Status of the JLab ERL

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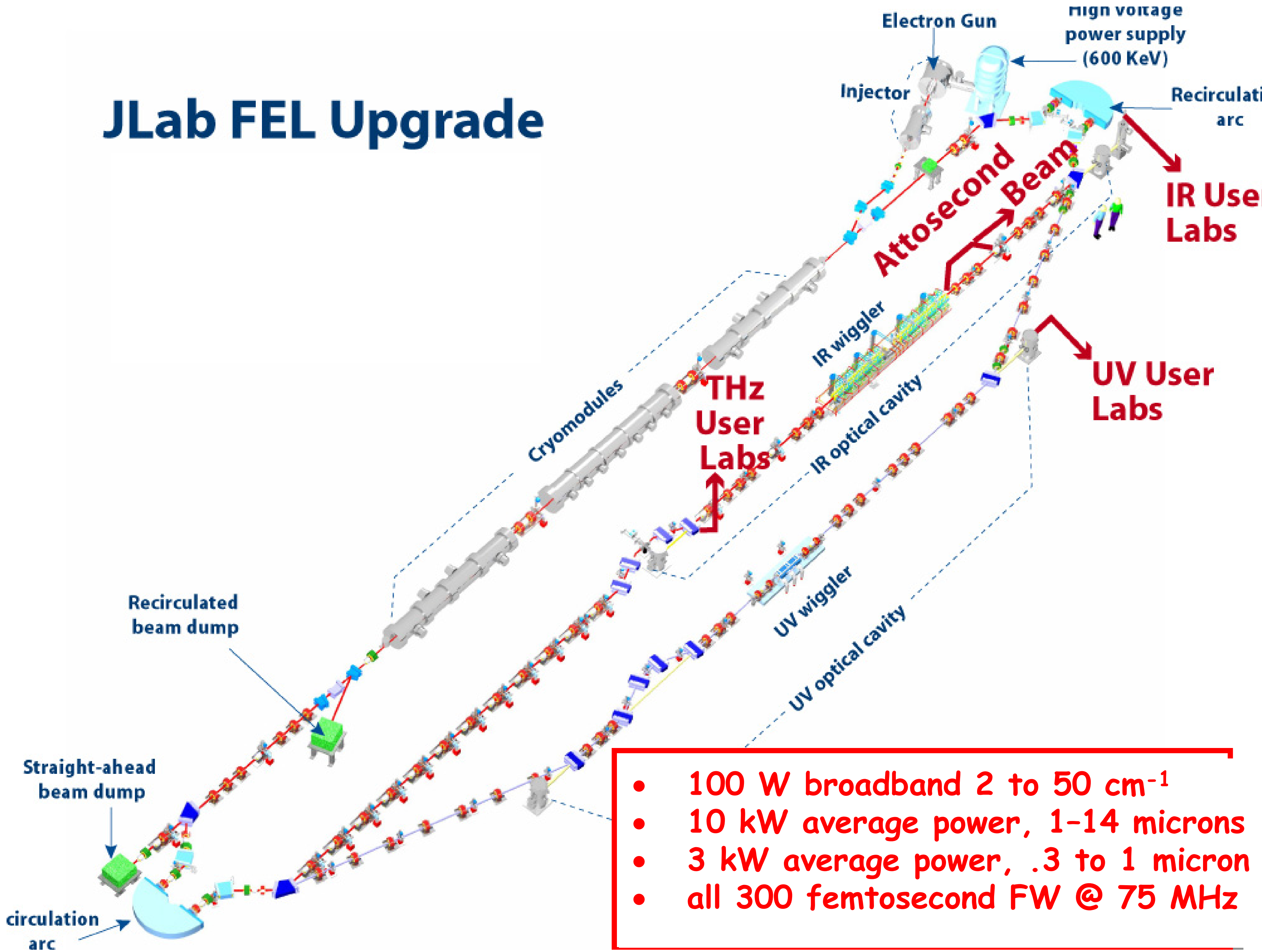
Jefferson Lab
Newport News, Virginia

ICFA FLS Workshop
Hamburg
May 16, 2006

JLab FEL Upgrade

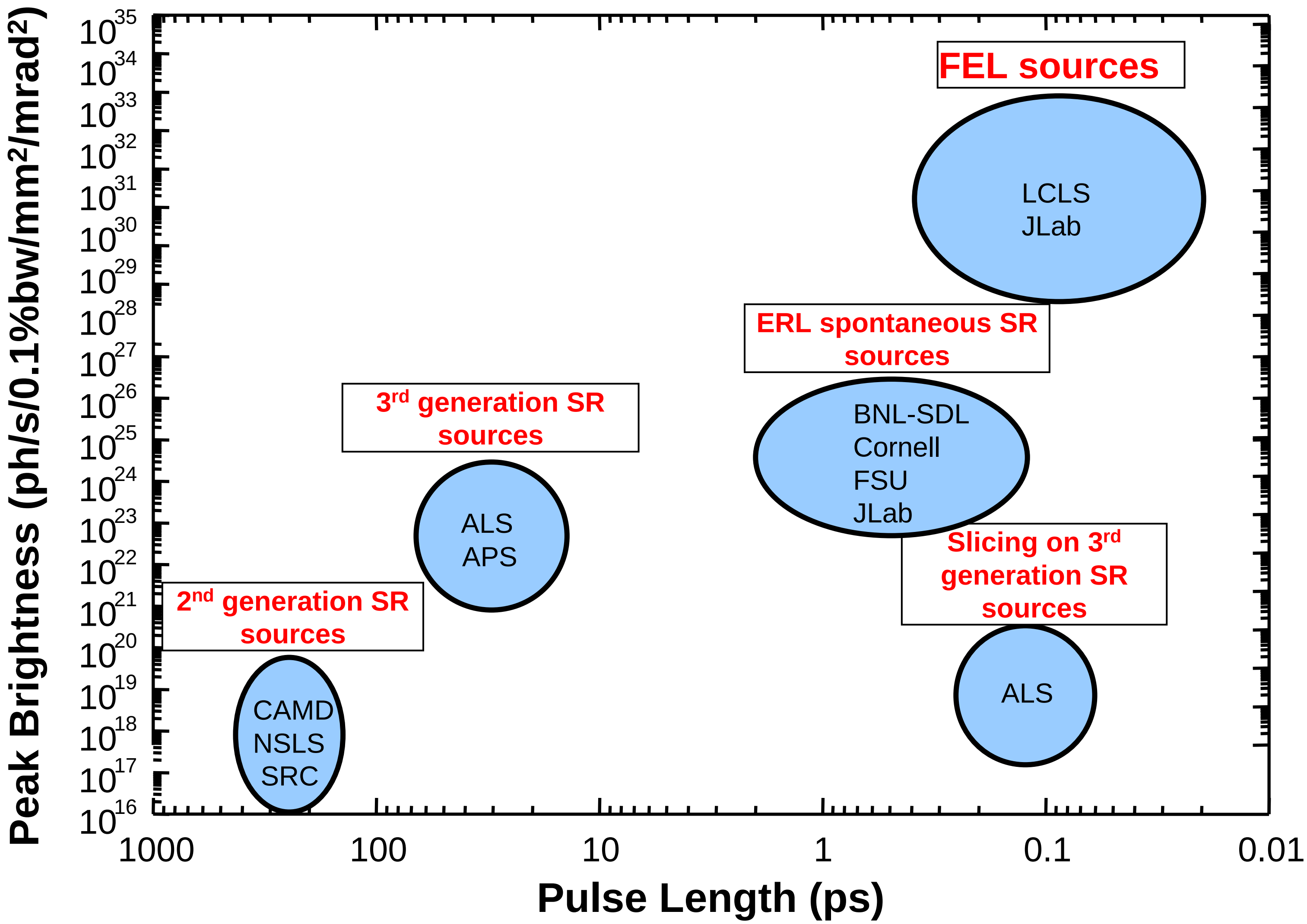


- 100 W broadband 2 to 50 cm^{-1}
- 10 kW average power, 1–14 microns
- 3 kW average power, .3 to 1 micron
- all 300 femtosecond FW @ 75 MHz

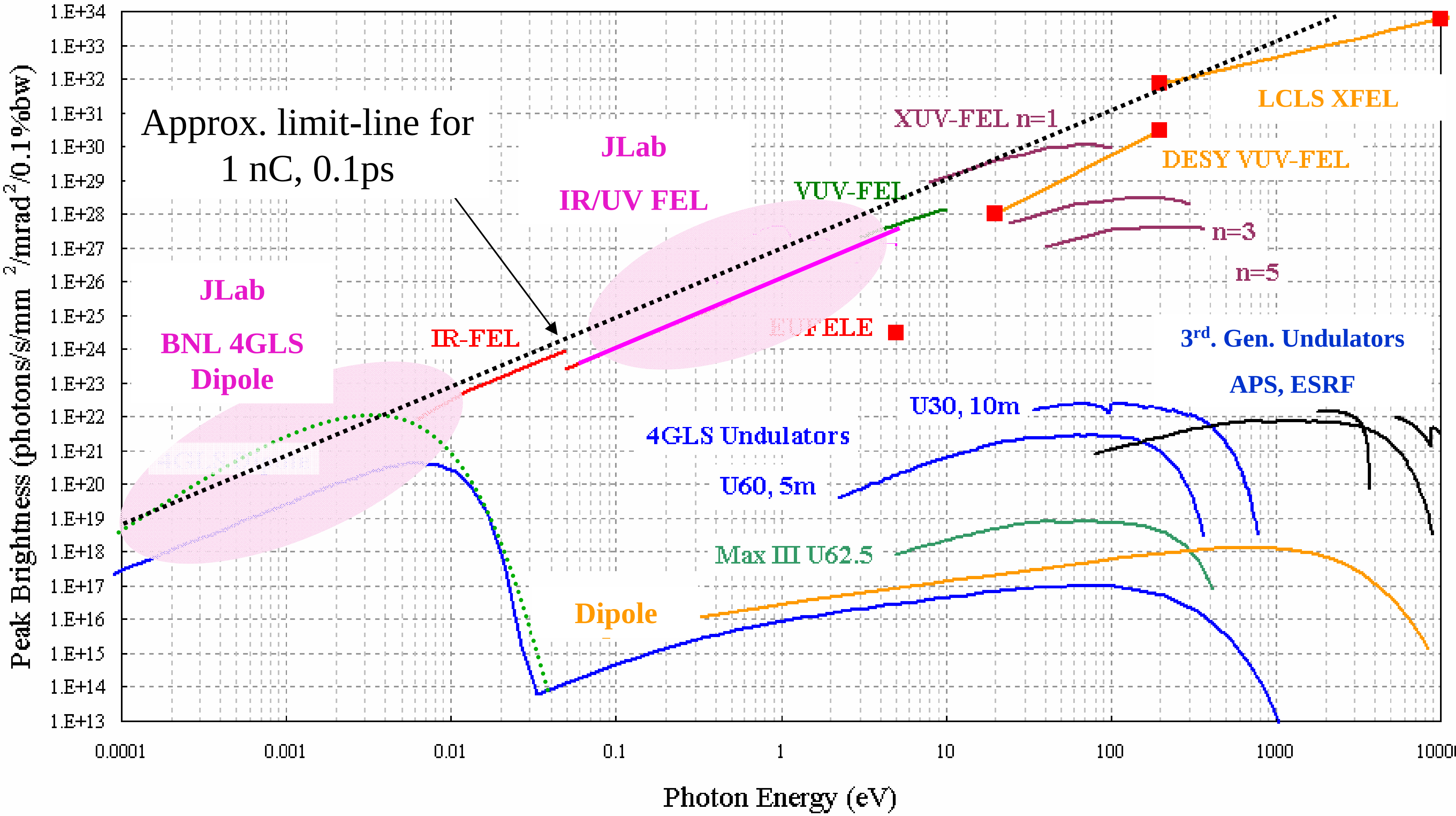
IR Upgrade Specifications

• Average Power	> 10,000 W
• Wavelength range	1 to 14 μm
• Micropulse energy	> 100 μJ, in pulse train 50 μs to CW, arbitrary
• Micropulse length	~0.1-2 ps FWHM (adjustable)
• PRF	74.85 MHz ÷ 2x down to 4.68 MHz
• Bandwidth	~ 0.2–3 % (always Fourier transform limited!)
• Position/Angle jitter	< 100 um, 10 μrad
• Polarization	linear, > 1000:1
• Transverse mode	< 2x diffraction limit. Gaussian profile
• Beam dia. at lab	2 - 6 cm, wavelength dependent

Light Source Landscape



Light Source Landscape



All data is approximate for illustrative purposes

Wendy Flavell Manchester University UK

JLab ERL Status

- IR Upgrade FEL running up to 10 kW
  - 10 kW average power lasing achieved at 6 microns
  - Lased 2 to 7 kilowatts at 1.0, 1.6, 2.8 microns with narrowband mirrors
  - Lased at 20-100 W from 0.7 to 4.8 microns, tuning over the full band in seconds using hole outcoupler
  - User experiments have begun: nanotubes, fat cell necrosis
- THz system installed and has begun user experiments
  - Power, spectrum, and noise being characterized
- UV installation deferred due to loss of funding in FY06
- UV FEL project hardware is in-hand and 90% complete
  - Attempting to re-establish program support for FY07

What have we learned in the last six months?

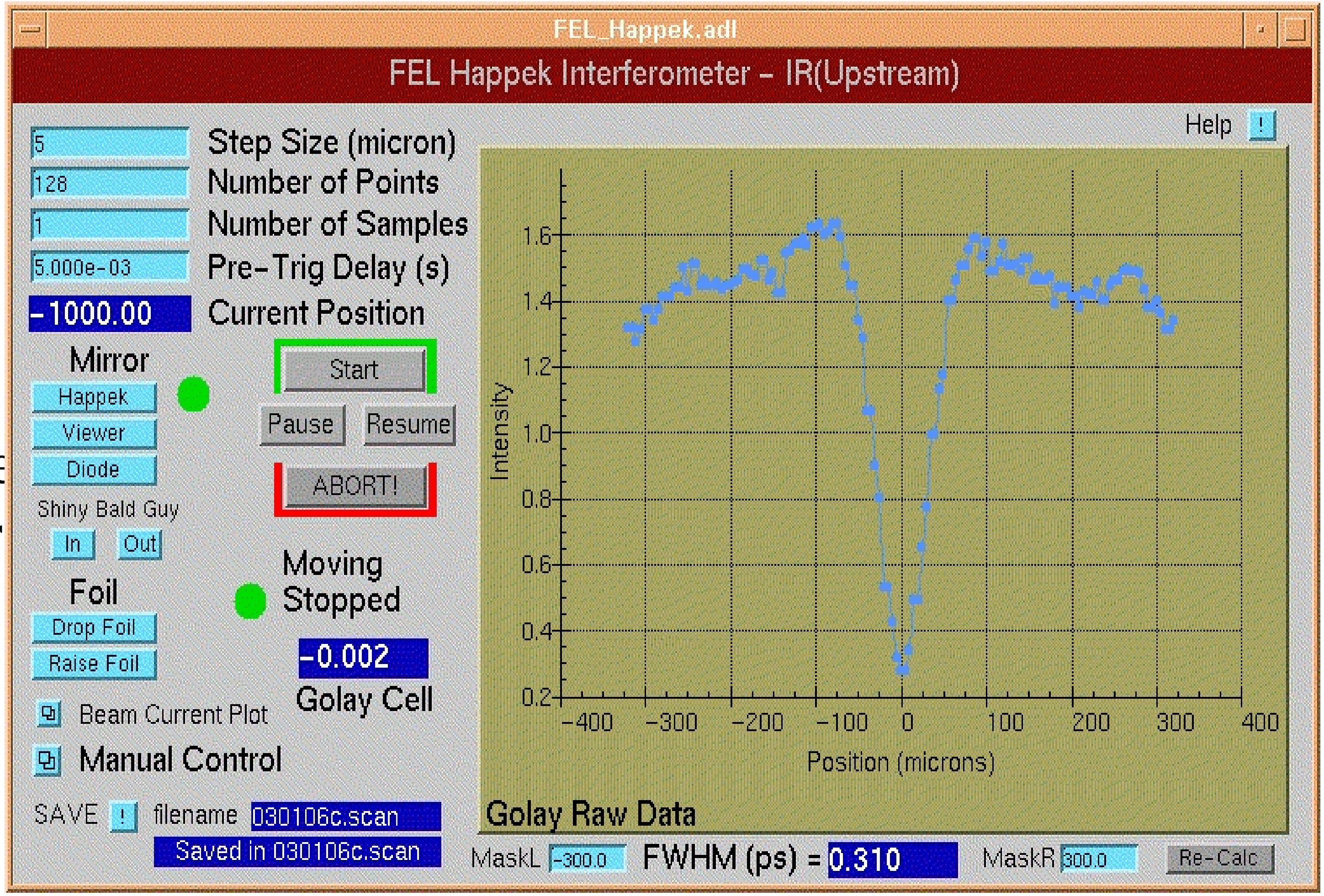
Accelerator

- **Stable, reproducible operation at 115 MeV**
- **Very short pulses at the wiggler (<350 fsec FWHM) that are maintained at currents > 5 mA CW for hours**
- **Excellent beam quality**
  - **Transverse core beam emittances in x and y ~6-8 mm-mrad but halo emittances 3-5x larger with significant envelope mismatch**
  - **Longitudinal emittance typically ~90 kV-psec**
    - **dp/p~0.5% at 115 MeV/c, σ_t~0.15 psec at wiggler**
- **Strong laser performance**
  - **Extraction efficiencies >1.7%**
  - **(have observed up to 2.6kW/mA=2.25%)**
- **Stable, robust, trouble free, long-lived gun operation**

Linac produces stable ultrashort pulses

We now regularly achieve 300 fs FWHM electron pulses

Optical pulses are of the same order at zero desynchronism when measured by FROG

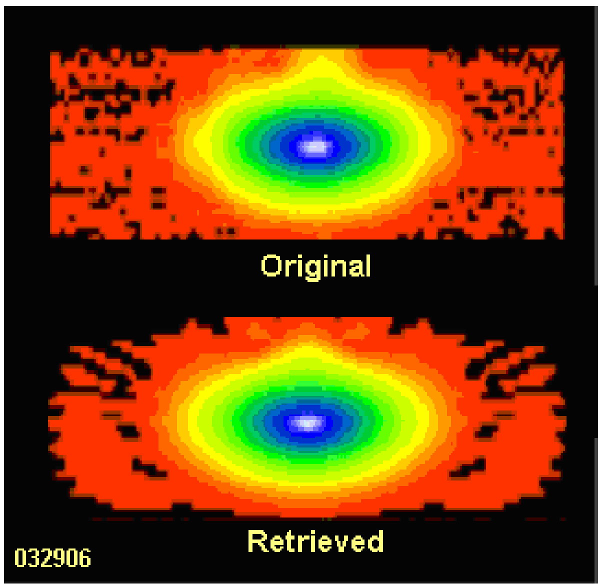


FROG Analysis of JLAB FEL Pulses

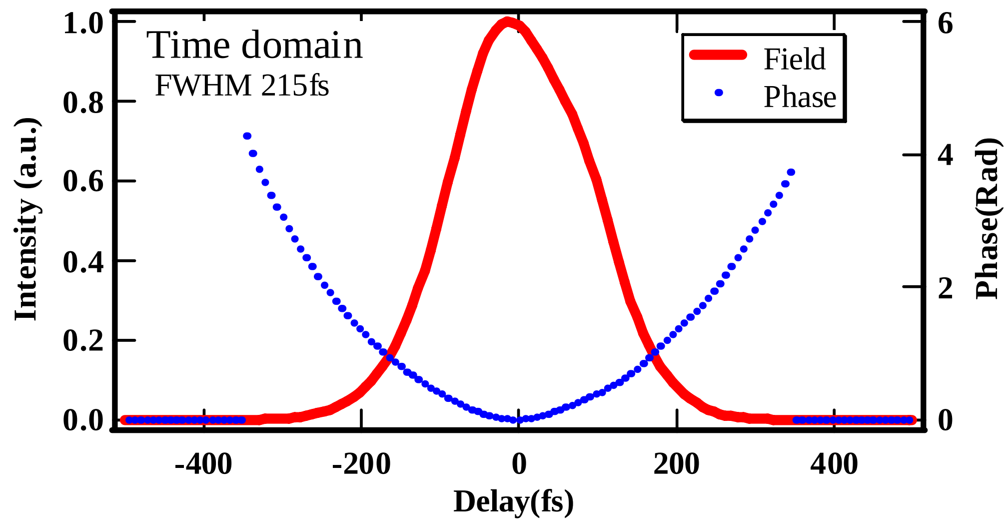
Courtesy S. Zhang

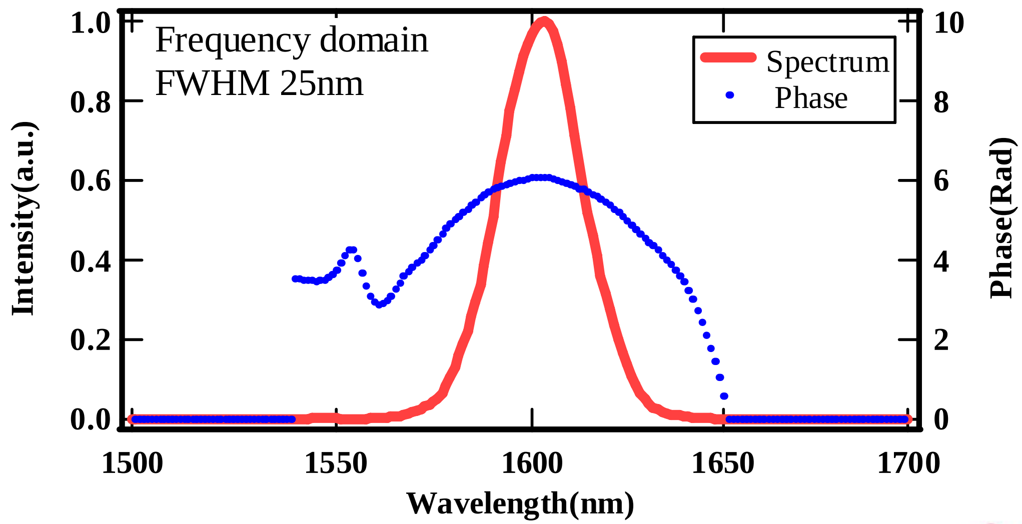
- Laser: CW 1KW in 9MHz
- Wavelength:1.6um

SHG FROG Traces



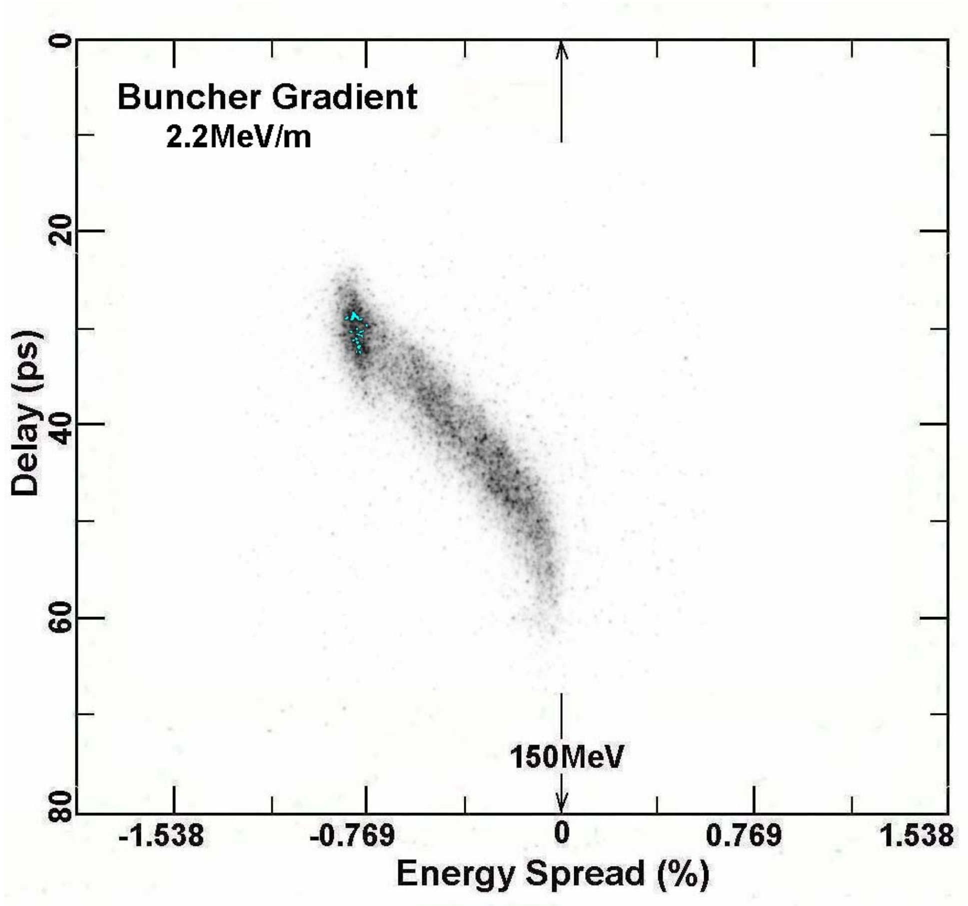
FROG error is 0.0015



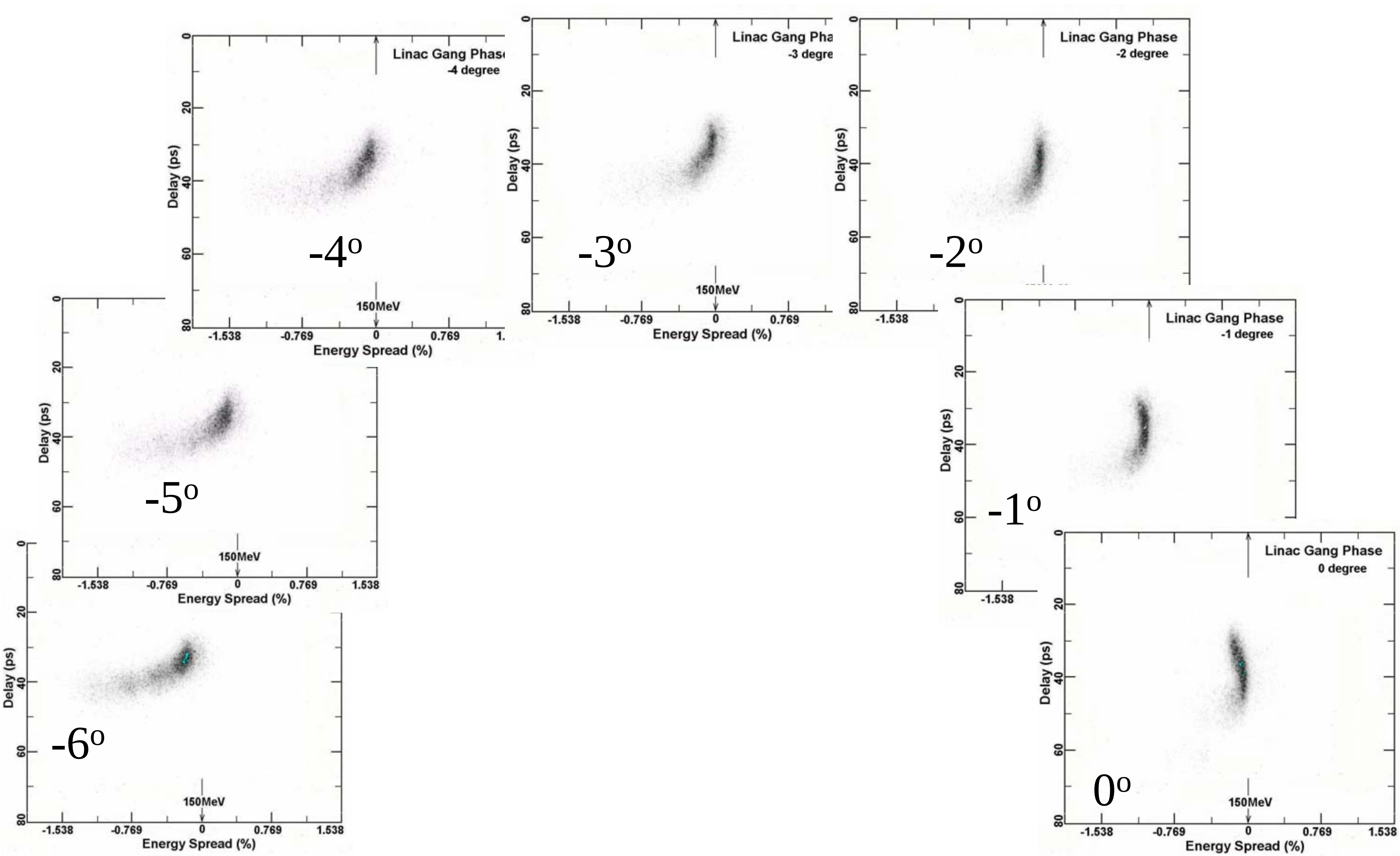


Phase space out of linac from streak camera

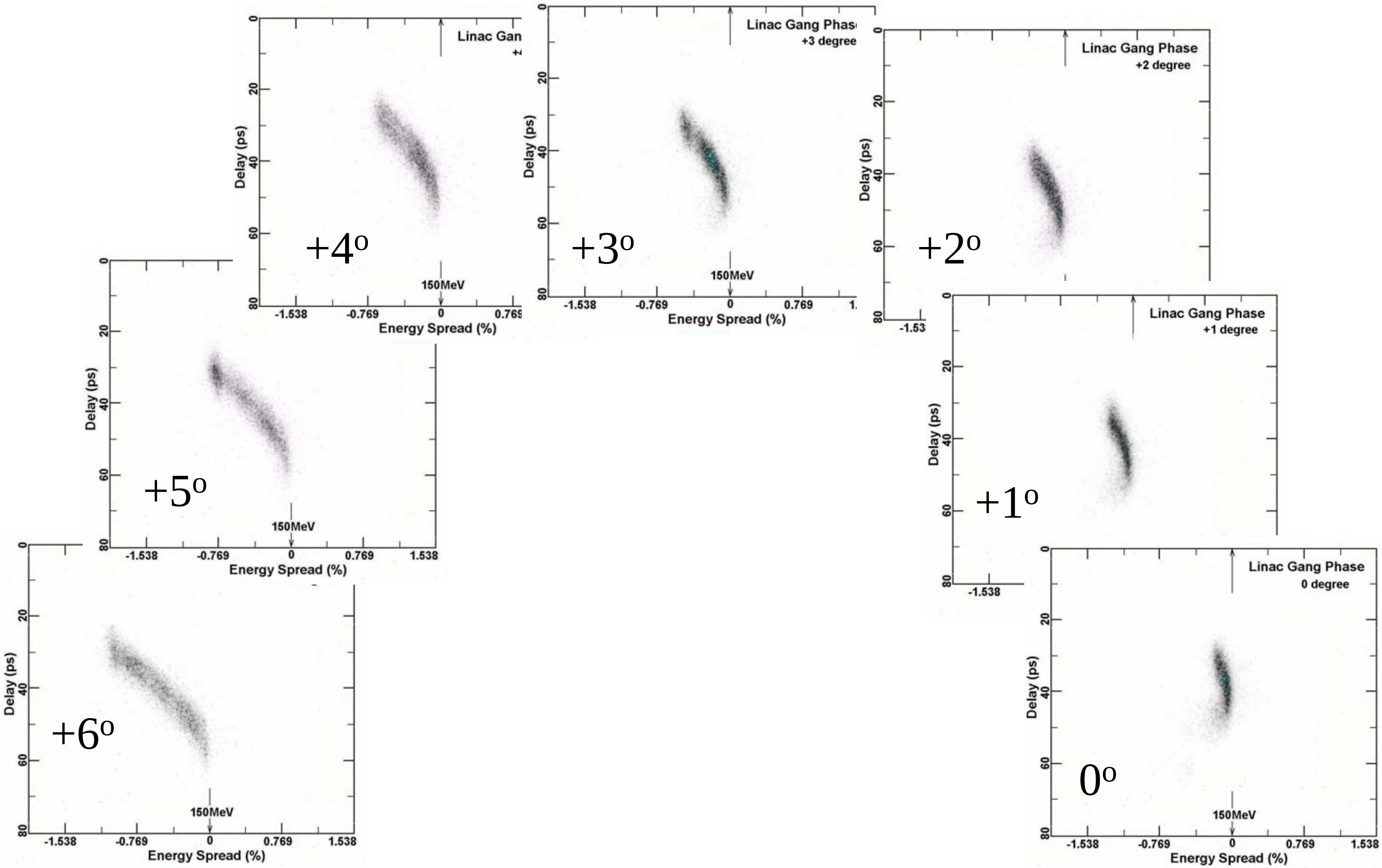
Beam Conditions:
150MeV
60Hz, 1 ms
9MHz
110pC



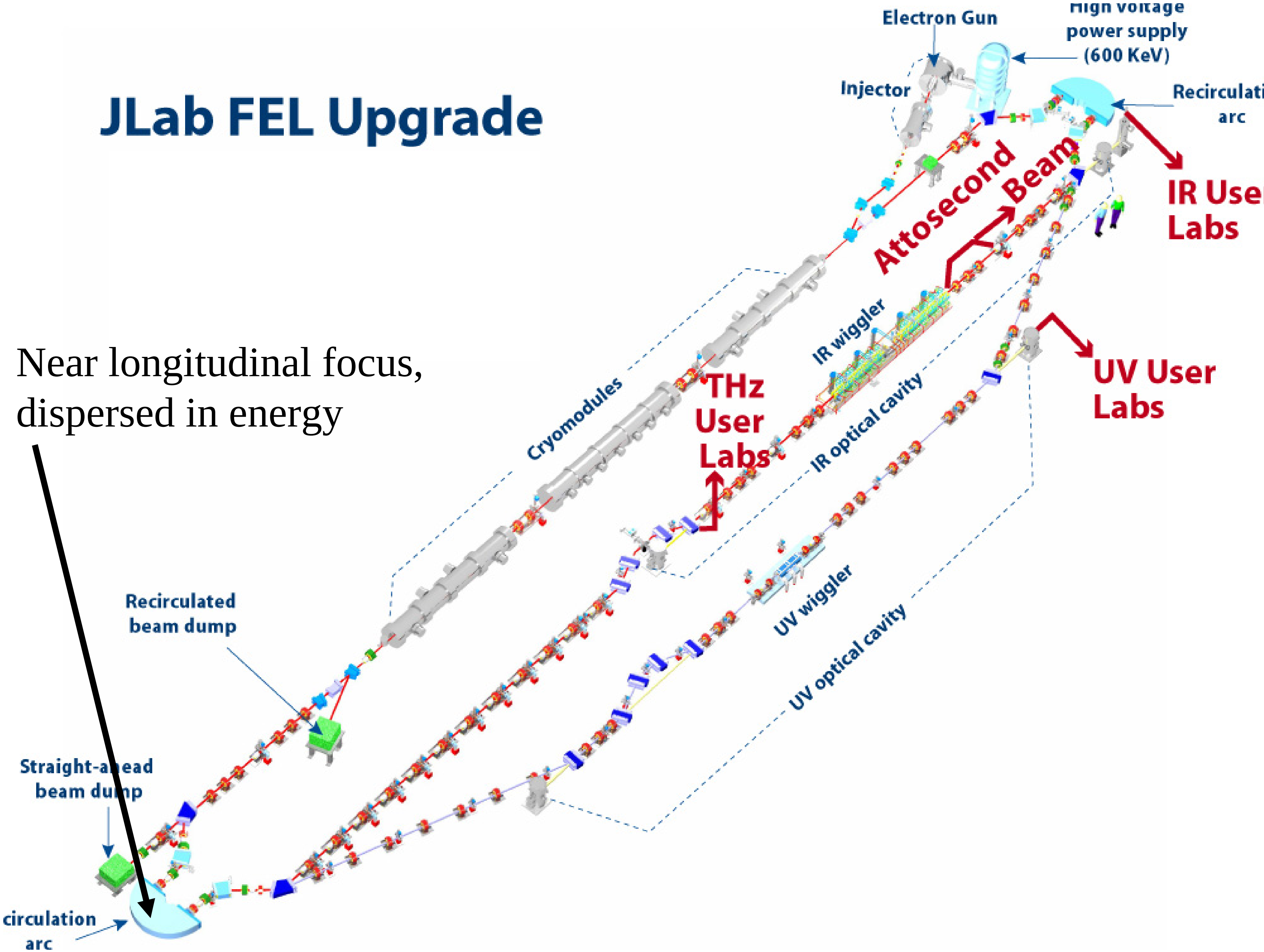
Phase variation between injector and linac



Phase variation between injector and linac



Near longitudinal focus, dispersed in energy



What have we learned? (cont.)

Wigglers

- Have now demonstrated efficiency of over 1.7% with three different wigglers.
- All three wigglers have demonstrated the ability to tune continuously over the bandwidth of the mirrors while lasing at high power.
- The gain-efficiency product of the pure wigglers is higher than for an optical klystron.
- Operating a high current beam with a small gap wiggler is more difficult than one might imagine. Losses need to be less than one part in one million for amp class ERLs. This is really hard to do. We often have losses 10 times this with a 13 mm clear aperture.

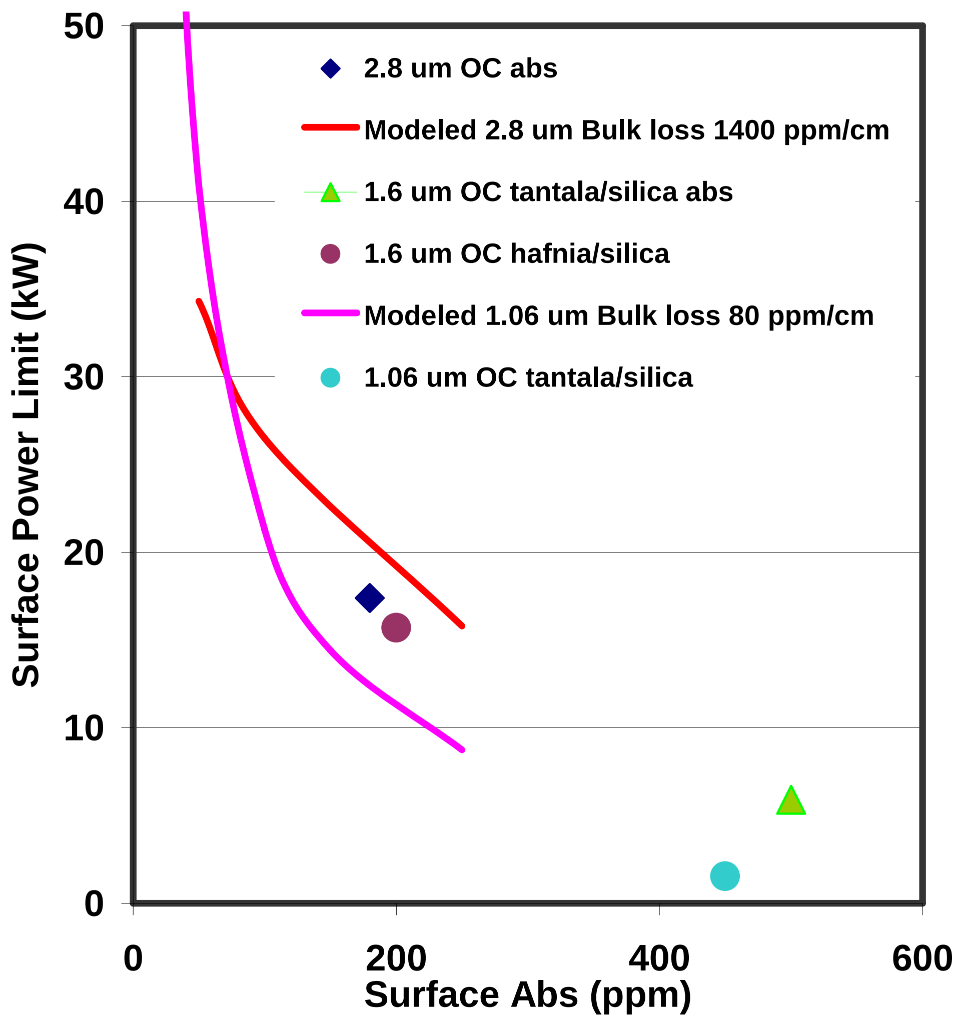
What have we learned? (cont.)

Optics

Hafnia/silica coatings have now eliminated UV induced losses previously seen in tantala/silica coatings.

Losses so low we can only say they are at or below 200 ppm

Output power limits due to mirror absorption at 20K



What have we learned? (cont.)

Optics

- Lasing can suppress BBU!
- THz loading on optics must be considered and dealt with
- High magnification oscillators are sensitive to astigmatism

- Minimization of aberration is essential. Careful engineering of mounting has now allowed us to meet spec at 1 micron and eliminated previous issues.

- Preparations underway on installation of cryogenically cooled outcoupler in FEL: helium cooling line to mirror can under construction for installation by summer. This will eliminate thermal distortion power limts

What have we learned? (cont.)

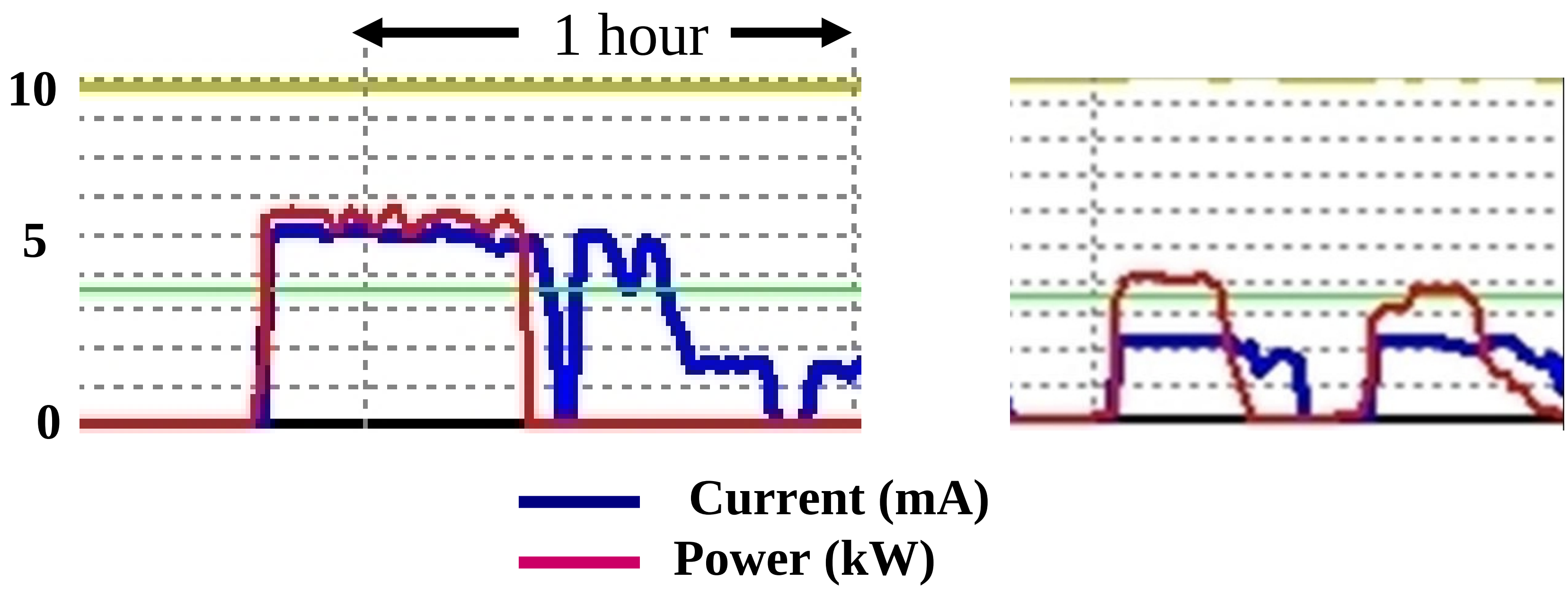
FEL Physics

- Using best estimates for electron beam and cavity parameters the calculated gain and efficiency compare well with the experimental values (for moderate Rayleigh ranges).
- At high power the FEL sometimes shows mode hopping behavior. This may be a transition to the non-Gaussian mode seen in simulations for short Rayleigh range systems.
- We continue to get shorter cavity length detuning curves than expected for the measured gain.
- The FEL is capable of harmonic lasing near the synchronous point (this is due to the behavior of the optical coating)
- We have also lased at 1 micron on the fundamental, third, and fifth harmonic of the wiggler settings

What have we learned? (cont.)

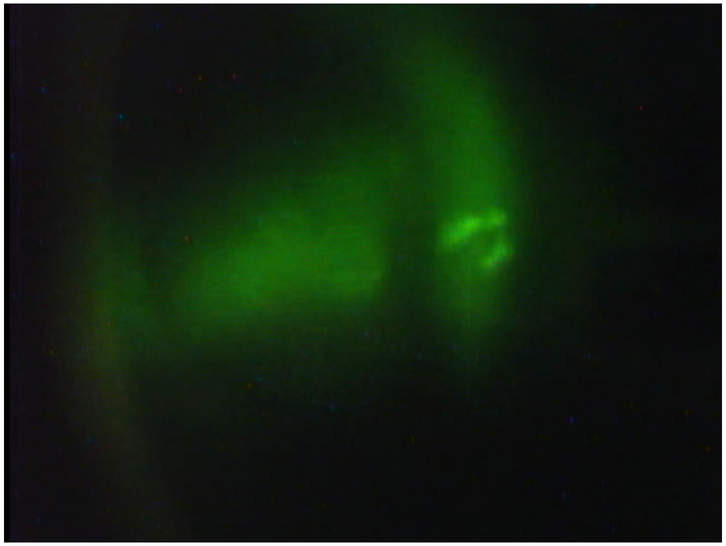
FEL Physics

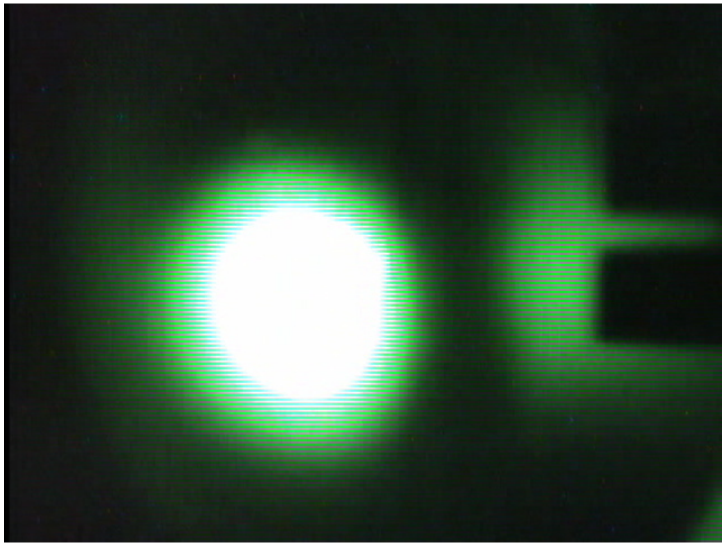
- **Power has been limited due to a roll off in efficiency at high powers. The cause of this is still under investigation**

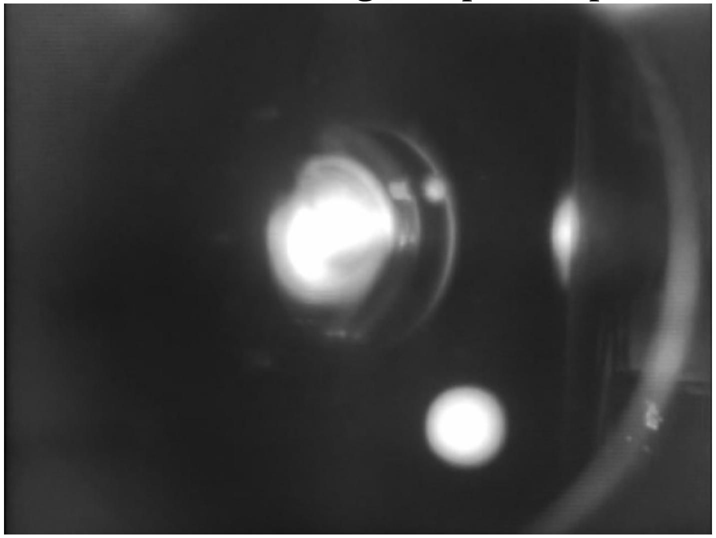


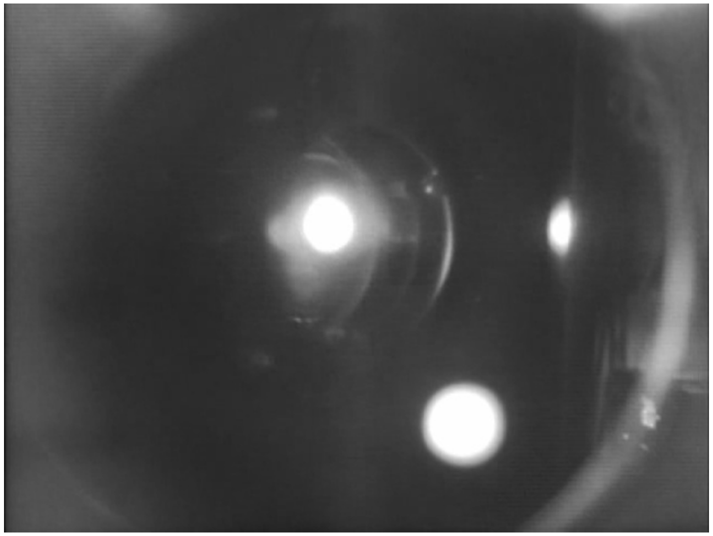
High Current: 1.1 kW/mA **Low Current: 1.7 kW/mA**

Harmonic vs. fundmental lasing

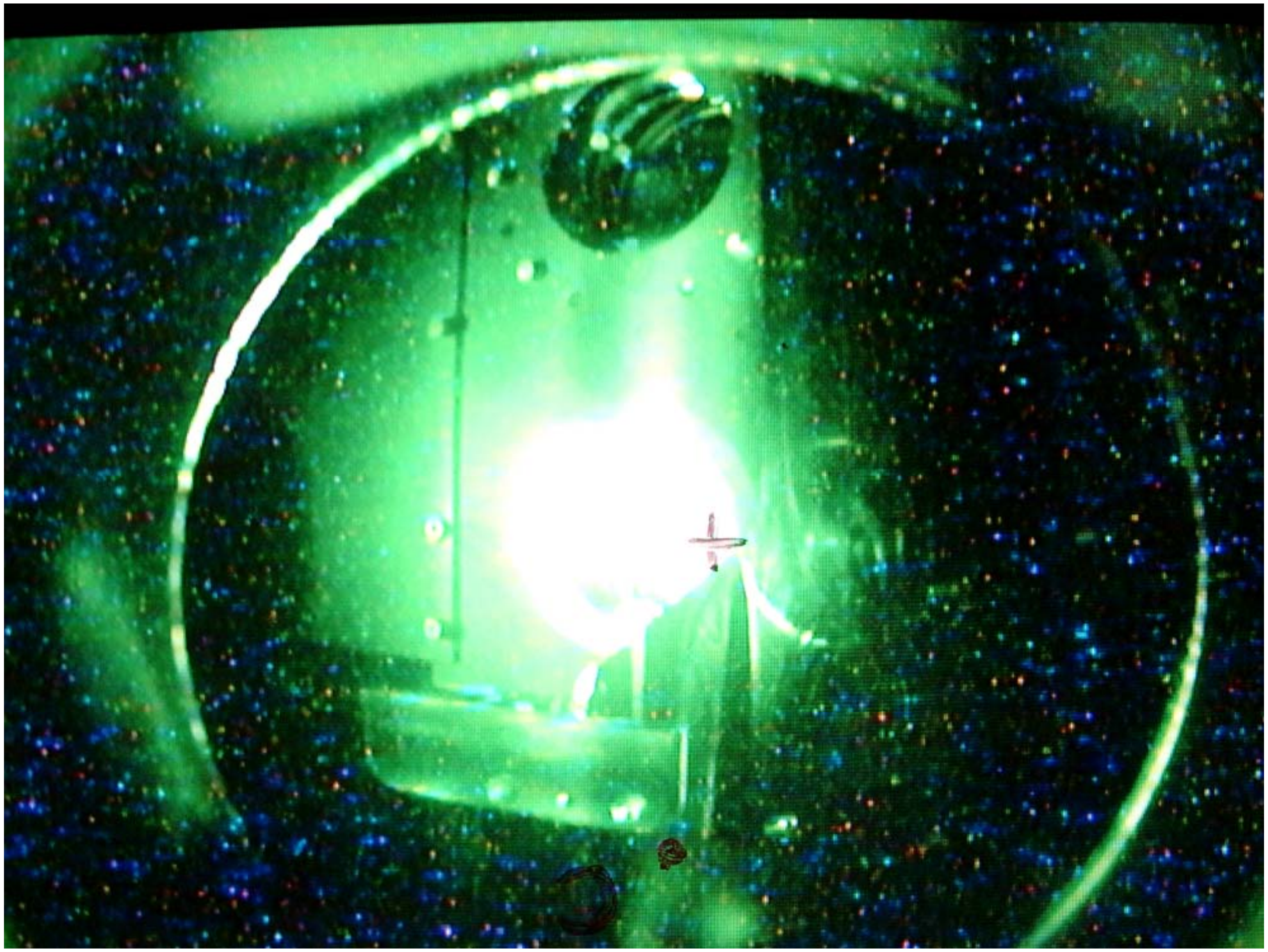

Fundamental lasing, Output coupler


Harmonic lasing, Output coupler

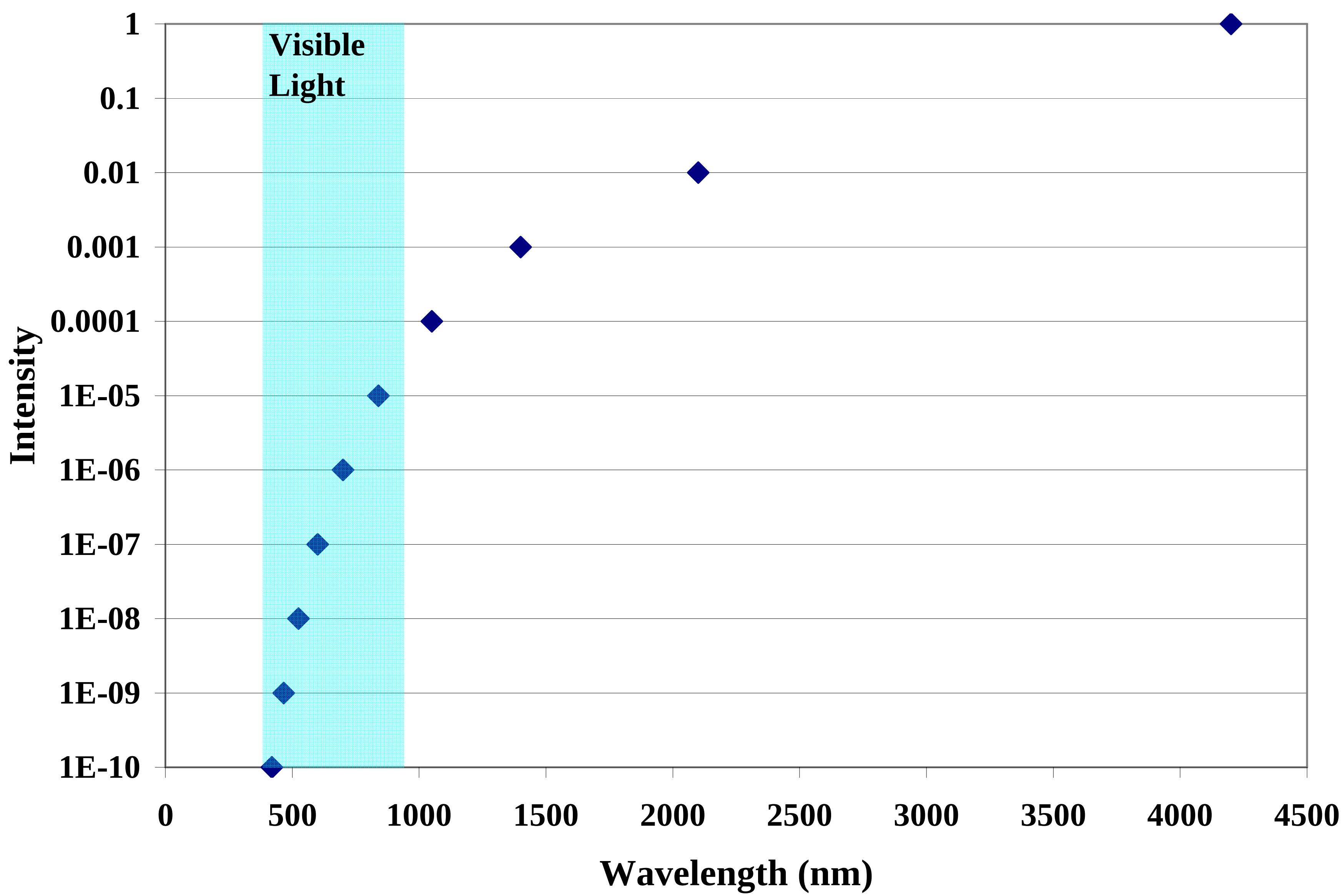

Fundamental lasing, High reflector


Harmonic lasing, High reflector

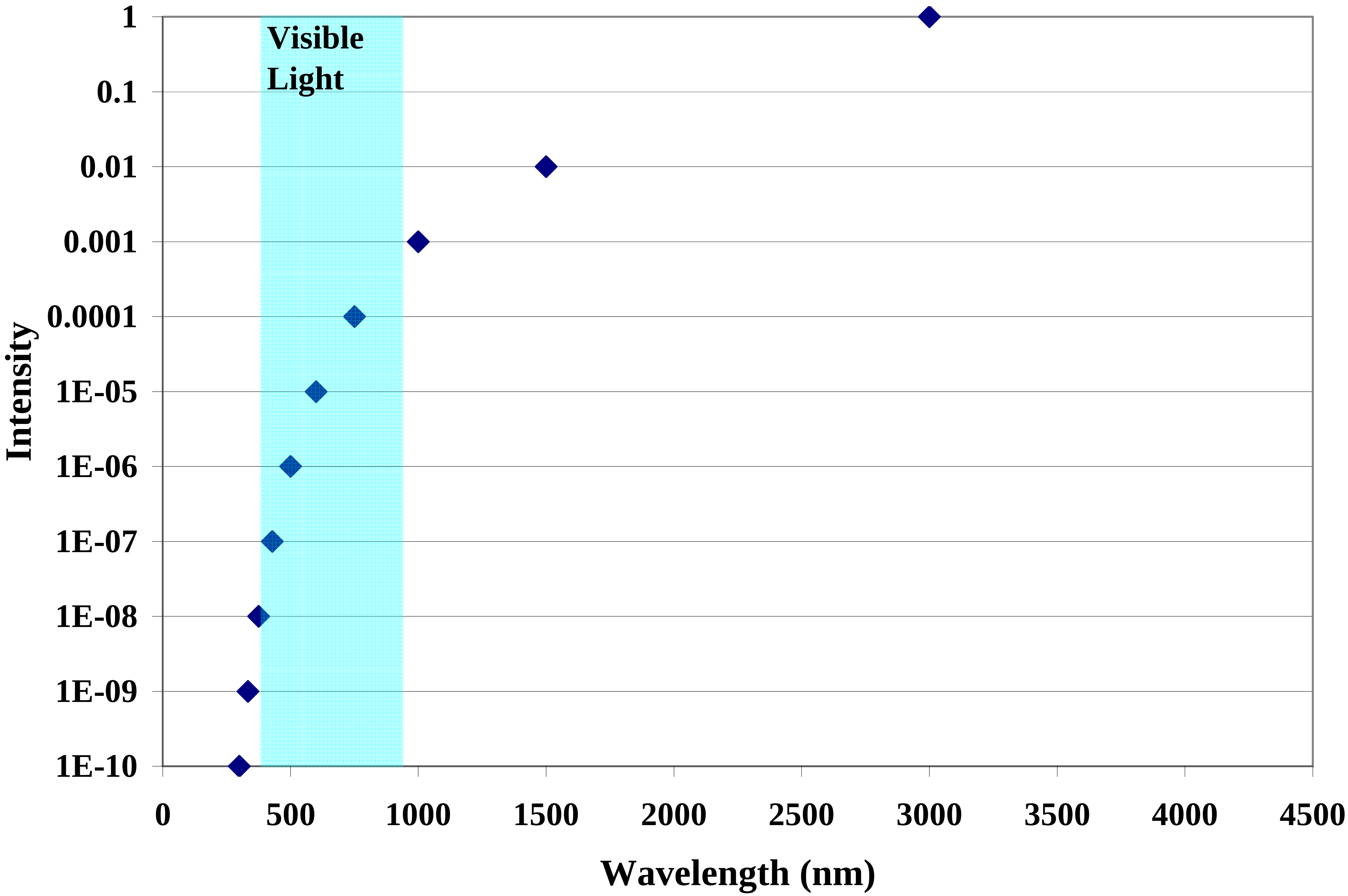
Third Harmonic Radiation (530 nm) while lasing at 1.6 microns



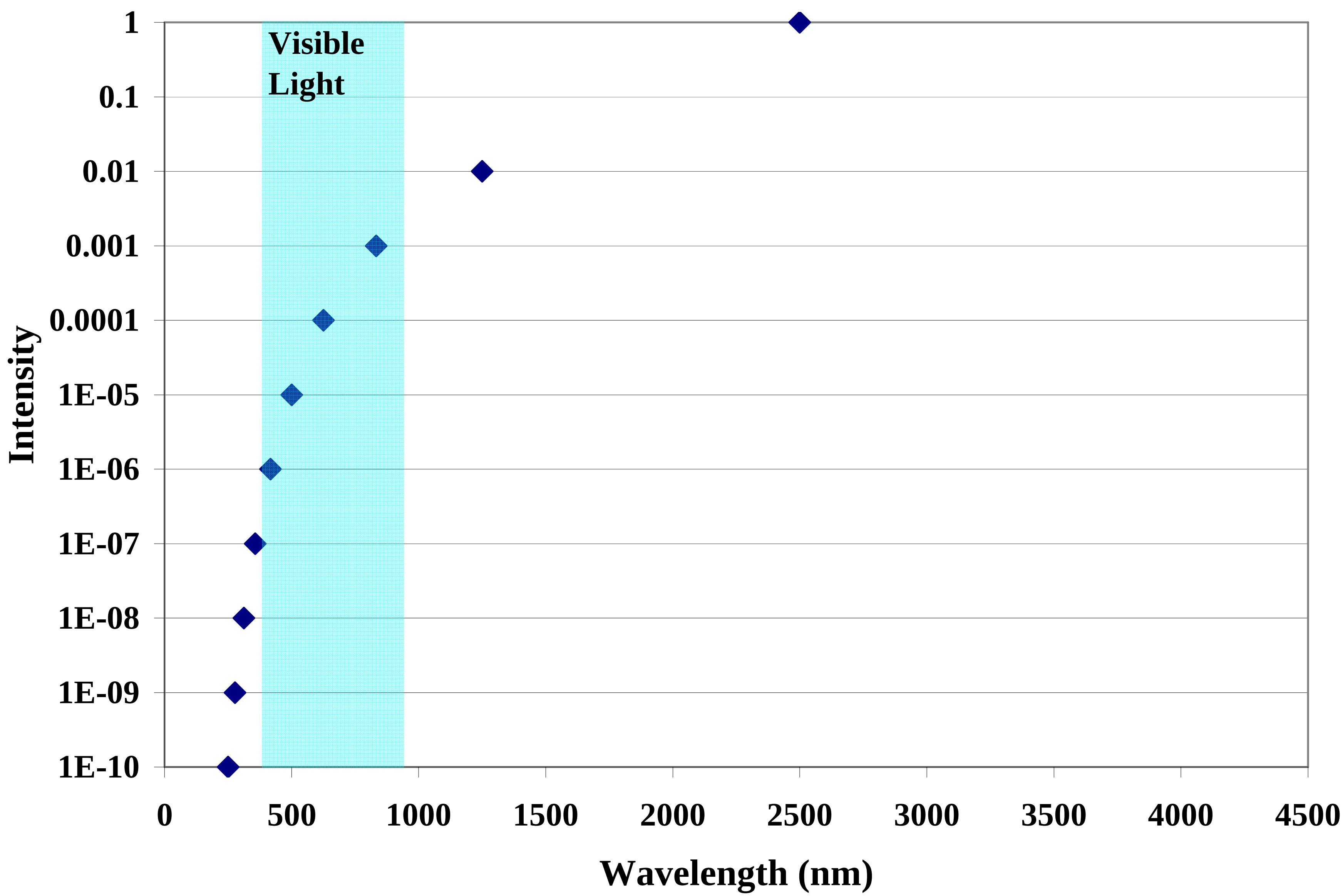
Harmonic Radiation while lasing



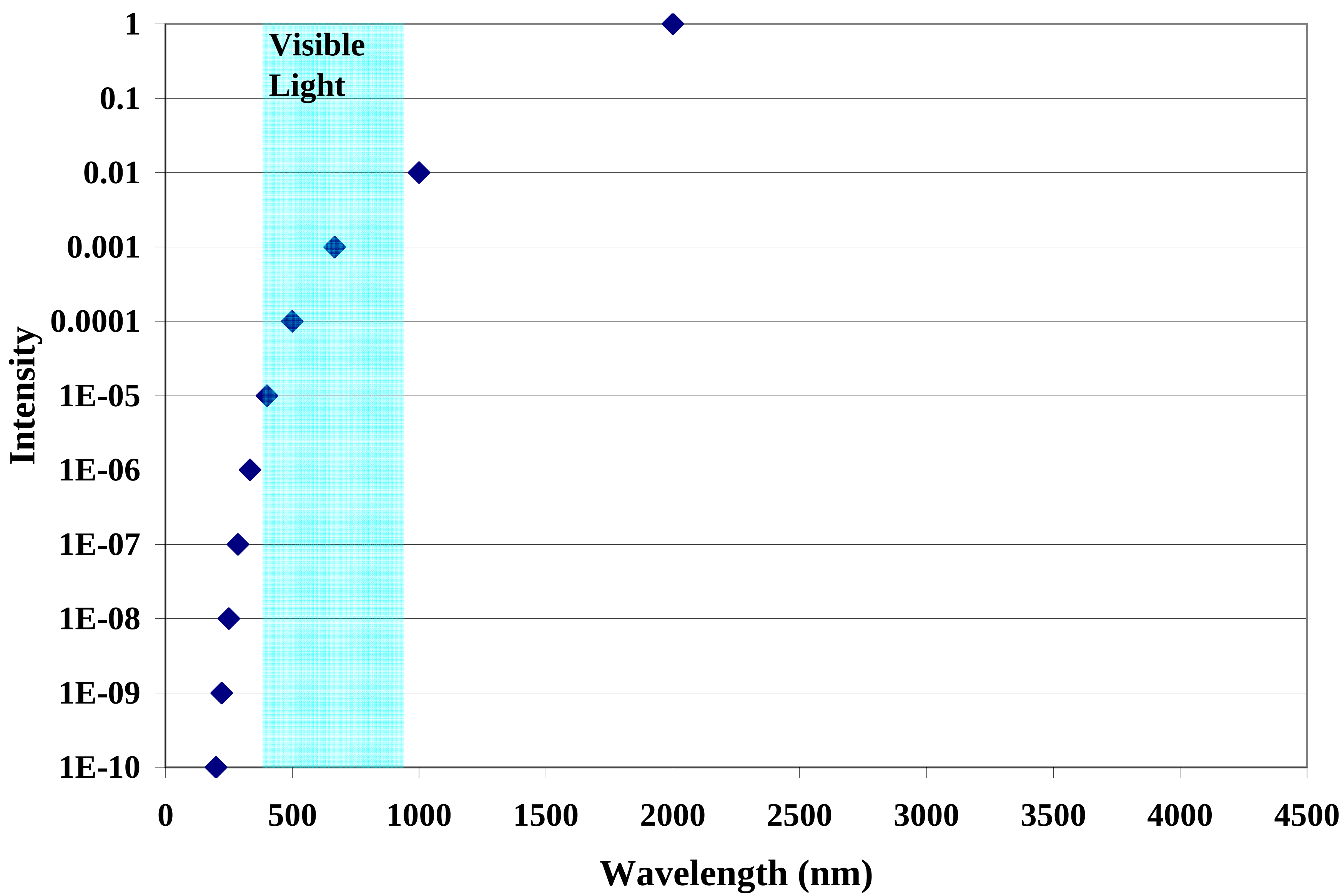
Harmonic Radiation while lasing



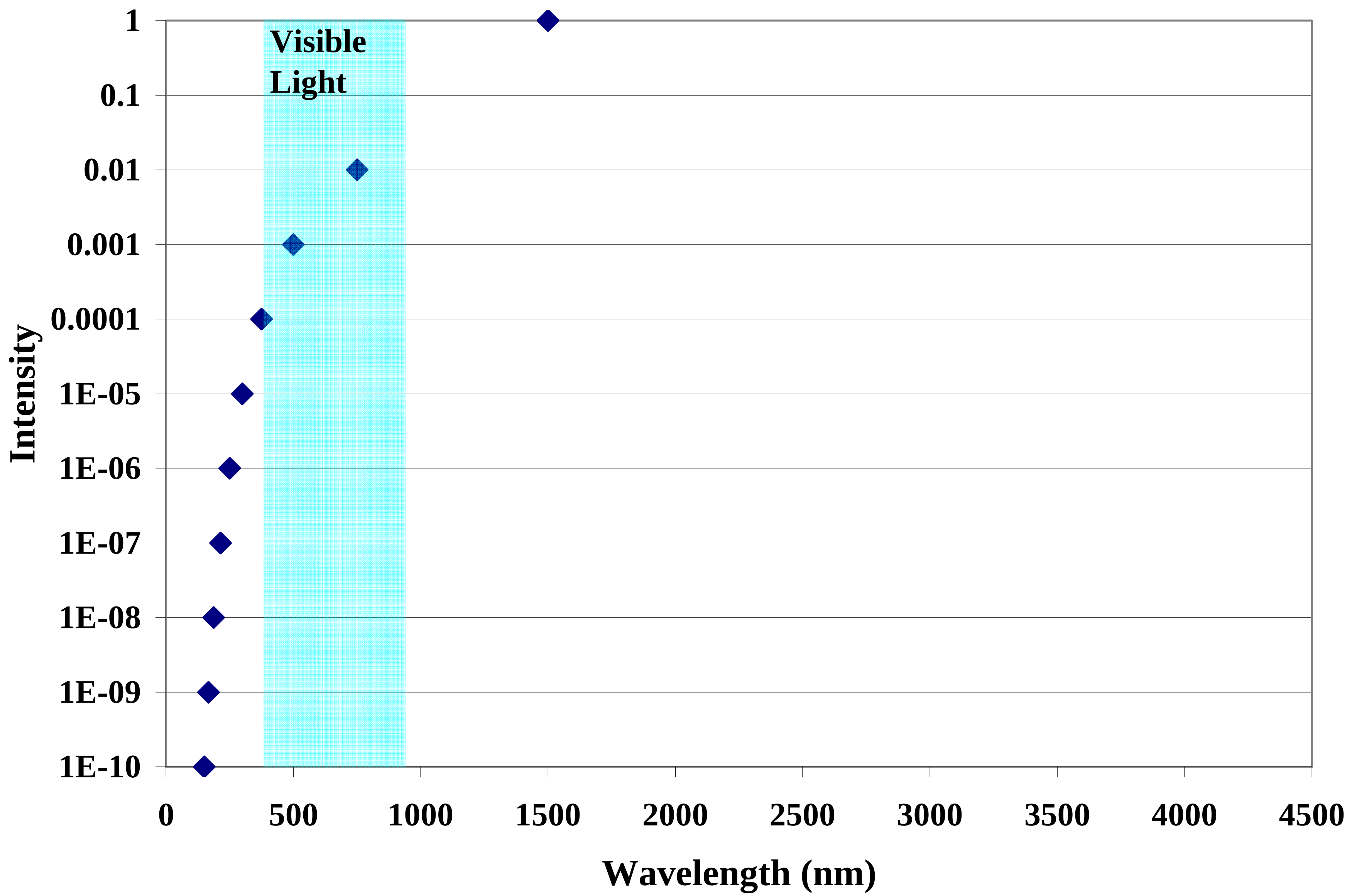
Harmonic Radiation while lasing



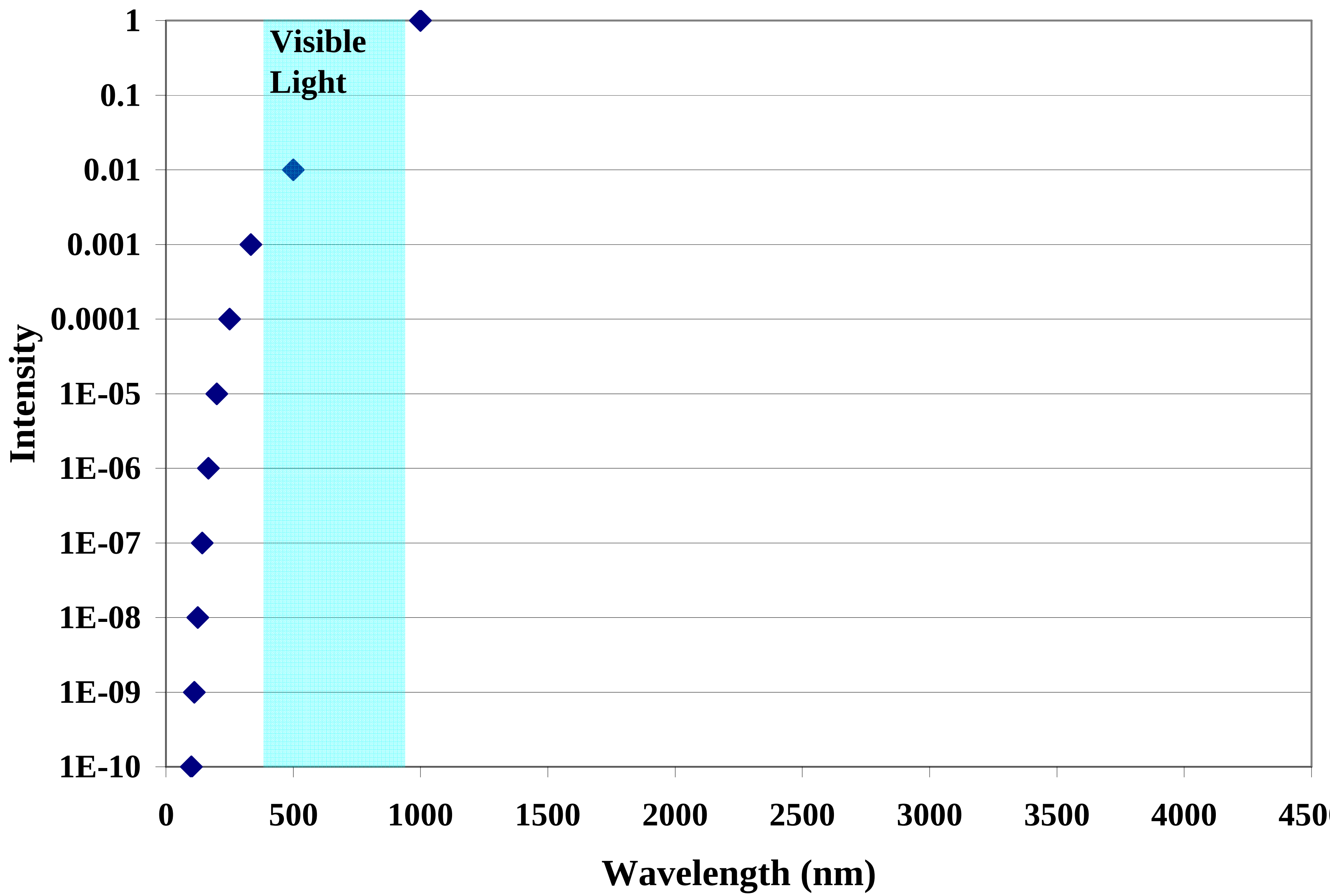
Harmonic Radiation while lasing



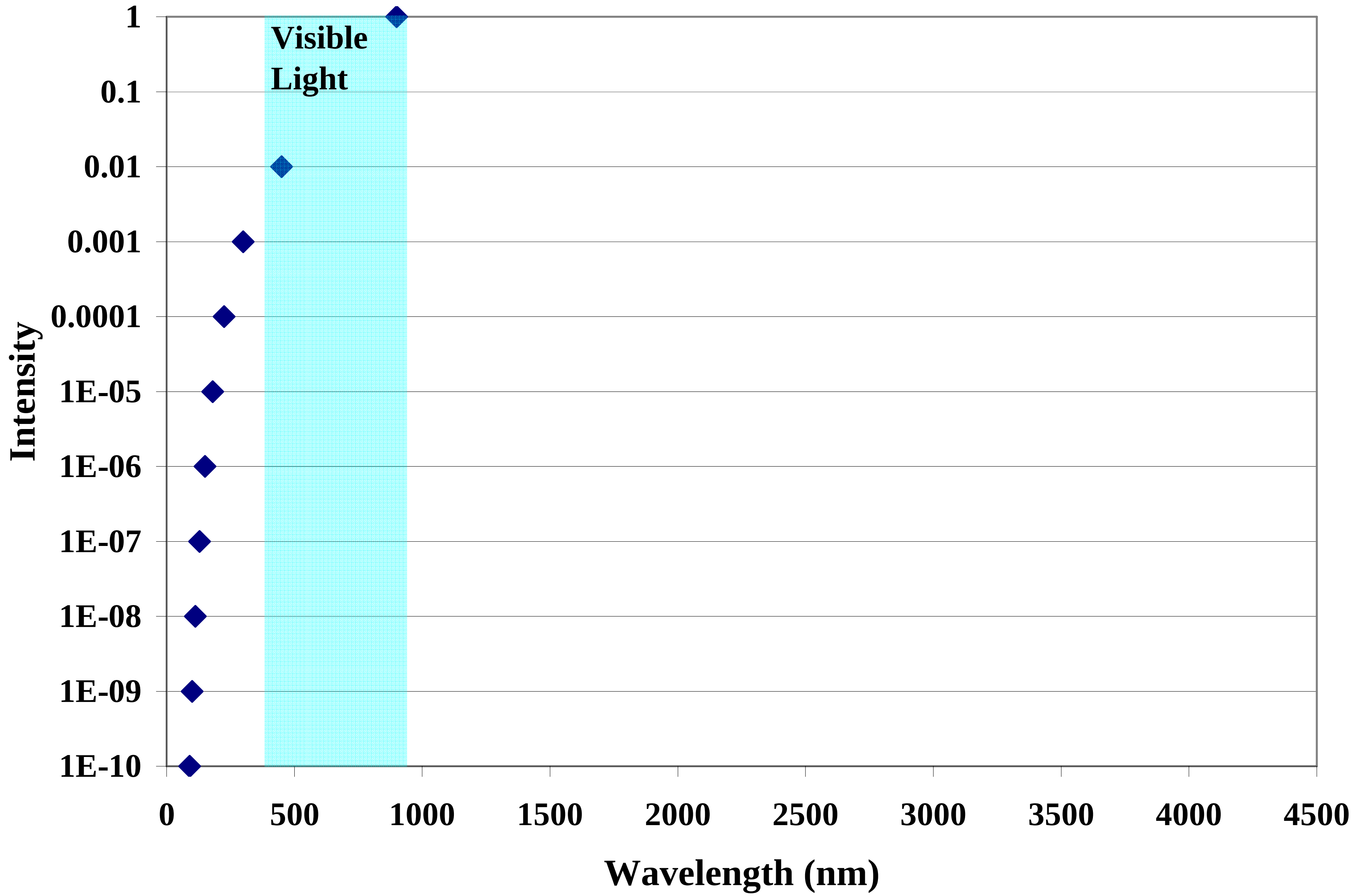
Harmonic Radiation while lasing



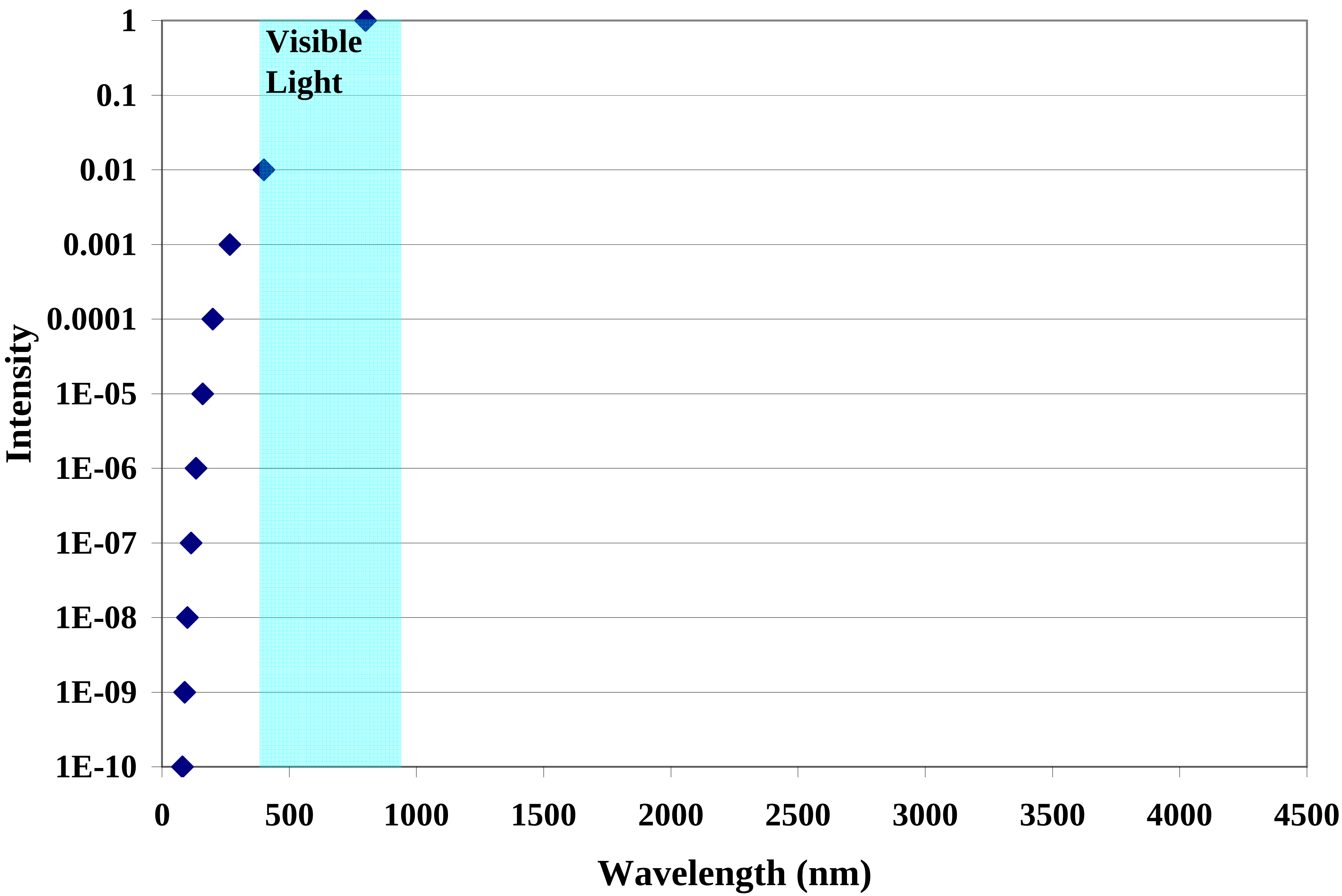
Harmonic Radiation while lasing



Harmonic Radiation while lasing



Harmonic Radiation while lasing



Thomas Jefferson National Accelerator Facility

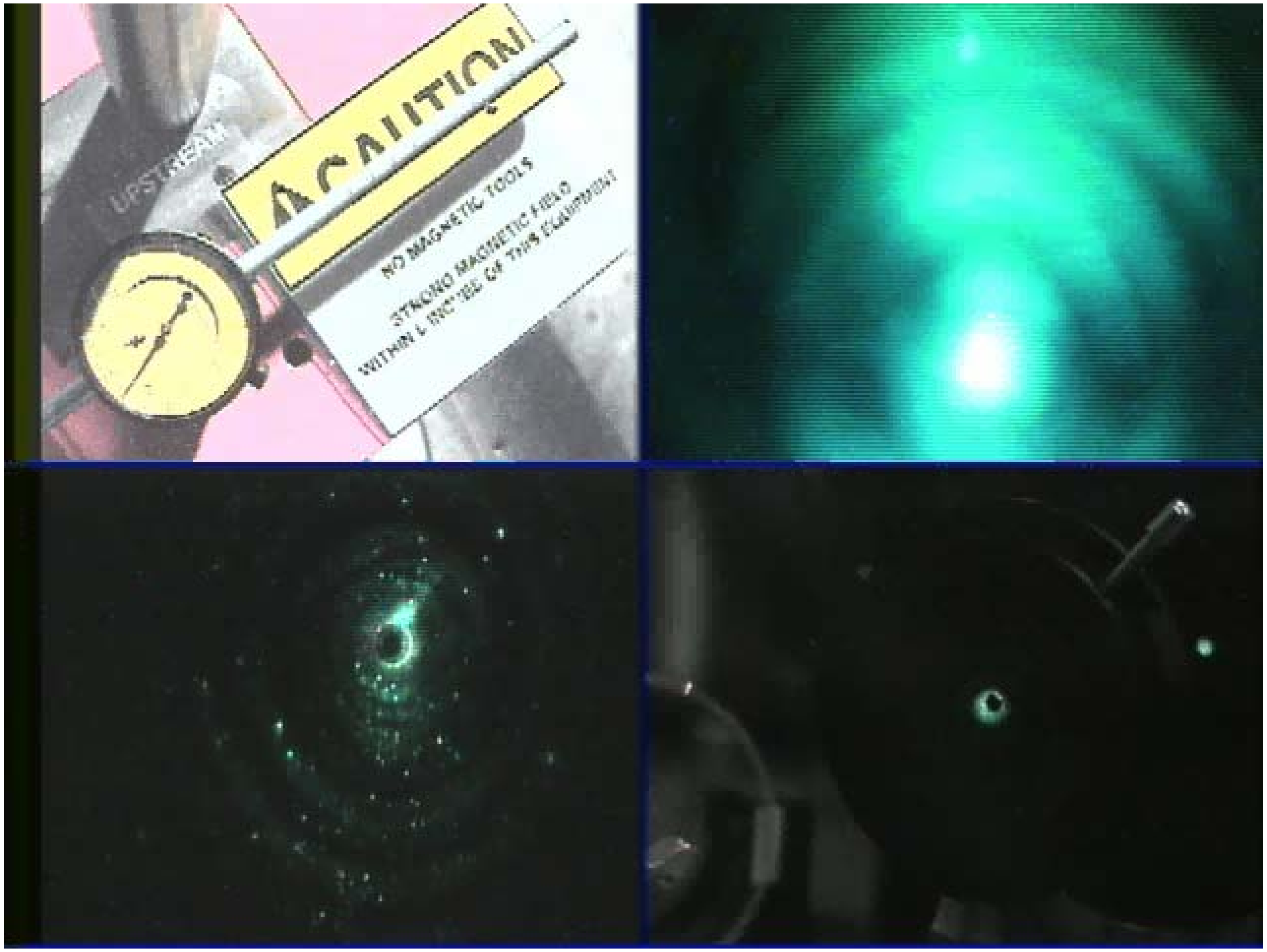
Operated by the Southeastern Universities Research Association for the U.S. Dept. Of Energy

Harmonic Radiation while lasing

Tuning movie

Wiggler gap

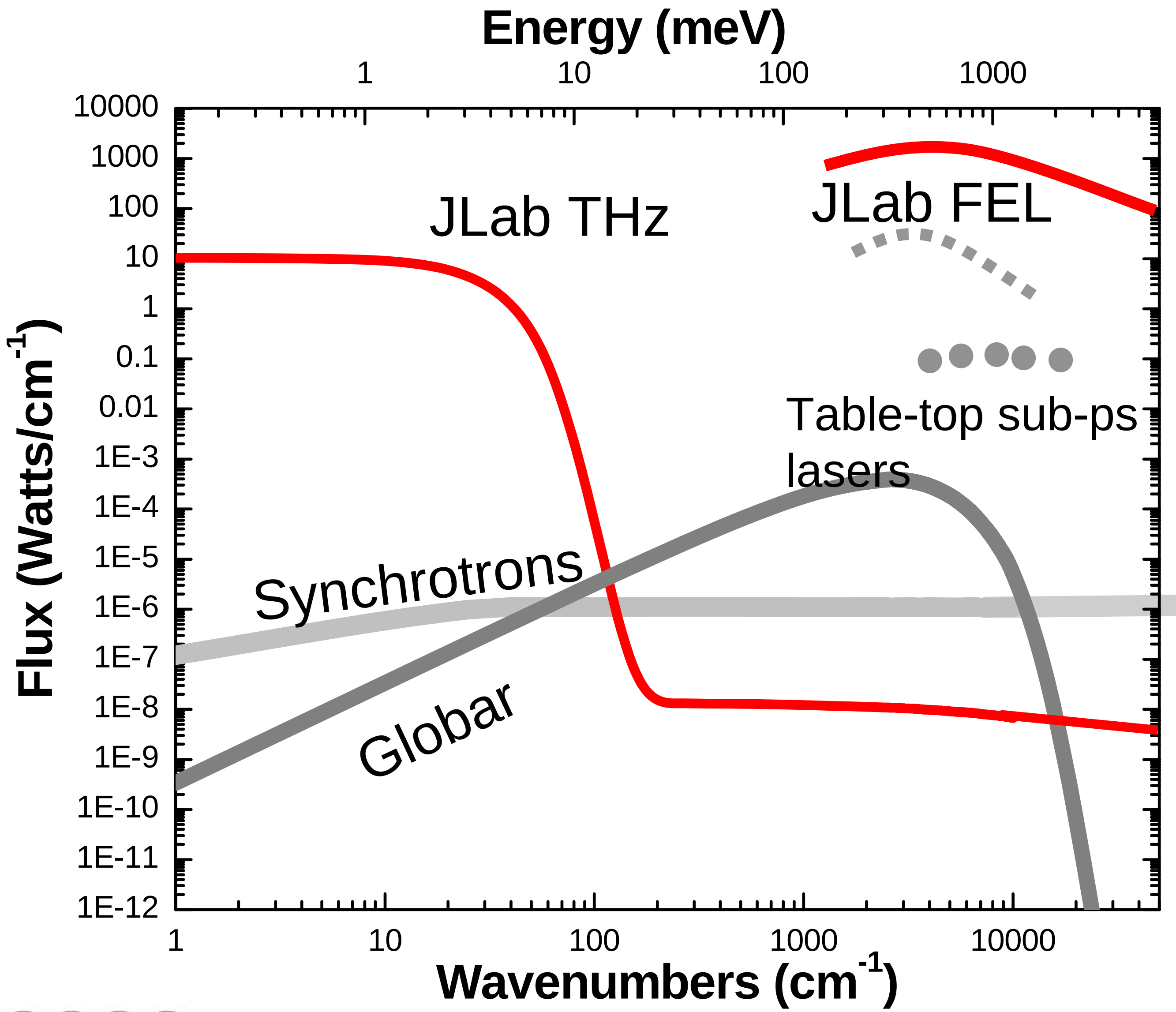
High Reflector



Hole Outcoupler

Beam in control room

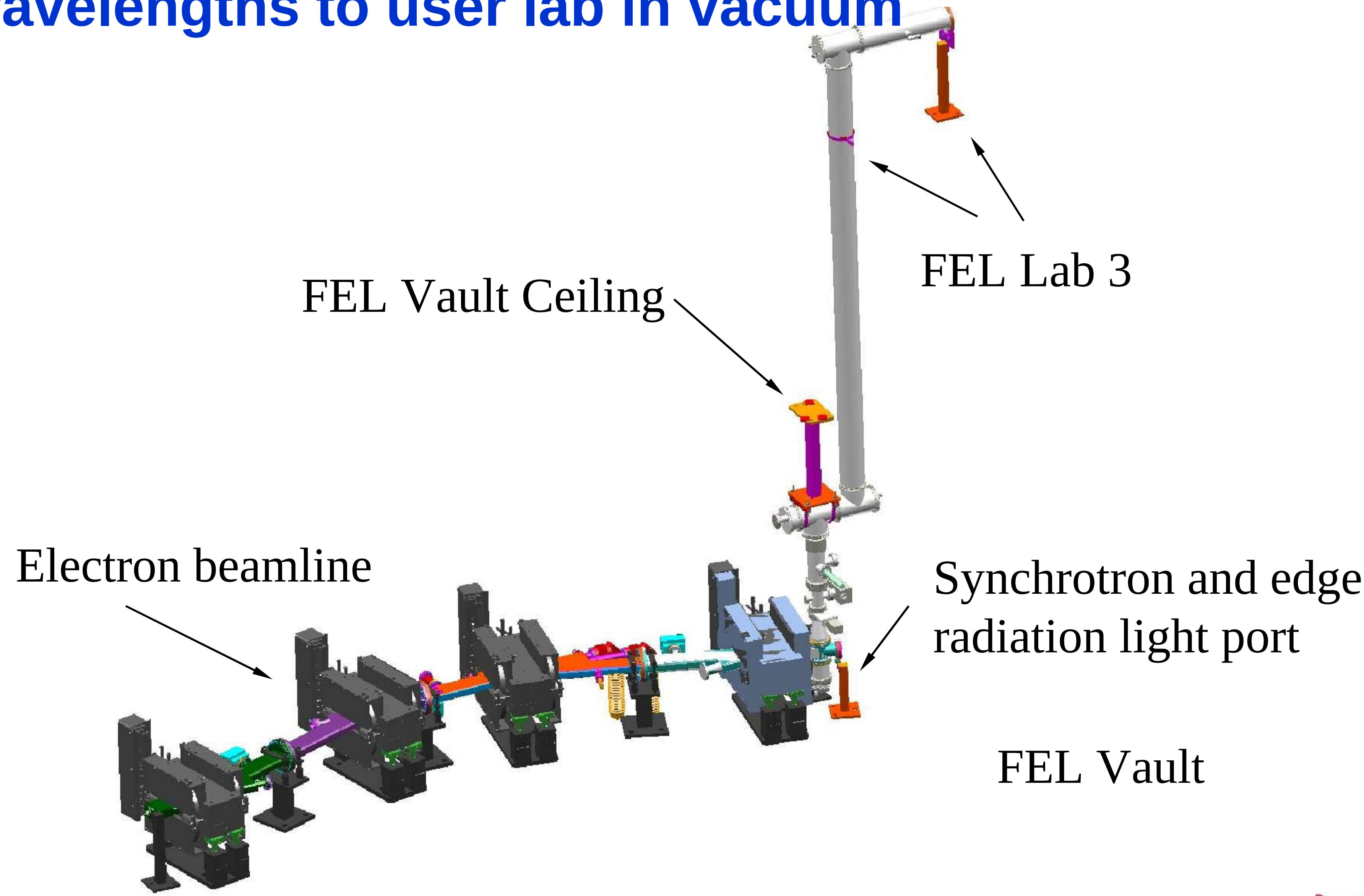
High power THz with sub-picosecond pulses is produced parasitically from electron beam



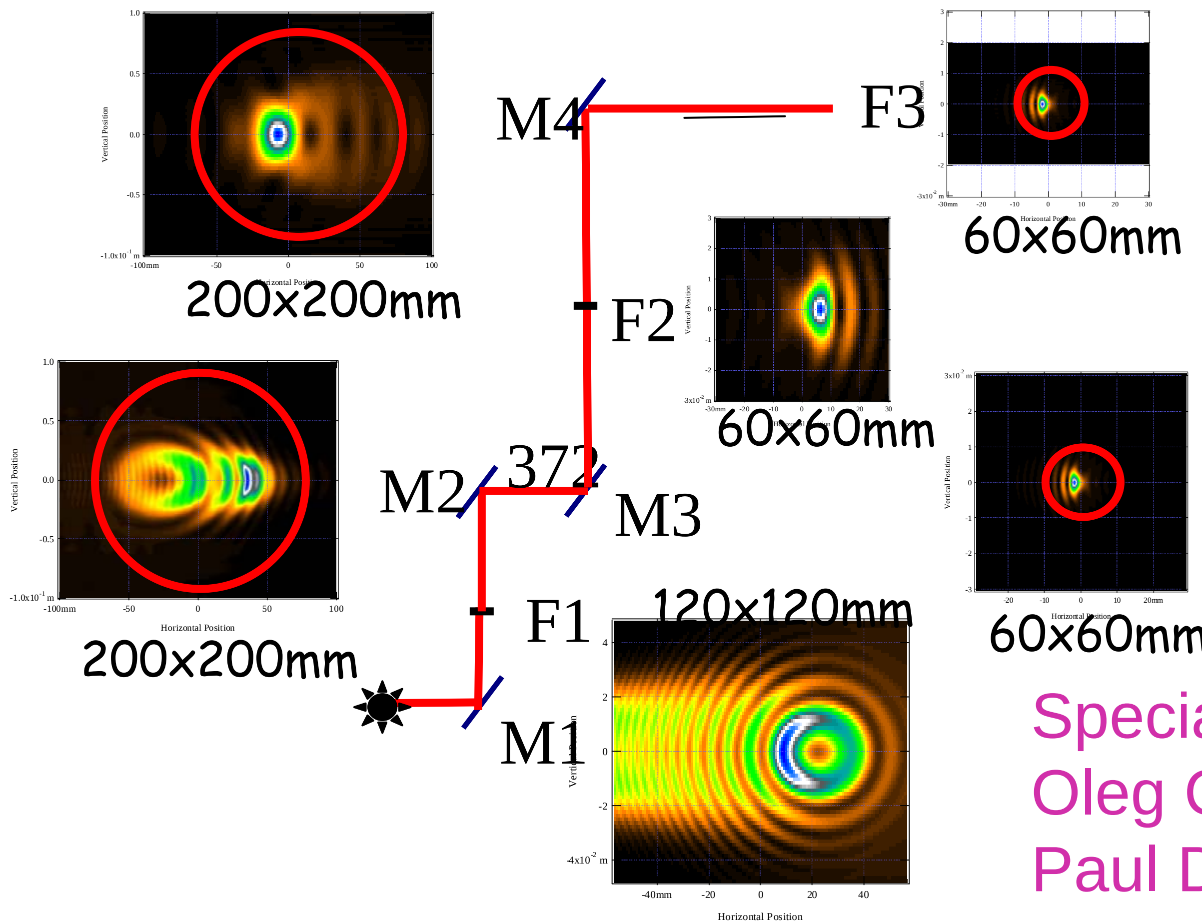
FEL proof of principle:
Neil et al. <u>Phys. Rev.Letts 84</u>, 662 (2000)

THz proof of principle:
Carr, Martin, McKinney, Neil, Jordan & Williams <u>Nature 420</u>, 153 (2002)

Terahertz beamline transports visible to 5 mm wavelengths to user lab in vacuum



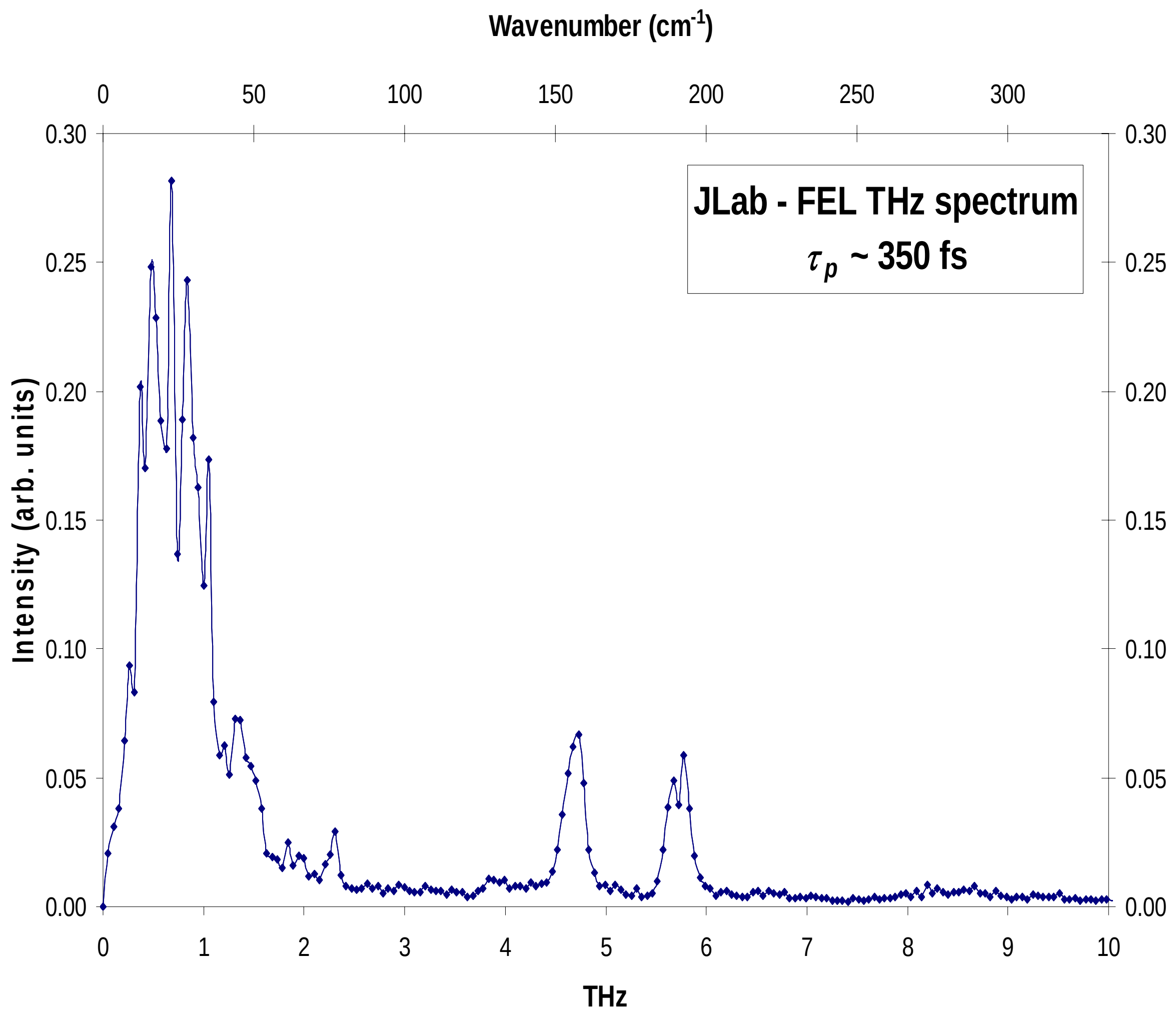
JFEL THz Beamline Calculated Optical Beam Patterns



Special thanks to
Oleg Chubar,
Paul Dumas.

JFEL THz as measured through our FTIR spectrometer (through air so shows H_2O lines)

Serves as excellent beam diagnostic
Requires FTIR spectrometer modification for pulsed measurement

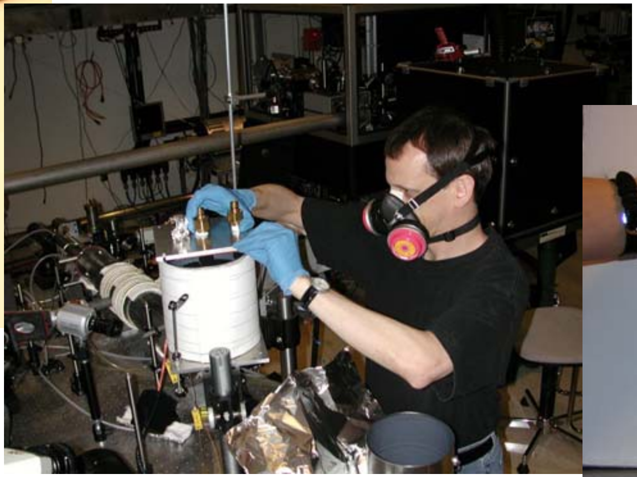


Courtesy M. Klopf

NASA/Jlab Nanotube Synthesis - Research to Production

New and used target

From Target to Product, 100% In-House



Product, ~1 hour of beam time

- Production with 750 W at 1.6 micron is now routine.
- Production rate of 2-6 g/hour of as-grown, high quality, "research grade" raw material is already cost competitive in $400/g market.
- Nanotube diameter is strong function of laser parameters, suggesting the possibility of "designer" tubes (selectable diameter likely… chirality, maybe?)
- Experimental trends indicate improved gross and net yield with soon-to-be-available shorter FEL wavelengths and higher power (no scale-up issues).

Mike Smith NASA LaRC

The benefits of high power, tunability and short pulses


THE TIMES 60p

Monday, April 10, 2006

Jefferson Lab
Exploring the Nature of Matter

6 NEWS — THE TIMES MONDAY APRIL 10 2006

THE TIMES MONDAY APRIL 10 2006 — NEWS 7

Fat-busting laser revolutionises treatment for acne and cellulite

A technique developed by American scientists could lead to fat-related conditions, including arterial heart disease, being melted away by high-intensity beams, reports Sam Lister

ZAPPING THE FAT

Using a free electron laser, which can provide intense and highly accurate beams of light, scientists have discovered a means of melting fat under the skin. They believe the technique could be a solution to problems caused by localised areas of fatty deposits

FREE ELECTRON LASER

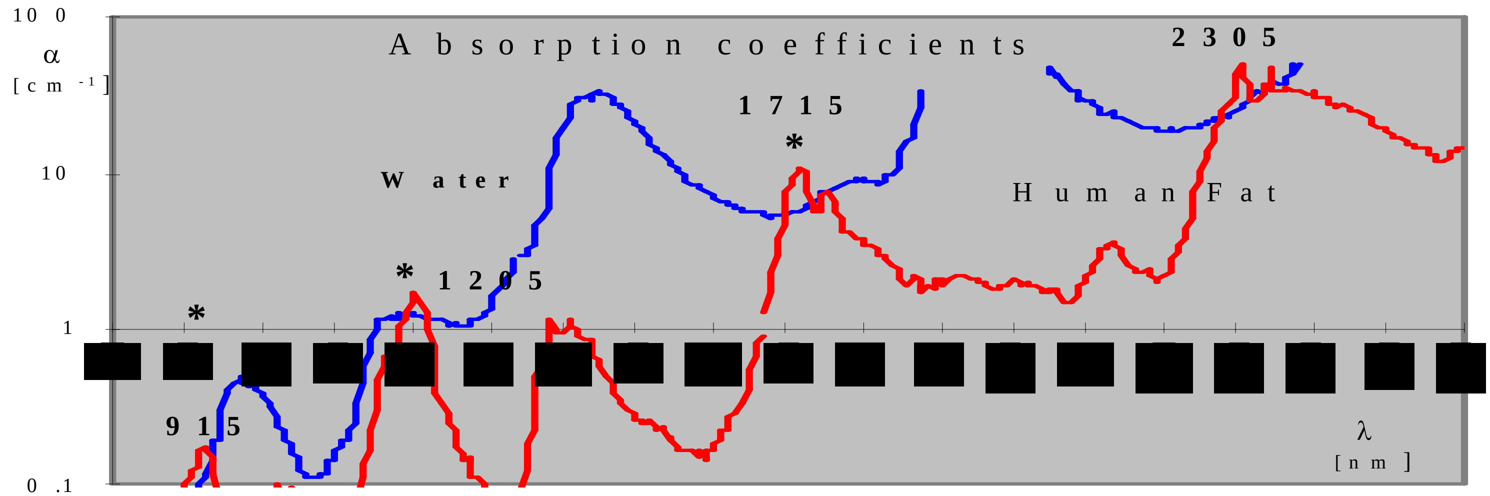
Seeing the light in hi-tech revolution

By Sam Lister

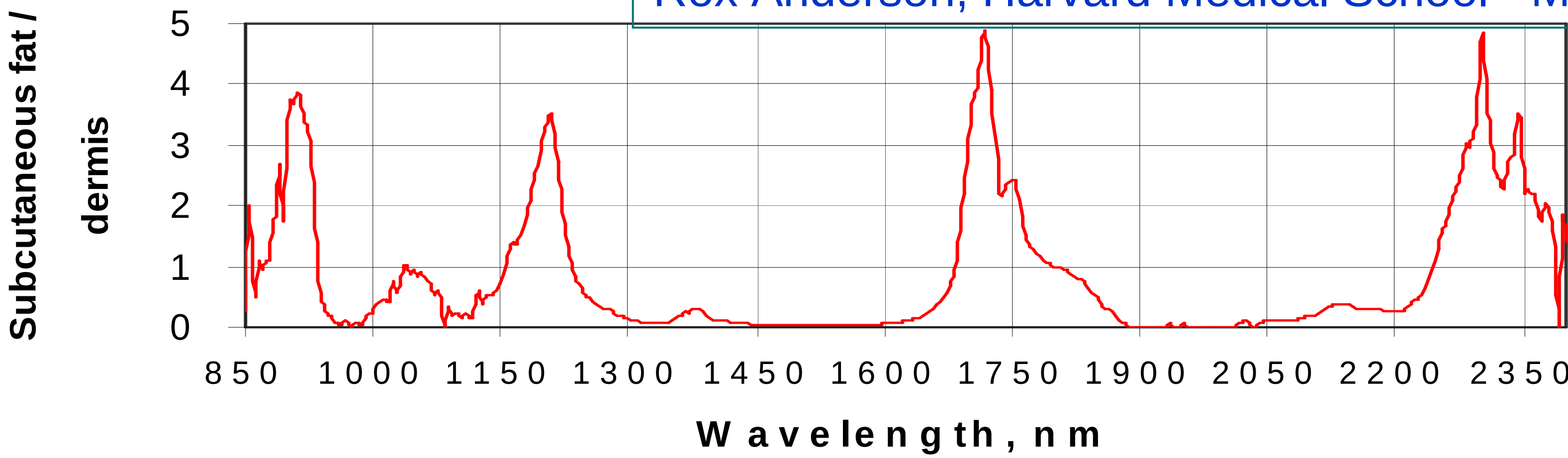
Trivial? Spots can truly blight teenagers' lives

DR THOMAS STUTTAFORD
MEDICAL BRIEFING

The benefits of high power, tunability and short pulses

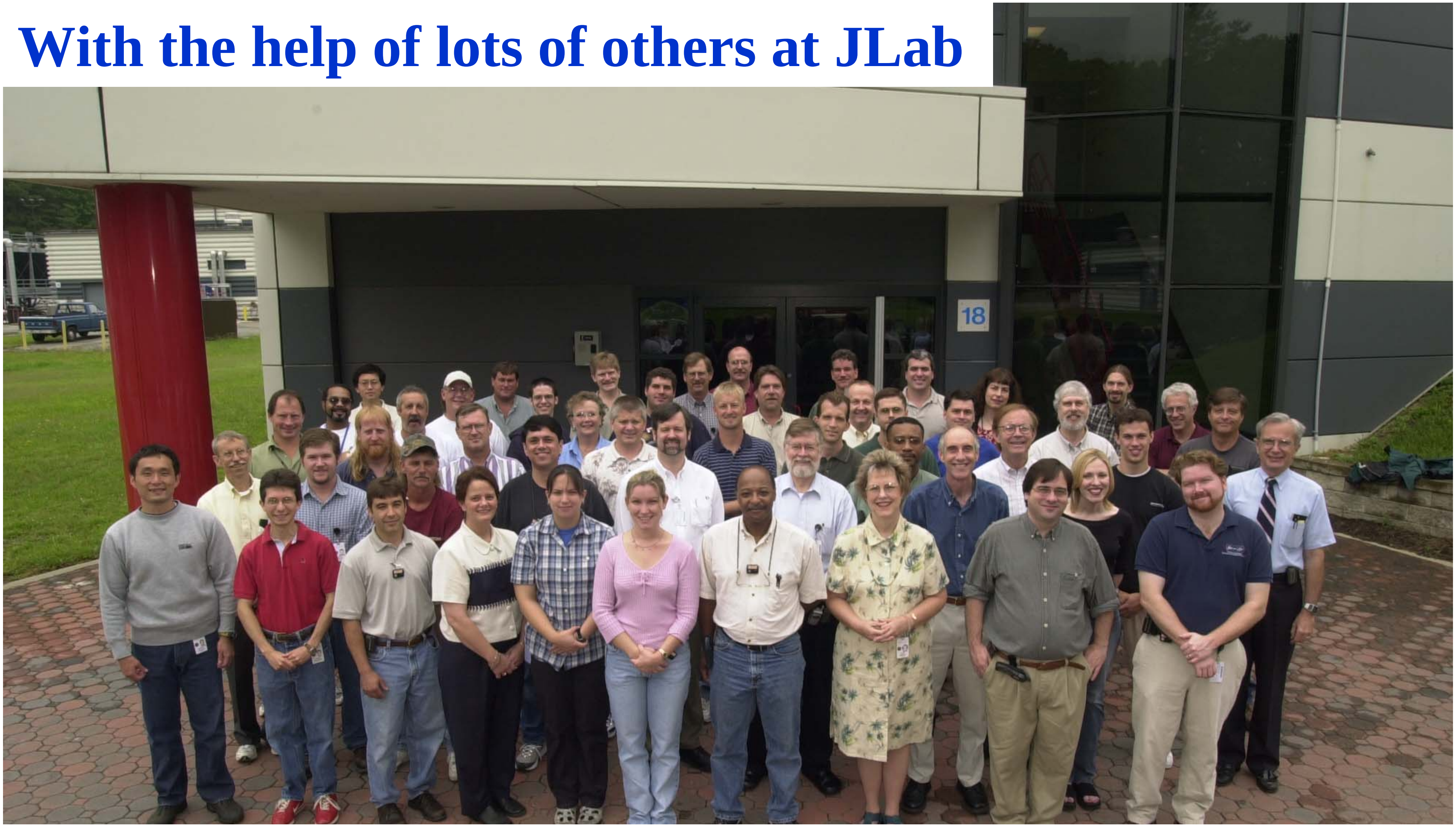


Rox Anderson, Harvard Medical School - MGH



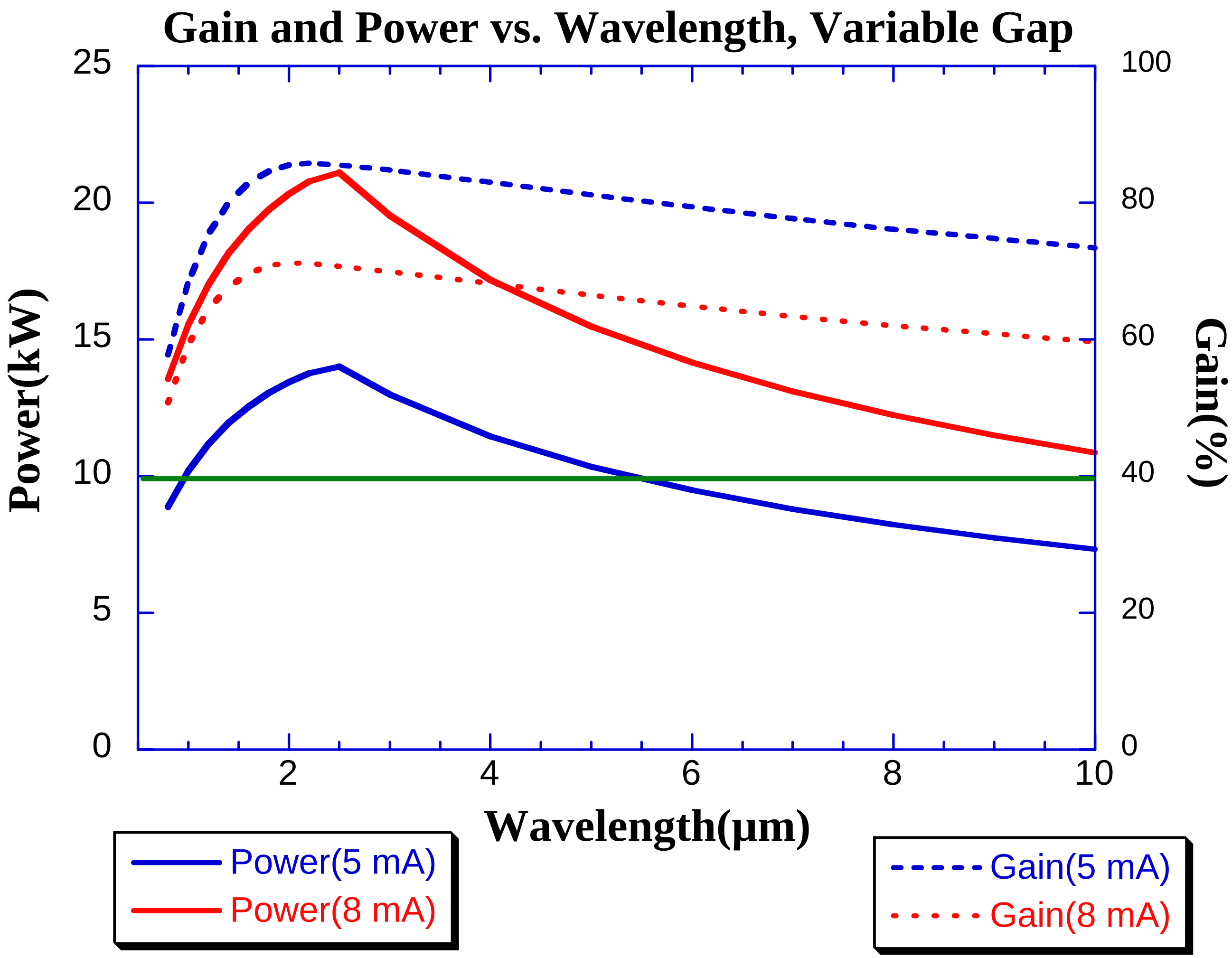
Fat and Water have nice “colors” in the NIR

With the help of lots of others at JLab



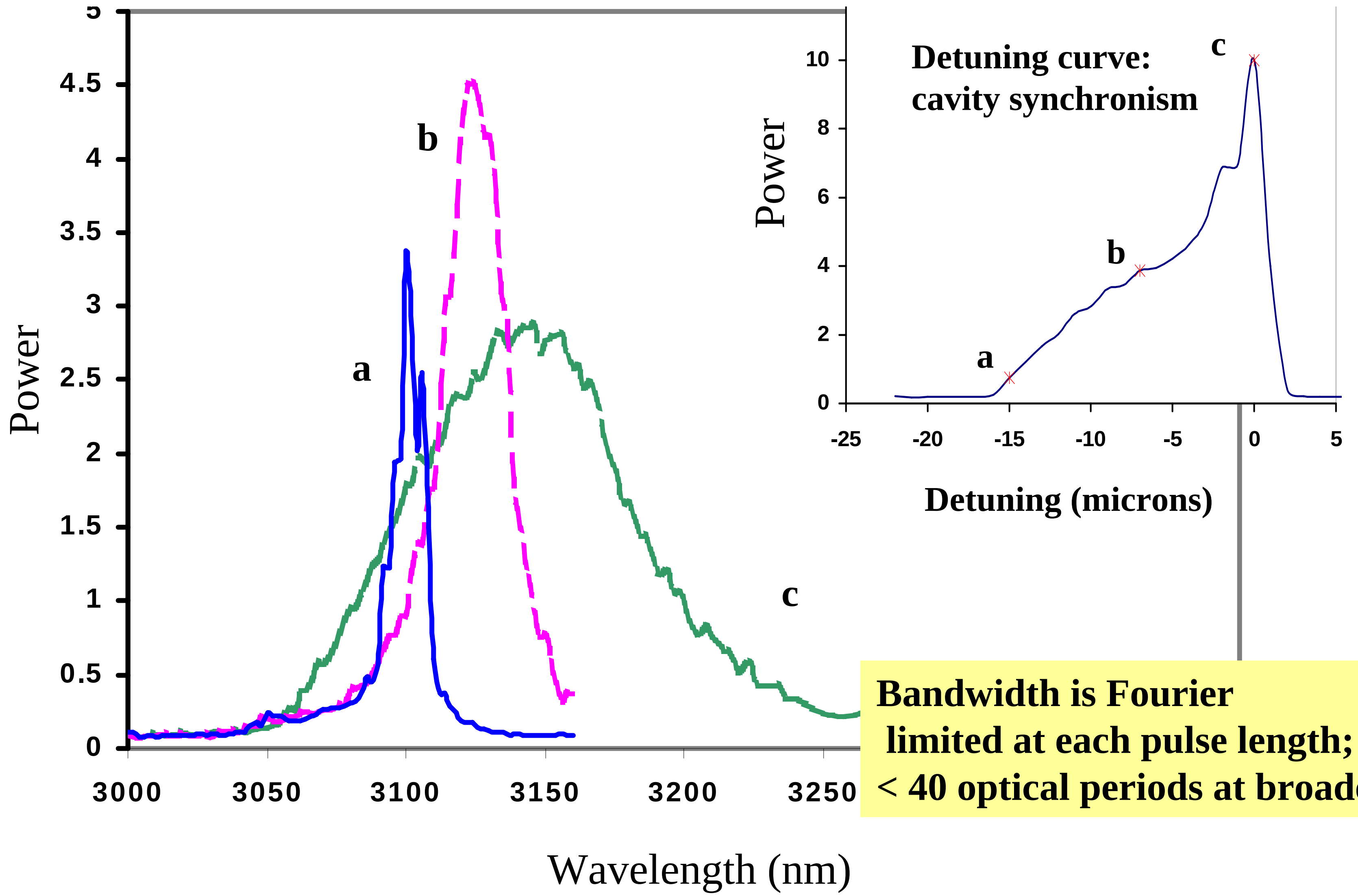
This work supported by the Office of Naval Research, the Joint Technology Office, the Commonwealth of Virginia, the Air Force Research Laboratory, and by DOE Contract DE-AC05-84ER40150.

Performance with Variable Gap PM Wiggler



Minimum beam energy=80 MeV, Energy <160 MeV. Energy spread constant

IR Demo measured bandwidth varied as a function of optical cavity length



Bandwidth is Fourier limited at each pulse length; < 40 optical periods at broadest!

UV Upgrade Performance: Installation TBD

•Tunable pulse energy to saturate electronic transitions

•Drive non-linear field effects

•High rep rate for S/N: e.g., molecular beams, gas phase