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Design and construction status of the Mu2e crystal calorimeter and its future upgrade

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The Mu2e experiment at Fermi National Accelerator Laboratory will search for charged-lepton flavour violating neutrino-less conversion of negative muons into electrons in the Coulomb field of an Al nucleus. The conversion electron has a mono-energetic
104.967 MeV signature slightly below the muon mass and will be identified by a complementary measurement carried out by a high-resolution tracker and an electromagnetic calorimeter (EMC), reaching a single event sensitivity of about 3×10^{-17}, four orders of magnitude beyond the current best limit.

The calorimeter is composed of 1348 pure CsI crystals, each read by two custom UV-extended SiPMs, arranged in two annular disks. The EMC has high granularity, 10% energy resolution and 500 ps timing resolution for 100 MeV electrons and will need to maintain extremely high levels of reliability and stability in a harsh operating environment with high vacuum, 1 T magnetic field and radiation exposures up to 100 krad and
10^{12} $\mathrm{n}_{1MeV_{eq}}/\mathrm{cm}^2$.

The calorimeter design, along with the custom front-end electronics, cooling and mechanical systems were validated through an electron beam test on a large-scale 51-crystals prototype (Module-0). Extensive test campaigns were carried out to characterise and verify the performance of crystals, photodetectors, analogue and digital electronics, including hardware stress tests and irradiation campaigns with neutrons, protons, and photons. After completing the QC phase for crystals and SiPMs, starting from summer 2022, the installation of the disk started. At the moment of writing, one disk in completely assembled with crystals and photosensors, while the stacking procedure for the crystals on the second disk in ongoing. Commissioning and first calibration tests will be also summarised.

In view of a possible Mu2e upgrade - Mu2e-II - relying on the existence of a more powerful source of protons from PIP-II, under construction at Fermilab, the R&D for the calorimeter has already started. The future experiment will try to salvage and refurbish as much of Mu2e infrastructure as possible, upgrading Mu2e components required to handle higher beam intensity.
The Mu2e-II calorimeter should have the same energy and time resolution as Mu2e and withstand neutron fluences of $10^{13}/\mathrm{cm}^2$ and TID up to 10 kGy. The crystals and photosensors of the front calorimeter disk will be largely replaced. A possible crystal candidate is BaF_2 because of the high radiation resistance and the 220 nm fast component. However, R&D on UV sensitive, solar-blind photosensors is necessary to suppress the slow component at 300-320 nm. Other solutions are under development with other possible crystal candidates under test, like LYSO, PbF_2, CRY18.

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