Status report on the Pisa activities for Tilecal

S. Leone, F. Scuri - Atlas/Pisa meeting – Sep. 24, 2103

Summary:

- The laser II project
  - construction and installation of the new system
  - analysis of the data taken with the test system in 175

  today

- The local lab activities (just a few words)

- Preliminary studies on the 2011-2013 calibration n-tuples (report next time)

Laser II project : construction and installation (I)

- Design of the optics box almost complete (A. Moggi)

- New optical pieces inserted in the layout:

  - a commercial beam-expander (2.5x) placed in front of the laser head; aim is to reduce the power density on the most critical optical elements (filters in the wheel) in terms of damge threshold;

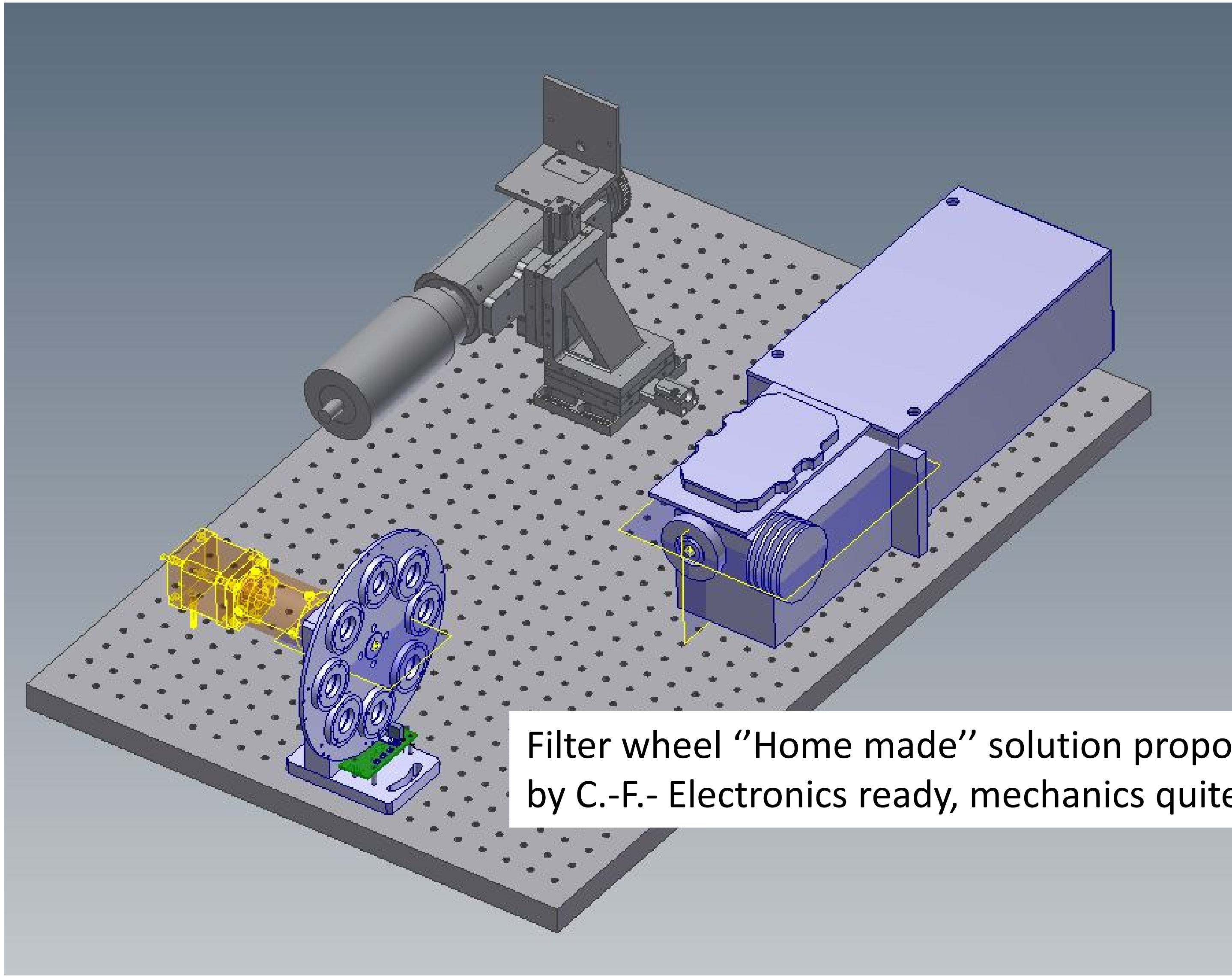
  - order for a Thorlabs beam-expander placed by Pisa;

  - Filter wheel: Clermont-Ferrand want to keep the responsibility for this element (due to the interface with the driving electronics). No decision still taken about the commercial or ''home made'' options ….

  - Both ''one wheel'' (8 filters) and ''two wheels'' (12-16 filters) options were studied as a function of the filter damage threshold and of the linearity scan requirements; a 8 filter single wheel option seem adequate.

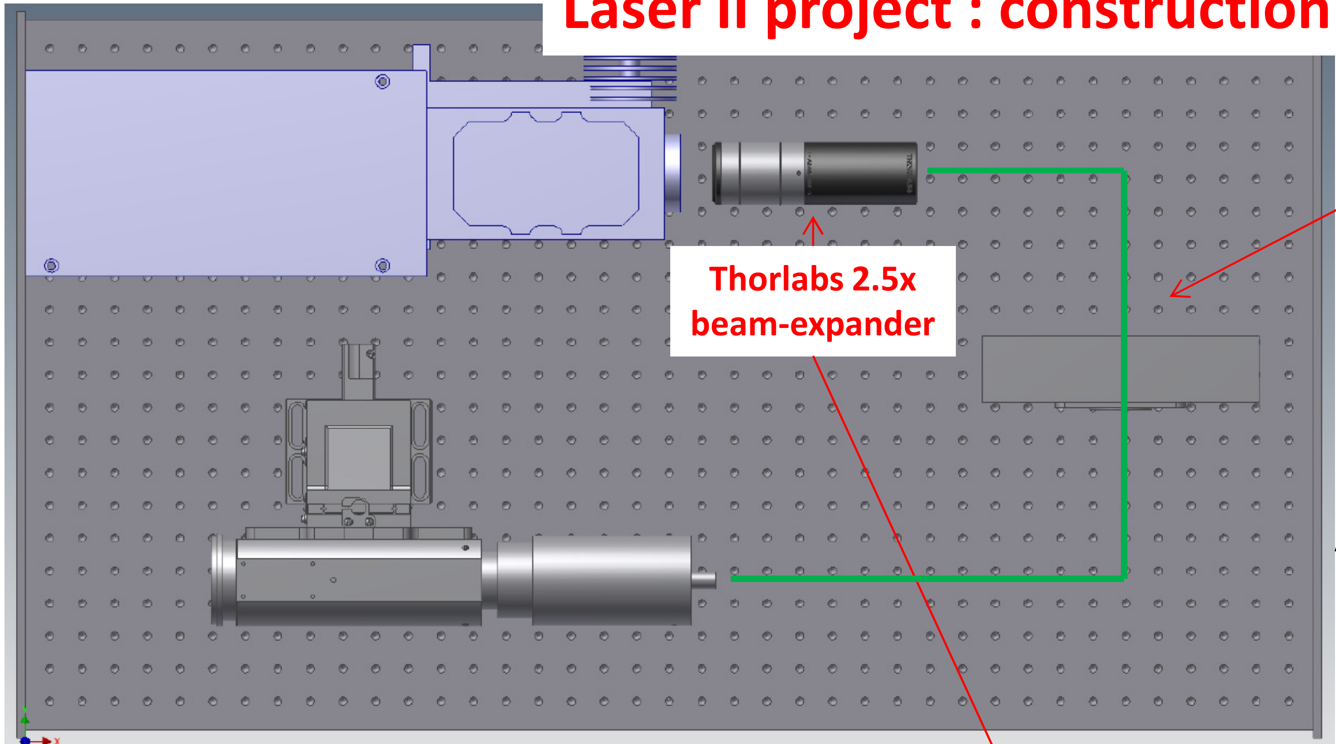
- Some details about the system to couple the 400 fiber bundle and the composite beam-expander to be fixed by Andrea

Laser II project : construction and installation (III)



Filter wheel ''Home made'' solution proposed
by C.-F.- Electronics ready, mechanics quite easy …

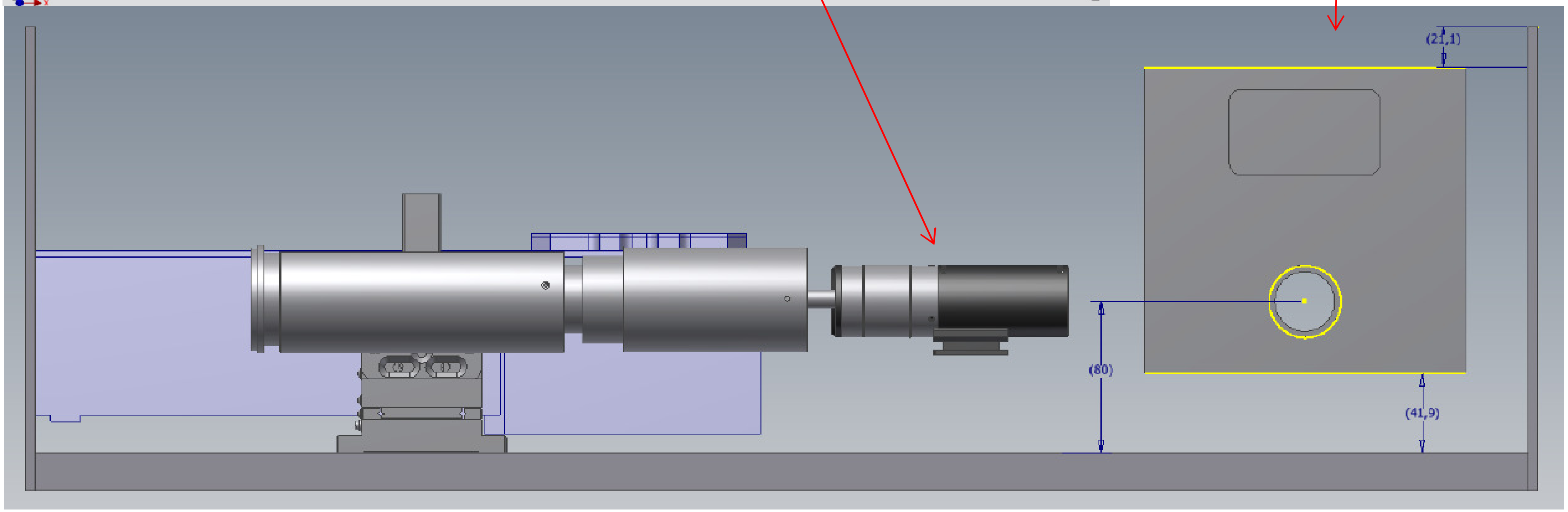
Laser II project : construction and installation (III)



Arrangement with the Newport filter wheel Mod. 74041

Other models from Thorlabs and Edmund Optics are also considered

Any solution with a commercial wheel will require additional mechanical pieces to be designed by Andrea



Laser II project : construction and installation (IV)

Fabrizio at CERN for Tilecal data quality shifts

Detailed time schedule proposed by Pisa	Desired date	Latest date
Design of the optics box (Pisa)	Sep. 30	Oct. 7
Construction of the box (Coimbra)	Oct. 20	Oct. 27
Delivery to CERN (Coimbra)	Oct. 25	Oct. 31
Start assembling elements in 175 (Pisa, Coimbra(?))	Oct. 30	Nov. 4
Laser and electronics back to CERN (Clermont)	Nov. 4	????
End of assembly in bld.175 (Clermont, Pisa (?))	Nov. 20	Nov. 30
Start of test with all monitors (diodes and PMTs) (Clermont, Coimbra, Pisa)	Nov. 21	Dec. 1
End of tests with monitors only (C-F, Coimbra, Pisa)	Dec. 15	Dec. 24
Start of tests with the drawer fibers (2) connected to the beam expander (CERN + others)	Dec. 16	Jan. 6
End of the test with the drawer (CERN + others)	Jan. 20	Jan. 31
Start of long term test with the Drawer and the Calibration SW of the experiment (CERN + others)	Jan. 21	Feb. 1
End of the long term tests	Installation in USA-15	

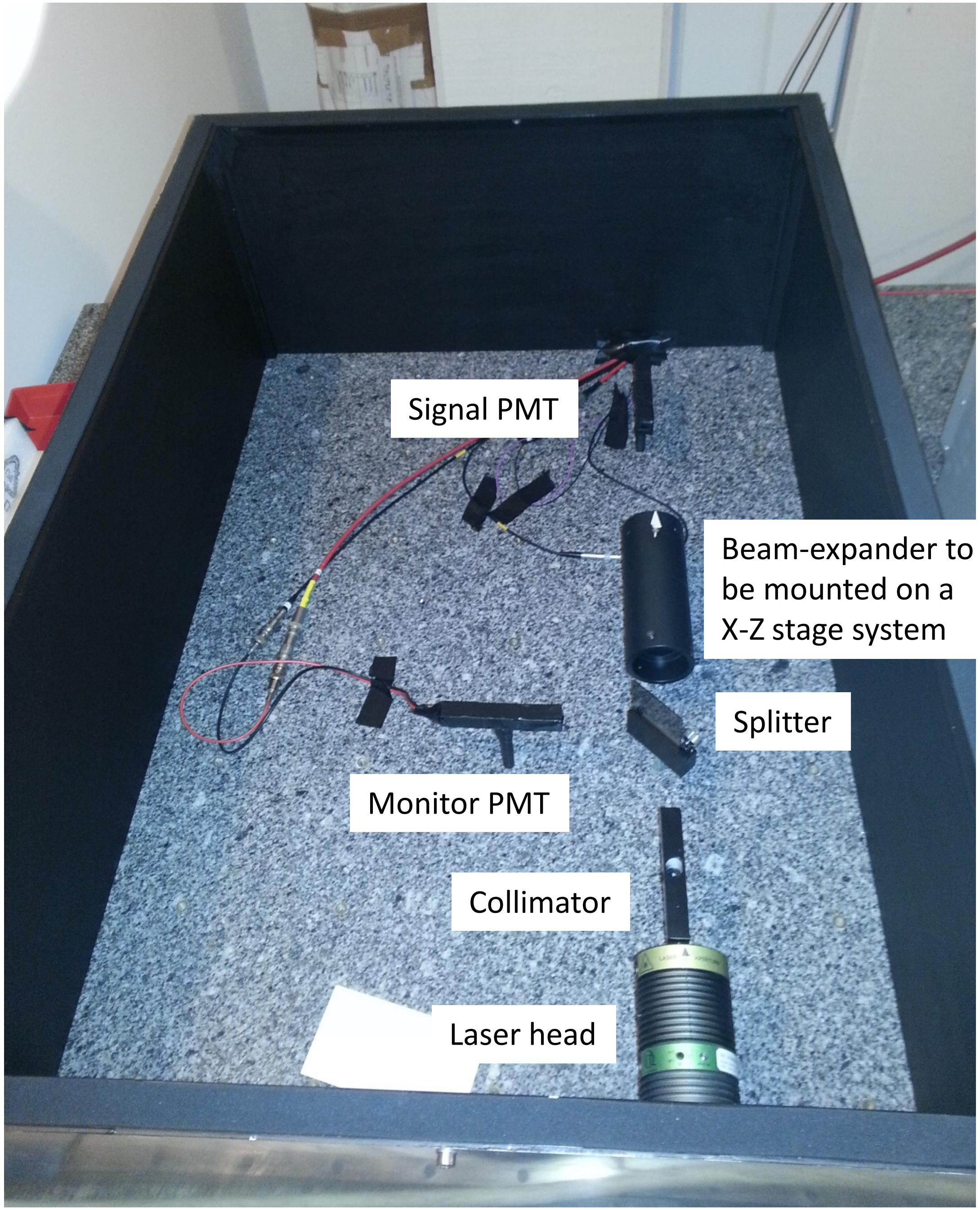
Optics closed in a new "black box" in the Atlas Pisa lab

Local test program:

1) Qualification of the 2.5X beam-expander before installation at CERN

2) Accurate mapping of the output of the beam-expander (not done in 175 because of the moving of the laser to C.F.

Who ?
When ?



On the absolute measurement of the PMT gain and laser performance using the data taken in building 175 with the test system for the laser II project

F. Scuri*) – I.N.F.N. Sezione di Pisa

on behalf of the laser II project group

Tilecal calibration, data quality, performance and processing meeting, Sept. 16, 2013

Outlook:

We use data taken during the 2012/13 test campaign with the laser system in bld.175 to study the conditions in which a statistical approach (''Pisa method'') can be used to monitor the laser performance and to measure the PMT absolute gain.

*) fabrizio.scuri@pi.infn.it

Foreword

- Tests with the set-up in building 175 were performed with the main goal of optimizing the performances (stability, light distribution (efficiency and uniformity), ….) of the optical line for the transmission of the laser calibration pulses.

- Procedures and experimental arrangements used in the tests were choosen only to achieve the goal above stated .

- The analysis shown today with the statistical approach normally used for the Tilecal laser calibrations is only a ''by-product'' of the full test program devolopped in bld. 175 since August 2012.

- The plan is to change the old laser in USA-15 with the one used in bld. 175 for tests; therefore, it's important a study of its performances before the installation.

Introduction

In general, several terms contribute to the RMS σ_q of the charge pulse distribution generated by any readout deivce (PMT, photo-cell (diode), ...)

$$\sigma_q^2 = \sigma^2_{photo-statistics} + \sigma^2_{light\ source} + \sigma^2_{electronics} + \ \ldots\ldots + \text{correlation terms}$$

In the following, we <u>assume</u> that:

a) the contribution of the noise from the amplification electronics is negligible ;

b) only the photo-electron generation and amplification, and the fluctuations of the laser intensity I contribute to σ_q :

(1) $$\sigma_q^2 = \sigma^2_{photo-statistics} + \sigma^2_{laser} = \sigma^2_{photo-statistics} + Var(I)$$

c) for the photo-electron emission holds the Poisson statistics :

(2) $$\sigma_{p.e} = \sqrt{\mu_{p.e.}}$$

$\boldsymbol{\mu_{p.e.}}$ = $<N_{p.e.}>$ Average number of photo-electrons

With these assumptions, the average outopput charge is:

(3) $$<q> = e \times G \times \mu_{p.e.}$$

Device (PMT) gain

Definitions (I)

- The PMT gain ***G*** which depends on the voltage applied to each dynode:

$$\boxed{G \equiv \delta_1 \cdot \delta_2 \cdot \delta_3 \cdots \delta_n}$$

(δ_i = Gain of the i-th dynode)

- The Equivalent Noise factor; in general :

$$\boxed{ENF \equiv \frac{\sigma^2_{Output}}{\sigma^2_{Input}}} \quad (4)$$

For a PMT:

$$\boxed{ENF = 1 + \frac{1}{\delta_1} + \frac{1}{\delta_1 \cdot \delta_2} + \cdots + \frac{1}{\delta_1 \cdot \delta_2 \cdots \delta_n}}$$

In the Tilecal PMT case:

$$ENF \cong 1.3$$

- In the assumption of eq. (1) and using eqs. (2-4) one has:

$$(5) \quad \frac{Var(q)}{<q>^2} = f \times \left(\frac{\sigma_{N_{p.e.}}}{<N_{p.e.}>^2} + \frac{Var(I)}{<I>^2} \right)$$

q is PMT charge distribution;
I = laser intensity;
e = electron charge
f = Equivalent Noise Factor

- and the observable used in the following is:

$$(6) \quad \frac{Var(q)}{<q>} = \underbrace{e \times G \times f}_{} + <q> \times \frac{Var(I)}{<I>^2} \times f$$

Constant term, assuming Poisson statistics for the photo-electron emission

Definitions (II)

At fixed PMT voltage, *G* and ***f*** are constants and they are related to the parameters of the ***q*** and ***I*** distributions according to eqs. (1 - 6)

(7) $$G = \frac{1}{e}\left[\frac{Var(q)}{<q>\times f} - <q>\times\frac{Var(I)}{<I>^2}\right]$$

Reference webpage : https://twiki.cern.ch/twiki/bin/viewauth/Atlas/TileLaserPisa

The laser intensity fluctuations (at fixed pumping frequency == fixed output power) are parametrized by the ratio ***k*** between variance and squared average of the pulse intensity distribution :

$$k = Var(I) / <I>^2$$

In TileCal (about 10,000 channels), two methods can be used to determine ***k***:

(a) $$k = \frac{Cov(q_i, q_j)}{<q_i>\times<q_j>}$$

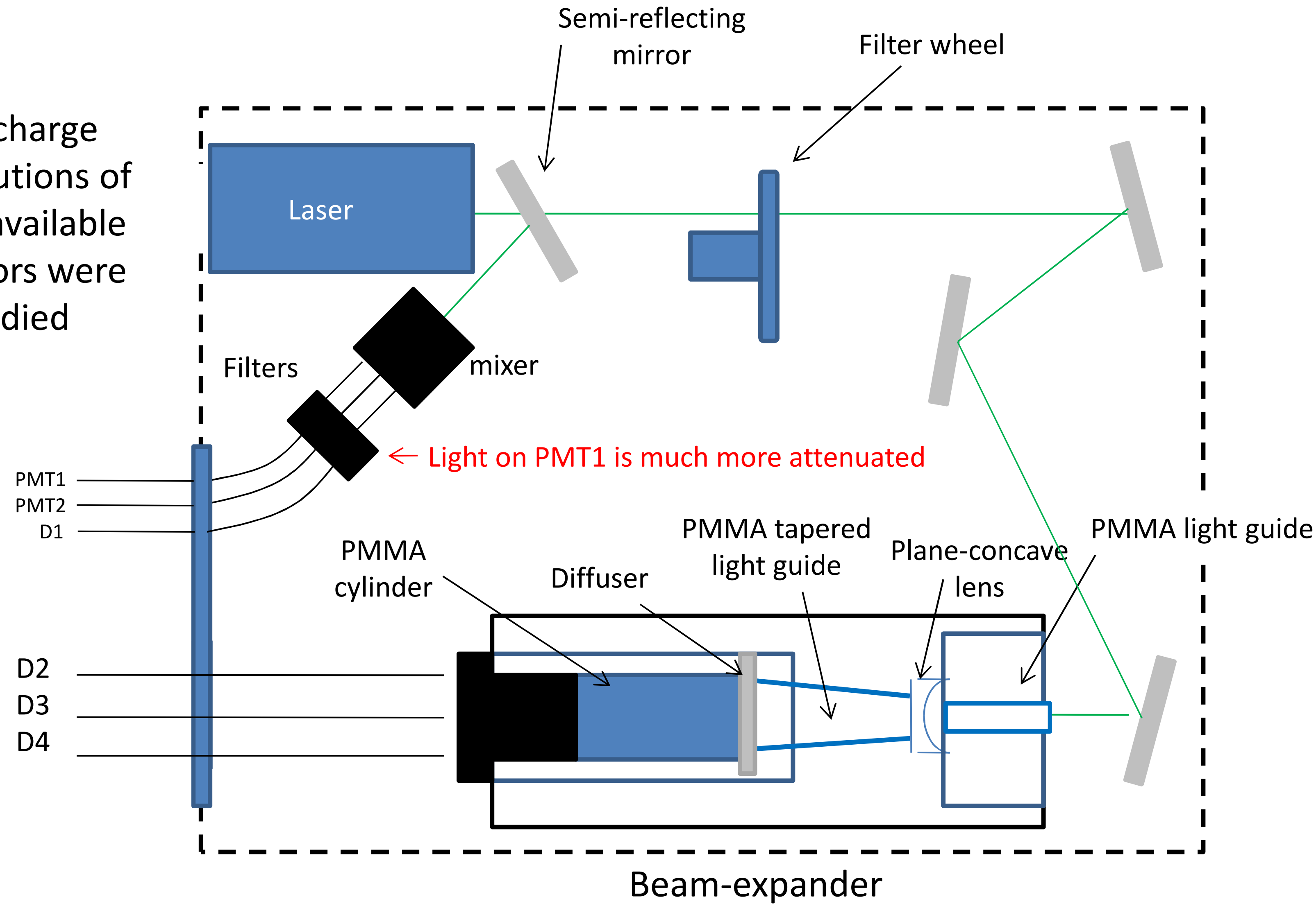
Cov(q_i,q_j): covariance of the charge distributions of any PMT pair i,j in a drawer at fixed laser pulse intensity.

(b) $$k = \frac{\frac{Var(q_2)}{<q_2>} - \frac{Var(q_1)}{<q_1>}}{<q_2> - <q_1>}$$

k can be extracted from individual PMT charge distributions (at least 2) at different pulse intensity (different attenuations (1 and 2), <u>same laser output power</u> !)

Optics box arrangement in building 175

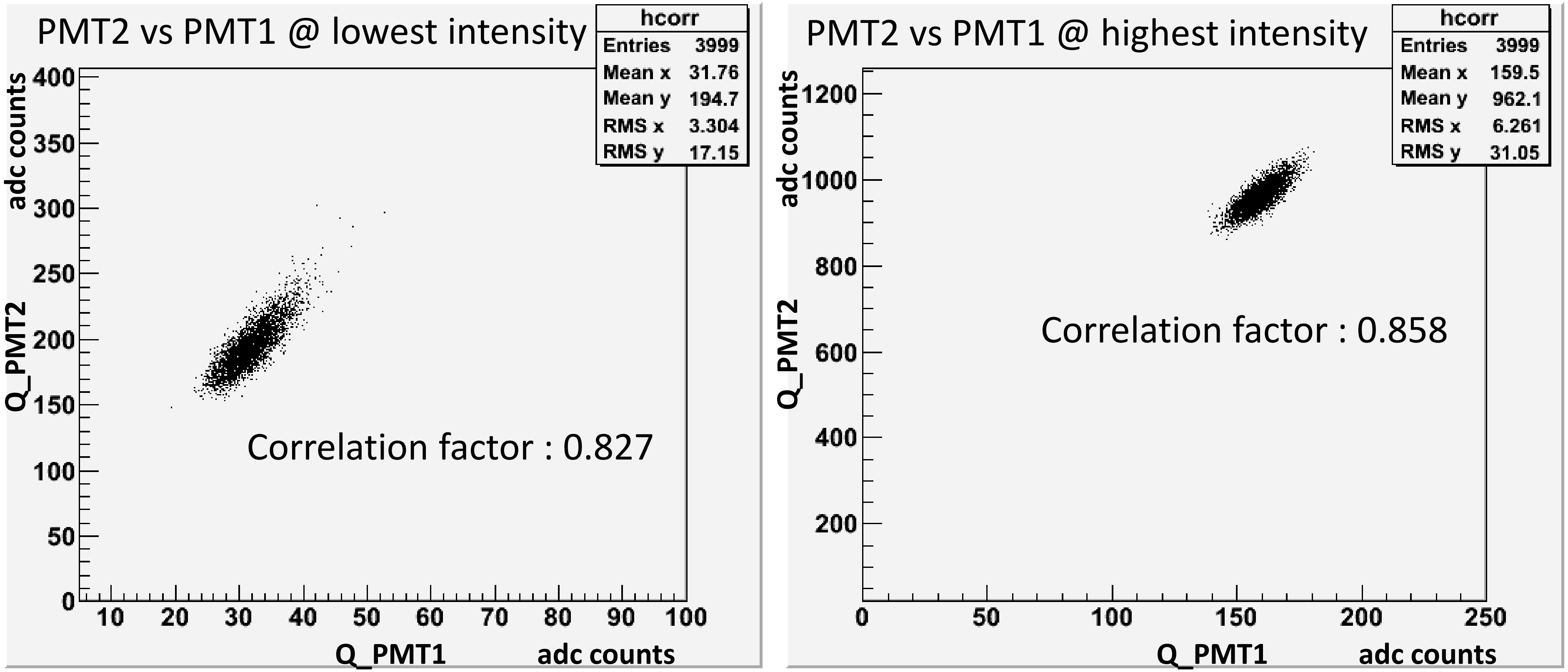
The charge distributions of the 6 available monitors were studied



Measurement of " k " with one energy scan made during the tests in bld. 175

With the energy scan data with the bld. 175 system we use, with some restrictions (see below), methods (a) (covariance at fixed laser intensity) and (b) (individual intensity variation on each device) to measure the laser characteristic "k".

Examples of PMT1-PMT2 correlations used in the <u>covariance method</u>.



Measurements at different laser intensities (energy scan)

Only method a) (detector pair correlations) is used to extract the parameter "k"

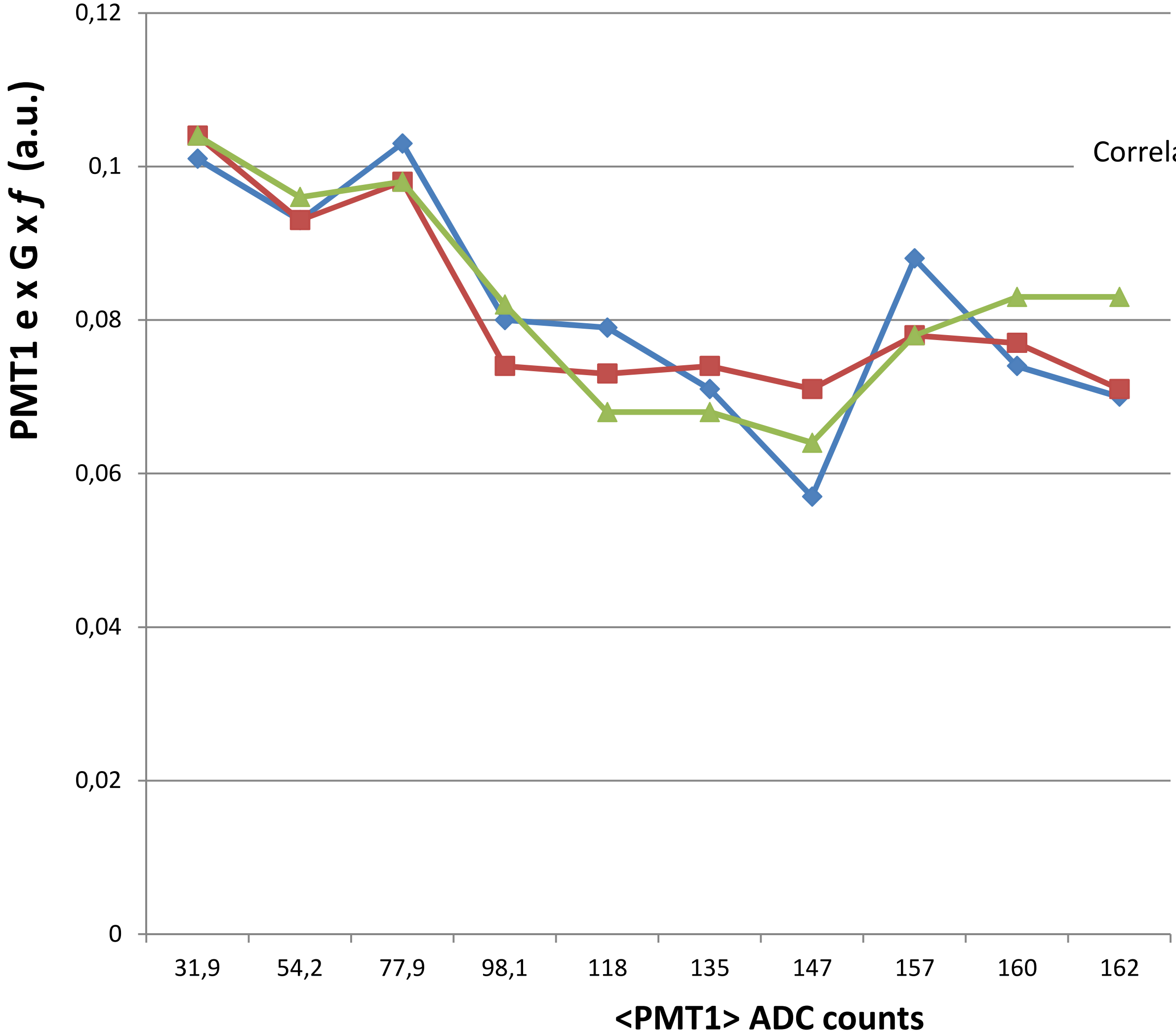
Energy scan of May 15, 2013 with the system in bld. 175

The factor k is measured with method a) (correlation), e x G x f is obtained from eq. (6)

Laser Intensity (a.u.)	<Q_PMT1> ADC counts	σ_{Q_Pmt1} ADC counts	<Q_PMT2> ADC counts	σ_{Q_Pmt2} ADC counts	Covariance (Pmt1,Pmt2)	Correl. factor	k x *f* factor	e x G x *f* PMT1 (a.u.)	e x G x *f* PMT2 (a.u.)
15.5 K	31.9	3.3	195	17.2	46.96	0.827	0.00755	0.101	0.045
16.0 K	54.2	4.3	331	22.6	82.31	0.847	0.00459	0.093	0.024
16.5 K	77.9	5.2	477	27.0	116.68	0.831	0.00314	0.103	0.031
17.0 K	98.1	5.6	596	29.5	142.50	0.863	0.00244	0.080	0.008
17.5 K	118.0	5.8	716	30.0	150.91	0.867	0.00179	0.079	-0.025
18.0 K	135.0	6.0	817	30.9	160.22	0.864	0.00145	0.071	-0.016
18.5 K	147.0	6.0	888	31.0	160.89	0.865	0.00123	**0.057**	-0.010
19.0 K	157.0	6.2	946	30.7	148.52	0.780	0.00100	0.088	0.022
19.5 K	162.0	6.3	973	31.0	169.63	0.869	0.00108	0.070	-0.063
20.0 K	160.0	6.3	962	31.0	167.65	0.858	0.00109	0.074	-0.050
							<eGf>	0.082	0.033*)
*) first 3 points only							σ_{eGf}	0.015	0.011*)

- We have verified that $k = Var(I)/<I>^2$ is not a constant if the intensity is changed !
  (PMT HVs and diode LVs weren't changed during all tests ==> *f* assumed constant)
- the total statistical relative error on each e x G x *f* value does not exceed 10% because all primary quantities (<Q_PMT>, σ_{Q_PMT}, cov(PMT1,PMT2)) have statistical error below 1%

Absolute gain measured with different correlated detectors



PMT1 e x G x *f* (a.u.)	average	RMS
PMT1_PMT2	0.082	0.015
PMT1_D1	0.081	0.012
PMT1_D2	0.082	0.014
all points	0.082	0.013

Statistical error on the total average is 0.002 (30 points)

PMT1, PMT2 and D1 are Laser intensity monitors

D2 is at the end of the line (beam-expander output)

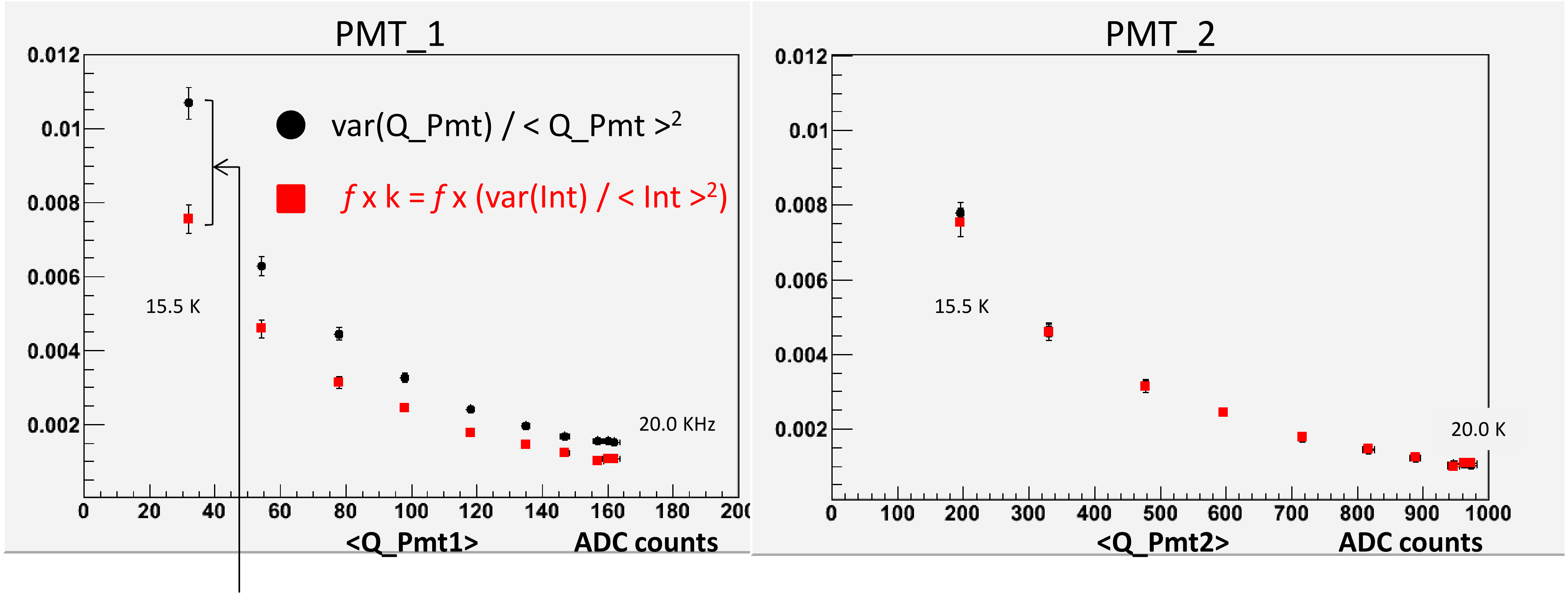
Caveat: for simplicity, we statistically treat the diode charge distributions as in the case of the PMTs, which is not fully correct because of the different mechanisms of primary charge generation (photo-electric effect vs. e-hole pair creation) and charge multiplication (electron extraction from dynodes vs. avalanche multiplication in strong reverse polarization)

Energy scan of May 15, 2013 with the system in bld. 175 (III)

Photo-statistics contribution

Plotted observable here is:

(5) $\mathrm{Var}(q)/\langle q\rangle^2 = f \times (\mathrm{Var}(\mu_{p.e.})/\langle\mu_{p.e.}\rangle^2 + \mathrm{Var}(Int)/\langle Int\rangle^2) = f \times (1/\mu_{p.e.} + k)$



This difference $f \times (1/\mu_{p.e.})$ is a measure the "size" of the photo-statistics contribution

The quantity $\mathrm{var}(Q\_Pmt) / \langle Q\_Pmt \rangle^2$ varies from 0.8% at 15.5 KHz to 0.3% at 20 K (max. $\boldsymbol{I}$)

Additional remarks on the approach using the statistical methods

a) Light transmitted to PMT1 and PMT2 is attenuated by different filters, so that:

- in the case of PMT1 the contribution of the photostatistics term is always > 25% of the total;

  ==> the gain factor e x G x f can be quite accurately measured;

- in the case of PMT2 the contribution of the photostatistics term is < 1% at pump. freq. > 16.5K;

  ==> the gain factor e x G x f cannot be measured at any intensity above 16.5K (a.u.) because the number of photo-electrons is too large.

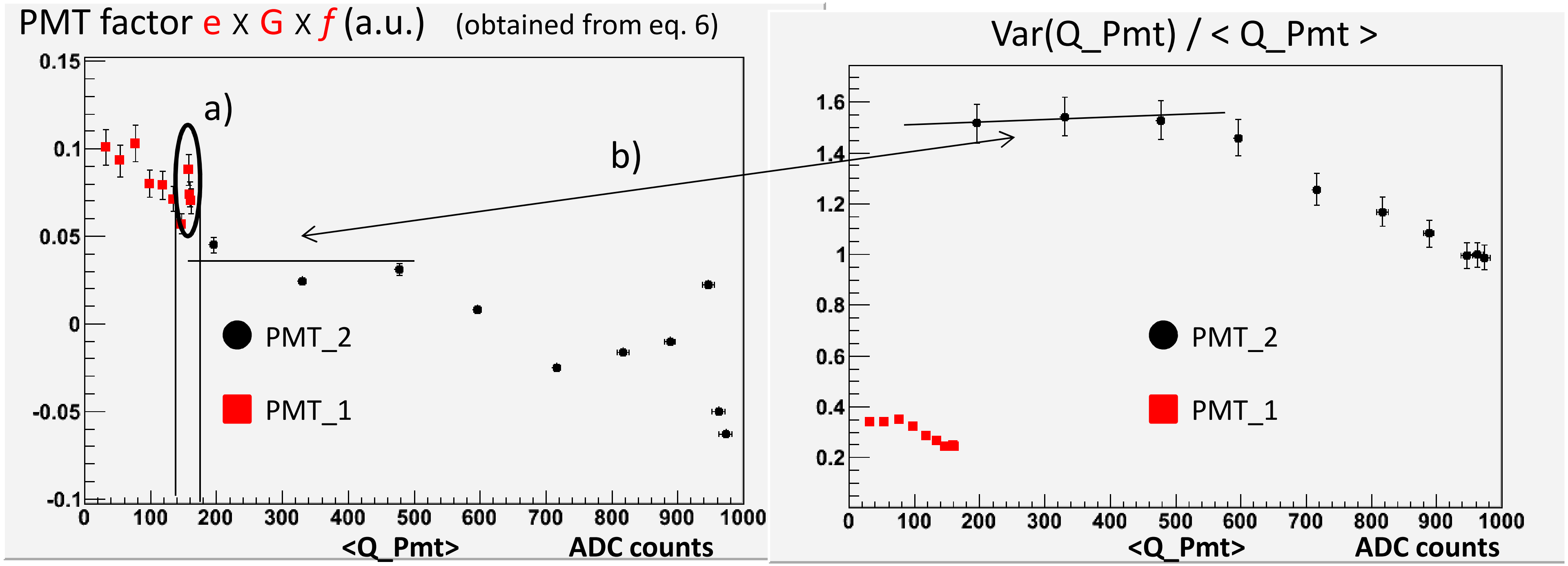
b) We already can set the conditions to operate the laser when we want use the statistical methods:

$$\sqrt{N_{pe}} / N_{pe} = 1 / \sqrt{N_{pe}} \text{ must be} \geq \begin{cases} 0.08 \text{ at } 15.5\text{ K} \\ 0.03 \text{ at } 20.0\text{ K} \end{cases} \quad \text{i.e. } Npe \leq \begin{cases} 160 \text{ at } 15.5\text{ K} \\ 1100 \text{ at } 20.0\text{ K} \end{cases}$$

to have good sensitivity to photo-statistics fluctuations when applying the ''Pisa method''

Energy scan of May 15, 2013 with the system in bld. 175 (II)

Systematic effects still to be understood



a) Last 3 points of PMT_1 (19.0, 19.5, 20.0 K) correspond to similar laser intensities, but the factor e x G x *f* varies by more than 20% .....

b) The only points (first 3) giving "reasonable" e x G x *f* factor values for PM_2are the ones where the photo-statistics contribtuion is at least 2-3% of the total (see previous slide) and where Var(Q_Pmt) / < Q_Pmt > behaves like e x G x *f* + k x < Q > (eq. (1))

Measurements at fixed laser intensities and variable intensity at the end of the line (by using the filter wheel)

Both method a) and b) are used to extract the parameter "k"

Measurements with fixed laser intensity (16 K in our a.u.) and variable intensity on the beam-expander diodes

I) The correlation method

$$k = \frac{Cov(q_i, q_j)}{< q_i > \times < q_j >}$$

The factor k is measured with method a) (correlation), e x G x f is obtained from eq. (4)

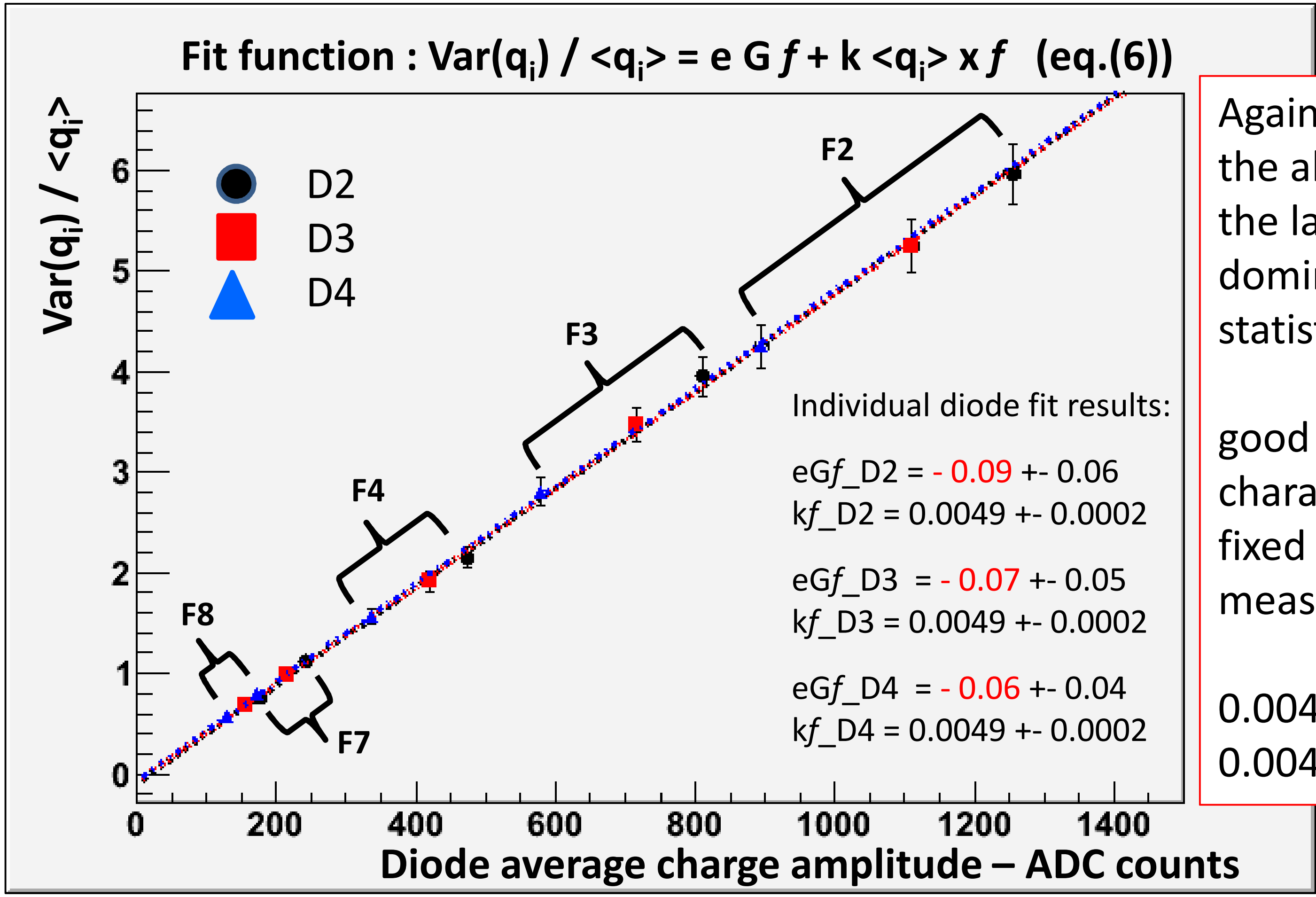
Filter wheel position	<Q_D3> ADC counts	σ_{Q_D3} ADC counts	<Q_D4> ADC counts	σ_{Q_D4} ADC counts	Covariance (D3,D4)	Correl. factor	Factor k x *f*	e x G x *f* D3 (a.u.)	e x G x *f* D4 (a.u.)
8 (0.3%)	173	12	215	15	172	1.005	0.00462	-0.008	-0.001
7 (1%) + 1 diffuser	128	8.5	157	10	85	0.970	0.00423	0.023	0.012
4 (3%) + 1 diffuser	337	23	419	28	647	0.994	0.00458	0.026	-0.008
3 (25%) + 1 diffuser	579	40	717	50	2021	1.005	0.00487	-0.015	-0.019
2 (39%) + 1 diffuser	895	62	1110	76	4655	0.987	0.00469	0.056	0.053
					$\boxed{<k \times f>}$	$\boxed{0.0046}$	<eGf>	0.016	0.007
					$\boxed{\sigma_k}$	$\boxed{0.0002}$	σ_{eGf}	0.029	0.028

Remarks:

1) Correlation factor always close to 1 == > laser fluctuations always dominate,
   == > no way to extract the diode gains;
2) The laser chacrateristics ''k'' measured with the correlation method is quite constant at fixed pumping frequency O.K.

Measurements with fixed laser intensity (16 K in our a.u.) and variable intensity on the beam-expander diodes

II) The intensity attenuation method



Again, no way to measure the absolute gain because the laser fluctuations dominate over the photo-statistics …. however:

good agreement of the laser characteristic "k" values at fixed 16 K laser intensity measured with the 2 methods

0.0046 +- 0.0002 method a)
0.0049 +- 0.0002 method b)

Conclusions

- The statistical approach (''Pisa method(s)'') was used for the first time to analyse data taken with the test set.up in bld. 175; results are consistent and both methods seem ''robust'' against changes of detector type (PMT ←→ diode)
- We have proven that the covariance method can be used also by combining detectors (e.g. PMT1-D2(3,4)) reading-out light pulses that follow different optical paths; at present, the covariance method is applied to the Tilecal detector calibration data by averaging ''k'' values obatined by combining separately even and odd cells in a drawer; the reasons of this choice are quite clear, but, if the almost dominating process is the laser intensity fluctuation, there is no reason not to apply the covariance method also by pairing cells of different drawers, with an expected sizable gain in statistical accuracy.
- Large systematic effects (to be understood) are present even in the case (PMT1) where the photo-statistics contribution to the charge RMS is not negligible. We made several energy scans at different times and with different optical arrangements, so we could understand more by analysing the full available data set of the bld. 175 tests.
- The main outcome of this preliminary analysis is that both statistical methods (a) and b)) may be extensively used to monitor the laser performance ''k'' regardless to the type (diode or PMT) of detector used and to its location in the optical path.
- In other words, the statistical approach may offer a powerful tool to monitor at the same the source (laser) and the destinations (PMTs)

Additional remarks

- The photo-statistics contribution is «measurable» only at low pulse intensities (i.e. low $N_{p.e.}$)
  Remember: we want also to calibrate PMTs in a luminous intensity range equivalent to [100 MeV – 1 TeV], i.e. 1(10) p.e. to 10^4(10^5) p.e., no matter the pulse intensity is varied (filter wheel and/or laser pumping frequency); so, for full scale linearity measurements, only the C.-F. method (normalization to reference detectors) can be used.

- We saw that the laser intensity is more stable at higher output intensities (i.e. larger $N_{p.e.}$ on the photo-detectors) but the statistiscal approach needs to operate with a small $N_{p.e.}$ value.

- This had some impact on the project of the optical line inside the optics box; we must have enough flexibility to operate with largely attenuated laser beam which should be quite intense at the origin (laser more ''stable''), and, at the same time, avoiding to approach the damage threshold of the optical elements.

- Have been sistematically studied all the effects mentioned above and documented for the 2011-2012 Tilecal calibration runs? Probably yes, we will check and compare ….
  We plan to carefully look at the ''Pisa method'' observables (k and G) available in the existing ''full'' and ''squeezed'' n-tuples. Thanks to Federico Bertolucci, we can now manage almost all the required SW tools to do it.

Main feedbacks after the presentation

- No questions were arised about the methods or the results; the presentation was quite well accepted ;

- We got the impression we fired some relevant points about the possibility to better use the ''Pisa method(s)'' in the calibration procedures for Tilecal, in particular on the extensive use of the correlation method.

- Henric Wilkens pointed-out that there are still bugs in the SW calculating the ''k'' factors to be corrected. In general, help and commitment from Pisa was asked for the revision of the calibration procedures and SW for the resuming the data taking.

- We will discuss about it on September 30 during the workshop on the Tilecal procedures and in specific meetings the day after with people involved in the calibration.