Performance of 3D trench pixel sensors irradiated up to $1 \cdot 10^{17}$ 1 MeV $n_{eq}\,cm^{-2}$

16TH PISA MEETING ON ADVANCED DETECTORS

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INTRODUCTION

The increase of instantaneous luminosity in high energy physics experiments will allow to increment the amount of data recorded per year, to have a chance to access to more rare events and to reduce the statistical uncertainties of the already studied phenomena.

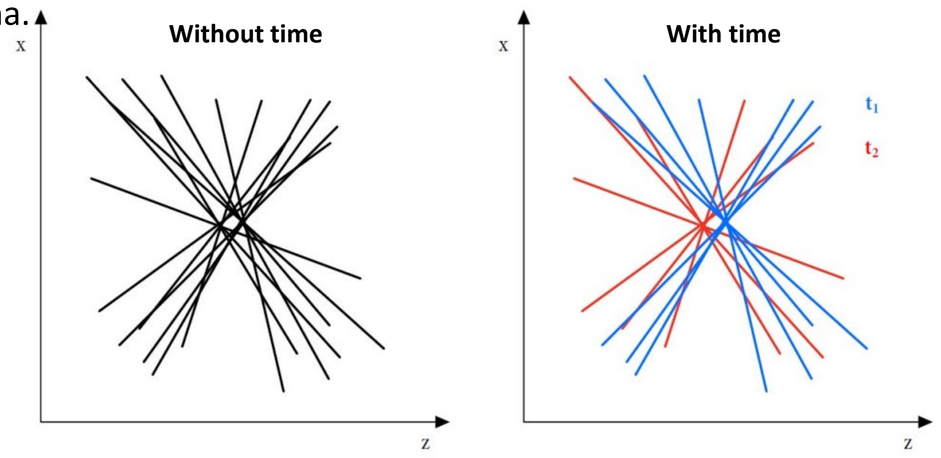
Issues

- The higher occupancy will severely affect the vertex reconstruction efficiency of tracking detectors.
- Higher radiation damage provided to the detectors $10^{16} \div 10^{17}$ 1 MeV $n_{eq}\ cm^{-2}$

Solutions

Measure the time of the tracks to cope with the increased occupancy and restore the timing information (50 ps/hit for the LHCb Vertex Locator detector [1]).

Develop sensors with higher radiation hardness and having better time resolution.

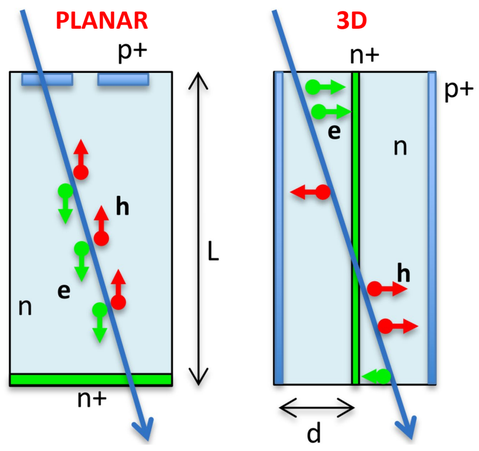


3D SENSORS

3D sensors one of the best candidate for tracking detectors close to particles interaction points.

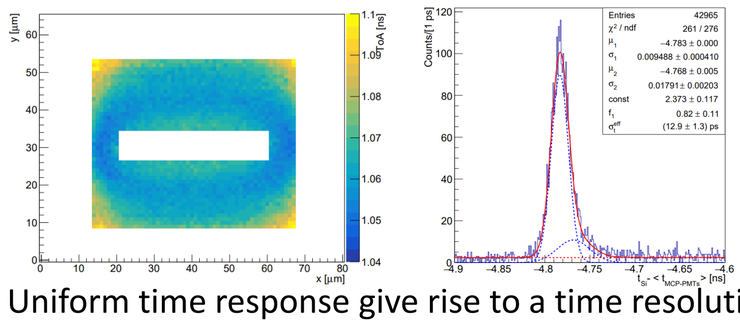
Shorter inter-electrode distance (d) since decoupled to sensor thickness (L):

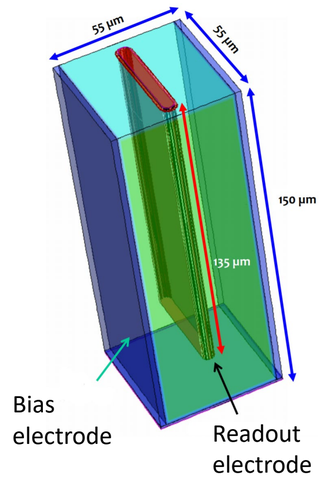
- give rise to extremely fast signals;
- unmatched radiation hardness >10^{17} 1 MeV n_{eq}/cm^{2}.



TimeSPOT sensors

3D trench sensors: 3D sensor optimized to achieve best timing performances [2].



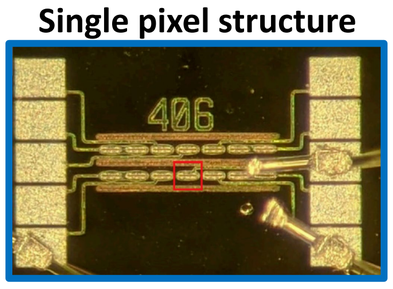


Uniform time response give rise to a time resolution of 11 ps for MIP detection [3].

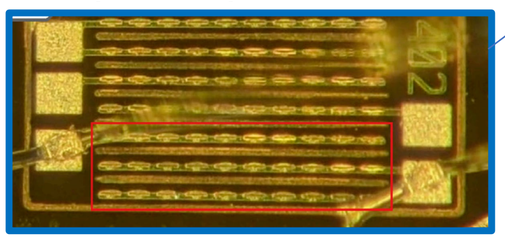
TEST STRUCTURES

Several test structures have been irradiated with neutrons at the TRIGA Mark II Reactor II, to evaluate the radiation hardness of this innovative sensors.

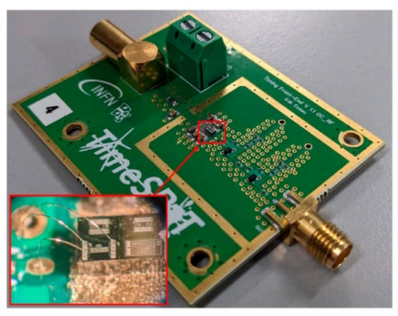
Single pixel structure



3-pixel-strip structure



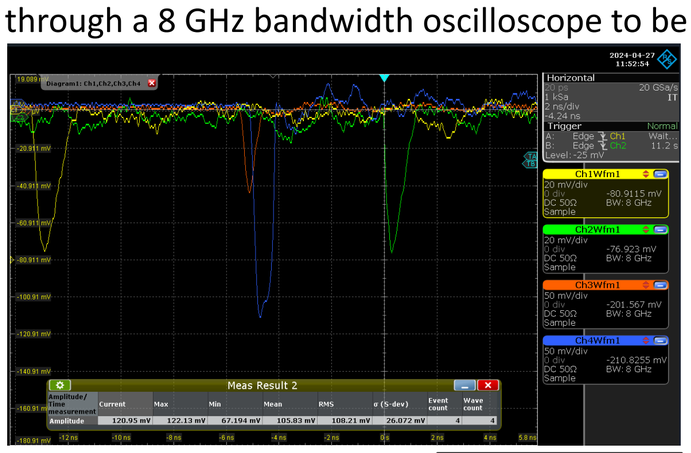
30 pixels with the readout electrodes shorted together, to have a device with larger area

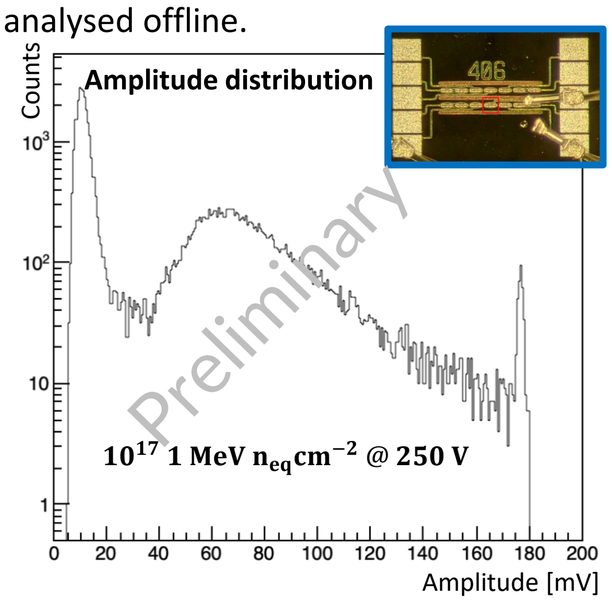


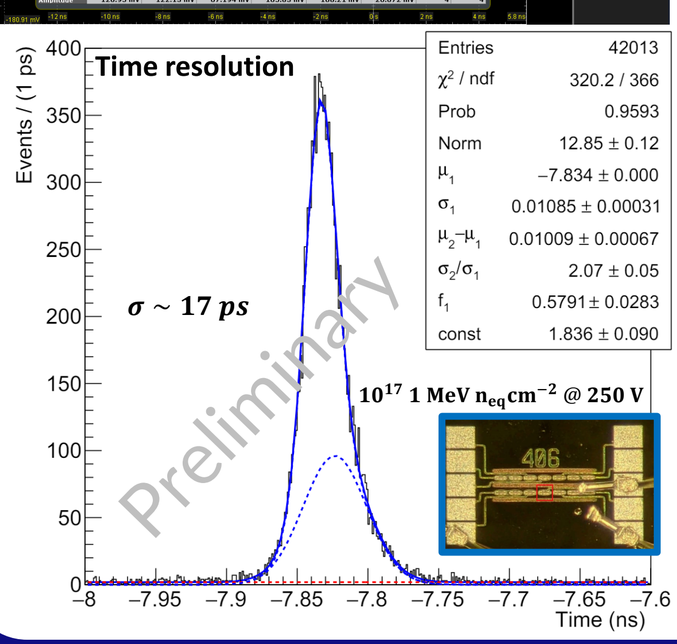
After irradiated up to $\mathbf{10^{17} 1\ MeV\ n_{eq} cm^{-2}}$ the structures were wire bonded to our front end electronic (TIA) amplifier and stored to -20°C to avoid annealing.

RESULTS: AMPLITUDE & TIMING

Analog signals from the two 3D trench sensors and the two MCP-PMTs were collected through a 8 GHz bandwidth oscilloscope to be analysed offline.



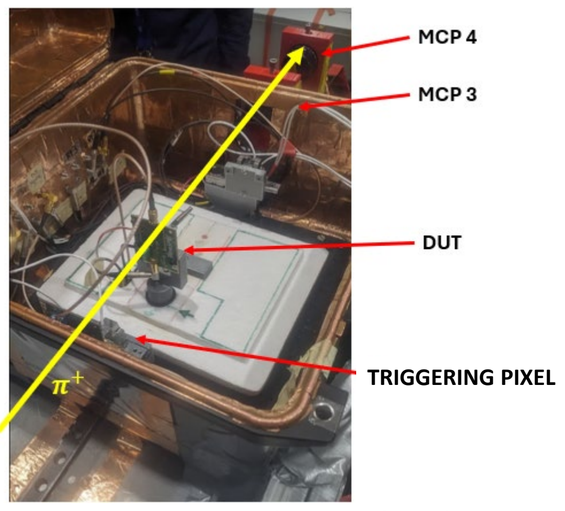




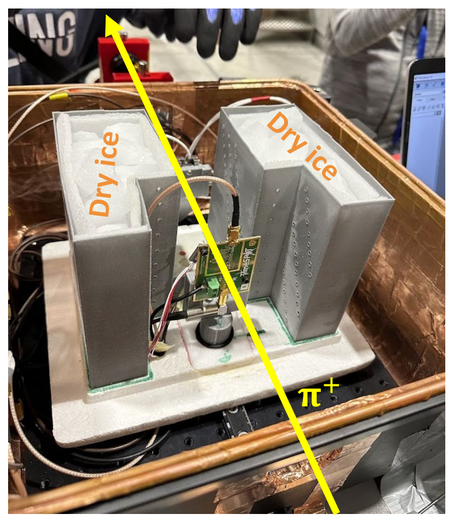
- Amplitude distribution similar to the one of non-irradiated pixels (if operated at higher bias voltage).
- Excellent time resolution $17{,}3 \pm 0{,}6\ ps$ (preliminary results).
- CFD based algorithm, margin for improvement.

THE SETUP

Test structure tested at the SPS H8 beam-line with a 180 GeV/c π^+ beam. The setup involves two MCP-PMT as a time reference with an accuracy better than 5 ps.



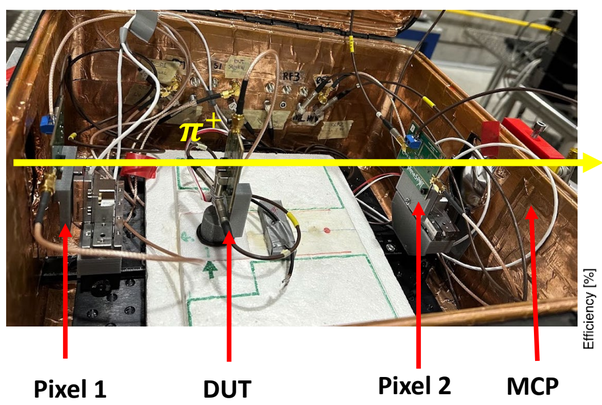
Non-irradiated pixel used for the trigger, to avoid to bias the measurements on the DUT (fine alignment of two 55 µm pitch pixels).



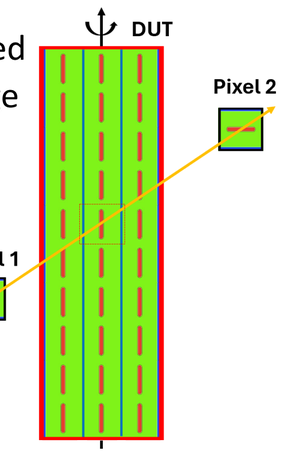
Irradiated sensors cooled with dry ice, and isolated with a polystyrene enclosure. Simple but effective system, allowing to operate from $[-40 \div -20]°C$ for 12 hours.

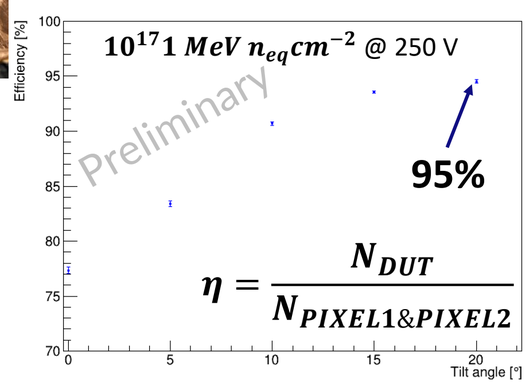
RESULTS: EFFICIENCY

Detection efficiency of $\mathbf{10^{17} 1\ MeV\ n_{eq} cm^{-2}}$ irradiated 3-pixel strip sensor has been measured at a bias voltage of 250 V as a function of the tilt angle.



Irradiated 3D trench at $\mathbf{10^{17} 1\ MeV\ n_{eq} cm^{-2}}$ close to full efficiency.





CONCLUSION

Accurate beam test characterizations have proven that 3D trench sensors irradiated at $\mathbf{10^{17} 1\ MeV\ n_{eq} cm^{-2}}$ maintain excellent performance in terms of **charge collection**, **time resolution** and **detection efficiency.** These results demonstrate that **3D trench pixels are a suitable technology for tracking detectors in high-radiation environments, extending their applicability not only to HL-LHC but also to FCC-hh experiments.**

REFERENCES

[1] LHCb Collaboration. Framework TDR for the LHCb Upgrade II Geneva: CERN (2021). Tech. rep.
[2] A. Loi, Design and test of a timing optimized 3D silicon sensor for HL-LHC experiments, Ph.D. Thesis, University of Cagliari.
[3] Borgato F, Brundu D, Cardini A, Cossu GM, Dalla Betta GF, Garau M, et al. Charged-particle timing with 10 ps accuracy using TimeSPOT 3D trench-type silicon pixels. Front Phys (2023).