Characteristics and properties of the Jefferson Lab ERL and applications to high pressure research

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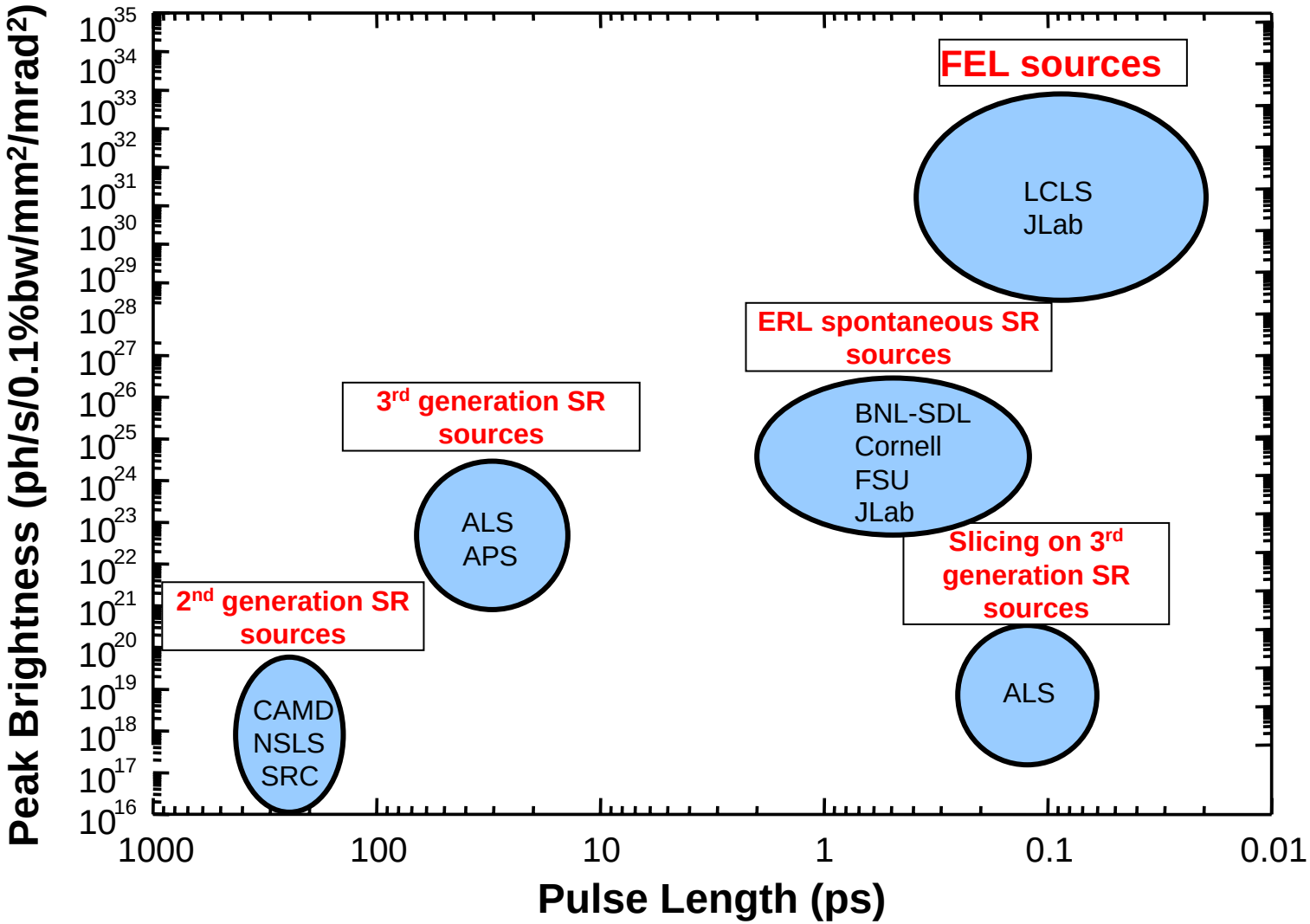
Jefferson Lab
12000 Jefferson Avenue
Newport News, Virgnia 23606

High Pressure Workshop,
Cornell, June 5, 2006

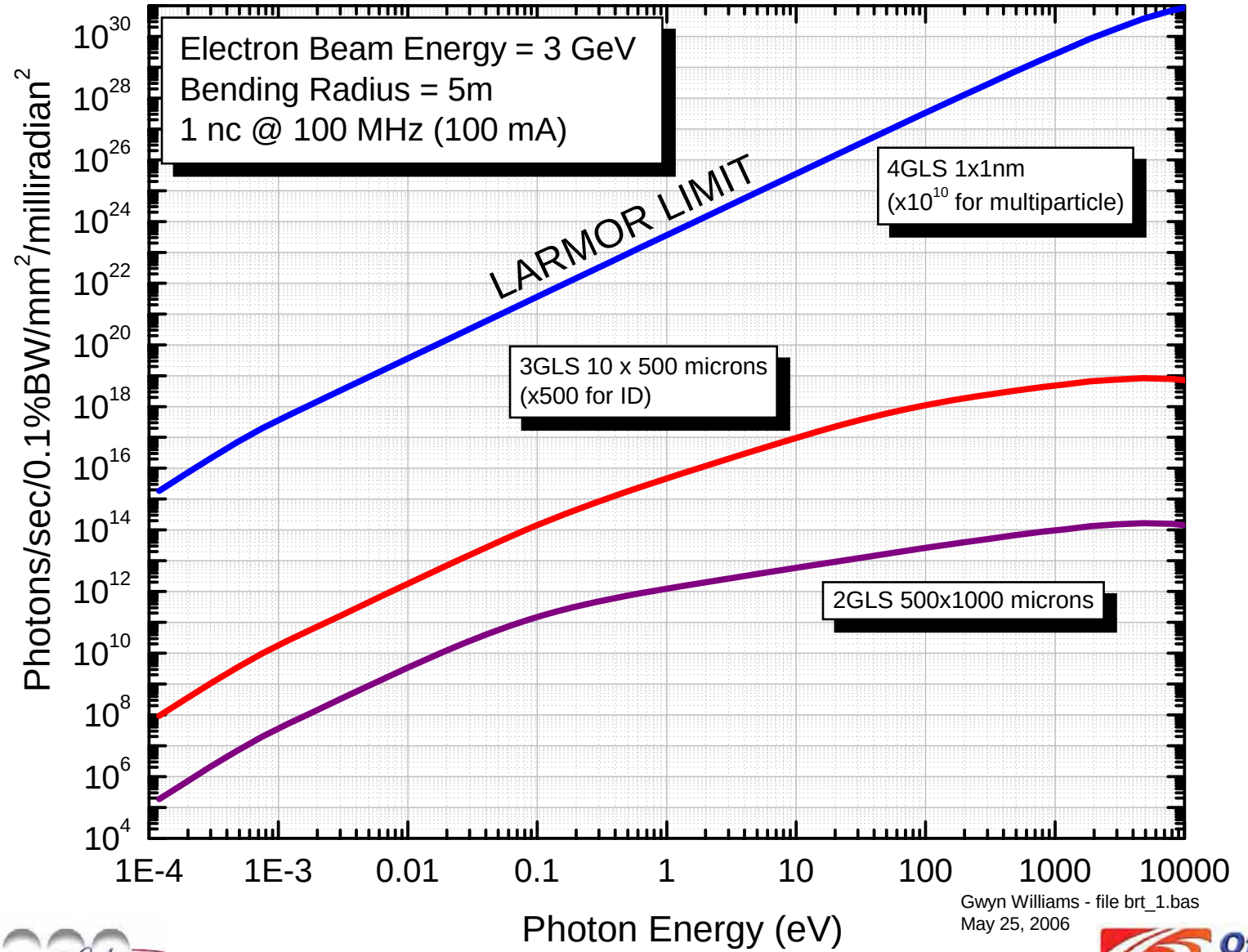
Talk Outline

- The landscape of 4th generation light sources
- The Jefferson Lab light sources
- Applications to high pressure research

Light Source Landscape

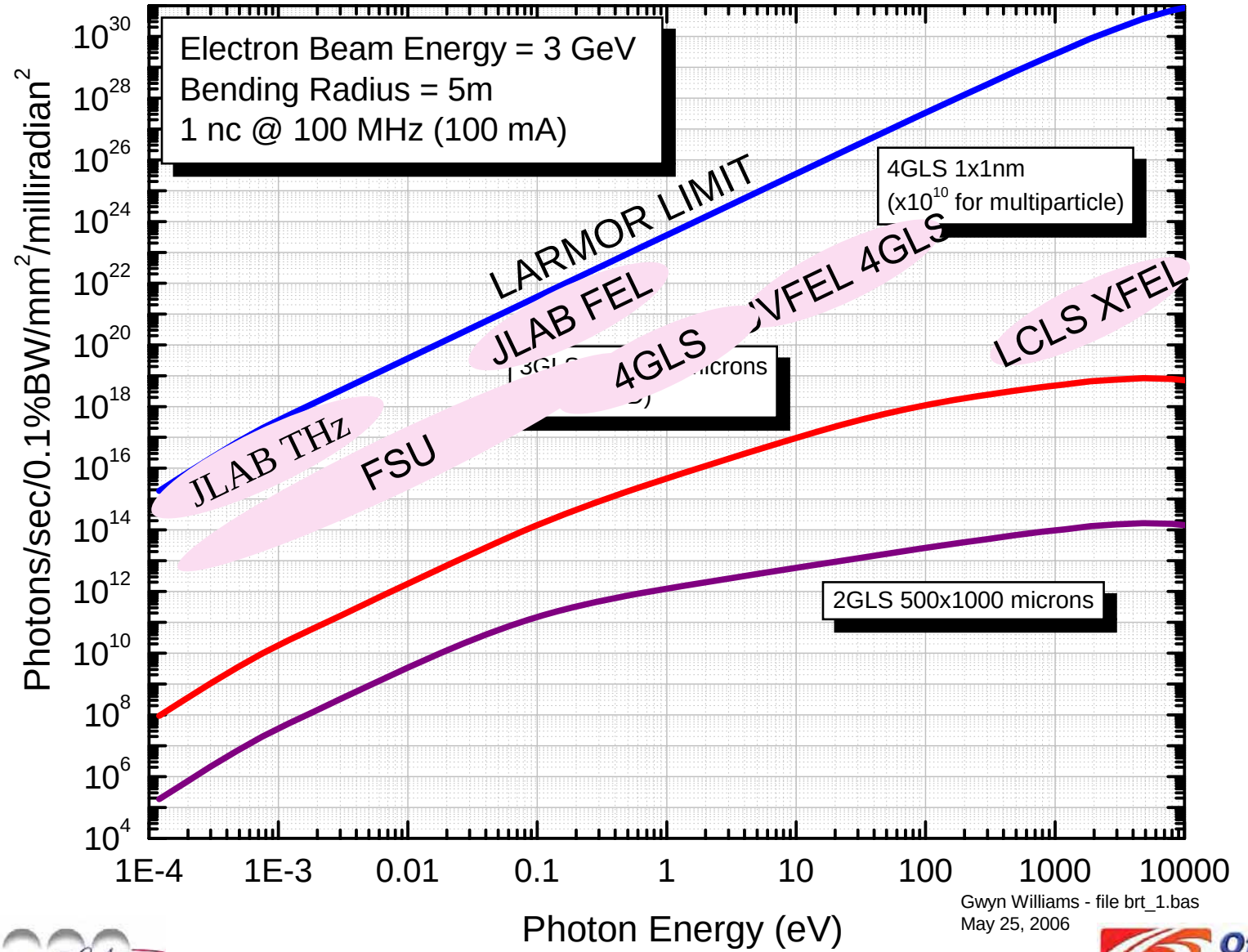


Light Source Landscape – Average Brightness



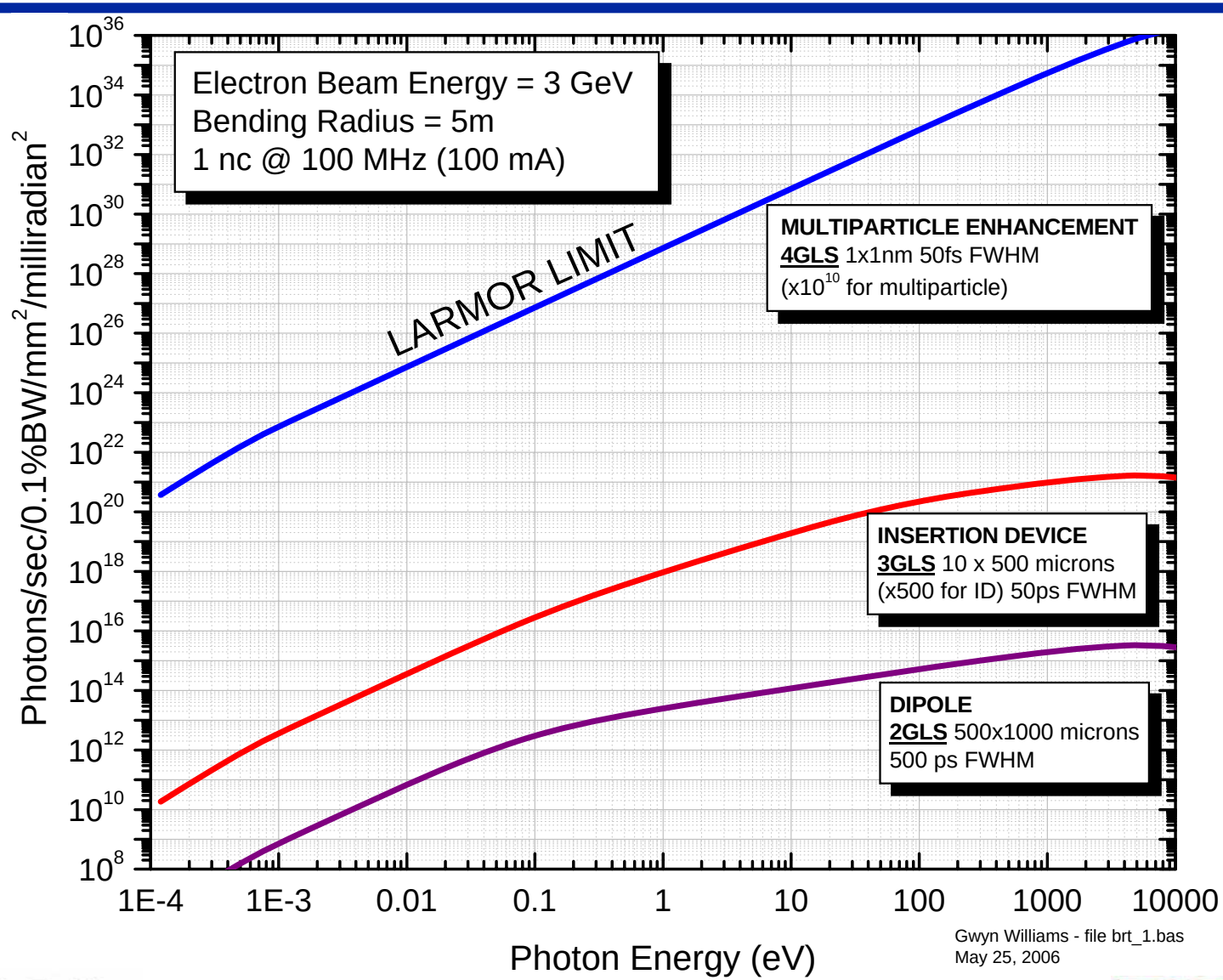
Gwyn Williams - file brt_1.bas
May 25, 2006

Light Source Landscape – Average Brightness



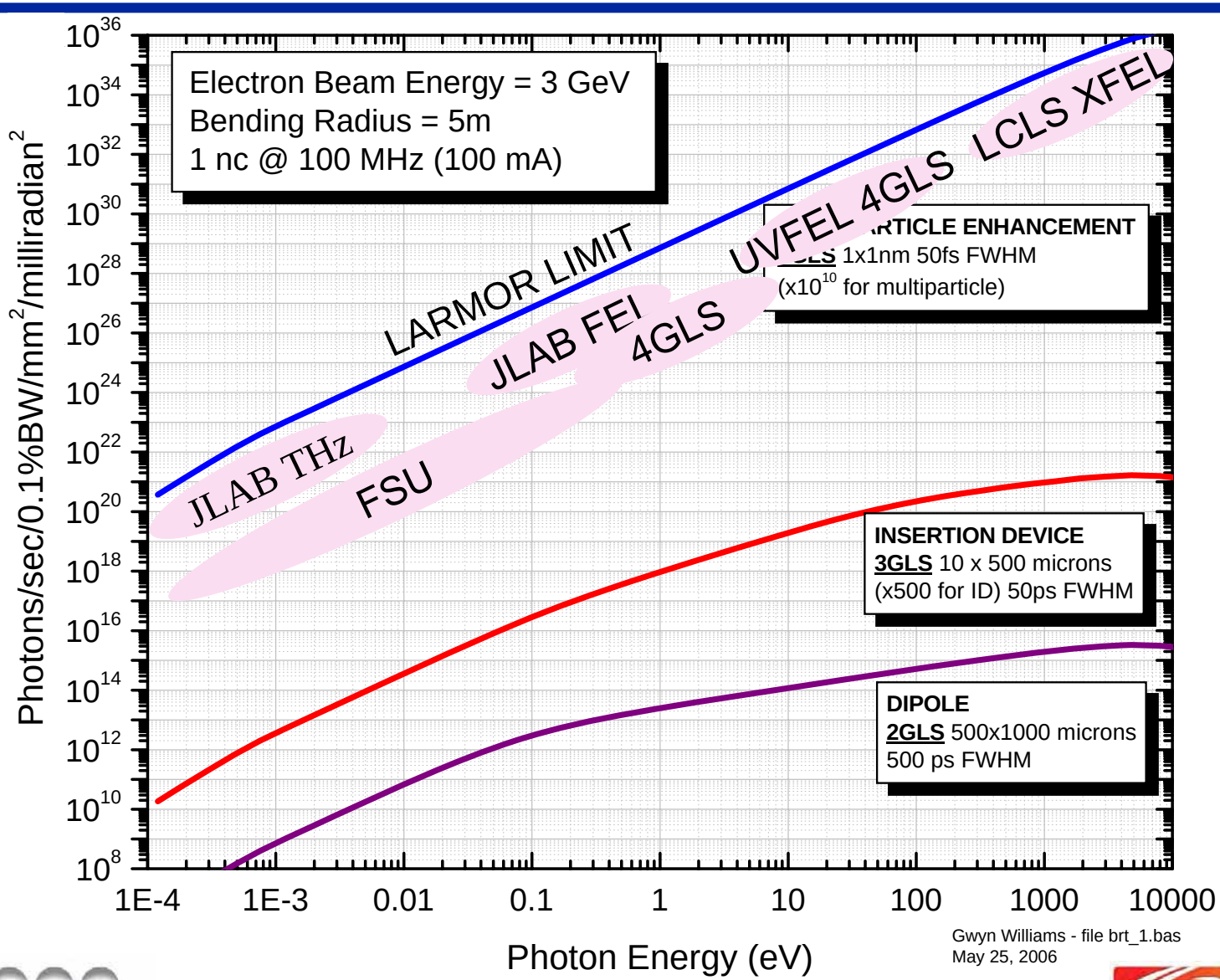
Gwyn Williams - file brt_1.bas
May 25, 2006

Light Source Landscape – Peak Brightness



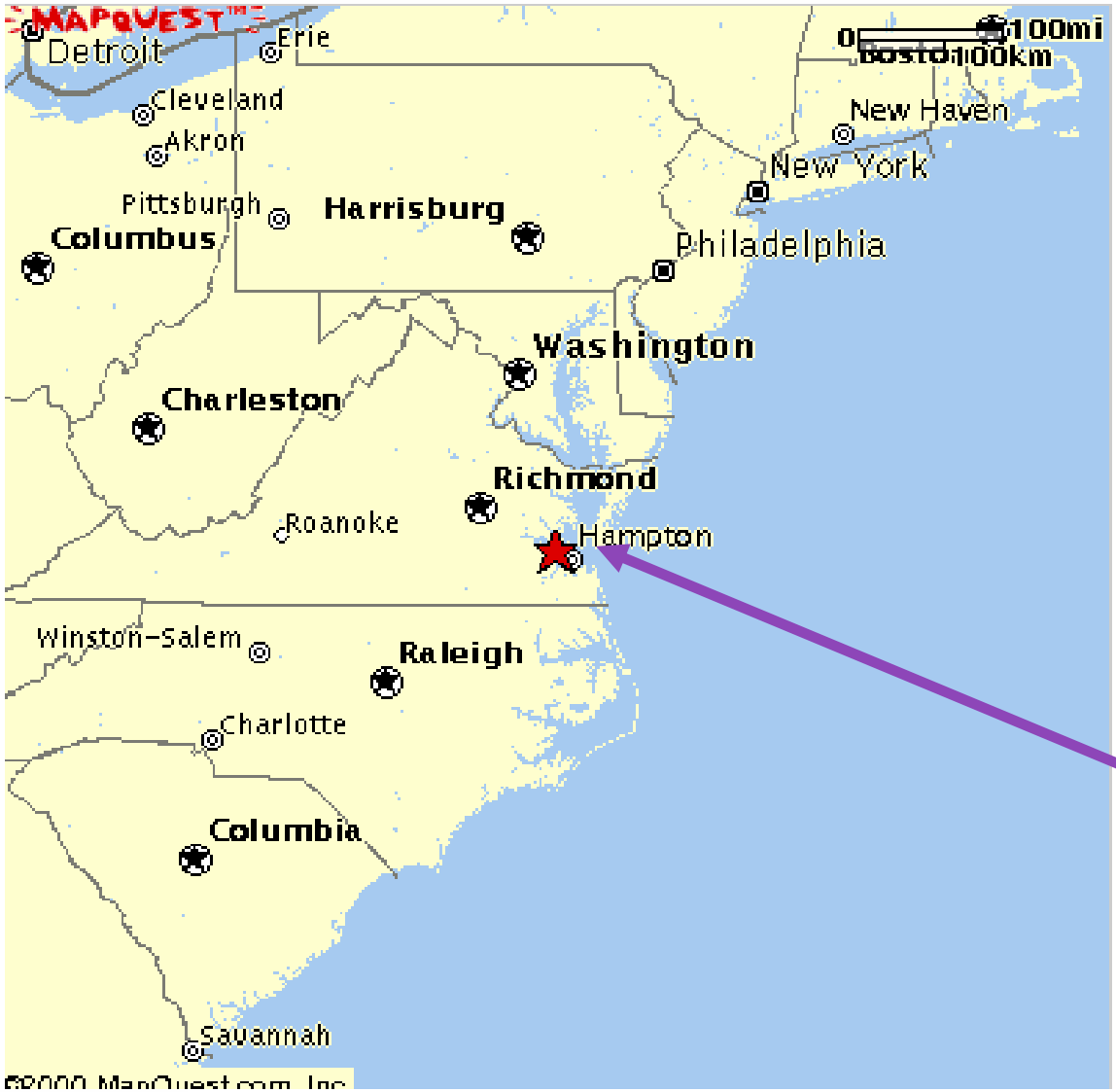
Gwyn Williams - file brt_1.bas
May 25, 2006

Light Source Landscape – Peak Brightness

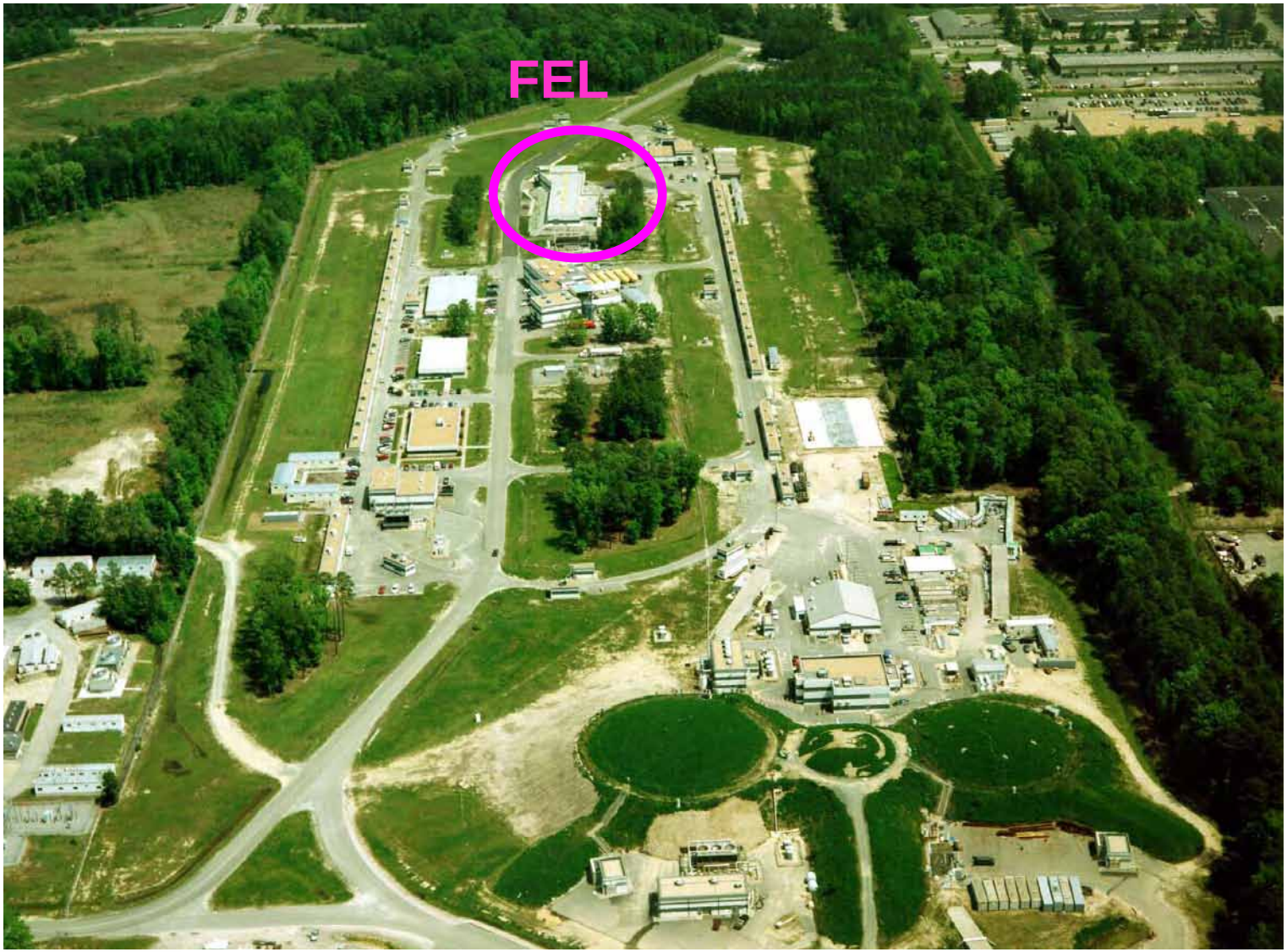


Gwyn Williams - file brt_1.bas
May 25, 2006

Jefferson Lab - where are we?



Jefferson Lab, Newport News, VA



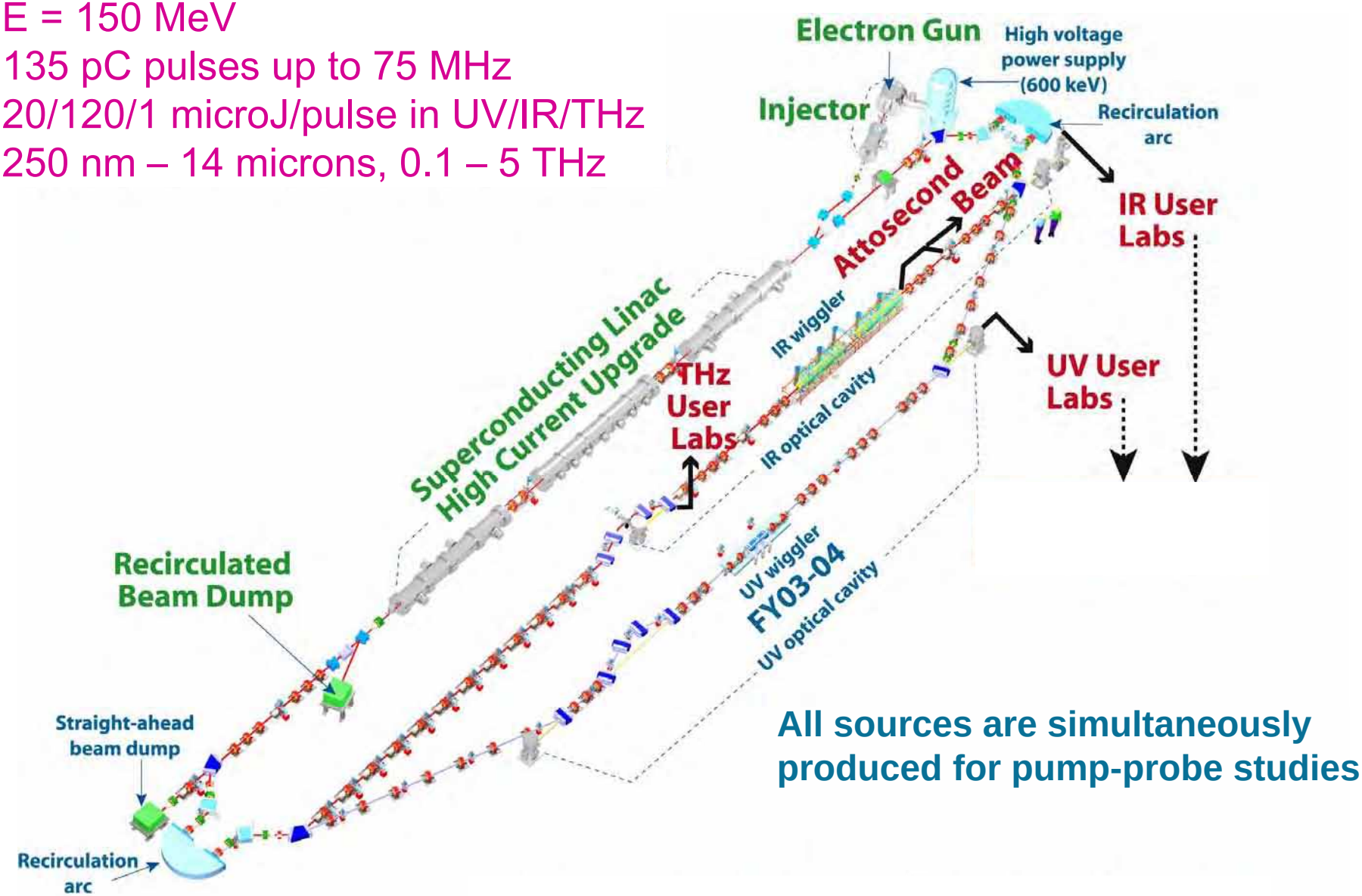
FEL Program Timeline

Evolution of JLab FEL:

• 1 kW IR FEL Demo	1996–1998
• IR Demo operations	2000–2001
• 10 kW IR Upgrade	2000–2004
— 10 kW IR Upgrade operations	2004–
• 1 kW UV Upgrade	2002–2006
— 1 kW UV Upgrade operations	2007–
• 100 kW technology development	2004–2012

JLab FEL facility schematic

E = 150 MeV
135 pC pulses up to 75 MHz
20/120/1 microJ/pulse in UV/IR/THz
250 nm – 14 microns, 0.1 – 5 THz



All sources are simultaneously produced for pump-probe studies

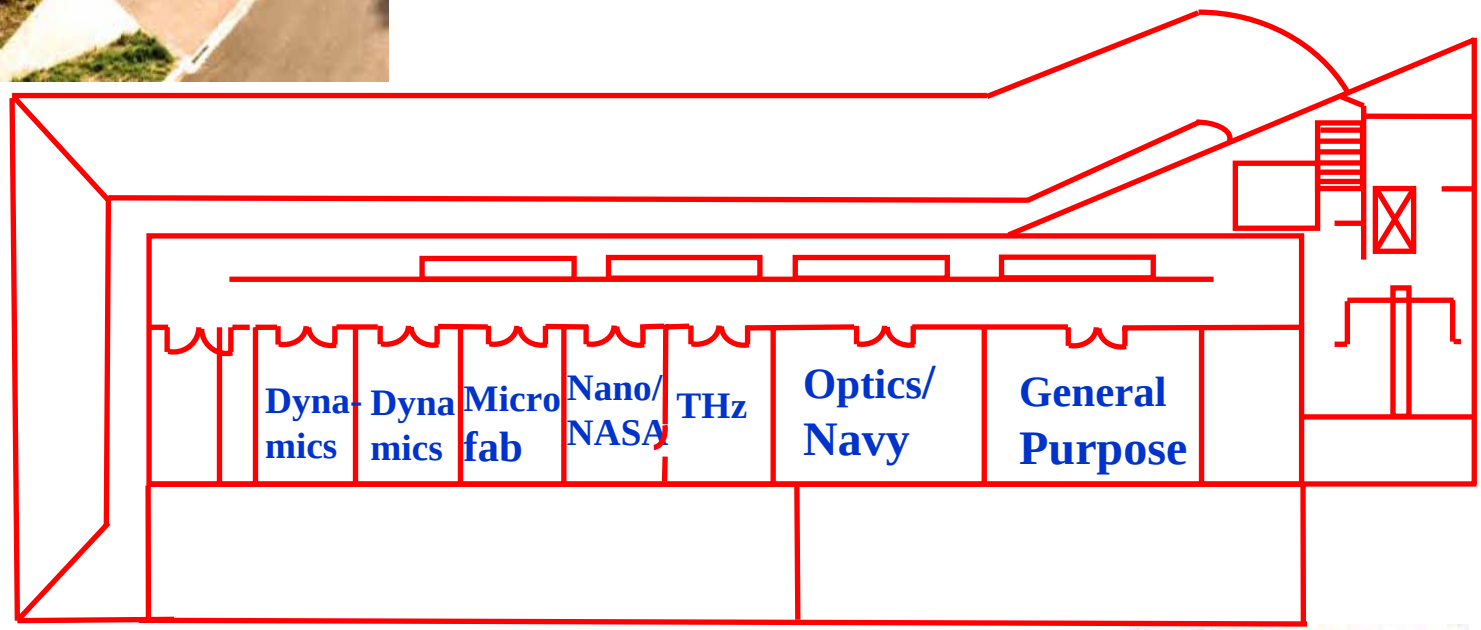
Jefferson Lab FEL Superconducting Linac

Superconducting Radio-Freq. Linac

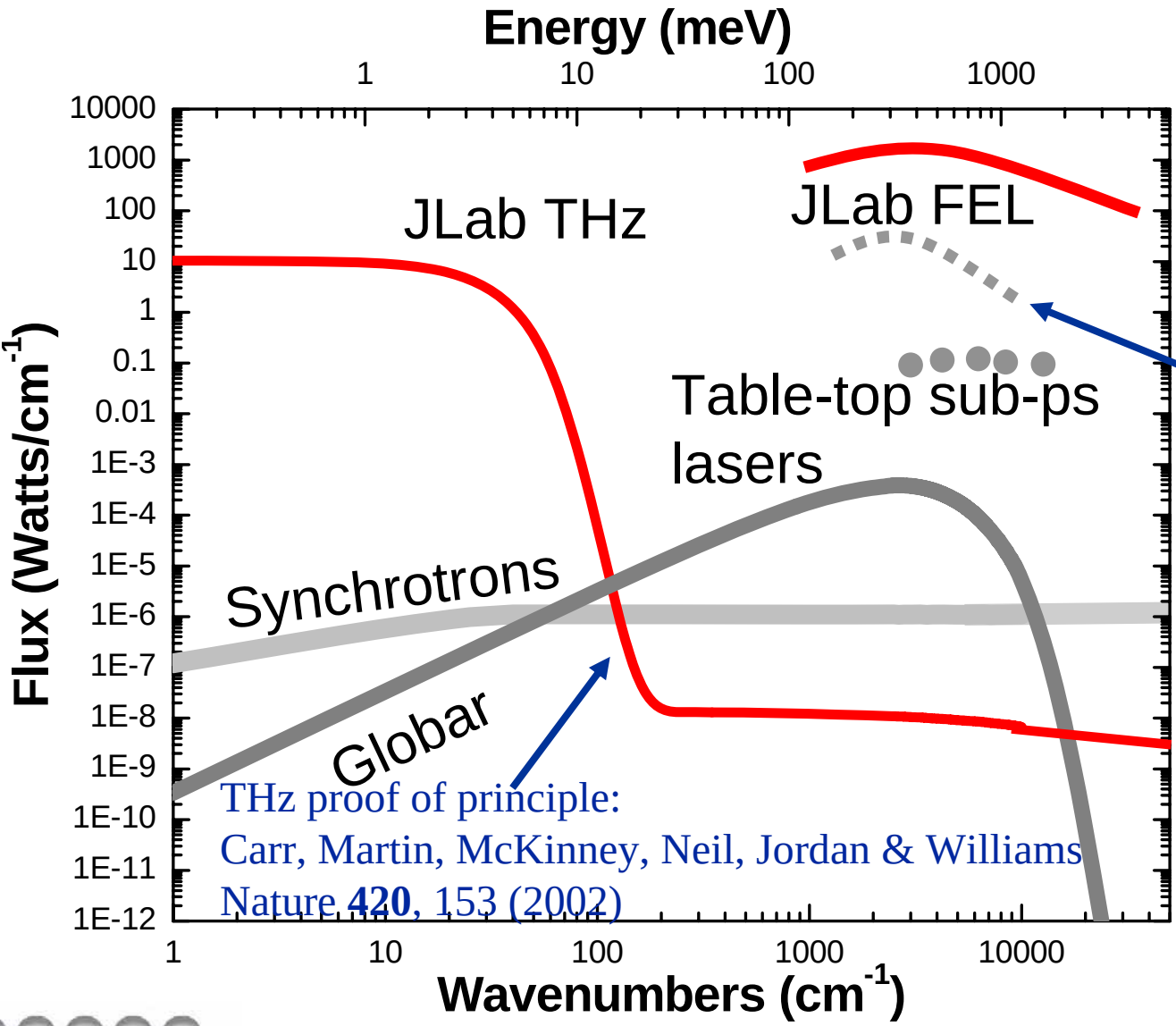
JLab FEL User Facility

Current User Facility has 7 Labs

- Lab1 General set-ups and prototypes
- Lab 2 Initial propagation studies (Navy)
- Lab 3 THz dynamics and imaging
- Lab 3b NASA nanofab
- Lab 4 Aerospace LMES
- Lab 6 FEL + lasers for dynamics studies



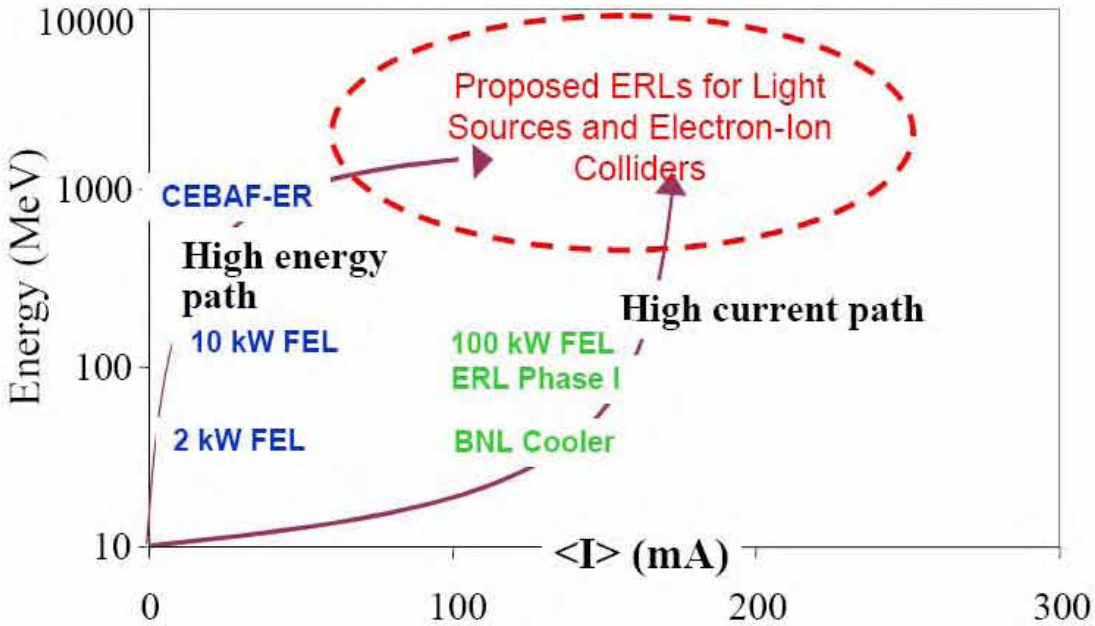
Jefferson Lab Facility Spectroscopic Range and Power

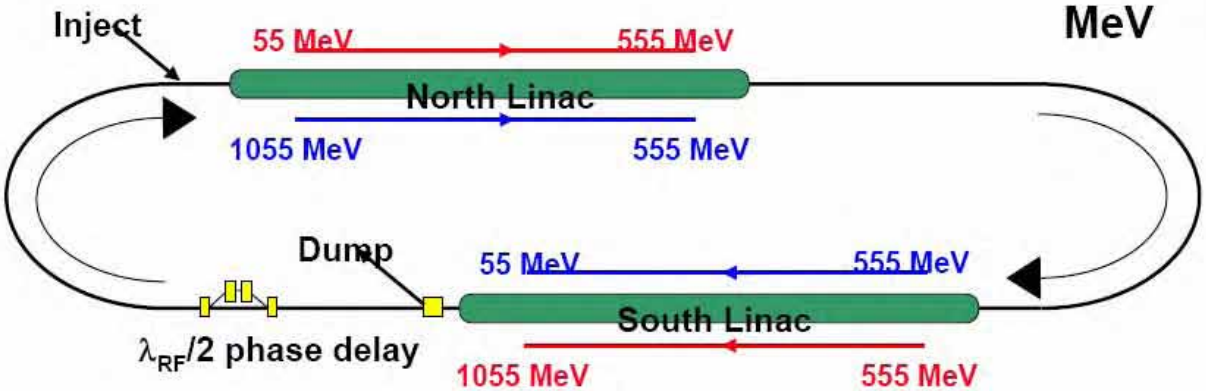


FEL proof of principle: Neil et al. Phys. Rev.Letts **84**, 662 (2000)

THz proof of principle: Carr, Martin, McKinney, Neil, Jordan & Williams Nature **420**, 153 (2002)

High Energy ERL Experiments at JLab's CEBAF



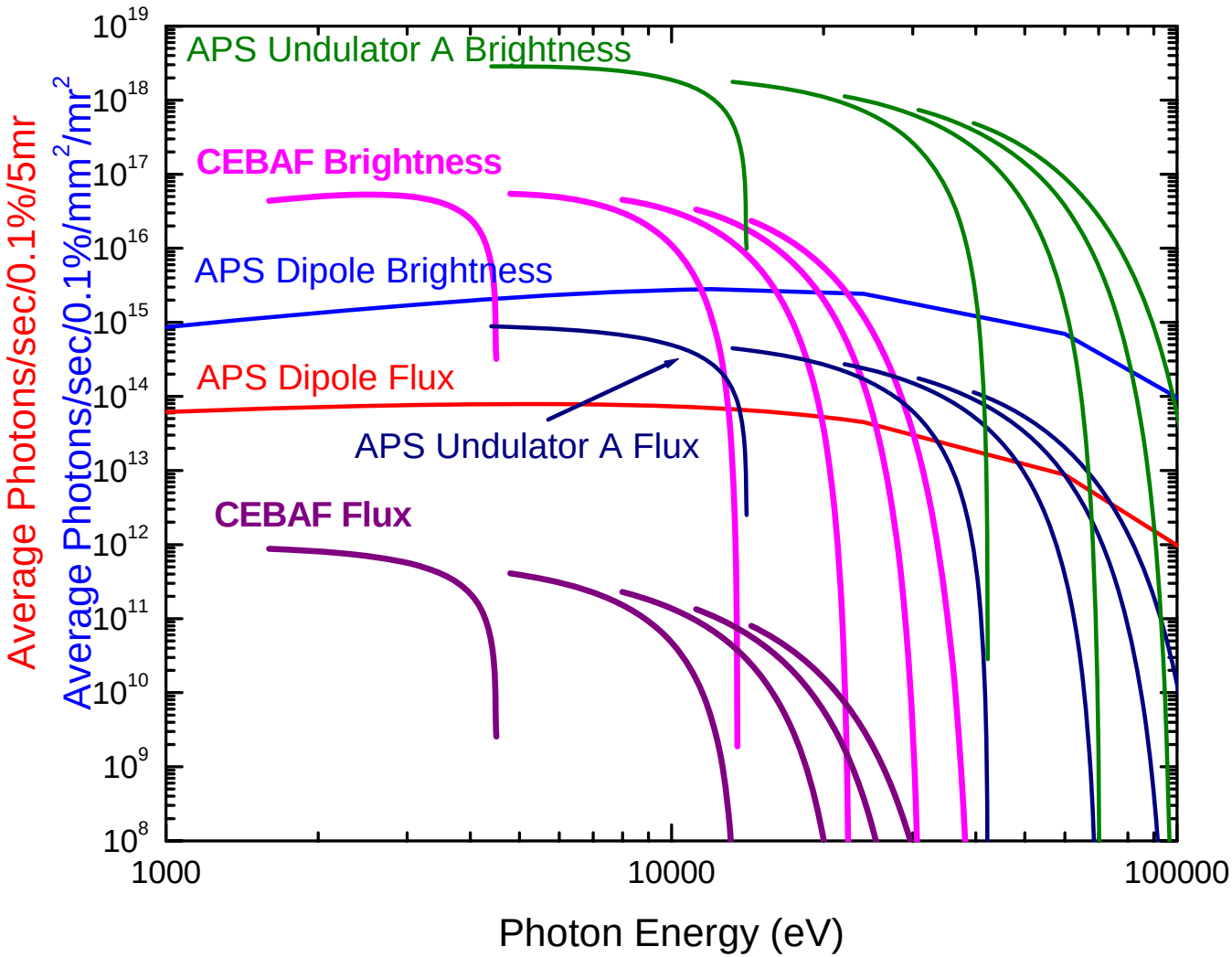


Proposed by D. Douglas in JLAB TN-01-018

Motivation: Validate high E_{acc}/E_{inj}

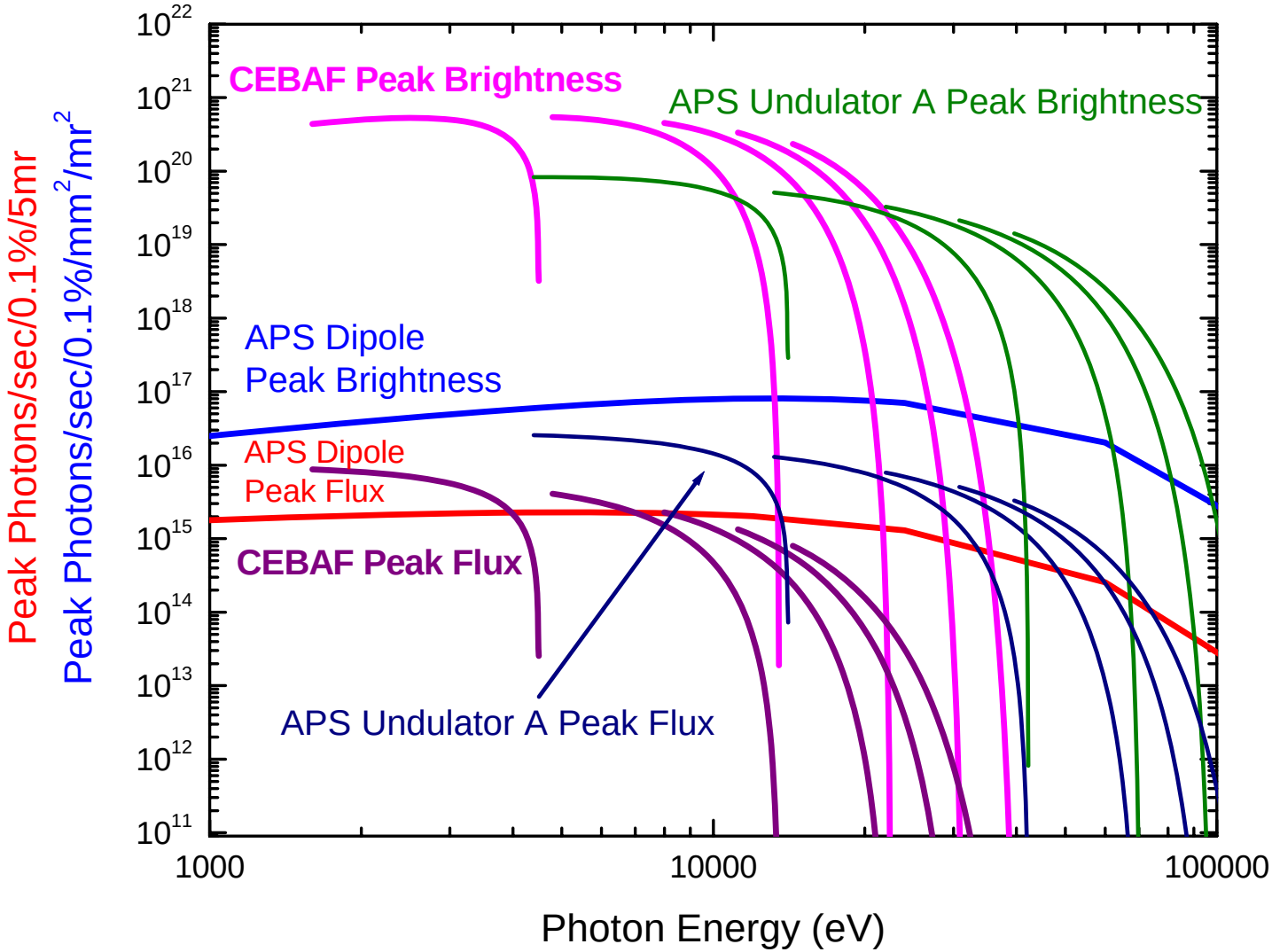
Achievement: 80 μA of CW beam accelerated to 1055 MeV and energy recovered at 55 MeV

CEBAF as a sub-picosecond X-ray Source



CEBAF undulator 70 x 28mm periods 10mm gap

CEBAF as a sub-picosecond X-ray Source



CEBAF undulator 70 x 28mm periods 10mm gap

Applications to High Pressure Research

Science

- Metallic hydrogen – Drude absorption
- Dynamics of intramolecular vibrons

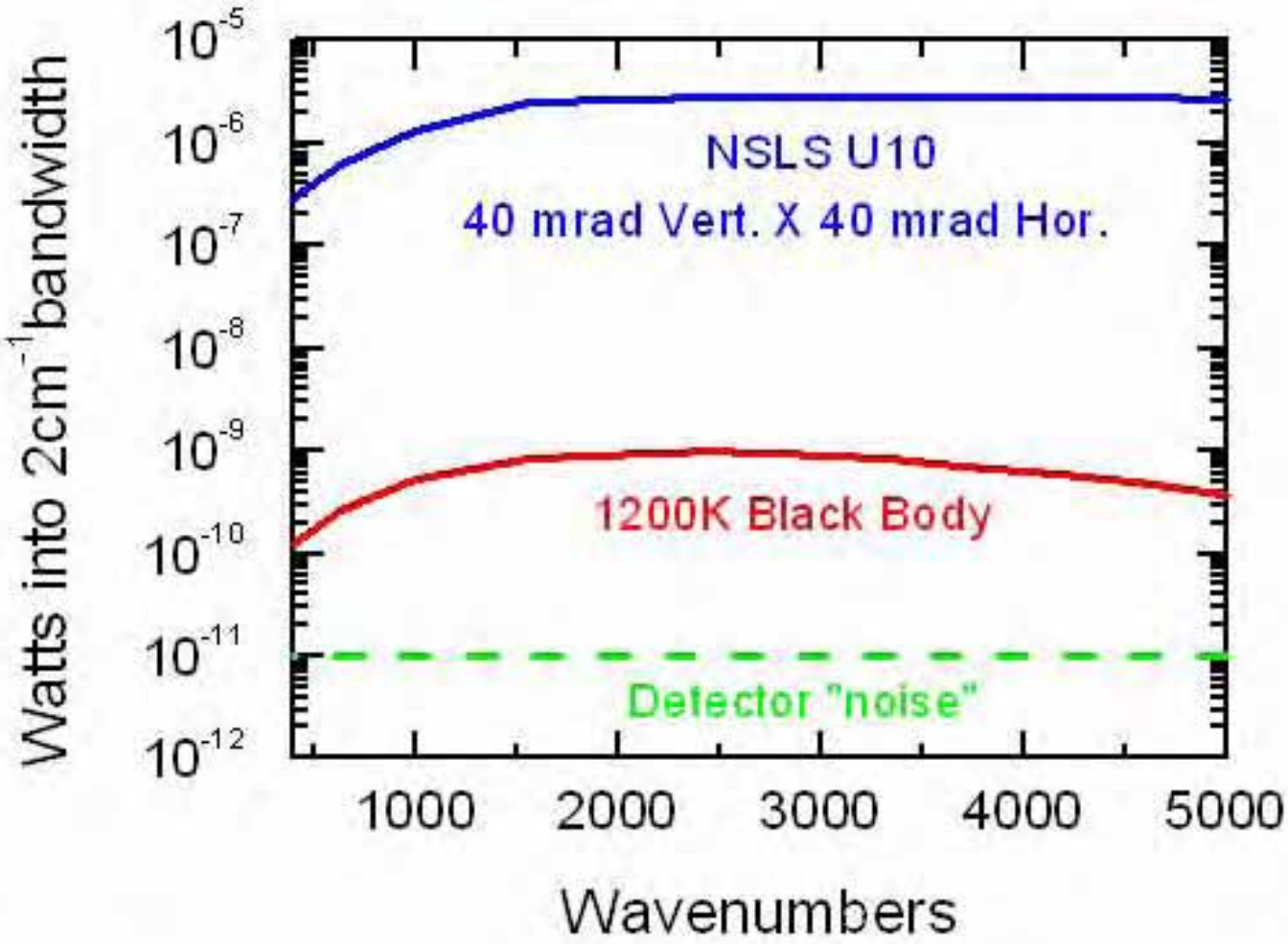
Techniques

- Spectroscopy
- Pump-probe dynamics

Issues

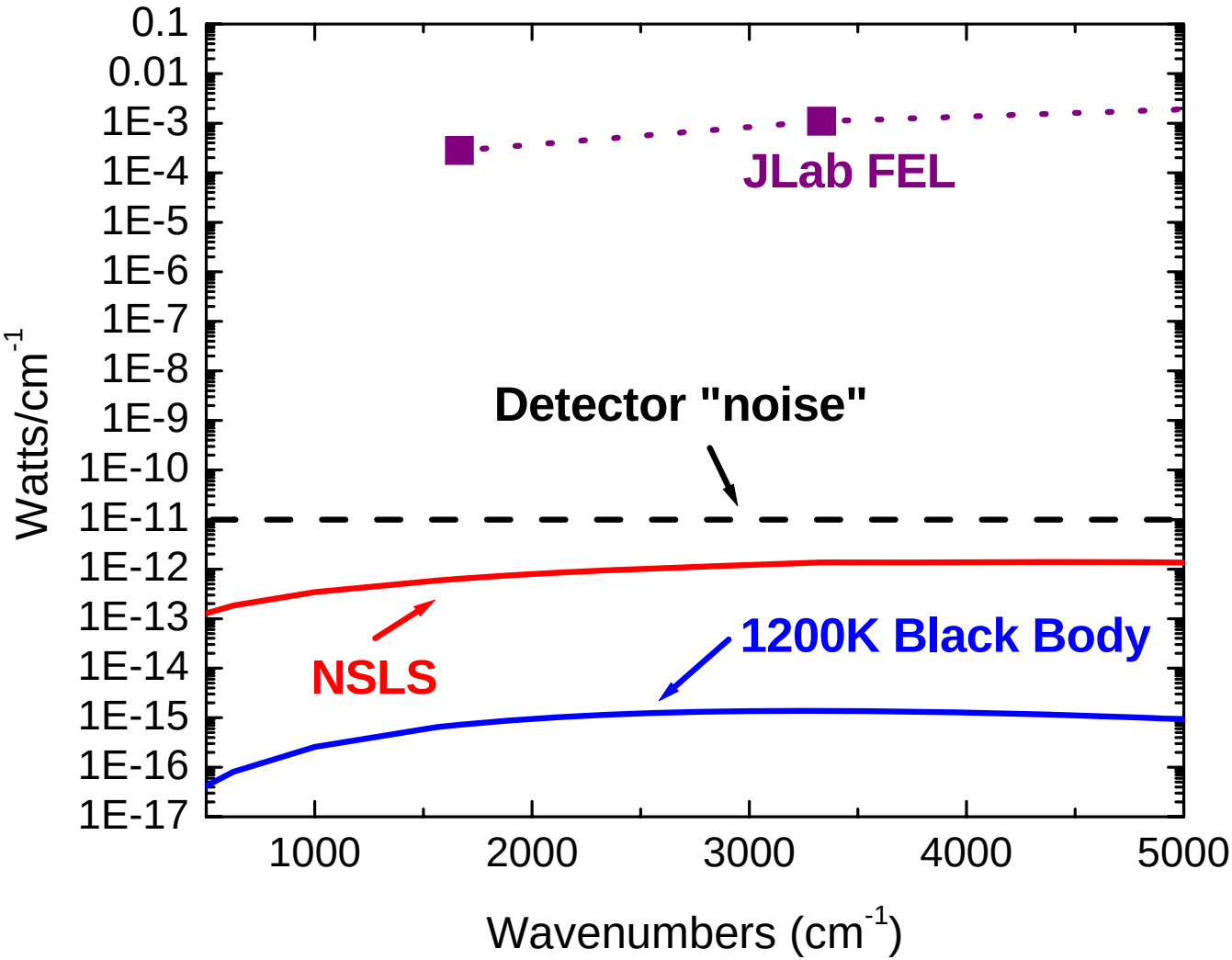
- Signal to noise

Signal into a 10 micron pinhole at f/1

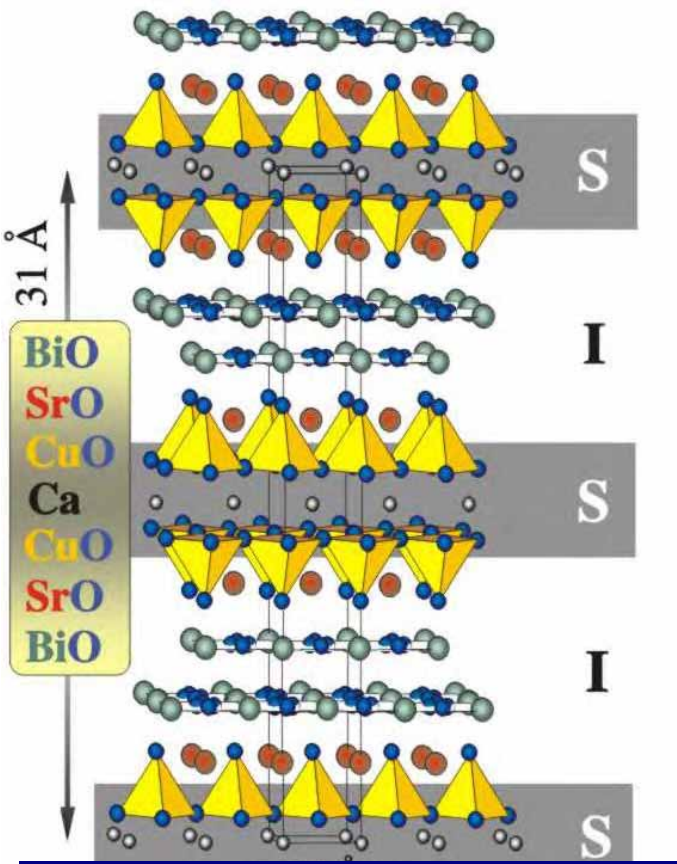


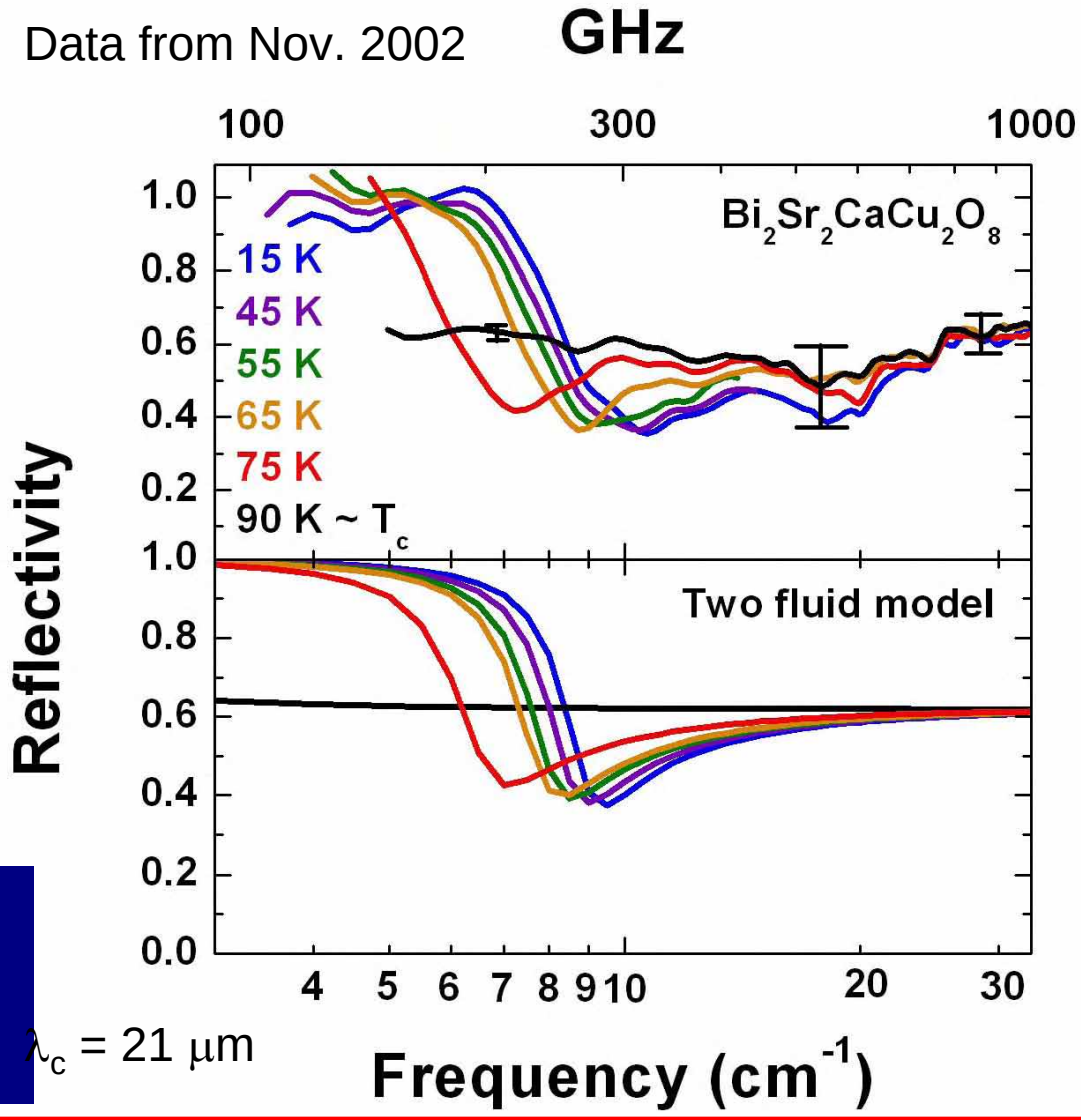
ca 1996

Signal into a 0.01 micron pinhole at f/1



First CSR Science: Josephson Plasma Resonance in $Bi_2Sr_2CaCu_2O_8$



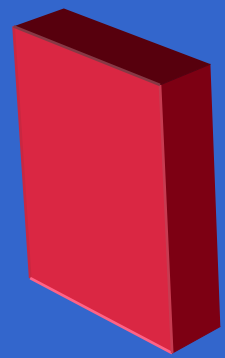


λ_c = 21 μm

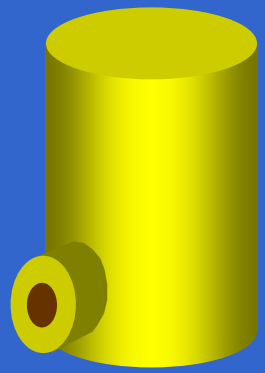
+ Indications for inhomogeneous superfluid

M. Abo-Bakr et al. Phys. Rev. B **69** (9), 092512 (2004).

Pump-probe Spectroscopy



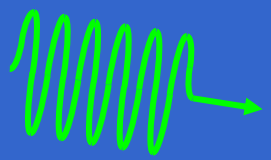
sample

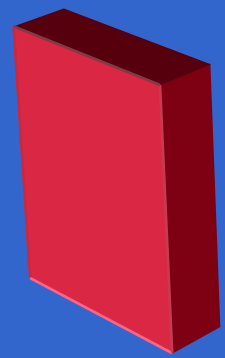


spectrometer
detector

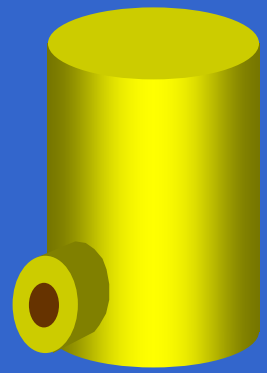
Pump-probe Spectroscopy

pump pulse
from laser



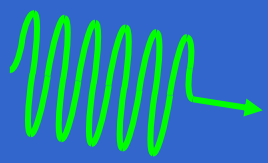


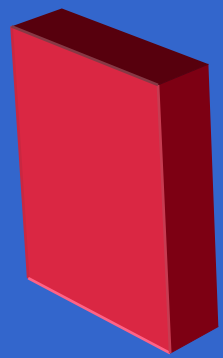
sample



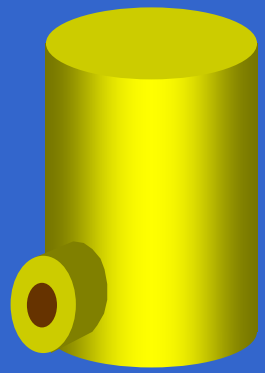
spectrometer
detector

Pump-probe Spectroscopy





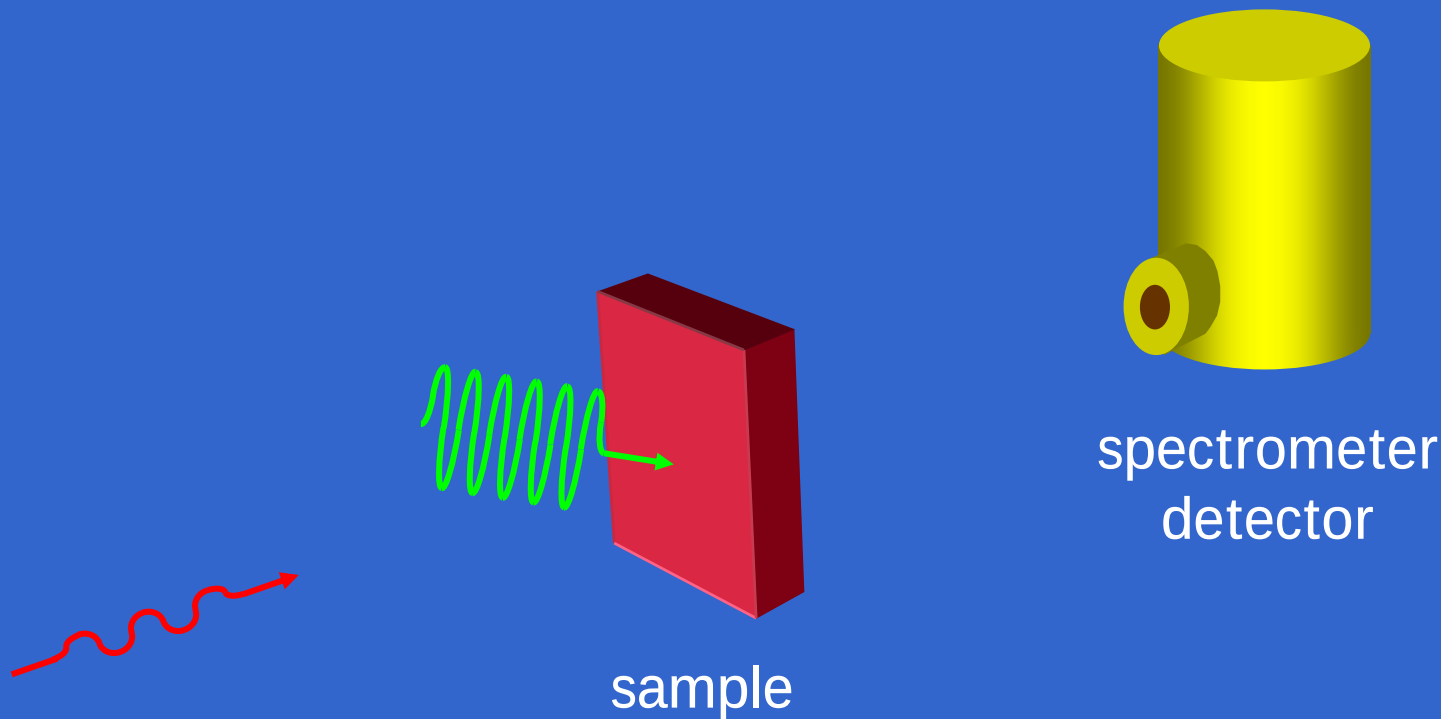
sample



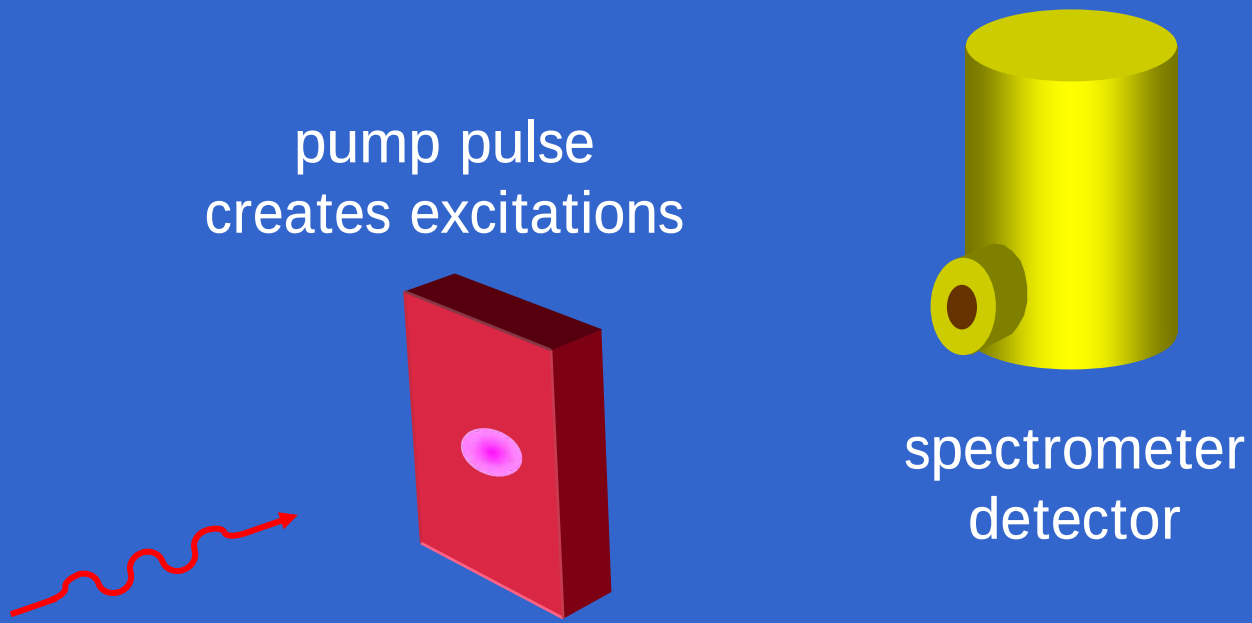
spectrometer
detector

IR probe pulse from
synchrotron follows
after time Δt

Pump-probe Spectroscopy

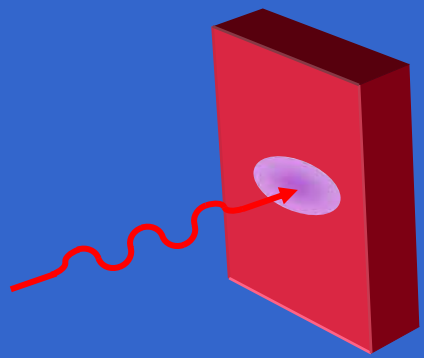


Pump-probe Spectroscopy

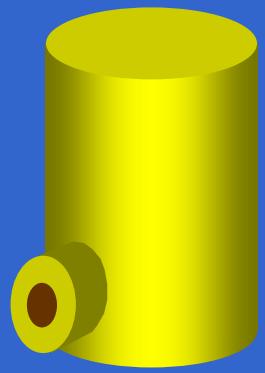


Pump-probe Spectroscopy

probe pulse senses
excitations at time Δt

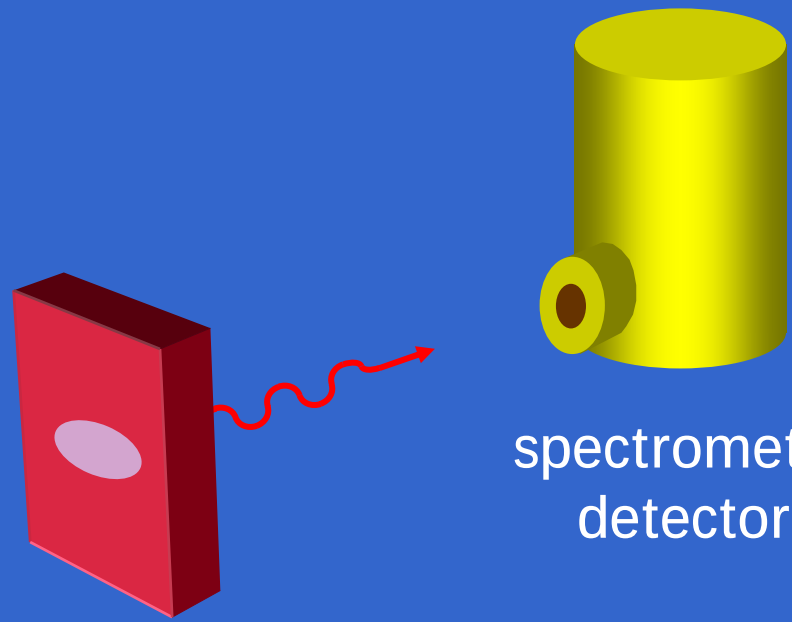


sample



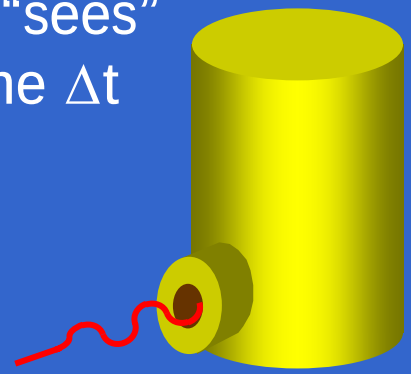
spectrometer
detector

Pump-probe Spectroscopy

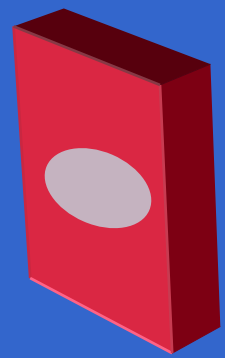


Pump-probe Spectroscopy

detector only "sees"
sample at time Δt

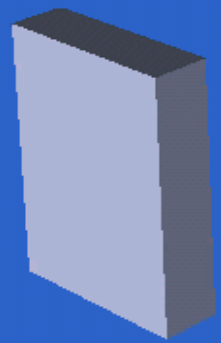


spectrometer
detector

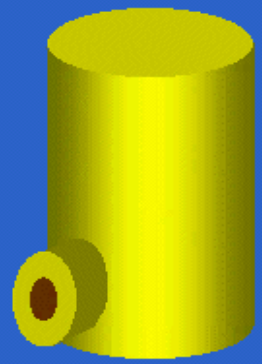


sample

Pump-probe Spectroscopy

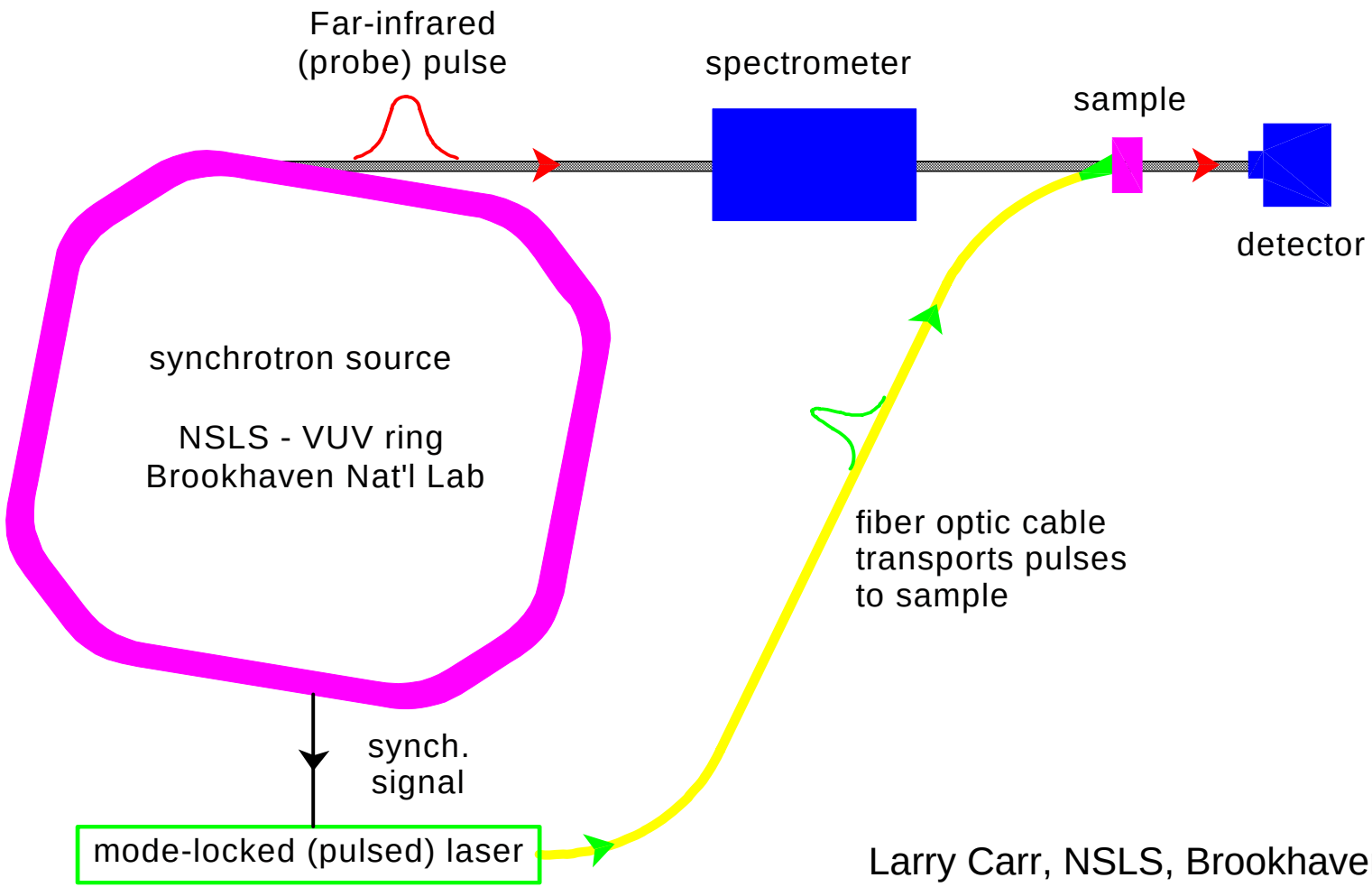


sample



spectrometer
detector

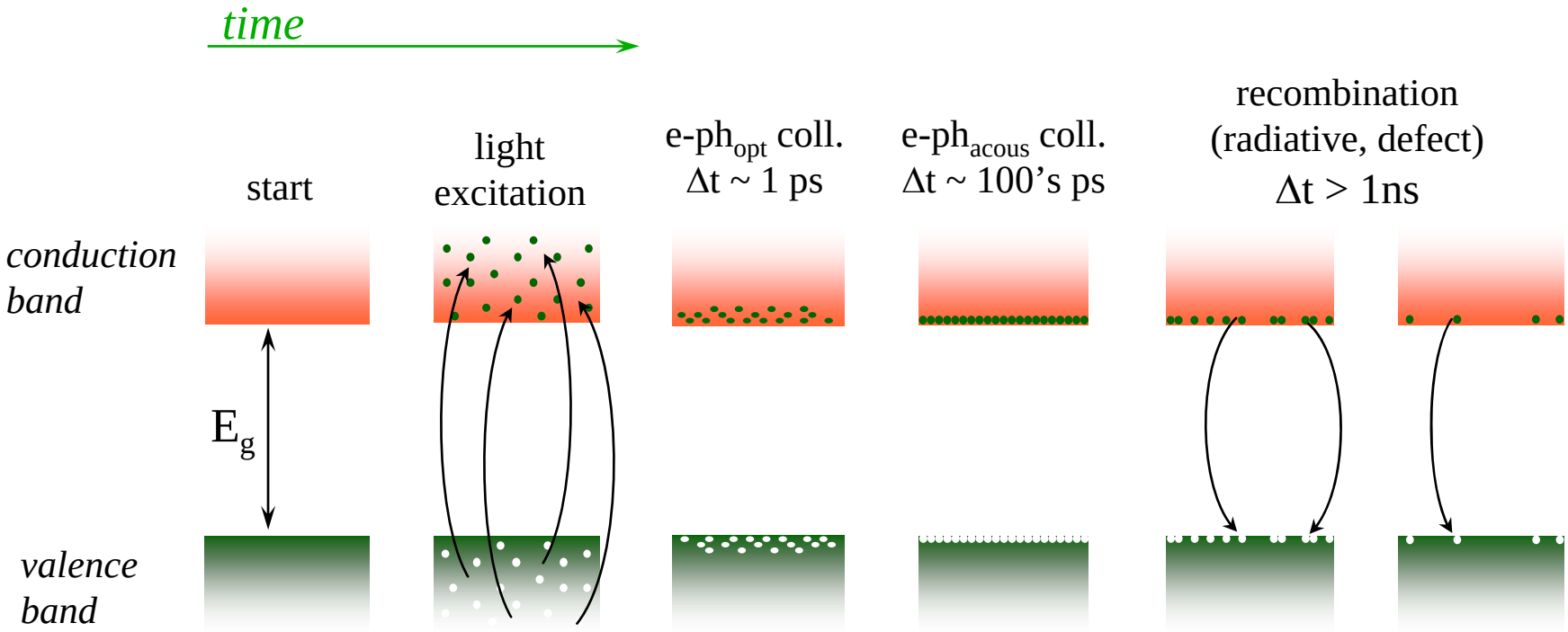
Pump-probe with synchrotron IR & laser pulses



Larry Carr, NSLS, Brookhaven

Photoexcitation and relaxation

Undoped semiconductor at low temperature



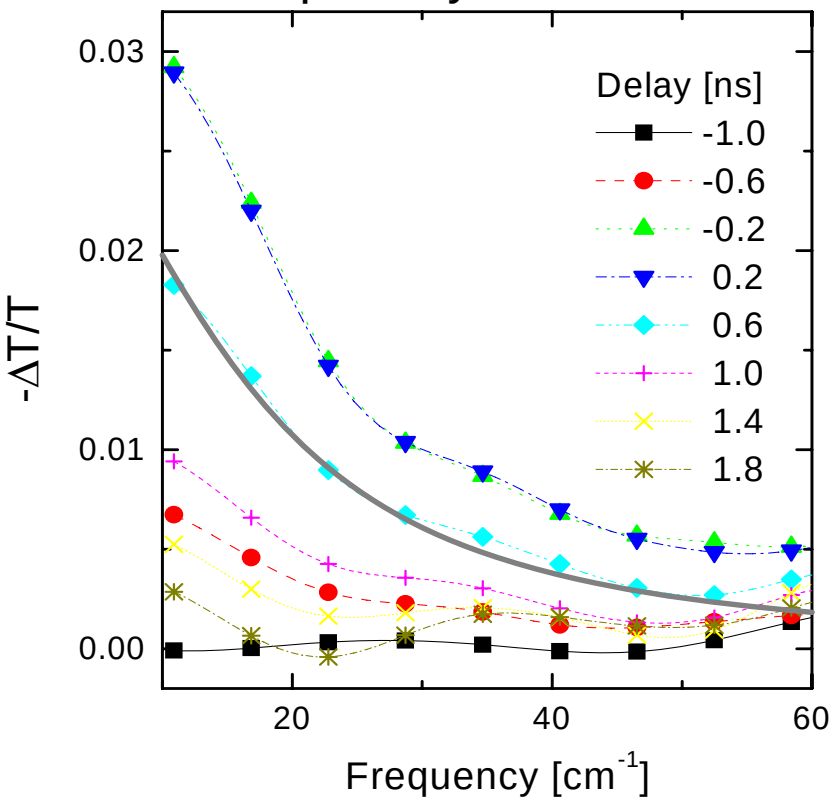
Subnanosecond, time-resolved, broadband infrared spectroscopy using synchrotron radiation
R. P. S. M. Lobo, J. D. LaVeigne, D. H. Reitze, and D. B. Tanner and G. L. Carr, Rev. Sci. Instr. 73 1 (2001).

Time-resolved demonstration

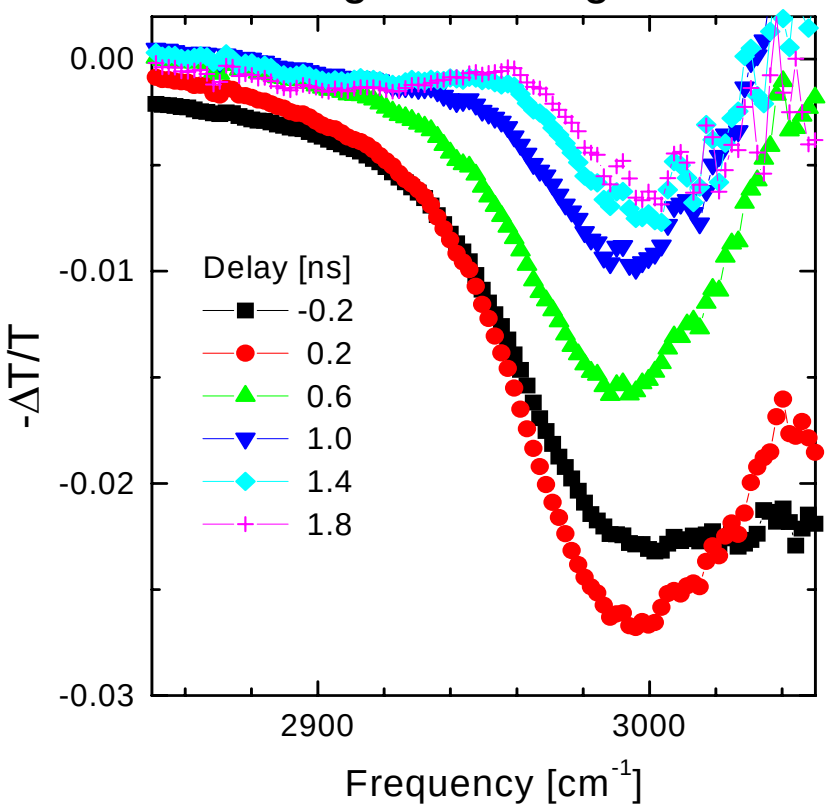
From Larry Carr, BNL

- Photoexcitation in HgCdTe: far-IR absorption, mid-IR bleaching.
- Wide-spectral coverage: allows use of oscillator strength sum-rule.

Drude absorption by excited electrons

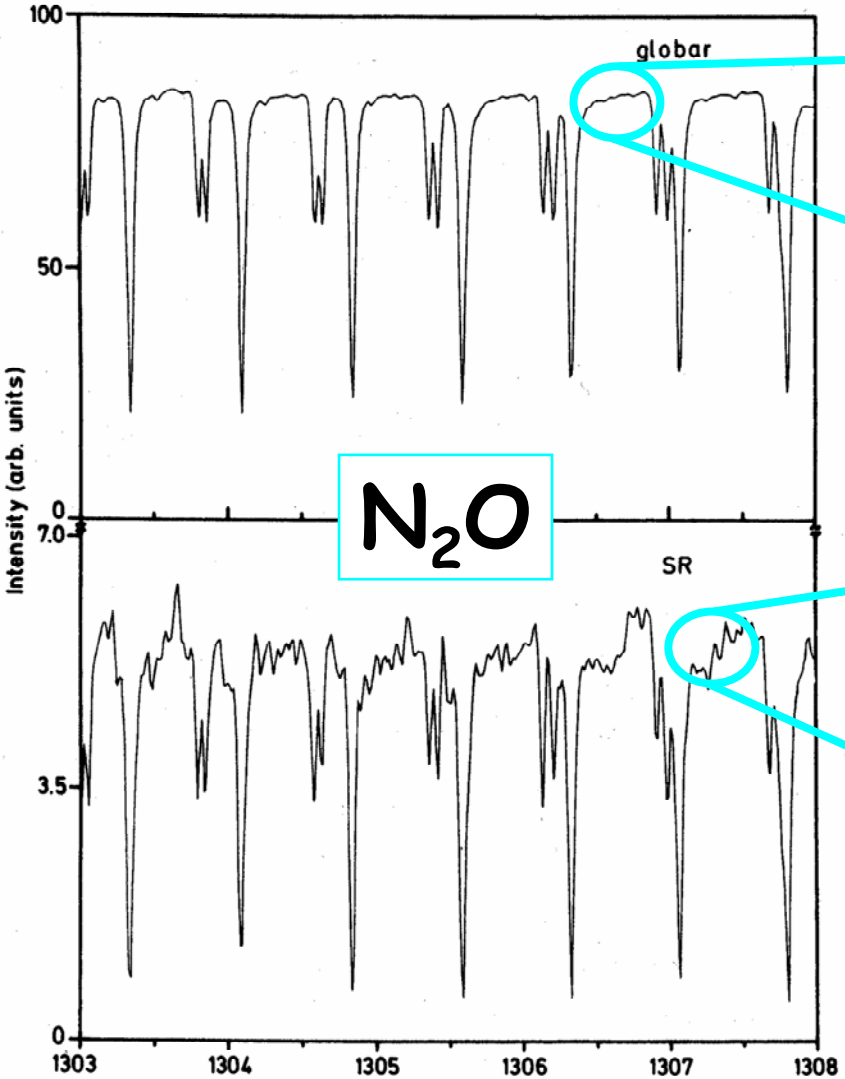


Band-edge bleaching



R. P. S. M. Lobo, J. D. LaVeigne, D. H. Reitze, D. B. Tanner & G. L. Carr, Rev. Sci. Instr. 73 1 (2001).

BUT……!!!!!!!!!!!!



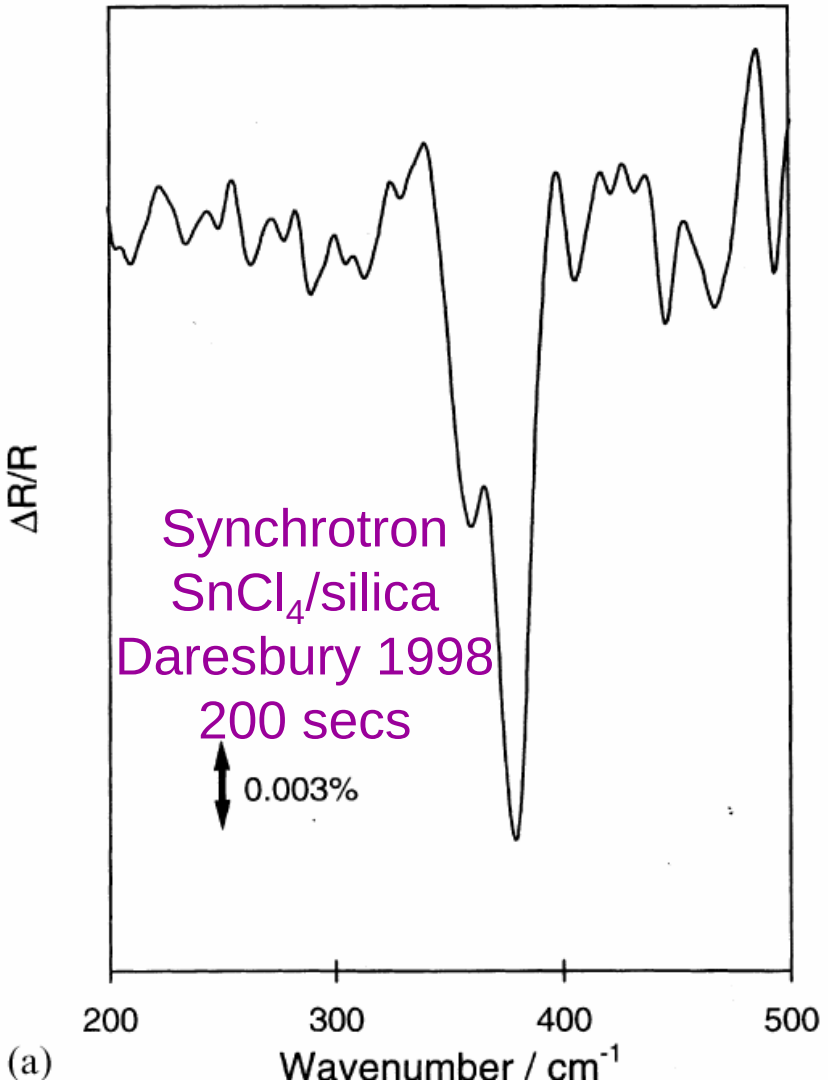
GLOBAR

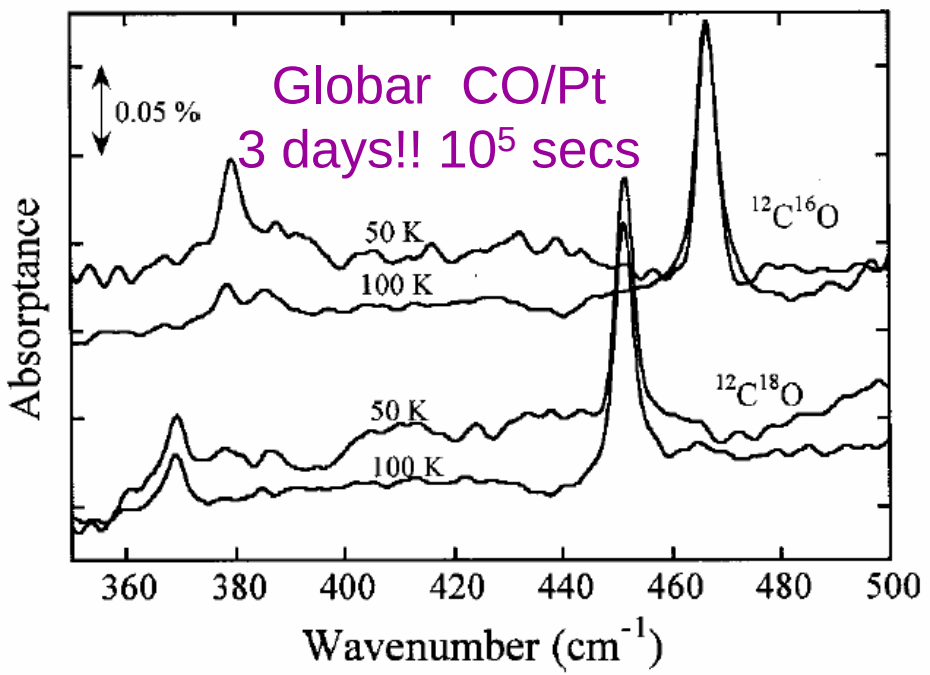
SYNCHROTRON!
>10x worse!!

BESSY 1 1985-86

Schweitzer, Nagel, Brain, Lippert and Bradshaw Nucl. Instr. & Methods A246 163 (1986)

Daresbury data holds world record!!





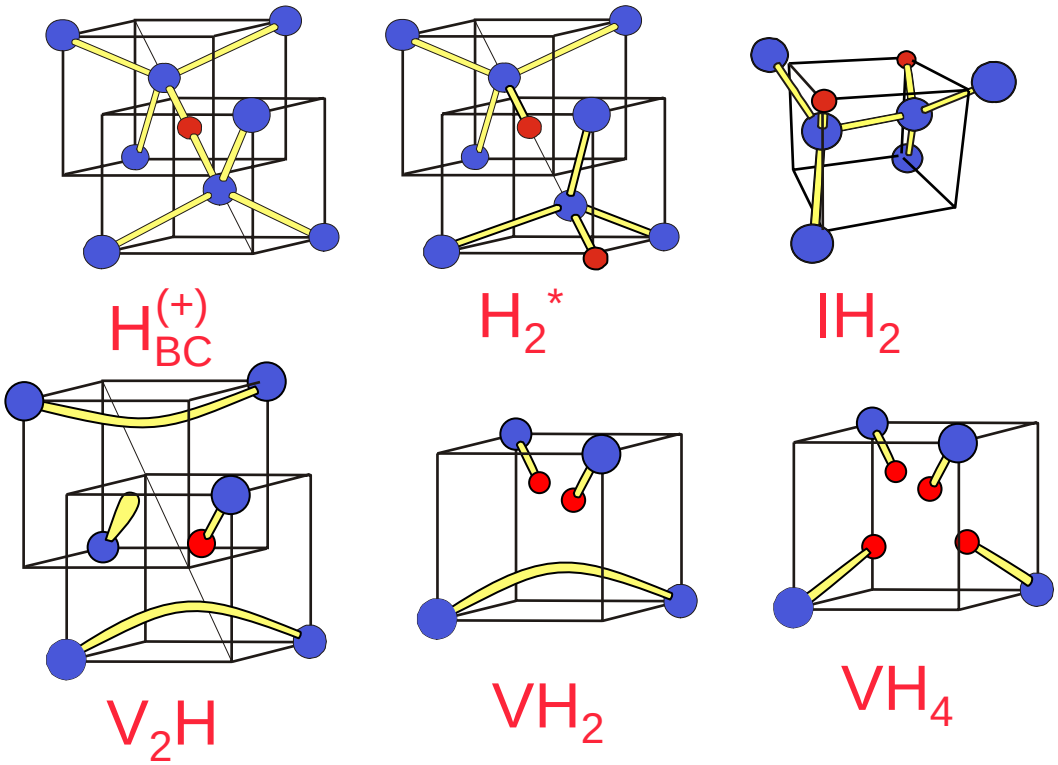
Engstrom and Ryberg,
J. Chem. Phys. **115** 519 (2001)

Paul Dumas and collaborators
- many papers

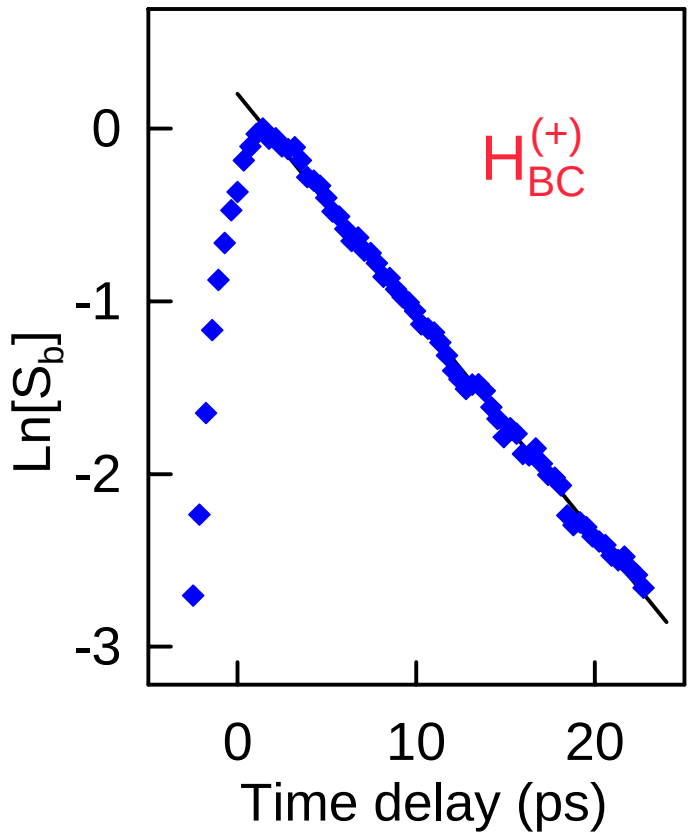
Pilling, Gardner, Pemble and Surman, Surf. Sci. **418** L1 (1998)

The benefits of tunability and short pulses → Si:H

Defect Dynamics



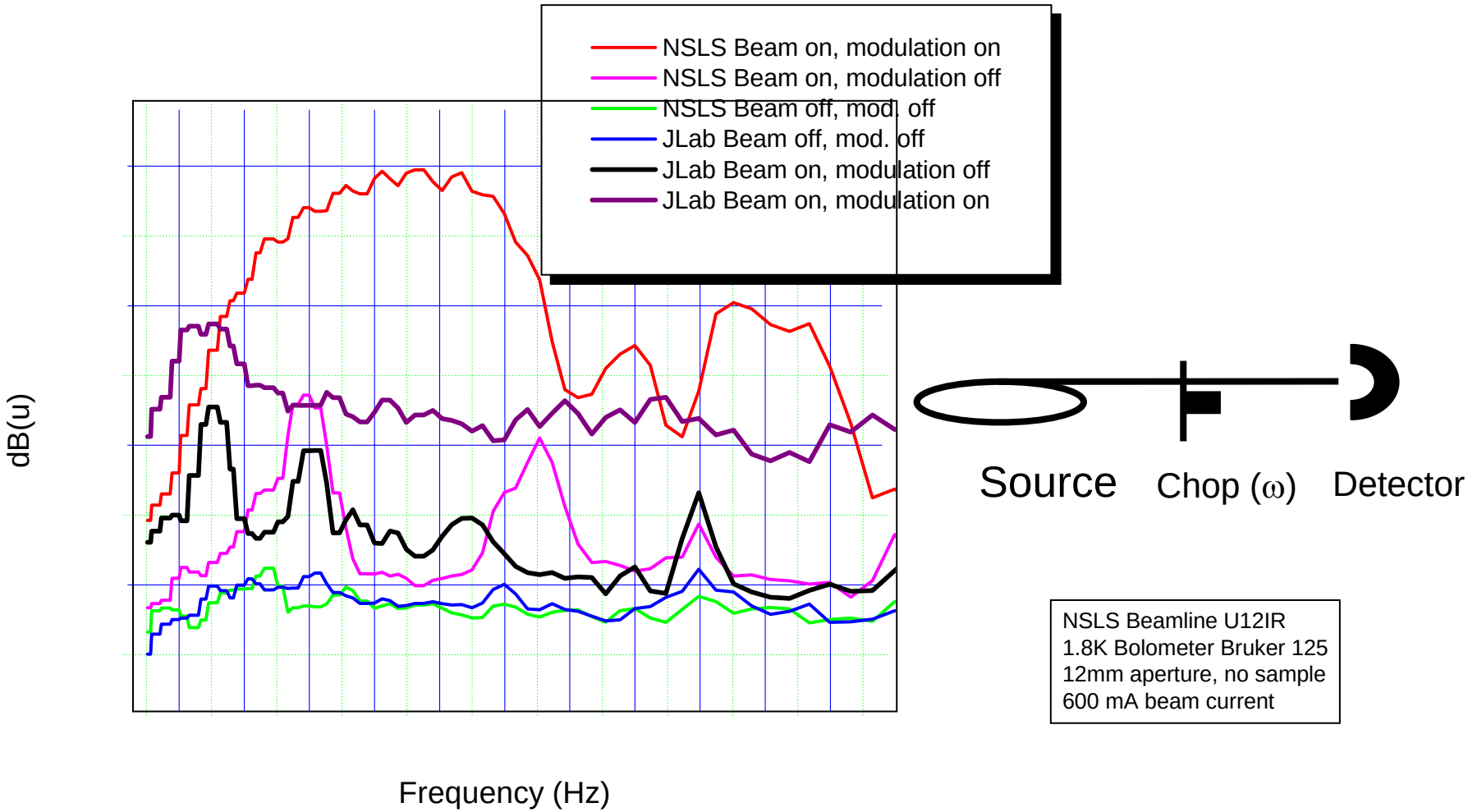
Luepke et al. CWM/Vanderbilt



$T_1 = 7.8 \pm 0.2$ ps

Luepke et al. Phys. Rev. Letts **85**, 1452 2000
Phys. Rev. Letts **88**, 135501, 2002
Phys. Rev. Letts **87**, 145501, 2001
Phys. Rev. **B63** 195203 2001
J. Appl. Phys. **93** 2316, 2003

Experimentation Issues



Concluding Remarks

- Over the past 10 years Jefferson Lab has constructed and commissioned a next generation light source based on an Energy Recovered Linac.
- Our experience with generating ultrafast electron beams and diagnostics, can help implementation of Cornell ERL.
- This ERL, or an x-ray ERL yielding THz light could have a huge impact on high pressure research.

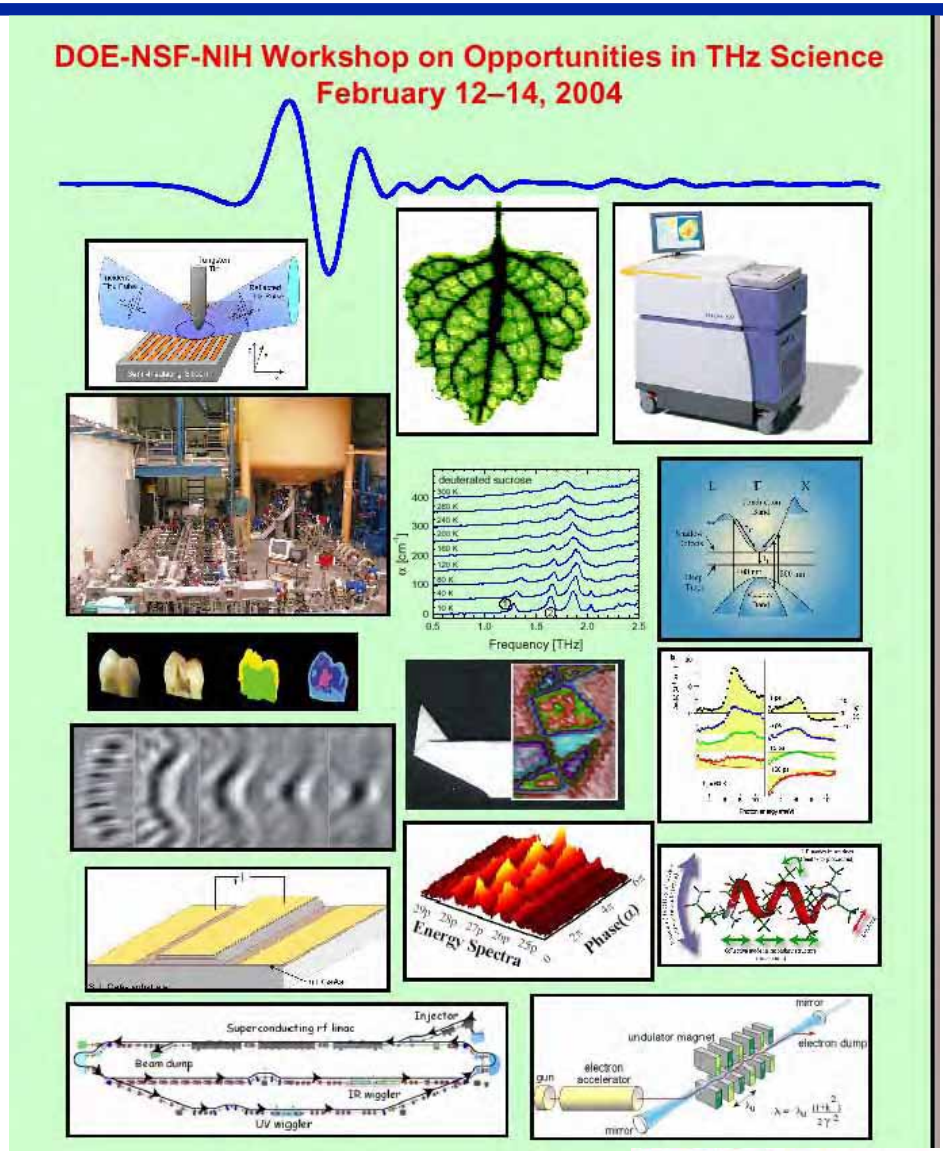
Some of the JLab Team

This work supported by the Office of Naval Research, the Joint Technology Office, the Commonwealth of Virginia, the Air Force Research Laboratory, The US Army Night Vision Lab, and by DOE under contract DE-AC05-84ER40150.

Applications of Jefferson Lab High Power THz facility

1. Basic research

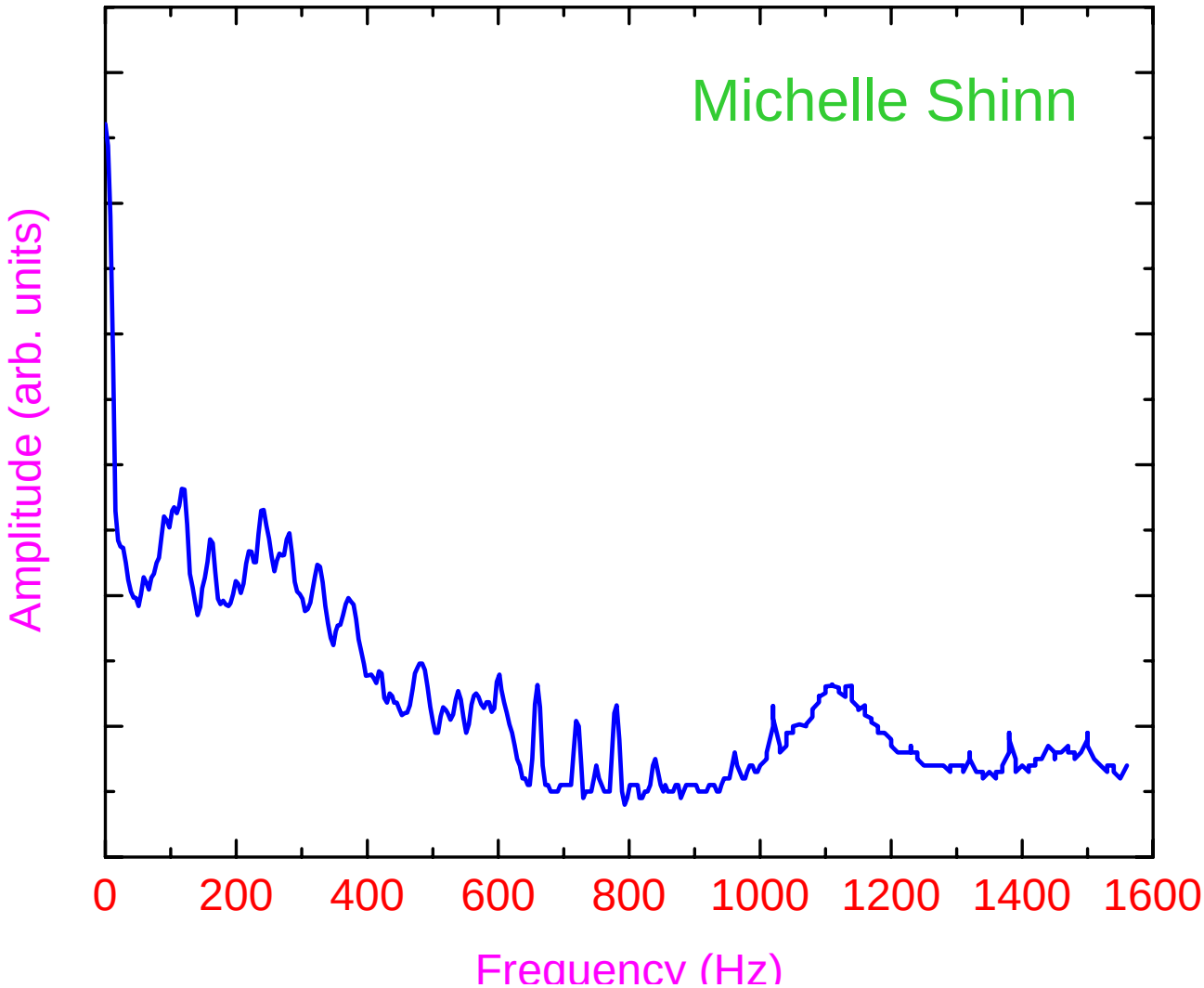
(a) Imaging
(b) Non-linear dynamics



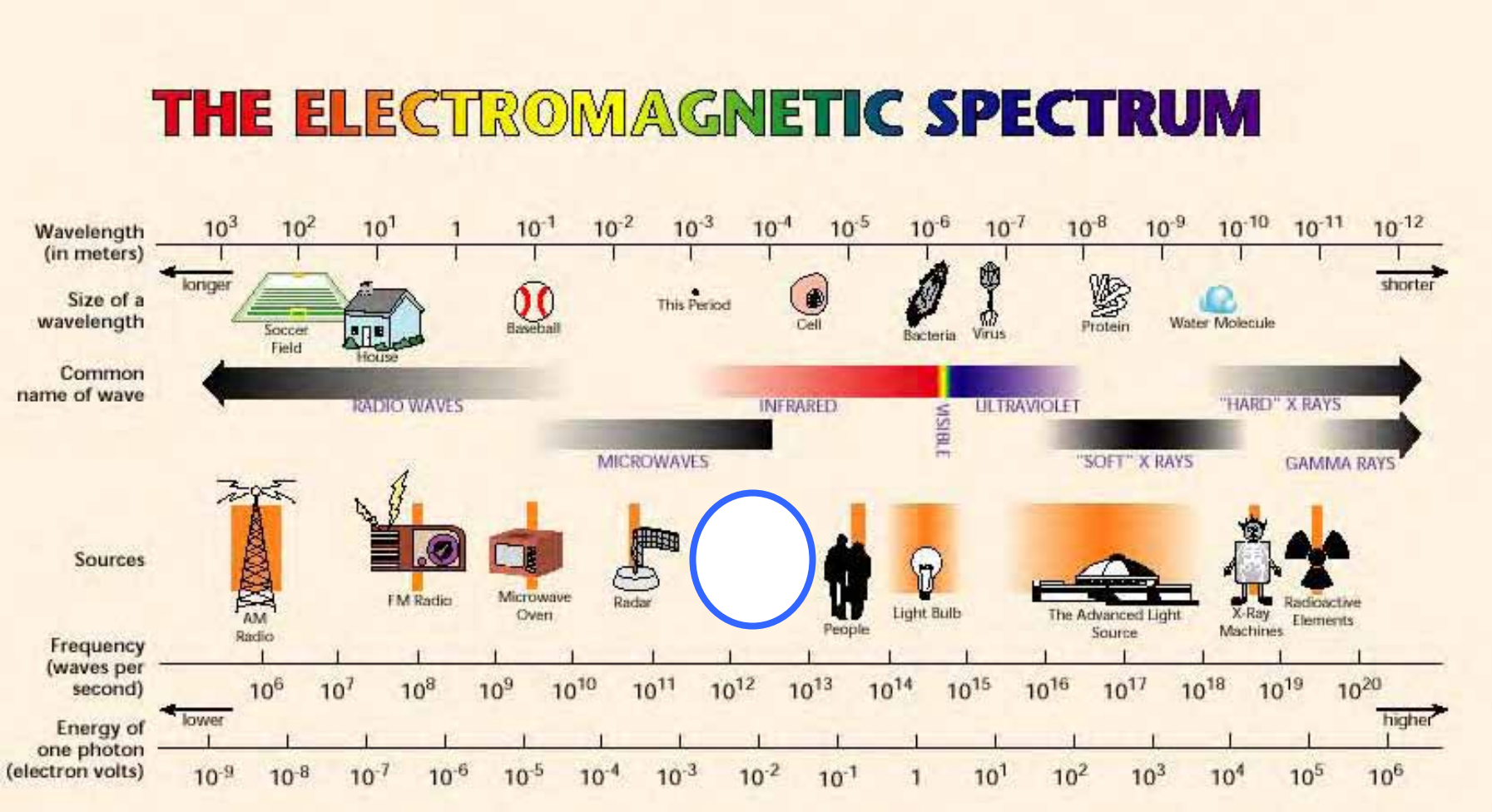
http://www.er.doe.gov/production/bes/reports/list.html

EXTRA SLIDES

JLab FEL Drive Laser Noise

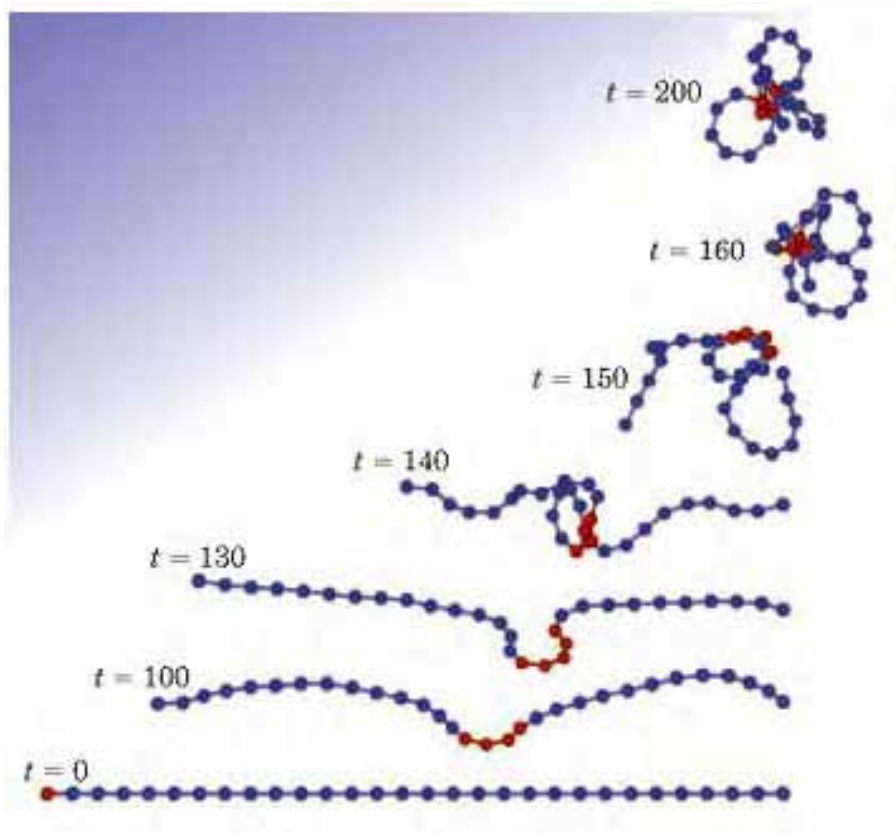


The THz Gap


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^{3} 10^{2} 10^{1} 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
FM Radio
Microwave Oven
Radar
People
Light Bulb
The Advanced Light Source
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}

Non-linear dynamical effects using high field THz light

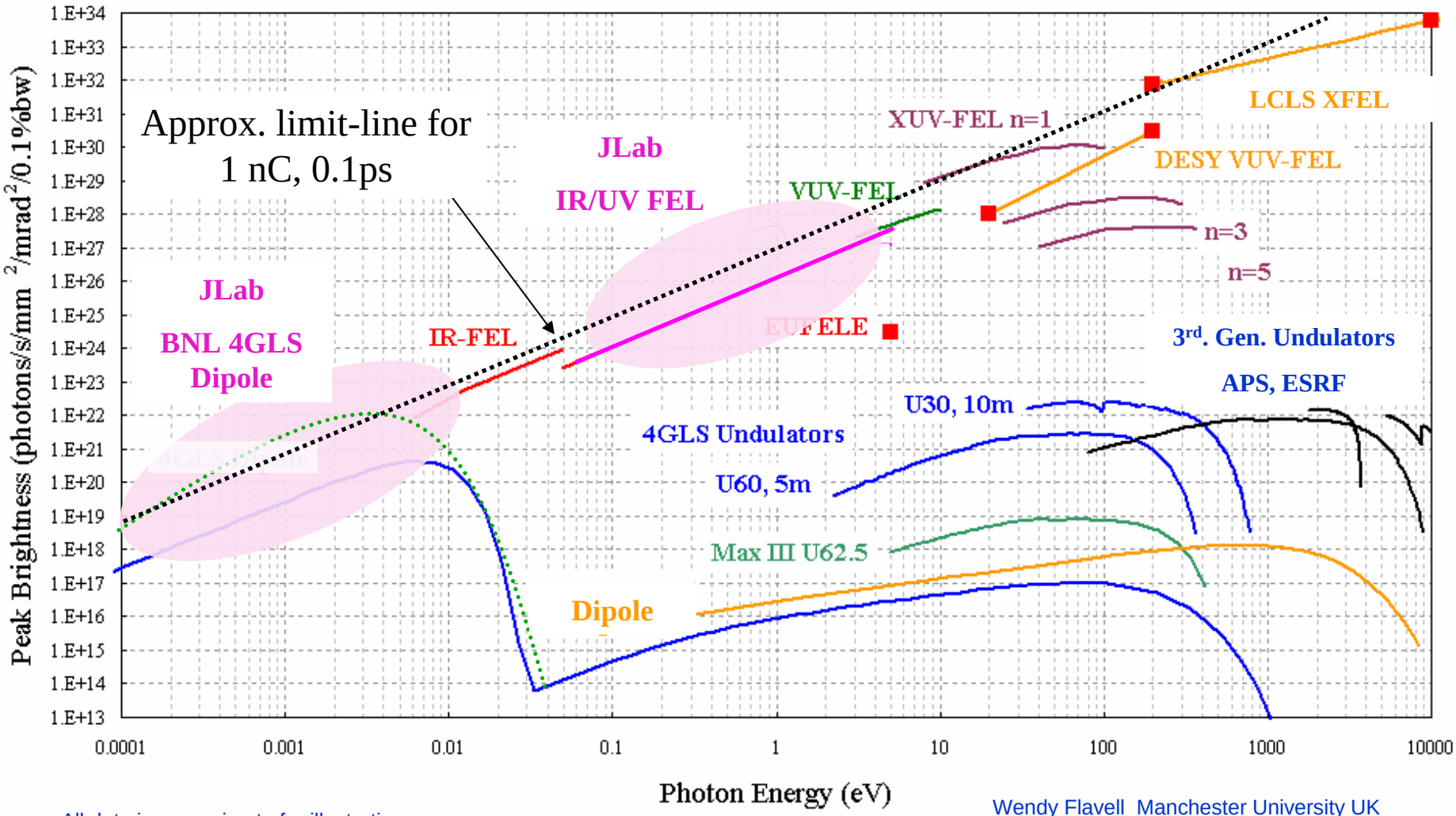
High electric fields are predicted to generate localized modes!



A biopolymer chain buckles and folds on itself due to an instability produced by a nonlinear localized mode – Physics Today Jan. 2004 p43.
Mingaleev et al Europhys. Lett. **59** 403 (2002)

JLab collaboration with Al Sievers, Cornell U.

Light Source Landscape



All data is approximate for illustrative purposes

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