Indian Participation in LHC and a Glimpse of the Road Ahead

V. C. Sahni
BARC, MUMBAI & RRCAT, INDORE, INDIA
Outline of the talk

- Indian Linkage with CERN & Involvement in LHC
  - Early Ties between DAE labs & CERN
  - Formal Evolution of DAE-CERN LHC Collaboration
  - Details of Contributions to LHC as Defined in Addenda
  - Contributions to Detectors: CMS & ALICE
  - Participation in LHC Grid Computing

- Road Beyond the LHC
  - Participation in New CERN Projects: CTF3 & Linac4
  - Benefit to Indian Programs from CERN Collaboration
  - New & Upcoming Collaborations: ILC; Project-X etc.

- Concluding Remarks
How the DAE-CERN collaboration started

- High Energy Physicists from TIFR had been doing experimental work at CERN since the 70s and took part in many studies.
- They also contributed to the L3 detector & used it for HEP research.
- TIFR-EHEP Group joined L3 experiment @LEP
  - Fabricated 1000 brass-tube proportional chambers for end cap HCAL;
  - Made major contributions to CORE software;
  - Important and strong participation in physics analyses for L3
    - Line shape analysis etc.
    - Higgs searches; QCD; b-bbar physics.
- CAT, Indore delivered some accelerator hardware for LEP

A formal agreement was signed in ‘91 between then DG, CERN & Chair of Indian, AEC.
CO-OPERATION AGREEMENT

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

and

THE DEPARTMENT OF ATOMIC ENERGY (DAE)

OF THE GOVERNMENT OF INDIA

concerning

THE FURTHER DEVELOPMENT OF SCIENTIFIC AND TECHNICAL CO-OPERATION IN THE RESEARCH PROJECTS OF CERN

Article 10
Duration

This Agreement shall be in force for a period of five years from the date of its signature and will be automatically renewed for the same period unless six months' notice of termination is given by either party to the other.

Done at Geneva on 28 March 1991 in two copies in the English language.

For the Department of Atomic Energy of the Government of India (DAE)

P.K. Iyengar
Chairman, Atomic Energy Commission

For the European Organization for Nuclear Research (CERN)

C. Rubbia
Director-General
WA93 Experiment at CERN-SPS

- In the 90s Indian High Energy Heavy Ion Team
  - Contributed to the construction of Photon Multiplicity Detector
  - Used it for WA93 experiments (with CERN-SPS)
  - Participated in data analysis and published many papers.
- Collaborating Indian Institutes were:
  - VEC Centre, Calcutta (Now Kolkata); Punjab Univ, Chandigarh; Univ of Rajasthan, Jaipur; Jammu Univ, Jammu.
- Authors on one of the paper were:

All these developments paved the way for Indian AEC’s decision, in 1996, to take part in the construction of LHC and also to join in building CMS & ALICE detectors for doing Physics studies.
PROTOCOL

TO

THE 1991 CO-OPERATION AGREEMENT

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

and

THE DEPARTMENT OF ATOMIC ENERGY (DAE)
OF THE GOVERNMENT OF INDIA

concerning

THE PARTICIPATION IN THE LARGE HADRON COLLIDER PROJECT (LHC)

ARTICLE 11
Safety

1. The personnel of each Party shall comply with the rules for conduct and
   safety in force at the host establishment.

2. Any equipment constructed and used by personnel from either Party
   shall conform to the rules for industrial safety in force at the host
   establishment where it will be installed and operated.

ARTICLE 12
Intellectual property

If either Party wishes to take out patents or otherwise to protect the
inventions, developments, know-how or software resulting from the scope
of this Protocol, it shall first consult with the other Party in order to agree on
the legal regime for the use and exploitation of such intellectual property.

ARTICLE 13
Duration

1. This Protocol shall be in force for a period of ten years from the date of
   its signature, subject to a corresponding renewal of the Agreement. In
   case of non-renewal, the remaining amount in the India Fund will be
   utilised as per Article 3.3 (a). However, every three years the execution
   of the Protocol will be evaluated and the validity of the basic
   assumptions governing the Protocol will be assessed.

2. At least two years before the end of this period, the extension of this
   Protocol will be discussed with the aim of ensuring a continued access of
   Indian scientists to the CERN programme.

The present Protocol shall form an integral part of the Co-operation
Agreement signed on 28 March 1991.

Done at ... , on ... , 29th March, 1996
In two copies in the English language.

For the Department of Atomic Energy (DAE) of the Government of India

R. Chidambaram
Chairman, Atomic Energy Commission and
Secretary, Department of Atomic Energy

For the European Organization for Nuclear Research (CERN)

C. H. Llewellyn Smith
Director-General
Arrangement for participation in the LHC accelerator construction

- Protocol only provided for “in kind” contribution.

- Delivery items jointly identified by DAE-CERN Joint Coordination Committee;
  - value of items assessed @ “European cost”.

- Joint Committee co-chaired by Directors of RRCAT & LHC, (RRCAT being the nodal DAE lab) has been meeting twice a year (once in India & once in CERN) to develop Addenda.

- Protocol adopted a 50% model
  - i.e. Half of “European cost” of each addendum value is taken as “Indian contribution to LHC”;
  - other half credited by CERN to an “Indian Fund”,
    - meant to support Indian scientists @ CERN & for other expenses.

- Like, USA, India is an “Observer State” @ CERN.
Indian Contribution to CERN-LHC

• Indian laboratories have delivered subsystems & expert help for the World’s Biggest Accelerator Large Hadron Collider (LHC) @CERN due to start later this year with p-p collisions of 7 TeV each.
• Overall Indian contribution to LHC accelerator is ~43 MCHF that includes
  – a variety of components and subsystems. Prominent hardware includes
    • 7080 Precision Magnet Positioning Stands jacks,
    • ~1800 SC corrector magnets,
    • 5500 Quench Heater Protection Supplies,
    • 1435 Local Protection Units,
    • 70 Circuit Breakers etc;
  – Skilled manpower support for magnetic tests and measurements and help in commissioning LHC subsystems.
    • ~ 125 man years towards subsystem evaluation & commissioning.
• Many institutions (BARC, RRCAT, VECC, IGCAR, ECIL, ATL, IGTR, BHEL etc.) have contributed.
# MCS & MCDO Magnet major specifications

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<th>MCS</th>
<th>MCD</th>
<th>MCO</th>
<th>Unit</th>
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<td>Nominal field along the X-axis (m)</td>
<td>1970 x² T/m²</td>
<td>1.2 x 10⁶ x⁴ T/m⁴</td>
<td>8200 x³ T/m³</td>
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<td>Overall length with shield</td>
<td>160 mm</td>
<td>110 mm</td>
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<td>Nominal operation current</td>
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<td>Working temperature</td>
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<td>Peak field</td>
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<td>Theoretical quench current at 1.9K / 4.2K</td>
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<td>1250/915</td>
<td>297/195 (MCD I_{nom})</td>
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<td>Material</td>
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<td>Dimensions bare conductor (mm²)</td>
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<td>Filament diameter (μm)</td>
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<td>Twist pitch (mm)</td>
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<td>18 ± 2</td>
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<td>Cu/SC ratio</td>
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<td>Critical current {5T, 4.2K} (A)</td>
<td>≥ 650⊥, ≥ 715</td>
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<td>≥ 100 ⊥, ≥ 110</td>
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4/13/08  APS Meeting, St. Louis
LHC SC Corrector Magnet Fabrication @ RRCAT

Magnet fabrication facility for SC magnets using local automatic coil winding machine

Finished Decapole & Octupole SC corrector magnet assembly

Warm magnet measurement setup

Cryogenic test facility at RRCAT
JACKS for LHC Cryo-magnets

• Precision alignment Jacks were Designed & Developed by a RRCAT team for LHC Cryo-magnets.
  – Each LHC cryo-magnets weighs ~32 Tons
• Mass production done by ATL, Bangalore & IGTR, Indore & supplied under RRCAT’s responsibility
  – 6800 PMPS Jacks + 280 Motorizable & Higher Precision

Test Set-up @ Bangalore to demonstrate setting resolution of 0.02 mm

Indian made PMPS Jacks being installed in LHC
To mark DAE’s contributions, CERN Gifted a Memento to Director, RRCAT on 20/3/07
Indian Participation in Hardware Tests

Man power for magnet tests & hardware commissioning ~125 man yrs

SM18: ‘Home’ for ~100 persons during 6 years ~2001 to 2007!

Indian Teams Involved in Commissioning of Sector 7-8 AT-MEL, AT-ACR, AB-PO Groups
Indian Participation in LHC Commissioning

• Cryogenic experts from RRCAT, participated in analysis of performance data generated during commissioning of LHC cryo-systems to help debug the deficiencies.

• For example:
  – Source of excessive frosting on the Distribution Feed Boxes.
  – Re-evaluation of safety valve size to withstand different accidental conditions
India reinforces its cooperation with CERN

On 25 May, the President of India, Dr. A.P.J. Abdul Kalam, found the time in his busy schedule between two state visits (to Russia and the Swiss Federation) to visit CERN. The President, a physicist himself and a self-confessed supporter of CERN, wanted to see with his own eyes the progress made in the world’s largest particle physics laboratory. He was accompanied by the Chairman of India’s Atomic Energy Commission, Dr. Anil Kakodkar, and a team of journalists.

Welcomed by CERN’s Director General; Robert Aymar, the President of India visited the LHC tunnel, the ATLAS experimental cavern and the test facility for the LHC magnets. There the President had the chance to meet Indian

India has been an active partner of CERN for many years and one of the first non-Member States to make significant contributions to the LHC. A formal collaboration agreement between India and CERN was first signed in 1991. In 2002, India was granted Observer Status to CERN.

India’s collaboration with CERN currently involves some 130 people with a contribution of about 30 MCHF, mainly in kind. Indian scientists are participating in CMS and ALICE, while many Indian universities and R&D organisations, as well as Indian industry, have been contributing to the LHC project, delivering state-of-the-art equipment. India is also participating in the establishment of a regional Tier-2 computing centre using GRID technology in order to provide a platform for their scientists to perform analysis of the LHC data.

Indian President A.P.J Abdul Kalam, surrounded by compatriots working at CERN.
Detectors & LHC GRID Related Activities

- Indian Scientists participate in CMS and ALICE detector building, installation, analysis software, detector monte carlo studies, physics simulation and analysis
- CMS (7 TeV + 7 TeV proton-proton collisions)
  - Detector: Tracker, Preshower, ECAL, HCAL,
  - Magnet
  - Physics Interest: mechanism of mass generation & Search for HIGGS; SUSY Search; Search for other new particles
- ALICE (Heavy Ion experiment)
  - PMD
  - Muon Chambers
- LHC Grid Computing
  - A project worth $8M for the period of 2002-07, extended to March 08.
  - Software development for LCG
  - Setting up Regional Tier II Centers
    - TIFR, Mumbai
    - VECC, Kolkata
  - 17 Tier III Centers around India (including BARC, IOPB, SINP)
  - Project to continue during LHC operation and physics data collection
India

5 Institutes
36 Collaborators
As of February 2003

**TRACKER**
Silicon detector purchase, electronics and module mechanics
PU, EHEP, HECR

**PRESHOWER**
Silicon detector procurement and testing
BARC, UD

**MAGNET**
Procurement
BARC, PU, EHEP, HECR, UD

**HCAL**
Barrel mechanics and optics
BARC, PU, EHEP, HECR

**KEY:**
- **BARC** - Bhabha Atomic Research Centre, Mumbai
- **PU** - Panjab University, Chandigarh
- **EHEP** - Tata Institute for Fundamental Research, Mumbai
- **HECR** - Tata Institute for Fundamental Research, Mumbai
- **UD** - University of Delhi South Campus, Delhi

4/13/08 APS Meeting, St. Louis
Indian Contribution to ALICE

**Indian Contribution**

1. Full responsibility for Station 2
2. 1.6 million channels of MANAS chips (100,000 chips) for the 5 stations of muon arm
3. Front-end Absorber parts
4. High Level Trigger

**Dimuon Spectrometer of ALICE**

**PMD in ALICE**
- Gas detector with hexagonal cells
- Cell cross section: 0.22 cm², depth: 0.5 cm
- Total no. of cells: 270,000
- Distance from vertex: 350 cm
- $\eta$ Coverage: 2.3 – 3.5
- Area of the detector: 4.8 m²

**PMD fully Indian Contribution to ALICE**

A prototype PMD unit for ALICE experiment

**Developed by SINP Kolkata, Fabricated @SCL Chandigarh**
CERN DAE Collaboration on LCG

- LHC Grid Software Development:
  - Indian DAE signed a Protocol in 2002,
    - So that DAE can help CERN in building software for LCG (ie GRID for LHC data analysis)
    - It involved 600 man-months amounting to 7.5 MCHF to be completed by December 2007.

- Software developed & deployed @LCG
  - Co-relation Engine - Fabric Management
  - Problem Tracking System (SHIVA)
  - Grid Operations (GRID VIEW)
  - Quattro Toolkit Enhancements
  - Data Management
  - Fortran Library Conversion
Completion of 600 Man-months as per MOU

MOU extended for three more years till Dec 2010
Regional LCG Tier-2 in India

Tier 0/1 Centre

CERN/Geant

Internet

45/622/1000 Mbps

34/100 Mbps

4 Mbps

34/100 Mbps

VECC

• Tier 2/3 Centers in India

Tier 2 and Alice users

Tier 2 Centre and CMS users

TIFR

BARC

CMS: Universities & Institutes Tier 3

Universities: Delhi, Punjab, Aligarh, Visha Bharati, IIT Powai, Rajasthan, Jammu

DAE/DST/ERNET: Geant link operational since August 2006

ALICE: Universities & Institutes Tier 3

Uses WLCG tools

Tier 3 and CMS Users

2/10 Mbps

34/100 Mbps

Pop in Mumbai

34/100 Mbps

2/10 Mbps

Universities & Institutes Tier 3

CMS: Universities & Institutes Tier 3

Tier 2 and Alice users

Tier 2 Centre and CMS users

TIFR

BARC

CMS: Universities & Institutes Tier 3

Universities: Delhi, Punjab, Aligarh, Visha Bharati, IIT Powai, Rajasthan, Jammu

DAE/DST/ERNET: Geant link operational since August 2006
Road Beyond the LHC

- Participation in New CERN Projects: CTF3 & Linac4
- Benefit to Indian Programs from CERN Collaboration
- New & Upcoming Collaborations: ILC; Project-X etc.
Novel Accelerator Technologies Cooperation

- Success of DAE-CERN partnership in LHC has led to a new cooperation on Novel Accelerator Technologies
- It has led to a two way collaboration between DAE-CERN
  - DAE’s participation in CERN’s LINAC-4 & CLIC Test Facility-3 projects
  - CERN’s contribution to DAE’s programs by way of delivering hardware.
After a high level scientific and technical discussion between scientists of BARC (Dr. P Singh), RRCAT (Dr.V.C. Sahni), and CERN representatives (R. Garoby and M. Vretenar),

- CERN management sent a letter to Dr. Anil Kakodkar, Secretary, Department of Atomic Energy
  - Outlining elements of a formal agreement between CERN-DAE

**Indian Interest: (CERN → Indian Laboratories)**
- 2 LEP klystrons, probably associated with some auxiliary equipment
- Sharing the design developments of CERN Linac4
- Training of young scientists both in the theory and practice of proton Linacs.

**CERN’s Interest: (Indian Laboratories → CERN)**
- A high voltage (100 kV – 20 A) pulsed power supply for pulsed operation of a LEP klystron
- Support for the design of Linac4 in 2006 and 2007
  - One Indian scientist at CERN for two years,
- for the commissioning of the 3 MeV test place in 2007 and 2008
  - Two Indian scientists at CERN for two years.
- Control software for the 3 MeV test place.

**To help meet tight deadline and accelerate the realization of the power supply, CERN specialists in power converters will be involved and will support Indian team.**
- This device would also be valuable for DAE laboratories future tests of Linac structures.
RRCAT: Long Pulse Solid State Modulator

- RRCAT has designed a state of the art long pulse Solid State modulator for 1MW klystron for RFQ of LINAC 4.
  - One modulator has been assembled and tested at CERN based on the common design,
  - Another modulator is in advanced stage of development at RRCAT.
- One LEP klystron to be sent to India is awaiting final tests on actual load.

Bouncer Modulator Chassis
Interlock and controls
Power supplies integration

4/13/08 APS Meeting, St. Louis
CLIC Test Facility3 (CTF3)

• Establish the principle of a 3-5 TeV e+-e- Collider using the idea of
  – A “drive beam” creating an “in situ 12 GHz RF source”,
  – Extracting RF power via PETS (Power Extraction & Transport System)
  – Using this RF power to accelerate electron & positron beams that will collide.

• RRCAT Contributions to CTF3
  – The final design of TL–2,
  – built vacuum chambers and magnets for it
  – software support & would help in CTF-3 commissioning.
RRCAT: Hardware for TL2-CTF3

Dipole Magnet L-1 on Measurement Bench

Completed vacuum chambers
LEP Equipments for DAE Laboratories

- CERN has given LEP Cryomodule, RF Power & Wave Guide components for use by Indian Laboratories

LEP cryomodule being shipped from CERN
DAE intends using this CM to accelerate electron up to ~ 40 MeV,
- Use bremstrahlung to explore different applications.
CERN also shipped LEP Wave guide parts
- Are being used to compare wave guide parts built @ RRCAT with those received from CERN.
Fermilab-Indian Institution, SLAC-Indian Institution Collaboration

- Fermilab and Indian Institutions have signed an Addendum MOU “Fermilab, RRCAT, BARC, IUAC and VECC Collaboration on ILC Main Linac SRF Accelerator Technology R&D”
  - Focus is on ILC Cavity and Cryomodule Development
  - Indian Institutions Infrastructure development

- Indian Accelerator Program
  - High Intensity Proton Accelerators (SNS, ADS)
  - Radioactive Ion Beam
  - Related SRF infrastructure development

- Collaboration on High Intensity Proton Accelerator is under discussion
  - Fermilab Proton Accelerator R&D (Project-X, HINS)

- SLAC and Indian Institutions have signed an Addendum MOU “SLAC, RRCAT, BARC, IUAC and VECC Collaboration on ILC RF Power Sources and Beam Dump Design R&D”
Developing US Collaboration With India
Memorandum of Understanding
between
US Universities & Accelerator Laboratories
and
Indian Universities & Accelerator Laboratories
concerning
Collaboration on R&D for Various Accelerator Physics and High Energy Physics Projects
January 9, 2006

1. Introduction

1.1 General Description

This Memorandum of Understanding (MOU) establishes a collaboration framework between various US and Indian Accelerator Laboratories and

4.2 Approvals
The following concur in the terms of this Memorandum of Understanding:

Piermaria Oddone, Director, FNAL
Date 1/4/08

Vino C. Sahni, Director, AT
Date 3/5/06

Jonathon Dohi, Director, SLAC
Date 1/23/06

Bikash Sinha, Director, VECC
Date March 9, 2006

Christoph Ludwig, Director, TJNA
Date

Anil Roy, Director, IUAC
Date March 9, 2006

Harish R. Jagannath, Director, Newmar Lab
Date

S. Bhattacharya, Director, TIFR
Date April 17, 2006

Srikumar Rajagopalan
Date

M. Baranage, Director, BARC
Date March 19, 2006

Deepak Pandit, Vice Chancellor, DU
Date April 10, 2006

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

7 Management and Approval:

The work under this MOU will be jointly managed by Dr. Shekhar Mishra, Fermilab and Dr. Vino 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 Vino C. Sahni, Director, RRCAT

Dr. Piermaria Oddone

Dr. Shekhar Mishra

Deputy IL/ C Program Director, FNAL

4/13/08 APS Meeting, St. Louis
Development of 1.3 GHz Cavity Die

- Using the design from Tesla Technology Collaboration RRCAT is fabricating 1.3 GHz cavity Die for Fermilab
  - These would be put to use by US and Canadian Industries

Loading arrangement of dies on the 200 Ton Hydraulic Press at RRCAT

Blank Loading for Forming

Half cups of finally formed parts of cavity
Frequency and E-field Measurement

RRCAT: Trial Prototype Elliptical 1.3 GHz Cavity Made of Two Cu Half Cells

2 Half Cells+ beam pipe & Flanges

Assembled Cavity with beam pipe & Flanges

Bead Pull Measurement Setup for Assembled Cavity

Freq. F= 1.304847183 GHz

Freq. F1= 1.304847183 GHz
Freq. F2= 1.66426 GHz
Freq. F3= 1.83880 GHz
SC Cavity End Group - Design for Manufacturing

• ~50% of Superconducting 1.3 GHz ILC cavity cost is
  – Due to expensive fabrication required for end groups
  – Larger manufacturing time, due to many e-beam weld steps needed.

• Concept 1:
  – Prune cost by reducing the manufacturing time that is machine the entire end group from a single Nb block.
  – It will also minimize EB welding & pre weld processing which are costly & time consuming.

• Extensive prototyping and testing is now on @ RRCAT.
  – If successful, SC Cavity cost can be reduced by 30-40%.

• Status: First 2 prototypes made from single Cu block ready.
HGR Pipe: Design for Manufacturing

- In the ILC/Project-X Cryomodule design the Helium Gas Return (HRG) pipe supports all cavities.
- The HRG has to be manufactured with great precision as cavity alignment depends on it.
  - Needs straightness 3 mm in 12 m length. So an expensive approach
- New cavity hanger design to utilize commercially available pipes.
EB welding Fixture- Design for Manufacturing

- **Goals**
  - Eliminate one cycle of EB welding.
    - This will significantly (10%) lower the cost of SC Cavity.
  - Control of welding distortion possible.

- **Status**
  - Design is complete.
  - First set of fixtures under fabrication.

- **Strategy**
  - Control distortion by changing sequence of tacking & compensating pressure.
  - By preheating with e-beam.
DAE Addendum with SLAC, USA

Goal of Addendum

The goal of this Addendum to the MOU is to describe collaboration on ILC R&D between Indian Institutions and SLAC. SLAC and Indian Institutions will work to jointly develop an ILC beam dump design and prototypes. Indian Institutions, SLAC and Fermilab will jointly develop an ILC RF-Unit. SLAC and Indian Institutions will focus on the RF Power sources while Fermilab and Indian Institutions will focus on the cavities and cryomodules.

Their work will develop on two parallel paths.

1) Indian Institutions will join the international beam dump design team with a scientist or engineer stationed at SLAC for a short time. Subsequent design work will be mainly carried out at Indian Institutions.

2) Indian Institutions will join the international RF distribution system design team with one or more scientists and engineers stationed at SLAC for short periods. Subsequent work on Design for Manufacture of components will be mainly carried out at Indian Institutions and the Indian Institutions will construct components for an ILC RF-Unit, as per mutual agreement, for use at SLAC. This effort may evolve to include work on other aspects of the RF sources in the future.

It is expected that this addendum will evolve and undergo revision based on initial results. Further work will be carried out under subsequent Addenda.

4. Scope of Work in CY08-09

We propose to start with relatively small projects, utilizing current Indian technical strength and progressively develop more complex hardware. It is expected that Indian
"These devices are expensive, they are potential radiation sources, they're under the ground, they are full of water, they vibrate and you can't go near them once they're in use," said SLAC physicist Ray Arnold. "But the electrons have to be stopped. Basically we're taking 40 years of work, and pushing it by a factor of 10 or 15 in power."

Last January, Satyamurthy Polepalle of India's Bhabha Atomic Research Centre (BARC) came to SLAC to join the collaboration addressing future accelerator beam dump design, which was the result of the memorandum of understanding between U.S. and Indian universities and laboratories signed in December 2007. Satyamurthy brings to the collaboration years of experience working with proton beams, and says that his three-month stay at SLAC has resulted in a very fruitful exchange of ideas and will continue through this year and beyond.

"Together with SLAC colleagues and with the help of my design team back at BARC, we've been able to fine tune the system parameters based on both the first principle estimations and also complex fluid dynamics studies," said Satyamurthy. "We've made quite good progress during this period and identified the plan of work for the nearest future. It is proposed to continue this collaboration for eventual development of the multi-MW beam dump design."
Concluding Remarks

• Partnership of Indian DAE lab scientists in 70s & 80s *(that grew out of individual level contacts)* with groups in accelerator labs overseas, have blossomed into strong inter Institutional Collaborations.

• This has now evolved in to two way partnership:

• Enabling Indian labs to contribute to Accelerator based International Mega Science High Energy Physics Projects, and through sharing of ideas, bring benefit to programs in India as well as those that are being pursued in labs abroad.