



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

Research topic of my PhD program

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

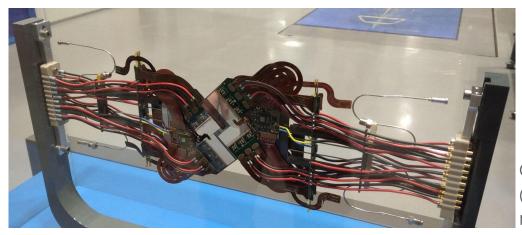
• Position resolution: $\sigma_{_{\rm X}}$ ~ 10 μ m @ HL-LHC, less for next-gen experiments;

• **Ultrafast timing:** σ_{t} ~ 50 ps @ HL-LHC, less for next-gen experiments;

• Radiation tolerance: $\phi \sim 5x10^{16}$ @ HL-LHC up to $5x10^{18}$ 1MeV n_{eq} /cm² for next-gen experiments.

Research topic of my PhD program

- 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).



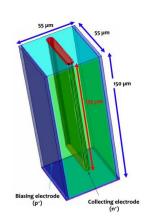
Current VeLo modules (Image taken by M. Verdoglia in the LHCb museum room)

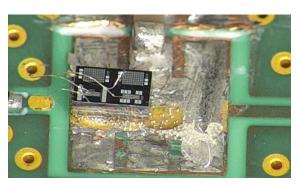
Objectives of my PhD program

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 $\mu \rm m$ pitch pixel, 150 $\mu \rm m$ thik





High irradiated TimeSPOT test structure, Φ = 10¹⁸ 1 MeV n_{eq}/cm² (microscope image)

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

(Attended in Jan.2025)

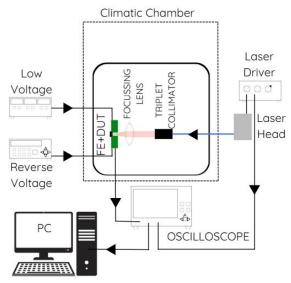
6) XXII **Seminar** on Software for Nuclear, Subnuclear and Applied Physics

(passed, 4CFU);



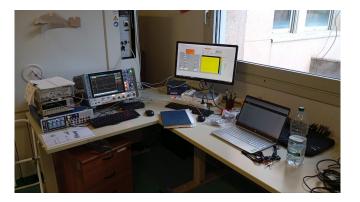
22nd Seminar on Software for Nuclear, Subnuclear and applied Physics (Attended in June.2025)

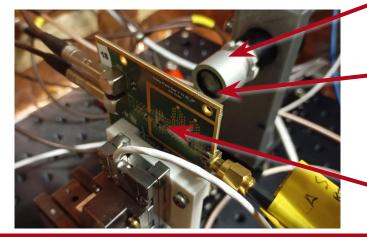
In-pixel studies using the Cold-TCT setup



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







In-pixel studies using the Cold-TCT setup

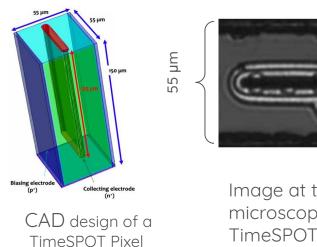
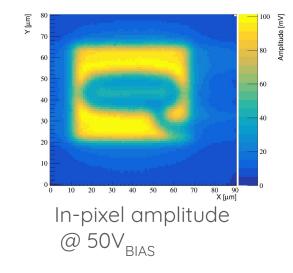
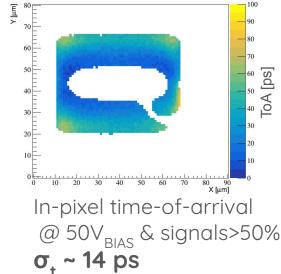


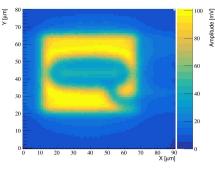
Image at the microscope of a TimeSPOT pixel



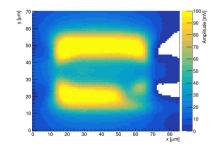


In-pixel studies of highly irradiated sensors using the **Cold-TCT** setup and at the **test beam**:

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

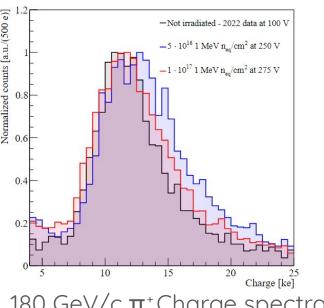


Not irradiated In-pixel amplitude @ 50V_{RIAS}



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



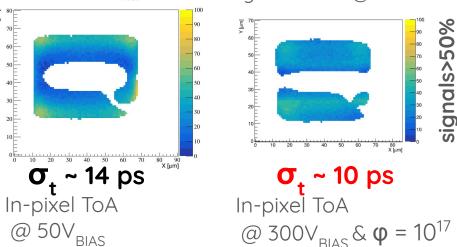


180 GeV/c π^+ Charge spectra (test beam @ SPS-H8)

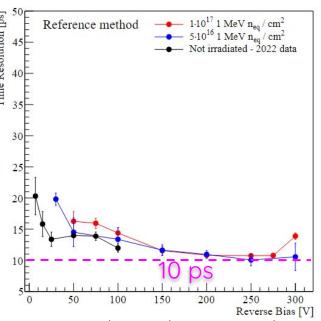
In-pixel studies of highly irradiated sensors using the Cold-TCT setup and at the

test beam:

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

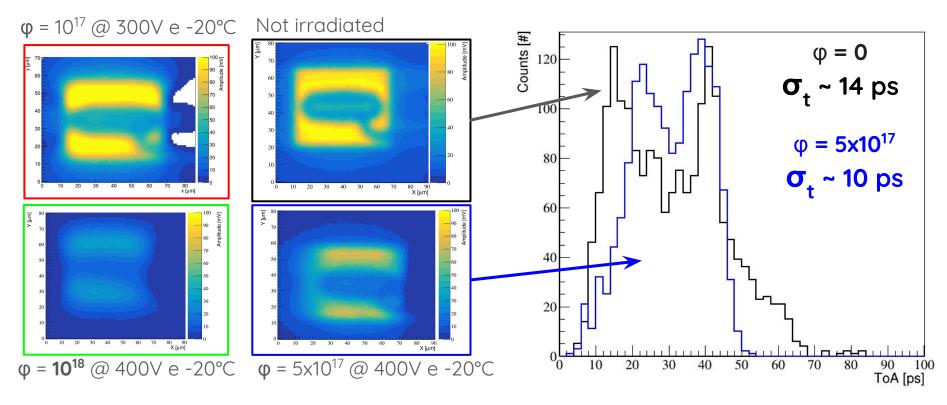


Radiation tolerance up to 10¹⁷!!!

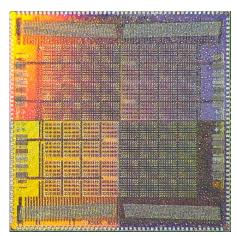


Temporal resolution at the test beam @ SPS-H8

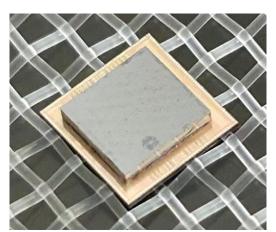
In-pixel studies of highly irradiated sensors using the **Cold-TCT** setup:



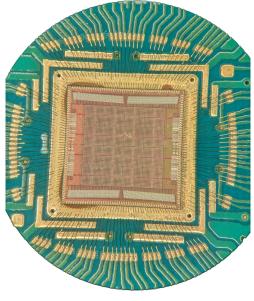
Characterization of 64x64 pixel matrices in laboratory (using the Cold-TCT setup) and at the test beam.



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)



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





Other academic achievements



+ IFAE 2025 Proceeding (coming soon)



A. Lampis 68. A. Loi 6. M. M. Obertino 23. S. Vecchi 10 and Università di Padova, Padova, Italy, "INFN, Sazione di Cagliari, Cagliari, Italy, "Dipartimento di Fisica

Addison M. Belliona A. Borgato F. Brundu D Cardini A. Cossu GM. Dalla Betta GF. La. Delfa L. Lai A. Lampis A. Loi A. Obertino MM. The 3D trench silicon pixel sensors developed by the TimeSPOT collaboration Vecchi S and Verdogla M (2024)

A Lameis

RECEIVED 16 September 2024

Characterisation of 3D trench silicon pixel sensors imadiated at 1-10¹⁷ 1 MeV n_{les} cm⁻² have demonstrated exceptional performance, even after exposure to extreme radiation fluences up to 1-10¹⁷1MeVn_{so}/cm². This study assesses the radiation tolerance of these sensors using minimum ionizing particles during a beam test campaign. The results indicate that while radiation damage reduces charge collection efficiency and overall detection efficiency, these losses can be @ 2024 Addison, Beliera Borgato Brundu Cardini, Cossu, Dalia Betta, La Delfa, Lai, Lampis, Loi, Obertino, Vecchi and Verdogli This is an open-access article distributed mitinated to levels comparable to non-irradiated sensors by increasing the reverse bias voltage. Charge multiplication was observed and characterised for the first time in 3D trench sensors, revealing a distinct operating regime postirradiation achievable at bias voltages close to 300 V. Additionally, the timing performance of irradiated sensors remains comparable to their non-irradiate counterparts, underscoring their resilience to radiation damage. Currently, 3D the copyright owner(s) are credited and that the original publication in this journal is cited in accordance with accepted academic trench silicon detectors are among the fastest and most radiation-hard pixel concers available for vertex detectors in high-energy physics colliders. These practice. No use, distribution or reproduction is permitted which does not comply with findings highlight the potential of these sensors for new 4D tracking systems of

future experiments at the Future Circular Hadron Collider (FCC-hh), advancing particle tracking detectors, solid-state detectors, timing detectors, 4D tracking, radiation hardness, high time resolution, high luminosity, FCC-hh

the capabilities of radiation-hard sensor technology.

1 Introduction

Tracking particles at extremely high fluences is one of the primary challenges for future hadronic collider experiments. To cope with the O(10) increase in instantaneous luminosity at the High Luminosity Large Hadron Collider (HL-LHC) compared to the current LHC, several innovative detector solutions have been proposed. Among these, 3D trench silicon pixel sensors have emerged as a promising candidate due to their excellent spatial and temporal resolution, along with their radiation hardness, which was already proven up to fluences of 2.5 · 10¹⁶ l MeV n_/cm² [1]. These sensor are particularly well-suited for high-occupancy tracking detectors operating close to



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)



CERN-LHCC-2024-010 LHCb-TDR-026 July 26, 2024

LHCb Upgrade II Scoping Document

LHCb collaboration

Abstract

A second major upgrade of the LHCb detector is necessary to allow full exploitation of the LHC for flavour physics. The new detector is proposed for installation during the long-shutdown 4 (LS4), and will operate at a maximum luminosity of 1.5×10^{34} cm⁻² s⁻¹. By upgrading all subdetectors and adding new detection capability it will be possible to accumulate a sample of 300 fb⁻¹ of high energy pp collision data, giving unprecedented and unique discovery potential in heavy flavour physics and other areas. The baseline LHCb Upgrade II detector has been presented in a Framework Technical Design Report in 2022. Here, updated and additional scoping options with reduced detection capability and different choice of operational luminosity are presented. The costs and physics performance of each scenario are discussed, and an overview of the project management plans is presented

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>40 papers within I HCb collaboration

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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 !!!





THANKS !!!

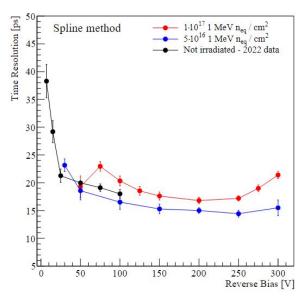




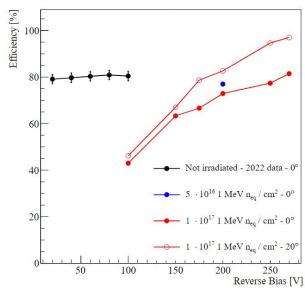
Backup slides

Test Beam campaign results:

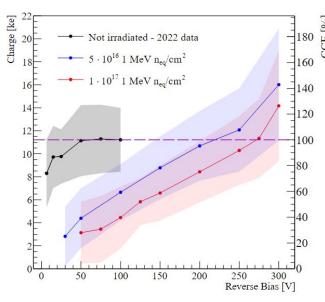
Some results: time resolution, efficiency and charge collection efficiency:



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%

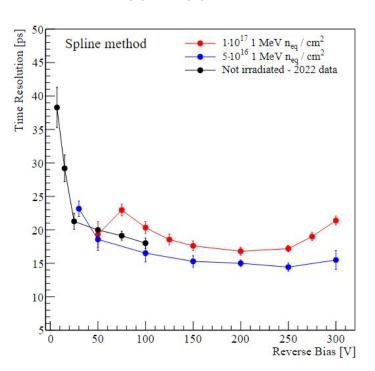


Charge collection can be restored by acting on the reverse voltage. We also discover "multiplication" effects on this type of technology.

Characterisation of highly irradiated test structures

Time resolution comparison





⁹⁰Sr source

