Laser Production for NASA's Global Ecosystem Dynamics Investigation (GEDI) Lidar

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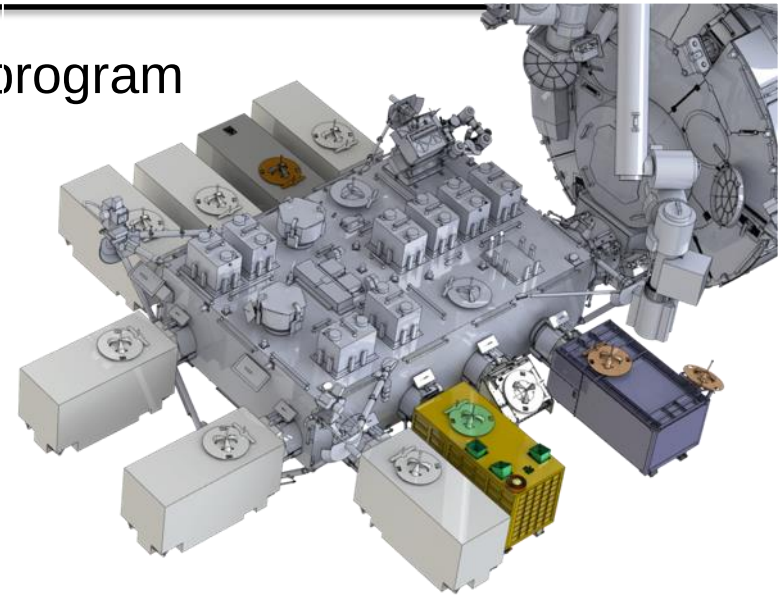
NASA-Goddard Space Flight Center

GEDI Mission Overview

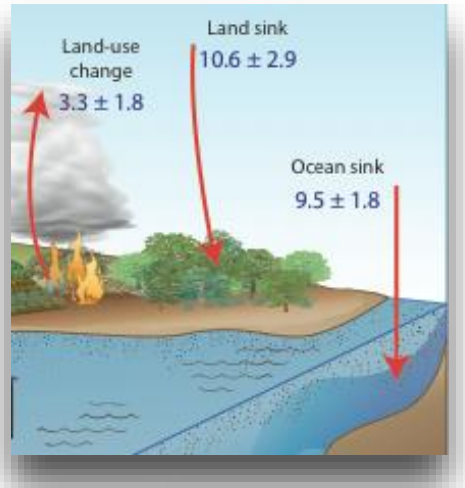


- NASA Earth Ventures Instrument (EVI) program
- $90 M , cost capped, “PI-Led” mission
- Class C, 1-2 year mission
- Multi-beam waveform lidar instrument with 10 ground tracks
- Launch Vehicle: Space-X Falcon 9/Dragon or equivalent
- Platform: International Space Station,
- Japanese Experiment Module Exposed Facility, Site: EFU#6
- Orbit: 415 km average; 51.6 degrees
- Payload Allocations (TBR): 600 Kg., 887 W, 5.4 Mbps
- Science and Mission Operations Ground System, B.32 GSFC

2015	2016	2017	2018			2019	2020
SRR 6-15	PDR 4-16	CDR 1-17	PER 8-17	PSR 5-18	LRD 8-18	Primary Mission: 365 Days of Science Collection	Extended Mission to Account for ISS Induced Downtime

Science Goal

Characterize the effects of changing climate and land use on ecosystem structure and dynamics



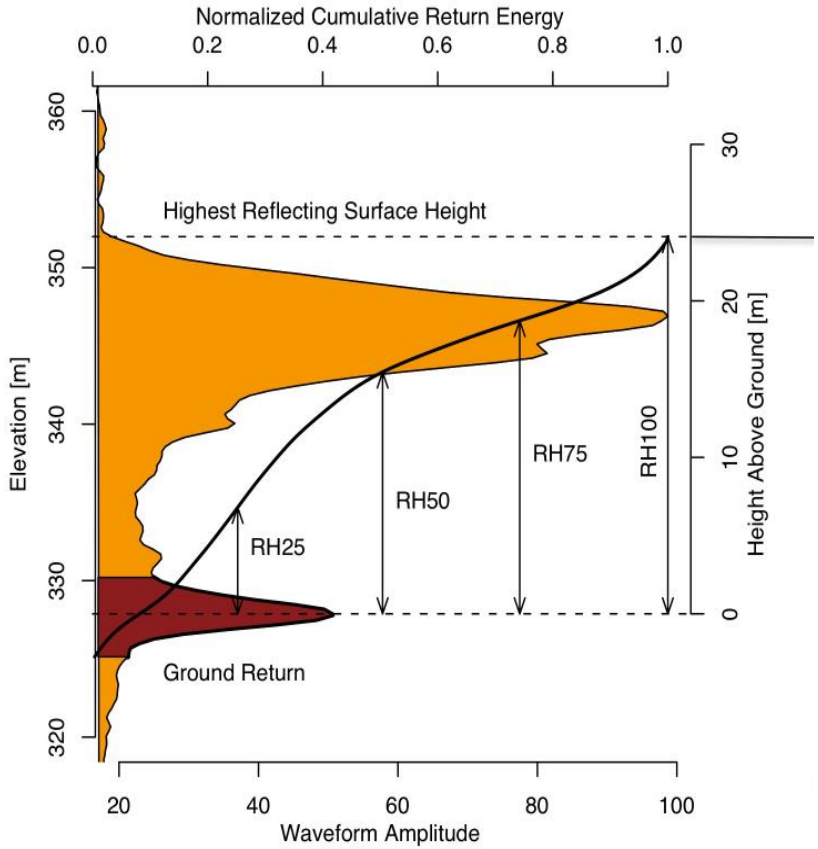
CARBON CYCLE

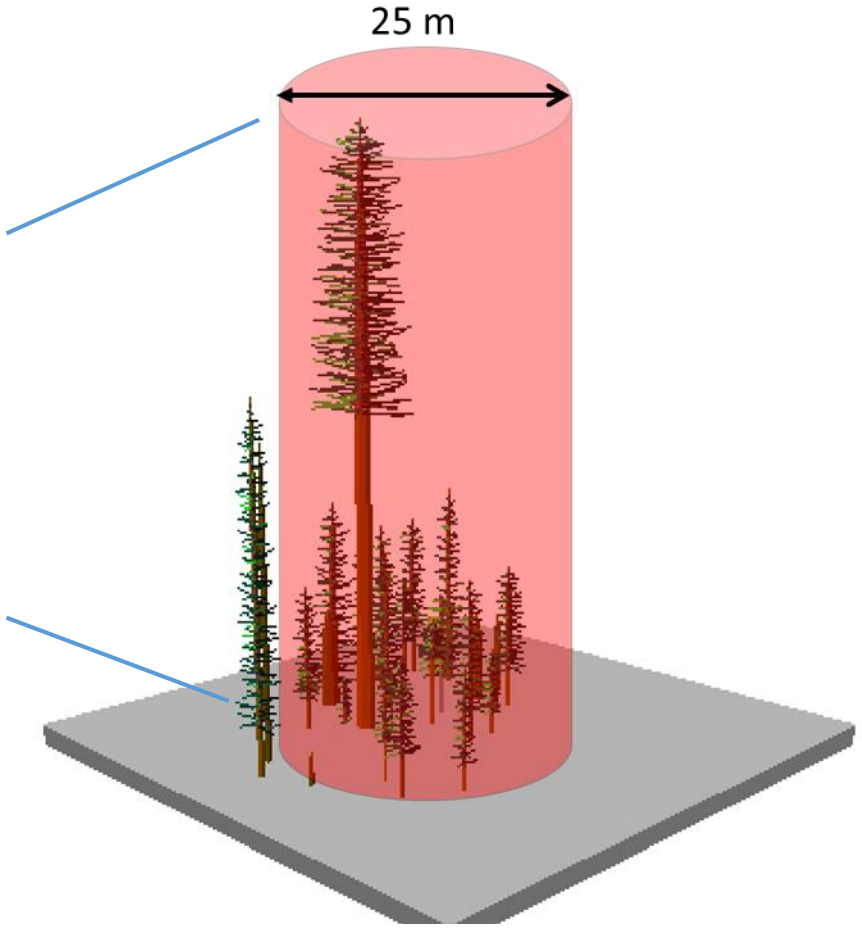
BIODIVERSITY

GEDI provides the Earth's first comprehensive and high-resolution data set of ecosystem structure

Lidar Measurement

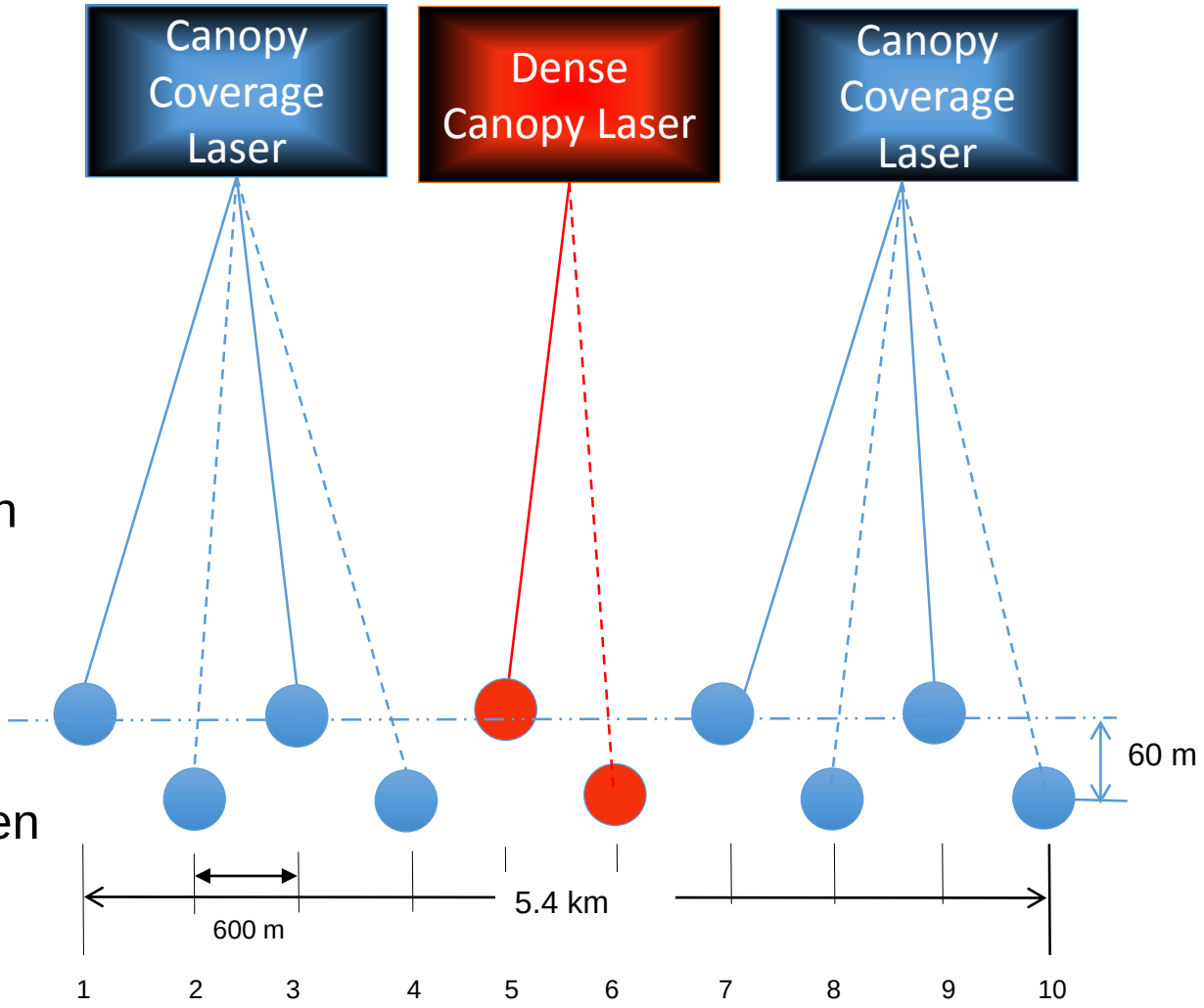
- Sole GEDI observable is the lidar waveform
  - Provide ground elevation, canopy height, canopy cover and various vertical profiles and metrics



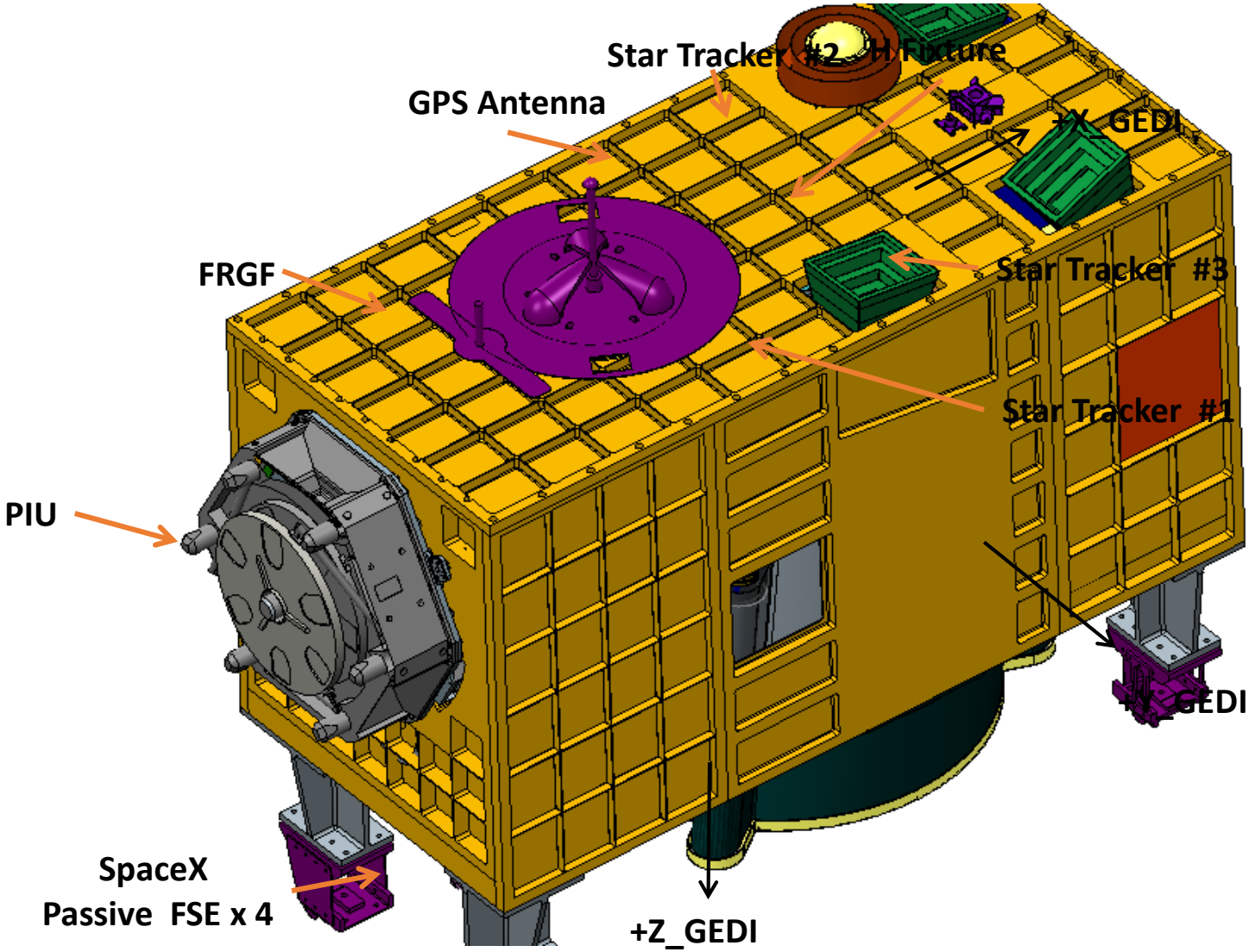


GEDI Laser Ground Track Coverage

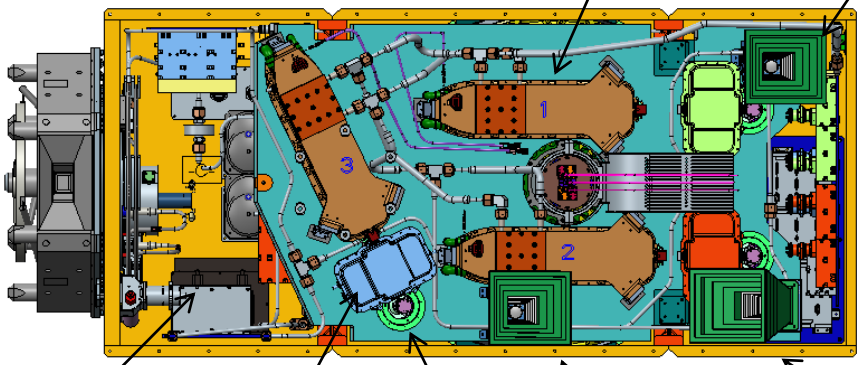
- GEDI is self-contained laser altimeter
- 3 lasers produce a total of 10 ground tracks
- Precise ranging, attitude & position sensors enable precise geo-location of each laser footprint (10-m knowledge)
- Active Pointing Control Mechanism (PCM) provides even distribution and complete coverage of ground tracks (225-m control)

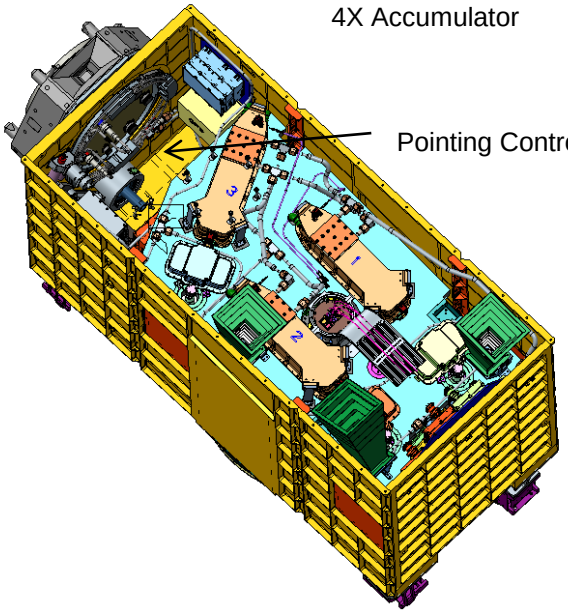


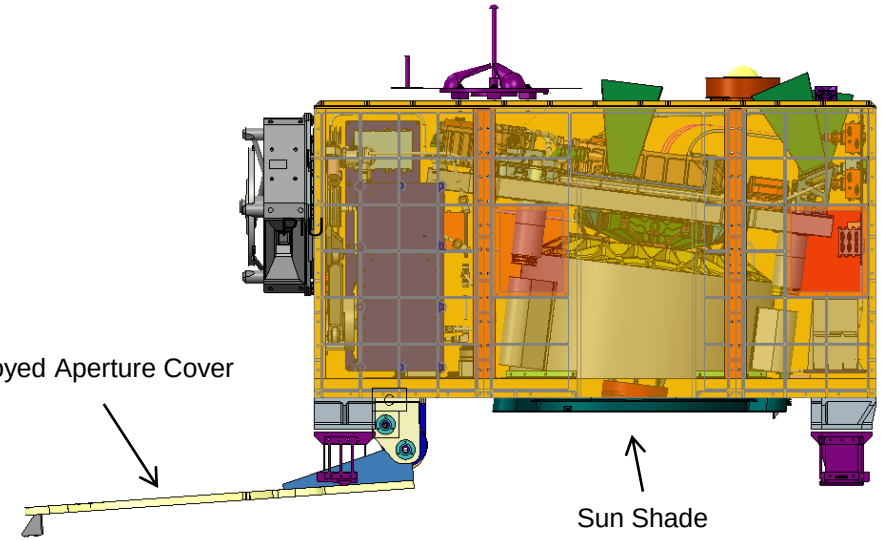
GEDI Instrument



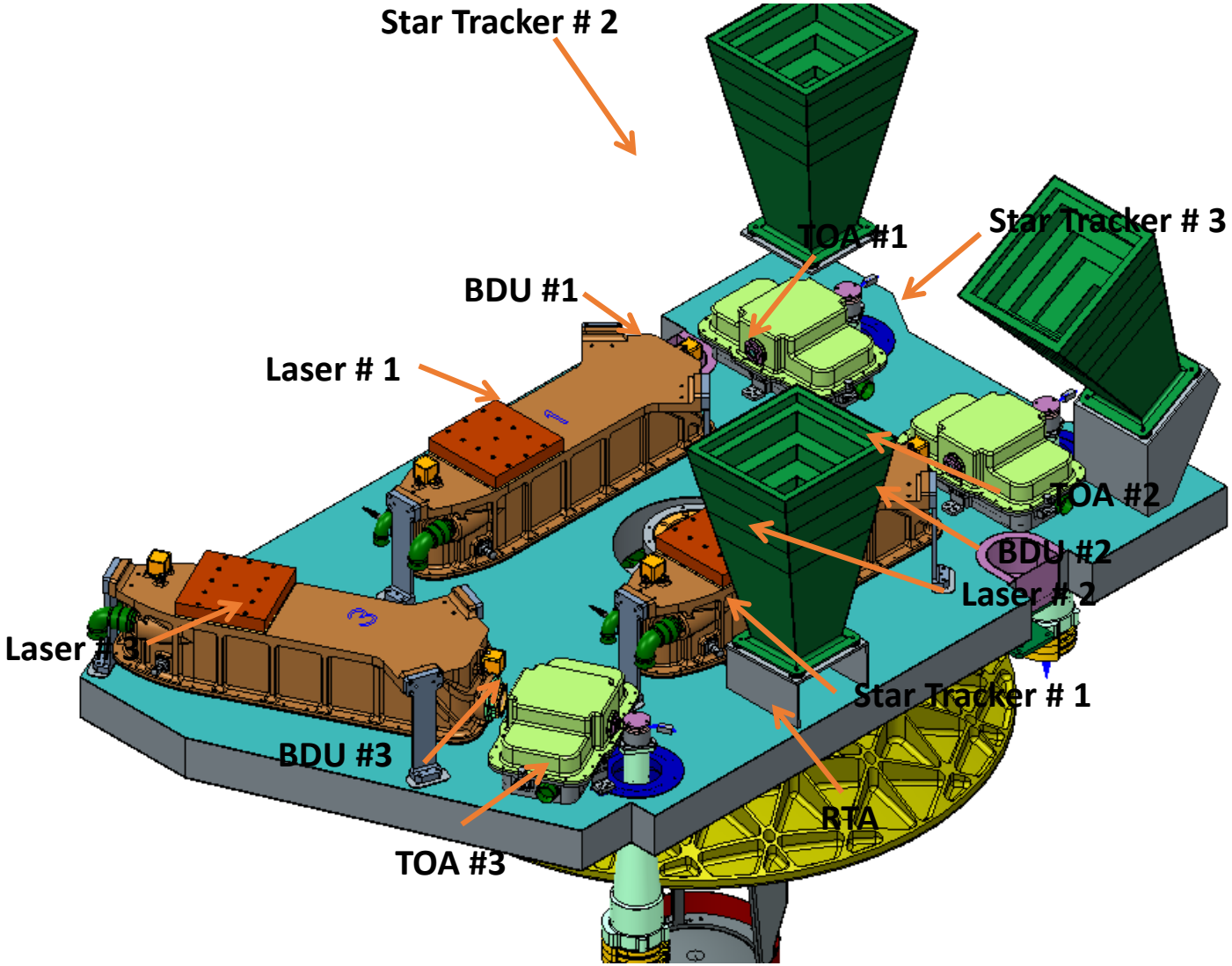
GEDI – Internal Views



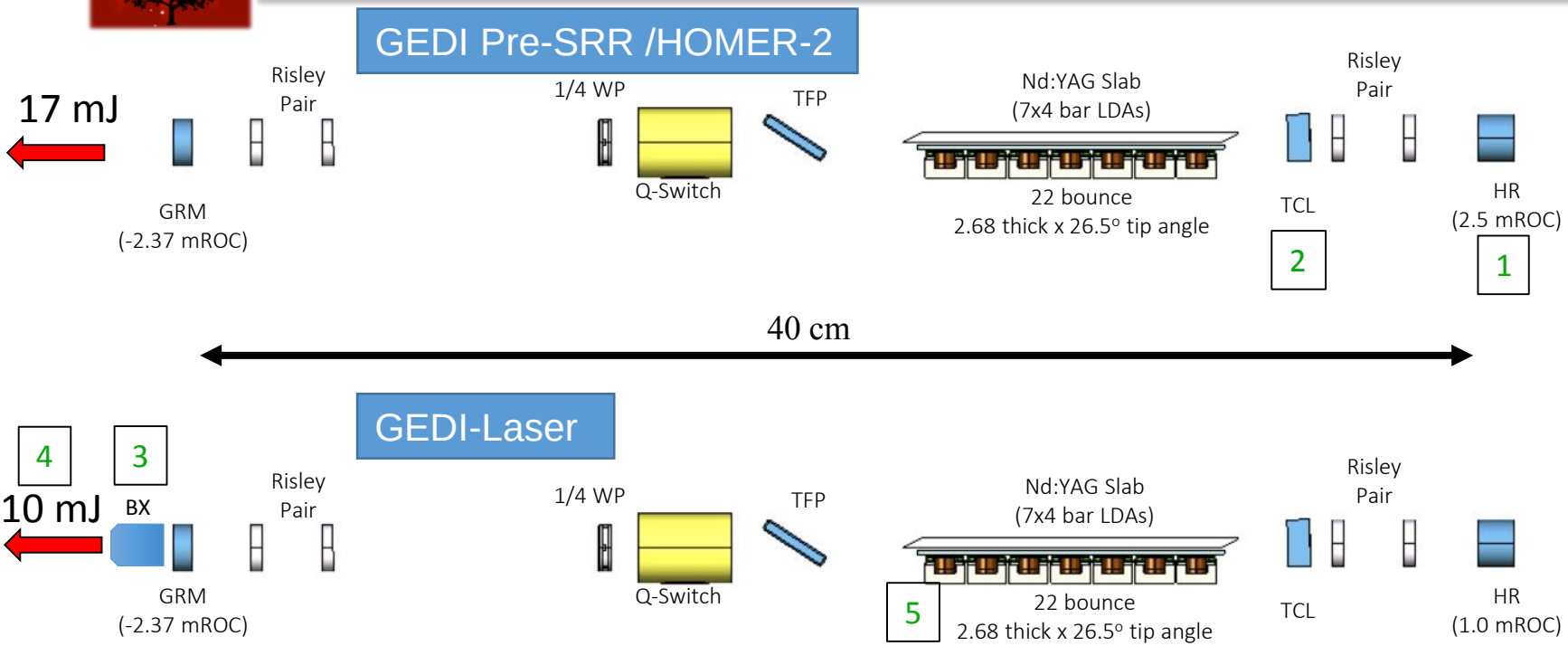




GEDI Optical Bench



Laser Optical Design Overview



HR = high reflective mirror
TCL = thermal compensation lens
TFP = thin film polarizer
QS = Q-Switch
1/4 WP = 1/4 wave plate
GRM = gradient (Gaussian) reflective mirror

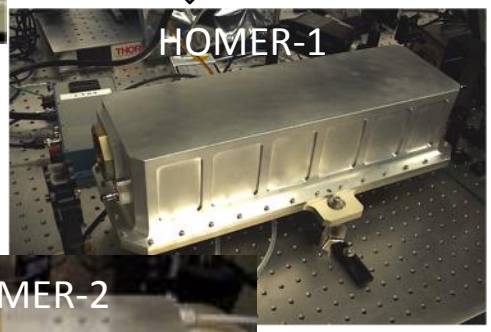
1. HR mirror prescription change 2.5 mCC to 1.0 mCC
2. The TCL focal length is “adjusted” for each cavity or slab installed, to best match thermal lensing. (TCLs ordered at a range anyway)
3. Mini-BX added to adjust for change in divergence
4. Reduction in output power from 17 mJ to 10 mJ to maintain same damage margins
5. Reduction of power allocation from 50 W to 40 W

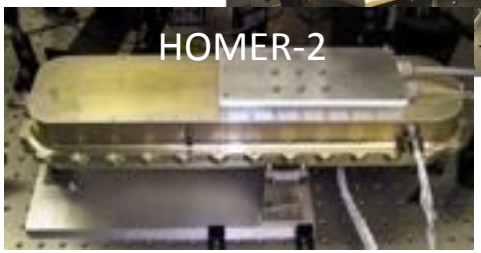
HOMER Class Heritage and Philosophy

Design:
-Model
-Best practices
-Margins

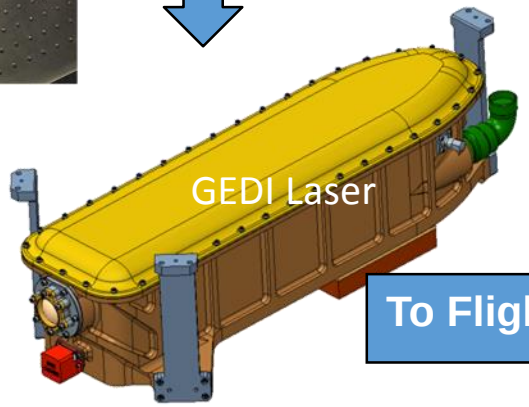
Bread Board:
- Confirm basic performance
- Confirm "laser physics" margins
- COTS parts

Hardened bread boards/EDUs:
- Confirm mechanical margins
- Environmental/Life Testing





ETUs:
- Flight-like procedures
- Test to flight levels
- Life testing

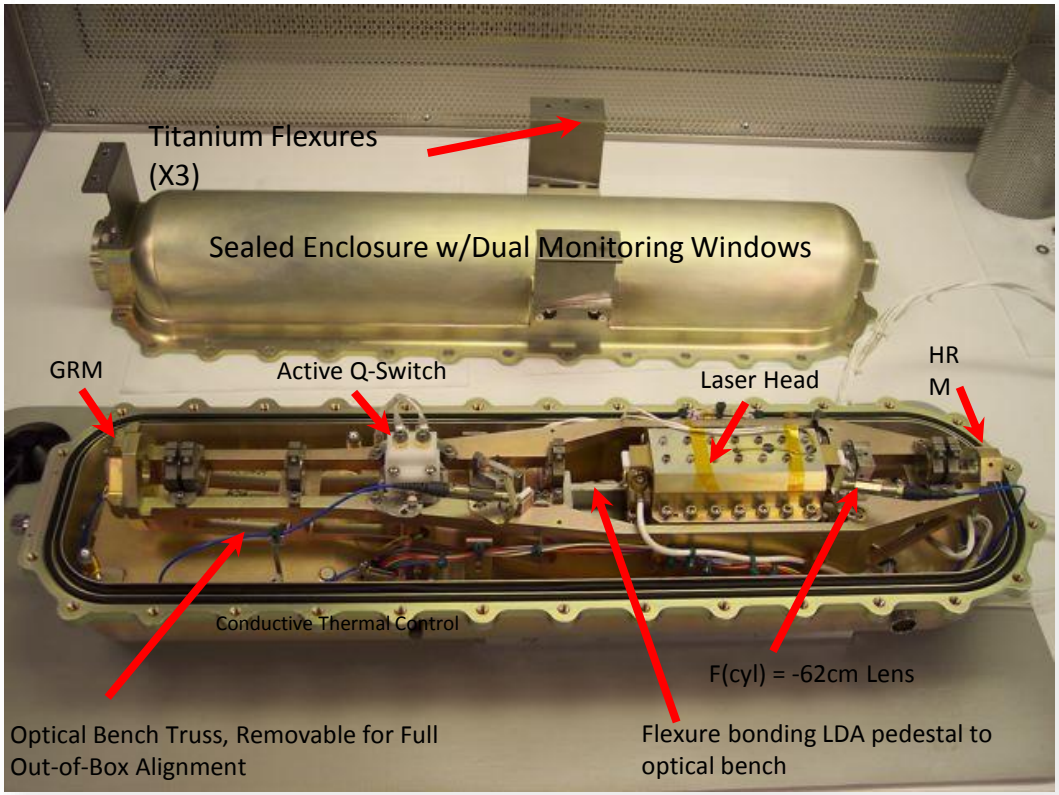


To Flight

Any change to laser is checked for impact to performance and margins

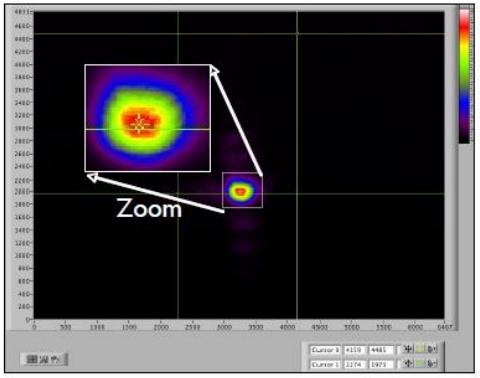
HOMER TRL-6 Performance Summary

Parameter	HOMER Output
Energy	20 - 15 mJ
Pulse Width	12 +/- 1 ns
Rep Rate	250 -100 Hz
LDA Current	48-80 A
LDA Derating	50%
TRL 6 Mass	6 kg
Total QS Shots HOMER Design	15+ Billion



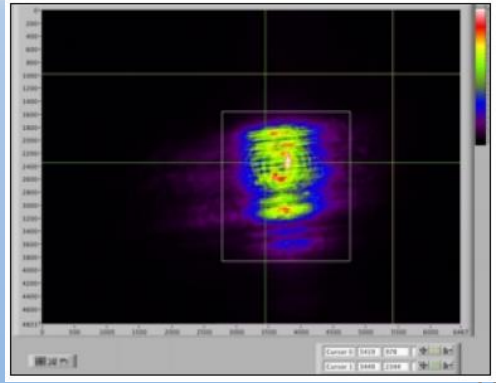
Single Mode Far Field Image
D_x/D_y = 0.99/0.96 mRad

Laser Settings:
- Diode Pulse = 65us
- I = 48 A (~55% derated)
- F = 241 Hz

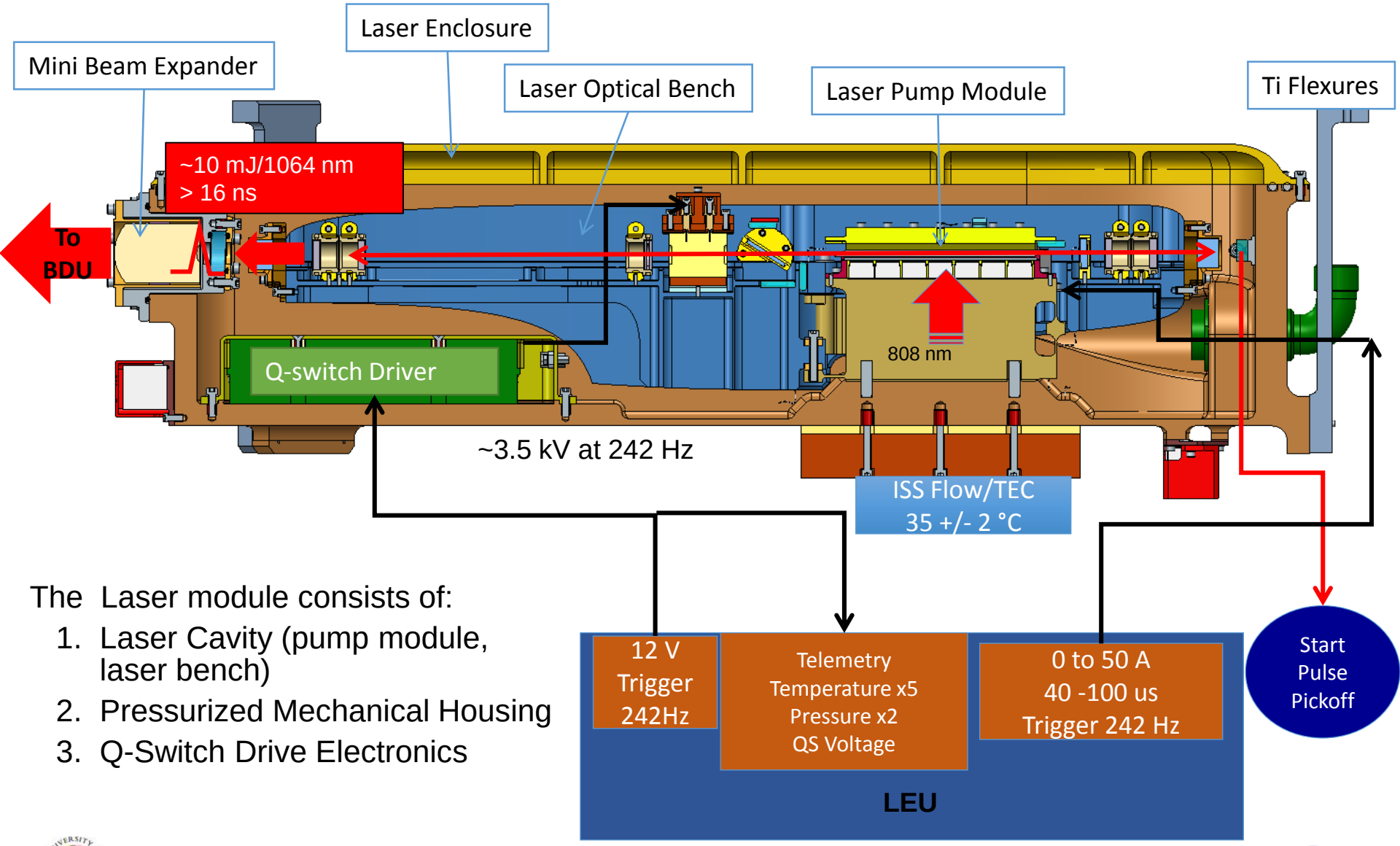


Reported 01/06/2010
HR mirror Near Field Image
W_x/W_y = 1.8/2.12 mm

Laser Output:
- E = 16 mJ
- Q-switch pulse ~11ns
- Fluence < 2.5 J/cm^2



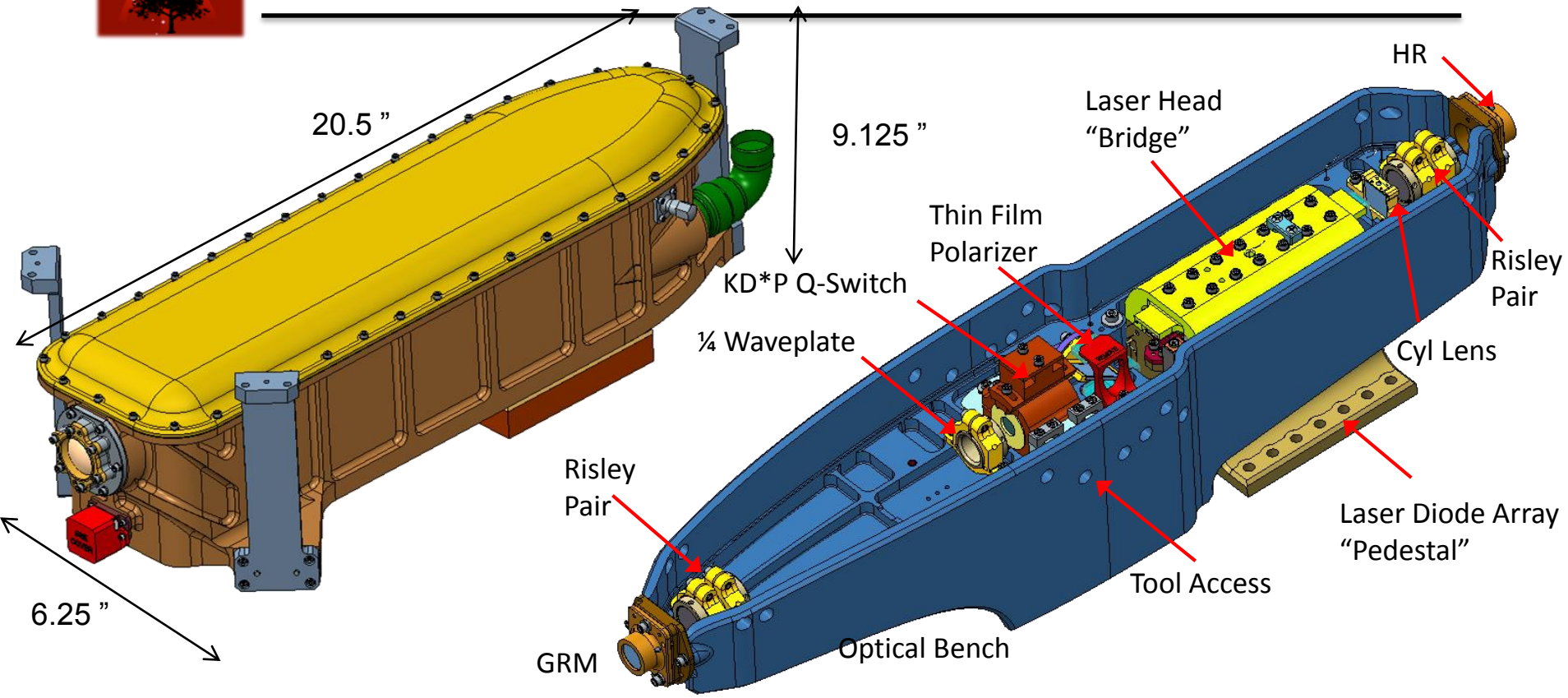
GEDI Laser Interface and Functional Overview



The Laser module consists of:

1. Laser Cavity (pump module, laser bench)
2. Pressurized Mechanical Housing
3. Q-Switch Drive Electronics

GEDI Laser Mechanical Overview

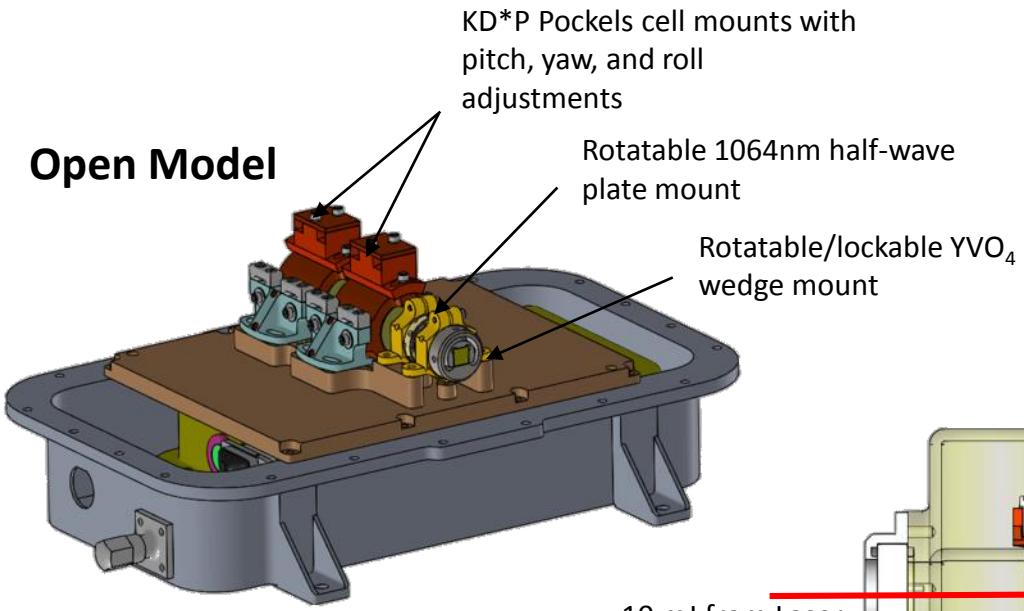


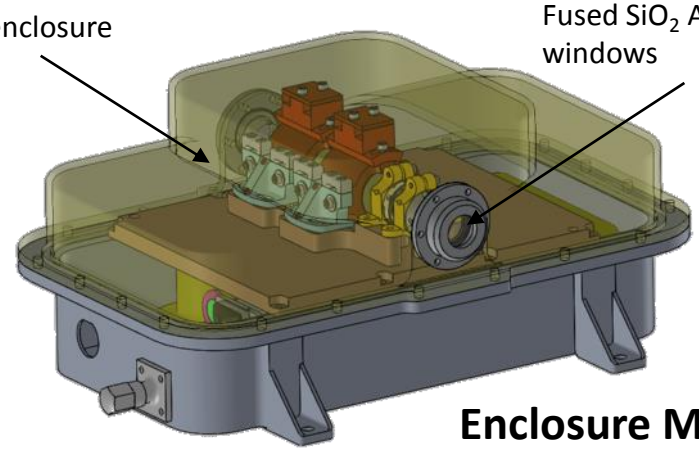
40 cm Cavity Length from mirror to mirror

- Incorporating all opto-mechanical lessons learned from HOMER-2, LOLA, MLA, CALIPSO, DESDYNI, & ESA’s ALADIN
- Modular design allows complete laser assembly, alignment, and substantial performance without the enclosure if necessary
- Preliminary leak rate, structural, and thermal analysis performed and will be tested

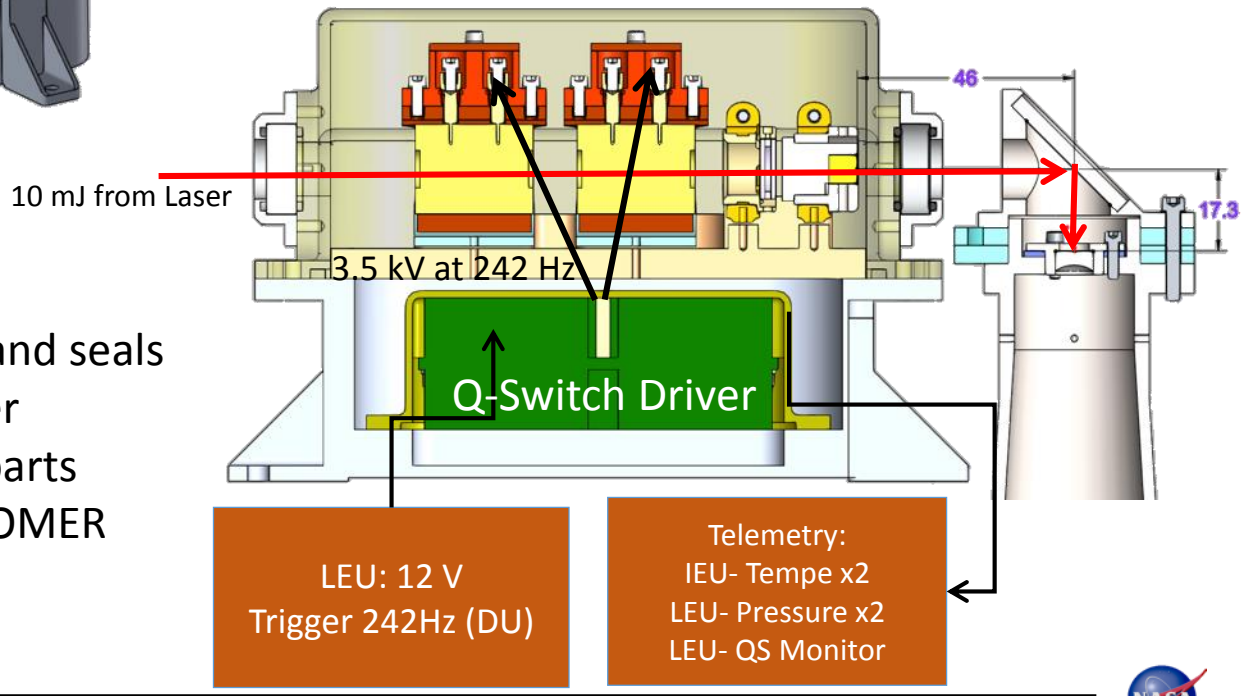
BDU Design Overview

Open Model





Enclosure Model

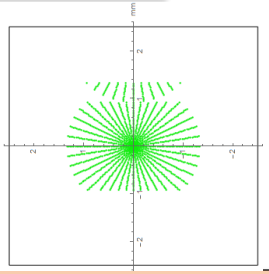


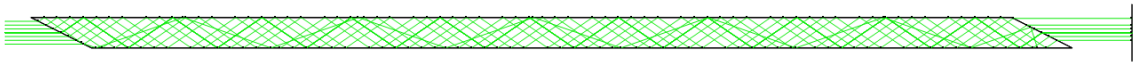
CBE Total Mass: ~1.81 kg

All optics, mounts, sensors, and seals (except the wedge) are either directly using or leveraging parts already being using in the HOMER laser

Side Lobe Description Summary

Beam Image of Slab Exit:





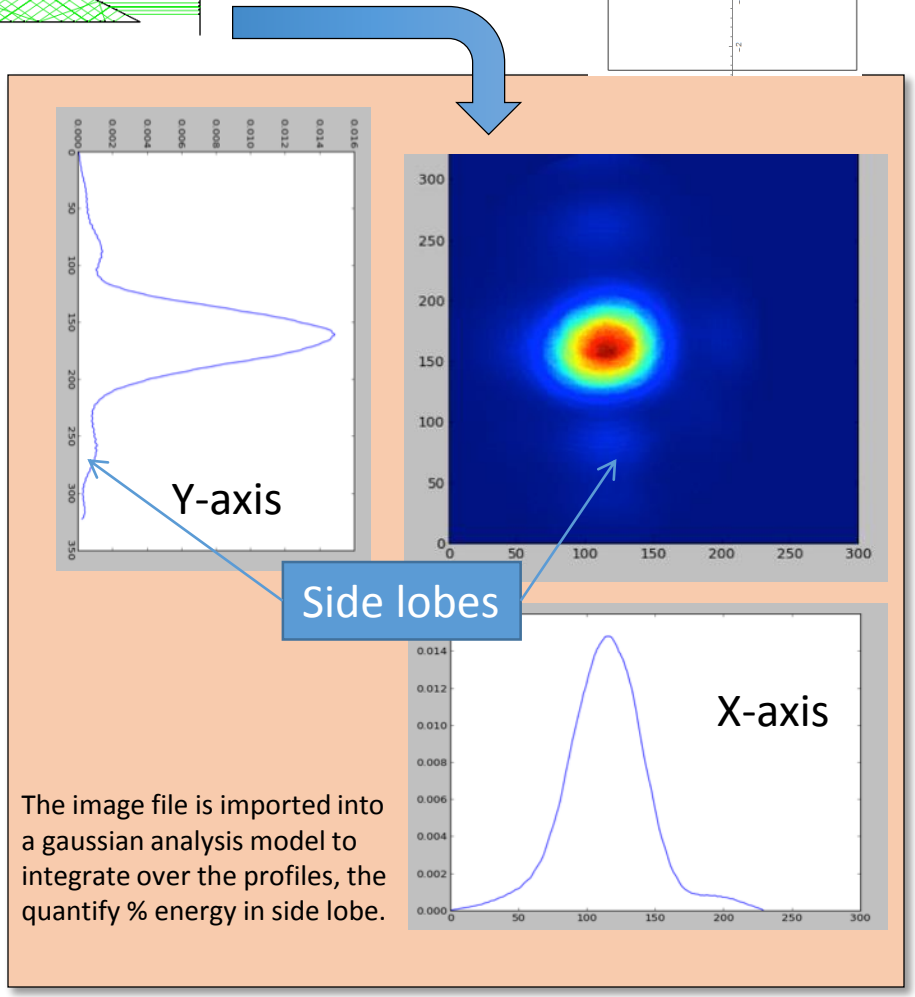
A few rays at “top” of Y-axis travel a different path. This produces a clipping effect, or “lobe” at the slab output end.

This creates problems for science differentiating between sloped ground and tree height.

To remove this you can either:
1) Clip off the side lobes outside the cavity
2) Make the beam smaller
3) Make the slab bigger

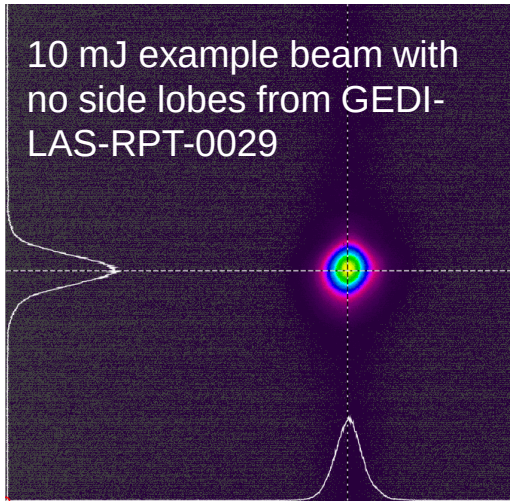
All options were explored and GEDI selected option 2 by changing HR Mirror curvature.

Options were reviewed externally by NESC supervised laser team from 554, 562, and expert from NGS.
See GEDI-LAS-REVW-0004

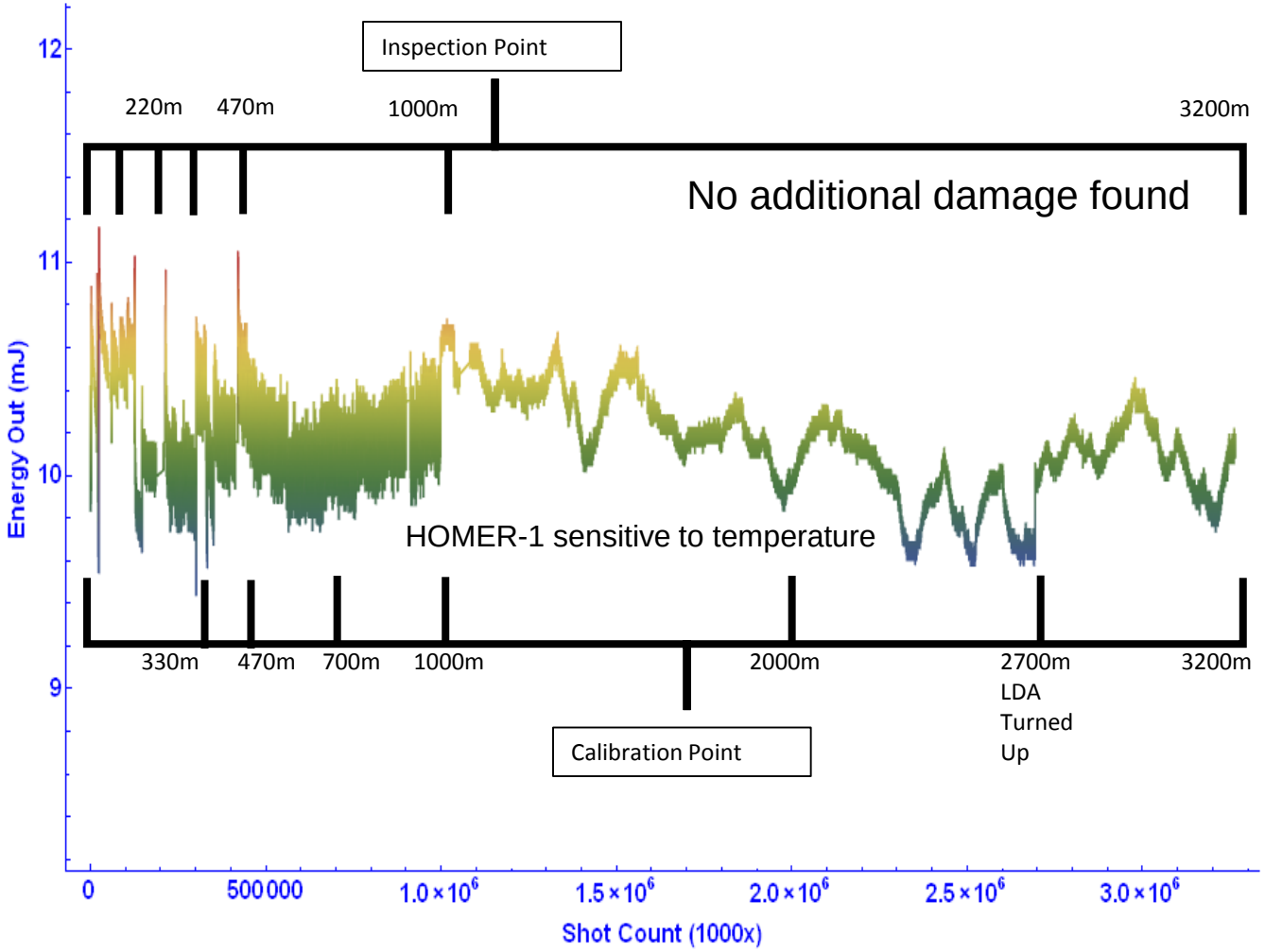


Laser Testing Performance Summary

Parameter	Value	Unit
Average Energy	10.2	mJ
Frequency	242	Hz
Pump Width	71-77	µs
Current	55	A



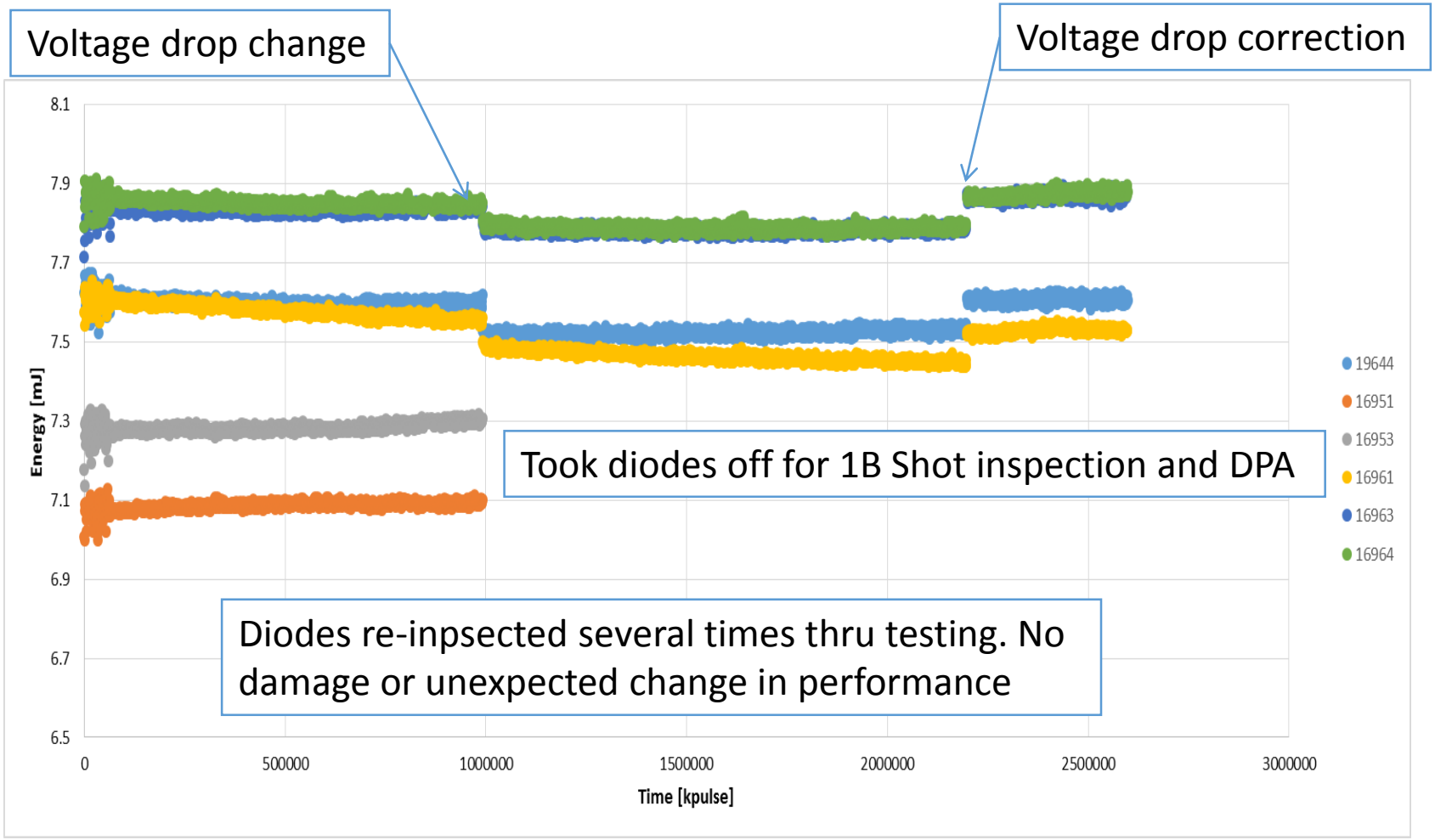
HOMER-1 1 mCC HRM Life Assessment Testing



Parametric Testing :

- Thermal lensing
- Diode distance
- End mirror tolerance

ETU Diode Life Test Results



Energy measurements were corrected for the LDA temperature change. Efficiency of the LDA decreases as the temperature increases.

Cavity Fluence Estimates

Energy (avg) Inside laser cavity with output coupler reflectivity $R_{OC} = R_{GRM}$:

$$E_{in} = E_{out} \times \frac{(1 + R_{GRM})}{(1 - R_{GRM})}$$

But our reflectivity changes with beam size on the GRM, so we have to estimate:

$$R_{GRM} = \frac{1}{pa^2} \cdot \int_0^{2p} \int_0^a R_0 \cdot \exp\left[\frac{-2r^2}{w^2}\right] \cdot r \cdot dr \cdot dq$$

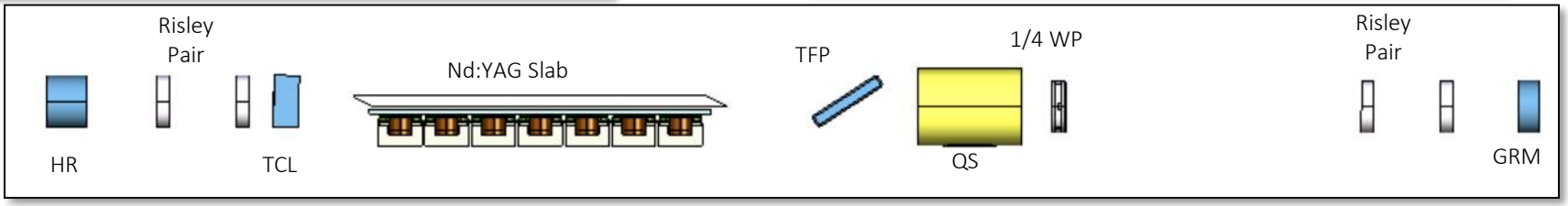
So we can calculate the fluence on each optic:

$$j_{calc} = E_{in} \times \frac{2}{p \times w_{calc}^2}$$

… To get the operational damage margin for each optic:

$$M_D = j_{LIDT} / j_{calc}$$

*worst case: round beam at GRM-end of slab



	HR	Risley Pair	TCL	Slab Face	Slab TIR	Slab Face		TFP	QS	¼ WP		Risley Pair	GRM
Meas LIDT (J/cm²) j_{LIDT}	11.5	44	25	>10	12*	>10		20	>10	>10		44	4
Calc Fluence (J/cm²) j_{calc}	1.75	1.95	2.08	2.37 (1/2.23)	2.37* (1/1.56)	2.37 (1/2.23)		2.22	2.69	2.85		3.06	3.24
Margin M_D	4.2	22.6	15.3	>9.4	6.1*	>9.4		9.0	>3.7	>3.5		14.4	1.23
Sigma	0.32	0.36	0.37	<0.43	0.43*	<0.43		0.4	0.48	0.51		0.55	0.58

GEDI Laser Requirements Verification

O = Occasional
C = Continuous
X = One Time Measurement

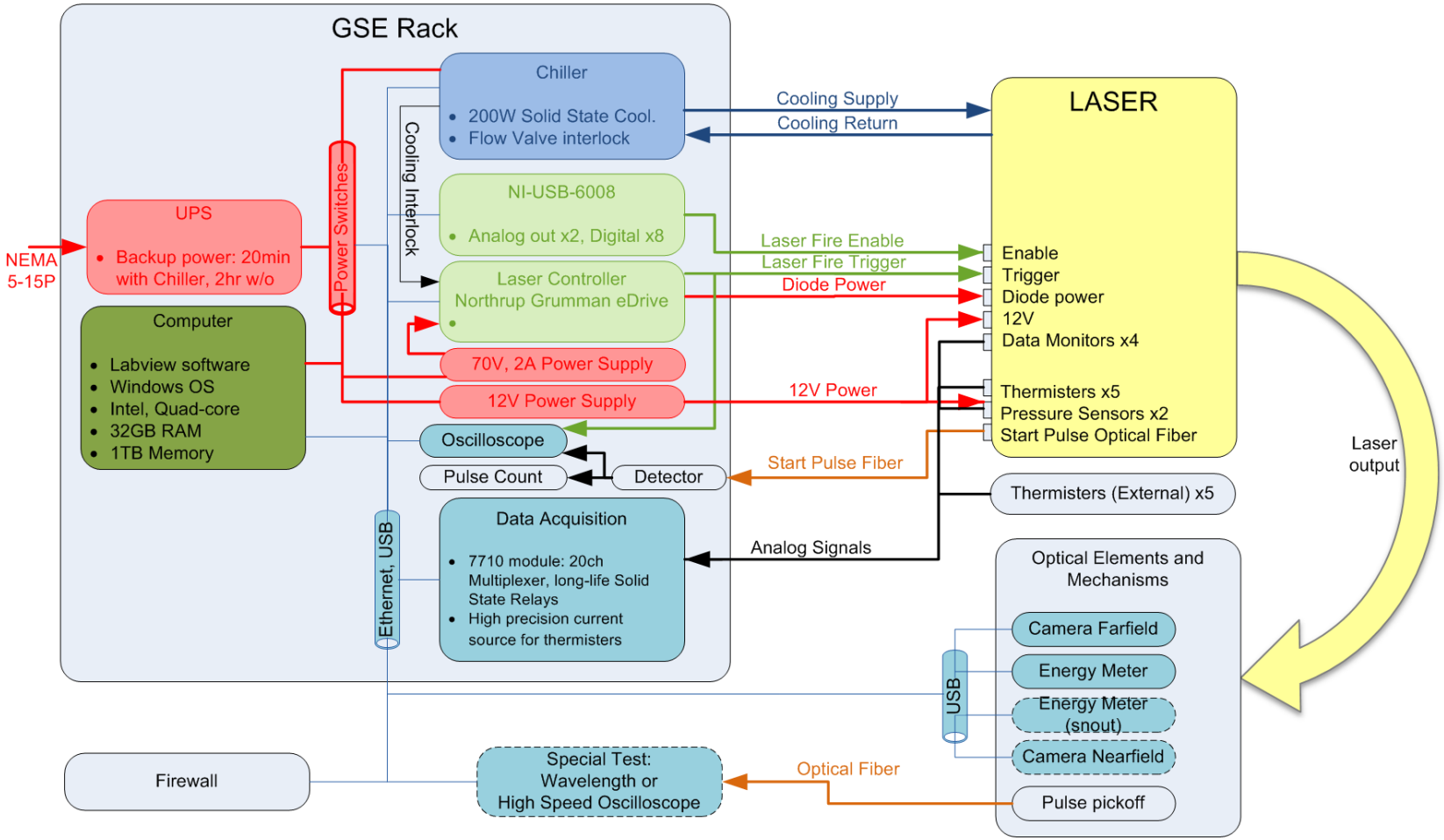
ID	Requirement	Values	FT	CPT	Life test	Technique Used
1	Laser Wavelength	1064.5 nm ± 0.2 nm in vacuum		x	O	Pickoff beam. Use built in software to calibrate measurement for vac. Take vacuum and air values
2*	Laser Output Energy	10 mJ +5% fully captured beam at the output	x	x	C	Measuring Total Output Energy using energy meter with 10ms integration time. CPT - energy meter put at the end of the snout to get full output. Used to calibrate pickoff measurement as well FT/Lifetest - calibrated pickoff
3*	Far-Field Divergence of the Central Lobe	0.6 mrad ±0.08mrad $1/e^2$ div.	x	x	C	Spiricon camera (raw beam data) 5-10 captures Computer Analysis and post processing for side lobes FT-50 cm lens CPT - Rayleigh Range
6	Laser Output Polarization Ratio	≥ 200:1		x	O	Measure by hand using wave-plate/hi ratio polarizer configuration
9	Pulse Repetition Rate	242 ± 2 Hz	x	x	C	Confirm pulse with Tektonix 2024C and use e-drive output reading for continuous measurement
10	Pulse Width	<16ns ns Full-width and half-max	x	x	C	FT- 200 MHz Oscilloscope Average of 16 captures of laser pulses CPT -2 GHz scope. High speed Oscilloscope compiling 10,000 shots with histogram through computer analysis and post processing. LMB will be measured as well.
12	Laser Pulse Energy Concentration in Far-Field Outside of Central Lobe	≤ 0.5% of $1/e^2$ Central Lobe per energy concentration		x	O	Spiricon camera (raw beam data) 5-10 captures Computer Analysis and post processing
13*	Number of Laser Shots for Life Testing	3.2 billion shots	x	x	C	GSE shot counter will monitor shots for every test. ETU life time shot count will be monitored continuously
24	LDA Operating Temperature	35 +/- 2 °C		x	C	.Internal 10k thermistors read by EGSE

GEDI Laser Test Matrix GEDI-SYS-PLAN-0019

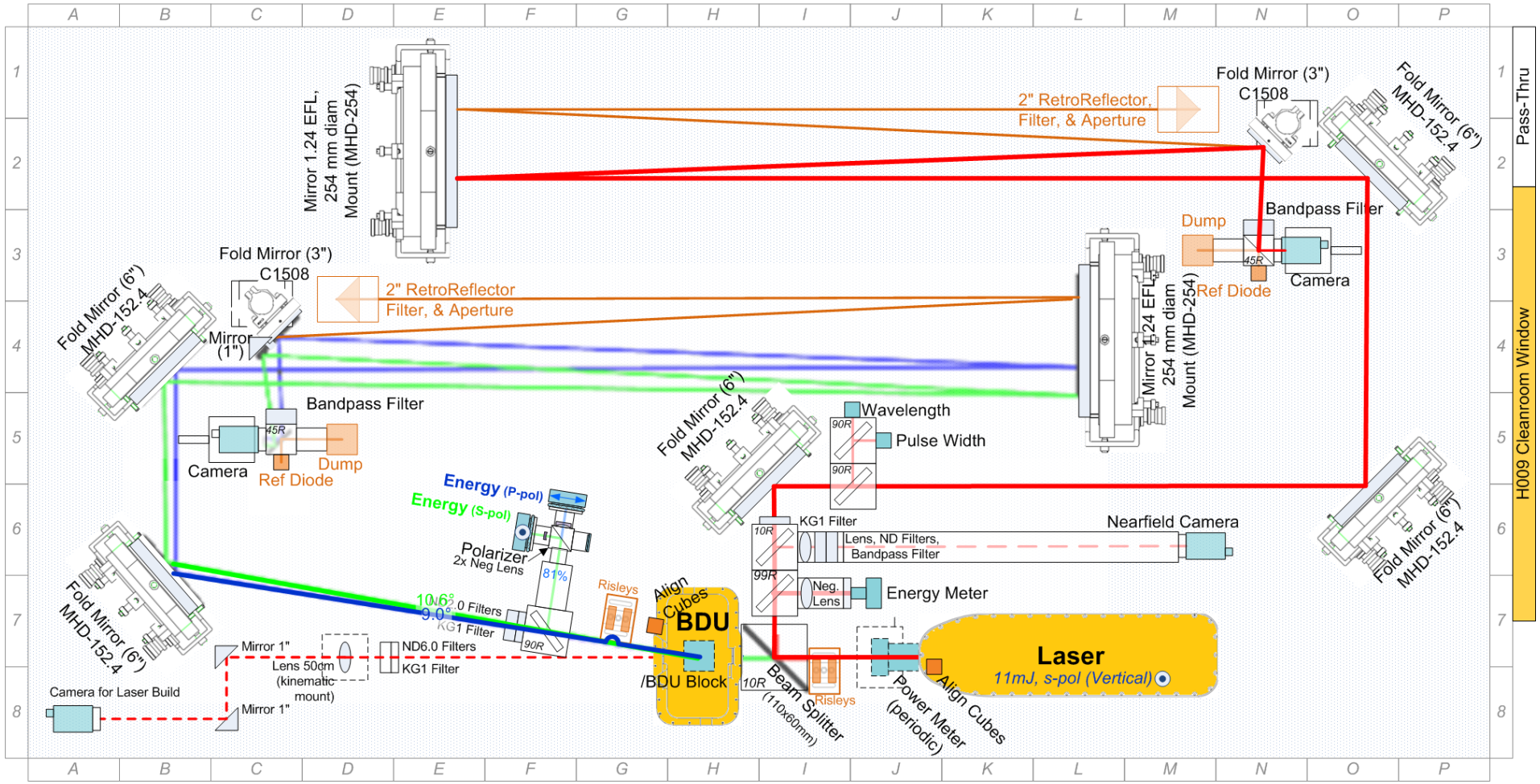
Level of Assembly	Item	Supplier	Quantity	Hardware Type	Structural Mechanical												Interface Tests	EMI/EMC & Magnetics (1,2)							Thermal / Vacuum (3)					
					Modal Survey	Strength - Design Loads (11)	Sine Survey (Sine Sweep)	Sine Vibration	Random Vibration	Acoustics	Mechanical Shock	Metrology/Dim Inspection	Pressure Profile	Mechanical Function	Torque Ratio	Life Tests	Mass Properties		Conducted Emissions	Radiated Emissions	Conducted Susceptibility	Radiated Susceptibility	Self Compatibility	Magnetic Properties (AC)	Magnetic Properties (DC)	Leak Test	Pressure Test	Thermal Vacuum [# of Cycles]	Thermal Balance	Thermal Cycling - Ambient [# of Cycles]	Bakeout
C	Laser	GSFC	3	PF		T	T		T							I	T	T	T	T	T	T			T	T	T[8]			T

- Environmental Testing performed on ETU and Flight units
  - ETU: Vibration, TVAC, EMC, and life test
  - Flight: Vibration, TVAC, EMI/C (at instrument level)
  - CPTs before and after each test (or specific cycles)
- Interface testing: BDU, LEU, DOE

Laser GSE Functional Diagram

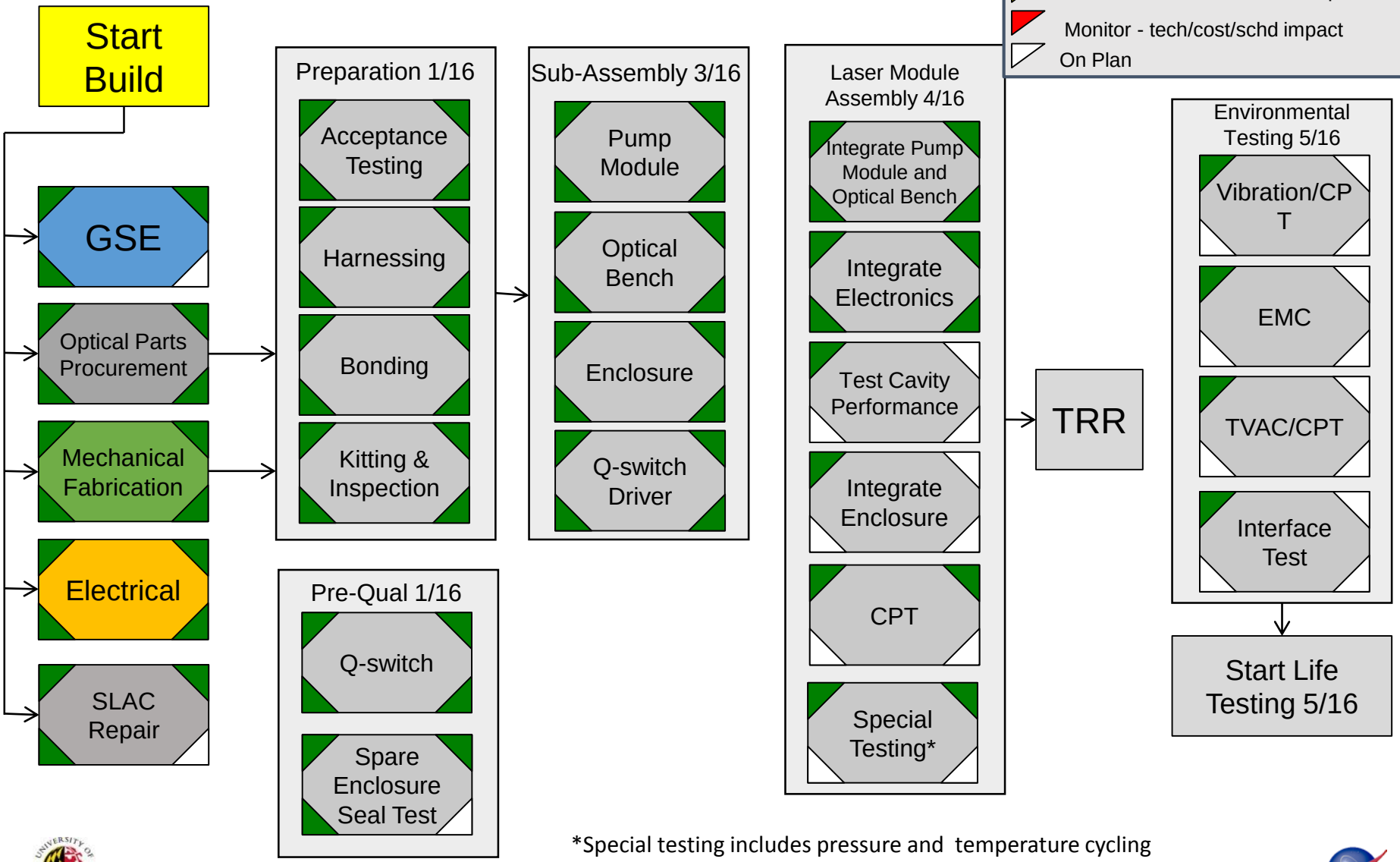


Optical Setup – Laser Lifetest w/BDU



Laser & BDU Lifetest Optical Table (8' x 4')

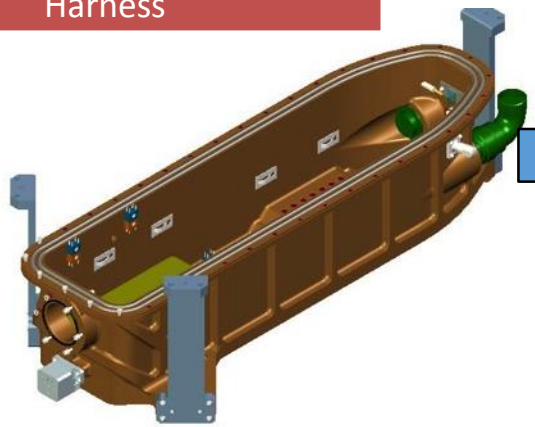
ETU Laser Development Flow



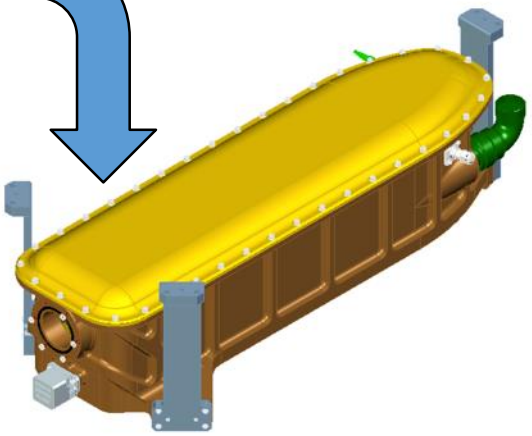
*Special testing includes pressure and temperature cycling

Laser Assembly Flow

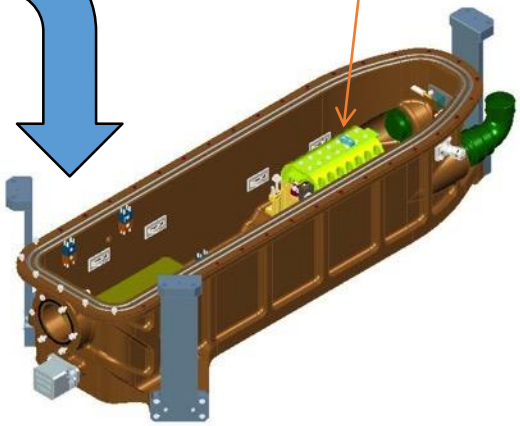
Assemble bucket:
- Flexures
- QSD
- Harness



Workmanship Test Seals
(Qualify on ETU)

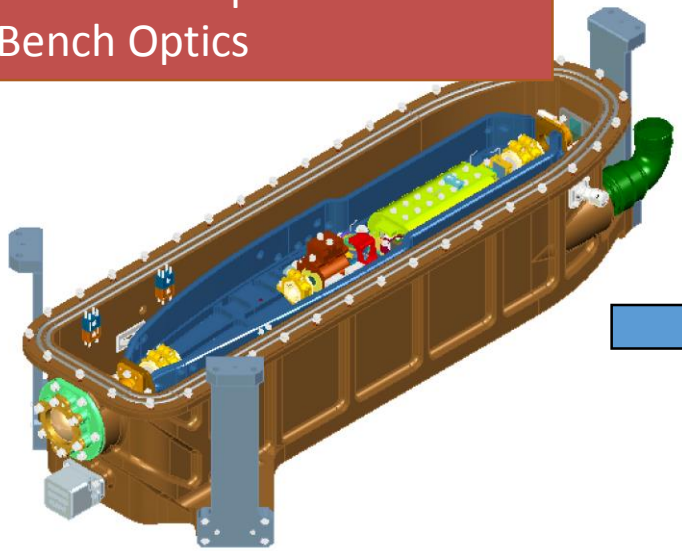


Add Pump Module:
- Safe-to-mate GSE
- Test Fire Diodes



Laser Assembly Flow

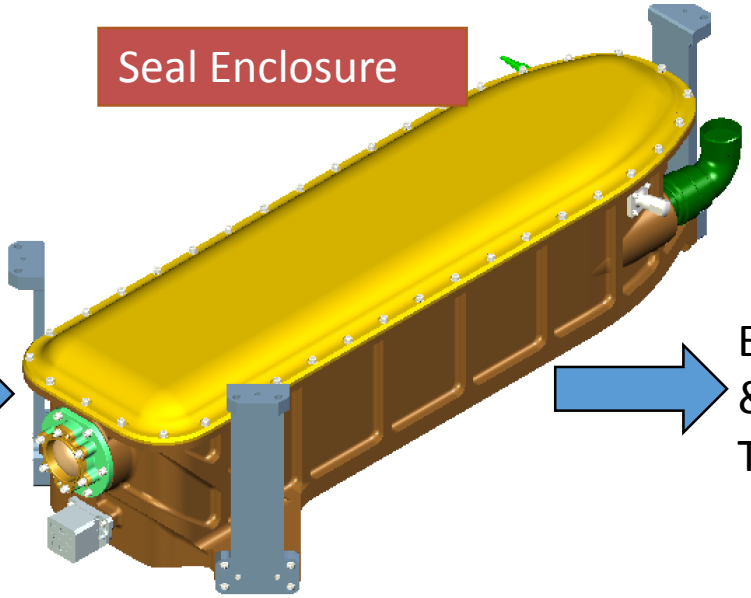
Add Laser Optical Bench & Bench Optics



Functional Test:
LASER-2,3,9,10,11

Special Test:
- Lab Temp Cycle
- FT every 0.5 C

Seal Enclosure



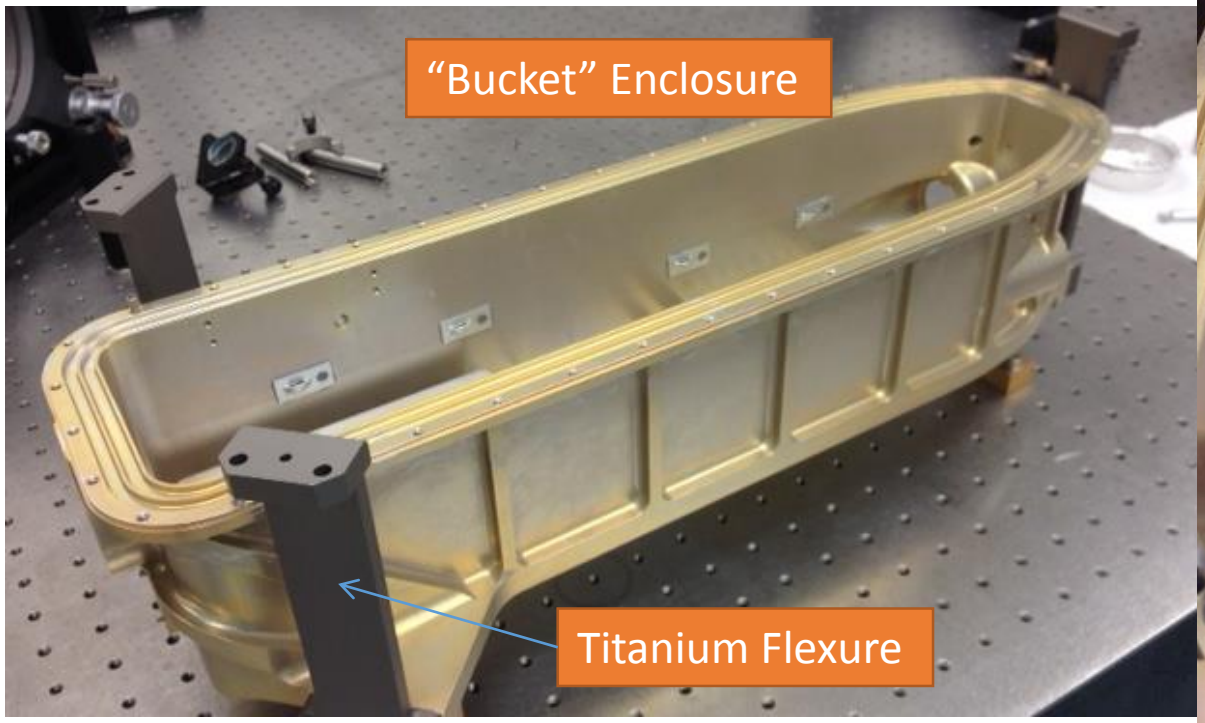
Comprehensive Performance Test:
LASER-1,2,3,4,5,6,7,8,9,10,11,12,15,1

Special Test:
- Lab Pressure Test
- FT min/nom/max pressure

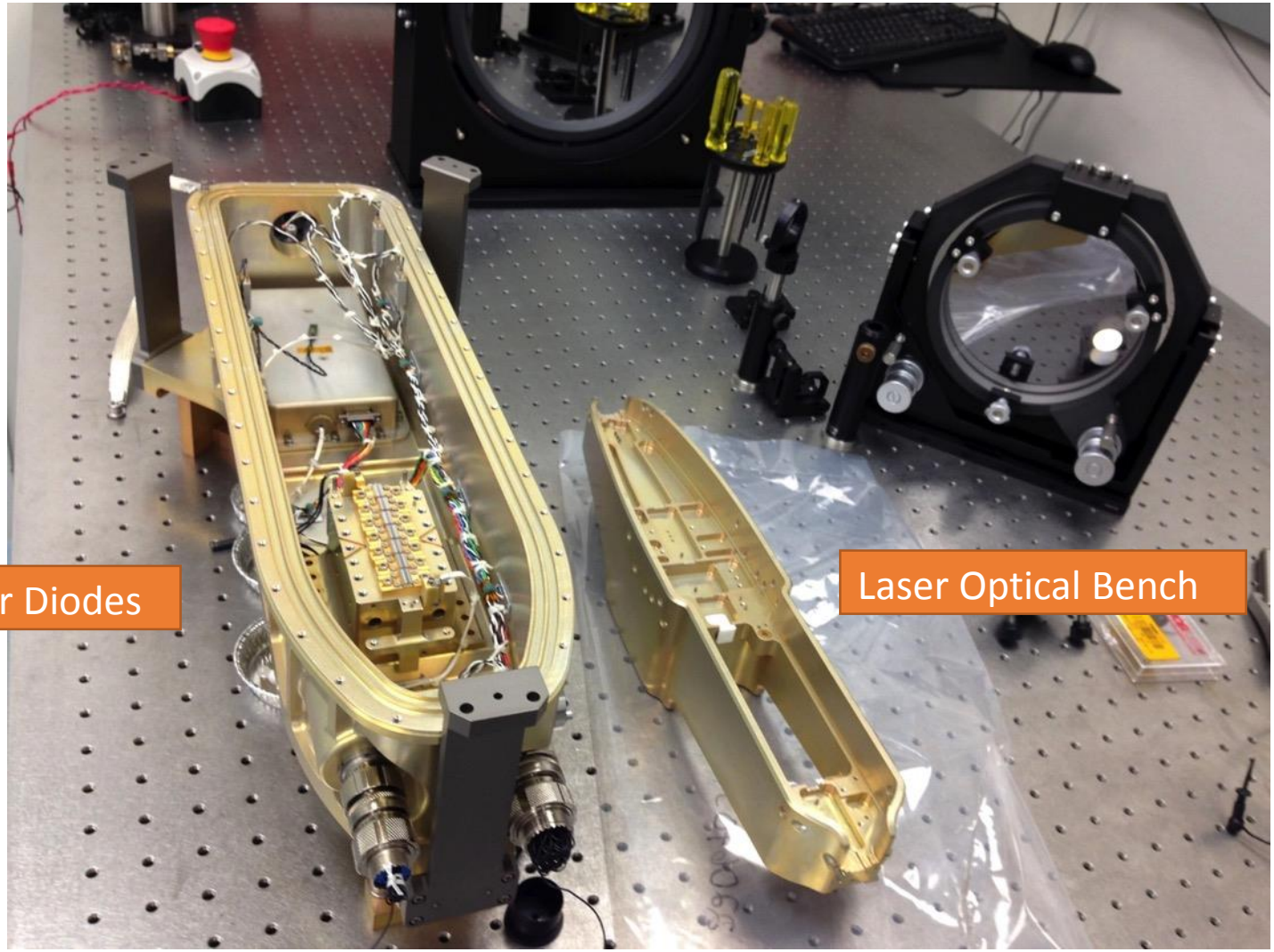
Special Test:
- Lab Temp Cycle
- FT every 0.5 C

Environmental & Interface Testing

Laser ETU Bucket and Driver Assembly



Laser ETU Diode and Bench Assembly



BDU ETU Assembly Test Configuration