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Radiation Tolerance Specification & Testing Campaign For the Mu2e Experiment at Fermilab

We present an overview of the approach of the Mu2e experiment at Fermilab to address radiation tolerance issues in the front-end electronics. The campaign includes simulations, specifications, testing, and mitigation strategies. The tests include tolerance measurements of Total Ionizing Dose (TID), Non-Ionizing Energy Loss (NIEL), and Single Event Effects (SEE). We describe how the simulations were performed, the resulting performance requirements, the test setups developed, the campaigns executed, and some of the mitigations that were required.

Summary

Work is in progress to build the Mu2e experiment at Fermilab. The goal of the experiment is to measure the ratio of the rate of the neutrino-less conversion of muons into electrons in the field of a nucleus, relative to the rate of ordinary muon capture. This would be an example of charged lepton flavor violation (CLFV), which has never been observed experimentally. Observation would provide unambiguous evidence for physics beyond the Standard Model.

The experiment will use a high intensity, low energy muon beam, with a detector capable of efficiently identifying 105 MeV electrons while minimizing background from conventional processes. The detector has several subsystems: a 20,000 channel Tracker used for measuring the trajectory of charged particles; a 3,500 channel Calorimeter used to measure energy, position and time; and a 29,000 channel Cosmic Ray Veto, which surrounds the detector to identify cosmic rays that can cause backgrounds. The detectors all have front-end electronics that amplify and digitize the detector signals, and programmable logic for processing ant transmitting data off-detector. Data is read out over optical links, which also provide the system timing (clock-encoded data.) DC-DC converters are used on the front-ends, which receive input voltages from off the detector and convert to levels needed by the front-end circuitry. A technical decision was made early on to not use any custom integrated circuits in the front-end electronics, and instead use only commercial off-the-shelf (COTS) parts.

Beginning in 2015, we began to study the radiation levels in the front-end electronics of the experiment, primarily using MARS15, with some simulations done with GEANT4. MARS15 simulations start with events from proton-on-target,and follow the traversing of particles through the detector components. Fluxes of electrons, photons, and hadrons at critical locations are simulated, and Total Ionizing Dose (TID) is derived. and flux of electrons and hadrons. Further processing of the data produces 1 MeV neutron equivalent fluence (Non-Ionizing Energy Loss, or NIEL,) and the fluence of hadrons in specified energy bins, from which the fluence of Single Event Effects (SEE) can be derived. Applying the strategy and experience gathered from the ATLAS and CMS experiments at the LHC, we observed that the radiation tolerance required for the tracker electronics for a 5-year running period was of order 600 krad TID, 6E12 n/cm2 NIEL fluence, and 1E11 p/cm2 SEE fluence. These levels were much higher than originally estimated, and pose a challenge for COTS parts. The Mu2e Electronics Integration Team began coordinating radiation tolerance measurements of front-end components. Issues with all designs were encountered the tracker and calorimeter subsystems. One outcome was a decision to use the VTRx optical transceiver developed at CERN for the data and timing interface on the front ends, and to use rad-hard Draka fiber for the fiber optics.

We will present the process that we developed to assess the radiation tolerance requirements for this large, multi-subsystem detector. We will describe some of the radiation measurement campaigns, and some of the surprises that we encountered that necessitated design changes.

Primary authors: DRAKE, Gary (Fermilab); BYRUM, Karen (Argonne National Laboratory); CERAVOLO, Sergio (Laboratori Nazionali di Frascati dell'INFN, Frascati); CORDELLI, Marco (Laboratori Nazionali di Frascati dell' INFN, Frascati); CORRADI, Giovanni (Laboratori Nazionali di Frascati dell'INFN, Frascati); DIOCIAIUTI, Eleonora (Laboratori Nazionali di Frascati dell'INFN, Frascati); DONGHIA, Rafaella (Laboratori Nazionali di Frascati dell' INFN, Frascati); MISCETTI, Stefano (Laboratori Nazionali di Frascati dell'INFN, Frascati); MORESCALCHI, Luca (INFN Sezione di Pisa); PEDRESCHI, Elena (INFN Sezione di Pisa); PRONSKIKH, Vitaly (Fermilab); RUSU, Vadim (Fermilab); SPINELLA, Franco (INFN Sezione di Pisa); WHITMORE, Julie (Fermilab); ZENETTI, Anna (Laboratori Nazionali di Frascati dell'INFN, Frascati)

Presenter: DRAKE, Gary (Fermilab)

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