Università degli Studi di Padova

INFN Cagliari

High spatial and temporal resolution pixelated radiation sensors characterization for next generation experiments in fundamental physics

TFPA

Detectors, lasers and optics

Michele Verdoglia

XXXIX Cycle

Supervisors:

Alessandro Cardini

Adriano Lai

Andrea Lampis

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Research topic of my PhD program

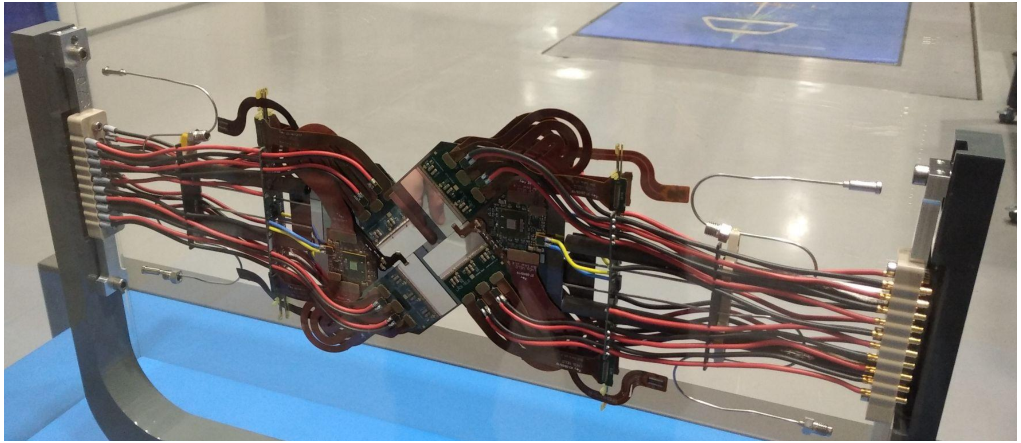
R&D of solid state detectors for future HEP experiments at colliders.

- **Position resolution:** $\sigma_x \sim 10\ \mu m$ @ HL-LHC, less for next-gen experiments;
- **Ultrafast timing:** $\sigma_t \sim 50$ ps @ HL-LHC, less for next-gen experiments;
- **Radiation tolerance:** $\varphi \sim 5 \times 10^{16}$ @ HL-LHC up to 5×10^{18} 1MeV n_{eq} /cm^2 for next-gen experiments.

Research topic of my PhD program

1) Specifically, my PhD project consists in the characterization and optimization of 3D-trench silicon sensors for fast timing applications;

2) The case study of the PhD project is the upgrade of the LHCb Vertex Locator (VeLo) detector (planned for 2036, LHC Run 5).



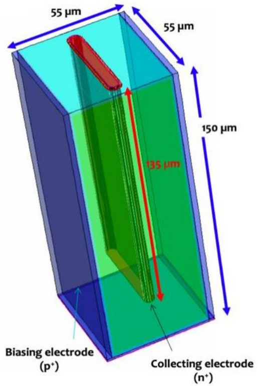
Current VeLo modules
(Image taken by M. Verdoglia in the LHCb museum room)

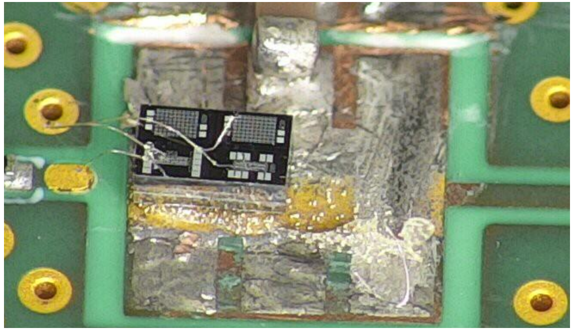
Objectives of my PhD program

The objectives are:

1) **Assessing** the potential of 3D-trench silicon pixel technology for the LHCb VELO upgrade and next-generation experiments.

CAD design of a TimeSPOT 3D-Trench silicon Pixel, 55 μm pitch pixel, 150 μm thik





High irradiated TimeSPOT test structure, Φ = 10^{18} 1 MeV n_{eq} /cm^2 (microscope image)

2) Study the **performance** and the **operability range** in terms of *irradiation level* φ, *temporal resolution* σ_t and *position resolution* σ_x;

Overall planning

1 Year: Characterization and testing of highly irradiated test structures (with neutrons @ 10^{17} 1MeV n_{eq}/cm^2), studying the time resolution, efficiency and charge collection efficiency in laboratory and test beam;

2 Year: Characterisation of extreme irradiated sensors (with neutrons ~ 10^{18} 1MeV n_{eq}/cm^2) using a custom innovative Cold-TCT setup developed by me (hardware and software);

3 Year: Characterisation of proton irradiated 3D-trench silicon sensors.
Study of 64x64 pixels matrices bonded to the ASICs using the Cold-TCT setup. Design build and successfully test a 4D-telescope (tracking and timing) at the test beam in spring 2026.

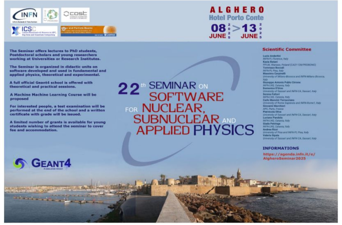
Courses, the exams and other training activities

1) Electronic Systems in High Energy Physics (passed, 4CFU);
2) Novel Detectors for future experiments at colliders (passed, 2CFU);
3) Solid State Detector (lessons attended in September);
4) Advanced Scientific programming in MATLAB (passed, 4CFU);
5) CHIPP Winter **School** of Particle Physics 2025;

CHIPP Winter School of Particle Physics 2025
Swiss Institute of Particle Physics

(Attended in Jan.2025)

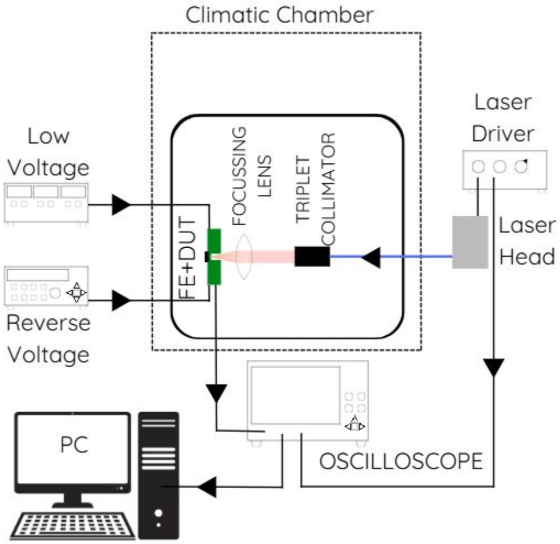
6) XXII **Seminar** on Software for Nuclear, Subnuclear and Applied Physics (passed, 4CFU);



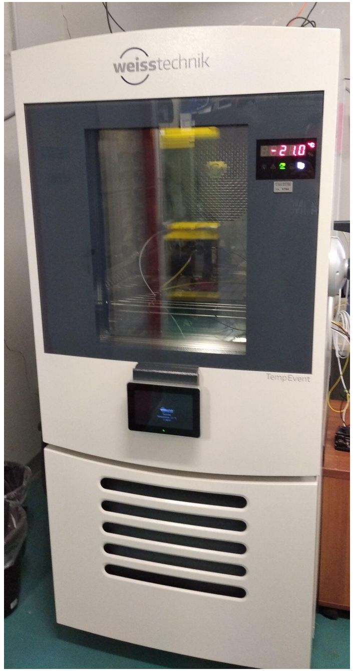
22nd Seminar on Software for Nuclear, Subnuclear and applied Physics (Attended in June.2025)

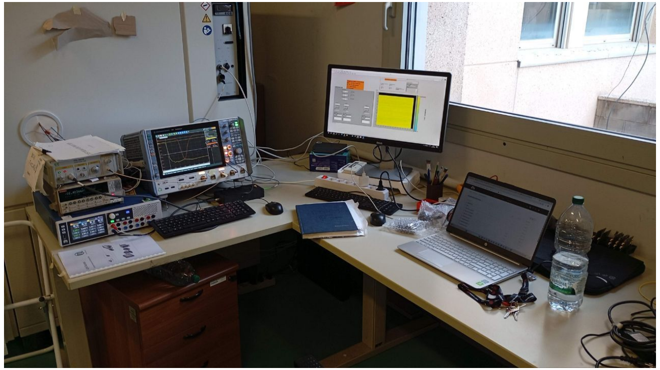
Research activities **carried out so far** and those planned for the 3rd year

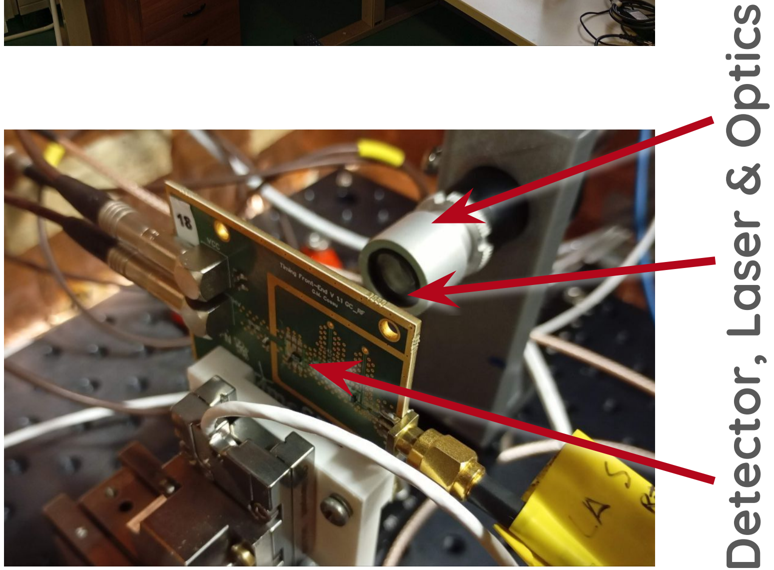
In-pixel studies using the Cold-TCT setup



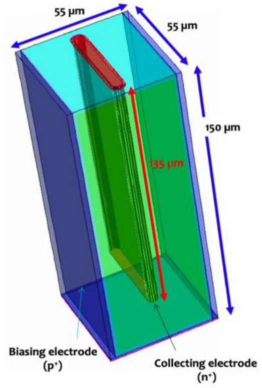
Schematic of the Cold-TCT setup I developed to test extreme irradiated sensors







In-pixel studies using the Cold-TCT setup



CAD design of a TimeSPOT Pixel

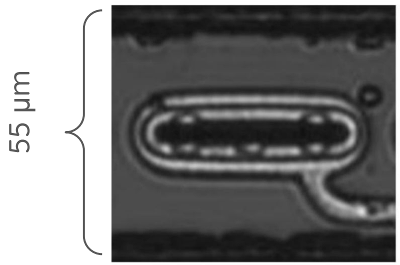
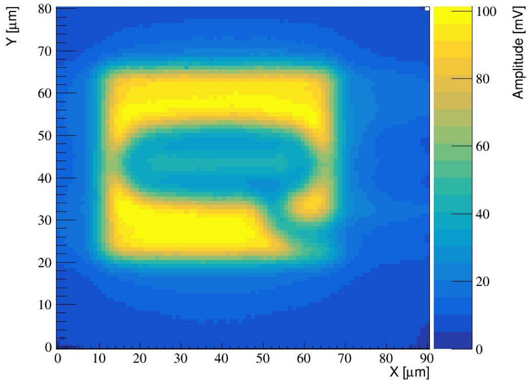
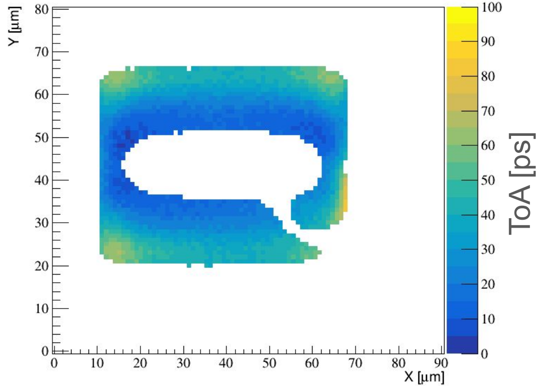


Image at the microscope of a TimeSPOT pixel



In-pixel amplitude @ $50V_{BIAS}$



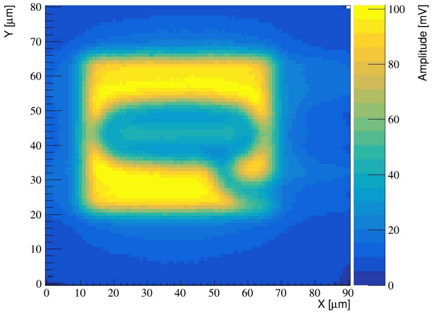
In-pixel time-of-arrival @ $50V_{BIAS}$ & signals>50%

σ_t ~ 14 ps

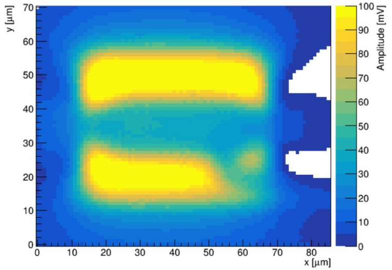
Research activities **carried out so far** and those planned for the 3rd year

In-pixel studies of highly irradiated sensors using the **Cold-TCT** setup and at the **test beam:**

In-Lab measurements using Cold-TCT @ -20°C

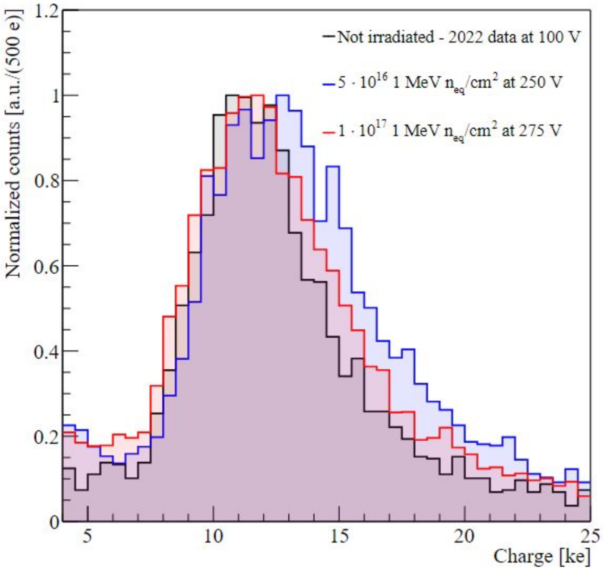


Not irradiated
In-pixel amplitude
@ $50V_{BIAS}$



In-pixel amplitude
@ $300V_{BIAS}$ & $\varphi = 10^{17}$

Full CCE recovery !!!



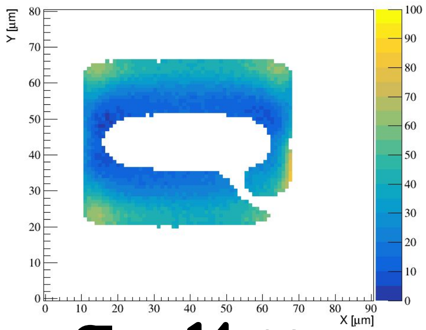
180 GeV/c π^+ Charge spectra
(test beam @ SPS-H8)

https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2024.1497267/full

Research activities **carried out so far** and those planned for the 3rd year

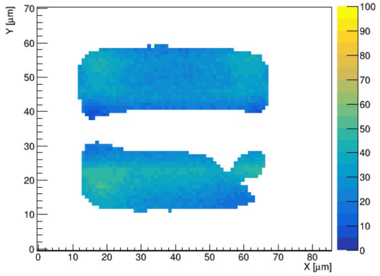
In-pixel studies of highly irradiated sensors using the **Cold-TCT** setup and at the **test beam:**

In-Lab measurements using Cold-TCT @ -20°C



σ_t ~ 14 ps

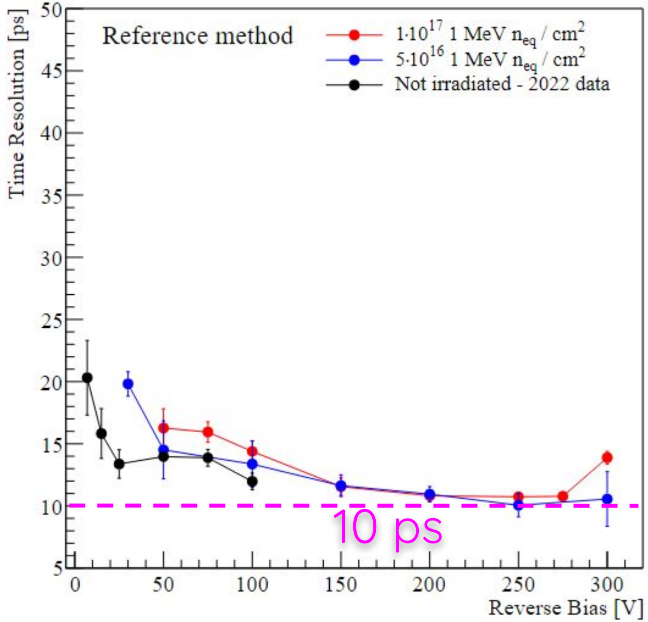
In-pixel ToA
@ $50V_{BIAS}$



signals>50%

σ_t ~ 10 ps

In-pixel ToA
@ $300V_{BIAS}$ & $\varphi = 10^{17}$



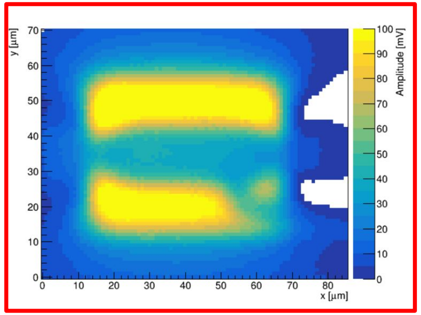
Temporal resolution at the test beam @ SPS-H8

Radiation tolerance up to 10^{17} !!!

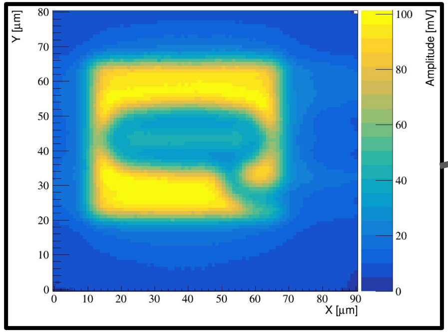
https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2024.1497267/full

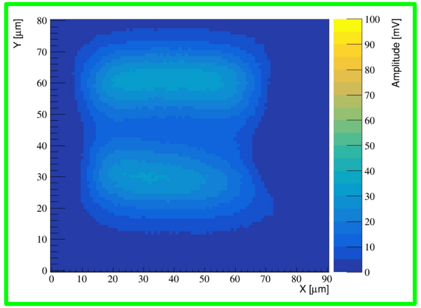
In-pixel studies of highly irradiated sensors using the **Cold-TCT** setup:

φ = 10^{17} @ 300V e -20°C

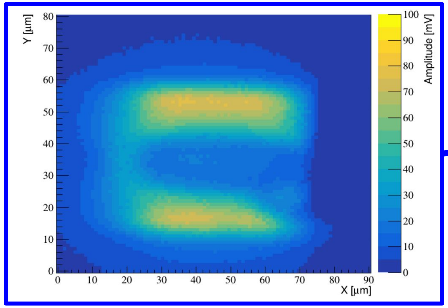


Not irradiated

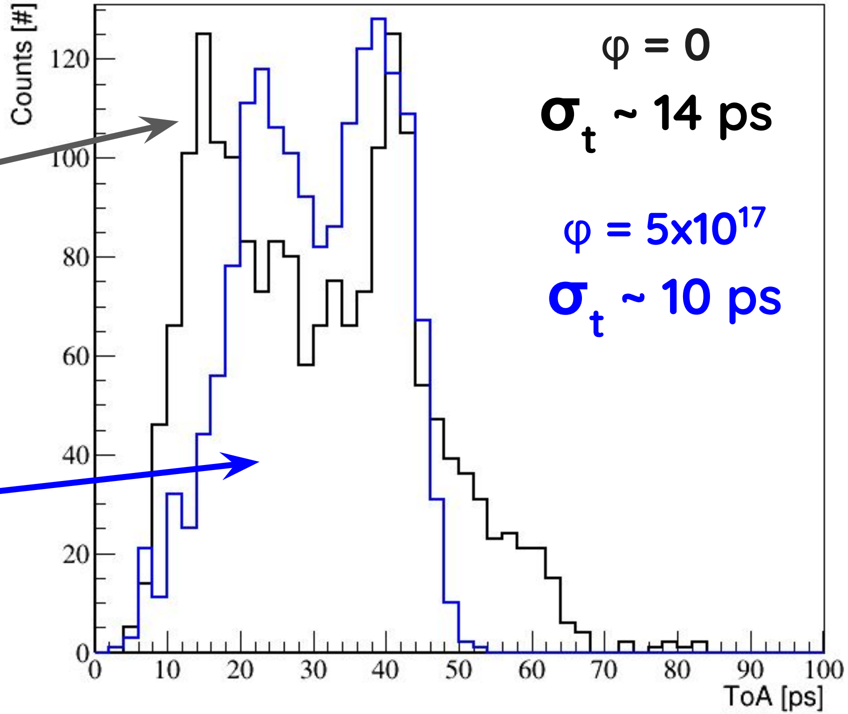




φ = **10^{18}** @ 400V e -20°C

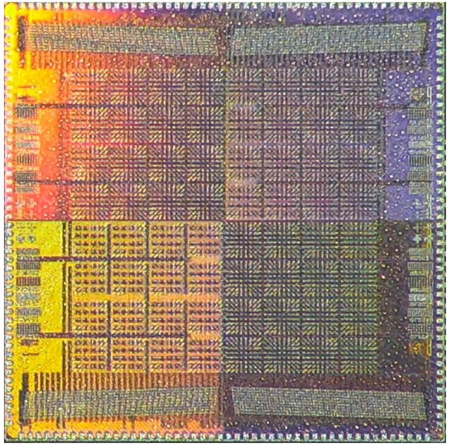


φ = $5x10^{17}$ @ 400V e -20°C

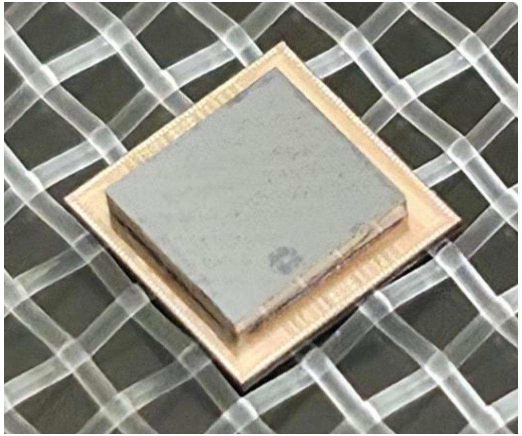


Research activities carried out so far and those planned for the 3rd year

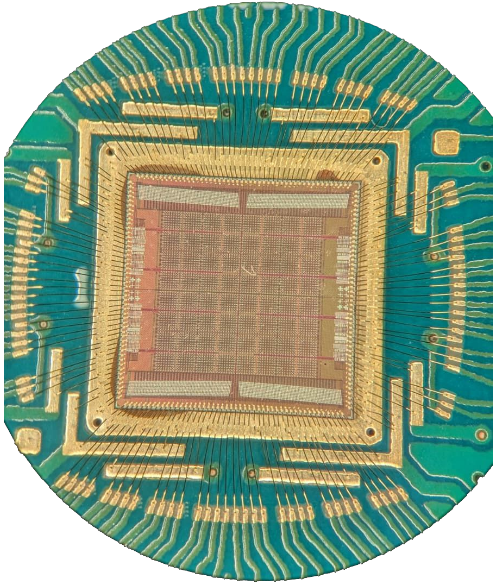
Characterization of 64x64 pixel matrices in laboratory (using the Cold-TCT setup) and at the test beam.



IGNITE64
28nm CMOS ASIC



3D-Trench Sensors
connected
to the IGNITE64 ASIC



ASIC wirebonded to the
FE-electronics

Other academic activities

Talk at TREDI24 (Feb.2024)

Talk at SIF 2024 (Sept.2024)

Talk at IFD 2025 (Mar.2025)

Talk at IFAE 2025 (Apr.2025)
A proceeding will be published soon in *Nuovo Cimento*!!

LHCb VeLo Recabling & Recommissioning (Feb.2024)
shift as VeLo-Piquet (Nov.2024)

CERN IRRAD Proton Facility

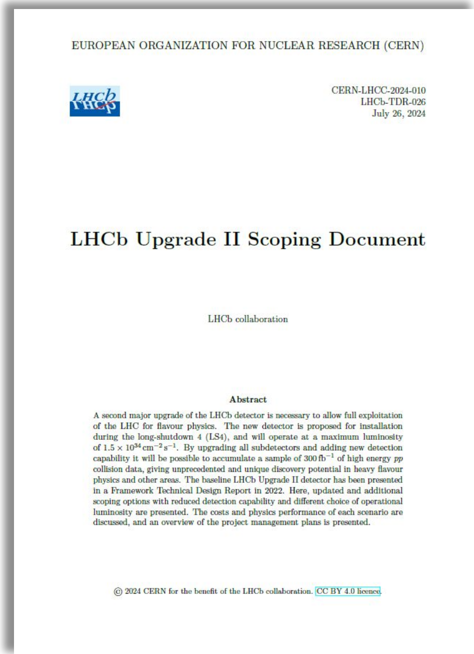
Responsable of TimeSPOT test structures proton irradiation at IRRAD (CERN) (Apr.-Sept. 2025)

Kick-off meeting
July 10-11
2024 Padova

TECH – FPA PhD
Retreat 2025
l'aquila 17-21 feb

Other academic achievements

+ IFAE 2025 Proceeding (coming soon)



>40 papers within LHCb collaboration

Conclusions

The results of the first two years of PhD can be summarized as follows:

- I am involved in the R&D of solid state detector for the LHCb VeLo detector upgrade and next-gen experiments;
- I studied in-pixel performances of highly irradiated test structures using a custom Cold-TCT setup developed by me;
- I took part in a test beam campaign where highly irradiated test structures were characterized, **paper published on frontiers**
- I presented the results in **four different conferences.**
- I will start soon the 64x64 matrices characterization in laboratory !!!

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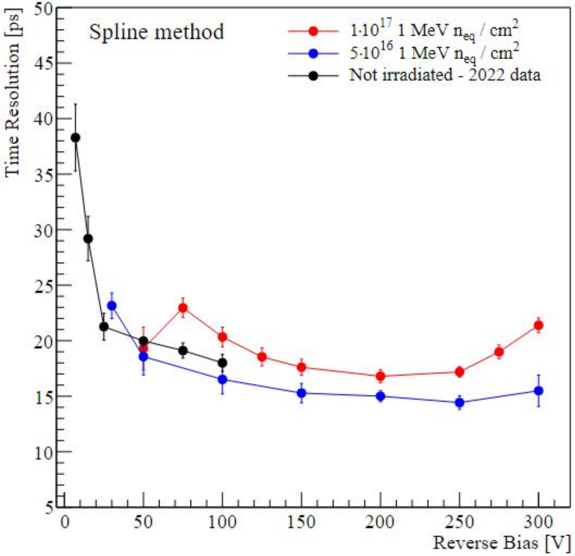
THANKS !!!

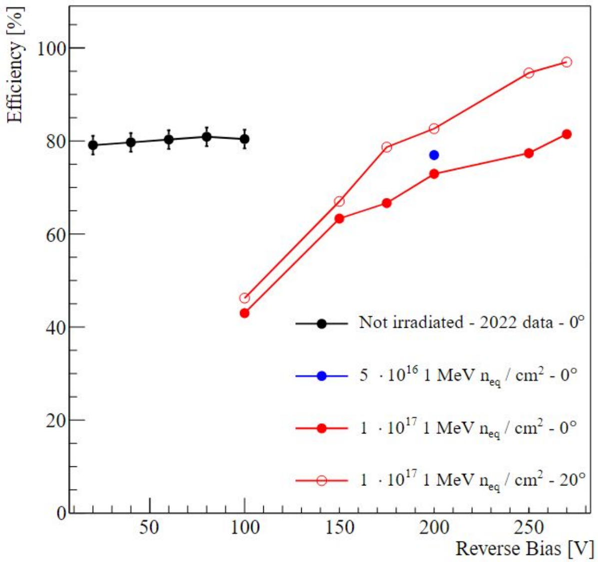
Backup slides

Test Beam campaign results:

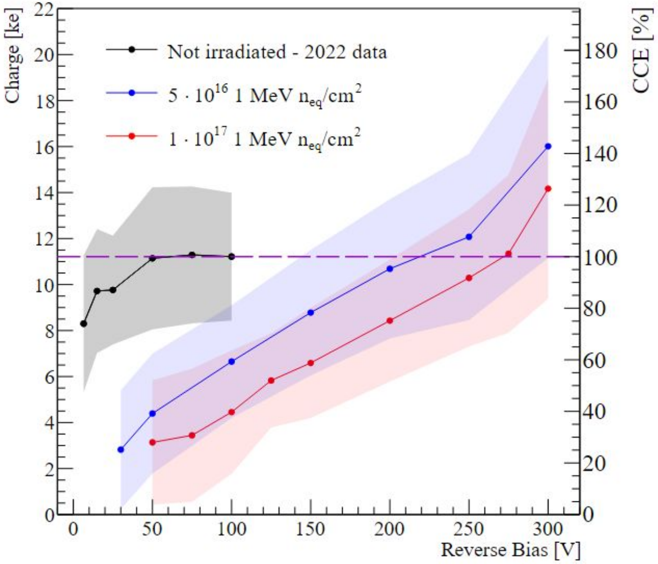
Some results: time resolution, efficiency and charge collection efficiency:



Time resolution (calculated with spline method) less than 20 ps



Efficiency, calculated as the number of DUT signals over Triggers signals can rise up to 97%

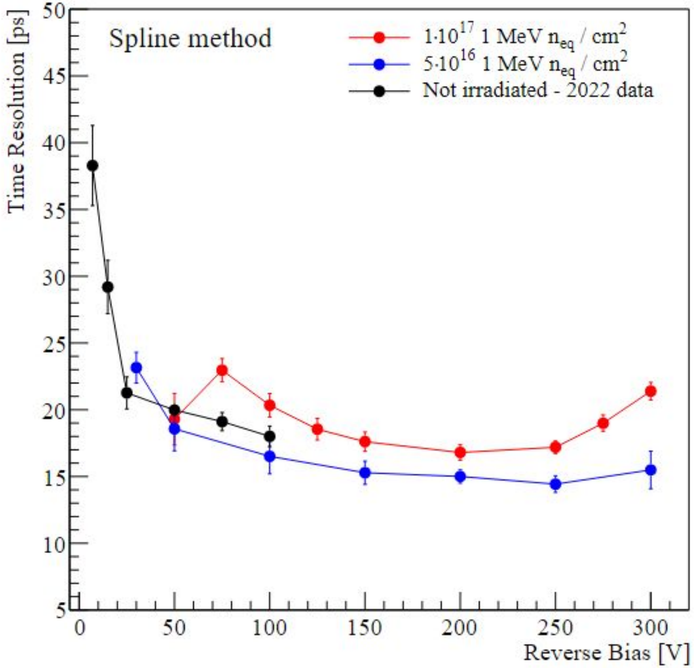


Charge collection can be restored by acting on the reverse voltage. We also discover “multiplication” effects on this type of technology.

Characterisation of highly irradiated test structures

Time resolution comparison

Test-Beam



^{90}Sr source