Laboratory Measurements of FBK Trench-Isolated LGADs in Torino

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Outline

Extensive testing campaign of FBK TI-LGADs (see previous talk by G.Paternoster) in Torino:

- ❖ TCT characterization
  - ➢ Pads Isolation
  - ➢ Gain
  - ➢ Inactive area width (Interpad)
- ❖ Measurement with a β source setup
  - ➢ Comparison of measured signals with simulation predictions
  - ➢ Time resolution

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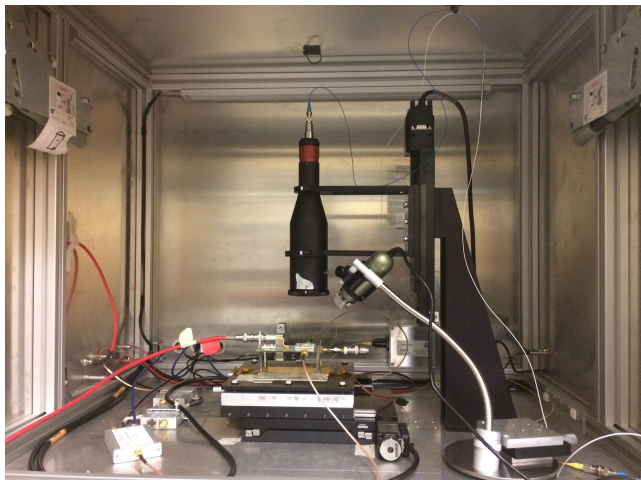 ➢ Time resolution
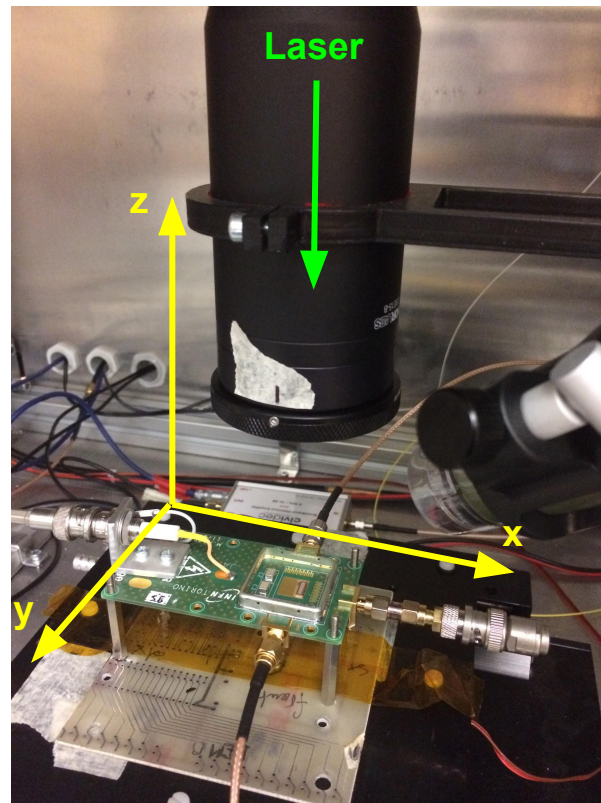
TCT
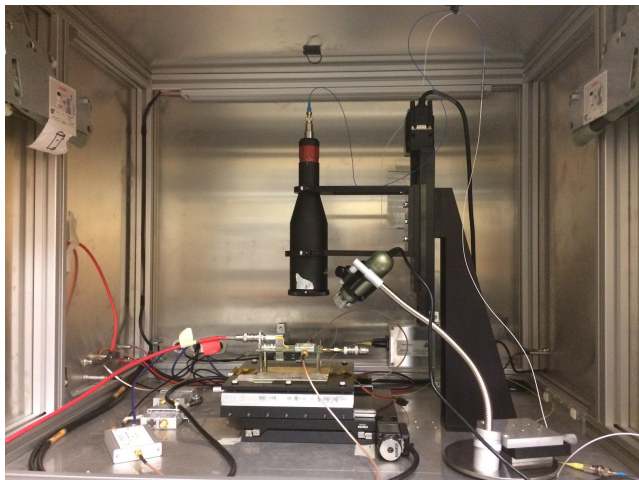
TCT Setup
in Torino

Particulars TCT setup:

TCT

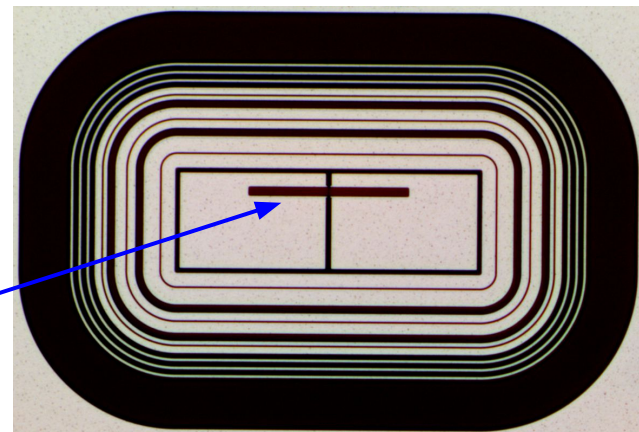*TCT Setup
in Torino*

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

TCT: Pads Isolation

- **2x1 TI-LGAD** with optical window for laser testing
- Shoot with laser on one pad to **prove it is isolated from the neighbouring one**
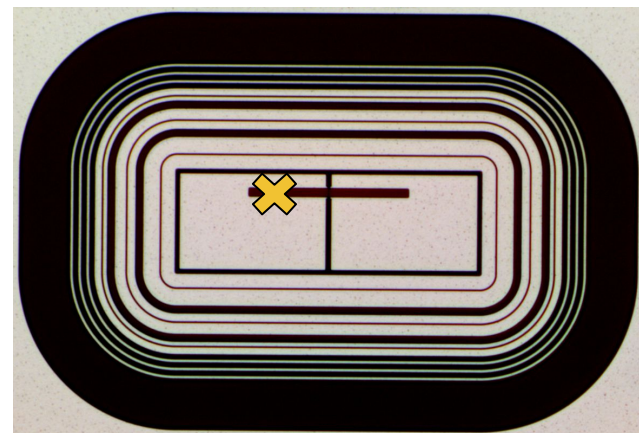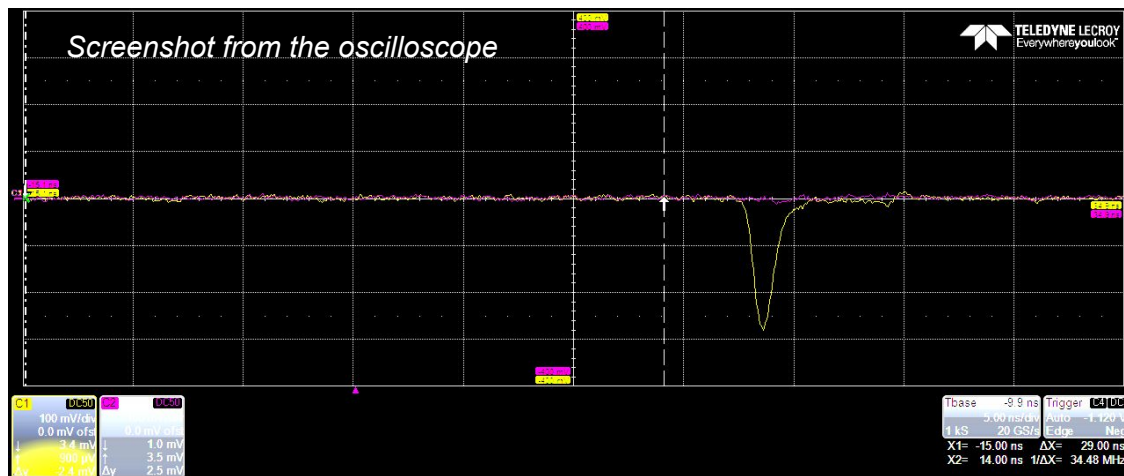- Both pads read-out, connected to an oscilloscope

optical window

2x1 FBK TI-LGAD

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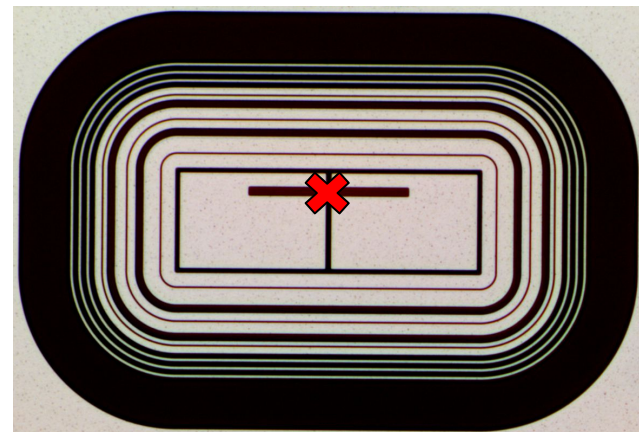- Both pads read-out, connected to an oscilloscope

2x1 FBK TI-LGAD

Shooting on Pad1 → no signal on Pad2

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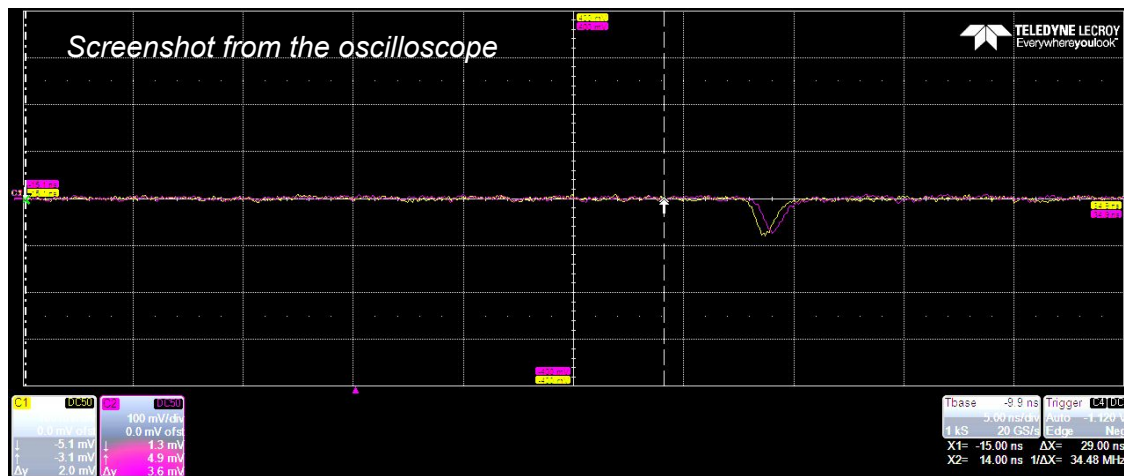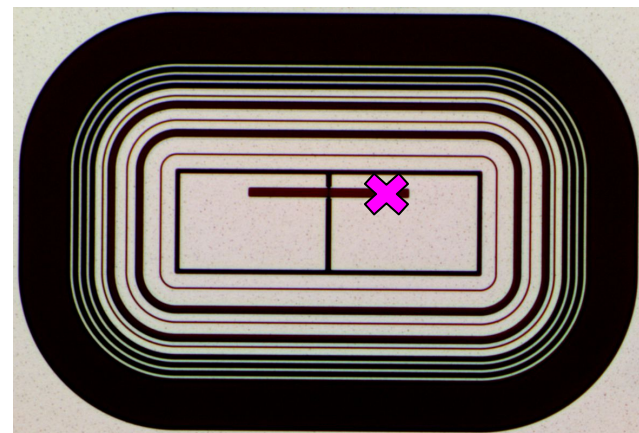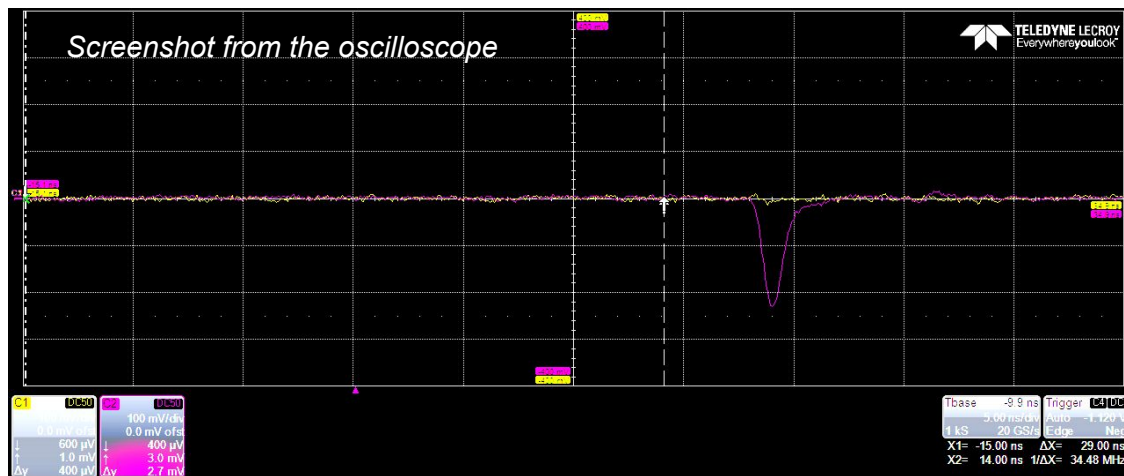- Both pads read-out, connected to an oscilloscope

2x1 FBK TI-LGAD

Shooting between pads

TCT: Pads Isolation

- **2x1 TI-LGAD** with optical window for laser testing
- Shoot with laser on one pad to **prove it is isolated from the neighbouring one**
- Both pads read-out, connected to an oscilloscope

2x1 FBK TI-LGAD

Shooting on **Pad2** → no signal on **Pad1**

TCT: Pads Isolation

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- Shoot with laser on one pad to **prove it is isolated from the neighbouring one**
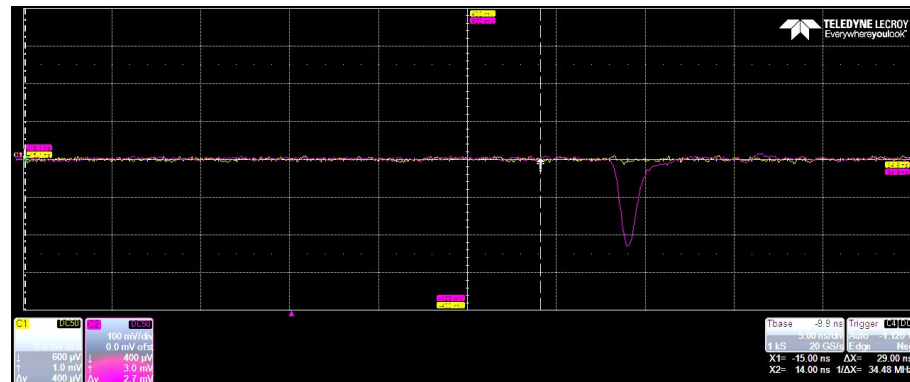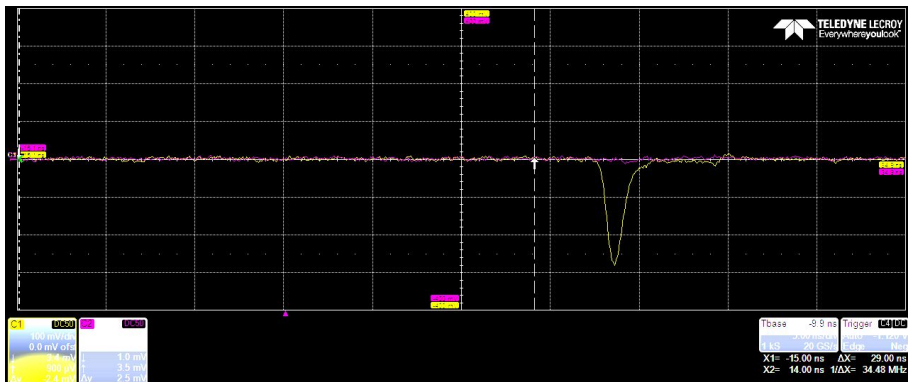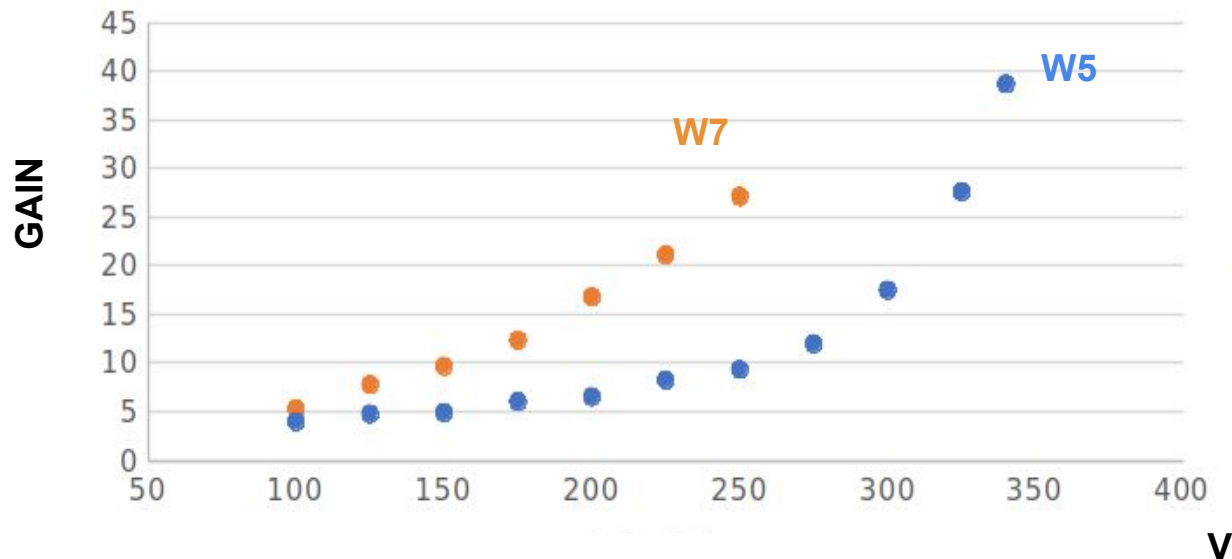- Both pads read-out, connected to an oscilloscope

➔ **Pads are well isolated by trenches**
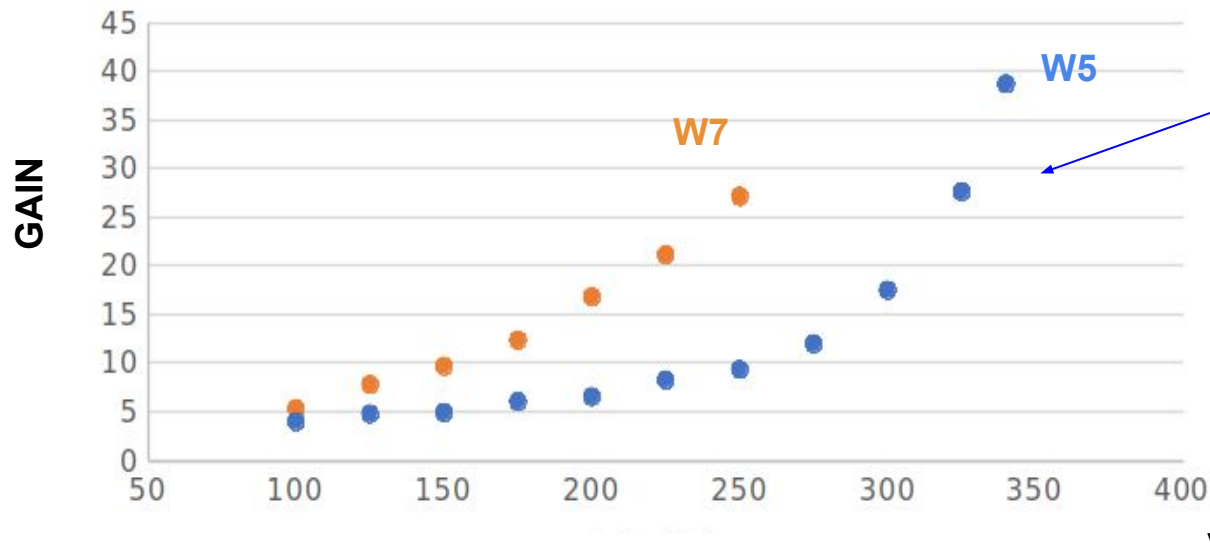➔ **Signals as those of standard LGADs**

TCT: Gain measurement

- Laser focused on the optical window of the device
- Laser intensity set to ~ 1 MIP
- Collected charge Q measured at each voltage for both LGAD & PiN → **GAIN = Q$_{LGAD}$ / Q$_{PiN}$**
- LGAD and PiN have the same geometry and termination structures

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Exponential trend as standard LGADs (as seen in IV characterization)

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W5

W7

GAIN

V
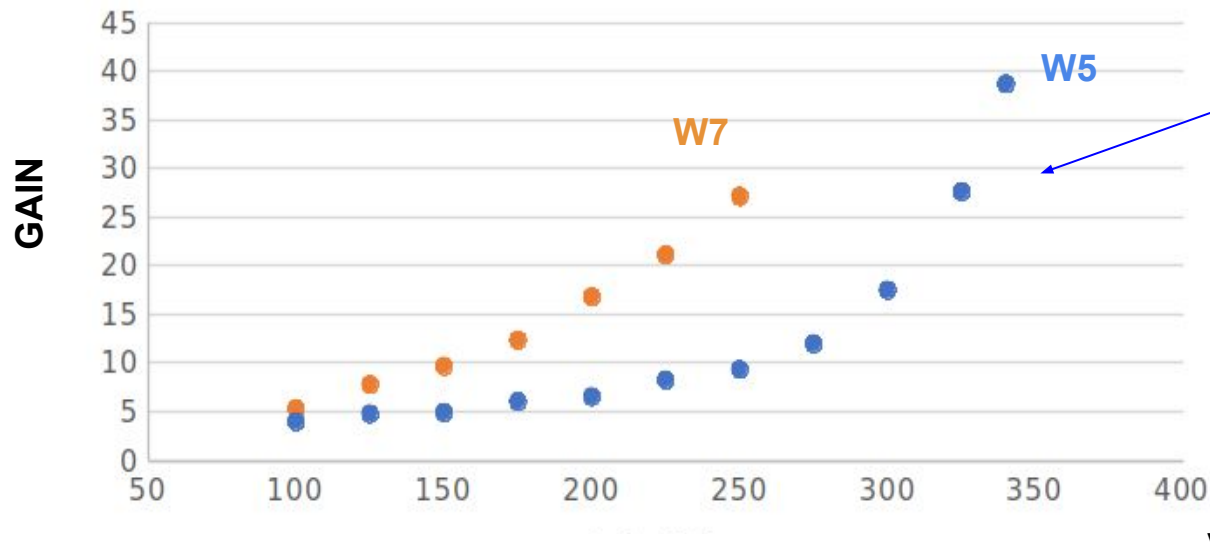
Exponential trend as standard LGADs
(as seen in IV characterization)

W7 more doped than W5 → steeper curve as expected

TCT: Interpad

- We measured the inactive area width of the tested sensors with the TCT
- **Get the width** by scanning two nearby pads → **charge vs position**

Charge

Position

Gaussian laser
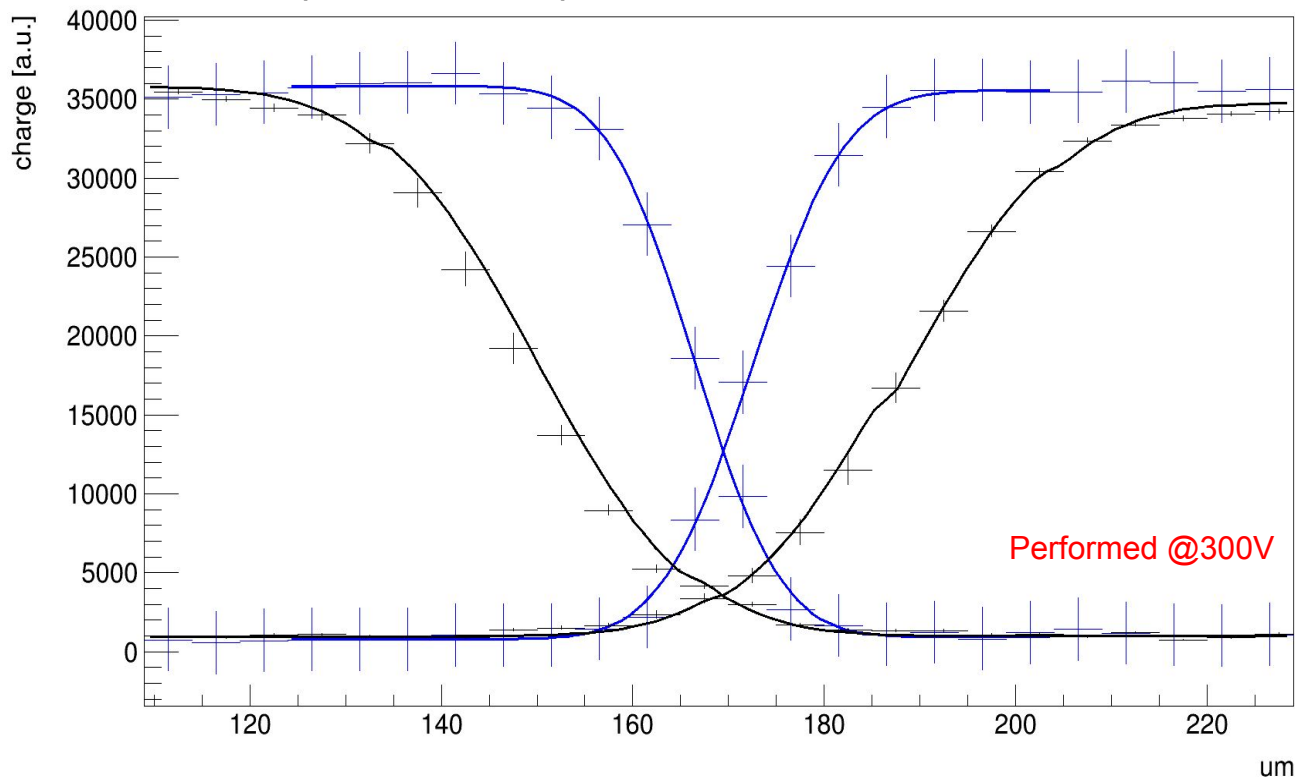
Width: distance between 50% of the s-curves
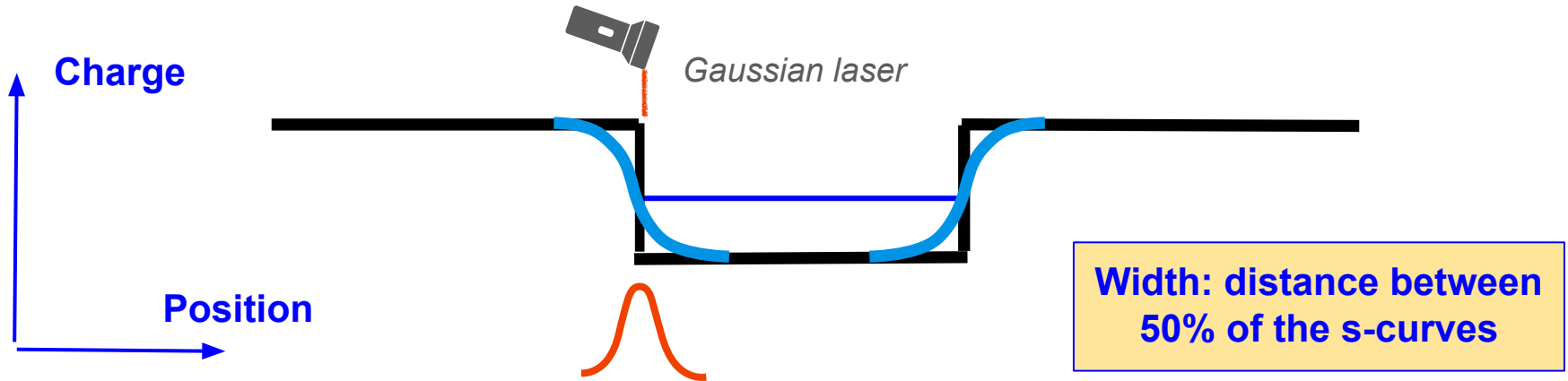
→ The profile is a convolution of the step function with a gaussian (= **s-curve**)

Interpad: TI vs standard LGAD

Comparison of FBK productions: UFSD3 vs Trench-Isolated

Performed @300V
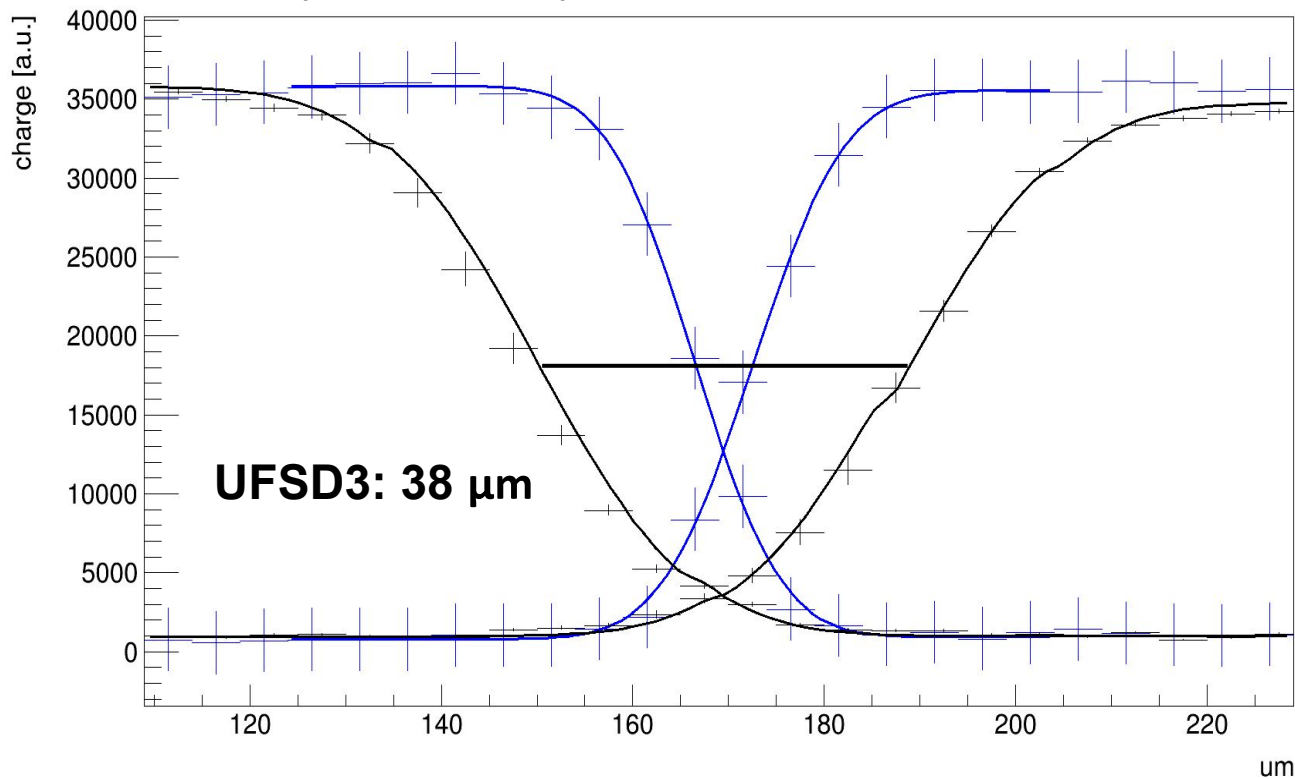
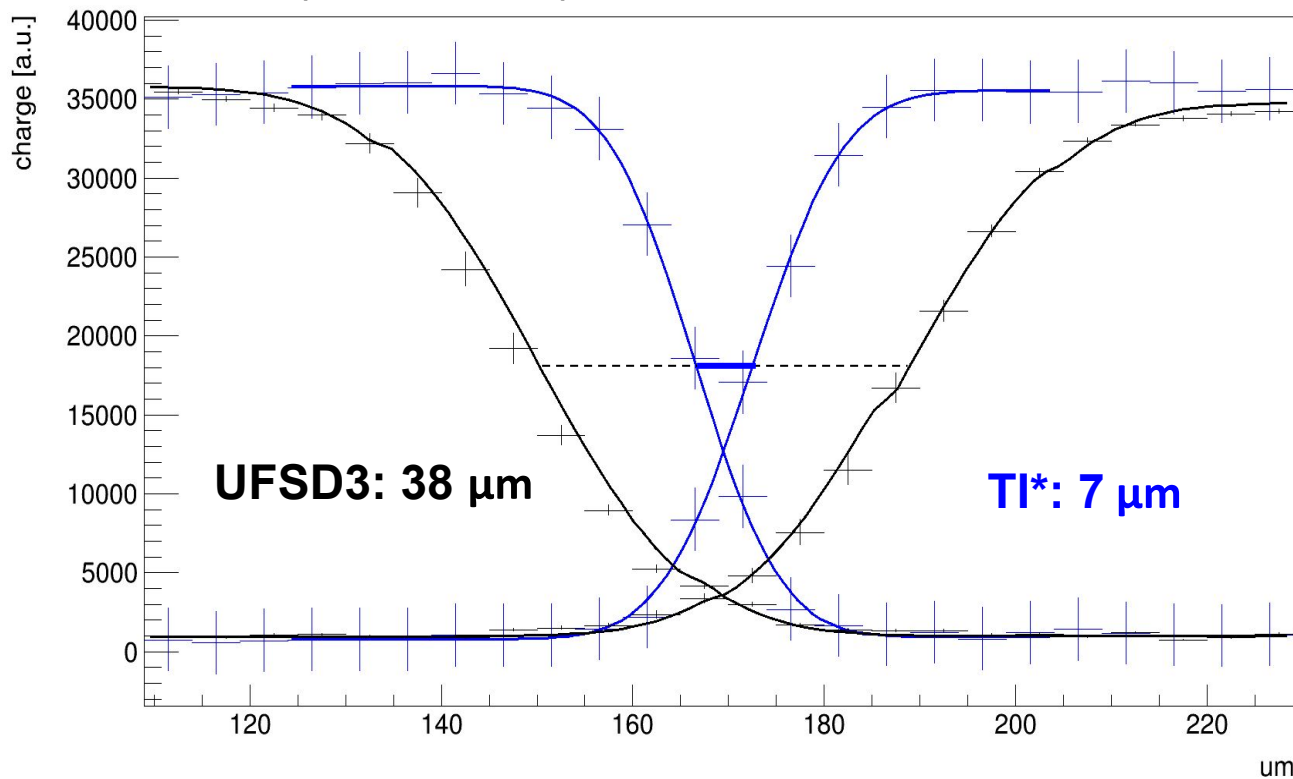# Interpad: TI vs standard LGAD

Comparison of FBK productions: UFSD3 vs Trench-Isolated

UFSD3: 38 μm

Interpad: TI vs standard LGAD

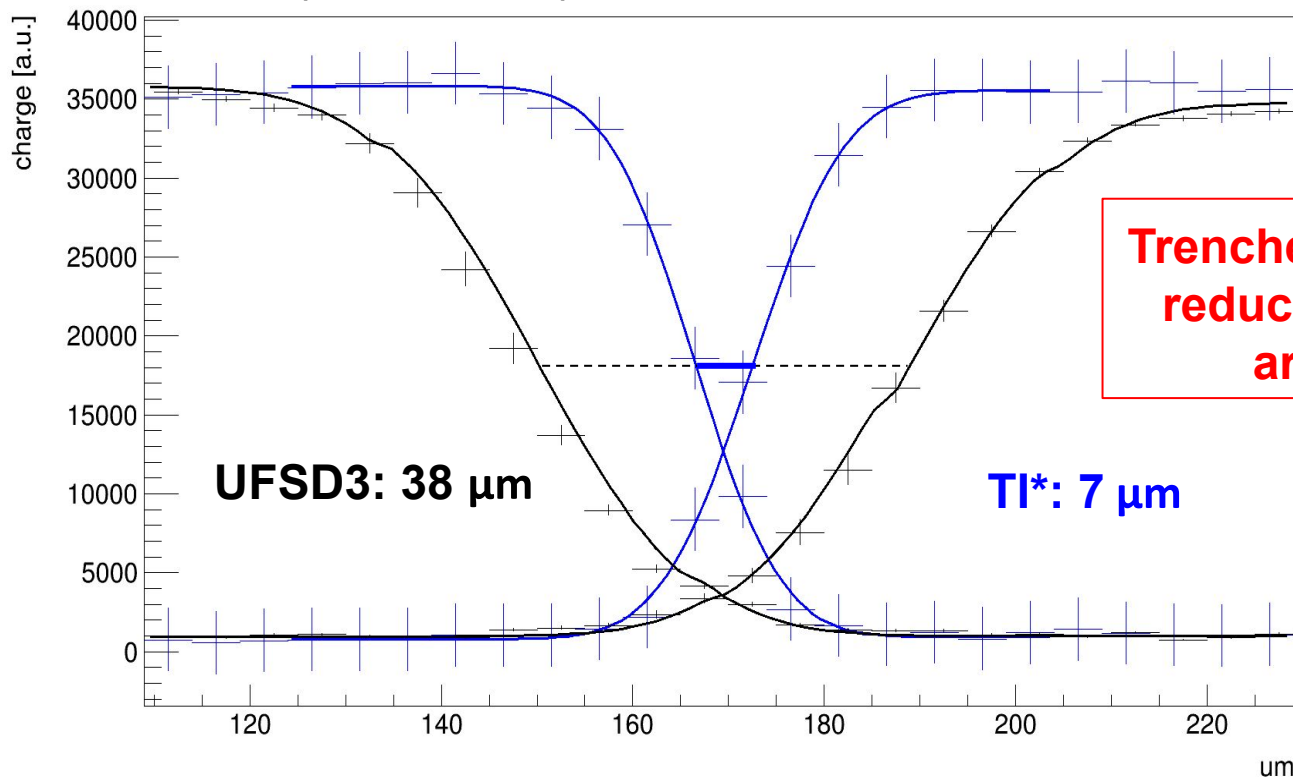Comparison of FBK productions: UFSD3 vs Trench-Isolated

UFSD3: 38 μm

TI*: 7 μm

*2 trenches device
(see next slide),
Wafer5

Interpad: TI vs standard LGAD

Comparison of FBK productions: UFSD3 vs Trench-Isolated

UFSD3: 38 μm

TI*: 7 μm

Trenches significantly reduce the inactive area width!

2 trenches device (see next slide), Wafer5

Interpad: 1 vs 2

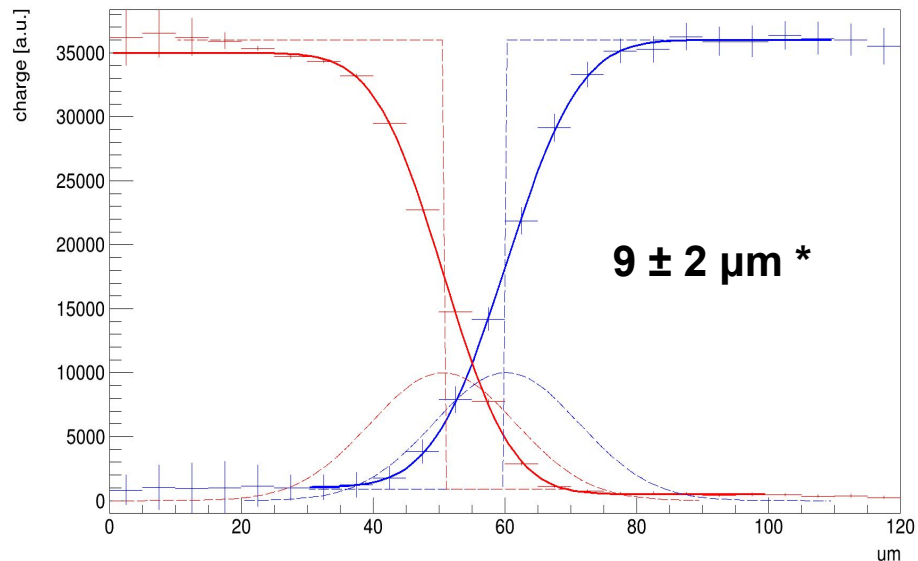TI-LGADs feature either single-trench and 2-trenches isolation

single-trench

2-trenches

Interpad: 1 vs 2

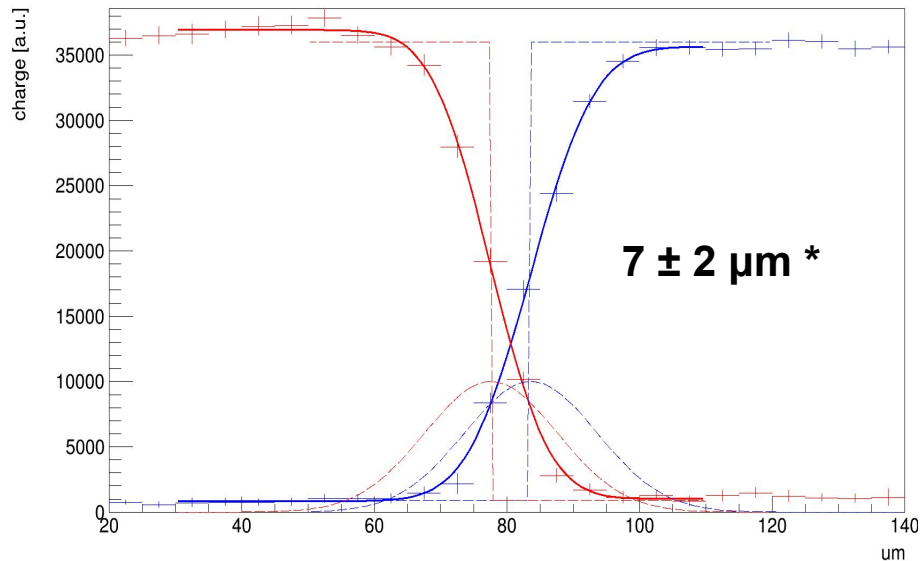TI-LGADs feature either single-trench and 2-trenches isolation

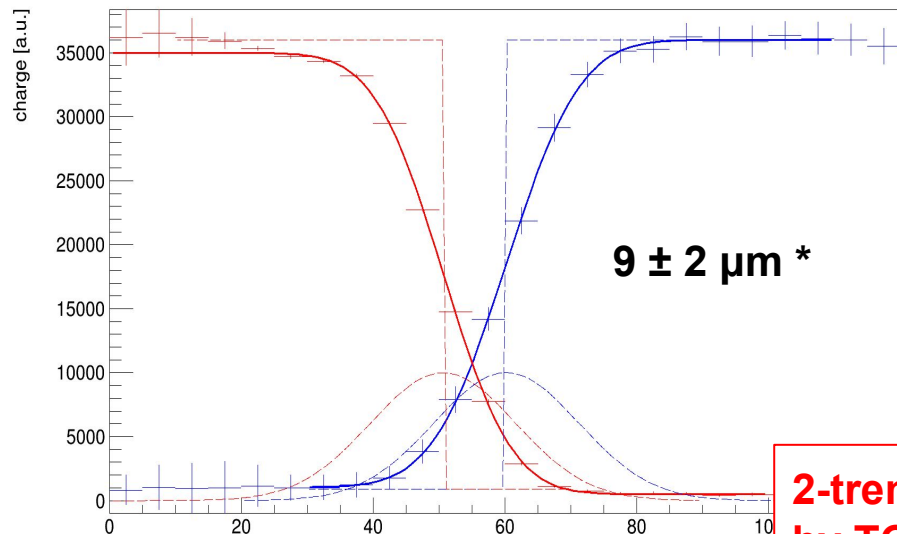
*Average of 4 different measurements
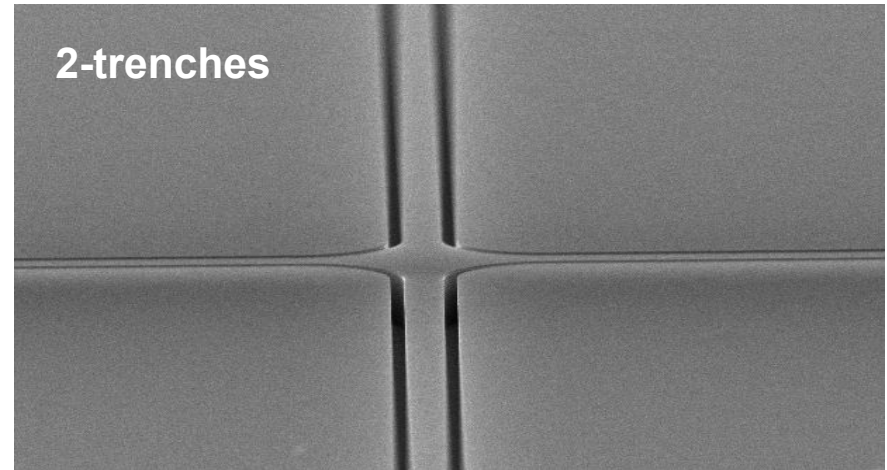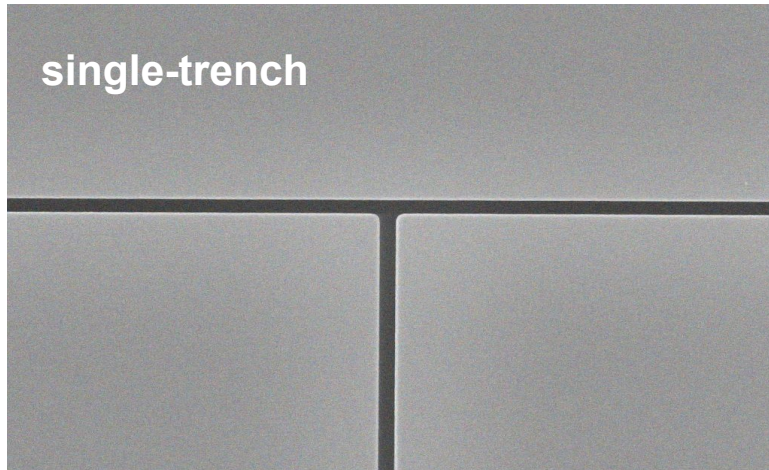
Interpad: 1 vs 2

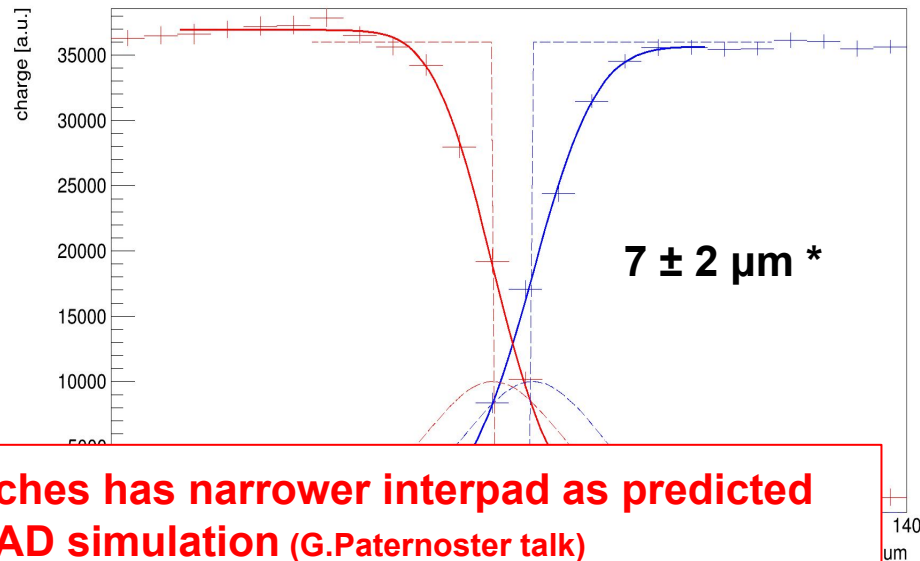TI-LGADs feature either single-trench and 2-trenches isolation

1 Trench (Wafer 5) @300V

9 ± 2 µm *

2 Trenches (Wafer 5) @300V

7 ± 2 µm *

2-trenches has narrower interpad as predicted by TCAD simulation (G.Paternoster talk)

*Average of 4 different measurements

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- ❖ Measurement with a β source setup
  - ➢ Comparison of measured signals with simulation predictions
  - ➢ Time resolution

Beta setup in Torino

- Sr90 β-source
- Measurements at Room temperature
- DUT & Trigger inside a dark box
- Single channel read-out board optimized for timing
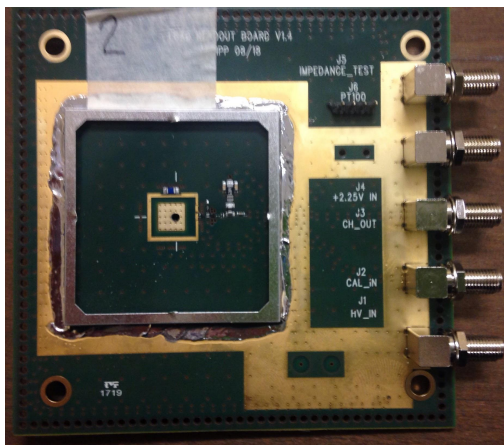
1ch read-out board made by Artel
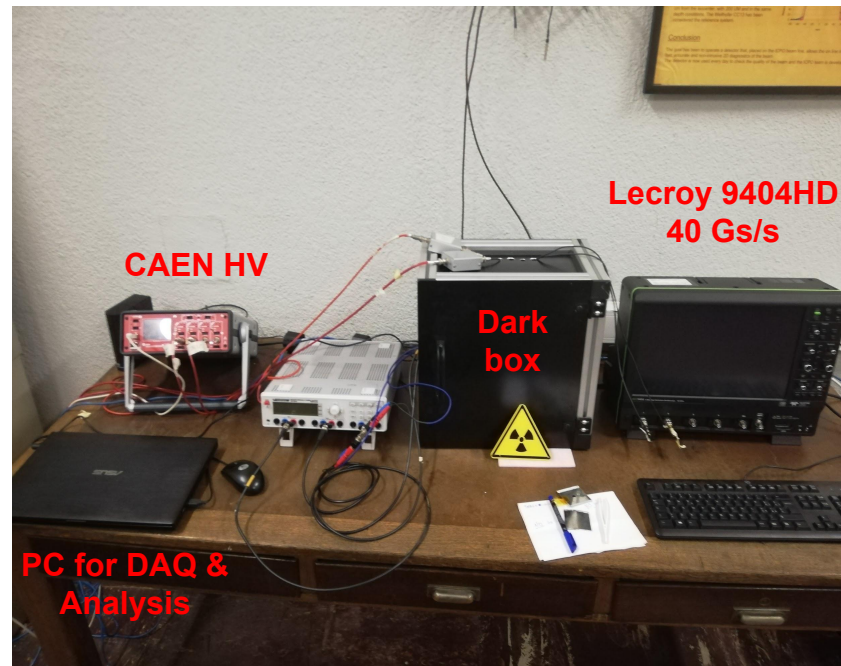
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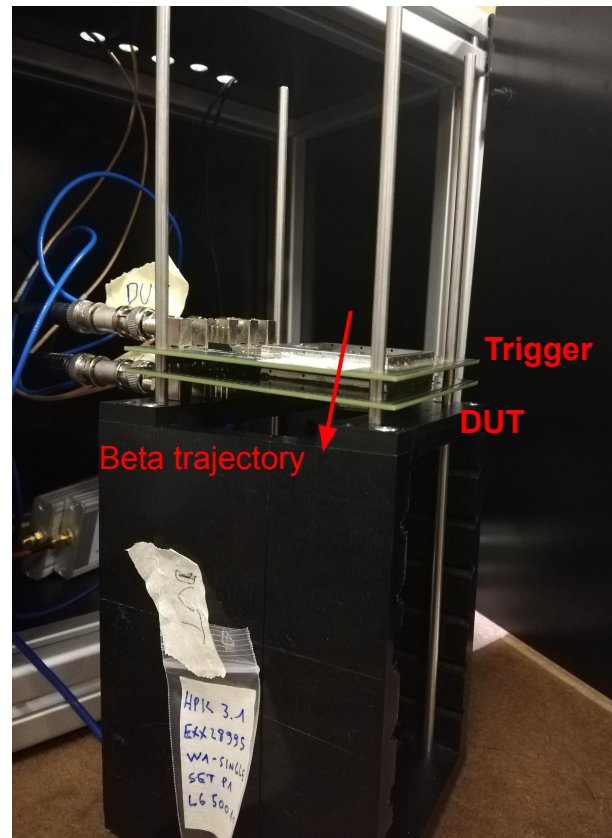- DUT + Trigger Telescope, placed inside a specific structure for alignment
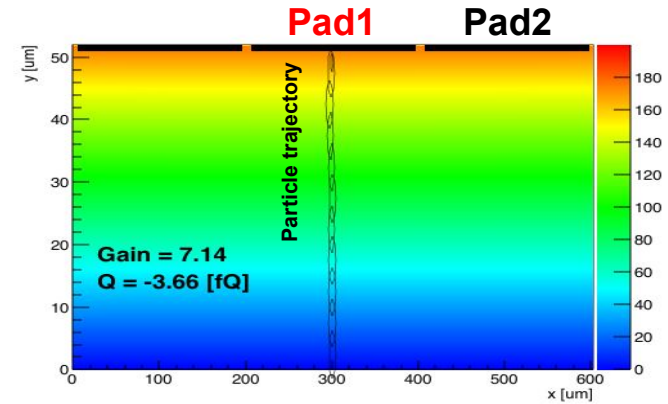
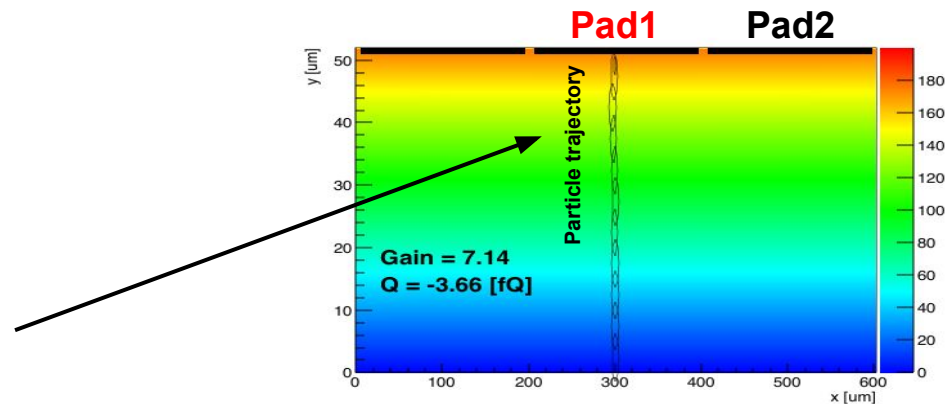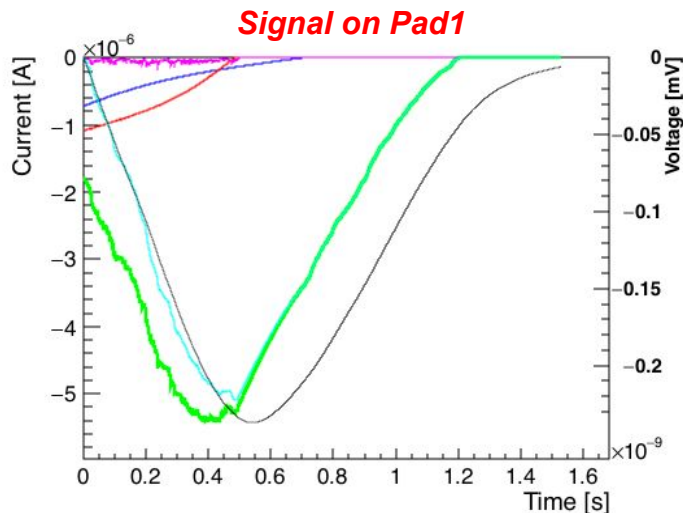# Comparison of measured signals with simulation predictions

- TI-LGAD with two pads → **Pad1 is read-out**

Simulated with **WeightField2** (http://personalpages.to.infn.it/~cartigli/Weightfield2/Main.html)

Comparison of measured signals with simulation predictions

- TI-LGAD with two pads → **Pad1 is read-out**

Signal on Pad1

Pad1   Pad2

Gain = 7.14
Q = -3.66 [fQ]

Particle trajectory

Comparison of measured signals with simulation predictions

- TI-LGAD with two pads → **Pad1 is read-out**

Signal on Pad1

Pad1   **Pad2**

Gain = 7.37
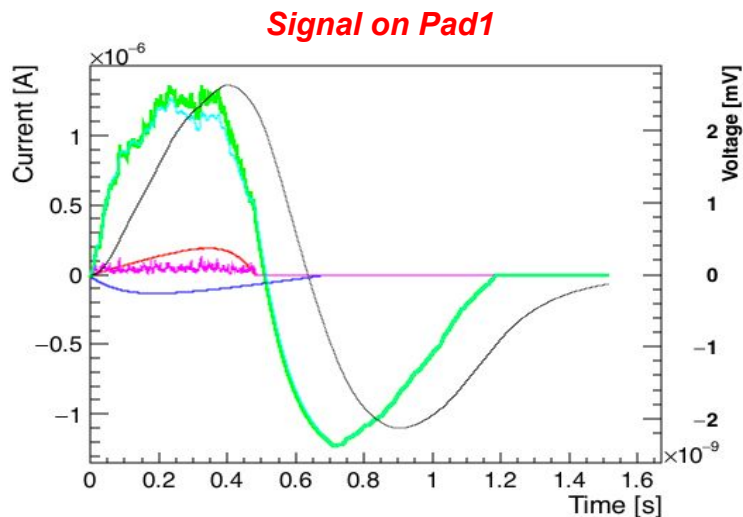Q = -0.00293 [fQ]
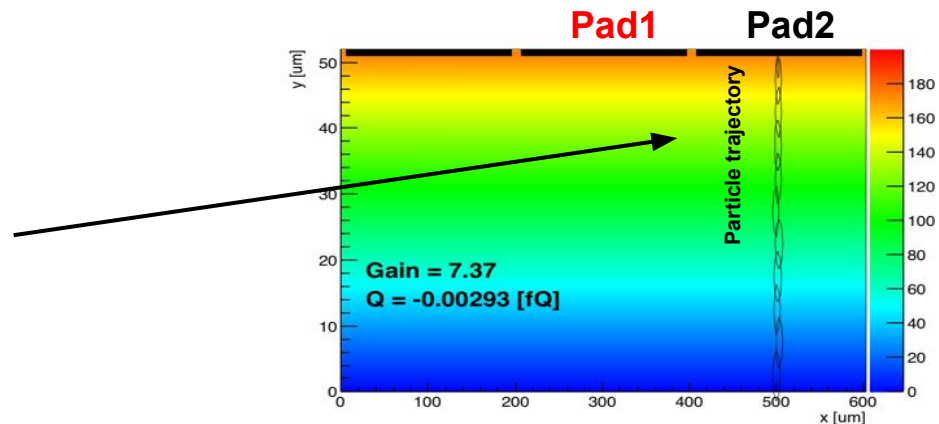
➔ We expect a **bipolar signal on Pad1** when particle passes through Pad2

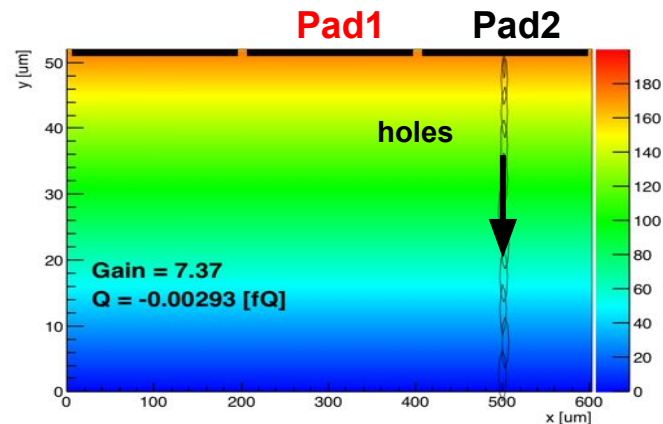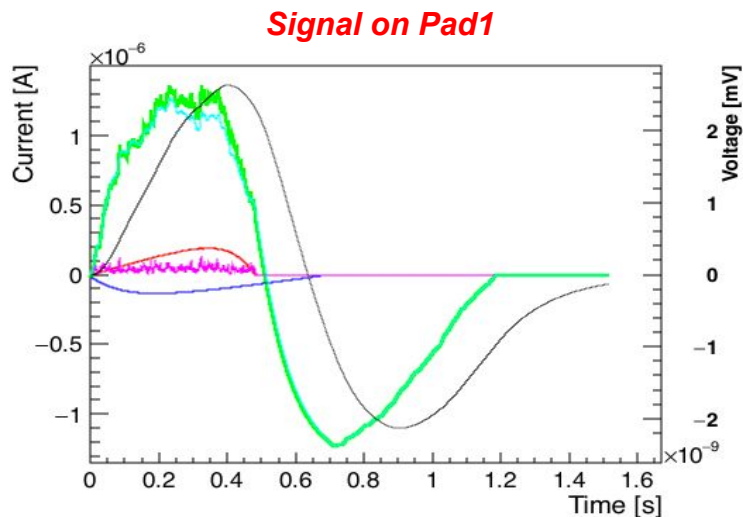# Comparison of measured signals with simulation predictions

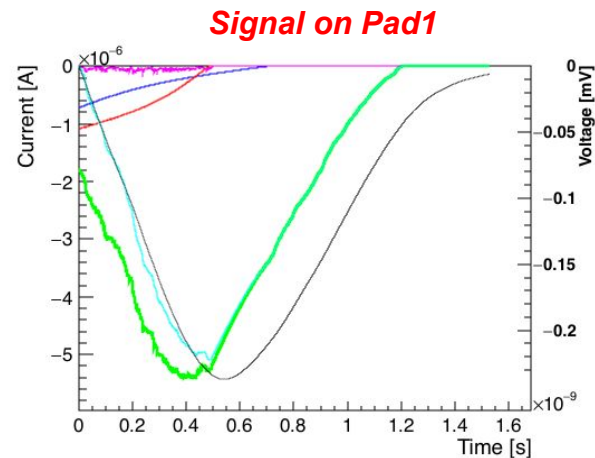- TI-LGAD with two pads → **Pad1 is read-out**

Signal on Pad1

➔ We expect a **bipolar signal on Pad1** when particle passes through Pad2
➔ Pad1 sees holes produced in gain layer of Pad2 drifting towards the anode (first lobe is indeed positive)

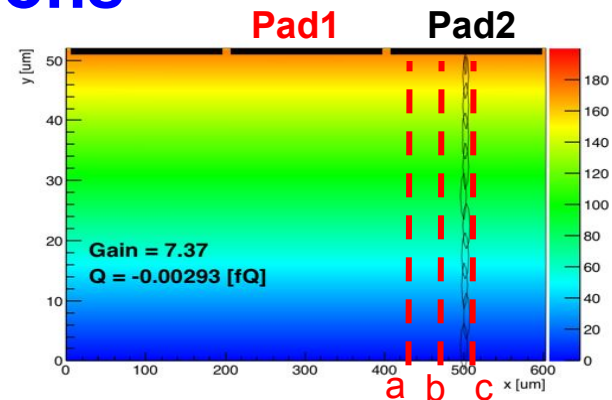# Comparison of measured signals with simulation predictions

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Signal on Pad1
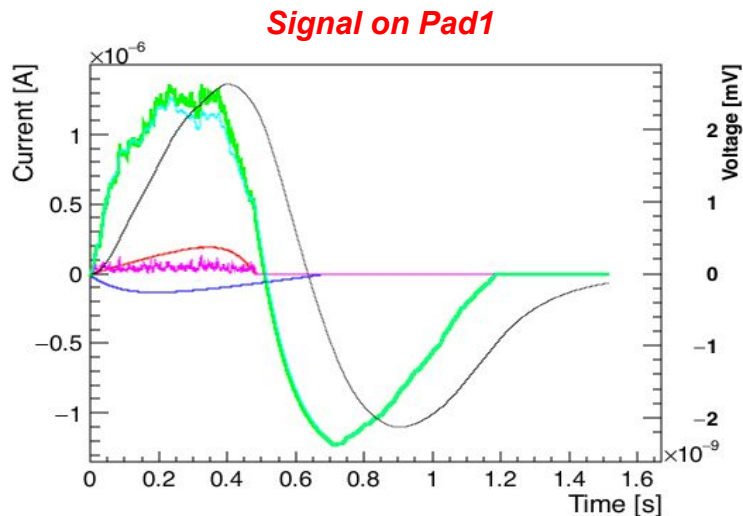
Signal on Pad1

- Same duration
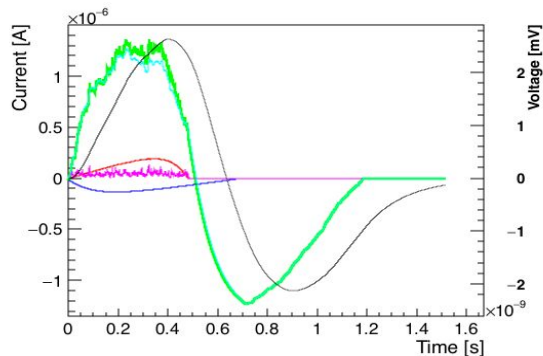- Dipolar signal is ~ the derivative of the standard LGAD signal

Comparison of measured signals with simulation predictions
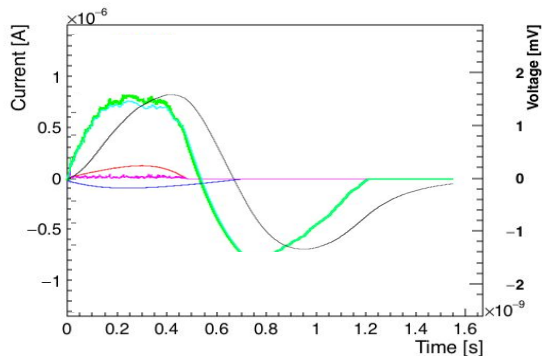

Pad1 Pad2

Gain = 7.37
Q = -0.00293 [fQ]

a b c

- Bipolar signal on Pad1 gets smaller as the particle crossing Pad2 moves further
- Disappear at about 100µm from center of inactive region ("mid gap")

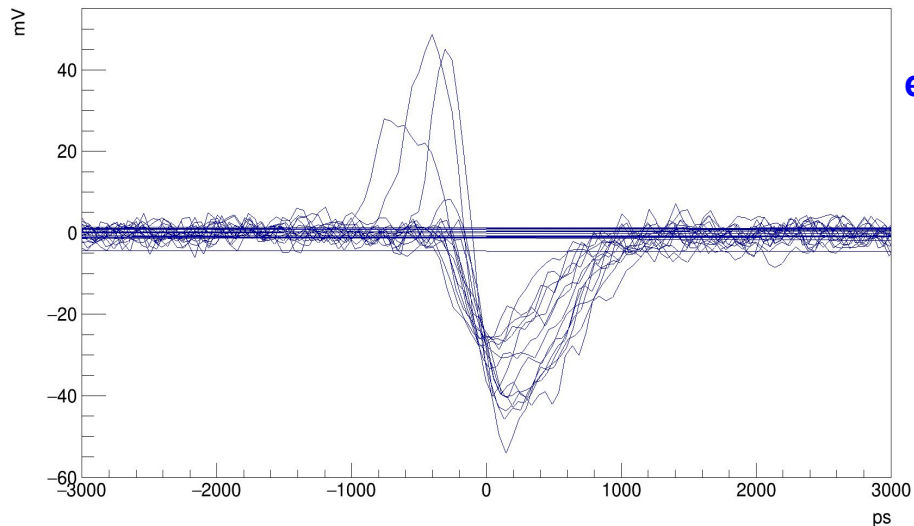*(a) 35 µm from mid gap*

(b) 65 µm from mid gap
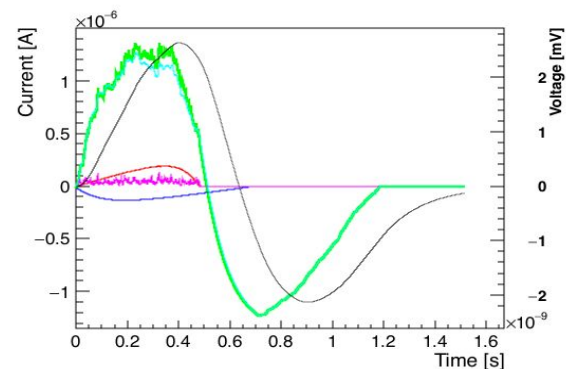
(c) 95 µm from mid gap
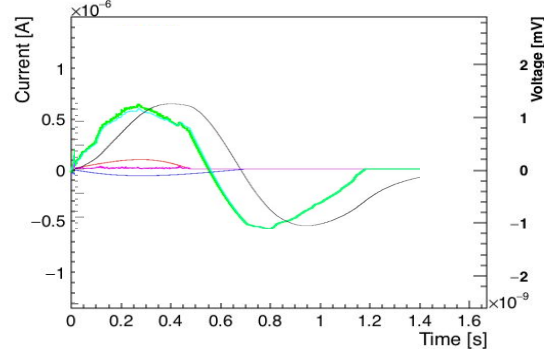
Comparison of measured signals with simulation predictions

Signals on Pad1 when particles hits Pad2

Confirmed by experimental data!

- Effect **not seen in standard LGADs** because of the much wider distance between gain regions
- This is an important **proof of the very narrow gap separating active areas in TI-LGAD**

Time resolution

To measure the time resolution:

- Times of passage of the particle in DUT and Trigger are measured → t_{DUT} , $t_{Trigger}$
- Define the time difference: $\Delta t = t_{DUT} - t_{Trigger}$ → Δt has a gaussian distribution
- $\sigma_{Measured}$ of Δt distribution is the squared sum of DUT and trigger resolutions
  - $\sigma_{Trigger} = 30ps$ is known and fixed → $\sigma_{DUT} = \sqrt{(\sigma_{Measured}^2 - \sigma_{Trigger}^2)}$

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2-trenches TI-LGAD (W5) @300V

MPV ~ 70mV

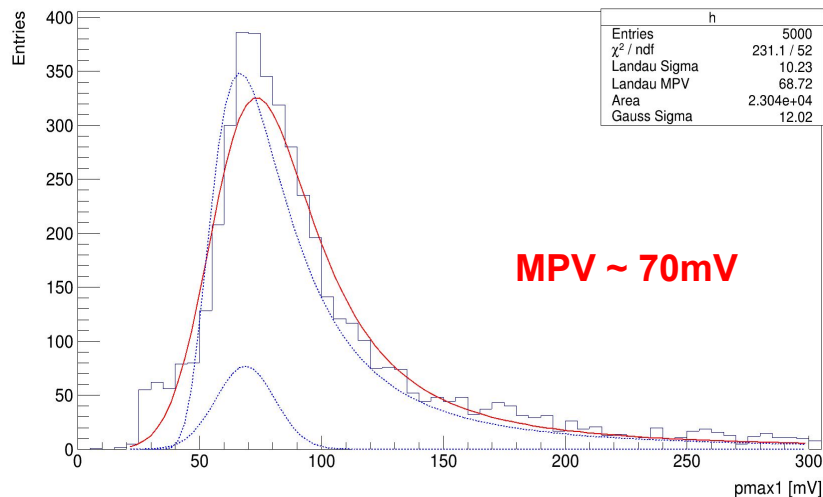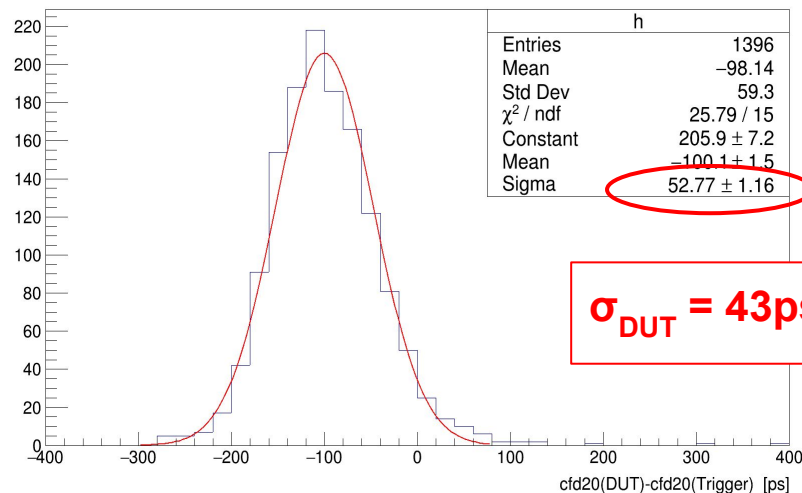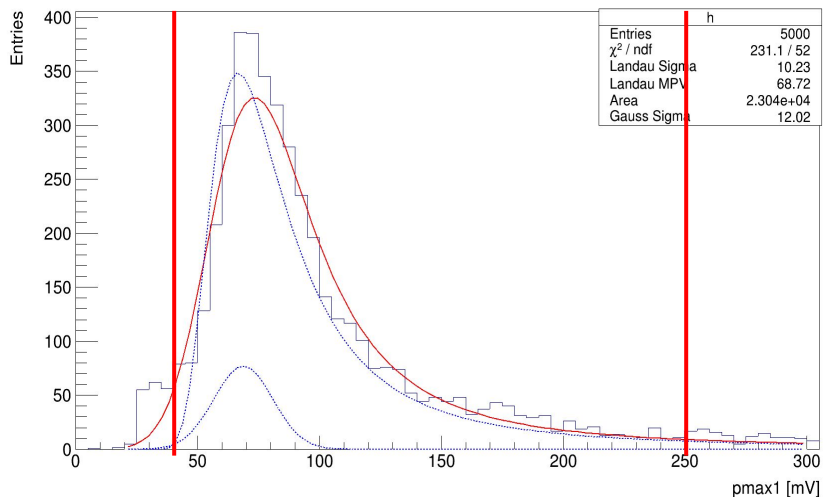| h	
Entries	5000
χ^2 / ndf	231.1 / 52
Landau Sigma	10.23
Landau MPV	68.72
Area	2.304e+04
Gauss Sigma	12.02

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2-trenches TI-LGAD (W5) @300V

σ_{DUT} = 43ps

Conclusion

- Trench-Isolated LGADs are innovative detectors with a significantly improved fill factor compared to standard LGADs
- An extensive testing campaign has been carried on in the laboratory of Innovative Silicon Detectors of Torino University / INFN
- Laser characterization with Particulars TCT setup was performed:
  - **Pads of TI-LGAD devices are isolated** → trenches work well
  - TI-LGADs exhibits gain as standard LGADs
  - **Inactive area width of only 7-9μm** almost a factor 5 less than standard LGADs
- **Time resolution of 43ps achieved** with Sr90 source

  ➔ **A promising detector for future experiments requiring very high fill factor!!!**

Thank You!
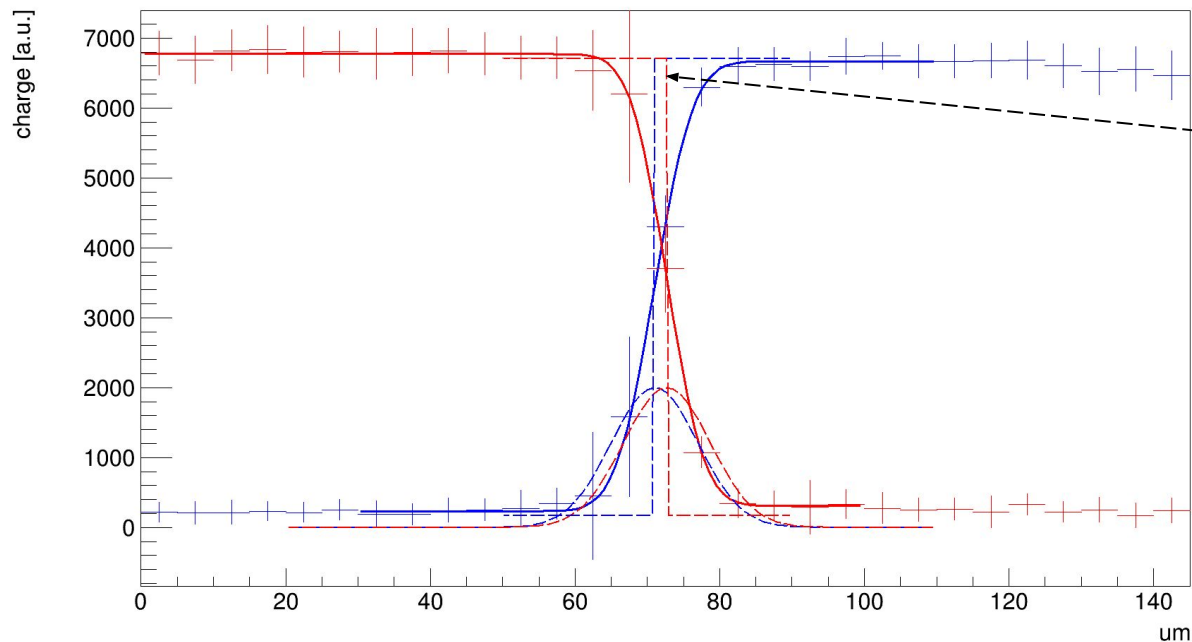
Acknowledgements

We kindly acknowledge FBK for providing sensors and support during the testing campaign
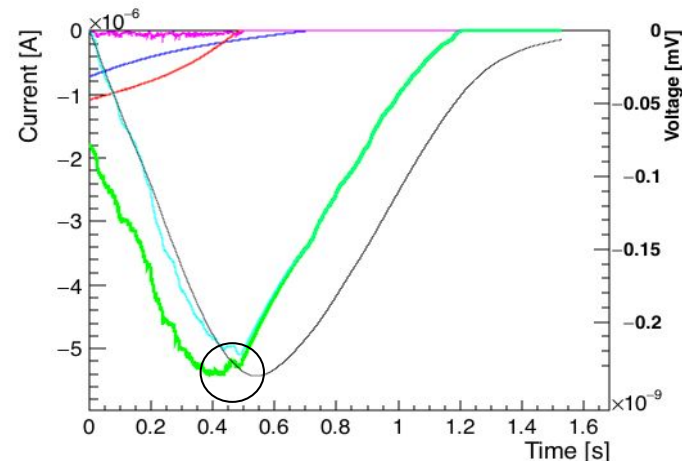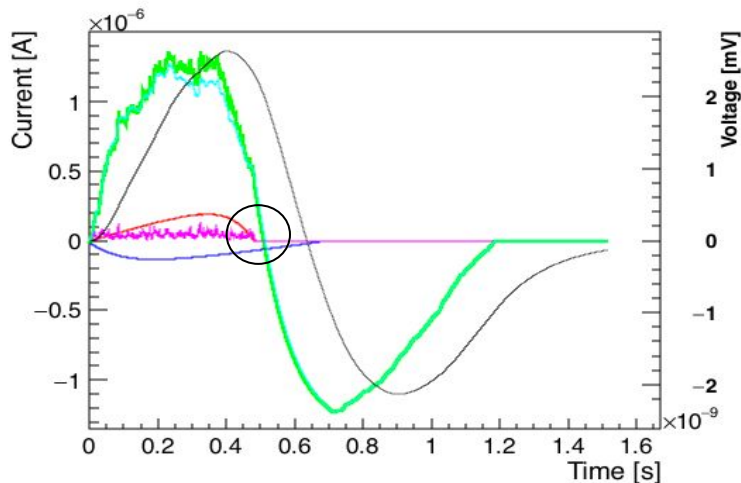
Backup

Interpad of a PiN structure

TI PiN(Type 1) Interpad Distance

Attempt to measure interpad of a no-gain structure:

- Interpad is negative (-2 ± 2 μm)
  → compatible with 0 μm
- The limit of the system is reached
- **A 0 μm interpad can be measured with TCT**

Comparison of measured signals with simulation predictions

- Same duration, standard LGAD signal ~ symmetric in time → end of positive lobe at signal maximum (reasonable)
- Signal max when last electron reache GL → end of charge production → bipolar signal goes to zero (no variation in time, bipolar signal is the derivative)