The readout controller for the calibration system of Muon g-2 experiment

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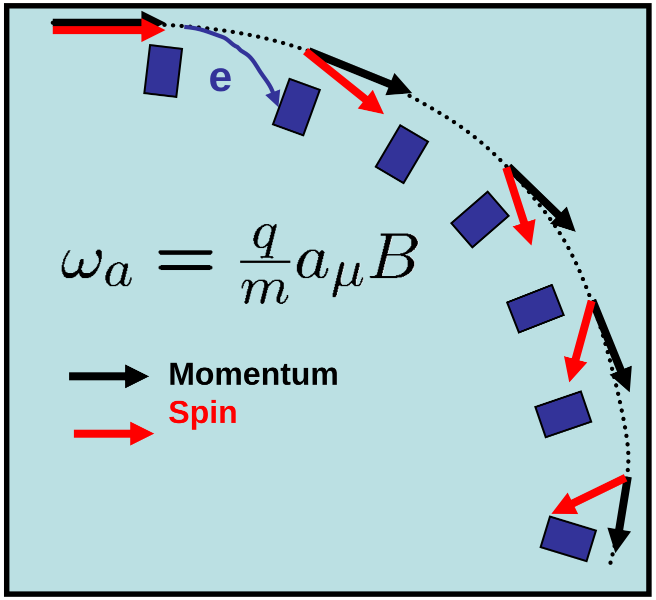
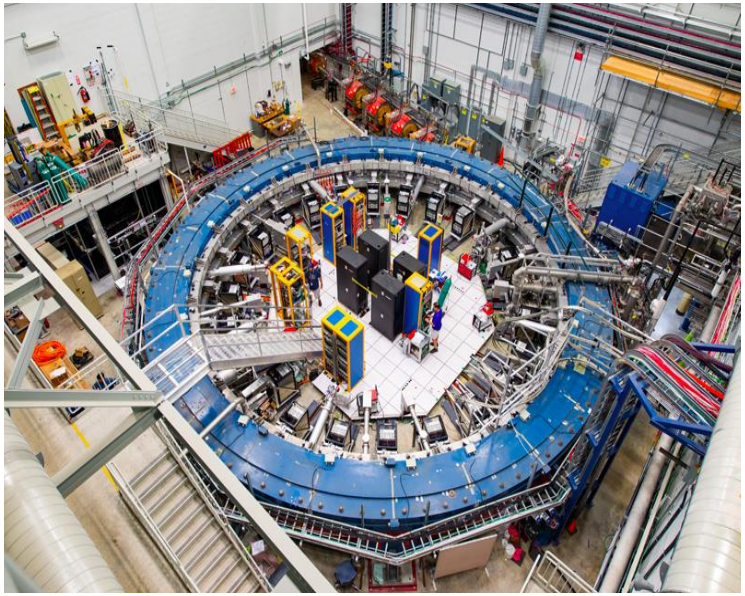
Outline

- *Muon g-2 experiment at FNAL*
- *The Laser calibration system*
  - *Monitoring system*
- *Data acquisition cycle*
- *The readout Controller board*
  - *block diagram*
  - *board layout*
- *DAQ chain*
- *Test results*
- *Installation at FNAL and first results*
- *Conclusions*

A Case for Challenging the Standard Model

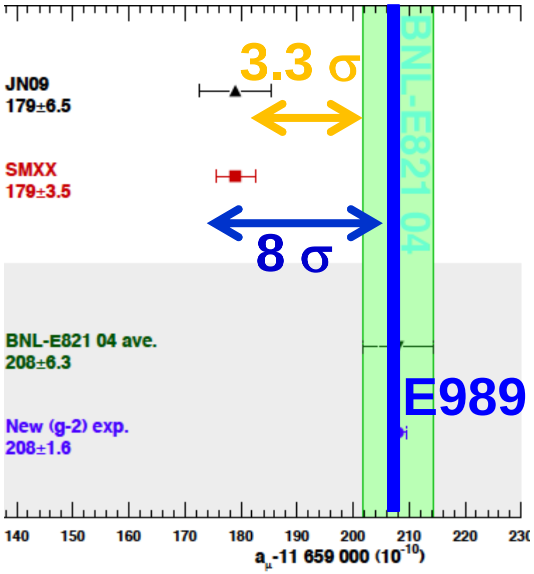




The experiment compares how fast a muon spin rotates in a magnet compared to the predictions from theory

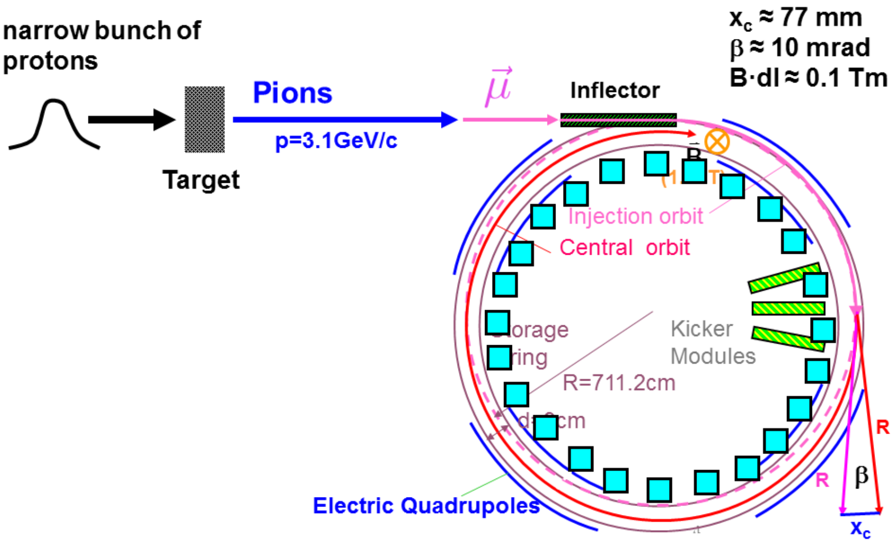
E989 Goal: 0.14 ppm, 0.10 ppm stat., 0.07 ppm for both ω_a and ω_p → $\delta a_\mu/4$ (improved by a factor 4)

If the central value remains the same ⇒ 5-8 sigma from SM* (enough to claim discovery of New Physics!)



E989 Experimental Technique

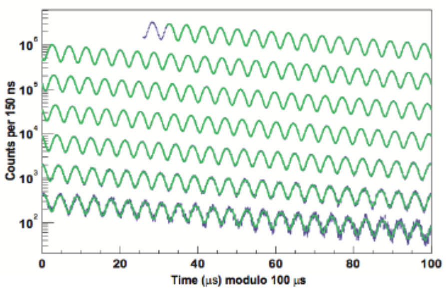
- ✓ Muon storage ring – weak focusing betatron
- ✓ Muon polarization
- ✓ Injection & kicking
- ✓ Focus with electric quads
- ✓ 24 e.m. calorimeters



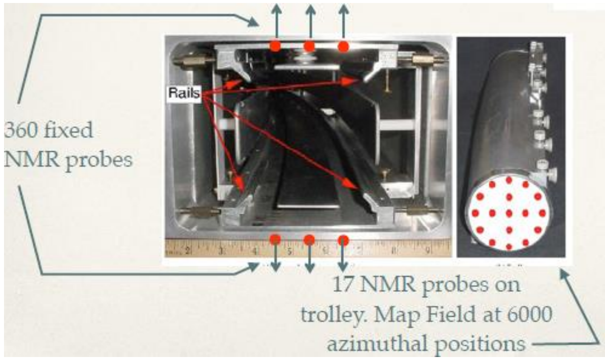
Muon anomaly a_μ ➡ $$\omega_a = \frac{q}{m} a_\mu B$$

Measuring anomalous frequency ω_a with positrons (above E_{th})

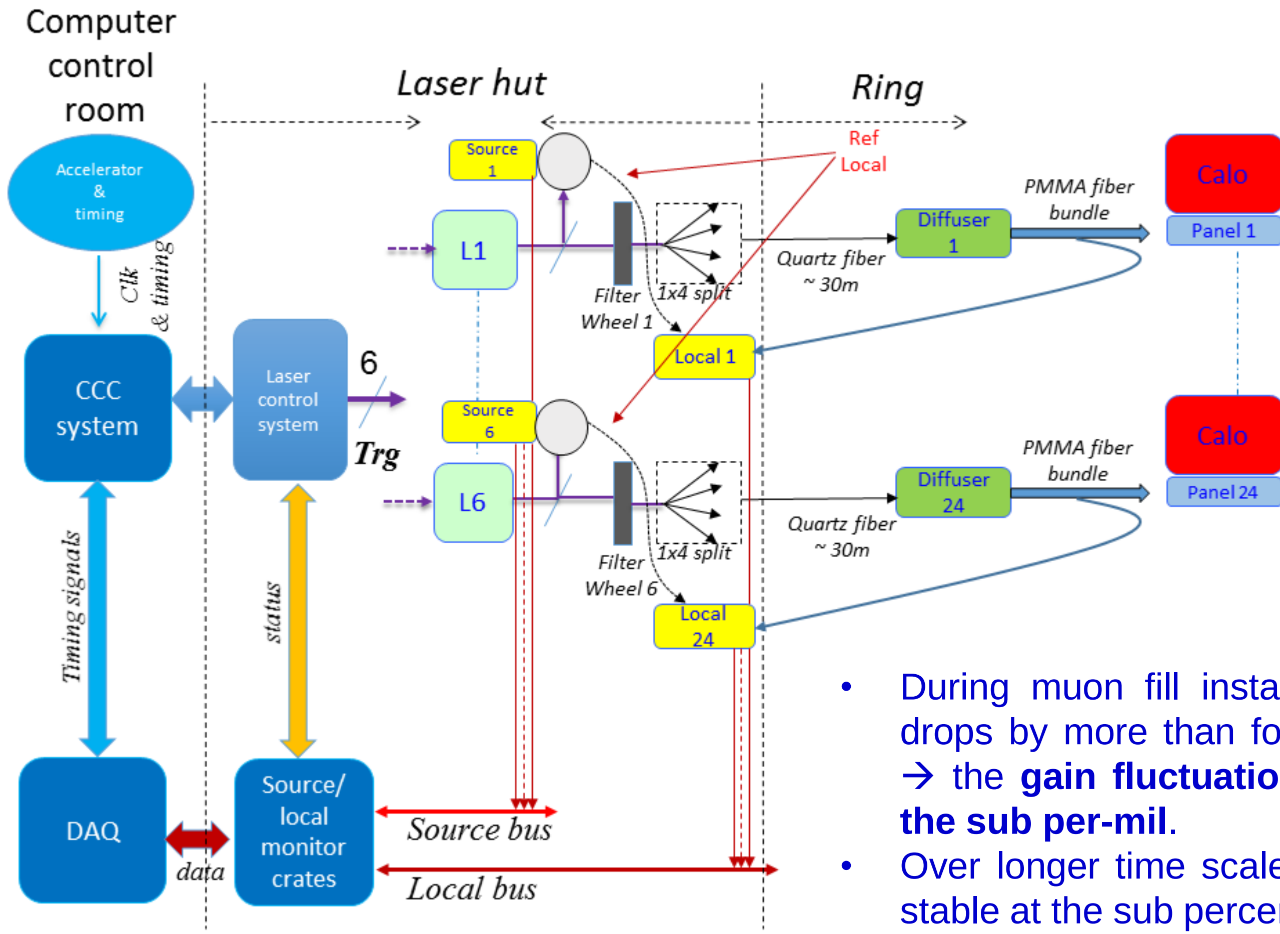
B filed measured with proton NMR



- Calorimeters 24 6x9 PbF_2 crystal arrays with SiPM readout
- New electronics and DAQ, 800MHz WFDs



Laser Calibration Scheme



- During muon fill instantaneous positron rate drops by more than four orders of magnitude → 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.

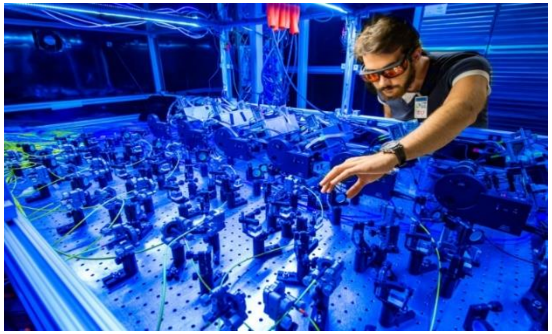
The intensity of the light source and the stability of the light distribution system are monitored at 10^{-4}

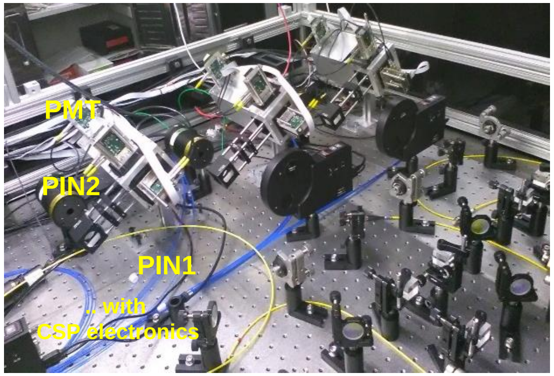
Installation complete:

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

Source/local monitor

Laser hut



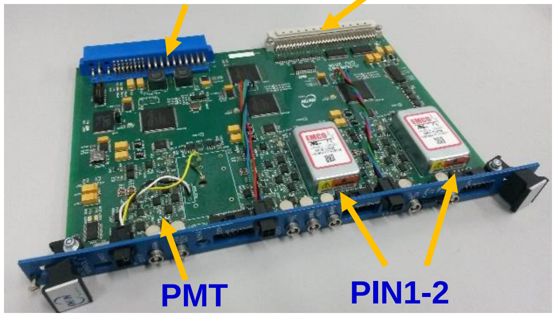


Source Monitor

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



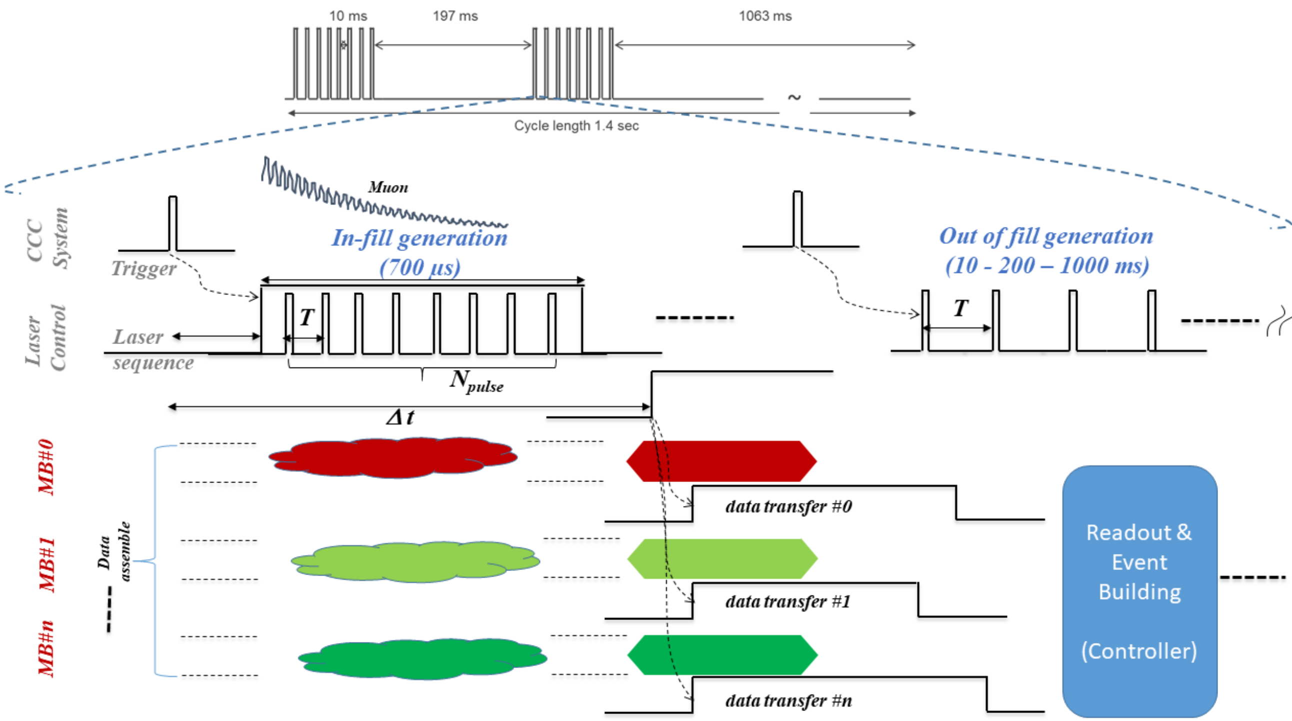
CSP on a daughter board

Monitoring Board → signal processing and data readout

- Power supplies
- Stabilize the sensors (PIN/PMT) and electronics
- CSP up to 800 mV/pC
- Charge converted with 14 bit ADC
- Data stored in FIFOs
- Provides calibration signal (DAC)
- Trigger for asynchronous signal (Am)
- Temperatures measurements (CSP/MB/envir with res. of 0.1 ° C)

Configuration/Monitor & Data Readout by crate Controller

Laser Calibration data readout cycle



Laser pulses

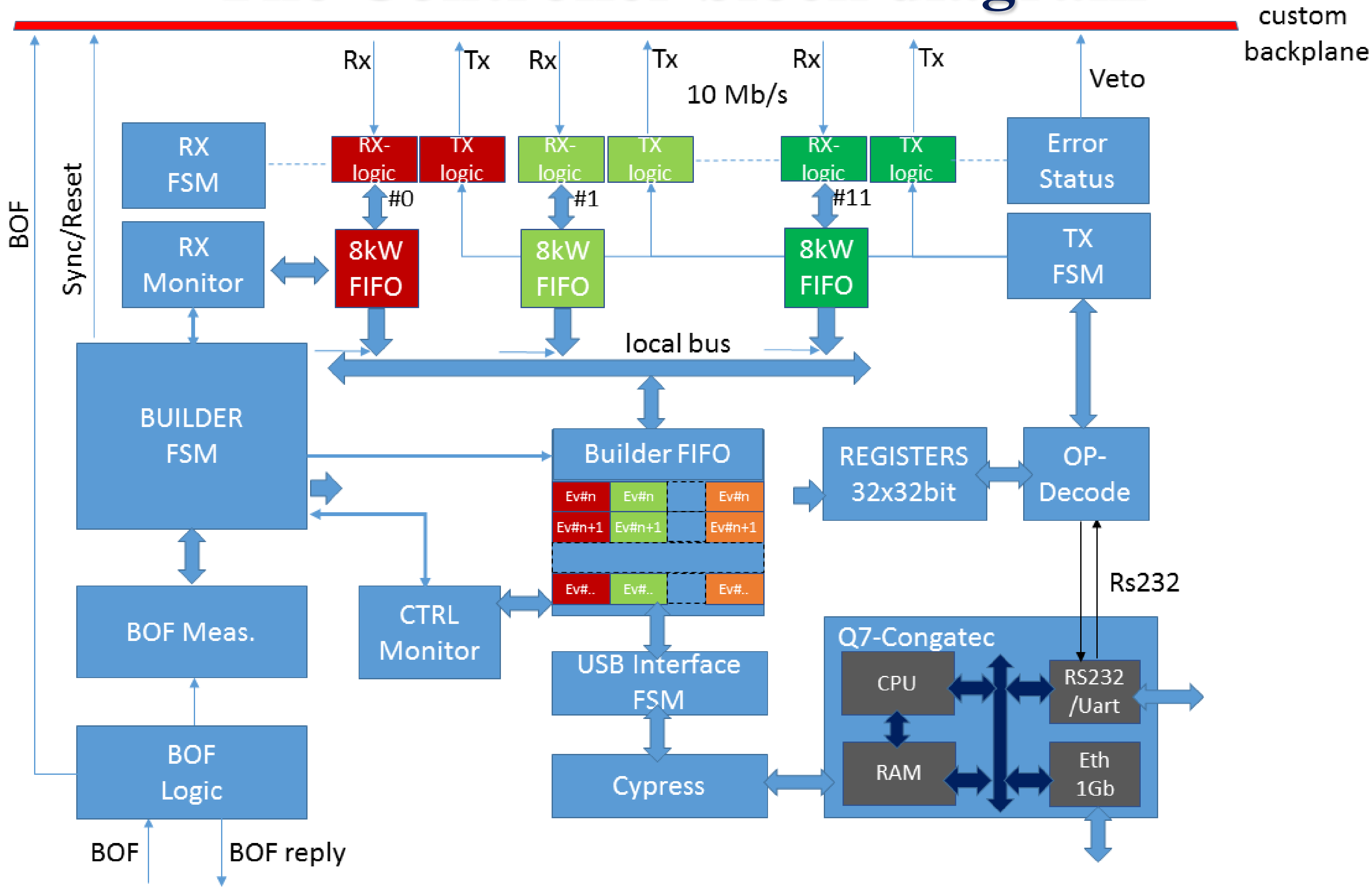
- ***In-fill*** superimposed to the Muon fill → short term calibration with a goal of 10^{-3} ; pulse rate in large range (1-100 kHz);
- ***Out-of-fill*** for a long term calibration at percent level; pulse rate up to 10 kHz
- **Test and calibration runs** (i.e. flight simulator for event simulation 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

Controller readout

- ✓ Buffer FIFO for each MB/channel → signal processing and data storage based on self-triggered; each MB data frame is labelled with **a trigger number**; data transfer begins with a request by the Controller
- ✓ Data size each pulse/ch= 10 byte
- ✓ Data from MB over a serial link in a RS232 fashion (Start/16-bit word/Stop) using 10 MHz reference
- ✓ The Controller performs data acquisition and the event building in an **event-driven** algorithm
- ✓ An embedded CPU manages the data collection over an **USB bus** and sends the data to the on-line farm over 1Gb Ethernet;
- ✓ A real-time monitoring is accomplished in a hardware without additional overhead on the data acquisition and CPU activities

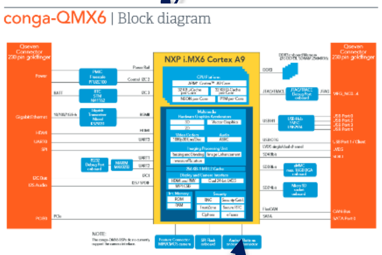
The Controller block diagram

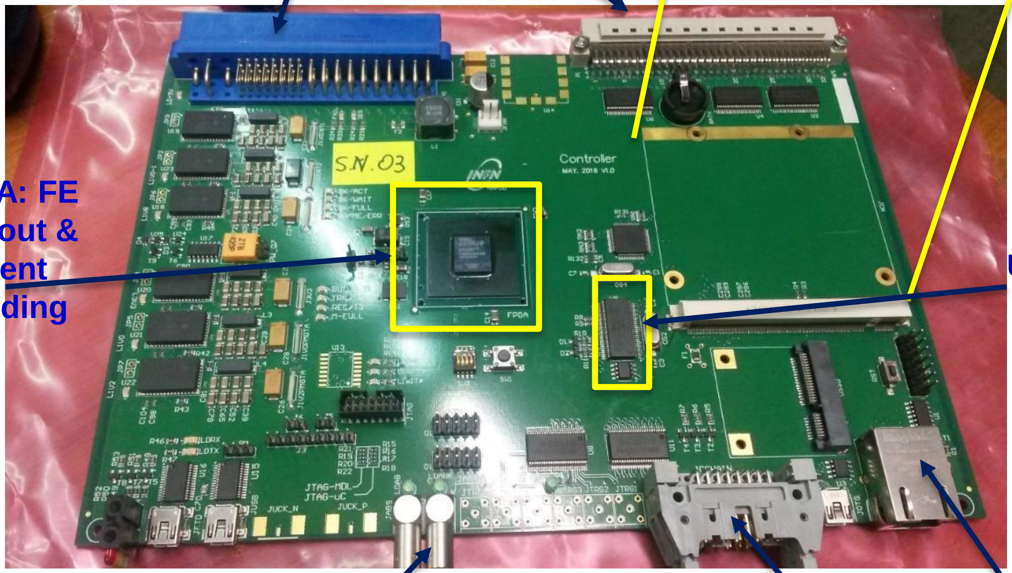


- Data collection from 12 Receivers by means of a trigger driven architecture
- Data integrity check
- FIFO bank to buffer and decouple
- Event building in hardware → Builder FIFO
- CPU embedded to final readout through USB device
- Configuration and setup of all MB
- Spy & Monitoring of the data taking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

The Controller: single board computer layout

- NXP i.MX6 Quad ARM Cortex A9 (Qseven Rev. 2.0 | 70x70 mm)
  - ✓ 2 GB (RAM) / 4 GB eMMC and Onboard MicroSD socket
  - ✓ Several I/O Interfaces 5x USB 2.0, 1x SATA II | 1x SDIO | 1x PCIe 2.0 | I²C Bus | CAN Bus | SPI
  - ✓ Linux OS (Debian 7)
- Artix-7 FPGA
  - ✓ Reconfigurable remotely
- Cypress CY7C68013A: USB Microcontroller High-Speed USB Peripheral Controller
- Backplane section
  - Power
  - Data (12 Tx / 12 Rx / 8 control/8 monitor signals)
  - $Z_0 = 50\Omega$





DAQ architecture

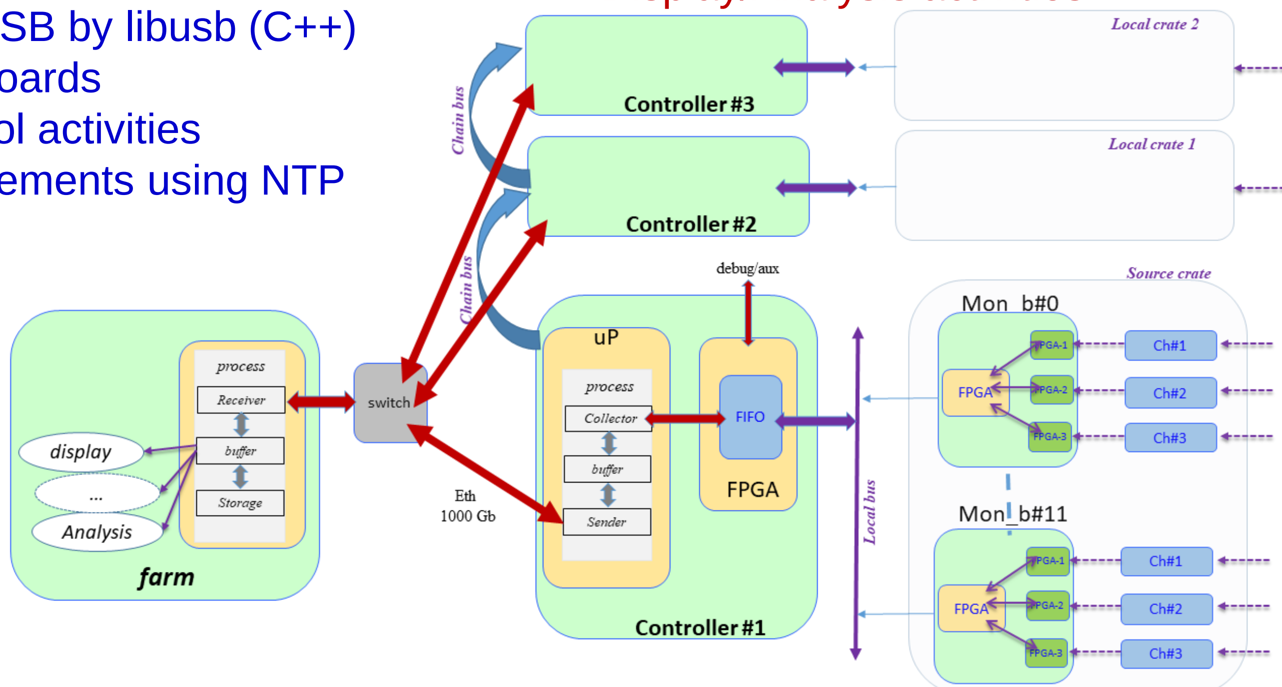
Multiple crates → several boards can be chained together for a complex DAQ sys

Crate level

- ❑ Hardware
  - ✓ Sub-event building
  - ✓ Bus activity for each SM can be monitored (start of transfer, duration and any interrupt.)
  - ✓ Chain connection between Controllers for timing and control signals
  - ✓ Single master on Chain bus
- ❑ Software
  - ✓ Data collection over USB by libusb (C++)
  - ✓ Configuration of MB boards
  - ✓ Monitoring/Slow control activities
  - ✓ Absolute time measurements using NTP

Farm level

- ❑ Hardware level
  - ✓ Server with storage system; switch 1Gb/s
- ❑ Software
  - ✓ Data collection from Controllers CPU
  - ✓ Complete event building
  - ✓ Data storage
  - ✓ Display/Analysis activities

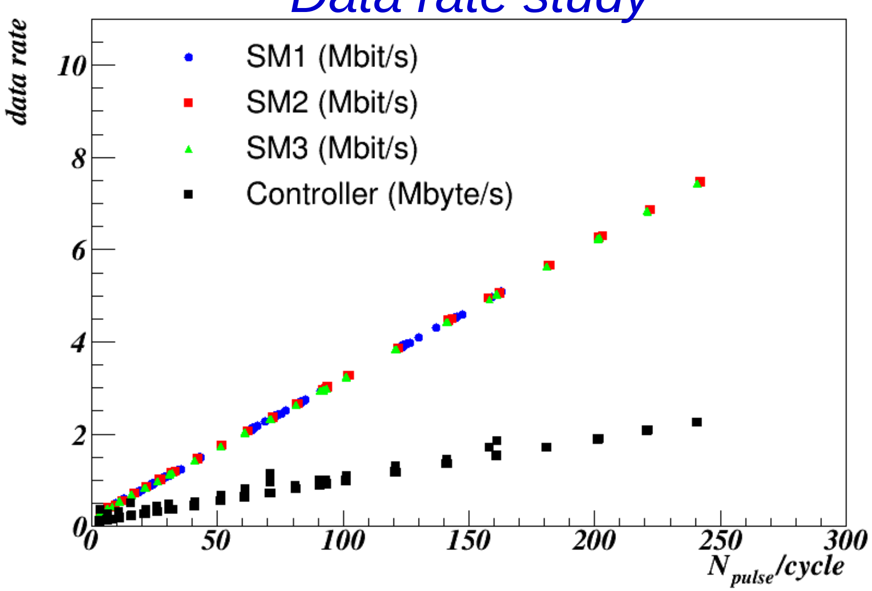


Test results

Test bench @ Naples

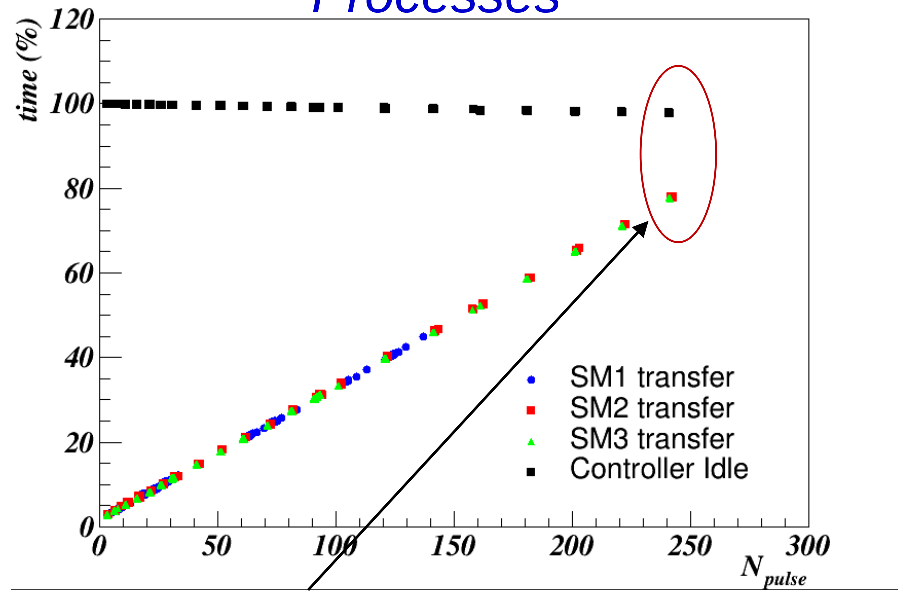
- Hardware
  - ✓ 3 SM boards
  - ✓ Controller
  - ✓ Laser Control set with 100 cycle/s and N_{pulse} each cycle
  - ✓ PMT & PINs signals
- Software
  - ✓ Custom scripts for data collection
  - ✓ Data Integrity check
  - ✓ Monitoring activities
- Long data taking

Data rate study



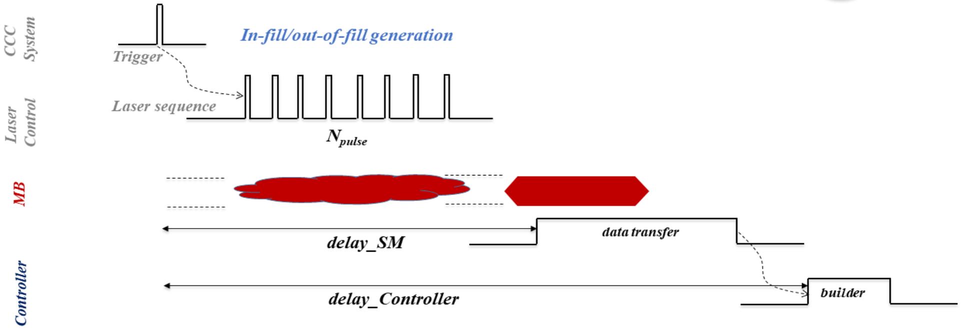
Good linearity → maximum rate on SM is 9Mb/s

Processes

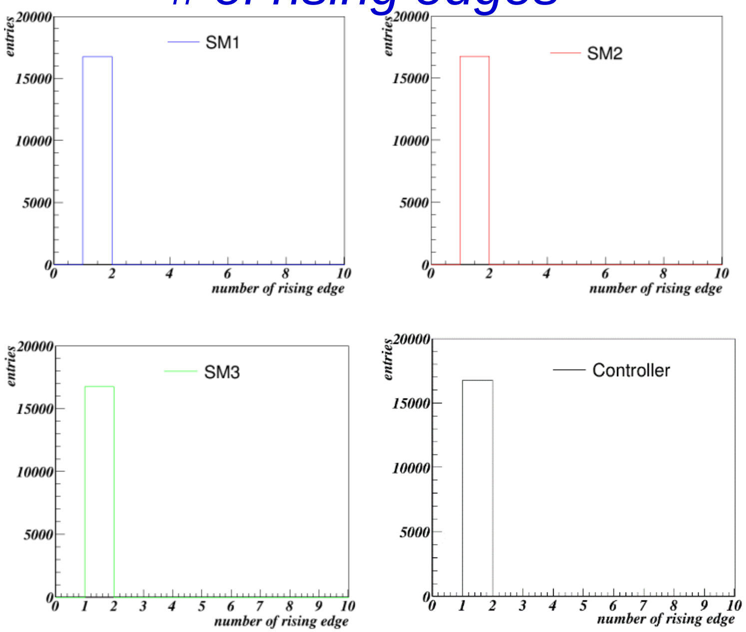


SM transfer & Ctrl builder FIFO almost empty

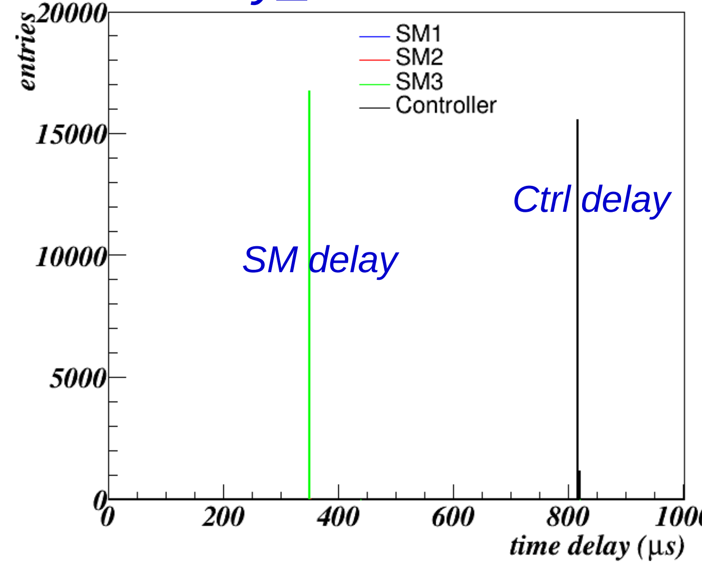
Monitoring of data taking



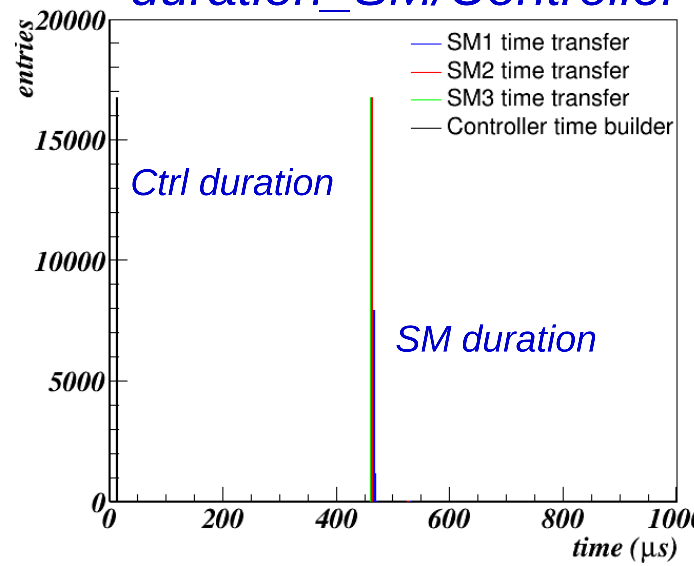
of rising edges



delay_SM/Controller



duration_SM/Controller



Tracking:

- ❑ Drifting of data frame from FE to Builder
- ❑ Anomalous data transfer
- ❑ On line check

The Controller @ FNAL

Present status

- 1 crate of Source Monitor
  - ✓ 6 MBs with CSPs installed and fully tested in Spring 2017
  - ✓ 1 Controller board with all software tools for data readout, configuration and control; installed during summer 2017
  - ✓ PC server for storage

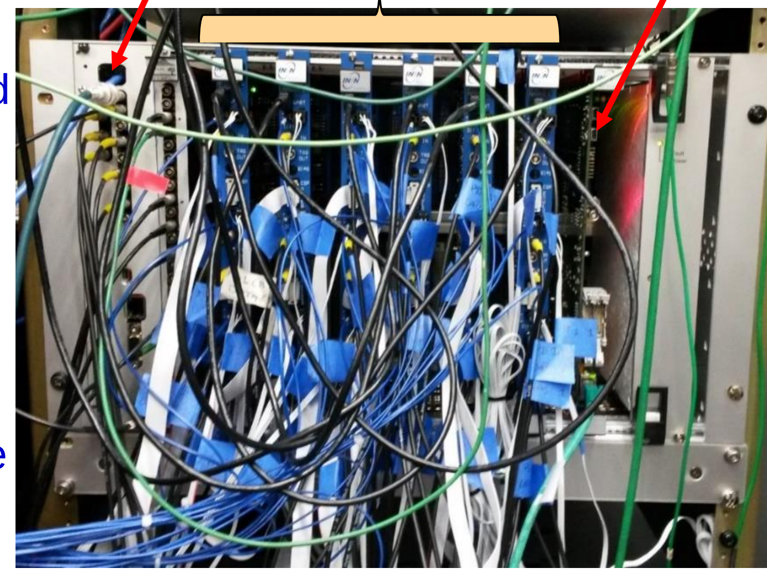
Next step

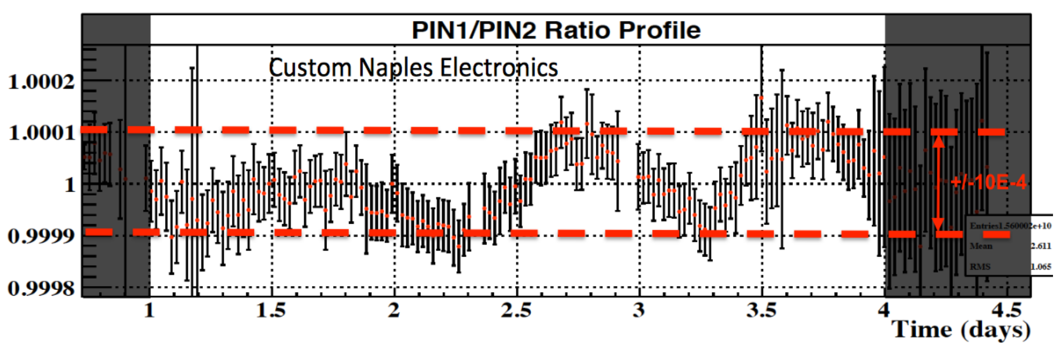
- ✓ 1-2 crates of Local Monitor (8 MBs with CSPs and 1 Controller each crate)
- ✓ Integration of the Laser Calibration data with the DAQ main stream based on MIDAS framework
- ✓ Optimization of overall the system

Laser Control & fanout

Controller board

6 Source Monitor boards





PIN ratio <10^{-4}

Conclusions

- The Controller board has been designed to manage the data readout from the Source/Local Monitor boards of the Laser Calibration system for the Muon g-2 experiment @ FNAL;

- It is based on an event-driven data collection on a custom bus implementing seral link connections (RX/TX) from/to 12 Source Monitor boards;

- The event-building is fully realized in hardware; an embedded CPU hosted on the board allows the final data readout accessing an high speed USB FIFO and sends them to the online farm;

- Several Controller boards can be chained realizing a complex DAQ system;

- The Controller has been intensively tested and now installed at FNAL in the Source Monitor crate for the forthcoming data taking; a second crate with Local Monitor boards and 1 Controller will be installed during the first shutdown (Feb 2018) and integrated within the MIDAS framework;

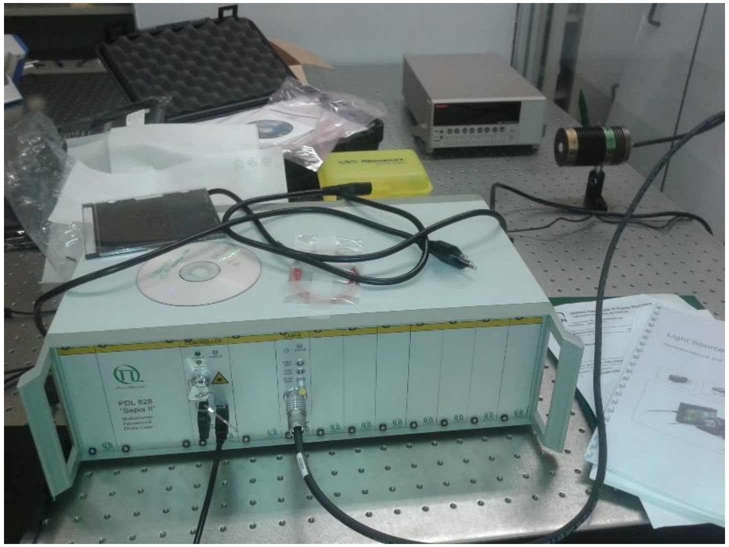
- This research has been supported by MUSE project

Thank you!

backup

Diode Laser from Picoquant

- **Multilaser 8 channel sepia LDH-P-C-405M**



Wavelength: 405 nm ± 10nm

Pulse FWHM: < 700 ps

Average Power (@ 40 MHz): 28 mW

Power stability 12h, ΔT < 3K:
1 % RMS, 3 % p to p

Measured light output: 750 pJ/pulse @ 10 kHz

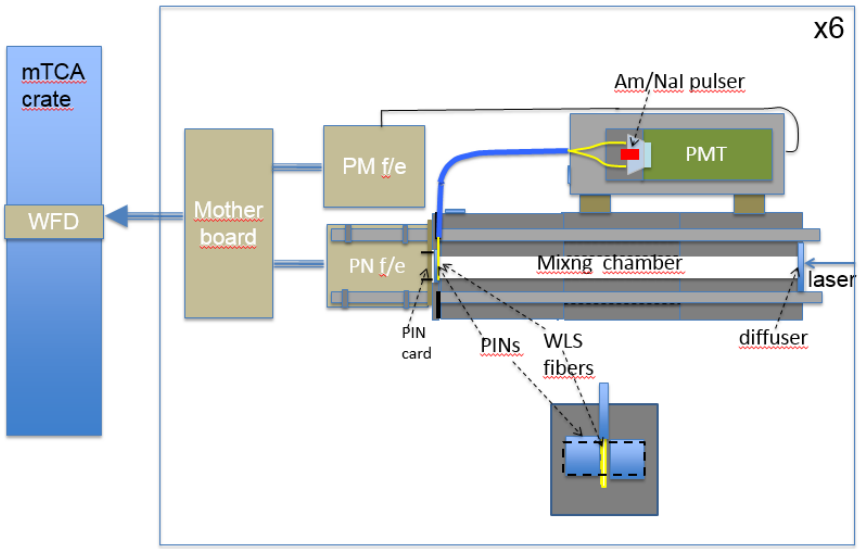
Source monitor

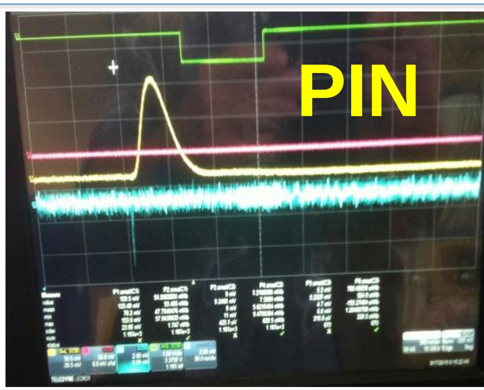
- **2 PIN diodes and readout electronics**
- **1PMT with Am/NaI pulser**

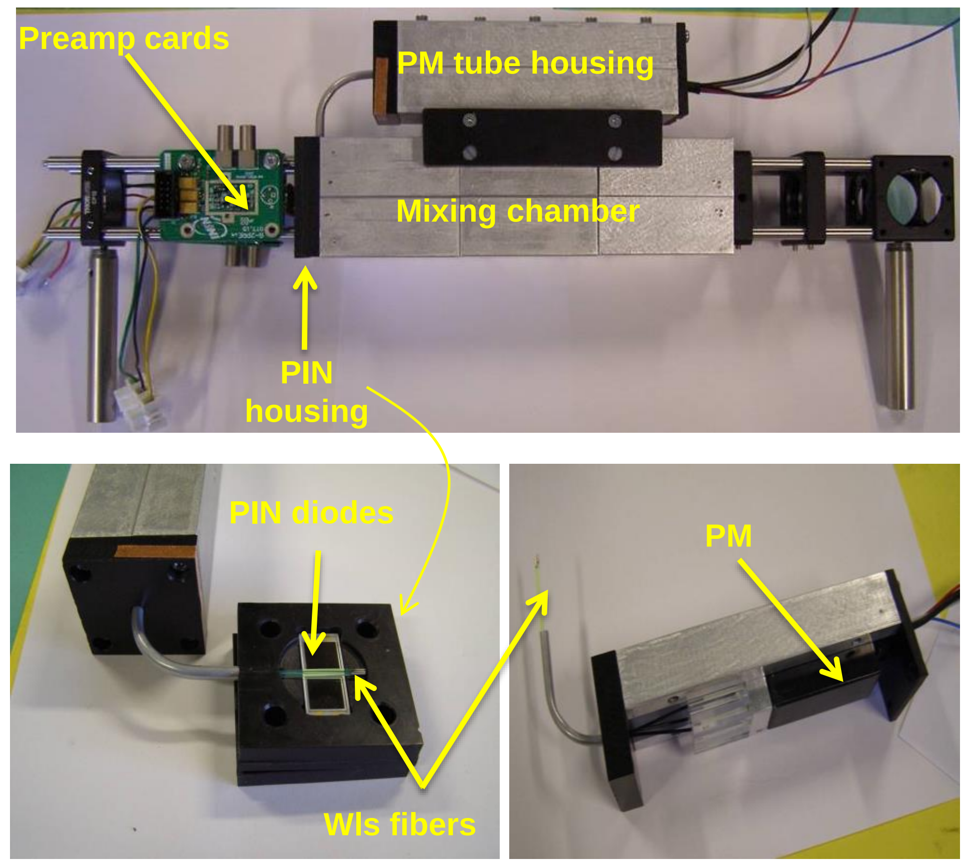
signal input:
~150 pJ/pulse~3x10^{8} γ

Systematics are measured with reference to a *Am/NaI "pulser" with rate of ~10Hz* → need ~ 3 hours for 0.01% statistical accuracy

Expected uncertainty: 0.1% statistical on single pulse, 10^{-4} systematics on 2 hours

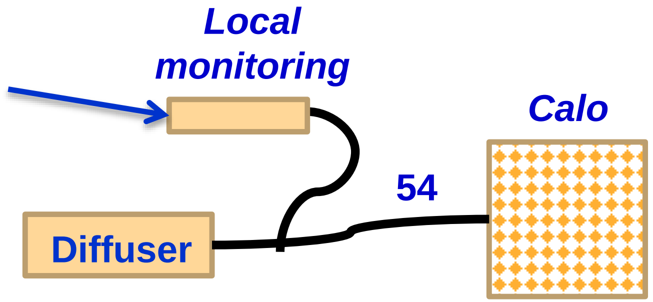


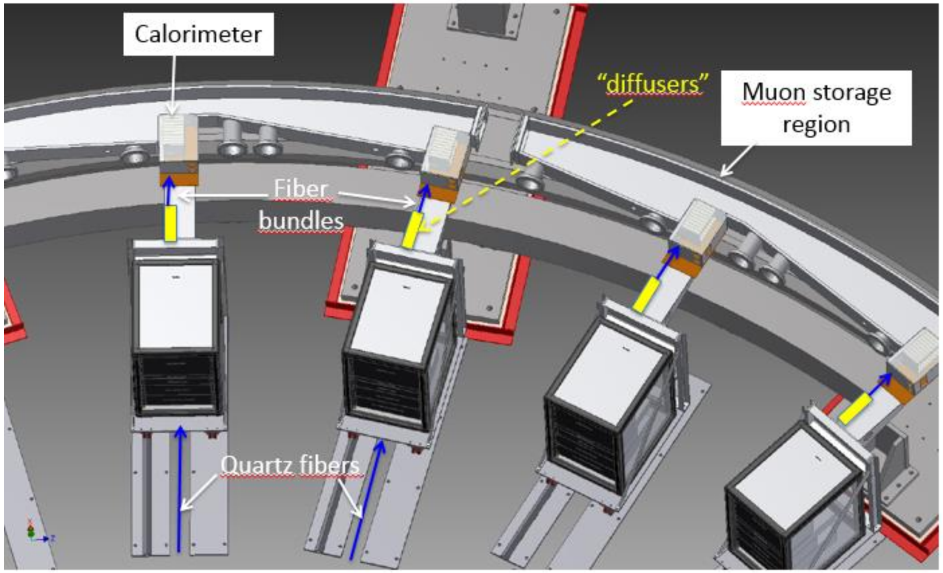


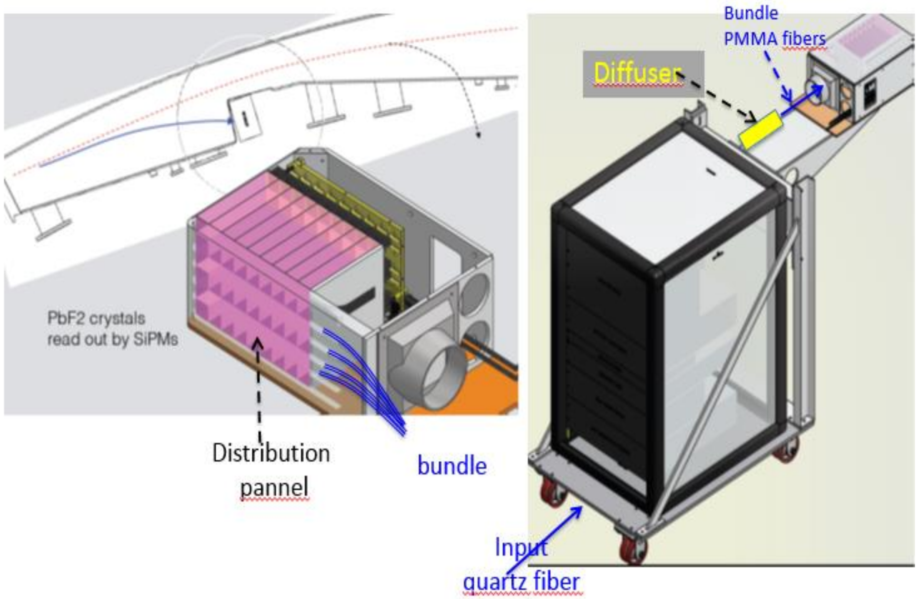


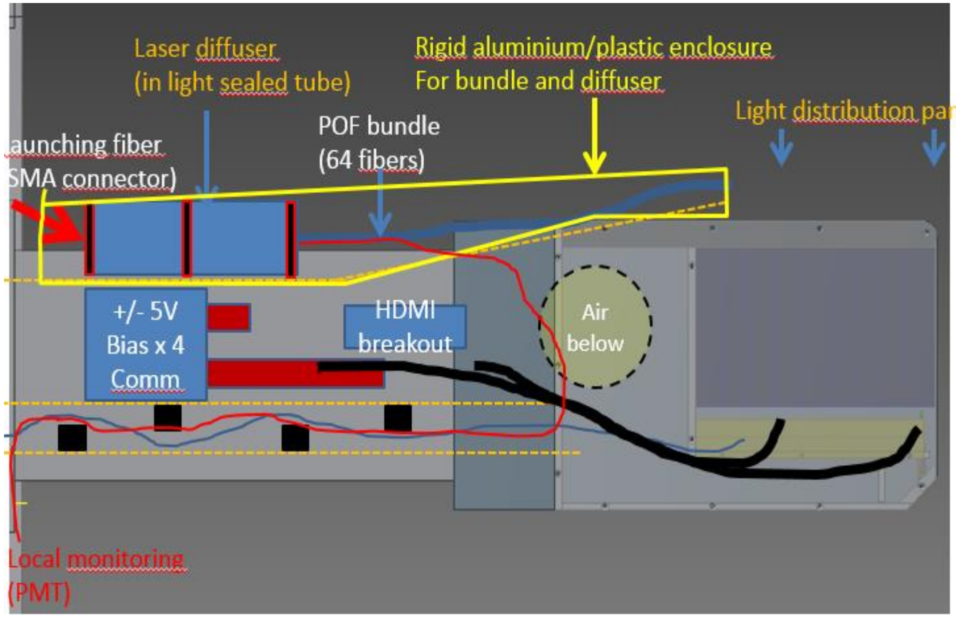
Local monitor

- Local monitoring will deal with low light (0.1pJ ~ 10^5-10^6 γ)
- Useful to study common fluctuations of the SIPMS (the Si/<Sipm> is blind to that)
- 2 PMT's

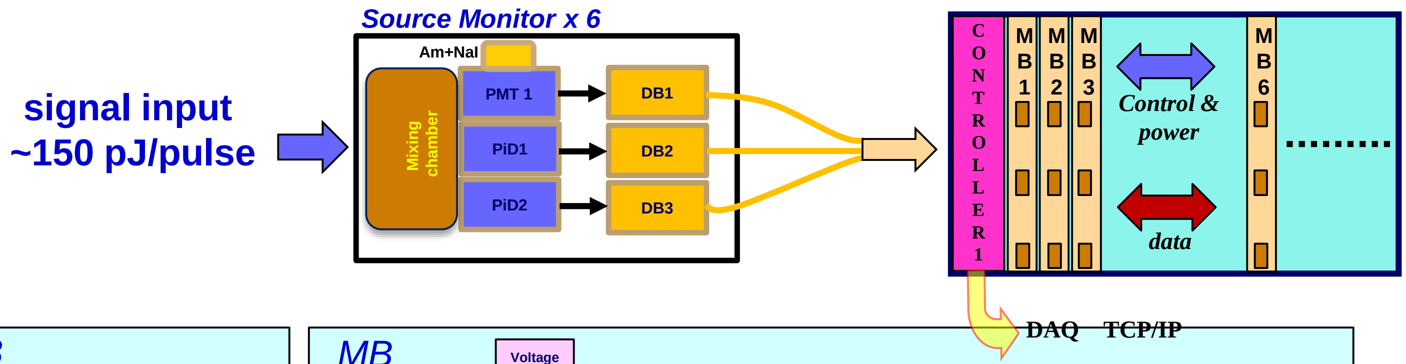


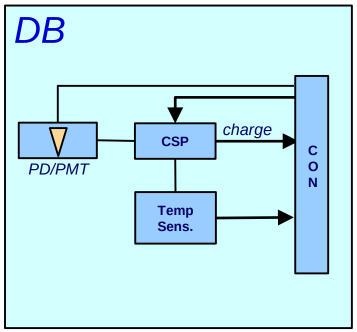


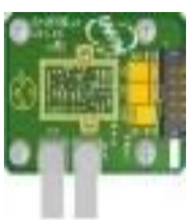


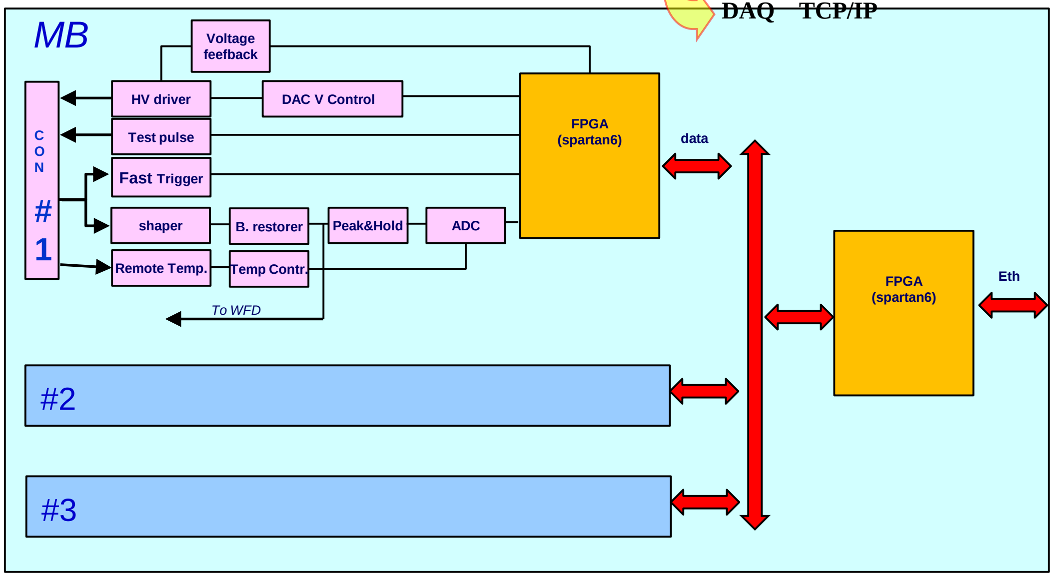


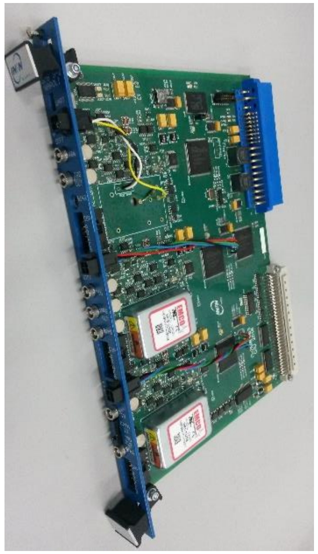
Source Monitor electrnonics











MB → Source/Local signal readout and processing

- Power supplies with EMCO modules & feedback
  - ✓ HV and bias for PiD
  - ✓ HV for PMT
- Stabilize the sensors (PiD/PMT) and electronics
- Provides the calibration signal (DAC)
- CSP/MB/envir temperatures (res. of 0.1 ° C)
- Time measurements for each pulse
- CSP with 800 mV/pC
- Charge converted with 14 bit ADC
- Trigger for asynchronous signal (Am)