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Advancements in Silicon Carbide-based detectors for high-performance radiation dosimetry and beam monitoring: from simulations to test phase

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Abstract: Silicon Carbide (SiC) based detectors have been appointed as possible candidates for new-generation detectors for both radiation and charged particles. SiC is in fact a material characterized by a high radiation hardness, a strong mechanical resistance and thermal stability. This contribution describes the ongoing activity related to the study of Silicon Carbide devices as dosimeter or real time beam monitor, in the framework of SAMOTHRACE ecosystem. In particular, the development of accurate simulations, using the Geant4 toolkit, that consider the possible different configurations and manufactures of the detector, will be reported. This activity is a crucial step in understanding the contribution from the inter-pixel regions.

Keywords: Detector modelling and simulations I (interaction of radiation with matter, interaction of photons with matter, interaction of hadrons with matter, etc); Solid state detectors; Radiation-hard detectors; Detector modelling and simulations II (electric fields, charge transport, multiplication and induction, pulse formation, electron emission, etc)

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2025 JINST 20 C09015

Contents

1 Introduction

The possibility to use Silicon Carbide (SiC) based detectors has emerged in the last decades as a viable alternative with respect to Si-based ones, due to some advantages of the material: SiC, in fact, has a three times larger bandgap and thermal conductivity, a ten times higher breakdown electric filed strength and higher saturation velocity in comparison to Silicon. Also, SiC material is characterized by high radiation hardness, strong mechanical resistance, and insensitivity to light [1–3]. All those characteristics makes SiC-based technology as a strong candidate to be used for charged particles detectors, and its biocompatibility and relative dose rate independence from energy makes it a possibility for new generation active dosimeters. On the other hand, some drawbacks are still present: the material in fact does not exist in liquid phase, and the only way to have a SiC crystal is by epitaxial growth from a gaseous form [4].

Recently, a collaboration between the University of Catania – UniCT, the National Institute of Nuclear Physics-Laboratori Nazionali del Sud (INFN-LNS) and the INFN – Sezione di Catania has started inside the wider SAMOTHRACE ecosystem [5]. It aims to realize the vision of a global collaboration environment among major actors in several areas — such as 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 in Spokes and Pillars. The first ones will develop horizontal activities that span across all the six areas of interest of the ecosystem (agriculture, health, mobility, energy, cultural heritage, environment). Regarding the second ones, those are focused on more specific areas, looking across the spokes by identifying, highlighting and supporting the development of specific champions or flagship activities of the SAMOHTRACE ecosystem. The present activities belong to the Spoke 5, focused on Micro-Accelerators and Detectors for Innovation and Sustainability and are related to health pillar. Its aim would be to increase the radiation device know-how, and the characterization of innovative segmented SiC detector [6] for real-time beam monitoring and dosimetry. The activity consists in simulations and experimental tests carried out to characterize the performances of the detector in both time and energy resolution.

2 The code: development and comparison with the experimental results

In this phase, the optimization of the detector must pass through a thorough evaluation of all the possible sources of uncertainties brought from both the electronics and the physical construction of the detector itself. The latter issue involves simulations that must take into account the geometry and the regions of reduced or negligible sensitivity within the device, as well as the dependence of

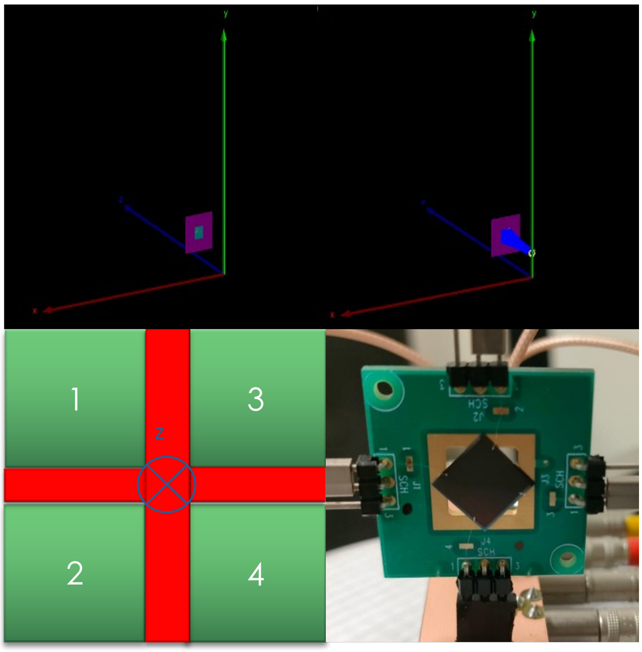

Figure 1. Upper panels: simulation of the experimental conditions, being the beam oriented as the z- axis. Lower panels: detector geometry (left panel, pads in green and inter-pixel region in red) and detector prototype (right).

improper or missing reconstruction of events; given the padded geometry (2×2, see figure 1, lower and top-right panels) there will be events that will pass through the gaps between the pixels, leading to a missing event or to a not well reconstructed value for the energy. Furthermore, it is possible that such poorly reconstructed event will appear in adjacent pixels with lower energy than expected. This effect may be caused by crosstalk, electric field interactions, or the migration of electron-ion pairs from inter-pixel regions to neighbouring pads s. Also, the so-called "edge effects" must be considered. It is then crucial (given the purposes of the detector) to understand how and why physical signals can be improperly or not-completely reconstructed, or missing.

For such reasons, using the GEANT4 toolkit for nuclear physics, a simulation code that realistically mimics the features of the detector has been developed [7]. The code is in principle capable to simulate any kind of particle at any energy in experimental conditions (both vacuum chamber and in room conditions), focusing for the moment in the comparison between the simulations and the experimental tests performed at LNS [8] on two detectors with the same geometry but different thickness, 10 µm and 100 µm respectively, irradiated with 3-peaks (^{239}Pu – ^{241}Am – ^{244}Cm) and mono-peak (^{148}Gd) α-source. The thinner detector will be used for dosimetry [9], while the thicker one is similar to the ones that will be used for beam tagging.

From the experimental point of view, the detectors have been coupled with two different electronic chains: the detector signals have been acquired via a Mesytec MPR-16 coupled with a CAEN DT5742 16 channel digitizer, and using an AMETEK ORTEC 570 coupled with the MAESTRO Multichannel Analyzer Emulation Software for comparison. The resolution in the first case (between 1% and 2%) is still worse than the one expected from similar detectors reported in literature (below 1%) [1], and a comparison with the second electronics chain has given far better results (resolution at about 0.37% for the same detector), showing how much room for improvement is available on the electronic side.

2025 JINST 20 C09015

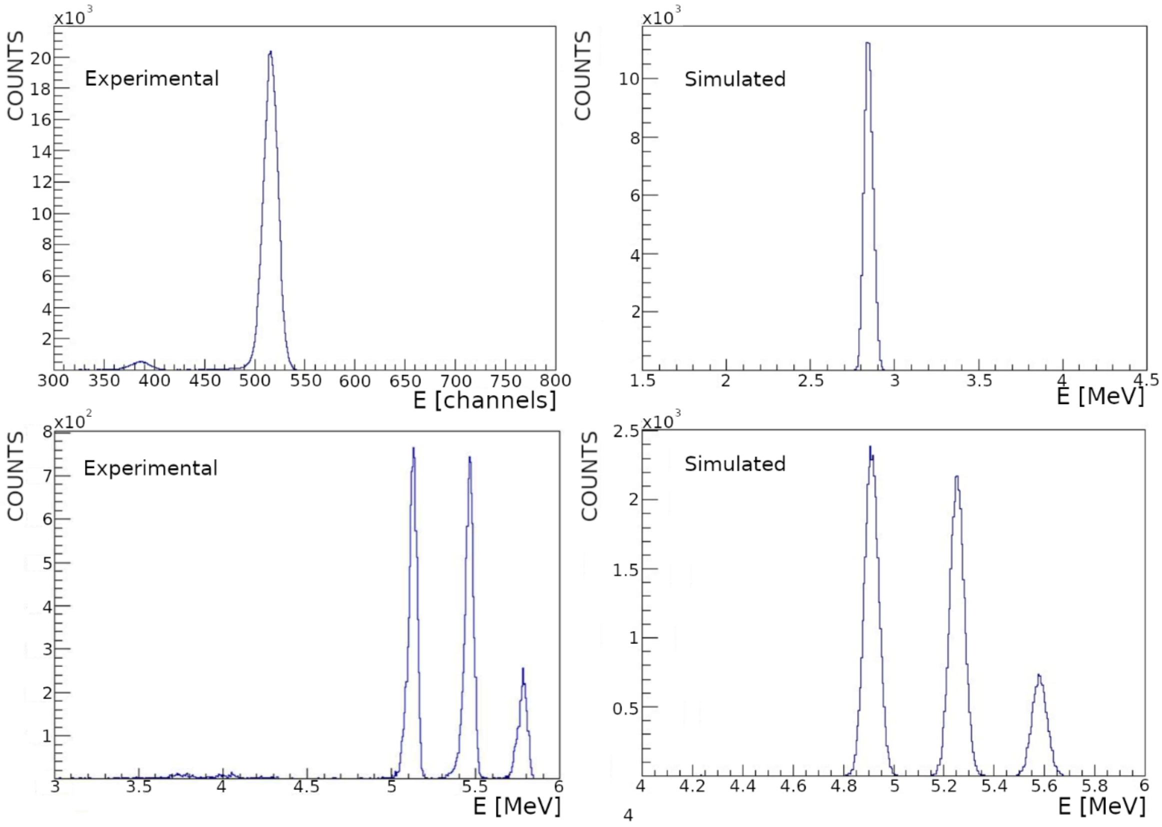

Figure 2. Comparison between experimental (left panels) and simulated data (right panels) for the 10 µm (top) and 100 µm (bottom) thick detector for just one of the four pads, with the two different α-sources (^{148}Gd top, 3-peaks α-source bottom). As it is visible, the simulation is able to reproduce both the expected resolution and position of the experimental peaks.

In the simulation, the generation of particles is made by a double random extraction in both x and y axes (figure 1, top-left panel), keeping the z axis fixed to reproduce the dimensions of the source. As it can be seen, the simulation yields far fewer events at lower energies compared to the experimental data (figure 2): this is possibly due to a not realistic assumption made in the code regarding the composition of the detector — especially at the edges of the pixels — or to electric field effects, which may be inappropriately considered by GEANT4.

3 Inter-pixel contribution and conclusions

Given the structure and purpose of the detectors, one of the crucial steps consists in understanding if — and how — a signal coming from the inactive part of the detector (inter-pixel) behaves: in this case, in fact, the signal can be lost, or it can be detected by adjacent pixels of the detector. Neither scenario can be ruled out in advance, and some effort must be made from a simulative standpoint, given that, although rare, such events should not be overlooked, as it can lead to both misidentification of particle type and inaccurate dose estimation.

From the previous cases, the first one is more trivial: a straightforward comparison between the total counts from the realistic simulation with one modified to have a single padded (1 cm^2)

2025 JINST 20 C09015

geometry, leads to a solution consistent with experimental data. Less than 0.0001% of the total expected particles is effectively lost.

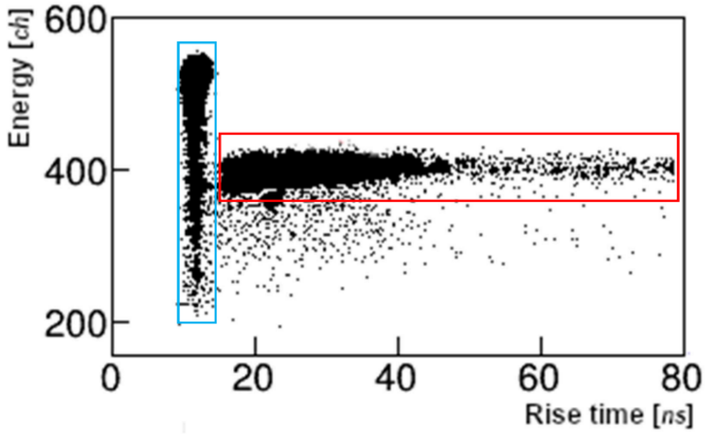

Figure 3. Energy vs. rise time spectrum for a ^{148}Gd α-source on the 10 µm SiC detector. The edge effect (red box) is evenly spread on a long rise time span and at a fixed energy, hindering the correct extraction of the correct energy (blue box). As it is visible, events coming from the edge effect generate a locus, ending up in a parasite, unphysical parasite peak, that must be considered.

The second issue, on the other hand, has proven to be more complex: in this region, in fact, the experimental data already show a non-negligible number of reconstructed events that, although in the energy tail of properly reconstructed ones, have a rise time with much broader distribution than expected (figure 3 red box). For the 10 µm detector the effect is quite problematic to handle: it is in fact located as a “parasite” structure, located within the low-energy tail of the expected distribution (figure 3 light-blue box) and evenly spread on a long rise time tail.

For this reason, the simulation takes also into account for inter-pixel effects. In first approximation, this has been done considering a linear extrapolation, assuming that the energy of such particles is distributed linearly between the two adjacent pixels. In this configuration, the signal sharing is proportional to the distance between the centres of the adjacent pixels and the interaction point. Specifically, if D is the distance between the two centers and d is the distance between the center of the detector and the interaction point, the energy will be distributed as $E_{\text{tot}} \cdot (D - d)/D$. Furthermore, the exact number of inter-pixel events strongly depends on the dimensions of the inter-pixel region considered for the simulations.

Despite its simplicity, this assumption is consistent with experimental results (figure 4), and a reasonable agreement also on the number of the inter-pixel events has been reached (around 0.5% of the total). Further assessment of the shape of the electric field is nonetheless necessary, but a reliable simulation that accounts for the electric field produced by the different pads of the detectors can be very tricky. Nonetheless an attempt to realistically simulate the electric field will be made using *Synopsys* [10, 11], and further efforts in this direction are therefore necessary.

On an experimental point of view, it is also evident that an increase of the bias voltage of the 10 µm detector (from −20 V to −160 V) leads to a more efficient charge collection from the edges. Such effect may serve as a hint that the slower rise time at nominal bias is due to imperfect charge collection effects. Such a test has not been performed on the 100 µm one due to limitation on the maximum bias for the preamplifiers, but further investigation with different electronics is in preparation.

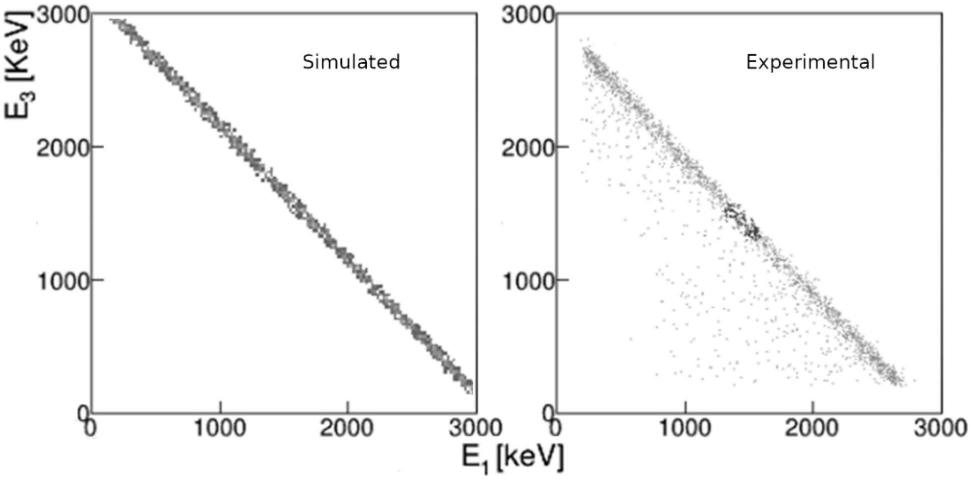

Figure 4. Comparison between the shared energy signals for two adjacent pads (1–3 in this case), for the ^{148}Gd α-source on the 10 µm SiC detector. As it can be seen, data from the simulations (left pad), obtained by considering the simple "linear" approximation explained in the text, are in reasonable agreement with experimental data (right panel).

Acknowledgments

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References

[1] S. Tudisco et al., *SiCILIA — Silicon Carbide Detectors for Intense Luminosity Investigations and Applications*, *Sensors* **18** (2018) 2289.

[2] G. Parisi, F. Romano and G. Schettino, *Microdosimetry for hadron therapy: A state of the art of detection technology*, *Front. Phys.* **10** (2022) 1035956.

[3] M. De Napoli, *SiC detectors: A review on the use of silicon carbide as radiation detection material*, *Front. Phys.* **10** (2022) 898833.

[4] S. Tudisco et al., *A new large area monolithic silicon telescope*, *Nucl. Instrum. Meth. A* **426** (1999) 436.

[5] https://samothrace.eu.

[6] G. Cardella et al., *A monolithic silicon detector telescope*, *Nucl. Instrum. Meth. A* **378** (1996) 262.

[7] G. D'Agata et al., *SiC detectors for nuclear physics simulations inside the SAMOTHRACE innovation ecosystem*, *Nuovo Cim. C* **2** (2025) 72.

[8] N.S. Martorana et al., *Development of a SiC detector array within the SAMOTHRACE ecosystem*, *Nuovo Cim. C* **2** (2025) 62.

[9] A. Barbon et al., *First results on characterization of a silicon carbide dosimeter in the framework of SAMOTHRACE ecosystem*, *Nuovo Cim. C* **48** (2025) 70.

[10] https://www.synopsys.com.

[11] A. Barbon et al., *Silicon carbide detectors for particle therapy within the SAMOTHRACE ecosystem*, 2025 *JINST* **20** C07058.

[12] N.S. Martorana et al., *Advancements in the characterization of SiC devices within the SAMOTHRACE ecosystem*, 2025 *JINST* **20** C07064.