Status of Indian Superconducting RF Activities under IIFC-PIP II

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On behalf of IIFC team

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Department of Atomic Energy

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Outline

i) Introduction

ii) Indian Participation in Mega Science Projects

iii) Indian Institutes Fermilab Collaboration in SCRF

SSR1, 325MHz SSPAs, HB650 five-cell cavities,650MHz SSPAs,

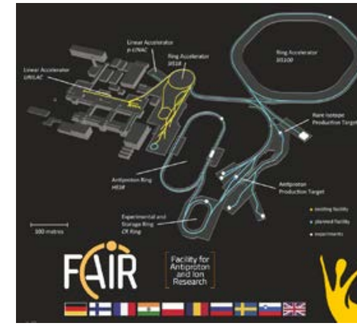
infrastructure facilities, etc….some details

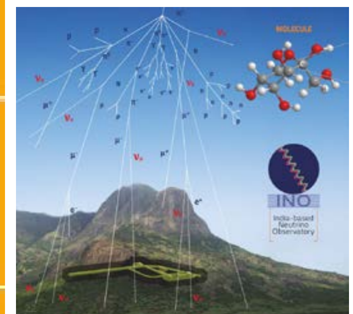
i) Summary

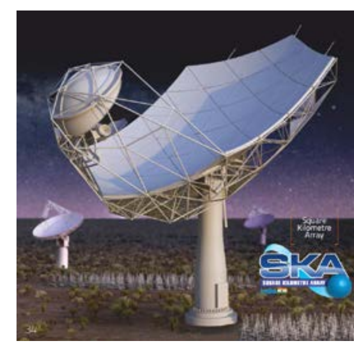
Introduction

- India participating in International Mega Science Projects like: CERN-(LHC/Linac4/CTF3/CMS/ALICE/GRID),FAIR,INO,ITER,LIGO,SKA,TMT, MACE. (ref. http://www.vigyansamagam.in)
- Large number of the contributions were made in Indian industries.
- India is interested in High Intensity Superconducting Proton Accelerator (HISPA) for building Indian Facility for Spallation Research (IFSR), radio-isotope production, Radio-active Ion Beam (RIB) facility, etc.
- India is participating in PIP-II at Fermilab to get proven HISPA technology by contributing a wide spectrum of components to PIP-II construction, besides involvement in the PIP-II R&D phase.
- Superconducting RF technology forms an important area to achieve the proton accelerator development for various applications
- RRCAT has build 2.5 GeV SRS Indus 2, IR-FEL, 10MeV Linacs for food irradiation besides having a major laser program.
- BARC is developing electron and proton accelerators e.g., Cargo scanning Linac, Low Energy High Intensity Proton Accelerator etc.
- VECC has constructed 3 cyclotrons, K130 operating since 1977, recently commissioned superconducting cyclotron and a 30MeV medical cyclotron and built a RIB facility (ANURIB).

Indian Mega Science Projects





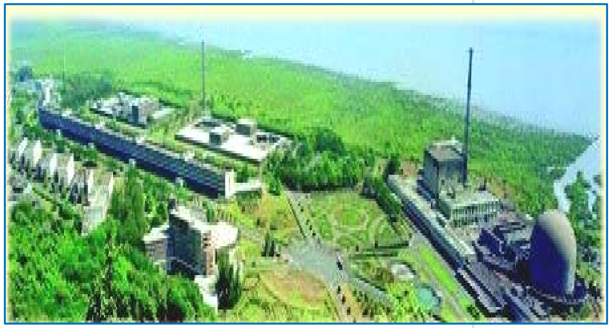


http://www.vigyansamagam.in

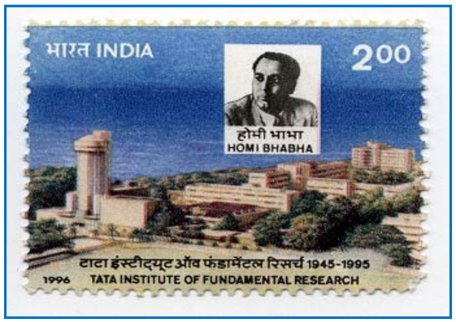
Artistic impression of various Mega Science Projects probing the universe

http://www.vigyansamagam.in

Major DAE R&D Centres in CERN and IIFC Collaboration



BARC, Mumbai, CERN-LHC/CMS/GRID and IIFC



TIFR, Mumbai (CERN -CMS)

RRCAT, Indore:
CERN- LHC/CTF3/Linac4(SPL) and IIFC

VECC, Kolkata, CERN-ALICE and IIFC

IOP, Bhuvaneshwar, CERN -ALICE

SINP, Kolkata, CERN -ALICE

Indian Participation in CERN Accelerators

Participation in LHC construction & commissioning

(co-operation agreement 28th March 1991, protocol for (LHC) on 29th March 1996, “in-kind” contributions)

- **Hardware contributions for construction of LHC**
- **Commissioning and re-commissioning**
- **Software development**

Participation in Novel Accelerator Technology Projects

(NAT Protocol March 2006)

- Compact Linear Collider (CLIC) Test Facility (CTF3)

  Hardware contributions(Vacuum chambers, dipole magnets)
  Optics Design and Commissioning of TL2
  Controls software development

- Linac-4, the front end of Superconducting Proton Linac

  Linac-4 is a new injector linear accelerator for increasing the luminosity of LHC originally conceived as front end of SPL project. Contributed 100kV solid state modulators, waveguide couplers, expert support for commissioning subsystems

Table 1: Participation in LHC protocol for LHC accelerator construction/commissioning

Sr.	Description	Qty
1	Liquid Nitrogen tanks 50000 litres capacity	2
2	Superconducting corrector magnets : Sextupole, Decapole and Octupole	1146 616
3	Precision Magnet Positioning System (PMPS) Jacks	7080
4	Quench Heater Power Supplies, QHPS	5500
5	Integration of QHPS units into racks	6200
6	Control electronics for circuit breakers of energy extraction system	70
7	Local protection units (LPU)	1435
8	SC Dipole magnet measurements, expert support. Eq. man-years	100
9	LHC commissioning: Cryogenics, Controls, Converters, protections, man-years	20
10	Software development for LHC subsystems, eq. man-years	41

Table 2:Joint Participation in NAT protocol for construction of [CLIC(CTF3)/SPL(LINAC4):

1	Design, development, magnetic tests of dipole magnets for TL2 of CTF 3	5
2	Design, Development, vacuum tests of vacuum chambers, for CTF3 + spares	64+62
3	Optics design, simulations, analysis and results for TL 2 of CTF 3, eq man months	9
4	Expert support for commissioning, operation of controls for CTF3, man months	41
5	Expert support for the commissioning of the subsystems of Linac 4, man months	25
6	100kV, 20A solid state modulator for CERN LINAC 4	1
7	20kW Broad Band solid state amplifier for harmonic buncher for CLIC linac	1
8	Development, supply of prototype components for Linac 4	6
9	Development, supply of copper coated SS power couplers for DTL for Linac 4	4
10	Tests and supply by CERN: 1MW CW 352.2 MHz klystrons, 1MW CW circulators, waveguide hardware, four sets each, LEP eq. for DAE's SNS/ADS	4 sets

Major DAE Contributions to LHC

Corrector Magnets
(616 MCDO & 1146 MCS)

Quench Heater Power Supply
(QHPS) HDS units 5500

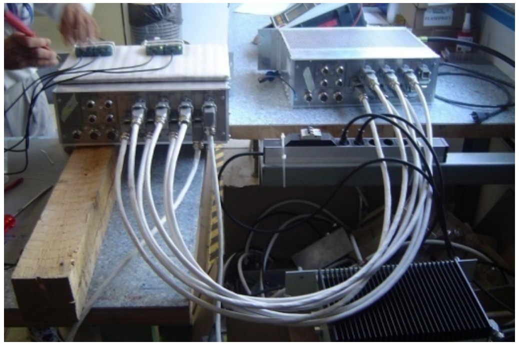
Local protection units
(LPU) 1435

Precision Magnet
Positioning System
PMPS 7080

- Expert support for SC Dipole magnet measurements 100 Man years
- Support for LHC hardware commissioning
  20 Man years. (16 Man years completed)

Tests and Qualification of the LHC Superconducting Dipoles
Commissioning of LHC Hardware Subsystems

DAE engineers worked at SM18 Hall at CERN and completed crucial performance tests and qualification of all the LHC superconducting dipole magnets. H.E. Dr. A. P. J. Abdul Kalam the President of India at SM 18 Hall of CERN with DAE's engineers on May 25, 2005.



High voltage test set-up for nQHPS

nQPSRacks ready for installation

Determination of excessive frosting in cryogenic subsystem & re-evaluation of safety valve size etc.

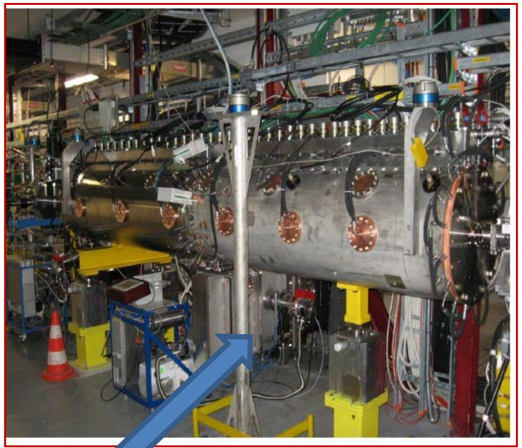
Indian experts participated in the commissioning of new Quench Heater Protection Systems, Cryogenic Systems, Power Converters Systems. Total support of ~18 man years was provided for LHC commissioning.

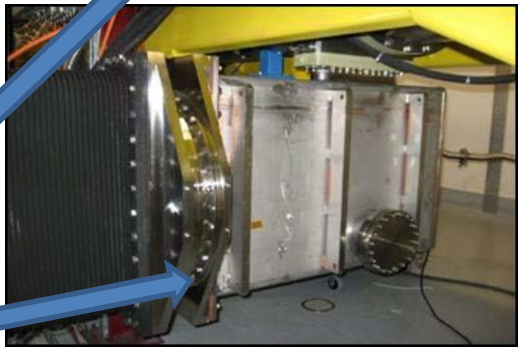
Collaboration: NAT Protocol LINAC 4 project

- **100kV state of the art prototype solid state bouncer modulator for LINAC4**
- **WR 2300 waveguide components, power couplers for LINAC4**
- **Participation in commissioning of the LINAC4 subsystems.**
- **India received four 352.21 MHz, 1MW CW klystrons and circulators along with RF waveguide components for our projects on SNS at RRCAT and ADS/LEHIPA at BARC.**

100kV solid state modulator designed, developed and commissioned by RRCAT, Indore, for LINAC 4 cavity tests.

CERN klystron and circulator tested at 1MW peak power at RRCAT test stand.





Two Cu coated SS WR 2300 waveguide power couplers installed in the DTL/CCDL in LINAC 4 tunnel at CERN

Collaboration activities under NAT Protocol
Contribution to CLIC/CTF3 at CERN

- Optics design of TL2
- 5 dipole magnets
- 62 Vacuum chambers
- Software development for controls for CTF3
- Components of Power extraction and Transfer Structure, PETS bars
- 20 kW Wide Band Solid State RF Amplifier for harmonic buncher for CLIC

Dipole magnets

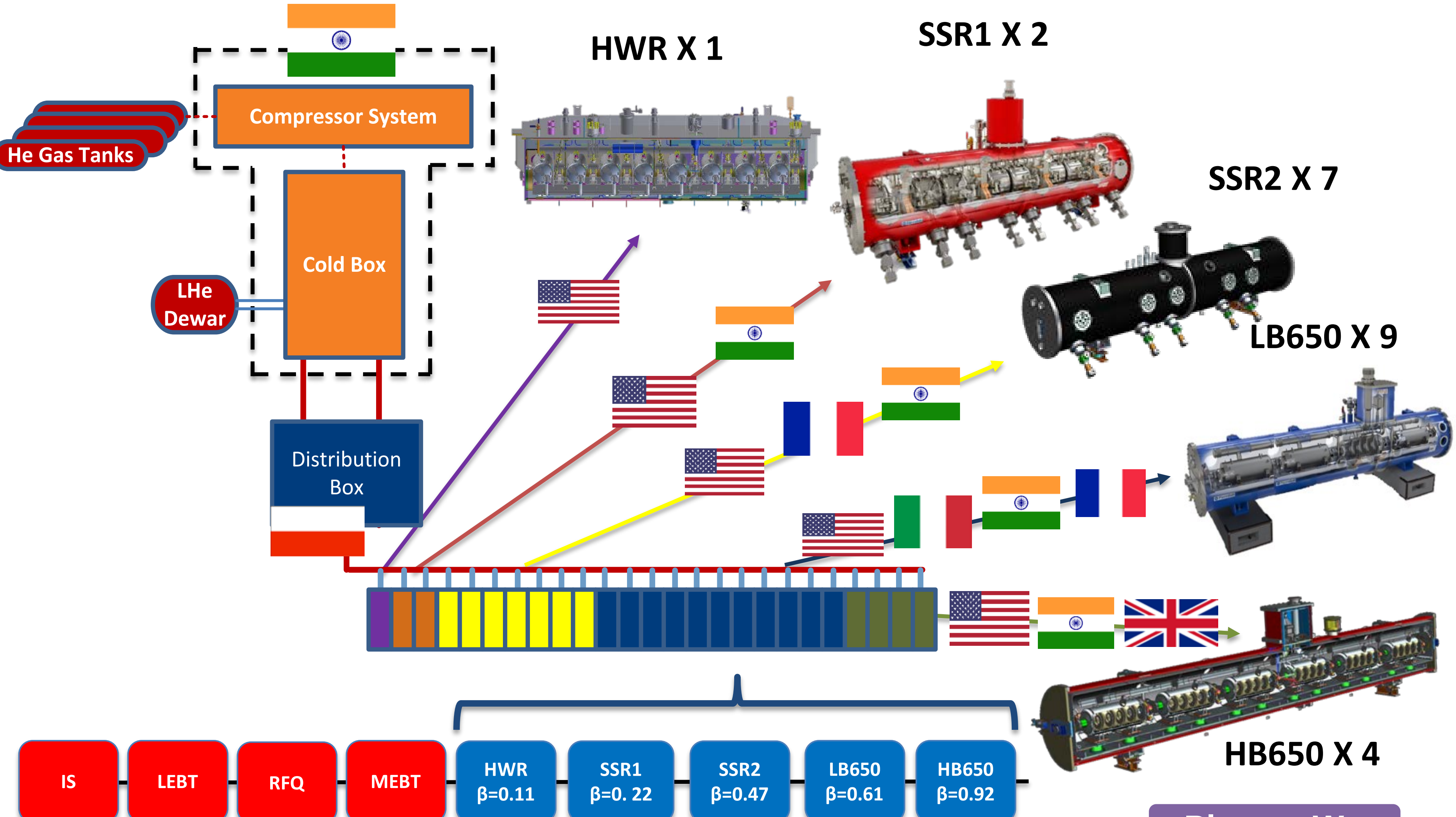
Vacuum chambers of various profiles in TL2 of CTF3

20kW wide band SSPA delivered to CERN

SCRF Activities under Indian Institutions
Fermilab Collaboration, IIFC (PIP-II)

DAE
BARC, Mumbai
RRCAT, Indore
VECC, Kolkata

PIP-II SRF Linac & Areas of International Interest



Plenary-Wu

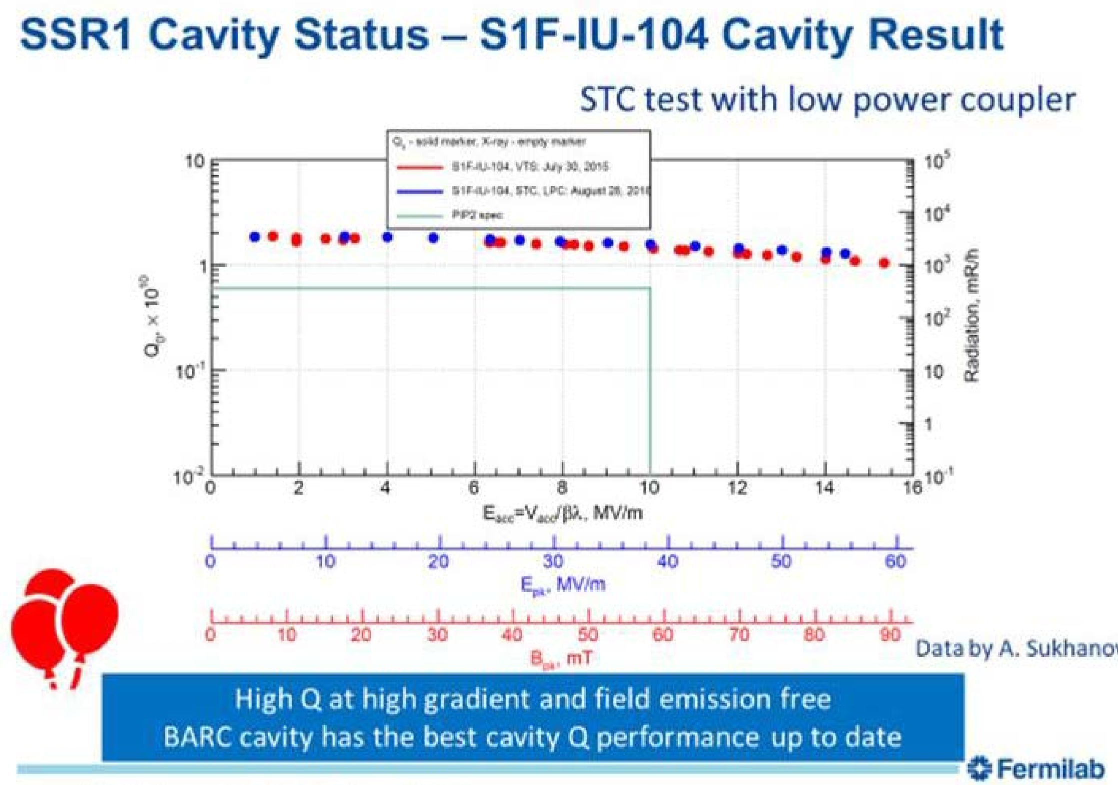
PIP-II Project benefits from world-leading expertise, facilities.

"Timing is perfect" Courtsey: Lia Merminga, FNAL

Indian involvement in SCRF for PIP-II R&D Phase

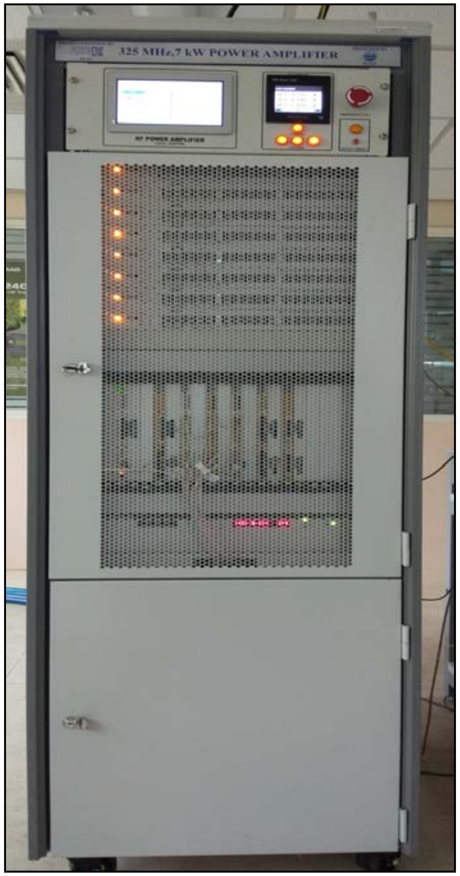
1) SSR1 cavity fabrication and dressing
2) SSR2 cavity design, fabrication, dressing, processing and testing
3) LB650 cavity design, fabrication, dressing, processing and testing
4) HB650 cavity design, fabrication, dressing, processing and testing
5) SSR2 and HB650 cryomodule design
6) RF couplers at 325 & 650 MHz
7) 325 MHz RF amplifiers (7 kW & 20 kW)
8) 650 MHz RF amplifiers (40 kW and 70 kW)
9) LLRF & RFPI systems
10) HTS

SSR1 cavities and components



Two 325 MHz Single Spoke Resonator (SSR)-1 type Niobium cavities manufactured & dressed (jacketed) with SS Helium vessel by DAE under IIFC.

325 MHz Solid State RF Amplifiers



First 7kW, 325 MHz RF amplifier has been successfully tested in presence of Fermilab & DAE officials and shipped to Fermilab.

LLRF & RFPI systems

LLRF

Digital Module

Boards of Resonance Control System

RFPI

LLRF & RFPI systems installed and operating in the LEHIPA accelerator at BARC.
Advanced versions will be tested at HTS at RRCAT.

HB650 cryomodule with cavities & components

1. Design of 70K Thermal Shield

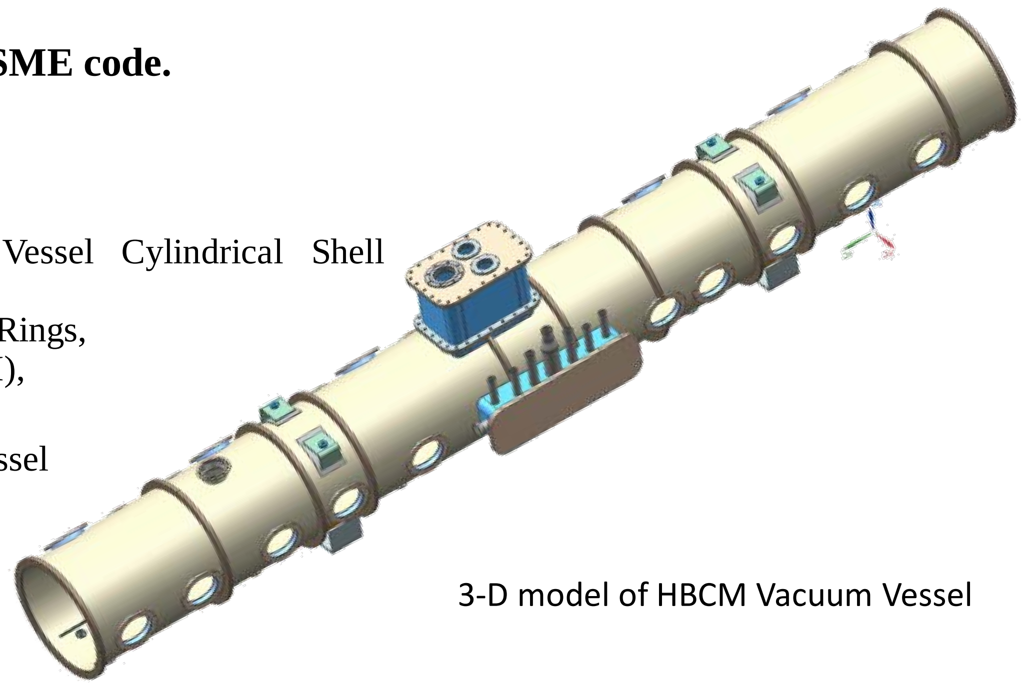
- Calculations for mass flow rate and h value finished, Transient thermal analysis of shield indicates 24 Hrs safe linear cool down.
- Experimentation in scale down thermal shield are under progress

2. Design of Vacuum Vessel for HBCM

Vacuum vessel design note prepared as per ASME code.

Calculations and analysis done for:

- Vacuum Vessel Cylindrical Shell Thickness,
- Permissible Out of Roundness of the Vessel Cylindrical Shell Thickness,
- Analysis and Calculations for the Stiffening Rings,
- Main vessel Shell Openings (As per Sec VIII),
- Saddle support of Vacuum Vessel
- Flanges, Bolts and Welds for the Vacuum Vessel



3-D model of HBCM Vacuum Vessel

650 MHz Solid State RF Amplifiers

650 MHz RF amplifier acceptance testing at RRCAT by Fermilab Team

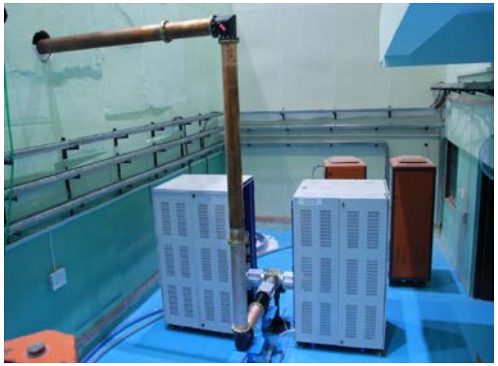
Tests : Output Power (650 MHz) : 36 kW ,

harmonics < -30 dBc

Gain: 70 dB, RF radiation<0.1 mW/cm2 at 1m,

Input Mains supply: 3 Phase AC

650 MHz amplifier integrated with HTS at RRCAT



Efforts at RRCAT for HB 650 SCRF cavities under Indian Institutes Fermilab Collaboration	
Physics design of Superconducting RF Cavities	
Engineering design of Superconducting RF Cavities	
Machining of components for Superconducting RF Cavities	
Fabrication of Superconducting RF Cavities	
Processing of Superconducting RF Cavities	
Tuning of multi-cell Superconducting RF Cavities	
Chemistry of Superconducting RF Cavities	
RF Characterization Room Temp., VTS, HTS	

Steps and Infrastructure

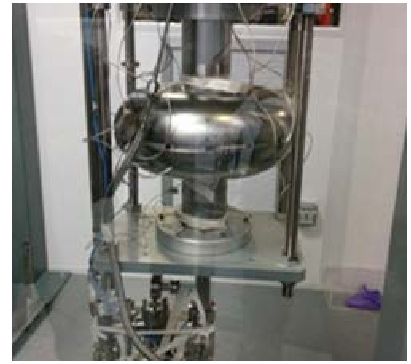
- Cavity Manufacturing
  - Forming, Machining, EB welding and its pre-qualification (mech. Vacuum and RF)
- Cavity Tuning setup
- Cavity Processing infrastructure
  - EP, CBP, HPR, Furnace, Clean room
- VTS facility to test bare cavity
- Cavity Dressing infrastructure
  - Controlled Environment Glove box
  - Dressing exercises in progress

Initial Efforts with 1.3 GHz SCRF Cavities

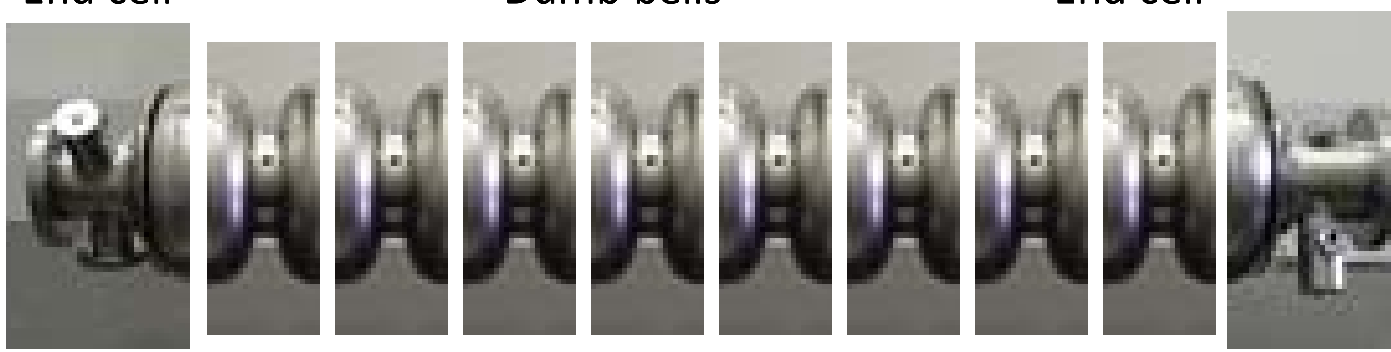
Forming

EB welding

single cell cavity



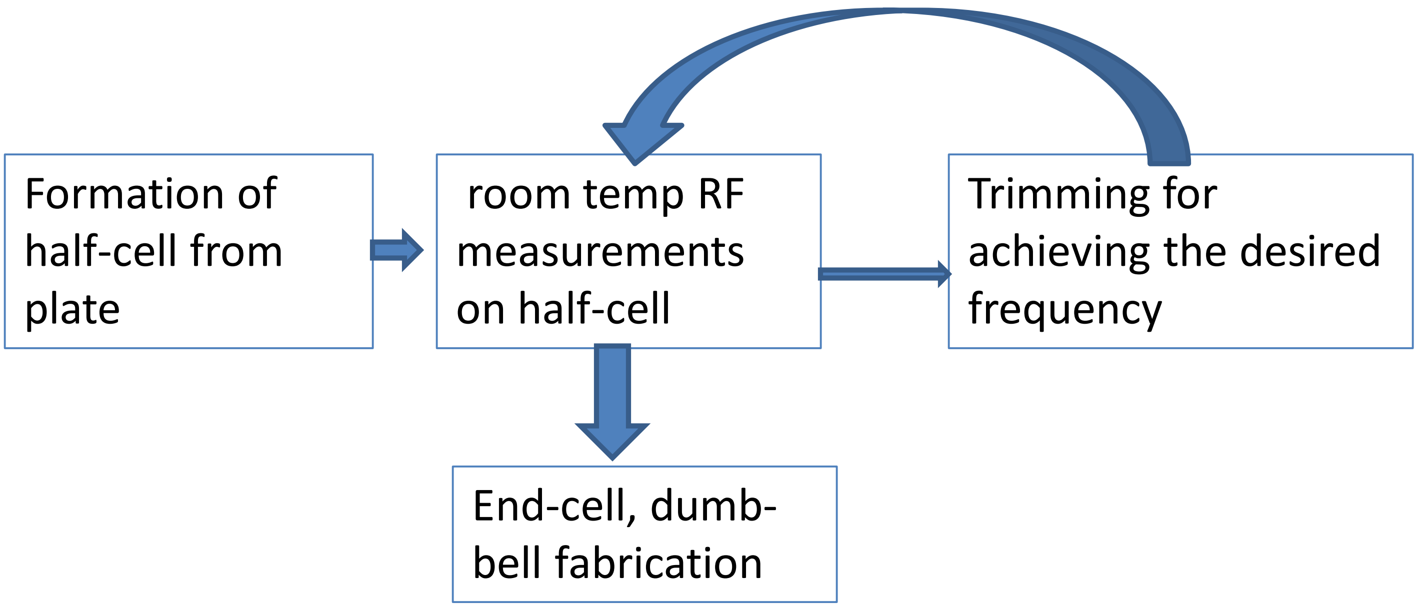
End cell Dumb bells End cell



Nine-Cell 1300 MHz SCRF cavity

RF measurements during fabrication of cavity parts

- RF testing goes hand in hand in each stage of the cavity fabrication and development starting first half-cell is formed until the complete cavity is fabricated, processed and finally tested.
- The initial part of the RF testing and characterization is done at room temperatures during the fabrication process.



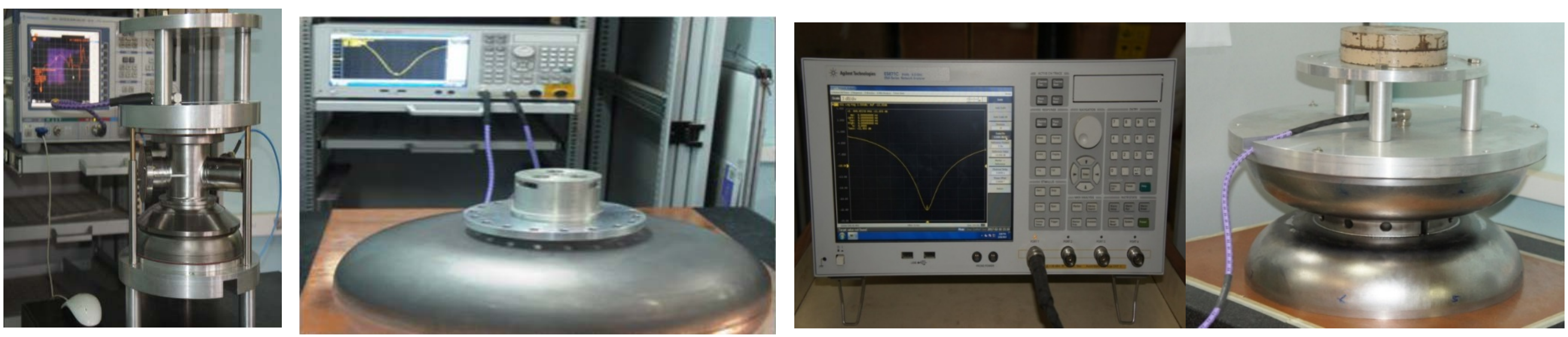
RF measurements during fabrication of cavity

✓For half-cell/end-cell structure precise measurement of resonant frequency corresponding to the mechanical length of the cavity is done.

✓These measurements are carried out in setup which provides a good conductive boundary to both the iris and the equator.

✓ The resonant frequency of the resultant cavity structure is then determined by measurement of either S11 or S21 using a VNA. For measurement a small pick up antenna is used so as not to perturb the cavity. RF measurement of dumbbell structures is more complex.

✓It is more important to identify the dumbbell asymmetry



HB 650 Beta 0.92 half cell and dumbbell structures

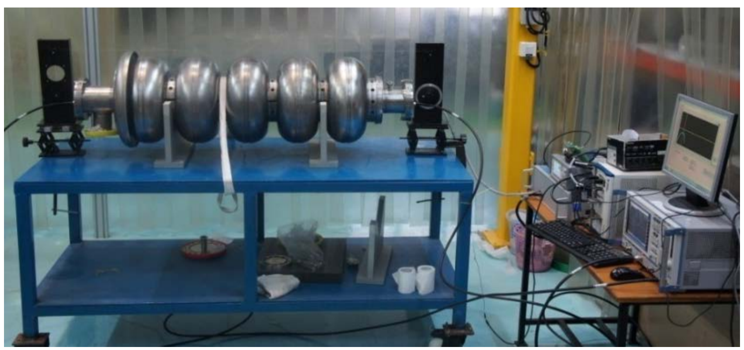
Room Temperature RF Characterization

Field flatness by Bead pull

5 cell 650 MHz SCRF Cavity (HB501 with FP end bellow welded)

Frequency & Field Flatness Measurements

After welding the multi cell cavity is qualified for its field flatness by bead-pull measurement.



Bead pull test on 5 Cell HB650 MHz cavity.

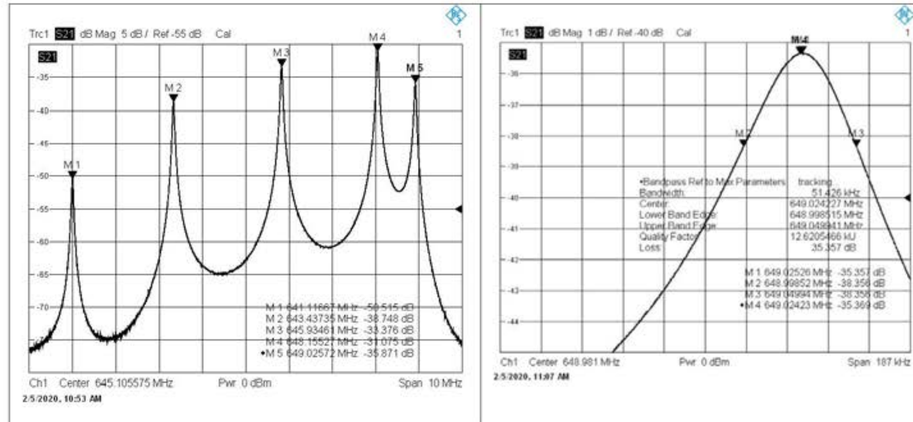


Fig. 1 :- Frequency spectrum at 20 ^{0}C (π mode frequency - 649.025 MHz)

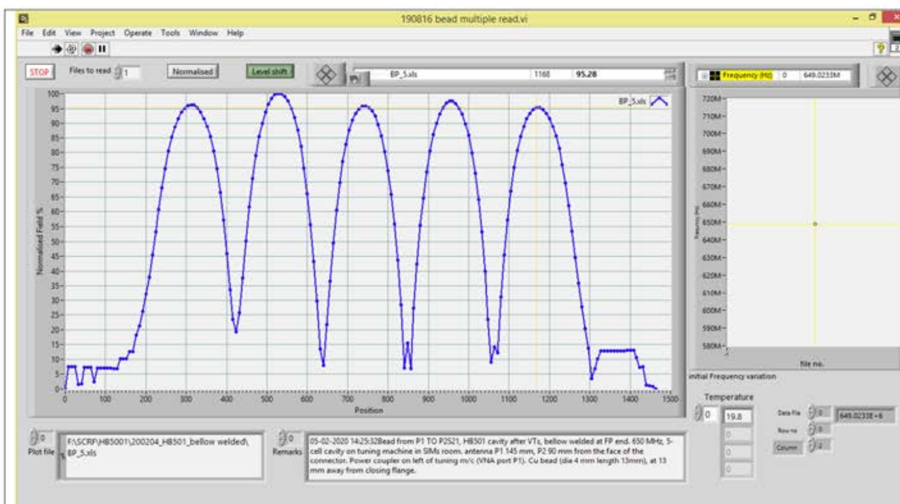
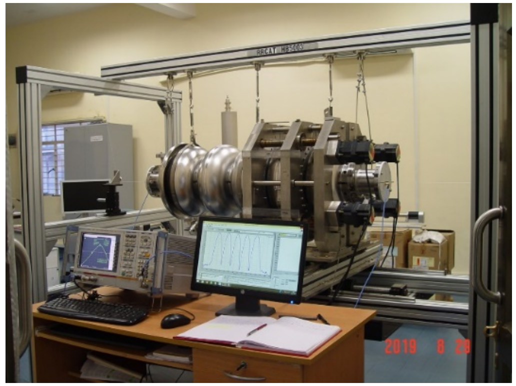


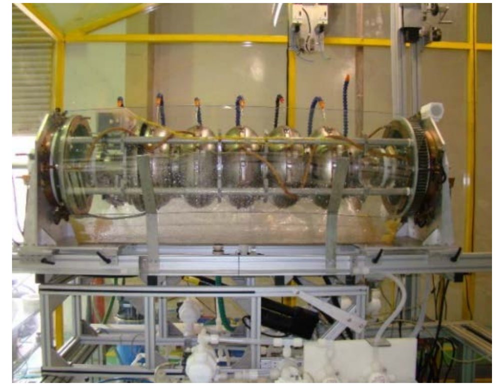
Fig. 2 :- Field profile of cavity 501 (Field flatness ~ 95%)

Infrastructure for SRF cavities

Optical Inspection

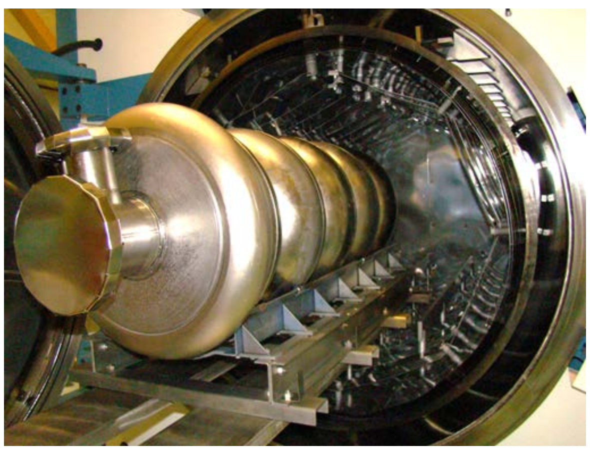


Cavity Tuning



Electropolishing

High Pressure Rinsing



High Temperature Annealing

Low temperature baking at 120°C

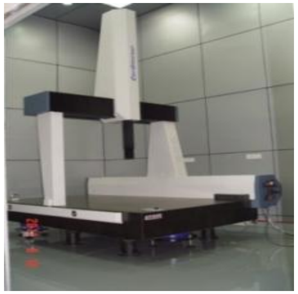
Cleanroom Assembly

Infrastructure for SRF cavity fabrication & inspection

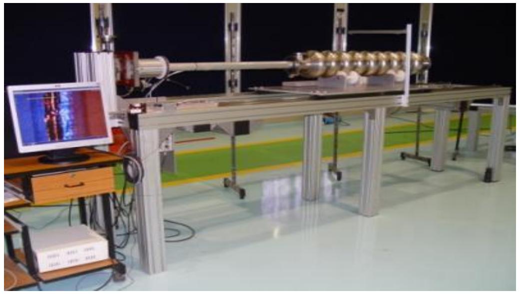
Cavity fabrication & inspection facility

Cavity Forming Facility

15 kW EBW Machine



3D CMM



Optical Inspection Bench

Material Characterization facility

SIMS Facility

Universal Testing Machine

Laser scanning confocal microscope

Centrifugal Barrel Polishing

CBP Machine for single-cell 1.3 GHz cavity

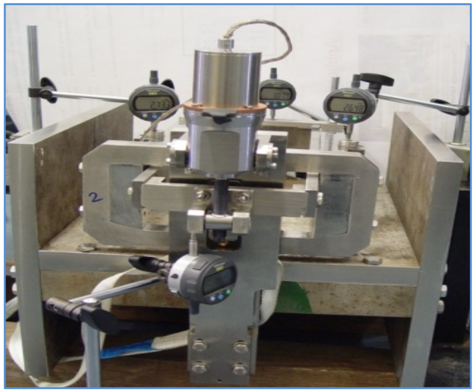
CBP Machine for five-cell 650 MHz cavity

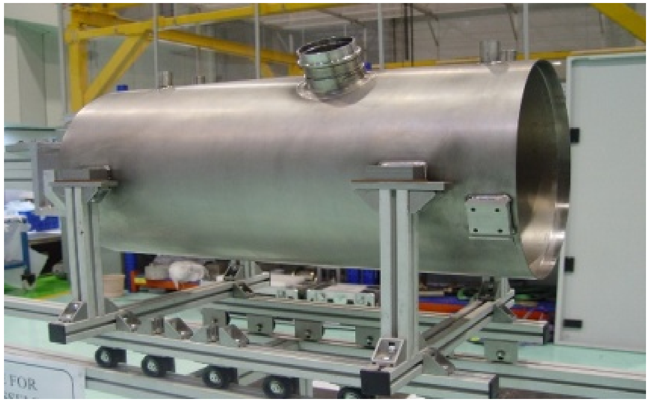
The CBP machine for five-cell 650 MHz cavity is unique machine for this size of cavity

- Controlled temperature
- Can polish 4 five-cell 650 MHz cavities simultaneously

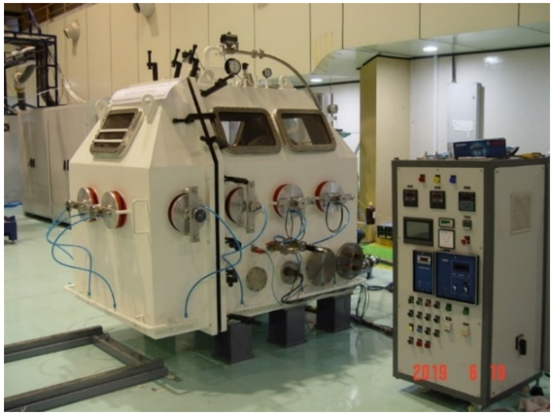
HB650 five-cell SCRF cavity development


Bare five-cell cavities

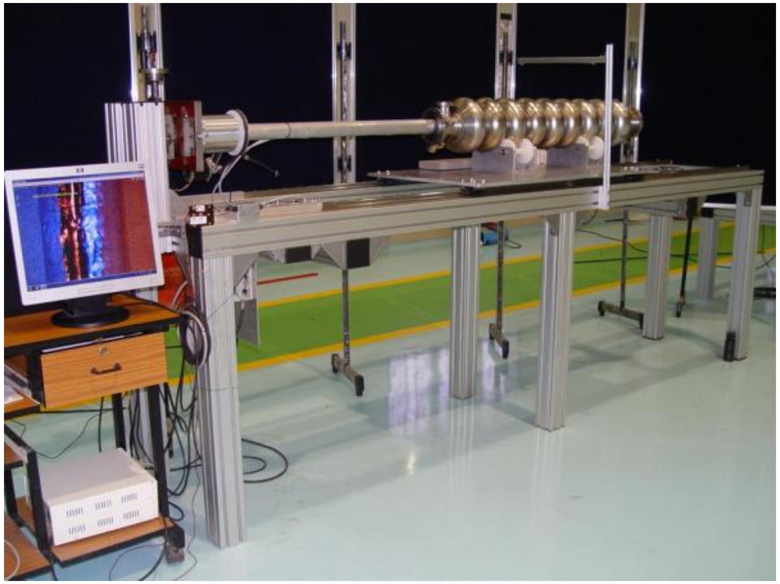

Lever Tuner


Helium Vessel


Insertion bench

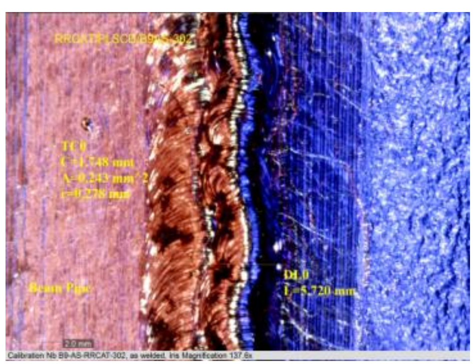

Welding glove box

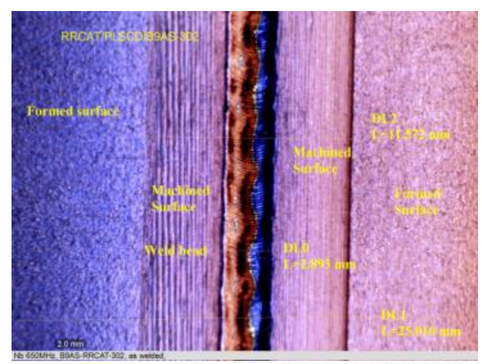
Optical Inspection of internal surface of the cavity



Inspection of nine-cell 1.3 GHz cavity

Inspection of 5 -cell 650 MHz cavity



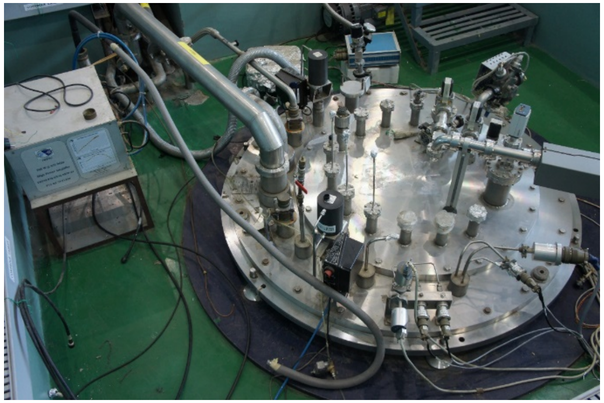


Images from optical bench (650 MHz cavity)

Infrastructure for testing of SRF cavities VTS

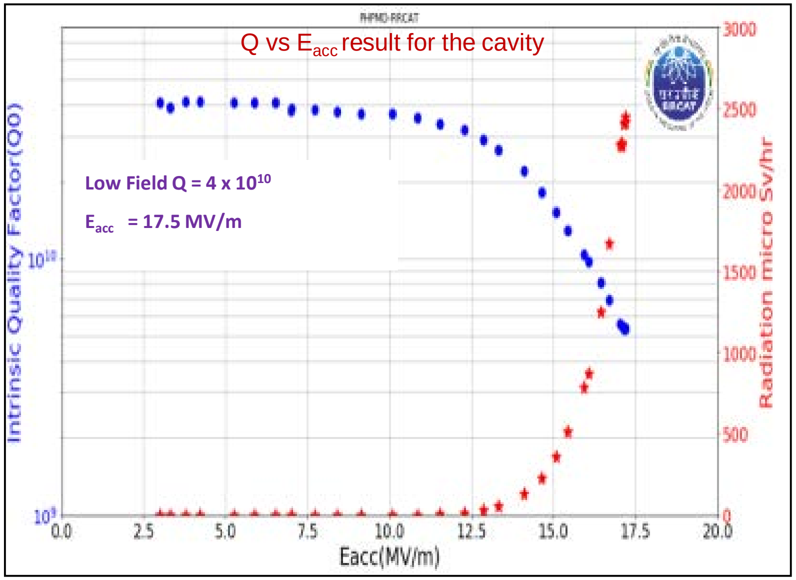
Cavity on VTS insert

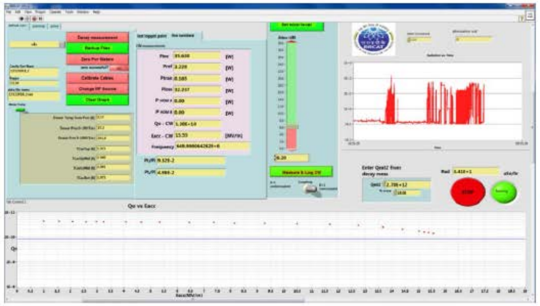
Lowering in VTS cryostat



VTS interconnections

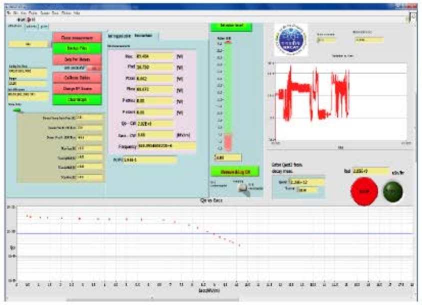
RF System and RF Controls





The cavity achieved E_{acc} = 15.5 MV/m with low field Q = 5x10^{10}

Cavity # B92A-RRCAT-501



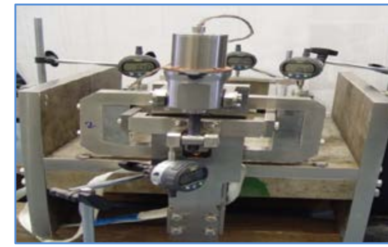
VTS test result

The cavity achieved E_{acc} = 10.1 MV/m with low field Q = 6x10^{10},

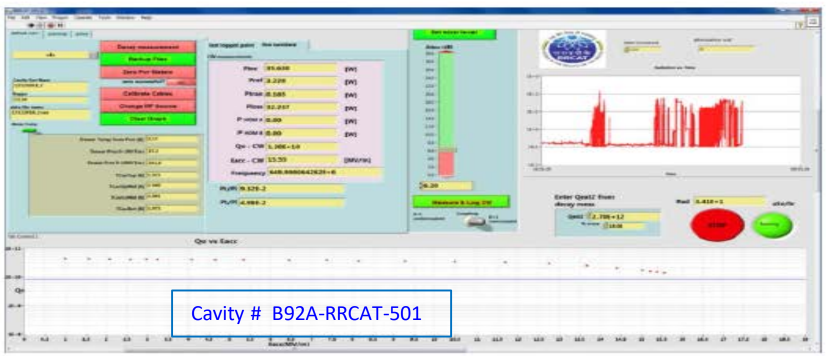
Cavity # B92A-RRCAT-502

HB650 cavities & components: Achievements

➢Four Five-cell SCRF cavities fabrication have been completed.

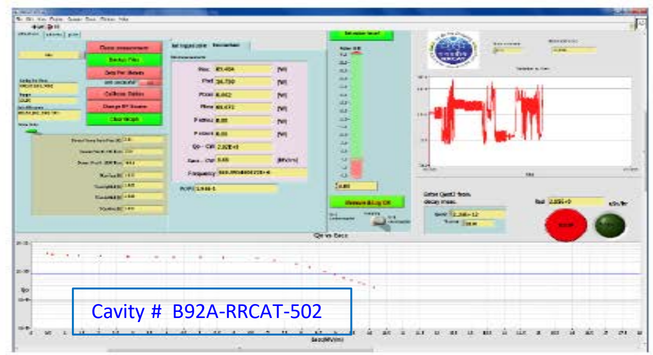


Lever Tuner – Testing and qualification up to LN2)



The cavity achieved E_{acc} = 15.5 MV/m with low field Q = $5x10^{10}$

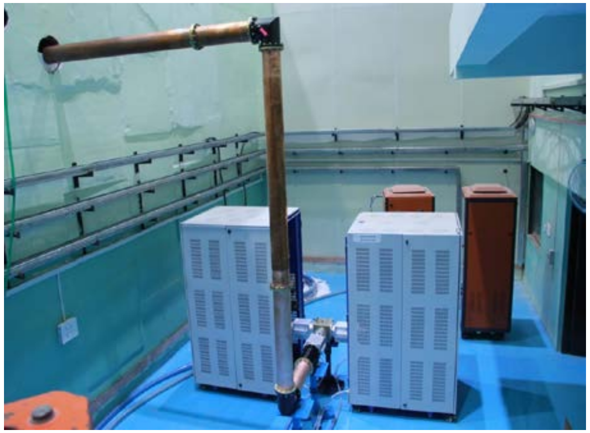
VTS test result



The cavity achieved E_{acc} = 10.1 MV/m with low field Q = $6x10^{10}$,

- Cavity # B92A-RRCAT-502 : Shipped to Fermilab
- Cavity # B92A-RRCAT-503 : Ready for VTS test after modifications in RF
- Cavity # B92A-RRCAT-504 : Under processing
- Cavity # B92A-RRCAT-501 : Preparation to dressing

Infrastructure for testing of SRF cavities HTS



HTS Cryostat, 650 MHz RF amplifier and LLRF-RFPI installed at HTS Site

Summary

- DAE created a strong base of high technologies while participating in various Mega Science Projects.
- DAE institutes have delivered crucial components, hardware and software for International Accelerator projects.
- DAE has a strong interest in HISPA technology and therefore in participation in SCRF program in PIP-II.
- Much SCRF infrastructure has been set up, technology has been developed, training in the PIP-II R&D phase.
- DAE is gearing up to augment SRF infrastructure.

Thank you for kind attention