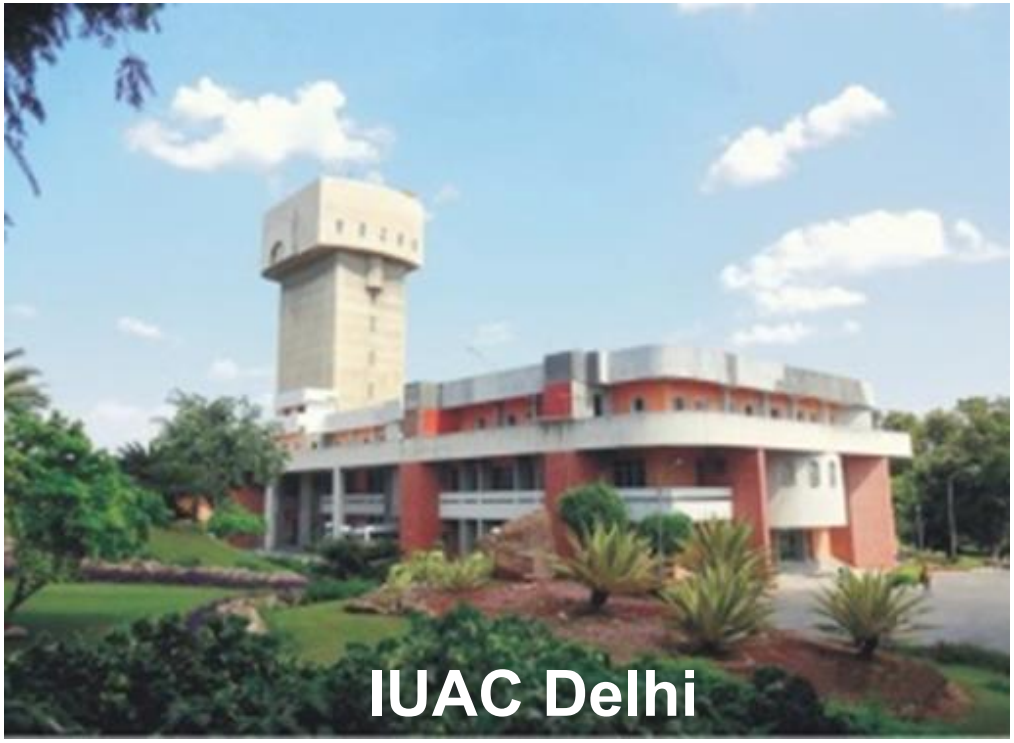
Rapid Growth of SRF in India

Dinakar Kanjilal

Inter-University Accelerator Centre
New Delhi 110067
India



Superconducting LINAC Boosters in Operational India

- Tata Institute of Fundamental Research (TIFR) Mumbai

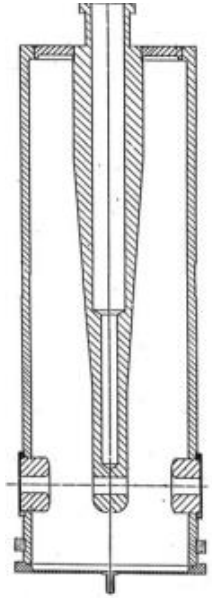
  150 MHz 2 gap 29 QWRs, Pb-plated on Cu, $\beta = 0.1$

- Inter-University Accelerator Centre (IUAC) Delhi

  97 MHz 2 gap 27 QWRs, Bulk Niobium, $\beta = 0.08$

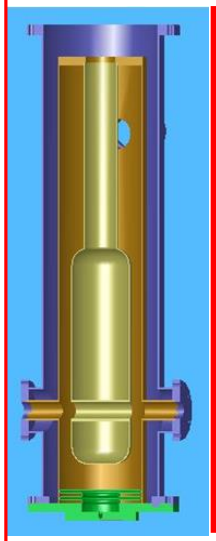
  97 MHz, 2 gap 8 QWRs (prototype is fabricated), $\beta = 0.05$

TIFR Mumbai



IUAC Delhi

Medium beta



Low beta

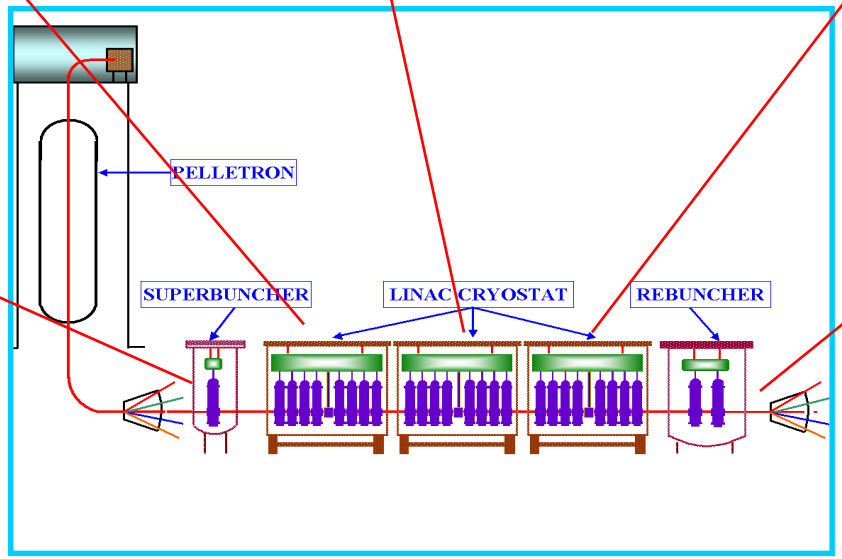
Major SRF Projects taken up in India

Major projects initiated by Department of Atomic Energy (DAE), India:

- **Accelerator Driven Sub-critical System (ADSS) at Bhaba Atomic Research Centre (BARC), Mumbai**,
- **Indian Spallation Neutron Source (ISNS), Raja Ramanna Centre of Advanced Technology (RRCAT), Indore**
- **Advanced National facility for Unstable and Rare Isotope Beam (ANURIB), Variable Energy Cyclotron Centre (VECC), Kolkata.**
- **IIFC Collaborations**

In these projects, different types of niobium resonators e.g. half wave, spoke, elliptical resonator in the frequency range of ~ 150 MHz to 1.3 GHz are being developed. Simultaneously the cryostats, power couplers, frequency tuners, RF, control systems etc. are also being developed.

Subsystems of the LINAC



Consists of 27 identical Quarter Wave resonators, $\beta_0 = 0.08$, $f_0 = 97$ MHz

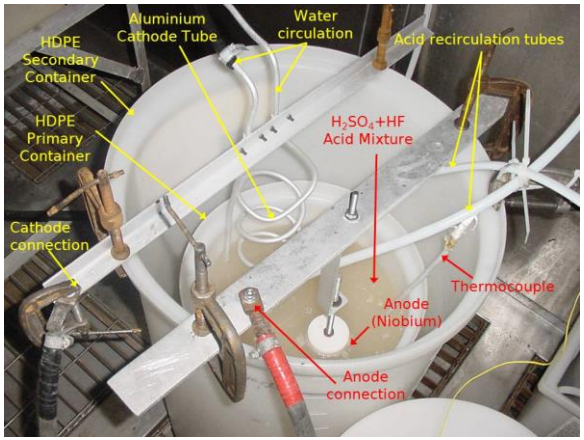
Collaboration with ANL and Facility Development

- The first 12 QWR (bulk Nb, Nb/SS, Nb/Cu explosively bonded) were built in collaboration with ANL, USA.
- Remaining QWRs were built at IUAC using in-house facilities.
- All Cryostats and distribution lines were built by Indian vendors.
- LN2 and He Plant had been purchased.
- Successfully delivered Ion beam from Linac since 2008 onwards ranging from **^{12}C to ^{107}Ag**. In 2013. All five cryostats were operational.
- Time width of the Beam at target ~ 180 ps

SRF Infrastructures developed at IUAC Delhi

Electron Beam Welding facility

Surface Preparation Lab



Electropolishing Process

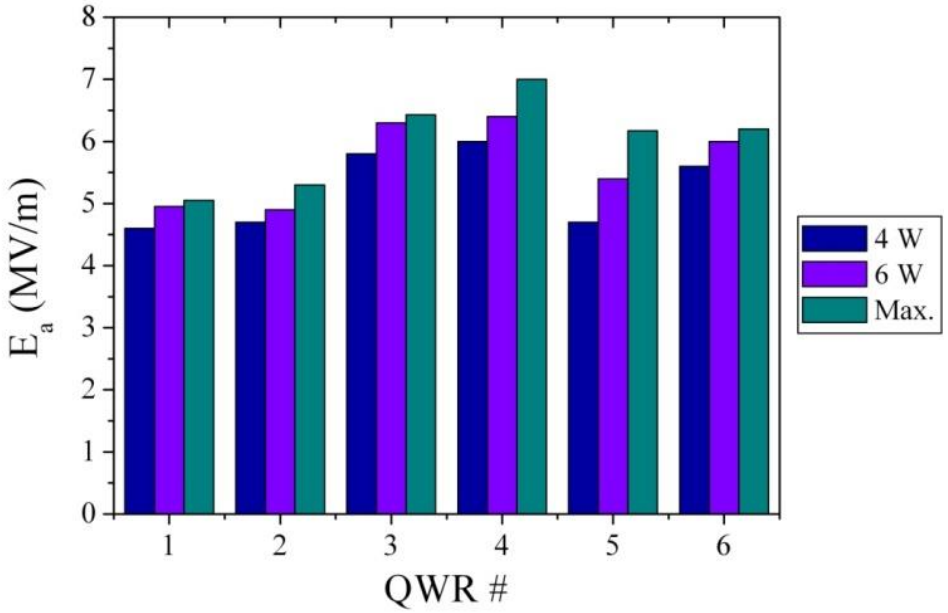
High Vacuum Furnace (HVF)

Bottom side of HVF

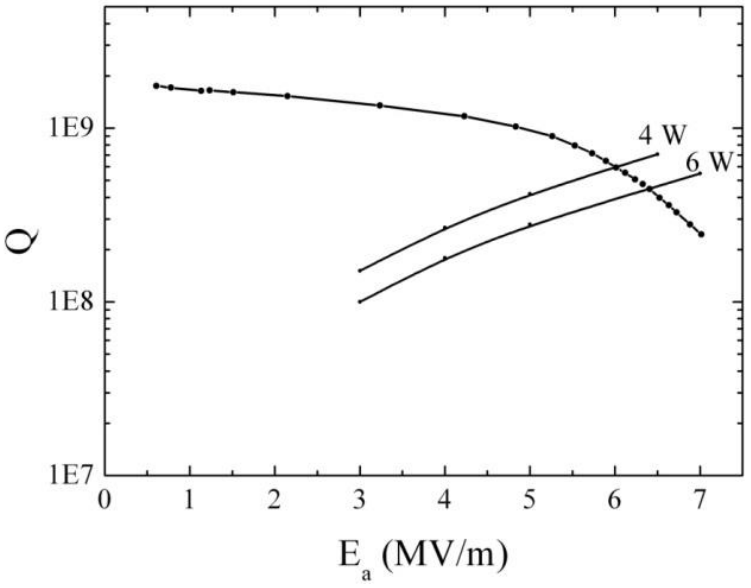
Test Cryostat (partially buried)

Test Results

All the QWRs for the 2nd and 3rd Modules for the Superconducting Linac were built using the SRF Infrastructure set up at IUAC.



Performance of the indigenously built Quarter Wave Resonators.



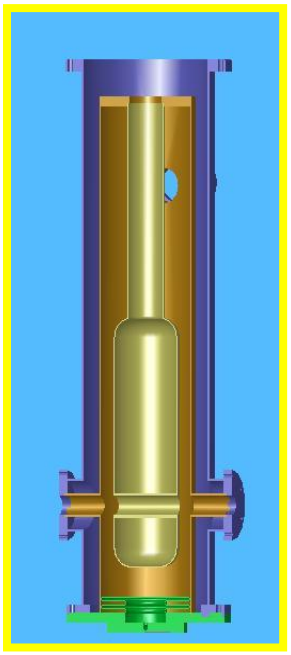
Typical performance of an indigenously built QWR at 4.2 K.

Stages of Fabrication

Central Conductor

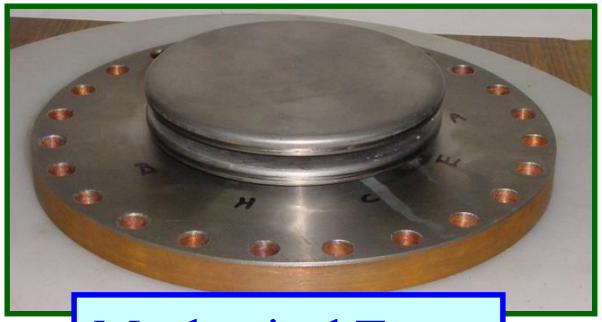
Electropolished niobium Central Conductors

Top Flange



Central Conductor & Housing

Electropolished niobium Top Flanges (top middle), major Assemblies of the QWRs (above) and Slow Tuner bellows (left).



Mechanical Tuner

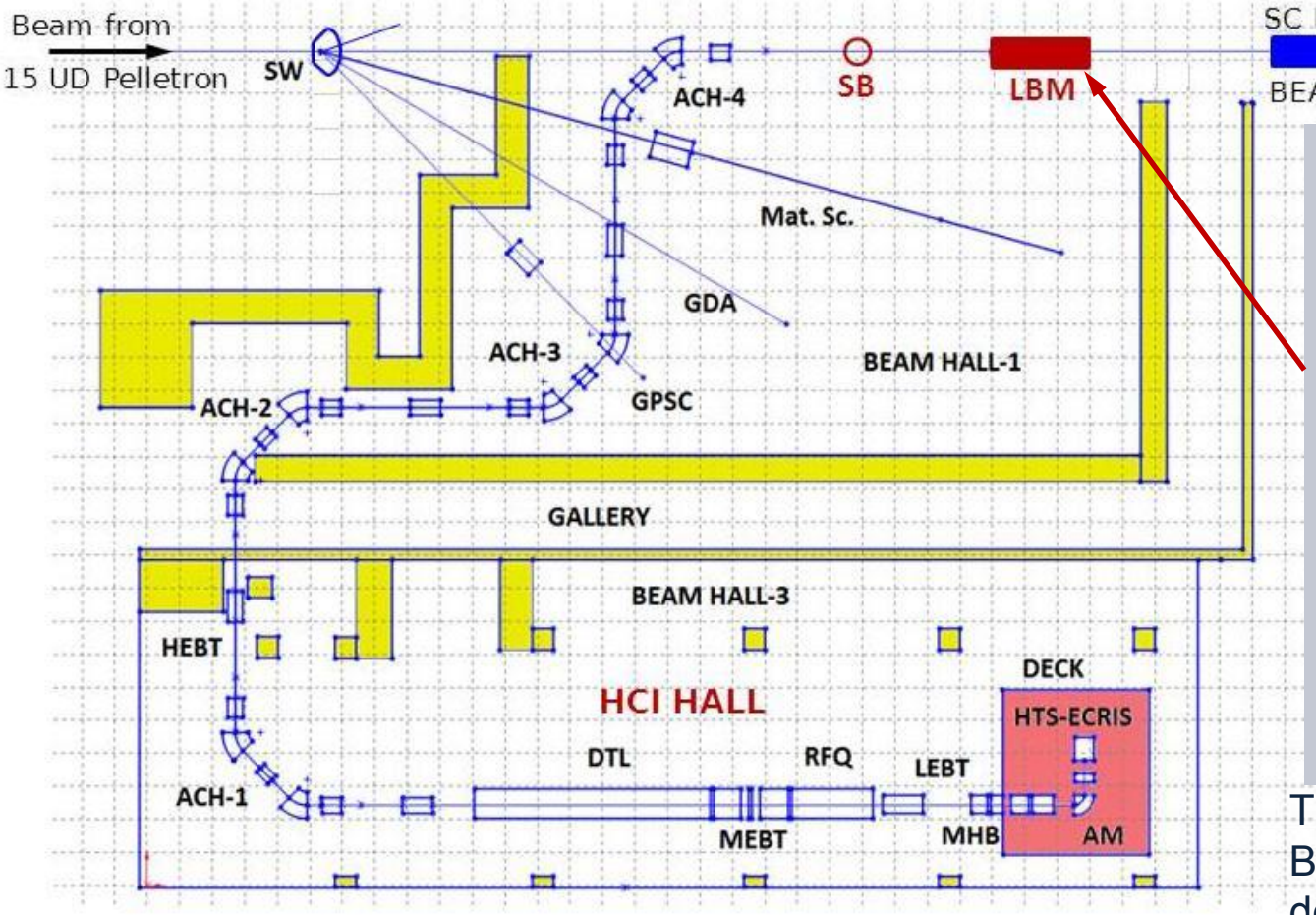
Stages of Fabrication

Resonators

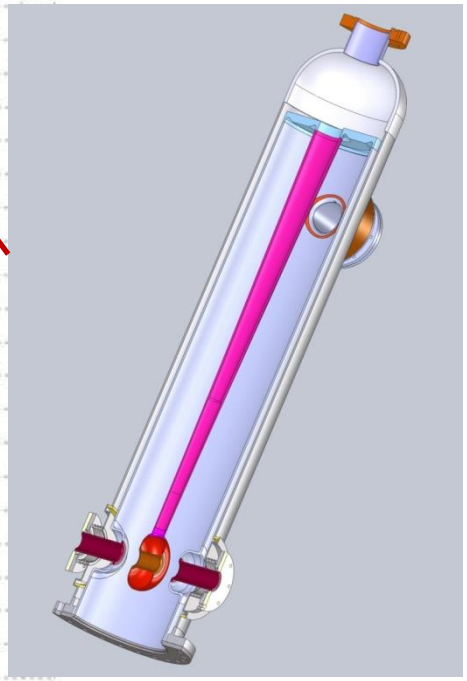
Mechanical Tuner

Superconducting Niobium Quarter Wave Resonators (left) and Nb Slow Tuner bellows (above), built at IUAC for the Superconducting Linac.

Low Beta Resonator



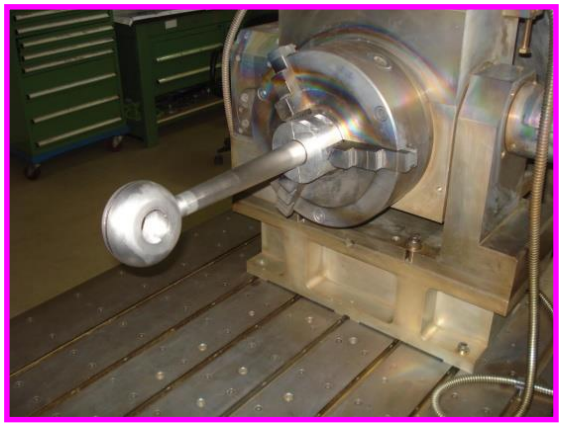
Layout showing the High Current Injector along with the proposed location of the Low Beta Module (LBM).

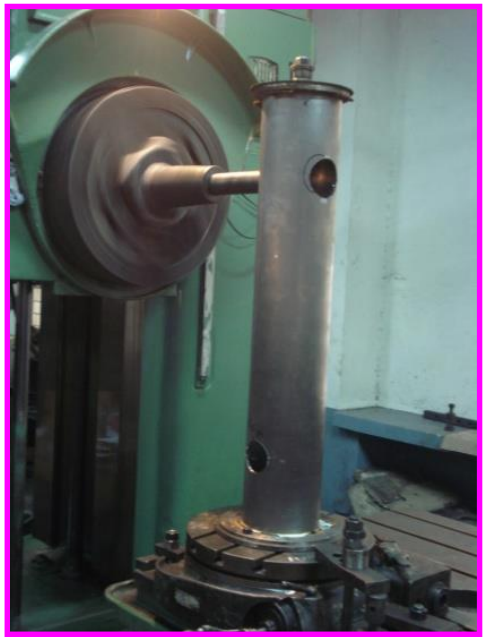


The new niobium Low Beta Resonator (LBR) developed for the LBM.

8 LBRs in the LBM

Design and Development of Low Beta Resonarot





Dedicated Building for SCRF Cavity Development

RRCAT has setup facilities for SCRF cavities fabrication, welding, inspection, processing & testing.

Cavity Fabrication Facility

15 kW Electron Beam Welding Machine

Inner size of chamber	3650 x 1500 x 1800 mm^3

Cavity Fabrication Facility

Facility for Forming & Machining

Forming

Inspection

120 T - HYDRAULIC PRESS

Machining

Formed Niobium Half cell

Cavity Fabrication Facility

Nd-YAG laser beam welding facility – for 1.3 GHz single-cell cavity

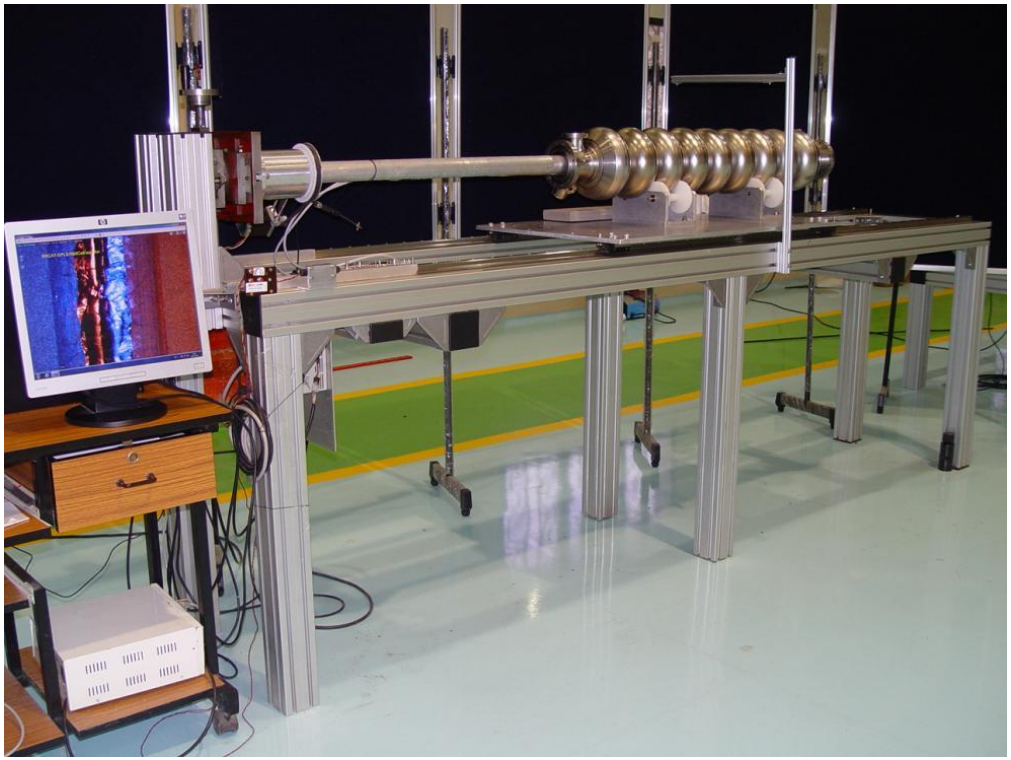
A novel technique of fabrication of SCRF cavities using Nd-YAG laser welding process, has been developed at RRCAT. The process has received patent from Japan.

A 1.3 GHz single-cell cavity fabricated using the facility was processed and tested at Fermilab. The cavity produced an accelerating gradient > 31 MV/m

SCRF Cavity Inspection Facility

Optical Inspection Bench

- Cavity internal surface measurement using a digital CCD camera with 10X-200X magnification.
- Tri-color LED for illumination
- Smallest measurable feature size : 10 microns



Cavity Processing Facility

Centrifugal Barrel Polishing (single Cell)

Main features of CBP machine

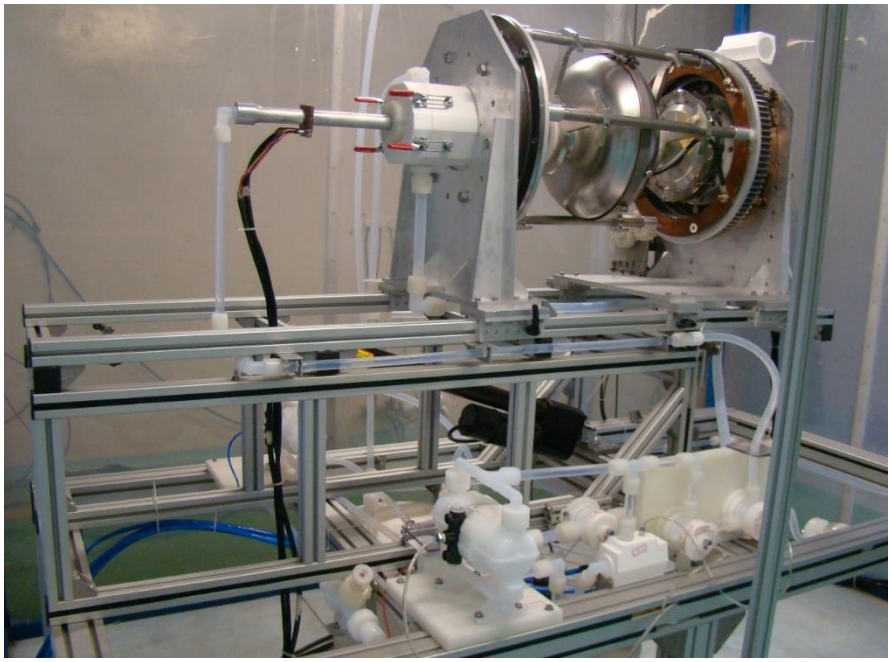
- Turret and Barrel rotate in opposite direction
- Turret speed – 0 – 200 rpm (variable)
- Barrel speed – 0 – 200 rpm (variable)
- Barrel size – 320 X 320 X 500 mm

Barrel Polishing Machine

Cavity Processing Facility

Electro-polishing setup for 1.3 GHz & 650 MHz Cavities

EP bench for 1.3 GHz Cavities

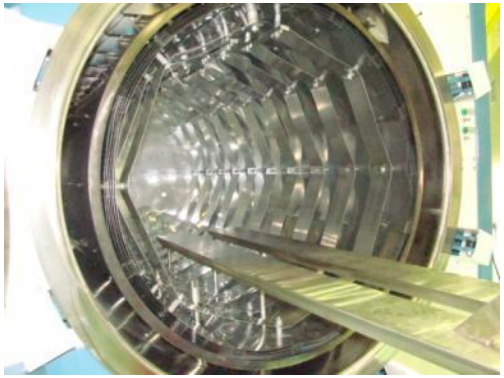


EP bench for 650 MHz Cavities

Thermal Processing Facility

High Vacuum Annealing Furnace

Specification of High Vacuum Furnace	
Orientation	**Horizontal**
Temperature range	**1400°C Max**
Working Vacuum	**<1 x 10^{-7} mbar (600°C -1000°C) <1 x 10^{-6} mbar (> 1000°C)**
Working Volume	**Diameter 825mm Depth 1500mm**



SCRF Cavity Tuning Machine

Tuning Setup of SCRF Cavity

- Manual tuners – Axial & radial (under development).
- Separate Semi-automatic tuning facility for 1.3 GHz and 650 MHz cavities

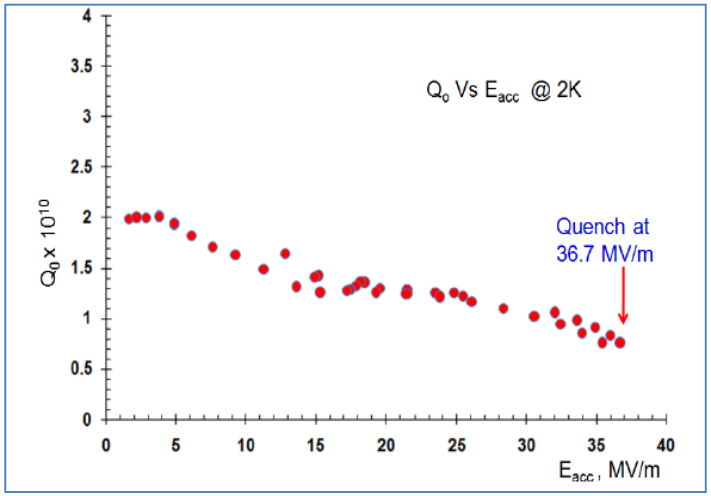
Semi-automatic tuning facility

2K Vertical Test Stand Facility

Cryostat & Cavity Insert Assembly

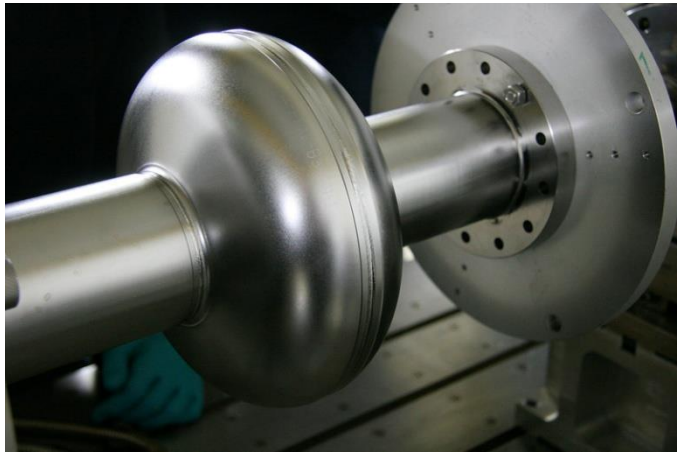
Transfer of liquid helium

RF testing in progress



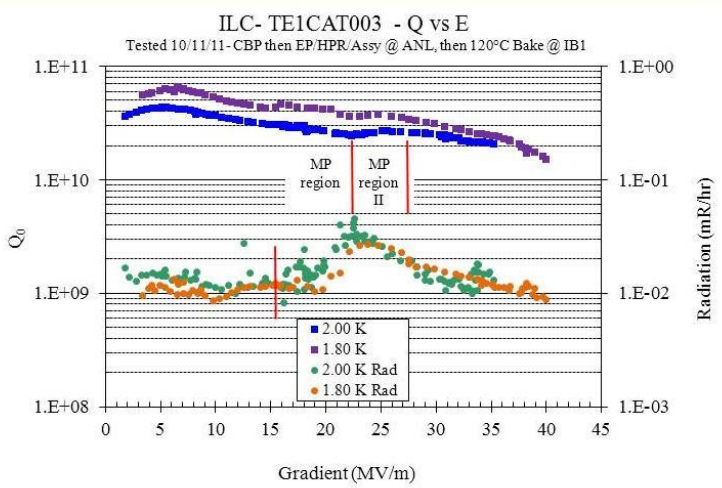
The 2K cryostat & electronics was developed in collaboration with Fermilab under IIFC

1.3 GHz Single Cell Cavities



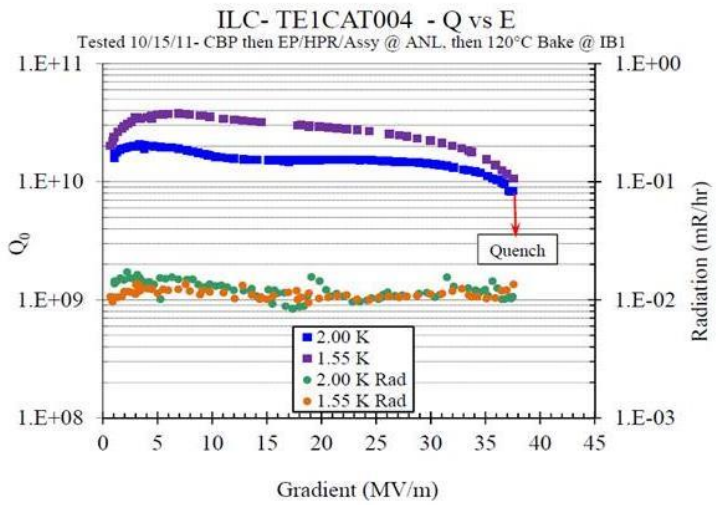
1.3 GHz TESLA-type cavity no. 3

1.3 GHz TESLA-type Single Cell Niobium Cavities were developed jointly by Raja Ramanna Centre Advanced Technology, Indore and IUAC, New Delhi.



@ 2 K:
E_a =35 MV/m

@ 1.8 K:
E_a =40 MV/m



Q_0 as a function of Accelerating Gradient in MV/m (tests conducted at Fermilab)

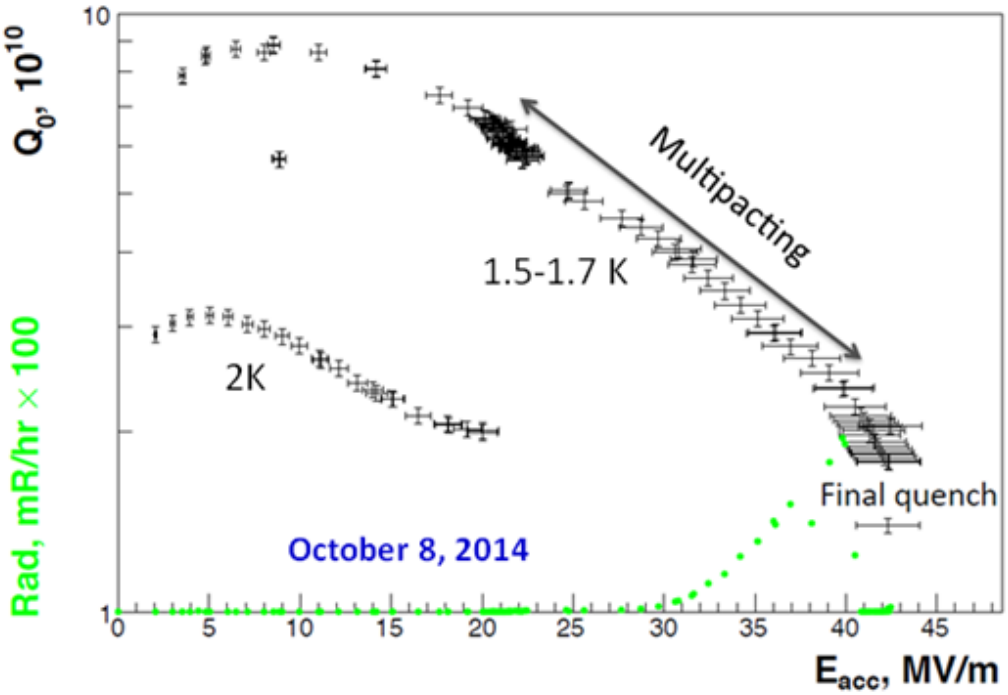
@ 2 K:
E_a =37.6 MV/m

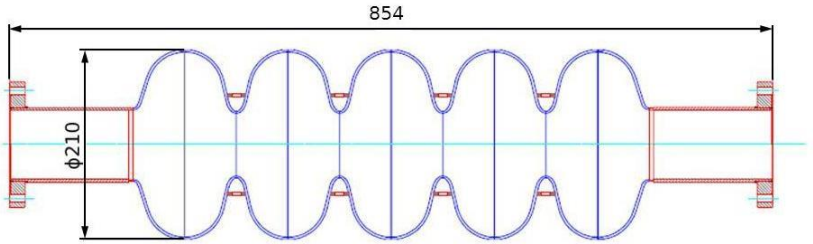
These results compare very well with those achieved in other labs in the world.

1.3 GHz 5-Cell Cavity

Two halves of the 5-Cell Cavity.

First multi-cell niobium cavity built in India.

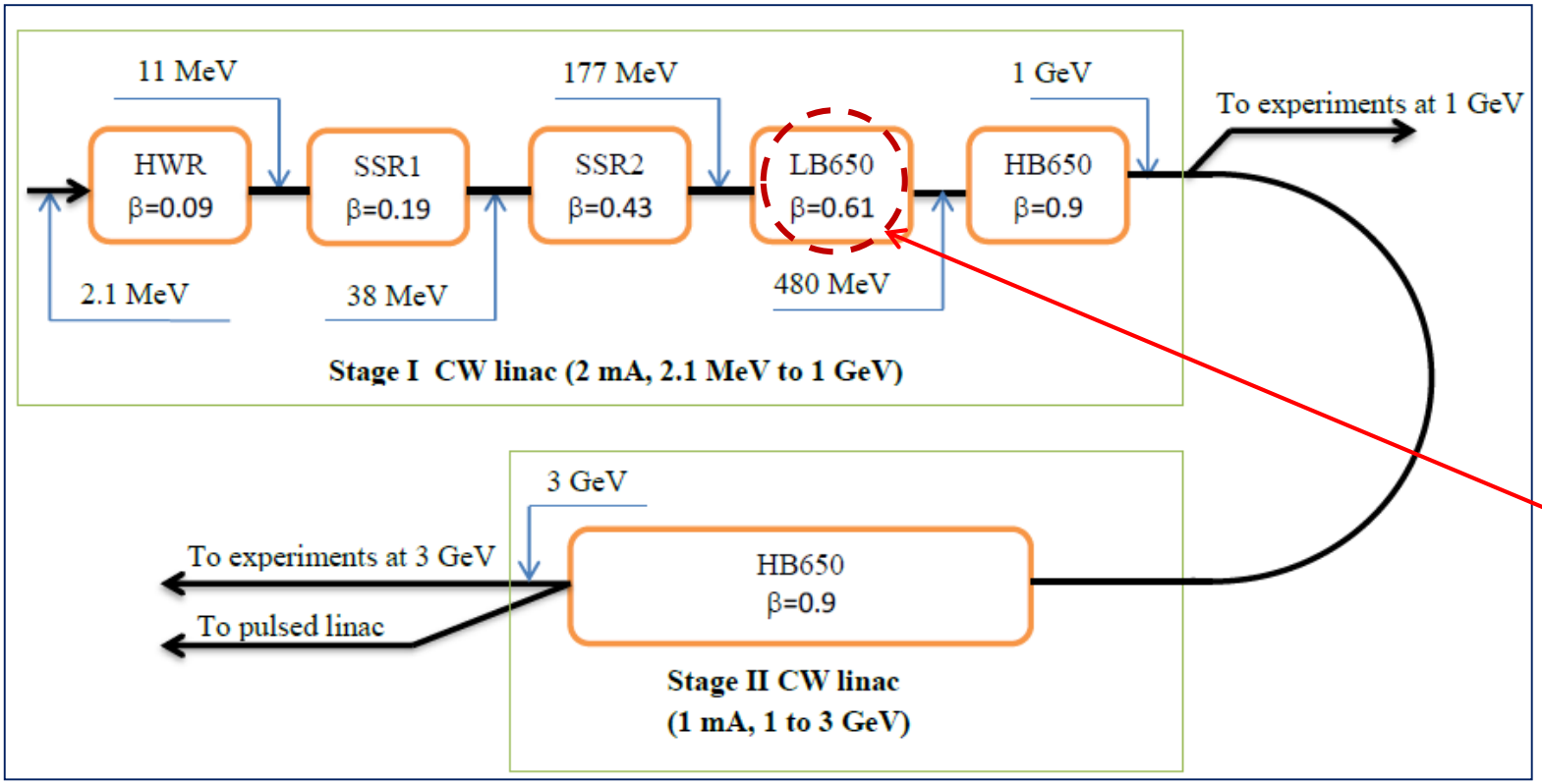




1.3 GHz 5-Cell Cavity.

Result of the cold test performed at Fermilab. The cavity reached 20.3 MV/m @ 2 K, and 42 MV/m @ 1.5-1.7 K.

DEVELOPMENT OF SUPERCONDUCTING CAVITY FOR HIGH INTENSITY PROTON LINEAR ACCELERATORS (UNDER INDIAN INSTITUTES FERMILAB COLLABORATION)



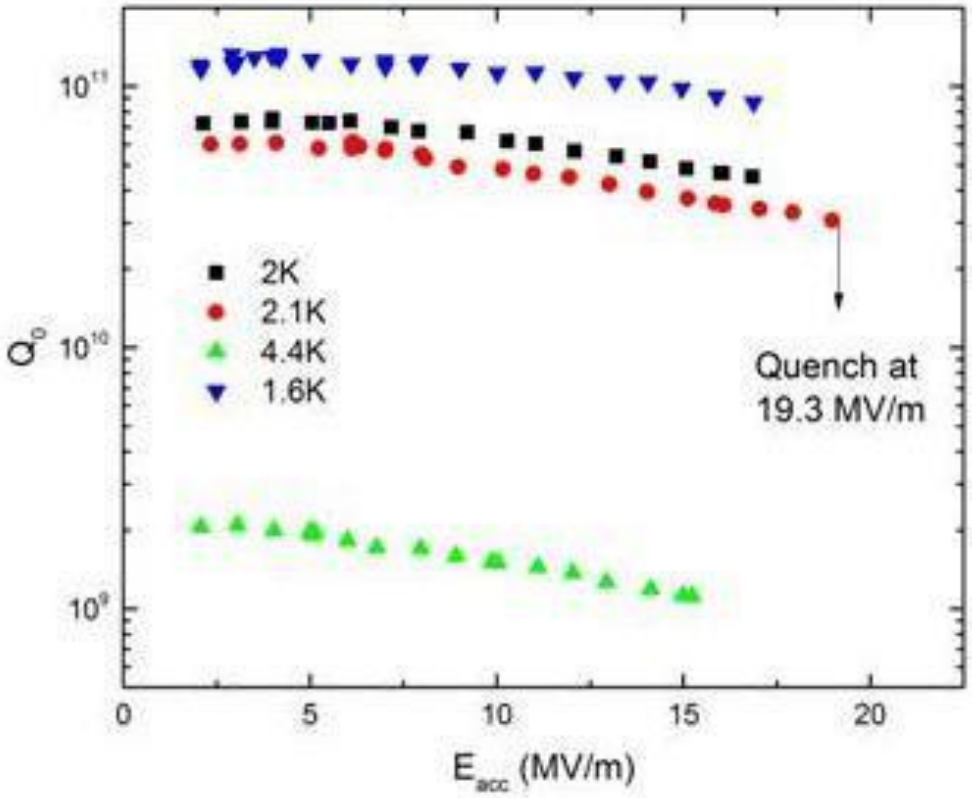
VECC is responsible for the design and development of 650 MHz, β=0.61, 5-cell cavity

- **Technical collaboration with FERMILAB, USA for their proposed PIP-II project (1 GeV, 2 mA, CW Proton Linear Accelerator)**
- **In line with proposed DAE Accelerator Programmes – ADSS & SNS**
- **Superconducting 5-cell elliptical cavity made of high purity Niobium (with RRR≥ 300) -- high gradient (≥ 17 MV/m) to be operated at 650 MHz, β=0.61**

650 MHz, β=0.9 Single Cell Cavity

- This effort was initiated by RRCAT, Indore.
- IUAC provided its expertise and facilities to carry out the work.

First 650 MHz, β=0.9 Single Cell Niobium Cavity.



Performance of the 650 MHz, β=0.9 Single Cell Niobium Cavity tested at Fermilab. The cavity achieved 19.3 MV/m gradient at $Q_0=3\times10^{10}$, exceeding the design goal of 17 MV/m at $Q_0>2\times10^{10}$.

650 MHz Single Cell Cavity

- This effort was initiated by Variable Energy Cyclotron Centre (VECC), Kolkata.
- IUAC provided its expertise and facilities to carry out the work.

650 MHz, β=0.6 Single Cell Niobium Cavity.

650 MHz, β=0.6 Cavity model.

The niobium cavity will be sent to Fermilab for processing and 2 K testing.

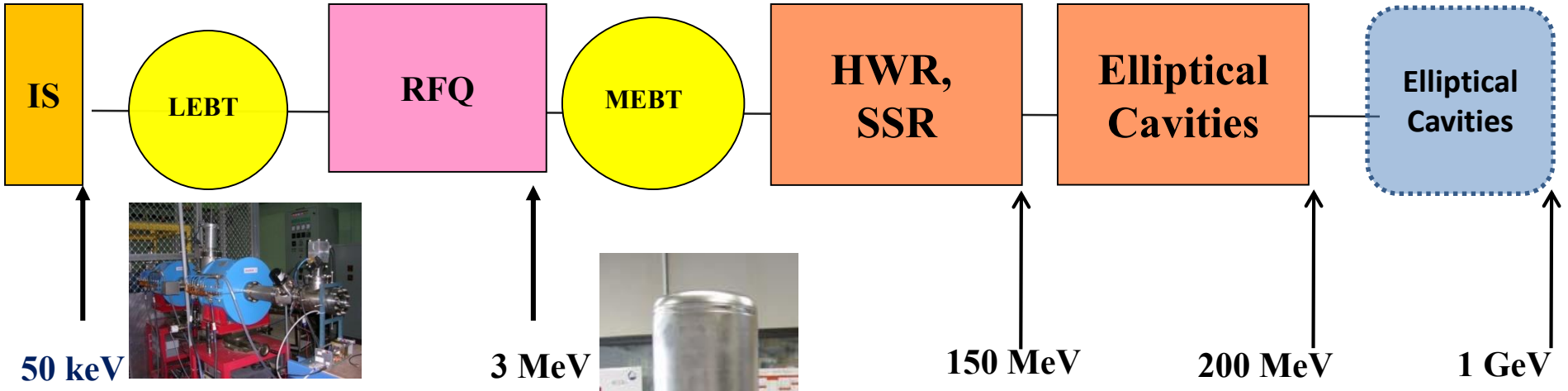
• VERTICAL TEST CRYOSTAT (FOR 650 MHz, β=0.61, 5-CELL SRF CAVITY) HAS BEEN DESIGNED IN-HOUSE AT VECC AND GOT FABRICATED BY INOX-INDIA AND INSTALLED AT VECC (RAJARHAT CAMPUS).

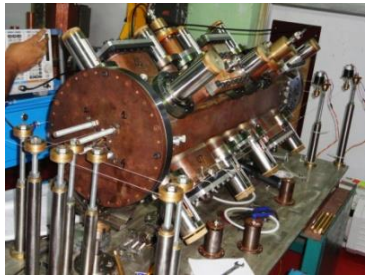
- Outer Vessel Dimension: Height : 2695 mm., Dia. 1350 mm. , Thk. 6 mm.
- LHe Vessel Dimension: Height: 1796 mm., Dia. 610 mm., Thk. 5 mm.
- PIT Dimension: Height : 2500 mm., Dia.: 1500 mm.

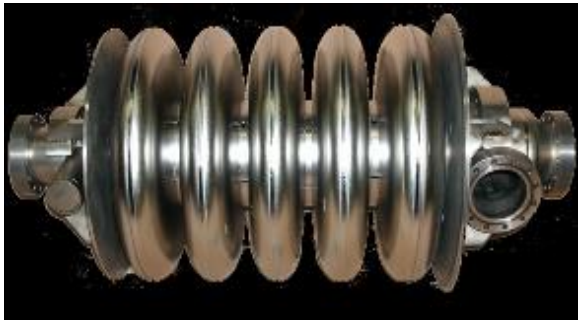
Injector Cryo Module of the e-Linac of VECC Kolkata at TRIUMF

Scheme for the 1 GeV High Intensity Superconducting Proton Accelerator for ADS

Frequency: 325 and 650 MHz

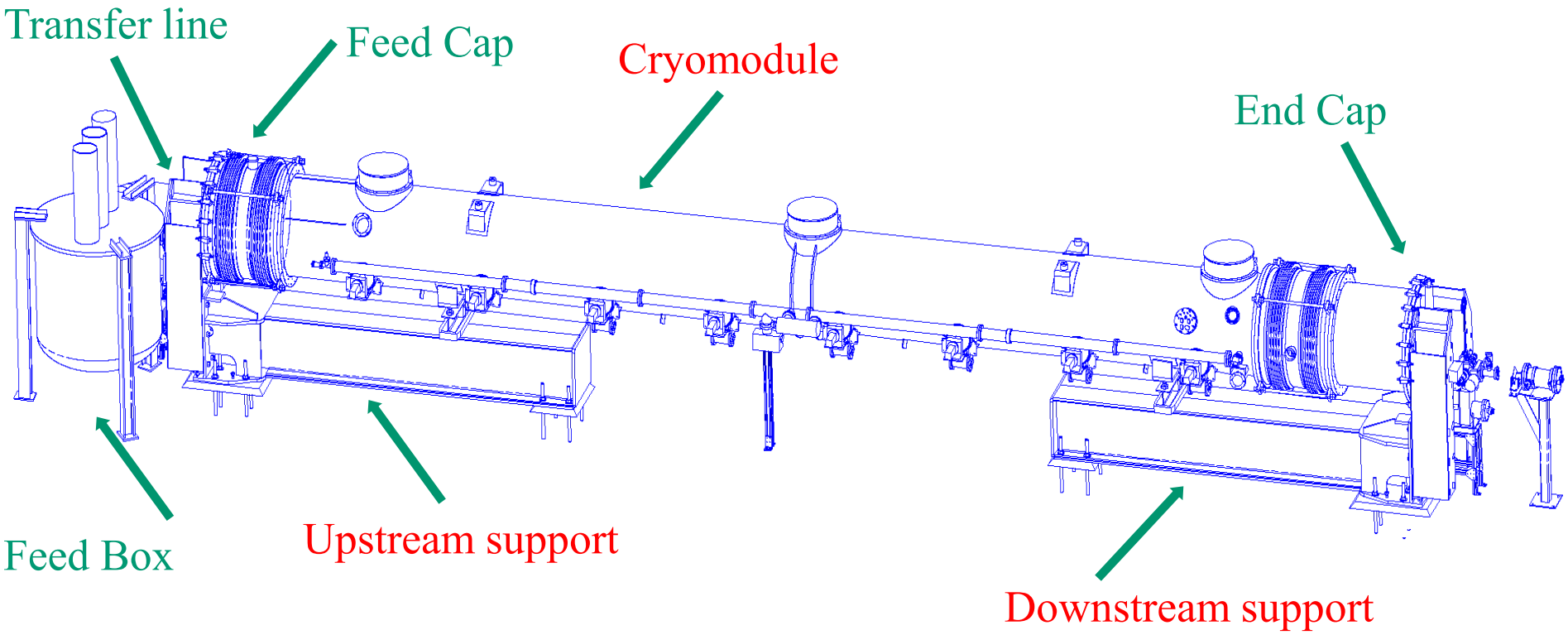






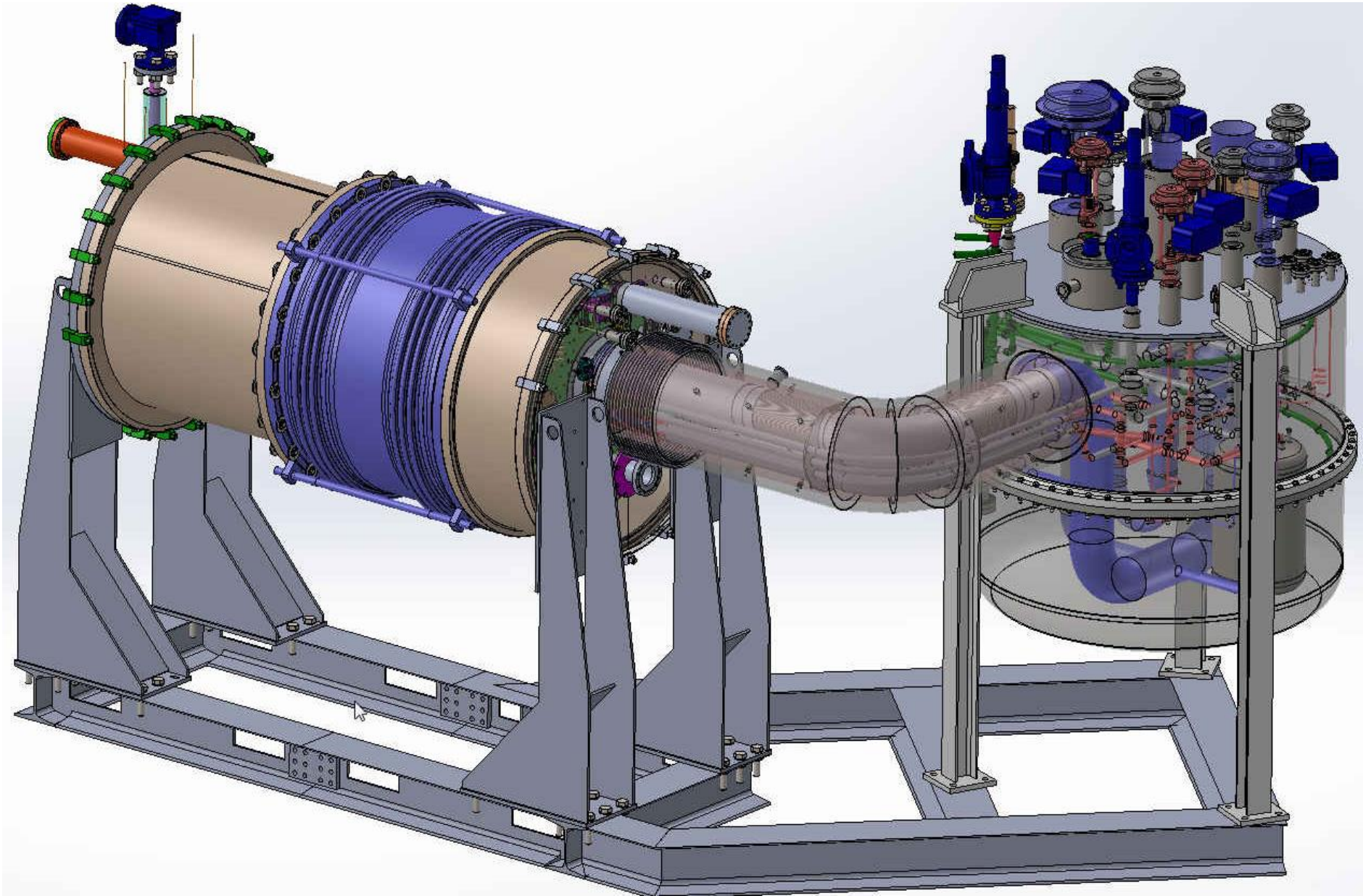

BARC Wedge Tuner

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



Solid State RF amplifiers at 325 MHz:

1 kW Amplifier

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

3 kW Amplifier

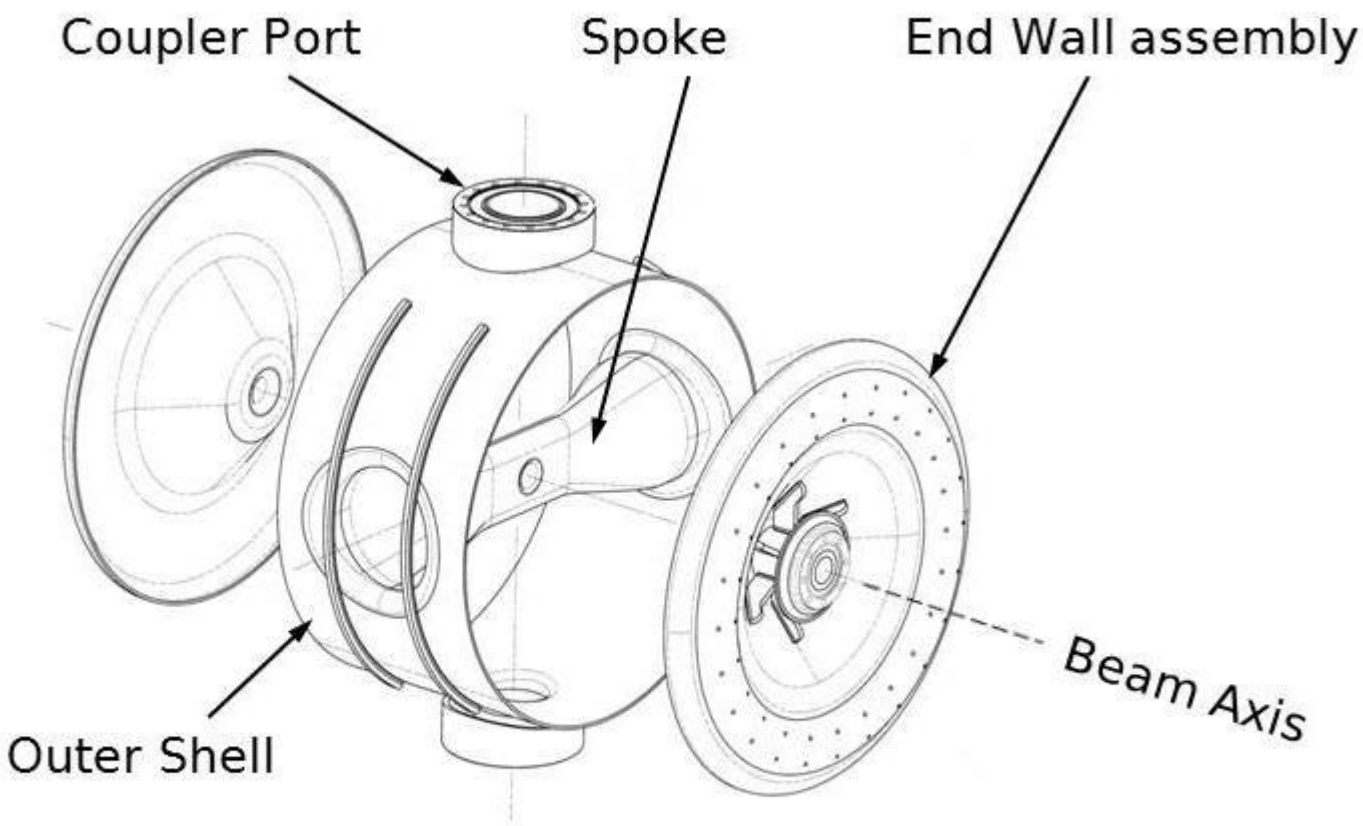
- Power: 3 kW
- Overall Gain: > 65 dB
- Efficiency : 65 %
- 2nd Harmonics: - 41.9 dB
- Status: Completed and delivered

7 kW Amplifier

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

Fabrication of Single Spoke resonator

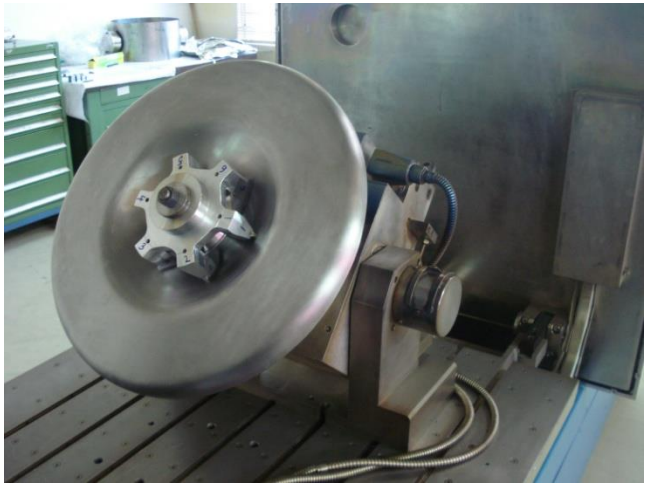
IUAC constructed two SSR1



SSR1 - β=0.22, 325 MHz, Niobium Assembly

Fabrication of Single Spoke resonator

Niobium Spoke

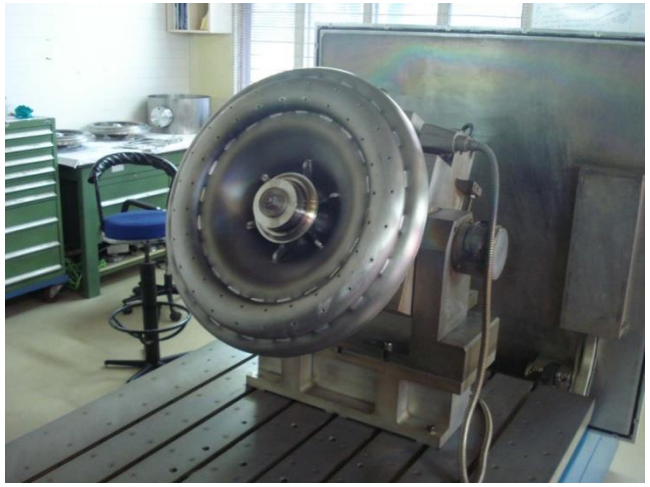


End Wall to Daisy Rib EBW

Coupler Port Flange

Shell with Coupler Ports

Fabrication of Single Spoke resonator



EBW – End Wall to Donut Rib

End Wall assemblies

Close up view of an End Wall assembly

Outer Shell EP setup

Fabricated SSR1s

Handing over of the first niobium Single Spoke Resonator (SSR1) to Fermi Lab, USA. From L to R: Kishore Kumar Mistri, Dr Shekhar Mishra, Dr P.N.Prakash, Abhishek Rai (partly hidden) and Dr Sundeep Chopra (March 13, 2015, IUAC, New Delhi).

Acknowledgements

The help and slides received from my colleagues Dr. P. N. Prakash and Dr. S. Ghosh from IUAC Delhi and the Scientists and Engineers of RRCAT Indore, BARC & TIFR Mumbai and VECC Kolkata are thankfully acknowledged.

Thank You for your kind attention