Presentation for admission to the 2nd year

PhD Program of National Interest in
"Technologies for fundamental research in Physics and Astrophysics"
(Curriculum: Detectors, Lasers and Optics)

Dr. Tommaso Croci

PhD TECH-FPA, XXXIX cycle, A.Y. 2023/2024

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Perugia, 06/09/2024

Outline

- Research topic, objectives and overall planning
- Courses, exams and other training activities
  - ❑ 1st academic year
  - ❑ 2nd academic year
- Research activities and academic achievements
  - ❑ 1st academic year
  - ❑ 2nd academic year (planning)

Research topic

- Development of innovative radiation-hard silicon particle detectors for 4D tracking in future high-energy physics experiments (e.g., Future Circular Collider – FCC, at CERN, Geneva, Switzerland)

- Objectives → Activities

❑ Development of **Technology-CAD** (**TCAD**) **simulation methodologies** and **models** for **particle sensors** and **radiation-induced damage effects** at extreme fluences (10^{16}-10^{17} 1 MeV n_{eq} cm^{-2}) → TCAD simulation

❑ **Electrical characterisation** and **beam test** of the **available sensor samples** by means of proper test equipment and accelerator centre facilities, **before** and **after irradiation** → Experimental measurement

❑ **Irradiation** of the **available sensor samples** by means sources and irradiation facilities → Irradiation

❑ **Calibration** and **validation** of the **developed TCAD model** based on the agreement between simulation and experimental data → Model validation

❑ **Dissemination** of the research activities at **conferences**, through the publication of **articles** and the production of the **final thesis** → Dissemination

Objectives & overall planning

- Development of innovative radiation-hard silicon particle detectors for 4D tracking in future high-energy physics experiments (e.g., Future Circular Collider – FCC, at CERN, Geneva, Switzerland)

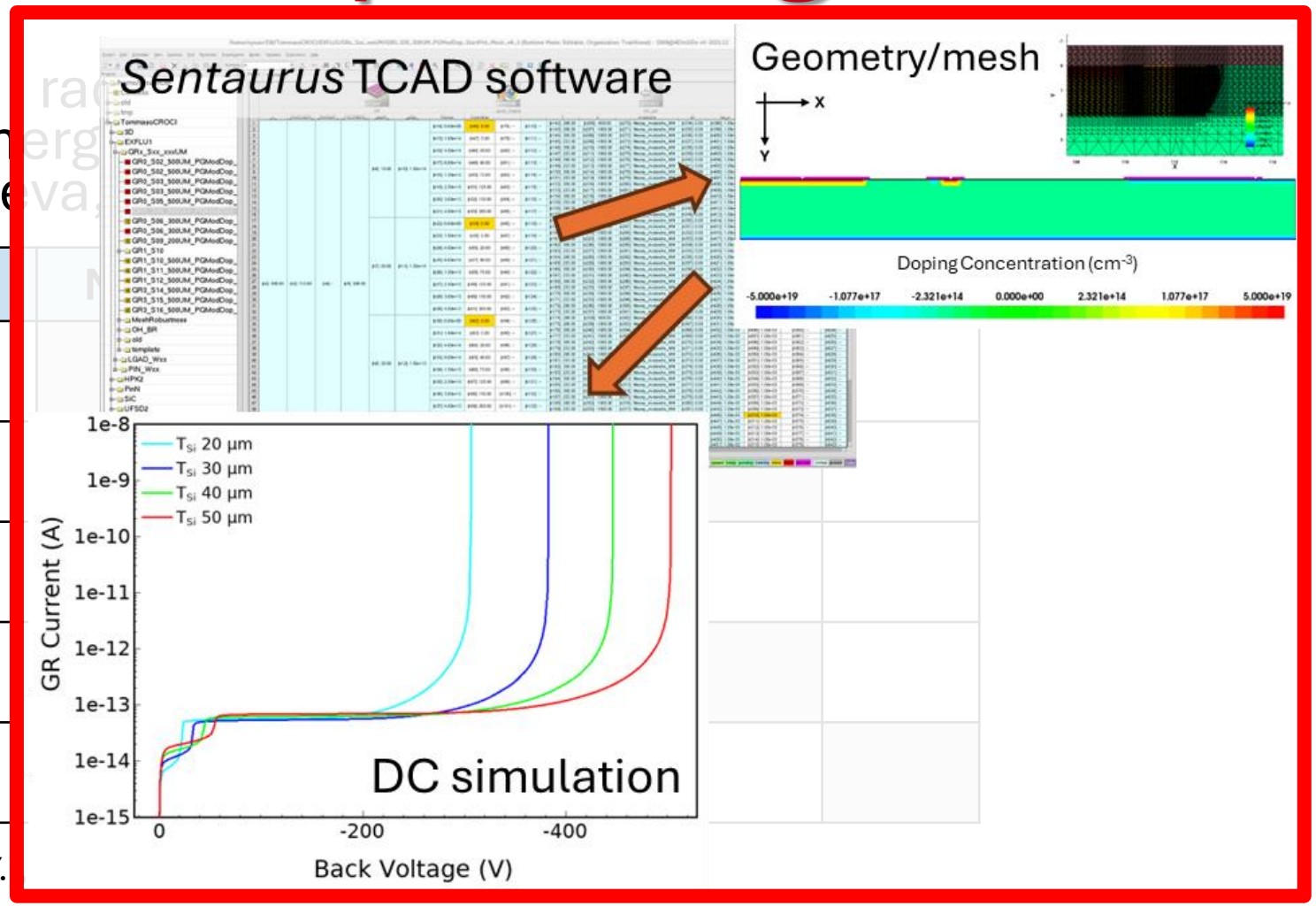
Activities	M6	M12	M18	M24	M30	M36
TCAD simulation						
Experimental measurement						
Irradiation						
Model validation						
Dissemination						

M6-M12 (1st A.Y.), M18-M24 (2nd A.Y.), M30-M36 (3rd A.Y.), A.Y. (academic year).

Objectives & overall planning

- Development of innovative ra
  4D tracking in future high-en erg
  Collider – FCC, at CERN, Gene va,

Activities
TCAD simulation
Experimental measurement
Irradiation
Model validation
Dissemination

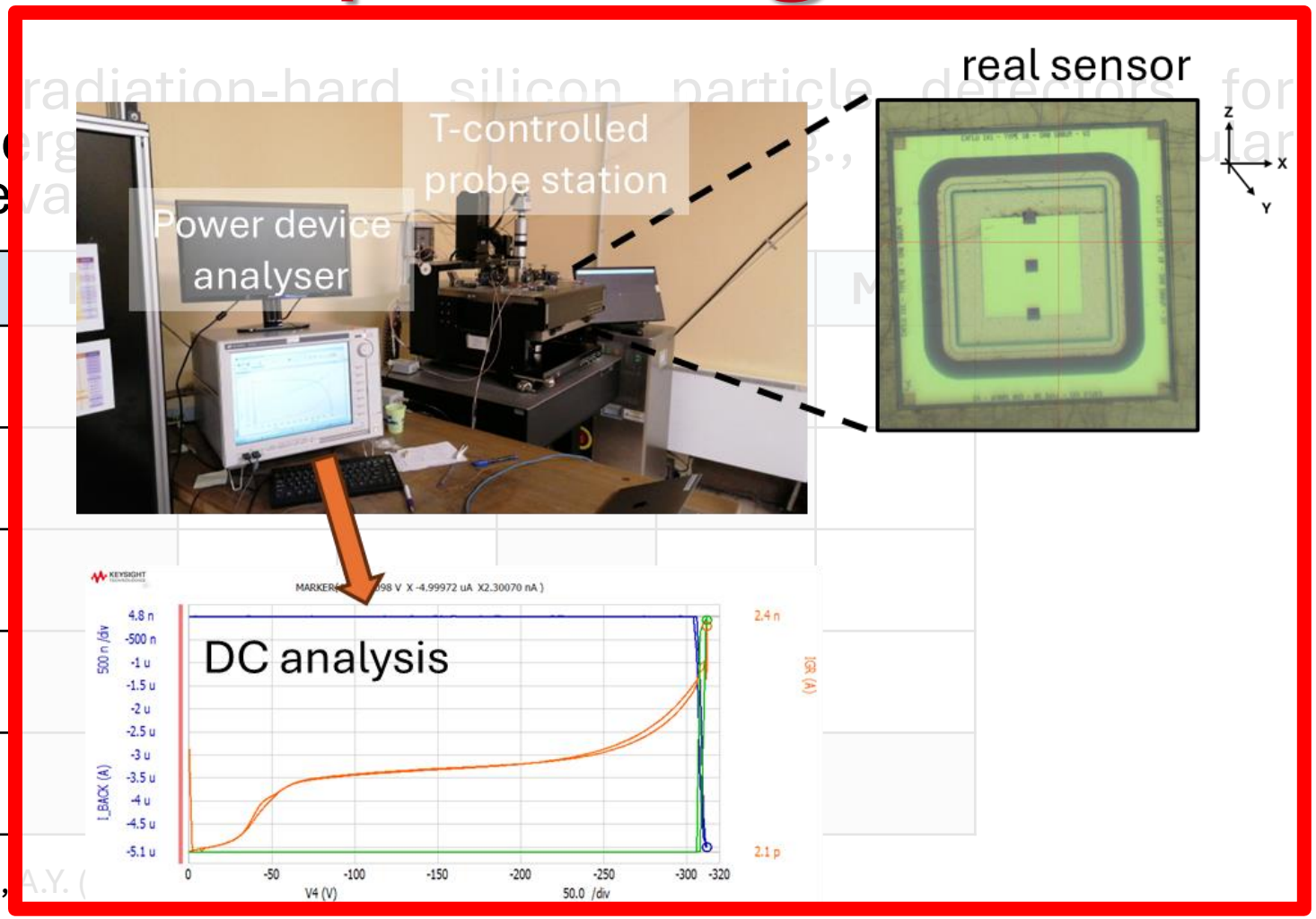


M6-M12 (1st A.Y.), M18-M24 (2nd A.Y.), M30-M36 (3rd A.Y.

Objectives & overall planning

- Development of innovative radiation-hard silicon particle detectors for 4D tracking in future high-energy [illegible] Collider – FCC, at CERN, Geneva

Activities
TCAD simulation
Experimental measurement
Irradiation
Model validation
Dissemination



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Objectives & overall planning

- Development of innovative rad … for 4D tracking in future high-energy … lar Collider – FCC, at CERN, Geneva,

Activities	M
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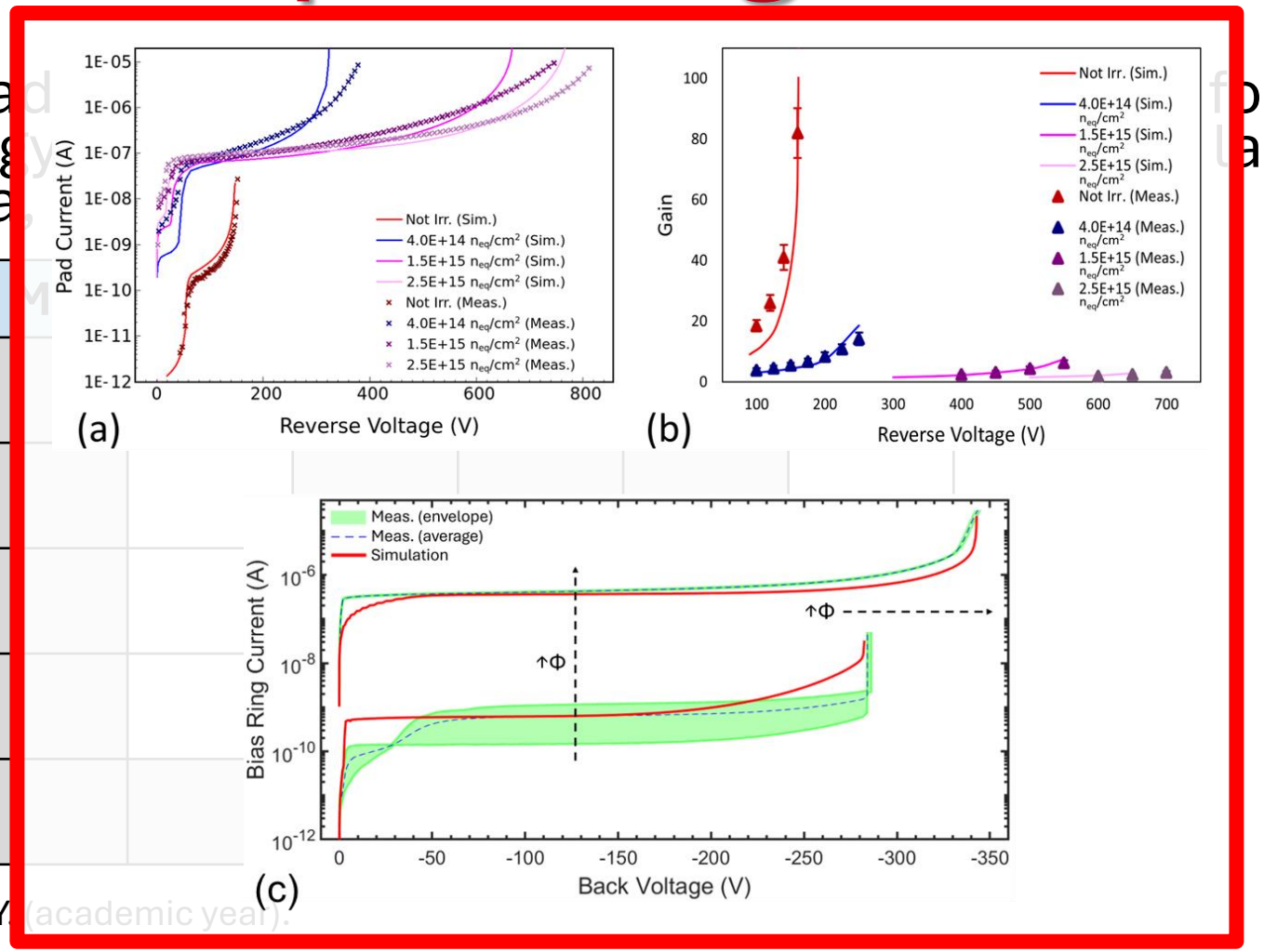

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Objectives & overall planning

- Development of innovative ra… for 4D tracking in future high-energ… Circular Collider – FCC, at CERN, Geneva

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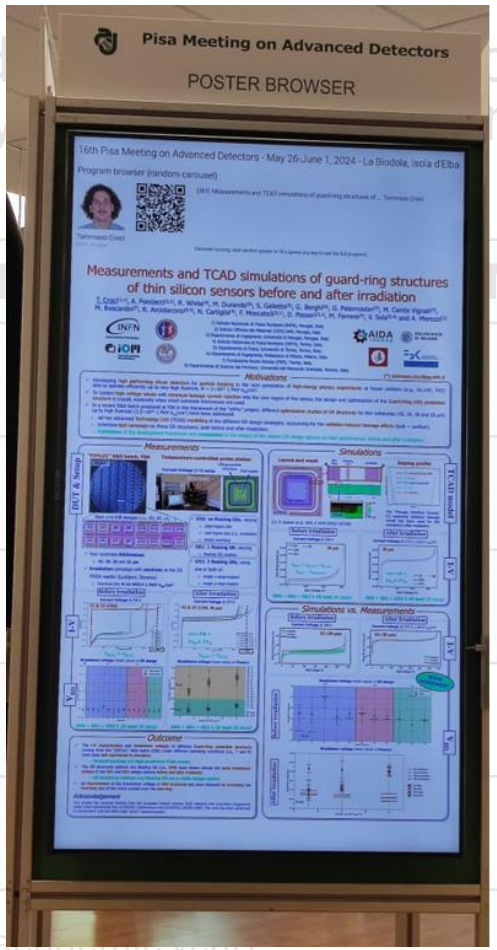

Courses, exams and other training activities (1/2)

- 1st academic year

❑ *Course*: "Advanced Scientific Programming in Matlab" (**22 Jan-28 Feb 2024**, Politecnico di Torino, course held online, 4.0 CFU)

❑ *Schools*:

- "Nuclear Physics meets Electronic Technology" (https://agenda.infn.it/event/38974/), **17-21 Jun 2024**, INFN Rome Unit, Italy.

  Topics: comprehensive understanding of how high-energy particles interact with semiconductors. This encompasses the theory behind these interactions, the effects of energetic ions on electronics, and the techniques used to characterize electronic devices with ion beams and test their radiation hardness.

- "Kick-off event of the TECH-FPA PhD course" (https://agenda.infn.it/event/41182/), **10-11 Jul 2024**, INFN Padova Unit, Italy.

  Topics: get to know each other and the teaching staff; understand the mission, structure, organisation and services of INFN and INAF; know the main scientific and technological challenges that motivate the research of the two institutions and the tools used to carry it out; visit the scientific and technological infrastructures of the RFX and INFN Legnaro National Laboratories.

❑ *Seminar*: "Advanced UK Instrumentation Training 2024" (https://indico.cern.ch/event/1401451/), **22 Apr-22 Jun 2024** (lectures held online).

Topics: background knowledge involved in silicon detector development, from solid-state theory to electronics and remote software tutorials. Lectures are grouped into the following themes: Semiconductor Theory, Electronics and DAQ, Mechanics and cooling, Fabrication and structures, Experimental techniques, TCAD electric field and transport simulations, Software tools, Short topics.

Courses, exams and other training activities (2/2)

- 2nd academic year

❑ *Courses*:

- "Machine Learning Programming in Physics" (**1 Oct-5 Nov 2024**, INFN and University of Bari, course held online, 2.5 CFU)
- "Design of readout integrated circuits for particle detectors" (**Nov 2024**, INFN and University of Bari, course held in dual mode, 2.5 CFU)
- "Numerical simulation of electronic devices with TCAD tools for HEP applications" (**Jun 2025**, INFN and University of Perugia, course held in dual mode, 2.5 CFU)

❑ *Schools*: "Events" of the TECH-FPA National PhD course (national days/guided tours)

- … (intentionally left blank)

Research activities and academic achievements (1/3)

- 1st academic year

❑ **Design**, **simulation**, and **electrical characterisation** of **Guard Ring** (**GR**) **protection structures** for thin silicon detectors (p-i-n and Low-Gain Avalanche Diode, LGAD) for radiation and particle detection in **harsh radiation environments**:

- **simulation** and **design** in **TCAD** environment (Synopsys Sentaurus) - collaboration with the INFN Torino Unit and the Fondazione Bruno Kessler (FBK) foundry of Trento, ERC "CompleX" R&D project;
- **electrical characterization** of different GR design strategies for thin p-i-n and LGAD detectors, **before** and **after irradiation**;
- **validation** of the **TCAD model** based on the agreement between simulation and measurement data;
- **study** of the **radiation-induced damage effects** and "**popcorn**" **noise** on the different GR structures.

❑ **Design** and **simulation** of **4D tracking silicon detectors** for particle position and timing reconstruction in **future high-energy collider experiments**:

- **TCAD simulation** and **design** of different **LGAD-based Resistive Silicon Detectors** (**RSDs**) design strategies for 4D tracking - collaboration with the INFN Torino Unit and the FBK foundry of Trento, RD50 CERN collaboration.

Research activities and academic achievements (2/3)

❑ **Presentations at conferences**:

- *Oral*: “TCAD simulations of signal sharing in DC-RSD LGAD devices for future 4D tracking”, 19th Workshop on Advanced Silicon Radiation Detectors - TREDI2024 (https://agenda.infn.it/event/39042/), **20-22 Feb 2024**, INFN Torino Unit, Italy.
- *Poster*: “Measurements and TCAD simulations of guard-ring structures of thin silicon sensors before and after irradiation”, 16th Pisa Meeting on Advanced Detectors - Pisa Meeting 2024 (https://agenda.infn.it/event/37033/), **26 May-1 Jun 2024**, La Biodola, Elba Island, Italy.

❑ **Publications** (continue in the next slide):

- T. Croci et al., "Measurements and TCAD simulations of guard-ring structures of thin silicon sensors before and after irradiation", Nuclear Inst. and Methods in Physics Research, A (**2024**), Volume 1069, 169801, ISSN 0168-9002, DOI: 10.1016/j.nima.2024.169801.
- A. Fondacci et al., "TCAD investigation of Compensated LGAD Sensors for extreme fluence", Nuclear Inst. and Methods in Physics Research, A (**2024**), Volume 1068, 169811, ISSN 0168-9002, DOI: 10.1016/j.nima.2024.169811.
- R. S. White et al., "Characterisation of the FBK EXFLU1 thin sensors with gain in a high fluence environment", Nuclear Inst. and Methods in Physics Research, A (**2024**), Volume 1068, 169798, ISSN 0168-9002, DOI: 10.1016/j.nima.2024.169798.
- L. Menzio et al., "First test beam measurement of the 4D resolution of an RSD pixel matrix connected to a FAST2 ASIC", Nuclear Inst. and Methods in Physics Research, A (**2024**), Volume 1065, 169526, ISSN 0168-9002, DOI: 10.1016/j.nima.2024.169526.
- M. J. Large et al., "Dosimetry of microbeam radiotherapy by flexible hydrogenated amorphous silicon detectors", Published **26 July 2024**, Physics in Medicine & Biology, Volume 69, Number 15, DOI: 10.1088/1361-6560/ad64b5.
- V. Sola et al., "The first batch of compensated LGAD sensors", Nuclear Inst. and Methods in Physics Research, A (**2024**), Volume 1064, 169453, ISSN 0168-9002, DOI: 10.1016/j.nima.2024.169453.

Research activities and academic achievements (3/3)

❑ Publications:

- F. Moscatelli et al., "Measurements and TCAD simulations of innovative RSD and DC-RSD LGAD devices for future 4D tracking", Nuclear Inst. and Methods in Physics Research, A (**2024**), Volume 1064, 169380, ISSN 0168-9002, DOI: 10.1016/j.nima.2024.169380.
- G. Mazza et al., "A Front-End Circuit in 28 nm CMOS for Hydrogenated Amorphous Silicon Detectors in Clinical Dosimetry," 2024 13th International Conference on Modern Circuits and Systems Technologies (MOCAST), Sofia, Bulgaria, **2024**, pp. 1-4, DOI: 10.1109/MOCAST61810.2024.10615398.
- F. Moscatelli et al., "TCAD Simulations of Innovative Low-Gain Avalanche Diodes for Particle Detector Design and Optimization", Proceedings of the 31st International Workshop on Vertex Detectors (VERTEX2022), Published **24 June 2024**, DOI: 10.7566/JPSCP.42.011031.
- N. Cartiglia et al., "Resistive Read-out in Thin Silicon Sensors with Internal Gain", Proceedings of the 31st International Workshop on Vertex Detectors (VERTEX2022), Published **24 June 2024**, DOI: 10.7566/JPSCP.42.011029.
- M. Menichelli et al., "Characterization of Hydrogenated Amorphous Silicon Sensors on Polyimide Flexible Substrate," in IEEE Sensors Journal, vol. 24, no. 8, pp. 12466-12471, **15 April 2024**, DOI: 10.1109/JSEN.2024.3359861.
- R. Mulargia et al., "Characterization of thin carbonated LGADs after irradiation up to 2.5·1015 1 Mev neq/cm2", Published **10 April 2024**, Journal of Instrumentation, Volume 19, DOI: 10.1088/1748-0221/19/04/C04022.
- L. Tosti, "HASPIDE: a project for the development of hydrogenated amorphous silicon radiation sensors on a flexible substrate", Published **10 April 2024**, Journal of Instrumentation, Volume 19, DOI: 10.1088/1748-0221/19/04/C04025.
- T. Croci et al., "A Two-Prong Approach to the Simulation of DC-RSD: TCAD and SPICE," in IEEE Transactions on Nuclear Science, vol. 71, no. 2, pp. 127-134, **Feb. 2024**, DOI: 10.1109/TNS.2024.3356826.
- T. Croci et al., "Advances in the TCAD modelling of non-irradiated and irradiated Low-Gain Avalanche Diode sensors", Published **17 January 2024**, Journal of Instrumentation, Volume 19, DOI: 10.1088/1748-0221/19/01/C01022.
- Daniele Passeri et al., "TCAD modelling of a-Si:H devices for particle detection applications", Materials Science in Semiconductor Processing, Volume 169, **2024**, 107870, ISSN 1369-8001, DOI: 10.1016/j.mssp.2023.107870.

Research activities and academic achievements (1/2)

- 2nd academic year (planning)

❑ **Simulation** and **electrical characterisation** of **Guard Ring** (**GR**) **protection structures** for thin silicon detectors (p-i-n and Low-Gain Avalanche Diode, LGAD) for radiation and particle detection in **harsh radiation environments**:

- **electrical characterization** of different GR design strategies for thin p-i-n and LGAD detectors on **n-type substrate** ("CompleX1" R&D production), **before** and **after irradiation**, and **calibration/validation** of the **TCAD model** based on the agreement between simulation and measurement data; **study** of the **radiation-induced damage effects** and "**popcorn**" **noise** on the different GR structures.
- **Continuation** of the **study** of the **radiation-induced damage effects** and "**popcorn**" **noise** on the different GR design strategies for thin p-i-n and LGAD detectors on **p-type substrate** ("EXFLU1" R&D production).

❑ **Design**, **simulation**, and **beam test** of **4D tracking silicon detectors** for particle position and timing reconstruction in **future high-energy collider experiments**:

- **Continuation** of the **TCAD simulation** and **design** of the different RSD design strategies, **before** and **after irradiation** (up to $2\text{-}3 \cdot 10^{15}$ 1 MeV $n_{eq}\,cm^{-2}$), for 4D tracking in different occupancy conditions.
- **Beam test** of **LGAD-based DC-coupled Resistive Silicon Detectors** (**DC-RSDs**) at the DESY (German Electron Synchrotron) accelerator centre in Hamburg, Germany, to study their **charge containment mechanism** and **sharing properties**, to be compared with those of the RSDs - collaboration with the INFN Torino Unit and the FBK foundry of Trento, CSN5 "4DShare" R&D (week 9-16 Dec 2024).

❑ **Six-month** abroad **internship** at **CERN** within the "Detector Technologies Group", tentatively scheduled **from April to October 2025**,

- to **advance** on the **TCAD radiation damage model** for **extreme fluences** (10^{16}-10^{17} 1 MeV $n_{eq}\,cm^{-2}$) with **defect spectroscopic measurements** - i.e., Deep Level transient Spectroscopy (**DLTS**), and Thermally Stimulated Current (**TSC**) techniques, on **p-in-n** and **compensated substrates**;
- to **improve** the **radiation tolerance** of the detector bulk and surface material (both p- and n-type silicon) based on the understating of the kinetics and the relation between the electrical active microscopic defects and the macroscopic detector properties (**defect engineering strategy**).

Research activities and academic achievements (2/2)

❑ Presentations at conference:

- 17th Vienna Conference on Instrumentation - VCI2025 (https://vci2025.hephy.at), **17-21 Feb 2025**, Vienna University of Technology, Wien, Austria. Topics: new detector developments in Particle, Astro-particle and Nuclear Physics, and associated detector electronics.
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❑ Publications:

- *Article*: "Guard-Ring protection structures for radiation-hard thin silicon particle detectors: design, tests, and performances".
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THANKS FOR YOUR ATTENTION!

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Perugia, 06/09/2024

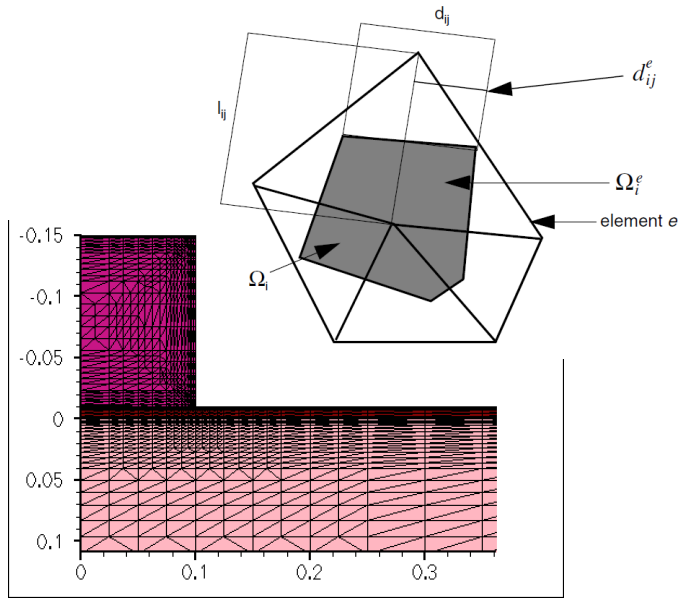
BACKUP

Technology-CAD (TCAD) simulations

- **TCAD simulation tools** solve fundamental, physical partial differential equations, such as *diffusion* and *transport* equations for *discretized geometries* (finite element meshing).
- This deep physical approach gives TCAD simulation **predictive accuracy**.
- **Synopsys© Sentaurus TCAD**

$$\begin{cases} \nabla \cdot (-\varepsilon_s \nabla \phi) = q \ \ (N_D^+ - N_A^- + p - n) & \text{Poisson} \\ \dfrac{\partial n}{\partial t} - \dfrac{1}{q} \nabla \cdot \vec{J}_n = Un & \text{Electron continuity} \\ \dfrac{\partial p}{\partial t} + \dfrac{1}{q} \nabla \cdot \vec{J}_p = Up & \text{Hole continuity} \end{cases}$$

$$\vec{J}_n, \vec{J}_p$$



$$U_{n,p} = G - R$$

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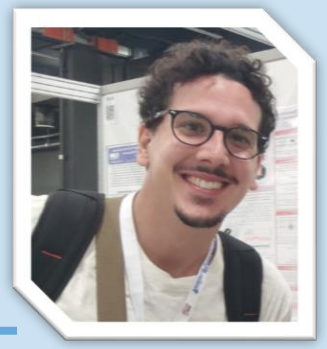
Istituto Nazionale di Fisica Nucleare



- **Educational background** @ University of Perugia (UNIPG), Department of Engineering (DI) - Perugia, Italy
  - ❑ Bachelor's Degree in *Computer Science and Electronic Engineering* (curriculum: *Electronics*)
  - ❑ Master's Degree in *Electronic and Telecommunication Engineering* (curriculum: *Electronics and Radio Frequencies*)
- **Research and work experience** @ INFN Perugia Unit & DI UNIPG

  Development of technologies for radiations and particles detection, with a special focus on the field of sensors and their related readout electronics.
  - ❑ **TCAD simulation** and **design** (Synopsys Sentaurus)
    - DC-coupled Resistive Silicon Detector (**DC-RSD**): development of a hybrid approach (TCAD + Spice), design and optimization in terms of spatial resolution and reconstruction of the particle impact positions.
    - Low-Gain Avalanche Diode (**LGAD**): design and optimization of the gain layers of thin LGAD detectors and the related guard-ring protection structures (radiation hardness and high voltage operations).
  - ❑ **Development** and **validation** of the **surface and bulk radiation damage numerical model** ("University of Perugia" TCAD model)
  - ❑ **Experimental measurements** (i.e., electrical characteristics and response to radiation stimuli - laser and β source) in **laboratory** of p-i-n and LGAD devices, before and after irradiation.
  - ❑ **VLSI design**, **simulation** and **verification** (Cadence Virtuoso, Synopsys Custom Compiler)
    - Monolithic Active Pixel Sensors (**MAPS**) in 110 nm LFoundry CMOS technology
    - integrated 10 μm-pitch Active Pixel Sensor (**APS**) arrays in standard CMOS technology (LFoundry 110 nm).
  - ❑ **PCB design** (KiCAD EDA) of an **acquisition system** (based on the Arduino platform) for the measurement of analog signals generated by active pixel test structures.

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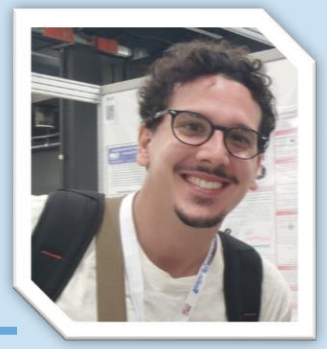

- **Current position within the PhD TFPA**
  - ❑ Hosting institution: National Institute for Nuclear Physics (INFN), Perugia Unit
  - ❑ Supervisor: Dr. Arianna Morozzi, Prof. Daniele Passeri, Prof. Pisana Placidi
  - ❑ Curriculum: Detector, Laser and optics
  - ❑ A.Y.: 2023/2024

- **Topics of the technological research work to be carried out in the PhD**
  - ❑ TCAD simulation methodologies and models for particle sensors and radiation-induced damage effects.
  - ❑ Analysis of state-of-the-art CMOS technologies for the fabrication of monolithic sensors and related readout electronics.
  - ❑ Integrated sensors and readout electronics technologies for High Energy Physics experiments in the next generation of high-performance particle colliders (e.g., Future Circular Collider – FCC, at CERN, Geneva, Switzerland).