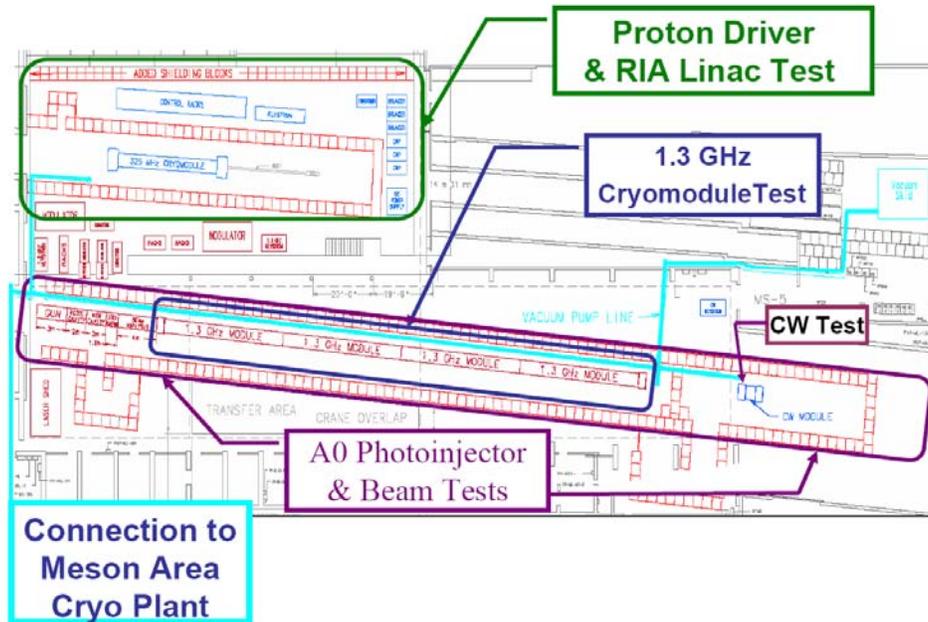


Expression of Interest for the Superconducting Module & Test Facility (SMTF)

FNAL Meson Area SM&TF Layout Concept



Institutions Involved in Discussions

Argonne Laboratory (ANL), Brookhaven (BNL), Cornell University, Fermilab, Jefferson Laboratory (JLAB), Lawrence Berkeley National Laboratory (LBNL), Los Alamos National Laboratory (LANL), MIT-Bates Laboratory, Michigan State University National Superconducting Cyclotron Laboratory (MSU-NSCL), Northern Illinois University (NIU), Spallation Neutron Source (SNS) at Oak Ridge, University of Pennsylvania, and Stanford Linear Accelerator Center (SLAC).

International: DESY, INFN, KEK

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1. Executive Summary

This Expression of Interest (EOI) describes a new US initiative in Superconducting RF (SCRF) research and development. The goal is to strengthen capabilities in high gradient and high-Q SCRF superconducting accelerating structures and related subsystems in support of the International Linear Collider (ILC) and other accelerator projects of interest to US laboratories. It is envisioned that a central test facility, designated the “Superconducting RF Module and Test Facility” (SMTF), will be constructed in the Meson Area by a consortium of US laboratories and universities coordinated by Fermilab. The SMTF will seek to complement existing and planned SCRF infrastructure and capabilities at other U.S. laboratories. This effort should be coordinated with the ILC-Americas and ILC international collaborations that will develop components for the ILC main linac. The facility and its components will be constructed in phases, roughly over the period 2005-2008.

The centerpiece of SMTF will be the SCRF cavity test facility with beam operation capability, which will share infrastructure with three additional areas for $\beta < 1$ and for CW (100% duty factor) cavities, in support of other programs of interest within the U.S. (such as ILC, RIA, Proton Driver, and 4th generation light sources). Possible collaboration with the international HEP laboratories DESY, KEK, INFN and others is being discussed as part of the global R&D program for the ILC. It is likely that the main ILC linacs will be constructed by all three regions in the world. Therefore expanding present US industrial, laboratory, and university capabilities to contribute significantly will become essential for the success of the ILC. To this end goals at SMTF will be to work with and integrate US industrial capabilities. The test facility and fabrication capability will be critical to the advancement of the ILC linac R&D effort.

The SMTF EOI is formulated with recognition of the JLab Center of Excellence plan proposal (SRF Accelerator Science and Technology Center plan). Discussions are underway to join these two concepts in a way that makes best use of resources and capabilities and tries to minimize overall projected cost.

SMTF is envisioned as:

- A multi-laboratory collaboration on SRF development over a broad range of applications. The synergy of expertise will benefit all four areas.
- A facility where different module types and linac systems can be tested (some with beam).
- An organization that will develop inter-laboratory collaboration (including non-US participation) on cold linac technology, including module development and fabrication. The area specific to ILC will be carried out under ILC direction.
- The SMTF collaboration will have organizational boards that work through Fermilab management for the direction of the projects.

Four main areas planned for the program are:

- 1) International Linear Collider (ILC):
 - a. Establish a high gradient, 1.3 GHz cryomodule test area at Fermilab with a high quality pulsed electron beam using an upgraded A0 injector.
 - b. Fabricate four 1.3 GHz high gradient cryomodules (eight cavities each) using industrial and laboratory partners in the US. The fabrication R&D will be carried

out as a collaborative effort under the leadership of Fermilab for the ILC-Americas organization.

- c. Test cryomodules and other rf components as fabrication and operation experience is acquired and designs are optimized.

2) CW:

- a. Fabricate the highest attainable Q-value cryomodules.
- b. Establish a test area that will extend the reach of present US program in CW capabilities.

This facility will be located in the same beam line (M-East) as the $\beta=1$ test beam to allow limited testing with the pulsed beam from an upgraded A0 photo injector.

3) Proton Driver (PD): $\beta < 1$

- a. Fabricate test structures and cryomodules for Proton Driver applications.
- b. Establish an area for high power RF testing of $\beta < 1$ accelerating structures in pulsed mode (~1% duty factor).
- c. The Proton Driver also uses $\beta=1$, 1.3 GHz cavities cryomodules. These cryomodules are nearly identical to the ILC Cryomodules. We anticipate an overlap in ILC and PD R&D activities in this area.

4) Rare Isotope Accelerator (RIA):

- a. Cleaning and cold-testing of individual cavities, after chemical processing
- b. Clean assembly of cavities into cavity strings, forming a sealed assembly including RF couplers, beam line valves, and vacuum manifold and valves.
- c. Assembly of cryomodules incorporating the cavity strings.
- d. Cold test of assembled cryomodules.

Some specific program goals include:

- Demonstrate for ILC and the Proton Driver 1.3 GHz cavity operation at 35 MV/m with beam currents up to 15 mA at a 1% duty factor.
- Develop the capability to reliably fabricate high gradient and high-Q SCRF structures in US industry and laboratories for the stated applications.
- Develop and demonstrate high gradient, pulsed mode, $\beta < 1$ cavity operation at 1.3 GHz and 325 MHz for Proton Driver applications, and CW operation at various frequency cavities for the RIA project.
- Demonstrate 20 MV/m CW cavity operation with Q values $\sim 3E10$ for light source applications.

We propose that the SMTF test area will be constructed in the meson experimental area at Fermilab, in phases, over the next several years.

- Phase 1: Installation of infrastructure culminating in the RF power tests of a single ILC cryomodule within the 1.3 GHz, $\beta=1$ high gradient pulsed test area. This cryomodule will likely be provided by TESLA Collaboration.

Relocation and commissioning of the Fermilab NICADD photo injector in the SMTF. Initiate beam tests of a single ILC cryomodule utilizing the photo injector.

Start fabrication of a US cryomodule using a combination of industries, laboratories and universities.

Commission the proton driver, light sources, and RIA test areas. Pulsed RF power tests (325 MHz) of $\beta < 1$ spoke resonators and CW RF sources for 345 MHz RIA cavities.

- Phase 2: Install, and operate with beam, a complete SMTF-ILC RF unit consisting of two high gradient cryomodules, of which at least one is fabricated by the ILC-Americas collaboration with industrial partners. This may be powered by a high power modulator and a 10 MW multibeam klystron if available.

The $\beta < 1$ proton driver test area and next generation light sources area will evolve in a similar manner to the ILC area.

The proton driver $\beta < 1$ area will initially include a 325 MHz pulsed RF system and a test cryostat for pulsed-mode operation of RIA-type SCRF spoke resonators. The RIA area will initially include 345 MHz and other frequency CW RF systems. In later phases of operation, the addition of an H- source, radio frequency quad (RFQ), and medium-energy beam transport (MEBT) would complete a beam-capable test bed for LLRF and resonance control when driving low-beta ion beams with multiple cavities powered from a single klystron.

- Phase 3: Install, and operate with beam, two complete SMTF-ILC RF units consisting of four high gradient cryomodules, two high power modulators and two 10 MW multibeam klystrons.

Improve the photo injector with the addition of cryomodules of 1.3 and 3.9 GHz.

This Expression of Interest outlines the rough goals and scope of the SMTF project. Ideally the SMTF would support concurrent operation of all four areas. The SMTF should also provide a large amount of calendar availability for each of the four programs in every year of operation we expect that a dialog among Fermilab, the participating laboratories, and funding agencies will commence after this report is reviewed. In response to this EOI, the collaboration hopes to receive guidance on how to proceed with the next steps toward a full proposal.

2. Introduction and Motivation

A variety of projects are being planned in particle physics, nuclear physics, and fields of basic energy sciences such as condensed matter physics and biological physics that propose to use superconducting RF (SCRf) linac technology. These projects are distributed across many of the major US laboratories funded by DOE and NSF. This expression of interest is to inform Fermilab management that we will propose to construct a superconducting RF module and test facility (SMTF) in the meson area at Fermilab. A medium energy electron beam and a low energy H⁻ beam would permit a unique opportunity for characterization of the properties of superconducting RF cavities and for beam-related experiments. The members of the team are from a consortium of several US laboratories and universities.

We list several possible future projects that use RF Superconductivity.

- 1) International Linear Collider (ILC)
- 2) The Rare Isotope Accelerator (RIA) (located at Argonne or MSU)
- 3) Proton driver at Fermilab or BNL.
- 4) Upgrades (12 GeV) to JLAB electron linac, the extensions of the FEL and the proposed ELIC (Electron Light Ion Collider)
- 5) SNS (Spallation Neutron Source) upgrades to higher beam power ~ 4 MW.
- 6) Fourth generation light sources at ANL, BNL, Cornell, JLAB, LBNL, and MIT using SCRf linac technology for ERLs (energy recovery linacs) or FELs (free electron lasers).
- 7) Brookhaven plans to use ERLs for electrons colliding with RHIC heavy ion beams (E-RHIC) and for electron cooling of the RHIC beams.

These projects have common or similar rf systems and require development that would benefit from a coordinated effort among the laboratories. Several of the laboratories have infrastructure to carry out SCRf development but have limited fabrication capabilities. The current efforts in SCRf are broadly funded by USDOE HEP, Nuclear, Basic Energy Sciences and the NSF. Many of the above projects would benefit from a cryomodule test facility with beam capabilities, which is presently not available in the US. We propose such a facility and refer to it as the SMTF. It would fill the gaps in the existing SCRf development capabilities.

The critical tests that groups from the above projects could perform at this facility include:

- 1) Demonstrate for ILC 1.3 GHz cavity operation at 35 MV/m with beam currents up to 15 mA at a 1% duty factor in two cryomodules with 8 cavities each.
- 2) Demonstrate for CW applications 20 MV/m cavity operation at Q values $> 3E10$.
- 3) Demonstrate for the Proton Driver 1.3 GHz, $\beta \sim 0.5-0.8$, elliptical cavity operation at > 15 MV/m at $Q > 5E9$ and a 1% duty factor with multiple cavities being driven by one klystron.
- 4) Demonstrate for the Proton Driver and related applications high gradient operation in pulsed mode of 1.3 GHz and 325 MHz, $\beta < 1$ cavities and cryomodules.
- 5) Demonstrate individual cavity resonance control with multiple cavities driven from one klystron, using fast ferrite phase shifters, at both 1.3 GHz and 325 MHz
- 6) Demonstration of RIA cavities and cryomodules.

These demonstrations encompass research and development topics critical for the continued

iteration and evolution of SCRF linac systems, for the development of cost effective low to medium β linac sections needed for proton/ion linacs, and development of lower power cost (driven by refrigeration costs) CW operation for the many upcoming light source applications and for the future ILC.

Thus the SMTF goals are to:

- Collaborate on SRF technology development including industrial collaboration
- Provide a structure for SRF module and systems design evolution and fabrication
- Provide a test environment and infrastructure for module and linac systems test and evaluation

3. The JLab Accelerator Science & Technology Center Plan (ASTC) and the SMTF Plan

JLab has been asked by the DOE Office of Science to provide a progressive plan for improving US SRF capabilities. It is important to have a concept of how this plan and SMTF could merge to a consistent picture.

The JLab plan addresses three capability levels:

- Near Term needs (RIA, 12GeV Upgrade)
- Capability for design and delivery other SRF systems (exclusive of LC) in collaboration with partners
- Construct an integrated cryomodule prototype production plant with focus on LC and the need for industrial technology transfer.

This last effort has significant cost associated with it.

Discussion is underway among the interested labs how to implement initial activities. This SMTF EOI is a start in that direction.

In the longer term, substantial investment in SRF capability for the ILC will be necessary in order to get to a state of preproduction capability and industrial technology transfer in the US. Just what will eventually be needed for this long term goal needs careful planning and analysis, as the facilities could be a major investment and every effort should be made to minimize costs while accomplishing the development toward industrialization goals necessary for an ILC.

A model is under discussion where the two plans (ASTC and SMTF) could mesh and utilize the strengths of the two major player labs in the module development, JLab and FNAL. It would also be important to integrate the SCRF capabilities and infrastructure that exists in labs such as LANL, MSU, Argonne and Cornell. Industrial participation in these activities and planning for industrialization can be developed. The synergy of SCRF expertise in the US would greatly strengthen the activities. Certainly it is clear that pre-industrial capability should be developed with a coherent plan that uses and builds on existing laboratory strengths. Equally clear is the importance of individual US labs having and developing their SRF capabilities on a scale compatible with R&D on the smaller than pre-industrial scale. The large scale of the ILC effort calls for a combination of the existing strength of the US SCRF community.

4. Proposed SMTF Plan

We propose to develop the meson east area at Fermilab into a cryomodule test area. The document is organized around the three main SCRF areas: the 1.3 GHz, $\beta=1$ ILC Cryomodule test facility, the CW test area for next-generation CW light source, and the $\beta < 1$ test area for PD, and the RIA facility. These R&D activities will operate under a shared infrastructure of the Meson cryogenic facility, pulsed rf and modulator power sources, controls, safety and technical support.

The allocated space should be able to accommodate initially three test areas. The high gradient pulsed work and the CW activities would be located in a single 100-150 meter beam line. A second area would be large enough to accommodate the 325 MHz $\beta < 1$ cryomodule activities. We anticipate three different communities using the facility. At the same time these communities will have strong interactions to benefit all four areas. One community will concentrate on 1.3 GHz pulsed high gradient tests, such as needed for the ILC and Proton Driver. Another community will focus on cryomodule operation needed for the fourth generation light source and FEL accelerators that use high Q, CW operation. The third community will emphasize $\beta < 1$ activities at various rf frequencies. We envision that the regions will initially operate in two different modes. In one region, physicists would perform high power cryomodule tests as well as beam tests with a medium energy electron beam (40 - 300 MeV). This is the energy of the injector into the first spectrometer. We would also develop a beam analysis section downstream of the cryomodule. In the parallel region, tests (initially without beam) could be ongoing with low beta demonstration cryomodules. Shielding between the two regions will be necessary for flexible operation. The details of the layout are still being worked out.

The electron beam test area in SMTF would consist of an electron beam injector, a beam analysis region after the injector and before the cryomodules in order to measure incoming beam properties, a section of up to four cryomodules, which constitutes two ILC RF units (defined later), and space afterwards to evaluate the outgoing beam properties. The CW activities are located downstream of the ILC cryomodules. The existing Fermilab FNPL (A0 injector) would be an appropriate initial source. To achieve 40-300 MeV will require an upgrade to the source as described later. This consists of a gun and accelerating section, and is about 15 m (upgraded eventually to 25 m) in length. We estimate that 20 m of beam analysis space is needed to measure beam properties, followed by space for four 12-17 m cryomodules, and an additional 20 m of analysis space for the outgoing beam and a beam dump, for a total of 100-150 m.

The cryogenics plant in the meson area needs an upgrade. We propose a two step approach. For the first step we make minimal modifications to the existing infrastructure and utilize what we can to supply the area quickly with about 60 Watts of refrigeration at 2K. Each TESLA Test Facility (TTF) cryomodule (eight 9-cell cavities) consumes about 19 Watts of refrigeration at 2K. The third step will require a new refrigeration plant that can handle ~300 Watts. The cryogenics are described in Appendix II. Medium energy electron beams will be used for testing the cryomodules in the area and dark currents should be expected from the cavity modules, therefore the appropriate radiation shielding will be necessary.

To get started quickly we propose to initially use an eight cavity cryomodule that was produced for the TTF. We expect that the TESLA collaboration will provide this cryomodule. In parallel, we would aggressively move to construct cavities, auxiliary components (power couplers, HOM

couplers, tuners, helium vessels), and cryomodules in the US. We note that US industry considerably lags European industry in SCRF technology and our plans would help correct this situation. This is especially desirable given the large number of SCRF projects in the US, and the large scale of the ILC. We also note that significant infrastructure exists at US laboratories and will need upgrading. We plan to incorporate existing infrastructure and expertise at US labs and universities as well as US industry to build cavities, carry out bare cavity tests in vertical Dewars, perform dressed cavity horizontal tests, and assemble cavity strings and cryomodules. In addition we would build couplers and tuners and other cryomodule components to extend the full range of expertise and technology required for the major projects envisioned.

In Phase I it is expected that ILC-Americas, Proton Driver, RIA, CW and $\beta < 1$ interests will launch independent but collaborative activities to build cryomodule(s). Individual laboratories would assume responsibility for major subsystems and pre-testing efforts. This EOI proposes that, with coordination from the ILC-Americas collaboration, Fermilab will lead the effort of fabricating and testing the ILC and PD cryomodule and ANL will lead the RIA cavities testing and production work. The leadership of CW cryomodule fabrication for light source applications is not yet established. See Appendix III for more details on cavity and cryomodule fabrication and testing infrastructure that will be required of such a facility.

This document is organized around the four main SCRF areas: 1.3 GHz and $\beta = 1$, CW, $\beta < 1$ for Proton Driver and RIA programs. Even though we present the four research concentrations separately for ease of reading, the resources and goals significantly overlap. Each area will benefit from the collaborative effort.

5. 1.3 GHz Fabrication & Test Facility Program

We plan to proceed with three main phases in the development of an ILC module test bed (See Figure 1.). This section describes these three main phases.

An ILC rf unit will eventually need to be defined for both the 500 GeV and 1 TeV ILC designs. In our discussions, we are moving towards an ILC cryomodule with 35 MV/m, 1.3 GHz cavities for both 500 GeV and 1 TeV operation. The power sources currently being developed can provide 10 MW of RF power so it is natural to define an RF unit as the number of cavities powered by such a source (i.e., one modulator and one klystron). Given the state of cryomodule development and the desire to have some overhead in choosing the ILC beam current, we define an SMTF-ILC rf unit for test purposes as two cryomodules with eight TESLA-like (9 cell) cavities each. Assuming 6% rf transport losses, each cavity in the rf unit could be powered up to 530 kW with a 10% overhead. At 35 MV/m, a 15 mA beam could be accelerated, which is about 15% more current than in the TESLA 800 design. We note that our present concept for the ILC cryomodule is based on the TESLA Test Facility (TTF) design, which contains eight nine-cell cavities. It may be cost effective for the ILC to have 12 nine-cell cavities per cryomodule as was proposed and costed for the TESLA Technical Design Report (TESLA TDR).

1) We propose to bring into operation one cryomodule with the goal of demonstrating 35 MV/m cavity operation. It is expected that it may take more than one module iteration to achieve this gradient.

The A0 photo injector¹ will be moved, installed and recommissioned with the cryomodule (step 1) in order to perform beam measurements, which are discussed below.

We will initiate beam tests of a single ILC cryomodule utilizing the photo injector.

2) We will bring into operation one SMTF-ILC rf unit, defined as two cryomodules each containing eight 9-cell cavities, one high power modulator, one 10 MW multibeam klystron and perform beam measurements.

The injector will be upgraded to include the Fermilab built 3.9 GHz accelerating and deflecting cavities.

3) We propose to bring into operation two SMTF-ILC rf units and associated rf power, instrumentation and controls.

We also envision an upgrade of the injector to use eight 1.3 GHz cavities and four 3.9 GHz cavities in cryomodules. This would also enable us to perform accelerator physics measurements.

These three phases will allow for iteration of component and integrated linac systems designs as they evolve toward final industrial prototypes. They will allow investigation and iteration of beam and accelerator measurements. Though these steps are closely aligned with similar

¹ Transplant the A0 photo injector (A0PI)

activities at TTF, we believe it is imperative for a project the size of ILC that each region carries out fundamental developments of the large systems, such as the linac². The ILC test bed at SMTF would allow for certification of cavity performance, testing with different klystrons, couplers, and low level rf (LLRF) systems, and the study of performance under different beam loading conditions as well as measurements of beam properties. The SMTF might also act as the main database for these test results.

The preliminary outline of time scale for the three phases described above is 1) 2005-2006, 2) 2006-2007, 3) 2007-2008. The timeline has been developed to coincide with ILC goals and is expected to evolve.

The injector and its upgrade are described later in this document and in detail in Appendix I.

1.3 GHz Cryomodule Test Facility

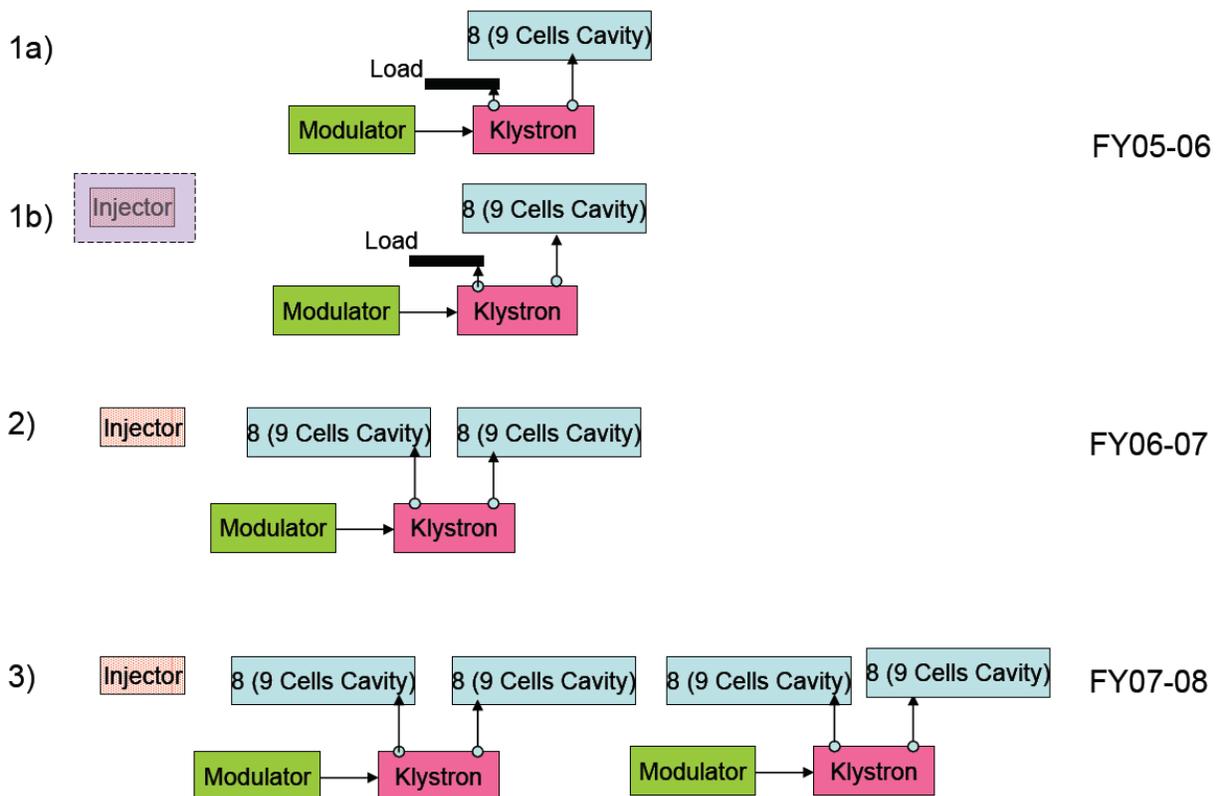


Figure 1. Phases of the SMTF 1.3 GHz test facility.

In phase 1, we want to first establish operation of a TESLA Collaboration and/or 1st US cryomodule at some intermediate gradient in order to establish our abilities with the technology. We would then establish high gradient performance along with Q and dark current measurements without beam. Tuner tests with the cryomodule would be performed to establish the necessary specification. Beam commissioning could proceed after the static tests were complete.

² We expect availability of TTF will be limited due to its transformation into a FEL user facility

We believe it is important to follow a parallel path of constructing and processing new cavities and cryomodules in the US. The first cryomodule fabrication and testing might be divided into four major steps as outlined below. Different labs might be given responsibility for these different activities based on their capabilities. As an example scenario, we consider the fabrication processing and component testing of US $\beta=1$, 1.3 GHz cryomodules in five stages.

First stage: Bare Cavity (working with industrial partners.)

- 1) procure and verify pure niobium
- 2) construct $\beta=1$ cavities,
- 3) tune the cavities,
- 4) apply chemical processing,
- 5) bake cavities
- 6) repeat chemistry
- 7) high pressure rinse (HPR)
- 8) vertical dewar test

Requires: chemistry, vertical dewar, shielding, low power rf, cryogenics

Second stage: Dress Cavity

- 1) attach helium vessel
- 2) check tune
- 3) re-acid etch and HPR
- 4) dress for horizontal cavity test
- 5) perform horizontal cavity test

Requires: chemistry, horizontal module, shielding, low power rf, cryogenics

Third stage: Components

- 1) acquire cryostat components
- 2) acquire rf power source and wave guides
- 3) input coupler fabrication, clean assembly and conditioning

Fourth stage: String Assembly

- 1) re-clean for string assembly
- 2) string assembly
- 3) acquire parts for string: magnets, BPM, gate valves, bellows, cold input coupler, etc

Requires: chemistry, large clean room for assembly

Fifth Stage: Module Assembly

- 1) prepare cold mass
- 2) assemble string to cold mass
- 3) mount warm couplers
- 4) install into cryostat for testing

Requires: large industrial space, cold mass parts, string, warm input coupler, magnetic shielding, tuner

Sixth Stage: Module Testing

- 1) Prepare and test cryomodule with beam

Also needed for this fabrication and future R&D:

- 1) Electro-Polishing R&D
- 2) Cryomodule test area infrastructure development

5.1 Power for Two Complete RF units (steps 1-3)

The power system at the facility will need to accommodate two complete 1.3 GHz rf units (each unit contains two eight-cavity cryomodules). Each rf unit is nominally powered by one 10 MW klystron and modulator. These klystrons will likely be purchased from one or more of the three vendors (Thales, CPI and Toshiba) that DESY has contracted to develop such tubes. These vendors have produced prototype 10 MW tubes but none has yet performed at the level required for the SMTF. The development of these tubes by DESY will likely continue, especially as they will probably be used for the DESY-based XFEL project as well. In the meantime, FNAL owns commercial 5 MW tubes that could be used instead (one per cryomodule). Specifically, they have a Thales 2104 klystron that is a spare for the A0 injector and they recently acquired six Thales 2095 tubes that were originally at LANL (5 were in operation there). It is anticipated that, with coordination from the ILC-Americas collaboration, SLAC will lead the ILC rf power source efforts, and source development and testing will be carried out there as well.

Two modulators for SMTF are currently under construction at Fermilab. These are designed specifically to power any of the following: the 10 MW 1.3 GHz multi-beam klystrons from Thales, CPI, or Toshiba; the 325 MHz JPARC/Toshiba klystron planned for the $\beta < 1$ linac, or the commercial 5 MW, 1.3 GHz klystrons. The modulators can be reconfigured to support pulse widths of 1.5 msec for ILC and 3 msec or 4.5 msec for the Proton Driver.

5.2 Cryogenics Needs

The cryogenic need for phase 1, 2 and 3 at 5 Hz are 30, 80 and 130 watts, respectively, at 2 degrees K as described in detail in Appendix II. The meson cryogenic plant can provide up to 60 watts at 2 deg K. We propose to operate the cryomodule at a lower repetition rate for phase 2 and for phase 3 until the cooling capability is increased as discussed below. In the meson cryogenic system there are three thermal shields, operated at 2.0K, 4.5K, and 80K. The 80K shield will be liquid nitrogen, the 4.5K shield is gaseous helium, and the 2.0K shield is super-fluid helium.

Other items that will be needed are the phase separators, control systems, vacuum pump (sub-atmospheric to lower temperature to 2 K.), transfer lines, and a feedbox. The feedbox contains a low pressure heat exchanger, numerous control valves, instrumentation and must connect to cryomodules via an input cryogenic feed cap. A cryogenic end cap will be needed.

Care in avoiding contamination of the helium is necessary because the system is running at a sub-atmospheric pressure. This implies that regular maintenance for decontamination will be necessary.

One additional requirement for phase 3 is that the cryogenic distribution must feed the cryomodule and the three connections to the A0 photo injector. Three additional smaller feedboxes will be constructed.

The time needed to install the cryogenic distribution system is about 6 months. The feedbox will require about 9-12 months to complete.

For 5 Hz operation of the 2 rf units, a larger cryogenic system will be required. The long-lead item for phase 3 is a ~300 Watt, 2 K refrigerator where it is estimated that it will take two years to acquire. There are at least two companies that can build this unit and possibly others. It is desirable that we place an order as soon as possible.

See Appendix-II for a more detailed discussion of the cryogenic system.

5.3 Measurement and Tests

5.3.2 Electron Beam Tests

We outline below possible studies with an electron beam for the SMTF. First, the rf performance of the cavities can be measured directly with beam and secondly, the impact of the cavity on the beam can be assessed. An initial set of measurements would include:

- Beam energy: a spectrometer would provide an independent and accurate measurement of the accelerating gradient (rf based techniques are not as accurate).
- Long-range wake-field characterization: Measure frequency spectra of bunch positions downstream of cryomodule to search for high Q cavity dipole modes that could cause beam break-up in the ILC. Correlate these data with HOM power measurements.
- Tests of low-level rf system: demonstrate that a < 0.1% bunch-to-bunch energy spread can be achieved in a 1 msec bunch train.
- Impact of the SCRF cavity on transverse beam dynamics: measure the beam kicks caused by the fundamental mode fields.
- Study beam centering based on HOM dipole signals.

To study basic cavity performance during beam operation, the injector at SMTF should provide bunch trains comparable to those envisioned for the ILC. The main requirements include:

- bunch charge: up to $2e^{10}$ electrons
- bunch length: as low as 300 microns rms bunch spacing: nominally 337 ns with option of halving this.
- bunch energy stability < 1% rms average
- current stability < 1% rms (preferably < 0.1% rms)
- number of bunches: up to 2820
- pulse rep rate = up to 5 Hz

This broad range of measurements will present several technical challenges, the details of which have to be worked out.

5.3.3 Other Studies:

- Determine the maximum operating gradient of each cavity & its limitations.
- Evaluate gradient spread and its operational implications.
- Measure dark currents, cryogenic load, dark current propagation, and radiation levels.
- Measure alignment of the quadrupole, cavities and BPM in-situ using conventional techniques (e.g. wire or optical).
- Measure vibration spectra of the cryomodule components, especially the quadrupole magnet.
- Measure system trip rates and recovery times to assess availability.
- Develop LLRF exception handling software to automate system and reduce downtime.
- Evaluate failures with long recovery times: vacuum, tuners, piezo controllers, and couplers.

5.4 Photo Injector Upgrade

5.4.1 Three Possible Upgrade Plans

The A0 photo injector will be moved to SMTF and will be upgraded in a phased approach. The present plan at A0 is to reconfigure the injector to include: a normal conducting gun, and two Tesla cavities (one operating at 12 MV/m and one at 25 MV/m). This configuration requires a high power klystron/modulator system (~4-5 MW) for the normal conducting gun, and two low power systems (~300 KW nominal each) for the two Tesla cavities. The high power modulator system is very similar to that discussed above for a 10 MW klystron. The main difference is the multi-beam klystron with its higher efficiency. The multibeam klystron can supply higher output power than a conventional single beam klystron when either is powered by the same modulator. Both the gun and the modulator would need to be upgraded for 5 Hz long pulse operation.

A further step would incorporate two 3.9 GHz cavities of two different designs, presently under development. One of these cavity types (3rd Harmonic) is operated in deceleration mode and linearizes the beam bunch energy with time. The other operates in a deflecting mode and is used as a diagnostic to measure beam properties within the different time slices of the beam bunch. The cavities require ~4 KW power. To implement these two cavities requires two additional low power modulators; one of which is similar to that needed for the individual TESLA cavities (above), and one that is a gated CW modulator.

A Model for Size & Scope Tesla TTF 2 Modules with beam compression

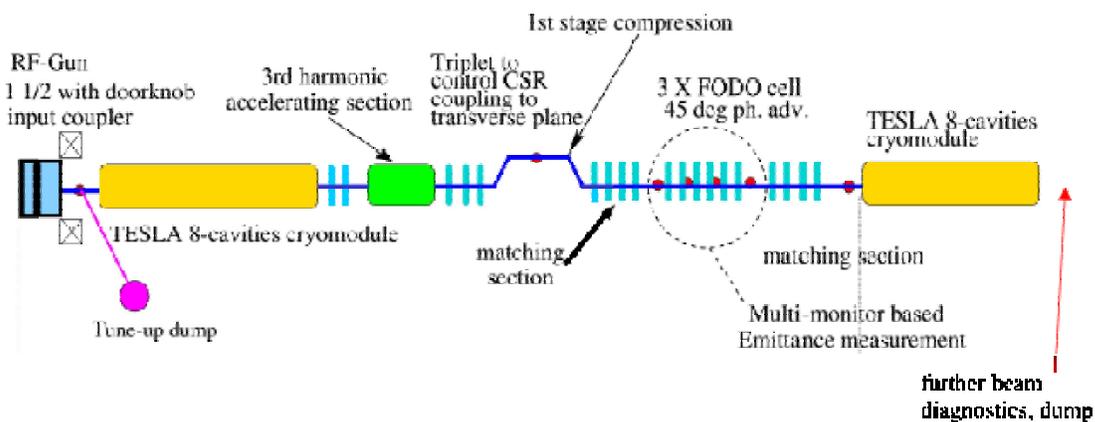


Figure 2 Upgraded Photo injector

Eventually it might be desirable to upgrade the injector to a system similar to that now at TTF. The two TESLA cavities would be replaced by an eight cavity module with some of the cavities operating at ~12MV/m and the rest at ~25 MV/m. Alternatively the module could be in addition

to the two cavities, and installed downstream of them. This module would require a high power (5 MW) klystron/modulator system. The one 3.9 GHz decelerating cavity would be replaced by a module of four 3rd Harmonic cavities and would require an 80 KW klystron that could actually be the same unit as before, but operated at higher power.

We plan to expand the infrastructure at Fermilab to have the ability to make measurements on “bare” 3.9 GHz cavities in collaboration with Argonne. A test system will require space for a vertical Dewar and possibly a horizontal single cavity test cryostat. These will be needed to accomplish measurements on both bare and dressed cavities. We plan to adopt the DESY Dewar and cryostat designs³. See appendix-III for a more detailed discussion.

³ The vertical Dewar is actually a Fermilab design (Fermilab’s contribution to TESLA).

5.5 SMTF RF Systems Table

System	Phase	Cavity	Klystron nominal power	Klystron status	Modulator	Modulator status
One Module	1,	8 cavity module	Thales TH2104C 5 MW	exists\spare	“Big”	Under fab/parts procure
Injector	1	NC gun	Thales TH2104C 5 MW	Exists	“Big”	exists needs upgrade
		Tesla cavity 1	Phillips YK 1240 300KW	Exists	“Small 1”	exists, planning to rebuild
		Tesla cavity 2	Phillips YK 1240 300KW	exists, under rebuild	“Small 2”	under fab/parts procure
		3 rd Harmonic	CPI VA 908K2 80 KW	In fabrication	“Small 3”	under fab/parts procure
		3.9GHz Def (CKM)	CPI VKC 7810F 3KW	Exists	“ CW”	under fab
2 Cryo-modules injector	2	2, 8 cavity Cryomodule	10 MWatts	New	“Big”	New
	2 same as 1					
4 Cryo-modules	3	4, 8 Cavity Cryomodule	10 MWatts	New	“Big”	New
Injector	3 same as 2 with upgrade					
Injector upgrade 1.3	3	8 cavity module	Thales TH2104C 5 MW	need or use TH2095A	“Big”	Need
Injector upgrade 3.9	3	4 cavity 3 rd Har 3.9GHz module replaces single cavity	same RF as before CPI VA 908K2 80 KW	may need 2 nd Klystron	same mod as before “Small 3”	
spare			Thales, Thompson TH 2095A ~5 MW	6 units mod anode		

6. CW, $\beta=1$ Test Facility and Program for Next-Generation Light Sources

6.1 Introduction

Superconducting RF structures operated in CW mode have advantages in providing high accelerating gradients, extremely stable RF fields, inherently small perturbative effects on the beam, and with RF power requirements considerably less than equivalent normal conducting structures. Taking advantage of advances made in superconducting RF technology in recent years, several proposals have been developed for a variety of applications of CW SCRF, including free electron lasers, energy recovery linacs (ERL's), recirculating linacs, and beam conditioning devices such as harmonic cavities for manipulation of longitudinal phase space, and transverse deflecting cavities.

The high quality factor of superconducting structures ($Q_0 \sim 10^{10}$) results in a very long filling time of 2.4 s for unloaded 1.3 GHz structures, and very small intrinsic bandwidth (\approx Hz) for stable operation. Over-coupling the cavity to the RF power input port reduces the quality factor to a low external Q (Q_{ext}) and decreases the filling time, but requires additional RF power to overcome reflections introduced at the coupler. In some applications the beam loading requirements provide a strong reason to lower the Q of the cavity resonance such that input conditions closer approximate a match to the beam loading. But for many applications where the system is not heavily beam loaded, significant over-coupling has a direct consequence in increased RF power costs. In such cases then, the coupling and the filling time are limited primarily by the ability to provide feedback of the system against field fluctuations induced by microphonics. For example, a 50 Hz cavity/feed system bandwidth results in an external quality factor Q_{ext} of 2.6×10^7 for 1.3 GHz, multicell cavities and the cavity filling time is then several milliseconds. Typically, power is applied to pulsed standing wave cavities for about three time constants before the beam enters the structure, to allow time for energy to build up in the cavity so that the required field can be developed. The applications of interest discussed here require bunch rates significantly exceeding the capabilities of a system with 1-10 ms time constant, and the superconducting linac must be operated in continuous wave (CW) mode. The resultant power dissipation due to RF currents on the cavity inner surfaces increases significantly over the pulsed design parameters, for example a TESLA cavity operating at 20 MV/m CW dissipates approximately 40 W at liquid helium temperature, compared with \sim 1 W for the nominal pulsed operating mode (at about 1% duty factor). Operating in CW mode at a gradient of up to 20 MV/m requires development and testing of systems to accommodate the large thermal load.

Application of CW SCRF in such facilities drives advances in a broad range of accelerator communities, including synchrotron light facilities, free-electron lasers (FELs), electron-ion colliders, and nuclear physics facilities. Recirculating linacs and ERLs, driven by CW SCRF linacs, are proposed advanced accelerator-based x-ray sources that allow high peak and average brilliance, high temporal and spatial coherence, and ultra short light pulses covering wavelengths from infra-red to x-rays, depending on the beam energy. Using stable beams from a CW SCRF linac allows utilization of the very low 6-dimensional electron beam emittance produced in high-brightness electron sources – a significant advantage over storage ring beam quality which is limited by stochastic effects (quantum emission, intra-beam scattering, radiation damping).

ERLs also allow high average photon flux by using very high beam power (high bunch rate) and recovering the beam energy. Energy recovery is achieved by passing the electron beam following acceleration and x-ray production, back into the linac in the opposite phase to the accelerated beam. The energy in the electron beam is deposited into the SCRF cavities, building field for acceleration of fresh beam from the electron source, and providing enormous savings in electrical power. There have been several demonstrations of the ERL technique, most recently at JLAB up to 1100 kW average beam power has been recovered in an ERL by recirculating 7.5 mA of beam current, and up to 9 mA average beam current has been recirculated

LBNL and MIT are developing accelerator concepts based on proposed developments of the TESLA technology into the CW operating mode. These facilities are designed for high peak x-ray flux and brightness from FELs using high-quality electron beams accelerated in CW SCRF linacs, either recirculating or single-pass.

Cornell and TJNAF are developing light sources based on x-ray production by spontaneous emission in insertion devices with high coherence achievable from high-brightness electron beams, and using an ERL to achieve high average power. Cornell for example is conducting a study towards a 100 mA, 5 GeV beam with the equivalent of 500 MW of power. At BNL a high-current ERL for electron cooling of the RHIC beams is under development, with the aim providing of Ampere-scale beams using a superconducting linac.

Several RF structures are being developed for CW applications, at different frequencies and with different parameters, but with similar and some key overlapping issues to be addressed. A number of facilities are currently operational and active in research and development of CW SCRF for application in specific projects for light sources and nuclear physics facilities, and a number are in the proposal stage. Existing experimental capabilities include facilities at Cornell, BNL, and TJNAF. R&D interests in application of CW SCRF include:

- Demonstrate high gradients in CW operations ~ 20 MV/m
- Demonstrate high Q values in CW operations. One goal, with most relevance to multi-GeV linac applications, is $Q_0 > 3 \times 10^{10}$
- Demonstrate high external Q values at operating gradients of ~ 20 MV/m, with a goal of $Q_{\text{ext}} > 1 \times 10^7$ for low beam loading applications
- Demonstrate high stability and control of microphonics, with a goal of phase error $< 0.1^\circ$ and amplitude error $< 10^{-4}$
- Demonstrate wakefield suppression and stable operations with realistic beam parameters (strongly dependent on application)

6.2 Goals for a CW SCRF test facility

Existing R&D facilities mentioned above are already addressing many of the outstanding and pressing questions in application of CW SCRF in particle accelerators. The SMTF would provide for experimental study of aspects of cryomodule performance not specifically addressed by other programs. The SMTF goals may be specifically identified as demonstration of the following:

- High Q values in CW operations at 20 MV/m, goal of $Q_0 > 3 \times 10^{10}$
- High stability and control of accelerating fields, goals of phase error $< 0.01^\circ$ and amplitude error $< 10^{-4}$

- The above performance in the presence of electron beam of 1 nC charge, repetition rate ~ 10 kHz

The more demanding phase stability of 0.01° presents a challenge not addressed at other facilities, and the presence of a CW test area in the SMTF would allow experimental investigation of CW SCRF cryomodules to address this and other issues listed above. The cryomodule and cavities may be constructed in US industry, and processed and tested using existing infrastructure at US labs.

The above goals encompass research and development topics critical for the development of CW operation for many proposed applications. Continued development of SCRF for CW applications will also need to address the following major issues, especially when related to supporting high beam current. The 1.3 GHz cryomodule tested at SMTF can be subsequently tested at higher beam currents at Jlab or at Cornell.

The first tests at SMTF can also address some of the following issues:

- Thermal management for a range of projected Q values
- HOM damping validation
- Cavity tuning control
- Power coupler designs

Equipment will be required to allow determination of cavity Q values, gradient, stability, HOM characteristics, thermal load at a variety of locations within the cryomodule, input power, dark current, etc.

In addition couplers and tuners and other cryomodule components would be fabricated to extend the full range of expertise and technology required for the major projects envisioned.

Capabilities of the SMTF to facilitate future operation of a CW test stand would include ability to explore high gradient CW performance along with Q and dark current measurements without beam. Tuner tests, HOM measurements, and cavity microphonic tuning feedback systems test with the cryomodule would be performed to establish the necessary specifications.

Average beam power requirements are modest, 1 nC at 10 kHz, and would require an RF photocathode source. Beam tests will be important to demonstrate the performance goals as outlined above, under realistic beam conditions.

6.3 A prototype CW cryomodule for SMTF

The multi-cell cavity for the ILC, at 1.3 GHz, offers an existing design which has parameters suitable to application in CW mode to meet the needs of future facilities with modest beam loading ($\sim 10 \mu\text{A}$). To take advantage of developments to date in SCRF, use of the cavity design developed for ILC would provide a suitable prototype to address the performance questions listed above for CW operations. These particular questions are not being addressed at other facilities, and the SMTF would provide a location and infrastructure for development of CW SCRF systems specific to these needs, and complementary to the existing facilities and R&D programs. Strong intellectual and technical interactions between CW and ILC enthusiasts (many of whom are the same people) would be of benefit to both communities.

6.3.1 Thermal management

The dynamic heat load in the CW SCRF cavities is inversely proportional to the cavity unloaded Q value, Q_0 . Development of high Q cavities, $Q_0 > 3 \times 10^{10}$ has significant advantages to CW operations, particularly for larger, multi-GeV, linacs.

Lowering the temperature to 1.8 K increases the theoretical Q reachable to more than 6×10^{10} . Allowing for a reduction by a factor of two due to residual losses, a target of 3×10^{10} would reduce the dynamic heat load to 13 W/m. Excellent magnetic shielding will be necessary to screen the earth's field down to about one mGauss. (The earth's field flux quanta get trapped in the niobium walls, due to the presence of imperfections, impurities and oxides, thereby limiting the Q-value).

Operating at 1.8 K to reduce the BCS resistance and increase the theoretical maximum Q-value will demand larger pumps to reach the lower helium vapor pressure corresponding to 1.8 K. Even though the goal is to reach a Q of 3×10^{10} , a CW SMTF module should be equipped with features to handle Q values down to 10^{10} , so that we may learn how to deal with high heat loads, if the high Q's aimed for are not realized, or partially realized.

A cavity operating in CW mode at 20 MV/m with a Q_0 of 1×10^{10} may be expected to generate approximately 40 W heat load at 2 K as a result of RF current flow on the inner surfaces of the cavity. Added to this is approximately 8 W heat entering the cavity niobium body from the input RF power coupler. This dynamic heat load is to be transferred through the niobium to the cavity outer surface in the super-fluid helium liquid bath, then to the super-fluid helium surface where boiling occurs at 1.8 K, without quenching the cavity. In a super-fluid helium test bath there is no problem transferring this heat from the cavity outer surface to the super-fluid helium surface, however, the transport of about 50 W from the cavity outer surface through the helium tank, the feed-pipe and the header-pipe requires careful engineering.

In order to provide sufficient heat transfer from the cavity outer surface to the surface of the liquid in the header, the following cryogenic module design issues are to be addressed:

- The number of feed pipes between the RF cavity helium tank and the two-phase helium stand pipe
- The location of the helium feeds on the helium tank
- The inside diameter of the helium tank relative to the cavity outer diameter, to control the spacing between the cavity convolutions and the cavity helium tank inner wall through which heat must flow
- The diameter of the liquid helium feed pipes from the stand-pipe to the tank
- The diameter of the two-phase helium header pipe

Lower frequencies also reduce the BCS resistance of a cavity, and other laboratories are pursuing designs based on lower frequencies. This work would be complementary to SMTF.

6.4 Control of cavity HOM's and wakefields

For high average power operations, cavity Higher Order Modes (HOMs) may present significant problems due to the perturbative effects of the wakefields persisting from one electron bunch to the next.

Since the SCRF cavities require very smooth boundaries and transitions, HOM damping devices are located at the ends of the cavities, in the beam pipe, and may be in a cold section of the cryomodule or external in a warm section.

Effective HOM damping is required to reduce beam impedance, raise coupled-bunch instability thresholds (Beam Break-Up or BBU), and allow stable operations.

Although the majority of these tests can be meaningfully conducted at high average current facilities, beam tests planned with the SMTF CW beam (1 nC, 10 kHz) would help validate bench measurements of modes and Qs. These results would be useful input to beam stability assessment for various applications at higher currents.

6.4.1 Feedback control of cavity tuning variations

A significant problem for the use of superconducting cavities is the fact that systematic as well as random tuning errors are orders of magnitude larger than the intrinsic bandwidth. An example for the systematic part is by the detuning by the radiation pressure forces or Lorentz force detuning, which may be as large as 360 Hz for a gradient of 20 MV/m. While this is of great concern for pulsed cavities, it can be easily corrected in the CW application where the field is continuous.

More serious are the random tuning deviations. The random tuning perturbations fall in two categories:

- A. Relatively slow perturbations, with periodic intervals in the minute range. Random variations of the helium pressure represent a common cause.
- B. Fast perturbations due to microphonics in the acoustic frequency range, caused by local mechanical stimuli (pumps, turbulence in the helium flow etc). The response is shaped by structural resonances and directional sensitivities of the cavities.

Slow mechanical tuners may be used to eliminate the slow perturbations. Faster feedback systems are required to control the effects of microphonics, which may extend their influence to approximately ± 25 Hz from the RF frequency. To control against such rapid tuning variations, the RF system must provide sufficient generator power to establish the nominal field in the cavity under worst-case conditions of full detuning by microphonics. The RF power requirement P_g can be expressed analytically by:

$$P_g = \frac{P_c}{4\beta} \left\{ (1 + \beta + b)^2 + \left[2 Q \frac{\Delta f}{f} - b \tan(\Psi_B) \right]^2 \right\}$$

where P_c is the cavity wall dissipation, b is the ratio beam power/cavity wall power, Ψ_B is the beam stable phase from crest, β is the cavity coupling factor, and Δf is the cavity detuning (determined by the microphonics spectrum).

In addition, the impact of beam loading from a 1 nC charge at 10 kHz needs to be investigated. Such a bunch would shock-excite the cavities and introduce transient behavior of the RF fields that must be corrected by feedback systems.

Although phase control of 0.1° will be demonstrated elsewhere, the SMTF will provide a test bed for the more demanding requirement of 0.01° stability required for some applications. Thus, the requirement to maintain field in the cavities under the influence of microphonics and beam

loading at modest (~ 10 kHz) bunch rates has strong impact on the cavity RF feedback system and RF power requirements, and thus costs. Techniques to minimize detuning from microphonics may have significant impact in CW SCRF systems design.

6.5 Power couplers

Superconducting RF systems require very little power to generate large accelerating gradients – for example the TESLA cavities may develop 20 MV/m with only 40 W input power under ideal conditions. In order to accommodate for tuning variations as discussed above, however, significantly larger RF drive power is required at the lower external Q, typically 10-15 kW per cavity for $Q_{\text{ext}} \approx 107$.

Power couplers must transport this power from warm waveguide or coaxial supply lines, through intermediate temperatures, thermally isolating sections, vacuum windows, to liquid helium temperature components, and have mechanically adjustable components, while avoiding multipacting and excessive heating.

6.6 Infrastructure requirements for a CW SCRF test facility

The SMTF should provide capability for measurements of CW SCRF cryomodules, with the installation of RF power, cryogenic fluids and transport, and test beams of electrons.

The CW tests will require, for each cavity, a klystron (or IOT) with approximately 15 KW of power to establish 20 MV/m operating field with control margin for dealing with microphonics at the optimum external Q value, estimated to be about 2×10^7 . A high voltage power supply and a small amplifier are needed to supply the klystron. We envision testing cryomodules initially with two cavities per cryomodule.

The cryogenics plant for cavities operating at cw at 20 MV/m with Q of 1×10^{10} would be 60 W/m at 2 K allowing for a safety factor of 1.5. Assuming advances in technology would triple the obtainable Q value, the cw cryomodule refrigerator would be sized for 20 W/m at 1.8 K and about 5 W/m at 4.5 K. However, to ensure capabilities in early design stages, where the higher Q_0 values may not be initially obtained, the cryogenics plant should be designed with capacity of 120 W at 2 K, allowing two cavities to operate with a 50% design margin on cooling capacity. Additional pumping will be provided to allow operation at 1.8 K. Electron beam availability is highly desirable for measurement of cavity performance under transient effects induced by bunches of 1 nC at a repetition rate of approximately 10 kHz. Cavity voltage and phase, and wakefields in the complicated electrodynamic environment of cavities assembled in a cryomodule would be essential in gaining confidence for employing CW SCRF in demanding light-source applications. Bunch lengths of 1 – 10 ps, and transverse emittance of order mm-mrad would be required.

7. $\beta < 1$, Pulsed Power Test Facility and Program for the Proton Driver

The Proton Driver is an 8 GeV proton linac. The last 85% of the linac (1 GeV to 8 GeV) is comprised of $\beta=1$ TESLA modules and will benefit from the ILC program. The synergy between ILC R&D and Proton Driver is further reinforced by the almost complete overlap of an ILC module test bed (Steps 1&2) and what will be needed for many aspects of Proton Driver R&D. The proton driver will need 288 TESLA cavities in 36 cryomodules, as well as 96 low beta elliptical cavities in 12 cryomodules, all at 1.3 GHz. Two main uses are foreseen for the $\beta < 1$ test area: pulsed-mode front end linac for the Proton Driver, and a possible production test facility for RIA cavities and cryomodules.

The initial RF systems will support pulsed mode operation at 325 MHz (one quarter of the ILC's 1300 MHz) and extend the TESLA-style RF fan out from one large Klystron to a large number of cavities. This will support development of a family of "ILC-compatible" $\beta < 1$ superconducting cavities to be developed by members of the SMTF collaboration. These include single, double, and potentially triple spoke SCRF cavity resonators. At higher beta, the Proton Driver will also use cryomodules with 1300 MHz elliptical cavities that will be tested in the 1300 MHz test area.

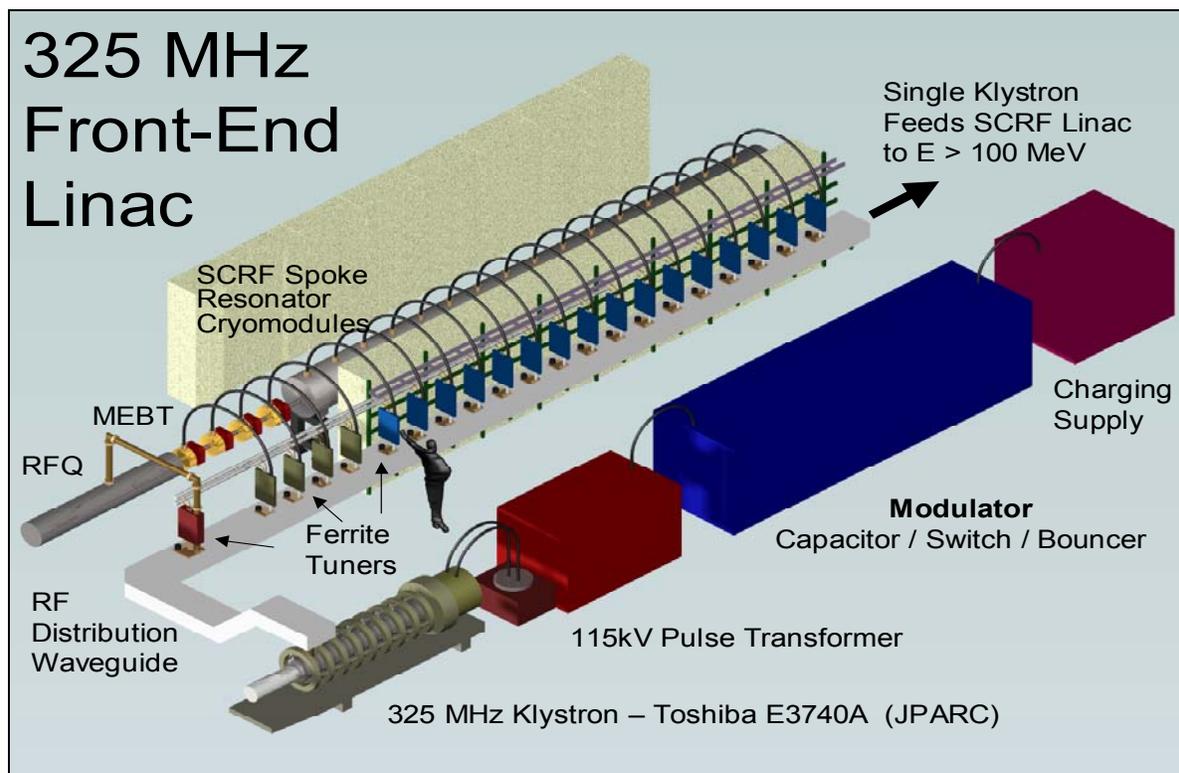


Fig. 3 - Beta <1 test area. The entire front-end linac is driven by a single 325 MHz klystron. Although the single klystron should be capable of driving the entire front end linac up to energy of ~ 100 MeV, the beam energy will be limited to ~ 30 MeV by the length of beam line enclosure available.

Beam Tests. A second phase of operation would add an H- source, and RFQ, and Medium Energy Beam Transport (MEBT) operating from the same pulsed Klystron that operates the SCRF cryomodules. This would provide a beam-based test bed for LLRF and resonance control when driving low-beta ion beams with multiple cavities driven from a single Klystron. Emittance measurements, chopping, and laser stripping experiments will be possible.

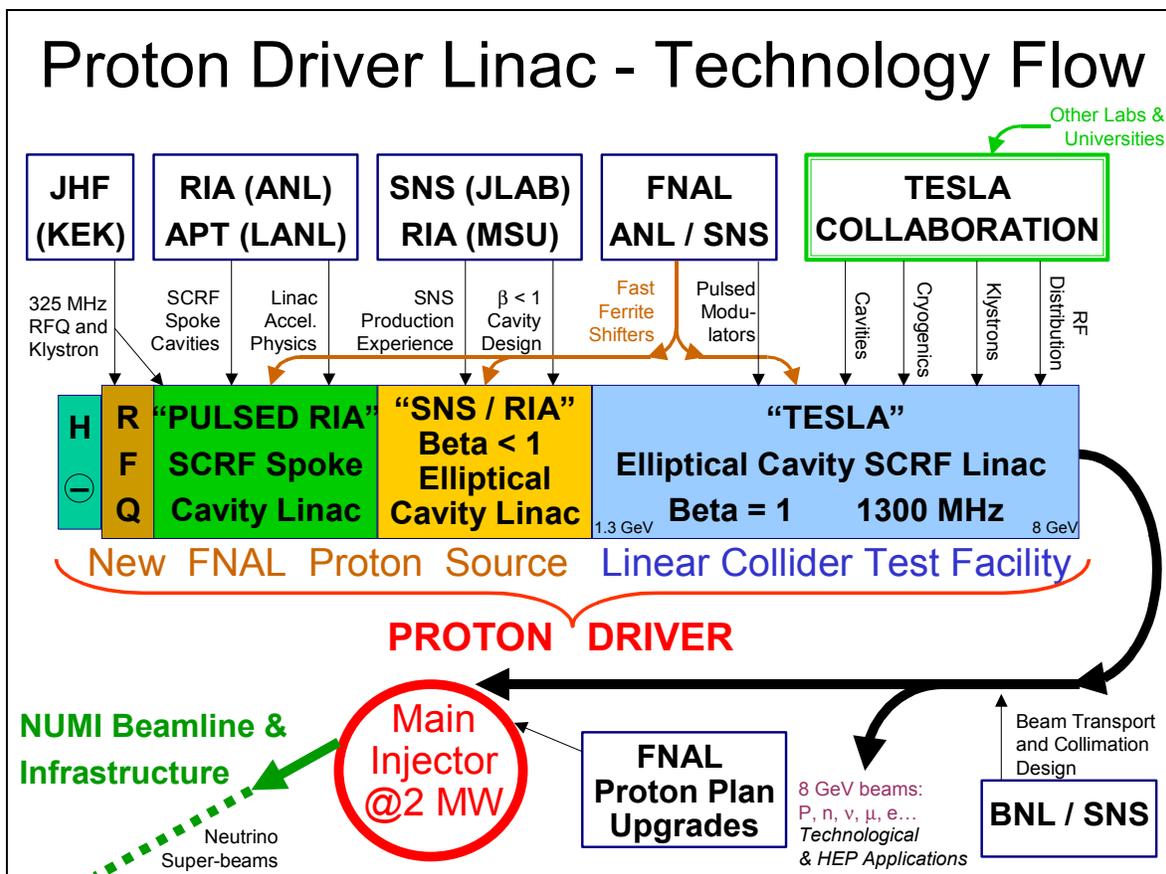


Fig. 4 – Evolution of technology to be tested in SMTF beta<1 linac. The beta<1 test area would support a 325 MHz front end linac patterned on the JHF/JPARC front end, then use SCRF spoke resonators patterned on the RIA cavities. The 1300 MHz test area would support beta<1 elliptical cavities and cryomodules, as well as beta=1 section patterned on the ILC main linac.

A key new technology is the demonstration of fast high-power phase shifters for SCRF resonance control of individual cavities while driving a large number of cavities from a single large Klystron.

7.1 325 MHz Pulsed RF Systems for $\beta < 1$ Test Area

A single 3MW Klystron (the Toshiba E740A currently in production for JPARC) will provide pulsed RF power for the 325 MHz beta<1 linac. See fig.5.

The RF systems would be designed to support both the initial and upgrade beam pulse parameters for the Proton Driver. Initial operation would support beam pulses of (8.3 mA x 3 msec x 2.5 Hz), with an upgrade scenario requiring (25 mA x 1 msec x 10 Hz). Two modulators are currently under construction which can be reconfigured to support either of these

pulse parameters.

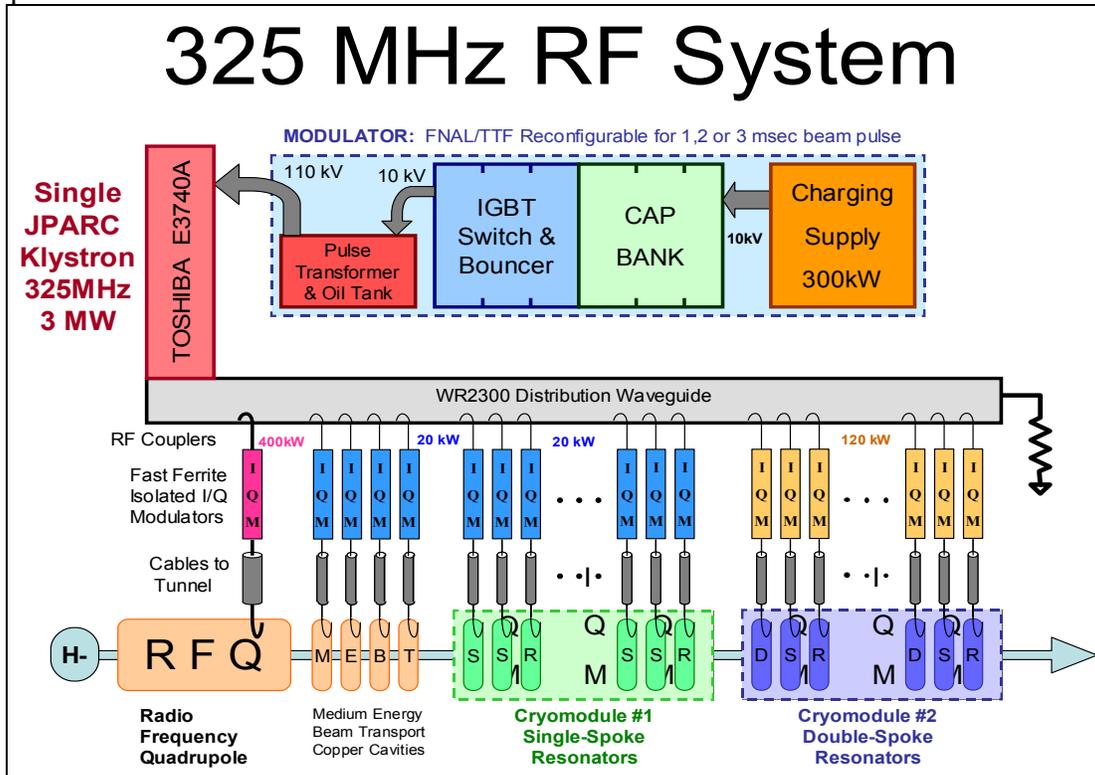


Fig. 5 - The RF distribution system for the 325 MHz beta<1 pulsed SCRF linac. In a TESLA-like scheme, directional couplers are used to split off power for each cavity from a long waveguide running parallel to the linac. Individual resonance control for each cavity is provided by fast tuners using magnetically biased YIG ferrite to provide individual phase and amplitude control for each cavity.

7.2 Program sequence for the 325 MHz Pulsed Linac $\beta < 1$ Test Area

- 1) Modulator construction (already underway).
- 2) Order the 325 MHz Klystron, for delivery in FY05.
- 3) In parallel, construct and begin cold tests of the RF fan out waveguide and directional coupler, to understand cross talk between couplers and related issues.
- 4) Continue development of the fast-ferrite tuner modules, with the goal of having functional prototypes at each required power level by the end of FY05.
- 5) Begin prototyping of 325 MHz cavities in various beta ranges by members of the SMTF collaboration.
- 6) Funds permitting, begin procurement of the H-/RFQ front end.
- 7) Continued development and simulation of LLRF hardware and control algorithms using the ferrite tuners.
- 8) Integrated system test of the front-end linac, 325 MHz Klystron, RF distribution, ferrite tuners and LLRF control.

8. $\beta < 1$, CW Fabrication and Test Facility for RIA

The U.S. Rare Isotope Accelerator Project (RIA) will include the construction of nearly 500 superconducting cavities of as many as 10 different types to accelerate ions over a velocity range $0.02 < \beta < 0.85$. These cavity types will include TEM-class cavities such as those shown in Figure 6. RIA will require facilities to clean and test the individual cavities and also facilities to clean, assemble, and test cavity strings and cryomodules. These facilities need not be at the RIA site, and could in principle be included in SMTF. This said, however, proximity to the RIA site would be useful in simplifying transport and storage issues.

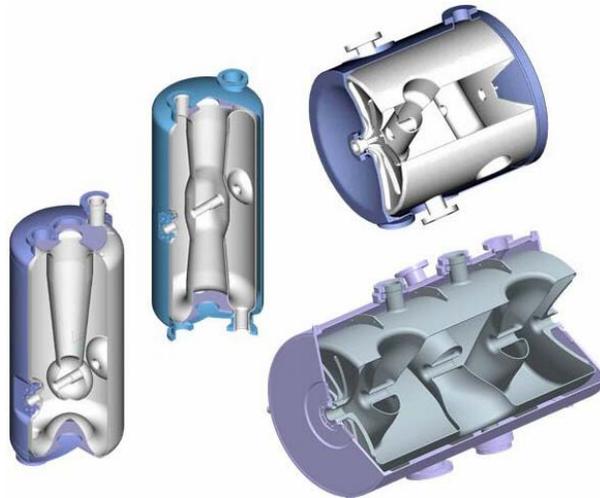


Figure 6. Some TEM superconducting cavities being developed for RIA. From the left, a 115 MHz QWR, a 172 MHz HWR, and two multi-cell 345 MHz spoke-loaded cavities.

Recent development of TEM-class, drift-tube cavities for RIA has achieved new levels of performance by adapting ultra-clean surface preparation techniques originally developed for TESLA velocity-of-light structures to TEM cavities. This convergence of SRF technology of low-velocity structures with that of high-velocity structures opens a possibility of a processing and test facility being able to serve the needs of both communities.

If SMTF can in fact be structured to accommodate such a broad range of cavity types, it would be a unique facility in bringing together under one roof the practitioners of several different types of SRF technology. The opportunity thus afforded for discussion and sharing of technical problems and solutions on a daily, nuts and bolts level amongst groups with different experience and perspective could create a fertile and creative environment for SRF development.

Within the RIA project there will be several classes of task that could possibly be accommodated at SMTF:

- 1) Cleaning and cold-testing of individual cavities, after chemical processing
- 2) Clean assembly of cavities into cavity strings, forming a sealed assembly including RF couplers, beam line valves, and vacuum manifold and valves.
- 3) Assembly of cryomodules incorporating the cavity strings.
- 4) Cold test of assembled cryomodules.

A number of resources will be required to perform the above tasks at SMTF. Some are similar to those required for other groups of users, such as clean areas with provision for ultrasonic cleaning and high pressure rinsing with ultra-pure water and clean storage for cavities and associated components.

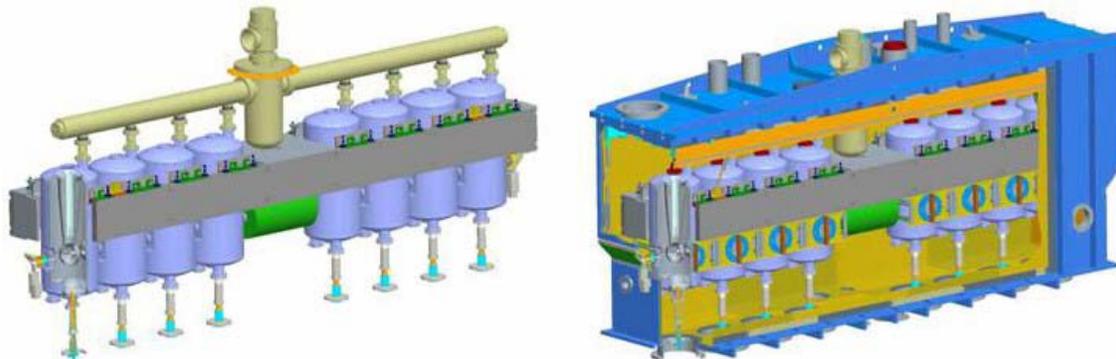


Figure 7: Left: A 5-meter long cavity string assembly of eight QWR cavities. Right: the cavity string in a top-loading, box cryomodule suitable for RIA.

Because RIA uses low-frequency cavities which can operate at higher temperatures than velocity of light structures, 4 K refrigeration at the level of a few hundred watts will be needed for both single-cavity and cryomodule cold-test capability. For single-cavity tests the ability to operate at 2 K is needed, and also possibly for cryomodule tests with 805 MHz elliptical-cell cavities.

CW RF power at the level of a kilowatt will be required at several different frequencies to test the different types of cavities required. A single-cavity test cryostat can be designed to test most if not all of the different cavity types and frequencies, but several RF sources will be required for one of the configurations of the RIA driver being considered, RF power at 57, 115, 172, and 345 MHz would be needed

The facilities required for RIA overlap to some extent with those required for the front end of the proposed FNAL proton driver, which will also require TEM-class cavities operating at 4.2K. The principal difference is that for the proton driver the cavities will be operated in a pulsed mode rather than cw, but the cavity types, cryomodules, couplers, and tuners are likely to be similar in design.

Table 1 shows the resources that will be needed for various tasks during the construction of RIA, which is expected to extend over a two to three year period. Some of these facilities would also be useful for the proton-driver, if schedules do not conflict.

Table 1. SMTF requirements for several RIA tasks

Task	Minimum Floor Space	Ultra-pure water	Cold-test Facilities	Cryogenics	RF Power
Cavity Production	~500 sq ft of clean area	yes	3 single-cavity cryostats	150 watts, at 2 - 4K	1 kW at several frequencies
String Assembly	~1200 sq ft of clean area	yes	-	-	-
Cryomodule Assembly	~1000 sq ft high-bay area	no	-	-	-
Cryomodule Cold-test	~1000 sq ft high-bay area	no	Space for 2 cryomodules	300 watts at 4K	1 - 10 kW at various frequencies

9. M&S Funds and Labor

The details of the funds required for the SMTF will be presented at the time of the proposal.

10. Summary

A group of laboratories and universities, working with US industrial partners, is planning to construct a Superconducting Module & Test Facility at Fermilab. The facility would be used for testing and validating designs for both pulsed and CW systems. The facility would bring together the expertise in cryogenic accelerators in the US and help form the accelerator team that would help design the main linac for the ILC. The SMTF will also fabricate several complete cryomodels in collaboration with US industry, laboratories and universities. With this expression of interest, we are informing the laboratory of this activity and we are looking for direction on how you would like to receive such a proposal.

Appendix I

11. Electron beam: Fermilab/NICADD photo injector laboratory

11.1 Introduction

Since 1992, Fermilab has been engaged in the production of high-brightness electron beam. In conjunction with the TESLA collaboration, it has constructed and operated an L-band (1.3 GHz) photo injector, a copy of which was installed at the TESLA test facility in DESY Hamburg, for various tests, especially for the proof-of-principle UV SASE free-electron laser experiment. The Fermilab/NICADD photo injector laboratory (FNPL) is used as a test facility for beam dynamics studies associated to high brightness beam and its associated diagnosis, along with application to advanced accelerator physics.

11.2 Facility and existing capabilities

FNPL consists of a 1+1/2 cell L-band RF-gun equipped with a high quantum efficiency Cesium-Telluride photo-cathode allowing the photo-emission of electron bunches with charge up to ~20 nC). The generated bunches are further accelerated, up to 16 MeV, by a downstream superconducting TESLA cavity operating with a nominal accelerating gradient of ~12 MV/m (see Fig.1). Downstream of the cavity the beam line includes a set of quadrupoles and steering dipoles elements for beam focusing and orbit correction, a skew quadrupole channel that allows the generation of flat beam using an incoming angular-momentum dominated beam, and a magnetic bunch compressor chicane which can enhance the bunch peak current up to approximately 2.5 kA. The diagnostics for measuring transverse beam properties consist of electromagnetic beam position monitors, optical transition radiation (or YaG) screens (for measuring beam transverse density) and three emittance measurements station based on the multi-slit mask technique. The bunch length measurement is performed by a streak camera that streaks optical transition radiation pulses emitted by the bunch. An alternative frequency-domain bunch length diagnostics based on Martin-Puplett interferometry of coherent transition radiation is also available. Downstream of the beamline, the beam can be bent in a dispersive section, to measure the beam energy distribution, or transported in a straight ahead user experimental area. The FNPL facility can be operated remotely. So far teams from LBNL, and DESY have used this capability to remotely perform beam physics experiments.

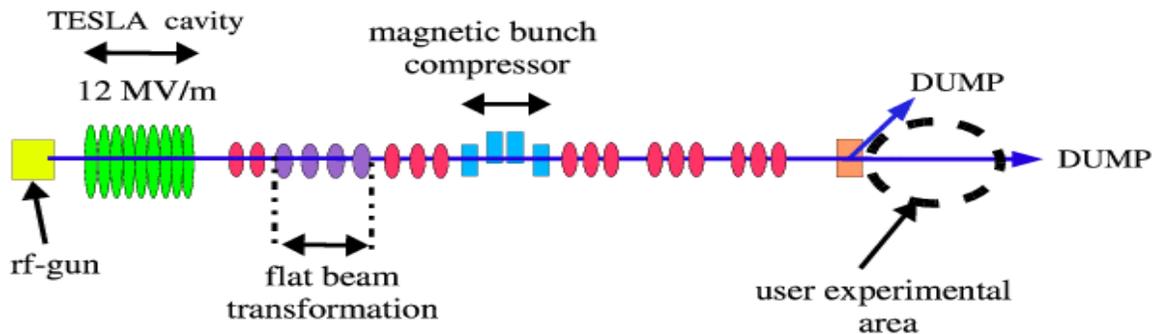


Figure 1: Overview of the FNPL facility in its present configuration.

11.3 Current activities

Several beam dynamics and beam diagnostics activities are being actively pursued at the FNPL photoinjector. Our main current efforts are (1) photoinjector production of flat beam with emittance high emittance ratio (goal > 100), (2) longitudinal beam dynamics studies using a two macro-particle bunch, (3) study of emittance control versus shape of the photo-cathode drive-laser, and (4) emittance evolution of highly charge electron bunches (15 nC). All these experimental studies also involve theoretical and numerical modeling.

Collaborators from NIU and UCLA have been performing experiment on plasma-wakefield acceleration. The experiment consists of injecting a high charge (typically 10 nC) short (typically 3 ps) electron bunch in Argon plasma. The experiment has both concentrated on demonstrating beam plasma deceleration and acceleration. Recently the amplitude of the plasma wake-field has been measured to be 130 MV/m. A refinement of this experiment based on a drive/witness bunch set-up has been commissioned by splitting the cathode drive-laser pulse into two pulses whose transverse size and charge can be independently controlled.

Recently our UCLA collaborators have installed an experiment devoted to realize an electron source based on the so-called plasma-density transition. The experiment is now in its commissioning phase.

A team from the University of Rochester has developed a laser functioning on the TM_{01}^* mode, a mode with a longitudinal electric field component. The laser is now ready and we plan, after the foreseen energy upgrade of FNPL (see next section), to “couple” the laser and electron beams with an open iris structure. At energies above 40 MeV, we will be able to observed laser-based acceleration.

11.4 Upgrade Plans

The TESLA collaboration has recently offered to provide a second TESLA cavity that has been tested to achieve accelerating gradient up to approximately 35 MV/m. We plan to install this second cavity downstream of the first one to boost the beam energy to approximately 45 MeV. Such an energy increase (by a factor ~ 3 compared to the present setup) will considerably reduce the impact of space-charge forces on the beam dynamics and thereby resulting in a better control of transverse envelope and emittance. The FNPL upgrade will also allow the support of various “user experiment” like, for instance, the laser acceleration experiment (using the laser developed by University of Rochester).

In the process of this beamline extension we also configure the beam line to allocate room for two 3.9 GHz superconducting cavities being developed at FNAL: a deflecting and an accelerating mode cavity. The deflecting mode cavity was developed in the context of the Kaon separation out of the secondary beam produced at the main injector at FNAL (so-called CKM experiment). It has also applications in the LUX proposal at LBNL to generate ultra-short X-ray pulses. The deflecting mode cavity was developed to linearize the longitudinal phase space and thereby enhance the peak current of accelerator working on the 1.3 Ghz frequency. Such a “linearizer” has applications in the context of light source (TESLA VUV/X-ray FELs, LUX project at LBNL, etc...) and also linear collider (TESLA post damping ring bunch

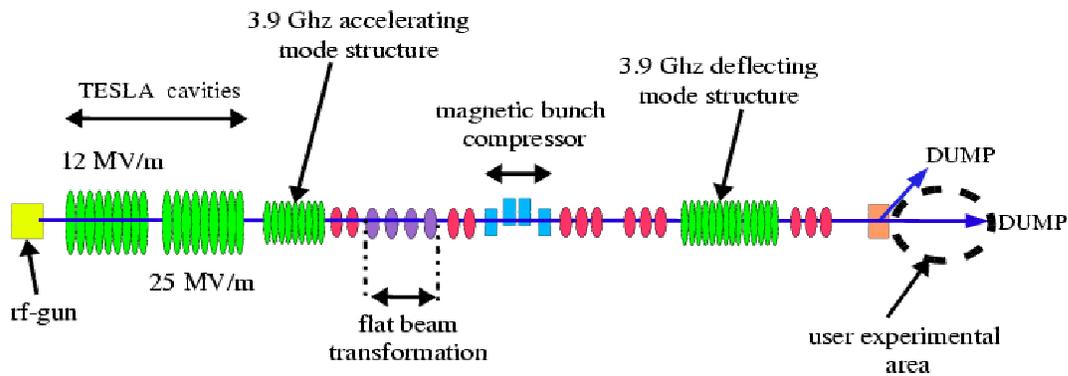


Figure 2: Overview of the upgraded FNPL facility. The facility will incorporate two TESLA cavities, one accelerating and one dipole mode 3.9 Ghz cavities.

compressor). At FNPL the use of these two cavities simultaneously will provide a direct measurement and optimization tool of the longitudinal phase space linearization concept. The deflecting cavity alone also provides a unique diagnostics that should allow the measurement of beam parameters within the bunch (so-called slice parameters) and provide a refinement in understanding the beam dynamics of space-charge-dominated electron beams. A schematic of the proposed FNPL upgrade is shown in Figure 2.

11.5 FNPL upgrade as an e- injector for SMTF

In the context of SMTF, the upgraded version of FNPL would provide an ideal injector that could, at a later stage, be transplanted on the SMTF site. A configuration consisting of an RF gun followed by the two TESLA cavities, as planned to be operated at FNPL, would provide a transverse emittance-compensated beam. According to preliminary numerical studies, such a beam could then be subsequently accelerated by a TESLA accelerating module operated at any accelerating gradient without significantly impacting the transverse emittance (see example in Figure 3). Such a feature means that an injector consisting of an rf-gun with two TESLA cavities only (in the present case operated at 12.5 and 25 MV/m average accelerating gradient) would be an independent entity that could provide controllable beam parameters to be injected in SMTF. The current FNPL facility (one RF-gun followed by one TESLA cavity) does not provide such a capability: the beam is still strongly emittance-dominated: even over a short drift the beam parameters tend to degrade. Therefore FNPL upgrade, while enabling the extension of the current advanced accelerator physics program, could also be viewed as the first phase of SMTF. Parametric studies and subsequent optimization of the system should allow the production of high quality beam with the nominal linear collider charge such a beam could then be injected. The FNPL upgrade will also provide operational experience and training for future scientist working at SMTF. We anticipate the upgrade of FNPL (to be ready for SMTF) to include: the installation of the TESLA cavity offered by DESY, an upgrade of the photocathode drive-laser (to improve the reliability of the facility) and at a later stage the installation of the two 3.9 GHz cavities. In parallel we advise the development and construction of a new symmetric RF-gun cavity such as the one in operation at the TTF-2 FEL facility.

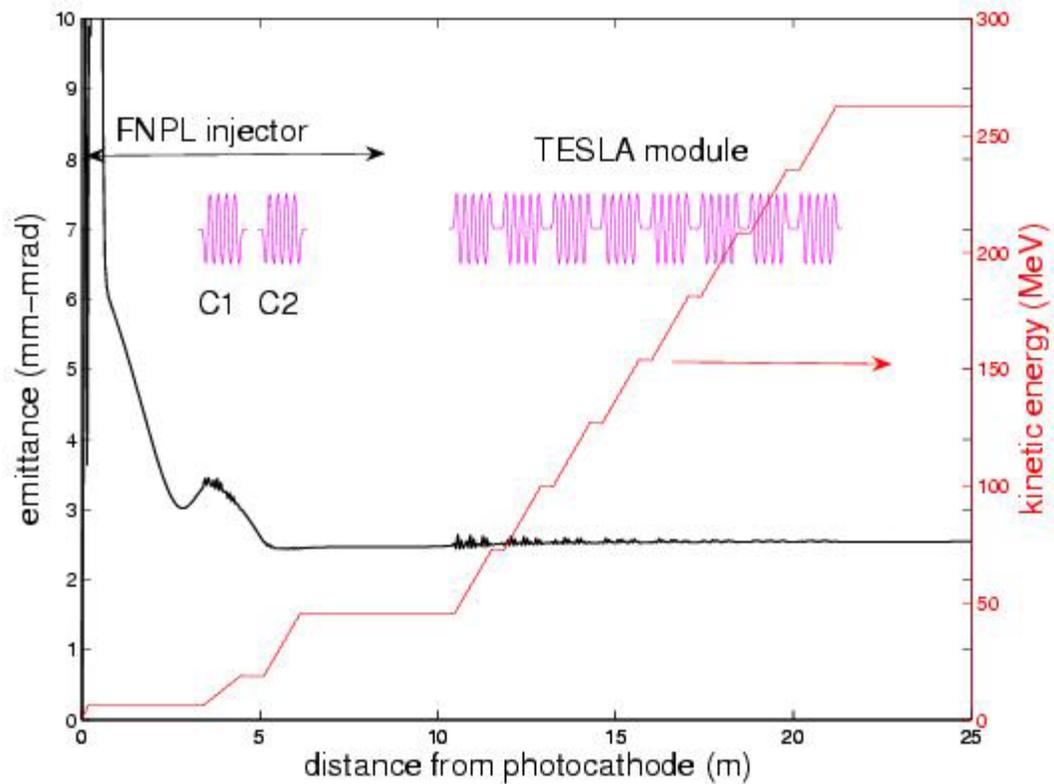


Figure 3: Example of transverse emittance (black) and kinetic energy (red) evolution for a 3.2 nC bunch (TESLA nominal charge). C1 and C2 are the two TESLA cavities to be operated in the FNPL upgrade (here operated at 12.5 and 25 MV/m average accelerating gradient). The upgraded FNPL injector extend from $z=0$ to $z=8$ m. The beam is then injected in a TESLA accelerating module. The magenta curves stands for the longitudinal fields, i.e. the location of the TESLA cavities.

Appendix II

For more information on Cryogenic for SMTF at Fermilab please see URL. This file is not attached due to its size.

<http://ilc-dms.fnal.gov:1352/Members/mishra/cryogenics.pdf>

Appendix III

For more information on cavity and cryomodule fabrication and testing and supporting infrastructure please see URL. This file is not attached due to its size.

http://ilc-dms.fnal.gov:1352/Members/mishra/Cavity_fabrication.pdf