An automated QC Station for the Calibration of the Mu2e Calorimeter Readout Units

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Abstract

The Mu2e calorimeter will employ readout units (ROUs), each made of two Silicon Photomultipliers arrays and two Front End Electronics boards. To calibrate them, we have designed, assembled and put in operation an automated Quality Control (QC) station. Gain, collected charge and photon detection efficiency are evaluated for each unit. In this paper, the QC Station is presented, in its hardware and software aspects, summarizing also the tests performed on the ROUs and the first measurement results.

1. The Mu2e Electromagnetic Calorimeter Readout

Mu2e will search for Charged Lepton Flavour Violation via the conversion process: $\mu^- \, {}^{27}\text{Al} \rightarrow e^- \, {}^{27}\text{Al}$, aiming to improve the current sensitivity on the ratio between the conversion and capture events rates by four orders of magnitude, reaching a sensitivity of 8×10^{-17} at 90% CL [1]. The Mu2e calorimeter is formed by two annular disks, each one containing 674 undoped CsI crystals. This detector will have to work in a 10^{-4} Torr vacuum, 1T magnetic field and withstand a total ionizing dose of up to 100 krad and a neutron flux of $\sim 6 \times 10^{10} n_{1\text{MeV-eq}}/\text{cm}^2/\text{year}$ on the first disk. Nevertheless, it has to satisfy strict requirements on time resolution $\sigma_t < 500$ ps, spatial resolution $\sigma_x < 1$ cm and energy resolution $\sigma_E/E < 10\%$ for 100 MeV electrons. Each CsI crystal is readout by two UV-extended Hamamatsu Silicon Photomultipliers (Mu2e SiPMs), each made by a 2×3 matrix of 6×6 mm^2 monolithic cells. Two Mu2e SiPMs glued on a copper holder and two independent Front End Electronics (FEE) boards form a Readout Unit (ROU) (Fig. 1).

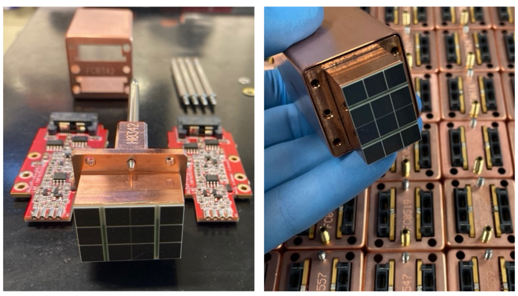

Figure 1: Picture of the Readout Unit. On the left the Front End Electronic Boards can be seen. On the right the assembled ROUs are shown.

2. The LNF Quality Control Station for the Readout Units

To qualify and calibrate the O(1500) assembled ROUs, we have designed, realized and put in operation an automated QC station at LNF (Laboratori Nazionali di Frascati of INFN).

In this station, the crystal luminescence light is mimicked by a 420 nm LED which illuminates the sensors through an attenuating set of filters held by an automatic wheel. This allows to obtain nine different and calibrated light intensities. A metal box ensures light-tightness and houses two sandblasted glass layers to uniformly diffuse the light on the SiPM faces. The Al plate holding the ROUs is temperature stabilized at 25 °C via a chiller. In Fig. 2 a schematics of the station is shown. A Mu2e Mezzanine board, USB connected to a PC, controls the supplied high voltage to the SiPMs and provides the analog signals for digitization. The data acquisition, triggered by the LED driver signal, is based on a CAEN waveform digitizer. Two power supplies are used at the station, one Low Voltage to power the Mezzanine and one High Voltage to provide the SiPM bias voltage. Both are remotely controlled via TCP/IP.

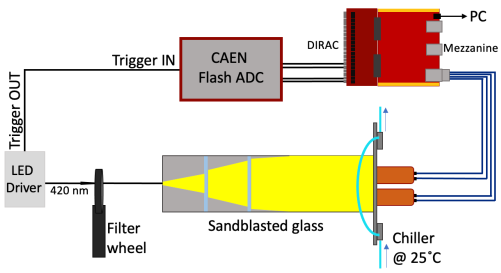

Figure 2: Schematics of the LNF ROU QC Station.

Data acquisition is performed on two ROUs at the same time. Since the SiPMs will sustain some radiation damage during detector operation, we plan to decrease their bias voltage (V_b) to limit the leakage current. To study the SiPM response dependence on V_b, a scan is performed around the SiPM operational voltage (V_{op}), from $V_{op}-4$V to $V_{op}+2$V, in 1V steps. For every voltage value, 10^4 events per wheel position are acquired. Underlying C++ and python programs control the data acquisition and thanks to the high level of parallelization of the analysis, a full scan is performed in 7 minutes. This setup allows to determine the SiPM gain, photon detection efficiency (PDE) and the collected charge for each voltage step so to study their V_b dependence. A sensor on the FEE boards allows to monitor the detector temperature and thus evaluate the temperature dependence of the gain.

3. Calibration and Quality Control results

An example of a scan result over the nine filter positions at one voltage value is shown in Fig 3. From the measurement of σ_Q/Q it is possible to extract the SiPM gain through the relation:

$$\frac{\sigma_Q}{Q}(Q) = \sqrt{\frac{p_0}{Q} + \frac{p_1^2}{Q^2} + p_2^2}. \quad (1)$$

The gain is evaluated as $G = p_0/(q_e[pC])$. This result is obtained for each supplied voltage value so that the gain as a function V_b can be determined. The obtained behaviour is shown in Fig.4 as a function of the overvoltage $\Delta V = V_b - V_{op}$.

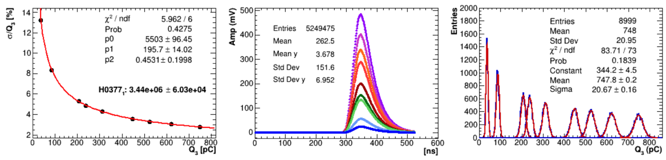

Figure 3: Result of a scan in light intensity for the 9 filters at V_{op}. The plots show σ_Q/Q (left), the wave profile (center) and the collected charges (right) for the 9 positions.

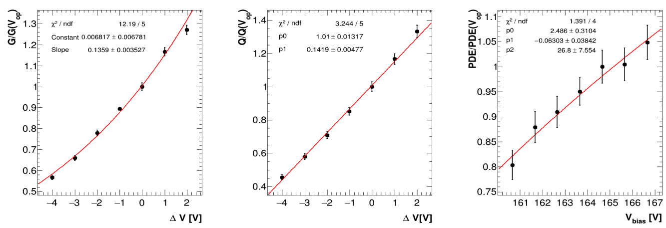

Figure 4: Behaviour of gain (left), charge (center) and PDE (right) as a function of ΔV. Gain is fitted with an exponential, the charge with a linear function and the PDE with a specific expression from [2].

The reproducibility of the gain measurement has been tested and it is evaluated to be better than 2%. The temperature dependence has also been evaluated and it has been found that the breakdown voltage variation due to a temperature increase causes a gain decrease of 1.6% /°C. This value has been extracted from the temperature profile of the gain in a range of ±2°C around 25°C, as shown in Fig. 5 (left). To build a uniform ROU database and to have comparable data we have corrected the gain values to 25°C. The temperature corrected gain distribution is shown in Fig. 5 (right).

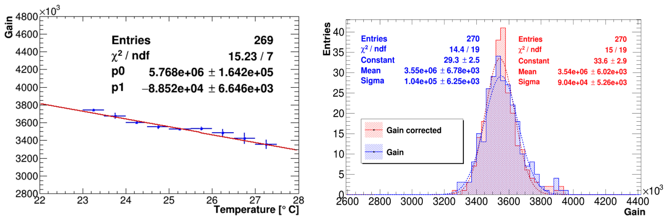

Figure 5: Left: Temperature profile of the gain. Right: histogram of the gain with the temperature correction applied.

4. Conclusions

The Mu2e Calorimeter has strict requirements in terms of performance and stability. To ensure these requirements are met, a full characterization of the ROU parameters has been implemented. The QC station allows to perform a HV scan of 2 ROUs at the time in 7 minutes, with a reproducibility better than 2% on the final gain. The dependence of gain, charge and PDE on the SiPM overvoltage and on temperature has been studied. The average gain value at operational voltage is 3.6×10^6, with a spread along production of the order of 3% that well satisfies the Mu2e calorimeter requirements.

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