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The calibration system of the muon $g-2$ experiment at Fermilab

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Summary. — The Muon $g-2$ experiment at Fermilab aims to measure the muon anomalous magnetic moment, a_μ, to an unprecedented precision of 140 ppb. To reach this goal each channel of the 24 calorimeters must be calibrated with a relative accuracy at the sub-per-mill level. Such accuracy level is a challenge for the design of the calibration system because it has never been previously required and realized.

1. – The calibration system

The calorimeters of the Muon $g-2$ experiment are designed to measure the precession-related fluctuations in the energy of positrons from the muon decay [1]. There are 24 calorimeters, each of them is composed of 54 PbF_2 crystals read out by SiPMs [2]. It follows that the total number of channels to be calibrated is 1296. The calibration is based on the distribution of light from a common light source to each of the calorimeter channels.

Given the large number of calorimeter channels involved, 6 laser-based light sources (LDH-P-C-405M from PicoQuant) are needed to satisfy the power requirements of the system [3]. The light sources are pulsed lasers characterized by a maximum pulse energy of 1 nJ, 700 ps wide pulses of 405 nm wavelength and a repetition rate up to 40 MHz. The repetition rate used in the experiment does not exceed the 10 kHz. The generation of the light pulses is triggered by a custom laser control board interfaced with an 8-channel multi-laser driver (PDL828 Sepia II) that controls all the 6 laser heads.

The light of each laser is split into two parts: 70% is sent to a distribution chain consisting of optical elements which split the light of each laser equally into four parts. Each part is then focussed into 25 m long quartz optical fibers. These fibers carry the light from the source to each calorimeter via a diffuser, a fiber bundle and a panel with optical prisms which couple the fibers to the crystals.

The remaining 30% of the laser light enters a Source Monitor (SM) which measures the fluctuations of the pulse intensity shot by shot. Once corrected for these fluctuations

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the corresponding light pulses observed in each calorimeter channel become reference signals for monitoring gain fluctuations in the calorimeter response. Each of the 6 SMs consists of an integrating sphere which distributes the incoming light uniformly among 2 large-area PIN diodes for fast monitoring and, a PMT, also exposed to an Am/NaI “light pulser”, for slow absolute calibration [4]. All is contained inside a solid aluminium case with large thermal inertia which also serves as a Faraday cage.

The stability of the distribution system is monitored by 24 Local Monitors (LMs) each composed by two PMTs [3]. Two signals are sent to each LM: a first pulse from the SM as reference signal and a second pulse from the diffuser just upstream of the calorimeter which is carried back by PMMA return fibers. The ratio of the two pulses is a measurement of eventual instabilities in the light distribution chain.

Another important function of the laser system is the calibration of the calorimeter response to light pulses in terms of their number of photoelectrons. This is done by varying the laser-pulse intensity by means of a filter wheel, positioned before the optical elements of the distribution chain, and relying on Poisson statistics to correlate averages and uncertainties of the measured intensities to the corresponding number of photoelectrons [3]. Knowledge of this number is essential for the correction of SiPM saturation and the measurement of the energy deposited in the crystal. The test beam demonstrated that the correction provided by the calibration system is highly accurate [3].

2. – Test beam results

A test of the calibration system was performed at the Frascati Beam Test Facility [3]. A subset of 4 elements of the calorimeter was tested by a 450 MeV monoenergetic electron beam. The calorimeter response ($\mu_E^{\text{uncorrected}}$) was corrected for gain fluctuations using the laser light signals (μ_L):

$$\mu_E^{\text{corrected}} = \frac{\mu_E^{\text{uncorrected}}}{\mu_L / C_{\text{MONITORS}}}, \tag{1}$$

where C_{MONITORS} is the correction factor that accounts for the fluctuations into the laser source and the distribution chain measured by the source and the local monitors. A stability at sub-per-mill level on the monitoring system has been achieved in few hours.

3. – Conclusions

The construction and assembly of the laser calibration system of the Muon $g-2$ experiment at Fermilab is close to be completed. An engineering run is planned for June 2017 and data taking is expected to begin in Fall 2017. The laser system will operate during the data acquisition providing the monitoring of calorimeter stability and calibration with the required accuracy. It will also be used for timing alignment within and between calorimeters.

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