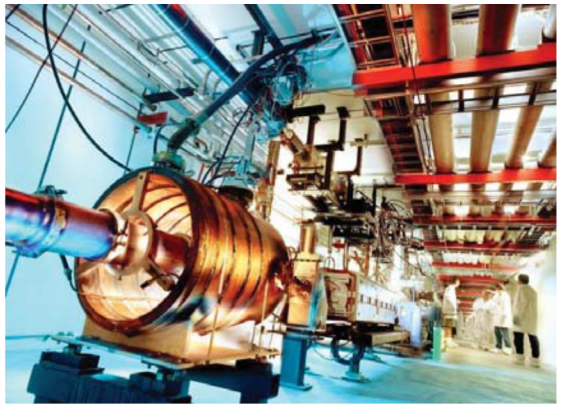
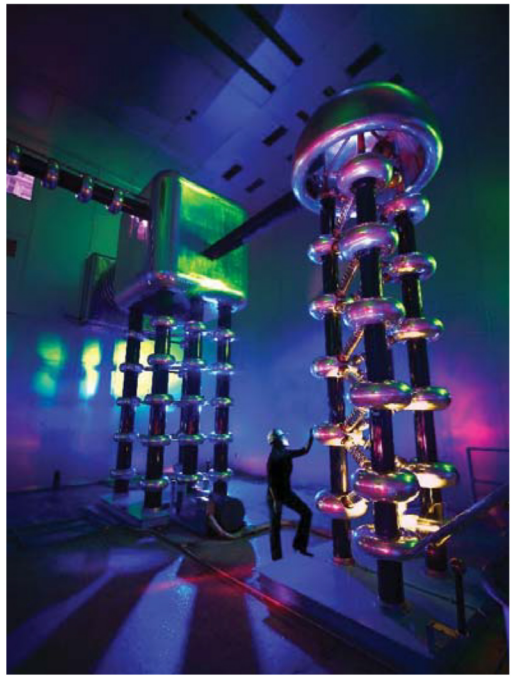
Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Fermilab Accelerator Capabilities and Infrastructure





Illinois Accelerator Research Center - IARC

Fermi National Accelerator Laboratory

- Dedicated to High Energy Physics Research (Discovery Science)
- Design & Operate: High Energy, High Power (MW), High reliability Accelerators
- Largest U.S. Accelerator complex, 6800 acre site, ~$380M/yr budget, 7 accelerators, 16 km of accelerator and beam lines > 2200 users
- Staff = 1700, ~ 300 accelerator scientists and engineers (+ANL)
- Largest collection of Accelerator experts in North America

Leverage of Basic Research for Commercial Application

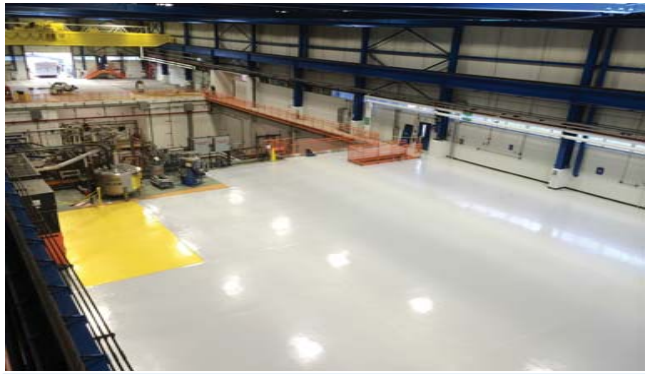
- Prototype proton CT scanner developed by Fermilab and Northern Illinois University
- The proton CT scanner would better target radiation doses to the cancerous tumors during proton therapy treatment.
- Physicists recently started testing with beam at the CDH Proton Center in Warrenville.

Illinois Accelerator Research Center

The Illinois Accelerator Research Center (IARC) is a new accelerator research facility being built at **Fermi National Accelerator Laboratory. IARC** will provide a state-of-the-art facility for research, development and industrialization of particle accelerator technology. A major focus of IARC will be to develop partnerships with private industry for the commercial and industrial application of accelerator technology for energy and the environment, medicine, industry, national security and discovery science. **IARC** will also offer unique advanced educational opportunities to a new generation of Illinois engineers and scientists and attract top scientists from around the world.

The Office, Technical and Education Building (OTE) was built to better facilitate collaborations between IARC users and Fermilab technical experts. The OTE building holds office space for 120 people, has 4 meeting rooms, a lecture hall for 170 people a roughly 4000 sqft. technical area and an eating area for 80 people.

OTE Building *Picture courtesy of Ross Barney Architects, Kate Joyce Studios)*



The Heavy Assembly Building (HAB) was the home of a Tevatron collider detector and is now being repurposed for IARC. It is 42,000 sq ft with a 50 T crane; deep pit for radiation shielding of accelerators; cryogenic, electrical and cooling water infrastructure; IT networks; meeting space and ~40 offices.

In Fermilab's High-Brightness Electron Source Lab, electron beam sources that don't need a laser are being developed in an industrially led collaboration that joins academia, industry and Fermi. A new irradiation facility to develop novel accelerator applications is funded and expected to be available in FY2016.

Industrial Applications for Accelerators:

Advanced manufacturing
Environmental cleanup
Food and beverage processing
Food packaging and safety
Energy and utilities
Defense & security
Medicine

Dr. Bob Kephart
Director, Illinois Accelerator Research Center

Dr. Charlie Cooper
General Manager, Illinois Accelerator Research Center

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Accelerator Simulation

Accelerator Simulation

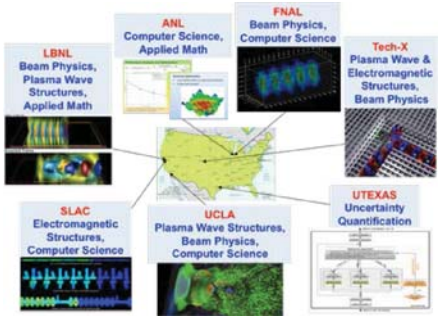
Understanding the dynamics of many bunches of 10^{11} charged particles inside of a metal vacuum chamber is a complicated problem that can only be handled with numerical simulations. Detailed simulations can help us optimize existing accelerators as well as design new machines in furtherance of Fermilab's mission and our responsibilities as stewards of accelerator knowledge and capabilities.

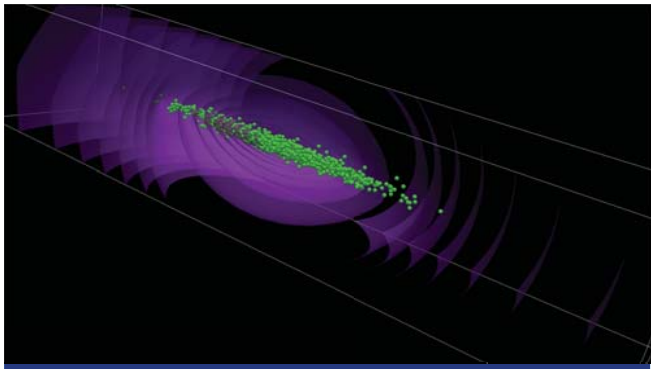
Synergia

Synergia is a Fermilab developed accelerator simulation package that specializes in detailed simulations of collective effects of *space charge* and *wakefields*. Synergia simulations can be small enough to run on a laptop or large enough to require supercomputing technology.

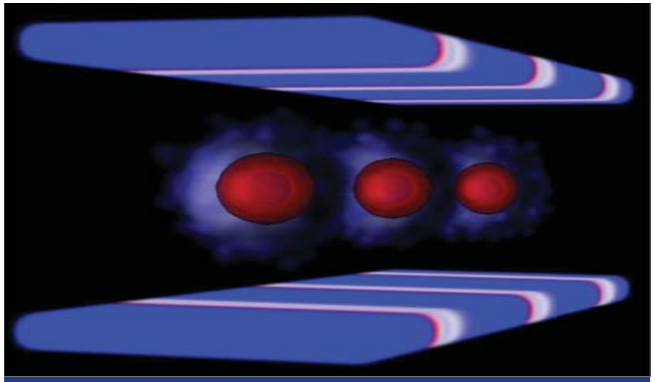
ComPASS Collaboration

The ComPASS collaboration led by Fermilab is a multi-institution collaboration combining the best computer science, applied mathematics and accelerator physics to the problem of accelerator simulations. ComPASS is funded by the DOE SciDAC program.

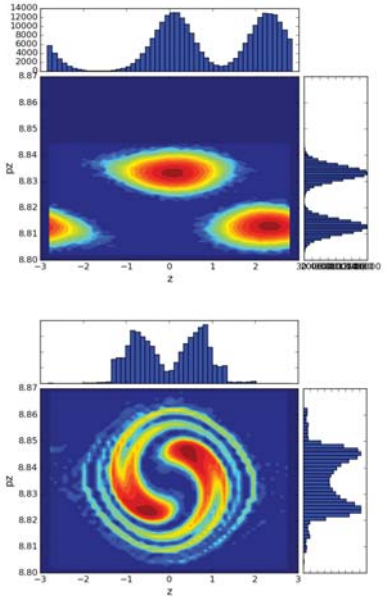




Space charge **is the electromagnetic repulsion among the particles in a beam bunch. Its effects increase as intensity increases. Pictured above is a self-consistent Synergia space charge simulation. The green particles generate the purple fields which in-turn affect the motion of the particles.**



Wakefields **are electromagnetic fields generated in accelerator structures by passing beams. Pictured above is a self-consistent Synergia simulation of three bunches of particles producing wakefields in the surrounding beam pipe which in turn affects the motion of the particles.**



Fermilab uses a technique called *slip stacking* to combine pairs of bunches in order to create a more intense beam. The flexibility of Synergia allows us to simulate the detailed beam manipulation that occurs during slip stacking. Synergia simulations of slip stacking, shown to the left, allow us to investigate potential problems that may arise during the production of the higher intensities as well as mitigation strategies to ensure success of the future Fermilab program.

Synergia runs on a variety of platforms from desktop/laptops to Linux clusters to supercomputers. Pictured are: a MacBook, the Wilson Cluster at Fermilab, the Mira supercomputer at Argonne National Laboratory, the Edison supercomputer at National Energy Research Scientific Computing Center.

Dr. James Amundson
Chief Synergia Architect
Head, Scientific Software Infrastructure Dept.

Dr. Eric Stern
Synergia Developer
Leader, Accelerator Simulation Group

Dr. Panagiotis Spentzouris
ComPASS P.I.
Head, Scientific Computing Division

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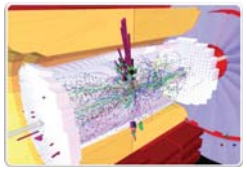
Fermilab Scientific Computing Capabilities

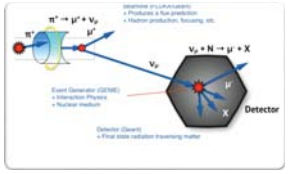
Bytes to PetaBytes

Detector & Physics Simulation

Dr. Daniel Elvira
Head of Scientific Computing Simulation Department

Large-scale simulation of detectors, computer-generated event data that behaves exactly as real data, and computational models of the physics processes, are crucial parts of designing and operating detection instruments. Fermilab contributes to the development and support of Pythia, for collider physics, Genie, for neutrino physics and Geant4, for modeling detectors. Geant4 is also in use for space science, nuclear, and medical physics. Simulation software is used to understand detectors and data from small to large scales. There is ongoing R&D to adapt the toolkits to use modern computer architectures, e.g. general purpose GPU and Intel-Phi, for fine granularity parallelism in multithreaded simulation applications.

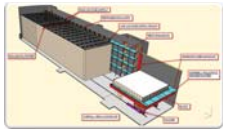




Digital Electronics & Data Acquisition

Dr Kurt Biery
Head of Real Time Systems and Engineering Department

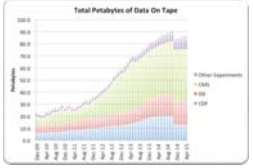
artdaq is a framework for developing data acquisition systems used by neutrino, muon, and dark matter experiments. It is an integrated system with extensions for each experiment across multiple performance scales.artdaq interfaces to many of the custom electronics and readout systems developed both by the experiments and Fermilab engineering. A research (LDRD) project is underway to provide a low-cost, scalable system architecture based on commercial technology developed for the "Internet of Things." Off-the-Shelf DAQ (OtSDAQ) connects intelligent front-end digitizers directly to a standard network without additional layers of custom readout electronics. The goal is to provide an off-the-shelf solution that provides immediate hardware, firmware, and software DAQ functions. The system will scale from a few MB/s to hundreds of GB/s using inexpensive commodity networking equipment and interface modules.



Data Archiving & Preservation

Dr. Gene Oleynik
Head of Data Management and Storage Department

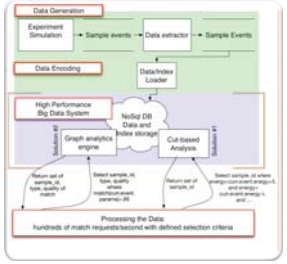
Fermilab currently stores more than 50 PB of data on tape, and supports the software and systems that provide high throughput multi-stream storage and retrieval of the files, sharing of tape drives, and intelligent placement of the files.
The Active Archive Facility (AAF) is a high performance active (aka nearline) service offered to researchers through the Strategic Partnership Project (SPP). The AAF has a capacity of tens of petabytes and multiple gigabytes per second of aggregate bandwidth and is providing long-term preservation and custodial care along with high-performance retrieval. Data is protected through policies and procedures, together with periodic read validation, as well as on-request replication of files for redundancy.



Big Data Analysis R&D

Dr. Andrew Norman
Head of Scientific Data Management Applications

"Big Data" techniques, in which data is not moved to the computational resource but the computation is moved to the data, are a promising avenue to reduce the time to physics results. These techniques remove the lines between the different analysis tasks, allowing efficient selection of portions of event data, or "skims" directly on the entire set of files (dataset). Key is striping data storage across sites and running portions of the selection codes where the data resides. We are now exploring such techniques for both the CMS and the NoVA neutrino experiments to provide easy selection and understanding of interesting phenomena from 10s of terabytes of disk-resident event data and using globally "federated" disk stores of the preliminary processed data.



Distributed Data Processing

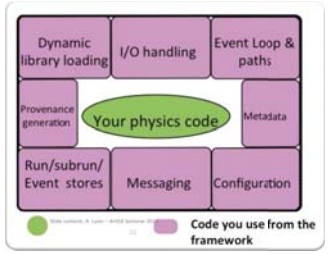
Dr. Robert Illingworth
Head of Serial Analysis with MetaData (SAM) Project

Data distribution tools ensure physics data is sent to and received from remote universities and collaborators over the Internet. The Serial Analysis with MetaData (SAM) system is used by multiple experiments to keep track of millions of files together with their parentage, contents and types. SAM includes project-specific metadata in addition to supporting data storage and analysis sites worldwide. Fermilab is a leading contributor to the Open Science Grid multi-disciplinary community of computing and storage owners, software providers and scientific researchers.

Software Frameworks

Dr. Jim Kowalkowski
SCD Assistant Head for R&D & Architecture

art, a generalizable data analysis and processing framework based originally on the CMSSW CMS experiment framework, is now in use by multiple experiments at Fermilab and elsewhere. Many scientists analyze the data together to produce physics results and discoveries. Shared software frameworks provide common components of an application (such as data input and output, including external common plotting and histogramming libraries, and error message detection and reporting) and the means to integrate experiment/project specific physics algorithms. Common frameworks also encourage documentation and training that can be shared by all. Fermilab teams are extending these Frameworks for with new Computer architectures. The Software code repositories and build-and-release systems are supportedas part of the broader software ecosystem to give the physicists easy to learn and use end-to-end systems.



Dr. Rob Roser
Fermilab Chief Information Officer

Dr. Panagiotis Spentzouris
Head, Fermilab Scientific Computing Division

Ruth Pordes
Deputy Head Scientific Computing Division

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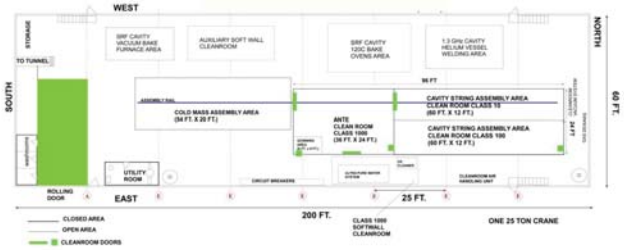
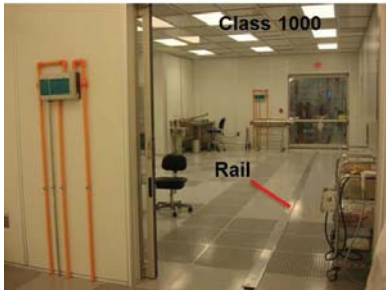
Fermilab TD & AD Cleanrooms

CAF-MP9 Cleanroom located in TD

The largest cleanroom at Fermilab is located at the Cryomodule Assembly Facility (CAF) at MP9 building in Technical Division. (TD)

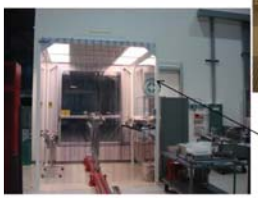


Production Floor Layout of CAF-MP9



Cavity String Assembly Clean Room (A ~250 square-meter clean room):

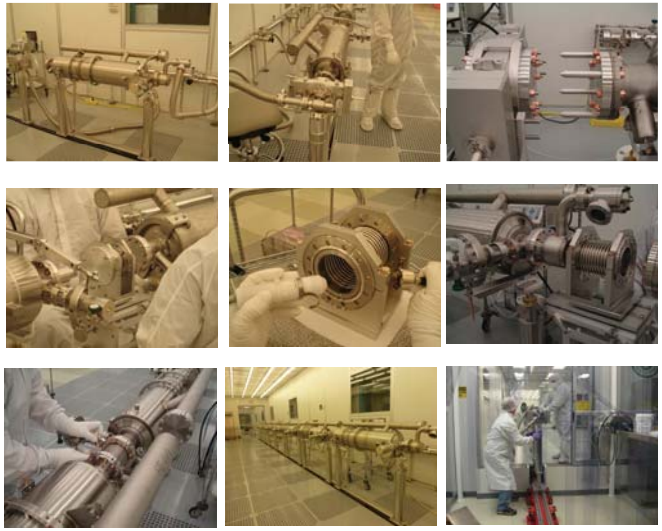
- Class 1000 (ISO6) ante clean room area (12 m x 8 m): Preparation of the dressed cavities for transportation into the assembly clean room.
- Class 100 (ISO5) sluice area: Parts and Fixtures final preparation to enter the Class 10 assembly area.
- Class 100 (ISO5) area (20 m x 4 m): Parts and Fixtures preparation for assembly.
- Class 10 (ISO4) assembly clean room area (20 m x 4 m): Where the cavities vacuum is vented to interconnect them with bellows.



Class 1000 cleanroom for the dressed/qualified cavity preparation to enter the cleanroom

UHV cleaning area

Cleanroom infrastructure



Cavity String Assembly in Class 10 (ISO 4) area

CMTF Cleanroom located in AD

The cleanroom at CMTF (Cryomodule Test Facility) is located in Accelerator Division. (AD)

Cleanroom has a 900 square foot space that has the capability to clean and assemble high vacuum (HV), ultra-high vacuum (UHV), and UHV low-particulate parts. It is divided into three cleanroom areas: Class 10,000-production, Class 100-preassembly, and Class 10-assembly

One small and two medium-sized ultrasonic tanks are located in the Class 10,000 area for cleaning and rinsing components and three 204-gallon (28”x70”x24”D) tanks are located in the pre-clean area adjacent to the cleanroom for processing of larger parts. This space also holds an automated parts washer for first-pass cleaning and degreasing of hardware and small parts.

Tug Arkan
Group Leader, Cryomodule Fabrication Group

Jerry Leibfritz,
Lead Engineer, Cryomodule Test Facility (CMTF)

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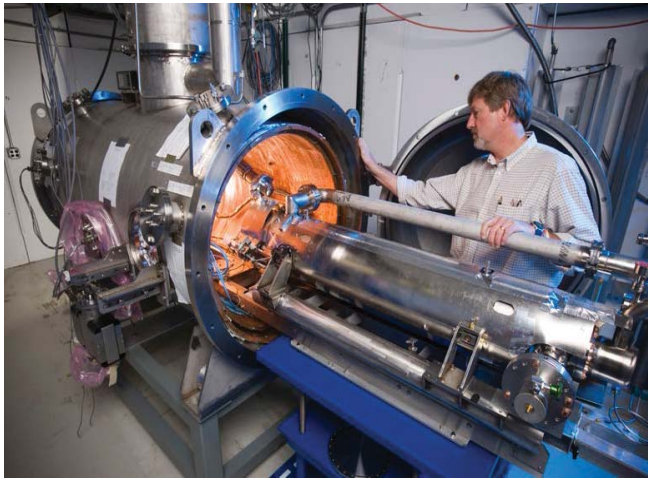
Superconducting RF Cavity Horizontal Test Facility

Fermilab's Horizontal Test Facility

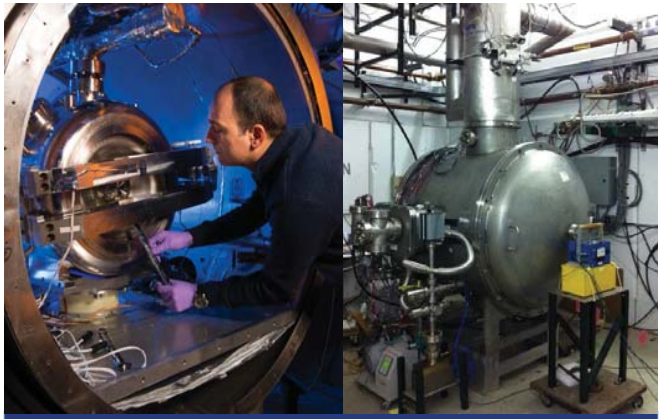
Superconducting radio-frequency cavities are an enabling technology for high energy and high efficiency particle accelerators. They can provide very high electric fields that can be used to accelerate particles, with lower operating (energy) costs than conventional accelerating structures. To reach this high level of performance, these cavities are fabricated from superconducting materials, such as niobium. The cavity surfaces must also be very smooth and clean of any foreign matter which could affect their performance. The cavities typically undergo a sophisticated regimen of surface preparation that includes chemical or electro-polishing of the surface, furnace treatments to remove hydrogen, and cleaning with ultra-pure water at very high pressure to remove any foreign particles. Before they can be used in an accelerator, they must be tested to verify their performance. They first undergo testing in the Vertical Test Stand (VTS) which verifies that their fabrication and surface treatment has been successful and the cavity can reach its performance goals. They are then equipped with additional components such as tuners which maintain the cavity at the desired operating frequency, high power couplers that are used to power the cavity, and other ancillary systems that are needed to ensure the cavity will perform well in the accelerator. This integrated system is then tested once again in the Horizontal Test Facility (HTF) to make sure that all of these auxiliary components work together to achieve the required performance. Fermilab has established three test stands at the HTF designed to test different types of accelerating cavities.

Horizontal Test Stand-1 (HTS-1)

The HTS-1 is designed to test multi-cell elliptical cavities operating at either 1.3GHz or at 3.9GHz. It uses liquid helium to cool the cavities to 2K (near absolute zero!), their operating temperature. The HTS-1 includes RF systems to power the cavities, system to control the RF power and cryogenic system, and diagnostics to allow full characterization of the cavity, coupler, tuner, and other associated components.



The HTS-1 Cryostat, shown as a 1.3GHz cavity system is installed for testing.



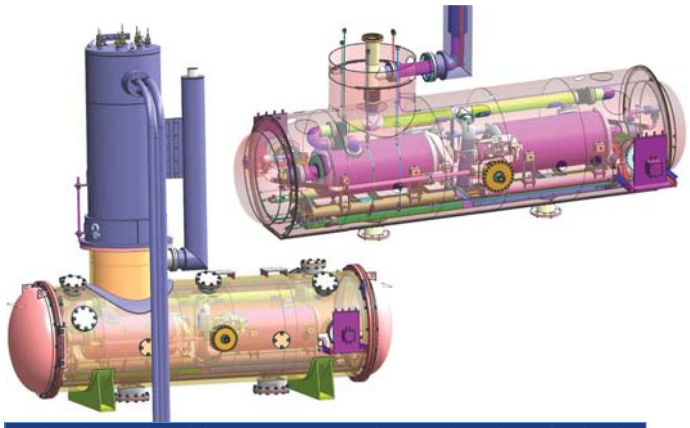
A 325MH spoke cavity that will be part of a PIP-II prototype cryomodule is being installed in the STC cryostat on the left. On the right the STC cryostat is closed up and being cooled down in preparation for RF testing of the cavity.

Spoke Test Cryostat (STC)

The Spoke Test Cryostat (STC) was designed to test lower frequency cavities (325MHz) used primarily for accelerating beams of heavy ions or protons. These so-called spoke cavities are a critical element of Fermilab's Proton Improvement Plan-II (PIP-II), comprising the low-energy portion of that accelerator. Like the HTS-1, the STC includes low and high power RF systems, ultra-high vacuum systems, control systems for RF and cryogenic operations, and diagnostics, data acquisition and logging systems used to assess cavity and associated system performance. The STC was originally commissioned in to operate at 4K, and then was modified in 2014 to operate at 2K.

Horizontal Test Stand-2 (HTS-2)

The PIP-II project requires in addition to 325MHz spoke cavities, elliptical cavities operating at a frequency of 650MHz. In order to test these cavities HTS-2 is being designed and implemented at Fermilab. The design and fabrication of the HTS-2 cryostat is a joint effort between Fermilab and the RRCAT laboratory in India. The HTS-2 cryostat will be able to accommodate up to two 650MHz (or 1.3GHz) cavities at a time, dramatically increasing test throughput. Like its predecessors, when commissioned in early 2017, the HTS-2 will operate at 2K, and employ a full suite of RF, cryogenic, and data acquisition systems for cavity characterization.



Engineering models of the HTS-2 cryostat and cryogenic feedcan, showing the capability for concurrent testing of two 650MHz elliptical cavities.

Joe Ozelis
Sr. Engineering Physicist
Horizontal Test Facility Manager

Joe joined Fermilab in 1989, working on applied superconductivity for accelerator applications. He spent some time at Jefferson Lab as Test Facility Coordinator and QA Manager during the construction of the Spallation Neutron Source, and then rejoined Fermilab initially to guide the development and operations of the Vertical Test Stand (VTS) and now as the HTF Manager. He has over 25 years experience in cryogenic instrumentation, data acquisition, applied superconductivity, SRF technology, and test facility management.

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SRF Processing and Tuning Facilities at Fermilab

Heat Treatment Facilities

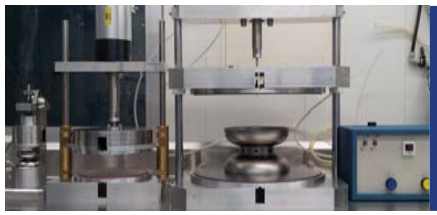
Two high temperature vacuum furnaces and two low temperature ovens are used to perform heat treatments on SRF cavities. A major focus is to develop and optimize recipes and create new Niobium (Nb) compounds aimed at reducing RF losses in the cavities which can dramatically reduce operating costs.

IB4 High temperature vacuum furnace being loaded with a 1.3 GHz 9 cell cavity. The maximum operating temperature is 1200 C and the base vacuum is 10^{-8} Torr. High temperature furnaces are used to degas and dope cavities.

Low temperature ovens, up to 300 C, are used to bake cavities and UHV devices. A separate UHV vacuum cart is used to evacuate cavities.

RF Tuning Facilities

The RF Clean Room in IB4 has wide variety of low power RF measurement and tuning capabilities for multiple projects.



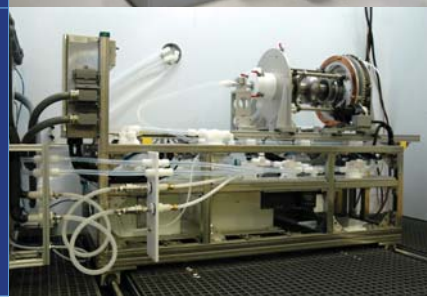
The RF clean room is equipped with various RF QC and manual tuning fixtures for 650 MHz, 1.3 GHz, and 3.9 GHz half-cells, dumbbells, and cavities.

Surface Processing Facilities

The IB4 Cavity Processing Lab possesses centrifugal barrel polishing and electropolishing capabilities of up to 1.3 GHz sized SRF 9-cell cavities. High quality polishing is essential to deliver maximum accelerating gradients and high quality factors in SRF cavities.

IB4 High centrifugal barrel polishing tool repairs 1.3 GHz inner surfaces when defects appear. Two 9-cell 1.3 GHz cavities can be tumbled simultaneously.

Electropolishing R&D on 1-cell 1.3 GHz cavities occurs on a semi-automated tool. The tool is upgradable to 9-cell 1.3 GHz capacity.



The automatic tuning machine (CTM) at the IB4 RF clean room is being used for RF QC and tuning the 1.3GHz Tesla style 9-cell cavities.

Processing Cleanroom Facilities

SRF cavity cleanroom assembly capability is essential to good cavity performance. The IB4 CPL contains a full suite of hardware and cavity cleaning capabilities, including high pressure rinsing, ultrasonic cleaning, and particle elimination devices.

IB4 CPL Cleanrooms include Class 10 particle-free assembly space, ultra-pure water high pressure rinsing, and Class 1000 UHV part cleaning facilities. SRF cavities of many varieties can be cleaned, rinsed, and assembled in the IB4 Cavity Processing Lab cleanroom space.

Byron Golden assembling a 1.3 GHz 9-cell cavity in the IB4 Class 10 cleanroom.

CPL Class 10 cleanroom with HPR tool and SRF cavity assembly infrastructure.

Mr. Allan Rowe
Deputy Head, SRF Development Department
SRF Cavity Processing Group Leader
Mechanical Engineer

Ms. Margherita Merio
SRF Heat Treatment Facilities Manager
SRF Cavity Processing
Aerospace Engineer

Mohamed Hasan
RF Lab Manager, SRF Department
RF Group
Electrical Engineer

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Conventional Magnet Area at TD

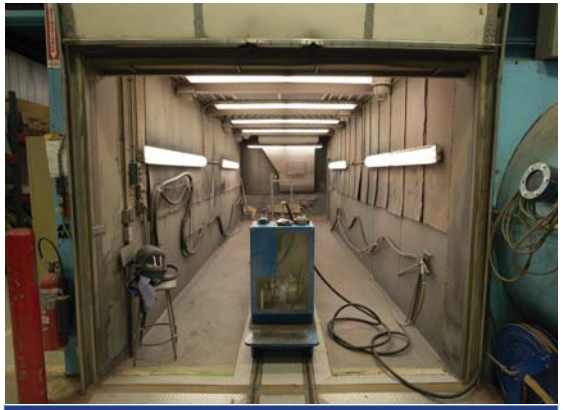
Magnet systems department provides support for the FERMILAB accelerator complex by repairing or refurbishing existing accelerator magnets and magnet components, as well as designing, fabricating and testing of new devices for improvements of the accelerator complex

Large vacuum oven for outgassing and impregnation of magnet coils or related parts. Equipped with drive cart to move magnet parts into or from the oven. Vacuum oven is 6.5 ft diameter and 24 ft long

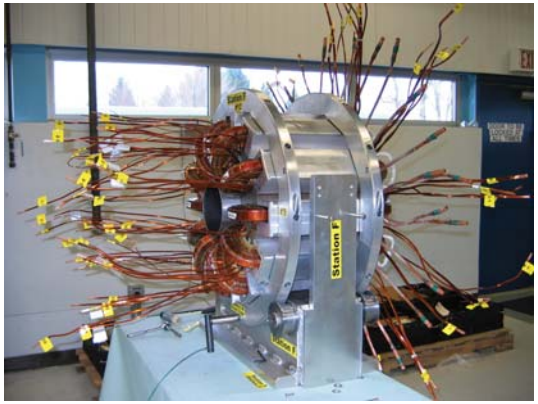
Coil Winding System with tensioner developed at Magnet System Department for manufacturing of the large toroidal coils for 12 GeV upgrade of the CEBAF Large Acceptance Spectrometer (CLAS12) at Jefferson Lab

24 ft long Wisconsin oven for curing of magnet parts. Programmable temperature control up to 375 F with airflow for best heat distribution in the chamber.

Large Coil Winding Table equipped with tensioner. Broomfield 350 winding table is also available for winding of small coils (see the inset)

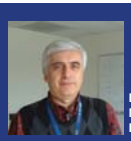


Large Grit Blasting Booth for stripping magnet components with the Aluminum oxide media

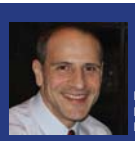


Multi-element corrector magnet designed and fabricated at Magnet Systems Department for correction of the Fermilab Booster beam orbits

Hydraulic Stacker Complex exerting a maximum force of over 100,000 lb. Stacked lamination core of the Lambertson magnet is shown (see the top inset)



Dr. Guram Chlachidze
Magnet Systems Department
Fermilab Technical Division



Dr. Luciano Elementi
Magnet Systems Department
Fermilab Technical Division

Steven Krave
Magnet Systems Department
Fermilab Technical Division

Fermilab

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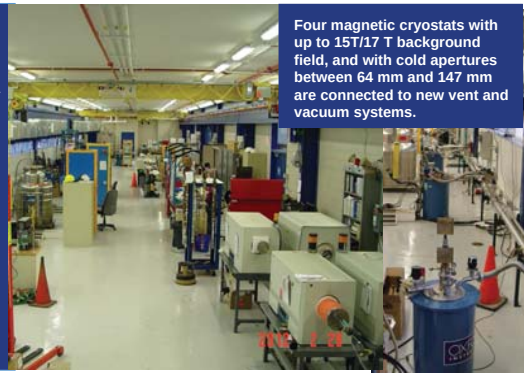
Superconducting Magnets

The facility for heat treating and testing strand is located in IB3A, a 6000 square foot addition that was built in 2010 with ARRA funds.

Critical current density of superconductor is measured at various temperatures and external magnetic fields.

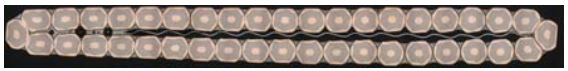


Four magnetic cryostats with up to 15T/17 T background field, and with cold apertures between 64 mm and 147 mm are connected to new vent and vacuum systems.

Each system has its own DAQ crate and power supplies up to 2400 A. Variable temperature inserts allow measurements between 1.5 K and 60 K. There are five ovens up to 1250C for heat treatment in Argon and in Oxygen.

100bar MTI high pressure processing furnace (shown at left) with capability of heat-treating materials to 900 degrees C in gas pressure (Ar + O2 mix) up to 100 bar.

Prototype superconducting cable is produced in Technical Division. The Fermilab cabling machine is shown below. NbTi or Nb_3Sn cable of up to 42 strands are used on various superconducting magnet projects, supporting the R&D needs of Fermilab, CERN and other labs. Cable of round, rectangular or trapezoidal shapes are manufactured with cross sectional accuracies of +/- 6 microns. To the right are spools of strand and a section of completed cable.



Superconducting Magnet Fabrication

Fermilab has been at the forefront of superconducting magnet fabrication for particle accelerators since its inception, beginning with the Tevatron and continuing through the SSC, the LHC, and many others. Capabilities include heat treatment and testing of conductor, as well as fabrication and testing of cable and complete magnets.

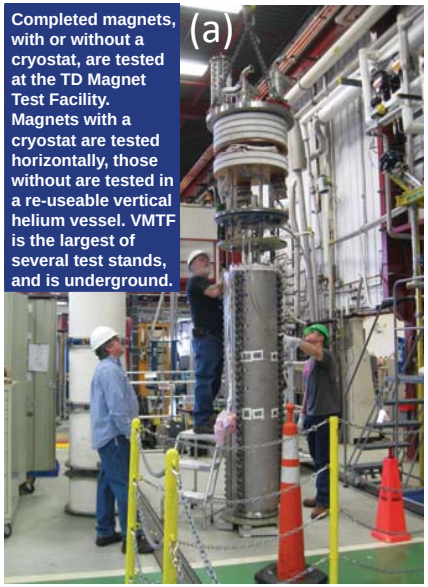
Dipole

Quadrupole

The cable is insulated, then wound into a coil. Each turn must be placed precisely into position to achieve the proper magnetic field shape. Coils may be wound into various configurations, but are usually either dipole (to bend the beam) or quadrupole (to focus the beam). The winding machine for the LHC upgrade is being commissioned above. In the current configuration, coils can be wound up to 6.5 meters long, but it can be configured to wind coils over 16 meters in length.

Once a Nb_3Sn coil is produced, it must be heat treated to give the coil its superconducting properties. This is done in a large "reaction oven" as shown above. The coil is heated in steps to various temperatures up to 650 degrees Celsius for a period of nearly 2 weeks, then removed from the oven and impregnated with epoxy.

Completed magnets, with or without a cryostat, are tested at the TD Magnet Test Facility. Magnets with a cryostat are tested horizontally, those without are tested in a re-useable vertical helium vessel. VMTF is the largest of several test stands, and is underground.



Vertical Magnet Test Facility

Large SC Magnet R&D
{ <0.625m OD, <3.7m long }

Temperature 1.9 K to 4.6 K
Current up to 30 kA

Quench Protection
{ dump resistor, heaters }

Quench Characterization
{ ~100 voltage taps
isolation amplifiers
fast data loggers }

Splice resistance
AC Loss measurement
Magnetic measurements
Warm bore tubes

Photos:
a) Magnet hookup to top plate assembly
b) Insertion into 6m deep helium cryostat
c) Magnetic measurement cart with rotating coil drive tower mounted over top plate

Dr. Emanuela Barzi
Superconducting R&D Program Leader
Fermilab Technical Division

Mr. Rodger Bossert
Mechanical Engineer
Fermilab Technical Division

Dr. Michael Tartaglia
Head, Test & Instrumentation Department
Fermilab Technical Division

Fermilab

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SC Materials R&D Test Equipment

Keyence LSCM VK9700

Laser microscope used for non-contact high-precision (1nm resolution) 3D surface profile measurements. Images can be observed at high magnifications with a high depth of field. Software allows for a variety of analysis including profile, roughness, and 3D measurement. Up to 400 images can be scanned and stitched together for analysis. There are 5 objective lenses available:

JEOL 5900LV SEM with Oxford EDS and EBSD detectors

The scanning electron microscope has magnification range from 18x to 300,000X. The accelerating voltages are from 0.3 to 30 kV. The SEM is used for studying surface features of biological and non biological samples. The Oxford Energy Dispersive Spectrometer (EDS) is used for qualitative elemental analysis. The Oxford Electron Backscatter Detector (EBSD) is used to evaluate microstructure and provides absolute crystal orientation allowing identification of phases, boundary characterization and deformation of a material.

Quantum Design PPMS

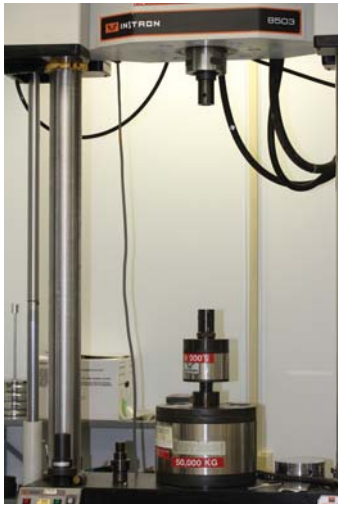
This Physical Property Measurement System is designed for a variety of automated measurements including heat capacity and thermal conductivity, DC magnetization and AC susceptibility, and electrical resistivity. Sample environment control includes magnetic field of up to 9 tesla with temperature range of 1.9- 400 K.

Instron 5967
10 kN Maximum Load

Electromechanical, universal testing machine for tensile, compression and flexural testing.

Instron 8503

500 kN Maximum load
Servo-hydraulic, universal testing machine for tensile, compression, and flexural testing. Working space between the bottom of the load cell and the end of actuator is 63 inches.



Donna Hicks Engineering Physicist
Laboratory Manager of the Instron and Microscope Rooms
Technical Division Chemical Hygiene Officer
SRF Program/Technical Division

Yulia Trenikhina
Research Associate
SRF Program/Technical Division

Alexander Romanenko
Scientist
SRF Program/Technical Division

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Cryomodule Test Facility (CMTF)

Cryomodule Test Facility (CMTF)

The Cryomodule Test Facility (CMTF) is a research and development facility for accelerator science and technology, in particular, the testing and validating of Superconducting Radio Frequency (SRF) components. CMTF provides the necessary test bed to measure and characterize the performance of SRF components with and without beam. CMTF contains a superfluid cryogenic plant, a 15,000 sq. ft. high-bay that contains a 20-ton overhead crane, two Cryomodule Test Stands (CMTS), a test area for RF components and electrical systems, a cleanroom area for particle-free preparation of components, and a control room/office area.

The Cryomodule Test Facility (CMTF) was built to be a dedicated R&D facility for testing superconducting accelerator components with and without beam

CMTF contains two independent test stands, a 20-ton crane, a superfluid cryogenic plant, a cleanroom, and office space

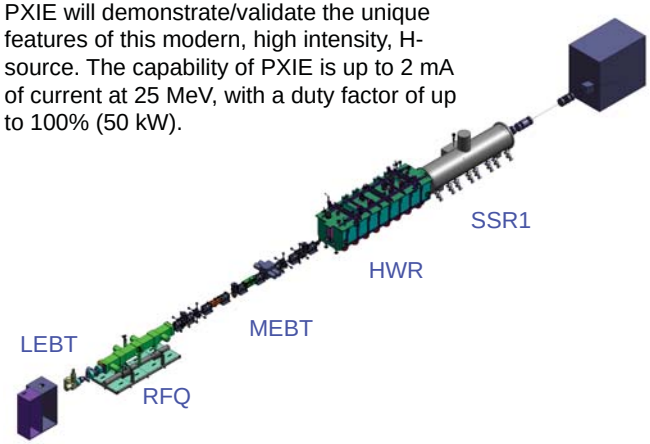
The Superfluid Cryoplant (SCP) located at CMTF will supply helium cryogenics to the various cryomodule test stands. It is capable of producing over 500 W of 2K refrigeration.

Superfluid Cryoplant

The Superfluid Cryoplant (SCP) is a state of the art 2K Helium Cryogenic Coldbox which will supply refrigeration to the various test stands at the Cryomodule Test Facility (CMTF). The SCP is a flexible cryogenic plant capable of simultaneously providing refrigeration at 40K, 5K and 2K temperatures. It also has the capability of supplying cool down flow with operator specified temperatures between 300K-40K in order to meet the controlled cool down demands of a Cryomodule. The 2K refrigeration cycle utilizes a hybrid design of three cold compressors in series with a warm vacuum pump. By utilizing a hybrid cycle the plant can be turned down to ~25% of it's total capacity, thus allowing it to run efficiently at a variety of heat loads.

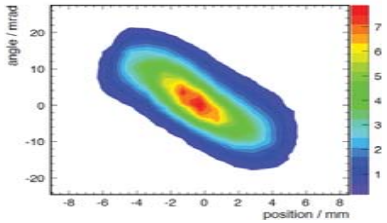
PXIE (PIP-II Injector Experiment)

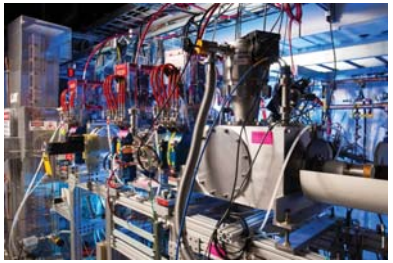
PXIE will demonstrate/validate the unique features of this modern, high intensity, H- source. The capability of PXIE is up to 2 mA of current at 25 MeV, with a duty factor of up to 100% (50 kW).



PXIE is being constructed at Fermilab by a consortium of laboratories including Fermilab, Argonne National Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, and the Bhabha Atomic Research Center (Mumbai)

PXIE has accelerated beam from the 30 keV H- source through the LEBT. The beam has been characterized and meets the established specifications. The RFQ is currently in fabrication at LBNL and will be delivered to Fermilab for installation this summer. The two superconducting acceleration modules are under construction at ANL and Fermilab, and will be delivered in 2017.





Jerry Leibfritz
Project Leader, Cryomodule Test Facility

Dr. Steve Holmes
PIP II – Project Manager

Benjamin Hansen
CMTF Cryosystem Manager, Deputy

Fermilab

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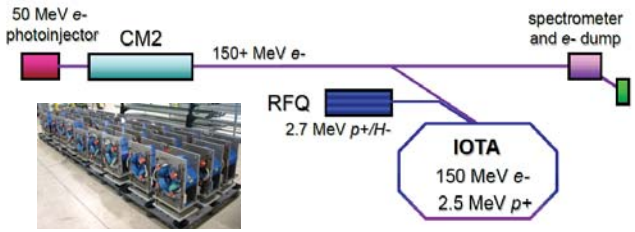
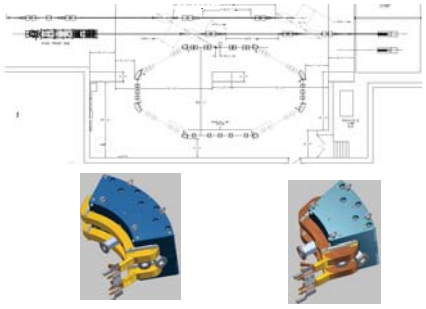
Integrable Optics Test Accelerator/Advanced Superconducting Test Accelerator

Advanced Superconducting Test Accelerator

The Advanced Superconducting Test Accelerator (ASTA) is a high-brightness electron accelerator to support advanced accelerator research & development. There is a photoinjector electron gun to produce the electrons by means of the photoelectric effect. Ultraviolet laser light produced outside of the accelerator enclosure is transported and focused on to a cathode at the back face of the gun. The laser's high power and small spot size results in a high intensity 'bright' beam of electrons. Superconducting Radiofrequency technology is exploited to accelerate the electrons.

The ASTA injector accelerated its first particles to 20 Million electron volts (MeV) in March 2015. Addition of another superconducting RF cavity later this year will increase the energy to 55 Mev. By 2017 additional upgrades will enable electrons to be pushed to energies as high as 300 MeV.





IOTA will be a 40 meter circumference storage ring capable of accepting 150 MeV electrons or 2.5 MeV protons. It will be fed from either ASTA or a dedicated proton souce. The main elements include focusing and bending magnets.

The injector beam line of the advanced superconducting test accelerator is designed to accelerate, transport, and provide space to study a high quality electron beam at energies up to 55 MeV. Recently it accelerated its first electrons to an energy of about 20 MeV after seven years of design and installation. Acceleration is accomplished by means of superconducting radiofrequency technology.

Integrable Optics Test Accelerator

IOTA is a small storage ring now under construction. The goals of experiments with it are to demonstrate the possibility to implement nonlinear integrable optics with a large betatron frequency spread, $\Delta Q > 1$, and stable particle motion in a realistic accelerator design. If successful, this concept has direct impact of enhanced performance of circulator particle accelerators such as the Large Hadron Collider, LHC, at CERN and future circular accelerators. Benefits include:

- increased Landau damping
- improved stability against perturbations
- resonance de-tuning.

Cryomodule 2, containing a string of 8 superconducting radiofrequency cavities which are powered together, has achieved an accelerating field of 250 million Volts (MV), among the highest in the world. It is the first one to achieve the International Linear Collider performance specification of 31.5 MV/m per cavity. CM-2 is the second cryomodule of its kind assembled and tested at Fermilab using cavities fabricated in industry. A team of highly-qualified scientists, engineers, and technicians specially trained to master this technology are based at Fermilab.

The core elements of superconducting radiofrequency technology are cavities made of high purity niobium fabricated to exacting standards in industry. A mirror-like smooth finish on the inside is achieved through a variety of mechanical and chemical processes. Assembly must be done in particle-free clean rooms.

Dr. Vladimir Shiltsev
Fermilab Accelerator Physics Center

Dr. Alexander Valishev
IOTA Project Leader

Elvin Harms
Superconducting RF Systems

Dr. Daniel Broemmelsiek
ASTA Operations

Fermilab

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TD/Quality & Materials/Quality Control Department

Department Overview

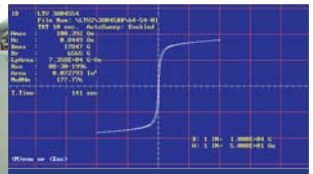
The Quality Control Department provides a wide variety of services with emphasis on dimensional metrology. The QC Lab is well equipped with state of the art equipment and expert personnel providing measurement services to the Technical Division as well as other areas of the laboratory.

Wilson/Rockwell Series 500 Hardness Tester measures the hardness of metals, alloys, and plastics.

Typical applications of standard Rockwell Scales:
- A Scale - thin steel, shallow casehardened steel
- B Scale - copper alloys, soft steels, aluminum alloys
- C Scale - Harder steels, hard cast irons
- D Scale - thin steel, medium casehardened steel
- F Scale - annealed copper alloys, thin soft sheet metals
- G Scale - phosphor bronze, malleable irons

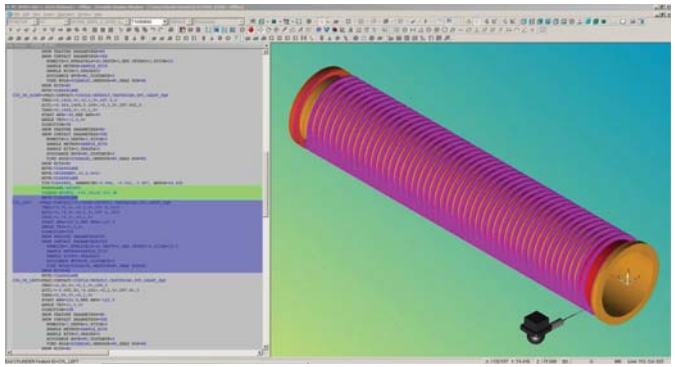
Derek Plant measuring the pressure sensitivity of a 325 MHz Single Spoke Resonator type 1 (SSR1) for the PIP-II project.

CMM (coordinate measuring machine) measuring a medium energy target housing. The housing is water-cooled through helical channels found along the OD of the cylinder. An aluminum jacket will be welded to the helically grooved tube, and then the graphite ME Target will be mounted within.



LDJ 5500 Hysteresigraph measures magnetic permeability and hysteresis.

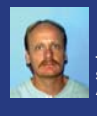
Above is a B-H curve measured by the LDJ 5500 showing the relationship between magnetic flux density (B) and magnetic field strength (H).



Bruker handheld S1 Turbo X-ray Fluorescence (XRF) analyzer being used to measure material composition. With count rates in excess of 100,000 cps, the S1 Turbo SD can generate the statistics necessary for detecting trace concentrations of the lightest elements including magnesium.

The Bruker S1 Turbo allows for fast and easy identification and sorting of the following materials: tool Steel, low alloy steel, stainless steel, cobalt, nickel, copper, titanium, aluminum, zirconium, tungsten, & zinc alloys.

Jamie Blowers
Quality Assurance Manager; Head of the Machine Shop and Quality & Materials Departments



Ted Beale
Supervisor of the Quality Control Department
ASQ Certified Quality Engineer & Certified Quality Auditor

Fermilab

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Neutron Irradiation & MuCool Test Area

Neutron Irradiation Facility

The Neutron Irradiation Facility is available for various irradiation applications.

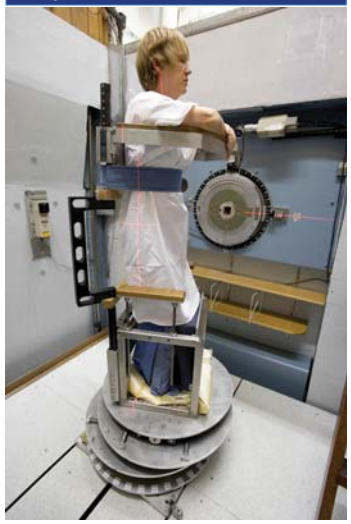
- Radiobiology
- Electronics
- Mutagenesis studies

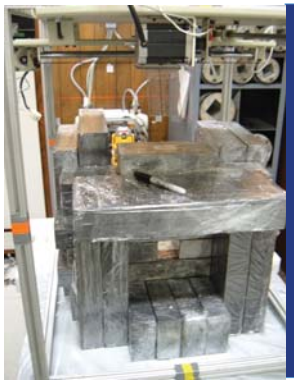
Quasi-monoenergetic with maximum energy of 66 MeV

Historically used to treat over 3,000 cancer patients.

Neutron Therapy -
Patients were able to be treated in standing or sitting position.

Chair platform can be disassembled and used as remote positioning for sample irradiations.





Neutron Energy Spectrum Modification

Shown is an apparatus built to enhance the epithermal energies and suppress fast neutrons.

Suitable for radiobiology – Neutron Capture Therapy.

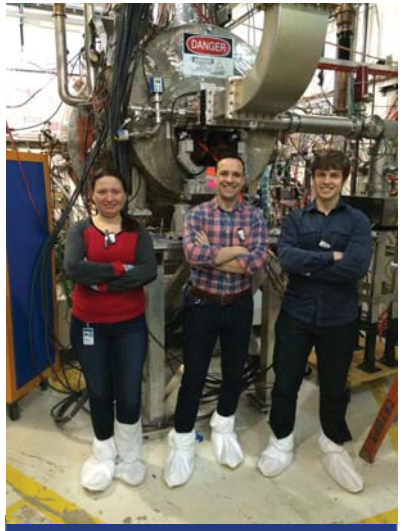
Uses a secondary lead collimator, tungsten filter (not shown), and graphite reflectors.

The MTA beam line leading to the experimental area.

400 MeV protons

MuCool Test Area

- High intensity beams for development of radiation-robust detector technologies
- Experimental infrastructure to support R&D on RF structures in strong magnetic fields
    - 805 MHz – 12 MW Klystron
    - 201 MHz – 4.5 MW Triode Power Amplifier
- Provides a large bore (44 cm ID) 5T solenoid for detector and RF studies in high magnetic field
- 400 MeV Linac beam aligned with solenoid bore for beam tests in magnetic fields between 0 and 5 Tesla
- Class 100 portable clean room
- Current R&D focus of the facility is on studying RF breakdown in strong magnetic fields. Near-future effort will include detector and instrumentation testing in high-radiation and/or strong magnetic field environments



5 Tesla Solenoid with an 805 MHz cavity mounted inside

A Class-100 portable clean room in the MTA helps protect sensitive experimental apparatus during installation.

Dr. Thomas Kroc
Head, Neutron Irradiation Facility

Fermilab

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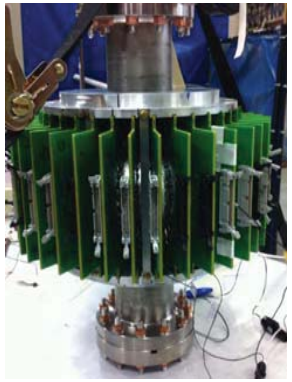
SRF Vertical Test Facility

Vertical test facility at Fermilab

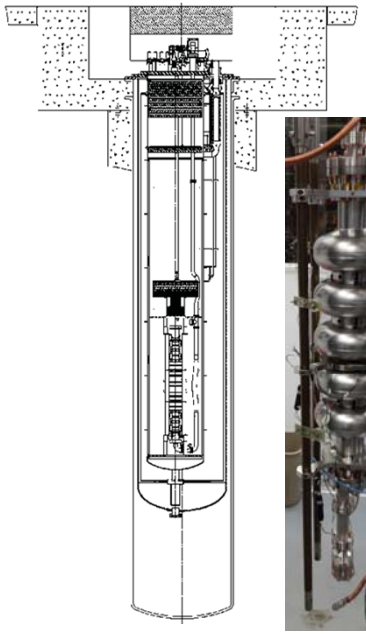
Three liquid helium dewars, LLRF control system with phase lock loop and high power amplifier, and cryogenic system capable of supporting vertical RF cavity tests for single cell and multi-cell cavities at 325MHz, 650MHz, and 1.3GHz (currently upgrading to 3.9GHz).

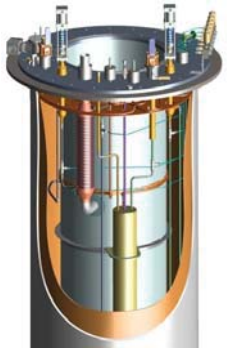


1.3GHz single cell cavities:
with full temperature map system (left) and
external magnetic field coils, temperature and magnetic field sensors (right)

Single cell cavity suspended on vertical test insert during preparation for installation into the dewar

Top view of the dewar with the vertical test insert top plate, showing cryogenic and electrical connections for RF cavity signals





Schematic of the vertical test dewar with the insert and a cavity (left & right)

photo of 1.3GHz cavity with second sound system prepared for vertical test (middle)

Features and instrumentation

Ability to perform tests in the temperature range of 1.4K-4.2K

Ability to adjust dewar cool-down rates for controlling ambient magnetic field flux expulsion

Second sound quench detection system

Magnetic field and temperature sensors on the cavity

Externally controlled magnetic field

Operator area for cavity RF measurements, monitoring, temperature pressure, and radiation level

Dr. Anna Grassellino
Technical Division, SRF Department

Dr. Oleksandr Melnychuk
Technical Division, SRF Department

Fermilab

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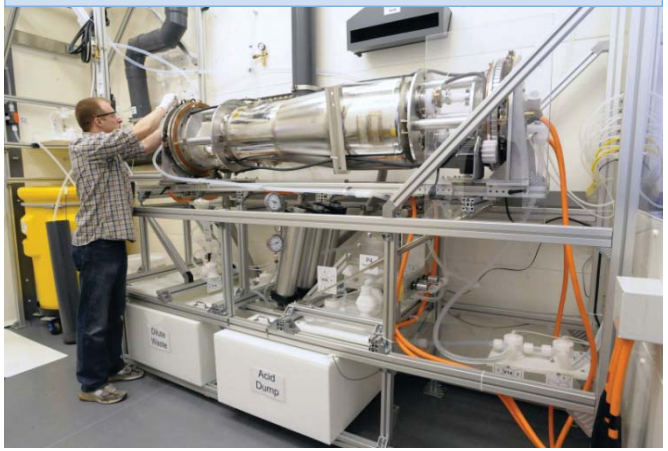
Joint Argonne-Fermilab Cavity Processing Facility at ANL

Argonne National Laboratory and Fermilab have developed and continuously operated a joint cavity surface processing facility since 2006. Through 2014, hundreds of electropolishing and chemical polishing procedures and more than 1000 separate cavity high-pressure rinsing operations have been completed on more than a dozen different superconducting cavity geometries. These include low-frequency quarter-wave, half-wave and spoke cavities, 650 MHz, 704 MHz, 1.3 GHz and 1.5 GHz elliptical cell cavities, and two cavity types for crabbing applications. The infrastructure includes two separate chemical processing rooms each with capability to perform electropolishing and buffered chemical polishing on a variety of cavity types. The chemistry rooms are connected to two separate class 100 clean rooms with automated high-pressure rinsing tools used for cleaning all of these cavity types. The facility continues to support major DOE projects including the LCLS-II, FRIB and the APS-U, as well as, R&D for the LHC upgrade and a future electron ion collider.

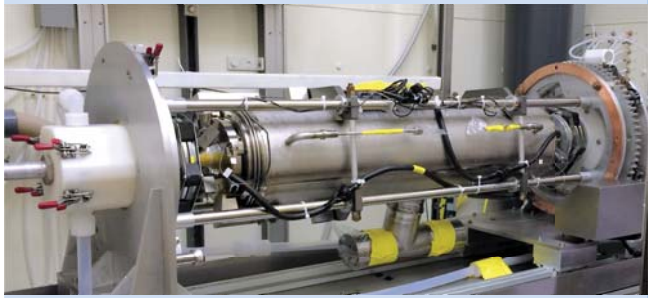
BELOW – A unique capability in the world is ANL electropolishing (EP) for complete helium-jacketed low-beta cavities (quarter-wave and half-wave). This is done as the *final* step in fabrication on cavities with no demountable flanges. The image below shows the EP system with a recent 72 MHz quarter-wave cavity. Seven of these electropolished cavities are operating in Argonne's ATLAS heavy-ion superconducting accelerator since July 2014 with performance that is easily the best anywhere for this class of cavities.



Electropolishing system for ILC-style 9-cell elliptical cavities was designed and built in house at Argonne in 2006-2007 and has been in routine (weekly) operation since then. Cavities processed for ILC R&D routinely reached 35 MV/m with Q of $1x10^{10}$. The tool is also used almost exclusively to process Fermilab cavities for the high-gradient R&D effort for LCLS-II. The Joint Facility is designed to be easily reconfigurable.

Two separate class 100 clean room assembly areas are used for assembling low-beta superconducting cavities, as well as, all of the elliptical cavities processed in the chemistry rooms. A 72 MHz quarter-wave (left) and a 322 MHz half-wave (right) are shown.

ABOVE- Close up of a nine-cell cavity into the electropolishing tool. The image shows the 'quick-release' frame, the copper electrical connections and the rotating electrical and acid handling assembly (far right).



ABOVE- The electropolishing tool accommodates dressed nine cell cavity (i.e. with helium vessel) and also the helium gas return 'tee'.

BELOW – An adjustable external water cooling system is used during electropolishing to minimize temperature gradients over the cavity surface.

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Radio Frequency (RF) Capabilities at Fermilab

High Level RF

The Fermilab accelerator complex utilizes a wide range of RF power sources and transmission lines with frequencies of operation from a few MHz to 3.9 GHz, both pulsed and CW systems, power ranging from Watts to MWatts. Depicted here are several examples of operational systems used throughout the accelerator complex.

Top left: 2.5 MW 325 MHz klystron 3 msec @ 10 Hz, Top right: 325 MHz @ 10 kW CW, Bottom: Inductive Output Tube (IOT) amplifiers operate in CW or pulsed mode 400-800 MHz & 1.3 GHZ @ 30 kW

Dedicated Staff of RF professionals in Low Level RF, Control and Feedback, RF Power Generation.

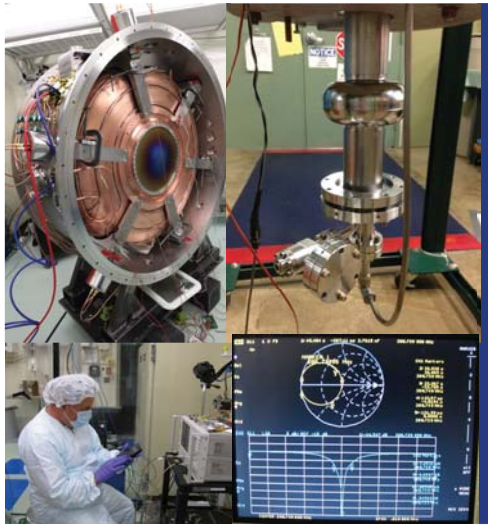
RF Systems

Radio Frequencies are used extensively in telecommunications, medical scanners, electronic sensors, advanced manufacturing systems, and homeland security. RF systems for accelerators consist of low level RF, high level RF, power distribution, and cavities. Brought together, these systems allow for beam acceleration and manipulation with novel techniques. These same advances have potential in industrial applications.

LLRF circuitry combines both analog and digital hardware with DSP and FPGAs for powerful computational capabilities.
Features: 16 ch ADC,8 ch DAC, Hi speed PCIe data bus, 14-bit 65 Msps ADC, 14-bit 275 Msps DAC

Low Level RF

Sophisticated state of the art LLRF controls the RF systems amplitude and phase by means of feed-forward and feedback. Digital techniques allow real time RF manipulation that was unimaginable a decade ago.



Experience with copper, aluminum, and niobium cavities.

Left: 201 MHz Cavity for Muon Ionization Cooling Experiment (MICE)

Right: 2.45 GHz single cell SRF cavity driven by an injection locked magnetron.

Below: clean room cavity tuning

Cavities and Kickers

Structures to support large voltage gradients for acceleration, beam manipulation, bunching, and diverting kickers. Extensive experience with a variety of CAD modeling software for development of such structures. Fabrication facilities in house and expert outside vendors.

Broadband Kickers for Beam Deflection. 1GHz Bandwidth plus/minus 250 Volts

Ralph Pasquinelli
RF Engineer with 37 years experience with RF, instrumentation, and accelerator systems.

Brian Chase
Electrical Engineer with 20+ years in Digital RF Control Systems and other precision signal processing applications.

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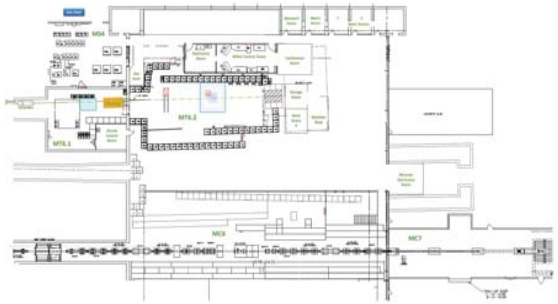
U.S. DEPARTMENT OF ENERGY | Office of Science

Fermilab Test Beam Facility

Facility Overview

The Fermilab Test Beam Facility is a high energy beam facility devoted to detector research and development. The goal of the FTBF program is to provide flexible, equal, and open access to users, in a coordinated safe manner with low bureaucratic overhead. The facility uses two beamlines to provide a variety particle types and energies to test detectors and equipment.

Fermilab Test Beam Facility



Work Rooms, Storage Areas, and several Climate Controlled Areas are available for use.

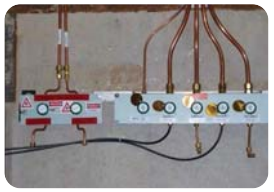
Beam Types

- **120 GeV: Protons**
- **66 - 8 GeV: Pions**
- **32 - 1 GeV: Pions, electrons, kaons,** or broadband **muons**
- **1 GeV - 200 MeV: Protons, pions, kaons** (Only available in 'Tertiary' Beamline)

The Facility offers technical support with installing detectors as well as electronics racks and remote monitoring with cameras

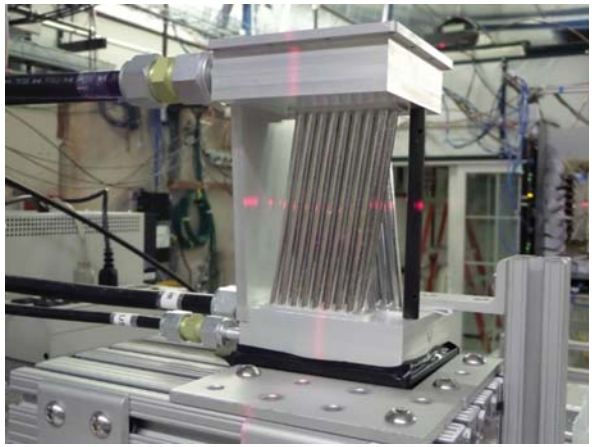
Infrastructure at FTBF

FTBF offers a gas patch panel with the capability of providing flammable gas and three motion tables. There is a variety of detectors to provide information about the beam and augment a user's setup.



4 MWPC Tracking System

Lead Glass Calorimeters



The MT6.2 Enclosure has a system of lasers installed so users can determine the exact location of the beam (x and y planes), and setup their apparatus accordingly.

Dr. Mandy Rominsky
FTBF Coordinator

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