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

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Introduction

The Muon *g-2* experiment at Fermilab aims to measure the muon anomalous magnetic moment to an **unprecedented precision**: **0.14 ppm**. To reach this goal each channel of the 24 calorimeters must be calibrated with a **relative accuracy at the sub per-mill level**. The calorimeters are designed to measure the precession-related fluctuations in the energy of positrons from the muon decay. Each of them is composed of 54 PbF_2 crystals readout by SiPMs. The sub per-mill level is a challenge for the design of the calibration system because such calibration accuracy has **never been previously required** in particle physics.

Method

The calibration method is based on the **distribution of light from a common light source** to each calorimeter channel. The stability of each channel can then be monitored to the accuracy with which the **stability of the common light source and that of the distribution system are monitored.** The large number (1296) calorimeter channels involved requires the use of 6 laser-based light sources, each of which is monitored by a Source Monitor (SM). The stability of the distribution system is monitored by 24 Local Monitors (LM).

Laser source

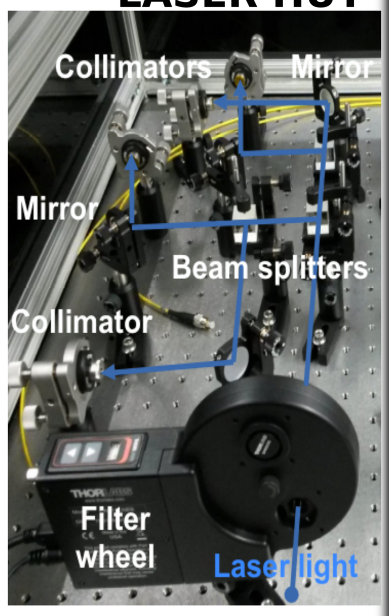
The light sources are **pulsed lasers**:

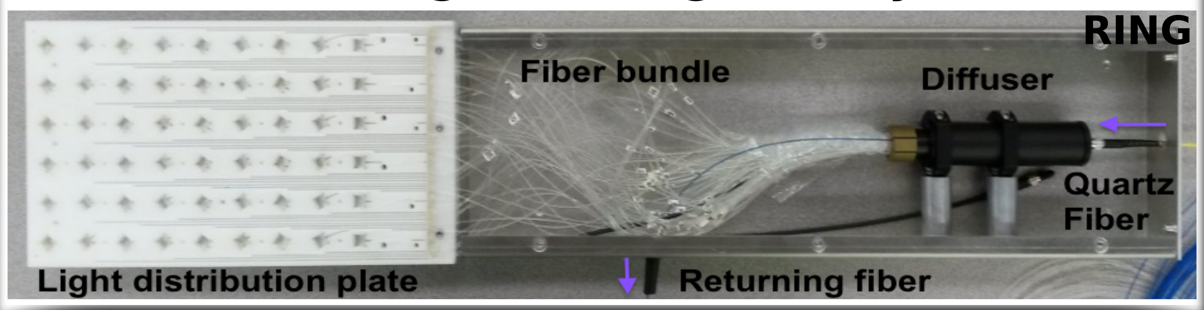
- maximum pulse energy **1 nJ**;
- pulse width of **700 ps**;
- wavelength of **405 nm**;
- repetition rate **up to 40 MHz**.

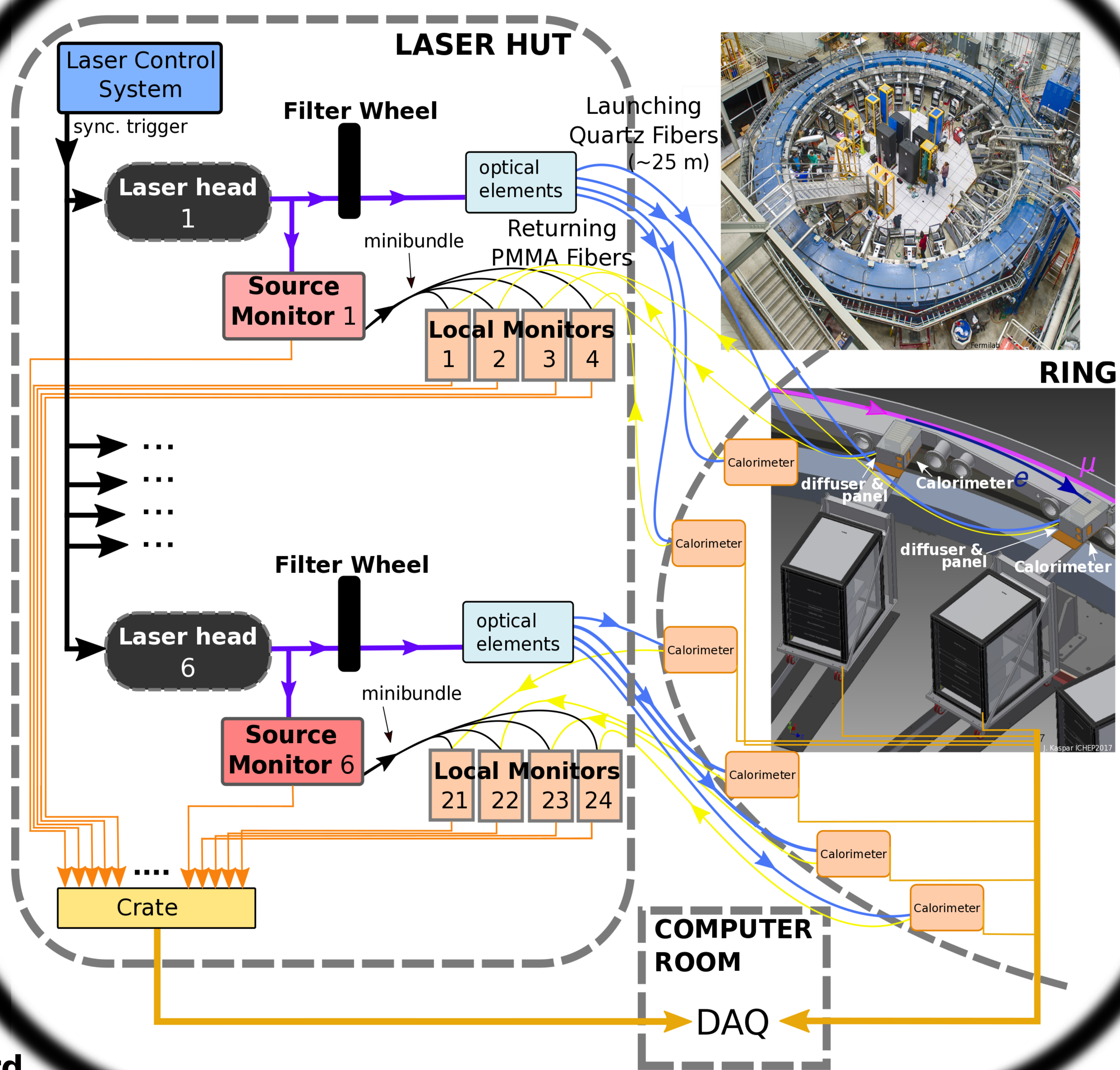
The calibration system is composed of 6 laser heads (LDH-P-C-405M from PicoQuant) driven by a single 8 channel multi-laser driver (PDL828 Sepia II). **The intensity of each laser is sufficient for light distribution to 4 calorimeter** (216 channels). The generation of the light pulses is triggered by a custom **laser control board** interfaced with the laser driver. The laser source, the first part of the distribution chain and the monitors are contained in an enclosure called **LASER HUT**.

Distribution chain: from LASER HUT to calorimeters

The distribution chain consists of optical elements with the pourpose of **equally dividing** the light of each laser into 4 parts and **coupling** each part into quartz optical launching fibers. These fibers **carry the light from the laser hut to each calorimeter.** Each calorimeter is equipped with a diffuser, a fiber bundle and a panel which **distribute the light among the crystals**.







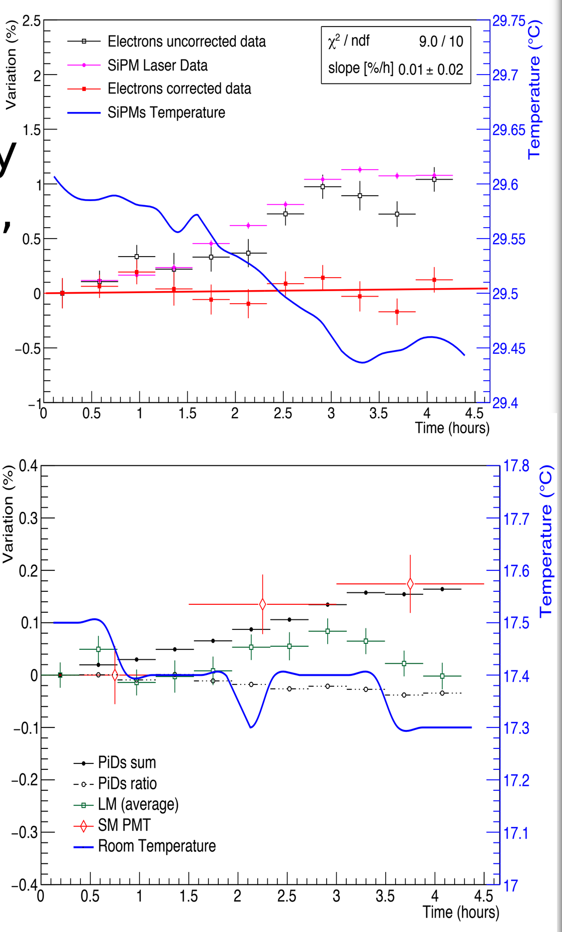
Test Beam Results

A test of the calibration system was performed at the Frascati BTF. A subset of 4 elements of the calorimeter was illuminated with a 450 MeV monoenergetic electron beam. The calorimeter response, as is affected by the SiPM gain fluctuations, was **corrected with reference to the laser light signals** as follows:

$$\text{Electrons corrected data} = \frac{\text{Electrons uncorrected data}}{\frac{\text{SiPM Laser Data}}{\text{Monitors Data}}}$$

where:

$$\text{Monitors Data} = \text{PiDs Sum} \cdot \text{LM}$$



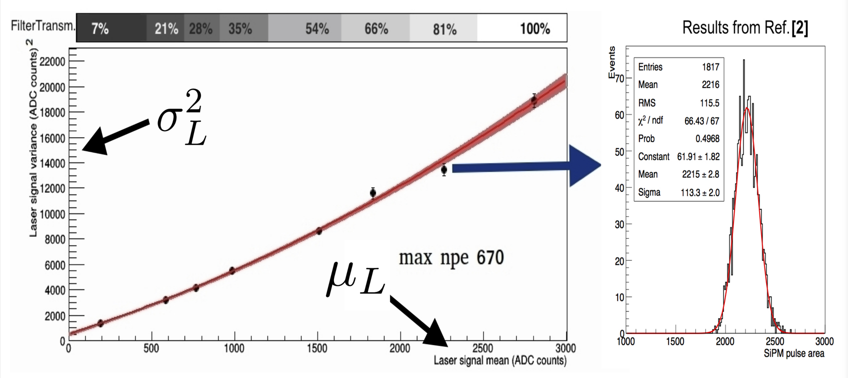
The motorized filter wheel for the photon calibration

The filter wheel allows for **attenuation** of the laser light intensity so that, by applying Poisson statistics:

$$\begin{cases} \mu_L = k n_{p.e.} \\ \sigma_L^2 = \sigma_{noise}^2 + (k\sqrt{n_{p.e.}})^2 + \alpha (k n_{p.e.})^2 = \sigma_{noise}^2 + k\mu_L + \beta \mu_L^2 \end{cases}$$

electronic noise, Possion stat., intrinsic fluct.

the **pulse-area/p.e. conversion factor** (k) can be extrapolated from fit of the above expression to data:



Knowledge of $n_{p.e.}$ is essential for the correction of **SiPM saturation** and the measurement of the **energy deposited** in the crystal.

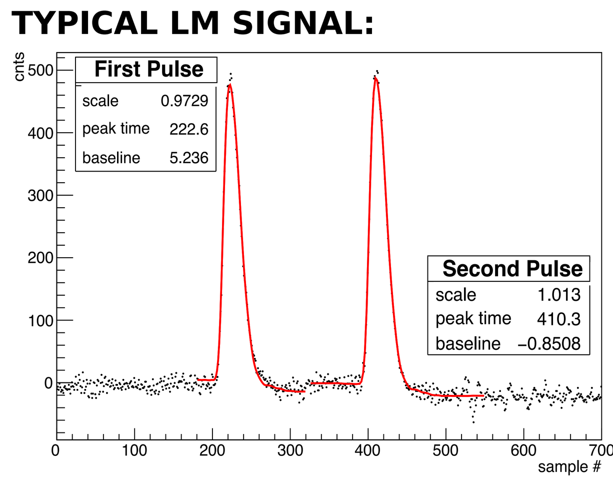
Local Monitors (LMs)

The LMs detect instabilities that might be introduced by the light distribution chain. There are **24 LMs**, each composed by a Photonics **PMT**.

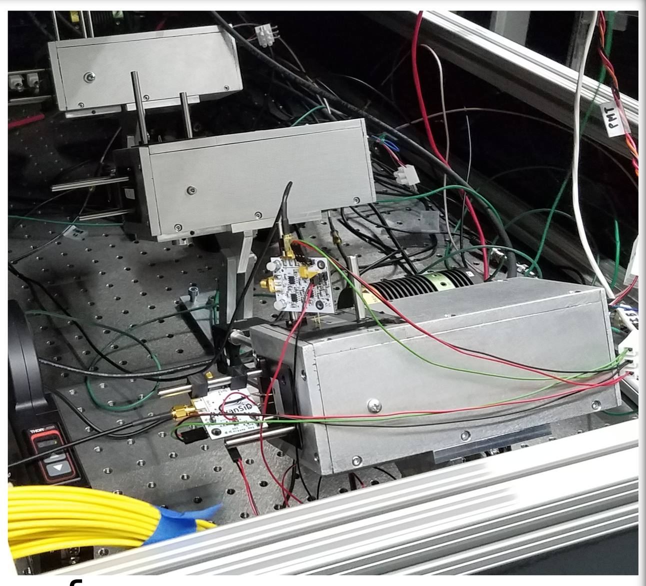
Each LM receives two signals:

first pulse: reference signal from the SM;
second pulse: signal from the diffuser just upstream of the calorimeter.
The ratio of the two pulses is a measurement of the distribution chain

TYPICAL LM SIGNAL:



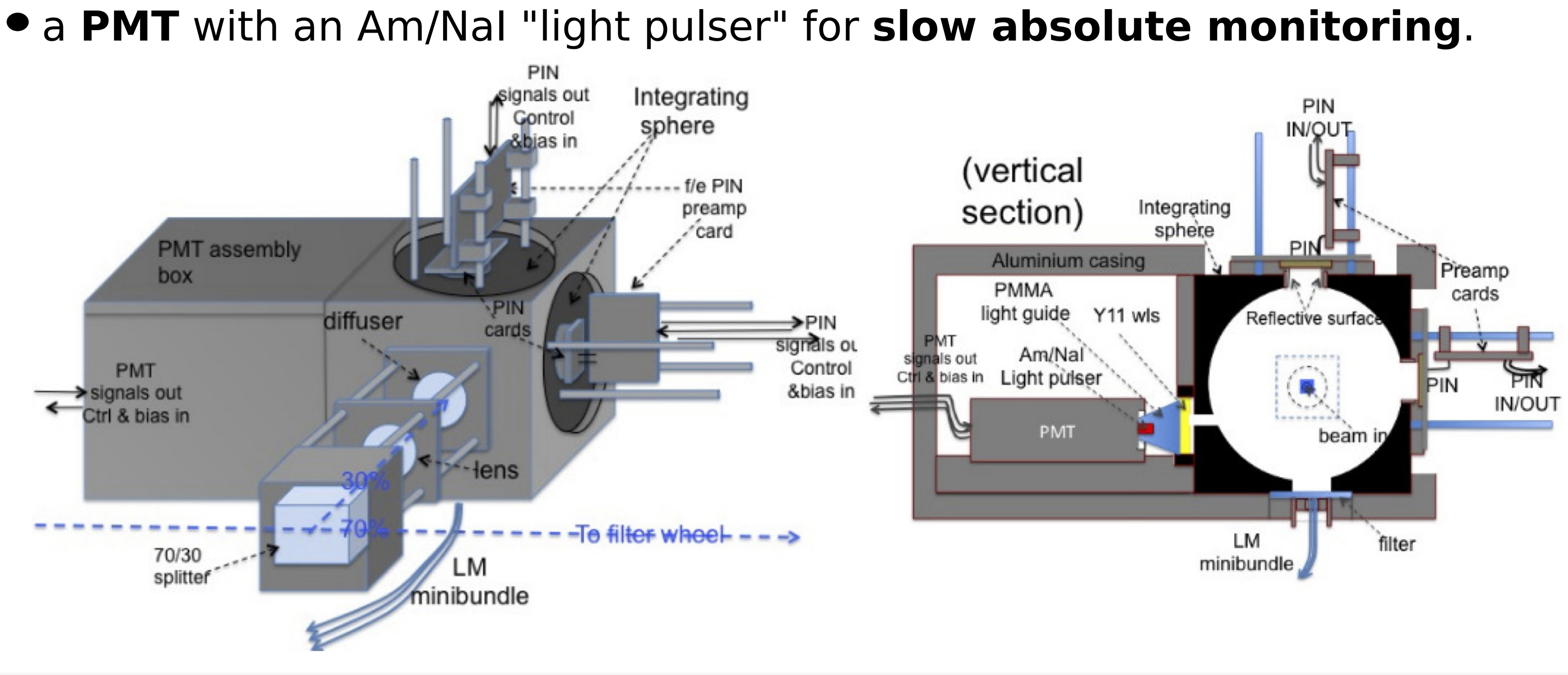
Source Monitors (SMs)



A SM measures **shot-by-shot fluctuations of the laser pulse light intensity** of each laser light source. Once corrected for these fluctuations the corrisponding **light pulses observed in each calorimeter channel become reference signals**.

There are **6 SMs**, one for each laser source. Each SM is contained inside a **solid aluminum case** (for thermal inertia) and consists of:

- an **integrating sphere** to distribute light uniformly among detectors;
- 2 large area PIN diodes (**PiDs**) for **fast monitoring**;
- a **PMT** with an Am/NaI "light pulser" for **slow absolute monitoring**.



Conclusions

The construction and assemby of the laser calibration system of the muon *g-2* experiment at Fermilab is nearing completion. **Data taking**, with muons injected into the ring, **is expected to begin in Fall 2017**. The laser system will operate during the data acquisition providing the monitoring of calorimeter stability with the required accuracy. It will also be used for timing alignment within and between calorimeters.

References

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