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The Mu2e electromagnetic calorimeter: readout electronic and qualification

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The readout system of the Mu2e electromagnetic calorimeter is composed of a front-end which collects and transmits the SiPM signals to a waveform digitizer performing a 200 MHz sampling. The Mu2e harsh operational environment (Total Ionizing Dose (TID) of 12 krad and neutron fluence of 5x1010 n/cm2 @ 1 MeVeq (Si)/y, 1T magnetic field, level of vacuum of 10-4 Torr) has made the design particularly challenging. We report on the design, specifications, architecture, and results of the qualification test.

Summary (500 words)

The Mu2e experiment at Fermilab searches for the muon neutrinoless coherent conversion in the field of an Al nucleus. The kinematics of this process is well-modelled by a two-body decay, resulting in a mono-energetic conversion electron (CE) with the energy of approximately the muon mass (104.967 MeV).
After three years of data taking, Mu2e will reach the sensitivity level of $R_{\mu e} \leq 6\times10E-17$ (@ 90% C.L.) and improve the current limit by four orders of magnitude. A very intense pulsed muon beam (~10E10μ/s) is stopped on an Aluminum target inside a very long, curved solenoid where the detector is located. The Mu2e detector consists of a 3.2 m long straw-tube tracker, an electromagnetic crystal calorimeter, and an external veto for cosmic rays. The electromagnetic crystal calorimeter provides excellent electron identification, complementary information to aid pattern recognition and track reconstruction. The detector has been designed as a state-of-the-art crystal calorimeter and employs 1348 pure Cesium Iodide (CsI) crystals readout by UV extended Silicon PhotoMultipliers (SiPM) and fast front-end and digitization electronics. A design consisting of two annular disks positioned at the relative distance of 70 cm downstream the aluminum target along the muon beamline satisfies Mu2e physics requirements. The front-end electronics consists of two discrete chips (Amp-HV) for each CsI crystal directly connected to the back of the SiPM pins. These provide the amplification and shaping stage, a local linear regulation of the SiPM bias voltage, monitoring of current and temperature of the sensors and a test pulse. The SiPM and front-end control electronics is implemented in a battery of mezzanine boards each equipped with an ARM processor that controls a group of 20 Amp-HV chips, distributes the low voltage and the high-voltage reference values, sets, and reads back the locally regulated voltages. The mezzanine boards are hosted in crates located on the external lateral surface of the calorimeter disks. The crates also host the Digitizer ReAdout Controller board (DiRAC) that performs digitization of the amplified and shaped SiPM signals and transmits the digitized data to the Mu2e TDAQ. The TDAQ (Trigger and Data Acquisition) system provides a continuous data stream from the DiRAC boards to the TDAQ farm, which performs the online event reconstruction. The events are then selected based on the decision of dedicated software filters.
The core of the DIRAC board is a large FPGA SoC (MicroSemi® Polarfire MPF300T) which handles 10 ultralow-power 12-bit double channels analog-to-digital converters ADCs (TexasInstruments® ADS4229) with a maximum sampling rate of 250 MSPS, sparsifies and compresses the digitized data and forms a data packet. Digitized data are sent using a custom protocol to the main TDAQ system through a custom optical transceiver (VTRX) designed by CERN. Calorimeter electronics is hosted inside the magnet cryostat and must sustain very high radiation level and magnetic fields. It was thus necessary to qualify it for operation in this harsh environment. The constraints on the calorimeter front-end and readout electronics, the design technological

choices and the qualification tests will be reviewed.

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