The Monitoring System and the Data Acquisition of the Laser Calibration System in the Muon g-2 Experiment

Atanu Nath
(On behalf of the Muon g-2 collaboration)

MUSE general meeting 2019
24th October 2019, Frascati (remotely), Italy

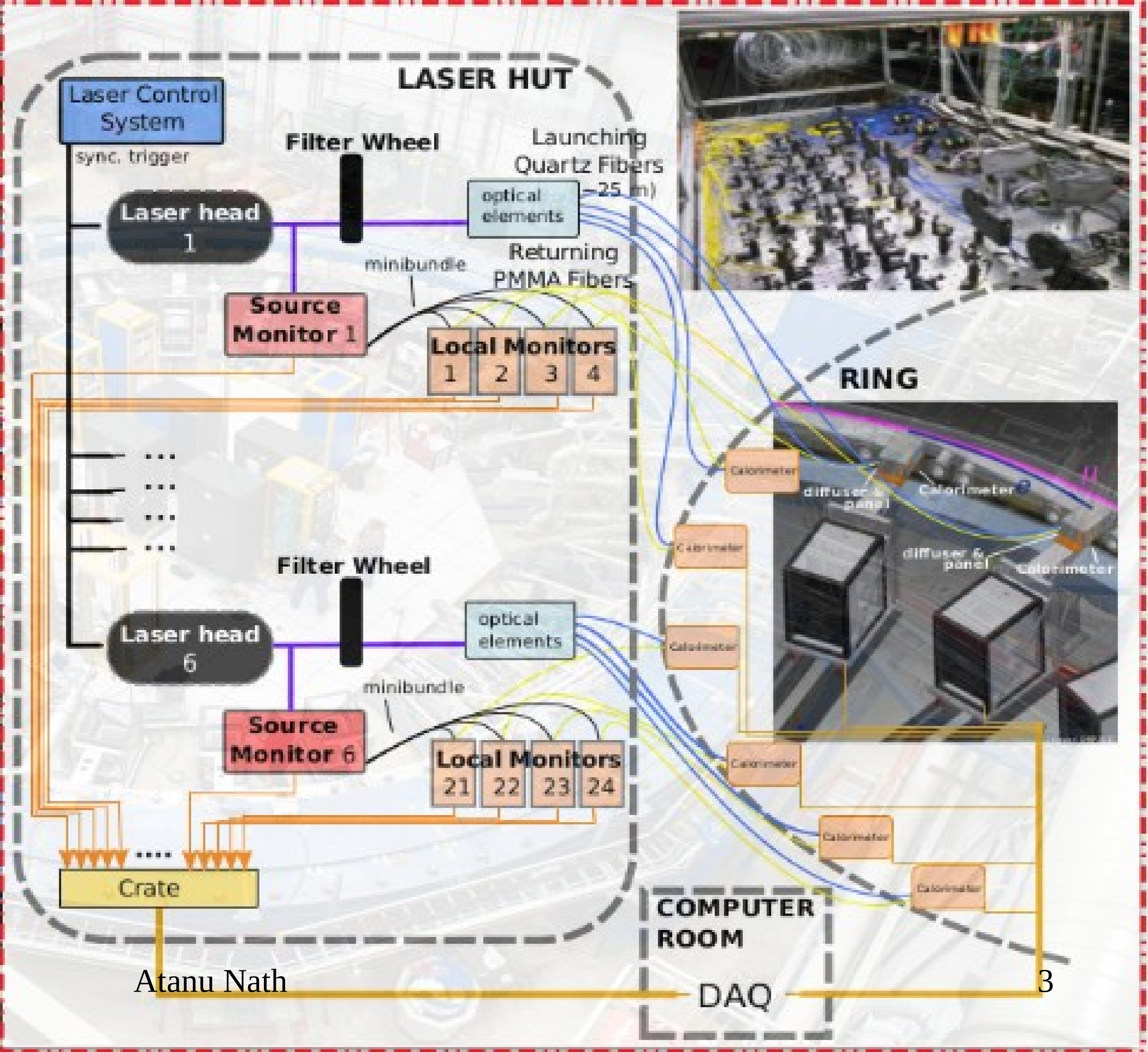
Outline

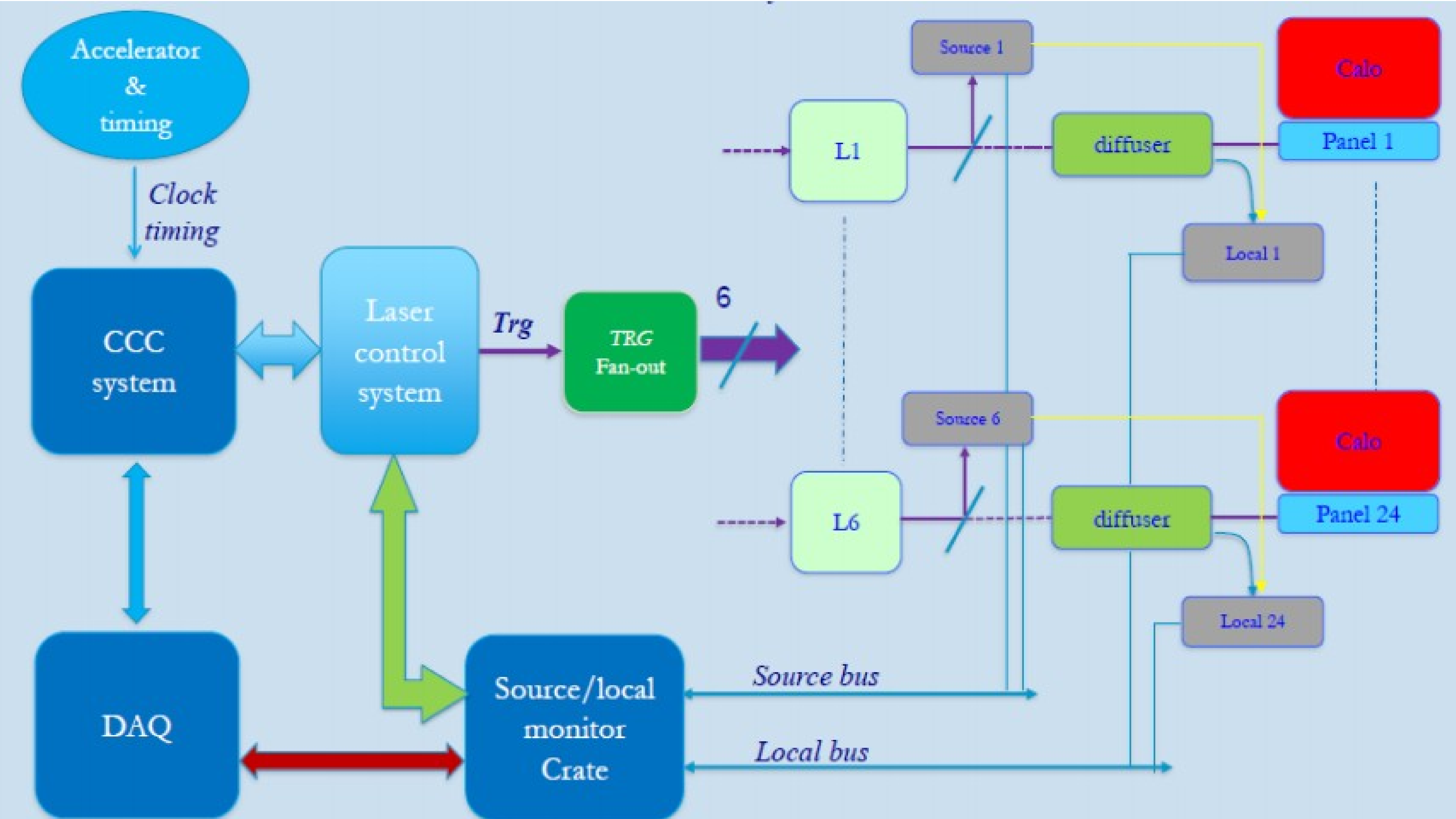
The main components

- Laser control system
- *Source Monitors (SM)*
- *Local* Monitors (LM)
- The *Monitoring* Board and the *Controller* Board

Data acquisition & monitoring systems

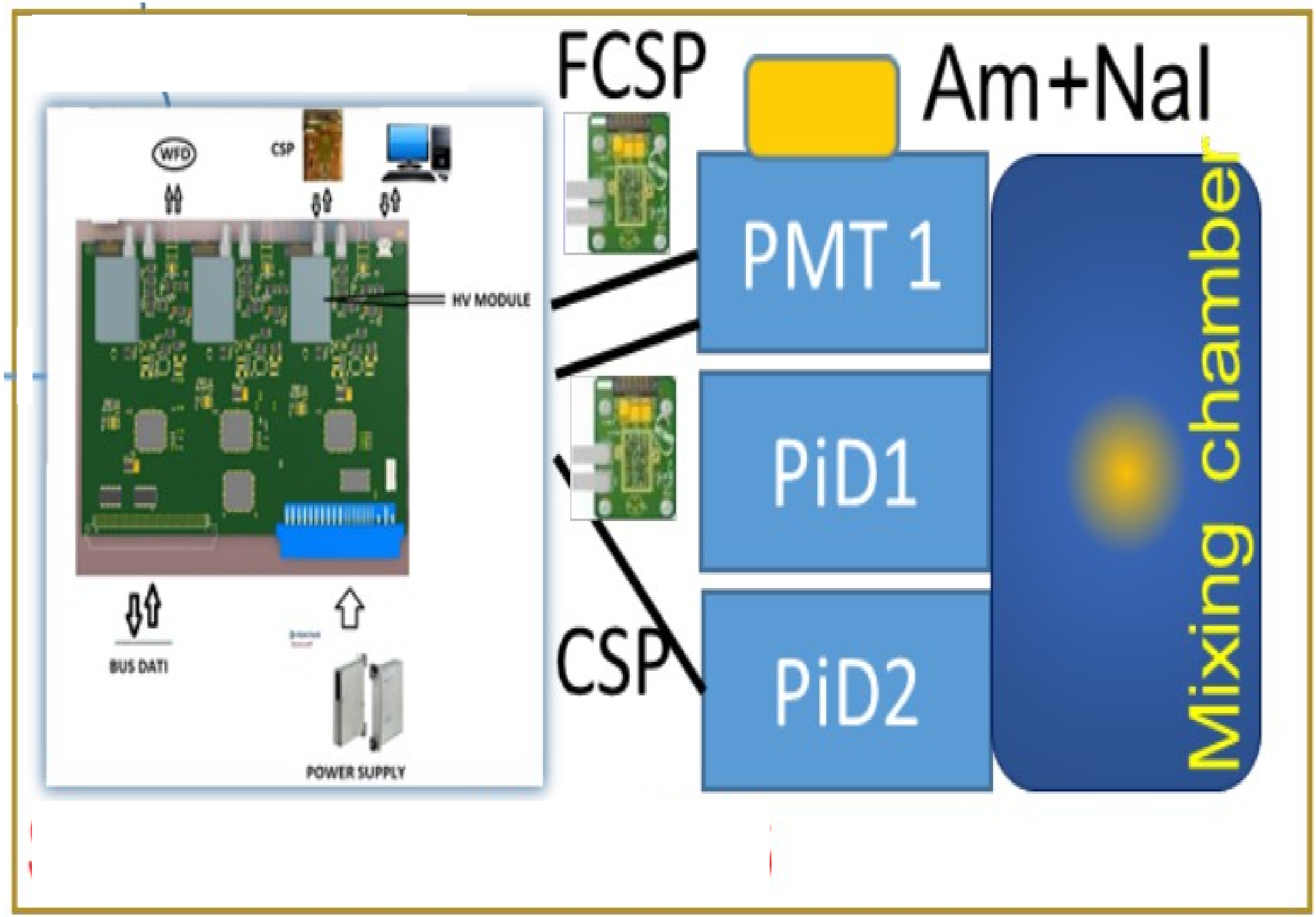
- MIDAS DAQ and Data Monitoring
- Naples DAQ and Data Monitoring

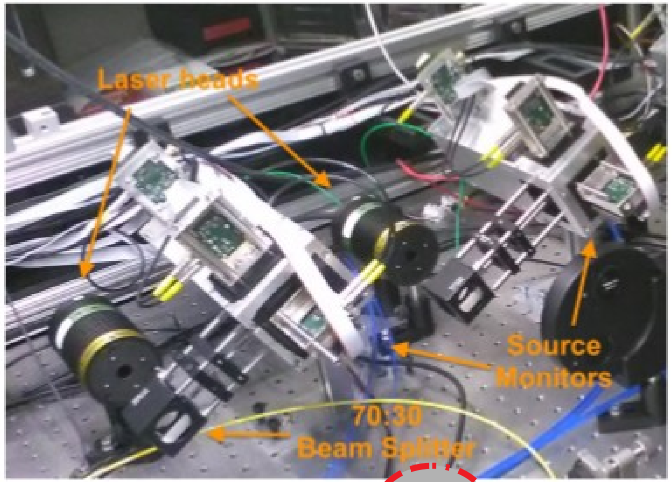

LASER HUT
Laser Control System
sync. trigger
Filter Wheel
Launching Quartz Fibers
optical elements
Laser head 1
minibundle
Returning PMMA Fibers
Source Monitor 1
Local Monitors
1 2 3 4
RING
Filter Wheel
optical elements
Laser head 6
minibundle
Source Monitor 6
Local Monitors
21 22 23 24
Crate
COMPUTER ROOM
DAQ

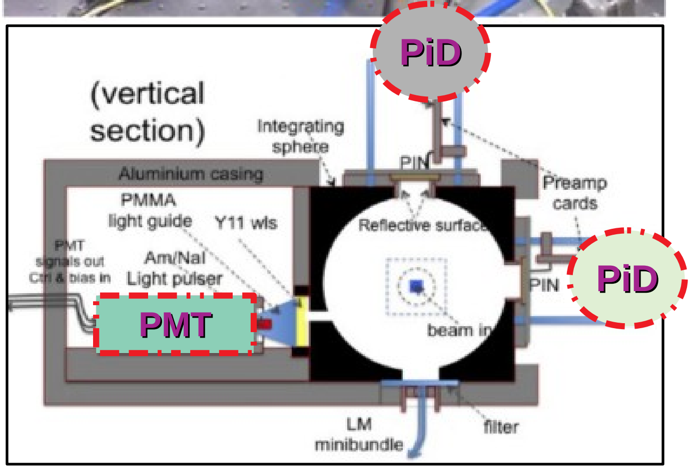

Accelerator & timing
Clock timing
CCC system
Laser control system
Trg
TRG Fan-out
6
DAQ
Source/local monitor Crate
Source bus
Local bus
L1
L6
Source 1
Source 6
diffuser
diffuser
Local 1
Local 24
Calo
Panel 1
Calo
Panel 24

The Monitors...

Source Monitors × 6

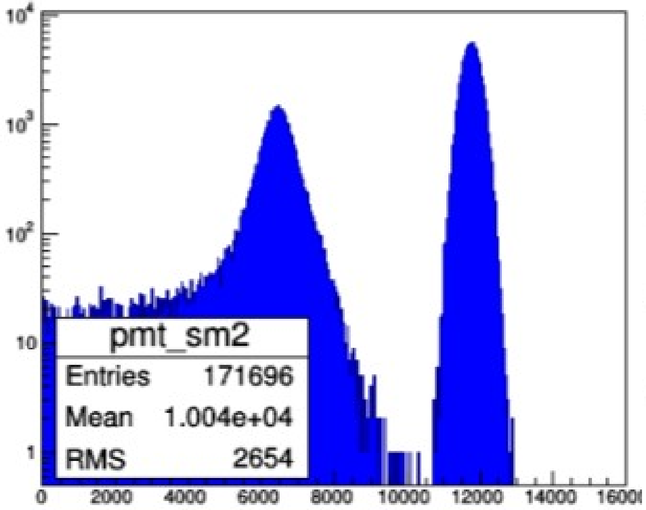




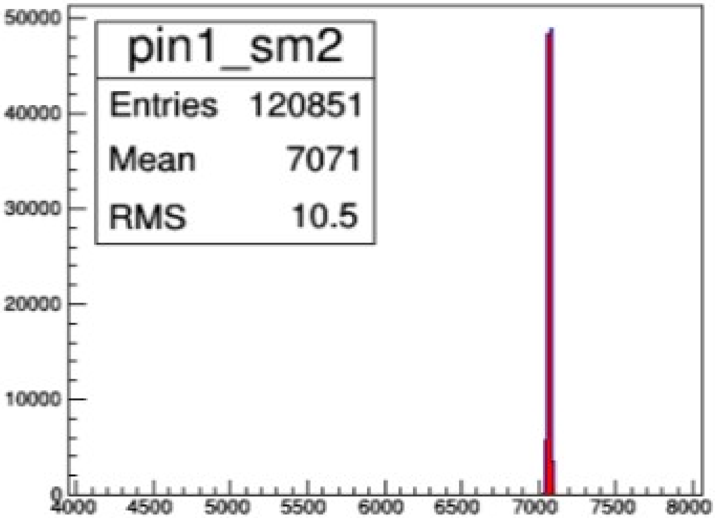


Source Monitors × 6

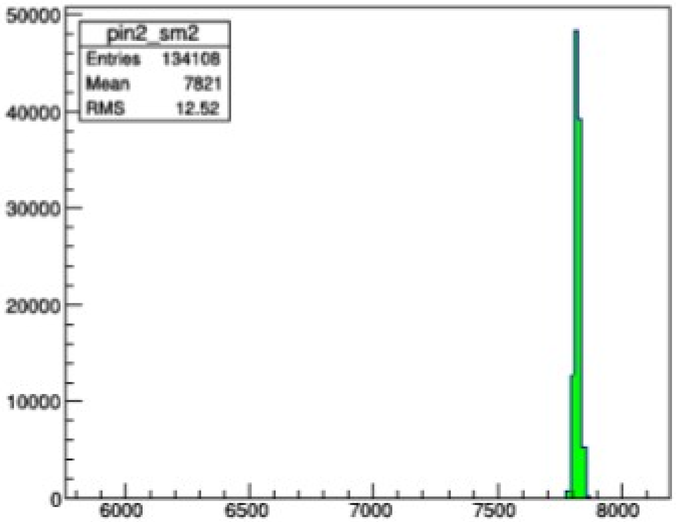
PMT



PiD-1



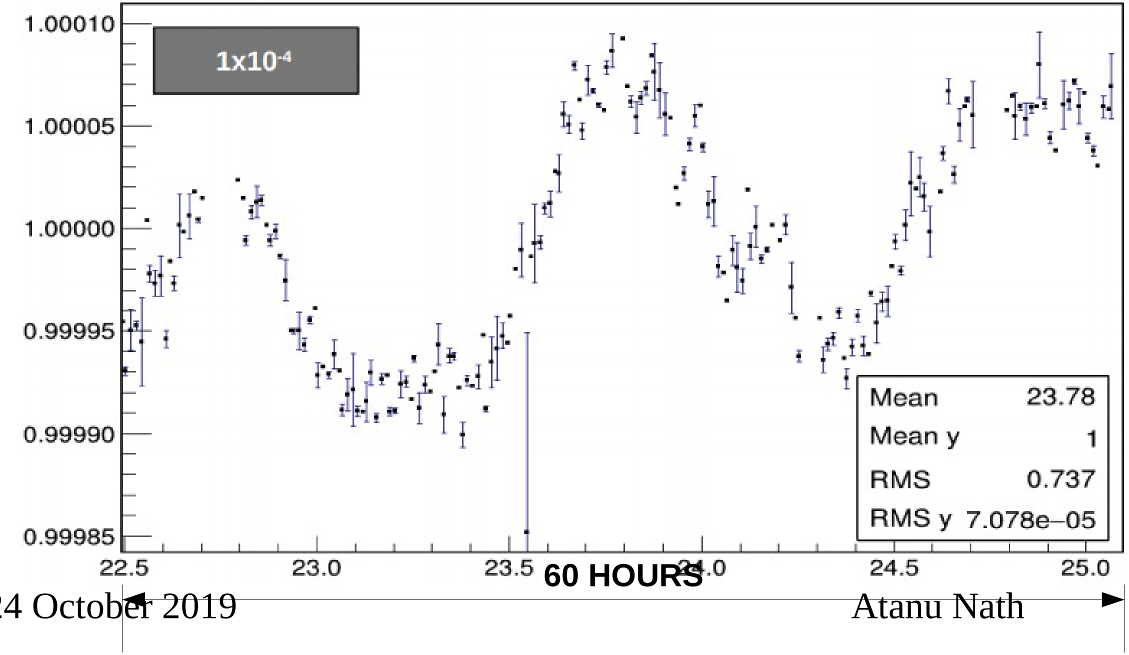
PiD-2

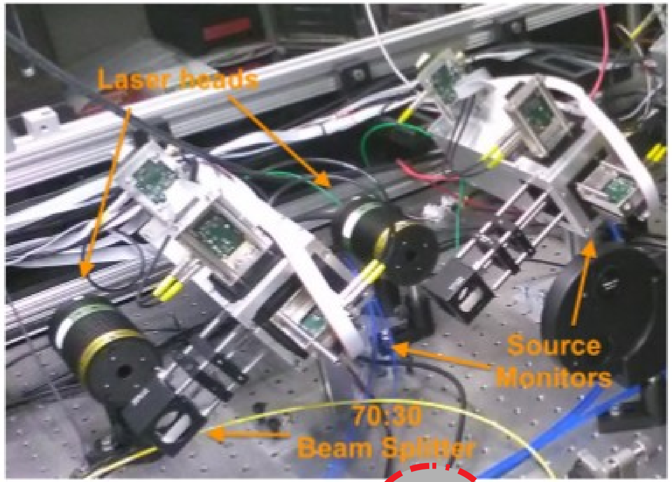


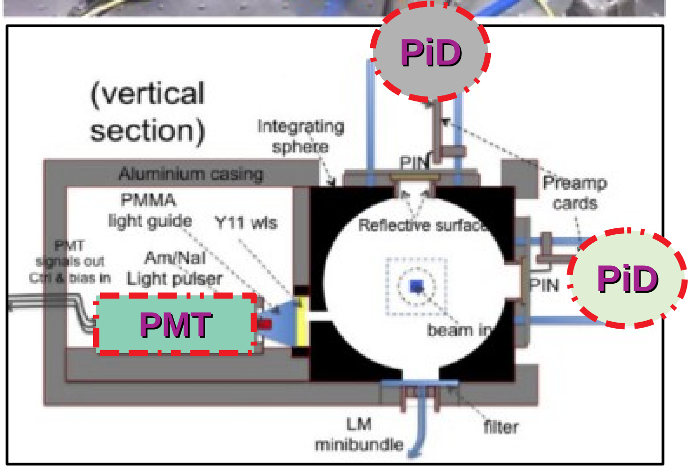
Source Monitors × 6

- **2 Pin Diodes** : receive **laser** pulses directly from the **source**.

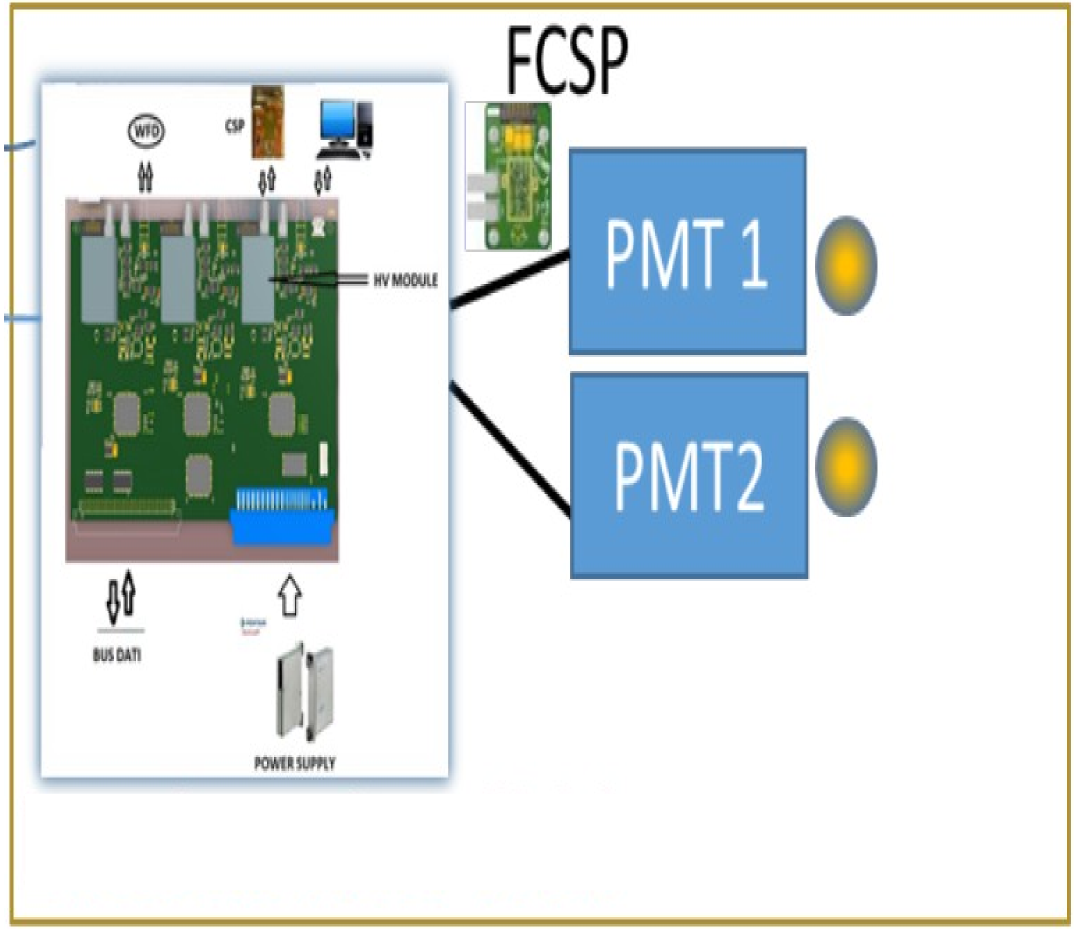
Pin-1/Pin-2 ~
stability at ***sub per mil***

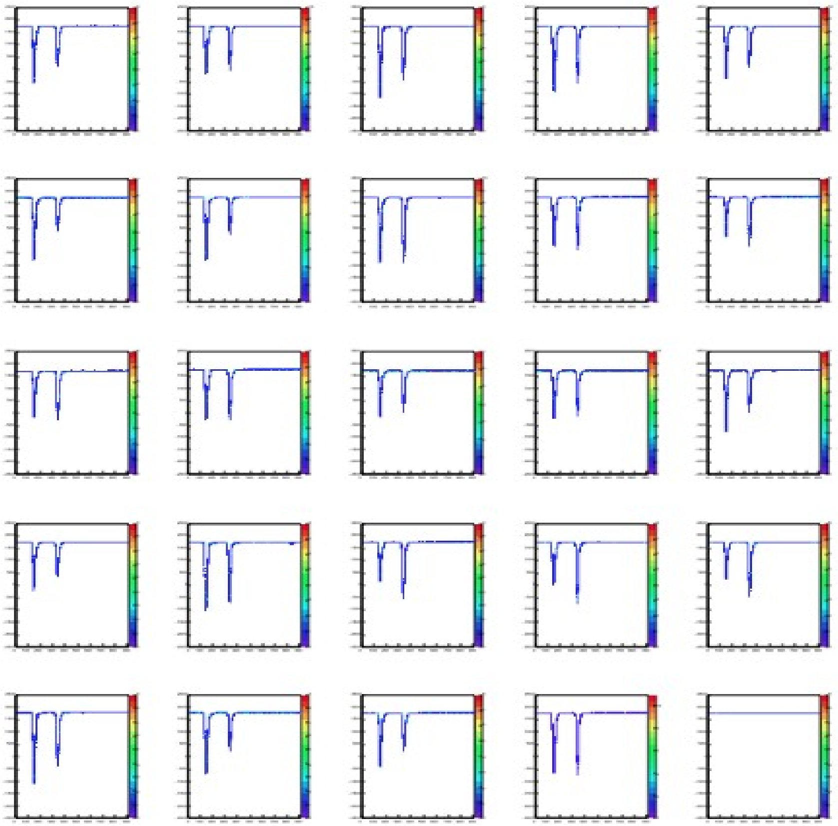






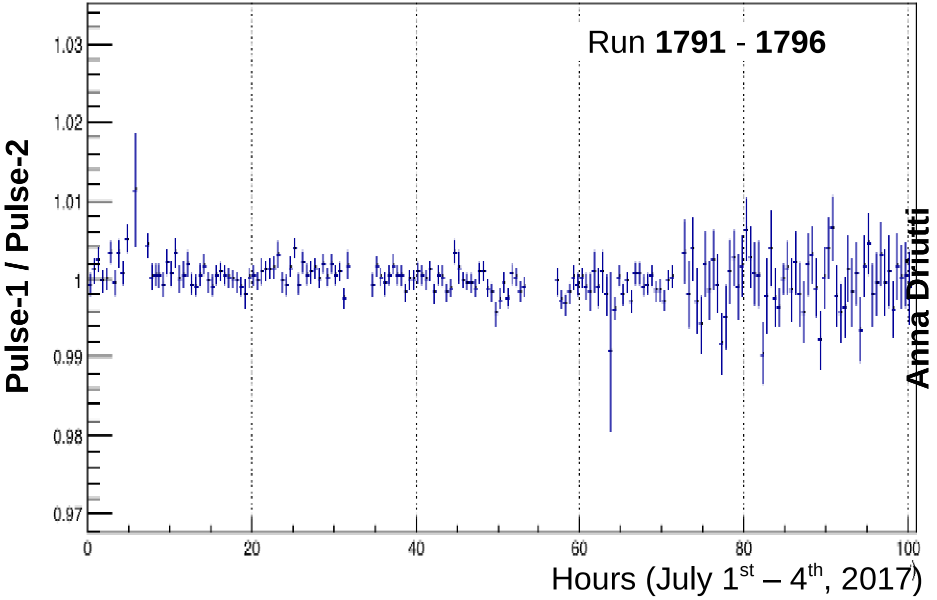
Local monitors × 24

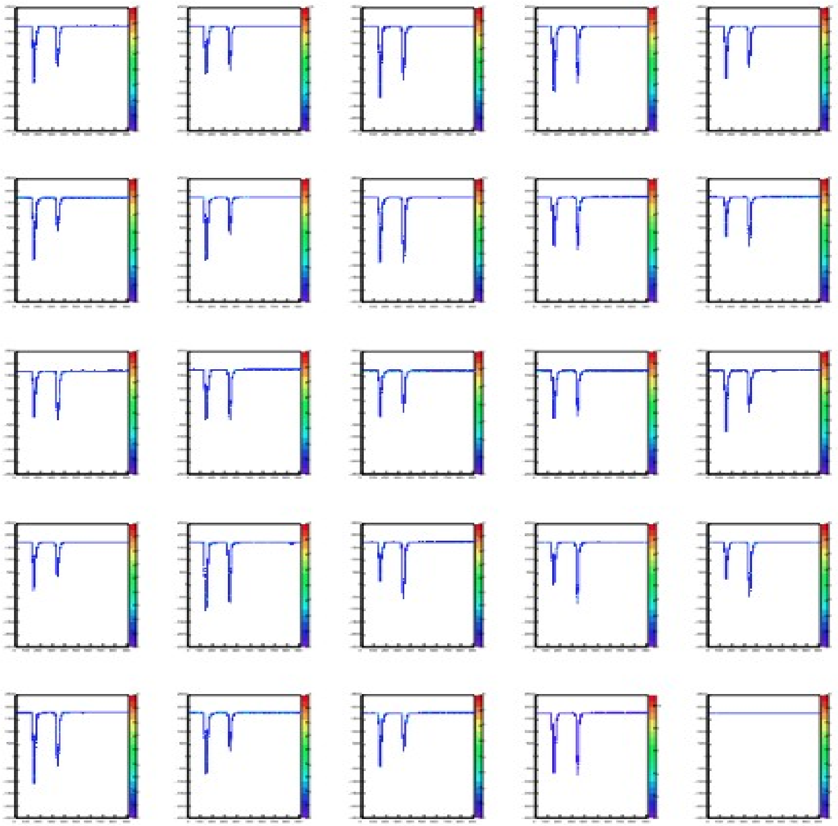




Local monitors × 24

- **1 PMT (Plan of 2 actually)** : receives **laser** pulses directly from the ***Source Monitors*** (Pulse-**1**) as well as light coming back from the **calorimeters** (Pulse-**2**).
  - **Pulse-1**/**Pulse-2** ~ stability of the **Local Monitors.**



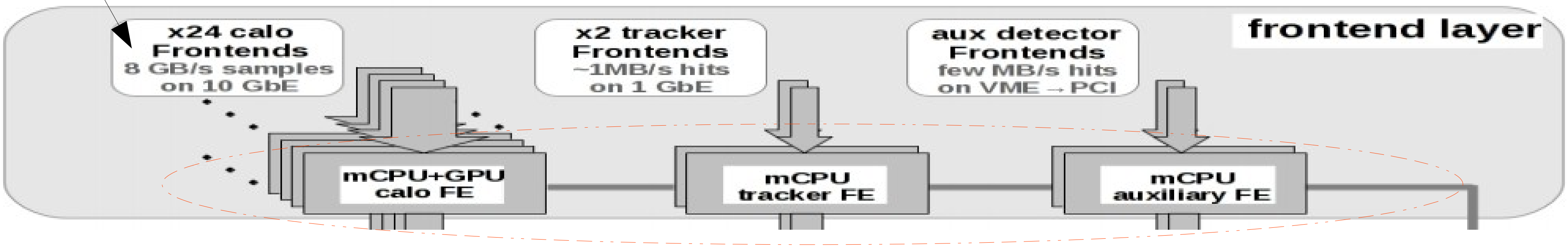


Data Acquisition Systems

MIDAS DAQ & Monitoring System

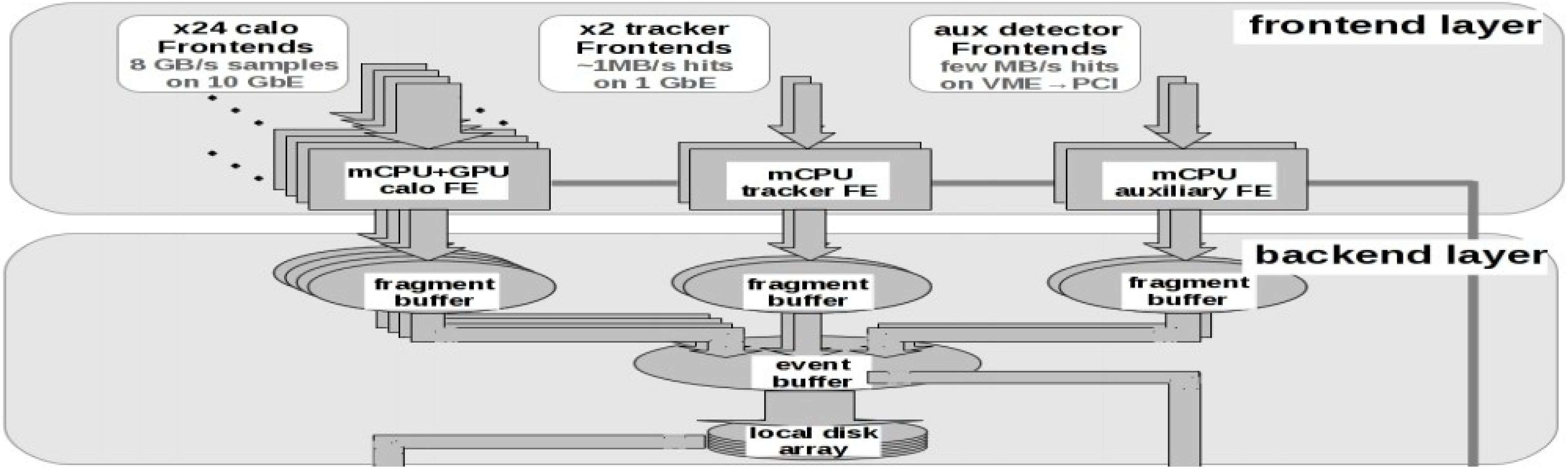
12 Hz muon spill

MIDAS DAQ

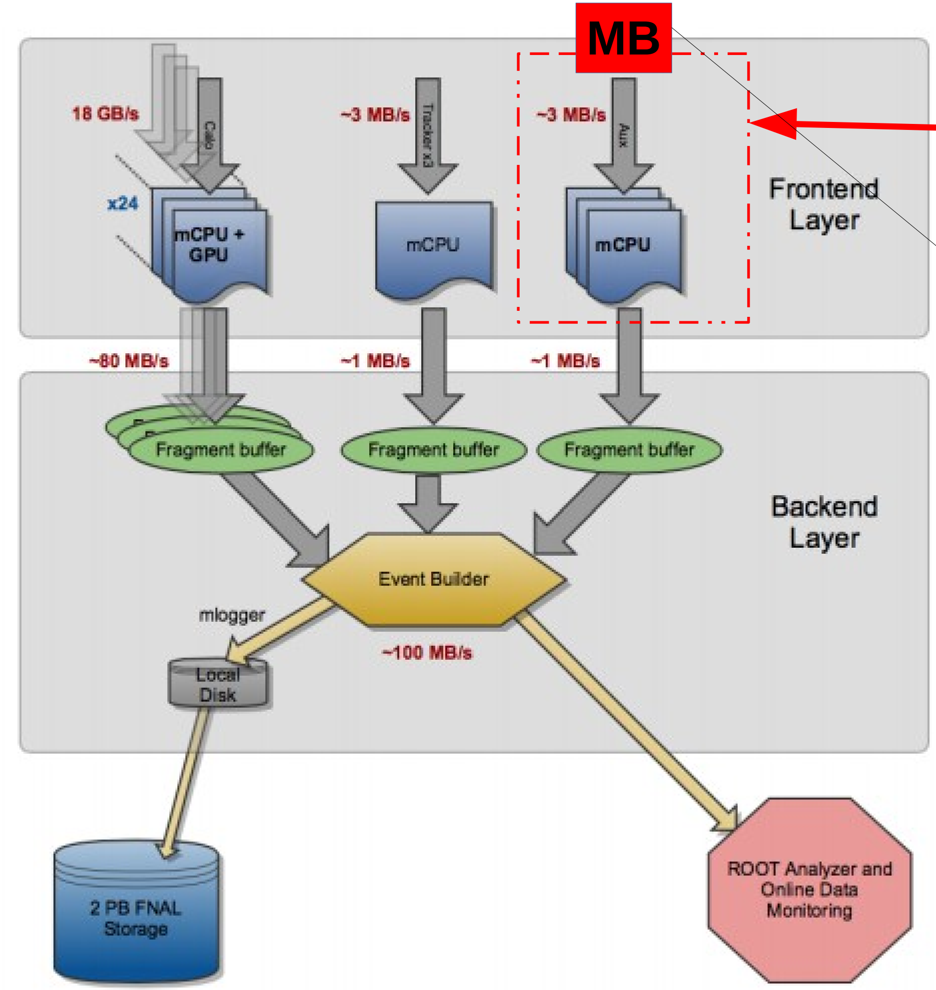


At this layer, acquired raw data (~**80 GB**/s) is processed using GPUs (CUDA subroutines used T, and Q-methods) and lossless compression, a processed data of (100 times reduced in size) is produced.

MIDAS DAQ



At this layer, processed data from ~ 30 segments (front-ends) are assembled together into one event frame (rate ~ **80 MB/s**) and sent to local (online database) and remote storage (≤ **200 MB/s**). **6PB** expected to be written in total.



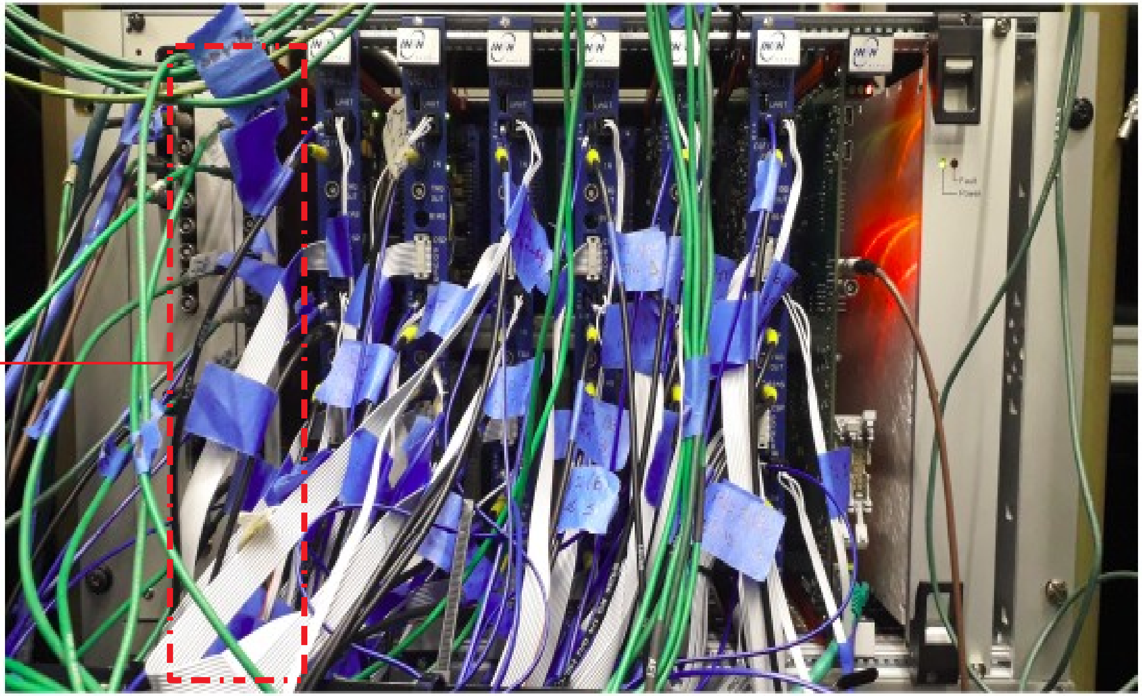
Auxiliary front-ends including **laser**

Custom designed **M**onitoring **B**oards

Laser DAQ

Laser Control

Custom made **Source Monitor** crate



Defines the laser pulses, frequency, pattern, type (normal calibration pulse, exponential simulation pulse, double pulses etc)..

It is coupled with the clocks and provides triggers to the DAQ (main and laser DAQ).

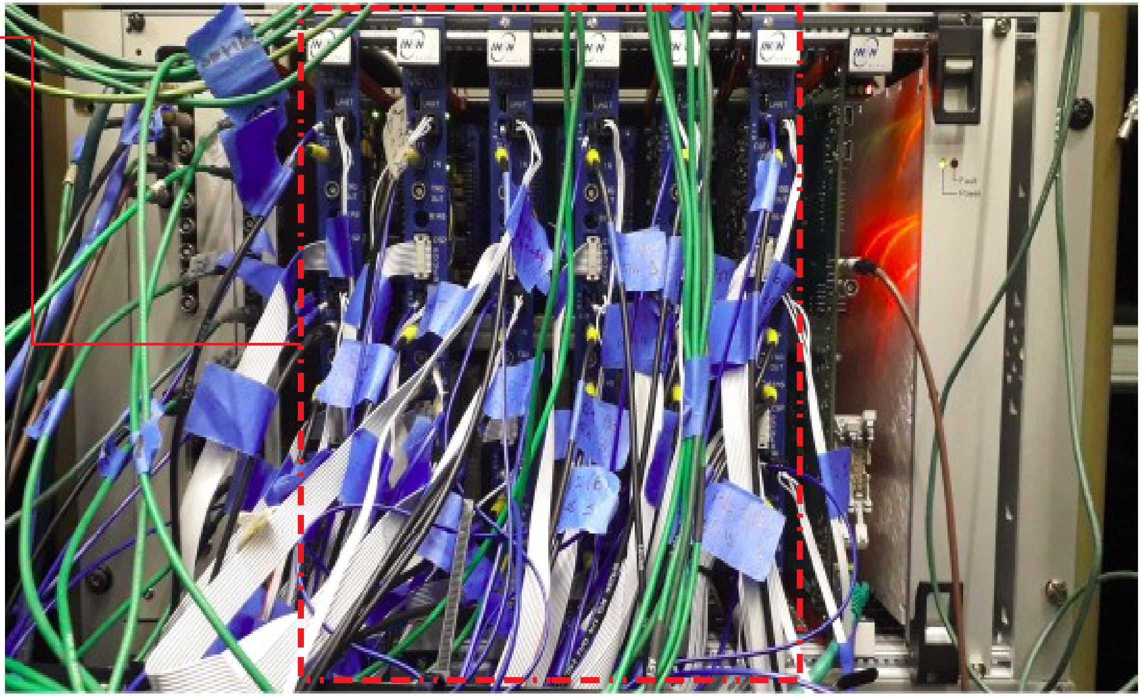
Laser DAQ

Custom made **Source Monitor** crate.

MBs – 1 to 6

Pre-amplifier
Shaper
Digitizer.

Provides bias/HV to the detectors.



Laser DAQ

Custom made **Source Monitor** crate.

MBs – 1 to 6

PiD/PMT Signal

↓

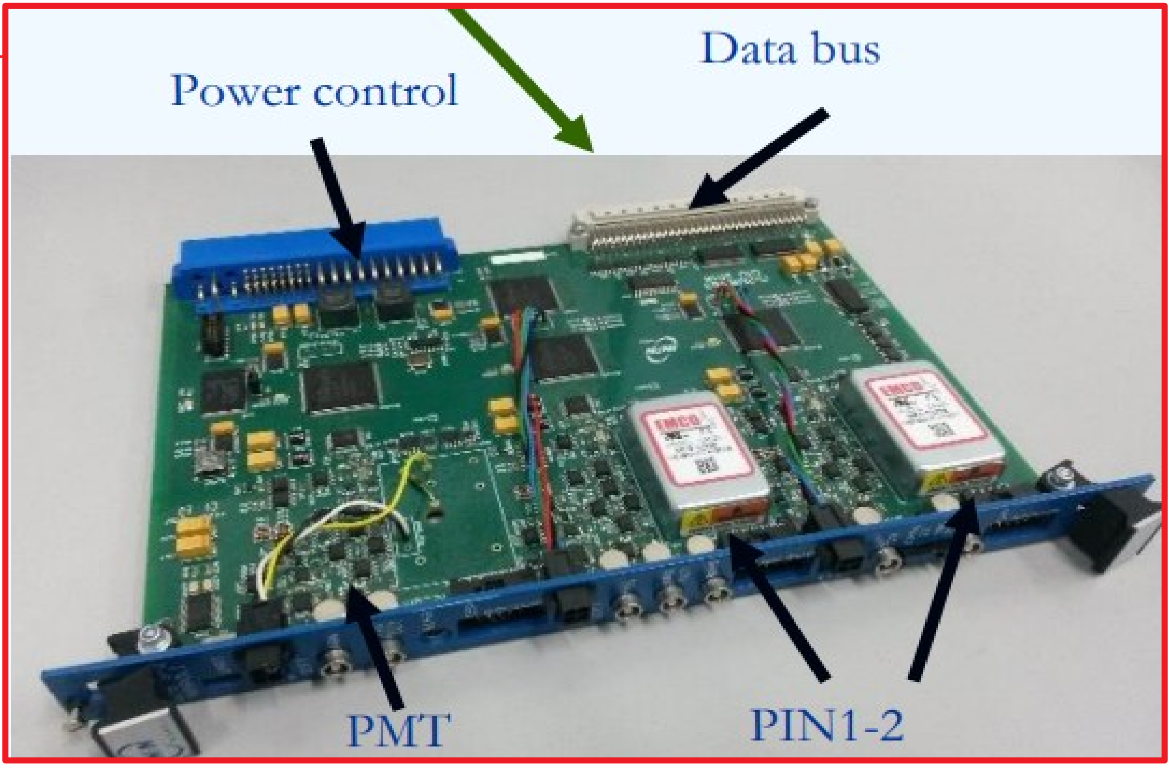
Shaper Long-tail (20 us) Semi Gaussian)

↓

Baseline restorer

↓

Digitizer

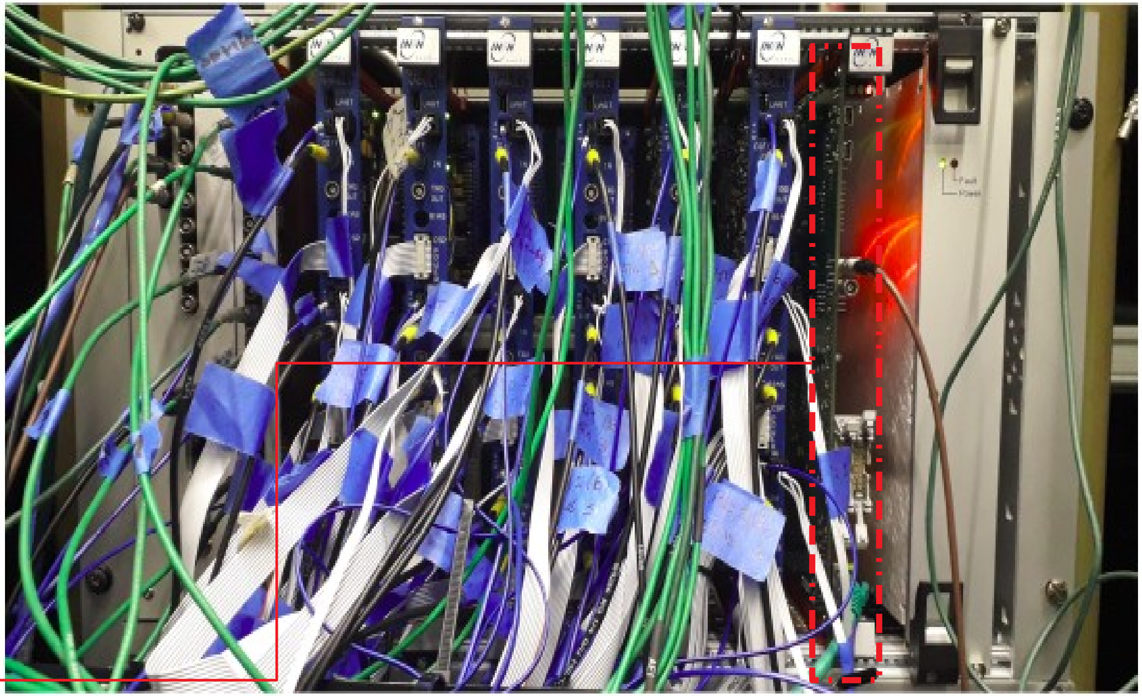


Laser DAQ

Custom made **Source Monitor** crate**.**

Receives data frame from all the 6 **SM boards** and checks for errors and then builds the final data frame containing information of 6x3 = 18 channels.

Sends the data frame to **Naples Database** over ethernet.



SM Event Builder (Controller Board)

Laser DAQ

Receives data frame from all the 6 **SM boards** and checks for errors and then builds the final data frame containing information of 6x3 = 18 channels.

Sends the data frame to the data farm over ethernet.

SM Event Builder (Controller Board)

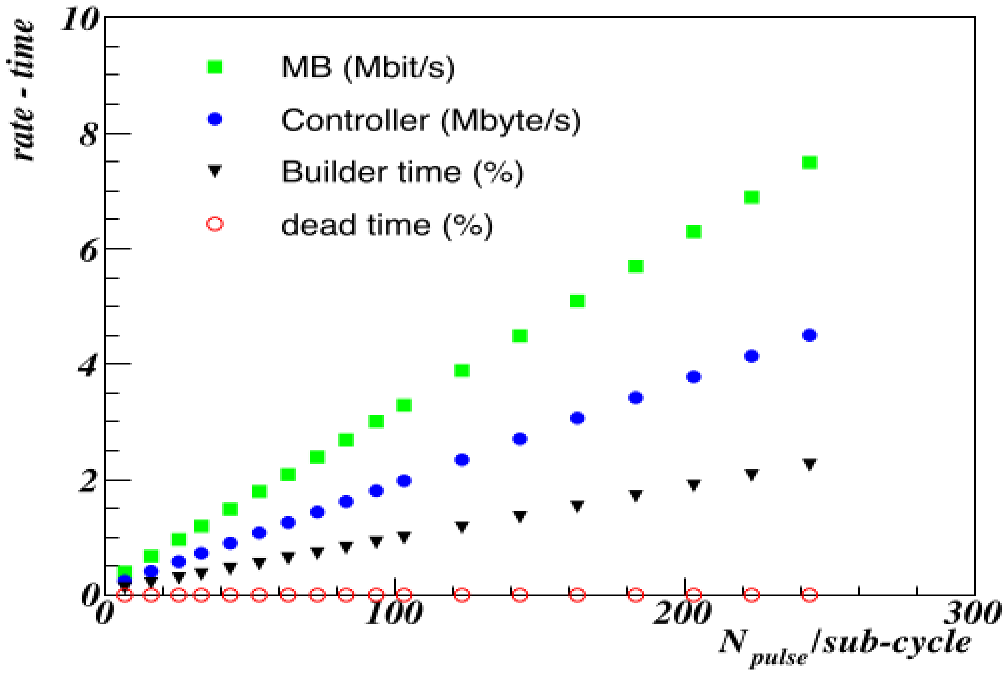


Fig. 1. Data transfer rates measured at the output of each slave board (MB) and of Controller. The time percentage of builder process and the dead time are also reported.

0.1 ^{o}C Sensitivity

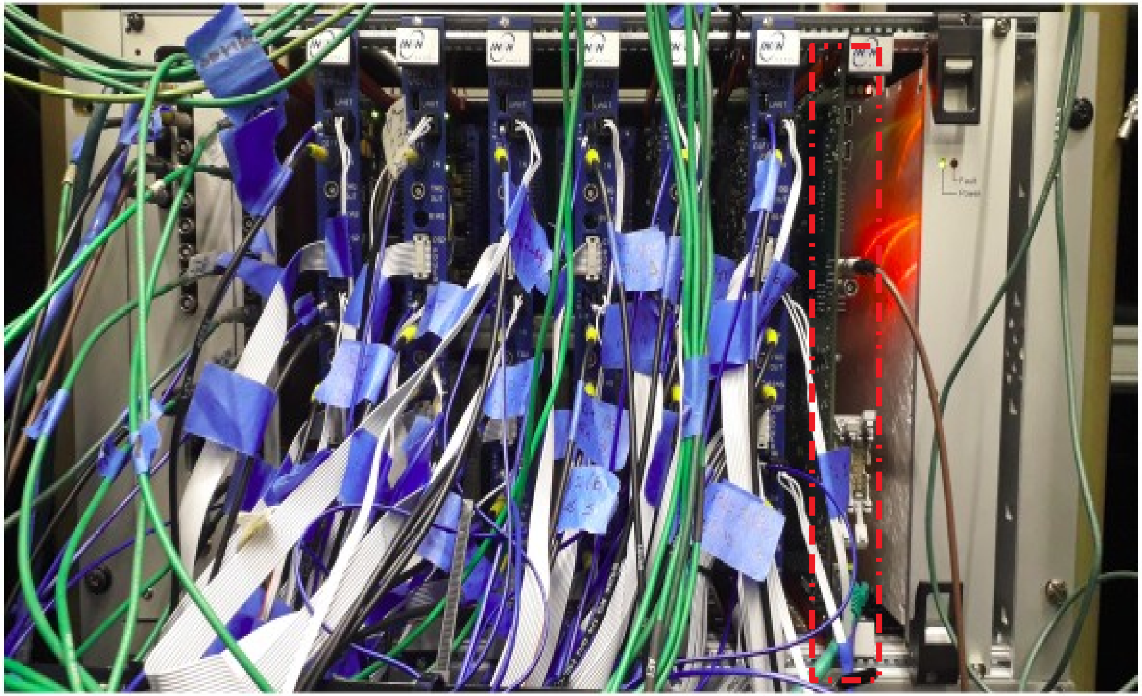
Laser DAQ

Custom made **Source Monitor** crate**.**

3 x 6 = 18 Board Temp. sensors

3 x 6 = 18 Pre Amp. Temp. sensors

2 x 6 = 12 Laser-hut Temp. sensors

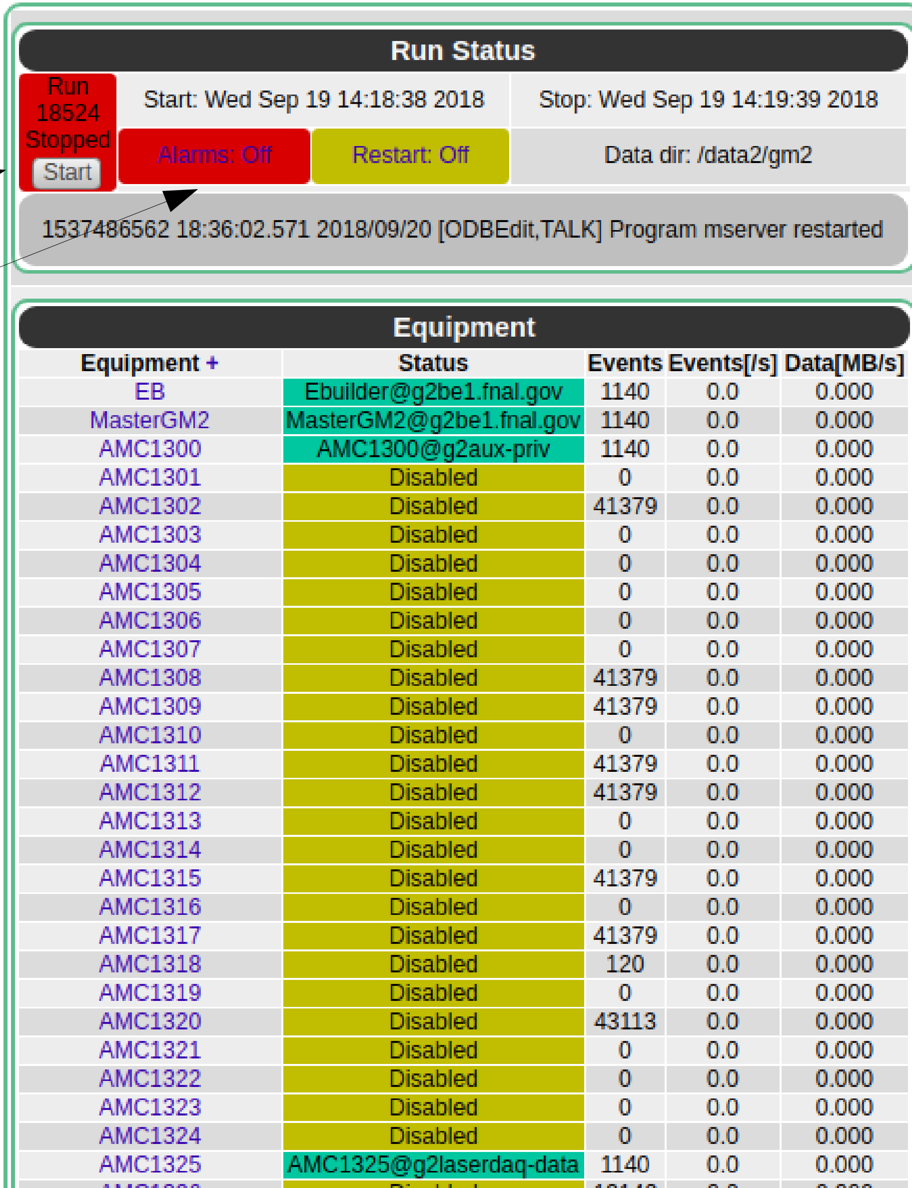


MIDAS RUN CONTROL

- **Runs** can be **start**ed and **manage**d from the web-interface.

- **Alarm** goes off when something goes wrong.

- Configurations can be changed in the **Online Data Base**.



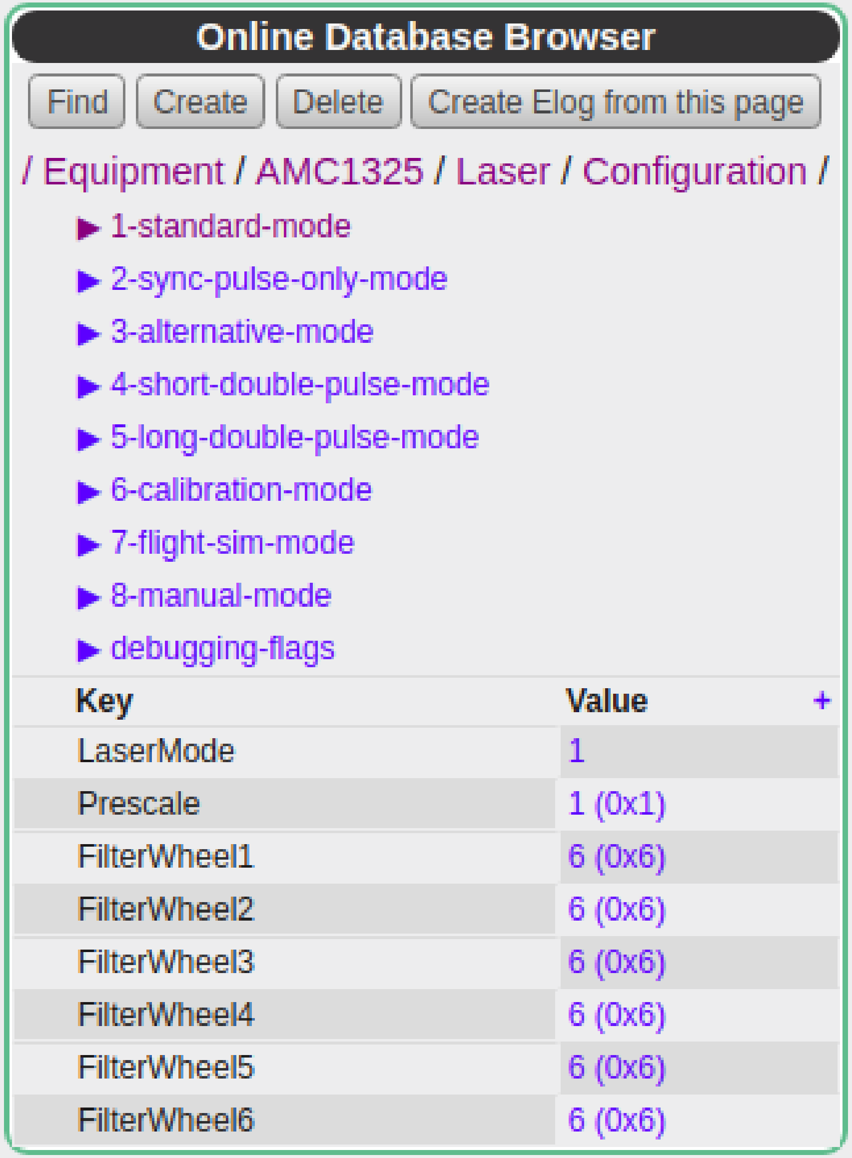
Run Status

Run 18524 Stopped Start	Start: Wed Sep 19 14:18:38 2018	Stop: Wed Sep 19 14:19:39 2018
	Alarms: Off / Restart: Off	Data dir: /data2/gm2

1537486562 18:36:02.571 2018/09/20 [ODBEdit,TALK] Program mserver restarted

Equipment

Equipment +	Status	Events	Events[/s]	Data[MB/s]
EB	Ebuilder@g2be1.fnal.gov	1140	0.0	0.000
MasterGM2	MasterGM2@g2be1.fnal.gov	1140	0.0	0.000
AMC1300	AMC1300@g2aux-priv	1140	0.0	0.000
AMC1301	Disabled	0	0.0	0.000
AMC1302	Disabled	41379	0.0	0.000
AMC1303	Disabled	0	0.0	0.000
AMC1304	Disabled	0	0.0	0.000
AMC1305	Disabled	0	0.0	0.000
AMC1306	Disabled	0	0.0	0.000
AMC1307	Disabled	0	0.0	0.000
AMC1308	Disabled	41379	0.0	0.000
AMC1309	Disabled	41379	0.0	0.000
AMC1310	Disabled	0	0.0	0.000
AMC1311	Disabled	41379	0.0	0.000
AMC1312	Disabled	41379	0.0	0.000
AMC1313	Disabled	0	0.0	0.000
AMC1314	Disabled	0	0.0	0.000
AMC1315	Disabled	41379	0.0	0.000
AMC1316	Disabled	0	0.0	0.000
AMC1317	Disabled	41379	0.0	0.000
AMC1318	Disabled	120	0.0	0.000
AMC1319	Disabled	0	0.0	0.000
AMC1320	Disabled	43113	0.0	0.000
AMC1321	Disabled	0	0.0	0.000
AMC1322	Disabled	0	0.0	0.000
AMC1323	Disabled	0	0.0	0.000
AMC1324	Disabled	0	0.0	0.000
AMC1325	AMC1325@g2laserdaq-data	1140	0.0	0.000



Online Database

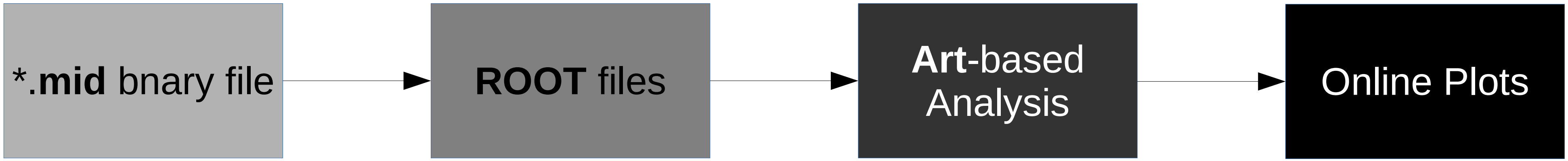
- Various configurations like

laser mode

filter-wheel position

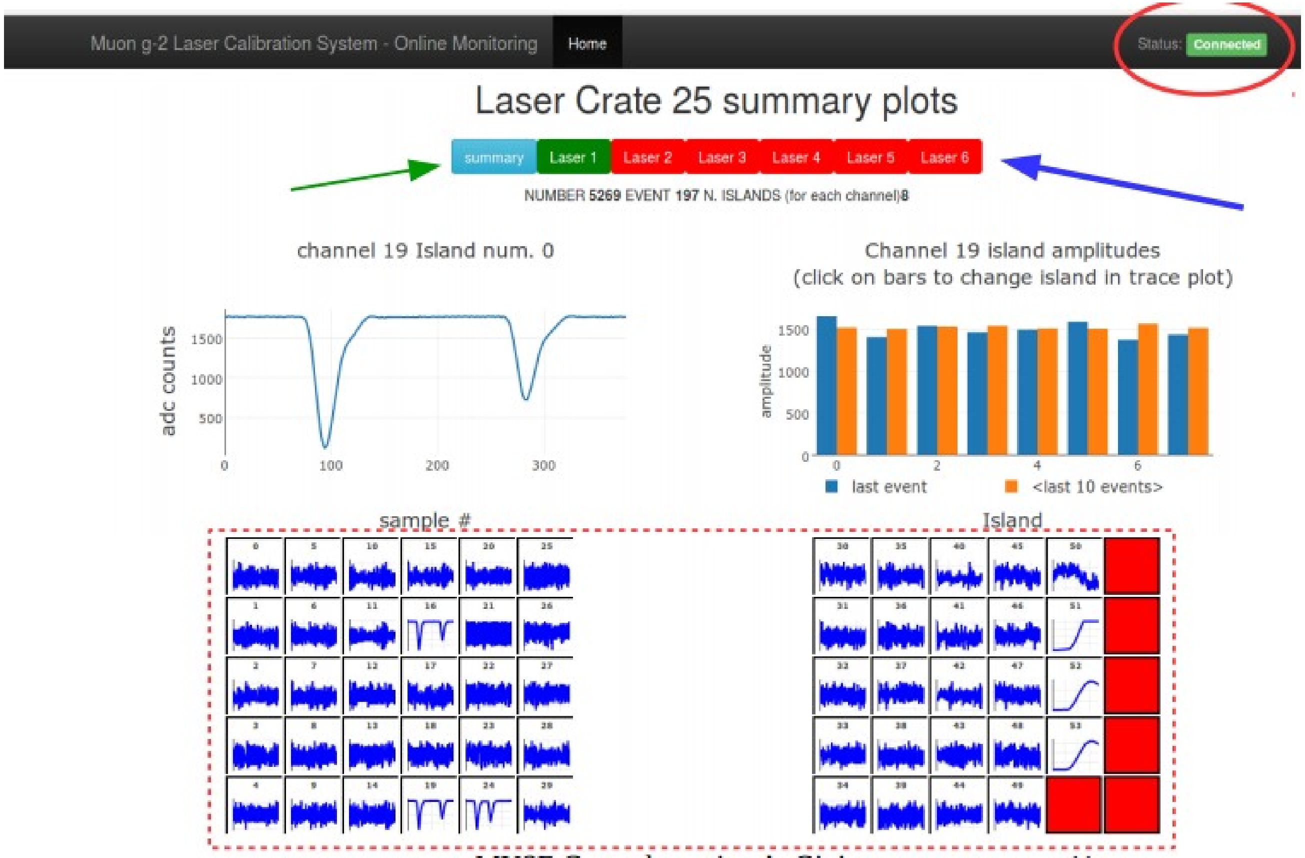
etc can be set in the ***Online Data Base*** browser.

Online **D**ata **Q**uality **M**onitor



Online Data Quality Monitor

- Server **connection** status.
- **Traces** of laser signals.
- **Stability** of laser pulses over various runs.
- **Alarms** go off when things go wrong.



Slow-control DQM

BIAS & HVs

Laser Slow Control

FILTERS & MIRRORS

TEMP.

Laser traces - Muon Fill view

Last update Thu May 17 2018 12:30:38 GMT+0200 (CEST)

Source Monitor Bias Voltage

Last time Thu May 17 2018 12:08:55 GMT+0200 (CEST)

SM DEV	PMT SET	PMT MON	PID 1 SET	PID 1 MON	PID 2 SET	PID 2 MON
SM 1	0.63	0.64	49.14	49.20	7.80	8.30
SM 2	0.54	0.54	49.14	49.21	49.14	49.29
SM 3	0.60	0.60	49.14	49.19	49.14	49.28
SM 4	0.69	0.69	49.14	49.27	49.14	49.03
SM 5	0.65	0.65	49.14	49.43	70.00	70.25
SM 6	0.60	0.59	49.14	49.53	49.14	49.34

Devices reachable on network

Last time Thu May 17 2018 12:08:51 GMT+0200 (CEST)

DEVICE	NETWORK RESPONSE
LASER CONTROL BOARD	IS ALIVE
SOURCE MONITOR BOARDS CONTROLLER	IS ALIVE
LOCAL MONITOR HV	IS ALIVE
DELAY GENERATOR	IS ALIVE
LASER HUT WORKSTATION	IS ALIVE
SOURCE MONITOR WORKSTATION	IS ALIVE

Laser Driver

Last time Thu May 17 2018 12:08:59 GMT+0200 (CEST)

LASER	CURRENT SETTINIG	CURRENT MONITORING	INTERLOCK STATUS
1	0.9	0.9	UNLOCKED
2	0.9	0.9	UNLOCKED
3	0.9	0.9	UNLOCKED
4	0.9	0.9	UNLOCKED
5	0.9	0.9	UNLOCKED
6	0.9	0.9	UNLOCKED

NETWORKS

Local Monitor High Voltage Power Supply

Last time Thu May 17 2018 12:08:54 GMT+0200 (CEST)

HV CH	HV SET	HV MONITOR	I MON	STATUS	POWER
0	635	635.31	148.59	1	ON
1	585	585.34	137.47	1	ON
2	585	585.38	135.79	1	ON
3	555	555.29	130.35	1	ON
4	635	635.32	149.29	1	ON
5	550	550.38	128.82	1	ON
6	545	545.28	127.34	1	ON
7	510	510.33	119.21	1	ON
8	585	585.35	136.78	1	ON
9	590	590.38	137.91	1	ON
10	525	525.38	123.50	1	ON
11	525	525.36	122.54	1	ON
12	535	535.37	125.00	1	ON
13	545	545.52	127.38	1	ON
14	550	550.46	128.60	1	ON
15	540	540.49	126.92	1	ON
16	500	500.39	116.82	1	ON
17	510	510.42	119.89	1	ON
18	510	510.27	119.16	1	ON
19	500	500.39	116.85	1	ON
20	580	580.45	135.64	1	ON
21	535	535.46	125.87	1	ON
22	550	550.38	128.47	1	ON
23	560	560.35	130.81	1	ON
24	650	650.42	152.00	1	ON
25	1100	1100.29	154.70	1	ON
26	1100	1100.34	154.50	1	ON
27	980	980.38	137.75	1	ON
28	1000	1000.38	140.46	1	ON
29	1000	1000.40	140.58	1	ON
30	0	2.69	0.08	0	OFF
31	0	2.57	0.03	0	OFF
32	0	1.15	0.03	0	OFF
33	0	2.28	0.01	0	OFF
34	0	1.64	-0.01	0	OFF
35	0	2.63	0.05	0	OFF
36	0	1.10	0.08	0	OFF
37	0	1.47	0.11	0	OFF
38	0	1.85	0.11	0	OFF

Filter wheels actual position

Last time Thu Mar 01 2018 23:40:50 GMT+0100 (CET)

NUMBER	1	2	3	4	5	6
POSITION	6	6	6	6	6	6
TRASMISSION	0.37	0.37	0.37	0.35	0.35	0.37

Flip Mirrors actual position

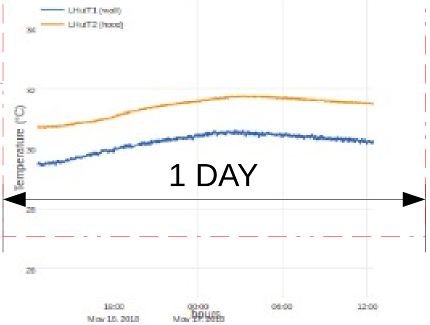
Last time Thu May 17 2018 12:09:00 GMT+0200 (CEST)

NUMBER	1	2	3	4	5	6
MIRROR POSITION	DOWN	DOWN	DOWN	DOWN	DOWN	DOWN

24h Temperature Monitor

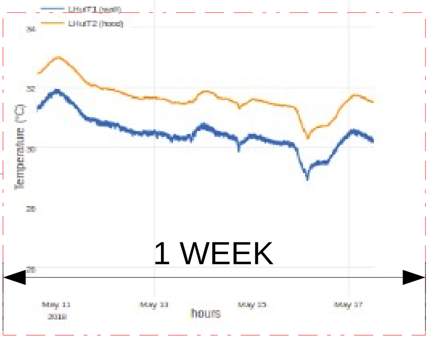
Last time Thu May 17 2018 12:29:37 GMT+0200 (CEST)

Last 24 hours



1 week Temperature Monitor

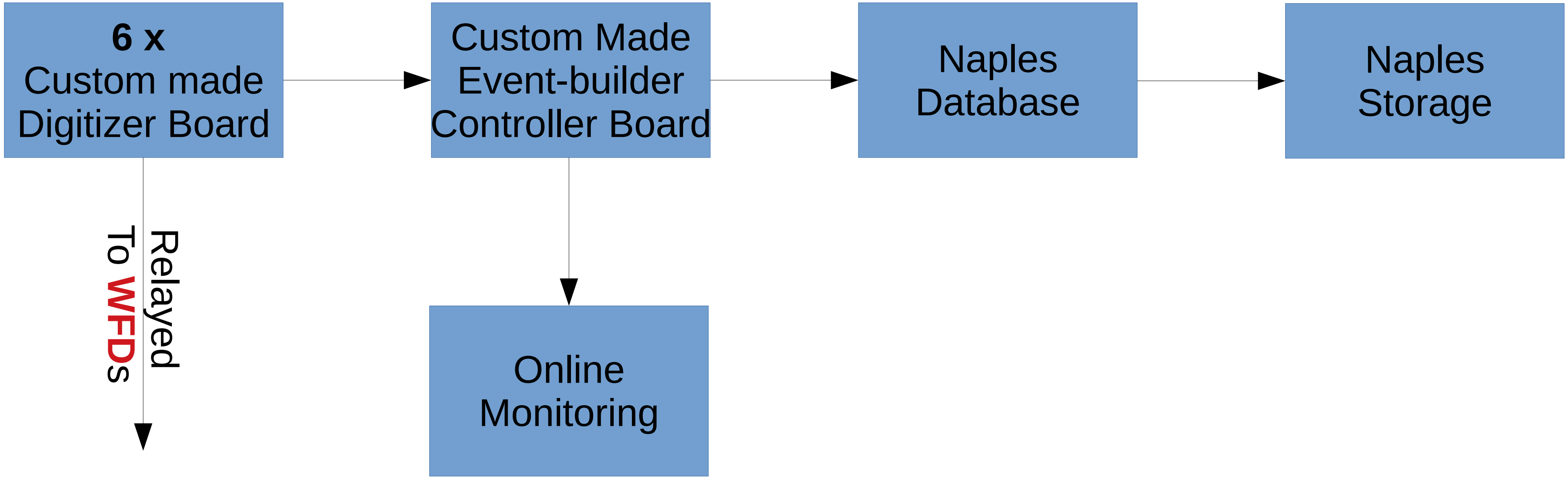
Last 168 hours

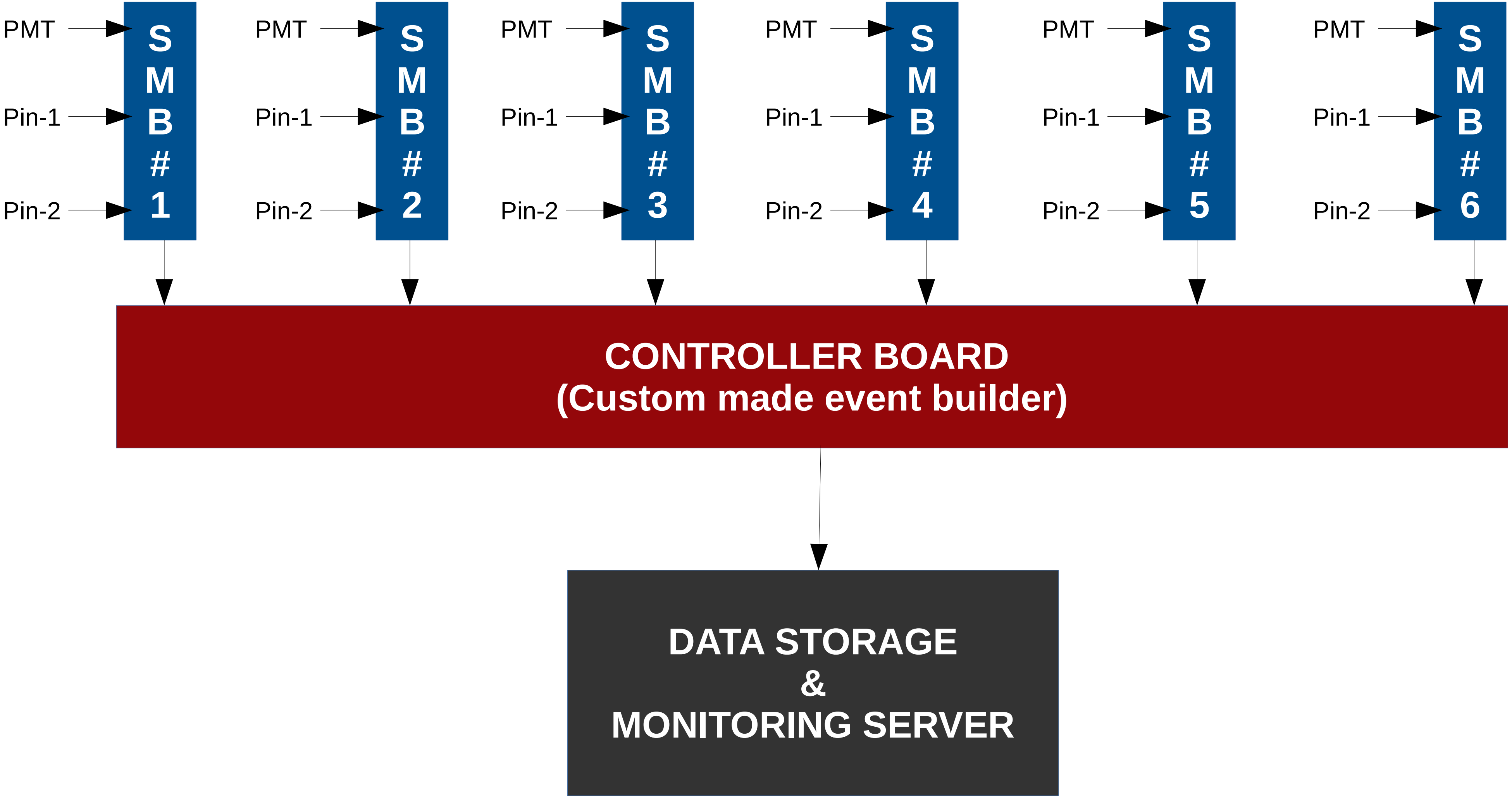


Naples DAQ & Monitoring System

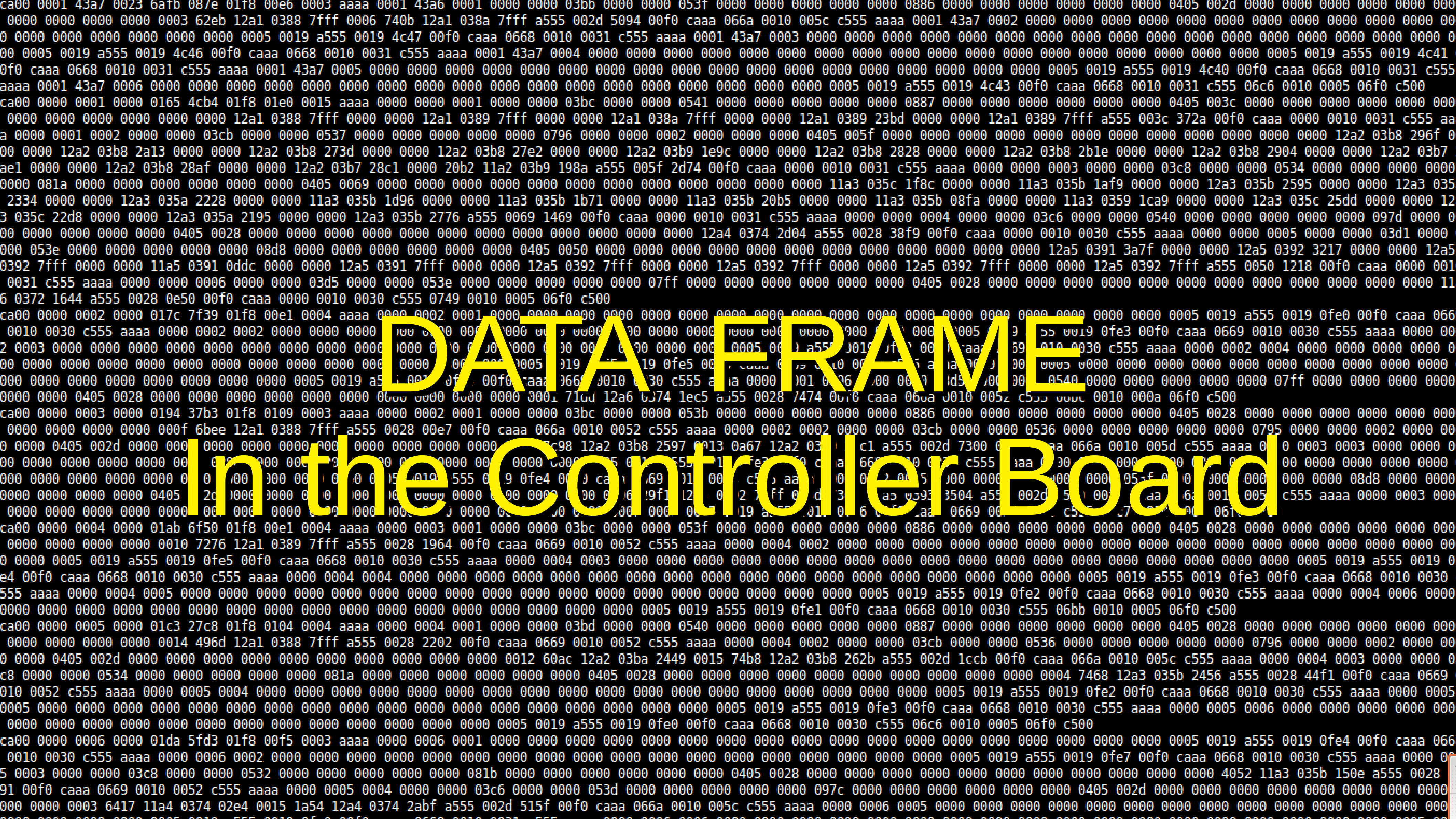
Naples DAQ

Custom made (bash, c++, ROOT, PHP, MySQL) Naples DAQ and Monitoring Package

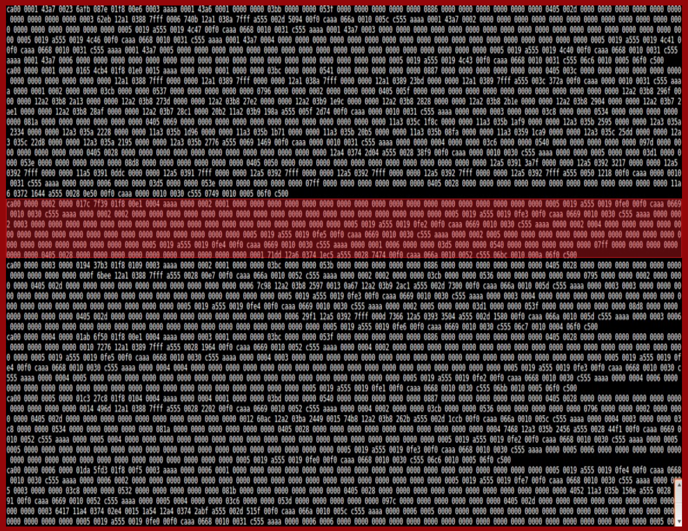



PMT
Pin-1
Pin-2
SMB#1
SMB#2
SMB#3
SMB#4
SMB#5
SMB#6
CONTROLLER BOARD
(Custom made event builder)
DATA STORAGE
&
MONITORING SERVER

Naples Monitoring...


DATA FRAME
In the Controller Board

CONTROLLER BOARD



MONITORING SERVER

Asks the controller board to send the latest data frames

Analyzes the latest frames on arrival and stores the results in a buffer…

(1) Displays the results of latest frames.

(2) Displays the results of last several hours.

Online Summary Table

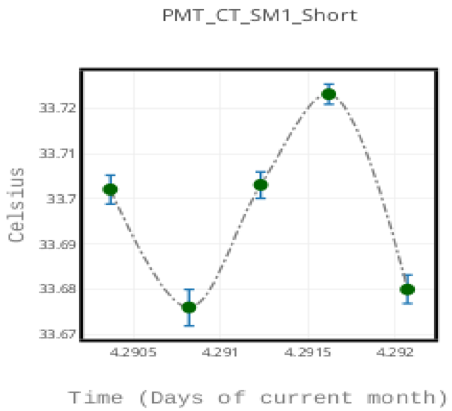
FERMILAB TIME: 2019-10-22 00:22:02

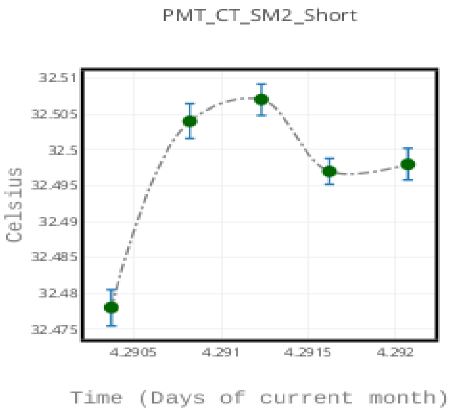
Home Summary Stability Short Term Profiles Long Term Profiles

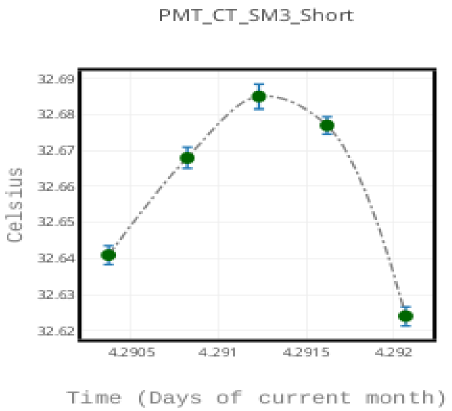
MIDAS DAQ	NAPLES DAQ	MONITOR STATUS	DATA STATUS	LASER STATUS	LASER MODE	DATA FILL RATE
UP	UP	UP	GOOD	UP	UNKNOWN	22 / sec

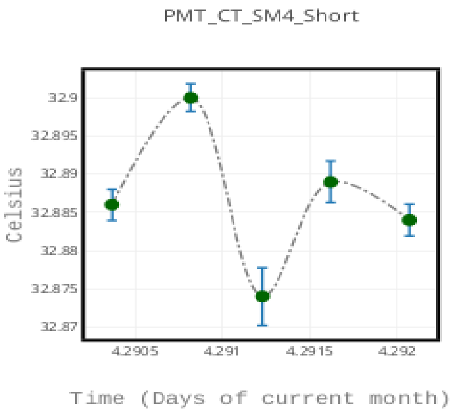
	SM-1	SM-2	SM-3	SM-4	SM-5	SM-6
MEAN ADC						
PIN-1	6991.59	7165.2	4896.7	6660.17	6405.58	6277.35
PIN-2	9028.68	7909.06	6226.5	6947.51	7025.06	6438.4
LASER	8937.63	13538.2	13342.6	13224.4	10285	7720.93
AMERICIUM	5498.31	7451.11	7882.69	8496.91	6138.91	6011.04
MEAN BIAS (V)						
PIN-1	49.2166	49.3841	49.0945	49.2483	49.4204	49.5808
PIN-2	49.5474	49.2425	49.3754	49.0674	49.257	49.3424
PMT	0.6141	0.5897	0.6422	0.7402	0.6389	0.6342
BOARD TEMP (°C)						
PIN-1	36.077	36.582	36.663	36.468	36.37	35.49
PIN-2	34.523	35.881	35.881	35.151	35.014	36.094
PMT	35.302	36.061	35.686	35.897	36.111	35.393
CSP TEMP (°C)						
PIN-1	32.551	33.294	32.806	32.158	32.437	32.189
PIN-2	32.595	32.896	32.635	31.805	31.82	32.629
PMT	33.174	32.729	32.517	32.028	31.811	32.206
EXT TEMP (°C)						
PIN-1	26.869	NAN	27.564	27.206	28.26	26.4
PIN-2	28.217	27.054	27.576	27.169	27.576	27.007

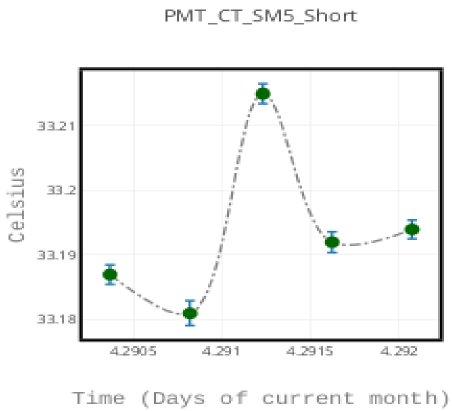
Short Term Trends

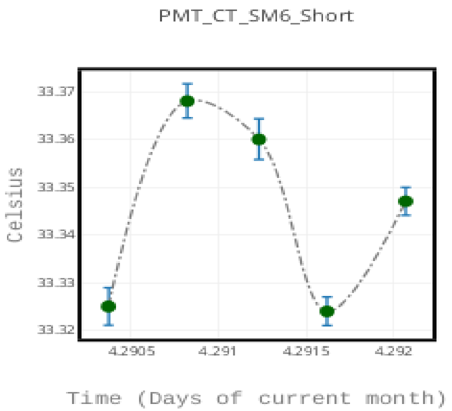




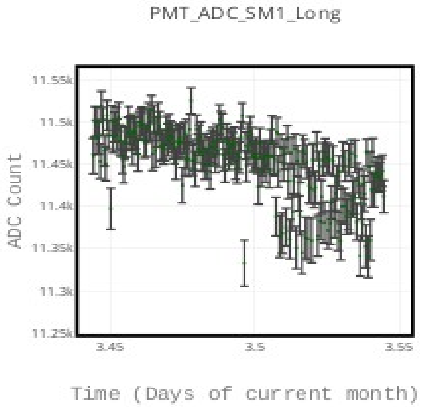


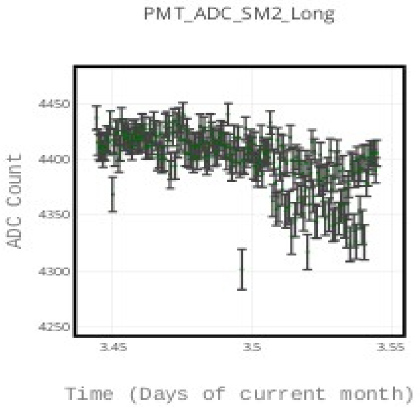


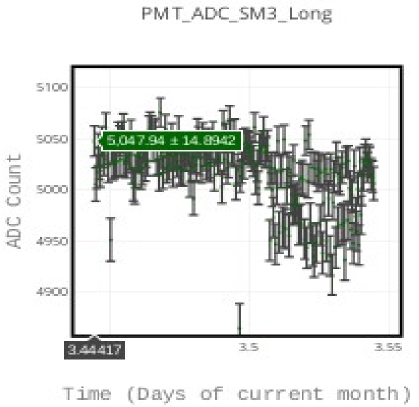


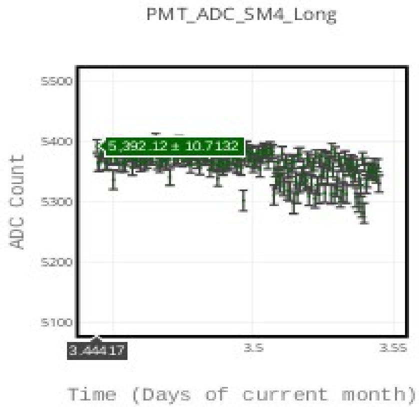


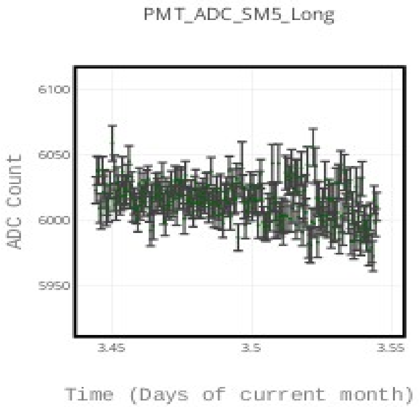
Long Term Trends

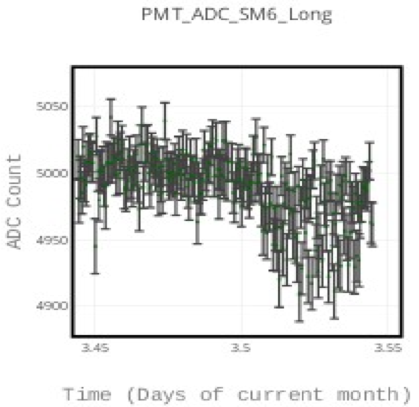




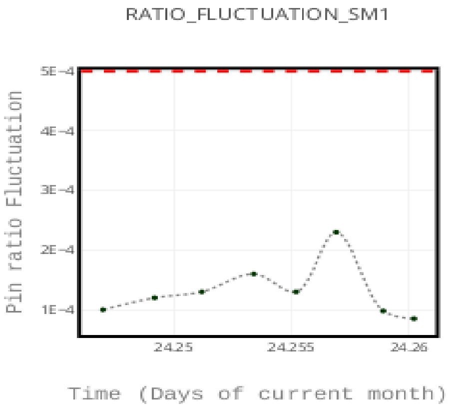


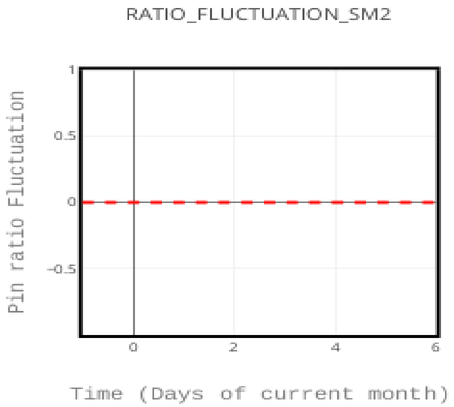


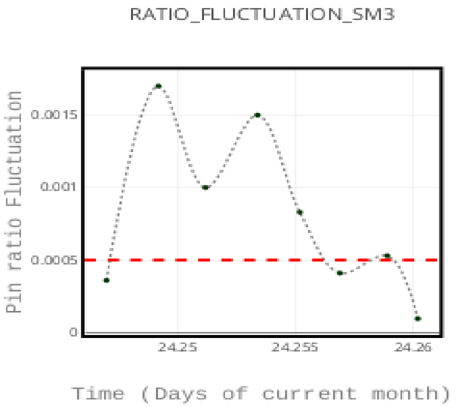


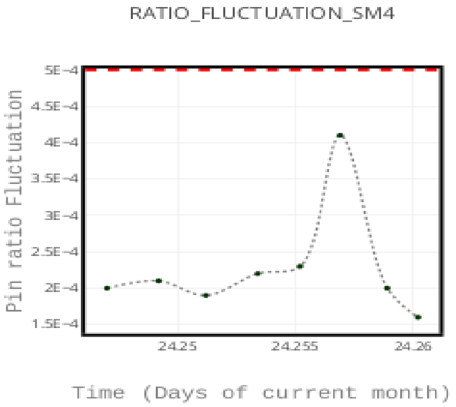


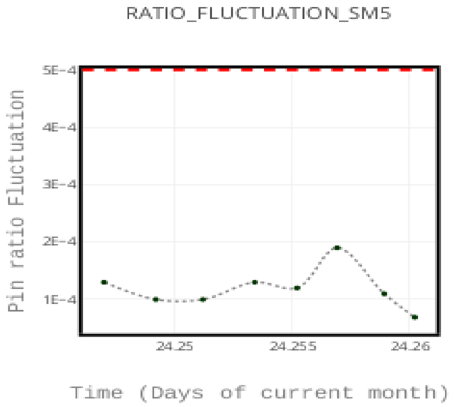
Stability Plots

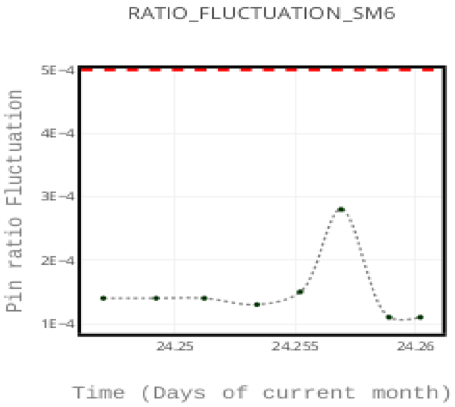






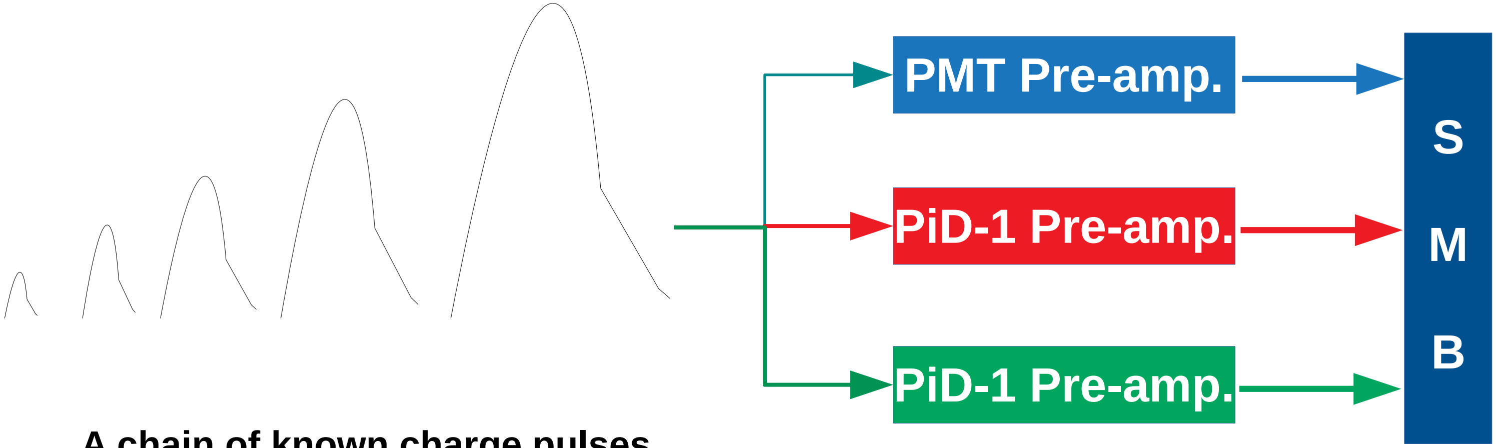






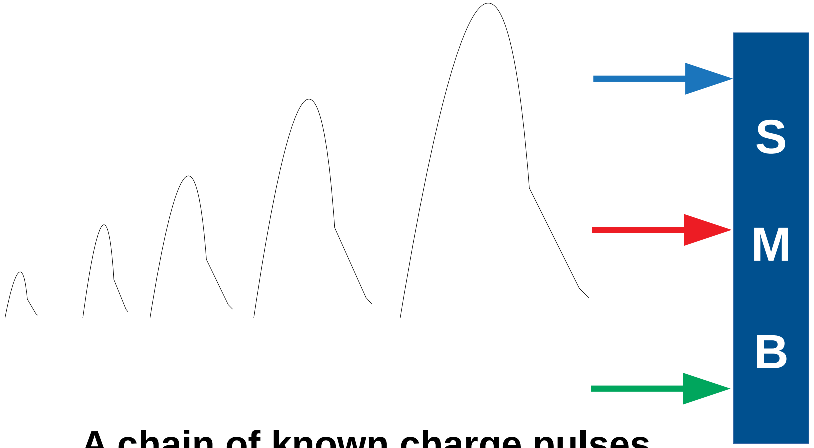
Electronic Calibration DAQ

Calibration of The Electronics



A chain of known charge pulses
Called "DAC"s

Linearity Test



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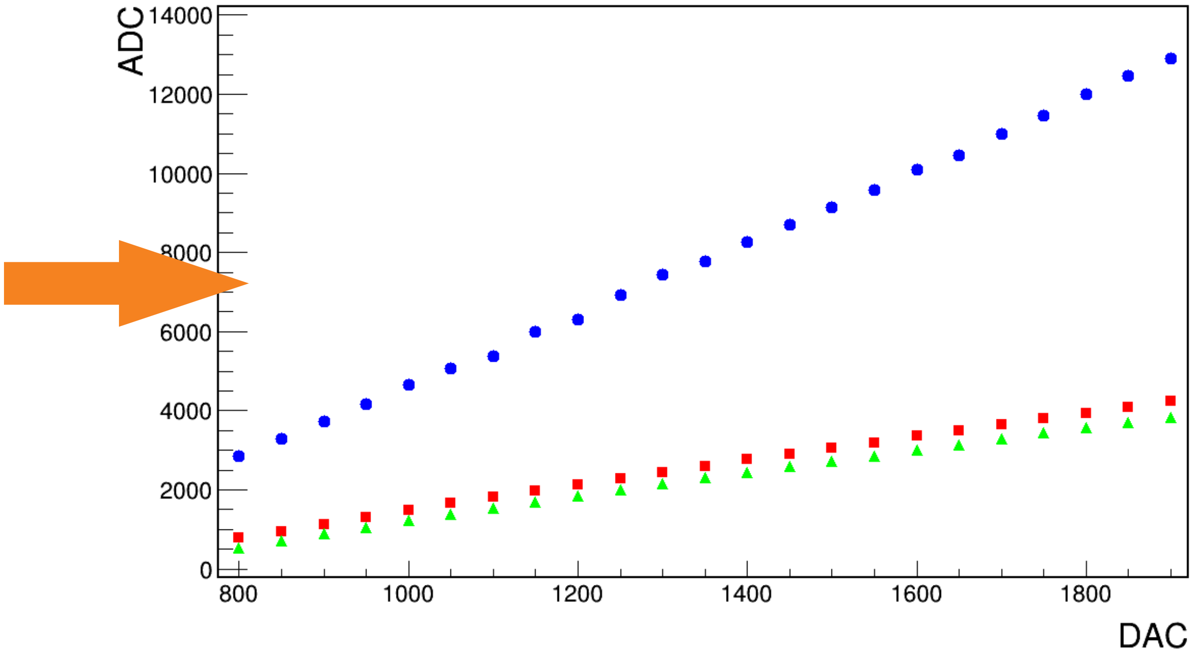
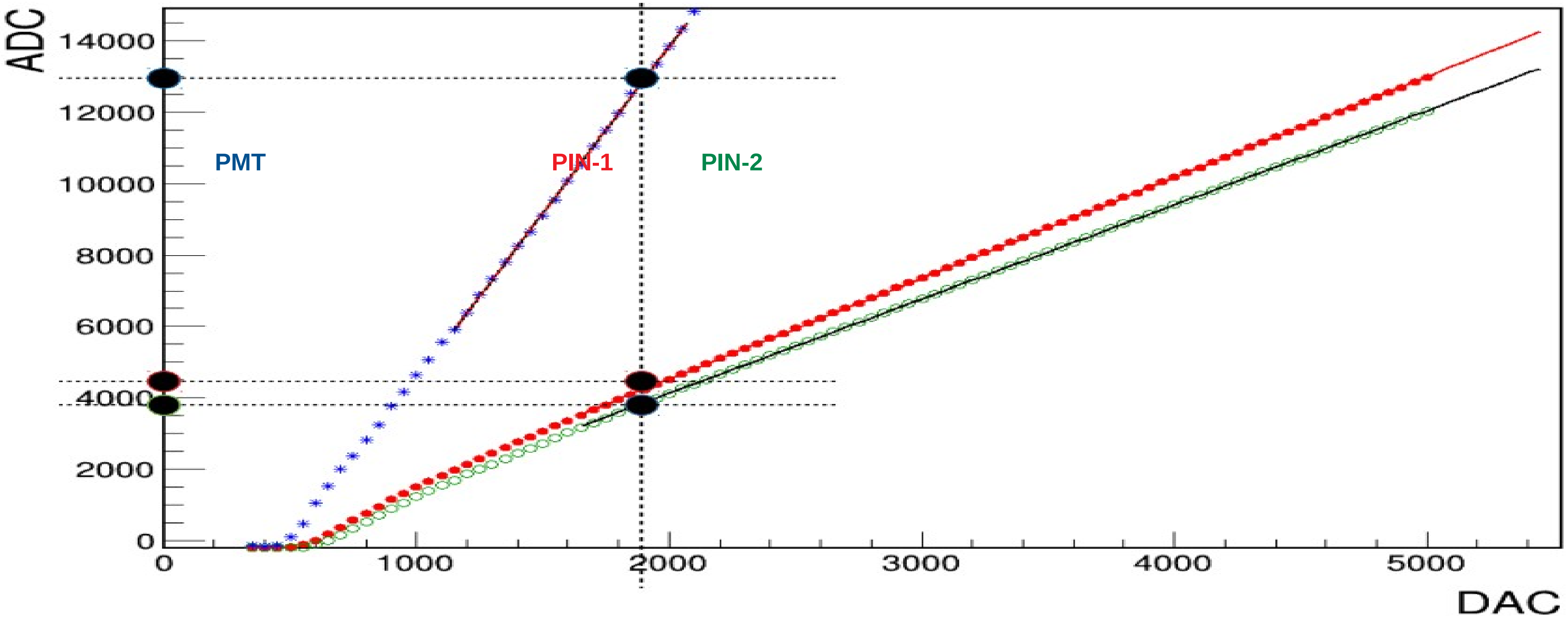


Temperature Correction



CALIBRATION RAMPING

Current Status and Plans

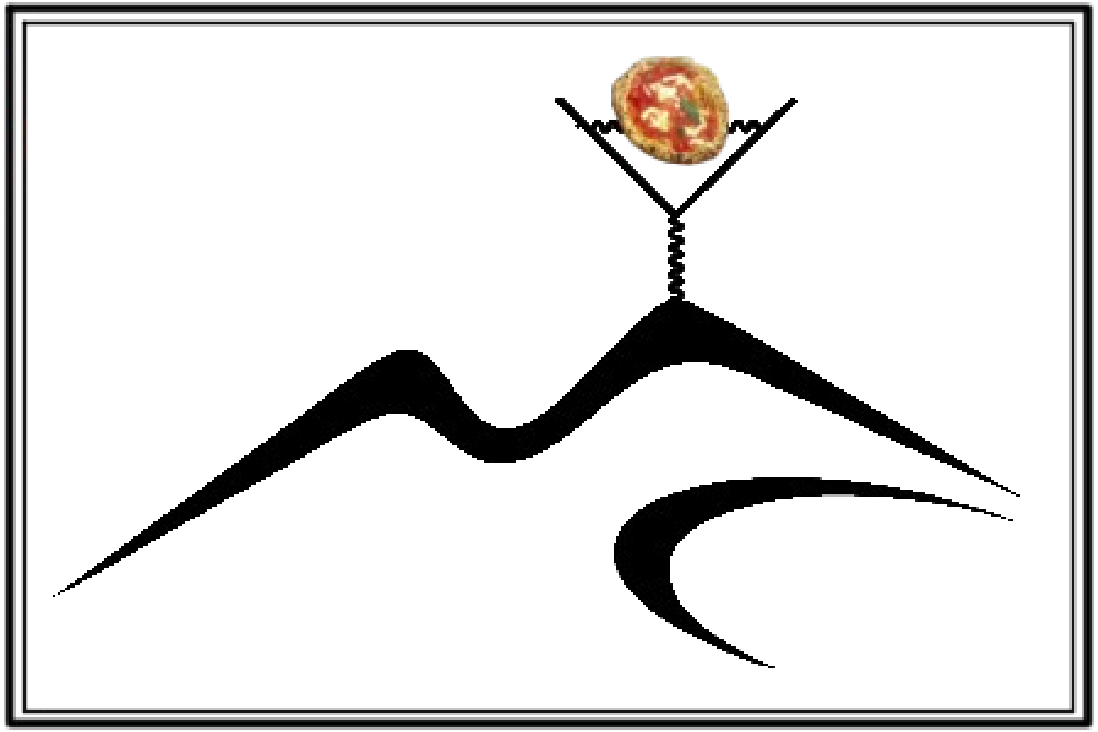
- Laser DAQs (MIDAS & Naples) are running **24x7** flawlessly since the beginning (2017).
- Monitoring of **short**-term
  - **event** by event
  - last **minute**

  and

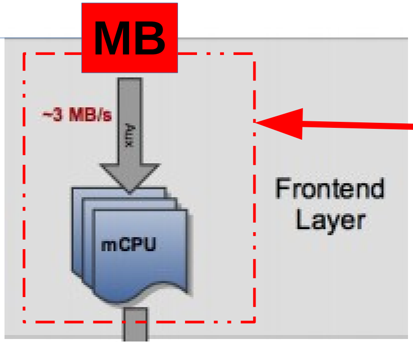
- **long**-term
  - last **24 hours** of laser trend
  - last **few weeks** of temperature trends

  are running smoothly.

GRAZIE



BACKUP SLIDES

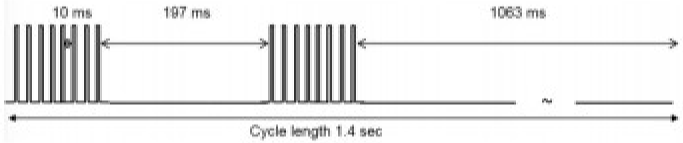


Laser front-end **(12 bit WFD in uTCA crate)**

Custom designed **M**onitoring **B**oard: a module that processes LM/SM signals. When a Signal exceeds the threshold, it saves a data frame containing ***baseline***, ***peak***, *and* ***time*** Temporarily in a local FIFO buffer. An MB frame has a header of **twenty-five** 16 bit words, containing event number, voltages, temperatures, and other control words. Then the body contains laser pulse related words, **5 words per pulse**.
Several such **MBs** send data frames to an event builder (custom designed controller), which then assembles the frames syncing them according to their event numbers and time stamps and builds the event frame. This event frame also contains a header and a footer that contains data control words based on the data quality check that it does while assem--bling the MB frame data.

Rate requirements

- Accommodate 12 Hz average rate of muon fills that consist of sequences of eight successive 700 μs fills with 10 ms fill-separations.



- Time-averaged rate of raw ADC samples is 20 GB/s, which must be reduced by a factor of 100.
- Data is processed in GPUs to accomplish this task.
- Total data on tape after 2 years of running will be 7 PB.

Source	MB Per Fill	MB Per Second
Raw data	1,600	19,400
T-Method	9.4	112.5
Q-Method	4.0	48.5
Prescaled Raw	1.6	19.4
Tracker	0.75	9
Laser Monitor	0.08	1
Auxiliary	0.33	4
Event Builder:	**16.2**	**194.4**

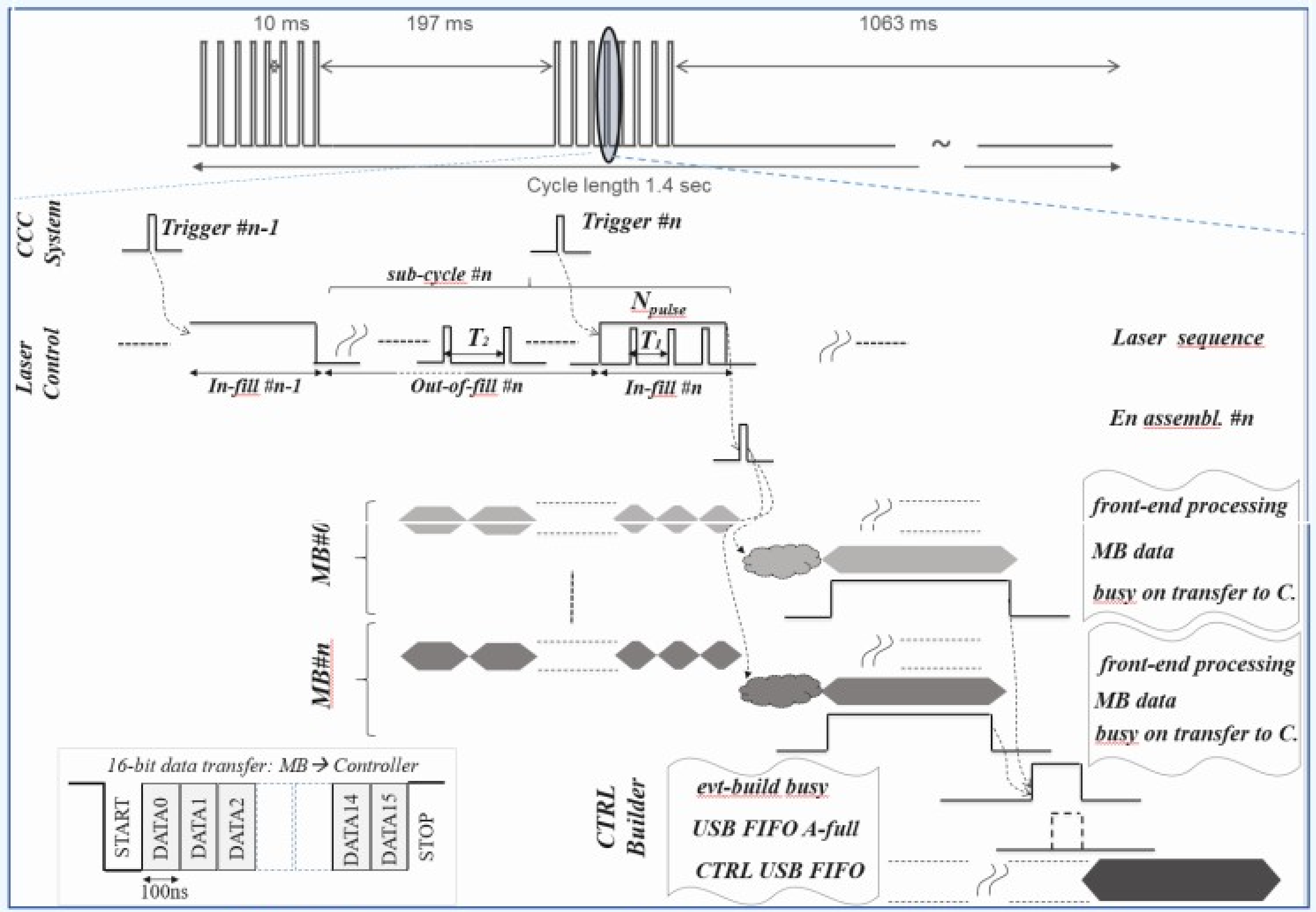
Fermilab

34 7/26/17 W. Gohn I MIDAS DAQ for Muon g-2

In order to dimension the DAQ architecture it is essential to determine the laser firing program with respect to the main cycle of the accelerator machine. Muons are injected into the storage ring in trains of bunches separated by 200 or 1000 ms. Each bunch consists of 8 repetitions of muon fill and decay windows (fill, 700 μs long) separated by 10 ms (out-of-fill). The data of the calibration system are organized for each sub-cycle, namely fill and out-of-fill.

The laser is operated in two distinct modes concerning physics or test runs and the program is defined by the Laser Control [5]. During physics runs the generation of pulse trains occurs during both the fill (superimposed to the physics data coming from the muon decays) and the out-of-fill time windows. The second mode is devoted to the test runs without beam in order to exercise DAQ and detector according to the exponential decreasing time function generation ($\langle N_{pulse} \rangle$ is 96) to simulate the real data. The expected value for $\langle N_{pulse} \rangle$ for both the modes should not exceed 100 per sub-cycle.

The final version of the Source Monitor crate was installed at FNAL and it is now fully functional. Several test have been done on the system to evaluate the calibration features. Here we report on the measurements to study the data flow and DAQ performance. The system under test consists of a Controller, a Laser Control and 6 MBs. A pulse generator simulates the beam cycle set at a rate of 100 Hz, corresponding to a sub-cycle every 10 ms, higher than what expected in the experiment.



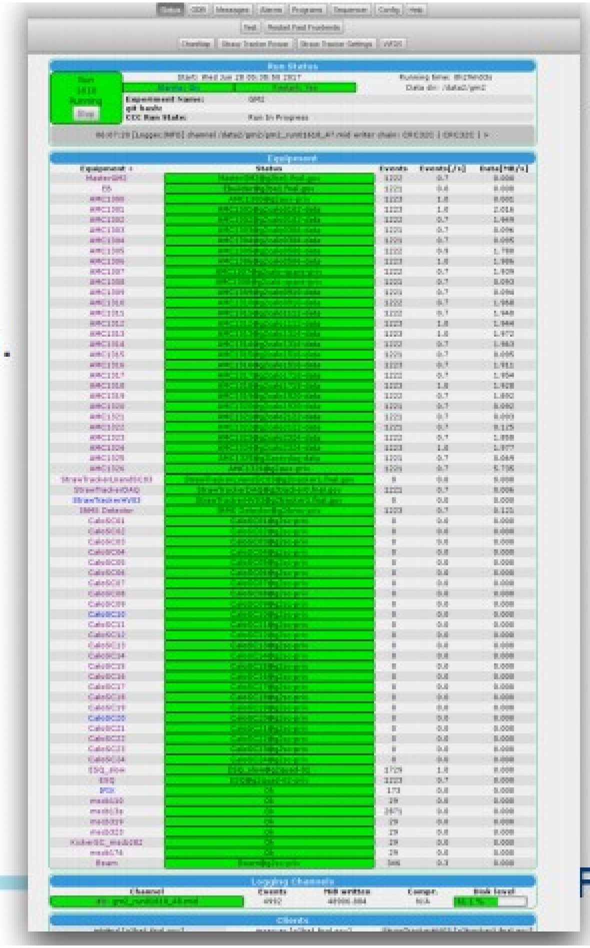
Timing scheme of the data readout cycle

Input sources

- Digitization is performed in custom uTCA based waveform digitizers.
- Each digitizer runs at 800 MSPS, so each time bin is 1.25 ns, and a 700 us fill is 560,000 clock ticks.
- Each uTCA crate contains 12 WFD5s or 60 channels of digitization.
  - Crate 0 reads data from the clock and control center (CCC)
  - Crates 1-24 each read data from one calorimeter (+ spare channels)
  - Crate 25 reads data from the laser system
  - Crate 26 reads data from the Auxiliary detectors (Harps, Quads, and Kickers)
  - Crate 27 reads data from the three tracker detectors.
- Data from each crate is sent to a DAQ computer via a dedicated 10 Gb fiber. The total data rate is 20 GB/s.
- The data is then processed in Nvidia K40 GPUs.

MIDAS configuration

- 32 fast frontends (data at beam fill rate).
- 35 slow control frontends.
- Midas alarm system.
- Midas sequencer used for calibration runs.
- ODB dumped to JSON file and saved to Postgres database at each end of run.
- Online analyzer using *art* and javascript.
- Separate MIDAS experiment running for magnetic field DAQ.



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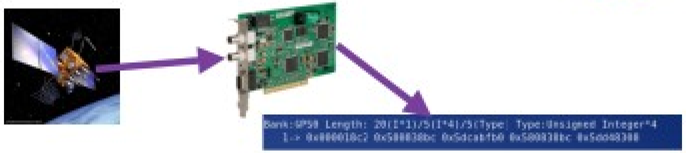
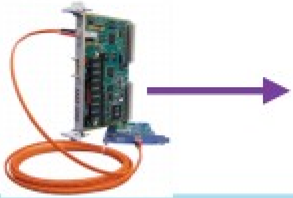
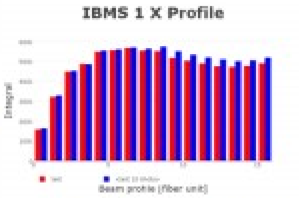
6 7/26/17 W. Gohn I MIDAS DAQ for Muon g-2

MIDAS Frontends

- Master:
  - Communicates with other frontends with RPCs, sets up CCC, and writes GPS timestamps from Meinberg GPS unit.
- AMC13 frontend:
  - Main frontend for processing data from calorimeters, laser, fiber harps, quads, and kickers.
  - Processes the data with Nvidia Tesla K40 GPUs
- Tracker frontend:
  - Data comes from multihit TDCs that are read via FC7 cards.
- IBMS frontend:
  - Data from the inflector beam monitoring system (IBMS) is read out via a CAEN digitizer.







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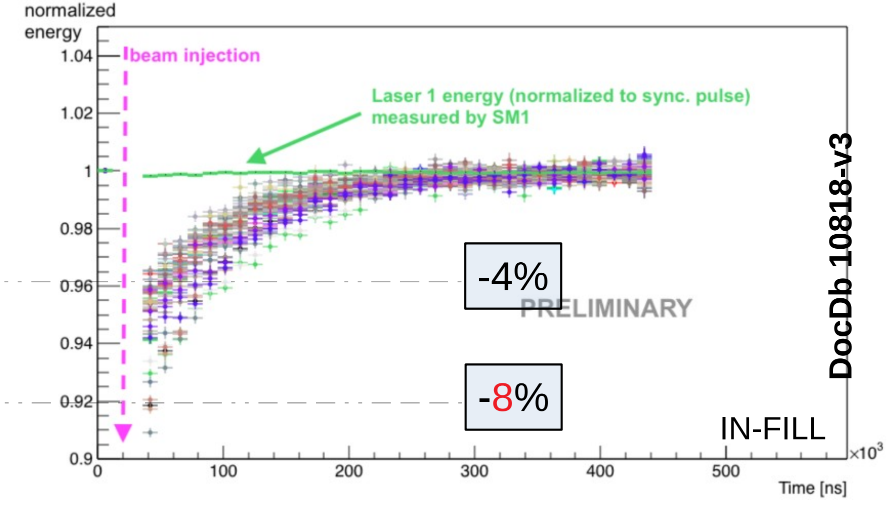
Numbers:

- SM input 150 pJ/pulse
- LM input 0.01 pJ/pulse
- Americium ~ 10 Hz

- Laser source: pico quant, 750 pJ @ 450 nm, average power 28 mW
-

Why Laser Calibration?

Why laser calibration?



Time [ns]

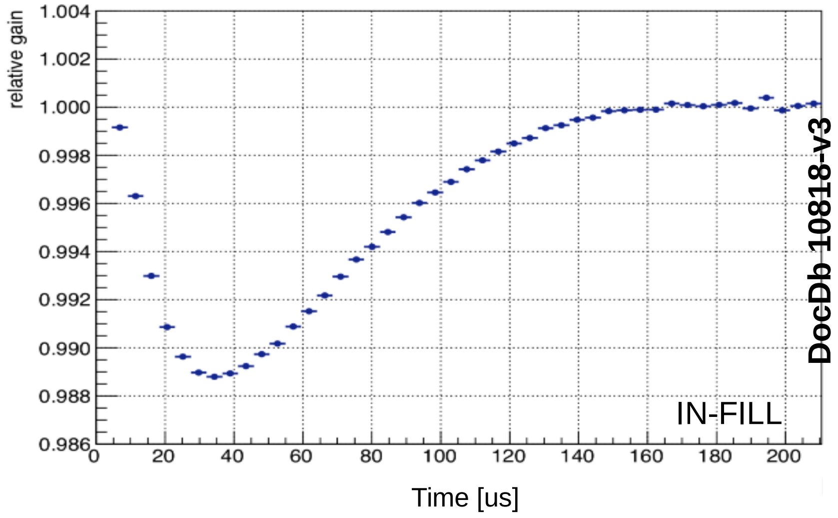
VERY SHORT

Two **nano-secs** apart particles hitting the calorimeter ~ typical SiPM charging up time.

Why laser calibration?

QUITE LONG

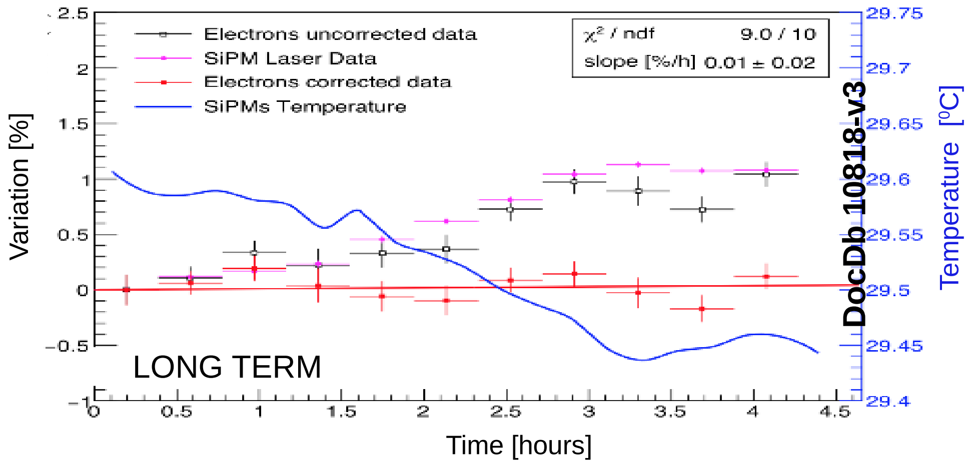
High load in the first few micro-secs after the injection results in a SiPM gain recovery time ~ few **tens** of **micro**-secs



Why laser calibration?

VERY LONG

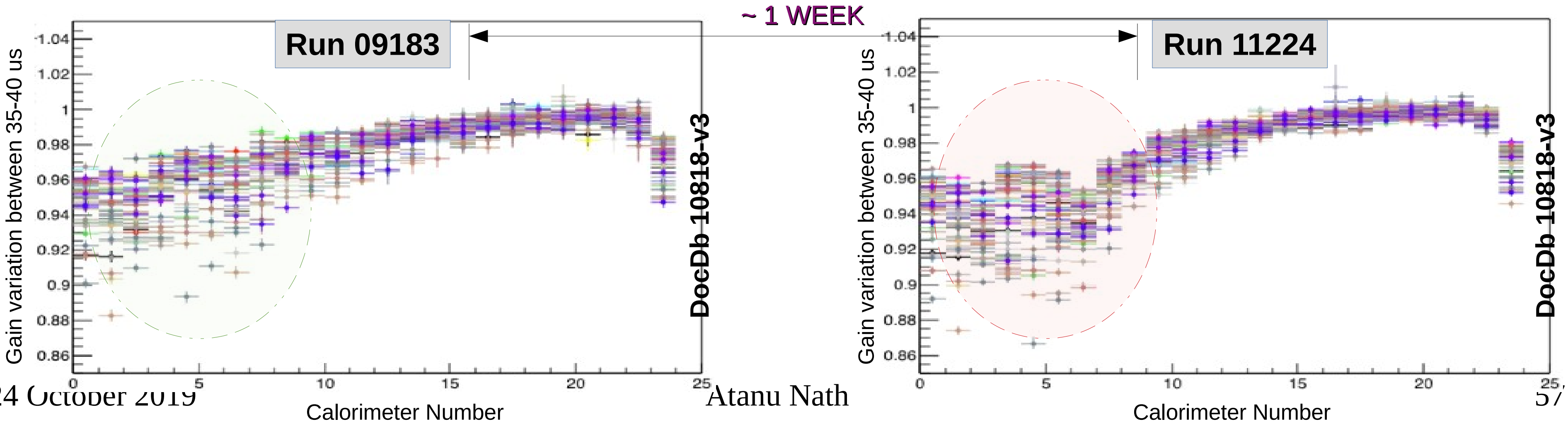
Much slower gain changes over longer time (**hours/days**) Can occur due to temperature change, aging etc.



Why laser calibration?

ANOTHER LONG ONE..
SAME CALO CAN SAG DIFFERENTLY @ DIFFERENT TIMES

In-fill gain function can be different in different runs separated by **weeks** due to different beam conditions.



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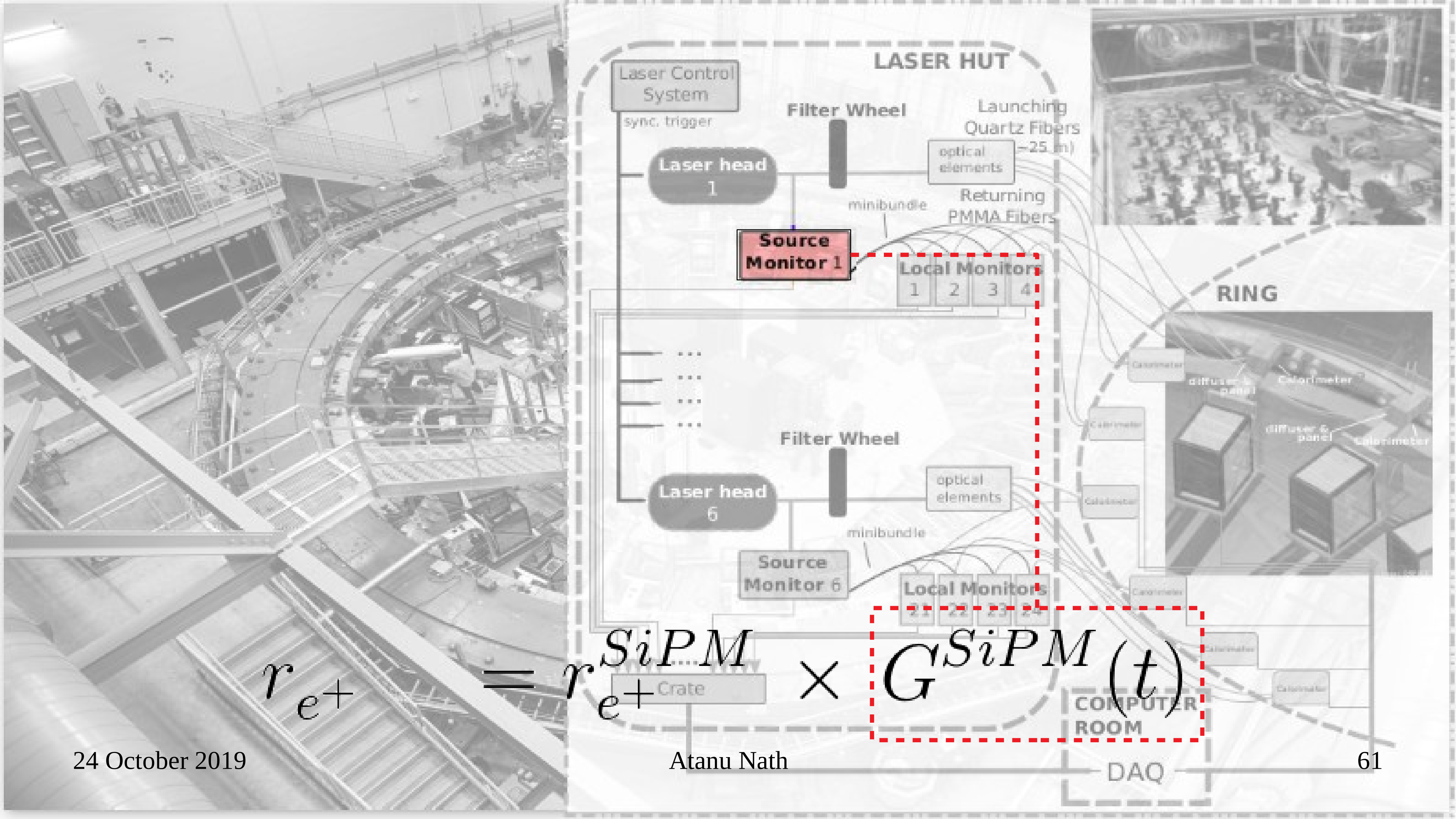
  But those pulses have to be **known**, stuff like temperature and aging can also affect the laser sources, that's why we need a ***monitor***ing system for the laser ***source***s right after the light leaves the source :

  - *the **Source Monitors***



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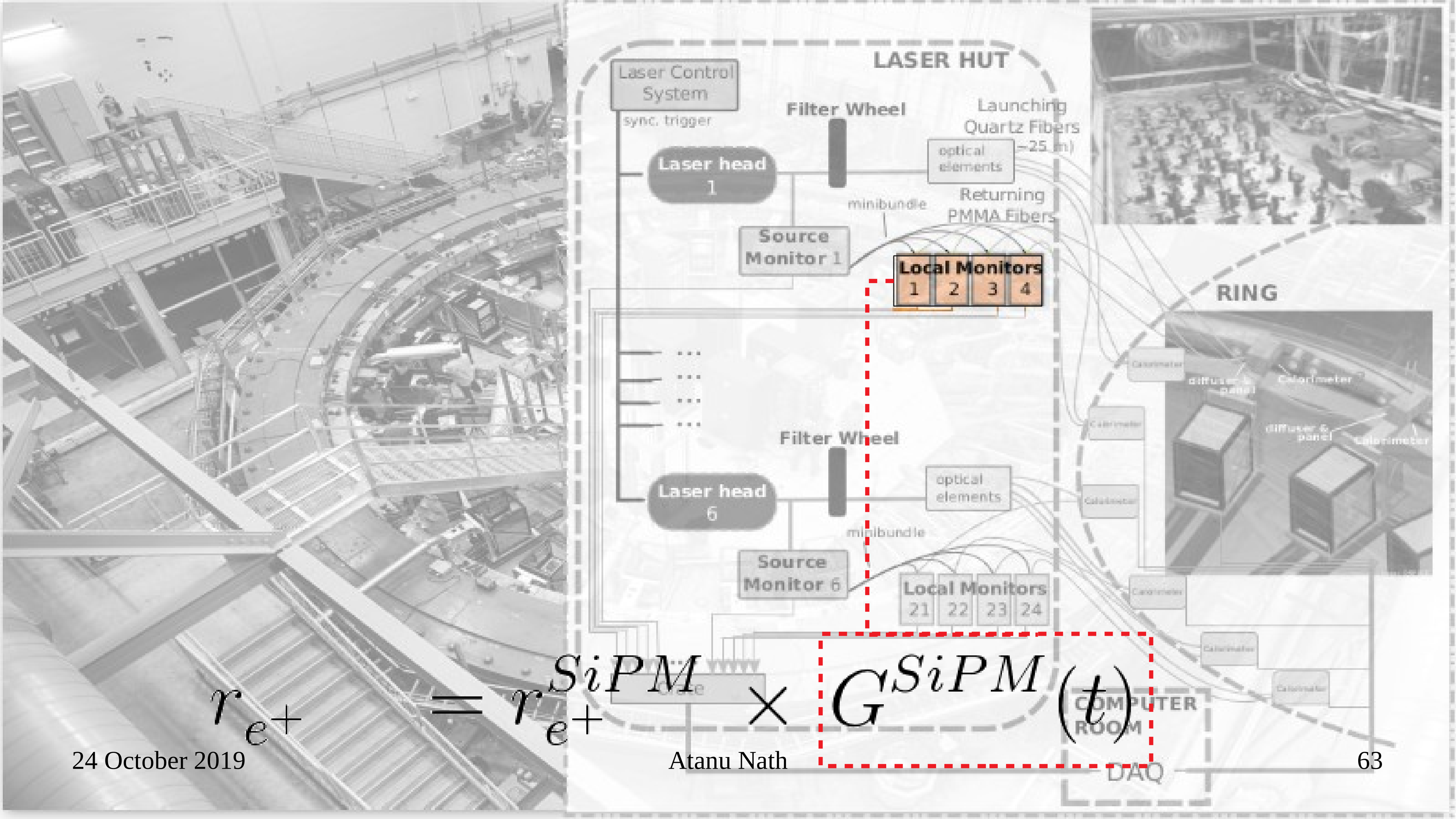

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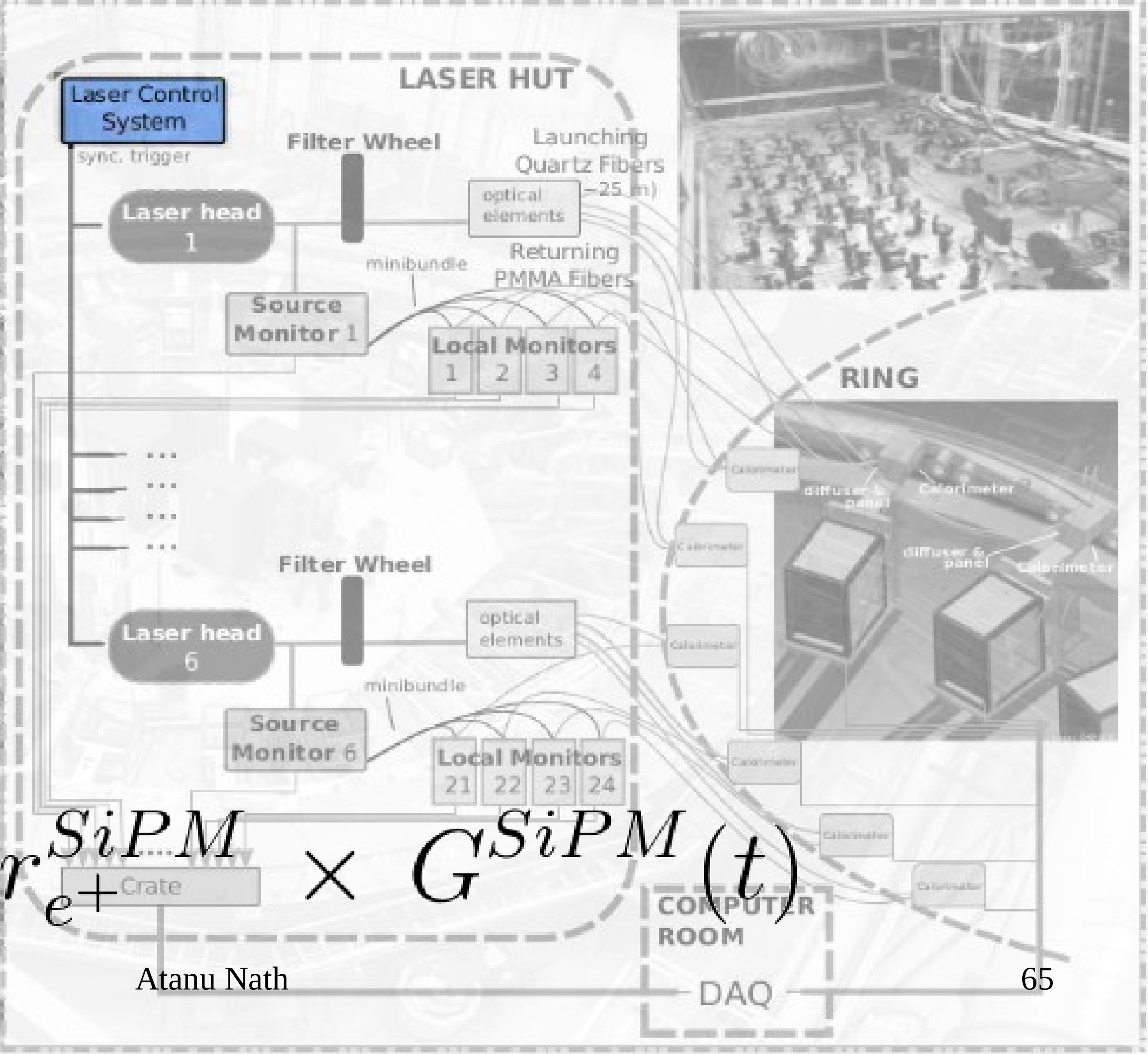
  – But wouldn't these ***laser*** pulses mess with the ***positron*** signal? They would! That's why we need to ***control*** the ***laser*** pulses in a specific manner so that a few pulses during the ***muon fills*** and a few outside of that suffice to get us the gain function :

  - *the **Laser Control***



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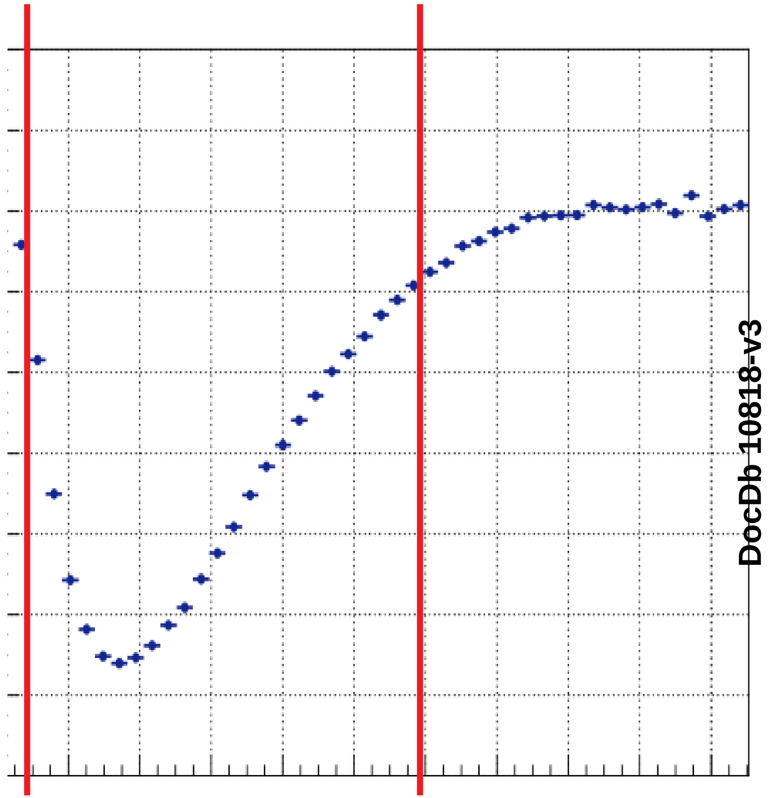
Laser Control System

- **In-Fill** : **2** pulses **200 us** apart are sent in a fill to minimize the damage
  - Then these pulses are shifted by **5 us**, it takes **40** such steps (**40** fills and not necessarily consecutive fills) to scan the whole range of **400 us** fill window.
  - In standard DAQ in-fill pulses are sent every ***10 fills***.



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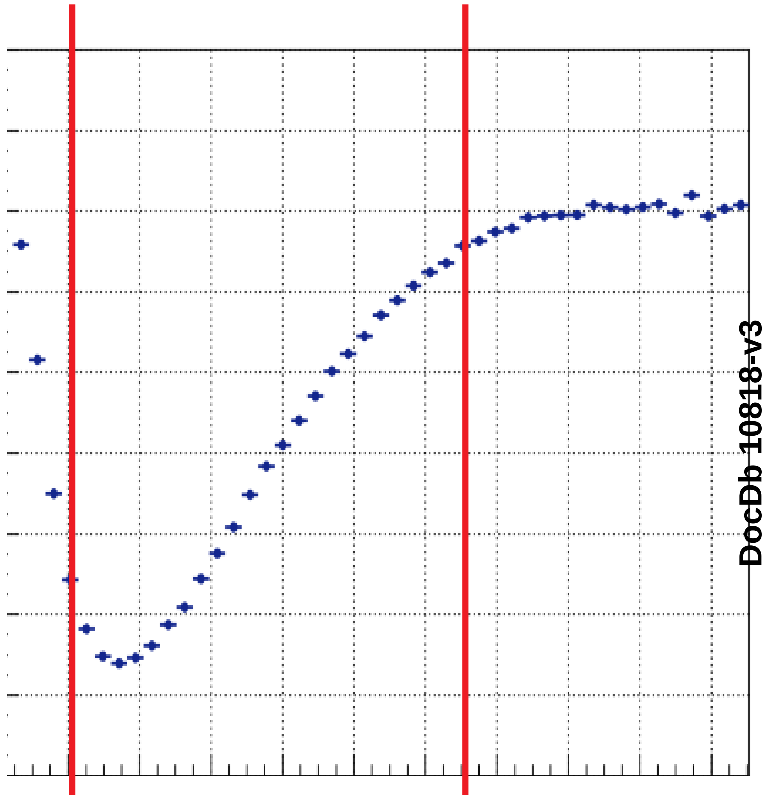

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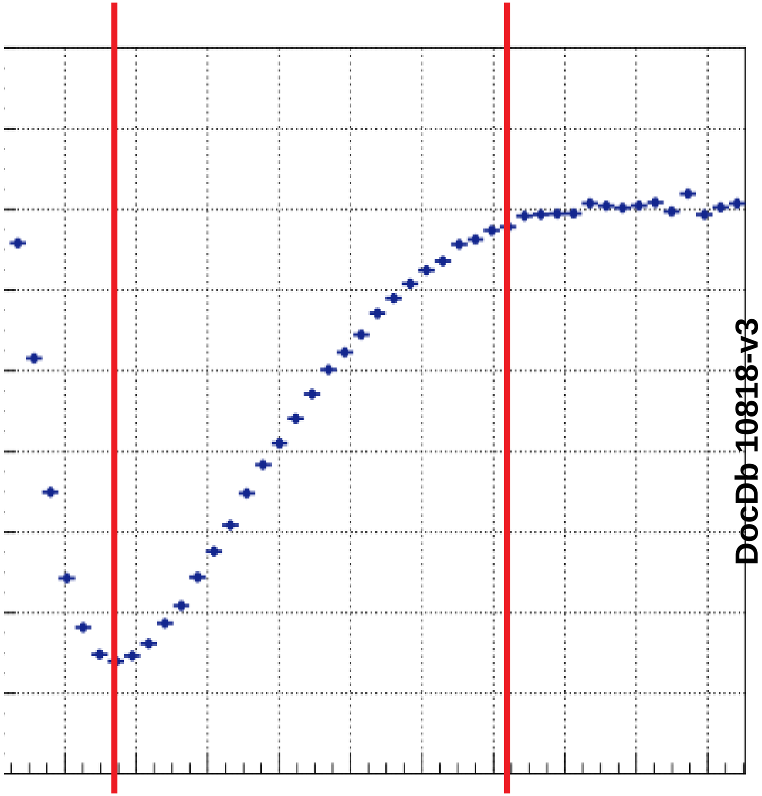

DocDb 10818-v3

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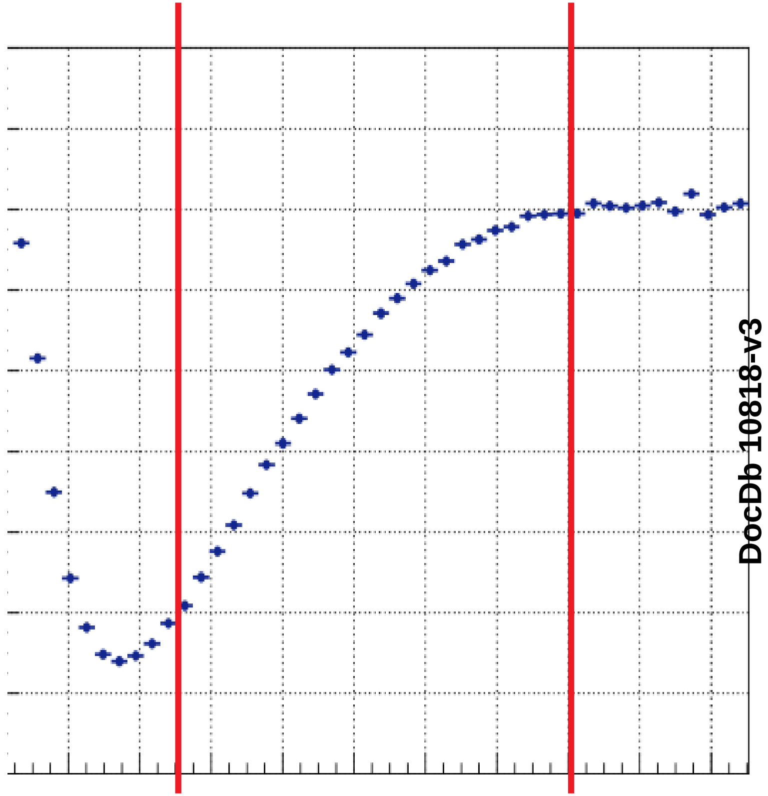

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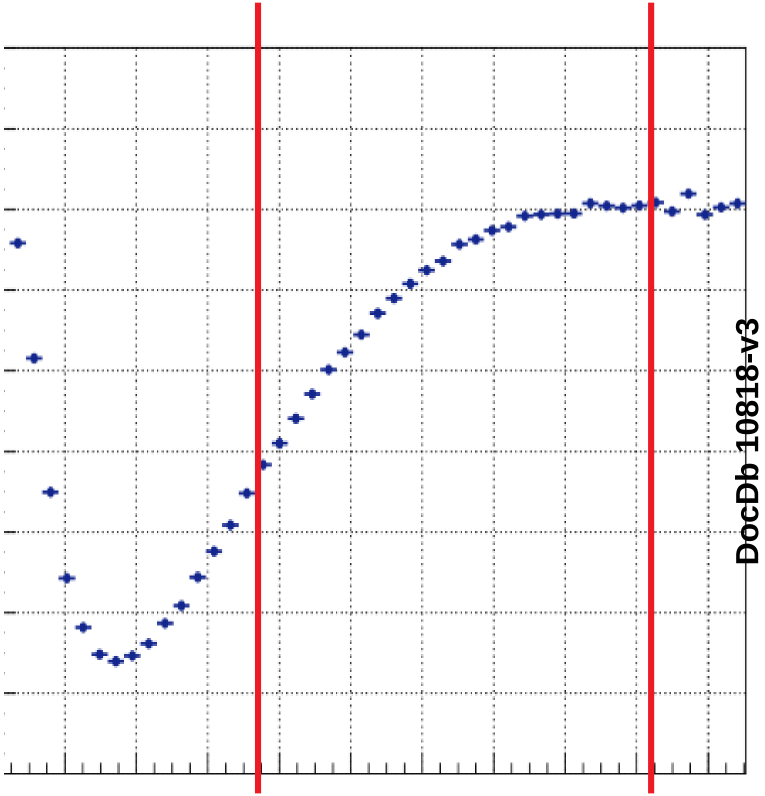
Parameter	Current value	Default value
T_{SYNC} (μs)	7	7
T_0 (first laser pulse) (μs)	30	30
prescale	1	10
N_{InFill}	2	2
Δt (μs)	200	200
T_{shift} (μs)	5	2.5

ODB: Laser pulse settings.



Temperature Correlations...