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Fermilab Programs in Accelerator Training and Education

Prepared in response to DOE/OHEP RFI on

"Strengthening U.S. Academic Programs in Accelerator Science"

DOE national labs are America's steward for accelerators in knowledge, skills, abilities, facilities, infrastructure and equipment. Having highly trained accelerator personnel is essential for DOE labs to create the workforce they need to accomplish their missions. High-energy, high-intensity/luminosity accelerators require a good understanding of underlying beam physics and, consequently, talented accelerator scientists.

U.S. academic programs in accelerator science and technology are of critical importance for Fermilab, as the national lab with the largest accelerator staff. Fermilab's Accelerator and Technical divisions total about 650 members. About half of them are accelerator scientists, engineering physicists and engineers that usually come from either other labs and abroad, another third come from U.S. universities and the rest are home-grown via programs such as the USPAS and others (see below)[1].

It is generally recognized that over the past decades it has become more and more difficult to get good accelerator physicists into the lab and, in general, to attract the best students in the field of high-energy particle accelerators. While development of Fermilab's accelerator workforce strongly relies on the U.S. academic programs, there several lab-supported accelerator training and education programs that have established to address the need. All of them are closely coordinated via Fermilab/AD's Accelerator Physics Center[2], which states in its mission that it is to "…train accelerator scientists and engineers." Below are brief descriptions of the efforts:

1. Joint University-Fermilab Doctoral Program in Accelerator Physics and Technology

The Joint University-Fermilab Doctoral Program[3] was established in 1985 as a way to encourage students to pursue a career in accelerator physics and technology by providing research opportunities using facilities and expertise available at Fermilab. The Ph.D. program works in a

[1] T.Myers, presentation to the HEPAP USPAS Review committee, March 2015
[2] http://apc.fnal.gov/
[3] http://apc.fnal.gov/programs2/joint_university.shtml

joint agreement with universities. Fermilab reimburses the university for the student's salary, provides the research project and provides supervisors. The student maintains a relationship with the home institution's advisers, who oversee the student's progress toward a Ph.D. degree from the university. Typically, between six and eight Ph.D. students carry out research in Fermilab Accelerator, Technical and Scientific Computing divisions every year. The average duration of the support is about three years. The Ph.D. program committee (currently chaired by Dr. Vyatcheslav Yakovlev of the Technical Division) not only selects the participants but also regularly assesses the status of the research at the monthly Budker Seminar series and at the regular meetings with the student's mentors and supervisors. Usually, Ph.D. students are deeply involved either Fermilab accelerator R&D programs (see Appendix 1), employing R&D and test facilities, including Fermilab Accelerator Science and Technology (FAST) Facility, the Mucool Test Area (MTA), High-Brightness Electron Source Lab (HBESL), superconducting RF and superconducting magnet and material test facilities in the Technical Division, or carrying out research at the operational machines (currently the Proton Source, Booster, Recycler, Main Injector) or in the beam physics and technology research groups in AD, TD and SCD. The full list of the Ph.D. program graduates since the programs' beginning (48) is given in Appendix 2. Many Ph.D. students carry out accelerator research at Fermilab without direct support from the lab (i.e., being supported by their universities directly). See Appendix 3 for the last decade's graduates.

2. Fermilab Hosts the US Particle Accelerator School (USPAS)

The US Particle Accelerator School[4] is a national graduate program that provides graduate-level educational programs in the science of particle beams and their associated accelerator technologies that are not otherwise available to the scientific and engineering communities. It also promotes the development and publication of advanced technology textbooks. USPAS conducts graduate and undergraduate level courses at U.S. universities, holding two such programs per year, one in June and one in January. Average attendance is about 300 per year. These courses, which are two weeks in duration, take place at leading universities across the United States. By successfully completing the two-week course requirements, which include 45 contact hours as well as daily problems and examinations, students earn three semester hours of university credit.

The USPAS was recently (2015) reviewed by HEPAP, and detailed information can be found in *Report of the HEPAP Subcommittee for Review of the United States Particle Accelerator School* (May 2015)[5].

[4] http://uspas.fnal.gov/index.shtml
[5] http://science.energy.gov/~/media/hep/hepap/pdf/Reports/HEPAP_USPAS_Subcommittee_Final_Report.pdf

3. Lee Teng Internship (joint with Argonne National Laboratory)

The Lee Teng undergraduate internship program[6] provides a unique summer research experience for undergraduate students at the college junior level in the area of accelerator science and technology. The program was established in 2008 and is carried out jointly by Argonne National Laboratory, Fermi National Accelerator Laboratory and the US Particle Accelerator School (USPAS). At present (2015), Dr. Eric Prebys of Fermilab chairs the Lee Teng Internship Committee. Undergraduate students from any university in the United States (required), preferably those finishing their junior year in either physics, engineering or computer science, are eligible to apply. Approximately 10 students are selected from the applicant pool each year. These students are given a mentored research project at either Argonne or Fermilab in equal numbers – i.e., five at Fermilab and five at Argonne – which they carry out during their 10-åweek summer residency. The Lee Teng internship provides an integrated approach to accelerator science and technology by including exposure to the field beyond the individual research projects. The Lee Teng students attend the US Particle Accelerator School (USPAS) for two weeks out of the 10-week period. Here they get the equivalent of a semester course in accelerator physics, receiving credit from the host university. Attendance at USPAS gives an academic grounding in the subject. There are several activities common to the Argonne and Fermilab interns that take place during the summer. Besides the two weeks together at the USPAS, there is a one-day tour of Fermilab and a one-day tour of Argonne lab.

4. PARTI International Summer Internship

Since 1999, Fermilab's Physics of Accelerators and Related Technology for International Students (PARTI) program[7] offers 10-week summer internships to students from universities in the Former Soviet Union majoring in physics and engineering. These internships offer a chance for students to work with Fermilab scientists and engineers at the frontier of scientific research in the physics and technology of particle accelerators. The interns are assigned only to projects associated either with accelerator physics or accelerator-related technology in AD, TD and/or SCD. The range of topics is wide, from tuning an accelerator to upgrading a beam simulation program to improving radio-frequency cavities or accelerator magnets. The interns use a wide range of skills (performing experiments, data analysis, programming, etc.) and knowledge of physics (electrodynamics, solid state physics, etc.), at the end of the session they prepare and present oral reports, which are later published on the Web. The PARTI program committee, currently chaired by Dr. Alexander Valishev, selects on average 10 students annually. Many

[6] http://www.illinoisacceleratorinstitute.org/lee_teng_internship.html
[7] http://apc.fnal.gov/parti
andhttp://ed.fnal.gov/interns/programs/parti/

students (~1/6) later enroll in the M.S./Ph.D. programs in accelerator science and technology in U.S. universities

5. Italian Engineering Graduate Student Internships and Laurea Thesis Program

Jointly with several Italian universities and funding agencies, Fermilab annually supports some 20 nine-week summer internships to outstanding graduate engineering students. In this comprehensive program, interns work with scientists or engineers on projects related to Fermilab's research program. They also attend career planning and numerous training/informational sessions. The program is led by Dr. Emanuela Barzi of the Fermilab Technical Division.

These collaborative activities started in 1984, when Italian Istituto Nazionale di Fisica Nucleare created a summer students program to support four physics students from University of Pisa at Fermilab. Since 2004 there has been official support from the U.S. Department of Energy. Agreement between Fermilab and Scuola Superiore Sant'Anna (Pisa) was signed in 2007 to jointly support of four SSSA students each year. In 2010 the Italian Scientists and Scholars in North America Foundation (ISSNAF) started fundraising for a similar program in several science institutions in the U.S., including Fermilab.

The Italian Summer Internship program[8] lasts from the end of July to the end of September. Each student is assigned to a mentor (Fermilab employee) responsible for the training program and, with a supervisor, for overseeing the student's work on a daily basis. Students also attend seminars and introductory courses on high-energy physics and advanced technologies.

Students submit a written report to Fermilab at the end of the program. Students majoring physics and engineering come from University of Pisa, Roma, Padova, Siena, Trieste, Trento, Bologna, Torino, Naples, Sant'Anna Engineering School of Pisa, Polytechnic of Turin, Polytechnic of Milan, and Order of the Engineers of the Italian Provinces

Jointly with Italian Universities, Fermilab also supports *Laurea* (Master's) degree research of one to two Italian students annually primarily in Fermilab's Technical Division. See the list of 23 graduates since 1999 in Appendix 4. Five of the graduates are currently employed as scientific staff at the Fermilab. The program is also coordinated by Dr. Emanuala Barzi.

6. Fellowships (Peoples, Bardeen, Wilson, Toohig)

Fermilab supports several fellowship programs for outstanding young researchers in the field of accelerator science and technology: the Peoples Fellowship[9] (2000-present), the Bardeen

[8] http://ed.fnal.gov/interns/programs/ital-sssa/index.shtml
[9] http://fnal.gov/pub/forphysicists/fellowships/john_peoples/index.html

Fellowship[10] (2005-present), the US LARP Toohig Fellowship[11] (2006-present) and, in the past, the Wilson Fellowship (1988-1998). All past and current fellows, total of six, 14, 11 and five, correspondingly, are listed in Appendix 5.

The Peoples Fellowship was created at Fermilab with the goal of attracting outstanding accelerator scientists early in their careers, both to enhance Fermilab's capabilities in accelerator science and related technologies and to train and develop the accelerator scientists and technologists who will carry our field forward in the future. The Peoples Fellows program targets entry-level accelerator physicists, specialists in accelerator technologies and high-energy physics postdoctoral researchers who wish to embark on a new career in accelerator physics or technology. Peoples Fellows have extraordinary latitude in choosing their research activities and are provided with significant research support. Current areas of research that are of interest at Fermilab include (but are not limited to): stochastic and electron cooling, high-intensity proton beams, high-intensity neutrino sources, muon storage rings, superconducting magnets, superconducting RF, linear colliders, high-luminosity hadron colliders, beam-beam effects and their compensation, accelerator controls and feedback, and computational physics and modeling.

Fermilab seeks Peoples Fellows candidates with outstanding credentials who have the potential to be leaders of the field. There are two options for eligibility. 1) Candidates must have received within the prior three years a Ph.D. in accelerator physics or accelerator-related technology, in which case postdoctoral experience is not required, or 2) they must have received within the prior five years a Ph.D. in high-energy physics or a related field, in which case they are typically expected to have at least three years of postdoctoral experience in high-energy physics or a related field. The initial term of the fellowship for candidates with less than two years of postdoc experience is an initial four-year appointment, eligible to be considered for a second three-year term. For candidates with two or more years of postdoc experience, the term is an initial three-year appointment, eligible to be considered for a second two-year term. At present, Prof. Swapan Chattopadhyay of Northern Illinois University and the Acceerator Division chairs the Peoples Fellowship committee.

The John Bardeen Engineering Leadership Program (Fellowship) is designed to provide full-time entry-level opportunities for outstanding engineering graduates who are interested in working in a cutting-edge research environment. Fermilab provides opportunities in the fields of electrical, electronics, radio-frequency systems, power distribution, magnets, RF cavities, mechanical, materials science and cryogenic engineering. The program honors John Bardeen's revolutionary achievements as both a physicist and engineer. Applicants must be recipients of a Master or Doctoral degree in engineering from an accredited institution and apply within three years of graduation or completion of a first postdoctoral position. A thesis consisting of independent study must have been a significant part of the graduate degree. Degrees consisting of only classroom work do not qualify. Candidates who rank in the top quarter of their graduating class

[10] http://www.fnal.gov/pub/forphysicists/fellowships/john_bardeen/index.html
[11] http://www.interactions.org/toohig/index.html

are considered favorably. This program provides successful candidates full-time employment without term limit.

The Toohig Fellowships in Accelerator Science at the LHC were established in 2006 with support from the US LHC Accelerator Research Program (LARP). LARP is a collaborative initiative of the U.S. DOE Office of Science, Division of High Energy Physics and DOE Office of Science laboratories, with Fermilab playing a key role. The Toohig Fellow postdoctoral positions are for recent Ph.D. scientists or engineers and support research activities related to CERN's Large Hadron Collider and the LHC High-Luminosity program. Currently, Dr. John Fox of SLAC chairs the Toohig Fellowship Committee. The term of the fellowship is two years, extendable to three with mutual interest. Fellows are hosted by one the U.S. DOE laboratories involved in the LARP collaboration, with opportunities for CERN-based research as part of experimental efforts, commissioning of LARP-developed equipment, and for collaborative projects with CERN related to the HL-LHC program. Out of a total 11 fellows, three were hosted by Fermilab. See Appendix 5.

7. Joint Appointments and Adjunct/Visiting Professorships

Academic appointments prove a powerful recruitment tool for the world's leading scientists. At present, there are four joint appointees pursue pioneering collaborative accelerator research at Fermilab and local universities:

Prof. Swapan Chattopadhyay (NIU)
Prof. Philippe Piot (NIU)
Prof. Young-Min Shin (NIU)
Prof. Pavel Snopok (IIT)

These appointments enrich research programs at the lab and the universities, playing a major role in the recruitment of top scientific talent in the Chicago region and advancing technology and discovery throughout the United States. Fermilab greatly benefits from the appointee's scientific and technical contributions, the influx of the student they supervise and additional support of the accelerator research at the lab that the appointees bring in form of research grants.

These appointments are joint tenure or tenure track position in accelerator physics at the level of Full, Associate or Assistant Professor, they are funded 50 percent by Fermilab and 50 percent by the university, with a commensurate reduction in the teaching load. They offer unique opportunities to carry out accelerator physics-related research in both national laboratory and university settings.

To further strengthen academic collaborations in accelerator science with Chicagoland universities, two Fermilab leading accelerator scientists have been recently appointed part-time/adjunct professors:

Dr. Sergei Nagaitsev – Professor Part-time, University of Chicago, Department of Physics; Dr. Vladimir Shiltsev – Adjunct Professor, Northern Illinois University, Department of Physics.

8. U.S. and Foreign Universities in Fermilab's Accelerator Programs

Fermilab offers access to its many R&D and operational accelerator facilities to many U.S. and foreign universities. A recent review of these activities was presented by Dr. Sarah Cousineau (U.Tennessee/ORNL) at the HEPAP GARD Subpanel meeting at Fermilab in August 2014[12]. See summary table in Appendix 6. Many foreign universities are actively involved, too, including Imperial College London, University of Mexico, IAP Frankfurt and Oxford.

[12] https://indico.fnal.gov/conferenceDisplay.py?confId=8832

Below are Fermilab's responses to the RFI specific questions:

Increasing the Recognition of Accelerator Science in Academia

1. Does your institution regard accelerator science as an academic discipline? Why or why not?

Yes, Fermilab regards accelerator science as academic discipline of key importance for the laboratory as it directly affects the performance of the current accelerator complex and its future development. Some 40 peer-reviewed publications in leading high-impact US and international journals are published annually by Fermilab accelerator staff and our collaborators.

2. If your institution offers graduate training in accelerator science (several questions):

Yes, Fermilab offers Joint University-Fermilab Accelerator Ph.D. program (see above). Some six to eight students are supported annually.

3. If your institution no longer offers graduate training in accelerator science, why was the program terminated?

n/a

4. What funding sources for accelerator science are you aware of?

DOE OHEP, BES, ASCR, and NP, NSF, national laboratories (e.g., Fermilab)

Integrating the Roles of the Universities and the U.S. National Laboratories

5. How can the national laboratory system be best utilized by the university accelerator science community?

Boost the research via free access of the university faculty and students to operational accelerators and beam R&D facilities – e.g., Fermilab Accelerator Science and Technology (FAST) facility - that might have particularly high impact for small minority-serving institutions and historical black colleges and universities, which now have a hard time participating in and contributing to lab accelerator programs because of a lack of basic infrastructure and training at their home institutions; expanded possibilities to attract lab's scientists for the collaborative work and supervision of university students; expand the number of joint appointments between labs and universities and number of adjunct professorship positions for lab scientists in the U.S. universities.

6. What are the current barriers (*e.g.* technical, operational, and economic) that prevent closer collaboration between universities and the national laboratories?

Many universities do not have strong faculty in accelerator and beam science; some universities do not consider the accelerators as priority for their scientific activities.

7. Does your university accept accelerator course credits from other institutions?

n/a

8. Do accelerator science students at your institution routinely take courses and training elsewhere?

Yes, usually at the USPAS (see above).

9. What could be done to strengthen the participation of academia in the operation and improvement of existing national laboratory accelerators?

Expand the number of joint appointments between labs and universities and number of adjunct professorship positions for lab scientists in the U.S. universities.

10. Considering disciplines other than accelerator science what mechanisms are in place at your university for collaboration with national laboratories? Could these mechanisms be extended to accelerator science?

See above 8 activities in accelerator science training and education supported by Fermilab.

Contemporary Models of University Accelerator Science

11. What examples exist of thriving academic accelerator science programs?
f. Are there joint appointments with a nearby national laboratory or a private company engaged in accelerator R&D? How many?

Yes, three with NIU and 1 with IIT – see above

12. Are there successful examples of academic programs from other technologically oriented disciplines that you believe are relevant to the establishment or improvement of an accelerator science program? What key attributes make the program successful?

n/a

13. Are there successful examples of academic accelerator science programs from other countries that you believe are relevant to the U.S. system? What key attributes make the programs successful?

There are two examples of successful programs in accelerator science overseas: 1) at CERN, there are many (dozens to hundreds) positions for Ph.D. students and fellows from all over Europe that come to do either graduate of limited-term postgraduate research and development; they participate in the accelerator complex operations and accelerator R&D and make very valuable contributions to the lab, and, at the same time, allow to attract the best accelerator talent to the organization; 2) in Russia, most of the Ph.D. research work is done at research (not educational) institutions and the Ph.D. degrees are granted by them as well (not by universities). In both cases, very high-class research and many talented young scientists are produced because of several factors: easy access to the world leading accelerator facilities, everyday work with and supervision by world leading "practical" accelerator scientists and engineers, and sustainable support of these activities or programs over many years.

Possible Mechanisms To Encourage Academic Accelerator Science

14. What specific, cost-effective actions could be taken to:
a. Raise the academic status of accelerator science? Examples in this category might include: Funding named accelerator science faculty positions or named scholarships.

Yes (agree)

b. Improve the business case for accelerator science in a university setting? Examples in this category might include grants and practices designed to increase interactions with private industry.

Yes (agree); Illinois Accelerator Research Center (IARC) [13] at Fermilab can be instrumental for that

c. Encourage students to choose a career in accelerator science and technology? Examples in this category might include a grant for young faculty to conduct R&D in accelerator science, a tuition stipend for a co-terminal master's degree, or grants to develop instructional materials.

Yes (agree)

d. Increase the enrollment in education opportunities at the baccalaureate and master's level?

Offer more opportunities for the master thesis work at the near-by national accelerator labs

[13] http://iarc.fnal.gov/

e. Increase the availability of hands on training opportunities in accelerator technology?

Offer one to two weeks of hand-on classes a la USPAS at the technology development facilities at large national labs (e.g., at Fermilab's IARC/FAST or at Argonne).

Other Factors

15. Other than the actual award of funding, is there any specific funding agency behavior that impacts positively or negatively on the success of an accelerator science program?

Strategic planning toward, e.g., more effective use of the unique accelerator facilities and infrastructure at the national labs and balanced approach to prioritization of the accelerator R&D programs supported by DOE and NSF to reflect the long-term aspirations of HEP, BES and NP should be publicly announced by the funding agencies and can help to properly orient university based accelerator science programs.

16. Are there other factors not addressed by the questions above that contribute to the strength or weakness of U.S. academic accelerator science?

In the part in which the U.S. academic accelerator science programs depend on support from federal funding agencies, they are subject to the annual budget cycle uncertainties and risks and greatly affected by the level of bureaucracy in the grant competition and reporting processes

Sincerely,

Vladimir Shiltsev
Director, Accelerator Physics Center/AD
Fermilab

Appendix 1: Fermilab Accelerator R&D Programs

	Coordinator	Collaboration
Fermilab Accelerator Science and Technology facility (FAST)	Shiltsev	ANL, Berkeley, BNL, Budker Institute of Nuclear Physics, CERN, Chicago, Colorado State, Fermilab, IAP Frankfurt, JINR Dubna, Kansas, LANL, LBNL, Maryland, Michigan State, Northern Illinois, ORNL, Oxford, RadiaBeam Technologies, RadiaSoft LLC, Tech-X, Tennessee, Vanderbilt
High Power Beam Targetry	Hurh	ANL, BNL, CERN, CIEMAT, ESS, Fermilab, KEK, Michigan State, LANL, ORNL, Oxford, PNNL, PSI, STFC
Muon Accelerator Program (MAP)	Palmer	ANL, BNL, Cornell, Fermilab, IIT, ICL, JLab, LBNL, Mississippi, Muons Inc, Particle Beam Lasers, Princeton, SLAC, SUNY Stony Brook, UC/Berkeley, UCLA, UC/Riverside, Virginia Tech
Muon Ionization Cooling Experiment (MICE)	Long / Bross	Belgrade, BNL, Brunel, CERN, Cockroft, Daresbury, Fermilab, DPNC Geneva, Glasgow, Harbin, IIT, ICL, Iowa, JLab, Kyoto, LBNL, Liverpool, Milano, Mississippi, Napoli, New Hampshire, NIKHEF, Osaka, Oxford, Pavia, RAL, Roma III, Sheffield, Sichuan, Sofia, Strathclyde, UC/Riverside, Warwick
LHC Accelerator Research Program (LARP)	Apollinari	BNL, CERN, Fermilab, LBNL, SLAC, JLab, Old Dominion
Superconducting RF	Romanenko	ANL, CERN, Cornell, DESY, ESS, Fermilab, India (RRCAT, BARC, UECC, IUAC), IHEP/Beijing, INFN, JLab, KEK, Korea (RISP), MSU(FRIB), Northern Illinois, Northwestern, SLAC, TRIUMF, NHMFL
High-Field Superconducting Magnets and Materials	Zlobin	BNL, CERN, Fermilab, Florida State/NHMFL, LBNL, KEK/NIMS, Ohio State

Appendix 2: Joint Fermilab-University Accelerator PhD Program graduates (1987-2014)

Mike Syphers 1987 University of Illinois-Chicago
An Improved 8-GeV Beam Transport System for the Fermi National Accelerator Laboratory

Nikolitsa Merminga 1989 University of Michigan
A Study of Nonlinear Dynamics in the Fermilab Tevatron

Leonid Sagalofsky 1989 University of Illinois
Third-order Charged Particle Beam Optics

Mark Stahl 1990 Northwestern University
Beam Dynamics in the Fermilab Booster in the Presence of Space Charge

Peilei Zhang 1991 University of Houston
A Study of Tunes Near Integer Values in Hadron Colliders

Xiao-qing Wang 1991 Illinois Institute of Technology
A Study of Longitudinal Coherent Effects of Unbunched Beams Near Transition in the Fermilab Accumulator.

John Palkovic 1991 University of Wisconsin
Gabor Lens Focusing and Emittance Growth in a Low-Energy Proton Beam
1993 APS DPB Outstanding Doctoral Thesis Research in Beam Physics Award Recipient

Todd Satogata 1993 Northwestern University
Nonlinear Resonance Islands and Modulational Effects in a Proton Synchrotron

Ping Zhou 1993 Northwestern University
A Study of Ion Trapping and Instability in the Fermilab Anti-proton Accumulator

Kathy Harkay 1993 Purdue University
A Study of Longitudinal Instabilities and Emittance Growth in the Fermilab Booster Synchrotron

Bill Graves 1994 University of Wisconsin
Measurement of Transverse Emittance in the Fermilab Booster

Xianping Lu 1994 University of Colorado
Study of a Longitudinal Coupled Bunch Instability in the Fermilab Main Ring

Donna Siergiej 1995 University of New Mexico
Beam-beam Interaction Effects in the Fermilab Collider

Ping Jung Chou 1995 Northwestern University
The Nature of Transverse Beam Instabilities at Injection in the Fermilab Main Ring

David Olivieri 1996 Massachusetts University
A Dynamic Momentum Compaction Factor Lattice for Improvements to Stochastic Cooling in Storage Rings

Linda Spentzouris 1996 Northwestern University
Coherent Nonlinear Longitudinal Phenomena in Unbunched Synchrotron Beams
1997 APS DPB Outstanding Doctoral Thesis Research in Beam Physics Award Recipient

Eric Colby 1997 UCLA
Design, Construction, and Testing of a Radiofrequency Electron Photoinjector for the Next Generation Linear Collider

Katya Langen 1997 University of Wisconsin
Microdosimetric Investigation at the Fast Neutron Therapy Facility at Fermilab

Oleg Krivosheev 1998 Tomsk Polytechnic
University Object Oriented integrated System for Beam Incuded Energy Deposition Simulations for Tevatron and Upgrades

Michael Fitch 2000 University of Rochester
Electrooptic Sampling of Transient Electric Fields from Charged Particle Beams

Jean-Paul Carneiro 2001 Paris XI
Etude Experimentale du Photo-injecteur de Fermilab

Vadim Kashikhin 2001 Efremov Institute
Design and Optimization of Superconducting Accelerator Magnets

Vincent Wu 2002 Cincinnati University
Design and Testing of a High Gradient Radio Frequency Cavity for the Muon Collider

Linda Imbasciati 2003 TU-Vienna

Studies of Quench Protection in Nb3Sn Superconducting Magnets for Future Particle Accelerators

Mohammad Alsharoa 2004 Illinois Institute of Technology
Electromagnetic and Mechanical Design of Gridded Radio-frequency Cavity Windows

Kip Bishofberger 2005 UCLA
Tevatron Beam-Beam Compensation

Ludovic Nicolas 2005 Glasgow
Radiation environment simulations at the Tevatron, studies of the beam profile and measurement of the Bc meson mass

Sergei Seletskiy 2005 Rochester University
Attainment of Electron Beam Suitable for Medium Energy Electron Cooling

Robert Zwaska 2005 Texas University
Accelerator systems and instrumentation for the NuMI neutrino beam

Xiaobiao Huang 2005 Indiana University
Beam Diagnosis and Lattice Modeling of the Fermilab Booster

Bernardo Bordini 2006 Pisa
Thermo-magnetic instabilities in Nb3Sn superconducting accelerator magnets

Pavel Snopok 2007 Michigan State
Capture of a Large Phase Space Beam

Phil Yoon 2007 University of Rochester
Error-Induced Beam Degradation in Fermilab's Accelerators

Alexei Poklonsky 2008 Michigan State University
Optimization and Control of Tevatron Parameters

Ryoichi Miyamoto 2008 University of Texas, Austin
AC Dipole Diagnostics of Fermilab's Tevatron
2010 APS/DPB Outstanding Doctoral Thesis Research in Beam Physics Award Recipient

Timothy Koeth 2009 Rutgers University
The first observation of a Transverse to Longitudinal Emittance Exchange

U.Mavric 2009 University of Ljubljana

The LLRF control system for the international linear collider main LINACs

W.M.Tam 2010 Indiana University
HINS H- source and beam diagnostics

Dan McCarron 2010 IIT
Measurement and Simulations of intensity Dependent Effects in the Fermilab Booster Synchrotron

A.Saini 2012 University of Delhi
Study of the beam dynamics in the International Linear Collider and in the Project X linac

T.Maxwell 2012 NIU
Measurement of sub-picosecond electron bunches via electro-optic sampling of coherent transition radiation

Alexey Petrenko 2012 Budker Institute of Nuclear Physics
Model-independent analysis of the Fermilab Tevatron turn-by-turn beam position monitor measurements.

Denise Ford 2013 Northwestern University
Insights to Superconducting Radio-Frequency Cavity Processing from First Principles Calculations and Spectroscopic Techniques

Meghan McAteer 2014 University of Texas - Austin
Linear optics measurements in the FNAL Booster and in the CERN PS Booster

Timofey Zolkin 2014 University of Chicago
Beam Dynamics (Fermilab Boost); Non-linear intergrable accelerators

Gene Kafka 2014 Illinois Institute of Technology
Lattice Design of the Integrable Optics Test Accelerator and Optical Stochastic Cooling Experiment at Fermilab

Yulia Trenikhina 2014 Illinois Institute of Technology
Investigation of Nb surface structure and composition for improvement of superconducting radio-frequency cavities

Ao Liu 2014 Indiana University
Design and simulation of the nuSTORM facility

Appendix 3: Accelerator PhDs granted on base of research done at Fermilab (2004-2014)

Matthew Thomson 2004 UCLA
Plasma Density Transition Trapping of Plasma Electrons in a Plasma Wake Field Accelerator

Yin-e Sun 2005 University of Chicago
Round-to-Flat beam transformation at A0 Photoinjector

Rodion Tikhoplav 2006 Rochester University
"Laser Acceleration in Vacuum at A0 Photoinjector"

Jian-Jian Li 2008 IIT
"SC RF Cryomodule Couplers"

Chris Prokop 2014 NIU
Advanced Phase Space Manipulations at the Fermilab's Advanced Superconducting Test Accelerator

Francois Lemery 2015 NIU
Beam Acceleration and Manipulation Using Dielectric Linear Waveguides

Appendix 4: Italian Laurea graduates on base of research done at Fermilab (1999-2014)

1. Cristian Boffo – Mechanical Eng., University of Udine, 1999: *Magnetization Measurements at 4.2K of Multifilamentary Superconducting Strand,* Prof. G. Pauletta, E. Barzi Advisors – TD (hired at FNAL)
2. Michela Fratini – Nuclear Eng., Pisa University, 2002: *A Device to Test Critical Current Sensitivity of Nb3Sn Cables to Transverse Pressure*, Prof. C. Angelini, Prof. F. Fineschi, E. Barzi Advisors – TD (hired at CEA/Saclay)
3. Sara Mattafirri – Nuclear Eng., Pisa University, 2002: *Kinetics of Phase Growth during the Cu-Sn Diffusion Process and the Nb3Sn Formation. Optimization of Superconducting Properties,* Prof. C. Angelini, Prof. F. Fineschi, Prof. S. Lanza, E. Barzi, J.M. Rey Advisors – TD (hired at LBNL)
4. Licia Del Frate – Nuclear Eng., Pisa University, 2004: *Design of a Low Resistance Sample Holder for Instability Studies of Superconducting Wire,* Prof. C. Angelini, Prof. F. Fineschi, Prof. S. Lanza, E. Barzi Advisors – TD (hired at INFN)
5. Vito Lombardo – Computing/Automation Eng., Sant'Anna School (Pisa), 2007: *Automation of Short Sample Facility for Critical Current and Low Field Instability Measurements of Superconducting Strands at Cryogenic Temperatures,* Prof. M. Innocenti, Prof. L. Pollini, E. Barzi, D. Turrioni Advisors – TD (hired at FNAL)
6. Marco Danuso – Mechanical Eng., Sant'Anna School (Pisa), 2008: *Parametric Analysis of Forces and Stresses in Superconducting Magnets Windings,* Prof. M. Beghini, E. Barzi, A. Zlobin Advisors - TD
7. Gabriella Norcia – Mechanical Eng., Pisa University, 2009: *Design of Modular Test Facility for HTS Insert Coils,* Prof. M. Beghini, E. Barzi Advisors – TD (hired at Ansaldo)
8. Giuseppe Gallo – Mechanical Eng., Pisa University, 2010: *Mechanical Modeling of Superconducting Rutherford-type Cable Fabrication,* Prof. M. Beghini, Prof. L. Bertini, E. Barzi Advisors – TD (hired at FNAL)
9. Antonio Bartalesi – Mechanical Eng., Pisa University, 2010: *Design of High Field Solenoids made of High Temperature Superconductors,* Prof. M. Beghini, E. Barzi Advisors – TD (at CERN)
10. Alessandro Quadrelli – Electrical Eng., Pisa University, 2010: *Automated Control of the Tuning of Superconducting RF Cavities,* Mirko Marracci, Franco Bedeschi Advisors (Warren Schappert supervisor) - TD
11. Matteo Scorrano – Electronic Eng., Pisa University, 2010: *Development of a Control System for Superconducting Cavities with Fast Tuners,* Giovanni Pennelli, Franco Bedeschi Advisors (Youri Pischalnikov supervisor) – TD
12. Simone Moio – Physics Eng., Turin Polytechnics, 2011: *Effect of Subelement Size, RRR and Strand Size on Stability of RRP Nb_3Sn Strands,* Prof. R. Gonnelli, E. Barzi Advisors – TD (hired at Magneti Marelli)

13. Donato Passarelli – Mechanical Eng., Pisa University, 2011: *Analysis of the mechanical behavior of the Superconducting Single Spoke Resonator type 1 in tests at cryogenic temperature*, Prof. M. Beghini, L. Ristori Advisors – TD (hired at FNAL)
14. Federico Puccinelli – Mechanical Eng., Pisa University, 2011: *Detector support structure and installation system for the Mu2e experiment*, Prof. Marco Beghini, Sandor Feher, Rodger Bossert Advisors - TD
15. Paolo Berrutti – Physics Eng., Turin Polytechnics, 2011: *Radio frequency design and optimization of the low-medium-beta section for a 3 GeV linear particle accelerator*, Prof. Gianni Coppa, Slava Yakovlev Advisors – TD (hired at FNAL)
16. Andrea Pisoni– Physics Eng., Milan Polytechnics, 2012: *Implementation of Nano Scale Formations in A15 Brittle Superconductors*, Prof. R. Bertacco, E. Barzi, T. Rajh Advisors – TD (PhD at University of Lausanne)
17. Giulia Collura– Electronic Eng., Turin Polytechnics, 2012: *Beam Test of a High Pressure RF Cavity for the Muon Collider*, Prof. Felice Iazzi Advisor (Alvin Tollestrup Supervisor) - APC
18. Pietro Giannelli – Electronic Eng., Turin Polytechnics, 2012: *Design of a Signal Conditioner for the Fermilab Magnet Test Facility*, Prof. Marco Parvis Advisor (Darryl Orris Supervisor) - TD
19. Vincenzo Li Vigni – Electronic Eng., Palermo University, 2012: *Design and testing of a digital regulator for Fermilab magnet power systems*, Prof. Giuseppe Capponi, Valeria Boscaino, Andrzej Makulski Advisors - TD
20. Silvia Zorzetti – Electronic Eng., Pisa University, 2013: *Development of the world's first digital direct-current current transformer (DCCT) to measure particle beam intensities*, Prof. Luca Fanucci, Manfred Wendt Advisors – AD (at CERN)
21. Federico Reginato – Physics Eng., Milan Polytechnics, 2014: *Electrochemical Synthesis of Nb-Sn Coatings for High Field Accelerator Magnets*, Prof. Silvia Franz, E. Barzi Advisors - TD
22. Matteo Grandini – Mechanical Eng., Pisa University, 2014: *Design of a liquid helium transfer line support system*, Prof. Bernardo Disma Monelli, Thomas Page Advisors - TD
23. Andrea Palagi – Mechanical Eng., Pisa University, 2014: *ASME Verification and Pressure Sensitivity optimization of the Cryostat of the 1.3 GHz Cavity*, Prof. Marco Beghini, Prof. Leonardo Bertini, Allan Rowe Advisors - TD

Appendix 5: Fermilab Fellowships in Accelerators: Wilson Fellows (1988-1998), Peoples Fellows (2000-2015), Bardeen Fellows (2009-2014), Toohig Fellows (2006-2015)

Wilson Fellows		*now at:*
James Rosenzweig	1988	UCLA
Gerald Jackson	1988	Hbar Technologies
Andrei Gerasimov	1991	Liberty Power (finance)
Vladimir Shiltsev	1996	Fermilab
Sergei Nagaitsev	1998	Fermilab

Peoples Fellows	*now at:*
Pierre Bauer	European Fusion Development Agreement (ITER)
Markus Huening	DESY
Andreas Jansson	ESS
Andrea Latina	CERN
Philippe Piot	Northern Illinois University
Lionel Prost	Fermilab
Alex Romanenko	Fermilab
Yin-e Sun	Argonne Nat'l Lab
Katsuya Yonehara	Fermilab
Robert Zwaska	Fermilab
Tengmin Shen	Fermilab
Charles Thangaraj	Fermilab
Anna Grasselino	current Fellow, since 2013
Daniel Bowring	current Fellow, since 2013

Bardeen Fellows		*now at:*
Julien Branlard	2005	DESY
Nandhini Dhanaraj	2006	TD/Superconducting RF Cavity Department
Torben Grumstrup	2007	Colorado State
Vito Lombardo	2007	TD/Superconducting RF Cavity Department
Mohamed Hassan	2010	TD/Superconducting and RF Development
Kevin Ammigan	2012	AD/Targetry Department

Toohig Fellows		*now at:*
Rama Calaga	2006-08 (BNL)	CERN
Helene Felice	2007-09 (LBNL)	LBNL
Darius Boscian	2008-11 (FNAL)	INP, Poland
Ryoichi Miyamoto	2008-11 (FNAL)	ESS
Ricardo de Maria	2010-11 (FNAL)	CERN
Themis Masteridis	2010-11 (SLAC)	California Polytech
Valentina Previtali	2011-13 (FNAL)	Geneva
Simon White	2010-13 (BNL)	ESRF
John Caseratto	2011-14 (SLAC)	Philips
Ian Pong	2013-now (LBNL)	
Silvia Verdu-Andes	2013-now (BNL)	

Appendix 6: US Universities carrying out accelerator R&D at Fermilab (2014)

(from S.Cousineau (U.Tennessee/ORNL), presentation to the HEPAP GARD Subpanel meeting, FNAL, August 2014)

University	**Primary Topic(s)**	Funding agency
IIT	SRF technology; machine concepts; novel accelerator technologies	DOE-HEP grant, NSF
U. of Chicago	Beam dynamics (IOTA)	Fermilab, NSF, U.of Chi
NIU	SRF technology; beam dynamics (IOTA); accelerator technology	DOE-HEP grant, NSF, DOD, NIU
IU	Beam dynamics; machine concepts	DOE-HEP grant
U. of MD	Beam dynamics	DOE-HEP grant, NSF, ONR
U. Tenn.	Accelerator technology; beam dynamics	DOE-HEP grant
U. Wisc.	SRF technology	DOE-HEP grant
MSU	SRF technology; beam dynamics; machine concepts	DOE-HEP grant; NSF
U. Colorado	Beam dynamics; accelerator technology	DOE-SBIR
Colorado State Univ.	SRF technology	ONR, High-Energy Laser Joint Tech Office
Cornell	SRF technology	DOE; NSF
MIT	Machine concepts	NSF