Muon g-2 Calibration system data flow

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on behalf of Muon g-2 Collaboration

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Abstract: In the Muon g-2 Experiment at Fermilab, a calibration system based on laser source and a light distribution network has been designed and implemented by the INFN group. The light pulses are read by specific photo-detectors, whose signals are digitized by a custom electronics modules designed to match the experiment requirements. The data frames of each module are transmitted to a controller board that performs the event-building process and transfers the reconstructed data to the online farm. In this work we present the architecture and data flow of the acquisition system that depends on the laser calibration program defined inside the Laser Control board. Experimental results on the overall system performances also including the software processes running both at controller and farm level will be described..

Introduction

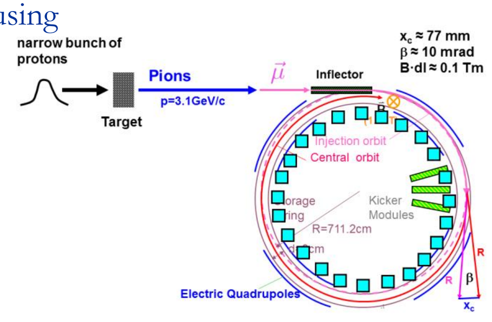
The muon's anomalous magnetic moment $a_\mu=(g-2)/2$ is a low energy observable that is calculable and measurable with extraordinary precision. A signicant discrepancy between the measurement and the Standard Model prediction of a_μ would imply the existence of new particles and it is sensitive for new physics.

E821 E989

E989 Experimental Technique

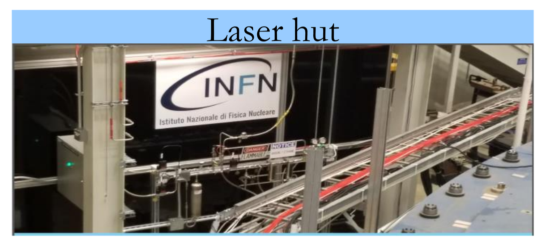
- The experiment compares how fast a muon spin rotates in a magnet compared to the predictions from theory
- E989 Goal: 0.14 ppm, 0.10 ppm stat., 0.07 ppm for both ω_a and ω_p → $da_m/4$ (improved by a factor) 4

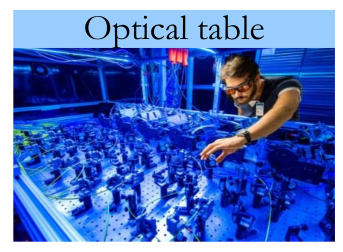
- ✓ Muon storage ring – weak focusing betatron
- ✓ Muon polarization
- ✓ Injection & kicking
- ✓ Focus with electric quads
- ✓ 24 e.m. calorimeters

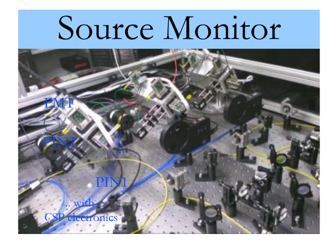


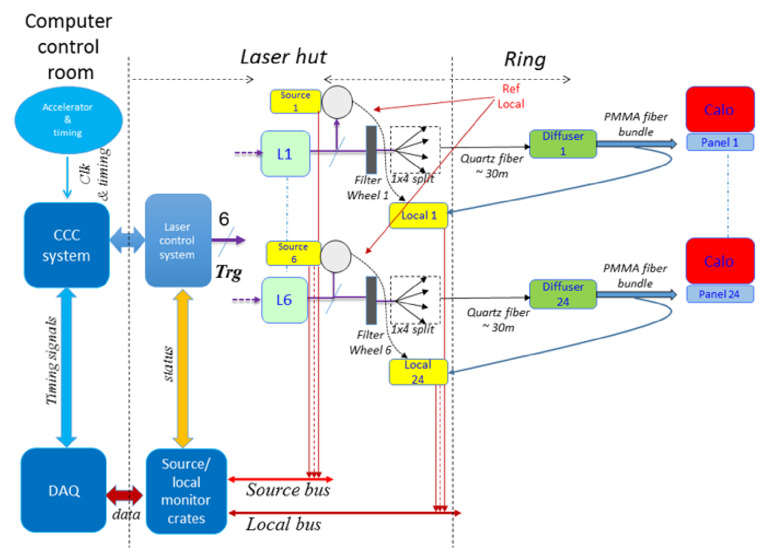
Muon anomaly a_μ $$\omega_a = \frac{q}{m} a_\mu B$$

The Calibration system









Installation complete:
- 6 laser heads
- 6 filter wheels
- Beam splitters, mirrors and collimators
- 6 source monitors with electronics
- 24 local monitors

Source Monitor
30% of the laser light distributed to 3 photo-detectors: 2 PIN diodes and 1 PMT;
PIN diodes monitor stability at sub-0.1% level;
PMT also views an Am/NaI light pulse for long term absolute stability.

Local Monitor
2 PMTs each calorimeter; reference signal from Source Monitor

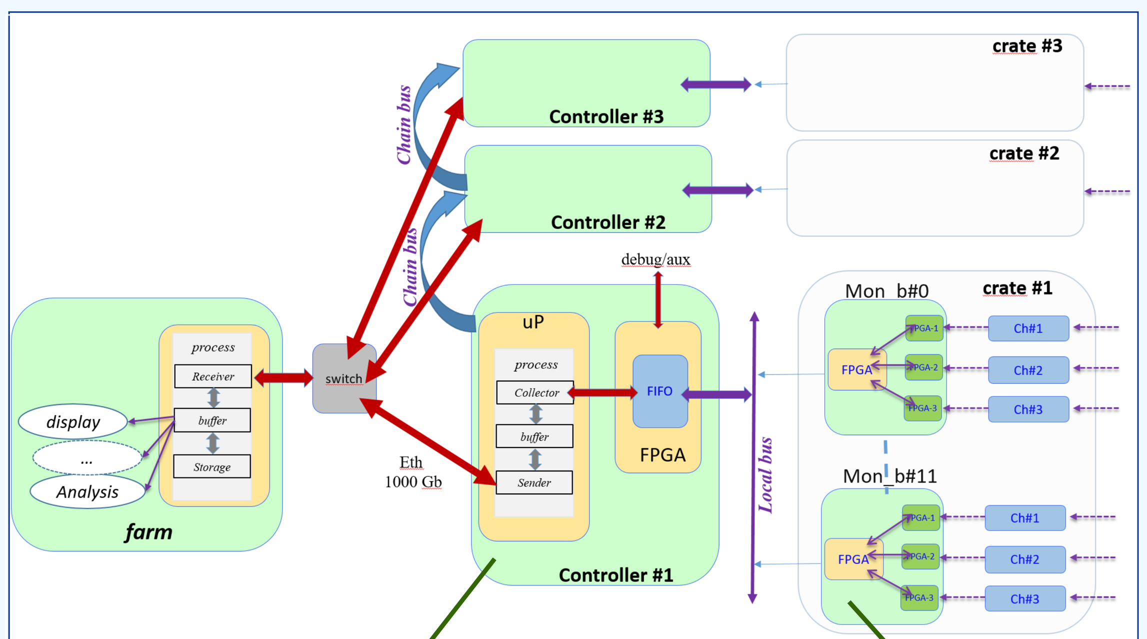
- During muon fill (~700 µs) the gain fluctuations must be limited at the sub per-mil.
- Over longer time scales, the gains should be stable at the sub percent level.

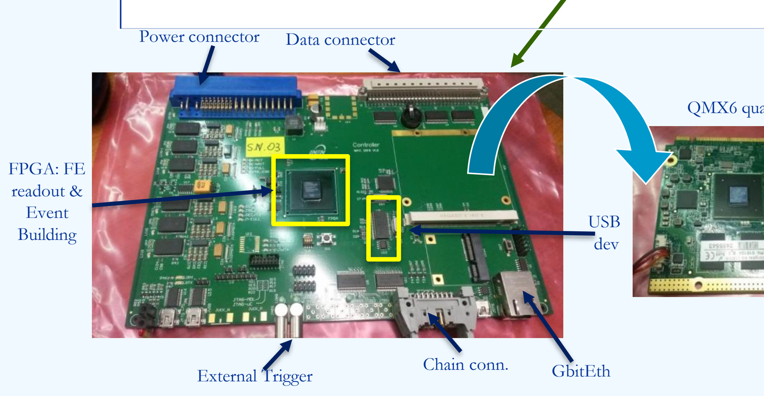
The intensity of the light source and the stability of the light distribution system are monitored at 10^{-4}

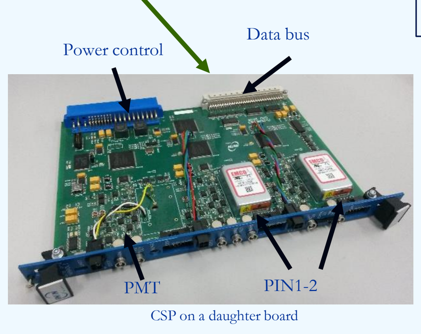
The data readout system

DAQ is based on a multiple crate system. Each crate contains up to 12 Monitoring boards (MB) that manage the signal processing and data readout from up to 36 photodetector channels.

- MB module:
  - preamplifier circuit, shaper and ADC conversion
  - Modules can be customized (i.e. between Source and Local Monitor) by means of the loaded configuration files of FPGAs
- Controller board collects the slave data by using a custom bus and sends them to the online farm.







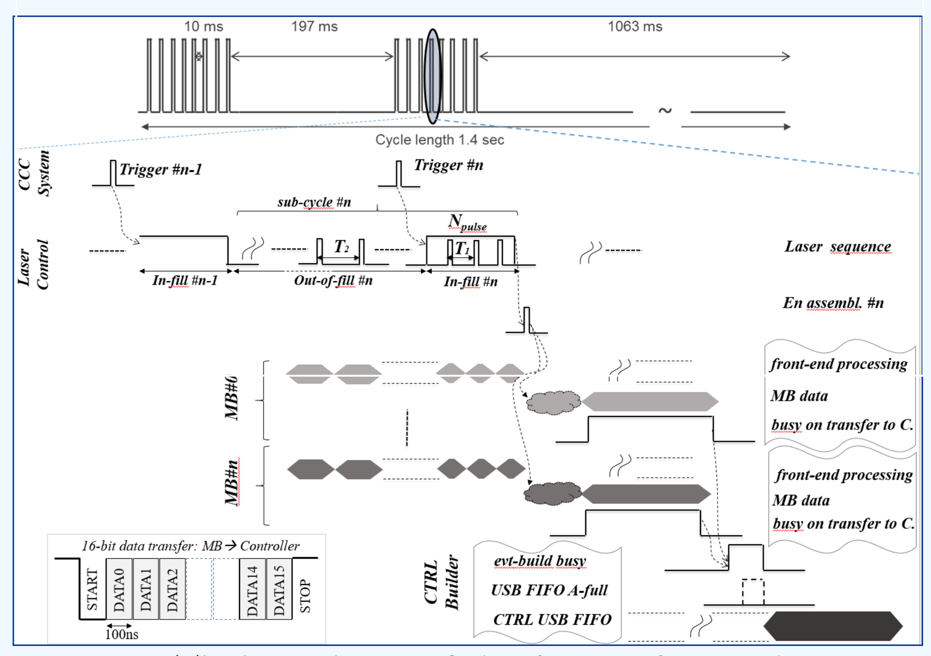
Controller **Monitoring board**

The data readout must be able to accommodate several calibration modes and many types of light pulse generation in terms of pulse rate and data transfer.
The readout chain is based on a trigger-driven algorithm.

- When a trigger arrives, each MB board performs the data assembling and transfers data frames to the Controller for event building purposes
- The Controller performs the sub-frames collection from MB slaves pertaining to the same trigger number, checks the data integrity, adds control and monitoring words and stores the frame in a FIFO accessible by an embedded processor for the final readout.
- Data size for each pulse =10 byte/ch; header and footer are attached for control and monitoring
- Data from MB over a serial link (Start/16-bit word/Stop) using 10 MHz reference
- An embedded CPU reads the data from USB device and sends them to the on-line farm over 1Gb Ethernet;
- A real-time monitoring is accomplished in a hardware without additional overhead on the CPU activities

Laser program [1]
- *In-fill* superimposed to the Muon fill → short term calibration with a pulse rate in large range (1-100 kHz);
- *Out-of-fill* for a long term calibration at percent level; pulse rate up to 10 kHz
- Test and calibration runs (i.e. flight simulator for event simulation for DAQ and detector check, gain calibration etc..) →with peak of rates spanning from Hz to fraction of MHz

Average ~ 2-3 Mb/s each MB
with peak of 10-20 Mb/s each MB

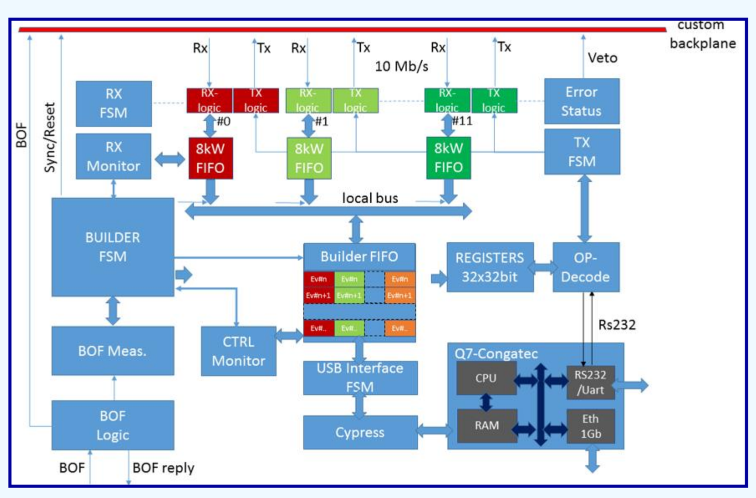


Timing scheme of the data readout cycle

The implementation

The Controller is a Single-Board-Computer that integrates an Artix7 FPGA by Xilinx and an ARM-based Qseven processor

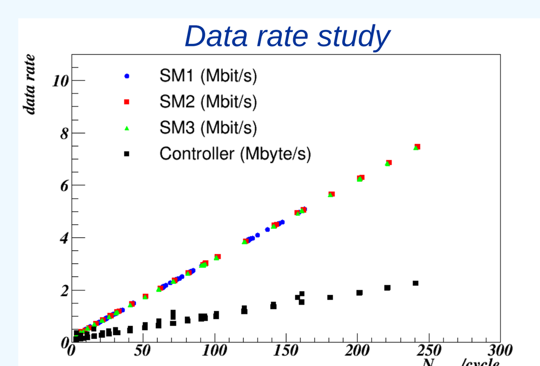
- Data collection from 12 Receivers
- Data integrity check
- FIFO bank to buffer and decouple
- Event building in hardware → Builder FIFO
- CPU embedded to final readout through USB device
- Configuration and setup of all MB
- Spy & Monitoring of the data taking with error log



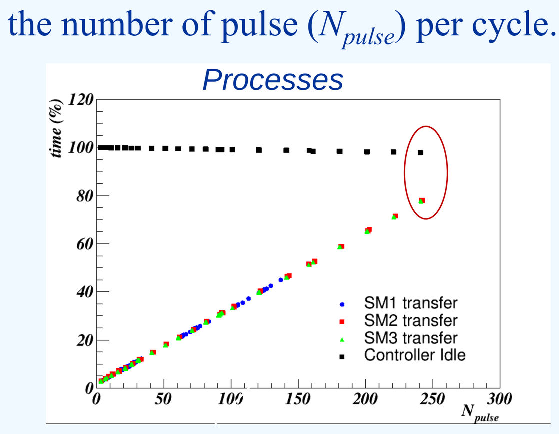
Qseven modules support different operating systems. Debian 7 version has been installed on the module.
Collector processes, based on *libusb library*, continuously read USB FIFO using.
The *Run Control* is based on the MIDAS data acquisition software developed at PSI and TRIUMF. The package includes a web interface.

Test results

A slice of the DAQ system was assembled at the Naples laboratory in order to integrate and test all the DAQ components under real conditions.
The trigger logic was replaced by a pulse generator to simulate the beam cycle set at a rate of 100 Hz that exceeds the rate of the experiment.
In this set-up we measured the data transfer rate by changing the number of pulse (N_{pulse}) per cycle.



Linear behavior of the data transfer: SM and Controller measurements are carried out inside the Controller.
The maximum value of slave data transfer is ~ 8 Mb/s.
By design the peak value is about 9 Mb/s.



The Controller operates a real time tracking of the SM data transfer to optimize the overall performance.
Duty cycle and toggle rate of all the *busies* are measured and attached to the data frame to be immediately correlated to the laser pulse pattern

Conclusions

The DAQ of the Laser Calibration system for the Muon g-2 experiment @ FNAL has been designed around a custom bus protocol and specialized hardware modules to manage the data readout from the Source/Local Monitors and to realize an event building capability.
The Source Monitor crate has been intensively tested and installed at FNAL for the first data taking; a second crate devoted to the Local Monitor electronics will be installed during the first shutdown (Summer 2018) and integrated within the MIDAS framework.

References:
[1] A. Anastasi et al. , "The laser control of the muon g−2 experiment at Fermilab", JINST 13 (2018) no.02, T02009