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Design and qualification of the Mu2e electromagnetic calorimeter radiation monitor system

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The Mu2e calorimeter and read-out electronics are hosted inside the superconducting magnet cryostat and exposed to an intense flux of ionizing and non-ionizing particles. The performance of a number of components is compromised by radiation damage. This includes the scintillating crystals and silicon photomultipliers (SiPM) whose performance degrades proportionally to both dose and neutrons fluence. The development of a radiation monitor is of vital importance for a reliable detector operation. A system that measures the dose and neutron fluence based on 24 peripheral stations and 4 master units distributed along the detector was built and calibrated.

Summary (500 words)

The Mu2e electromagnetic calorimeter is hosted inside the superconducting magnet cryostat and is made of 1348 undoped CsI crystals distributed in two identical annular matrices (disks). Each crystal is coupled to 2 large area SiPM directly connected to the front-end amplifier. To reduce the cable length and minimize pass-through connections, also the read-out electronics is placed inside the cryostat on the lateral surface of the disks. The high intensity muon beam interaction with the Al target generates a huge amount of ionizing and non-ionizing particles, mainly photons and neutrons to which the calorimeter is heavily exposed. Monte Carlo simulation estimate the crystals and SiPMs will be exposed to a dose of approximately 100 krad and 10E12 neutrons (1 MeV equivalent) in 3 years of Mu2e data taking (including safety factors). Numerous studies report on the effects of the radiation damage due to neutrons on SiPMs performance. These studies show that neutrons with energies of the order of 1 MeV generate a significant increase of noise and leakage current. This could compromise the performance of such devices in an operational environment characterized by high levels of neutron fluence. For the scintillating crystals, radiation damage generates a decrease of the light output and also phosphorescence effects. In both cases, annealing allows a partial recovery. The development of a radiation monitor for the Mu2e calorimeter was deemed essential for a number of reasons, including performing predictive maintenance and studying the origin of the detector performance deterioration. This monitor system was designed, built and named T-RAD. It consists of a variable number of up to 36 sensor cards connected to 4 master cards that collect data and transmit them via optical fiber to the Mu2e DAQ / slow control system. The sensor boards include 3 different devices: a RADfet model Varadis VT01 with a 100 krad full-scale value, a 1-wire DS18S20 temperature sensor and a SiPM used as neutron fluence sensor. The choice of the SiPM for this application was a spin-off of the original R&D for the calorimeter development which required an intense SiPM qualification campaign. We ran a thorough irradiation test campaign at the FNG-ENEA calibrated neutron facility and we determined the real-time variation of the SiPM dark current as a function of neutron fluence. This was done also in a considerable range of temperatures. This allows to directly use the SiPMs selected for the Mu2e calorimeter also as non-expensive and reduced-size sensors. Tests of the sensor cards for the absorbed dose were performed at the Calliope gamma source at ENEA Bracciano. We verified that the VT01 performance is as expected from the Varadis specifications and that the DS18S20 temperature sensor withstands a dose above 200 krad. In the T-RAD monitor system up to 9 sensor boards are connected to 1 master card. The master card is a modified version of the calorimeter digitizing and readout board.
The design, construction and qualification of the T-RAD system are described.

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