G-2 laser calibration system

C. Ferrari

INO, UOS Pisa, Via G. Moruzzi 1, 56124 Pisa
LNF, INFN Frascati

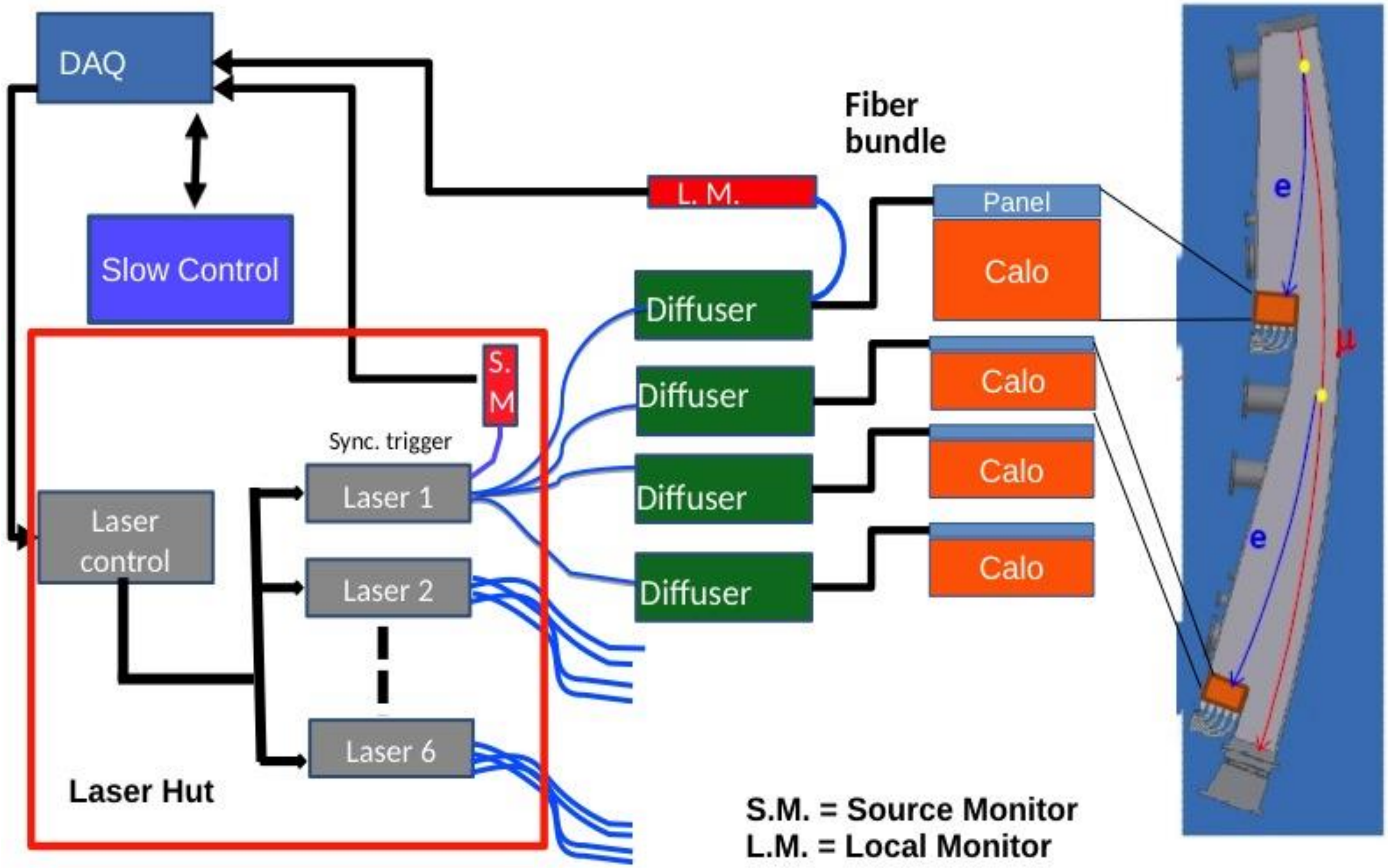
Why a laser calibration system?

Time reference:
The 24 calorimeters WFD are not syncronized.
We send a laser pulse before the Muon fill to each photosensor (SiPM).

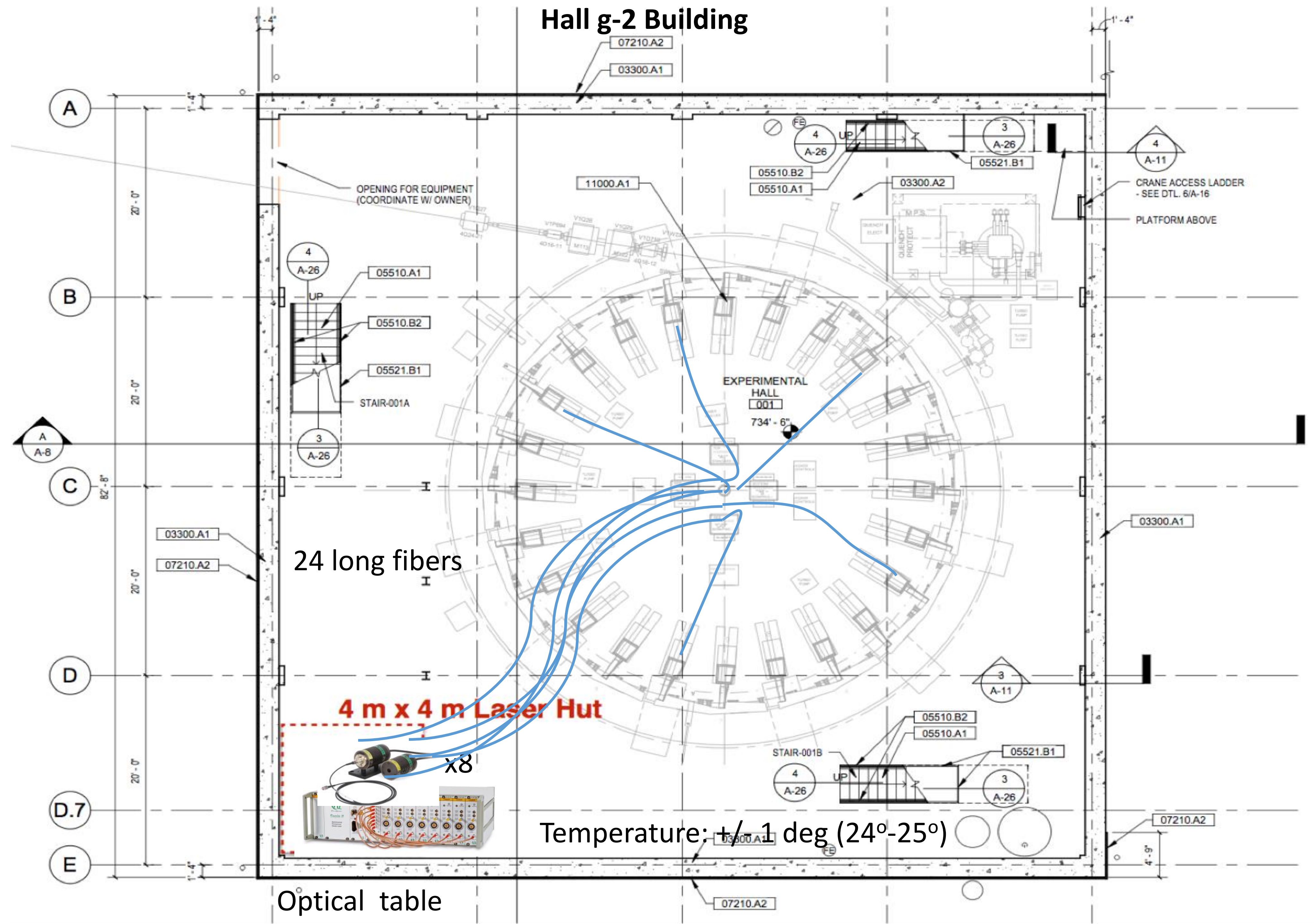
Energy calibration:
The photon detection efficiency of the SiPM must be calibrated.
We send laser pulses with different intensity (filter wheel).

Gain calibration (short and long term):
SiPM gain is not stable, it depends on temperature, bias voltage and rate.
We send a reference laser pulse (known energy) to each photosensor.

Laser calibration scheme



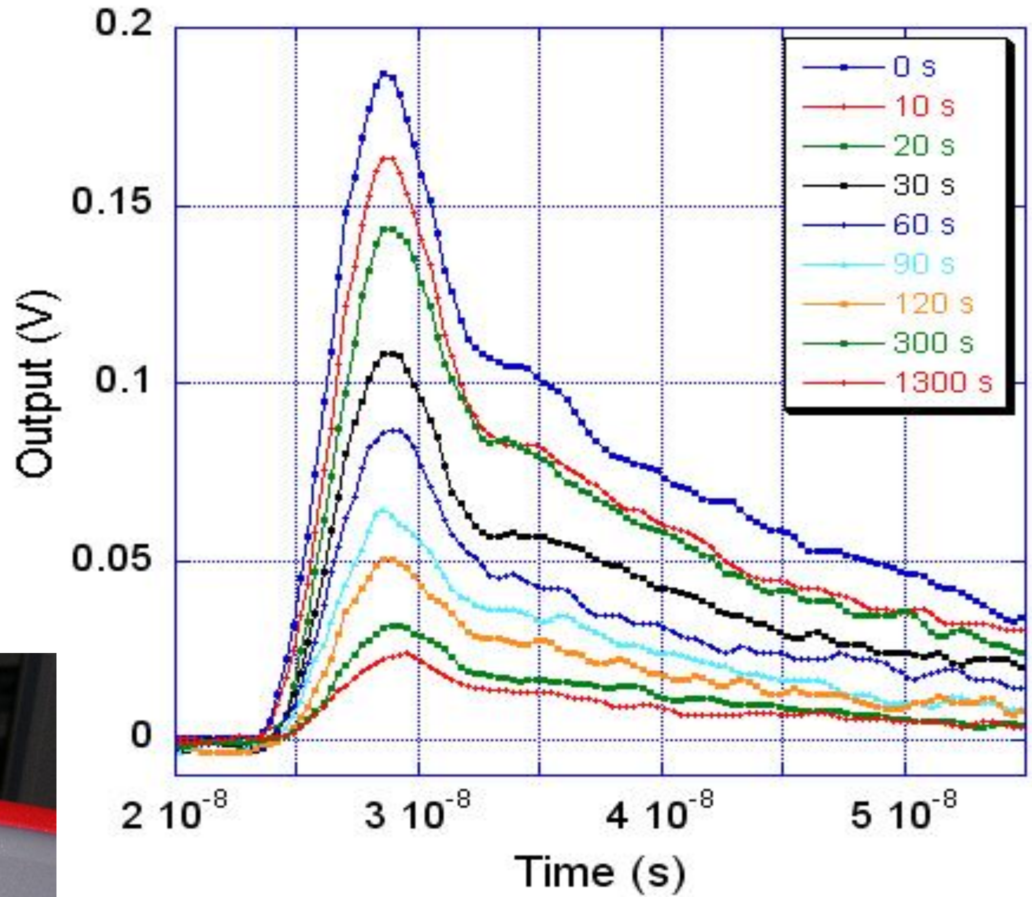
Multilaser with 6 heads; 24 launching fibers; 24 diffuser, 6 Source monitoring; 24 local monitoring


Hall g-2 Building
24 long fibers
4 m x 4 m Laser Hut
x8
Temperature: +/- 1 deg (24°-25°)
Optical table
EXPERIMENTAL HALL
001
734' - 6"
OPENING FOR EQUIPMENT (COORDINATE W/ OWNER)
CRANE ACCESS LADDER - SEE DTL. 6/A-16
PLATFORM ABOVE
STAIR-001A
STAIR-001B
07210.A2
03300.A1
03300.A2
11000.A1
05510.B2
05510.A1
05521.B1
A
B
C
D
D.7
E
20' - 0"
82' - 8"
1' - 4"
4' - 9"

SiPM gain(T)

Laser:
5 pJ/pulse, repetition rate 10 kHz.

<u>Gain instability !!!!</u>

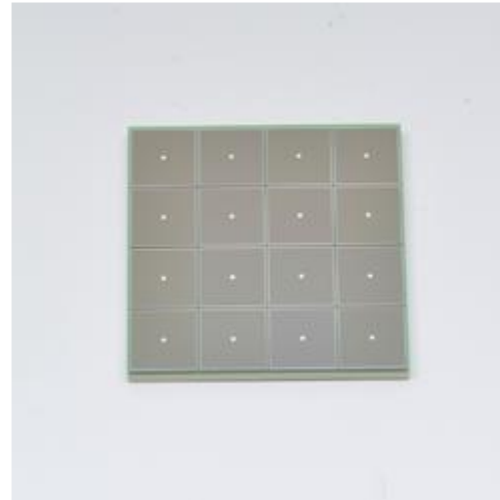


What's wrong?

The SiPM was closed in a light-tight box, <u>without cooling system</u>

Photosensor (SiPM)

The multi-pixel photon counter (MPPC) is one of the devices called silicon photomultipliers (SiPM).
It is a photon-counting device using multiple avalanche photodiode (APD) pixels operating in Geiger mode.



Benefits:

- ✓ Low bias voltage
- ✓ High gain (10^6)
- ✓ High speed response (10 ns)
- ✓ Excellent time resolution
- ✓ Wide spectral response range
- ✓ Immune to magnetic field, no ferromagnetic parts

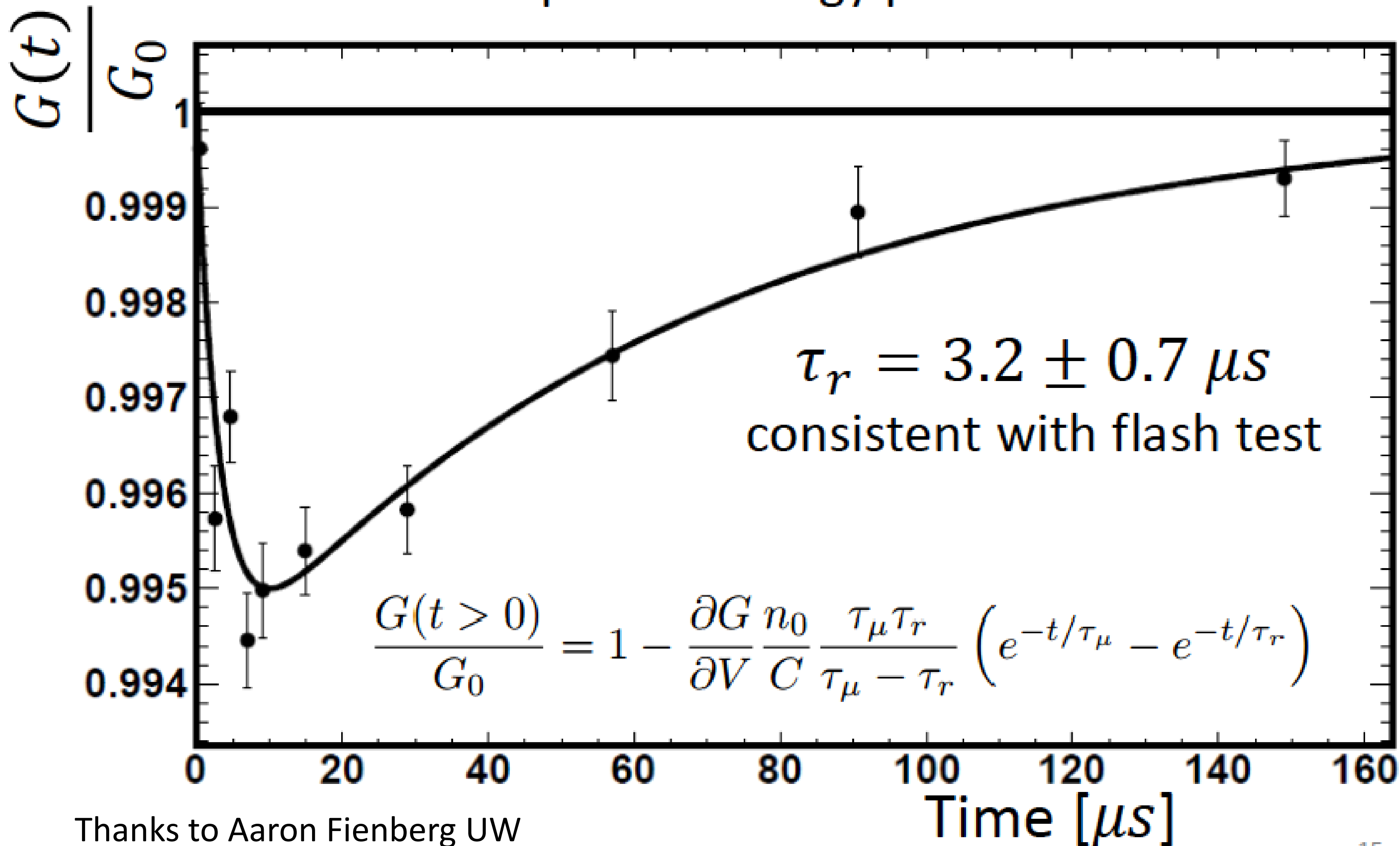
Drawbacks:

- ✓ Afterpulse and crosstalk
- ✓ Thermally generated avalanche (dark count rates: 1000 cps)
- ✓ Fixed amount of charge collected per avalanche (10^7 e)
- ✓ Gain fluctuation with T, V_{bias}, rate

Short term SiPM gain fluctuation

G(t) result for LED ~ 2300 MeV/shot

10x expected energy per shot



Thanks to Aaron Fienberg UW

Optical components glossary

Picoquant: LDH-P-C-405M (transversal multimode)

PDL 828 ‘Sepia II, drives up to 8 laser heads

λ = 405 nm
Pulse FWHM: < 600 ps
Average Power (@ 40 MHz): 25 mW
Energy/pulse > 625 pJ
12 hours, ΔT (ambient) < 3 K: 1 %
RMS, 3 % peak to peak

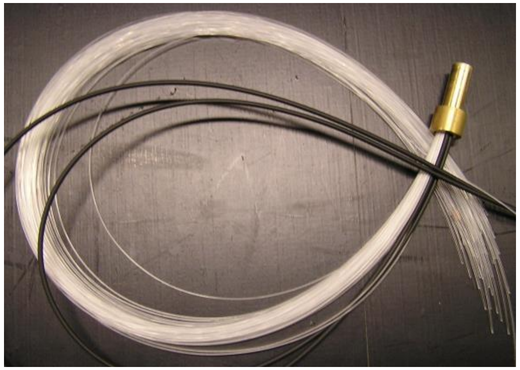
Filter wheel

Beam splitter

Collimator

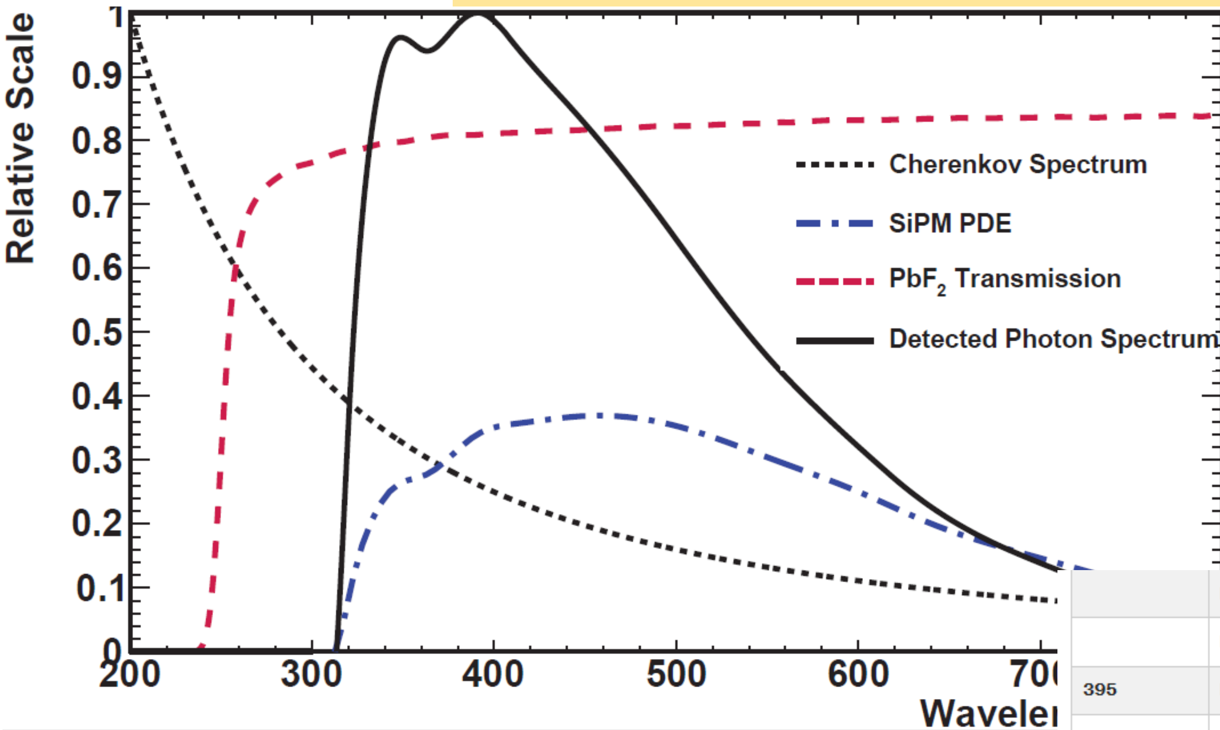
Right angle prism

Integrating sphere



Fibers bundle

Laser choice



LDH Picosecond
Pulsed Diode Laser Heads

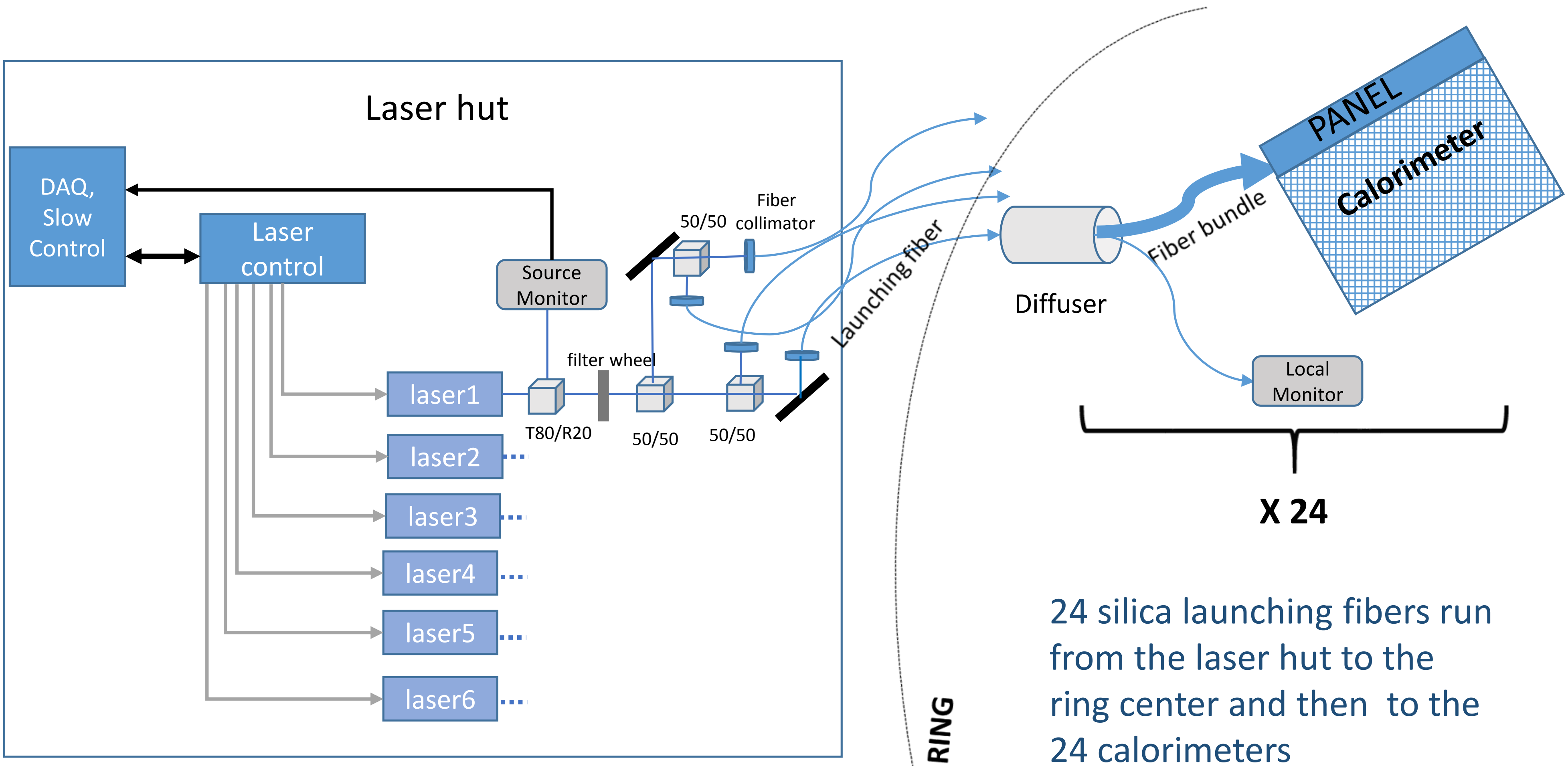
	P-C-375M	--	< 90	2.5	< 300	10.0
	D-C-375M	50	< 90	2.5	< 300	10.0
395	P-C-390	--	< 70	1.0	< 300	5.0
	D-C-390	30	< 70	1.0	< 300	5.0
405	P-C-405	--	< 50	0.4	< 300	2.0
	P-C-405B	--	< 50	1.0	< 500	3.0
	D-C-405	50	< 50	1.0	< 500	3.0
	P-C-405M	--	< 90**	10.0	< 600	25.0
	D-C-405M	200	< 90**	10.0	< 600	25.0
420	P-C-420	--	< 70	0.5	< 300	5.0
	D-C-420	30	< 70	0.5	< 300	5.0
440	P-C-440	--	< 70	0.4	< 300	2.0
	P-C-440B	--	< 70	0.8	< 500	4.0
	D-C-440	50	< 70	0.8	< 500	4.0
	P-C-440M	--	< 100**	10.0	< 500	25.0
	D-C-440M	200	< 100**	10.0	< 500	25.0

E = 750 pJ/pulse

Repetition rate from single shot to 80 MHz
Power stability: 1 % RMS, 3 % peak to peak

Thanks to Aaron Fienberg/ Jarek Kaspar UW

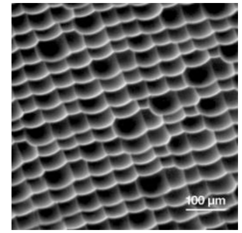
G-2: the laser calibration system

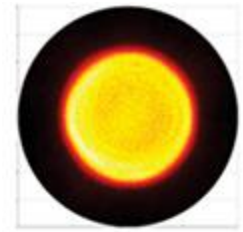


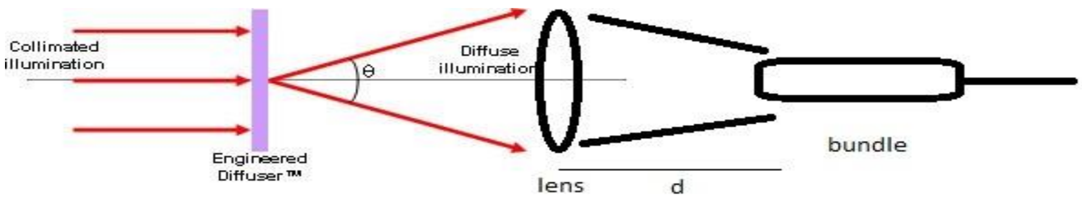
24 silica launching fibers run from the laser hut to the ring center and then to the 24 calorimeters

Laser Diffuser

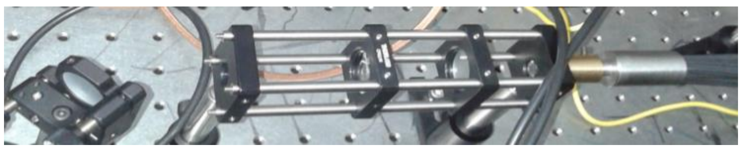
Engineered diffuser ED1-S20
by RPC Photonics – Thorlabs

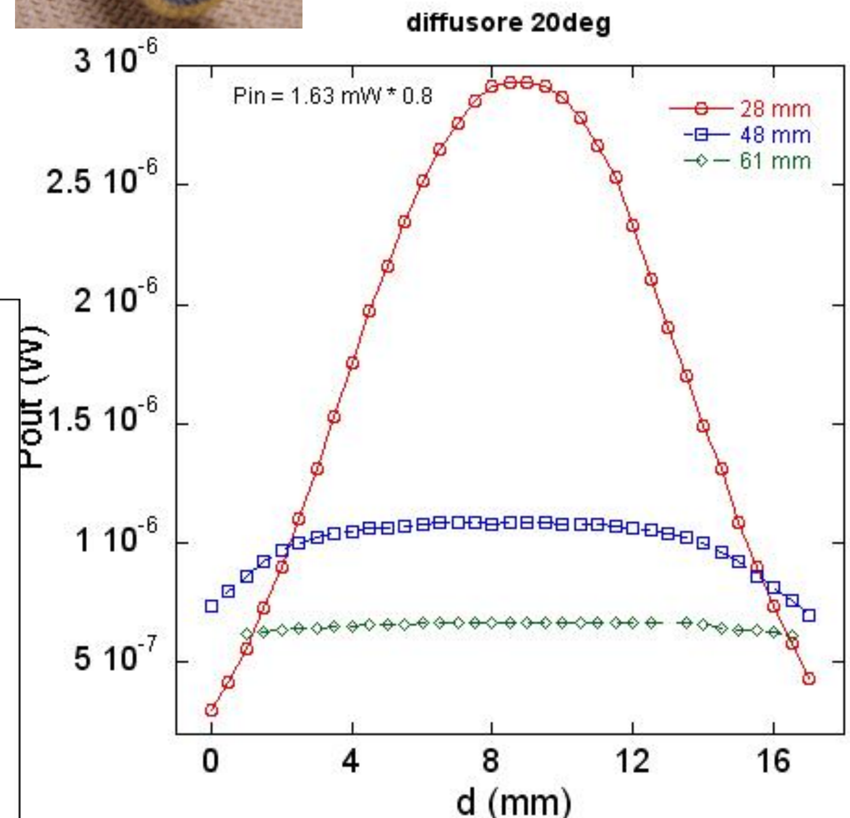


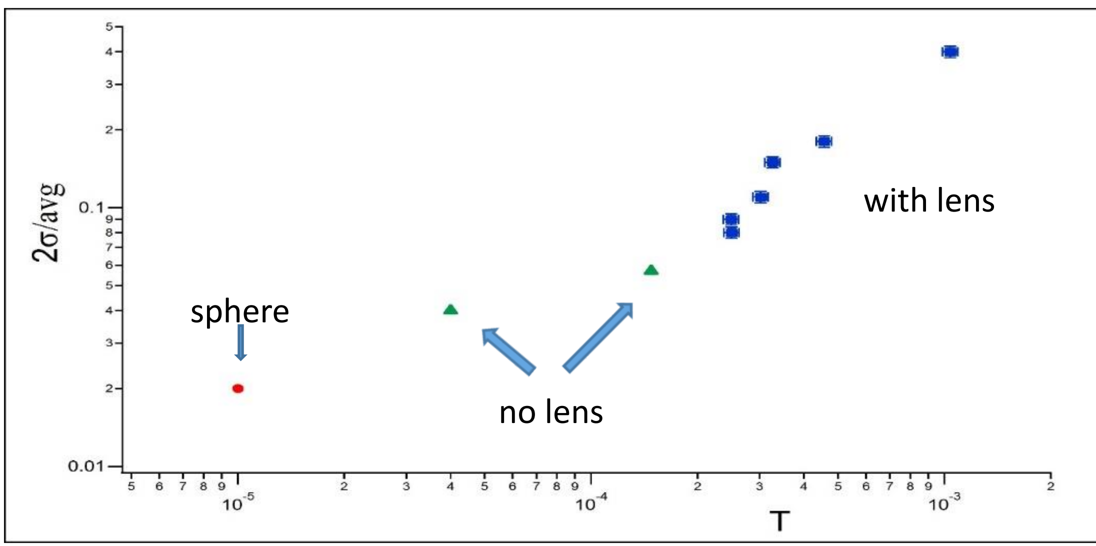




no lens

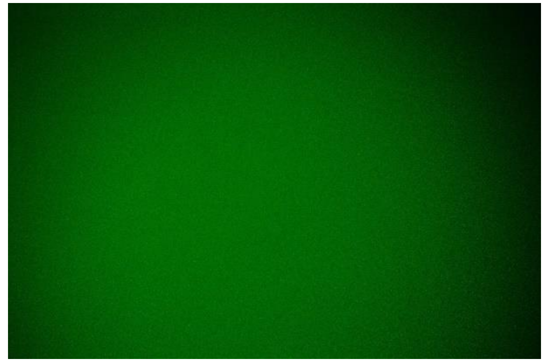


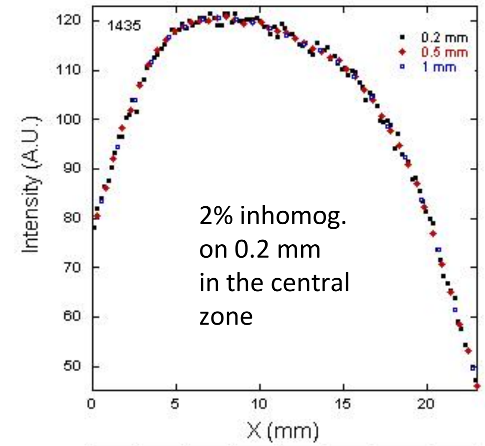




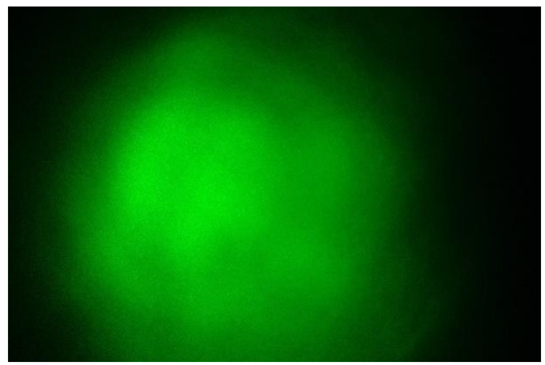
Diffuser

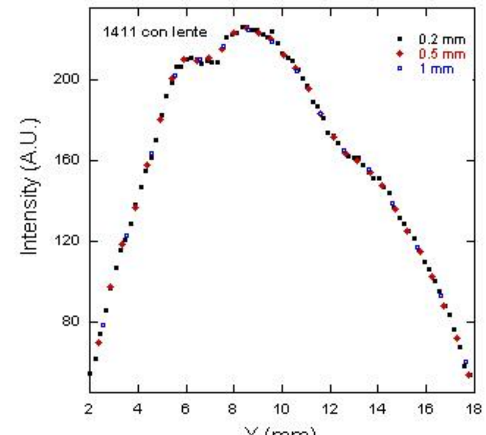
no lens

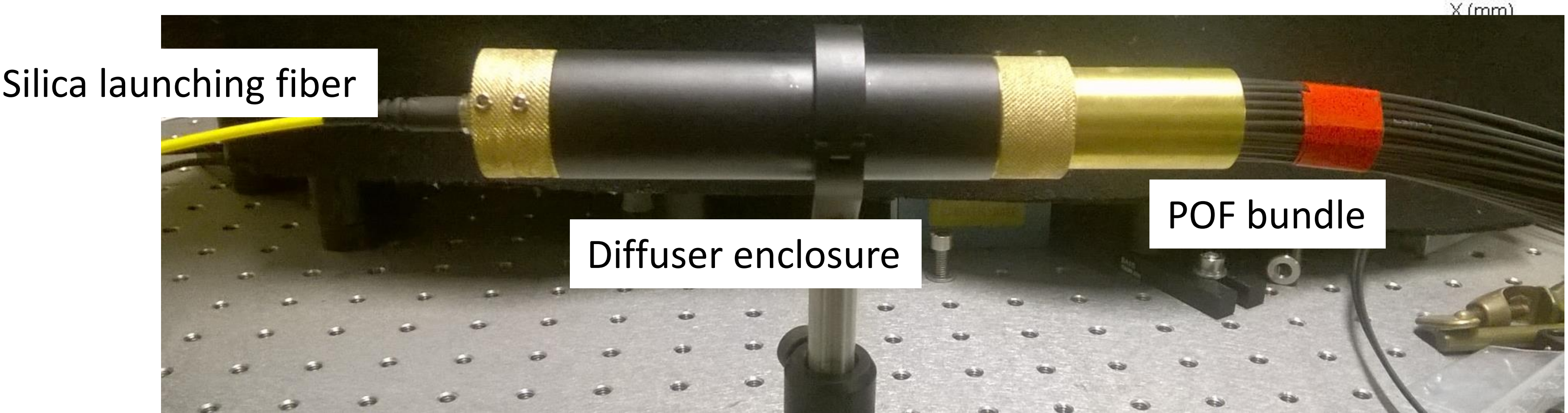




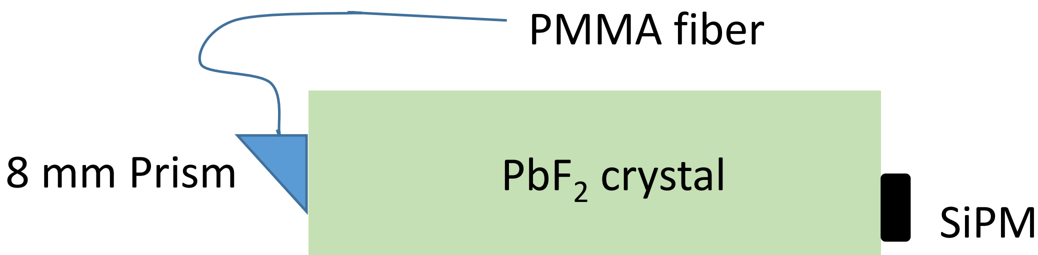
with lens

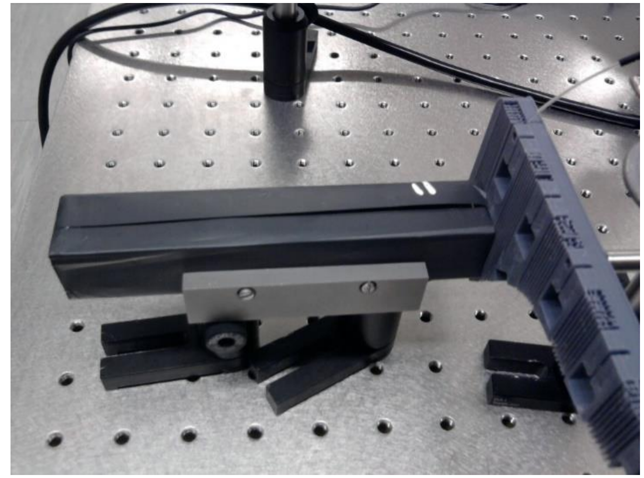




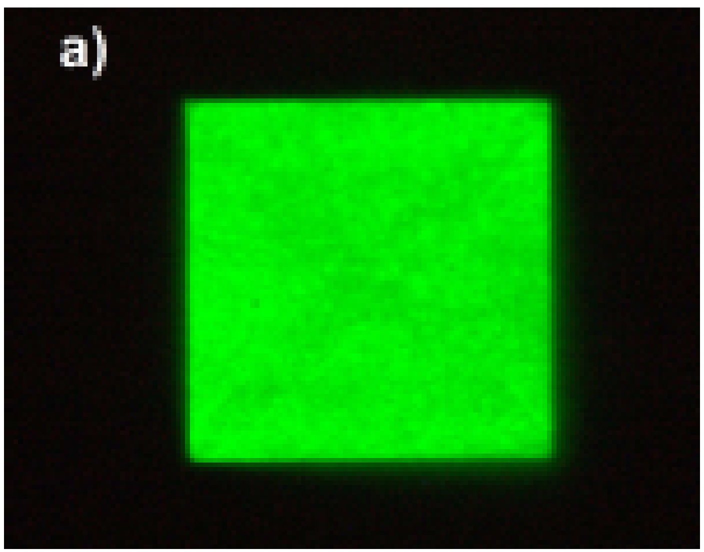


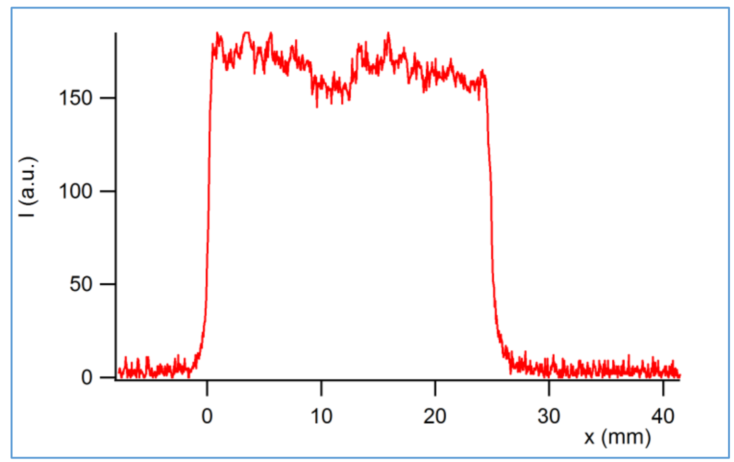
Light distribution panel





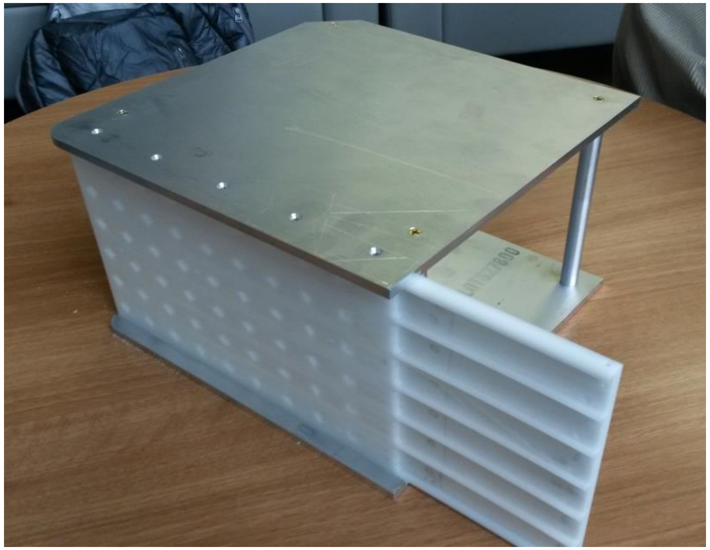
1mm PMMA fiber NA=0.49

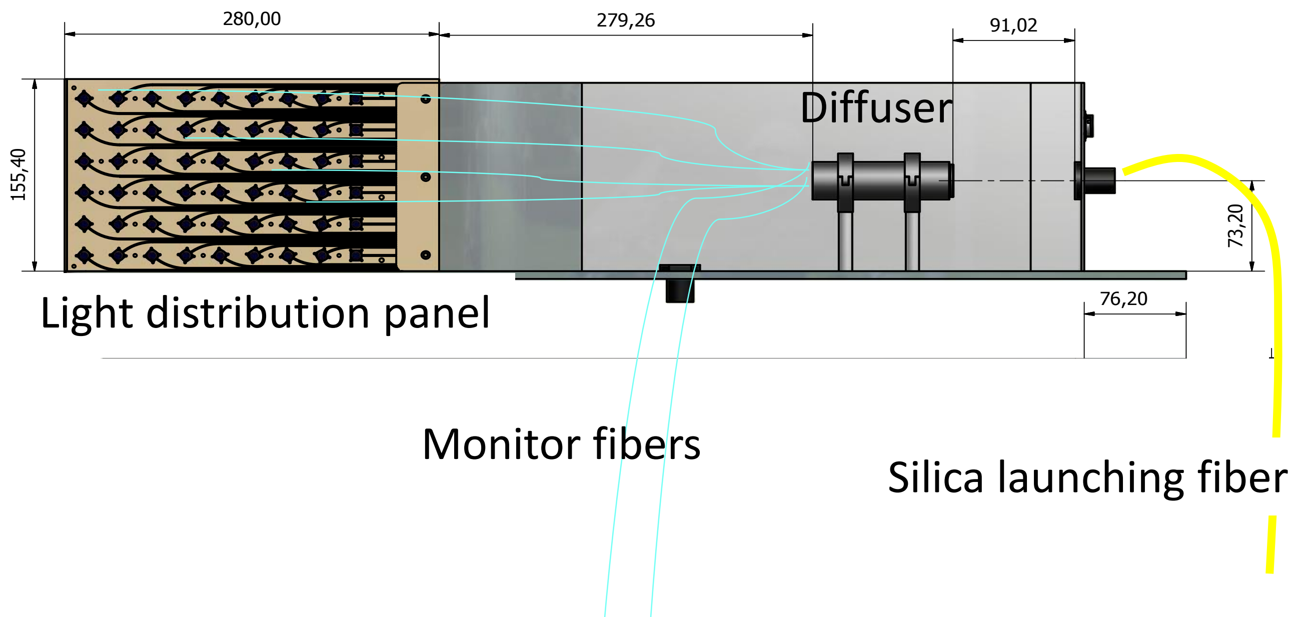


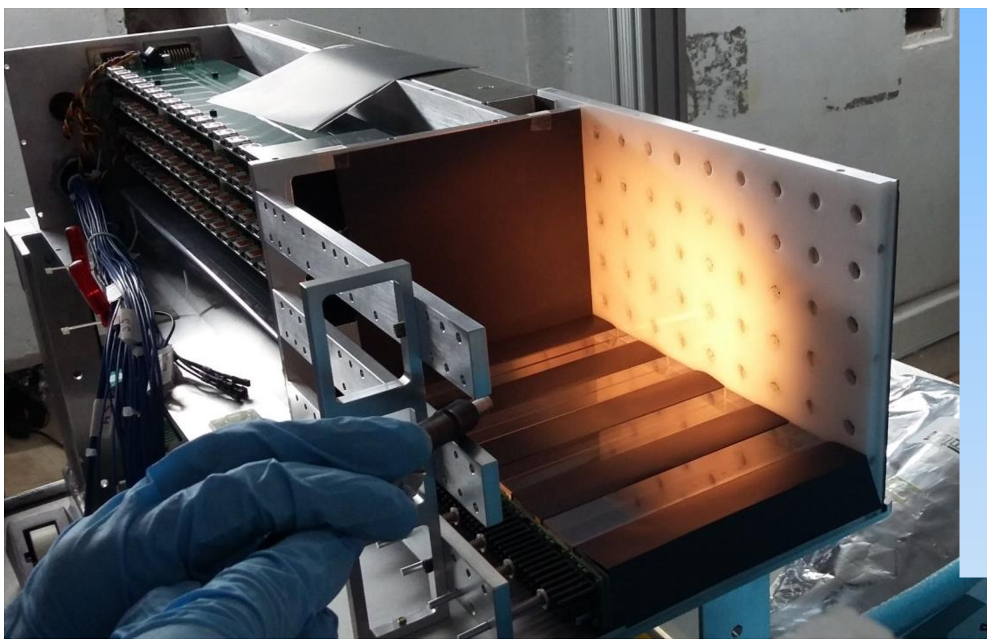


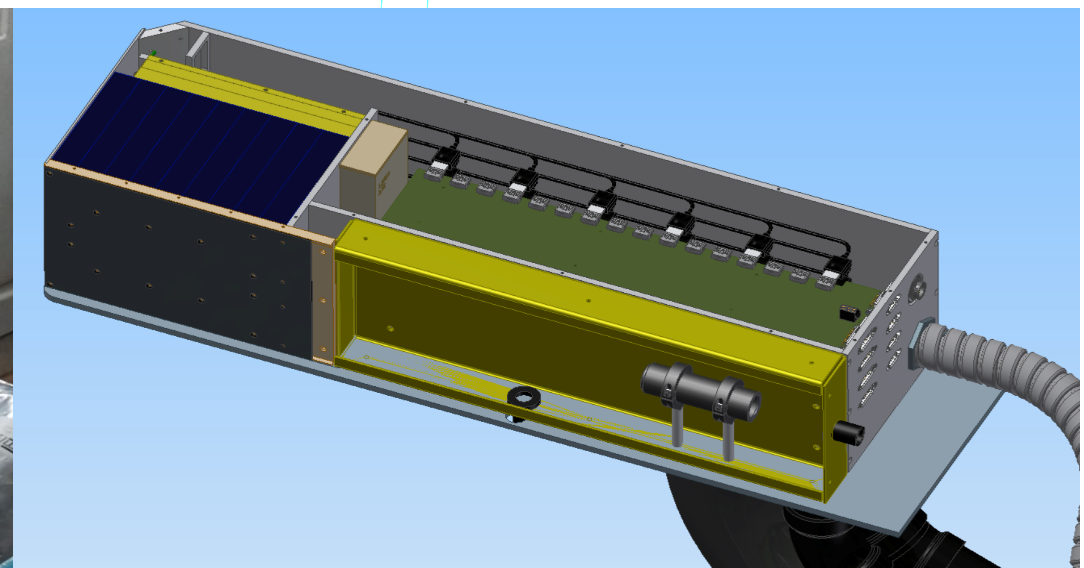
Disomogeneity 3% on 12 mm 1D

Calorimeter assembly

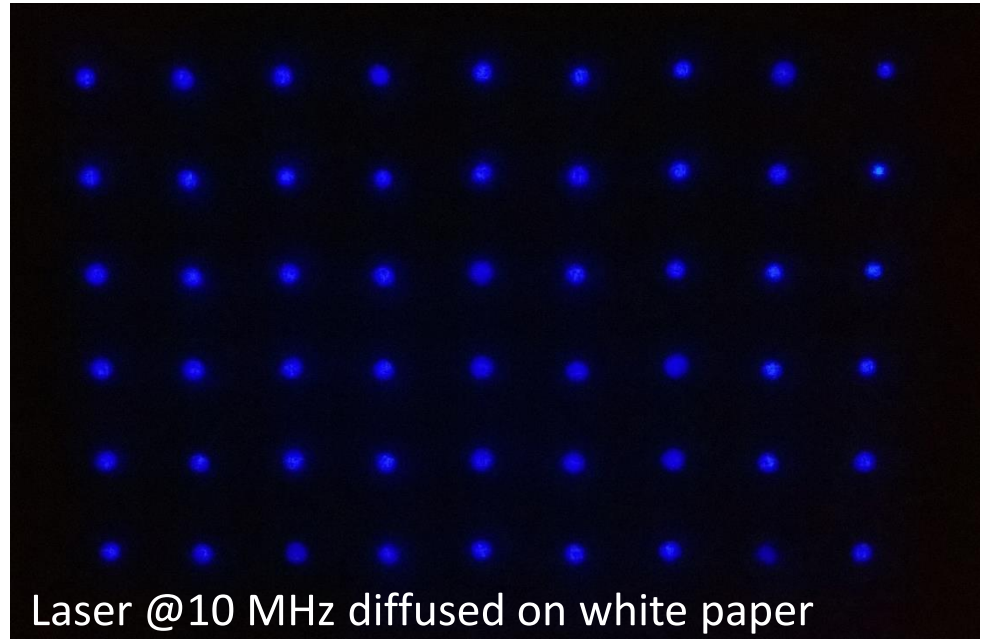




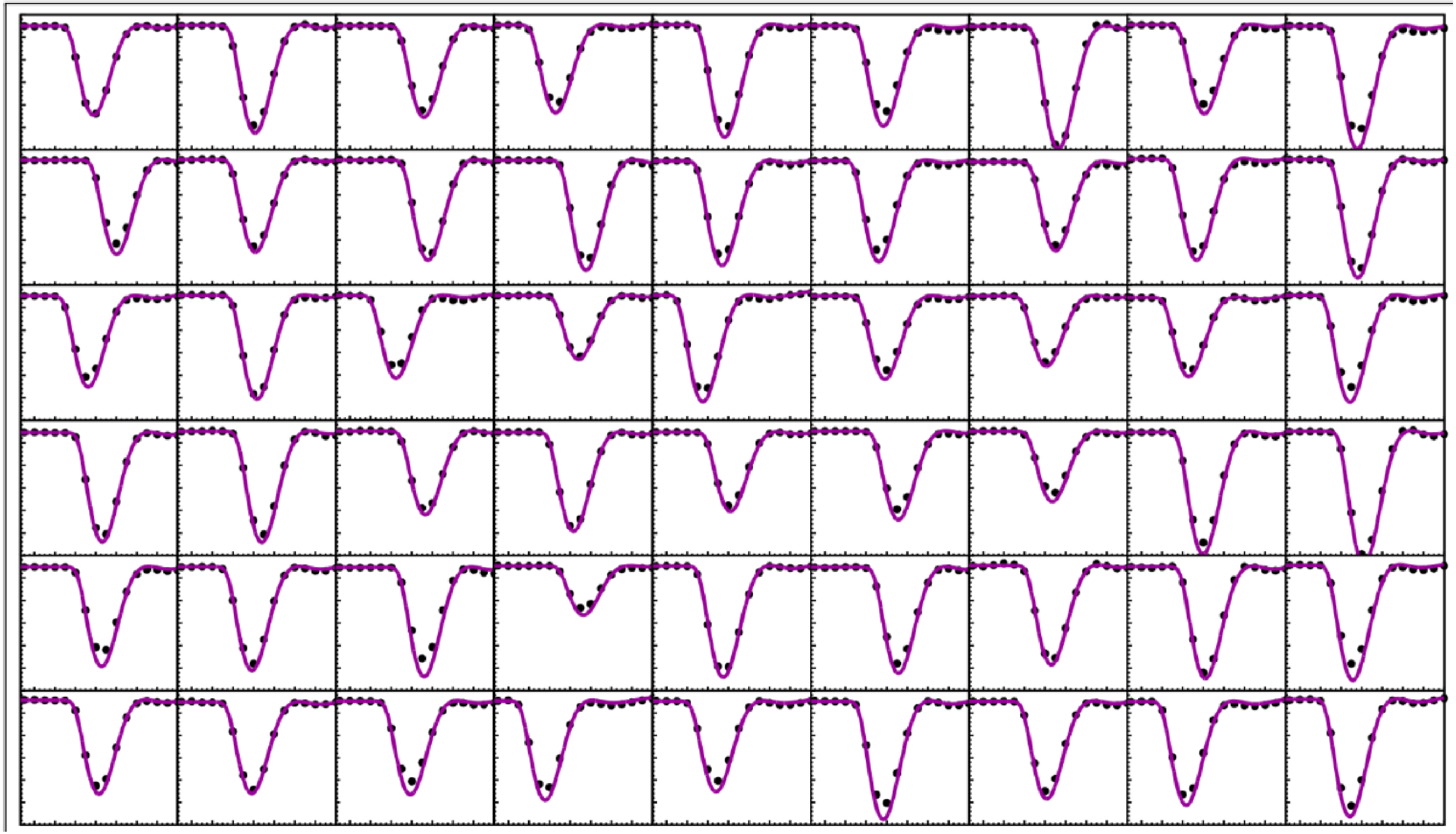




Light distribution panel



Laser @10 MHz diffused on white paper



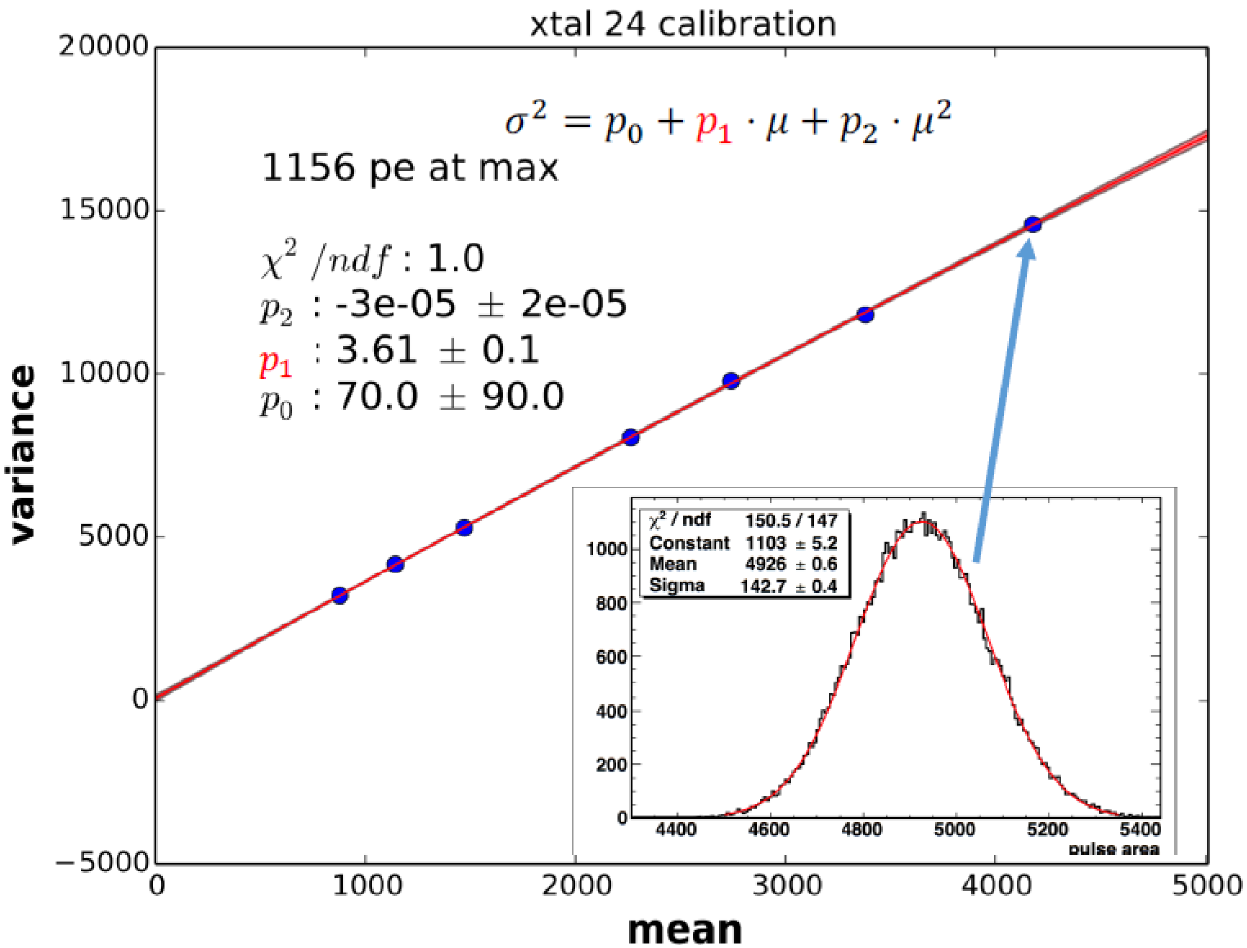
laser pulse

Aaron Fienberg UW _ SLAC test beam

Absolute calibration through photostatistics

For a normal distribution: $\sigma^2 = n_e^2 + \mathbf{g}\mu + \sigma_l^2\mu^2$ ($\mu/g = N_{pe}$)

The charges/avalanche and the PDE (QE*$P_{avalanche}$*filling factor) vary with T and Vbias: the calibrations constant should be tracked through time and updated.



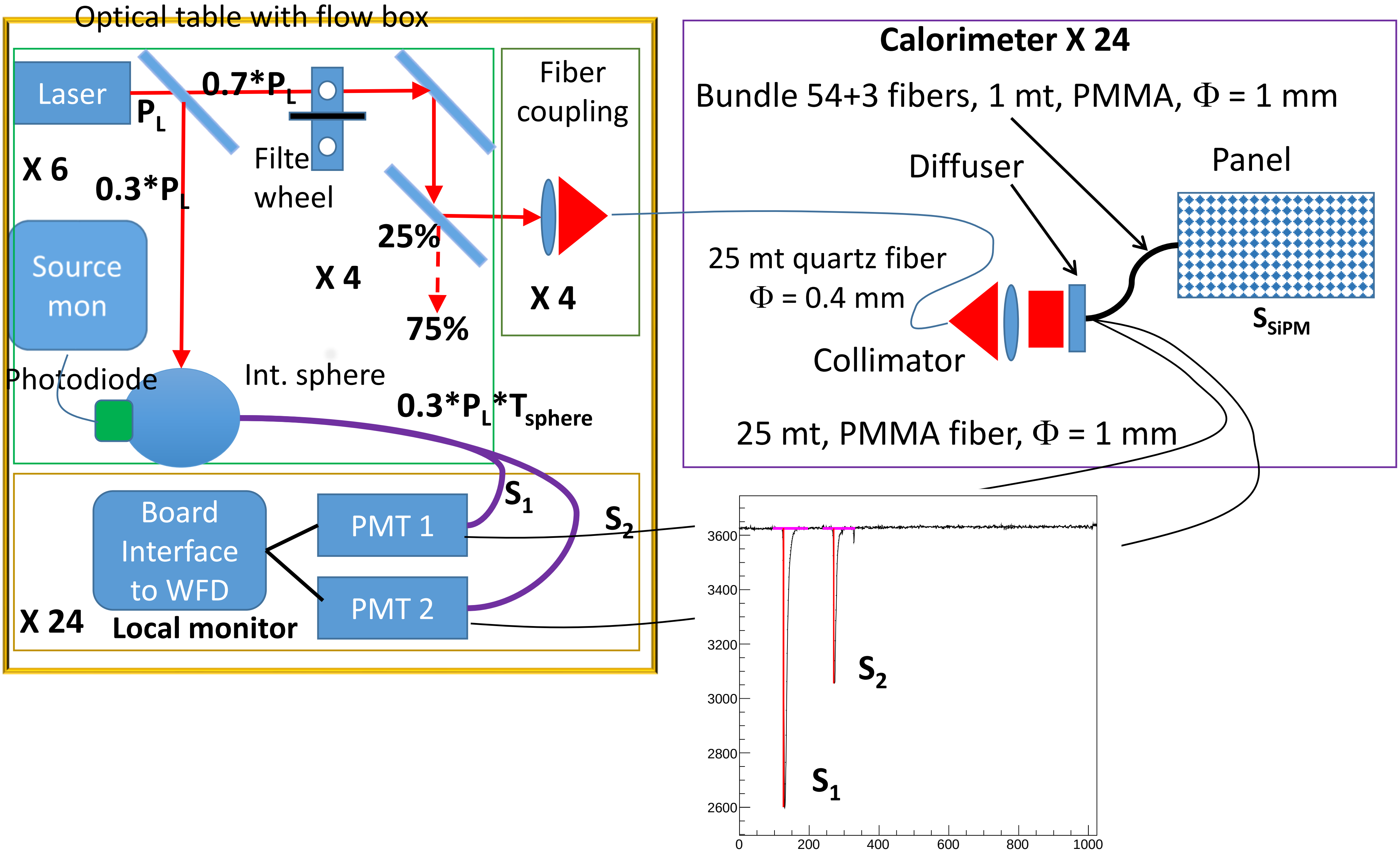
- vary laser intensity with filter wheel
- measure pulse area variance vs mean
- Identify p_1 as pulse area/pe (gain)
- measure beam energy in pe
- this technique does not require that each segment receive same light

The effective N_{pe} serves as a proxy for energy deposited in the crystal.

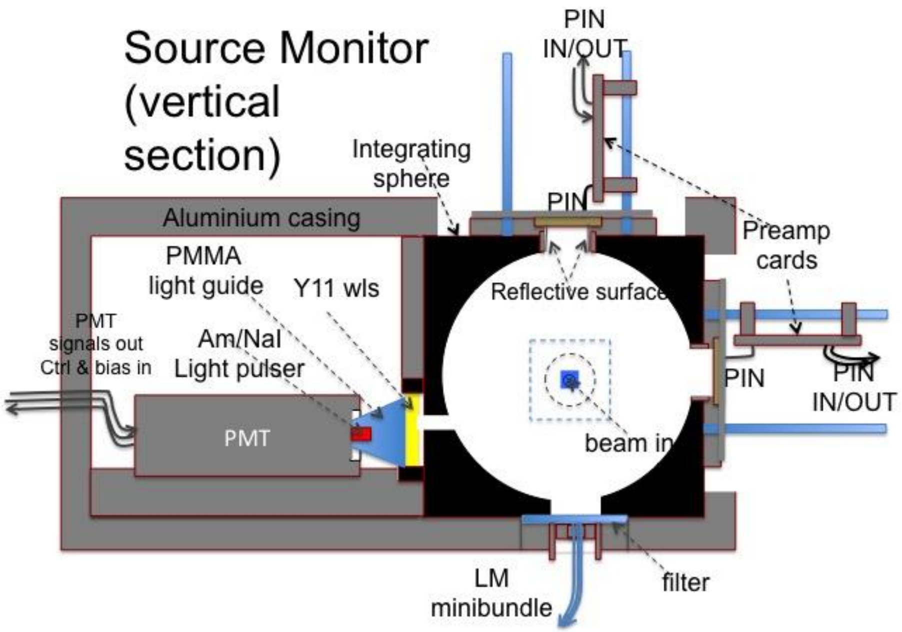
From the test beam: 0.9 N_{pe}/MeV

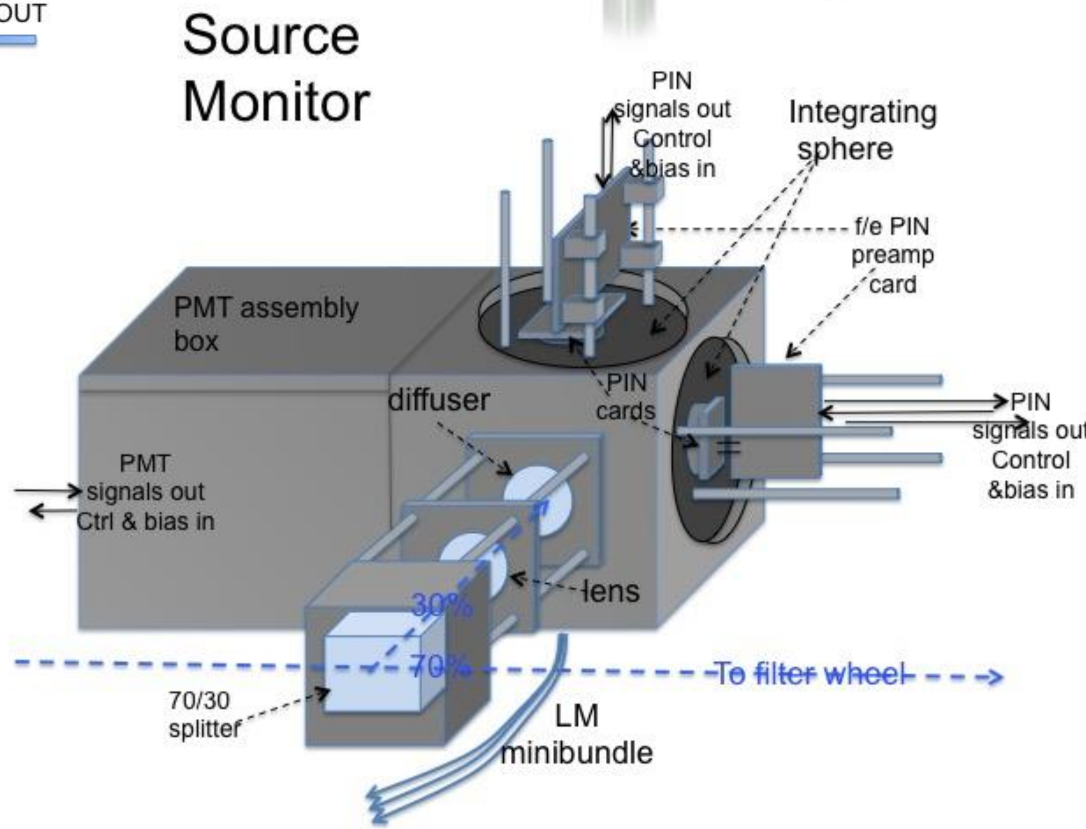
Thanks to Aaron Fienberg UW_ SLAC test beam

Source and Local monitor

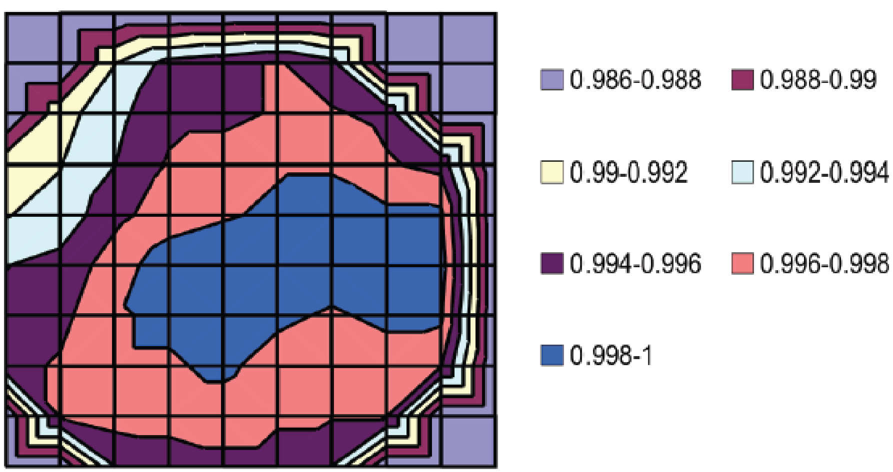


Details of the Source monitor

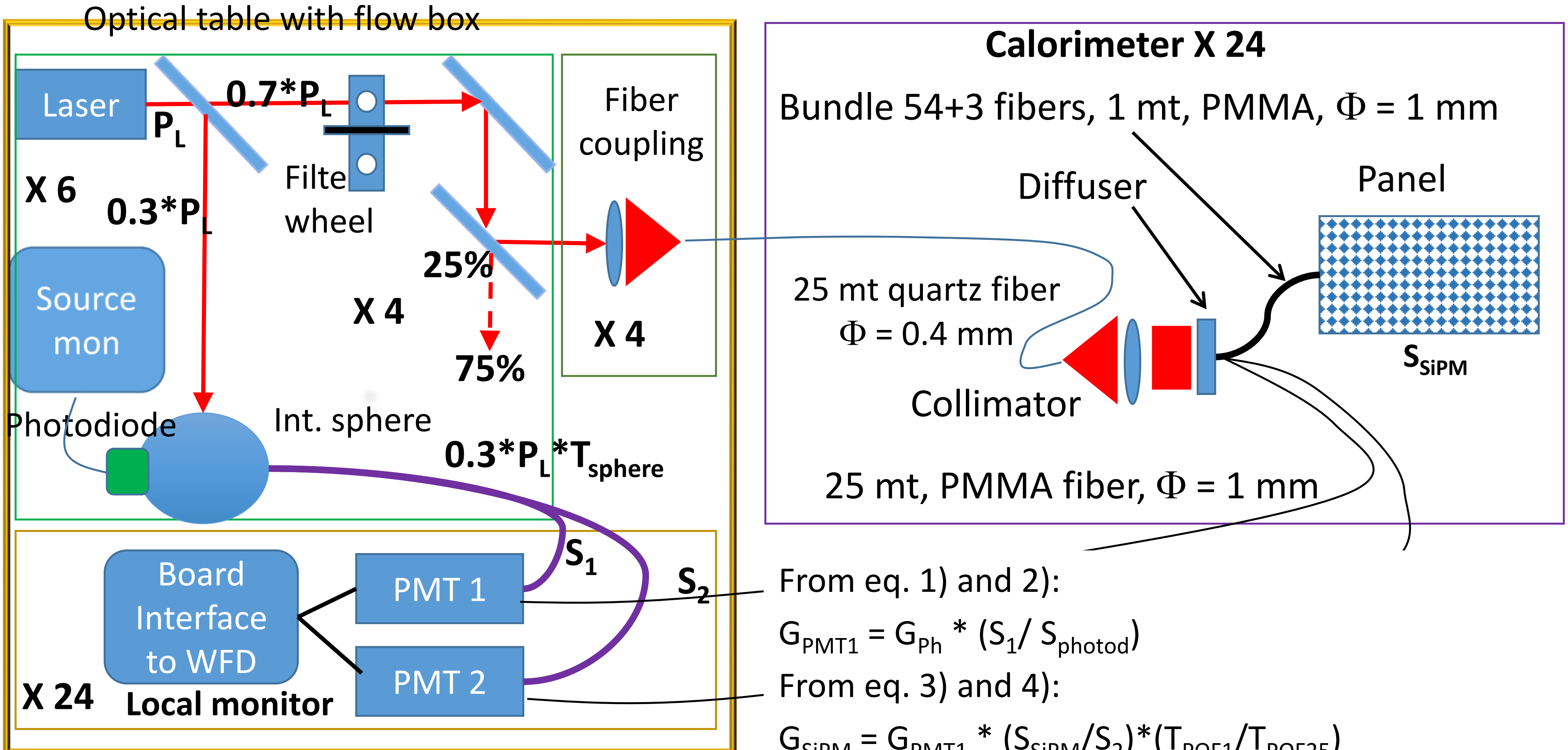




TYPICAL LUMINANCE UNIFORMITY MAPPING



Source and Local monitor



From eq. 1) and 2):

$G_{PMT1} = G_{Ph} * (S_1/ S_{photod})$

From eq. 3) and 4):

$G_{SiPM} = G_{PMT1} * (S_{SiPM}/S_2)*(T_{POF1}/T_{POF25})$

$\Rightarrow G_{SiPM} = G_{Ph}*(S_1/S_2)*(S_{SiPM}/S_{Ph})*(T_{POF1}/T_{POF25})$

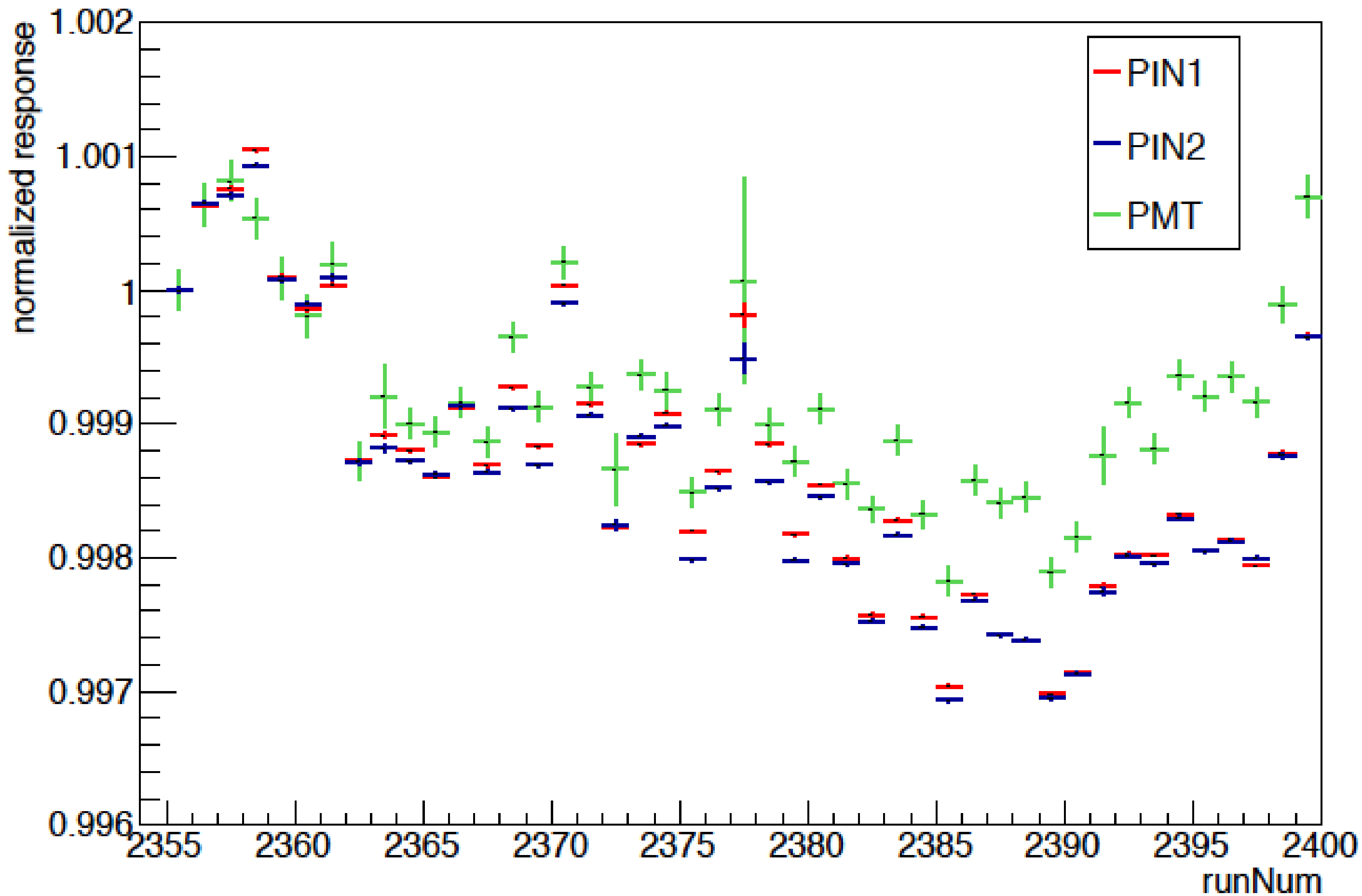
1) $S_{Ph} = 0.3 * P_L * T_{sphere} * G_{Ph}$

2) $S_1 = 0.3 * P_L * T_{sphere} * G_{PMT1}$

3) $S_2 = 0.7 * 0.25 * T_{collimator} * T_{fiber25q} * T_{diffuser} * T_{POF25} * P_L * G_{PMT1}$

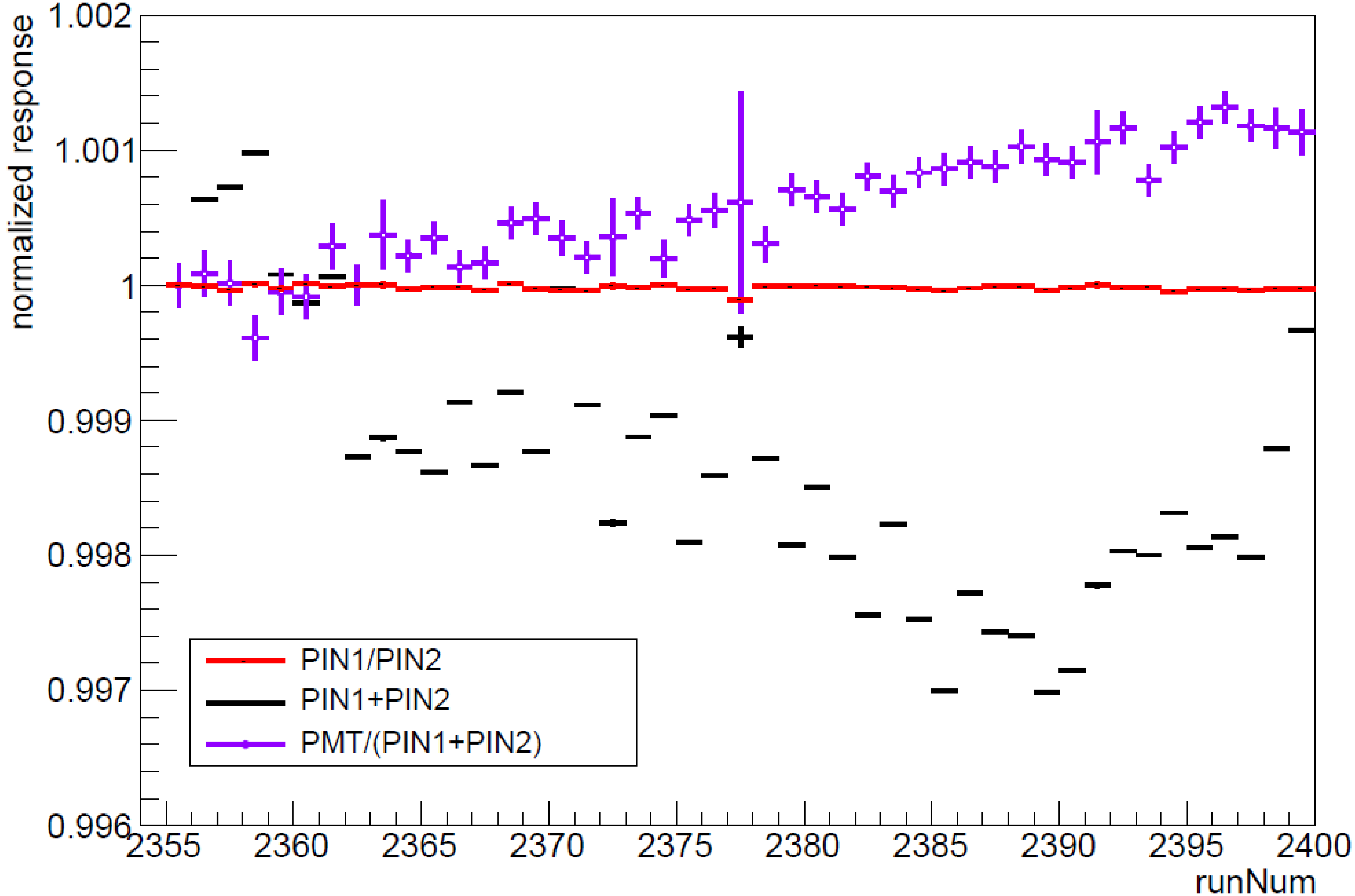
4) $S_{SiPM} = 0.7 * 0.25 * T_{collimator} * T_{fiber25q} * T_{diffuser} * T_{POF1} * P_L * G_{SiPM}$

Long term Laser stability



- 2.5 hours of data
- Laser fill $\sim 350 \mu s$ and pulses at 100 kHz
- max. fluctuation $\sim 0.3\%$

Long term PIN stability

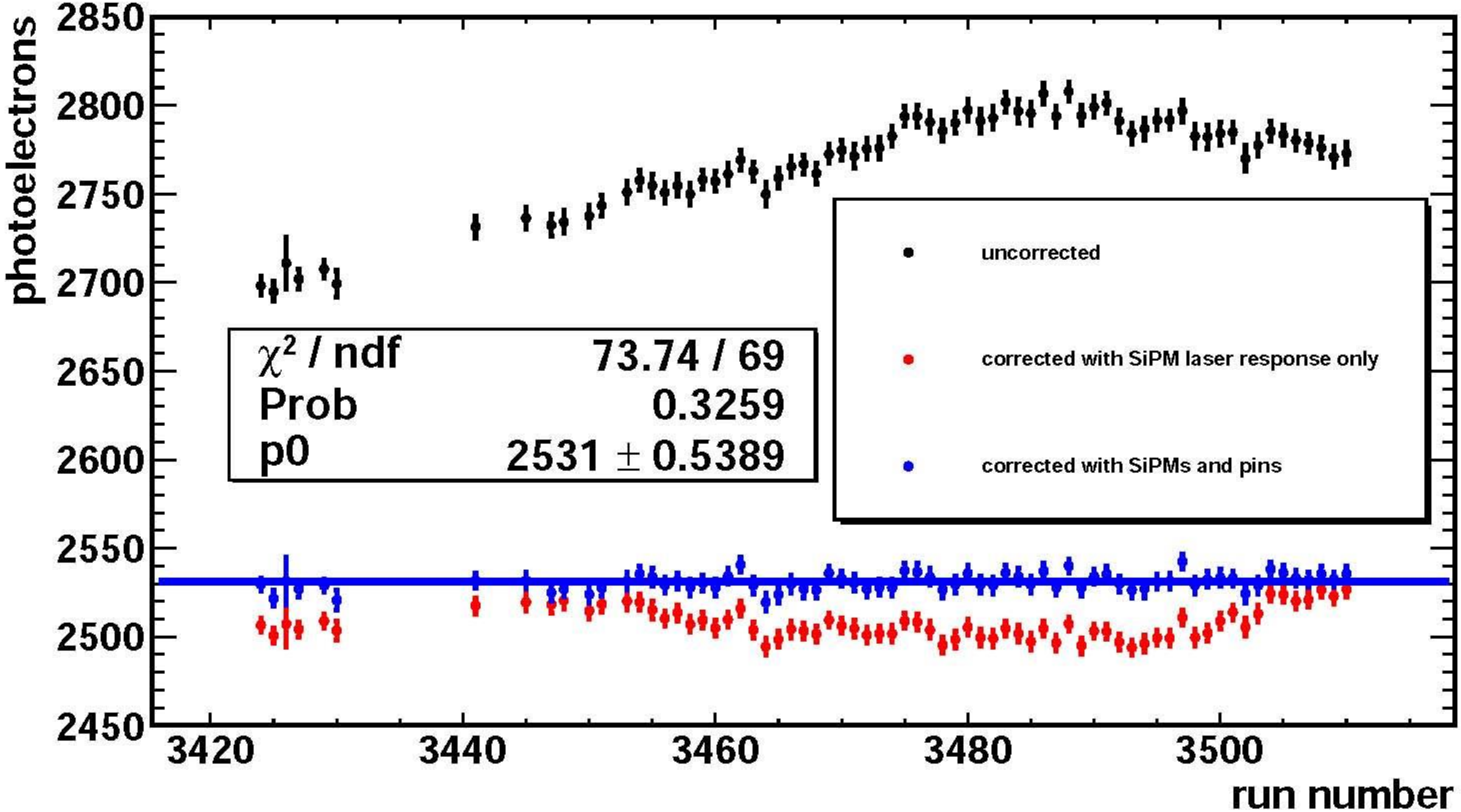


The PIN ratio is very constant
The PINs sum describes the laser instability
The PMT/(PINs sum) shows the gain instability of the PMT

Anna Driutti_UD_ SLAC TB

SLAC test beam

Aaron Fienberg UW _ SLAC test beam



Averages are taken over one fill. The correction seems quite effective, and including the source monitor definitely improves the result.

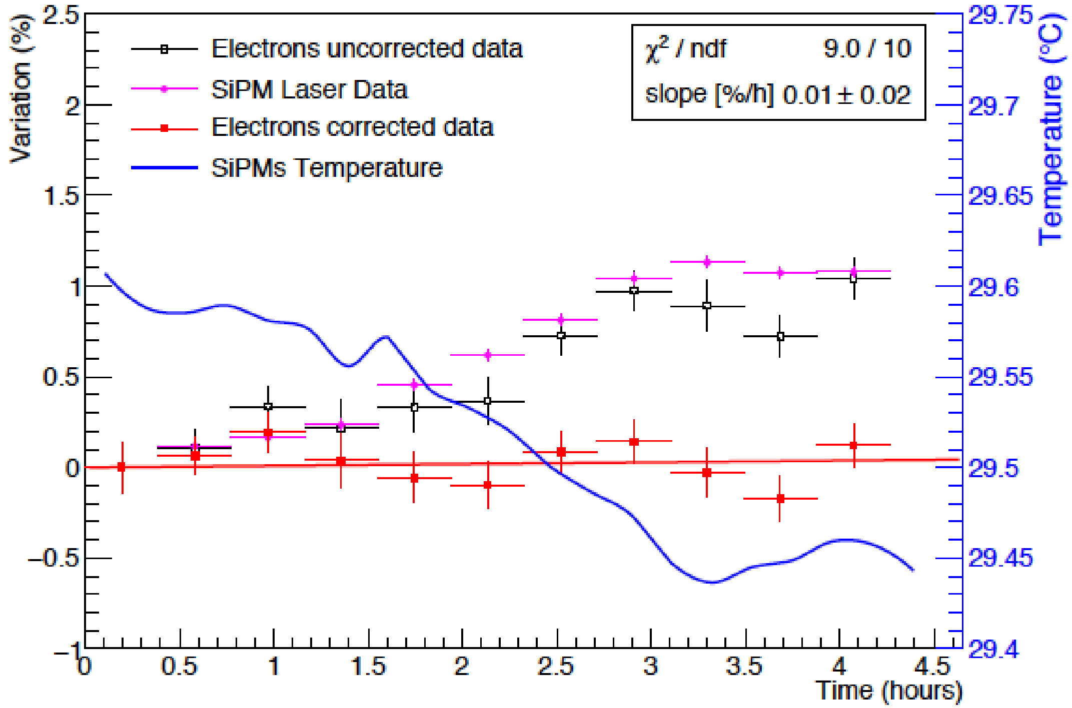
These runs span a period of about 8 hours. All points are 3 GeV single electron values.

Frascati test beam

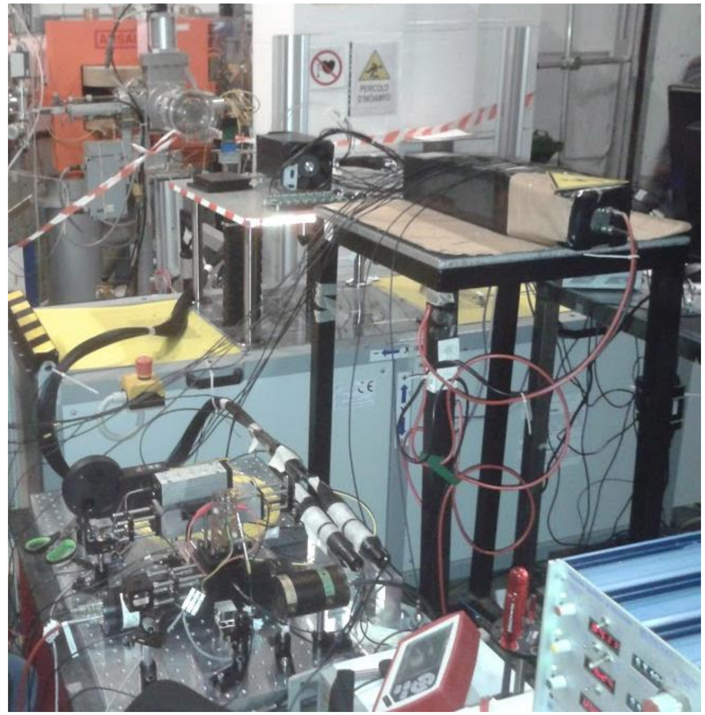
- 5 channels calorimeter
- 500 MeV e-
- Final distribution system
- SM in 2 different conficguration
- LM in a simplified configuration
- CAEN Digitizer
- Laser control board

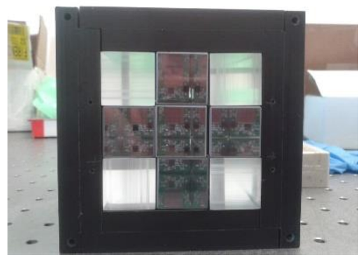
Electron beam test of key elements of the laser-based calibration system for the muon $g-2$ experiment

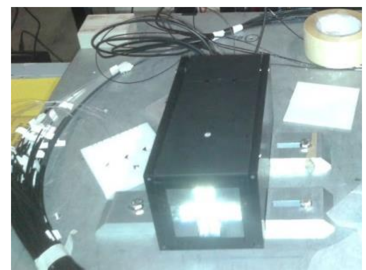
A. Anastasi[a,c,*], A. Basti[m], F. Bedeschi[m], M. Bartolini[m], G. Cantatore[d,g], D. Cauz[d,i], G. Corradi[a], S. Dabagov[a], G. Di Sciascio[f], R. Di Stefano[j,e], A. Driutti[i], O. Escalante[h], C. Ferrari[a,b], A.T. Fienberg[l], A. Fioretti[a,b], C. Gabbanini[a,b], A. Gioiosa[o,p], D. Hampai[a], 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]



$$R_{el}^{SiPM} = \frac{r_{el}^{SiPM}(t)}{f_{gain}^{SiPM}(t)} = r_{el}^{SiPM}(t)\cdot\frac{R_{laser}^{SiPM}\, f_{laser}(t)\, f_{distribution}(t)}{r_{laser}^{SiPM}}$$







Laser power budget

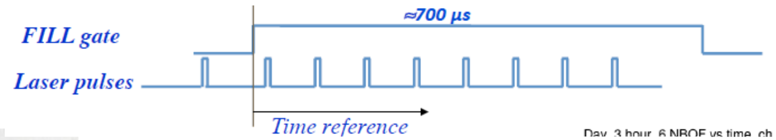
Distribution system transmission:
6 lasers/ 24 diffusers

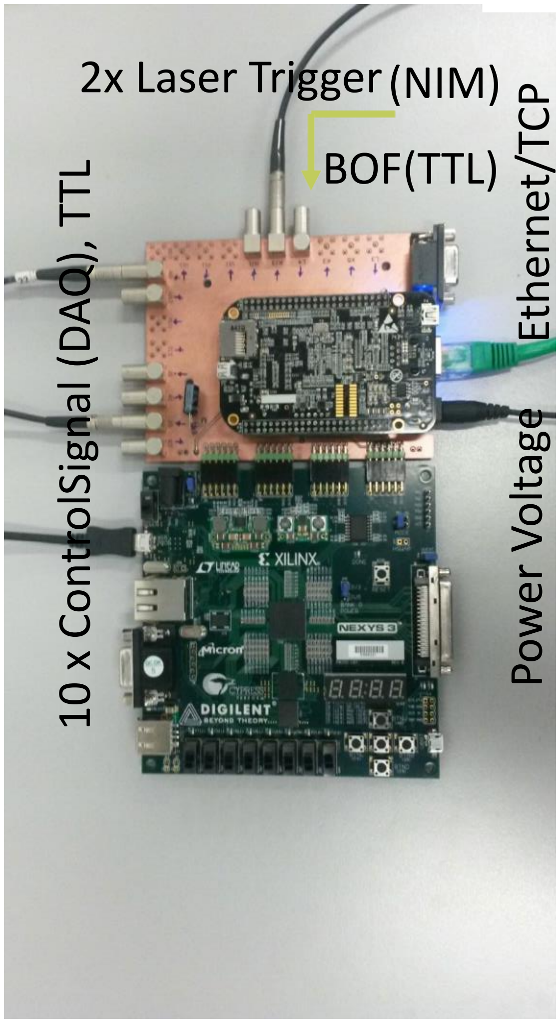
Required value of the output of each crystal: 0.01 pJ/pulse (el. 2GeV);

for each calorimeter: 0.6 pJ/pulse

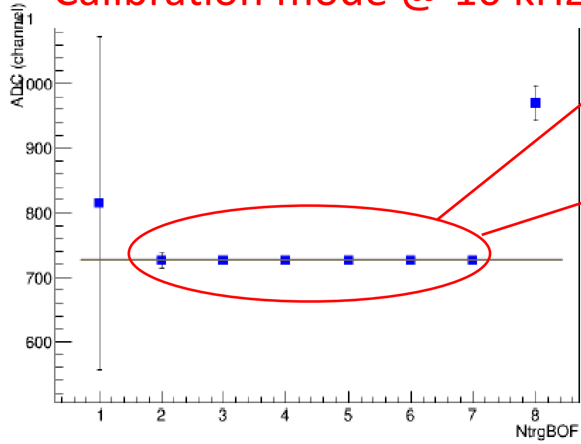
Element	Transmission	Energy (pJ)	Notes
Laser Picoquant output		750	100% current intensity
Source monitor sampling	70%	525	225 pJ/pulse for the source monitor (2 PD and 1 PMT)
Filter wheel	100%	525	
Division into four beams	21%	110	7% loss every cube splitting
Fiber coupling + 25 mt quartz fiber	70%	75	Measured
Diffuser with bundle (54 fibers) + 3 local monitors	10%	7.5	It can increased by reducing uniformity
1 mt bundle POF (200 dB/km)	90%	7	
Prism coupling	65%	4	Prism with anti-reflection coating and with metallized reflecting face
PbF_2 crystal reflection + absorption (20%)	65%	3	
Total per calorimeter		**3**	**Required: 0.6 pJ /pulse /calorimeter**

Laser control board



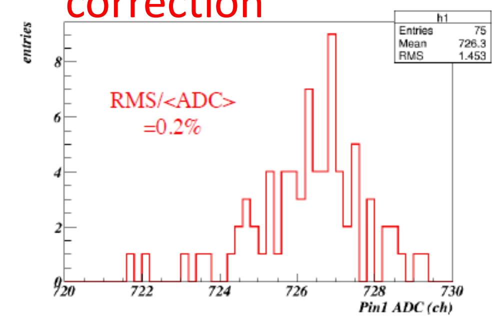


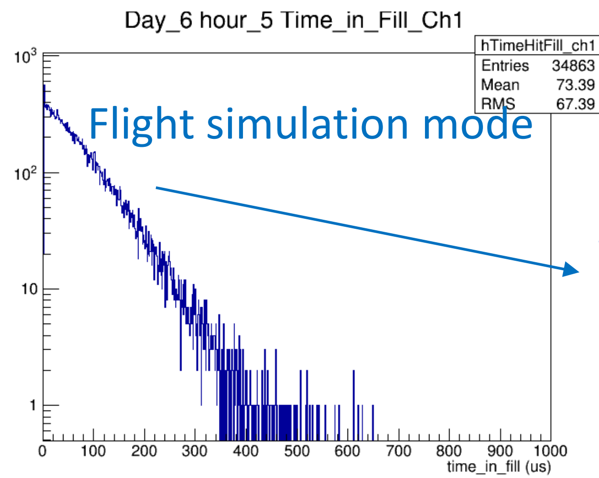
Calibration mode @ 10 kHz



Calibration pulses in fill do not depend on number of pulse

Each pulse within the fill is stable in 0.2% without any temp. correction

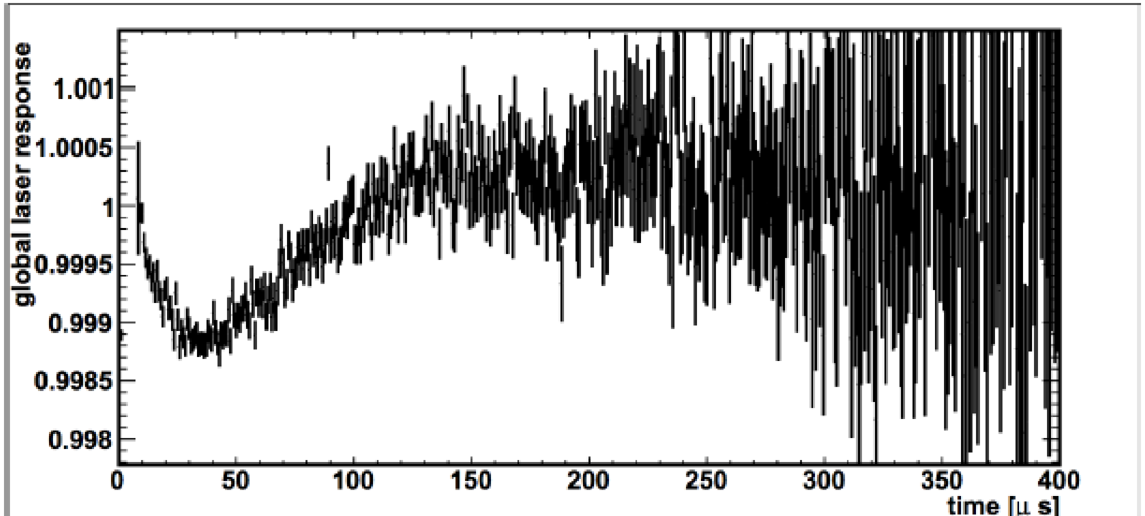




Flight simulation mode

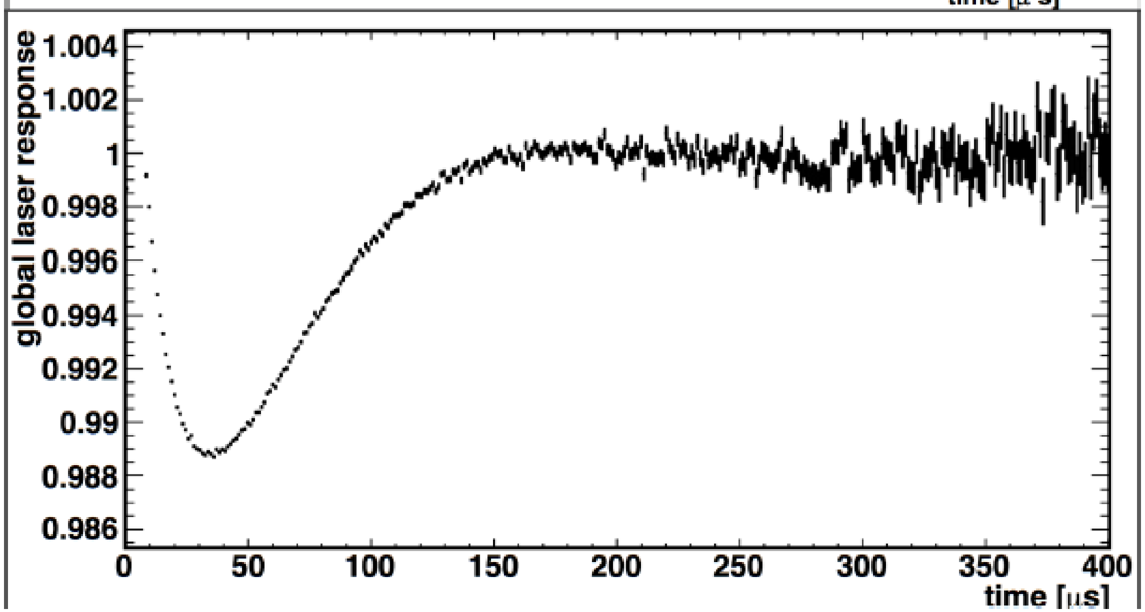
The readout system sustained the data rate > 10 kHz, no deviation from exp. up to 30-40 kHz

In fill gain fluctuation



filter wheel setting 5 (35%)

average 64 pulses per fill



filter wheel setting 1 (100%)

average 96 pulses per fill

Order status

Laser driver Sepia II:	available
Laser driver for D0:	ordered
Laser head for D0:	available
Laser head x6:	ordered
Optical components for laser hut:	available
Optical components for D0:	available
Forward quarz fibres:	available
Backward POF fibers:	available
Diffusers:	available
Fiber bundles for calos:	ordered
Panels and prisms:	available
Box for diffusers:	ordered
Electronics for source monitor:	ordered
Electronics for local monitor:	under construction

Conclusions

- Laser distribution system fulfills specs (gain stability at 0.04%).
- Many tests in Lab and with beam (Frascati, SLAC)
- Source/Local Monitor OK
- Purchases: almost finalized
- Installation on schedule (August-November 2016)

People (Italy)

- INO-CNR Pisa: C. Ferrari, A. Fioretti, C. Gabbanini
- INFN Pisa: F. Bedeschi, A. Lusiani, M. Bartolini
- LNF-INFN Frascati: G. Venanzoni, A. Anastasi, E. Rossi, S. Dabagov, D. Hampai
- INFN Roma: G. Di Sciascio, D. Moricciani, N. Raha
- INFN Trieste: G. Cantatore, M. Karuza, F. Marignetti
- INFN Udine: G. Pauletta, D. Cauz, A. Driutti, L. Santi
- INFN Napoli: M. Iacovacci, S. Mastroianni, O. Escalante, R. Di Stefano
- INFN Lecce: G.M. Piacentino, A. Gioiosa