The Calibration System of the new muon g-2 experiment at Fermilab

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Abstract

The muon anomaly $(g-2)_\mu/2$ has been measured to 0.54 parts per million by E821 experiment at Brookhaven National Laboratory, and at present there is a 3 to 4 standard-deviation difference between the Standard Model prediction and the experimental value. A new muon g-2 experiment, E989, is being prepared at Fermilab that will improve the experimental error by a factor of four to clarify this difference. A central component to reach this fourfold improvement in accuracy is the high-precision laser calibration system which should monitor the gain fluctuations of the calorimeter photodetectors at 0.04% accuracy.

1. Introduction

The muon anomaly $a_\mu = (g-2)_\mu/2$ is a low-energy observable, which can be both measured and computed to high precision [1]. Therefore it provides an important test of the Standard Model (SM) and it is a sensitive search for new physics [2].

From the experimental side, the error achieved by the BNL E821 experiment is $\delta a_\mu^{\mathrm{EXP}} = 6.3 \times 10^{-10}$ (0.54 ppm) [3]. A new experiment, E989 [4], to measure the muon anomaly to a precision of 1.6×10^{-10} (0.14 ppm) is under construction at Fermilab. The goal of this new experiment is to measure the muon g-2 anomaly a_μ to a precision of 1.6 $\times 10^{-10}$. Many improvements are needed with respect to the previous experiment and in particular, it will require a continuous monitoring and recalibration of the detectors, whose response may vary on both the short timescale of a single fill, and the long time scale of an entire run.

2. Laser Calibration System

A high performance calibration system is required for the online monitoring of the output stability of each individual tower in all calorimeter stations. It is estimated that the detector response must be calibrated with relative accuracy at sub-per mil level to achieve the goal of the E989 experiment to keep systematics contributions to the accuracy on the measured observables at 0.02 ppm level. This is a challenge for the design of the calibration system because the desired accuracy is at least one order of magnitude higher than that of all other existing, or adopted in the past, calibration systems for calorimetry in particle physics.

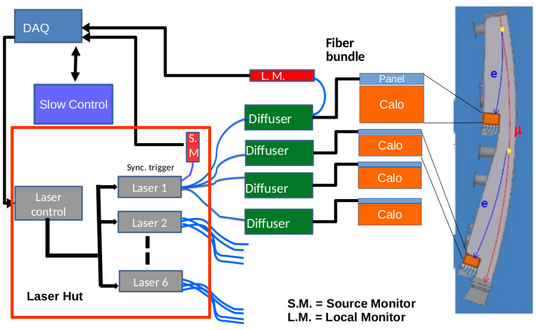

Figure 1: Schematic view of the Laser Calibration System design.

As almost 1300 channels must be kept calibrated during data taking, the proposed solution is based on the method of sending simultaneous light calibration pulses onto the readout photodetector through the crystals of the calorimeter. Light pulses should be stable in intensity and timing in order to correct for systematic effects due to drifts in the response of the crystal readout devices. A suitable photo-detector system must be included in the calibration architecture to monitor any fluctuation of the light. The guidelines given by the experiment to define in the correct way the architecture of the entire system could be

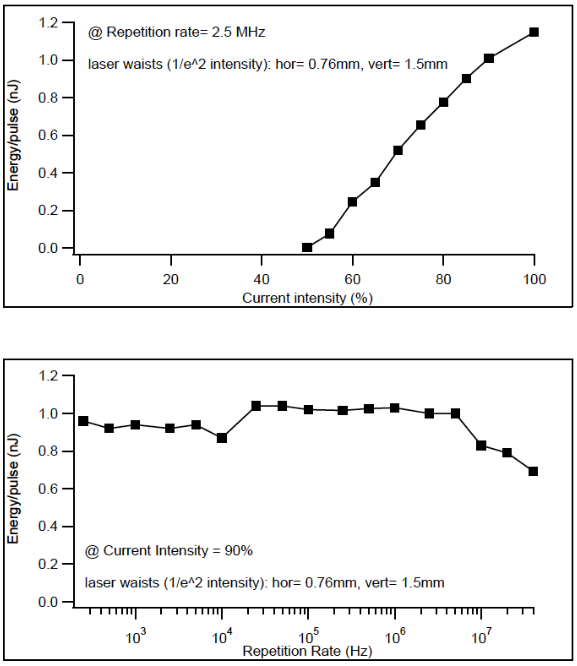

Figure 2: Laser energy/pulse with respect to the current (upper figure) and with respect to the repetition rate (lower figure).

found in [5]. A sketch of the actual design of the calibration system is shown in Fig. 1. The crucial point for the realization of this system are: the light source, the distribution system that shares the light to the calorimeters with sufficient intensity and sufficient homogeneity among them. The light source should be in the same spectral range accepted by the photodetectors and has to be powerful enough to ensure a sufficient amount of light for each calorimeter station considering losses due to the distribution chain. In the final configuration the laser source is composed by 6 lasers LDH-P-C-405M from PicoQuant driven by a single PDL 828 Sepia II 8 channel multi-laser driver, with a measured light output: 1000 pJ/pulse @ 10 kHz (Fig. 2). Each laser gives light to four calorimeter stations and it is very important to share its light between the calorimeters in a uniform way. The task of the distribution chain is to divide and carry the light from the laser source to the different calorimeter stations placed around the ring. The first step consists in collecting the light of the laser using optical fibers. The attenuation loss of the fibers should be minimized because the distance from the laser to a single calorimeter station could be ~25 m. For this reason the fibers used are quartz fibers with an attenuation of 20 dB/km @ 400 nm. Each laser is splitted in four and coupled to quartz fibers; each output is coupled with an engineered diffuser ED1-S20 by RPC Photonics. The diffuser is needed to to make a uniform light pattern for a fiber bundle that distributes light to each crystal of the calorimeter.

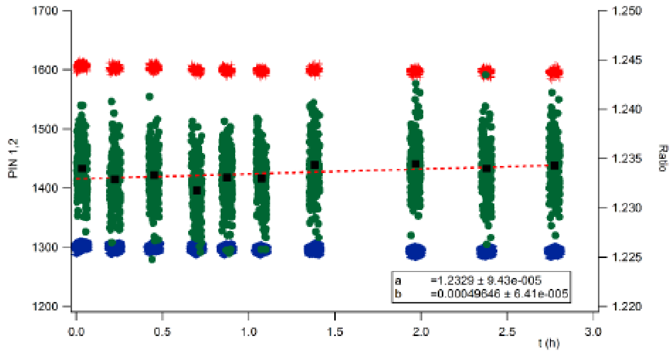

Figure 3: Stability measurement of the calibration system vs time. The red and the blue points are the signals read by Pin2 and Pin1 respectively and must be red on the left axis. The green points represent the ratio between the two signals and refers to the right axis.

3. Laser Calibration stability

The most important feature of this calibration system is the time stability. In fact is requested a stability of the order of 10^{-4} over 2 hours.

In Fig. 3 are shown the results obtained. To ensure that this level of stability is maintained during data taking a monitoring procedure has to be included in this calibration system. The monitoring system is composed of two parts. The source monitor (made of two pin diodes, a PMT, and an ^{241}Am pulser for absolute calibration), checks all the possible fluctuations of the laser sources. The number of source monitors is the same number of the laser sources. The local monitor (which has to be different from the source monitor because of different position and light characteristics) checks the stability just before the light injection to the calorimeters.

4. Conclusion

The Laser Calibration system for the new E989 experiment in preparation at Fermilab has a crucial role due to the strictly requirements needed for the systematic error reduction with respect to the previous experiment. To reach the goal of a 0.04% uncertainty on a_μ is necessary a stability of 10^{-4} over an entire calibration run. The choice of the components of this calibration system has to provide an high levels of stability in intensity and time. Moreover all the device have to be as much as possible unaffected by effects of aging to not variate during the expected two years of data taking.

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