleted condition



$$R = \frac{R_{Pixel-Pixel} \cdot R_{Pixel-GuardRing}}{R_{Pixel-Pixel} + R_{Pixel-GuardRing}}$$





Only trench process P1 and depths D1-D2 are investigated

Pre-Irradiation:
- **10s TOhm** of resistance

Post-Irradiation:
- **100s GOhm** of resistance (neutrons)
- **10s TOhm** of resistance (X-rays)

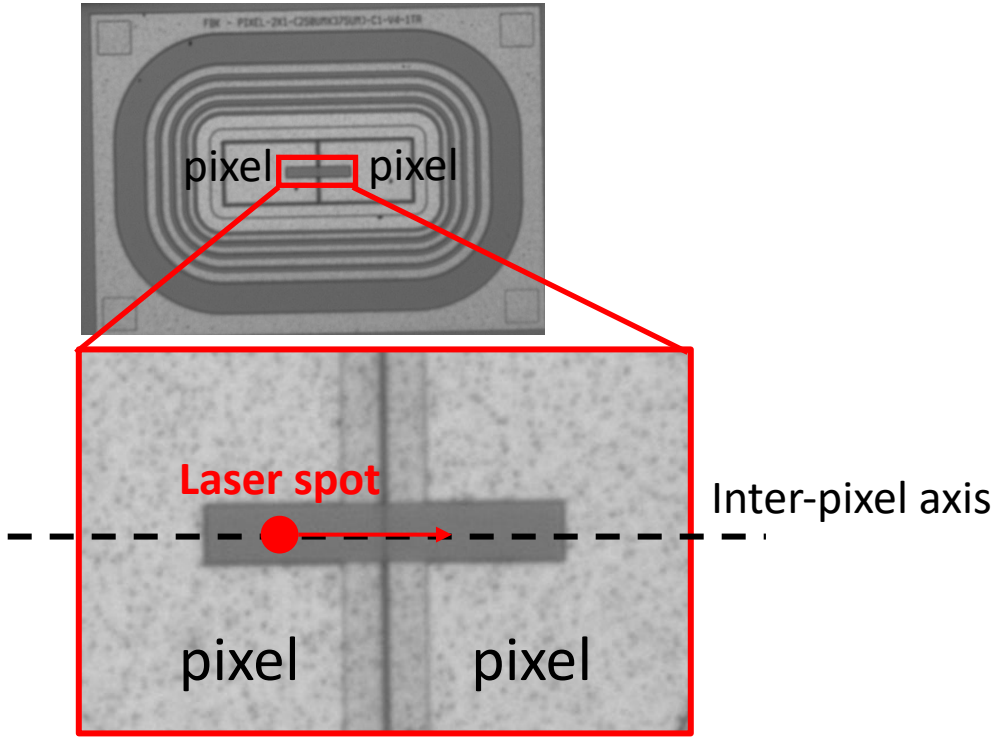
No dependence of ***R*** upon **pixel border type** (pre and post irradiation)

Pixel isolation is maintained up **to** **$1.5 \cdot 10^{15}$ n_{eq}/cm^2** (neutrons) **and 10 MRad** (X-Rays)

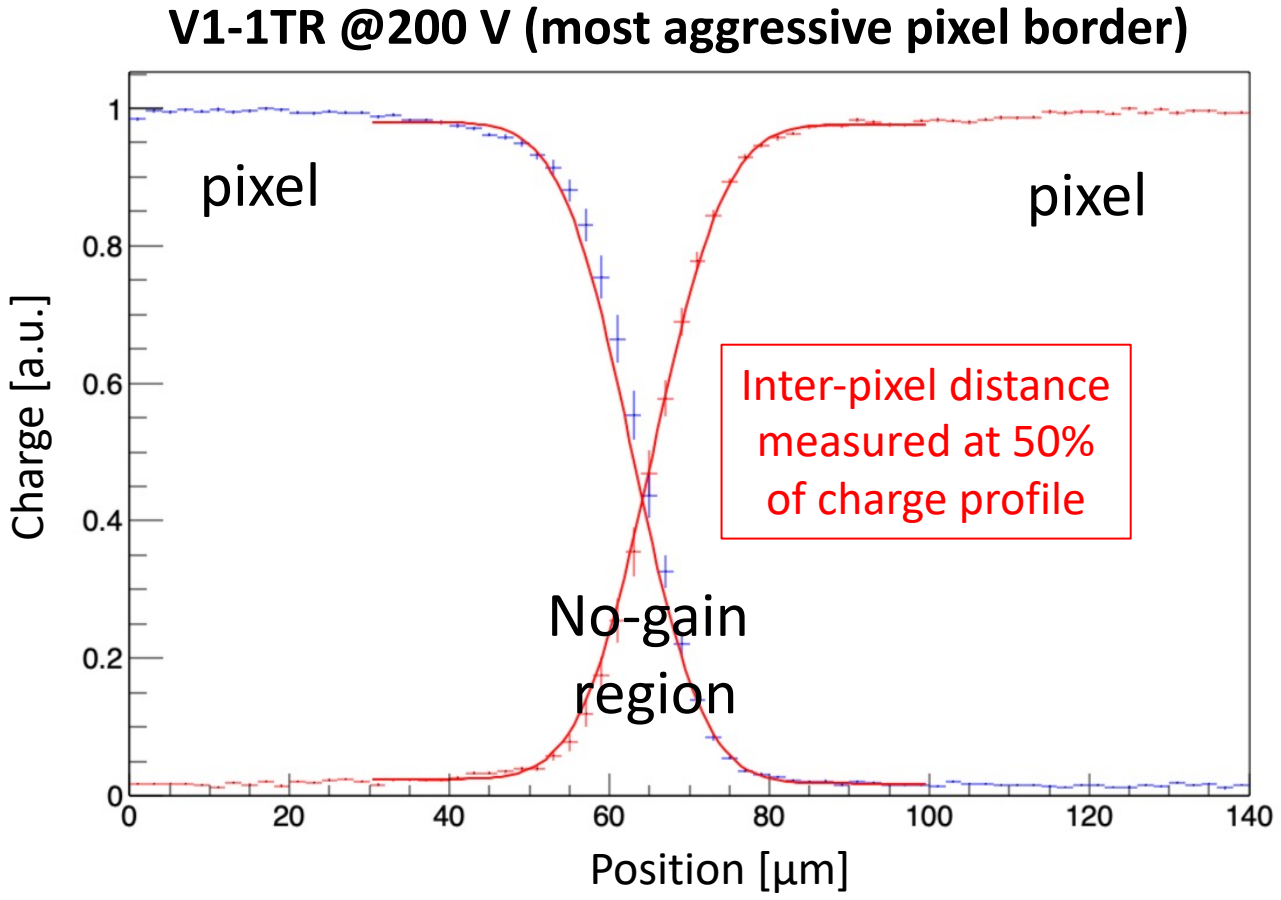
Same results for trench depth **D1**

Inter-pixel distance (pre-irradiation)

6 inter pixel layouts from W1(D2;P1) have been investigated



- Measurement performed with front-TCT setup at room T
- Laser intensity: 3-10 MIPs
- Laser size: 10 µm



Perfect pixel isolation in most aggressive pixel border

Inter-pixel distance (pre-irradiation)

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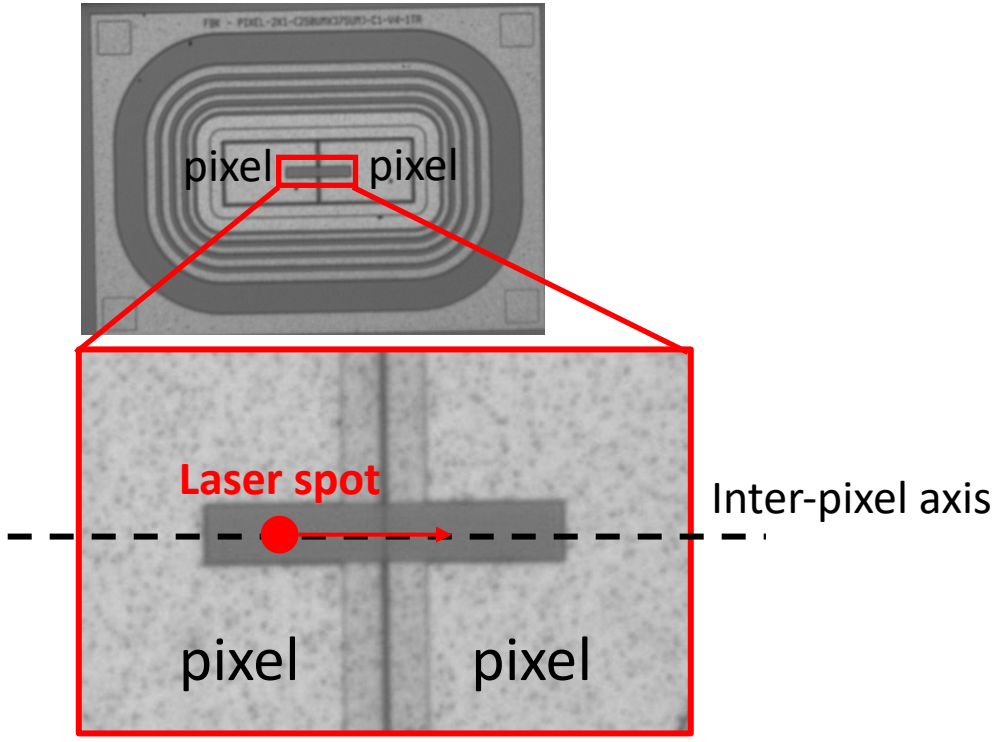
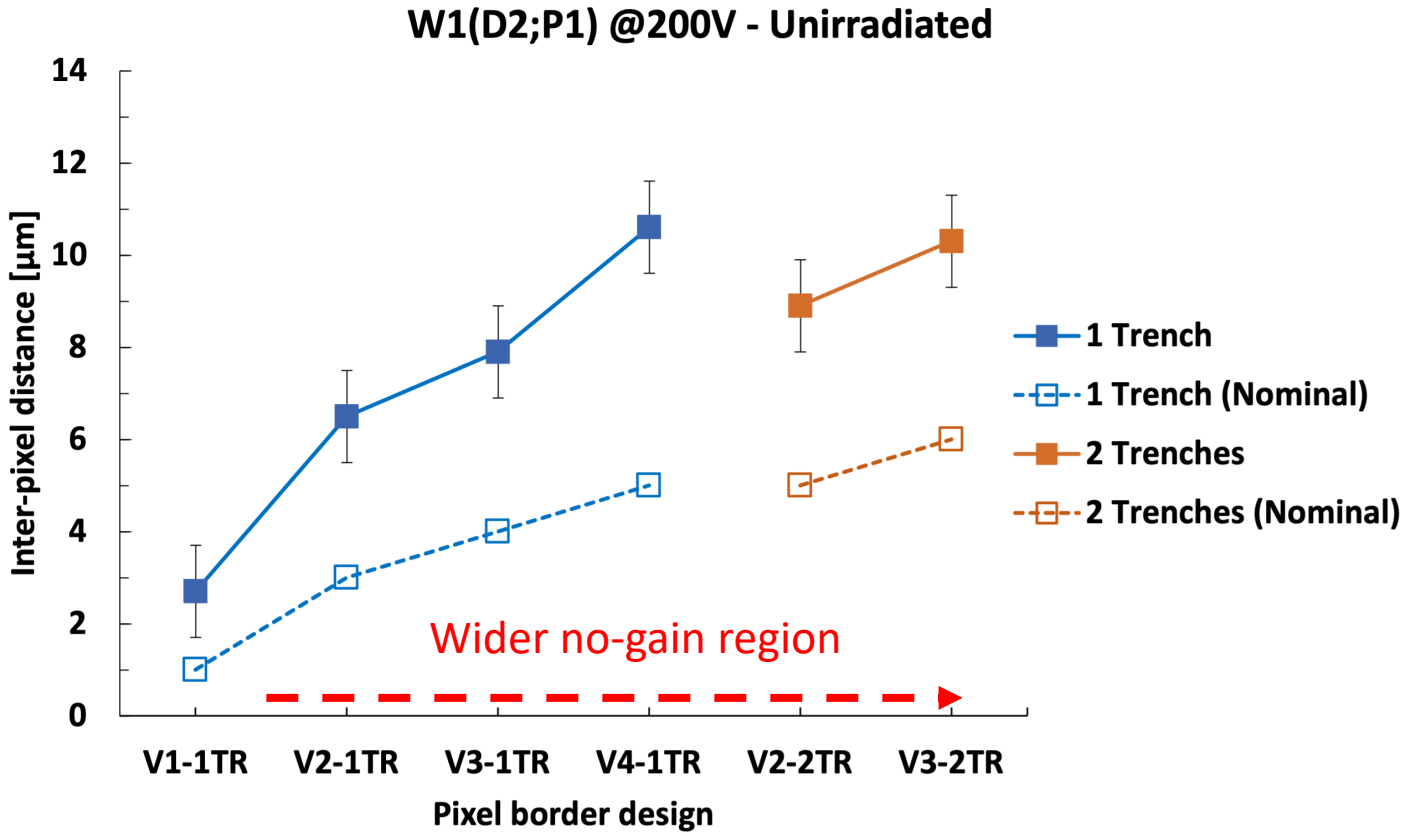
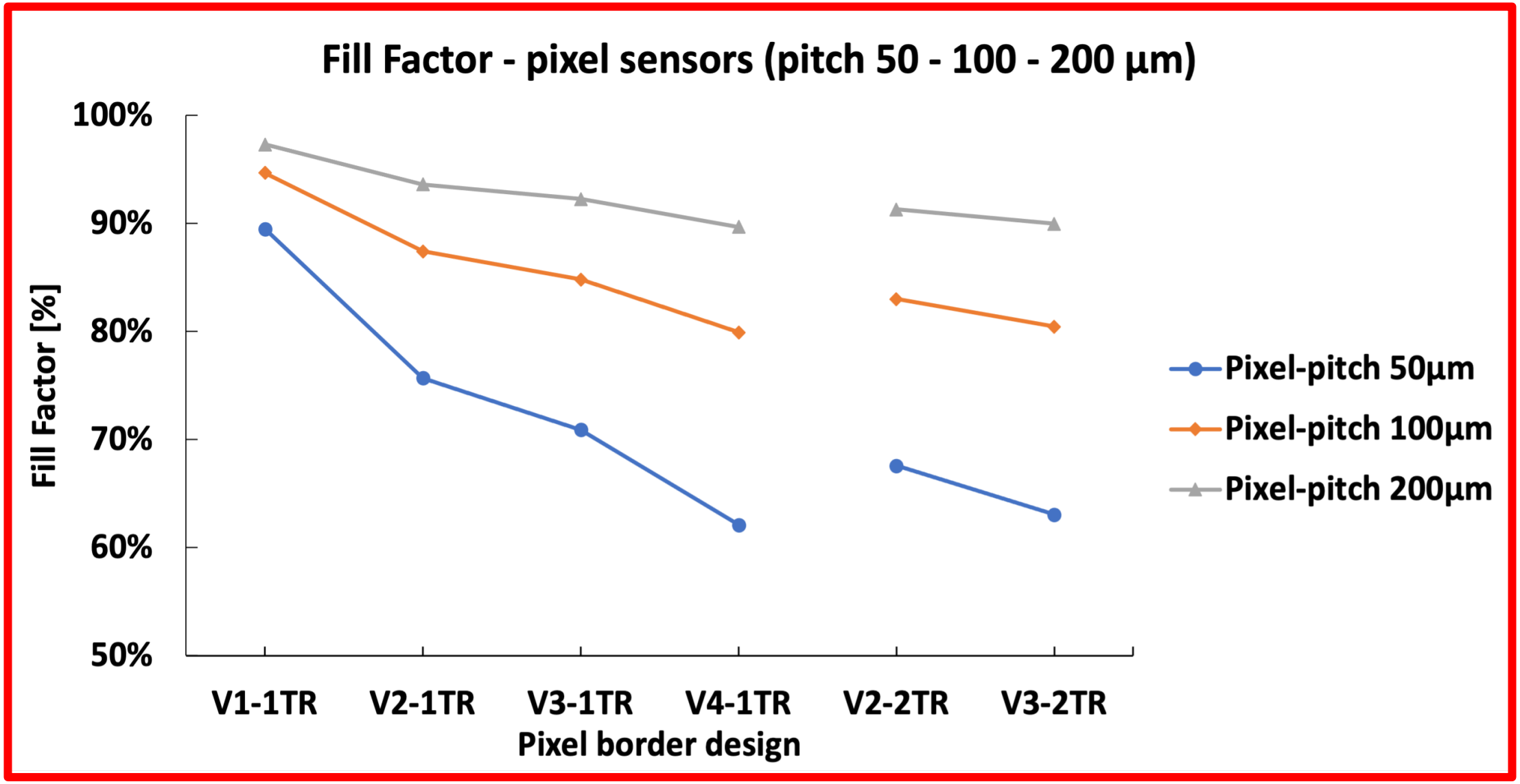




- Measurement performed with front-TCT setup at room T
- Laser intensity: 3-10 MIPs
- Laser size: 10 µm

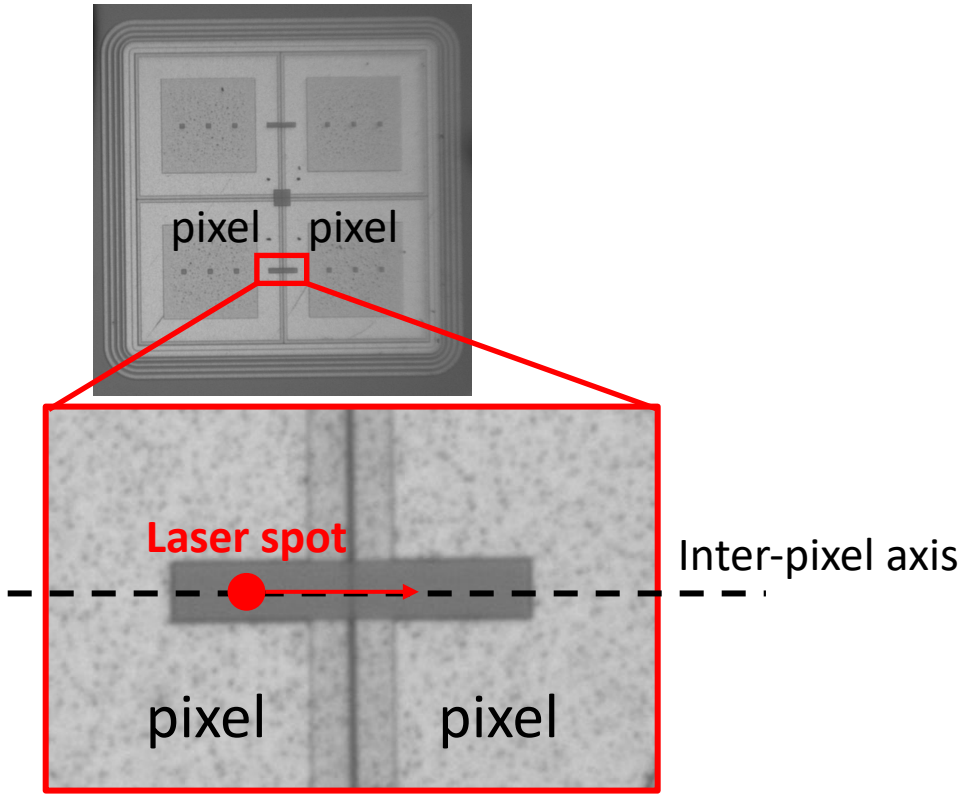
- **Inter-pixel distance between 2 and 10 µm**
- Inter-pixel distance 5-20 time narrower than LGADs with JTE and p-stop (Fill-Factor improvement)

Fill-Factor in pixelated TI-LGADs

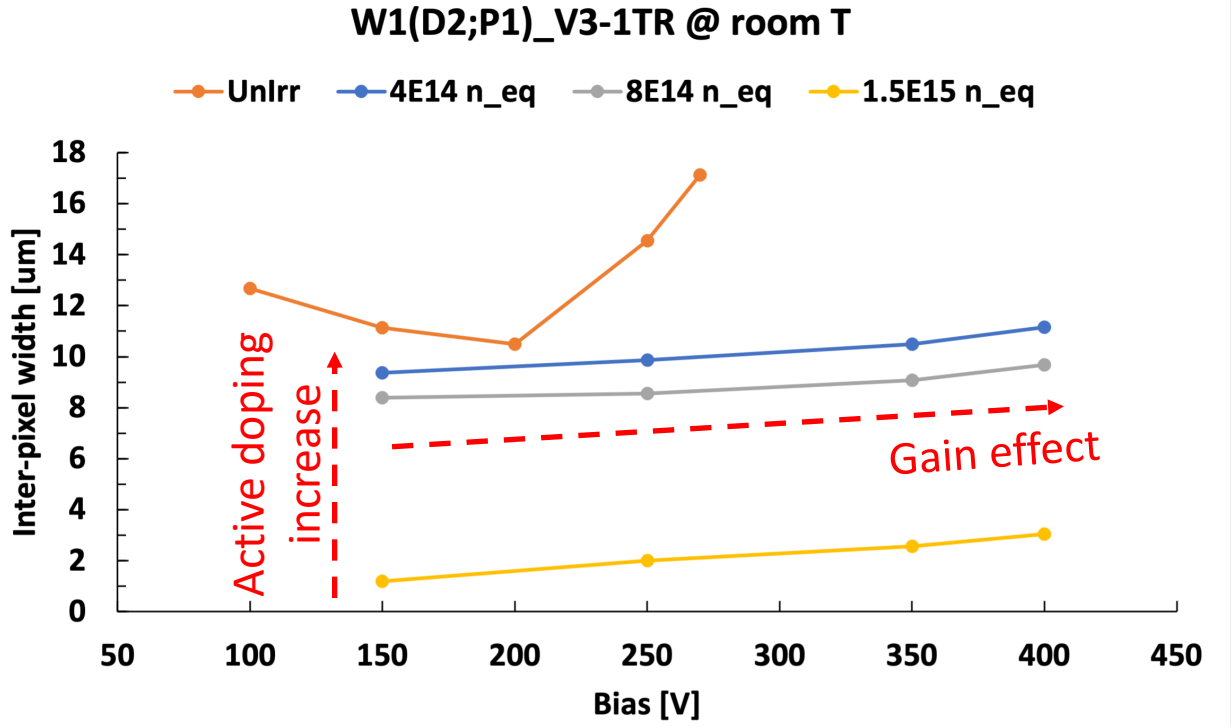


Inter-pixel distance (post neutrons Irr.)

Pixel-border V3-1TR from W1(D2;P1) has been investigated



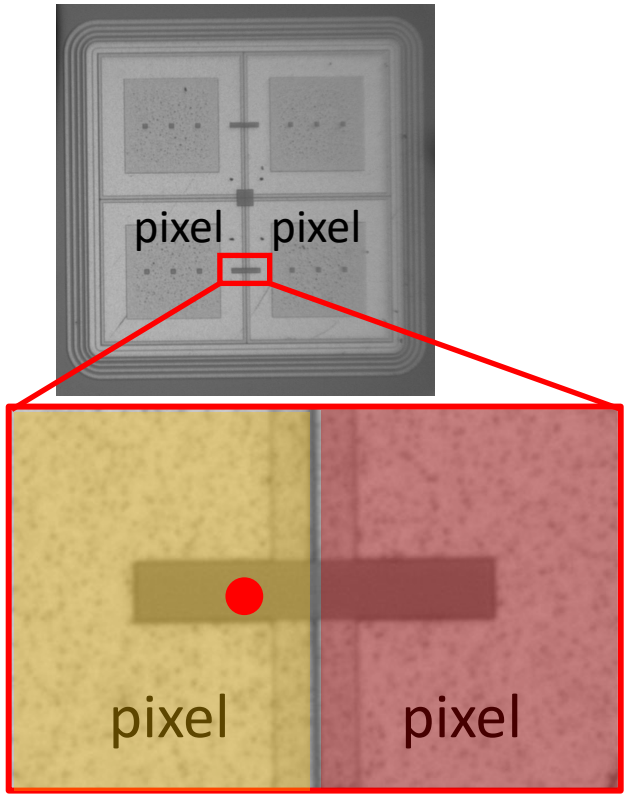
- Measurement performed with front-TCT setup at room T
- Laser intensity: 3-10 MIPs
- Laser size: 10 µm

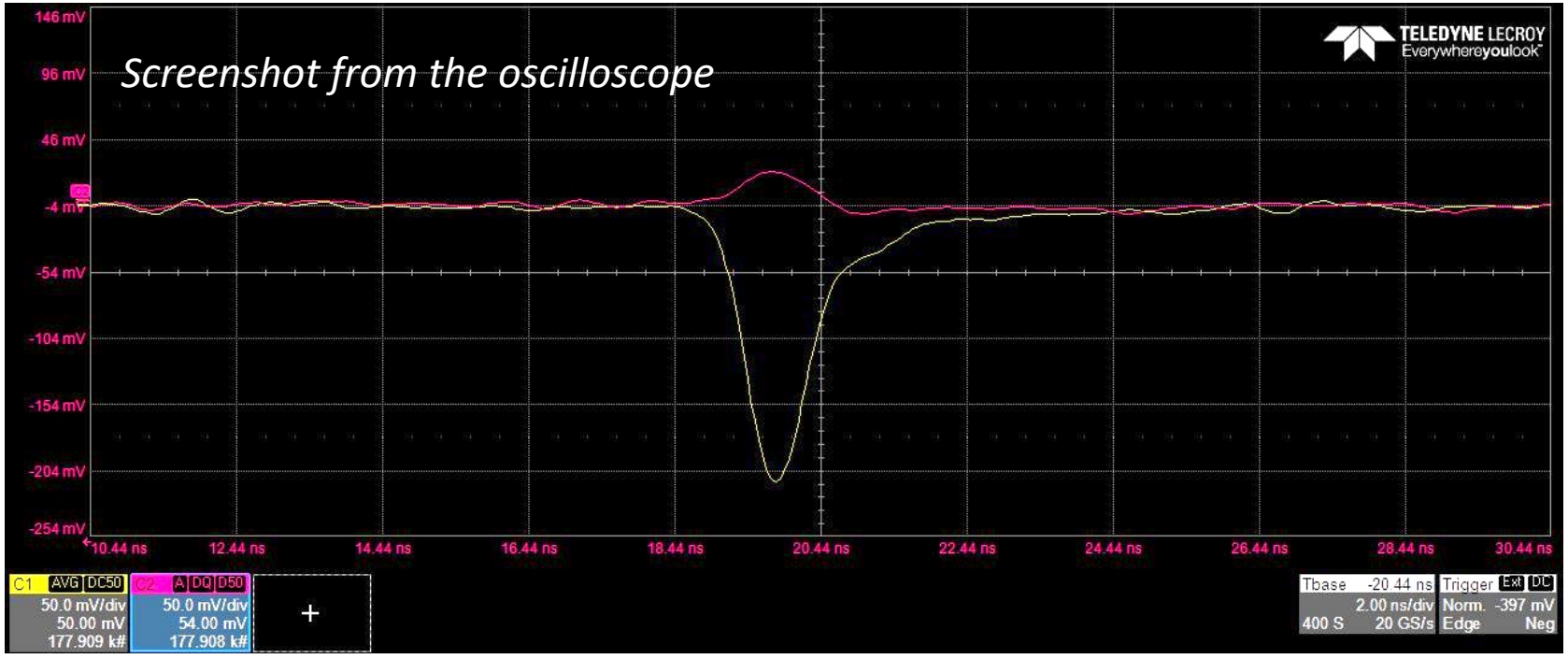


- Clear correlation between IP-width and active doping into Gain Implant
- Weak correlation between IP-width and sensor bias
- **Perfect pixel isolation kept up to $1.5 \cdot 10^{15}$ n_{eq}/cm^2**

Signals shape

W1(D2;P1) V3-1TR (new)
Bias = 200 V



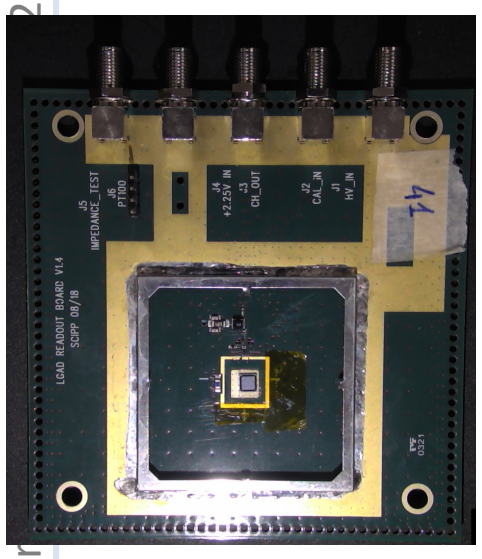


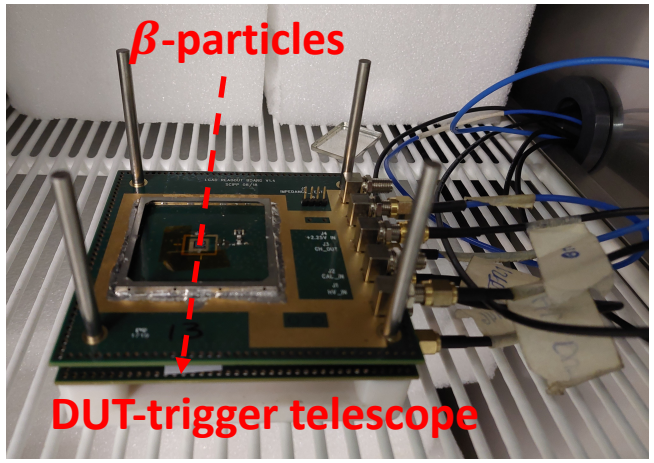
- Measurement performed with front-TCT setup at room T
- Laser intensity: 3-10 MIPs
- Laser size: 10 µm

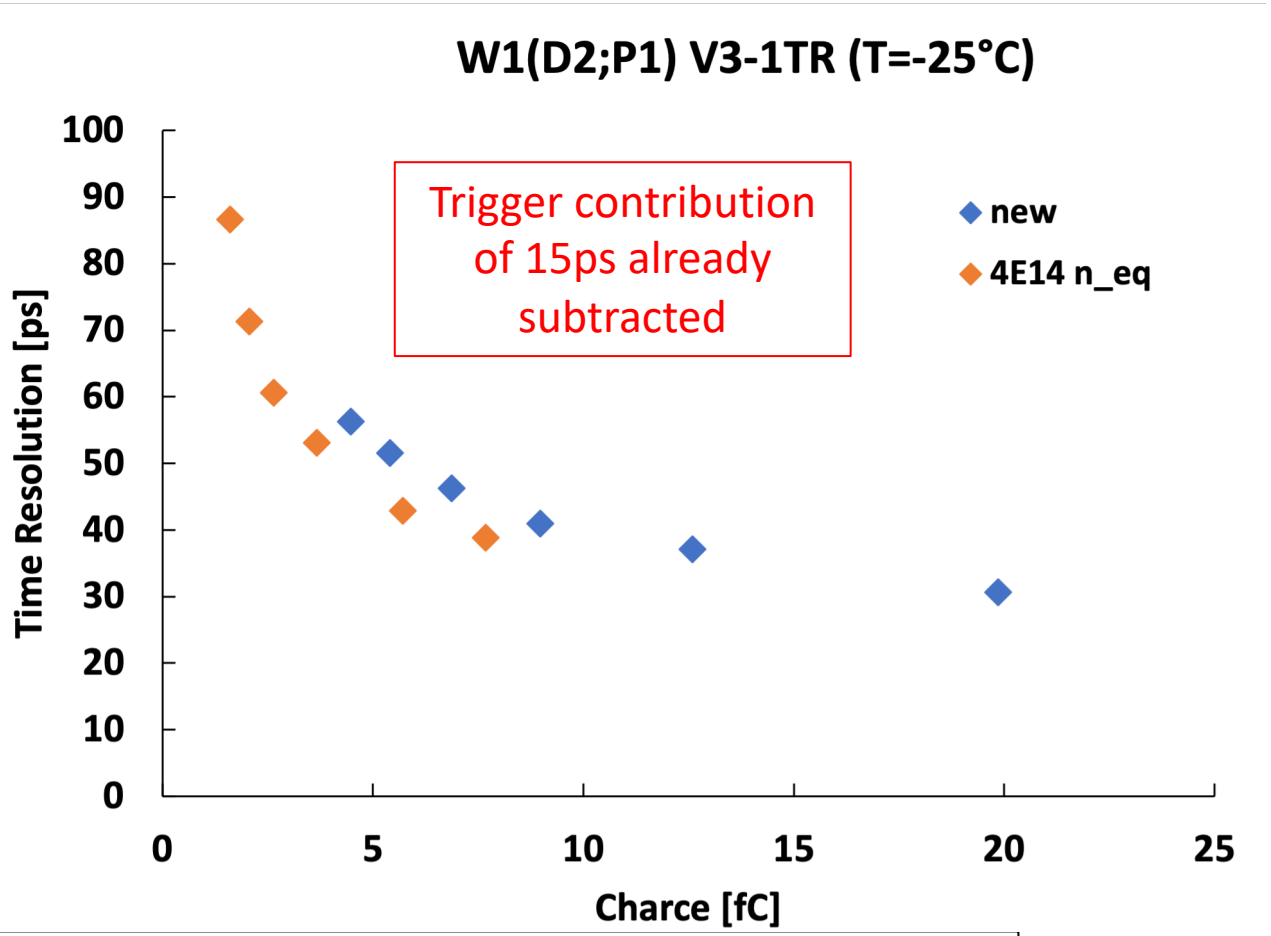
Shooting near the border
Bipolar signal induced on the neighbouring pixel

Time resolution

- Sr90 - β source
- Measurements at -25°C in a climatic chamber
- Single channel readout board optimized for timing
- Two amplification stages
- Trigger time resolution of 15-20 ps







- **30 ps time resolution achieved in a new sensor**
- **40 ps time resolution achieved in a $4 \cdot 10^{14}$ n_{eq}/cm^2 irradiated sensor** (gain layer not optimized in term of radiation resistance)
- **No micro discharges** have been observed before the breakdown voltage in both tested sensors

Summary

- Trench-Isolated LGADs produced by FBK within a RD50 project:
  - three **trench depths (D1<D2<D3)** and **processes (P1;P2;P3)** have been implemented
  - several **pixel borders** with **1 and 2 trenches** have been designed

- Excellent **pixel isolation pre and post-irradiation** (neutrons and X-rays) shown by:
  - IV characteristics
  - Inter-pixel resistance
  - TCT inter-pixel scan

- Good **BD resilience to floating** pixels in wafers with **trench process P1**

- Inter-pixel distance measured between **2 µm** and **10 µm** (5-20 time lower than in standard LGADs)

- **Time resolution below 40ps** achieved in new and irradiated (4E14 n_{eq}/cm^2) sensors
  - **No micro-discharges noise** degrades the sensors performances

- **Trench isolation is a reliable and radiation hard segmentation technology for LGADs**

Acknowledgements

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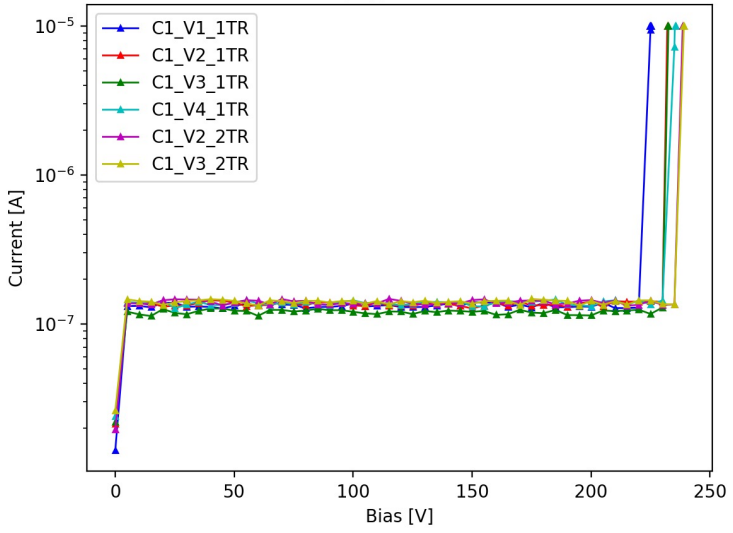
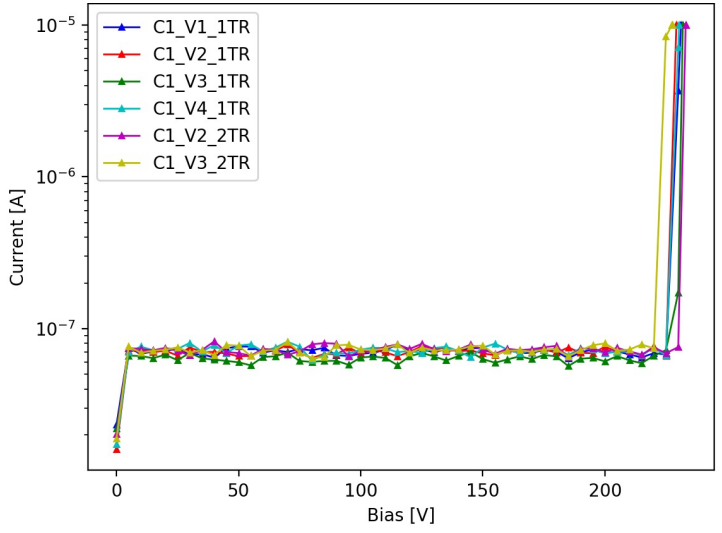
Buck up

Breakdown in new pair-LGADs W7/9/11

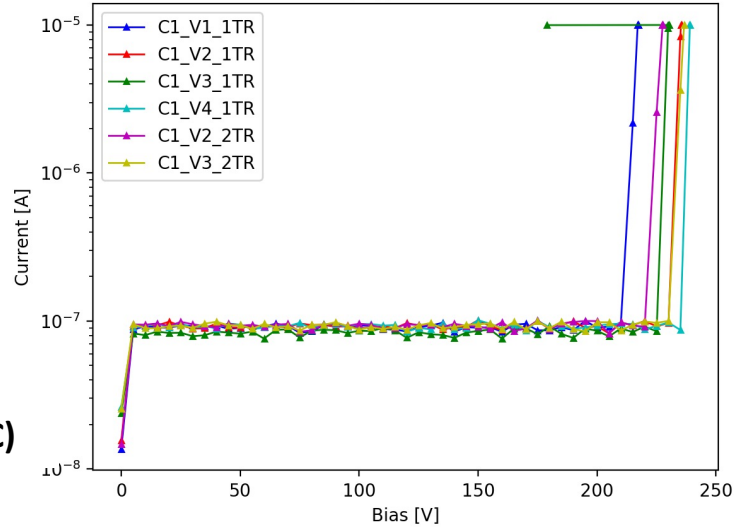
W7(D2;P2) - 1x2 LGADs – Total current (T—30°C)



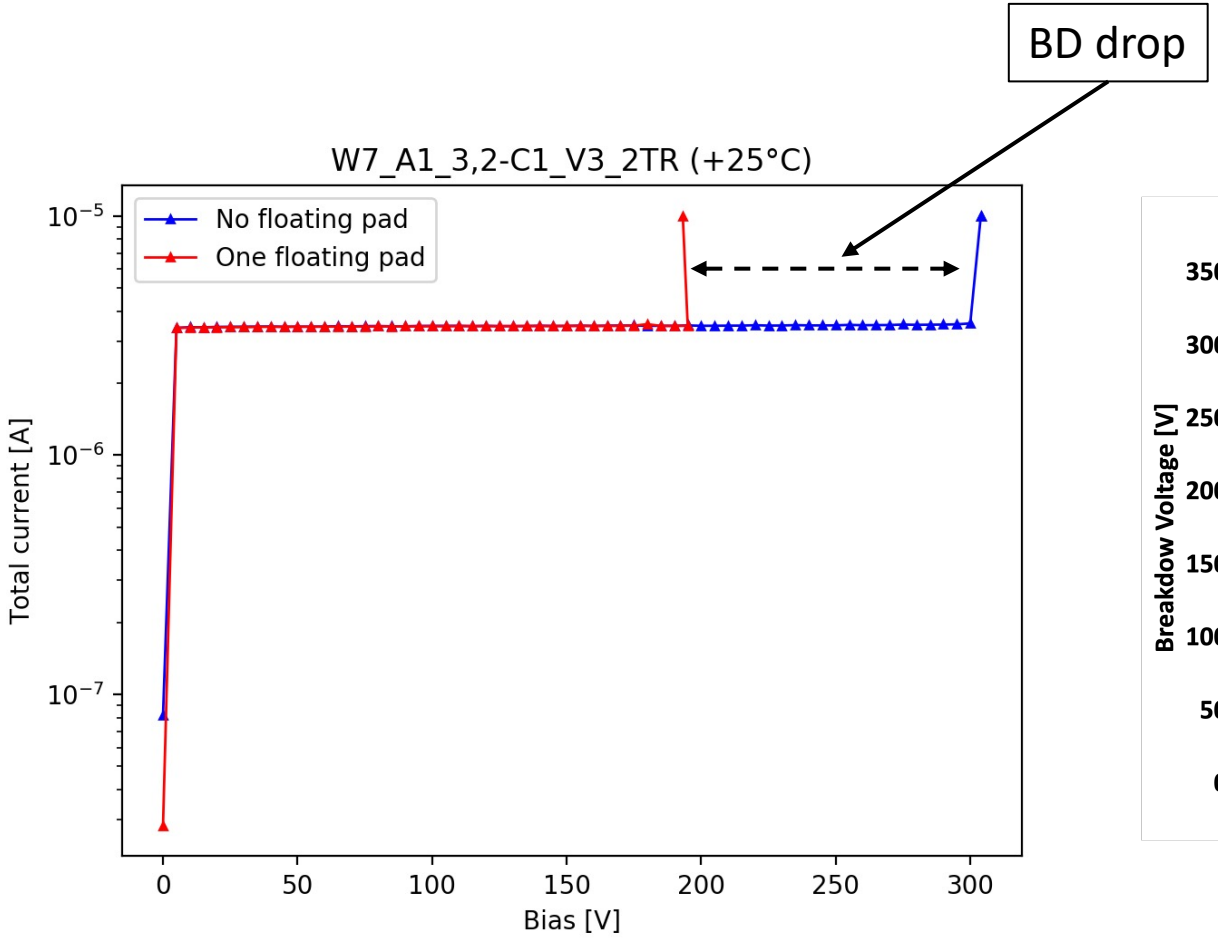
W11(D1;P1) - 1x2 LGADs – Total current (T—30°C)

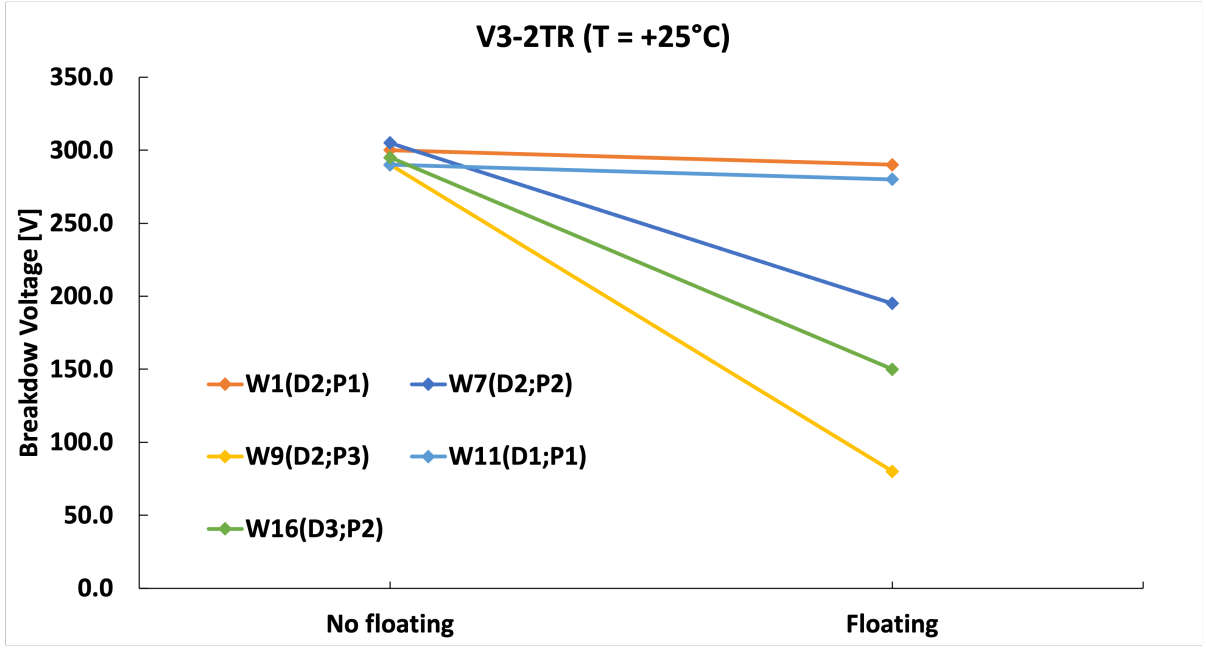


W9(D2;P3) - 1x2 LGADs – Total current (T—30°C)

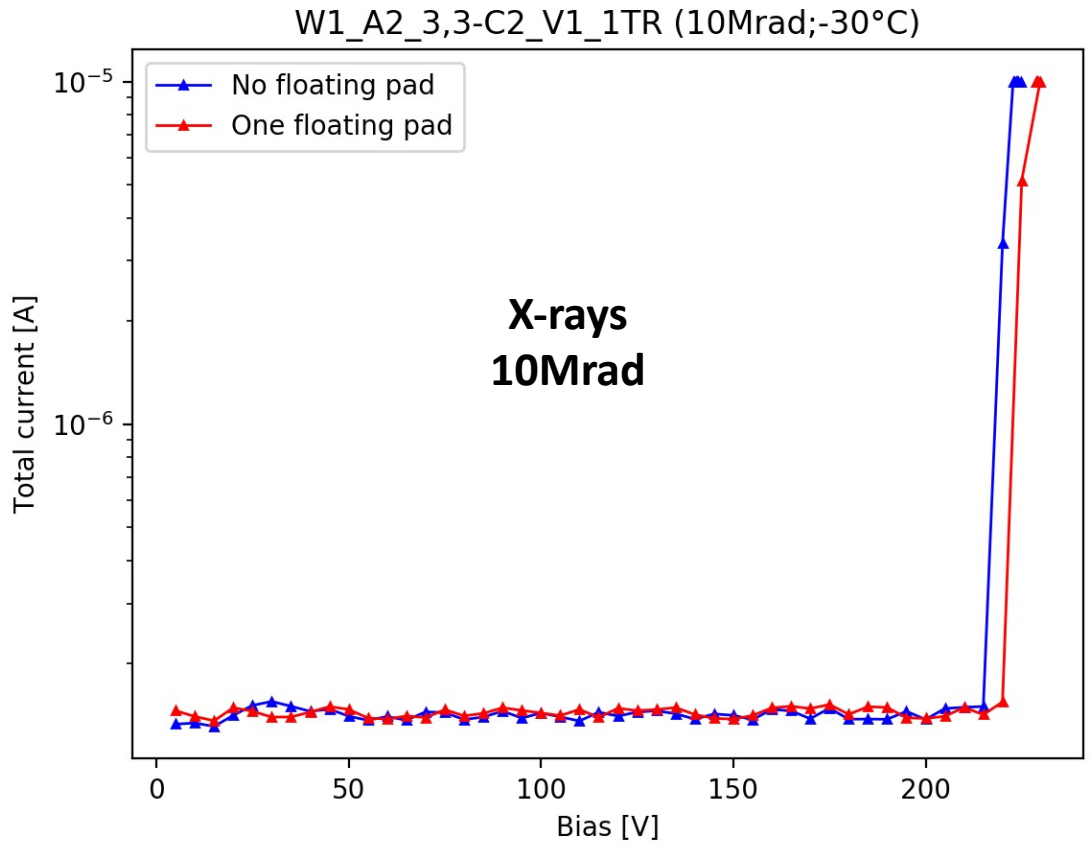


BD resilience to floating pixels



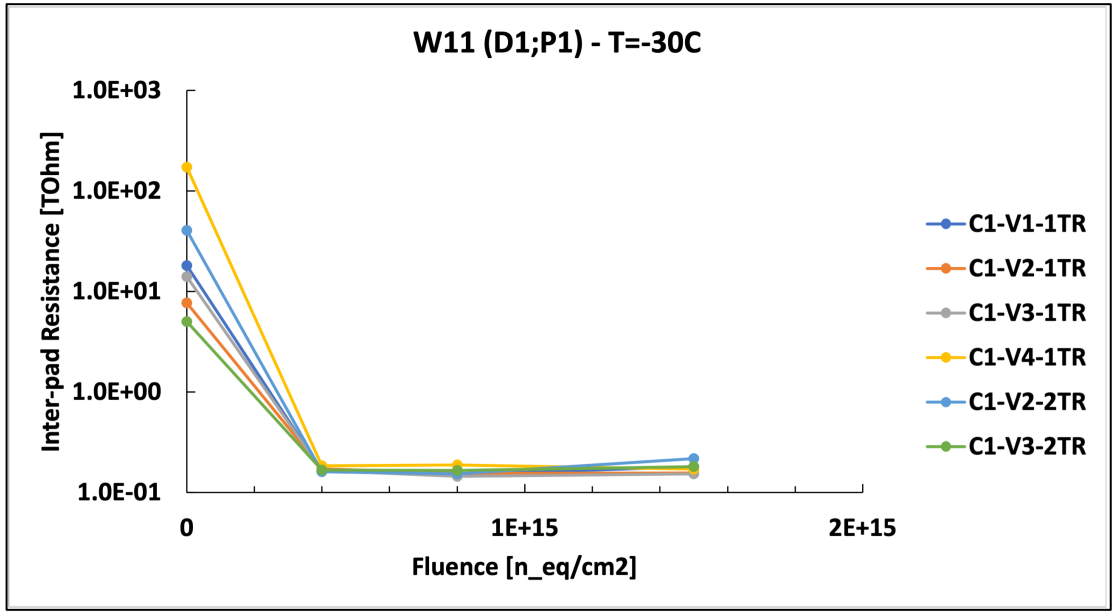


BD resilience to floating pixels after X-rays irradiation

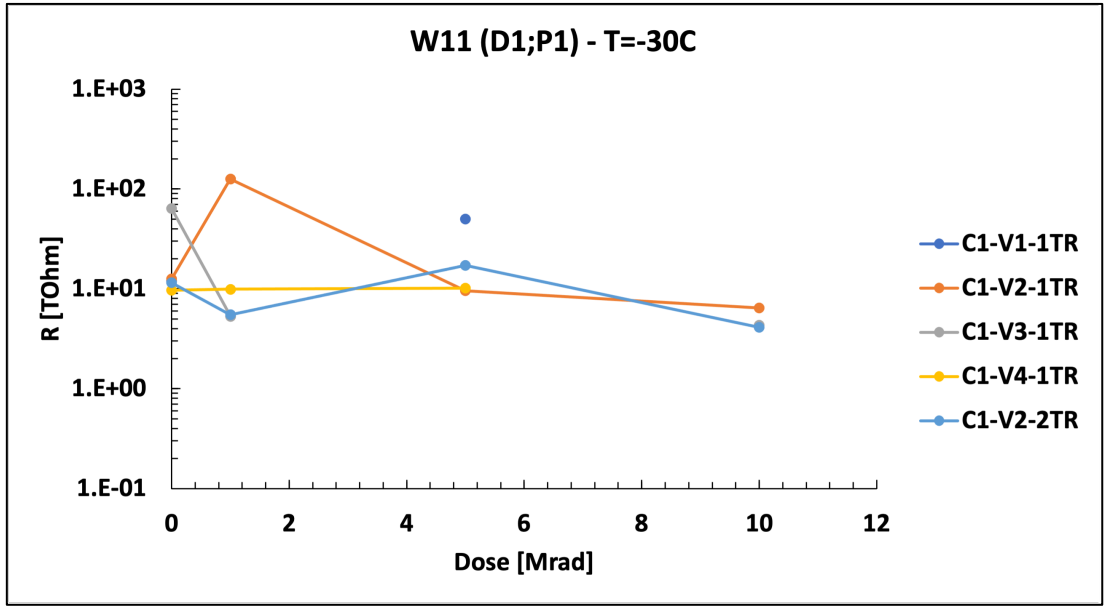


Inter-pixel resistance W11(D1;P1)

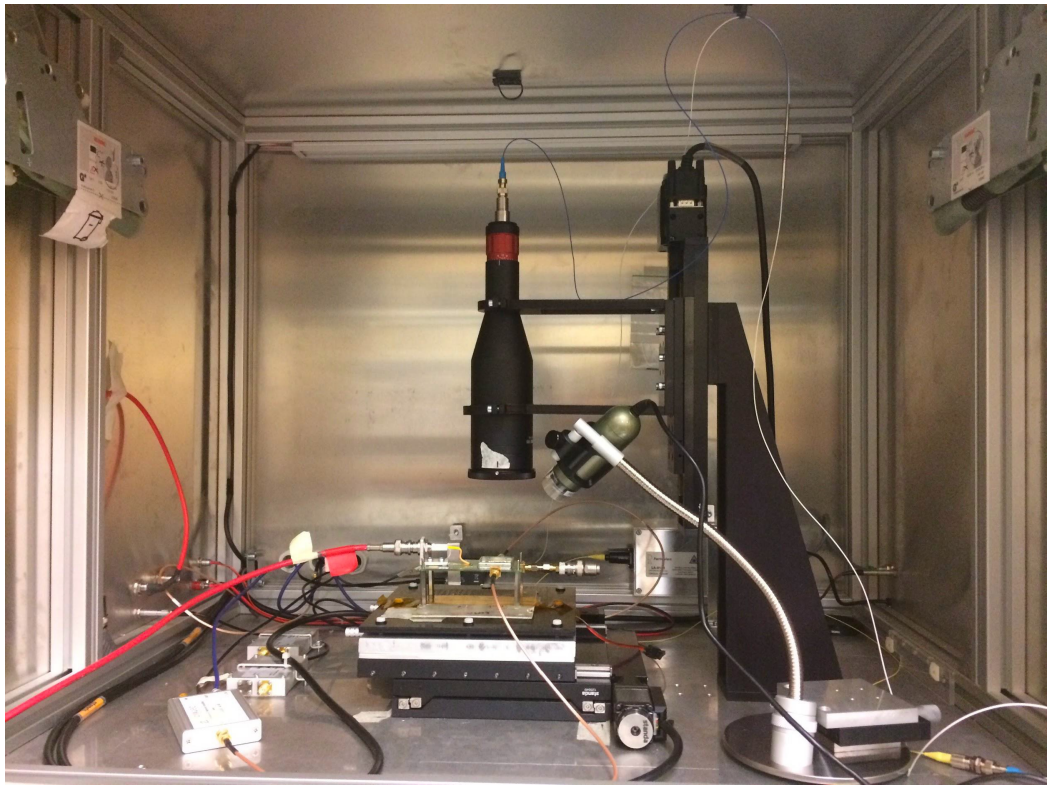
Neutrons Irradiation

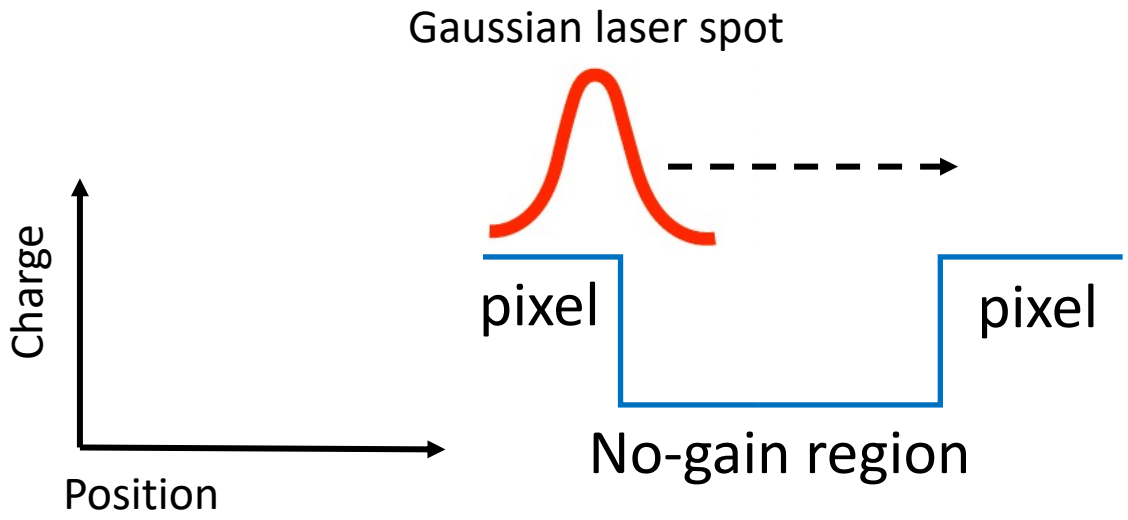


X-Rays Irradiation



TCT - setup





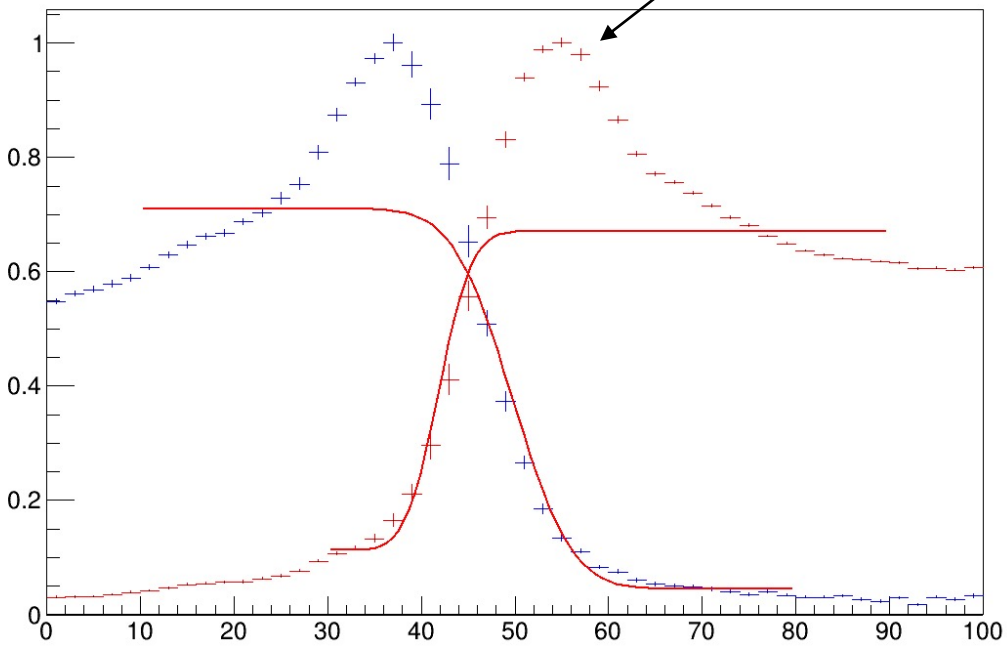
Particulars TCT setup:

- IR pulsed laser (1060 nm) → 10-15 µm spot
- xy-stage with sub-µm precision
- Stage control and DAQ via Labview software

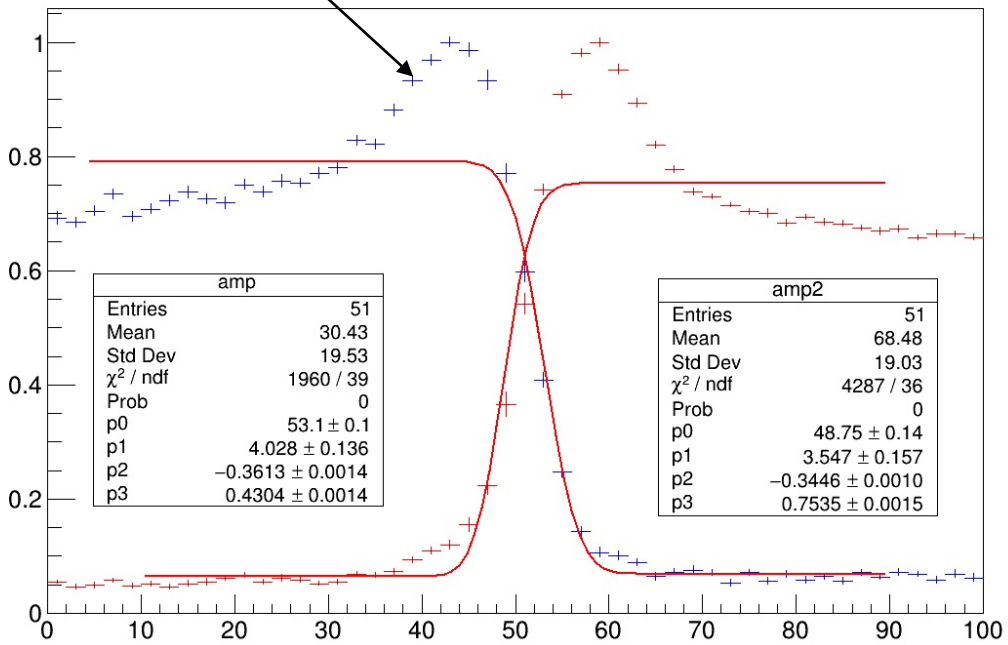
Inter-pixel distance

Peaks of electric field

W16 at 270V (Room T)

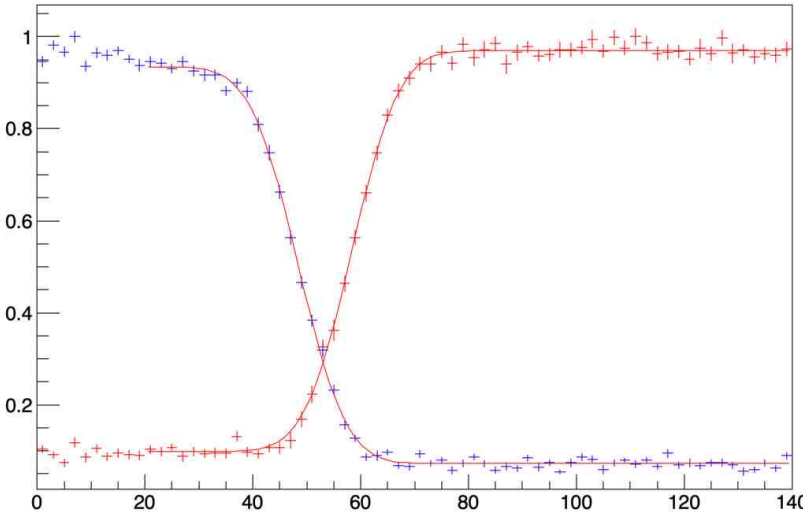


W9 at 270V (Room T)

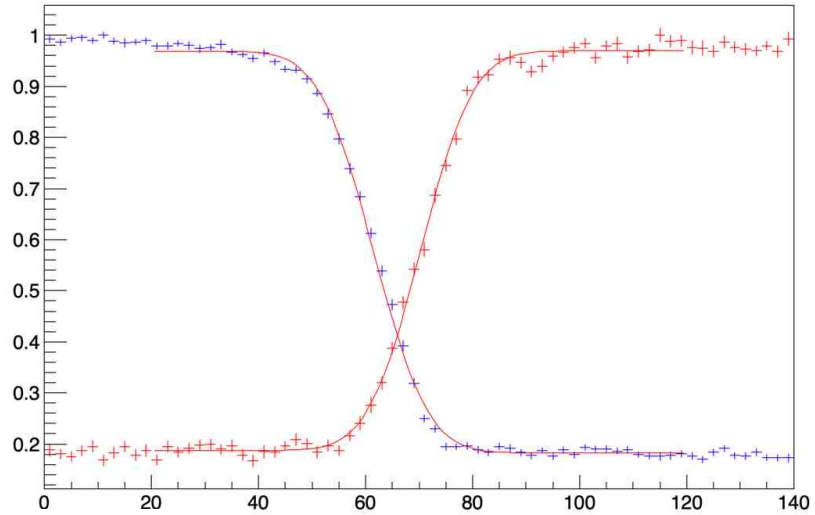


Inter-pixel distance – post irradiation

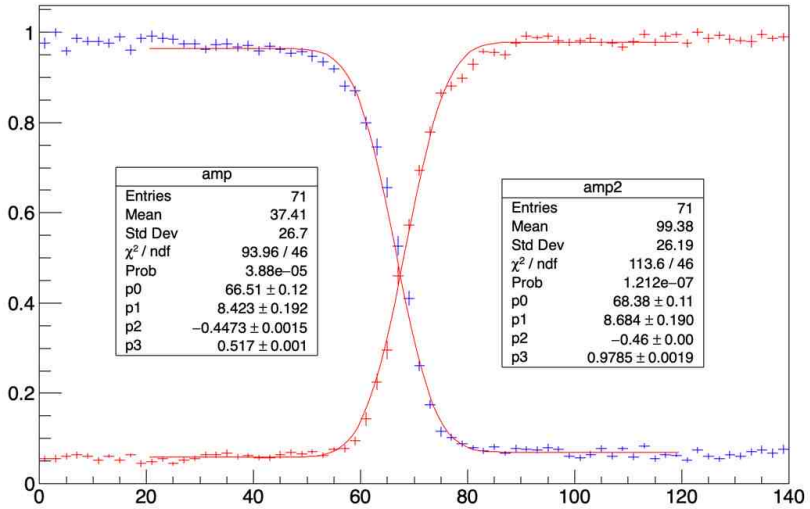
W1(4E14 n_{eq}) at 250V



W1(8E14 n_{eq}) at 250V

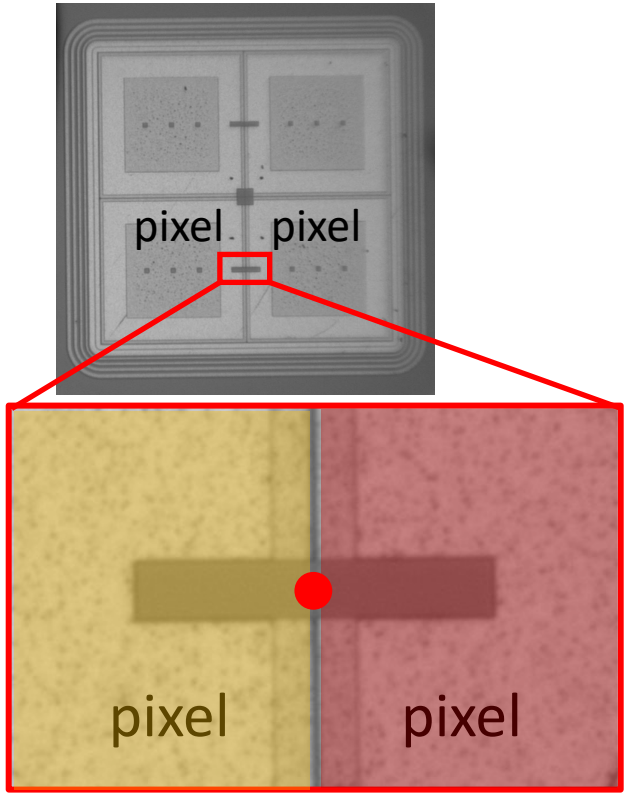


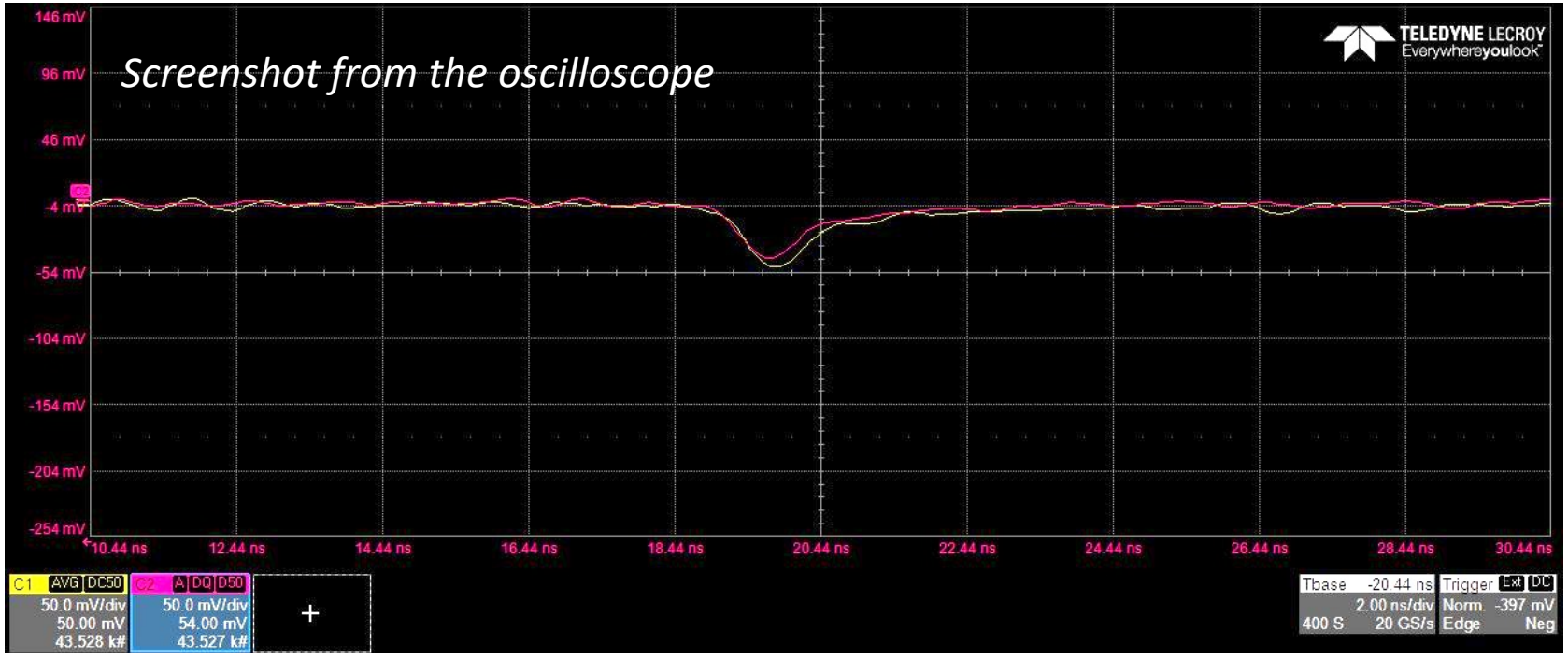
W1(1.5E15 n_{eq}) at 250V



Signals shape

W1(D2;P1) V3-1TR (new)
Bias = 200V

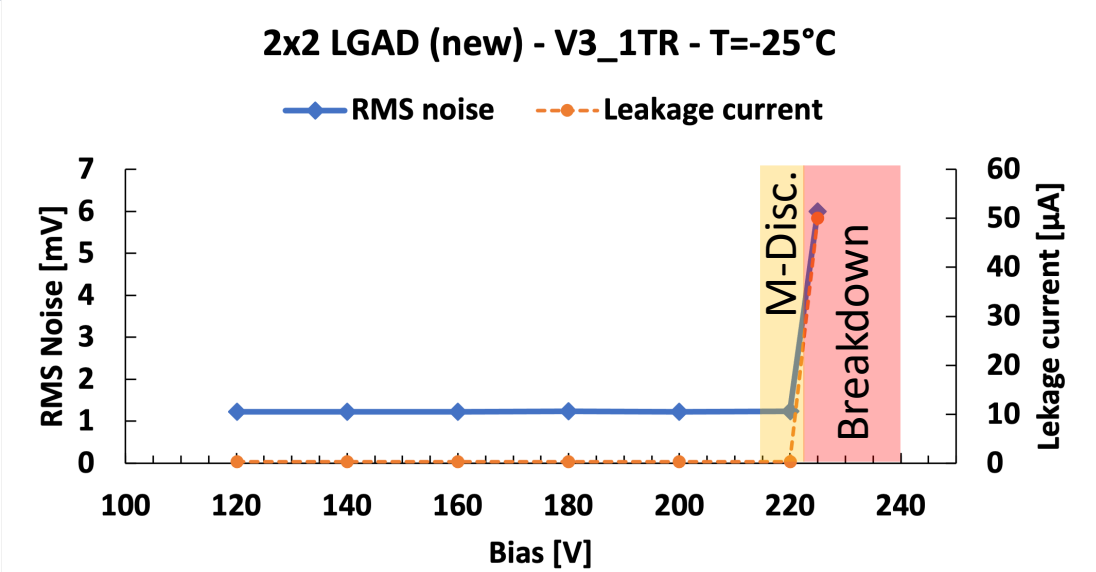




- Measurement performed with front-TCT setup at room T
- Laser intensity: 3-10 MIPs
- Laser size: 10µm

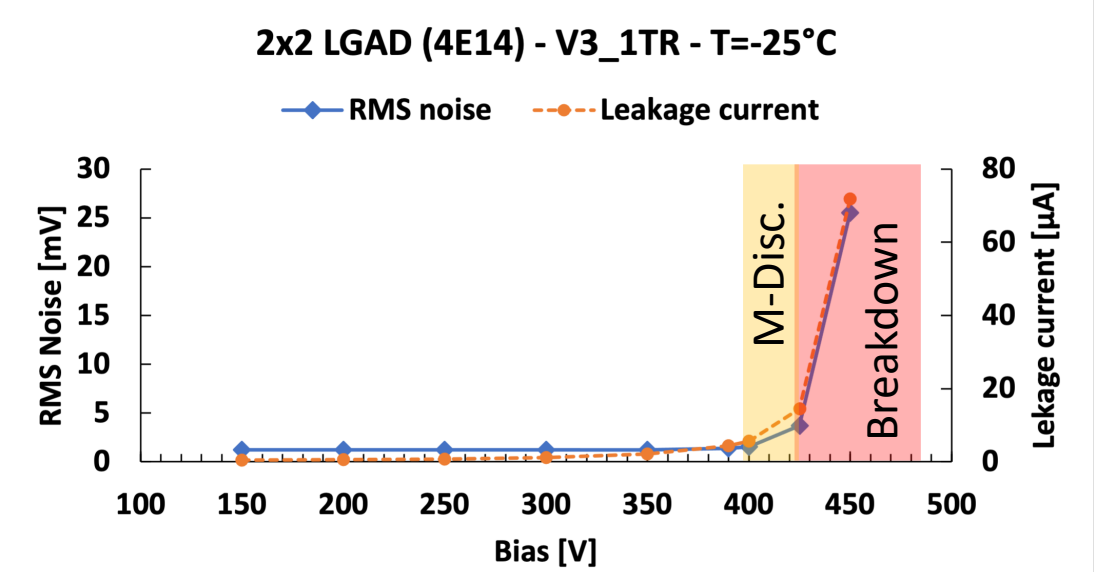
Shooting on the middle
Signal split between the two pixels

Noise and micro discharges



New Sensor

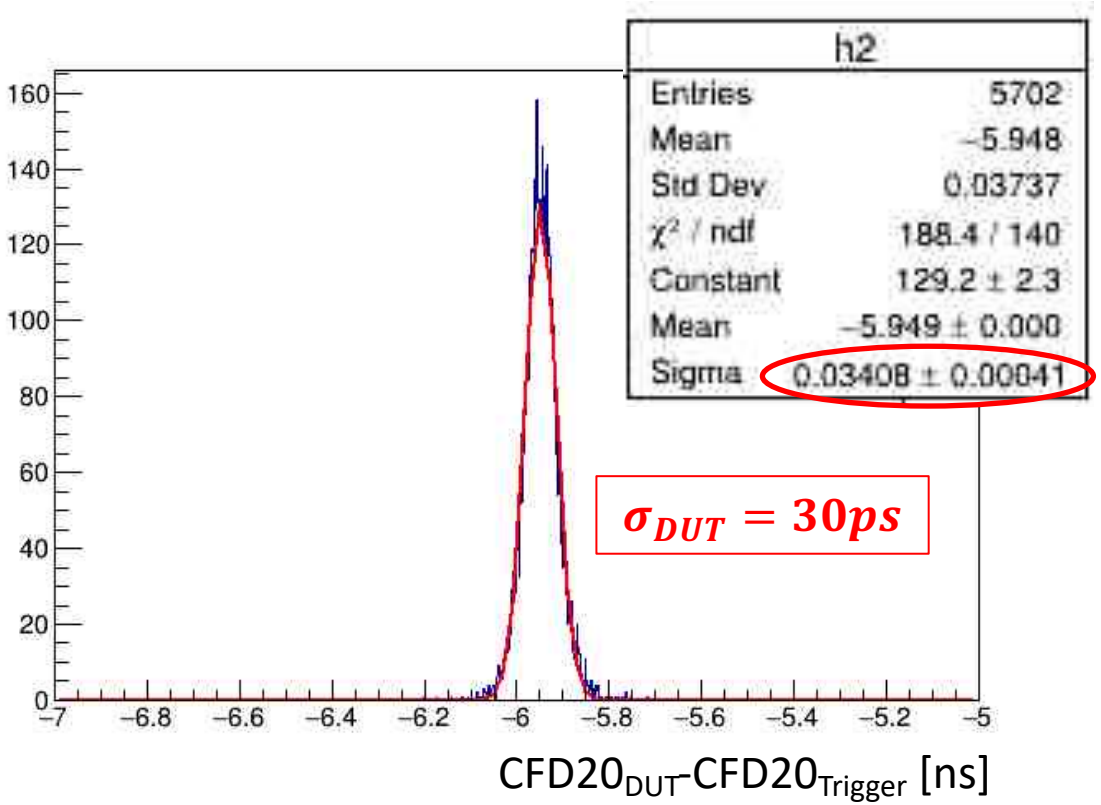
- Micro discharges appear at 215V (10V before the Breakdown)
- At 215V MD<25mV
- At 220V MD<40mV



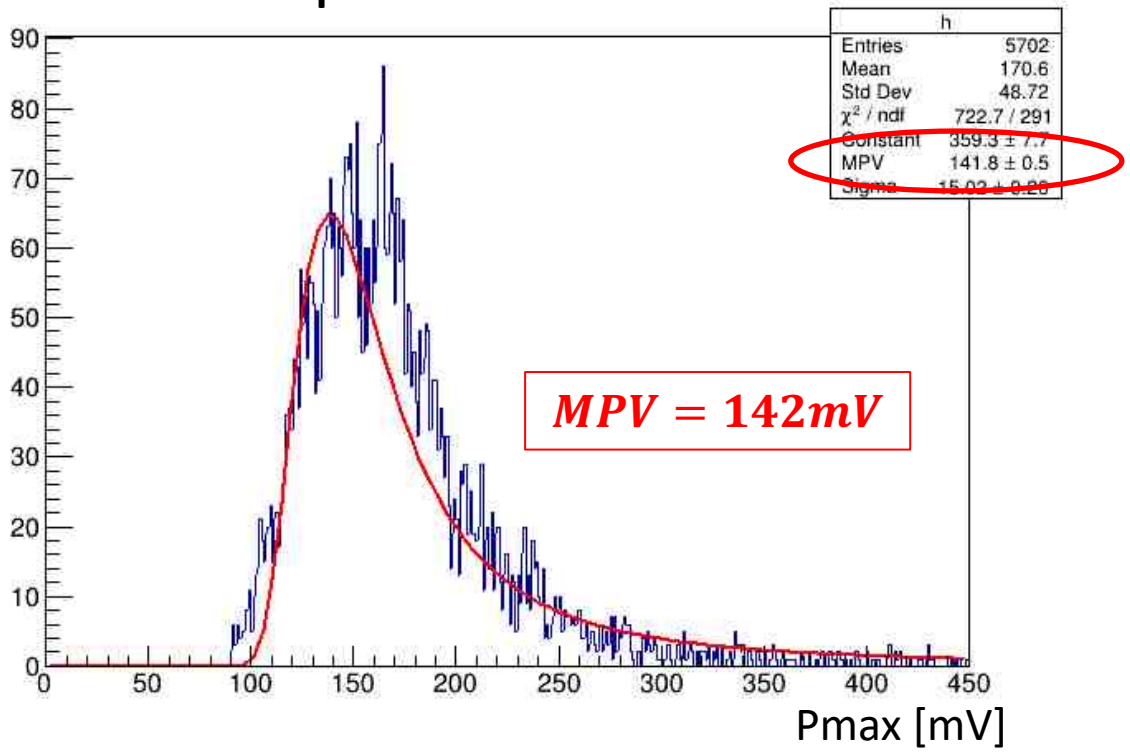
Sensor irradiated at 4E14 n_{eq}

- Micro discharges appear at 400V (~20V before the Breakdown)
- At 400V MD<25mV
- At 425V MD>35mV

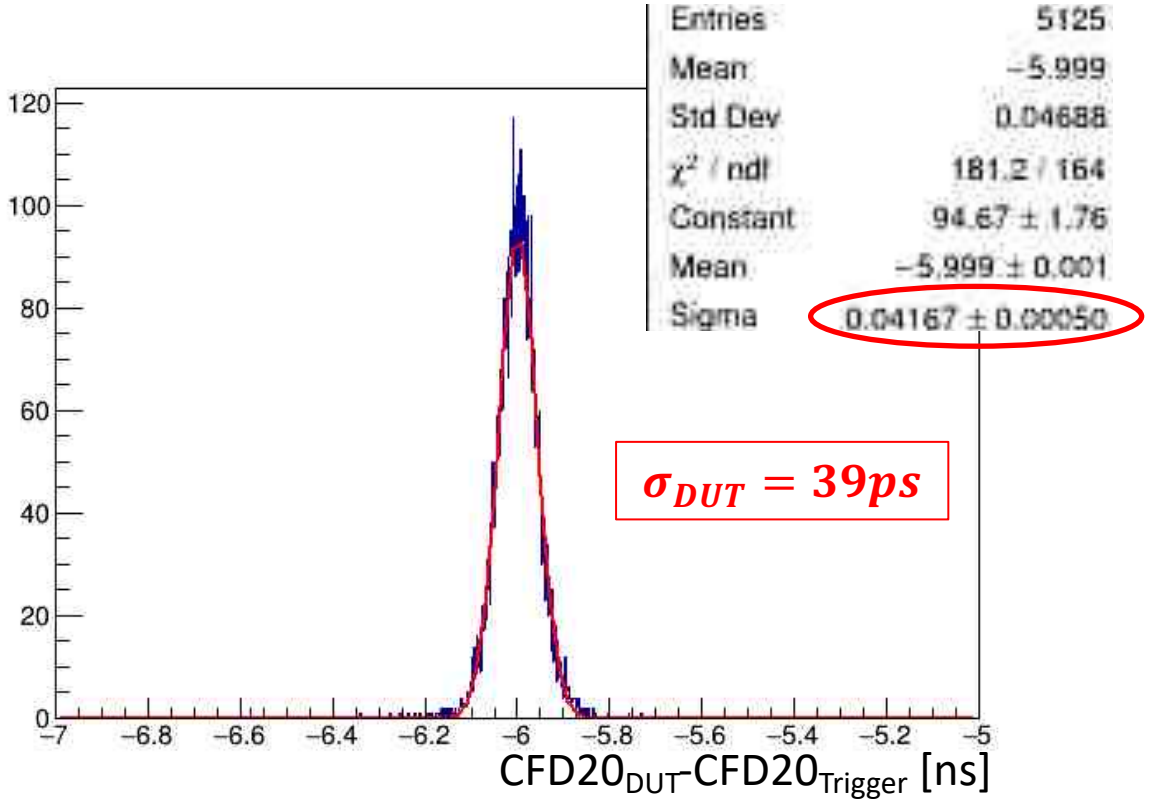
Time resolution – W1 (new) V3_1TR– 220V



Amplitude Distribution



Time resolution – W1 ($4E14n_{eq}$)–375V



Amplitude Distribution