

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 VIII: "Fermilab and Indian Accelerator Laboratories
Collaboration on Accelerator Physics issues for High Intensity Proton
Accelerator"**

Aug 22, 2011

1. Authority and Limitations

Pursuant to the Memorandum of Understanding ("MOU") between the U.S. Universities & Accelerator Laboratories and Indian Universities & Accelerator Laboratories dated January 9, 2006, and its extension dated Aug 22, 2011 Fermilab and Indian Accelerator Laboratories (the "Parties") intend to undertake the work described in this Addendum VIII. The Parties acknowledge that their intended work shall be consistent with the terms and conditions of the MOU, the terms and conditions of their respective contracts and programs, and subject to the availability of appropriated funds as provided to them. The Parties further acknowledge and understand that their agreement with and signature to Addendum VIII does not create a legal, contractual obligation for either Party nor may form the basis of a claim for reliance thereon. The Parties agree to comport their activities under Addendum VIII in conformance with all applicable U.S. and Indian laws and regulations, including those related to export control.

2. Introduction

The work detailed in this document falls within the scope of the MOU cited above. It addresses in some detail the one key area of collaboration mentioned in the main MOU, which is Superconducting Radio Frequency (SRF) Acceleration Science and Technology,

including setting up test facilities and a high current proton driver. 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 work between Indian Institutions and the Fermilab, in the accelerator physics design of two Indian proton accelerators, one each at BARC and RRCAT and the Fermilab Project-X. The BARC accelerator is a high intensity continuous wave superconducting proton linac for the Indian Nuclear Energy Applications (INEA). The RRCAT accelerator complex will have a high intensity pulsed superconducting proton linac injected into an accumulator ring for the Indian Spallation Neutron Source (ISNS).

3. Background

Indian Institutions and Fermilab have been collaborating on high energy physics experiments and on the accelerator research and development under Addendums (I, II, III and IV) to the MOU. Addendums MOU V to VII are at the final stage of approval in the Department of Atomic Energy, India (DAE). Indian Institutions have made significant progress on the work that was outlined in these Addendums. The work outlined in this addendum is extension of the work in the area of Accelerator Physics and design issues connected to the High Intensity Proton Accelerators.

4. Work to be performed

Indian Institutions are interested in physics issues related to two 1-2 GeV high intensity proton linacs that DAE plans to construct at BARC and RRCAT. The high intensity accelerator at BARC (INEA) will be a CW linac built for nuclear energy applications and that at RRCAT (ISNS) will be a pulsed machine mainly used for material science/condensed matter studies. BARC is already building a 20 MeV, 30 mA, front-end, comprising a 3 MeV RFQ and a 20 MeV DTL. There is an overlap with the Fermilab Project-X. Also, BARC is now evaluating the superconducting option from 3 MeV to 200 MeV in the second stage of accelerator development for the Indian Nuclear Energy Programme. Another area of overlapping interest with Project-X is the design of the front end for a pulsed H⁻ ion injector linac for the spallation neutron source.

Given the commonality between Indian Institutions projects and Project-X at Fermilab, there are significant opportunities for useful collaborations in various areas that may add value to BARC, RRCAT and Fermilab programmes.

Indian Institutes and Fermilab will work on linac designs for the three accelerators with as much overlap as possible. There would be interactions between FNAL and Indian institutions in the form of regular meetings and personal exchanges, plus design

reviews throughout the design, construction and commissioning of these three accelerators, INEA, ISNS and Project-X. Collaborating institutions may request participation of scientists and engineers in the formal design reviews.

5. Scope of Work

It is expected that the scope of work described by this Addendum will be executed over a three to four year time period. The scheduled start and end of the various activities may be staggered to meet the overall plan and available resources of the collaboration. Indian Institutions in collaboration with Fermilab will establish a Team Centre Data and Document Management system for seamless sharing of the design information. In India such a centre would be established and managed by BARC.

The following physics issues, related to extending the linac to 1 GeV, are of Indian interest for potential collaborations with Fermilab.

Collaboration of Superconducting linac

- (i) For the way forward from 20 MeV to around 200 MeV, superconducting spoke resonators (325 MHz) will be evaluated. Detailed electromagnetic design of these resonators, and optimization of the design, using suitable electromagnetic codes such as Microwave Studio, HFSS, needs to be performed. The Indian Institutions already have experience in using these codes for the design of the RFQ and DTL, but Indian Institutions have no experience specific to spoke resonators.
- (ii) At higher energy, elliptic superconducting cavities are preferred. Detailed design of these multi-cell cavities need to be performed, including design decisions in the transition energy to higher frequencies (650 MHz) of the cavities, taking into account accelerating gradient, beam aperture, shunt impedance, etc.
- (iii) Design of matching beam-transport sections between the various accelerating sections is very important in proton linacs, since mismatches would lead to beam halos that can in turn lead to severe beam loss. Therefore, careful design of these beam-transport sections is essential, in particular ensuring matching of the phase-advance per unit length, and other parameters. The issue of emittance growth, particularly due to space charge will be studied and optimization studies to minimize the emittance growth and beam losses will be done.
- (iv) Detailed, end-to-end beam dynamics simulations are needed, using codes such as Lorentz-3D, TRACK and IMPACT package (IMPACT, FIX3D, THETA), to confirm efficient transmission of the beam through the linac system, and also to simulate

formation of beam halos. These simulations need also to take into account mechanisms for mitigating or removing beam halos, such as scrapers, etc.

- (v) A theoretical and simulation study of beam halos, not necessarily linked to the particular linac design, would be useful in understanding the growth mechanisms of these halos, and in devising methods of addressing this problem. Typical methods used include multi-particle PIC simulations, and semi-analytical Maxwell-Vlasov equation approaches. Any understanding developed even on ideal systems, would be very useful in the linac design to avoid this problem.
- (vi) Monte Carlo simulation studies using the codes MARS14, MCNP5 & MCNPX are required to obtain radiation shielding requirement for beam losses occurring in the machine at various stages of accelerating structures of proton linac like beam chopper, beam dumps and beam scraper etc. The code calculation will help in estimating the prompt and residual radiation in and around the proton linac for realistic assumptions and geometry under normal and accidental operating conditions. It will help in the shield design and analysis to meet regulatory requirements for external shielding, hands on maintenance and ground water activation.
- (vii) In superconducting cavities, Higher Order Modes (HOMs) can couple with beam modes to produce instabilities that destroy the beam. Some analytic and simulation studies have been performed on understanding the effect of the geometry of superconducting cavities, on HOMs, and in devising shapes that will minimize these HOMs. Detailed investigations, for different cavity shapes, such as spoke resonators, and for multi-cell structures, would help developing cavities that have reduced HOMs, and are therefore more efficient.
- (viii) There are several computer codes that are needed for electromagnetic design and beam dynamics simulation studies. For example, SLANS is needed for electromagnetic design simulation and TOUTATIS, TraceWin, GenLinWin, PARTRAN, MULTIPART for beam dynamics studies. Since these computer codes are not available in India, Fermilab would help in procuring these computer codes, which are essential tools for the design study. Fermilab will make available relevant simulation and design software resources, including commercially licensed software to Indian collaborators while they are visiting Fermilab. In instances where essential codes are not available in India, Fermilab would provide assistance and support to facilitate their acquisition by collaborating Indian institutions in conformity with existing laws and international agreements.

Collaboration on the accelerator physics of other accelerator components:

Fermilab has design expertise in all area of proton accelerators, but was not involved in the design of the Spallation Neutron Source and its accumulator. Brookhaven National Laboratory and Oak Ridge National Laboratories are members of Project-X Collaboration. Fermilab would help facilitate interactions between Indian institutions and US laboratories working on SNS.

- (ix) Design of beam choppers is required to generate a desired pulse structure in the H- ion beam for its injection into the accumulator ring of the proposed Indian Spallation Neutron Source. Design studies of such beam choppers will be carried out.
- (x) Design of 1 GeV Accumulator Ring will be carried out for the proposed Indian Spallation Neutron Source. The injection and extraction scheme, physics design of the magnetic lattice, the collimator section etc. to minimize the beam loss in the Accumulator Ring will be studied.
- (xi) Studies related to laser based striping of H- ion beam for effective injection of linac beam into accumulator ring will be carried out.

Development of software:

- (xii) Indian Institutions & Fermilab would like to jointly develop software both for end to end, envelope-oriented simulations and particle tracking. Special attention should be put on the development of open software that could be used for machine control, diagnostics and commissioning. Code should also include simulation of time-dependent loss mechanisms in pulsed machines (e.g. losses at beginning/end of bunch train / rf pulse)

6. Schedule and Review

The detailed scope and schedule of work described in this Addendum to the MOU would be described in an accelerator physics project document. The priorities and schedule of the work will be prepared by the IIFC Accelerator Physics Point of Contacts and approved by the Collaboration Coordinators. The schedule and progress will be jointly reviewed every six months and tasks may be added, deleted, or modified by

mutual agreement. Both groups agree to report and evaluate progress at individual laboratory reviews by their respective funding agencies.

7. Funding

Consistent with General Provision 2.3 of the MOU, each Party shall be responsible for funding its participation activities. All participation activities and related procurements are subject to the availability of appropriated funds, personnel, and resources.

Fermilab and the Indian Institutions agree to establish an India Institutions and Fermilab Collaboration Account (IIFCA) at Fermilab. This account will be funded by Fermilab through a credit of fifty percent of the U.S. cost for each hardware component provided by Indian Institutions for use at Fermilab during the R&D phase. If the U.S. cost is unavailable, the amount of Fermilab credit for each component will be decided by mutual agreement of the Parties. The IIFCA would be managed, Project-X, International Collaboration Coordinator for the Indian Institutions and Fermilab Collaboration. Such expenses may include: 1) supporting the local expenses of all Indian scientists and engineers visiting Fermilab for work and meetings under this Addendum and 2) procuring materials and technical components not available in India that will be returned to Fermilab. IIFCA funds may not be used to purchase hardware components from non-US vendors, if it can be supplied by a US vendor. Time to time Fermilab would also send experts to Indian laboratories for collaborative work. This fund will be used to support their travel expenses.

All labour, materials and components available in India will be supplied by the Indian Institutions. Any hardware needed for use and development of the Indian laboratory infrastructure for the work to be performed under this Addendum will be paid by Indian Institutions. Fermilab will not charge for any technical assistance provided for the design of SRF infrastructure at Indian Institutions. Indian Institutions will provide visiting US scientists and engineers with local accommodations when possible at the laboratory site. The cost of travel for Fermilab staff to India will be covered by Fermilab funds. The Parties mutually agree that costs associated with shipping materials and components shall be borne by the shipping Party and that any customs or duties applied to the items so shipped shall be borne by the receiving party.

8. Proposed mechanism for IPR sharing

The Intellectual Property Rights (IPR) sharing has already been well defined and described in detail between the Institutes involved in two documents: (1) Memorandum of Understanding between U.S. Universities and Accelerator Laboratories and Indian Universities and Accelerator Laboratories concerning collaboration on R&D for various

Accelerator Physics and High Energy Physics Projects and (2) Tesla Technology Collaboration Memorandum of Understanding. (http://tesla-new.desy.de/sites/site_tesla/content/e19/e24/infoboxContent581/MoU.pdf). It is to be noted that for all collaborative work under this MOU the proposed mechanism for IPR sharing will be exactly as envisaged in these two documents.

9. Project Management, Responsibilities and Approval:

The Project management, responsibilities and approval authorities are described in detailed in the document "Management Plan for Fermilab Participation in the Indian Institutions and Fermilab Collaboration"

(http://iifc.fnal.gov/IIFC_FNAL%20Management%20Plan-Final-102210.pdf)

The following concur on the terms of this Memorandum of Understanding Addendum.



Dr. R. K. Sinha,
Director, BARC

22-08-2011

Date



Dr. Piermaria Oddone
Director, FNAL

8/22/2011

Date



Dr. P.D. Gupta
Director, RRCAT

Date

