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The Digitizer ReAdout Controller (DIRAC) of the Mu2e electromagnetic calorimeter at Fermilab

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We report on the design and performance of the Digitizer ReAdout Controller (DIRAC) of the Mu2e electromagnetic calorimeter, which consists of a 670 CsI crystals matrix readout by SiPM. The 20-channels DIRAC performs 200 MHz sampling of the SiPM signals transmitted by the front-end electronics. Operation in the Mu2e hostile environment expected Total Ionizing Dose (TID) of 12 Krad and neutron fluenceof 5x1010 n/cm2 @ 1 MeVeq (Si)/y, 1T magnetic field, level of vacuum of 10-4 Torr has made the DIRAC design challenging. We describe design, specifications, architecture and results of the performance tests performed on the DIRAC prototypes.

Summary

The goal of Mu2e experiment is to measure the ratio of the rate of the neutrino-less muon-to-electron coherent conversion in the field of a nucleus, relative to the rate of ordinary muon capture. The observation of this process would be the first evidence of Charged Lepton Flavor Violation and would provide unambiguous evidence for the existence of physics beyond the Standard Model.
The Mu2e detector system consists of a low-mass straw tube tracker to measure particle momentum and an electromagnetic calorimeter made of pure CsI crystals to measure particle energy. The calorimeter is made of two disks each composed of 674 un-doped CsI crystals. Each crystal is read out by two large area MPCC. The calorimeter has three main tasks: provide an additional rejection factor of 200 on cosmic muons, a tracker-independent trigger and improve pattern recognition quality and efficiency for the electron tracks.
Monte Carlo simulation has shown that the calorimeter fulfills all these requirements if it reconstructs the conversion electron energy with a resolution of O(5%) and determines its time of arrival with a resolution better than 500 ps @ 100 MeV. This implies that the front-end signals should be sampled with 12-bit resolution and a sampling frequency of 200 MHz.
The Mu2e calorimeter is a high-granularity crystal calorimeter consisting of 1348 un-doped CsI crystals, arranged in two disks and located inside the detector cryostat. In order to limit the number of pass-through connectors and the length of the cables, the calorimeter readout and digitization electronics will be located inside the cryostat. This choice has made the DIRAC design challenging due to the hostile environment: neutron fluence 5x1010 n/cm2 @ 1 MeVeq (Si)/y, TID 12 Krad, 1T magnetic field, which have required an extended campaign of tests to qualify the employed electronic components, and a level of vacuum of 10-4 Torr, which has required the design of a dedicated cooling system for power dissipation. Given the expected challenging DIRAC performance in terms of sampling frequency and amount of processed data with no equivalent in literature, we have to setup numerous tests campaigns, described elsewhere, in several laboratories to fully qualify the complete set of employed components.
The DIRAC core is a Microsemi® FPGA, that handles the entire ADCs protocol and timing, sparsifies and compresses the digitized data and forms a data packet that is sent to the card or to the DAQ servers through optical fibers. We have chosen the TI ADS4229 ADC and the optical transceiver VTRX developed at CERN.
The readout of the entire Mu2e calorimeter requires a complex system of 140 DIRAC cards, for a total of 2800 digitization channels. The DIRACs will be located in custom designed crates, which implement a dedicated cooling system and positioned on the external lateral surface of the calorimeter disks.

The DIRAC prototypes have been designed, built and tested. We have performed a full vertical-slice test with cosmic rays over a matrix of 20 CsI crystals readout with the full SiPM and front-end electronics. System performance will be reported.

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