

# Indian Institutions and Fermilab Collaboration: Project X and Particle Physics



**Shekhar Mishra**

**Project X, International Collaboration Coordinator**

**Co-Chair, IIFC-CC**

**Fermilab**



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# Introduction



International Laboratory



India





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# Project X and Its Physics Program



**Stage 1-3:  
Neutrino Physics:**

- **Mass Hierarchy**
- **CP violation**
- **Precision measurement**

1 GeV

**S1&2:  
Nuclear edm  
experiments**

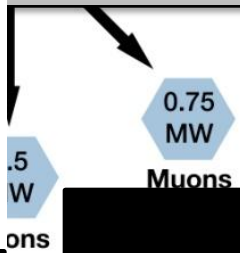
- Beam Quality
- Beam Loss Mechanism
- Fault Tolerant Design
- Beam-Target Interface



Beam Delivery System  
Instrumentation and Controls

**S1&2:  
 $K^+ \rightarrow \pi^+ \nu \nu$ : >1000  
events, Precision rate  
and form factor**

- Liquid-metal target components
- Chemistry Control
- Remote Handling
- Windowless Design



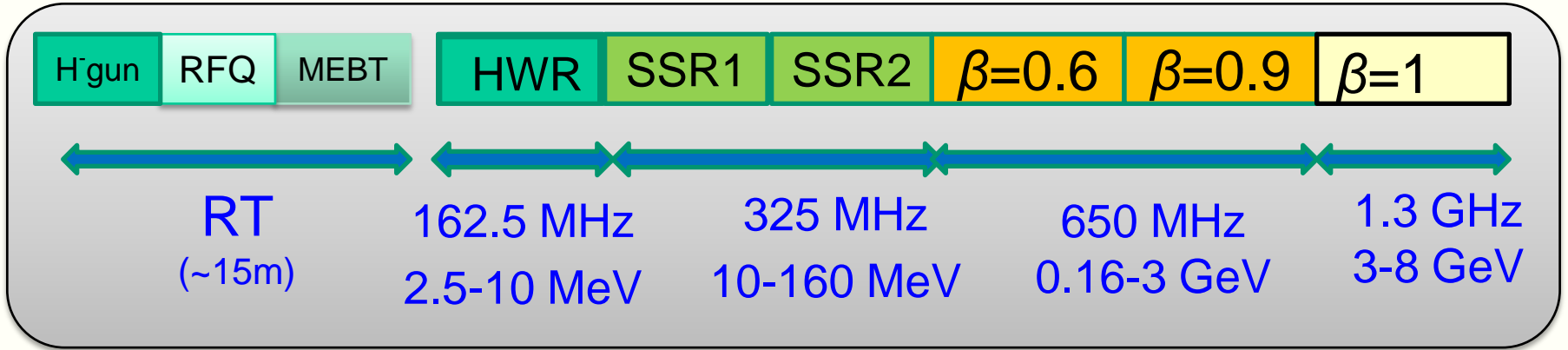
**S1&2:  
Next generation muon-  
to-electron conversion  
experiment**

Technology Demonstration  
Facility



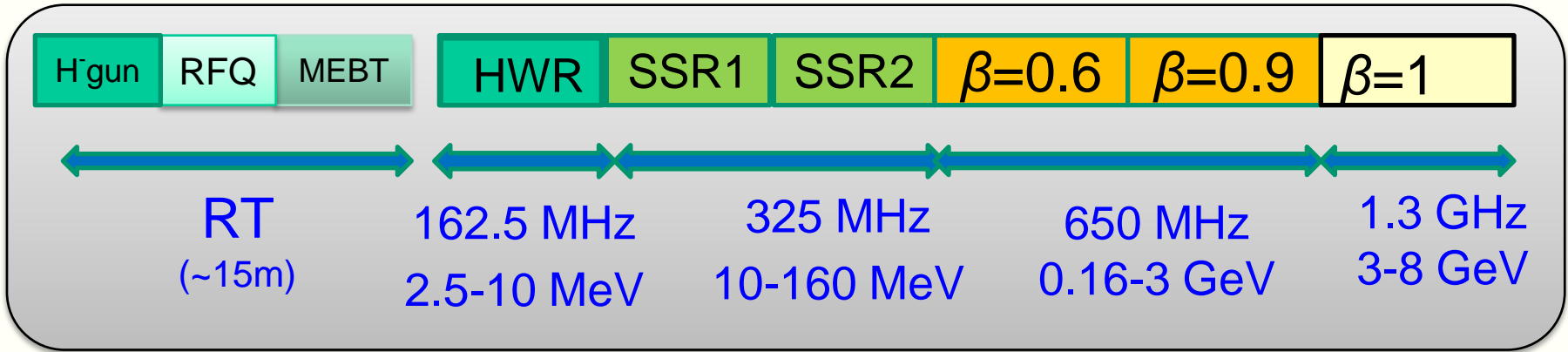
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# Project X

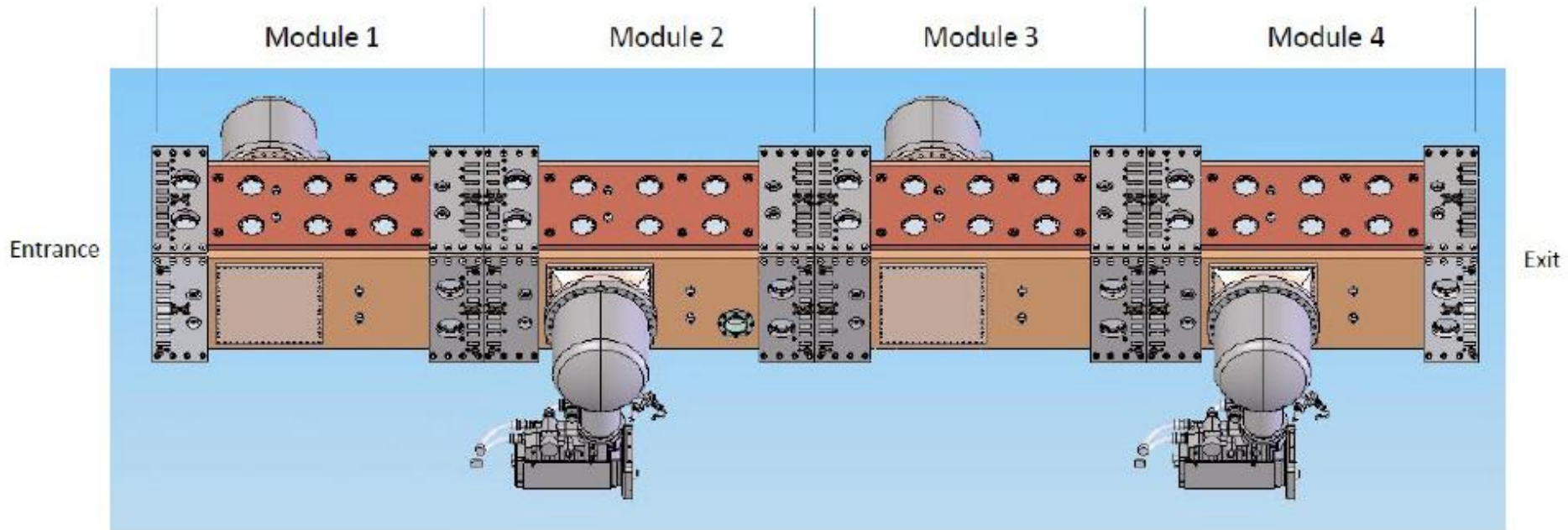


Section	Freq	Energy (MeV)	Cav/mag/CM	Type
HWR ( $\beta_G=0.1$ )	162.5	2.1-10	9/6/1	HWR, solenoid
SSR1 ( $\beta_G=0.22$ )	325	10-42	16/18/ 2	SSR, solenoid
SSR2 ( $\beta_G=0.47$ )	325	42-160	36/20/4	SSR, solenoid
LB 650 ( $\beta_G=0.61$ )	650	160-460	42/14/7	5-cell elliptical, doublet
HB 650 ( $\beta_G=0.9$ )	650	460-3000	152/19/19	5-cell elliptical, doublet
ILC 1.3 ( $\beta_G=1.0$ )	1300	3000-8000	224 /28 /28	9-cell elliptical, quad

# Project X: Warm Front End



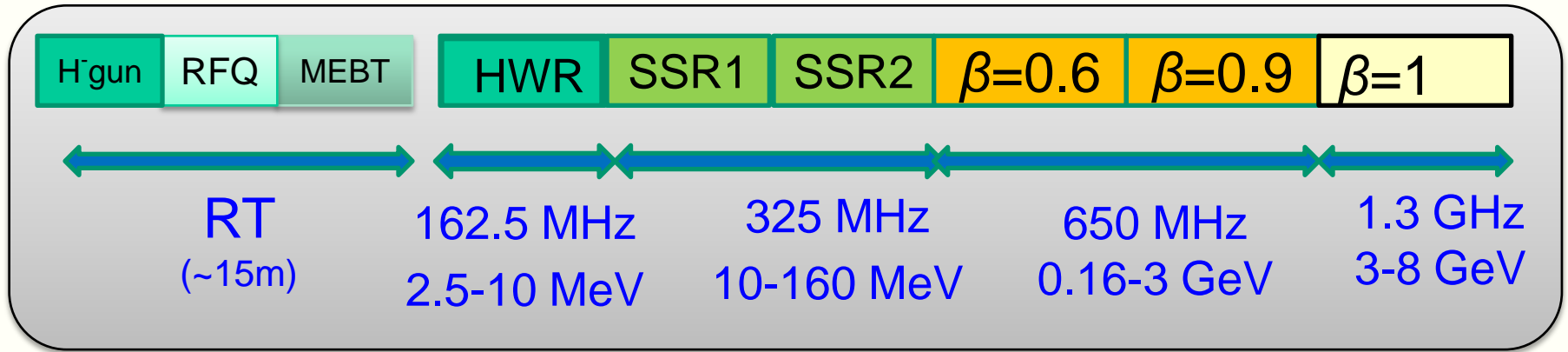
## RF Structure



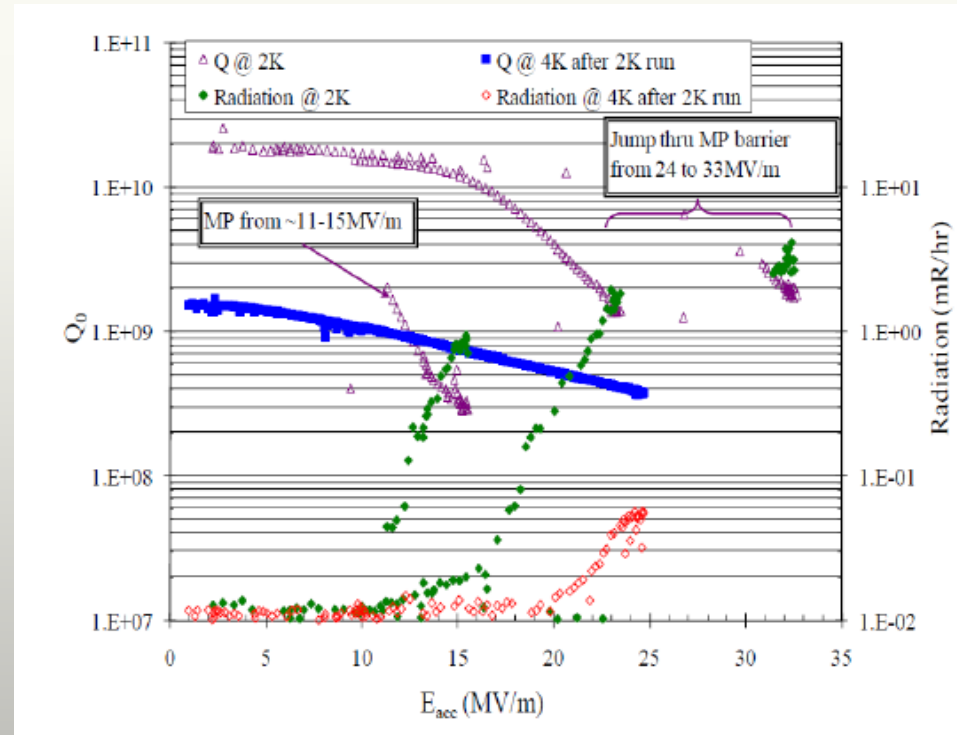


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# Project X: SRF Linac



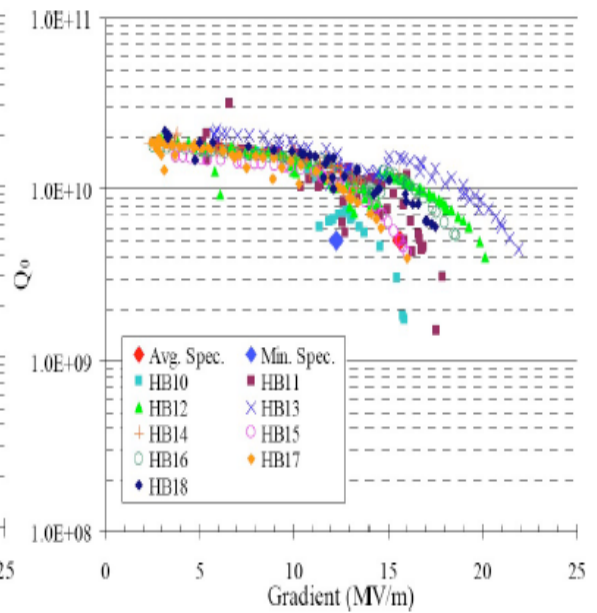
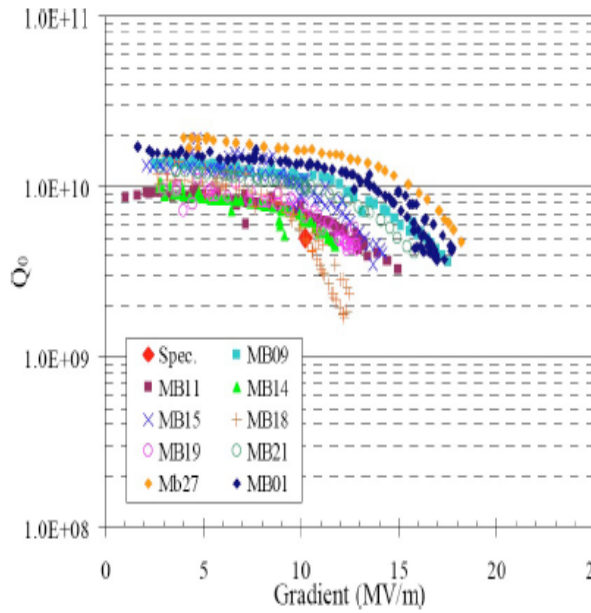
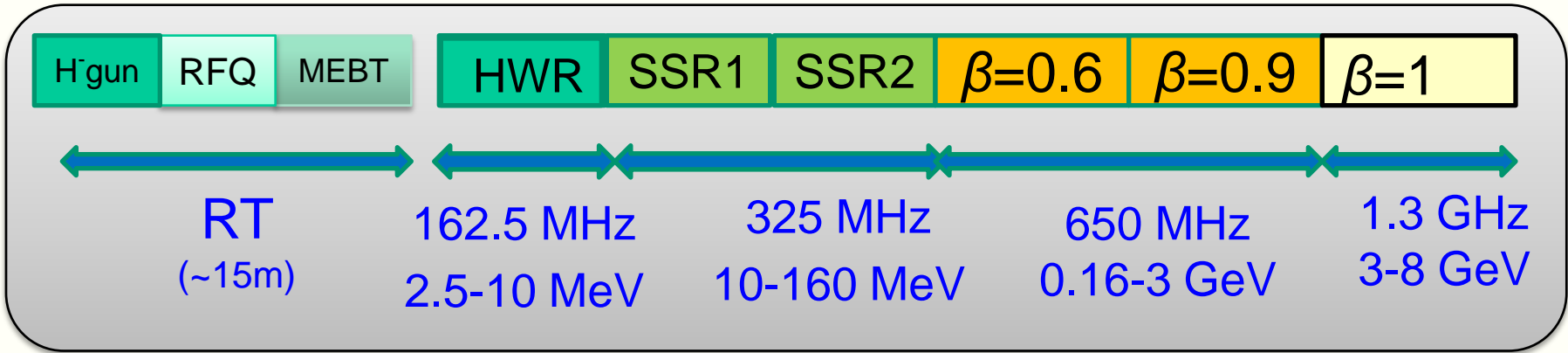
## SSR1





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# Project-X: SRF Linac



SNS Cavity



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# Fermilab SRF Infrastructure



All of these infrastructures were focused on 1.3 GHz. With India Collaboration we are upgrading them to 325 and 650 MHz

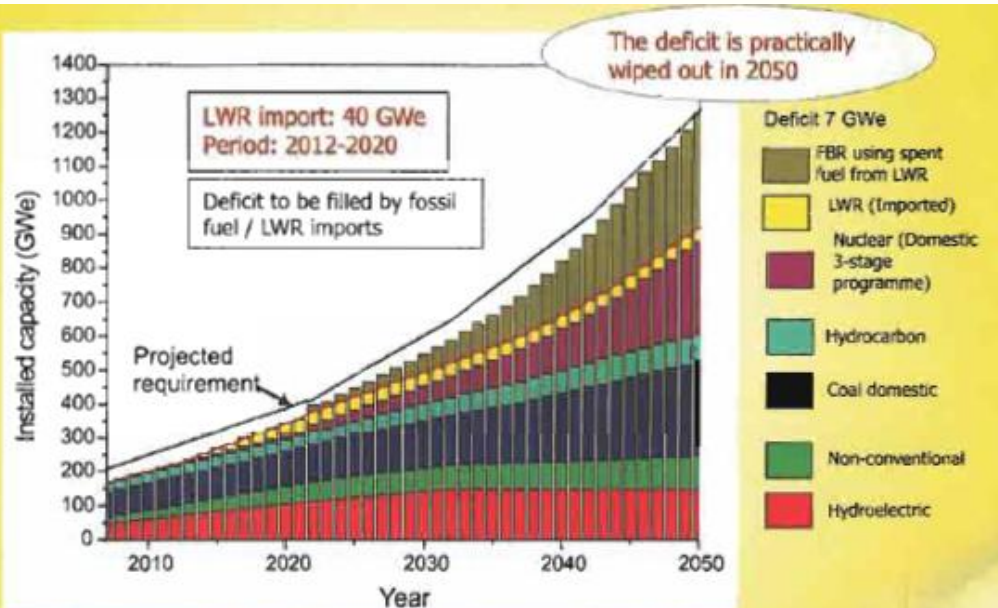




# Indian Interest in Fermilab



- In 1950's Bhabha presented a vision that included a 3 Stage Domestic Nuclear Program for India.
- The current growth in Indian economy and its technical strength provides an **“Opportunity”** for realizing this vision.
  - **But India needs efficient accelerator technology**
    - Transmutation of nuclear waste
    - Converting Thorium into fissile material
- India have plans to develop other accelerators
  - SNS, Light Source(s), Medical isotopes, Agriculture and Industrial
- Physics experiments at Fermilab
  - Training of technical manpower



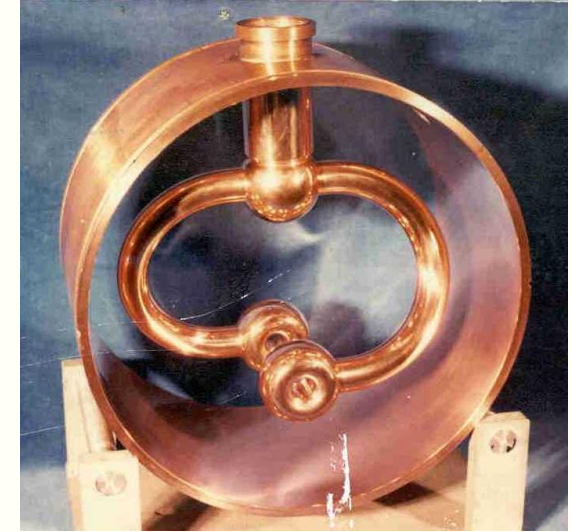
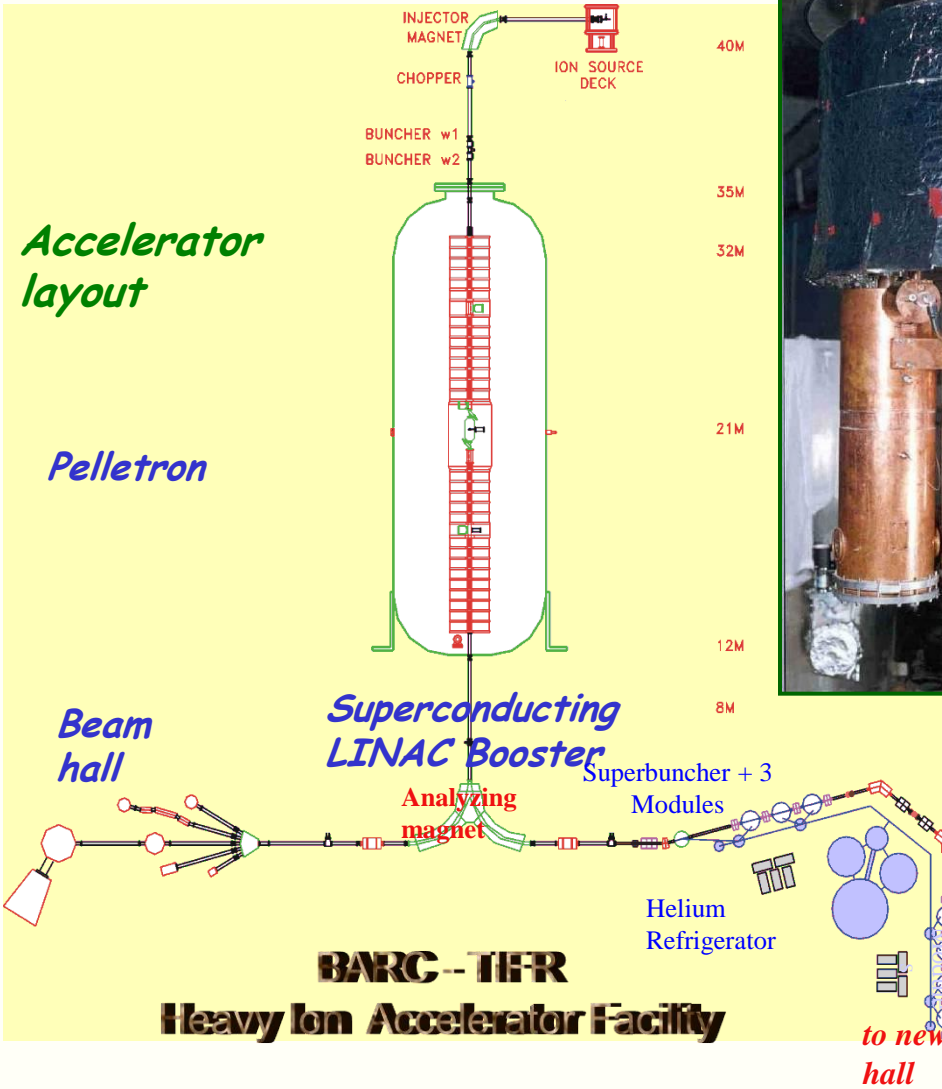
Indian Energy Crisis





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# BARC-TIFR: Heavy Ion Accelerator

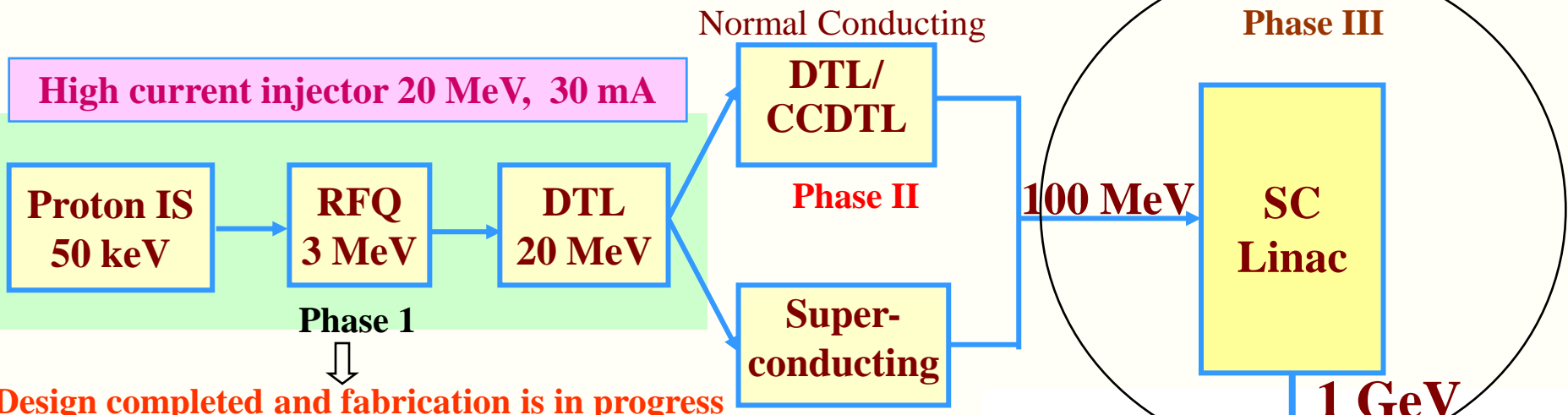


to new beam hall



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# BARC: Accelerator Development for ADS

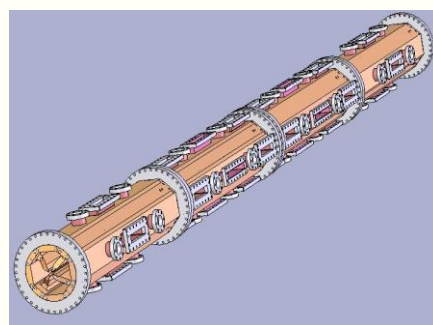


Design completed and fabrication is in progress

ECR Ion Source



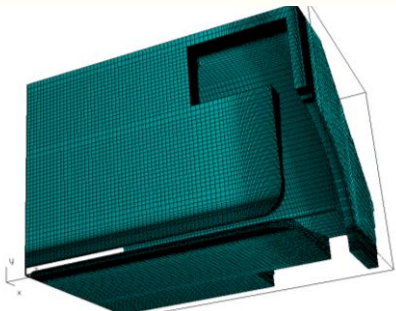
RFQ



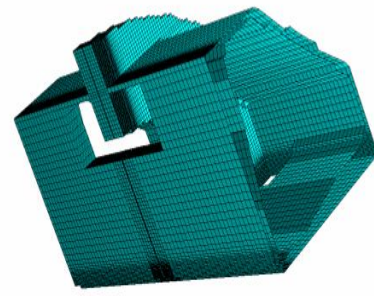
DTL



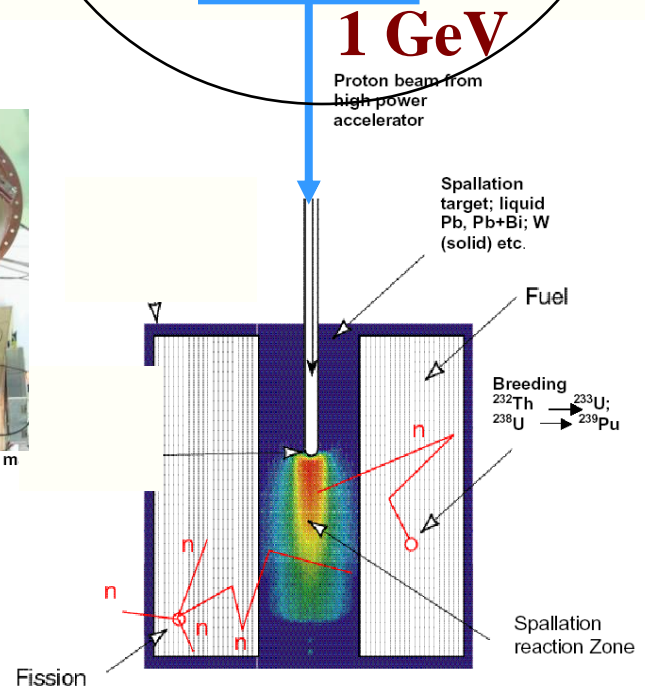
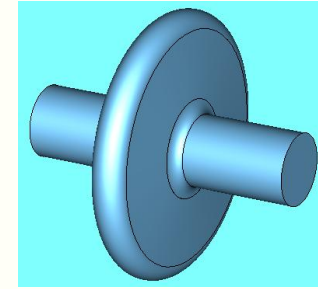
Beginning/End Cell



Coupling Cell



Elliptical SC Cavity



1 GeV

Proton beam from high power accelerator

Spallation target; liquid Pb, Pb+Bi; W (solid) etc.

Fuel

Breeding  $^{232}\text{Th} \rightarrow ^{233}\text{U}$ ;  $^{238}\text{U} \rightarrow ^{239}\text{Pu}$

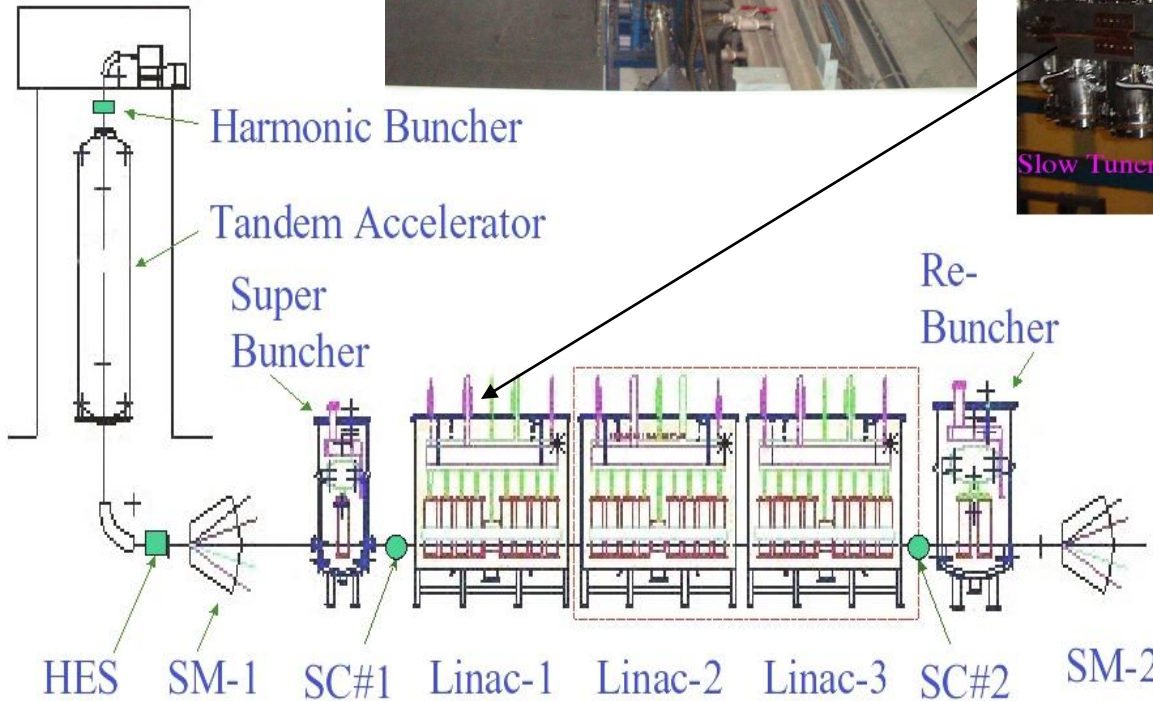
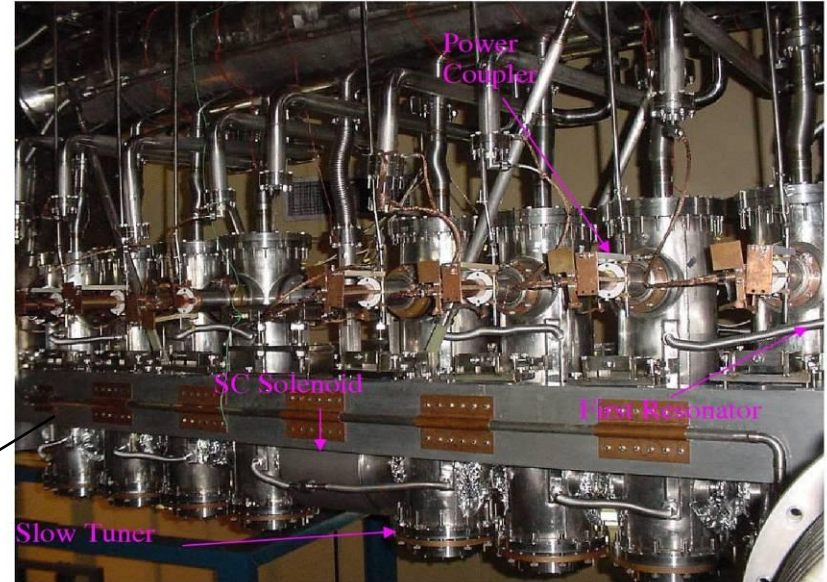
Spallation reaction Zone

Fission



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# IUAC: Pelletron and SRF Linac



Upgrade to ECR based High Current Injector

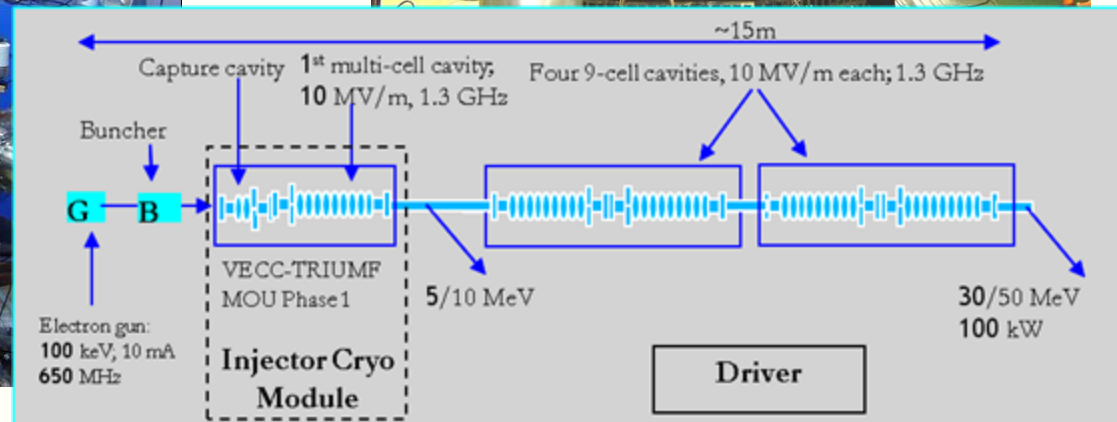
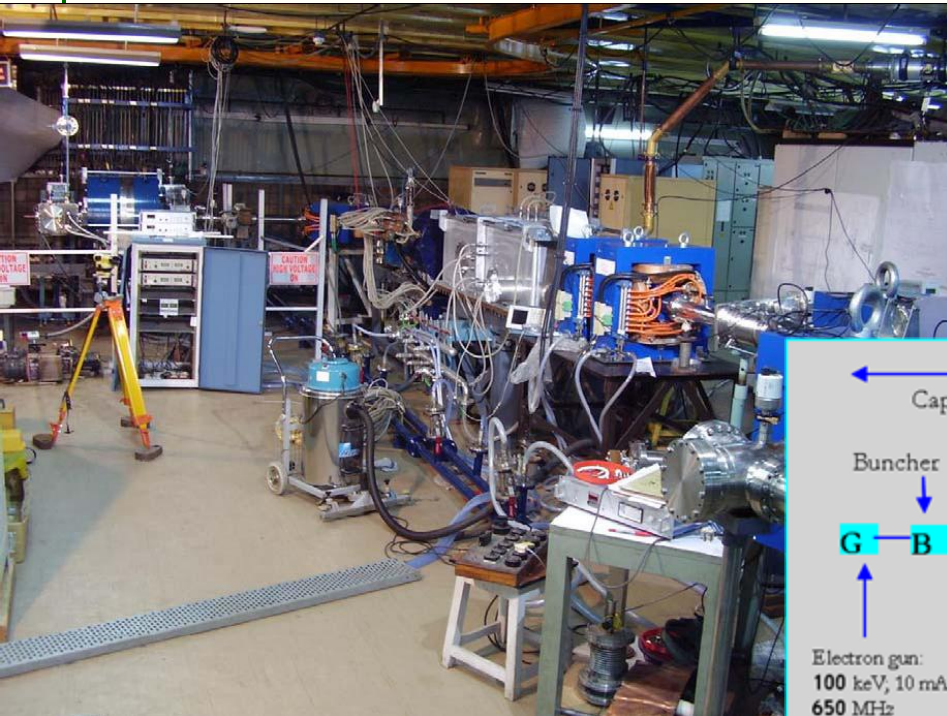


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# VECC: Nuclear Physics



- Superconducting Cyclotron
- Radioactive Ion Beam Facility
- R&D on Superconducting RF Linac
- Strength
  - Cryogenic
  - Mechanical Engineering
  - RF Power





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# RRCAT: Indus-II



Indus-2 Ring in the Tunnel



RF Cavities installed in Indus-2 Ring



Long Straight Section LS-6 Assembly



Transport Line-3 Joining on to Indus-2



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# India: LHC Accelerator



7080 Nos. Magnet Positioning System Jacks



MCS (1146 Units) & MCDO (616 Units)



Magnetic measurements teams- ~100 Man-years



5500 Nos. Quench Heater Power supplies(QHPS)



1435 Nos. Local Protection Units



A part of DAE's contributions installed in LHC Tunnel at CERN





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# Nuclear Power Reactor



**KUDANKULAM  
ATOMIC POWER PROJECT**



**RAJASTHAN  
ATOMIC POWER PROJECT**



**KAIGA  
ATOMIC POWER PROJECT**



CD-3 to CD-4 in Five yrs.

Indo-US Nuclear Treaty



- **In 2002:**
  - We had just finished Main Injector Commissioning (1999) and the Recycler Commissioning Team was in its last phase of commissioning.
  - Fermilab was getting ready for Run-II
  - Discussion of LHC turning on had started,
  - ILC was on the front burner with two technologies competing, Fermilab part of both
  - Indian HEP physicists had already announced
    - Pulling out of Fermilab after Run-II (after 20 years)
    - Participating at CERN and European laboratories will grow
    - Reflected in their 5 yrs funding (02-06 and 07-11)
    - Looking for another Mega Science Project
  - We initiated a discussion of future new collaboration with Indian Institutions with Prof. V. S. Ramamurthy, Secretary, Department of Science and Technology (NSF), India.
    - Ramamurthy: “Get our scientists excited about the science at Fermilab and we will collaborate”.
    - Ramamurthy requested an “Interaction Meeting”



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# 1<sup>st</sup> Indo-US Interaction Meeting



- **1<sup>st</sup> Indo-US Interaction meeting, Nov. 2003, New Delhi.**
  - Supported by High level Indian and US government & management
  - 19 US physicists and 70+ Indian Scientists participated.
    - US-India discussed accelerator and neutrino physics collaboration
    - Working group formed to develop collaboration
- **Outcome:**
  - Indian science management and Fermilab agreed to develop a new collaboration in HEP
    - Established joint working group to formulate a plan for collaboration





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# Institutes to Institutes MOU: Jan 2006



## 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

The following concur on the terms of the original MOU and outlined in the extension of the Memorandum of Understanding.

TCS  
Dr. Ratan Kumar Sinha  
Director, BARC  
Date 30-01-2012

R. Bhandari  
Dr. Rakesh Kumar Bhandari  
Director, VECC  
Date 24/3/2012

P. D. Gupta  
Dr. P. D. Gupta  
Director, RRCAT  
Date 30-01-2012

M. Barma  
Prof. Mustansir Barma  
Director, TIFR  
Date 2/3/2012

M. Sanyal  
Dr. Milan Sanyal  
Director, SINP  
Date 23/3/2012

Piermaria Oddone  
Dr. Piermaria Oddone  
Director, FNAL  
Date 1/19/12

Shekhar Mishra  
Dr. Shekhar Mishra  
Project-X, Co-Chair IIFC  
Fermilab  
Date 1/19/12



## 4.2 Approvals

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

Piermaria Oddone  
Piermaria Oddone, Director, FNAL

Date 1/9/05

Jonathon Dorfman  
Jonathon Dorfman, Director, SLAC

Date 1/23/06

Christoph Lee  
Christoph Lee, Director, TJNAJ

Date 1/18/06

Maury Tigner  
Maury Tigner, Director, Newman Lab

Date

Date

Date

Date

Vinod C. Sahni  
Vinod C. Sahni, Director, CAT

Date March 8, 2006

Bikash Sinha  
Bikash Sinha, Director, VECC

Date March 9, 2006

Amit Roy  
Amit Roy, Director, IUAC

Date March 9, 2006

S. Bhattacharya  
S. Bhattacharya, Director, TIFR

Date April 17, 2006

Srikanth Banerjee  
S. Banerjee, Director, BARC

Date March 14, 2006

Deepak Pental  
Deepak Pental, Vice Chancellor, DU

Date April 10, 2006



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# 2006-7: 1<sup>st</sup> visit of Indian Accelerator



- **BARC and RRCAT physicists and engineers visited Fermilab to discuss details of technical collaboration.**

## Focused on ILC Cavity Development Accelerator Physics

### 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

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

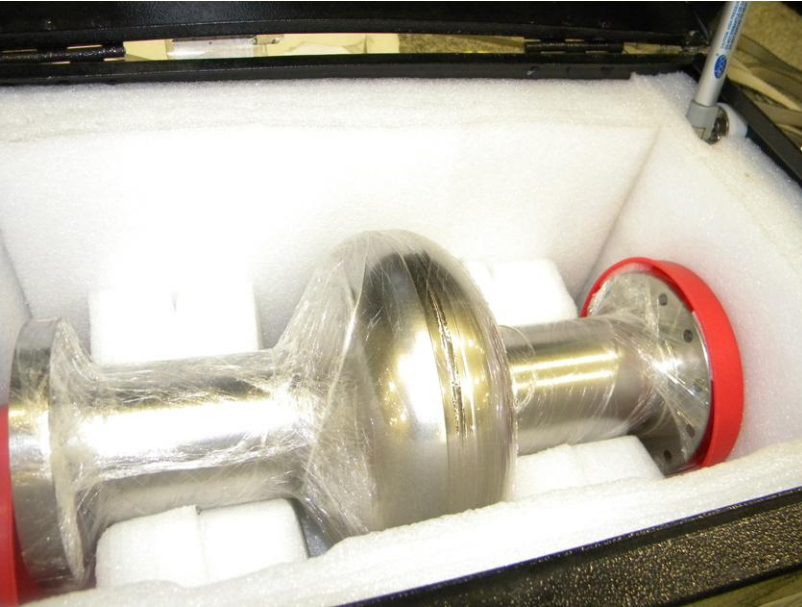
Dr. Shekhar Mishra  
Deputy ILC Program Director, FNAL





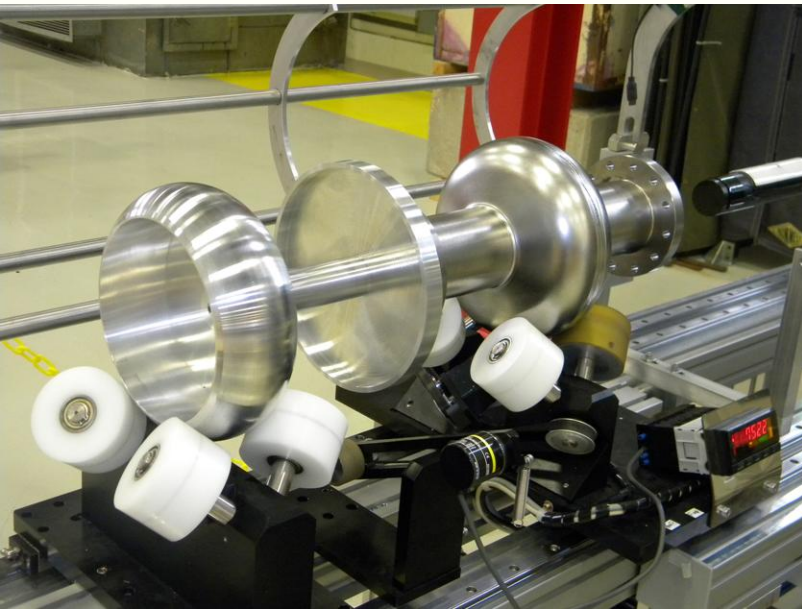
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# 1.3 GHz Cavity Development



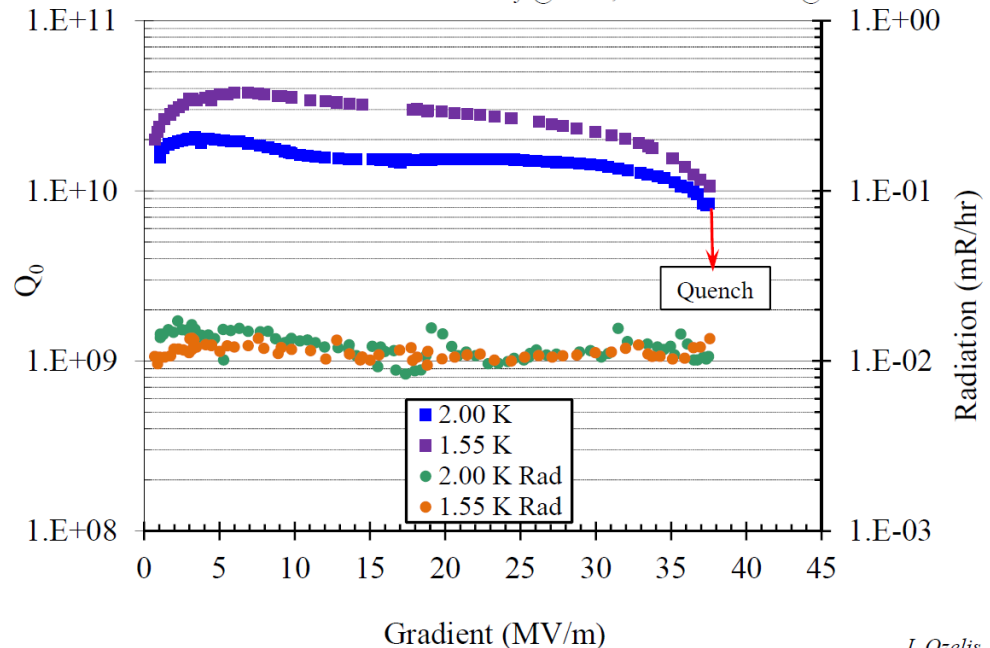
• Fabrication of cavity at RRCAT in collaboration with IUAC

• Processing and testing at FNAL/ANL



ILC- TE1CAT004 - Q vs E

Tested 10/15/11- CBP then EP/HPR/Assy @ ANL, then 120°C Bake @ IB1





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# 2008 Budget Crisis → Project-X



Fermi National Accelerator Laboratory  
P.O.Box 500 • Batavia, IL • 60510-0500  
630-840-3211 FAX 630-840-2900

Director's Office

January 4, 2008  
(By E-Mail and Facsimile)

Dr. Anil Kakodkar  
Chairman, Atomic Energy Commission of India  
Secretary, Department of Atomic Energy  
Anushakti Bhavan  
CSM Marg  
Mumbai – 400001, India



सर्वोच्च  
शासक सरकार  
Government of India

डॉ. अनिल काकोडकर  
Dr. Anil Kakodkar

No. 22 -2008

Dear Prof. Oddone,

Thank you for your letter dated January 4, 2008 and very supportive views about the collaboration between Fermilab and Indian Institutions. I am glad that this collaboration is moving so well.

I am also happy to inform you that Dr. Mishra met me as scheduled on January 15, 2008. He apprised me with the details of 'Project X' and its linkage with the R&D required for ILC. I also learnt

अध्यक्ष, परमाणु ऊर्जा आयोग

ए

सचिव, परमाणु ऊर्जा विभाग

Chairman, Atomic Energy Commission  
&  
Secretary, Department of Atomic Energy

January 21, 2008

Dr. Pier Oddone, wrote a letter to Dr. Anil Kakodkar, Secretary, DAE inviting India to collaborate on High Intensity Proton Accelerator

Last year I convened the Fermilab Steering Group to develop a strategic roadmap for the evolution of the accelerator-based High Energy Physics program, focusing on facilities at Fermilab that would provide discovery opportunities in the next two to three decades. The

I have asked Shekhar Mishra to provide you with additional technical details on the present collaborative efforts, Project-X R&D and its commonality with Indian accelerator programs, when he meets you on Jan 15th.

Sincerely,

Piermaria J. Oddone,  
Laboratory Director

Dr. Kakodkar sent a very positive response: Requesting developed of a "Phased Collaboration Plan"

With best regards,

Yours sincerely,

  
(Anil Kakodkar)  
Jan 21, 08

Prof. Piermaria J. Oddone,  
Laboratory Director,  
Fermi National Accelerator Laboratory,  
P.O.Box 500,  
Batavia IL 60510-0500, USA



# 2009: Project X



- Jan 2009, During the signing of the Addendum MOU III at Indore, Dr. Kakodkar and Dr. Oddone met privately
  - Concept of “Total Project Collaboration” emerged
  - Fermilab changed the HIPA design from Pulsed to CW



- Jan 2010, Dr. Dennis Kovar, Assistant Secretary, US-DOE-HEP visited DAE
  - Idea of three Phase Collaboration Developed
- Dr. Brinkman, Dr. Banerjee and Dr. Grover discussed
  - Fermilab-Indian DAE & DST collaboration.





# Banerjee: Road Map

- **May 2010 Banerjee requests US-DOE for a Road Map for the Fermilab collaboration on High Intensity Proton Accelerator**
  - Daniel Poneman, Brinkman, Miller, Banerjee and Meera Shankar, Indian Ambassador met in Washington to discuss this Road Map
    - Poneman and Banerjee agreed to develop DOE-DAE agreement
  - The concept of “Discovery Science” collaboration developed
- **Dr. Banerjee charged the IIFC to prepare a plan that would expand the accelerator collaboration to include physics collaboration with Fermilab.**
  - The program should be rich in Physics
  - Indian contribution should be significant and DAE-DST Ownership
  - Contribution should have synergy with interest and expertise in India
  - Development of Indian manpower, laboratory and industrial infrastructure
- **Fermilab and Indian-DAE established working groups to develop plans for**
  - Project X and Indian Accelerator Program
  - Indian Collaboration in Fermilab physics program



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# DOE-DAE Implementing Agreement



IMPLEMENTING AGREEMENT

BETWEEN

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA

AND

THE DEPARTMENT OF ATOMIC ENERGY

OF THE REPUBLIC OF INDIA

FOR COOPERATION

IN THE AREA OF ACCELERATOR AND PARTICLE DETECTOR R&D

AND DEVELOPMENT FOR DISCOVERY SCIENCE

दिल्ली में दिनांक 19.07.2011 को अंग्रेजी एवं हिन्दी भाषाओं में, दो-दो प्रतियाँ (दोनों भाषाओं के प्रलेख समान रूप से प्रामाणिक) हस्ताक्षरित।

श्रीकुमार बतजी  
भारत गणराज्य के परमाणु ऊर्जा  
की ओर से

संयुक्त राज्य अमेरिका के ऊर्जा विभाग की ओर से  
विभाग

**Discovery Science: The United States' Department of Energy and India's Department of Atomic Energy signed an Implementing Agreement on Discovery Science that provides the framework for **India's participation in the next generation particle accelerator facility at Fermilab.****

<http://www.state.gov/r/pa/prs/ps/2011/07/168740.htm>



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# Technical work under MOU



1. "Fermilab and Indian Accelerator Laboratory for High Intensity Proton Accelerator" (Signed on: November 10, 2009)
2. "SLAC and Indian Accelerator Laboratory for High Intensity Proton Accelerator" (Signed on: November 10, 2009)
3. "Fermilab and Indian Accelerator Laboratory for High Intensity Proton Accelerator" (Signed on: November 10, 2009)
4. "US and Indian Accelerator Laboratory for High Intensity Proton Accelerator and Detector Development" (Signed on: November 10, 2009)
5. "Fermilab and Indian Accelerator Laboratory for High Intensity Proton Accelerator" (Signed on: November 10, 2009)
6. "Fermilab and Indian Accelerator Laboratory for High Intensity Proton Accelerator" (Signed on: November 10, 2009)
7. "Fermilab and Indian Accelerator Laboratory for High Intensity Proton Accelerator Control for High Intensity Proton Accelerator" (Signed on: November 10, 2009)
8. "Fermilab and Indian Accelerator Laboratory for High Intensity Proton Accelerator" (Signed on: November 10, 2009)

## Covering all aspects of Project X and Fermilab Neutrino Program



Aug 2011



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# Indian DAE → Project X R&D



- Indian DAE laboratories are now working on all major components of 3 GeV CW linac.
  - In some cases they are leading the R&D with Fermilab specifications.

## IUAC:

- SSR1

## VECC:

- SSR1 Dressing,
- 325 MHz CM components  
 $\beta=0.6$ , 650 MHz, Cavity Dressing, Magnet etc

## BARC:

- SSR2 and CM components

- 325 MHz RF Power

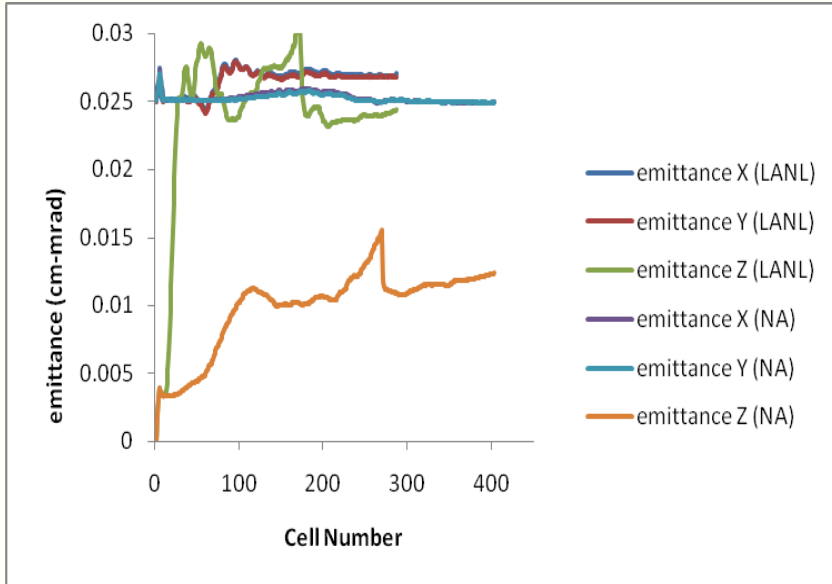
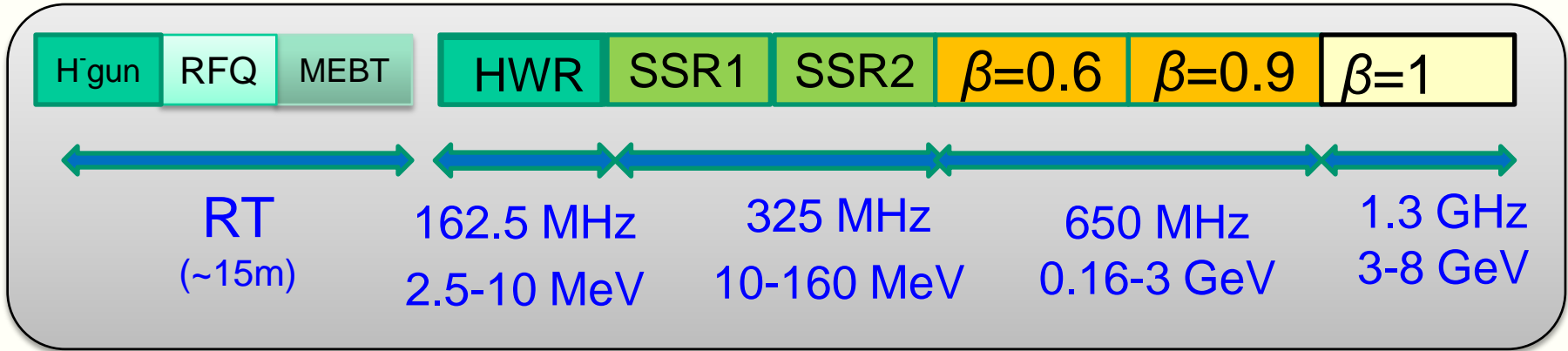
- 325 MHz power coupler

- BPM, LLRF

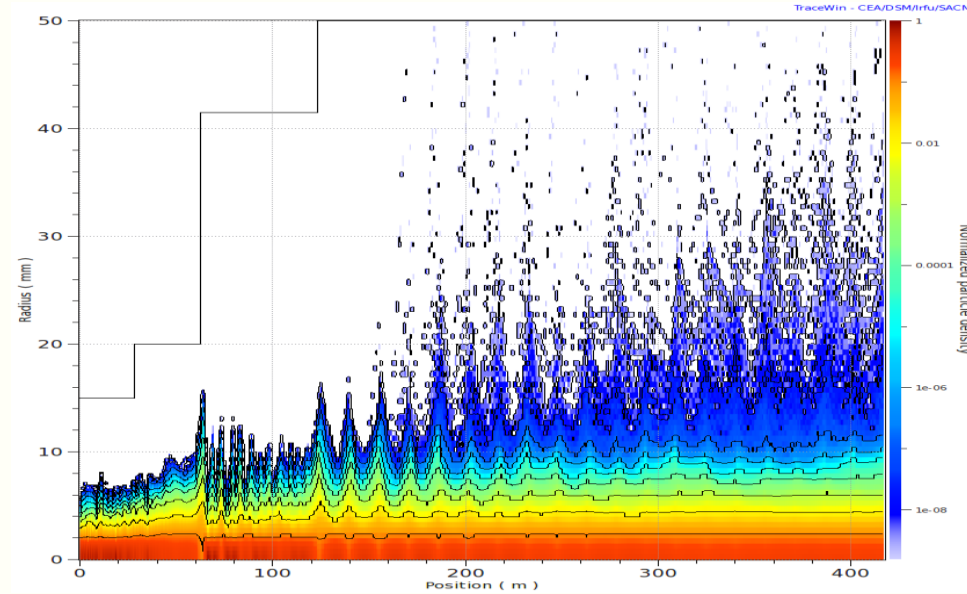
- Controls

## RRCAT:

- $\beta=0.9$ , 650 MHz Cavity Dressing, Magnet etc
- 650 MHz RF Power



Evolution of emittances RFQ



Beam envelope 2x all errors



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# 325 MHz, SSR1 Cavity IUAC



- IUAC, New Delhi has developed tooling for the fabrication of SSR1 cavities. The built to print cavity drawings were provided by Fermilab.



BARC has initiated work on SSR2

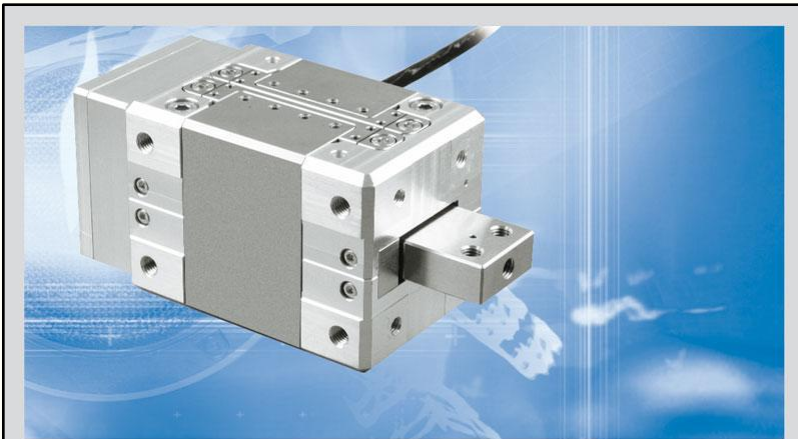
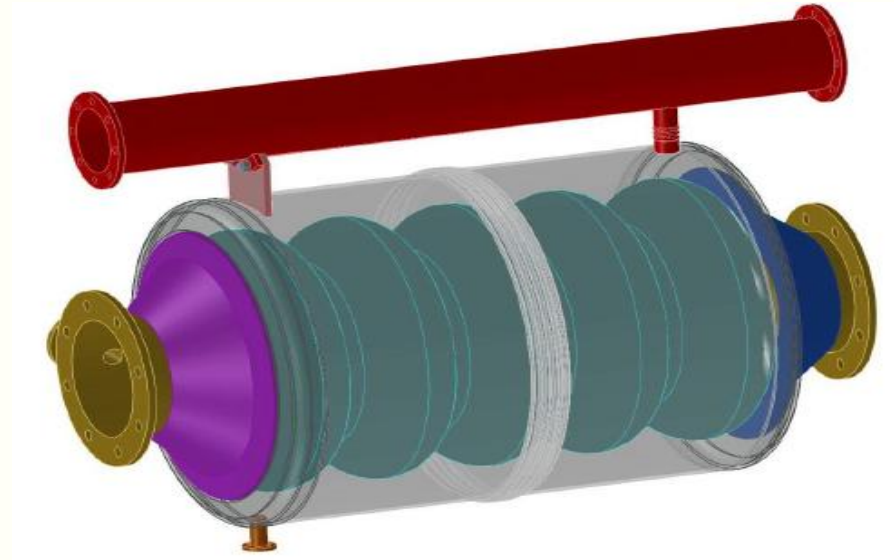


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# $\beta=0.6$ , 650 MHz Cavity



- VECC, Kolkata is working on design, fabrication and testing of  $\beta = 0.6$  cavity for Project-X.





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# $\beta = 0.9$ , 650 MHz RRCAT Progress



- 650 MHz  $\beta = 0.9$  1-cell and 5-cell cavities to be built, based on experienced gained from 1.3 GHz work at RRCAT and IUAC.



Die- Punch Set at RRCAT



Aluminum blank, 3mm thickness



Die-Punch Set mounted on Press at RRCAT



Beginning of forming trials with aluminum





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# e-beam → Laser Welding



- RRCAT has significant expertise in laser. They have proposed to use laser to weld Nb cavities, replacing very delicate and expensive e-beam welding.



Indigenously developed Laser System  
By SSRL, RRCAT for this task



Laser welded half cells of SC Cavity  
at CMEL, RRCAT



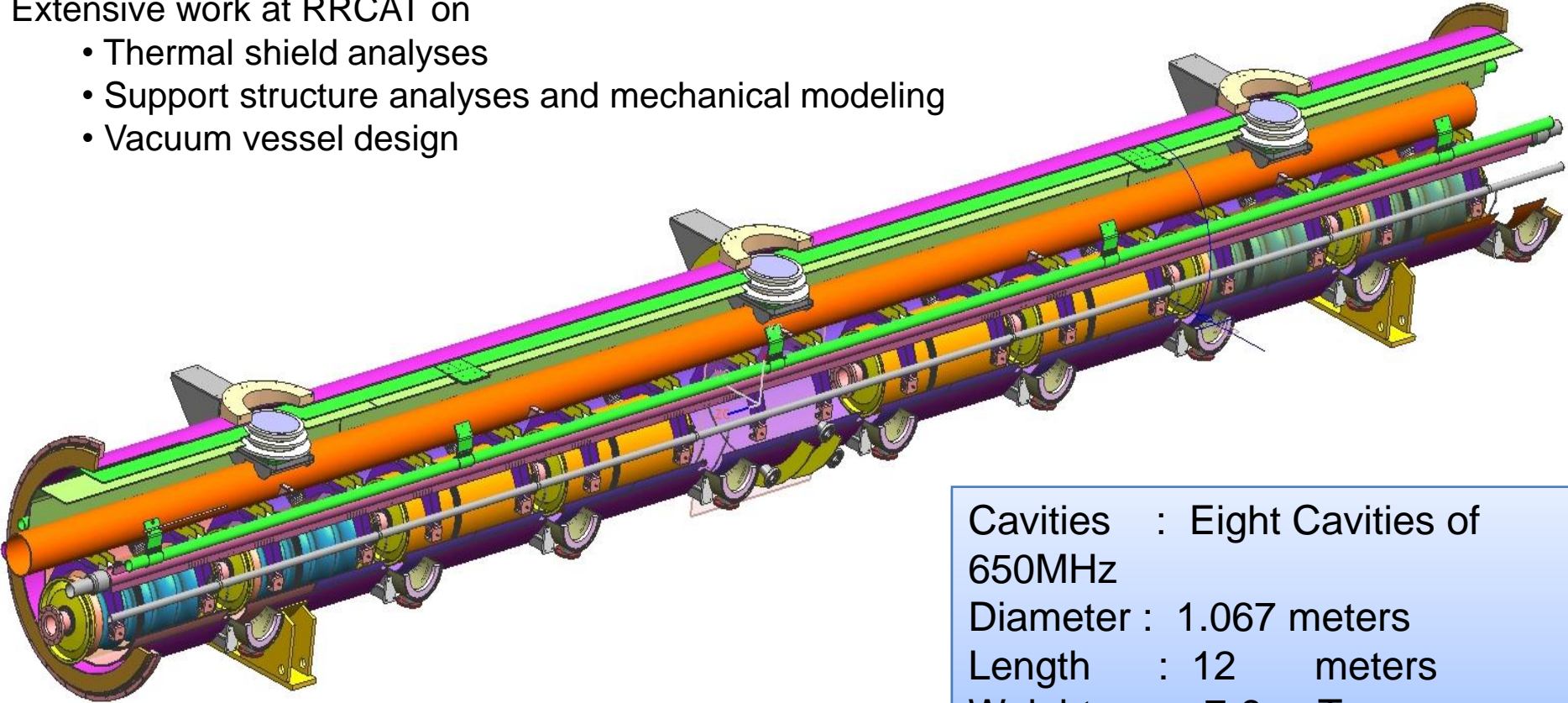
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# RRCAT: Status of 650 MHz Cryomodule



Extensive work at RRCAT on

- Thermal shield analyses
- Support structure analyses and mechanical modeling
- Vacuum vessel design



Cavities : Eight Cavities of  
650MHz  
Diameter : 1.067 meters  
Length : 12 meters  
Weight : 7-8 Tons

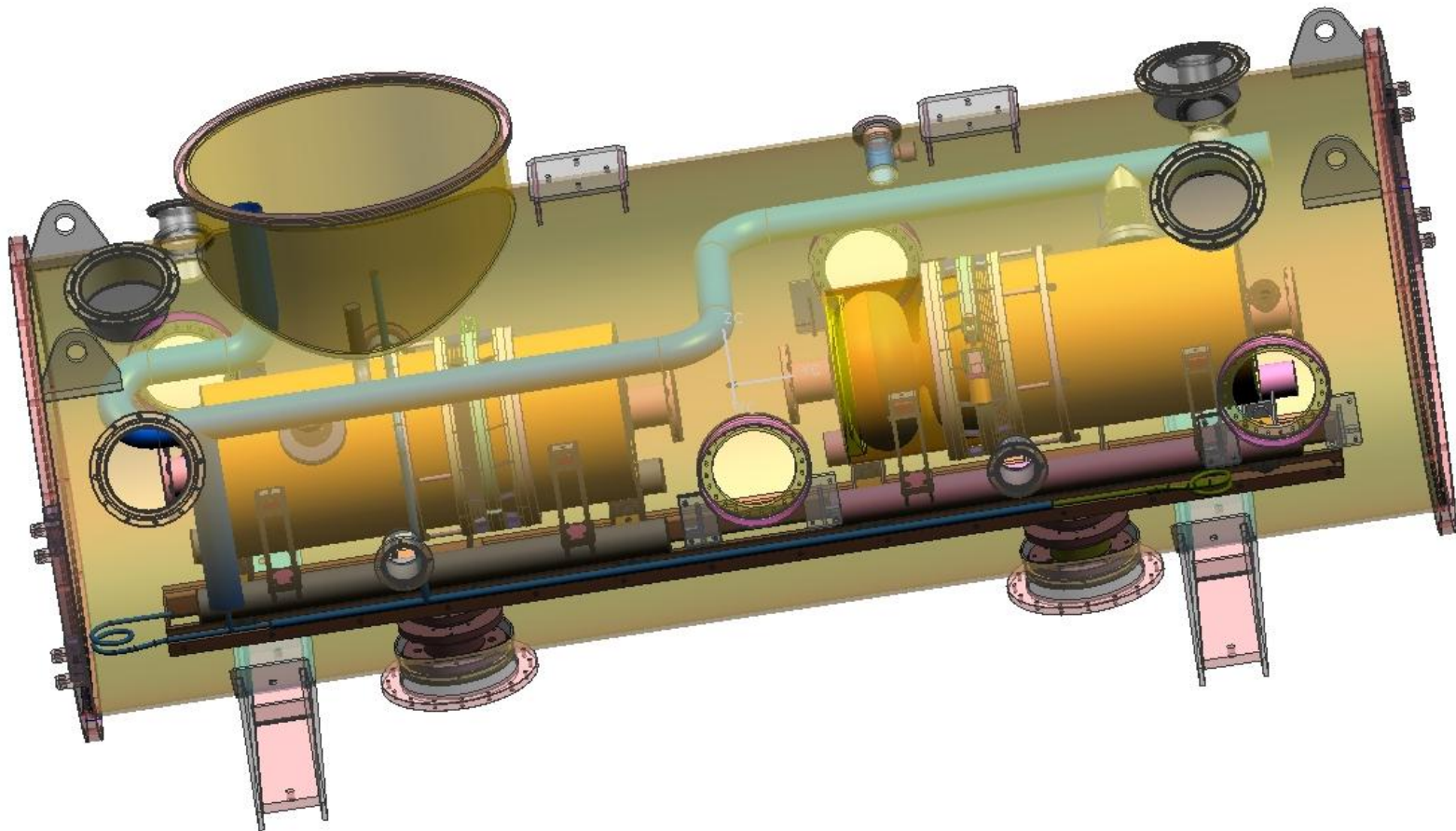


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# RRCAT: Horizontal Test Stand



- In collaboration with Fermilab RRCAT is developing a multipurpose CW, Horizontal Test Stand for Fermilab.





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# RRCAT: SRF Facility



- RRCAT in collaboration with Fermilab and TTC is developing a complete SRF cavity facility under one roof.
- It is design to take Nb Sheet to fully processed, dressed and tested cavities





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# Solid-state Amplifiers at 325 MHz



- BARC using the specifications provided by Fermilab is developing 325 MHz RF source for Project X.
- **Similar development is underway at RRCAT for 650 MHz**



## Preliminary test results

1. Center frequency : 325 MHz
2. Power output (CW) : 834 W
3. Gain : 22.2dB
4. Cooling : Water Cooled
5. Efficiency (Total) : 69.7%

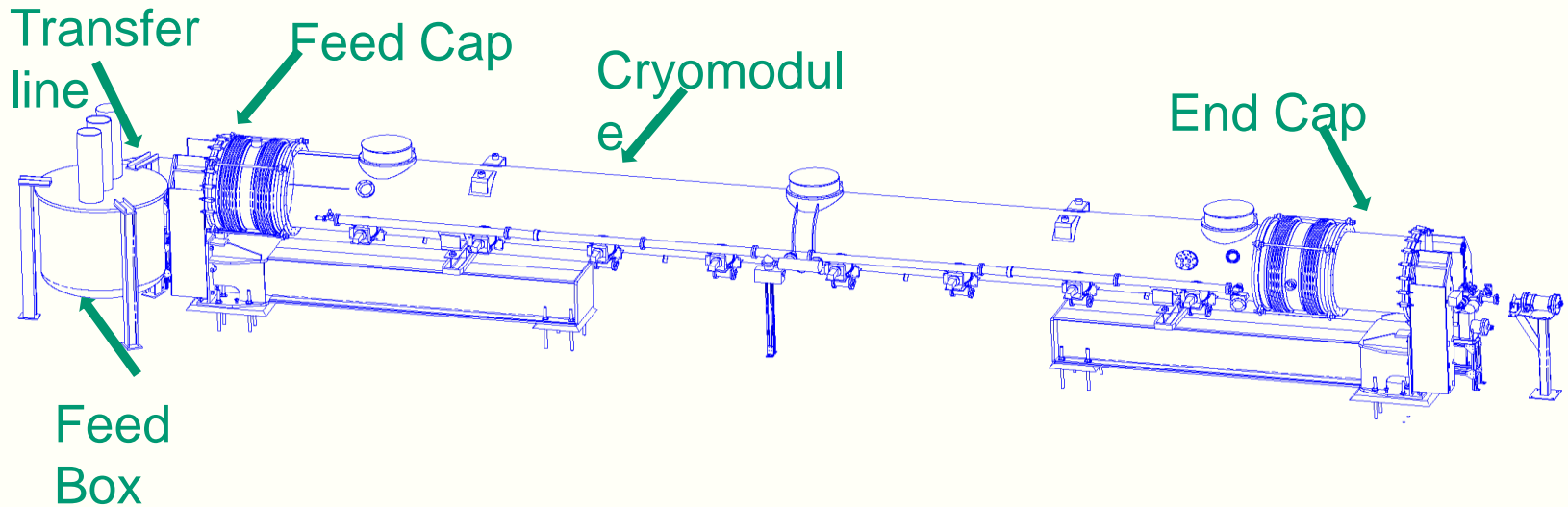


1 kW RF module



# BARC: Cryomodule Test Stand

- **Conceptual Arrangement of Feed Box, Feed Cap, End Cap & Transfer Lines.**



- **Status: Design & Drawing of all three sub assemblies is taken up. Ready to order material.**

- **CMTF (FY16): 650 MHz CW Test Stands for Project X**

- Install shielding, RF, cryo for PX test stands
- 1300 MHz (pulsed) CM test stand (with India)
- 650 MHz (CW) CM Test Facility (with India) ← Integrated System



- **Beam Position Monitor(BPM) for Project X**
- **C&I for CMTF**
  - **Integration of 325 MHz and 650 MHz Solid State RF systems developed in India.**
  - **RF Power Protection Interlock System**
  - **LLRF**
  - **Cryogenic Temperature Monitoring System**
  - **Software for the integrated operation of the CMTF from the control room**



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# IIFC – Accelerator 2010



Technical people in  
India ~100





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# What Next



- The magnitude of the Next Phases of the Project-X and Fermilab Experimental program Collaboration with India is very large.
  - DOE and DAE are negotiating this with help from the Indian Institutions and Fermilab Collaboration



USA

India

We  
are making a  
bridge from  
R&D to  
Construction



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# Project Annex I & II



## PROJECT ANNEX I

TO THE IMPLEMENTING AGREEMENT  
BETWEEN  
THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF  
AMERICA  
AND  
THE DEPARTMENT OF ATOMIC ENERGY  
OF THE REPUBLIC OF INDIA  
FOR COOPERATION  
IN THE AREA OF ACCELERATOR AND PARTICLE DETECTOR  
RESEARCH AND DEVELOPMENT FOR DISCOVERY SCIENCE  
FOR  
HIGH INTENSITY PROTON ACCELERATOR

Accelerator Collaboration  
Development

Physics Collaboration  
Development

## PROJECT ANNEX II

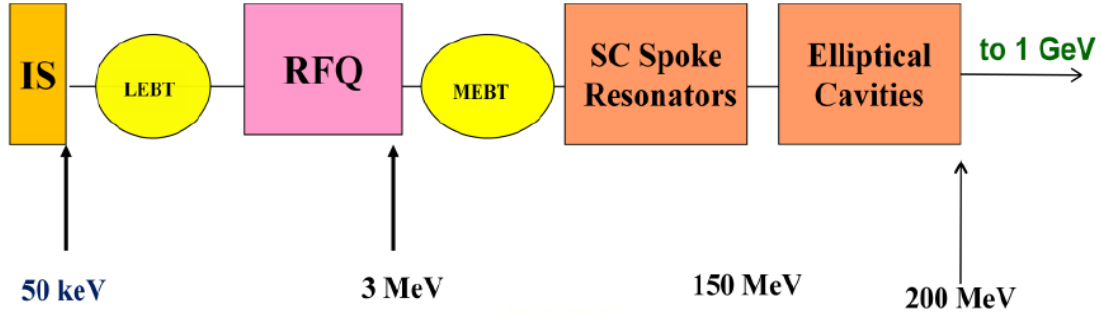
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IN THE AREA OF ACCELERATOR AND PARTICLE DETECTOR  
RESEARCH AND DEVELOPMENT FOR DISCOVERY SCIENCE  
FOR  
HIGH INTENSITY PROTON PHYSICS COLLABORATION

Being Negotiated by DAE and DOE/Fermilab



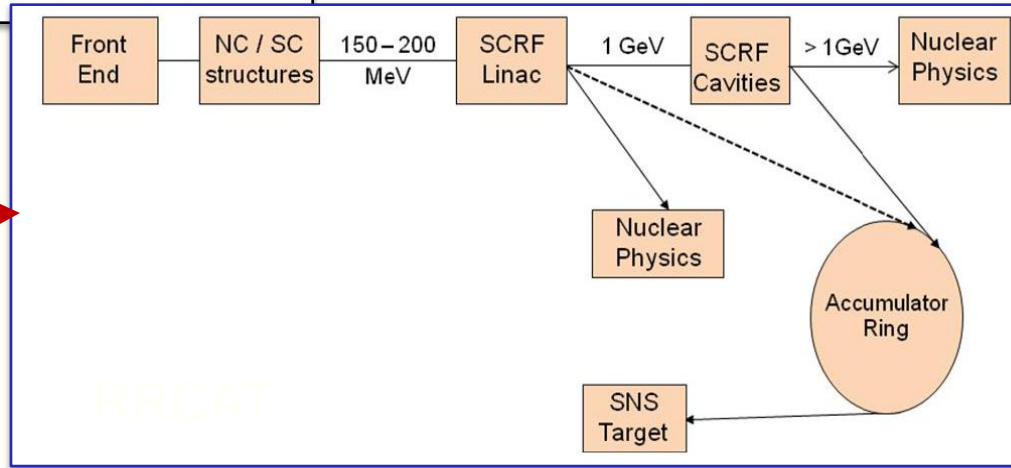
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# CD0 – CD1 in one Hour IIFC

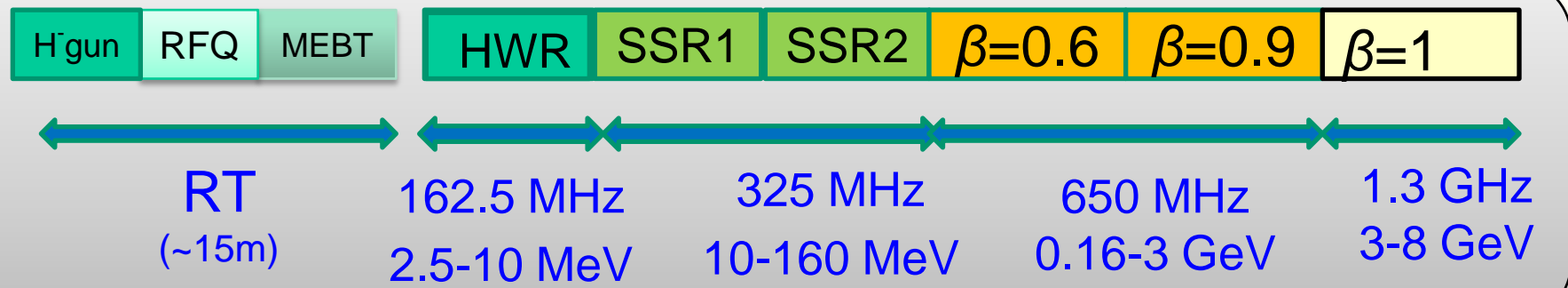


1 GeV CW Linac  
325 and 650 MHz

1-2 GeV Pulsed Linac  
325 and 650 MHz



Project X





# Indian DAE → Project-X



- Indian DAE laboratories working in collaboration with Indian industries and Fermilab are expected to deliver 1/2 of all the major technical components for the 3 GeV CW linac.

## IUAC:

- SSR1

## VECC:

- SSR1 Dressing,
- 325 MHz CM components  
 $\beta=0.6$ , 650 MHz, Cavity Dressing, Magnet etc

## BARC:

- SSR2 and CM components

- 325 MHz RF Power

- 325 MHz power coupler

- BPM, LLRF

- Controls

## RRCAT:

- $\beta=0.9$ , 650 MHz Cavity Dressing, Magnet etc
- 650 MHz RF Power

## DAE:

- Cryogenic plant



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# IIFC – v P



- **Eight Indian Institutions have joined the Fermilab Neutrino Physics Program.**
  - MINOS, MINOS+
  - LBNE
  - NOvA (**Just last week**)
- **We are expecting a total of 20 Ph.D. students from India under this program.**
  - **50% funded by the Indian Governments.**
  - **Faculties participation and infrastructure fully funded by India**
- **This collaboration is growing**
  - **We continue to include more institutions and**
  - **Recruiting faculties and postdoctoral fellows.**



GAURAV AGGARWAL  
Scientist-C  
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E-mail: [gaurav.dst@nic.in](mailto:gaurav.dst@nic.in)

भारत सरकार  
विज्ञान और प्रौद्योगिकी मंत्रालय,  
विज्ञान और प्रौद्योगिकी विभाग,  
टेक्नोलॉजी भवन, महारौली रोड,  
नई दिल्ली-110016

GOVERNMENT OF INDIA  
MINISTRY OF SCIENCE AND TECHNOLOGY,  
DEPARTMENT OF SCIENCE AND TECHNOLOGY,  
TECHNOLOGY BHAVAN, NEW MEHRAULI ROAD,  
NEW DELHI-110016

D.O No. SR/MF/PS-03/2010

02.04.2012

Dated .....

Sub: The proposal by Indian Physicists to Collaborate on Neutrino Projects at Fermilab (USA).

Dear Dr. Choudhary,

This is with reference to the above mentioned proposal.

I have to inform you that the above proposal has been sanctioned to 8 participating institutions at a total cost of Rs. 1106.96 lakh for a period of 3 years and sanction orders to all the participating institutions have been issued.

Kindly initiate necessary action for smooth implementation of the project.

With best regards,

**\$2.2M M&S**

Yours sincerely

(GAURAV AGGARWAL)

Dr. Brajesh Chandra Choudhary  
(Project Spokesperson)  
Department of Physics & Astrophysics  
University of Delhi  
Delhi - 110 007

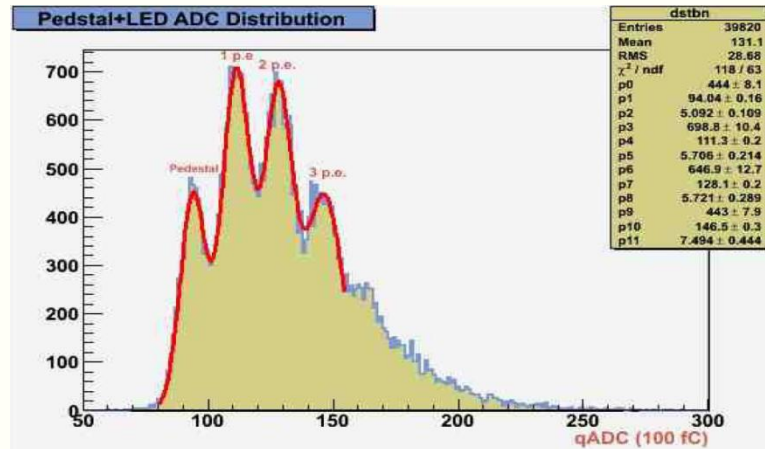
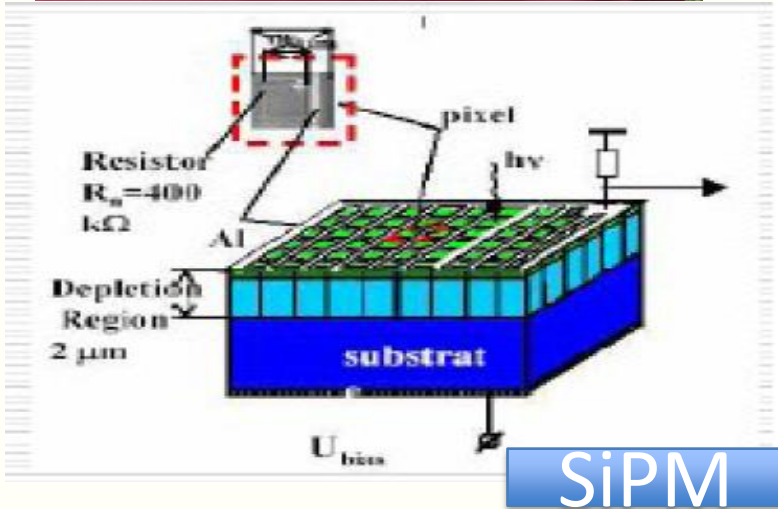
# Indian Participation in LBNE

- **Inspiration from the Indian Science Funding Agencies**
  - **The program is Physics Rich**
    - ✓ **Compelling Neutrino Physics**
      - ❖ *In long run expect dozens of Ph.Ds from Indian Institutions*
    - ✓ **Physics of Near Detector**
      - ❖ **Participation by Experimentalists / Engineers**
      - ❖ **Exploration by theorists due to richness of the program**
  - **Indian contribution should be significant and should have DAE-DST ownership**
    - ✓ **Design, built, and operate Magnet + ECal + Muon system**
  - **Contribution should have synergy with interest and expertise in India and with INO program**
    - ✓ **Expertise exists in magnet design, scintillator (for ECal and/or muon) and RPC (muon) detectors and SiPM (Ecal) readout**
    - ✓ **Compliments Indian Neutrino Observatory physics program**



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# Detector Development in India





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# Physics Collaboration



- Neutrino Physics
- Rare Decay (Kaon, Muon)
- Particle Physics with Nuclei
- Particle Production and Hyper Nuclei
- Nuclear Energy
- Detector R&D in support of these Physics program

**Considerable expertise exists in India to participate in these program and at the same time develop Indian programs**



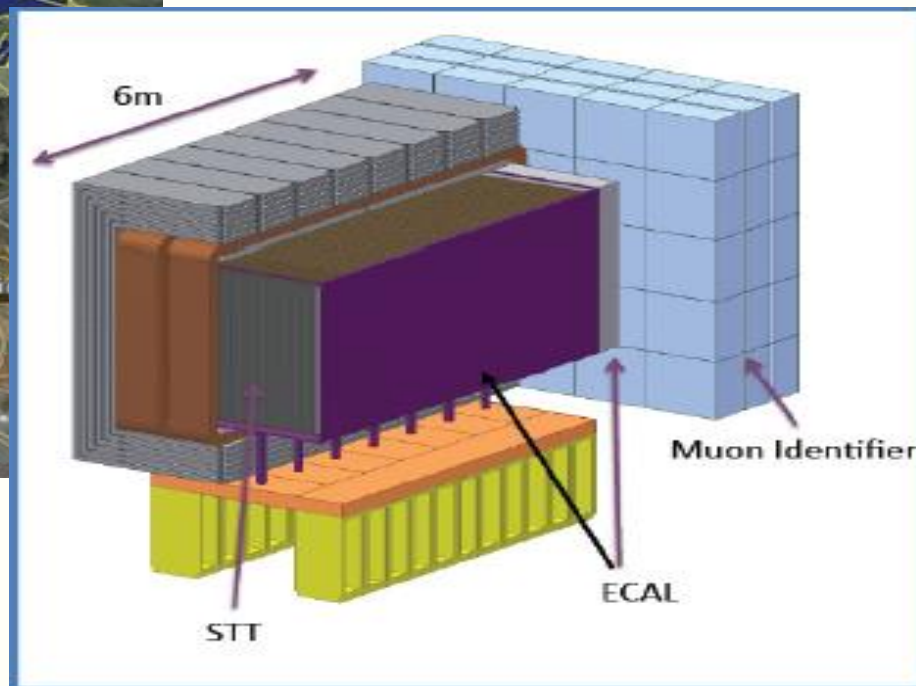


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# LBNE and India Collaboration



**Indian Institutions have proposed to take a leading role in the R&D, Construction and Operation of the LBNE Near Detector**





# Summary

- **Fermilab along with its US and Indian collaboration is making significant R&D, infrastructure and industrial progress that could lead to the Project X construction starting 2017.**
- **We have set the foundation of a very strong technical collaboration with Indian Institutions.**
  - **Fermilab has the support of DAE management**
  - **US-DOE and Indian DAE are working to finalize the next 10 yrs of funding. (two five years plans of India)**
- **Indian Institutions and Fermilab Collaboration could by 2025 lead to**
  - **LBNE (in South Dakota) on surface with 10Kt LAr (US-DOE) and a onsite near detector (Indian Contribution).**
  - **Project X (0-3 GeV CW) with US-DOE and Indian Contribution, with injection at 1 GeV into existing the Booster.**

# Thanks to All who helped

