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Study of Radiation-induced Soft-errors in FPGAs for Applications at High-luminosity e+e- Colliders

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Static RAM-based Field Programmable Gate Arrays (SRAM-based FPGAs) [1, 2] are widely adopted in Trigger and Data Acquisition (TDAQ) systems of High-Energy Physics (HEP) experiments for implementing fast logic due to their re-configurability, large real-time processing capabilities and embedded high-speed serial IOs. However, these devices are sensitive to radiation effects such as single event upsets (SEUs) or multiple bit upsets (MBUs) in the configuration memory, which may alter the functionality of the implemented circuit. Therefore, they are normally employed only in off-detector regions, where no radiation is present. Special families of SRAM-based FPGAs (e.g. the Xilinx Virtex-5QV) have been designed for applications in radiation environments, but their excessive cost (few 10k USD), with respect to their standard counterpart ($\sim$ 500 USD), usually forbids their usage in many applications, including HEP. Therefore, there is a strong interest in finding solutions for enabling the usage of standard SRAM-based FPGAs also on-detector. Methods based on modular redundancy and periodic refresh of the configuration, i.e. configuration scrubbing, are used in order to mitigate single event effects, which become more significant as the technological scaling proceeds towards smaller feature sizes. In fact, latest devices also include dedicated circuitry implementing error correcting codes for mitigating configuration errors. The expected bit configuration upset rate is valuable information for choosing which protection strategy, or which mixture of strategies, to adopt.
Typically, test campaigns are carried out at dedicated irradiation facilities by means of heavy ions, proton and neutron beams [3,4,5] and they permit to determine the particle to bit error cross section. However, a reliable prediction of the upset rate, and of radiation effects in general, requires the knowledge of the cross section as function of the particle species and their spectra and it depends on a detailed knowledge of the radiation fluxes. Often such information is not available with sufficient precision, and when possible an in situ (or in flight for space applications) measurement of the upset rate is highly recommended. For instance, experiments at the Large Hadron Collider have been monitoring SEUs in readout control FPGAs [6], experiments in space have been launched in order to measure single event effects rates and compare them to predictions based on cross sections [7]. Furthermore, over the last decade, FPGA vendors have been carrying out experiments aimed at measuring SEUs induced by atmospheric neutrons in their devices [8].

In February 2016 the SuperKEKB [9] e^+e^- high-luminosity ($8 \cdot 10^{35} cm^{-2} s^{-}1$) collider of the KEK laboratory (Tsukuba, Japan) has been commissioned and it has been operated until June 2016 completing the so-called Phase-1.

In this work, we present direct measurements of radiation-induced soft-errors in a SRAM-based FPGA device installed at a distance of $\sim$ 1 m from the SuperKEKB beam pipe.
We designed a dedicated test board hosting a Xilinx Kintex-7 FPGA. In order to distinguish between FPGA failures from those of other devices, our board hosts only passive components other than the device under test. Power and configuration are fed to the board over dedicated cabling from a remote control room. A single board computer manages configuration and read back via a JTAG connection.
During the SuperKEKB operation, we continuously read back the FPGA configuration memory in order to spot single and multiple bit upsets (SBUs and MBUs) and we logged power consumption at the different power rails of the device. Since the operation current of the SuperKEKB collider spanned a range between 50 and 500 mA for both the electron and positron rings, the experimental scenario allowed us to perform measurements in different radiation conditions.

We discuss the measured FPGA configuration error rate for both SBUs and MBUs and the power consumption variation in the view of applications in Belle2, but also taking into account other experiments operating in similar radiation conditions.
Our study will continue in 2018 during the Phase-2 operation of the SuperKEKB collider, when the ring currents will increase and the final focusing magnets will be installed for providing e^+e^- collisions. The background radiation is expected to rise as well as related effects in FPGAs.

This work is part of the ROAL SIR project funded by the Italian Ministry of Research (MIUR).

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Summary

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