SCRF Science & Technology and Proton Accelerator Programme at RRCAT

P. D. Gupta
Director, RRCAT

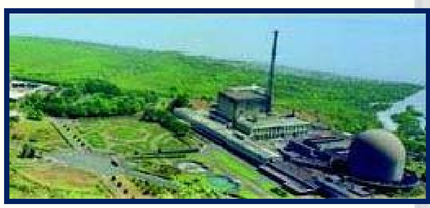
Indian Institutions and Fermilab Collaboration Meeting,
Fermilab, April 7-8, 2011

Indian Institutions in Collaboration with Fermilab

Raja Rammana Centre for Advanced Technology (RRCAT), Indore : Home for 2 SRS; Running SCRF Program Nodal DAE institute for CERN Collaboration

Inter University Accelerator Centre (IUAC), Delhi : 15 UD Pelletron & SC Booster - Nuclear Physics & Material Science.

Variable Energy Cyclotron Centre (VECC), Kolkata: Hosts Variable Energy Cyclotron; SC Cyclotron has been set up; Building RIB Facility



Bhabha Atomic Research Centre (BARC), Mumbai: Folded Tandem Ion Accelerator, Building an injector for HIPA

Raja Ramanna Centre for Advanced Technology

Inauguration of CAT by President Giani Zail Singh. Seen along with him (L to R) are—Dr. R. Ramanna, Chairman, Atomic Energy Commission; Shri P.C. Sethi, Union Home Minister; Shri Arjun Singh, Chief Minister of M.P.; Shri Bhagawat Dayal Sharma, Governor of M.P.; Shri Shivraj Patil, Union Minister for Energy; Shri Rajendra Dharkar, Mayor, Indore Municipal Corporation & Shri C. Ambasankaran, Chairman, P&IC, CAT.

Foundation Stone of (RR)CAT was laid on 19th Feb 1984, by the then President of India, Sh.Gyani Zail Singh

Prime Minister Dr. Manmohan Singh visited RRCAT on 17th Dec.2005, and renamed CAT as RRCAT.

Scientific activities commenced in 1987

Mandate of RRCAT

R & D in Accelerators, Lasers and Related Technologies & Their Applications

Staff strength 1283 **Annual Budget ~ Rs. 230 - 250 Crores (~ 50 – 55 M$)**

Core Programs

- Synchrotron Radiation Sources (Indus-1 & 2), Advanced light sources using insertion devices and FEL
- High energy proton accelerator development for SNS/ADS programs
- Smaller accelerators for societal applications (e.g. Agriculture)
- Solid state & gas lasers and their applications in different fields (Medical, Nuclear, Industrial, Laser driven fusion, Biomedical research, Non-linear optics etc.)
- Carry out R&D in materials, cryogenics, superconductivity etc.
- Collaborations in international projects

Plan of Talk

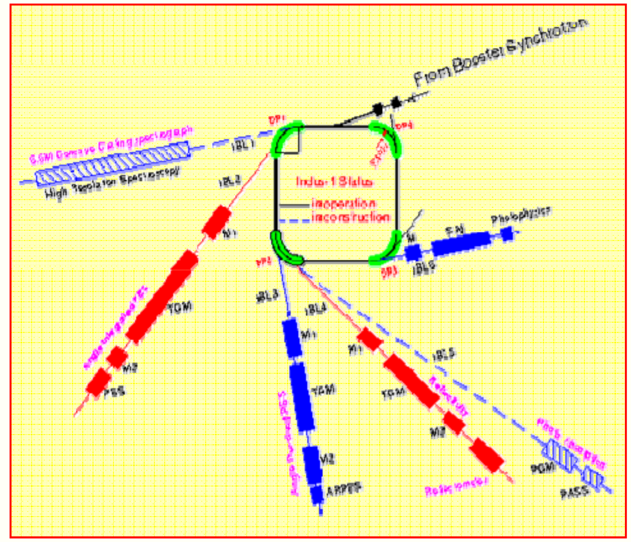
- Brief Overview of Accelerator and Laser Activities
- Development of Subsystems of Proton Accelerator
- Superconducting RF Science and Technology Programme

Brief Overview of

Accelerator and Laser Activities

Indus - 1 SRS

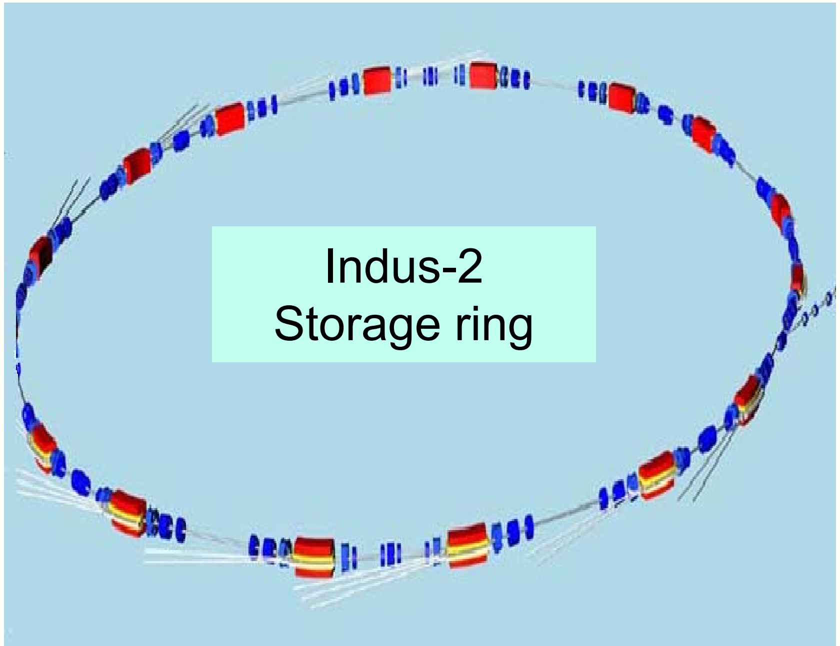
- 450 MeV, 100 mA current
- Round the clock operation
- 3 weeks operation followed by 1 week for maintenance

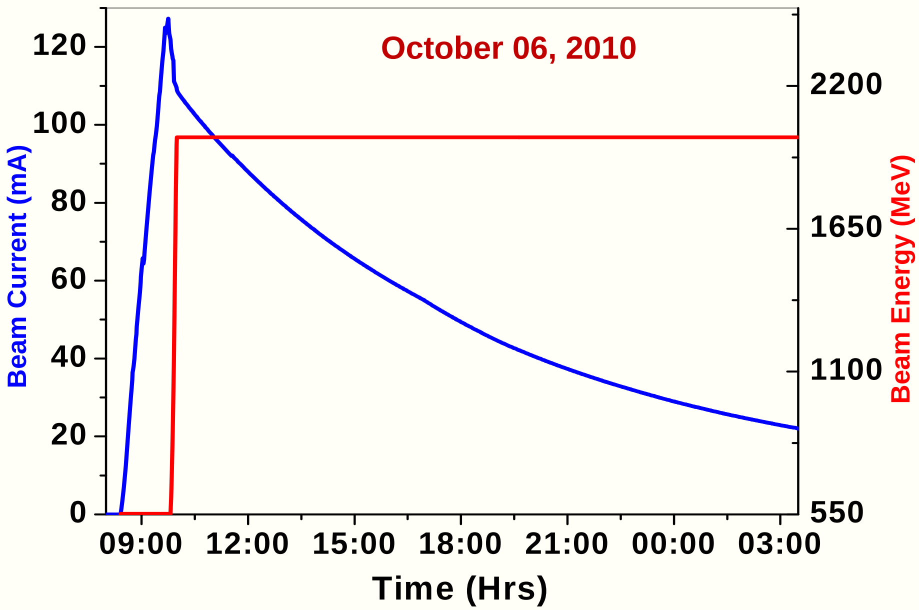


Five beamlines are operational

- Soft X-ray reflectivity
- Angle Integrated Photo Electron Spectroscopy
- Aangle Resolved Photo Electron Spectroscopy
- Photophysics
- High resolution Vacuum Ultra Violet

Indus - 2 SRS



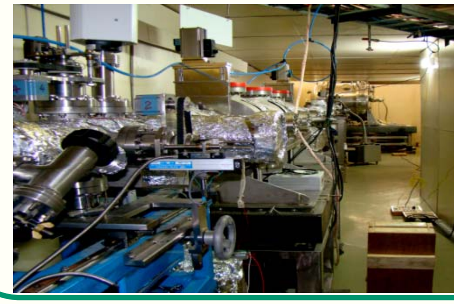


- Presently operating at 2.0 GeV, 100 mA current
- Round the clock operation
- Beam lifetime at 2 GeV, 100 mA current ~ 10 hours

Indus -2 Beamlines under Commissioning

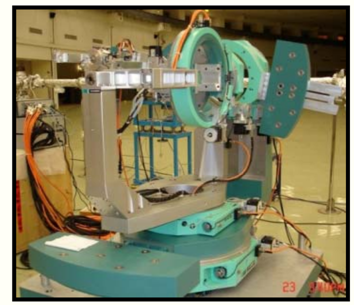
Micro-focused XRF beamline (BL-16)

X-ray PES Beamline (BL – 14)



X-ray Lithography beamline (BL-7)

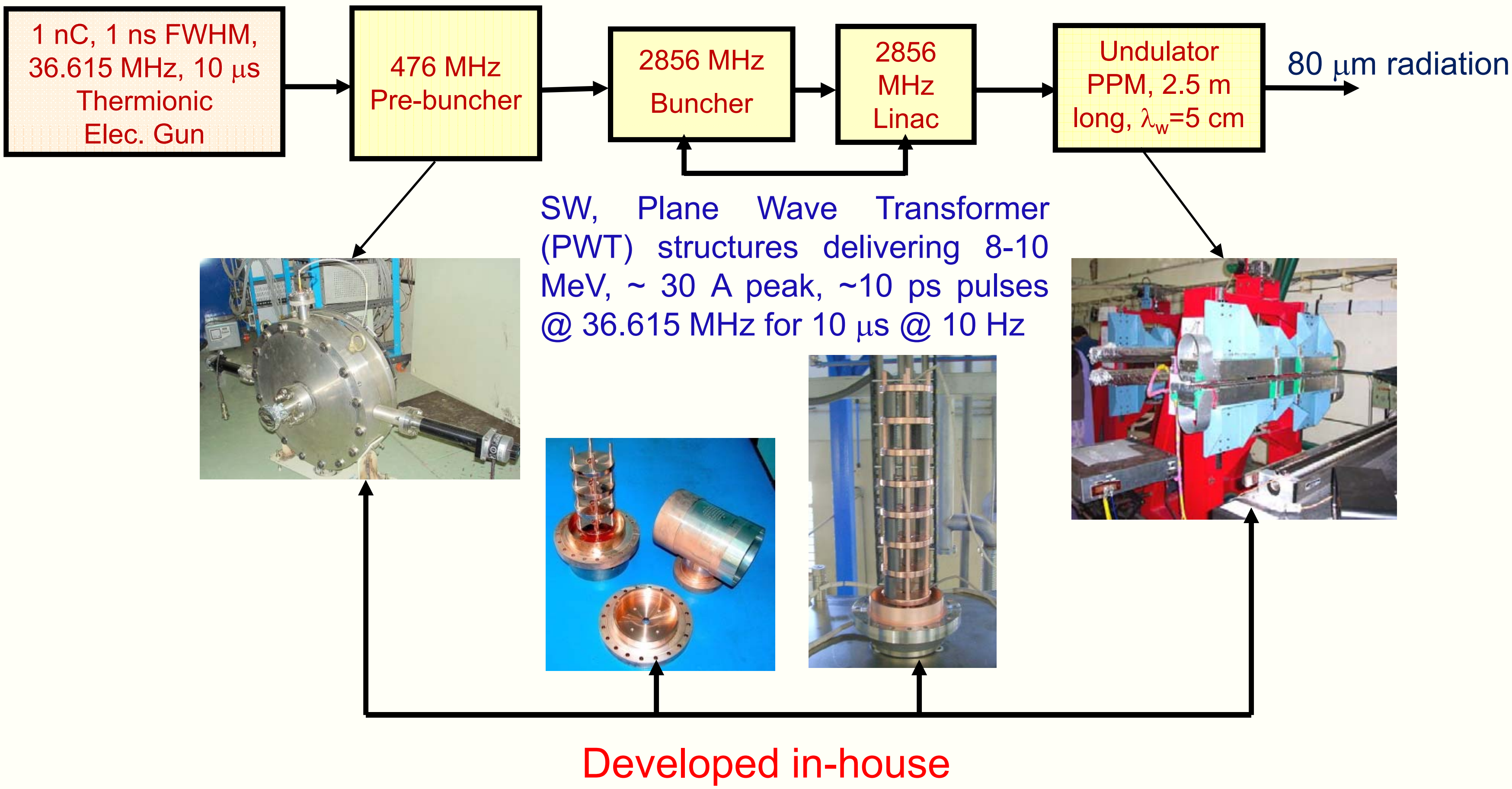
GIXS Beamline (BL – 13)



Protein Crystallography Beamline (BL – 21)

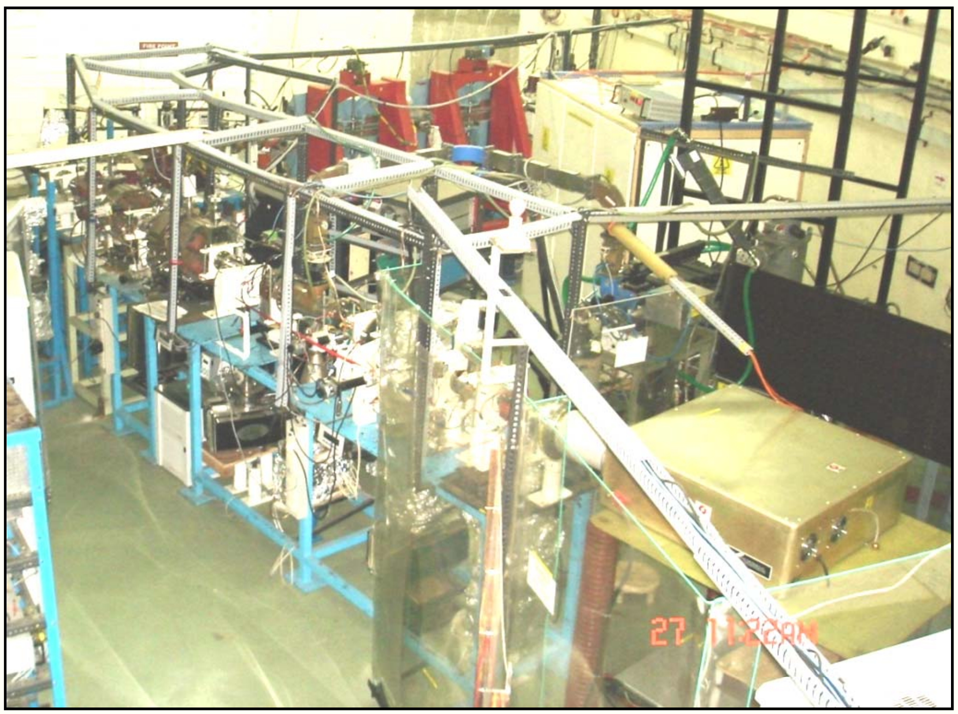
Free-Electron Laser Activity

- A compact ultrafast Terahertz free electron laser (CUTE-FEL) is presently being developed to generate radiation at 80-100 μm employing an electron linac (10 MeV) and a 2.5 m long permanent magnet undulator of 5 cm period



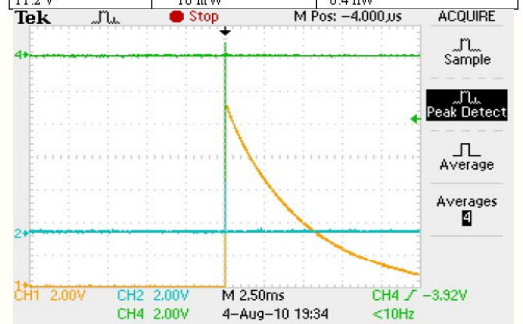
Compact Ultrafast Terahertz Free Electron Laser (CUTE-FEL) Setup

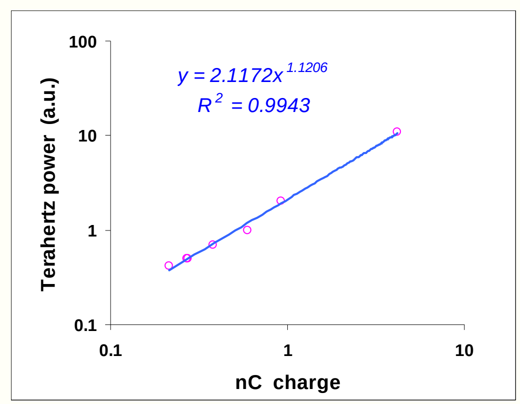
An accelerated (~ 6.5 MeV) electron beam transmitted through the 50 period, 2.5m long undulator of the CUTE-FEL setup, generated terahertz radiation that was detected using a liquid helium cooled bolometer.



THz power measurement

Output of Bolometer	Power per pulse (0.2µs)	CW average Power (@2Hz)
11.2 V	16 mW	6.4 nW

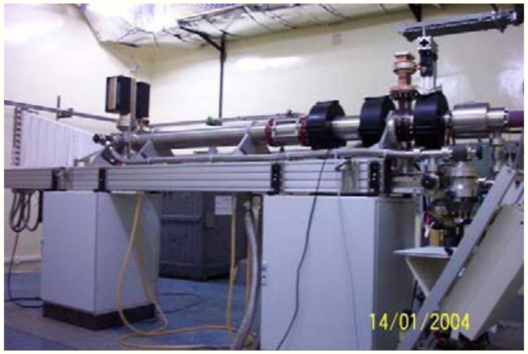




Medium Energy Accelerators for Irradiation of Food and Medical Products

750 keV DC Accelerator

Seed irradiation for disinfestation



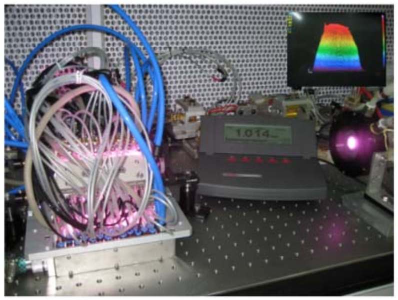
10 MeV 10kW Accelerator

Control Room

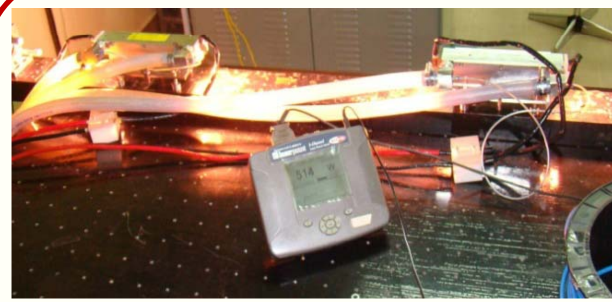
- Agricultural Radiation Processing Facility to be setup near Choithram Mandi
- Electron linacs for food irradiation applications

Development of Laser Systems

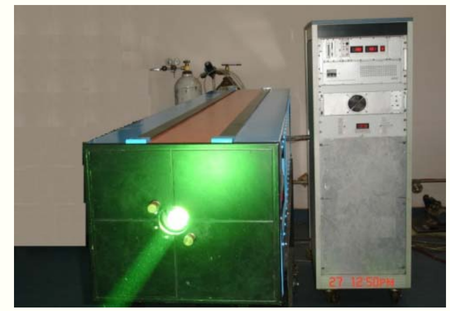
RRCAT is carrying out R&D work on lasers for various applications in the Department, Industry, Medical etc.



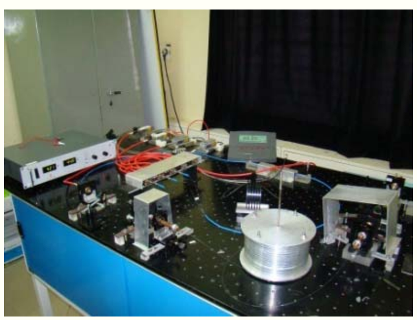
Diode pumped Nd:YAG laser with 1kW cw output power for laser material processing



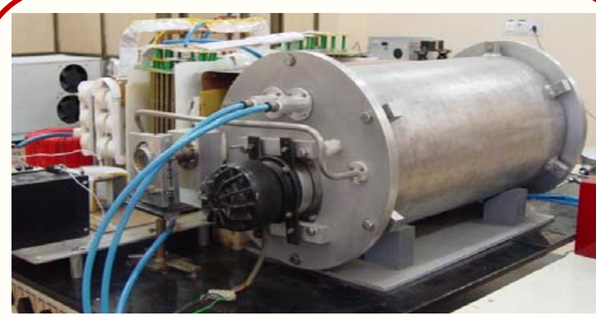
10 kW peak power industrial Nd:YAG laser for cutting of thick stainless steel components



Copper Vapour Laser With solid state pulser, 40 W, 6kHz



Fiber laser with 50W cw output power suitable for micromachining.



XeCl excimer laser (λ = 308 nm, UV region) providing 150 mJ pulses at 100 Hz rep. rate

Single mode dye MOPA system and dye oscillator giving 1.1 watt average power at 200 MHz line width

Laser Applications in Nuclear Power Programme

RRCAT has developed high power Nd:YAG lasers alongwith fiber optic delivery system with remote control operation. These are being used for various cutting and welding operations in nuclear reactors.

Laser cutting mock-up for bellow lip

Welded bellow lip

Separated bellow lip

Salient features

- MANREM reduction
- Ease in system handling
- Time saving (Cost saving)
- Reliable operation

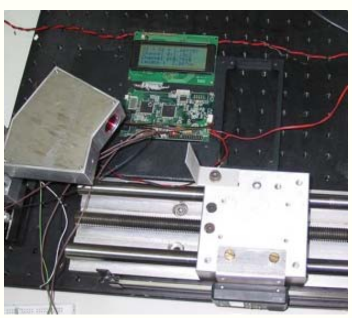
- Laser cutting of bellow lips during en-masse coolant channel replacement (EMCCR) in PHWRs
- Laser cutting of irradiated fuel sub-assembly of FBTR
- Laser cutting of pressure tubes removed from reactors during EMCCR for easy storage
- Underwater cutting of spent fuels with lasers
- Decanning of rejected fuel bundles
- Repair of leaking weld joint inside calendria

Laser Based Instruments in Nuclear Power Programme

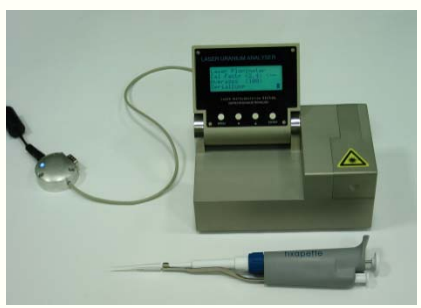
Laser Uranium analyzer for glove box use

Dip type probe tips for Pu

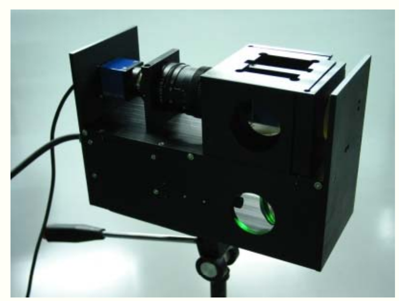
- Laser Uranium analyser (Glove box use)
- Optical dip type probes for remote plutonium measurement
- Laser scan guage for mixed carbide fuel metrology
- Fuel pellets inspection system
- Laser non-destructive testing system for structural components of reactors
- Underwater inspection head for metrology of FBTR spent fuel bundles



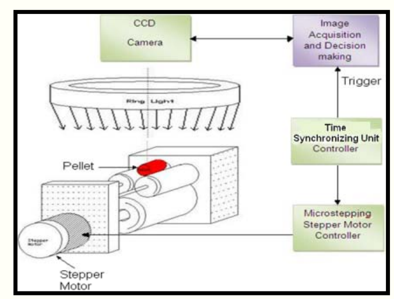
Under water inspection head



Laser Uranium analyser



Speckle shear camera



Pellet inspection system

Opthalmic Green Laser

A laser photo-coagulator developed to treat Diabetic Retinopathy and given to Aravind Eye Hospital, Madurai.

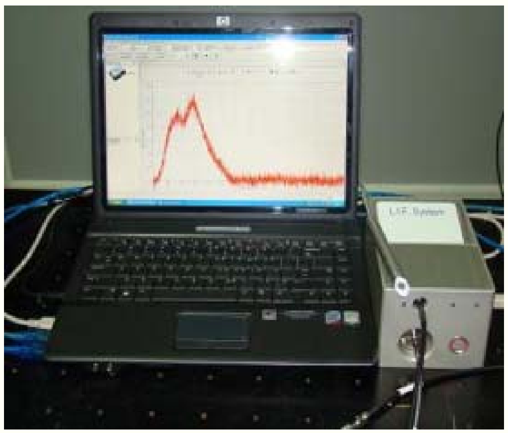
Fiber - Coupled Nitrogen Laser

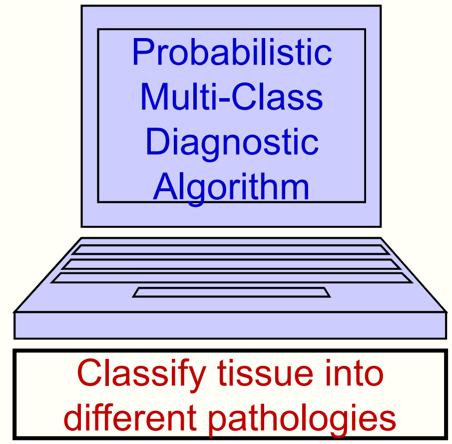
for Treatment of Tuberculosis

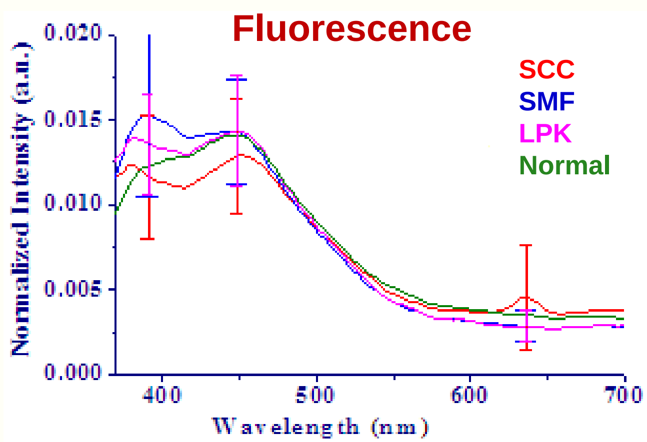
Technology for manufacture of this system transferred to Nexus Mechatronics, Pune.

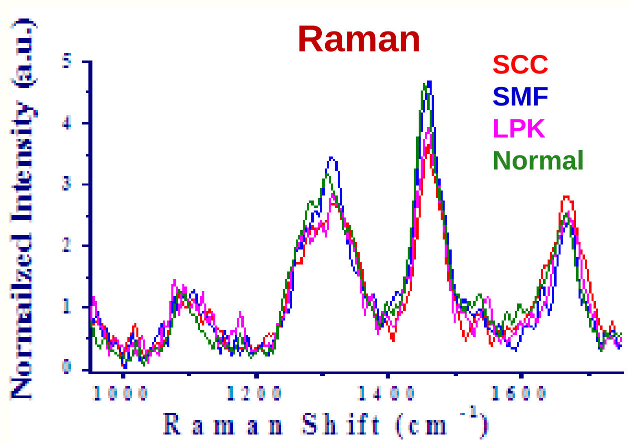
Raman and Fluorescence Spectroscopy for Optical Diagnosis of Oral Cavity Neoplasia

Comparative study for classifying oral cavity tissue into different histopathological categories







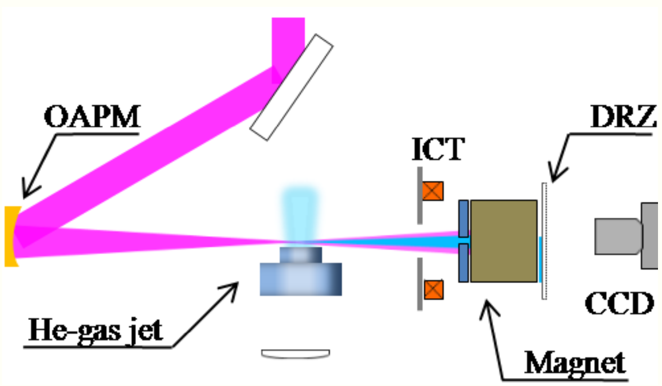


Predictive accuracy in classifying oral cavity tissues into different pathologies for fluorescence method is about 76% and that for Raman is ~ 91%

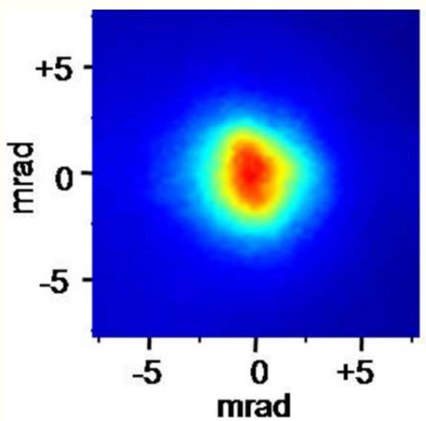
Laser Driven Electron Acceleration

Laser based electron acceleration can provide very high accelerating fields of 300GV/m as compared to only 20-30 MV/m by using standard RF technology

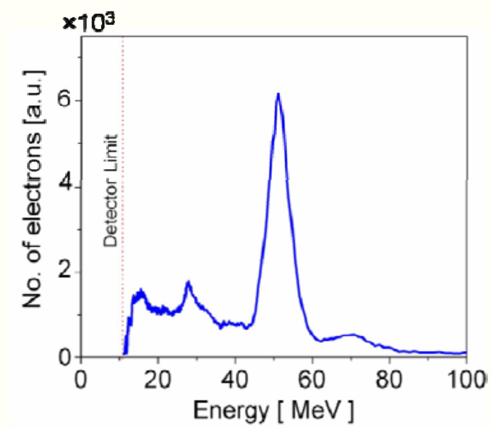
- Future accelerators may become very compact and of much less in cost
- Table-top applications : Medical isotope generation, compact synchrotron radiation sources with innovative features



10 TW , 45fs Ti:Sapphire laser



Div ~ 5 mrad

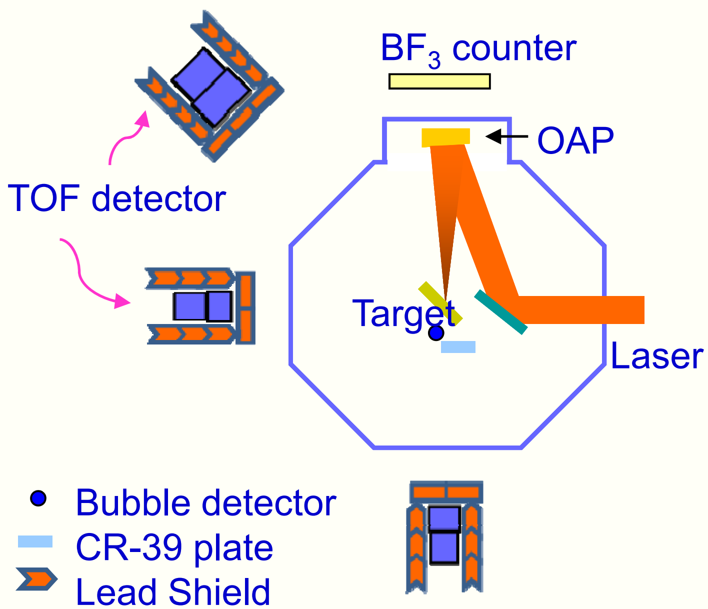


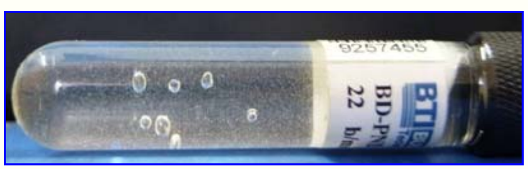
10s of pC charge in the mono-energetic beam

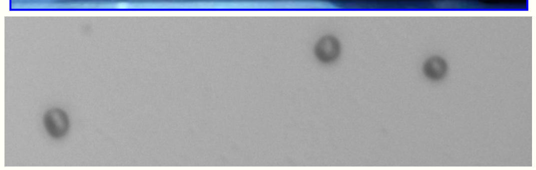
150 TW Ti:Sapphire laser lab with 1m thick concrete walls for experiments in relativistic laser plasma interaction.

Laser Driven Fusion Neutron Generation

10 TW, 45 fs Ti:sa laser irradiation of CD_2 target at ~ 2×10^{18} W/cm^2





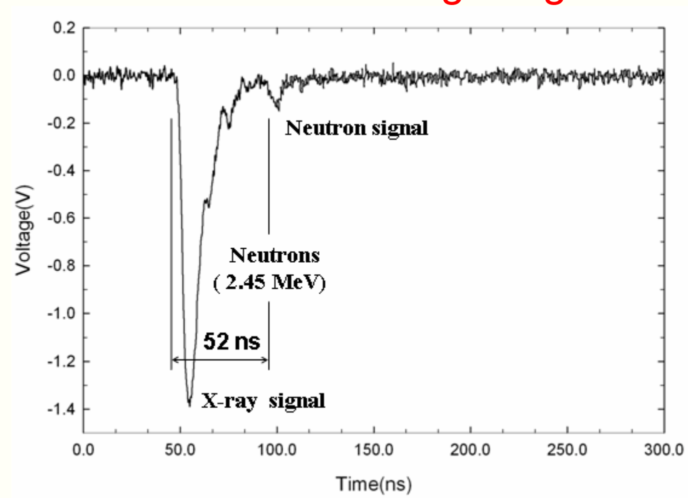


D + D ⟶ He + n (2.45 MeV)

Fusion neutrons detection using in-house developed

- Neutron time of flight detector
- CR-39 detector
- Bubble detector

Neutron Time of flight signal



About 10^4 neutrons per shot have been observed in 4π sr

DAE - CERN Collaboration

(RRCAT is the Nodal DAE Institute for this Collaboration)

- DAE has provided subsystems & skilled manpower support for LHC construction and helped in LHC commissioning. Additional help in recommissioning provided in 2009.

- Participation in CERN's Novel Accelerator Projects :
  - Compact Linear Collider (CLIC)Test Facility CTF3
  - Linac-4, the front end of Superconducting Proton Linac (SPL)

Major DAE Contributions to LHC

Corrector Magnets
(616 MCDO & 1146 MCS)

Quench Heater Power Supply
(QHPS) HDS units 5500

Local protection units
(LPU) 1435

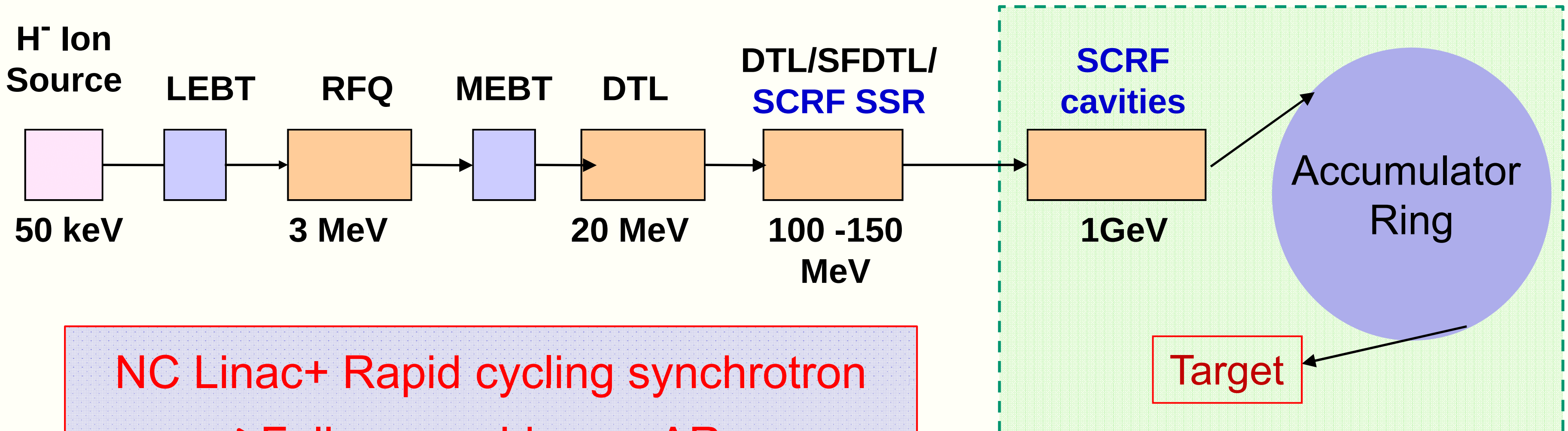
Precision Magnet Positioning
System PMPS 7080

- **Support for LHC hardware commissioning 20 Man years**
- **Expert support for SC Dipole magnet measurements 100 Man years**

Development of Sub-systems of Proton Accelerator

- A long term program on setting up of a 1GeV Proton Accelerator is envisaged for the development of a Pulsed Spallation Neutron Source

Schematic of 1 GeV pulsed proton linac for SNS



NC Linac+ Rapid cycling synchrotron
→ Full energy Linac + AR

- Super conducting RF cavity technology development.
- Development of low energy front end part (H^- ion source, 3 MeV RFQ).

Development of Frontend Components

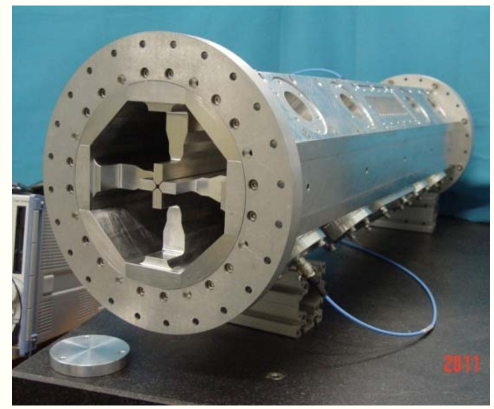
Plasma chamber for H- ion source

NdFeB magnets for generating multi-cusp field geometry

Beam extraction chamber

This will house beam extraction electrodes

First segment of prototype 352 MHz RFQ



Fabricated in Al to validate the design

SCRF Science and Technology Programme at RRCAT

For any large scale programme of building high energy proton accelerators for ADS/SNS and various other possible applications, it is essential to develop necessary technologies for the various building blocks involved

- Pursuing a comprehensive programme for design & development of SCRF cavities, cryomodules and related infrastructure

- Involved in international collaborative programmmes with mutual scientific benefits

Memorandum of Understanding between US Universities and Accelerator laboratories and Indian Universities and Accelerator laboratories

concerning collaboration on R & D for Accelerator Physics and High Energy Physics Projects (JAN 09,2006)

Addendum 1: "Fermilab, RRCAT, BARC, IUAC and VECC Collaboration on ILC Main Linac SRF Accelerator Technology R&D" (August 20, 2007)

Addendum 2: "SLAC, RRCAT, BARC, IUAC, and VECC collaboration on ILC RF-power sources and beam dump design R&D" (December 3, 2007)

Addendum 3: "Fermilab & Indian Accelerator laboratories colaboration on High intensity Protron Accelrator and SRF Infrastructure development" (February 10, 2009)

Different Facets of SCRF Programmme at RRCAT

- **Superconducting Materials**
  - Materials R & D for SCRF application
  - Characterization of indigenously developed materials
- **SCRF Cavity & Infrastructure Development**
  - Physics design
  - Cavity fabrication
  - Cavity processing and test facilities
- **Cryogenic Engineering & Infrastructure**
  - Cryogenic infrastructure development
  - Test stands for SCRF cavities
  - Cryomodule design and prototyping
- **RF Technology Development**
  - RF power infrastructure
  - CW RF power amplifiers for SCRF cavities

Superconducting Materials R&D

Superconducting Materials R&D at RRCAT

Overall Aim

- Superconducting properties of Niobium material for fabrication of an energy efficient and cost effective SCRF accelerator structure.
- Achieving reliability and reproducibility in the SCRF cavity performance.
- Gain knowledge and experience to venture into newer energy efficient and superior superconducting materials.

Qualification of Nb Materials for SCRF Cavity Fabrication

- All cavities fabricated in the same way do not give high gradients and cavity gradients are often way below theoretical maximum ~ 55 MV/m
- High residual resistivity ratio (RRR) Nb material is used for SCRF cavities. However it is found that superconducting properties of Nb may get affected / limited during fabrication and processing of the cavities.

An improved materials qualification scheme shall include H_p (first penetration of field line) and R_S (RF surface resistance) since these set limits on achievable SCRF accelerating gradients.

[S. B. Roy et al. Superconducting Science and Technology 21, 65002 (2008) and 22, 105014 (2009)]

Points we are examining (in Nb & other SC materials)

Role of H_P and R_S how they may be varying with,

- the methods of materials preparation, grain size ?
- the surface chemical treatment of Nb: Electropolishing versus BCP ?
- thermal treatment -- annealing temperature and time ?

Our study is based on various types of Nb materials coupons obtained from Jefferson Lab., IUAC, New Delhi and Fermi Lab.

We try to simulate the actual SCRF-Cavity conditions on the small samples:

Same chemical, thermal, mechanical treatments and also controlled welding.

Some Results of Magnetic Measurements of Superconducting Nb-Materials

- Effect of BCP treatment (samples from J Lab)
  - BCP treatment lowers the field at which magnetic flux lines enter the material as compared to that in pristine Nb.
  - RF cavity prepared with such BCP Nb would reach maximum 30-32 MV/m
- Effect of EP treatment (samples from IUAC)
  - Effect of EP treatment on SC properties of Nb is rather small. EP treatment is therefore preferable for handling Nb cavities.
- Effect of Ta impurities (samples from J Lab)
  - Higher Ta impurity only marginally affects SC properties. A less refined Nb material may be deployable for cavity applications, provided the inclusions of Ta does not influence the surface conductivity of Nb significantly.

Development of Thin Film Nb-Materials for Nb-coated Copper RF Cavity

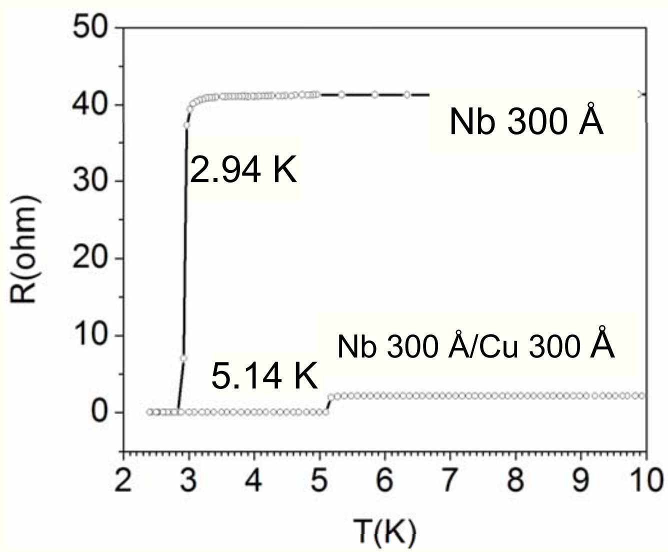
- Combining superconductivity of Nb with much higher thermal conductivity of Cu
  - Better thermal stability (resistance to "quench") due to much higher thermal conductivity of the OFHC copper.
  - Reduction in materials cost (Cu is cheaper than Nb)
- Best Nb/Cu cavities (at 1.7 K) have reached maximum gradient of 15 MV/m (with Q dropping below 10^{10}), which is much less than bulk Nb cavity gradient of 40 MV/m.
- Studies to compare superconducting properties of Nb thin films with bulk Nb, and investigate methods of improvement.

Superconducting Properties of Nb Thin Films

Nb thin films on Si substrate	Nb/Cu bilayer on Si substrate

- Nb thin films grown by ion-beam sputtering
- Studies carried out on variation of superconducting properties w.r.t. thickness of the film and their comparison with properties of bulk Nb.

Electrical resistivity measurements



Sample	***T_c (K)***
Nb 300 Å	2.94
Nb 400 Å	3.84
Nb 700 Å	4.84
Nb 1000 Å	5.04
Nb 300Å / Cu 300 Å	5.14
Nb 400Å / Cu 300 Å	5.74
Bulk Nb	9.2

- Optimization of grain size of Nb materials, surface/interface roughness in Nb/Cu bilayers, preparation of films by different techniques.

Indigenous Development of Nb for SCRF Application

NFC, Hyderabad

- Development of material, testing of mechanical properties

RRCAT, Indore

- Electrical, Superconducting properties, Elemental analysis

- RRR is ~ 100
- Size 300 mm x 2.8 mm thickness
- Suitable for 1.3 GHz Cavities
- SC properties acceptable
- Hardness ~ 100 Hv (need < 50Hv)
- Purity / Chemical composition
  C,O,H,N ~ 125 ppm (need<32 ppm)

Indigenous Niobium sheets, 3.9 GHz half cells formed at Fermi lab

SCRF Cavity & Infrastructure Development

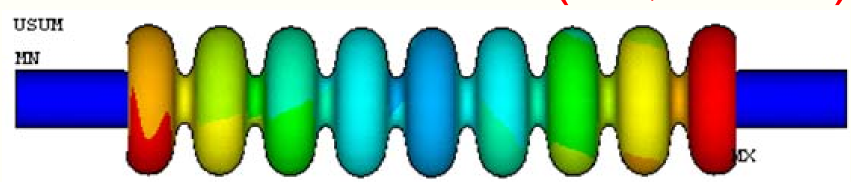
Major activity under IIFC

Physics Design

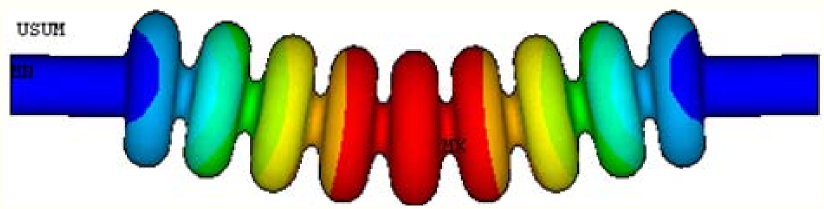
Design Simulations of SCRF Cavities

- Carried out 2-D and 3-D electromagnetic simulations of multi-cell β=0.81 cavities at 1.3 GHz using SUPERFISH, CST and ANSYS.
- Lorentz Force Detuning (LFD) has been studied. The effect of sag and stiffeners on LFD has been simulated for the 1.3 GHz, β=0.81 cavities.

Simulation Results (3D, 9 cell)



⇨ Lorentz force only (+50 Hz)



⇨ Sag + Lorentz force (+188Hz)

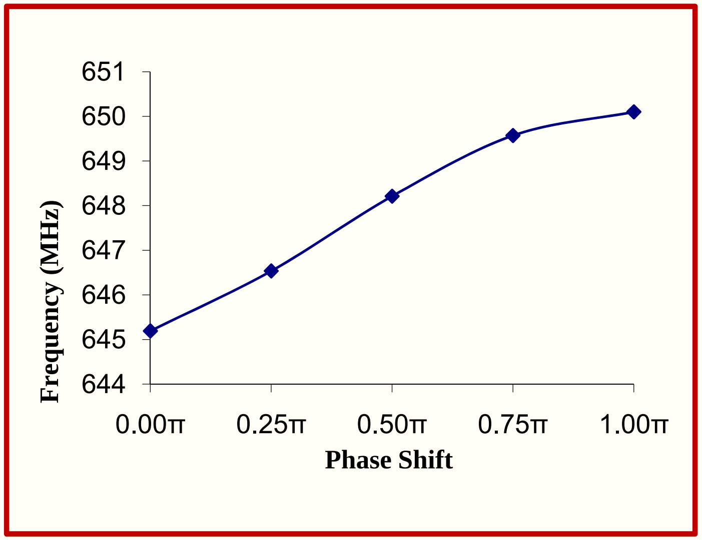
- Comparison was made with results of 2-D LFD analysis at FNAL using SLANS

Another recent study

Effect of deformation in the cavity geometry at the time of forming on frequency shift in 1.3 GHz, β = 0.9 cavities was analytically studied and results compared with simulations using ANSYS

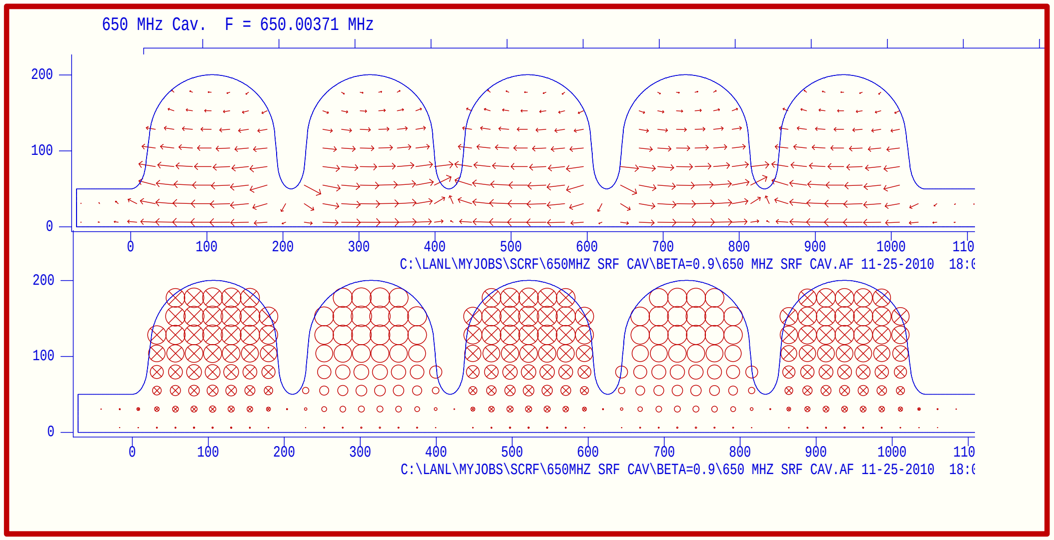
Design simulation of β=0.9, 5-cell, 650 MHz SRF cavity

- 2D (SUPERFISH) simulations done for β=0.9, 5-cell, 650 MHz cavity



Dispersion diagram

(Coupling coefficient $(k) \sim 0.76$)



E and B field configuration [for π mode]

(π mode configuration; field flatness ~ 94.2%)

- Reasonably good agreement obtained with SLANS simulations at FNAL

Accelerator and Beam Physics Activity

- Physics design of RFQ
- Physics design of beam transport lines (LEBT, MEBT)
- Physics design of DTL
- Electromagnetic design and beam dynamics studies of superconducting elliptic cavities
- Physics design of synchrotron/ accumulator ring

A group of accelerator physicists are working on the above issues.

Cavity Fabrication

Development of 1.3 GHz, $\beta = 1$ SRF Cavity Forming and Machining of Half Cells 2008-2011

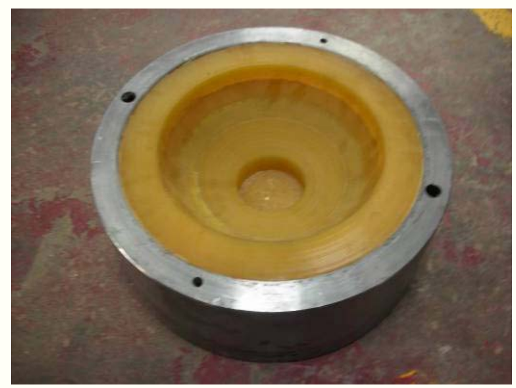
Half Cell Tooling (Aluminum alloy 7075-T6 from Fermilab)

Forming process

Machining

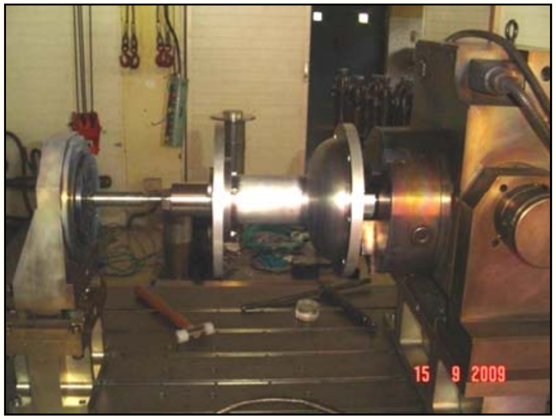
Inspection on CMM

Formed Niobium Half cell



Improvement - rubber pad forming tooling completed

Stages of Cavity Manufacturing & In-Process Qualifications

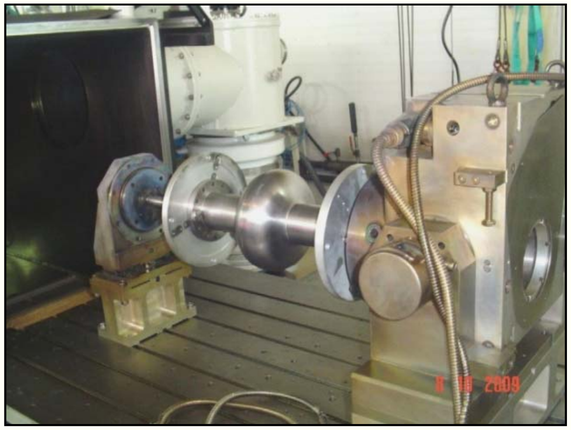


Outside iris welding

Equator trimming

Frequency measurement

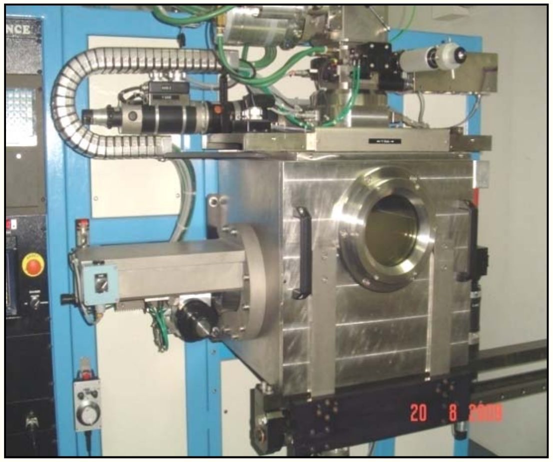
Mechanical inspection



Final equator welding

1.3 GHz Prototype Single cell Aluminum Cavity with Industry

- Our technology development efforts started with Aluminum prototype cavities
- This has helped us to
  - Develop cavity manufacturing process
  - Test & qualify the welding fixtures
  - Understand various mechanical & RF qualification procedures
  - Aluminum cavities are now becoming potential candidate for thin film deposition R&D



EBW Machine : 6 kW, 60 kV,
450 x 450 x 500 mm chamber size,
Vacuum < 5 x 10e-05 m-bar

M/s Laxmi Technology &
Engineering Industry Coimbtour

Prototype Aluminum cavities

1.3 GHz Single Cell Cavity Prototype in Niobium

IUAC EBW machine

RRCAT-IUAC Team members with First 1.3 GHz Single cell cavity

Beam Power – 15 kW, 60 kV, 250 mA
Chamber 2.5 m × 1 m × 1 m

The present EBW facility is not adequate to accommodate 1.3 GHz 9-cell / 650 MHz 5-cell cavity. This will need some modification.

1.3 GHz Single Cell SCRF Cavity R&D @RRCAT

Three different types of prototype Single cell cavities developed in stages

Inspection & Testing

The cavities underwent various testing as part of pre-dispatch qualification

Dimensional measurement

Frequency measurement

Leak testing of Single cell cavity at 300 K

Leak testing of Single cell cavity at 77 K

Prototype 1.3 GHz Single-Cell Cavities to Fermilab

The cavities were dispatched to Fermilab for processing and testing at 2K for performance evaluation

Processing & Testing at Fermilab and ANL

The two prototype single-cell cavities underwent a series of processing stages before finally tested at 2 K

Electro-polishing

Centrifugal barrel polishing

High pressure rinsing

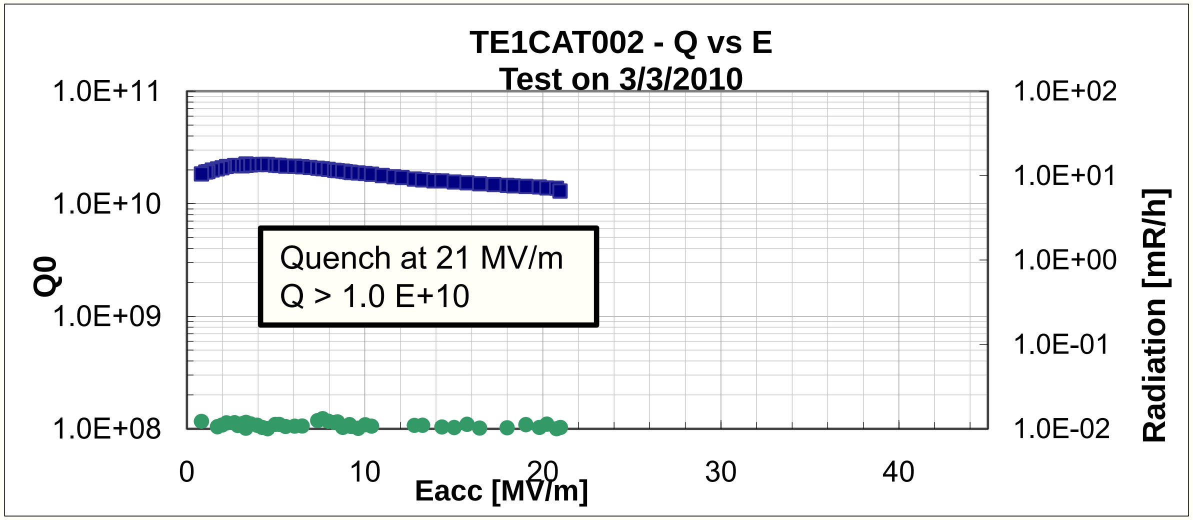
Heat treatment

Centrifugal barrel polishing at FNAL

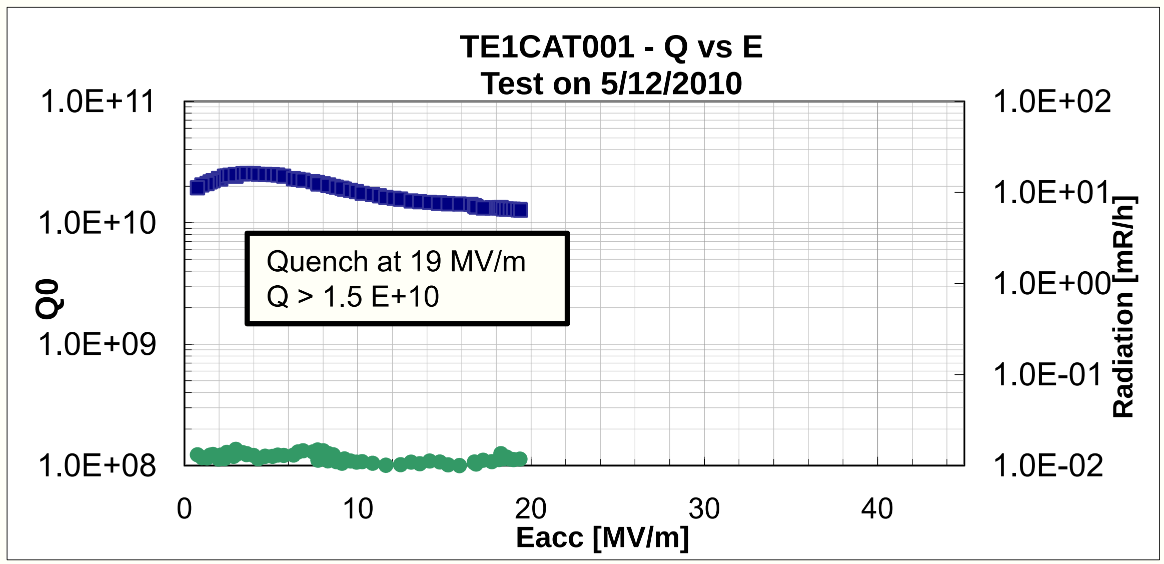
Electro-polishing at ANL

Cavity connection vacuum & RF

2 K Test Results



1.3 GHz Single cell
Prototype cavities



Cavity TE1CAT002 was quench-limited to 21 MV/m.

TE1CAT002: Second Processing 2 K Test Results

2nd set of processing

- CBP
- Light EP ~ 20 μm
- HPR   85 bar for 6 hrs
- Clean room assembly
- Low temperature backing 120 C - 48 hrs

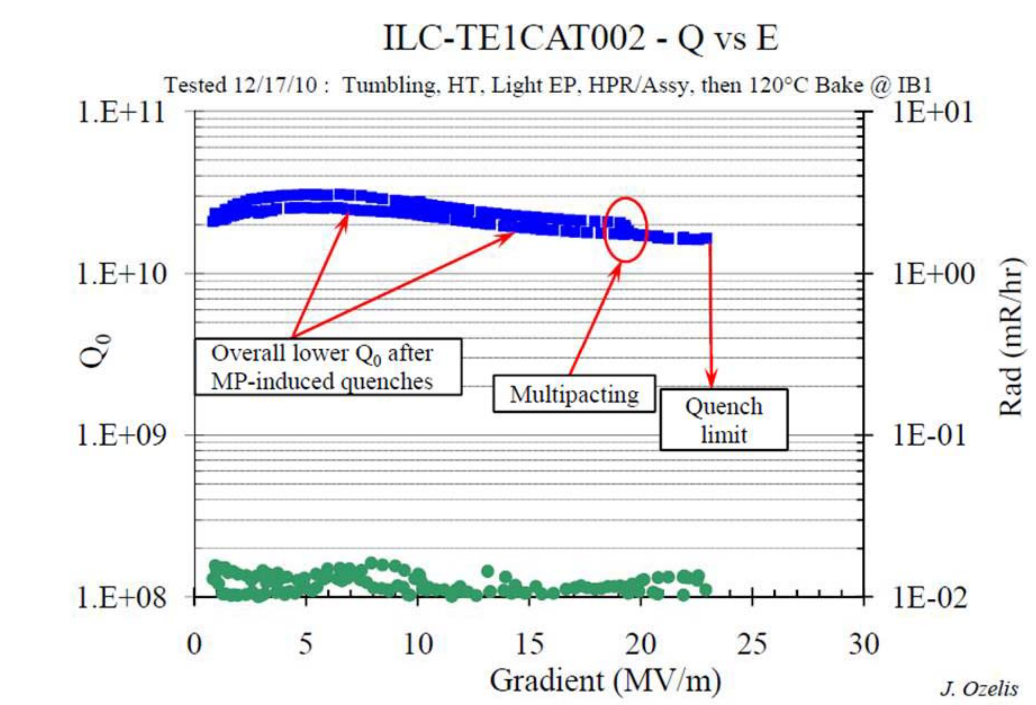


Figure 1. Q_0 vs E @ 2K.

(E_{acc}) of 23 MV/m at quality factor (Q) > 1.5E10   (17 Dec 2010)

More 1.3 GHz Single SCRF Cavities

- 3rd Single cell cavity has also been completed
  - Made with improvements based on the experience gained during first two prototype
- After all pre dispatch qualification it is now getting ready for shipment to FNAL.

- Parts for the 4th have been sent to IUAC Delhi for e-beam welding

Moving Towards 650 MHz β = 0.9 SCRF Cavity

Work Plan

- Process improvement
  - 1.3 GHz β = 1 single-cell cavity (2 Nos.)
- Capacity building
  - 1.3 GHz β = 1 multi-cell cavity
- 650 MHz β = 0.9 cavity
  - Single-cell cavity : Q4 – 2011
  - First 5-cell cavity : Q4 – 2012 (Q1–2013)
  - 4 + 1 spare, 5-cell cavities : Q2 – 2014

Forming of 650 MHz , β=0.9 SRF Cavity Half Cells

- Work is based on cavity shape received from Fermilab in June 2010.

650 MHz cavity forming dies
(Material Aluminum alloy 6061 – T6)

Prototype formed half cell in Aluminum (March 2011)

- Design of prototype forming dies, in-house manufacturing, CMM Inspection and forming trials in aluminum were done.
- Next step is to fabricate half cell in Nb

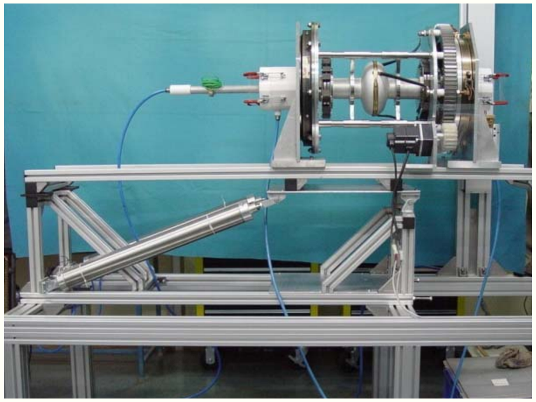
SCRF Infrastructure

Infrastructure for SCRF Cavity Development

Infrastructure installed

- Electro-polishing setup
- Centrifugal barrel polishing machine
- High pressure rinsing
- Cavity forming facility

Cavity forming facility



Electro-polishing setup

Centrifugal barrel polishing machine

High pressure rinsing Set up

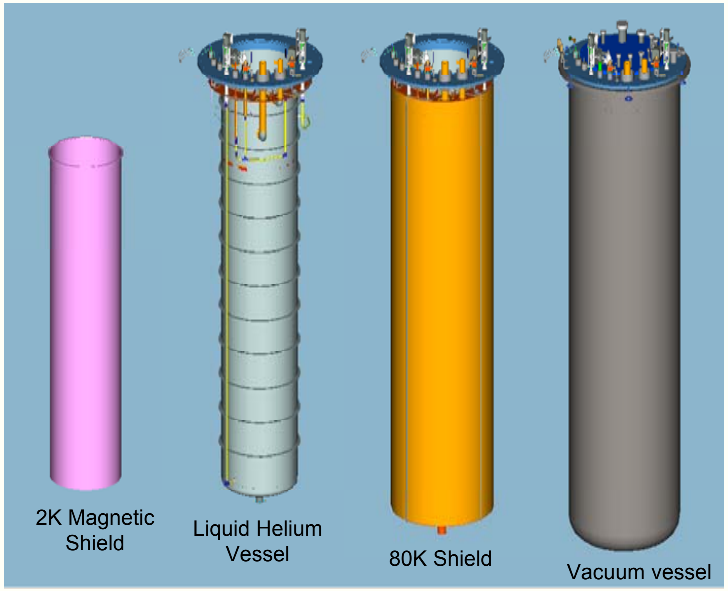
Infrastructural Work In Progress

Infrastructure being set up

- Clean room (class 10000 to 10)
- Electron beam welding machine
- High vacuum annealing furnace
- Cavity machining facilities
- CMM, SIMS etc
- Building construction nearing completion (area 70m x 20m)

Development of Vertical Test Stand

A VTS-2 has been designed in collaboration with Fermilab for testing of the following cavities at 2 K :



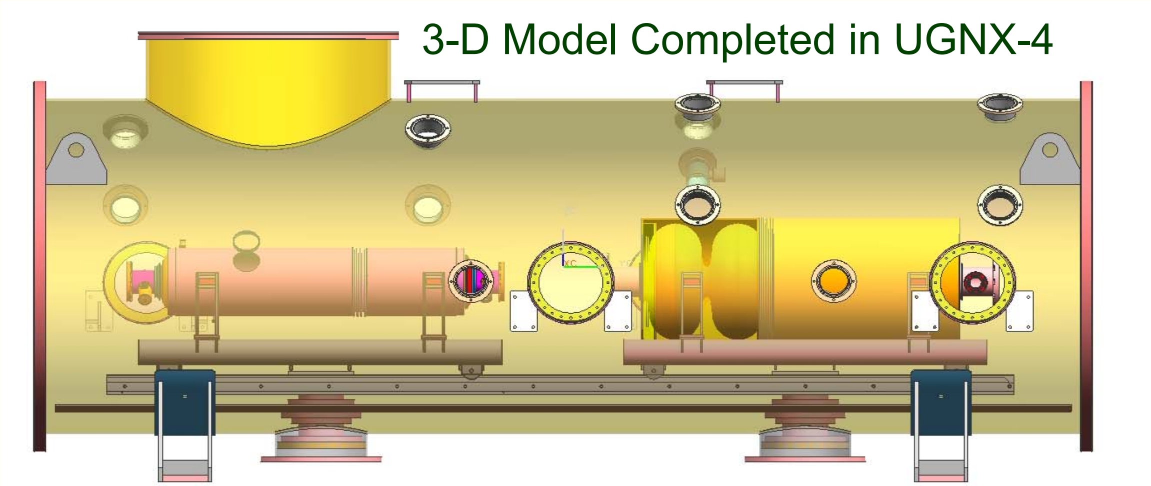
3-D Models of VTS-2 Vessels

- Single & multi-cell SCRF cavities
- Single spoke resonator cavity 325 MHz
- Triple spoke resonator cavity 325 MHz
- Two VTS cryostats for Fermilab and one for RRCAT are under fabrication by a US vendor under joint supervision

- RF and DAQ for VTS underway, Building under construction
- Commissioning at RRCAT December 2011

Horizontal Test Stand (HTS-2)

Design and development work of a horizontal test stand has been taken up in collaboration with Fermilab



Functional requirements

- Capability to test two dressed cavities at a time but separately.
- Testing of both 650 MHz and 1.3 GHz cavities.
- Throughput of 4 cavities in 6 weeks.

An important aspect of this effort is the improvements in design based on operational experience of HTS at Fermilab

Cryo-Engineering & Infrastructure

Helium Cryogenic Facility

Linde, UK, Model TCF20
Capacity 40 L/hr,
Installed in Year 2000

Helium gas recovery system uses locally made gas bags and gas recovery compressor

- It has produced more than 300,000 litres of liquid helium.
- Helium gas recovery arrangements in Indus Complex will be ready within one year, facilitating experimentation using liquid helium on Indus beamlines.

Superconducting Corrector Magnets for LHC

- Under DAE-CERN collaboration 1850 superconducting corrector magnets for LHC, prototype developed & qualified .
- Warm magnetic measurement at 300 K and Cryogenic testing at 4 K.
- Uninterrupted supply of Cryogens was made available for 3 years
- Liquid Nitrogen: 3,50,000 Liters, Liquid Helium : 2,10,000 Liters

Cryocoolers Development

- G-M cycle based cryocoolers have been indigenously developed for various scientific applications

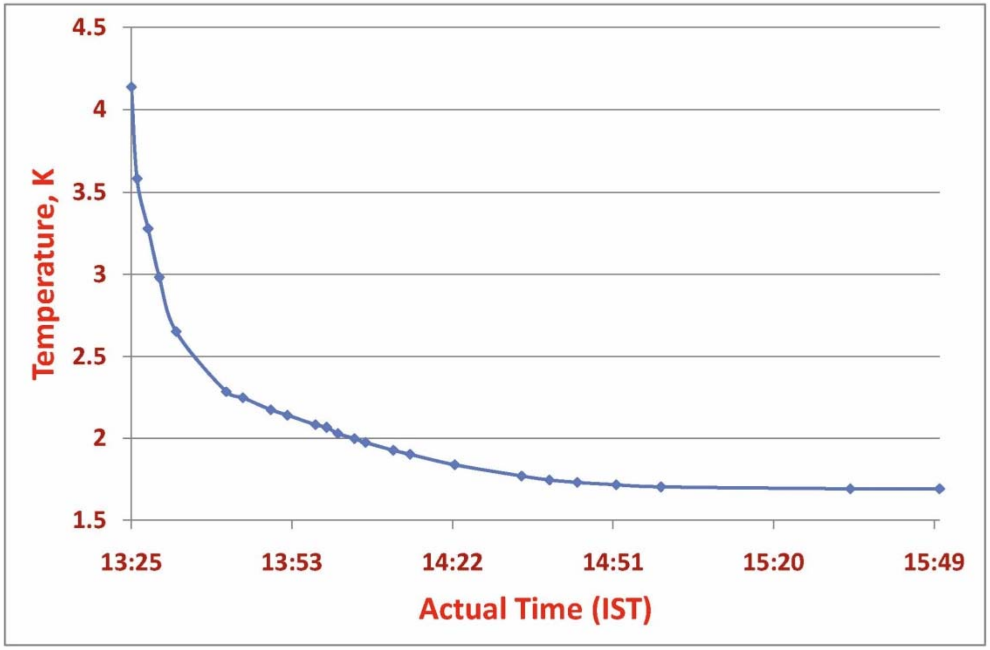
30 K Cryocooler

10 K Cryocooler expander designed for experiments at Indus

- 30 K cryocoolers have cooling capacity of 3 W at 30 K to 20 W at 50 K
- 10 K cryocooler has cooling capacity of 1.5 W

Development of 2 K Cryostat

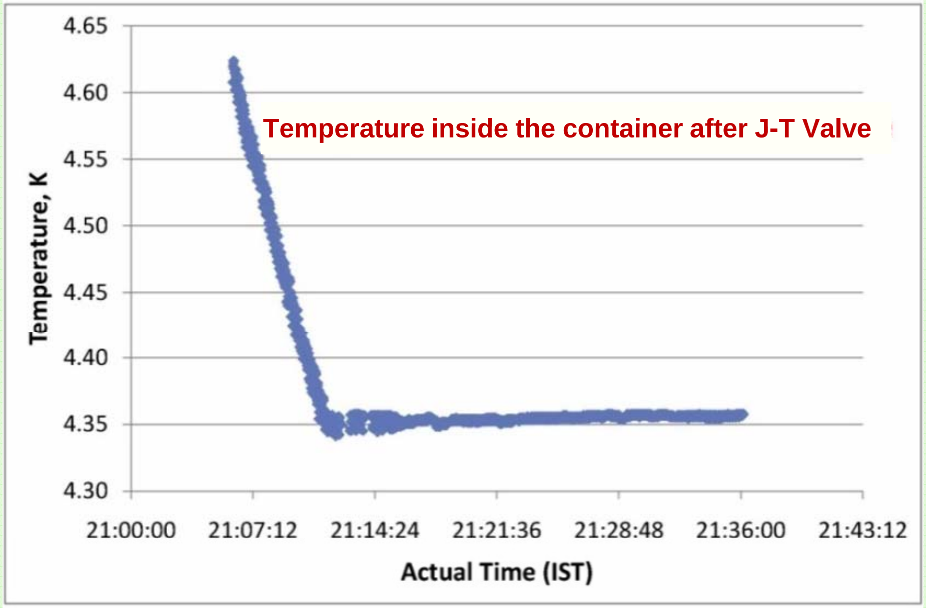
A saturated bath type 2 K cryostat has been indigenously designed, built and commissioned



The cryostat has a working volume of cylinder of 200 mm dia and 200 mm height. It is being used for temperature sensor calibration down to 1.7 K

Indigenous Development for Helium Liquefier

Helium liquefaction achieved for the first time in the country using indigenously developed system



- Produced more than 150 litres of Liquid Helium in its maiden run, with an average liquefaction rate of 6 lit/hr.

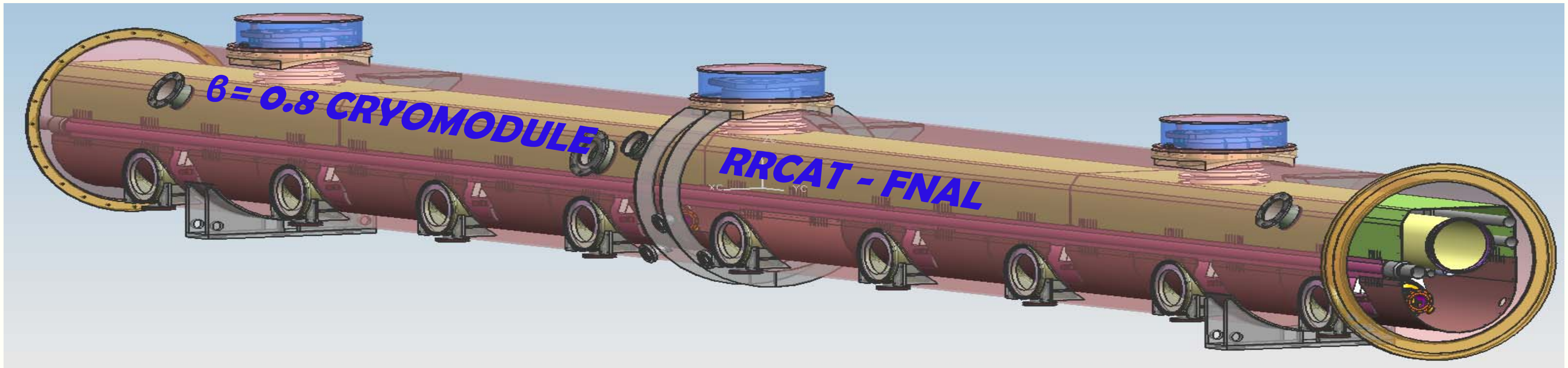
Cryomodule for SCRF Cavities

Efforts initiated in 2008

- Indian engineers visited Fermilab to witness assembly of cryomodule CM1, and proposed certain value engineering concepts at Fermi Lab and TTC meeting.
- Next the design of 1.3GHz Beta=0.8 cryomodule was taken up.
- Due to changed Project-X configuration, the cryomodule design goal was switched to a CW cryomodule for 650MHz cavities

Design of Beta=0.8 Cryomodule

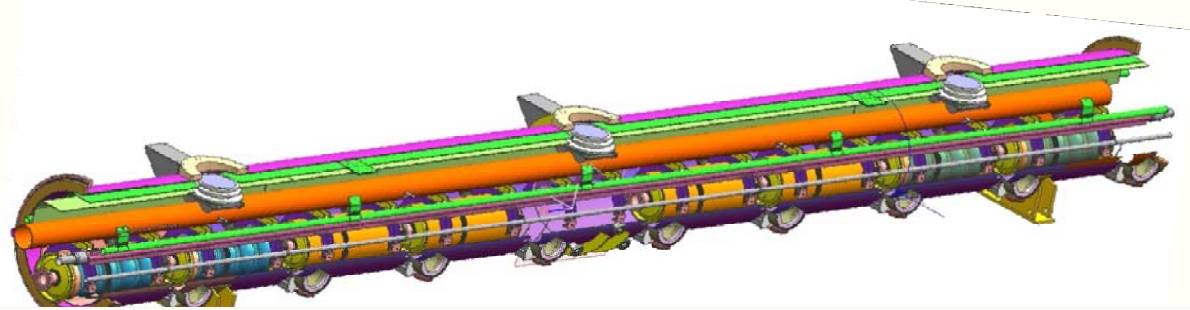
- Vacuum Vessel engineering Design note prepared
- Cavity support system analysis was completed
- 3-D Model was completed.



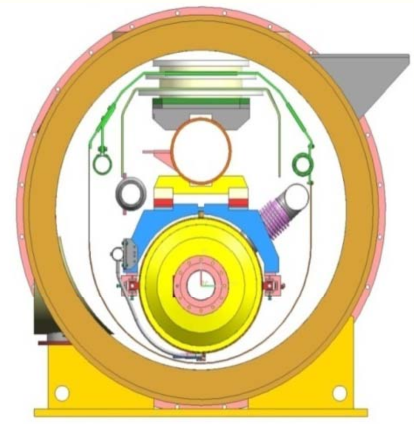
This gave good design experience to the team.

Design of Beta=0.6 & 0.9 Cryomodule for 650MHz Cavities

- Design effort progressing smoothly
- Major specifications of the cryomodule have been ascertained
- Engineering design has made considerable progress for vacuum vessel, thermal shield,cavity support system etc.



Cut Section of Cryomodule & subsystems



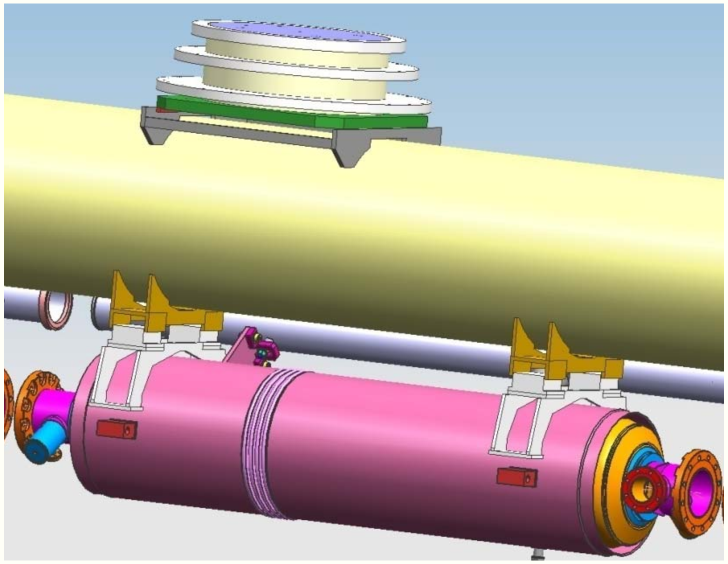
❖Unique Features of 650MHz standalone cryomodule

Thermal load of 250W cryomodule (about 10 times of Tesla type)

Diameter of 650MHz cavity is 400mm ~ 2 times of 1.3GHz cavity.

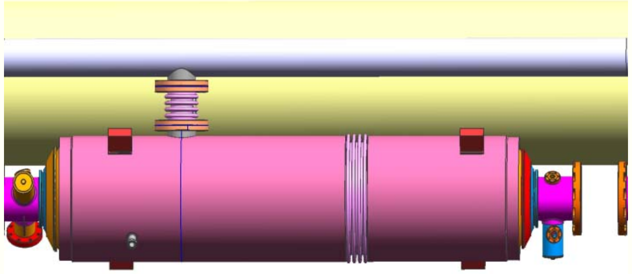
Some Newer Concepts for Better Functionality and Lower Cost

(Presented at Tesla Technology Collaboration meet)



Alternate cavity support system with C-T joints, for supporting cavities inside the cryomodule.

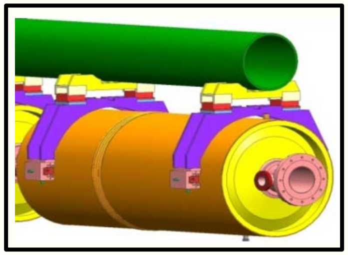
Prototyped end group in Nb made at RRCAT by machining solid Nb block for reducing cost from $27000 to $ 16000 and better functionality



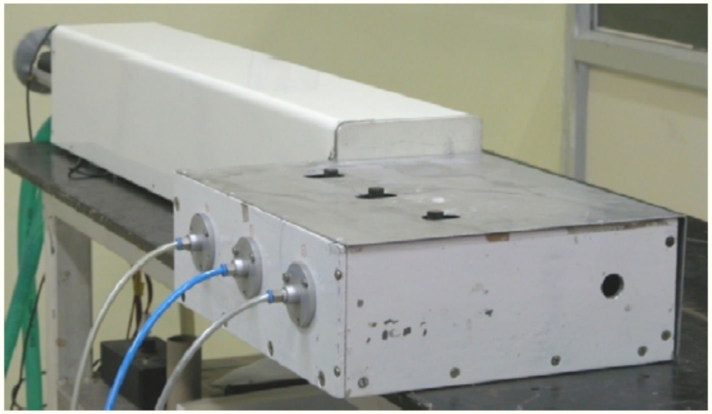
Modification in 2K supply line to reduce manufacturing cost and facilitate easier manufacturing

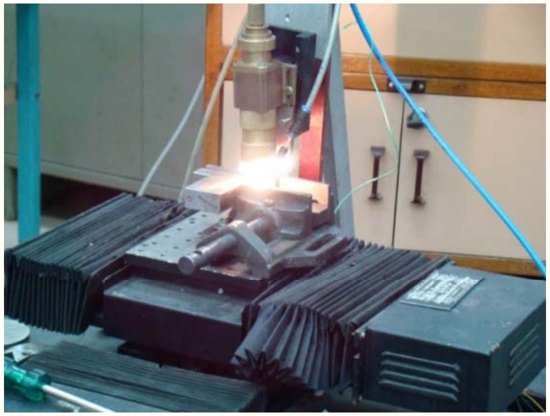
Laser Welding of Cavity Support System

- SCRF cavity support system in a cryomodule can be simplified by laser welding of SS hangers of the cavity and incorporating a C-T joint.



- Laser welding trials were carried out using indigenously developed Nd-YAG laser.





Post-welding distortion : 6 microns

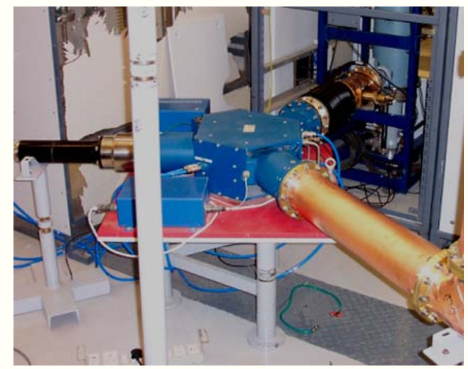
Joint's strength : 9 Tonnes

RF Technology :
Infrastructure Development

CW RF Power Systems at RRCAT

- Built RF power system for Indus-2 operating at 505.8 MHz delivering 250 kW CW power using multi-beam klystrons

RF cavities in Indus-2 tunnel



Klystron & circulator

RF supervisory PCs

- Also taken up upgradation of Indus-2 RF power system using IOT based amplifiers

Solid State RF Amplifier Development

- Interest in solid state amplifiers
  - High reliability
  - No high voltage
  - No high power circulator
  - Longer operational life
  - Easy and fast maintenance
  - Better RF spectrum (harmonics, phase noise etc.)
  - Expected better eficiency.
  - Continuos decrease in price/watt and size/watt.

1 kW Solid State RF Amplifier for Booster

Booster synchrotron of Indus Accelerator is in operation for nearly 15 years. Recently its tetrode tube based RF Amplifier has been replaced by indigenously developed 1kW Solid State RF Amplifier. This has resulted in improved performance .

1kW RF Amplifier test set up

Main Specifications

Frequency	**31.6 MHz**	**Output Power**	**1 kW**
Operation Mode	**CW**	**Gain**	**55 dB**
Harmonics	**-45 dBc**	**Efficiency**	**48 %**

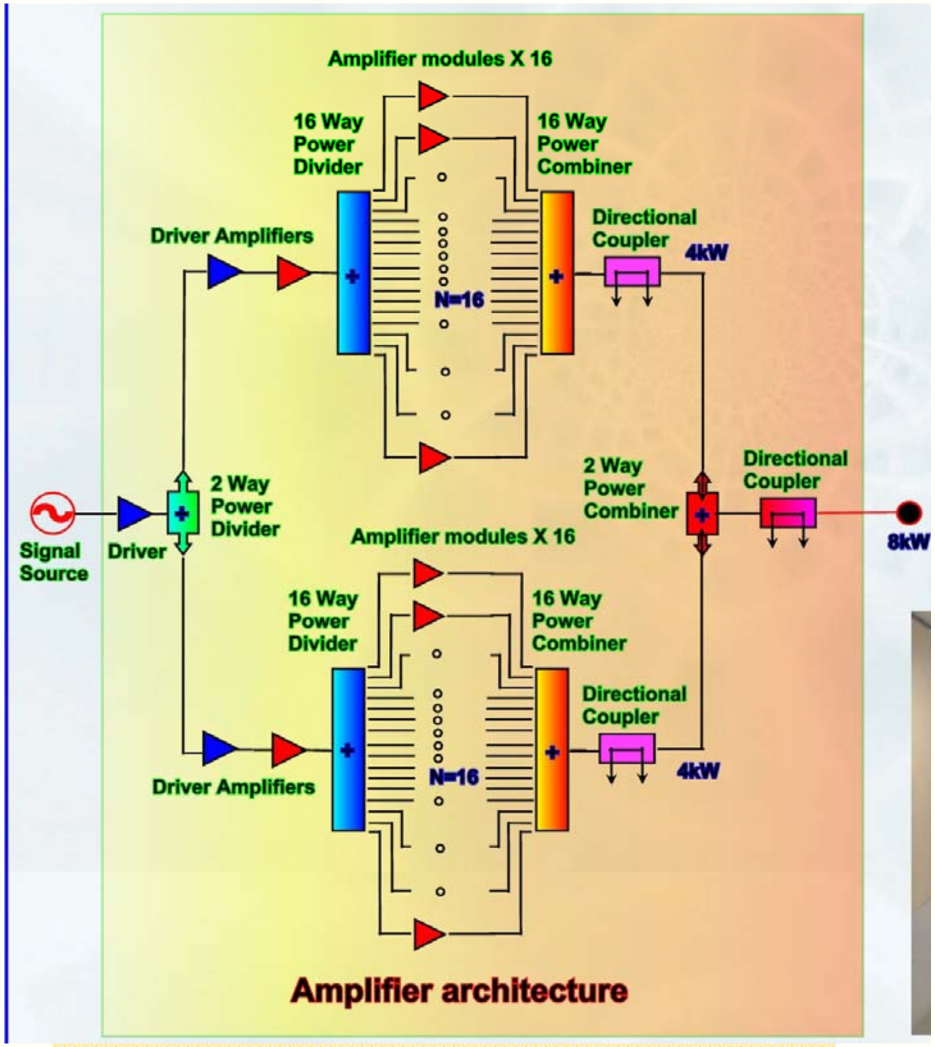
One of the four amplifier Modules (250 W) used in 1kW amplifier

CW RF Power Systems at RRCAT contd…

Developed 4 kW CW 352 MHz solid state amplifier and related components like power combiners, directional couplers, and RF dummy loads for H^- linac project.

Power Gain: 50-55 dB

8 kW Solid State Amplifier Scheme for Indus-2



8 kW Solid State Amplifier architecture

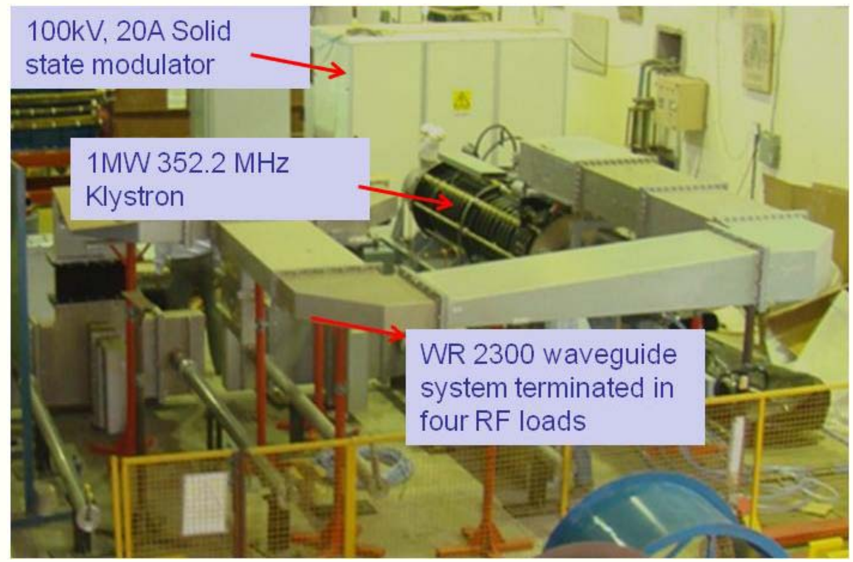
8kW unit is housed in a single euro rack with 32 amplifier modules of 270W RF power .

8 kW, 505.8 MHz Solid State Amplifier

Pulsed High Power RF Generation

Long duration solid state pulse modulator technology, high power RF generation & waveguides

100 kV, 800 μsec pulse duration, 2Hz PRR solid state bouncer modulator.



352.2 MHz, 1MW Pulsed Test Stand

- Solid state bouncer modulator developed for LINAC 4 (CERN)
- 1MW, 352.2 MHz, pulsed power achieved from the CERN LEP Klystron

WR 2300 Waveguide Feed Structures for Proton Accelerators

Design and development of high power rectangular waveguides

WR 2300 Waveguide components (Al alloy 6061) 1.5 MW Av. Power at 352.2 MHz

WR 2300 full height straight section

WR 2300 half height straight section

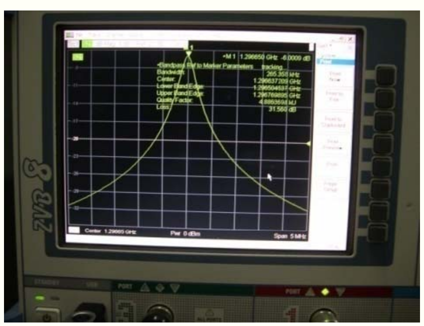
Coaxial to W/G transition

Technological capability to develop dual directional couplers, E and H plane bends, Magic TEE power dividers, High power RF loads etc.

RF Systems for SCRF Applications

RF Characterization of Prototype SCRF Cavity

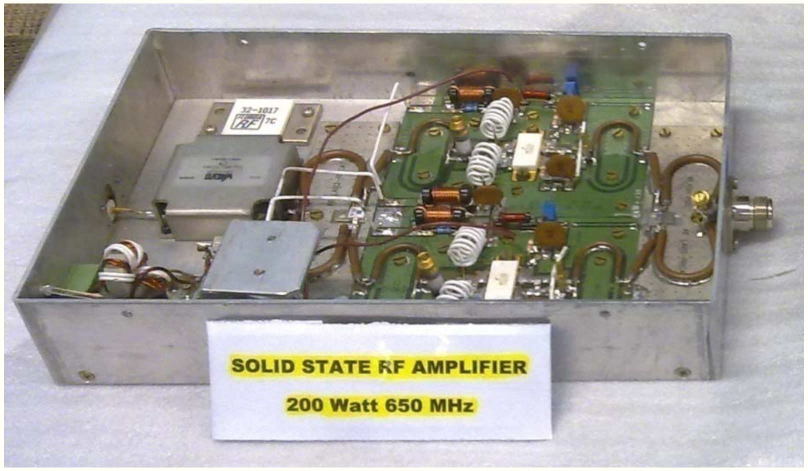
Frequency & Q-factor Measurements

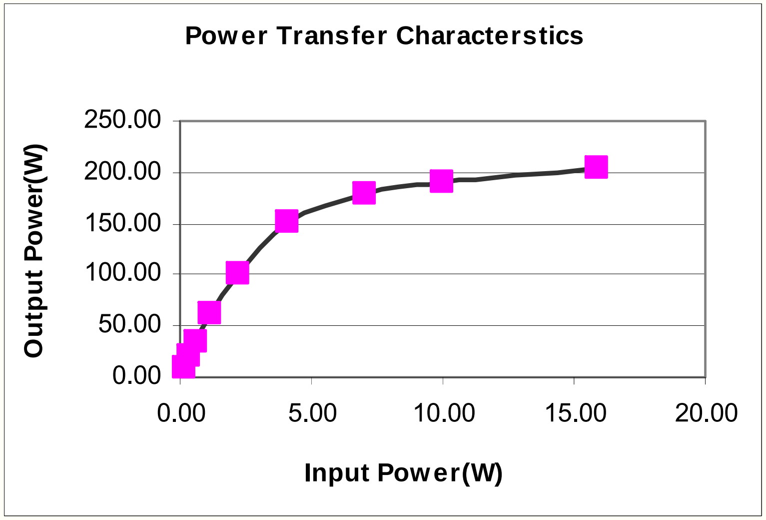


Frequency	TE1CAT001	TE1CAT002
FNAL (23 C)	1297.031	1296.793
RRCAT (27 C)	1296.926	1296.675
'Q' factor		
FNAL (23 C)	9961	9918
RRCAT (27 C)	9076	9328

200-300 W Module at 650 MHz

- Design and simulation have been carried out for 270-300W at 650 MHz.
- Recently, 200W module has been developed using available transistors.

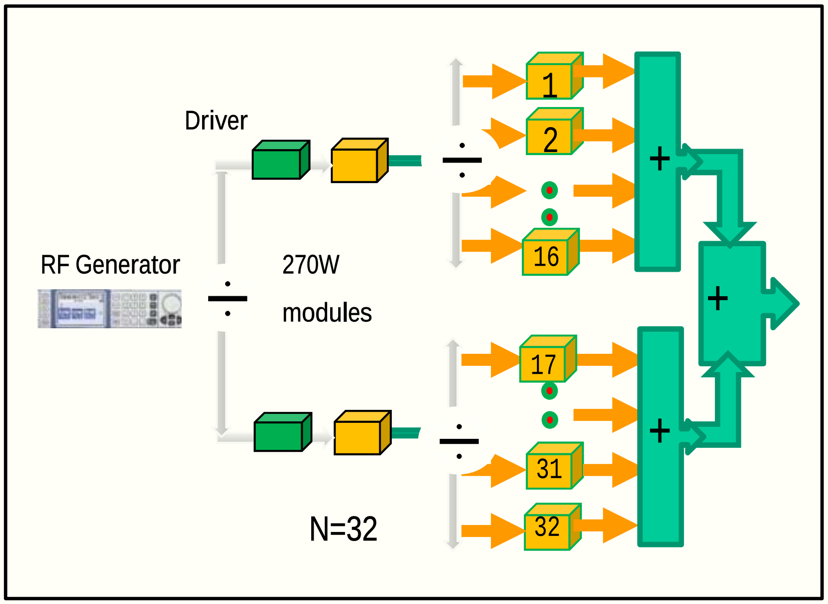




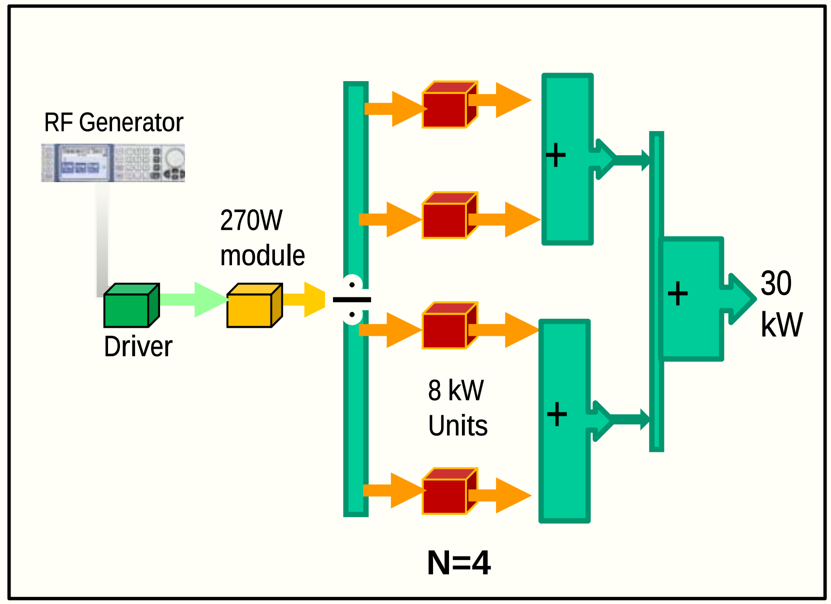
200 W solid state amplifier with measured power

Solid State Amplifier Development at 650 MHz

- 32 Nos. of 270 W RF modules will be used with suitable combiners and dividers to make a 8 kW RF amplifier module. Four such modules will be combined to obtain 30 kW RF power output.



8kW Amplifier Scheme



30kW Amplifier Scheme

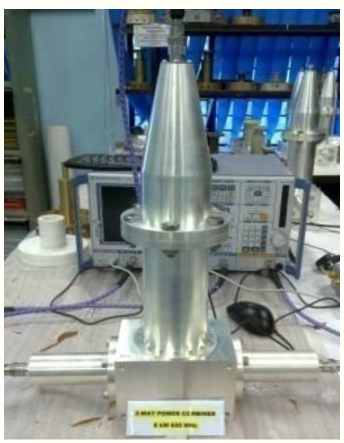
Development of RF Components at 650 MHz

- Several RF components have already been developed and tested for 650 MHz operation

20W Low Power Driver

200 W Amplifier Module

Coaxial Transitions

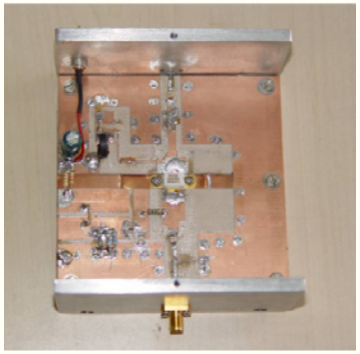


2-way 15kW Power Combiner

4kW & 1 kW Coaxial Directional Couplers

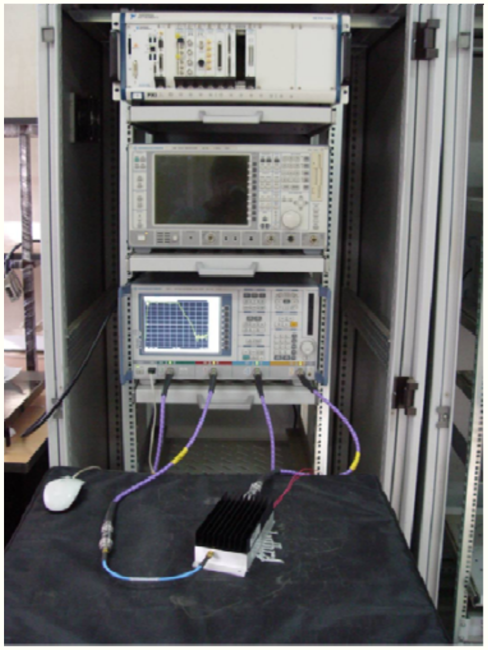
30 kW RF Dummy Load

VTS RF System Development at RRCAT

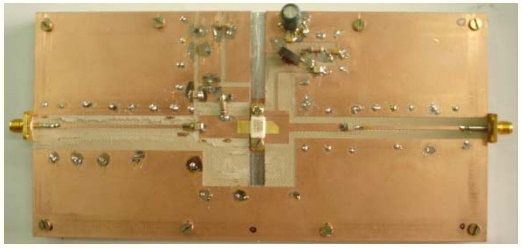


2W driver amplifier

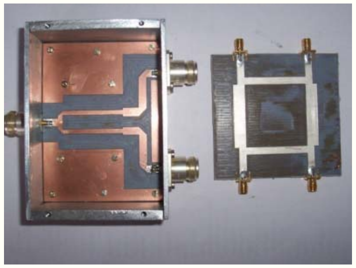
Multiple output DC power supply



Testing of components using VNA



10W 1.3 GHz SSPA



2 Way splitter/combiners

4 way splitter/combiner

IIFC gaining strength…….

Thank You