WP3: Muon g-2 Laser Calibration System

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MUSE Network General Meeting

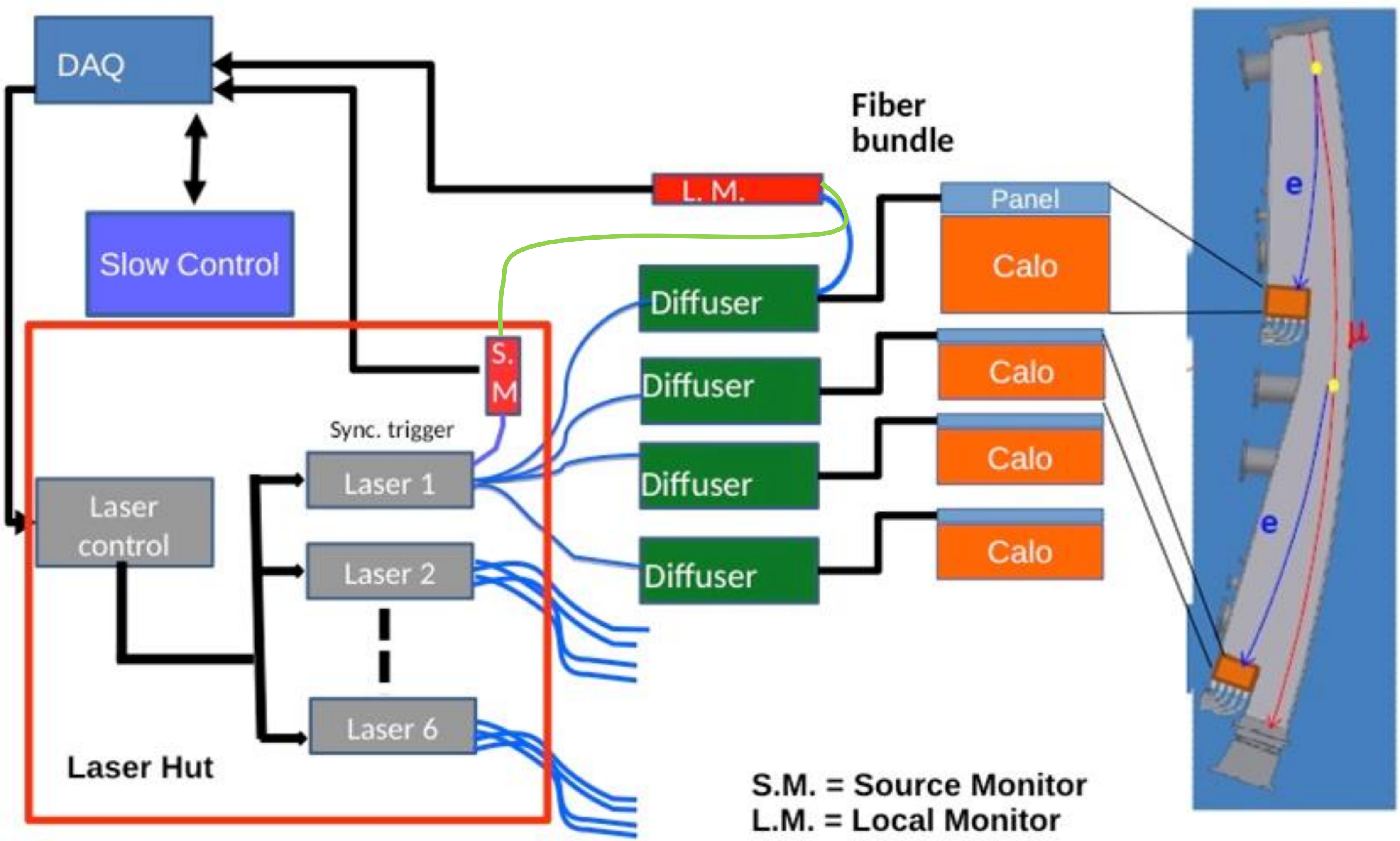
Oct 22[sd] 2018

Introduction

- The Muon g-2 experiment at Fermilab aims to improve the precision on the measurement of the anomaly $a_\mu = (g - 2)/2$ of the muon magnetic moment by a factor four relative to the previous Brookhaven experiment E821, to an uncertainty of $16*10^{-11}$ (± 14 ppm).
- Strategy:
  - increasing the total number of muon decays recorded,
  - control of the systematics at the level 3 times better than previously achieved (the systematic uncertainty has to match a target statistical error of 0.1 ppm).
- State-of-the-art laser calibration system ensures performance stability of the 1296 large-area silicon photo-multipliers, SiPM, which turn the light into an electric signal in the 24 calorimeters.
- These sensors are subject to large changes in the rate of particle hits as well as flash of additional quickly decaying background, leading to the most relevant systematic errors of the experiment (calorimeter gain variation).
- In order to reach the desired sensitivity the experiment must able to measure the average gain variation during the muon fill with an accuracy at the 10^{-4} level.
- Additional slower variations due to environmental effects on SiPMs, such as temperature, must also be monitored and corrected.
- Synchronization of traces from calorimeters and other detectors is a further task.

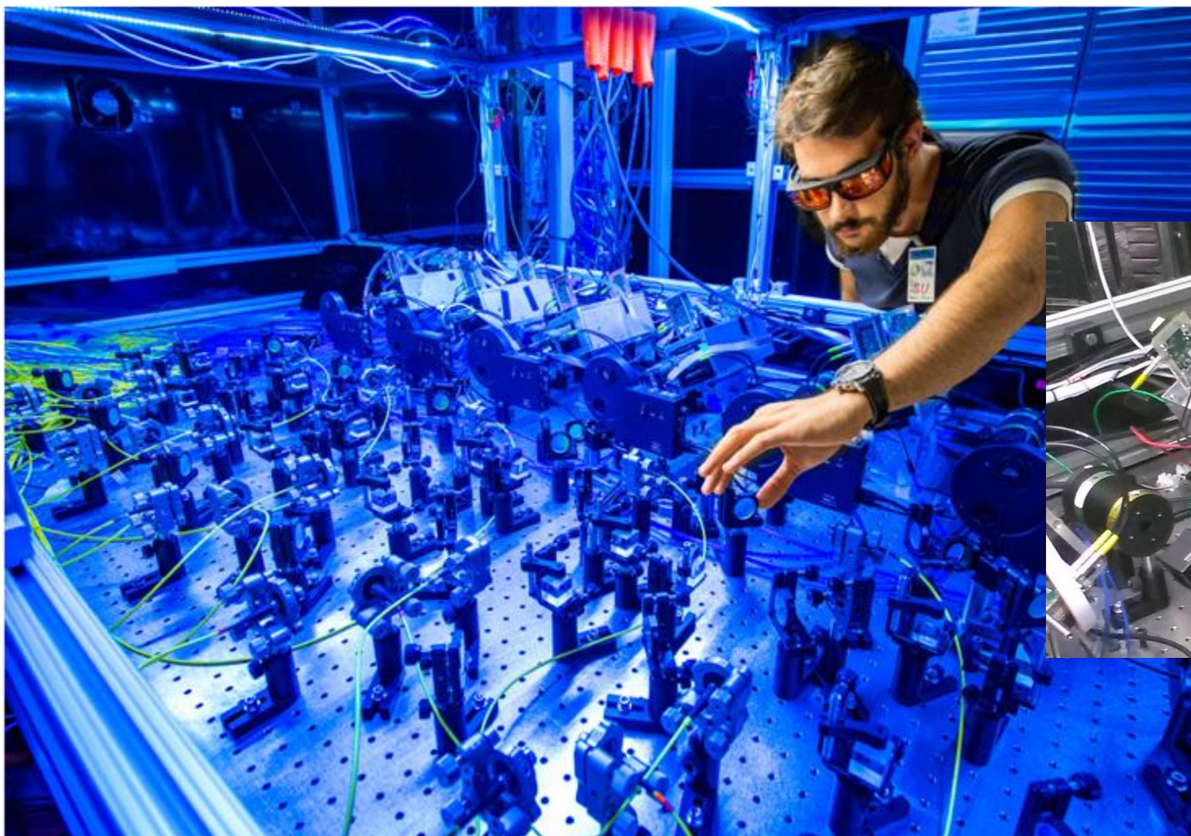
The laser system

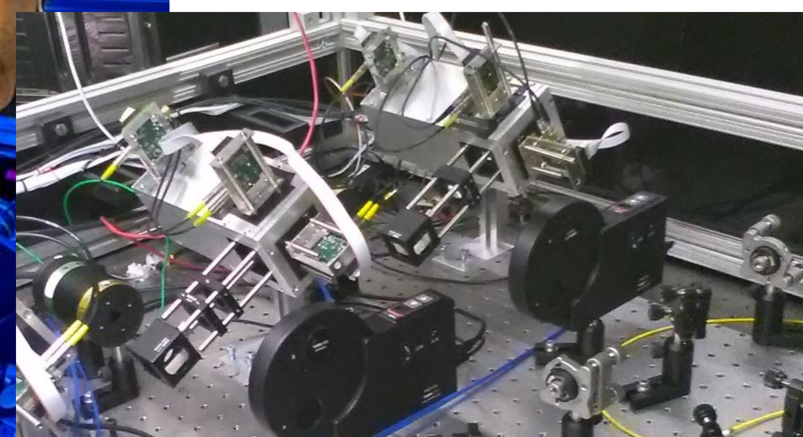
- The laser pulses are sent simultaneously to 1296 crytals/SiPMs located in 24 calorimeters along the muon storage ring. The laser apparatus is hosted in the Laser Hut.
- Additional laser pulses for timing/calibration purposes are sent to two other g-2 detectors: the T0 and the Fiber Harps.



The laser hut

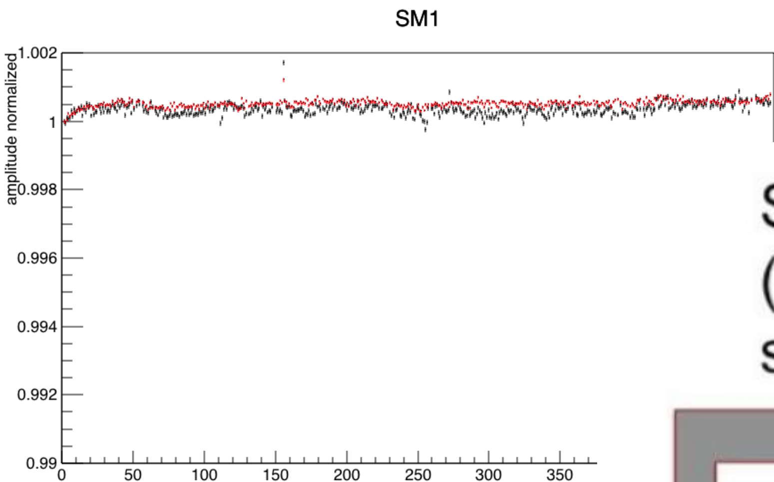
- 6 Picoquant laser heads (1 nJ/pulse @ 405 nm, 80 MHz max repetition rate)
- 6 source monitor (2 PIN diode, 1 PMT, 1 Am source each) + electronics
- 6 12-positions filter wheels for calibration purpose
- Splitting into 24 launching fibers
- 48 monitor fibers + PMTs (2 back from each calorimeter) + electronics

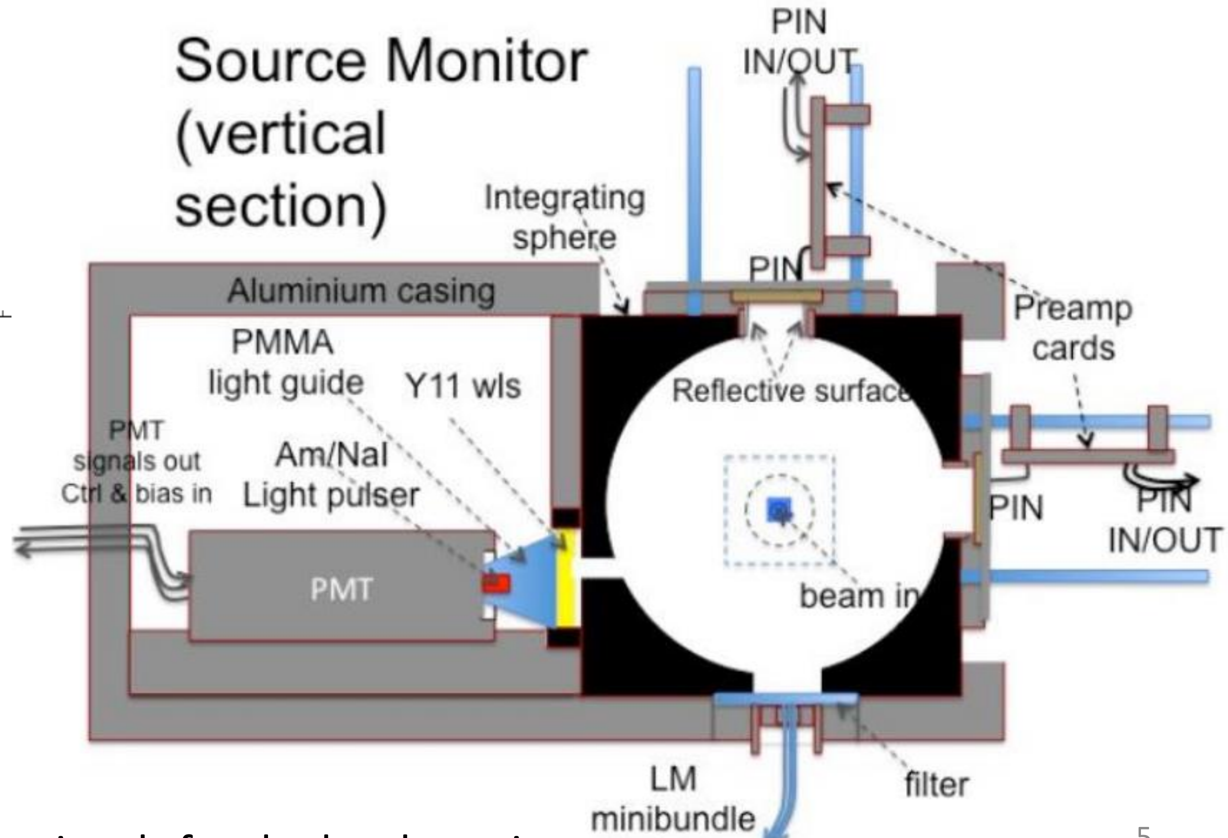




The source monitor

- Based on an integrating sphere: 2 photodiodes, 1 PMT with reference pulser (Am source)
- It provides an early reference signals for the PMTs of the local monitor.

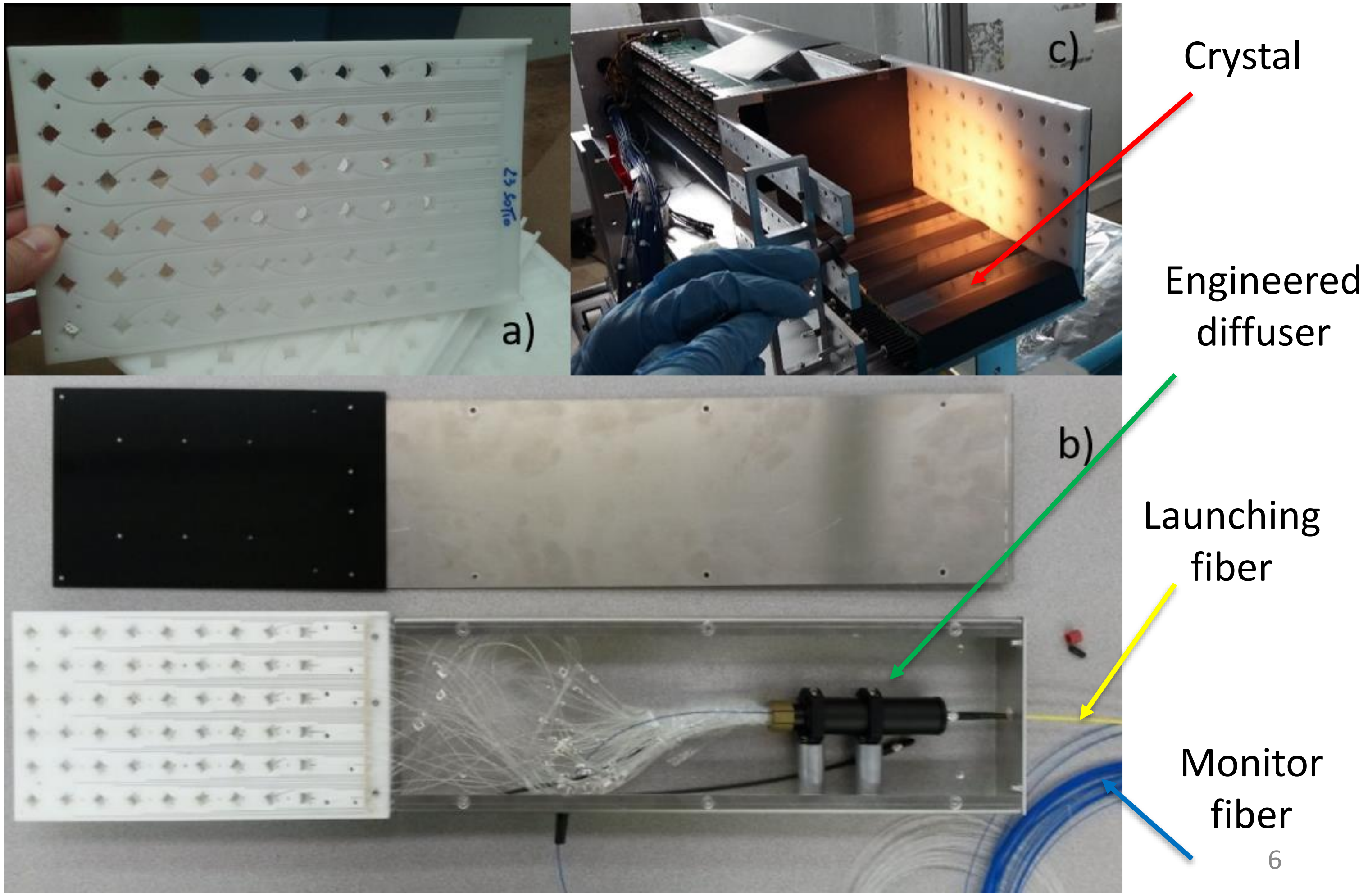




Reference signals for the local monitor

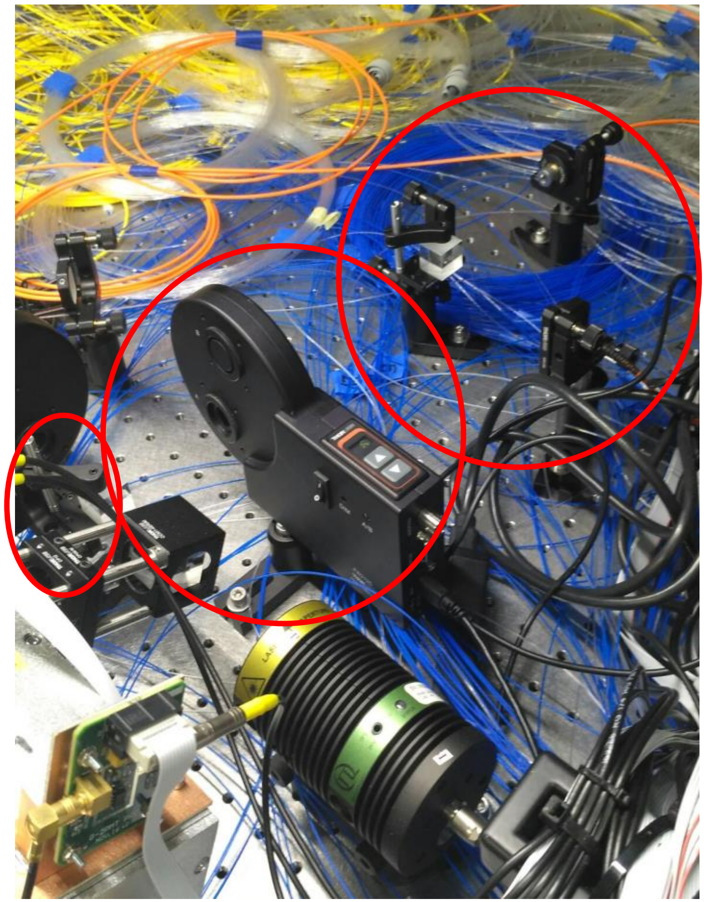
The light distribution panel for each calo

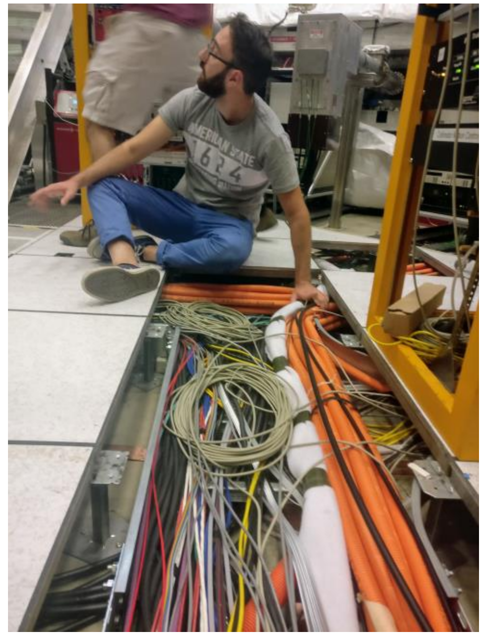
- An engineered diffuser performing the fan-out from the launching fiber to 54 fibers (b)
- A Delrin panel holding 54 reflecting prisms, one in front of each crystal (a, c)

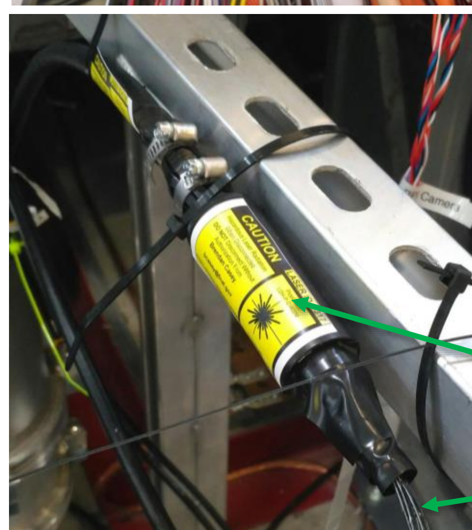


Aug 2018: Laser pulses to the Fiber Harps

- Installation of the optics and the two new optical fibers



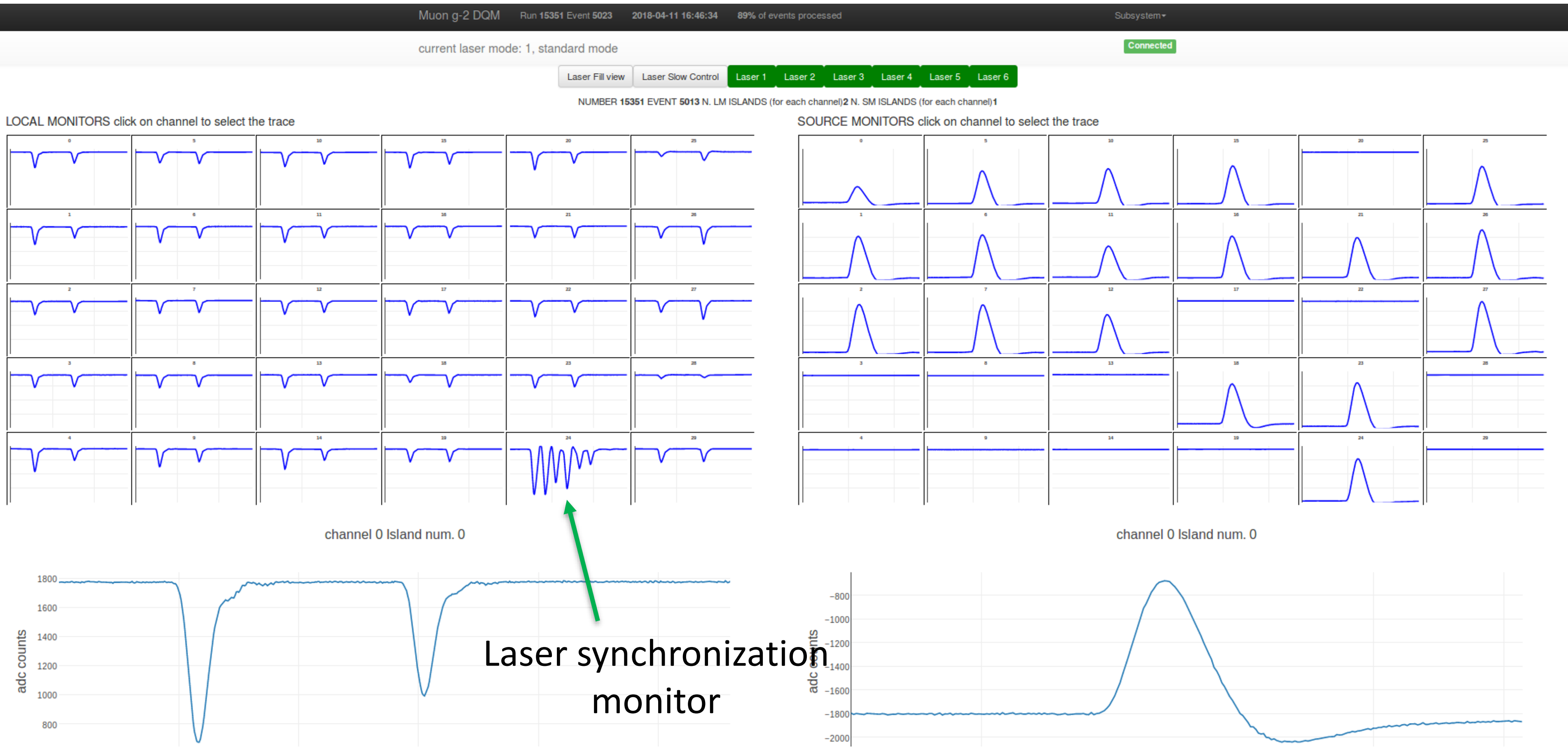




Engineered diffuser

32 fibers bundle

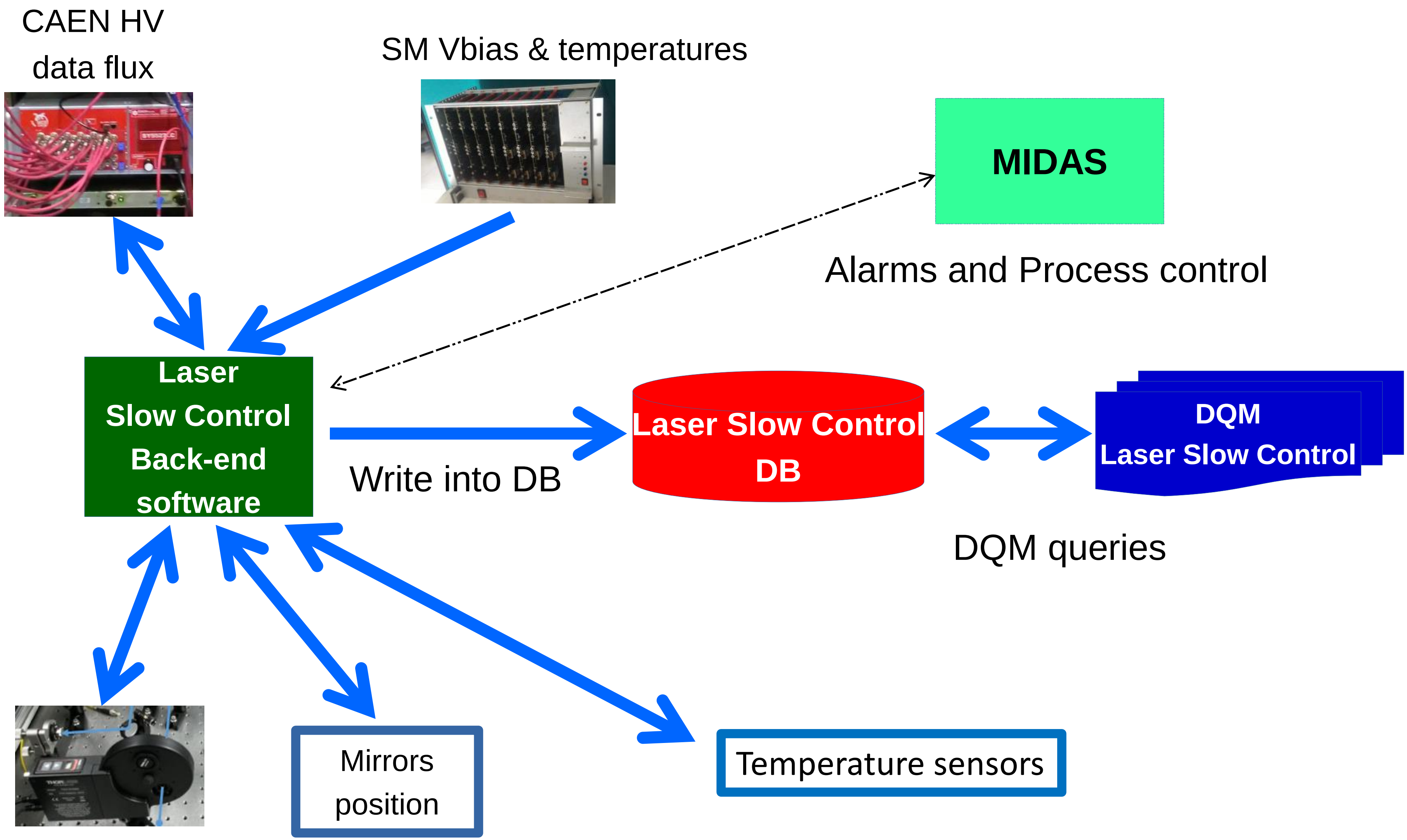
DAQ laser monitor page



Local monitor

Source monitor

Laser slow control and DB



DQM slow control laser page

Muon g-2 DQM Run 16919 Event 99968 2018-06-07 03:52:17 58% of events processed Subsystem

Connected

Laser Slow Control

Laser traces - Muon Fill view

Last update Thu Jun 07 2018 10:52:13 GMT+0200 (CEST)

Source Monitor Bias Voltage

Last time Thu Jun 07 2018 10:51:29 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	0.63	49.14	49.22	7.80	8.29
SM 2	0.54	0.53	49.14	49.23	49.14	49.26
SM 3	0.60	0.60	49.14	49.19	49.14	49.29
SM 4	0.69	0.69	49.14	49.28	49.14	49.03
SM 5	0.65	0.65	49.14	49.41	70.00	70.23
SM 6	0.60	0.59	49.14	49.53	49.14	49.32

Devices reachable on network

Last time Thu Jun 07 2018 10:51:47 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 Jun 07 2018 10:51:52 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

HV CH	HV SET	HV MONITOR	I MON	STATUS	POWER
0	635	635.36	148.62	1	ON
1	585	585.40	137.49	1	ON
2	585	585.42	135.79	1	ON
3	555	555.33	130.36	1	ON
4	635	635.41	149.32	1	ON
5	550	550.45	128.85	1	ON
6	545	545.31	127.36	1	ON
7	510	510.42	119.23	1	ON
8	585	585.34	136.78	1	ON
9	590	590.45	137.94	1	ON
10	525	525.44	123.52	1	ON
11	525	525.40	122.55	1	ON
12	535	535.45	125.02	1	ON
13	545	545.64	127.42	1	ON
14	550	550.52	128.62	1	ON
15	540	540.58	126.95	1	ON
16	500	500.44	116.83	1	ON
17	510	510.48	119.89	1	ON
18	510	510.34	119.18	1	ON
19	500	500.42	116.85	1	ON
20	580	580.53	135.66	1	ON
21	535	535.51	125.89	1	ON
22	550	550.43	128.49	1	ON
23	560	560.38	130.83	1	ON
24	650	650.46	152.01	1	ON
25	1100	1100.34	154.71	1	ON
26	1100	1100.38	154.51	1	ON
27	980	980.42	137.77	1	ON
28	1000	1000.44	140.46	1	ON
29	1000	1000.47	140.60	1	ON
30	0	2.76	0.10	0	OFF
31	0	2.58	0.05	0	OFF
32	0	1.18	0.05	0	OFF
33	0	2.29	0.02	0	OFF
34	0	1.64	-0.01	0	OFF
35	0	2.65	0.06	0	OFF
36	0	1.16	0.10	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

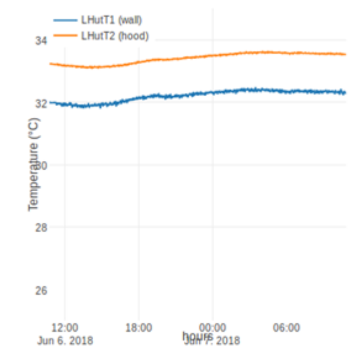
Last time Thu Jun 07 2018 10:51:47 GMT+0200 (CEST)

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

24h Temperature Monitor

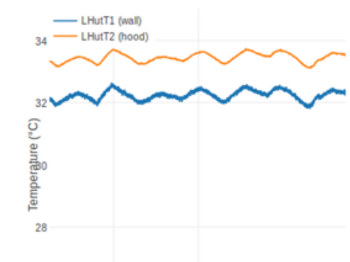
Last time Thu Jun 07 2018 10:51:30 GMT+0200 (CEST)

Last 24 hours

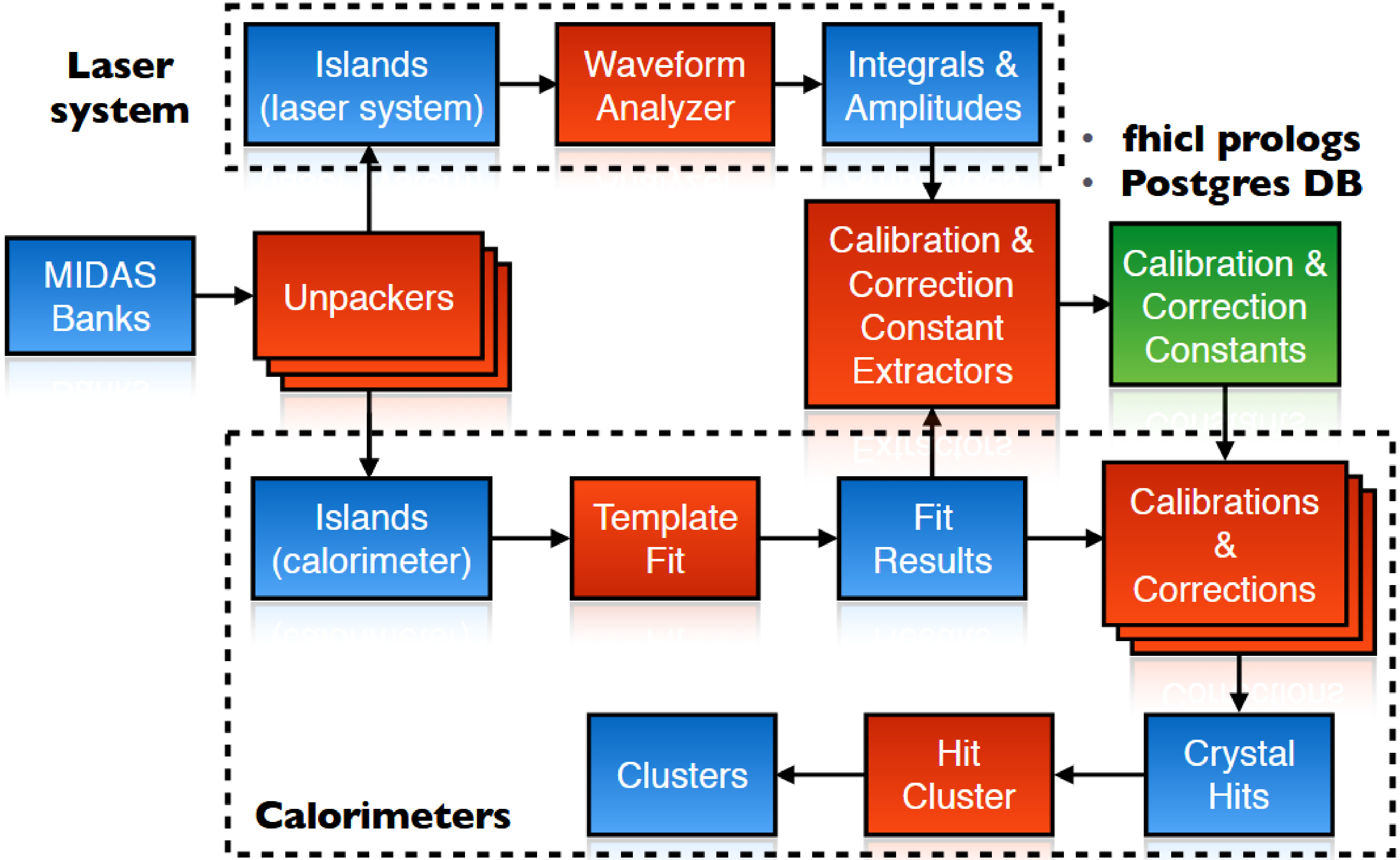


1 week Temperature Monitor

Last 168 hours

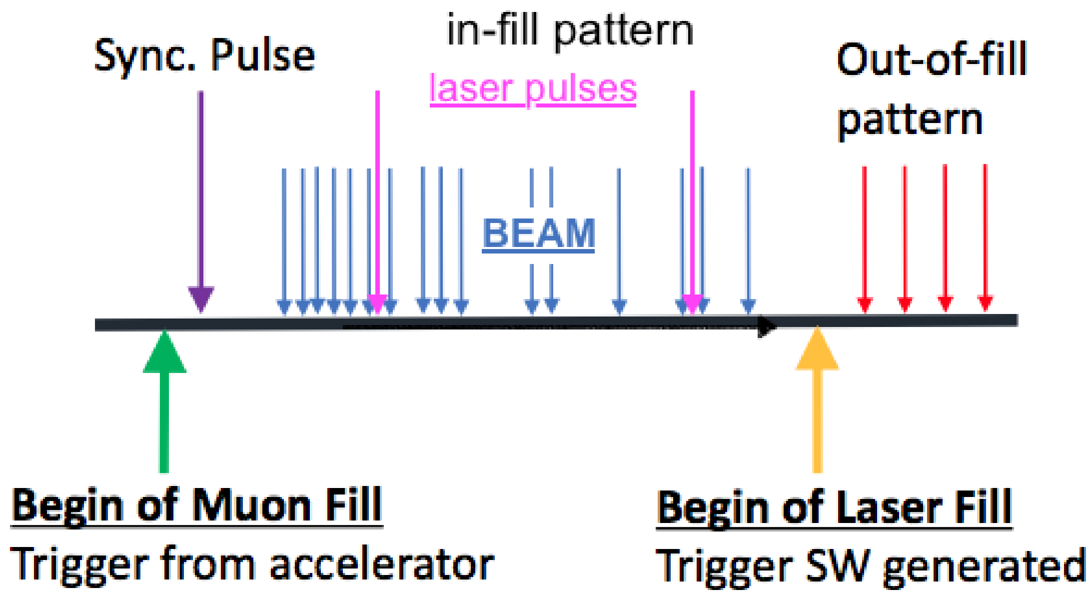


Data analysis scheme



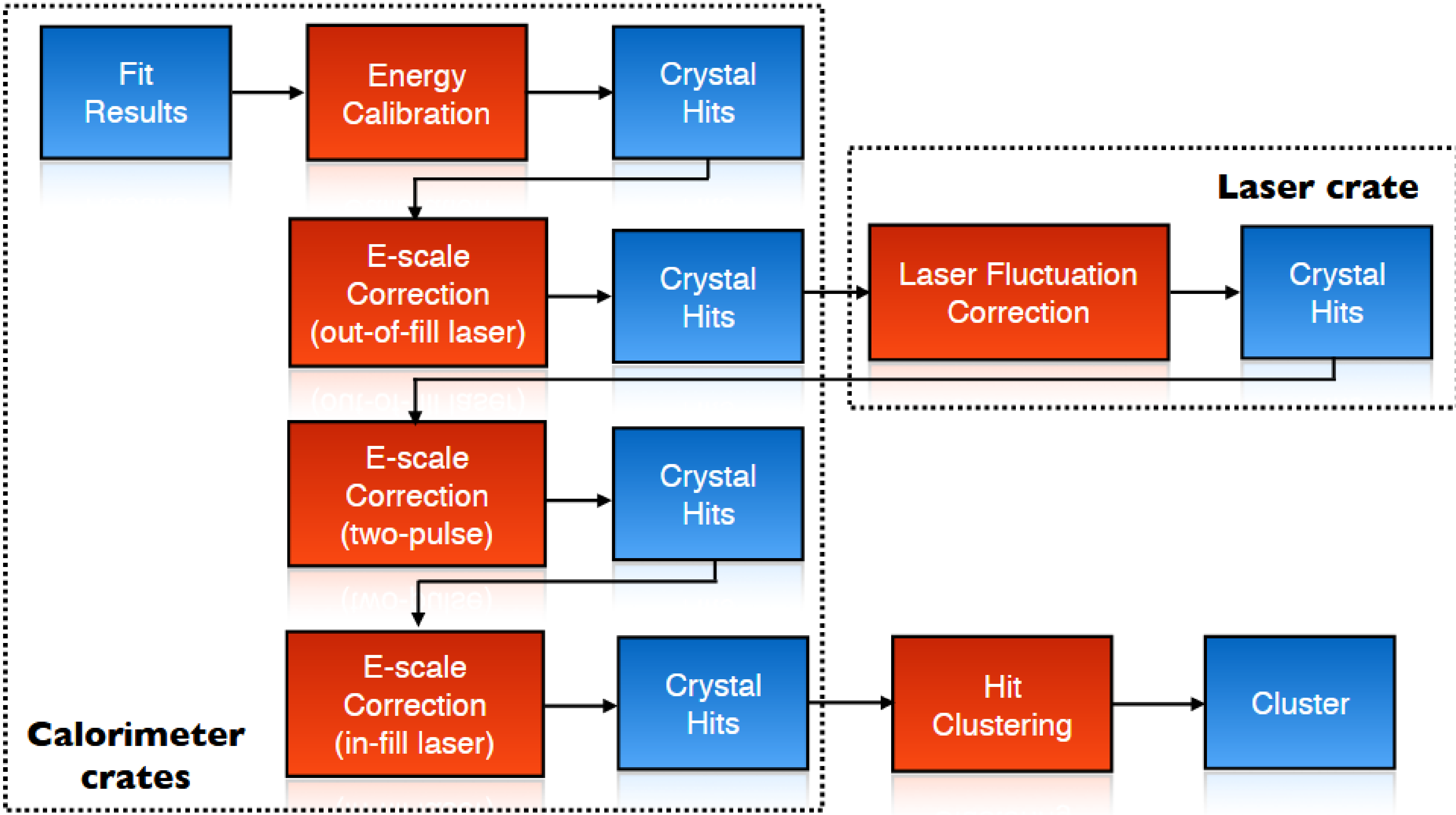
Laser Gain Correction Philosophies

- Out-of-fill
  - Why? To correct the long-term gain variation (mostly temperature dependence of the SiPMs)
  - How? By firing the laser between fills
- In-fill
  - Why? To correct systematic gain shifts while positrons are present
  - How? By firing the laser within fills
- Short and Long-time Double Pulse
  - Why? The SiPM gain drops after one pulse, so next could have lower energy
  - How? Separate DAQ mode to systematically vary E1, E2, dt

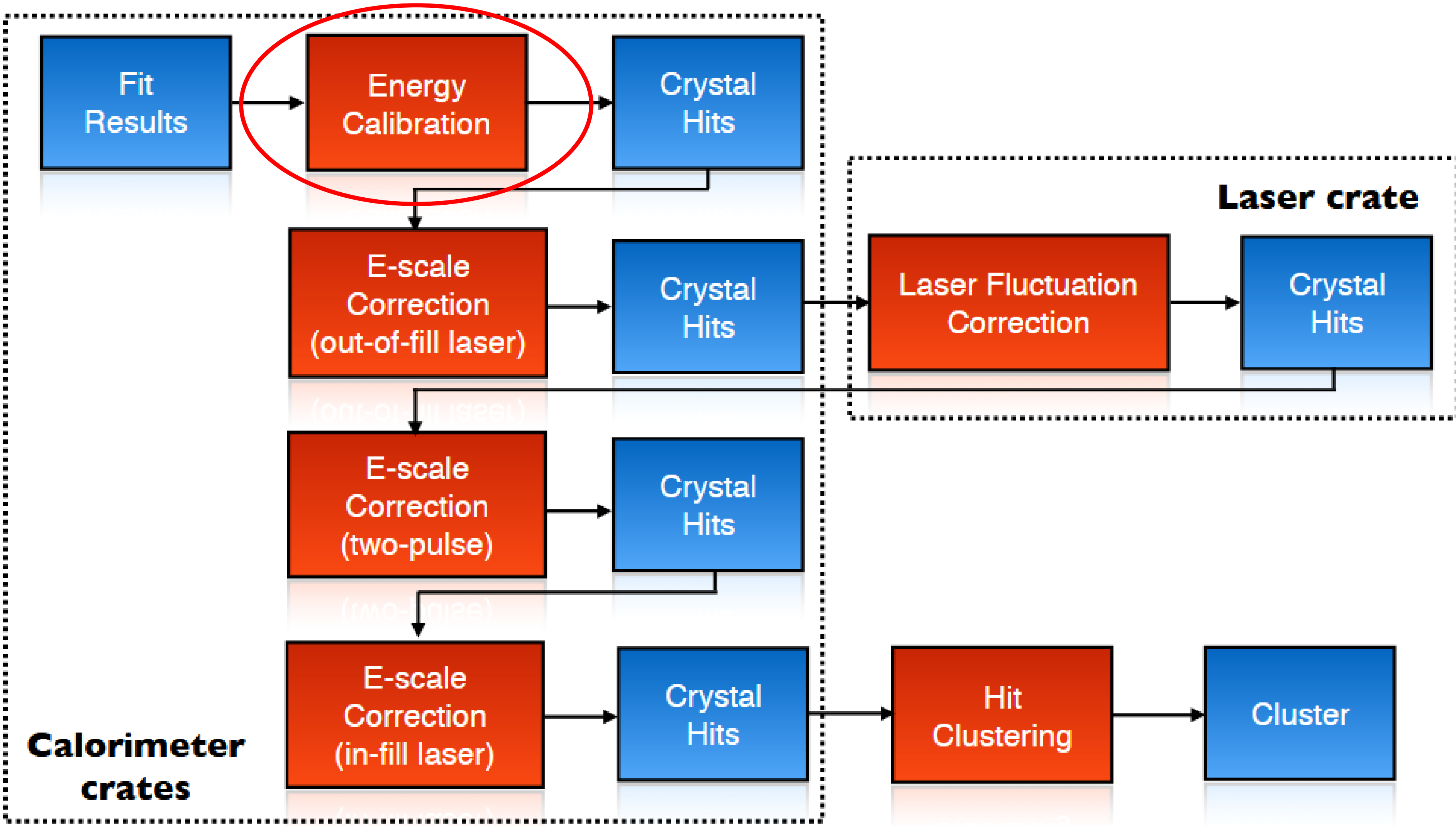


A. Driutti – INFN Udine

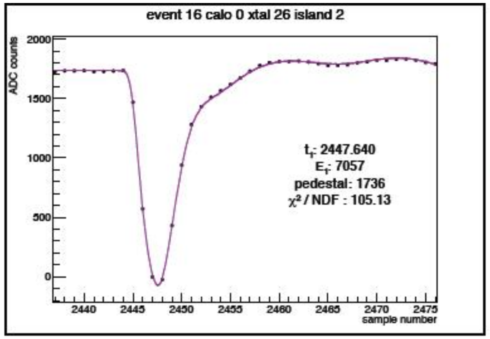
Calibration scheme

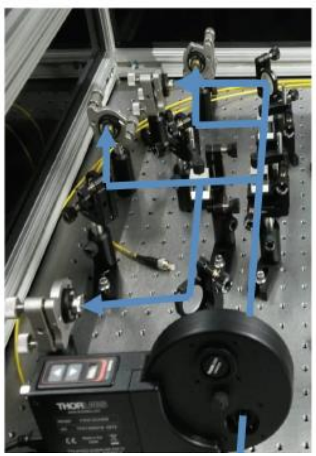


Calibration scheme



Energy calibration





(ADC/p.a. ~ 0.3)

E [pulse area (p.a.)]

gain [p.a./pe]
(~ 0.3)

Laser system
(filter wheel)

energy scale [p.a./MeV]

effective light yield [pe/MeV]

E [photoelectron (pe)] → E [MeV]

Test beam (0.76 pe/MeV)

We will try other approaches (End-point energy, muon MIP)

Gain calibration using filtwer wheels

The goal of the laser calibration is to convert the pulse integral of the SiPM into the effective number of photo-electrons (pe).

For a Poissonian distribution of photons from the light source, the number of pe is obtained from the ratio μ/σ^2, where μ is the mean of the distribution of pulses, and σ is the width of that distribution.

For a stable laser, the relationship is: $\sigma^2 = n^2 + g\mu$ ($\mu/g \approx N$pe)

where n is the amount of electrical noise in the system, and g is the parameter of interest (pulseintegral/pe). *N*pe stands for average number of photons registered by a SiPM.

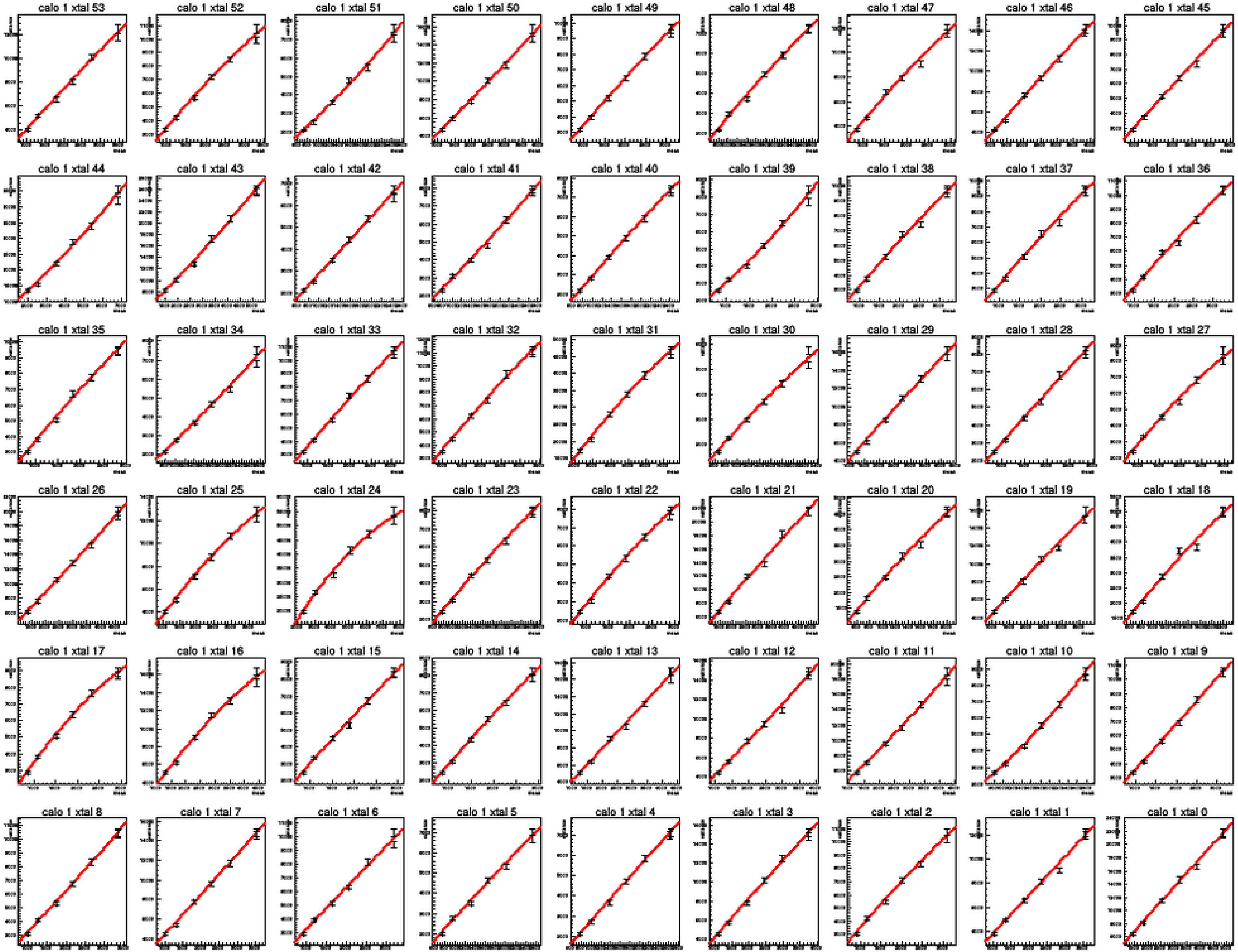
<u>Thus, by stepping through the filter wheel and extracting the linear term in the σ^2 vs mean curve, the desired gain constants are determined.</u>

Filter wheel calibration

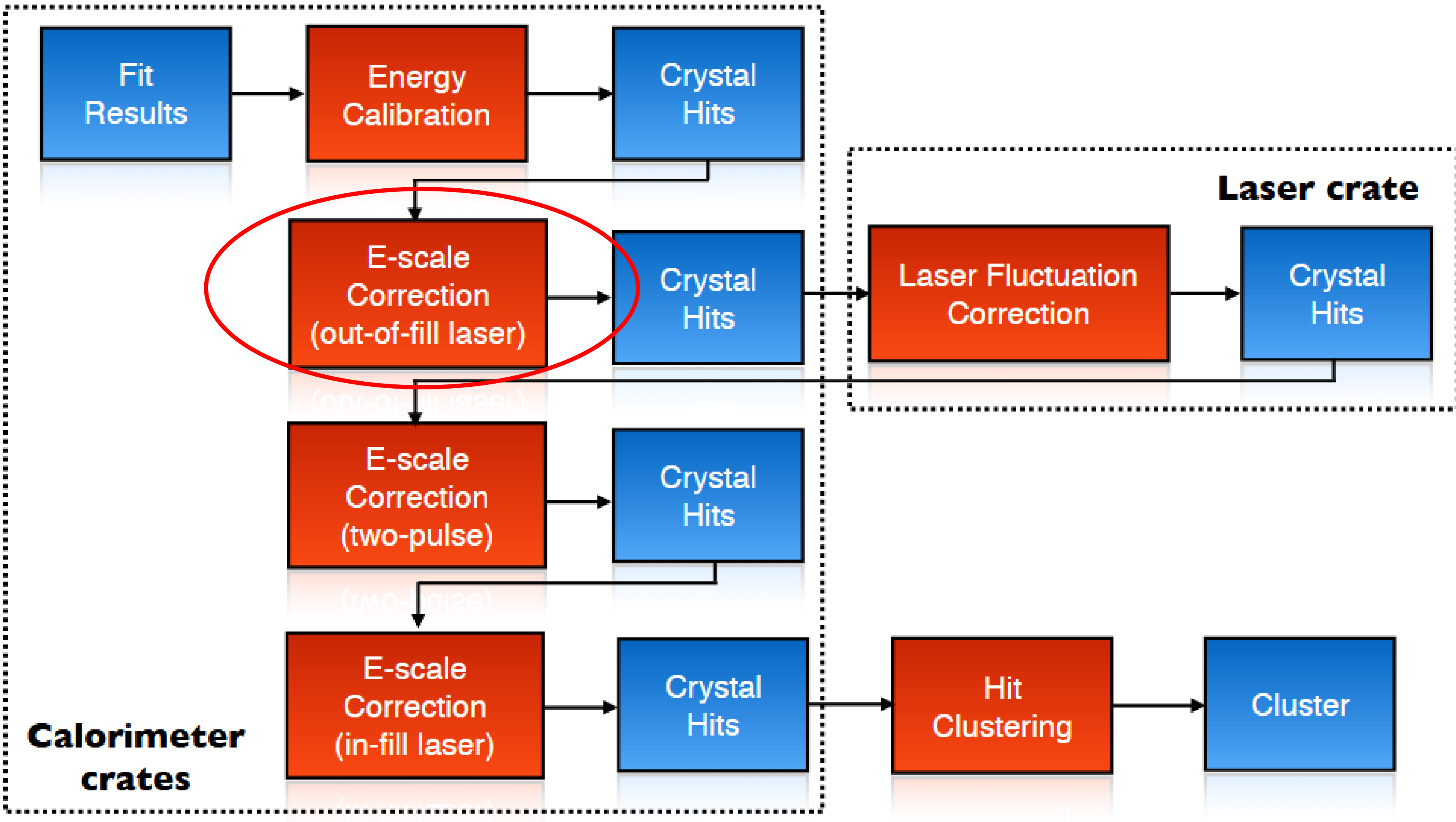
High rate laser pulses to each SiPM (crystal), fit with gaussian distribution.

Filter wheel calibration

Plot of variance σ^2 versus pulse-integral mean μ of the distribution. The discrete mean values are based on using a multi-step filter wheel to attenuate the light.

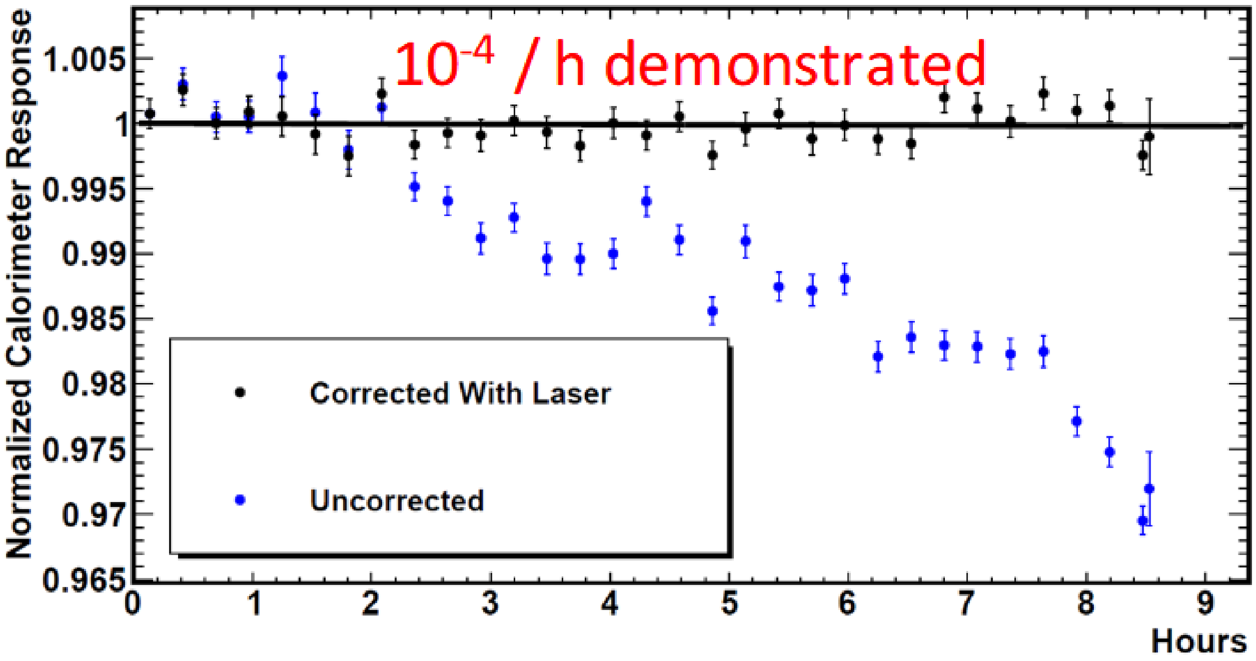


Calibration scheme

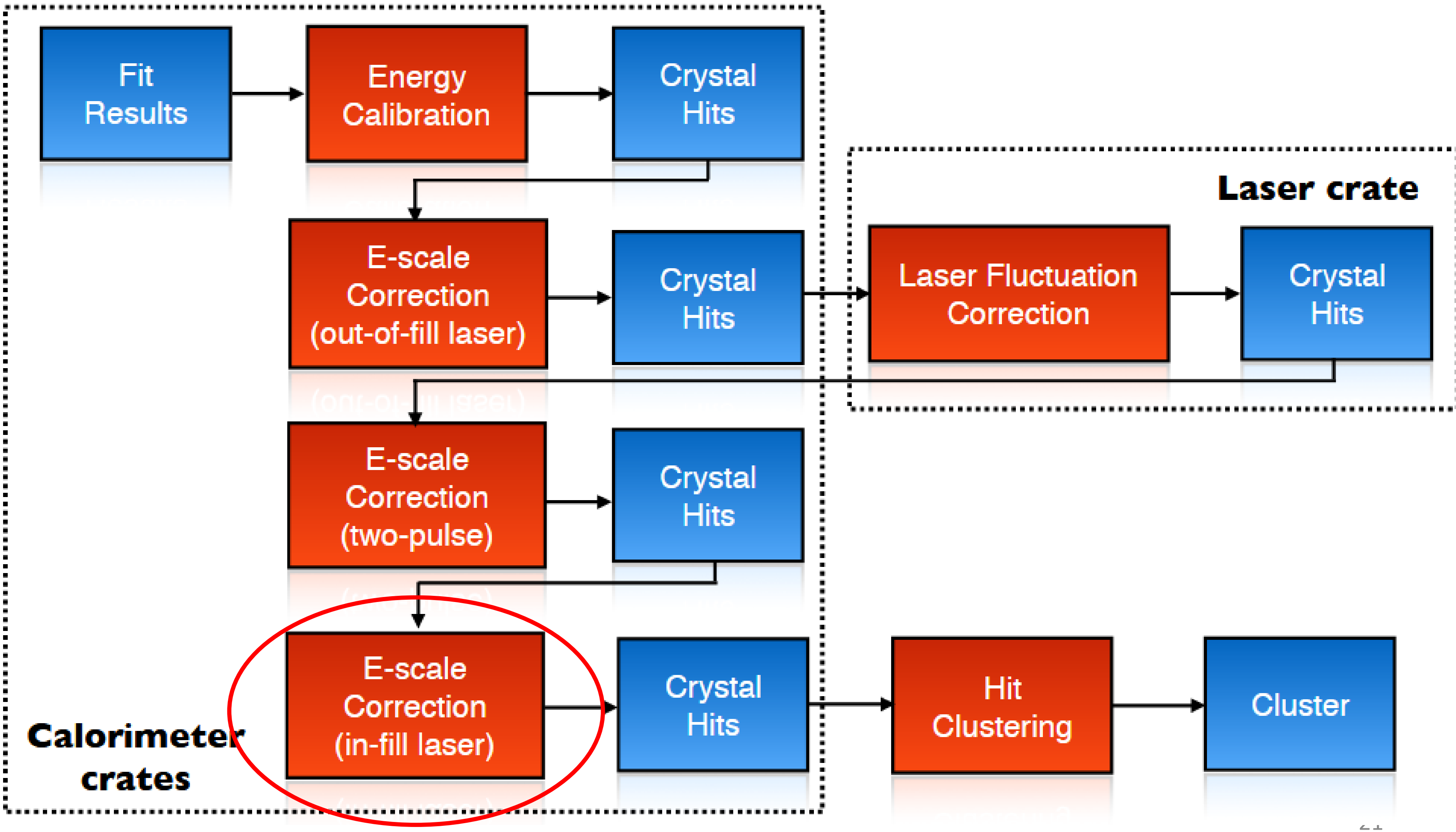


Out-of-fill corrections

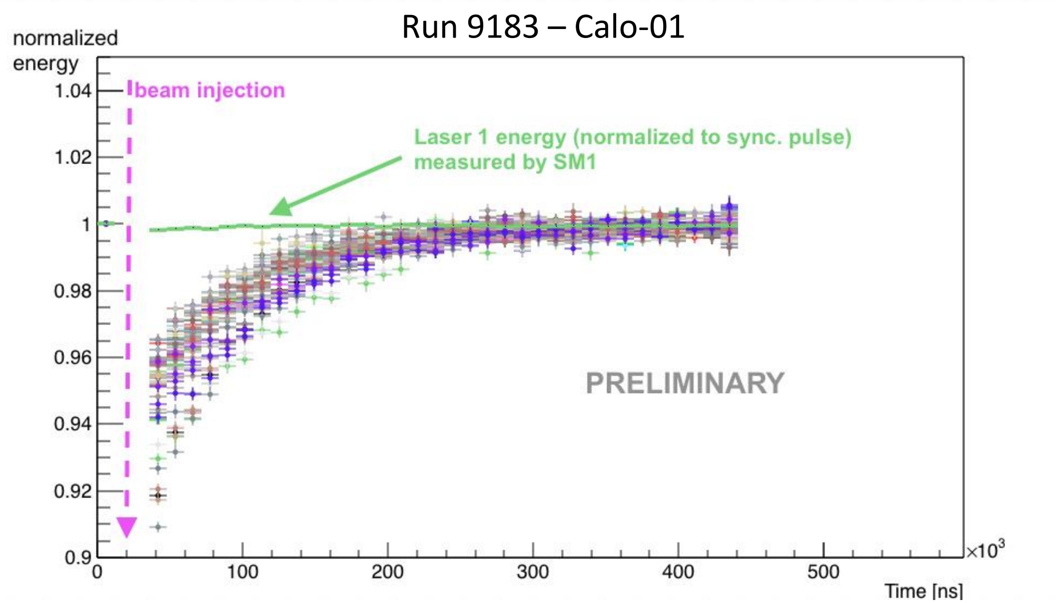
Long term drift of the SiPMs gain (due to temperature and ageing effects) can be corrected using the laser pulses and the source monitor corrections



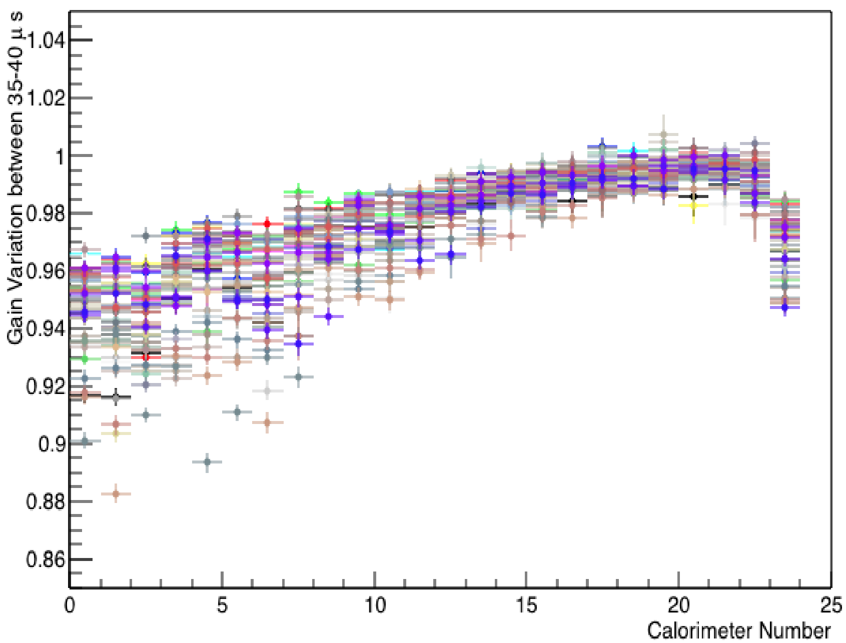
Calibration scheme

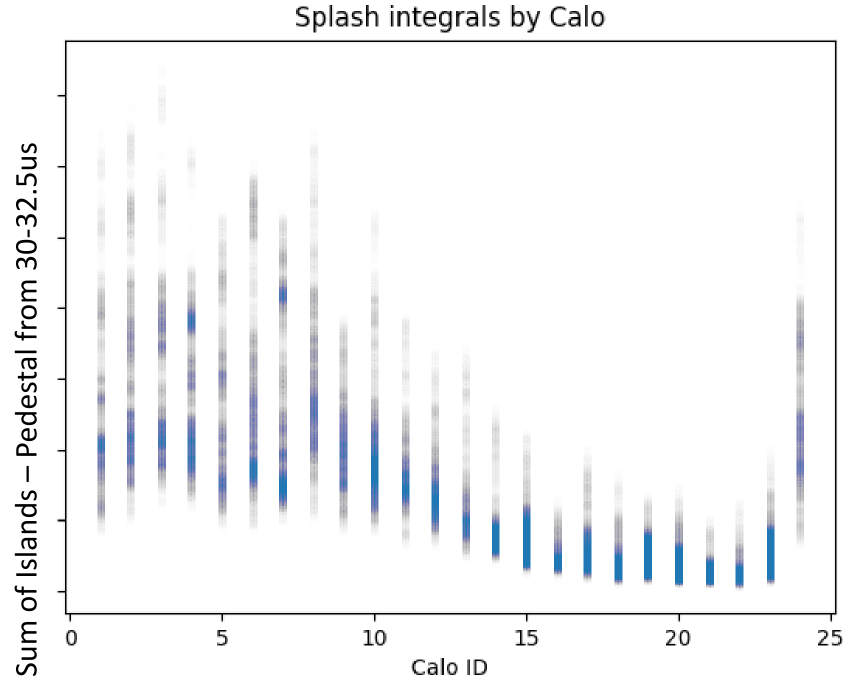


What we saw from the In-Fill laser pulses in February?



Larger gain drop than anticipated in many calorimeters!

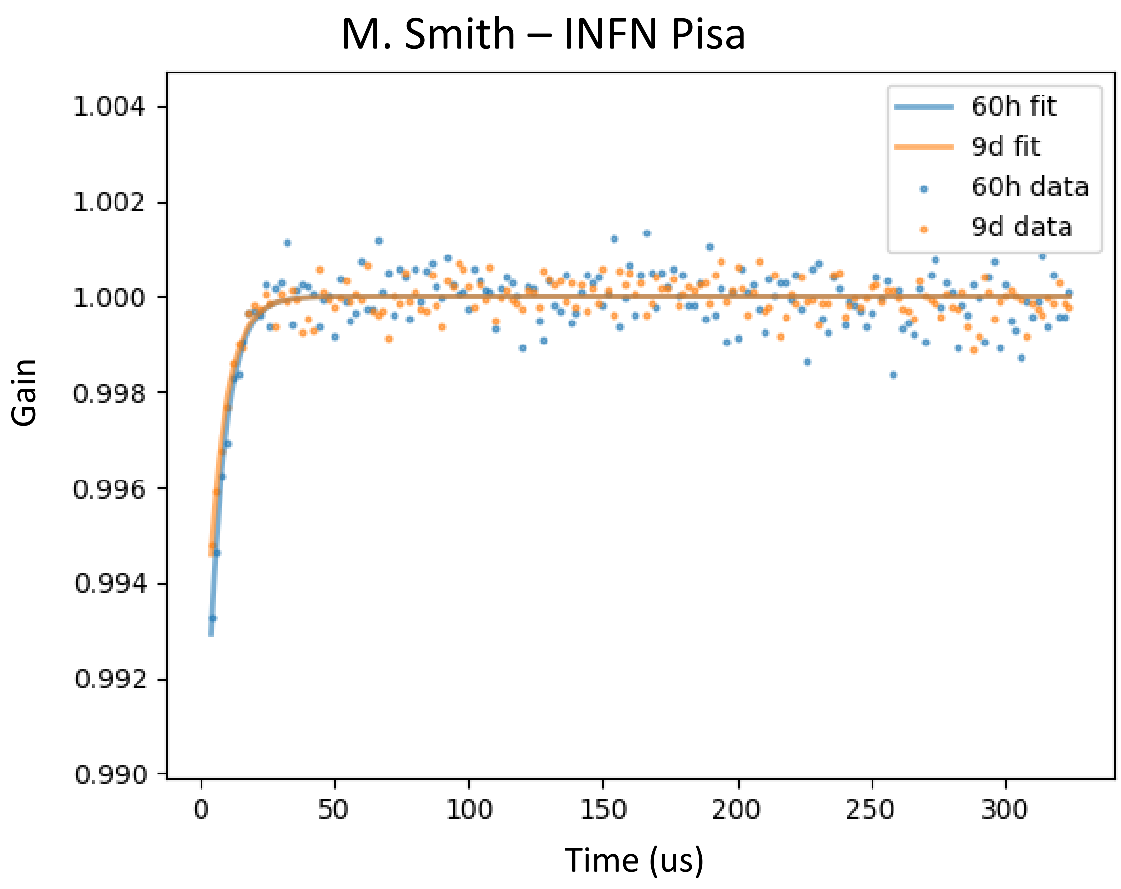




Gain sag was also found in Endpoint positron energy from Kim Siang

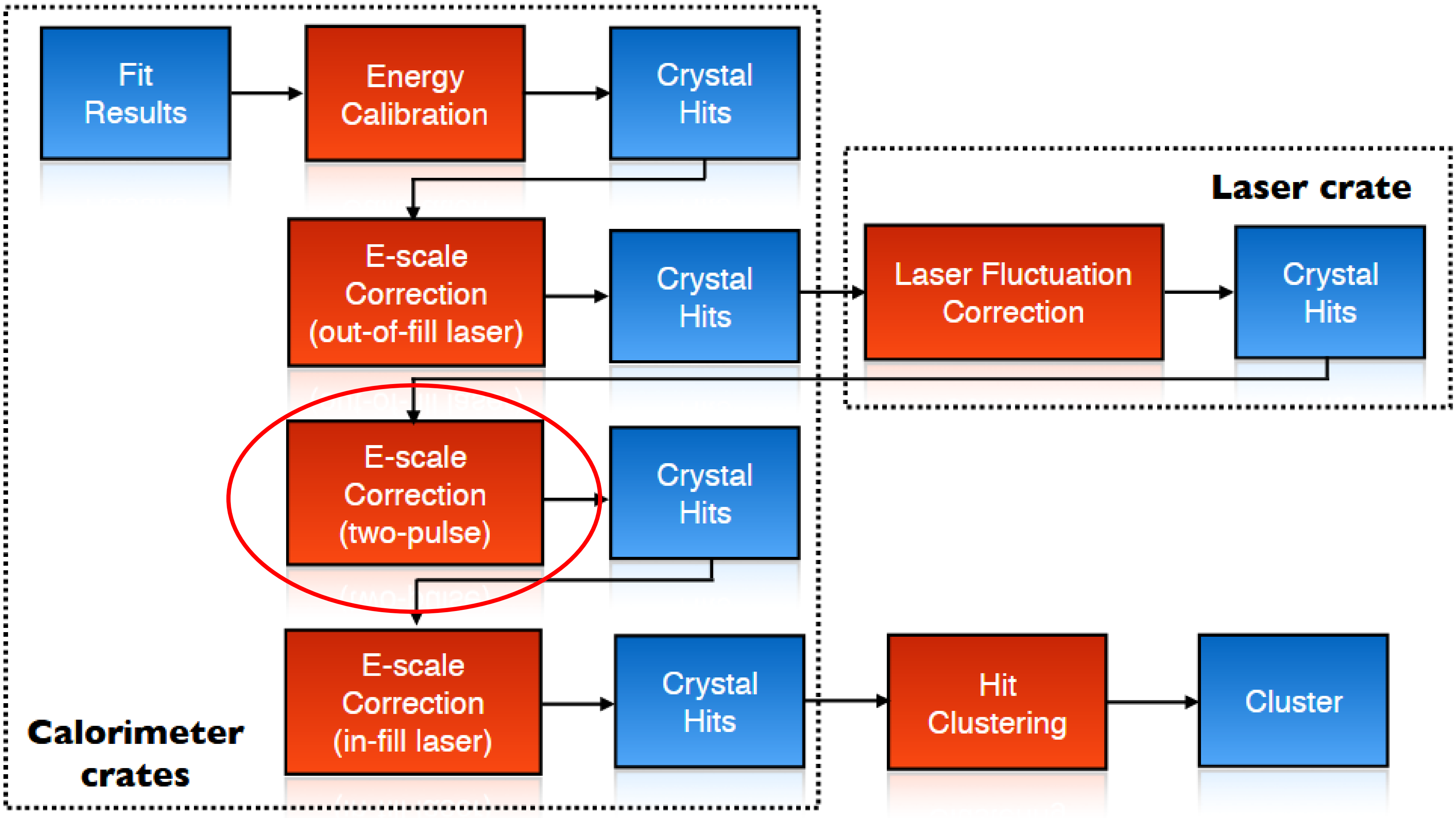
In-fill-gain corrections

(after extra capacitors installation)



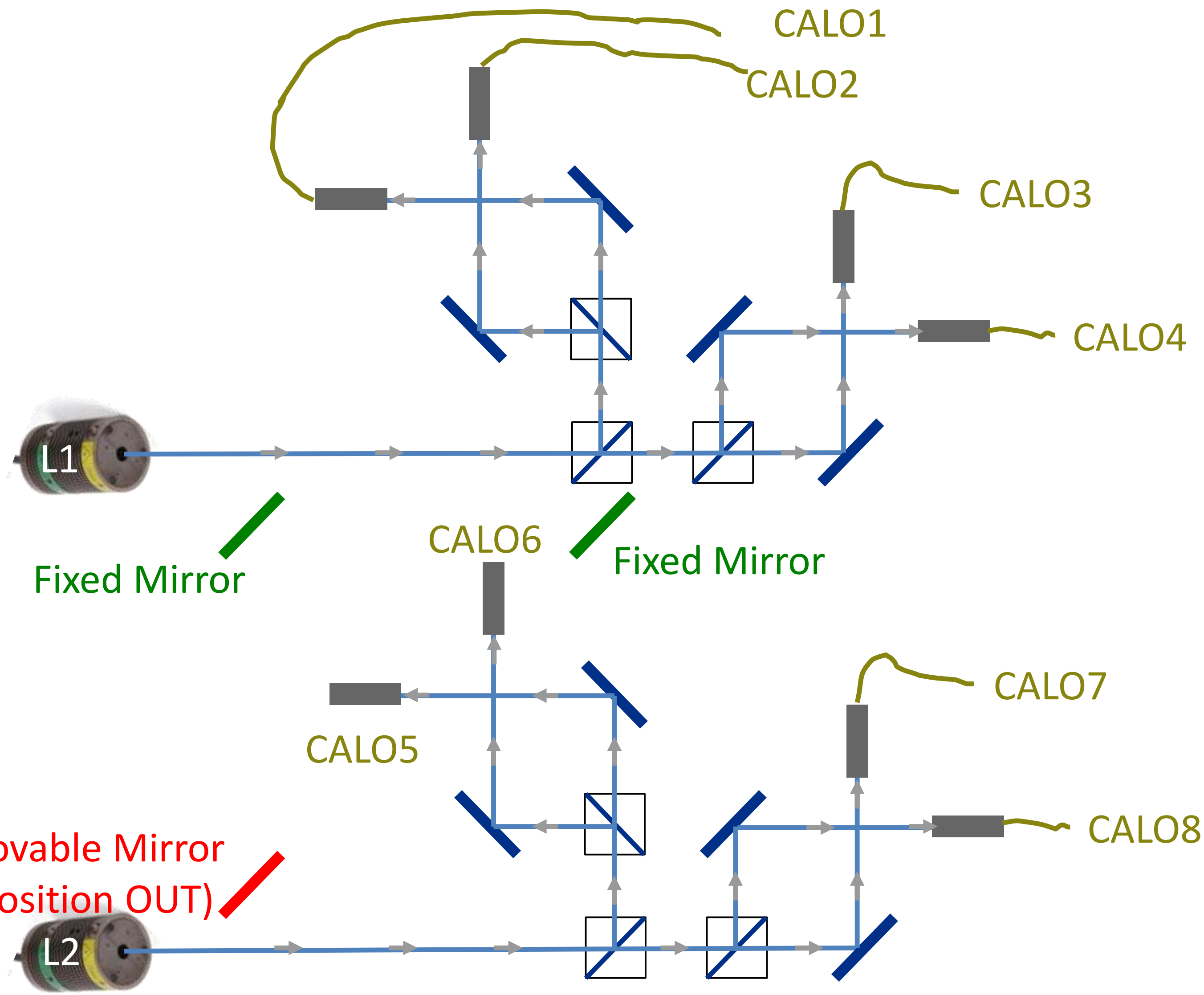
- Built the in-fill gain function for 9d to compare with 60h
- Preliminary results, functions similar but 9d consistently smaller

Calibration scheme

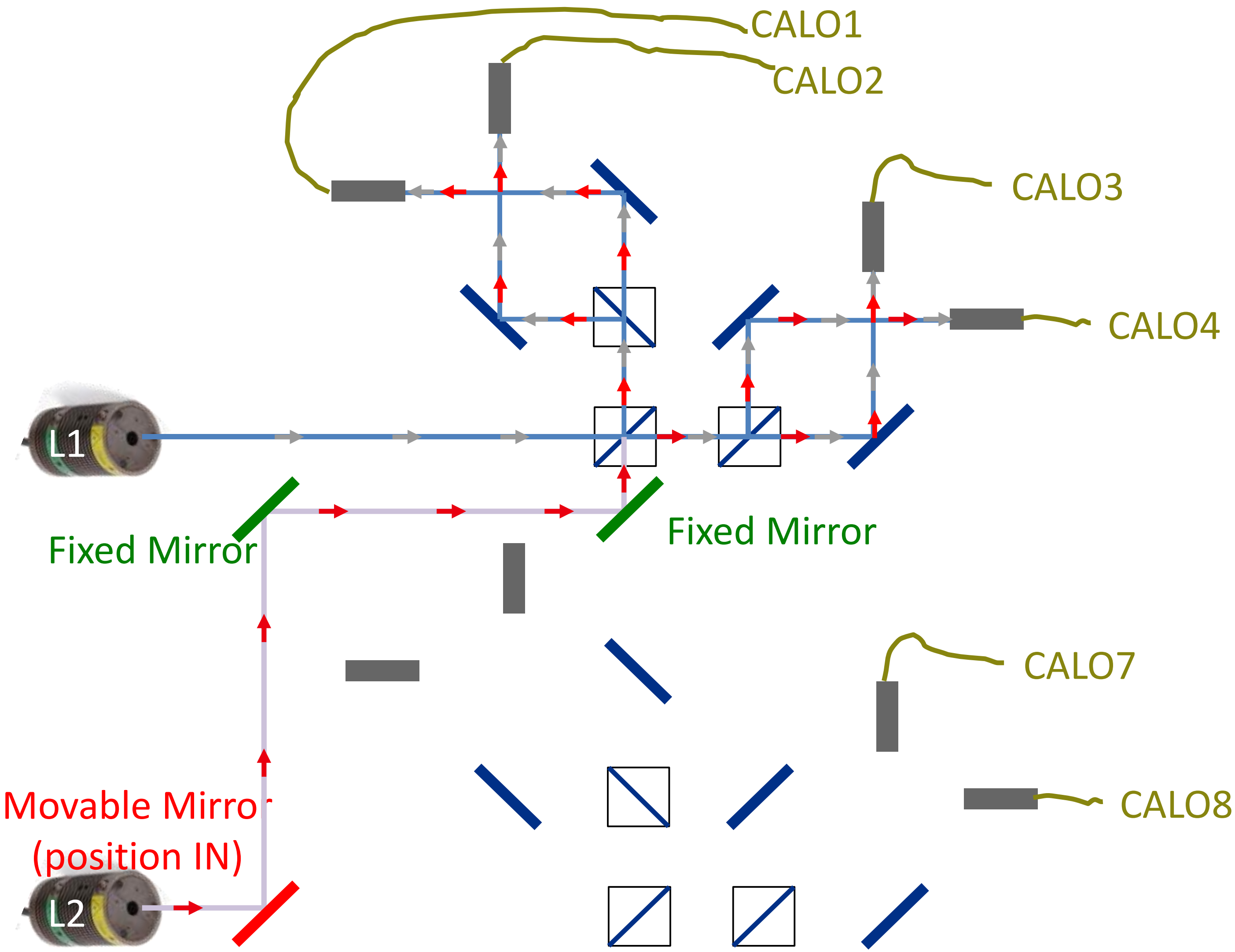


Double-pulse mode

In order to study the gain sag of the SiPMs

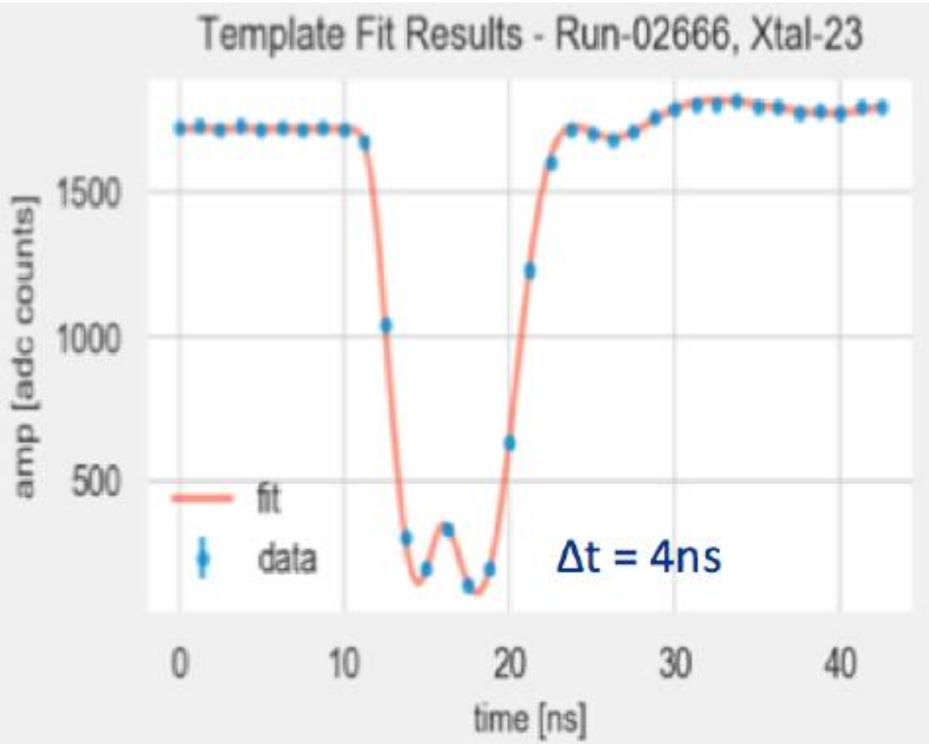


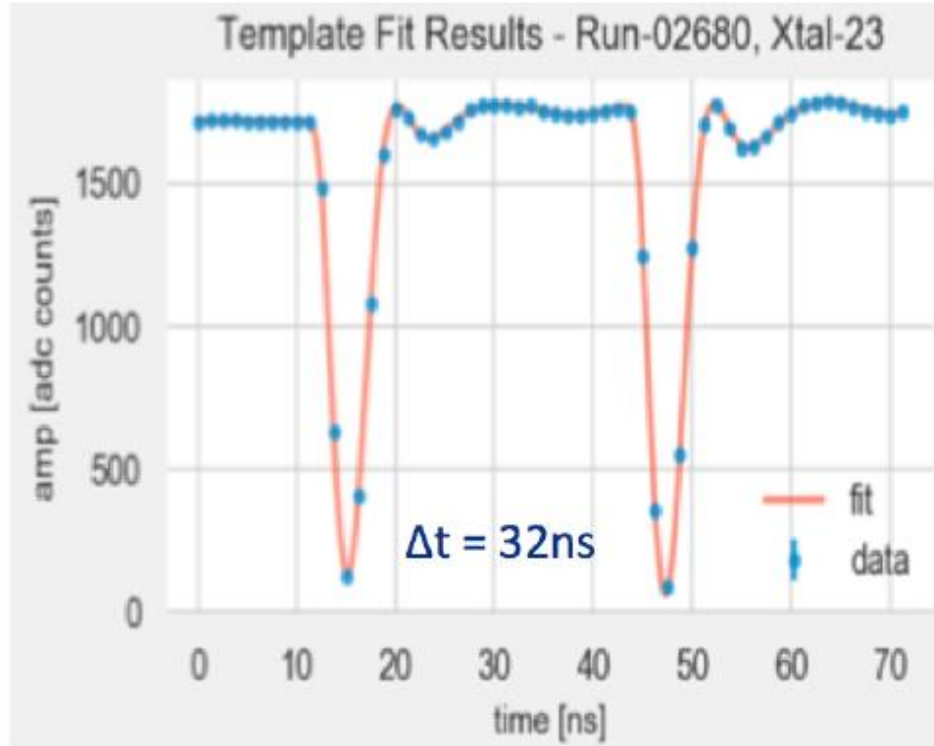
Double-pulse mode ON



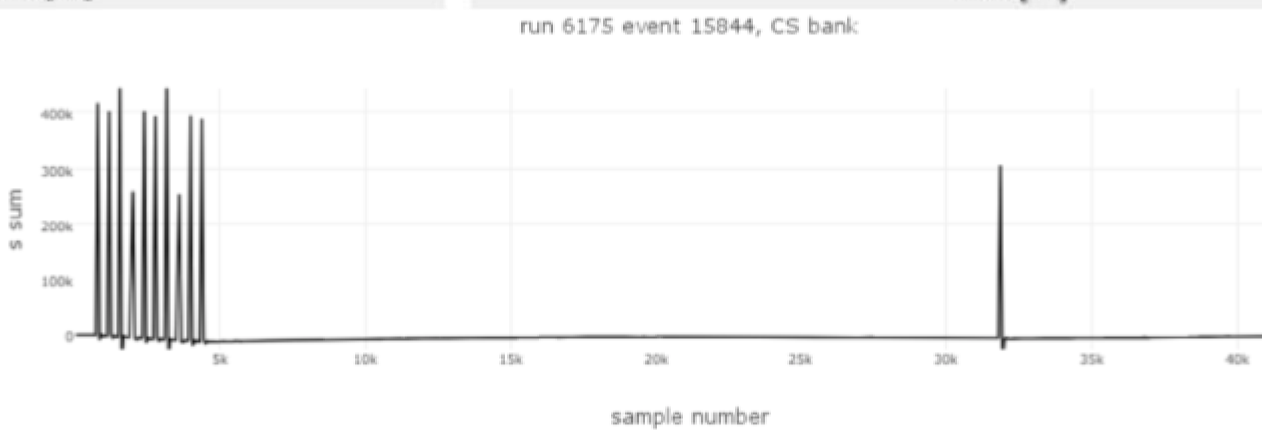
Double pulse feature

A digital delay generator (SRS DG645) is used to send prompt and delayed signals

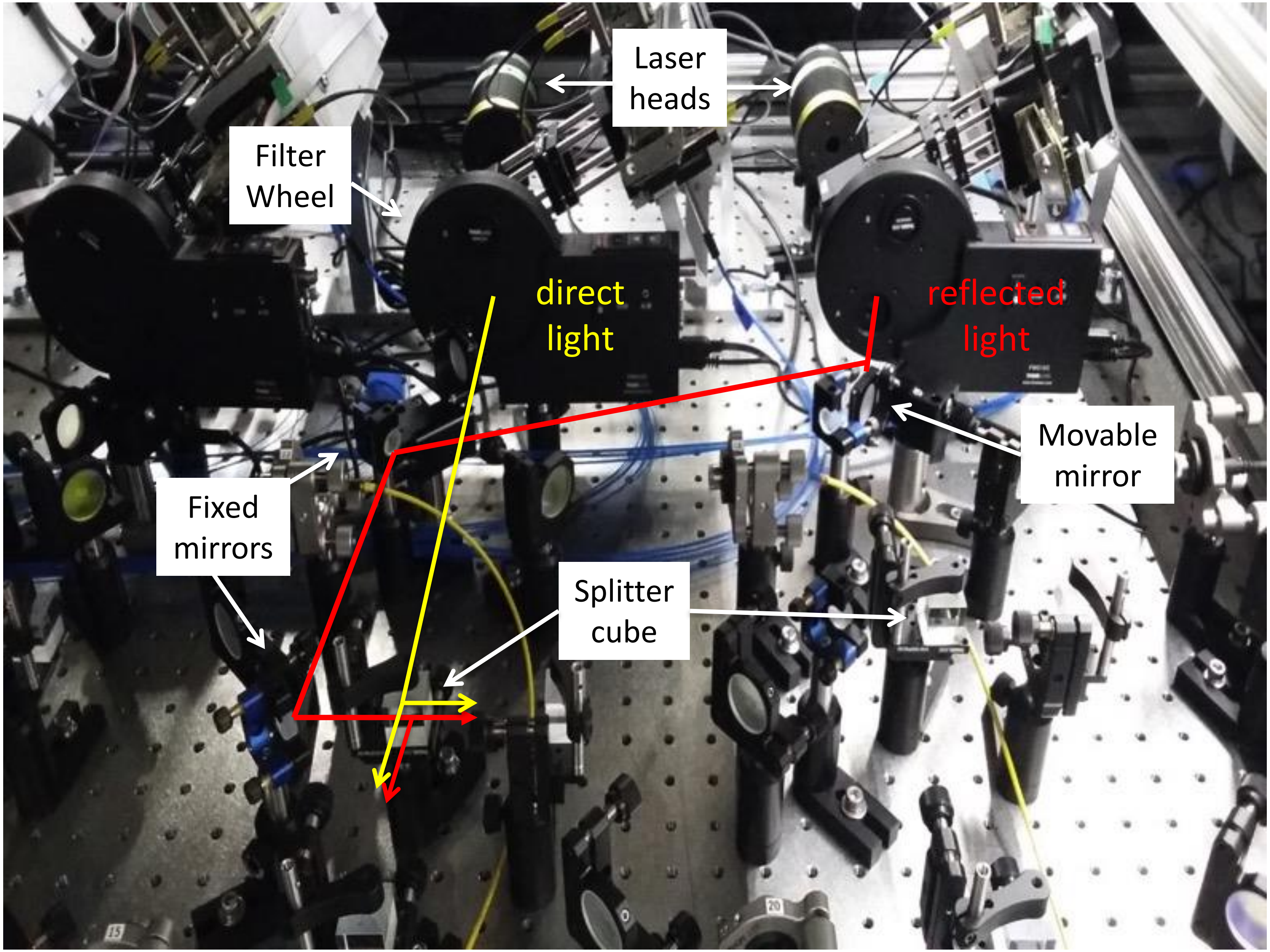




A pulse train is used to simulate the initial splash

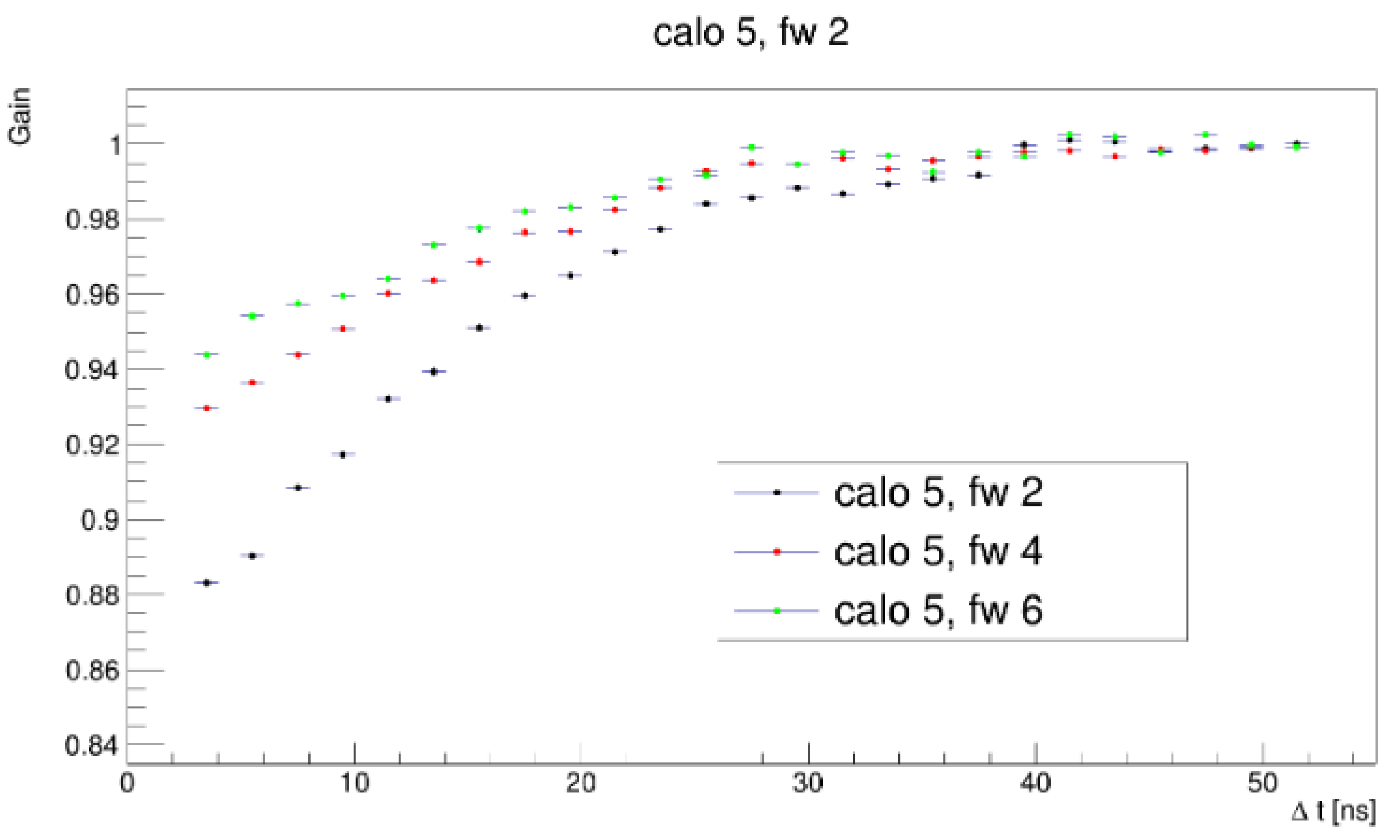


Double-pulse mode ON



Short term double pulse

Short term gain sag is due to SiPM response when two particles hit the SiPM at “short" time distances (it is a function of the energy of the pulse)



Long term double pulse

Long term gain sag is due to the high rate of hits which overload the bias power supply

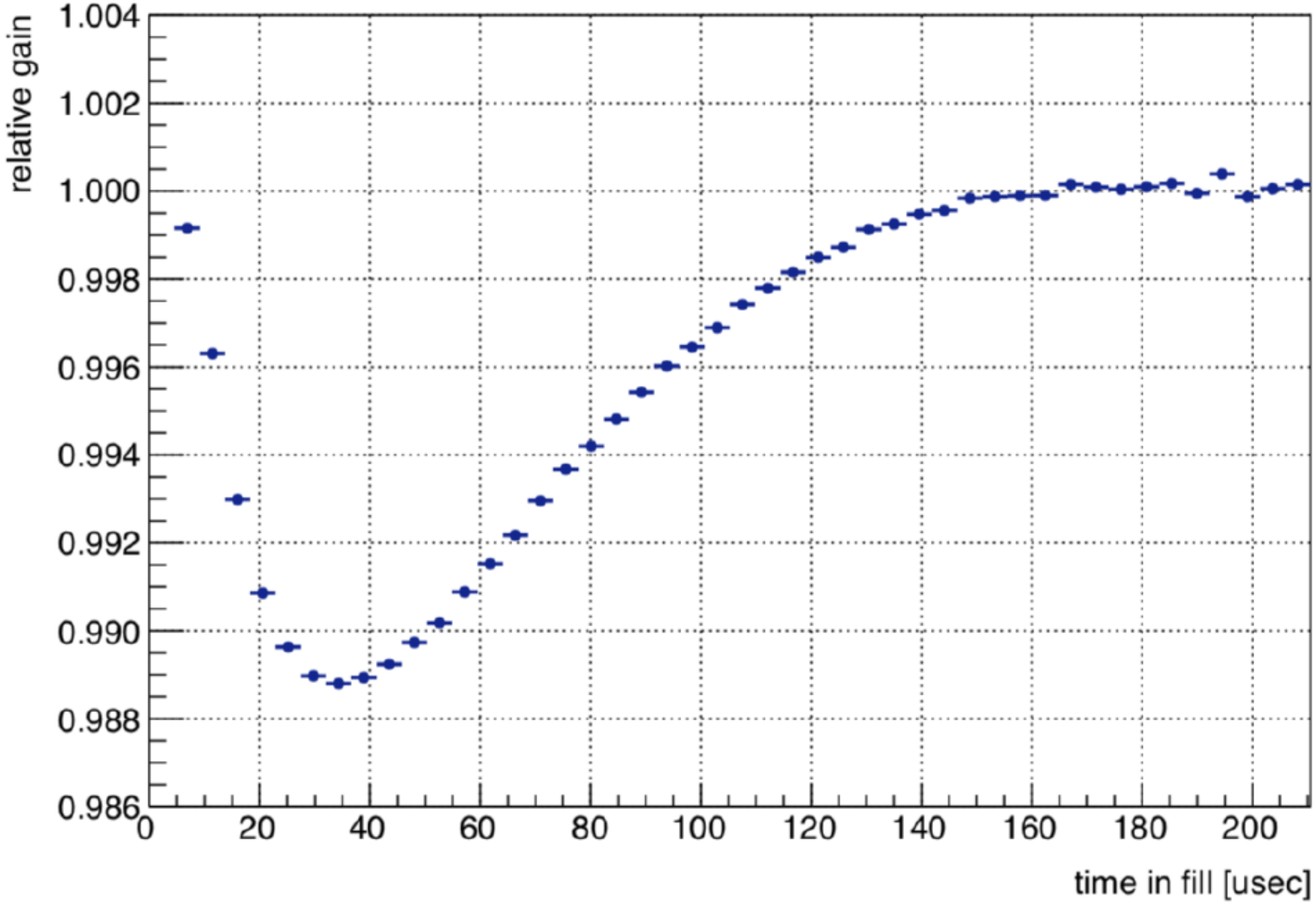
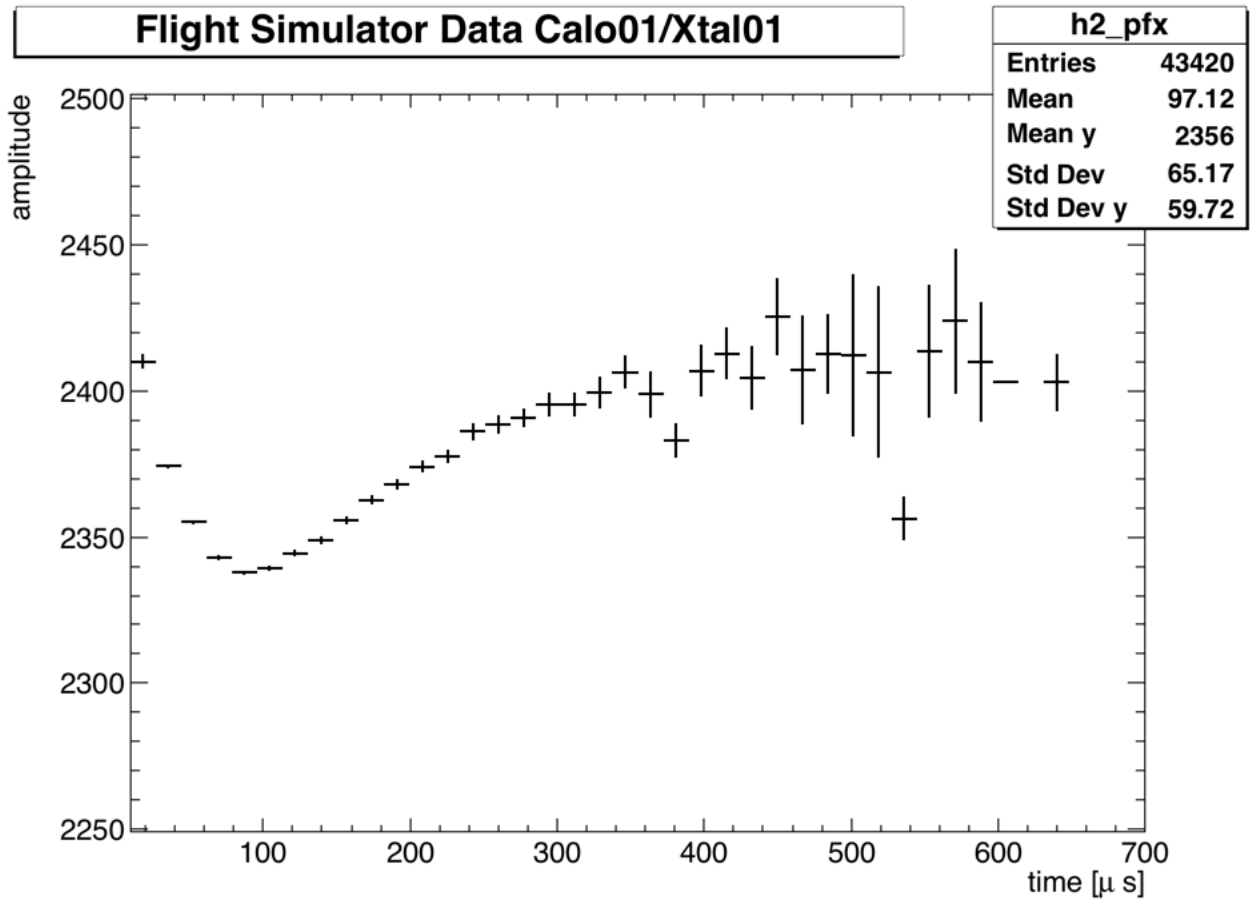


Fig. taken from J.Kaspar et al., “Design and performance of SiPM-based readout of PbF2 crystals for high-rate, precision timing applications", JINST 12 (2017) no.01, P01009

Flight Simulator mode

In the flight simulator mode the laser control board provides unevenly spaced laser pulses, with decreasing exponential distribution, which simulates the positrons pattern during a fill.



Conclusion

- Laser system has been installed and is properly working.