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SiC detectors for nuclear physics simulations inside the SAMOTHRACE innovation ecosystem

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Summary. — Silicon Carbide (SiC) detectors have emerged as a strong candidate in nuclear and particle physics as an alternative to silicon charged particle detectors and as a possible material for biomedical sensors and dosimeters, given their biocompatibility and relative insensitivity to light. This contribution presents the ongoing activity on a SiC detection system with a segmented geometry, where the effects coming from the interactions between different pads were analyzed as well as the cross-talk, the interaction between electric fields of different pads, the interpad contribution and the edge effects. Such a system will be developed for different purposes, from dose measurements in radiation dosimetry to real-time beam monitoring.

1. – Description

Silicon carbide (SiC) has drawn the attention of the scientific community in the last decade for several reasons; in particular, its hardness and its biocompatibility make it a possible candidate for a number of applications —from aerospace industry to medicine. On the side of nuclear physics and possible applications (in particular medical ones), it could be considered a good candidate for replacing standard silicon detectors [1] considering the radiation hardness and the achievable sensitivity of the detector built with this material [2]. Concerning medical applications, silicon carbide is benefited by an independence between energy deposited and dose rate.

In comparison with the well-known silicon, SiC material is characterized by its three times larger bandgap and thermal conductivity, and ten times higher breakdown electric field strength. Such features make SiC-based detectors strong candidates for new-generation devices. On the other hand, a minor drawback is represented by the fact that —unlike other semiconductor materials of technological interest— SiC does not have a liquid phase, and the only way to grow silicon carbide suitable for devices is by means of gaseous phases [3].

In recent years, a collaboration between UniCT, INFN-LNS and INFN-Sez. Catania has started with the aim to develop and characterize new innovative monolithic SiC detectors [3, 4]. Such activity received a further boost thanks to the SAMOTHRACE ecosystem [5], that aims at realizing the vision of a global collaboration environment among major actors in the area of microelectronics, microsystems, materials and micro technologies operating in the Sicilian Region. SAMOTHRACE focuses on the European Commission global challenge "Digital, Industry & Space" and it is structured with a matrix design articulated in Spokes and Pillars. The nine Spokes will develop horizontal activities that span across all the six area of interest of the ecosystem (agriculture, health, mobility, energy, cultural heritage, environment). Pillars are focused on each specific area looking across the spokes by identifying, highlighting and supporting the development of specific champions or flagship activities of the SAMOTHRACE ecosystem. The present activities belong to the Spoke 5, focused on Micro-Accelerator and Detectors for Innovation and Sustainability and are related to the Health Pillar, increasing the radiation device know-how that will be very useful in the next future [2].

In particular, one of the working groups is focused on the design study of a SiC particle detector for dose measurements in radiation dosimetry and real-time beam monitoring. The research activities consist in simulations coupled with experimental tests performed in laboratory in order to characterize the features of an innovative SiC device. The radiation hardness, the sensitivity, the fast response, and the energy and dose rate independence are studied in detail. In addition, the optimization of SiC devices in single and 2D array configurations will be developed. In our case, the chosen geometry for experimental application has been the padded one (2×2, see fig. 1 lower panels). While approaching a new detection system with a segmented geometry such as the one

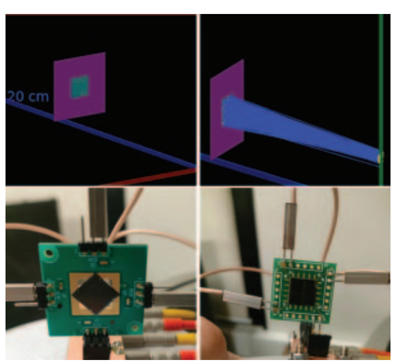

Fig. 1. – Upper panels: SiC geometry as simulated by means of Geant4; lower panels: pictures of SiC with same surface and different thicknesses (100 μm left, 10 μm right).

in development, the effects coming from the interactions between different pads must be properly addressed and taken into account. In particular, the cross-talk, the interaction between electric fields of different pads, the interpad contribution and the so-called "edge effects" must be considered. Given the structure and purpose of the detectors, it is crucial to understand how and why signals derived from the impinging particles can be improperly or not completely reconstructed, or can be missing.

Such problems must be tackled through proper simulations: for this reason, a realistically simulated detector —by means of a GEANT4 code— has been implemented in order to extract the expected events coming from two different alpha-sources, ^{148}Gd and standard 3-peaks α-source (^{239}Pu-^{241}Am-^{244}Cm). Such radioactive sources have been simulated reproducing the experimental conditions [6], in order to study the response of a 10 μm SiC detector in vacuum and a 100 μm one in vacuum and in room conditions. In both cases, the particles are generated following a double random extraction on the x and y axes, with fixed z (upper panels in fig. 1; the code is ready to be used also with real ion beams, even radioactive ones). The experimental data are acquired by means of a Mesytec 16 channel fast preamplifier (MPR-16), and the incoming signals are processed by means of a CAEN 571 8 channel digitizer. The readout and signal final processing is provided by a home-built acquisition code. The resolution expected (below 1%) for similar detectors in the literature [7] has not yet been reached by the SiC detectors that have been tested so far, giving an experimental resolution above 2%. A comparison between an amplified (AMETEK ORTEK 570 coupled with the MAESTRO Multichannel Analyzer Emulation Software) signal showed that in this way the signal can be greatly improved (resolution around 0.37% for the same detectors).

The simulation gives very few events at lower energies in comparison with experimental data (fig. 2). This can be due to the assumptions made regarding edge and electric field effects in our simulations in which cases the incoming particles can be detected at the same time by different pads. Thoroughly simulating this occurrence can be very tricky, due to the difficulties to properly mimic the electric field produced by the different regions of the detectors, and in first approximation we are assuming that the electric

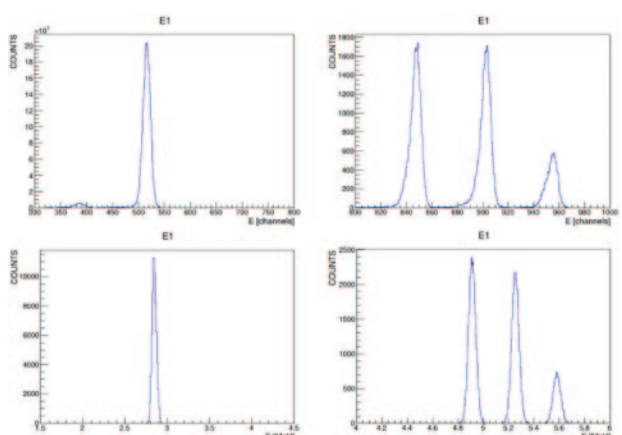

Fig. 2. – Comparison between experimental (higher panels) and simulated data (lower panels) for the 10 μm (left) and 100 μm (right) thick detector for just one of the four pads, with the two different α-sources (^{148}Gd left, 3-peaks α-source right).

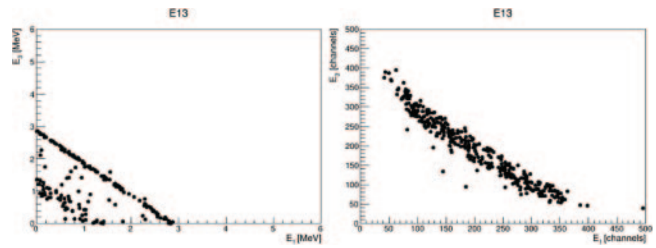

Fig. 3. – Interpad events comparison between simulations (left panel) and experimental data (right panels) for the 10 μm thick detector for two adjacent pads (coincidences events, ^{148}Gd α-source).

fields from the active zones do not interact with each other on the borders (interpad), and that no field distortions are generated by the detector geometry. In this way the charge collection in the two adjacent pads generated by an impinging particle is considered to be just directly proportional to the distance from the hit point and the centre of the pad. We can then obtain a first (rough) approximation of the number and energy of the charged particles detected in the interpad.

From the comparison shown in fig. 3, even though the slope of the two loci is somehow similar, the counting rate from the simulation is much lower than the experimental one, and this is probably due to effects coming from the mutual interaction of the electric fields of the different pads. Also, the slope at low E1 and E3 slightly changes, and this could be due to edge effects coming from the pads.

In conclusion, many of the issues we faced at the beginning of the testing phase (poor resolution, discharges, cross-talk between biased and non-biased pads of the detector) have been fixed, and simulations now are able to realistically reproduce the detector as a suitable means to detect charged particles.

A full understanding of the interpad behaviour, on the other hand, is still in progress, and simulations with different codes and tools (for example Synopsis [8]) are necessary. Regarding the edge effect, the difference between the simulation and the experimental data is unclear, and a more refined evaluation of the sheer geometry will be implemented in the future.

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REFERENCES

[1] De Napoli M., *Front. Phys.*, **10** (2022) 898833.
[2] Agodi C. *et al.*, *Eur. Phys. J. Plus*, **138** (2023) 1038.
[3] Tudisco S. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **426** (1999) 436.
[4] Cardella G. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **378** (1996) 262.
[5] `https://samothrace.eu.`
[6] Martorana N. S. *et al.*, these proceedings.
[7] Tudisco S. *et al.*, *Sensors*, **18** (2018) 7.
[8] `https://www.synopsys.com`.