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# Stabilized dye laser for crystal electromagnetic calorimeter monitoring

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## Abstract

An on-line active laser light output stabilization system is developed. The system compensates for slow variations of the laser light output caused by temperature drifts and by the aging of laser elements. The system is used for tracking PbWO<sub>4</sub> crystal transmission losses caused by the radiation damage for the CMS ECAL prototype tests at CERN. © 2002 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

Stabilization of laser light output is a general task important for different scientific and industrial applications. We describe here an application for a particle physics experiment, where laser light is used for monitoring the gain of an electromagnetic calorimeter built of lead tungstate (PWO) crystals. The calorimeter is used to measure the total energy of photons or electrons.

The PWO scintillating crystals, basic elements of the future CERN CMS [1], ALICE [2] and COMPASS [3] experiments' electromagnetic calorimeters, show certain optical transmission damage under irradiation. Although the magnitude of this damage is rather small, several percent for a collected dose of some kGys for the optimized crystals, a significant part of this effect appears very fast, after the first collected Grays [4]. This effect, along with a partial fast recovery [4], make PWO crystals unstable at the several percent level under the varying radiation conditions expected during LHC operation. It makes precise calorimeter response monitoring vitally important for interpreting the data.

Optimal monitoring requires injection into each crystal a number of photons that corresponds to

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those generated by the typical energy to be measured by each calorimeter channel. In case of the CMS ECAL, this corresponds to some  $10^7$  photons, equivalent to 100 GeV electromagnetic signal, injected in each of 80 K crystals. The monitoring light wavelength should be close to the crystal emission peak, 420 nm in case of PWO. Hence, the optimal monitoring light source should be a powerful blue (400–450 nm) laser. The light pulse stability should be very high, at the level of 0.1–0.2%, matching the very low constant term in the expression that describes the target CMS barrel electromagnetic calorimeter resolution [1]:

$$\frac{\sigma(E)}{E}(\%) = \frac{2.5}{\sqrt{E}} \oplus 0.5 \oplus \frac{0.155}{E}$$

where  $E$  is in GeV and  $\oplus$  indicates addition in quadrature. The first term of the equation is a stochastic term representing fluctuation in the shower containment and photostatistics, the second is a constant term, which summarizes contributions of calibration errors and all calorimeter cell and readout chain instabilities, while the third term is an electronics noise contribution.

Laser systems with such parameters are practically not available. In their absence, the CMS strategy would be to use a commercially available laser with about 10% output pulse instability, and to monitor it to the proper precision with the aid of stable PN diodes. Such systems were already built and operated well for the monitoring system of a number of the high-energy physics experiments [5]. But 0.1% stability for the 80 K elements system is very difficult to achieve. The laser light gain monitor becomes in this case a rather expensive and complicated sub-system, requiring its own stability control, etc.

The system described below represents a simpler solution. We stabilize the laser light output by adding an active light gain stabilizing feedback loop at the output of a commercial dye laser.

## 2. Laser stabilization system

The laser setup (Fig. 1) is based on a Laser Photonics<sup>®</sup> (Florida, USA) Nitrogen dye laser, model LN300C. A high-powered N<sub>2</sub> laser, emit-

ting short 4 ns, 280  $\mu$ J pulses at a rate of 1–30 Hz at a wavelength of 337 nm, is used to pump a dye laser. A blue dye with a peak emission at 425 nm and a conversion efficiency of 20% was used for the described measurements.

Besides the dye laser, the setup includes a stabilization system with a reference thermostabilized photo-detector, and an electro-optical modulator (shutter). The electro-optical modulator of longitudinal geometry controls the optical pulse intensity, maintaining its long-term stability. It is made of a KD<sub>2</sub>PO<sub>4</sub> (DKDP) [6] crystal assembled in a block with two crossed optical polarizers. Here the laser beam is polarized by the input polarizer. The DKDP crystal splits the light beam into two components polarized along the two crystal dielectric axes. These components interfere at the crystal output with a relative phase, which is changed according to the voltage, applied to the crystal [7]. This results in an effective polarization plane rotation. If no voltage is applied, there is no effective polarization rotation, and the light is strongly attenuated by the second polarizer, placed at 90° to the first one. If a voltage is applied, there is an effective rotation of the polarization at the DKDP crystal output, and the attenuation by the second polarizer is smaller. For the so-called “half-wave” voltage, the effective polarization rotation is about 90°, and the attenuation is minimal. The interference picture on the output of the system is shown in Fig. 2. The value of the shutter half-wave voltage is about 2500 V for the 425 nm wavelength.

The stabilization system includes a CAMAC unit carrying out control of the optical transparency of the electro-optical modulator. This is achieved by comparing the amplitude of laser pulses measured by the reference photo detector, which receive a small fraction of the output light deflected by the beam divider, with the reference voltage  $U_{\text{ref}}$ . A 12-bit DAC is used to transform a series of pulses from the signal comparator to the analog error signal. This signal, after being scaled and filtered, drives the electro-optical modulator via a high-voltage transformer.

The reference photo-detector is made of a HAMAMATSU S5106 PIN diode, with charge-sensitive pre-amplifier and shaping amplifier. To

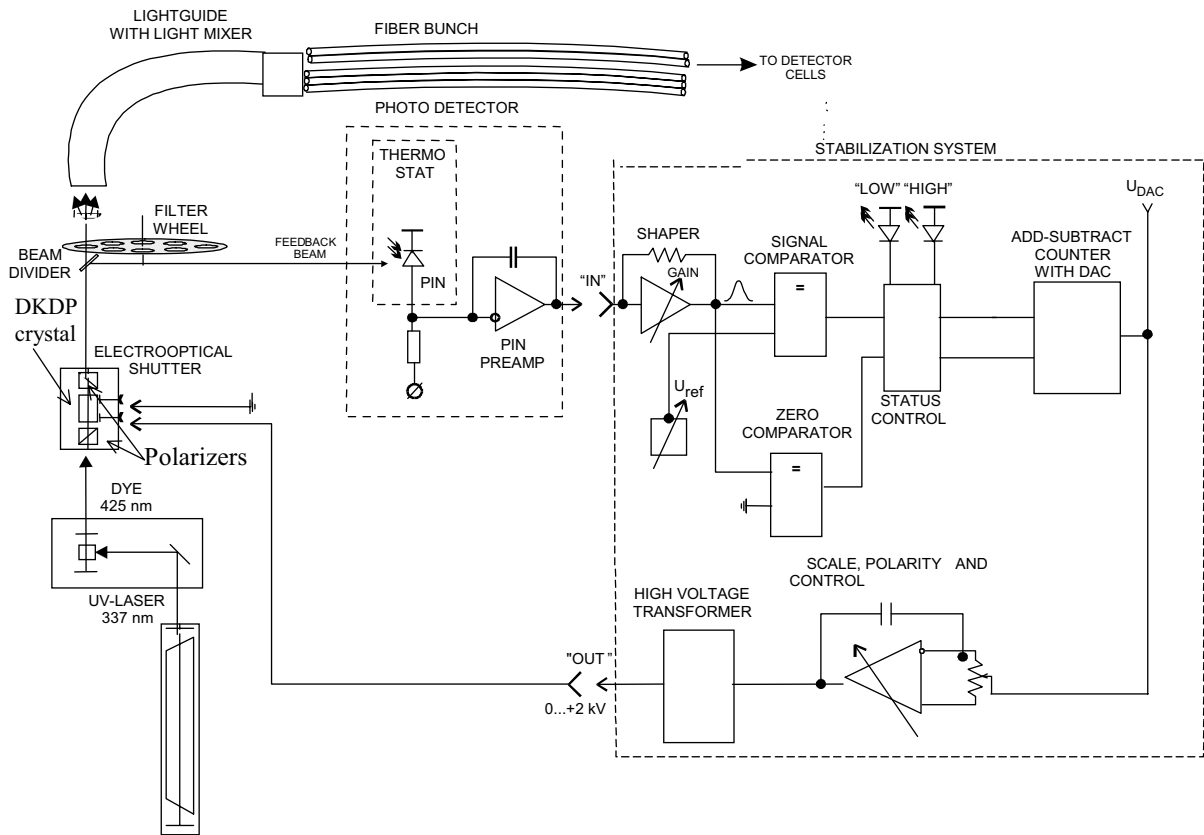


Fig. 1. Dye laser setup for gain monitoring of crystal calorimeter cells.

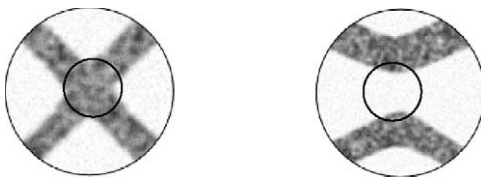


Fig. 2. Interference picture on the output of the electro optical shutter: zero applied voltage (shutter closed)—left, half-wave voltage (shutter opened)—right. The input of the shutter is limited to 4 mm by the input diaphragm (outer ring). The spatial zone of the maximum beam intensity is marked with the inner ring.

achieve appropriate long-term stability, the PIN diode is placed in an active thermostat which maintains a working temperature at  $35 \pm 0.1^\circ\text{C}$ . The intensity of laser pulses, impinging on the photo detector, can be tuned with a set of calibrated neutral density light filters, installed at the detector entrance.

Since the reference photo detector is sensitive to the light integral over the 4 mm diameter beam spot, the overall light intensity is stabilized, while the light intensity at any point on the beam spot is not stable. Hence, the light should be uniformized before distribution to the fibres. This is done by an irregular light guide: a 10 mm diameter bundle of thin  $20\ \mu\text{m}$  quartz fibres chaotically mixed in such a way that there is no correlation between each fibre position at the input and output of the bundle. The light mixer is connected to the transport fibre bundle which delivers monitoring light to the detector elements. Calibrated attenuation filters mounted on a filter wheel behind the shutter are used for the final light intensity adjustment. All optical elements including modulator, photo-detector, filter wheel, etc., are mounted on a light-protected optical bench, attached to the laser base plate.

The output light of the particular laser used for these measurements is not polarized, or its polarization (linear or elliptical) changes randomly from pulse to pulse or even within a single pulse. Thus, the light intensity is decreased by the factor 2 by the input polarizer. Some additional losses of about 30% are due to the non-coated optical elements and residual attenuation of the shutter. The overall system efficiency, given by the ratio of the number of photons delivered to the fibres bunch to the number of photons at the dye output, is about 0.3.

### 3. Stabilization system operation

The nitrogen laser has basically two types of instabilities: pulse-to-pulse one and slow drift. The pulse-to-pulse amplitude variation is about 5% for the laser used in the current setup. This is not very important if the laser is used for relatively slow control, which is the case for the calorimeter light monitoring, since one can use a mean value over several tens or even hundreds of pulses. The much more important slow drift, which can be caused by aging of the laser's active elements, temperature drifts, pumping element instabilities, etc., can change the light output by 30–50% during several days of operation. This is a typical stability time required by the particle detectors, a time needed for detector re-calibration by the physical events.

The task of the system is to correct the slow drift. For the range of regulation chosen,  $\pm 10\%$  in our case, the voltage on the DKDP crystal is initially selected to provide 90% transparency with respect to the “shutter opened” state (100% minus half of the regulation range). Each laser pulse, after being detected by the reference PIN diode, changes the voltage applied to the DKDP by one DAC (Digit-Analog Converter) step up or down, depending on the PIN diode signal amplitude with respect to its amplitude with the reference level. The full DAC range is 4096 counts (12 bits) which means  $\pm 2048$  steps of regulation. The system does not correct pulse-to-pulse amplitude variation. If the laser light is 5% away from the nominal value, it will be corrected after 1024 pulses, 200 s in case of the typical laser operation at 5 Hz. The intrinsic

system precision is in this case  $20\%:4096 = 0.005\%$ .

Note that the DKDP crystal itself is very fast: the change of the polarisation plane rotation takes some pico-seconds. The stabilization system reaction can be improved either by a higher laser pulsing frequency (typically 10 kHz for solid state lasers) or by larger steps. If the stabilization system step will be 10 DAC counts, the 5% signal regulation will take 20 s, and the precision will be 0.05%, quite sufficient for most applications.

### 4. System test results

The system stability was tested at the CMS GIF setup [8], which is used mainly for PWO radiation hardness and light monitoring tests. The output fibres were connected to several light detectors: two with PHILIPS photomultipliers (PMT) XP1921 and two with HAMAMATSU S1722-02 PIN diodes. The PMTs were powered by a stable HEIZINGER HNC-2500 power supply. The output signals of all detectors were digitized by a LeCroy 1182 12-bit charge ADC. The light signals from a stabilized LED-based light source [9] were also delivered to each light detector, and were used for the setup stability control.

The mean over 1000 pulses versus time without stabilization is shown in Fig. 3a for PMT and Fig. 3b for PIN reference detectors. The signal changes by about 7% during 20 h, which corresponds to the typical nitrogen laser performance. The ratio of PMT to PIN signals is shown in Fig. 4a. Although the signals are correlated the ratio varies by 3%, which results in about 1% stability for the PMT signal corrected by the PIN one. This value is worse than one obtained by for example the SELEX experiment, which means that our PIN and PMT channels do not fit well to each other.

The same data, normalized to the initial amplitude, together with data taken with the running stabilization system, are shown in Fig. 5. The system keeps the output signal stable at the sub-percent level during more than 60 h. The distribution of the mean over 1000 pulses for the PMT and PIN channels for the case of

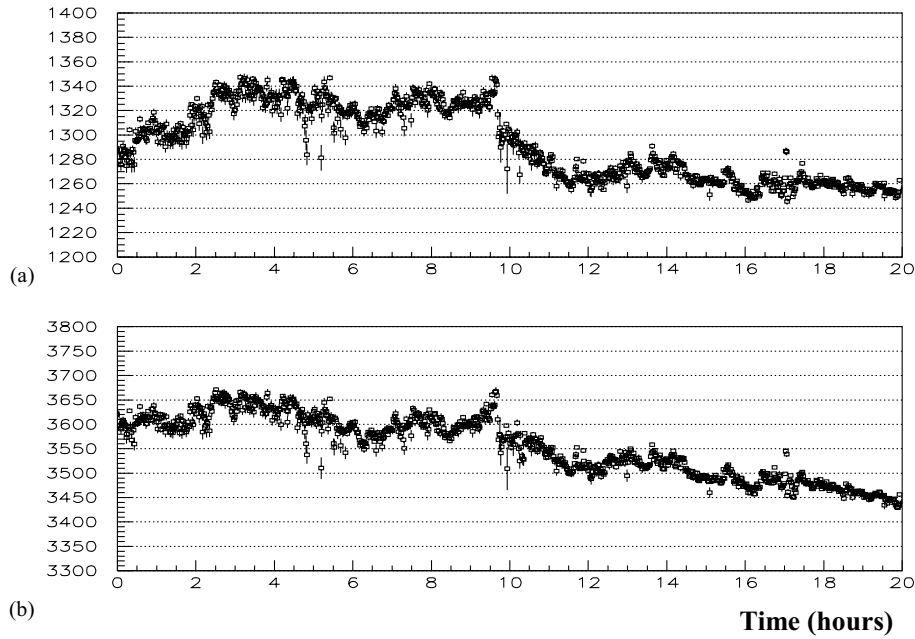


Fig. 3. Mean over 1000 pulses versus time for (a) PMT and (b) PIN readout. Stabilization system is OFF.

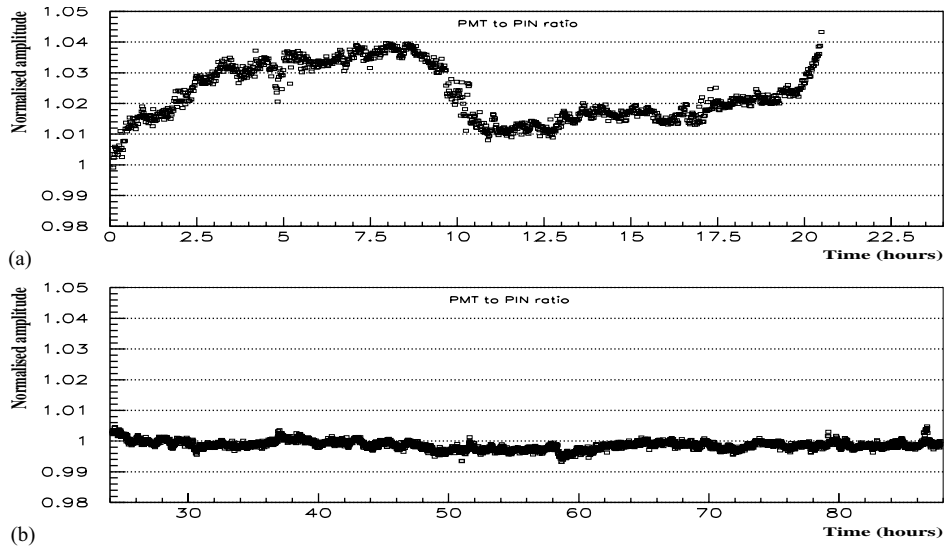


Fig. 4. PMT to PIN signals ratio: (a) stabilization OFF, (b) stabilization ON.

stabilization system ON and OFF is shown in Fig. 6. The mean value stability can be estimated from the distribution width (Fig. 5b and d) to be equal to about 0.3% for both PMT and PIN.

The overall measurement setup stability, including high-voltage power supply and ADC stability, is estimated to be 0.2%, based on stable LED measurements. Hence, the obtained value 0.3%

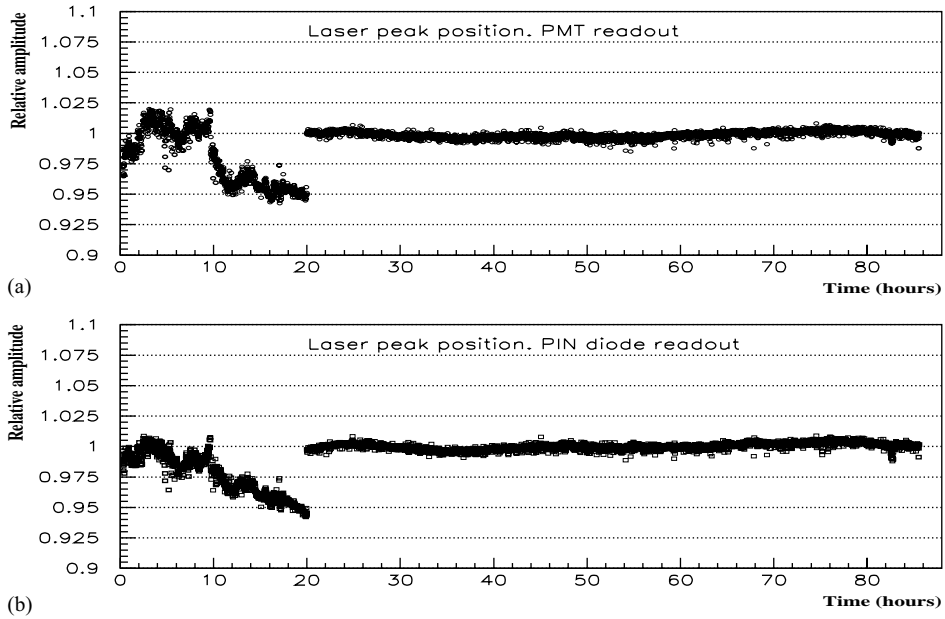


Fig. 5. Normalized mean signal versus time from (a) PMT and (b) PIN. The stabilization system was switched ON 20 h after the beginning the measurements.

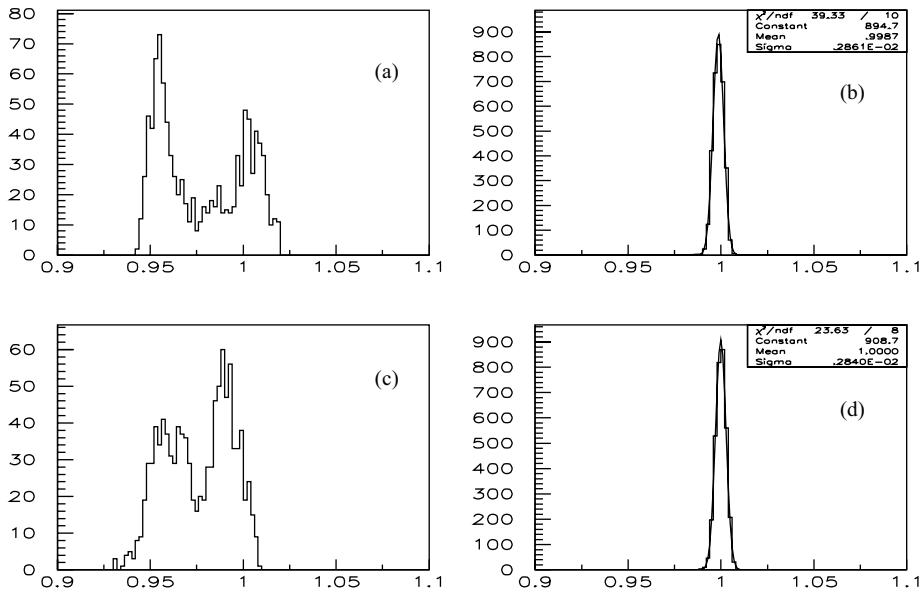


Fig. 6. Normalized mean signal for (a,b) PMT, and (c,d) PIN, with the stabilization OFF in (a,c) and ON in (b,d).

can be considered as an upper limit. Stability of the PIN to PMT signals ratio (Fig. 4b), free from the readout system instability, is better than 0.2%.

An application of the described system to the CMS ECAL crystals, and monitoring system prototype tests, will be discussed in a separate paper.

## 5. Summary and discussion

A slow laser output drift stabilization system is described. The system stabilizes the light output of a relatively inexpensive commercial dye laser to the level of 0.3%.

The use of a stabilized laser light source for monitoring of electromagnetic calorimeter crystals would simplify the monitoring system design, in particular for a complicated Hadron collider setup like CMS. It would reduce the number of expensive, precise, and stable elements inside the detector, in the highly occupied and strongly irradiated zone. It would also improve the overall monitoring system performance by removing the light output correction term.

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