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

MICHELE VERDOGLIA

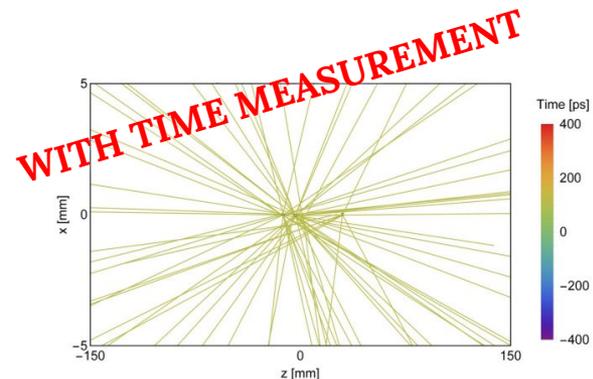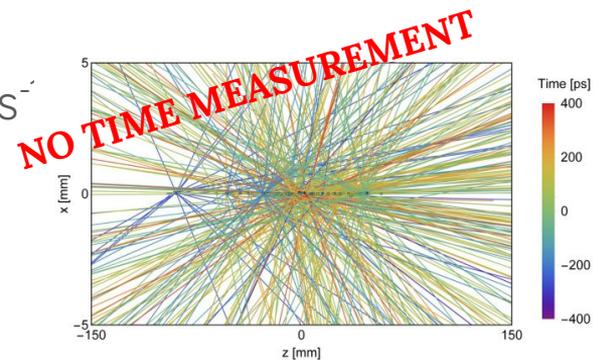(Ph.D. student of Tech-FPA: Technologies for Fundamental Physics and Astrophysics)

CHIPP Winter school of Particle Physics 2025

Challenges of future trackers

In the near and far future colliders will increase the *Luminosity* i.e. HL-LHC > 5×10^{34} cm^{-2} s^{-1}, FCC ~ 10^{36} cm^{-2} s^{-1}

This requires TRACKERS detectors capable of:
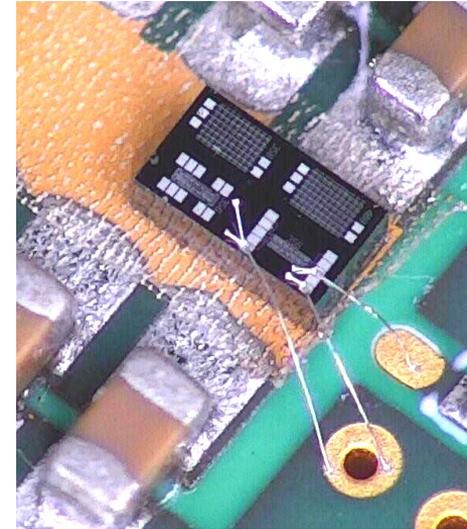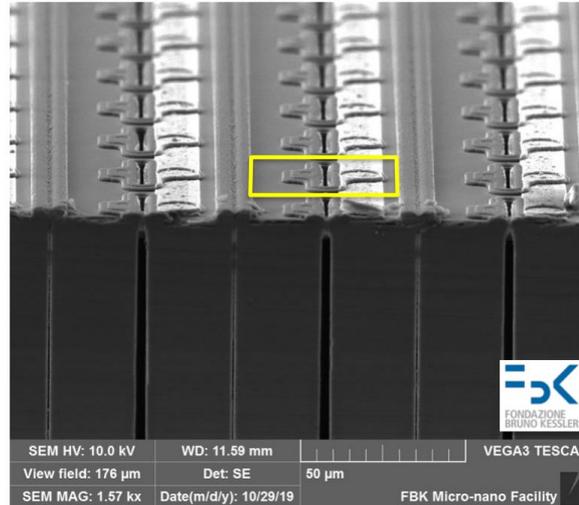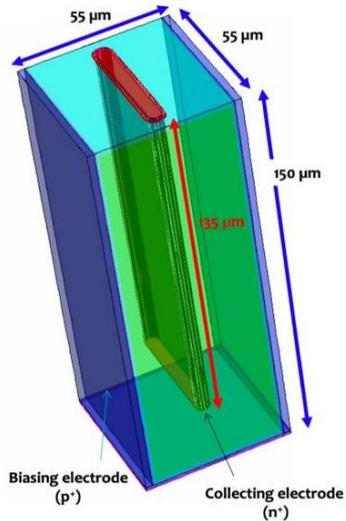
- Time measurements (σ_t ~ 50 ps or better)* in order to proper reconstruct the PVs.

- Radiation hardness ($\Phi > 10^{16}$ 1 MeV n$_{eq}$ cm^{-2})*, maintaining performance at that level of radiation (radiation damage).

*LHCb VELO UII

TimeSPOT sensors

- 3D silicon pixel technology is suitable for its *radiation hardness*;
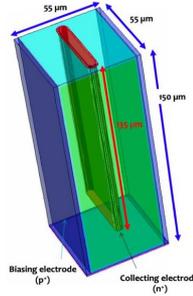- Geometry optimisation lead to excellent *timing performance*.
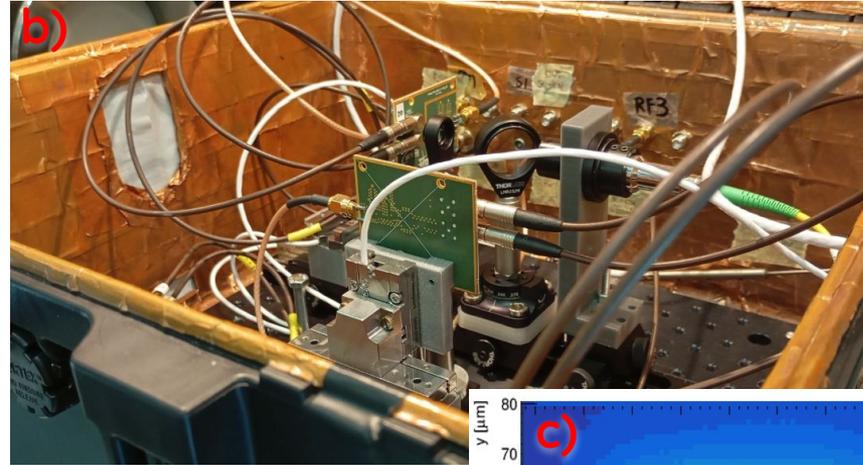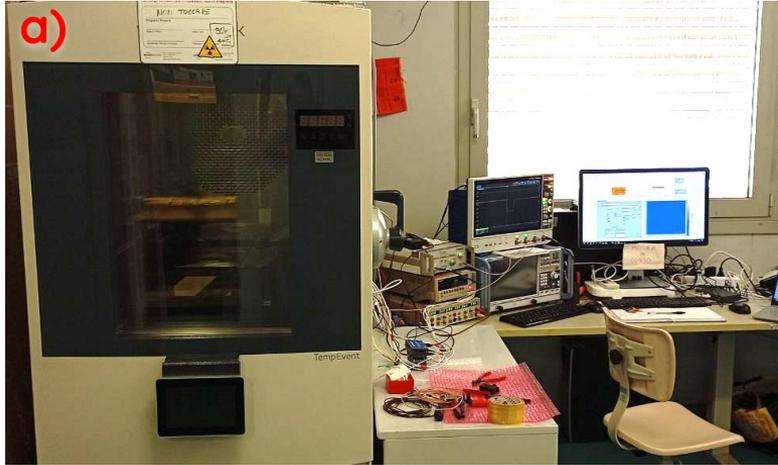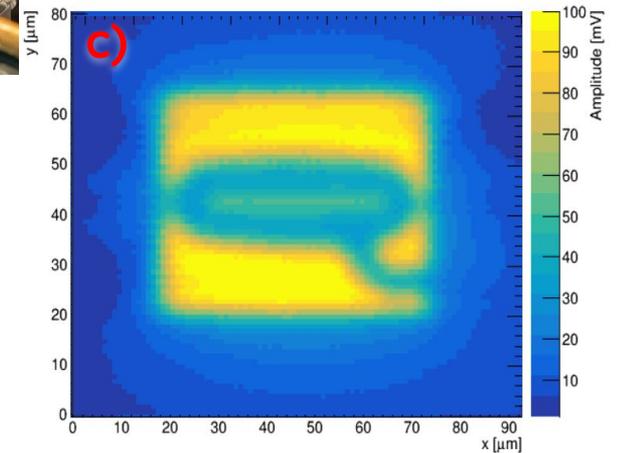

CAD Design

Sensor production at FBK

Test structure

Ph.D. Project

- Perform R&D in the field of P.V. trackers for future experiments at colliders
    a. Study case LHCb VELO UII:
        i. In-Pixel characterization using a micro focussed laser;
        ii. Test Beam campaigns;
        iii. Study of **radiation damage** on TimeSPOT sensors;
        iv. Study TimeSPOT **timing** performances;
        v. Geant4 simulations for measurements planning (laboratory measurements and test beam).

    b. FCC:
        i. Study of extreme irradiated sensors ($\Phi = 10^{18}$ 1MeV n_{eq} / cm^2).

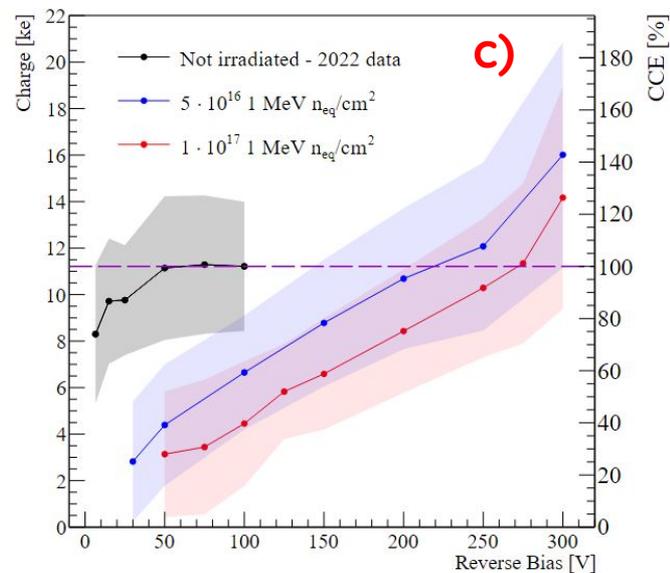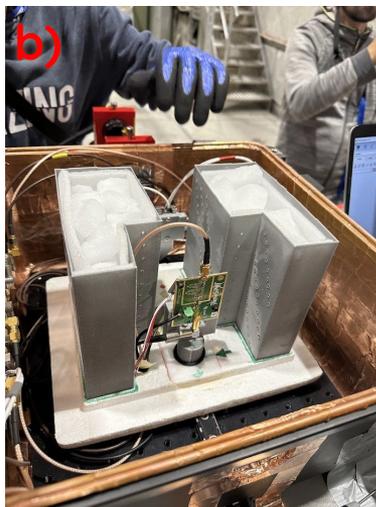- Study 28nm CMOS ASIC and **4D tracking** (April 2025).

In-Pixel characterization

a) Picture of experimental setup controlled by a LabVIEW software coded by me.
b) Picture of the optical setup inside the climatic chamber.
c) In-Pixel Amplitude map.

Test Beam campaigns

a) Picture of experimental setup at SPS H8;
b) Picture of the DUT and dry-ice cooling system;
c) CCE result plot[*]

Test Beam Results: $\Phi=10^{17}$, σ_t < 20 ps, Efficiency ~ 97%, full recovery of CCE

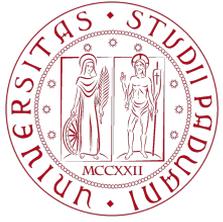[*]https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2024.1497267/full

What's next ?

Conclude the study of small test-structures

- $\Phi = 10^{18}$ - test beam (May 2025).

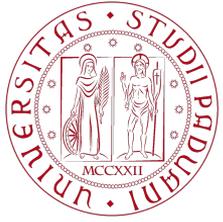28nm CMOS ASICs characterisation and **4D tracking** at test beam:

- The 28nm CMOS technology represents a good candidate for radiation-hardened front-end electronics; INFN has initiated the OPTIME project, to design and produce ASICs to couple with 3D sensors:

- Assemble a telescope using OPTIME ASICs bump-bonded to 3D TimeSPOT sensors and perform 4D particle tracking (position and arrival time) at test beam (~October 2025).
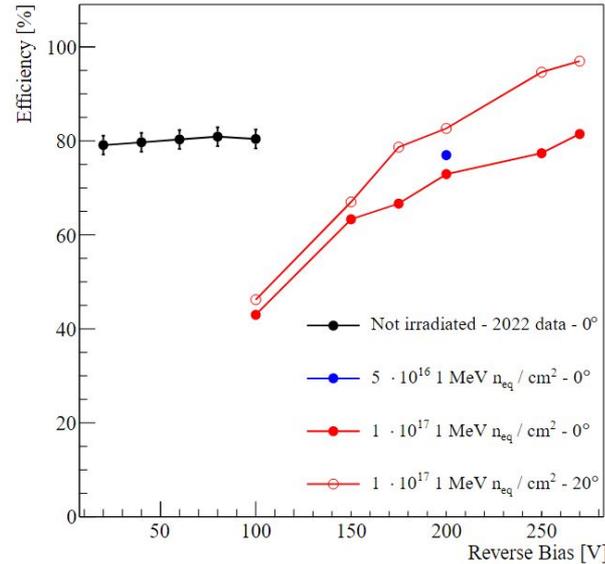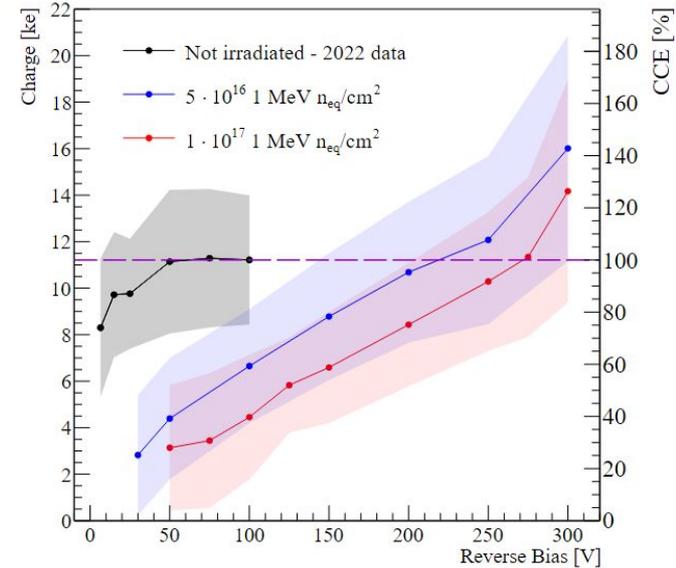
THANKS !!!

Back-up Slides

Some results: time resolution, efficiency and charge collection efficiency[*]:

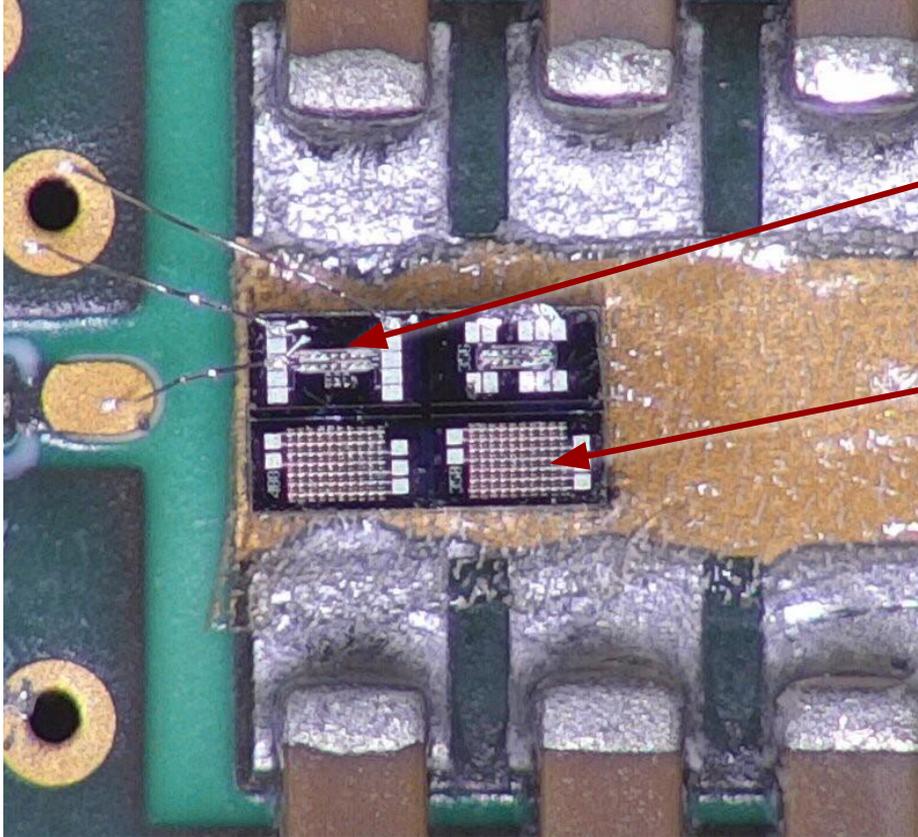Time resolution (calculated with spline method) less than 20 ps

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.
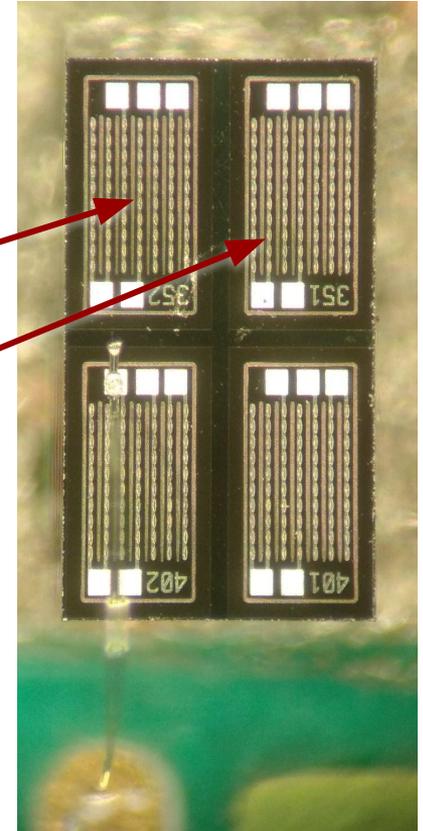
[*]https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2024.1497267/full
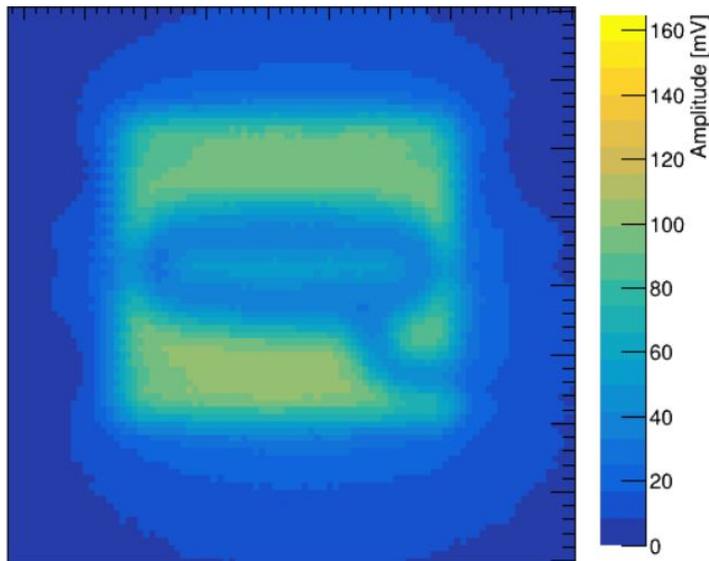
Test Structures

Single Pixel

Pixels 1-Strip

Pixels 3-Strip
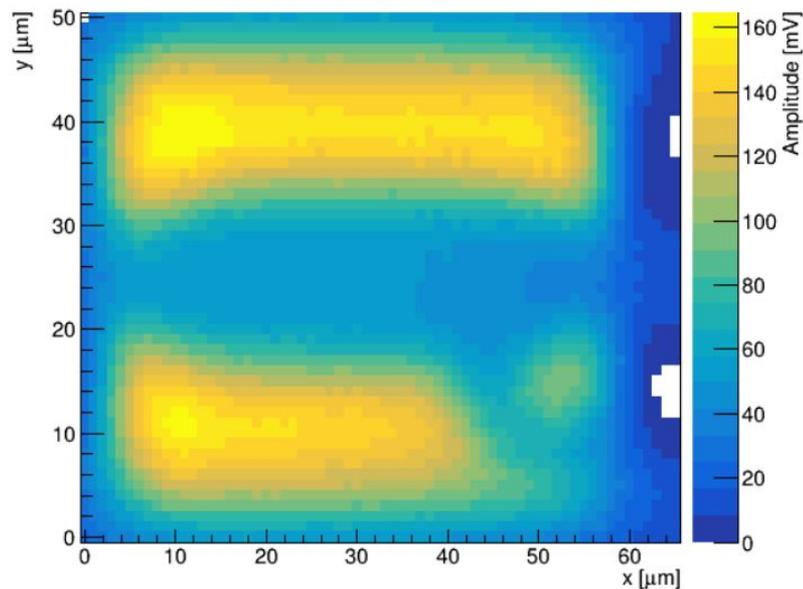
Φ=10^{17} Amplitude maps comparison
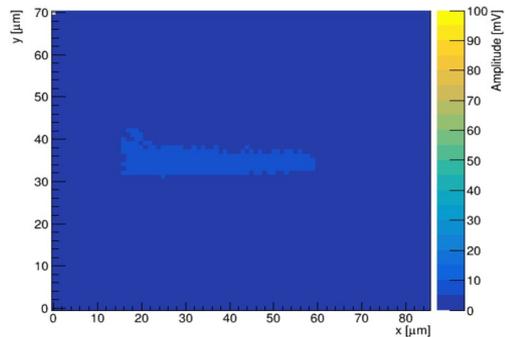
Max Amplitude = 165 mV
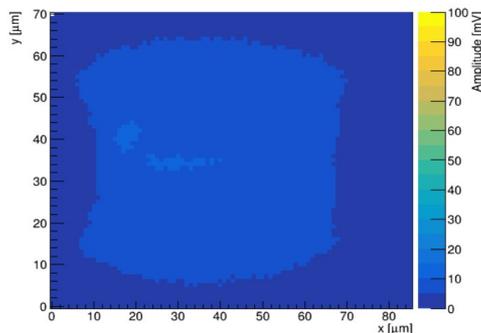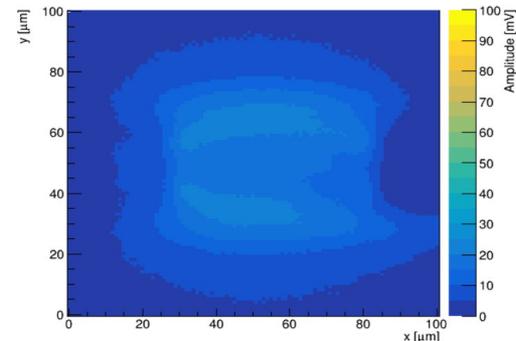
(Not Irradiated) @ HV = –50 V

10^{17} @ HV = –320 V

Φ=10¹⁷ Amplitude maps

HV = –50 V @ HV = –100 V @ HV = –150 V

HV = –200 V @ HV = –250 V @ HV = –300 V