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AlphaBeast: a CMOS-based neutron counter for radiation protection

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Neutrons are one of the main secondary radiations produced by particle accelerators. They are therefore a key element in the radiation protection of facilities used for fundamental research or medical and industrial applications (production of radionuclides, hadrontherapy, sterilization). The main risks relate both to the radiation dose received by people exposed to neutrons (workers, patients) and to the neutron activation. Whatever the field of application, reducing risks and optimizing processes requires a better understanding of the neutron fields produced by the operation of particle accelerators. However, the spatio-temporal characterization of secondary neutrons produced during irradiation is still very difficult to implement systematically. The current reference methods (activation foil, Bonner spheres systems, solid nuclear track detectors) have economic and human costs that severely limit the quantity and quality of the available data, which are essential for better neutron risk management.

In this context, the IPHC-DeSIs team works on the development of a CMOS-based counter for real-time monitoring of thermal and fast neutrons. The *AlphaBeast* CMOS sensor (XFAB technology 0.35 mum) was designed in 2022 (Figure 1), as an improved version of the *AlphaRad* prototype developed in 2017 [1,2]. This sensor is completely integrated, highly transparent to photons and optimized for low power consumption. Neutrons are detected from their conversion into protons (fast neutrons, PE converter) and alpha particles (thermal neutrons, 10B converter). Internal thresholds are used to separate the two populations, giving a distinct indication of the fluxes of thermal and fast neutrons. Several configurations of diodes and apertures in the top oxide layer were tested in order to determine which offered the best compromise between detection efficiency and alpha/proton signal separation.

Accurate measurements of neutrons in mixed fields requires a precise evaluation of the CMOS sensor response to photons, electrons, protons and alpha particles. We present a full experimental characterization of the *AlphaBeast*, based on several test beam experiments done in research (cyclotron), medical (linear accelerator) and industrial (rhodotron) facilities. A Geant4/GATE Monte Carlo simulation of the sensor is also carried out, incorporating 2D charge collection efficiency maps obtained from the AIFIRA (IP2I-Bordeaux) proton-alpha microbeam line. The Monte Carlo modelling is used to determine the efficiency and purity of the selection cuts for thermal (alpha) and fast (proton) neutron separation. We also discuss the various sources of background, such as direct interactions of neutrons in silicon, and the corresponding correction factors to be applied.

The *AlphaBeast* sensor is the central component of a future real-time neutron mapping system, dedicated to the radiation protection of particle accelerators and associated applications. This system will be designed as a network of connected autonomous CMOS sensors, strategically positioned in the irradiation room to enable real-time measurement of the spatial and energy distributions of neutron fluxes.

[1] N. Arbor et al., "Real-time detection of fast and thermal neutrons in radiotherapy with CMOS sensors", PMB, 62(5) (2018)
[2] N. Arbor, S. Higueret, D. Husson, « Micro-scale characterization of a CMOS-based neutron detector for in-phantom measurements in radiation therapy », NIM A 888 (2018)

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