

ADDENDUM
to the
Memorandum of Understanding
between
US Universities & Accelerator Laboratories
and
Indian Universities & Accelerator Laboratories
concerning
Collaboration on R&D for Accelerator Physics and High Energy Physics Projects

Addendum I: "Fermilab, RRCAT, BARC, IUAC and VECC Collaboration
on ILC Main Linac SRF Accelerator Technology R&D"

October 2, 2007

1. Introduction

The work detailed in this document falls within the scope of the Memorandum of Understanding (MOU) between US and Indian Institutions dated January 9, 2006. It addresses in some detail the four key areas of collaboration mentioned in the main MoU. These are (i) Accelerator for the International Linear Collider (ILC), (ii) Superconducting Radio Frequency (SRF) Acceleration Science and Technology, including setting up test facilities and a high current proton driver, (iii) General Accelerator Science and Technologies, including conventional and free electron lasers and (iv) Superconducting Materials R&D for SRF acceleration related work. All terms and conditions under which the work will be carried out are found within the main MOU.

This Addendum to the MOU outlines the collaborative accelerator technology R&D that Fermilab, Raja Ramanna Center of Advanced Technologies (RRCAT), Bhabha Atomic Research Center (BARC), Variable Energy Cyclotron Center (VECC) and Inter University Accelerator Center (IUAC) (referred as the Indian Institutions in this document) plan to carry out for the development of SRF cavities and cryomodules for the ILC, high intensity proton accelerator, and any other accelerator using similar SRF

technology. It is our understanding that Stanford Linear Accelerator Center (SLAC) will be developing Radio Frequency Modulator collaboration MOU with RRCAT and BARC. RRCAT, BARC and IUAC had applied, and were accepted as members of the TESLA Technology Collaboration (TTC), at the April 07 meeting at Fermilab.

2. Background

Fermilab and Indian Institutions have been collaborating on high energy physics experiments since 1985, first on the fixed target experiment E706 and then on the D0 collider experiment. The visiting scientists have made valuable contributions to the development and commissioning of the detectors, data taking and analysis, and publication of physics results. A few dozen students have received Ph.D. degrees under the Indian Institutions-Fermilab collaboration. This collaboration has been flourishing with continued participation of many scientists on D0 and the collaboration of University of Delhi scientists on ILC accelerator physics.

During the last decade or so the future high energy physics activities of Indian Institutions have focused on the LHC at CERN. Indian scientists have made several valuable contributions to both the LHC accelerator and CMS and ALICE detectors. The Indian contribution to the LHC accelerator includes Super-Conducting Corrector Magnets, LHC Magnet Stand with precision alignment, LHC Protection System, Vacuum System, Cryogenic System, Software Development, including Grid Computing, Support/Alignment and Magnetic tests and Measurements. These contributions have earned India the status of CERN "Observer State".

The International Linear Collider is a proposed future international particle accelerator and the highest priority recommendation of the International Committee on Future Accelerators (ICFA). The ILC would create high-energy particle collisions between electrons and positrons. The ILC would provide a tool for scientists to address many of the most compelling questions of the 21st century including questions about dark matter, dark energy, extra dimensions and the fundamental nature of matter, energy, space and time. Fermilab is the site proposed by DOE for a U.S. bid to host the ILC.

Fermilab and SLAC have been exploring the possibility of enhancing and expanding the existing collaboration with Indian Institutions to include accelerator R&D. US and Indian Institutions have held several meetings to discuss the areas of common interest in particle accelerator technologies. The last meeting in this series was held in India during the visit of the directors of Fermilab, SLAC, DESY and ILC-GDE to India in March 2006 followed by visit from DOE. Discussions with the Secretaries of the Department of Atomic Energy and Department of Science and Technology and the Directors of RRCAT, BARC, IUAC and VECC have motivated the development of this Addendum to the MOU.

The diagram illustrates the RF power system architecture, showing the flow from the front-end electronics through various components to the cryomodules.

- Cavity:** TESLA A shape, 31.5MV/m @ Q0=1E10, 135MV/m @ Q0=0.9E10 qualified; Blade tuner, Piezo tuner, TTF3 coupler
- Support post**
- O-magnet:** X&Y correctors - BPMs in center of cryomodule, O magnet in every 3 cryomodules
- Cryomodule connector**
- Cryomodule:** 3 cryomodules / RF unit, 8 cavities / cryomodule (total 24 cavities / RF unit)
- Linear RF Power distribution with circulator & stub or EH tuner for every cavity input**
- 20W Line**
- High power Att.**
- Bouncer Modulator**
- Front end electronics**
- 10MW Multi-beam Klystron socket assembly**
- 1:12 Pulse Trans**
- RF power system should accommodate 30MV/m operation.**

The building block of each ILC main linac is called a RF-Unit. The ILC main linac consists of about 560 RF-Units. The “baseline ILC” RF unit specifications can be found on the GDE website <http://www.linearcollider.org/>. An RF-Unit is also shown in Figure 1. Each RF-Unit is fed by one power system, which consists of a bounce style modulator that converts AC-power into high voltage, and high power to drive a 10 MW klystron that delivers RF power to the superconducting accelerating units called cavities, via room temperature waveguides and couplers. Each RF-Unit is composed of three cryomodules. Currently each cryomodule contains either nine (without quadrupole) or eight (with quadrupole) 9-cell SRF cavities, a helium vessel surrounding the cavity, input power couplers for each cavity, higher order mode couplers (HOM) for each cavity, slow and fast tuning systems for each cavity, and an overall alignment system. One of the three cryomodules contains a superconducting quadrupole, dipole, and beam position monitor for beam focusing, tuning, and diagnostics.

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4. Scope of Work in CY07-09

We propose to start with relatively smaller projects, utilizing current Indian technical strength and progressively develop more complex hardware. It is expected that Indian physicists and engineers will visit Fermilab to develop technical expertise.

- 1) Develop cavity fabrication tooling
- 2) Fabrication of 1-Cell TESLA shape cavity
- 3) Fabrication of 9-Cell ILC cavity (TESLA shape)
- 4) Fabrication of an ILC tuner
- 5) Collaboration on the design of the ILC cavity and cryomodule
- 6) Design and construction of cryogenic components for ILCTA at Fermilab

1) The scope of work begins with fabrication of cavity tooling sets for Indian Institutions and Fermilab's use. RRCAT will evaluate the designs of the tooling and prepare a bill of materials required at no cost from Fermilab. Indian Institutions will build three (3) sets of tooling, of which two will be delivered to Fermilab for US vendor development.

2 & 3) Indian Institutions will fabricate three single-cell 1.3 GHz solid niobium "TESLA design" accelerating cavities and then move towards the fabrication of three 9-cell cavities. The eventual goal of this R&D is for Indian Institutions to be able to fabricate an 8 (or 9) 9-cell cavity cryomodule that may be shipped to Fermilab for testing with beam at the ILCTA. We envision this work to develop in smaller steps as both Indian Institutions and Fermilab develop infrastructure. We are proposing to start with single-cell cavities, followed by 9-cell cavities, to put the fabrication, processing and testing infrastructure in place. It is expected that Fermilab will do the initial QC on the components and will share the associated expertise with the Indian Institutions.

The material (RRR-300 niobium as specified in the cavity fabrication document) for three single cell cavities, as well as one 9-cell cavity will be provided to the Indian Institutions by Fermilab. All drawings necessary for fabricating the single cell and multi-cell cavity designs will be made available on the password protected ILC-EDMS website by Fermilab, as it is available to any TTC member. After a single cell cavity is fabricated at an Indian institution, it will be shipped to Fermilab for processing, testing and qualification. Fermilab, in collaboration with other US laboratories, will initially process all cavities from India. Fermilab will work with the Indian Institutions in developing technical details of SRF infrastructure.

The Indian Institutions may also wish to develop a 9-cell cavity processing and vertical test facility to qualify subsequent cavities. Fermilab will collaborate on the design and

development of such a facility, including procurement of a 1.3 GHz RF Power source needed for the testing. Fermilab will make available on the password protected ILC-EDMS website drawings of the Fermilab processing and vertical test facility to the Indian Institutions. The Indian Institutions could add thermometry to their design to allow further diagnostics. Once the Indian Institution vertical test facility is developed, then comparisons of test results will be exchanged on the same cavities to permit calibrations of the facility.

4) The present ILC Baseline Design of the cavity tuner is the INFN Co-axial blade tuner. BARC will develop the infrastructure for fabrication of such a tuner. Fermilab, INFN and other collaborating institutions will help in warm and liquid nitrogen tests of these tuners in India. The final tuners will be installed on a cavity in US and will be tested with high power in the Horizontal Test Stand (HTS) at Fermilab. An individual tuner is needed for each cavity. Once a prototype is successfully developed, BARC will build 24 tuners, plus spares for an RF Unit. The tuner and cavity development is expected to take place in parallel.

5) The ILC collaboration is working on a new design of an ILC cryomodule. This work is being coordinated by Fermilab and requires extensive engineering and drafting. The Center for Design and Manufacturing, BARC and RRCAT can significantly contribute to this design effort. We propose to have a few design and/or drafting engineers stationed at Fermilab in the initial phase of this collaboration but most of the work would be carried out by the colleagues back at BARC and RRCAT. The Indian Institutions either already have or in process of acquiring the base software needed for this work. Fermilab will collaborate with BARC and RRCAT in the installation of ILC and TESLA Technology Collaboration EDMS and drafting software needed for this work.

6) Indian Institutions have considerable expertise in the design and construction of the cryogenic components needed for the ILC cryomodule and cavity and cryomodule testing. Examples include feed and end cans cryo-vessel for the Vertical Test Stand (VTS), cryogenic distribution pipes, cryomodule vacuum pipe etc. Fermilab has acquired these components in the open international market. Similar components are in use at the Indian Institutions. BARC, RRCAT, IUAC and VECC will work with Fermilab on the design of these cryogenic components.

5. Schedule and Review

The detailed schedule of this work will be finalized in a meeting between Dr. Shekhar Mishra, Fermilab and Dr. Vinod C. Sahni, RRCAT by the end of October 07. The schedule and progress on both sides will be jointly reviewed every six months. Both

groups agree to report and evaluate progress at individual laboratory reviews by their respective funding agencies. An initial schedule for the scope of work outlined in section 4 will be added as a supplement to this Addendum to the MOU before it is signed.

6. Funding

Fermilab and the Indian Institutions agree to establish an ILC-India account at Fermilab. This account can only be used by Fermilab and Indian Institutions for ILC R&D. Fermilab will deposit seed funds in this account to start this collaborative work. All materials and technical components that will return to Fermilab and are not available in India will be provided and paid by Fermilab ILC program funds. All labor, materials and components available in India will be supplied by the Indian Institute. For each hardware component that will be used in the ILC R&D at Fermilab or ILCTA, Fermilab will deposit 50% of its US cost in the ILC-India account at Fermilab. The amount will be decided by mutual agreement. Any hardware needed for use and development of the Indian laboratory infrastructure for the work to be performed under this MOU will be paid by India either through direct funds or through the ILC-India account established at Fermilab, if the component is acquired from a US Vendor. The ILC-India account will support the local expense of all Indian scientists and engineers visiting Fermilab for work and meetings under this MOU to work on the SRF accelerator program. Fermilab will not charge for any technical development in the design of the SRF infrastructure to the Indian Institutions developing SRF infrastructures. Indian Institutions will provide visiting US scientists and engineers with local accommodation when possible at the laboratory site. The cost of travel of Fermilab staff to India will be covered by Fermilab ILC program funds.

7 **Management and Approval:**

The work under this MOU will be jointly managed by Dr. Shekhar Mishra, Fermilab and Dr. Vinod C. Sahni, India. They represent the institutions in the respective countries and serve as a single point of contact.

The following concur on the terms of this Memorandum of Understanding:



Dr Vinod C. Sahni,
Director, RRCAT

Oct 2, 2007

Date



Dr. Piermaria Oddone
Director, FNAL

10/2/07

Date



Dr. Shekhar Mishra
Deputy ILC Program Director, FNAL

10/2/07

Date

