



UNIVERSITÀ
DEGLI STUDI
DI PADOVA



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

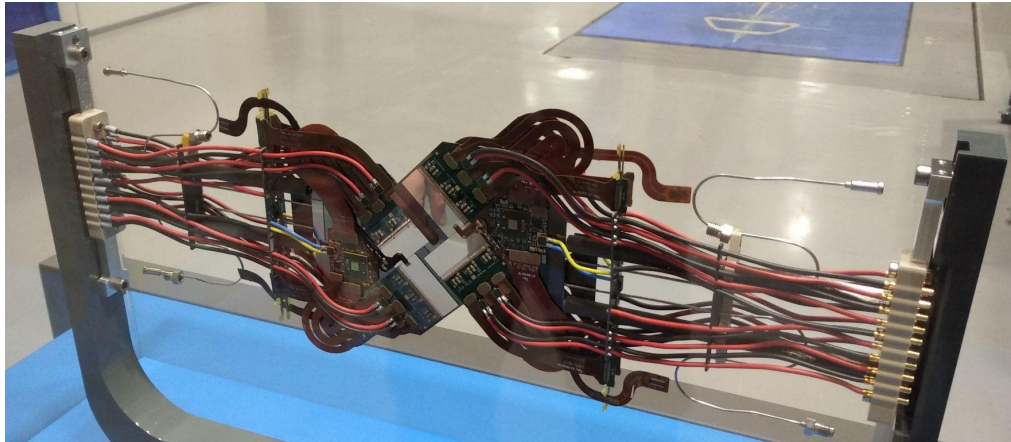
Research topic of my PhD program

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

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

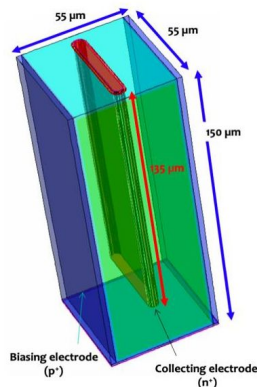


Current VeLo modules
(Image taken by M. Verdoglia in the LHCb museum room)

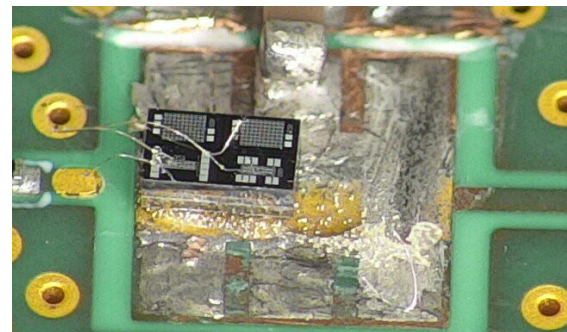
Objectives of my PhD program

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 thick



High irradiated TimeSPOT test structure, $\Phi = 10^{18} \text{ 1 MeV } n_{\text{eq}}/\text{cm}^2$ (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

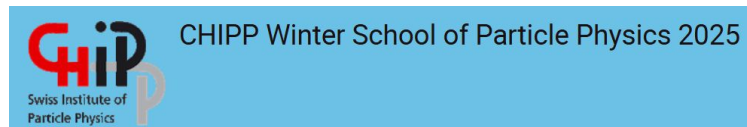
1 Year: Characterization and testing of highly irradiated test structures (with neutrons @ 10^{17} 1MeV n_{eq}/cm^2), studying the time resolution, efficiency and charge collection efficiency in laboratory and test beam;

2 Year: Characterisation of extreme irradiated sensors (with neutrons $\sim 10^{18}$ 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;



(Attended in Jan.2025)

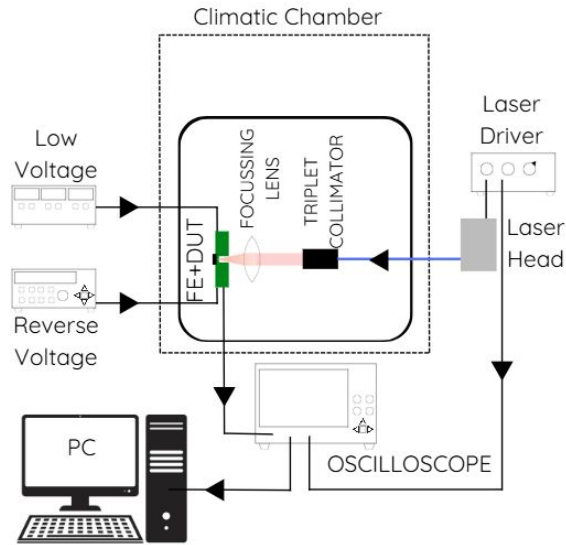
- 6) XXII **Seminar** on Software for Nuclear, Subnuclear and Applied Physics (passed, 4CFU);



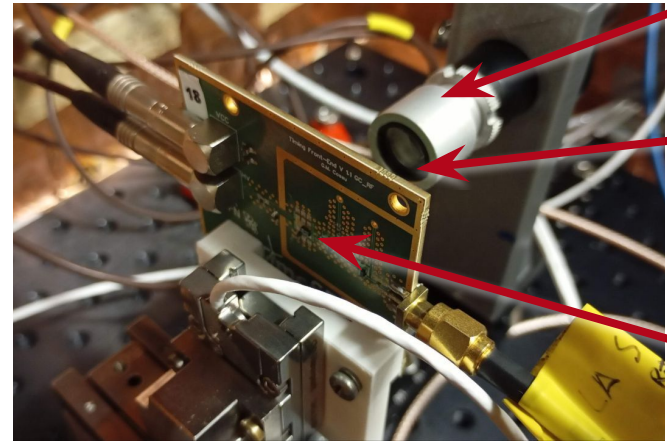
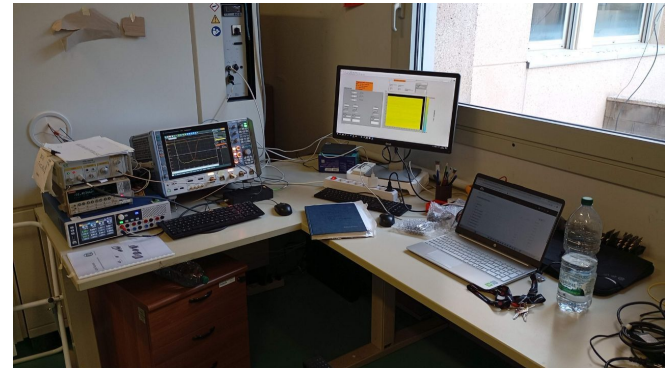
22nd Seminar on Software for Nuclear, Subnuclear and applied Physics (Attended in June.2025)

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

In-pixel studies using the Cold-TCT setup



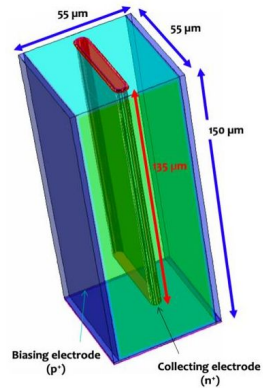
Schematic of the Cold-TCT setup I developed to test extreme irradiated sensors



Detector, Laser & Optics

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

In-pixel studies using the Cold-TCT setup



CAD design of a TimeSPOT Pixel

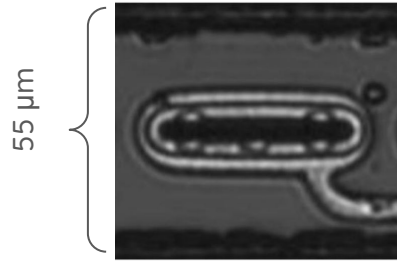
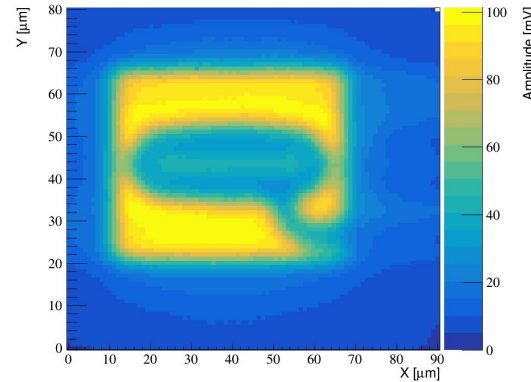
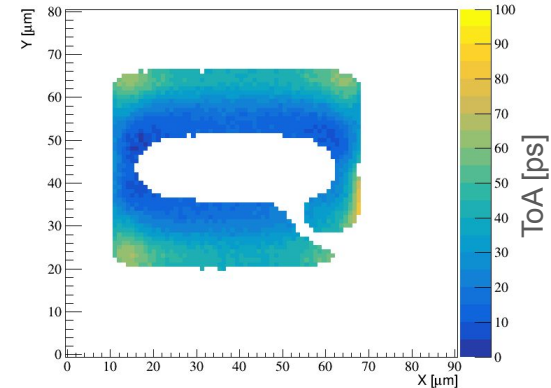


Image at the microscope of a TimeSPOT pixel



In-pixel amplitude
@ 50V_{BIAS}

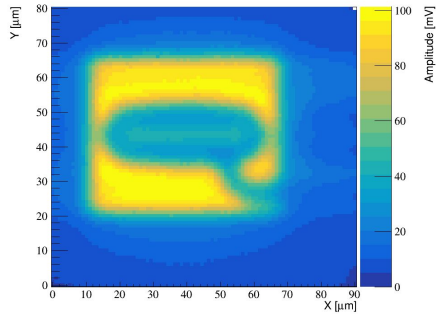


In-pixel time-of-arrival
@ 50V_{BIAS} & signals > 50%
 $\sigma_t \sim 14 \text{ ps}$

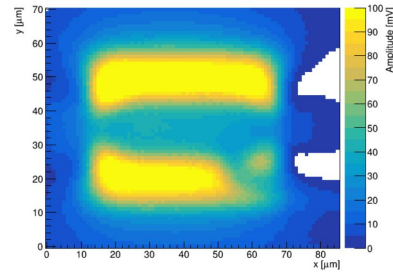
Research activities **carried out so far** and those planned for the 3rd year

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

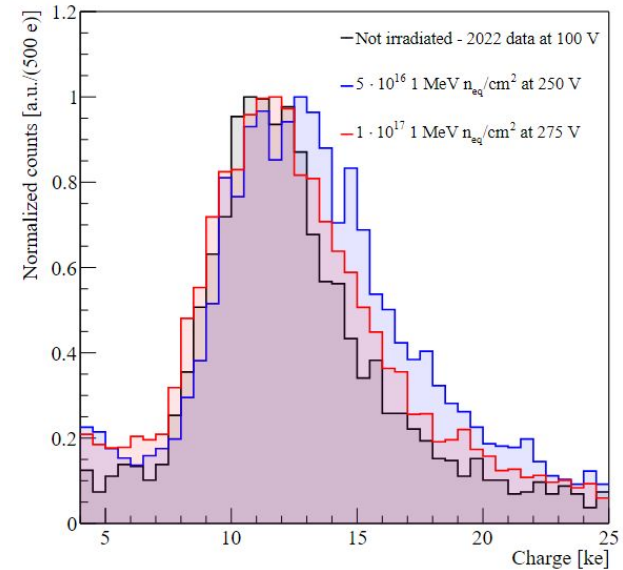


Not irradiated
In-pixel amplitude
@ 50V_{BIAS}



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

Full CCE recovery !!!

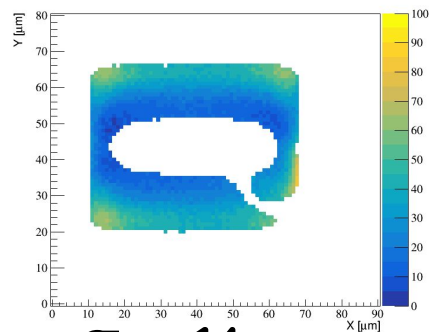


180 GeV/c π^+ Charge spectra
(test beam @ SPS-H8)

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

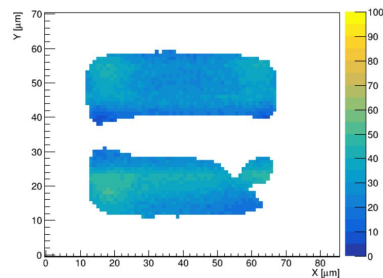
In-pixel studies of highly irradiated sensors using the **Cold-TCT** setup and at the **test beam**:

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



$$\sigma_t \sim 14 \text{ ps}$$

In-pixel ToA
@ 50V_{BIAS}

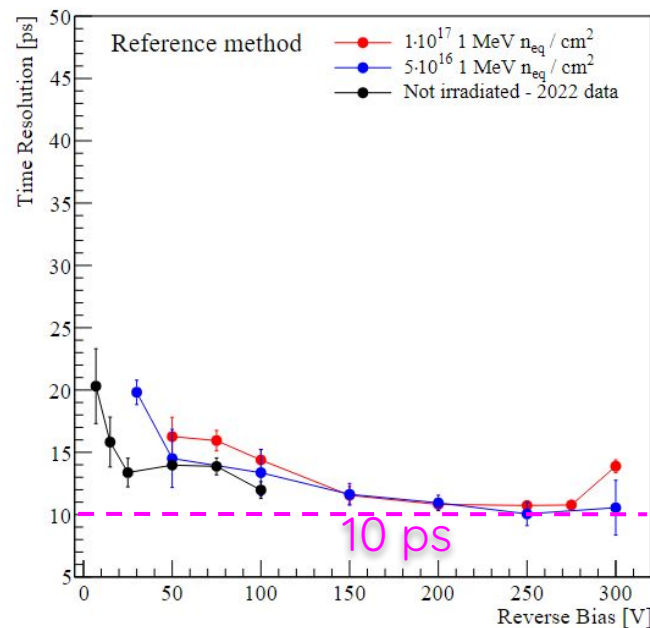


$$\sigma_t \sim 10 \text{ ps}$$

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

signals > 50%

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

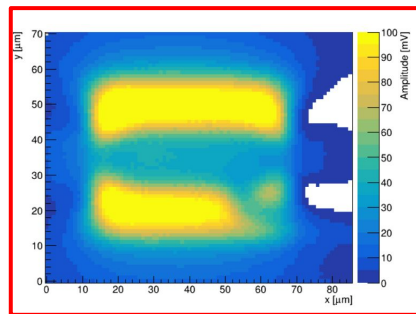


Temporal resolution at the
test beam @ SPS-H8

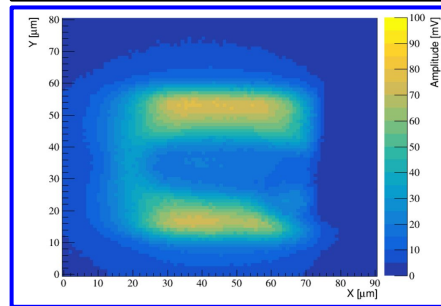
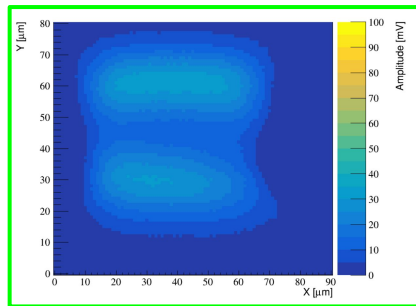
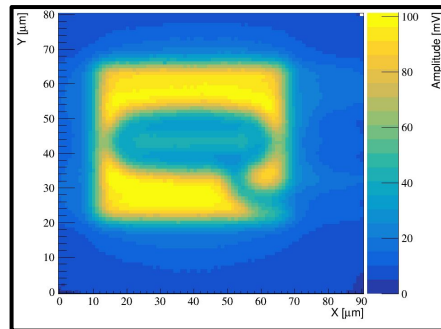
Research activities **carried out so far** and those planned for the 3rd year

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

$\phi = 10^{17}$ @ 300V e -20°C

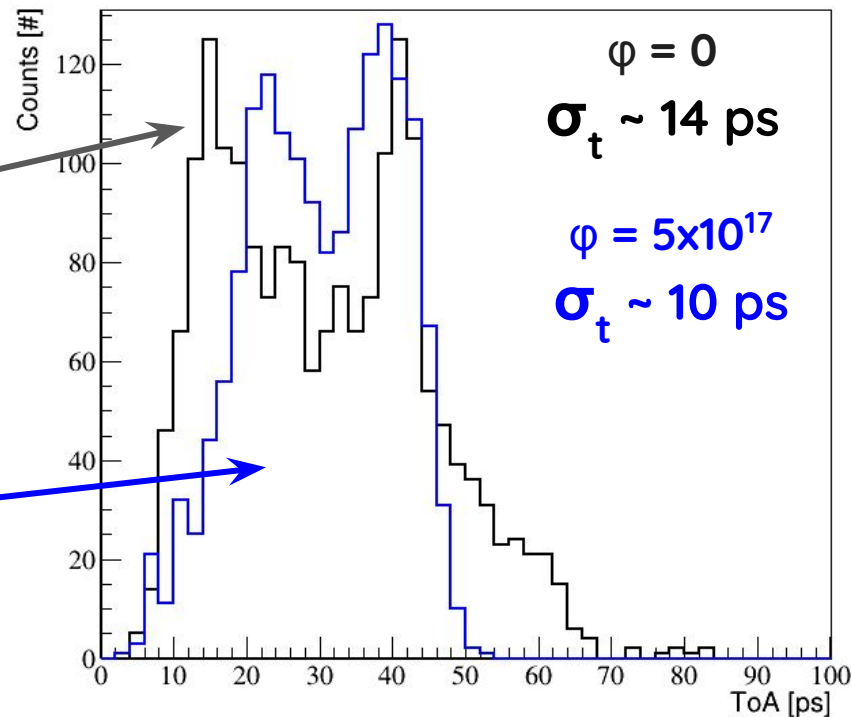


Not irradiated



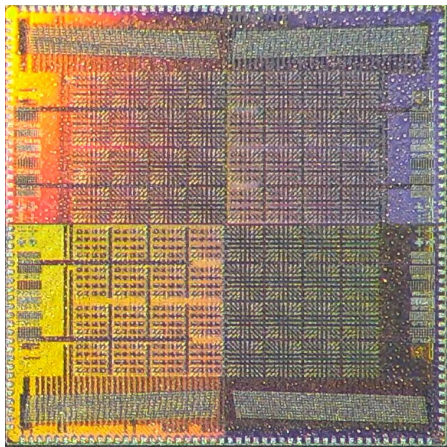
$\phi = 10^{18}$ @ 400V e -20°C

$\phi = 5 \times 10^{17}$ @ 400V e -20°C

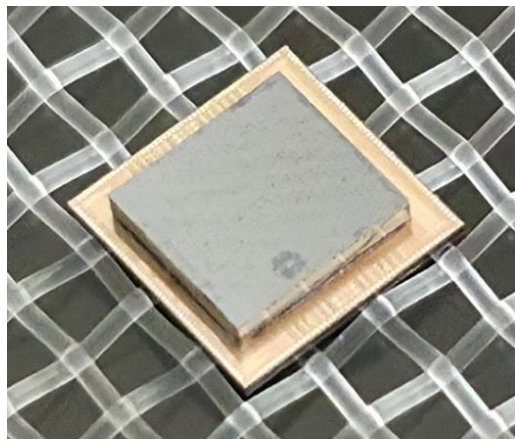


Research activities carried out so far and those planned for the 3rd year

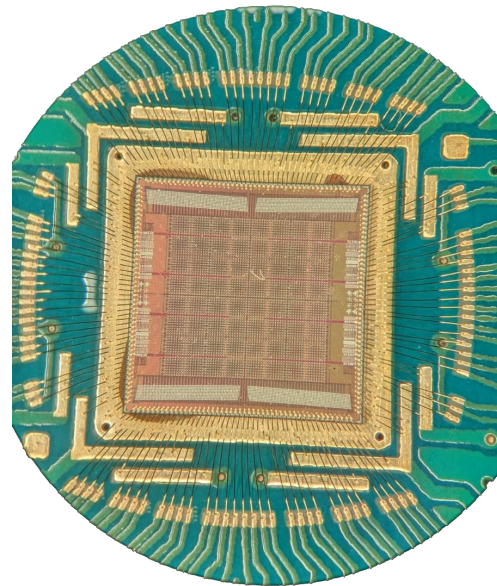
Characterization of 64x64 pixel matrices in laboratory (using the Cold-TCT setup) and at the test beam.



IGNITE64
28nm CMOS ASIC

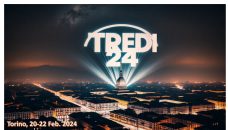


3D-Trench Sensors
connected
to the IGNITE64 ASIC



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)



Responsible 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

+ IFAE 2025
Proceeding
(coming soon)

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

LHCb Upgrade II Scoping Document

Abstract

© 2024 CERN for the benefit of the LHCb collaboration. CC BY 4.0 licence.

>40 papers within
LHCb collaboration

INPN-funded TimeSPOT project has developed an innovative 3D silicon pixel sensor optimized for high-precision timing: the 3D trench pixel sensor. This sensor has already demonstrated excellent time resolution and detection efficiency for detecting Minimum Ionizing Particles (MIPs) even after being irradiated at $2.5 \cdot 10^{14}$ MeV n_{eq} cm^{-2} [1,2] and $1.0 \cdot 10^{17}$ MeV n_{eq} cm^{-2} [3].

A new irradiation campaign has been carried out reaching a maximum radiation fluence of $1 \cdot 10^{18}$ MeV n_{eq} cm^{-2} , and a new laboratory laser setup has been recently developed to characterize irradiated sensors. This work presents preliminary results of the laser characterization

Tracking particles at extremely high fluences is one of the primary challenges for future hadronic collider experiments. To cope with the $\mathcal{O}(10)$ 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 $2.5 \cdot 10^{14} \text{ MeV}/\text{cm}^2$ [1]. These sensors are particularly well-suited for high occupancy tracking detectors operating close to

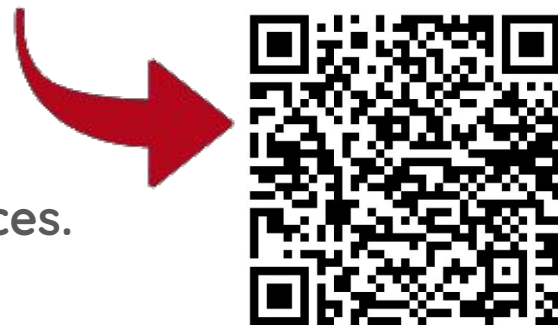
18/09/2025 - michele.verdoglia@studenti.unipd.it

14

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 !!!





UNIVERSITÀ
DEGLI STUDI
DI PADOVA



THANKS !!!



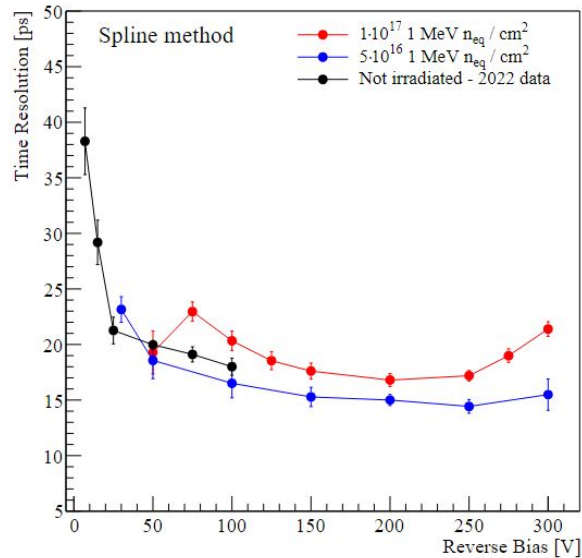
UNIVERSITÀ
DEGLI STUDI
DI PADOVA



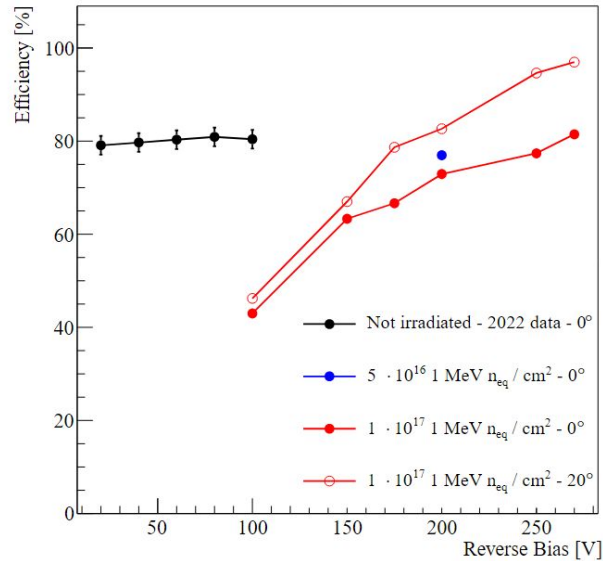
Backup slides

Test Beam campaign results:

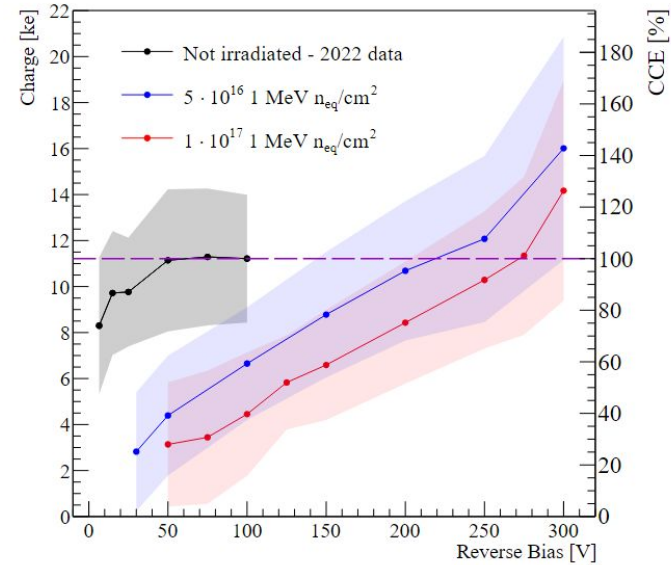
Some results: time resolution, efficiency and charge collection efficiency:



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%

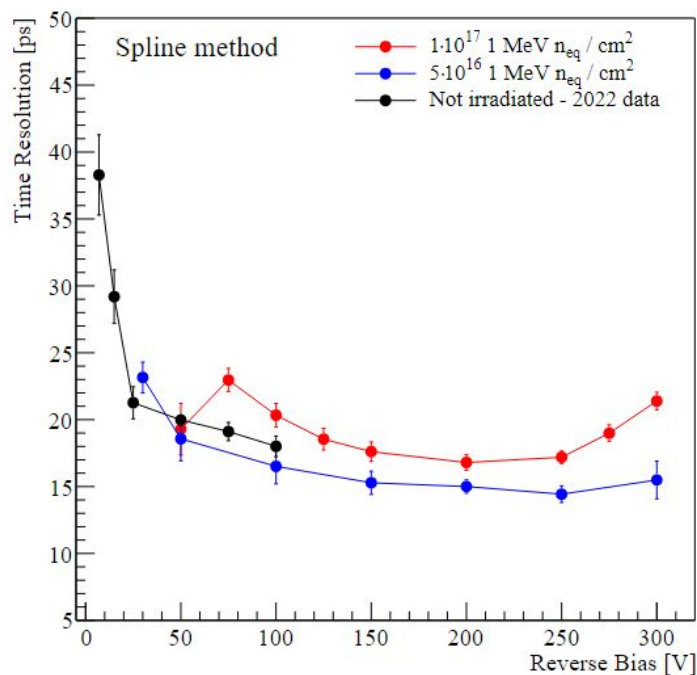


Charge collection can be restored
by acting on the reverse voltage.
We also discover “multiplication”
effects on this type of technology.

Characterisation of highly irradiated test structures

Time resolution comparison

Test-Beam



⁹⁰Sr source

