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Geant4 simulation for LHC radiation monitoring

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Abstract

Monitoring radiation background is a crucial task for the operation of LHC experiments. A project is in progress at CERN for the optimisation of the radiation monitors for LHC experiments. A simulation system based on Geant4, designed to assist the engineering optimisation of LHC radiation monitor detectors, is presented. Various detector packaging configurations are studied through their Geant4-based simulation, and their behaviour is compared.

Keywords

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Geant4 Simulation for LHC Radiation Monitoring

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Abstract — **Monitoring radiation background is a crucial task for the operation of LHC experiments. A project is in progress at CERN for the optimisation of the radiation monitors for LHC experiments. A simulation system based on Geant4, designed to assist the engineering optimisation of LHC radiation monitor detectors, is presented. Various detector packaging configurations are studied through their Geant4-based simulation, and their behaviour is compared.**

***Index Terms*— Geant4, Monte Carlo, radiation monitoring, LHC.**

I. Introduction

The radiation environment expected at the future CERN Large Hadron Collider (LHC) experiments will be composed of neutrons, photons and charged hadrons. This complex field is due to secondary particles generated by the proton-proton collisions and reaction products of these particles with the sub-detector materials of the experiment itself. This environment is a matter of concern due to radiation damage in all exposed particle detectors and electronic components.

To prepare appropriate countermeasures against such effects, it is necessary to monitor the radiation field starting from the early LHC experiment commissioning phase. A series of semiconductor sensors has been evaluated regarding their use as radiation s monitors for the LHC Experiments in terms of Total Ionizing Dose (TID) and 1-MeV neutron equivalent particle fluence (Φ_{eq}). Moreover, an integrated sensor carrier housing RadFET transistors for TID measurements and *p-i-n* diodes to record the Φ_{eq} has been produced. An overview of this work is given elsewhere [1]-[2]

Especially for RadFET dosimeters, the use of inappropriate materials located close to or around the sensor can modify the radiation response inducing errors in the TID measurements. These considerations clearly apply to the case of the RadFET dosimeters for the LHC experiments, where the commercially available transistor packaging could not satisfy the requirements in terms of dimensions and employed materials. Thus, a custom-made packaging was developed, studied and specially produced for this application.

Rough calculations of the effects of packaging materials are straightforward. However, in order to take rigorously into account all different effects of the materials inside the complex LHC field and in order to optimize the sensor packaging, the use of simulations tools is indispensable. A Monte Carlo model, based on the Geant4 [3]-[4] Simulation Toolkit, has been developed to study the effects of the packaging on the RadFETs response. The simulation model exploits Geant4 advanced capabilities to describe the sensors in detail, and a rich set of physics processes to study the effects induced by a complex radiation environment, such as expected at LHC.

Before the Monte Carlo models can be accurately applied to the complex simulation of the full mixed LHC environment, they need to be validated using a set of experimental data from “simple” (e.g. in terms of particle spectra, boundary conditions, etc.) irradiation experiments. Although these first experiments and simulations will not match the full complexity of the LHC environment, they might already be used to provide a guideline for the choice of suitable sensor packaging materials for the LHC. The aim of this work is therefore to present the developed Geant4 model and the first two experimental campaigns devoted to its validation. The validation was performed by measuring the response of RadFET dosimeters mounted inside the chip carrier proposed to the LHC Experiments and covered with different thicknesses of various materials. Furthermore, the impact of the presented results on the optimization process of the sensor carrier for the LHC experiments will be discussed.

II. Description of the Simulation Model

A Geant4-based simulation application has been developed to study the effects on the sensors when exposed to different radiation environments. A detailed description of the geometry of the sensors has been implemented in the simulation (Fig. 1); various packaging options can be selected for the study of specific configurations. The simulation activates a selection of physics processes out of those available in the Geant4 Toolkit for each particle type: models of the Low Energy Electromagnetic package for photons and charged particles, and a set of hadronic models covering different ranges from the very high energies typical of LHC down to intra-nuclear transport, pre-equilibrium and nuclear de-excitation. Various

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options of alternative physics models are available in the simulation to evaluate possible systematic effects.

The energy deposited in the sensors, resulting from primary and secondary particle interactions, is calculated by the simulation. The simulation produces analysis objects, which can be further handled by analysis tools to study the effects of radiation exposure on the sensors in various packaging configurations.

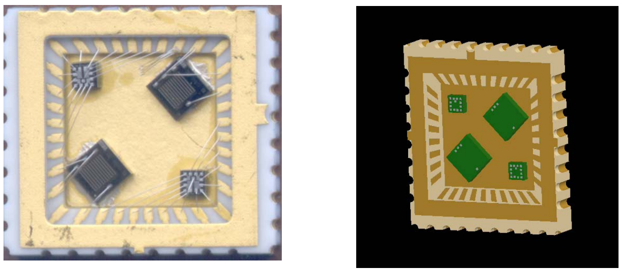

Fig. 1 Real (left) and simulated (right) configuration of the radiation monitor sensors and the carrier.

III. Results

Experimental data were collected in two test configurations.

The first irradiations were performed at the High Energy Proton Irradiation Facility (HE-PIF) of the Paul Scherrer Institut (PSI) in Villigen, Switzerland. The RadFET sensor carrier were irradiated with protons of 254 MeV at an average flux of about 1.0×10^8 protons/sec/cm^2. The samples were mounted in a frame and exposed perpendicularly to the beam-axis. The facility was pre-calibrated with accuracy in the flux/dose determination better than ± 5%. The contamination due to the neutron background at the irradiation position was calculated to be less than 10-4 neutrons/proton/cm2. The experimental data are shown in

Fig. 2.

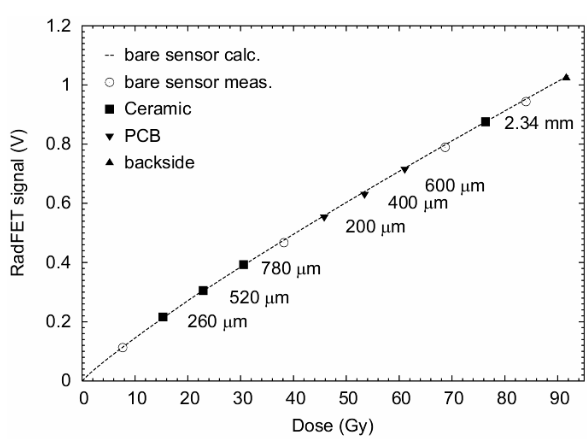

Fig. 2 Experimental results obtained at PIF facility.

The second set of tests was performed at the Reactor Research Centre at the JSI in Ljubljana (Slovenia), which has an experimental nuclear reactor of TRIGA type. The neutron spectrum available in this facility ranges from thermal to fast neutrons with energy of about 1 MeV and it has been determined by measuring the activation of foils of different materials. The irradiations of the RadFET carrier were performed placing it into the reactor core through an irradiation tube that occupies a fuel rod position and enters the reactor from above.

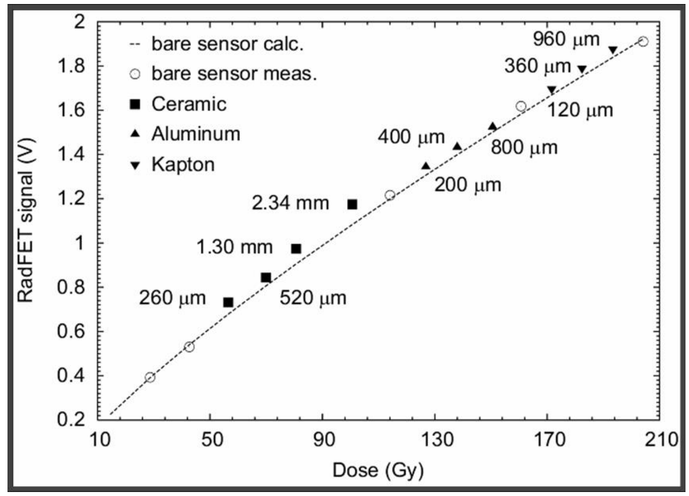

Fig. 3 Experimental data taken at the JSI facility.

The experimental configurations were reproduced in the simulation; the results of the simulation were compared to the experimental data to validate the simulation system developed. Once validated, the simulation system can be exploited as a predictive tool for the optimization of packaging, even where experimental data are not available.

A selection of simulation results concerning the irradiation with protons is shown in Fig. 4. No significant effect due to different packaging is evidenced for 254 MeV protons, in agreement with the experimental observations. This result is confirmed by a statistical analysis: the p-value of the Kolmogorov test is 0.416, which confirms the compatibility of the data distribution with a flat curve. Effects due to the different lid thicknesses are visible at lower proton beam energies (150 MeV and 50 MeV).

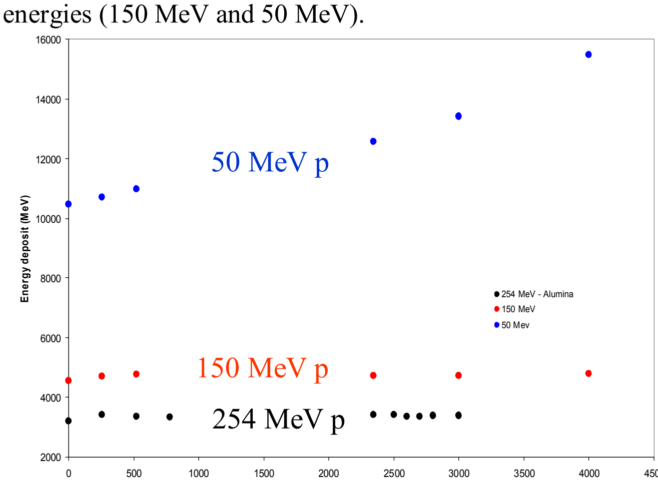

Fig. 4 Energy deposit in the sensors as a function of the lid thickness, resulting from simulated irradiation with protons at various energies (254, 150 and 50 MeV).

Preliminary results from a simulation reproducing the irradiation configuration at JSI are shown in Fig. 5. The simulation was performed with an incident neutron spectrum corresponding to the experimental one. Further studies are in progress to evaluate the contribution to the energy deposit due to the photon component contaminating the neutron spectrum.

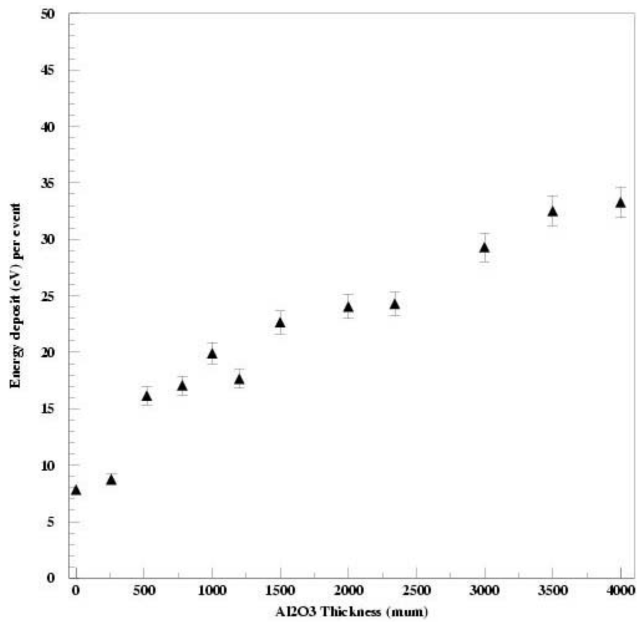

Fig. 5 Simulation results with incident neutrons.

IV. Conclusions

A simulation application based on Geant4 has been developed to study the effects of various packaging solutions for LHC radiation monitors. Preliminary results for protons are available; they highlight the sensitivity to a lid thickness at low (<150 MeV) proton energies, while no significant effects are visible at higher proton energies (250 MeV). Further studies concerning an irradiation with neutrons are in progress.

Thanks to Geant4 physics capabilities and accuracy, the simulation system developed can be used to further investigate the sensors' response to the radiation environment, and to optimize the packaging.

This study represents a novel application of Geant4 to radiation monitoring at LHC.

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