Implementation of a Software Feedback Control for the CMS Monitoring Lasers

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***Abstract*— Light monitoring will play a crucial role in maintaining energy resolution for the CMS lead tungstate crystal calorimeter *in situ* at LHC. Since 2003, a laser based monitoring system in its final design has been installed and used in beam tests at CERN. While the stability of the laser pulse energy and FWHM width, measured in 24 hours, is at 3% level, a long term degradation and a drift of the laser pulse center timing at 2 ns/day were observed. The degradation and drift were caused by the aging of the DC Kr lamp used to pump the Nd:YLF laser, and would affect the monitoring precision. This paper presents the design and implementation of a software feedback control which stabilizes laser pulse energy, width and timing by trimming the Nd:YLF laser pumping current. For laser runs lasted for more than 650 hours a stability of pulse energy and FWHM width at 3% level and a pulse timing jitter at 2 ns have been achieved when the laser pulse center timing is used as the feedback parameter.**

***Index Terms*— Calorimeter, lead tungstate crystal, radiation damage, laser monitoring, feedback control.**

I. INTRODUCTION

THE 76,000 lead tungstate ($PbWO_4$) crystals in the CMS electromagnetic calorimeter (ECAL) would suffer from radiation damage *in situ* at LHC [1]. Our previous studies concluded that the scintillation mechanism of $PbWO_4$ crystals is not affected by radiation, and the loss of light output is due only to the absorption caused by radiation induced color centers [1], [2]. The variation of $PbWO_4$ crystal's light output (damage and recovery) will be estimated by using a light monitoring system, which measures variations of crystal's transmittance. The light monitoring system is thus crucial in maintaining the energy resolution of the CMS $PbWO_4$ ECAL *in situ* at LHC [3]. A light source and high level distribution subsystem (LSDS) was designed and constructed at Caltech for the CMS ECAL monitoring system. The first blue/green laser system was installed and commissioned at CERN in August, 2001 [4]. The IR/red laser system and the second blue/green laser system were installed and commissioned at CERN in August, 2003 [5]. The LSDS system has been operated for more than 10,000 hours since 2003, and has been a crucial tool in both the ECAL beam and cosmic tests [6].

For typical laser runs lasted for about 24 h, the stability of the laser pulse energy and FWHM width was found to be at 3% level for the blue and IR lasers, much better than the 10% specification [7]. For runs beyond 24 hours a degradation of the stability and a drift of the laser pulse timing at a level of 2 ns/day were observed when the Nd:YLF laser's pumping current is fixed. This was due to the aging of the DC Kr lamp used to pump the Nd:YLF laser [8]. While the degraded stability may affect monitoring precision, the laser timing drift may affect synchronization between the laser pulses and the readout clock *in situ* at LHC. To address this issue a software feedback control was designed and implemented in 2006, which measures laser performance parameter and trim the Nd:YLF laser pumping current. By dong so, the stabilities of the laser pulse energy, FWHM width and pulse center timing are significantly improved. In this paper we present the CMS monitoring laser system, the design of the software feedback control and the laser performance with the software feedback control implemented.

This work was supported in part by the U.S. Department of Energy under grant DE-FG03-92-ER-40701.

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II. MONITORING LASER SYSTEM

Fig. 1 shows the monitoring light source and high level distribution subsystem (LSDS) for the CMS ECAL. It consists of three pairs of lasers with corresponding digital scope based slow monitor, a 5×1 optical switch, an 1×100 optical switch, a fast monitor, a logarithmic attenuator, a linear attenuator and a PC based DAQ controller. Each pair of lasers consists of a Nd:YLF pump laser and a Ti:Sapphire laser, providing laser pulses of dual wavelength. All three pump lasers are model 527DQ-S Q-switched Nd:YLF lasers, which are commercial product of Quantronix [9]. It provides frequency doubled laser pulses at 527 nm with a pulse intensity up to 20 mJ at a repetition rate up to 15 kHz. All three Ti:Sapphire lasers are custom made Proteus UV(SHG) lasers from Quantronix, which provide laser pulse intensity up to 1 mJ, corresponding to about 1.3 TeV energy deposition in $PbWO_4$ crystals, at a repetition rate up to 100 Hz.

Two wavelengths are available from each pair of lasers by selecting appropriate built-in interference filter in the Ti:Sapphire laser. Based on our previous studies [4], 440 nm was chosen as the monitoring wavelength. In order to guarantee 100% availability of the 440 nm light even when one laser system is in maintenance, two pairs of lasers provide the 440 nm (blue) and 495 nm (green) [7]. The third pair lasers provides 709 nm (red) and 796 nm (IR) for monitoring the gain variations of the readout electronics chain from the APD to the ADC. Only one laser pair is used at a time to provide monitoring laser pulses,

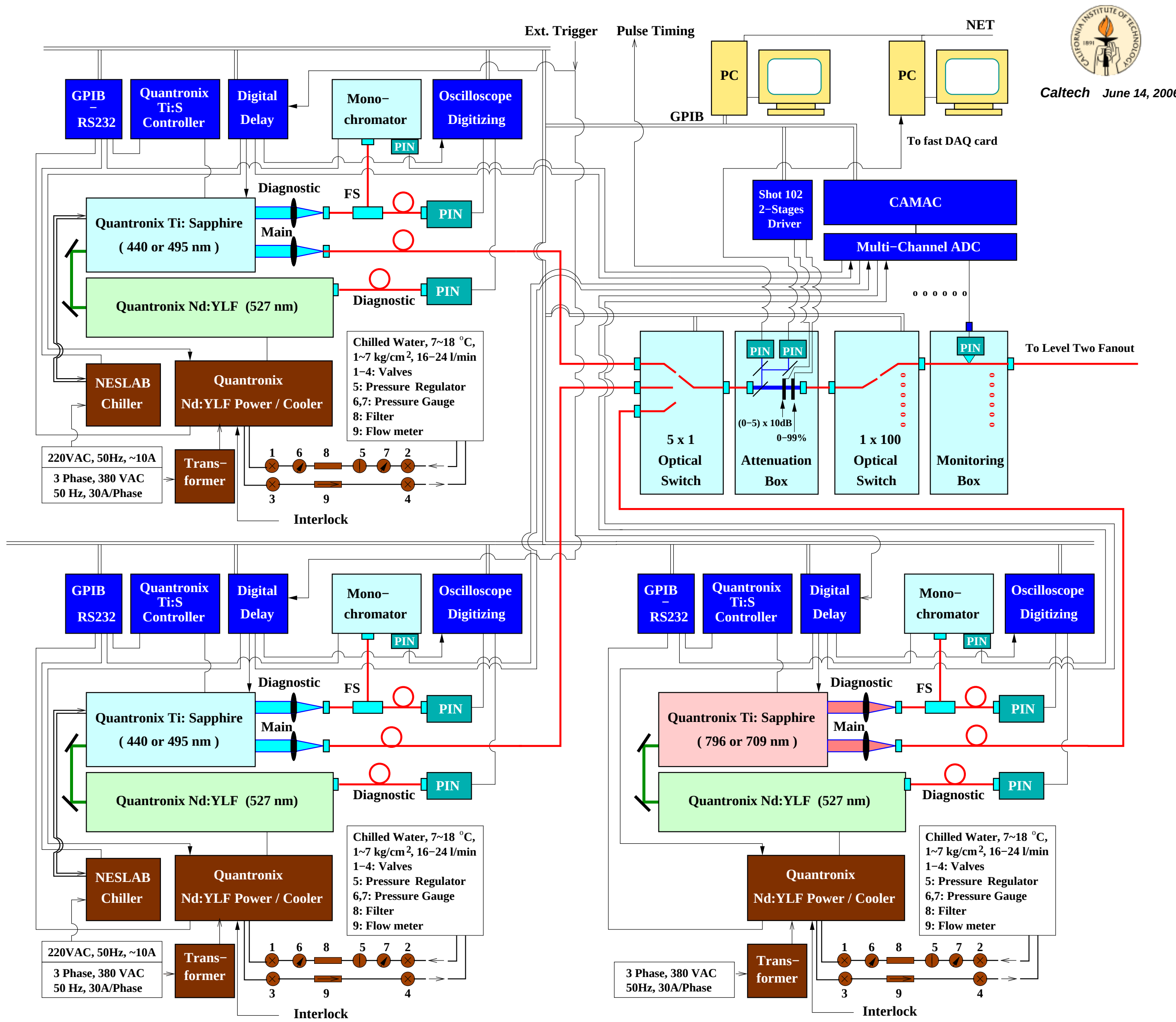

Fig. 1. A schematic showing the design of the CMS ECAL monitoring laser light source and high level distribution system (LSDS).

which is selected by using the DiCon 5×1 optical switch. By using the DiCon 1×100 optical switch the monitoring laser pulses are sent to one detector element among 88 half supermodules and Dees. The operation time needed to scan all 88 detector elements is about 30 minutes. Two attenuators are installed in the attenuation box between two switches: a logarithmic filter wheel (0 to 50 db in 10 db step) and a linear neutral density filter (1 to 99% in 1% step).

Laser operations are under control by a laser DAQ PC. It selects the laser pair, the detector element, the laser pulse wavelength and intensity attenuation. All the above parameters may also be defined by a up-level laser supervisor when the LSDS is running in the slave mode. In addition, the laser DAQ PC also controls internal laser parameter, which are not controlled by the laser supervisor, such as the YLF pumping current, the digital delays between various laser triggers and the slow monitor data taking. The Agilent digital scope based slow monitor analyzes laser pulses from the Nd:YLF laser and the Ti:Sapphire laser with sampling rate about 1 Hz at 2 GS/s. An Acqiris DP210 digitizer card, inserted between two optical switches, functions as a fast monitor, which analyzes every laser pulse delivered to the detector at 2 GS/sec. Laser pulse energy, FWHM width and pulse center timing are analyzed on-line during laser operation by both slow and fast monitors, and the resultant histories of these parameters as well as the histograms are stored on disk. While the slow monitor data taking are controlled by the laser DAQ PC, the fast monitor data taking are controlled by a dedicated PC as shown in Fig. 1.

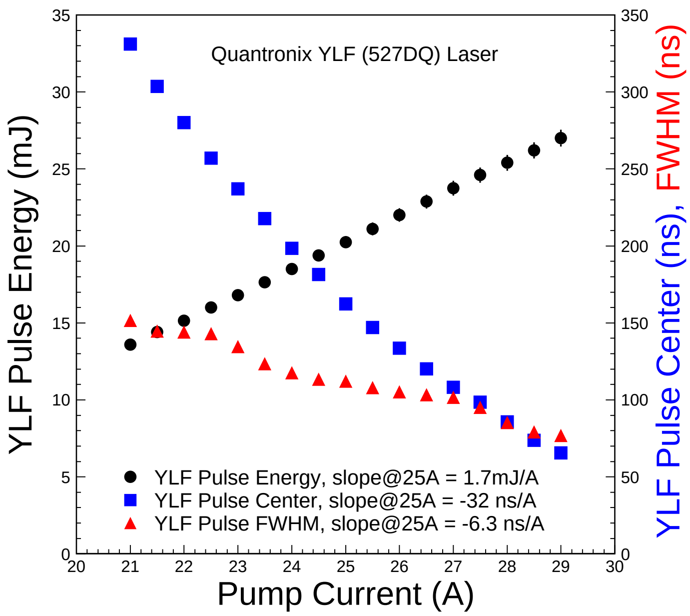

Fig. 2. Correlations between the Nd:YLF laser pumping current and the Nd:YLF laser pulse energy (black), FWHM width (red) and pulse center timing (blue).

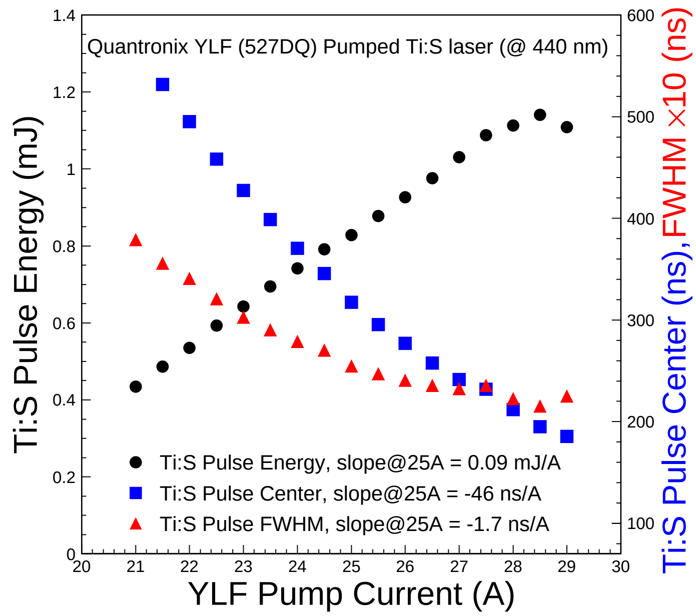

Fig. 3. Correlations between the Nd:YLF laser pumping current and the Ti:Sapphire laser pulse energy (black), FWHM width (red) and pulse center timing (blue).

III. Design and Implementation of the Software Feedback

Fig. 2 and 3 show correlations between the Nd:YLF laser pumping current and the laser pulse energy (black), FWHM width (red) and center timing (blue) for Nd:YLF laser and Ti:Sapphire laser respectively. Also shown in these figures are the numerical values of the slope defined at the Nd:YLF laser pumping current of 25 A. It is clear that the laser pulse energy increases and both the pulse FWHM width and the pulse center timing decrease when the Nd:YLF laser pumping current increases. This is understood since the optical gain of the Nd:YLF crystal increases when the pumping current increases, and thus the built-up time of the laser pulse in cavity decreases and a shorter pulse width is generated.

In principle, any parameter or a combination of these parameters can be used as the input to calculate feedback needed for trimming the Nd:YLF laser pumping current and thus compensating the DC Kr lamp aging effect. Looking into the slope values of these parameters in Fig. 2 and 3 and their sensitivities as compared to the corresponding r.m.s. values of the parameter, however, the Ti:Sapphire laser pulse center timing is preferred as the feedback input.

A software feedback control was designed in the laser control and DAQ program. Fig. 4 is a schematic describing the basis operation of the software feedback. Fig. 5 shows the control panel and setting window running under the laser DAQ program for the software feedback.

When the software feedback is enabled, the program first calculate an average of a selected parameter for a defined event number. This average is then compared to a predefined number and their difference is used to calculate an incremental variation of the Nd:YLF laser pumping current by using the corresponding slope. If the absolute value of the incremental variation is larger than 0.1 A, then the Nd:YLF laser's pumping current is trimmed correspondingly, otherwise not. This amplitude of 0.1 A is limited by the Quantronix Nd:YLF laser control hardware. Upper and low limits of the Nd:YLF laser pumping current are also set for laser safety. The Nd:YLF laser pumping current will stay unchanged when it reaches the upper limit, indicating that the DC Kr lamp needs to be replaced.

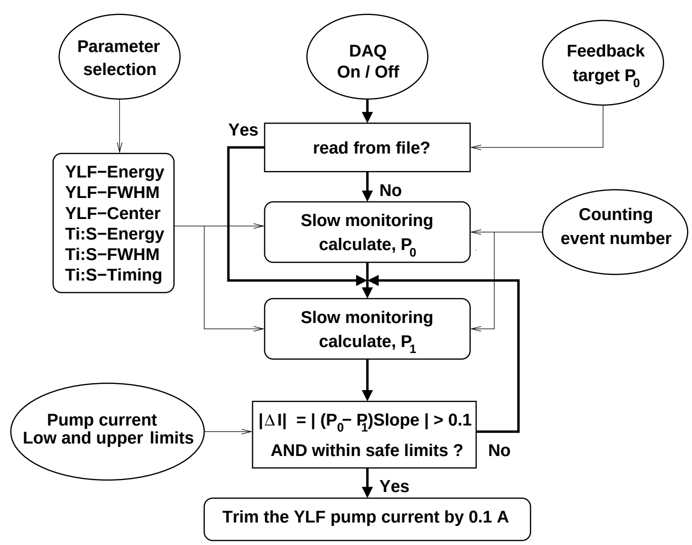

Fig. 4. A schematic describing the software feedback control.

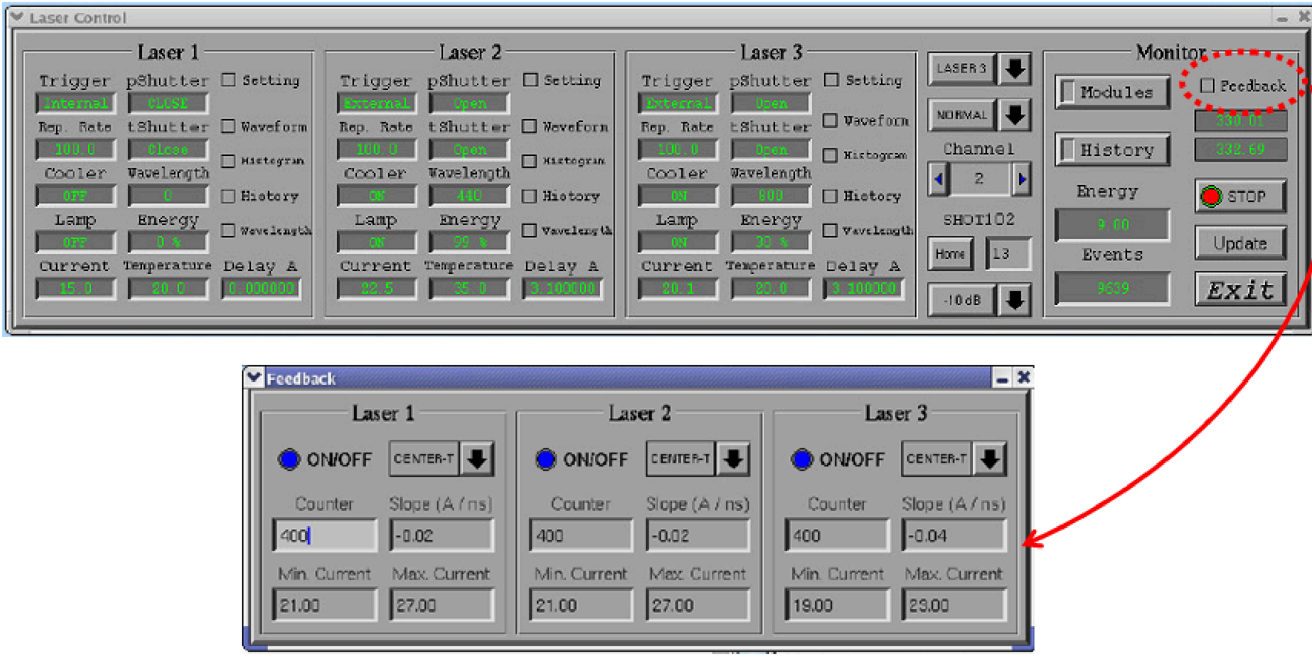

Fig. 5. The laser DAQ control panel (top) and the feedback setting window (bottom).

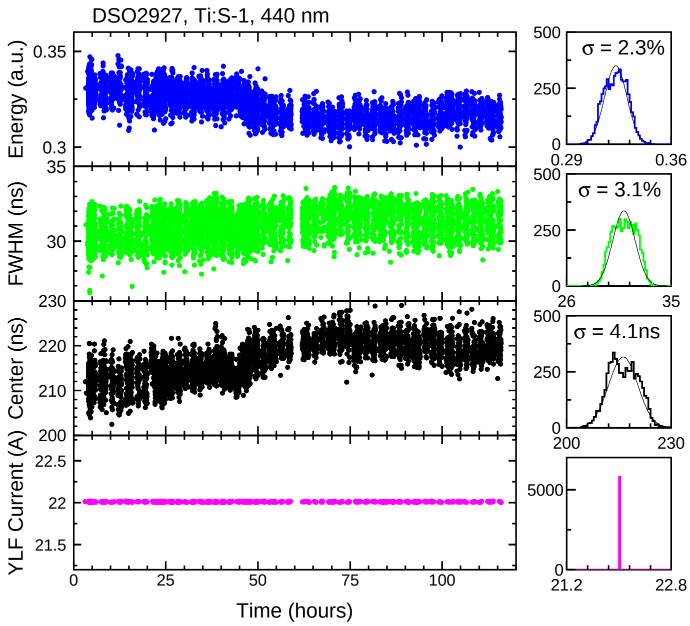

Fig. 6. Histories of the laser pulse energy, FWHM width, pulse center timing and corresponding YLF laser pumping current are shown as function of time for a Ti:Sapphire laser run at 440 nm without feedback for more than 130 hours. The corresponding histogram distributions are shown at right.

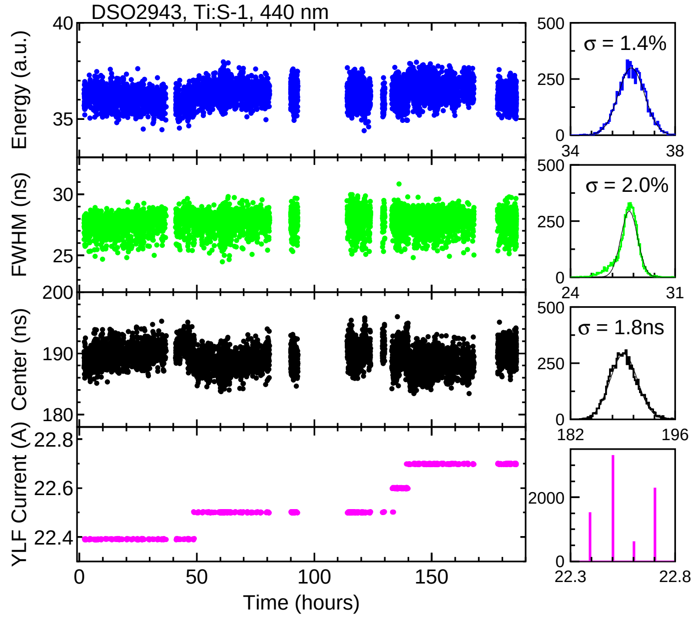

Fig. 7. The same as Fig. 6 for a Ti:Sapphire laser run at 440 nm for more than 180 hours by using the Ti:Sapphire laser pulse timing as the software feedback parameter.

IV. Laser Stability with Software Feedback

The software feedback control was first implemented for individual laser runs during ECAL tests in 2006 at CERN. Fig. 6 and Fig. 7 summarize typical laser performance at 440 nm for two laser runs without and with the software feedback control lasting for 130 and 180 hours respectively. The effectiveness of the software feedback is clearly observed. As shown in the histograms at right, significant improvement was observed in stabilities of the laser pulse energy (2.3% to 1.4%), pulse FWHM width (3.1% to 2.0%) and pulse center timing jitter (4.1 ns to 1.8 ns) by using the Ti:Sapphire pulse center timing as the feedback parameter.

By using a predefined parameter value, the software feedback control was made working across several runs. Fig. 8 shows history and histogram for combined Ti:Sapphire laser runs at 440 nm in September and October with a total run time more than 650 hours. At left is the history plots of the laser pulse energy, FWHM width, pulse center timing and the YLF pumping current. Each data point represents an one hour average of the slow monitor data. The effectiveness of the software feedback control is clearly shown in the laser pulse timing history, where degradations are compensated by the YLF pumping current adjustment at 0.1 A a step from 22 A to 23.4 A. The overall stability of the Ti:Sapphire laser pulse energy and FWHM width is 2.5% and 3.5% respectively, much better than the 10% specification. The corresponding pulse jitter during this period is 2 ns, much better than the 3 ns specification.

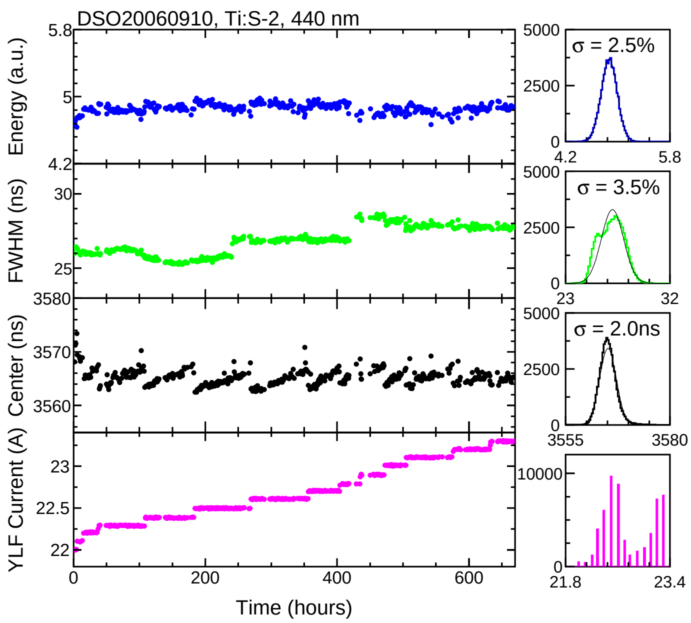

Fig. 8. The same as Fig. 7 for combined several Ti:Sapphire laser runs at 440 nm for more than 650 hours.

We also notice two jumps in the FWHM history occurred at 220 and 420 hour. These two jumps are suspected to be caused by temperature variations in the laser barracks at CERN test beam site. Although the Ti:Sapphire laser's SHG crystal is thermally stabilized by a Neslab chiller, variations of the room temperature would slightly change the Ti:S SHG crystal's matching angle, thus compromise the SHG crystal's conversion efficiency. These jumps may also related to the water filling operation for the Neslab cooler, which changes the stabilized temperature by 0.5°C.

Environmental temperature dependences of the Ti:Sapphire laser pulse performance were measured. The slope of the pulse energy, FWHM and center timing was found to be -4.3%/°C, 1.3 ns/°C and 7.9 ns/°C respectively. The poor temperature stability observed in the laser barracks at CERN test beam site would be improved *in situ* at LHC, where the laser barracks are central air-conditioned with a temperature stability of better than 0.5°C.

V. SUMMARY

Because of the natural aging of the DC Kr lamp used to pump the Nd:YLF laser the performance of Ti:Sapphire lasers are degraded in long runs. A software feedback control was designed and implemented to compensate this aging effect by trimming the Nd:YLF laser pumping current at 0.1 A steps. The result with the software feedback implemented shows a significant improvement. As demonstrated in several laser runs lasting for more than 650 hours, the stability of the Ti:Sapphire laser pulse energy and FWHM width can be maintained at 3% level, and the pulse center timing jitter can be reduced to 2 ns. This improvement will help maintaining the laser monitoring precision for the CMS ECAL *in situ* at LHC.

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