PIP Linac Laser Notcher Overview & Plans

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August 5, 2014

PIP Linac Laser Notcher System Installation Readiness Review

Topics

- Brief Notcher System Description
  - More detailed description Beams doc 4537-v2
- What we are doing in September & why ?

Jean-Paul and Kevin Presentations

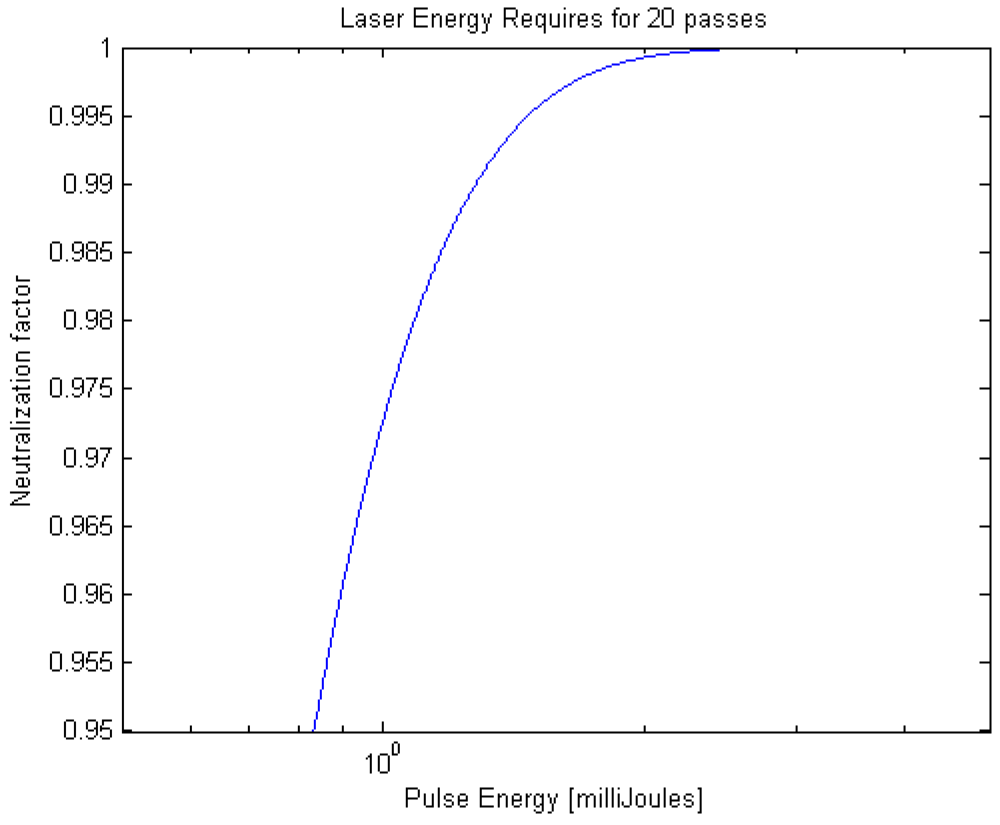
- Laser System Status and Plans

Requirements and Technique of Laser Notching of H-

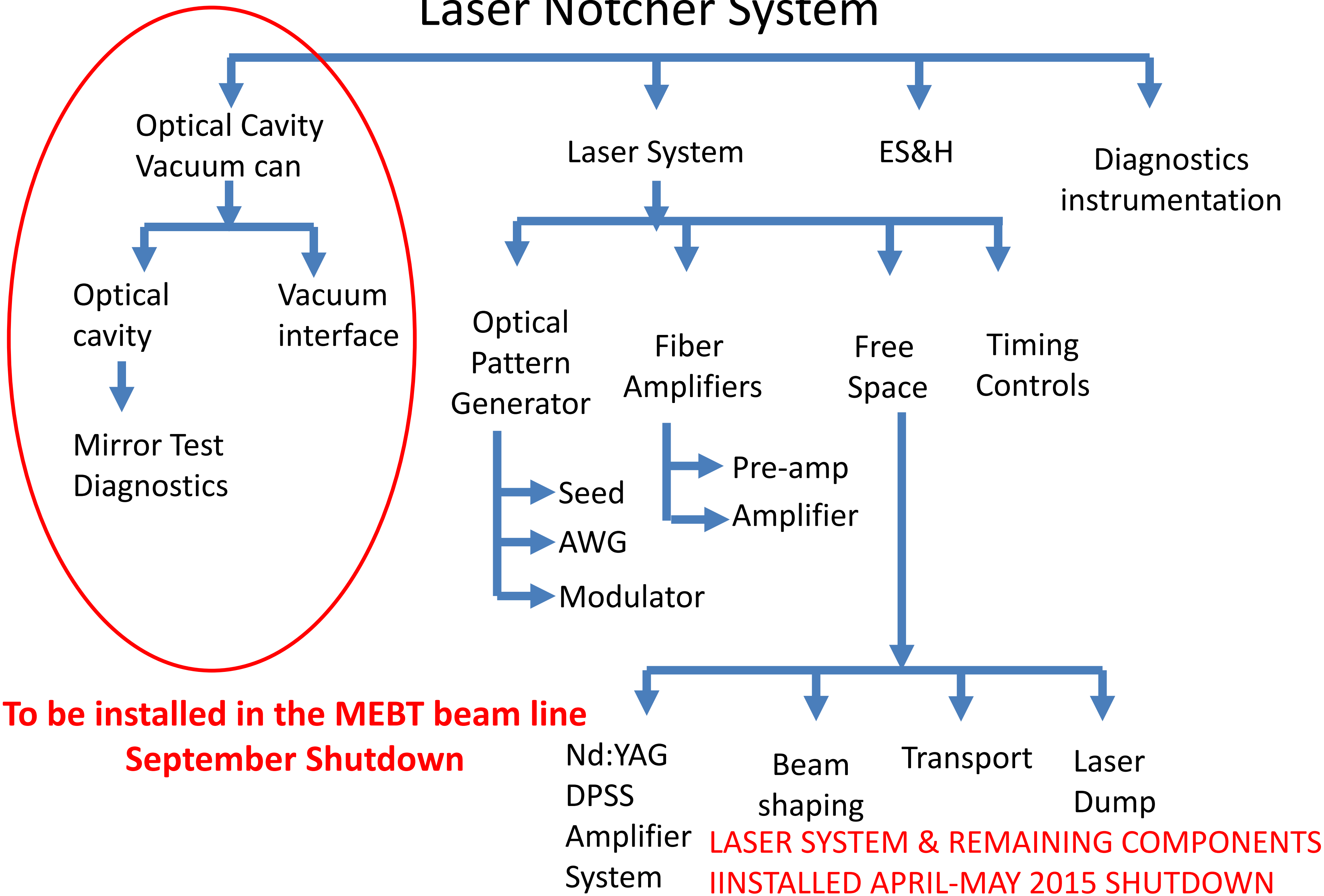
- **Requirements**
  - All ions in bunch should see the same photon density
  - The 201.25 MHz laser pulses must be phased with the RFQ
  - The laser pulse length =/> bunch length ~1.5 to 2 ns
  - Uniform temporal profile
  - The burst of 201.25 MHz pulses must match the Booster inj rev. freq.
  - The 450 kHz burst must have appropriate timing within the linac pulse
  - The pulse energy should neutralize > 99% of ions in each bunch

- **Technique**
  - Utilize a CW seed laser and wave-guide modulator to create required laser pulse pattern (both 200 MHz and 450 kHz) at low pulse energies (pJ)
  - Amplify pulse pattern using a three-stage fiber amplifier (nJ to uJ)
  - Further amplify using a free-space solid state amplifier (mJ)
  - Create a spatially uniform photon beam
  - Insert laser pulse into a linear zig-zag interaction cavity where the laser reflections inside the cavity match the ion velocity
    - to reduce required pulse energy by the number N of reflections in the cavity.

Neutralization vs Pulse Energy



Laser Notcher System

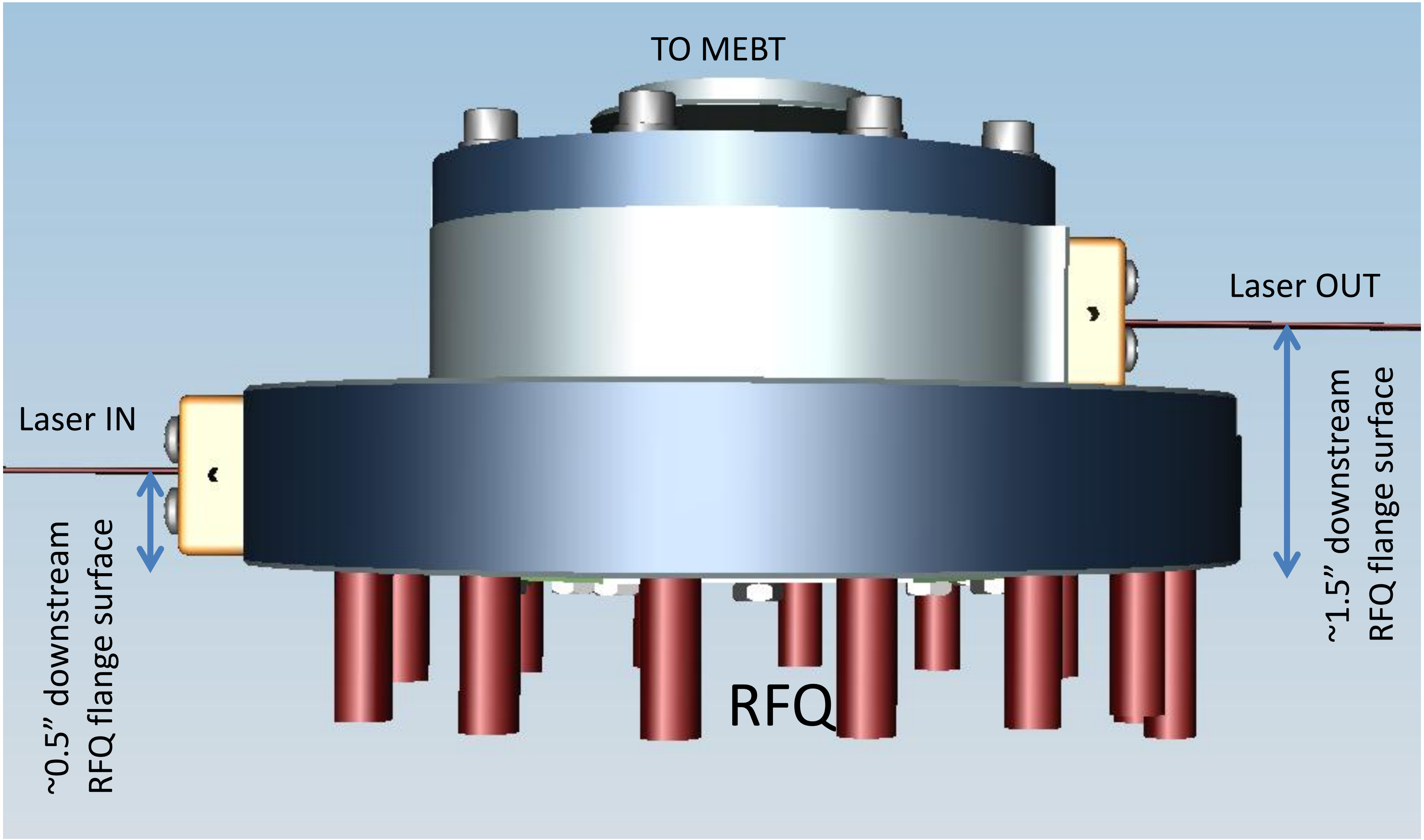


OPTICAL CAVITY &VACUUM FLANGE

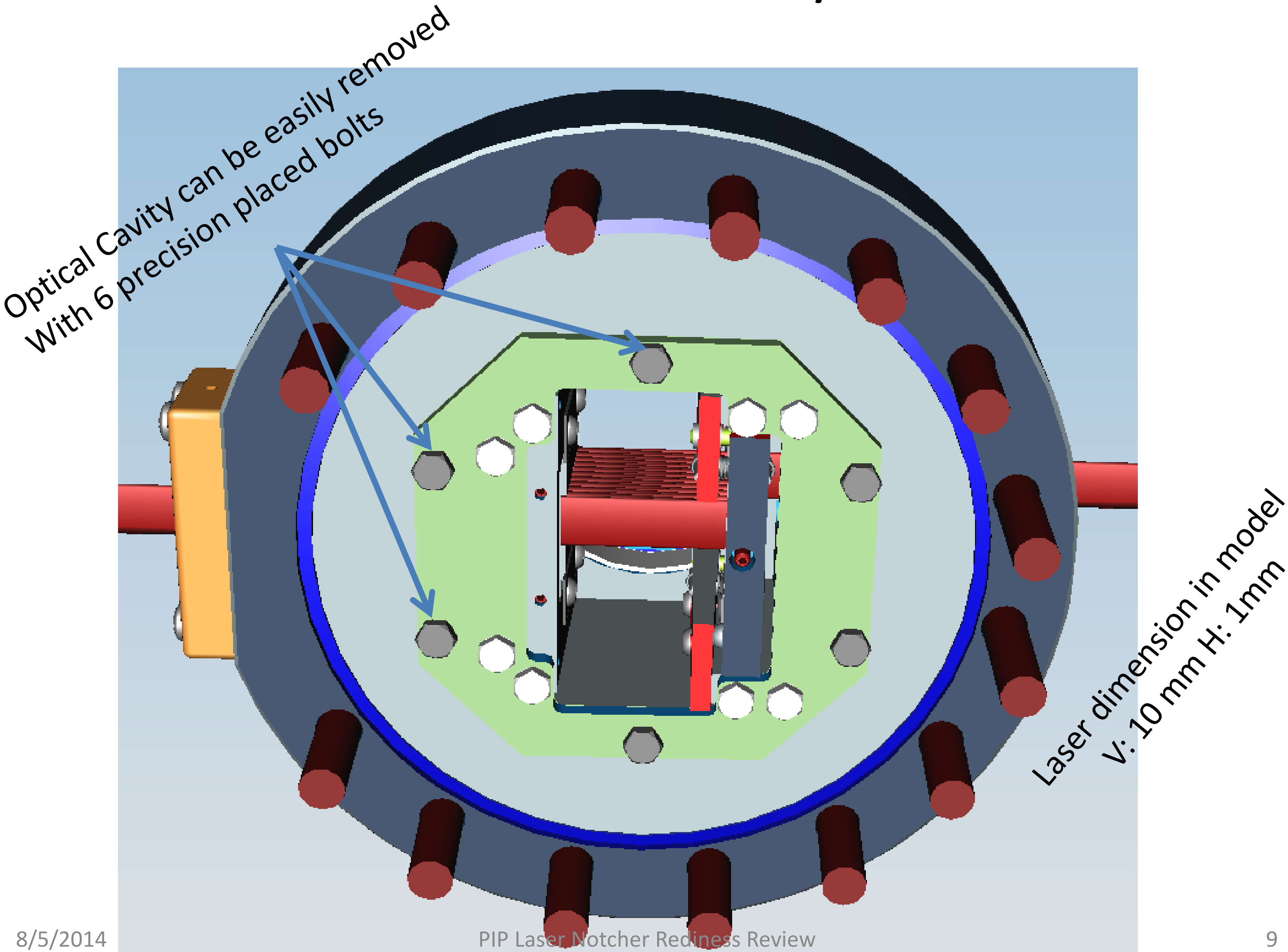
Why are we installing the optical cavity now?

– Opportunity !!!!
– We are interested in finding out how the dielectric mirrors behave in this location, specifically in terms of mirror reflectivity.
  >We believe there should be no problem
  - Vacuum level (residual gas) – install metal valve at downstream end of RFQ to allow for RGA.
  - Aperture between the mirrors should be sufficiently large that no H- should impact the mirrors
  - Electrons from the photoneutralization should exit downstream flange before striking beam pipe (result of simulations)
- ➢ Monitor the mirror reflectivity for any degradation with a low power 1064 nm laser and photo diodes-> interface into ACNET.
– We have designed the cavity/vacuum flange to be *"easily" removable* (flanged at both ends) and the optical cavity to be independent of the vacuum flange.
– Kevin will detail the installation plans.
– Next few slides show the flange and cavity geometry… and palns

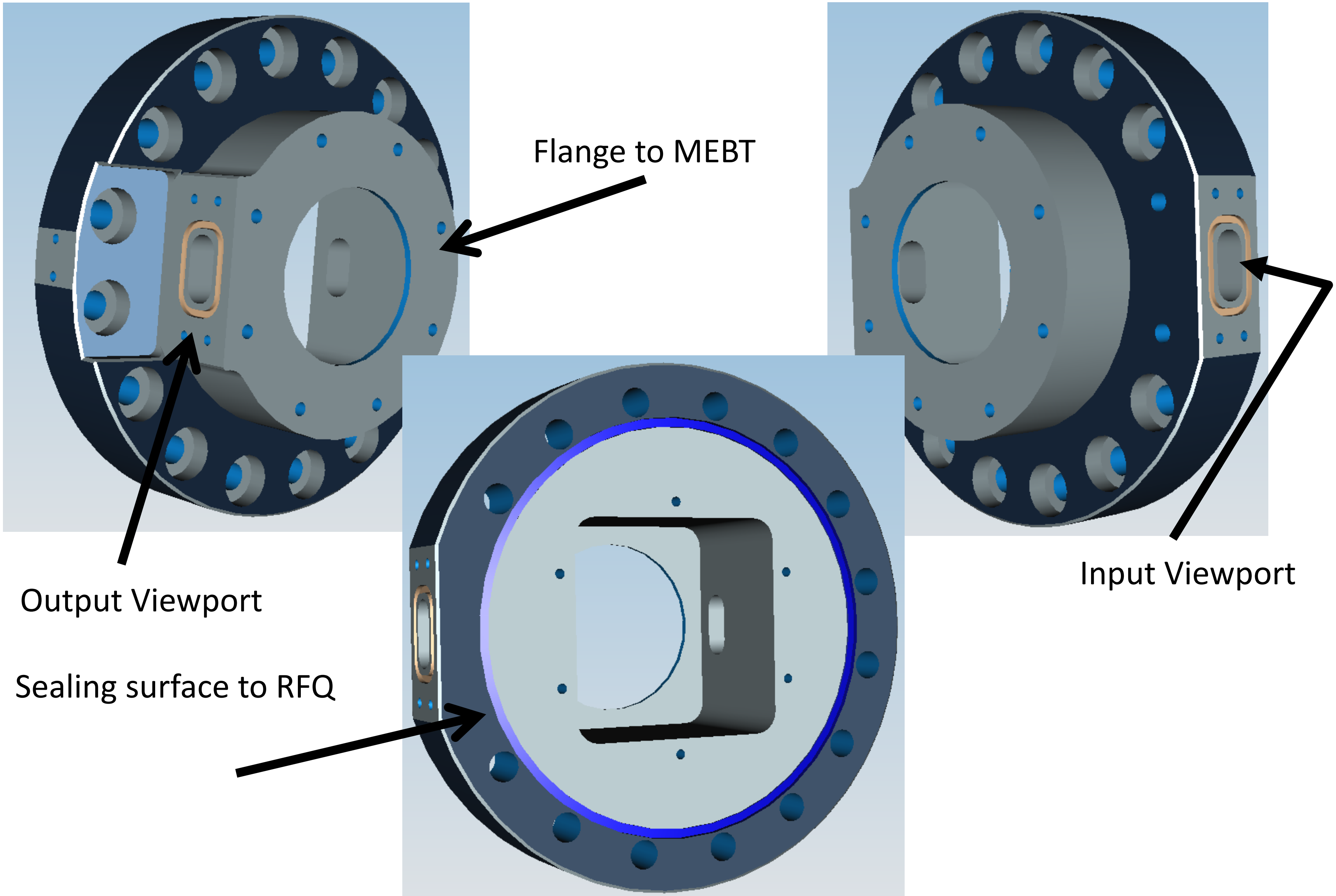
Vacuum Flange / Optical Cavity



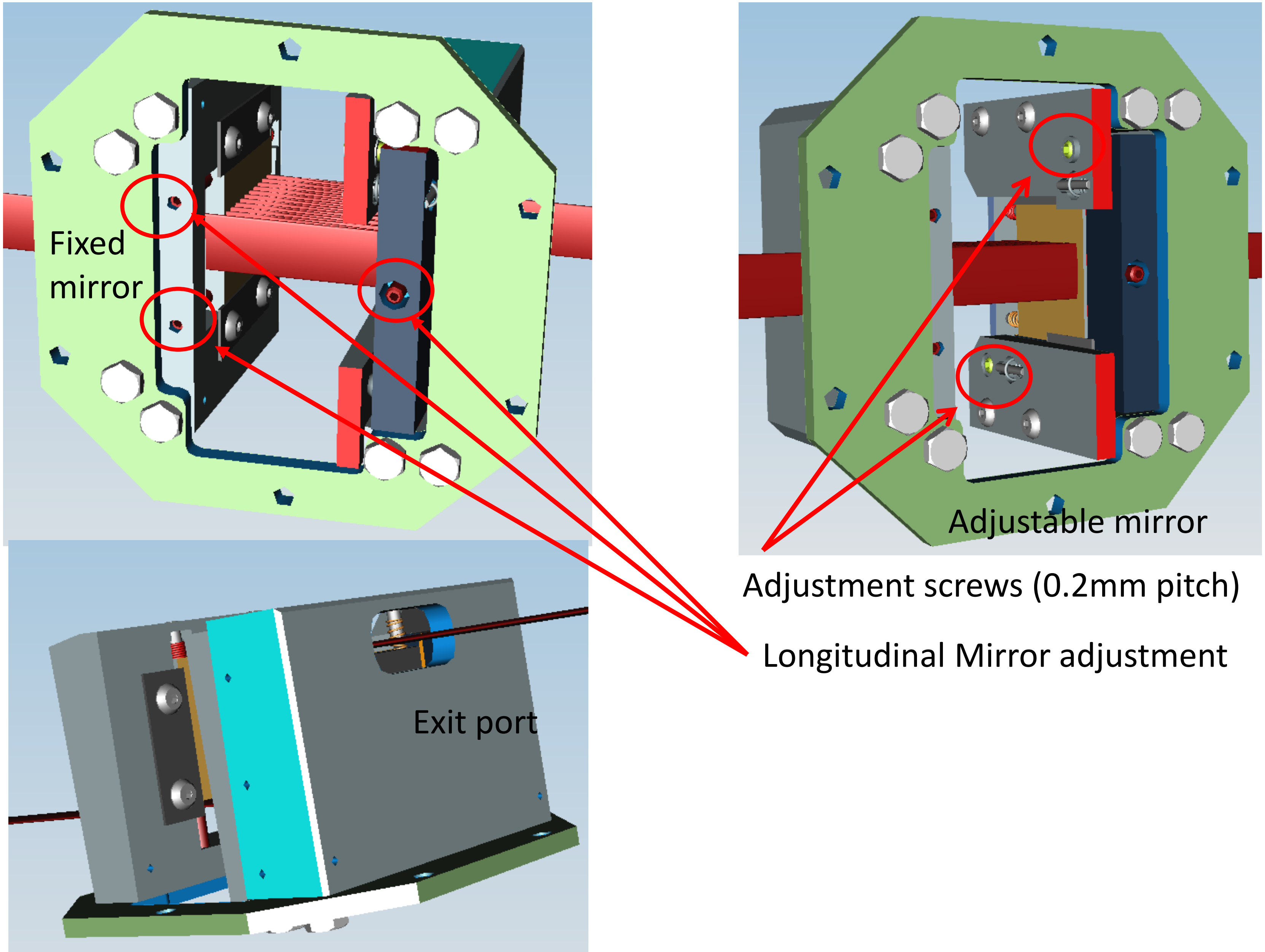
Rear View of VF/OC



One Piece Vacuum Can (Flange)



Optical Cavity Structure



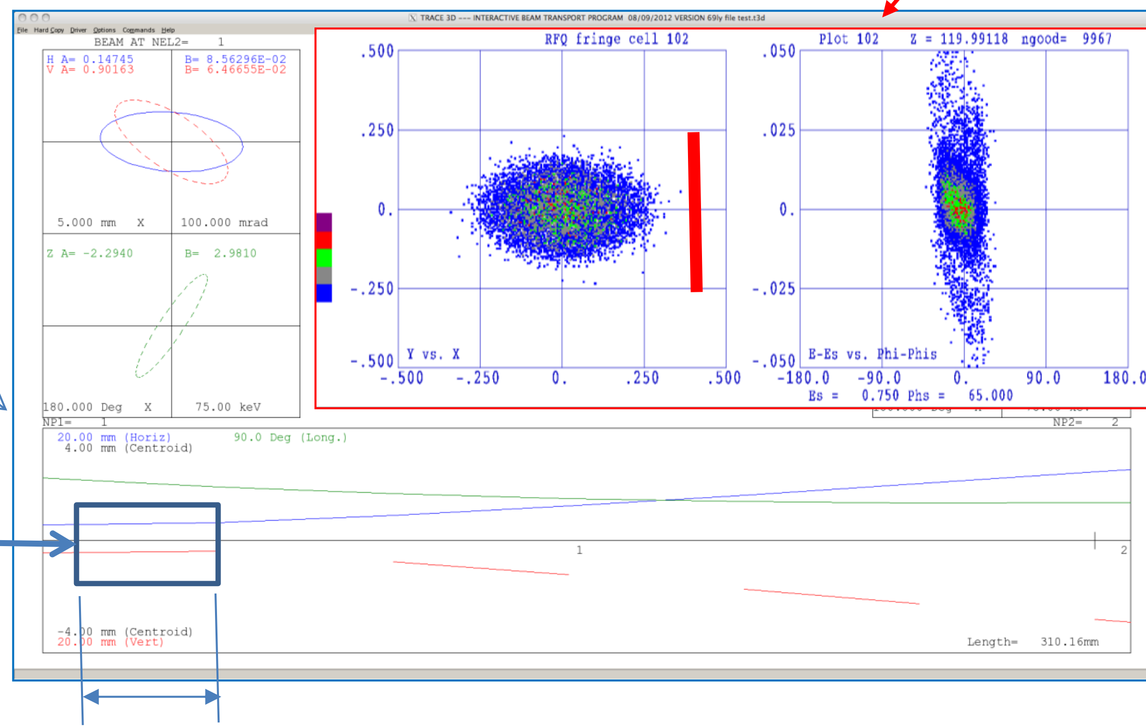
Expected Beam Dimensions

Additional simulations to be shown by JPC

- Phase space simulation at end of RFQ (figure 4.40 of 750 KeV Upgrade Plan)

- Trace 3D back calculation of beam size at exit of RFQ based upon emittance measurement at 178 kW power <u>August 9, 2012 CY Tan</u>.

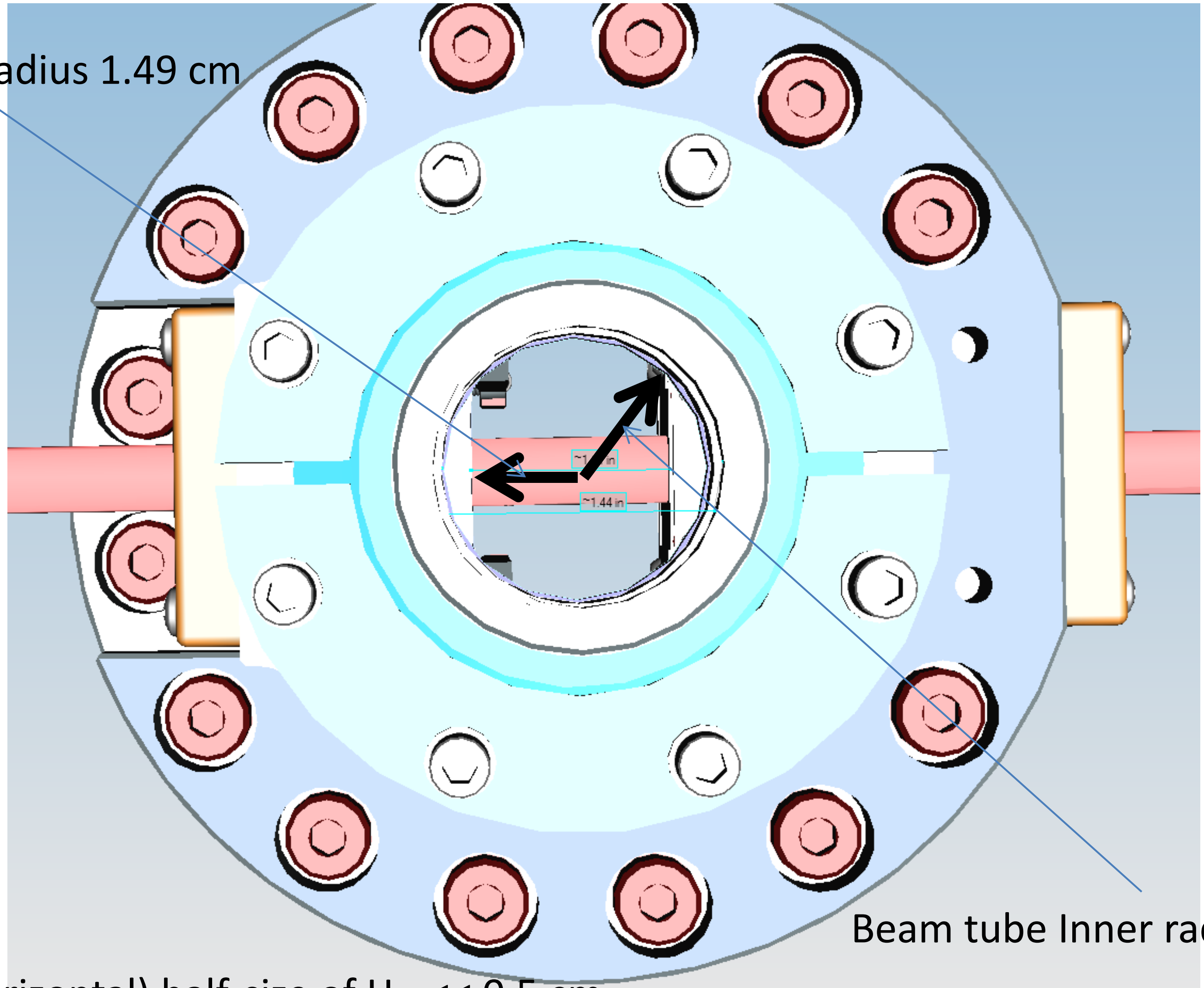
Laser beam vertical profile (1/e^2) ~ 5 mm.



Initial design assumed that the vertical laser beam dimension of 1 cm.
Beam measurements indicate vertical laser size could be reduced to 6 mm

Aperture
(looking from downstream)

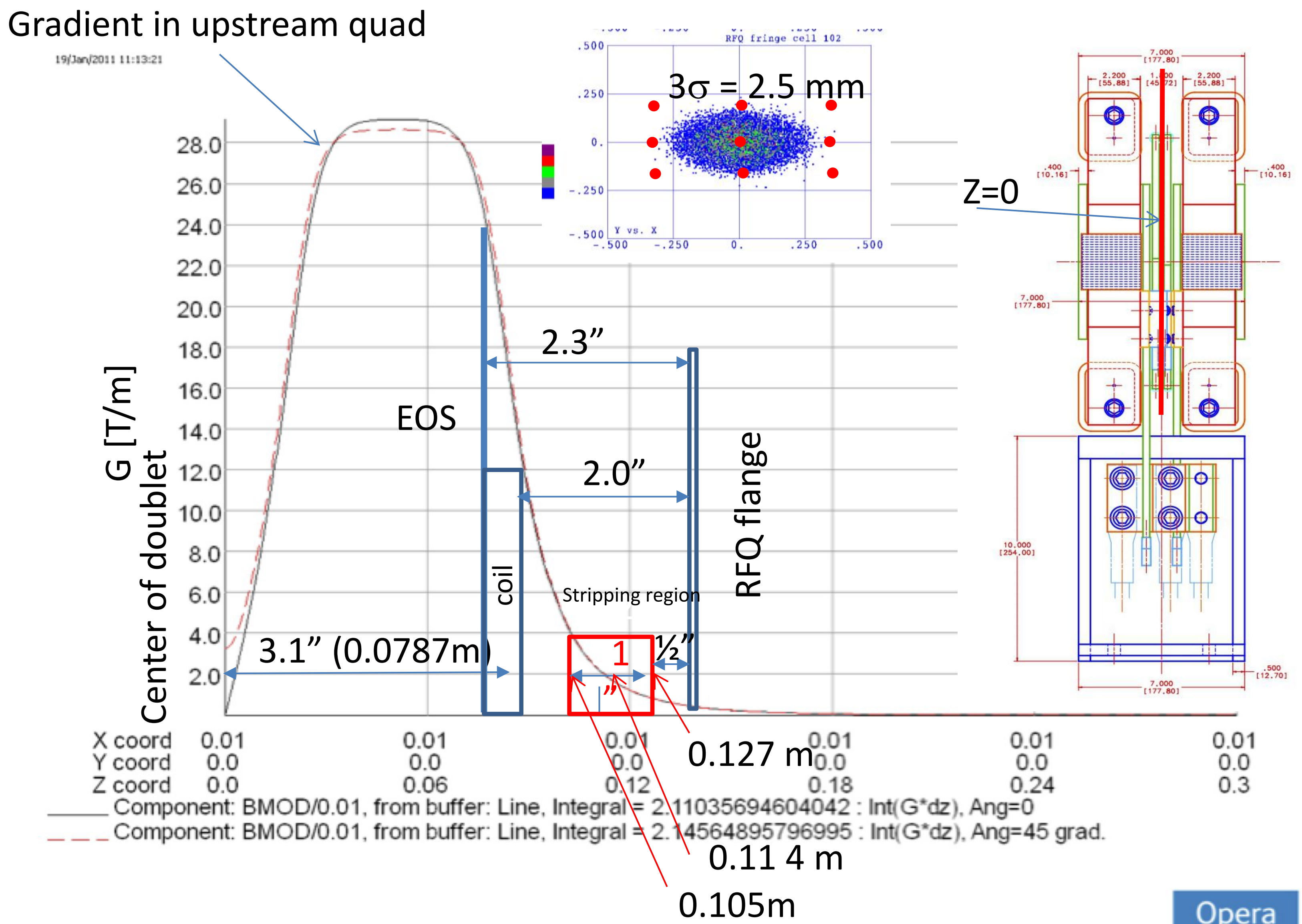
Mirror cavity radius 1.49 cm



Beam tube Inner radius 1.83 cm

Expected (horizontal) half-size of H- << 0.5 cm
(X3 smaller than mirror cavity radius)

Data For Simulations of Electron Trajectory in Quad Fringe Field

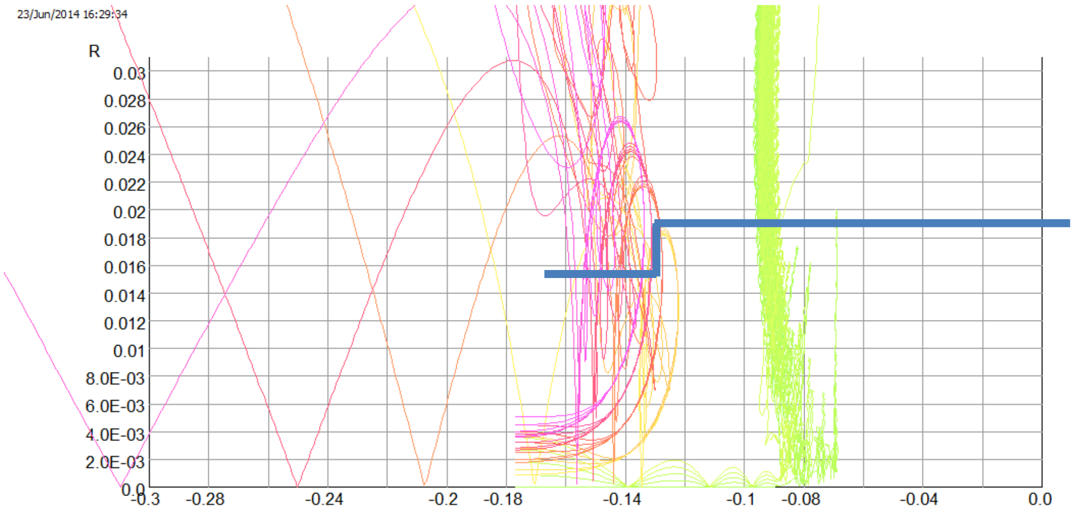


Electron Trajectory Simulations

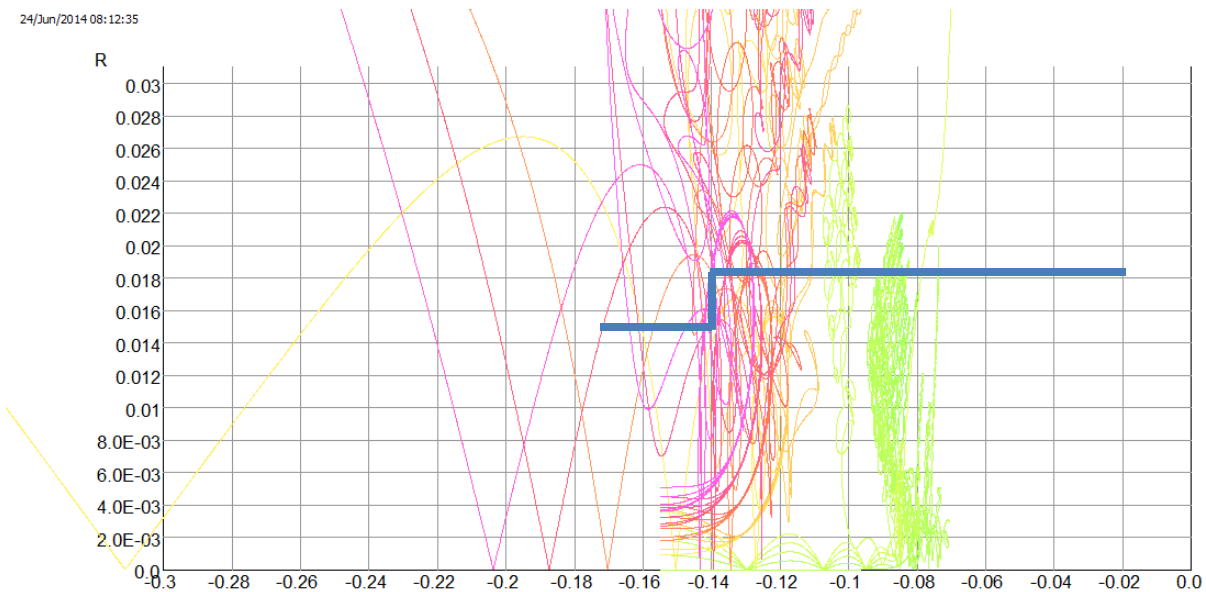
- **Electron Beam Trajectories for MEBT Quadrupole Doublet**
- V. Kashikhin, June 25, 2014
- Electron Trajectories calculated by TOSCA3d code for electrons having 409 eV kinetic energy.
- The beam of 9 electrons have sizes: +/- 3.6 mm, and +/-2 mm. The coordinate system is shifted -50mm in Z-axis. Coordinates -0.127,0.114,0.105m on the graphs are -0.177,-0.164,-0.155 m**. It looks that all electrons go out of 31 mm cylinder surface radius**. TPC =0,0,0 is for the beam parallel Z-axis, TPC=90,1,0 is for the beam rotated 1 deg. around X-axis, and TPC=0,1,0 is for the beam rotated 1 deg. around Y-axis

Example of Electron Trajectories in Quad Fringe Field

Vladimir Kashikhin



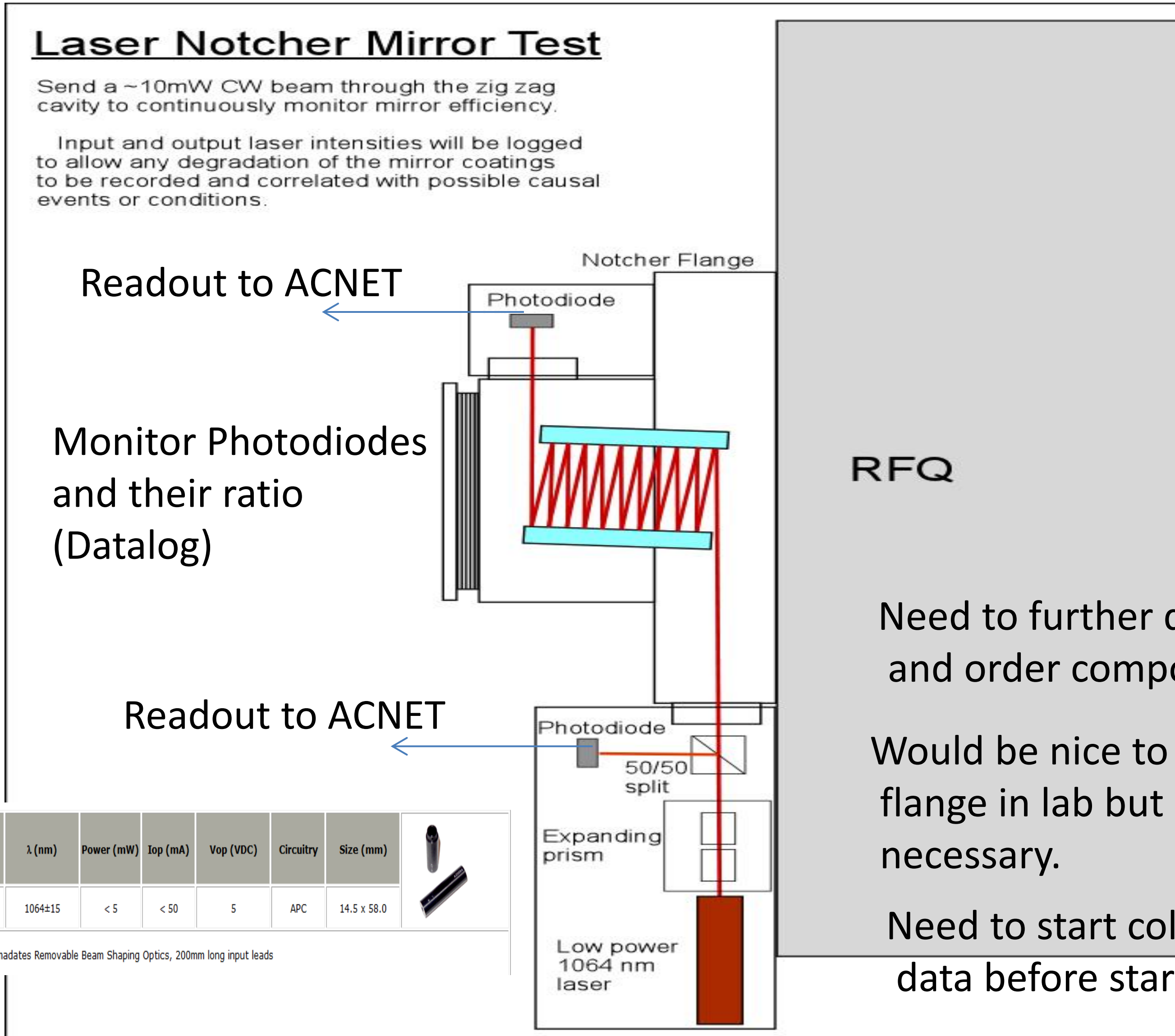
Z= -127 mm



Z = -105 mm

Optical Cavity Mirror Test

From: Todd Johnson



Readout to ACNET

Monitor Photodiodes and their ratio (Datalog)

Readout to ACNET

Need to further develop design and order components

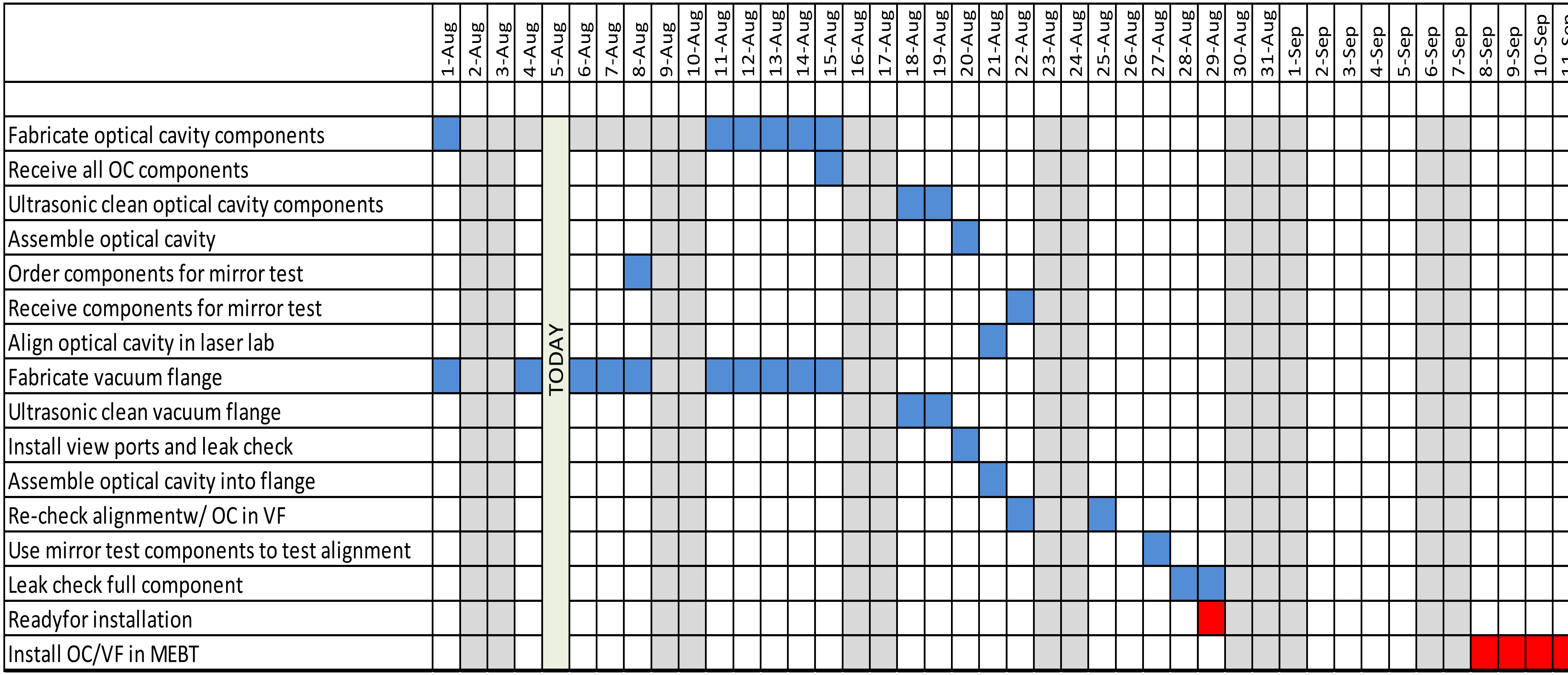
Would be nice to interface to flange in lab but not absolutely necessary.

Need to start collecting reflectivity data before start up of beam

Order Code	Price 1-9pcs	λ (nm)	Power (mW)	Iop (mA)	Vop (VDC)	Circuitry	Size (mm)
I064D-5G-DAP	$410.00	1064±15	< 5	< 50	5	APC	14.5 x 58.0

Glass Collimating Optics, Focusable, Accomadates Removable Beam Shaping Optics, 200mm long input leads

Pre-Shutdown Schedule for Optical Cavity/ Vacuum Flange



Kevin vacation – 8/6 thru 8/29

Machinist for flange – Phil should be done next week

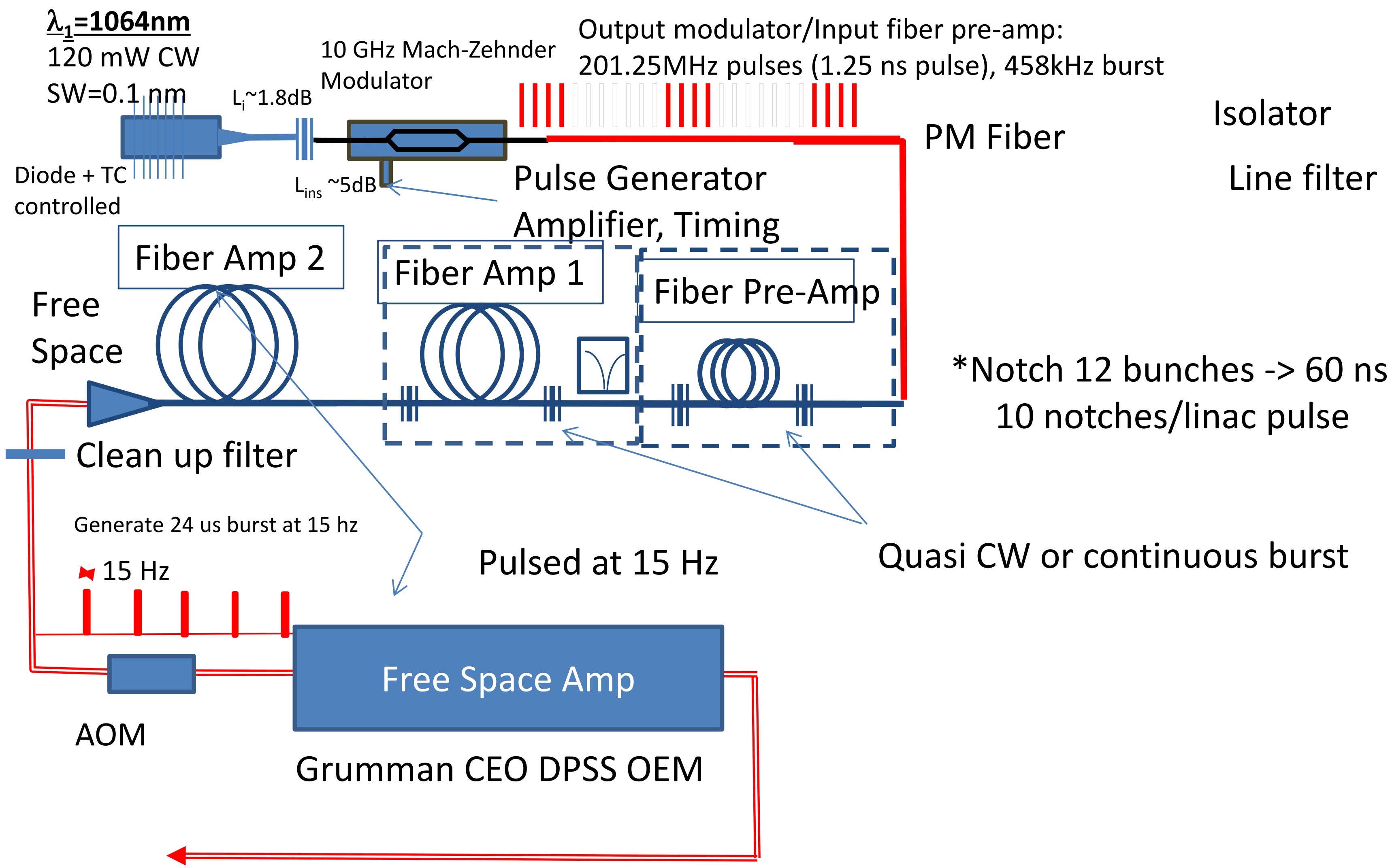
Machinist for optical cavity parts - Regis (return from vacation 8/11)

Components for assembly – some here some on order

Ultrasonic cleaning - Ben

Part II
Laser System

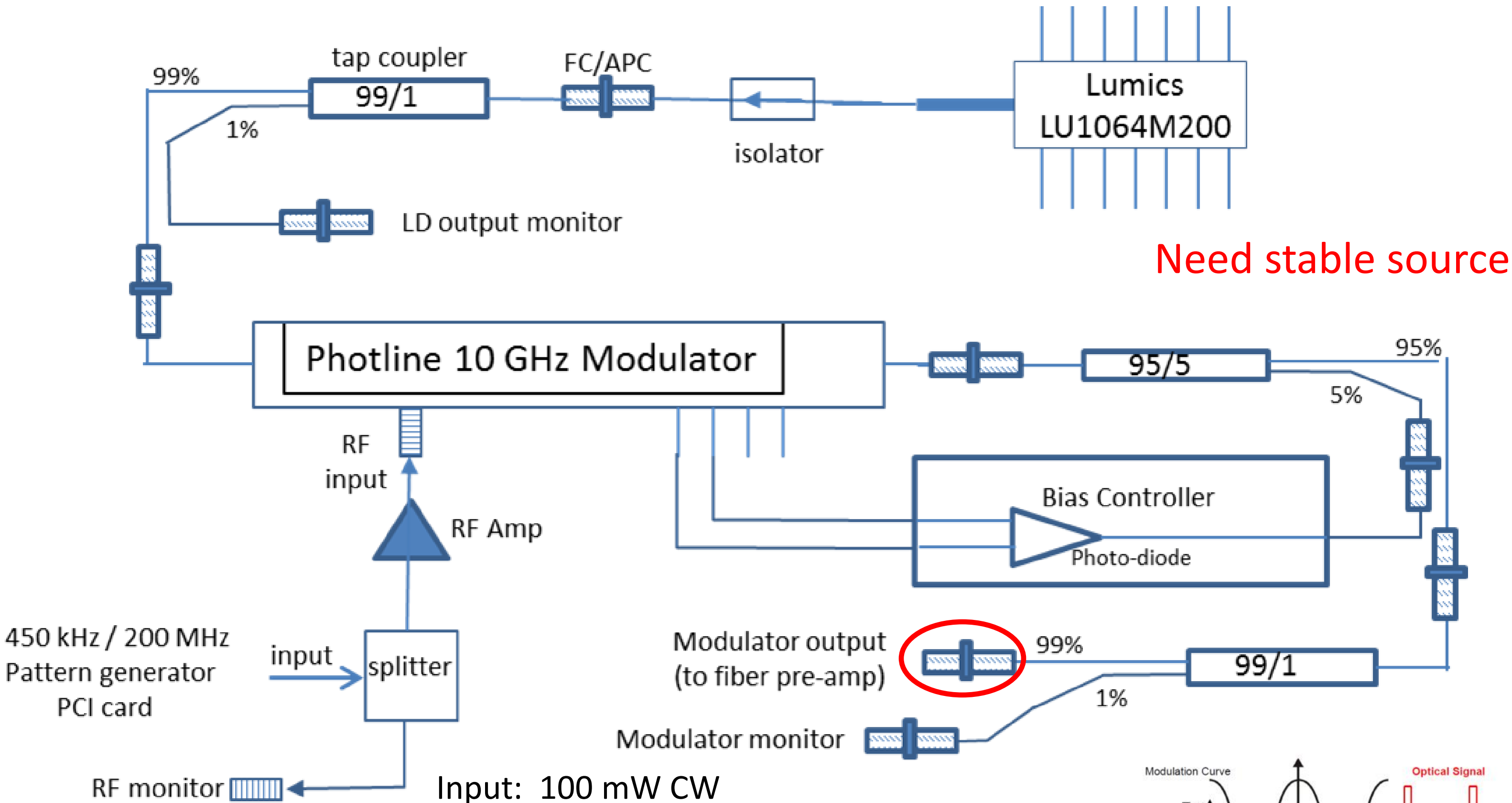
Burst mode seed pulses to Fiber Amplifier followed by Free Space Amp



TRANSPORT BEAM SHAPING OPTICS & OPTICAL CAVITY

OPTICAL PATTERN GENERATOR

Optical Pattern Generator



Input: 100 mW CW

Output: 48-54 pJ (1.5 ns/200 MHz)

260- 294 uW avg power at 450 kHz

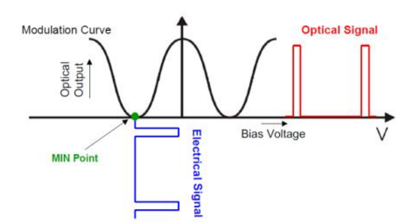
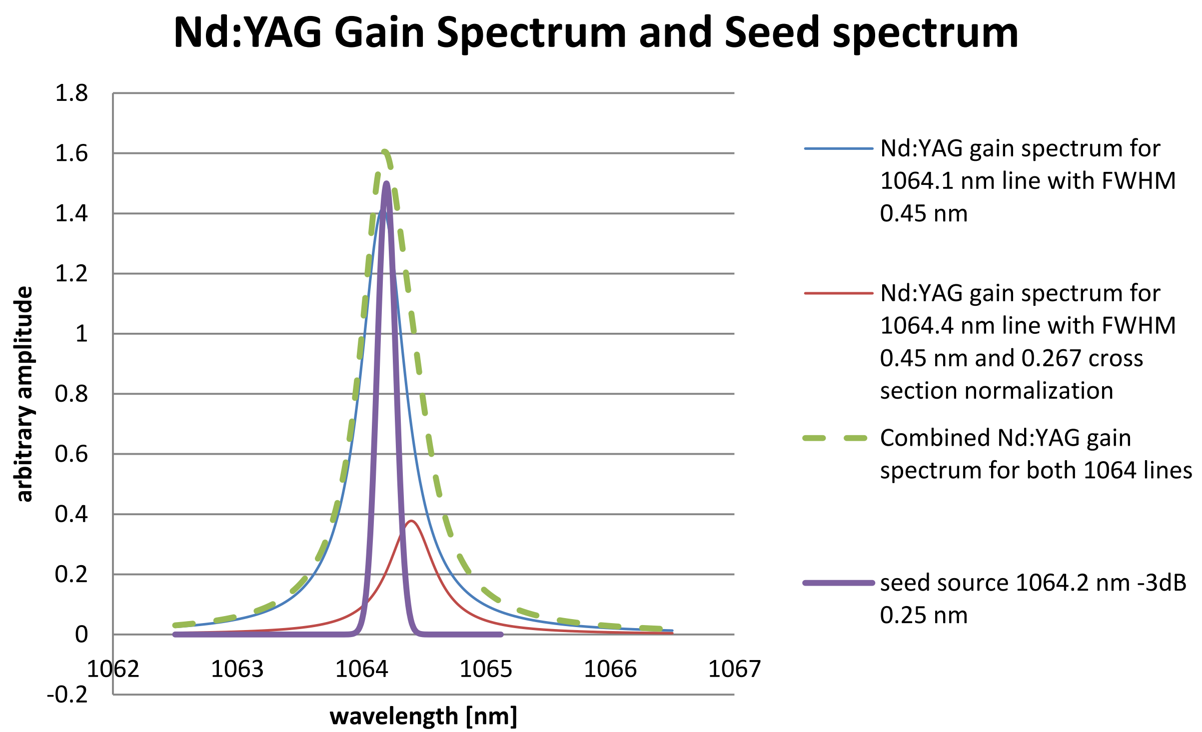


Figure 1 : Transfer function of a Mach-Zehnder modulator and output signal vs input signal at MIN operating point

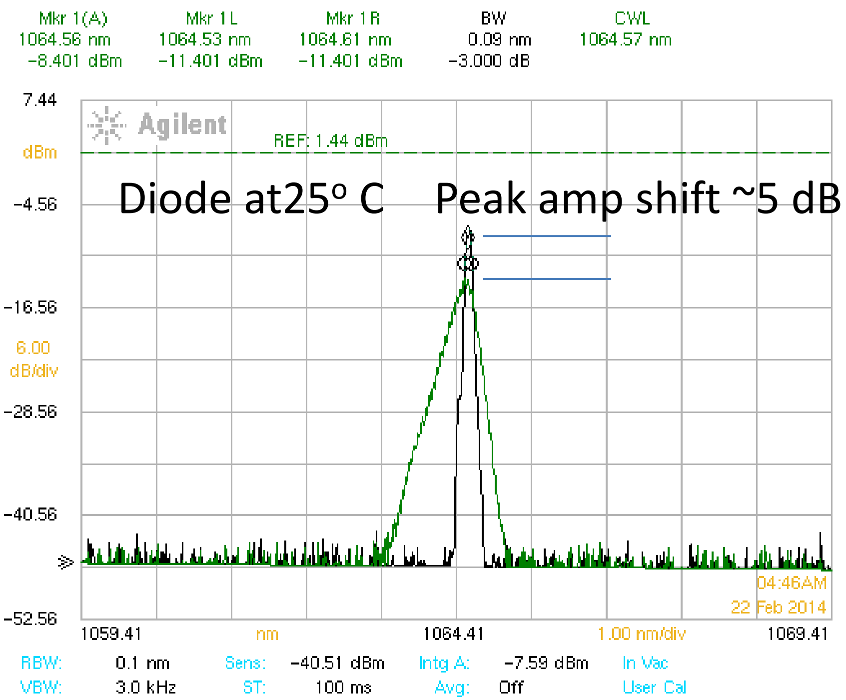
Seed Source

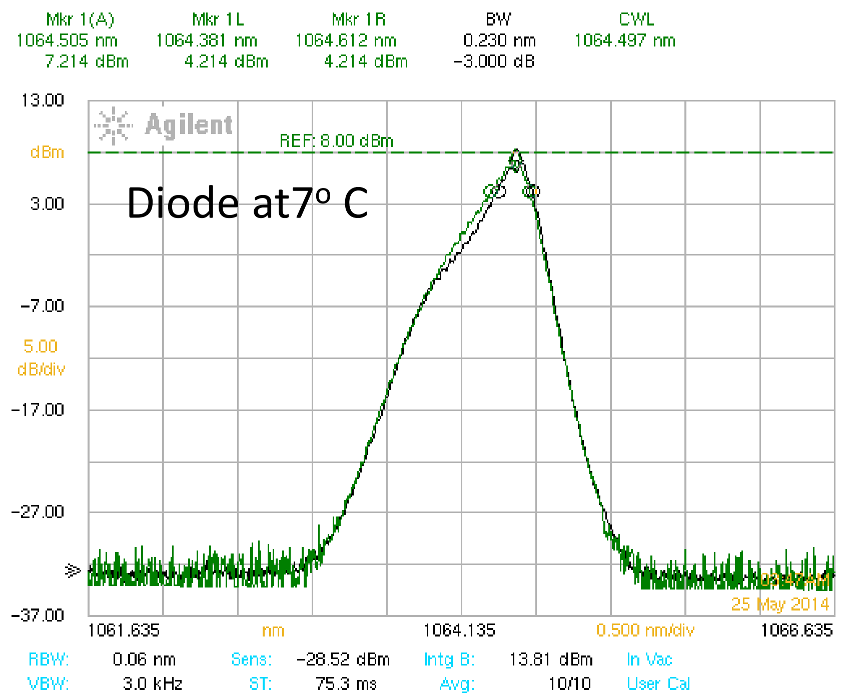
- Requirements:
  - center wavelength (1064.15+/-0.2 nm) -> determined by Nd:YAG gain spectrum
  - spectral width(0.1 to 0.3 nm) -> SBS threshold in fiber amplifiers
  - stability (< 1% p-p) - approximate goal
  - optical power (~200 mW) into isolator to provide net optical power 100 mW into modulator



Seed Source

- Current seed source not stable @ 25°C operation point. Wavelength too high (could be adjusted by Peltier Cooler on FBG.
- Current source more stable at 7°C (but don't want to rely on this long term). Should work for initial tests of fiber system.
- Plan on purchasing a new seed source (looking at options)



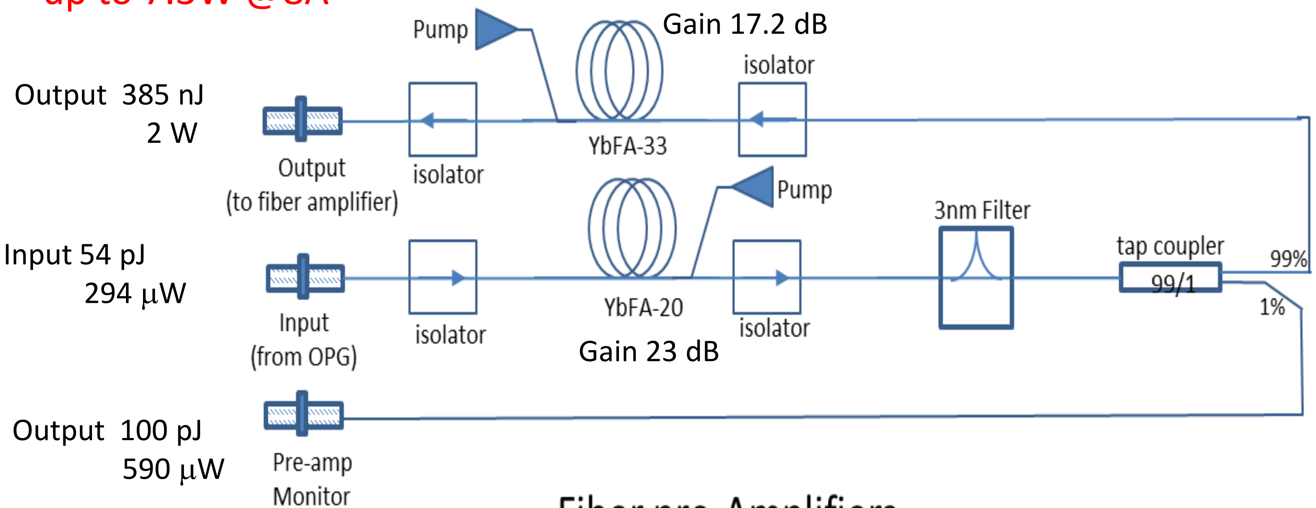


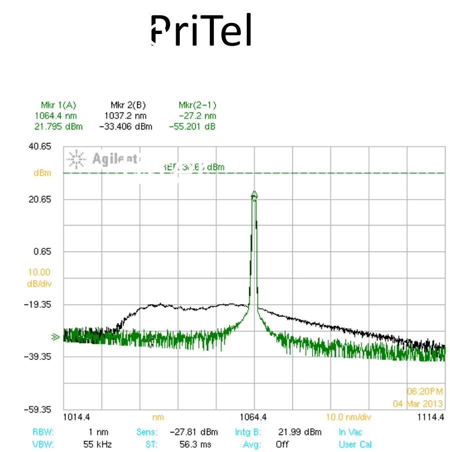
FIBER AMPLIFIERS

Fiber Pre- Amplifier System

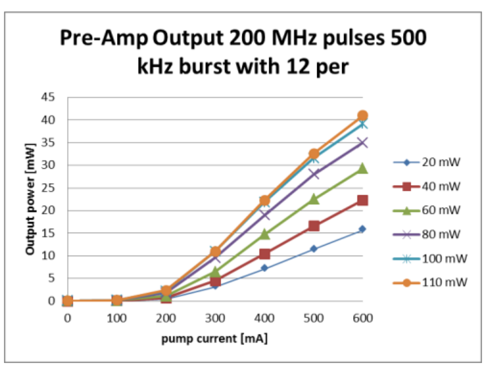
Pump: center λ 970.7 nm
(will shift higher due to heating)
up to 7.3W @8A

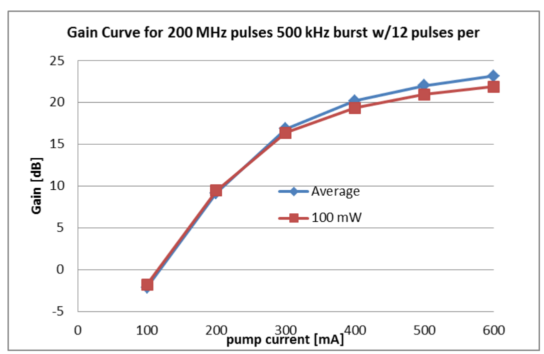
Gain Fiber 7.5 meters CorActive DCF-YB-6/128-PM ,
abs @975nm 2.6 dB/m, Core A 33 um^2

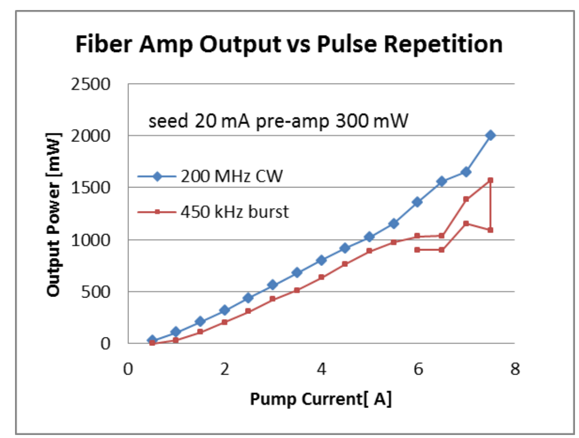




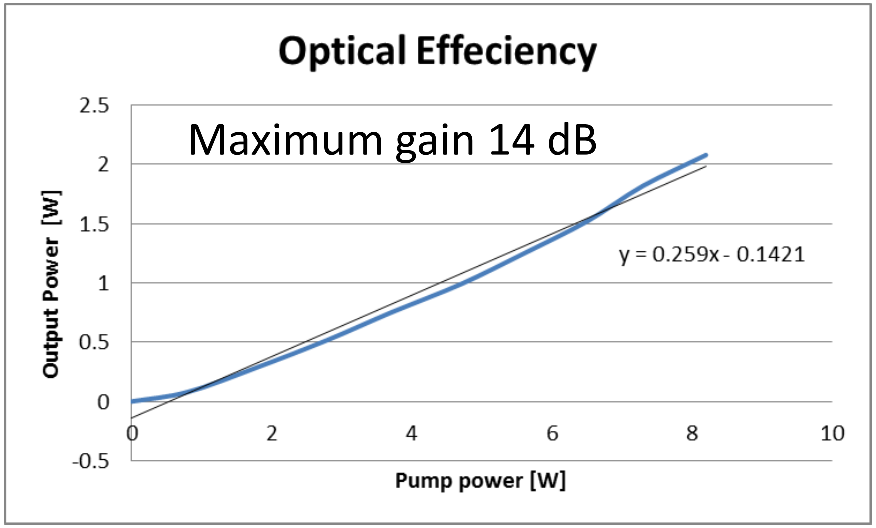
Fiber pre-Amplifiers





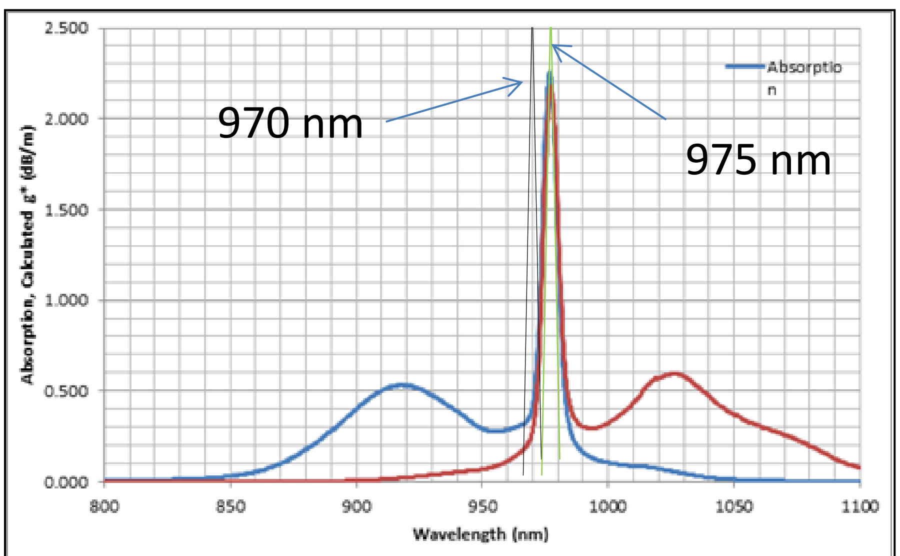


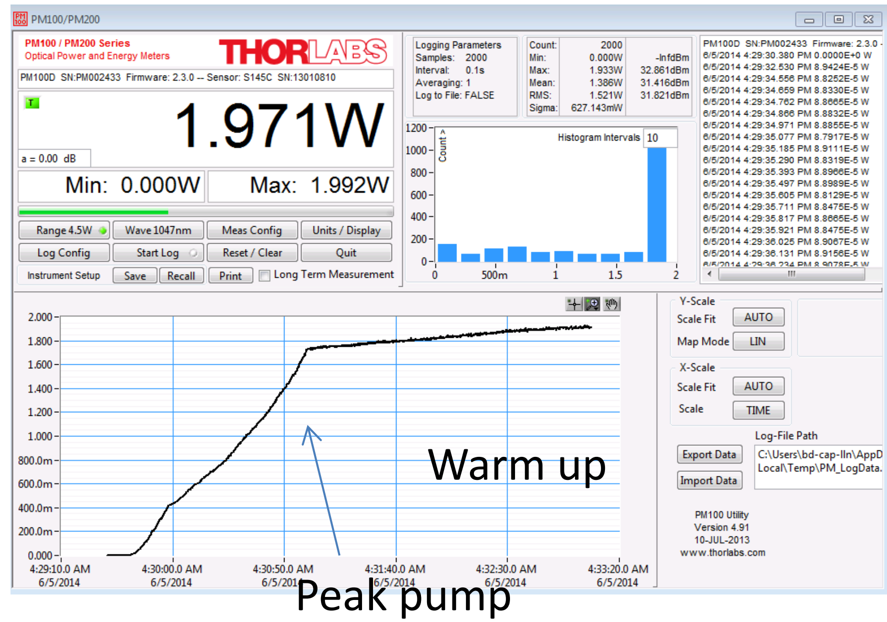
2W Amplifier Performance



Currently 9A pump gets 8.2W pump
Produces 2.1 W output -> 25% optical eff.
Should get 60-70% optical efficiency

Absorption Spectra for Yb doped Fiber





SBS

Interaction of signal and pump with acoustical phonons which transfers power out of signal to a backward reflected wave.

- SBS threshold (CW laser)
  - $P_{SBS} = 21 \frac{AK}{gL}\left(1 + \frac{\Delta\nu_S}{\Delta\nu_B}\right)$
- SBS in pulsed fiber amplifier
  - Signal line width For 0.1 nm line width -> 26 GHz
  - ➢ Pulse duration
  - ➢ Repetition rate
- Laser Pulse structure through CW section

A = fiber core area

K = polarization factor (=1)

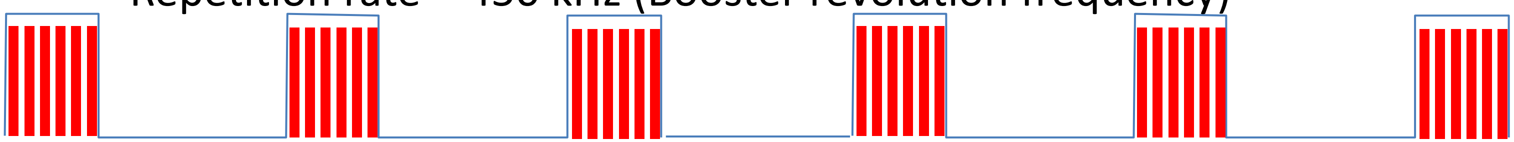
g = peak Brillion gain coefficient

L = effective fiber length

$\Delta\nu_S$= laser line width

$\Delta\nu B$= spectral width BGS (<100 MHz)

Repetition rate ~ 450 kHz (Booster revolution frequency)



Notch (N pulses on 201.25 MHz)
Typically N ~ 12 16 pulses (60-80 ns)

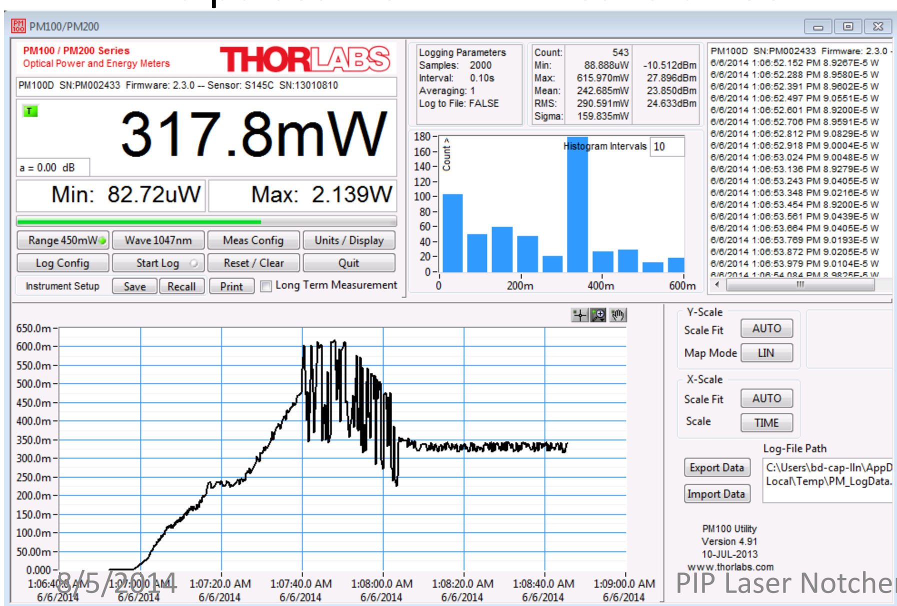
This is equivalent to 450 kHz repetition rate of 60-80 ns laser pulses

- We see detrimental effects due to both the pulse duration and repetition rate, although repetition rate has larger effect.

SBS

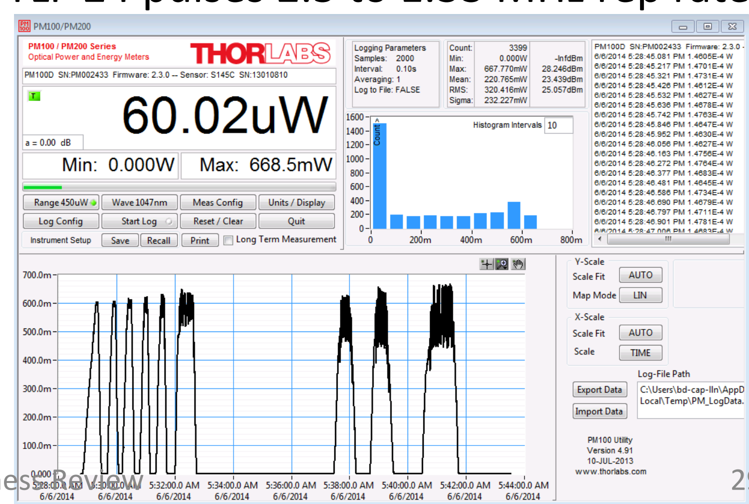
- SBS decreases signal output and increases back reflected power
- We do not currently have a means of measuring back reflected power from the 2 W amp.
- We look at where oscillations start in forward power
  - We see oscillations starting about 500 mW (seems to be the power threshold)
  - Need to be above 2 W for the SBS threshold so need factor 4 to 5 increase in threshold.
  - See increase in oscillation amplitude with decreasing frequency (2 MHz clean, need 450 kHz)
  - Pulse length not a strong impact data we will use 10-20 200 MHz pulses per burst (notch)

YLF 40 pulses 1.3 MHz threshold 480 mW



SBS vs rep rate

YLF 24 pulses 2.5 to 1.33 MHz rep rate



SBS Mitigation Plans

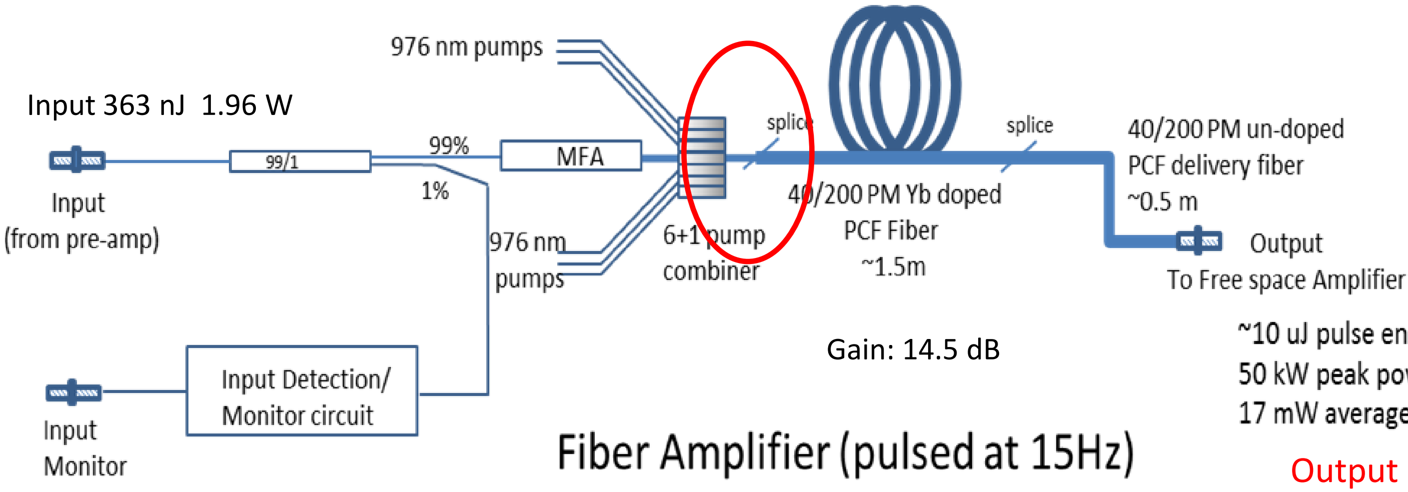
- Raise the SBS threshold a factor of 7.5 by:
  - utilizing a larger mode area gain fiber (x 3)
  - Utilizing a gain fiber with a higher absorption
    - Reduce length of gain fiber (x 2.5)
  - Better matching pump wavelength to improve optical-optical efficiency
    - Reduce pump power
  - Potentially reduce un-doped delivery fiber

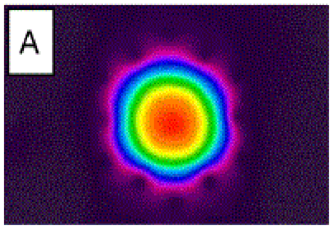
Plan for PriTel Amplifier

- Pritel is building a replacement amplifier with
  - Nufern PLMA-YDF-10/125 large mode area single mode fiber
    - Cladding absorption 4.95 dBm @ 976 nm (as compared to 2.6 for current fiber) -> increase efficiency
    - Mode area 95 um^2 (as compared to 32 um^2 for current fiber) X3
    - Reduced gain fiber length 3m (as compared to 7.5m for current amp) x2
  - New pump diode with center frequency 976 nm -> inc. eff.
  - New pump combiner
  - 2x1 tap to monitor backwards reflected power (SBS)
- Most (if not all components in hand)
- Currently testing the pumps and combiner
- Will be splicing in the gain fiber for tests this week
- On vacation for 2 weeks (starting next week)
- Should finish up the week he returns

Fiber Amplifier System

Optical Engines

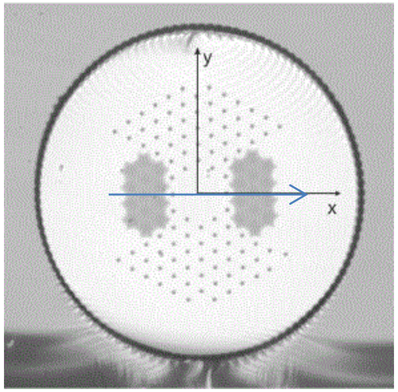




Gain: 14.5 dB

~10 uJ pulse energy
50 kW peak power
17 mW average power

Output to include mode stripper (to remove any pump light) and optics to match into first FS amp.

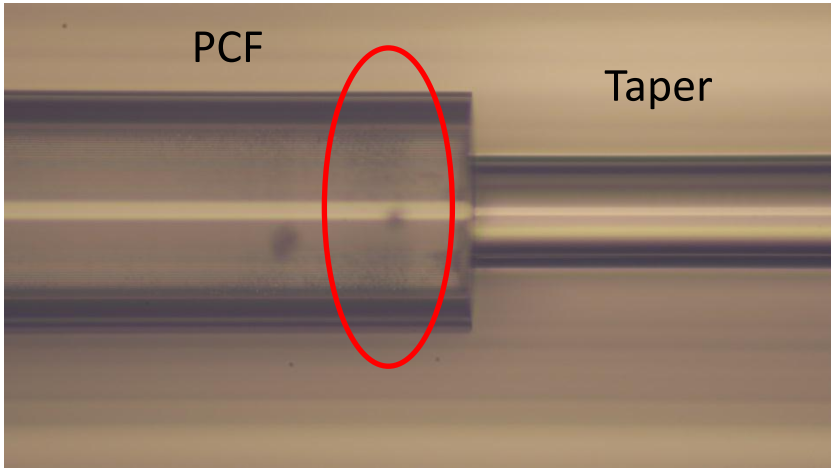


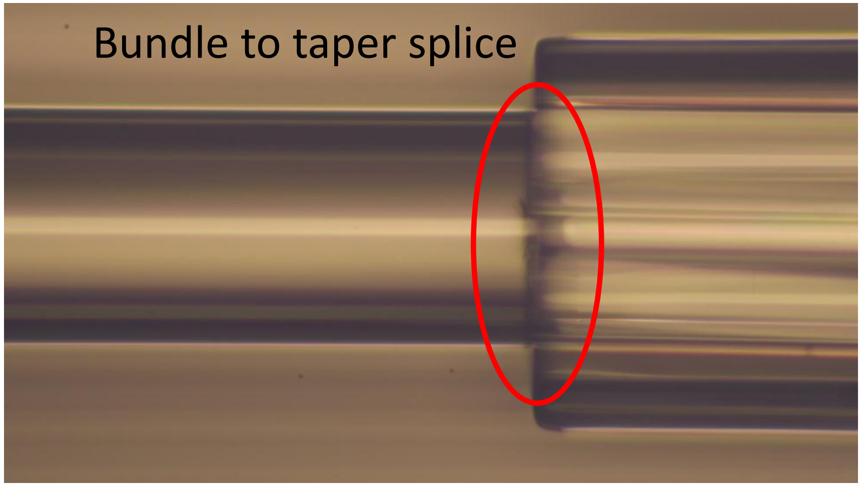
Micrograph of PCF fiber

Single mode, single polarization
Small NA (~0.03)
Large mode area
High peak power levels
High pump absorption (~10 dB/m)
High reliability

Initial tests of Fiber Amp

- Vendor test at their shop
- Commissioning with Pritel Amplifier(with OE engineer present). We found an instability in the seed/PriTel amplifier system caused damage in the bundle to taper splice and the taper to PCF splice. Not clear if there was an additional manufacturing issue which could have lead to the damage.
- These have been repaired (with an improved process) and we have the unit in hand.
- This will be re-tested once we obtain stable output from the 2W amplifier.
- Once we know the output pulse energy, we can finalize the specifications for the Grumman DPSS amplifier modules before the end of FY14.

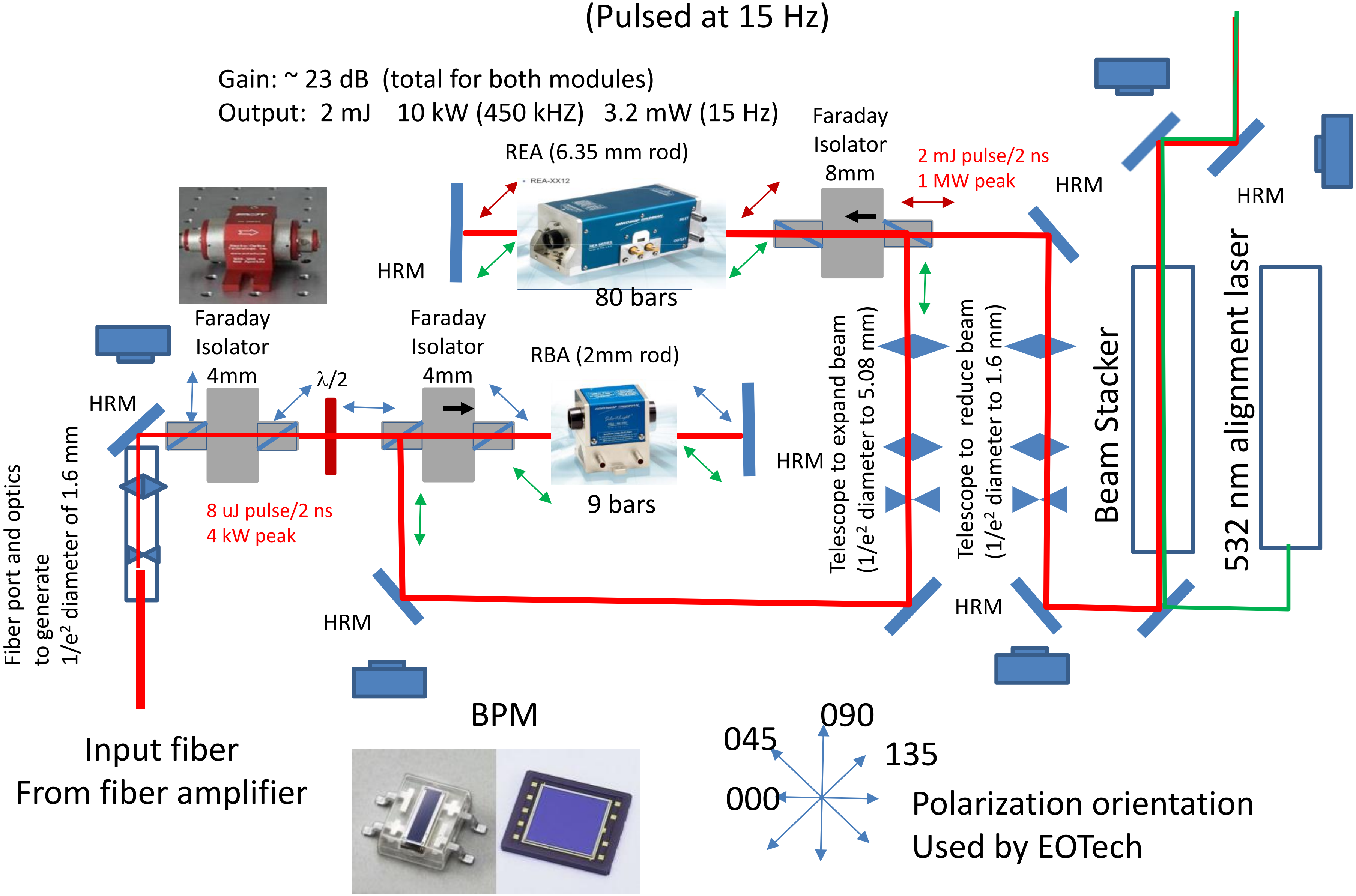




FREE SPACE AMPLIFIER

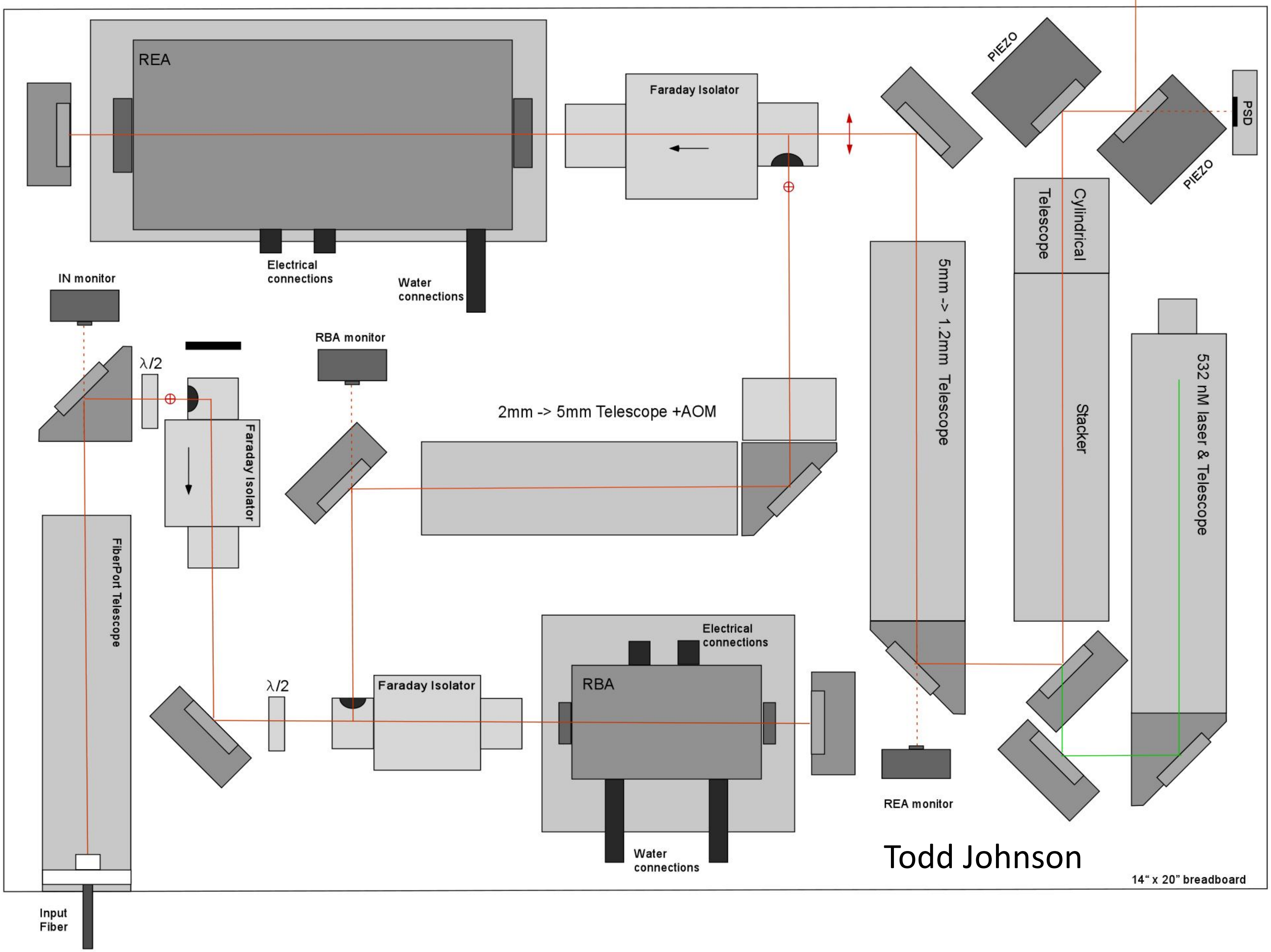
Free Space Amplifier configuration 2.2
(Pulsed at 15 Hz)

Gain: ~ 23 dB (total for both modules)
Output: 2 mJ 10 kW (450 kHZ) 3.2 mW (15 Hz)

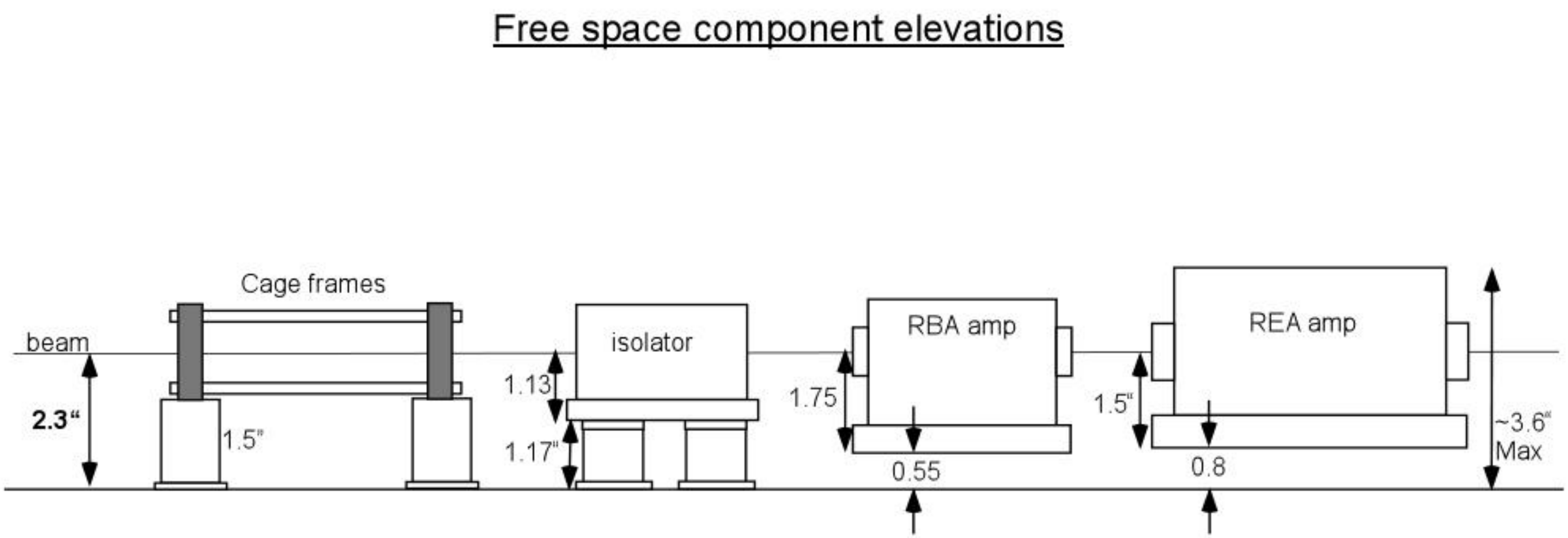


Notcher Free-Space Amplifier Layout v2.3

Shown in 14x20 inch footprint – space available ~18x36 inch



Todd Johnson



Available pedestal heights: 0.5", 0.75", 1", 1.5", 2", 3", 4".
Pedestal spacers: 1mm-10mm in 1mm increments. Plus laminated shims in .075mm layers

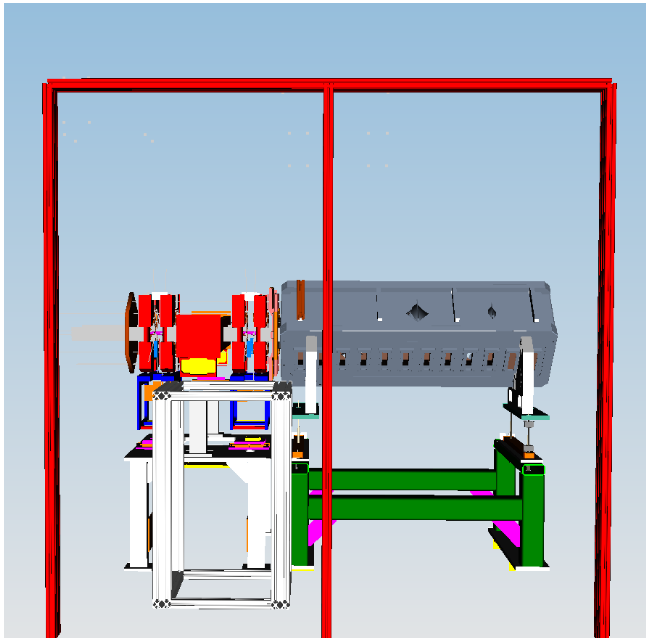
Cage plates: 1.5" pedestals
Isolator: 1" pedestals and 4+ mm spacers & shims
RBA, REA: Make custom mounting plates

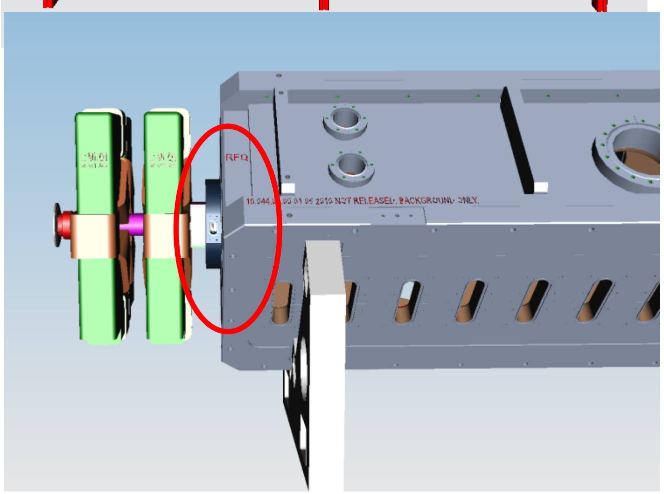
Todd Johnson

INSTALLATION

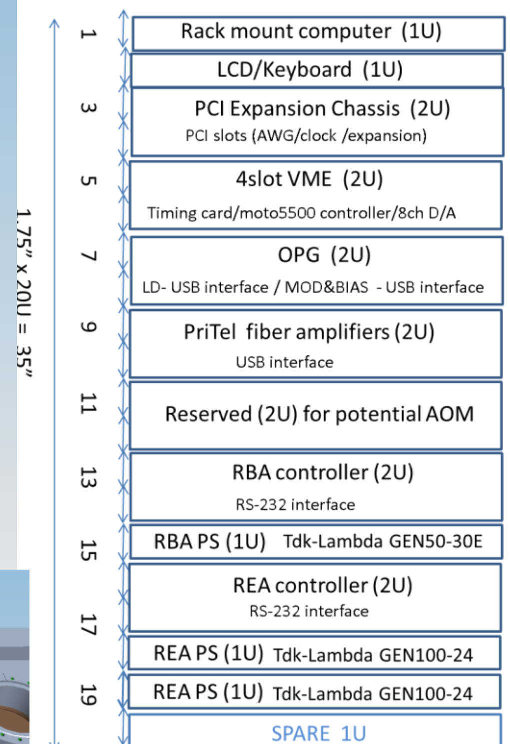
Installation

.... Currently set for April 2015





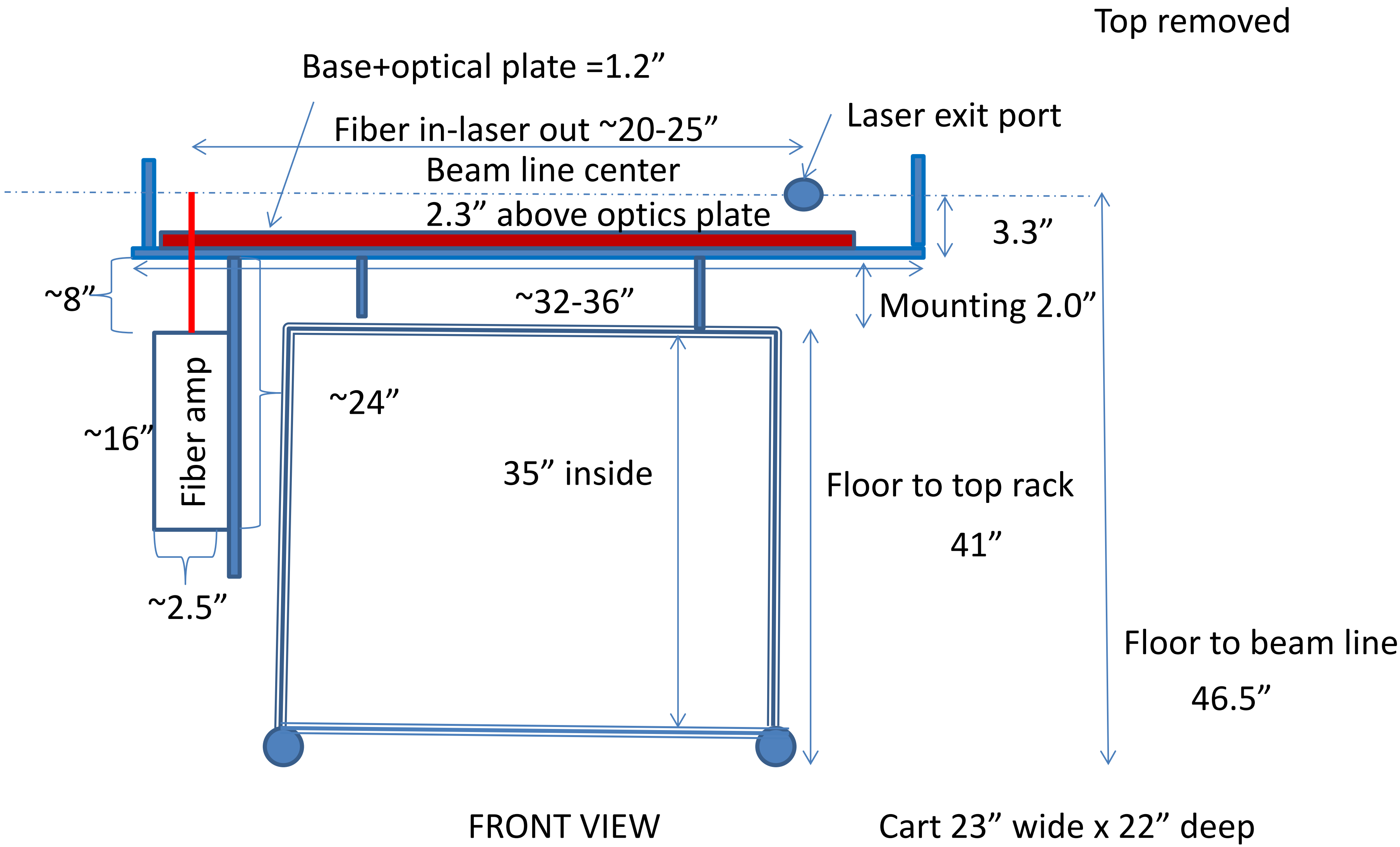
Laser Notcher Rack Layout (01-10-14)



Issues:

- Moveable for MEBT maintenance
- Electrical requirements
- Cooling requirements
- Effects of ion source sparking

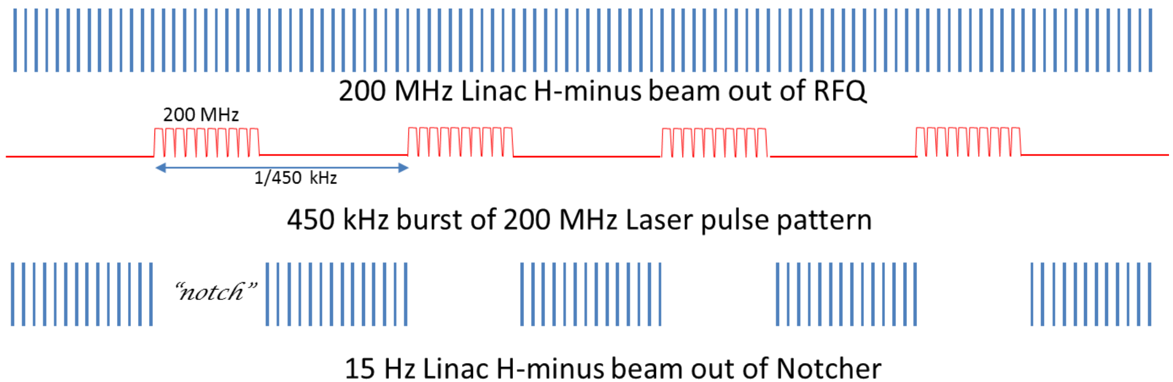
Concept for Optics Box and Fiber Amp Mounting



TIMING / CONTROLS

Timing Requirements

- Action of laser pulses of RFQ beam



- The 201.25 MHz laser pulses phase locked to bunch structure out of RFQ
- The 450 KHz burst frequency adjusted to match Booster revolution frequency.
- Provide a continuous 450kHz pulse structure to first stages of fiber amplifier
- Provide a 15 Hz trigger with delay (+/-2 us) for the PCF fiber amplifier
- Provide 15 Hz trigger(s) with delays (50-300 us) for the two Grumman DPSS amplifier modules
- Provide a 15 Hz trigger with delay for potential AOM or Pockels cell
- Provide 15 Hz arm and trigger with delay for instrumentation/diagnostics

Waveform Generator

- DA12000: 2 GS/sec 12 bit AWG
  - Programmable segment size, trigger, looping, etc.
  - Internal 2 GHz clock or external master clock (c.f. 2.0125 GHz)
  - Internal clock jitter < 2 ps (typical)
  - Delay between external trigger and output +/- 1 clock (+/- 0.5 ns)
  - 600 $mV_{p\text{-}p}$ (typical) into 50 ohms
- Two operational options for current AWG
  - Create a waveform with a single set of "200 MHz" pulses (with padding)
    - Clock the AWG with RFx10 from the RFQ
    - External trigger the AWG at "450 kHz" continuously to drive the 10 GHz modulator and create the optical pulses
    - Each set of 200 MHz pulses with jitter of +/- 500 ps (increase pulse width)
    - Could move to a DA14000 with 4 G/sec (+/-250 ps clock tic) if necessary
  - Create a waveform with a single set of "200 MHz" pulses and a length of $1/f_{REV}$ (c.f. 450.745 kHz -> 2.2185 us)
    - Clock the AWG with RFx10 from the RFQ
    - Internal looping of the complete waveform for 1 notch
- Status
  - Preliminary discussions with Peter and Mike on requirements and techniques
  - Looing at triggers and clock events

Computer Control

- All devices communicate over USB serial control and have software for communication
- Lab view interface – Preliminary discussions with Dave Slimmer.
- Interface with ACNET
- Should start implementing some software control this fall.
- Need to determine operational procedures for turning system on/off/fault recovery

ES&H

Laser Safety

- We are in constant contact with Matt, Dave, and Ray every step of the design to assure personnel safety.
  - Laser development lab
    - Interlocks
    - Operational procedures
    - Alignment procedures
  - Installation and operation of the laser system in Linac MEBT
    - Interlocks
    - Operational procedures
    - Alignment procedures (shielding / administrative controls)
  - Installation of the mirror test laser system

DIAGNOSTICS

Laser Diagnostics

- Instrument free space amplifier system with
  - optical bpm's
  - Slow intensity monitor (input /output of cavity)
  - Fast photo diode to monitor individual notch laser pulses
  - beam camera in the laser dump to monitor profile
  - Optical bpm in laser dump to monitor laser exit position

Plans

- Optical Cavity (detailed schedule in first part of presentation)
  - We should have all components for aligning the optical cavity by 1st or 2nd week in August. If all goes well (and no modifications are needed) should only take a couple of hours for alignment. Internal components will be ultrasonically cleaned and we will be wearing gloves for assembly.
  - We should have the vacuum flange in hand during the 1st or 2nd week in August for installation of view ports and then vacuum certification.
- OPG
  - We are still in search of a new butterfly seed source with stable output and spectral width of ~0.1 to 0.3 nm and a central wavelength of 1064.3 +/- 0.2 nm
  - We will (probably) need to add a Peltier Coolier to the FBG of the seed source to adjust the central wavelength of the seed to match the gain spectrum of Nd:YAG
- Fiber pre-amp
  - PriTel is actively working on constructing the power amplifier with LMA.
  - We should have this in hand by end of August.
- Fiber Amplifier (Optical Engines)
  - Once we have a stable 2W source (source and PriTel amplifier) for the Optical Engines amplifier, re-commission to determine the output pulse energy and average power.

Plans (2)

- Free space Amplifier /beam shaping /transport
  - Should be able to start laying out the optics (telescopes, isolators, bpm's, launch mirrors, etc.) within the next week.
  - Once this is laid out the design of the optics box can start
- Laser diagnostics
  - Read out position in free space optics at 15 Hz
  - Monitor intensity in / out of optical cavity
  - Have 1-D and 2-D optical bpm's in hand
  - Simulation & Prototyping electronics for readout started
  - Provision of camera monitoring the output profile at the laser dump
  - Need to further develop design and begin to construct
  - Need to determine the number of channels for readouts
  - Need to determine the number of triggers for electronics
- Timing card
  - Decide on implementation of AWG (triggered vs internal looping)
  - Finalize delay ranges and precision for amplifier pumps, scope triggers and diagnostics
  - Finalize design of deriving clock from RFQ
  - Determine how to sync with Booster revolution

Plans (3)

- Controls
  - Start thinking about Lab View interface
- H- Beam diagnostics
  - Want to look at bpm or wall current monitor
  - Only have initial concept at this point
- Installation
  - When we have free space system laid out start optics box layout
  - Alignment mechanics for optics box
  - Start to understand electrical requirements (do we need to add another circuit)