MUSE is a EU funded project under the Horizon 2020 Research and Innovation program. It coordinates the activities of about 70 researchers from various European research institutes (INFN, University College London, University of Liverpool, Helmholtz-Centrum Dresden-Rossendorf, Fermilab) and industries (PRISMA, CAEN, AdvanSid) for the participation to the experiments at the Muon Campus of the Fermi National Laboratory (FNAL), in USA.

Results from Test Beam

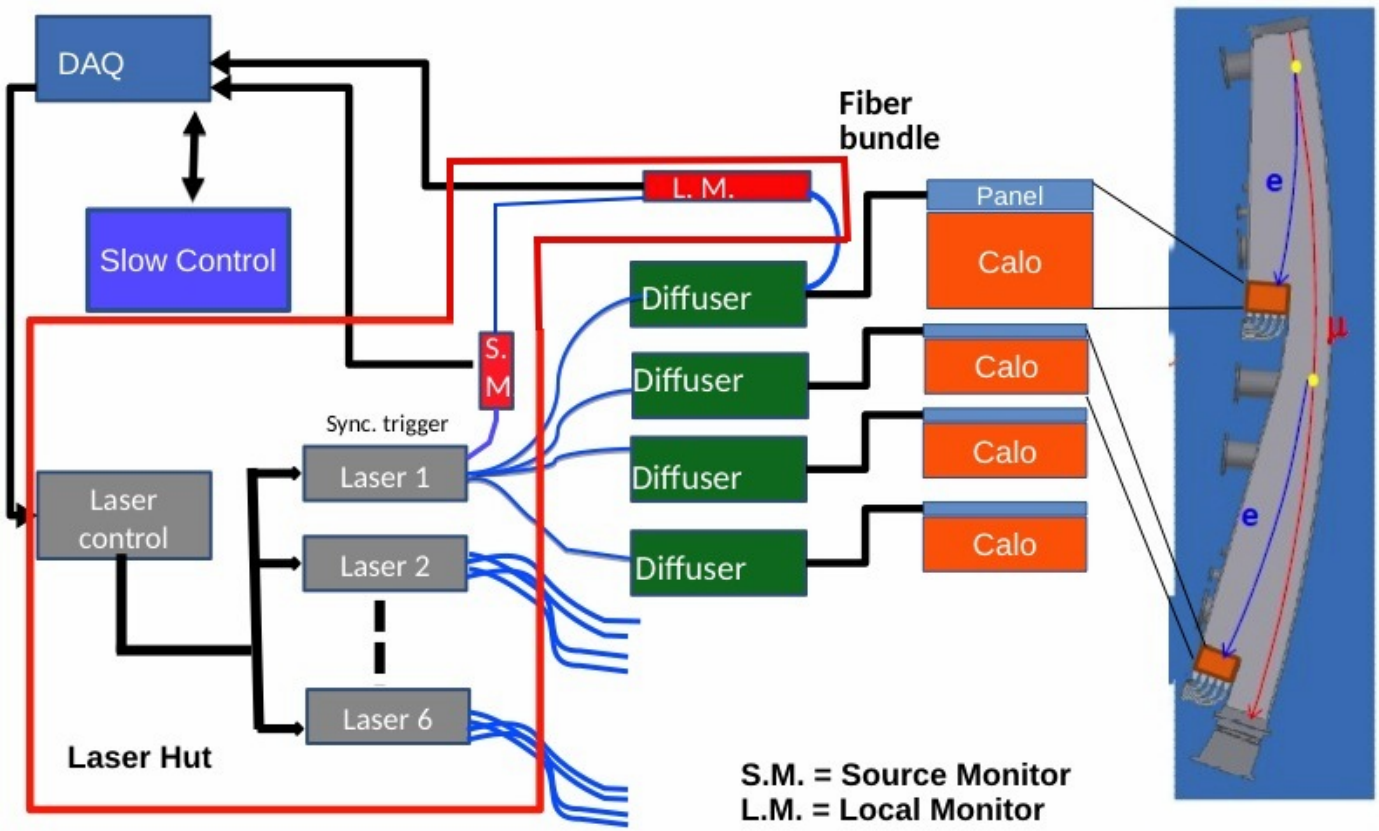
Anna Driutti
INFN & University of Udine

MUSE General Meeting
Pisa, September 29th 2016

Outline

Laser-based calibration system for the muon *g-2* experiment

- Objectives:
  - calibration of detection time;
  - equalization of crystal response and light intensity;
  - calibration of positron energy measurements;
- Key elements:



The Frascati Test Beam

Purpose:

- testing complete calibration system chain;
- calibrating equivalent luminous energy of the laser.

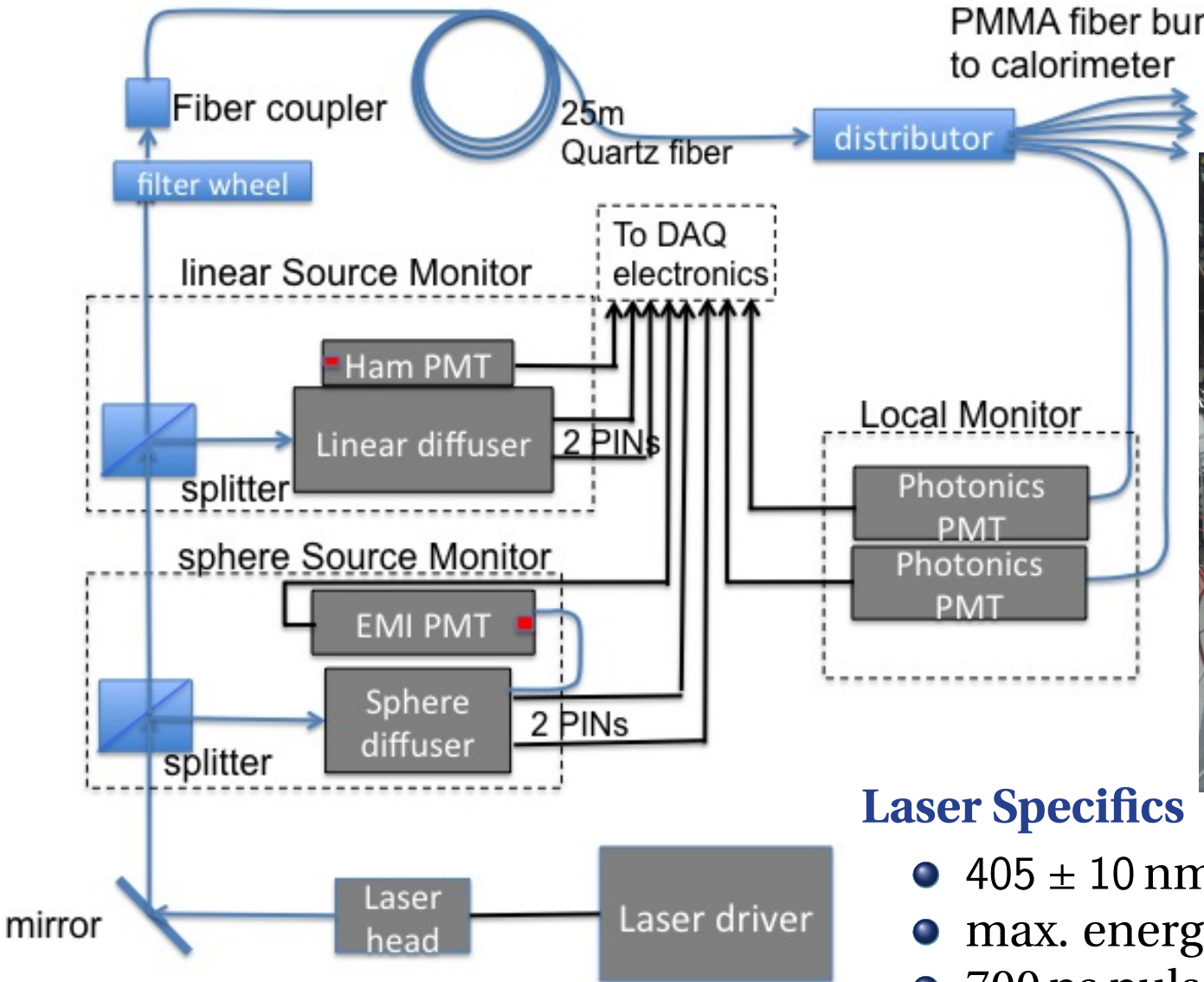
Beam Test Facility (BTF) @ Laboratori Nazionali Frascati (LNF)

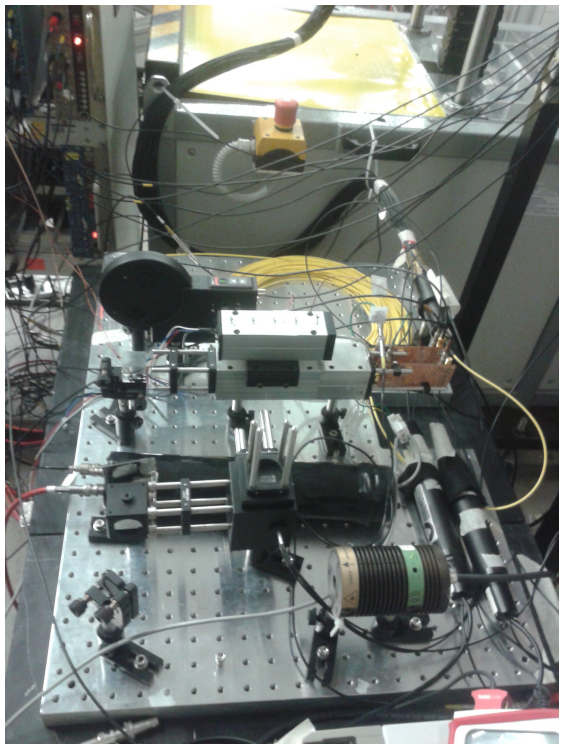
- BTF is part of the DAΦNE accelerator complex
- 100 m^2 instrumented experimental hall

The Electron Beam

- highly collimated;
- 450 MeV ±1% monoenergetic;
- 10 ns spill @ 50 Hz repetition rate;
- average of 1-3 electrons/pulse;
- 250 μm of diameter.

Experimental Setup: Laser Distribution System





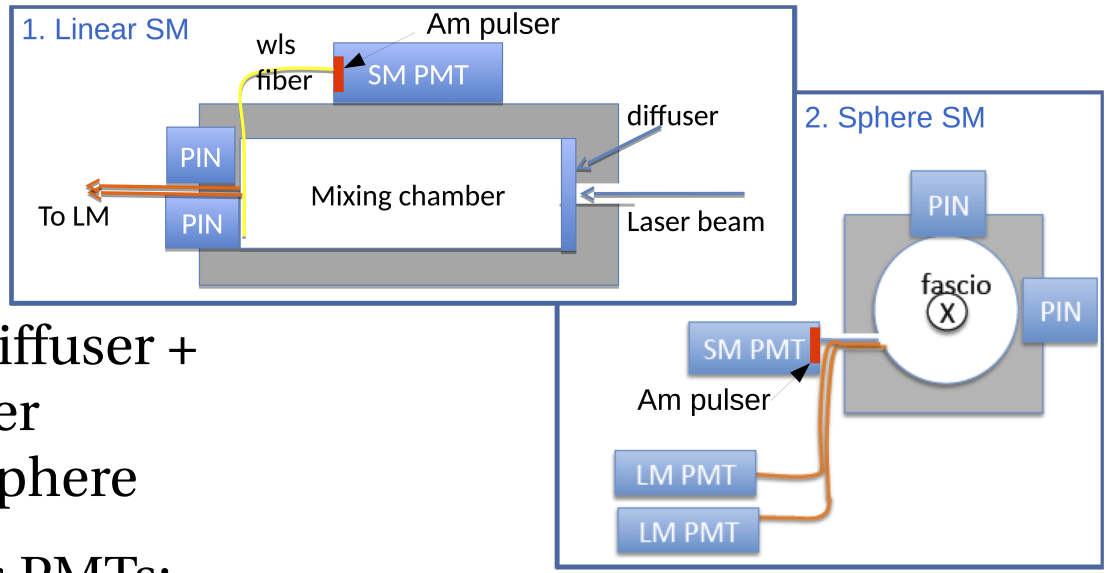
Laser Specifics

- 405 ± 10 nm laser by PicoQuant;
- max. energy pulse 1 nJ;
- 700 ps pulse width;
- up to 40 MHz repetition rate.

Experimental Setup: Monitoring system and Calorimeter

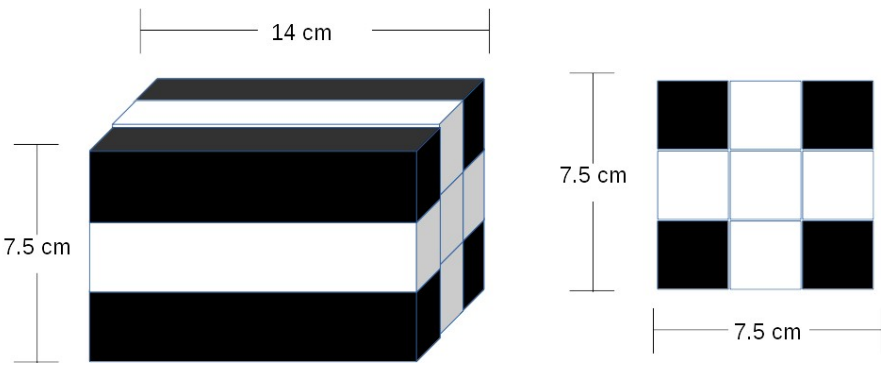
Monitoring System:

- two Source Monitor designs:
  1. Linear SM: engineered diffuser + reflective mixing chamber
  2. Sphere SM: integrating sphere
- Local Monitor: two Photonics PMTs;
- custom PIN frontend electronics;



Calorimeter:

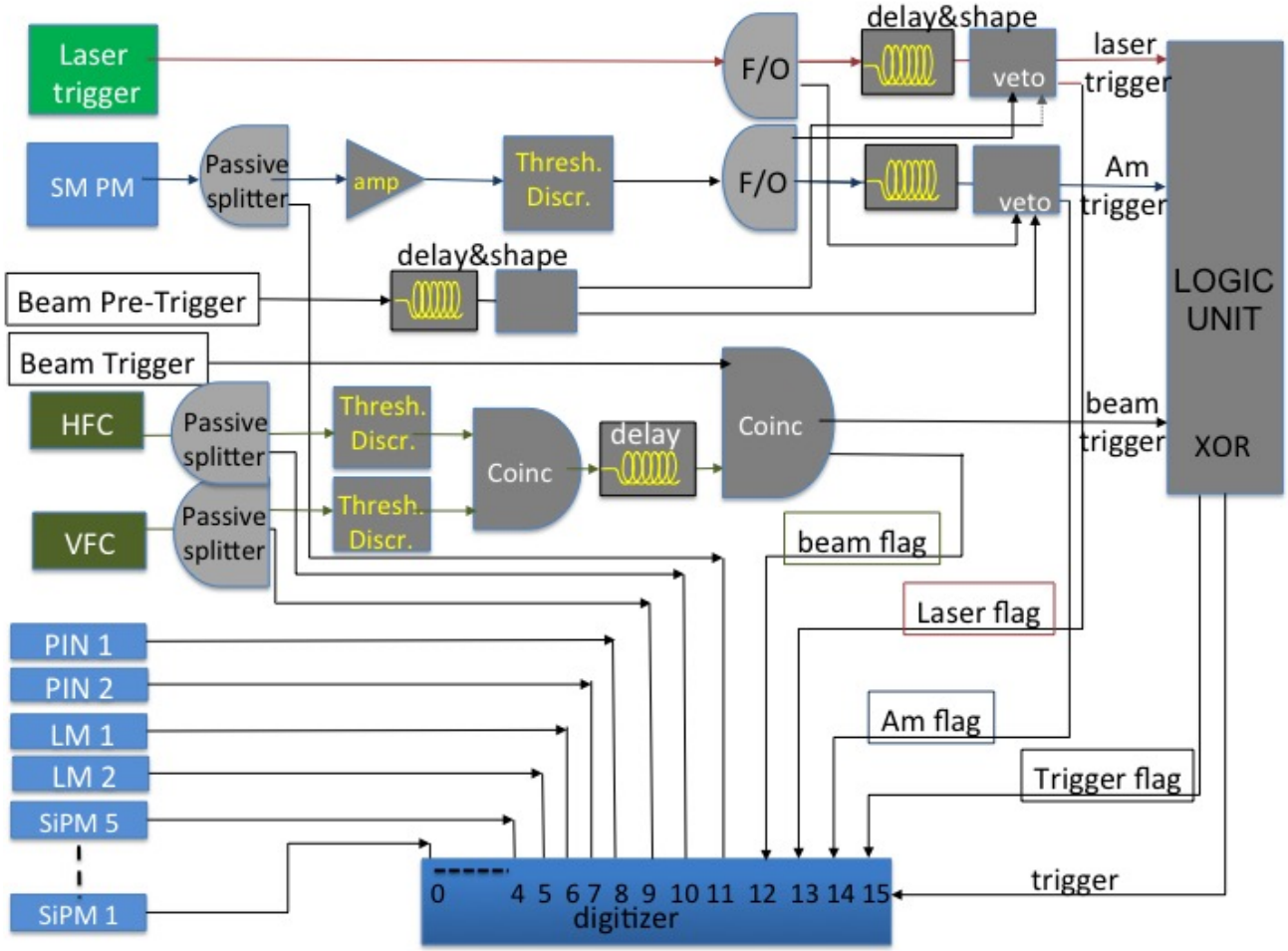
- final detector's subset of 5 elements;
- element = $2.5 \times 2.5 \times 14\ \mathrm{cm}^3$ PbF_2 crystal + 16 ch. Hamamatsu SiPM;
- 4 mock Plexiglass crystals.



Experimental Setup: Acquisition System

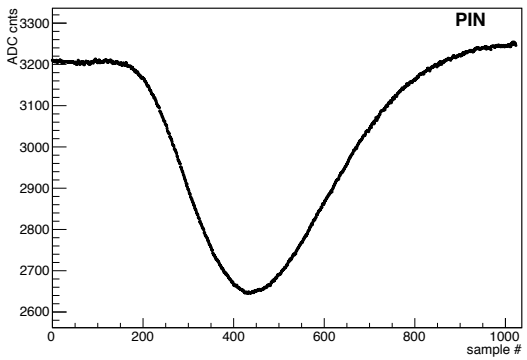
DAQ included:

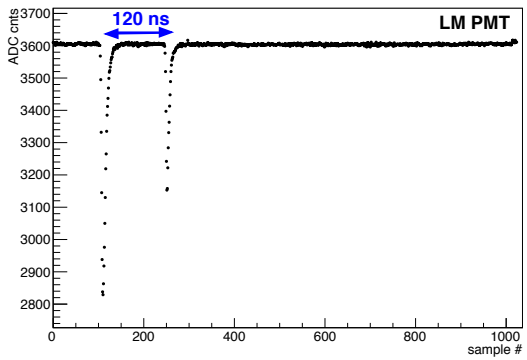
- two CAEN digitizer (5742, 5 GS/s);
- 3 triggers (beam, laser, Am) using NIM electronics;
- ambient and SiPMs temperatures.

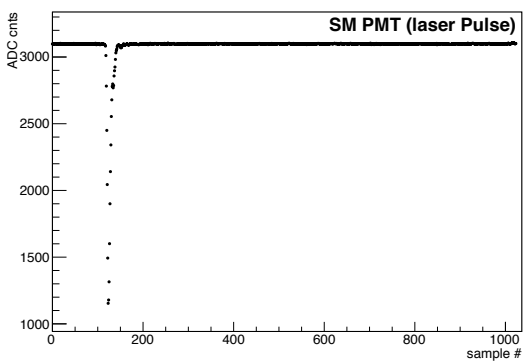


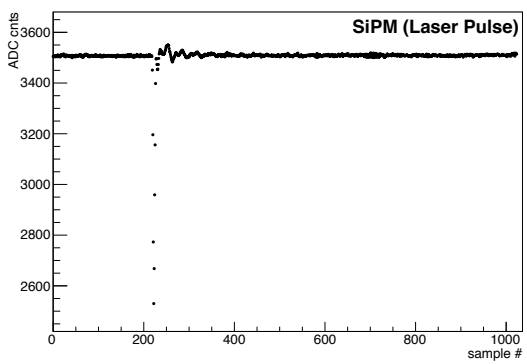
Experimental Setup: Typical Events

Laser Events

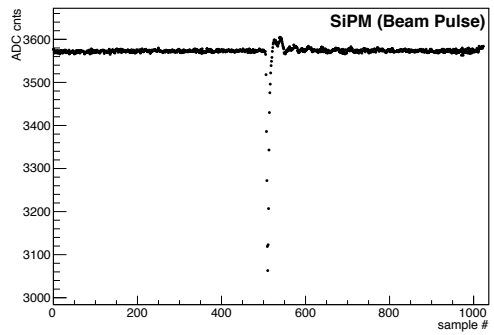




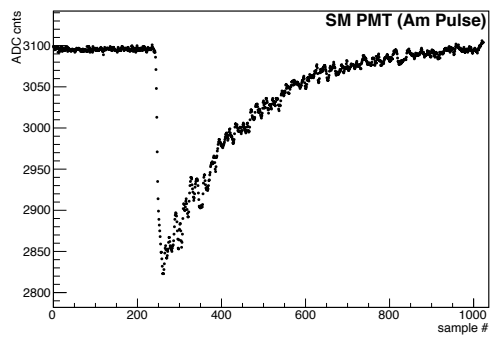




Beam Events



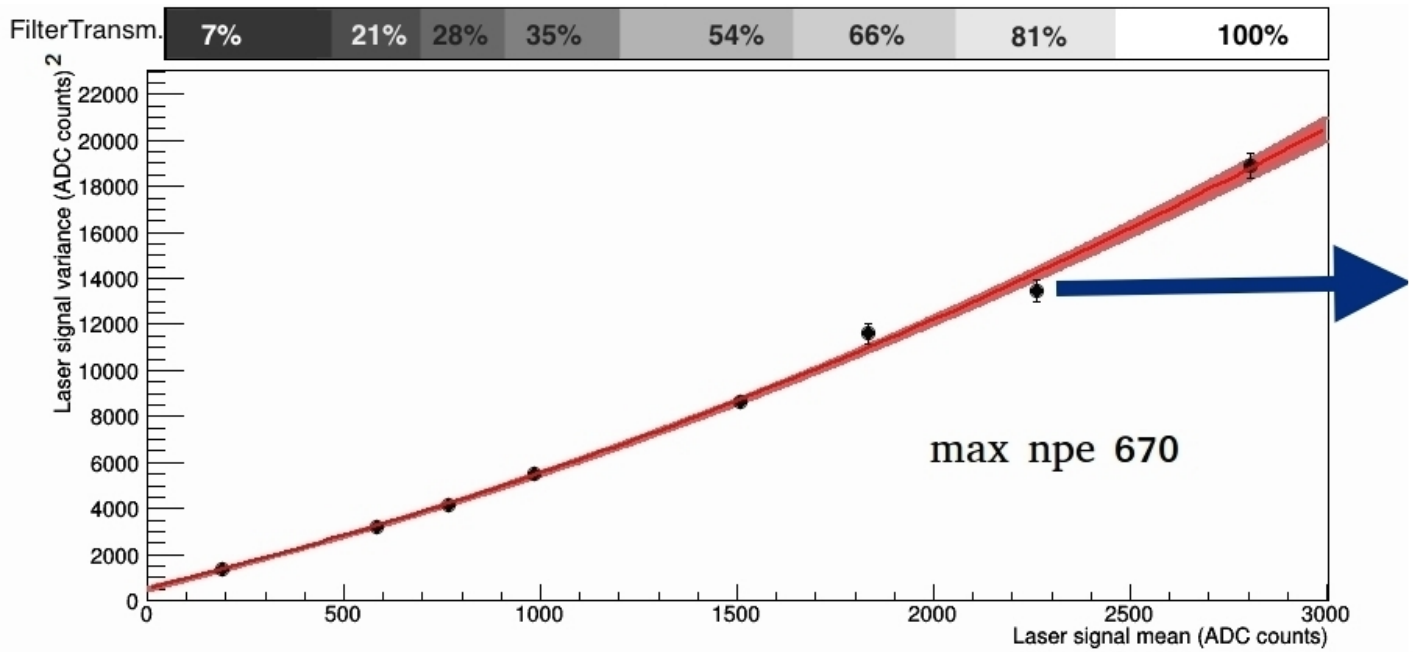
Americium Events

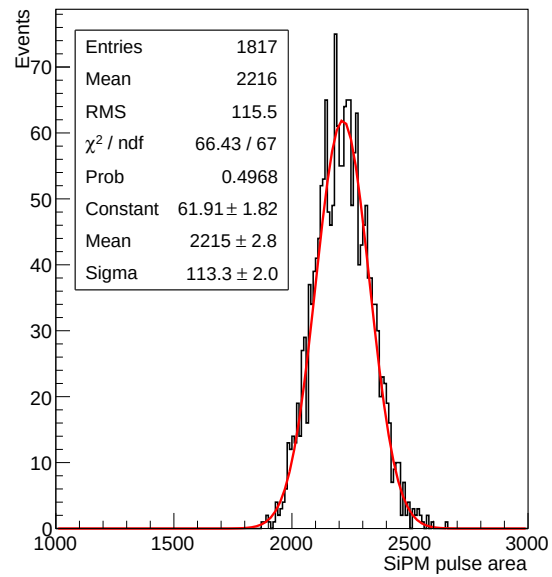


Results: Calibration trough photostatistics

- using laser data with different intensities obtained with filter wheel;
- laser-pulse area: mean (μ_L) *vs* variance (σ^2_L):

$$\mu_L = k n_{p.e.} \qquad \sigma^2 = \underbrace{\sigma^2_{noise}}_{\text{electronic noise}} + \underbrace{(k\sqrt{n_{p.e.}})^2}_{\text{Possion statistic}} + \underbrace{\alpha(k n_{p.e.})^2}_{\text{intrinsic fluctuations}} = \sigma^2_{noise} + k\mu_L + \beta\mu_L^2$$





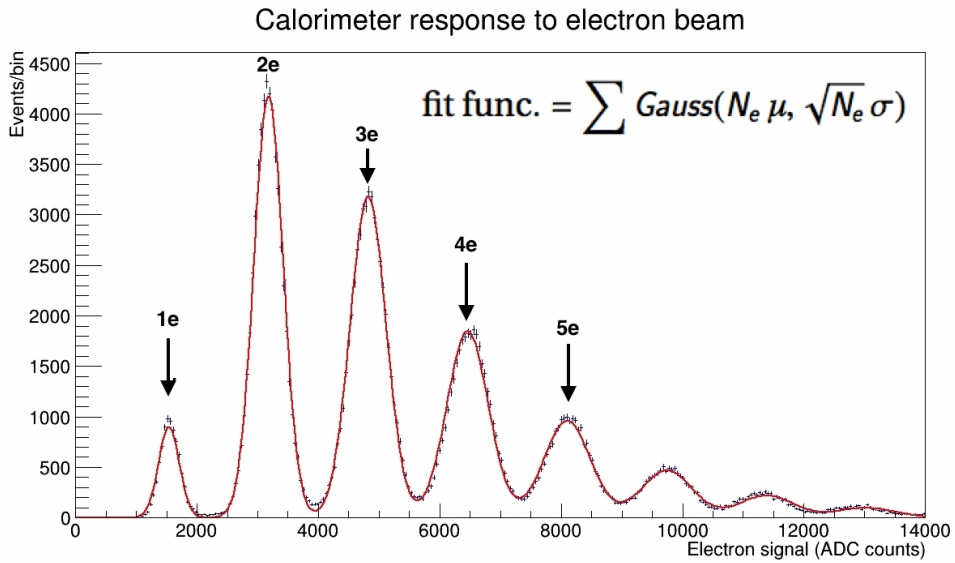
- from fit identify k as $p1$ the pulse area/p.e.
- measured 600-800 p.e. depending on SiPM, bias voltage and temperature.

Results: Equivalent light Calibration

Photoelectron yield from beam:

$$(\mu_{1e}/k) \,/\, 450\,\text{MeV} = 0.9\,\text{p.e./MeV}$$

- μ_{1e} single electron peak mean from fit.
- k from photoelectron calibration;
- 450 MeV e-beam energy;



Laser Equivalent Energy @ TB:

- μ_L mean-laser pulse area on SiPMs (filter 100% trasm.)
- $\mu_L/\mu_{1e} \sim 1.8 \Rightarrow$ Laser Equivalent Energy @ TB $\sim$ 800 MeV

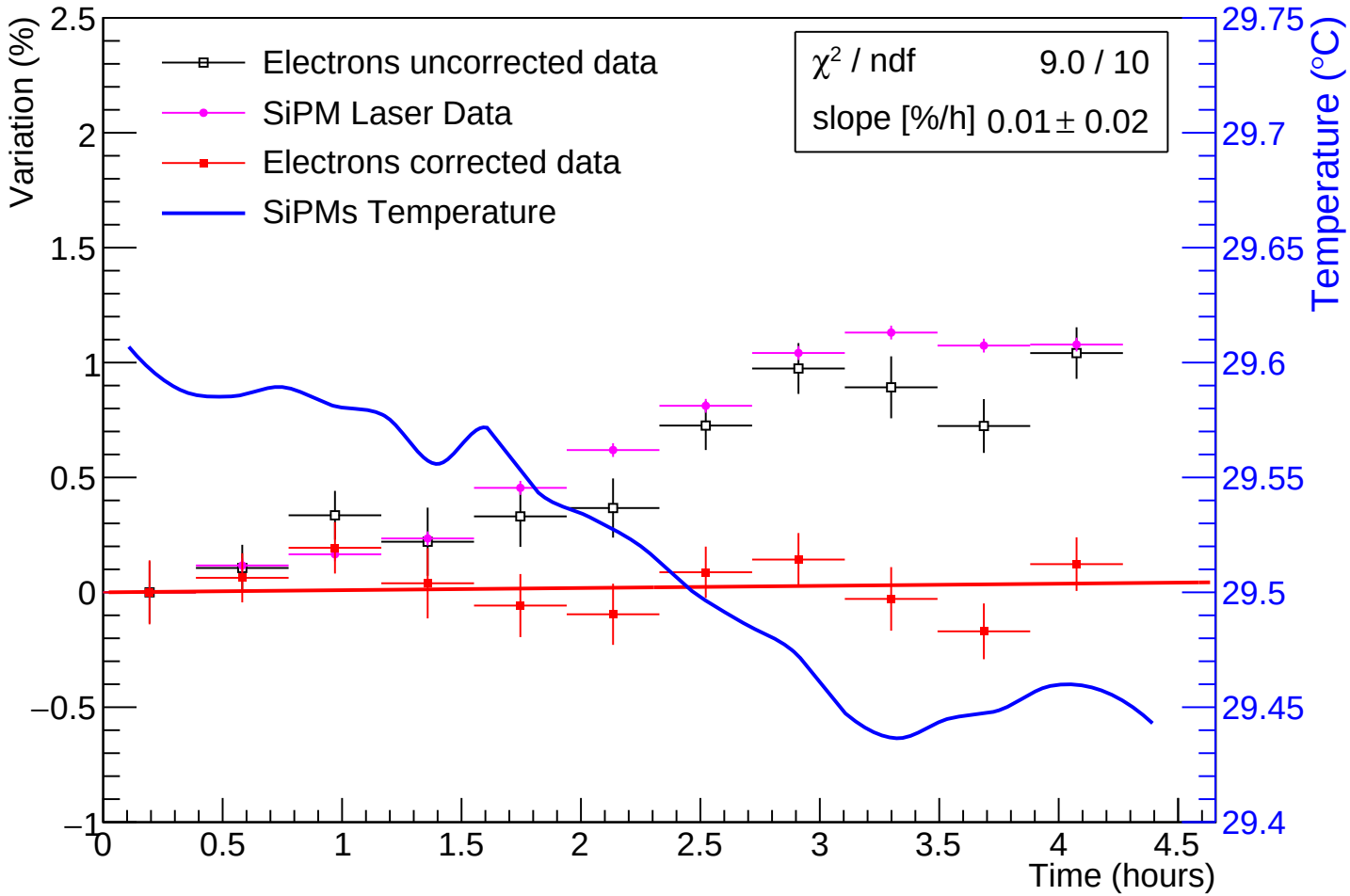
Scale to experiment:

- light power before calorimeter:

  11.2 pJ measured @ TB *vs* 141 pJ expected @ experiment

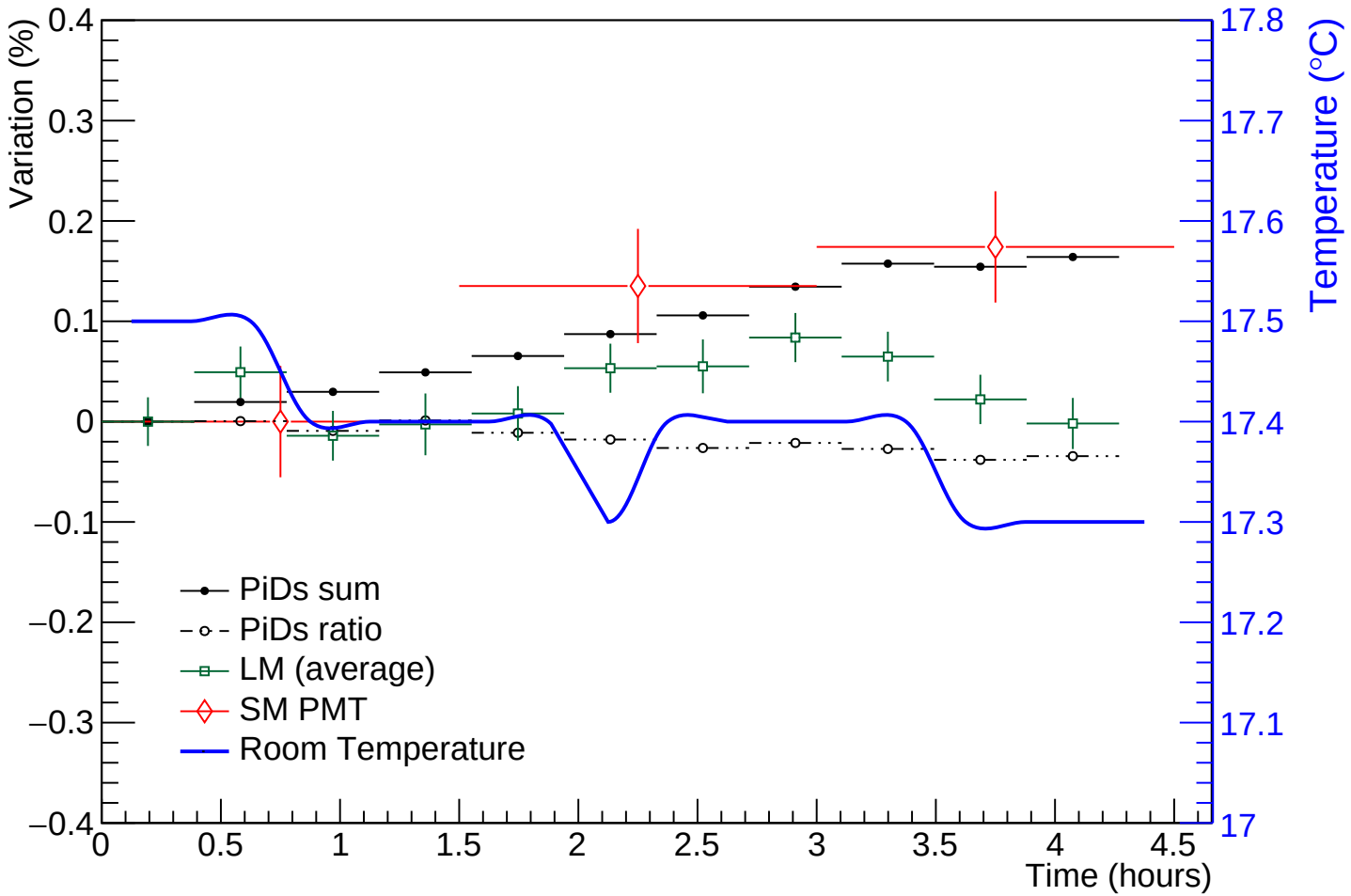
- Equivalent Maximum Energy: $800\,\text{MeV}/11.2\,\text{pJ} \cdot 141\,\text{pJ} = 10\,\text{GeV}$

Results: Stability monitoring and corrections



$$\text{Electron corrected data} = \frac{\text{Electron uncorrected data}}{\text{SiPM laser data/Monitor data}}$$

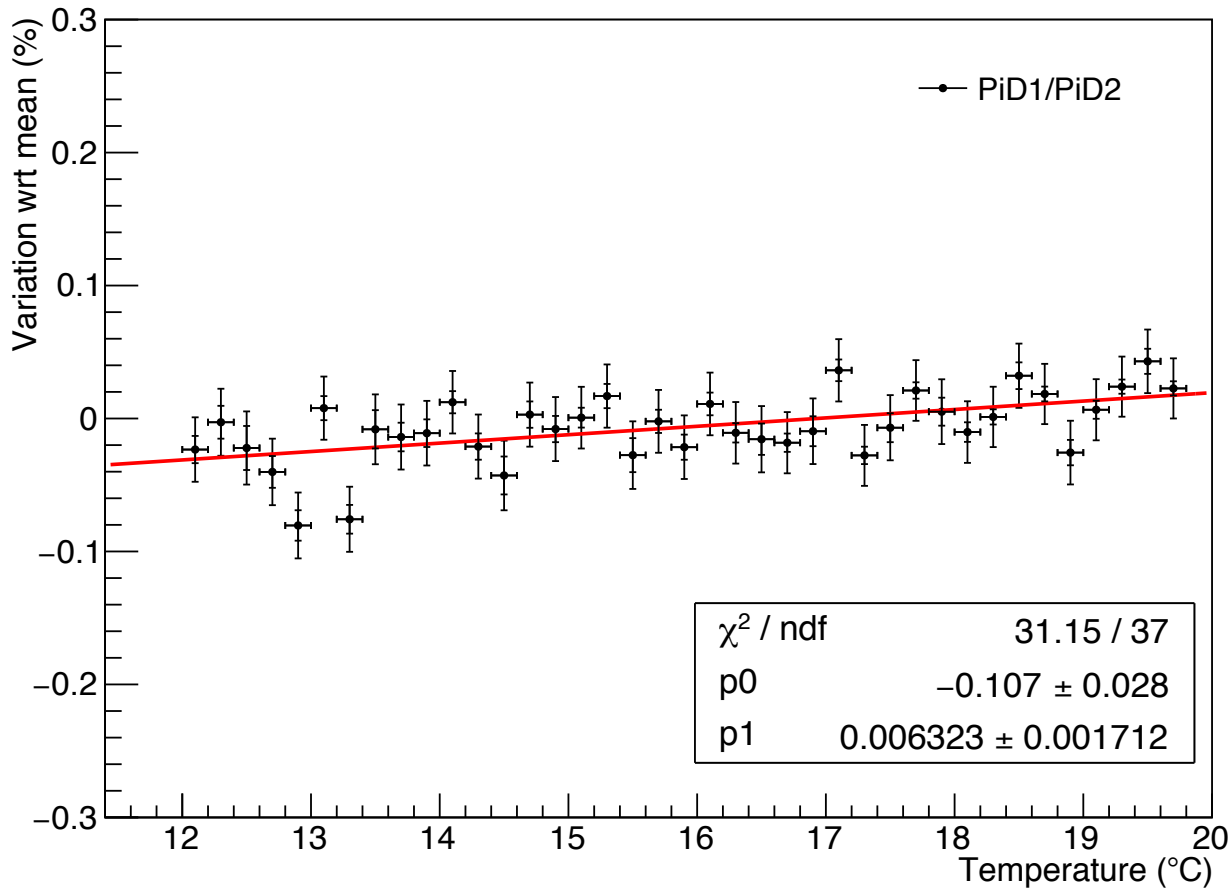
Results: Stability monitoring and corrections



Monitor data = PiDs Sum · LM (2nd pulse / 1st pulse)

Results: Temperature-dependence of PiDs response

- measured after TB with temperature-controlled chamber:
  - PIN under test: PiD1 inside chamber
  - reference PIN: PiD2 outside chamber
- PINs coupled with frontend electronics



The Frascati Test Beam in brief

- **Successful** test of the laser-based calibration system for the *Muon g*-2:
  - tested all system key elements;
  - measured electron-energy equivalent of the laser intensity: 10 GeV;
  - guaranteed light stability at sub-per-mill level (thanks to monitoring system);
- **Paper** to be submitted to Nuclear Instruments and Methods in Physics Research Sec. A (**NIM**) journal:

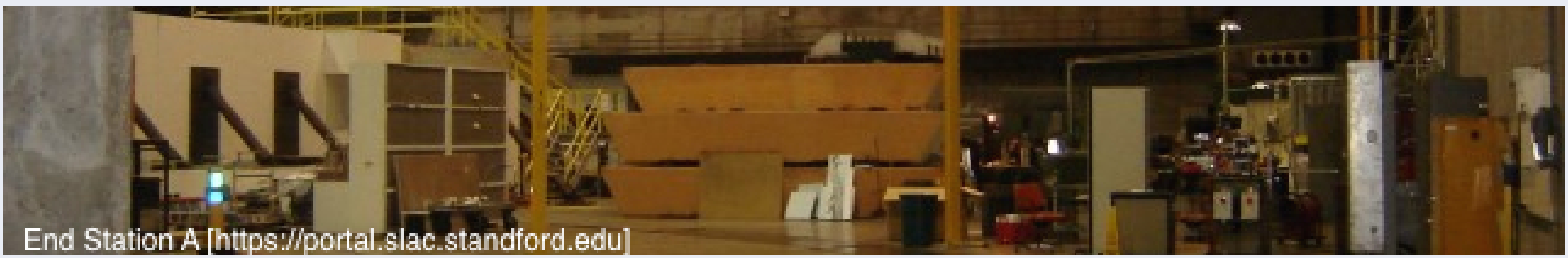
> Electron beam test of key elements of the laser-based calibration system for the muon $g-2$ experiment
>
> A. Anastasi[a,c,*], A. Basti[m], F. Bedeschi[m], M. Bartolini[m], G. Cantatore[d,g], D. Cauz[d,i], G. Corradi[a], S. Dabagov[a,q], G. Di Sciascio[f], R. Di Stefano[j,e], A. Driutti[i], O. Escalante[h], C. Ferrari[a,b], A.T. Fienberg[l], A. Fioretti[a,b], C. Gabbanini[a,b], A. Gioiosa[o,p], D. Hampai[a], D.W. Hertzog[l], M. Iacovacci[e,h], M. Karuza[d,k], J. Kaspar[l], A. Liedl[a], A. Lusiani[m,n], F. Marignetti[j,e], S. Mastroianni[e], D. Moricciani[f], G. Pauletta[d,i], G.M. Piacentino[o,p], N. Raha[f], E. Rossi[a], L. Santi[d], G. Venanzoni[a]

The SLAC Test Beam

Purpose:

- testing the full electromagnetic calorimeter system: from calorimeter to offline analysis.

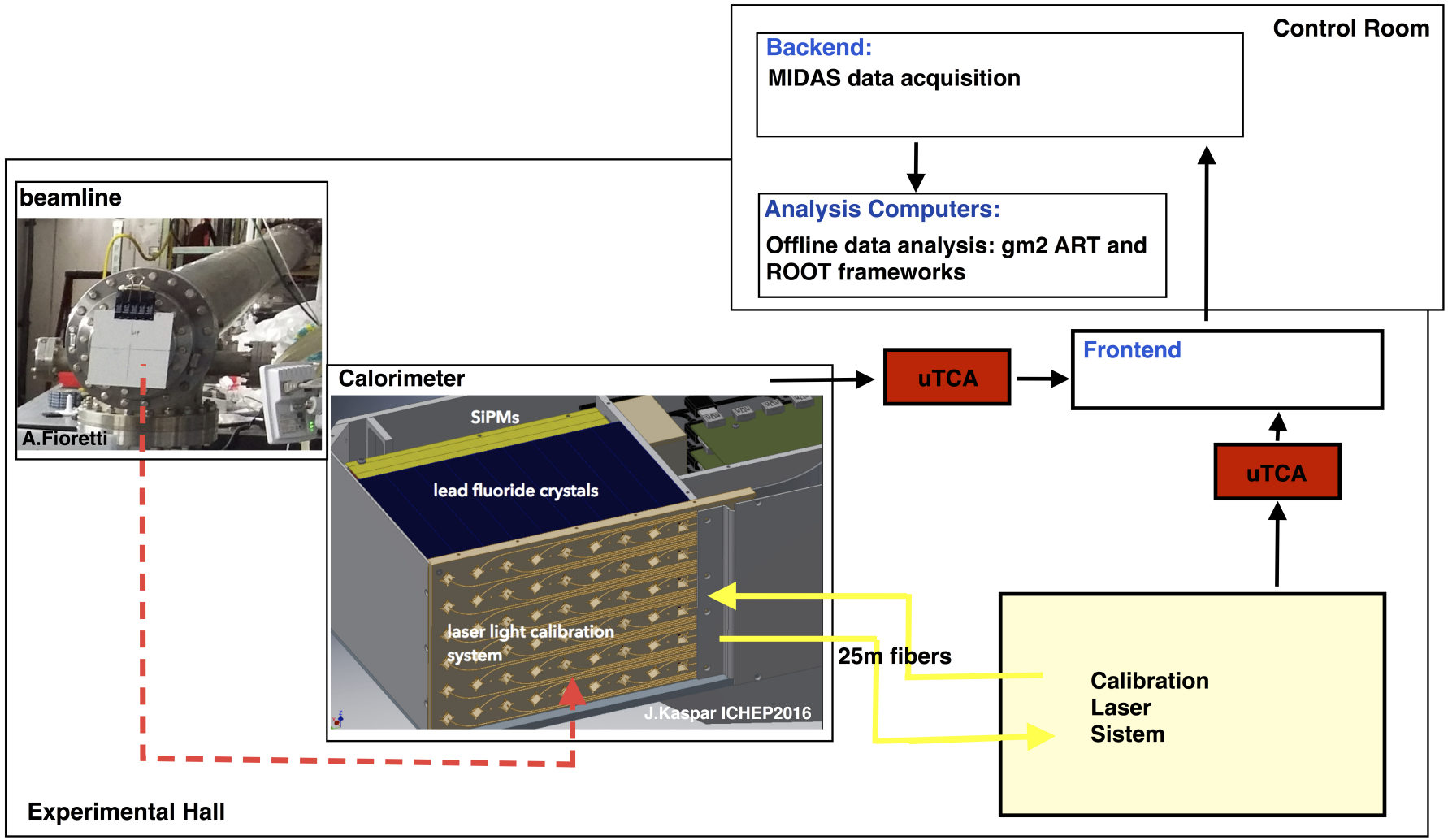
SLAC's End Station Test Beam (ESTB) Facility



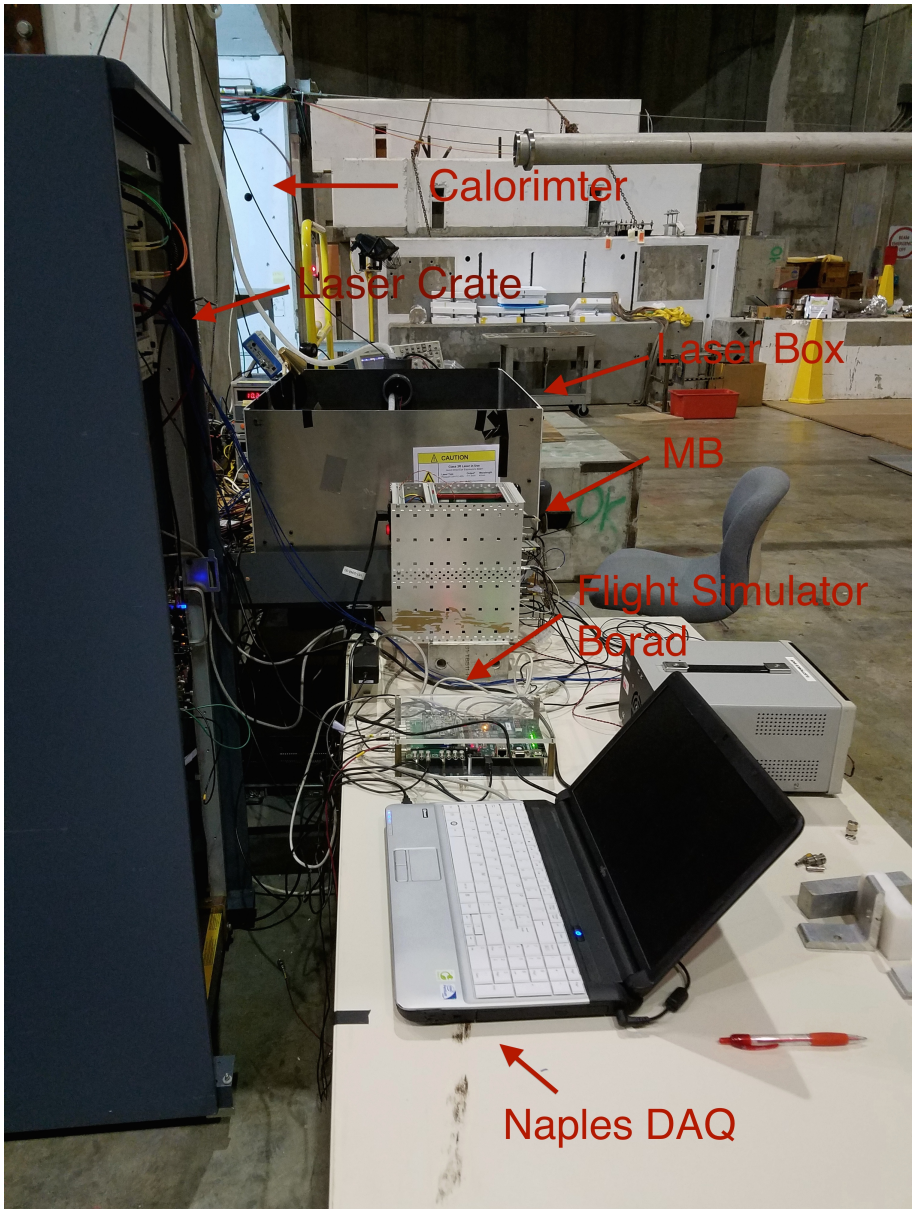
The Electron Beam

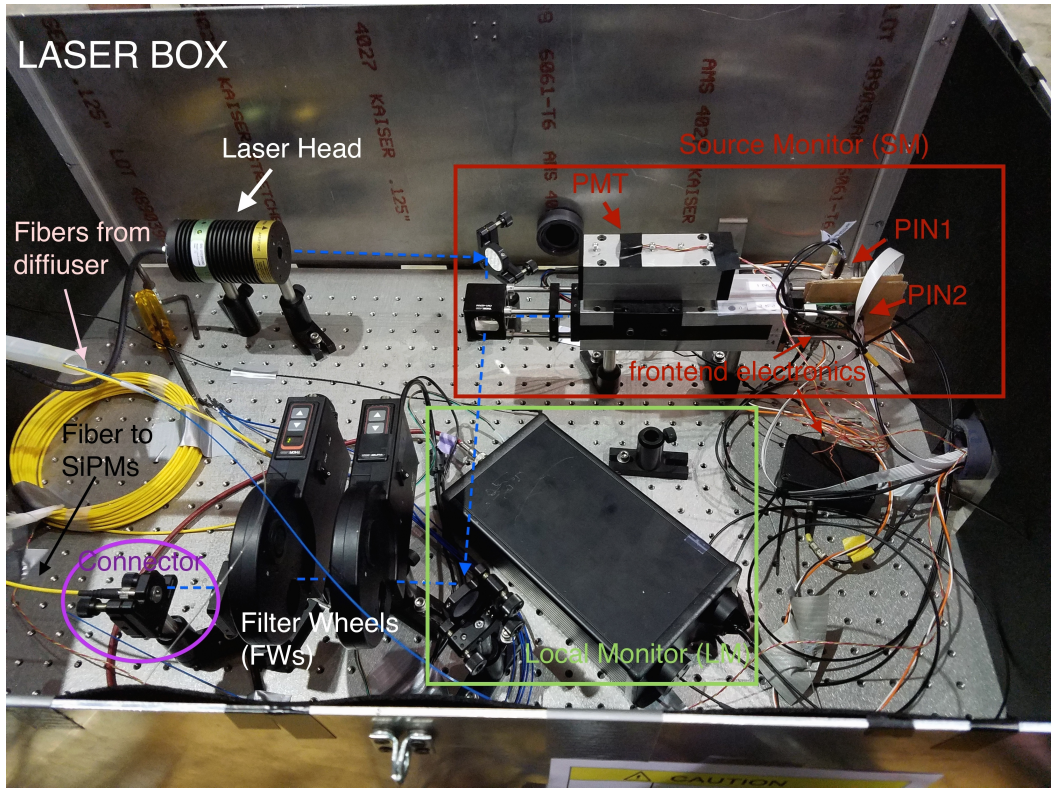
- well collimated;
- energies from 2 GeV up to 5 GeV;
- typical rate 5-10 Hz;
- single electron beam;
- two-bunch mode with 350 ns gap
- beam diameter ~ 1-2 mm.

Experimental setup



Experimental setup: Laser Calibration System



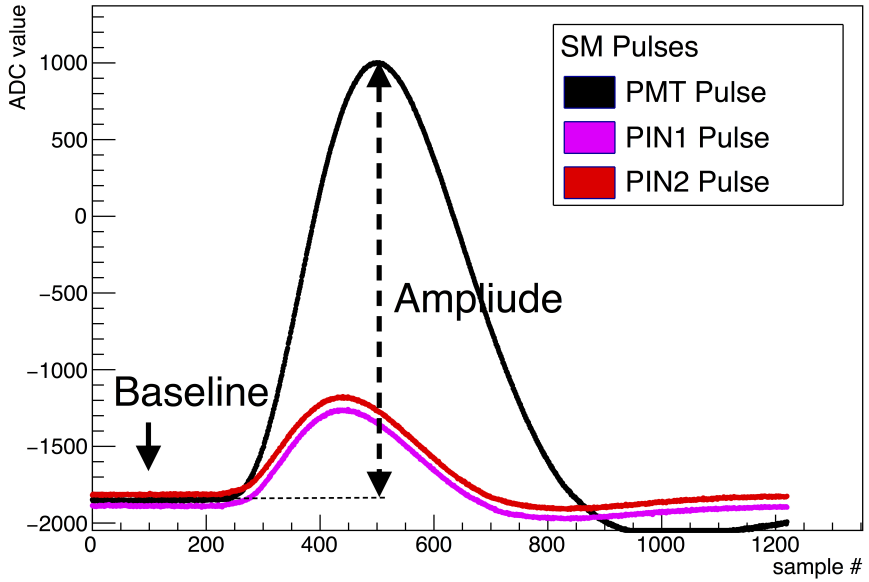


- linear SM and LM with one PMT;
- prototype of final version electronics;
- independent DAQ system;
- light chain as for experiment.

Monitoring System Performance

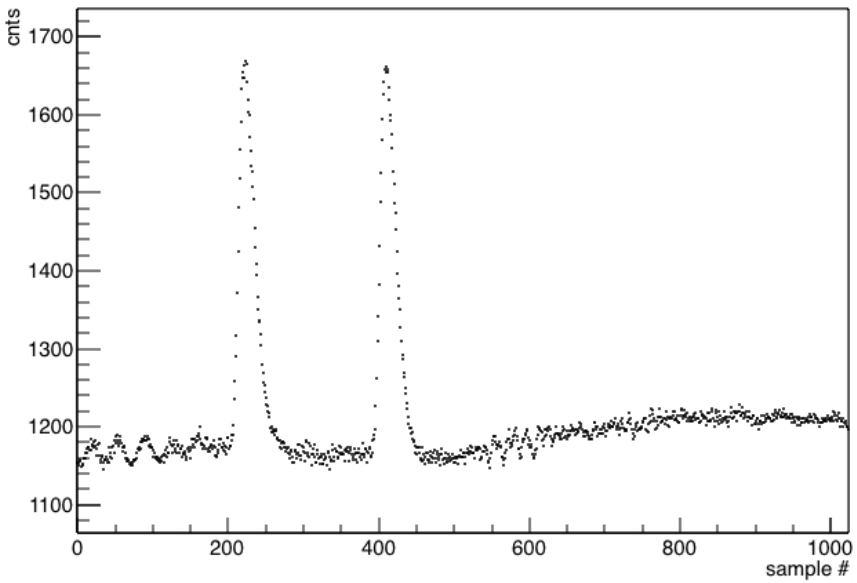
Source Monitor:

- PINs and PMT signals amplified, integrated, shaped and digitized by the electronics;
- SM signals sent to a dedicated μTCA digitizer (asynchronous readout not yet implemented);



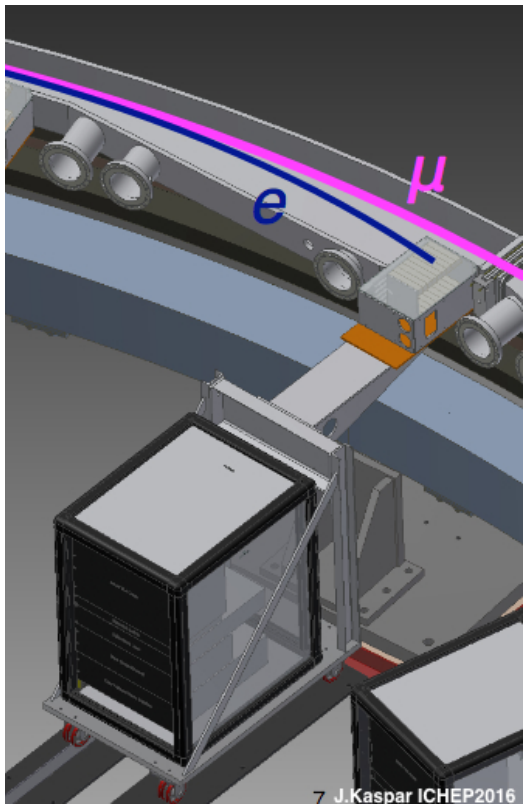
Local Monitor:

- LM readout by a dedicated μTCA digitizer;
- $\sim$ 240 ns time distance between pulses;
- new readout electronics in progress.



SLAC Test Beam in brief

- Tested the full calorimeter system for the *Muon g*-2 experiment:
  - calorimeter;
  - laser calibration system;
  - waveform digitizers;
  - DAQ;
  - offline data analysis framework.



- Results will be published soon.

Conclusions & Acknowledgements

- Two tests of the calorimeter system for the *Muon g*-2 experiment during 2016:
  - **Frascati Test Beam:** focused on the key elements of the laser-based calibration system;
  - **SLAC Test Beam:** integrated test of the full calorimeter system.
- Assembly and installation of the calorimeter system are in progress at Fermilab.

Acknowledgements: thanks to BTF and ESTB staff for support!