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The Linac Laser Notcher for the Fermilab Booster

David E. Johnson#, Kevin Laurence Duel, Matthew Gardner, Todd R. Johnson, David Slimmer (Fermilab, Batavia, Illinois), Sreenivas Patil (PriTel, Inc., Naperville, Illinois), Jason Tafoya (Optical Engines, Inc., Colorado Springs, Colorado)

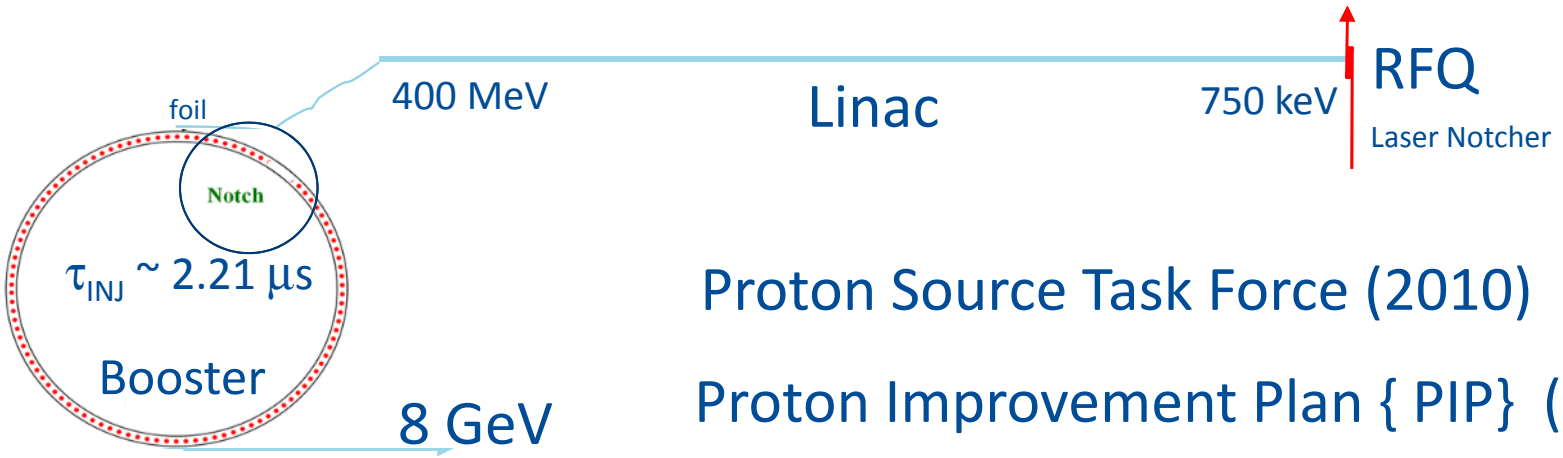
LINAC 2016 MSU, Lansing MI

29 September 2016

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- Don Sipes & Jason Tafoya of Optical Engines
- Jay Doster & Dennis Lockwood Grumman

A Little Background (The Proton Source)



Proton Source Task Force (2010)

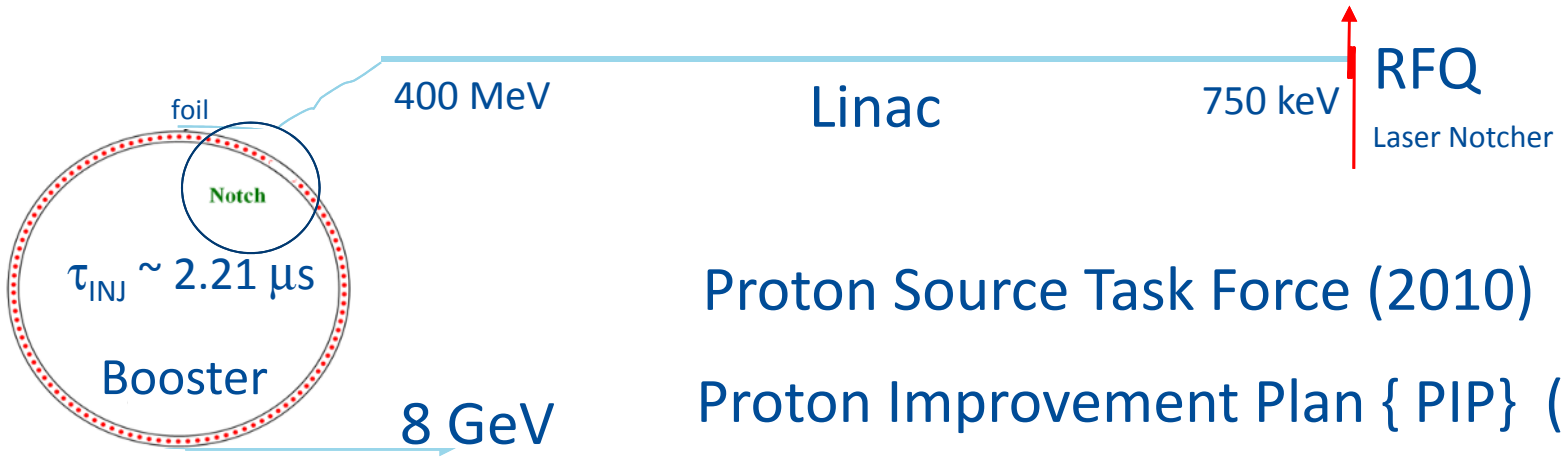
Proton Improvement Plan { PIP} (2012)

$\mathcal{F}_{RF}$ (injection) 38 MHz

- ❑ Notch created in Booster @ 400 MeV -> 1/3 total power loss
- ➢ Move this process out of the Booster tunnel
- ➢ Create Notches in Linac pulse



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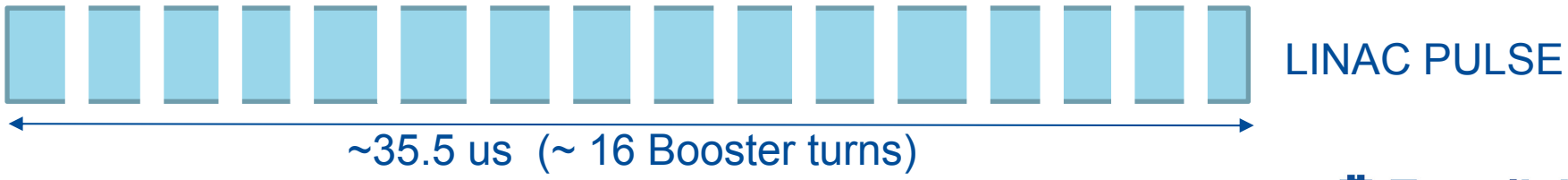


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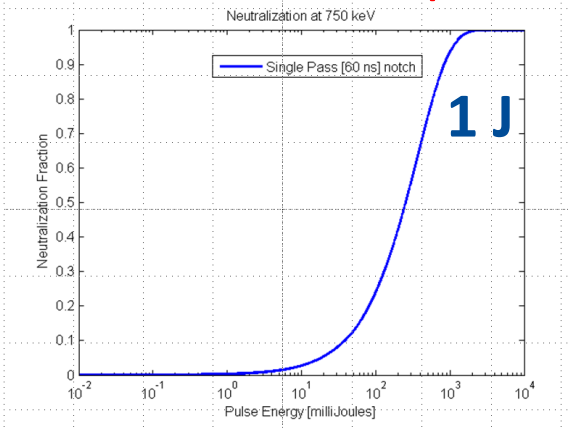


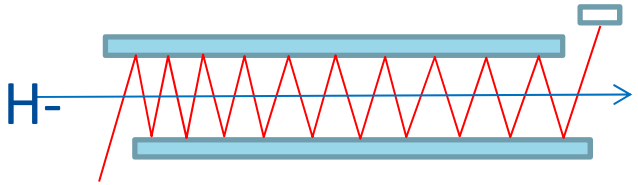
Technique: Photoneutralization

$$F_1 = N/N_0 = (1 - e^{-f_{CM} * \sigma(E) * \tau_{\text{crossing}}})$$

- 1 micron laser- near peak of cross section

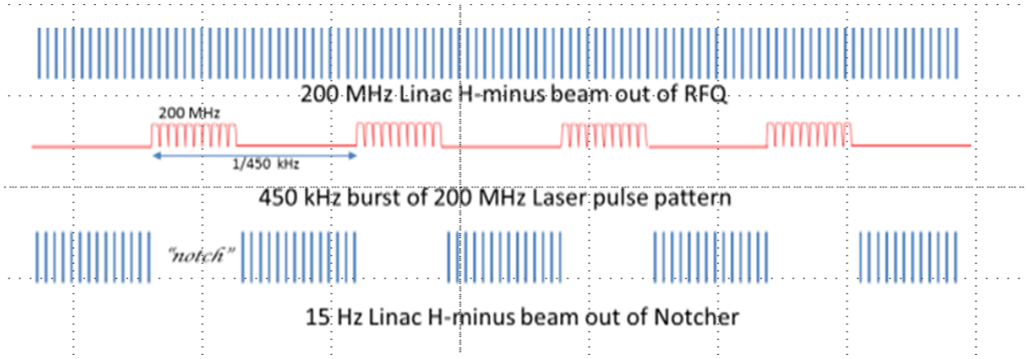
✓ Want to make process efficient -> minimize required laser pulse energy/average power

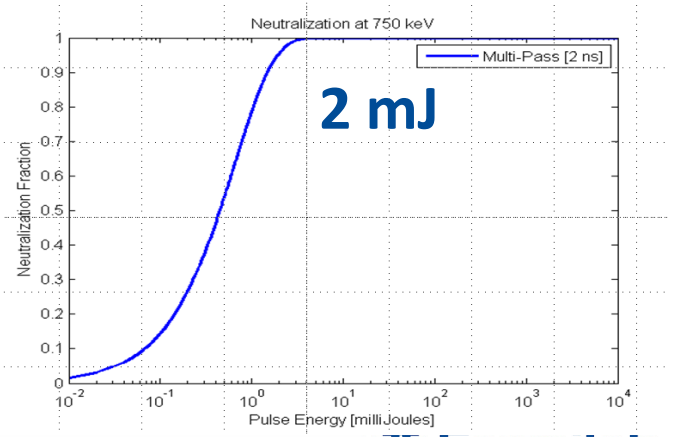




- Zig-zag optical cavity

- Match laser pulses to bunch parameters



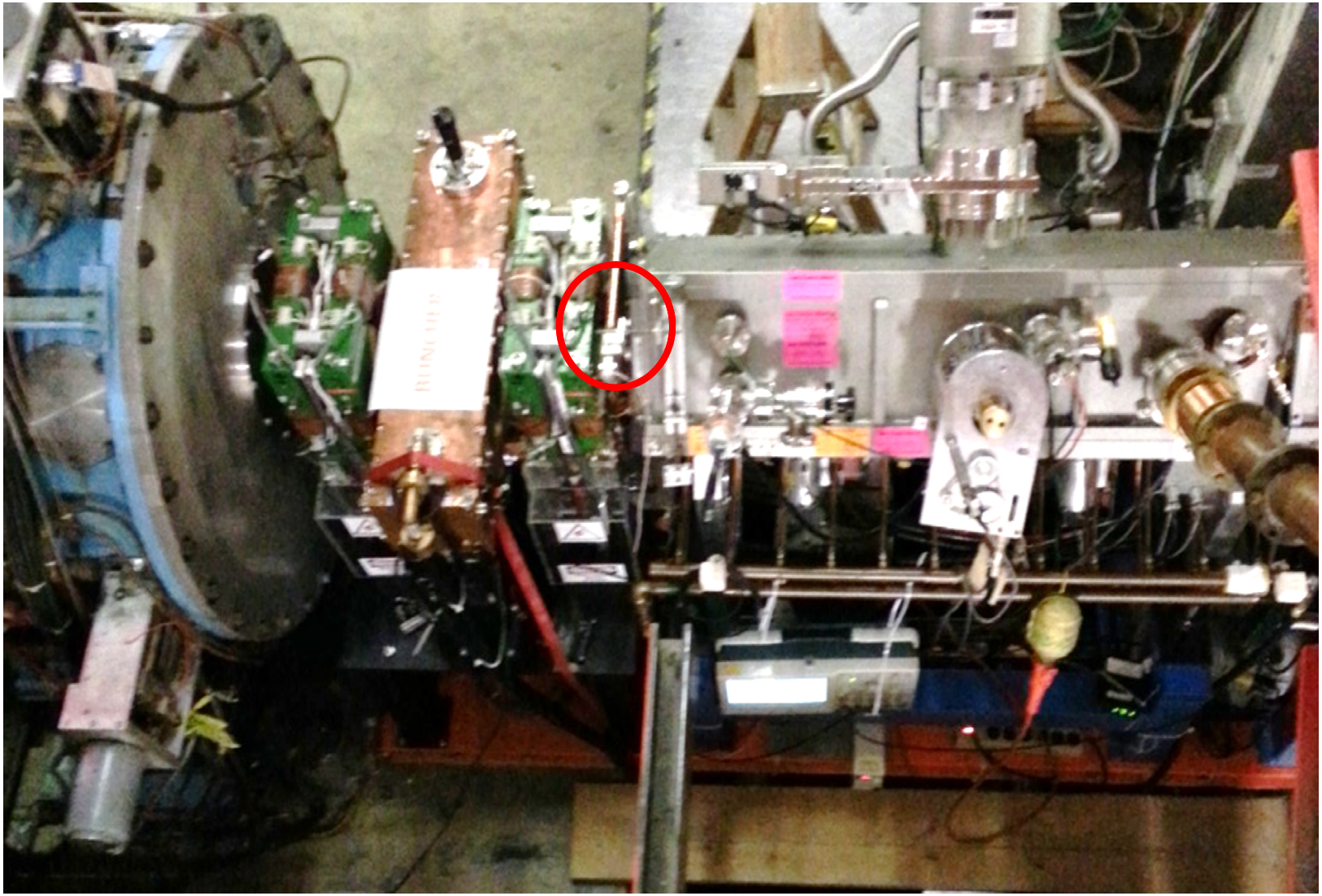


PIP Charge

- Develop a flexible laser system / optical cavity with the following attributes:
  - Create:
    - ✓ An arbitrary number of notches within a linac pulse
    - ✓ An arbitrary notch length for each notch
  - Provide:
    - ✓ 98% neutralization of the H- ions
  - Fit into the highly constrained space in the 750 keV MEBT where
    - ✓ component activation does not occur!
  - Create a system that is operationally robust

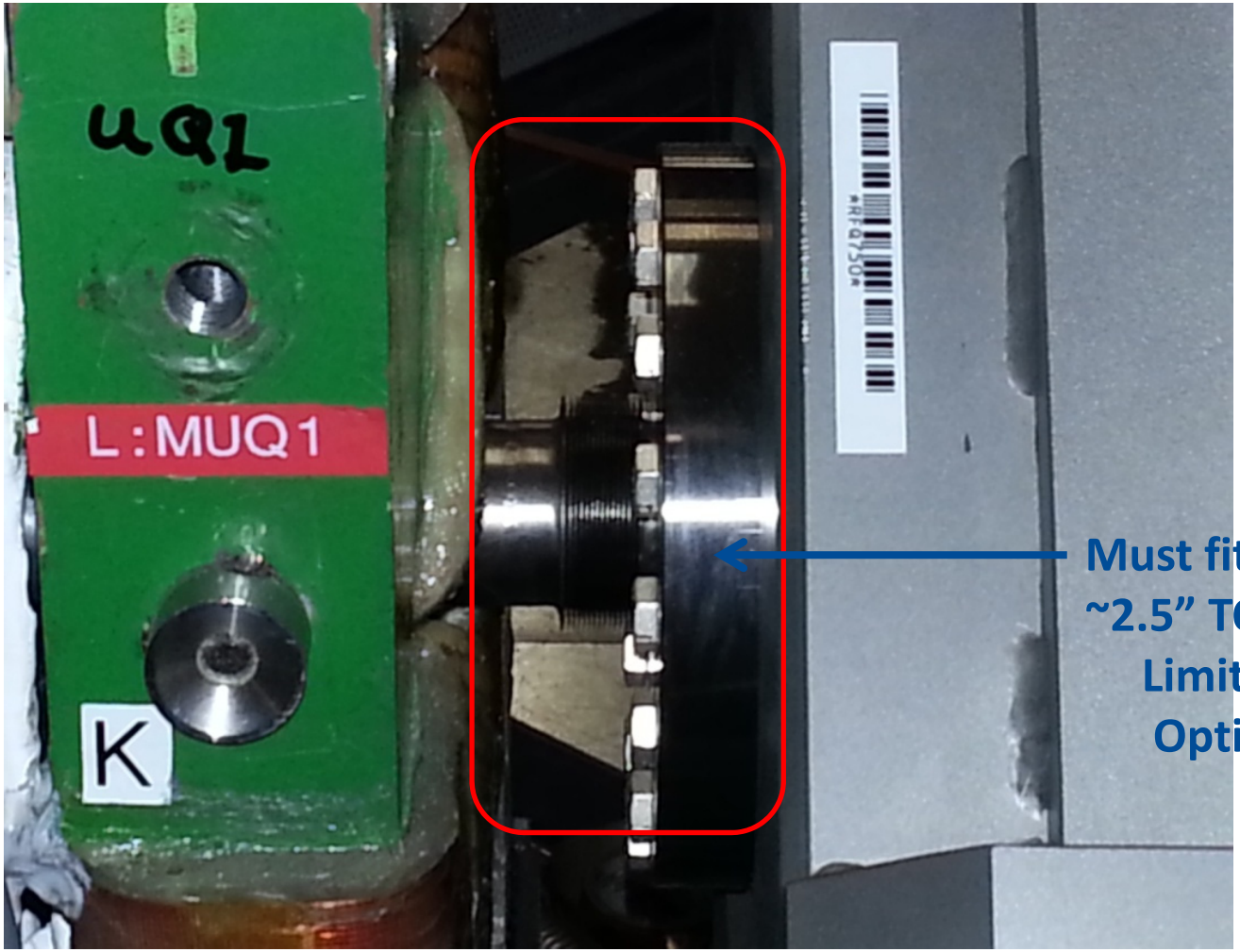
- This project is a task under the umbrella of PIP.

Location of the Zig-Zag Optical Cavity



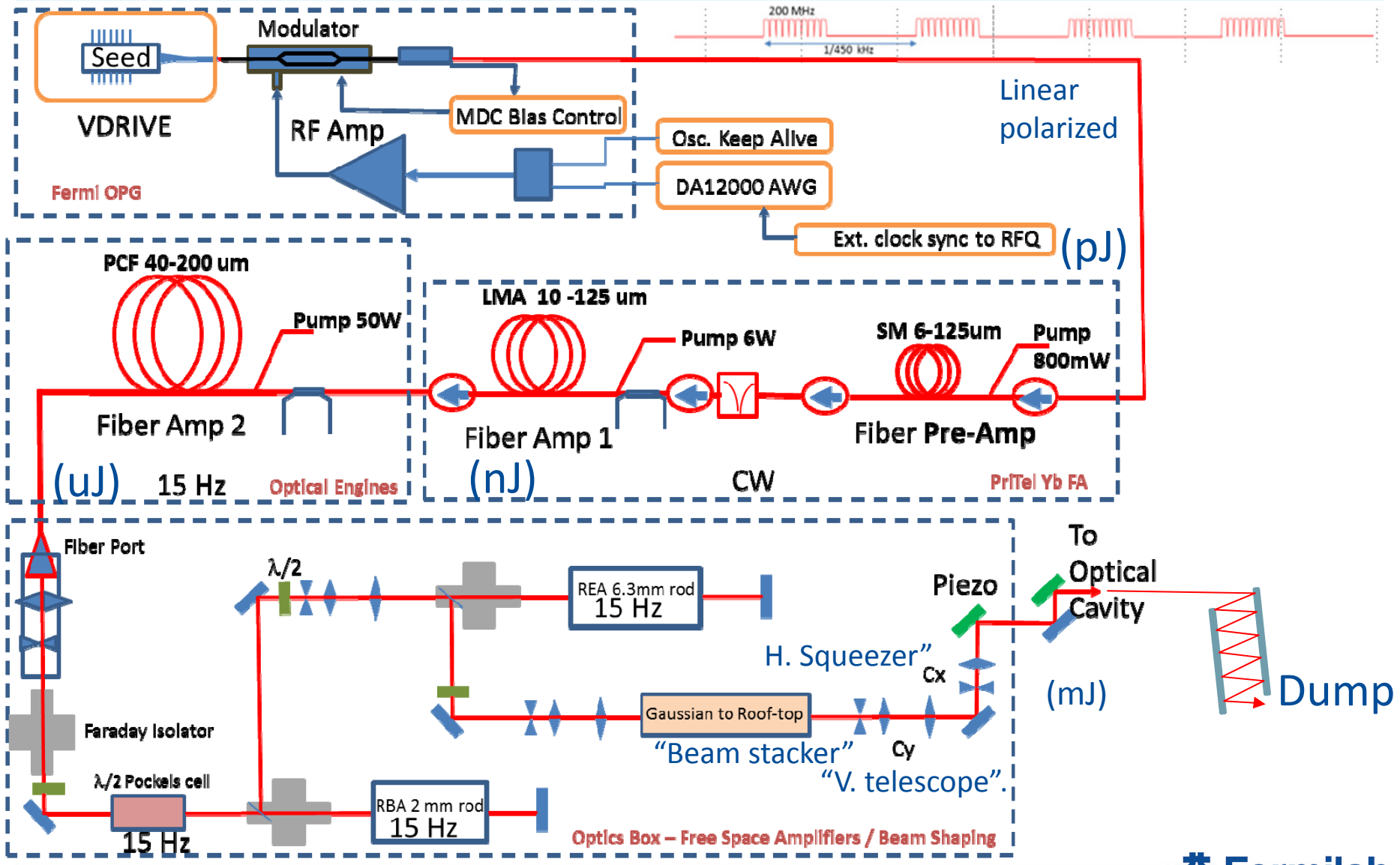
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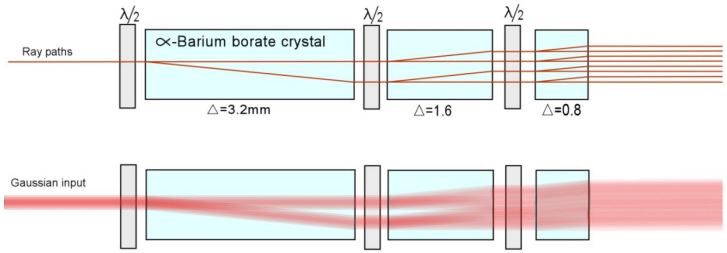
Must fit in this space
~2.5" TOTAL
Limits the length
Optical Cavity

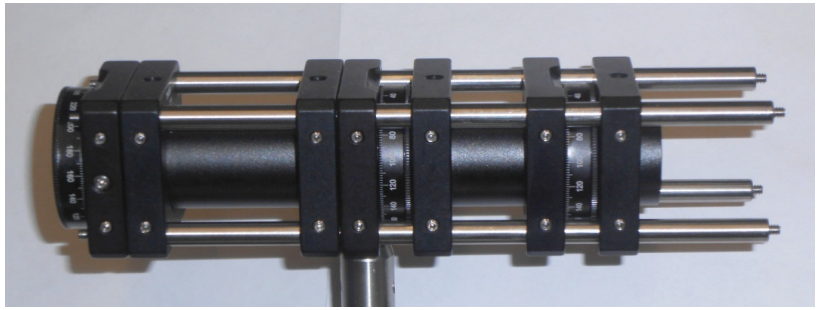
Laser System (Basic layout)

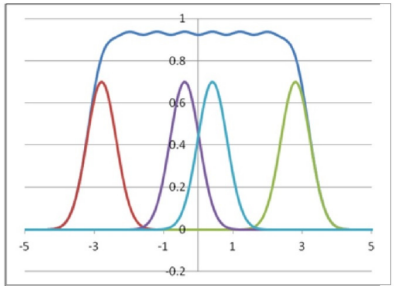


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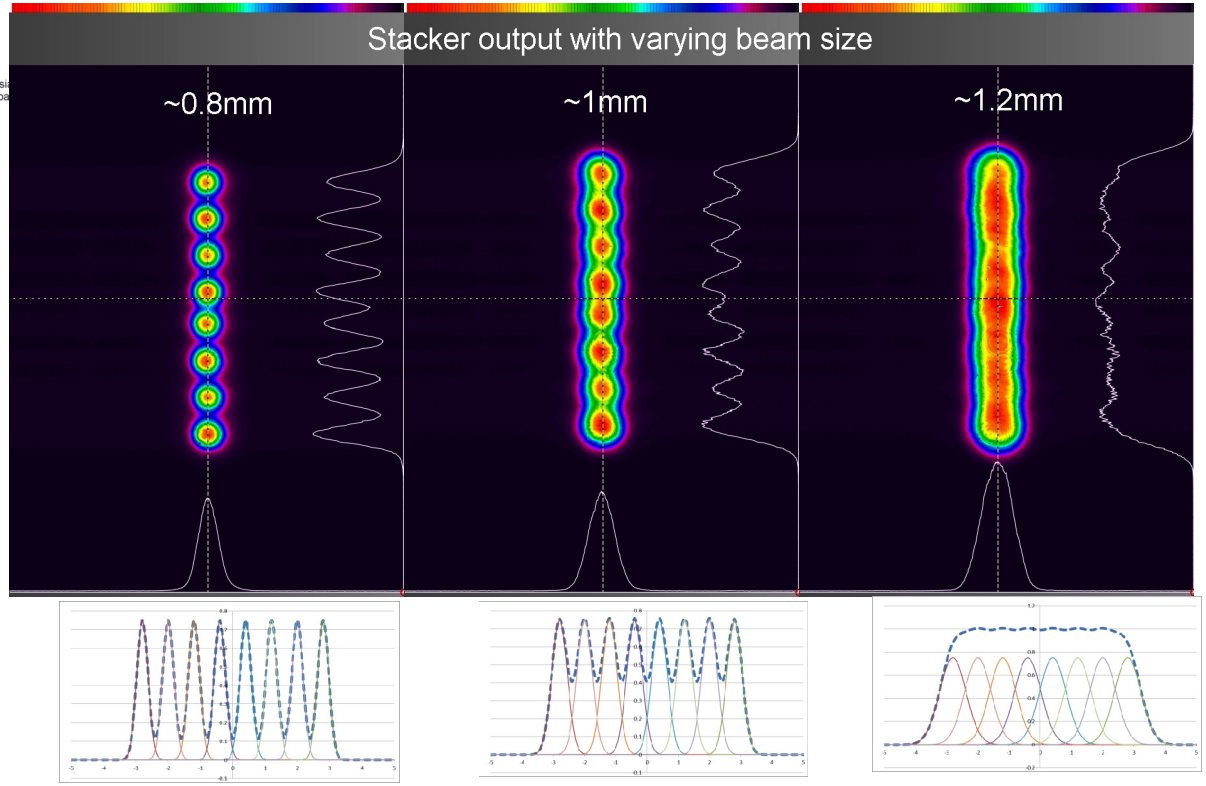
Creating a roof-top uniform profile



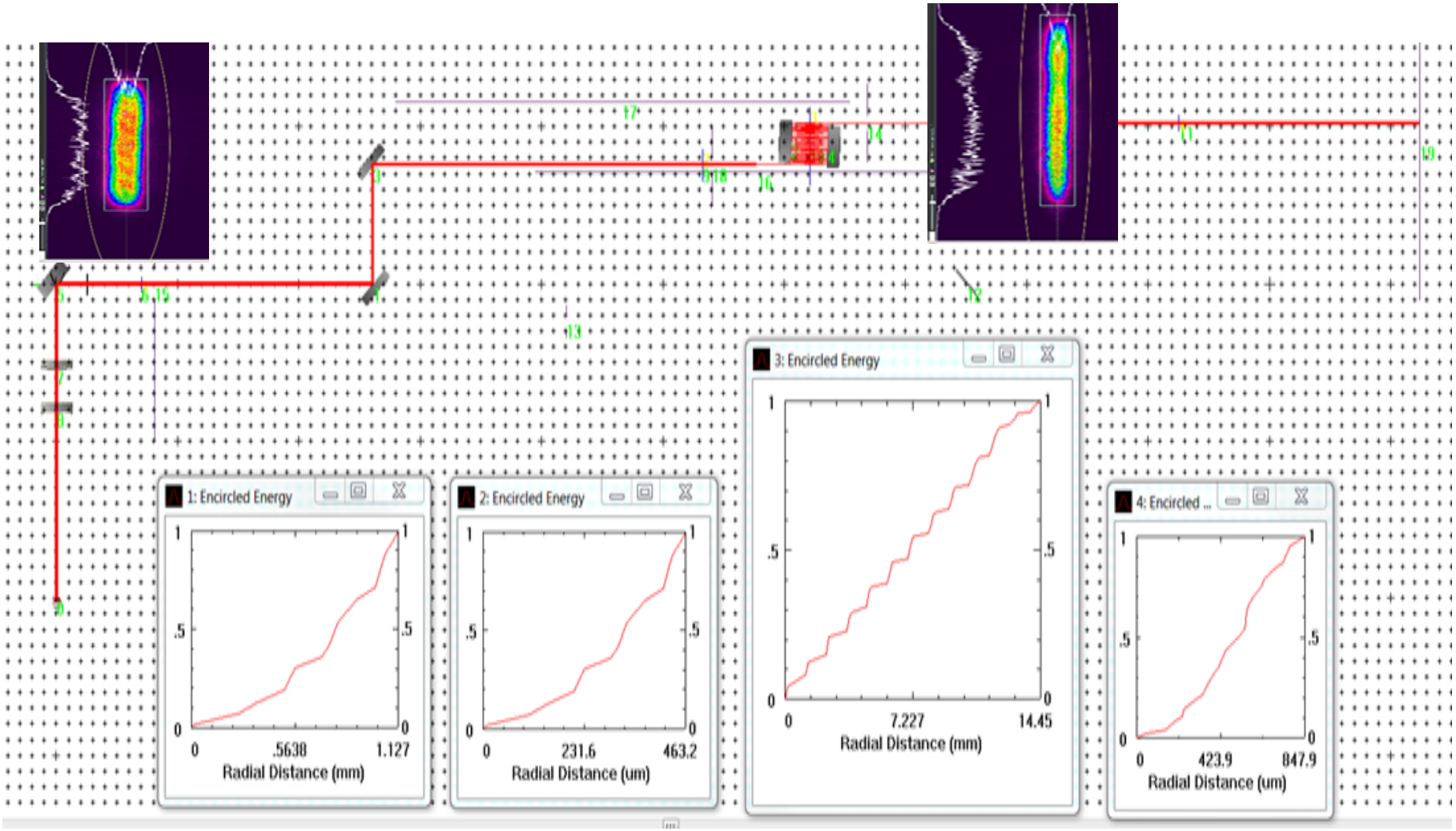




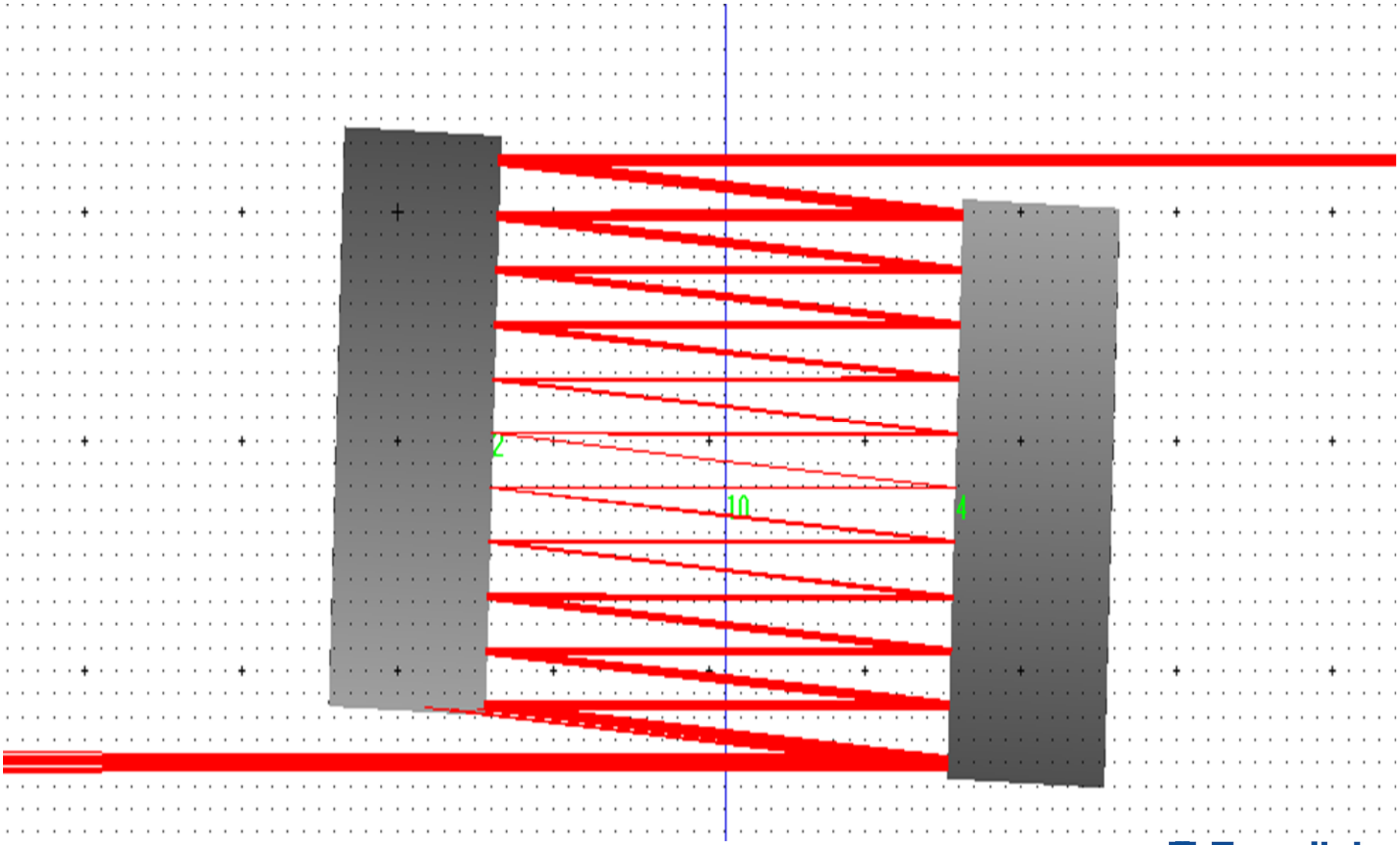
Simulation of 8 stacked gaussi
0.6mm sigma and 0.8mm sepa
(4 of 8 beamlets shown).



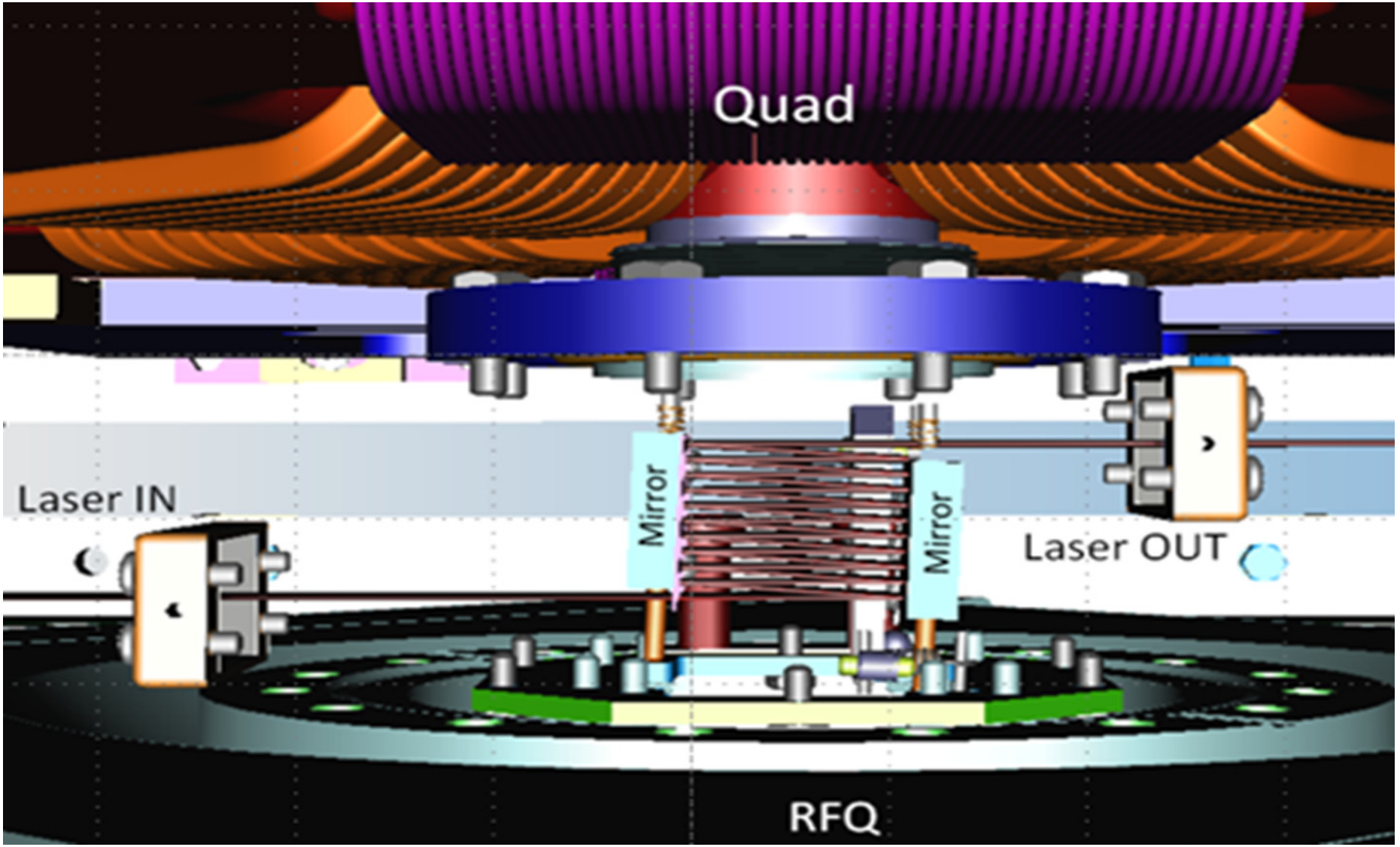
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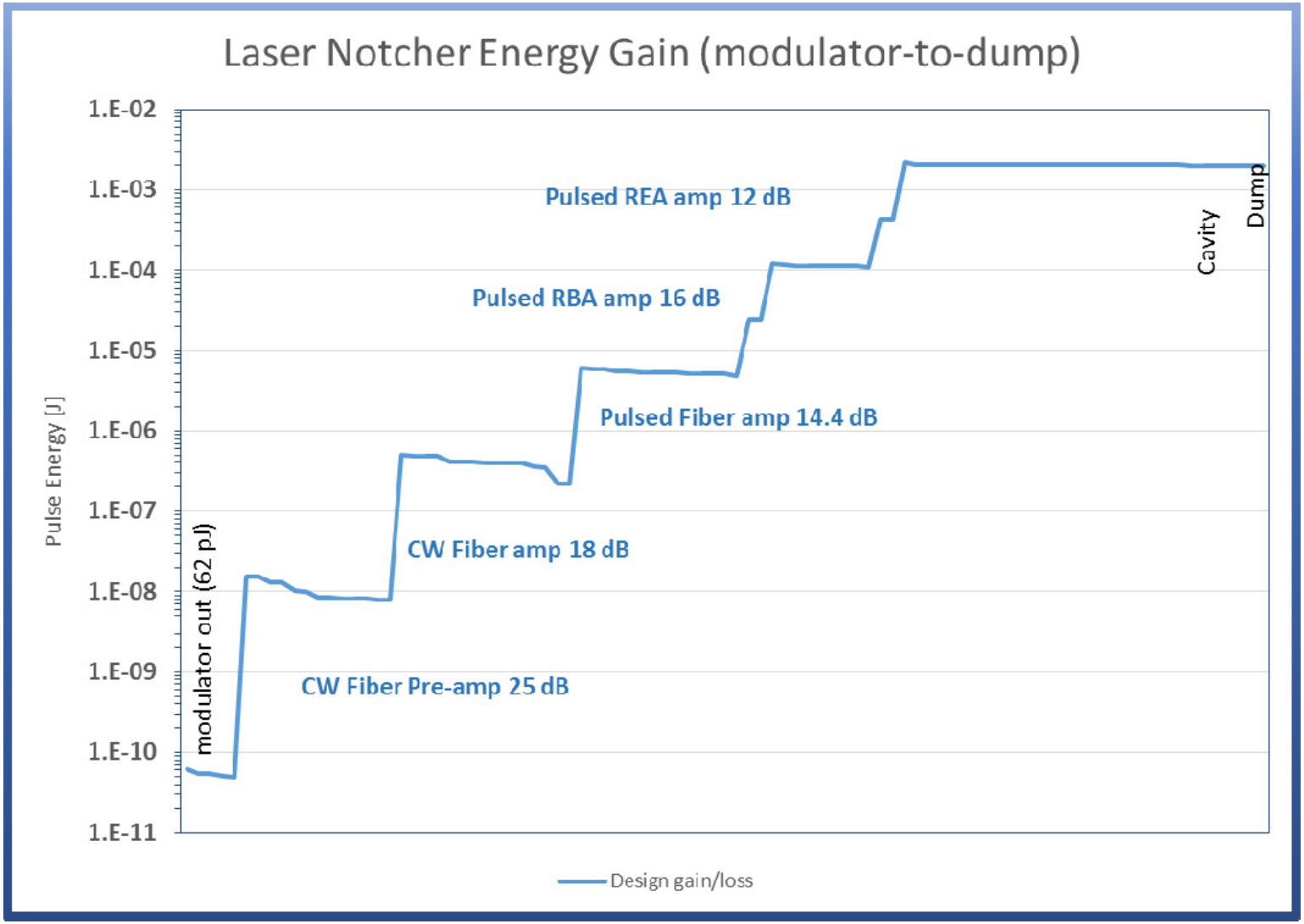
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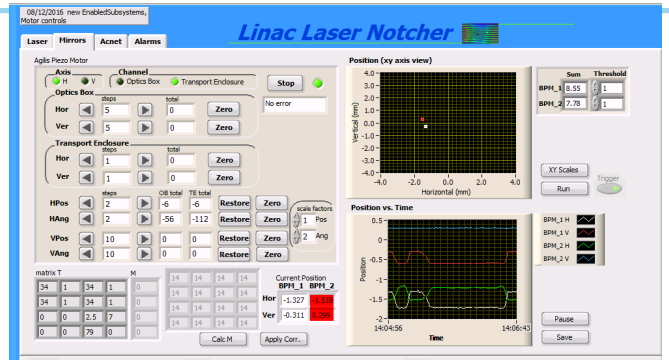
Optical Cavity



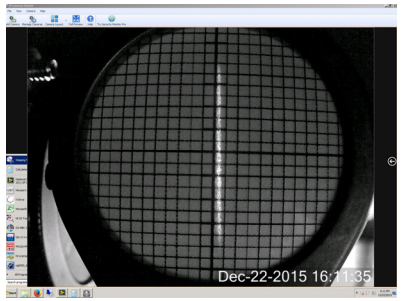
Pulse Energy Gain



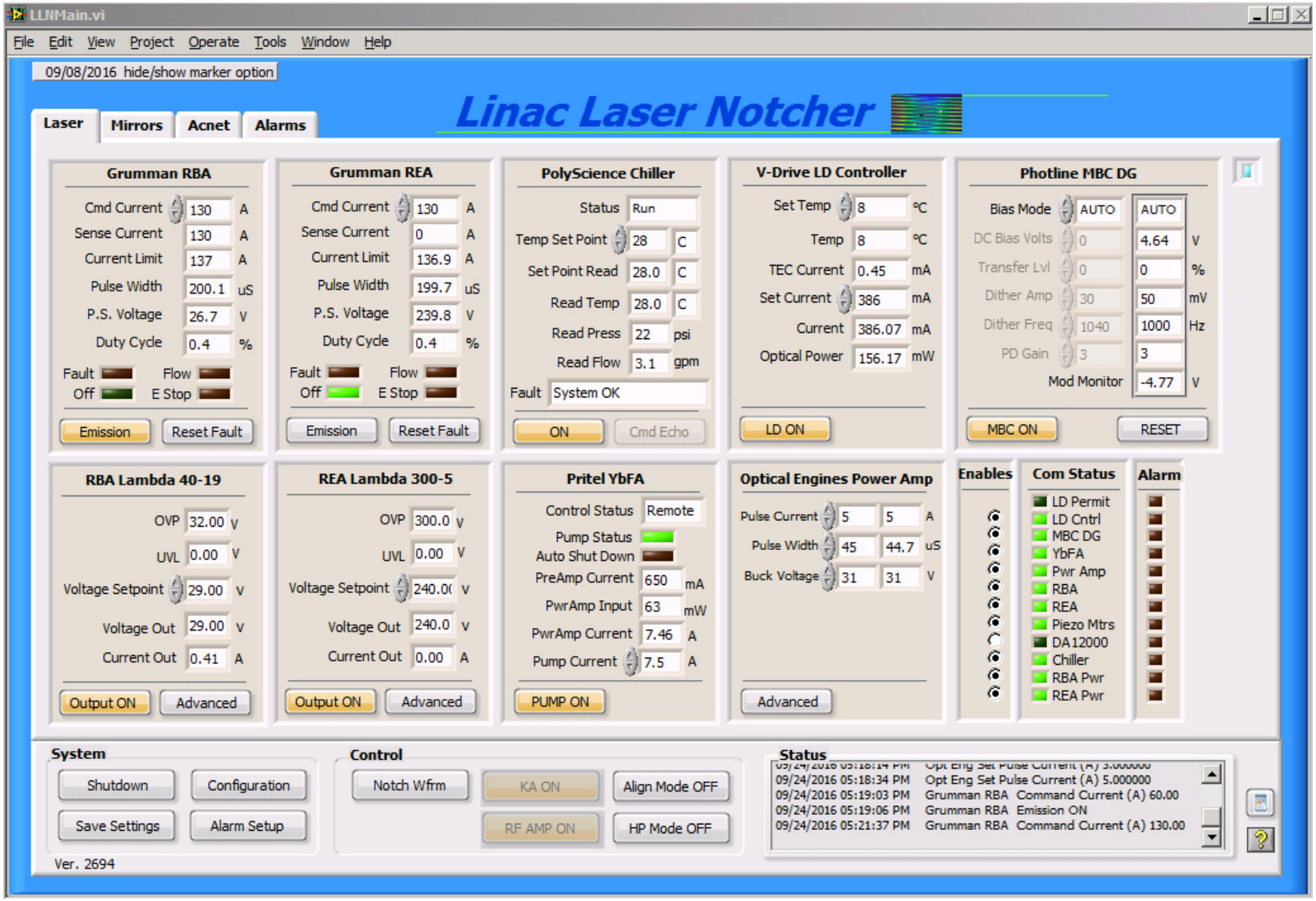
Instrumentation



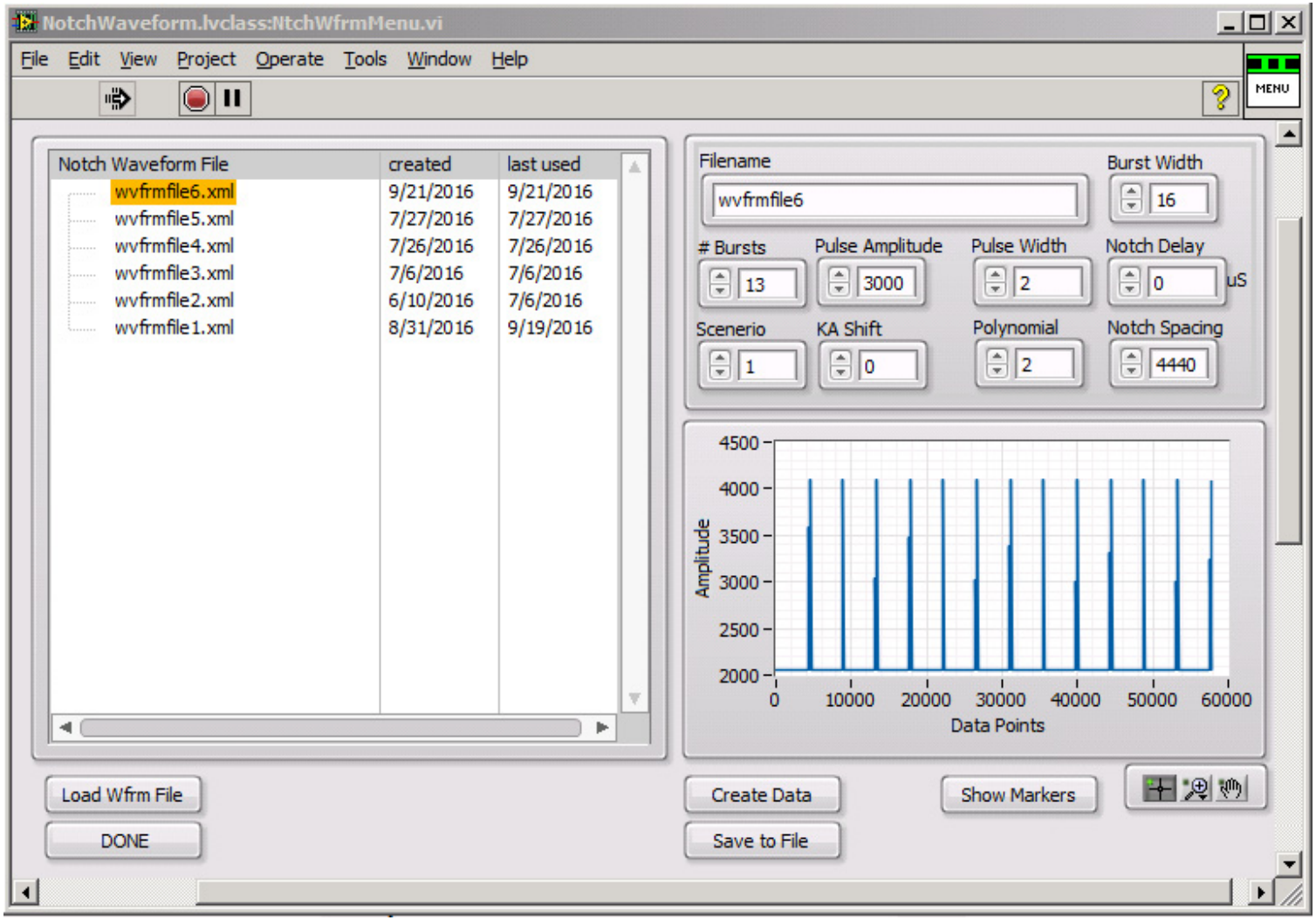
- Optical BPM's (fermi design)
  - Steering into cavity
- Fast photodiodes (2.1 GHz BW)
  - to monitor free space pulse peak
- Gated integrating spheres to measure power at 15 Hz in free space optics (fermi design)
- Pyroelectric energy meter in the Dump to measure the total laser energy each 15 Hz linac cycle.
- Video camera for
  - Qualitative profile measurement
  - monitoring laser position



Control Program

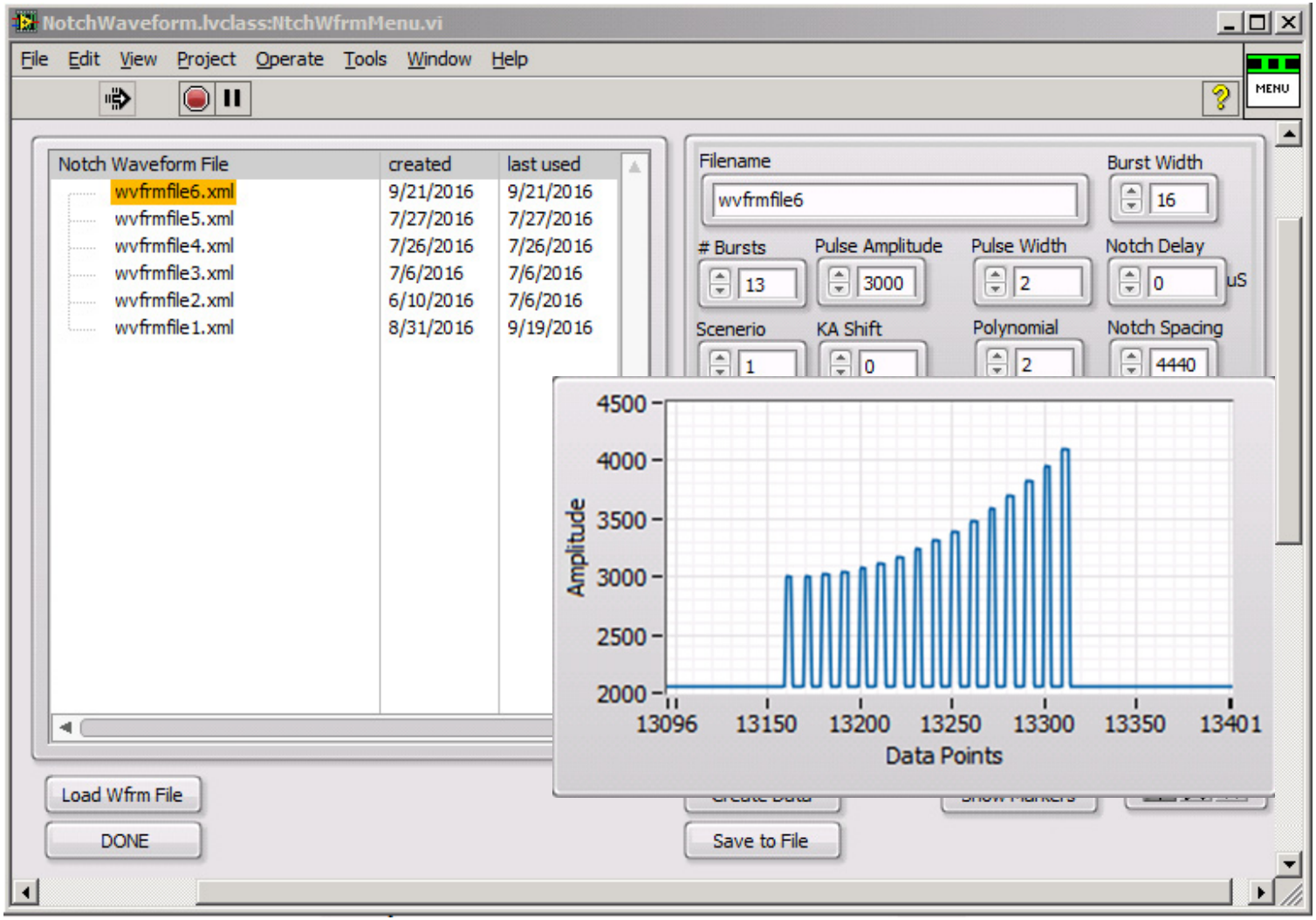


Arbitrary Waveform Generation



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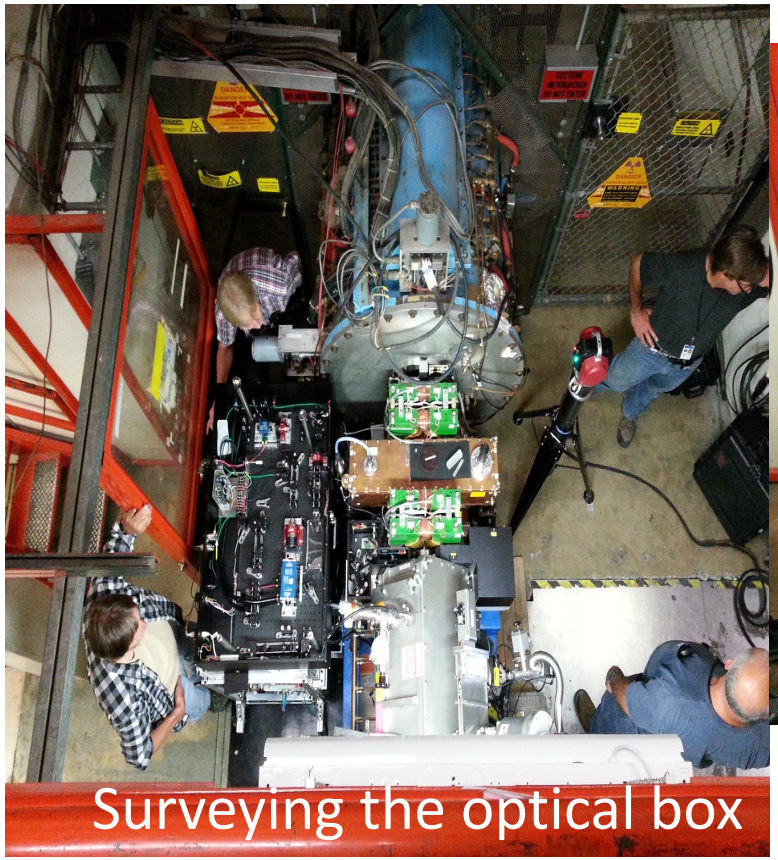
Arbitrary Waveform Generation



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July 2016 Commissioning Period (2weeks)

July Commissioning - Installation

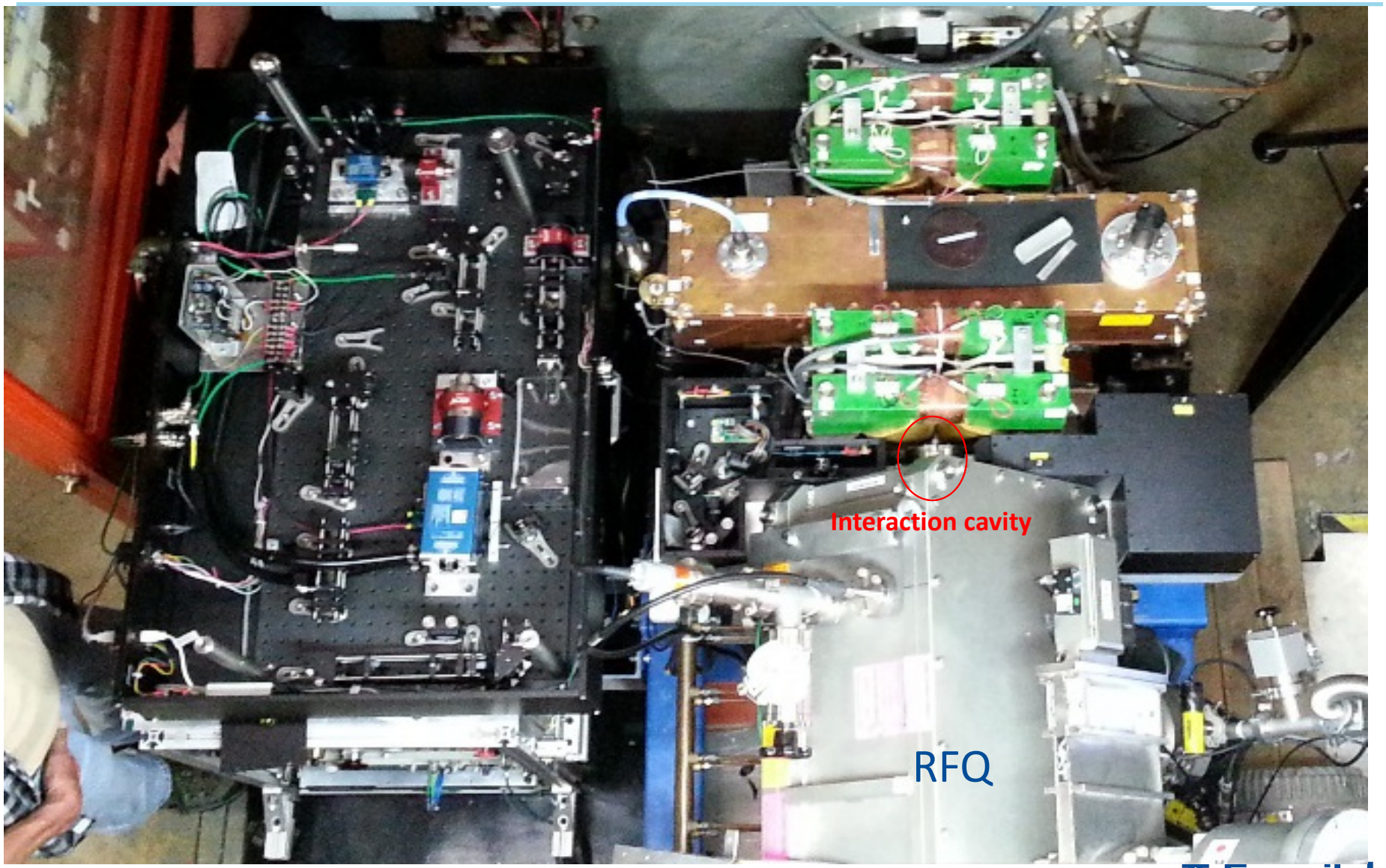

Surveying the optical box


Electronics rack

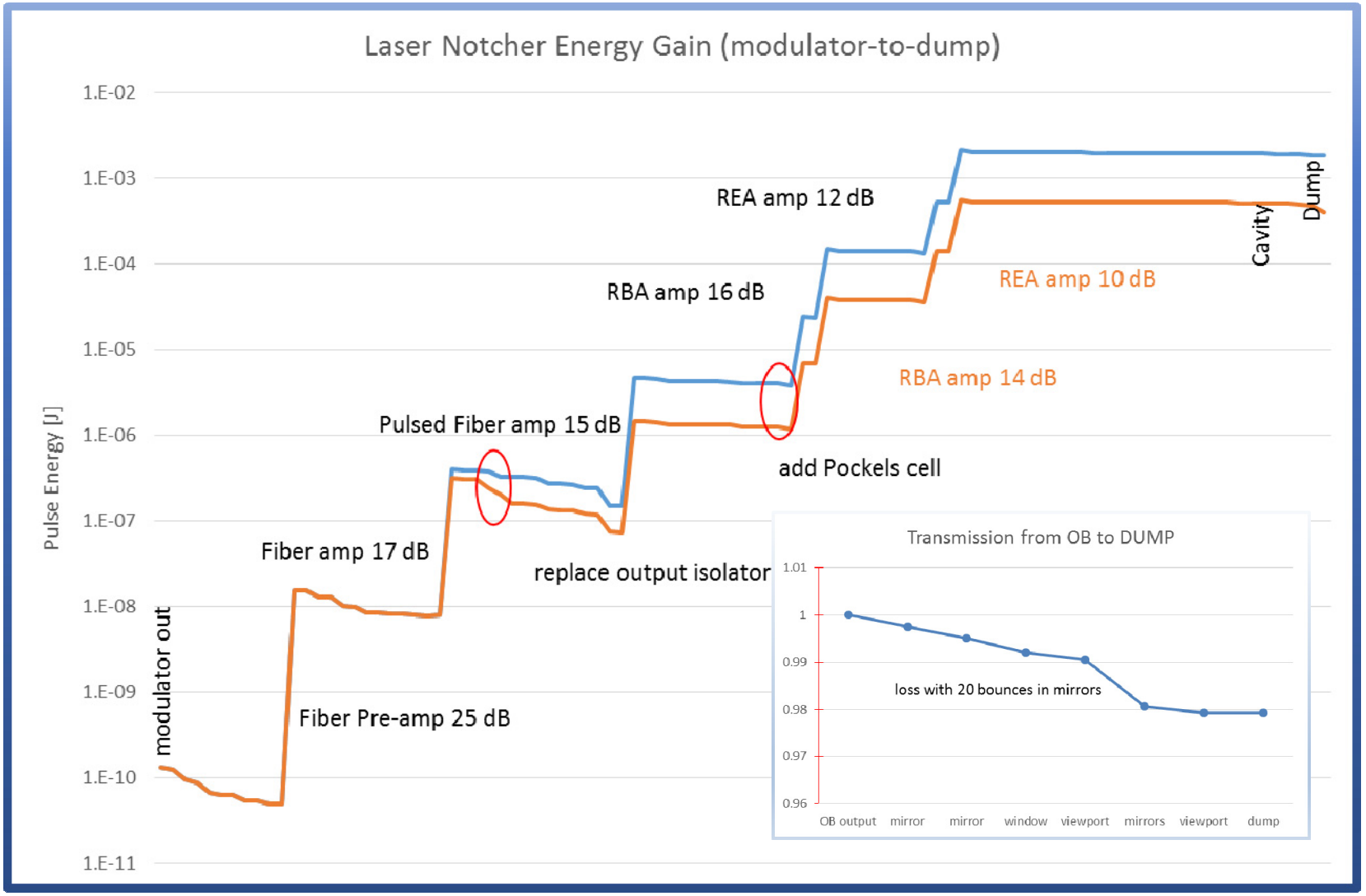

Pulsed fiber amplifier

- Tight quarters
- Light tight optical enclosures

July Commissioning - Installation

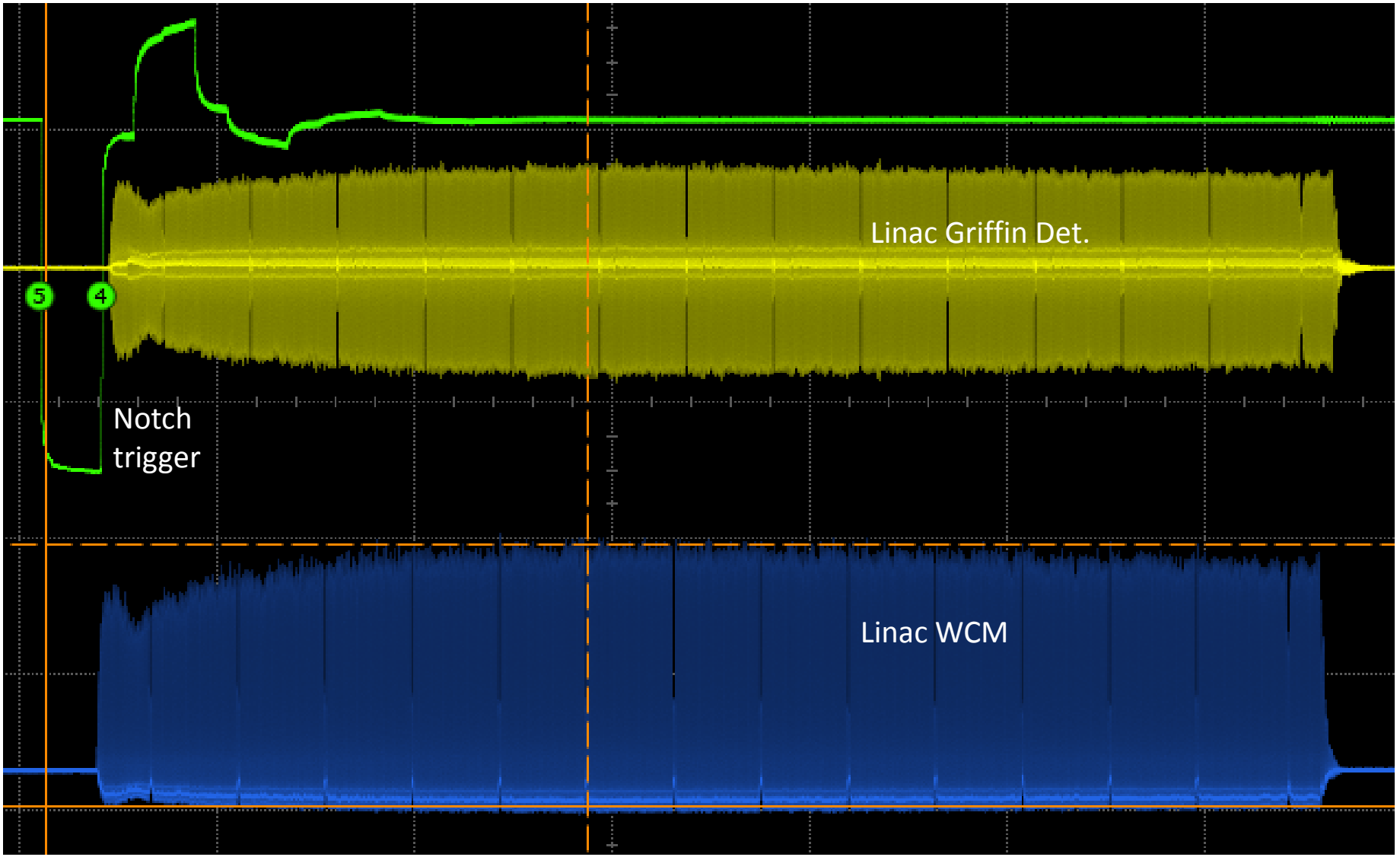


Pulse Energy Evolution through Laser Notcher System

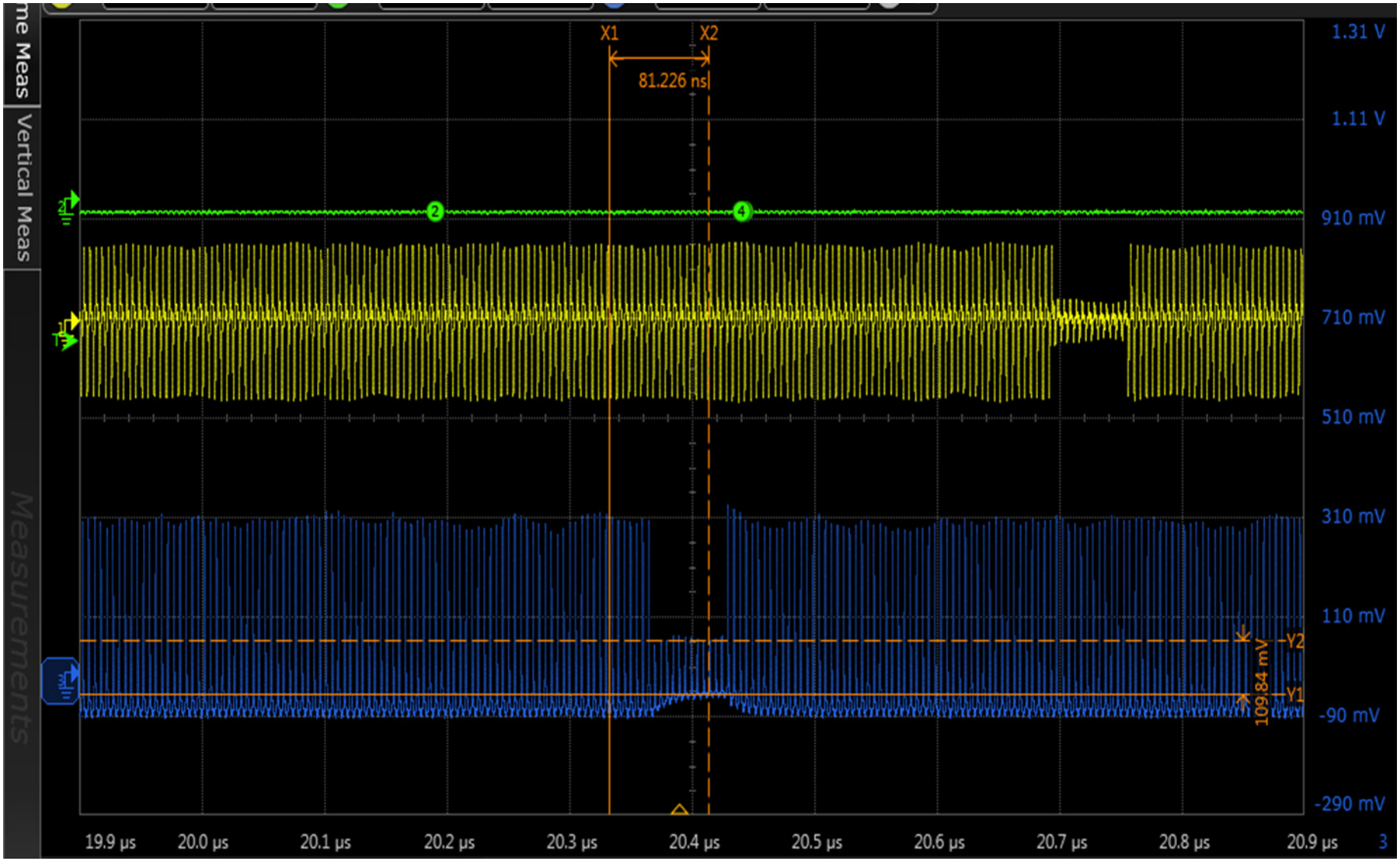


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First Observation of Multiple Notches in Linac Pulse



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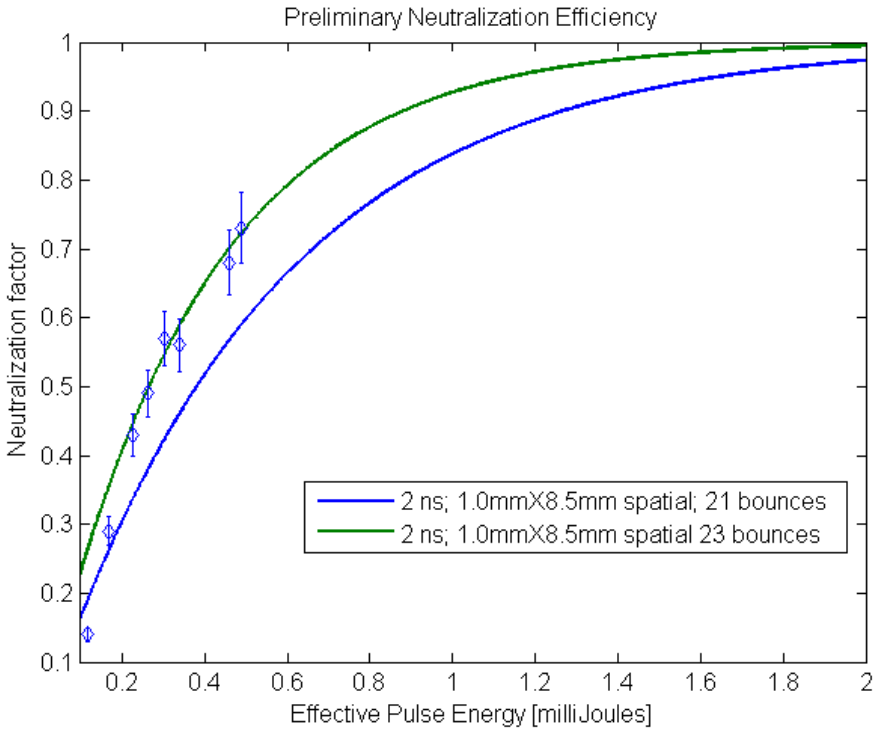


Preliminary Neutralization Efficiency

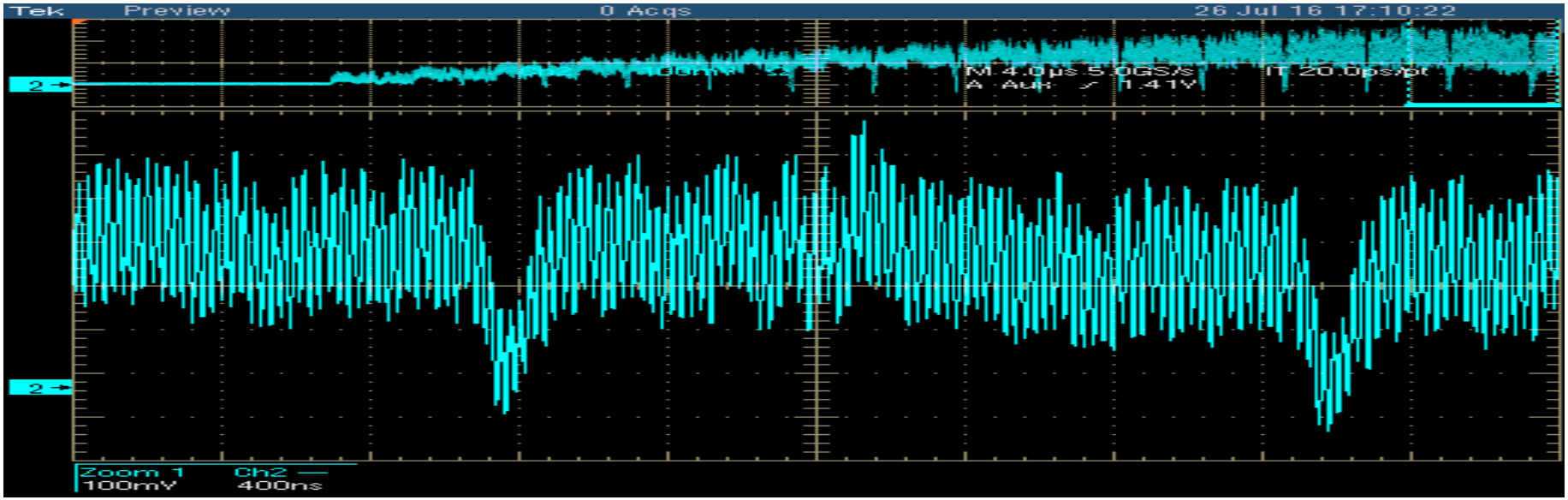
Vary laser pulse energy
Compare with estimation

Total Energy [mJ]	Energy in Notch Pulse [mJ]	200MHz pulse energy [mJ]	Measured Neutralization
47	18.471	0.118	0.14
66	25.938	0.166	0.29
90	35.37	0.227	0.43
104	40.872	0.262	0.49
120	47.16	0.302	0.57
135	53.055	0.340	0.56
184	72.312	0.464	0.68
198	77.814	0.499	0.73

Design goal is 2 mJ/pulse



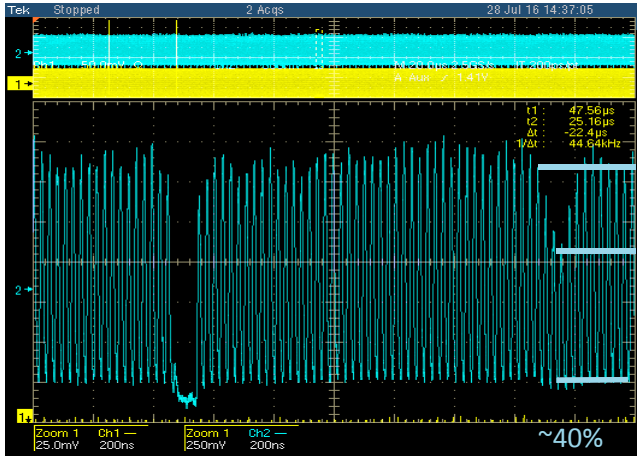
Notches Observed in Booster



a) Upper: Booster phase detector during injection showing notch formation from linac

b) Lower: Notch in the14th and 15th turn showing a bottom width with 38 MHz on (width at bottom ~ 60 ns)

c) Bottom Right: A few ms into cycle showing notch created in Booster (left) and notch created in linac (right)



➢ Simulations of capture details give tuning guidance to keep notch clean to a few % level

Conclusions/Take Away

- ✓ Successfully demonstrated “for the first time anywhere” the neutralization of multiple sections of H- ion bunch structure out of the RFQ.
- ✓ Although the laser system was not at design intensity (0.5 mJ/pulse) we demonstrated ~70% neutralization in the Linac pulse train.
- ✓ Although we saw survival of the notch ms after injection, it is clear that we need to address the survival of the notch in Booster when we turn back on (simulations encouraging)

and

- ✓ This technique may be used for bunch-by-bunch manipulations of H- ions for other applications…

Thank you for your attention