# Making of a Large Accelerator (Indian Accelerator Program)

**Shekhar Mishra**

**Fermilab**

# Outline

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- Introduction
- Why Accelerator
- Major Accelerators of the world
- International Linear Collider
- Indian Accelerator Program
- Summary

# Introduction

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"It is an inherent obligation of a great country like India with its traditions of scholarship and original thinking and its great cultural heritage to participate fully in the march of science, which is probably mankind's greatest enterprise today." Pundit Jawaharlal Nehru

- **There are many fundamental questions that we need to answer to Understand the Nature of Nature"**
- **Basic Scientific Research and Accelerator development is driving the development of advanced technologies.**
- **Accelerators have become an integral part of our life.**
  - **Medical treatment**
  - **Development of medicine**
  - **Development of material**

# Large Accelerators: Crucial Questions

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- What is the nature of the Universe and what is it made of?
- What are the Matter, Energy, Space and Time?
- How did we get here and where are we going?
  - Profound understanding of the fundamental particles and the physical laws that govern matter, energy, space and time: “Standard Model”
  - Only ~5% of the universe is made up of normal, visible matter described by the Standard Model.
  - ~95% of the universe remains a mystery

We have a scientific revolution at hand.

# Quantum Universe

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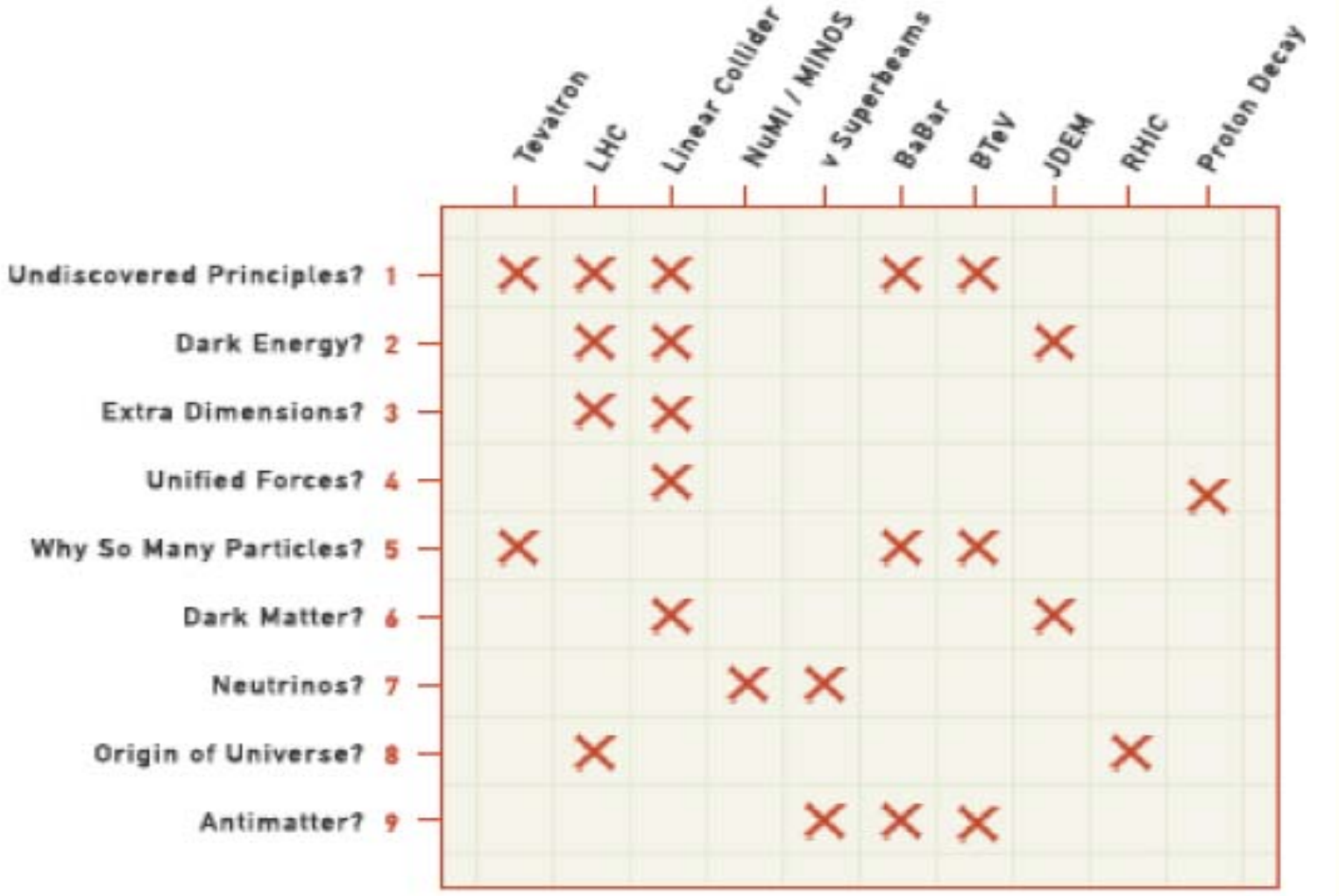
- Einstein's Dream of Unified Forces
  - Are there undiscovered principles of nature: New Symmetries, New Physics Laws?
  - How can we solve the mystery of Dark Energy?
  - Are there Extra Dimensions of Space?
  - Do all the forces become one?
- The Particle World
  - Why are there so many kinds of particles?
  - What is the Dark Matter? How can we make it in the laboratory?
  - What are neutrinos telling us?
- The Birth of Universe
  - How did the Universe come to be?
  - What happened to the antimatters?

# Quantum Universe: THE QUESTIONS



# Highest Energy Collider: Fermilab

Greatest window into new phenomena until LHC starts in 2008-9.

# International Collaboration

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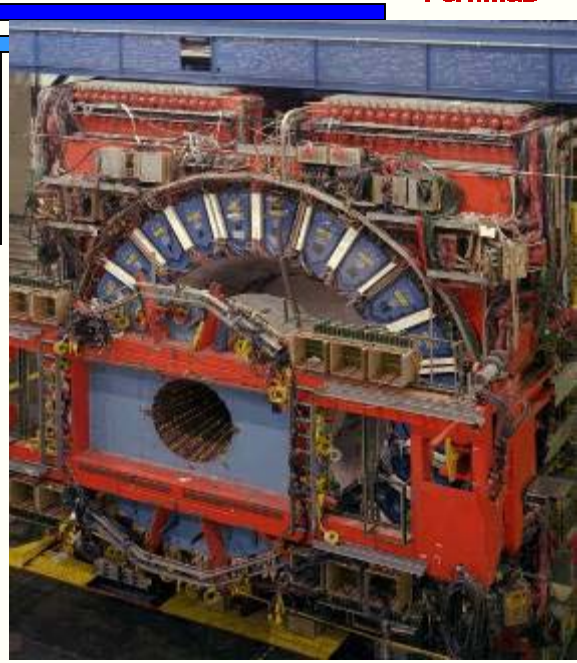
CDF
11 Countries



D0
18 Countries

MINOS
6 Countries

CMS
36 Countries

# Accelerators and the Energy Frontier

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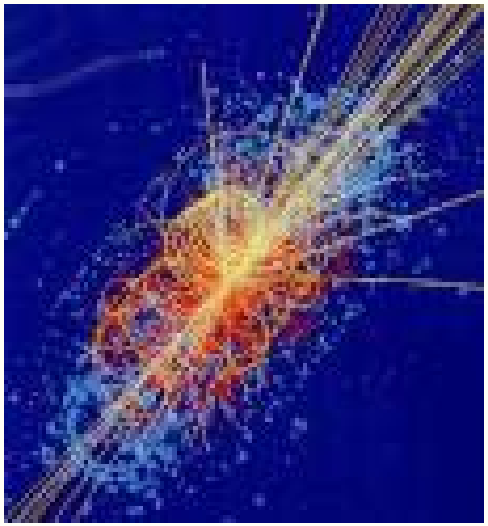
## Large Hadron Collider
## CERN – Geneva Switzerland



India has contributed significantly to the LHC.

# Why $e^+e^-$ Collisions ?

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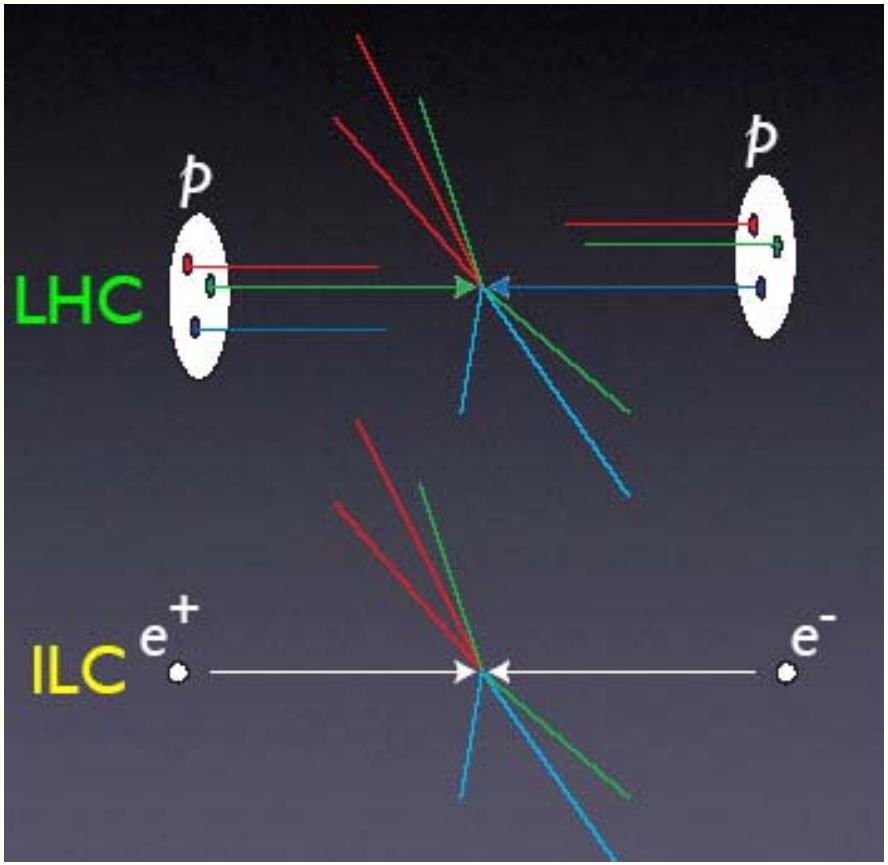
Next proposed large accelerator is an e+e- collider.

- elementary particles
- well-defined
  - energy,
  - angular momentum
- uses full Center Of Mass energy
- produces particles democratically
- can mostly fully reconstruct events



# The International Linear Collider

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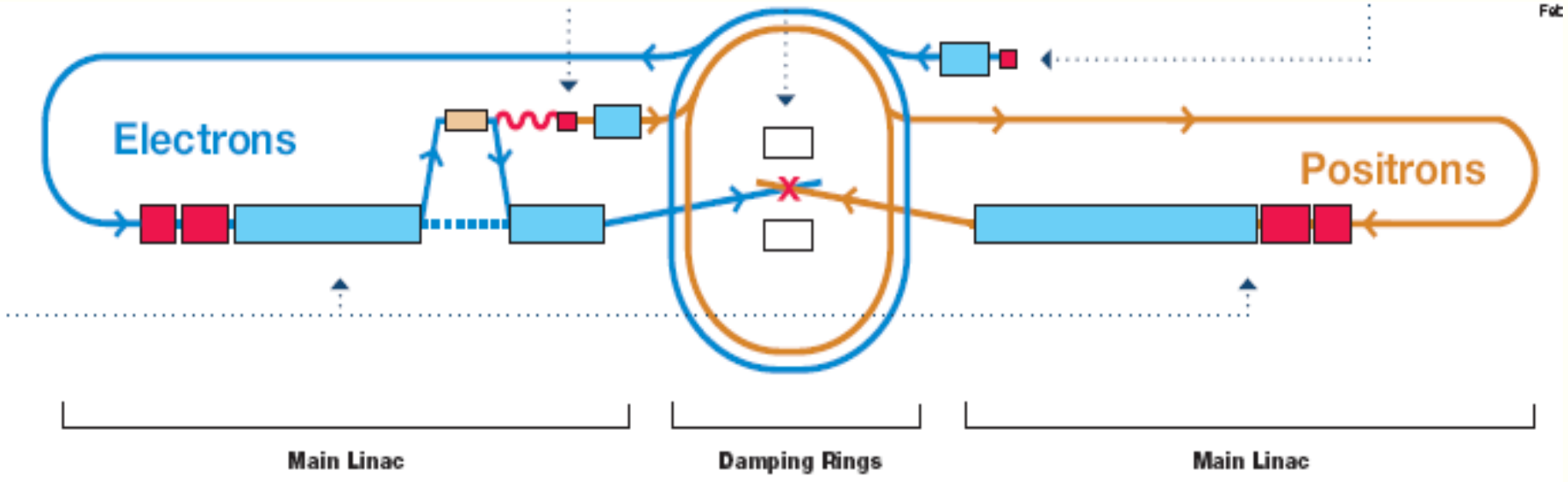
## The Baseline Machine (500 GeV)




ILC is one of the most complex accelerator with considerable technical and management challenges.

# Technical Challenge

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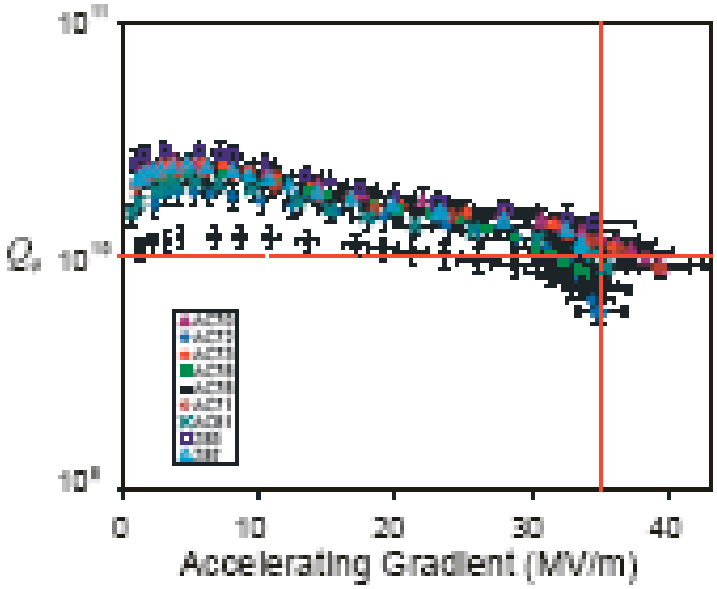
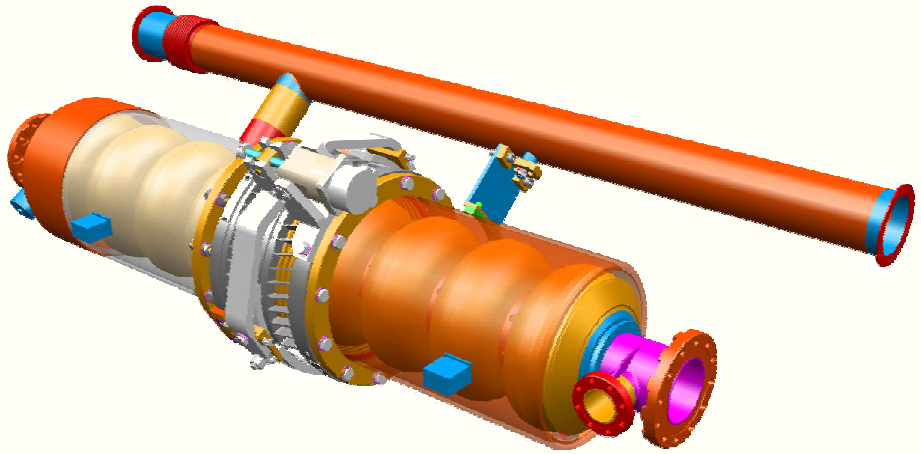
- Accelerating Gradient 35 MV/m
- Electron Cloud effect in the positron ring
- Preservation of small emittance in long linac
- Collision of two small size (10s nanometer beams)



# ILC Cryomodule 3-D Model

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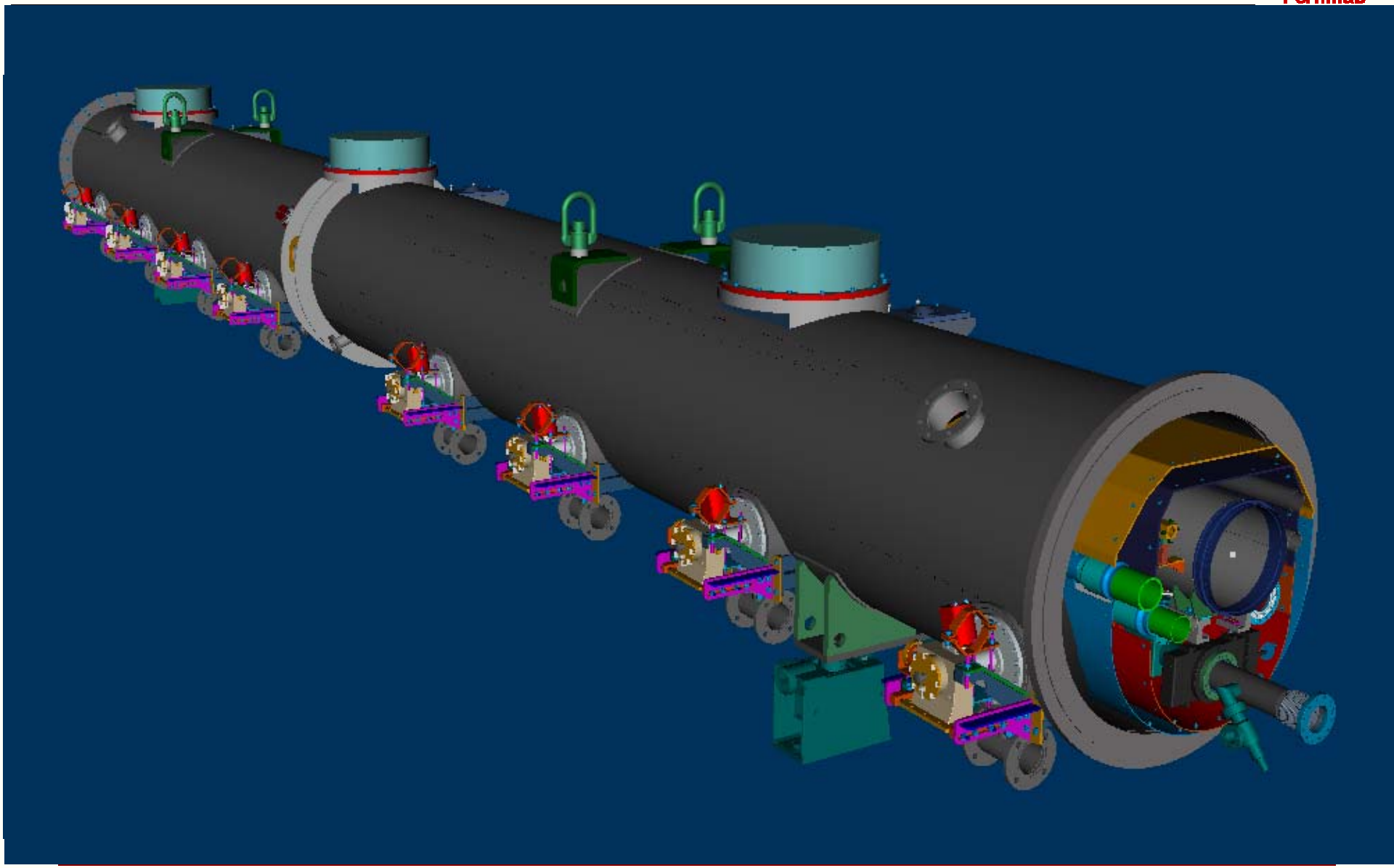

# India HEP Collaboration in the world

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- Indian scientists have been collaborating at CERN for decades.
- Its participation and contribution to LHC has given India an Associate Member State status with CERN.
- India has build accelerator and detector components for LHC/CMS.
- India also participates in experiments at KEK and DESY.

# 20 Years of Indo-US HEP Collaboration

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- **Indian Scientists have collaborated in a High Energy Physics Experiments from early 80's at Fermilab and other US laboratories.**
- **At Fermilab the collaboration started with Fixed Target Experiment and has now extended to D0 and Accelerator.**
- **Argonne National Laboratory has collaborated with India on Superconducting cavity development.**
- **Six Institutes from India collaborates on the STAR experiment at BNL.**
- **Many US laboratories have worked with Indian laboratories**
- **Indians are on staff of every US laboratories, universities and major US industries.**

# Indian Accelerator Laboratories

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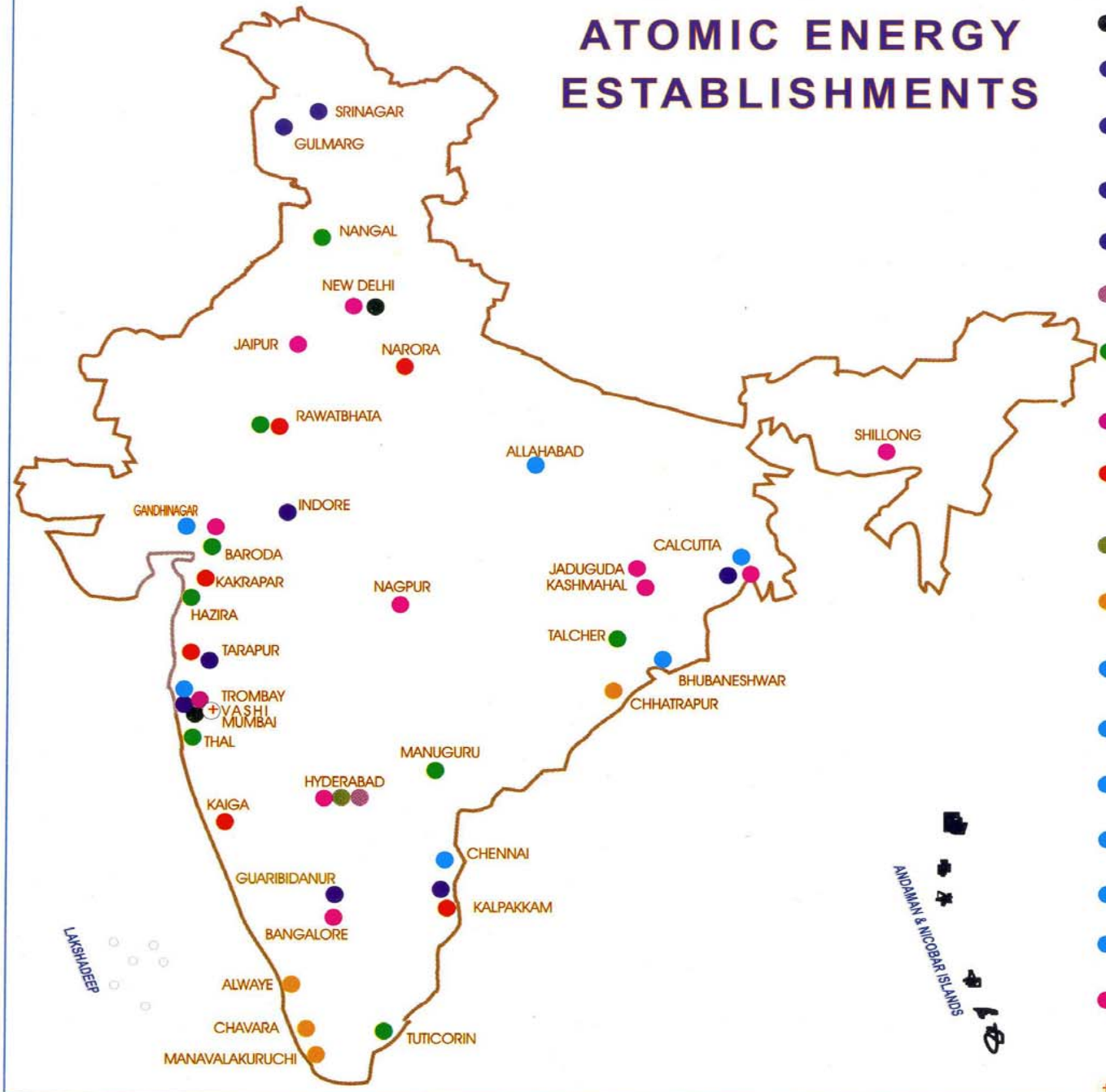
- Several Indian accelerator laboratories are in construction and/or operation today
  - VECC
  - RRCAT
  - BARC-TIFR
  - IUAC
- India collaborates on accelerators construction and operation around the world, including Fermilab and CERN.
- India has plans in place to develop modern accelerator for applied research and energy production R&D.
  - Radioactive Ion Beam Facility
  - Spallation Neutron Source
  - High Intensity Proton Linac for Accelerator Driven Sub-critical Reaction

# ATOMIC ENERGY ESTABLISHMENTS




- DEPT. OF ATOMIC ENERGY SECRETRIATE
  MUMBAI & BR. SECRETRIATE, NEW DELHI
- VARIABLE ENERGY CYCLOTRON CENTRE, CALCUTTA
- BHABHA ATOMIC RESEARCH CENTRE
  TROMBAY, TARAPUR, SRINAGAR, GULMARG, GAURIBIDANUR
- INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH, KALPAKKAM
- CENTRE FOR ADVANCED TECHNOLOGY, INDORE
- NUCLEAR FUEL COMPLEX, HYDERABAD
- HEAVY WATER PLANTS
  NANGAL, RAWATBHATA, BARODA, TALCHER, TUTICORIN, MANUGURU, THAL, HAZIRA
- BOARD OF RADIATION & ISOTOPE TECHNOLOGY. TROMBAY, VASHI.
- NUCLEAR POWER STATIONS,
  TARAPUR, RAWATBHATA, KALPAKKAM, NARORA, JADUGUDA, KAKRAPAR & KAIGA PROJECT.
- ELECTRONICS CORPN. OF INDIA LTD., HYDERABAD.
- INDIAN RARE EARTHS LTD.
  ALWAYE, CHAVARA, MANAVALAKURUCHI, CHHATRAPUR
- TATA INSTITUTE OF FUNDAMENTAL RESEARCH, MUMBAI
- INSTITUTE FOR PLASMA RESEARCH, GANDHINAGAR
- SAHA INSTITUTE OF NUCLEAR PHYSICS, CALCUTTA
- INSTITUTE OF PHYSICS, BHUBANESHWAR
- INSTITUTE OF MATHEMATICAL SCIENCES, CHENNAI.
- MEHTA RESEARCH INSTITUTE, ALLAHABAD
- ATOMIC MINERALS DIVISION
  HYDERABAD, NAGPUR, BANGALORE, JADUGUDA, BARODA, JAIPUR, NEW DELHI, KASHMAHAL, CALCUTTA, SHILLONG.
- \+ TATA MEMORIAL CENTRE, MUMBAI

# 224 CM VARIABLE ENERGY CYCLOTRON AT VECC

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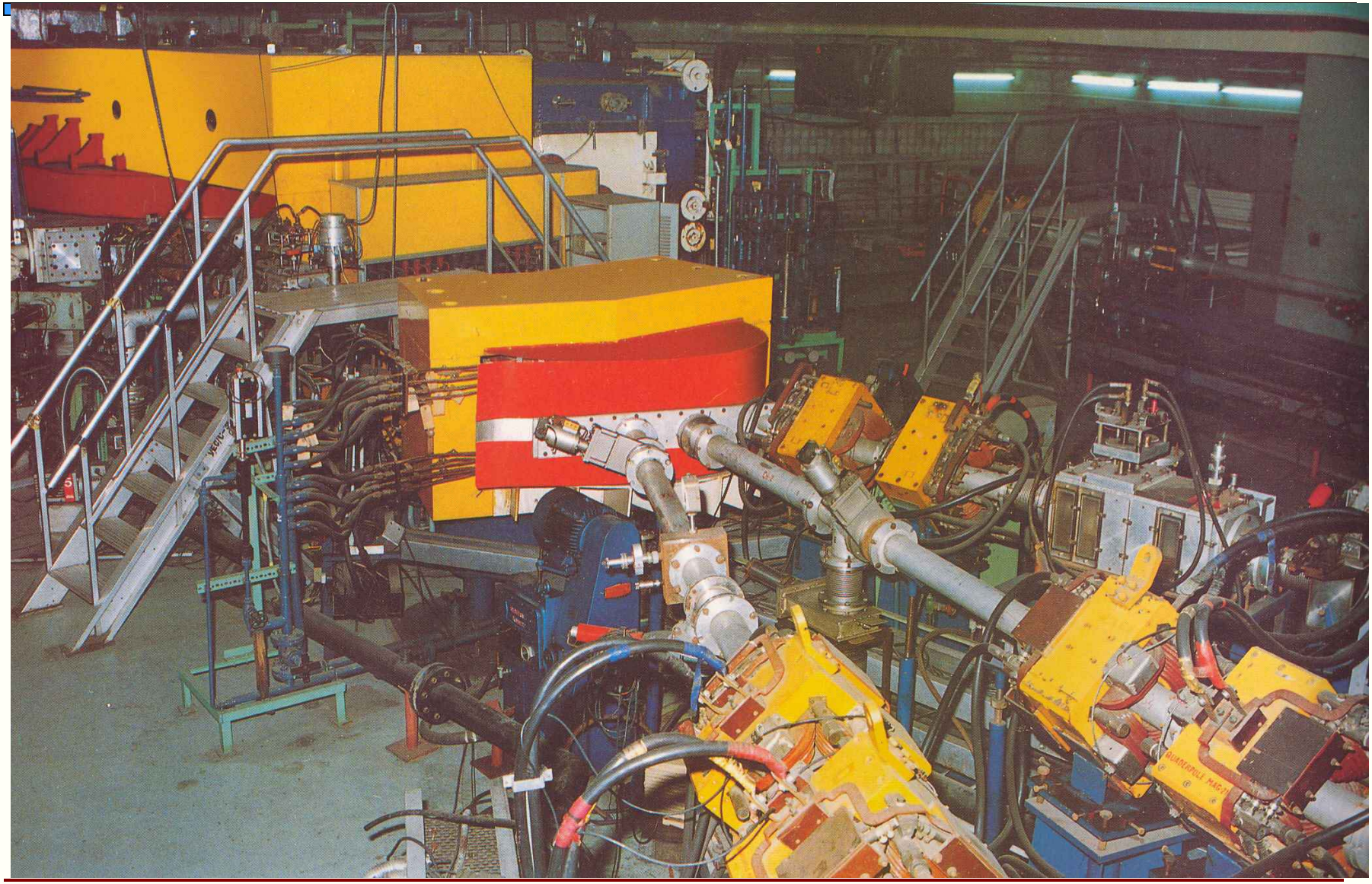
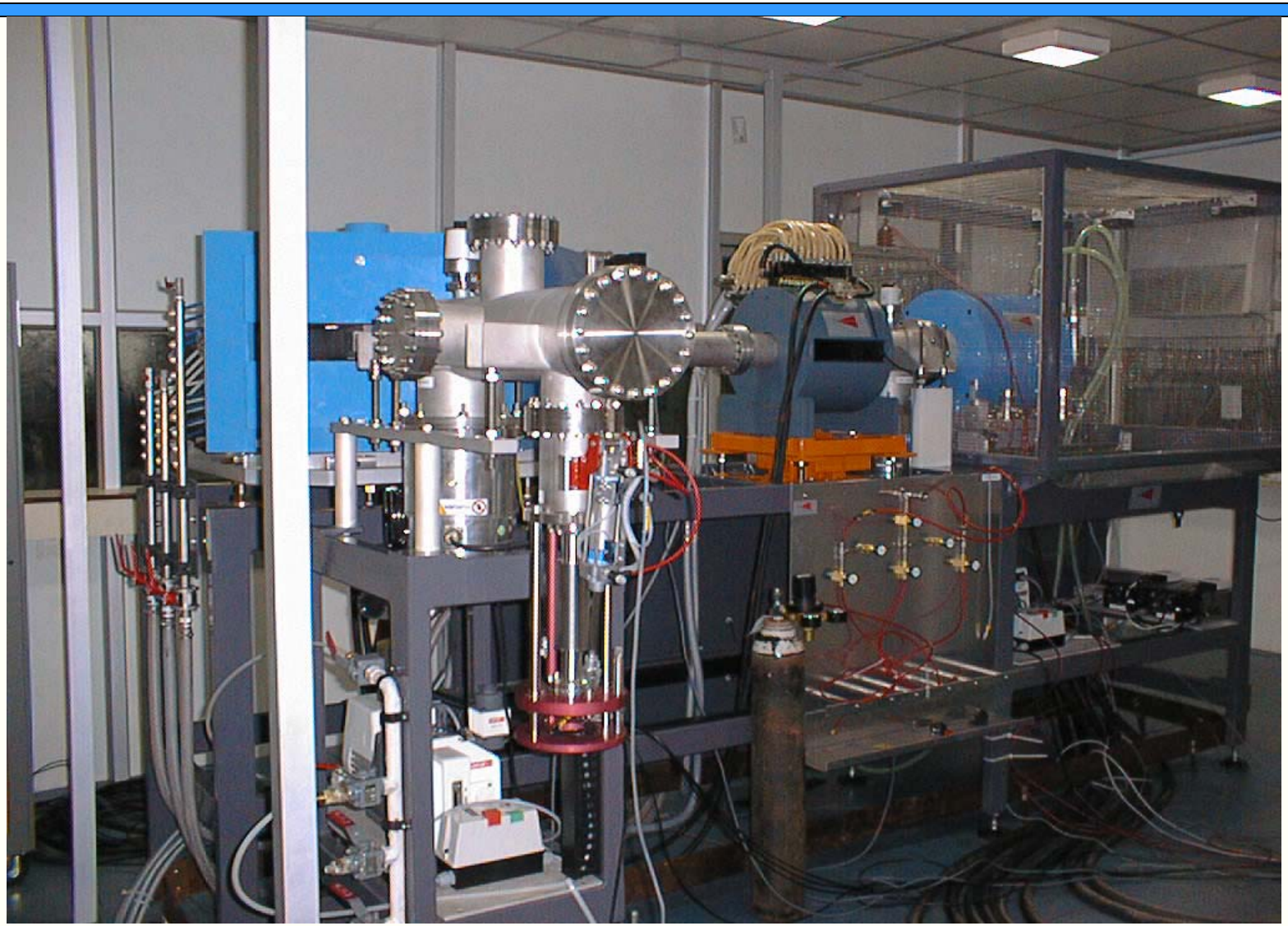


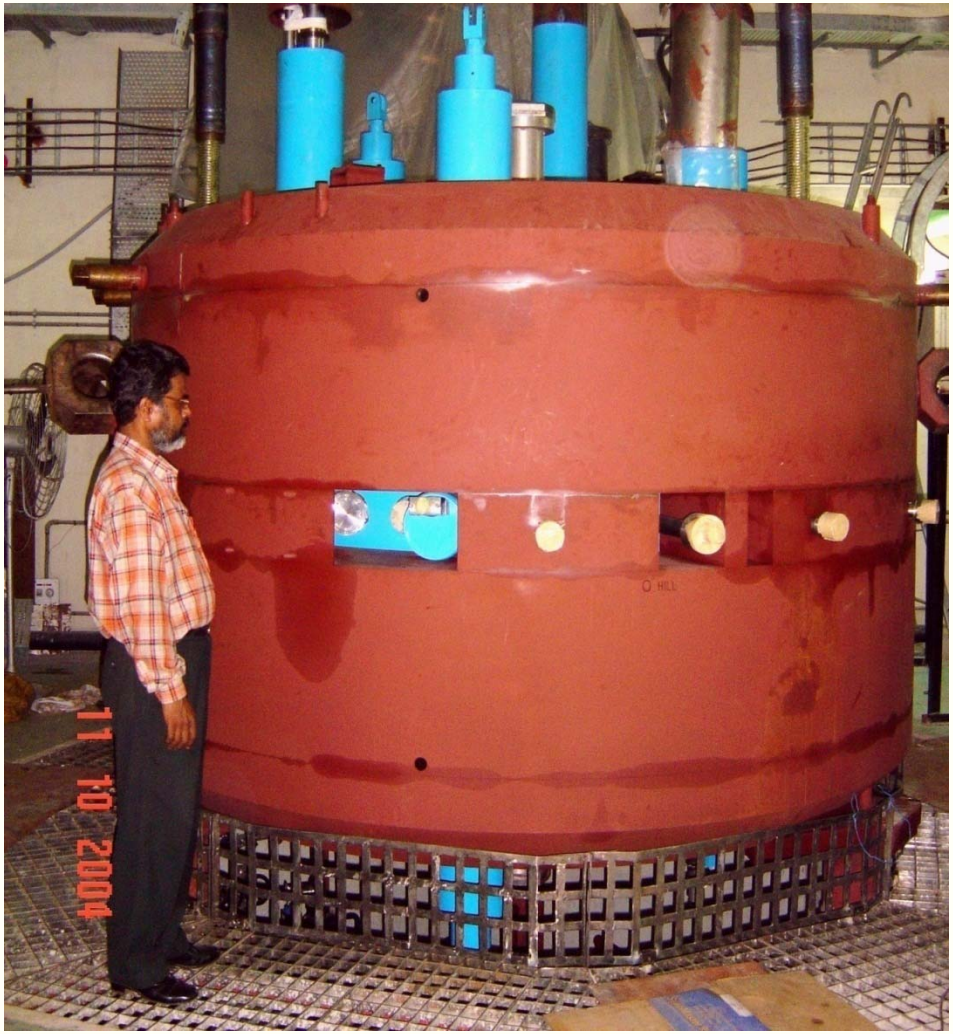
# ION SOURCE AND ANALYZING MAGNET : VECC

Fermilab

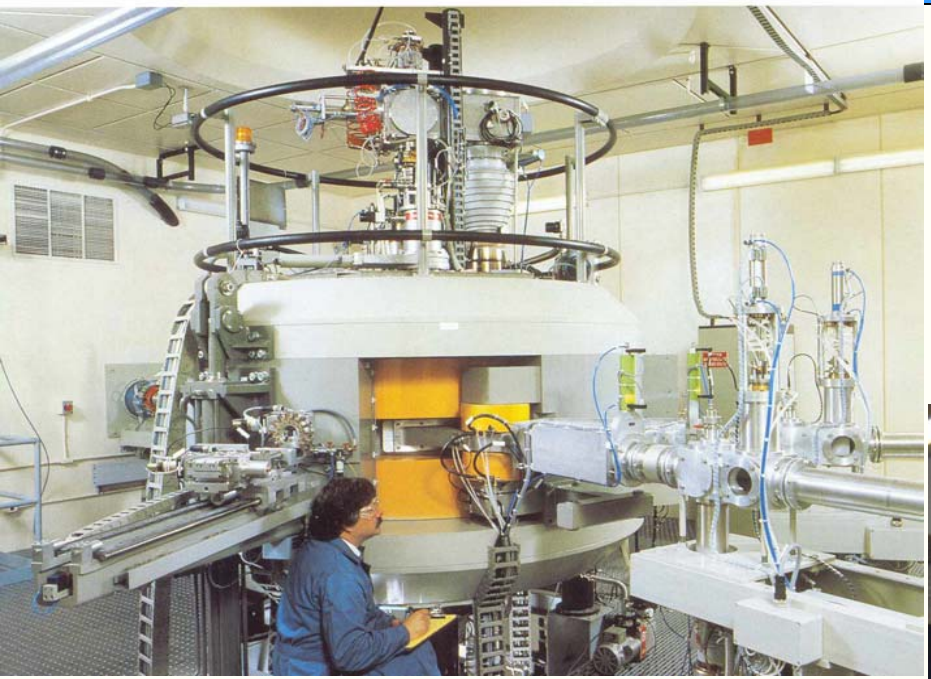


# CYCLOTRON MAGNET VECC

Fermilab

# Medical Accelerator: VECC

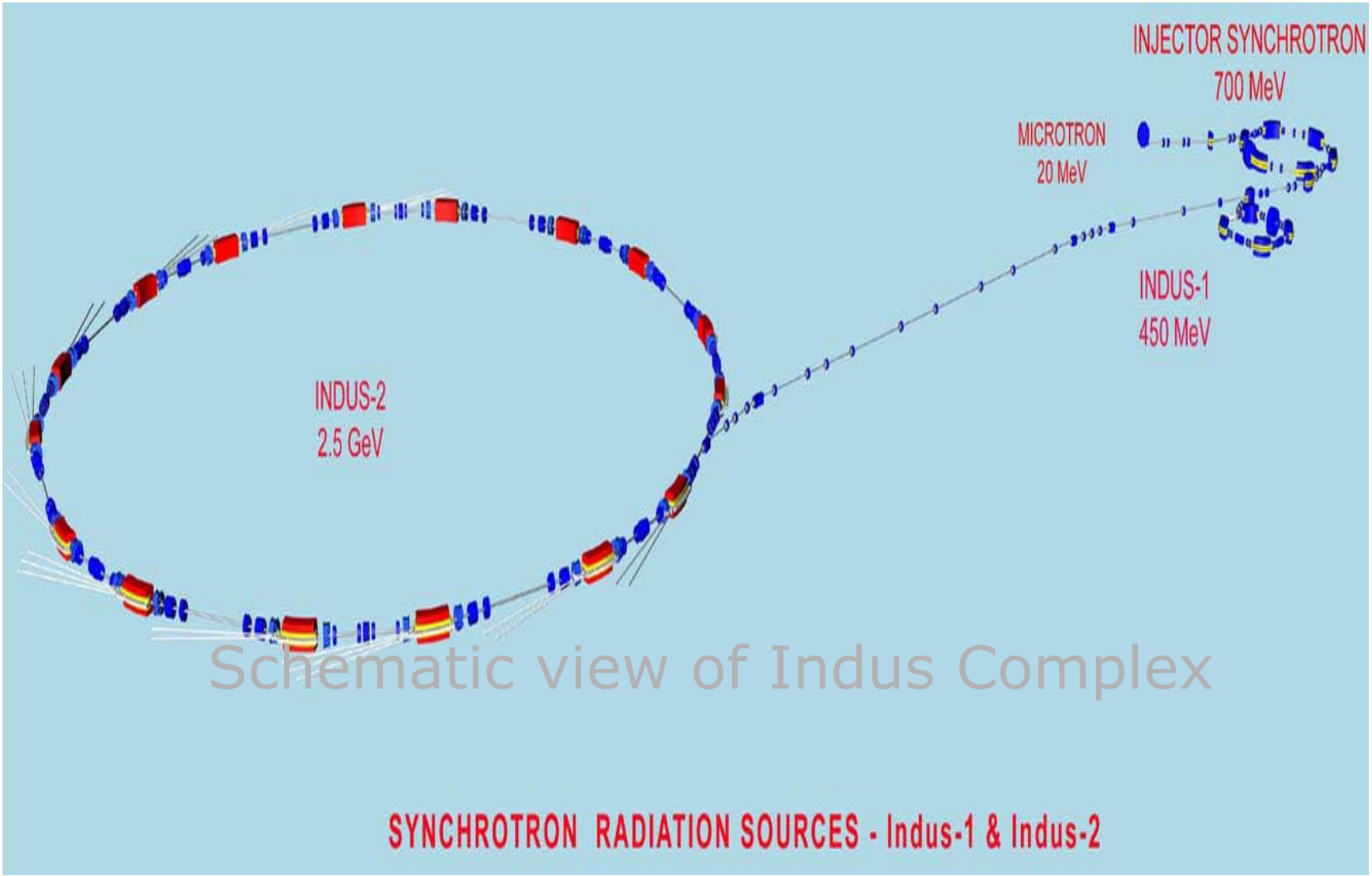


Medical Cyclotron

## 4 MV MEDICAL LINAC
## JEEVAN JYOTI - 2

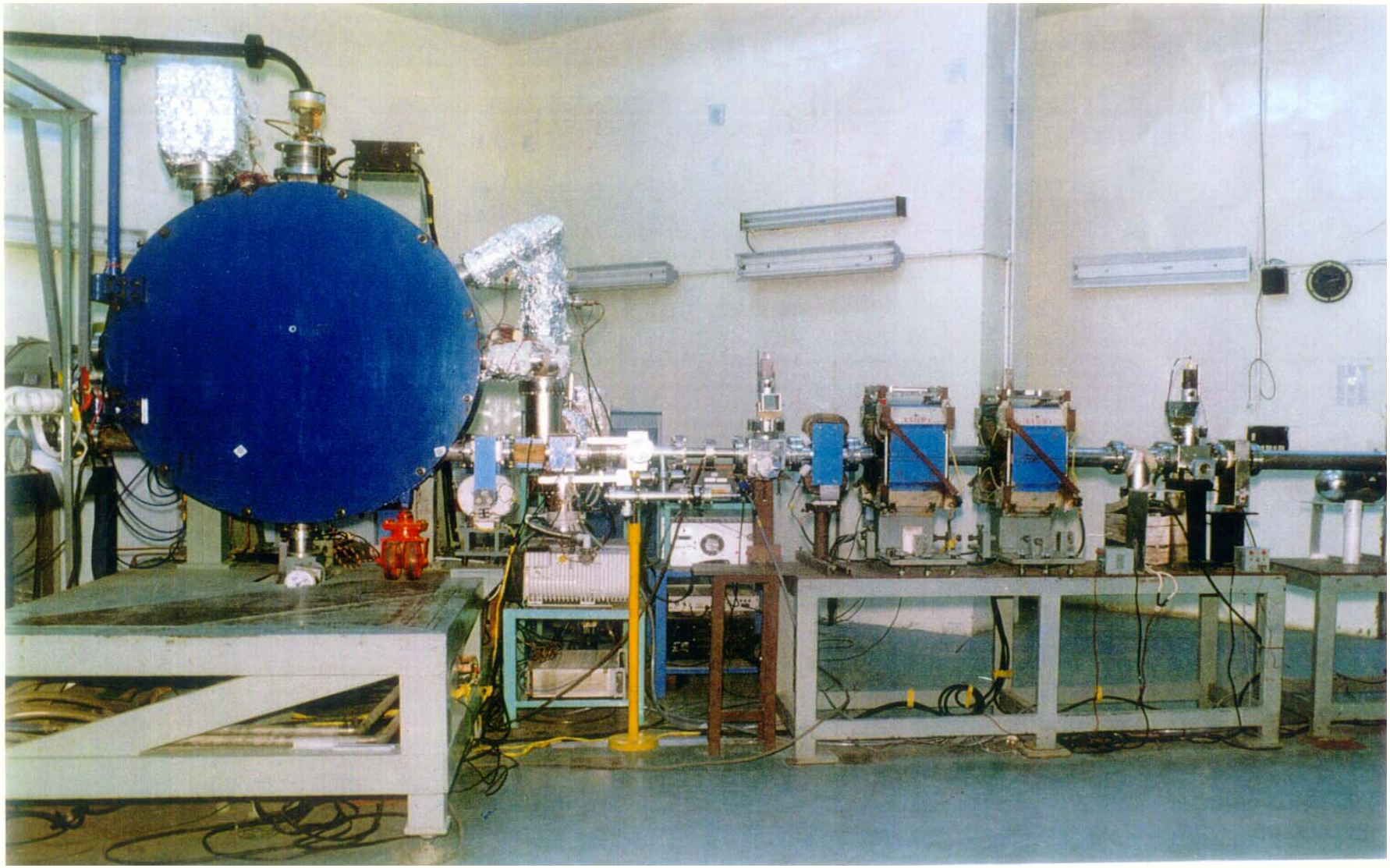
# RRCAT Accelerator Complex

Fermilab



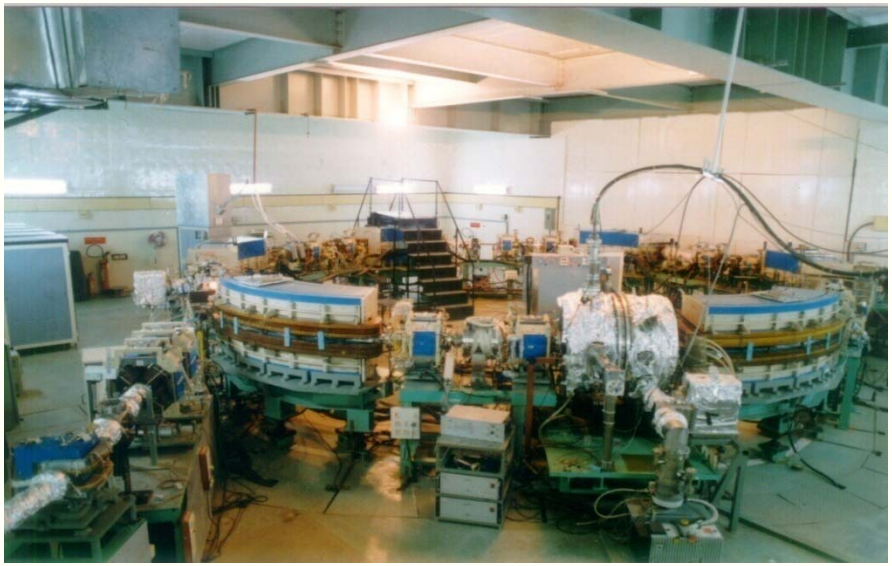
# RRCAT: Microtron

Fermilab



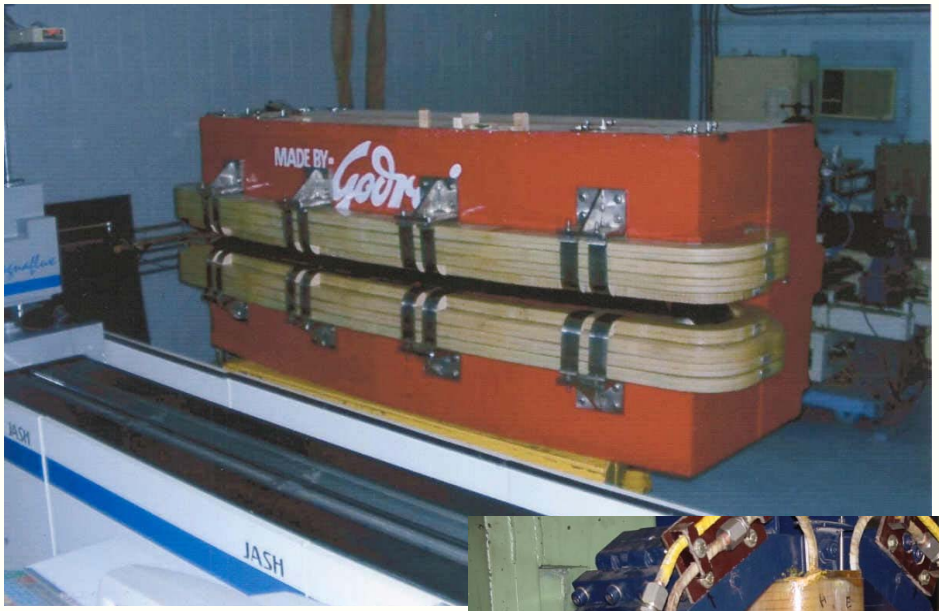
# RRCAT: Booster

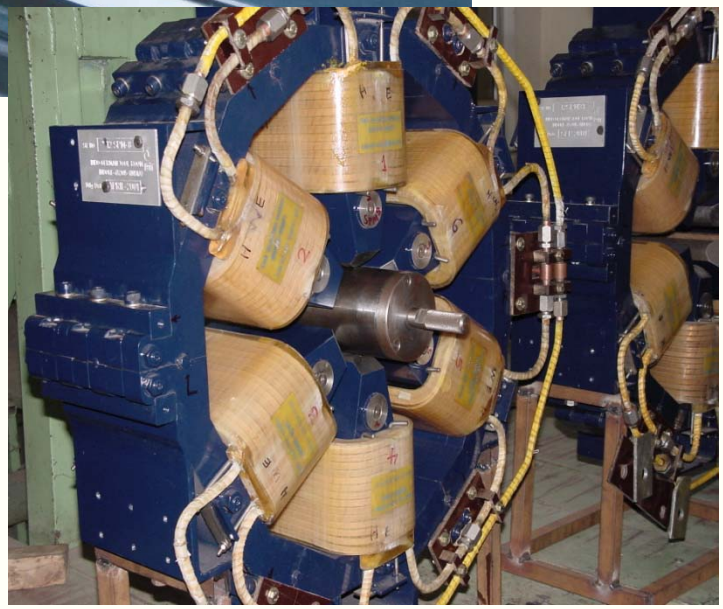
Fermilab

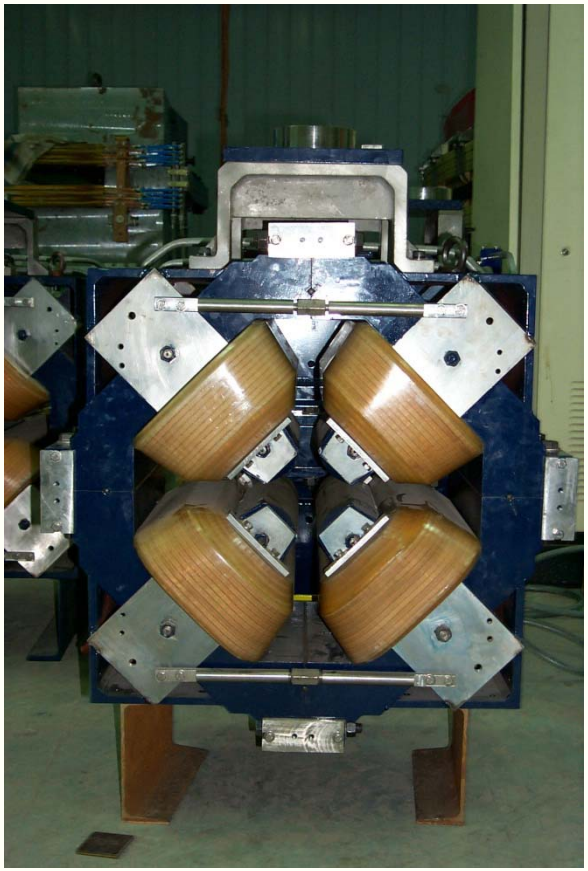


# Magnet for Indus-2 made by India

Fermilab





# Dipole Chambers Build in India

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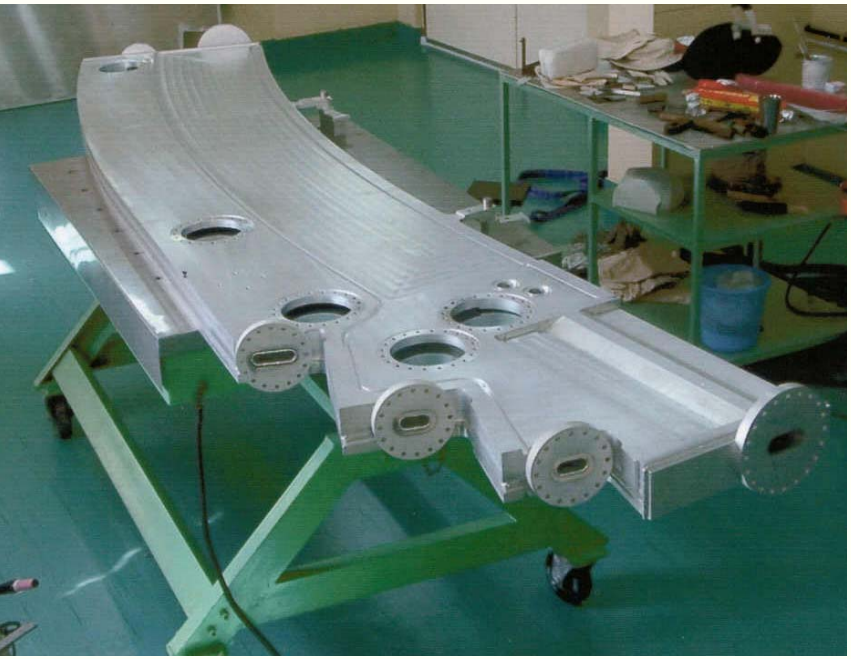
- Material: Aluminium alloy A5083-H321
- Two beam ports at $5^0$ and $10^0$ in each dipole chamber
- Additionally, port at $0^0$ is also provided in five dipole chambers for insertion devices



# Indus-II

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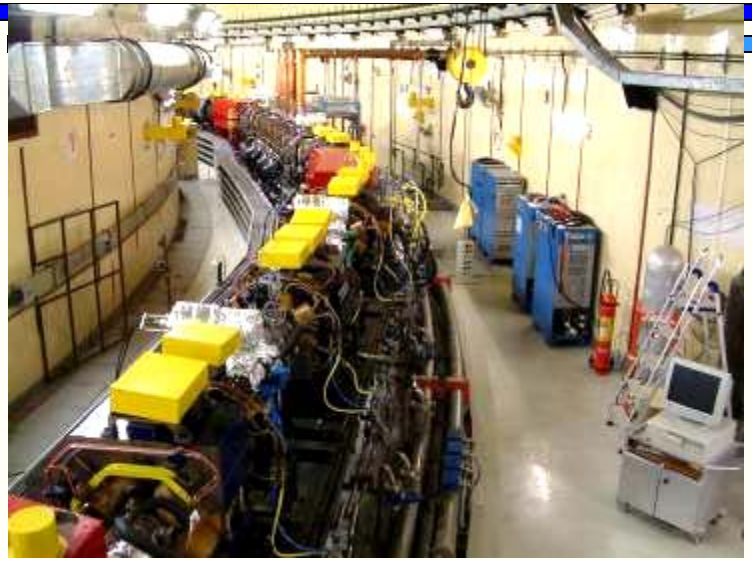


Indus-2 Ring in the Tunnel

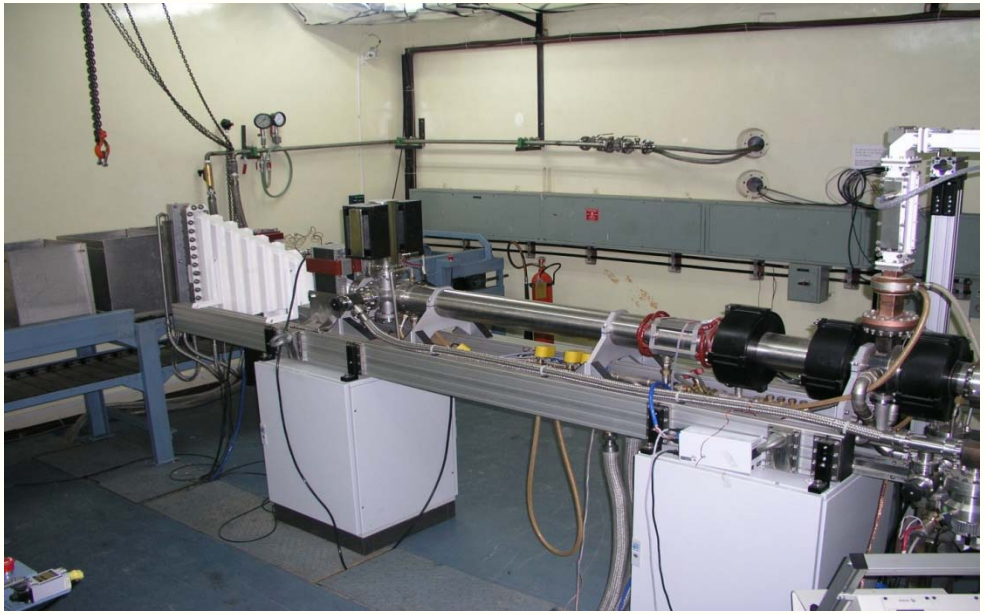
RF Cavities installed in Indus-2 Ring

Long Straight Section LS-6 Assembly

Transport Line-3 Joining on to Indus-2

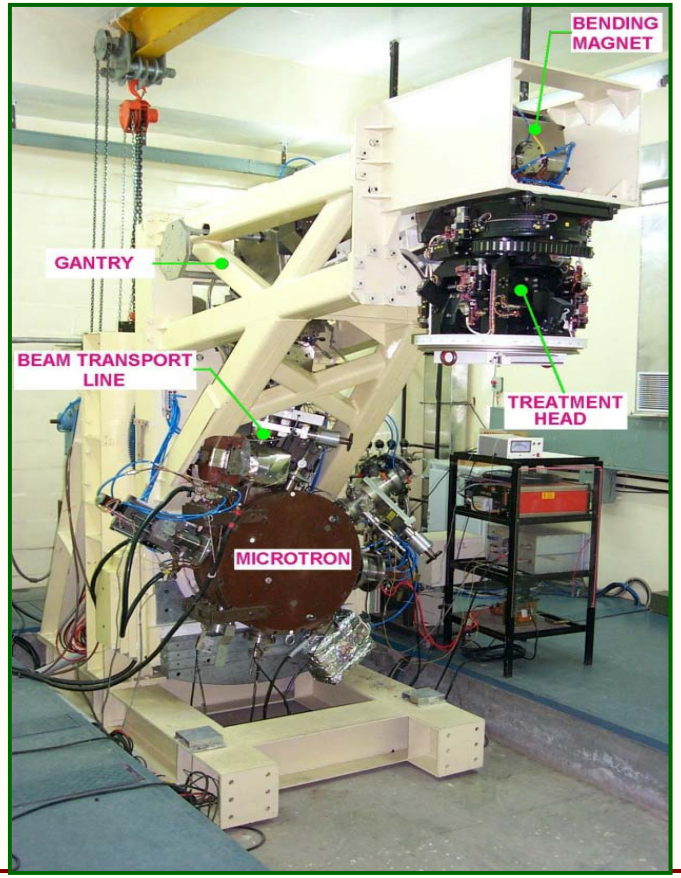
# RRCAT: Application Accelerator

Fermilab



10 MeV Electron Accelerator for Radiation Processing Applications

Microtron based prototype irradiator for life science related work



# India: LHC Collaboration

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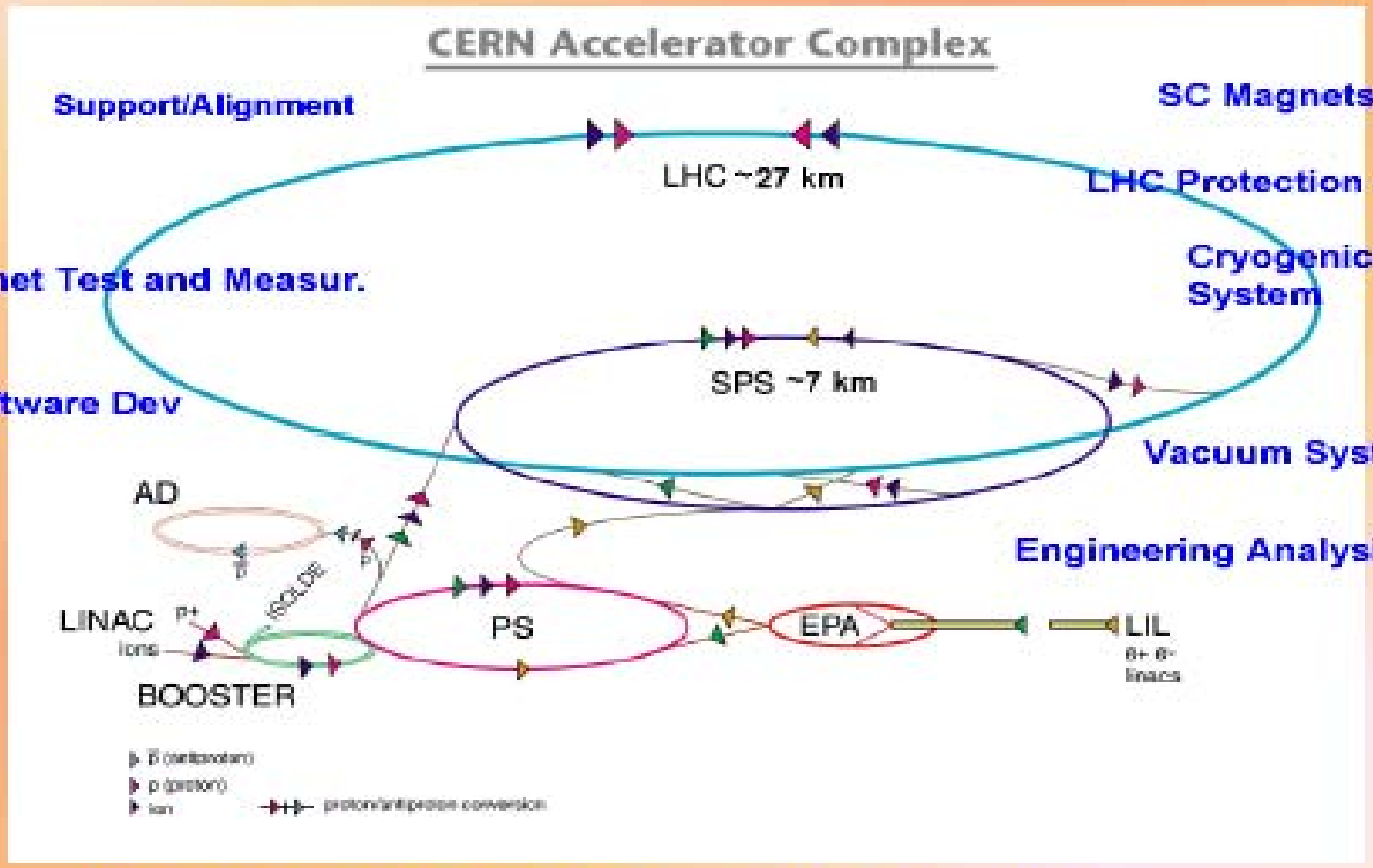


Indian Contributions – LHC domains

# LHC Contributions

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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

# BARC-TIFR Heavy Ion Accelerator

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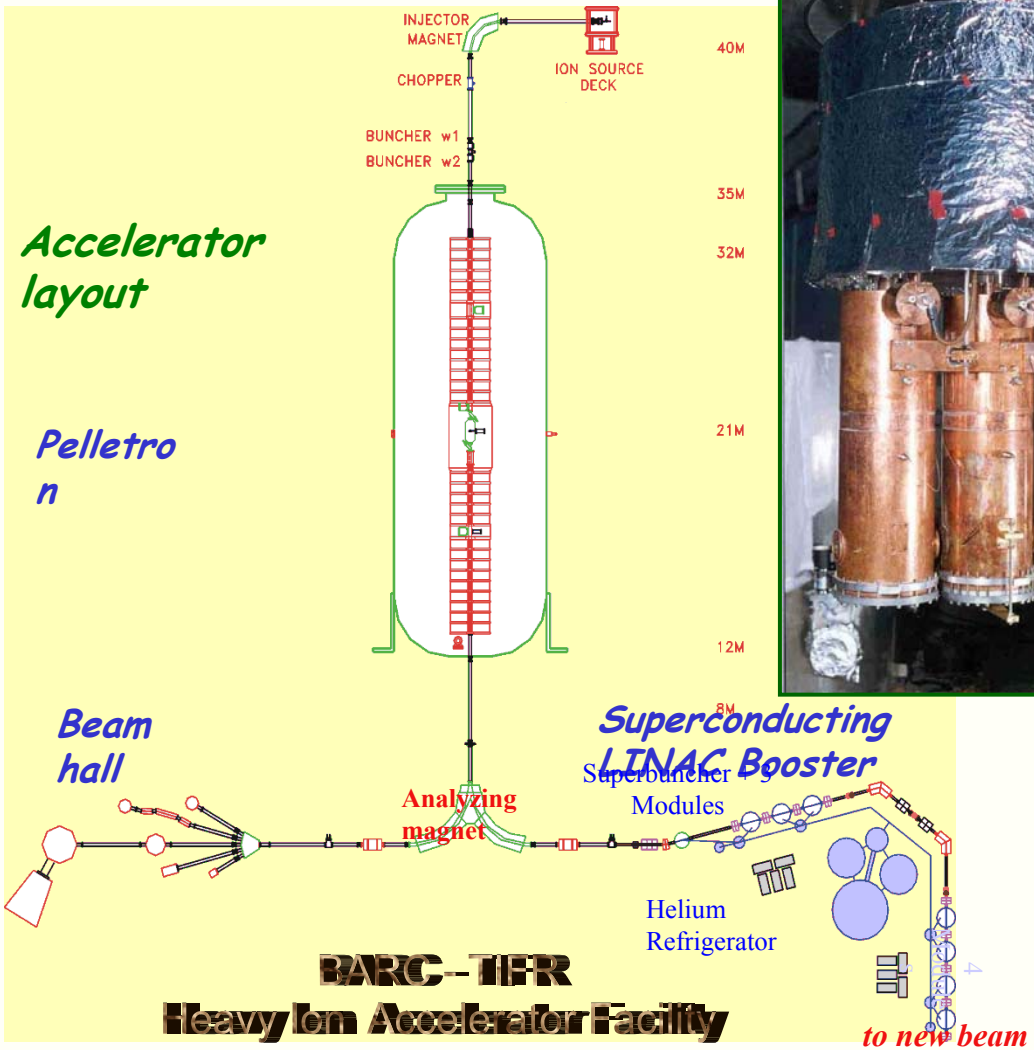


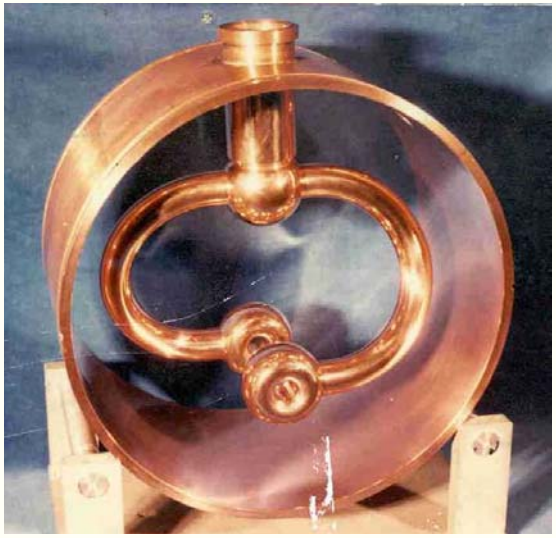

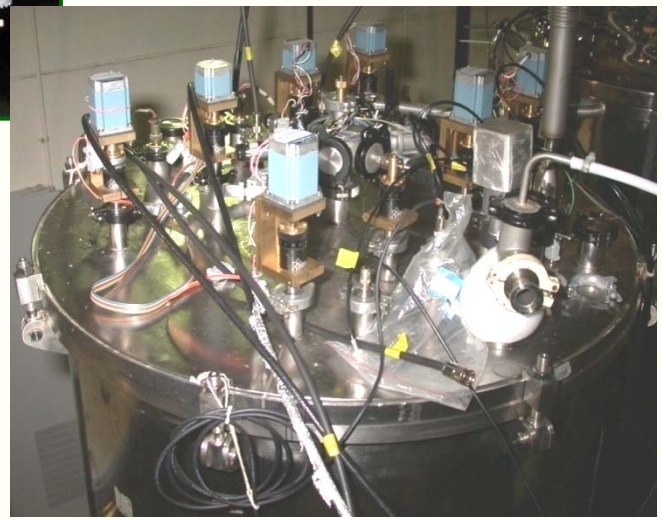

Cryostat modules housing the resonators with liquid He distribution box

# SCRF Facility at IUAC

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Electro-Polishing

BCP

Electron Beam
Welding Machine

# SCRF Cavity Build at IUAC

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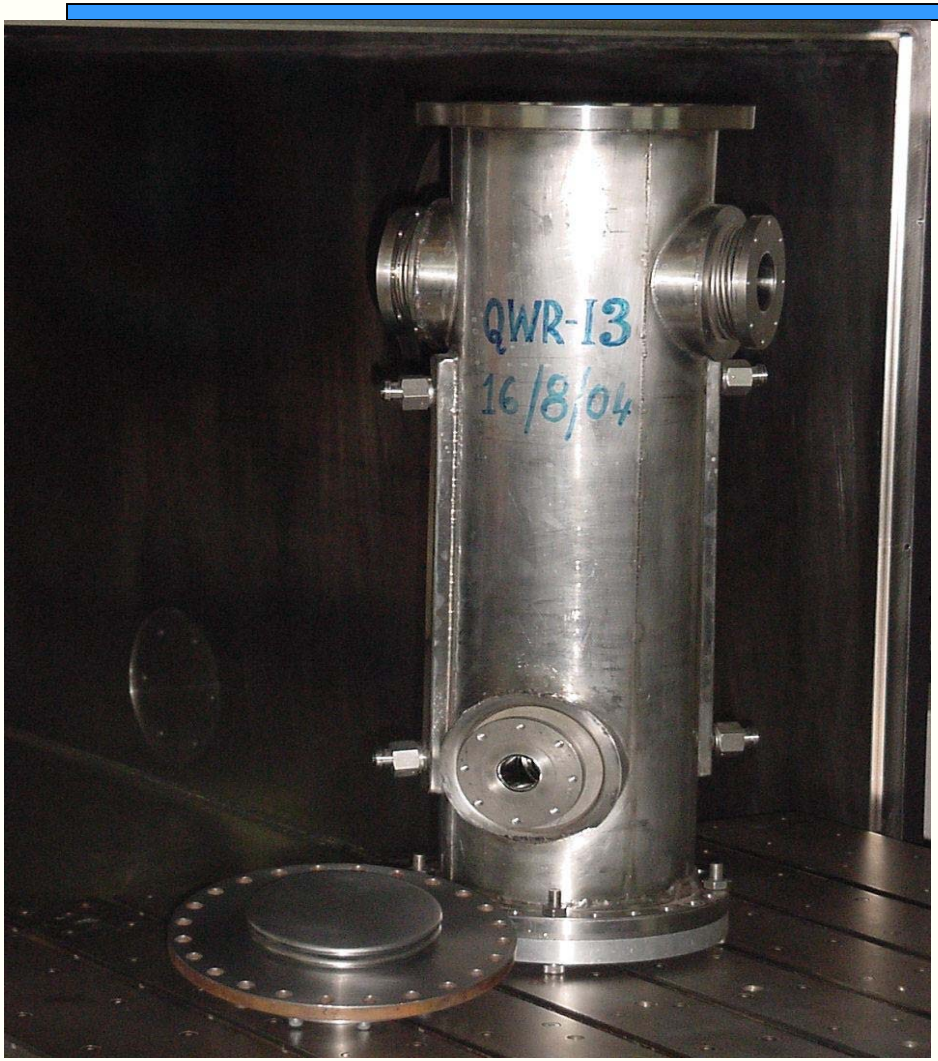


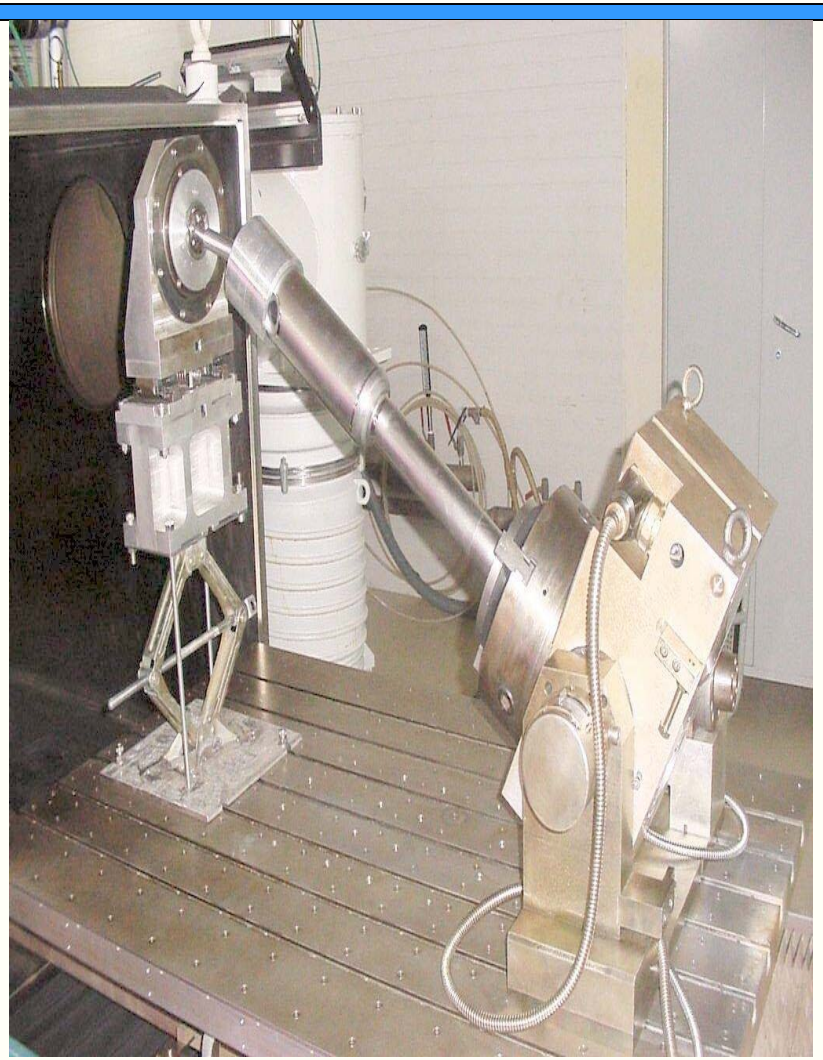

One of the two fully indigenously fabricated resonators at NSC along with its slow tuner bellows.

# IUAC: SRF Cavity

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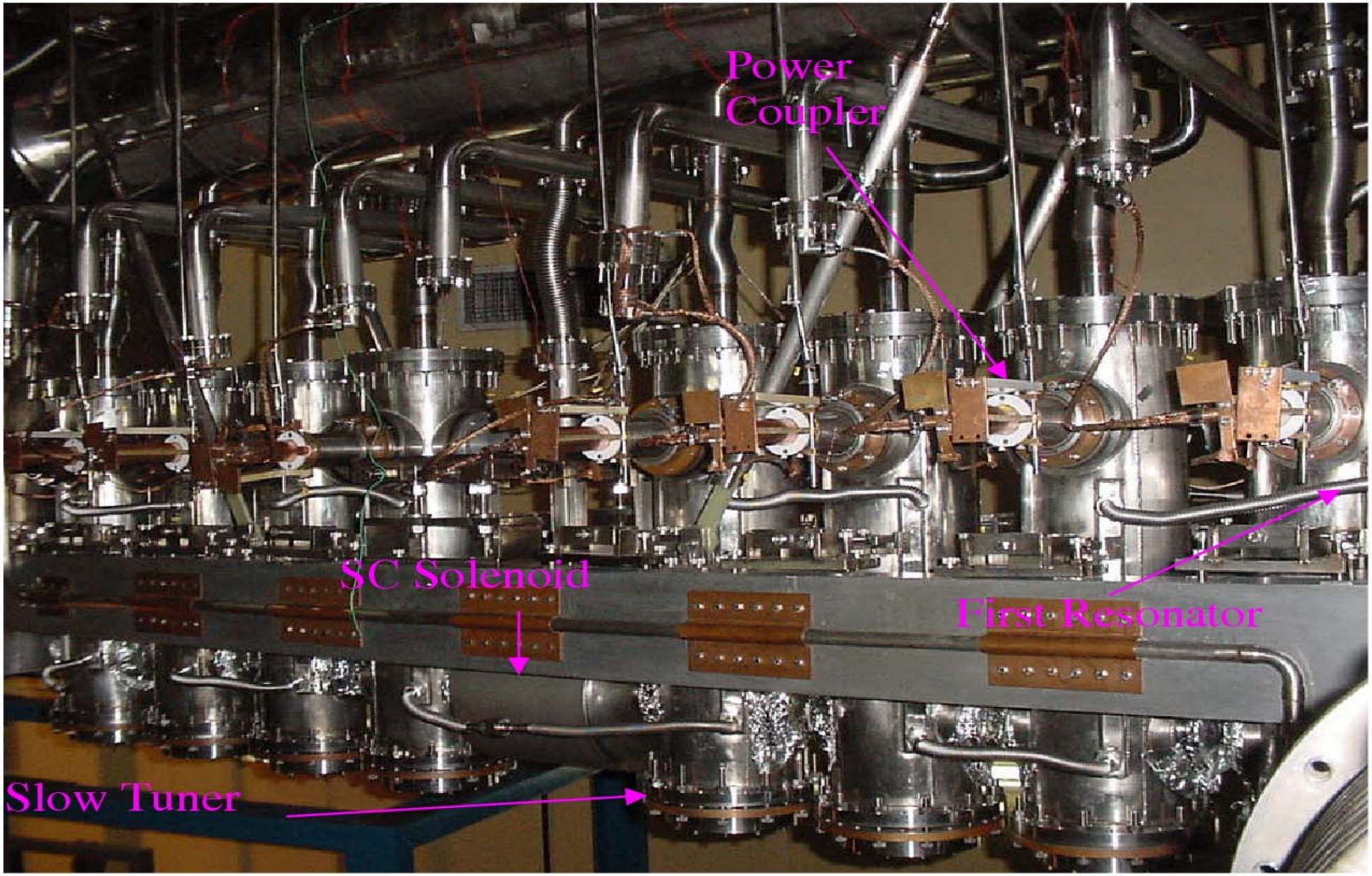

# Linac Module with Beam Line and Cryogen distribution lines

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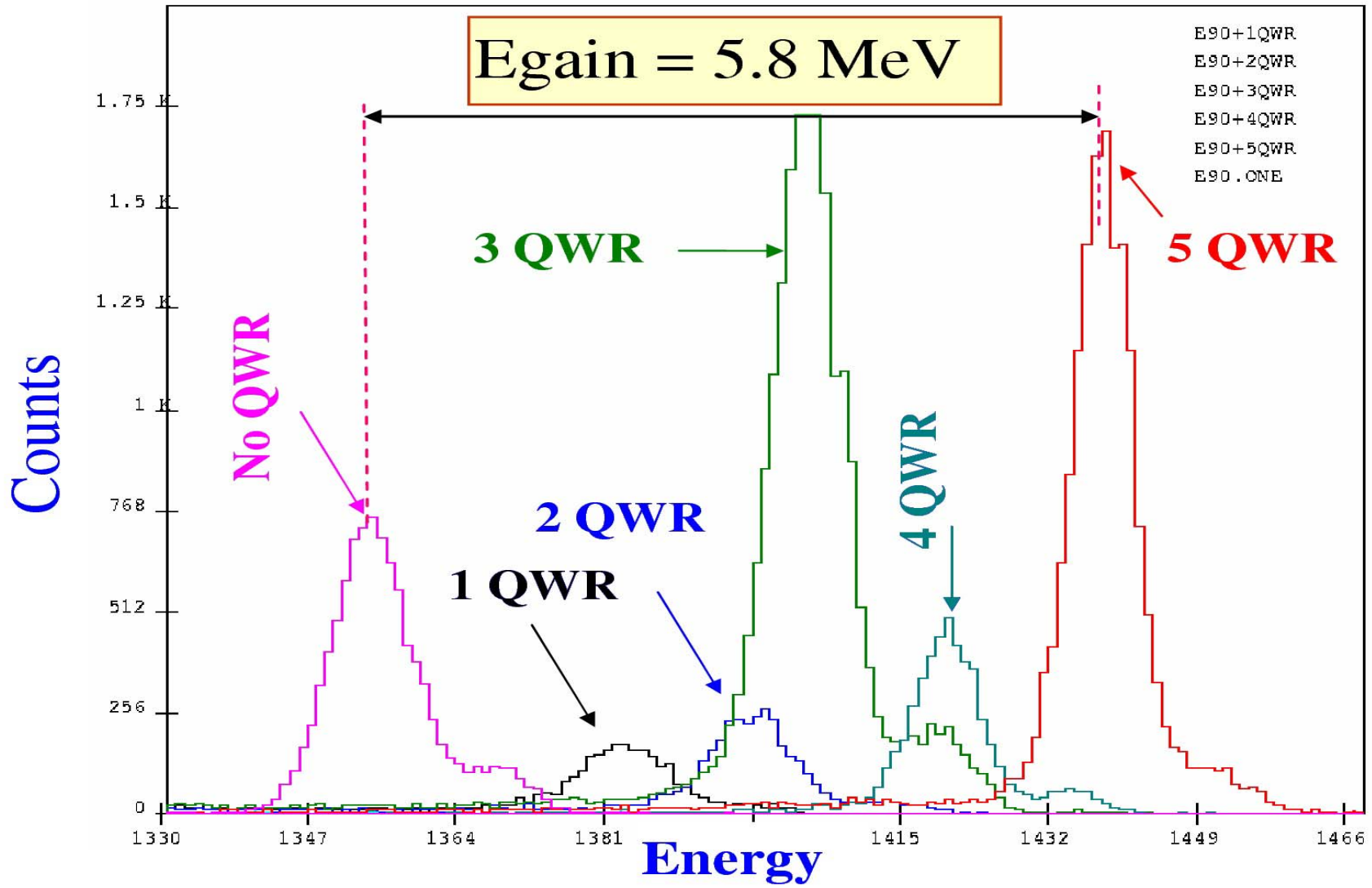
# Energy Gain as designed



# Scheme for Accelerator Development for ADS

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Normal Conducting

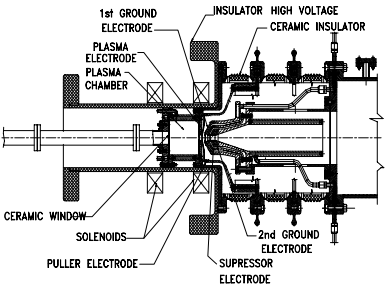
High current injector 20 MeV, 30 mA

Proton IS 50 keV → RFQ 3 MeV → DTL 20 MeV → DTL/ CCDTL / Super-conducting → 100 MeV → SC Linac → 1 GeV

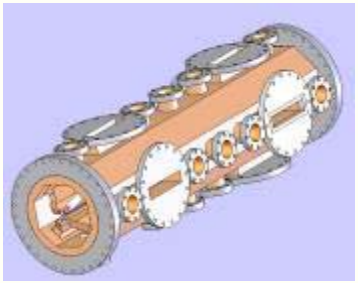
Proton beam from high power accelerator

Design completed and fabrication is in progress

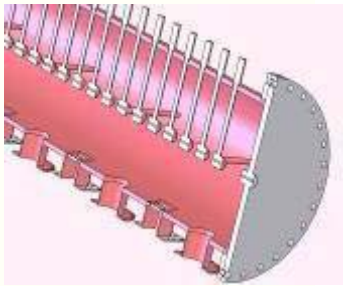
ECR Ion Source



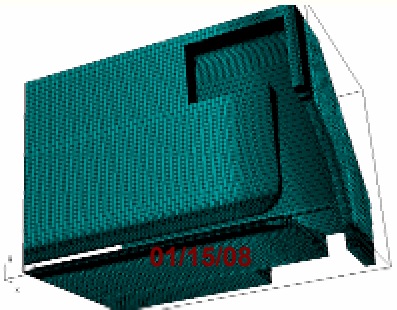

RFQ



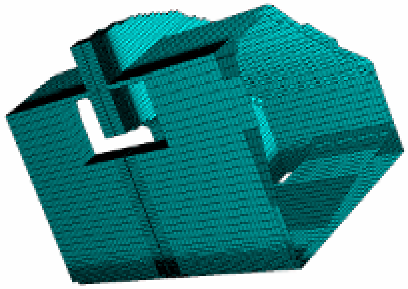
DTL



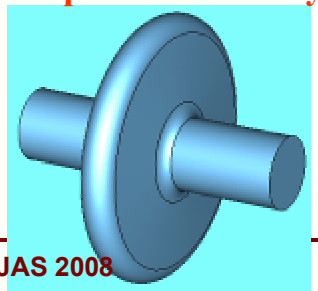
Beginning Cell

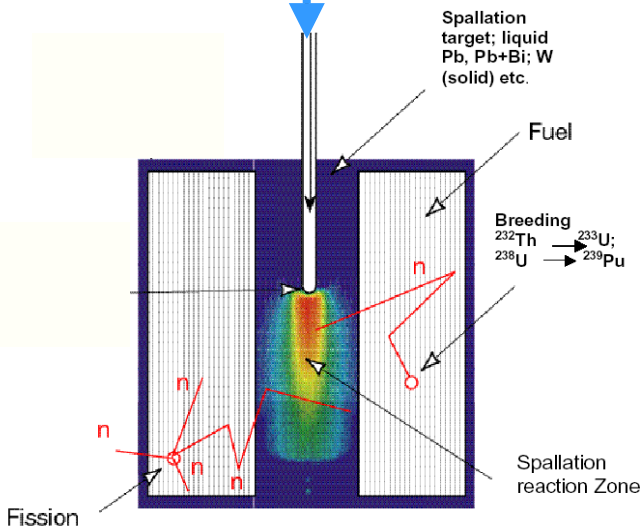


Coupling Cell



Elliptical SC Cavity





# Material R&D at RRCAT

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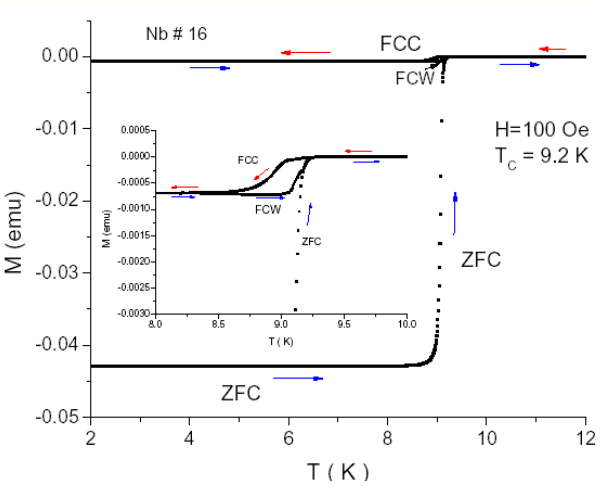
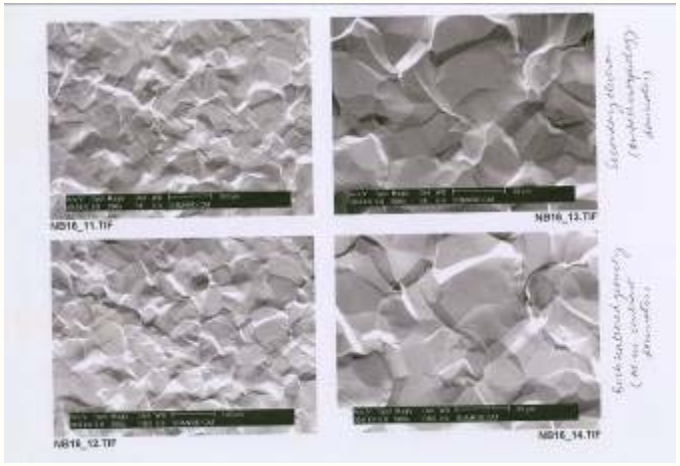
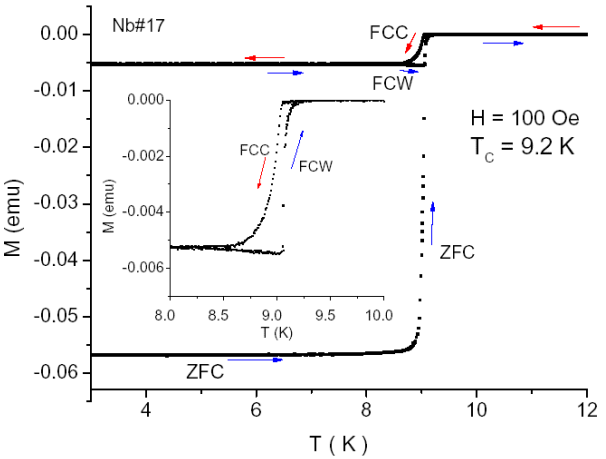
## Results on BCP Samples of Nb from Fermilab. (Large Grain Nb from Jlab also studied)

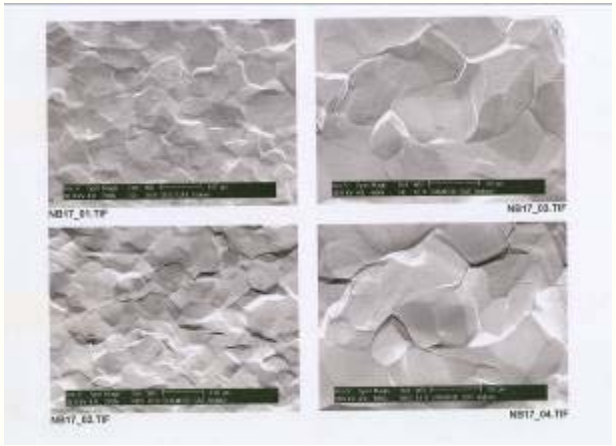
Sample # 16
Avg grain size
~ 30-35 Micron



Sample # 17
Avg grain size
~ 40-45 micron



# RRCAT: Cavity RF Simulation

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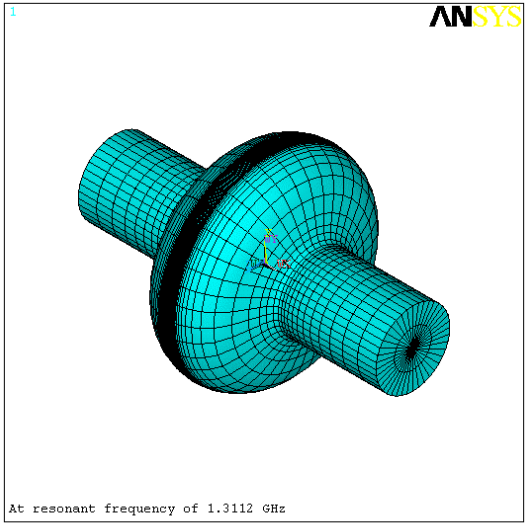
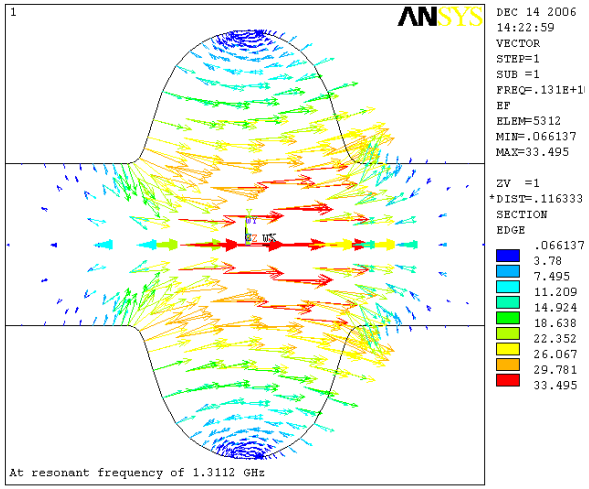
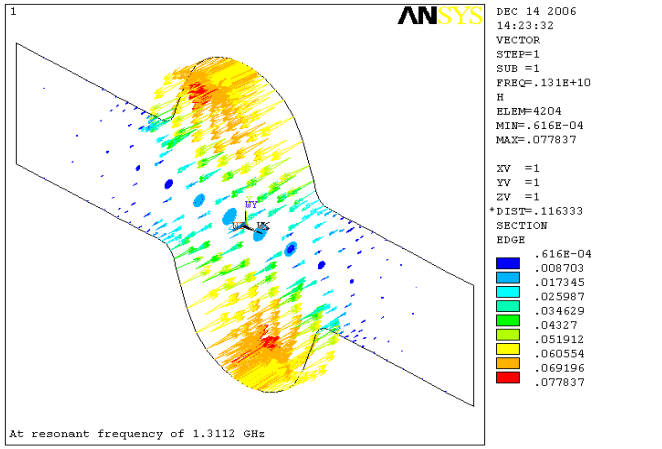
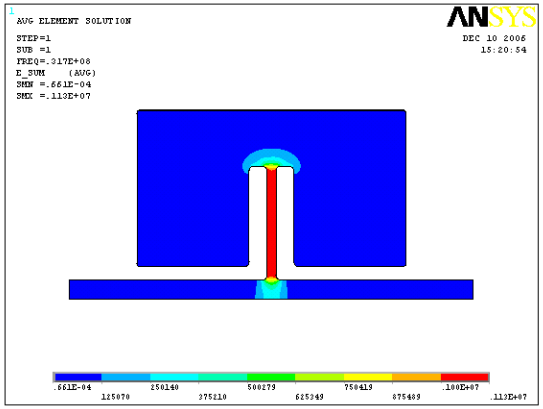
## 1.3 GHz Cavity

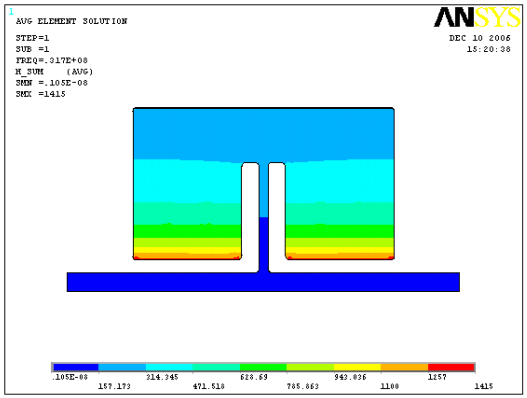


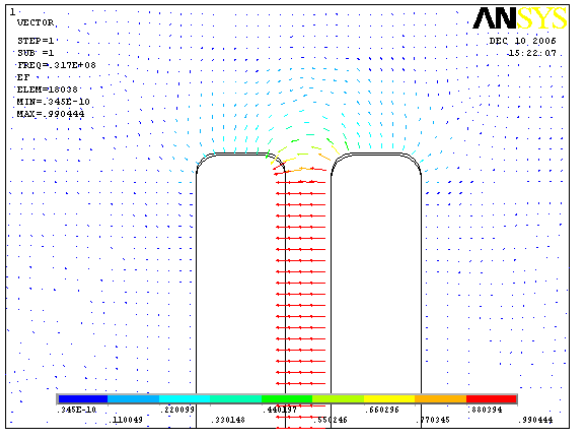




## 31.6 MHz Indus-1 Cavity



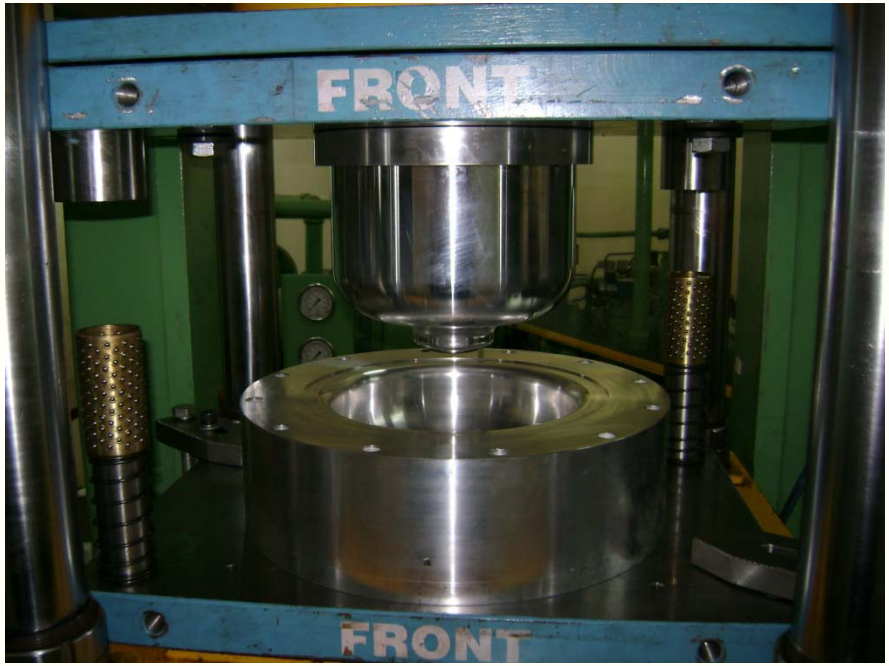
# Indian Laboratories work on ILC

Fermilab

- There exists a collaboration between Fermilab, SLAC and Indian laboratories to work on the Superconducting Main Linac Development.
- RRCAT and BARC are developing infrastructure for the development of the Indian accelerator program, while collaborating on international accelerators.
- The present focus is on Design for manufacturing of the Main Linac SRF components.
  - Tooling design and improvements
  - Cavity manufacturing value engineering
  - Cryomodule design and value engineering
  - Design and fabrication of cavity tuners.
- Indian engineering team stationed at RRCAT and BARC have made valuable contribution to the ILC program.

# Some Highlights of Indian Contribution

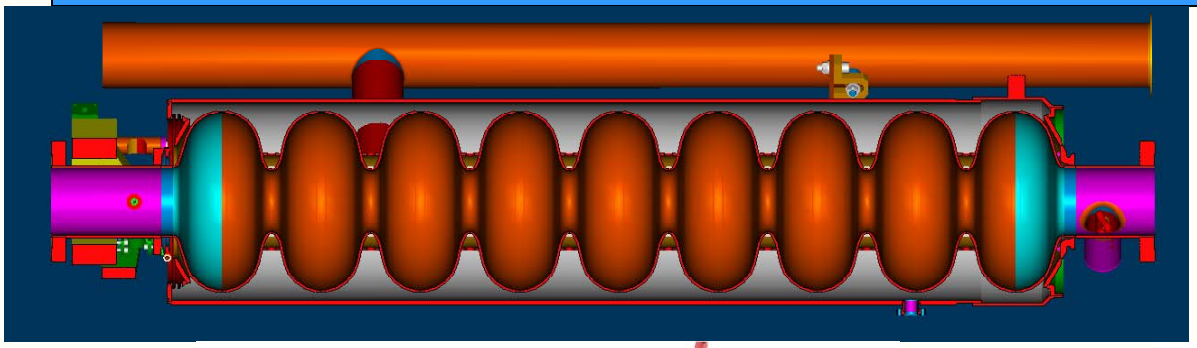
Fermilab

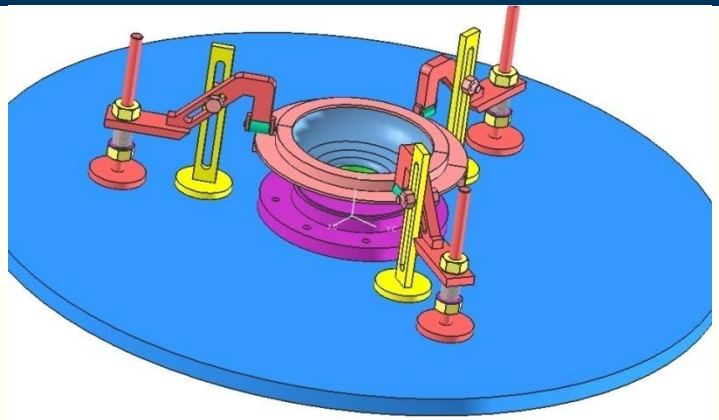


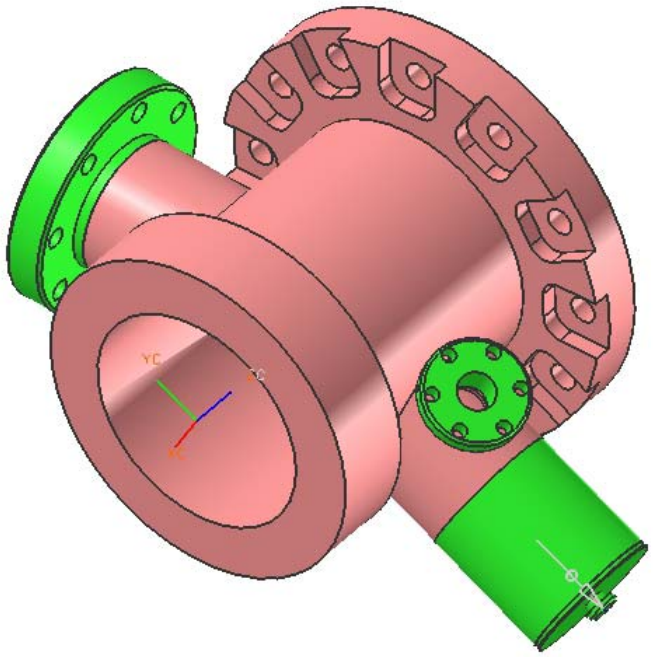


Cavity Fabrication tooling

# Highlights ….







There is a possibility of significant cost saving if we could just implement these two changes suggested by RRCAT engineering team.

# Summary

Fermilab

- The opportunity in accelerator science and technology development is the best ever both in India and abroad.

- The R&D on several international accelerator is progressing with India as an equal partner.

- Indian domestic accelerator program is developing with several accelerators under commissioning.

- Future accelerator plans in India is even more challenging.

- Indian scientific staff continues to make valuable contributions to International accelerator program.