Tracking and timing measurements on irradiated TI-LGADs

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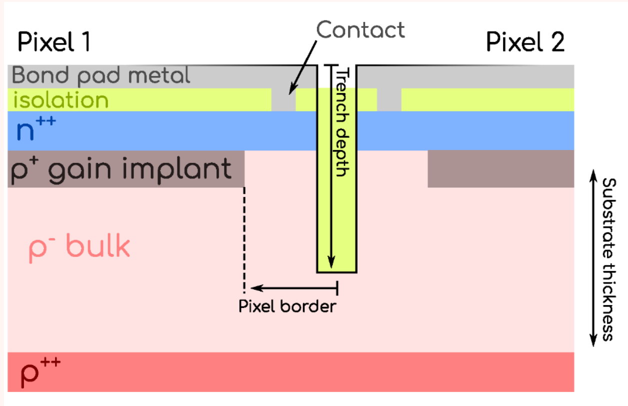
Introduction

- **The Challenge:** The High Luminosity LHC presents extreme conditions with up to 200 p-p collisions per bunch crossing creating severe high-density pile-up.
- **The Standard Solution:** ATLAS and CMS have developed the MIP TIMING SUBDETECTORS using Low Gain Avalanche Diodes (LGADs) silicon detectors in the endcap regions, targeting a time resolution of 30 ps to 50 ps.
- **The Bottleneck:** Conventional LGADs suffer from a limited Fill Factor. Edge termination structures create $\sim 80\,\mu$m inactive, "no-gain" regions between pads. Then, small pixels with good spatial resolution have a extremely low Fill Factor (25% for $100\,\mu$m pixel). This forces the use of large pixel cells (1.3 mmx1.3 mm) compromising spatial resolution.

TI-LGADs: The Solution

Trench Isolated LGADs overcome this limitation by replacing the edge termination structures with dielectric-filled trenches reducing the inactive interpad regions.

This architecture enables high fill-factor and 4D Tracking (good spatial and timing resolutions).



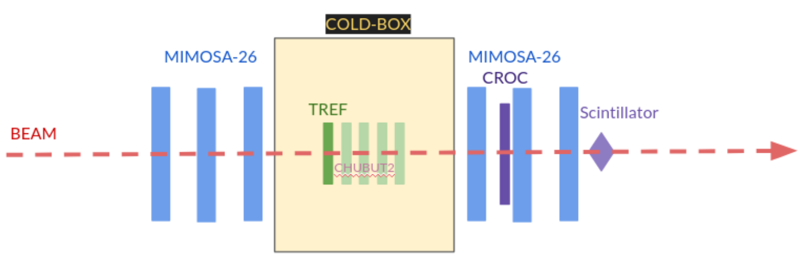
Transversal view of a TI-LGAD. Source: [1].

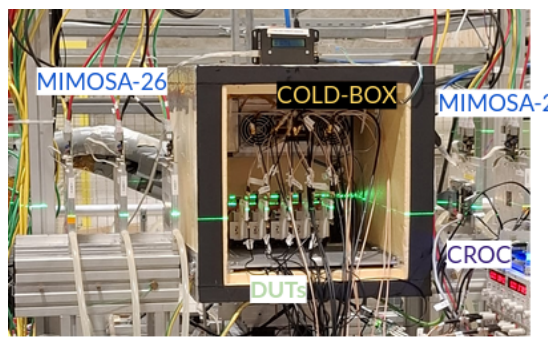
Experimental samples: Carbon-enriched TI-LGADs, produced by FBK [2] for the AIDAINNOVA production with the following parameters have been characterised:

- Version (gain layer-trench distance): V2
- Trench Widths (TW): 1, 2, 3, 4, 6
- Irradiation (ϕ): $0\,\mathrm{n_{eq}\,cm^{-2}}$, $1.5\times10^{15}\,\mathrm{n_{eq}\,cm^{-2}}$ and $2.5\times10^{15}\,\mathrm{n_{eq}\,cm^{-2}}$

Testbeam Setup

Measurements were performed at the CERN SPS H6 beamlines using an EUDET beam telescope with up to 6 MIMOSA26 planes. A CAEN DT5742 digitizer was used to record the waveforms in the DUTs and A CROC for ROI selection. The DUTs were placed inside a coldbox and operated at $-25\,^{\circ}$C.



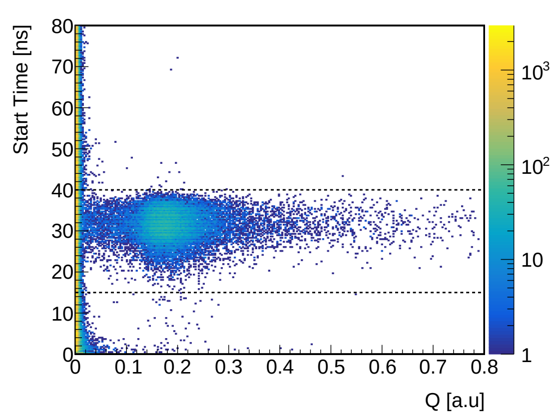


The EUDET telescope made of the MIMOSA26 planes, the CROC and the coldbox with the DUTs inside.

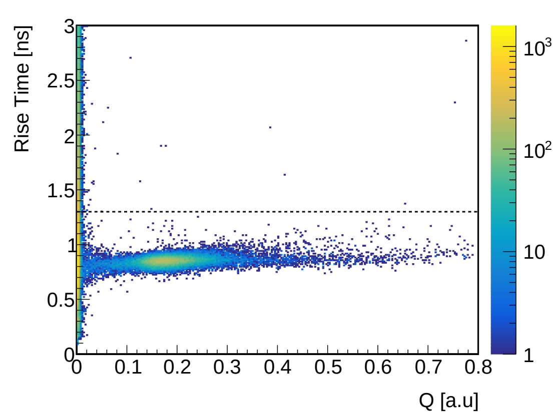
The trigger is defined by a CROC-Scintillator coincidence in the TLU. Offline waveform analysis was used to discriminate physical hits from empty waveforms.

Hit finding - Quality Cuts

Objective: Remove out-of-time and non-physical contributions, cuts in the signal start time and rise time are applied.



Start Time vs Charge. Lines at Start Time = 15 ns and 40 ns.

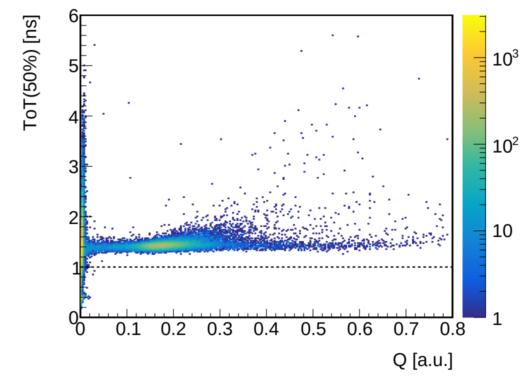


Rise Time vs Charge. Line at Rise Time = 1.3 ns.

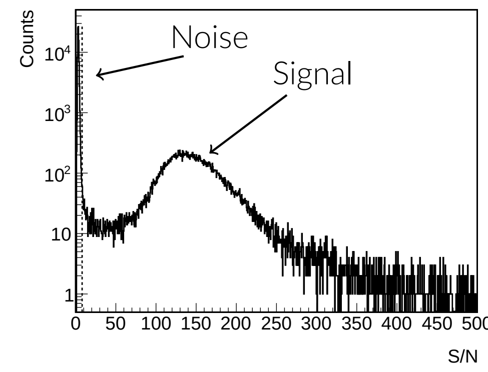
Non-irradiated TI-LGAD at $V = 165$ V.

Hit finding - Selection Cuts

Final hit selection obtained by applying cuts in the ToT at the 50% of the amplitude ($\mathrm{ToT_{50\%}}$) and the S/N.



$\mathrm{ToT_{50\%}}$ versus the Charge. Line at $\mathrm{ToT_{50\%}}$ = 1 ns.



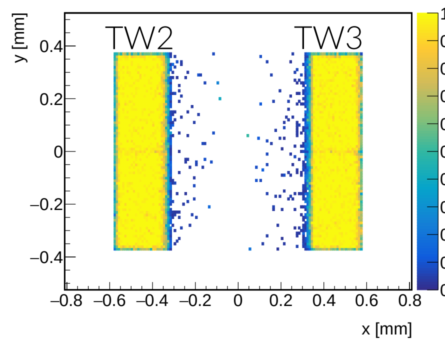
S/N distribution. Line at S/N = 8 separated noise and signal hits.

Non-irradiated TI-LGAD at $V = 165$ V after the quality cuts have been applied.

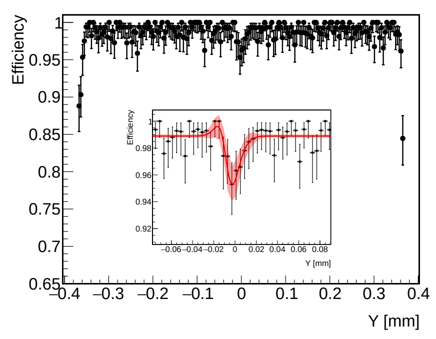
Tracking Results

The tracks reconstructed by the telescope are matched to the hits in the DUTs. With this the efficiency maps are constructed.

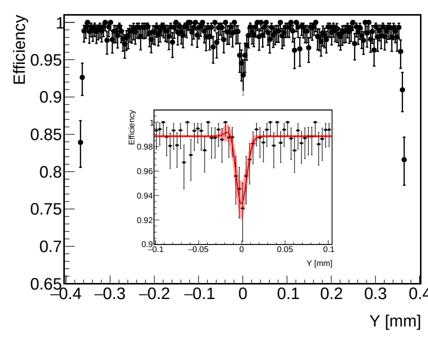
Efficiency projections are used to estimate the effective interpad distance. Also, it is observed that in the central region of the pixels the efficiency is $\sim 100\%$.



2D efficiency plot.



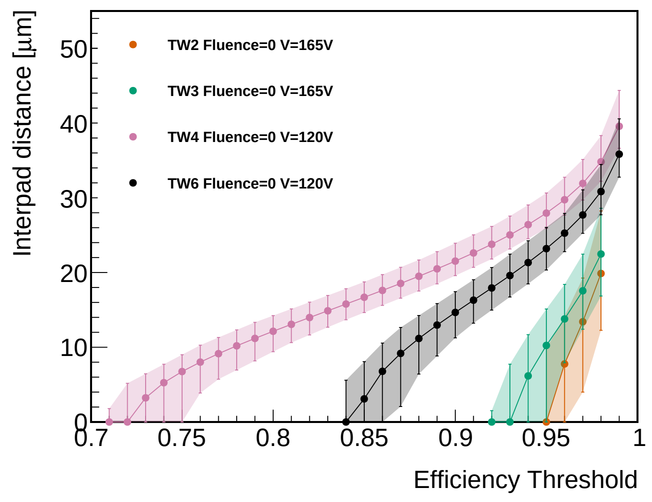
TW2.



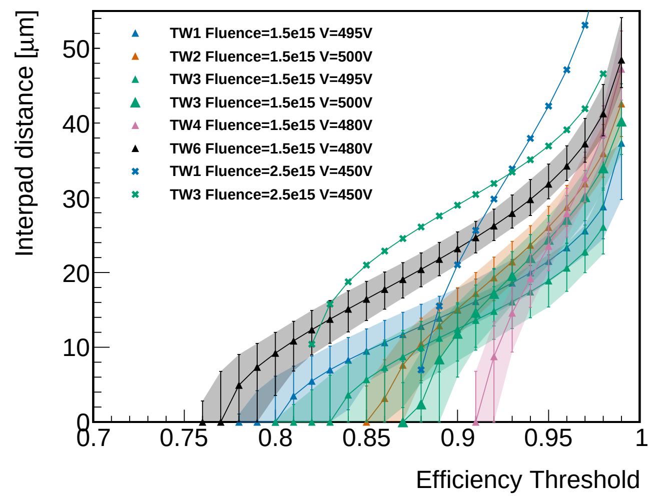
TW3.

Hit efficiency for non-irradiated TI-LGADs at $V = 165$ V.

When this is performed for all measured detectors the interpad of all of them is compared:



Non irradiated devices.



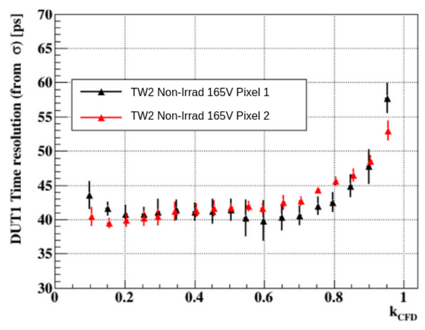
Irradiated devices.

Comparison of the interpad distance for different efficiencies between measured detectors.

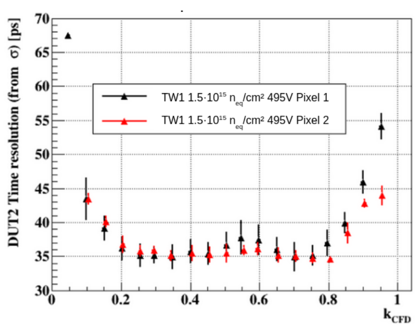
- Larger effective interpad distances are observed for the highly irradiated devices.
- TW2 and TW3 show the best performance between the non-irradiated devices.
- TW3 and TW4 show the best performance between the irradiated devices

Timing Results

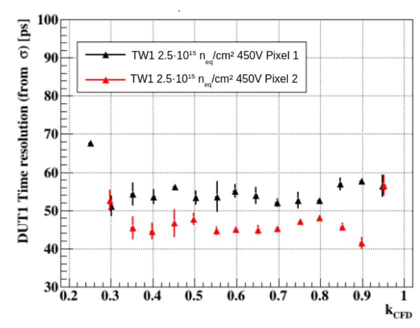
Timing resolution was computed using MIP signals and the three-sensor method with a CFD [3] used to overcome time walk effects. Timing resolutions between $35-50$ ps were obtained depending on irradiation.



Non-irradiated TI-LGAD, $V = 165$ V



Irradiated TI-LGAD ($\phi = 1.5\times10^{15}\,\mathrm{n_{eq}\,cm^{-2}}$), $V = 495$ V



Irradiated TI-LGAD ($\phi = 2.5\times10^{15}\,\mathrm{n_{eq}\,cm^{-2}}$), $V = 450$ V

Time resolution as a function of the CFD fraction.

Conclusions

- **MIPs characterization of:** Carbon-enriched V2 TI-LGADs irradiated up to $2.5\times10^{15}\,\mathrm{n_{eq}/cm^2}$.
- **0 interpad distance for:** $\geq 95\%$ efficiency (non-irradiated) and $\geq 90\%$ efficiency (irradiated).
- **Time resolutions** between 35 and 50 ps.
- **Geometry optimization:** TW2/TW3 perform before irradiation and TW3/TW4 after irradiation.
- **Future work:** inclined-track studies, timing maps, and trench optimization for DRD3.

References

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