DAE-DOE: Discovery Science Collaboration:

Indian Institutions and Fermilab Collaboration on Accelerator and Detector Technologies

Shekhar Mishra

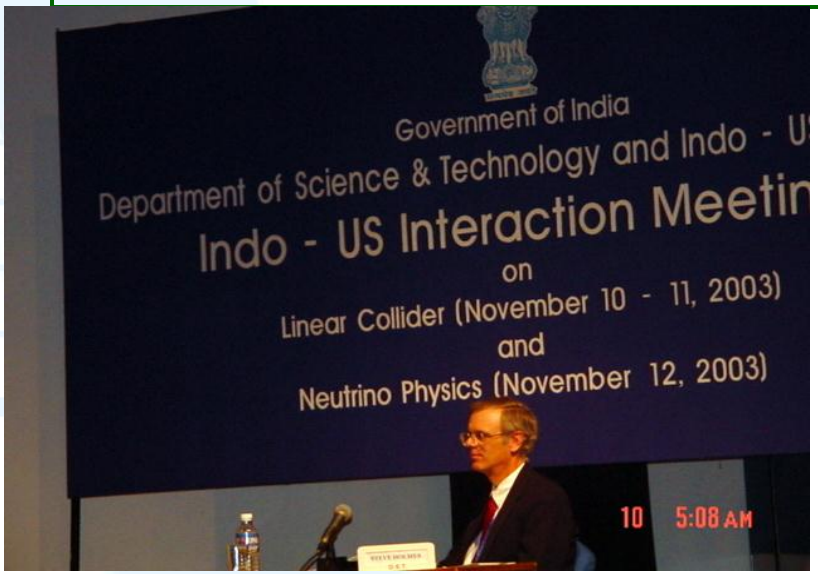
Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

Fermilab

10th Anniversary of Collaboration

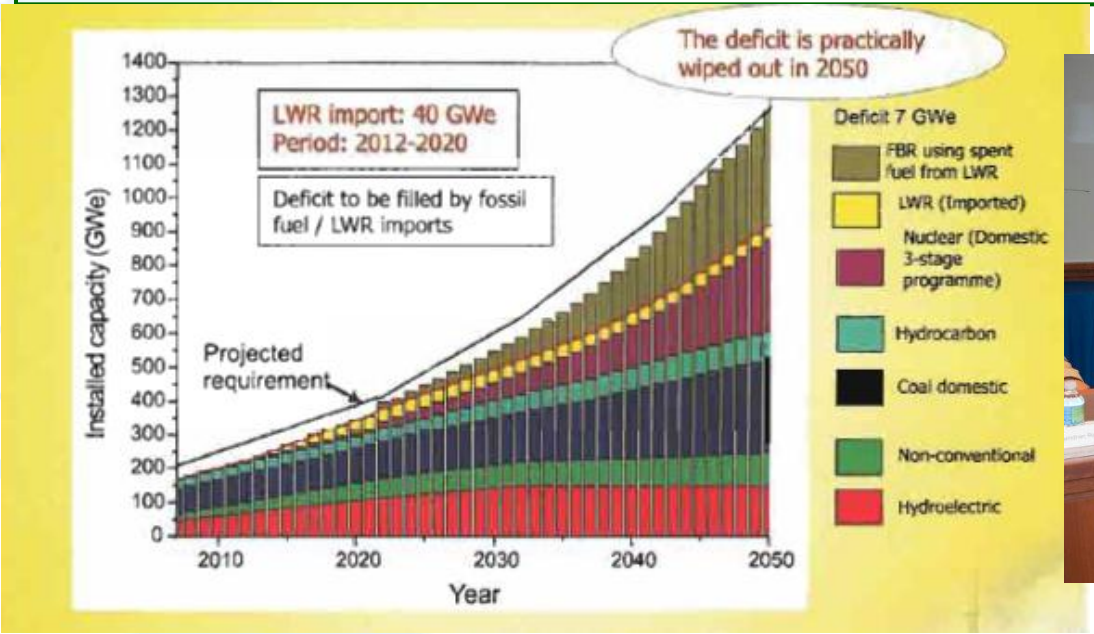
- 1st Indo-US Interaction meeting, Nov. 2003, New Delhi.
  - Supported by High level Indian and US government & management
  - 19 US physicists and 70+ Indian Scientists participated.
    - US-India discussed accelerator and neutrino physics collaboration
    - Working group formed to develop collaboration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



- Signed its first institutions level MOU in 2006
  - Eight addendum MOUs (2009-12)
- Today operates under the DAE-DOE Discovery Science Implementing Agreement to US-India Science and Technology Agreement

Indian National Interest

- 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.
  - India needs efficient accelerator technology
    - Transmutation of nuclear waste
    - Converting Thorium into fissile material
- Physics experiments at Fermilab
  - Training of technical manpower



US-India Strategic Dialogue

SCIENCE & TECHNOLOGY DIALOGUE, WASHINGTON, DC ///

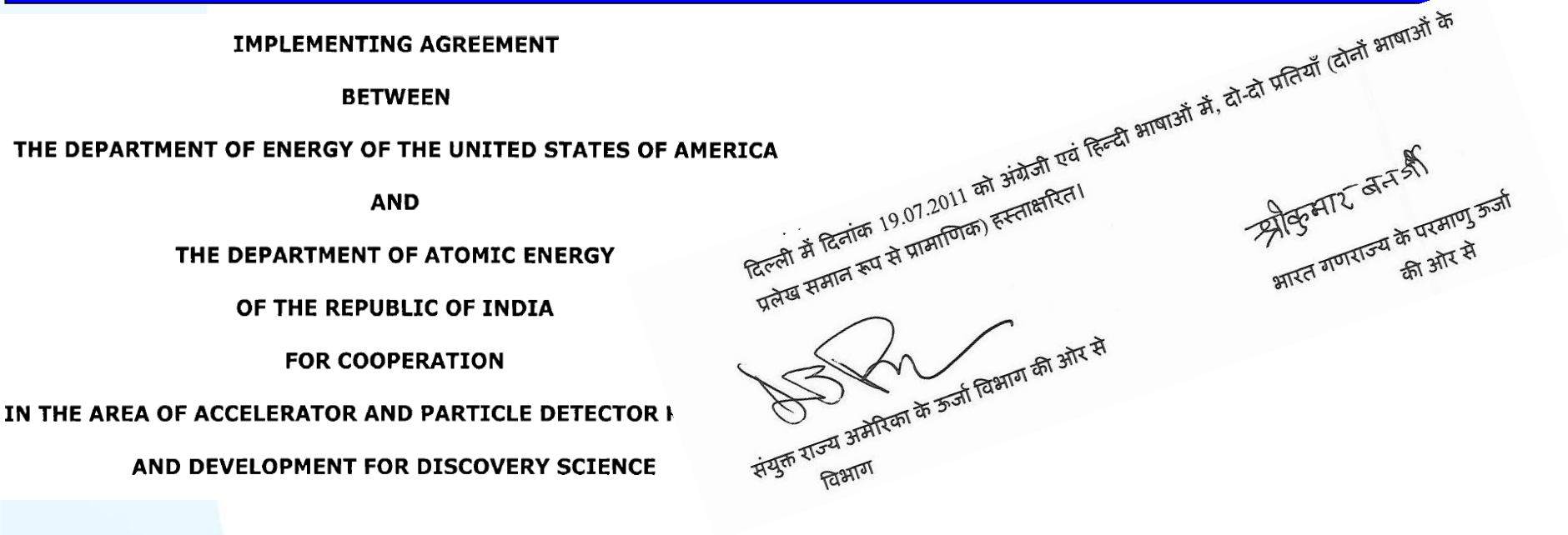
MEET THE CATALYST

June 11, 2012

At the end, the Joint Commission recommended several new directions of cooperation including research in the areas of high energy particle physics and gravitational wave detection under the 'Discovery Science Agreement' between Department of Atomic Energy and U.S. DOE. In Basic and Applied sciences — materials research, computer sciences and neurosciences have been identified as potential areas of future engagement.

Accelerator and Physics Programs Technical Collaboration are No 1 deliverables to the Joint US-India Coordination

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

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।

संयुक्त राज्य अमेरिका के ऊर्जा विभाग की ओर से

श्री कुमार बनर्जी

भारत गणराज्य के परमाणु ऊर्जा की ओर से

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.

IIFC Mission

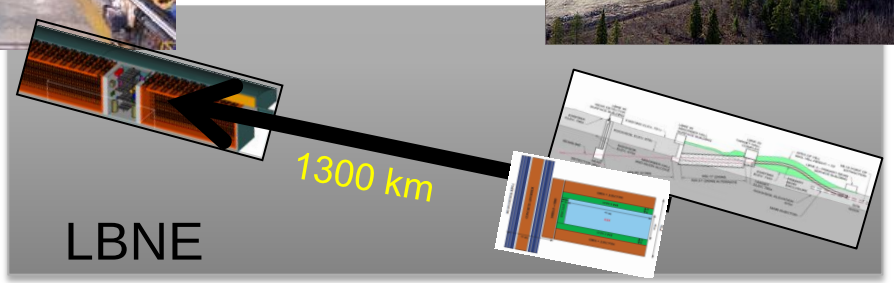
- **DAE-DOE collaboration has been developed to support the domestic accelerator and physics programs of both countries.**
  - **It is not a typical High Energy Physics collaboration** ⟷
- **Fermilab is the world leader in accelerator and detector technology development.**
  - **India to become a significant partner**
- **The collaboration is inspiring to become the world leader in accelerator-based Neutrino Physics at Fermilab,**
  - **10 → 35 kt Liquid Argon underground detector, located 1300 km from Fermilab and a High Resolution Neutrino Near Detector (LBNE-ND-India)**
  - **1.2 → ≥2 megawatt of beam power**
    - **Provided by a pulsed High Intensity Superconducting Proton Accelerator injecting beam at 6-8 GeV into the Main Injector complex.**
- **DAE (BARC and RRCAT) to build accelerators for Energy, Medical and Material Science in 12th and 13th plan.**

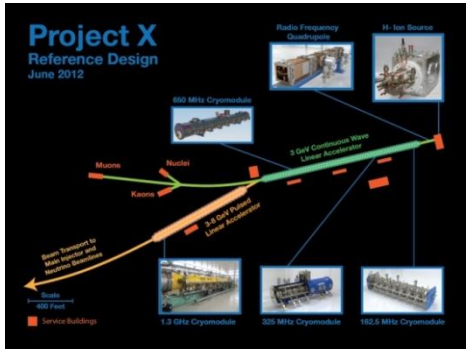
Total Project Collaboration

Indian Institutions at Fermilab

Before 2006

Now





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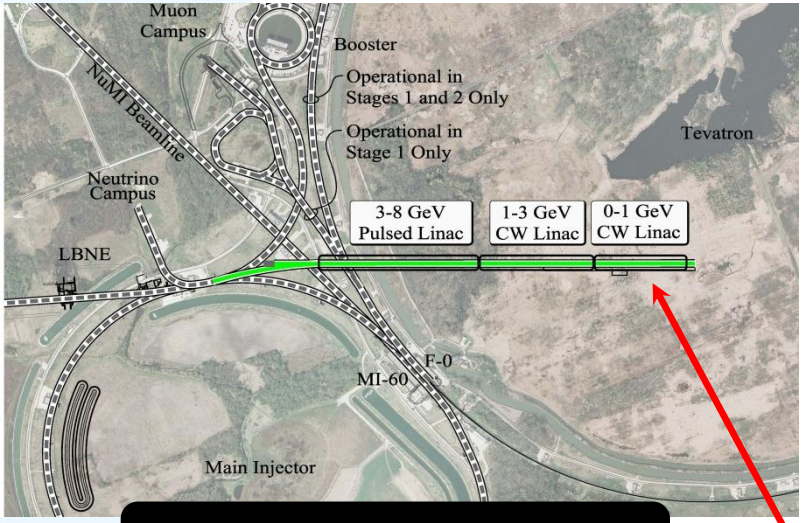
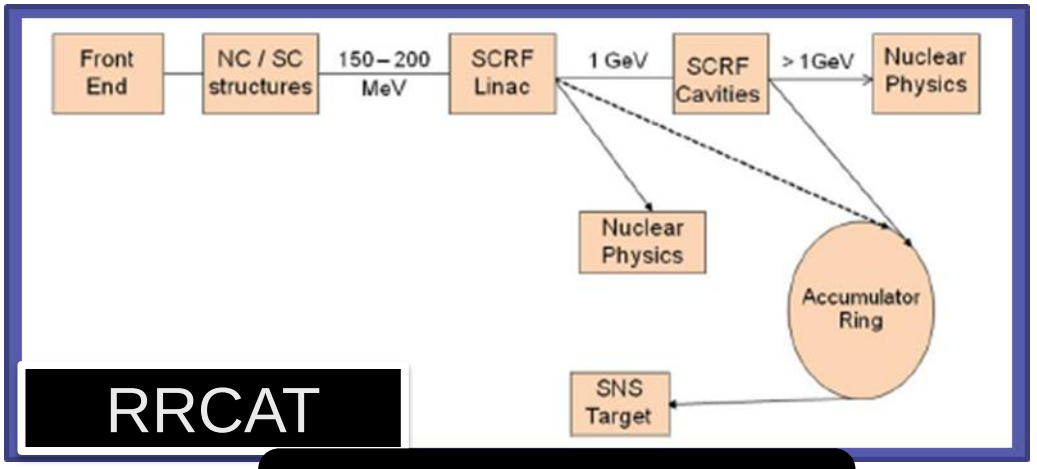
DAE-DOE Accelerator Projects



Basic Science

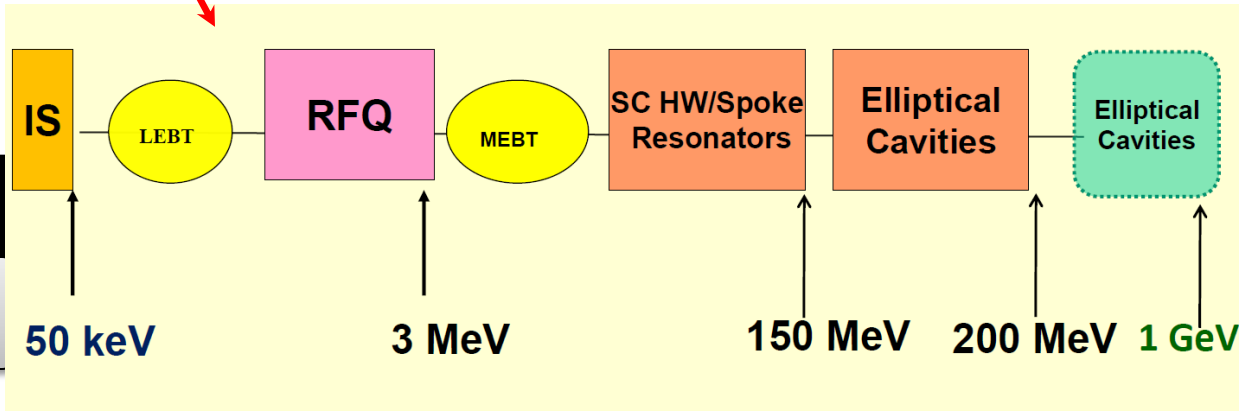


RRCAT

Material Science

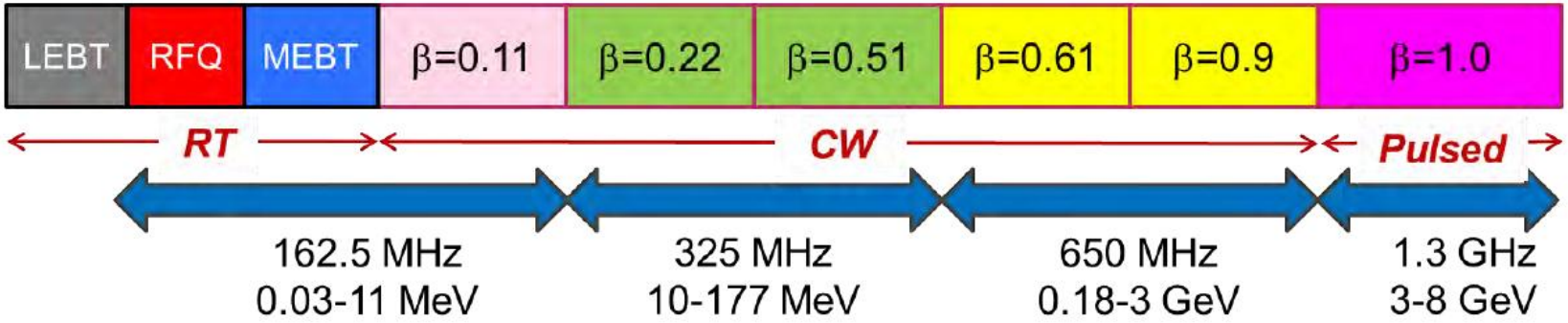
BARC

Energy and Medical



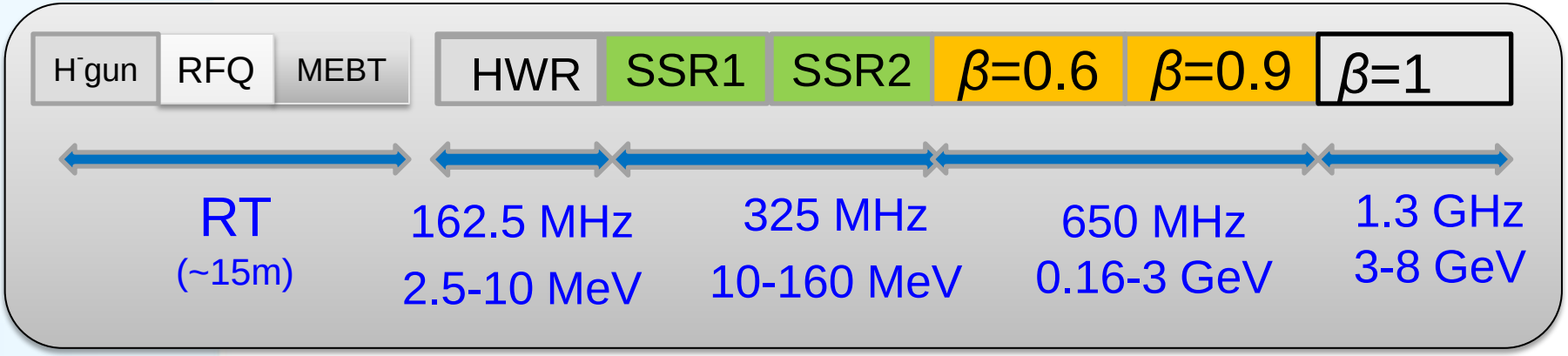
In the 12th and 13th plan of India

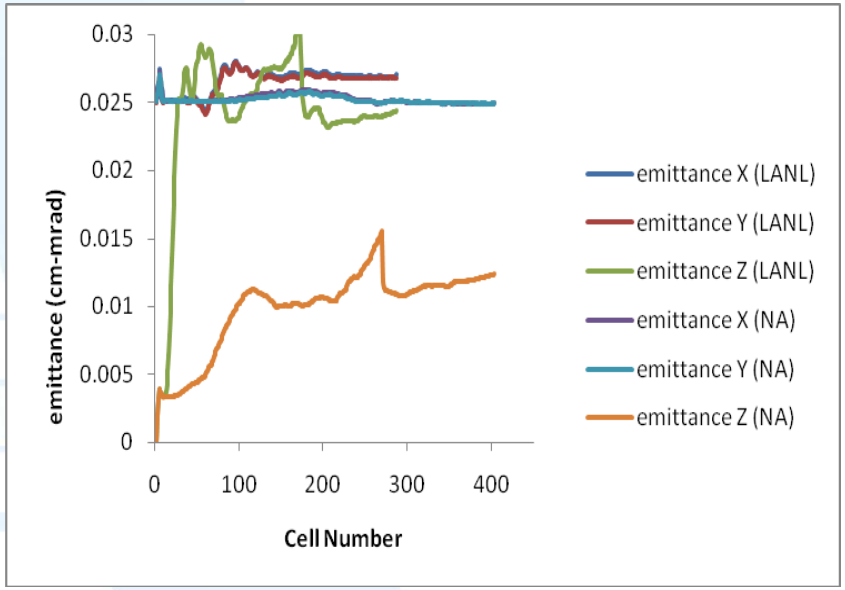
HISPA: SRF Linac



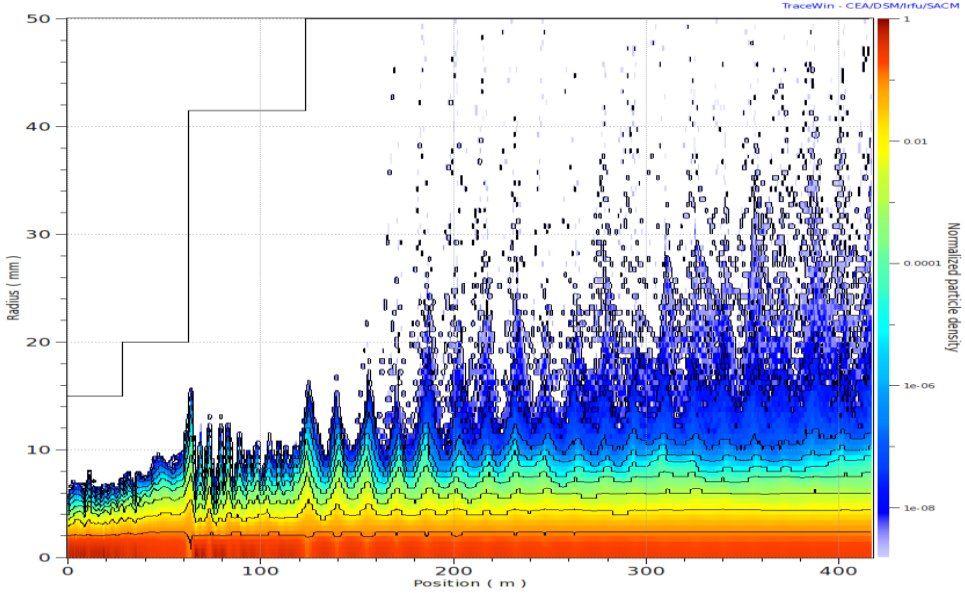
Sec-tion	Freq. (MHz)	Energy (MeV)	Cav/mag/CM	Gradient (MV/m)	Energy Gain (MeV)	Q_0@2K (10^{10})	CM Config.	CM length (m)
HWR	162.5	2.1-11	8 /8/1	8.2	1.7	0.5	8 x (sc)	5.8
SSR1	325	11-38	16 /8/ 2	10	2.05	0.2	4 x (csc)	5.2
SSR2	325	38-177	35 /21/ 7	11.2	5.32	1.2	sccsccsc	6.5
LB650	650	177-480	30 /20*/ 5	16.5	11.6	1.5	ccc-fd-ccc	7.1
HB650	650	480-1000	42 / 16†/ 7	17	17.6	2.0	cccccc	9.5
HB650	650	1000-3000	120 / 30†/ 15	17	17.6	2.0	cccccccc	11.2

IIFC: Accelerator Design





Evolution of emittances RFQ

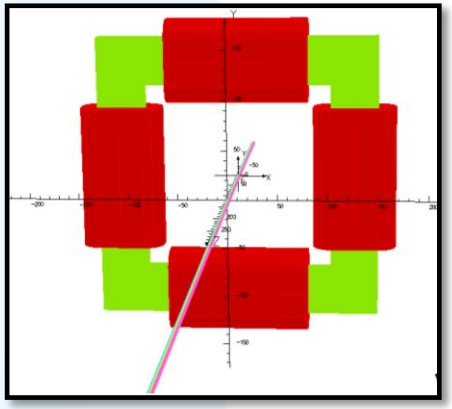


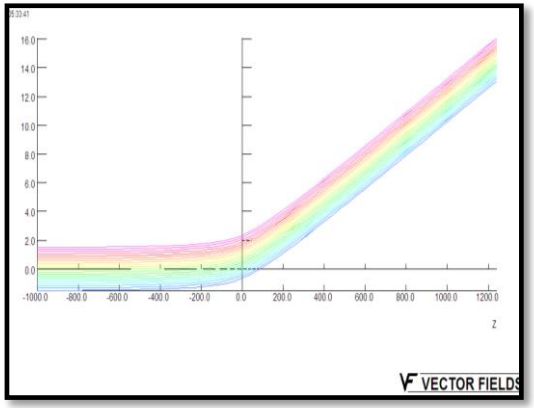
Beam envelope 2x all errors

BARC: Design and Development of MEBT Magnets

1. Electromagnetic design of Magnets- Quadrupole Focussing Magnets and dipole correctors
2. Engineering design and Development drawings
3. Fabrication and Geometrical inspection
4. Magnetic measurements(integral fields) including Quality checks and traveller
5. Qualification tests with H^+ beam at 2.5 MeV

Qualification of dipole correctors with proton beam at FOTIA facility, BARC

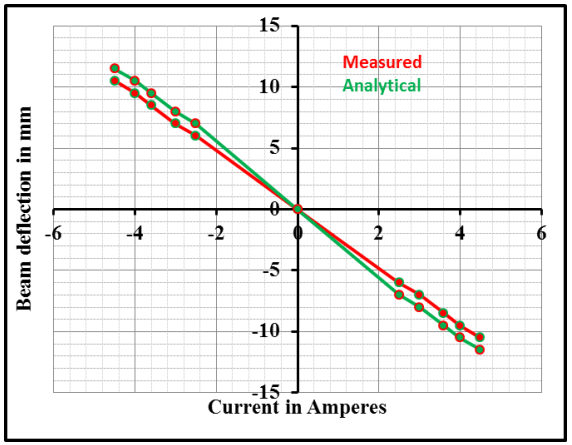




Particle trajectory simulations using OPERA ,Vector Fields

Sr. no	Beam Parameter	Value
1.	Beam	H^+
2.	Beam energy	2.5 MeV
3.	Beam Current	10nA
4.	Beam size	3 mm
5.	Target distance	1 meter

Dipole corrector magnet assembly installed in FOTIA beam line



Beam deflection - analytical vs. measured

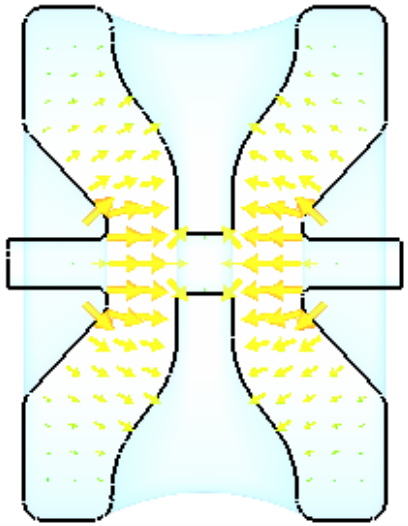
IUAC: R&D Status SSR1

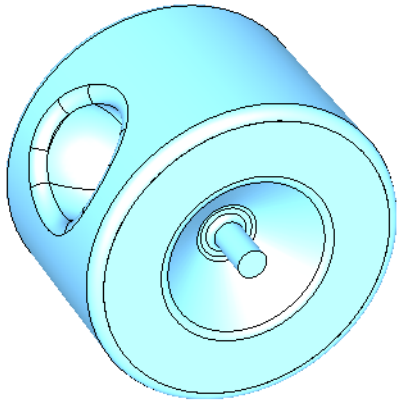
- **IUAC, New Delhi has developed tooling for the fabrication of SSR1 cavities. The built to print cavity drawings were provided by Fermilab**

Cavity to be tested at Fermilab 2014

BARC: SSR2 Preliminary Design

Optimization of SSR2 cavity



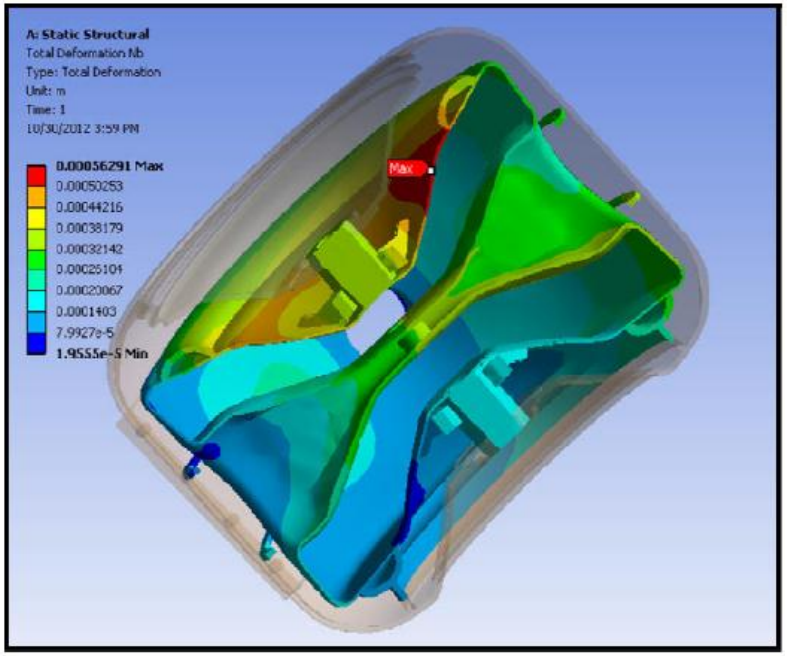


Parameter	Values
Geometrical beta	0.4
frequency	323.92 MHz
Peak electric field	9.15 MV/m
Peak Magnetic Field	13.66 A/m
Radius	26.13 cm
Cavity Length	36.81 cm

1st Prototype in 2015

VECC: SSR1 CM

- VECC is working on the Helium Vessel, Tuner for SSR1 and design of SSR1/SSR2 CM.
- Fermilab and VECC work on specific mechanical engineering tasks that are integrated in the design.



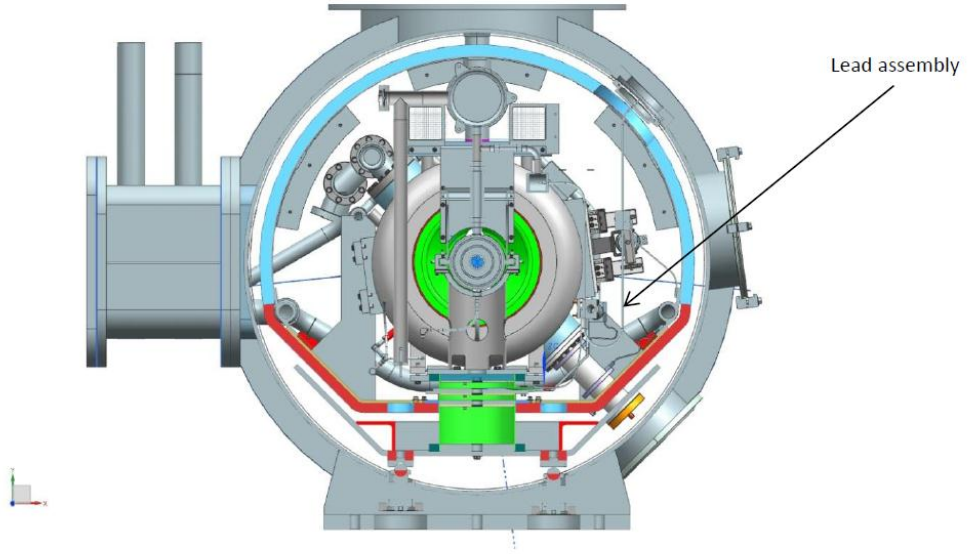


Figure 7. Formed lead assembly inside the cryomodule

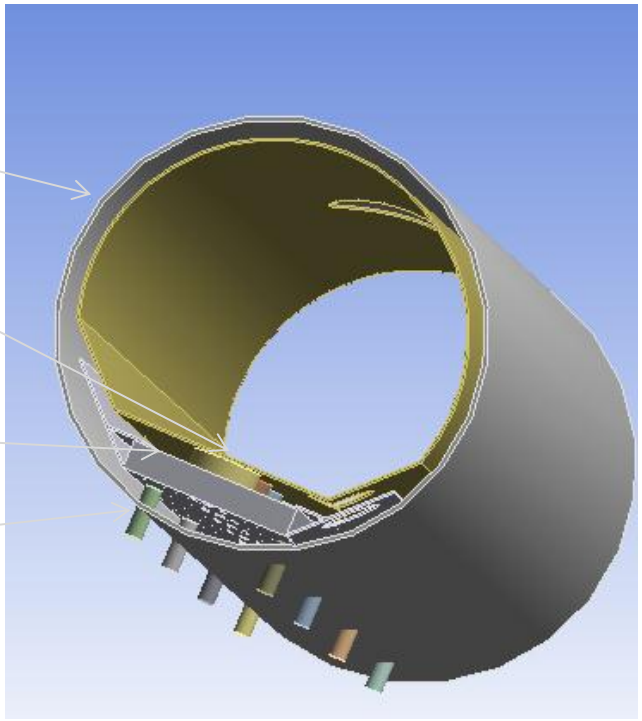
VECC: SSR1/2 CM 3D Model

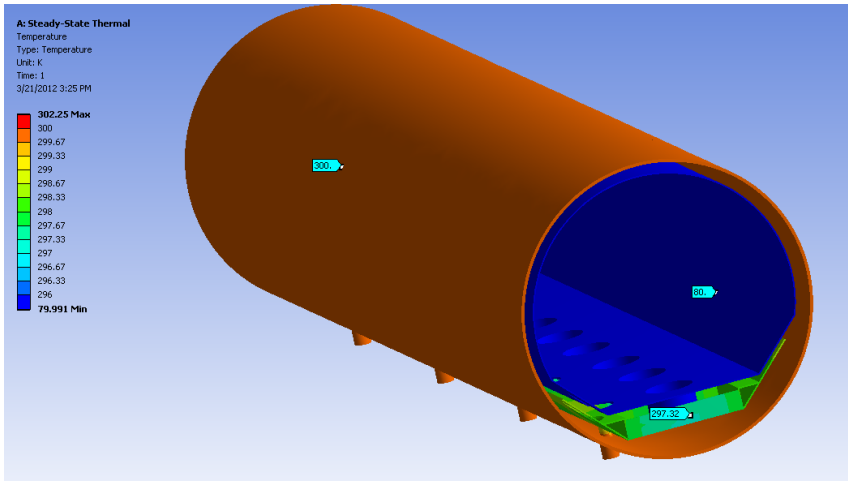
Outer vacuum vessel

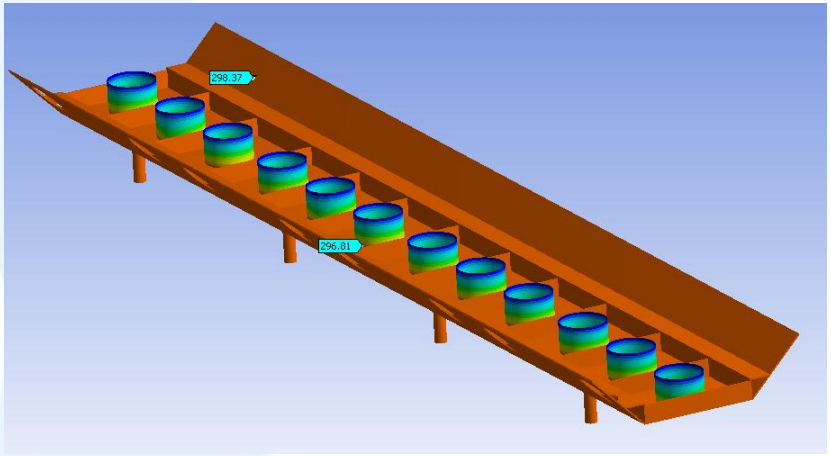
Support posts

Strong-back

Support pins



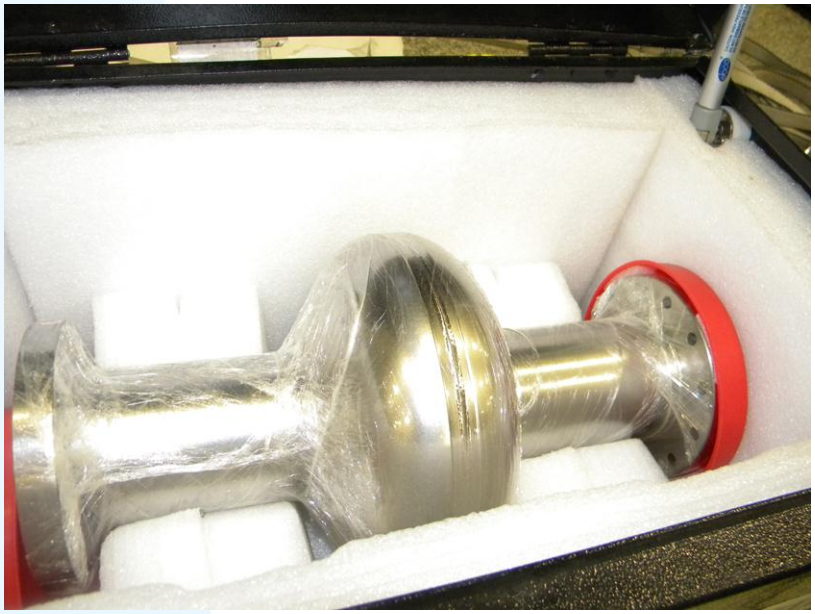


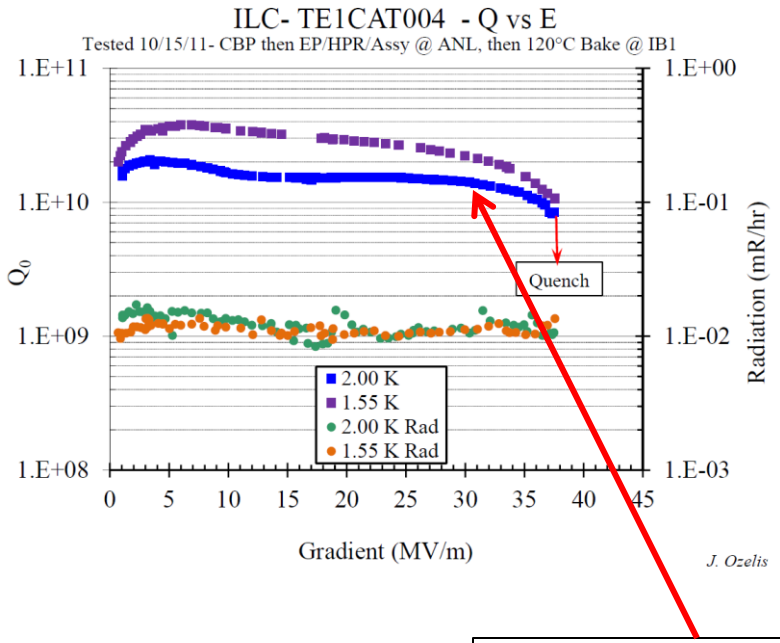


Temperature Distribution in SSR CM

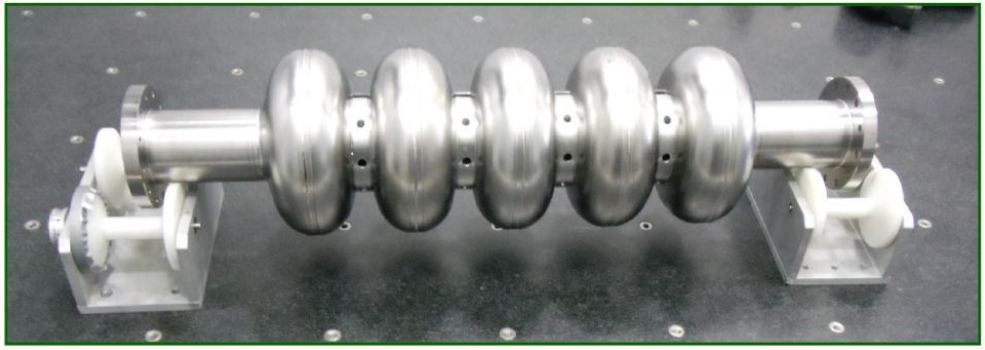
RRCAT: SRF Cavity R&D

1.3 GHz





World Class

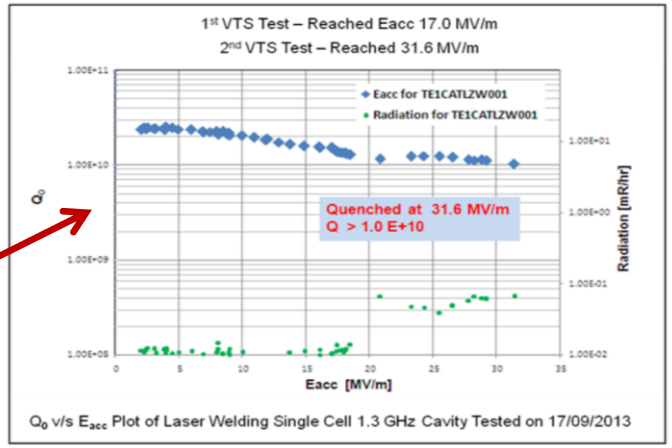


RRCAT: e-beam → Laser Welding

- **RRCAT has significant expertise is laser. They have used laser to weld Nb cavities, replacing very delicate and expensive e-beam welding.**

Indigenously developed Laser System
By SSLD,RRCAT for this task

Processed and tested at Fermilab

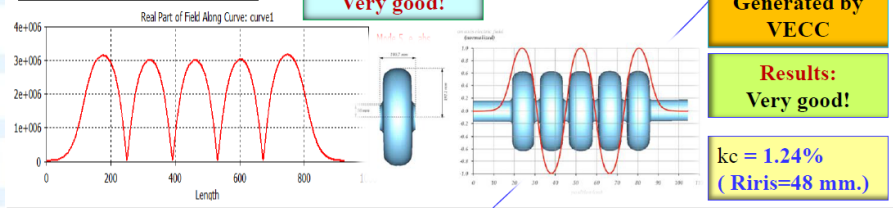


VECC: 650 MHz, β = 0.61

- **VECC has designed its own shape of 650 MHz, β = 0.61 cavity.**

Accelerating mode

Field flatness: Very good!



Data: Generated by VECC

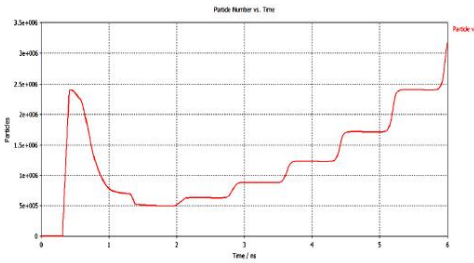
Results: Very good!

kc = 1.24%
(Riris=48 mm.)

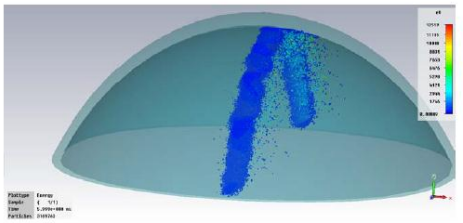
Fermilab has approved this design

	$\frac{A}{B}$ mm./ mm.	$\frac{a}{b}$ mm./ mm.	Equator radius D/2 mm.	Iris radius R_{Iris} mm.	Half-cell L/2 (inner) mm.	$\frac{R}{Q}$ Ω	G=Q.R_s Ω	E_{acc} MV/m	$\frac{E_p}{E_{acc}}$	$\frac{B_p}{E_{acc}}$	$f_{\pi-mode}$ MHz	Remarks
VECC Design1 Result	54/58	11.99/27	198.175	48	70.335	290	197	16.95	3.34	4.90	650.000	2D SUPERFISH 3D CST MWS $(\frac{a}{b})_{end}=\frac{20.66}{46.54}$ $(\frac{A}{B})_{end}=\frac{45.94}{49.35}$ α=3.6 deg Energy=118.8 J Mesh size=0.05
VECC Design2 Result	54/58	13.68/30.82	197.4	48	70.335	296	200	17.00	3.00	4.84	649.99869	2D SUPERFISH 3D CST MWS $(\frac{a}{b})_{end}=\frac{10.67}{24.02}$ $(\frac{A}{B})_{end}=\frac{54}{58}$ α =2.4 deg (mid) =4.5 deg (end) Energy=118.8 J Mesh size=0.05

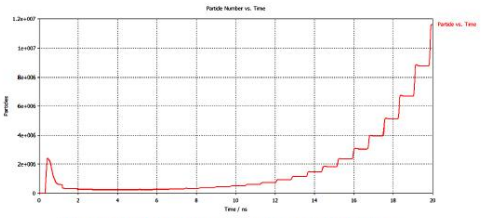
Multipacting simulation result for 650MHz, β=.61Cavity using CST Particle Studio



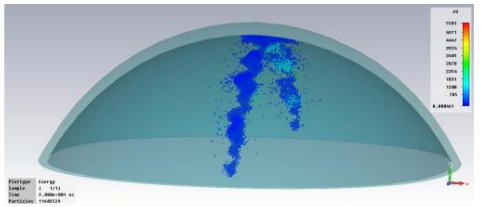
Particle Vs time(ns) at 6.8MV/m (Strong Multipacting)



Particle after 6ns at 6.8MV/m



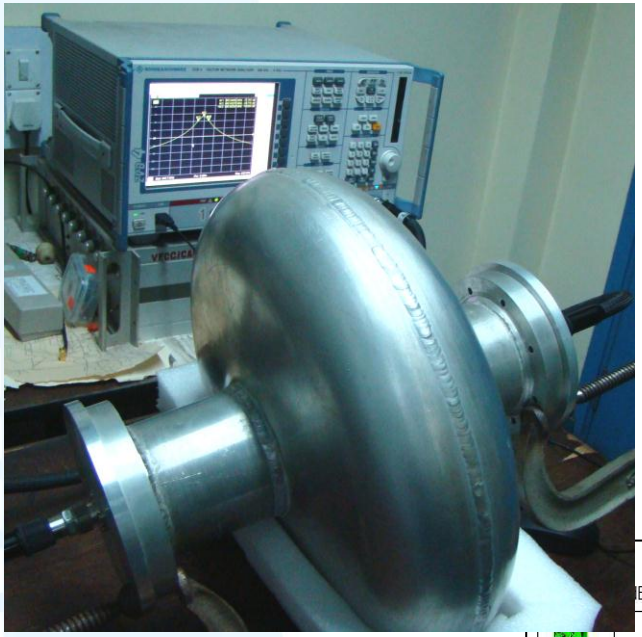
Particle Vs time(ns) at 9MV/m

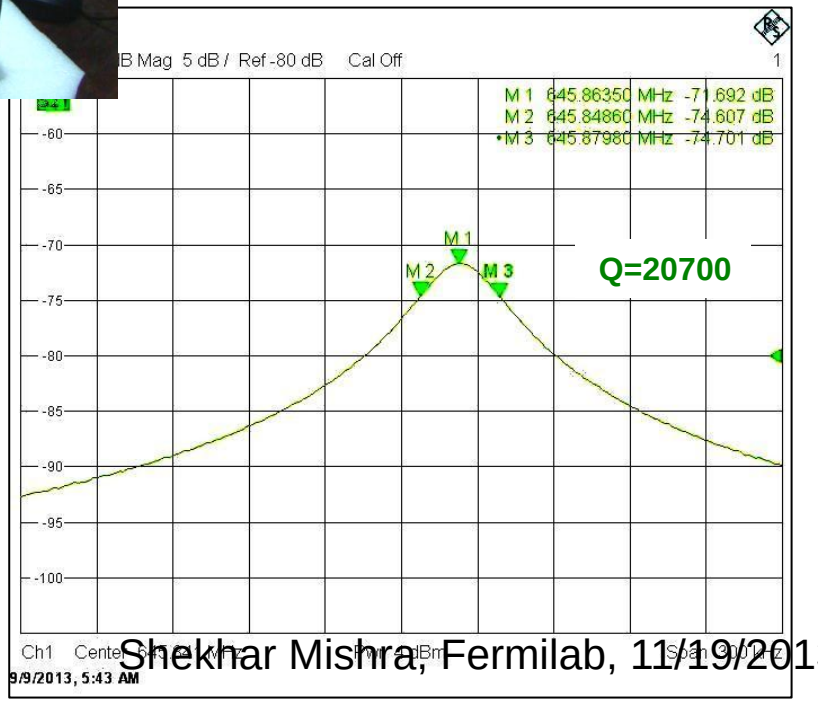


Particle after 20ns at 9MV/m

Developing infrastructure for fabrication, processing and testing

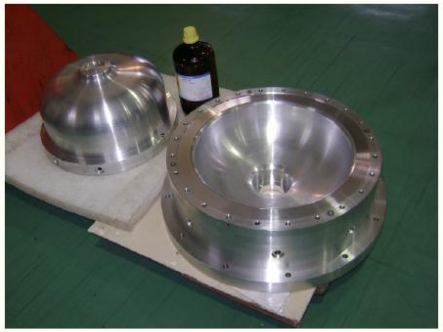
VECC: 650 MHz, β = 0.61





Resonant frequency, f_0 = 645.86350 MHz

RRCAT: 650 MHz, β = 0.9



Half cell forming die & Punch set

Die-Punch set mounted on the press

Coining operation setting

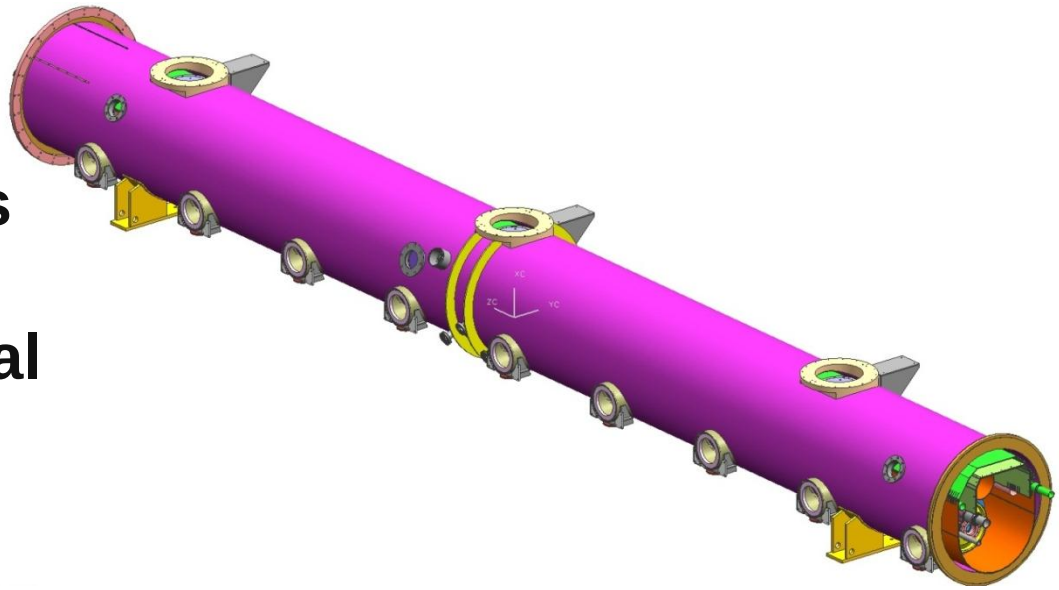
Formed Half cell – Alu, Cu, Nb

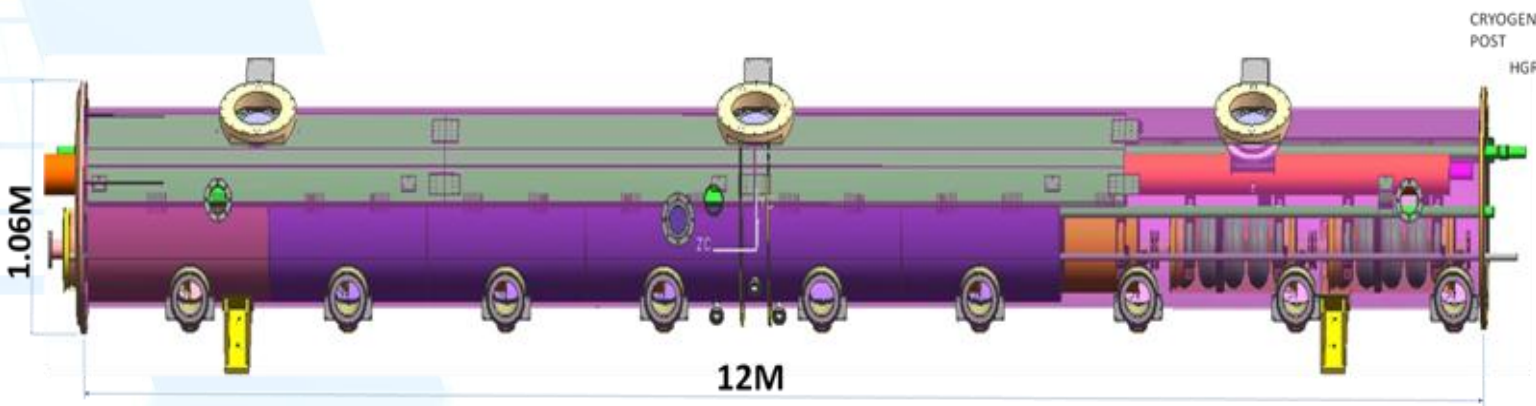
One 1-cell 650 MHz, Cavity has arrived at Fermilab for Processing and Testing

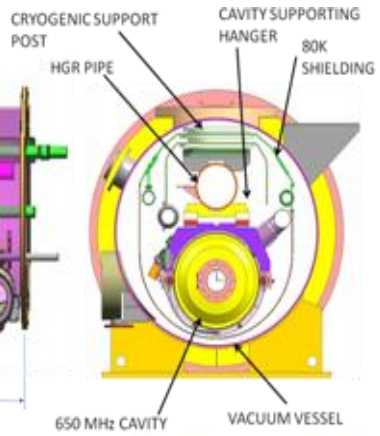
- **RRCAT in collaboration with Fermilab has started commissioning its SRF infrastructure also build with Fermilab.**
- **Starting 2015 it will be capable of producing a fully processed and vertically tested cavity.**
- **In production (2018) dressed and High Power Tested Cavity.**

RRCAT: 650 MHz Cryomodule

- Complete Mechanical Design
- Thermal shield analyses
- Support structure analyses and mechanical modeling
- Vacuum vessel design
- Testing the calculations with hardware



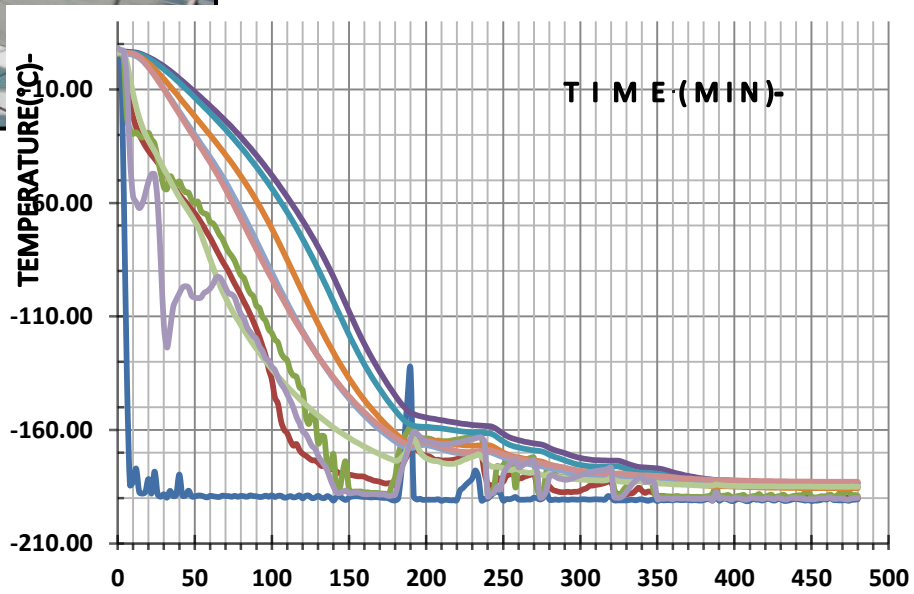




RRCAT: Cryomodule Component Testing

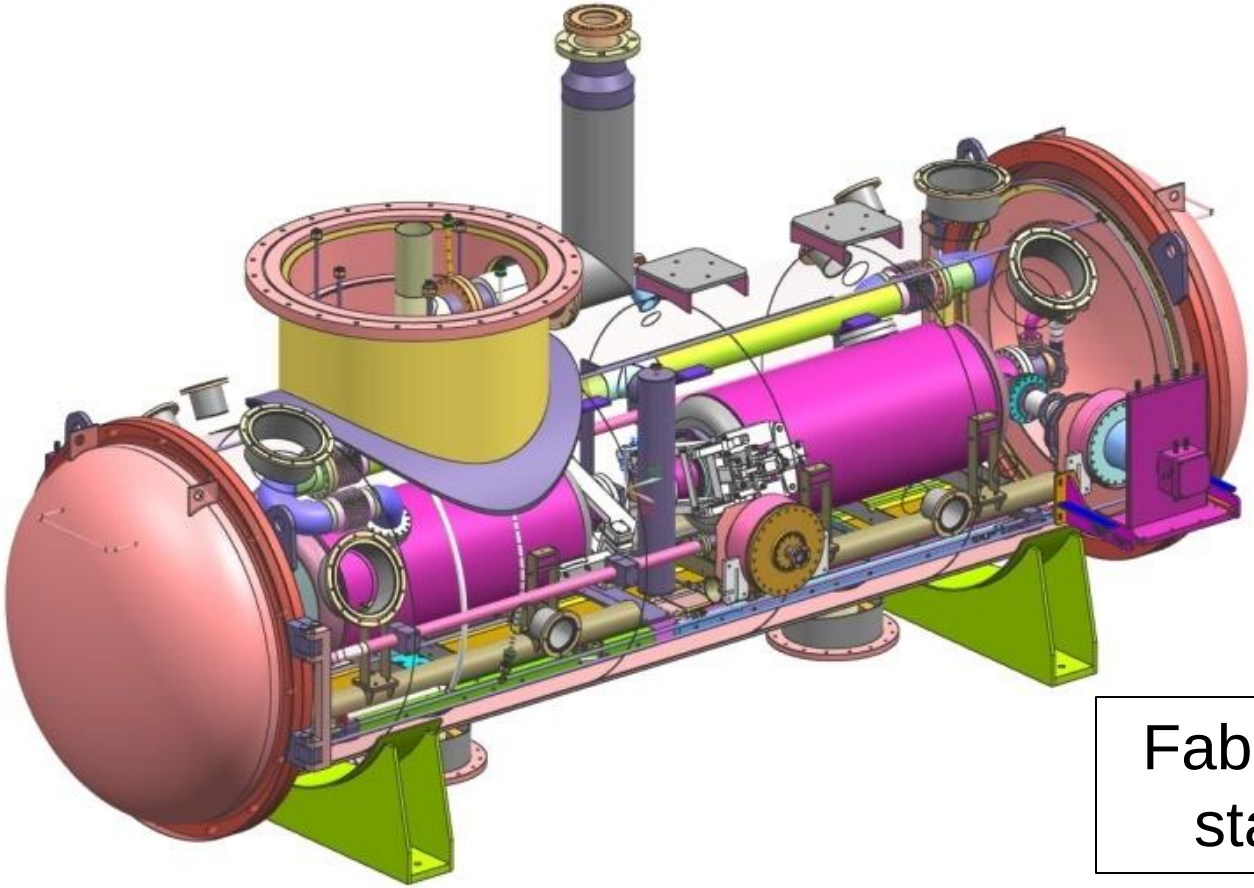
- Capability to test the components of cryomodule and HTS in 80K environment

- Results of 1st Cool down expt. on LN2 Cooled 80 K thermal shield of cryomodule



RRCAT: Horizontal Test Stand

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



Fabrication to start 2014

BARC: 325 MHz, 3-7 kW RF

Prototype testing of 3 kW RF amplifier

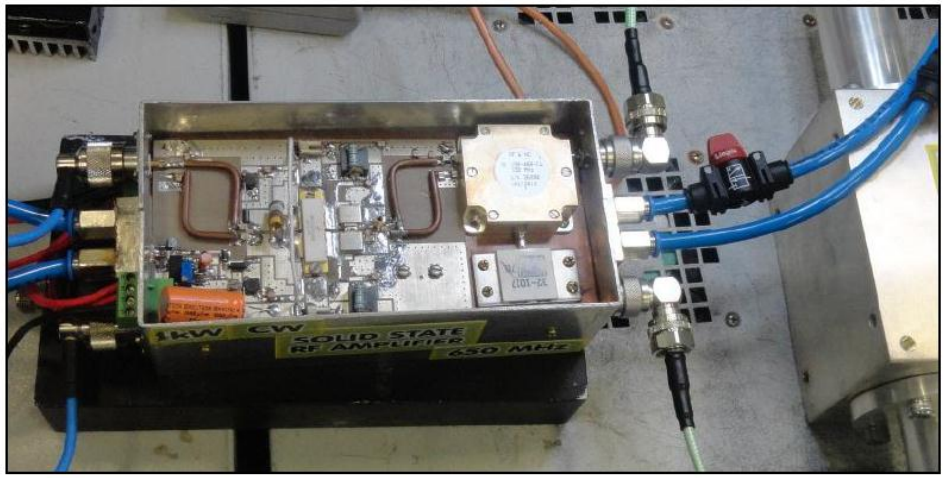
Fully assembled 3 kW whole Unit

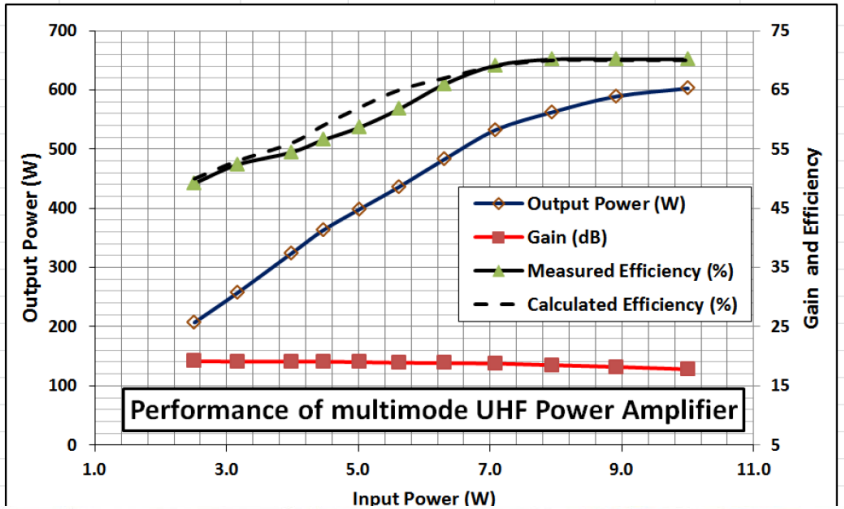
65% efficiency has been achieved for one unit

325 MHz, 7 kW Solid State RF Power Amplifier (SSRFPA) has been recently bench tested for its design values

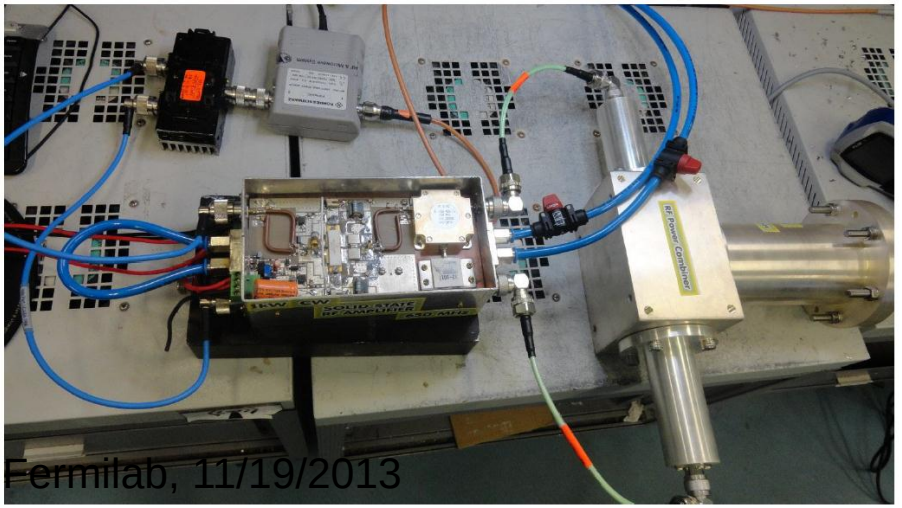
RRCAT: 650 MHz RF

- A 550 W Solid State amplifier Module has been designed. A prototype has been built and tested.



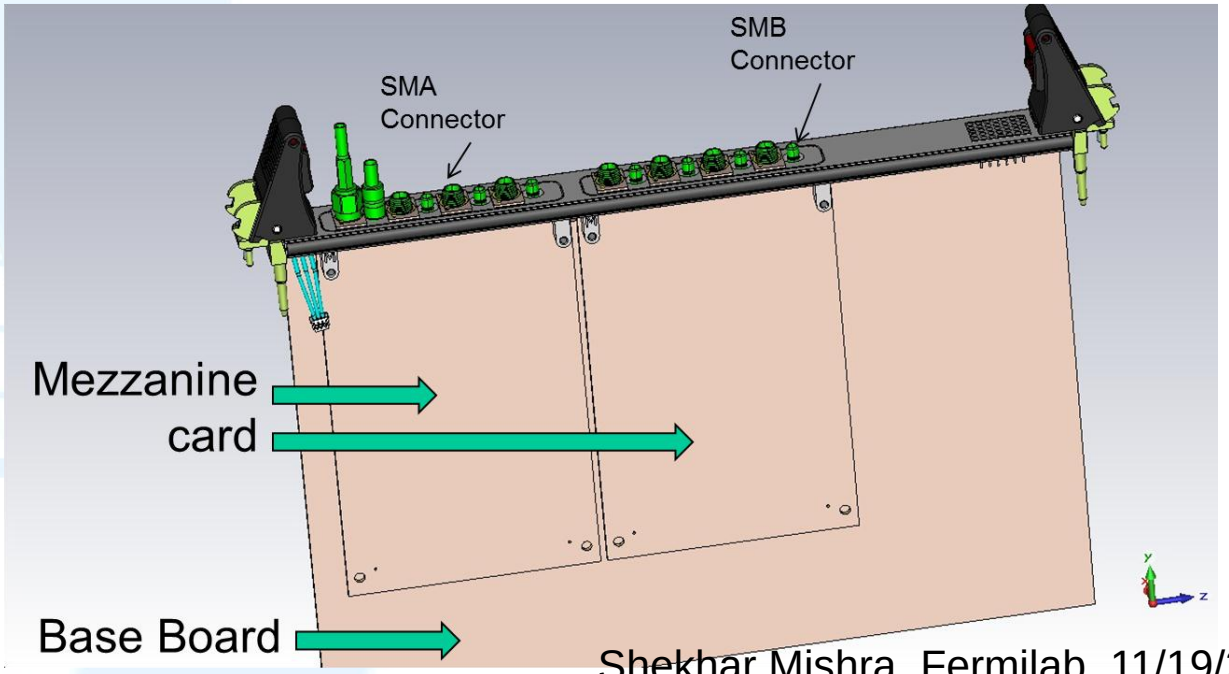


- A 1 kW Solid State amplifier Module demonstrated.



BARC: Controls and Instrumentation

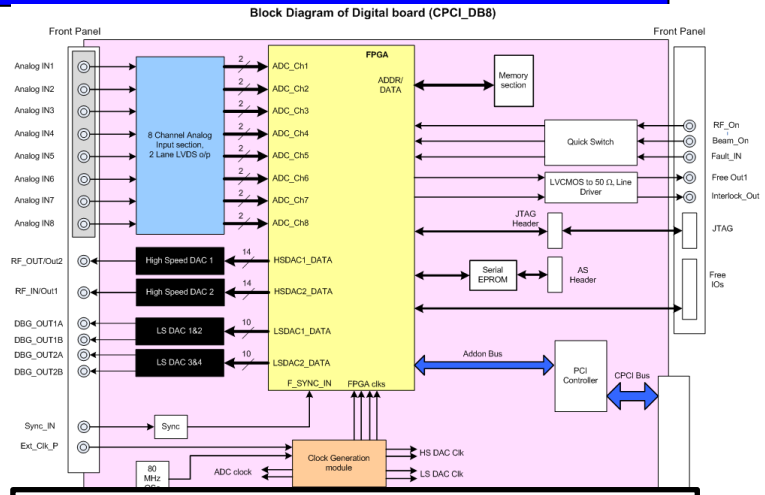
- **Areas of collaboration**
  - **RF Protection Interlock System (RFPI)**
  - **LLRF**
  - **Beam Position Monitors**
  - **Cryogenic Temperature Monitoring System**
  - **Software for the integrated operation of CMTF**
  - **In pipe-line – Beam Loss Monitors, Timing System**



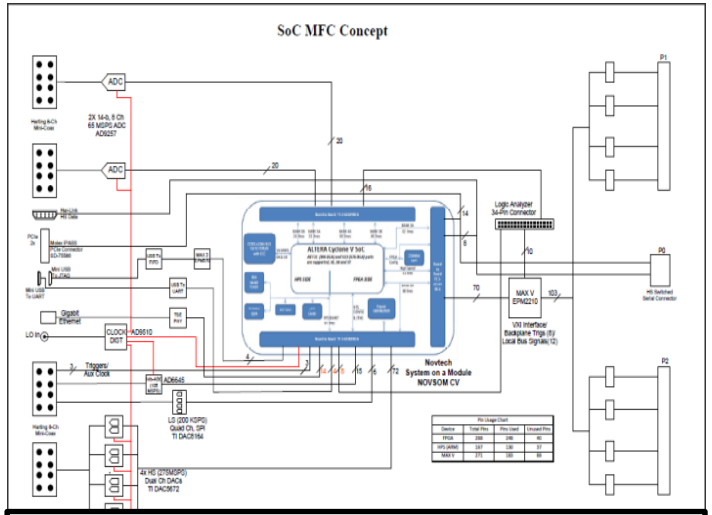
Developing a 4th Generation Technology

BARC: Low Level Radio Frequency

- **Prototype of 8 Channel LLRF system for control of two RF cavities is under lab testing.**
  - **Full digital approach employing under-sampling of RF signal**
  - **Demodulation, filtering and modulation code for one channel implemented**
  - **Results being analyzed to decide whether up/down converter will be required or not.**
  - **The system will be upgraded to 16 channel.**
- **The scheme of using System on Chip (SoC) suggested by Fermilab is being studied.**
- **EPICS Based software development**



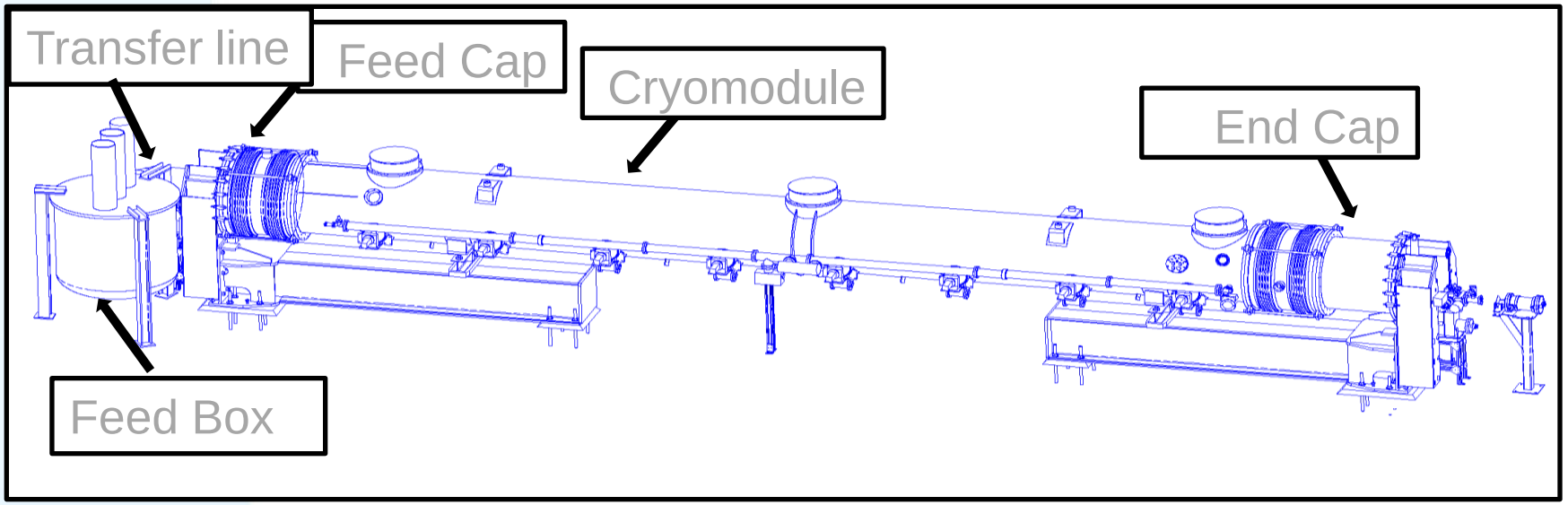
8 Channel CPCI based



SoC scheme

BARC: Cryomodule Test Stand

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



Status: Design & Drawing of all three sub assemblies are done. Material for fabrication ordered.

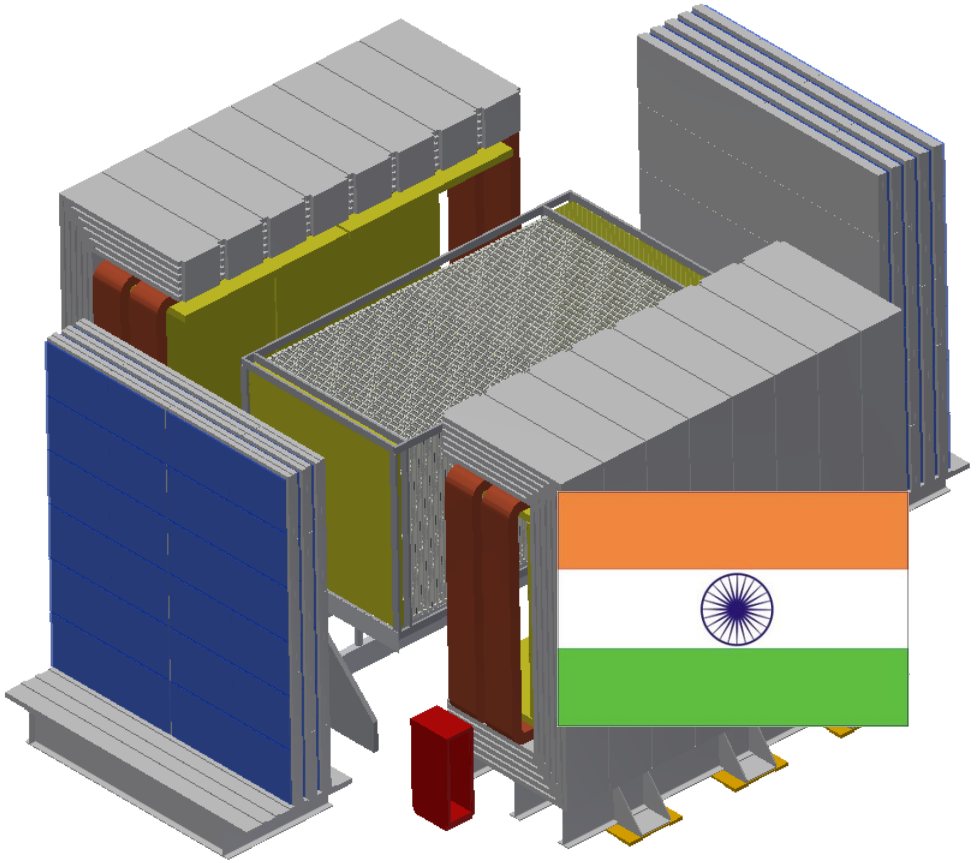
- **CMTF (FY16): 650 MHz CW Test Stands**
  - **1300 MHz (pulsed) CM test stand (with India)**
  - **650 MHz (CW) CM Test Facility (with India) ← Integrated System**

IIFC – νP Collaboration

- Eight Indian Institutions have joined the Fermilab Neutrino Physics Program.
  - MINOS, MINOS+
  - LBNE
  - NOvA
- We are expecting a total of 20 Ph.D. students from India under this program.
  - LBNE-ND effort centered and led by India will graduate 100+ Ph.D. students.
- This collaboration is growing
  - We continue to include more institutions and
  - Recruiting faculties and postdoctoral fellows.

IIFC: LBNE-ND Detector

- The details of how the collaboration will develop LBNE-ND is still under discussion.
- Major Subsystems
  - Straw Tube
  - Muon ID
  - ECAL
  - Magnet
  - Readout and DAQ
- Schedule
  - Conceptual Design CY14
  - Preliminary Design CY 15
  - Final Design and Prototype CY16
  - Infrastructure Development CY16-17



India: LBNE Near Detector

LBNE-India proposal to the US and Indian could jointly build the LBNE Near Detector with India as a leader.

US and Indian Management









Thanks to all

Summary

- **An Excellent collaboration with solid foundation is in place and making technical progress on all fronts.**
  - **It is not just bunch of MOUs, real three dimensional objects are being developed together**
- **Collaboration has a support of US and Indian administration.**
- **It must, should and is aligned to Indian National Interest and will advance the Indian domestic program**
- **Looking at 10+ yrs horizon this is an excellent opportunity for both US and India, that in my opinion must be capitalized on, solid foundation is in place.**

Dedication: My Father

In Jan 2003, when I met my dad for the last time he told me:

"Shekhar you have done so much for your adopted country, do something for your motherland who has made you this capable."

Dad this talk is dedicated to that last memories that you left me with.