Fermilab Muon g-2

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Muon g-2 experiment: The Laser Calibration System

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Final Presentation

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The "g" in g-2

Elementary particles have, amongst others, an intrinsic quantity named magnetic moment. It is a quantity that directly relates the charge, the spin and the mass of the particle.

$$\vec{\mu} = g\,\frac{Qe}{2m}\vec{S}$$

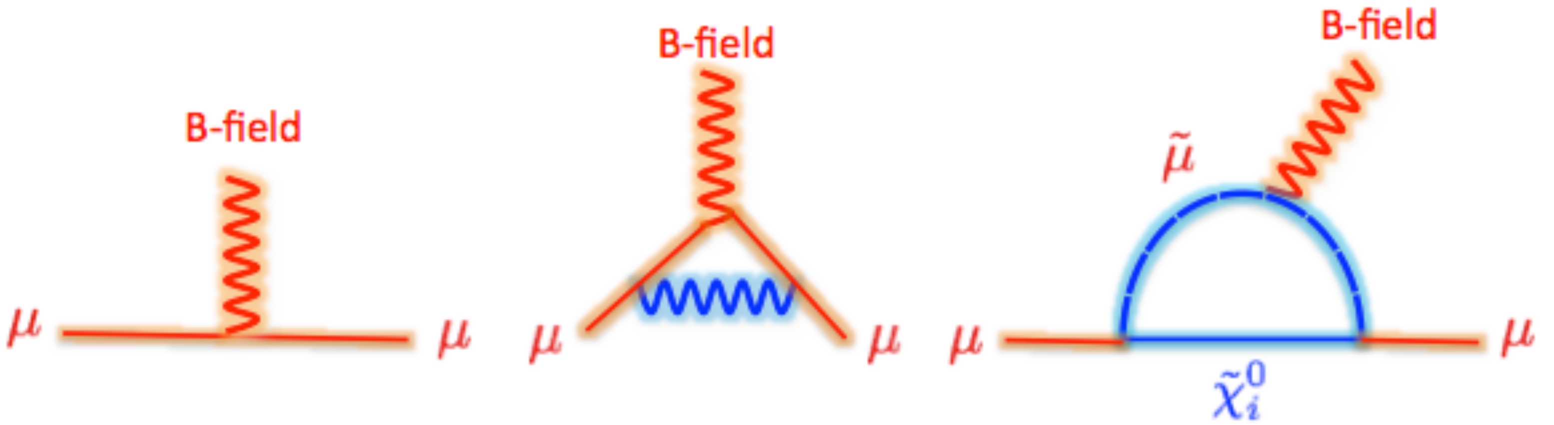
The g term is a dimensionless factor, that is exactly equal to 2 according to the Dirac theory, so that g-2 equals zero.

Actually, interactions of the particle with virtual particles in vacuum introduce a correction of the order of 0.1%. This anomaly is calculated as $a = \frac{g-2}{2}$.

The "g" in g-2

The simplest higher order interaction is the QED "Schwinger interaction", that contributes for exactly α/π. In the case of electrons, this is almost the only anomalous process.

Since other interactions involving new particles contribute to g-2 proportionally to $(m/M_\chi)^2$, in order to find new physics we need a more massive particle, and the muon is the perfect candidate!



"Dirac Interaction" g=2

QED "Schwinger Interaction" (g-2)=α/π

BSM SUSY interaction

The experiment

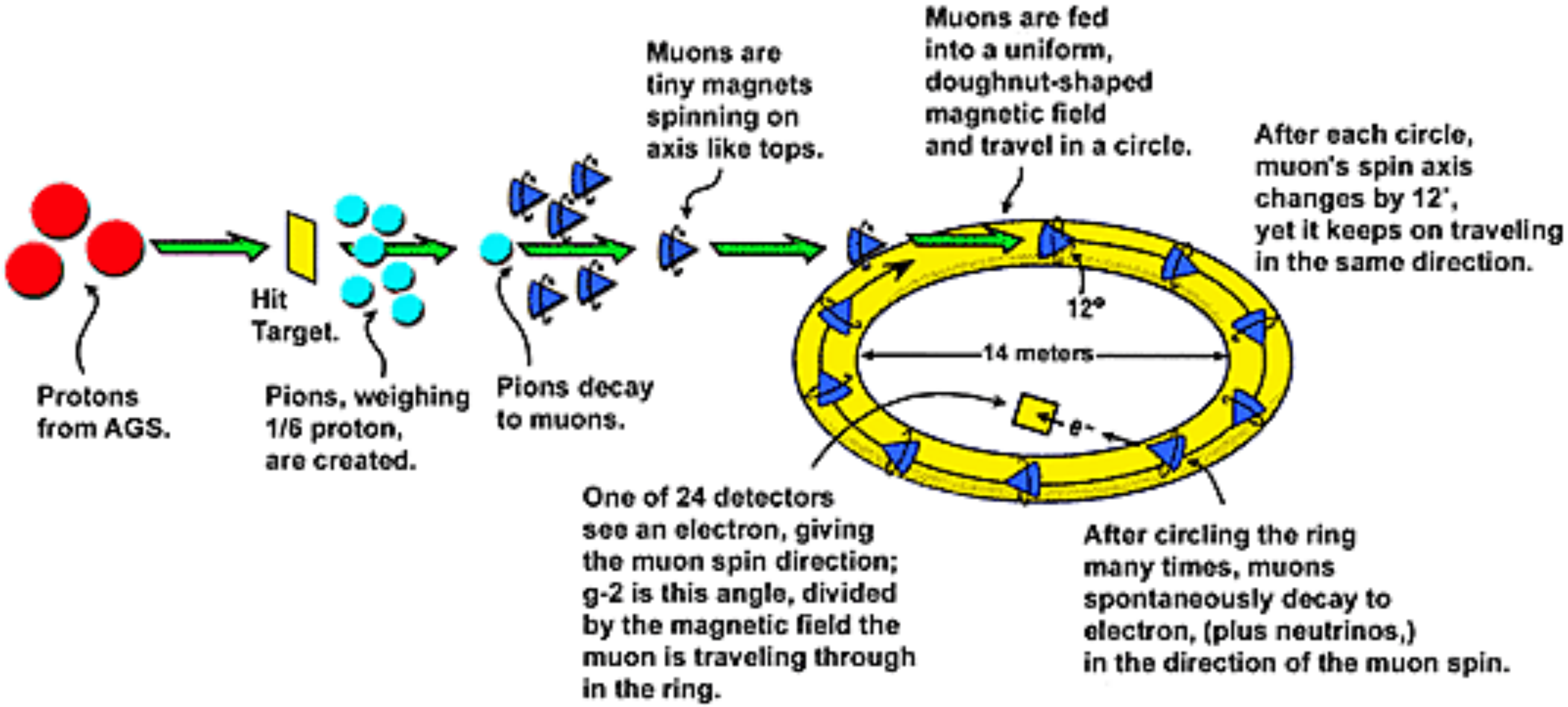
The goal of the experiment is to measure this anomaly as precisely as possible. It is actually an upgrade to a previously existing experiment at Brookhaven Laboratory, that lead to a value of

$$a_\mu = \frac{g-2}{2} = 11\,659\,208.0(5.4)(3.3) \cdot 10^{-10}$$

With a precision of 540 ppb and a 3.5 sigma significance difference between SM.

Now, the new Muon g-2 experiment will have 20 times the muons to finally increase the accuracy to the value of 140 ppb.

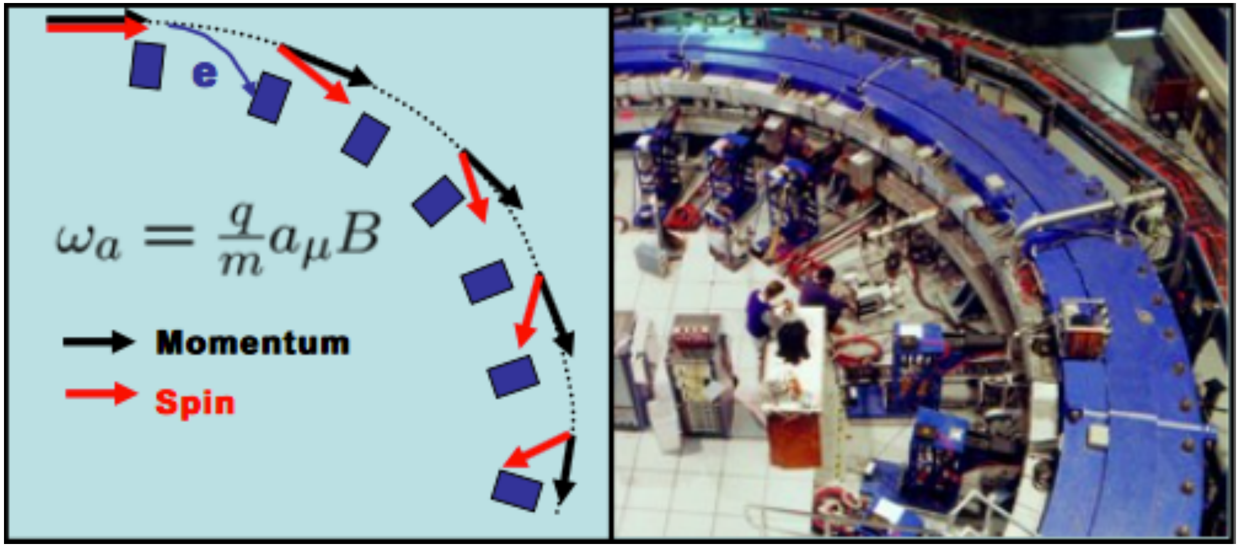
The experiment



The experiment

As muons circulate inside the magnet, the magnetic field causes their spin (and their magnetic dipole) to precess around the vertical axis.

Because of parity violation in the weak decay of the muon, a correlation exists between the muon spin and the decay positron direction.



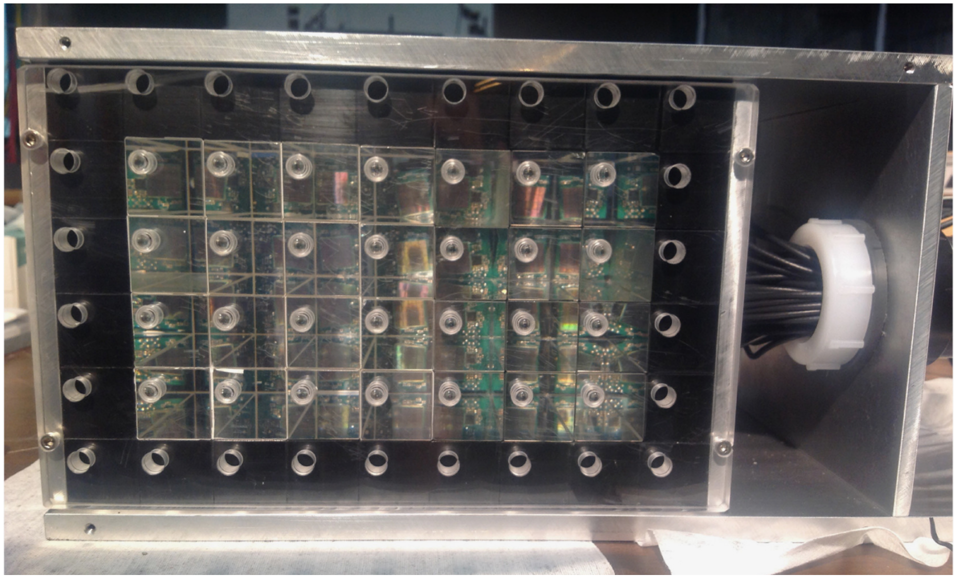
A set of 24 calorimeters are placed in the inner side of the magnet, to reveal the emitted positrons.

Calorimeters

Each calorimeter is a 9 wide by 6 high array of 14 cm long lead fluoride crystals. Positrons deposit energy in each crystal by emitting Cherenkov radiation in a few nanoseconds, and a large area SiPM encodes the light signal in a fast charge pulse.

Their purpose is to measure the energy of the positron – to have an energy threshold, and to precisely measure the time of detection.

Therefore, their energy and time response stability over time is crucial for a successful experiment.

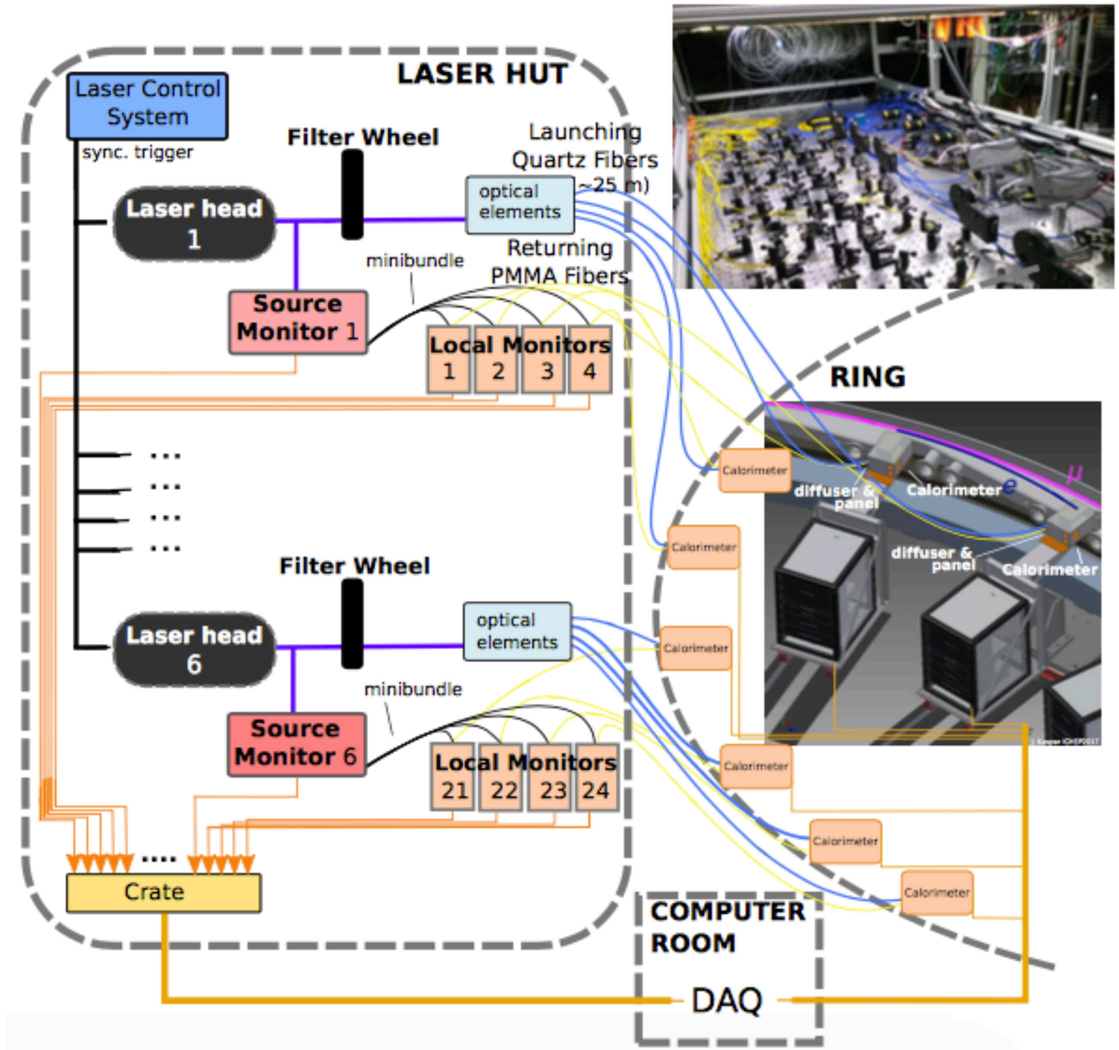


Calorimeter prototype tested at SLAC

The Laser Calibration System

In order to have a very precise measurement, it is required to have a very frequent calibration of the 24 calorimeters, also to monitor their gain stability.

A setup of 6 lasers and proper optics has the job to periodically send light pulses to all the calorimeters via 25 m long quartz fibers.



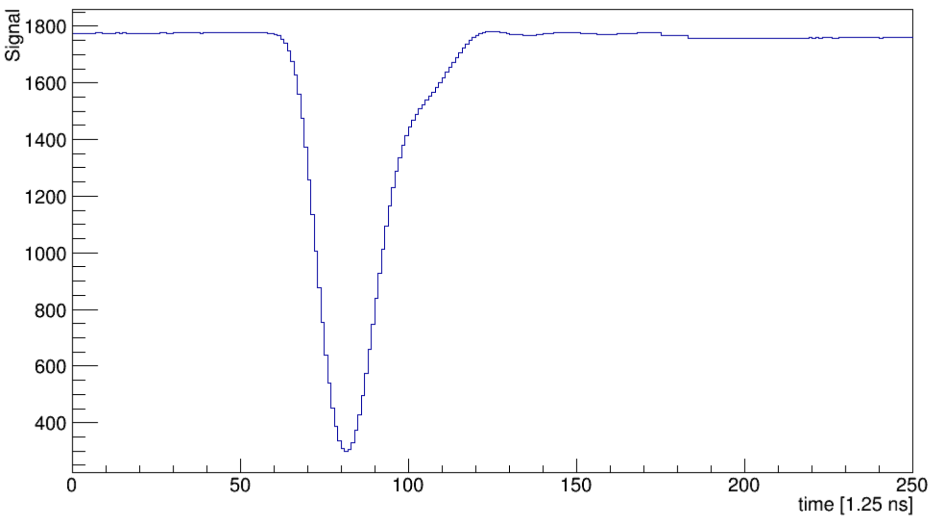
Calibrating the light output

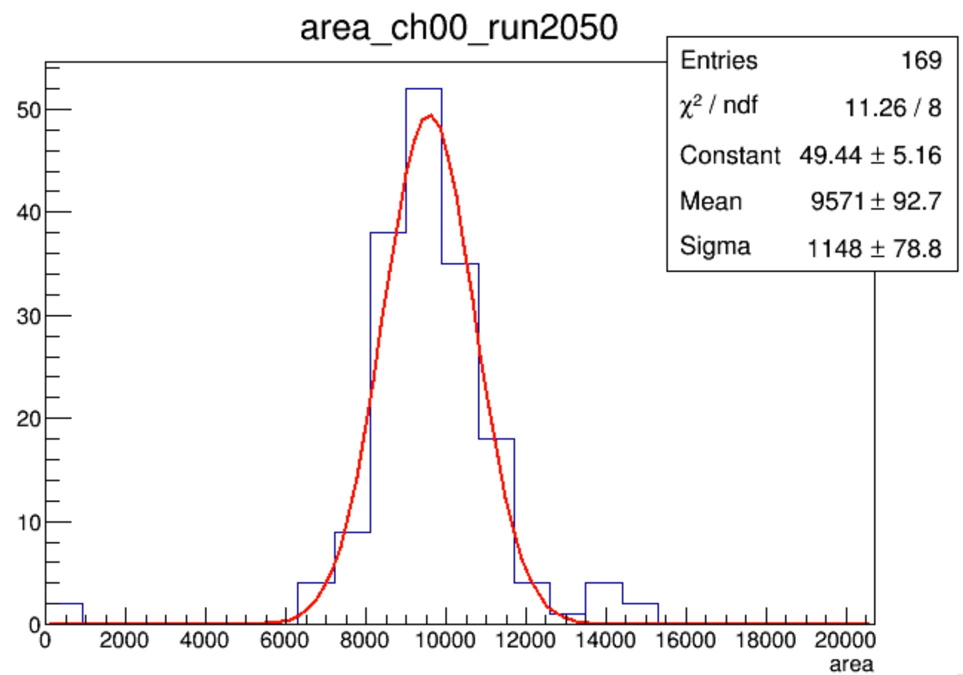
In order to calibrate the calorimeters, we need to know how much light we are sending through the fibers. Each calorimeter splits the light incoming by diffusing it to 55 fibers: 54 go to the crystals, and the remaining one is sent back to the laserhut.

A set of 24 PMTs (Local monitors) then convert the light of these returning fibers into electronically readable signals.

By applying several attenuating filters in front of the laser source it is possible to study the PMT response and then calculate the number of photons that reached the calorimeters.

Calibrating the light output

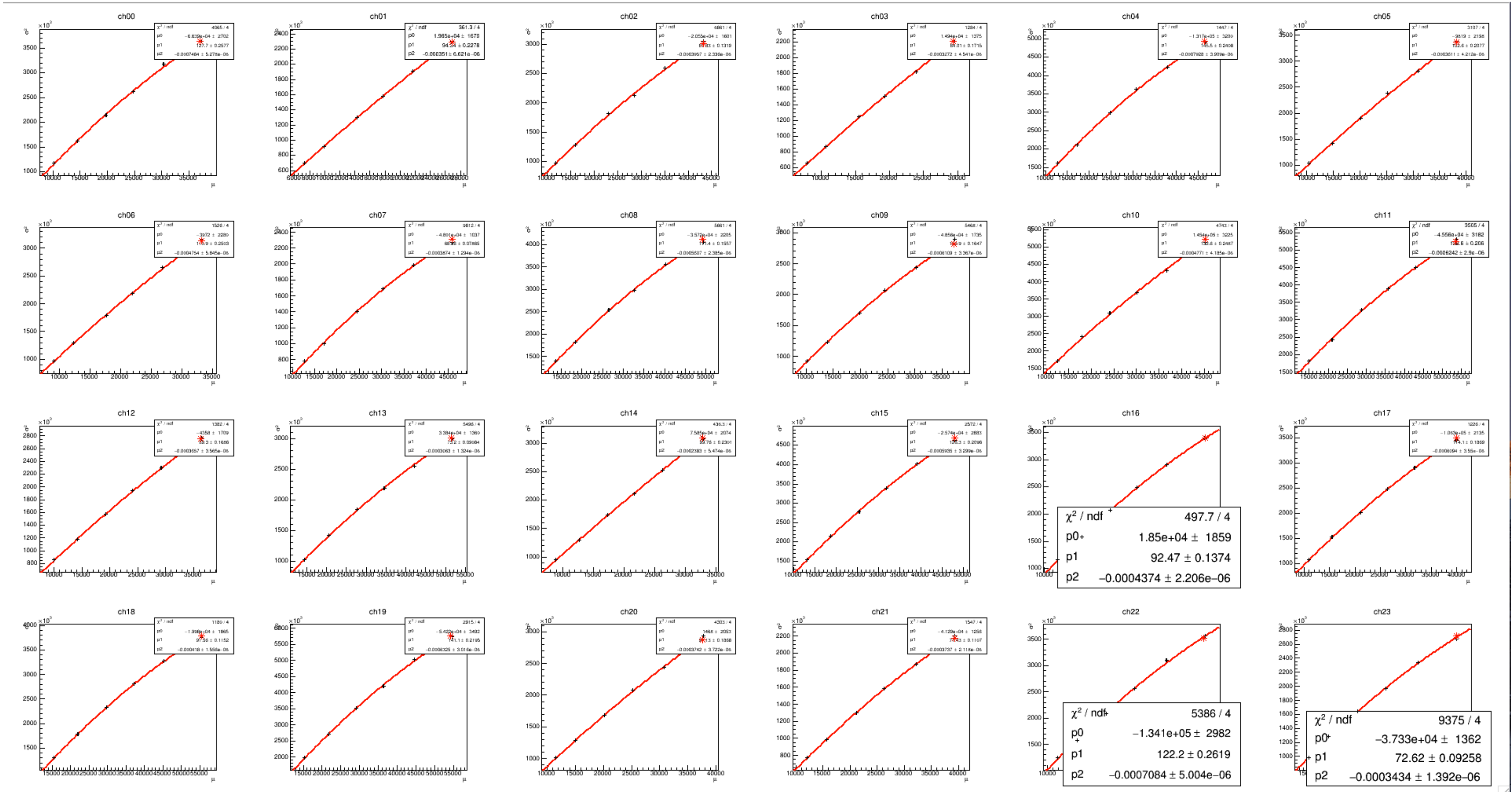




Typical signal shape produced by local monitors.

Distribution of the area of the signal, with gaussian fit.

Calibrating the light output



Plots showing σ^2 versus μ of the gaussian fit for each filter. The slope in the quadratic fit is a measure of the photoelectrons if divided by μ.

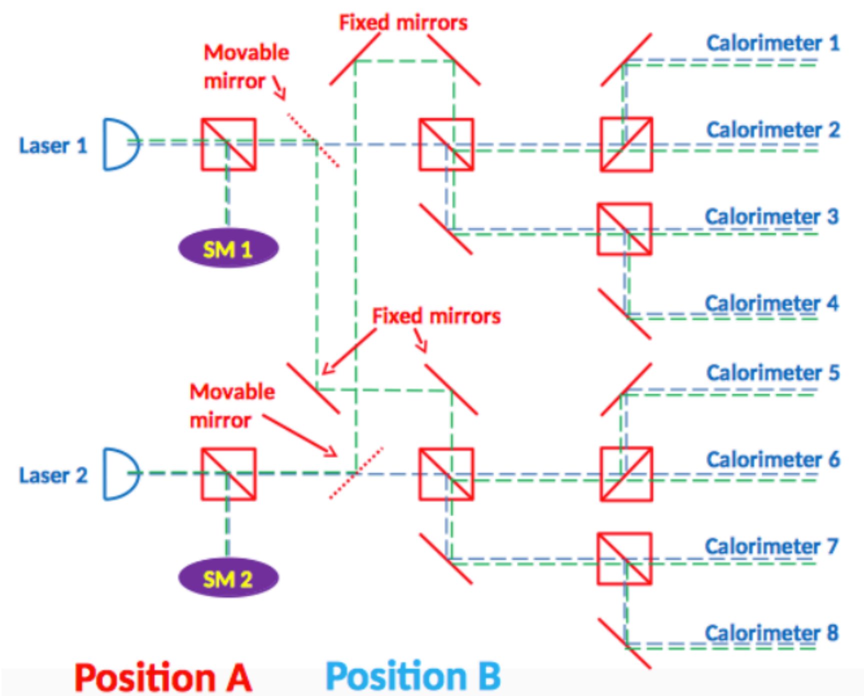
Calorimeter response

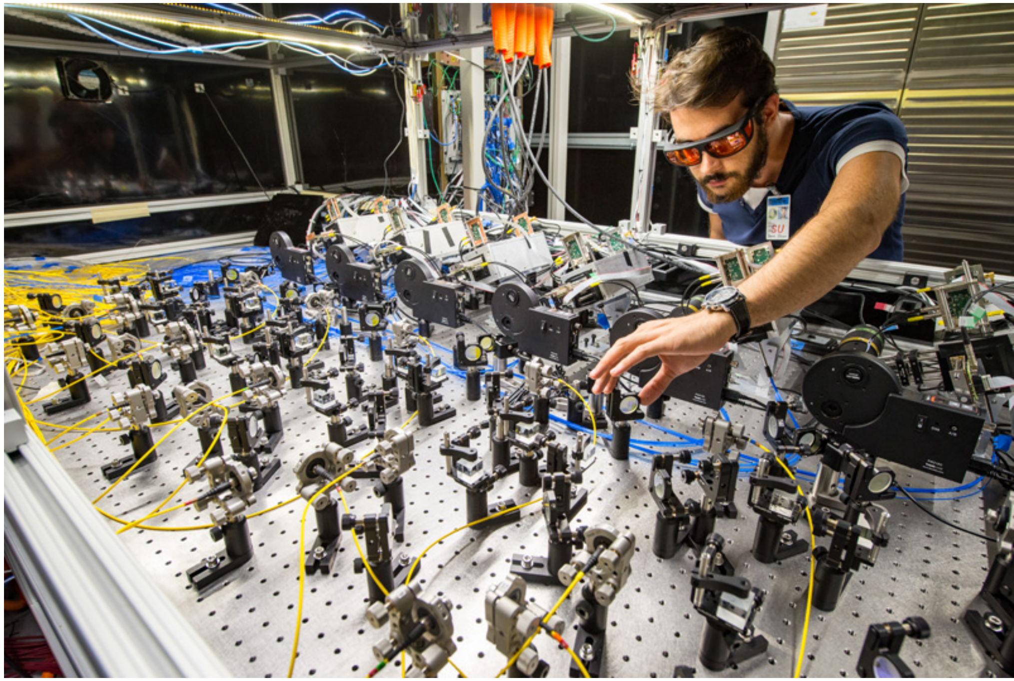
With the laser calibration system we also want to study the calorimeter response to two really close (in time) positrons hitting the detector.

The main goal of my work in these two months is to make this possible.

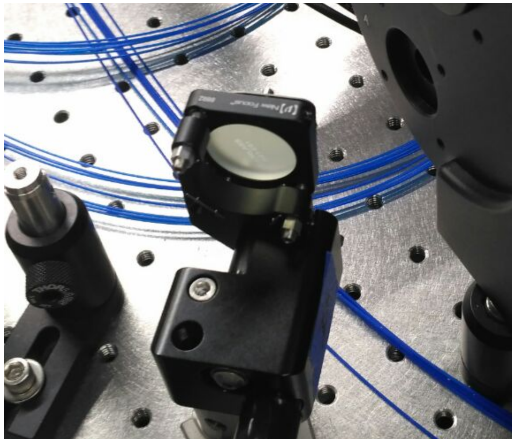
Double pulse – Optics

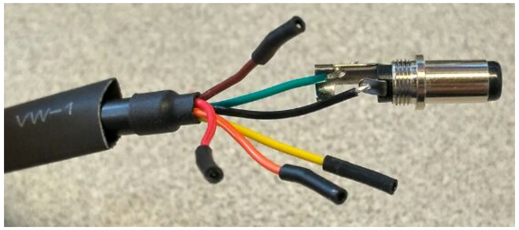
First of all, I helped building the optics necessary to deliver two lasers to the same calorimeters. A set of fixed and movable mirrors has been placed and aligned.





Double pulse – Motorized mirrors





- Motorized mirrors allow to have or not have the double pulse mode at any time.
- To control them, six TTL-232RG USB to TTL cables have been soldered and plugged in.
- The USB ends of the cables are connected to a 7-port USB hub, connected to a mini-pc.

Double pulse – Motorized mirrors

I then coded a C++ driver so that it is possible to control the position of the mirrors remotely from the control room.

It uses the GND (black) and RTS (green) wires of the serial port to send TTL signals to the mirrors.

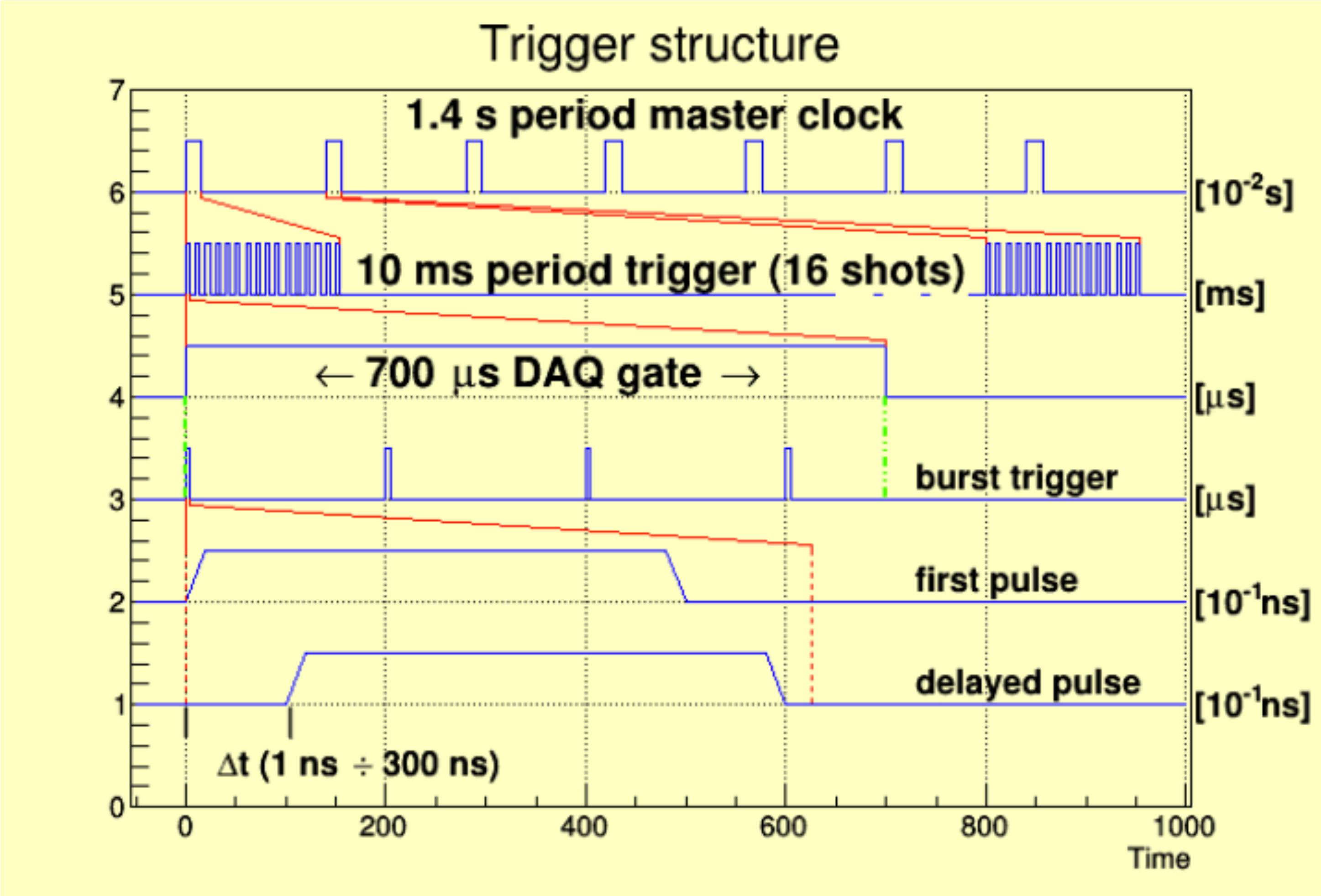
```
laserhut2@laserhut2> ./Laser
 ------ Driver to control laserhut mirrors - PGirotti -----
  | Usage: enter laser number and position                |
  | Laser numbers: 1,2,3,4,5,6,e,o,a  (even, odd, all)    |
  | Positions: 0,1 (down, up)                             |
  | Enter 0 to close                                      |
 ----------------------------------------------------------

 |1      |2      |3      |4      |5      |6      |
 |up     |up     |up     |up     |up     |up     |

e 0
Moving even mirrors down
 |1      |2      |3      |4      |5      |6      |
 |up     |down   |up     |down   |up     |down   |
```

Double pulse – Delay generator

Then I worked on a Digital Delay Generator, a device that, provided an external trigger, is capable to generate a pattern of pulses with very precise delays, with a resolution of less than 100 ps. This device is necessary to fire two lasers a few nanoseconds apart.

In particular, I coded a driver in C/C++ so that it is possible to reprogram the settings remotely from the control room via TCP/IP communication. This is necessary to change the delays automatically and to set a particular mode named “burst mode”.

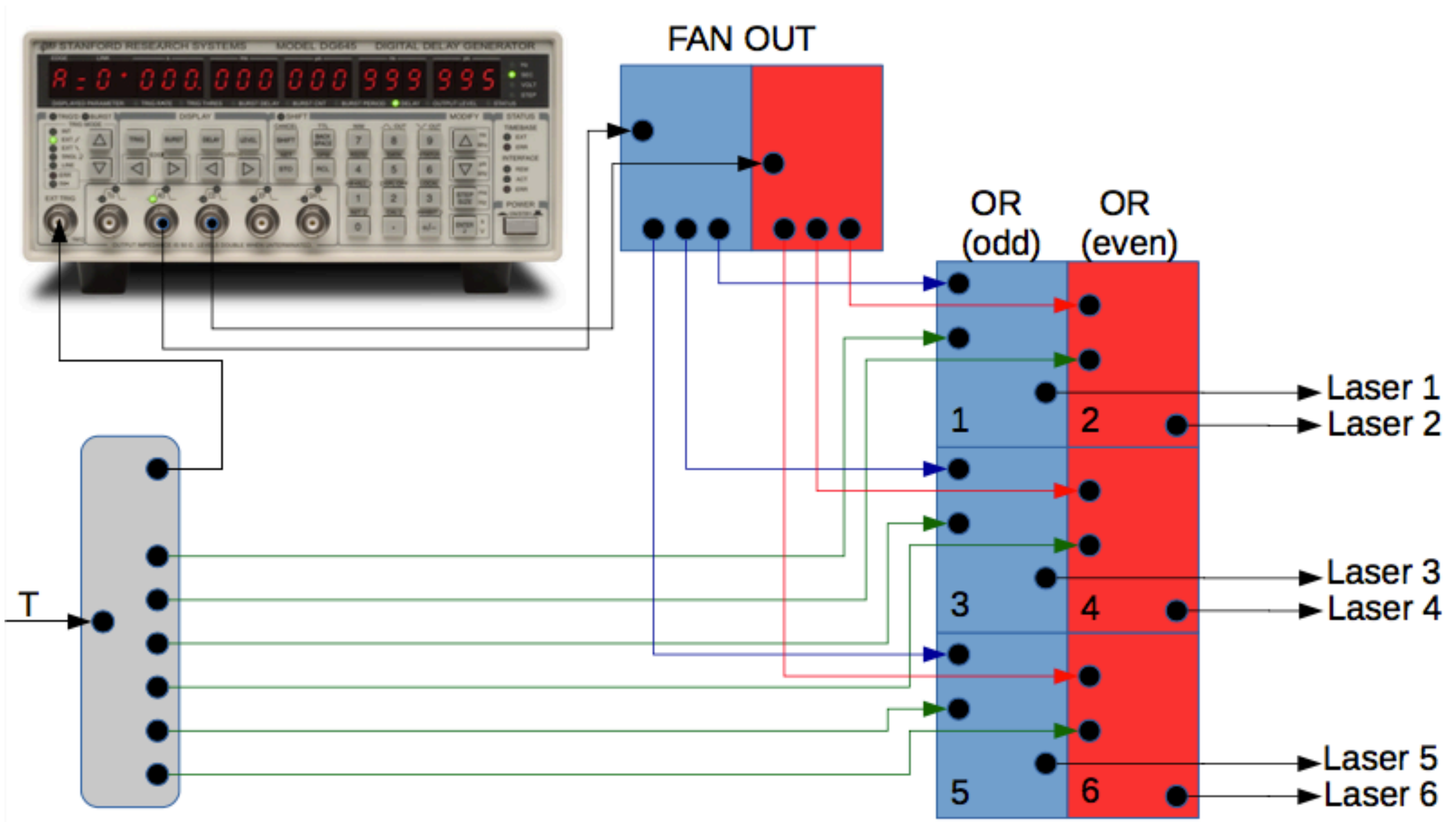
Double pulse – Delay generator



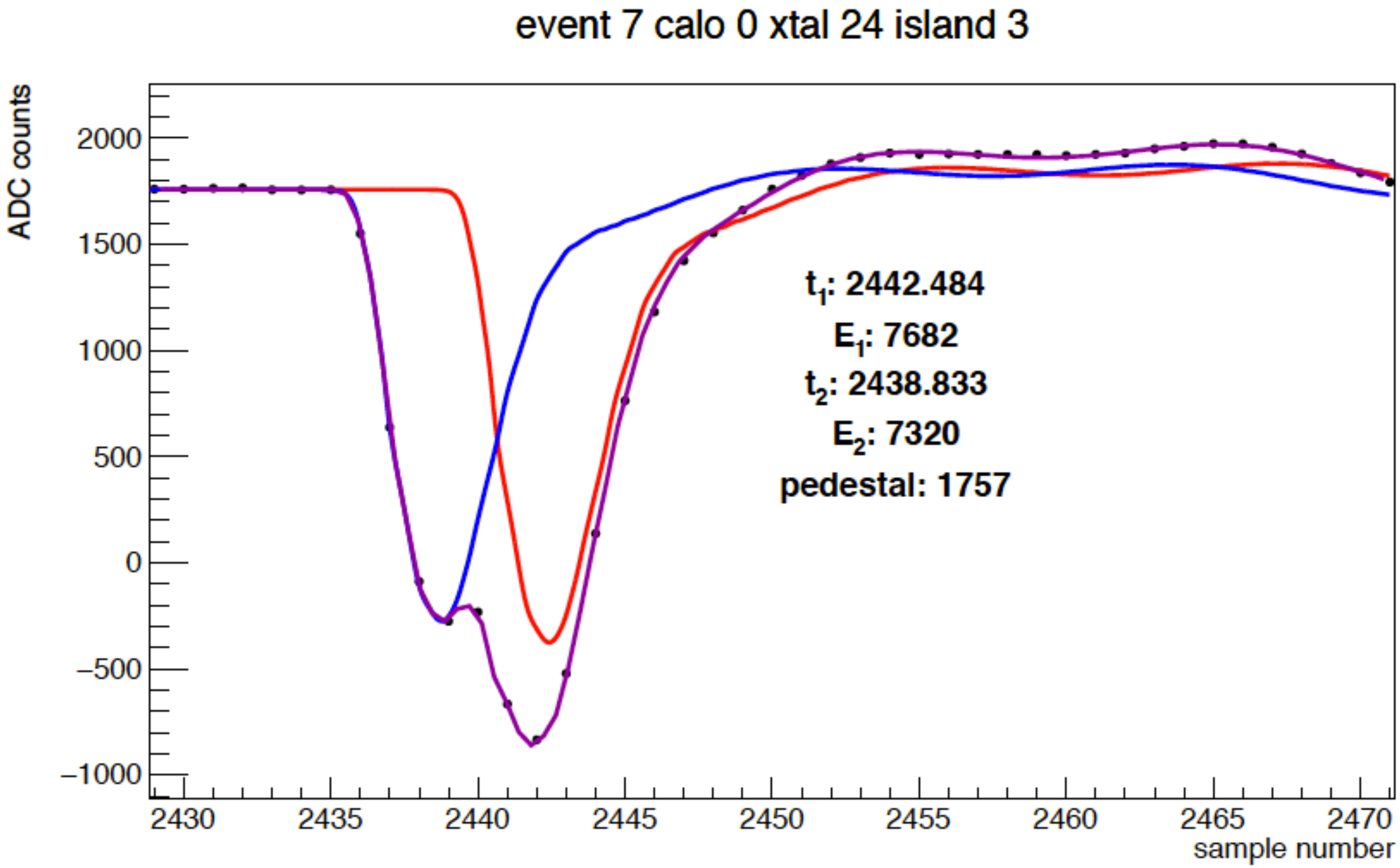
The output signals are sent toward the even and odd lasers respectively, with typical delays of 1-300 ns.

Double pulse – NIM logic

The last thing to be made was the physical connection between the delay generator and the lasers. A couple of NIM modules were utilized to FAN OUT the signal to the odd and even lasers.



Double pulse – Signals



Typical double pulse signal with 4 ns separation. A template fit of the two pulses is superimposed.

Double pulse – Conclusions

Unfortunately there were no time for me to complete the gain and response analysis of the double pulse system, also because changes of the g-2 analysis software were needed.

However the setup is now completed and functioning, and a full run with delays from 0 to 40 ns has been made for future work.

Fermilab 50th – Open House Event

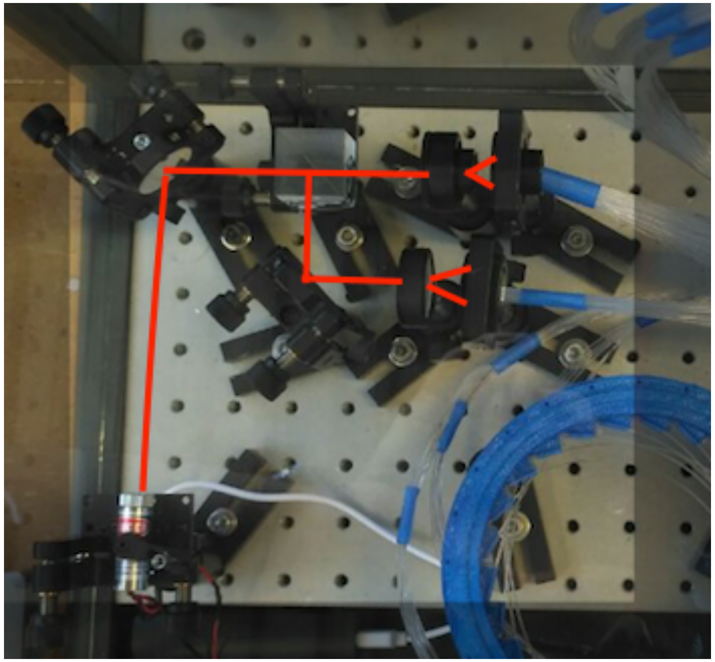
This year Fermilab turned 50, and a huge public event has been organized with more than 10’000 people participating.

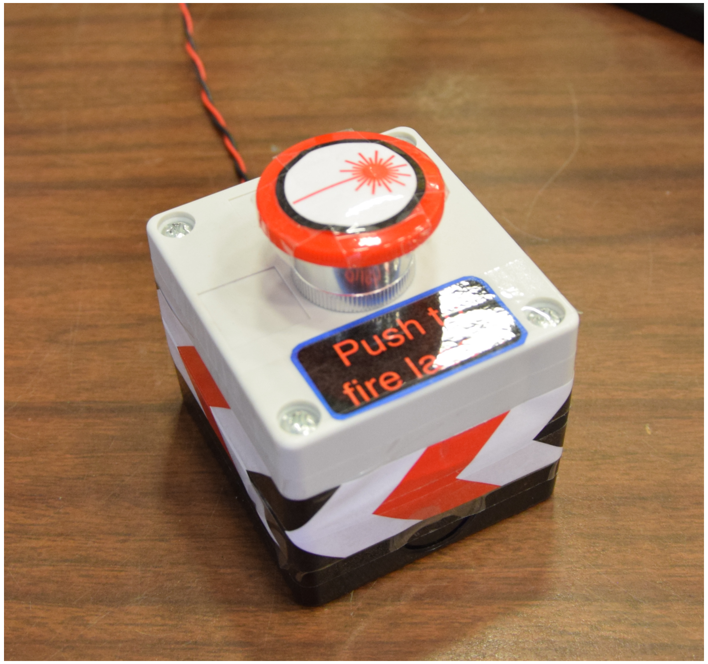
The Muon g-2 experiment had his own exhibition, allowing the visitors to enter into the magnet room. Many posters, videos, demos and display cases were arranged, and I contributed to this event by building a laser curio.

The plan was to build a smaller version of the laser calibration system with real components, and to allow the public to visually and phyisically interact with it.

Laser curio

We decided to have a simple setup with a laser and some mirrors to mimic the actual laser system. A red laser pointer fires a beam that gets divided with a cube splitter.
The two resulting beams go through a diffuser respectively.

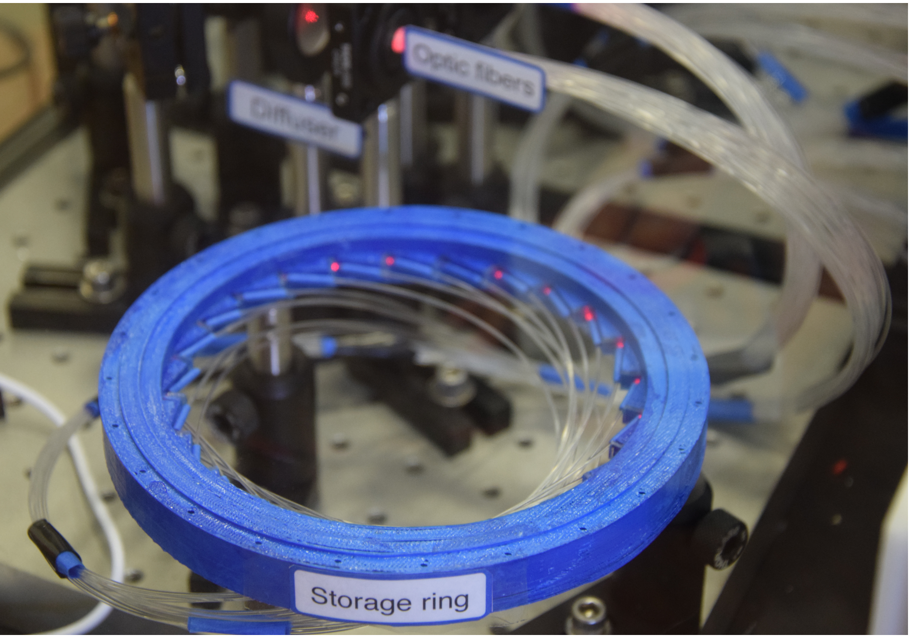


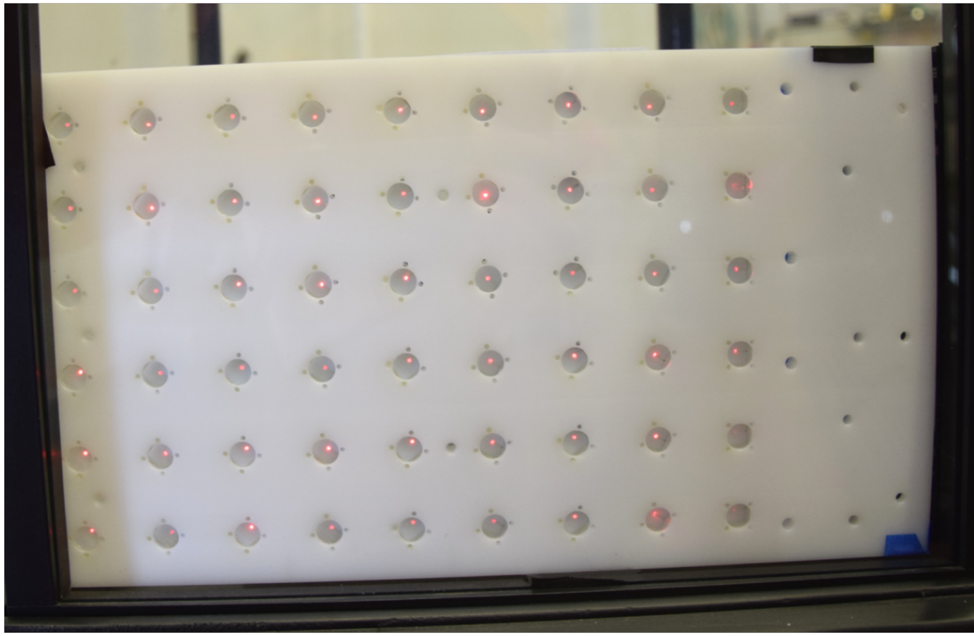


The public can fire the laser by pushing the button!

Laser curio

One beam lights a bundle of 24 plastic fibers. Those fibers go toward a 3D printed model of the magnet ring. Each fiber is glued to a piece of plexiglass, representing a calorimeter.

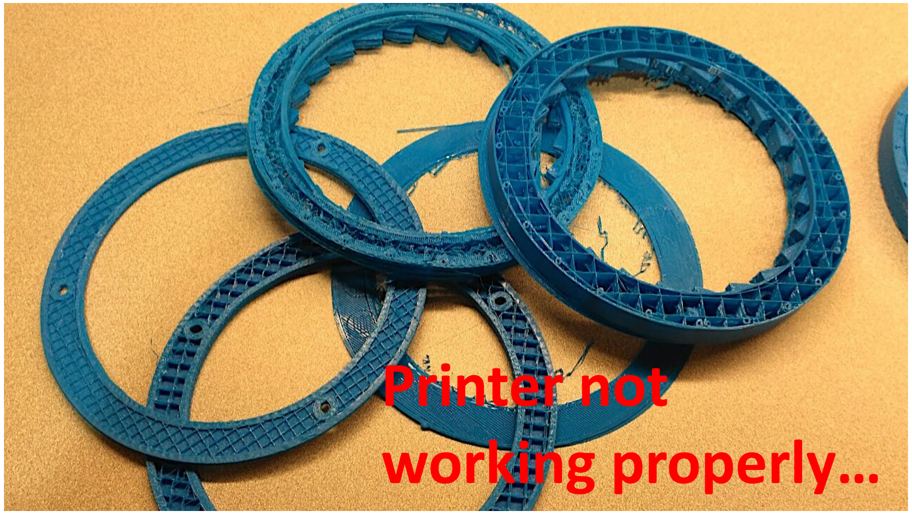


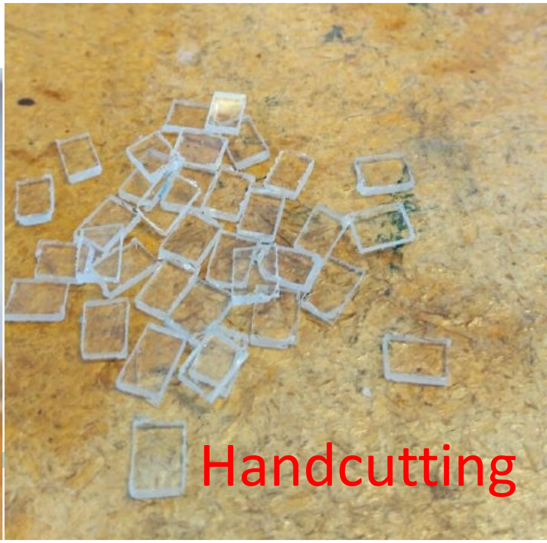


The other beam lights a bundle of 54 fibers. Those go inside a real panel with 54 prisms, used to bring light to the individual crystals of a calorimeter.

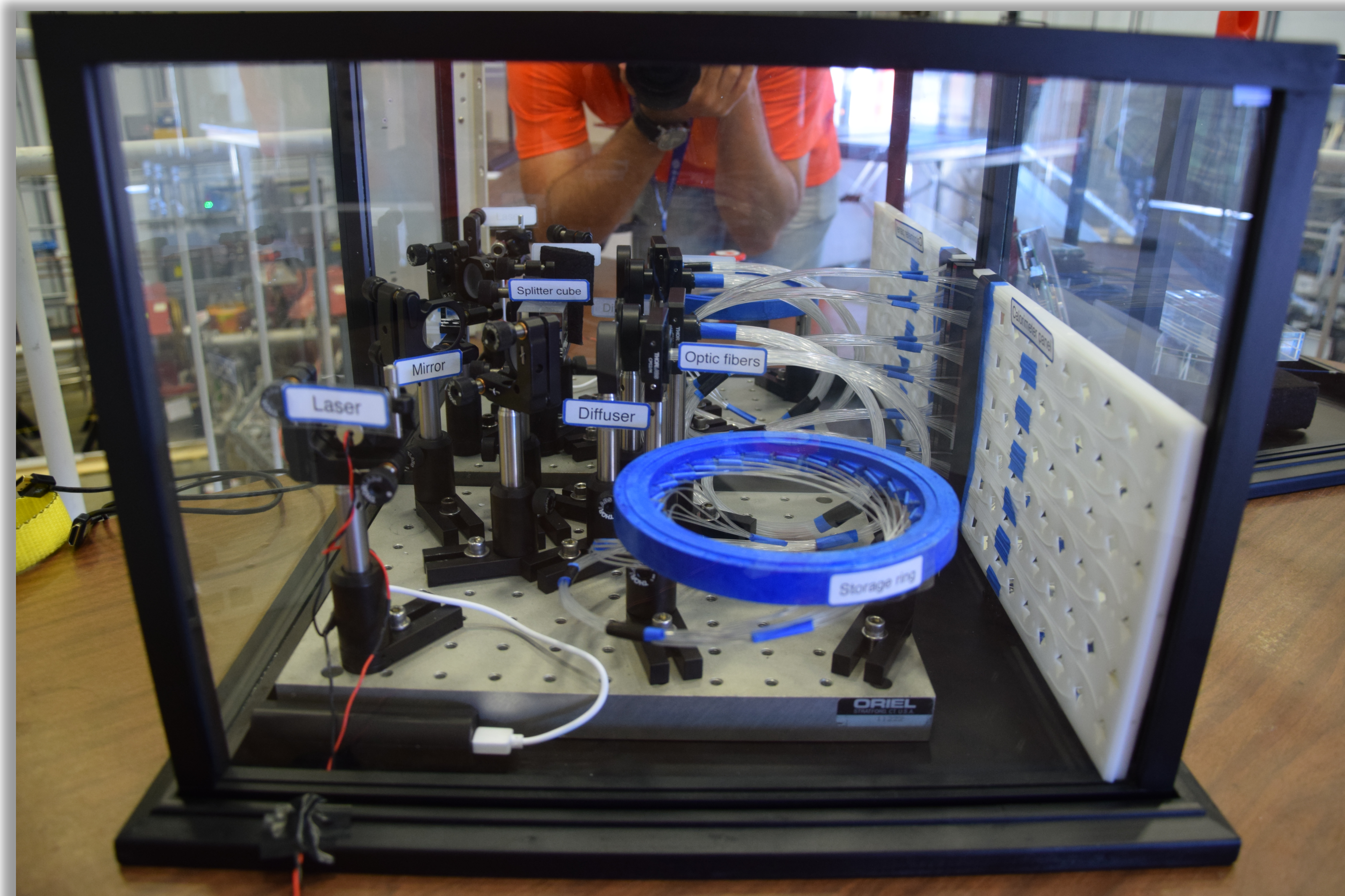
Hard times!

I struggled a lot to get a nice printing, to cut plexiglass and to glue fibers!





Laser curio



Fermilab

Conclusions

This experience was unique for me. I learnt a lot, both in the hardware and the software world, and I now understand what it means to work in such a rich environment as an international collaboration is. It is very satisfying to know that I contributed, yet in small part, to this important experiment.

I would like to thank all the Italian colleagues I had the honor to work with, for the sympathy and the professionality they brought to the workplace.

Thanks for your attention!