Outlne

- Design critera and first prototypes
- Tests of stability at high intensity and (without PIN amplification)
- Tests at intensities approachng operating conditions

All tests were conducted with laser fluctuations (5 -8%) much larger   than expected in operating conditions (< 1%)

Design criteria

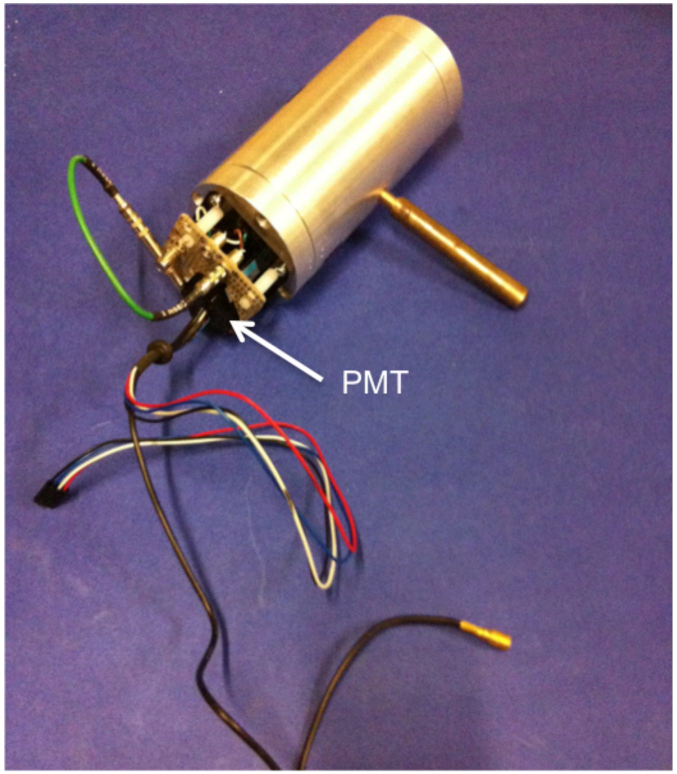
Assuming the signals of all calorimeter elements (S_{ci}) and the monitor (S_M) are subject to the same laser fluctuations f_L these fluctuations should be eliminated in the ratios $\left(S_{Ci} \cdot f_L / S_M \cdot f_L\right)$ of the observed signals. The resulting ratio (S_i / S_M) should then reveal calorimeter gain fluctuations affecting S_{ci} ***assuming S_M is subject only to the laser fluctuations***.

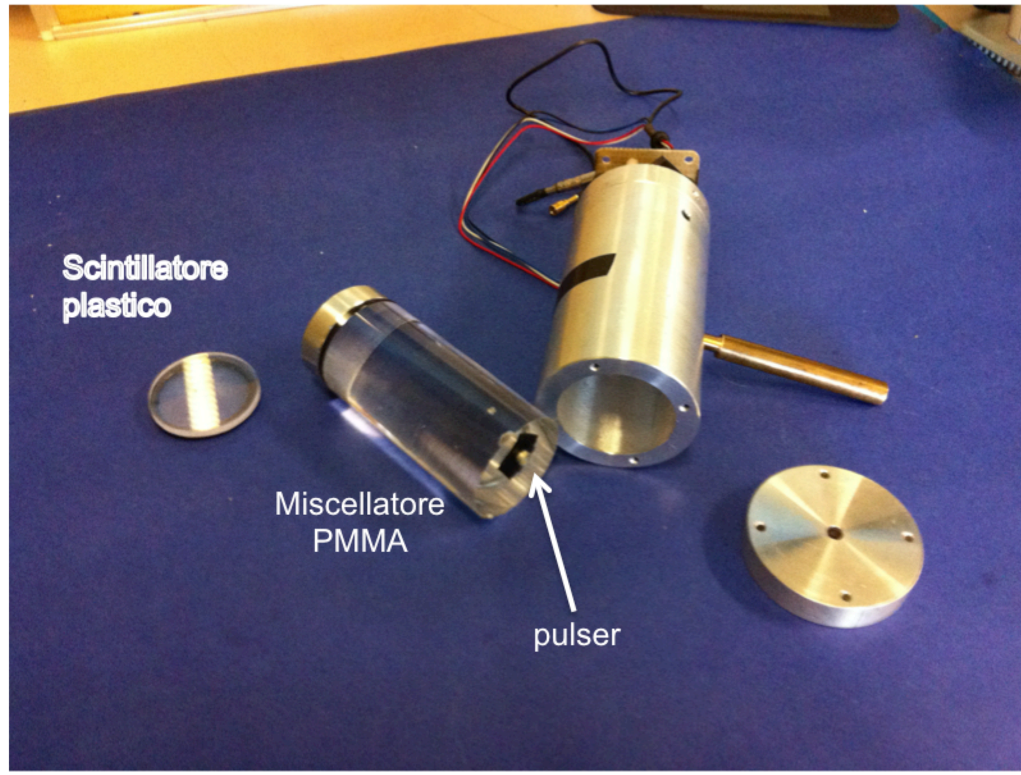
In order to opitmize the monitor stabilty:

- we use zero gain PIN diodes which are much more stable than SiPMs to variations in bias and temperature.
- We expose them to much higher light levels to minimize photoststistics while ensuring that they remain dominant w.r.t. to other fluctuations (e.g. electronic noise)
- we equip it with electronics designed for stabilty.
- we use redundant photodetectors and distribute them spatially in order to be sensitive to eventual "pointing" fluctuations which could influence the monitor and the distribution to the calorimeter elements in a differerent manner.
- we minimize "pointing fluctuations" by incorporating diffusion and mixing
- We incorporate an absolute radioactive reference

Fist prototypes

Our first attempt at incorporating these qualities are represented by the following prototype:



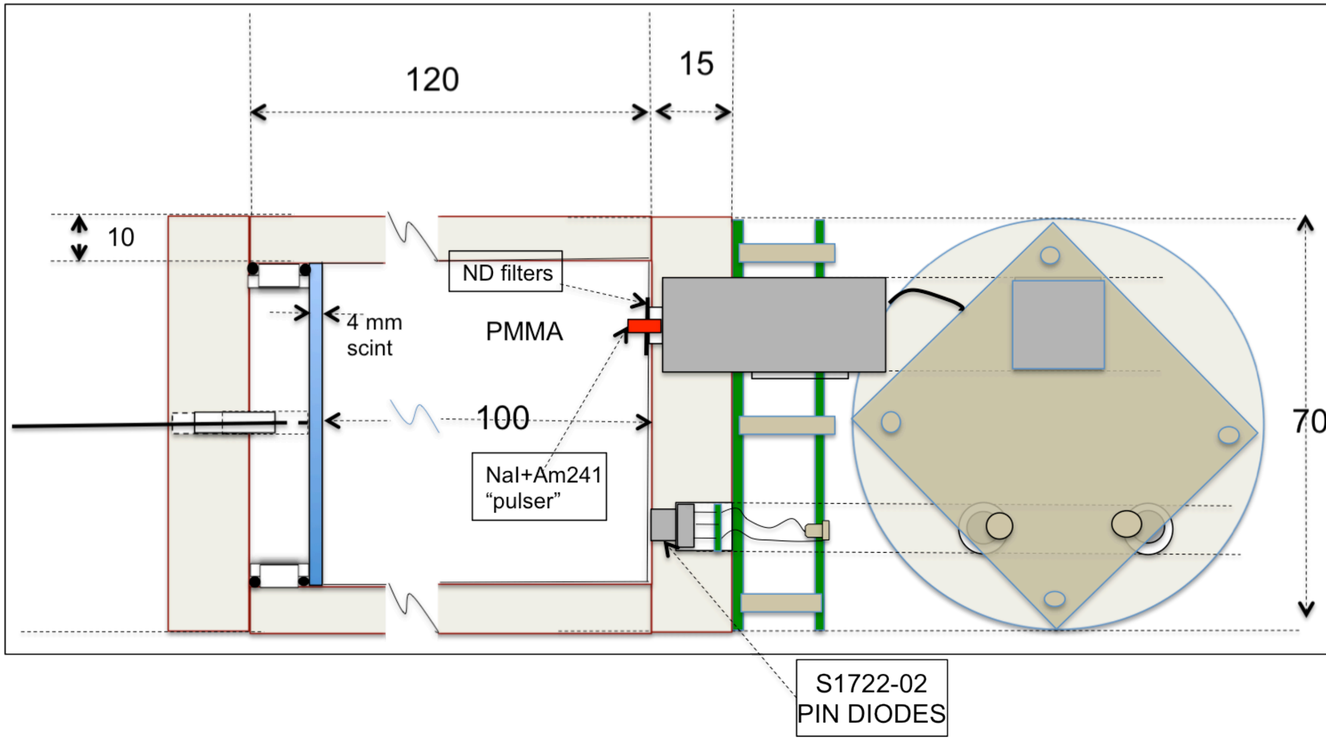


This prototype incorporates two PIN diodes and one PMT as potodetectors, a plastic scintillator as “ideal” diffuser and a PMMA cylinder as a “mixer” The photodetectors are widely distributed to maximize sensitivity to anisotropic fluctuatios and one of them views both le laser pulse and an NaI signal generated by a ^{241}Am source as absolute reference.

Short monitor prototype

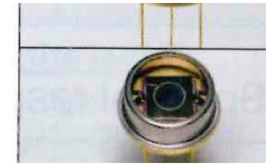
Prototypes of two different lengths but the same basic characteristics were construced. The shorter one is represented schematically below.

Laser light is injected by a quartz fiber on the left and excites a plastic scintillator which acts as an ideal diffuser becuase the emitted light is isotropic over 4π. The scintillator disk is faced up against a PMMA cylinder which acts a "mixer" .



This combination should be effective in minimizing "pointing" fluctuatons which could be produced by fluctuations in the emittance of the laser. These are improbable because the area of scintillator illuminated by the fiber is very nearly fixed a point source.
The scintillation light illuminates the photodetectors faced up against the other end of the PMMA mixer.

PIN diode Ham 1722 – 02 fast (~ 100 MHz)(quartz window)

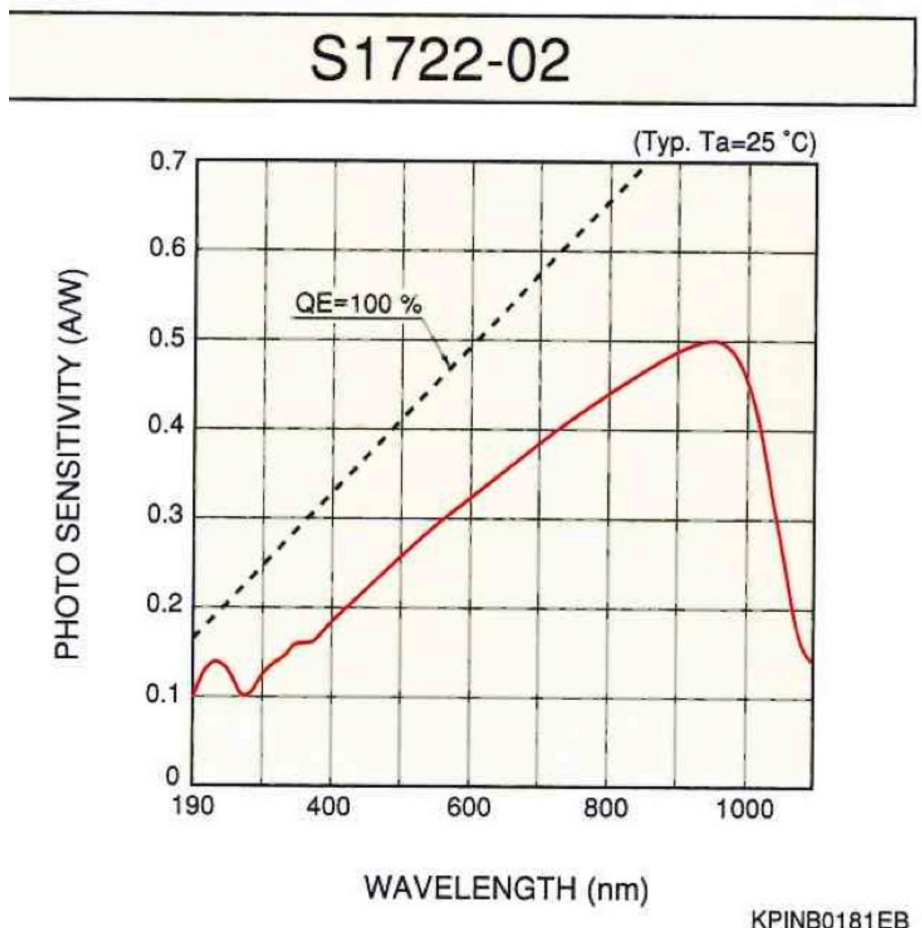
S1722-02	60 (V_R=100 V)	ϕ4.1	0.5 (λ=960 nm)	10 (V_R=100 V)	TO-8	

The photodetctors include two fast PIN diodes some of whose characteristics are summarized in this transparency.

Note the rlatively large diameter of *4.1 mm* (to maximize photostatistics)

The e PIN diodes are relatively slow (~ 10 ns pulse – width) compared to the laser pulses but fast enough given that they will be integrated by their electronics for stabilty.

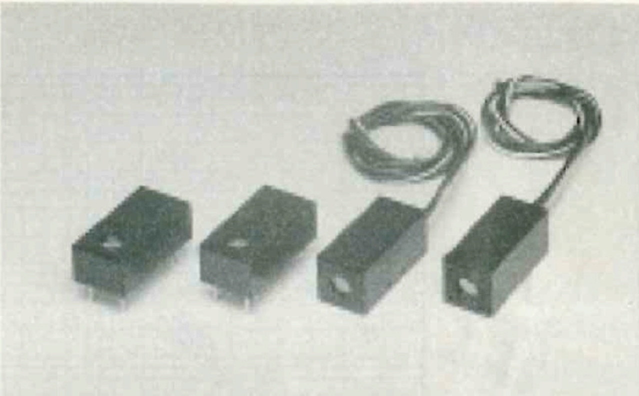
The third photodetector is a PM with a 8mm diameter cathode and a "cockroft-walton" base which generates its own HV. And operates at low voltage.



More detailed characteristics are given inthe next transparency.

Metal Package PMT

Photosensor Modules H5773/H5783/H6779/H6780 Series



The H5773/H5783/H6779/H6780 series are photosensor modules housing a metal package PMT and high-voltage power supply circuit. The metal package PMTs have a metallic package with the same diameter as a TO-8 package used for semi-conductor photodetectors, and deliver high gain, wide dynamic range and high-speed response while maintaining small dimensions identical to those of photo-diodes. The internal high-voltage power supply circuit is also compact, making the module easy to use.
Considering the mounting methods, a cable output type and a pin output type are provided, and a total of 7 types are available according to the wavelength range to be measured. P-type is also available with selected gain and dark count ideal for photon counting under extremely low light conditions.

Parameter			H5773 / H5783 / H6779 / H6780 Series					Unit
Suffix			None	-03, -06	-01, -04	-02	-20	—
Input Voltage			+11.5 to +15.5					V
Max. Input Voltage			+18					V
Max. Input Current			H5773 / H5783 Series: 9 H6779 / H6780 Series: 30					mA
Max. Output Signal Current			100					μA
Max. Control Voltage			+1.0 (Input impedance 100 kΩ)					V
Recommended Control Voltage Adjustment Range			+0.25 to +0.9					V
Effective Area			ϕ8					mm
Sensitivity Adjustment Range			1: 10^4					—
Peak Sensitivity Wavelength			420	420	400	500	630	nm
athode	Luminous Sensitivity	Min.	40	40	80	200	350	μA/lm
		Typ.	70	70	150	250	500	μA/lm
	Blue Sensitivity Index (CS 5-58)	Typ.	8	8	—	—	—	—
	Red/White Ratio	Typ.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The PMT is also exposed to the signal from a NaI crystal on which a very small quantity (~ 10 counts/sec) of ^{247}Am has been deposited. The combination is ecapsulated in an aluminum cilinder with a *5mm* trasparent window on the base faced up against the 8 mm – diameter PM potcathode so that the PM ca also see the laser light which must be attenuated (using neutral density filters because of the high ($\sim 10^6$) PM gain.

The manner in which the monitor signals are used to monitor stabilty can be explained as follows:

The monitor generates 4 sidnals

1) An unamplified signal induced by the laser in PIN 1. This signal is subject to fluctuatons in the laser intensity. $P1_L . f_L$

2) An unamplified signal induced by the laser in PIN 2. This signal is subject to fluctuatons in the laser intensity $P2_L . f_L$

3) An amplified ($10^5 – 10^6$) siignal induced by the laser in th PM. This signal is also subject to fluctuations in the PM gain. $PM_L . f_L . f_G$

4) An amplified signal induced byt the Am+NaI "pulser" in the PM. This signal is only subject to the PM gain $PM_P . f_G$

Laser fluctuations are eliminated event-by-event from the following ratios

$$R_{12} = \frac{P2_L.f_L}{P1_L.f_L} = \frac{P2_L}{P1_L} \qquad R_{31} = \frac{PM_L.f_L.f_G}{P1_L.f_L} = \frac{PM_L.f_G}{P1_L} \qquad R_{32} = \frac{PM_L.f_L.f_G}{P2_L.f_L} = \frac{PM_L.f_G}{P2_L}$$

Both statistical laser fluctuations and drifts in laser intensity are eliminated event-by event in these ratios, as they are in the ratios

$$R_{CiM} = \left(S_{Ci} \cdot f_L / S_{ML} \cdot f_L \right)$$

where S_{ci} is the signal from one of the calorimeter elements and S_{ML} is one or some combination of laser – induced calorimeter signals.

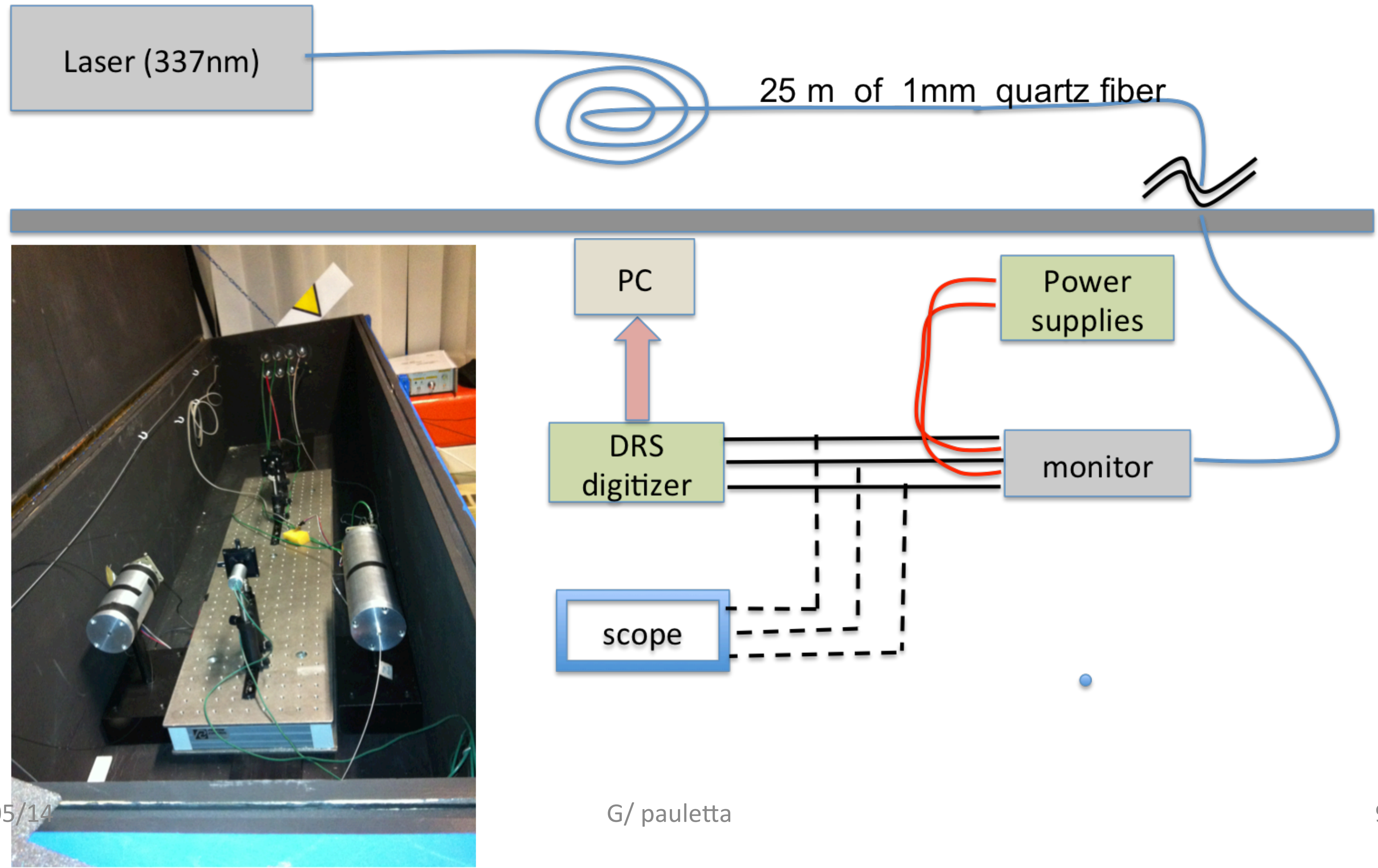
Fluctuations in PM gain (f_G) are monitored by R_{31} and R_{32} and can be used to correct gain fluctuations in the PM signal from the Am241+NaI “pulser” PM_P which is meant to be our absolute stability reference.

Implicit in these arguments is that the laser fluctuation f_L affects all signals in the same way, which explains why one must minimize eliminate/monitor distribution differences due to “pointing” fluctuations.

The ratio R_{12} is o monitors of PIN stability and “pointing instabilities.

Experimental setup to evaluate monitor stability

A high power Nitrogen laser was used as a light source (see next transparency for characteristics). The intensity was high enough to preclude the need for amplification of the PIN diode signals . Photostatistic fluctuations were therefore minimized and the signal was much larger than electronic noise.



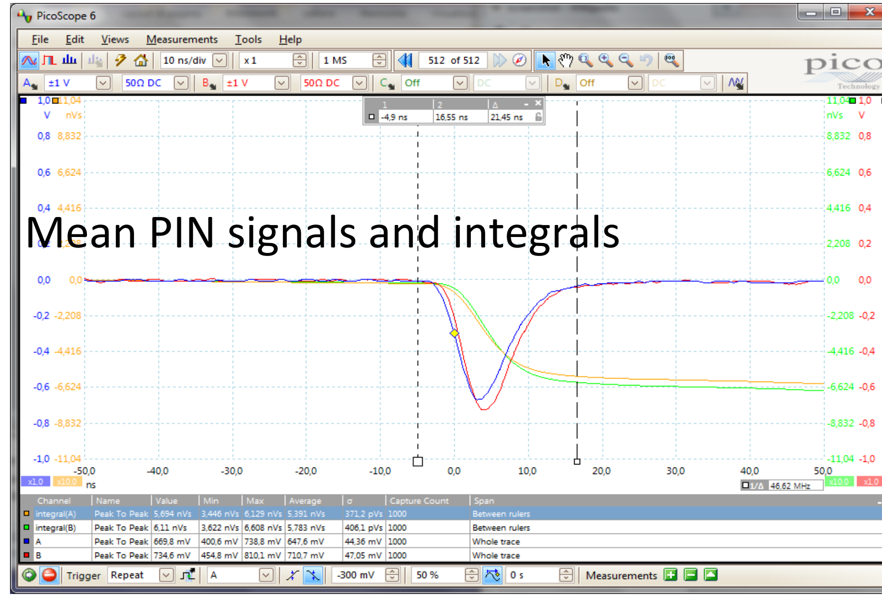
Nitrogen laser characteristics

Specifications for **laser 3371** by Laserpulse LLC. It is a pulsed, sealed-bottle, nitrogen **UV** laser. **Class 3b.**

Wavelength (nm)	337.1
Linewidth (nm)	<0.1
Pulsewidth (ns)	5
Pulse energy (@10 Hz) (μJ)	400 (+/-10%)
Pulse stability (@15 Hz)	<3% standard deviation over 1000 shots
Power peak (kW)	80
Maximum average power (mW)	20
Maximum repetition rate (Hz)	50
Pulse jitter (ns)	+/-1
Beam dimensions (mm)	3 x 7
Beam divergence (mrad)	2 x 5

The intensity was attenuated by a *10DB* neutral density filter and a *40 m* – long quartz fibe. The intensityinto the monitor was ~ *200 nJ/pulse*

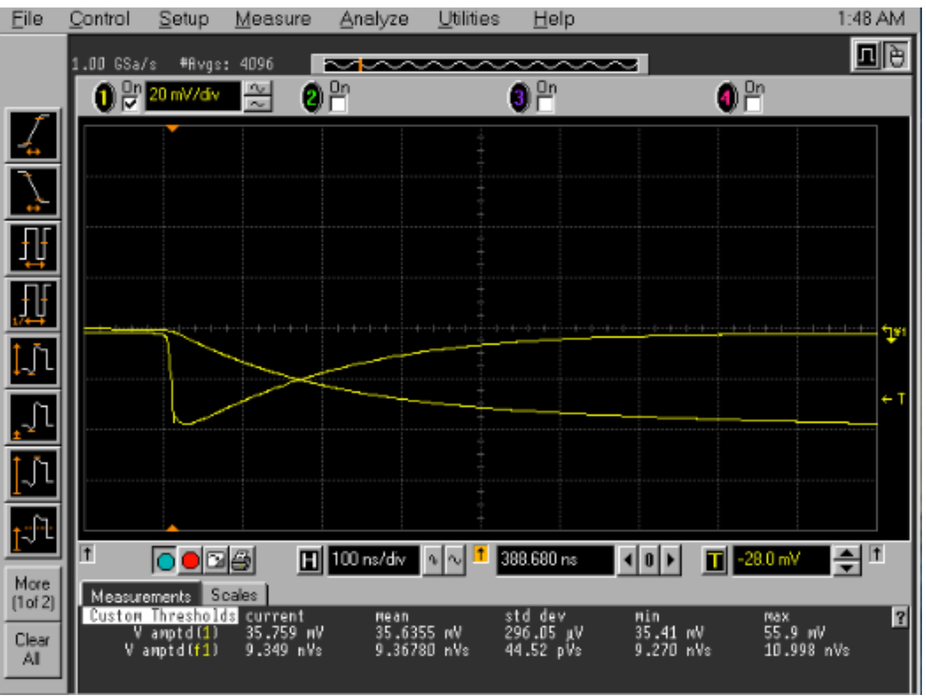
The averaged signals (P1 and P2) and corresponding integrals recorded with CRT.



For Pi amplitudes, $\sigma_{APi}/<A_{pi}> = 6,7\%$,

For Pi integrals $\sigma_{IPi} /<I_{pi}>= 6.1\%$

These reflect the fluctuations in laser intensity



The average Am241+NaI “pulser” signal.

For PM amplitude,

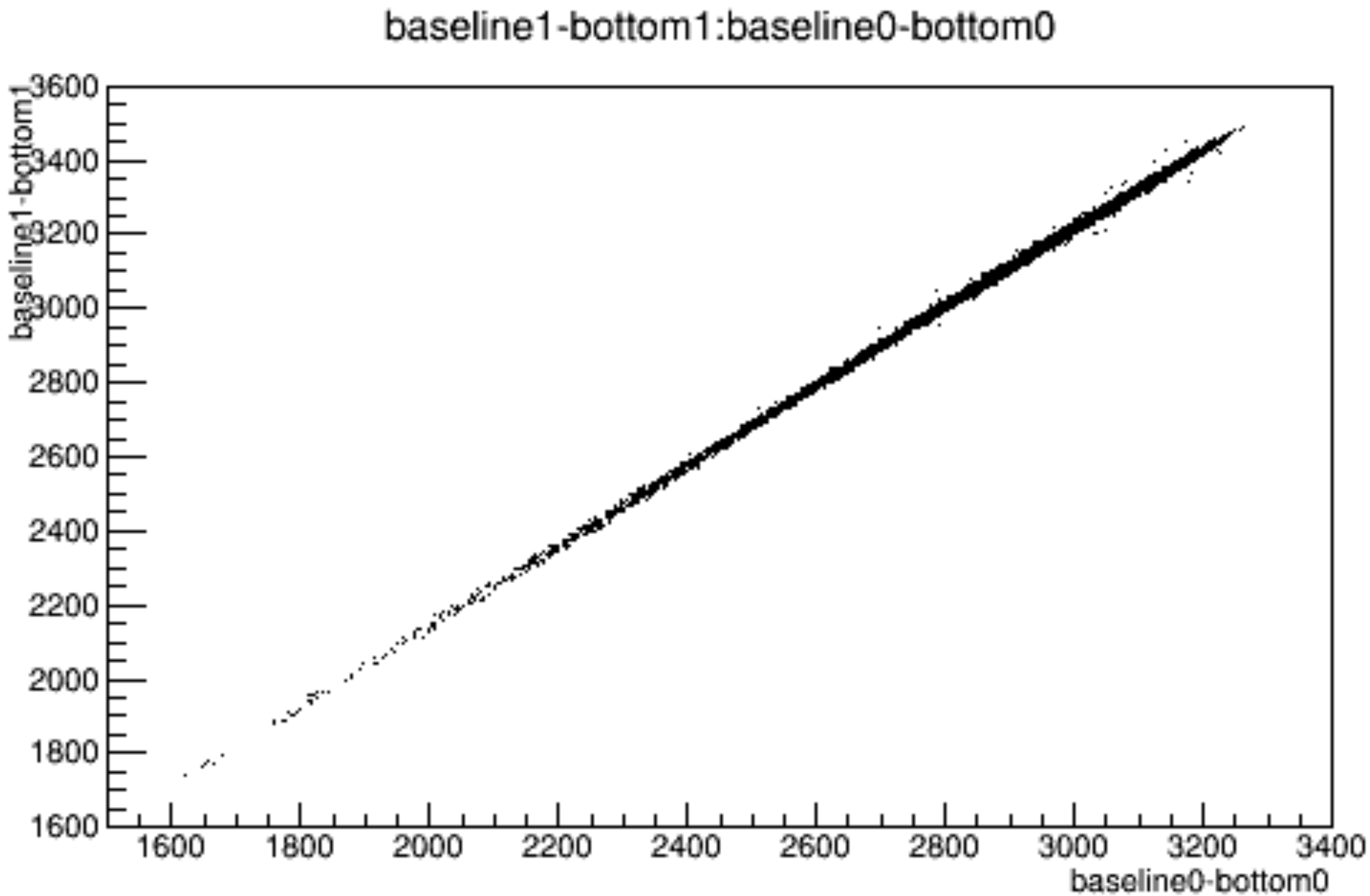
$\sigma_{<APM>}/<A_{pM}> = 1\%$ for 16 k events

For PM integrals $\sigma_{<IPM>} /<I_{PM}>= 0.04\%$

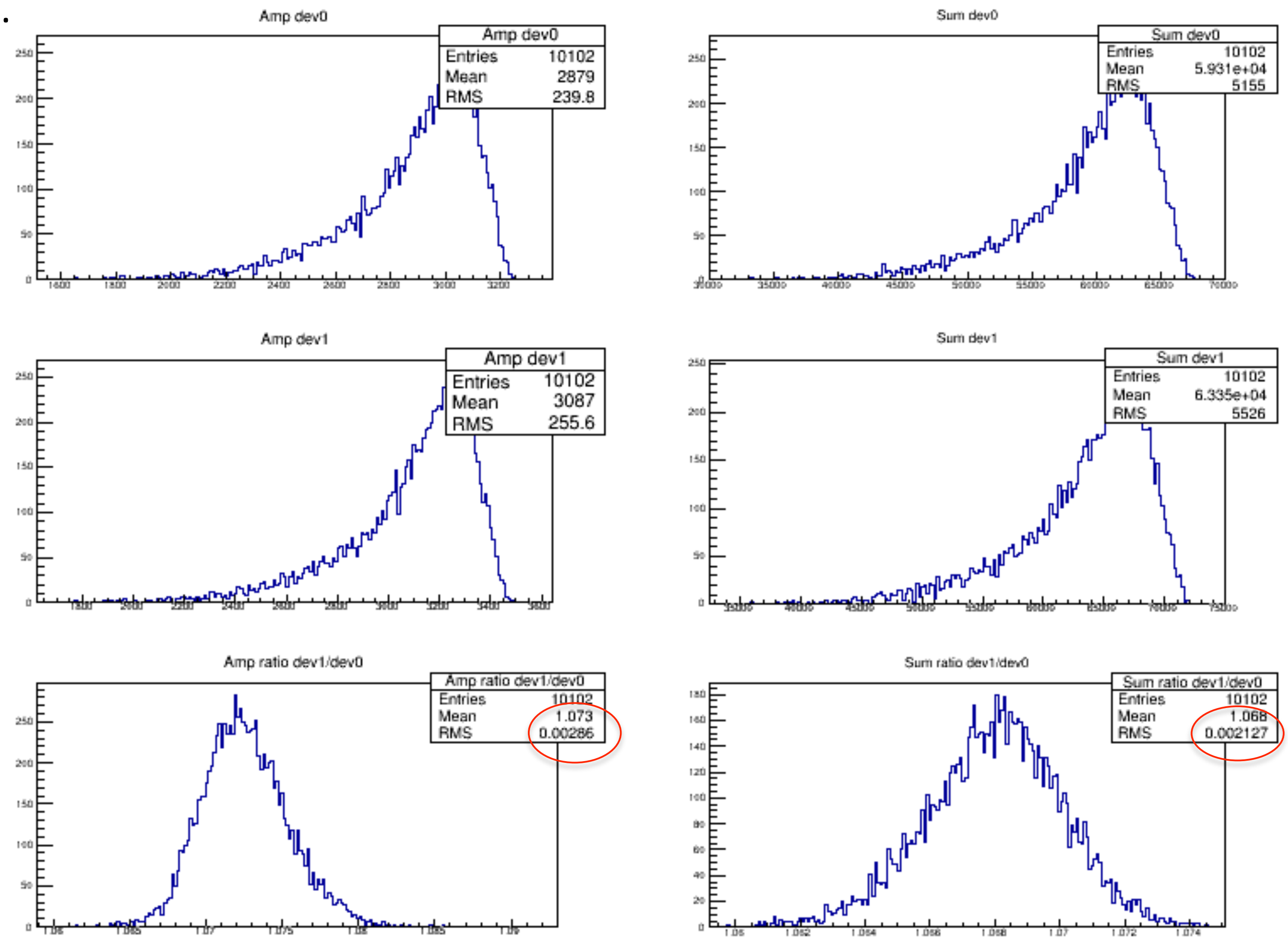
For 16k events collected over 20 min

σ_{IPM} is observed to vary statistically over this period

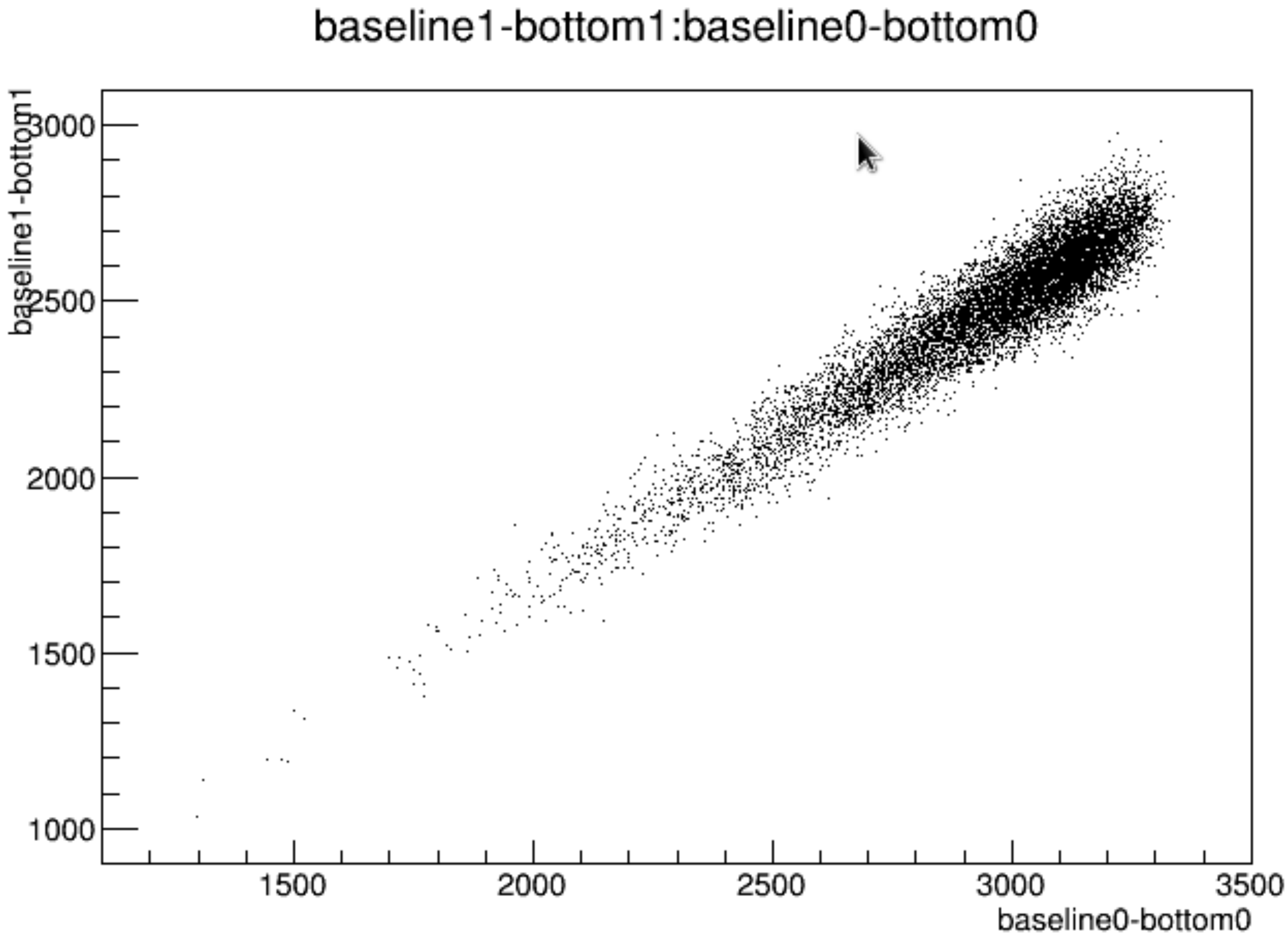
The $P2_L$ / $P1_L$ correlation



Shown here are amplitude, integral and R_{12} distributions. Note that σ_{R21} ~ 0.25% ***event-by-event despite the unusually large (~10%)*** laser fluctuations seen in the distributions of the individual signals and that the Gaussian ristribution is symptomatic of photostatistic dominance.

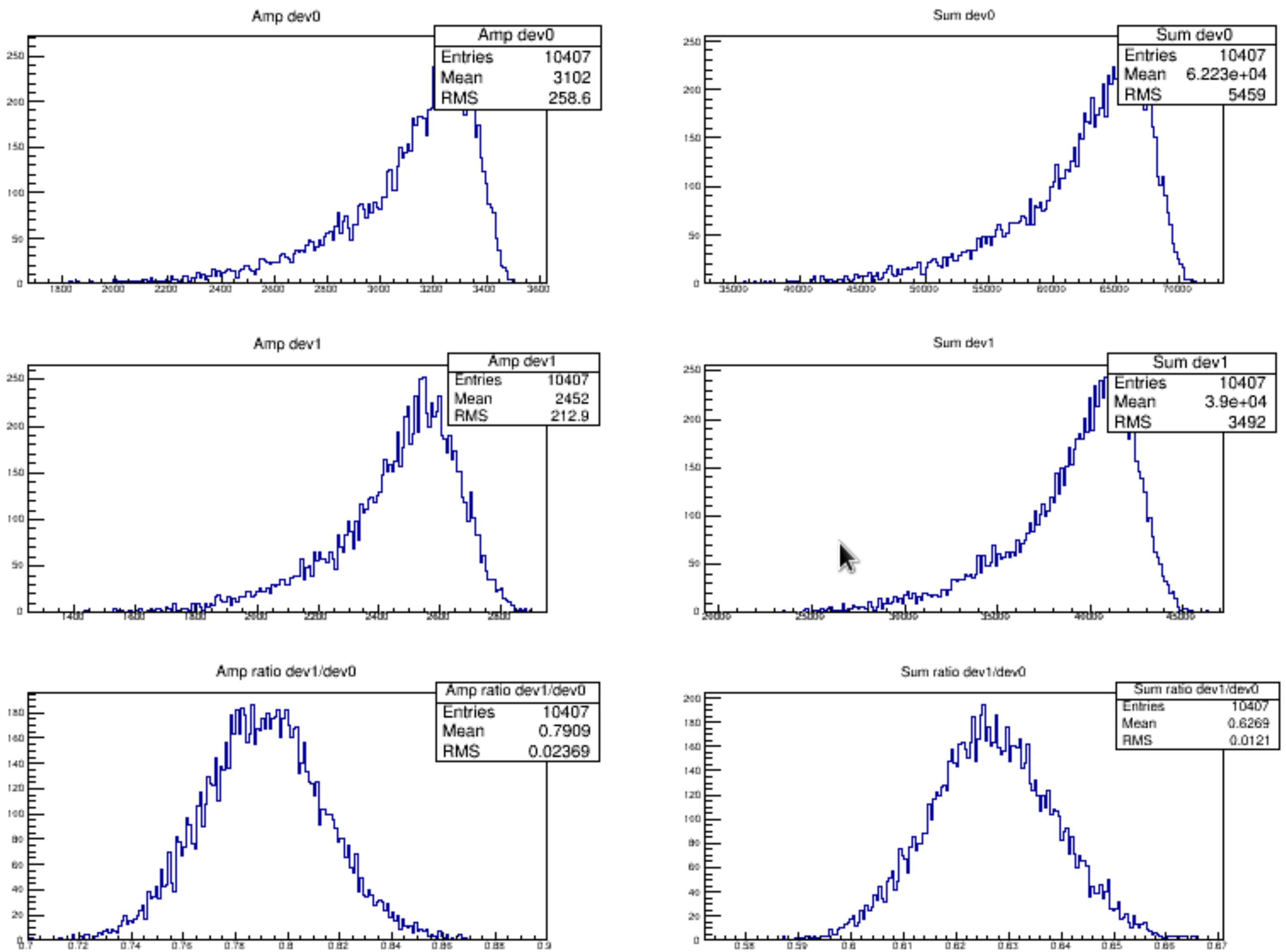


The PM/PIN1 correlation is not as well-defined



This is due to the increased PM photostatisc fluctuations: the PM sees 10^{5-6} less photons that the PIN diodes because we have to compensate for the larger gain by the introduction of ND filters

The associated σ_{R1} grows correspondingly to ~ 1.6%. The situation is expected to be similar for the SiPM / PIN correlations. However, what matters is the deviation of the mean which varies as $1/(N_{events} - 1)^{1/2}$ ... to the degree that statistics dominate.

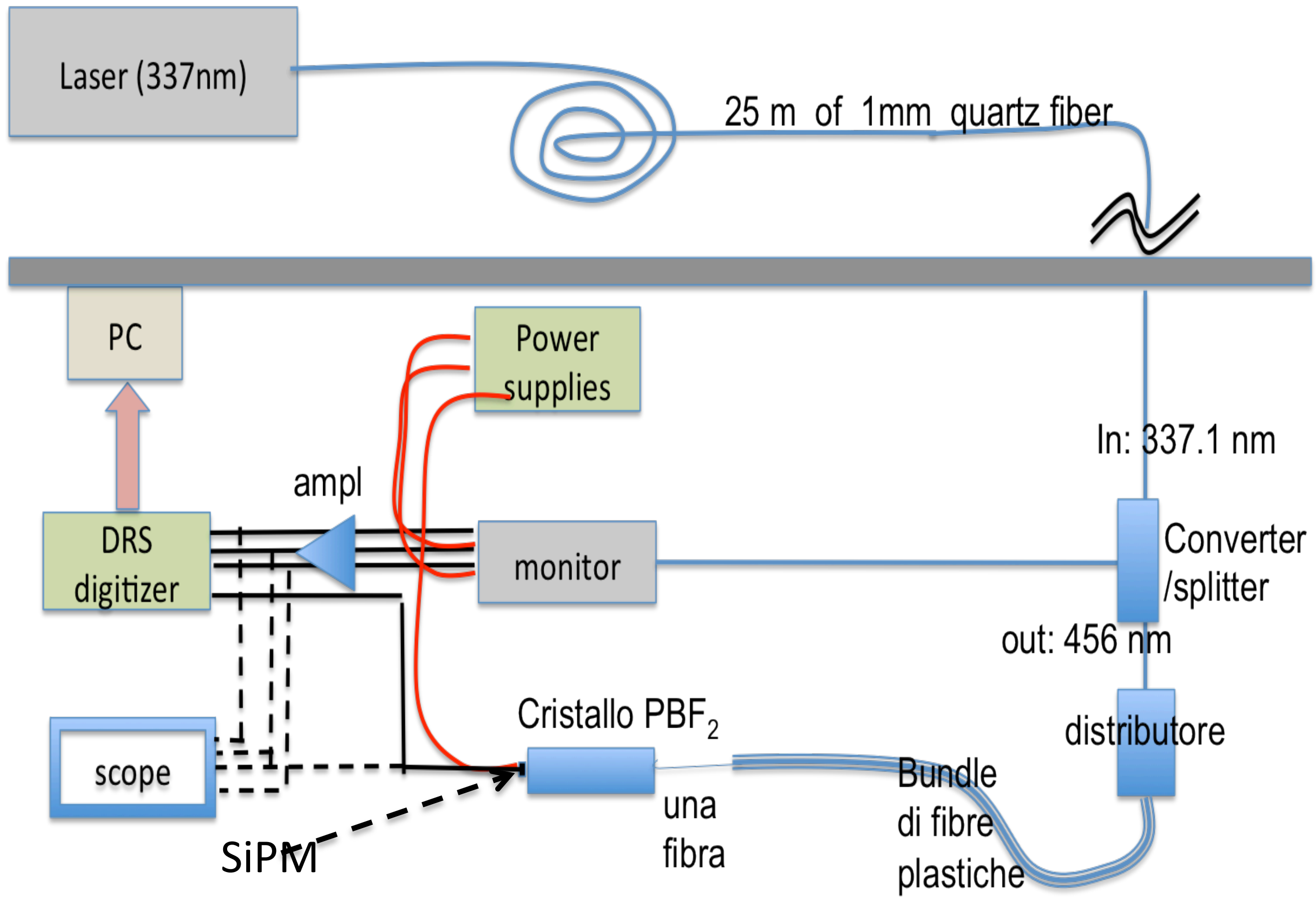


On the basis of these results we can say:

- We have evaluated ther performance of the first prototype of the monitor for the laser calibration system using laser with characteristics which are considerably less than optimal: -- it fluctuates considerably more (5-10 %) than the laser that will finally be used n is very noisy.
- From the distribution of the ratios PIN1/PIN2, we conclude that laser amplitude fluctuations were eliminated in the ratios at the level of 0.2% event-by-event for 10k events and appeared to be dominated by statistics over short (~ 1/2 hour runs).
- The Am-241+NaI refernce signal also appears to be dominated by statistics over analogous periods (1/2 hour) and capable of monitoring absolute stabilty at ~ 0.04% over these periods.
- The value (~1) and stability of R_{21} imples that "ponting" fluctuations are negligilel
- In these circumstances, where photostatistics dominate, there would be no difficulty in reducing the fluctuations of the mean to values well below those required.

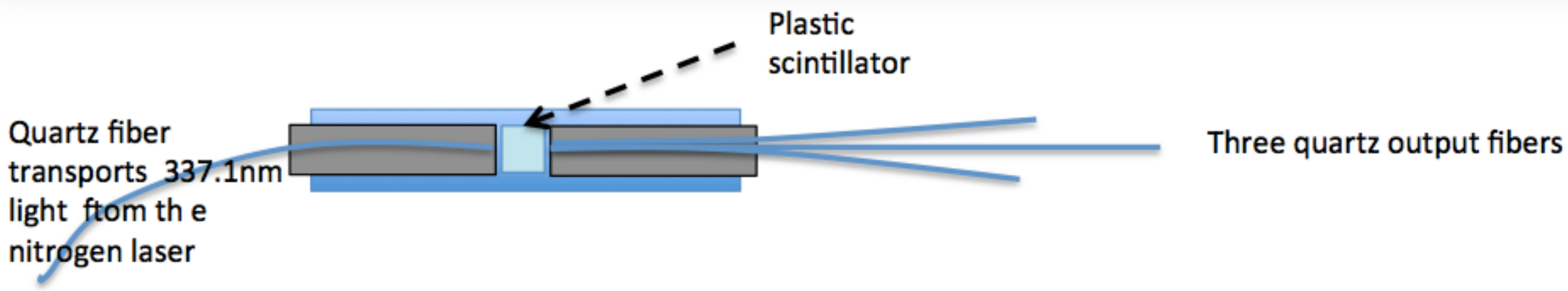
The situation could change with the reduction of intensity. Other fluctuattions (e.g. electronic noise and pickup) could become significant and the introduction of electronic signal amplification/conditioning may not be able to remedy the situation.

We have attempted to approach operating conditions. In the absence of the required laser (still on the way) and of the monitor electronics (almost ready) we have resorte to the following experimental setup.

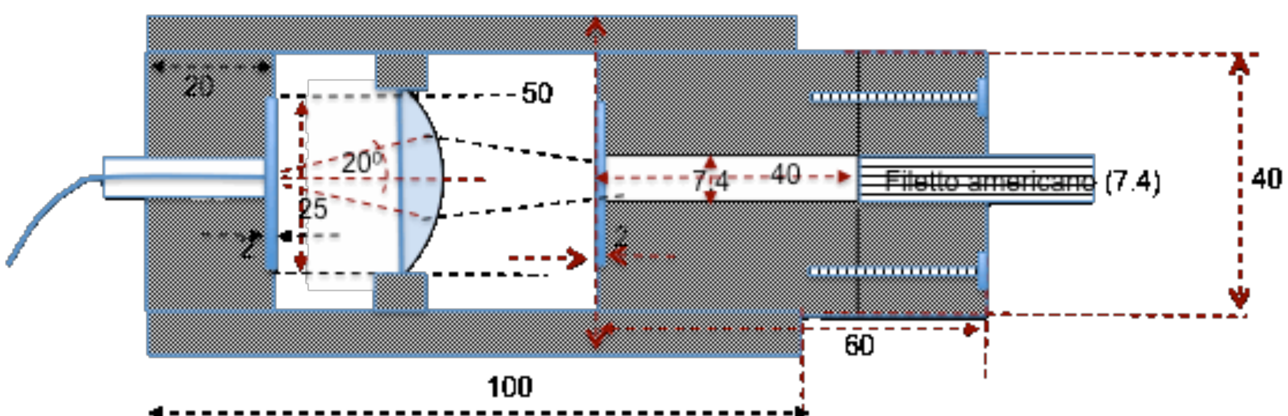


A wavellength-shifter/splitter (see next transparency) is used to convert the 337.1 nm laser light to 456 nm and to distribute it between 3 output quartz fibers. One of them (not shown here, generates a large trigger pulse by illuminating a PIN diode directly. The other two share the light between the monitor and the distributor

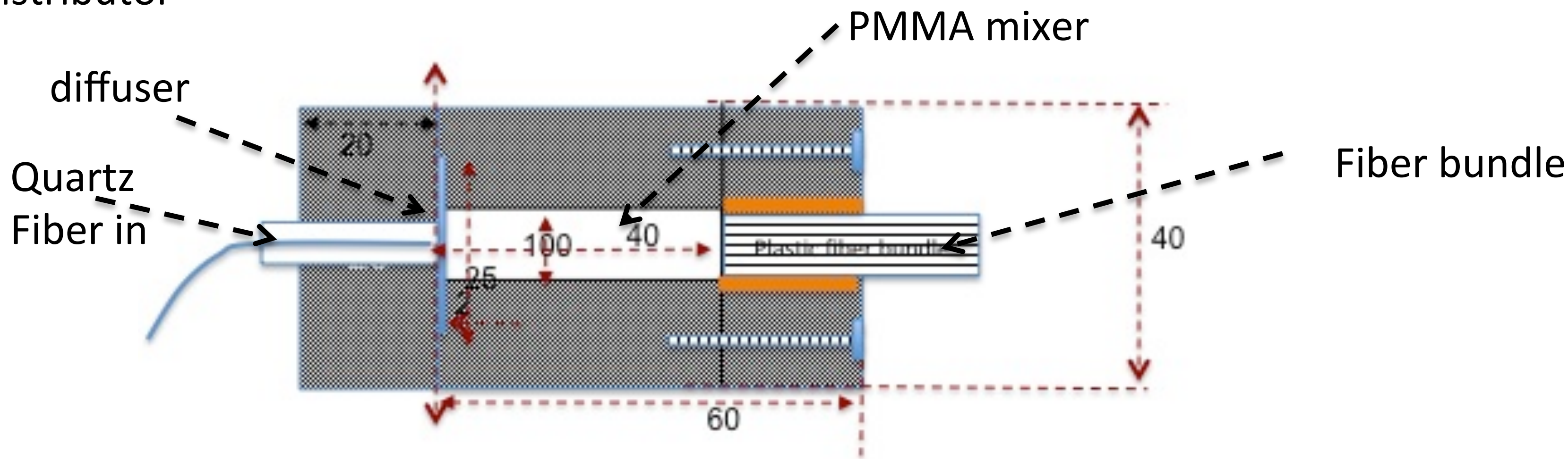
We resorted to the the following method for producing a light source of longer wavelength while, at the same time, splitting the signal



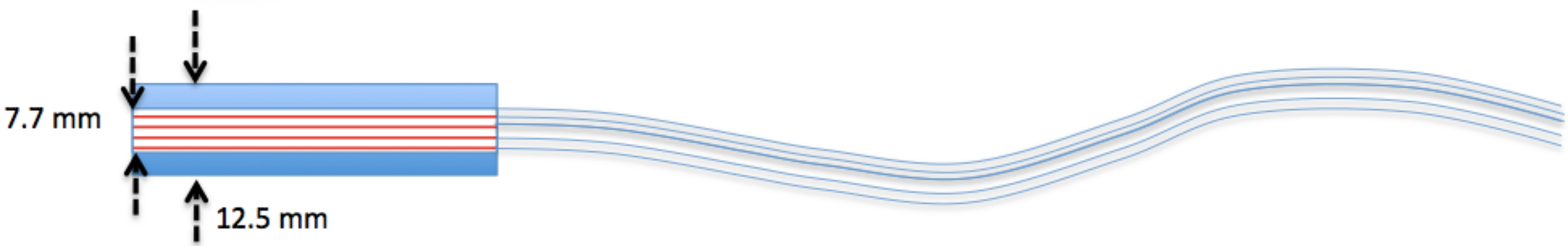
and having escertained that the combination of integrating sphere and the quartz fiber bundle at our disposal resulted in attenuations which were too large, we experimented in several versions of ATLAS style (beam expander + mixer_ distribution systems



For the systematic tests, reported below, we used a vey simple version of this type of distributor



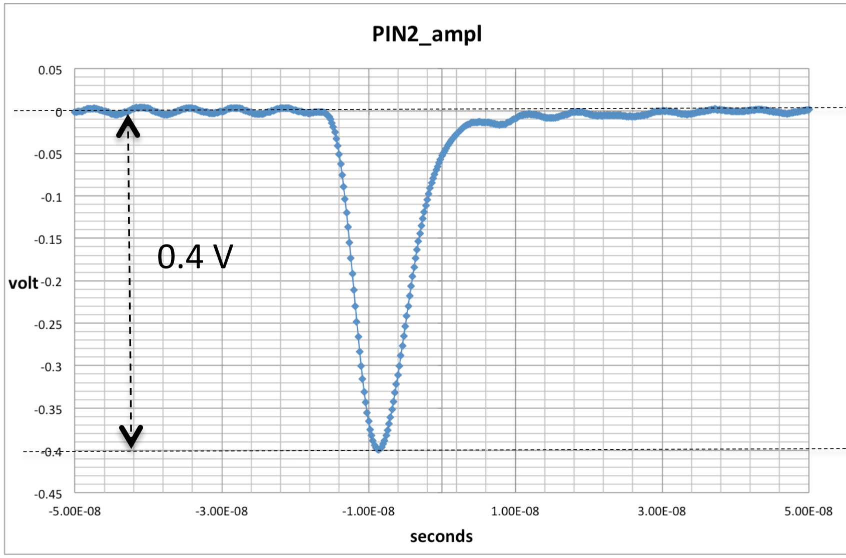
and a *1mm* – diameter plastic (Kuraray) 56 - fiber bundle which we constructed in-house

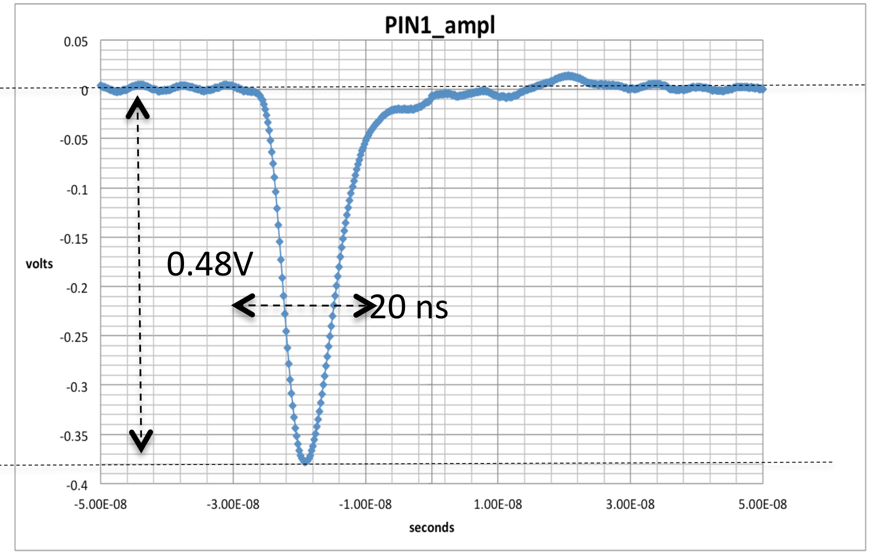


One of the plastic fibers is routed to one end of a PbF_2 crystal which is viewed, at the opposite end, by a FBK SiPM (RGB HD 2.2 x 2.2 mm^2) which is mounted directly on low-gain FBK electronics

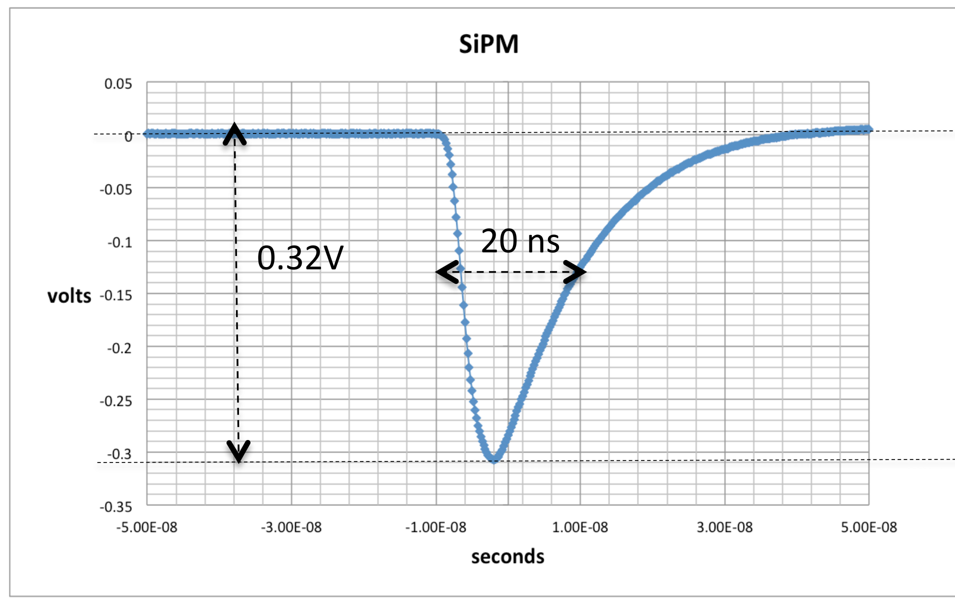
We ended up with ~ 10^3 photoelectrons / event in the SiPM which is in the operating range. The light intensity into the monitor is much smaller and the signals require amplification which we furnish (x8) close to the digitizer so that we expect to see relatively large electronic noise and picup.

Signals into the DRS waveform digitizer

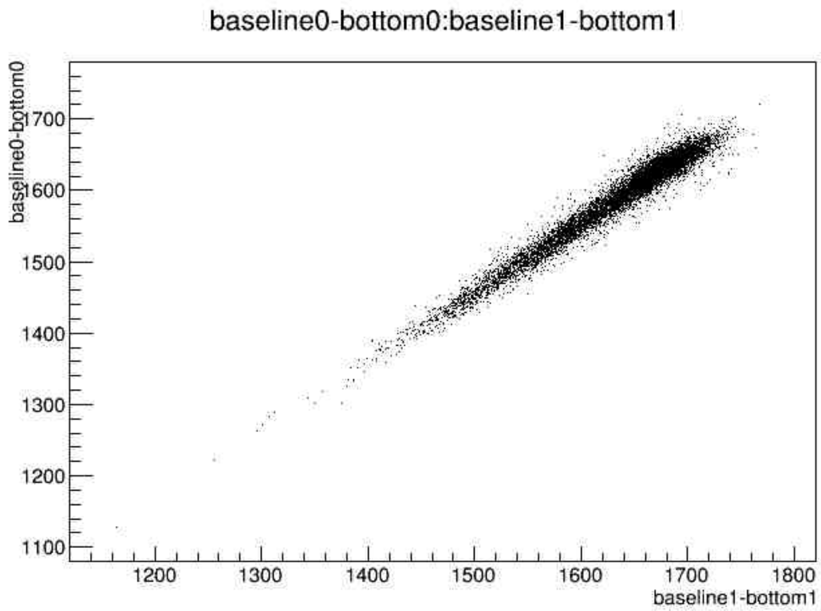


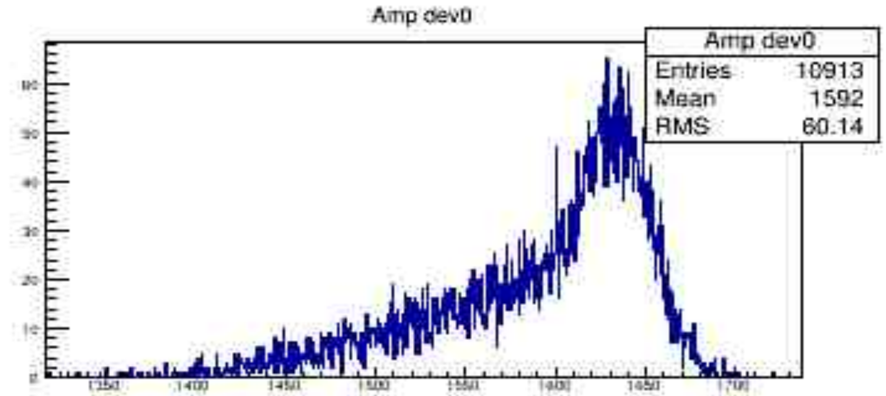


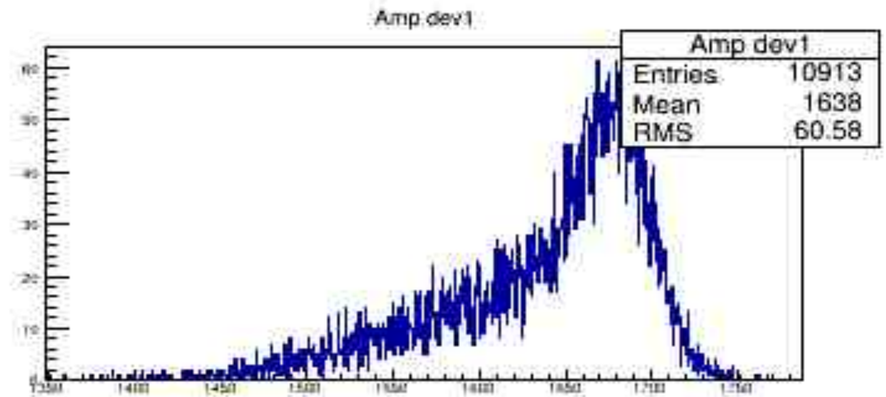
above: average PIN signals after x 8 amplification before input to digitizer. Note the high frequency pickup which does not zero out in the mean. Random electronic noise fluctuations are ~1%.

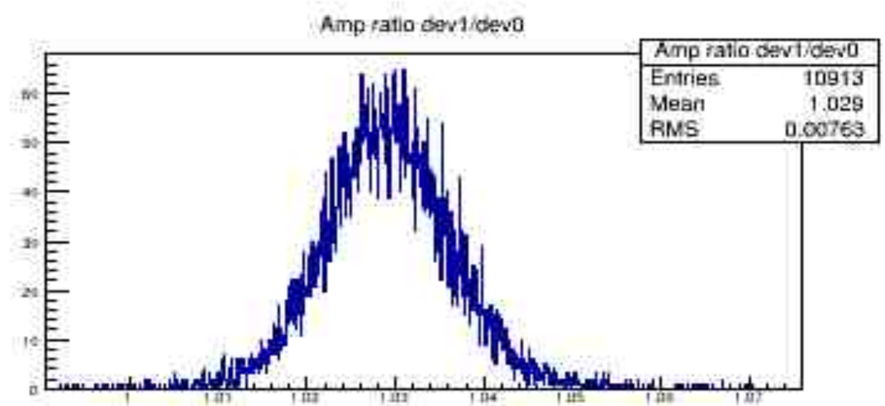


right: : average PIIN signal into the DRS. Note the absence of pickup because the SiPM si mounted on frontend electronics . Random electronic noise negligible.





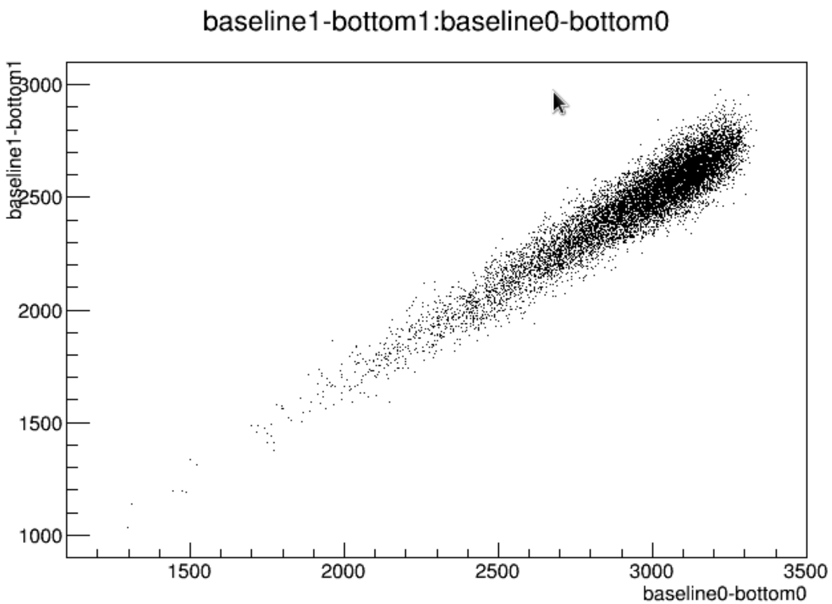


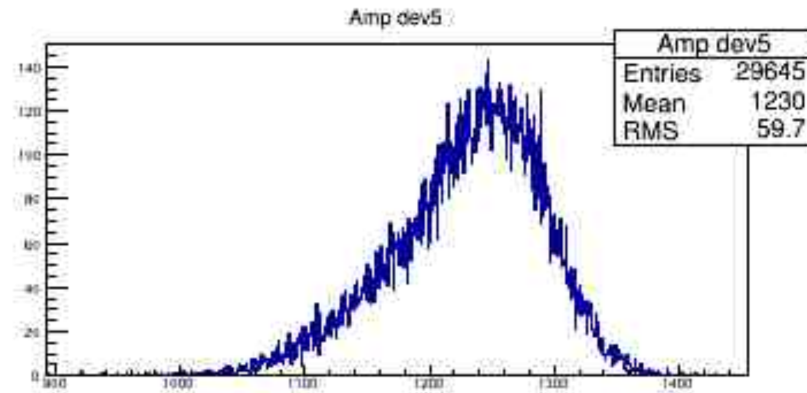


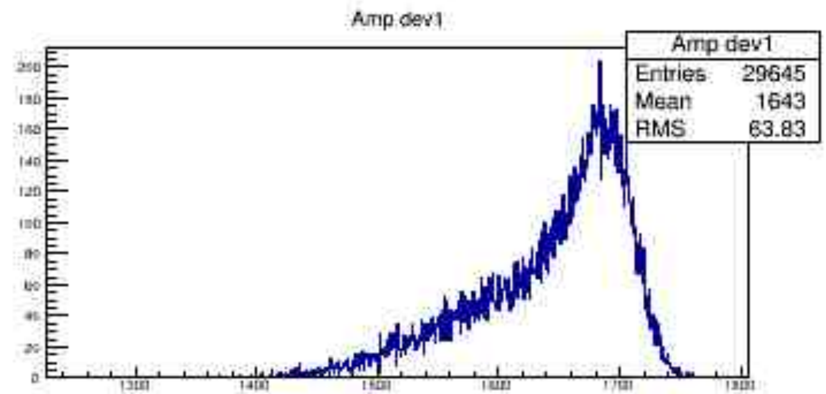
The correlation between $P1_L$ *and* $P2_L$ is, not as well – defined as at higher intensities but the gaussian behaiviour of the ratio implies that it is *still dominated by photostatistics*.

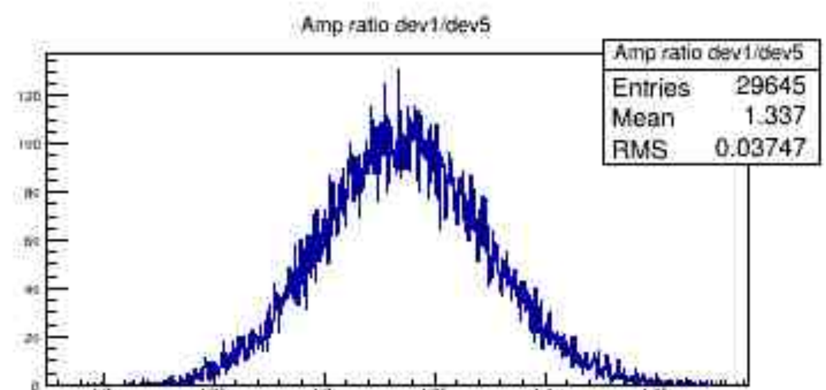
The RMS is ~0.08% evnt-by-event.

The correlation beween the SiPM signal and th PIN diodes is even less well-defined.





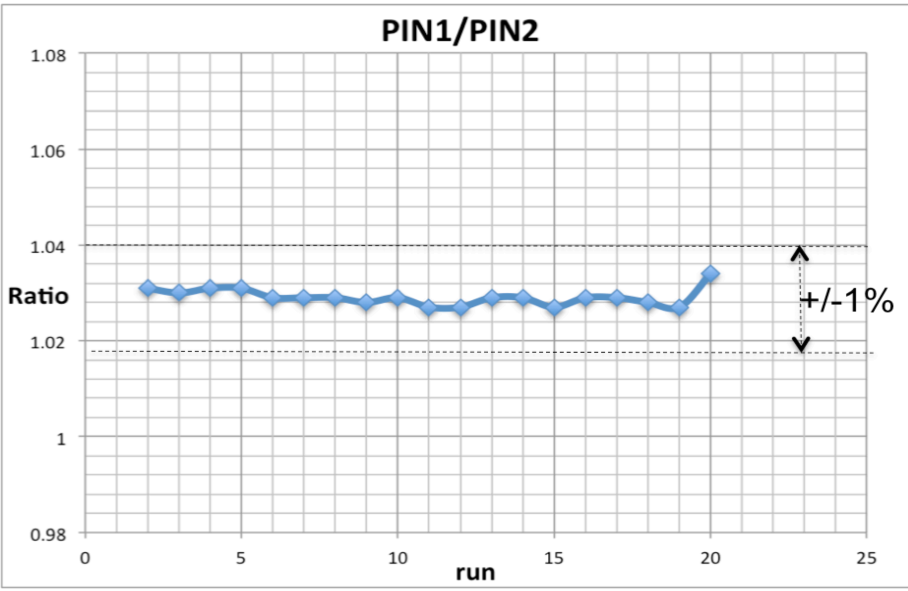


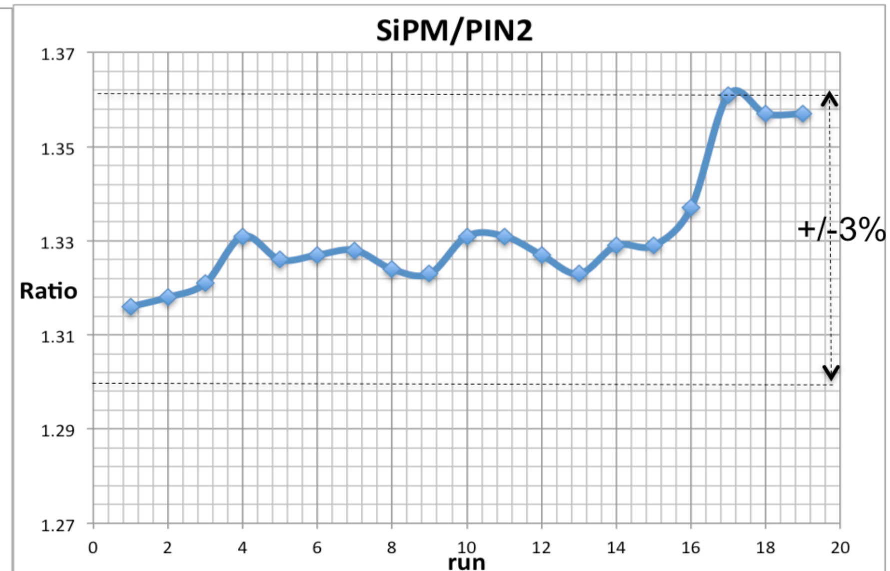


This is due to the poorer photostatistics: the event-by-event fluctuations for the SiPM are ~ 3% which is consistent with photostatistics for ~10^3 photoelectrons. The Gaussian distribution of the ratio SiPM/PIN2 suggests that photostatistics are dominant.

Fluctuations of the mean

In order to investigate the degree to which photostatistics dominate , the mean of ~ 10 k events was tracked over a period of ~ 10 days. The mean ratios are shown below as a function of run number



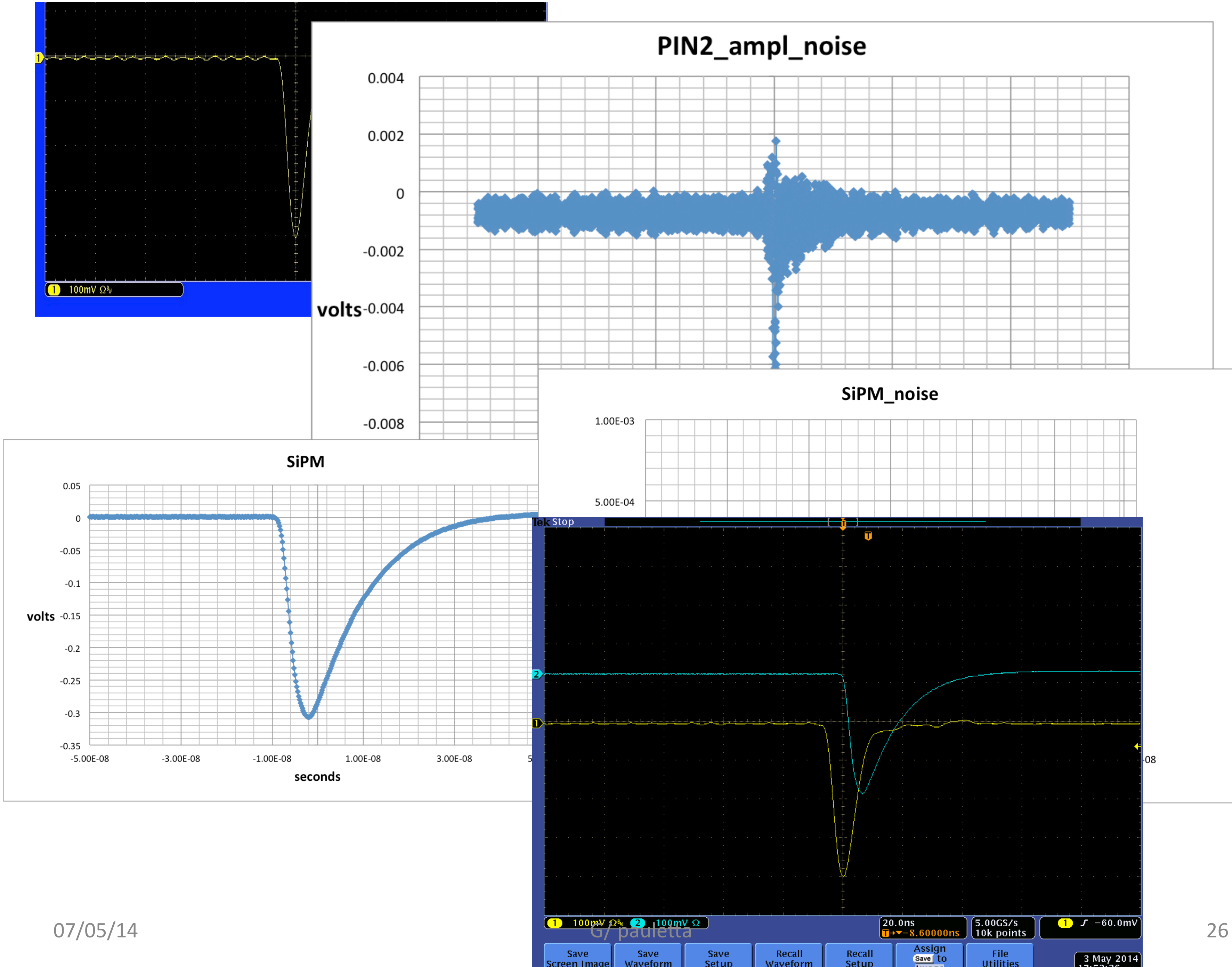


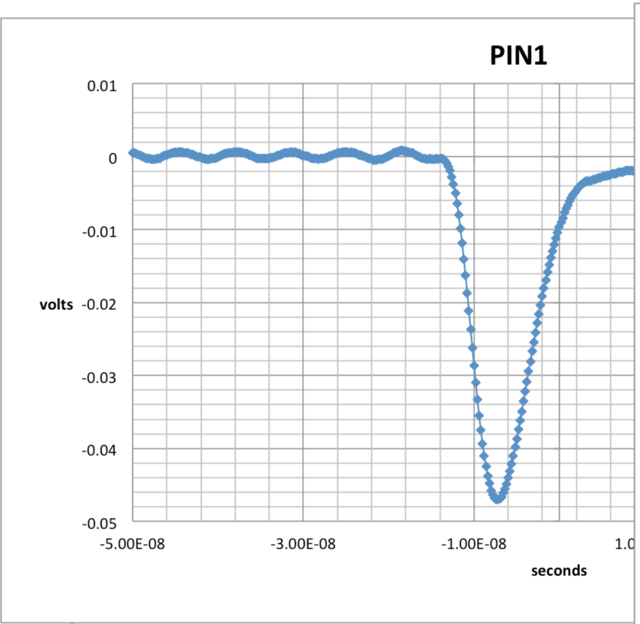
Fluctuations of the mean of R_{12} are 0.12% RMS for the set of measurements shown and tend to remain at around this value. This implies that fluctuations are dominated by other factors (e.g. electronic fluntuations) at this level and that *0.12% is our limit of stability with this setup*.

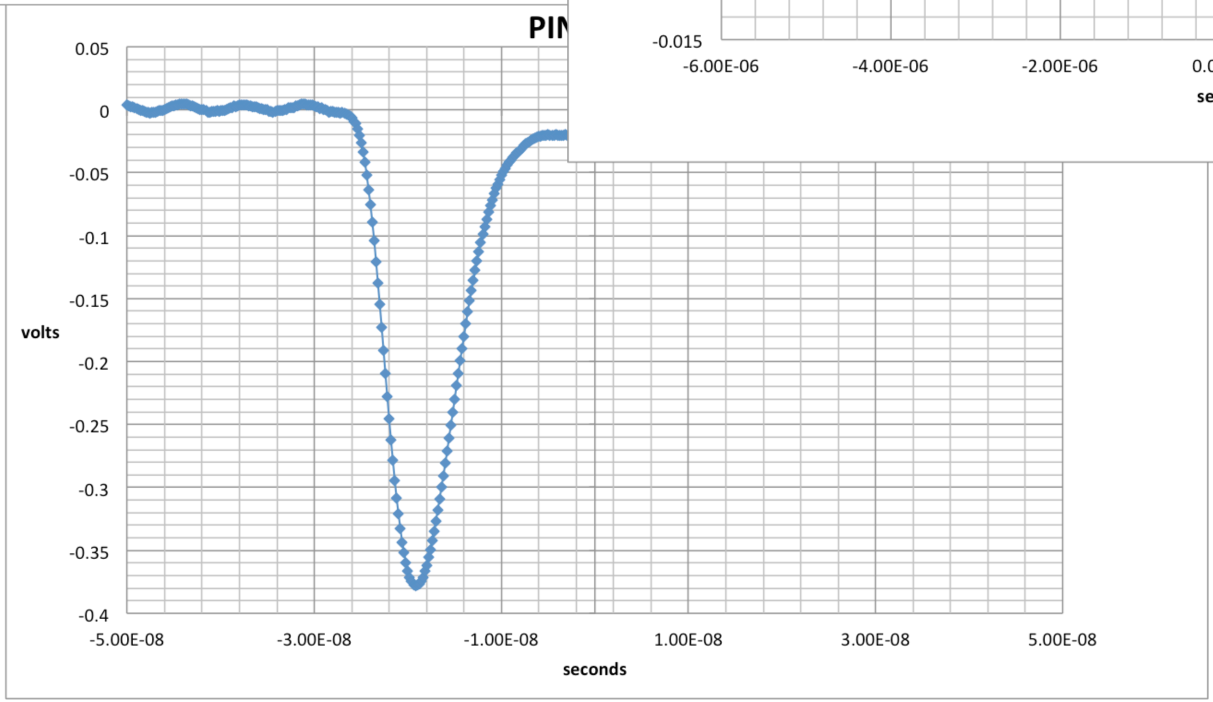
Fluctuations of the mean are 1.3% for the ratio SiPM/PIN2 but the fluctuations reported above show a definite trend and the last three exceed 1.3 %. (due to a change in temperature).
This ratio can be used to correct for SiPM gain instability at the level of 0.12%

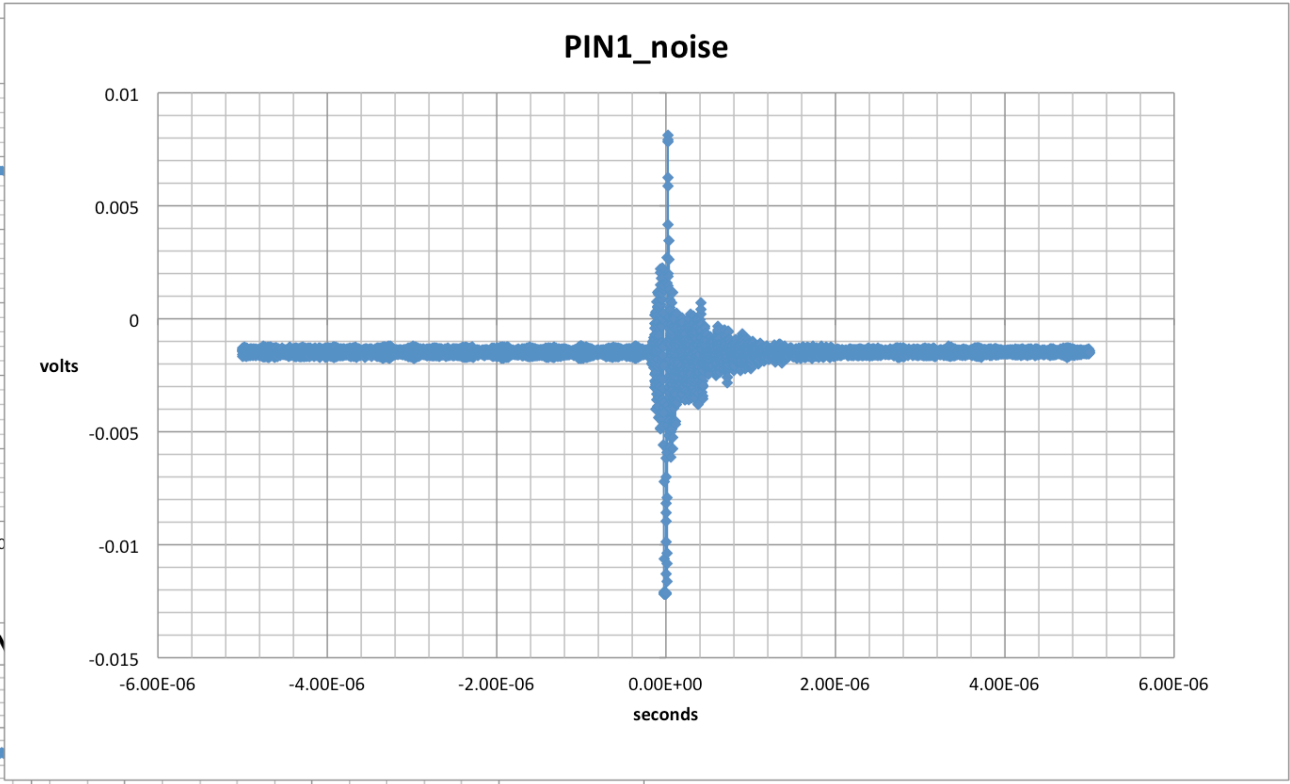
From these measurements, we concllude that, with a more stable laser and with the high stabilty electronics being devekoped for the monitor, we should be able to reach the level of stability of the mean requird by g-2.
 Event-by-event stability will however be limited to ~ 3 by photostatistics.

Backup


100mV Ω
PIN2_ampl_noise
volts
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
SiPM_noise
1.00E-03
5.00E-04
SiPM
volts
seconds
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-5.00E-08
-3.00E-08
-1.00E-08
1.00E-08
3.00E-08
Tek Stop
100mV Ω
100mV Ω
20.0ns
-8.60000ns
5.00GS/s
10k points
-60.0mV
Save Screen Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Assign Save to Image
File Utilities
3 May 2014
17:52:36


PIN1
volts
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-5.00E-08
-3.00E-08
-1.00E-08
seconds


0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
volts
-5.00E-08
-3.00E-08
-1.00E-08
1.00E-08
3.00E-08
5.00E-08
seconds


PIN1_noise
volts
0.01
0.005
0
-0.005
-0.01
-0.015
-6.00E-06
-4.00E-06
-2.00E-06
0.00E+00
2.00E-06
4.00E-06
6.00E-06
seconds

We recall that the purpouse of this calibration system is to monitor gain variations in the g-2 calorimeter by stimulating all the elements (PBF_2 crystals viewed by SiPMs) of the calorimeter and the monitor with a common light source .