# PRIMI APPROCCI AL SISTEMA DI CALIBRAZIONE LASER DI TILECAL

F. Scuri, 3 Ott. 2012

- Primo contatto con il gruppo per l'upgrade di TileCal al meeting del 1 giugno 2012 al CERN.
- Richesto da Chiara e dalla project-leader A. Herriques di collaborare al sistema di calibrazione laser.
- Partecipazione attiva ai meeting di lavoro dal 30 agosto 2012.
- Una settimana di intenso lavoro per prendere familiarità col sistema-replica dal 10 al 15/9/12.
- Ottimi rapporti di collaborazione con le persone di altre isituzioni maggiormente attive sul progetto: (Ph. Gris e C. Santoni – Clermont Ferrand, Alberto Blanco – Coimbra).
- Grazie a Chiara, Nino per avermi inserito molto bene nel gruppo di lavoro.
- Dal 20/9 e per altre 4 settimane ci aiuta Vassili Kazanine in visita a Pisa.
- Presentazione di oggi basata sull'ottimo sommario dello stato dell'arte fatto da Philippe Gris al meeting di TileCal upgrade del 28/9/2012;
- Altro materiale per la discussione nel back-up, derivato dal sommario dei risultati dei test svolti nella settimana del 10/9 e che ho presentato al meeting del working group di laser-II del 25/9/12

# The LASERII system

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F. Daudon[(a)], Ph. Gris[(a)], D. Lambert[(a)]

A. Blanco[(b)], B. Galhardo[(b)]

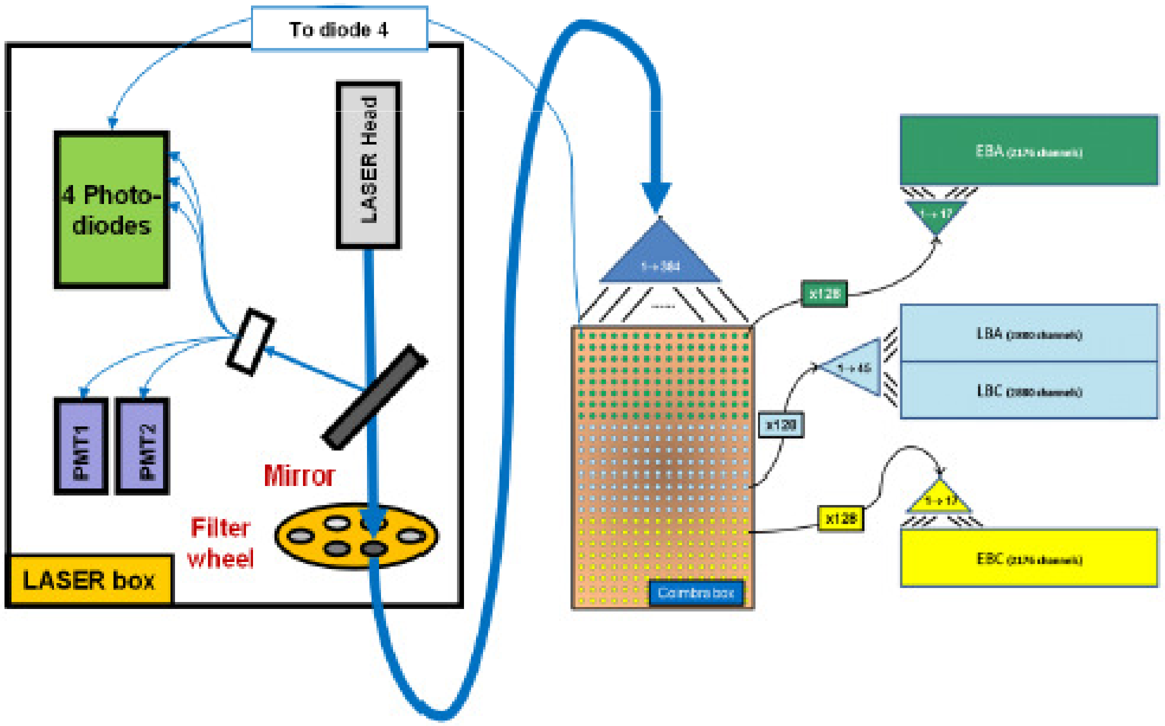
F. Scuri[(c)]

- The LASER calibration system in USA15
- The LASER calibration system in 175
- The LASERII calibration system

(a) LPC Clermont-Ferrand, France
(b) Universidade de Coimbra, Portugal
(c) INFN, Pise, Italy

# The LASER calibration system

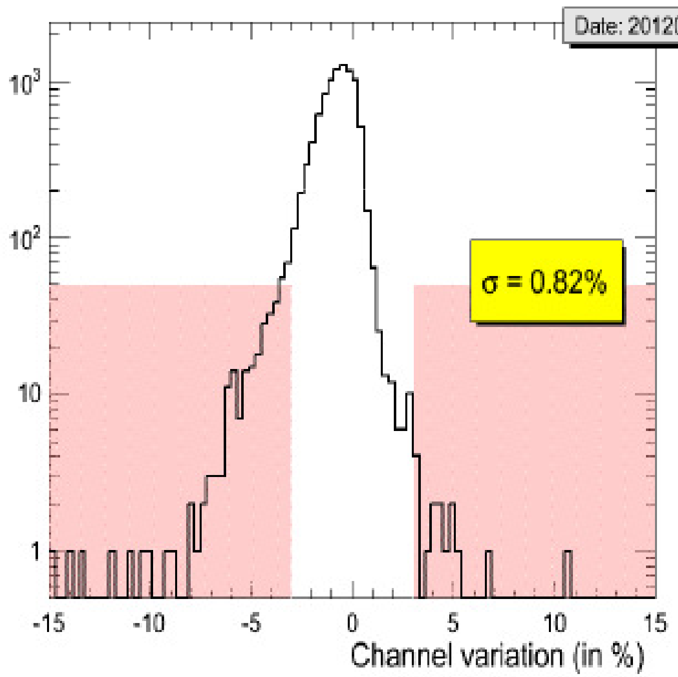
- *Aims at monitoring the ~10000 PMTs of the central hadronic calorimeter*
- *Composed of three part:*
  - *Optical : the LASER and photodiodes (to measure the light coming from the LASER)*
  - *Calibration: to monitor the photodiodes*
  - *Electronics: to drive and register*
- *In USA15:*

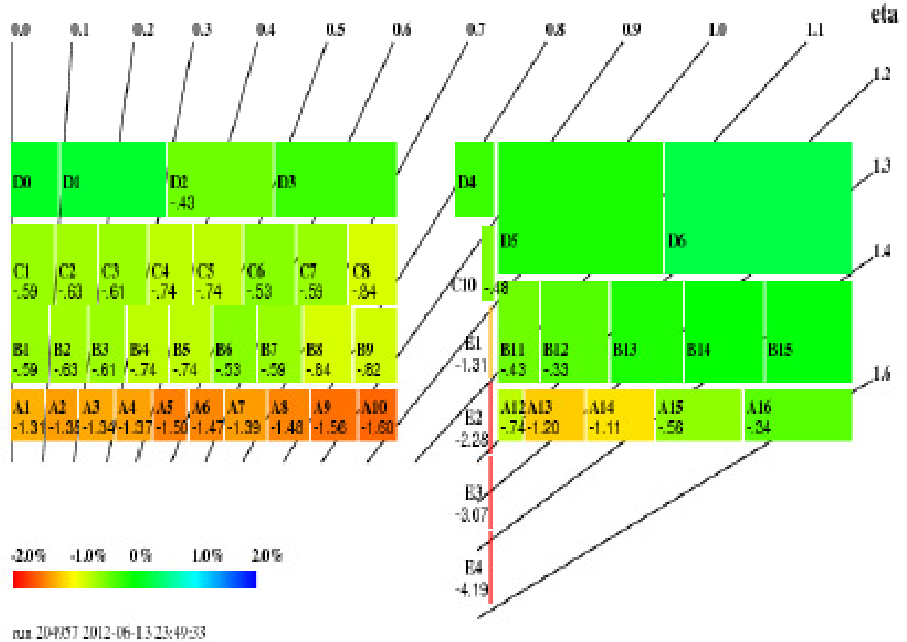


# *The LASER calibration system*

*Performance:*

- *Pedestal stability: 0.5%*
- *Photodiodes stability: 0.15%*

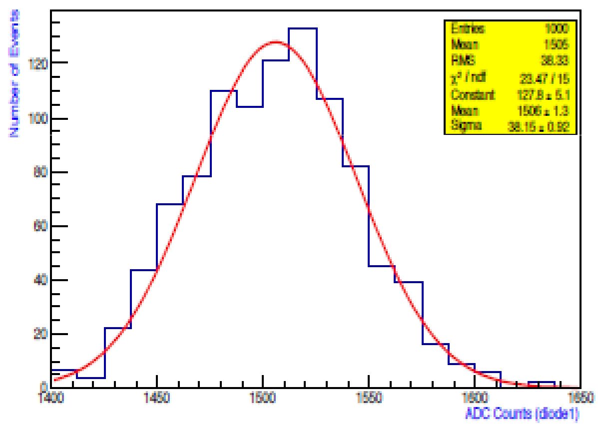


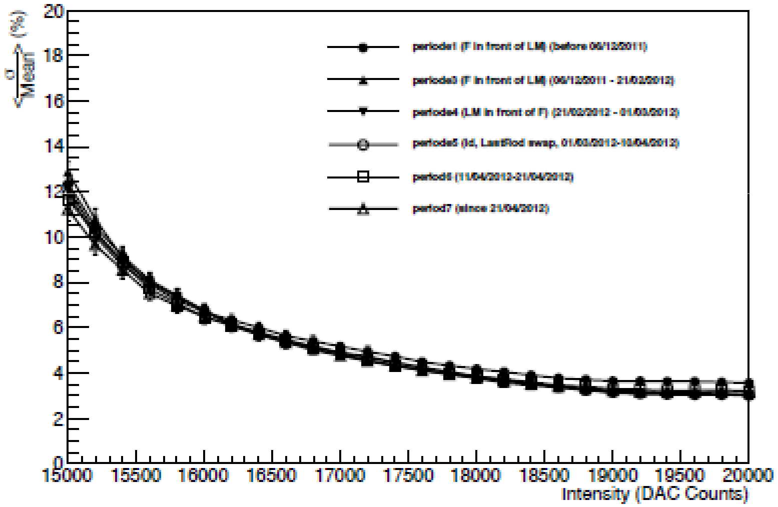



# La stabilità in intesità del laser non è eccezionale, ma secondo me non è e non deve essere "il problema" (vedi oltre)

## *The LASER in 175*

- *LASER runs: performed using the LASER in its full intensity range*



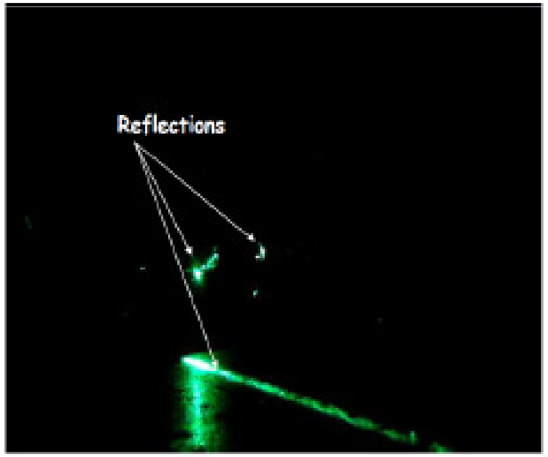

*Precision: from 3% (high intensities) to 12% (low intensities)*

# Riassunto delle misure effetuate da  settembre 2011 a giugno 2012

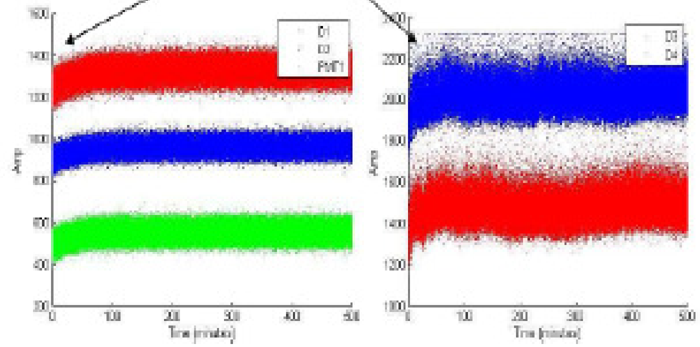
| Sorgente di sistematica | metodo misura | accuratezza relativa | |
|---|---|---|---|
| linearità ADC (11 bit) | iniezione carica | 0.1% | Dettagli nel back-up …. |
| Stabilità pedestalli | osservazione su lunghi periodi | 0.5% | |
| Stabilità risposta diodi | sorgente alpha | 0.15% | |
| Stabilità laser | misura con D1 su lunghi periodi | 3% - 12 % | Non è un problema se funziona il monitoring ! |
| Stabilità monitoring | Nessuna misura documentata in modo sistematico per il periodo considerato | | Questo è il problema ! A. Blanco ed io stiamo provando ad affrontarlo |

# The LASER in 175

- These daily runs were performed from september 2011 to june 2012
- Recently, some tests were performed on the optical part: Alberto (with the help of Bruno) and Fabrizio wanted, as newcomers, to become familiar with the system.
- Main problems seen by Alberto's tests (three days at the end of may):
  a) Sensitivity of the results to potential movements of the optical fibers
  b) Uncontrolled light reflections inside the box
  c) LASER drift as a function of time




It has been observed a drift in the absolute values measured that depends with the use of the laser. At some point it become stable.



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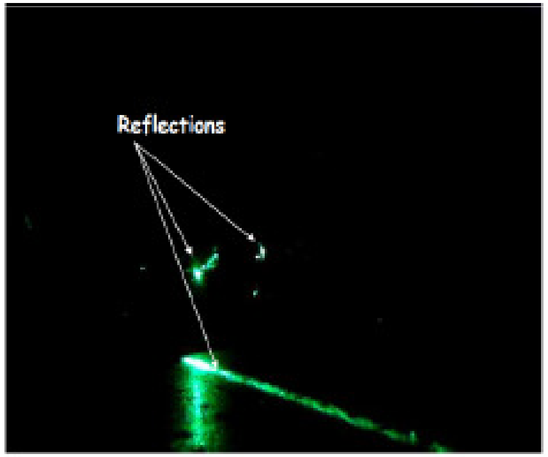


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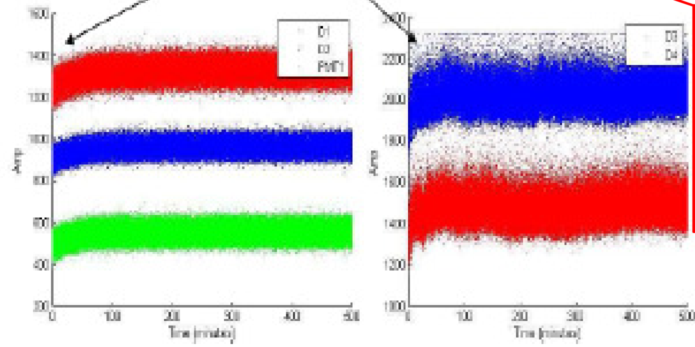

Si stupisce?
E' normale che un plasma in cavità si termalizzi ....

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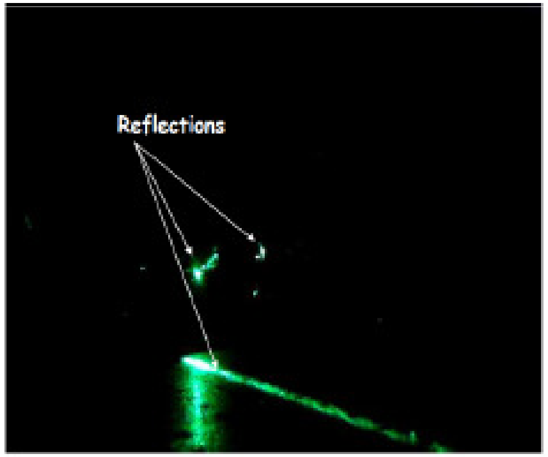
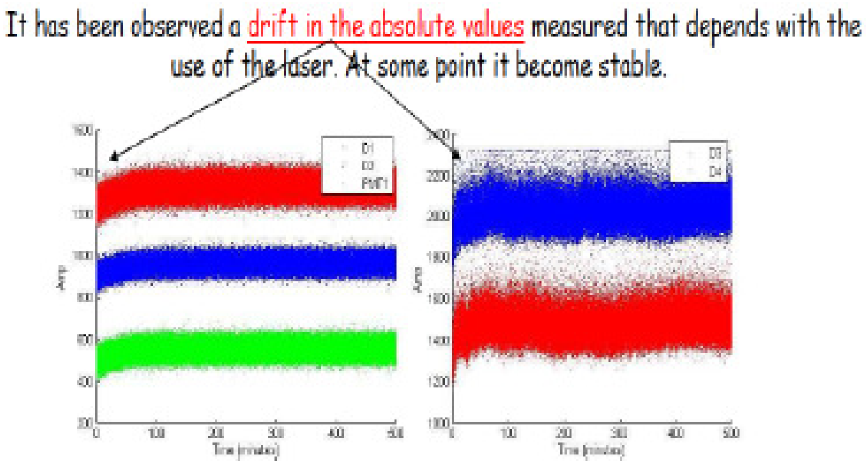
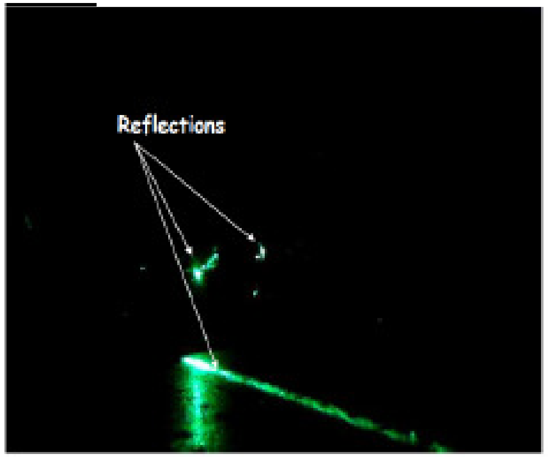



Le riflessioni hanno origine dai vari elementi sem-iriflettenti (beam splitter, filtri, …) disposti sul cammino ottico del fascio laser; tutte le superfici interne alla scatola ottica sono riflettenti !

# The LASER in 175

- These daily runs were performed from september 2011 to june 2012
- Recently, some tests were performed on the optical part: Alberto (with the help of Bruno) and Fabrizio wanted, as newcomers, to become familiar with the system.
- Main problems seen by Alberto's tests (three days at the end of may):
  - a) Sensitivity of the results to potential movements of the optical fibers → fix the cables
  - b) Uncontrolled light reflections inside the box → the inside of the box must be black-painted; optical parts must be properly orientated
  - c) LASER drift as a function of time → latency response of the LASER ?

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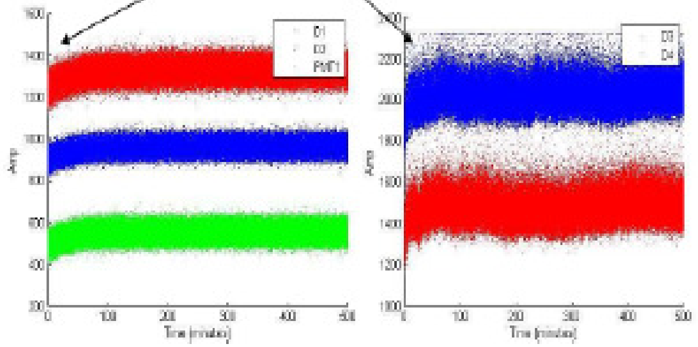
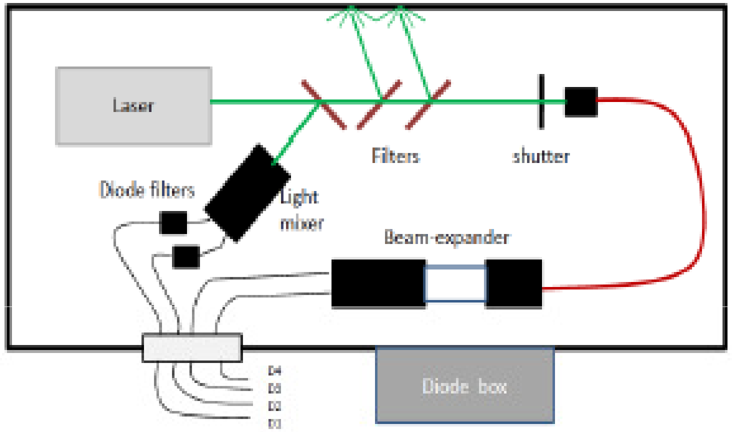
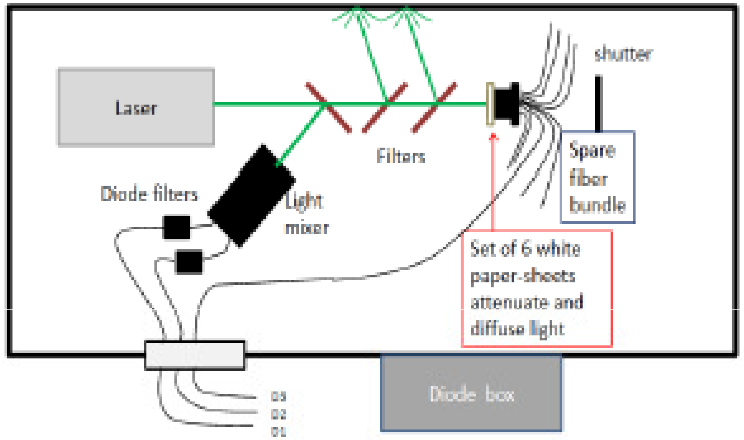


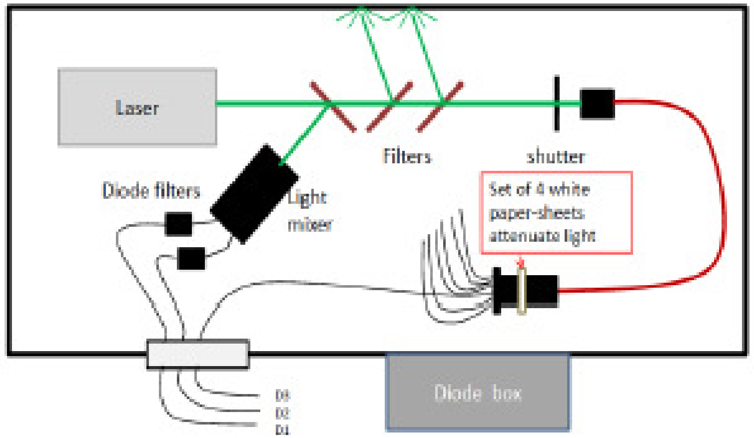
Nella settimana di test ho chiesto di monitorare il fascio ad ogni punto possibile del cammino ottico del fascio laser

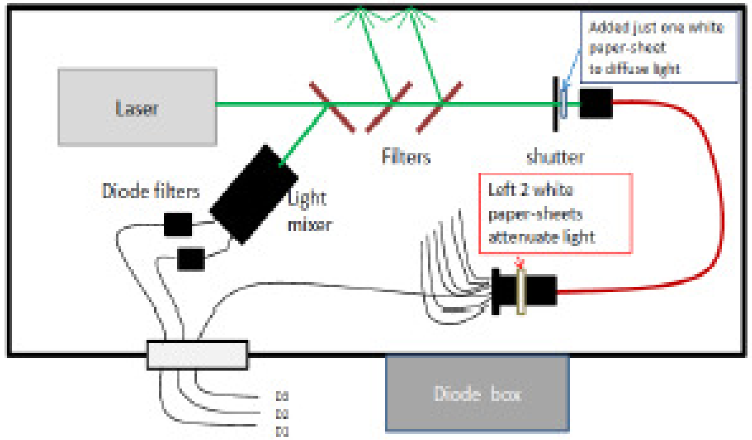
# *The LASER in 175*

- *Light measurements have been performed by Fabrizio and Philippe at each stage of the light path*



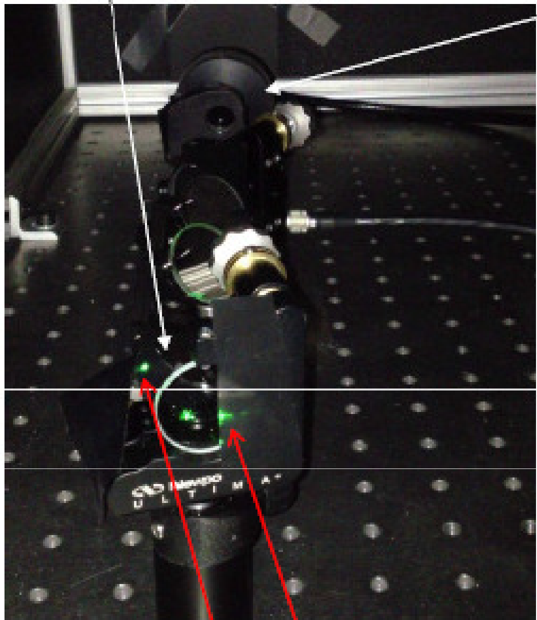



# First observation: reflections of stray beams were disappeared ….

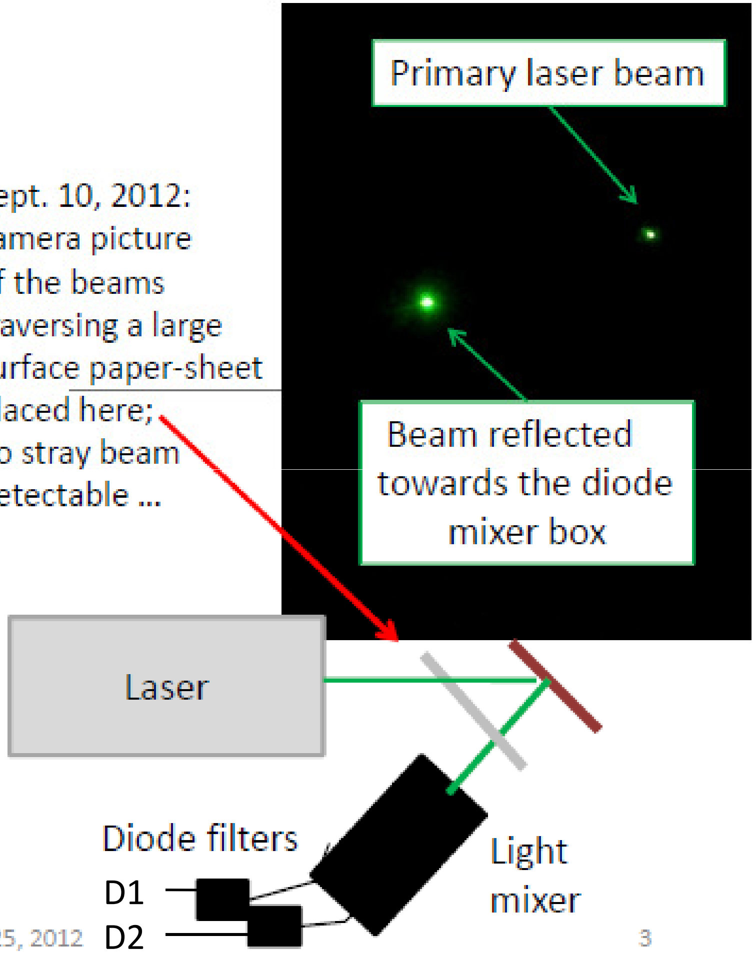
For example Reflective mirror and liquid fiber at the input.



Stray beam reflections

Picture taken from Alberto's talk
of August 30, 2012

Sept. 10, 2012:
camera picture
of the beams
traversing a large
surface paper-sheet
placed here;
no stray beam
detectable …



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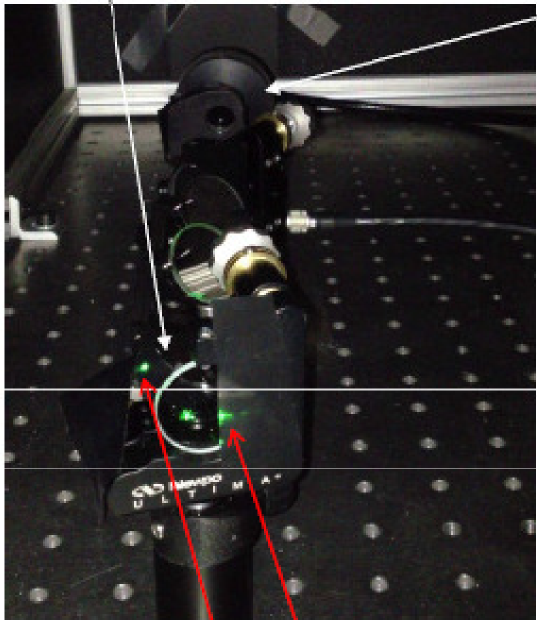
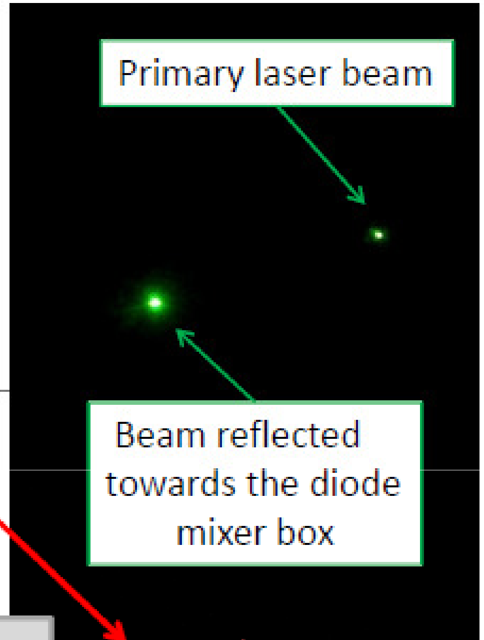
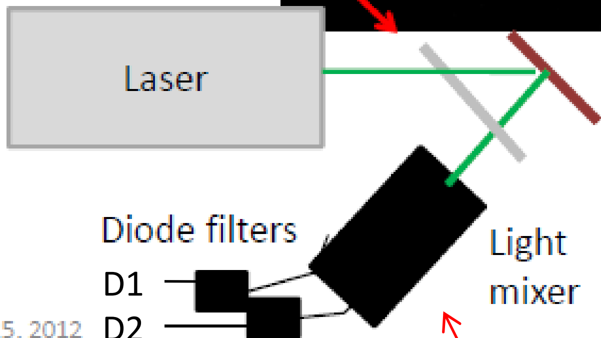


Stray beam reflections

Picture taken from Alberto's talk of August 30, 2012

Sept. 10, 2012: camera picture of the beams traversing a large surface paper-sheet placed here; no stray beam detectable …




A questo punto ho chiesto di studiare per prima cosa la stabilità del sistema di monitoring: mixer, filtri, diodi D1 e D2

# *The LASER in 175*

- *Highlight on some results: measurements of the gain and relative light transmission for the diodes 1 and 2 (swap of the optical fibers)*

$$\frac{D_1^O}{D_2^O} \Big/ \frac{D_1^S}{D_2^S} = \left(\frac{T_1^{mixer} \times T_1^{filter}}{T_2^{mixer} \times T_2^{filter}}\right)^2 \qquad \frac{D_1^O}{D_2^O} \times \frac{D_1^S}{D_2^S} = \left(\frac{G_1^{pre}}{G_2^{pre}}\right)^2$$

| Laser Intensity | <D1/D2> | RMS | <D2/D1>(*) | RMS |
|---|---|---|---|---|
| 15.0 K | 1.436 | 0.101 | 1.427 | 0.104 |
| 15.5 K | 1.443 | 0.041 | 1.425 | 0.043 |
| 16.0 K | 1.441 | 0.025 | 1.424 | 0.025 |
| 16.5 K | 1.444 | 0.019 | 1.426 | 0.018 |
| 17.0 K | 1.444 | 0.015 | 1.426 | 0.014 |
| 17.5 K | 1.446 | 0.013 | 1.426 | 0.012 |
| 18.0 K | 1.449 | 0.011 | 1.427 | 0.011 |
| 18.5 K | 1.451 | 0.011 | 1.426 | 0.010 |
| 19.0 K | 1.450 | 0.010 | 1.427 | 0.010 |
| 19.5 K | 1.451 | 0.010 | 1.426 | 0.010 |
| 20.0 K | 1.450 | 0.010 | 1.427 | 0.010 |
| 20.5 K | 1.449 | 0.010 | 1.427 | 0.010 |
| 21.0 K | 1.450 | 0.010 | 1.427 | 0.010 |
| 21.5 K | 1.450 | 0.009 | 1.428 | 0.010 |
| 22.0 K | 1.451 | 0.008 | 1.427 | 0.008 |
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| 23.0 K | 1.452 | 0.009 | 1.429 | 0.008 |
| 23.5 K | 1.452 | 0.009 | 1.430 | 0.008 |
| 24.0 K | 1.453 | 0.009 | 1.431 | 0.009 |
| 24.5 K | 1.454 | 0.009 | 1.431 | 0.009 |
| 25.0 K | 1.454 | 0.009 | 1.431 | 0.009 |

(*) D1,D2 swap

← Lower limit for laser operation

Sept.,10

$$\frac{2\,(\langle D1/D2\rangle_{max} - \langle D1/D2\rangle_{min})}{(\langle D1/D2\rangle_{max} + \langle D1/D2\rangle_{min})} = 0.9\ \%$$

Sept.,11

$$\frac{2\,(\langle D2/D1\rangle_{max} - \langle D2/D1\rangle_{min})}{(\langle D2/D1\rangle_{max} + \langle D2/D1\rangle_{min})} = 0.5\ \%$$

$$\left\langle \frac{D_1^O}{D_2^O} / \frac{D_1^S}{D_2^S} \right\rangle = \left\langle \left(\frac{G_1^{pre}}{G_2^{pre}}\right)^2 \right\rangle = 1.0155 \pm 0.0004$$

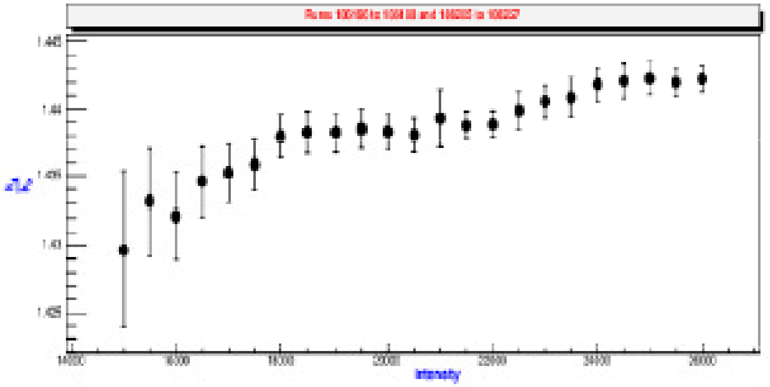
$$error = RMS\left(\left(\frac{G_1^{pre}}{G_2^{pre}}\right)^2\right) \Big/ \sqrt{N}$$

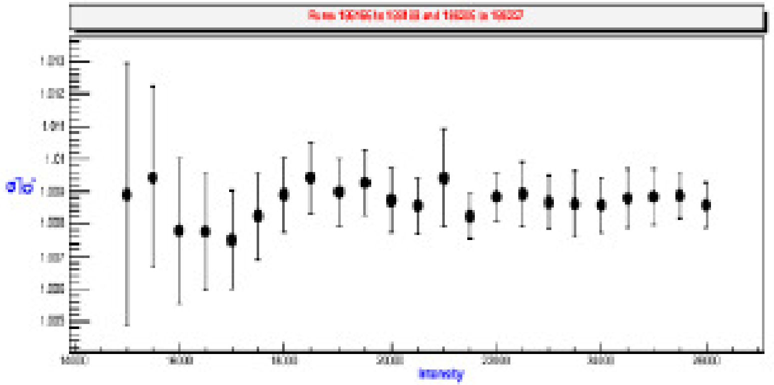
$$\sqrt{\left\langle \left(\frac{G_1^{pre}}{G_2^{pre}}\right)^2 \right\rangle} = 1.0077 \pm 0.0004 \approx \frac{G_1^{pre}}{G_2^{pre}}$$

Very nice result !

Good job with diode electronics ...

Parameters ratios measured by comparing data taken in same conditions with and without D1-D2 swap



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| Laser Intensity | <D1/D2> | RMS | <D2/D1>(*) | RMS |
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| 15.0 K | 1.436 | 0.101 | 1.427 | 0.104 |
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(*) D1,D2 swap

← Lower limit for laser operation

Sept.,10

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Sept.,11

$$\frac{2\,(\langle D2/D1\rangle_{max} - \langle D2/D1\rangle_{min})}{(\langle D2/D1\rangle_{max} + \langle D2/D1\rangle_{min})} = 0.5\ \%$$

$$\left(\frac{D_1^O}{D_2^O} \cdot \frac{D_1^S}{D_2^S}\right) = \left(\left(\frac{G_1^{pre}}{G_2^{pre}}\right)^2\right) = 1.0155 \pm 0.0004$$

$$error = RMS\left(\left(\frac{G_1^{pre}}{G_2^{pre}}\right)^2\right) \Big/ \sqrt{N}$$

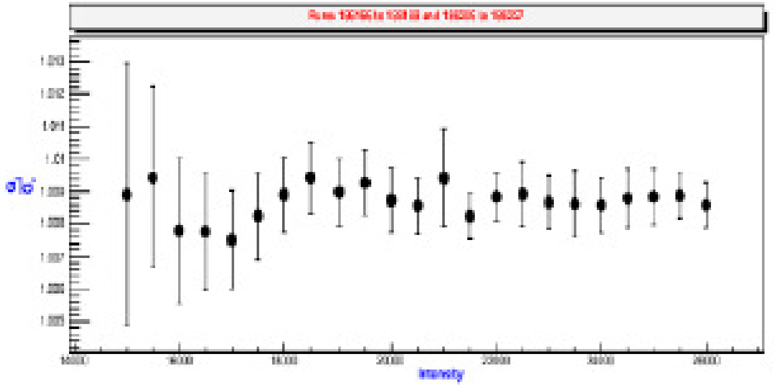
$$\sqrt{\left(\left(\frac{G_1^{pre}}{G_2^{pre}}\right)^2\right)} = 1.0077 \pm 0.0004 \approx \frac{G_1^{pre}}{G_2^{pre}}$$

Very nice result !

Good job with diode electronics ...

Parameters ratios measured by comparing data taken in same conditions with and without D1-D2 swap


Prima indicazione che il fascio si muove (con mixing verso D1-D2 buono, ma non perfetto)



# The LASER in 175

- *Highlight on some results: measurements of the light at the input of the liquid fiber*

| Laser Intensity | <D1/D2> | RMS | <D3/D2> | RMS |
|---|---|---|---|---|
| 15.0 K | 1.395 | 0.099 | 0.569 | 0.062 |
| 15.5 K | 1.411 | 0.038 | 0.576 | 0.026 |
| 16.0 K | 1.410 | 0.025 | 0.576 | 0.017 |
| 16.5 K | 1.414 | 0.018 | 0.581 | 0.012 |
| 17.0 K | 1.414 | 0.015 | 0.580 | 0.010 |
| 17.5 K | 1.414 | 0.013 | 0.580 | 0.008 |
| 18.0 K | 1.415 | 0.011 | 0.581 | 0.007 |
| 18.5 K | 1.415 | 0.011 | 0.582 | 0.007 |
| 19.0 K | 1.415 | 0.009 | 0.584 | 0.007 |
| 19.5 K | 1.415 | 0.010 | 0.586 | 0.007 |
| 20.0 K | 1.415 | 0.010 | 0.587 | 0.007 |
| 20.5 K | 1.415 | 0.010 | 0.588 | 0.007 |
| 21.0 K | 1.414 | 0.010 | 0.589 | 0.008 |
| 21.5 K | 1.415 | 0.009 | 0.590 | 0.007 |
| 22.0 K | 1.416 | 0.008 | 0.591 | 0.007 |
| 22.5 K | 1.416 | 0.009 | 0.591 | 0.007 |
| 23.0 K | 1.417 | 0.008 | 0.592 | 0.006 |

← Lower limit for laser operation

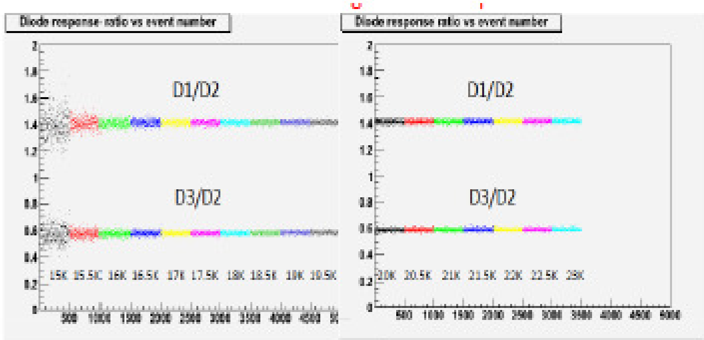
$$\frac{2\,(\langle D1/D2\rangle_{max} - \langle D1/D2\rangle_{min})}{(\langle D1/D2\rangle_{max} + \langle D1/D2\rangle_{min})} = 0.5\,\%$$

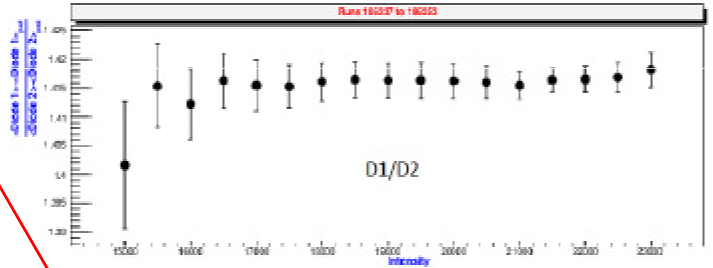
$$\frac{2\,(\langle D3/D2\rangle_{max} - \langle D3/D2\rangle_{min})}{(\langle D3/D2\rangle_{max} + \langle D3/D2\rangle_{min})} = 2.7\,\%$$

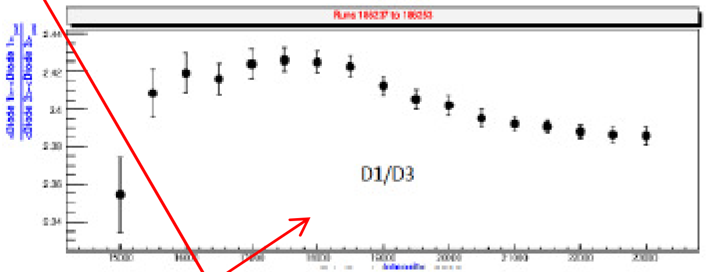
The trend of increasing ratio with increasing intensity much more significant in D3/D2.

Light to D1 and D2 is mixed, light to D3 is only attenuated and diffused

First evidence of effects due to laser beam displacements with intensity



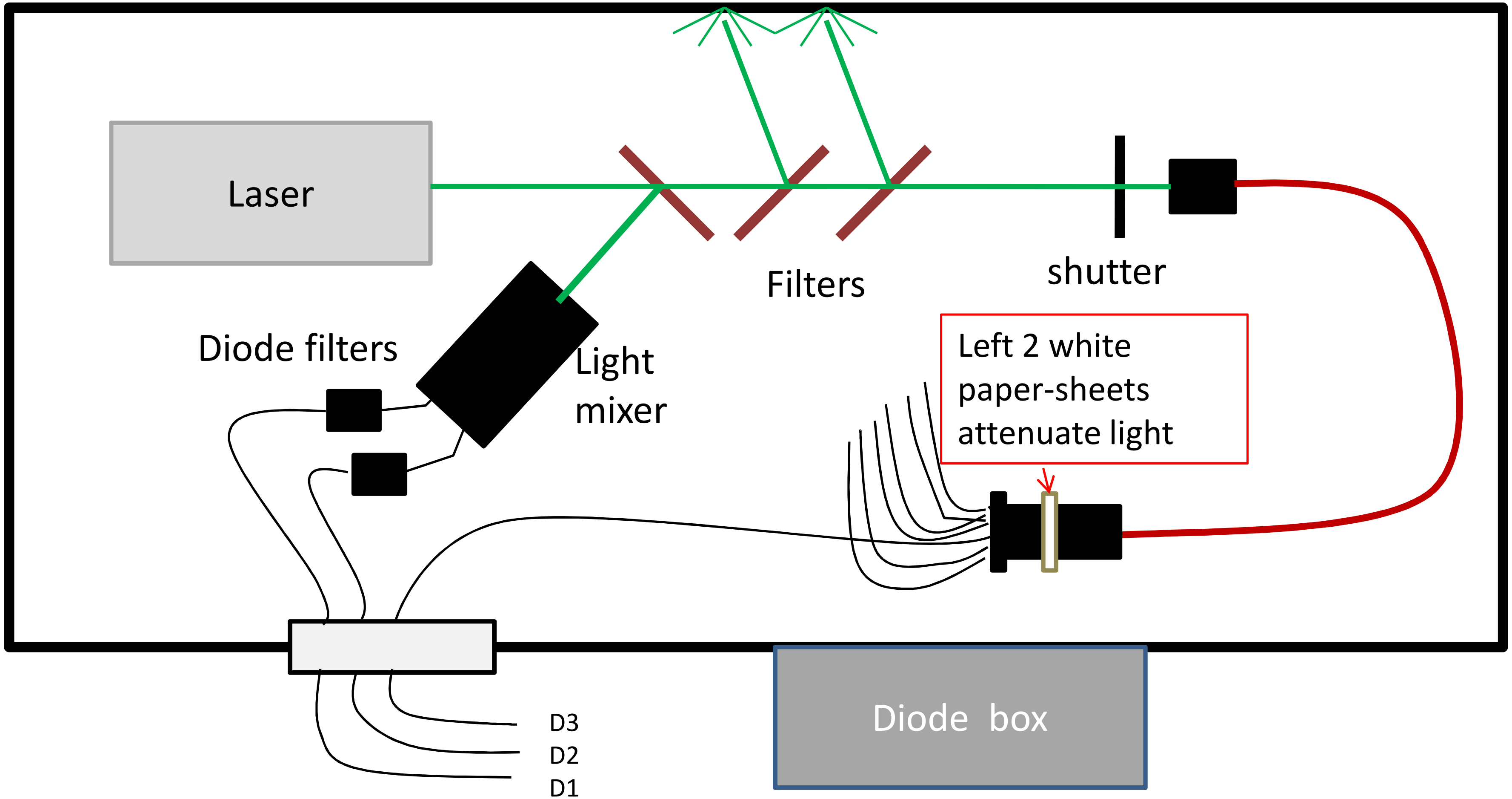



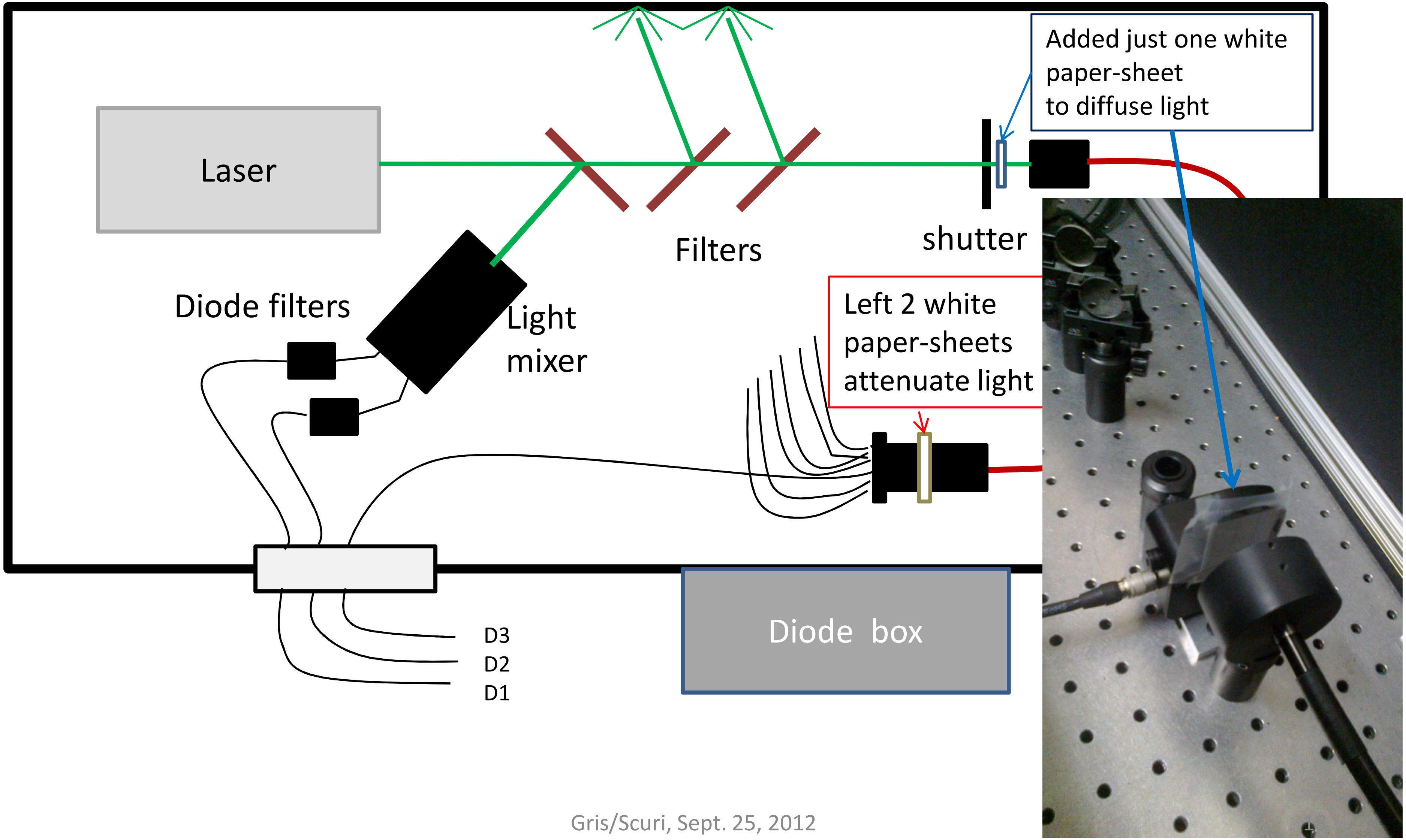


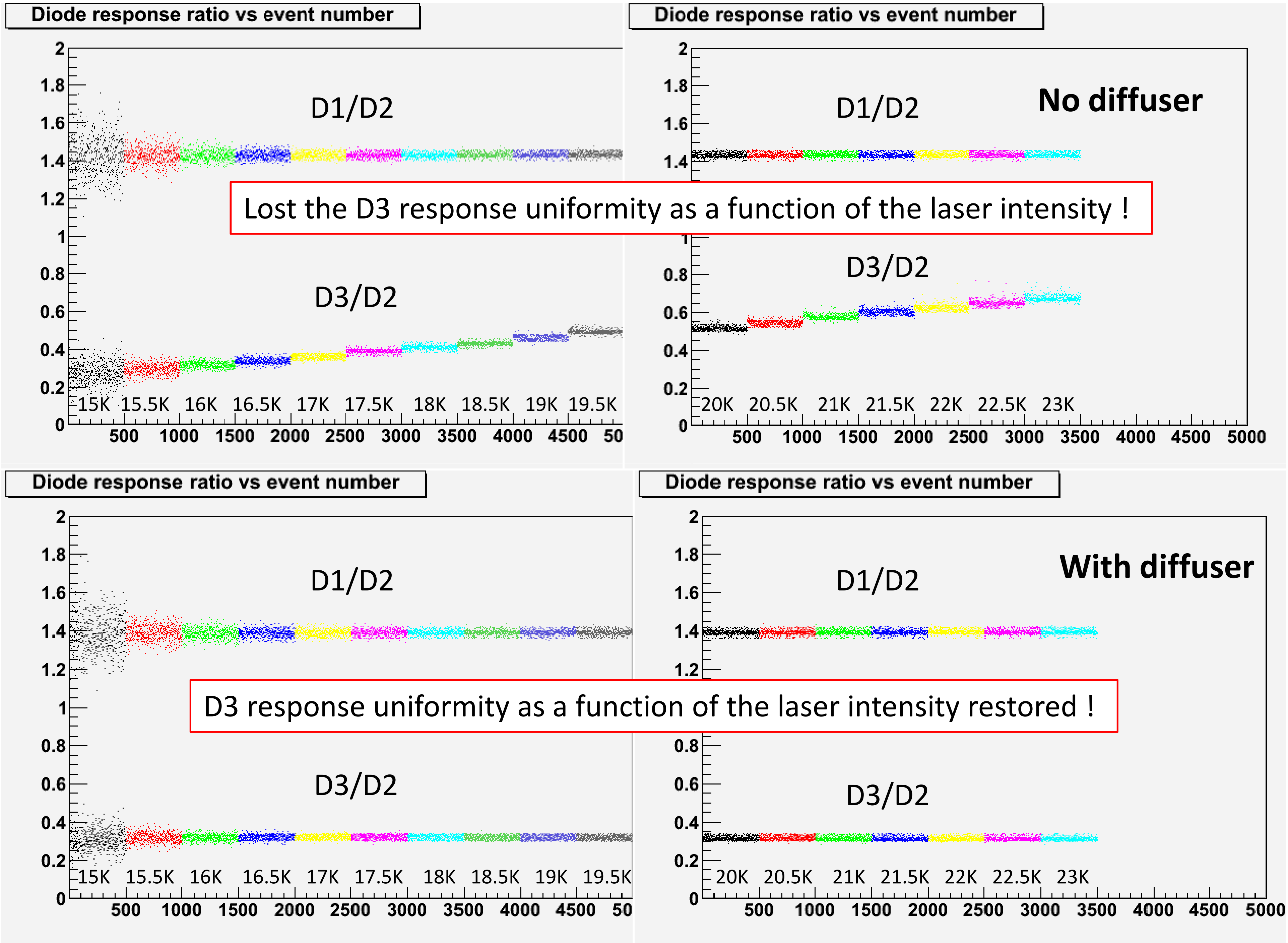

Altra indicazione che il fascio si muove con l'aumento dell'intensità; l'aumento di temperatura in cavità col pompaggio ne modifica (di poco) la geometria, cambia il peso relativo dei modi eccitati (appendice).

# La dimostrazione di come il mixing possa compensare gli effetti sistematici dovuti a spostamenti (minimi) del fascio laser (I)

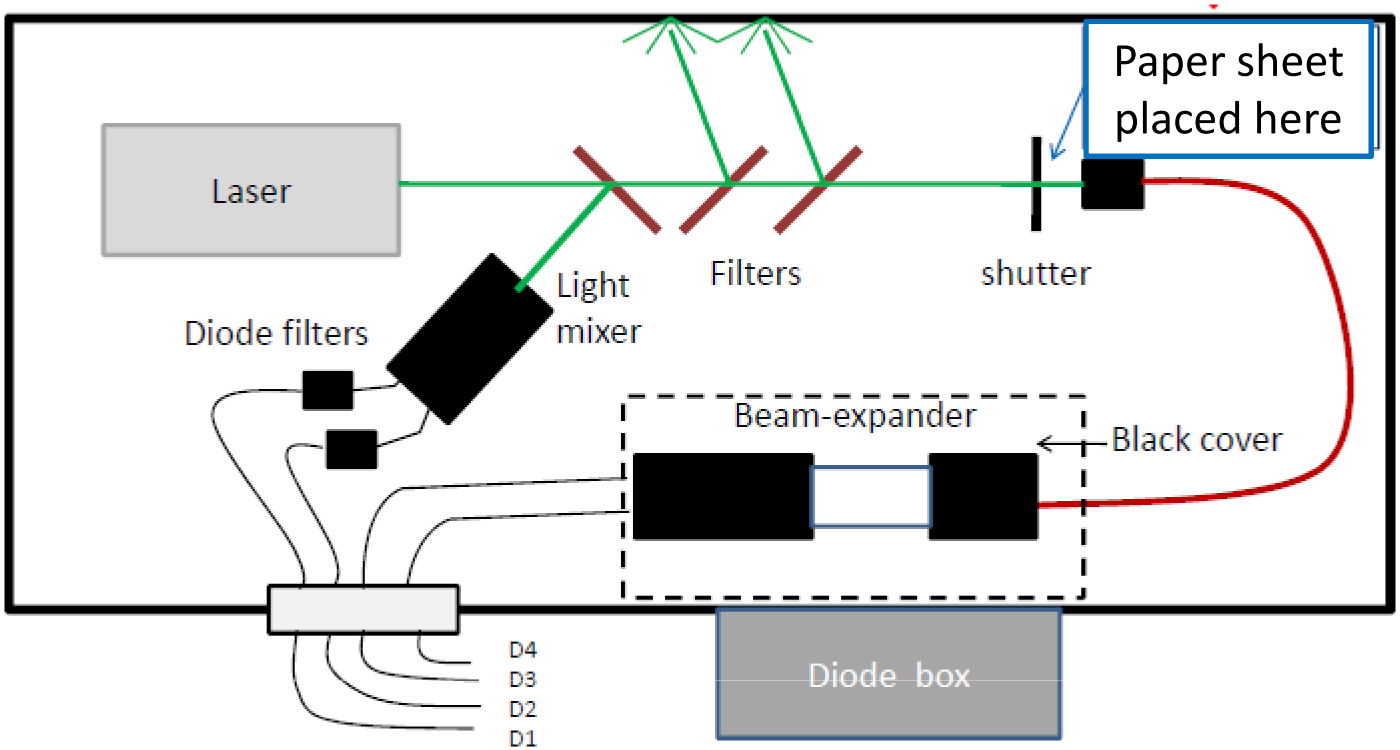


# La dimostrazione di come il mixing possa compensare gli effetti sistematici dovuti a spostamenti (minimi) del fascio laser (II)

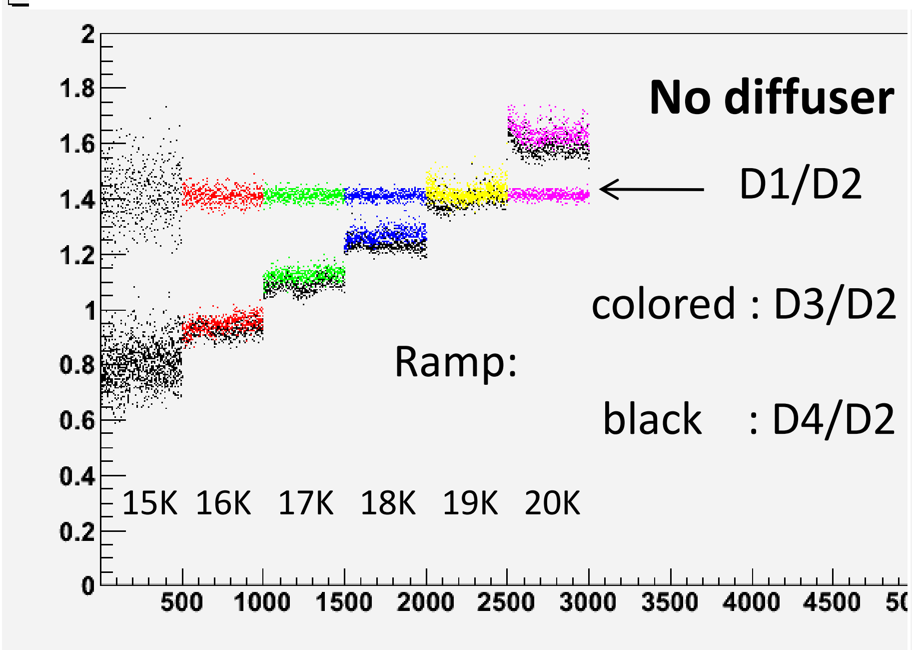


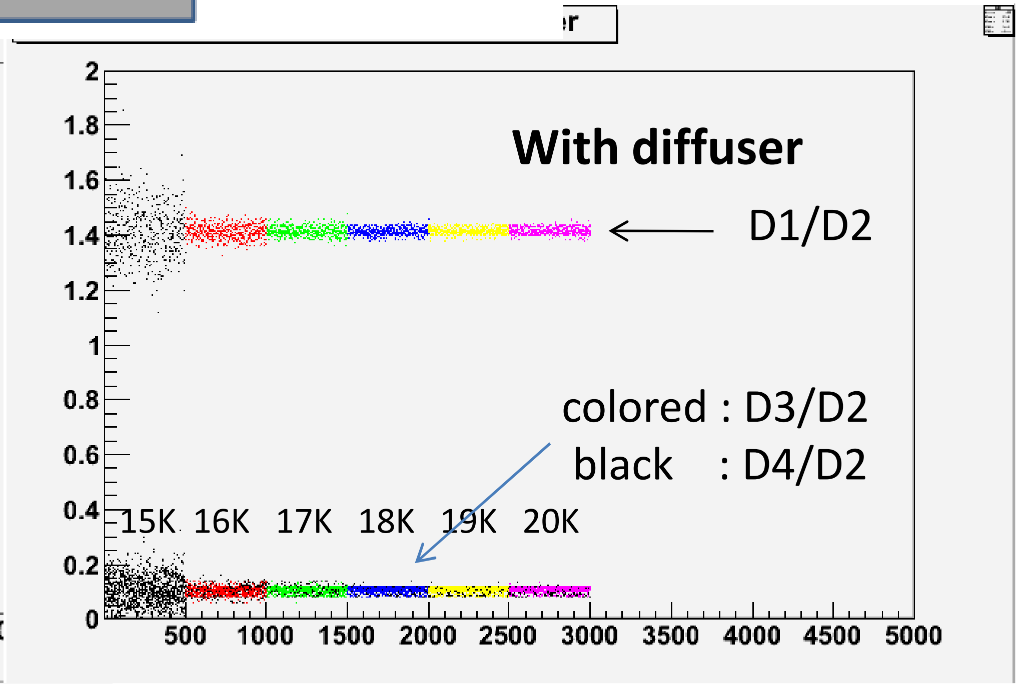


Diode response ratio vs event number
D1/D2
D3/D2
15K 15.5K 16K 16.5K 17K 17.5K 18K 18.5K 19K 19.5K
Diode response ratio vs event number
D1/D2
No diffuser
D3/D2
20K 20.5K 21K 21.5K 22K 22.5K 23K
Lost the D3 response uniformity as a function of the laser intensity !
Diode response ratio vs event number
D1/D2
D3/D2
15K 15.5K 16K 16.5K 17K 17.5K 18K 18.5K 19K 19.5K
Diode response ratio vs event number
With diffuser
D1/D2
D3/D2
20K 20.5K 21K 21.5K 22K 22.5K 23K
D3 response uniformity as a function of the laser intensity restored !



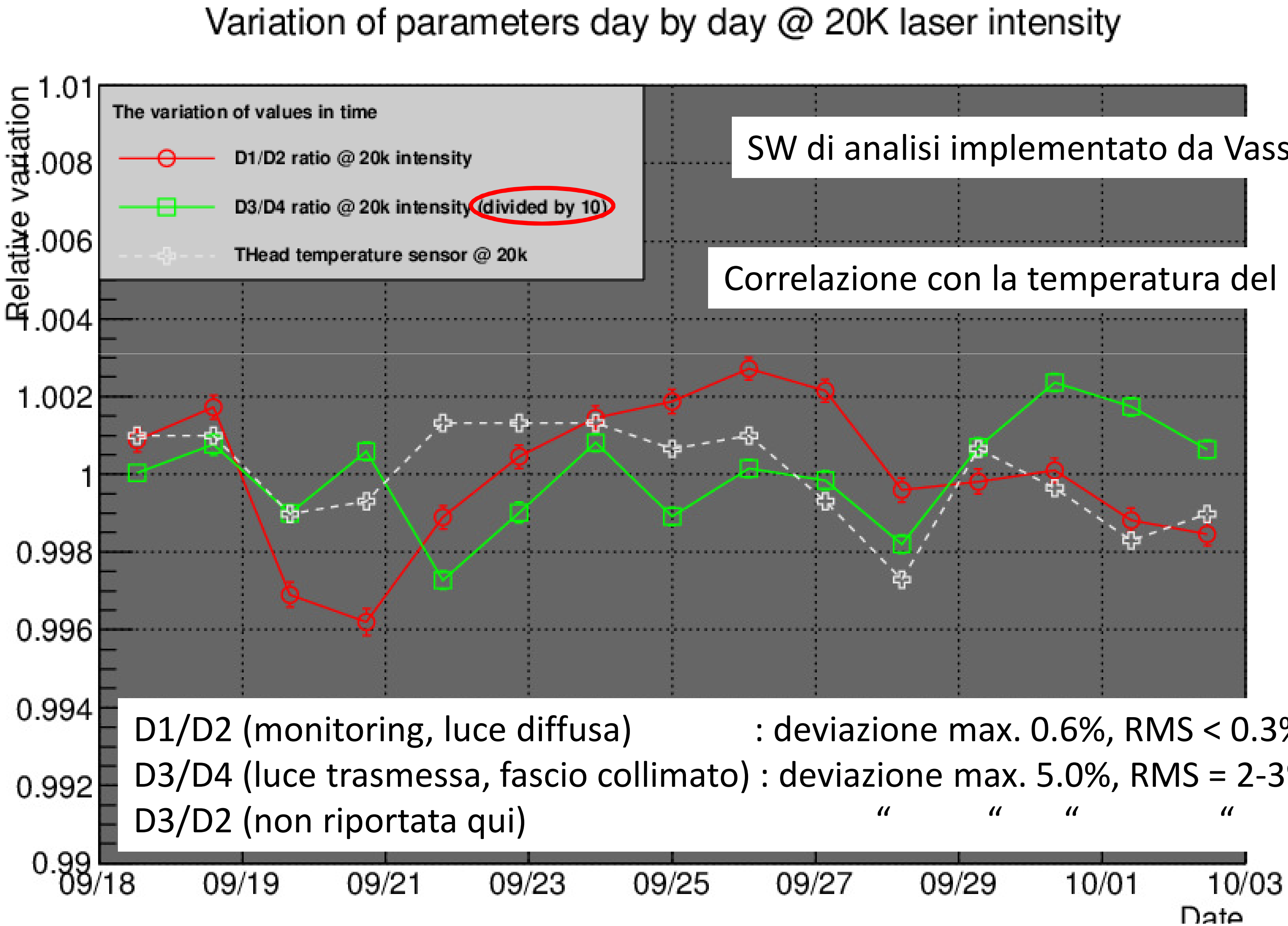

Stessa situazione all'uscita del beam expander …..



# Test di lungo periodo col set-up iniziale (niente diffusori)

Ogni giorno un crontab esegue uno scan di intensità e cos^ controlla la stabilità di monitoring (D1/
stabilità di risposta in uscita al beam expander (D3/D2, D3/D4) e stabilità intensità (D1+D2, D3+D4




SW di analisi implementato da Vassili K.

Correlazione con la temperatura del laser?

D1/D2 (monitoring, luce diffusa) : deviazione max. 0.6%, RMS < 0.3%
D3/D4 (luce trasmessa, fascio collimato) : deviazione max. 5.0%, RMS = 2-3%
D3/D2 (non riportata qui) " " " "

# The LASER in 175

- ***Preliminary conclusions:***

ora 20

1)- The intensity monitoring system (D1,D2) is stable during any intensity scan and at fixed intensity over longer time intervals (we tested for the moment during 10 days) at a level just below 1% - It could be not enough for a full detector PMT calibration at 1% level – Not much room for improvements, only we can do better mechanics and temperature stability, if demonstrated that electronics is sensitive at the percent level to environmental thermal drifts.

2)- We have experimentally verified a well known characteristic for Q-switched pumped lasers: the beam geometry slightly changes with emitted intensity; if we must change the laser intensity in the final calibration procedure, we need a very good light mixing system in order to have always (at any laser intensity, i.e. for any even very small change in the beam geometry) the same average intensity at the input of each individual fiber coupling the mixer to the system distributing light to PMTs.
The uniformity of light intensity on the full fiber bundle active section is practical but not strictly required; what matters is a reliable correlation, fiber-by-fiber, between monitored intensity and transmitted intensity.

3)- The whole present optical path has to be revised; with a collimated beam and the present geometry of the beam expander, poor or no mixing at all is produced.

4)- The liquid fiber, not the best choice to redirect a laser beam, could be used, together with a diffuser, for having a light pre-mixing.

5)- The method of two diode swap applied systematically to each fiber of the bundle, although slow and painful, could be the simplest and lowest cost way to measure in situ transmission uniformity and stability

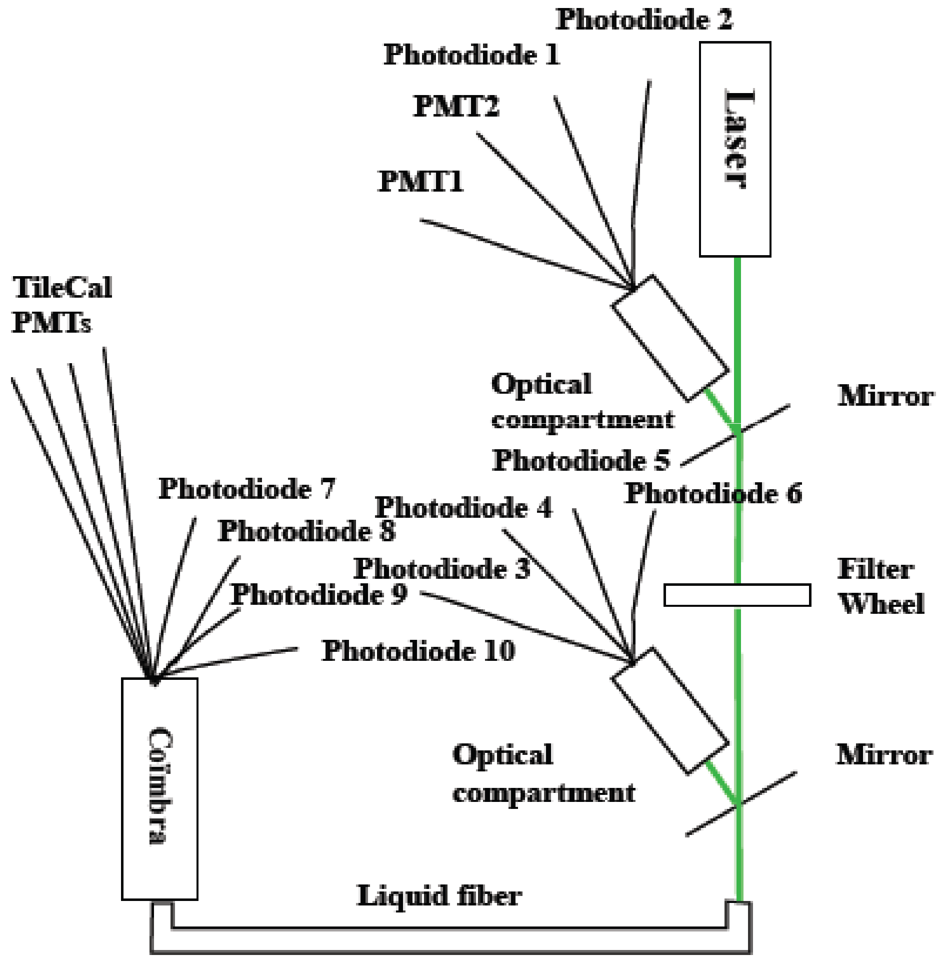
# The LASERII

- *Modifications/improvements wrt LASERI:* (Monitor + electronics !)
  - *Increase of the number of photodiodes: to monitor the light emitted by the LASER at each step: before the filter wheel, after the filter wheel, after the Coïmbra system. To ensure redundancy, ten photodiodes are necessary:*
    - *2 before the filter wheel*
    - *4 after the filter wheel*
    - *4 after the Coïmbra box*
  - *To increase the dynamic range of the electronics, ADCs with two slopes will be used (the photodiodes are not saturating).*
  - *It is difficult, while increasing the number of photodiodes, to maintain the α-source calibration system as it is. We will move to a calibration system using a LED to monitor the stability of the ten photodiodes. To monitor the light coming from the LED, an additional photodiode will be used. The stability of this photodiode will be monitored by an α-source.*

( Io ho qualche dubbio che il LED sia uniforme entro lo 0.5% … )

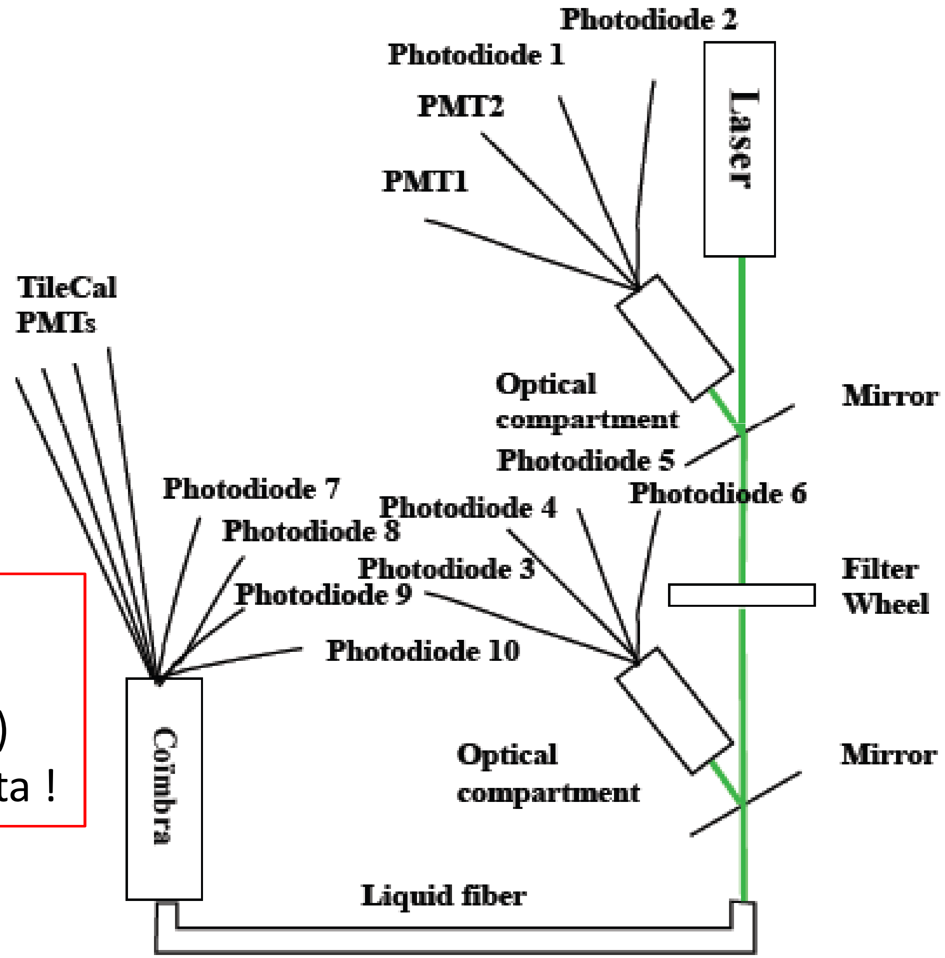
# The LASERII

## Optical part



# The LASERII

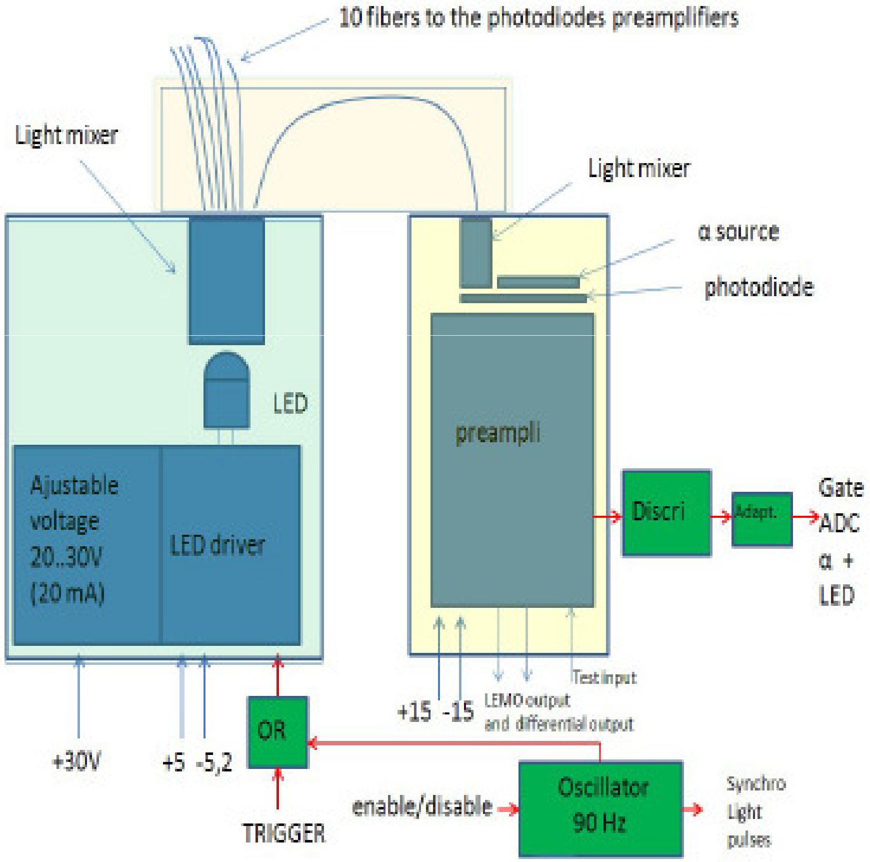
~~Optical part~~

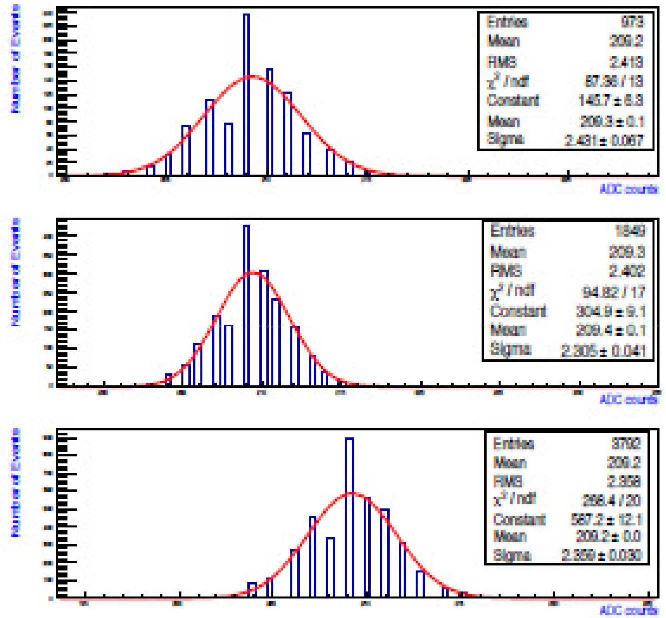



Secondo me è solo ridondanza di monitoring, non servirà a nulla se l'ottica (trasporto fascio, mixing) non sarà adeguatamente progettata !

# *The LASERII*

## *PHOtodiode CALibration system (PHOCAL)*




*LED runs:*

*$\sigma$ ~ 1%*

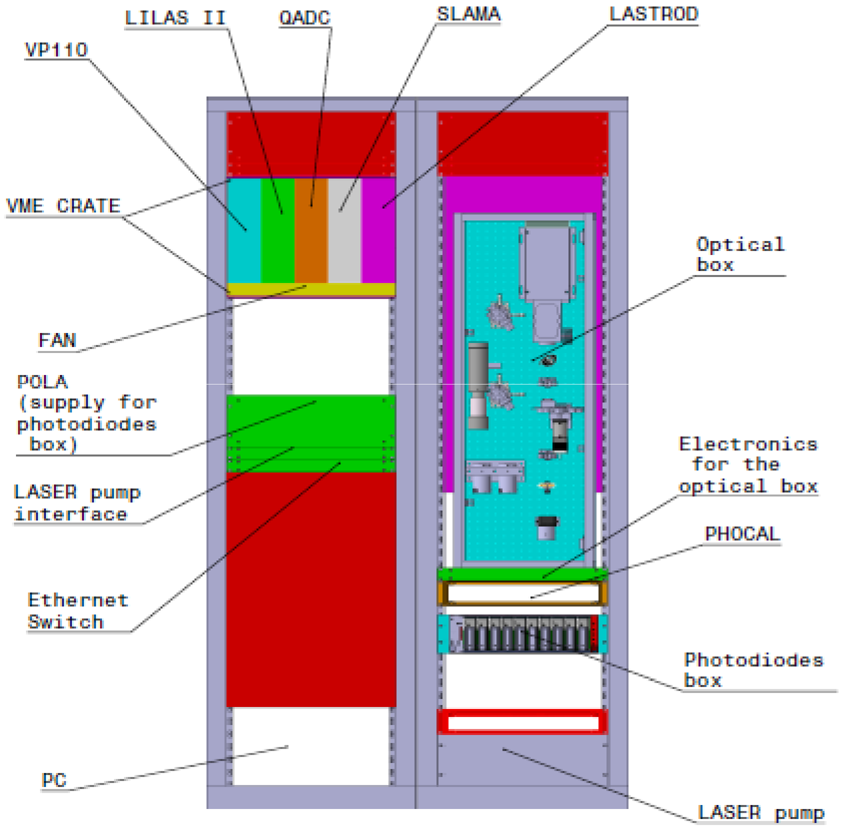
*stability: $\sigma$ ~ 0.3%*

(come temevo ….)

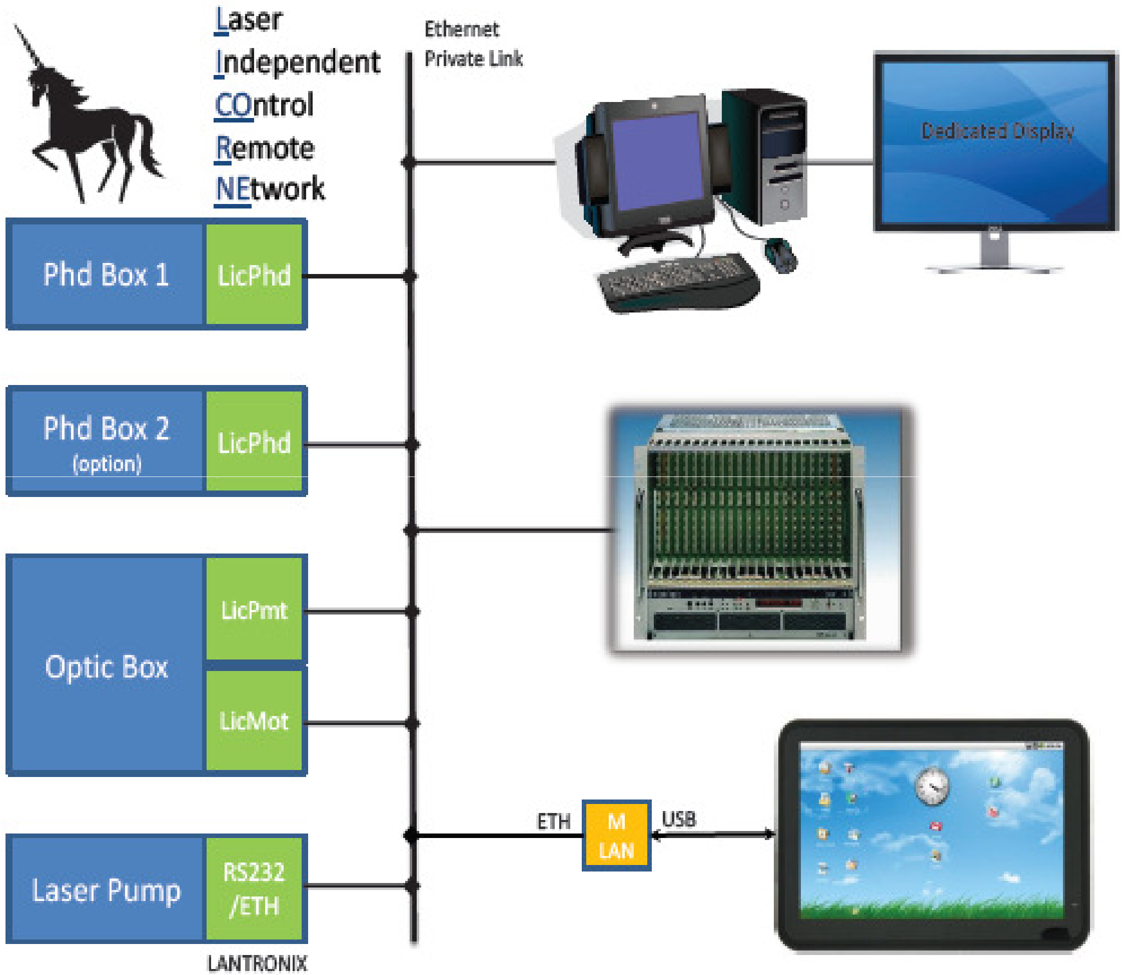
# The LASERII

Scheme of the system

(come è ora)



# The LASERII - DCS




Come sarà lo slow control

# The LASERII

- Open questions:
  - Light distribution in the optical box: results from 175 tend to indicate that the mixing of the light before the filter wheel is not optimal -> we would like to test optical component like a beam expander to try to improve this point.
  - The Coïmbra system is not completely tested and designed: Alberto and Fabrizio will work on this point in the nex coming months
  - Optical box: at the moment we have a design with a box in a vertical position. But it is not satisfactory (dust, maintainance). We are studying the possibility to dissociate the LASER head from the optical components so as to have the optical box horizontal.

# Beam expander ancora tutto da capire e definire

Richiesta: deve distribuire luce a 400 fibre lunghe oltre 100 mt in modo che l'intensità sia correlata a quella monitorata (D1/D2) entro il 1%, indipendentemente dall'intensità erogata dal laser e, quindi, dalla posizione (modi eccitati in cavità) del fascio collimato.

1) Per definizione, non si riesce a fare mixing su un fascio collimato (vedi back-up).
2) L'idea di usare blocchi di PMMA per il mixing (già fatto in Dream) può funzionare se la luce ha un'apertura angolare sufficiente (diffusore, prima o dopo la fibra liquida?)
3) Ottimizzazione della geometria -> simulazione -> volontari cercasi .....
4) Verifica stabilità luce distribuita alla fibre:

   a) – mapping uscita blocco PMMA; può essere fatta: a Coimbra (camera digitale)
   a Pisa (set-up di Dream)
   == > misura accurata ma non tiene conto dell'accoppiamento con le fibre.

   b) – si può usare quanto esiste ora: un bundle di fibre di readout da 20 circa che copre ca 2 $cm^2$; applicare il metodo dello swap dei diodi per misurare la trasmissione relativa di ogni fibra rispetto a una di riferimento.
   == > misura penosa e lunga, ma tiene conto di tutto.

# Programma a breve termine

Per il momento sono state accolte le mie richieste, e cioè:

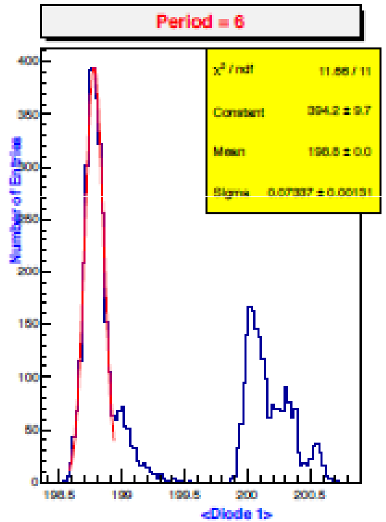
- Il CERN (C. Santoni) provvederà ad acquistare e a mettere i connettori ottici per tutte le fibre del bundle di read-out.
- Coimbra (vanta una buona offcina meccanica) prepara un diffusore calibrato di PMMA "unpolished"
- Pisa continua il monitoraggio di stabilità giornaliera del monitoring; mi ero impegnato sulla simulazione, ma mi serve trovare aiuto ….
- Tutti: appena pronto il bundle di readout e il diffusore si prova il metodo dello swap dei diodi in diverse configurazioni secondo lo schema che ho seguito a settembre; prima data possibile per Alberto, seconda metà di novembre, io sono al CERN per il TB di Dream. Nel beam expander io chiedo di mantenere il blocco di PMMA ma di rimuovere le lenti ed usare l'apertura numerica della fibra liquida per "aprire" il fascio.
- Se non funziona, occore studiare meglio la geomeria del mixer di PMMA ed, eventualmente, fare il mapping accurato in laboratorio

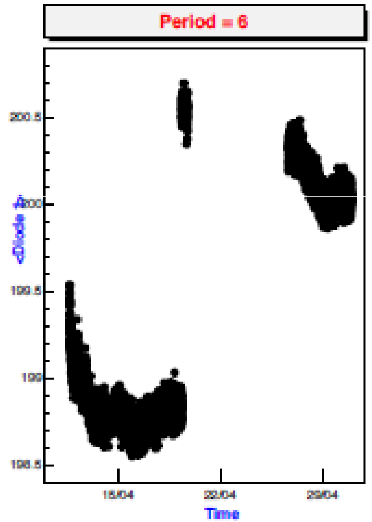
# BACK-UP

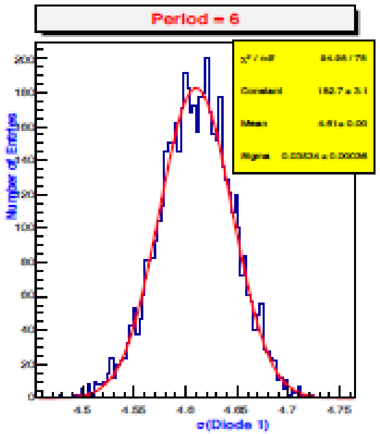
# The LASER in 175

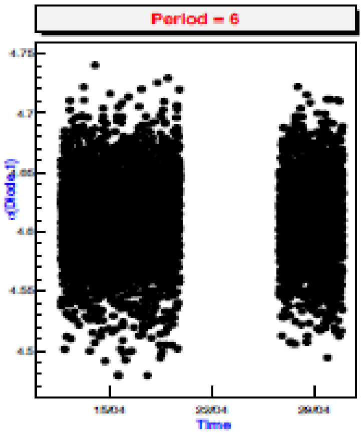
- *Replica of the system in USA15 with two caveats:*
  - *The LASER itself is not exactly the same*
  - *The setup (ie location of photodiodes, filters, ...) vary as tests are going on*

- *Extensive and continuous tests:*
  - *Pedestals -> electronics*
  - *Alpha-source runs -> photodiodes*
  - *Linearity -> electronics*
  - *LASER -> full system*



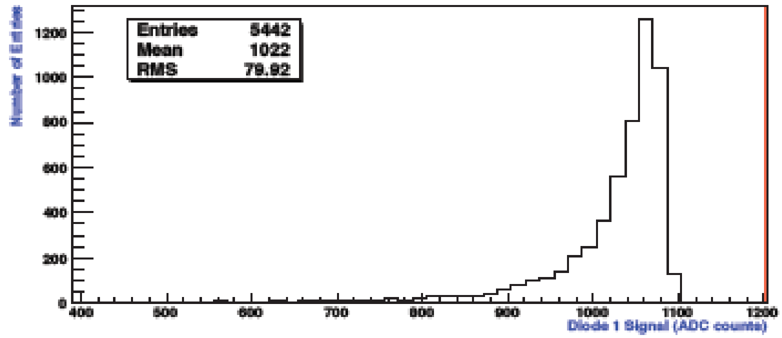



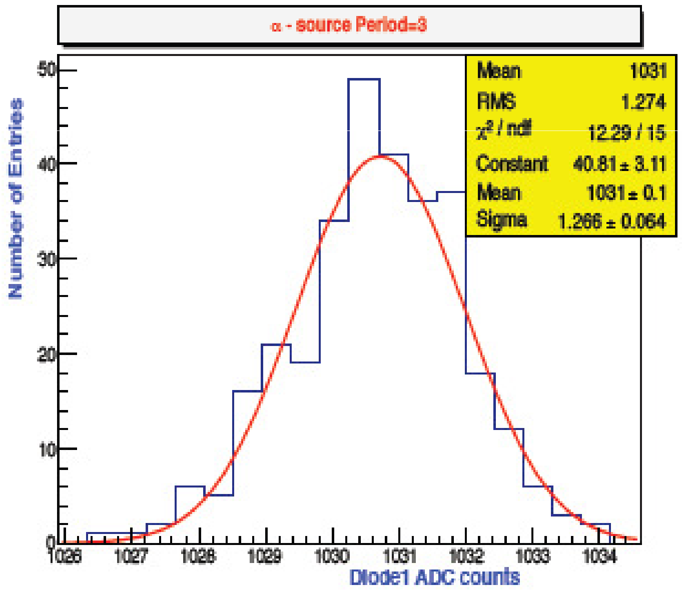

*Stability: 0.03% (mean), 0.6% (sigma)*

Questi sono i pedestalli !

# The LASER in 175

- *α- source runs: stability*



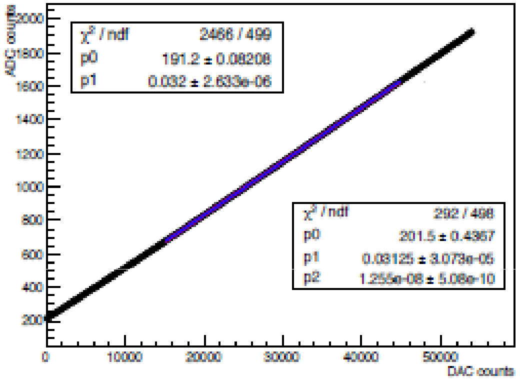



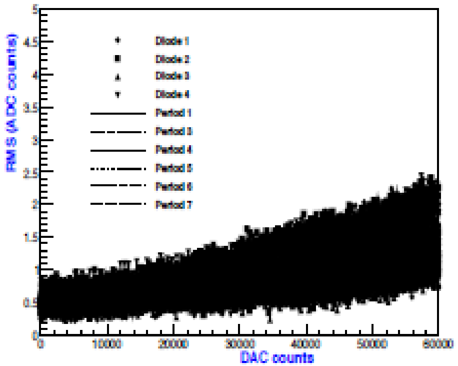

| Period | Photodiode 1 M | σ | $\frac{\sigma}{M}$(%) | Photodiode 2 M | σ | $\frac{\sigma}{M}$(%) |
|---|---|---|---|---|---|---|
| 1 | 1018.77 ± 0.48 | 2.18 ± 0.50 | 0.21 | 992.53 ± 0.28 | 1.71 ± 0.32 | 0.17 |
| 3 | 1014.78 ± 0.07 | 1.27 ± 0.06 | 0.13 | 988.50 ± 0.08 | 1.39 ± 0.07 | 0.14 |
| 4 | 1014.51 ± 0.11 | 1.25 ± 0.09 | 0.12 | 988.67 ± 0.13 | 1.35 ± 0.10 | 0.14 |
| 5 | 1014.91 ± 0.06 | 1.20 ± 0.05 | 0.12 | 988.13 ± 0.07 | 1.32 ± 0.05 | 0.13 |
| 6 | 1016.37 ± 0.10 | 1.23 ± 0.07 | 0.12 | 989.03 ± 0.11 | 1.39 ± 0.08 | 0.14 |

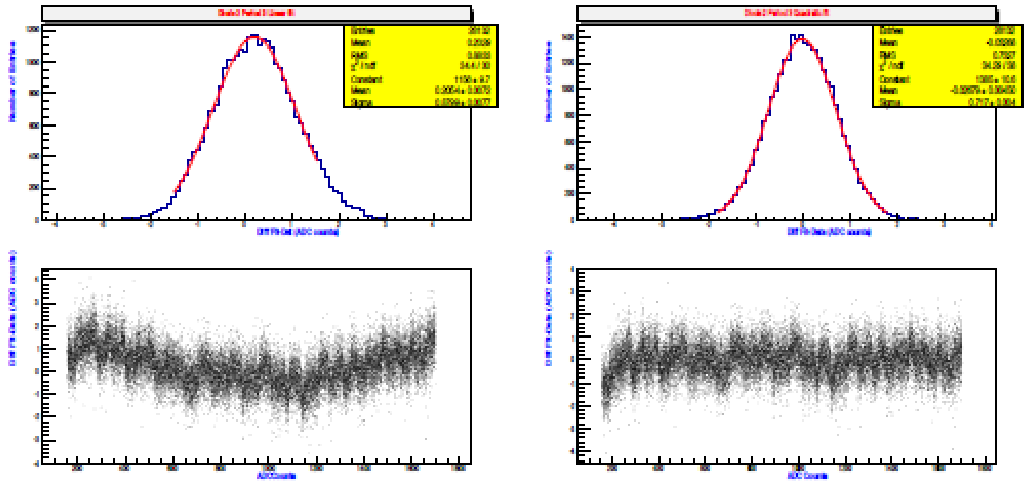
| Period | Photodiode 3 M | σ | $\frac{\sigma}{M}$(%) | Photodiode 4 M | σ | $\frac{\sigma}{M}$(%) |
|---|---|---|---|---|---|---|
| 1 | 977.08 ± 0.31 | 1.87 ± 0.31 | 0.19 | 1036.73 ± 0.36 | 1.99 ± 0.49 | 0.19 |
| 3 | 971.96 ± 0.07 | 1.26 ± 0.06 | 0.13 | 1030.71 ± 0.08 | 1.27 ± 0.06 | 0.12 |
| 4 | 971.76 ± 0.11 | 1.16 ± 0.09 | 0.12 | 1031.07 ± 0.12 | 1.29 ± 0.13 | 0.12 |
| 5 | 971.34 ± 0.06 | 1.29 ± 0.05 | 0.13 | 1030.45 ± 0.07 | 1.36 ± 0.05 | 0.13 |
| 6 | 971.45 ± 0.10 | 1.32 ± 0.08 | 0.14 | 1030.31 ± 0.13 | 1.61 ± 0.12 | 0.16 |

# The LASER in 175

- Linearity of the electronic: tested with a charge injection system
- An ADC (in addition to the ones digitizing the photodiodes signal) is devoted to the measurement of the injected charge.



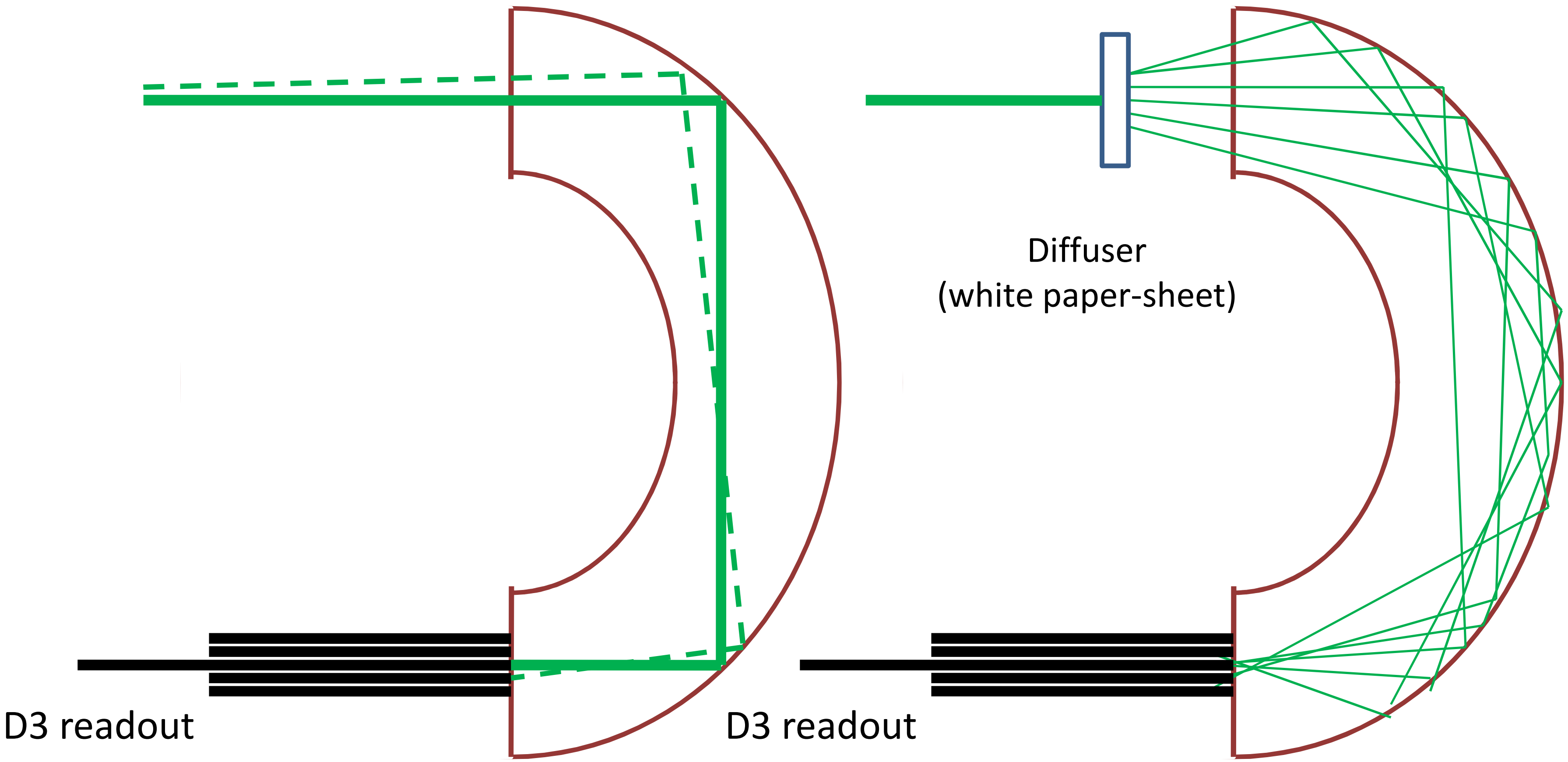



σ (fit-data) ~ 1 ADC count

Stability: σ ~1 to 2 ADC count

# Optics of the light transmitted by the bent liquid fiber




Laser beam straight onto the liquid fiber: even a small deviation in the incidence / point let some photons to miss the readout fiber !

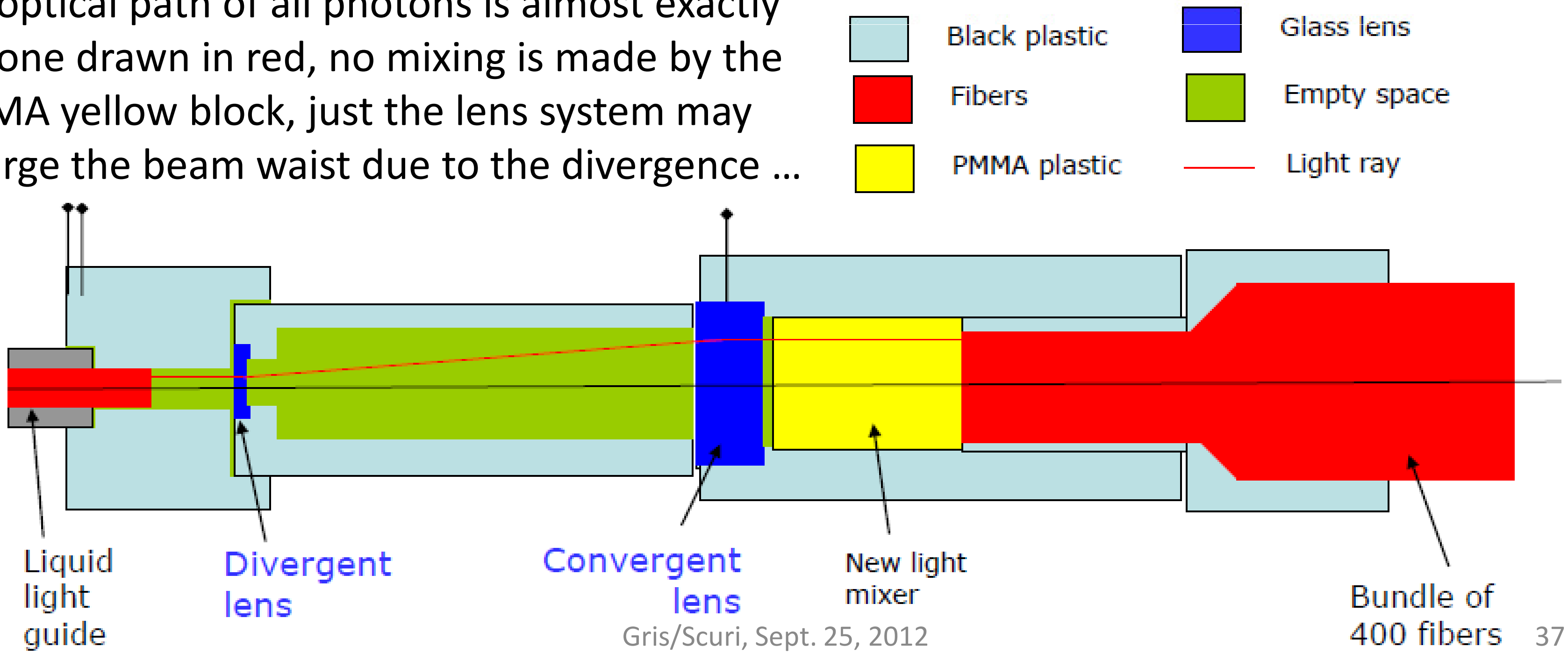
Light diffused at the fiber entrance: the number of photons hitting the readout fiber is almost constant for different incidence angle and point of the beam entering the liquid fiber

# Effects of the beam geometry on the light mixing power (I)

A picture in a document received from Coimbra

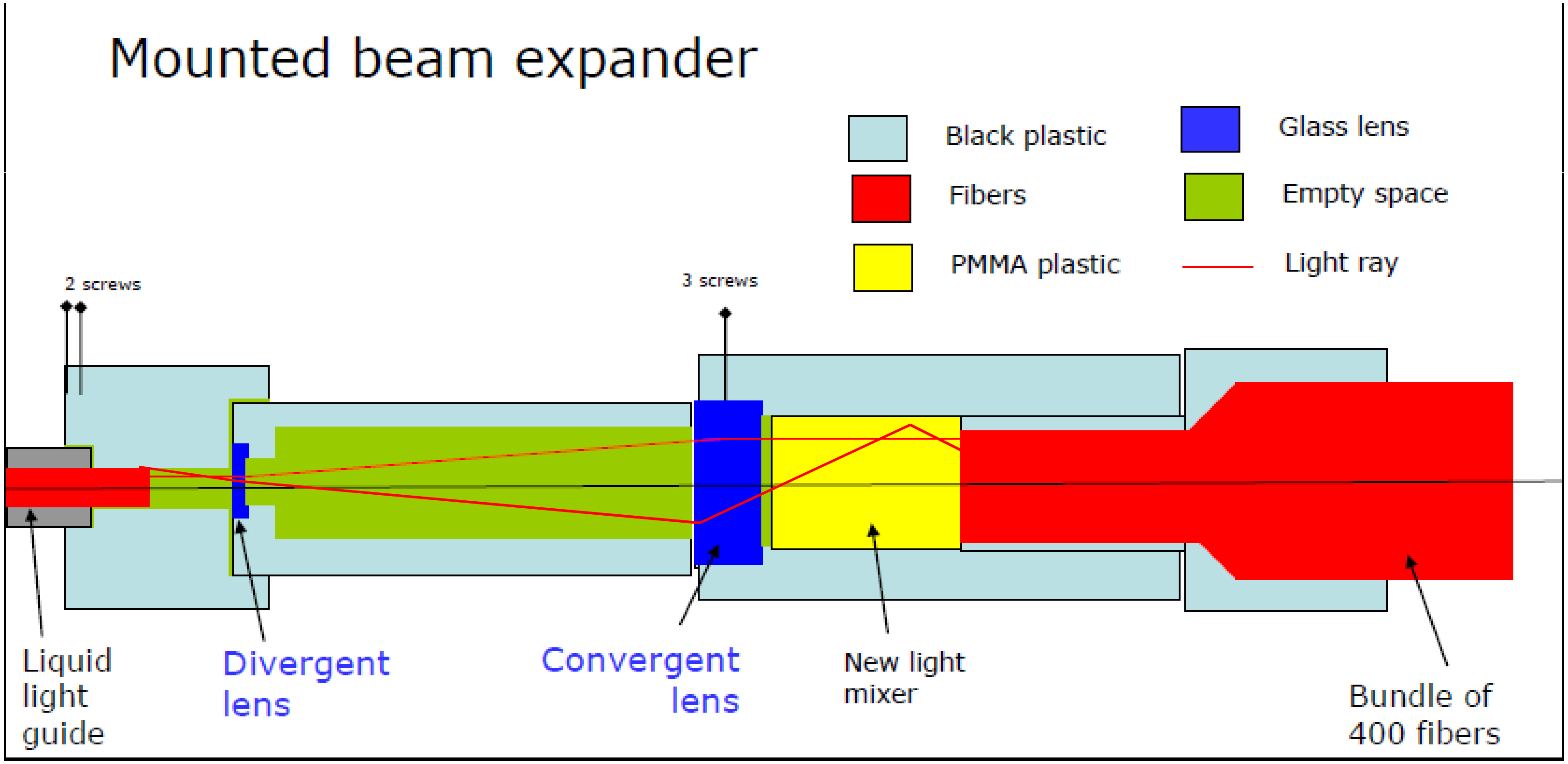
In the set-up of bld. 175 this piece is white and the whole system is not light tight

If the beam is collimated at the liquid fiber exit, the optical path of all photons is almost exactly the one drawn in red, no mixing is made by the PMMA yellow block, just the lens system may enlarge the beam waist due to the divergence …

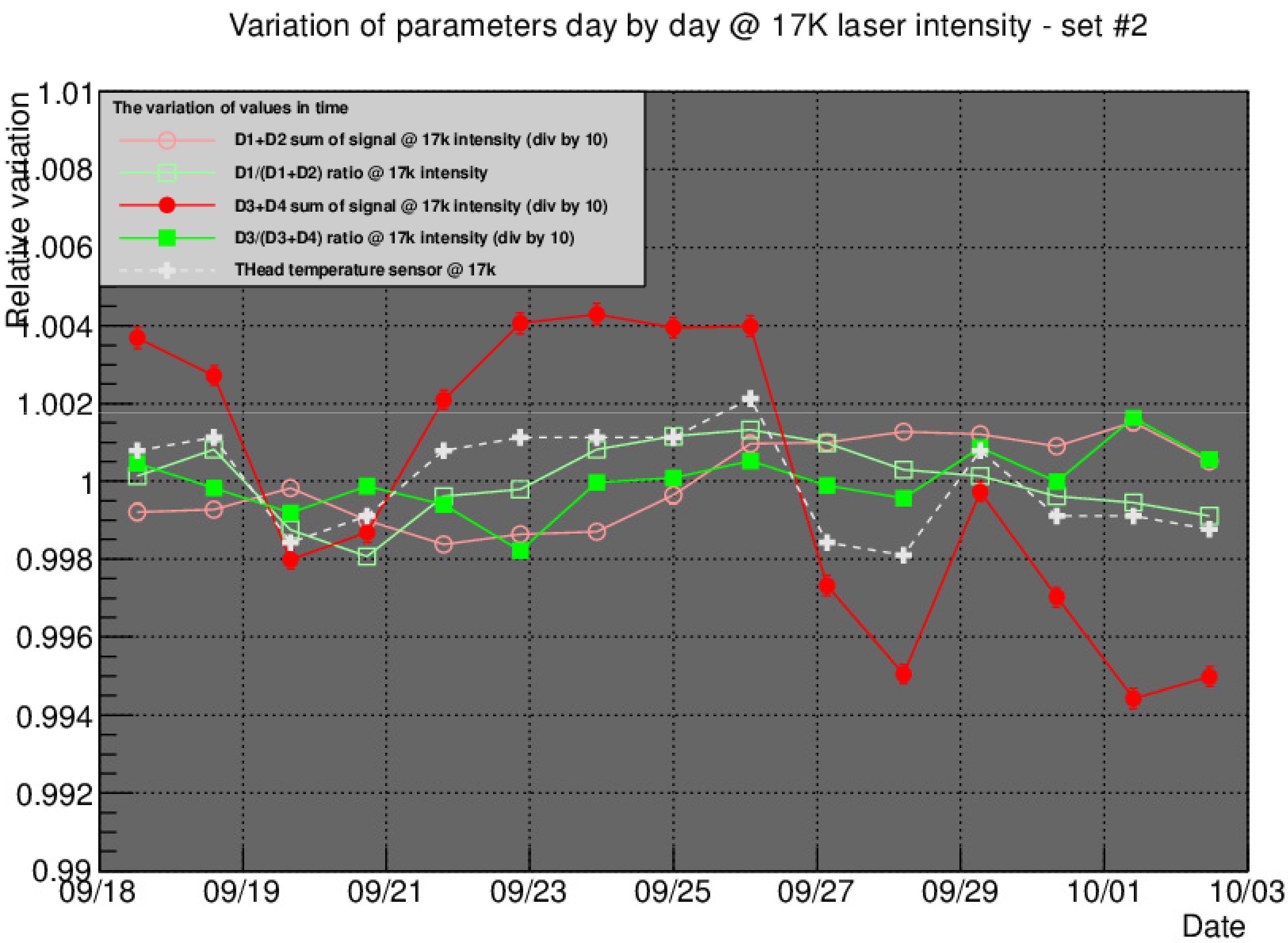


# Effects of the beam geometry on the light mixing power (II)

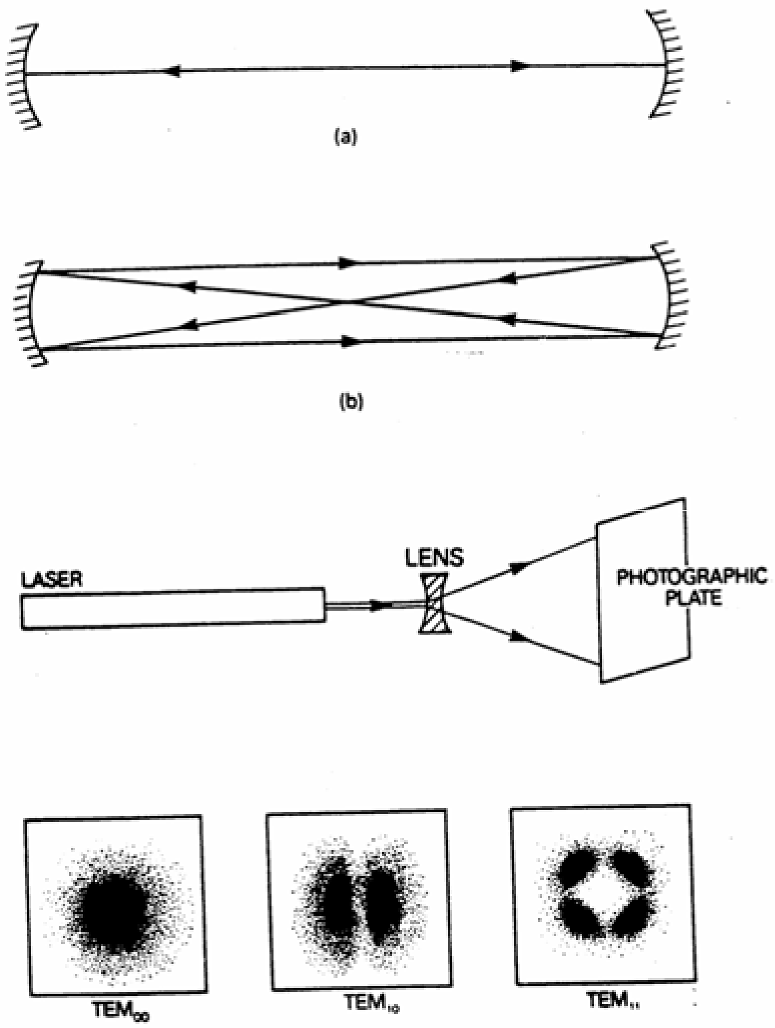
Only if the beam exiting the liquid fiber is not collimated, i.e. the case with the diffuser at the liquid fiber entrance, the present system can make some, even still poor, mixing !



Laser intensity much more stable at the monitor than at the beam-exp. e›

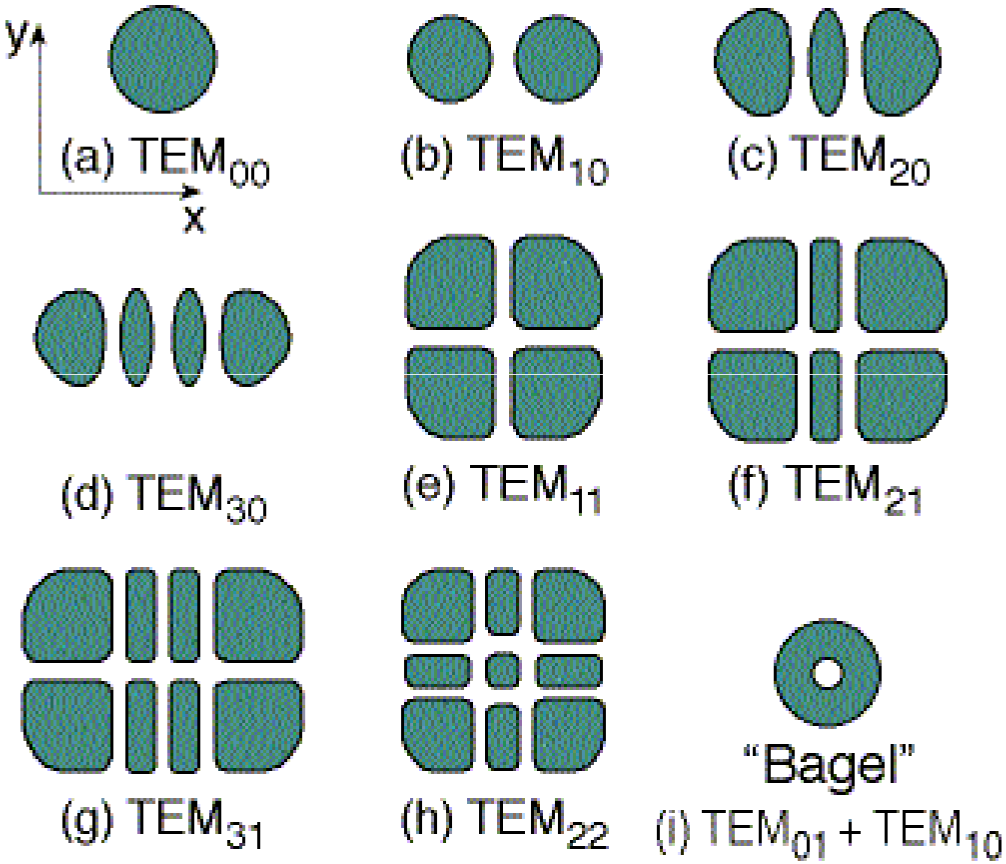


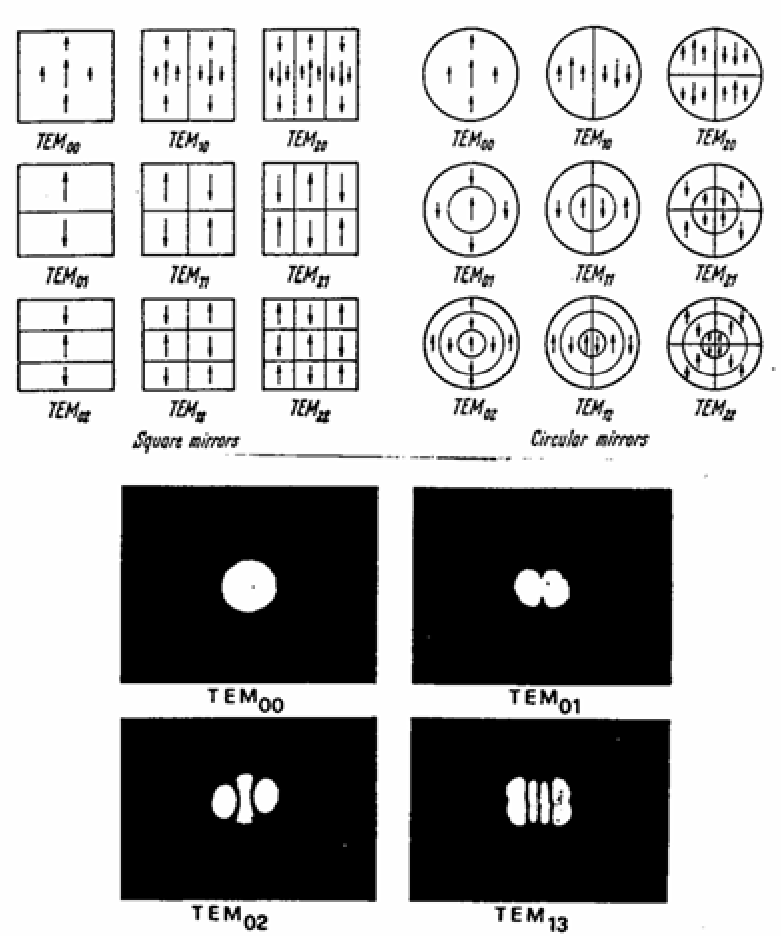
# MODI LONGITUDINALI E TRASVERSALI




**TEM: Transverse Electric and Magnetic field**

# MODI LONGITUDINALI E TRASVERSALI



Onda stazionaria in un parallelepipedo di lati A,B,C

$$\xi(x,y,z) = \xi_0 \sin(k_x x)\sin(k_y y)\sin(k_z z)\cos(\omega t)$$

| l | m | n | ω in unità $\frac{\pi}{c}$ |
|---|---|---|---|
| 1 | 0 | 0 | $\frac{1}{A}$ |
| 0 | 1 | 0 | $\frac{1}{B}$ |
| 0 | 0 | 1 | $\frac{1}{C}$ |
| 1 | 1 | 0 | $\sqrt{\frac{1}{A^2}+\frac{1}{B^2}}$ |
| 1 | 0 | 1 | $\sqrt{\frac{1}{A^2}+\frac{1}{C^2}}$ |
| 0 | 1 | 1 | $\sqrt{\frac{1}{B^2}+\frac{1}{C^2}}$ |
| 2 | 0 | 0 | $\frac{4}{A}$ |
| … | … | … | … |

$$\omega = ck = c\sqrt{k_x^2+k_y^2+k_z^2}$$

$$k_z = \frac{n\pi}{C} \quad n = 1,2,\ldots$$

$$k_y = \frac{m\pi}{B} \quad m = 1,2,\ldots$$

$$k_x = \frac{l\pi}{A} \quad l = 1,2,\ldots$$