Radiation Fields at High-Energy Accelerators and their impact on Radiation Damage

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1. Abstract

Radiation-induced errors in electronic devices and systems have become an important threat to the appropriate operation of high-energy particle accelerators, even more so with the increased use of commercial components at locations with significant radiation fields. The Radiation to Electronics (R2E) project is in charge of minimizing these effects in the LHC context [1]. In the scope of the PhD work here presented, the particularities of the accelerator environment on the Single Event error rate (SER) are investigated along with their implication on testing policies. In particular, the effect of the GeV-hadron spectra, the rich presence of pions or the impact of high-Z materials have been studied through simulations and partially tested for in experiments. Further radiation tests are programmed in order to obtain a better understanding of the different effects and their dependence on the radiation environment.

2. Simulation Tool

Simulations are performed in the context of the R2E working group using the FLUKA Monte Carlo (MC) transport code [2]. Two important applications of the simulation tool can be identified in this domain:

i. Simulation of the radiation environments in different accelerator regions or experimental areas [3]
ii. Simulation of the energy deposition in electronic devices on an event by event basis [4]

The combination of both can be used to obtain an estimated SER for a characterized device in a given location.

3. Monitoring

A wide variety of instruments are used to monitor the radiation environments at the LHC and dedicated test areas, such as beam loss monitors (BLMs), multi-wire proportion chambers (MWPC), scintillators, ionization chambers or the standard radiation monitor (RadMon [5]) developed at CERN, which measures the three main radiation damage types:

i. Single Event Effects (SEEs) (with an SRAM memory)
ii. Total Ionizing Dose (TID) (per means of a RadFET)
iii. Displacement Damage (DD) (using a PIN diode)

4. Complex Radiation Environment

The mixed particle type and energy field encountered at the LHC is composed of charged and neutral hadrons (protons, pions, kaons and neutrons), photons, electrons and muons ranging from thermal energies up to the GeV range (see Figure 1). This complex field has been extensively simulated by the FLUKA Monte Carlo code benchmarked in detail for radiation damage issues at the LHC [3]. The radiation is due to particles caused by :

- proton-proton (or ion-ion) collisions
- distributed beam losses (protons, ions)
- beam interacting with the residual gas

5. Testing

In-house tests are performed at CERN in the different test areas where LHC-like spectra are reproduced, such as H4IRRAD [6] or CNRAD [7]. The importance of such areas resides in the possibility of testing entire systems in an operation-like environment. Limitations arise from the restricted beam time and intensities, and the accessibility of the areas. Motivated by this, a new test facility to be constructed in the PS East Area is currently in preparation phase [8]. Moreover, testing at external facilities is also a common practice of groups at CERN concerned about radiation effects. Proton beams are available at PSI, Louvain and TRIUMF, a gamma source for TID effects is used in the Fraunhofer Institute, and DD studies are performed with the neutron spectra available at CEA.

6. PhD Thesis Scope

The goal of the work here presented, in the scope of the doctoral thesis and the R2E project, is to understand the particularities of the accelerator-like environment on the radiation-induced effects in electronic components and systems. Some characteristics of the field (GeV-energies, strong pion and neutron fluences, etc.) cannot be directly tested for in standard experimental facilities, therefore an improved understanding of the basic mechanisms responsible for the failures, as well as their dependence on the particle type and energy is essential to correlate test results with error rate estimations. In doing so, the combined use of the simulation tools, monitoring systems and testing capabilities is crucial.

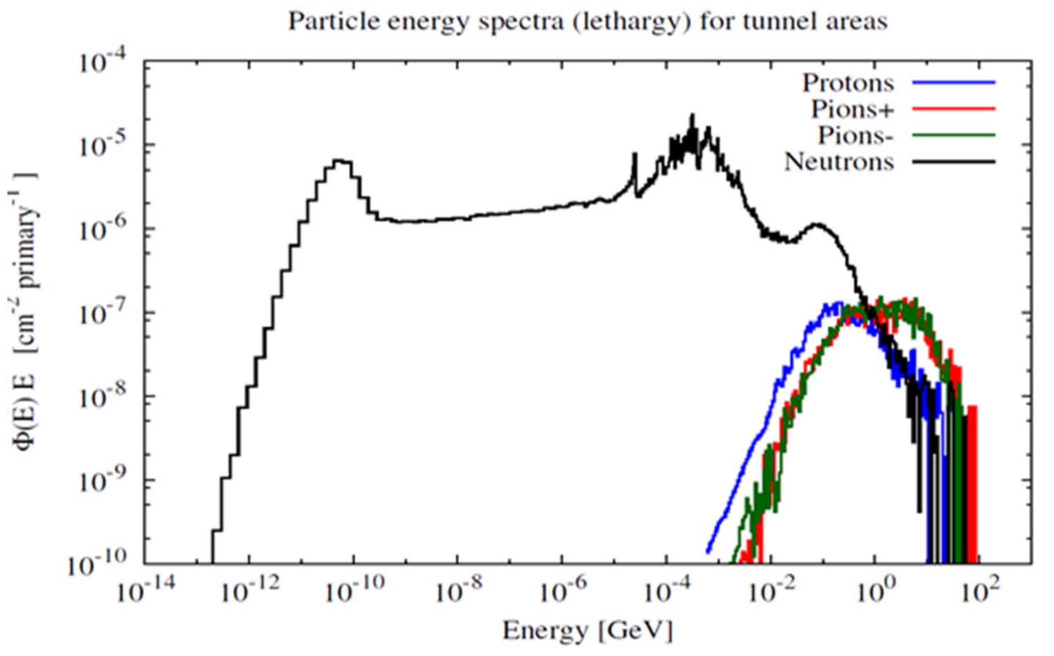

Figure 1: Simulated hadron energy spectra for a tunnel area in the LHC

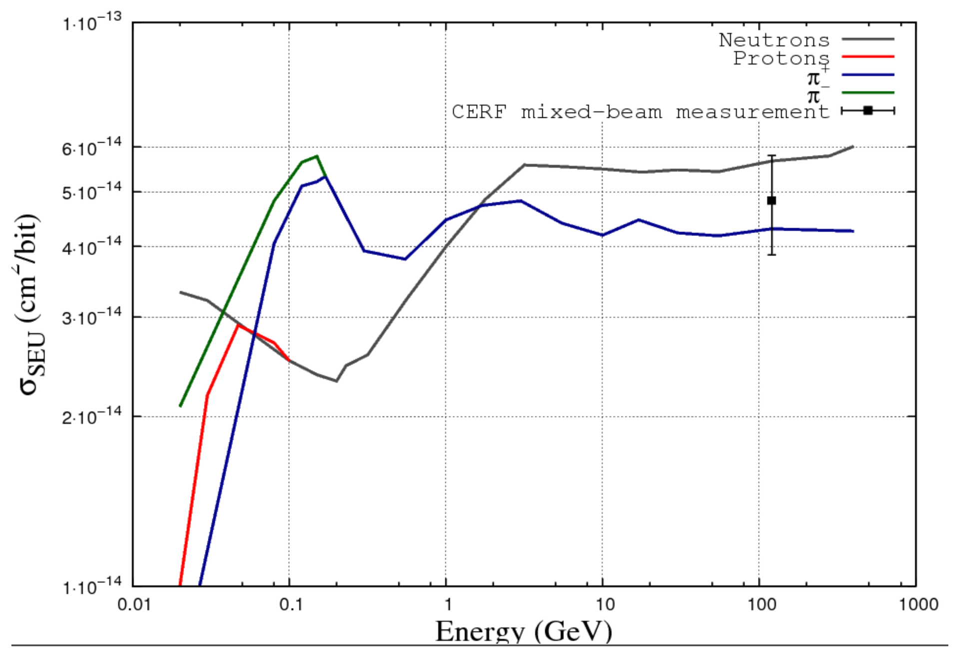

Figure 2: : Simulated SEU cross section for the ESA SEU Monitor SRAM memory, using the FLUKA MC code.

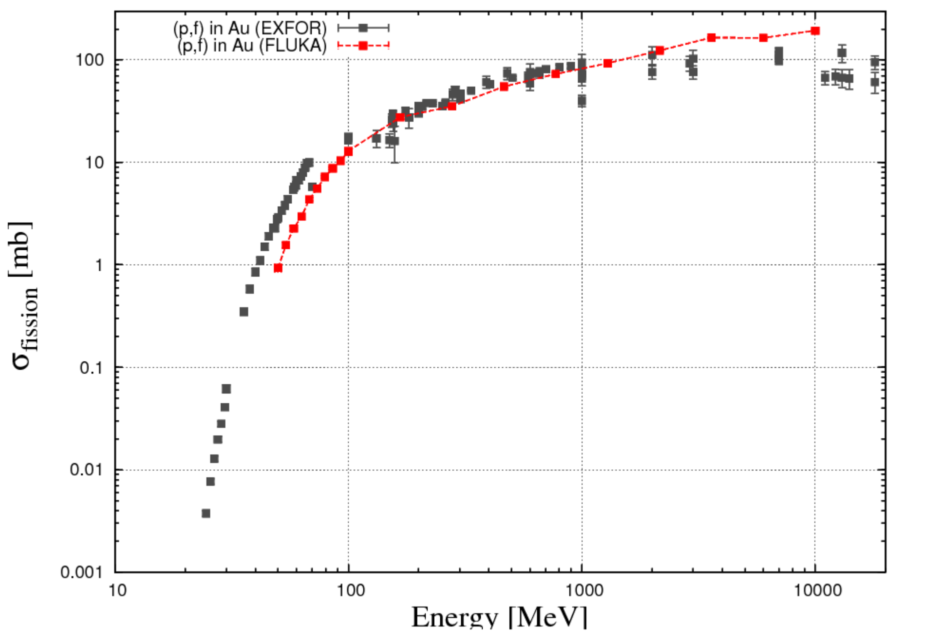

Figure 3: Proton-tungsten fission cross section, both experimental and simulated with FLUKA.

7. Results and future work

Single Event Upset (SEU) tests using the European Space Agency's radiation monitor were performed in the mixed-field available at H4IRRAD. In order to obtain an SER estimation, MC simulations were performed with the purpose of estimating the cross section for the different particles and energies of relevance for the environment (see Figure 2). A measurement at 120 GeV/c was performed using the mixed-beam at CERF [9] (1/3 protons, 2/3 pions). From these results, it is expected that the nucleon SEU cross section for this particular technology will increase by a factor ~2 from the maximum energies available at PSI (230 MeV) until reaching saturation at around 3 GeV. Moreover, as has been previously shown [10,11], the Single Event Latchup (SEL) cross section can significantly increase above the several hundred MeV energies for some devices, owing mainly to the presence of high-Z materials (notably tungsten) near the sensitive regions. Indeed, as shown in Fig. 3, the fission cross section does not saturate until ~3 GeV, and this process generates highly ionizing particles capable of inducing SELs. Different tests oriented towards improving the understanding and accounting for this effect in the accelerator context are programmed.

8. References

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