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Measurements and Simulations of Single-Event Upsets in a 28 nm FPGA

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Single-Event Upsets (SEUs) in the configuration memory of a 28 nm FPGA, used in the PANDA electromagnetic calorimeter, have been studied. Results from neutron and proton irradiations are presented. A GEANT4-based Monte Carlo simulation of SEU mechanisms in nanometric silicon volumes has been developed for studies of the energy dependence. At PANDA, a neutron flux of $1 \cdot 10^2$ cm^{-2} s^{-1} at the location of the front-end modules is expected at the lowest antiproton beam momentum and a luminosity of $1 \cdot 10^{31}$ cm^{-2} s^{-1}, leading to a predicted Mean Time Between Failures of 47(10) hours per FPGA in the calorimeter.

Summary

The Facility for Antiproton and Ion Research (FAIR) is currently under construction in Darmstadt, Germany. One of the experiments at FAIR is PANDA (Anti-Proton Annihilation at Darmstadt), where antiprotons with momenta between 1.5 GeV/c and 15 GeV/c will interact in a hydrogen target.

The Electromagnetic Calorimeter (EMC) of PANDA will be read out by approximately 600 front-end digitiser modules, each featuring two 28 nm FPGAs. PANDA will be hardware-trigger-less, and these modules form the EMC software-based trigger.

Single-Event Upsets (SEUs) in the FPGA configuration memory are expected. This has been measured in the past, but to estimate the rate of such errors in PANDA, information about the energy dependence of the SEU cross section is needed. This may be obtained through irradiations at known particle energies, combined with Monte Carlo simulations.

In the present work, one front-end module has been irradiated with neutrons and protons at different energies up to 184 MeV and the SEU cross sections have been determined.

The module was irradiated with neutrons at TSL in Uppsala, Sweden. The neutron beam had a continuous energy distribution between 0 and 180 MeV, and the SEU cross section was determined to be 7.4(6)*10ˆ−15 cmˆ2 bitˆ−1, assuming only neutrons above 10 MeV cause SEUs.

The module was irradiated with protons at KVI-CART in Groningen, the Netherlands. Measurements were performed at three beam energies: 80, 100 and 184 MeV. The SEU cross sections at these energies were determined to be 7.9(9)*10ˆ−15 cmˆ2 bitˆ−1, 6.7(5)*10ˆ−15 cmˆ2 bitˆ−1 and 5.7(6)*10ˆ−15 cmˆ2 bitˆ−1, respectively.

The measured cross sections agree with previous measurements, validating the experimental procedure.

A GEANT4 model of a memory cell containing four cubic Sensitive Volumes (SVs) has been developed. Neutrons and protons with energies matching those in the experiments were directed into the cell, and the SV size dˆ3 and the critical energy required to cause an SEU, E_crit were fitted to give the best agreement with experiments. With the resulting values d = 125(6) nm and E_crit = 4.6(2) keV both the experimental neutron and proton cross sections are reproduced. With a critical energy this low, even low-energy neutrons and protons potentially cause SEUs —this will be studied in further experiments and simulations.

The PandaRoot framework was used to simulate 2*10ˆ6 1.5 GeV/c pbar-p interactions in PANDA. Assuming a PANDA luminosity of 1*10ˆ31 cmˆ−2 sˆ−1, the maximum flux of neutrons at the location of the EMC digitisers was determined to be 1*10ˆ2 cmˆ−2 sˆ−1, giving a Mean Time Between Failures (MTBF) of 47(10) hours per

FPGA. Dependence of the MTBF on pbar momentum and luminosity will be studied further to determine the need for error mitigation.

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