A Diode-Pumped Solid State Blue Laser for Monitoring CMS Lead Tungstate Crystal Calorimeter at the LHC

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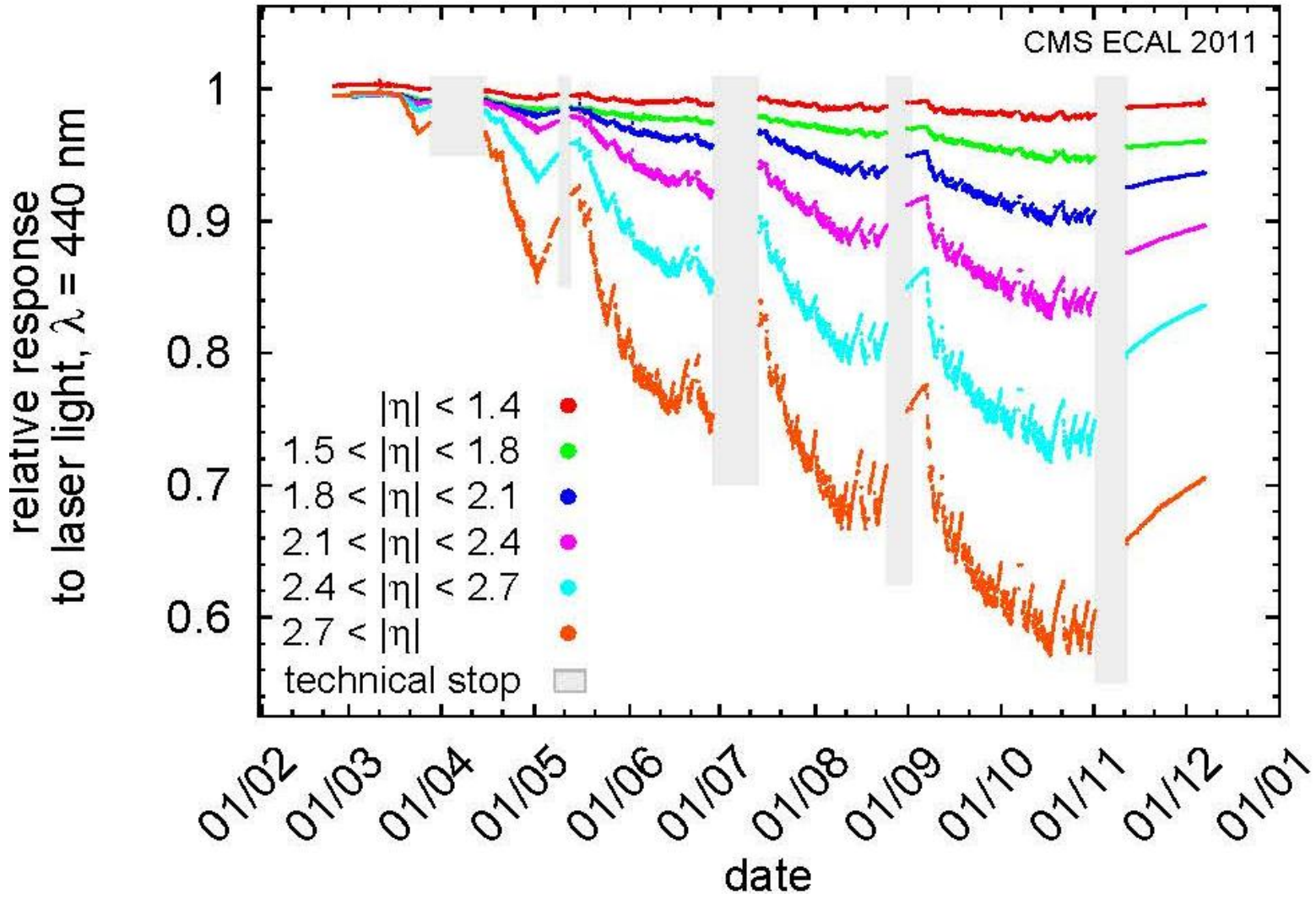
$PbWO_4$ Monitoring is Crucial

Light output loss in PWO observed at LHC in 2011

See the talks by T. Tabarelli and F. Ferri in this conference

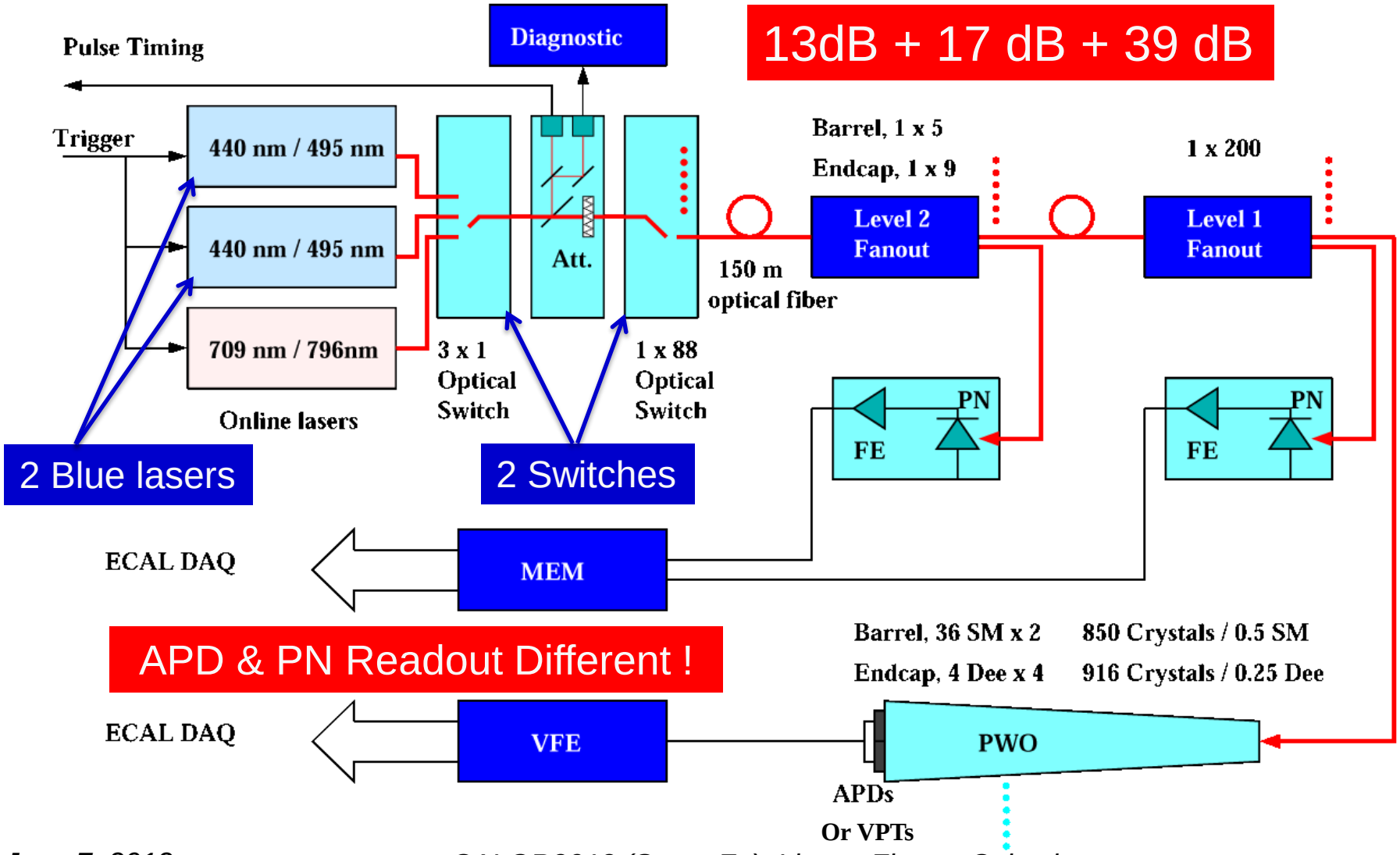


Specifications for Lasers

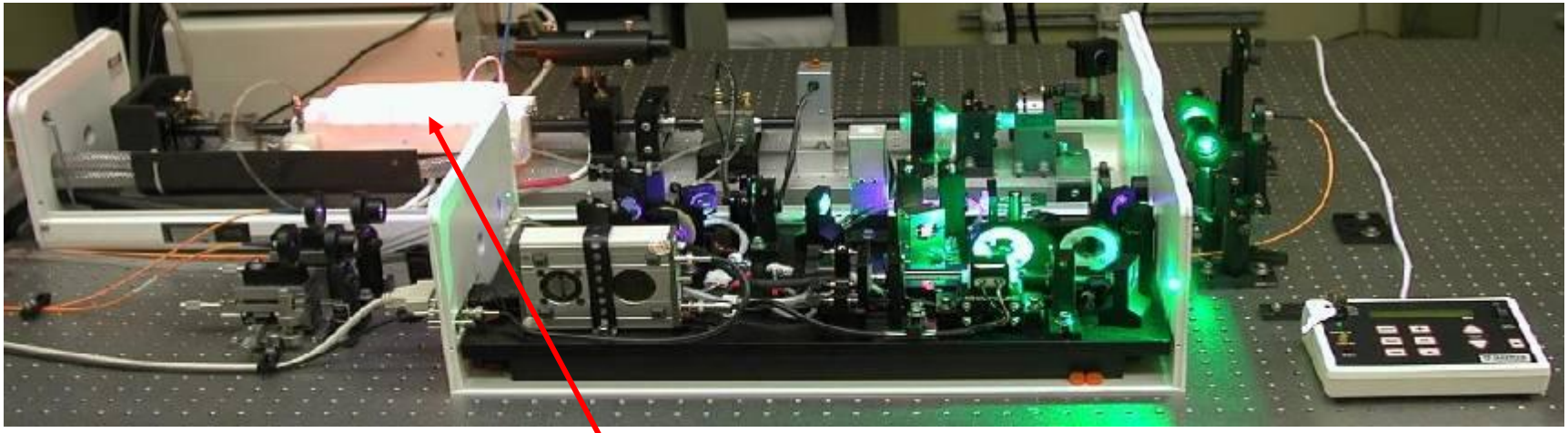
- **Pulse intensity:** 1 mJ/pulse at 440 nm, equivalent to 1.3 TeV in dynamic range.
- **Pulse intensity instability:** < 3%.
- **Pulse FWHM:** < 30 ns to match ECAL readout.
- **Pulse width instability:** < 5%.
- **Pulse jitter:** < 3 ns for synchronization with LHC.
- **Pulse repetition rate:** 0-100 Hz, scan of full ECAL in 20 minutes.
- **Immune to stray B field of 30 Gauss.**

CMS ECAL Laser System in 2011

Two blue lasers to guarantee 100% availability of 440 nm



Lamp pumped Lasers in 2011



Ageing DC Kr lamp reduces laser pulse intensity, increases laser pulse width and timing.

Issues in 2011 Laser System

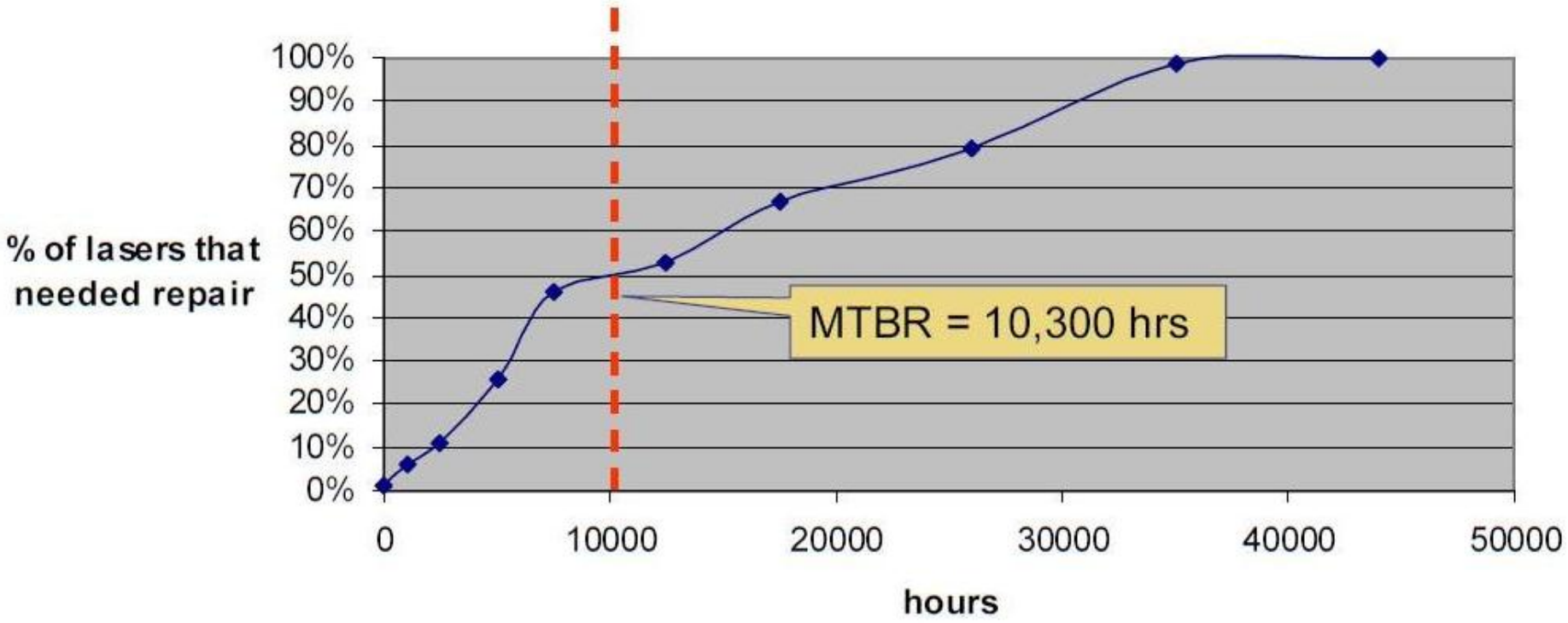
- Quantronix discontinued lamp pumped Nd:YLF laser in 2005. Laser parts are no longer available since 2009. Quantronix is actually merged into Continuum in 2012 and left ns laser market.

- Quantronix lasers are pumped by DC-Kr lamp, which needs to be replaced every month. Steps were observed in monitoring responses, some of which are laser intervention (lamp changing and retuning) related. A stable blue laser with no need of frequent interventions would improve.

- A decision was made by the CMS ECAL management in June, 2011, to procure a diode-pumped blue laser system to be ready for the 2012 runs.

Expected DPSS Laser Reliability

Unlike lamp pumped lasers, this kind of lasers does not need lamp changing and re-tuning.



MTBF is at 10,000 h for Diode pumped solid state laser

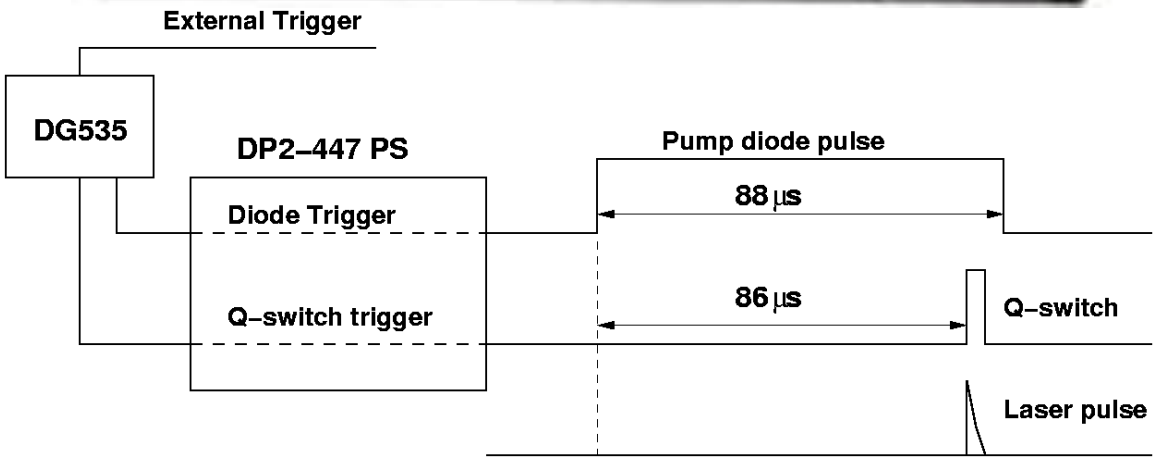
12 Manufactures Contacted

1. Photonics Industries International, Inc, 390 Central Ave., Bohemia, NY 11716
2. Continuum Sub. of GSI Group, 3150 Central Expy., Santa Clara, CA 95051
3. Quantronix, 41 Research Way, East Setauket, New York 11733
4. CrystaLaser LC, 4750 Longley Lane, Reno, NV 89502
5. Spectra-Physics Lasers, A Newport Corp. Brand, 3635 Peterson Way, Santa Clara, CA 95054
6. New Focus, A Newport Corp. Brand, 3635 Peterson Way, Santa Clara, CA 95054
7. JDSU, 430 N McCarthy Blvd., Milpitas, CA 95035
8. Coherent Inc., 5100 Patrick Henry Dr., Santa Clara, CA 95054
9. Teem Photonics USA, Sub. of Teem Photonics SA, 3594 Nyland Way, Ste. TP1, Lafayette, CO 80026
10. IPG Photonics Corporation, 50 Old Webster Rd., Oxford, MA 01540
11. Laserglow Technologies, 216-5 Adrian Ave., Toronto, ON M6N 5G4, Canada
12. Quantel USA, 601 Haggerty Lane, PO Box 8100, Bozeman, MT 59715-2001

Photonics and Quantronix were visited on 10/19/2011 and 10/20/2011
Photonics DP2-447 was selected in November, 2011

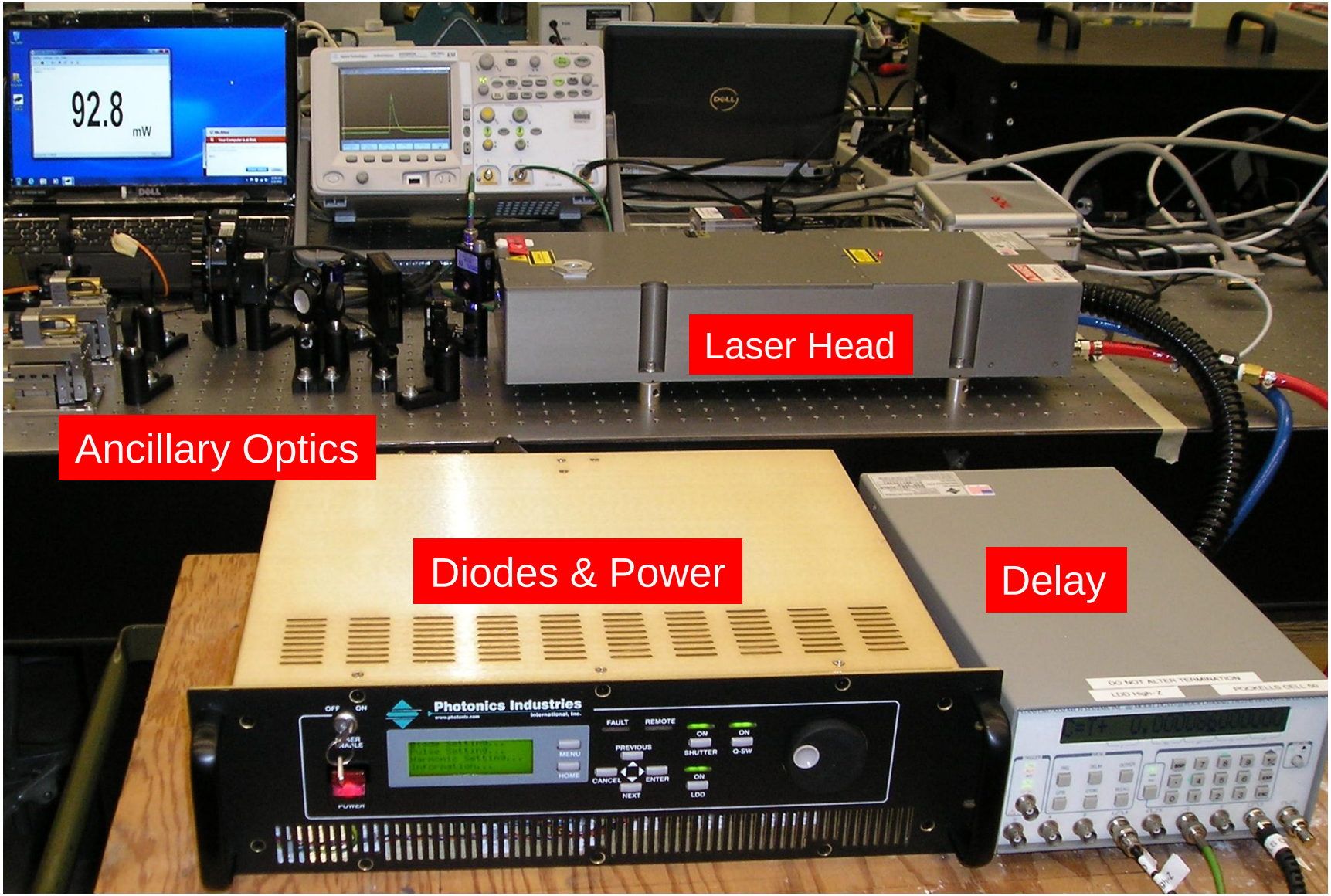
Photonics DP2-447 Laser

- Advanced Technology:
  - Nd:YVO_4 crystal
  - Proprietary intra-cavity frequency triple
- A Simple Laser:
  - 1 laser system (c.f. 2)
  - Compact laser head: 7.5” x 22” x 3.75”
  - Low power: no external chilled water needed.
- Designed to be robust and reliable: no user alignment needed.



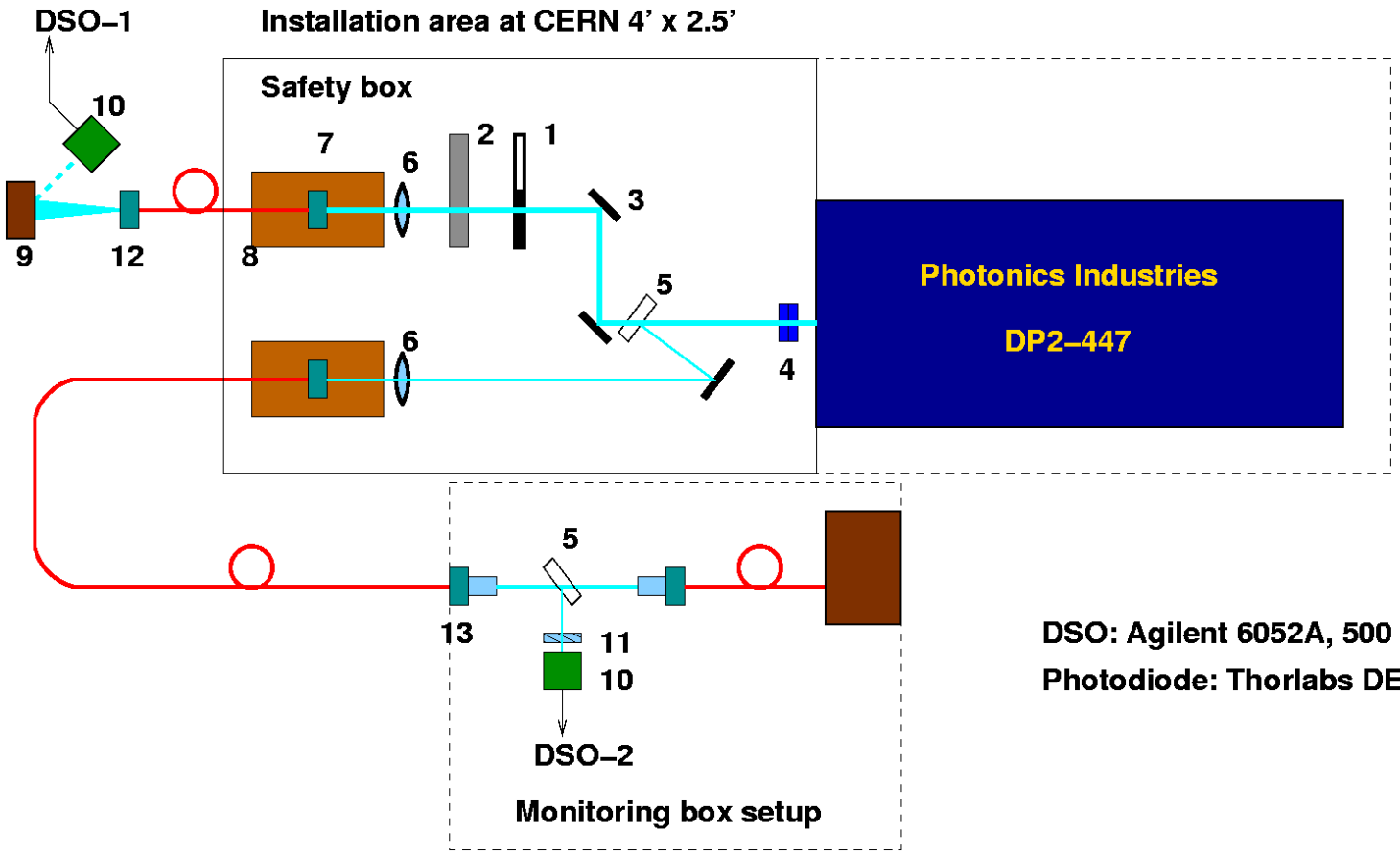
Order placed on 11/11/2011. Laser delivered on 2/3/2012

DP2-447 at Caltech (2/17/2012)



Laser Evaluation Setup at Caltech

DSO-2 was used to monitor DP2-447 Performance



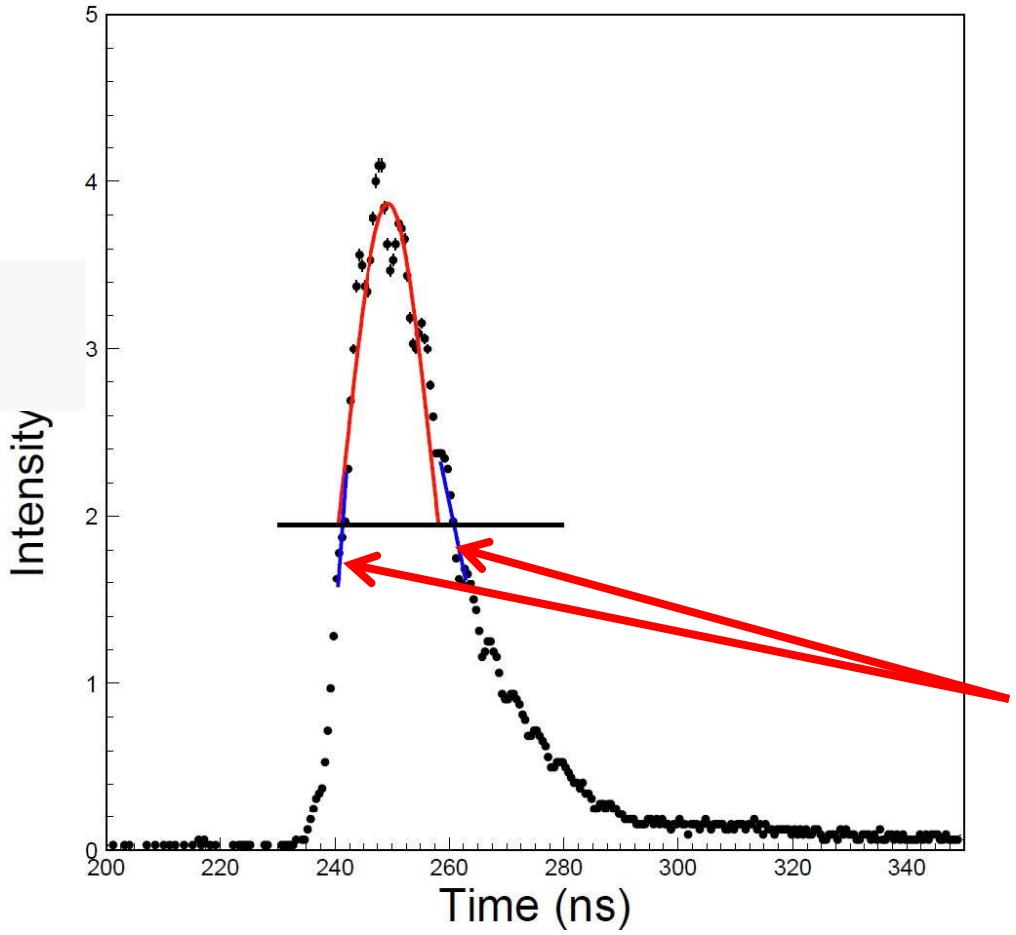
1: Beam shutter
2: Attenuator
3: Fold mirrors
4: Filter(s)
5: Beam sampler
6: Lenses
7: Fiber coupling stages
8: Optical fiber
9: Power meter
10: Photodiode
11: ND filter
12: FC connector
13: FC collimator

DSO: Agilent 6052A, 500 MHz, 2 Gsa/s

Photodiode: Thorlabs DET10A, risetime < 1 ns

Pulse Shape Reconstruction

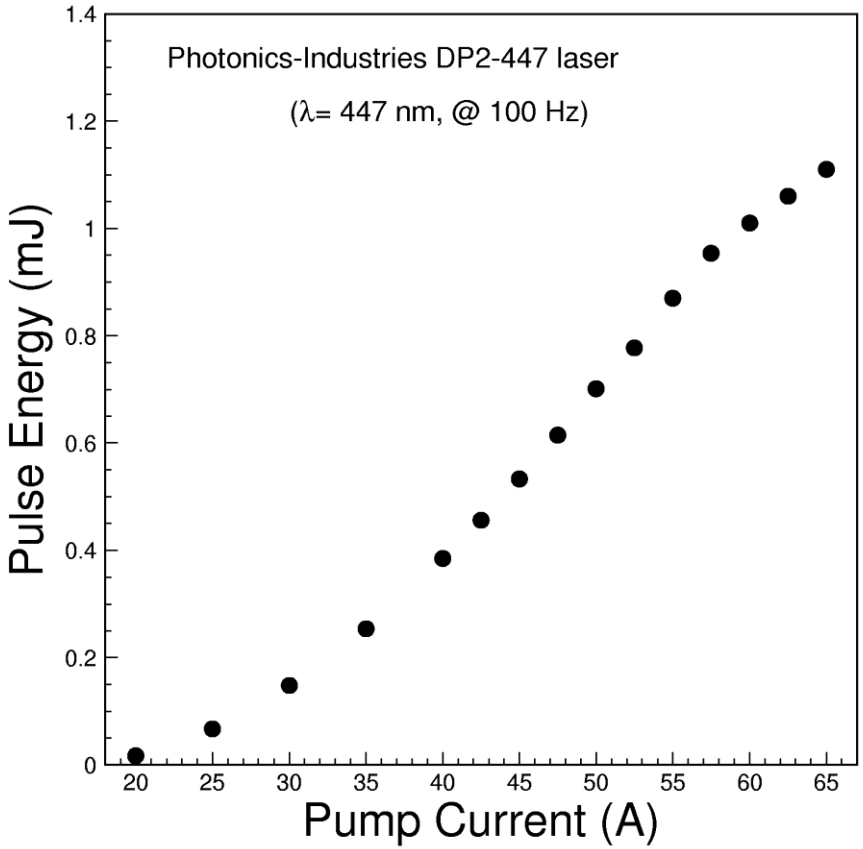
500 MHz, 2 GS/s DSO

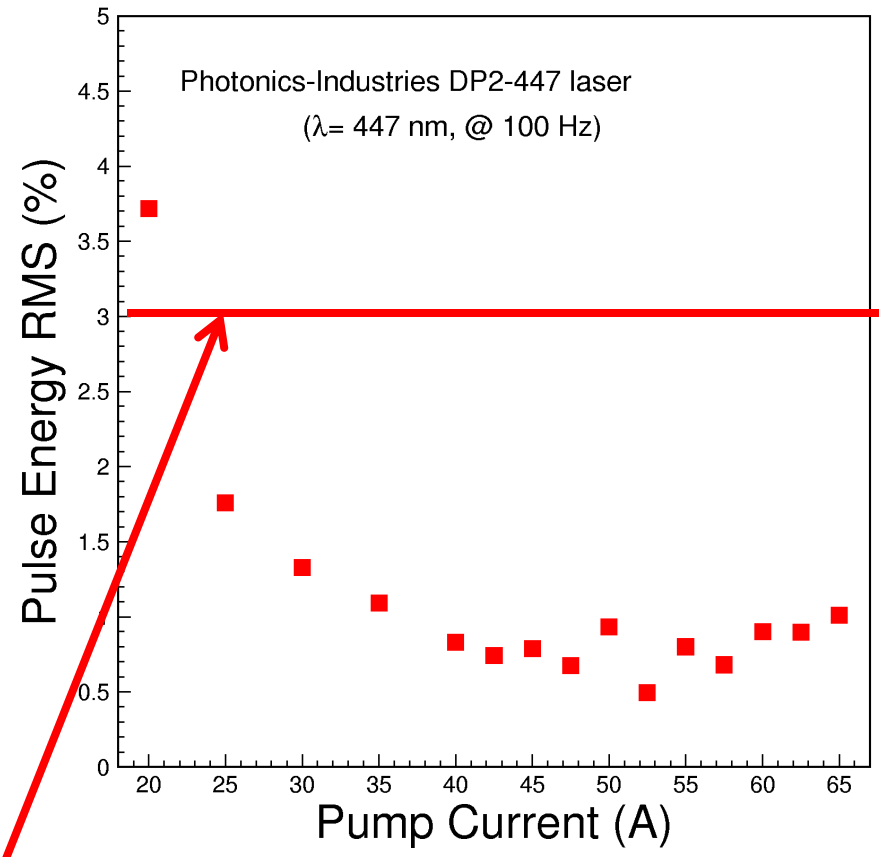


- Find peak V_m
- Find time at $V_m/2$: t_1 and t_2
- Gaussian fit in (t_1, t_2)
- Pulse energy: Σy_i in (-4σ, 8σ)
- Pulse center: $\Sigma t_i y_i / \Sigma y_i$ in (-4σ, 8σ)
- Pulse width: 5 points (2 before and 2 after) linear fits to find t_{1f} and t_{2f} at $V_m/2$. FWHM = $t_{2f} - t_{1f}$

Intensity and Instability vs. Current

All measurements were done with the default trigger setting.
Diode Trigger width: 88 µs. Q-switch trigger: 86 µs.





Pulse intensity instability exceeds specifications

Pulse Width and Center vs. Current

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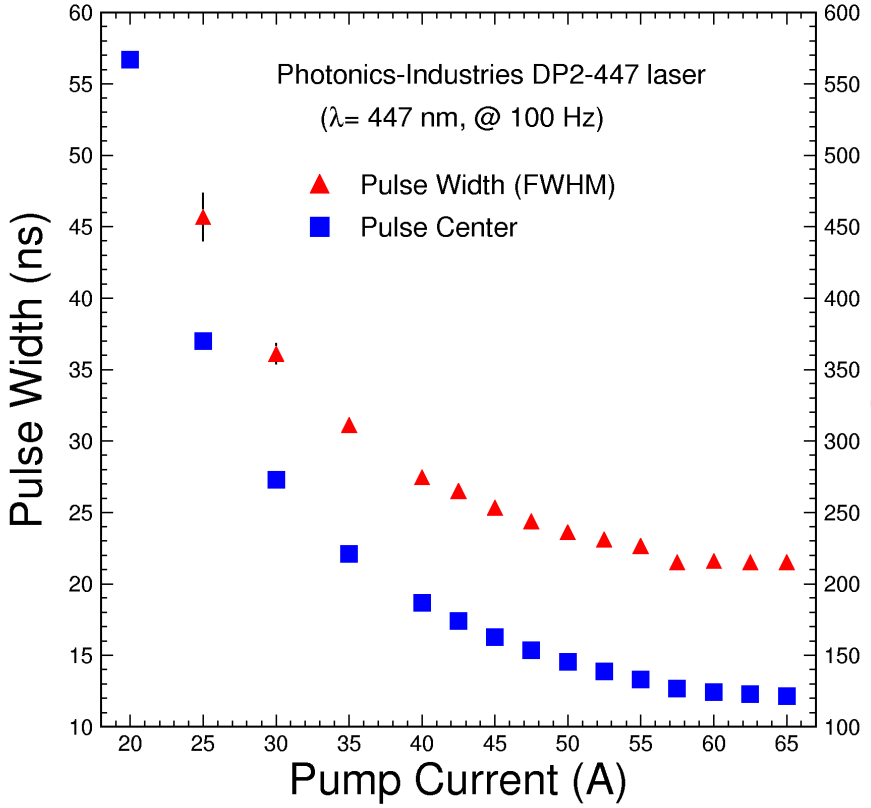
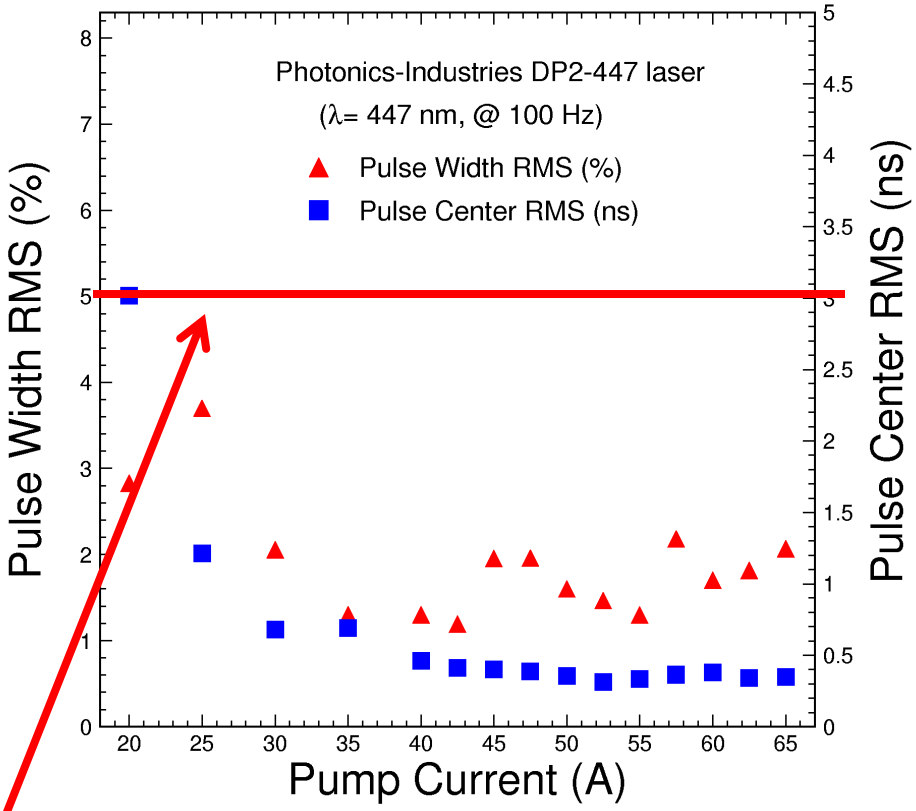
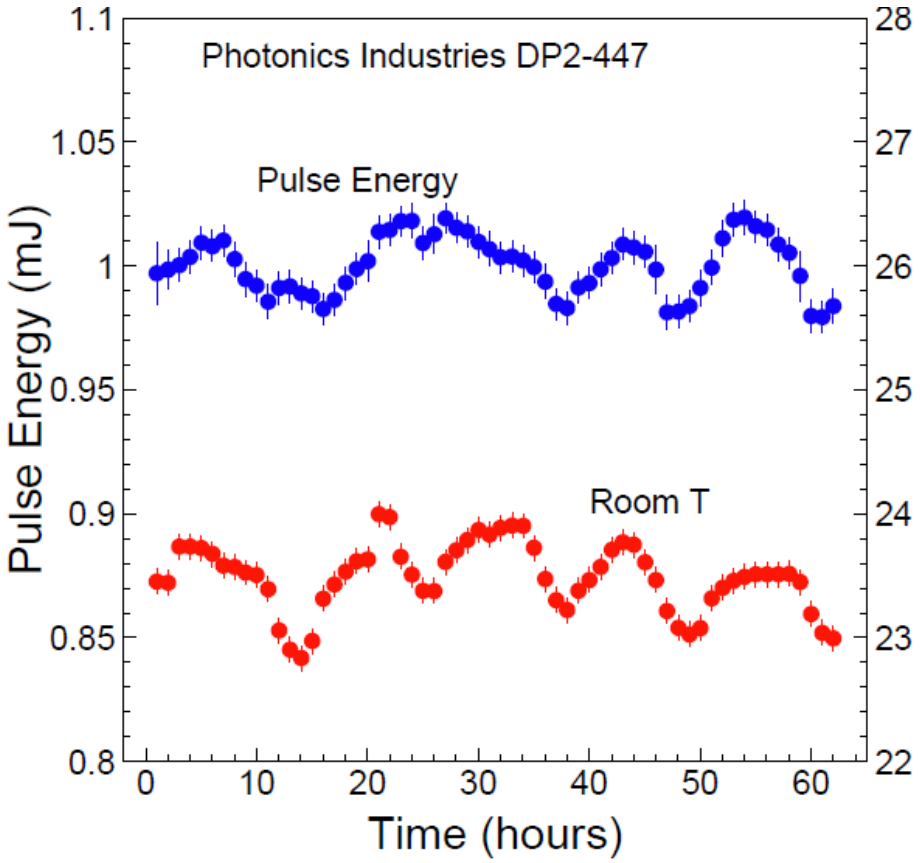


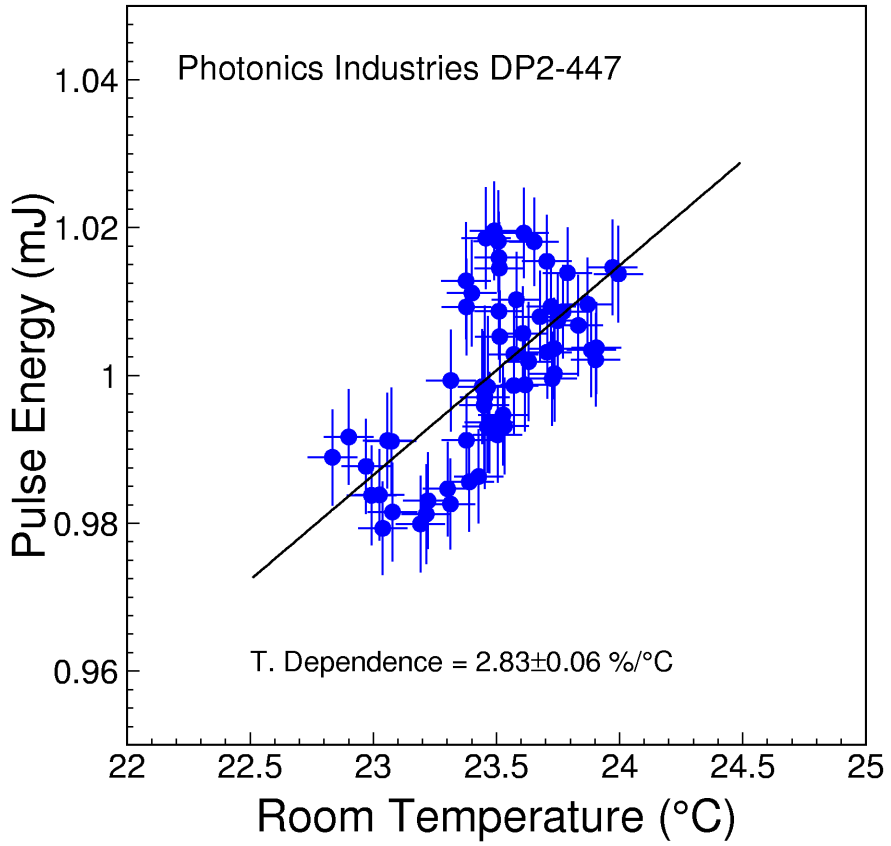


Pulse width/timing instability exceeds specifications

Pulse Intensity versus Temperature

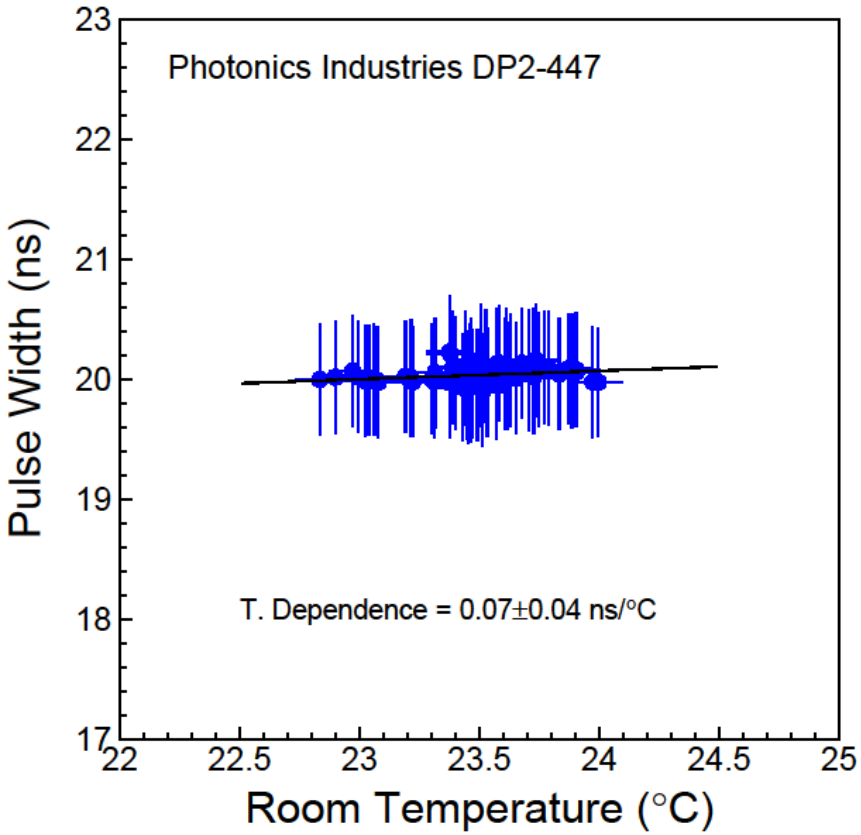
Room temperature needs to be stabilized to 1°C to maintain pulse energy stability at a level of 3%

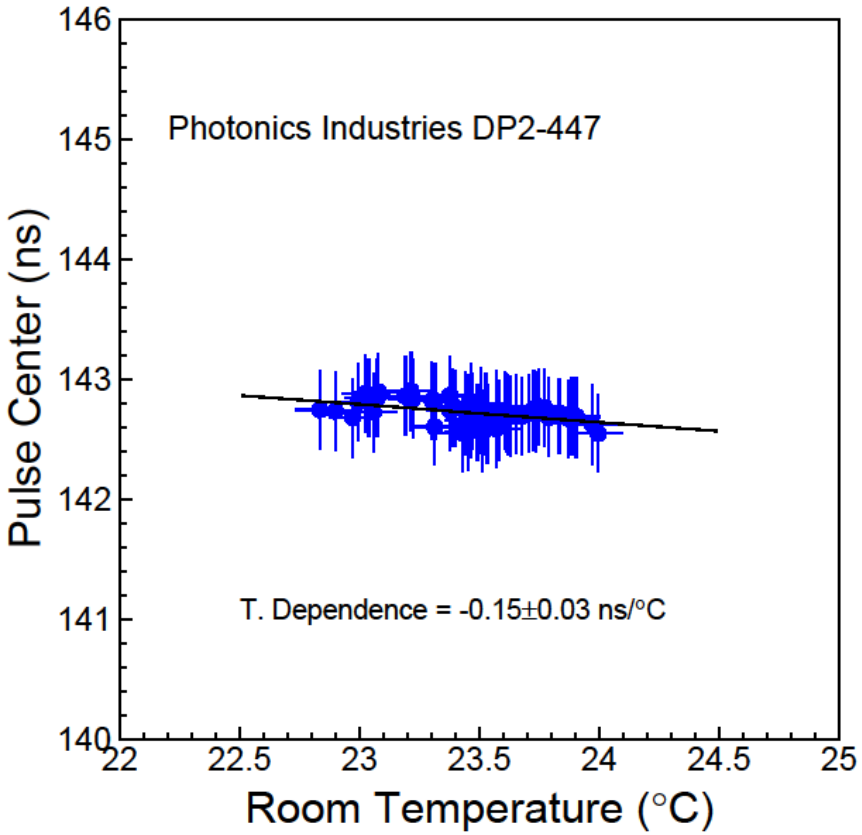




Pulse Width and Center vs. Temp.

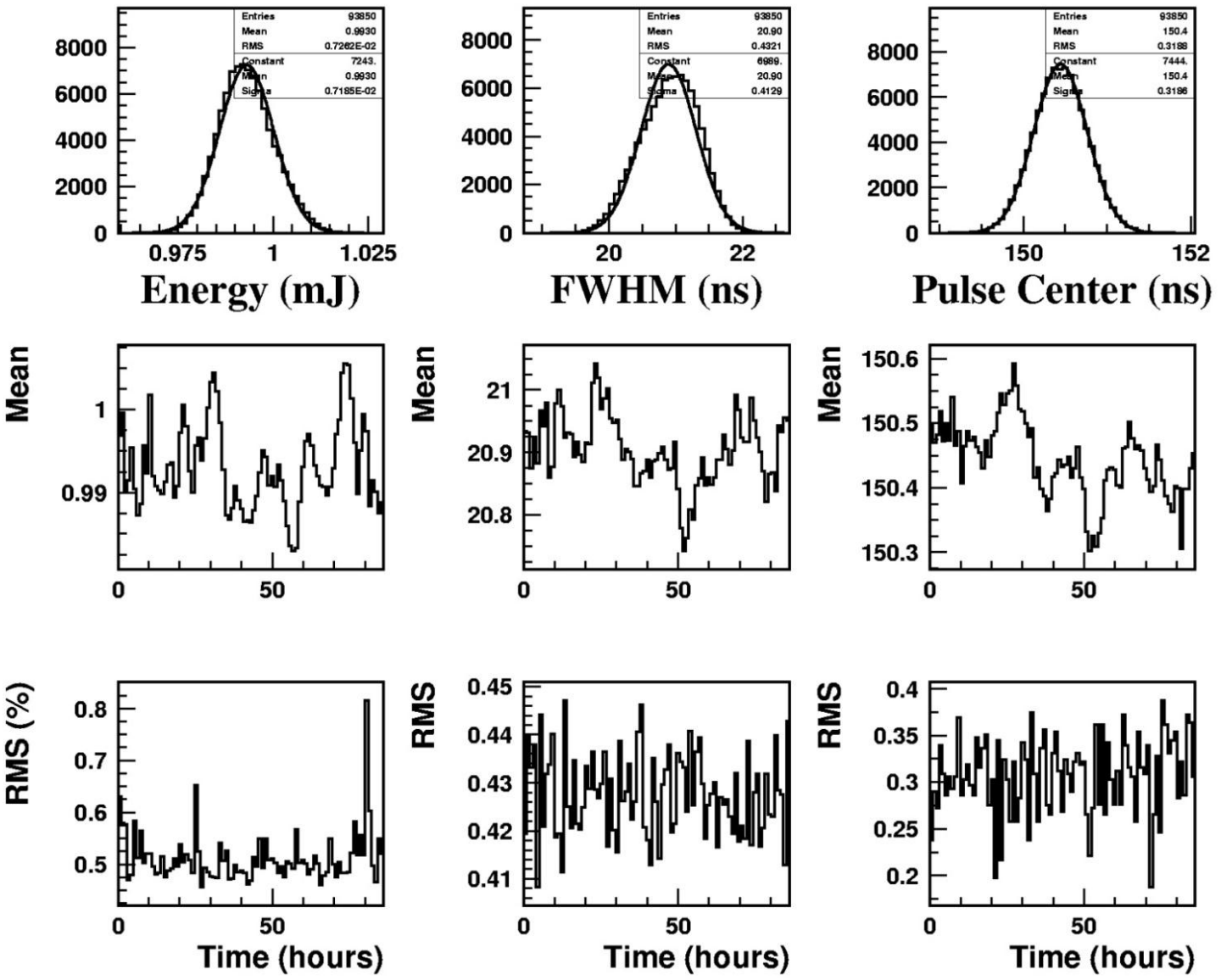
Pulse width and center are almost independent of the room temperature at 55 A pumping current



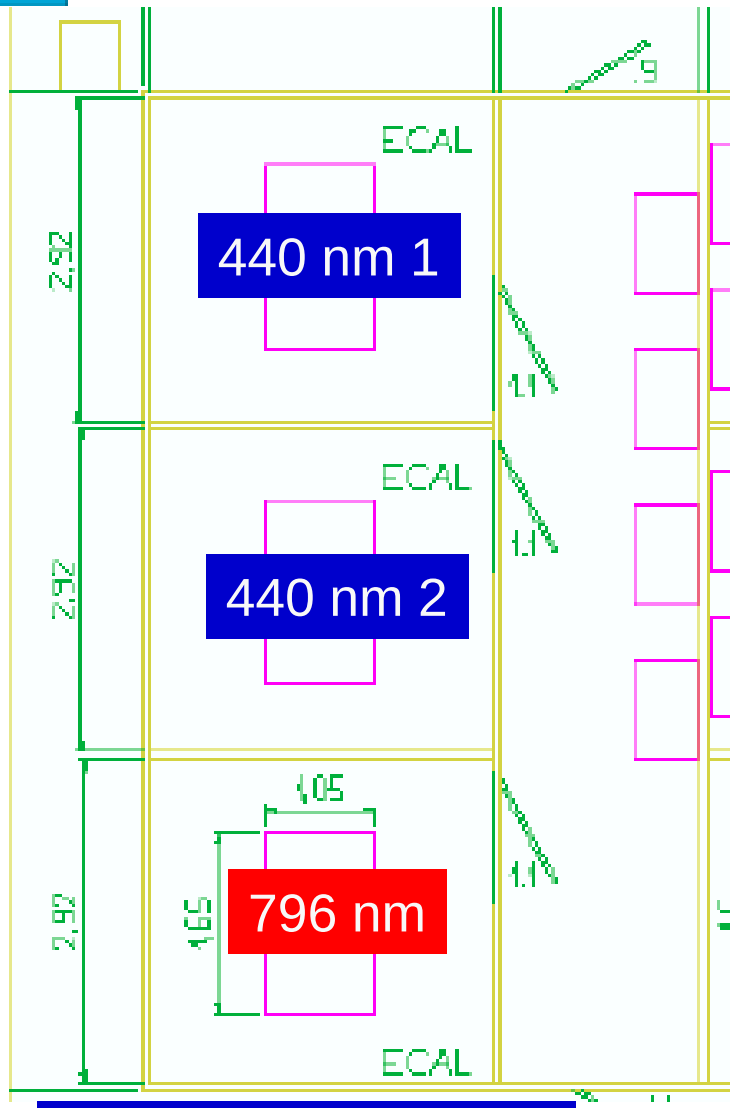


Stability of Intensity/Width/Jitter:

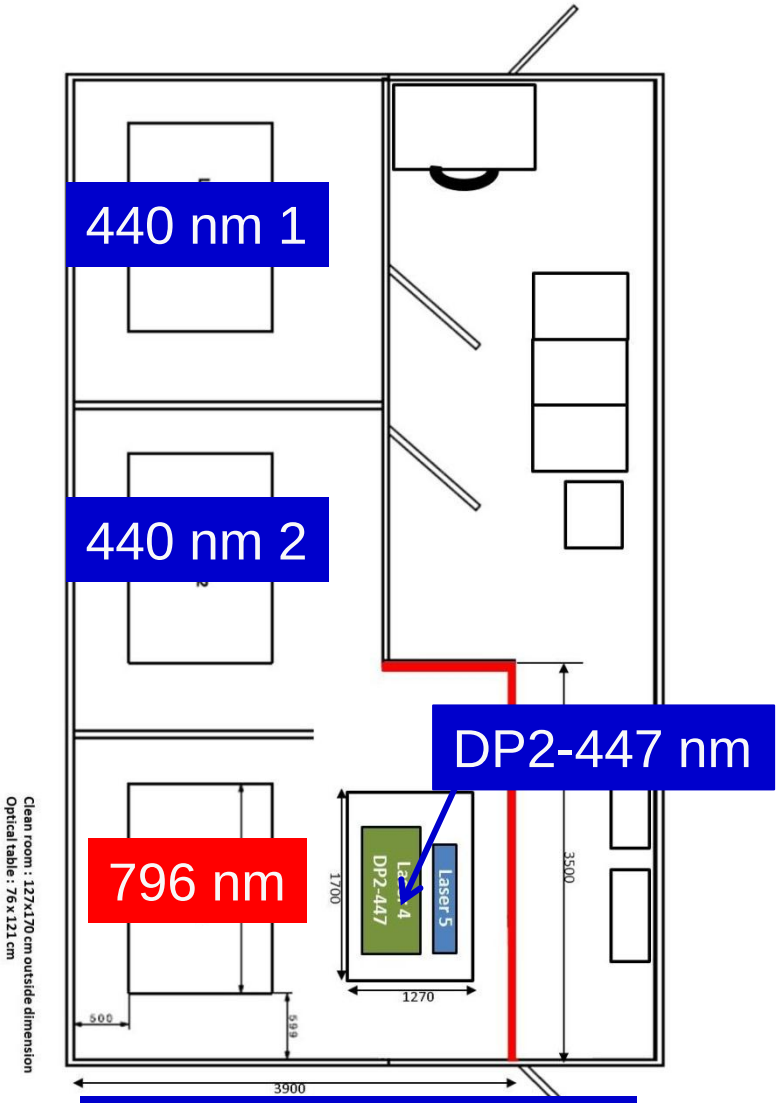
0.7%/2%/0.3 ns, exceeding 3%/5%/3 ns specifications



Laser Barracks at CMS Carven



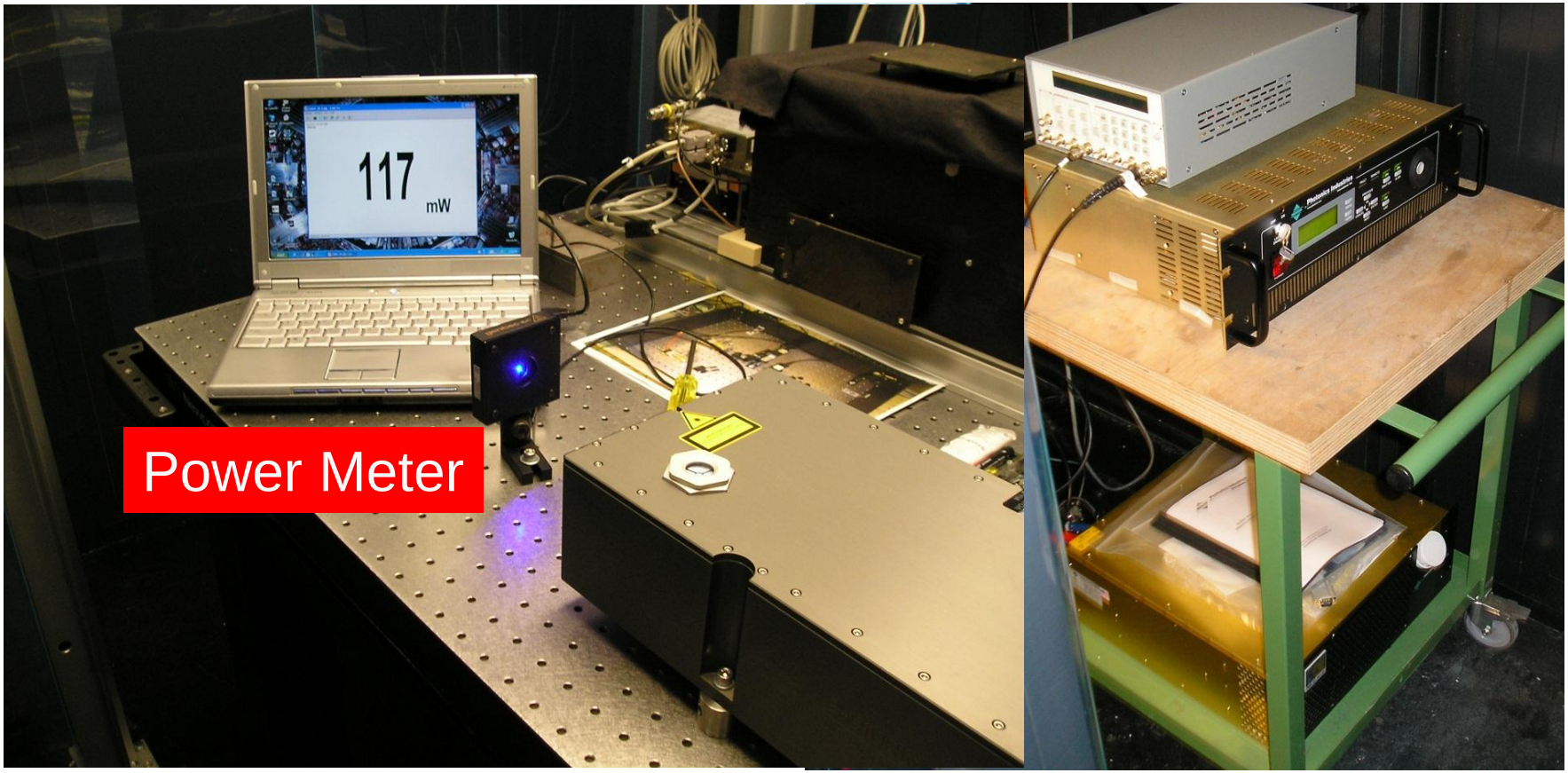
Existing Barracks



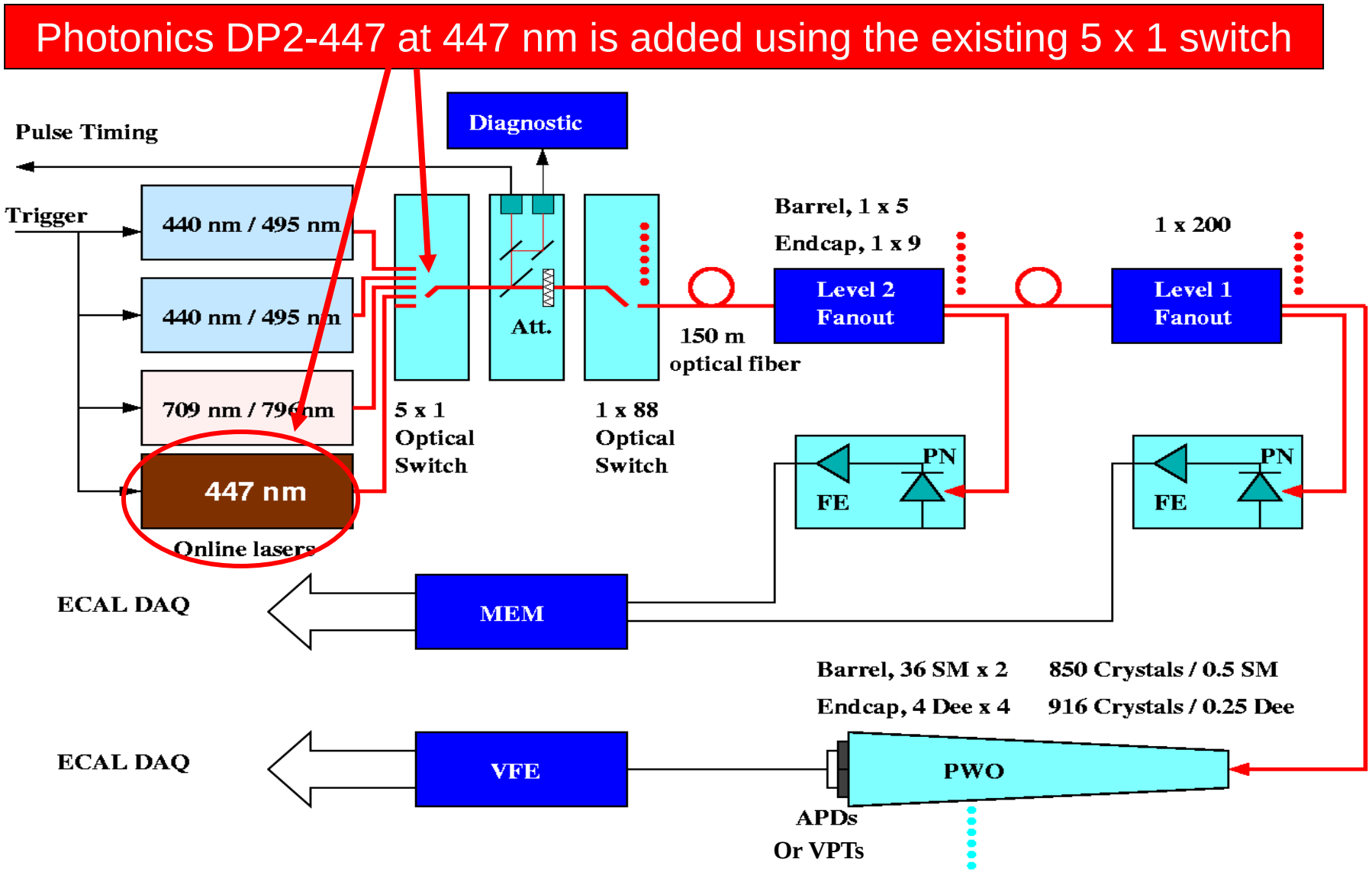
Modified Barracks

Installation at CERN

Laser system arrived CERN on 3/20/12, and was installed at CMS carven at P5 on 3/21/12 with output power consisting with what measured at Caltech, indicating no B field effect.

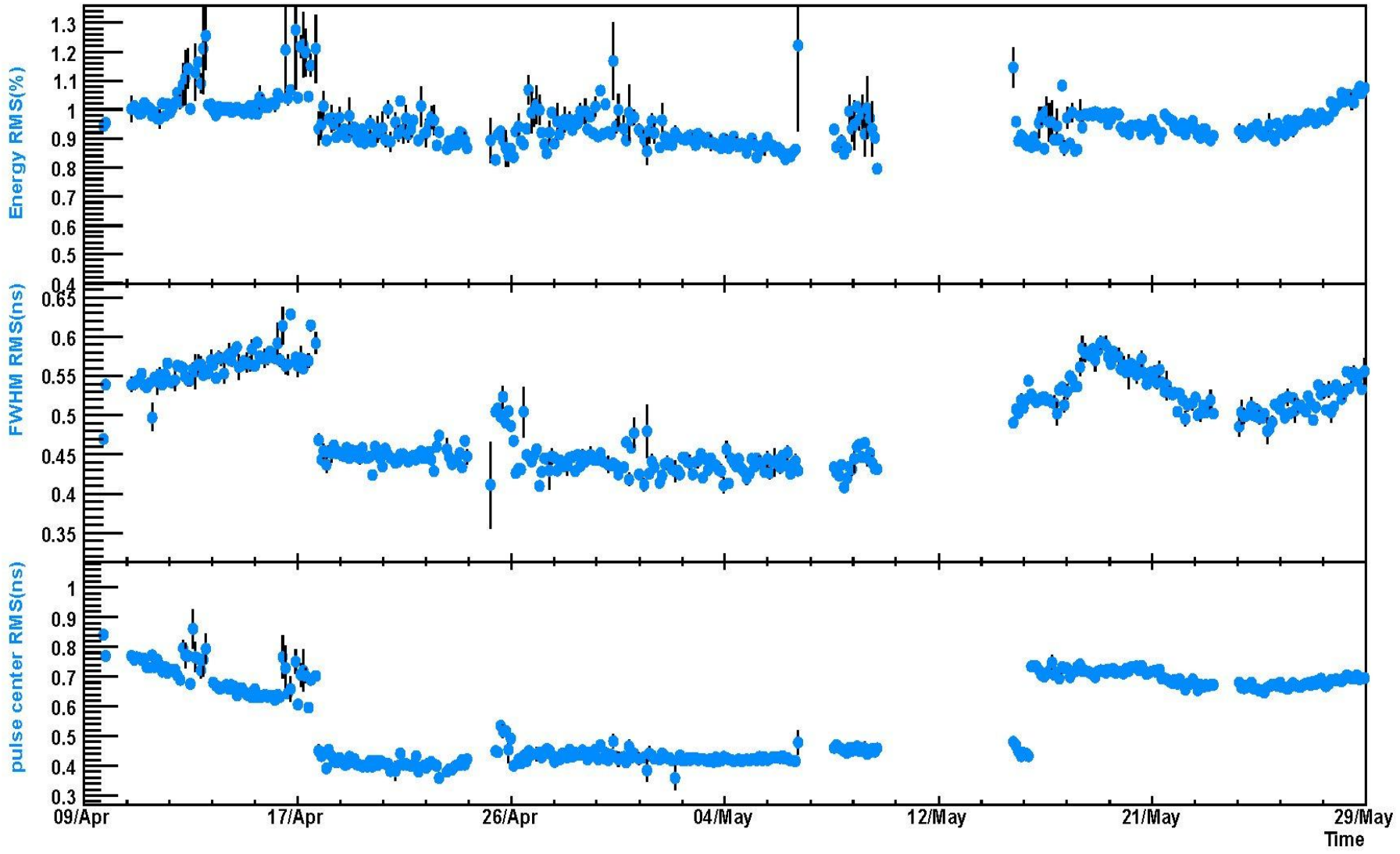


Laser System Integration



Stability of Intensity/Width/Jitter *in situ*:

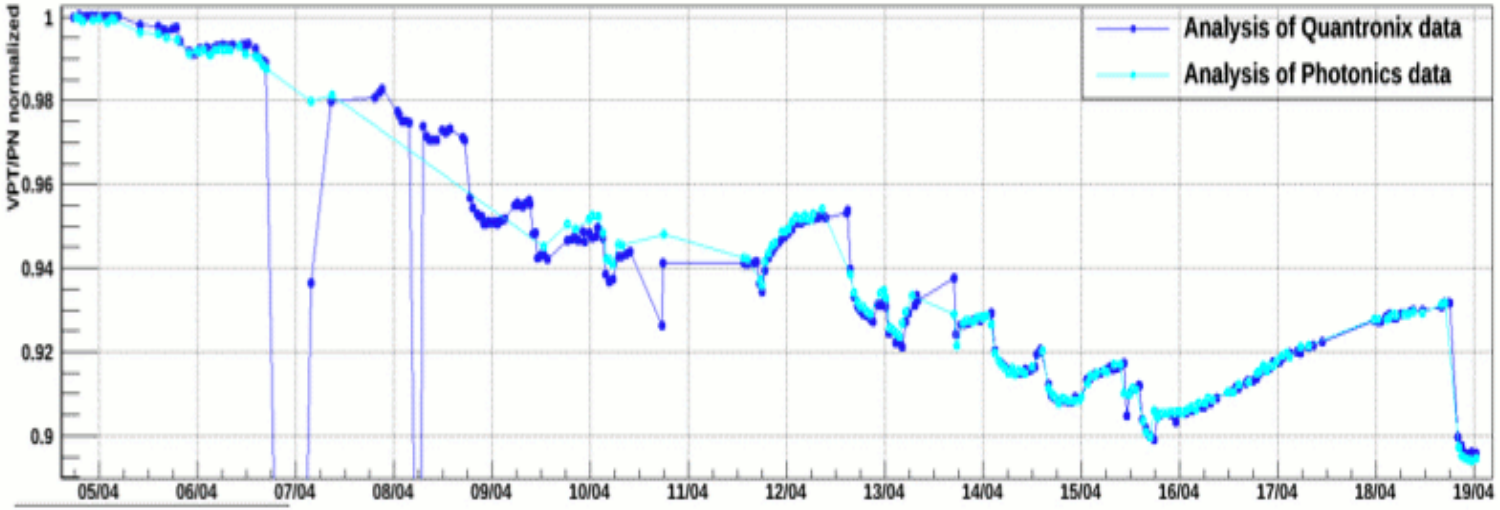
1%/2%/0.8 ns, exceeding 3%/5%/3 ns specifications



DP2-447 Very Stable *in situ* at LHC

See talk by F. Ferri in this conference for monitoring precision

EE: Quantronix and Photonics



Good consistency between Quantronix and Photonics lasers, Photonics very stable

Summary

A new commercial diode-pumped DP2-447 blue laser was commissioned at CERN for the 2012 operation of the CMS ECAL. This laser uses a Nd:YVO_4 crystal and a proprietary intra-cavity frequency triple technology. It has a simple structure and is expected to be more reliable than the existing lamp-pumped lasers used by the monitoring system.

Long term measurements at Caltech and *in situ* at LHC show that this DP2-447 laser has good stabilities of 1%/2%/1 ns for the laser pulse intensity/width/jitter.

This new blue laser system provides a good foundation for precision monitoring 76,000 PWO_4 crystals *in situ* at LHC.