Indian Activities under IIFC

Pitamber Singh

Head, Ion Accelerator Development Division

Bhabha Atomic Research Centre, Mumbai

Presentation on behalf of

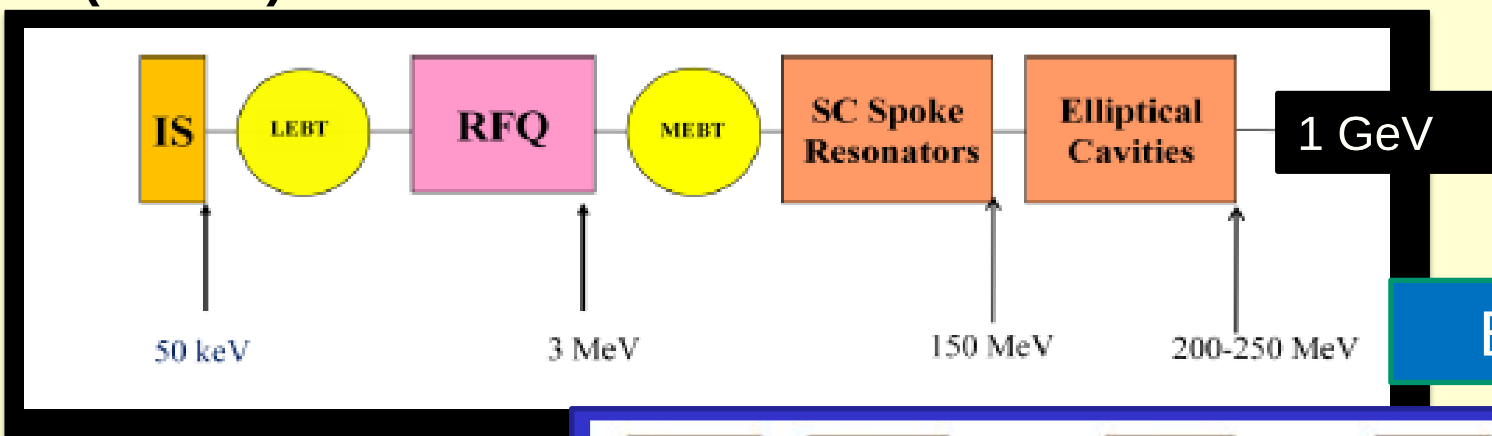
1. Bhabha Atomic Research Centre, Mumbai
2. Raja Ramanna Centre for Advanced Technology, Indore
3. Variable Energy Cyclotron Centre, Kolkata
4. Inter University Accelerator Centre, New Delhi
5. Fermilab, USA

June 3, 2014

DAE Accelerator Development Program

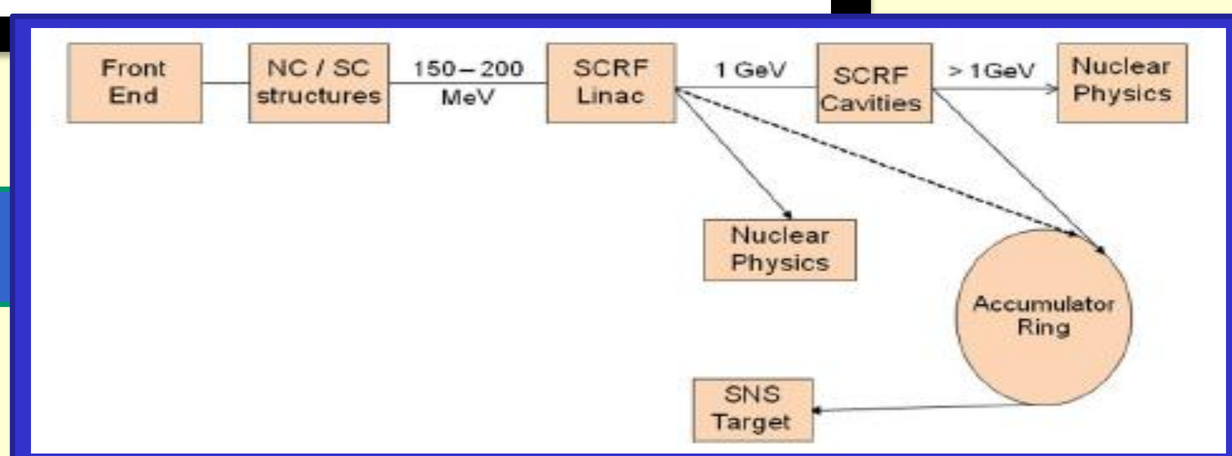
DAE laboratories have proposed (XII and XIII Plans)

- **Physics Studies and Enabling Technology Development for Ion Accelerators (BARC) (Approved by AEC)**
- **High Energy Proton LINAC Based Spallation Neutron Source (RRCAT)**



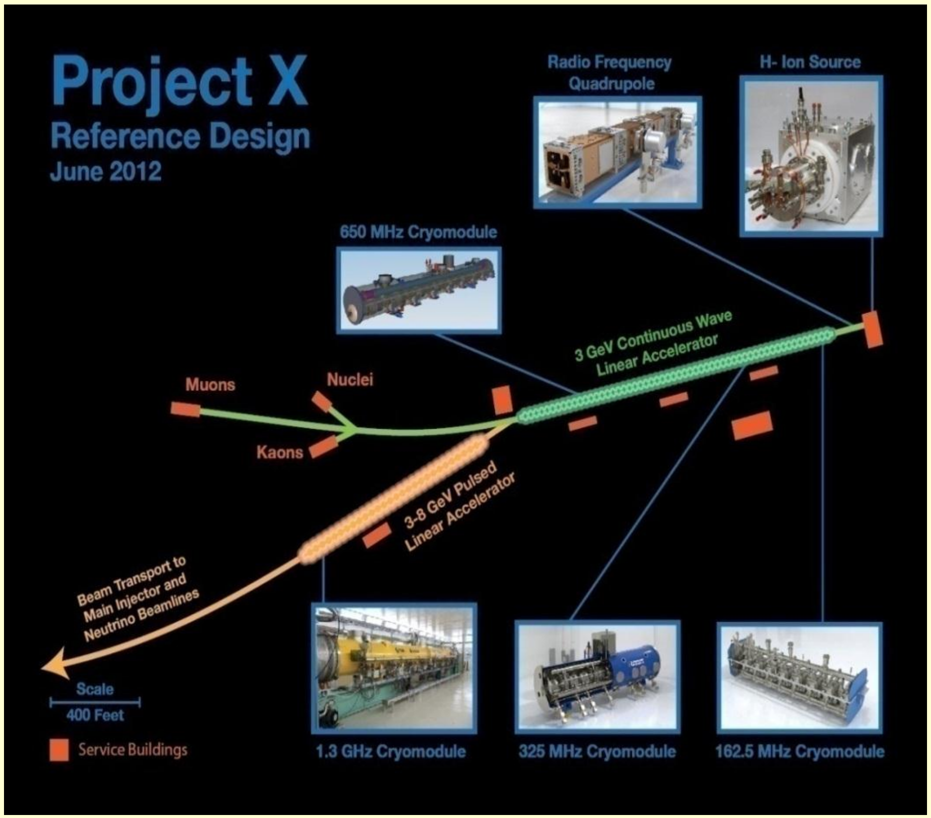
BARC

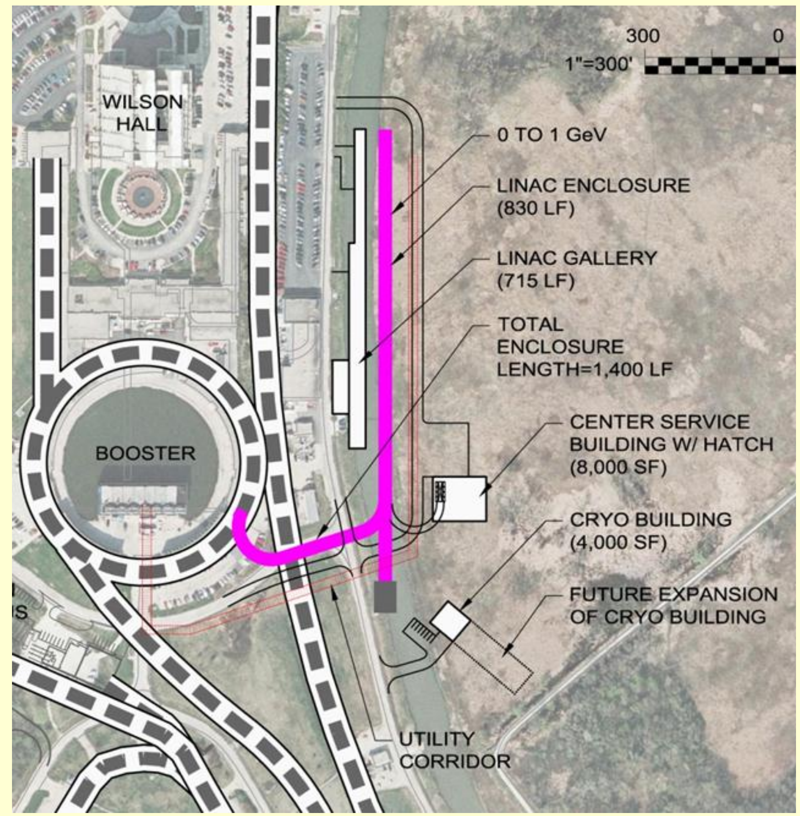
RRCAT



Project at Fermilab

- **Fermilab has proposed the construction of a High Intensity Superconducting Proton Accelerator (HISPA) (aka PIP-II)**





Phase I: PIP-II

Fermilab

Indian Institutions and Fermilab Collaboration

- **The collaboration signed MOU to collaborate on**
  - **High Intensity Superconducting Proton Accelerator for the respective domestic programs**
    - **Concept of “Total Project Collaboration” on Accelerator**

Technical work under MOU

1. Fermilab, RRCAT, BARC, IUAC and VECC Collaboration on ILC Main Linac SRF Accelerator Technology R&D" (October 2, 2007)
2. SLAC, RRCAT, BARC, IUAC and VECC Collaboration on ILC RF Power Sources and Beam Dump Design R&D" (December 3, 2007)
3. Fermilab and Indian Accelerator Laboratories Collaboration on High Intensity Proton Accelerator and SRF Infrastructure Development" (February 10, 2009)
4. Fermilab and Indian Accelerator Laboratories Collaboration on RF Power (325 MHz) Development for High Intensity Proton Accelerator" (August 22, 2011
5. Collaboration on RF Power (650 MHz) Development for High Intensity Proton Accelerator" (Aug 22,2011)
6. Collaboration on Instrumentation and Control for High Intensity Proton Accelerator" (Aug 22, 2011)
7. Collaboration on Accelerator Physics issues for High Intensity Proton Accelerator" (Aug 22, 2011)

DOE-DAE Implementing Agreement

IMPLEMENTING AGREEMENT

BETWEEN

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA

AND

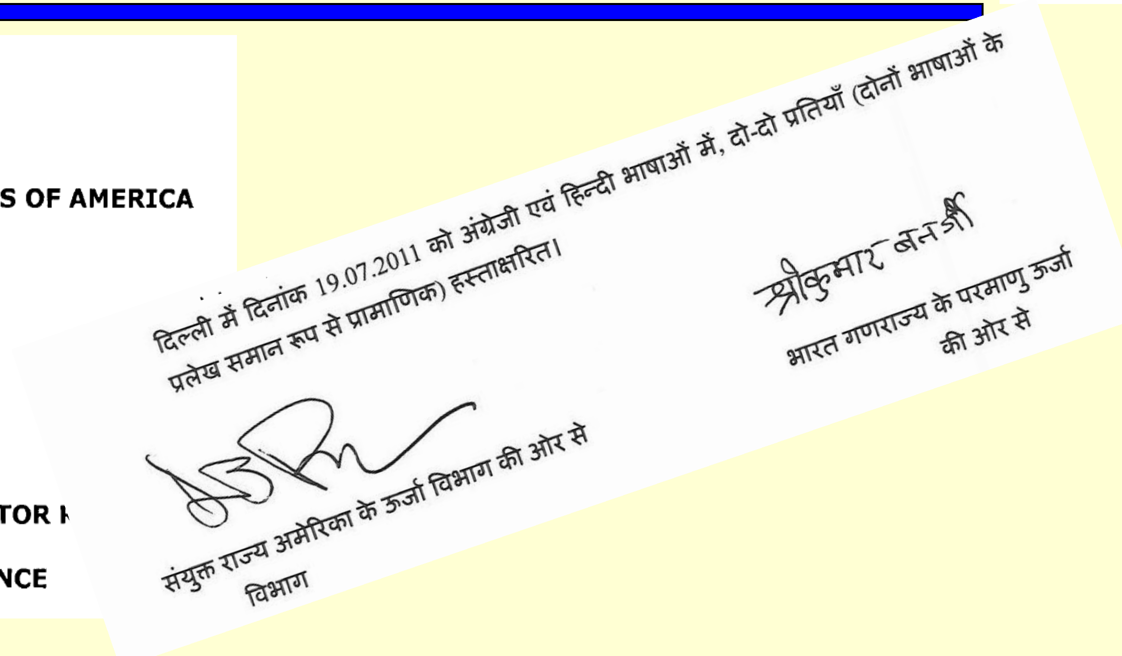
THE DEPARTMENT OF ATOMIC ENERGY

OF THE REPUBLIC OF INDIA

FOR COOPERATION

IN THE AREA OF ACCELERATOR AND PARTICLE DETECTOR R

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
विभाग

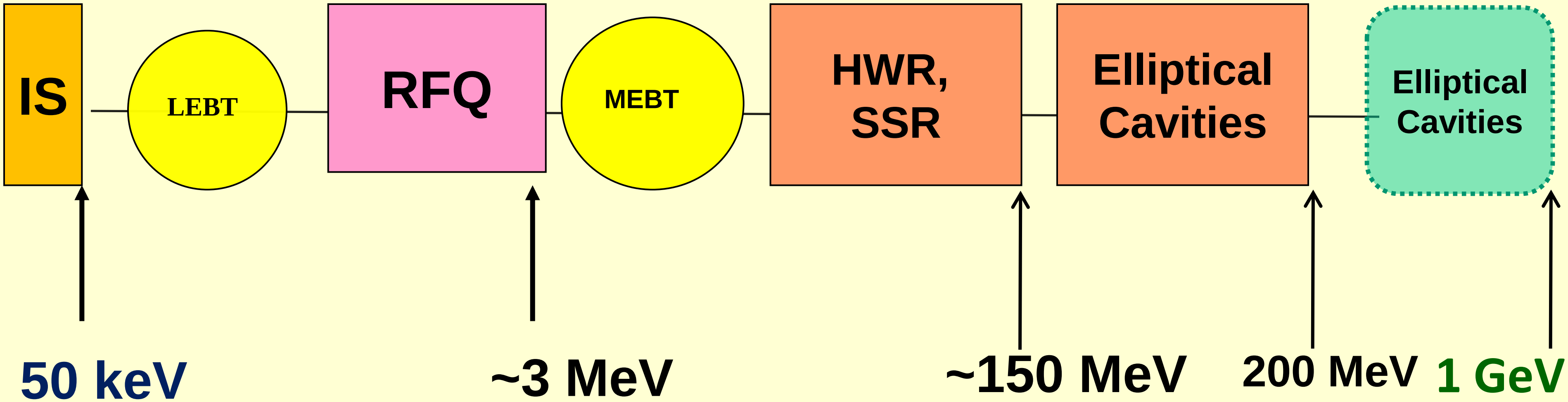
भारत गणराज्य के परमाणु ऊर्जा
की ओर से

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.

Project Annex 1 for HISPA Collaboration awaits final signature

Frequency: 325 and 650 MHz

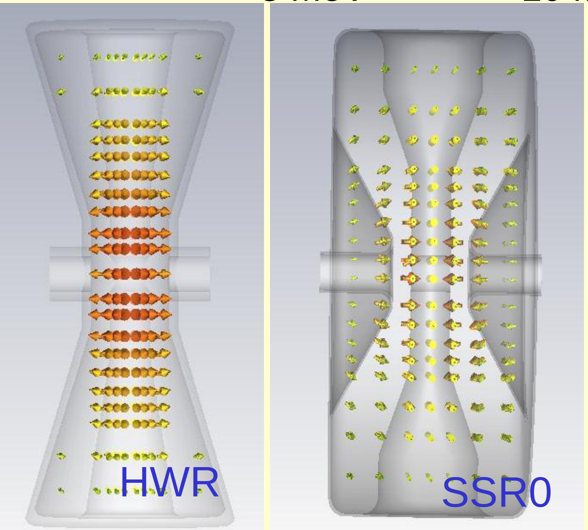
Scheme for the 1 GeV High Intensity Superconducting Proton Accelerator



- **We will go in steps but the initial design needs to be done for 30 mA**
- **1st Phase will be similar to PIP-II**

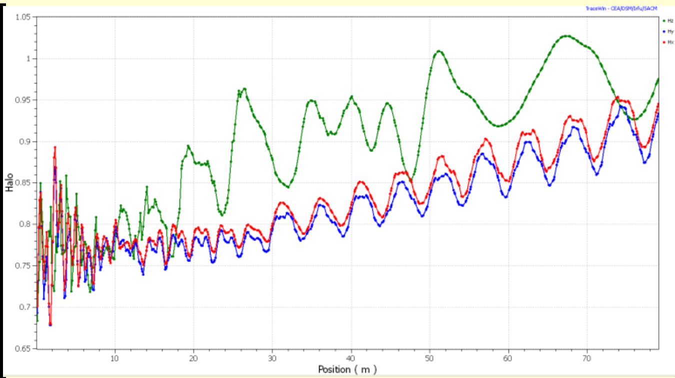
Layout of BARC Linac

IS	RFQ	HWR/ SSR0	SSR1	SSR2	5 cell elliptic Cavity
	3 MeV	~10 MeV	~50 MeV	~200 MeV	1 GeV

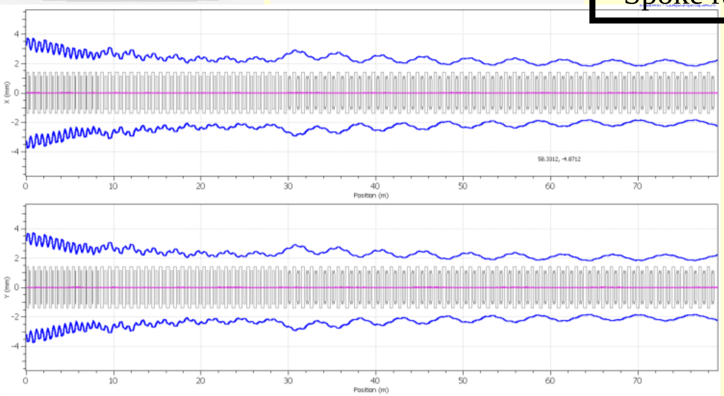


SSR0 & HWR cavities have been optimized to minimize peak fields.

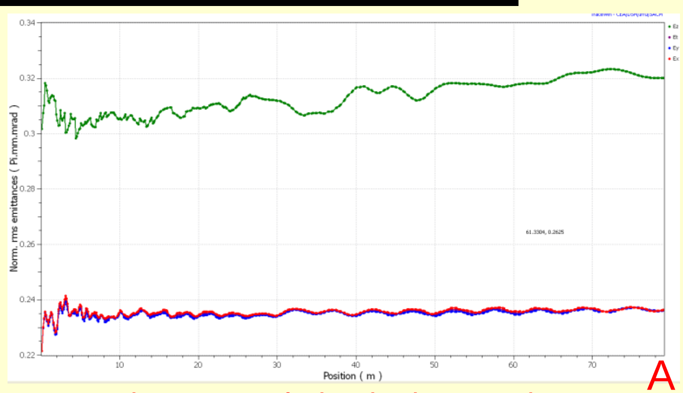
Parameters	HWR	SSR0	Units
β_G	0.11	0.11	
Frequency	162.5	325	MHz
E_{pk}/E_0	5.15	5.78	
B_{pk}/E_0	6.44	6.53	mT/(MV/m)
Height (H)	860	399.4	mm
Spoke radius	80	45	mm



Halo Parameter in the SC Linac



Beam profile in the SC Linac



Emittance evolution in the SC Linac

Sections	Cavities	Energy @ end (MeV)
SSR0	13	10.0843
SSR1	25	50.0197
SSR2	49	201.774

Input emittance
In x and y = 0.22 pi mm mrad
In z = 0.3004 pi mm mrad

Output emittances
In x and y = 0.2360 pi mm mrad
In z = 0.3197 pi mm mrad

A baseline beam dynamics design for the SC linac has been done for 30 mA H^+ beam upto 200 MeV.

Fermilab

RFQ for 200 MeV Linac

Requirement:

- Good beam quality (Longitudinal emittance small)
- Maximize the Transmission

Results:

Energy : 3 MeV

Length of RFQ : 3.8 m

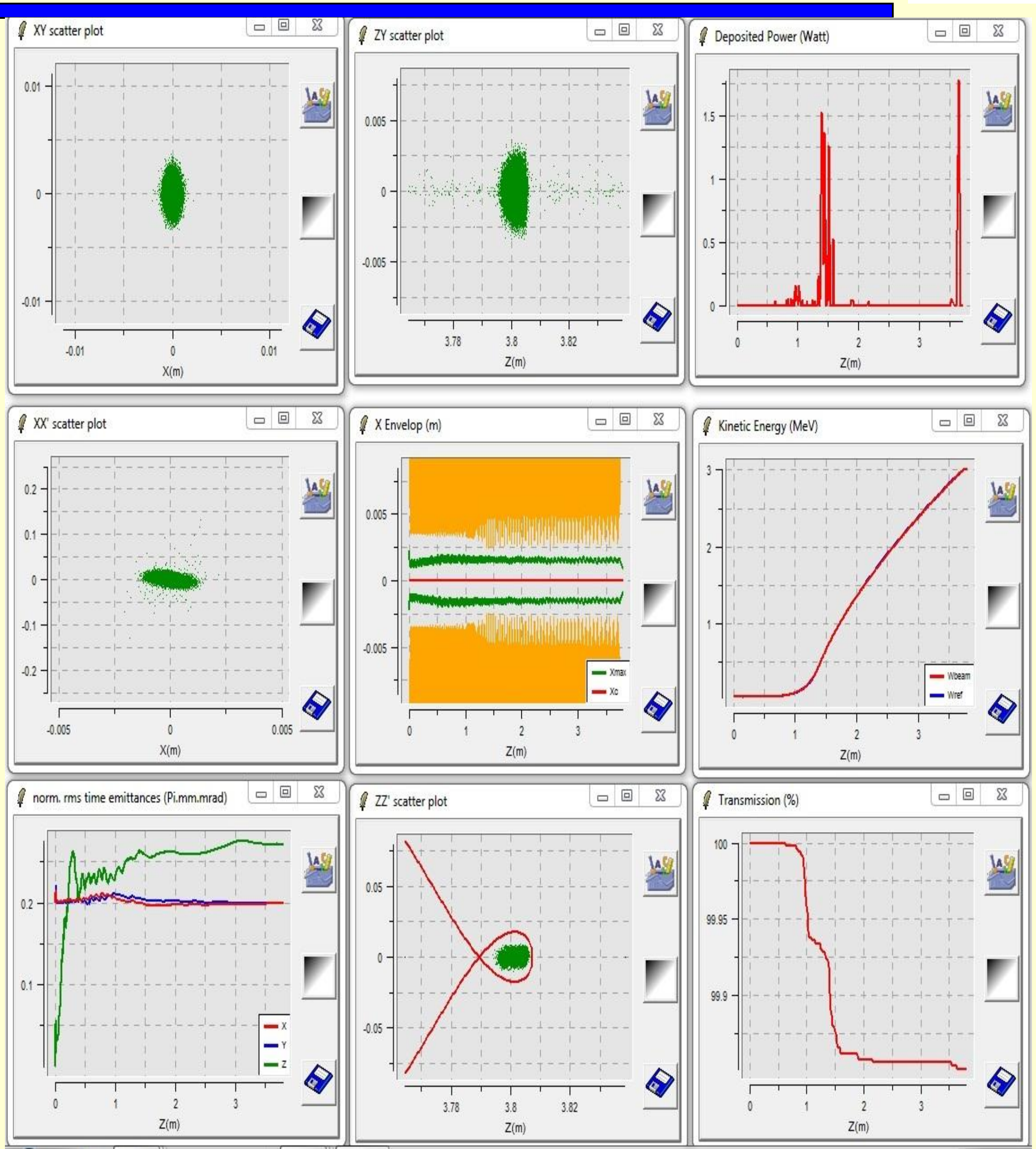
Transmission : 99.85 %

Accelerated : 99.44 % (3 ± 0.105 MeV)

RMS emittance at exit of RFQ:

O/P Trans emitt: 0.02 cm-mrad

O/P Long emitt: 0.03 cm-mrad



Design and Development of Focusing lenses for MEBT

Stages of Development work at BARC:

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

Current Status:

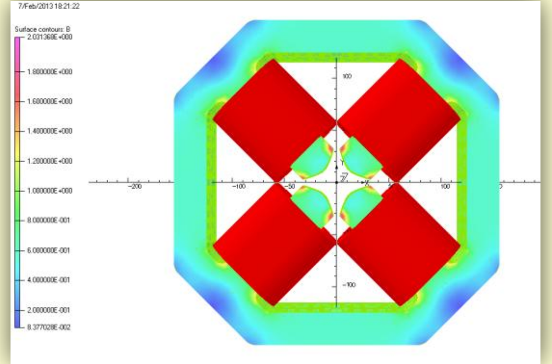
- A prototype of Quad F and dipole corrector has been developed and qualified for its magnetic, electric, thermal design & for beam focusing.
- The prototype magnets are planned to be shipped to Fermilab for detailed magnetic measurements and integration with PXIE beam line. Fabrication of triplet and doublet frames with Dipole corrector has been initiated at BARC.

Table1: Deliverables for PXIE MEBT/HEBT transverse focusing lattice with their optics requirements

S. no	Type	Qty.	Integrated Gradient / integrated field	Field homogeneity in GFR of 23 mm	Longitudinal space
1	Quadrupole F (QF)	18	1.5 T	1%	100mm
2	Quadrupole D (QD)	16	0.85 T	1%	50mm
3	H/V Dipole corrector(DC)	15	2.1 mT*m	5%	55mm

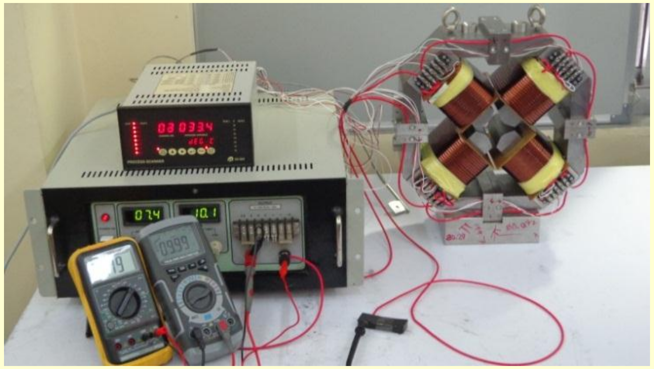
Development of Quadrupole - F Magnet

Electromagnetic Analysis



Electromagnetic design and analysis using TOSCA

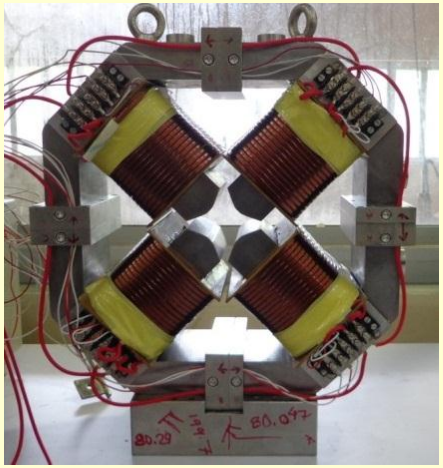
Thermal Qualification



Thermal qualification with embedded RTD sensors

Yoke Development

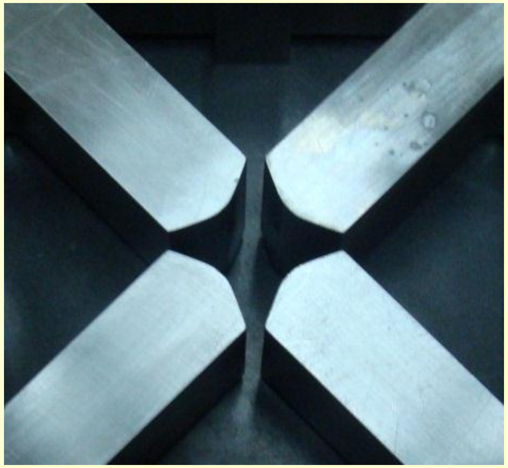
The Quadrupole magnet yoke



Quadrupole-F magnet assembly

SN	Particular	Values
1.	Current	9.98 A
2.	Initial Resistance	0.73 Ω
3.	Increase in Resistance	0.055 Ω
4.	Temperature coefficient of Resistivity	0.003862 K^{-1}
5.	Temperature Rise	19.40 °C

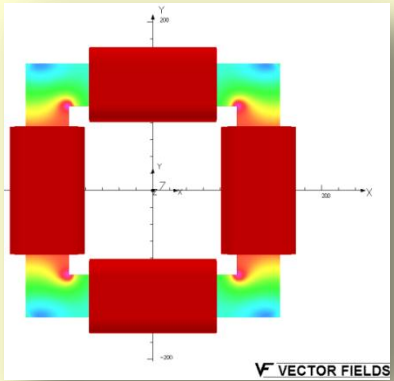
Results of heat run tests



Quad. Pole profile –dimensional accuracy 30 µm

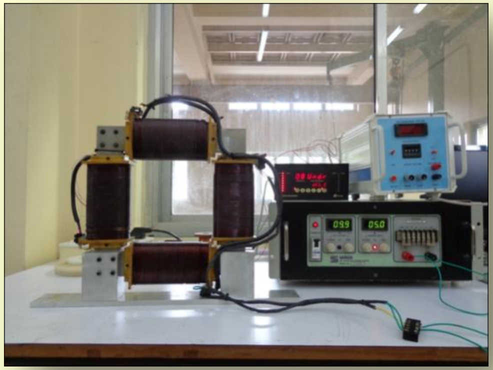
Design & Development Dipole correctors

Electromagnetic Analysis



Electromagnetic design and analysis using TOSCA

Thermal Qualification

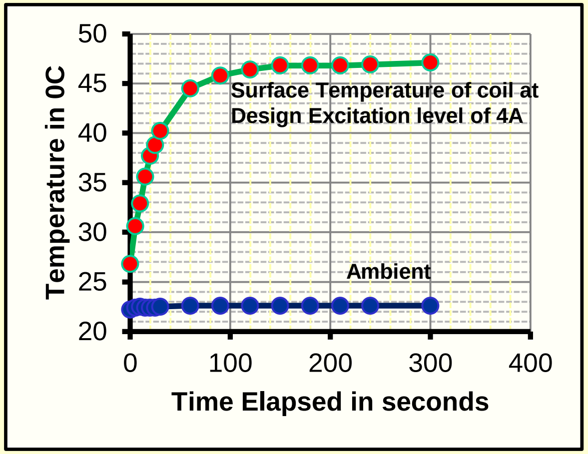


Thermal qualification with embedded RTD sensors

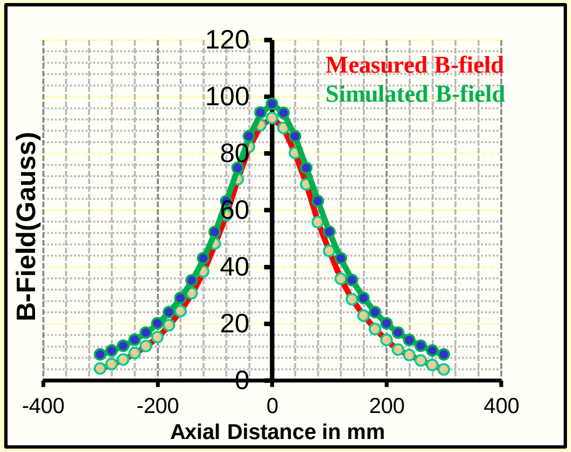
Magnetic Qualification

Magnetic measurement with Hall sensors at BARC

Fabrication and assembly of dipole corrector

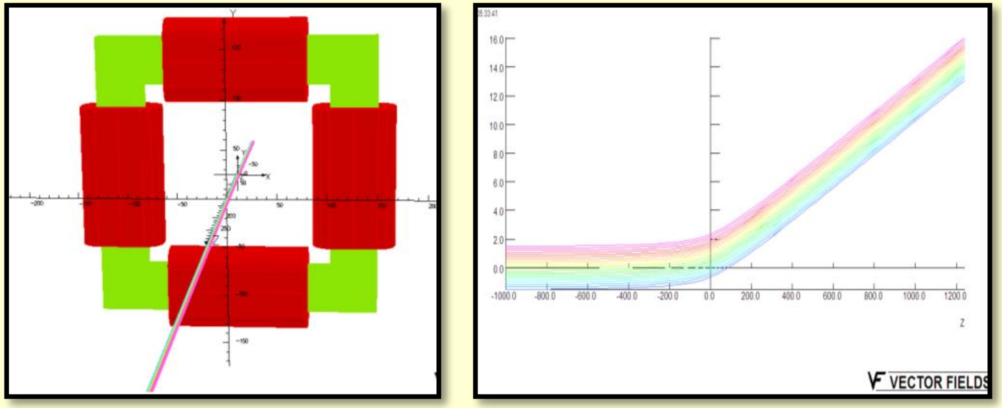


Results of thermal run test



Magnetic field measurement along axial length of magnet

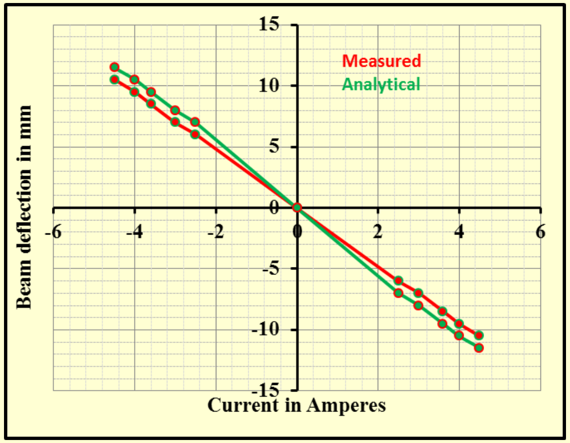
Qualification of dipole correctors with proton beam at FOTIA facility, BARC



Particle trajectory simulations

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

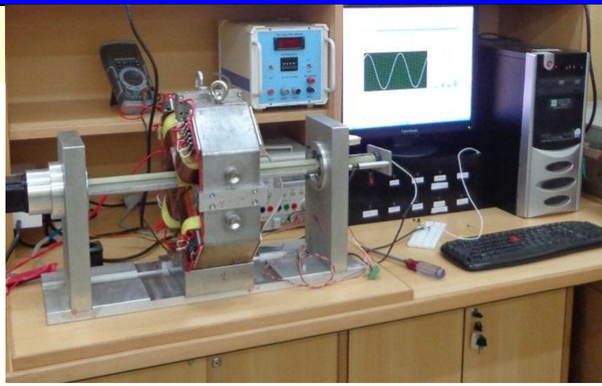
Dipole corrector magnet assembly installed in FOTIA beam line



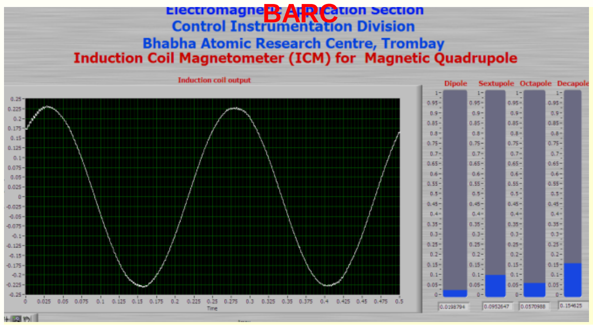
Steering of beam - analytical vs. measured

Magnetic Measurements and beam line Qualification of Quad F

Summary of magnetic measurements



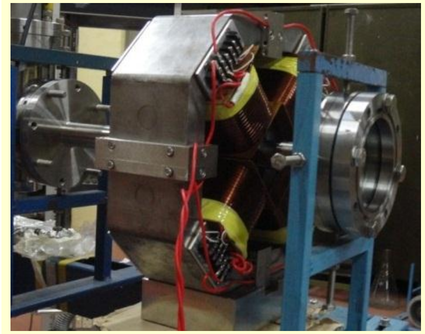
Magnetic measurement set-up comprising of Induction coil, flip coil and Hall probe at BARC

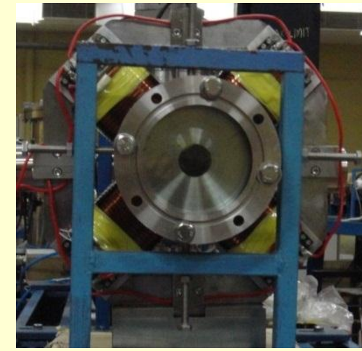


Magnetic field and its higher order multipoles measured using induction coil magnetometer

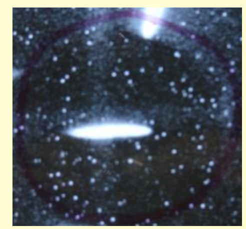
Parameter	Simulated	Achieved	Unit
Input MMF	1500	1500	AT
∫G.dl	1.533	1.59	Tesla
Magnetic Flux/pole	8.91	8.95	kmax

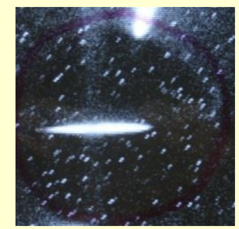
Summary of Beam line Qualification of Quad-F with 2.5 MeV H+ beam

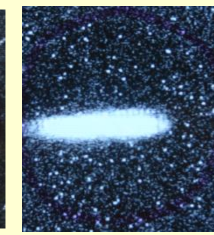




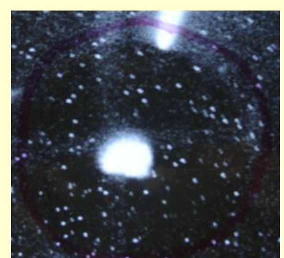
Quad-F assembly installed in FOTIA beam line



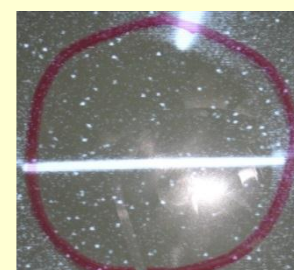




Focusing snap shots at different currents,
Beam focuses as current of Quad increases, and it tends to de-focus when focused beyond focal point



Beam snap shot (Quadrupole off)



Beam snap shots (Quadrupole on)

Single Spoke Resonator at IUAC

- IUAC is involved in the fabrication of two TEM-class 325 MHz, β=0.22, Single Spoke Resonators

- Apart from this, IUAC & RRCAT are collaborating to build TM-class Single & Multi-cell cavities operating at 1.3 GHz and 650 MHz.
  - Single Cell 650 MHz, β=0.9 Cavity
  - 5-Cell 1.3 GHz Niobium Cavity

In the last few months substantial amount of effort has been devoted for completing the two Spoke assemblies and subsequently attaching them to the Outer Shells.

The Single Spoke Assembly

In the last few months two Spoke assemblies have been completed and subsequently attached to the Outer Shells.

Before electro-polishing

After electro-polishing

Shell + Spoke Assembly

Recently the Spoke assemblies were successfully attached to the Outer Shells.

Next Step for SSR1

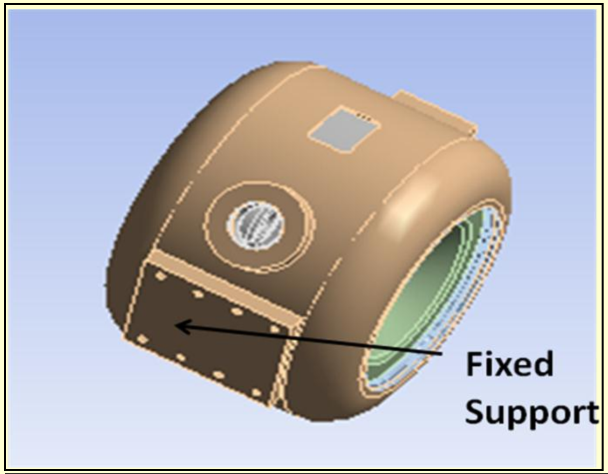
The next step is to tune the resonators and attach the End Walls to the Outer Shells. All the four End Wall assemblies are ready.

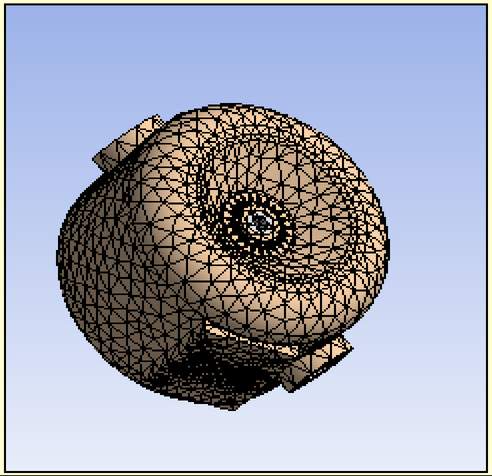
All the 4 End Walls (left), and electropolished RF side of an End Wall (right).

Measurements SSR1

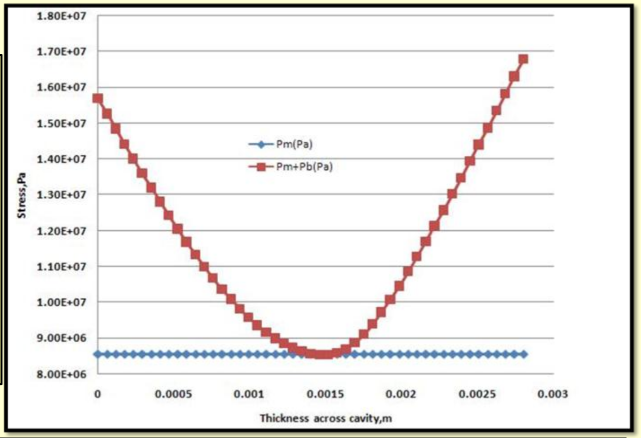
The Spoke + Shell assemblies and the End Wall assemblies are being readied now for frequency tuning.

VECC: He Vessel and Tuner



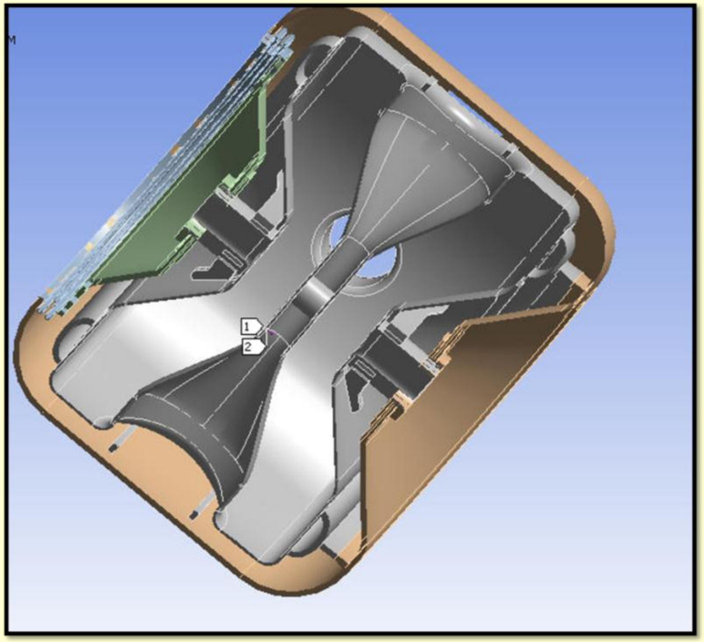


CASE II



CASE-I (2 bar at room temperature during initial cool down)
CASE-II (4 bar external pressure+ low temperature, 2K)

Figure: Stress Linearisation of primary stress:
Pm = 8.8 Mpa < Sm = 33 MPa
Pm+Pb = 17 Mpa < 1.5 Sm = 48 MPa



CASE II

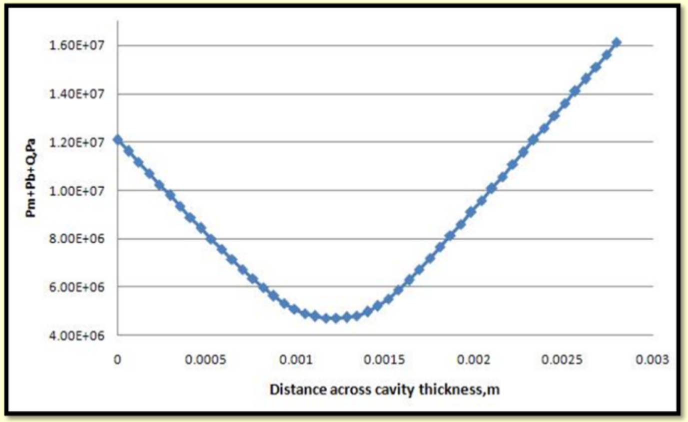
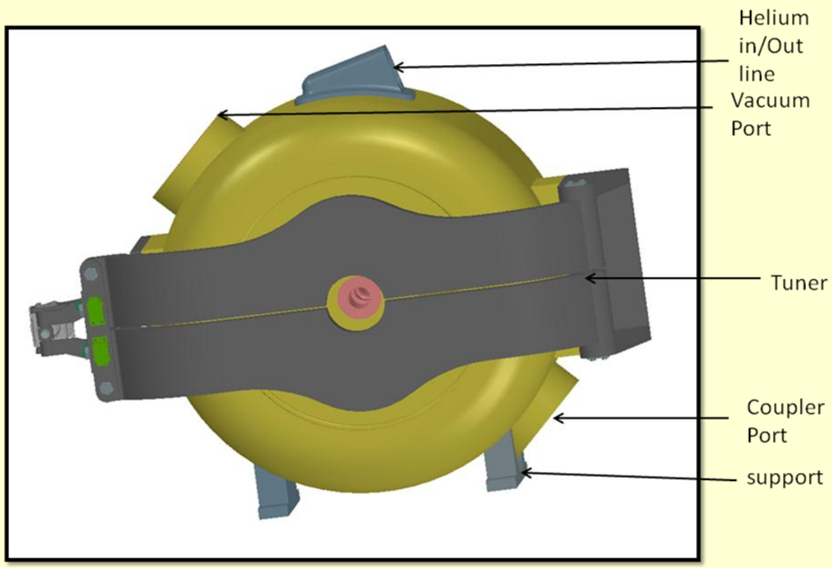
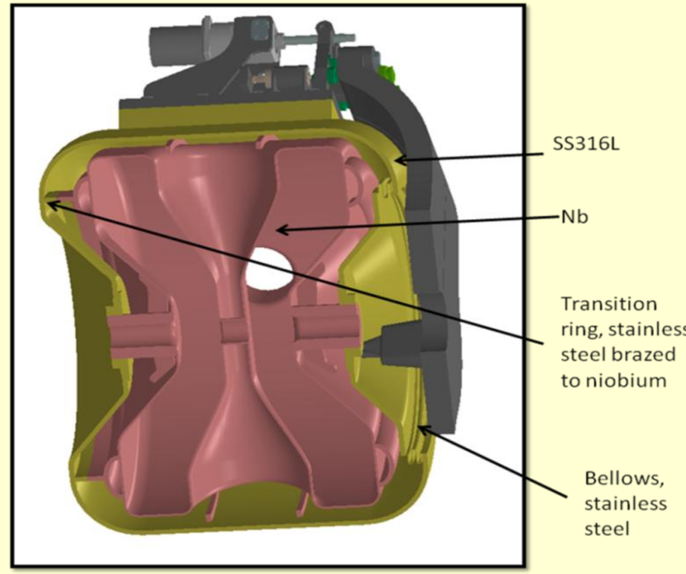
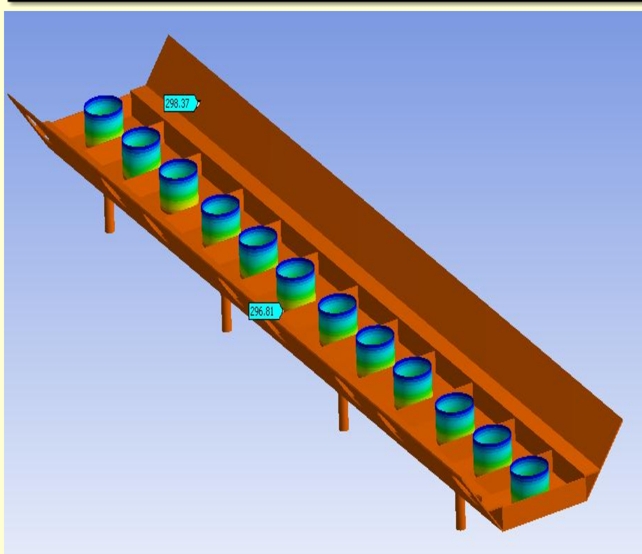


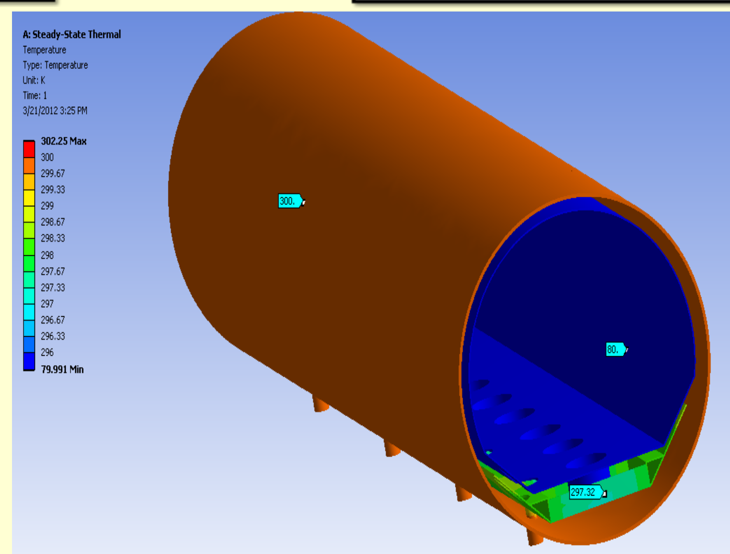
Figure: Stress Linearisation of primary stress
Pm+Pb+Q = 16 Mpa < 3 Sm = 309 MPa

Helium vessel and Cryomodule for SSR1









Strong Back Temperature distribution

- ✓**Details analysis is being done to find out the temperature**
- ✓**Temperature plot shows that the maximum thermal gradient is at the support posts**
- ✓**Challenging design and developmental job ahead!**

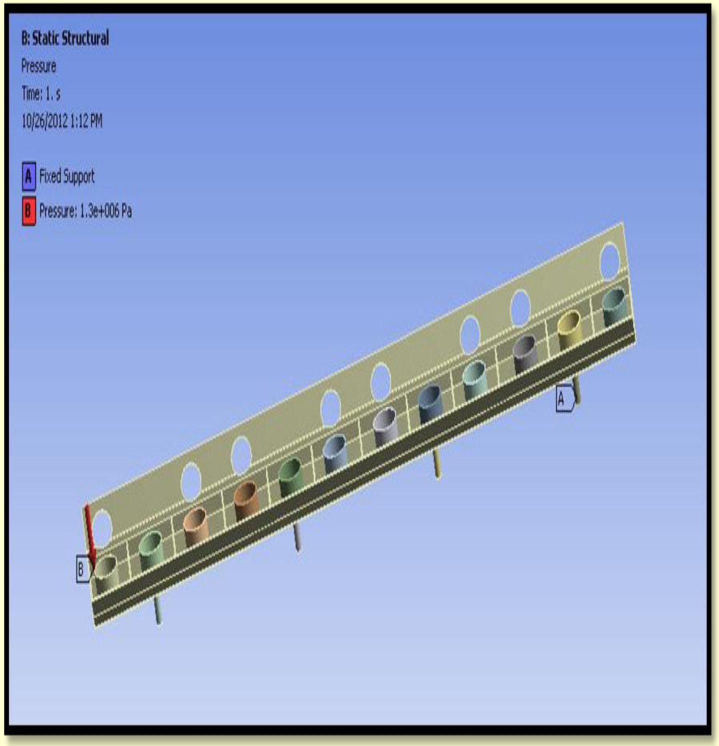
Fermilab

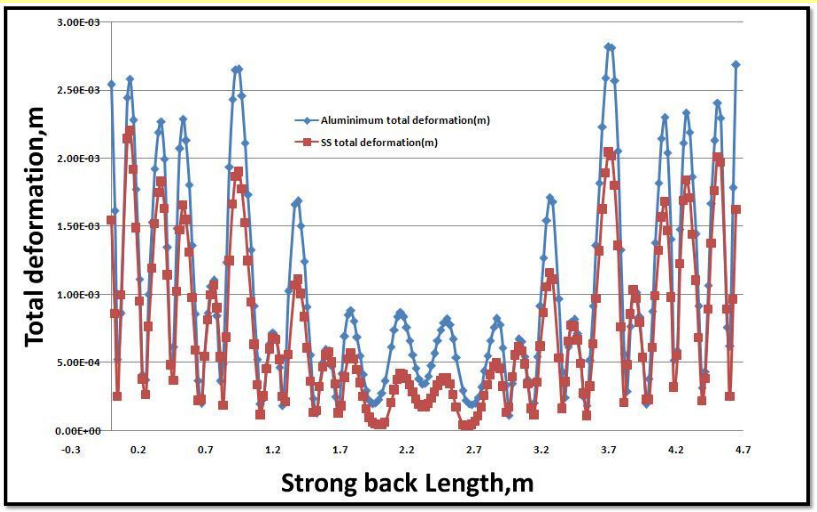
Structural Analysis: SSR1 CM

❖ The temperature distribution result of the model has been transported to structural analysis platform for subsequent coupled analysis.

❖ OVC end of the SS support pin is assumed to be fixed.

❖ Conservative approximation of dead load of helium vessel, helium, cavity, solenoid, thermal shield, associated cryogenic piping has been considered for structural analysis. Total approximate load of 24000N will act on 12 nos. of G11 support post having cross section area of 1551 mm^2. The whole load is converted to equivalent pressure load on each G11 support post and amounts to 1.3 MPa.





- Deformation is inversely proportional to Young's modulus for mechanical loading.
- For Aluminium 'E' Value is less than SS.
- For thermal loading deformation is proportionalto thermal expansion co-efficient, which is high for Al in comparison to SS.
- Hence Aluminium shows higher total deformation even though the ΔT is less for Aluminum.
- A lot of challenging jobs on analysis etc.!

BARC: Solid State RF amplifiers at 325 MHz

1 kW
Amplifier

- **Power: 1 kW**
- **Overall Gain: > 65dB**
- **Efficiency : 61 %**
- **2nd Harmonics: - 41.5 dB**

3 kW
Amplifier

- **Power: 3 kW**
- **Overall Gain: > 65 dB**
- **Efficiency : 65 %**
- **2nd Harmonics: - 41.9 dB**

7 kW
Amplifier

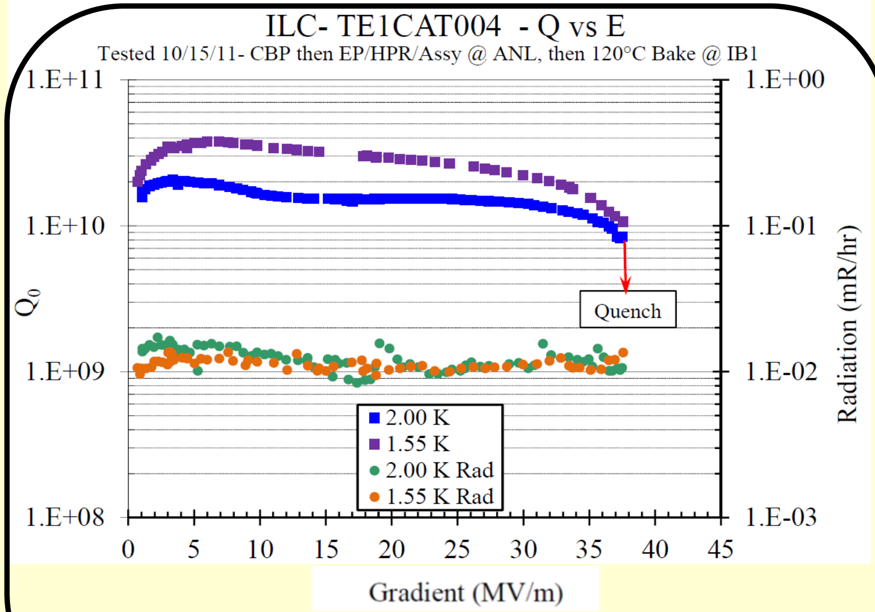
- **Power: 7 kW**
- **Overall Gain: > 90 dB**
- **Efficiency : 68 %**
- **2nd Harmonics: - 41.9 dB**

Assembled and wired unit of 7 kW SSRFPA

Development of Single-cell Cavities

- Four numbers of single-cell 1.3 GHz cavities fabricated at RRCAT / IUAC and tested at Fermilab.

1.3 GHz Nb Single Cell Niobium Cavity developed in India (RRCAT / IUAC)



(October (2011)

Acceleration gradient of 37.5 MV/m with Q > 10^{10} at 2K

1.3 GHz 5-Cell Cavity

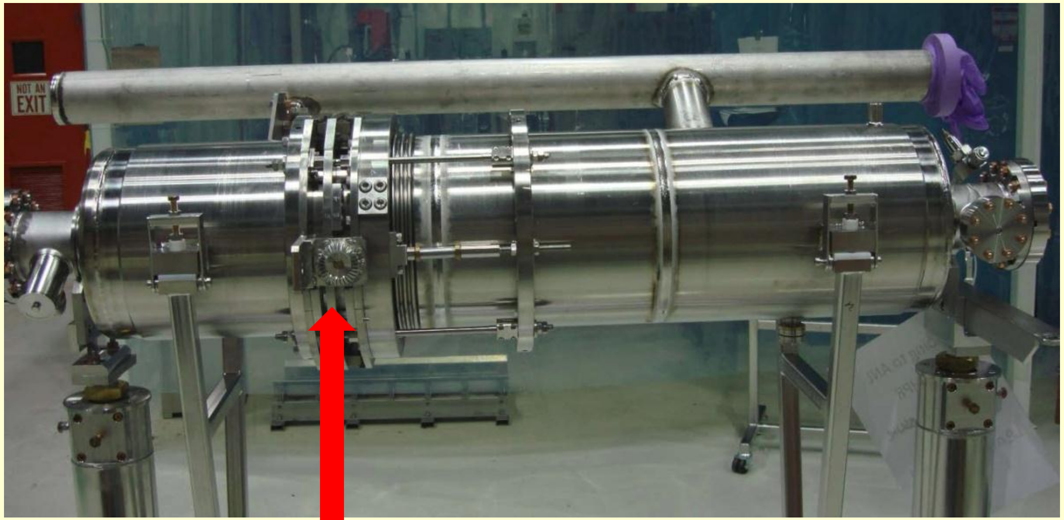
RRCAT & IUAC have also developed a 1.3 GHz TESLA-type 5-Cell Niobium Cavity.

Essentially to understand multi-cell cavity fabtication

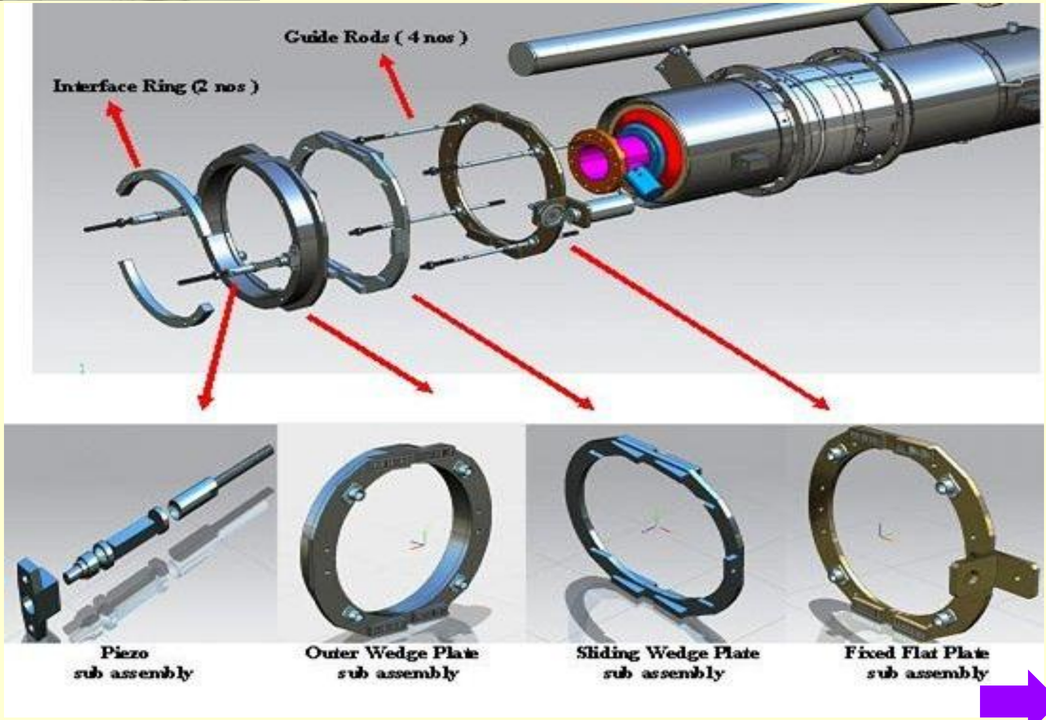
BARC: Wedge Tuner Assembly

A Double Wedge Tuner (DWT) has been designed and developed for compensation of Lorentz force detuning and micro phonics stabilization of the superconducting RF cavities. This is a co-axial device and can provide both the slow structure tuning and the fast tuning capabilities.

Wedge Tuner Installed for Testing at Fermilab

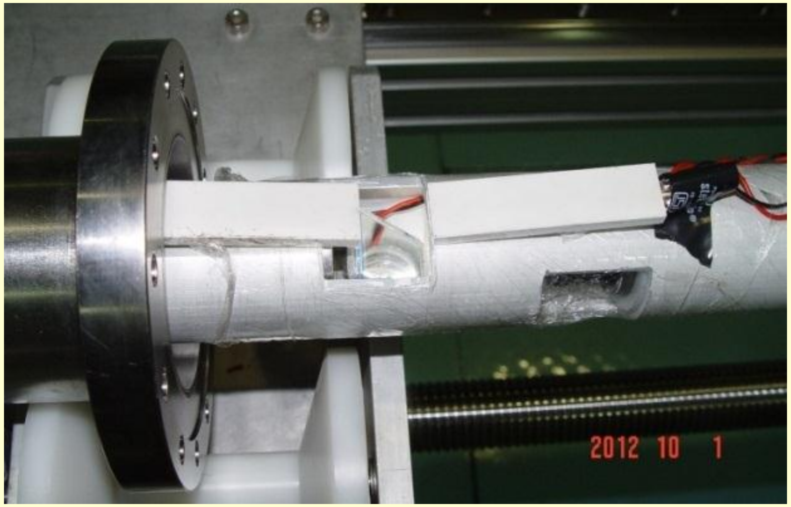


Wedge Tuner



RRCAT: Optical Inspection Bench for Multi-cell Cavities

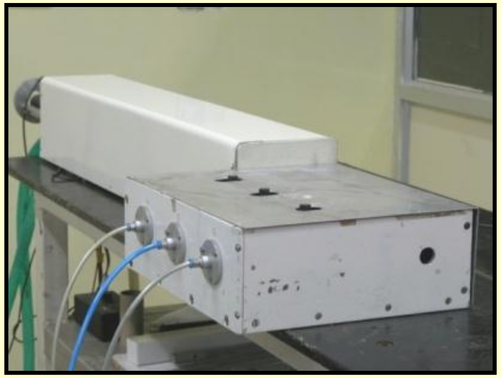
- An optical inspection bench has been developed to carry out internal inspection of multi-cell SCRF cavities.
- It consist of an optical imaging system and a cavity support bench. This is equipped with imaging software and provision for video recording.



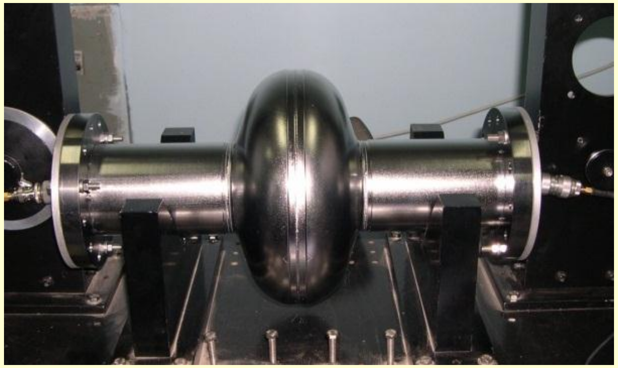
Optical inspection bench for multi-cell SCRF cavities

Laser Welding of Niobium Cavity

- RRCAT has made a technological innovation of fabricating superconducting cavities using laser welding.



10 kW fibre coupled Nd:YAG laser



World's first laser-welded single-cell 1.3 GHz niobium cavity

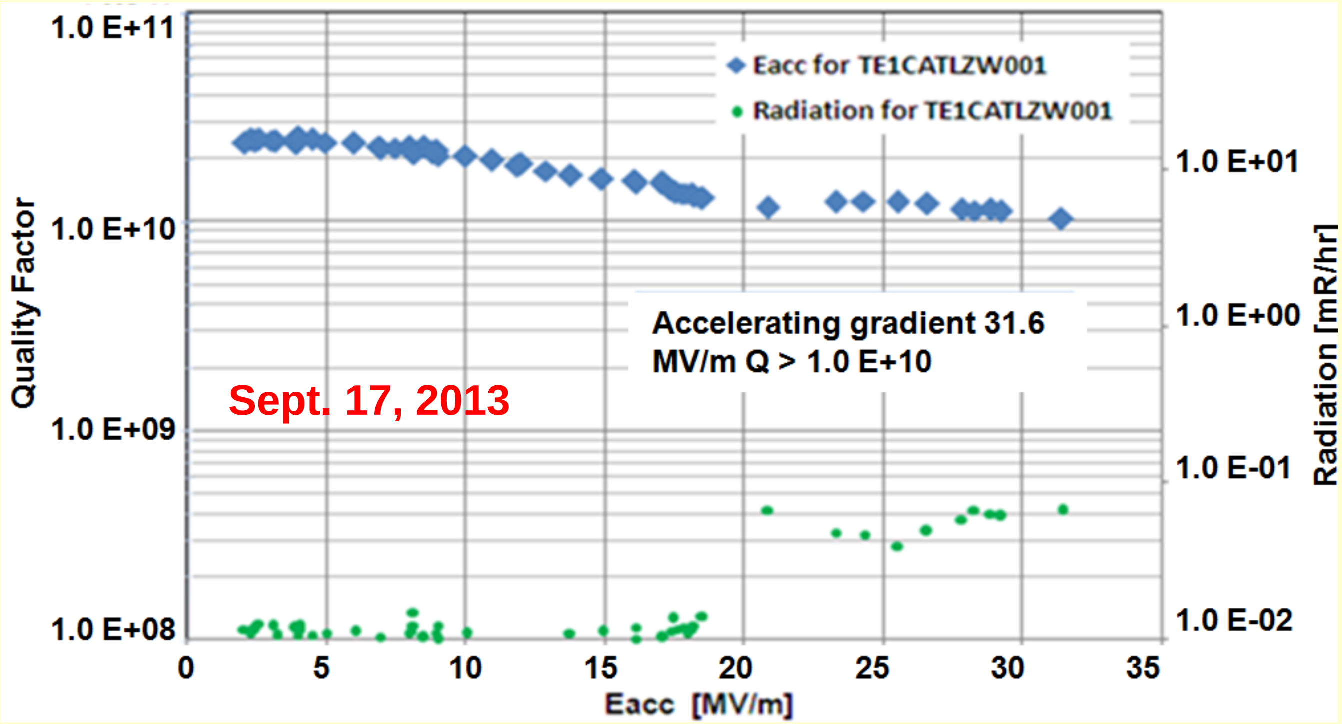
International patent applied

Advantages of laser welding over e-beam welding

- Smaller energy deposition : Less shrinkage and less distortion
- Not necessary to use vacuum
- Less cleaning requirement

Performance of Laser Welded Cavity

- The very first laser-welded 1.3 GHz SCRF niobium cavity developed at RRCAT and tested at Fermilab, USA achieved a high acceleration gradient of 31.6 MV/m with a quality factor of 10^{10} at 2K.

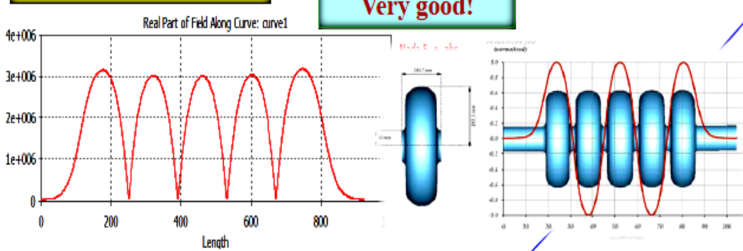


Design of 650 MHz cavities at beta = 0.61

Fermilab

Accelerating mode

Field flatness: Very good!



Data: Generated by VECC

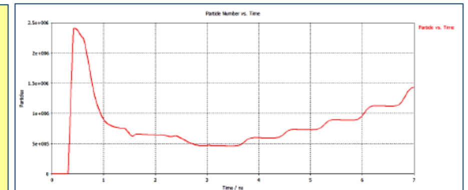
Results: Very good!

kc = 1.24% (Riris=48 mm.)

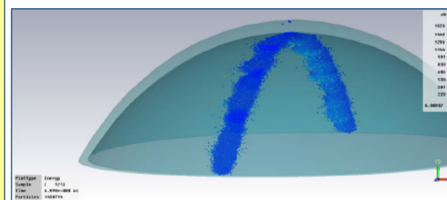
	$\frac{A}{B}$ mm./mm.	$\frac{a}{b}$ mm./mm.	Equator radius D/2 mm.	Iris radius R_{iris} mm.	Half-cell L/2 (inner) mm.	$\frac{R}{Q}$ Ω	G=Q.Rs Ω	E_{acc} MV/m	$\frac{E_p}{E_{acc}}$	$\frac{B_p}{E_{acc}}$	$f_{\pi-mode}$ MHz	Remarks
VECC Design1 Result	$\frac{54}{58}$	$\frac{11.99}{27}$	198.175	48	70.335	290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

Multipacting simulation results for 650MHz, β=0.61 SCRF Cavity using 3D CST Particle Studio

- 30 mm. of equator region has been simulated.
- Mesh: min 0.37 mm., max 0.74mm.
- Multipacting has been found between 5.8 MV/m to 11.5 MV/m
- Multipacting rate is very high in the region of 6.8 MV/m.
- At 11.6 MV/m, increase in partcle due to multipacting is very low.



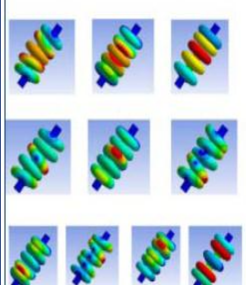
Particle vs. time(ns) at 5.8 MV/m



Particles after 7ns at 5.8 MV/m

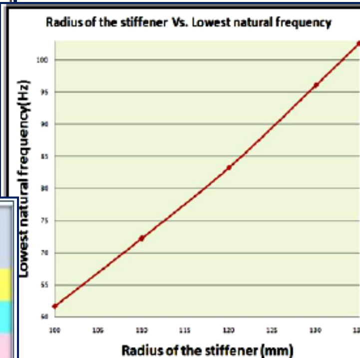
- Structural analysis carried out using ANSYS 3D code.
- Stresses are within the allowable limit.
- Mechanical modal analysis : (without stiffener) shows frequency within 100 Hz (NOT desirable!)

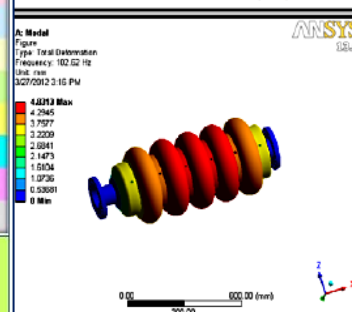
  (with stiffener) shows frequency >100 MHz



Mode	Frequency [Hz]
1.	3.0625
2.	5.9953
3.	8.6136
4.	10.776
5.	11.161
6.	24.688
7.	26.005
8.	27.449
9.	28.538
10.	57.485

Mechanical modal analysis (without stiffener)





	Modal Frequencies (Hz)	
	Both End Fixed	One End Free
650 MHz Cavity β=0.6	51.952	24.705
	101.72	73.351
	146.16	119.15
	182.75	158.05
	189.39	186.75
	419.78	353.67
	442.33	421.16
	467.10	444.88
	485.8	469.09
	975.59	486.47

Mechanical modal analysis (with stiffener)

Development of 650 MHz cavities at beta = 0.61

Fermilab

A SET OF HALF CELLS FOR 650 MHZ, β=0.61, RF LINAC CAVITY PROTOTYPE (ALUMINIUM) HAS BEEN MADE SUCCESSFULLY FOR HIGH ENERGY HIGH INTENSITY PROTON LINEAR ACCELERATORS

For Prototype Aluminium Cavity measurement (VNA):

Resonant frequency, f_0 = 645.86350 MHz.

Half power (–3dB) Bandwidth, $\Delta f = f_2 - f_1$ = 31.2 kHz.

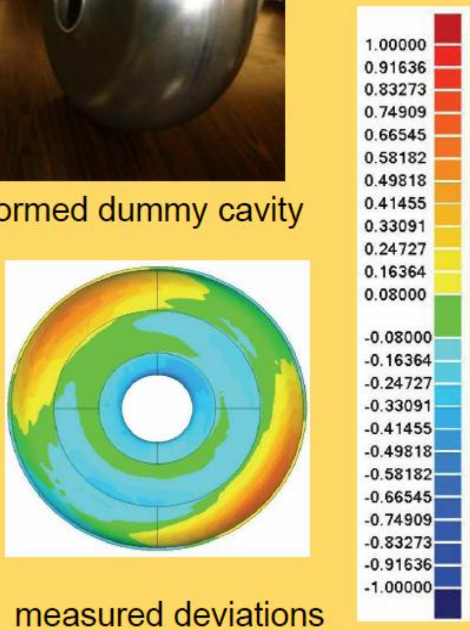
[f_1 = 645.84860 MHz; f_2 = 645.87980 MHz]

$Q = f_0 / \Delta f$ = 20700.

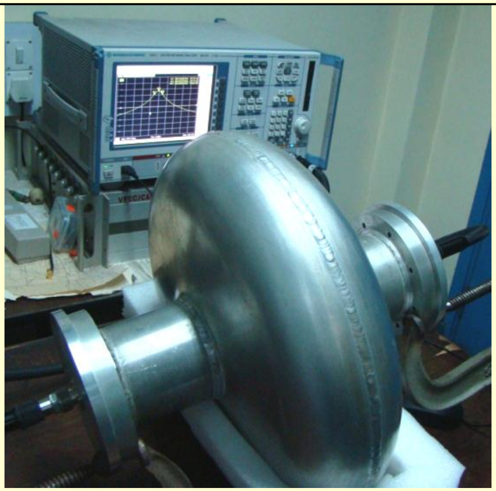

Die-punch

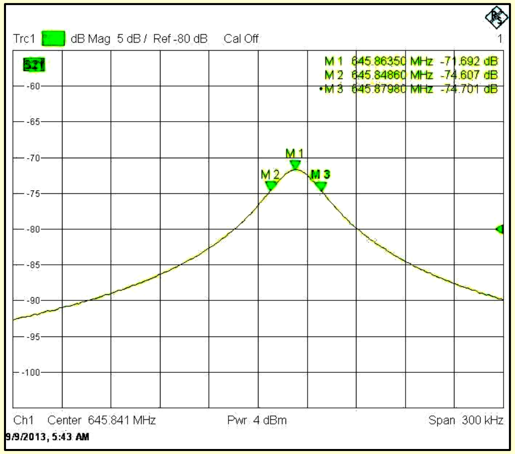

Formed dummy cavity


CMM inspection



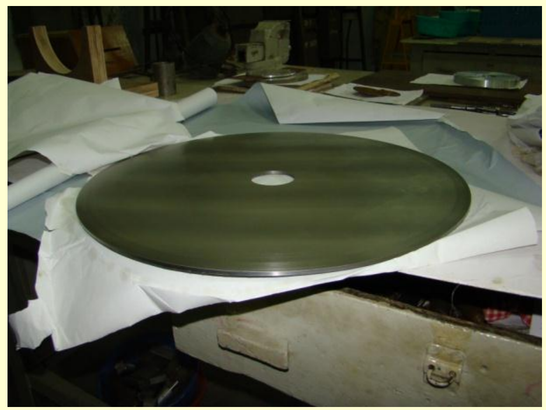
measured deviations





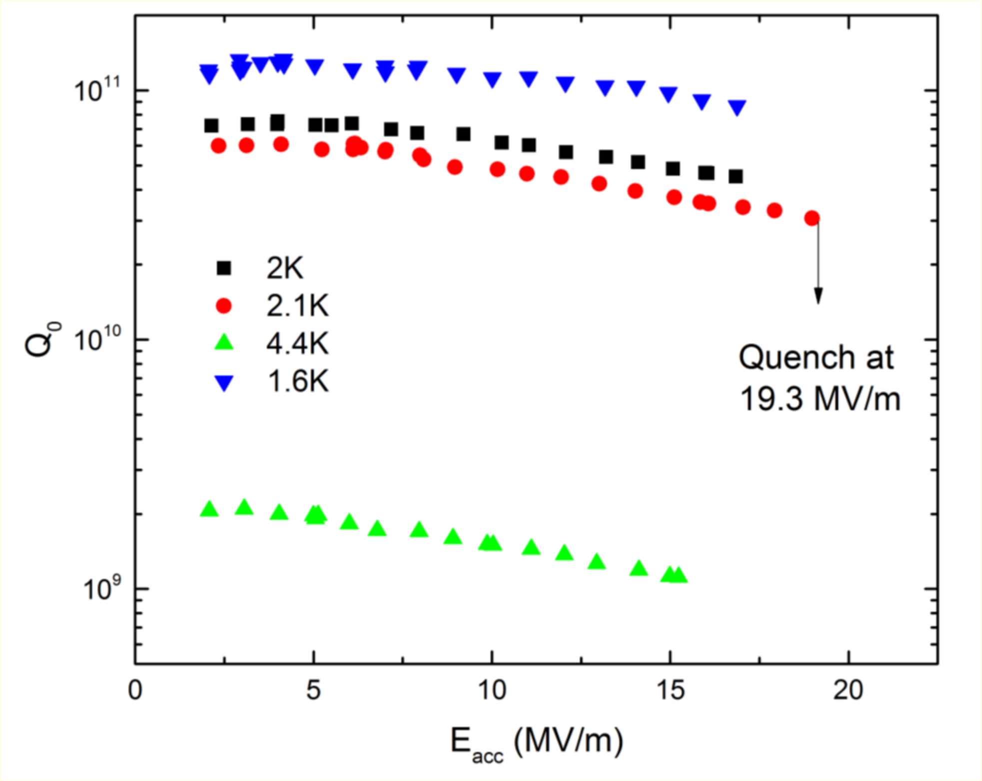
FABRICATION OF NIOBIUM HALF CELL FOR 650 MHZ,

β=0.61 CAVITY AT VECC

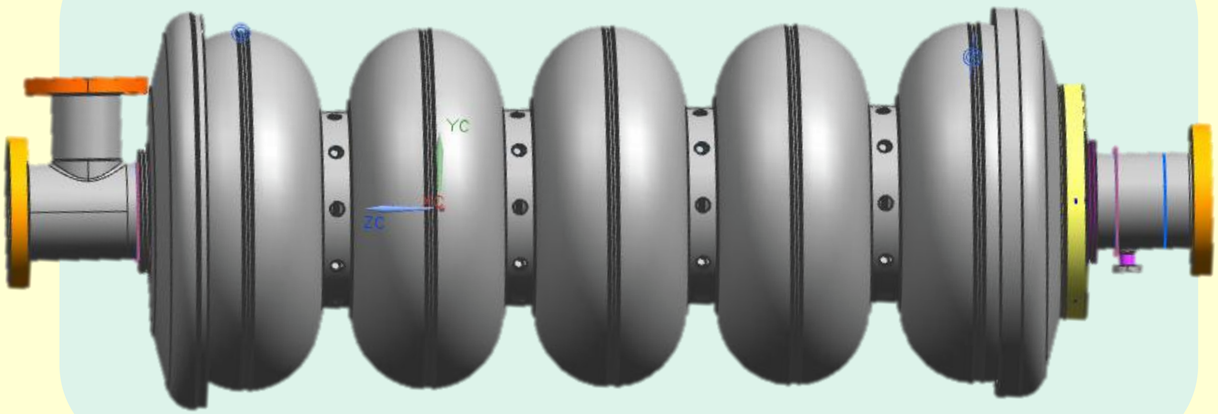


Status of progress on R&D activities under Supplement-1 to Addendum III to MoU

- First 650 MHz single-cell niobium cavity fabricated by RRCAT and IUAC was processed and tested at Fermilab during Dec-2013 and January 2014.
- The single-cell cavity reached E_{acc} of 19.3 MV/m and Q_o of of $7x10^{10}$ at 2K. This performance exceeds the design parameters.



Development 1st 650 MHz Beta=0.92 five-cell SCRF Cavity



650 MHz five-cell SCRF cavity 3-D model

- Drawing received from Fermi lab - Dec 2013
- Development of forming tools is being carried out at RRCAT
- First single-cell 650 MHz niobium cavity will be fabricated and tested before fabrication of 5-cell 650 MHz cavity.

Development Helium vessel for 650 MHz Beta=0.92 five-cell SCRF Cavity

Two trial vessels of Titanium, Grade-2 (similar in shape & size for 650 MHz cavity) have been manufactured in industry to understand the fabrication process

TIG welding was done without glove box using trailing shield and back purging arrangement. The vessels have been manufactured as per ASME B&PV code, Section IX. Both the vessels qualified Hydro-test and vacuum leak test.

Titanium vessels fabricated at M/s TITAN, Chennai

Preparation for Welding (back purging and trailing shield arrangement)

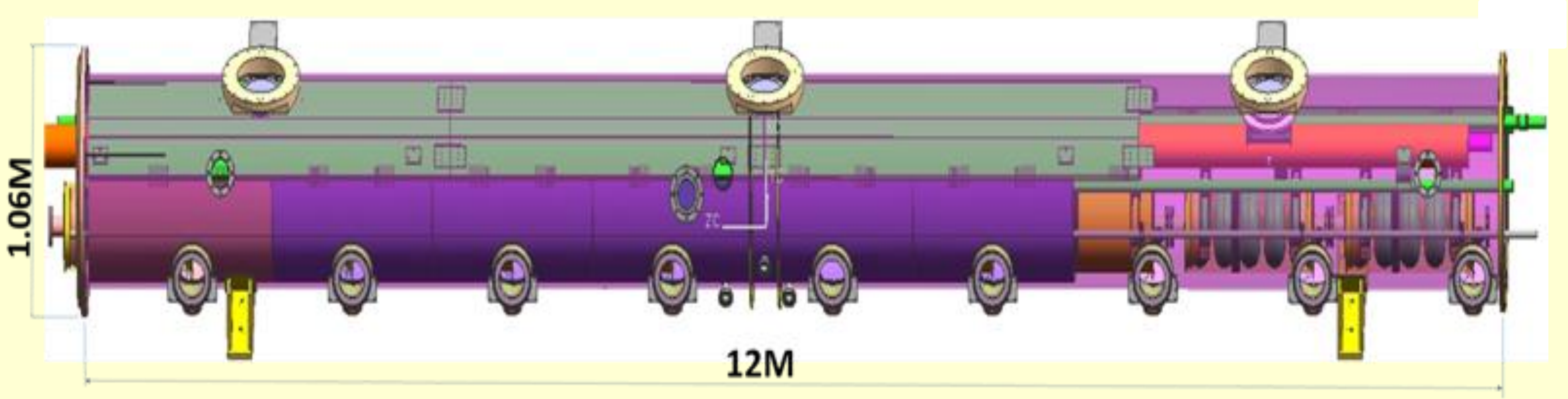
Welding in progress

The actual fabrication of helium vessel for 650 MHz cavity will be taken up after finalizing the design in collaboration with Fermi lab

Cryomodule for 650MHz SCRF cavities

Capability Exists for Design of Subsystems - Significant ground Covered

- **RRCAT proposed 5 options. FNAL selected Tesla type configuration.**
- **Design of vacuum vessel, cavity support system ,thermal shield completed**
- **3-D model completed .**



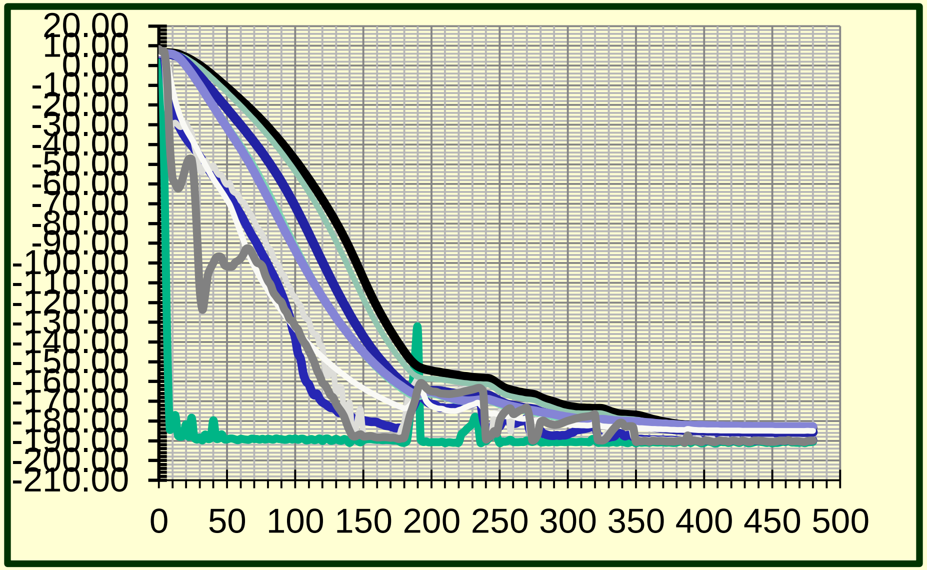
Cross-sectional view

Infrastructure Installed for Evaluating Design of Cryomodule Components : Cryomodule Component Test Rig

Fermilab

Evaluation of Designs By testing of prototypes: Results of 1st Experiment

- Prototype of thermal shield completed -tested
- Prototype of cryogenic support post completed- tested
- Prototype for cavity support system completed- to be tested

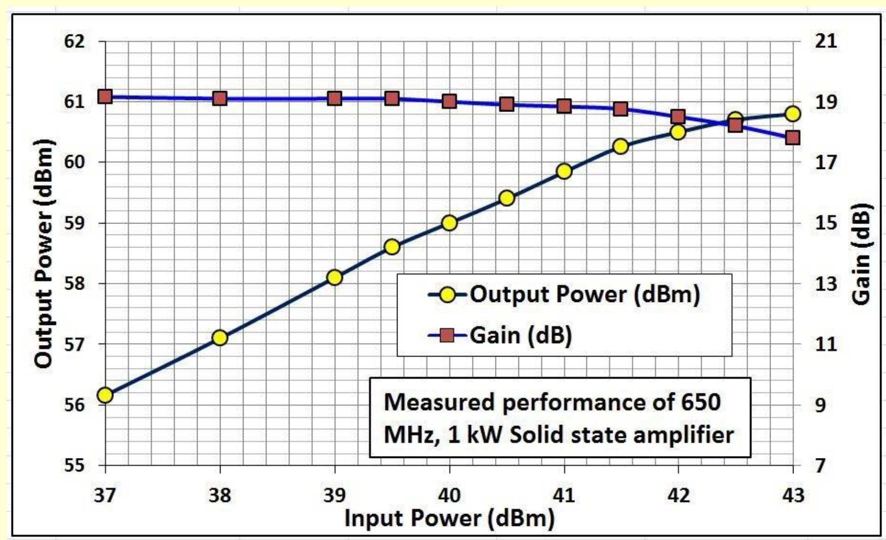


CCTR and Results of 1st Expt. on Thermal shield cool down

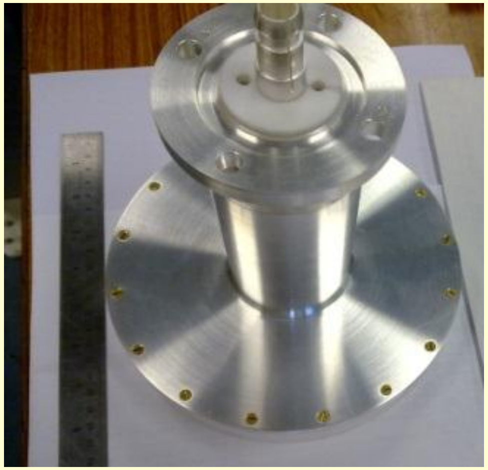
650 MHz, 12 kW Solid state amplifier

Each 12 kW unit will be housed in a single euro rack with 32 amplifier modules, each one using LDMOS giving output RF power of 500 W. The first unit is under evaluation & improvement.

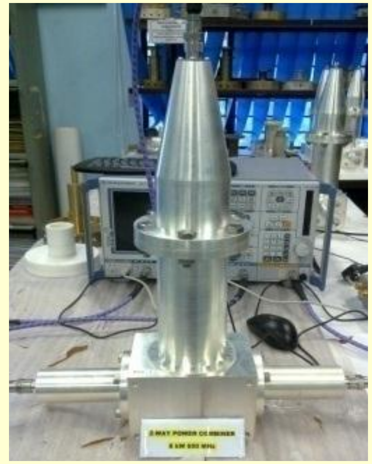
- Operating frequency: 650 MHz
- Output Power: 12 kW CW
- Gain: 60 dB
- Bias Voltage: 50 V DC
- Input Mains supply: 3 Phase



Development of 650 MHz RF Components

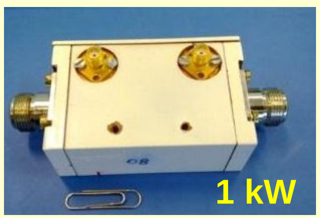


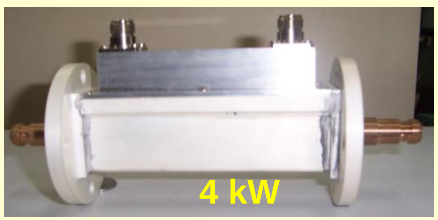
16-way 4 and 8 kW Power combiner



2-way 8 kW and 18kW Power combiners

Output port: 3-1/8” EIA





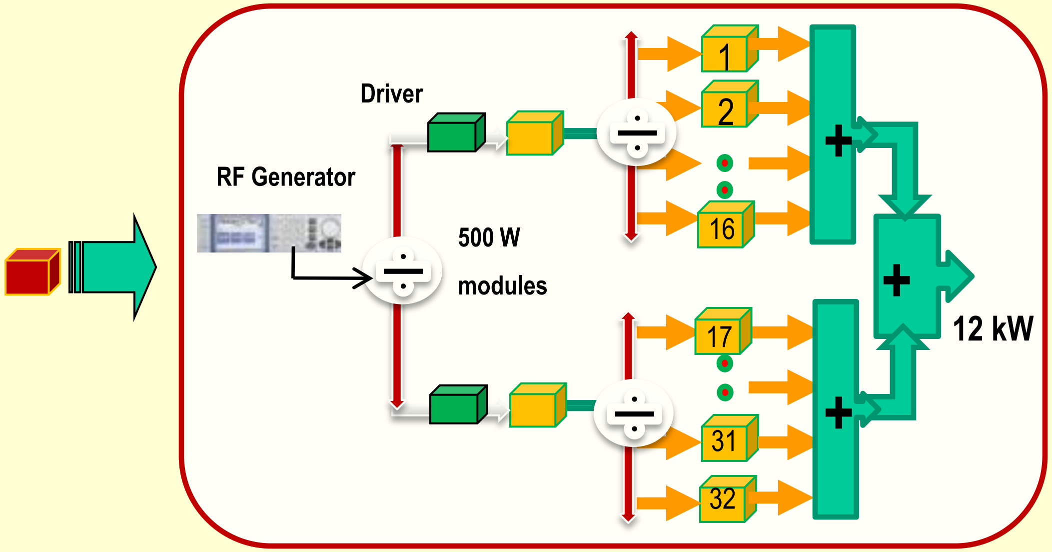
Wide-Band Directional Couplers

Coaxial Transitions 3-1/8” EIA to 1-5/8” EIA

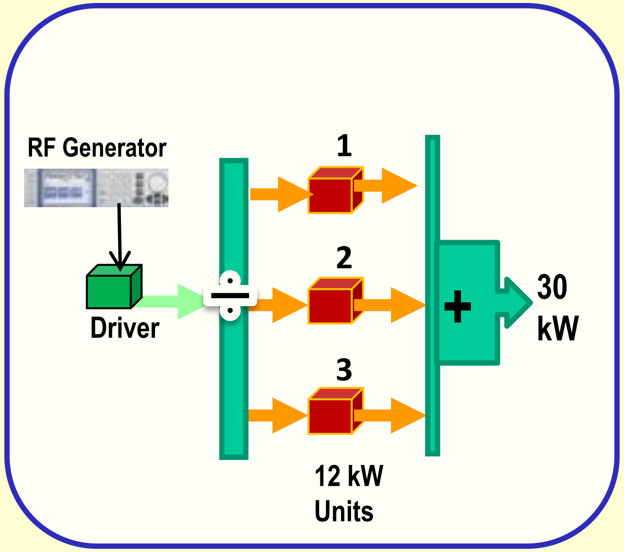
1-5/8” EIA to N Type

Status of progress on R&D activities under Addendum MoU –VI

Design Scheme for 650 MHz 30 kW RF Power Source



12 kW Unit scheme used in 30kW Amplifier



30kW Amplifier Scheme

- Proposed scheme for 30kW solid state amplifier -
    - 30kW power will be obtained by summing output of three 12 kW units.

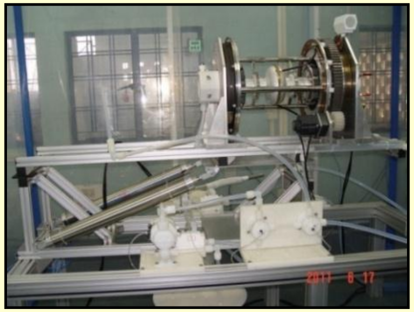
R&D Activities for SCRF H^- Ion Linac

R&D activities for a SCRF linac and accumulator ring for SNS include prototype development of various sub-systems and setting up of infrastructure in the following areas:

- H^- Ion source and front end components
- Materials R&D, cavity & cryomodule development
- Niobium cavity fabrication and processing facility
- Test facility for large number of SRF cavities and cryomodules
- Cryogenics setup for large size LHe Plant & supply network
- RF power sources and control electronics
- Sub-systems for 1 GeV accumulator ring including magnets, power supplies, RF cavity, UHV system and controls
- Manpower development and training

Infrastructure for SCRF Cavity Fabrication, Processing and Characterization

Cavity forming facility



Electro-polishing setup

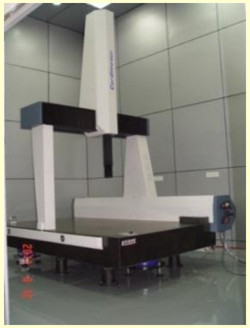
Centrifugal barrel polishing machine

High pressure rinsing Set up

15 kW e-beam welding machine

SIMS setup

Optical bench setup



3D CMM

SCRF Cavity Processing and Assembly Hall

E-beam welder installed and Commissioned

Vertical Test Stand at RRCAT

- SS vessel to test multi-cell 1.3 GHz and 650 MHz SCRF cavities at temperature down to 2K.
- Overall dimension of 5.4 m length and 1.37 m diameter.
- Installation in a pit completed and RF system (500 W, 1.3 GHz) coupled.
- Successfully Commissioned at RRCAT.

Assembly of external shield

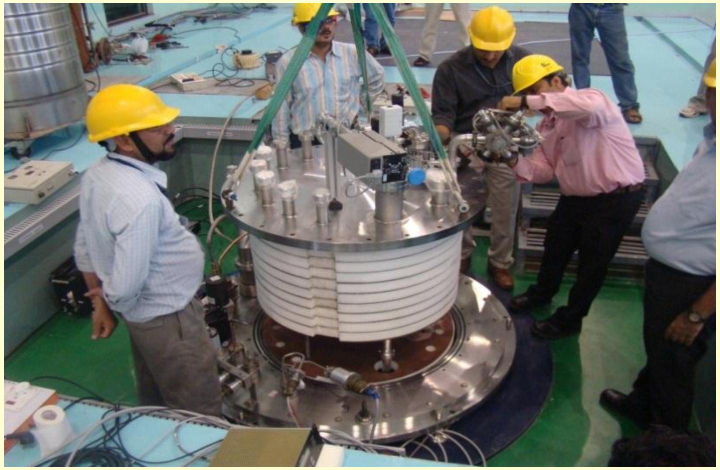
Installation of cryostat in pit

Automated RF instrumentation

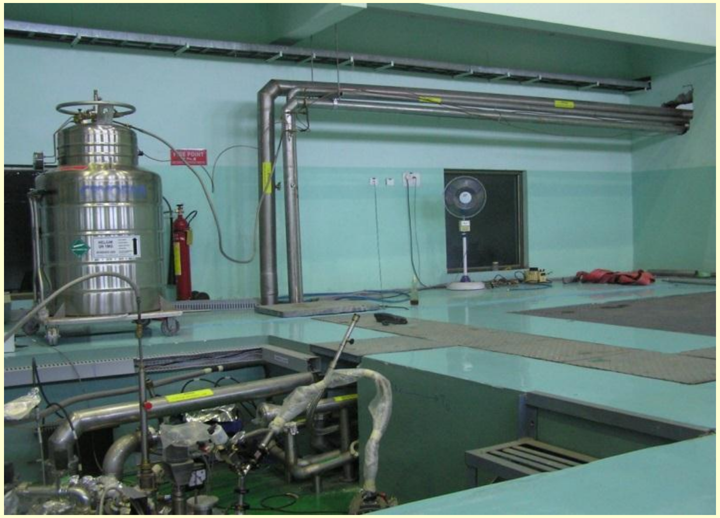
1.3 GHz 500W solid state RF amplifier

Insert assembly and Cryogenic Transferlines for VTS

Cavity Insert assembly



Lowering of cavity insert in VTS cryostat

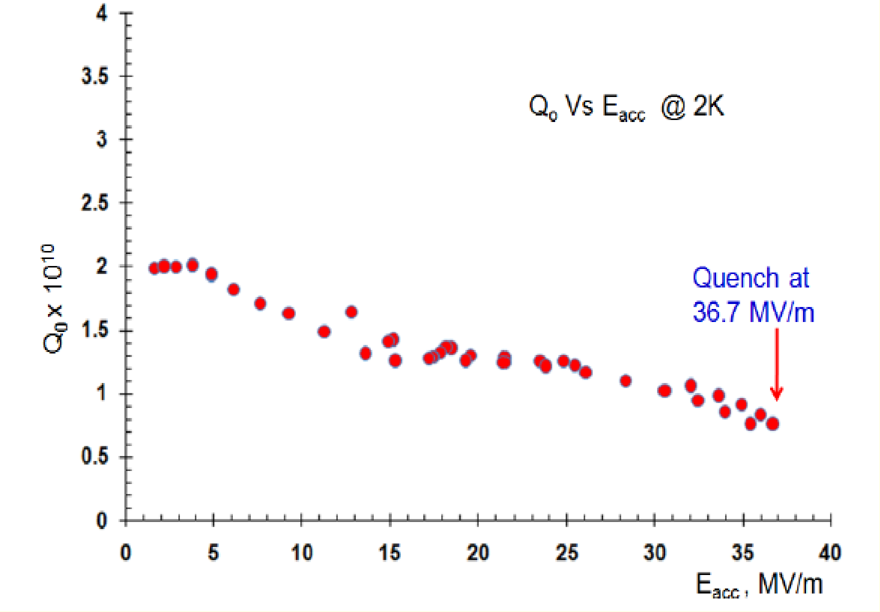


Cryogenic Transfer lines for VTS

Vertical Test Stand (VTS) Facility for SCRF Cavity Qualification

A vertical test facility for RF characterization of SCRF cavities at 2 K has been commissioned. A single-cell 1.3 GHz cavity has been successfully tested using the facility in January 2014.

Transfer of liquid helium in the VTS cryostat



Testing of single-cell 1.3 GHz SCRF cavity in the VTS facility at RRCAT

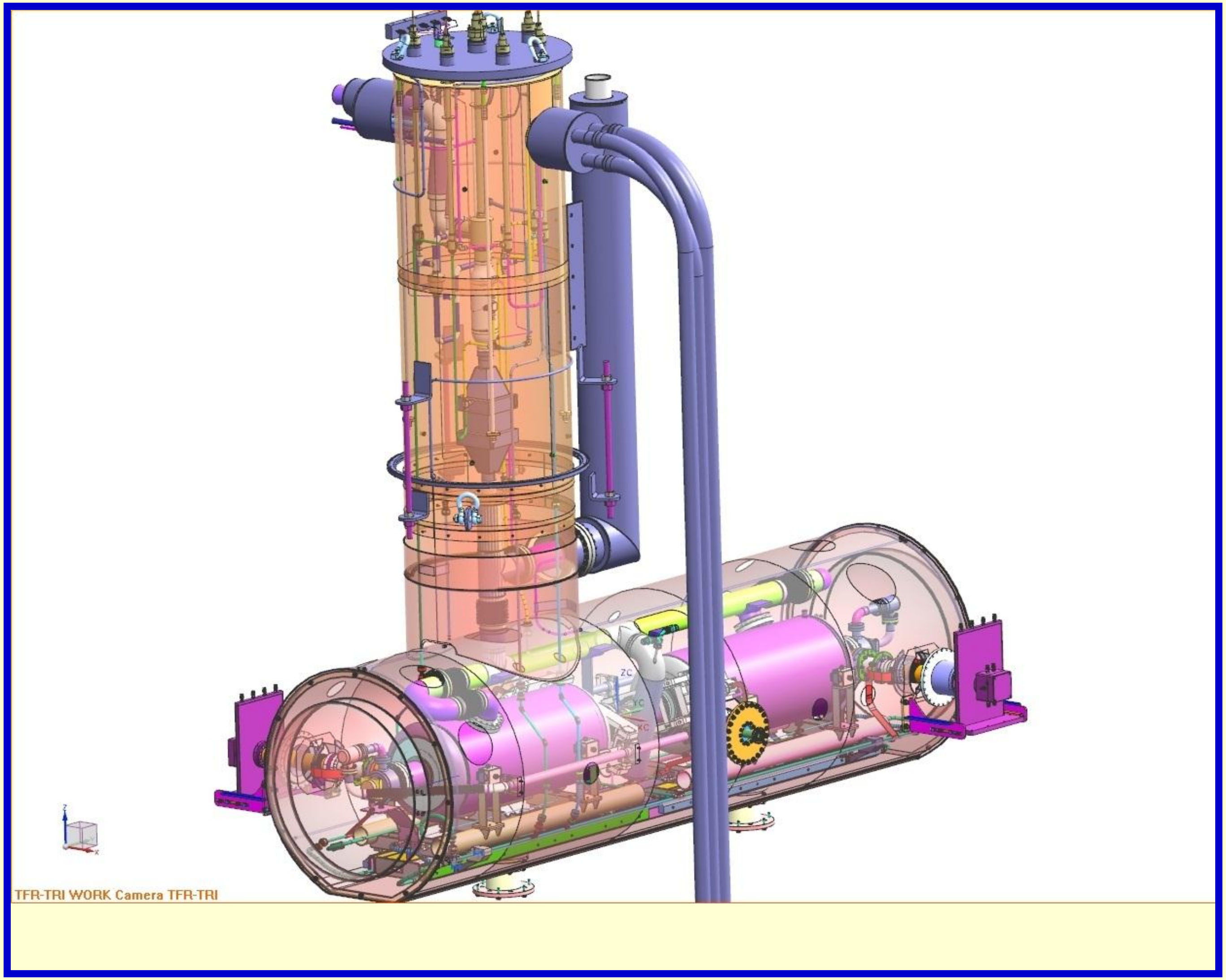
Horizontal Test Stand for 650MHz SCRF cavities – Under IIFC, Complete Engineering Design is being done at RRCAT

- **HTS-2 has capability to individually test two fully dressed SCRF cavities in single cycle under conditions similar to those in a cryomodule.**
- **HTS is akin to cryomodule in it's design. Same team which is designing cryomodule is responsible for HTS design.**
- **Design has been completed. 3-D model will be uploaded this week.**
- **Design report on subsystems up-loaded. A joint design review is expected shortly.**

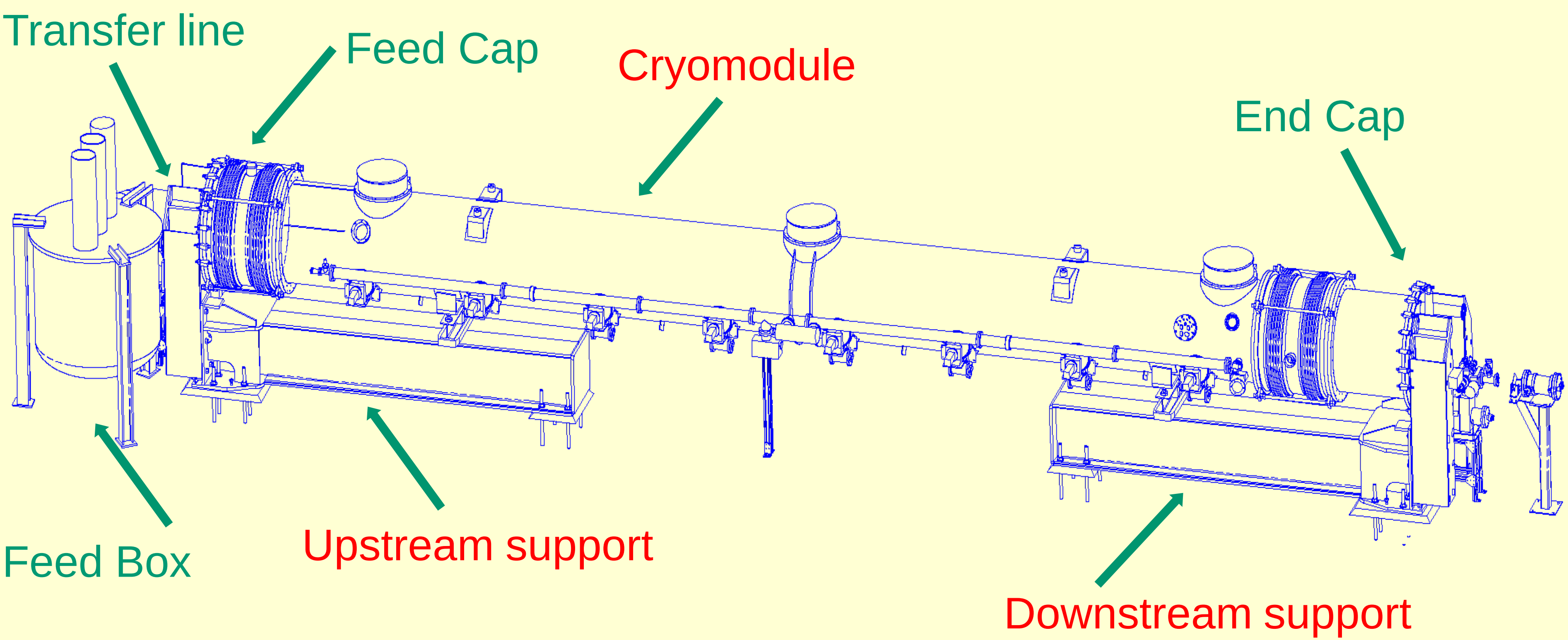
Design Evaluation by Prototyping and testing of Subsystems

- **Prototype of cryogenic support post completed- tested**
- **Scaled down frame bridge Prototype completed**
- **Prototype of thermal shield completed. Along with frame bridge and rolling cart it will be tested shortly in Cryomodule component test rig (CCTR).**

3-D Model of HTS-2

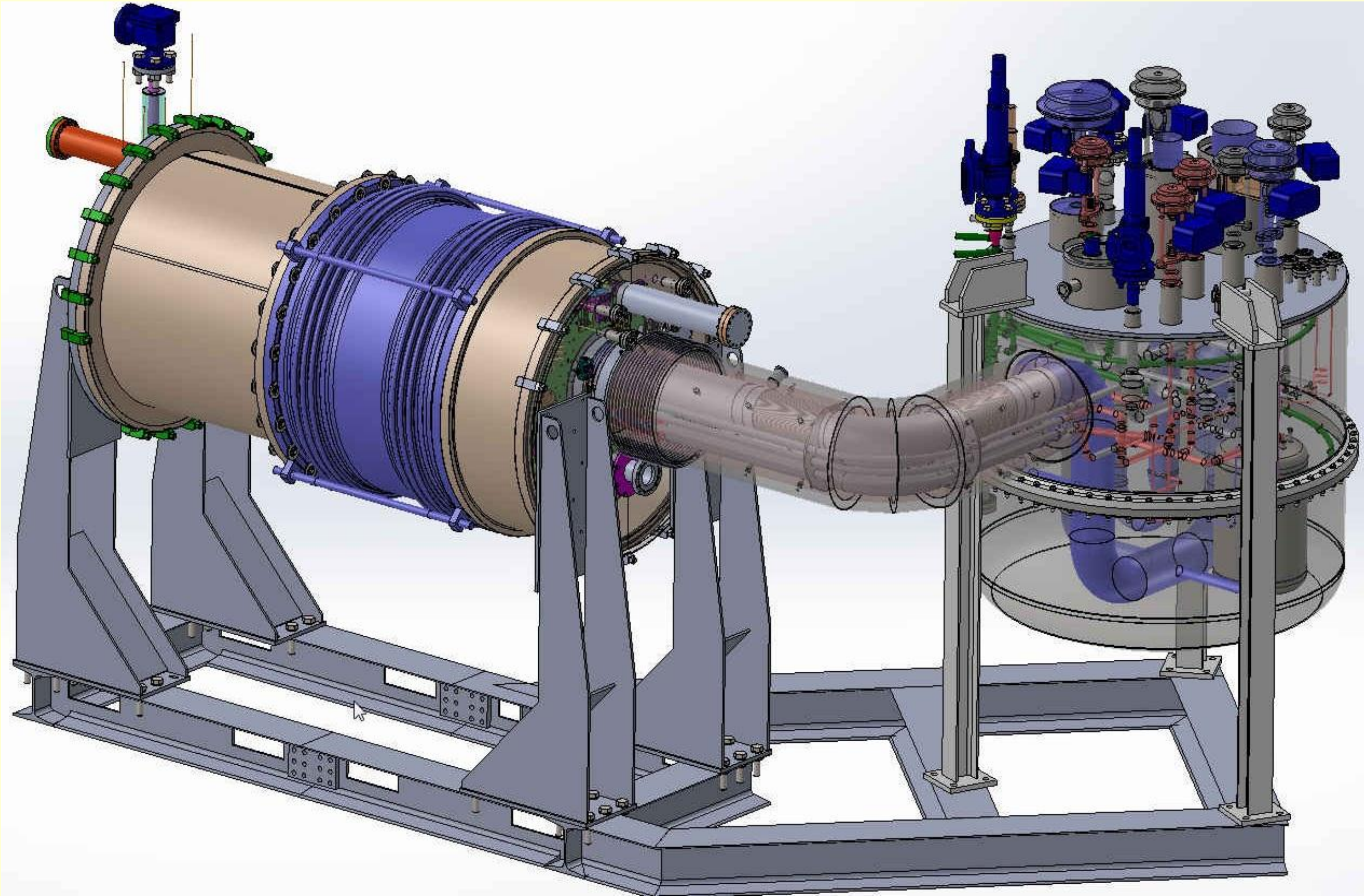


Cryo-module Test Facility for FNAL



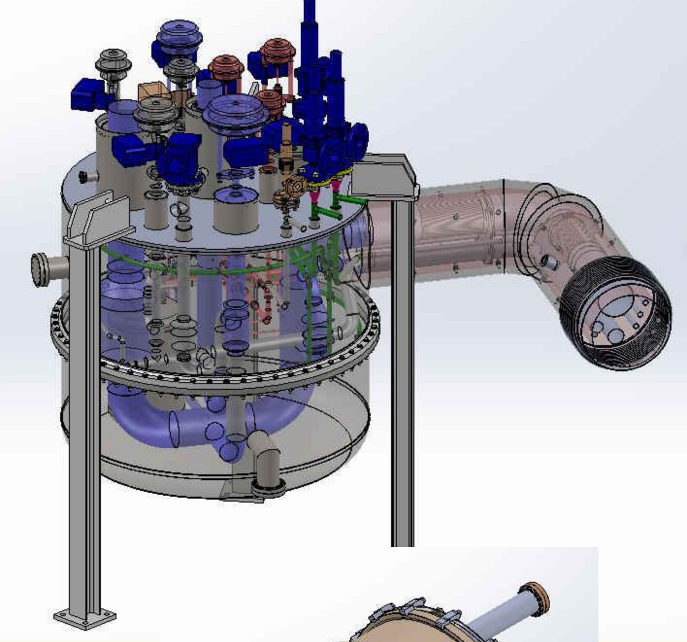
- Under IIFC 1.3 GHz Cryo-module Test Facility is to be built at FNAL.
- BARC will design, manufacture and supply Feed Box, Transfer Lines, Feed Cap and End Cap.(Items shown in green).
- Items shown in red are under scope of FNAL.

Cryo-Module Test System-I for 1.3GHz Cryo-Module

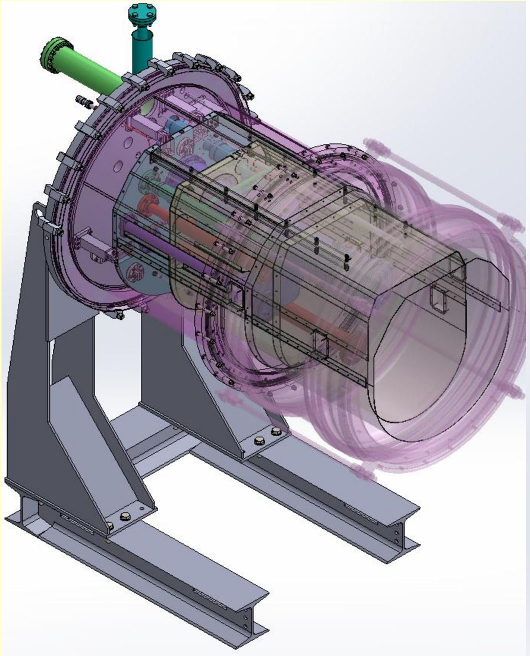


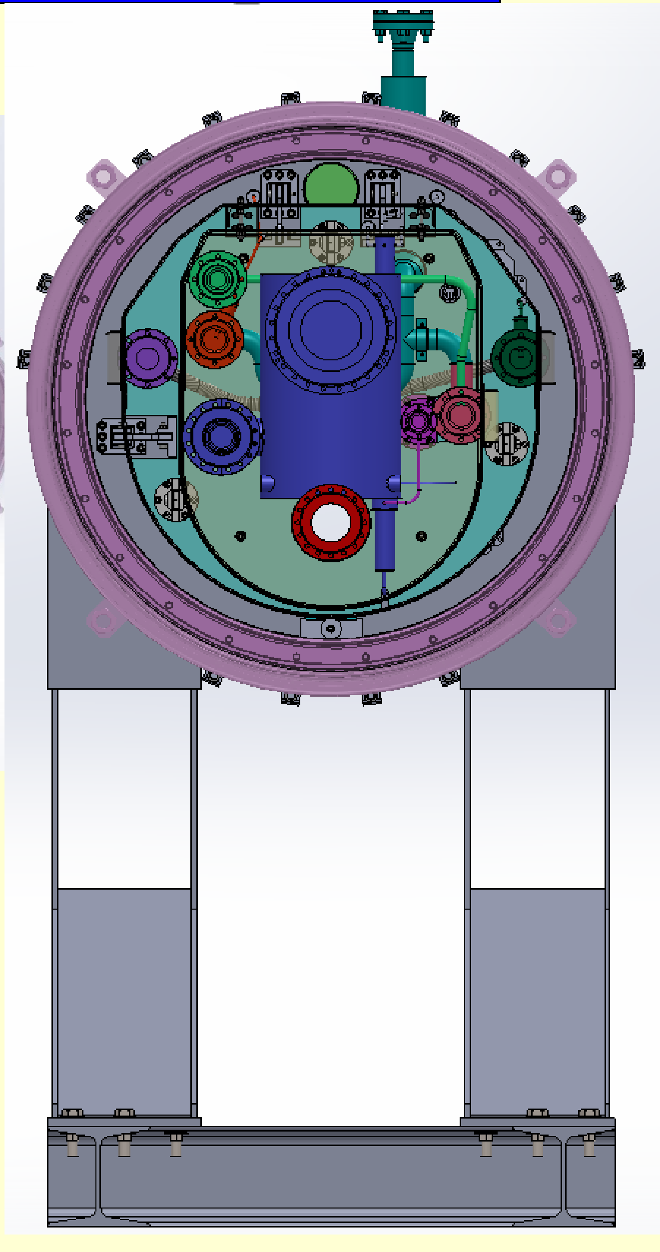
CMTS1: Sub assemblies

Feed Box

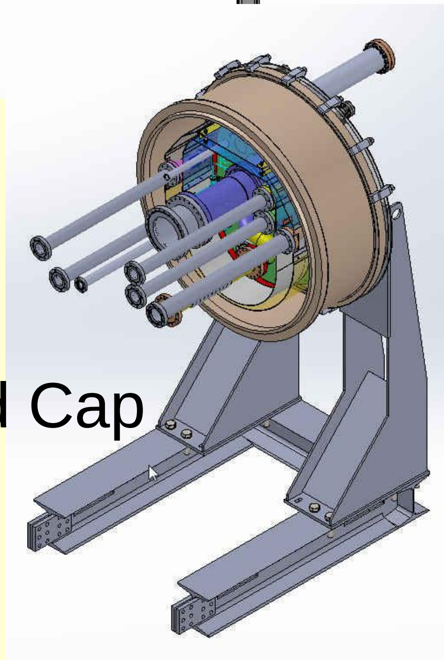


End Cap





Feed Cap



Control and Instrumentation Systems

Following systems are part of the collaboration

- **RF Protection Interlock (RFPI) System**
- **Beam Position Monitor (BPM) system**
- **Low Level RF (LLRF) system**
- **Integrated Control System for CMTS**

In the first phase work has got initiated on RF Protection Interlock system

RF Protection Interlock System - Overview

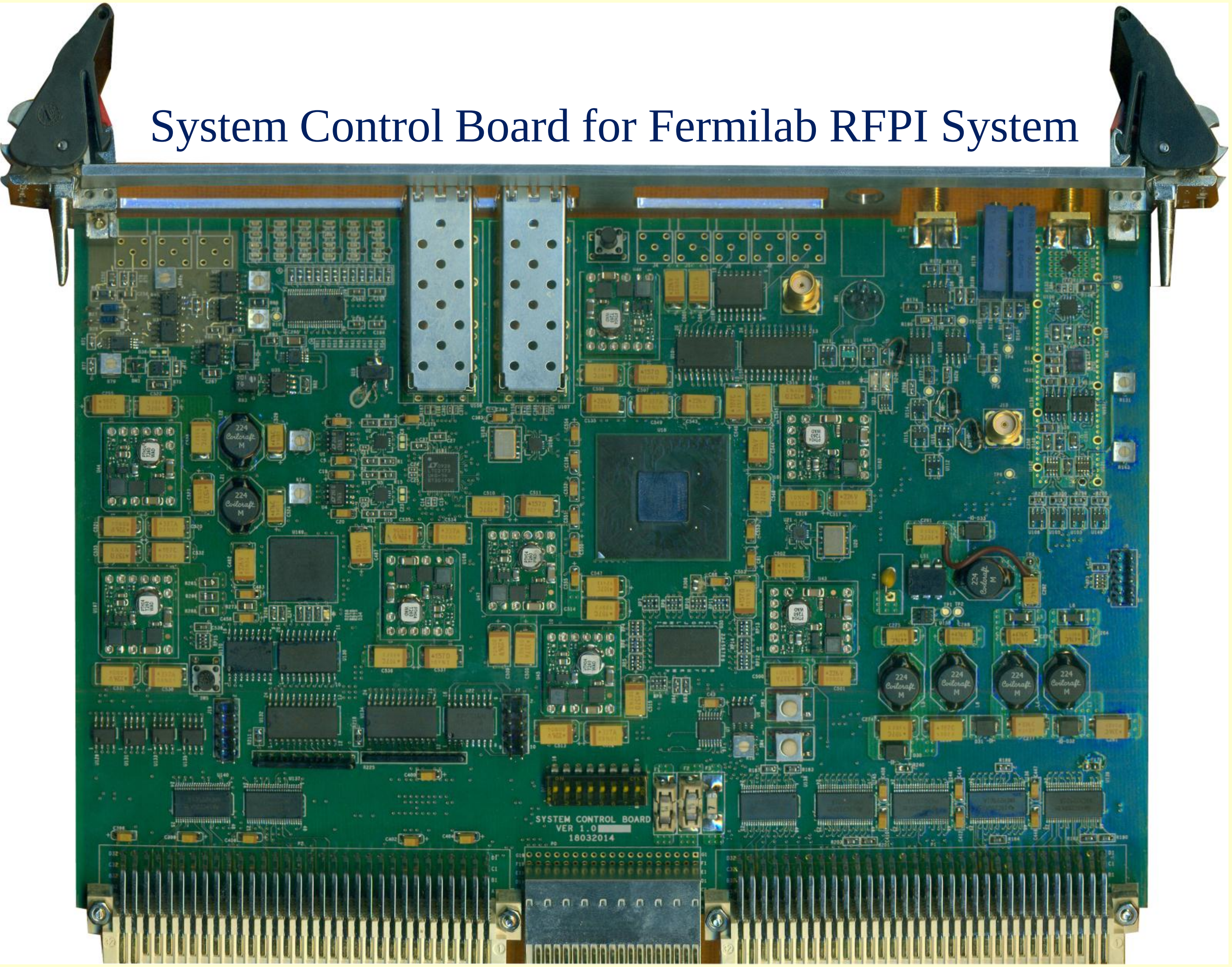
Protects the high power RF system under fault conditions

Consists of the following Mixed Signal Modules:

1. **System Control**
2. **Multi-trip Module**
3. **Field Emission Probe (FEP)**
4. **Photo-multiplier Tube (PMT)**
5. **Digital and Analog I/O**

RF Protection Interlock System - Status

1. System control Board designed and fabricated, presently under testing



System Control Board for Fermilab RFPI System

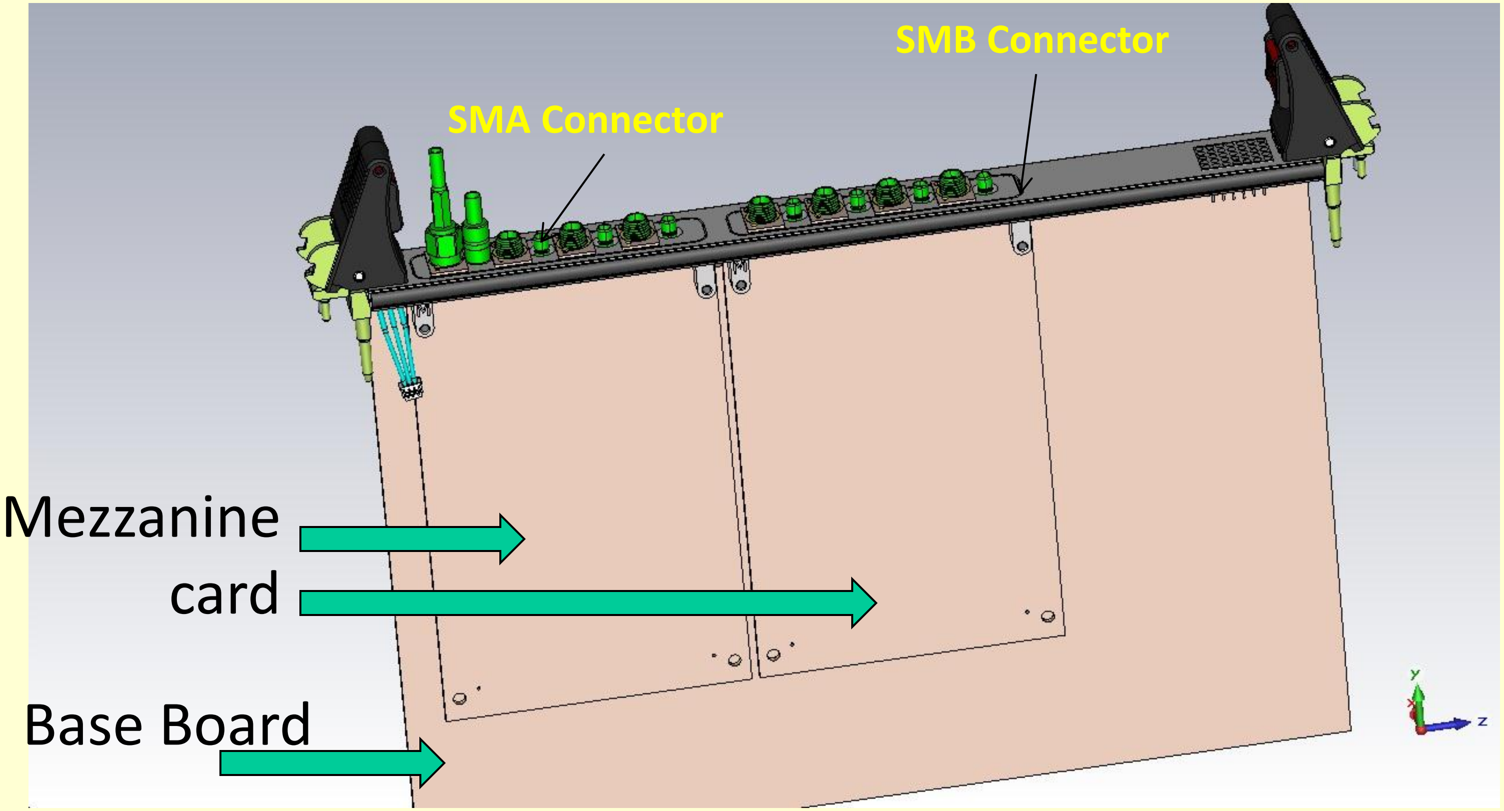
.

Features:

- VME-64x Interface
- 2 High Speed Serial transceivers @ 3.125 GbPS
- 4x PCIe interface
- One channel for Photo Multiplier Tube monitoring
- One channel for RF leakage Monitoring
- Four channel 80MSPS 14 bit ADC
- 256MB DDR3 RAM for 1 sec circular buffer on each channel

RF Protection Interlock System - Status

2. A mezzanine card based scheme evolved for the next generation
   - Common VME64X carrier board
   - Application specific functionality on mezzanine card



RF Protection Interlock System - Status

Mezzanine card based RFPI

- Design of the system (all the boards) completed
- Schematics prepared
- Fabrication of mezzanine card for multi-trip module initiated
- Base Board fabrication will be done after testing the system control board

We look forward to receive inputs on the following systems:

- Beam Position Monitor (BPM) system
- Low Level RF (LLRF) system
- Integrated Control System for CMTS

Fermilab

Visit to Electronics Corporation of India Ltd.

Solid State RF and Electronics to be built by ECIL

DAE and PXIE

- **Collaborating DAE laboratories are already working on the Research, Design and Development of almost all hardware of the High Intensity Superconducting Proton Accelerator.**
- **BARC has also proposed to develop similar 50 MeV linac.**
- **IIFC is already working on the following that would be used for PXIE**
  - **MEBT Magnets**
  - **SSR1 Cavity and CM**
  - **325 MHz Solid State RF Amplifiers,**
  - **RF Protection system**
  - **LLRF System**
- **We propose to send scientific and engineering staff to participate in PXIE construction, installation and commissioning.**
  - **We propose to take a leading role in jointly developing an integrated SSR1 CM (Cavity to RF). It is part of Project Annex I.**

Summary and Conclusions

- **Indian Institutions Fermilab Collaboration is making good progress towards R&D and infrastructure for high intensity Superconducting RF accelerator that could lead to construction of**
  - **High Intensity CW Proton Accelerator at BARC**
  - **High Energy Pulsed Proton LINAC Based Spallation Neutron Source at RRCAT**
  - **PIP-II (Project X) at Fermilab**

- **Indian Institutions Fermilab Collaboration has a very strong technical foundation and is mutually beneficial.**

Acknowledgements

I thank

- ❖ Shri Sekhar Basu, BARC
- ❖ Dr P.D. Gupta, RRCAT
- ❖ Shri S. Som, VECC
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Thank You !