

The Broadband High Power THz User Facility at the Jefferson Lab - FEL

J. Michael Klopf
Jefferson Lab

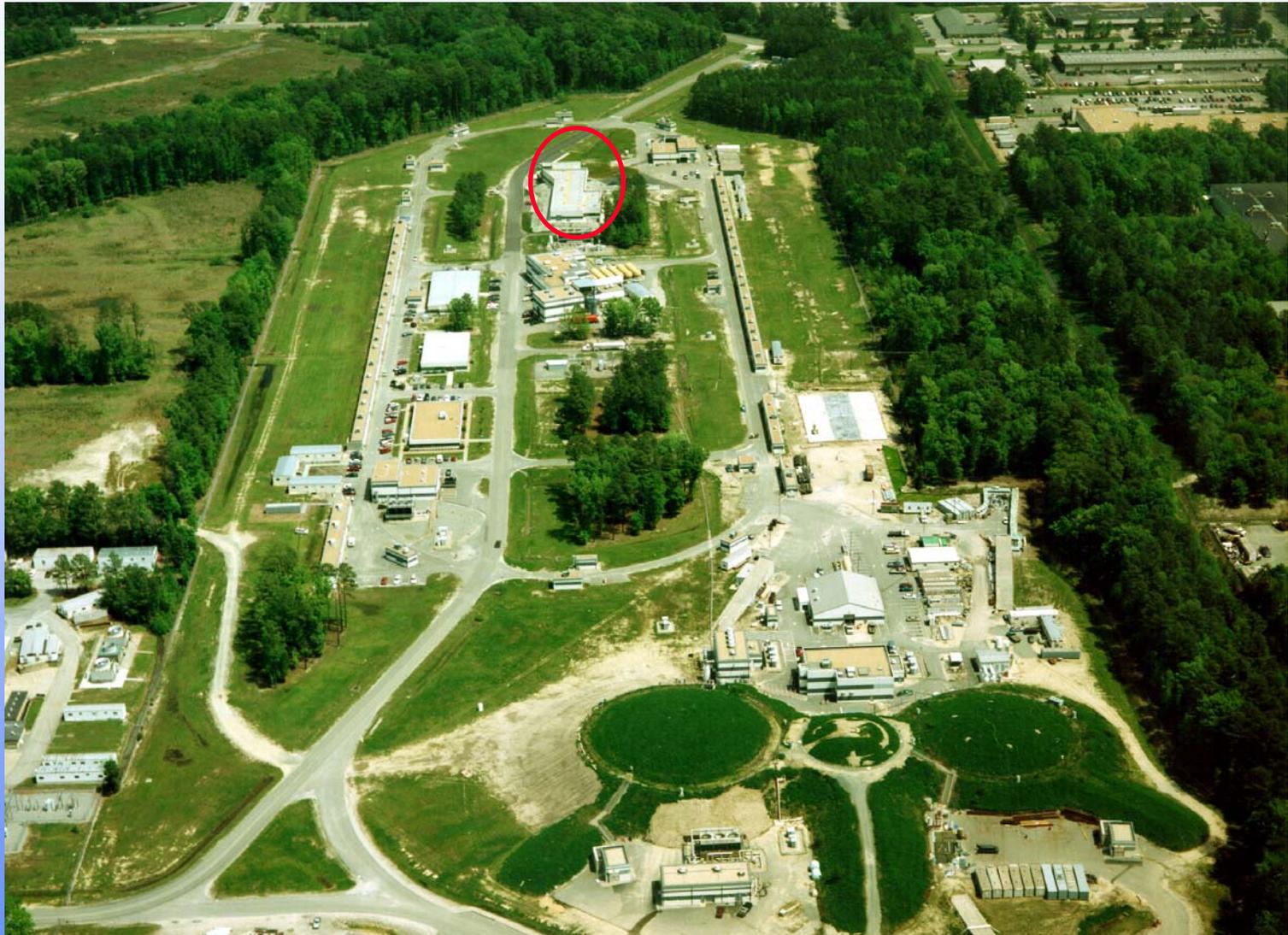
Core Managers Meeting
June 8, 2006



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Jefferson Lab Site



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Free Electron Laser Facility / THz Lab

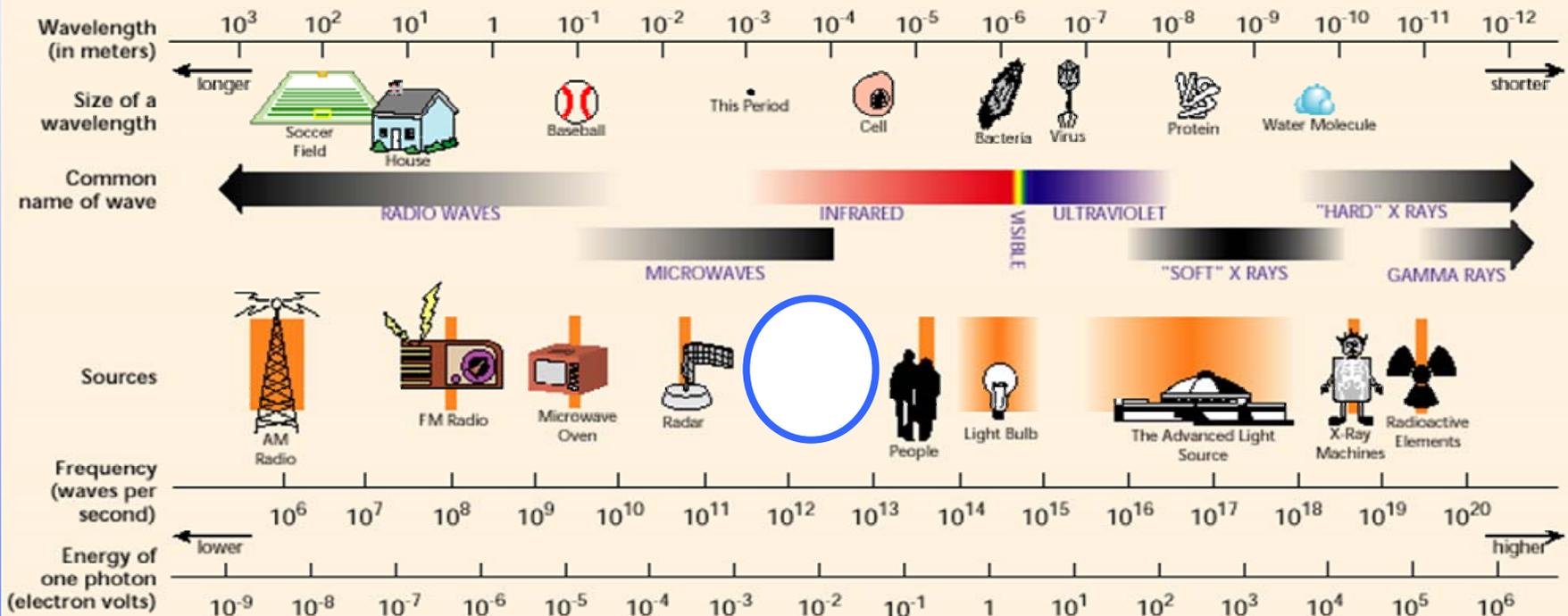


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What is the THz Gap?

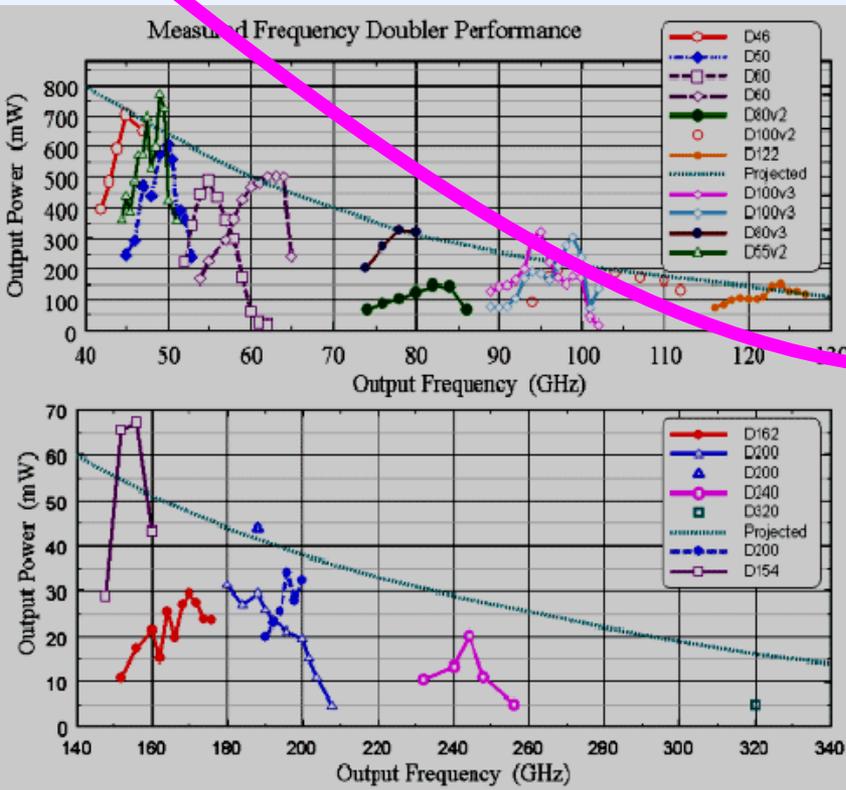
THE ELECTROMAGNETIC SPECTRUM



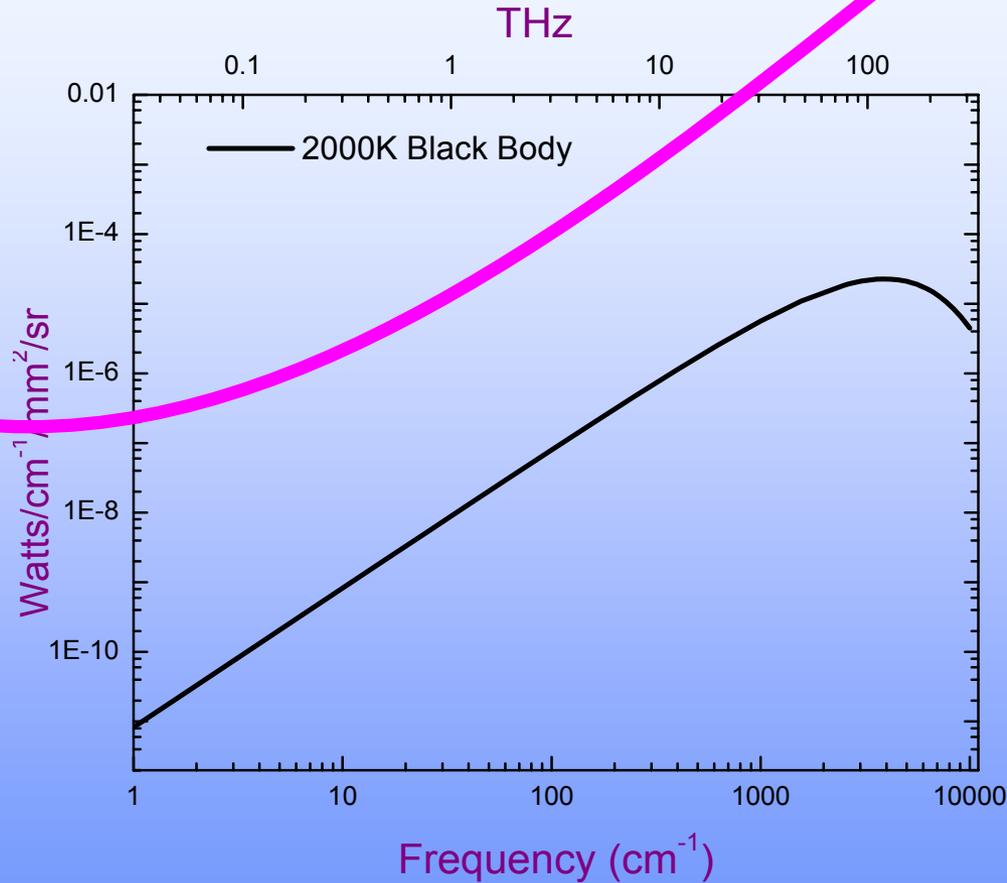
$$1 \text{ THz} = 10^{12} \text{ Hz}$$

Why is there a THz Gap?

Electronics - radios



Photonics – light bulbs



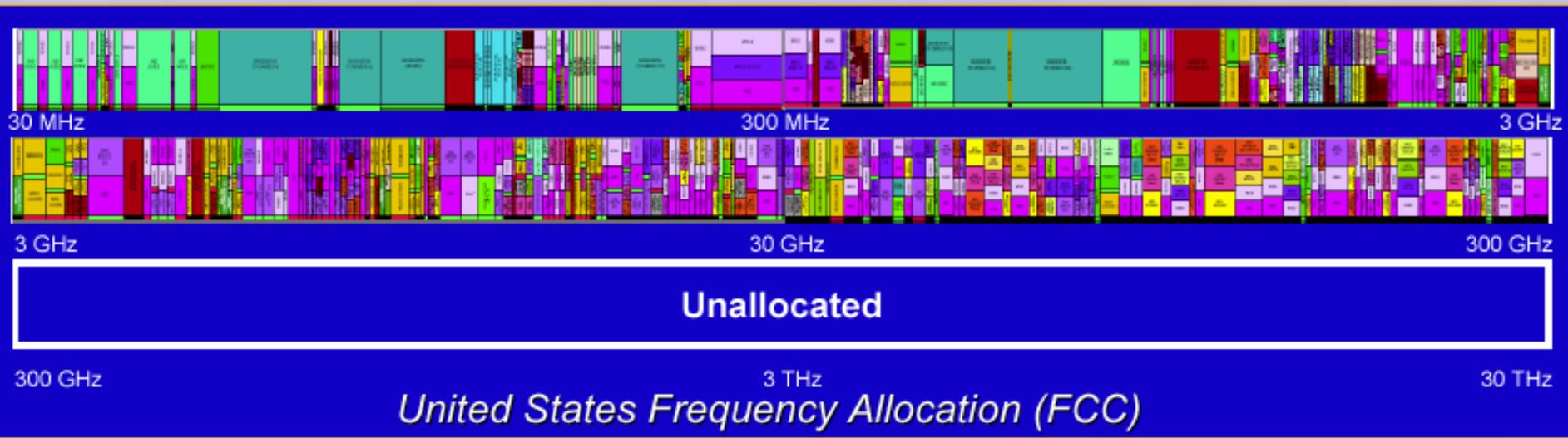
Tom Crowe, UVA



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The FCC and the THz Gap



THz radiation also lies in the unallocated frequency space due to the lack of sources and detectors



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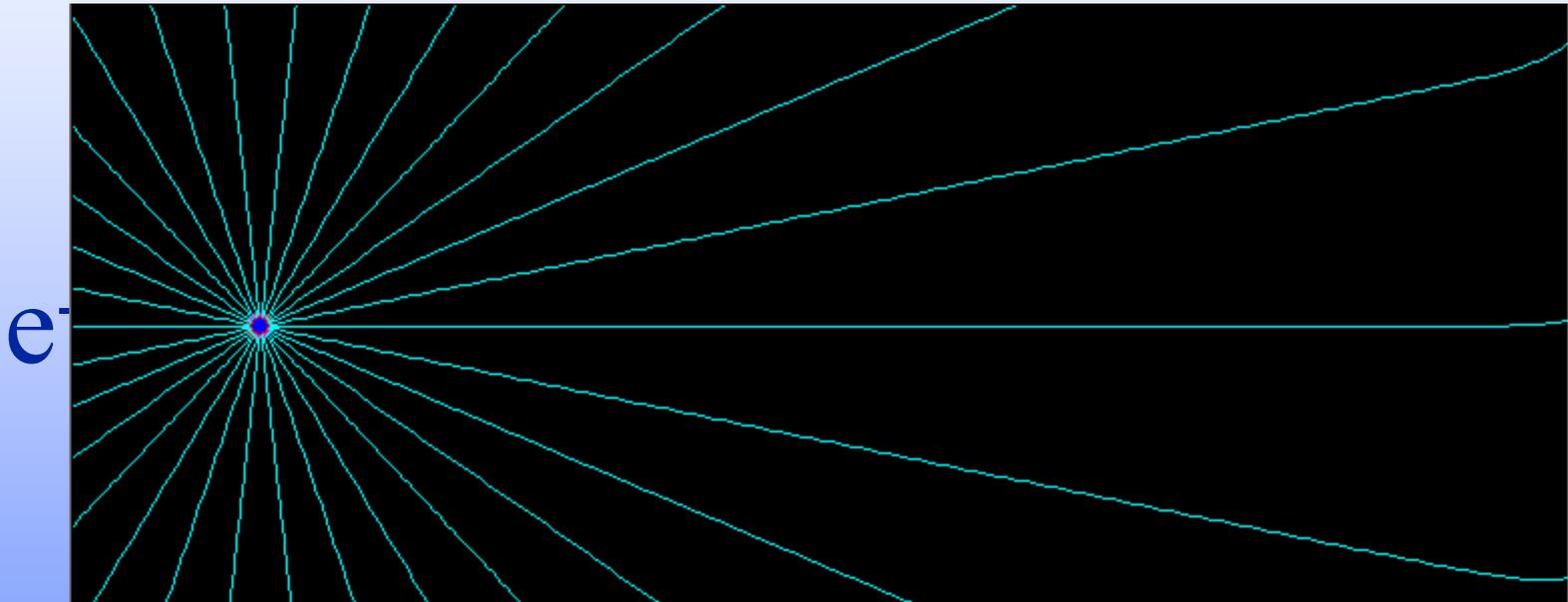
Why is THz Radiation Important?

- THz radiation can enable imaging capabilities complementary to X-ray imaging without the problems typical of ionizing radiation
 - medical imaging
 - security technologies
 - manufacturing
 - pharmaceuticals
- THz frequencies are resonant with many vibrational and rotational modes in molecules which could not previously be probed
- Energy range of THz spectrum – $\mathcal{O}(\text{meV})$ – overlaps with
 - band gaps of superconductors
 - excitation energy for protein folding
 - phonon energies
- Defense related applications in explosives/mine detection as well as short range communications
- THz pulses can be used for novel nonlinear optical experiments
- THz source at the FEL has proven to be a useful accelerator diagnostic



How Light is Produced

Light (electromagnetic waves) is made by accelerating an electron.



Radiated Power From an Electron

The power radiated by an accelerating electron is given by Larmor's Formula:

$$Power = \frac{2e^2 a^2}{3c^3} \gamma^4 \quad (cgs \text{ units})$$

$$\text{where } \gamma = \frac{m}{m_0}$$



Radiated Power From an Electron Bunch

When extremely short bunches of N electrons are accelerated, the power scales as:

$$Power = \frac{2(Ne)^2 a^2}{3c^3} \gamma^4$$

In most cases, such as in solid state electronics, $\gamma = 1$

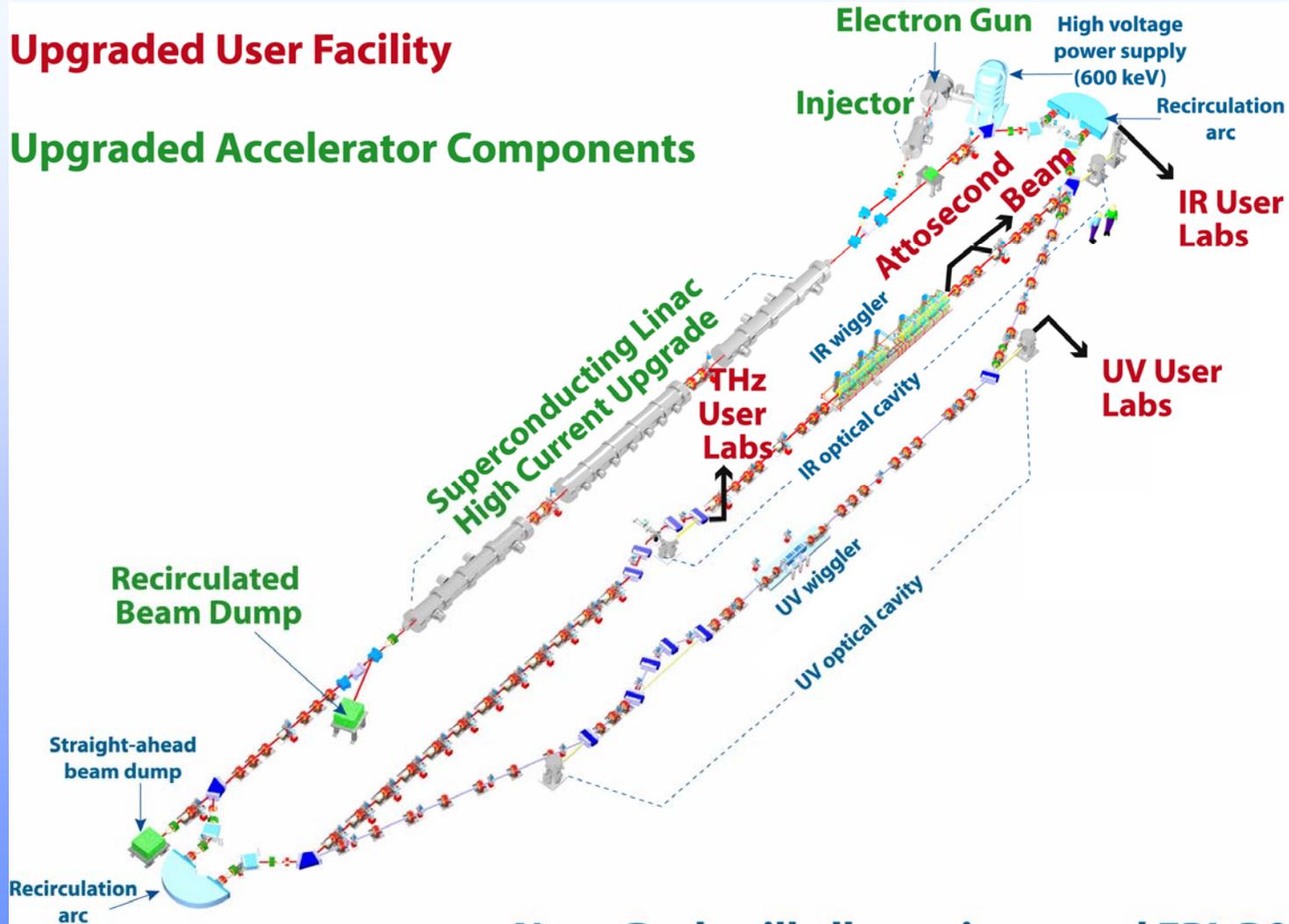
At the JLab FEL, $\gamma \sim 200$, which results in an increase in power of over 9 orders of magnitude!!!



JLab FEL and THz Source

Upgraded User Facility

Upgraded Accelerator Components



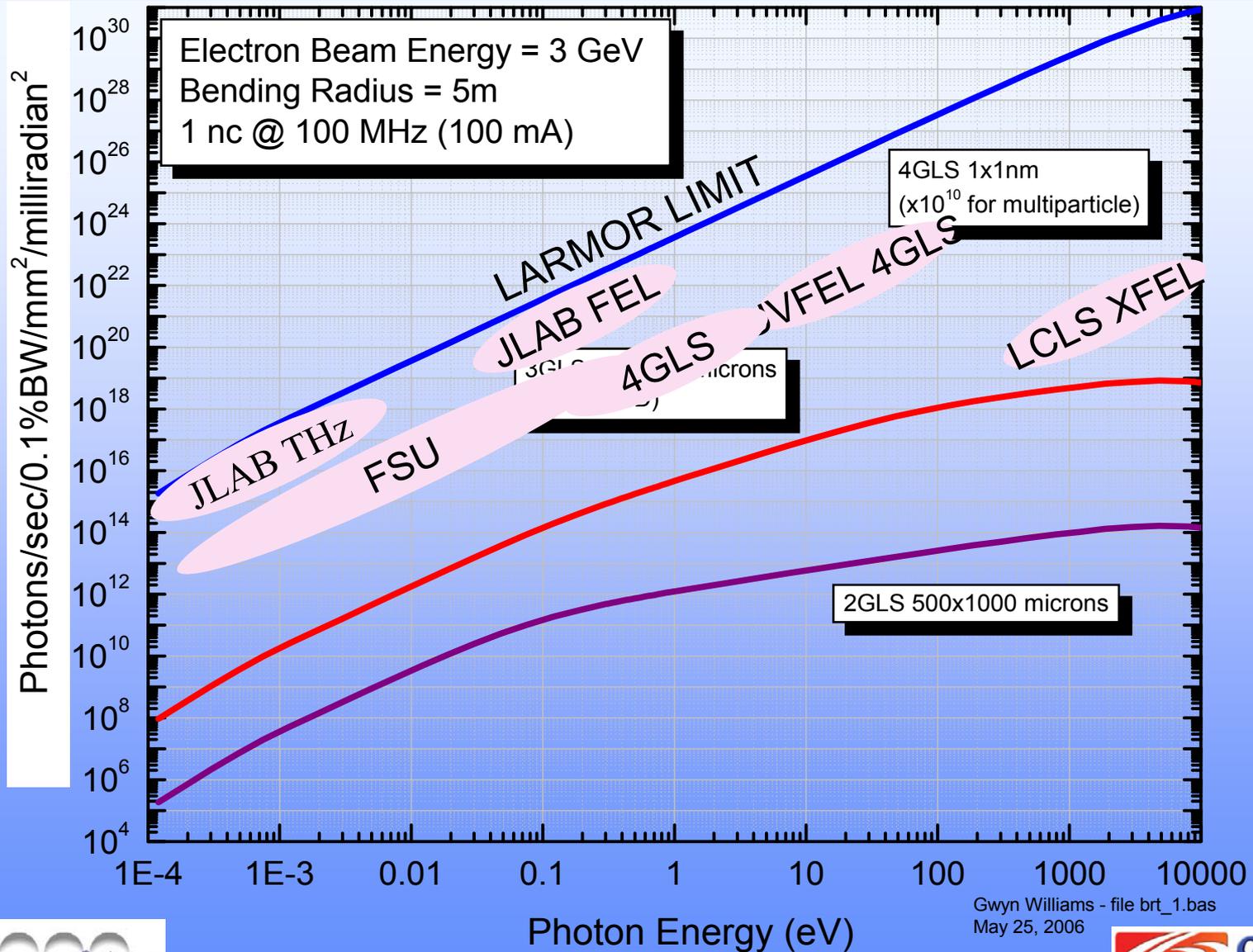
Note: Both will allow science and ERL R&D



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JLab FEL and THz Source



Gwyn Williams - file brt_1.bas
 May 25, 2006



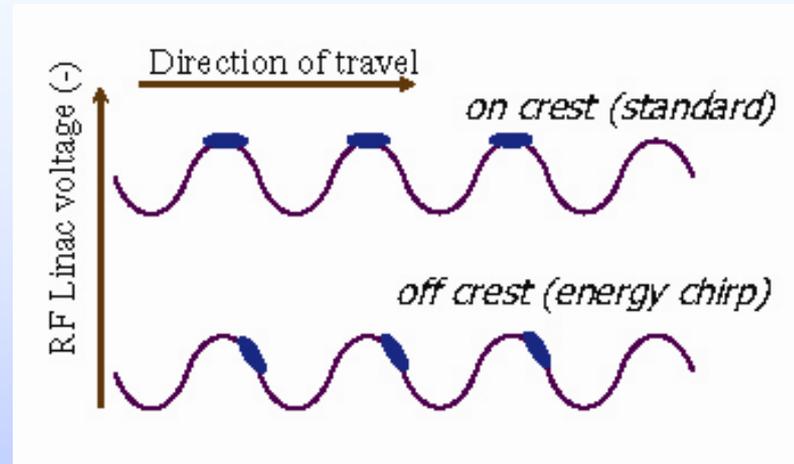
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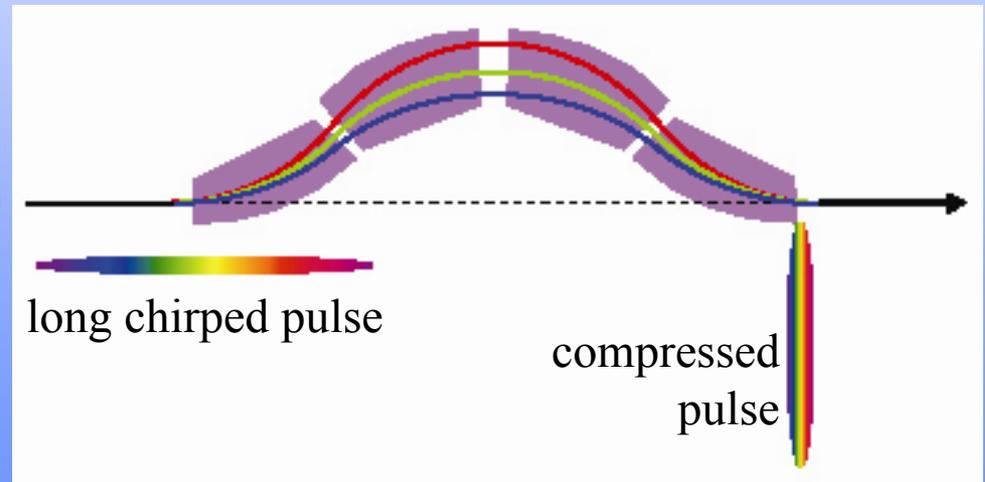
Coherent THz Radiation From Short Electron Bunches



- acceleration of e- bunches off crest produces a monotonic energy spread or chirp



- HR chicane provides dispersion and path geometry to compress the chirped pulses



G. Larry Carr, BNL



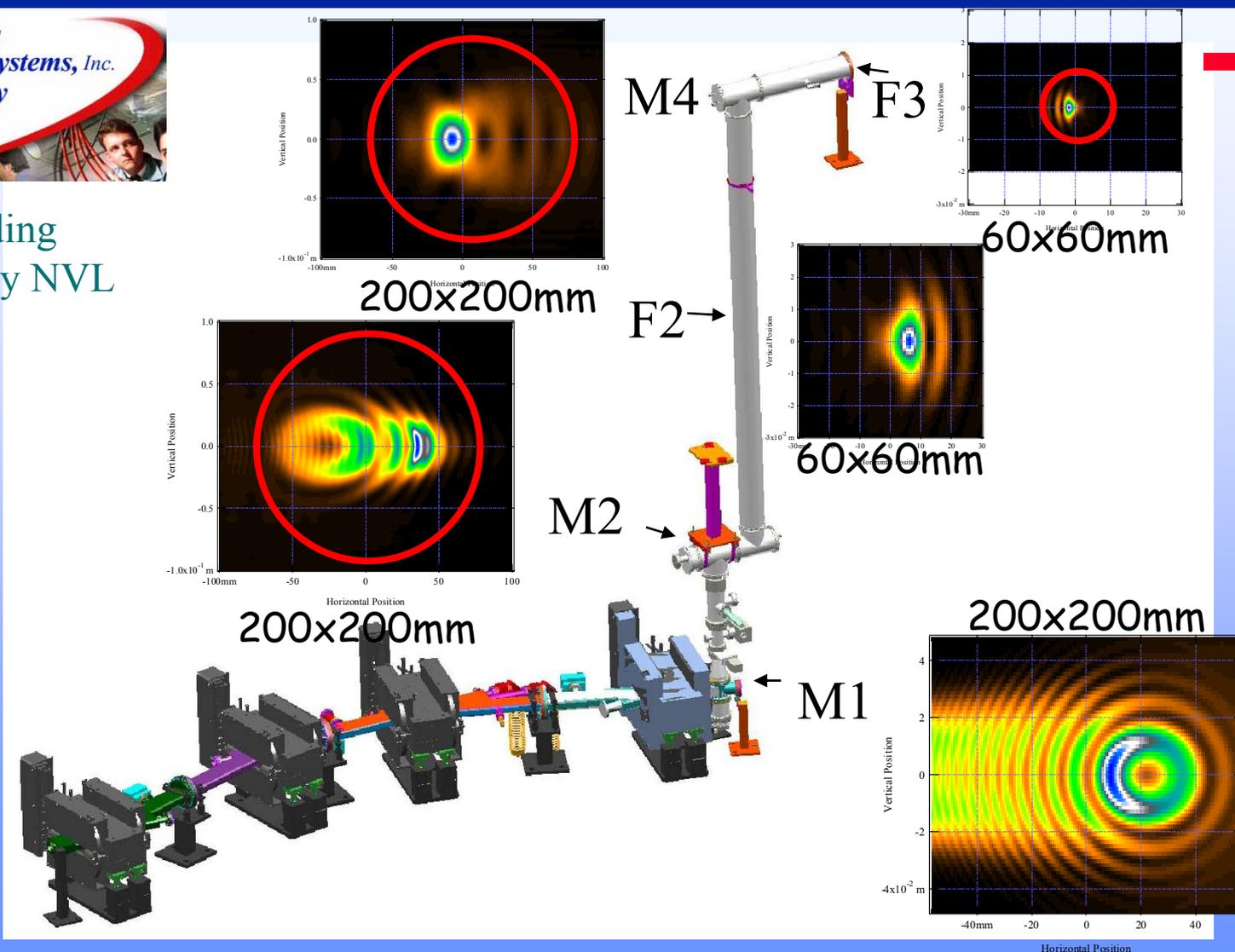
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JLab THz Beamline Optics



Funding
US Army NVL



→ THz
To User
Facility

Optical calculations by Oleg Chubar, Paul Dumas
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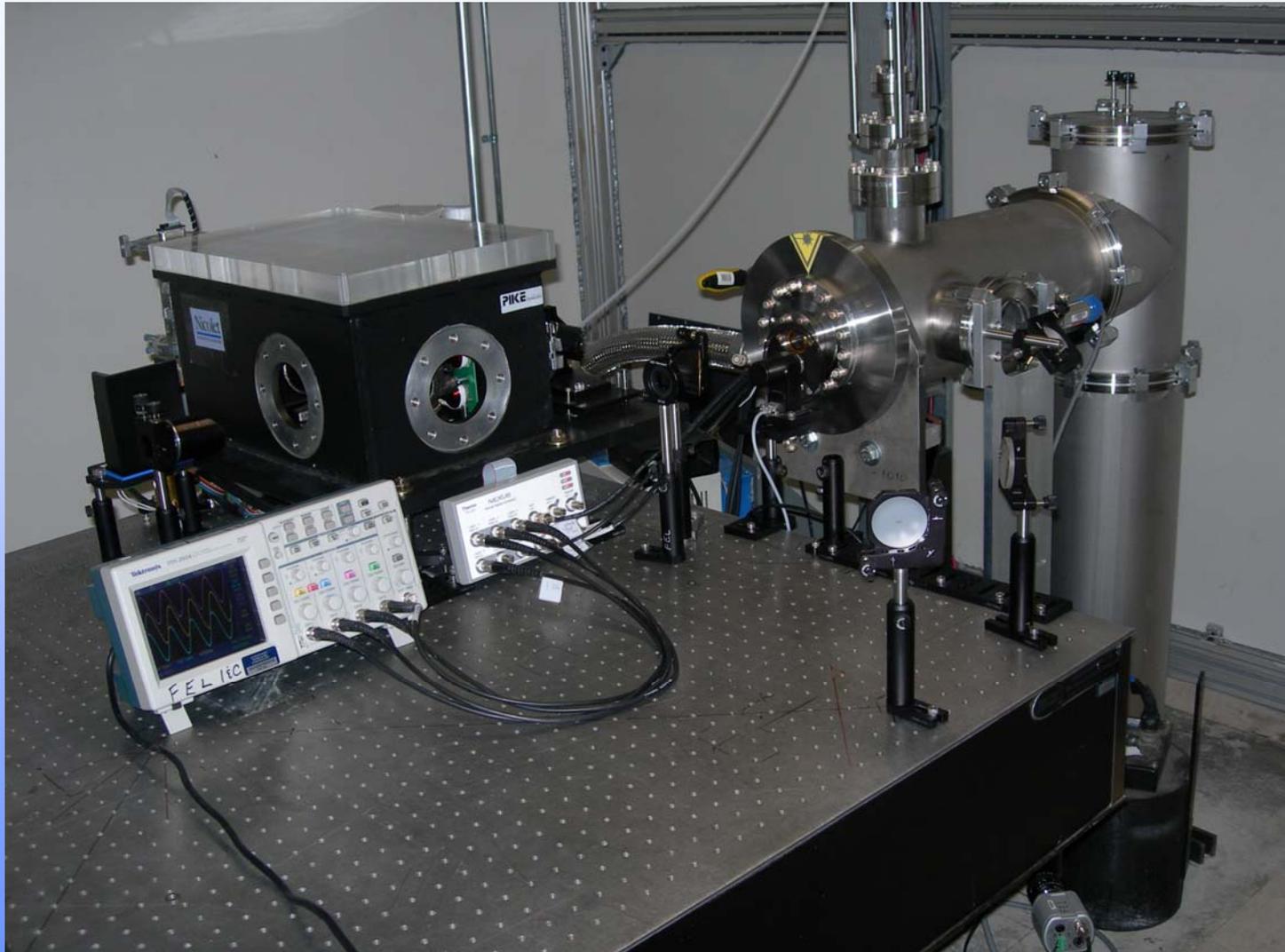
JLab THz Beamline



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JLab – FEL THz User Lab



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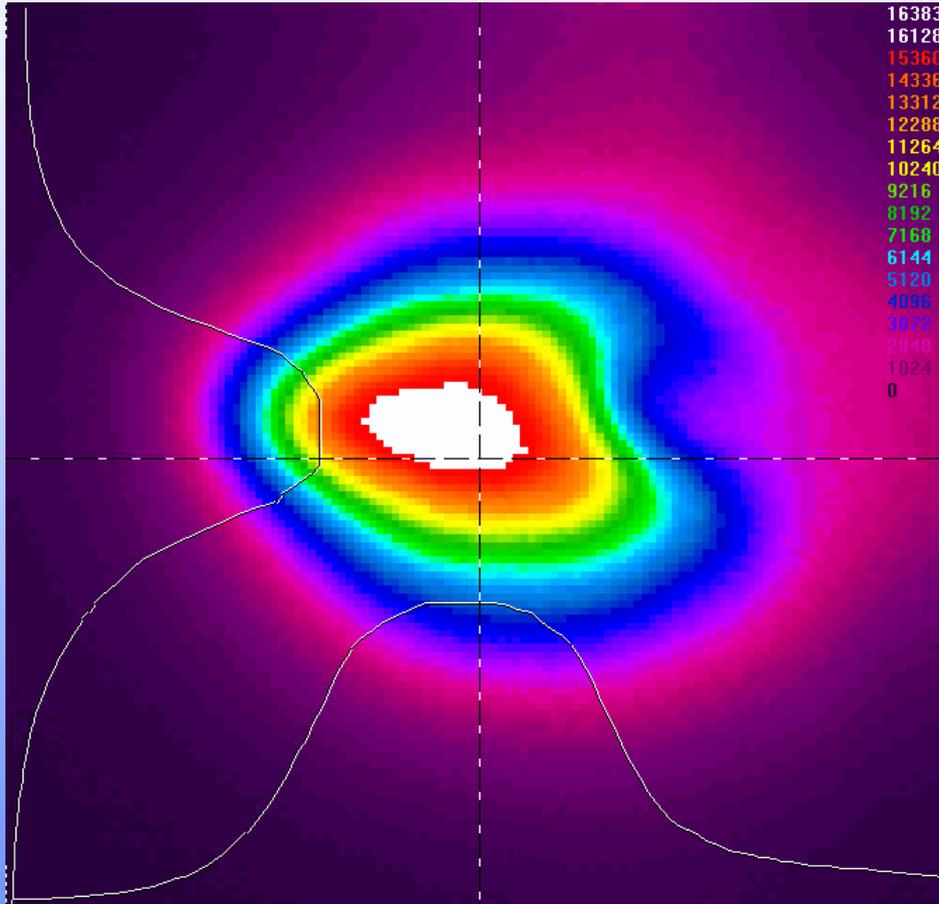
State of the JLab THz Source and User Facility

- The beamline has been commissioned and is operational.
- THz spectrum has been measured and is routinely used to for accelerator diagnostics.
- A new vacuum spectrometer has been tested and is being commissioned for vacuum operation.
- Beam power measurements are underway. As the first ever high power source, characterization methods must be developed and tested.
- The first imaging tests have been performed and beam profiling measurements are underway.
- Collaborative experiments on electro-optic switching have been conducted with a researcher from Cornell.
- Measurements to determine safety equipment have been conducted.
- Experiments to determine the effects of exposure to high power THz sources have been proposed for the JLab THz lab.

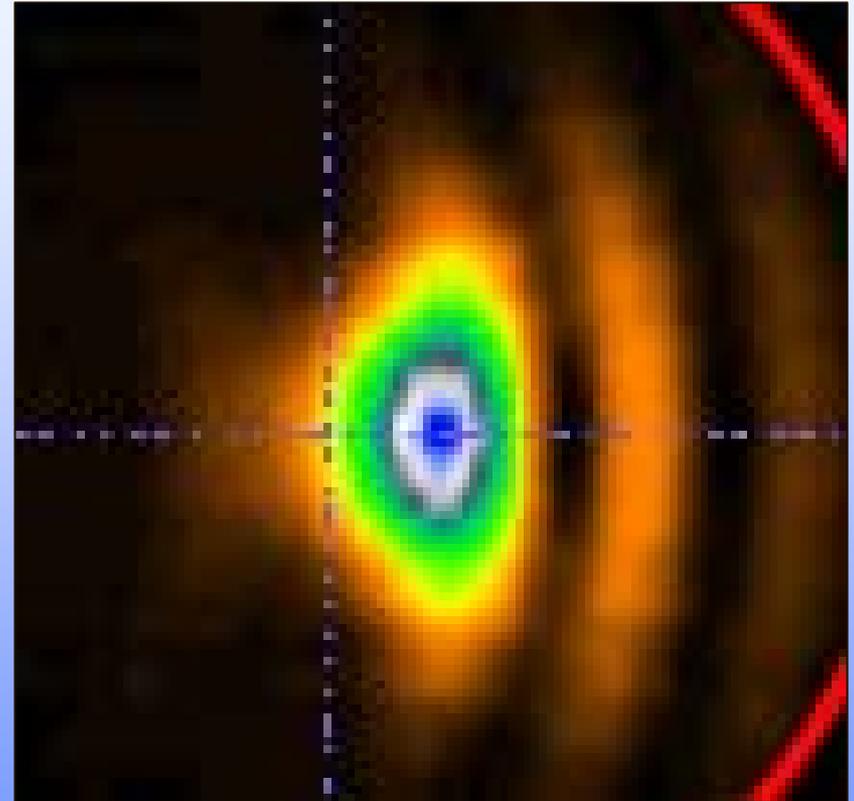


Beam Image of JLab –FEL THz Source

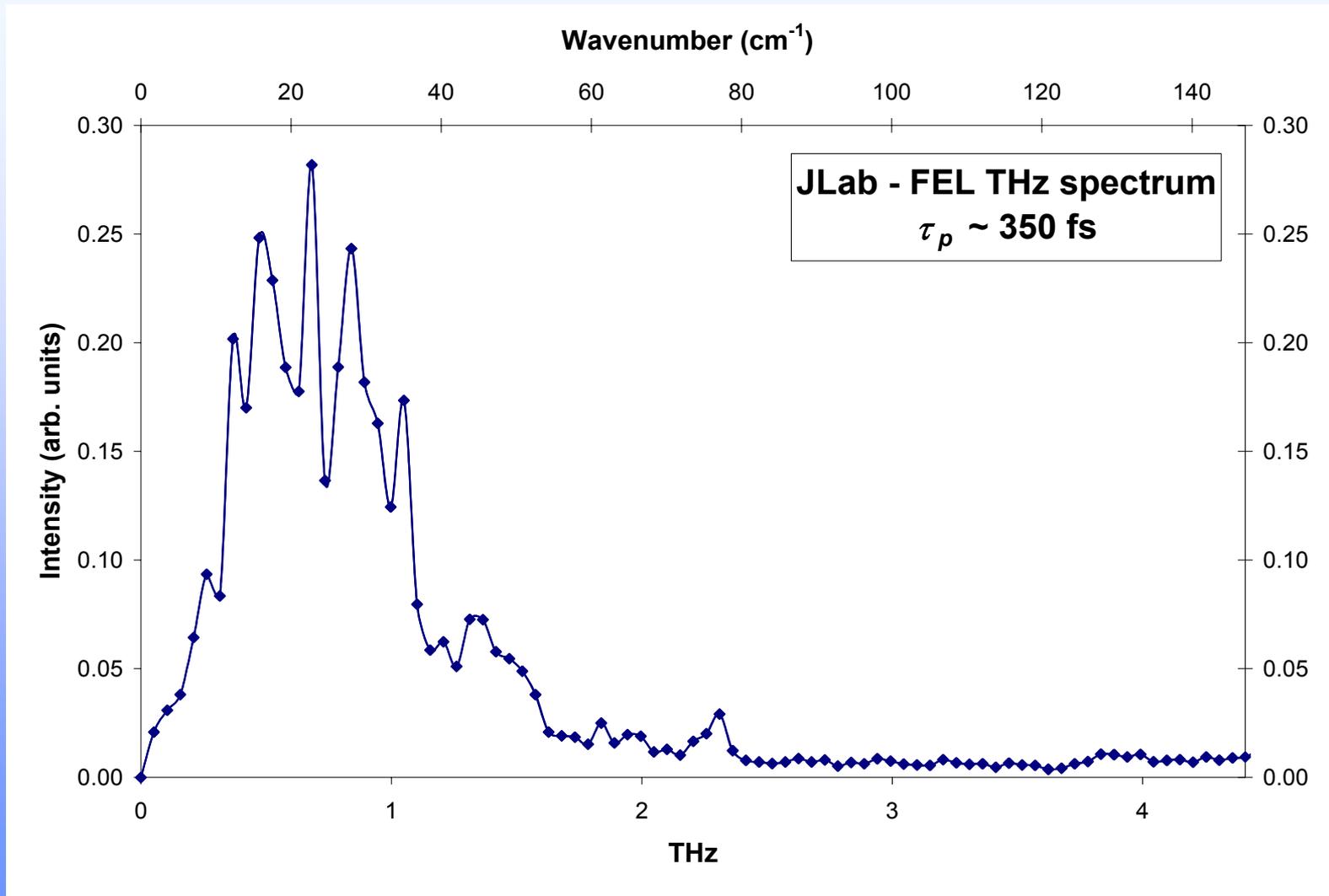
Measured



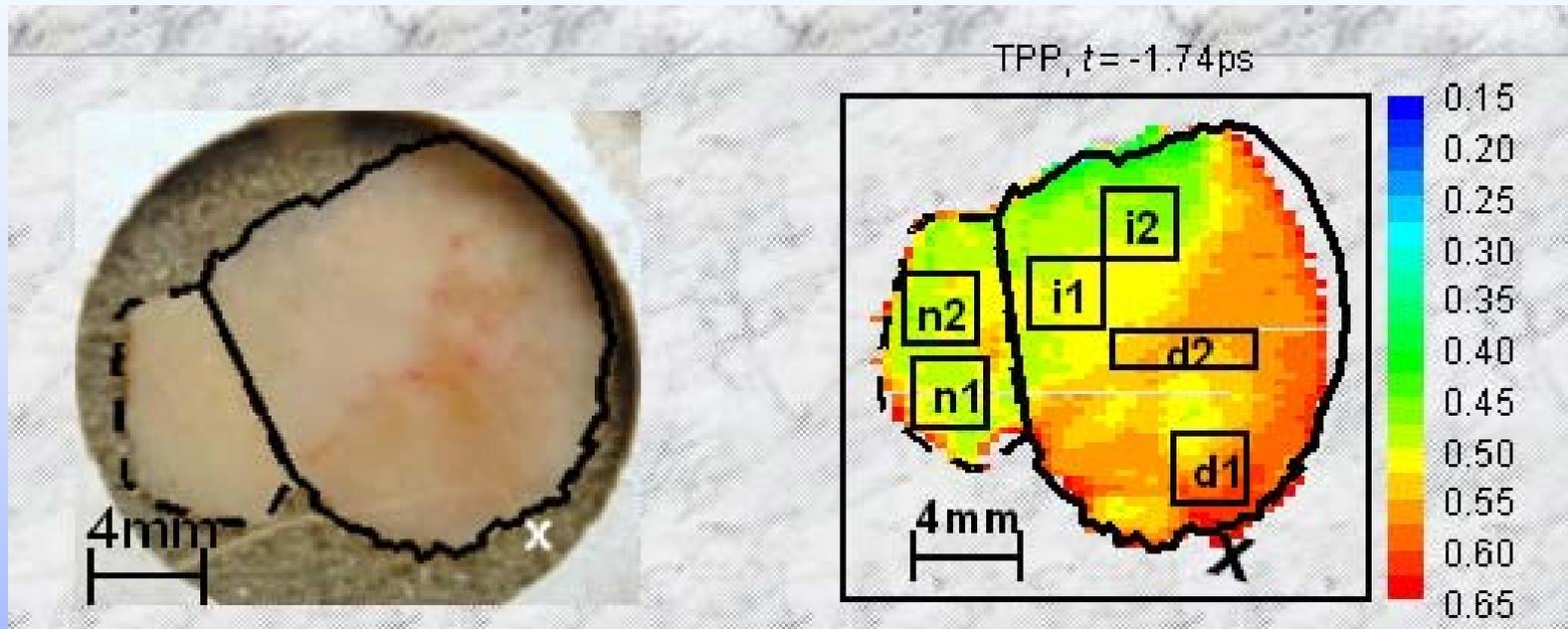
Calculated



Measured JLab – FEL THz Spectrum



Applications of JLab –FEL High Power THz Facility



**Basal cell carcinoma (skin cancer) shows malignancy in red.
(courtesy of Teraview Ltd.)**

1 mW source images 1 cm² in 1 minute

**100 W source images whole body (50 x 200cm) in few
seconds**

Applications of JLab –FEL High Power THz Facility



**A tooth cavity shows up clearly in red.
(courtesy of Teraview Ltd.)**

Applications of JLab –FEL High Power THz Facility

- proof of principal experiments for remote sensing with high resolution active imaging
- portable source development



Army



Evaluate the potential use of Terahertz light for applications such as land mine detection

Calculations using antenna coupled bolometer sensitivities
Indicate that about 100 W is required for this application



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Summary

- **A new generation broadband high power THz source has been commissioned at the Jefferson Lab – FEL, which offers novel capabilities and unprecedented opportunities for research, security, military, medical and other commercial applications.**
- **The Jefferson Lab – FEL THz source continues to be characterized and is already used routinely for accelerator diagnostics.**
- **Preliminary tests for developing the real-time imaging capabilities are underway.**
- **Measurements to determine the safety issues related to the high power source have been made and are continuing.**
- **A compact high power THz source is being developed at Advanced Energy Systems in collaboration with the Jefferson Lab – FEL.**
- **Started user program at Jefferson Lab – FEL, proposals invited.**



Acknowledgements

| | |
|-------------------|------------------------------|
| Larry Carr | NSLS, Brookhaven, USA |
| Oleg Chubar | Soleil Project, France |
| Paul Dumas | Soleil Project, France |
| Alan Todd | Advanced Energy Systems, USA |
| Vincent Christina | Advanced Energy Systems, USA |
| Tom Crowe | University of Virginia, USA |
| Fred Dylla | Jefferson Lab, USA |
| George Neil | Jefferson Lab, USA |
| Michelle Shinn | Jefferson Lab, USA |
| Joe Gubeli | Jefferson Lab, USA |
| Matt Thomas | SURA, USA |

Plus the JLab – FEL team.

Supported by:

U.S. Department of Energy - Contract DE-AC05-84ER40150

U.S. Department of Defense - ONR, AFOSR and ARO-NVL

Jefferson Science Associates - JSA



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Some of the FEL Team



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