Design, status and perspective of the Mu2e crystal calorimeter

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Abstract. The Mu2e experiment at Fermilab will search for the charged lepton flavor violating process of neutrino-less $\mu \to e$ coherent conversion in the field of an aluminum nucleus. Mu2e will reach a single event sensitivity of about $2.5 \cdot 10^{-17}$ that corresponds to four orders of magnitude improvements with respect to the current best limit. The detector system consists of a straw tube tracker and a crystal calorimeter made of undoped CsI coupled with Silicon Photomultipliers. The calorimeter was designed to be operable in a harsh environment where about 10 krad/year will be delivered in the hottest region and work in presence of 1 T magnetic field. The calorimeter role is to perform μ/e separation to suppress cosmic muons mimiking the signal, while providing a high level trigger and a seeding the track search in the tracker. In this paper we present the calorimeter design and the latest R&D results.

1 Intorduction

Observation of the neutrino oscillation during the last decades boosted the interest of the experimental comunity in the search of Lepton Flavour Violating (CLFV) processes also in the field of charged leptons. The muon conversion represents a powerful channel to search for CLFV, because it is characterized by a distinctive signal consisting in a mono-energetic electron with energy $\mathrm{E_{ce}} = \mathrm{m}_\mu - \mathrm{E_b} - \mathrm{E}_\mu^2/(2\mathrm{m_N})$, where m_μ is the muon mass at rest, $\mathrm{E}_b \sim \mathrm{Z}^2\alpha^2\mathrm{m}_\mu/2$ is the muonic atom binding energy for a nucleus with atomic number Z, E_μ is the nuclear recoil energy,

$E_\mu = m_\mu - E_b$, and m_N is the atomic mass [1]. In case of aluminum, which is the major candidate for upcoming experiments, $E_{ce} = 104.973$ MeV [2].

2 Calorimeter design

The calorimeter consists of two disks anulii, separated by 75 cm, with ineer (outer) radius of 37.4 (66) cm. Each disk is filled wih 678 undoped CsI crystals 20 x 3.4 x 3.4 cm^3. The inner region is left un-instrumented to avoid interactions with low energy electrons, while the separation between the disks maximize the acceptance for the conversion electrons (CE). Each crystal is read out by two arrays 2x3 of 6x6 mm^2 SiPM. Each SiPM array is matched to a front end electronics board (FEE) that provides an amplification stage and also local voltage regulation. Signal form the FEE is then digitized by a custom made waveform digitizer @ 200 Msps [3]. Figure 1 shows a 3D representation of the calorimeter and a picture of the crystals

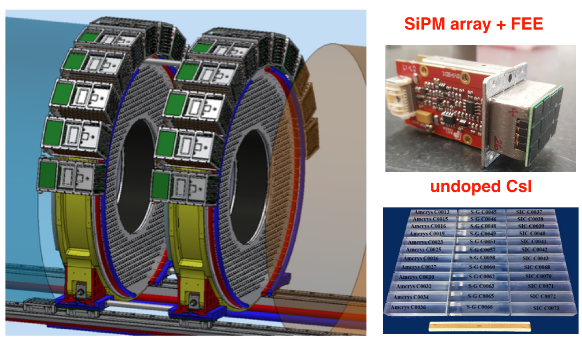

Fig. 1. Left: Calorimeter design. Right: Undoped CsI crystals from the pre-production and one SiPM + FEE module.

and SiPM from the pre-production. A more detailed description of the calorimeter desgin can be found on reference [4].

3 Role of the caloriemter in Mu2e

The main role of the calorimeter in Mu2e is to provide particle identification capabilities that are essentials to distinguish Cosmic μ @ p=105 MeV/c mimicking the CE. The rejection algorithm is based on a likelihood ratio that uses as input the following observables: 1) E/p: ratio of the track momentum and the calorimeter cluster energy; 2) Δt: time residual between the calorimeter cluster and the track time as extrapolated to the calorimeter. Figure 2 shows the distribution of E/p and Δt for CE and μ @ p=105 MeV/c. The calorimeter information are also useful for driving the track search in the tracker by means of time and spatial correlations with the hits in the chamber associated to the same particle that produced the calorimeter

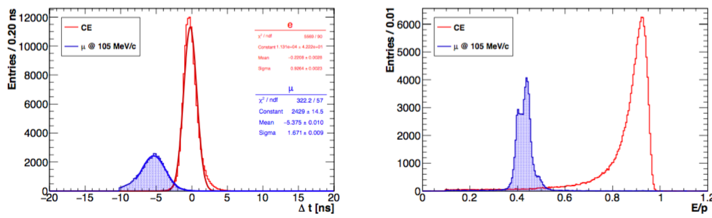

Fig. 2. Left: distribution in Δt for CE and μ @ p=105 MeV/c. Right: Distribution in E/p for CE and μ @ p=105 MeV/c.

cluster [5]. Figure 3 shows how the hits pre-selection reduces the number of background hits in a typical event with one CE overlaid with the expected background.

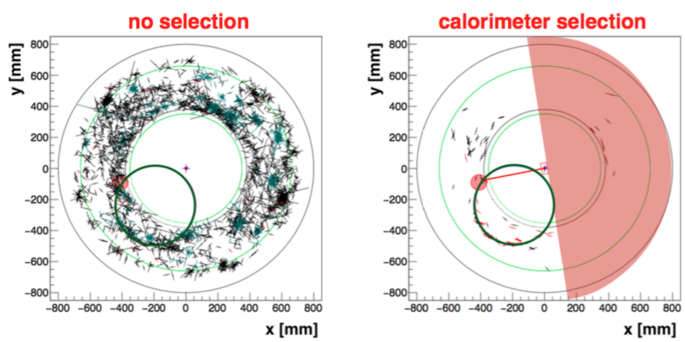

Fig. 3. Transverse view of an event display for a CE event with background hits included, with (right) and without (left) the calorimeter pre-selection. The black crosses represent the straw hits, the red bullets the calorimeter clusters, and the red circle the CE trajectory.

4 R & D

During late 2016 we started the pre-production of the crystals, SiPM and FEE boards that were used for the assembly of the final calorimeter prototype, see figure 4. This prototype has a key role in validating the expected physics performance and also check several mechanical properties, like the performance of the cooling system and the assembly procedures. During May 2017 a test beam was performed at the Beam Test Facility in Frascati (Italy) [6] using an e^- beam in the range [60, 120] MeV.

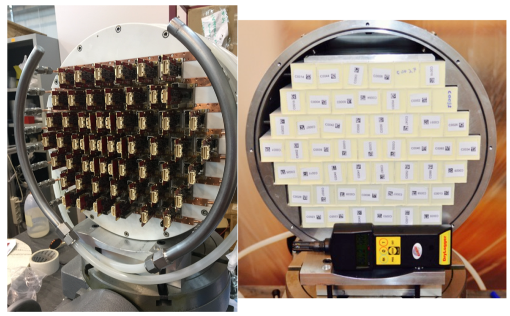

Fig. 4. Calorimeter prototype during the assembly phase.

5 Summary

In this paper the calorimeter project for the Mu2e experiment has been presented. We showed that the Mu2e calorimeter design is able to provide particle identification capabilities, an high level trigger and is also a helpfull tool for improving the tracking pattern recognition. A test beam with a prototype of the calorimeter was performed during May 2017 using an electron beam in the energy range [60, 120] MeV.

Acknowledgment

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