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Laser calibration system for the Muon $g-2$ Experiment at Fermilab

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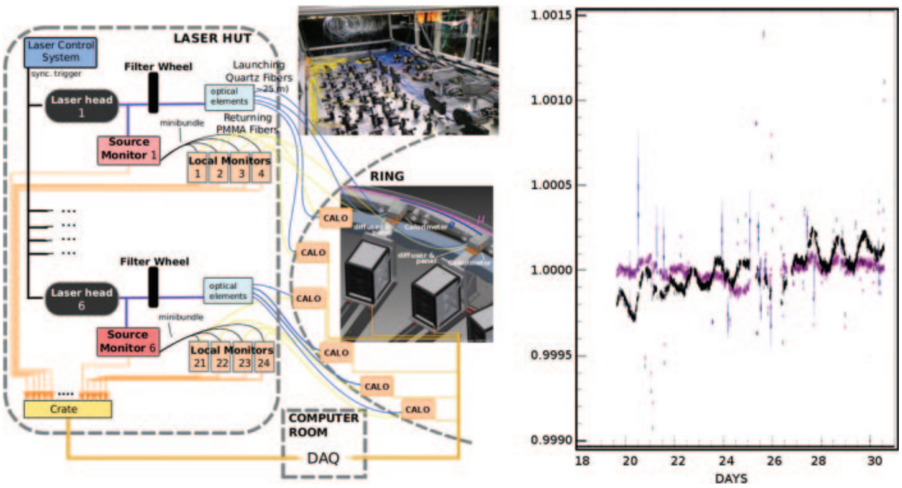
Summary. — Muon $g-2$ experiment at Fermilab is going to measure the anomalous magnetic moment of the muon with a precision of 0.14 ppm like never before. This fourfold precision goal compared to the previous $g-2$ experiment at BNL required improvements in all fronts, a big part of which will come from the gain correction of the SiPM-based calorimeters using a complex laser calibration system developed by INFN.

1. – Description

Muon being much heavier than the electron and not so short lived (like tau), gives us the best opportunity to probe new physics ($\sim m_\mu^2/\Lambda^2$) through the low-energy observable $a_\mu = (g-2)/2$ directly related to the muon's anomalous magnetic moment. Results from the previous (BNL) experiment is suggesting exciting indication of new physics that has inspired the new muon $g-2$ experiment [1] at Fermilab that aims for a fourfold precision goal, 0.14 ppm. The detector consists of 24 calorimeters stationed across the full ring. These calorimeters equipped with SiPMs are recording the Cerenkov light emitted by the decay positrons from the muons when passign through the PbF2 crystals [2]. To achieve the precision goal it is very important to understand how the gain behaves at various time scales, especially during the muon fill window ($\sim$700 μs). The equation $r_{e^+}^{Total} = r_{e^+}^{Real} \times G^{SiPM}(t)$ represents well the situation, where $r_{e^+}^{Total}$ is the total response of the SiPM to a positron event and $r_{e^+}^{Real}$ is the response that we would see if the gain was not sagging at all. $G^{SiPM}(t)$ is the SiPM gain function. The laser calibration system [3] sends laser pulses of known intensity to those calorimeter-SiPMs at different intervals of times, both during muon fill as well as outside of it. An array of photodetectors is used to construct a monitoring system consisting of two main parts, the *source monitors* that monitor the intensity of the laser pulses right after they leave the laser heads and *local monitors* that monitor pulses that have travelled the whole optical paths (from laser sources to the calorimeter crystals), the local monitor also receives a part of the



(a) (b)

Fig. 1. – (a) Schematic of the laser calibration system and (b) the pin diode signal ratio of a source monitor over 10 days which is represented by the black curve, the purple one is after temperature correction ($\sim 10^{-4}$).

source monitor signal to compare how it changes after travelling the whole optical path of several meters and being independent of the gain fluctuation of its photodectector. The third component of the laser system is the *laser control board*. We will discuss about these three components separately in the following section.

2. – The monitoring and the laser control system

The source monitor is made of two pin diodes and a PMT and it monitors the instability (if any) of the laser source, there are 6 source monitors monitoring the six laser sources. The ratio of the two pin diode signals represents the stability of the source monitors, the observed stability is of the order of 10^{-4} over many hours, well within our expectations. There are 24 local monitors corresponding to 24 calorimeters. A local monitor consists of two PMTs, both receiving two signals, the first signal coming from a source monitor and the other that has traveled the whole light distribution system, the ratio of these two pulses represents the stability of the local monitors or, in other words, the stability of the light distribution system.

A laser control system [4, 5] controls the number and frequency of laser pulses that should be sent during and outside the muon fills. A muon fill lasts for a few hundred μs and the gain takes about 200 μs to recover, therefore in a standard mode, three laser pulses with 200 μs separations are sent inside a fill, every 10 fills we repeat this procedure but shift the positions of those pulses inside a fill by 2.5 μs, so in 48 such steps, we scan the whole range of gain sagging and construct the SiPM gain function $G^{SiPM}(t)$ using the response to these pulses from the SiPM. Laser pulses are also sent outside the muon fills all the time that helps us extract the long-term gain variations due to aging, temperature effects, etc. Figure 1(b) shows the stability of the source monitor over 10 days of April 2018.

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