Ultrafast oscillator and kHz amplifiers for use in FELs and Synchrotrons: meeting performance and reliability demands

11/11/2012

COHERENT®

Overview

- Application requirements (laser industry, point of view)
- Highly-stable, reliable & flexible oscillator design: Vitara
- High power/energy & stable amplifier configurations: Legend Elite HE+
- Supporting large-scale installation

Coherent installations at FEL/accelerator facilities

Ps/fs UV photo-injection
(THG of Ti:S)

UV FEL seeding
(DUV OPA)

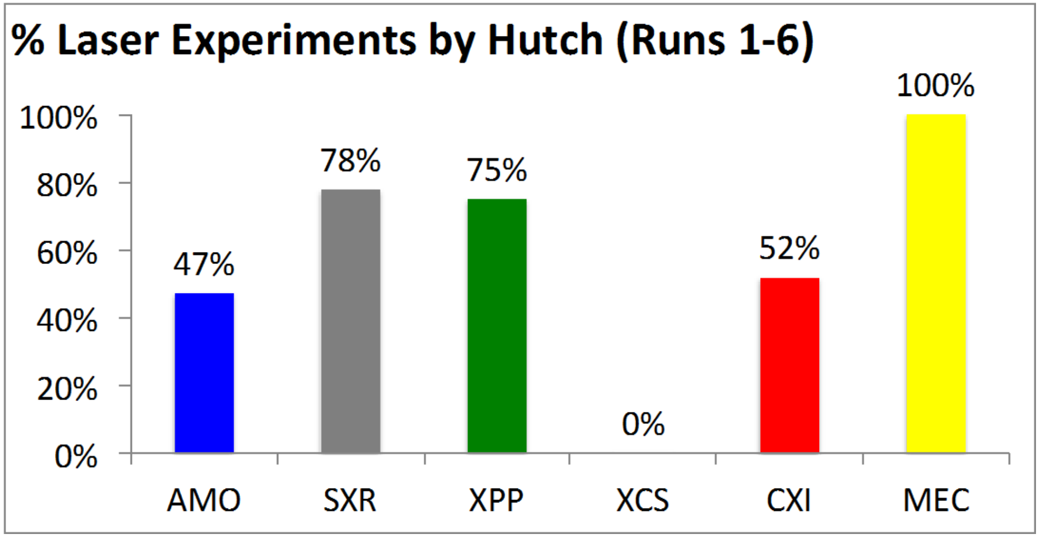
Pump (or probe) beam at experiment location
(UV to mid-IR, THz)

Ideally all lasers synchronized to FEL with jitter comparable to laser/FEL pulse

Examples: LCLS at SLAC - Stanford

- FEL Photo-injection
  - Customized Legend Elite amplifier (1 ps, 760 nm)
    - Home-built MPA to 20 mJ/120 Hz
    - Chirped to 3-5 ps at compression
    - THG (~ 2 mJ) at 253 nm (for maximum QE)
    - Spatial mask imaged on Cu photocathode at ~ tens of μJ
- Experiment (hutches)
  - Five Legend Elite USPs seeded by Vitara, most with home MPAs to 20-25 mJ compressed at 120 Hz
    - Four OPAs
    - THz generation via 800 nm (Ti:S) / 1.5 micron (OPA) in LiNbO / DAST using optical rectification method
- Home-built timing synchronization with Vitara actuator slaved to LCLS electronics

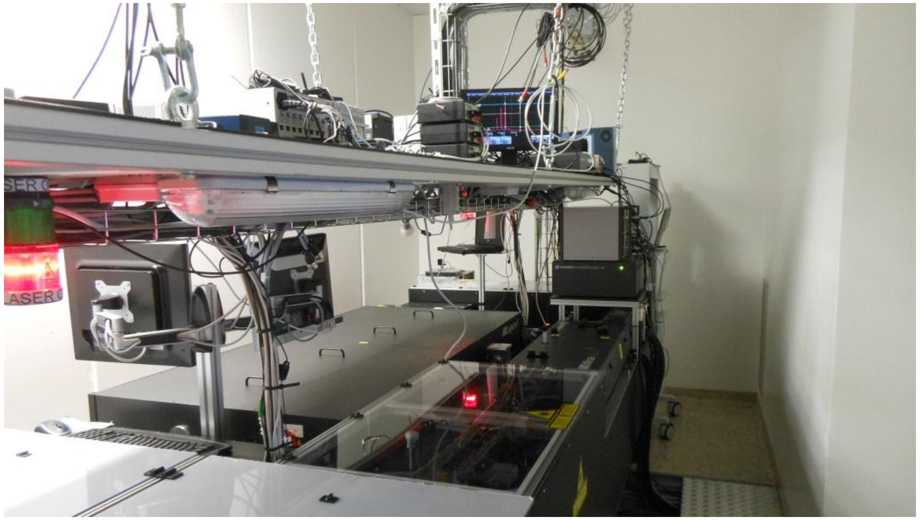
Examples: LCLS at SLAC - Stanford

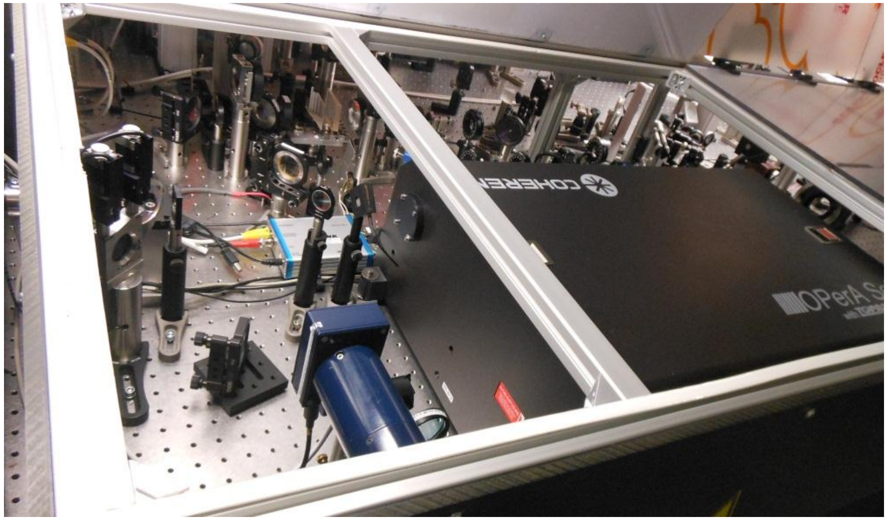


- Ti:sapphire
  - 400 nm, 266 nm & 200 nm: BBO/nonlinear upconversion
- OPA
  - UV to Visible to IR (240 nm to 2600 nm): signal & idler harmonics & SFG
  - mid IR (4 micron to 18 micron): DFG with signal & idler in GaAs
- THz
  - tilted pulse front optical rectification, organic crystals, plasma generation
- Deep UV
  - Gas target HHG in development

Examples: FERMI at Elettra - Sincrotrone di Trieste

- FEL Photo-injection
  - Hidra Elite amplifier (780 nm, 18 mJ at 50 Hz 100 fs)
    - Regen+ 2 stage 2PA
- FEL seeding
  - Legend Elite amplifier + Opera Solo OPA (240 nm output)
- Home-built timing synchronization





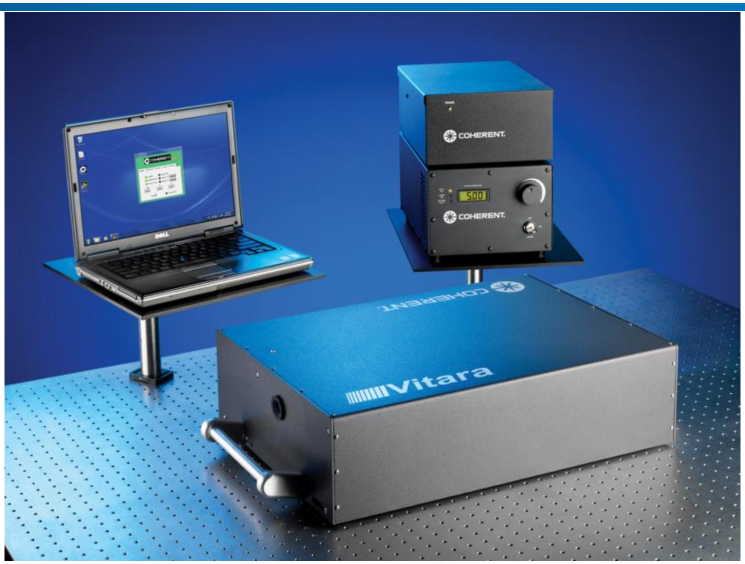
Key parameters/relevance

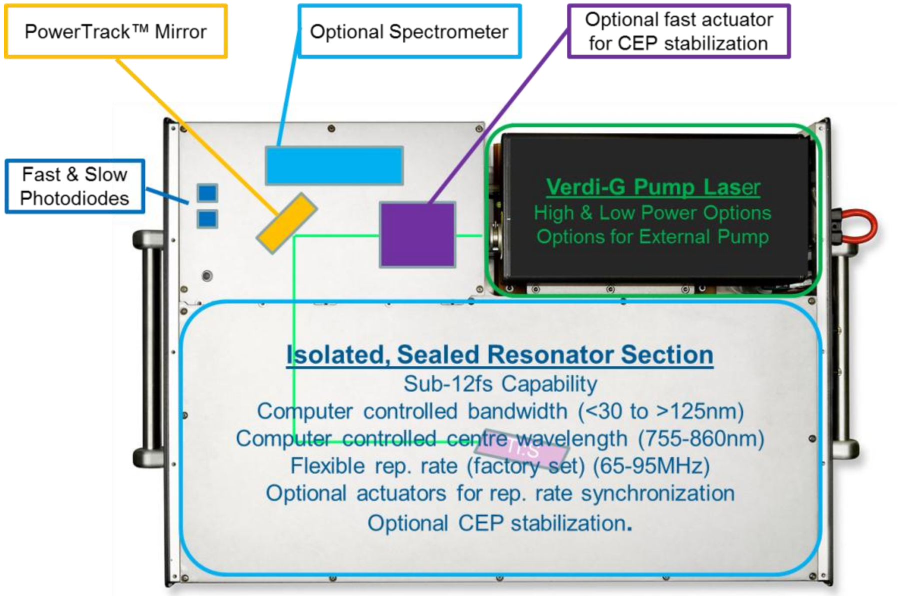
- Most "amplified" UF applications require non linear devices (HG, OPA, HFC, EUV, THz, attosecond)
- Power & overall stability of the laser are key for time-efficient, accurate, high S/N ratio data generation

- Photo-injection:
  - Beam spatial and temporal profile
  - Pulse to pulse stability
  - THG pulse energy (> 2-3 mJ) & conversion efficiency
- FEL Seeding:
  - Tuneability (via OPA) around 240 nm
  - Wavelength and bandwidth stability
- Experiment:
  - Standard Pump and probe requirements from 200 nm to 20 micron, up to THz (+ synchronization)

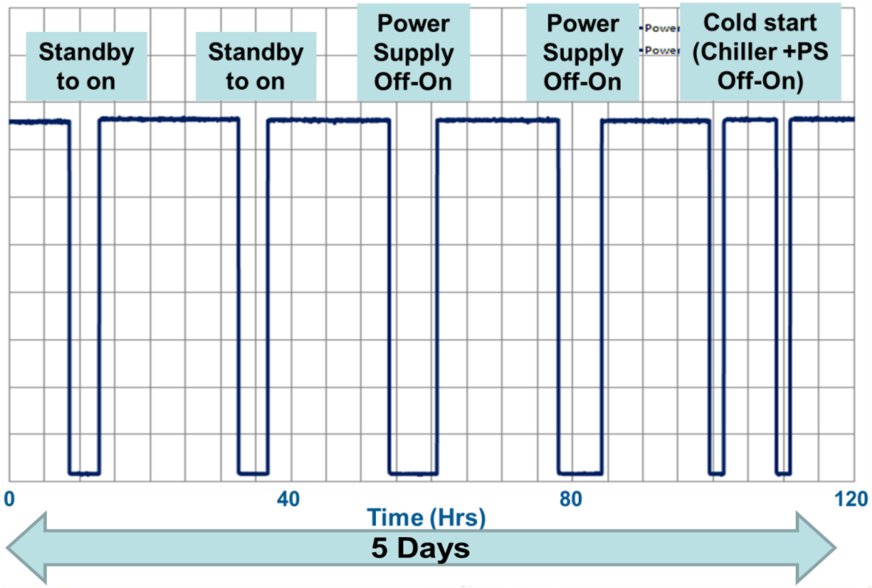
Vitara flexible & hands-off UF oscillator (2011)

- Broadband: 125 nm
- Tunable: 110 nm
- Computer-controlled
- Actively and passively stabilized
- Sealed & clean-room built
- Flexible: rep rate, CEP, external synchronization

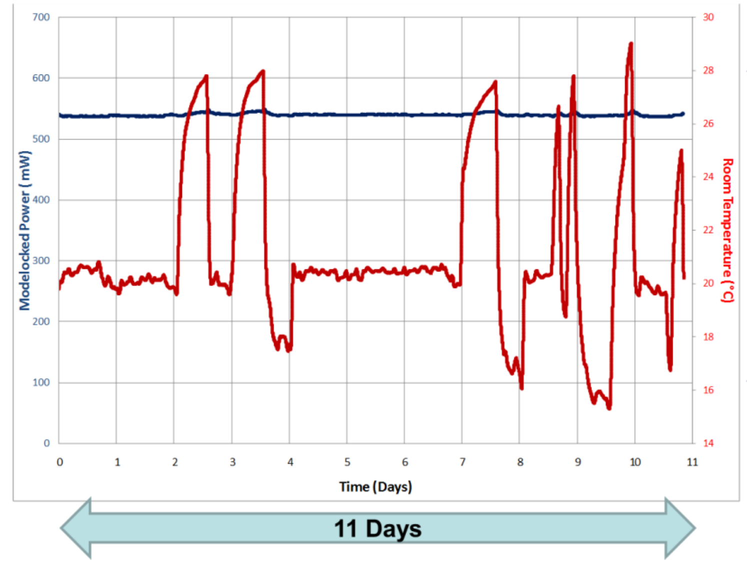


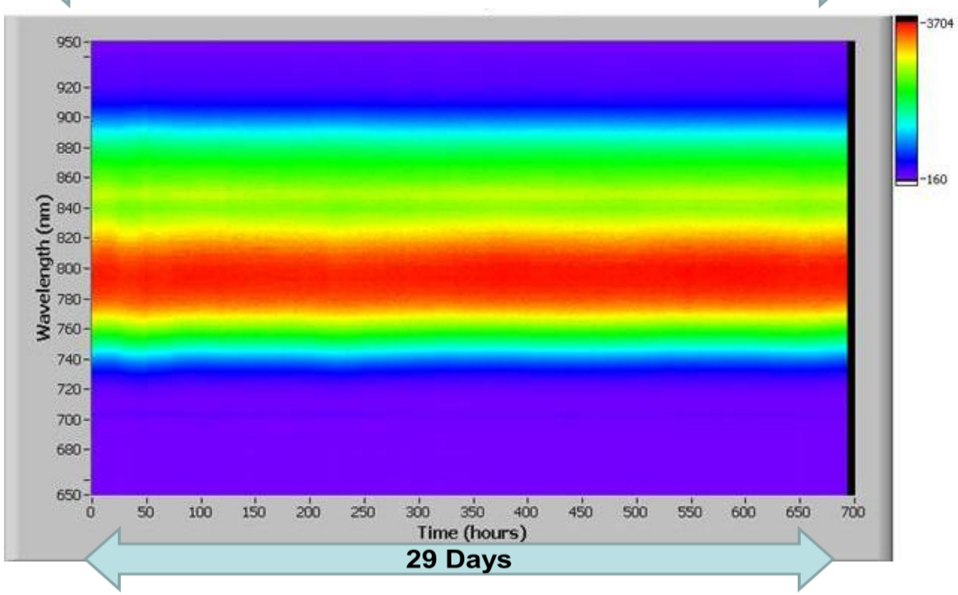


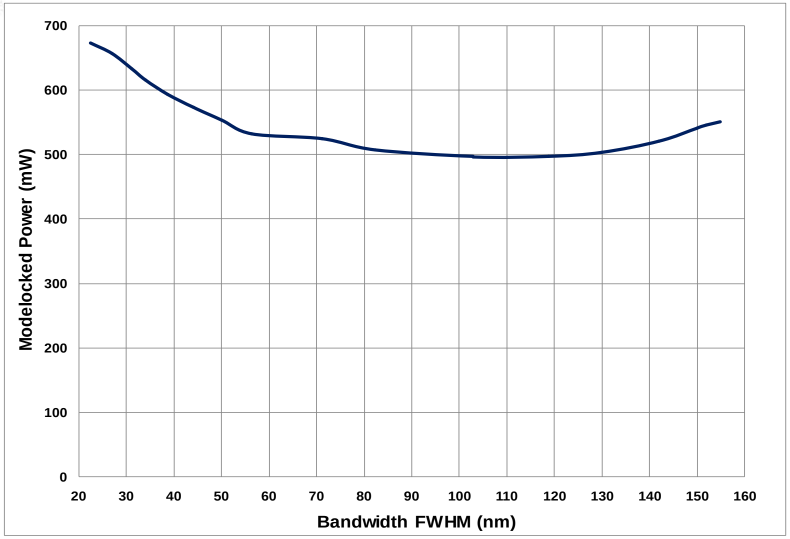
Vitara: designed and built for stability



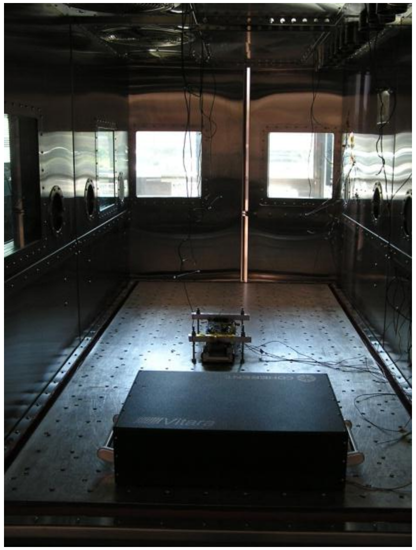
RMS Power Stability = 0.63% over 260 hours



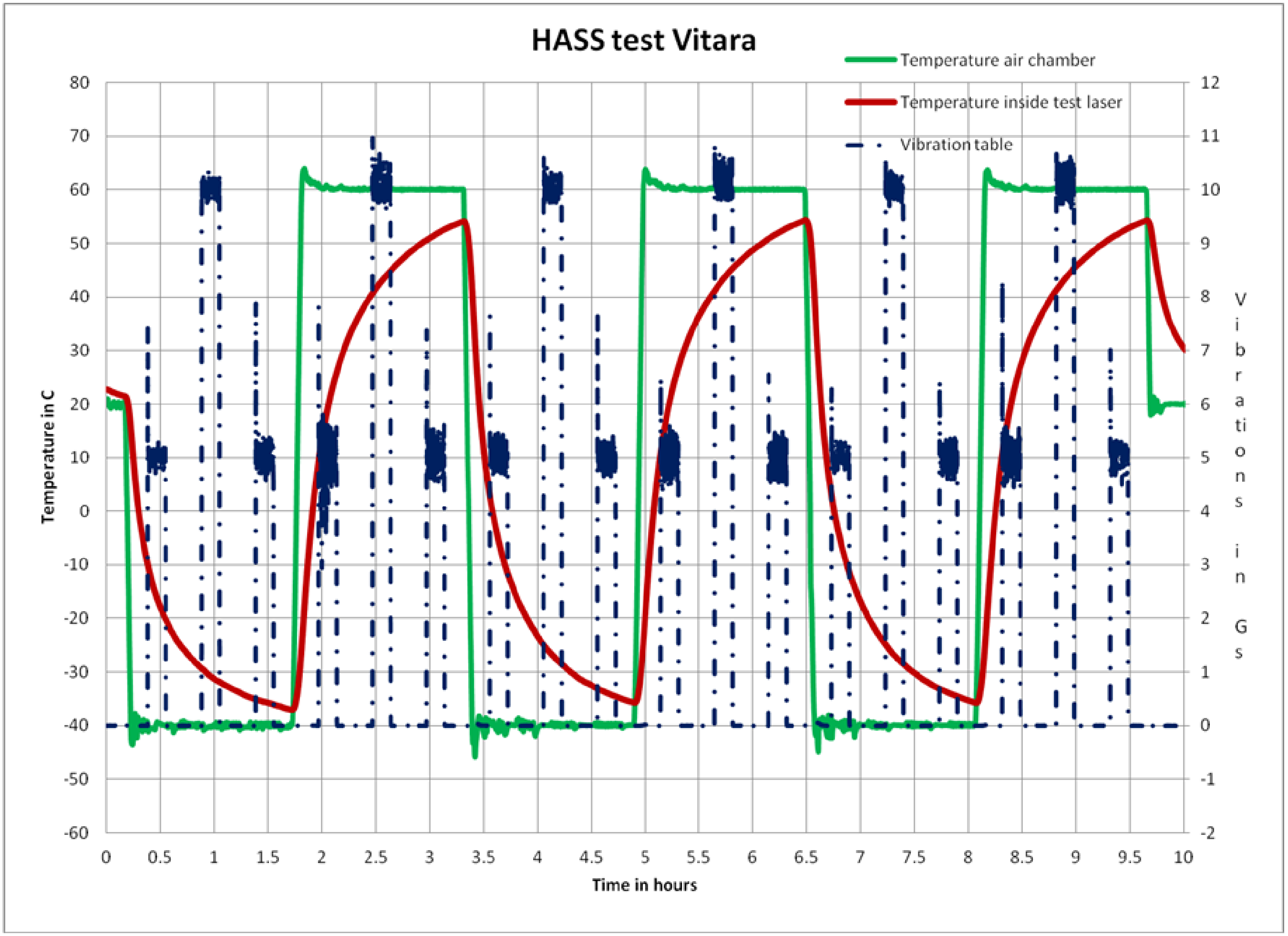




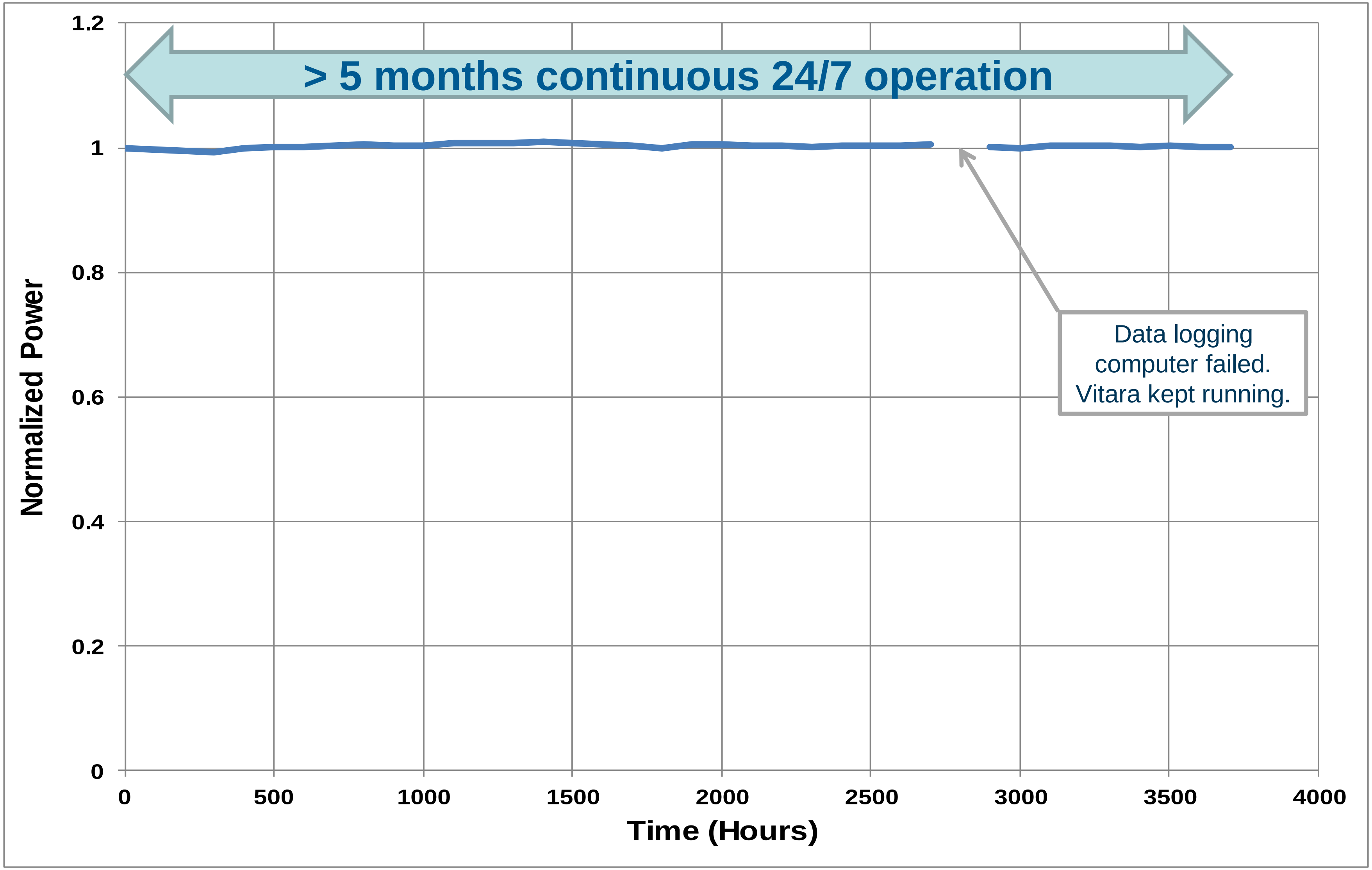
Highly Accelerated Stress Screening (HASS)



- Production Vitara lasers are subjected to 10 hours of stringent stress testing
  - Temperature cycling from -40°C to +60°C
  - Three axis vibrations cycles to 10G



Lifetime example



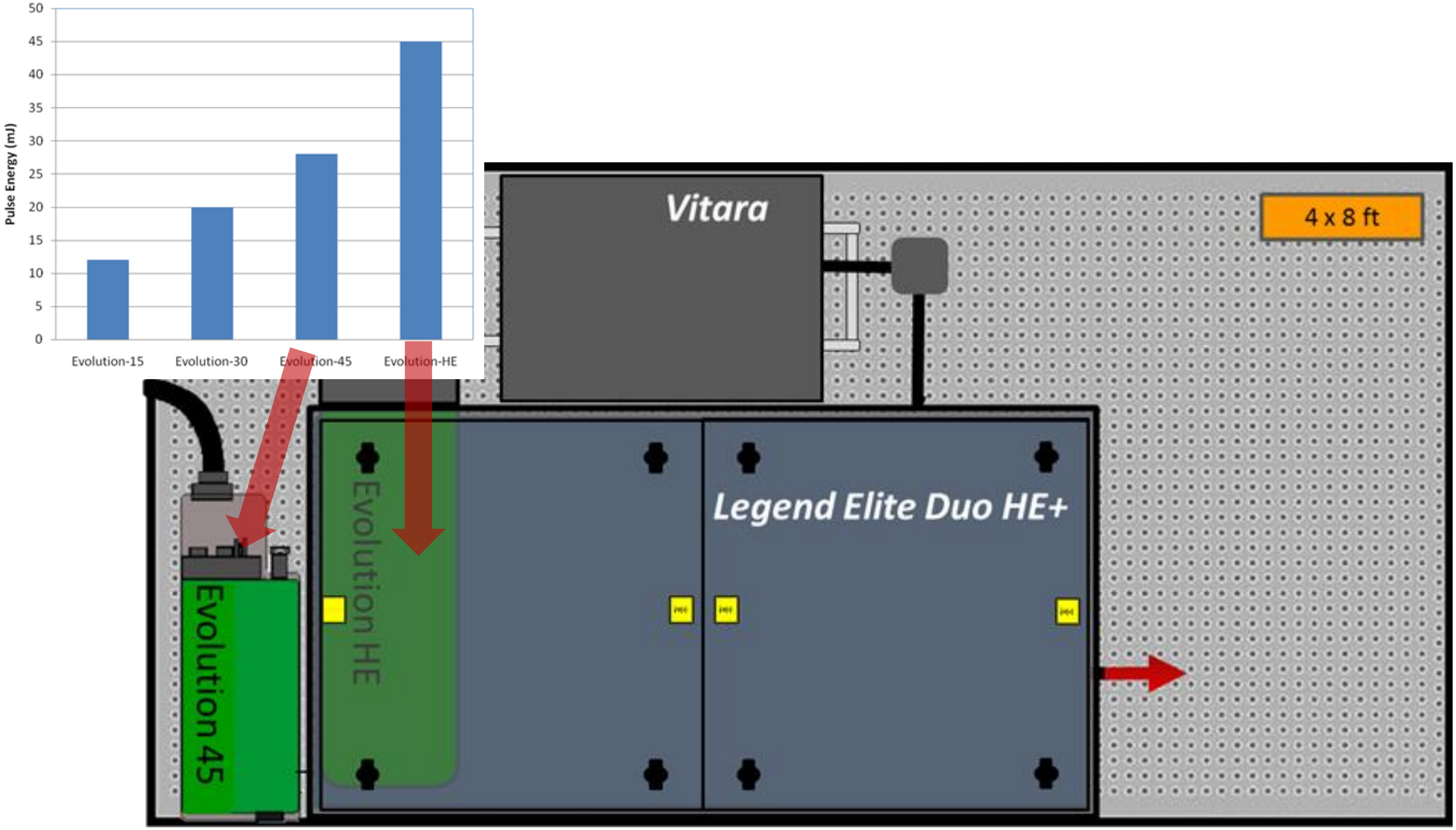
Legend Elite and Libra: Power

Legend Model	Configuration	Evolution pump(s)	cooling	Energy (at 1kHz)	CEP comp?	Pulse duration (fs)
Libra	Regen (1-box)	15	Water	1mJ	No	50 /100
Libra HE	Regen (1-box)	30	Water	4mJ	No	50/100
HE+	Regen	15	Water	1mJ	Yes	25/35/130/ps
HE+	Regen	30	Water	4mJ	Yes	25/35/130/ps
HE+	Regen	45	TEC	5mJ	Yes	25/35/130/ps
Duo HE+	Regen+SPA	HE	TEC	8mJ	Yes	25/40/130/ps
Duo HE+	Regen+SPA	30+HE	TEC	10mJ	Yes	25/40/130/ps
Duo HE+	Regen+SPA	45+HE	TEC	12mJ	Yes	40/130/ps

Regen + Power Amp (1kHz)	Output Power [W]	M2
Single-pass	8.0	1.1-1.2
Double-pass	10.2	1.5-1.6

- SPA approach minimizes thermal aberration of amplified pulses

12 mJ/1 kHz Legend Elite HP+: Pump enabled



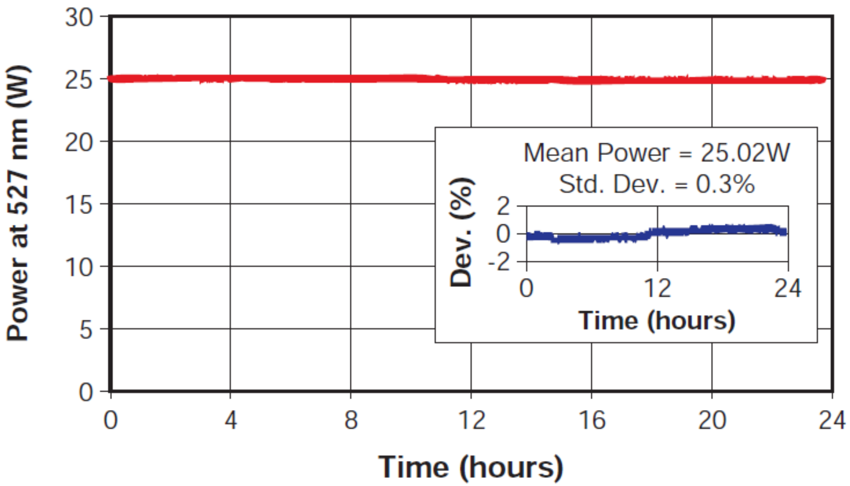
- Unique high-energy pump laser provides foundation for high power
- Next step: thermal management and stable design

FEL and lasers: KHz Vs. Hz

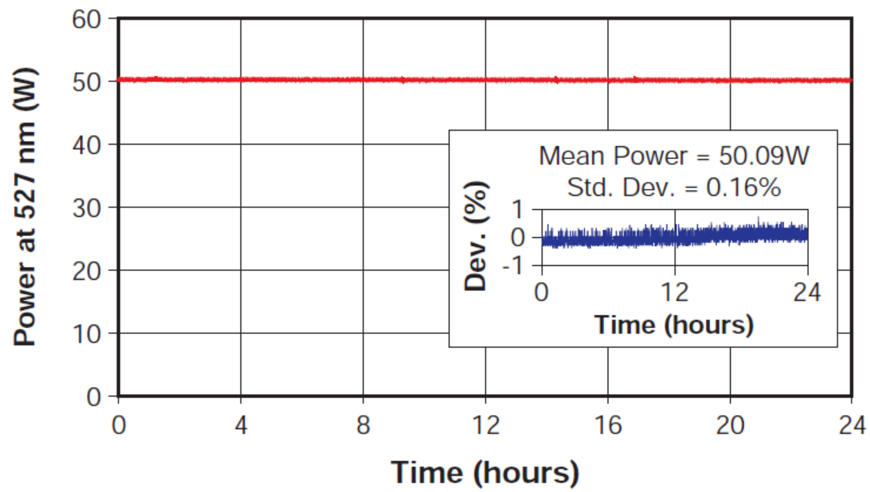
- Most FELs require laser operation at 10-100 Hz level
- Amplified TiS ultrafast systems architecture:
  - 5-20 Hz: flash lamp pumped Q-switched green laser
  - ~ 100 Hz: QCW diode-pumped Q-switched green laser
  - 1-10 kHz: CW diode or CW flashlamp-pumped Q-switched green laser
  - ~ 100 kHz: CW diode-pumped, CW green laser
- CW diode pumping provides inherently lower noise to the green pump and amplifier than any other approach
- Trade off is energy/pulse Vs. average power
  - 100 Hz/100 mJ ←→ 1 kHz/10 mJ

Pump and regenerative amplifier stability

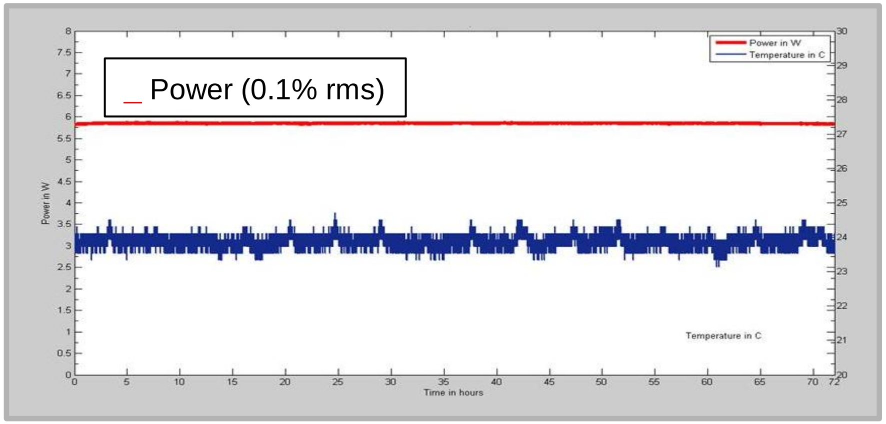
Typical Evolution-30 Power Stability



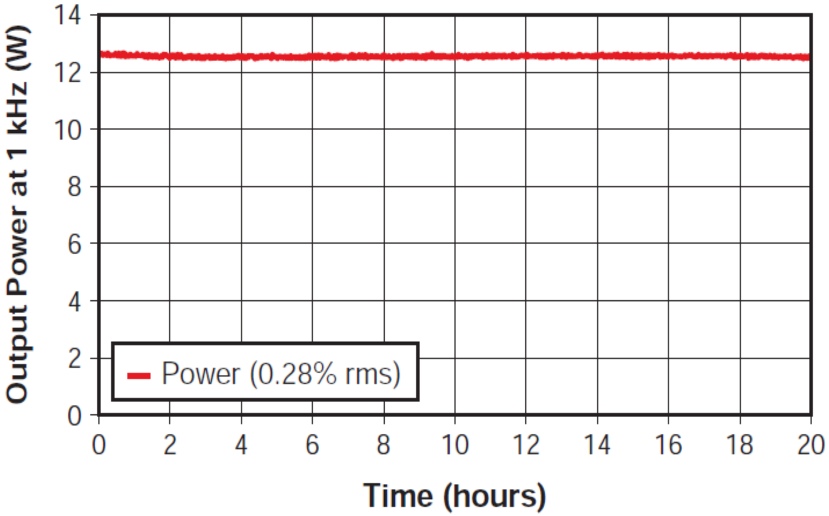
Typical Evolution-HE Power Stability



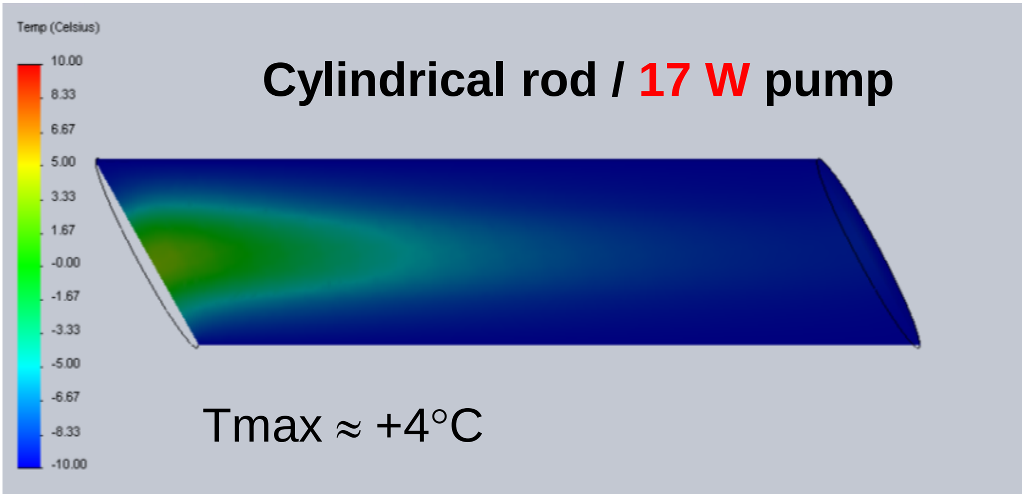
Legend Elite HE+
Long Term Power Stability

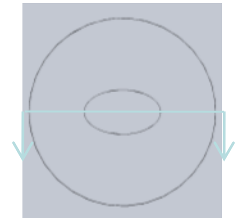


Legend Elite Duo HE+
Long Term Power Stability



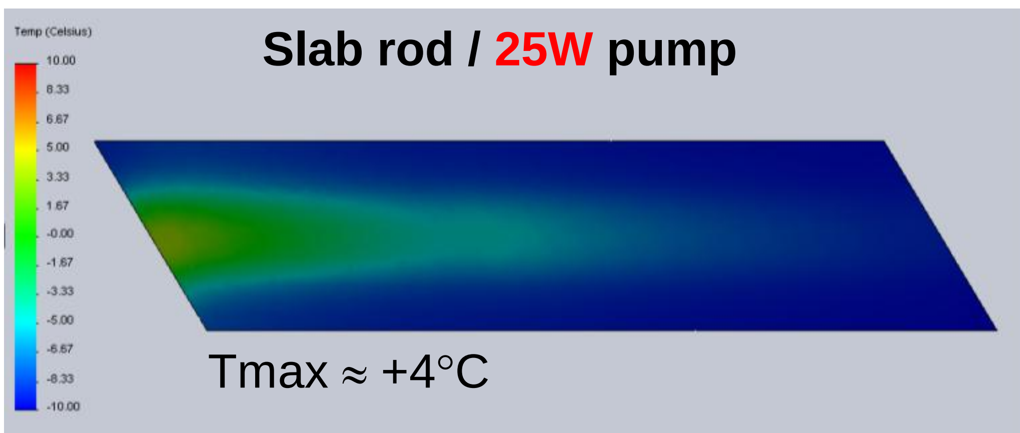
Slab rod design: managing high power





Φ=6.35mm

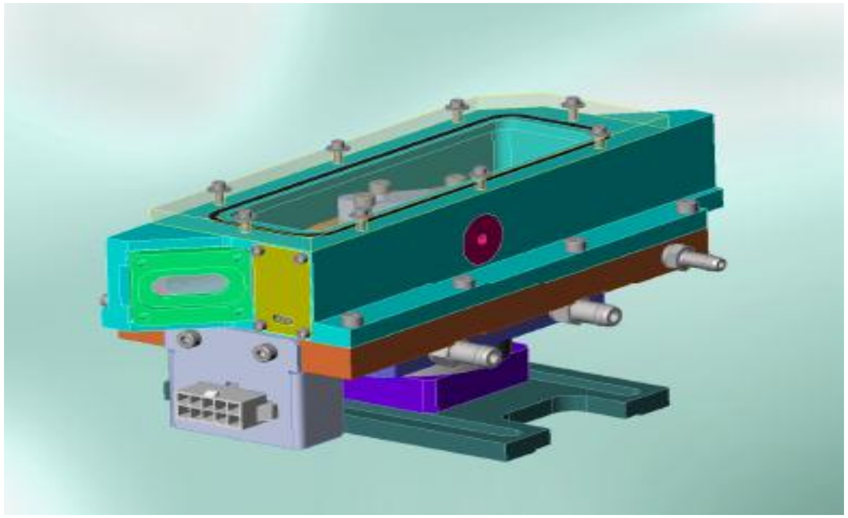
-10°C boundary condition on outer surface of rod

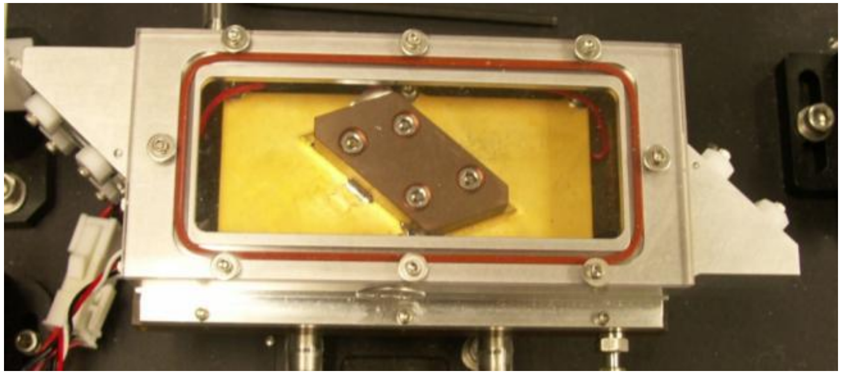


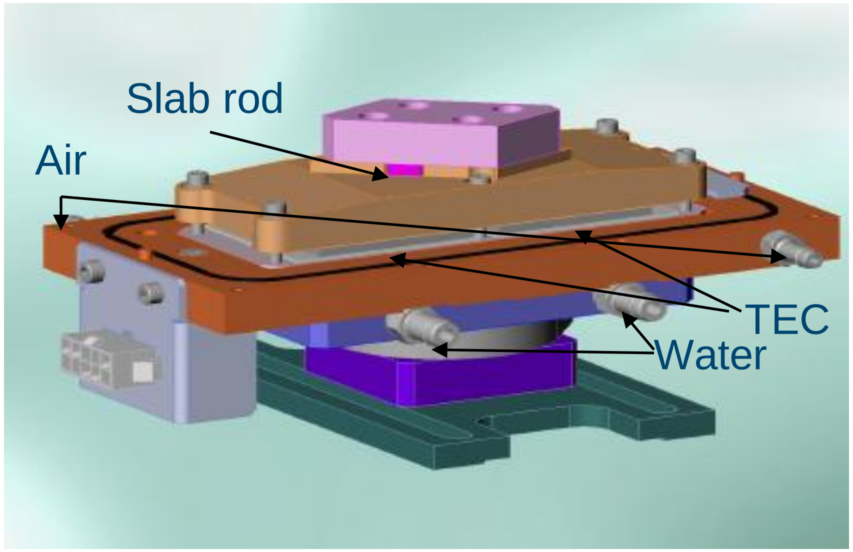
6.35mm
x
3mm

-10°C boundary condition on top and bottom surfaces of slab

Advanced Rod Housing





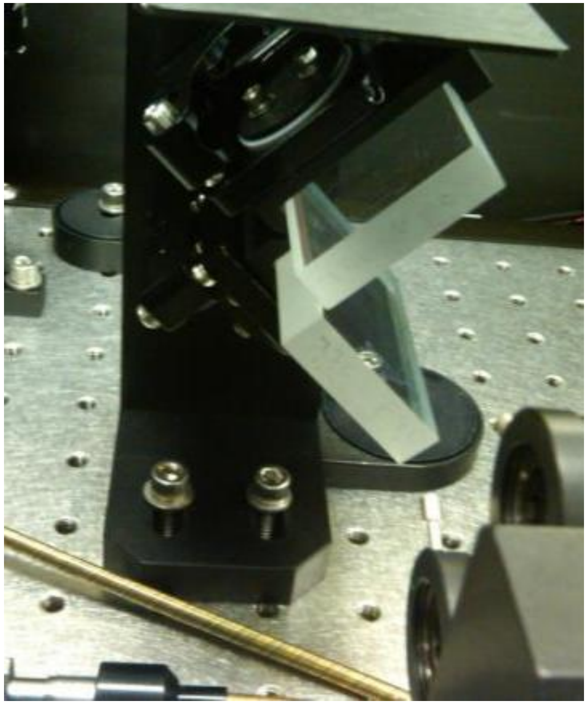


- Enhanced TE-cooling rectangular cross section rod:
  - better heat management
  - better thermal contact with mount

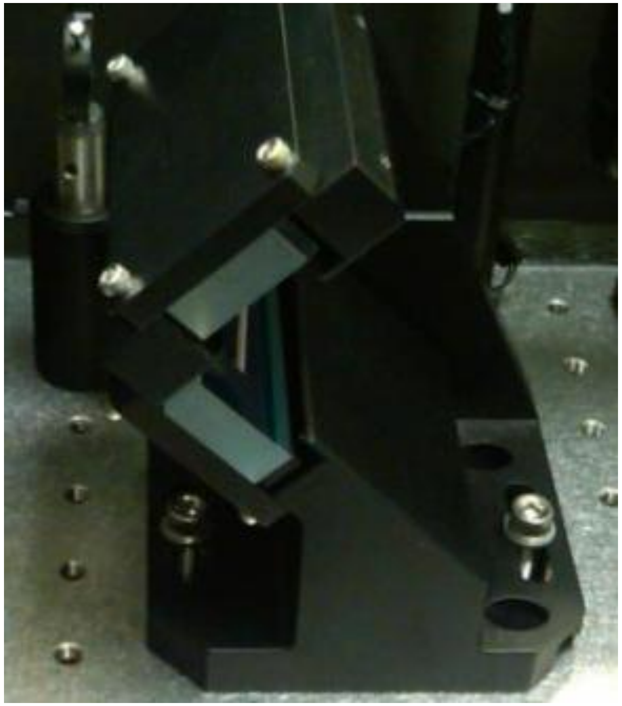
Legend Elite Duo HE+: The CEP lesson

- All Legend Elite HE+ benefits from CEP (Carrier to Envelope Phase) stabilization expertise
  - All HE+ models are CEP-ready
- Robust monolithic stretcher/compressor mounts and optics

Pre-CEP style

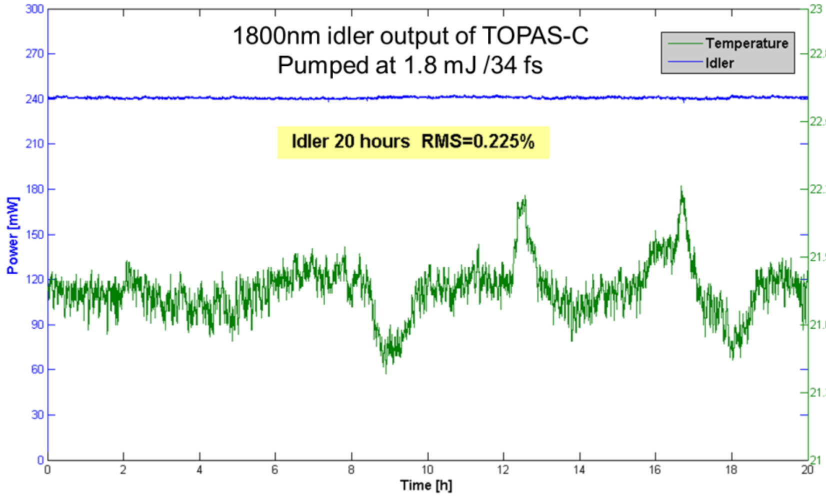


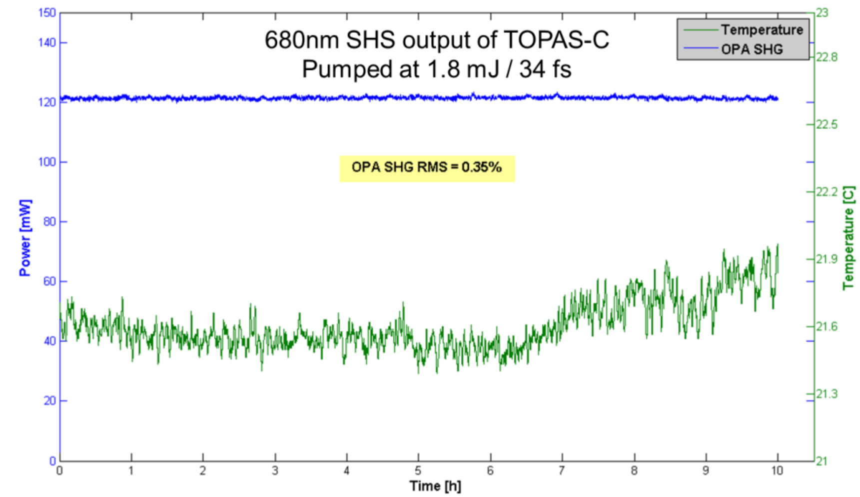
CEP re-design



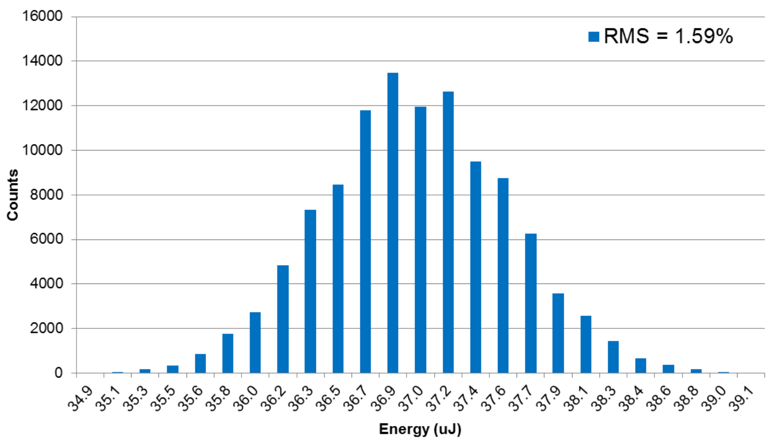
Other view

Legend Elite HE +: OPA noise and stability

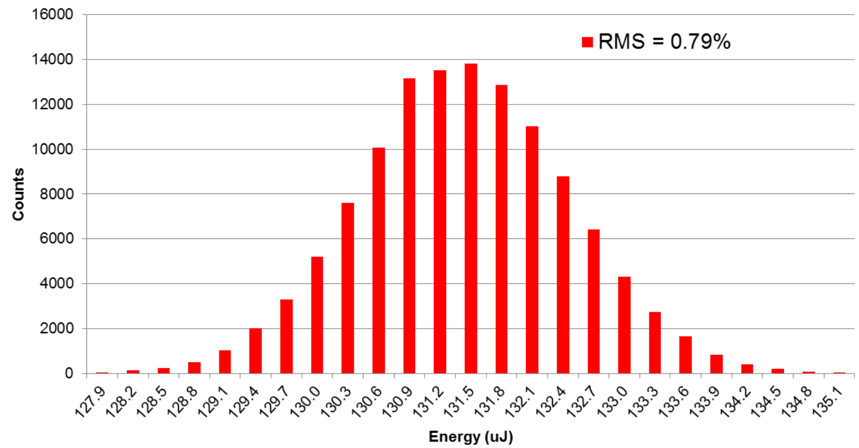




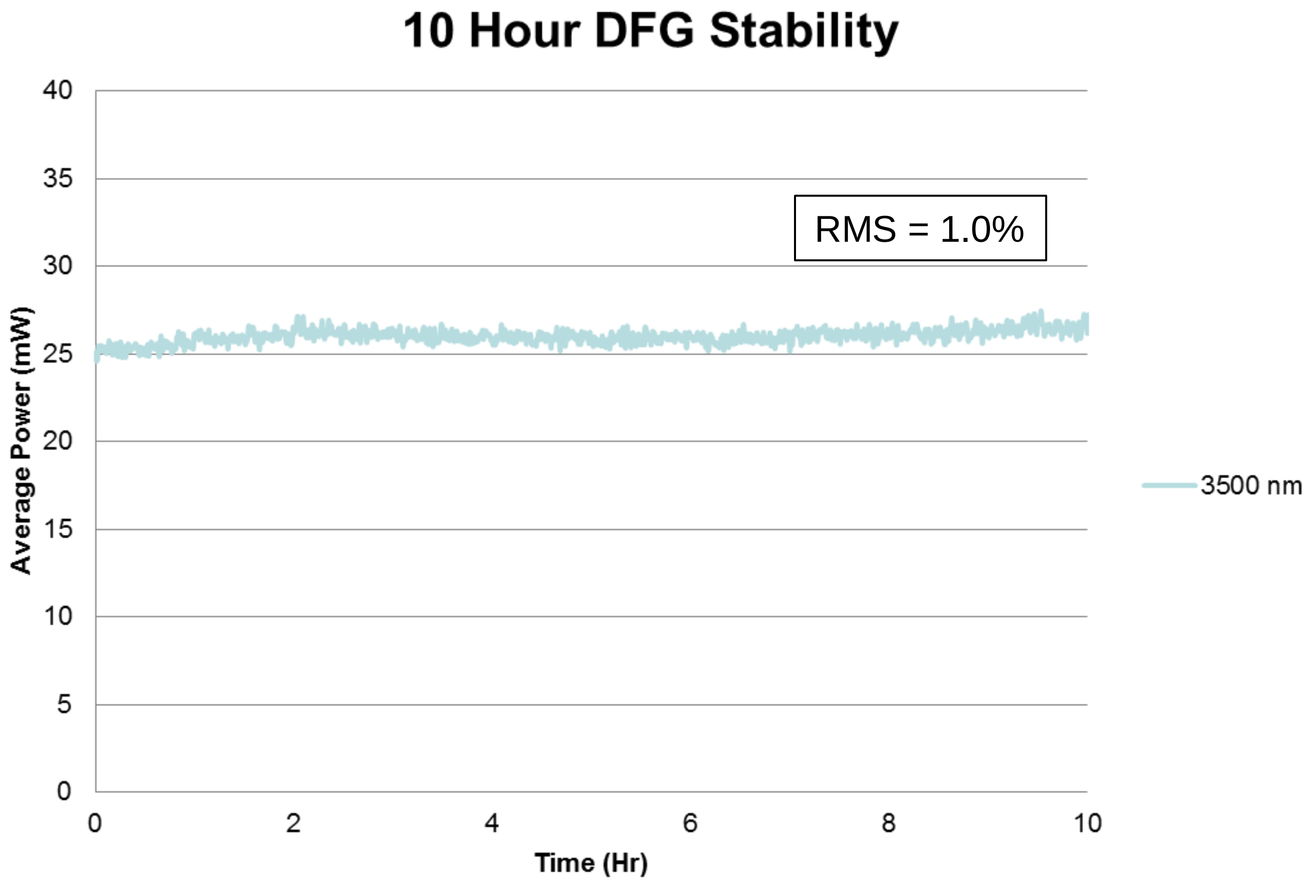
OPA FHS 2 min Shot-to-Shot Stability (340 nm)



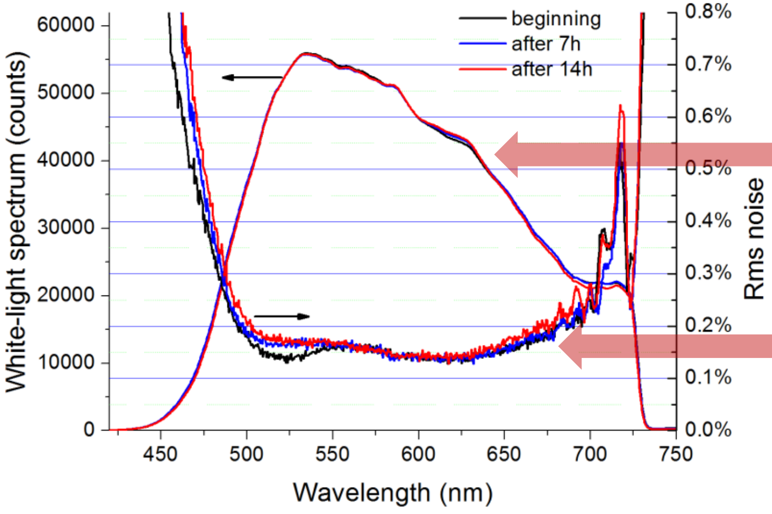
OPA SHS 2 min Shot-to-Shot Stability (680 nm)



OPA DFG noise and stability at 3.5 micron



White Light continuum stability: Libra HE

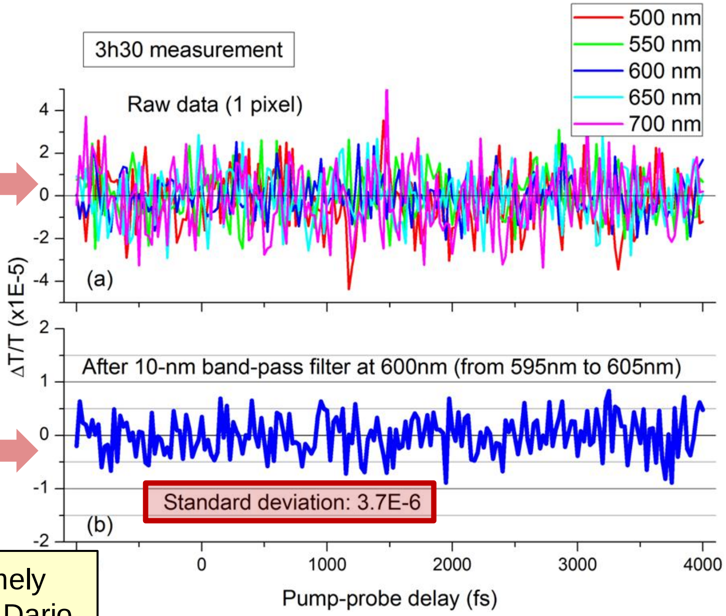


White Light power spectrum over 14 hrs

White Light spectral noise over 14 hrs

Pump & Probe noise at 5 wavelengths (3.5 hrs)

Pump & Probe noise at at 600 nm (3.5 hrs)



"The 3.7E-6 standard deviation noise at 600-nm (lower panel) is extremely low, typically achievable only with high-rep-rate lasers/oscillators." (Dr.Dario Polli, Assistant Professor, Polytechnic of Milan, Prof. Cerullo's group

Lasers and beam lines: uptime and support optimization

Non-standard laser specifications

Exceedingly high beam time value

Multi-laser installations

Need/opportunity for application-specific support

- Built-in reliability through HALT/HASS design procedures
- In-depth, customized user service training
- Advanced replacement laser (sub)systems
- Incentives towards user purchase of recommended stock parts
- Warranty extension
- Preventive maintenance plan

Support strategy - rationale

- In-depth, customized user service training
  - At Coherent Santa Clara facility
  - → Enables expert in-house system maintenance/service, minimizes downtime
- Advanced replacement laser (sub)systems
  - Applicable typically to non-field serviceable systems (clean-room mftg. items)
  - Two-day shipment from regional warehouse with APlus agreement
  - → Minimize downtime, easy system replacement
- Incentives towards user purchase of recommended stock parts
  - Coherent customizes recommended spare part list at discounted price
  - → Cost/uptime benefit
- Warranty extensions, tailored to cover all Coherent lasers at facility
  - → Covers seamlessly parts at a predictable & budgeted user cost
- Preventive maintenance plan
  - Coherent personnel system inspection to ensure above-spec performance
  - → System re-optimization, uncover possible degradation paths

Conclusion

- Requirements for power/energy and stability are common to most UF non-linear applications
- FEL/particle beam facilities bring in additional challenging demands:
  - Synchronization
  - Non-standard specification
  - Uptime/maintenance requirement
- Addressing these requirements satisfies also bulk of other UF applications, with benefits for the UF user community at large