The High Power FEL Development at JLab

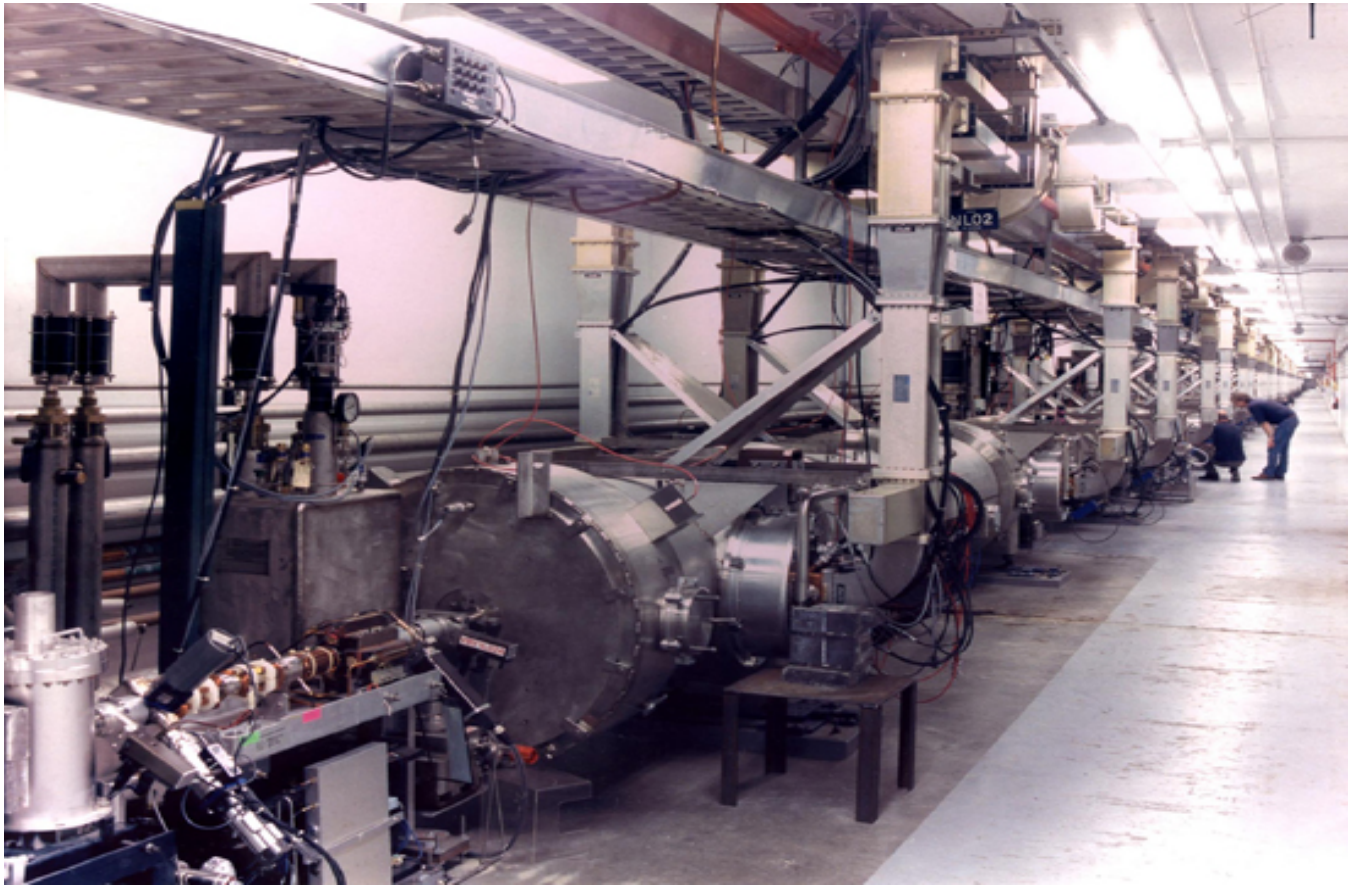
George Neil for the FEL Team

With congratulations to Kwang-Je Kim on his retirement

3/15/2019

Jefferson Lab's CEBAF accelerator was the first major project built using superconducting SRF technology and was based on pioneering work by Stanford, Cornell and others.

It was 10 years in planning, took 5 more years to build and cost ~$600M in 1990-1995.



JLab's Linear Accelerator

Superconducting cavities are assembled in Class 10 cleanroom

Surface electric fields are high during acceleration so any internal contamination leads to field emission.

Eliminate this during assembly and seal the cavity

I told George he should use the CEBAF linac for an FEL. Maybe KEK should try it, too.

Parallel tracks:
Designs, Proposals and the Hunt for $

1990: "Applied Research and Technology " grant from VA's CIT

1991: First Design for standalone kilowatt class IR-UV FEL

1994: Reference Design completed for expanded collaboration:
"The Laser Processing Consortium"

1994: Submitted to DOE/DOC for $25m with $10m of partner $
(didn't make the cut ~ 0.1% of proposals funded)

1995: Project reviewed by NASA for DOE
Sec. O'Leary: ***"great project, a model for the nation"***
"…good luck in finding the money"…

1995: With help from NPS and VA Congressional delegation,
$10M in FY 96 appropriation to Navy Research

IR Demo Project Launched (1996)

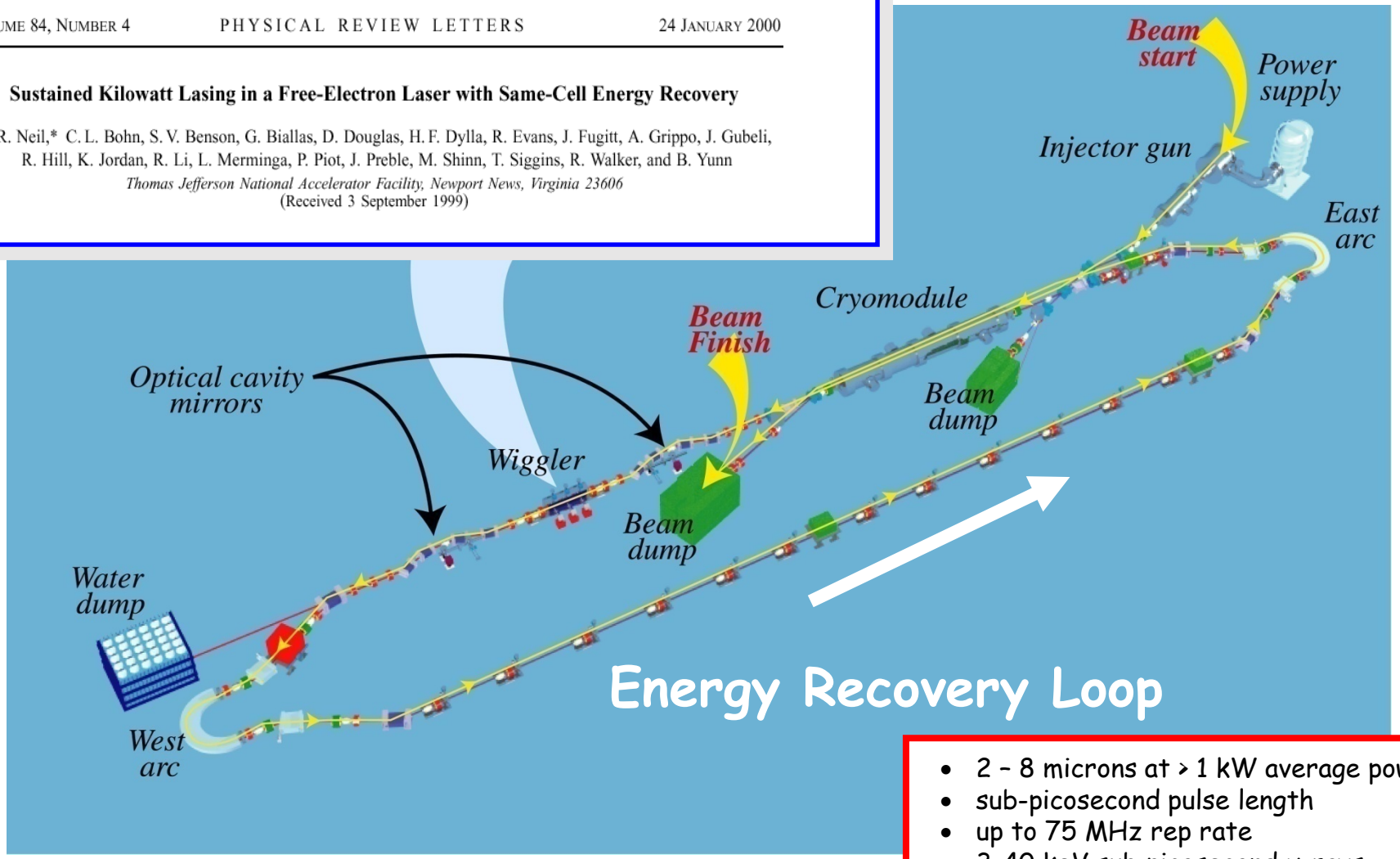
- 1 kW IR FEL using spare cryomodule parts donated by DOE-NP
- Multipurpose FEL Facility and User Labs built with VA funds
- Cliffhanger: delayed federal funds due to FY96 shut-down; federal funds arrived shortly before VA funds disappeared
- Construction project compressed to 18 months (including 14 reviews)

JLab's first FEL: IR Demo: 1996-2001

VOLUME 84, NUMBER 4 PHYSICAL REVIEW LETTERS 24 JANUARY 2000

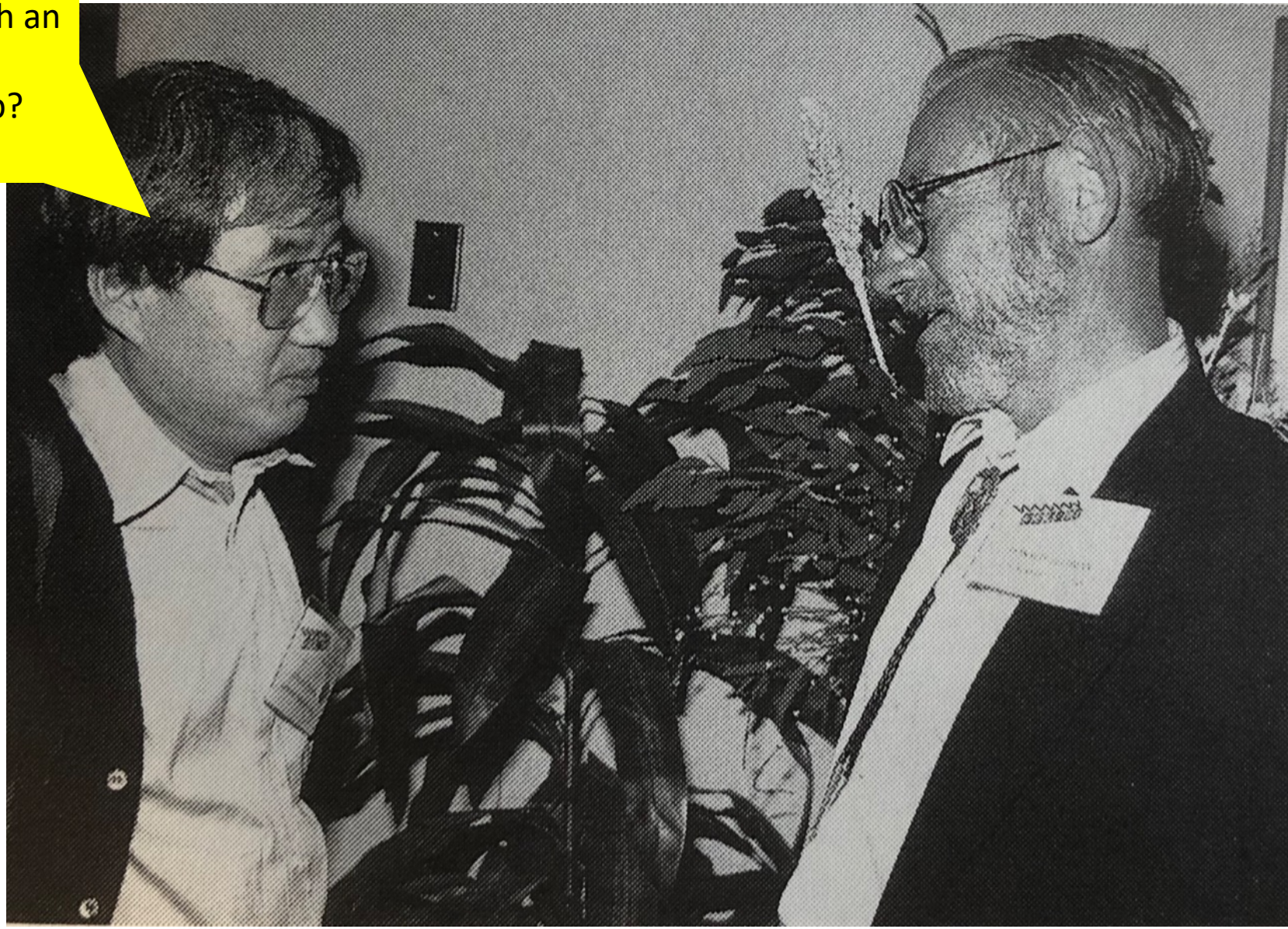
Sustained Kilowatt Lasing in a Free-Electron Laser with Same-Cell Energy Recovery

G. R. Neil,* C. L. Bohn, S. V. Benson, G. Biallas, D. Douglas, H. F. Dylla, R. Evans, J. Fugitt, A. Grippo, J. Gubeli, R. Hill, K. Jordan, R. Li, L. Merminga, P. Piot, J. Preble, M. Shinn, T. Siggins, R. Walker, and B. Yunn
Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606
(Received 3 September 1999)

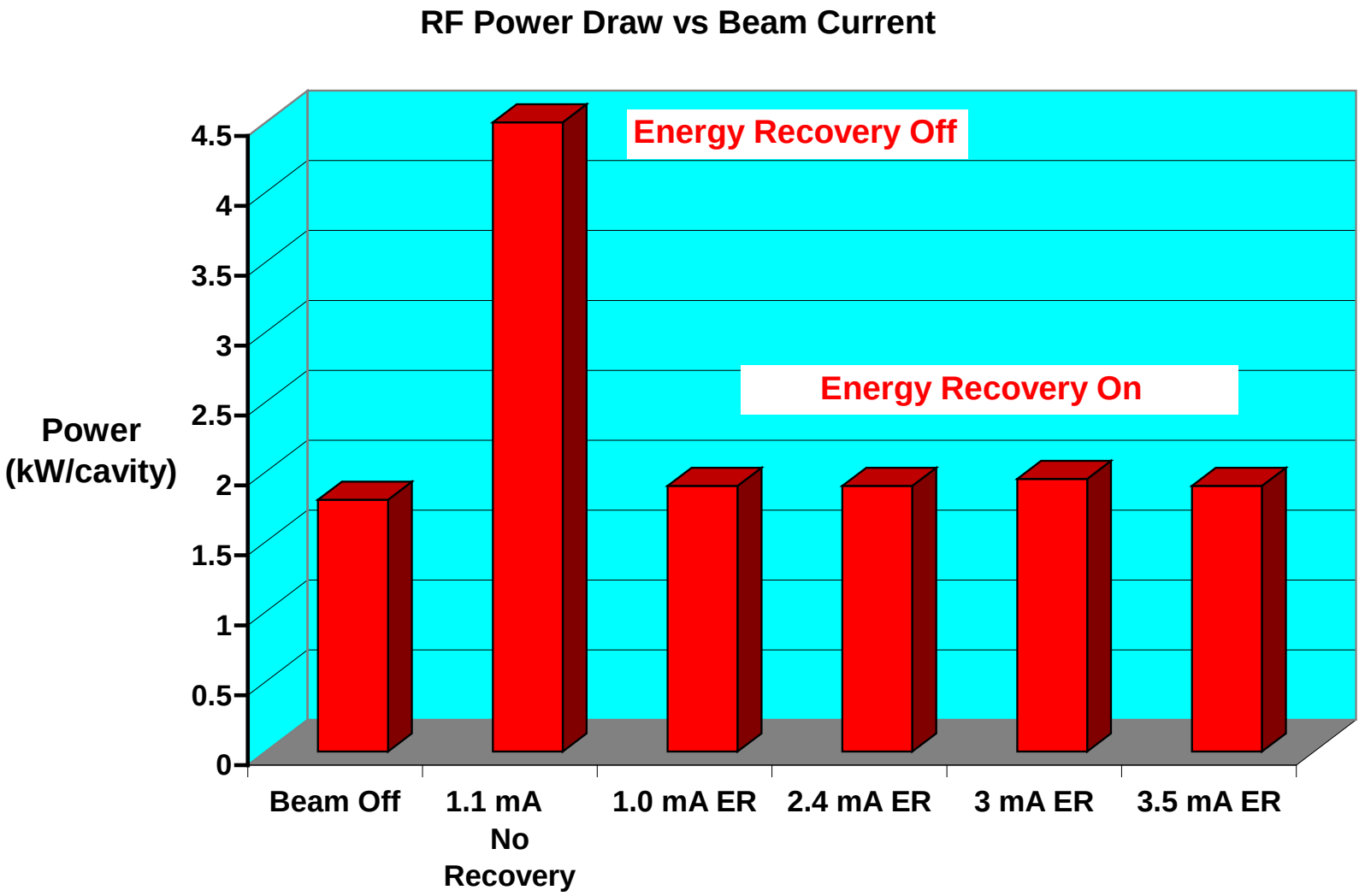


- 2 – 8 microns at > 1 kW average power
- sub-picosecond pulse length
- up to 75 MHz rep rate
- 3-40 keV sub picosecond x-rays

So why doesn't LANL use energy recovery with an SRF linac like Jefferson Lab?



Energy Recovery Works

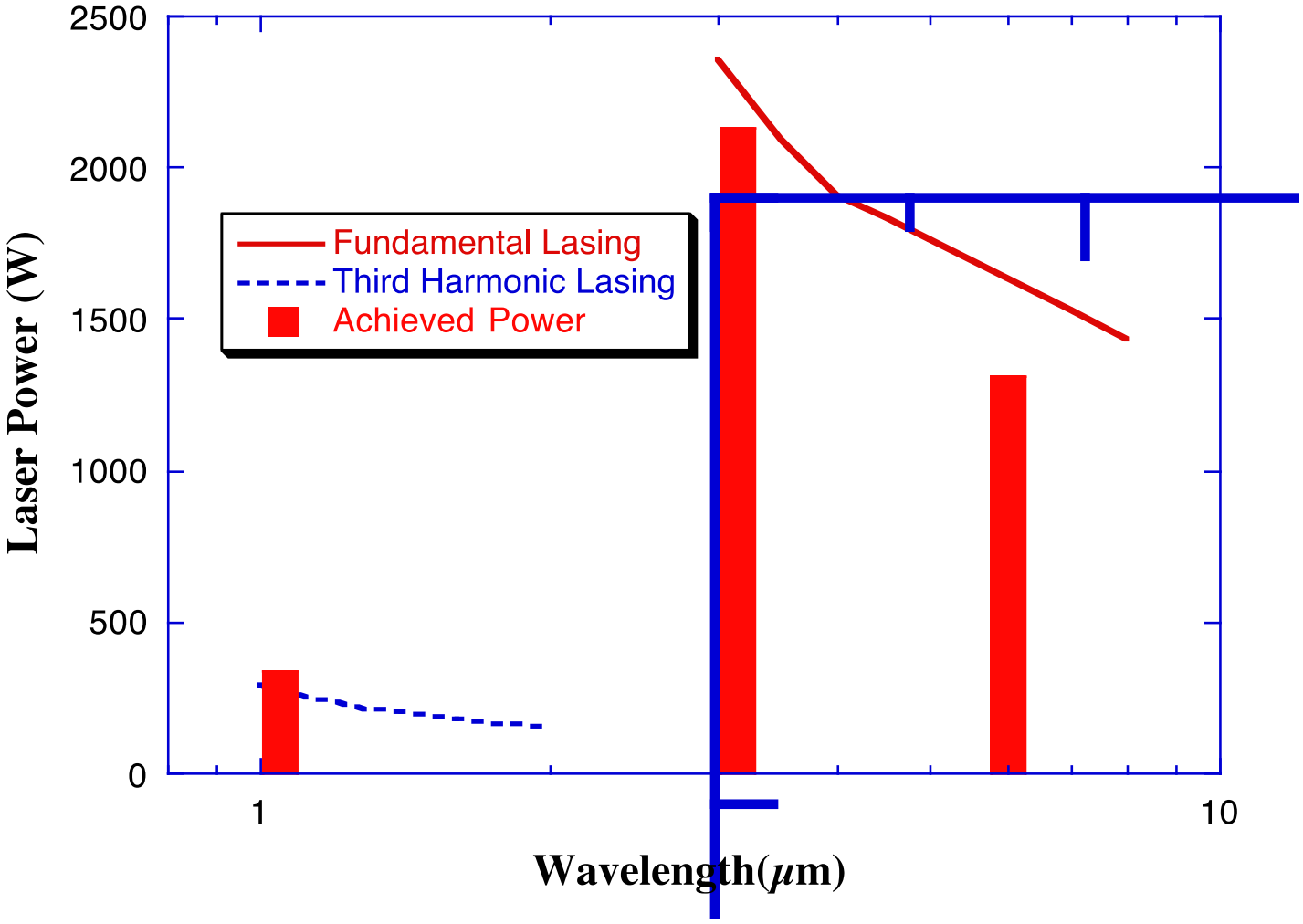


Attempts to Demonstrate ERLs

Over 50 years of attempts, the three JLab FEL drivers are the *only* CW ERLs to achieve "break-even" i.e., the beam power exceeded the installed linac RF drive:

- **Chalk River (pulsed copper)**
- **Bates (pulsed copper)**
- **Novosibirsk (CW copper, but with much more RF drive than beam power, even including wall losses)**
- **HEPL (pulsed only)**
- **CEBAF FET (source and beam loss limited to low power)**
- **IR Demo (5 mA x 45 MeV > 200 kW; only 40 kW installed in linac)**
- **CEBAF-ER (source and beam loss limited to low power)**
- **IR Upgrade (8.5 mA x 150 MeV = 1.25 MW; only 120 kW installed in linac)**
- **ALICE (pulsed only - due to SRF issues)**
- **UV Demo (2.5 mA x 135 MeV = 335 kW; only 120 kW installed in linac...)**
- **BNL ERL (failed)**
- **KEK cERL (beam loss limited to 1 mA -> below or barely at breakeven)**
- **S-DALINAC, ERL just started up at Darmstadt**

Predicted Optimum Lasing Performance vs. Experiment for IR Demo

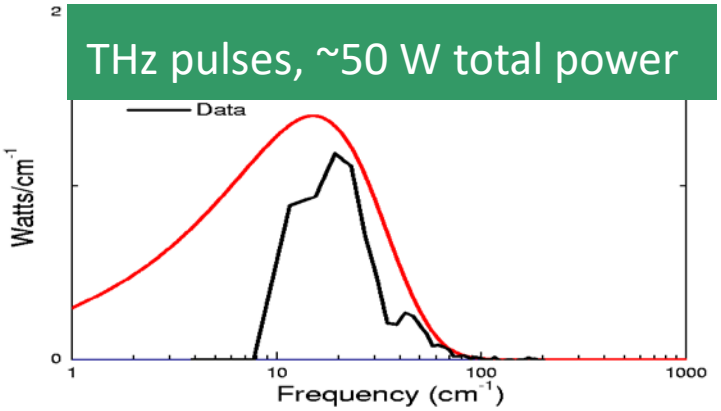


Simultaneous production of 3 μm, THz, and 10 keV X-ray femtosecond pulses

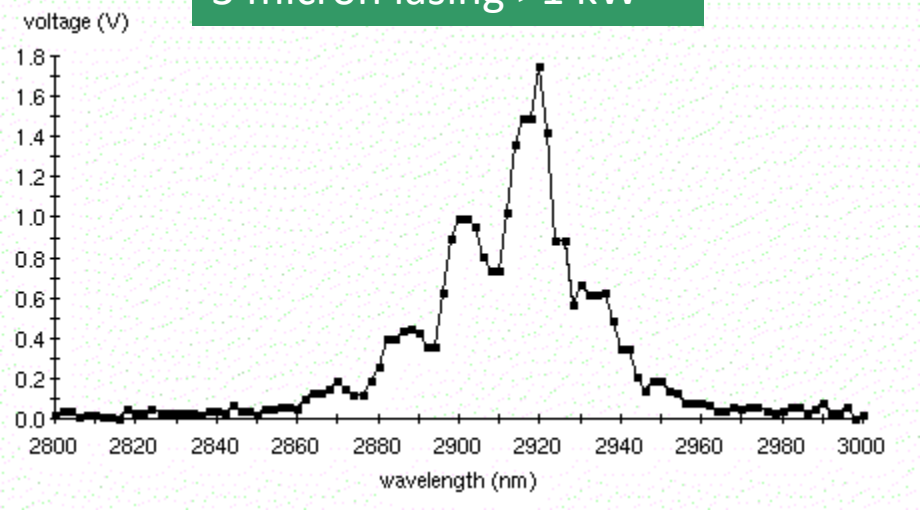
- 800 fsec pulses at 37.4 MHz
- Synchronized to <<psec levels (same beam!)
- **All three wavelengths at world class fluxes**

Sample

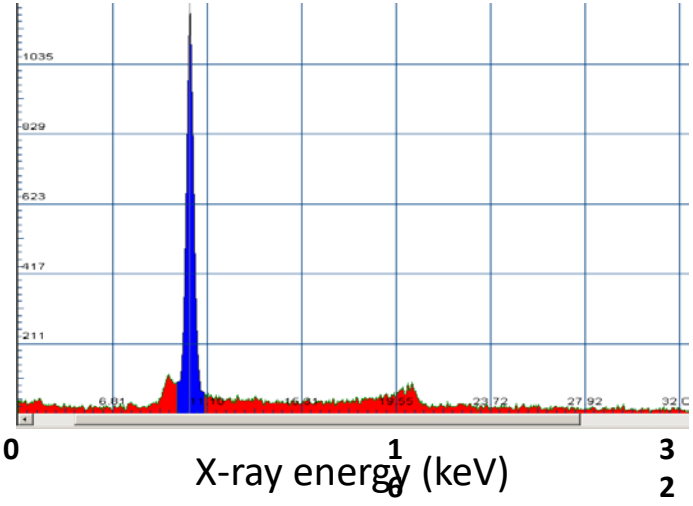
THz pulses, ~50 W total power



3 micron lasing >1 kW



10 keV X-ray > 10^5 ph/sec/0.1% BW



FEL Team celebrating the “kilowatt prize”

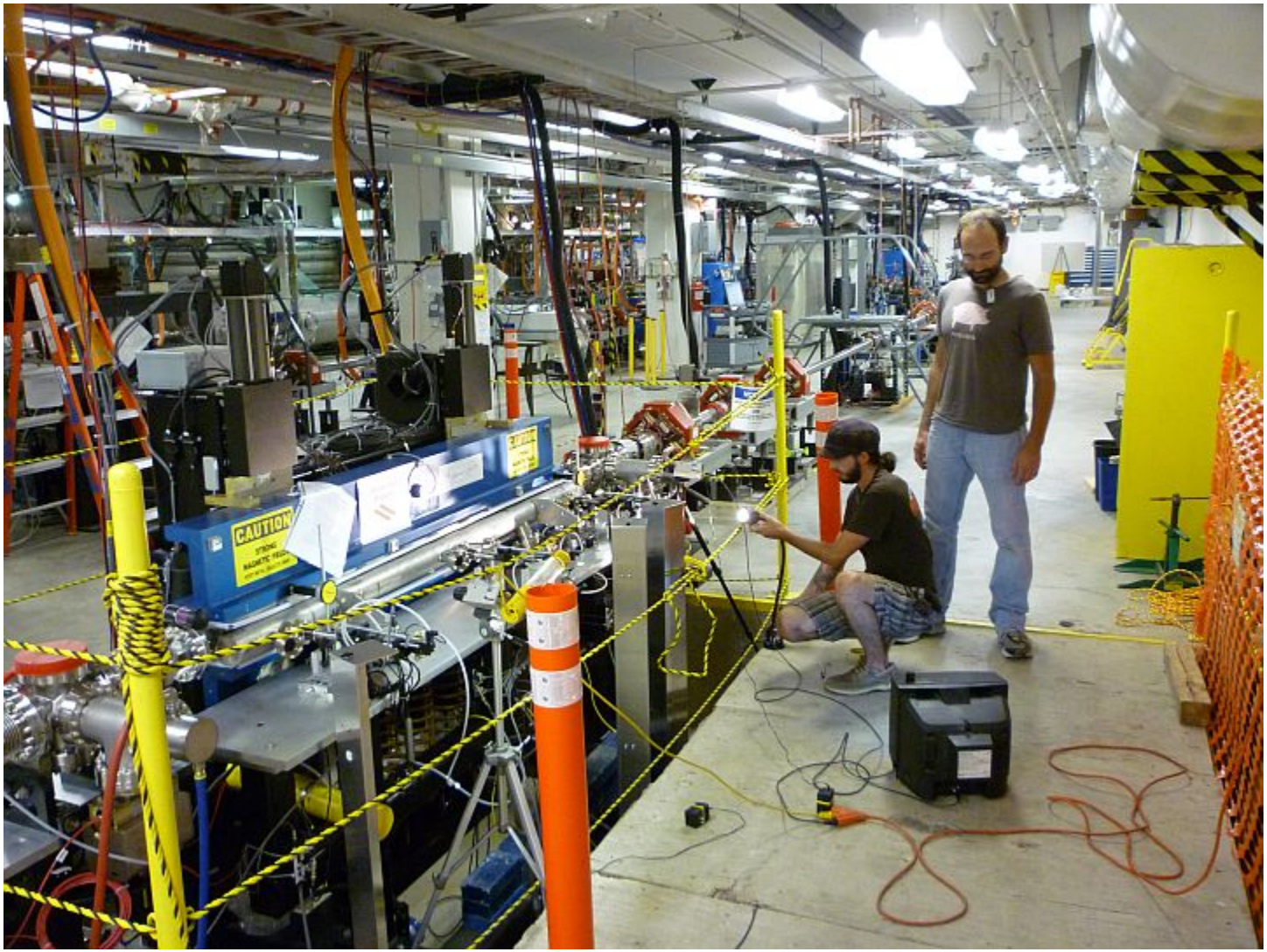
So George, why don't you get a UV undulator and lase at shorter wavelengths? The rest of these guys won't know what hit them.

FEL Prize winners

But I can’t afford another undulator

FEL Prize winners

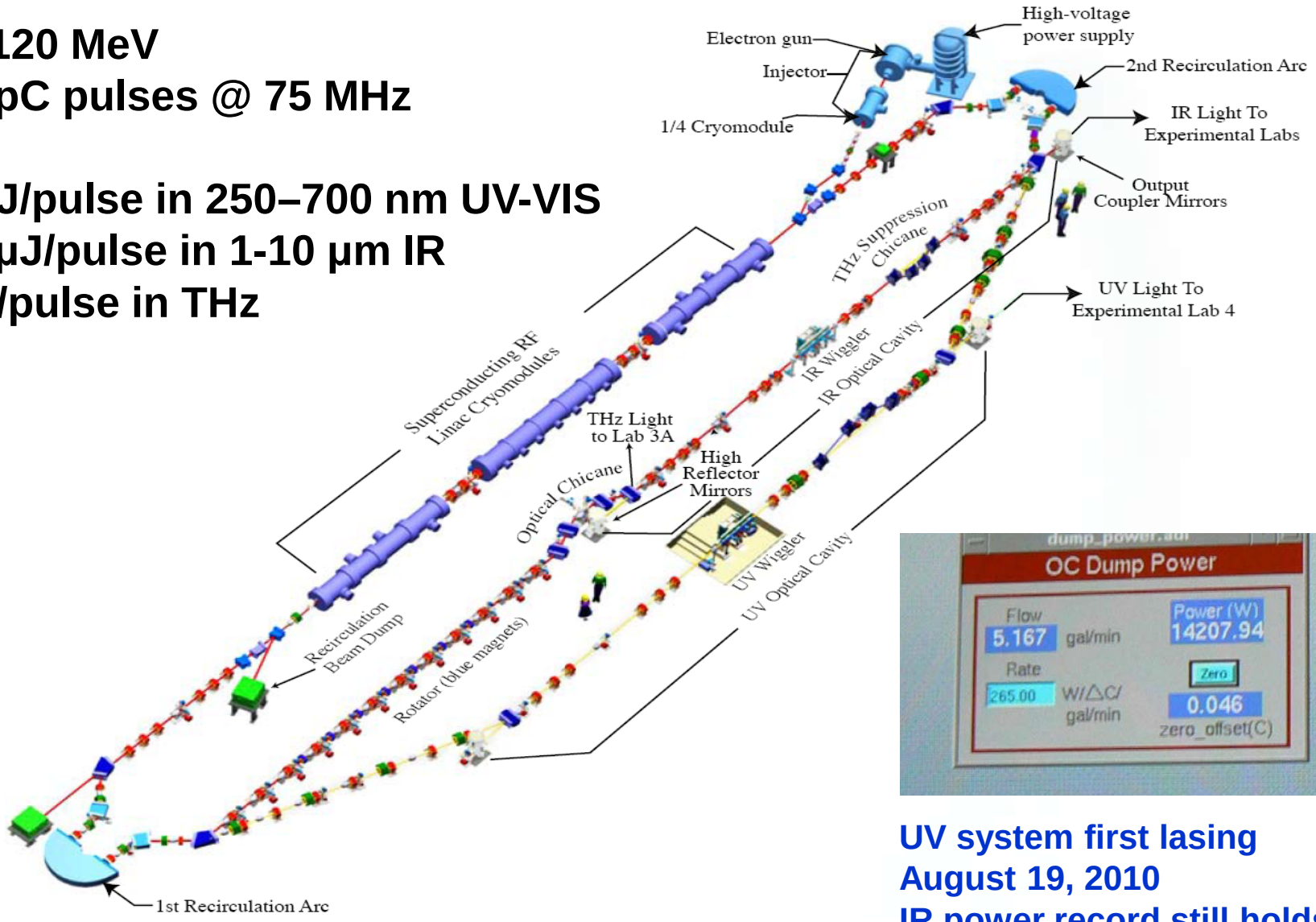
APS Undulator A – with a little help from our friends



JLab's IR/UV 4th Generation Light Source

E = 120 MeV
135 pC pulses @ 75 MHz

20 μJ/pulse in 250–700 nm UV-VIS
120 μJ/pulse in 1-10 μm IR
1 μJ/pulse in THz



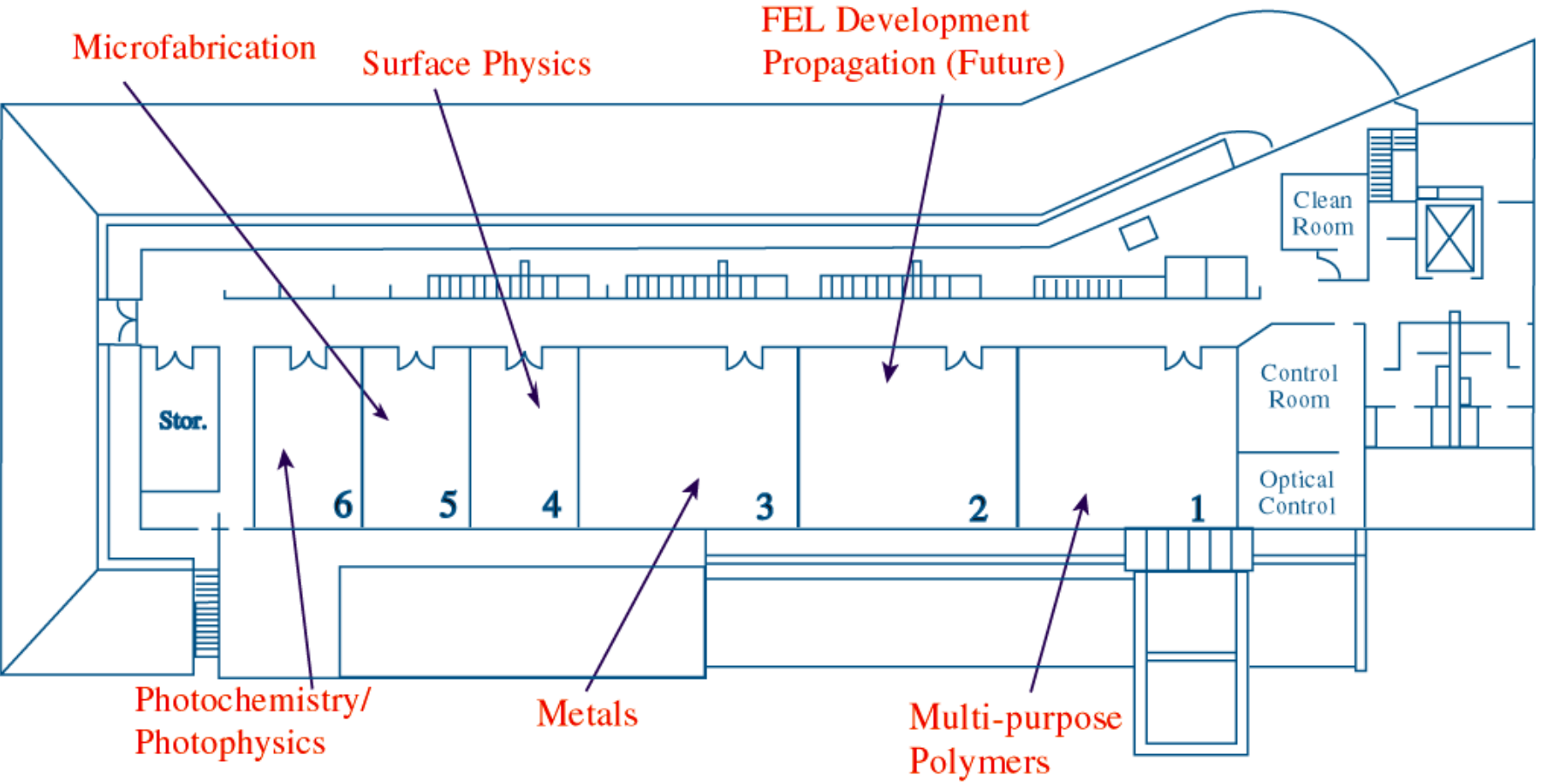
UV system first lasing
August 19, 2010
IR power record still holds

Jlab FEL Program Accomplishments

FEL Physics and Technology (6 different FELs have operated in the facility)

- **First demonstration of high power lasing in an ERL**
- **Highest average output power in a tunable laser (14.3 kW)**
- **First demonstration of 2nd and 5th harmonic lasing**
- **High average power in the UV (150 W)**
- **Continuous tuning of a CW laser over two octaves of wavelength change**
- **Highest average THz power emitted in any accelerator**
- **Demonstration of off-axis Thompson backscattering in an FEL**
- **Demonstration of inverse tapered operation in an FEL**
- **Operation of a FEL with cryogenic mirrors**

FEL Facility User Lab

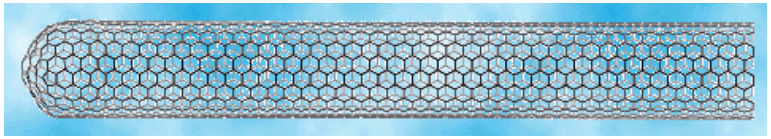


6600 ft^2 User Labs
40'x240' FEL Vault

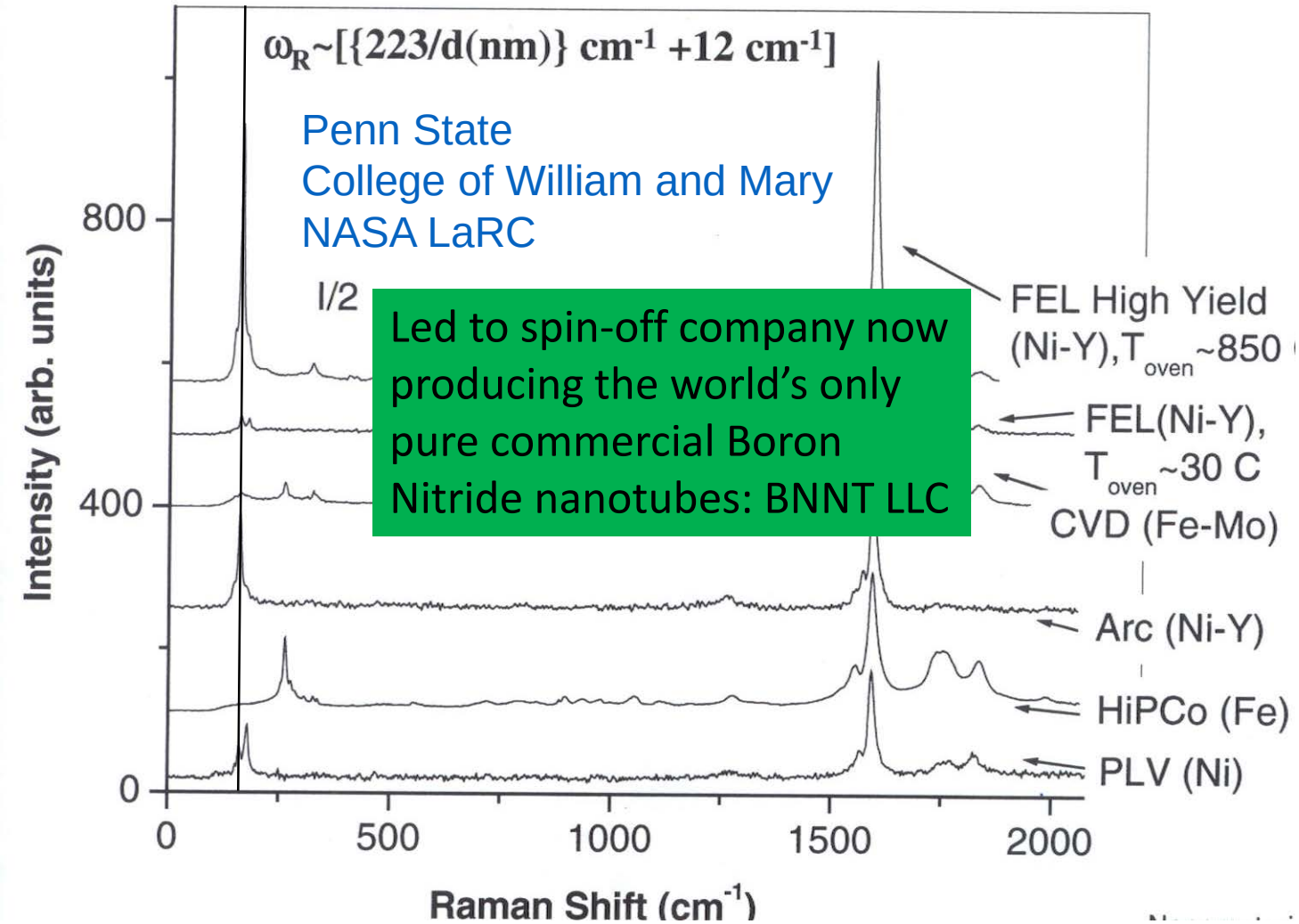
Jefferson Lab

Sampling of FEL User Results

- **Spectroscopy**
  - **H-Si (Luepke, CWM)**
  - **Amide-I in myoglobin (Austin, Princeton)**
  - **Dark Matter search (Baker,Yale; Boyce, JLab; Milner, Fisher, MIT)**
  - **THz studies at high power (Klopf, Williams, JLab)**
- **Ablation**
  - **Resonant PLD of polymers – (Kelley, CWM; Haglund, Vanderbilt)**
  - **Non-resonant, high quality magnetic/SC films – (Reilly, CWM; Shinn, JLab)**
- **Micro/nano-fabrication**
  - **C-nanotubes – (Jordan, JLab; Smith, NASA)**
  - **UV/visible micro structuring of glasses (Helvajian, Aerospace Corp.)**
- **Surface processing**
  - **Laser nitriding of metals (Schaff, Göttingen)**
  - **Laser amorphization of metals (Kessel, Dominion Power)**
- **Biomedical**
  - **Selective photothermolysis of lipid rich tissues (Anderson, MGH)**



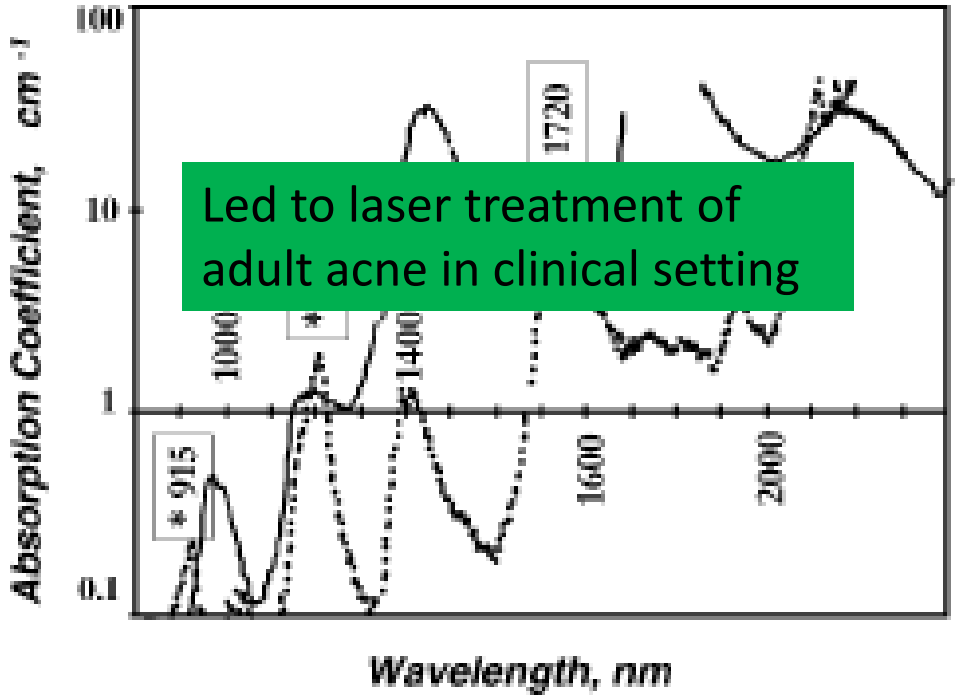
Nanotubes at the JLab FEL



Collaboration with MGH

Selective Photothermolysis of Lipid-Rich Tissues:

R. Rox Anderson et al, Lasers in Surgery and Medicine 38:913–919 (2006)



Led to laser treatment of adult acne in clinical setting

Infrared absorption spectra of water (solid line) and human fat (dotted line), noting approximate wavelengths of fat absorption maxima.

Some of the JLab FEL Team who made all this possible

Photo taken Jan 16, 2007

What to do in retirement?

Join me at Burning Man?

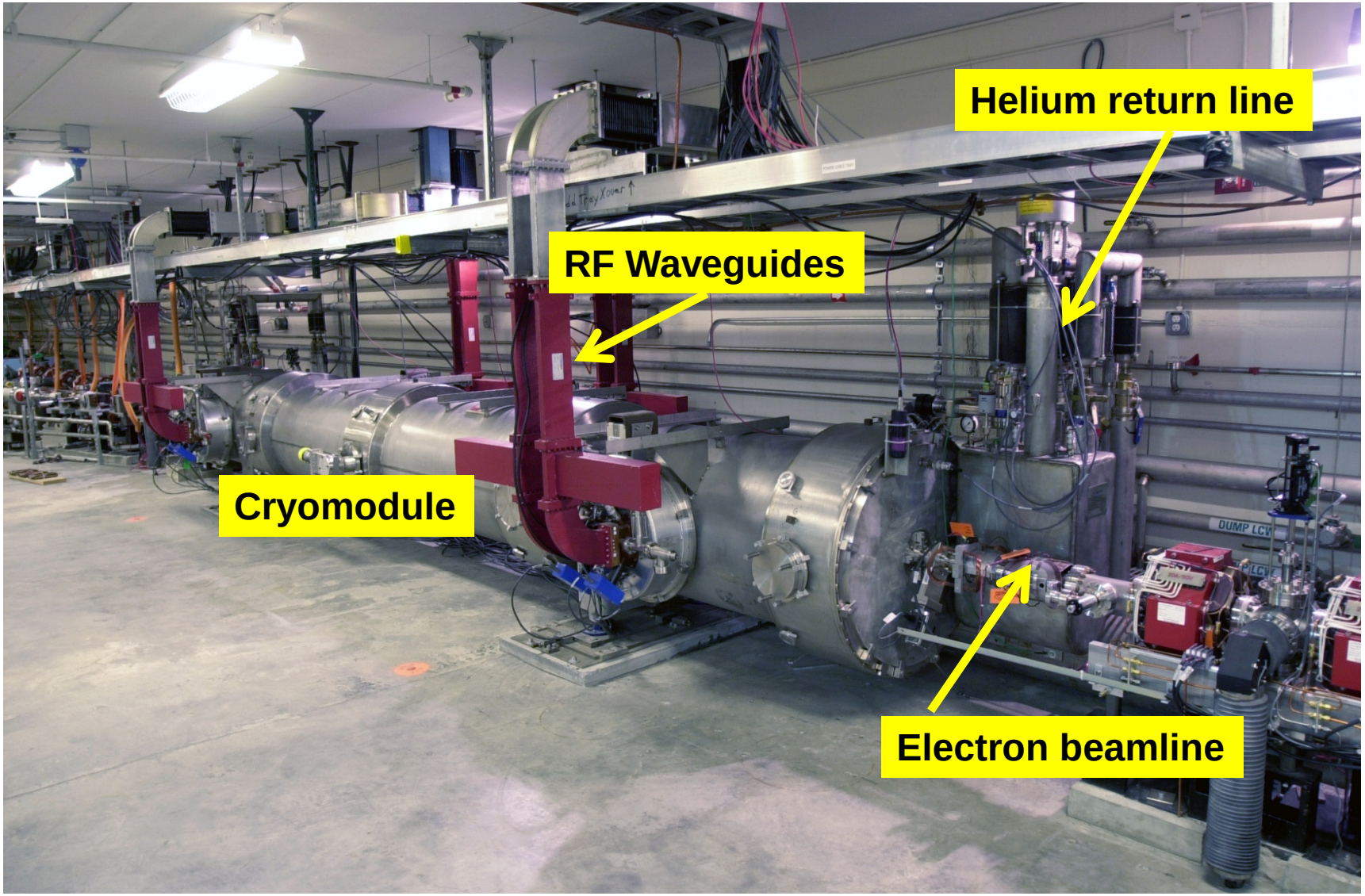
Courtesy www.doublehelixart.com
See us at GLEAM2019

GLEAM
ART IN A NEW LIGHT

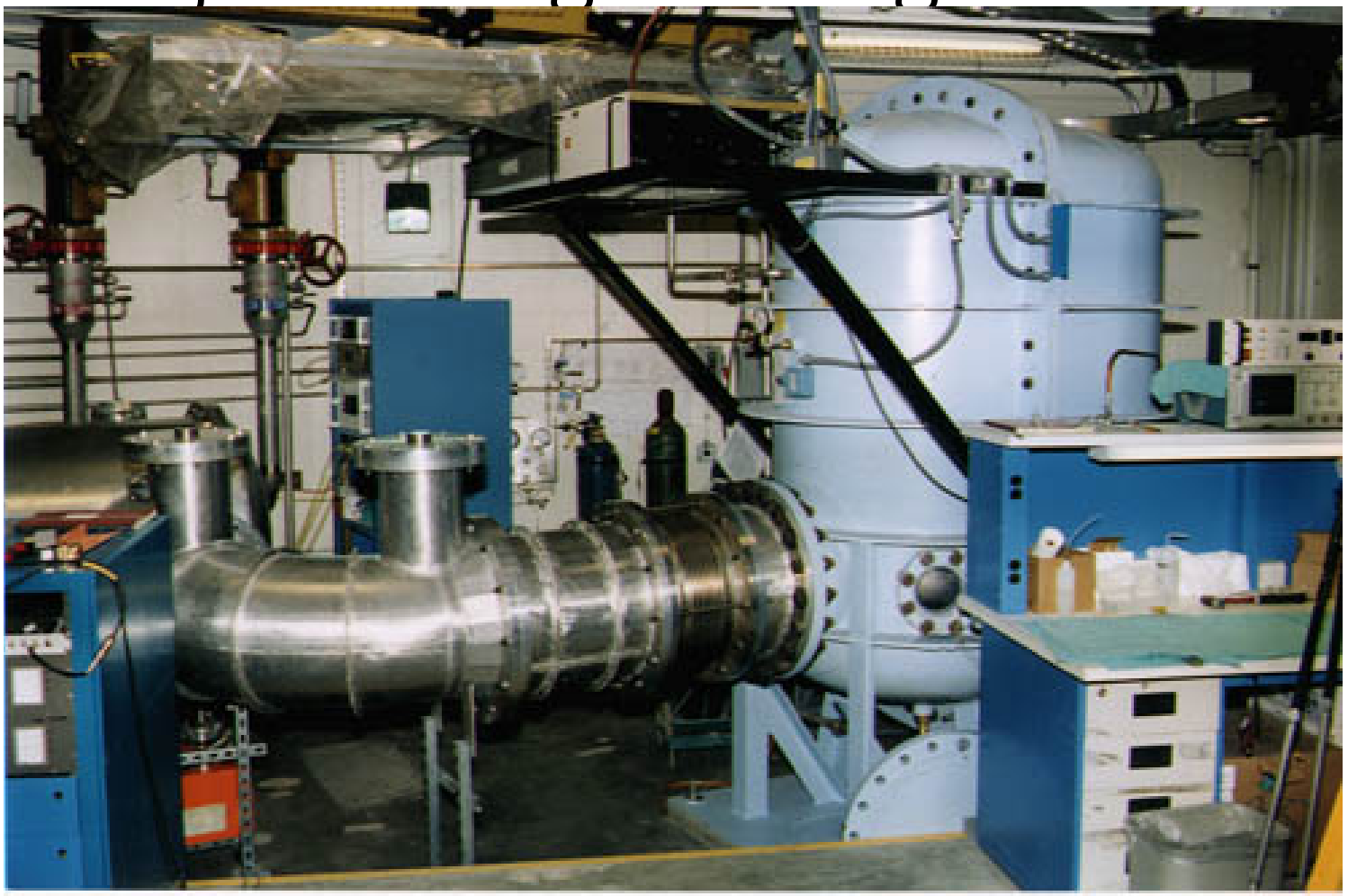
Madison WI Aug.24-Oct.26

Backups

Superconducting cryomodules

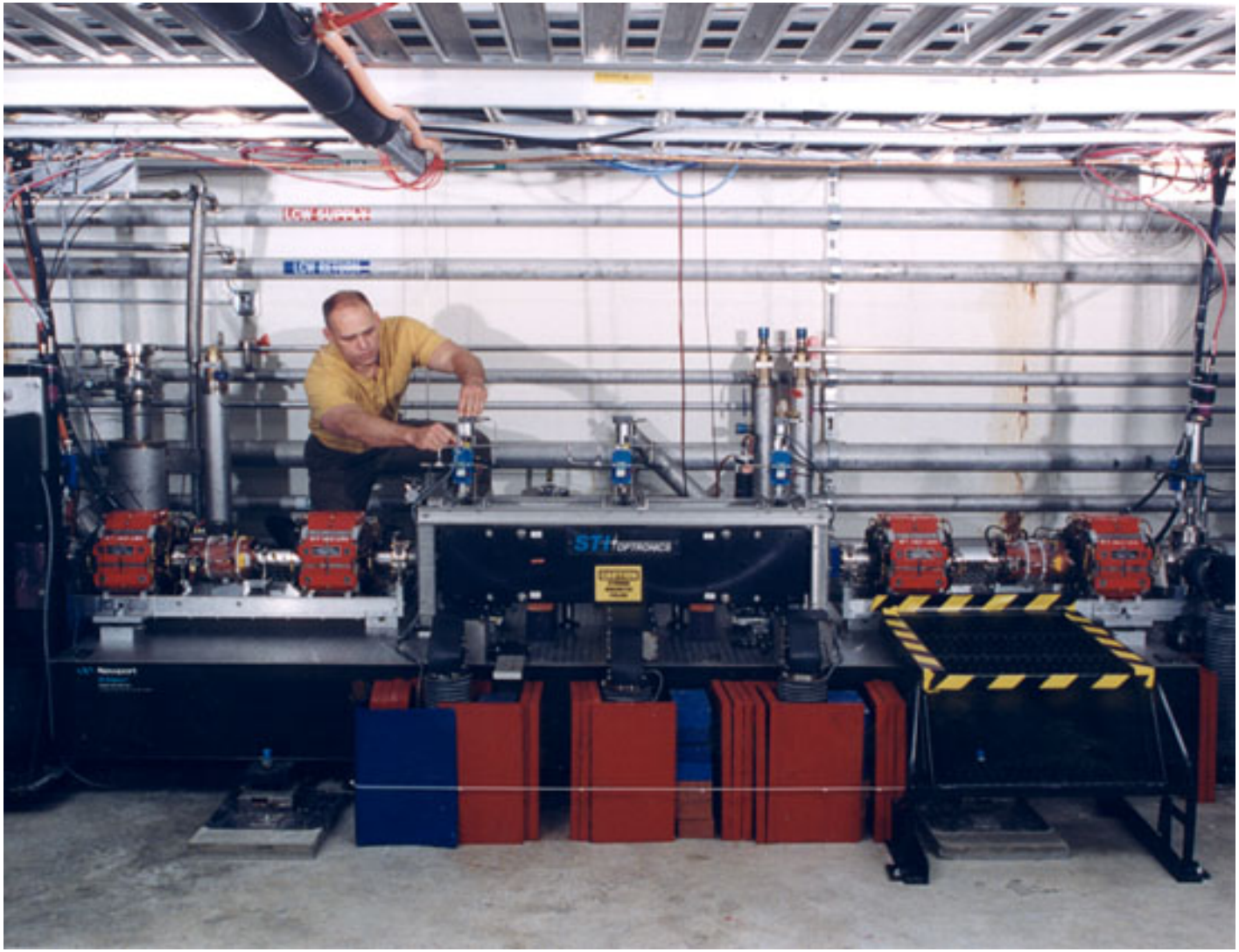


Injector High Voltage Power



600kV Power Supply for FEL

IR Demo Wiggler



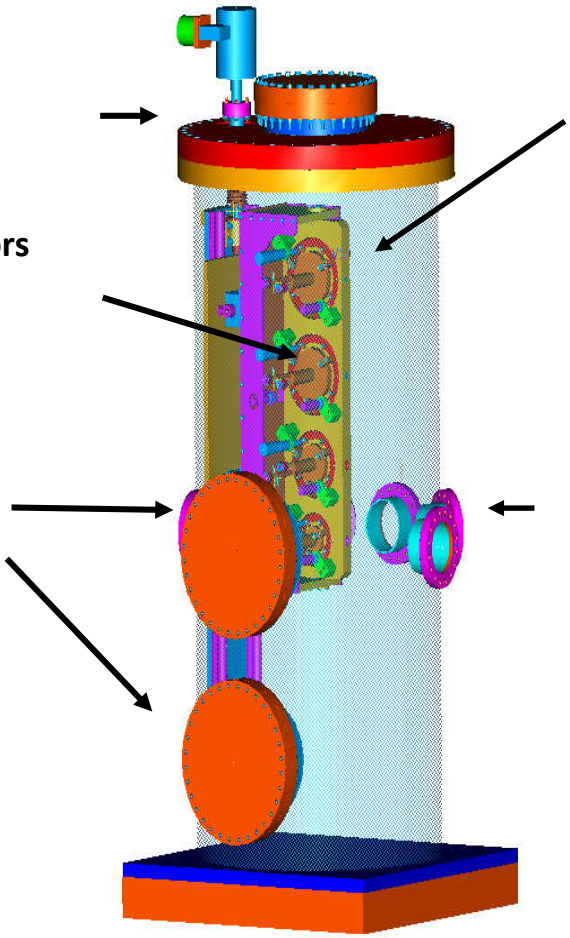
Recirculation Pi Bend transport > 10% energy spread

JLab IR/UV Mirror Cassette works to very high power

Conflat seals to achieve vacuum rating.

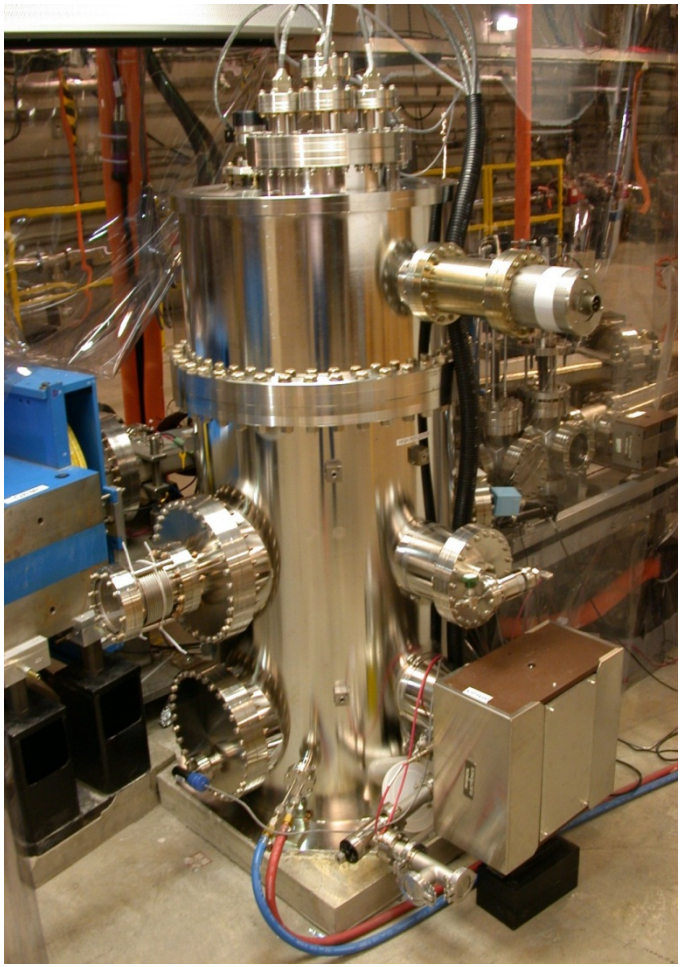
Deformable mirrors correct thermal distortion

Access ports for installation or replacement of components.



Mirrors on translation stage to change wavelength ranges

Access ports for Survey and Alignment Team and diagnostics.



Control Room (familiar shot)