



39<sup>th</sup> RD50 Workshop  
Valencia, Spain  
17-19 November 2021

# Status and first results of the "RD50 TI-LGAD" Project

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On Behalf of the TI-LGAD project  
(an RD50 project)

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# TI-LGAD Project

**GOAL:** Design and production of fine segmented LGAD based on “Trench-isolated technology” with small pixels ( $\leq 100 \mu\text{m}$ ) and high Fill Factor ( $> 80\%$ )

## APPLICATIONS:

- 4d-tracking
- Soft x-rays detection
- ...

- Partially Founded by RD50
- 10 Partners
- 1 produced batch
- Started in August 2019

## Activity plan

Activity	Status
Numerical simulation and detector design	done
Layout and reticle production	done
Batch Production	done
Automatic Electrical Characterization	done
Functional Characterization (IPD, Timing,...)	ongoing
Sensors Irradiation	ongoing
Sensor UBM and bonding to ROC	ongoing

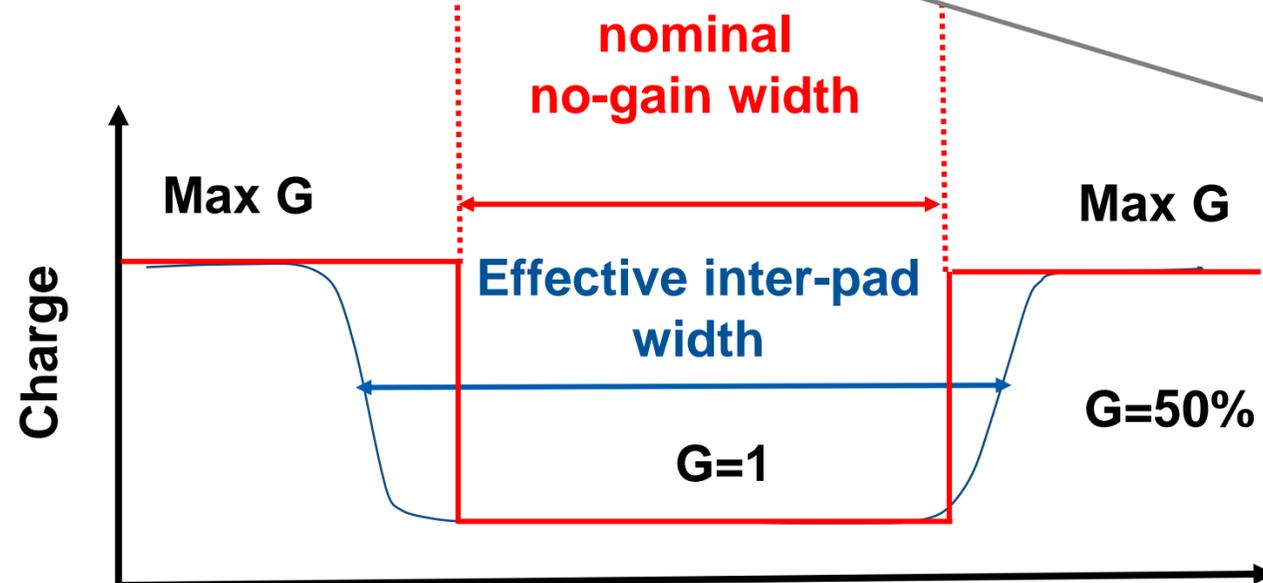
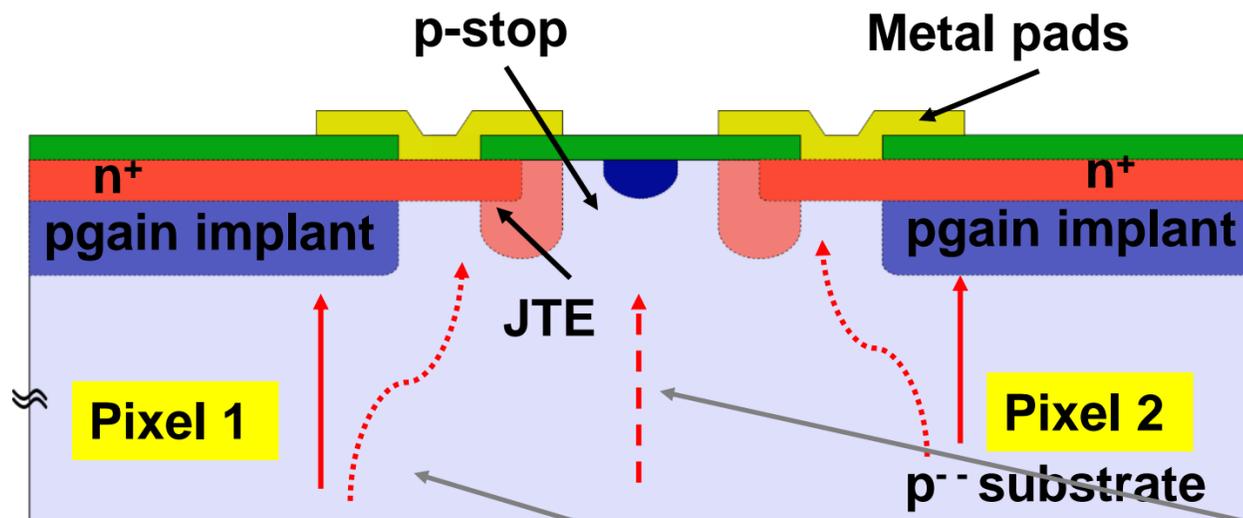
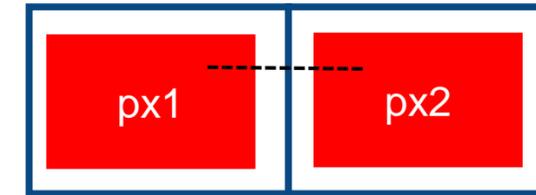
## Partners

- Fondazione Bruno Kessler
- INFN Torino
- KIT
- University of Zurich
- Paul Scherrer Institut
- Institut Jozef Stefan
- University of Birmingham
- UC Santa Cruz
- Nikhef
- Hamburg University



# Ti-LGAD Motivations

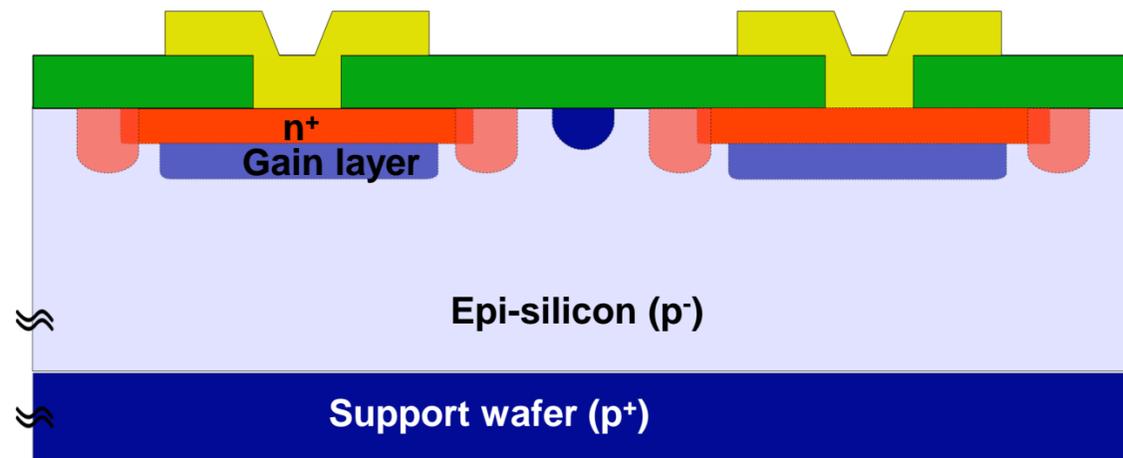
Typical nominal no-gain width in standard LGADs is 40-80  $\mu\text{m}$



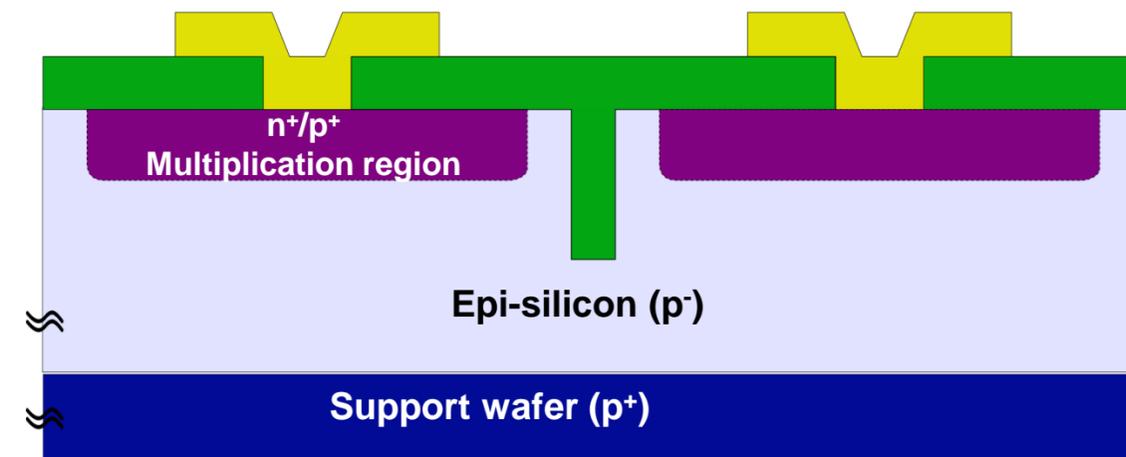
- Inter-pixel region hosts the isolation and termination structures:
  - P-stop
  - Junction Termination Extension (JTE)
  - Virtual GR
- **The pixel border is a dead-region.** The carriers generated in this area are not multiplied.
- Some carriers, even if generated below the nominal gain layer, are collected by the deeper JTE and does not pass through the gain layer. These carriers are multiplied with reduced gain

# TI-LGAD Technology

## Segmented Standard LGAD

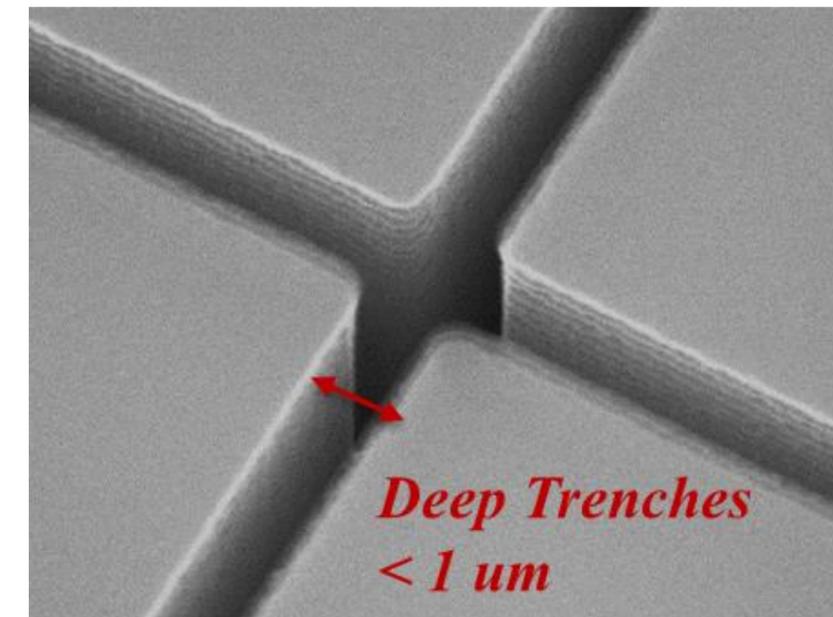


## Trench-Isolated LGAD



New **TI-LGAD** technology proposed by FBK:

- **JTE and p-stop are replaced by a single trench.**
- Trenches act as a drift/diffusion barrier for electrons and isolate the pixels.
- The trenches are a few microns deep and  $< 1\mu\text{m}$  wide.
- Filled with Silicon Oxide
- The fabrication process of trenches is compatible with the standard LGAD process flow.



# TI-LGAD Batch: Technological Splits

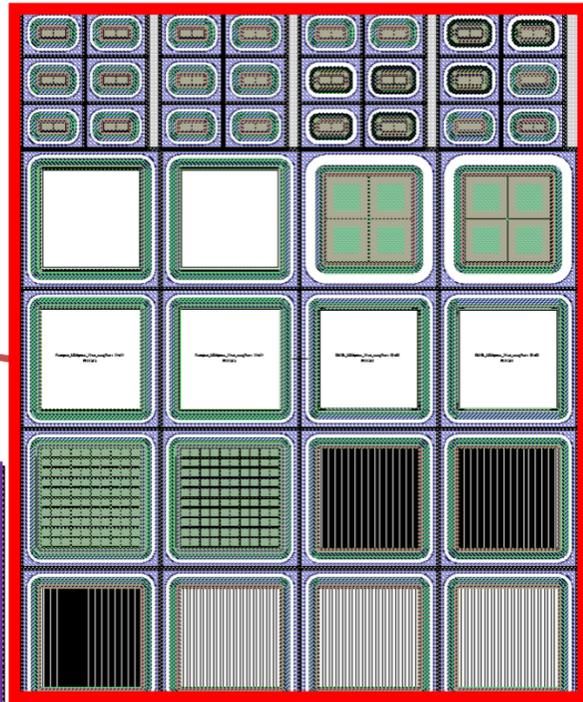
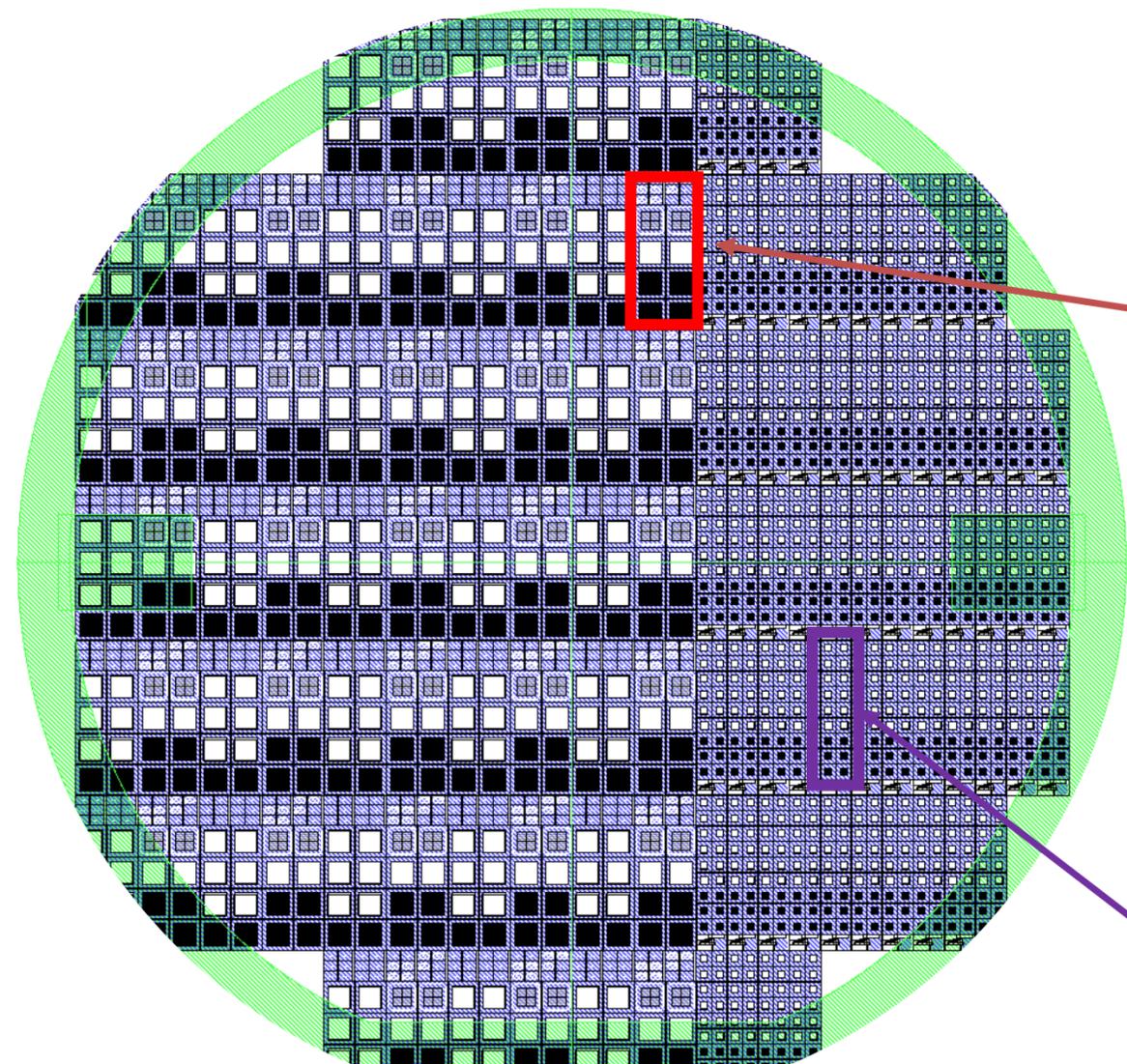
Wafer n.	Trench Depth	PGAIN dose	Diffusion	Trench Process
1	D2	B	HD	P1
2	D2	B		P1
3	D2	A	LD	P1
4	D2	A		P1
5	D2	C	HD	P1
6	D2	B		P2
7	D2	B		P2
8	D2	B		P2
9	D2	B		P3
10	D2	B		P3
11	D1	B		P1
12	D1	B		P1
13	D1	B		P2
14	D1	B		P3
15	D3	B		P1
16	D3	B		P2
17	D3	B		P2
18	D3	B		P3

## Technological Splits:

- 3 PGAIN doses ->  $A < B < C$
- 3 Trench depth ->  $D1 < D2 < D3$
- 2 Dopant diffusion processes (L & H)
- 3 Trench isolation processes (P1, P2, P3)

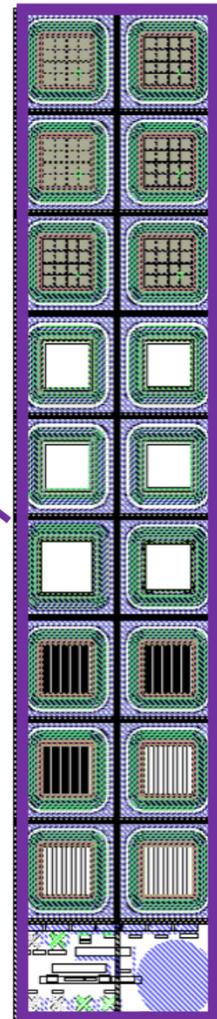
- All the wafers are 45 um thick epi
- No Carbon co-implantation (possibility to be added in the next batches)

# TI-LGAD Batch: Layout splits



4x4 mm<sup>2</sup> chips

Structure	Pitch (μm <sup>2</sup> )	NxN	AA Size (μm <sup>2</sup> )
Pixel	250 x 375	1 x 2	250 x 750
Pixel	100 x 100	30 x 30	3000 x 3000
Pixel	1300 x 1300	2 x 2	2600 x 2600
Pixel	55 x 55	55 x 55	3025 x 3025
Pixel	50 x 50	60 x 60	3000 x 3000
Pixel	300 x 300	10 x 10	3000 x 3000
Structure	Pitch	N strips	AA Size
Strip		50	60 3000 x 3000
Strip		100	30 3000 x 3000

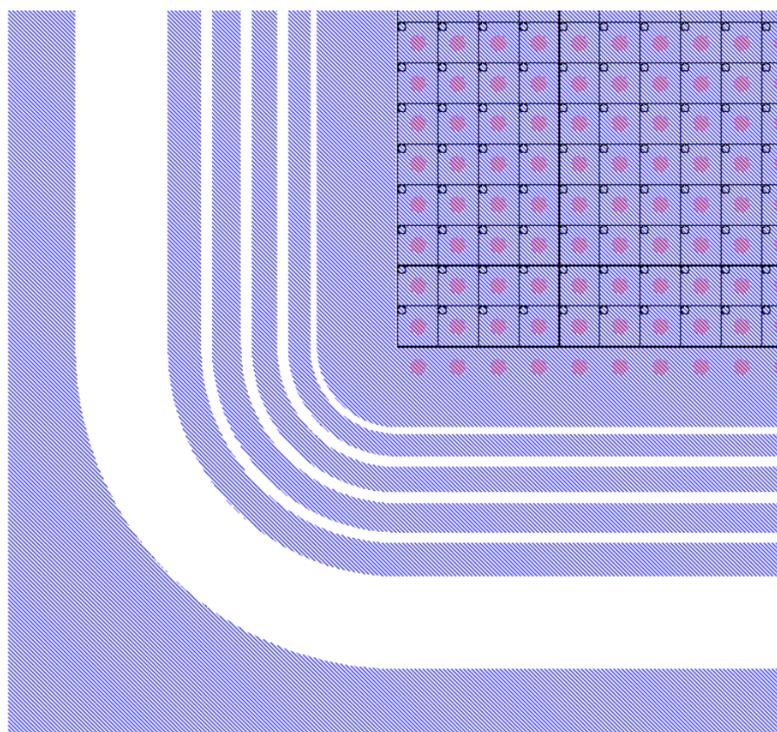


2x2 mm<sup>2</sup> chips

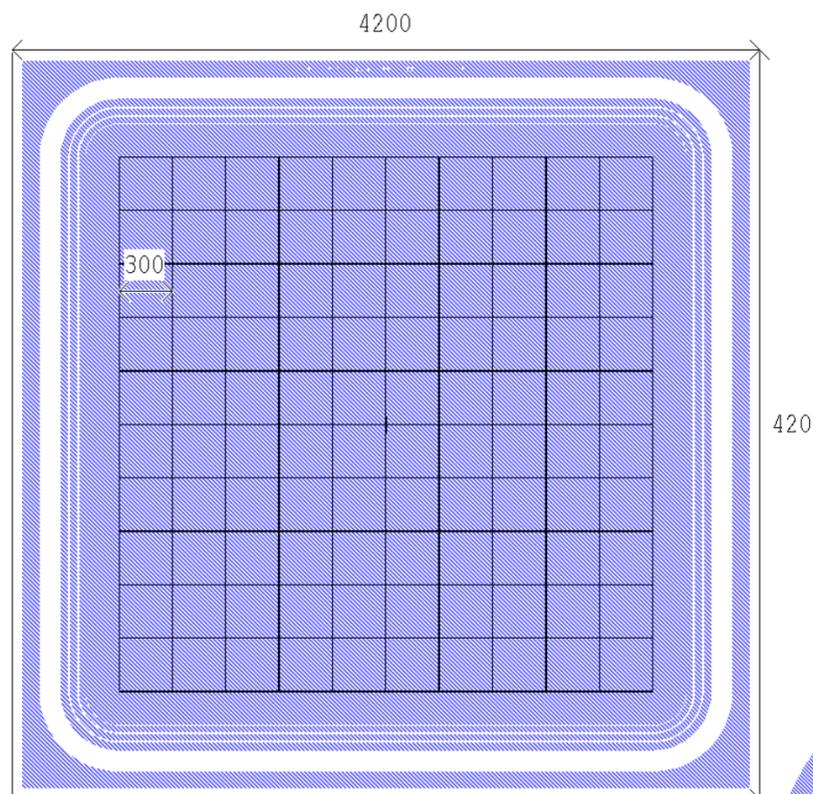
Structure	Pitch (μm <sup>2</sup> )	NxN	AA Size (μm <sup>2</sup> )
Pixel	250 x 250	4 x 4	1000 x 1000
Pixel	75 x 75	13 x 13	975 x 975
Pixel	55 x 55	20 x 20	1100 x 1100
Pixel	50 x 50	20 x 20	1000 x 1000
Structure	Pitch	N strips	AA Size
Strip		50	20 1000 x 1000
Strip		100	10 1000 x 1000
Other			
Test	\	\	\

# TI-LGAD Production Batch: Layout splits

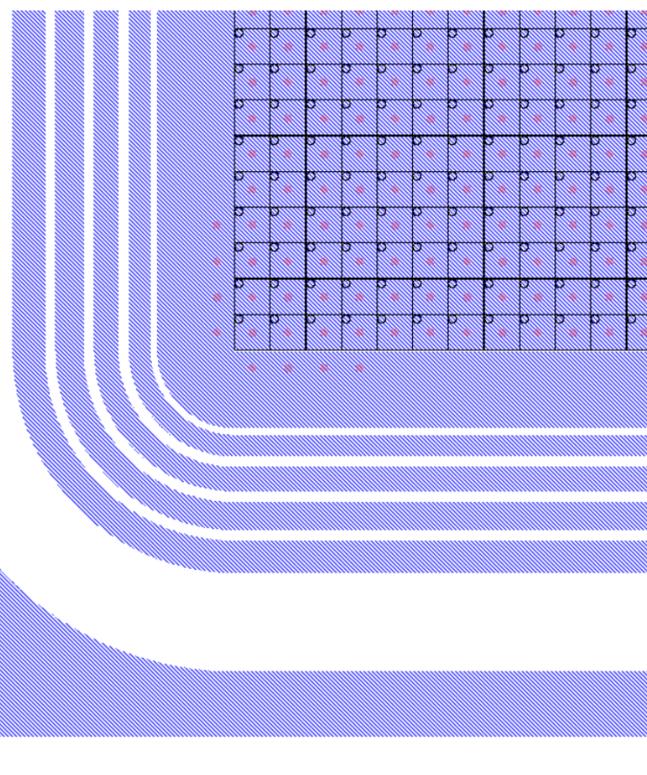
Many different small pixels sensors have been included, compatible with many different ASICs



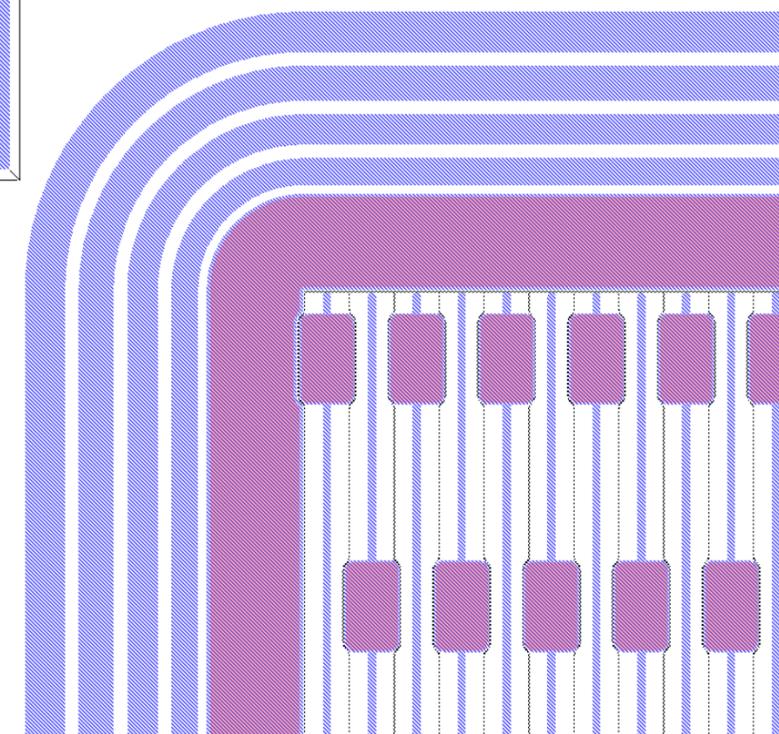
**Pixels**  
 $55 \times 55 \mu\text{m}^2$   
(Medipix/Timepix)



**Pixels**  
 $300 \times 300 \mu\text{m}^2$   
(NA62)



**Pixels**  
 $50 \times 50 \mu\text{m}^2$   
(RD53A/Moench)



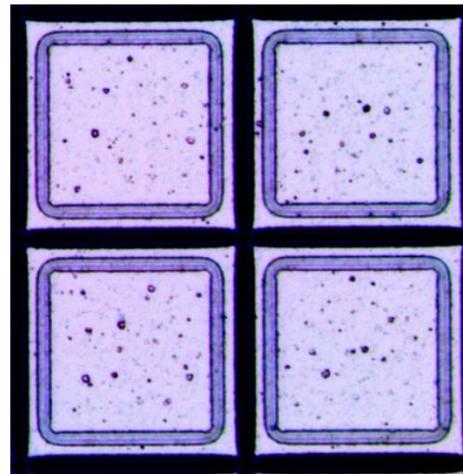
**Strips**  
 $100 \text{ \& } 50 \times 3000 \mu\text{m}^2$

# TI-LGAD Production Batch: Layout & Technological splits

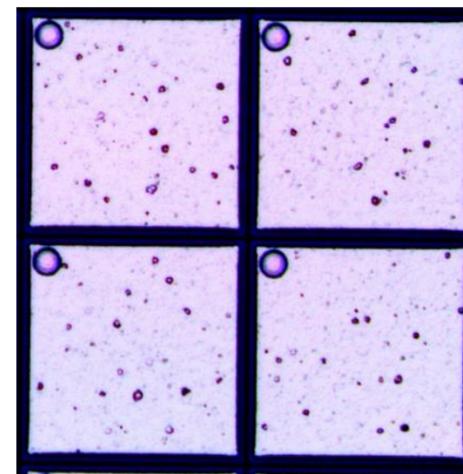
## Three principal layout split

### Contact Layout

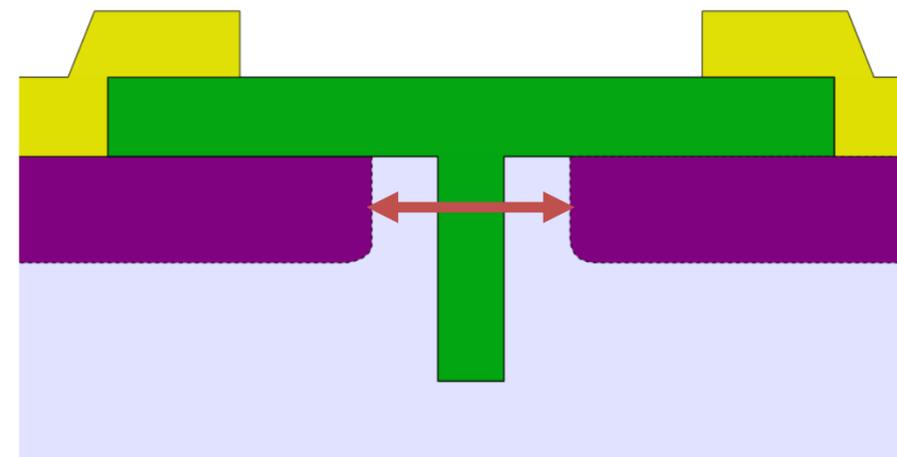
**C1**  
Ring-type  
contact  
GAIN below  
contacts



**C2**  
Hole-type  
contact  
no GAIN  
below  
contact



### Gain to Gain distance



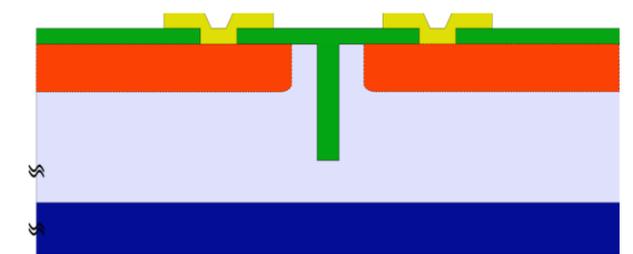
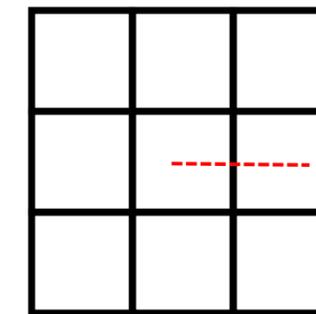
Nominal no-gain width

- $V1 < 1\mu\text{m}$
- $V2 < 3\mu\text{m}$
- $V3 < 4\mu\text{m}$
- $V4 < 5\mu\text{m}$

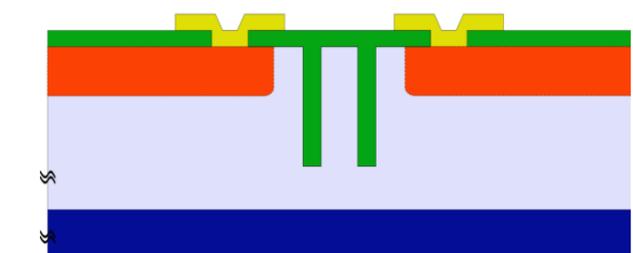
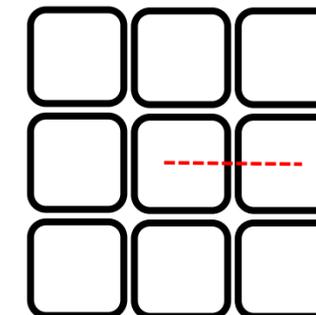
\* Referred to 1-trench version

### Number of trenches

➤ 1 Trench Layout (trench grid)



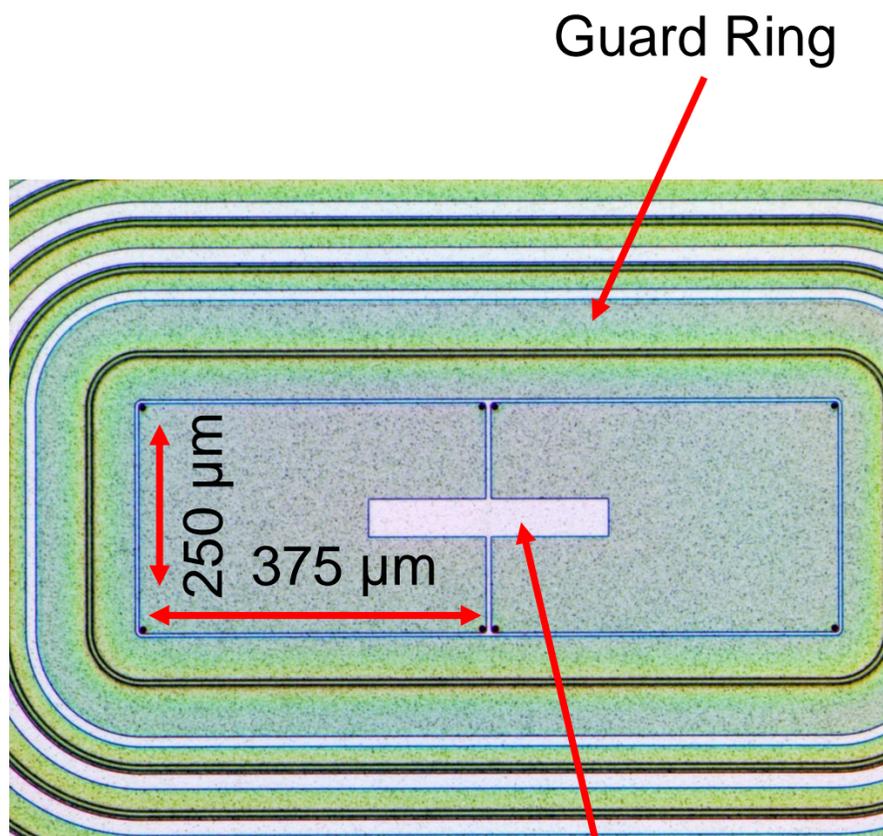
➤ 2 Trenches Layout



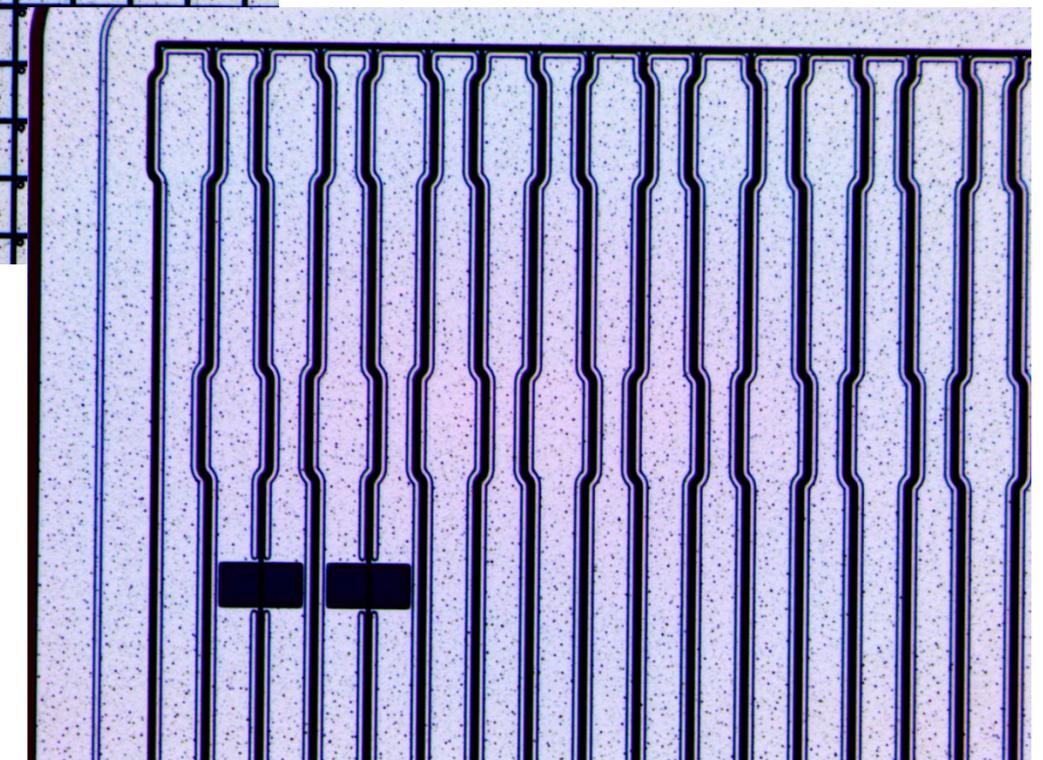
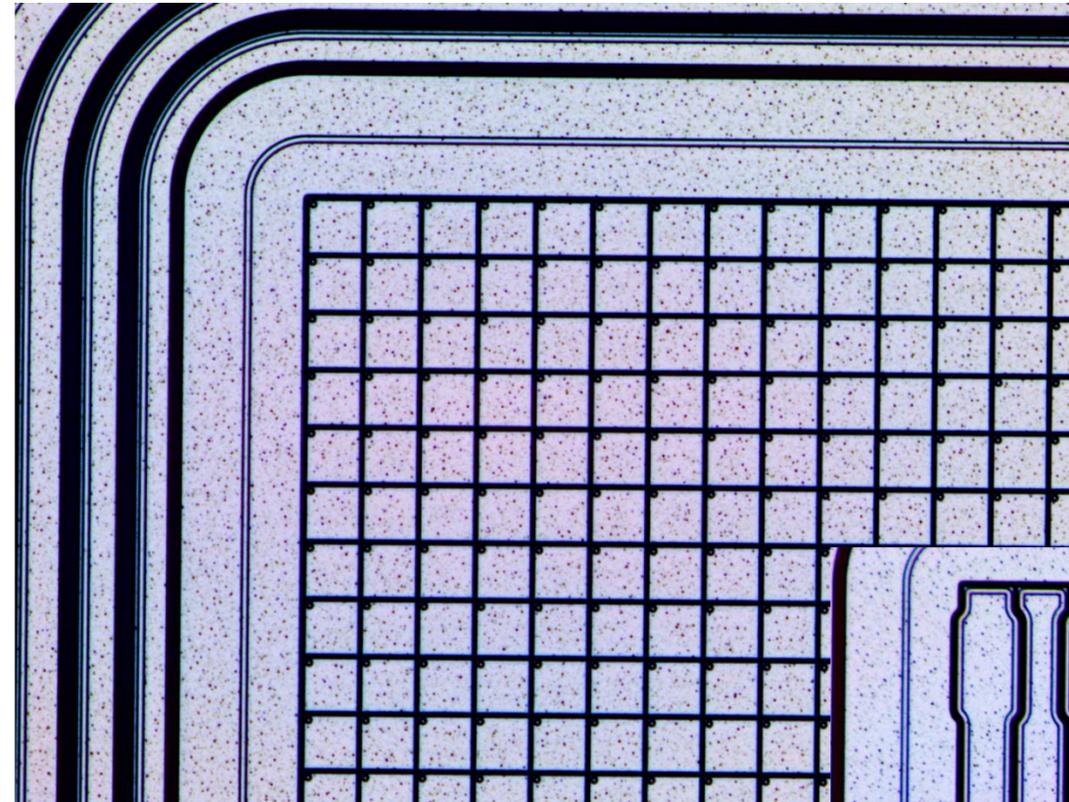
\* 2-trenches version has wider no-gain region

# TI-LGAD Production Batch: Layout & Technological splits

**2x1 pixels Test Structures**  
designed in more than 30  
flavors



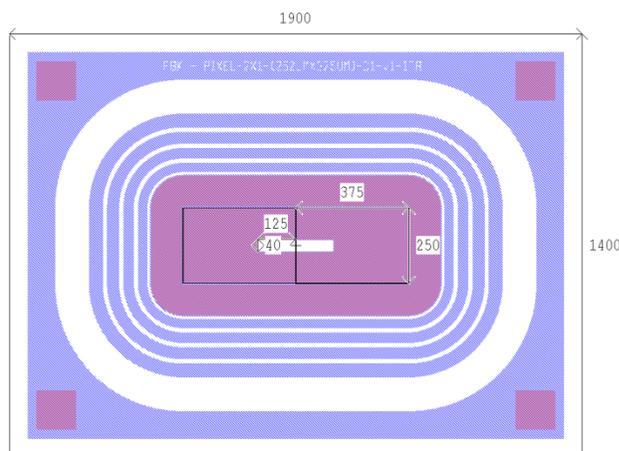
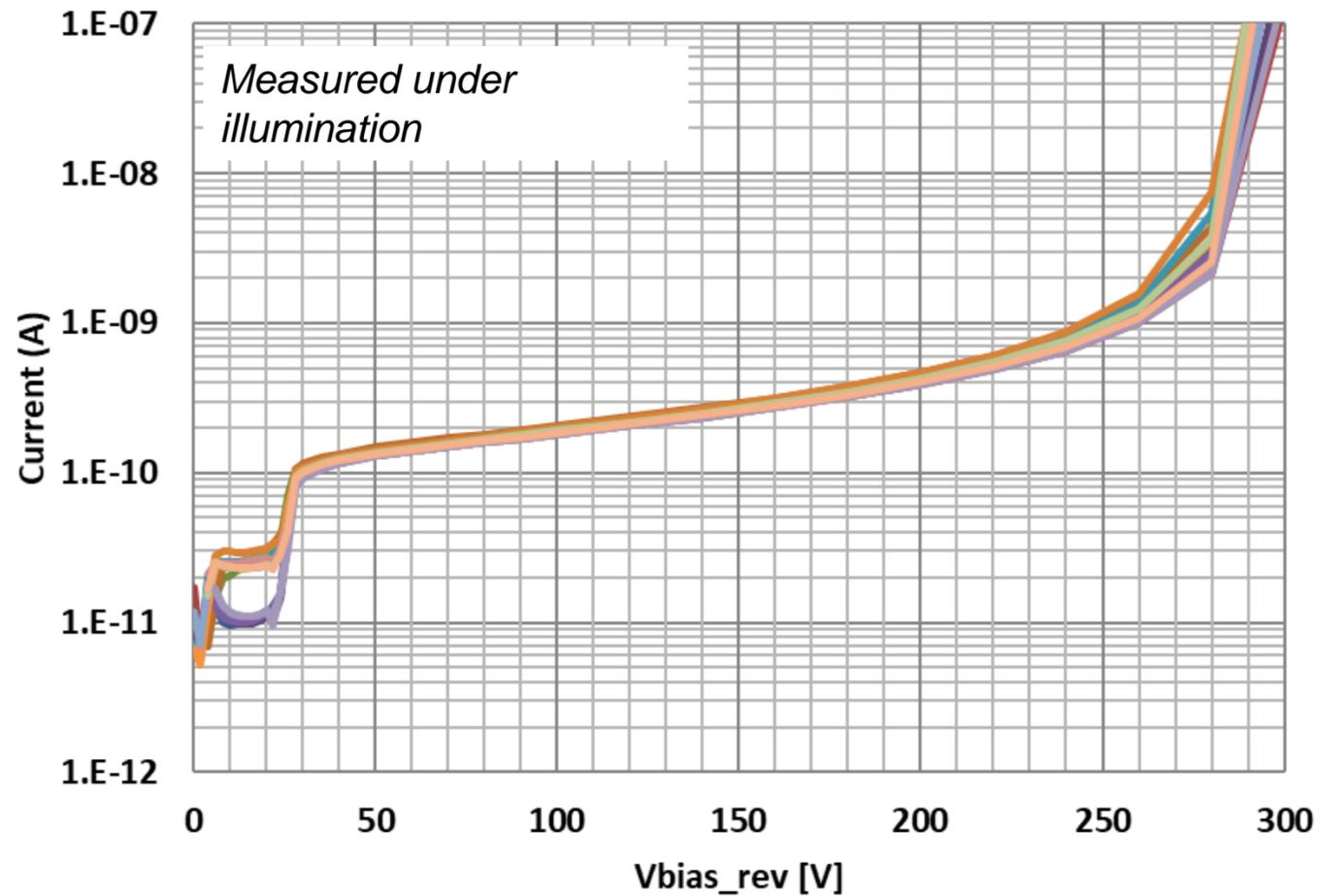
Optical Window for  
laser illumination



	Nominal FF
Pixel 55 μm	87%
Pixel 50 μm	86%
Strip 50 μm	93%

# TI-LGAD Production Batch: Electrical characterization

Automatic IV - W1 - 2x1



2x1 pixels

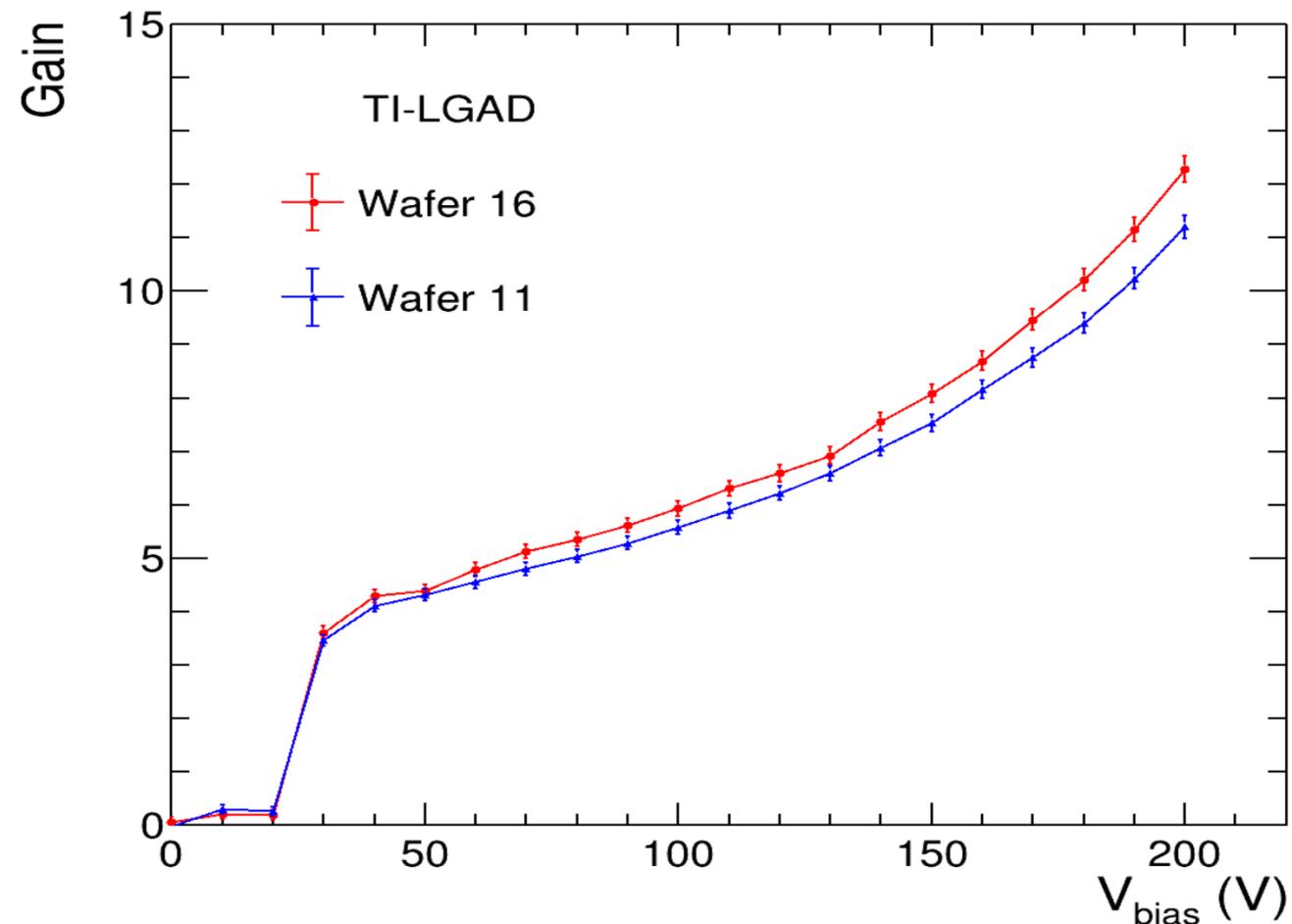
## Automatic IV characterization

- Wafer 1
- 2x1 pixels devices
- Measurements with light
- > 500 device/wafer measured
- All layout version together

## Results

- IV curves show expected behavior for LGADs
- Layer Depletion Voltage at ~ 25 V
- Breakdown > 250 V (it depends on PGAIN dose)
- Same breakdown for all border versions (gain Breakdown, no premature breakdown for any split)
- > 500 samples/wafer **yield >98%** (but it is small area detector)

# TI-LGAD Production Batch: Electrical characterization

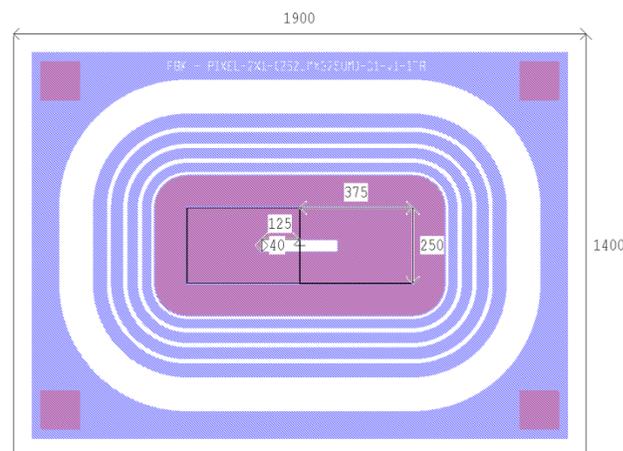


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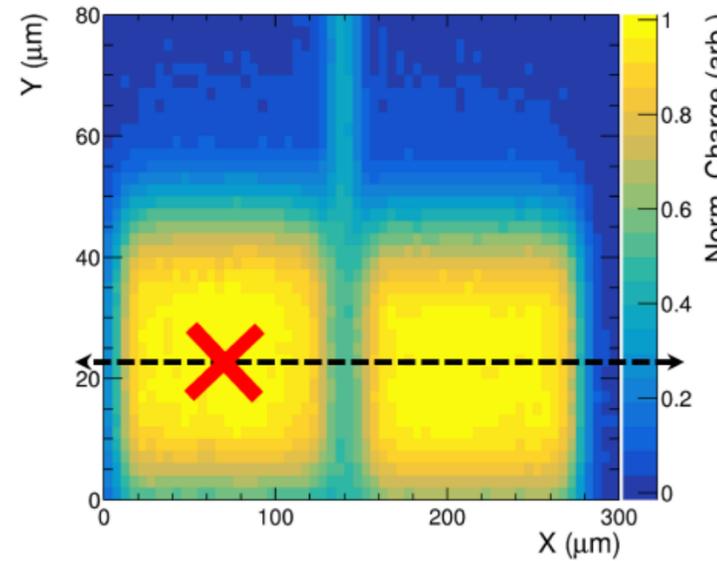


2x1 pixels

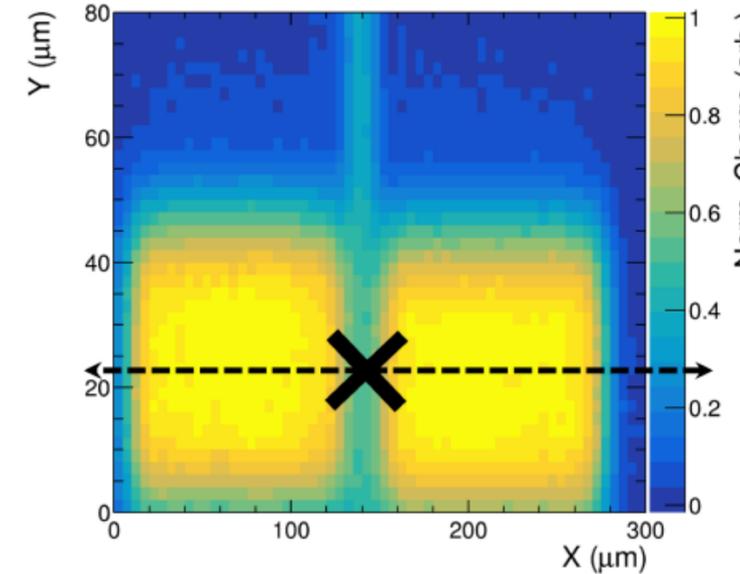
# Ti-LGAD Production Batch: Pixel isolation

- Ti-LGAD (2 x 1) with optical window for laser testing
- Laser is scanned through the pixels
- Signals from both pixels is shown.

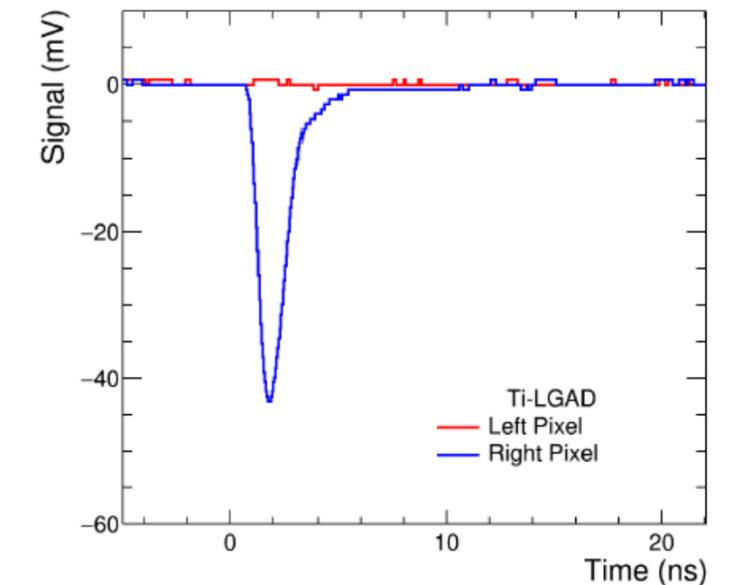
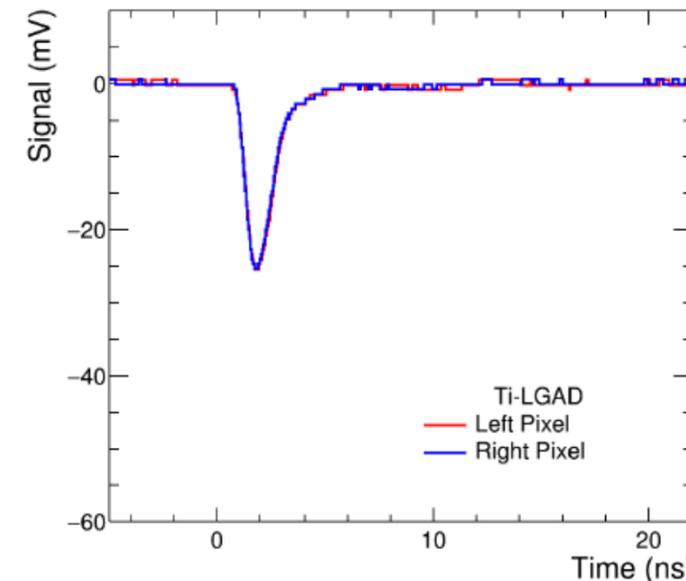
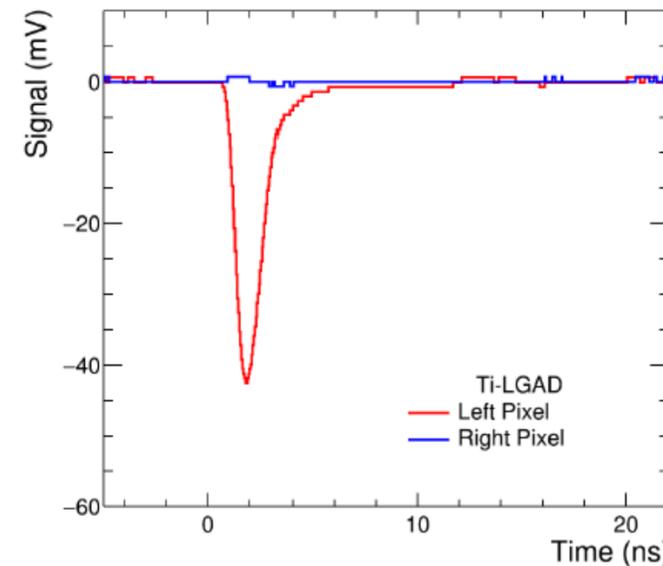
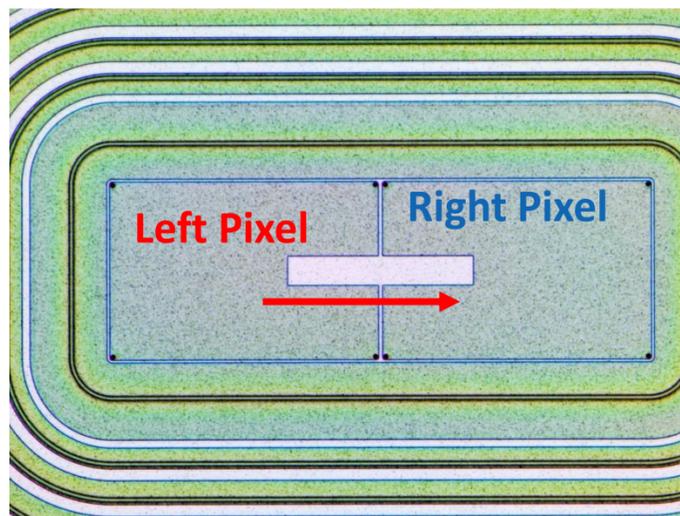
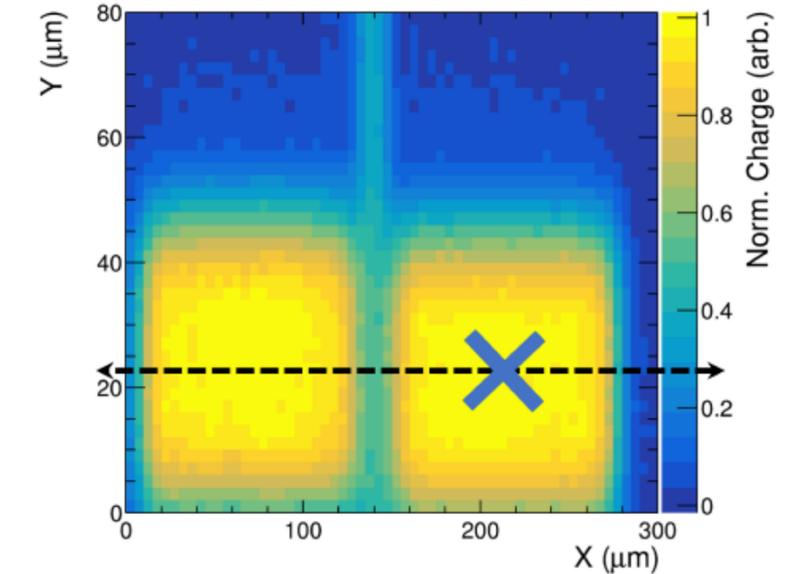
Shoot **Left Pixel**



Shoot **Center**



Shoot **Right Pixel**

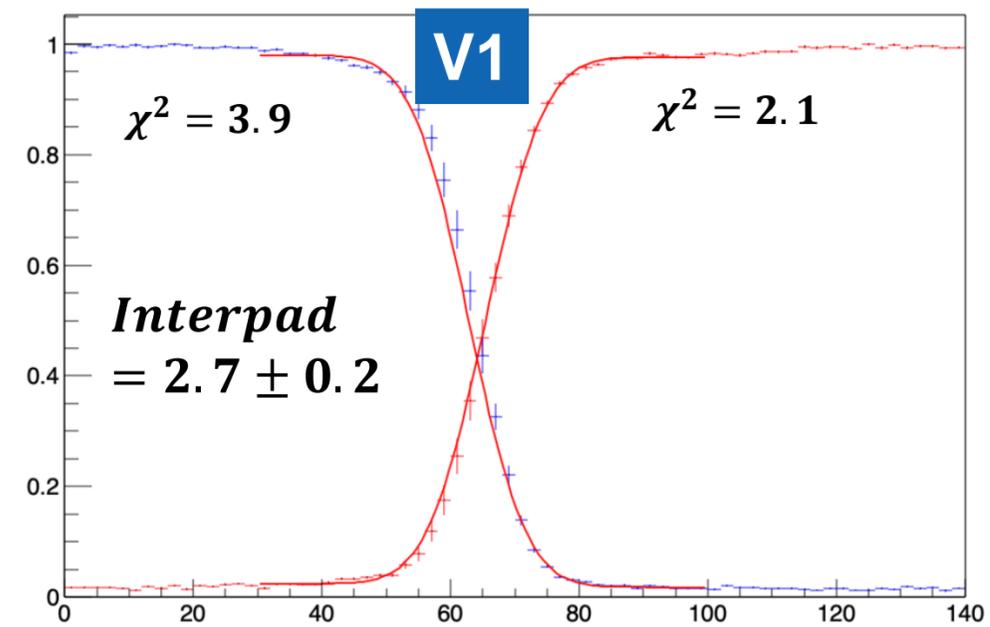
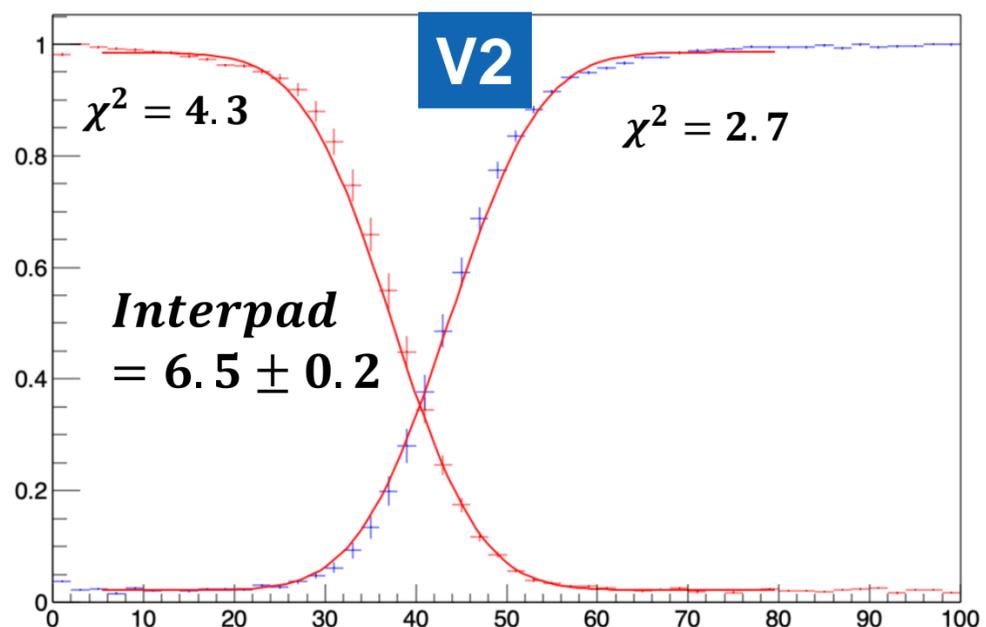
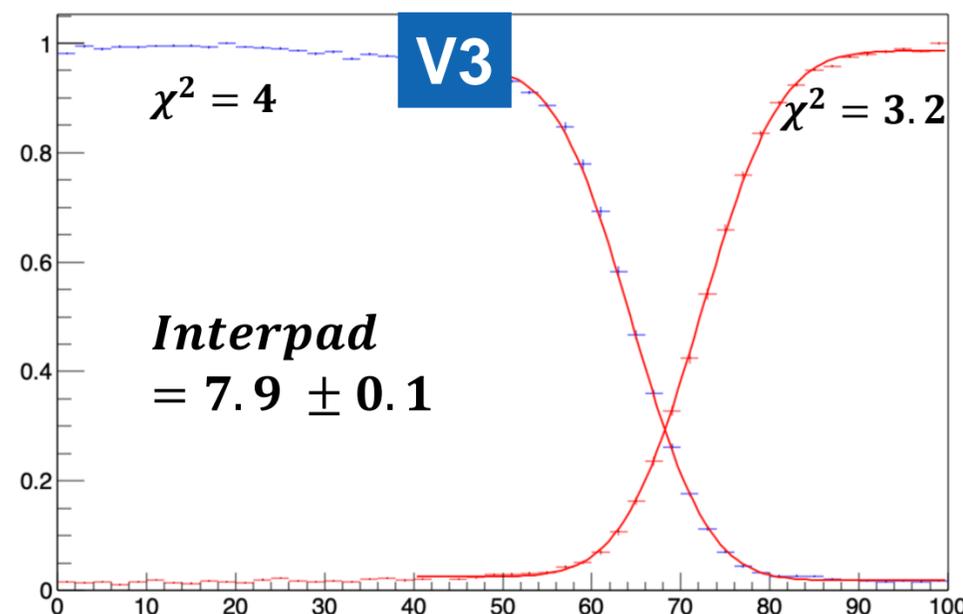
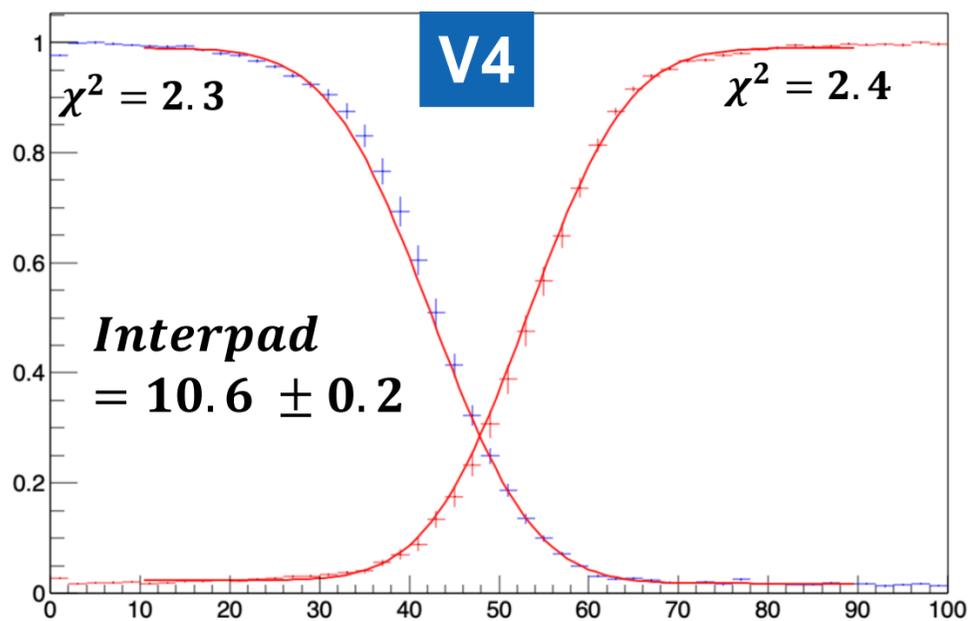


**Good pixel isolation**

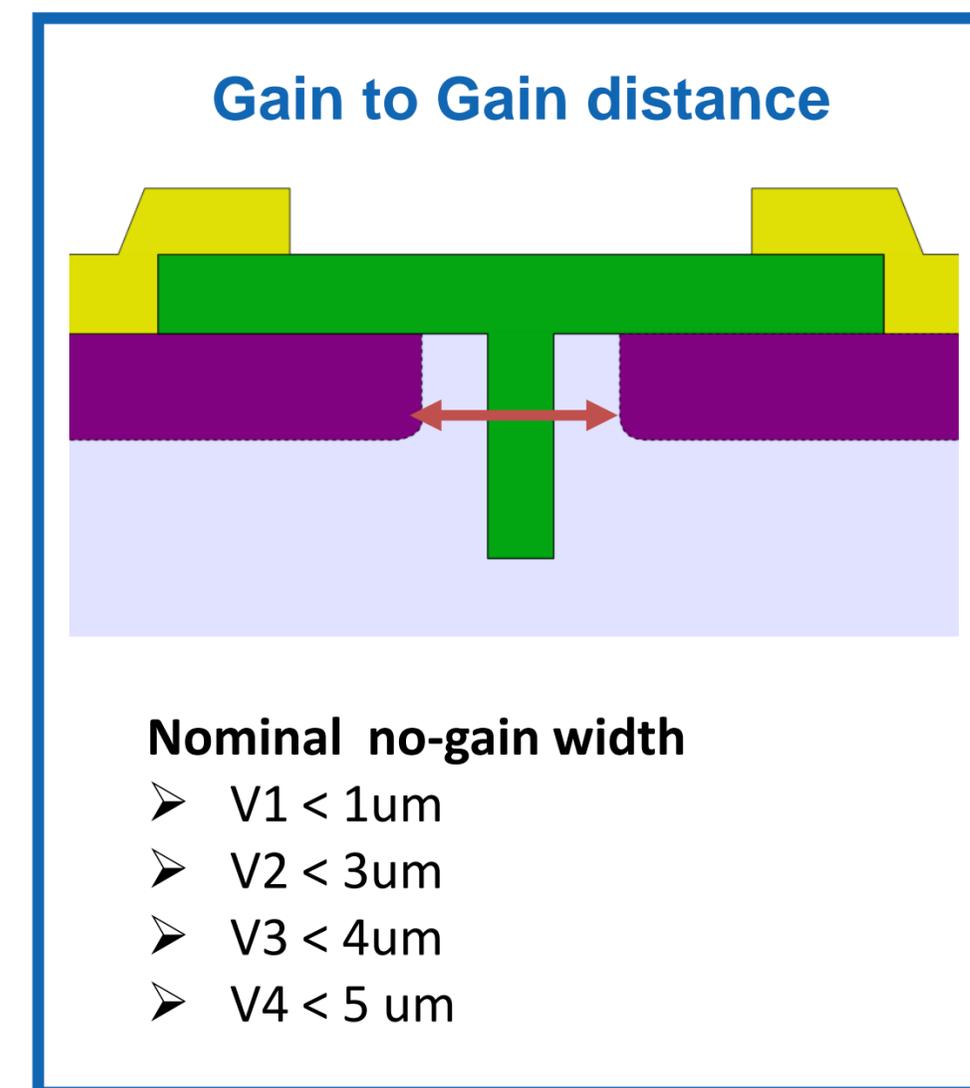
# TI-LGAD Production Batch: InterPad characterization

Structure: 2x1 pixel - C1 – 1 TR From Wafer 1

Measured at INFN TO  
(courtesy of M. Ferrero)



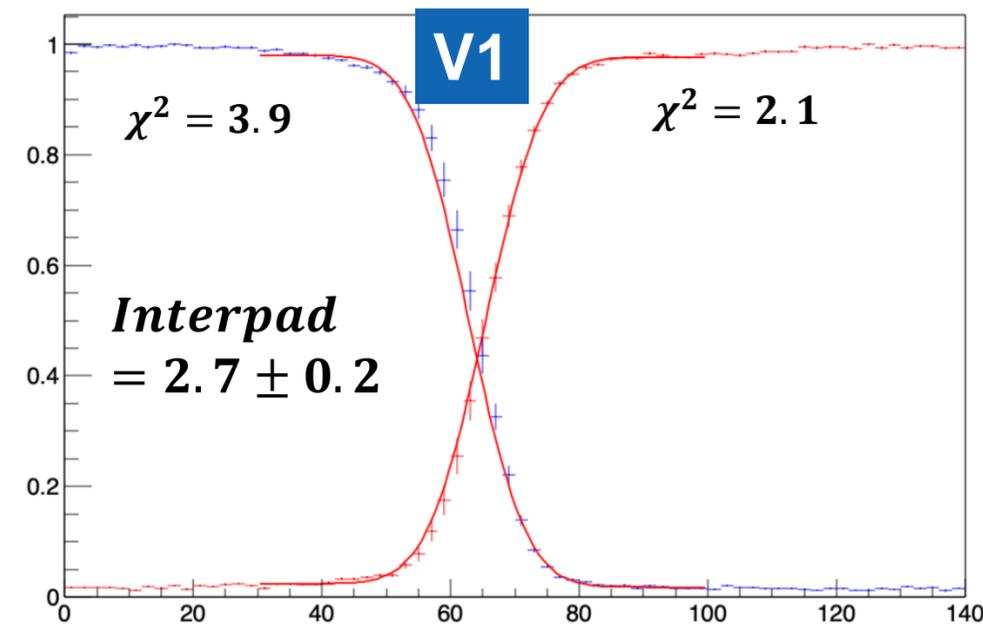
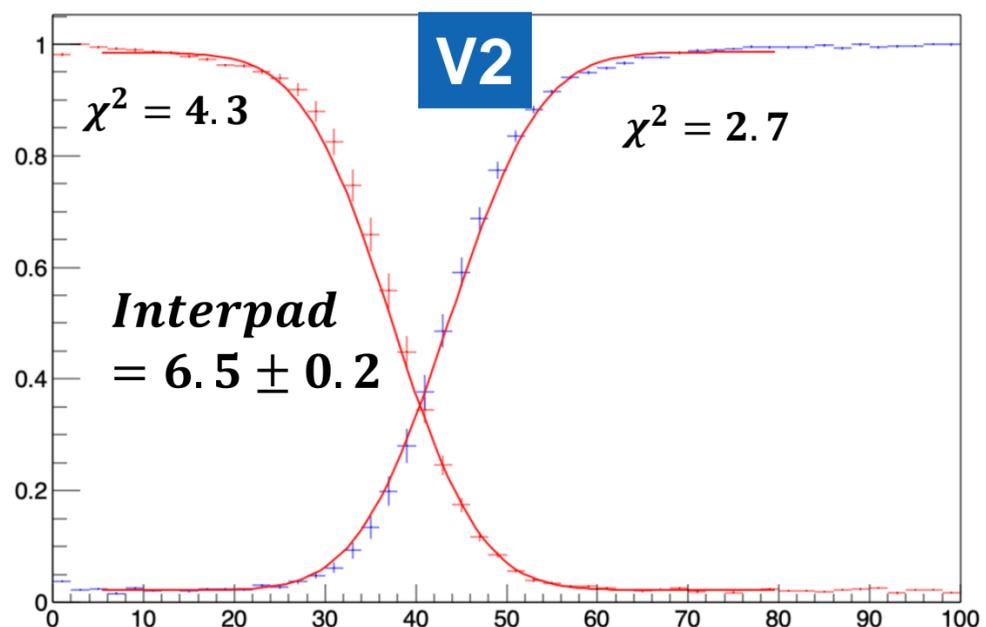
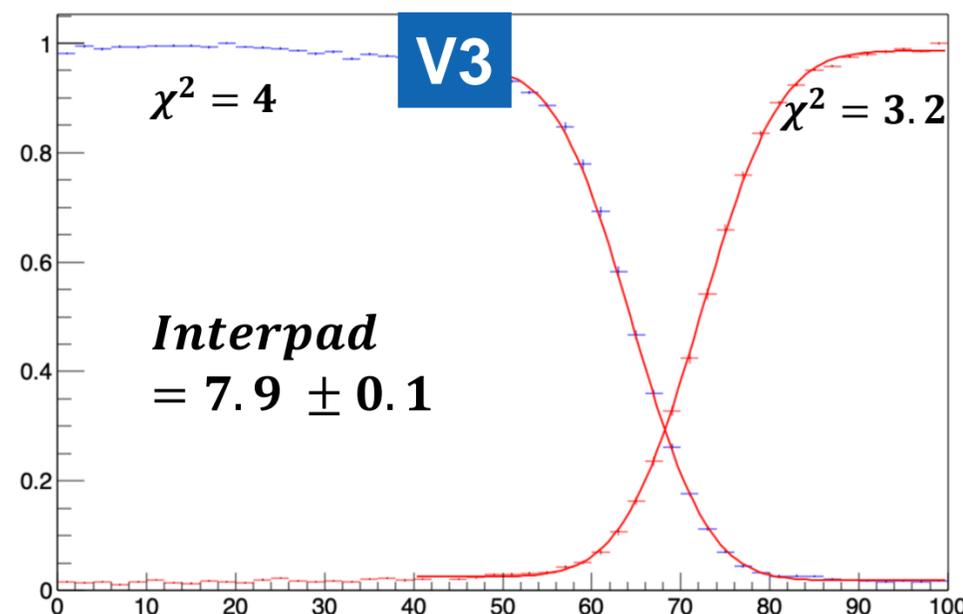
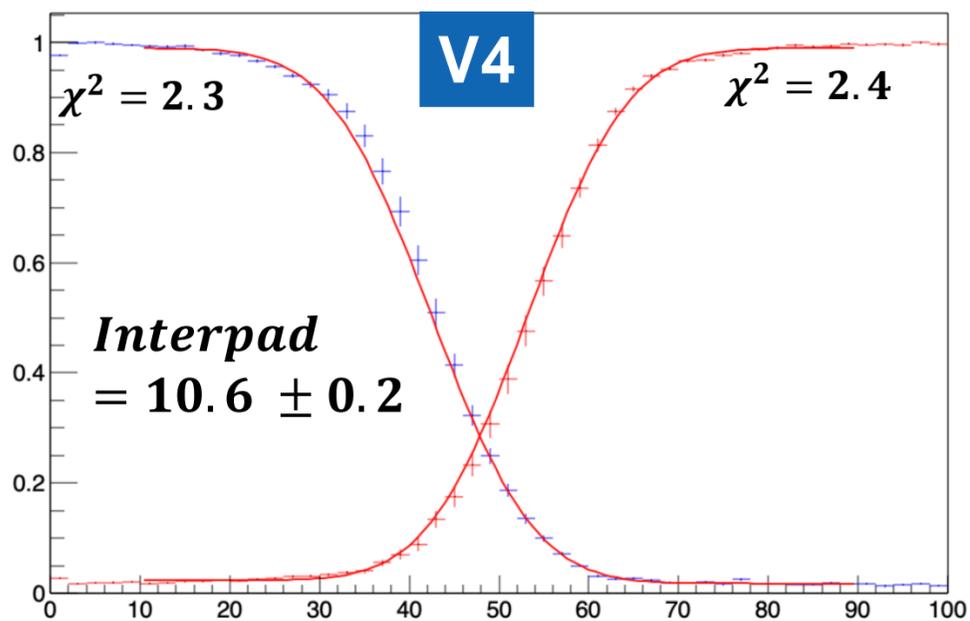
Wafer n.	Trench Depth	PGAIN dose	Diffusion	Trench Process
1	D2	B	HD	P1



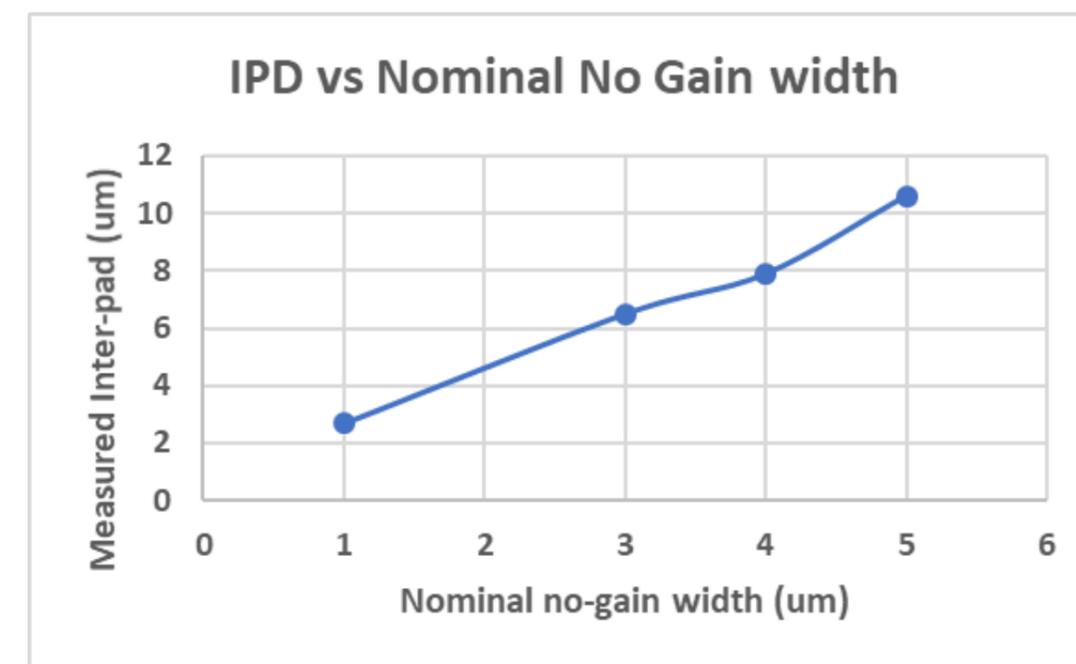
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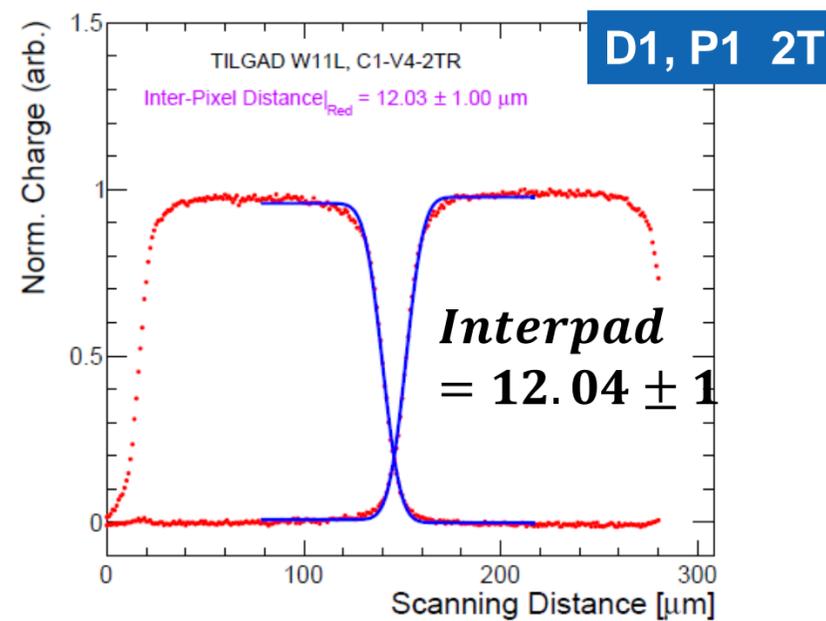
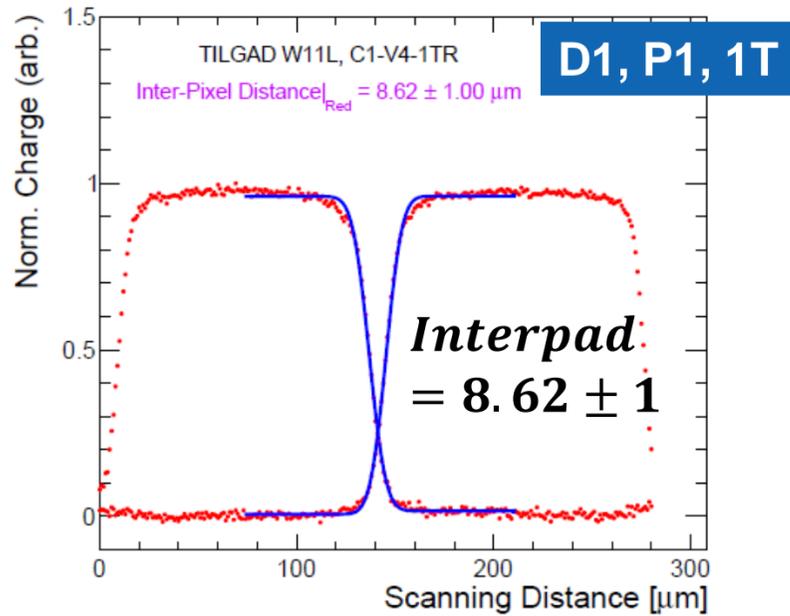
Version	Nomina no-gain Width	Measured IPD
V1	~ 1 $\mu\text{m}$	$2.7 \pm 0.2$
V2	~ 3 $\mu\text{m}$	$6.5 \pm 0.2$
V3	~ 4 $\mu\text{m}$	$7.9 \pm 0.1$
V4	~ 5 $\mu\text{m}$	$10.6 \pm 0.2$



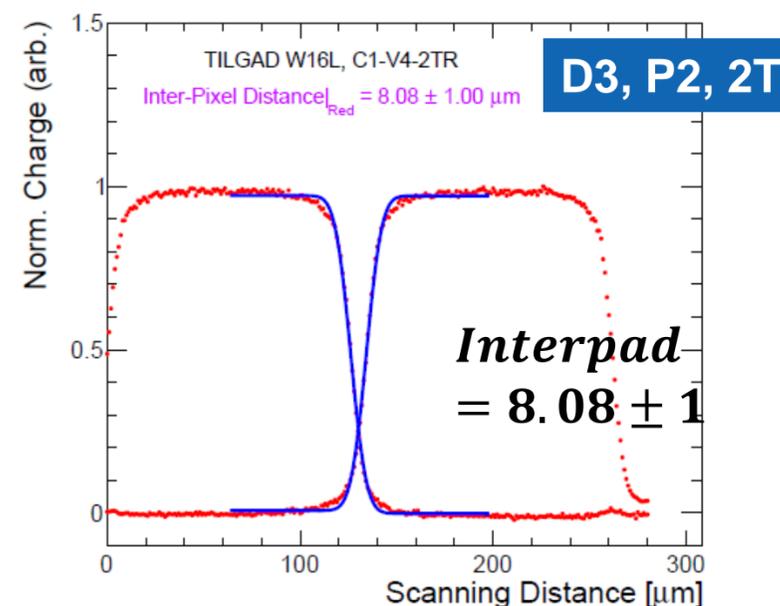
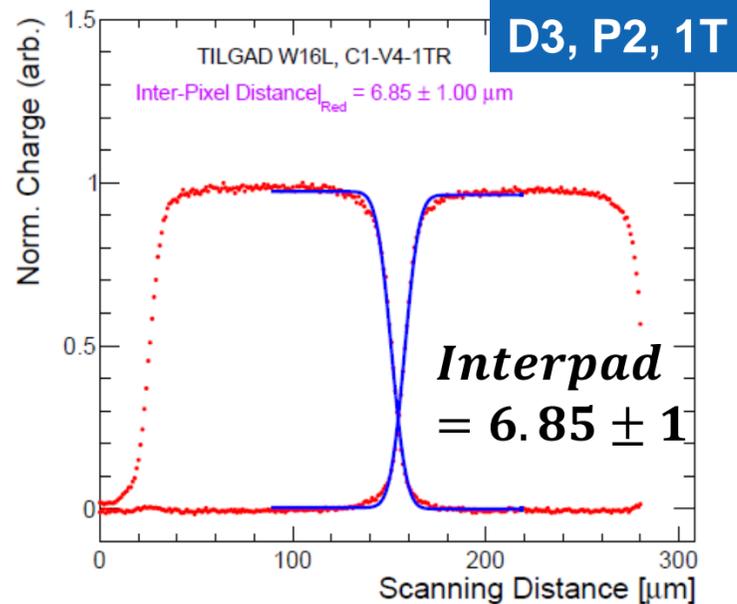
# TI-LGAD Production Batch: InterPad characterization

A. Bisht, NSS-MIC, 2021

1 Trench -> 2 Trenches



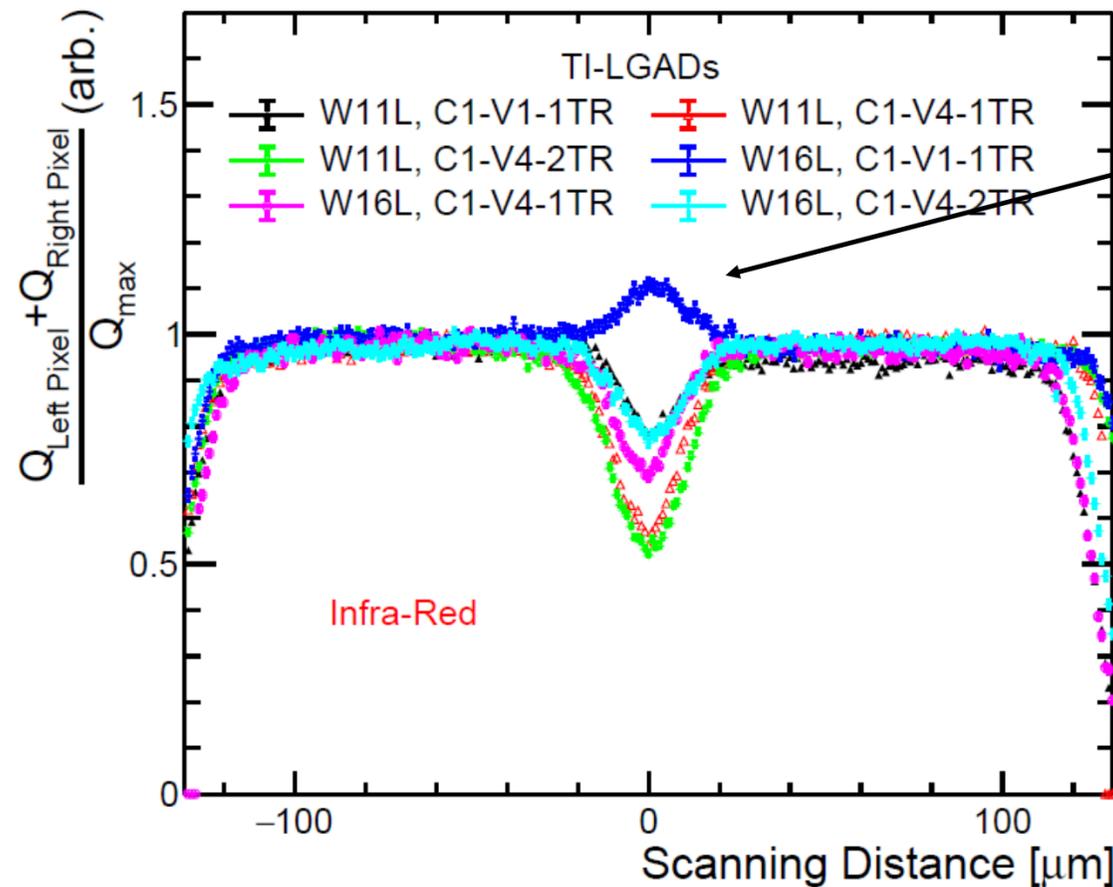
Deeper trench, P1->P2



Structure: 2x1 pixel - C1 – V4

- Inter-pad decreases by increasing the trench depth
- Inter-pad increases by moving from 1 to 2 trenches

# TI-LGAD Production Batch: InterPad characterization

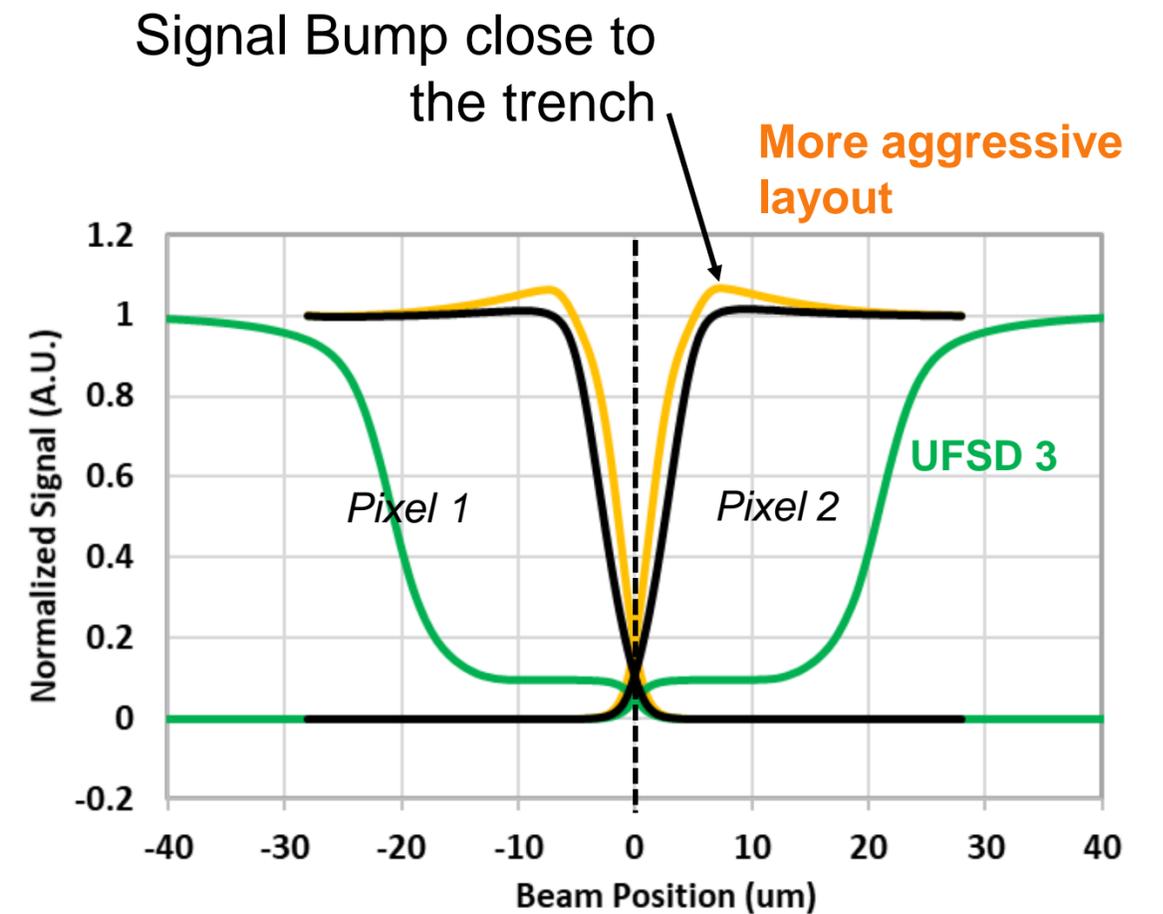


Most aggressive layout  
V1, 1Tr, D3, P2

Higher gain in trench  
region artificially  
reduces IPD.

Design optimization  
trade-off between **minimization of the gain-loss  
region** and **reduction of E-field at the border.**

## Simulations



# TI-LGAD Project: Ongoing and next activities

More than 500 samples have been shipped to all the partner institutes

## *Some (not exhaustive list) ongoing activities...*

Fondazione Bruno Kessler	<b>I-V and IPD</b> with TCT setup of different layout and technology splits to optimize the technology.
INFN Torino	<b>I-V and TCT</b> characterization of the inter-gap; resilience to floating pads; <b>irradiation</b> campaign is ongoing
University of Zurich	<b>testing with TCT setup</b> , <b>timing</b> in pre-irradiated devices, <b>irradiation campaign</b> , <b>bonding to Medipix3</b>
Paul Scherrer Institut	TI-LGADs strips wire-bonded to <b>PSI photon-counting and charge-integrating readout chips</b> . They will be tested (and scanned) using X-rays ( <b>and soft X-rays</b> )
UC Santa Cruz	<b>testing with TCT setup</b> . The sensors are under testing for a possible use in the <b>PIONEER</b> experiment
Hamburg University	<b>I-V /C-V characterization</b> , <b>timing</b> measurements with beta-setup. It is planned to test TI-LGADs with <b>Timepix3</b> .
Nikhef	characterisation of the test structure is started ( <b>C/V and laser characterization</b> ) in preparation of tests with the 55 um pitch matrices on <b>Timepix4 ASICs</b> .

# Conclusions

- **The TI-LGAD Project** aimed at developing highly segmented LGADs with small pixels (down to 50  $\mu\text{m}$ ) and high FF ( $>80\%$ )
- **One batch** was produced with multiple layout and technological splits
- First measurements show **good electrical behavior** (no premature BD) for all the splits
- TCT laser setup was used to measure the inter-pad distance. The value depends on the layout and **IPD down to 3-5  $\mu\text{m}$**  have been measured
- Many test structures and **segmented sensors**, compatible with different chips, have been distributed **to several institutes for characterization**. Measurements are ongoing

# Thank you for your attention

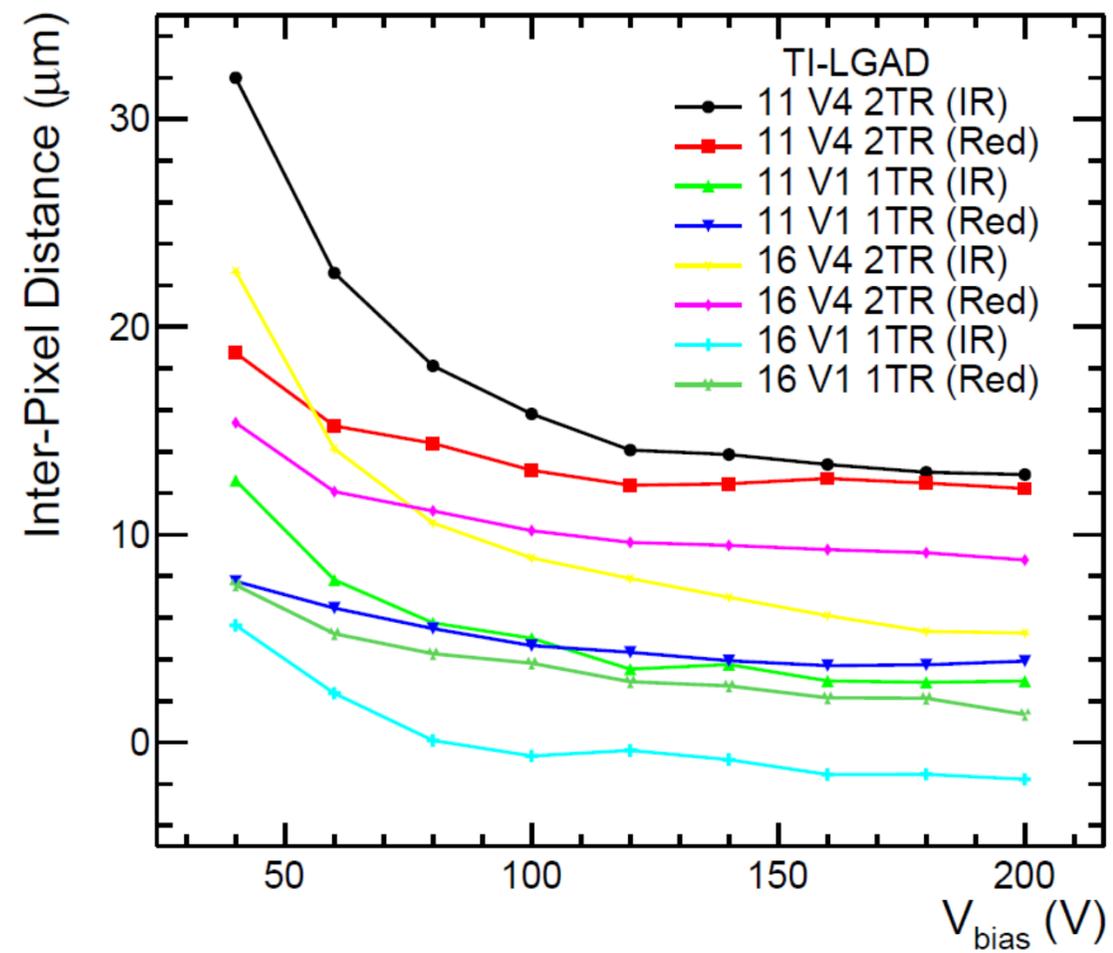
## Acknowledgements

- Part of the work has been performed in the framework of RD50
- Thanks to all the partners of the project:



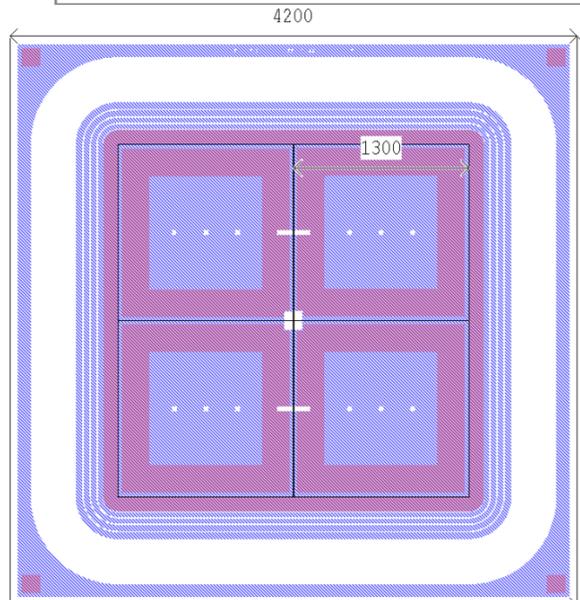
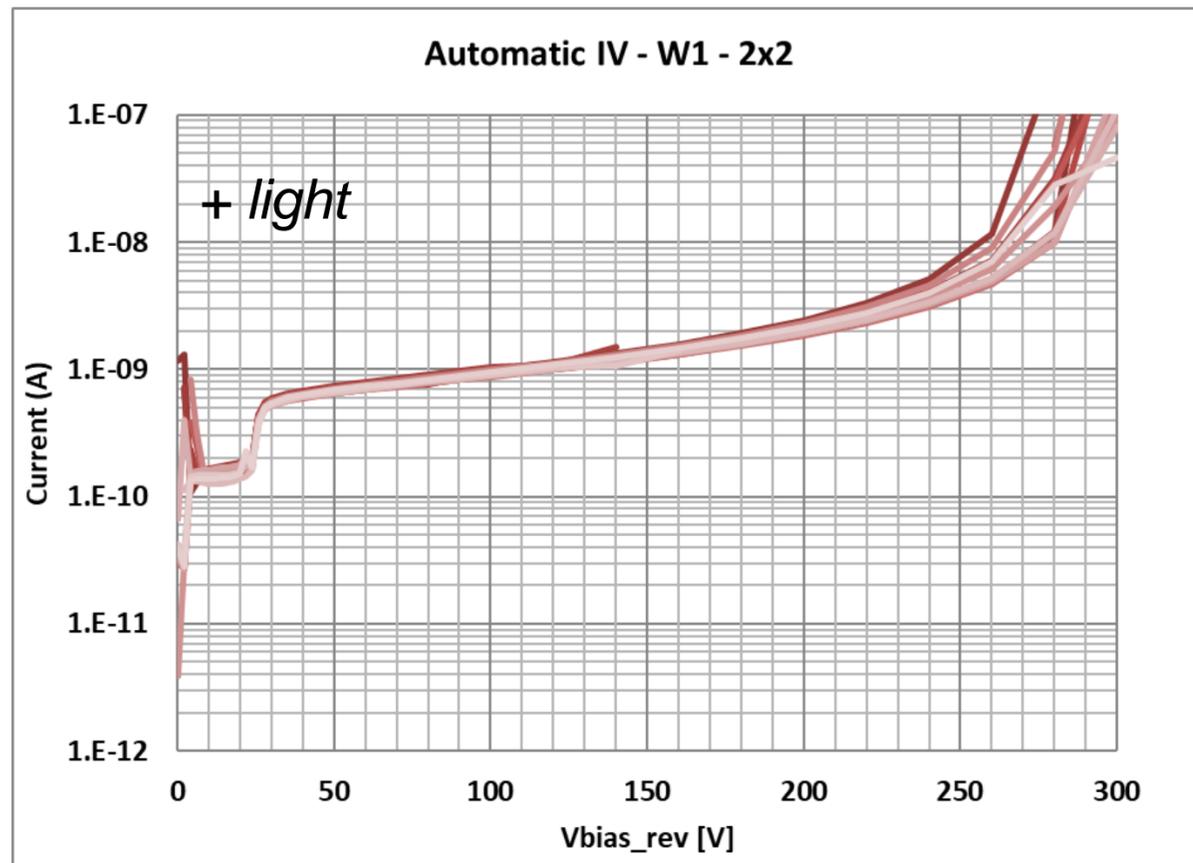
# Backup

Comparison of Trench Depth



# TI-LGAD Production Batch: Electrical characterization

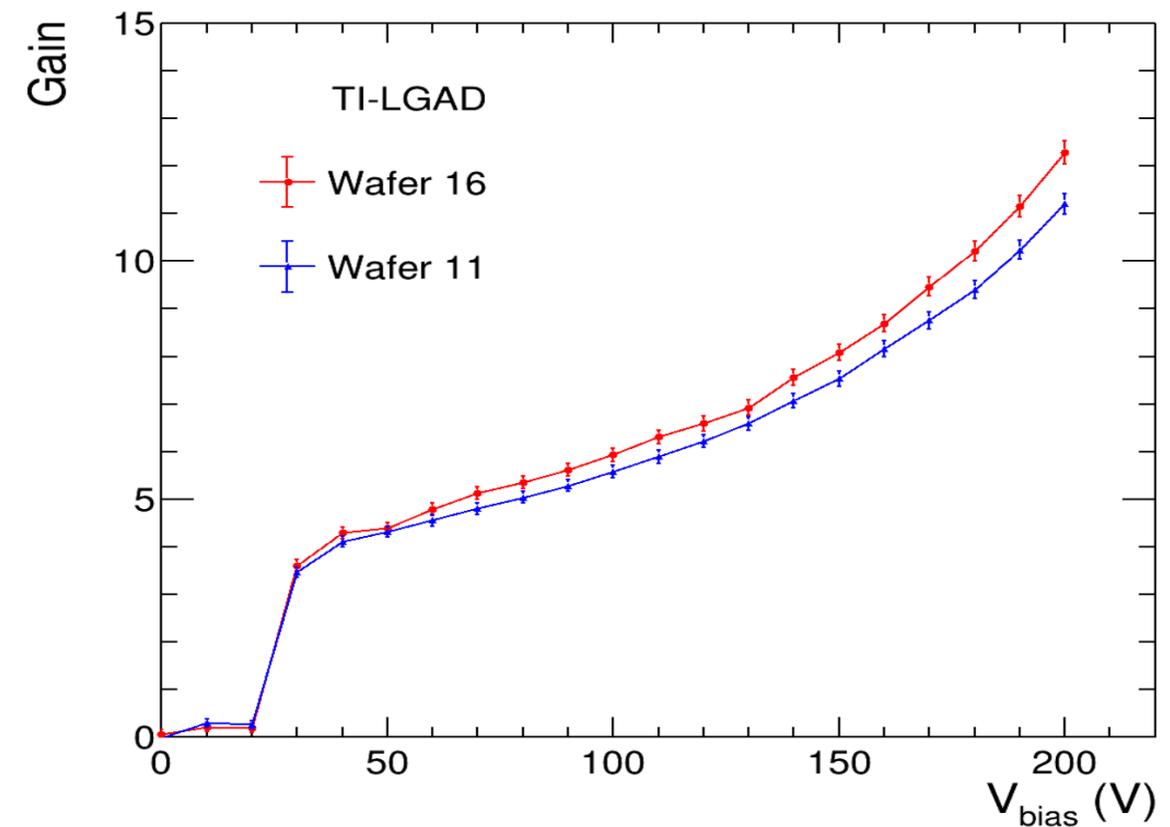
## Automatic IV characterization



Dark current  $\sim 10$  pA/mm<sup>2</sup>

2x2 pixels  
1.3 mm<sup>2</sup> pixels  
ATLAS/CMS Timing Layer

## GAIN



- TCT Setup with IR Laser
- 200V and RT
- $$Gain = \frac{Q_{LGAD}}{Q_{PiN}}$$