# ATF Solid State Laser Operations

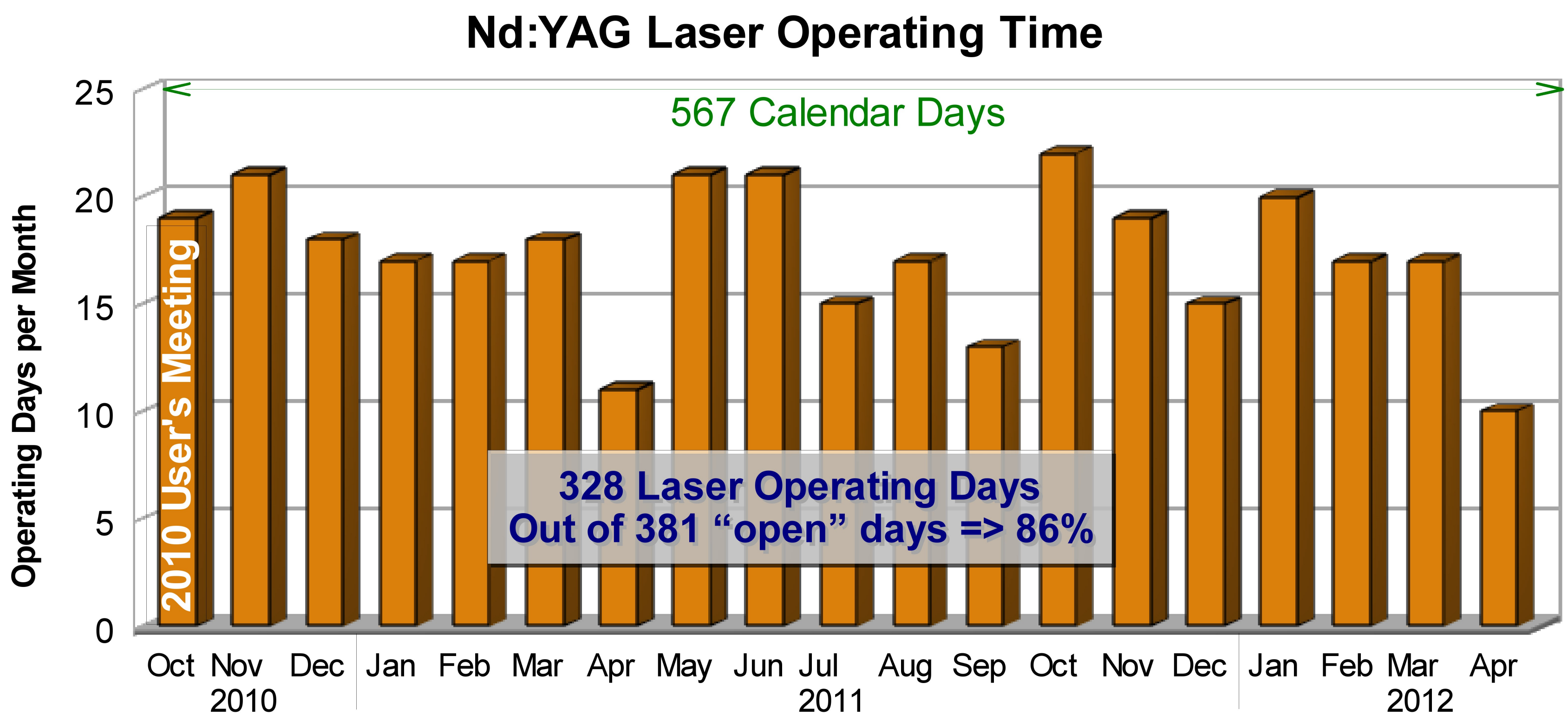
| | |
|---|---|
| Igor Pogorelsky | *$CO_2$ laser and experimental support* |
| Mikhail Polyanskiy | *$CO_2$ laser, simulations, diagnostics & data acquisition* |
| Marcus Babzien | *Solid state lasers, optical diagnostics* |
| Karl Kusche | *Laser safety, computer controls, and experimental support* |

# Current Nd:YAG Parameters

| | |
|---|---|
| Energy: (triple pulse mode) | |
| UV on cathode | 0-30 µJ x 1 pulse |
| IR to $CO_2$ laser | 10 mJ **x 2 pulses** |
| Laser output: total IR | 30 mJ |
| IR to gun | 7.5 mJ |
| Green | 2.5 mJ |
| UV | 500 µJ |
| Energy: (pulse train mode) IR | ~100 mJ / 20 pulses |
| Pulse duration (FWHM): | |
| Oscillator IR | 7 ps |
| Amplified IR | 14 ps |
| Green | 10 ps |
| UV | 8 ps |

| | |
|---|---|
| Transverse Distribution: | |
| Range of beam size on cathode (Ø) | 0.2 - 3 mm |
| Top-Hat Beam Profile Modulation (P-P) | <50% |
| Repetition rate | 1.5, 3 Hz |
| Shot-to-shot stability (rms): | |
| Timing | <0.2 ps |
| Energy | <0.8 % |
| Pointing (fraction of beam Ø) | <0.3% |
| Drift (8 hour P-P) | |
| Timing | <15ps |
| Energy | <5% |
| Pointing (fraction of beam Ø) | <1% |

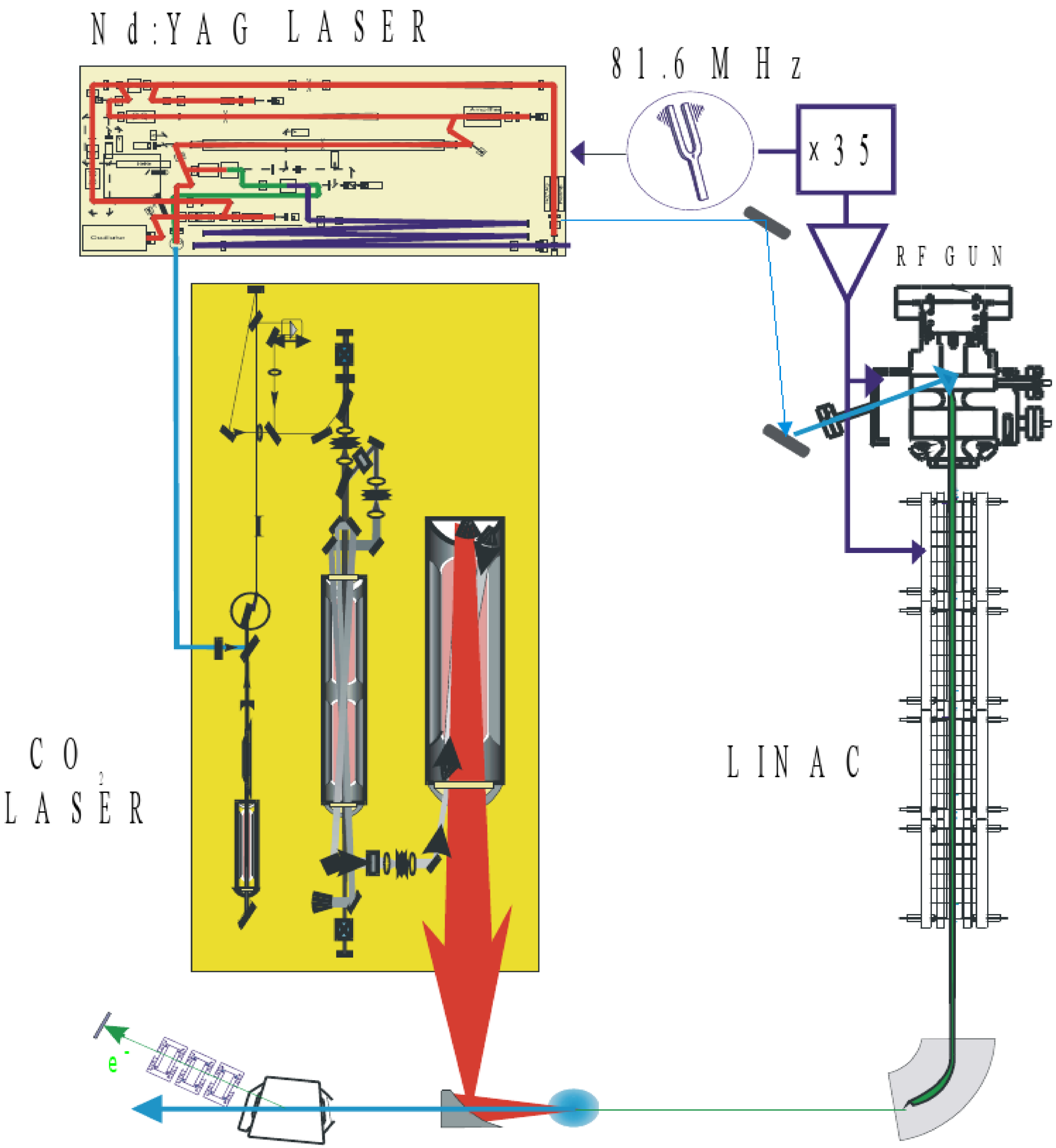
# Nd:YAG Running Time / Reliability




- Operating schedule demands increased since last meeting; laser delivered significantly more running time (67-86%)
- Now provide two pulses dedicated to $CO_2$ slicing in addition to photocathode pulse, no optical damage encountered in amplifiers
- Phase drift increased, necessitated feedback via Linac & RF system

# Drive Laser Central Role

- Generates primary facility user resources:
  -high brightness electron beam
  -high power $CO_2$ laser pulses
- Timing:
  time structure & synchronization of above to one another and other facility equipment (i.e. delay generators, data acquisition, diagnostics)
- Diagnostics pulses for experiments: e.g. Ion generation plasma density interferometry
- Cathode cleaning, detector characterization, optical timing fiducial, etc.



# New Drive Laser Goals

- ***Phase 1***: Replace current short pulse $CO_2$ slicing scheme to generate facility-synchronized short pulses at 10 $\mu$m wavelength
- ***Phase 2***: Replace current Nd:YAG laser generation of UV pulses for photocathode operation
- Improve above two functions primarily in temporal domain - shorter duration, broader bandwidth, lower timing jitter & drift
- Maintain or improve reliability & high uptime – affects availability of both beam & staff

# New Drive Laser Overview – Phase 1

FY 2010

**Oscillator**
20mW
40.8 MHz
170 fs
$60k

→

**2-stage Amplifier**
7 mJ
240 Hz
180 fs
$225k

→

**Parametric Generator**
Two-stage OPG
0.8->10.6μm ε~0.6%
<400 fs
$70k

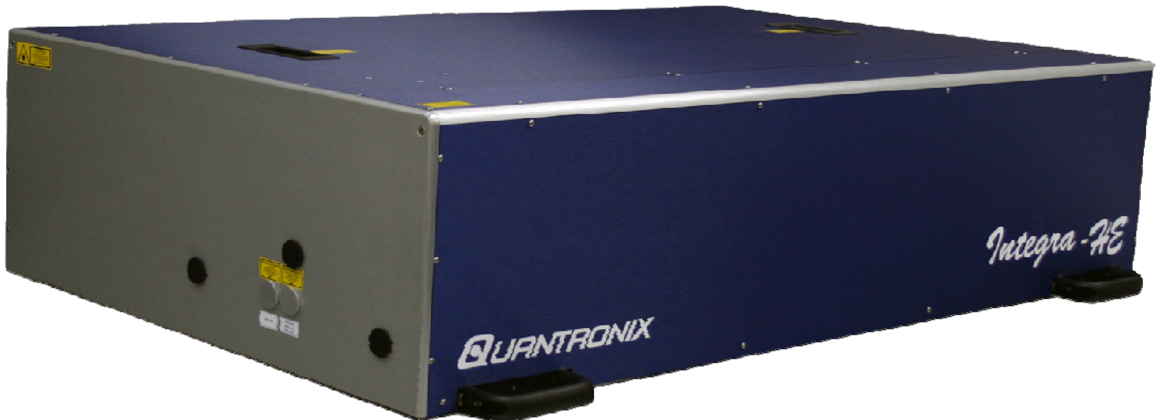
→

**Diagnostics**
FROG
& Misc.
$20k

- Fiber oscillator seeding for best stability and environmental insensitivity
- Ti:$Al_2O_3$ regenerative & multipass amplifiers for broad bandwidth, high energy near IR generation
- All diode-pumped system – regulated supplies unlike most flashlamp pumped systems
- 240 Hz repetition rate enables more online monitoring & feedback; serving multiple users via pulse switching in time domain
- Parametric generation for high MIR seed energy at shorter pulsewidth

# New Drive Laser Phase 1
# $CO_2$ Seeding

| | |
|---|---|
| Pulse Duration | <400 fs |
| Pulse Energy | ≥40 μJ |
| Repetition Rate | 240 kHz |
| Stability | <2% RMS |
| Beam profile | $M^2$<1.5 |

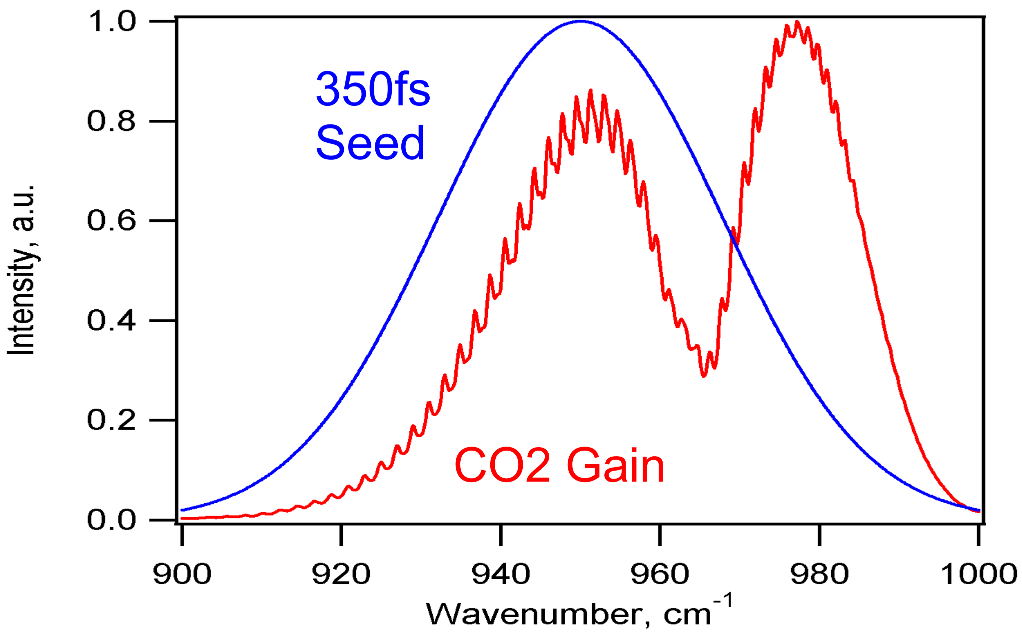



Amplifier footprint: 1x1.5 $m^2$

- State of the art has advanced to the level that Ti:$Al_2O_3$ ultrafast system can be more capable as well as smaller than the ATF Nd:YAG system.
- Nearly all commercial system with standard products
- Vendor selected & order placed  prior to end of FY2010

# $CO_2$ Seeding Improvements

- Bandwidth/duration as needed for amplification over entire $CO_2$ vibrational band – bandwidth filtering may be needed in the near term




- Energy: 0.1 μJ/3 ps → 40 μJ/350 fs & significantly higher contrast
- Shot-to-shot Stability: 20% → ~2%
- Compactness means more table space will be free after installation of new system (although more crowded during commissioning)

# Planned Benefits to Experiments

- Immediately (1 year) obtain 5x higher $CO_2$ power → higher $a_0$
e.g. ion beam energy increase
- Improved temporal resolution for PWFA interferometry, holography may be possible
- Ion beam generation experiment plasma density diagnostic pulses ~10x shorter, with lower jitter
- Higher gradient for IFEL experiments

# Anticipated Phase 2 Capabilities

| Oscillator | 2-stage Amplifier | Harmonic Generation | Shaping | Diagnostics |
|---|---|---|---|---|
| 20mW | 7 mJ | THG $\varepsilon$~10% | Temporal:TBD | FROG |
| 40.8 MHz | 240 Hz | <200 fs | ~$50k | Cross-correlator |
| 170 fs | 180 fs | $20k | Spatial:LCOS-SLM | Misc. |
| $60k | $190k | | $15k | $40k |

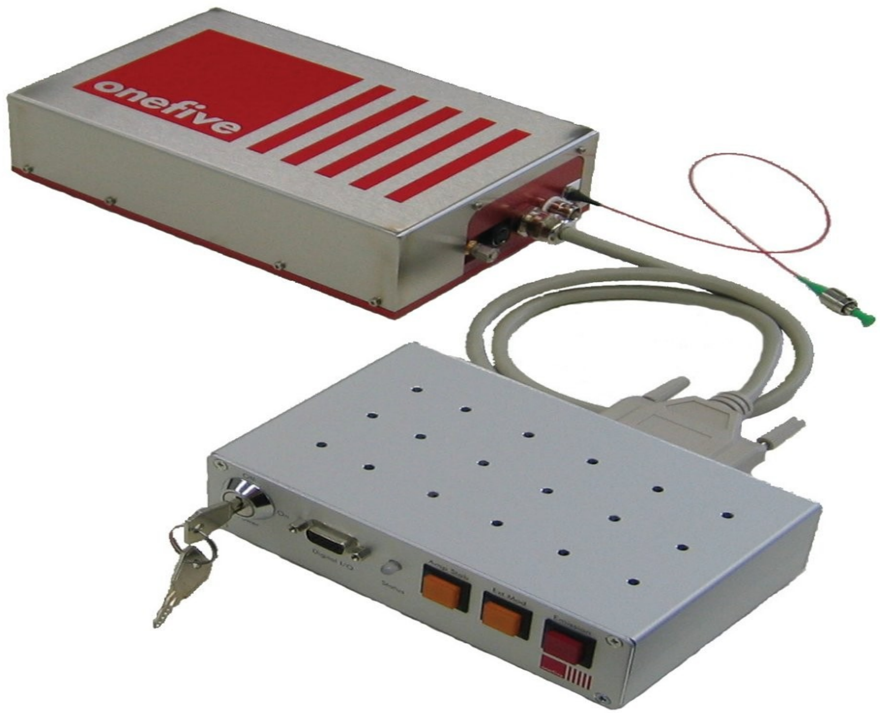
- Duplicate components include oscillator, amplifier, some diagnostics & controls.
- Much will be characterized from Phase 1

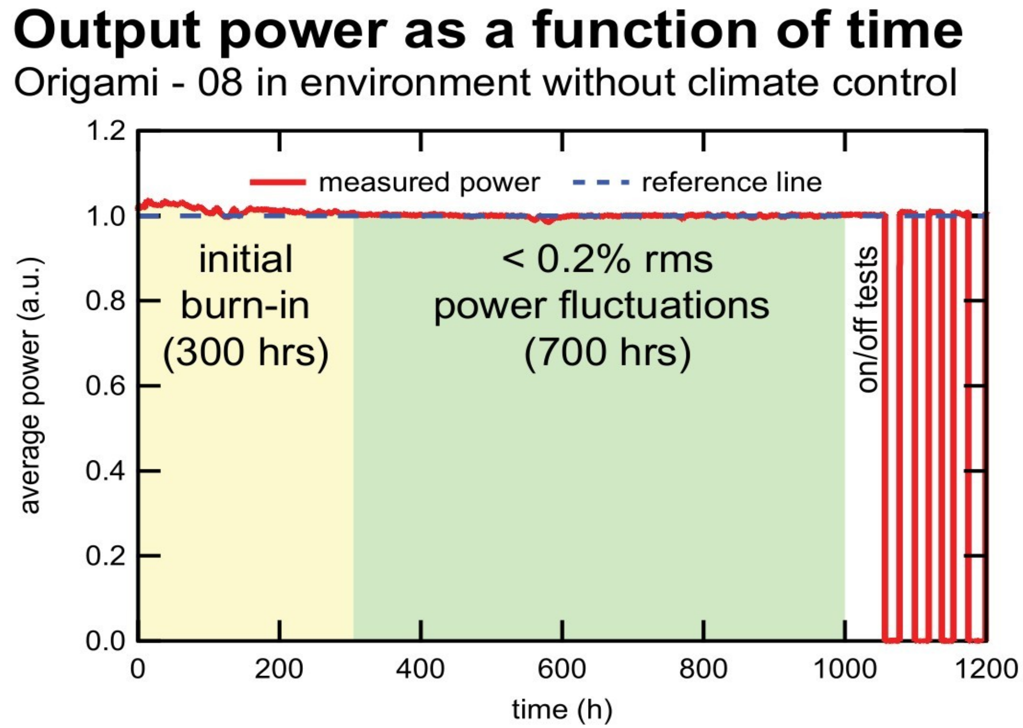
# Planned Photoinjector Benefit

| | |
|---|---|
| Pulse Duration | 0.2 – 10 ps |
| Pulse Energy | >600 uJ |
| Repetition Rate | 240 Hz |
| Stability | <2% RMS |
| Beam profile | $M^2<1.5$ |

- Short pulse: study 3D elliptical beam from photoinjector at low charges
- Stacked pulses: achieve flat-top in time – Lower emittance in high charge regime
- Spatial profile flattening possible with liquid crystal modulator

# Planned Operational Benefits




- Downtime expected to be comparable to present system because of newer components, diode pumping, reduced component count
- Most subsystems will be temperature regulated → minimal warm-up
- Alignment drift, component degradation to be determined, but new system is smaller. Offline characterization possible before installation.

# Upgrade Status: Phase 1

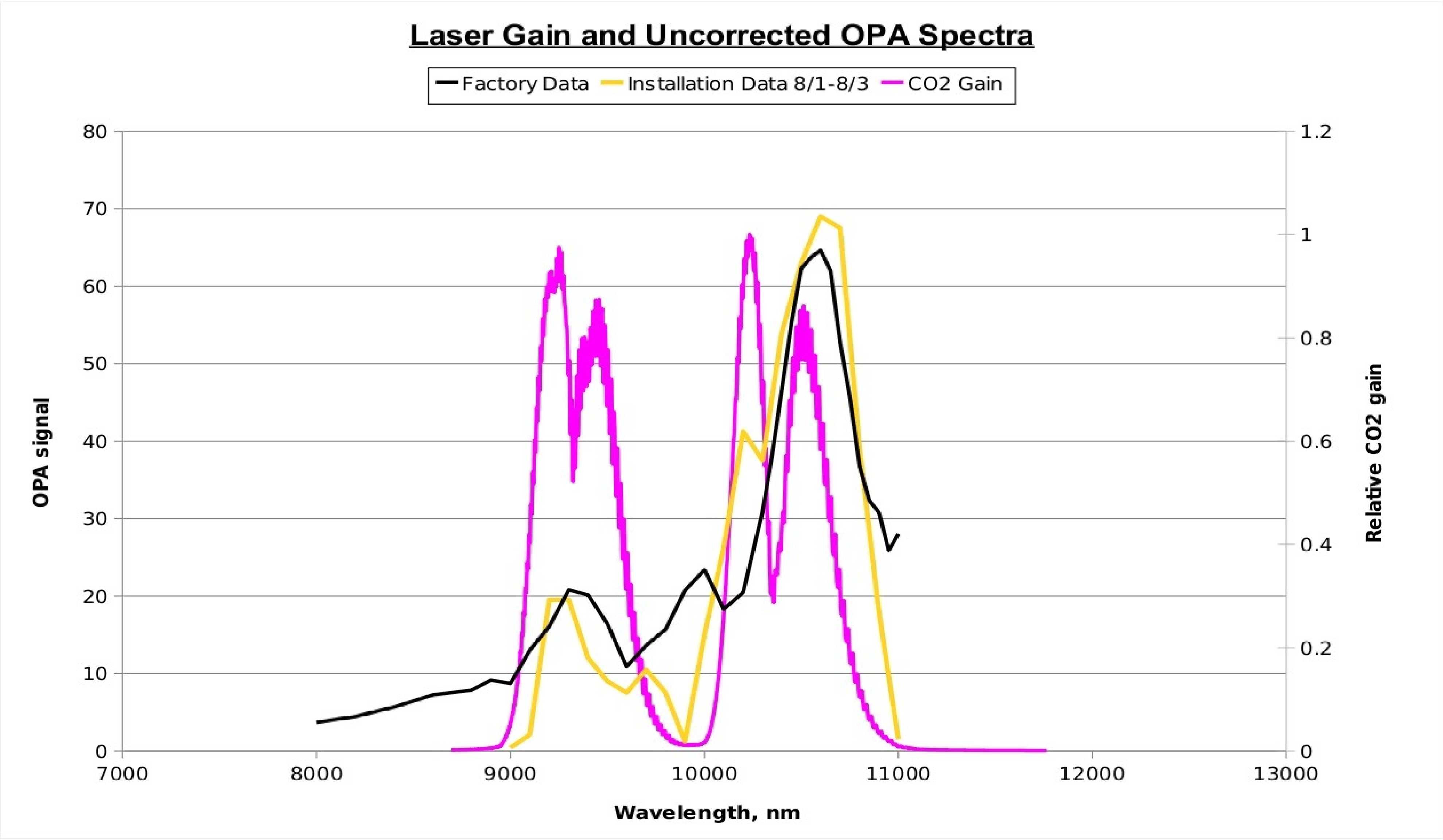
- Infrastructure upgrades completed as required (clock, timing system, mechanical utilities, personnel protection interlocks)
- Phase 1 system received July 2011 after some unanticipated delays
- Acceptance testing confirmed that design parameters could be achieved and identified items requiring improvement
- Currently working with vendor to develop long-range plans for system support
- System has been installed in temporary enclosure in $CO_2$ room
- Preparations for initial amplifier tests and integration of diagnostics (energy, spectrum, pulseshape) are in progress
- Expect amplification test results this fiscal year

# Phase 1 Testing Summary

- Oscillator provides turn-key operation after quality control issues were resolved
- Phase locking in progress
- Amplified NIR energy level & stability within specification:

  7mJ with 0.4%σ
- Parametric conversion: Measured 40uJ pulse energy in broad, tunable spectrum

# Phase 1 Tests – OPA Output

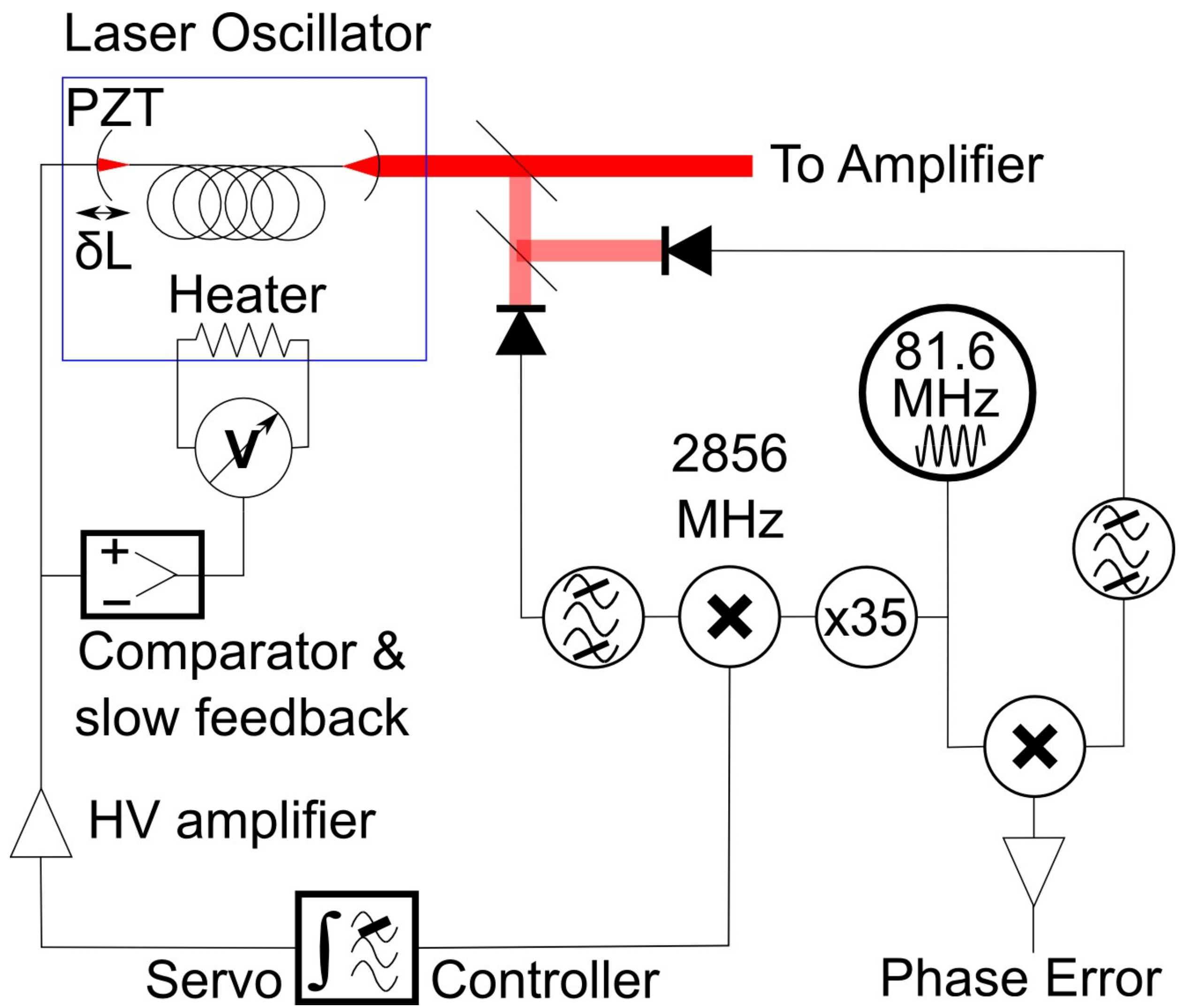


# Phase Locking Studies

- Fiber oscillator turnkey, but requires improved RF electronics
- Studied existing solutions, but few had significant usage in real world service at accelerator with our requirements & parameters
- Decision made to assemble phase lock loop in-house
- Component characterization and testing in progress

# Phase Locking Overview

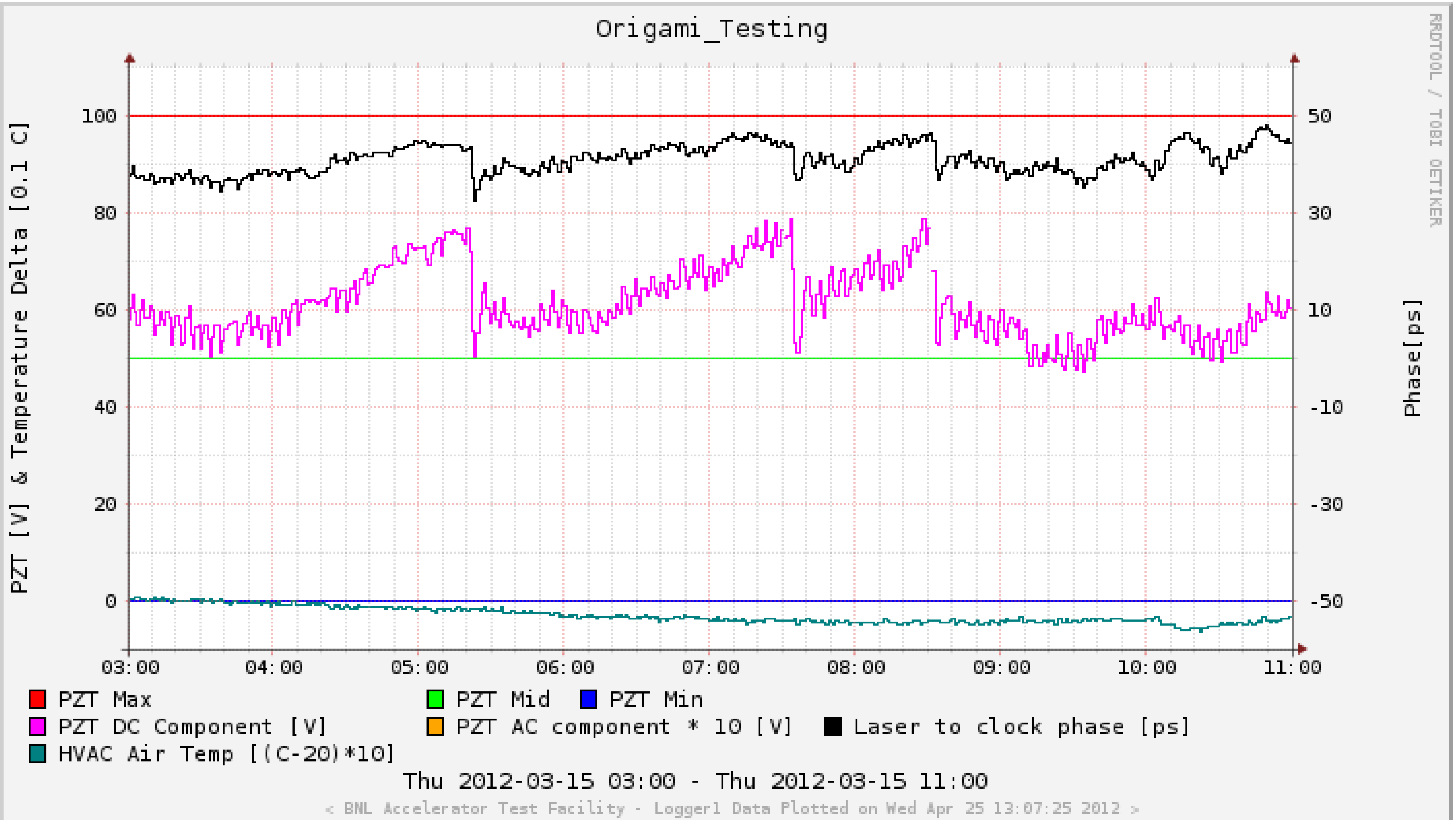
- Mixer inside PLL generates phase signal for locking
- Out-of-loop mixer independently measures error
- Currently locking laser to crystal clock
- Later, lock second laser oscillator via RF PLL
- Distribute optical signals via singlemode fiber to minimize drift



# PLL Testing

- dΦ/dT measured for all components
- Temperature-stabilized heat sinks for mixers running stable to 0.01˚C
- Chassis enclosure for full system nearing completion with ~0.1˚C temperature stabilization
- Critical component AM-PM conversion measured where manufacturer specification not available

# Current(Best) PLL Performance



# Phase 2 Status

- Purchase completed end of FY2011
- Factory testing performed with different seed oscillator
- Complete shipment received from vendor
- Unpacking to begin when finished with first system
- Acceptance testing and UV transport line construction required before commissioning with photocathode gun
- Purchase of second seed oscillator required for simultaneous operation of both $CO_2$ and gun laser systems ($60k) still pending further tests

# ATF Solid State Laser Operations

## *Thank you*

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