Accelerator Sciences and Technologies

Graduate & Undergraduate Research Opportunities at Jefferson Lab

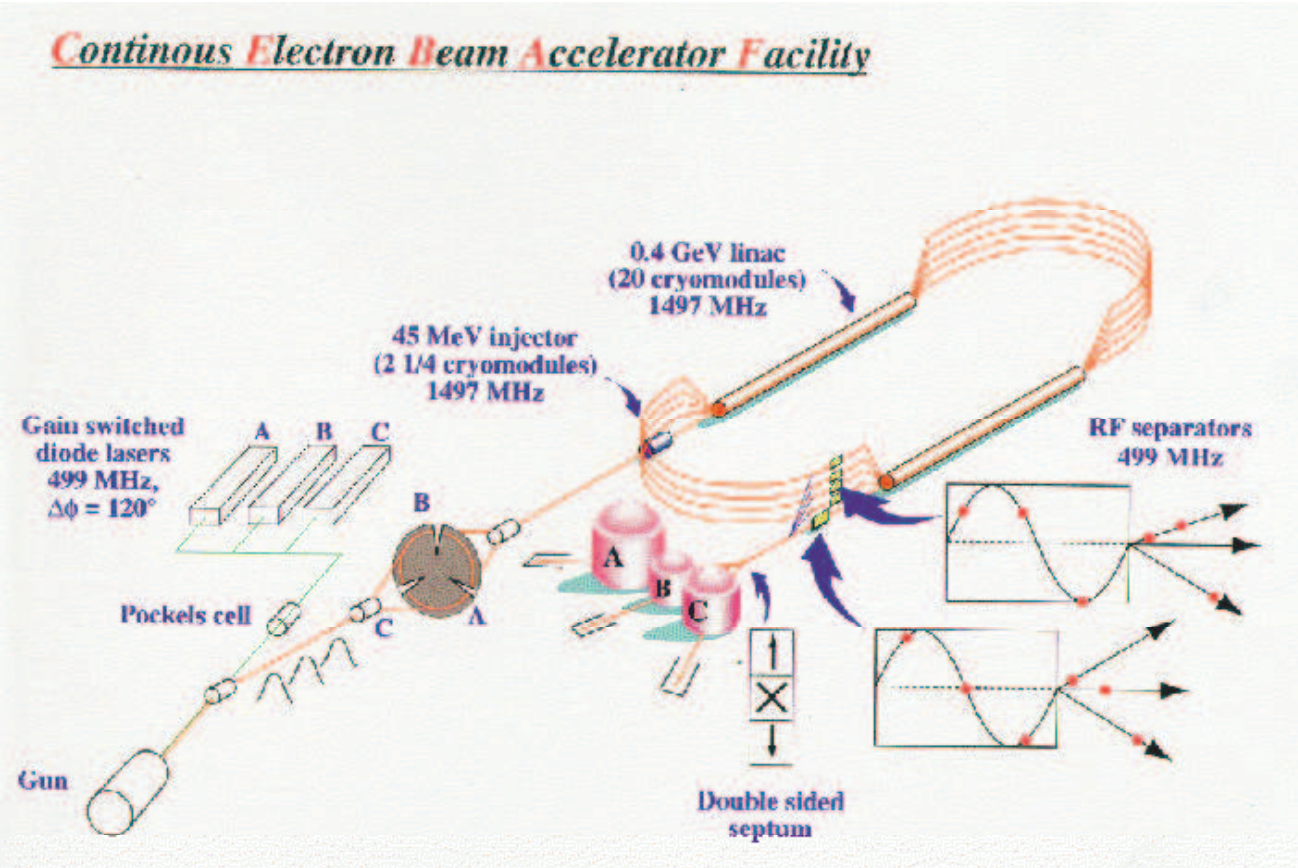
At Jefferson Lab—the Thomas Jefferson National Accelerator Facility in Newport News, Virginia—physicists and engineers are advancing the sciences and technologies of particle accelerators and light sources for use in basic science, applied science, and industry. In partnership with universities, JLab's Accelerator Division offers a spectrum of research opportunities for outstanding undergraduate and graduate students in accelerator-related physics or engineering curricula. Each student is guided by an advisor from the home institution and mentored by a JLab scientist or engineer, and produces a bachelor's or master's thesis or a doctoral dissertation based on original research conducted at Jefferson Lab.

Research fields include:

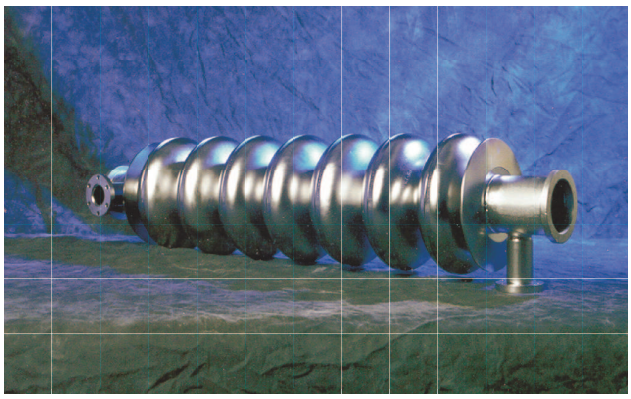
- superconducting radio-frequency (SRF) accelerating structures
- materials for future superconducting cavities
- rf controls for high-gradient, high-*Q* superconducting cavities
- beam dynamics in electron-ion collisions
- novel accelerator designs such as energy-recovery linacs (ERLs)
- high-current (hundreds of mA), high-polarization (>90%) electron guns
- light sources, including free-electron lasers (FELs) and synchrotrons
- simulation and visualization tools for the design and operation of accelerators
- diagnostic techniques for studying beam properties
- industrial-scale, real-time systems for accelerator control
- cryogenics
- accelerator-related mechanical and electrical engineering

CEBAF Accelerator

Nuclear physicists from across the country and around the world visit Jefferson Lab to investigate the quark structure of nuclei with the CEBAF accelerator, the world's largest installation of superconducting cavities for particle acceleration. Though CEBAF—the Continuous Electron Beam Accelerator Facility—was originally designed to deliver electrons of a maximum energy of 4 GeV, it now routinely delivers beam energies of up to 6 GeV. In a racetrack shape nearly a mile around, the underground accelerator consists of two linacs (linear accelerators) through which an electron beam is recirculated up to five times before delivery to any of three experimental halls. Experiments can receive beams from different passes, making it possible to run simultaneous experiments at different energies. The high intensity (up to 200 μA) and high polarization (up to 80%) of the electron gun enable unprecedented study of spin physics. A pending upgrade of CEBAF to 12 GeV will extend its research capabilities still further.



Machine schematic

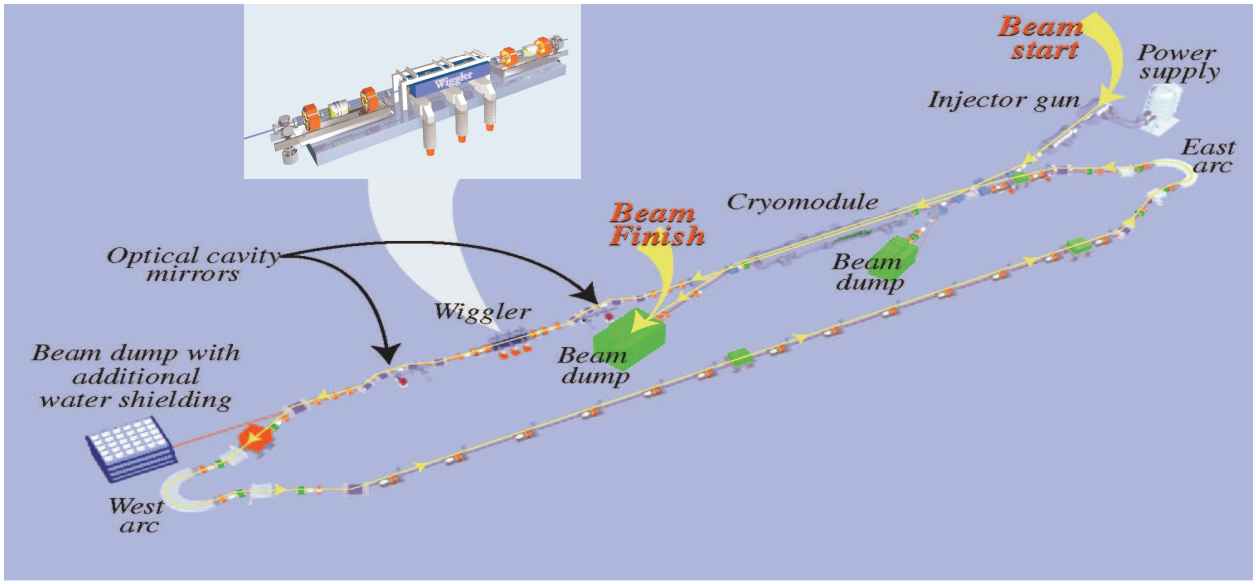


Cavity

Cryomodules in the accelerator tunnel

Free-Electron Laser

JLab has also applied SRF accelerating technology to create the world's most powerful tunable laser, a free-electron laser (FEL) driven by an energy-recovery linac (ERL). An FEL user facility near the center of the CEBAF accelerator site contains the FEL on its bottom floor, with six user labs on its upper floor. During the period 1999 to late 2001, JLab's Infrared Demonstrator FEL delivered subpicosecond laser light at 2 to 6.2 μm to user experiments. It reached 2.1 kW average power—over two orders magnitude higher than any previous FEL. In 2002, JLab's FEL is being upgraded for operation at 0.25 to 15 μm and average powers up to 10 kW, with kilowatt-scale ultraviolet operation as well.



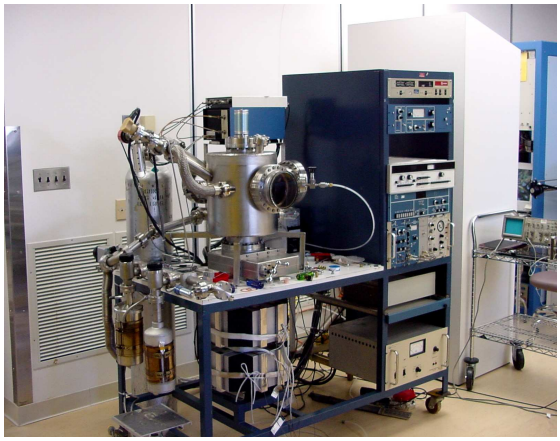
Free-electron laser schematic

Science and Technology Support Facilities

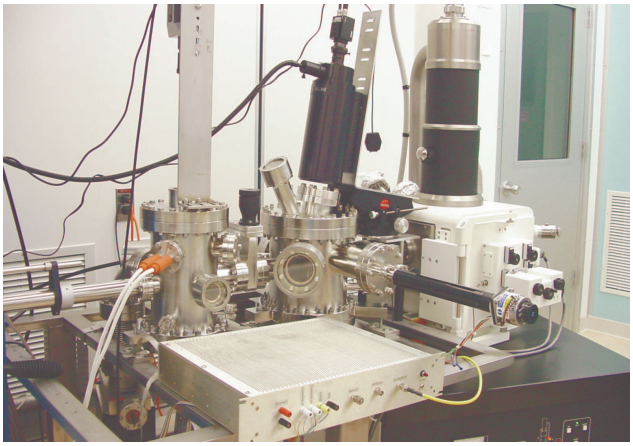
Jefferson Lab has some of the best facilities available anywhere for conducting research in superconducting radio-frequency (SRF) structures. The vertical test area (VTA) with eight dewars, six of them RF-equipped, is one of the finest in the world.

Vertical test area

Closed chemistry and high-pressure rinse cabinets in the clean room



Secondary ion mass spectroscope

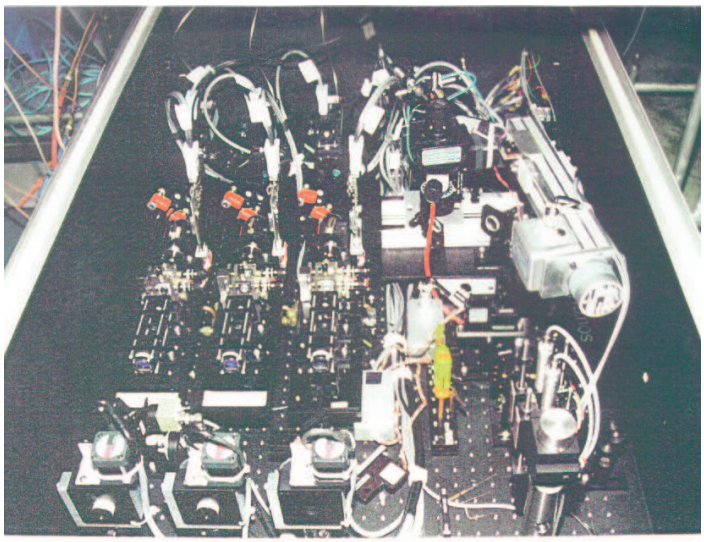


Scanning electron microscope

The materials science laboratory contains a scanning electron microscope, a scanning field emission microscope, a transmission electron microscope, a secondary ion mass spectroscope, and a scanning Auger microscope. Clean rooms

are available for cavity work and for sample preparation. Also available are excellent machine shops and an electron beam welder.

Jefferson Lab's Polarized Electron Source Group develops state-of-the-art photoemission cathodes for generating highly polarized electrons for nuclear physics research. The source laboratory has a test cave and equipment for developing the lasers and the controls.



Three-laser system to deliver independent beams to CEBAF's experimental halls

The Electrical Engineering Group develops diagnostic equipment to study beam properties and to control the beam. The group's expertise encompasses analog, digital, and RF technologies. The electronics laboratory contains a variety of test and diagnostic equipment and tools.

The Accelerator Controls Software Group uses modern real-time operating systems, database management tools, and large networked computers to manipulate the powerful electron beam in the machine. In association with the accelerator scientists, this group develops and implements control algorithms

The world's largest liquefier for 2 K helium supplies superfluid helium to CEBAF's SRF cryomodules. It also supports many types of cryotargets (liquid targets and cold gas targets) for nuclear physics research.

Also on the JLab campus is the Applied Research Center, which houses some two dozen laboratories associated with SURA universities and with nearby NASA Langley Research Center.

Along with this scientific and technological infrastructure, Jefferson Lab has a lively research atmosphere, with regular scientific gatherings, seminars, and colloquia. The laboratory is a major partner in national and international projects

including the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory in Tennessee, the envisioned Rare Isotope Accelerator (RIA), and the envisioned TeV Energy Superconducting Linear Accelerator (TESLA).

World-Class Mentors

The Southeastern Universities Research Association (SURA) operates Jefferson Lab for the U.S. Department of Energy. JLab's internationally recognized scientific and engineering staff naturally maintains strong ties with SURA's fifty institutions, which range geographically from Louisiana State University to the Massachusetts Institute of Technology. Several JLab staff members hold adjunct professorships at SURA universities. Within Jefferson Lab, mentors are drawn from the Accelerator Division, which includes the Center for Advanced Studies of Accelerators (CASA) and the Institute for Superconducting Radio Frequency Science and Technology (ISRFST). In addition, the division boasts a world-class photoinjector group, which develops and operates state-of-the-art polarized electron sources.

Stephen Benson, Ph.D., Stanford University, 1985. High-brightness electron sources, free-electron laser physics, high-power optical resonators. "Demonstration of harmonic lasing in a free-electron laser" (with J. M. J. Madey), *Phys. Rev. A*, 39 (1 Feb. 1989) 1579–1581. Also a co-author of "Optical modeling of the Jefferson Laboratory IR demo FEL," *Nucl. Inst. and Meth. in Phys. Res.* A407 (1998) 401–406 and "Sustained kilowatt lasing in a free-electron laser with same-cell energy recovery," *Phys. Rev. Lett.*, 84 (2000) 662. Won the Lasers '88 Prize, 1988, and the FEL Prize, 2000.

S. Alex Bogacz, Ph.D., Northwestern University, 1986. Beam dynamics of superconducting recirculating linacs; beam optics and lattice design, muon accelerator concept—design of large aperture recirculating linacs; nonlinear beam dynamics and emittance compensation schemes, theory of coupled betatron motion, crystal channeling; "Recirculating linacs for neutrino factory: arc optics design and optimization," *Nucl. Inst. and Meth. in Phys. Res. A* (2001) 14435; "Status of muon collider research and development and future plans," *Phys. Rev. ST Accel. Beams 2* (1999) 081001; "First observation of luminosity driven channeling extraction," *Phys. Rev. ST Accel. Beams 1* (1998) 022801; "Charged Particle High Frequency Laser", Bogacz, et al. United States Patent # 4,817,124 (1989).

Swapan Chattopadhyay, Ph.D., University of California, Berkeley, 1982. Fellow, American Physical Society. Physics and accelerator technology contributions impacting free-electron lasers and ultrafast phenomena, the Advanced Light Source (ALS) for synchrotron radiation sciences, the particle

collider (PEP-II) at the Stanford Linear Accelerator Center (SLAC) for studies of the matter-antimatter asymmetry in nature, and the recent advances in various femtosecond-X-ray source development towards studies of ultrafast phenomena mark but a few of his leading contributions to date. Dr. Chattopadhyay heads Jefferson Lab's Accelerator Division.

Yu-Chiu Chao, Ph.D., University of Michigan, Ann Arbor, 1986. Algorithm development for accelerator diagnostics, analysis and control, CEBAF 12 GeV upgrade design, accelerator operational configuration evaluation and optimization, control applications for CEBAF operation, orbit-correction configuration evaluation and optimization service to the accelerator community, general accelerator beam dynamic studies. "Optimization of orbit correction systems using generalized response matrices and its application to the LHC injection transfer lines" (with V. Mertens), *Proceedings of the 2001 Particle Accelerator Conference*; "A full-order almost-deterministic optical matching algorithm," *Proceedings of the 2001 Particle Accelerator Conference*; "Analysis and measurement of coupling effects in the transfer line from PS to SPS for the LHC proton beam" (with G. Arduini et al.), *Proceedings of the 2001 Particle Accelerator Conference*; "Analysis and optimization of orbit correction configurations using generalized response matrices and its application to the LHC transfer lines TI 2 and TI 8" (with V. Mertens), LHC Project Report 470, May 2001; "A transport arc design with minimized synchrotron radiation induced emittance growth," JLAB-TN 99-037 (1999); "Orbit correction methods—basic formulation, current applications at Jefferson Lab, and future possibilities," CERN Yellow Report 99-07.

Jean Delayen, Ph.D., Caltech, 1977. Physics and technology of superconducting linacs; RF structures design; phase and amplitude control of RF fields; interactions between particles and RF fields; beam instabilities; high-current effects in linacs; RF superconductivity; electromagnetic properties of superconductors; development of new materials and preparation techniques. "Medium-β superconducting accelerating structures" (Invited), *Proc. 2001 RF Superconductivity Workshop*, Tsukuba, Japan; "Cumulative beam breakup in linear accelerators with arbitrary beam current profile," *Proc. 2001 Particle Accelerator Conference*; "Fokker-Planck approach to the dynamics of mismatched charged-particle beams" (with C. L. Bohn), *Phys. Rev. E,* 50 (1994) 1516–1534. Member, Next Linear Collider Machine Advisory Committee 2000-present; member, Strategic Advisory Committee, College of Engineering and Technology, Old Dominion University, 1997–1998. Patent: RFQ Device for Accelerating Particles (with K. W. Shepard), 1995.

Yaroslav Derbenev, Soviet Doctoral Degree, Institute of Nuclear Physics, Novosibirsk, 1978. Fellow, American Physical Society. Beam optics, nonlinear beam dynamics, collective beam dynamics, colliding beams, beam cooling,

polarized beam in accelerators and storage rings, acceleration of charged-particle beams, microwave radiation of relativistic electron beams (FEL and CSR). Inventions: magnetized and crystalline electron cooling; electron-stochastic cooling, electron cooling of positron beams and generation of antihydrogen; Siberian snakes; spin-transparent quadrupoles; Compton polarization of electrons and positrons in storage rings, superconducting RF polarimetry, twisted spin synchrotron; vortex-plane beam adapter; relativistic electron cooling; hollow beams, ionization cooling of muons in helical transport; X-ray SASE FEL; image charge undulator; electron circulator. Conceptual studies at JLab: electron-ion collider; electron cooling in colliders (with groups at other labs); flat to round colliding beams; X and gamma ray sources on image charge undulator; electron injectors with hollow and flat beam source and beam concentrators; reactive RF control for superconducting linacs. "ELIC: An electron-ion collider based at CEBAF" (with L. Merminga) and "Advanced concepts for electron-ion collider," *Proc. 2002 European Particle Accelerator Conference*; "Advanced optical concepts for electron cooling," *Nucl. Instrum. Meth.* A 441 (2000) 223–233; "Circular modes, beam adapters and their applications in beam optics," *Phys. Rev. E* 66, 016503 (2002) (with A. Burov et al.); lead author, "Image charge wakefield undulator and SASE FEL," to appear in *Proc. 2002 Free-Electron Laser Conference*.

Geoffrey Krafft, Ph.D., U. California, Berkeley, 1986. Fellow, American Physical Society. Theoretical studies of collective effects; electron beam diagnostics devices; applications of recirculating and energy recovering accelerators; novel sources of electromagnetic radiation. "The Continuous Electron Beam Accelerator Facility at Jefferson Lab" (with C. W. Leemann and D. R. Douglas) *Annual Reviews of Nuclear and Particle Science,* 2001; "Short pulse synchrotron light from Jefferson Lab's nuclear physics accelerator," *Proceedings of the 1999 Particle Accelerator Conference*, 2448–2450; co-author of "Sustained kilowatt lasing in a free-electron laser with same-cell energy recovery," *Phys. Rev. Lett.* 84 (2000) 662.

Rui Li, Ph.D., U. Maryland, 1990. Accelerator beam physics, nonlinear dynamics, collective effects of high-brightness beams, classical electrodynamics, scientific computation. "Sensitivity of the CSR self-interaction to the local longitudinal charge concentration of a bunch," *Nucl. Instrum. Meth. Phys. Res*. A 475 (2001) 498; "Self-consistent simulation of the CSR effect on beam emittance," *Nucl. Instrum. Meth. Phys. Res.* A 429 (1998) 310.

Lia Merminga, Ph.D., U. Michigan, 1989. Director, Center for Advanced Studies of Accelerators (CASA). Accelerator physics; energy-recovery linacs; high-average-power FELs; linac-ring colliders; multibunch instabilities in recirculating linacs; RF control and modeling; nonlinear dynamics. "Energy recovering linacs," *Proc. XXI International Linac Conference,* 2002; lead author of "ELIC: An

electron–light ion collider based at CEBAF," *Proc. 2002 European Particle Accelerator Conference,* 203–205; "RF stability in energy recovering FELs: theory and experiment," *Nucl. Instrum. Meth. Phys. Res.* A 483 (2002) 107; co-author of "Sustained kilowatt lasing in a free-electron laser with same-cell energy recovery," *Phys. Rev. Lett.* 84 (2000) 662 and "Analysis of the FEL-RF interaction in recirculating, energy-recovering linacs with an FEL," *Nucl. Instrum. Meth. Phys. Res.* A 429 (1999) no.1–3, pp.58–64.

George Neil, Ph.D, U. Wisconsin, 1977. Fellow, American Physical Society. All aspects of FEL development. Formerly program manager, Free Electron Laser Program, and senior scientist on staff of the TRW Optics and Directed Energy Laboratory. Lead author of "Sustained kilowatt lasing in a free-electron laser with same-cell energy recovery," *Phys. Rev. Lett.* 84 (2000) 662; "Free electron generators of microwave radiation" (with H. P. Freund), *Electron Beam Generators of Microwave Radiation, Proceedings of the IEEE*, Vol. 87, No. 5 (May 1999) 782–803 (invited review); "Laser-powered beam-conditioner for free-electron lasers and synchrotrons" (with H. Liu), *Phys. Rev. Lett.* 70 (1993) 3557–3560. Holder or co-holder of six patents. Chaired 20th International Free Electron Laser Conference, Williamsburg, Virginia, August 1998; board member, International Executive Committee on Free Electron Lasers (1993 to present); Program Committee, LINAC'92, LINAC'94, LINAC'96, LINAC'98, LINAC2000.

Matt Poelker, Ph.D., Northwestern University, 1992. Photocathode electron guns; polarized electrons; drive laser technology. "Injection modelocked Ti-sapphire laser with discretely variable pulse repetition rates to 1.56 GHz" (with C. Hovater), *Nucl. Instrum. Meth. Phys. Res.* A 418 (1998) 280; "High power gain switched diode laser master oscillator and amplifier," *Appl. Phys. Lett.* 67 (1995) 2762.

Charles Reece, Ph.D., U. Rochester, 1983. SRF accelerator operational optimization; *in situ* helium processing of SRF cavities; characterization of performance-limiting effects on SRF surfaces; sources of field emission from niobium surfaces; information and knowledge management in an evolving, multidisciplinary technical context. Co-author of "Refining and maintaining optimal performance of the CEBAF SRF systems" and "A system for managing critical knowledge for accelerator subsystems: Pansophy," *Proceedings of the 2001 Particle Accelerator Conference,* and "Enhanced field emission from chemically etched and electropolished broad-area niobium," *J. Vac. Sci. Technol.,* in press.

Robert Rimmer, Ph.D., Lancaster University, U.K., 1988. Arrived 2002; past research interests included muon colliders and neutrino factories; normal conducting high-gradient structures for a muon cooling channel; high-power RF windows; damping-ring RF system for Next Linear Collider; RF cavity structures, windows, tuners, HOM loads; third-harmonic cavity system for the Advanced Llight Source; CW or high-duty-factor laser-photocathode RF guns for

recirculating linac light sources. "Closed-Cell 201.25 MHz RF Structures for a Muon Ionization Cooling Experiment, *Proceedings of EPAC 2002, Paris, France, June 3-7, 2002*. "A High-Gradient High-Duty-Factor RF Photo-cathode Electron Gun", *Proceeding of EPAC 2002, Paris, France, June 3-7, 2002.* "Comparison of calculated, measured, and beam-sampled impedances of a higher-order-mode-damped rf cavity", *Physical Review Special Topics -Accelerators and Beams, Vol. 3*, 102001 (2000).

Michelle Shinn, Ph..D., Oklahoma State University. Ultrafast dynamics in metals and insulators, laser-induced optical damage, materials processing, design of high-average-power lasers. Leads design, procurement, and installation of FEL optical systems. Two decades of active advocacy of women in physics. Lead author of "Spectroscopic and laser properties of Pm3+," *J. Quantum Electron.* QE-24 (1988) 1100 and co-author of "Sustained kilowatt lasing in a free-electron laser with same-cell energy recovery," *Phys. Rev. Lett.* 84 (2000) 662.

Andy T. Wu, Ph.D., Norwegian Institute of Technology, 1993. Surfaces of superconducting RF cavities; surfaces of materials; properties of superconductors; thin film engineering and applications; instrumentation; nanotechnology. "Successful fabrication of nanostructures of convex shape on the as-prepared surfaces of $Nd_1Ba_2Cu_3O_y$ single crystals" (with N. Koshizuka), *Applied Surface Science* 173 (2001) P164; "Nanostructures fabricated on the as-prepared surfaces of $Nd_1Ba_2Cu_3O_y$ high temperature superconductors using a scanning tunneling microscope"(with N. Koshizuka), *Nanotechnology* 12 (2001) P80; "Sensing humidity using nanostructure SiO thin films: mechanism and optimization" (with M. J. Brett), *Sensors and Materials* 13 (2001) 399.

Byung C. Yunn, Ph.D., Johns Hopkins U., 1973. Collective effects in recirculating linacs; injector beam dynamics; electromagnetic radiation sources. "Multipass quadrupole beam breakup instability," JLab-TN-01-023 (2001); "High brightness injectors based on photocathode DC gun," *Proc. 2001 Particle Accelerator Conference*.

Jefferson Lab Staff as Adjunct Professors

- Fred Dylla, College of William and Mary
- Peter Kneisel, Virginia Polytechnic Institute and State University
- Larry Phillips, Virginia Polytechnic Institute and State University
- Charles Reece, Virginia Polytechnic Institute and State University

Jefferson Lab Ph.D. Dissertations
in Accelerator Science or Technology

Completed:

- Nick Sereno (1994). *Experimental Studies of Multipass Beam Breakup and Energy Recovery Using the CEBAF Injector Linac.* U. Illinois, Urbana-Champaign.
- Zenghai Li (1995). *Beam Dynamics in the CEBAF Superconducting Cavities.* College of William and Mary.
- Mahesh Chowdhary (1996). *Online System Identification for Control System Applications in Particle Accelerators.* College of William and Mary.
- David Engwall (1998). *High-Brightness Electron Beams from a DC, High-Voltage GaAs Photoemission Gun.* U. Illinois, Urbana-Champaign.
- Philippe Piot (1999). *High Brightness Electron Beam Diagnostics and their Applications to Beam Dynamics in a Superconducting Energy-Recovering Free-Electron Laser*. Université Joseph Fourier Grenoble I, France.
- Joseph Grames (2000). *Measurement of a Weak Polarization Sensitivity to the Beam Orbit of the CEBAF Accelerator.* U. Illinois, Urbana-Champaign
- Raphael Akogyaram (2002). *Basis Function Repetitive and Feedback Control with Application to a Particle Accelerator*. Columbia University.

In process:
- Genfa Wu. *Energetic Deposition of Niobium Thin Film in Vacuum.* Virginia Tech.
- Tong Wang. *Enhanced Field Emission Studies on Niobium Surfaces Relevant to High Field Superconducting Radio-Frequency Devices.* Virginia Tech.

Fellowships Available

For undergraduate students: Jefferson Lab awards fellowships to qualified full-time undergraduates in fields related to Jefferson Lab accelerator sciences and technologies. A candidate must have an outstanding academic record, must exhibit potential for conducting research, and must be enrolled in a program requiring a written thesis. Normally, the student will be guided by both an advisor from the home institution and a Jefferson Lab staff mentor. Typical duration is two summers. A significant stipend is included. To apply, contact Ms. Jan Tyler (tyler@jlab.org). The application process will require at least two letters of reference from people in a position to assess the applicant's academic performance and research potential. Applicants should indicate JLab research fields of interest.

For master's students: This program is available to students enrolled in a full-time master's program who have an advisor at the home institution. Selection criteria include academic record, letters of reference, and availability of both a JLab staff mentor and funding. The candidate's interest must be compatible with Jefferson Lab's goals and resources. Financial support will be approximately GSRA

equivalent. The duration of the program is limited to two years. Applications may be submitted at any time. Applicants should contact Dr. Jean Delayen (Delayen@jlab.org).

For doctoral students: At the doctoral level, normal duration of a fellowship is three years, with the possibility of extension, and with support equivalent to a full GSRA in the student's graduate department plus a travel allowance to attend scientific meetings. In exceptional circumstances support for tuition may also be provided. The student must be formally enrolled in a doctoral program, must have an advisor at the home institution, must have completed graduate qualifying requirements, and must intend to conduct doctoral research in an area relevant to Jefferson Lab. Selection criteria include academic record, letters of reference, originality and quality of the proposed research, importance and potential impact of the proposed research, and availability of both a JLab staff mentor and funding. The candidate's interest must be compatible with Jefferson Lab's goals and resources. Applications may be submitted at any time. Applicants should contact Dr. Jean Delayen (Delayen@jlab.org). The application must include a curriculum vitae, an official academic transcript, a minimum of three letters of reference from people in a position to assess the applicant's academic performance, and a detailed research proposal.

For More Information

For a broad scientific overview of Jefferson Lab accelerator science and technology, please see the article "The Continuous Electron Beam Accelerator Facility: CEBAF at the Jefferson Laboratory," *Annual Review of Nuclear and Particle Science* 51 (2001) 413–450, available at http://nucl.annualreviews.org/2001/. For more general information about Jefferson Lab, please consult http://www.jlab.org. For more detailed information about graduate and undergraduate research opportunities, please write or e-mail Dr. Jean Delayen, Jefferson Lab, 12000 Jefferson Ave., Newport News, VA 23606 (Delayen@jlab.org).