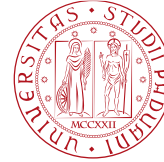




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## Annual report

**Name and surname:** Tommaso Croci

**Cycle and a.y.:** XXXIX cycle, a.y. 2023/2024

**Supervisor:** Dr. Arianna Morozzi, Prof. Daniele Passeri, Prof. Pisana Placidi

- **Research activity carried out during the year**

The research project aims to develop **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).

During the first year of the doctoral program, I focused my research activities mainly in two complimentary aspects of the project: i) the **design, simulation, and electrical characterisation** of **Guard Ring (GR) protection structures** for *thin silicon particle detectors* (p-i-n and Low-Gain Avalanche Diode, LGAD), on both **p-type** and **n-type substrates**, to be used in **harsh radiation environments**; ii) the **design and simulation** of **LGAD-based Resistive Silicon Detectors (RSDs)** to be used for the high-precision measurement of spatial position and timing of particle tracks (**4D tracking**) in **future high-energy collider experiments**.

The **design and simulation activities** were carried out using the state-of-the-art **Synopsys Sentaurus Technology-CAD (TCAD)** suite of tools and dedicated **high-performance workstations** (e.g., *DELL PowerEdge R640 Server* with 80 cores and 128 GB RAM). The main difficulty encountered in accomplishing these two activities was **handling large structures** and **refining their mesh** in the **3D simulation domain**. In order to **balance the accuracy** of the **simulation results**, which is strongly related to the correct implementation of the doping profiles (small variations in the doping profiles imply large variations in the breakdown voltage and gain), and the **time** required to obtain them (e.g., 500 thousand mesh points need 15 hours of simulation time), I **iteratively tuned the mesh refinement** of the structures until reaching a good compromise, as well as **compared the results** using **different impact ionisation numerical models**. Moreover, to speed up the simulation time, I took advantage of the capability offered by the TCAD software to perform **parallel numerical simulations**.

Concerning the **electrical characterisation** of the available **sensor samples** (e.g., the first R&D



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batch of the “eXFlu” project, which was produced at Fondazione Bruno Kessler foundry, Trento), I performed **steady-state** and “**popcorn**” **noise measurements** at both the “Laboratory for Innovative Silicon Sensors” (LISS) of the INFN Torino Unit and the clean room of the INFN Perugia Unit, using **proper test equipment** (e.g., *MPI TS-2000SE* temperature-controlled **probe station**, *Keysight B1505A* **device analyzer**, 40 GSamples/s 4 GHz *Lecroy 640Zi* **oscilloscope**, 40 dB 2 GHz *Cividec Broadband Amplifier*). The major difficulty encountered in this case was the measurement and subsequent data analysis of a large number of samples (about 600) characterised by different design strategies and substrate characteristics (thickness and doping). All these sensors were measured both **before** and **after irradiation** with neutrons up to a fluence of  $2.5 \cdot 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$  (*TRIGA Mark II* research reactor of the Jožef Stefan Institute, Ljubljana) in order to **calibrate** and **validate** the **developed TCAD model** based on the agreement between simulation and experimental data, and to conduct a **preliminary study** of the **radiation-induced damage effects** on the different structures.

- **List of attended courses and passed exams**

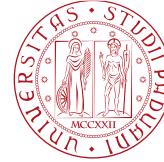
- “Advanced Scientific Programming in Matlab” (22 Jan-28 Feb 2024, Politecnico di Torino, course held online, 4.0 CFU)

- **List of attended conferences, workshops and schools, with mention of the presented talks**

- 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



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carry it out; visit the scientific and technological infrastructures of the RFX and INFN Legnaro National Laboratories.

### ○ Seminars:

- “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.

### ○ Presentations at conferences:

- *Oral*: “TCAD simulations of signal sharing in DC-RSD LGAD devices for future 4D tracking”, 19<sup>th</sup> 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.

## ● List of published papers/proceedings

- 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](https://doi.org/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](https://doi.org/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](https://doi.org/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](https://doi.org/10.1016/j.nima.2024.169526).



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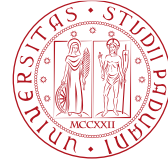
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- M. J. Large et al., "Dosimetry of microbeam radiotherapy by flexible hydrogenated amorphous silicon detectors", Published **26 July 2024**, Physics in Medicine & Biology, Volume 69, Number 15, DOI: [10.1088/1361-6560/ad64b5](https://doi.org/10.1088/1361-6560/ad64b5).
- 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](https://doi.org/10.1016/j.nima.2024.169453).
- 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](https://doi.org/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 (MOCASST), Sofia, Bulgaria, **2024**, pp. 1-4, DOI: [10.1109/MOCASST61810.2024.10615398](https://doi.org/10.1109/MOCASST61810.2024.10615398).
- 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](https://doi.org/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](https://doi.org/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](https://doi.org/10.1109/JSEN.2024.3359861).
- R. Mulargia et al., "Characterization of thin carbonated LGADs after irradiation up to  $2.5 \cdot 10^{15}$   $1 \text{ MeV } n_{\text{eq}}/\text{cm}^2$ ", Published **10 April 2024**, Journal of Instrumentation, Volume 19, DOI: [10.1088/1748-0221/19/04/C04022](https://doi.org/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](https://doi.org/10.1088/1748-0221/19/04/C04025).



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- 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](https://doi.org/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](https://doi.org/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](https://doi.org/10.1016/j.mssp.2023.107870).

● **Thesis title (even temporary)**

“Development of innovative radiation-hard silicon particle detectors for 4D tracking in future high-energy physics experiments”

**Date**, 2 September 2024

**Signature**

**Seen, the supervisors**

Arianna Morozzi

Daniele Passeri

Pisana Placidi