Status of the Photonics DP20-B527-18 laser at Caltech

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CERN

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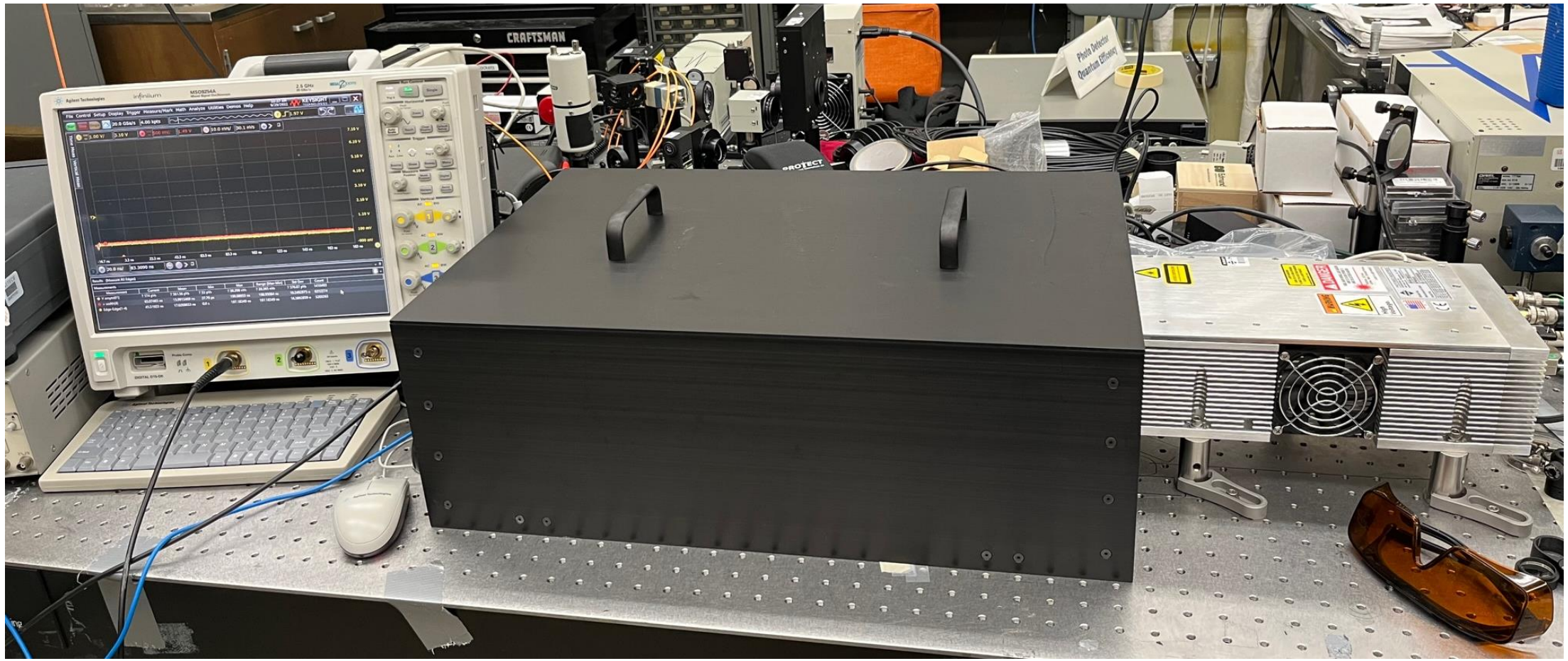
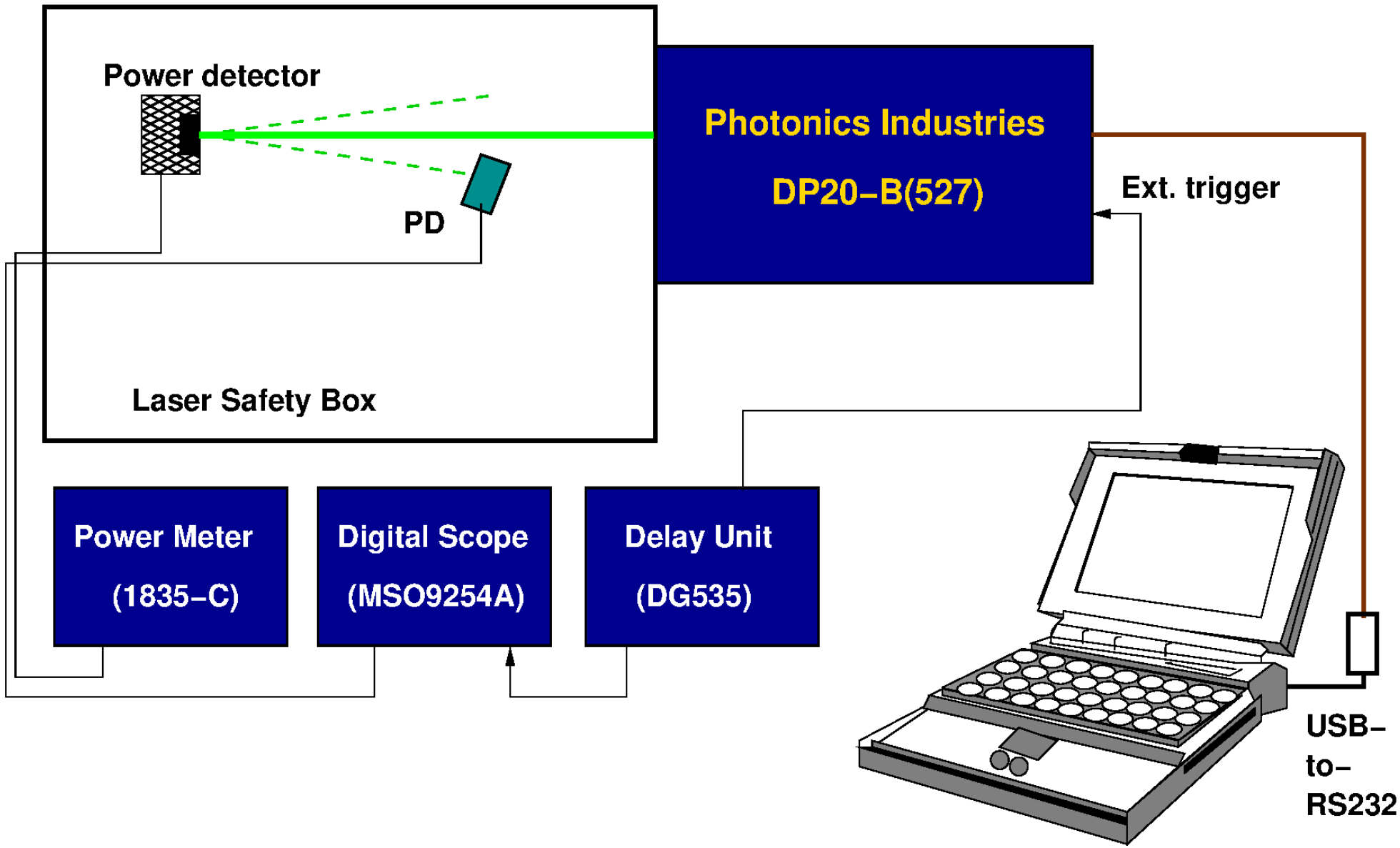
The 2nd Service at Photonics

The laser was sent back again to Photonics again from for the 2nd service 8/10/22 – 9/21/22
A cavity mirror in the laser head was found burned and was replaced by Photonics



Setup: Laser Evaluation

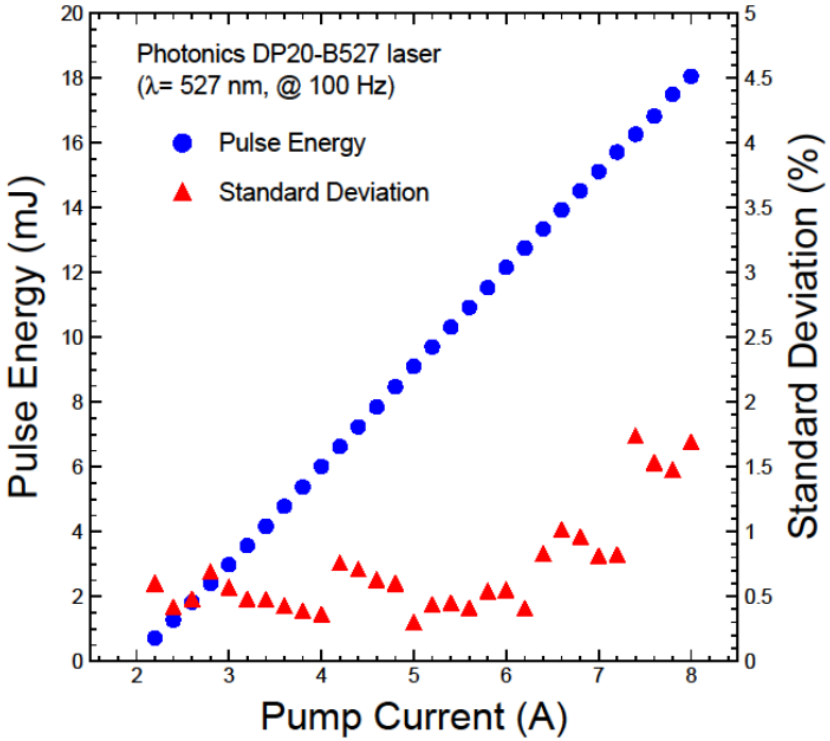


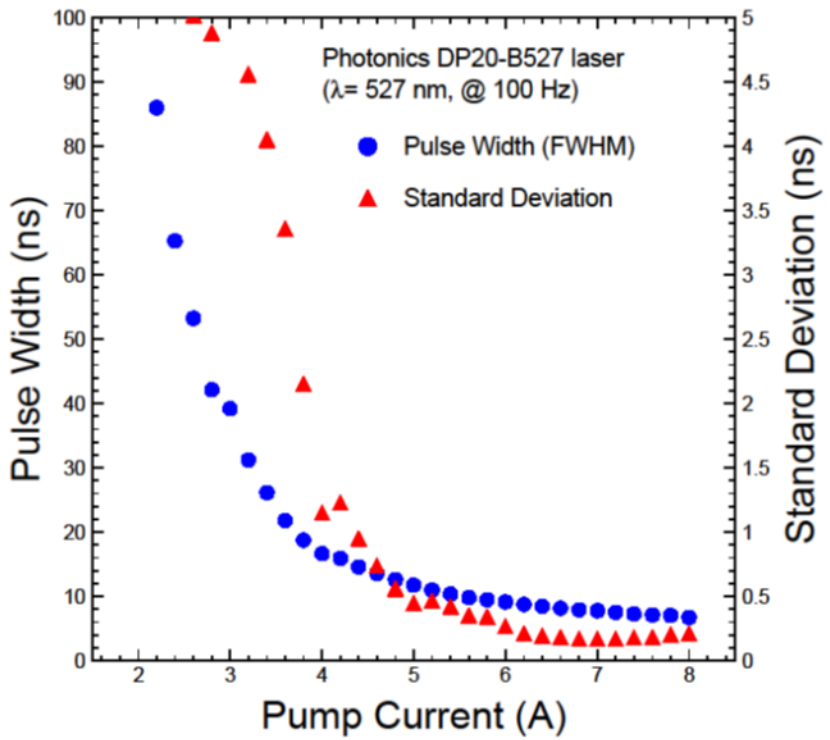
Laser pulse energy calculated by using average power measured by a Newport power meter

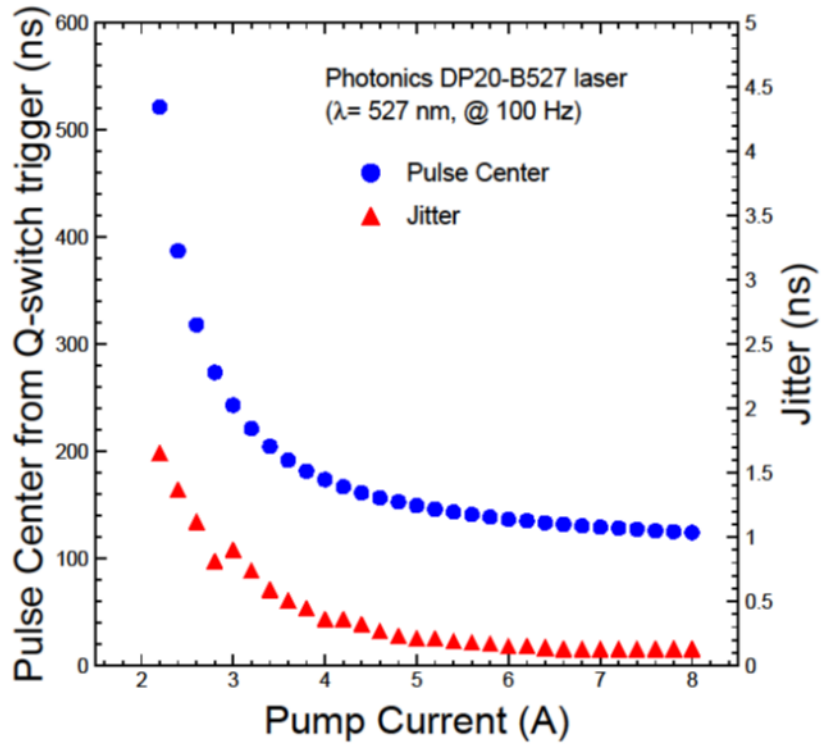
Stability of laser pulse energy, width, center timing (jitter) measured by using a digital scope (MSO9254A) and a fast photodetector

After the 2nd Service at Photonics

Laser meets CMS specification
Pulse energy reaches 18 mJ @ 8 A with rms < 2%
Pulse width < 10 ns @ > 5.0 A with rms < 0.5 ns
Pulse jitter < 0.5 ns @ > 3.5 A



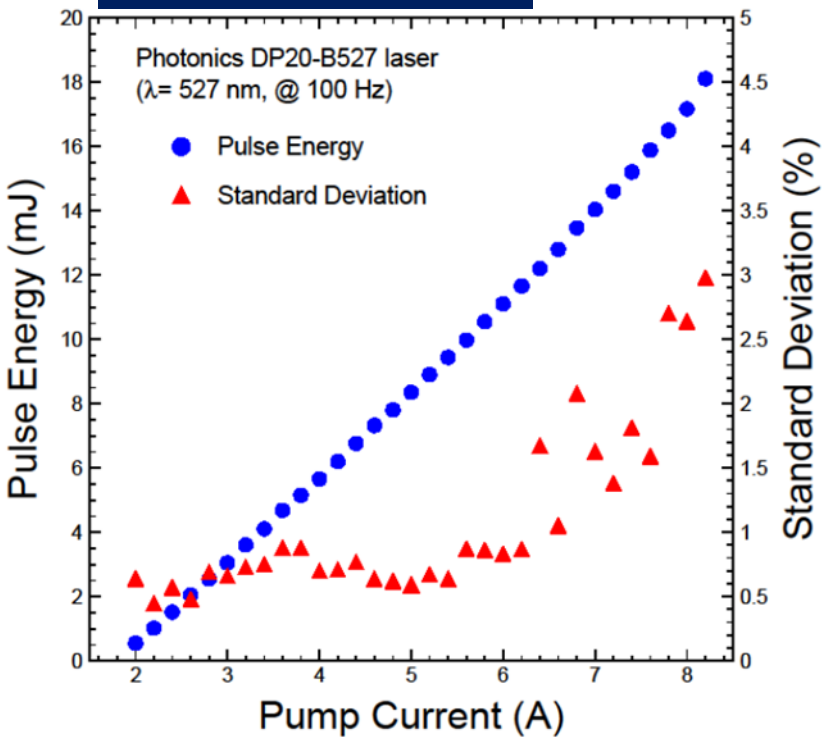




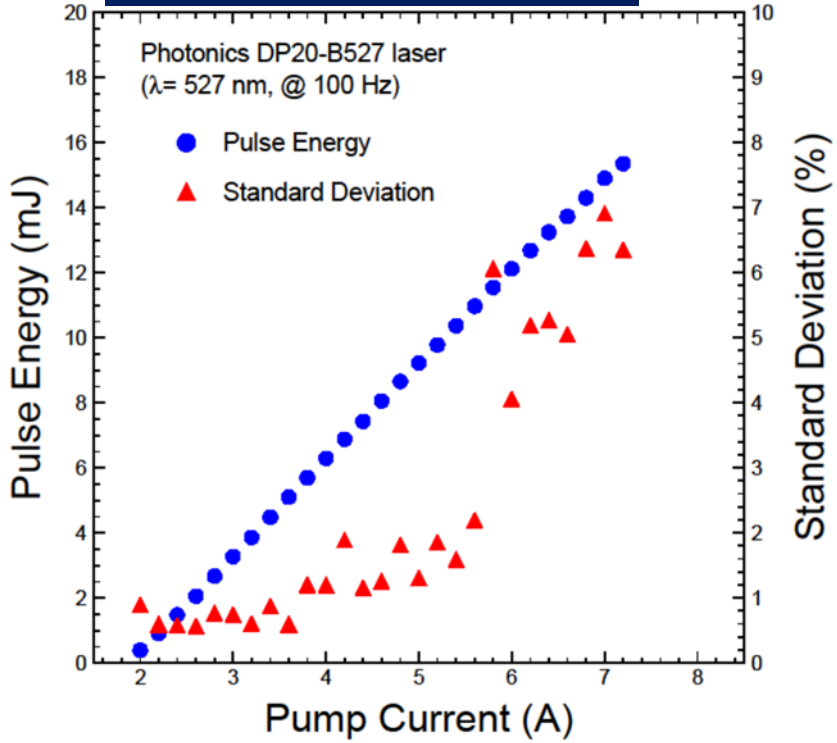
History: Laser Pulse Energy

Reached 18 mJ with rms of < 3% after the May delivery, but lost power at 16 mJ with rms > 6% after the 1st service. Reached 18 mJ with rms < 2% after the 2nd service.

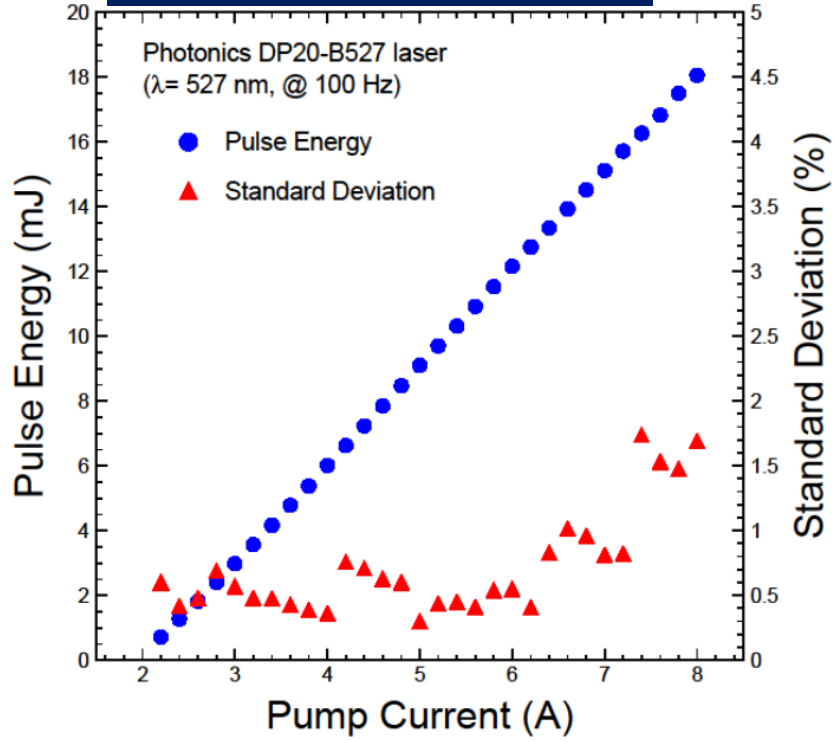
After delivery in May 2022



After the 1st Service in July 2022



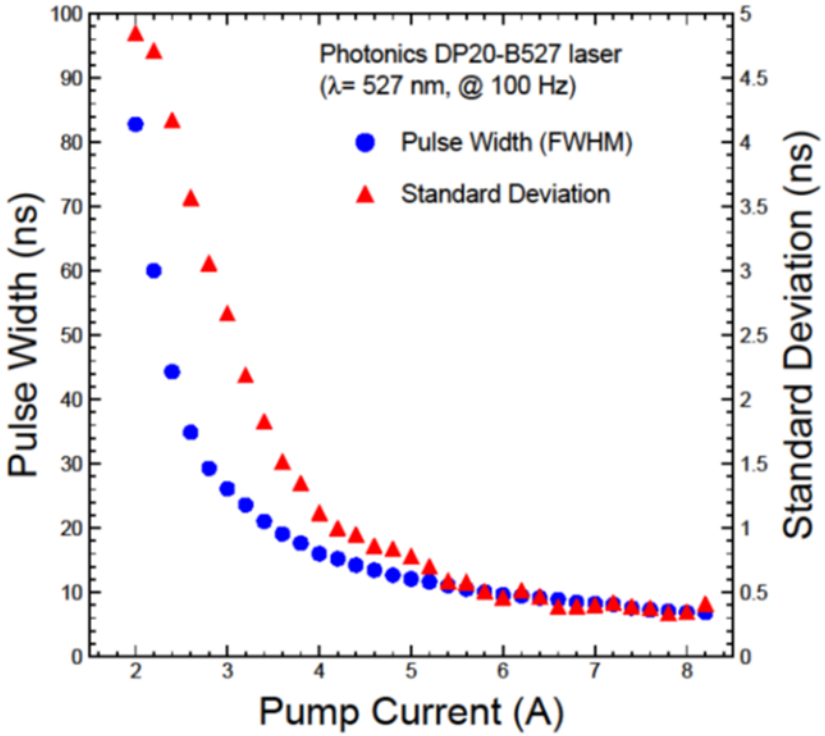
After the 2nd Service in Sept 2022



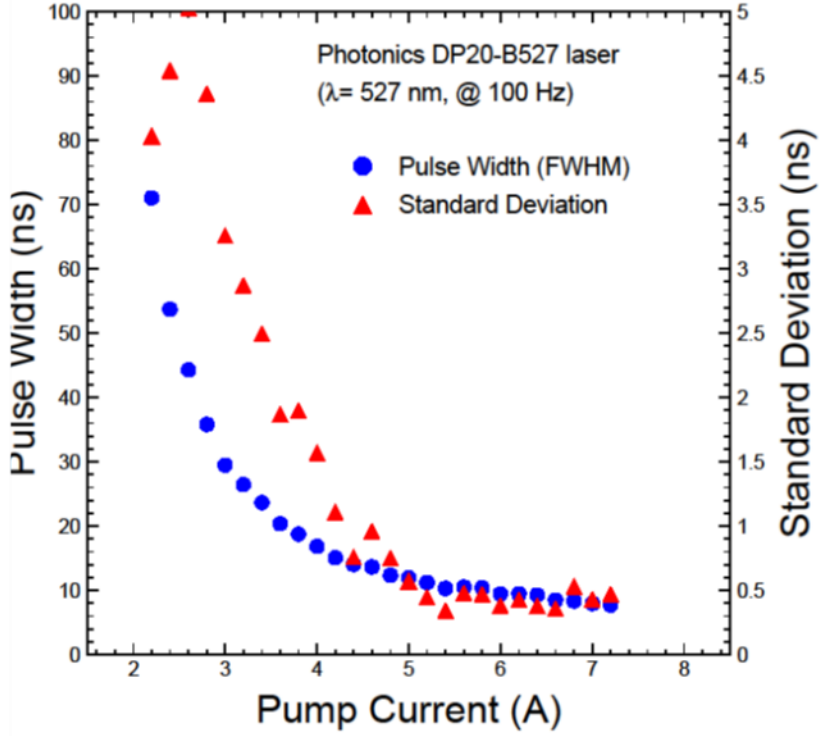
History: Laser Pulse Width

Reached 7 ns spec with rms improved from 0.5 ns to < 0.2 ns at > 6.2 A (10 mJ) after the 2nd service

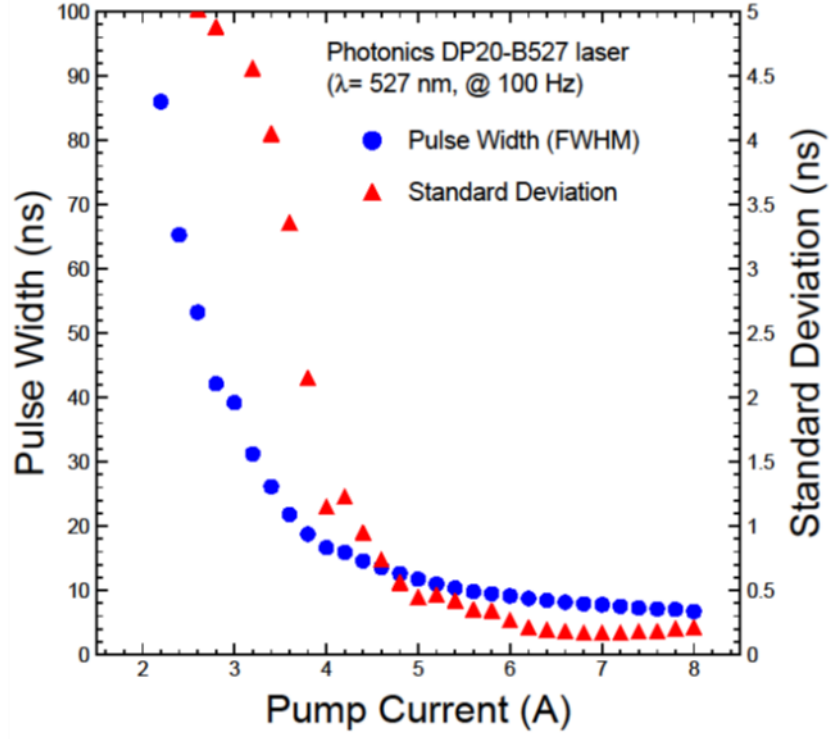
After delivery in May 2022



After the 1st Service in July 2022



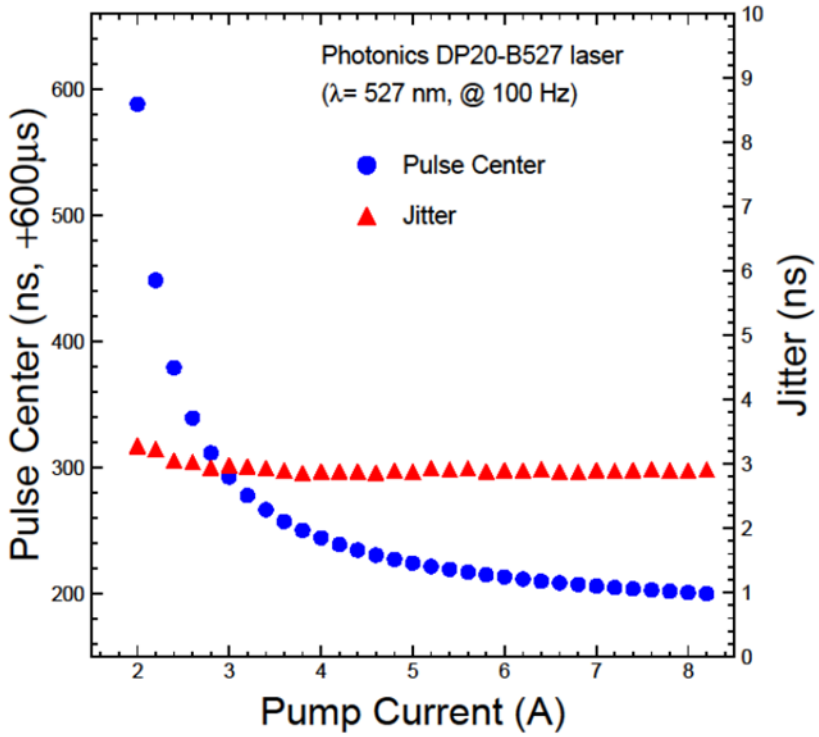
After the 2nd Service in Sept 2022



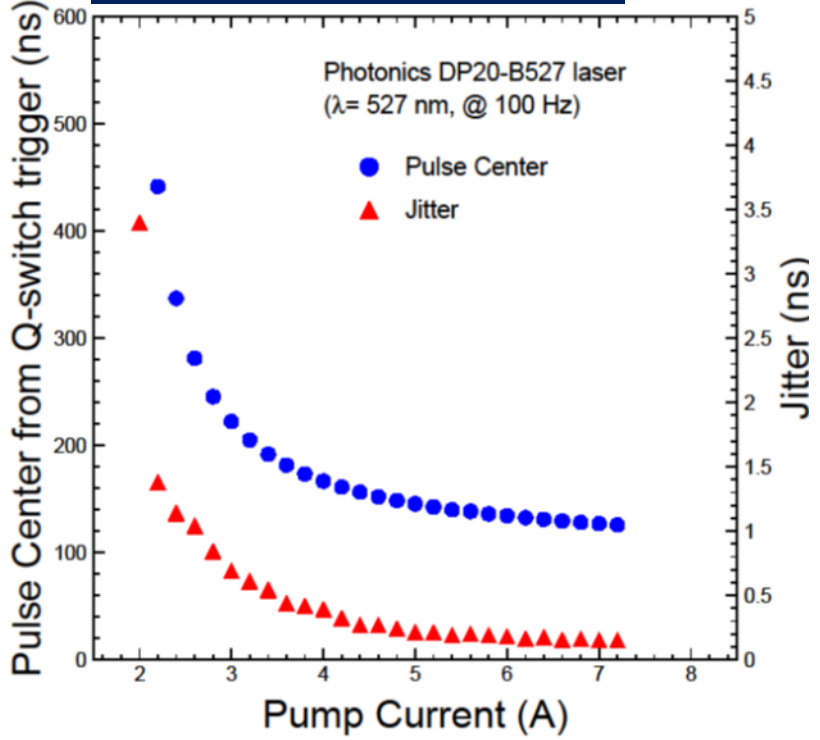
History: Laser Pulse Jitter

Jitter was 3 ns after the May delivery. Delay/jitter were reduced to < 200/0.5 ns respectively at > 3.5 A (10 mJ) after the 1st service

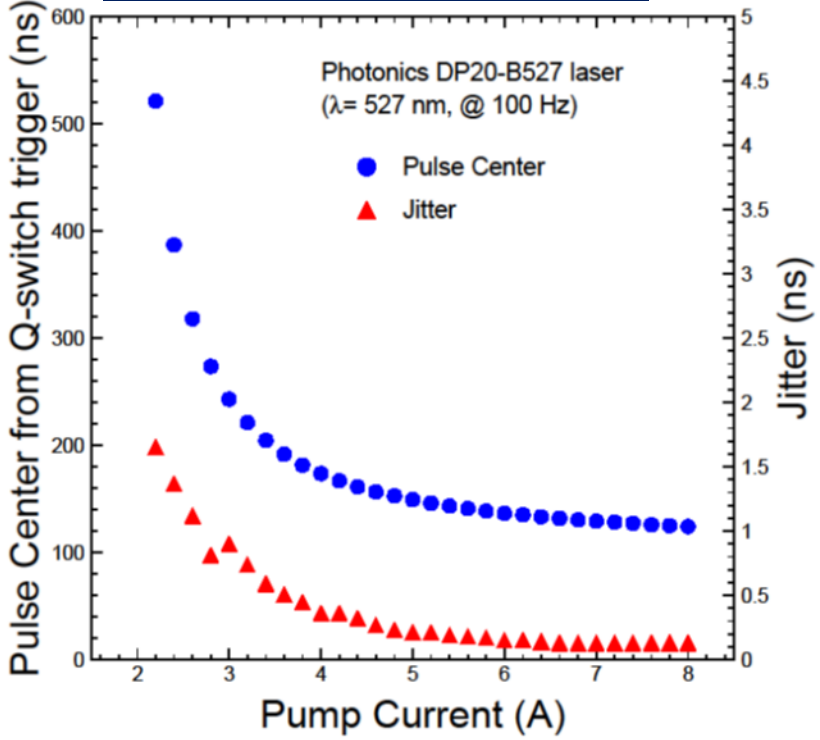
After delivery in May 2022



After the 1st Service in July 2022



After the 2nd Service in Sept 2022



Setup: Fiber Coupling & Laser Stability Test

Laser power measured by a power meter. Pulse energy, width and center averaged each minute by a fast PD and an Agilent DSO6052A DSO. A flash cleaved 365 μm quartz fiber input end survived 8.0 A with 14 mJ at the fiber entry for a short time (~15 min) with a coupling efficiency of up to ~80%.

D: power detector

F: fast shutter

PD: photodiode

L1–2: beam expander

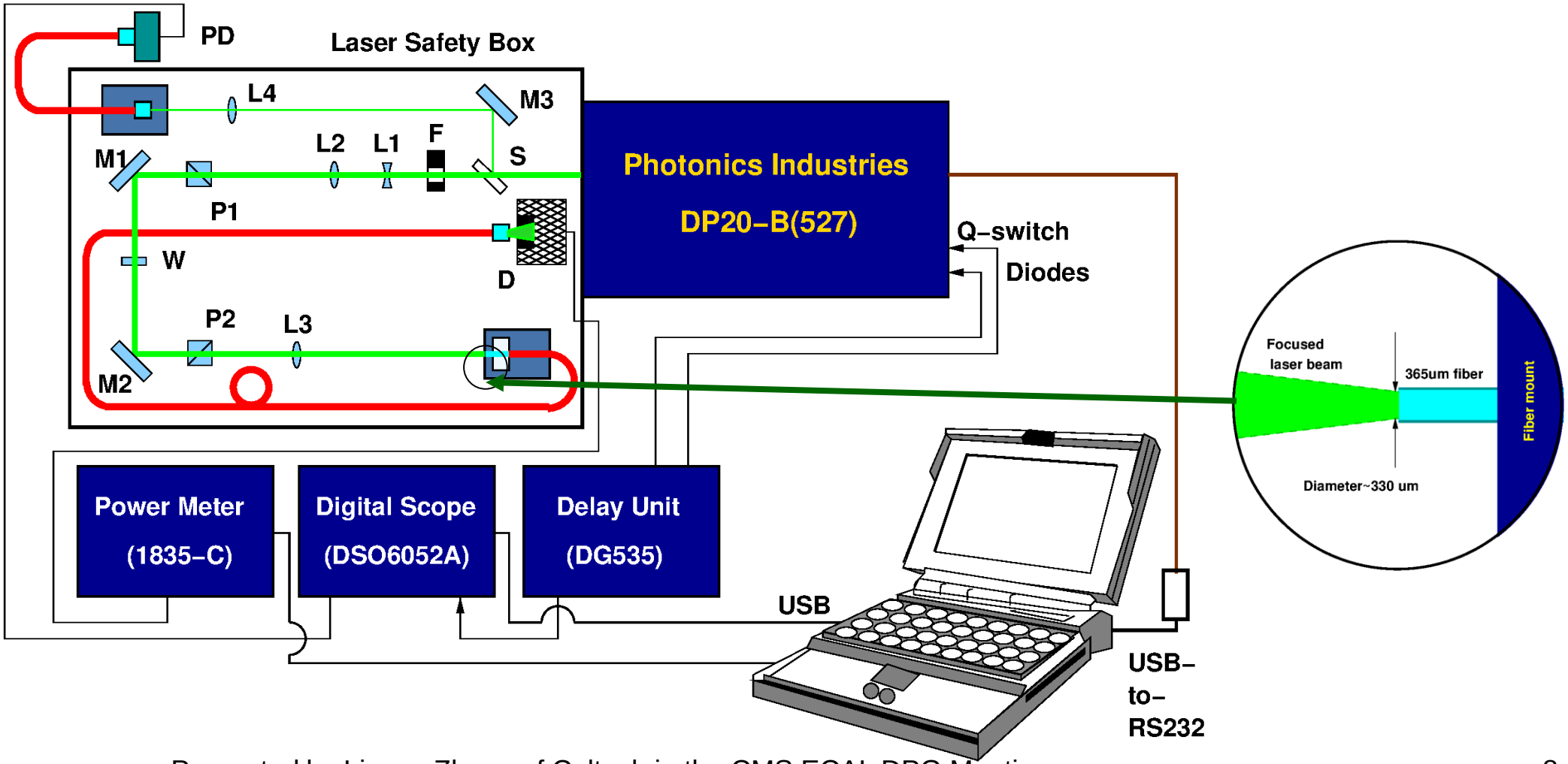
L3–4: fiber coupling

M1–3: HR mirrors

P1–2: polarizer

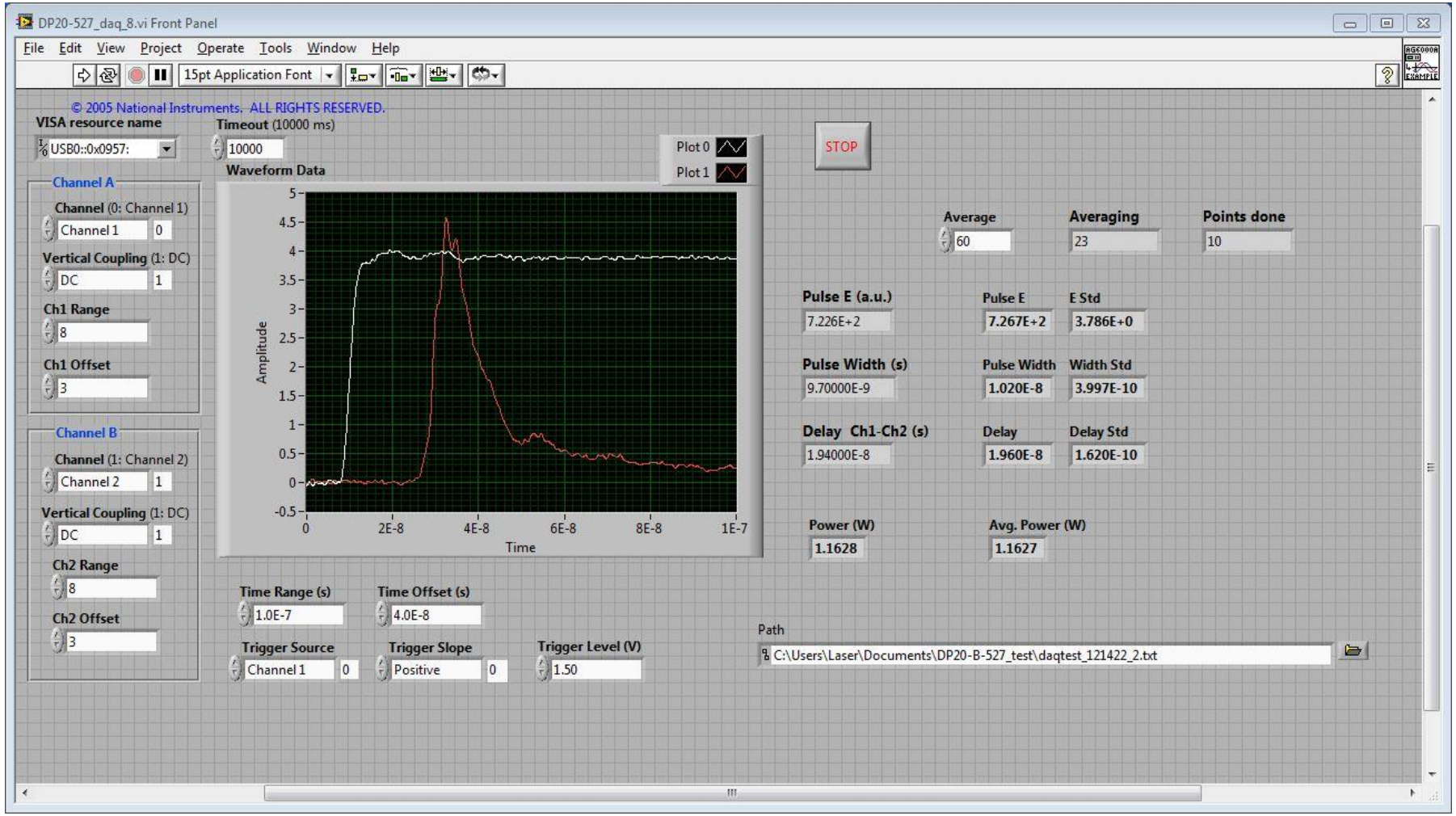
S: beam sampler

W: half–wave plate



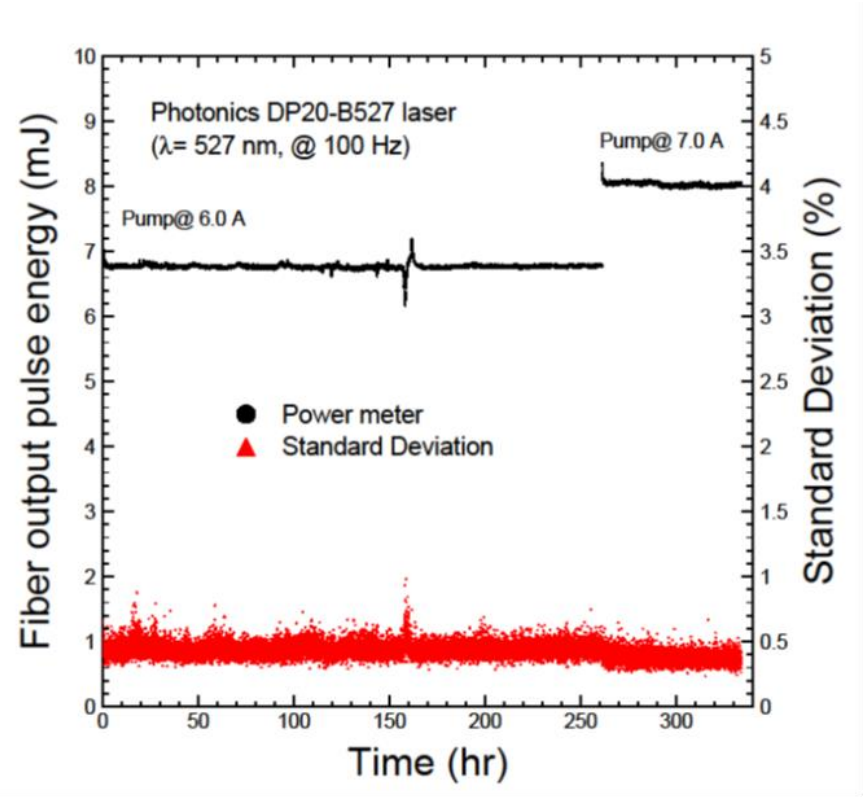
DAQ for the Long-Term Stability Test

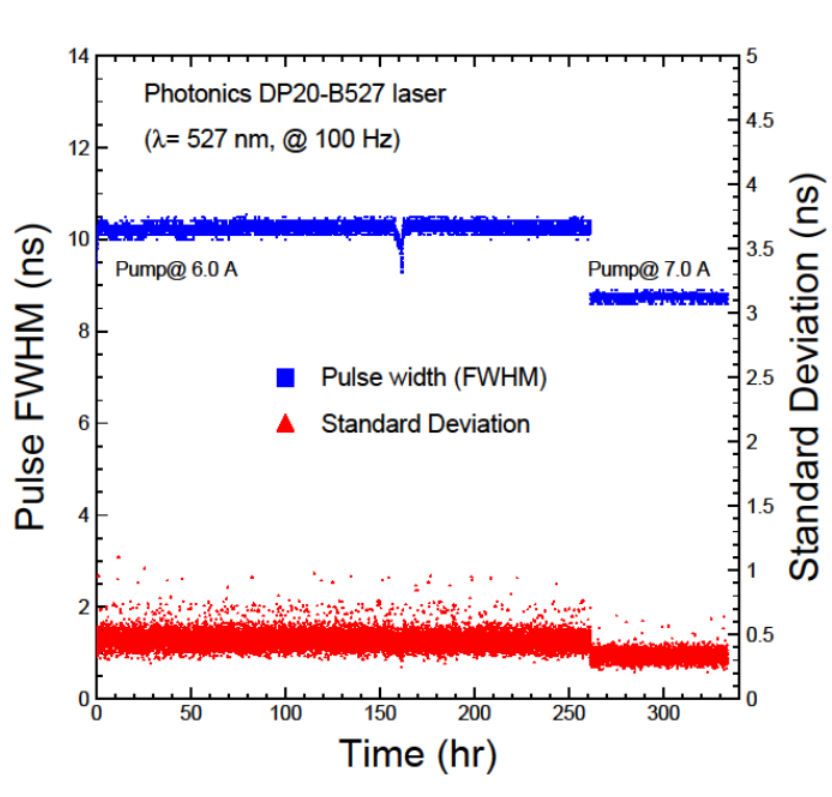
A LabVIEW-based DAQ records average and rms of laser pulse energy, width and delay from the monitoring PD at ~ 1 Hz, as well as the laser power from a meter

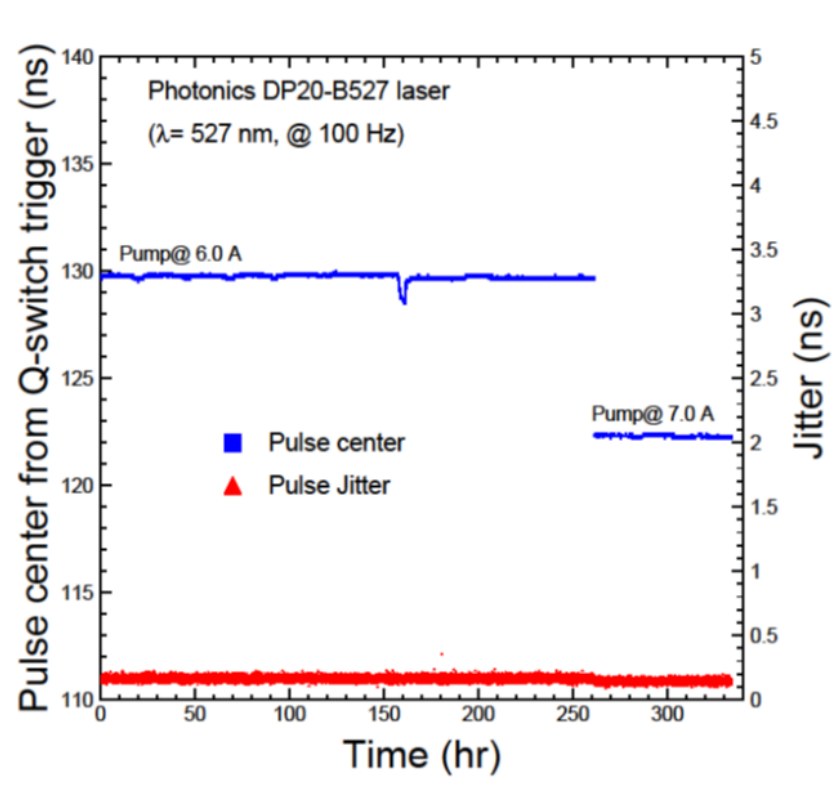


Result: Long-Term Stability Test

Stable operation with 6.0/7.0 A pumping current (6.8/8.0 mJ in fiber) for 11/3 days
The dip at ~160 hrs was caused by a campus-wide power interruption
A slight degradation observed after the pump current increased to 7.0 A
The quartz fiber output end burned at 8 A, indicating a damage threshold of 8-10 mJ







Laser Damage Threshold for Fibers

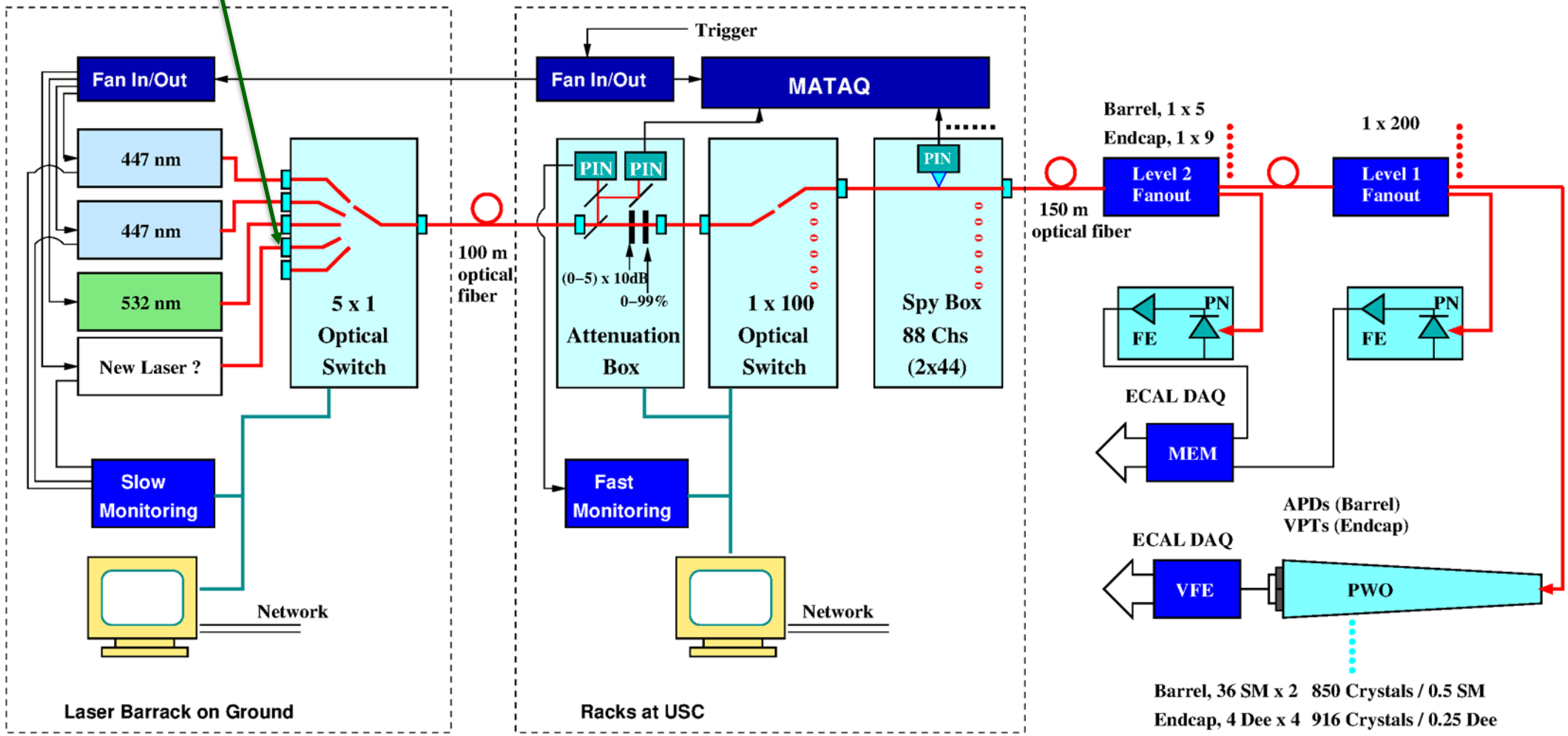
- Laser damage threshold (LDT) defines the maximum laser pulse intensity density for fibers, and thus the pulse intensity.

- According to OFS (the quartz fiber manufacturer), the LDT for HCG-M0365T 365 µm quartz fiber is about 10 J/cm^2 for 527 nm laser pulses of 7 ns FWFM, corresponding to 10 mJ/pulse.

The observed damage at 8.0 A consists with the OFS statement
More vulnerable is the FC connectors

The Most Vulnerable Part

The input FC connector in the 5 x 1 optical switch is the most vulnerable part
18 mJ will certainly damage the FC connector in the 5 x 1 switch



Setup: Damage Test for FC Connectors

Two optical fibers and an FC connector mimic the input FC in the 5 x 1 switch

D: power detector

F: fast shutter

FC: FC connector

PD: photodiode

L1–2: beam expander

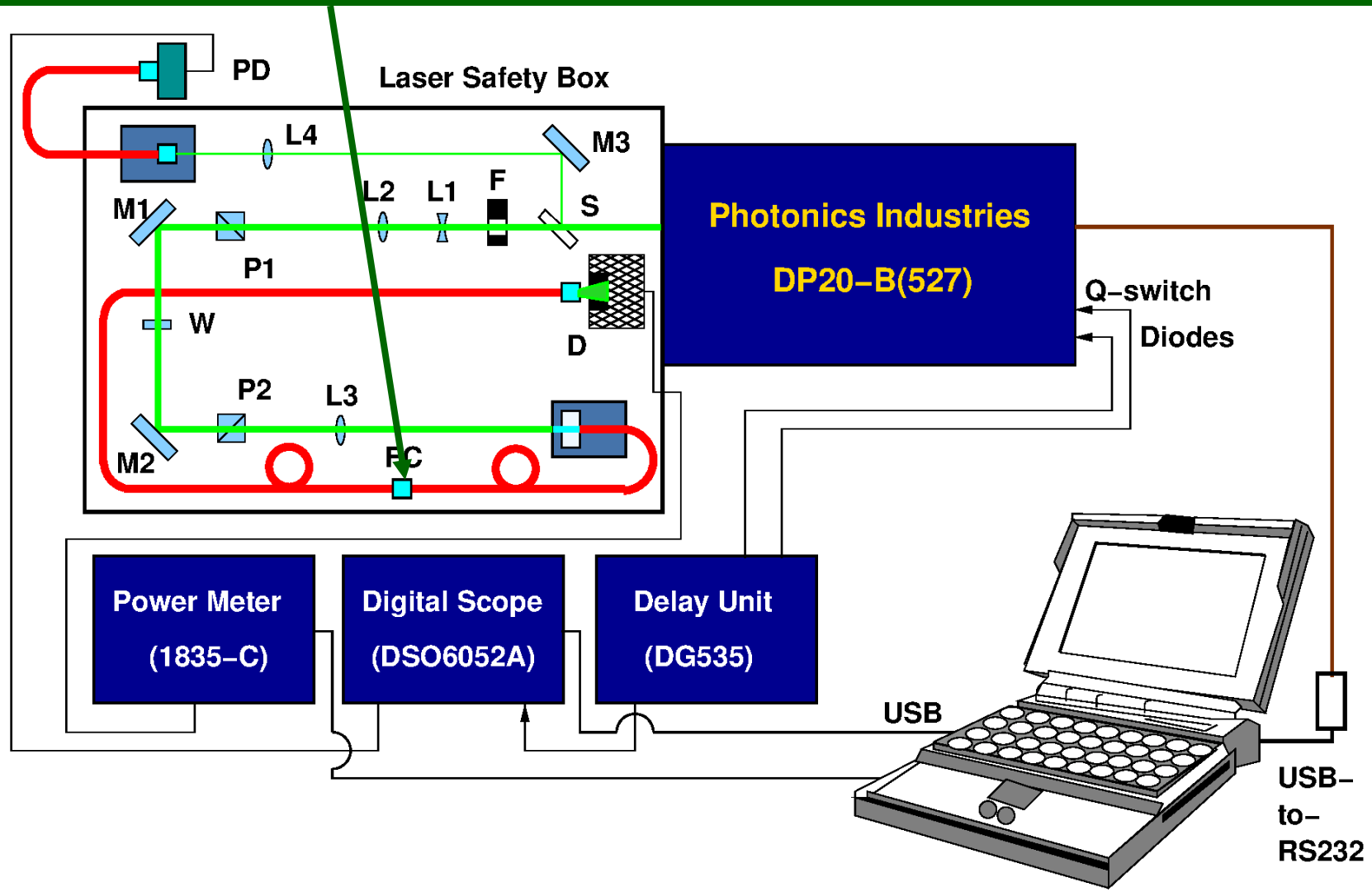
L3–4: fiber coupling

M1–3: HR mirrors

P1–2: polarizer

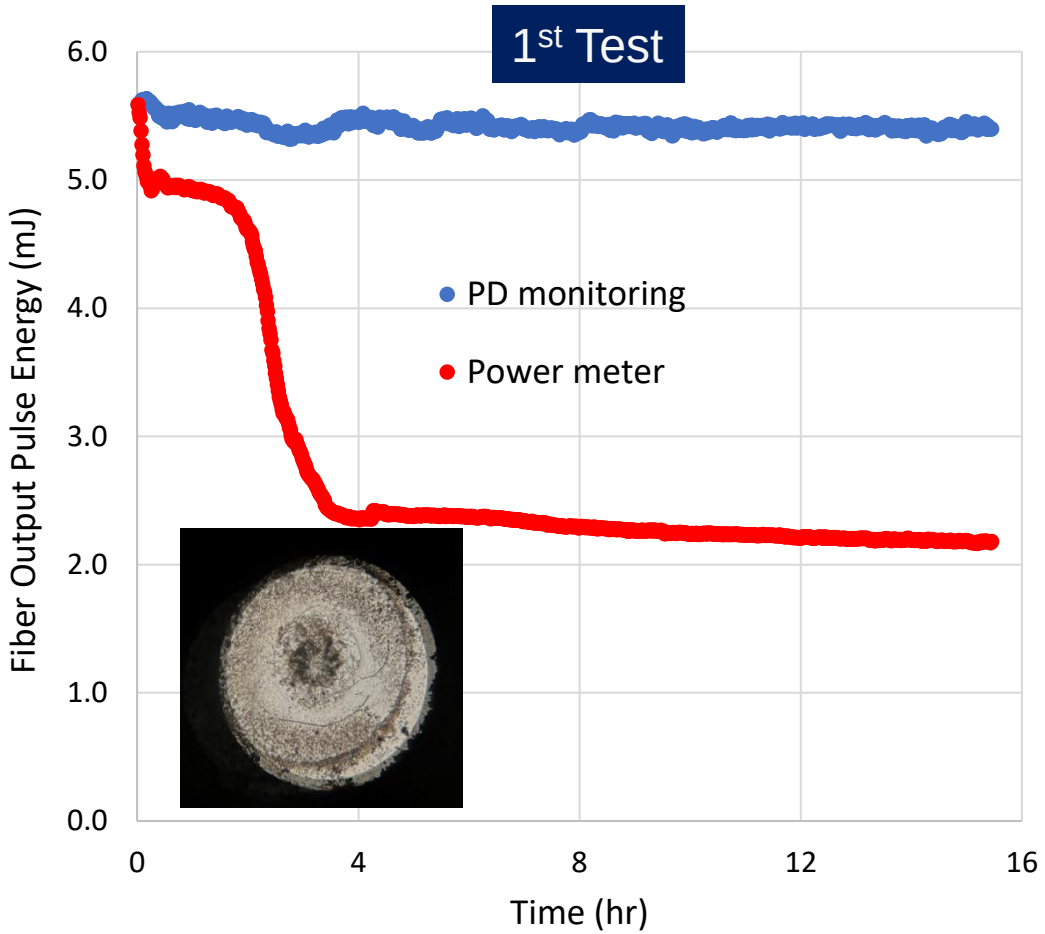
S: beam sampler

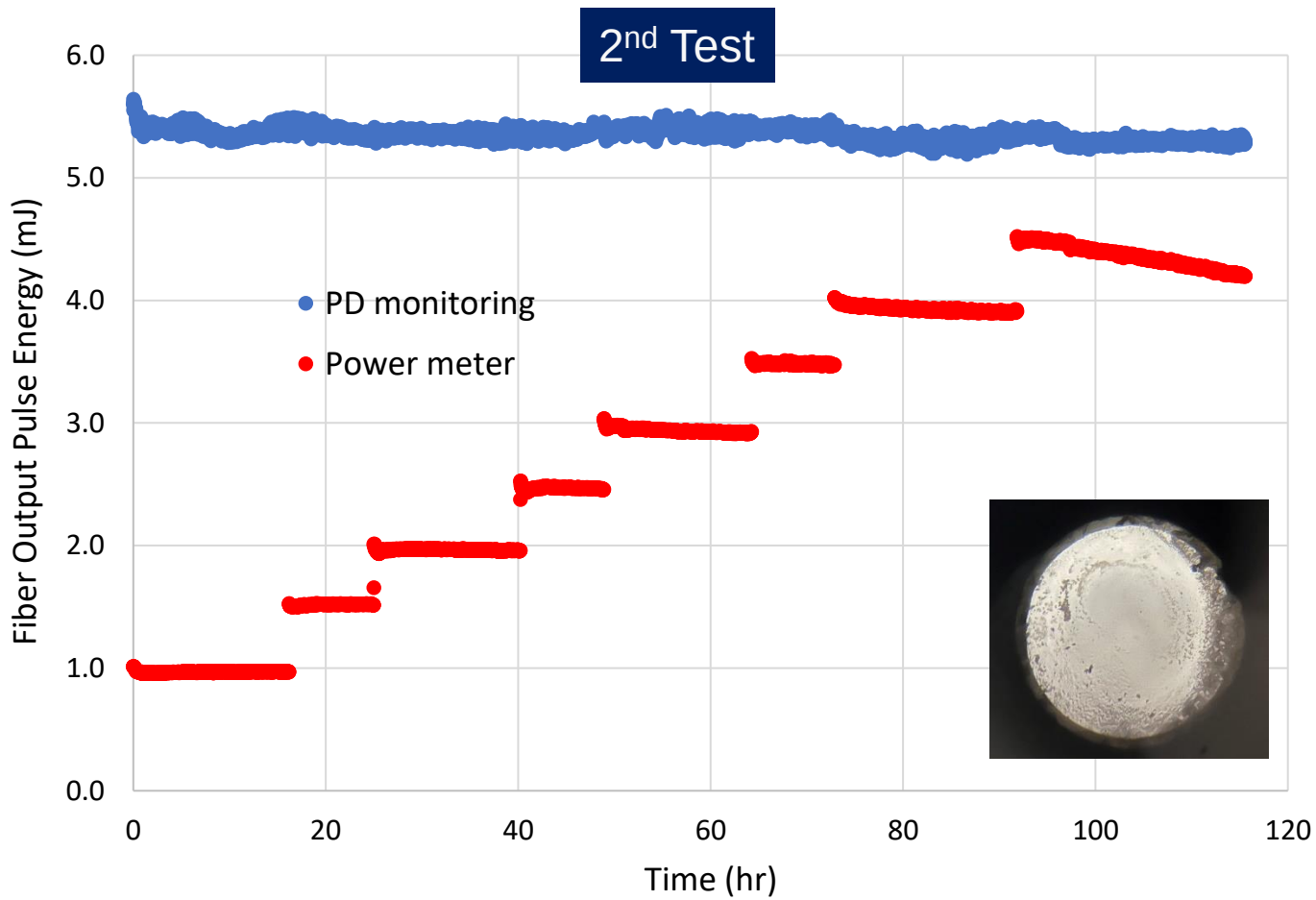
W: half–wave plate



Result: FC Connector Damage Test

The 1st test at 6.0 A (~8.5 mJ at the FC connector) led to power losses due to a black contamination in the FC connector, which was attributed to epoxy evaporation. In the 2nd test an attenuator was used to reduce input power for FC. The fiber output pulse energy was increased from 1 mJ with a 0.5 mJ step. Significant damage observed starting from 4 mJ output power.



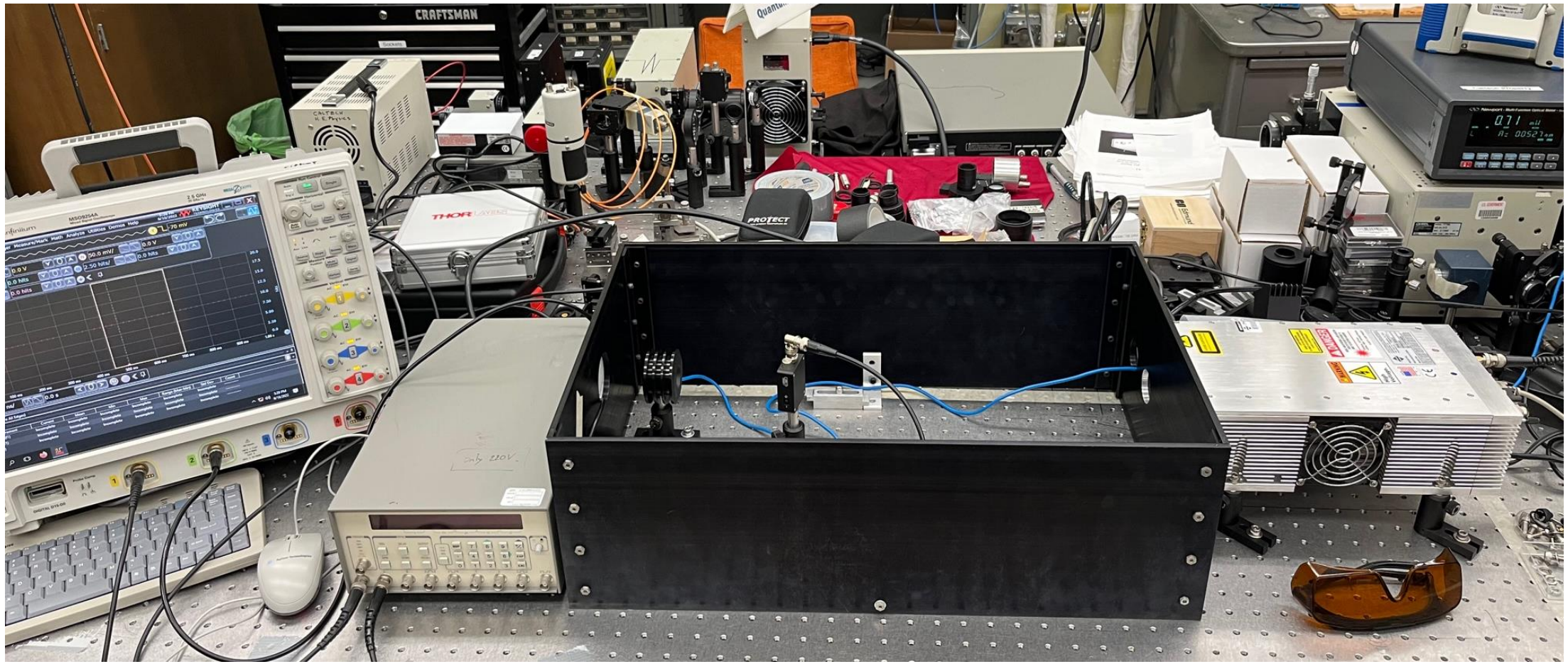


Summary

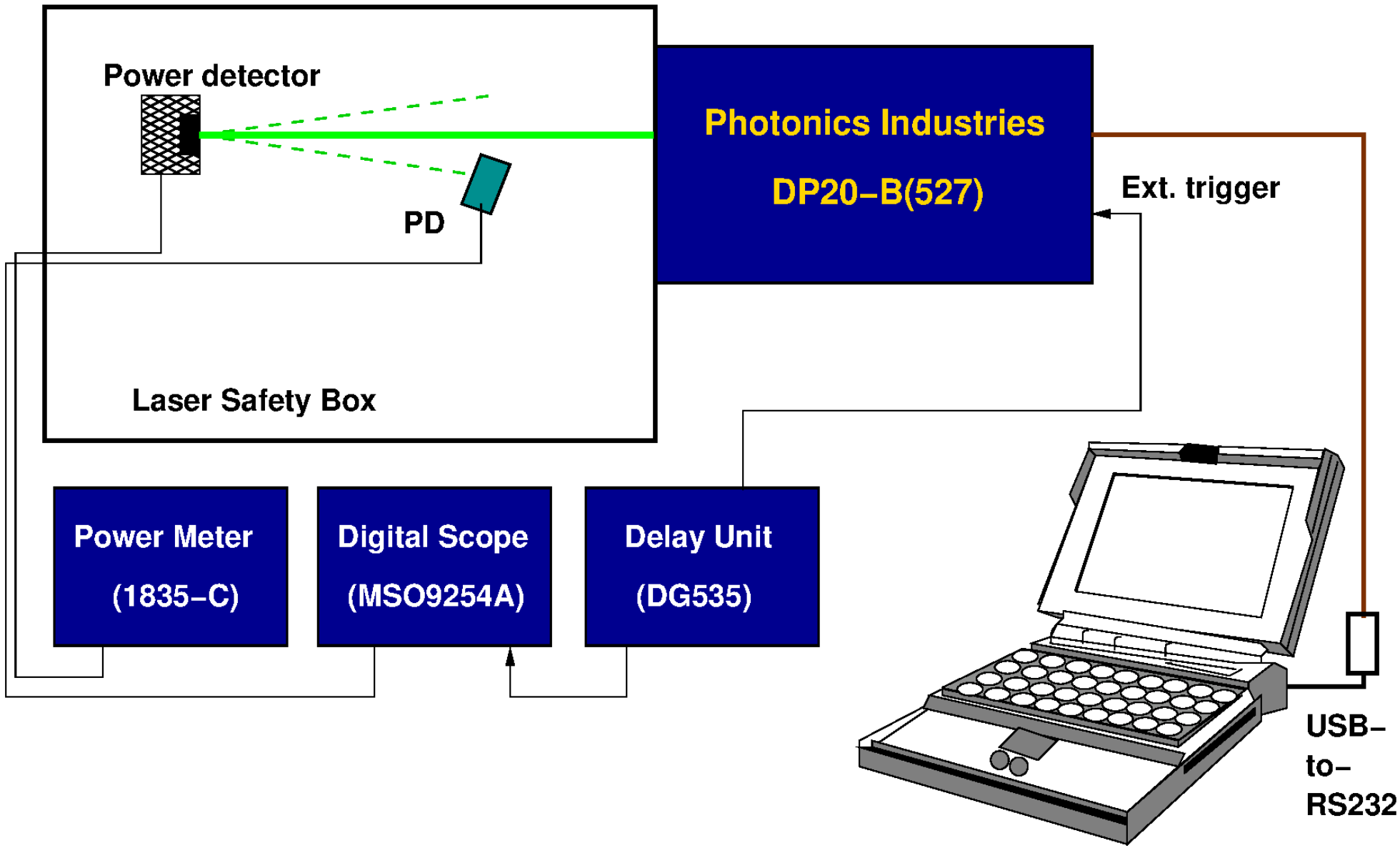
- The Photonics Industries DP20-B527 laser (18 mJ @ 527 nm) was delivered to Caltech on 4/28/22. Its performance was measured with an external trigger @100 Hz.
- Both pulse energy/stability and width/stability meet the CMS spec, but the jitter of ~3 ns is out of the spec, and the delay from the external trigger of 600 μs+ is longer than the 88 μs LHC beam gap.
- In the 1st service (Jun. 21 – Jul. 27) Photonics engineers reprogramed the internal FGPA and introduced an additional external trigger for the Q-switch. After the 1st service the jitter and the delay from Q-switch trigger were reduced to < 0.5 and 200 ns respectively at > 4 A (10 mJ). The laser, however, lost power during the investigation.
- In the 2nd service (Aug. 10 – Sept. 21), Photonics engineers replaced a cavity mirror in the laser head. After the 2nd service, the laser meets all specification.
- A fiber coupling test **shows a flash cleaved 365 μm quartz fiber input end** survived 14 mJ for 15 minutes with 80% coupling efficiency.
- A long-term test of 11 + 3 days with up to 8 mJ in the fiber shows that the laser pulse energy, width and jitter are stable and meet the CMS specification.
- The fiber output end was burned at 8.0 A, indicating a damage threshold of 8-10 mJ, which is consistent with the OFS statement.
- An FC connector damage test shows a lower damage threshold of ~4 mJ, indicating that the most vulnerable part of the ECAL monitoring system is the input FC connector in the 5 x 1 optical switch.
- Additional works are needed to increase the damage threshold for the FC connectors. Approaches in plan are using thermal resistant epoxy or FC connectors without epoxy.

Photonics DP20-B527 Laser at Caltech

The DP20-B527 laser (18 mJ @ 527 nm) was delivered on 4/28/2022
Its performance was measured with external trigger @ 100 Hz.



The Measurement Setup



Laser pulse energy calculated by using average power measured by a Newport power meter

Stability of laser pulse energy, width, center timing (jitter) measured by using a digital scope (MSO9254A) and a fast photodetector

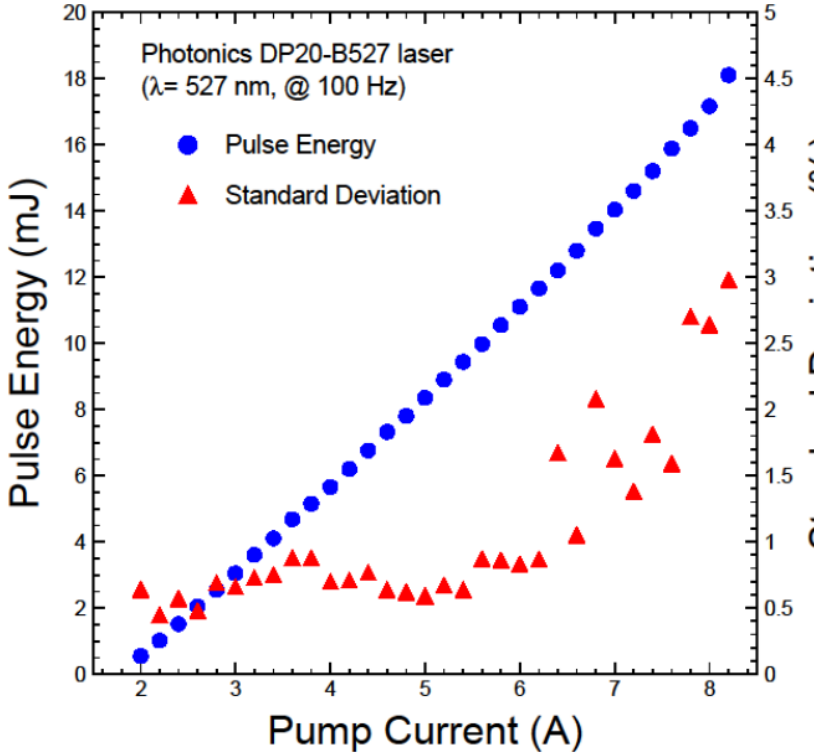
Trigger, Laser Pulse and Integration

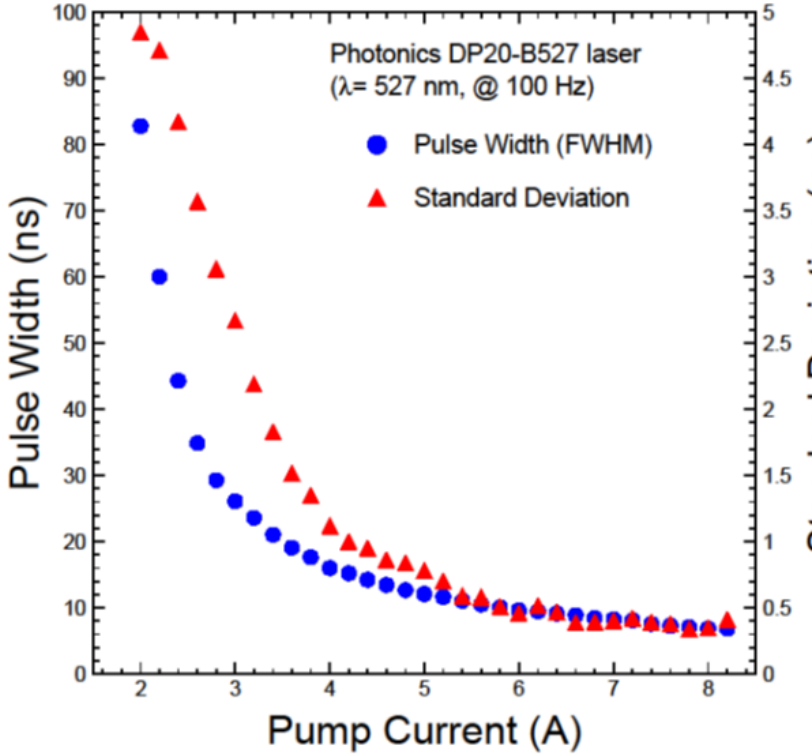
MSO9254A and a fast photodetector used to measure:

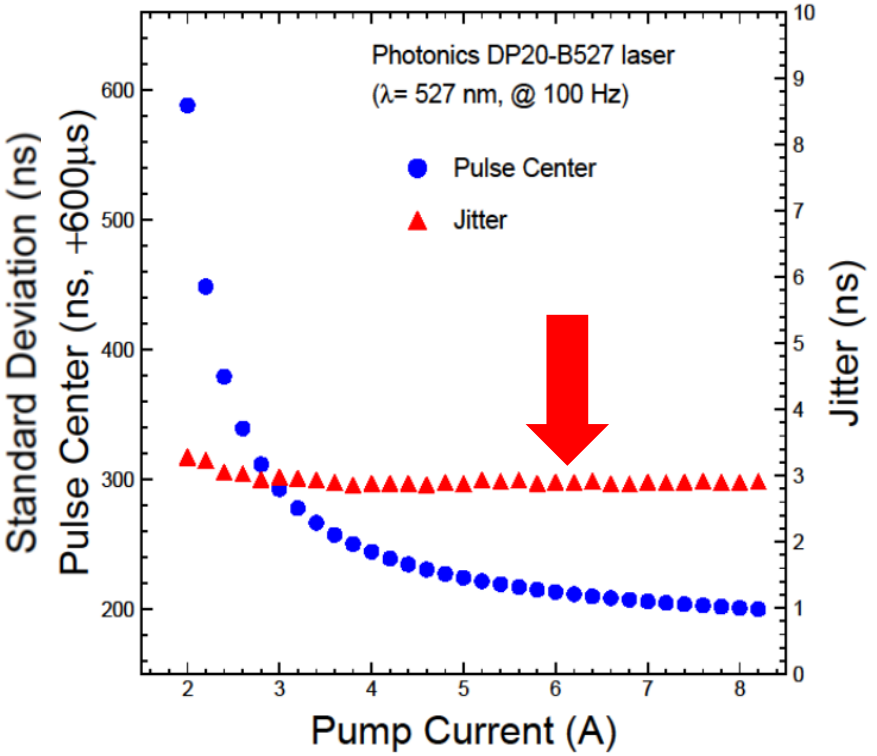
rms of pulse energy
pulse width & rms
pulse delay & rms (jitter)

Laser Pulse Energy, Width and Jitter

Pulse energy meets the 18 mJ spec at >8A with rms of 3%, which agrees with Photonics brochure
Pulse width meets the 7 ns spec at >7.5 A with an excellent stability of 0.4 ns rms
Pulse jitter is about 3 ns, larger than the 1~2 ns spec. Work with Photonics engineer is on-going.







A delay of 600 μs+ from external trigger required to pump diode

DP20-B527 Specification

Beam and output specifications

Wavelengths available: **1053 nm, 527 nm, 351 nm, 263 nm**

Pulse repetition rate: **Single shot to 100 Hz (option up to 200 Hz)**

Pulse width: **~4-8 ns**

Pulse energy stability, measured at ambient temperature of ± 2°C: **< 3% rms**

Long term stability, measured over 8 hours ± 1°C: **3% rms**

Beam spatial mode: **TEM_{00} M^2 < 2**

Beam pointing stability: **< 25 µrad**

Beam divergence: **< 4 mrad**

Beam diameter, at exit: **1 mm**

Photonics DP20 Series Brochure

Operational and system characteristics

Interface: **RS232, Ethernet, Software GUI, External TTL Triggering**

Warm-up time: **< 5 minutes from standby, < 10 minutes from cold start**

Electrical requirement: **100-240 V AC; or 32 V DC, 15 A**

Line frequency: **50-60 Hz**

Ambient temperature: **15°C to 30°C (59°F to 86°F) Operating Range, RH 90% Max, non-co**

Power consumption, typical: **~50 W**

Cooling system: **Air-cooled**

	DP20	DP20-MWB
Beam and output specifications		
Wavelength output type	Standard, single-wavelength output	Multi-wavelength blended output
Pulse energy, at 100 Hz		
-a. 1053 nm	20 mJ	
-b. 527 nm	18 mJ	
-c. 351 nm	8 mJ	

Pulse energy: 18 mJ
Pulse energy stability: <3% rms
Pulse width: ~7 ns
Pulse Jitter: ~1 to 2 ns

Specification in the Quotation

Description	Price
DP-527-18 Laser - Specifications Wavelength 527 nm Pulse Energy @ 100Hz 18mJ Pulse Width ~7 ns Beam Mode TEM00	$80,000
Low Jitter Option low jitter option which would reduce the jitter to ~1 to 2ns	$25,000
System Software DP Control software provides basic system operating controls in a convenient graphical user interface configuration.	Included
Utility Requirements Operating voltage is 100 to 240VAC, operating frequency is 47 to 63Hz, single phase power, 10 to 30°C.	
Warranty Standard Photonics Industries one-year parts and labor warranty. Warranty repairs are to be performed at Photonics Industries facilities or at customer's site. Travel and living expenses to be paid by customer.	Included
Total (US$)	**$ 105,000.00**

Comparison with DP2-447 Lasers

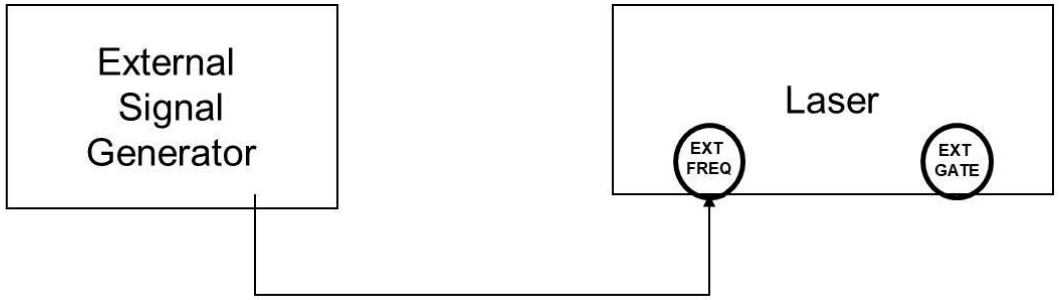
Parameter	DP20-B527	DP2-447*
Wavelength (nm)	527	447
Pulse energy (mJ)	18	1
Pulse energy instability (rms, %)	3	1
Pulse width (ns)	7	23
Pulse width instability (rms, ns)	0.4	0.4
Pulse delay (μs)	600 + ~200 ns	86 + 120 ns
Pulse jitter (ns)	~3 (to be improved)	~1

* L. Zhang, J. Phys.: Conference Series 404 (2012) 012042

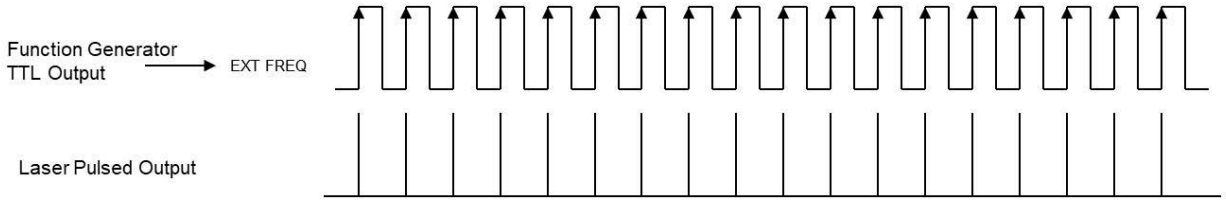
The Plan for Pulse Jitter Improvement

Revise the internal FPGA to introduce a Q-switch trigger similar to DP2, aiming at reducing the jitter to ~1 ns and the delay to <200 ns

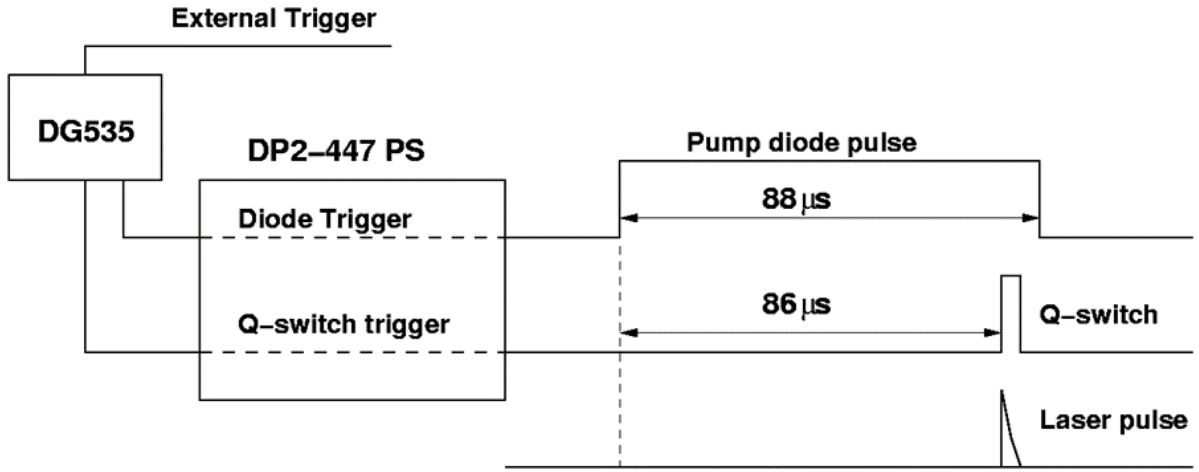
DP20-527 External Triggers



EXT FREQ : Each rising edge of an EXT FREQ TTL input triggers a laser output pulse. Any signal that generates a response in the laser controller is marked with an arrow.



DP2-447 External Triggers



After the 1st Service at Photonics

The laser was sent back to Photonics from June 21 – July 27, 2022, when the FPGA firmware was revised and two external triggers were introduced for pump diode and Q-switch respectively. The pulse jitter was reduced to 1~2 ns, meeting spec. A large pulse energy deviation and a large power drop by ~90% was observed, indicating a burned optic in the laser head.