Compact, Engineered, 2-Micron Coherent Doppler Wind Lidar Prototype for Field and Airborne Validation

IIP-04-0072

“Doppler Aerosol WiNd lidar (DAWN)”

Interim Review #1 (6 months)

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23 June 2006

IIP Key Personnel

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Mr. Paul Petzar	SAIC	Electronic Design
Mr. Karl Reithmaier	SAIC	Opto-mechanical design

Also many thanks to Brian Killough, Keith Murray, Garnett Hutchinson, and Ken Anderson

IIP Motivation

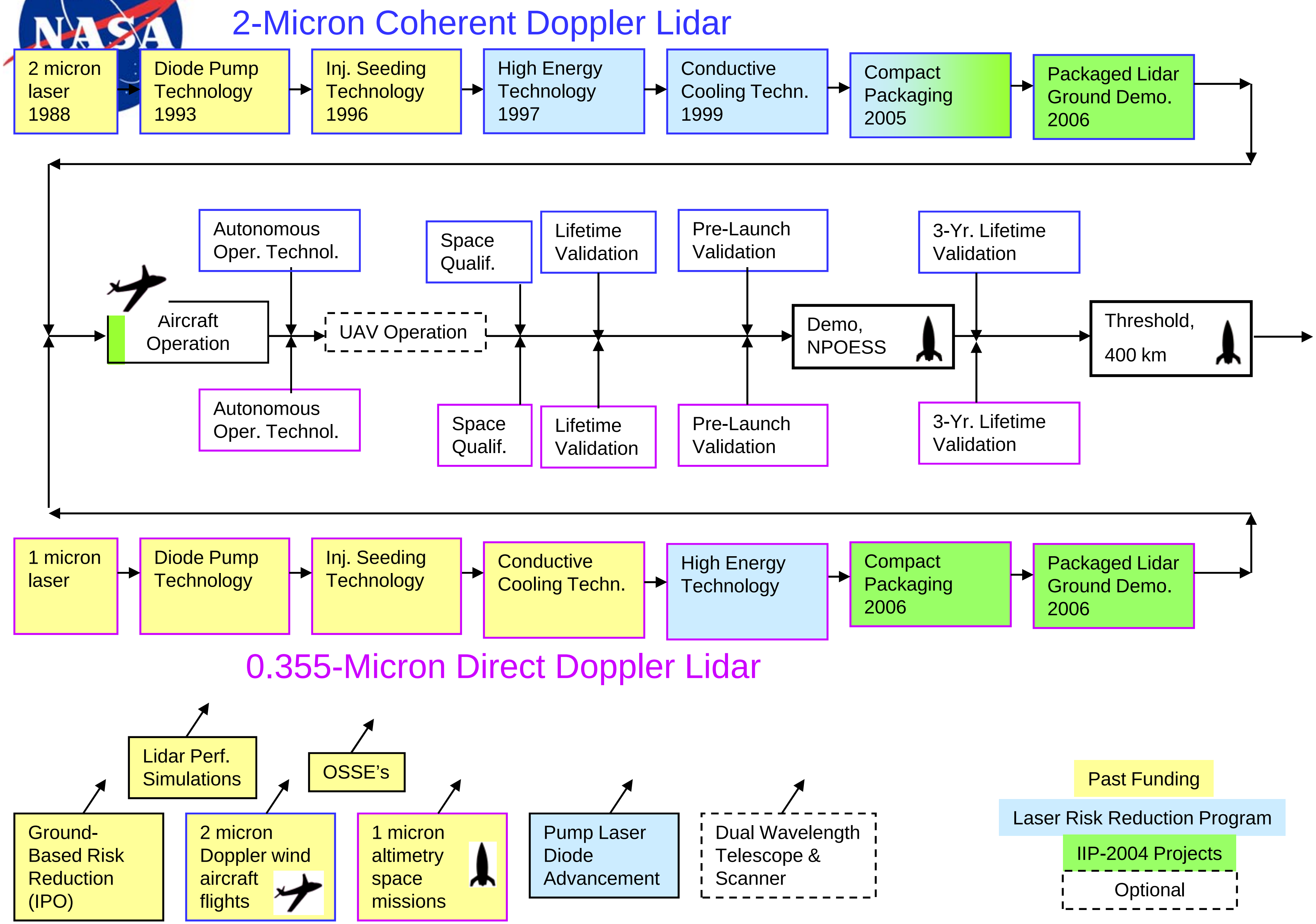
	Mission	Measurement	Technique	Technology
Primary	Science: Weather, Climate	Earth Vertical **Wind** Profiles	Scanning Doppler Lidar	Pulsed, 2-Micron, Ho Laser
Secondary	Science: Climate	Earth Vertical **CO_2** Concentration Profiles	Scanning DIAL Lidar	Pulsed, 2-Micron, Ho Laser
	Science & Exploration: Atmos. Char., EDL	Mars Vertical **Density** Profiles	DIAL Lidar (CO_2)	Pulsed, 2-Micron, Ho Laser
	Science & Exploration: Atmos. Char., EDL	Mars Vertical **Wind** Profiles	Scanning Doppler Lidar	Pulsed, 2-Micron, Ho Laser
	Science: Climate	Earth Vertical **Aerosol** Concentration Profiles	Backscatter Lidar	Pulsed, 2-Micron, Ho Laser
	Science & Exploration: Atmos. Char., EDL	Mars Vertical **Dust** Profiles	Backscatter Lidar	Pulsed, 2-Micron, Ho Laser

IIP Abstract

The state-of-the-art 2-micron coherent Doppler wind lidar breadboard at NASA/LaRC will be engineered and compactly packaged consistent with future aircraft flights. The packaged transceiver will be integrated into a coherent Doppler wind lidar system test bed at LaRC. Atmospheric wind measurements will be made to validate the packaged technology.

This will greatly advance the coherent part of the hybrid Doppler wind lidar solution to the need for global tropospheric wind measurements.

IIP and the Global Tropospheric Wind Profiles Roadmap



2-Micron Coherent Doppler Lidar

2 micron laser 1988

Diode Pump Technology 1993

Inj. Seeding Technology 1996

High Energy Technology 1997

Conductive Cooling Techn. 1999

Compact Packaging 2005

Packaged Lidar Ground Demo. 2006

Autonomous Oper. Technol.

Space Qualif.

Lifetime Validation

Pre-Launch Validation

3-Yr. Lifetime Validation

Aircraft Operation

UAV Operation

Demo, NPOESS

Threshold, 400 km

Autonomous Oper. Technol.

Space Qualif.

Lifetime Validation

Pre-Launch Validation

3-Yr. Lifetime Validation

1 micron laser

Diode Pump Technology

Inj. Seeding Technology

Conductive Cooling Techn.

High Energy Technology

Compact Packaging 2006

Packaged Lidar Ground Demo. 2006

0.355-Micron Direct Doppler Lidar

Lidar Perf. Simulations

OSSE's

Ground-Based Risk Reduction (IPO)

2 micron Doppler wind aircraft flights

1 micron altimetry space missions

Pump Laser Diode Advancement

Dual Wavelength Telescope & Scanner

Past Funding

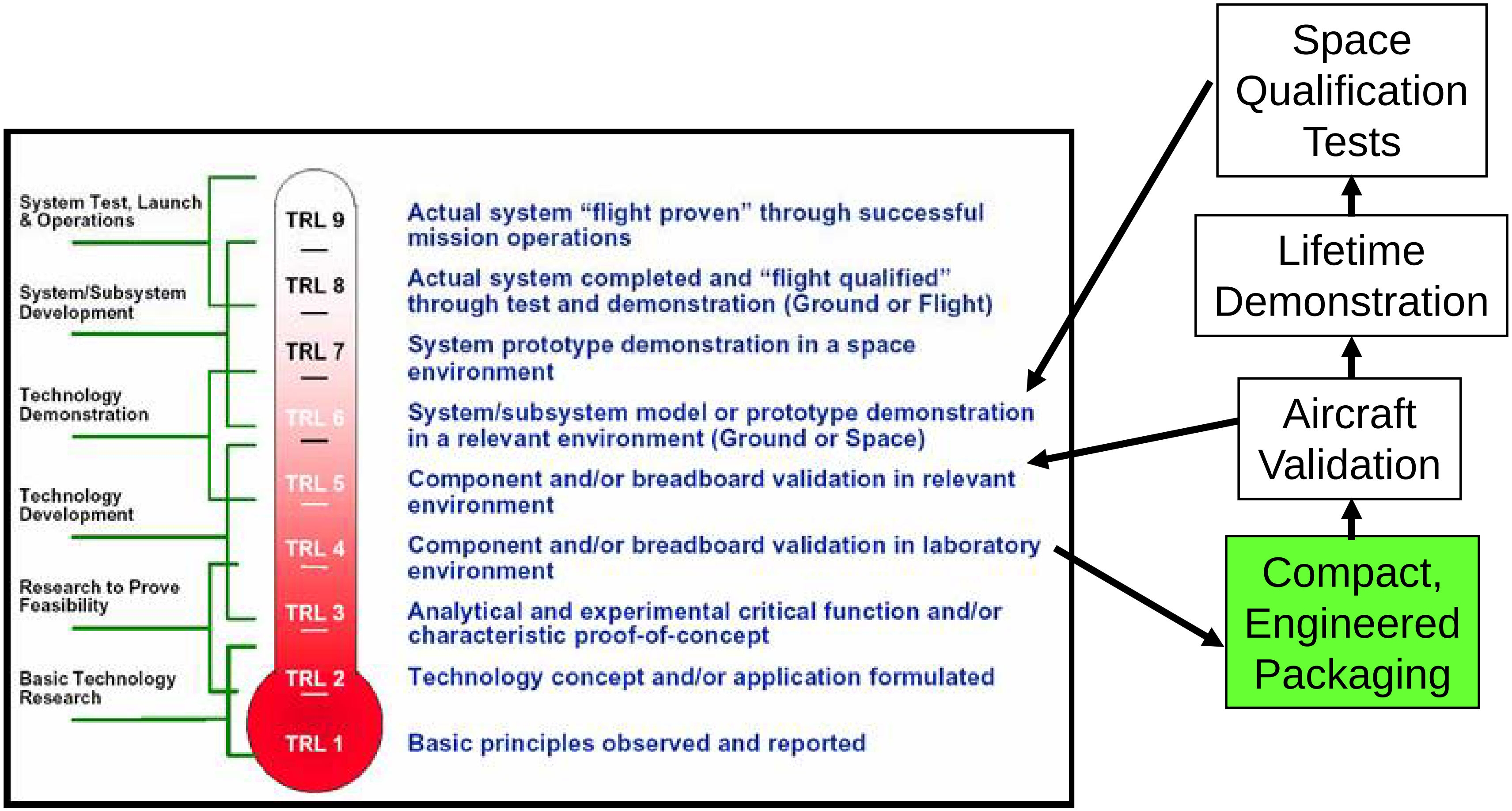
Laser Risk Reduction Program

IIP-2004 Projects

Optional

IIP TRL Advancement

“4 → 5”



TRL 9	Actual system “flight proven” through successful mission operations
TRL 8	Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)
TRL 7	System prototype demonstration in a space environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
TRL 5	Component and/or breadboard validation in relevant environment
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 2	Technology concept and/or application formulated
TRL 1	Basic principles observed and reported

Space Qualification Tests

Lifetime Demonstration

Aircraft Validation

Compact, Engineered Packaging

IIP and the LaRC Development of Pulsed, 2-Micron Laser Technology For Space

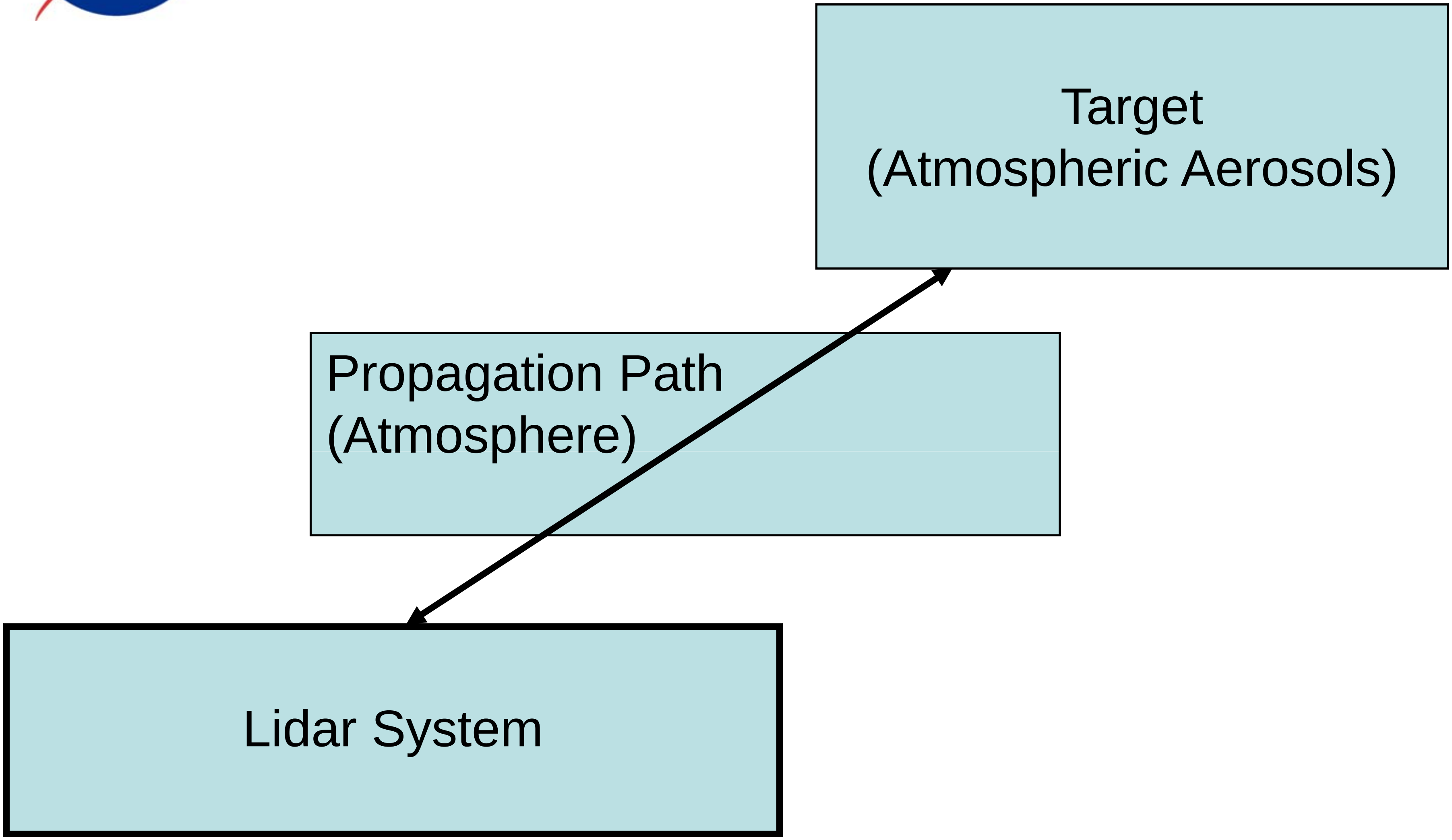
Category	Sub-Category/Date	6/02	9/02	2/03	4/03	11/03	2/05	12/05	LRRP	**IIP**	SPACE DEMO
Demonstrated (Side-Pumped, LuLiF)	Pulse Energy (J) (in double pulse)	0.135	0.355 /0.6	0.095	0.626/ 1.05	0.1/ 0.073	1/1.5	1.2		**0.25**	0.25
	Pulse Rate (Hz)	2	2	10	2	2/10	2	2		**10**	5-10
	Efficiency (%) (O-O)	3.65	3.66	2.57	4.10	2.78	5/6.2	6.5			
Laser Component	Oscillator	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Preamplifier						✓				
	Amplifiers		1 x 2-pass		2 x 2-pass		2 x 2-pass	2 x 2-pass	✓	**1 x 2-pass**	1 x 2-pass
Laser Mode	Q-Switched	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Double Q-Switched		✓		✓	✓	✓				
	Injection Seeded=SLM			✓						✓	✓
Cooling	All liquid				amp						
	Partially conductive	✓	✓	✓	osc		✓	✓		✓	
	All cond w/o heat pipe										
	All cond w/ heat pipe					✓			✓		✓
Pump Diodes	C Package				amp						
	A package	✓	✓	✓	osc	✓	✓	✓	✓		
	AA package									✓	
	G package										✓
Packaging	Laboratory Table	✓	✓	laser	✓	laser	✓	✓			
	Compact, Engineered			head		head			head	✓	✓

IIP Re-Plan, Fall 2005

	Original Plan	Proposed Replan	Citation/Notes
Contracts	$1850K to Raytheon over 3 years (450/650/750) for packaging the lidar transceiver	$1800K to in-house effort with small contracts as needed for packaging the lidar transceiver	IIP proposal, page 16
Starting Point	Some Raytheon IRAD spending during past few months	Completed compact design from $600K LRRP task in FY05	ESTO e-books report LRRP-05-0011-A-OCT-2005 plus CDR at LaRC on 11/28/05
Lidar Transceiver Pulse Energy	Packaging 100 mJ design	Packaging 250 mJ design	Closer to space & more validation options with higher energy
Packaged Transceiver Specifications Guaranteed	No (contractor will not inlcude IRAD in SOW per 12/2/05 comments on SOW)	Yes	See 12/2/05 comments on SOW from Raytheon
Hardened for Future Post-IIP Aircraft Flight	Not included in NASA funding; promised IRAD effort may do some hardening	Flight-designed; ready for passenger compartment flights; ready for 60 Kft pressure	Necessary for aircraft flight
Electronics Advancement	No planned effort	Yes, compact laser control electronics included; heading towards high altitude & autonomous operation electronics	Necessary for future high-altitude aircraft flight in external pod for space perspective validation
External-to-Transceiver Thermal Management	No work planned outside of packaged transceiver	Custom-designed chiller/pump in addition to packaged transceiver	Necessary for future aircraft flights
Autonomous Operation Sensors And Electronics	No planned effort	Novel quad detector in laser cavity to monitor alignment	Milestone towards auto-alignment maintenance of laser; required for high-altitude aircraft and space
Delivery Schedule	32 months after start	30 months after start	Earlier delivery allows more ground testing & validation

IIP – Scope of the Effort

Pulsed Doppler Wind Lidar Measurement Scenario

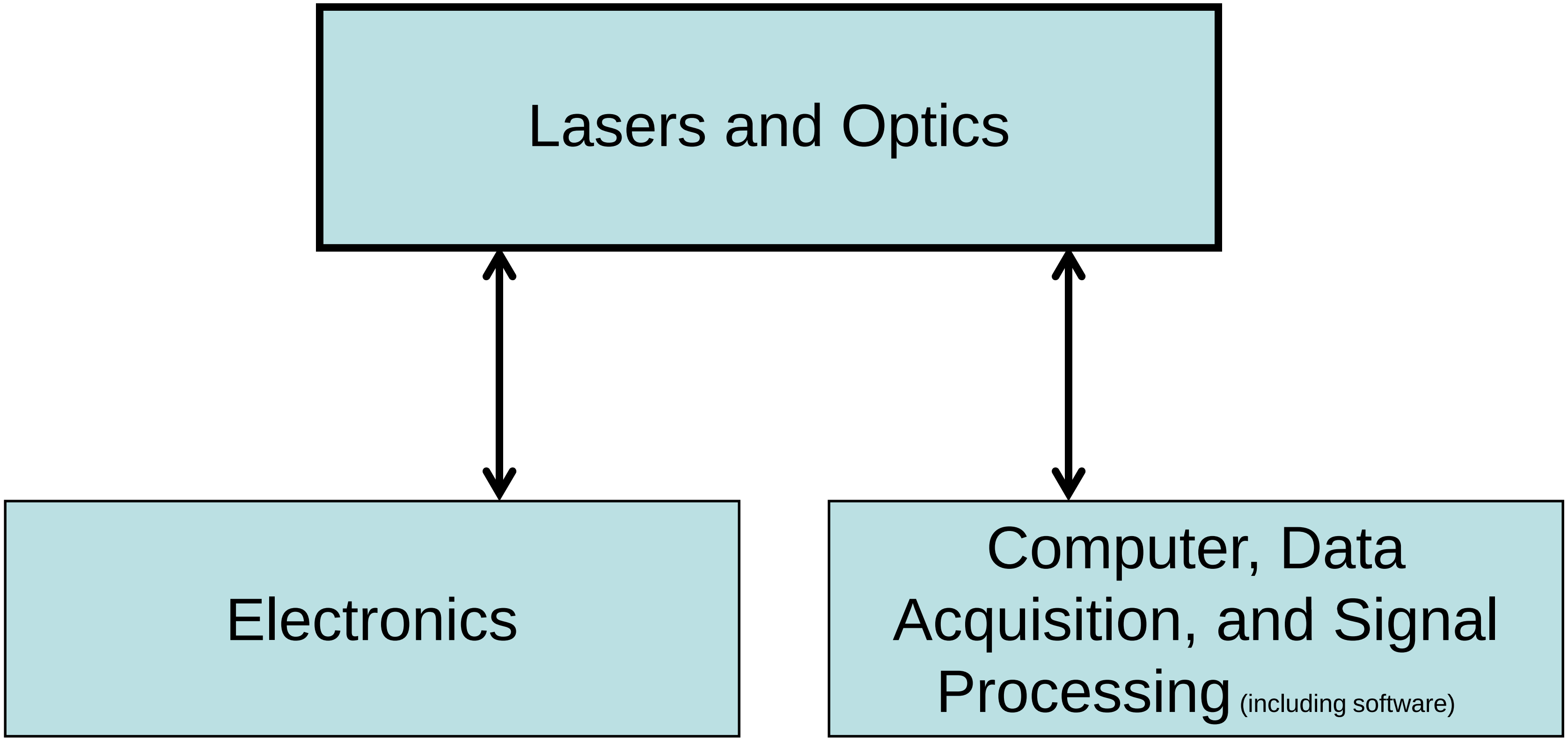


Target
(Atmospheric Aerosols)

Propagation Path
(Atmosphere)

Lidar System

Pulsed Doppler Wind Lidar System

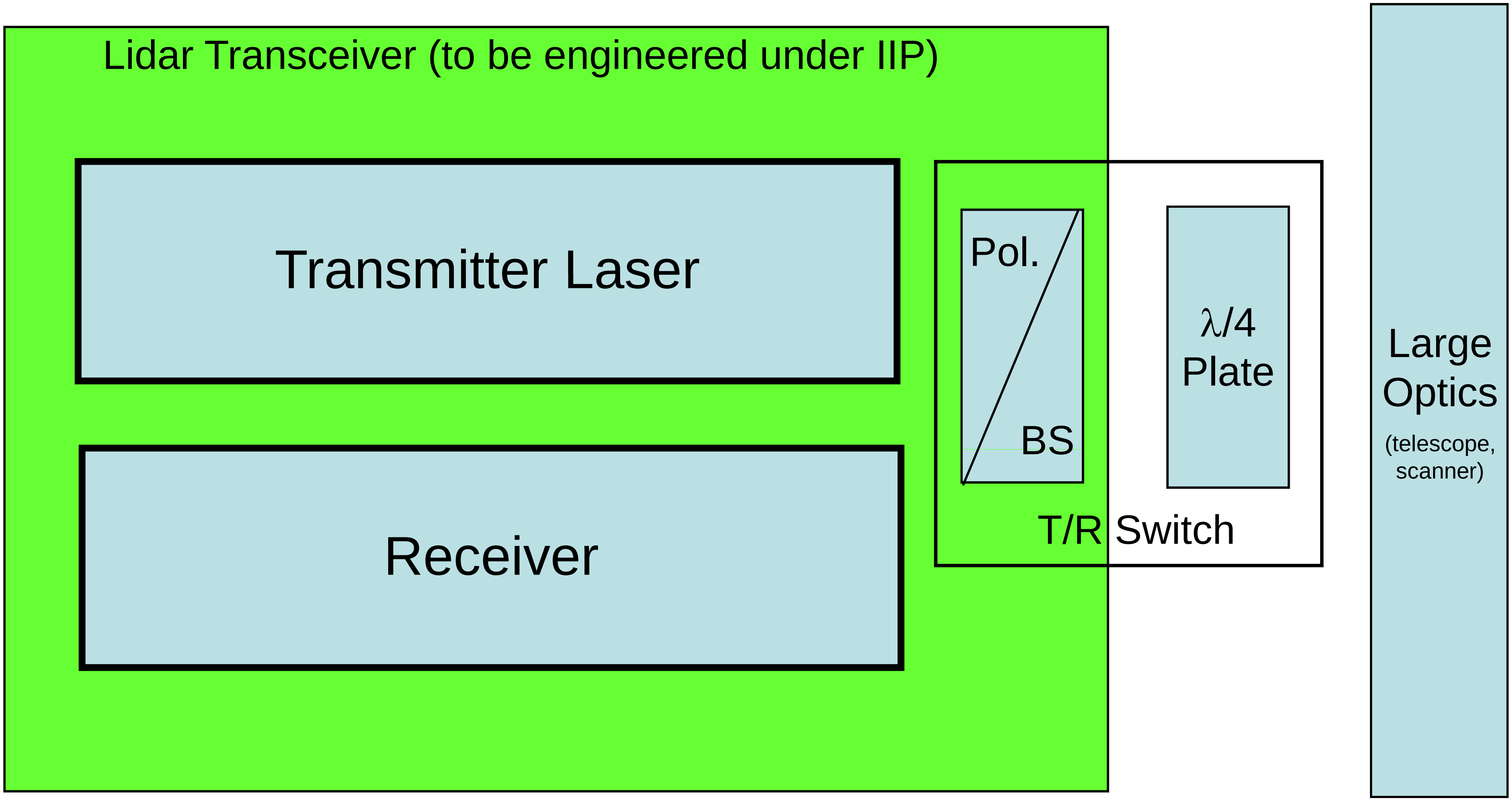


Lasers and Optics

Electronics

Computer, Data Acquisition, and Signal Processing (including software)

Lasers and Optics Portion



Lidar Transceiver (to be engineered under IIP)

Transmitter Laser

Receiver

Pol.

BS

λ/4

Plate

T/R Switch

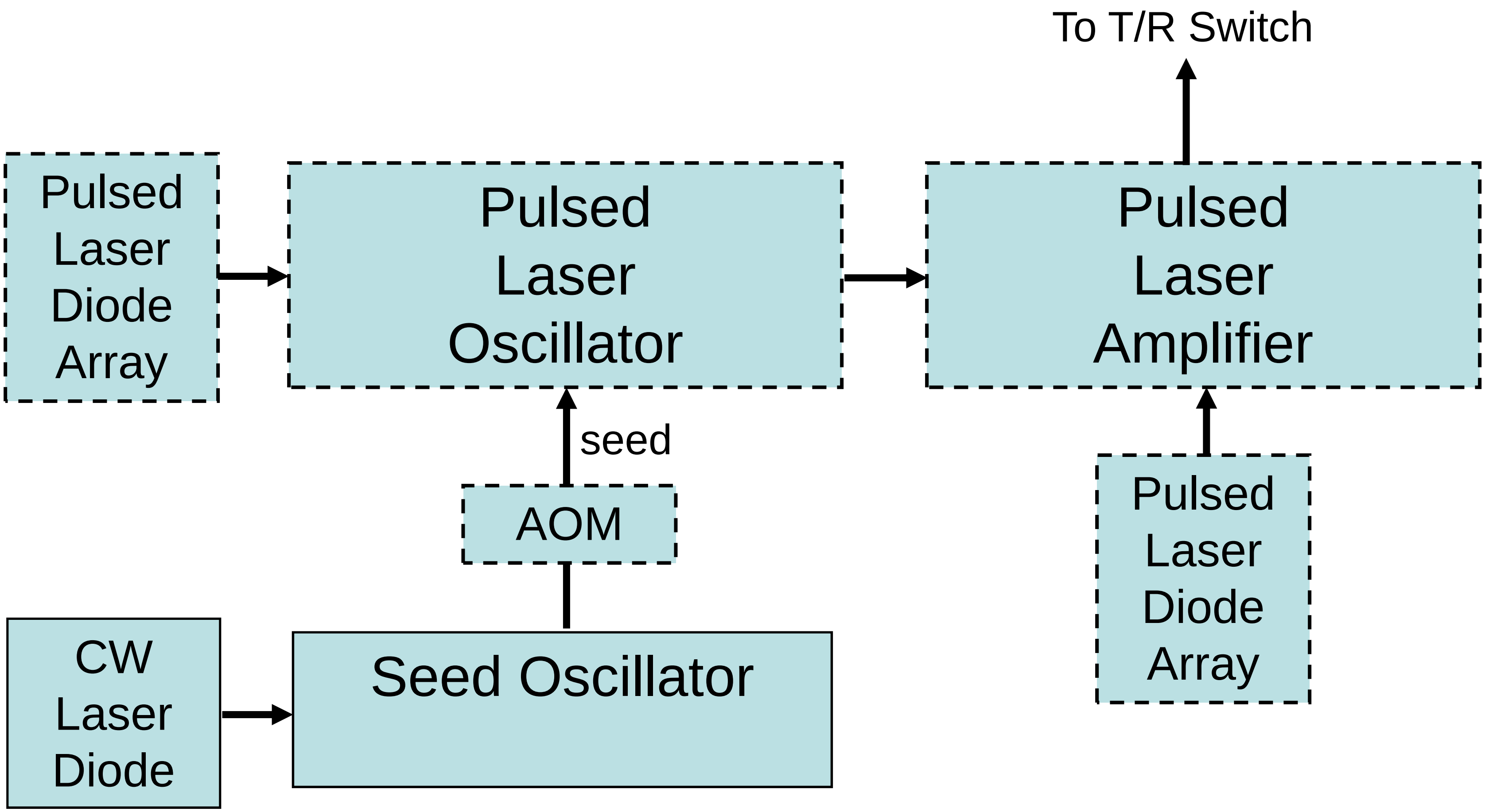
Large

Optics

(telescope,

scanner)

Transmitter Laser



To T/R Switch

Pulsed Laser Diode Array

Pulsed Laser Oscillator

Pulsed Laser Amplifier

seed

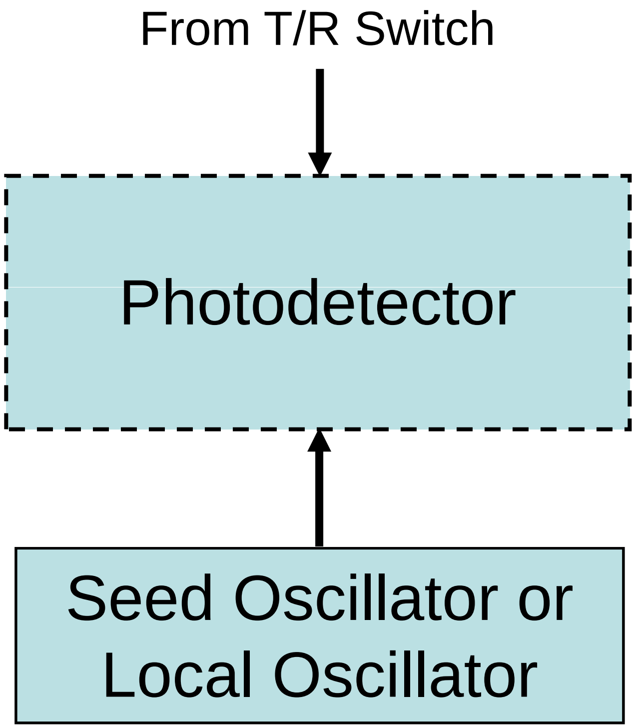
AOM

Pulsed Laser Diode Array

CW Laser Diode

Seed Oscillator

Receiver

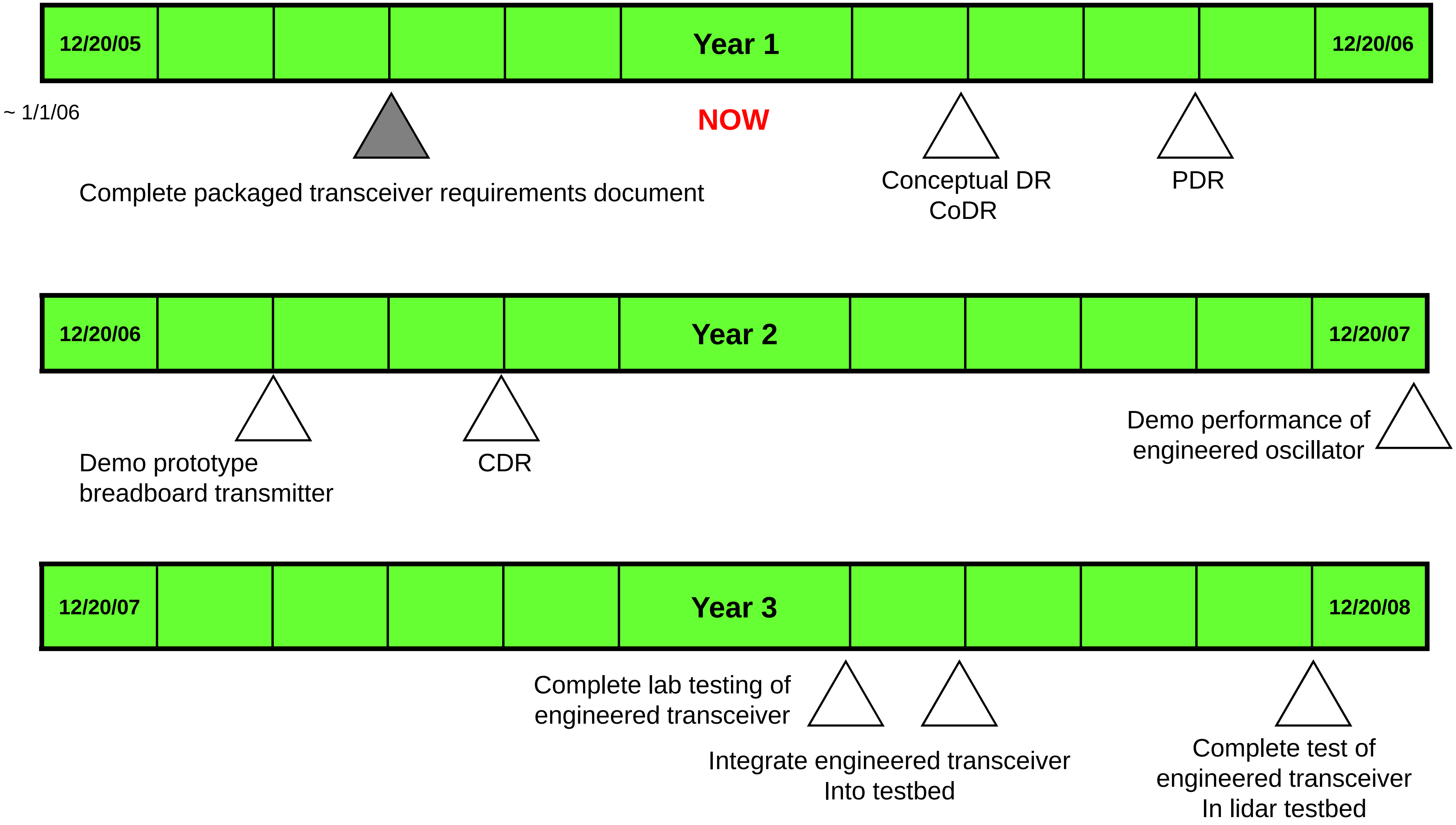


From T/R Switch

Photodetector

Seed Oscillator or Local Oscillator

IIP- Milestones & Schedule



12/20/05 **Year 1** **12/20/06**

~ 1/1/06

NOW

Complete packaged transceiver requirements document

Conceptual DR
CoDR

PDR

12/20/06 **Year 2** **12/20/07**

Demo prototype
breadboard transmitter

CDR

Demo performance of
engineered oscillator

12/20/07 **Year 3** **12/20/08**

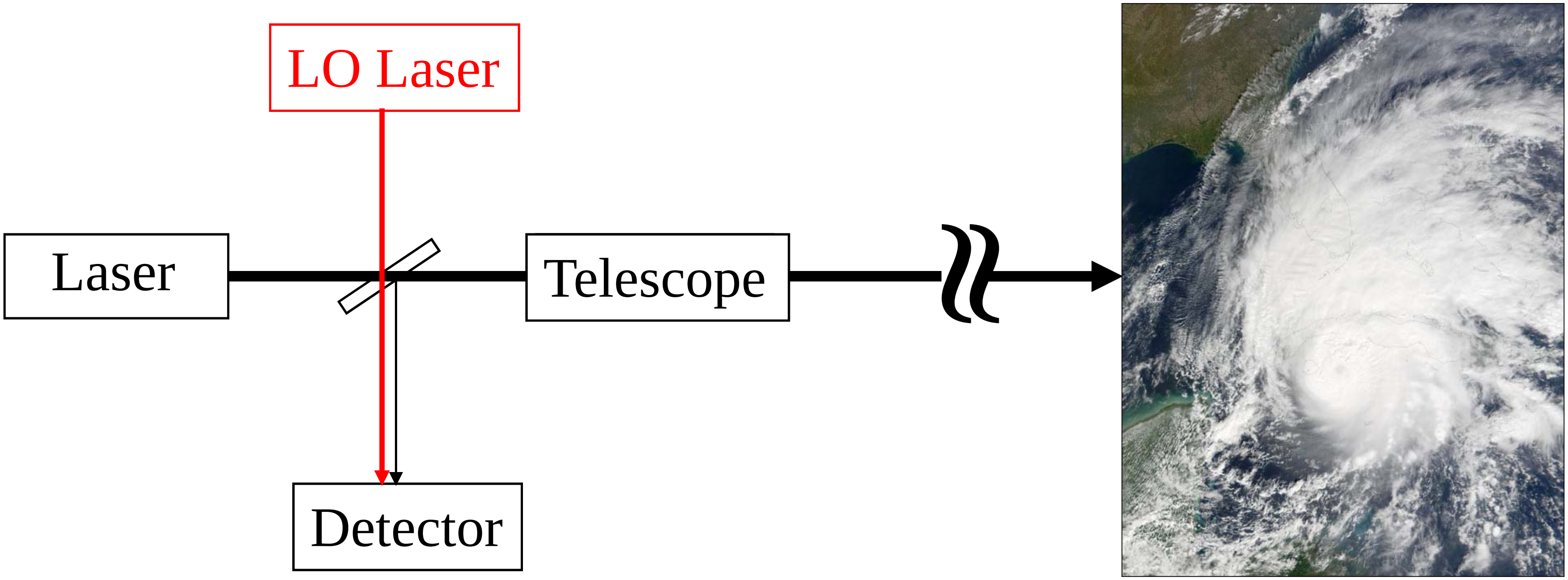
Complete lab testing of
engineered transceiver

Integrate engineered transceiver
Into testbed

Complete test of
engineered transceiver
In lidar testbed

Coherent Doppler Wind Lidar Technique

What Is “Coherent” Lidar?



LO Laser

Laser

Telescope

Detector

Benefits Of The LO Laser

- Heterodyne gain effectively eliminates signal shot noise, thermal or Johnson noise, dark-current noise, and amplifier noise. LO spatial filtering eliminates background light noise
- Translation of optical frequency to radio frequency allows signal processing with mature and flexible electronics and software, and reduces 1/f noise
- Extremely narrow bandpass filter using electronics or software rejects even more noise
- Frequency of beat signal is proportional to the target velocity - truly a direct measurement of velocity

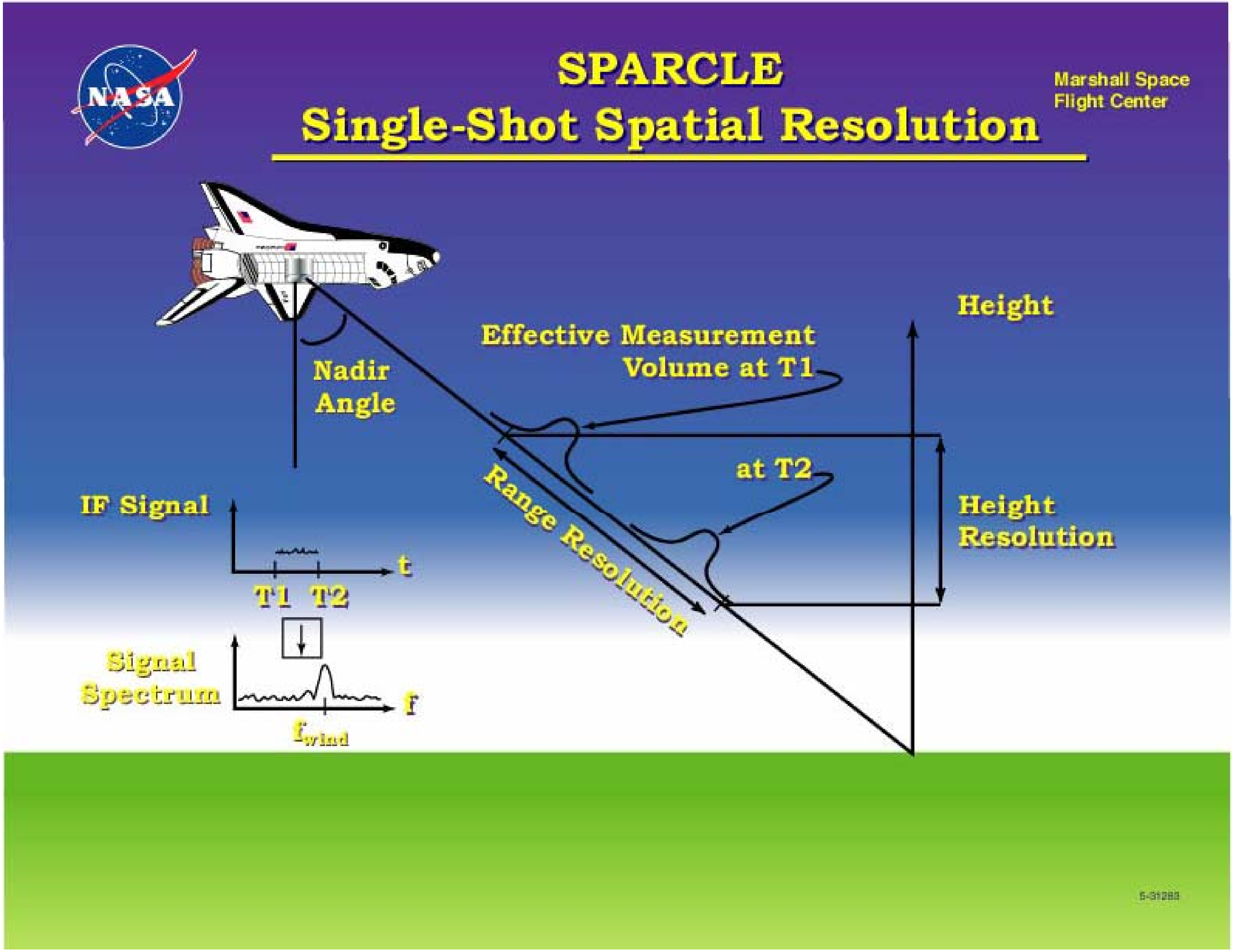
Benefits Of The LO Laser

- High accuracy
- High photon efficiency
- No intensity measurements needed

“heterodyne detection can allow measurement of the phase of a single-frequency wave to a precision limited only by the uncertainty principle”

Michael A. Johnson and Charles H. Townes
Optics Communications 179, 183 (2000)

Range and Height Resolution



SPARCLE

Single-Shot Spatial Resolution

Marshall Space
Flight Center

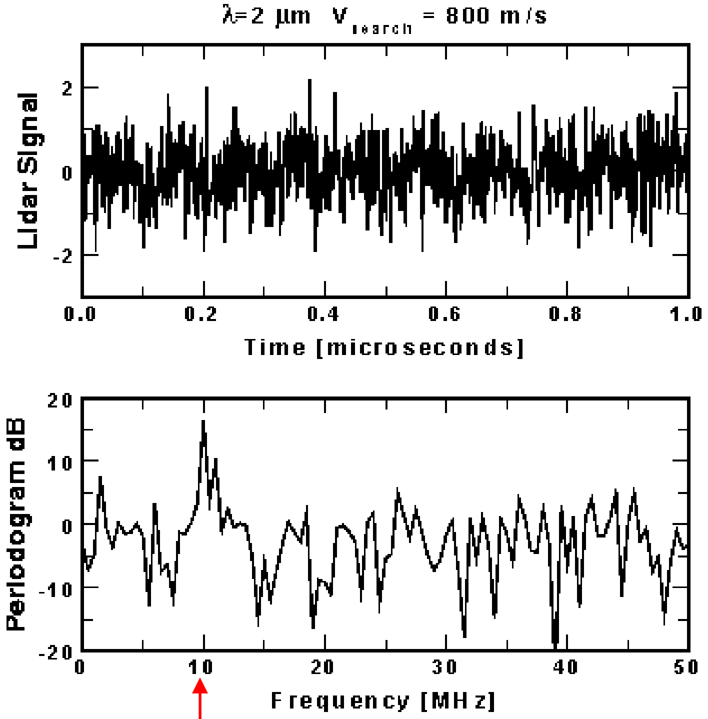
1 µs (150m) Of Lidar Data And Its Spectrum

$V=10.00$ m/s $M_s=8192$ $M=1600$ $MT_s=0.200\text{E-}05$ s

$\Phi=20$ $\Omega=2.0$ $w=0.100\text{E+}07$ Hz $w_v=1.00$ m/s

SNR=-19.031 dB SNR=0.01250 Bandwidth=800.0 MHz

"Good" Wind Estimate

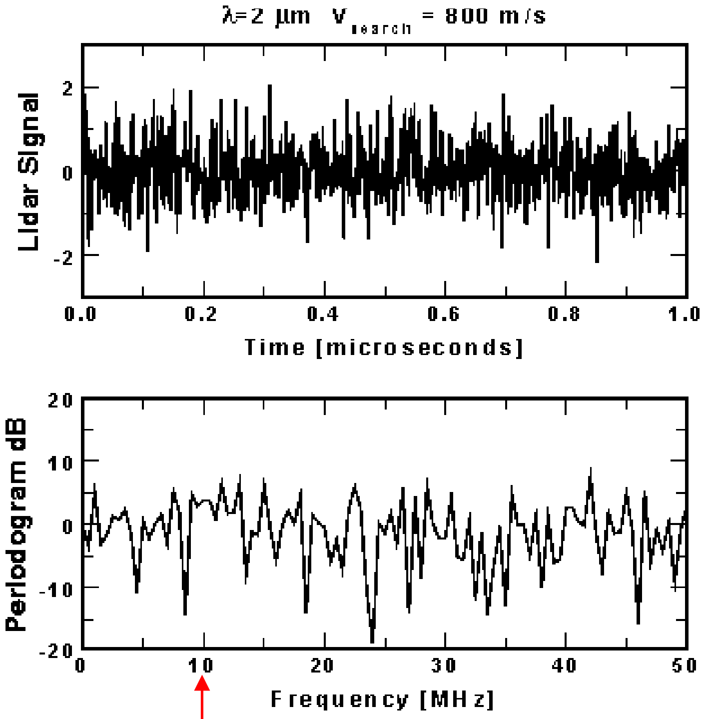


$V=10.00$ m/s $M_s=8192$ $M=1600$ $MT_s=0.200\text{E-}05$ s

$\Phi=20$ $\Omega=2.0$ $w=0.100\text{E+}07$ Hz $w_v=1.00$ m/s

SNR=-19.031 dB SNR=0.01250 Bandwidth=800.0 MHz

"Bad"Wind Estimate



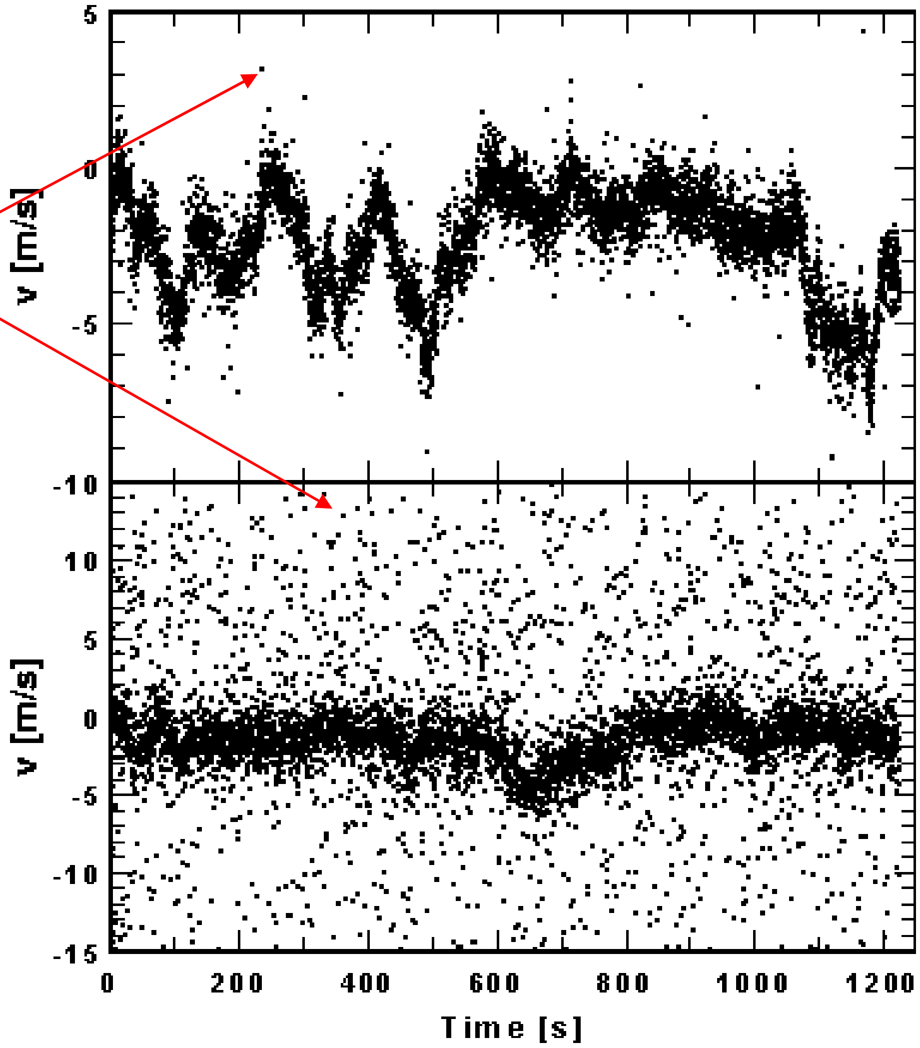
True wind, frequency = 10 m/s, 10 MHz

Effect Of SNR On Velocity Estimation

Rod Frehlich, Stephen Hannon, Sammy Henderson

J. Atmos. Oceanic. Tech. Vol. 11, 1517-1528, (1994)

Unsuccessful or “bad” wind estimates; <u>uniformly</u> distributed over “allowed” velocity range

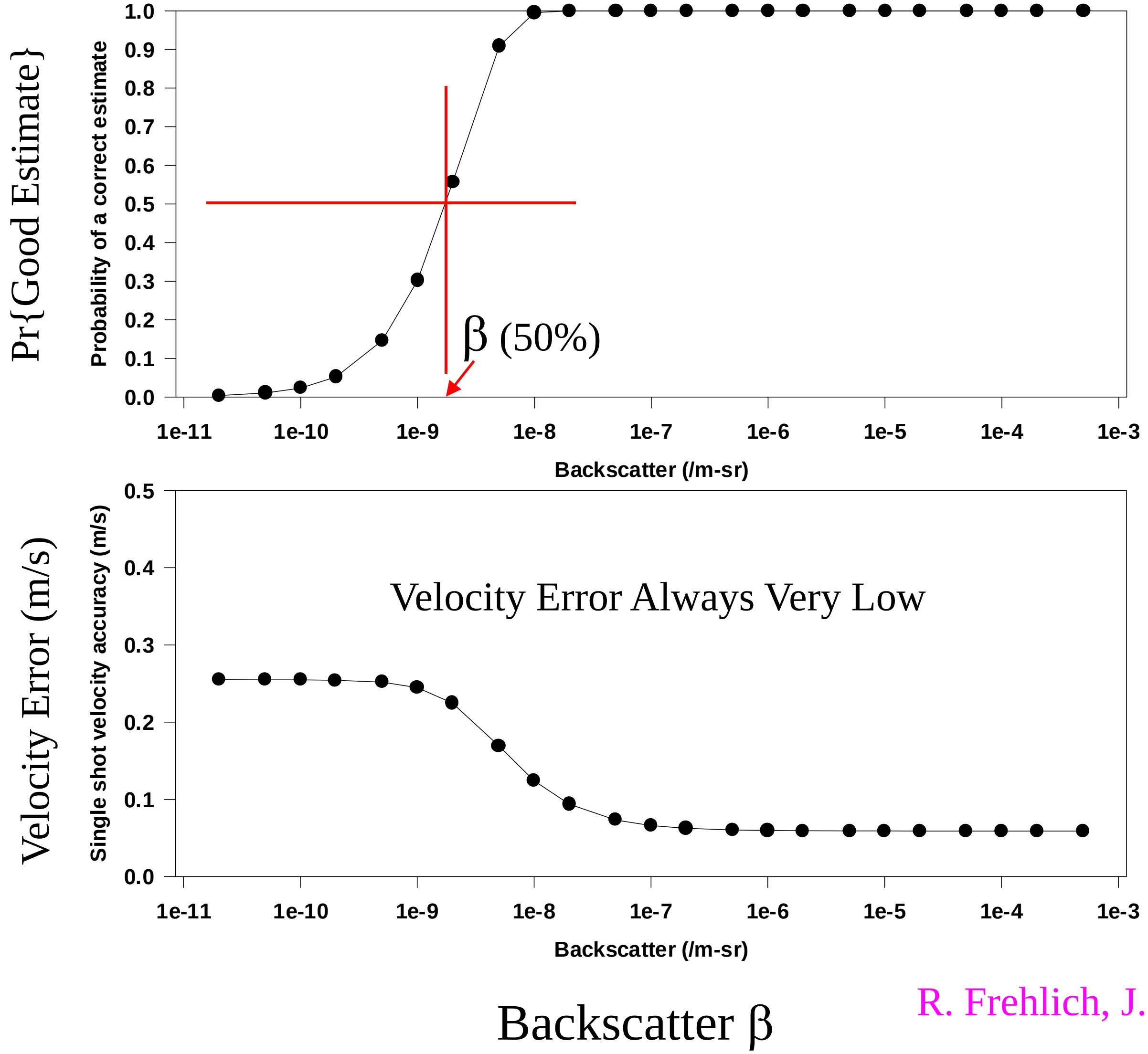


Actual lidar data
6000 shots at 4.9 Hz

Top = Figure 4, R = 1 km, high SNR

Bottom = Figure 5, R = 5 km, low SNR

Example of coherent lidar velocity estimator performance



Example plots are for a maximum likelihood estimator.

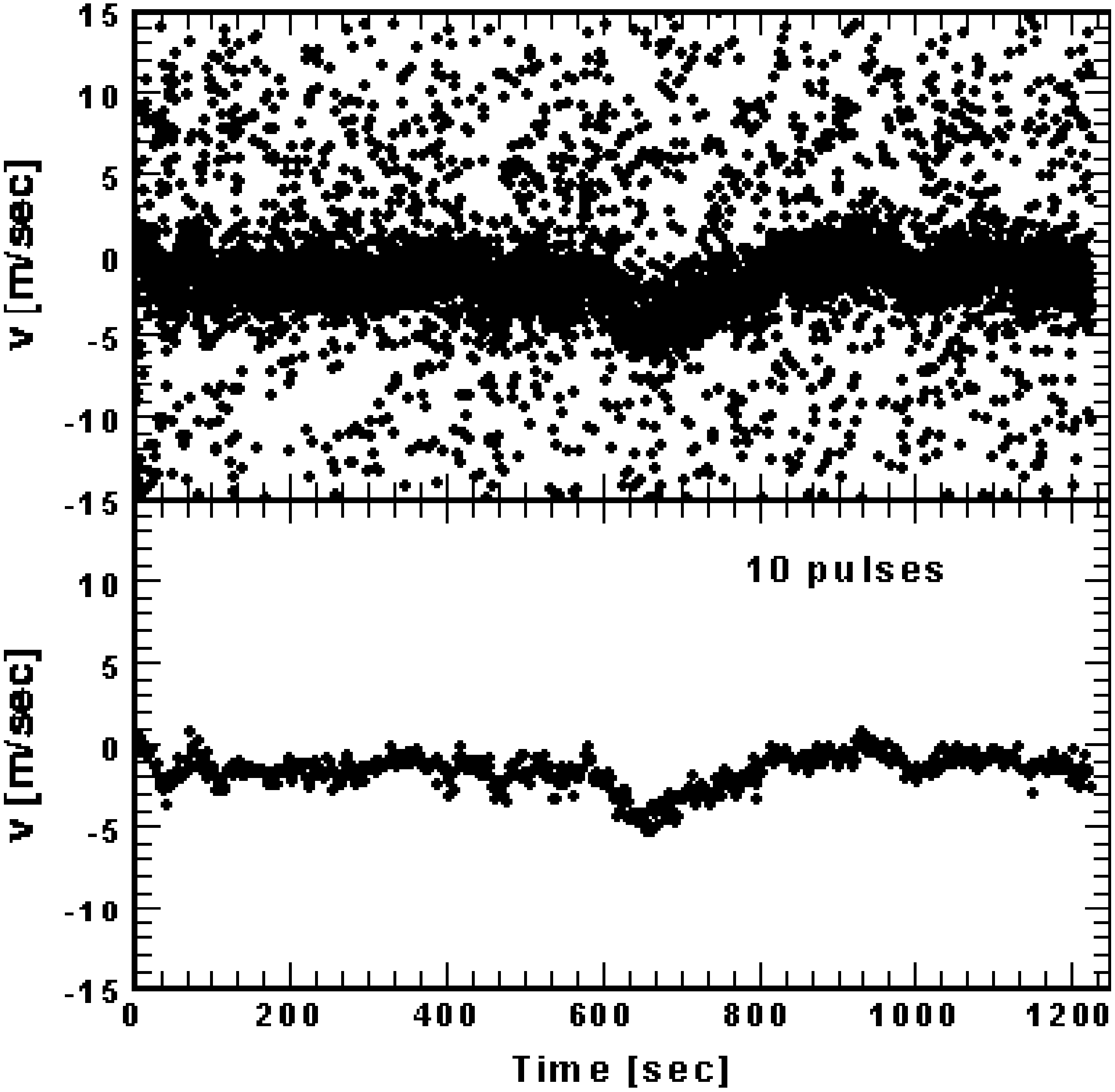
These curves ‘slide’ up and down the x-axis as a function of lidar design.

Maximum and minimum values and shape of each will vary with lidar parameters. However ‘S’ shape and the relationship between the two curves are characteristic of all advanced coherent lidar velocity estimators.

Theory and experiment agree to within 5%.

R. Frehlich, J. Atmos. & Oceanic Tech. 14, 54 (1997).

Shot Accumulation Improves Velocity Estimation
Trade Sensitivity For Time/Range/Resolution



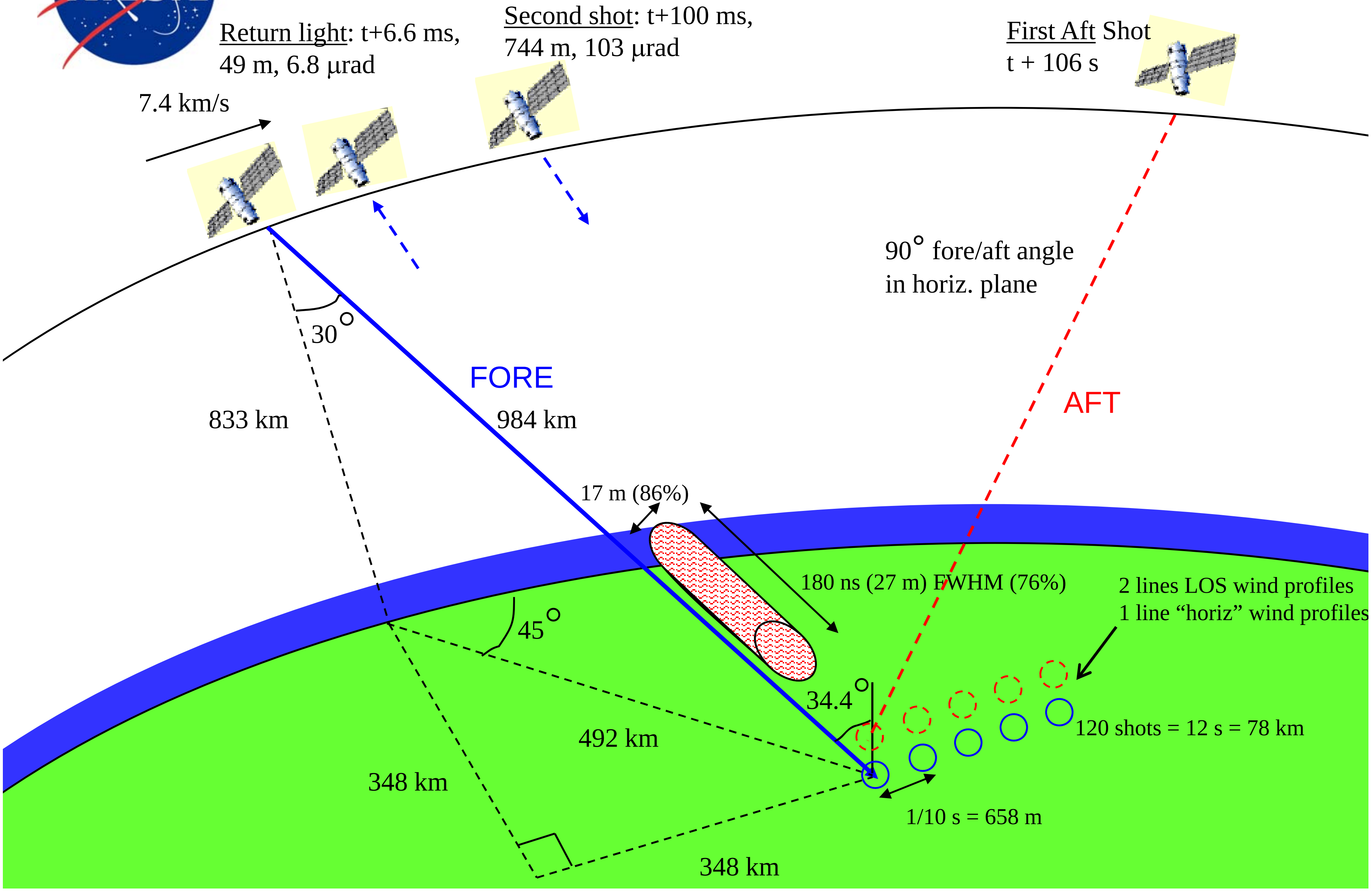
1 pulse
no accumulation

Actual lidar data

R = 5 km “low SNR”

6000 shots at 4.9 Hz

Doppler Wind Lidar Measurement Geometry: 833 km



<u>Return light</u>: t+6.6 ms,
49 m, 6.8 µrad

<u>Second shot</u>: t+100 ms,
744 m, 103 µrad

<u>First Aft</u> Shot
t + 106 s

7.4 km/s

90° fore/aft angle
in horiz. plane

30°

FORE

AFT

833 km

984 km

17 m (86%)

180 ns (27 m) FWHM (76%)

2 lines LOS wind profiles
1 line "horiz" wind profiles

45°

34.4°

492 km

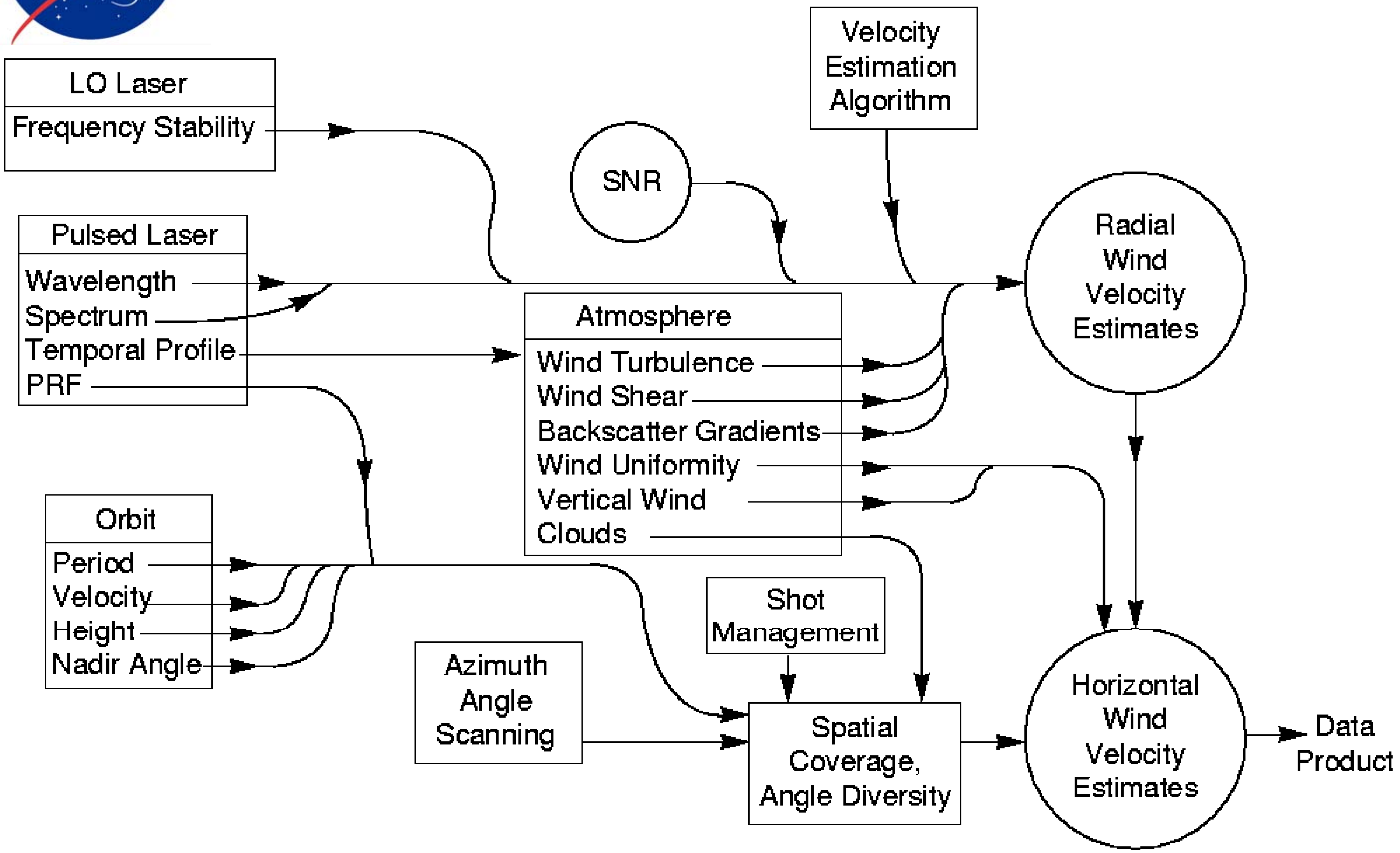
348 km

348 km

120 shots = 12 s = 78 km

1/10 s = 658 m

Space-Based Coherent Lidar Wind Measurement



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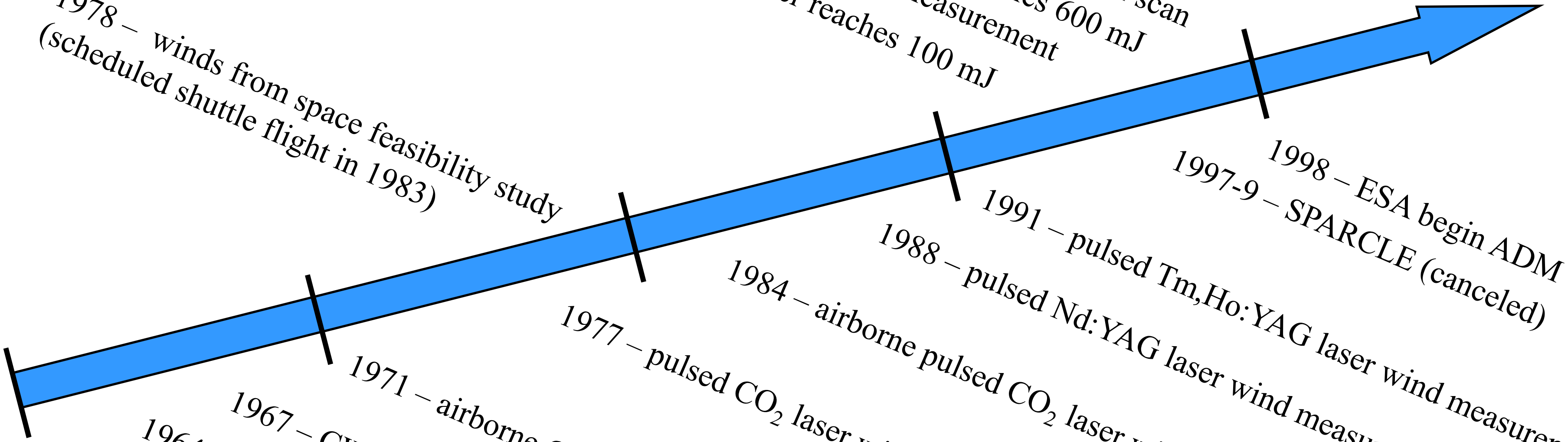
Doppler Lidar Firsts Relevant to this IIP



1960 – laser demonstrated

1964 – CO_2 laser demonstrated

1967 – CW CO_2 laser wind measurement

1971 – airborne CW CO_2 laser wind measurement

1977 – pulsed CO_2 laser wind measurement

1978 – winds from space feasibility study
(scheduled shuttle flight in 1983)

1984 – airborne pulsed CO_2 laser wind measurement

1988 – pulsed Nd:YAG laser wind measurement

1991 – pulsed Tm,Ho:YAG laser wind measurement

1994 – 2-micron pulsed laser reaches 100 mJ

1994 – airborne 2 micron pulsed laser wind measurement

1997 – 2-micron pulsed laser reaches 600 mJ

1997-9 – SPARCLE (canceled)

1998 – ESA begin ADM

1999 – airborne CO_2 pulsed laser winds with conical scan

2002 – begin NASA Laser Risk Reduction Program*

2003 – 2-micron pulsed laser reaches 1000 mJ*

2005 – selection of IIP winds proposals*

IIP Packaged Transceiver Requirements

Category	Requirement	Goal (if different) and/or Space Requirement	Reason
Laser Architecture	Master Oscillator Power Amplifier (MOPA)		High energy, beam quality, optical damage
Laser Material	Ho:Tm:LuLiF		High energy, high efficiency, atmospheric transmission
Nominal Wavelength	2.053472 microns		Atmospheric transmission
Pulse Energy	150 mJ	250 (space)	Computer modeling of measurement performance
Pulse Repetition Frequency	10 Hz	10-20 (space)	Shot accumulation, optimum laser diode array lifetime
Pulse Beam Quality	< 1.4 x diffraction limit		Heterodyne detection efficiency influence
Pulse Spectrum	Single Frequency	Few MHz (space)	Frequency estimation process
Injection seeding success	95%	99%	Shot accumulation
Laser Heat Removal	Partial Conductively Cooled	FCC (space)	No liquid lines in space
Packaging	Compact, engineered	Aircraft ready Space qual. (space)	As ready as possible for aircraft follow on

Laser Design Considerations

- Laser wavelength
- Laser material
- Laser pumping geometry
- Laser cavity design
- Laser architecture

Why Ho:Tm:LuLiF

- Why Ho laser?
  - Tm lasers in 2-µm region have such a low gain cross-section (σ_{em}~10^{-20} cm^2) that efficient, high-energy laser amplification is impossible without the risk of laser crystal or associated optics damage.
  - Ho lasers have large enough stimulated emission cross-section (σ_{em}~10^{-19} cm^2) for effective amplification to obtain high-energy.
- Why co-doped?
  - Takes advantage of diode pumping for Tm lasers
  - Takes advantage of the efficient Tm 1:2 relaxation energy transfer process
  - Takes advantage of the high emission cross-section of Ho laser

Why Ho:Tm:LuLiF – Cont.

- Why fluoride?
  - Fluoride
    - Long upper laser level lifetime ~ 15 ms, store more energy
    - Low up-conversion loss
    - Higher emission cross-section
    - Naturally birefringent material, no depolarization loss
    - Negative dn/dT –> weak thermal lensing
  - Garnet
    - Isotropic
    - Excellent thermo-mechanical properties

- Why Lutetium?
  - Lanthanide series ions
    - Lutetium, Yttrium, Gadolinium
  - Lutetium
    - Lutetium – larger crystal field
      - larger manifold stark splitting -> Small thermal population of ground state

Laser Architecture

Master Oscillator Power Amplifier (MOPA)

- Energy requirement
  - Single oscillator can’t produce required energy
- Beam quality
  - MOPA preserves the good beam quality
- Lifetime
  - Permits more derating of pump diodes
- Efficiency
  - Multiple pass amplifier improving the efficiency
- Optics Damage
  - Reducing intra-cavity fluence

Cavity Configuration

- Linear Cavity
  - Standing waves
  - Simple
  - Round trip - pass gain medium twice

- Ring Cavity
  - Traveling waves
  - No spatial hole burning in the gain-> single mode
  - Long cavity needed to obtain narrow linewidth
  - Beneficial for injection seeding through output coupler

Pumping configuration

- Pumping geometry
  - Side Pumping
    - Power scaling
    - Uniform pumping
  - End Pumping
    - Easy thermal management
    - Easy to mode match
    - Higher pump density
- Single Longitudinal Mode
  - Interferometric mode selection
  - Monolithic design, short cavity
  - Injection seeding

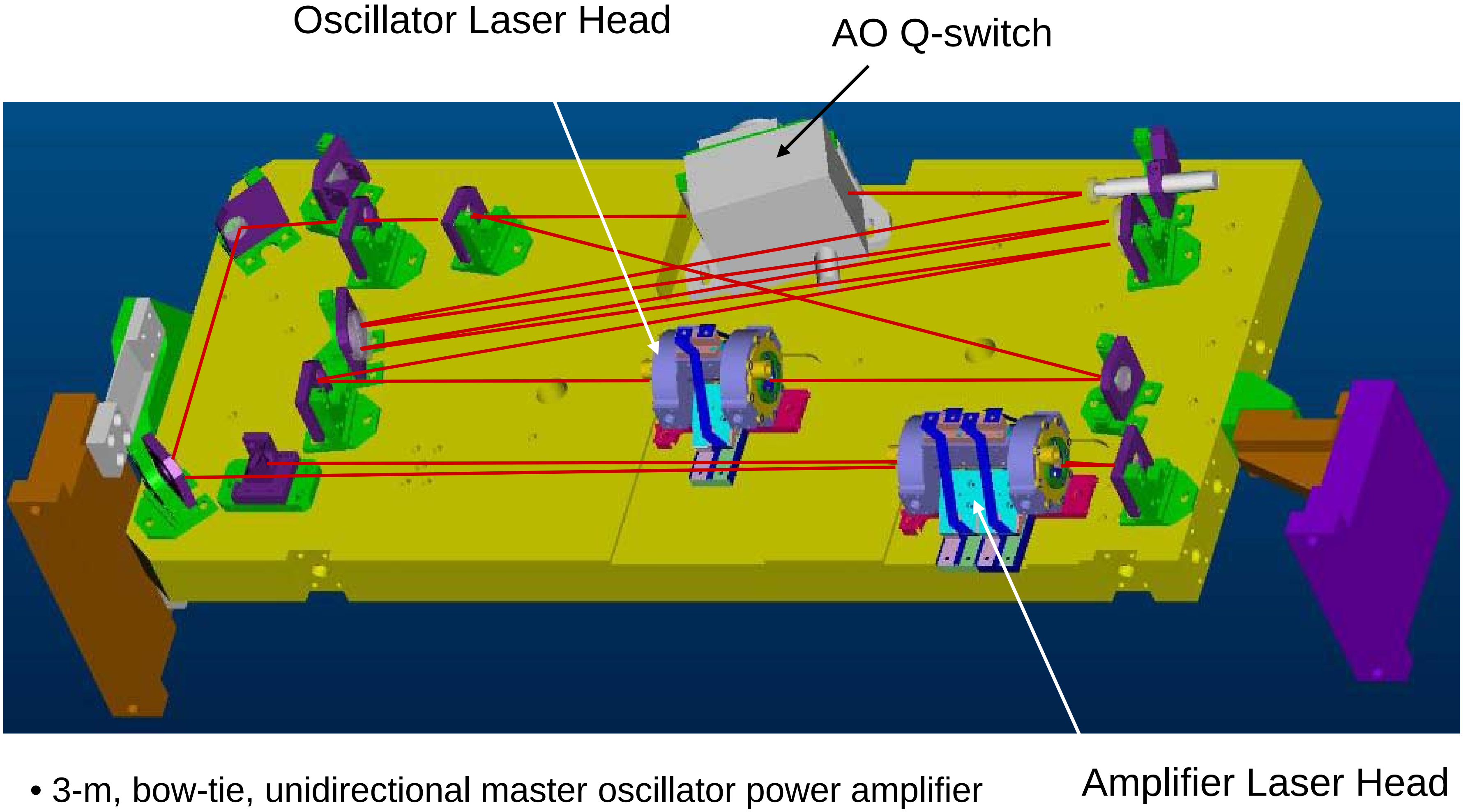
Optical Bench

- Two options:

  26.5 x 23.0 x 7 inch single side

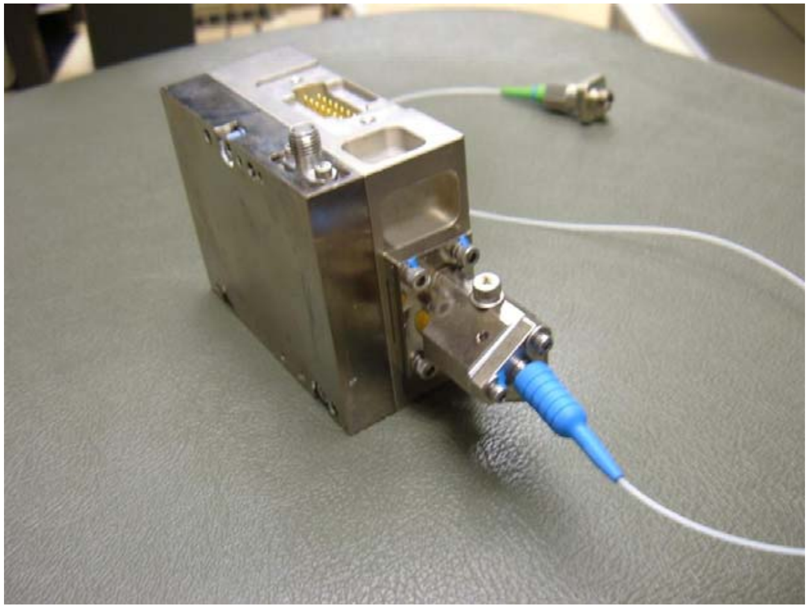
  26.5 x 11.5 x 7 inch double sided
- The split can be done such that the receiver optics and the seed laser on one side, and the power Oscillator amplifier on the other.
- Optical bench is water cooled, enclosed and dry purged.

LRRP Pulsed, 2-Micron Laser Transmitter Opto-Mechanical Design



- 3-m, bow-tie, unidirectional master oscillator power amplifier
- Seeding and receiver optics on reverse side
- Expect this hardware in about 8 weeks for LRRP

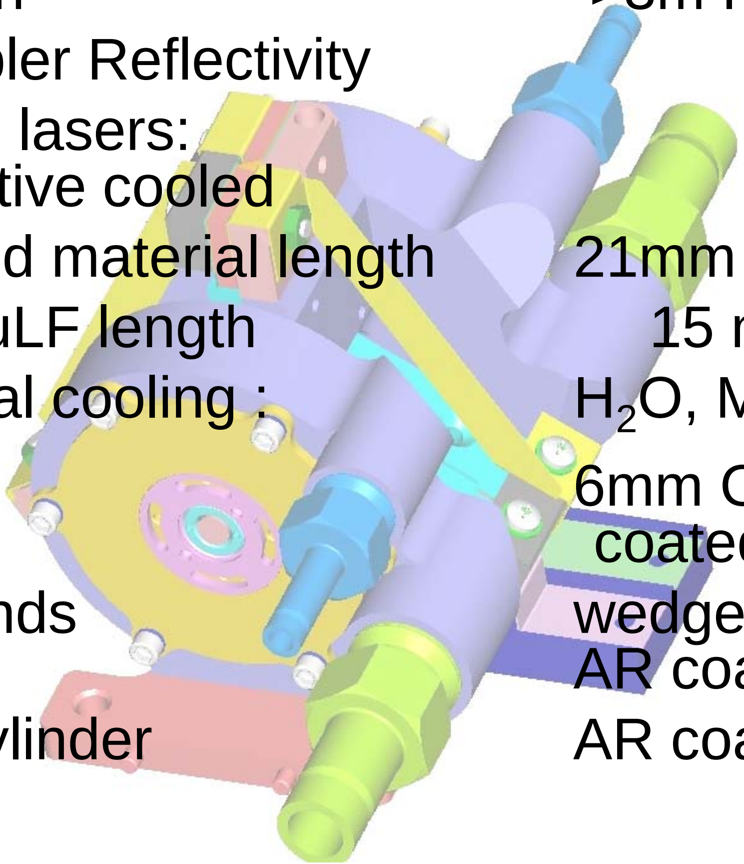
Seed Laser



CW seed laser

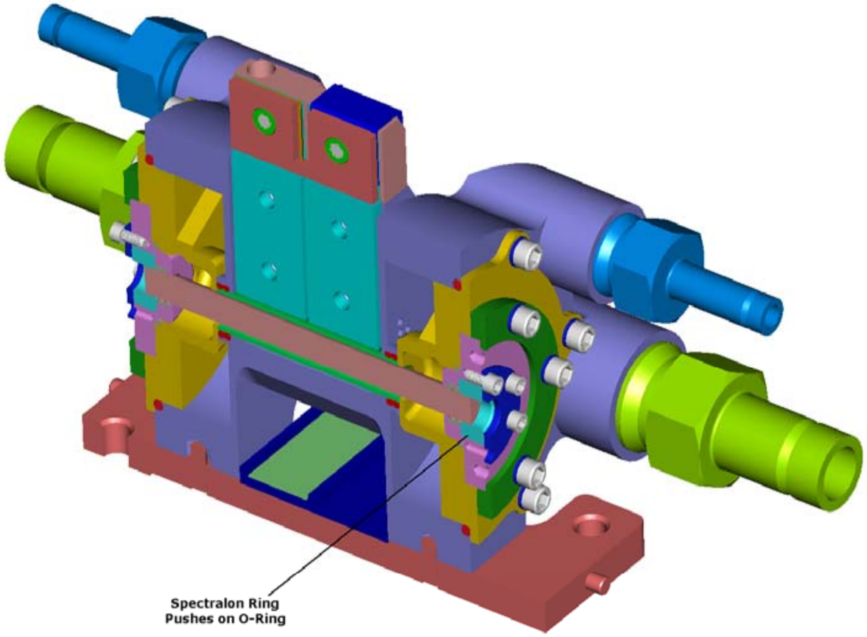
Seed laser driver

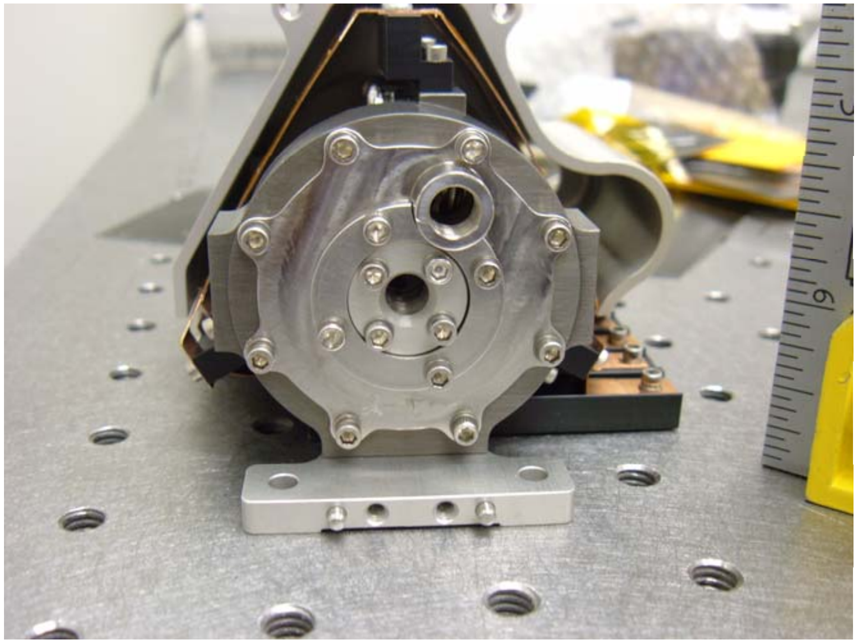
Oscillator features



• Injection seeded	
• Cavity length	>3m Ring
• Output coupler Reflectivity	~70%
• Diode pump lasers: conductive cooled	36 bars 100W/b
• crystal doped material length	21mm
• undoped LuLF length	15 mm
• Laser crystal cooling :	H_2O, Methanol
• Tube size:	6mm OD 5mm ID AR coated for 792nm
• Laser rod ends	wedged 0.5° along c-axis AR coated for 2.053µm
• Laser rod cylinder	AR coated for 792nm

Oscillator Head

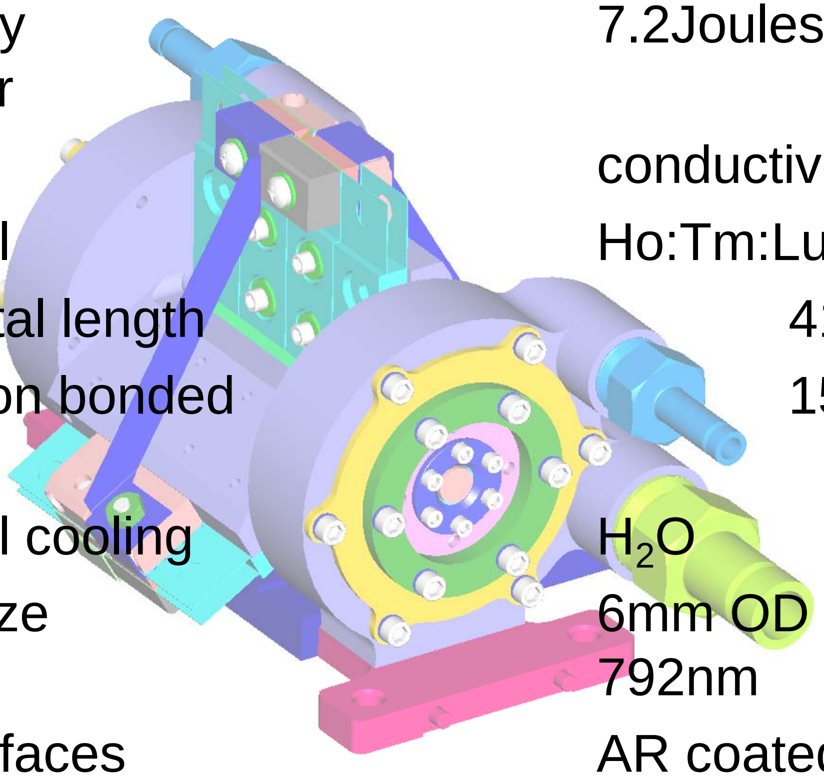




Oscillator cavity length

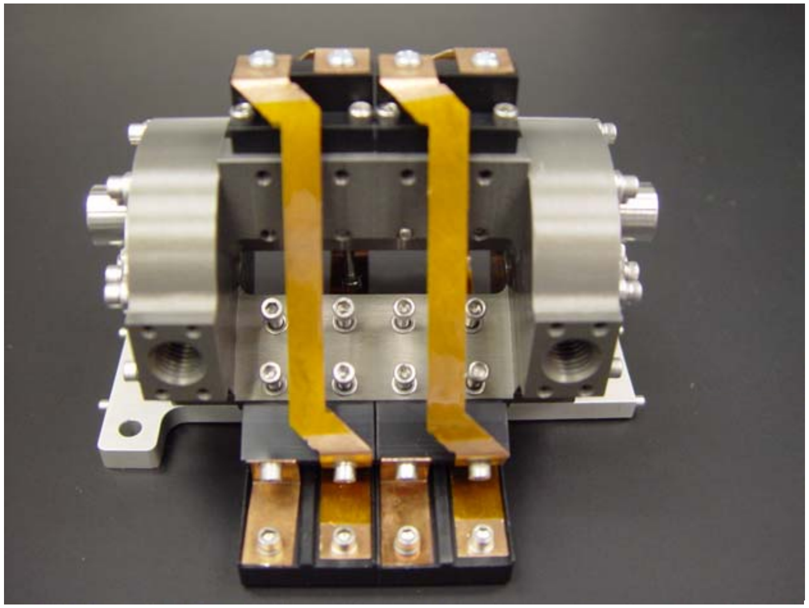
- Long cavity length is needed to obtain narrow linewidth
  - Pulse length is one of the critical parameters of a coherent Lidar.
  - A short pulse compromises frequency resolution while a long pulse compromises range resolution.
  - To meet the pulse length requirement, the oscillator length was changed from 2m to 3m. It prolongs the pulse width to near 200ns
  - The resonator has six mirrors and 8 bounces.

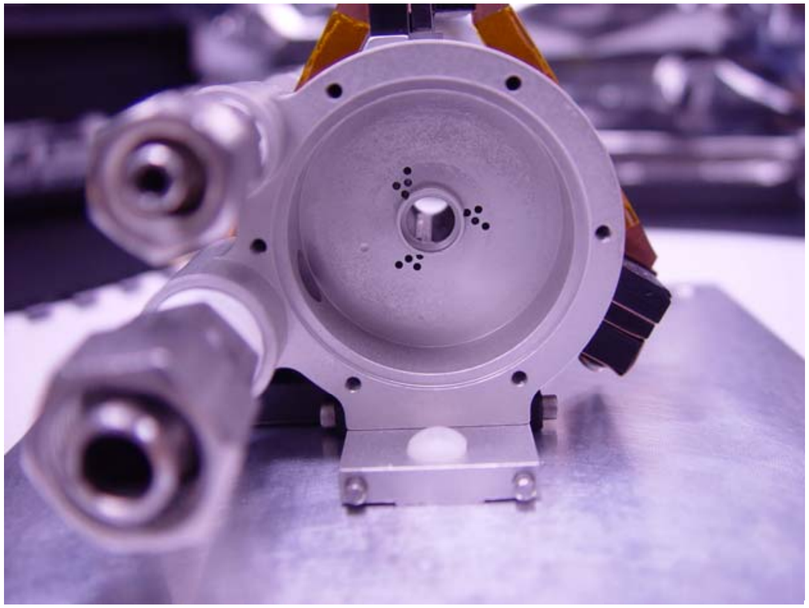
Amplifier features



Pump energy	7.2Joules12x6 bar arrays with 100watts/bar
Diode laser	conductive cooled ‘AA’ Pkg
Laser crystal	Ho:Tm:LuLF 0.5% Ho 6%Tm
Doped Crystal length	41mm
Ends diffusion bonded crystals	15 mm undoped LuLF
Laser crystal cooling	H_2O
Flow tube size	6mm OD 5mm ID AR coated 792nm
Rod end surfaces	AR coated for 2.053µm
Laser cylinder	AR coated for 792nm
Path configuration	double pass

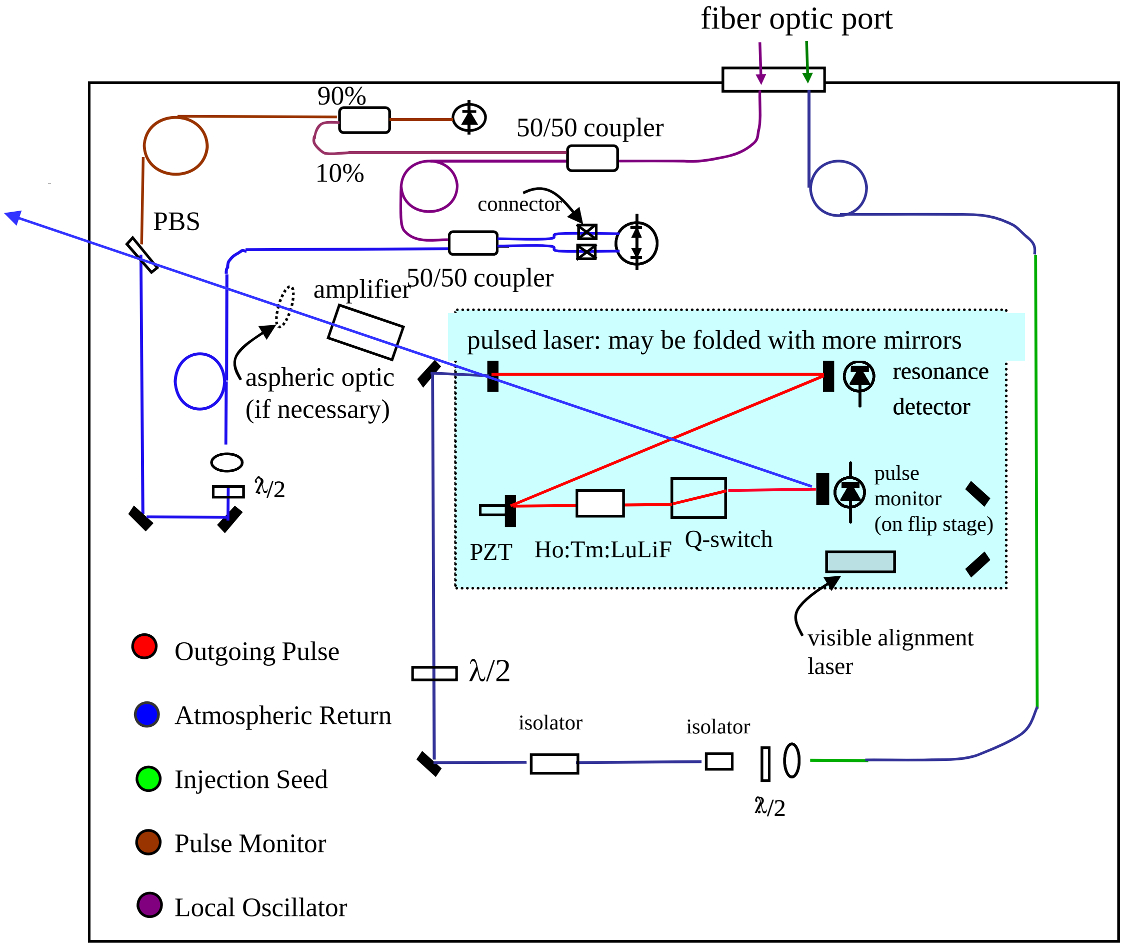
Amplifier Module





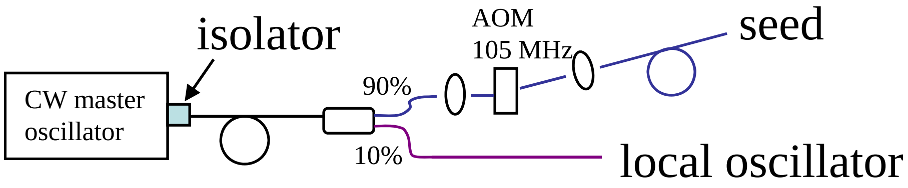
Proposed Transceiver “Box”

- Modular approach with injection seed & local oscillator separate from transceiver.
- Separate seed/LO allows flexibility to adapt to 3 measurements scenarios:
  - -simple, fixed frequency LO for ground or low platform speed.
  - - higher intermediate frequency for high platform speed
  - - swept LO for very high platform speed.
  - -DIAL of CO_2



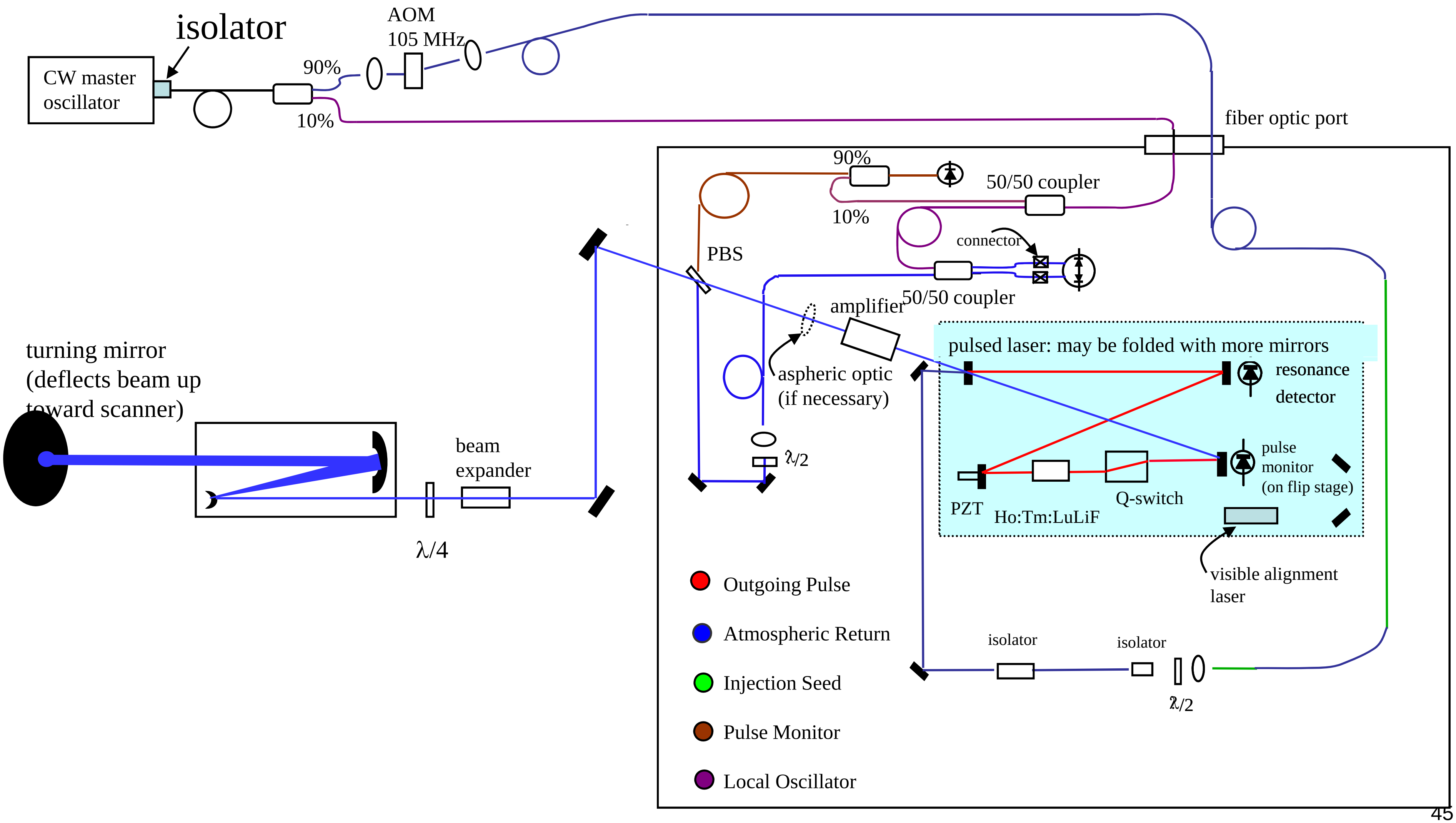
Note: only optical paths are represented; electrical and water paths are not shown.

Seed/LO Option 1

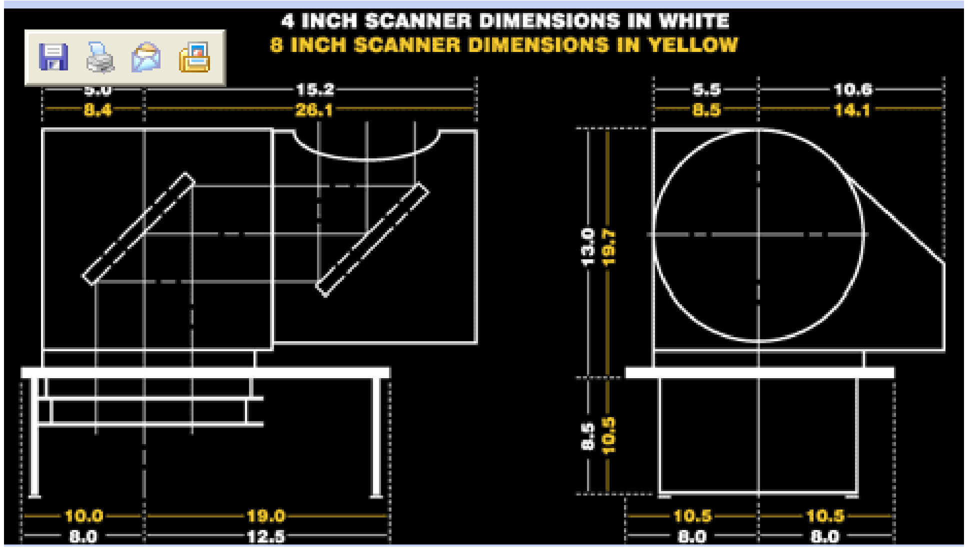


- baseline design for ground-based implementation.
- recommended for IIP demonstration.
- fiber-to-free space through AOM then back to fiber is disadvantageous—looking into fiber optic pigtailed AOM.
- could be packaged in rack-mount breadboard with fan for cooling (need thermal analysis).

Test Bed: Putting it all Together

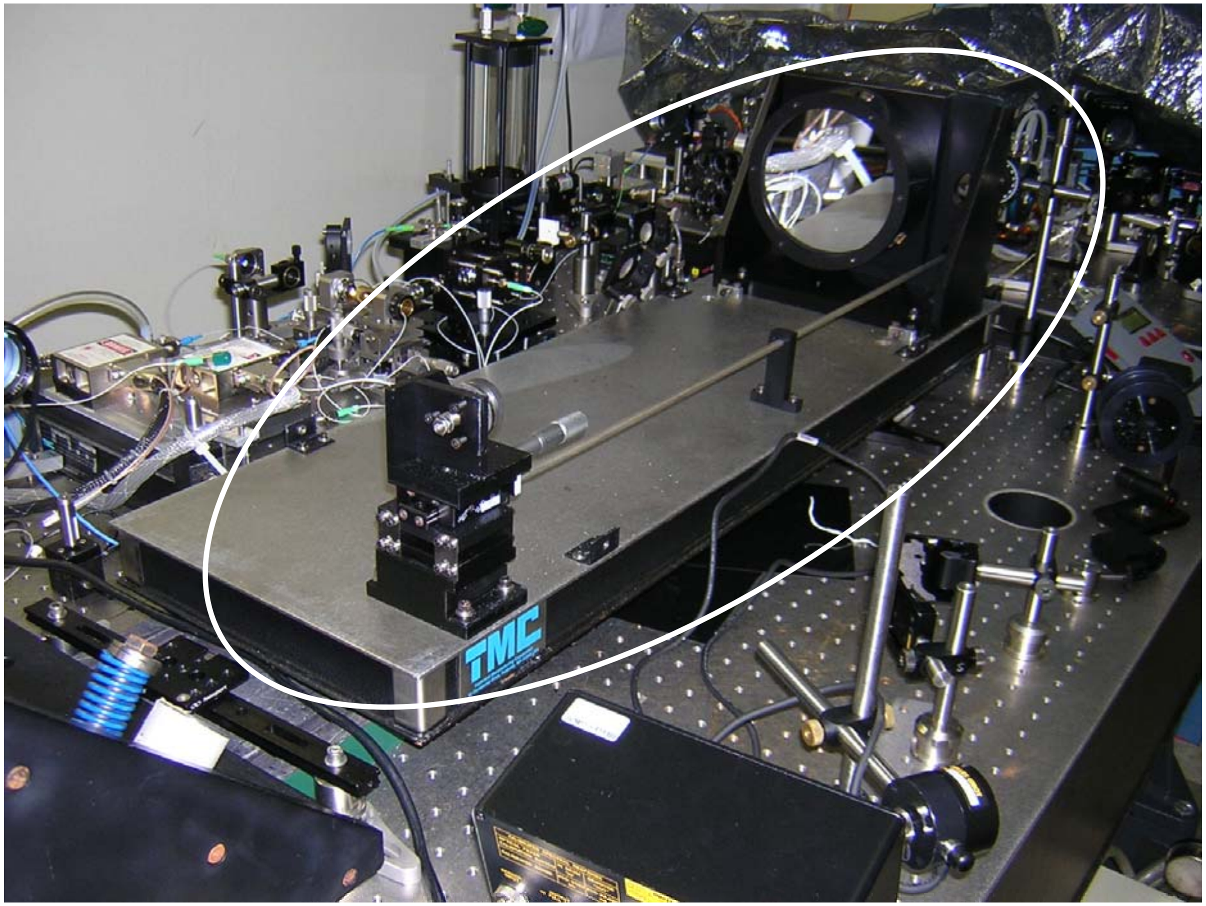


VALIDAR Scanner



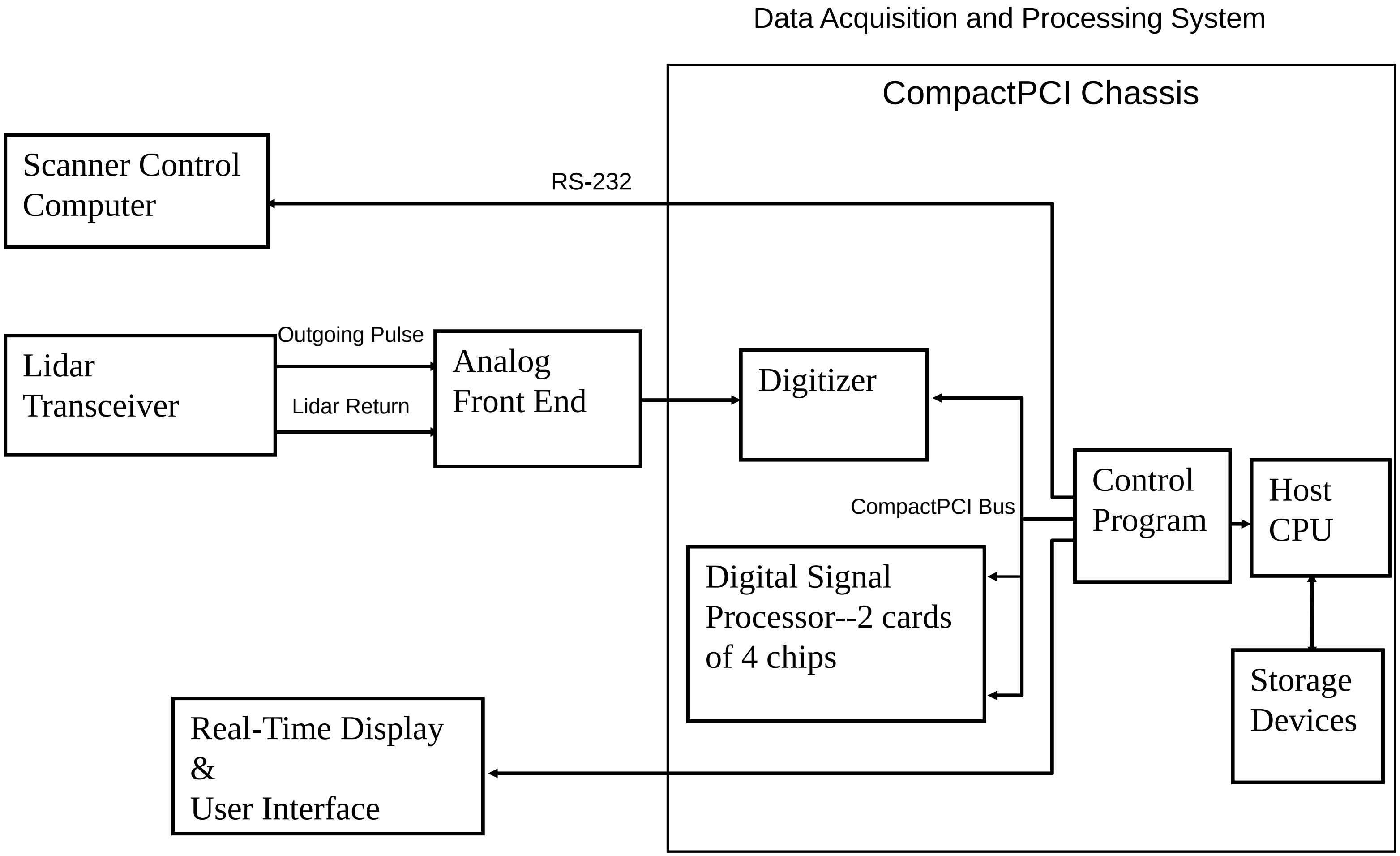
- scanner is mounted on roof of laboratory trailer.
- 8-inch clear aperture.
- can be pointed or scanned in elevation/azimuth for hemispherical coverage.
- linked to data acquisition computer for automated profiling of wind.

VALIDAR Telescope

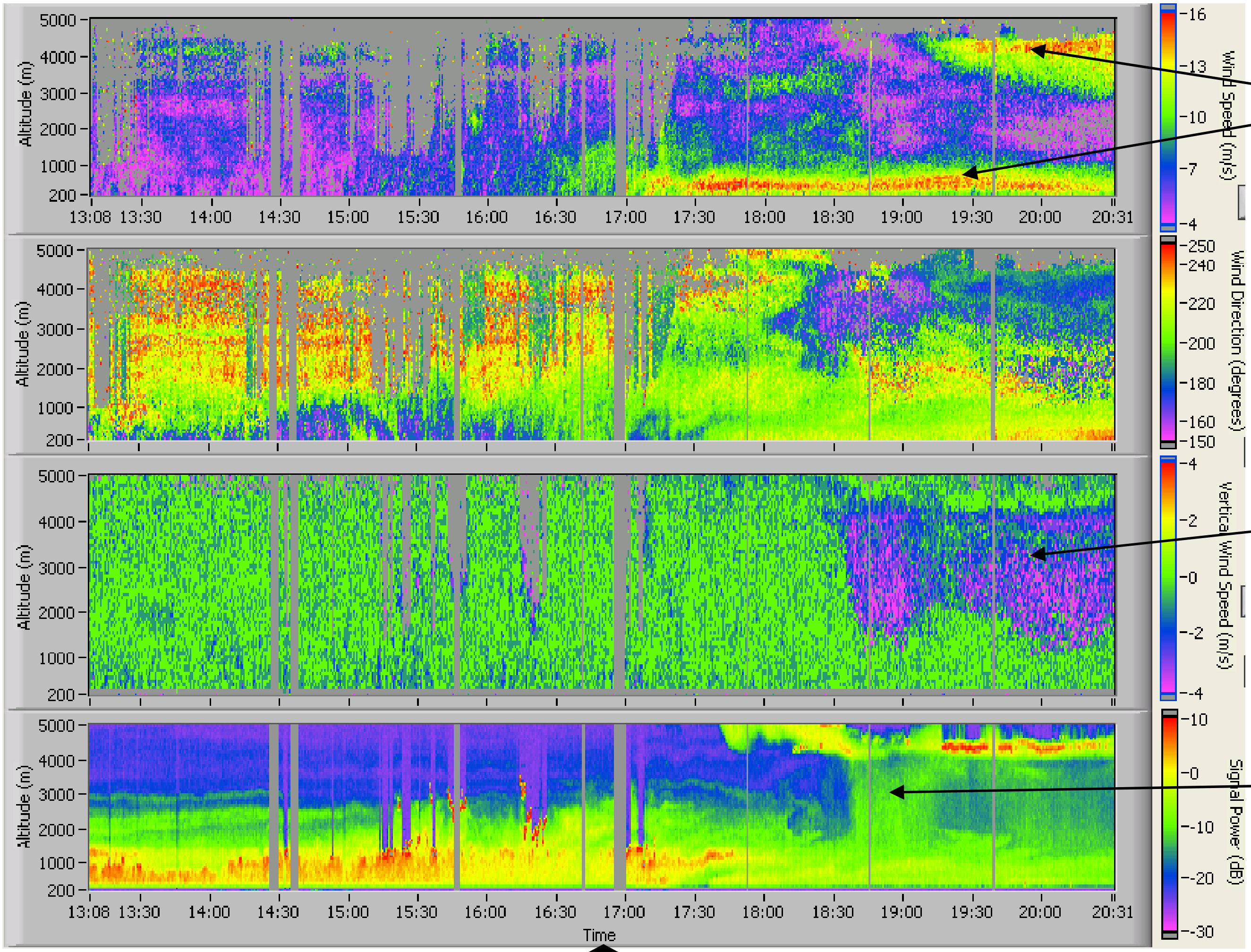


- off axis Dall-Kirkham design.
- 6-inch aperture
- 20X expansion

Data Acquisition and Processing (already built)


Data Acquisition and Processing System

Atmospheric Measurements
(will be better than this VALIDAR sample)



jets

virga

rain enhancing backscatter

passage of frontal system

Installation of Laser Timing Device

- The Laser Timing Device was installed in the VALIDAR system and tested in complete lidar.
- Significance of this new hardware:
  - Reduces size, weight, and complexity of control electronics associated with laser transmitter.
  - Improves performance of injection seeding and offers simpler adjustment of parameters.
  - Allows implementation of double-pulsing with injection seeding.
  - Graphical user interface.

Simplification of Hardware

BEFORE

8 separate electronic boxes

AFTER

19” rack-mount enclosure, 1.75 inches high

IIP Year 1 Financials

As of 6/8/06

	Budget	Committed	Obligated	Costed
FY05 Funds	$175.0K	174.6K	115.9K	24.2K
FY06 Total	841.3K	317.4K	272.7K	111.3K
Labor*	189.5K	48.3K	48.3K	48.3K
G&A	189.0K	29.1K	29.1K	29.1K
Service Pools	160.6K	33.9K	33.9K	33.9K
Procurement	296.9K	206.2K	162.4K	0
Travel	5.3K	0	0	0

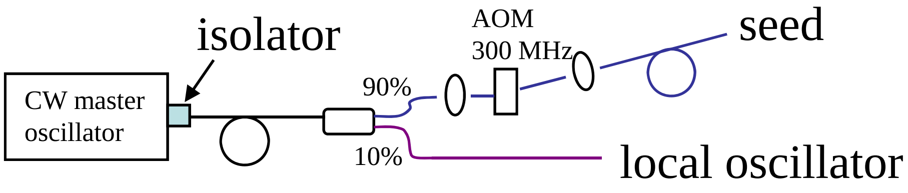
*1.45 FTE plan
0.57 FTE actual

Summary

- IIP project 6 months into 36 month effort
- On schedule and budget to date
- Leveraging LRRP work on compact laser in 05 and 06
- Plan on significant steps of compact, engineered packaging of state-of-the-art laser/lidar technology. TRL definitions do not reveal significant progress.
- Companion IIP at GSFC for noncoherent Doppler wind lidar will complement this project to permit hybrid DWL on aircraft and then in space
- Project very consistent with findings of NASA/ESTO Laser/Lidar Technology Requirements Working Group results (FY06). To be issued in final report
- Anticipate strong endorsement of global winds by NAS decadal study on earth sciences
- Same technology promises additional applications for earth and Mars

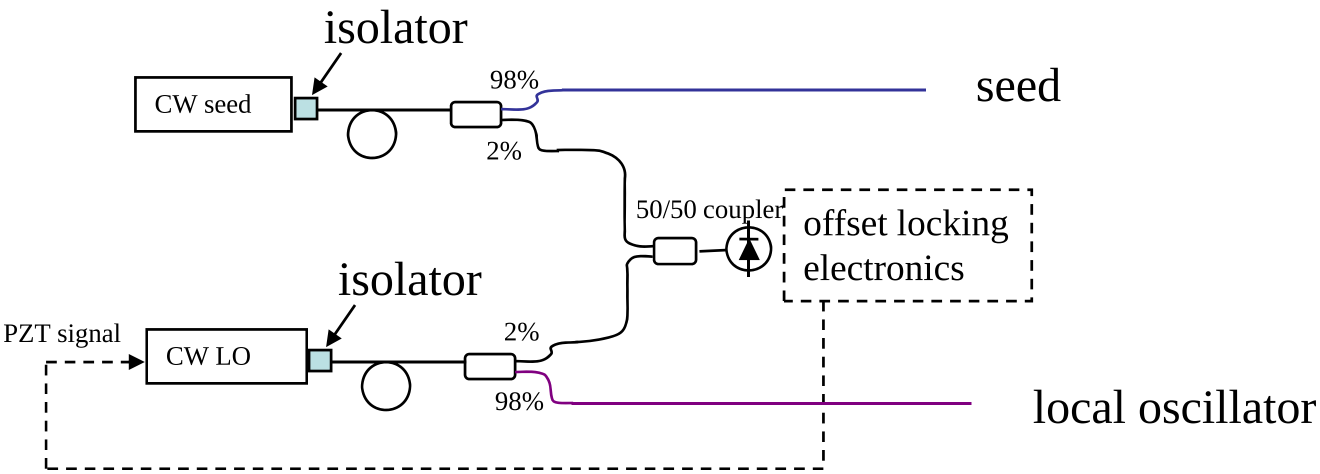
BACK UP

Seed/LO Option 2



- used for aircraft.
- same as Option 1, except AOM offset is higher.
- system may require replacement of heterodyne photodetectors.
- aircraft speed and scanner angle are used to select a frequency to beat down heterodyne signal to bandwidth of data acquisition system.

Seed/LO Option 3



- used with space mission with very high Doppler shifts from satellite motion. While IIP hardware would not be used for a space mission, useful system testing could be accomplished if this seed/LO option could be incorporated into system.

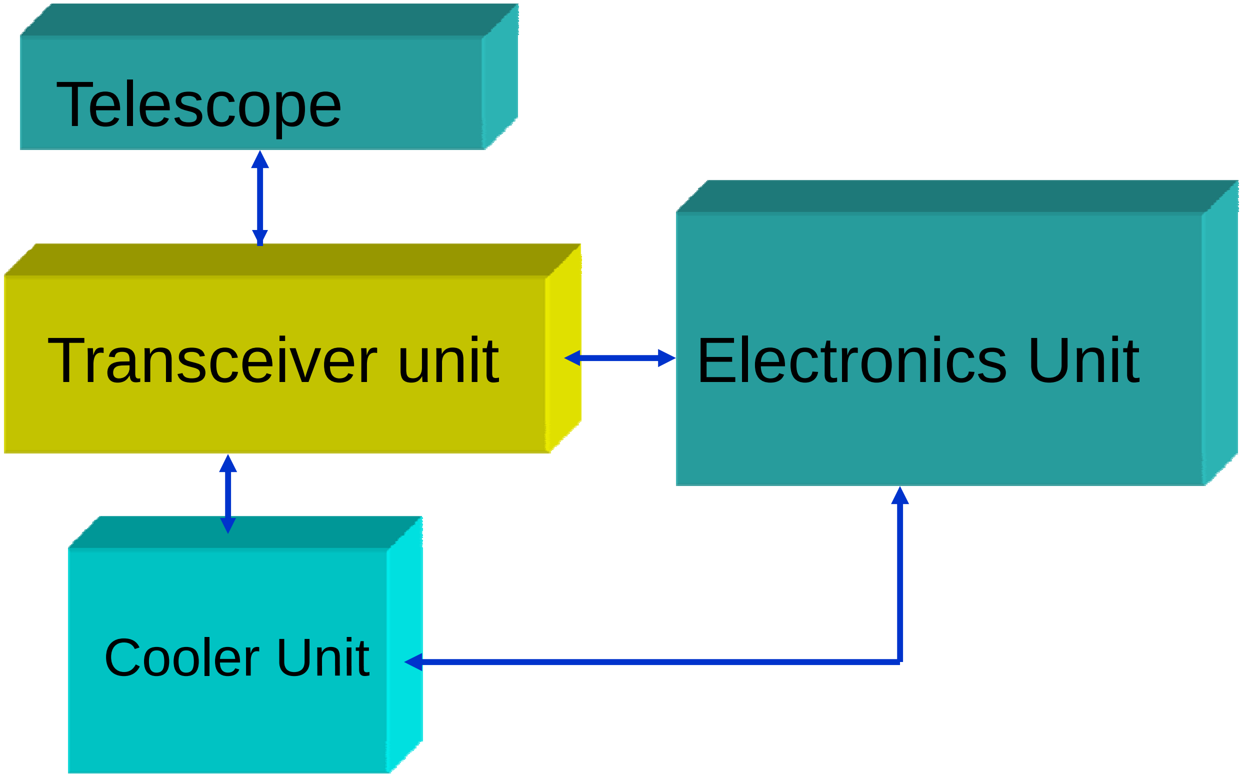
Solid State 2-micron Lasers

- Tm Lasers (pump diodes 780-805nm)
  - YAG, YLF, $YAlO_3$, YVO_4
- Ho:Tm Lasers (pump diodes 780-805nm)
  - LuLF, YLF, GdLF, YAG, YVO_4
- Tm pumped Ho lasers (pump diodes 780nm)
  - Tm solid state laser pumped Ho Laser
  - Tm fiber laser pumped Ho Laser
- Ho Lasers (pump diodes 1900nm)
  - YAG

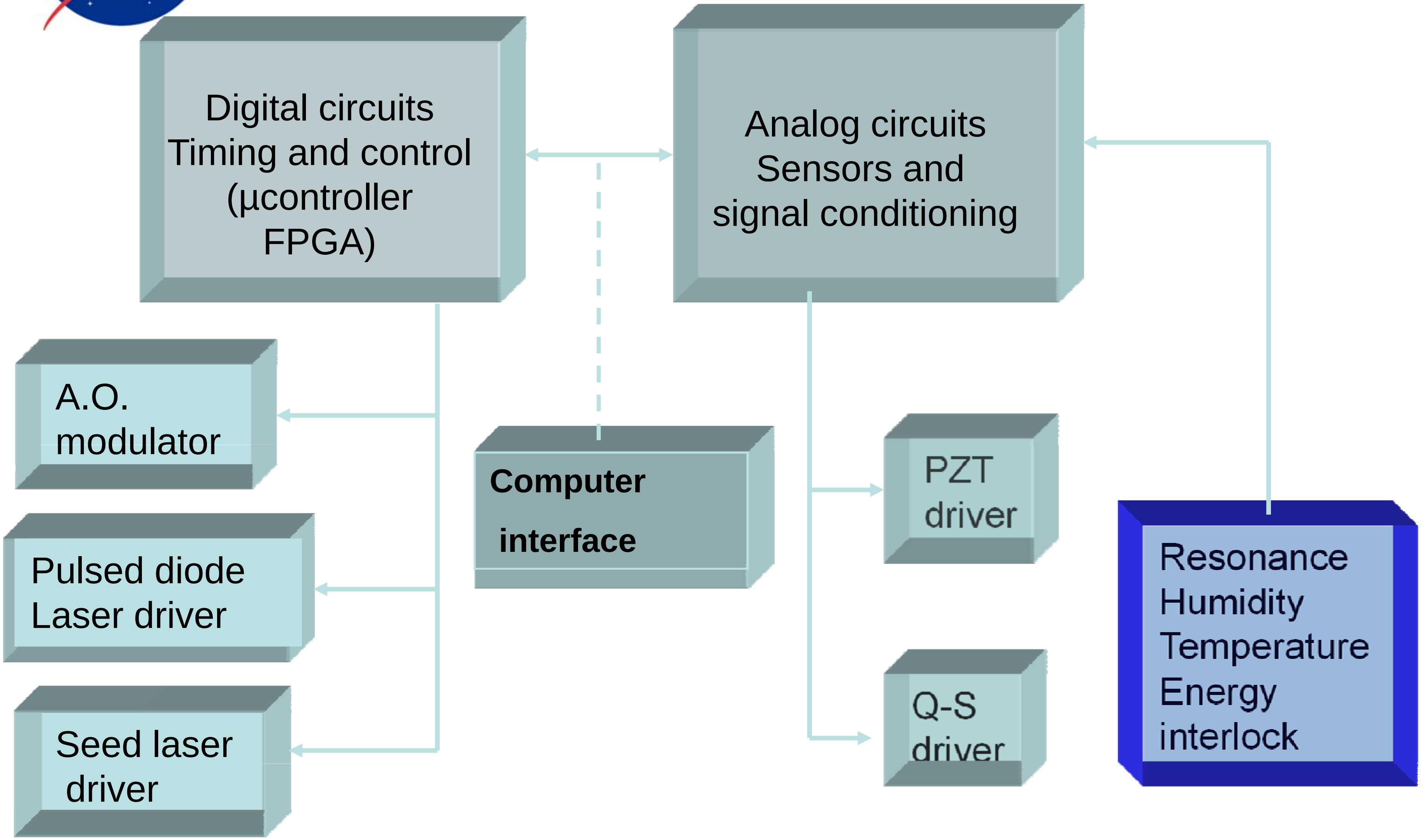
Transceiver Environment Requirements

Platform:	ground-based (Airborne qualify-able)
Operational Temperature	0°C -30°C
Non-Operational Temperature	-25° C; +50°C
Operating Altitude Range	Sea level to 30,000 ft
Humidity	<50% RH@25°C
Vibration	2.0 g-rms
Optical bench	temperature controlled
Coolant Temperature	5 °C
Coolant Flow	
– Laser rod	0.4 GPM
– Diode Laser	1.5 GPM
– Bench	1.5 GPM
Coolant Pressure	50 psi at 6 GPM

Wind Lidar Block Diagram



Electronics Block Diagram



Digital circuits
Timing and control
(µcontroller
FPGA)

Analog circuits
Sensors and
signal conditioning

A.O.
modulator

Pulsed diode
Laser driver

Seed laser
driver

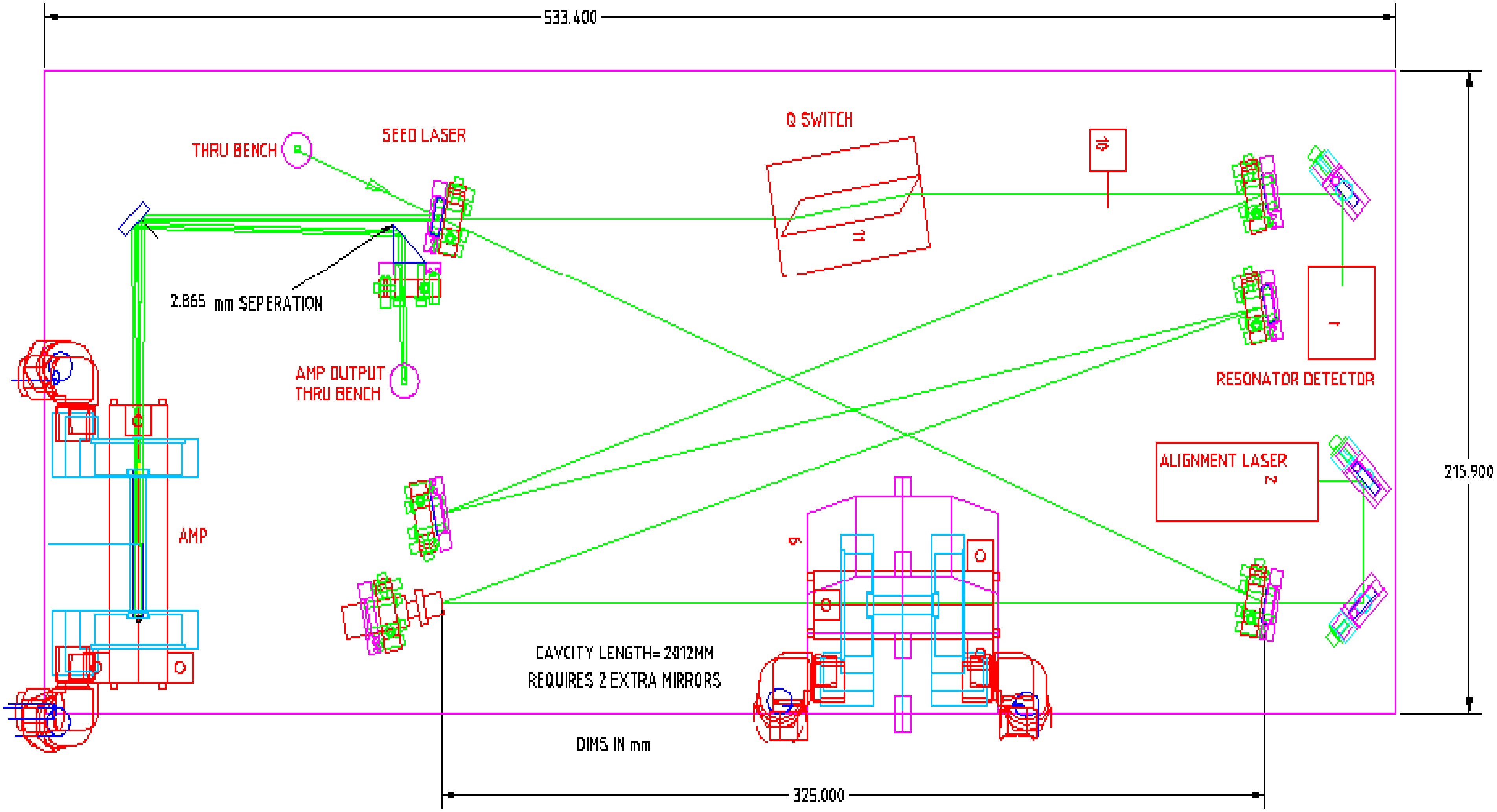
Computer
interface

PZT
driver

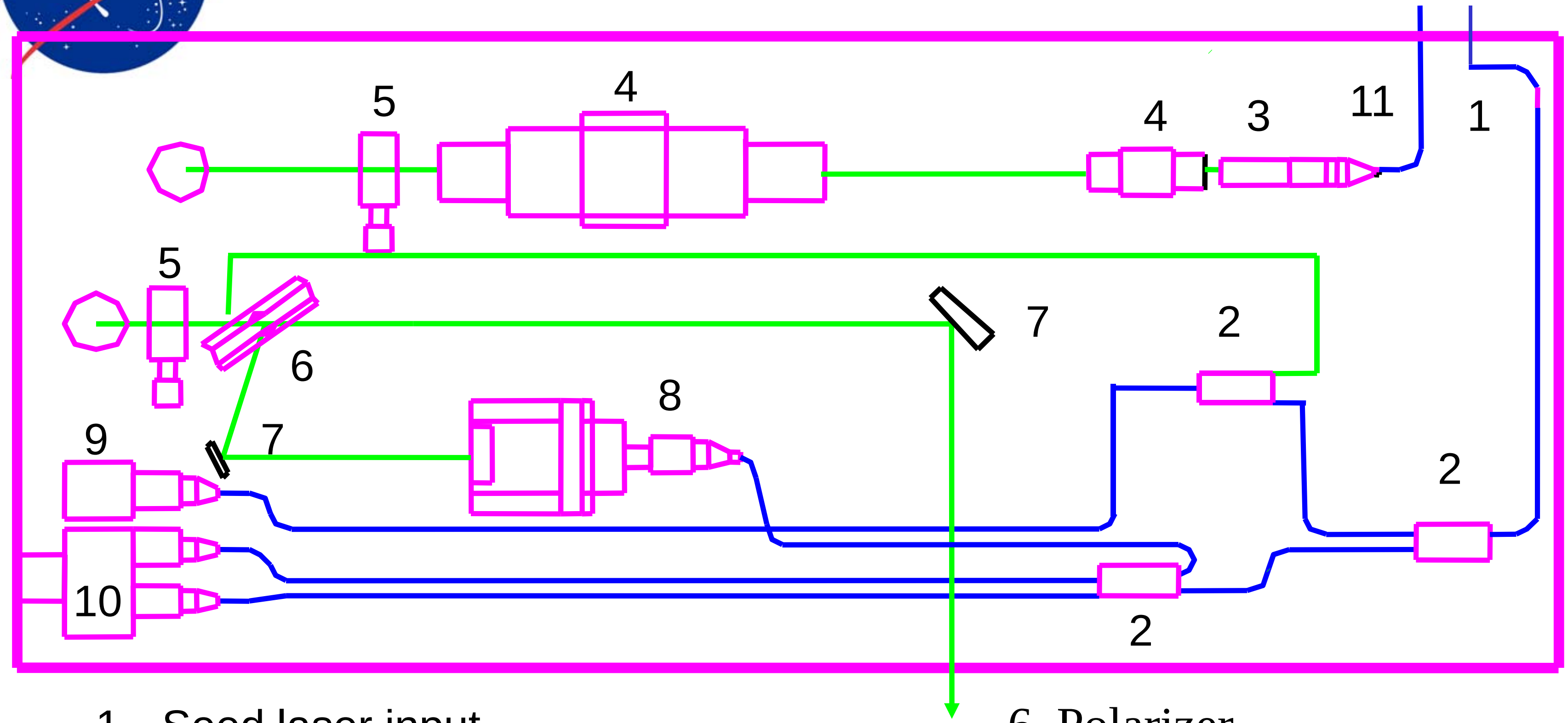
Q-S
driver

Resonance
Humidity
Temperature
Energy
interlock

Oscillator and Amplifier layout



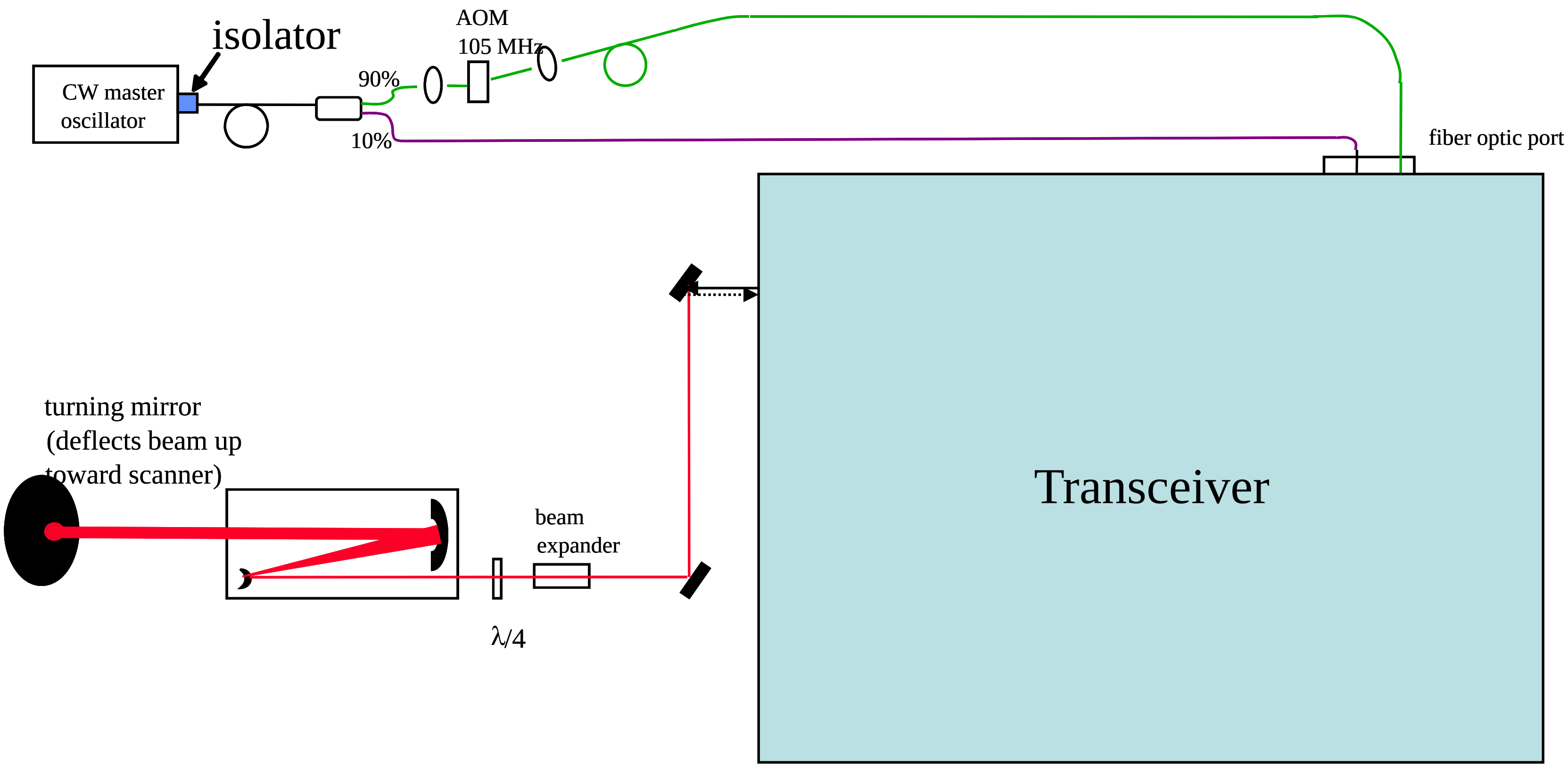
Receiver Optics layout



1. Seed laser input
2. Fiber beam splitter
3. Collimator
4. Faraday isolator
5. ½ wave plate

6. Polarizer
7.Beamsteering optics
8. Receiver signal optics
9. Heterodyne monitor
10. Receiver detectors
11. AOM output

Transceiver integration with lidar



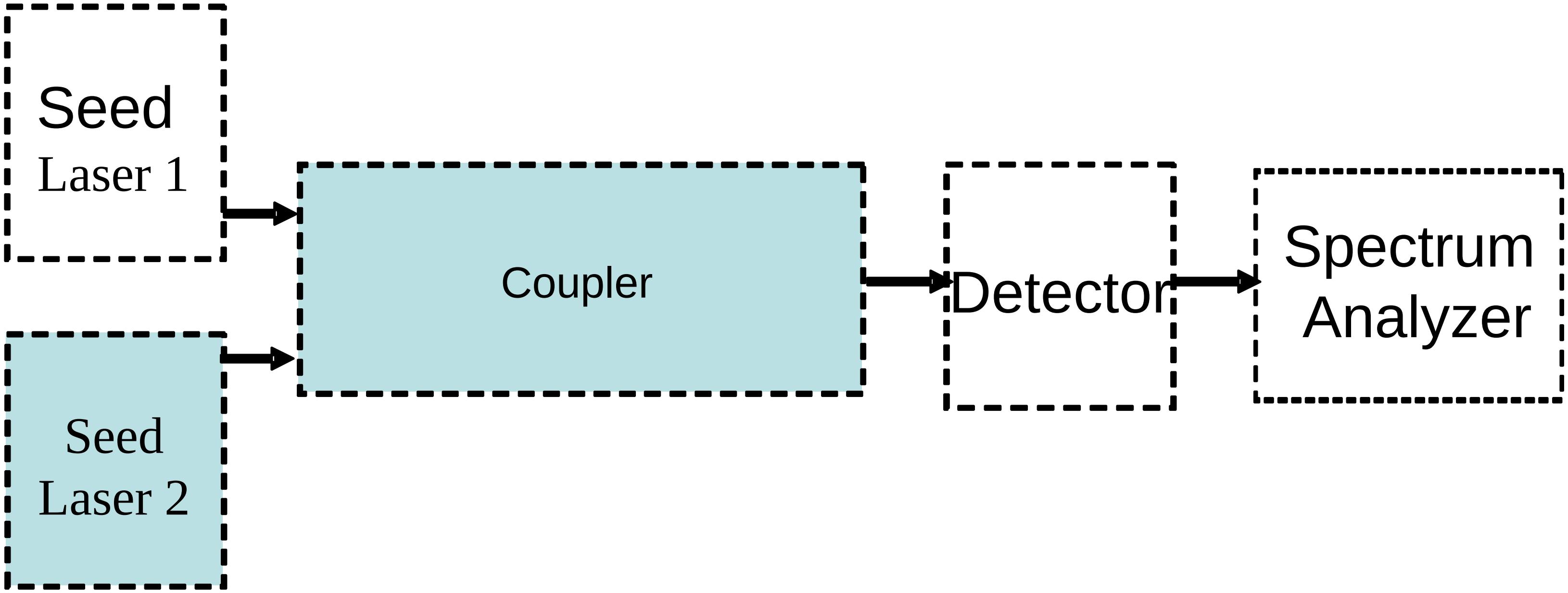
Sensors

- Optical detectors:
  - Energy monitor (InGaAs or Pyroelectric)
  - Temporal pulse and energy monitor (Photo electro-magnetic detector)
  - Resonance detector (InGaAs)
  - Seeding quality (InGaAs)
  - Return signal (dual input InGaAs fiber coupled)
- Humidity sensors
- Temperature monitors

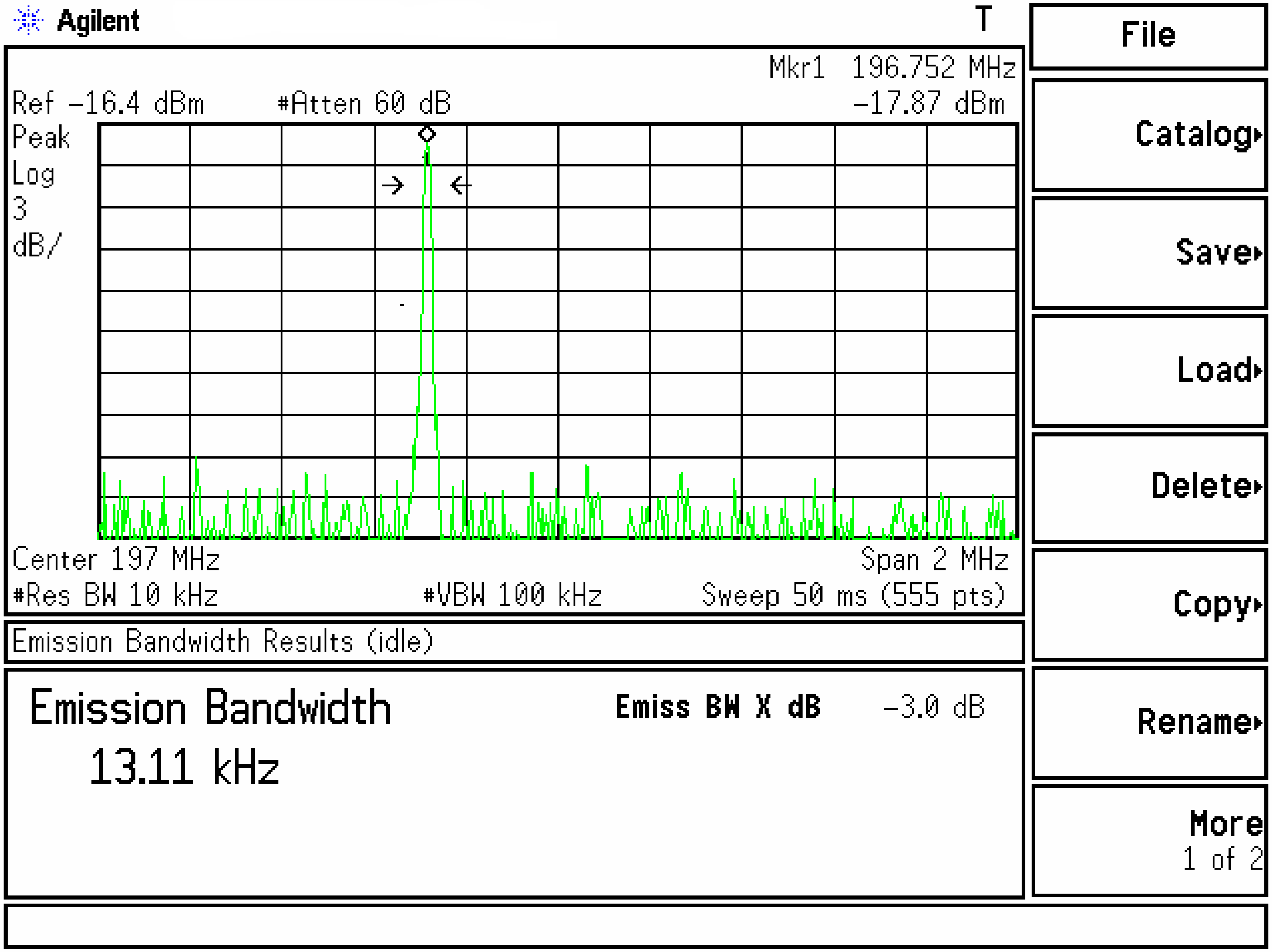
Seed Laser

Spatial mode	TEM_{00} Gaussian
Output	>35mw
Output isolation:	60dB fiber coupled
Additional protection:	>50 dB between the oscillator and the AO modulator
Fiber type	single mode polarization preserving
Fiber core diameter	6µm
Operating conditions	20° to 25°C heat sink temperature

Seed Laser Linewidth Measurement



Seed laser line width



Mkr1 196.752 MHz
-17.87 dBm

Ref -16.4 dBm #Atten 60 dB

Peak
Log
3
dB/

Center 197 MHz Span 2 MHz

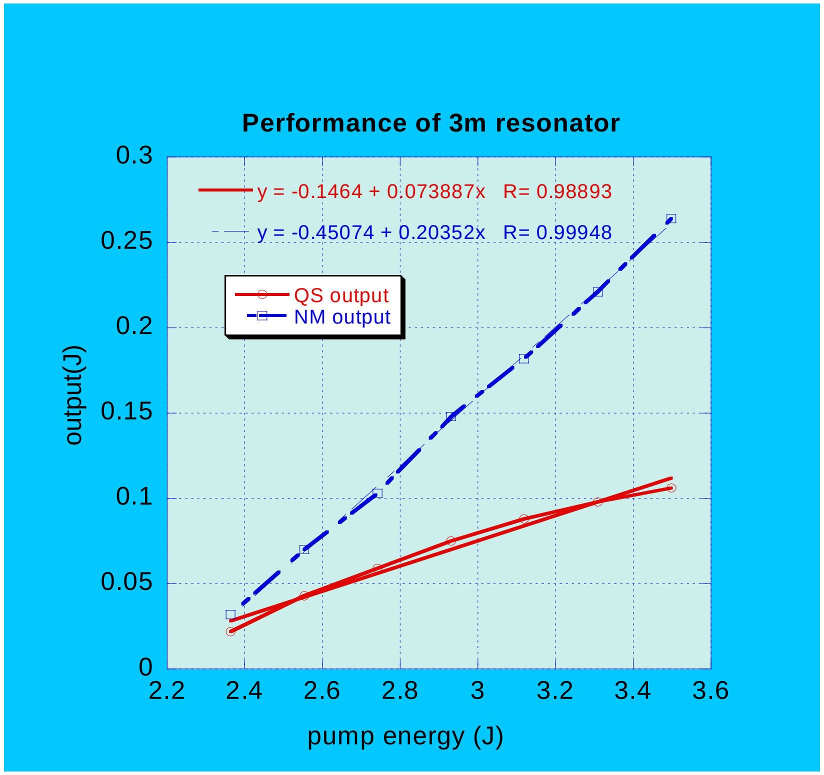
#Res BW 10 kHz #VBW 100 kHz Sweep 50 ms (555 pts)

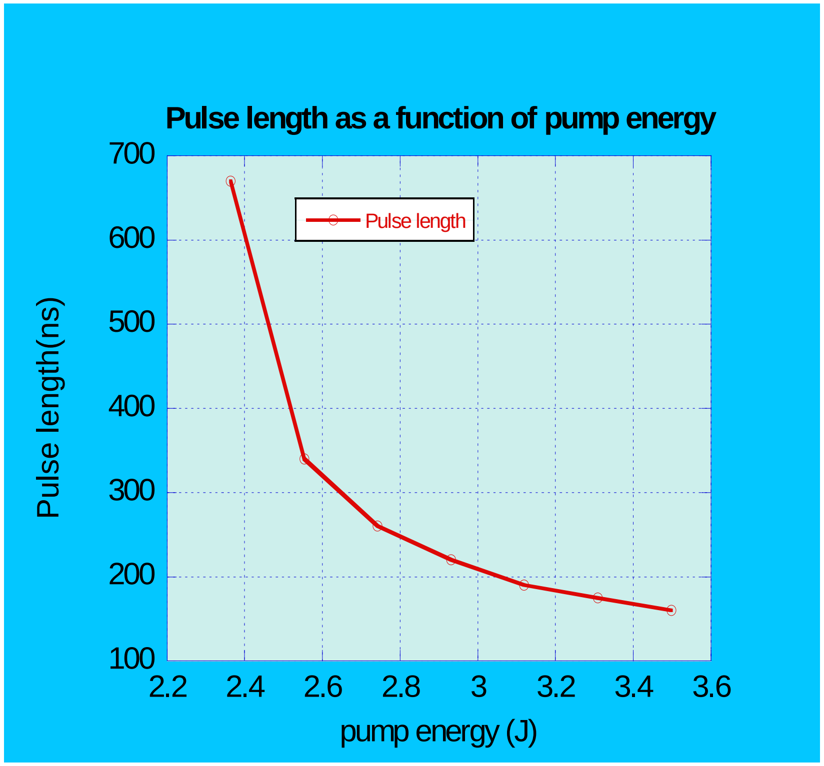
Emission Bandwidth Results (idle)

Emission Bandwidth
13.11 kHz

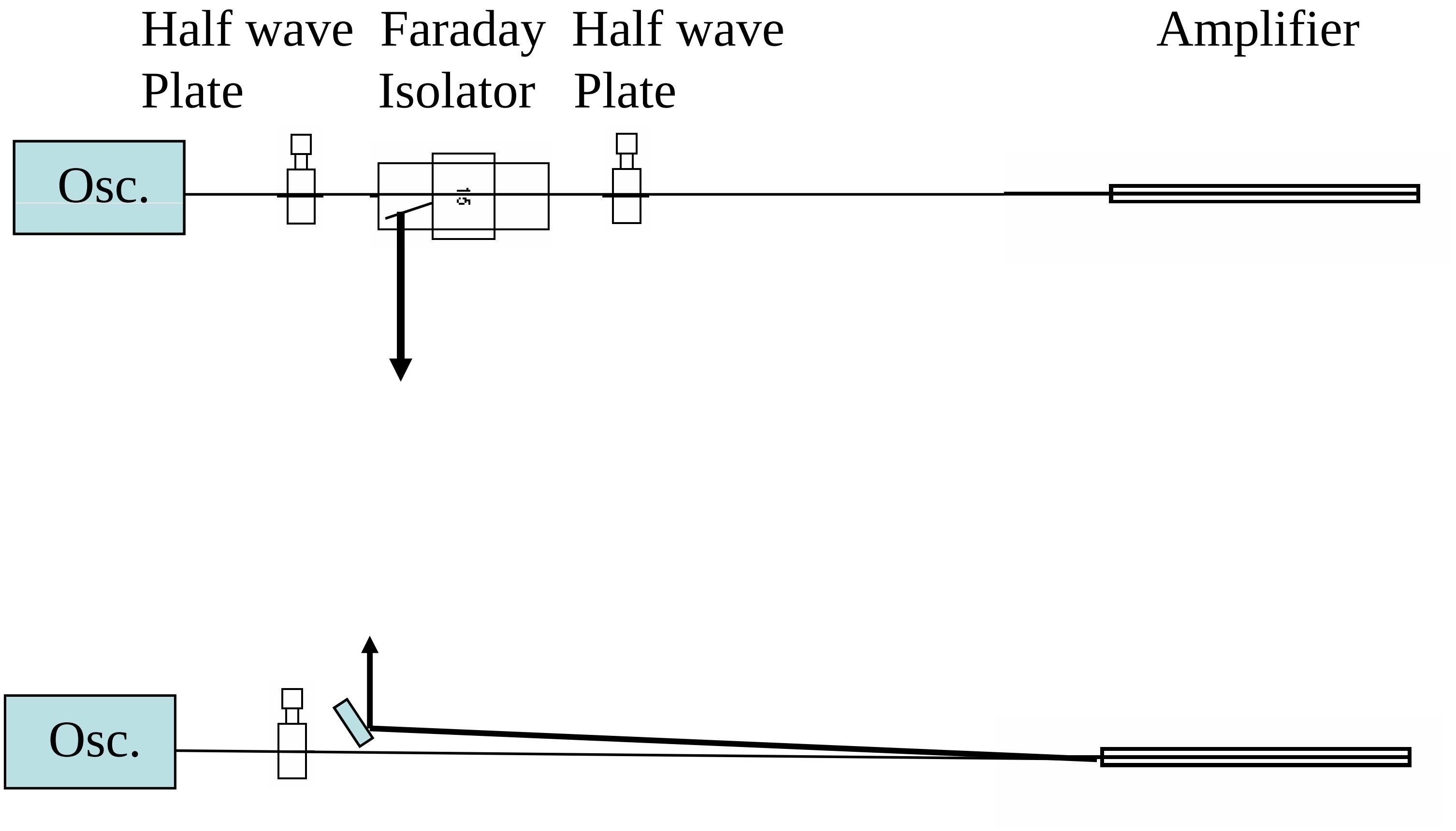
Emiss BW X dB -3.0 dB

10Hz Oscillator performance





Amplifier Architecture



Half wave Plate

Faraday Isolator

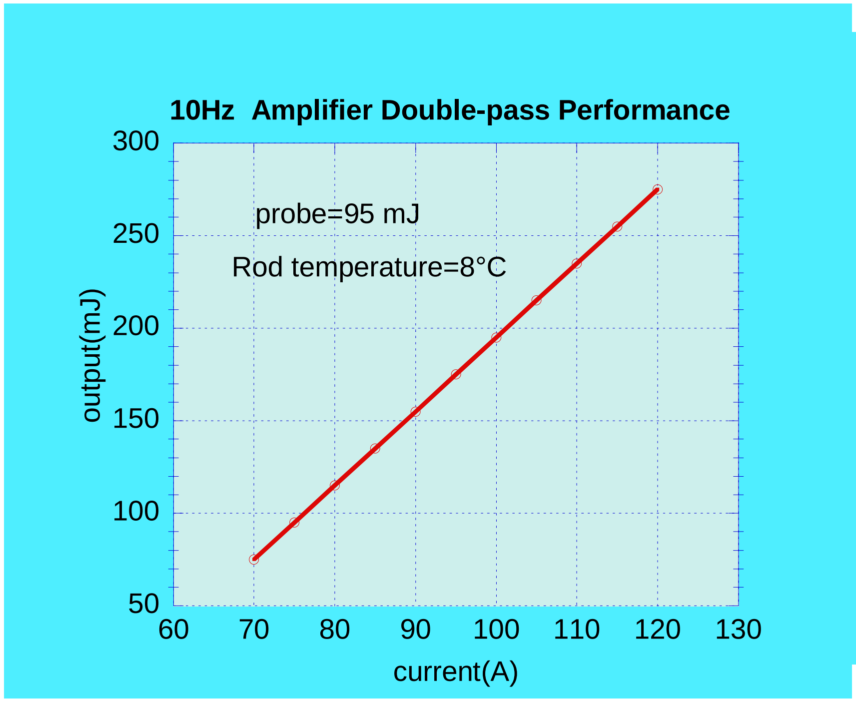
Half wave Plate

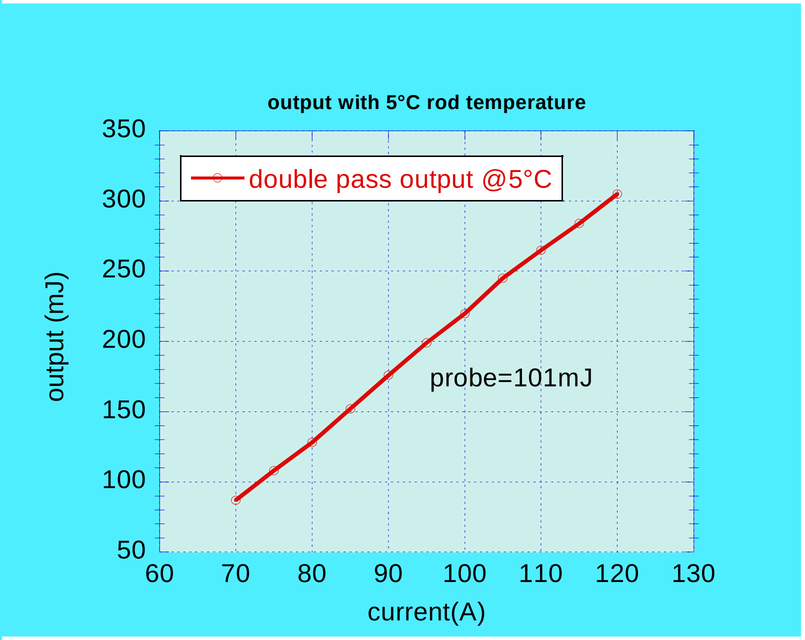
Amplifier

Osc.

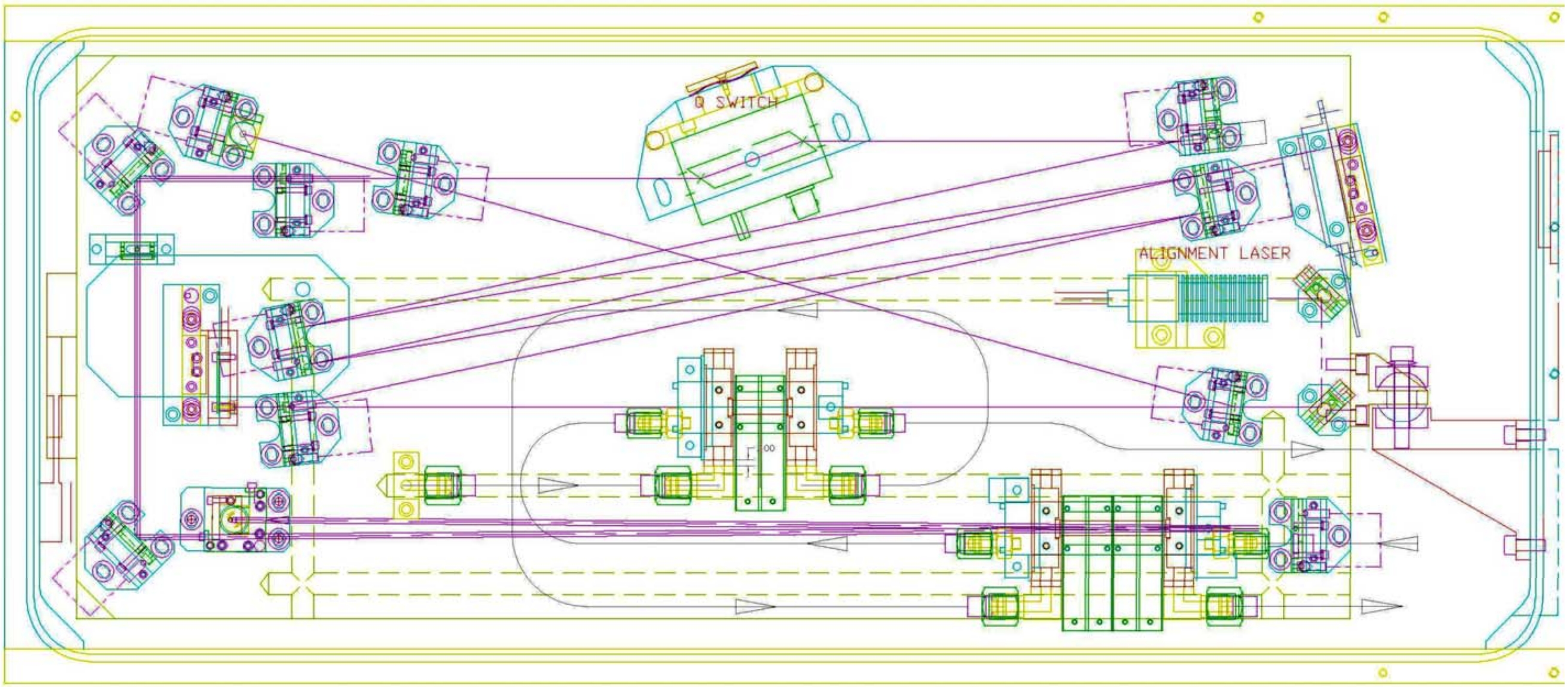
Osc.

Double pass amplifier performance

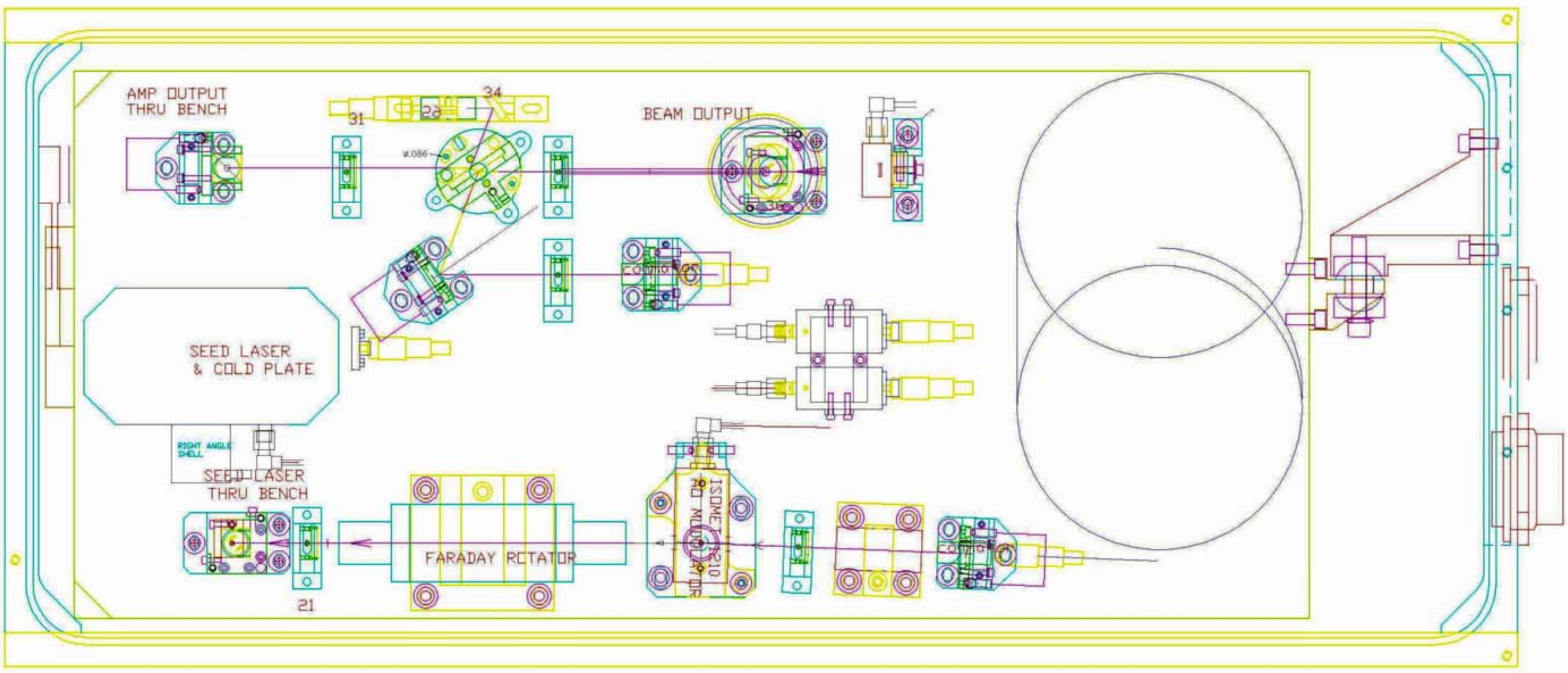

10Hz Amplifier Double-pass Performance


output with 5°C rod temperature

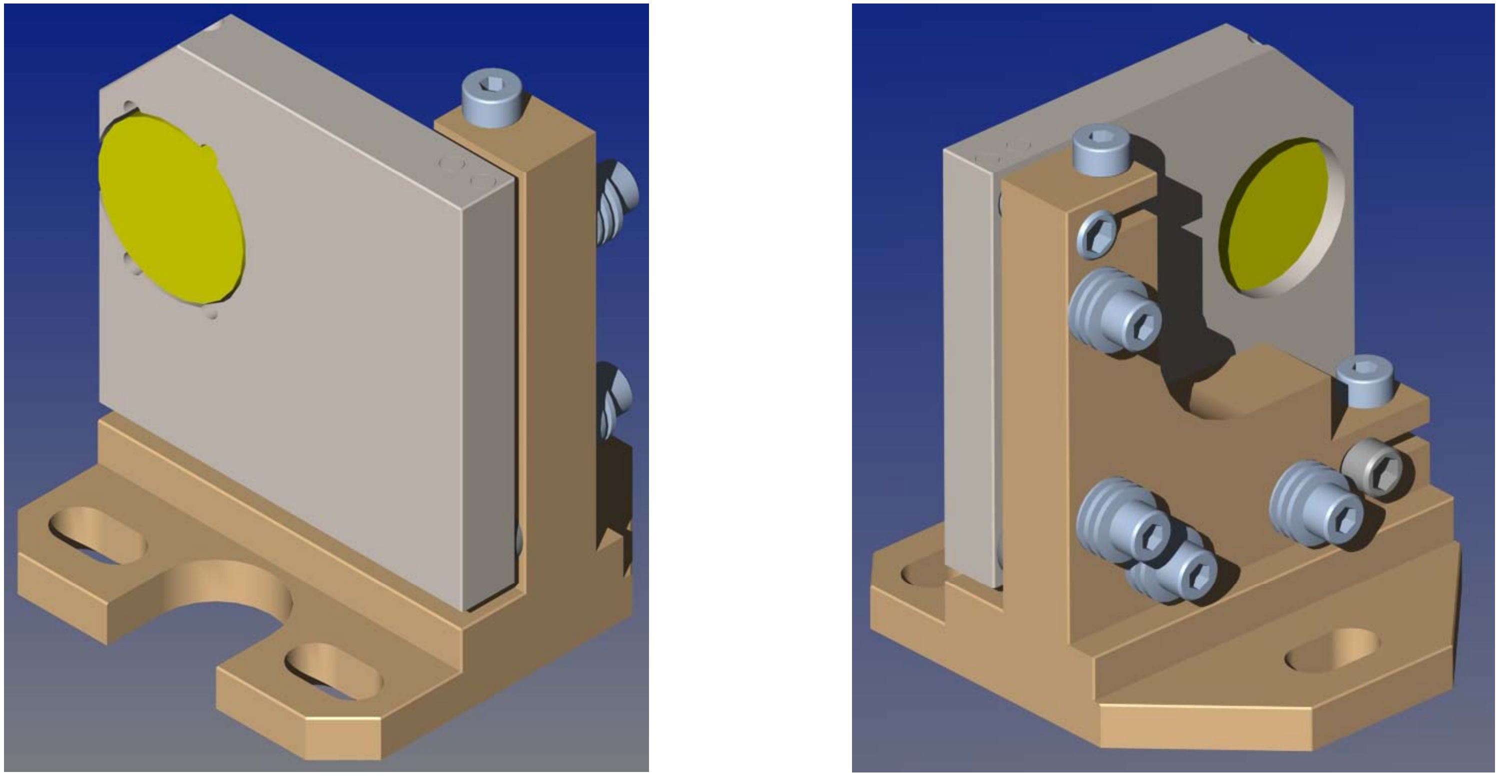
Preliminary layout (side 1)



Preliminary layout (side 2)

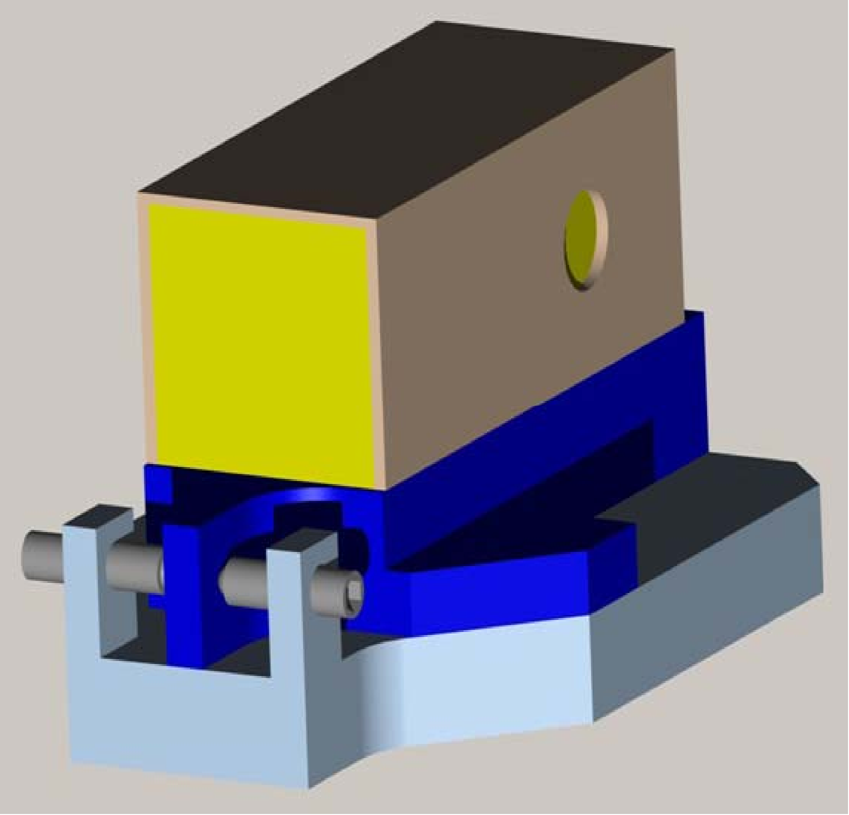


Optical Mirror Mount



Optical Component Mounts

AO modulator



Q-Switch