Indian Activities on Project-X

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Mumbai, India

IIFC: BARC, RRCAT, VECC, IUAC

Project X Meeting Nov 27, 2012, Fermilab

Accelerators in India

Heavy Ion

- **6 MV Folded Tandem Ion Accelerator (BARC, Mumbai)**
- **14 MV Pelletron (Mumbai)**
- **Superconducting Linac booster at Mumbai (Pb plated cavities)-Mumbai**
- **16 MV Pelletron (IUAC, New Delhi)**
- **Superconducting Linac Booster at IUAC (Niobium cavities)-IUAC**
- **K=130 Room temp cyclotron (VECC, Kolkata)**
- **K= 500 Superconducting Cyclotron at Kolkata (VECC, Kolkata-under commissioning)**
- **3 MV Tandetron at Hyderabad**
- **8 MeV Cyclotron at Chandigarh**

Electron

- **450 MeV INDUS-I (SRS at RRCAT, Indore)**
- **2.5 GeV INDUS-II (SRS at RRCAT, Indore)**
- **10 MeV, 10 kW Linac at Mumbai for industrial application (BARC, Mumbai)**
- **20 MeV Microtron (Mangalore)**
- **10 MeV Electron Linac at RRCAT**
- **7 MeV Electron accelerator (BARC, Mumbai)**
- **2 MeV Electron Linac (ILU-6) at Mumbai**
- 750 keV Electron DC accelerator at RRCAT

Proton (projects) and R&D

- ✓ **1 GeV, 30 mA Linac (Injector: 20 MeV LEHIPA)- BARC**
- ✓ **1 GeV SNS [100 MeV H^- Linac+ RCS]- proposal by RRCAT, Indore**

SCHEMATIC OF INDUS COMPLEX at RRCAT, Indore

Booster Synchrotron
(700 MeV)

Microtron
(20 MeV)

TL-1

TL-2

TL-3

INDUS-1

Indus-2, 2.5 GeV SR

(Trials to store the beam began)

December 2005

Indus-1
(450 MeV, 100 mA)

Both Indus-1 & Indus-2 are being run for users.

14 MV BARC-TIFR Pelletron at Mumbai

a)

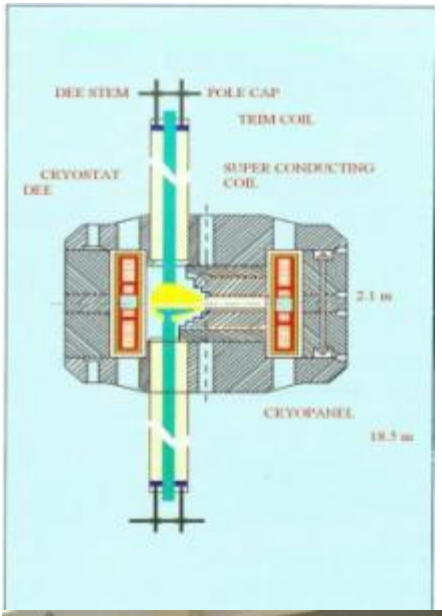
b)

a) 14 UD Pelletron Facility at Mumbai b) High voltage column section

Superconducting LINAC Booster

28 Pb plated QWR in 7 Cryomodules , Energy Gain 14 MeV /q

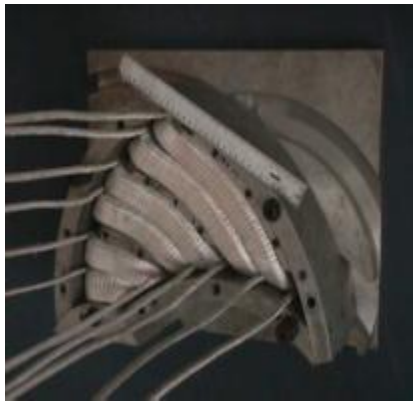
K=500 Superconducting Cyclotron at Kolkata



K=500

Superconducting Cyclotron

Magnet assembly at the fabrication site

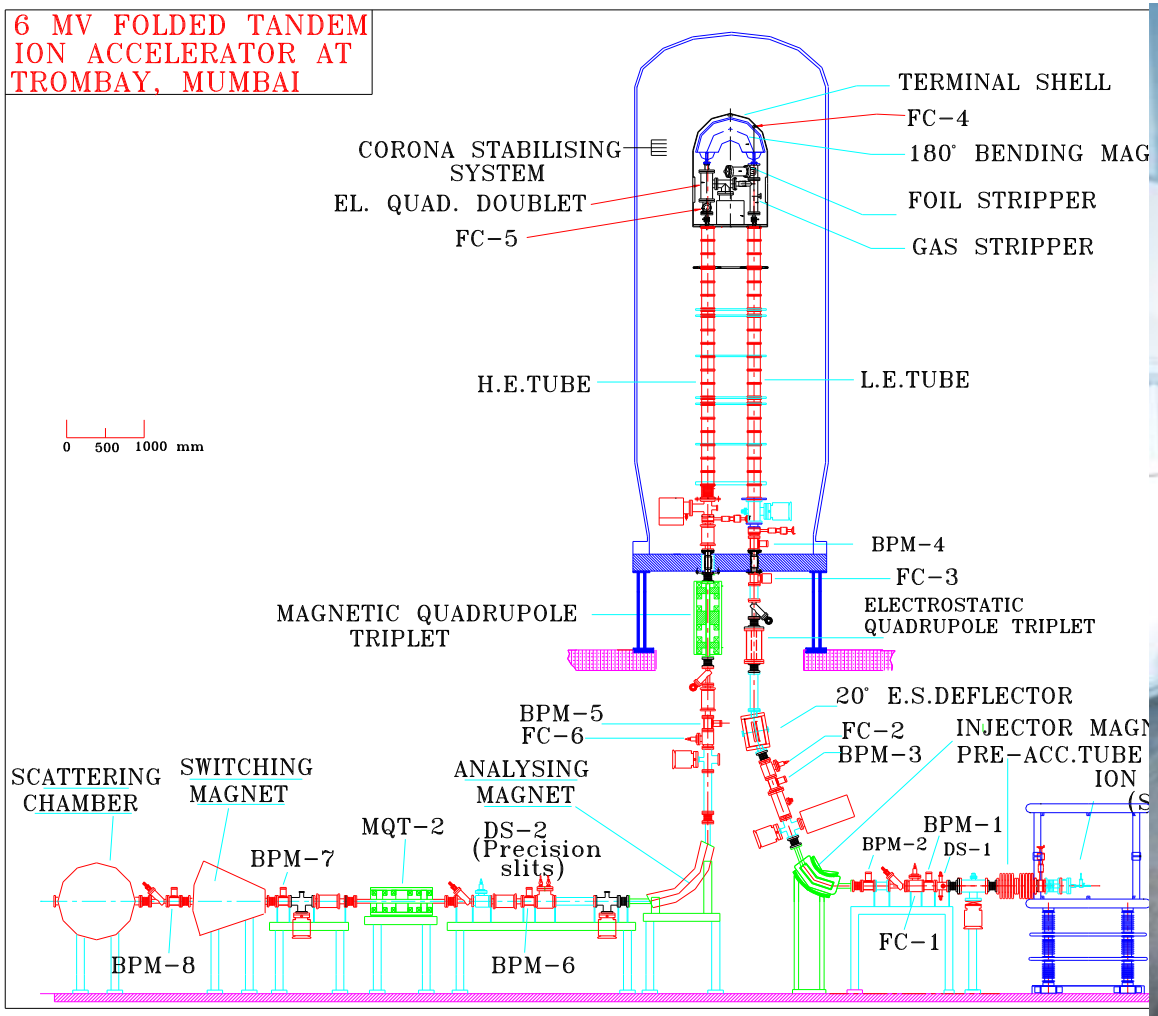


Trim coils wound on pole tip before potting

Vertical cross-sectional view

Pole tip assembly

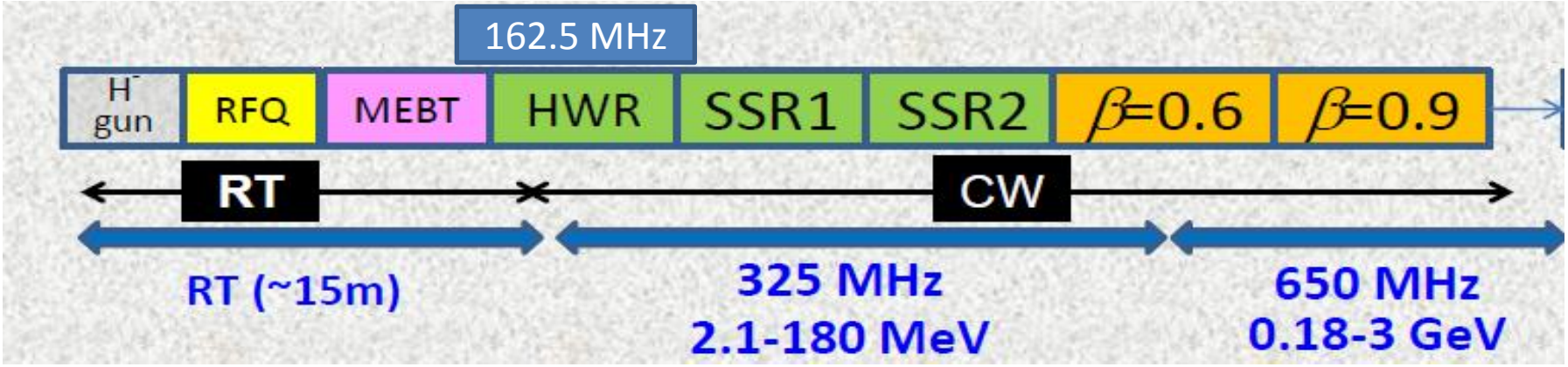
6 MV Folded Tandem Ion Accelerator



Inter-twinning of Indian & Fermilab Programs

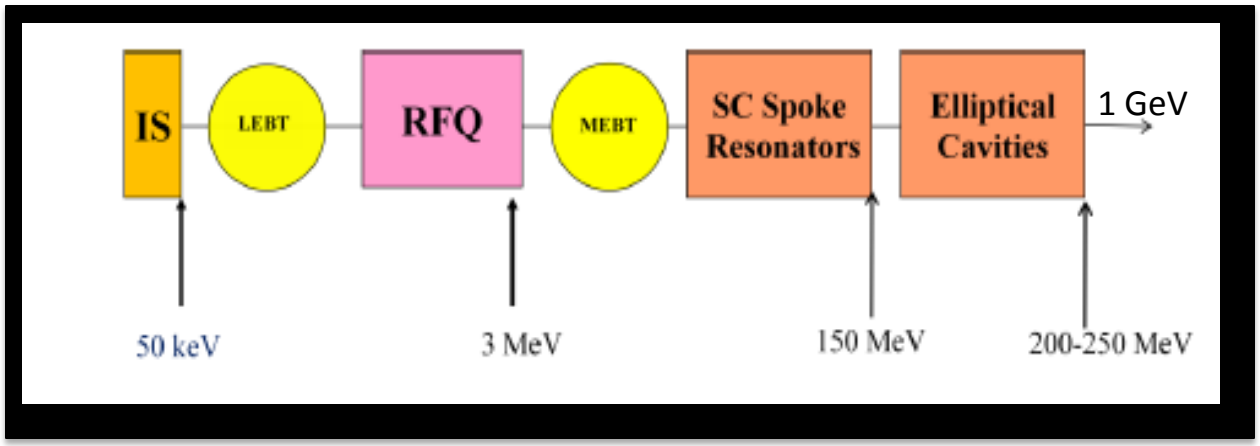
Building High Power Proton Linacs is of great interest to India for its own present /future R&D programs based on accelerators.

A multi-MW Proton Source for Project-X, is Fermilab's strategy for future development.



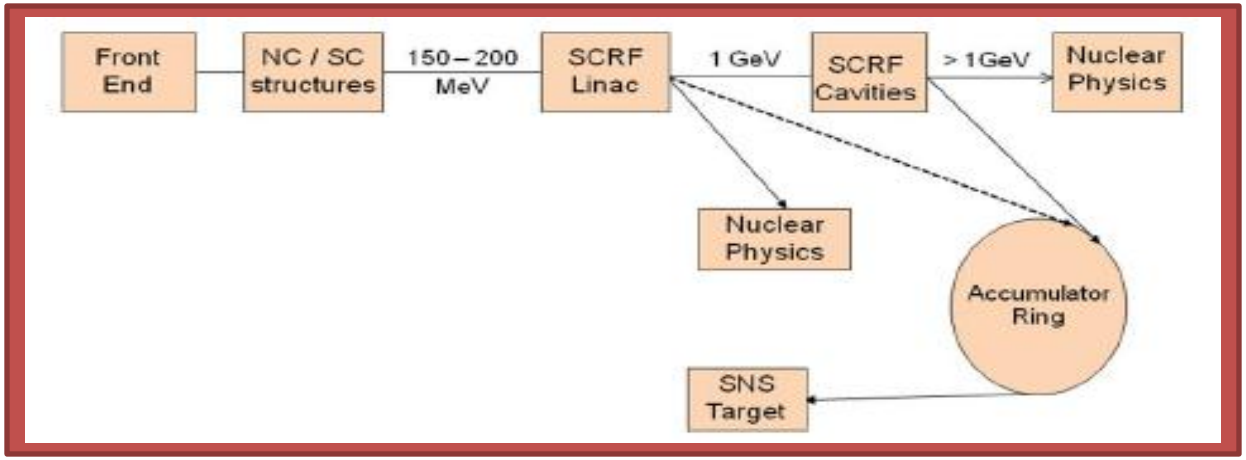
DAE Accelerator Development Program

- DAE labs have proposed
  - Physics Studies and Enabling Technology Development for Ion Accelerators (BARC)
  - High Energy Proton LINAC Based Spallation Neutron Source (RRCAT)



BARC

RRCAT



Indian Institutions & Fermilab Collaboration

Addendum III: Fermilab and Indian Accelerator Laboratories Collaboration on High Intensity Proton Accelerator & SRF Infrastructure Development

Signing of addendums at Mumbai on Aug 22, 2011

Indian Institution Fermilab Collaboration (IIFC)

Key areas of activity

- Work on accelerator physics of high intensity proton linacs.
- Good progress on Niobium SCRF Cavity development & creating test facilities.
- Develop new design to bring down cryo-module (CM) costs.
- Evolve CM designs to handle high power beams.
- Work on Integrated Accelerator Control & Instrumentation System through interaction between groups on both sides.
- Focused dialogue on design of RF system needed for high current proton accelerator.
- Train young Indian engineers who will contribute to program in both countries.

IIFC activities @ BARC

(a) Accelerator physics of high intensity proton linacs.

BARC & Fermilab scientists have started interacting.

(b) Design & Development of SSR2

Work has been just initiated.

(c) Design & Development of CMTS

CDM, BARC & Fermilab engineers are regularly interacting &making progress.

(d) Integrated Accelerator Control & Instrumentation

Work going on in LLRF, protection systems, BPMs & temperature monitoring etc.

(e) Solid state power amplifiers & RF couplers

BARC & Fermilab teams are in touch; 1 & 3 kW systems have been developed.

(f) Development of magnets for MEBT

Discussions on this topic have just started.

IIFC activities @ RRCAT

(a) Development of 1.3 GHz single cell β=1 SCRF cavity

4 Nos. of single cell cavities have been built & tested at Fermilab with highest gradient realized in the best cavity approaching 40 MV/m.

(b) Development of 1.3 GHz five cell β=1 SCRF cavity

1 five cell cavity has been built & is being inspected. It will be shipped soon for processing and tests at 2K at Fermilab.

(c) Making end group for 1.3 GHz nine cell β=1 cavity

A prototype has been built & is being checked for fabrication conformance.

(d) Development of 650 MHz single cell SCRF cavity

Half cells in Al & Cu have been built & under going conformance checks.

(e) Design of HTS-2 for SCRF cavity evaluation

Essential elements of design have been captured by RRCAT + Fermilab team.

(f) Development of 650 MHz cryomodule

Design of a number of components is done; work on others is in progress.

IIFC activities @ VECC, Kolkata

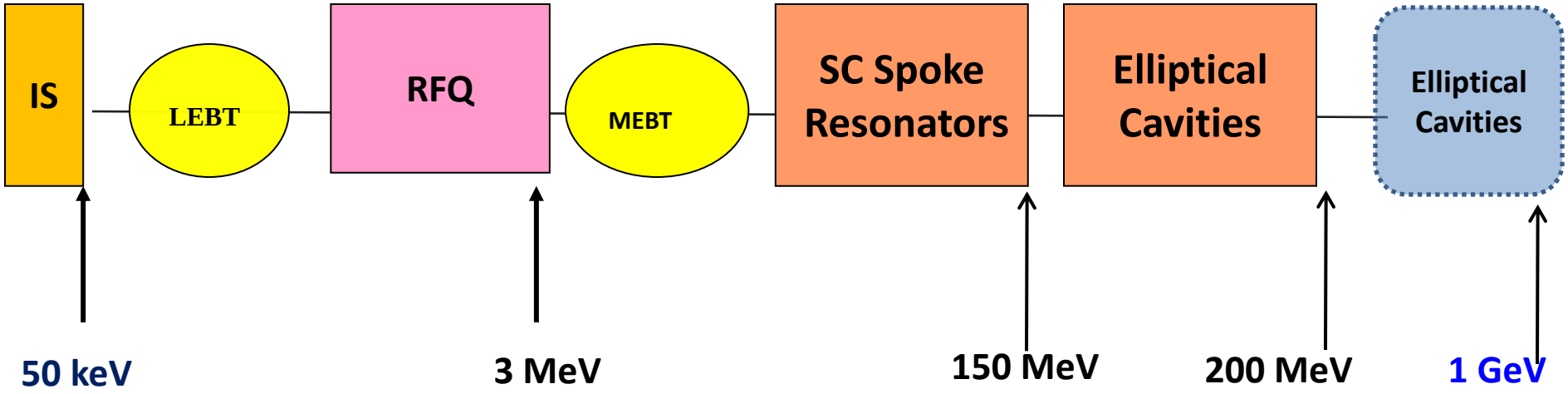
Ongoing programs: (a) Development of 5 cell, 650 MHz, β=0.61 SCRF cavity & (b) Work on cryomodule for SSR1

Present status of these activities:

- **EM design and analysis, Structural analysis, Mechanical modal analysis of the 5-cell 650 MHz, β=0.61, SCRF cavity has been carried out.**
- **Fabrication of die has been done and deep drawing trial of aluminum half-cell is in progress by local vendor.**
- **After successful completion of aluminum prototype, fabrication of Niobium cavity will start.**
- **600 x 600 x 4 mm. Nb sheet (RRR > 300) already procured from ATI Wah Chang.**
- **Electron Beam Welding of Nb Half Cells will be carried out at IUAC, New Delhi (MOU already signed!)**
- **For SSR1, Strong Back temperature distribution (3D analysis) has been carried out. Waiting to start fabrication of SS jacketing for SSR1 (Final version of Drawing yet to be received)**

BARC CW Proton Accelerator

We will go in steps but the design needs to be done for 30 mA



Frequency: 325 and 650 MHz

Scheme for 200 MeV High Intensity Proton Accelerator (a front end of the 1 GeV Linac)

Solid State RF Power Amplifiers

Development of 325 MHz Solid-State RF Power Amplifiers for Project X, under Addendum-V of IIFC

- Deliverables under IIFC (Addendum V)

A. 1 kW, 325 MHz, solid state power amplifier

B. 3 kW, 325 MHz, solid state power amplifier

C. 7 kW, 325 MHz, solid state power amplifier

Manjiri Pande, IADD

325 MHz, 1 kW Amplifier

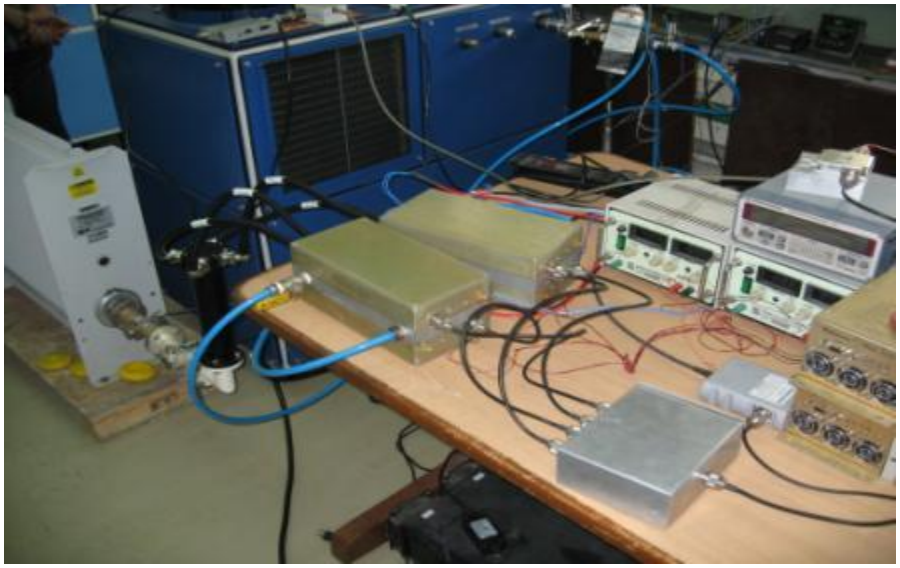
- 1 kW power amplifier assembly with 6 U rack (integration of interlock & protection system is underway)

325 MHz, 1 kW unit under testing

- **After three design iterations and their evaluation, basic (1 kW) amplifier module board has been finalized.**
- **The 1 kW whole unit has been tested at 1.2 kW for six hours for three consecutive days.**
- **No deviation was observed in amplifier parameters. Further long term testing and evaluation is underway.**

Manjiri Pande , IADD

325 MHz, 3 kW unit



Prototype testing of 3 kW RF amplifier

Two 1 kW RF units mounted back to back on heat sink

3 kW power combiner

Manjiri Pande, IADD

IIFC: Control &Instrumentation

- C&I for CMTS
  - RF Protection Interlock System (RFPI)
  - Low Level RF (LLRF) Control System
  - CMTS Control System
- Beam Position Monitor (BPM)

Two systems taken up for development in the first phase:

1. ***RF Protection Interlock System(RFPI)***
2. ***Low Level RF (LLRF) Control system***

Beam Position Monitor

- Exact Specifications are expected from Fermilab

- The development of electronics system for the BPM for SPIRAL2, GANIL was also presented to Fermilab team. The design has been reviewed by a team of GANIL experts and is currently under fabrication.

CMTS -2 C&I

- Specifications of control system for CMTS-2 are yet to be finalized.

- Documents on the existing CMTS at Fermilab can be a good start, if made available.

Gopal Joshi, ED

High power couplers

Rajesh Kumar, IADD, BARC , participated in the following high power coupler related studies during his visit to Fermilab (26th June - 20th Aug. 2012)

- Electromagnetic design simulations of 30 kW, 325 MHz Project-X (PX 325) and 650 MHz, 120 kW Project-X (PX 650)
- Multipacting simulations of PX Couplers
- Static and dynamic thermal analysis
- Discussions towards understanding PX 325 manufacturing drawings and Technical specification document
- High power conditioning of 1.3 GHz coupler

High power couplers

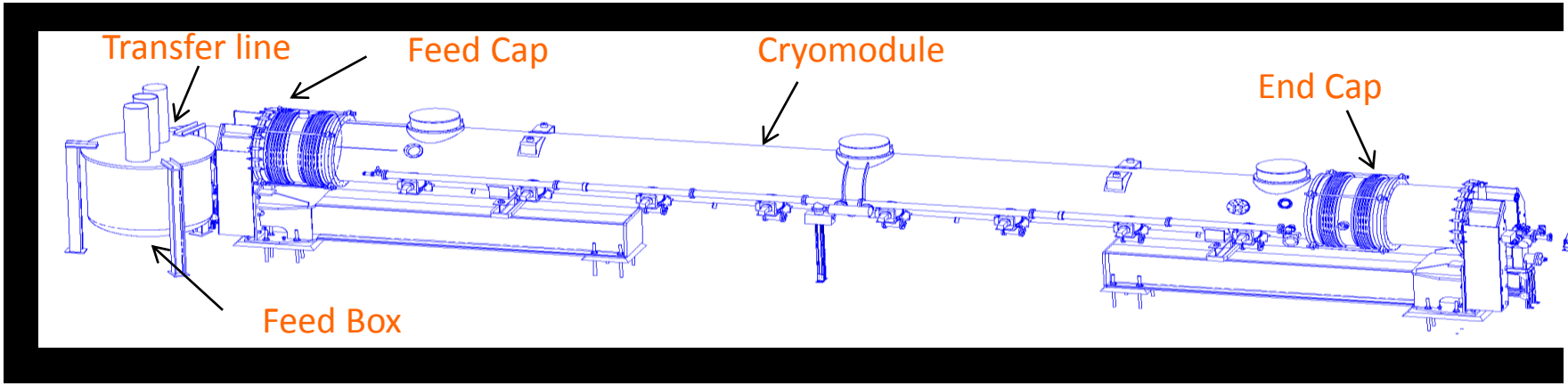
- Proposed to take up fabrication of one prototype each of PX 325 MHz and PX 650 MHz couplers in India.
- The design details of 30 kW, PX325 coupler are made available by Fermilab. Fabrication is being taken up (2013).
- Complete design details of PX 650 coupler are not available. Needs more discussions (2014).

Present status of prototype fabrication:

1) Vendor's for supplying metallized alumina have been identified.
2) It is planned to take up the fabrication of RF window part first as it is most critical. Vendor's have been identified for this job.
3) We are in the process of identifying vendors for TiN coating on alumina.

BARC: Cryomodule Test Stand

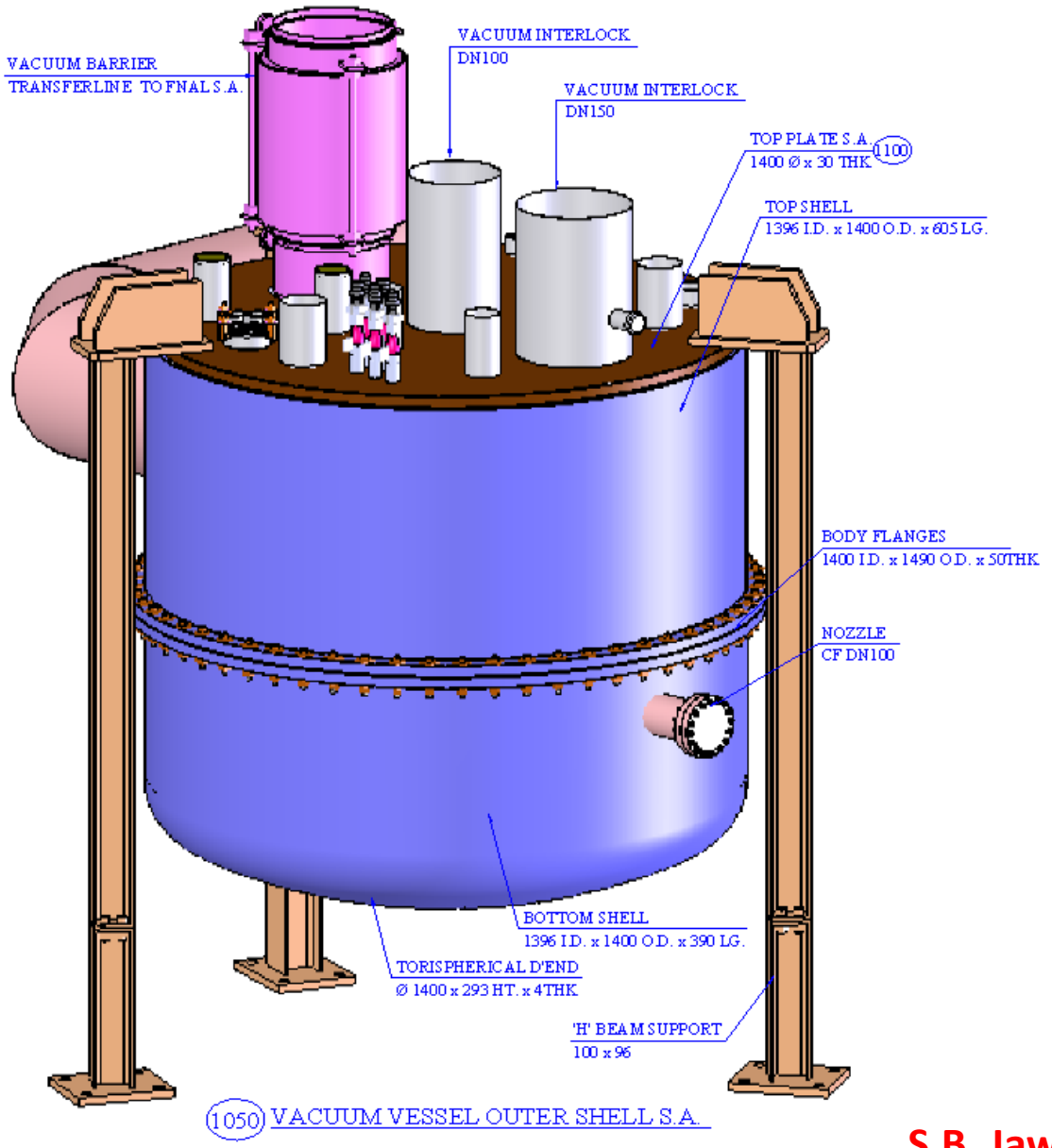
- Conceptual Arrangement of Feed Box, Feed Cap, End Cap & Transfer Lines.



  - Status: design and drawing of all three sub assemblies is taken up. Ready to order material

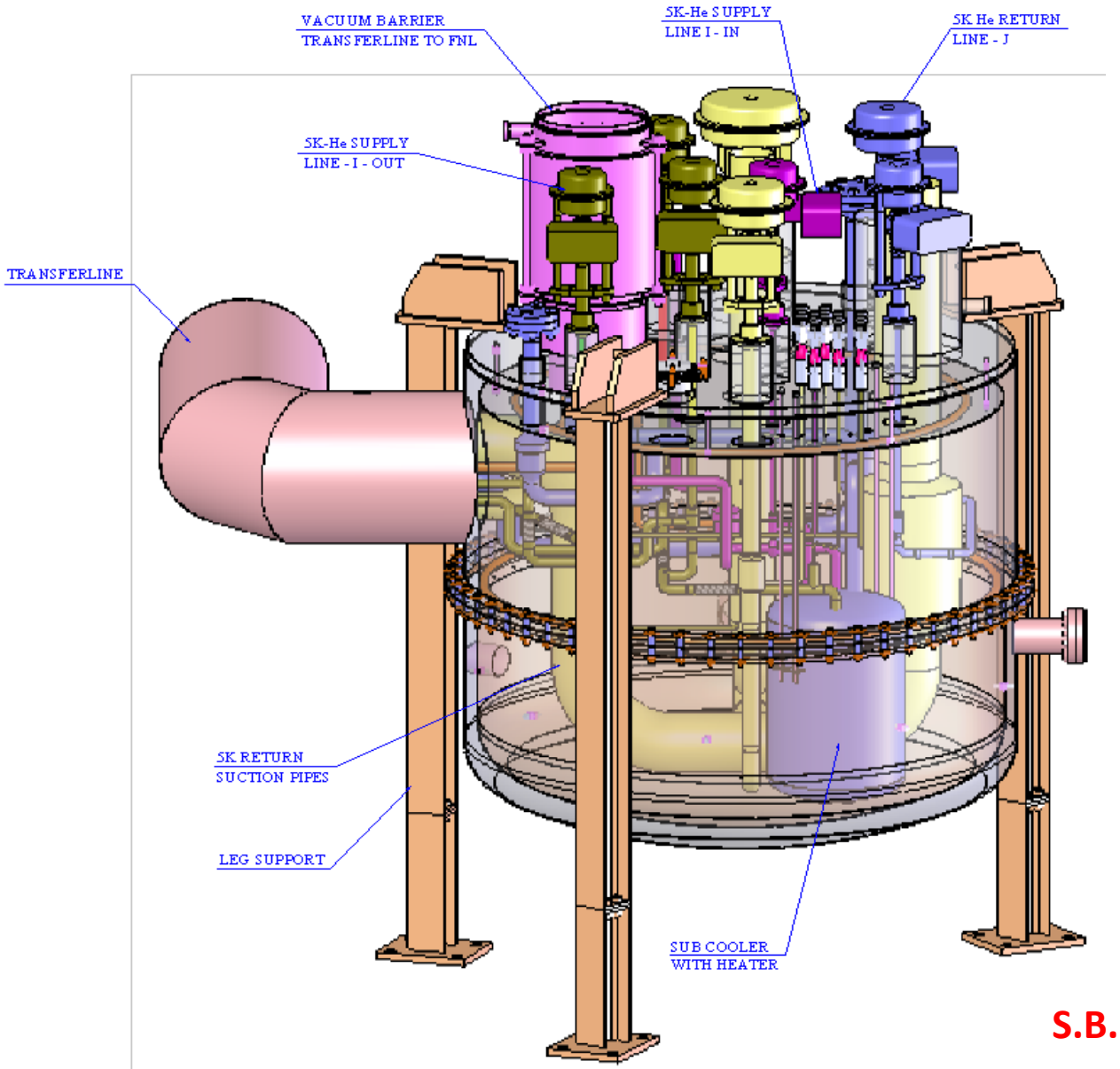
- CMTF (FY 2016): 650 MHz CW test stands for project X
  - Install shielding, RF, cryo for Project X test stands
  - 1300 MHz (pulsed) CM test stand (with India)
  - 650 MHz (CW) CM test facility (with India) ← Integrated system

Feed Box (Outer View)



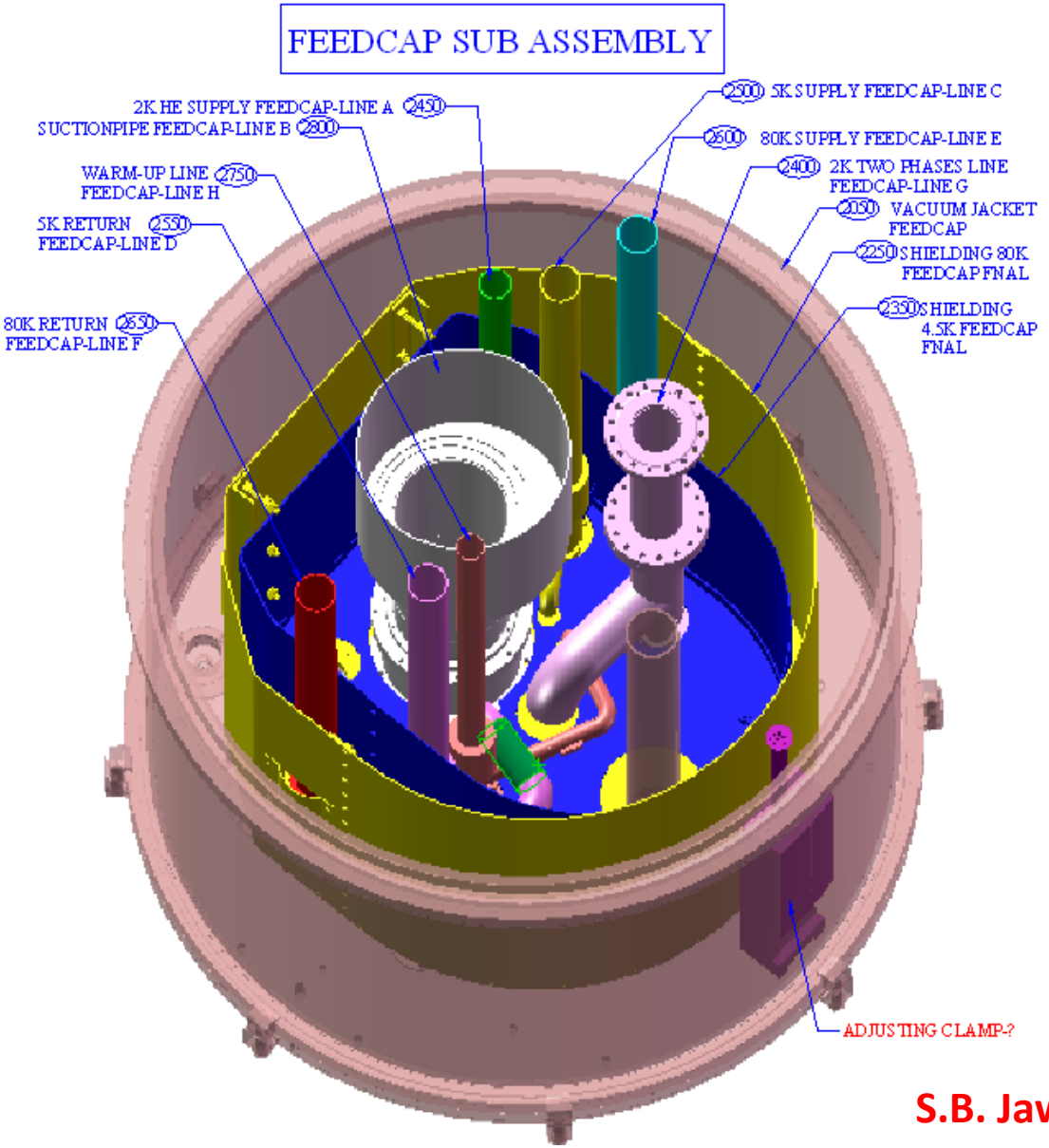
S.B. Jawale, CDM

Feed Box (Inner details)



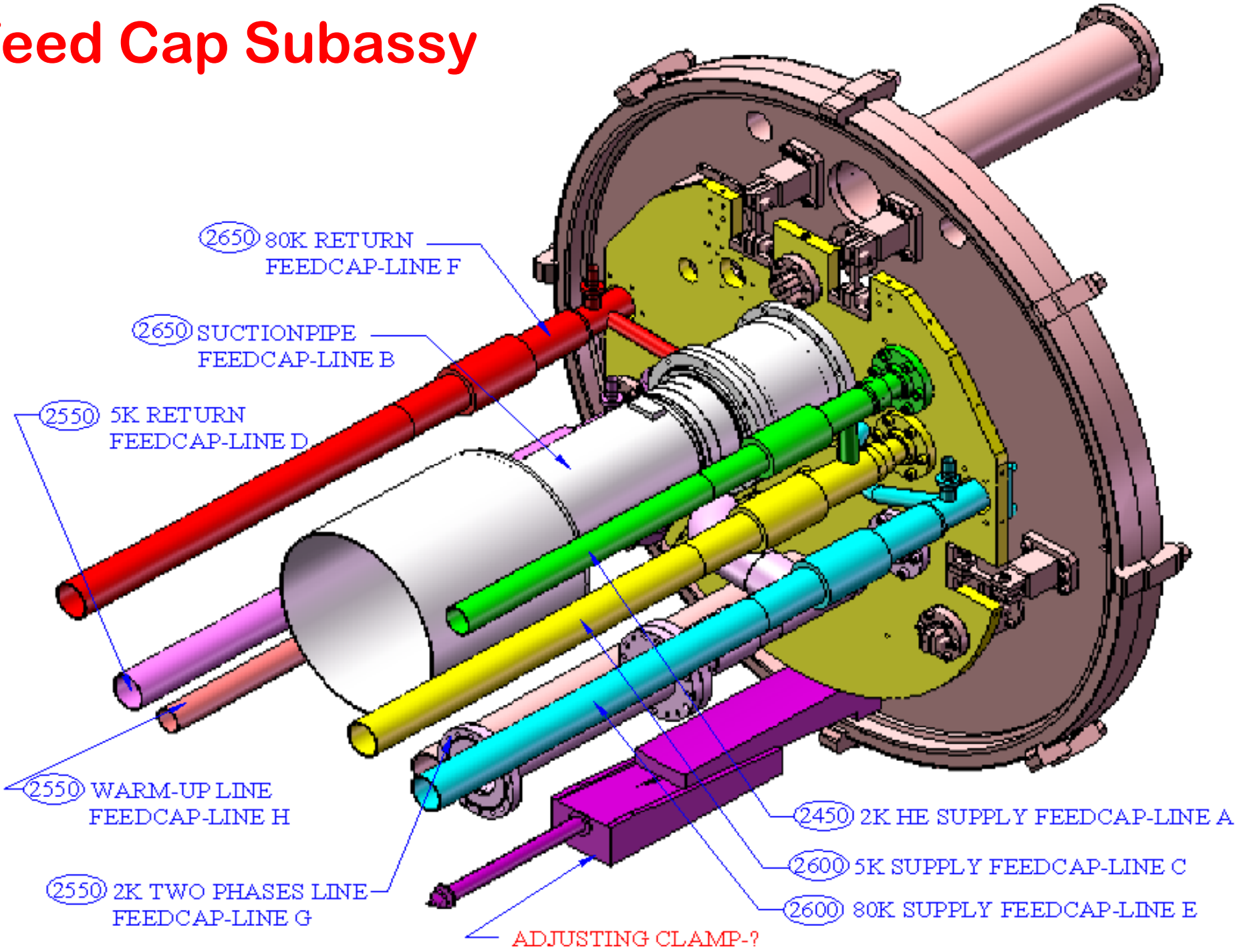
S.B. Jawale, CDM

Feed Cap Subassy

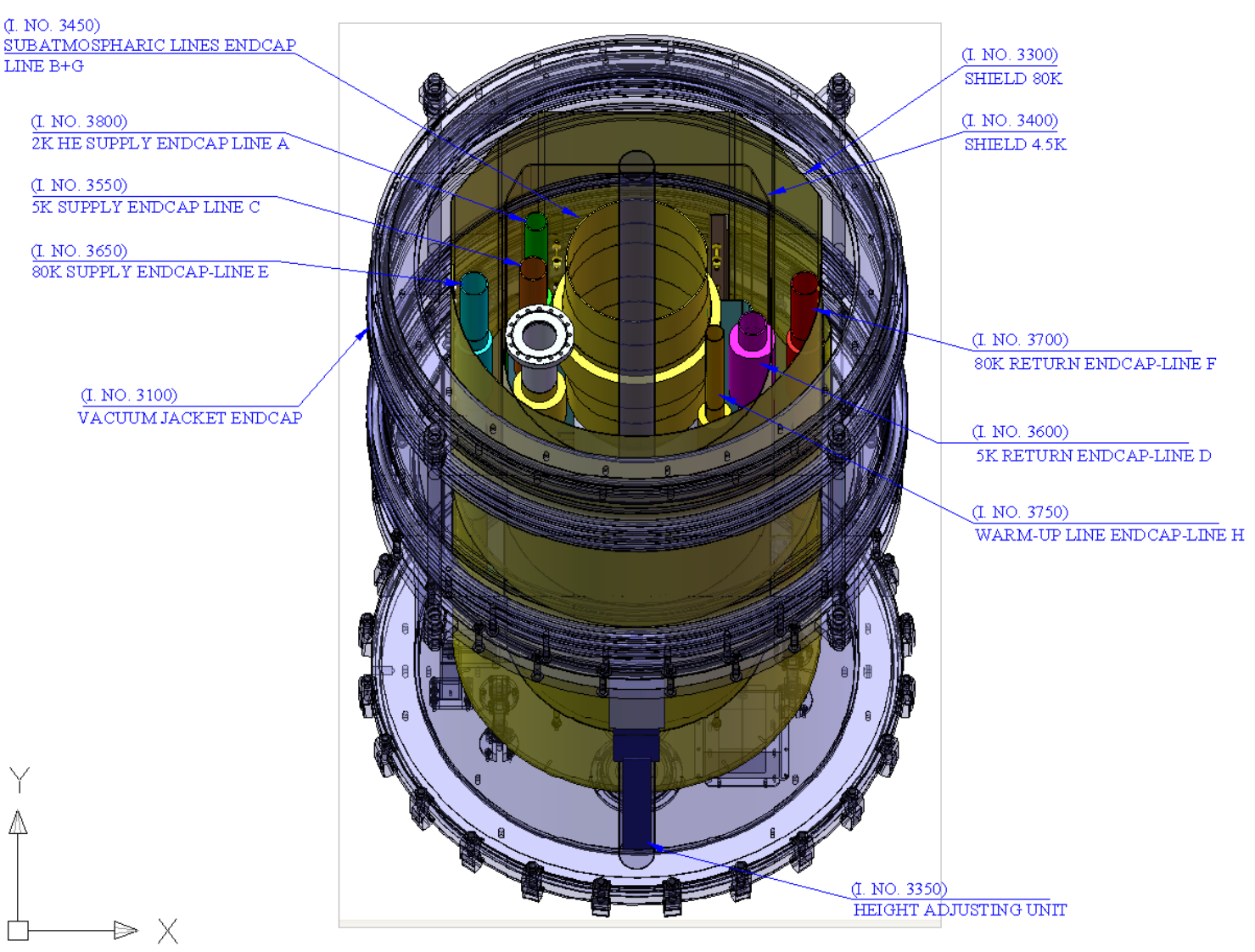


S.B. Jawale, CDM

Feed Cap Subassy

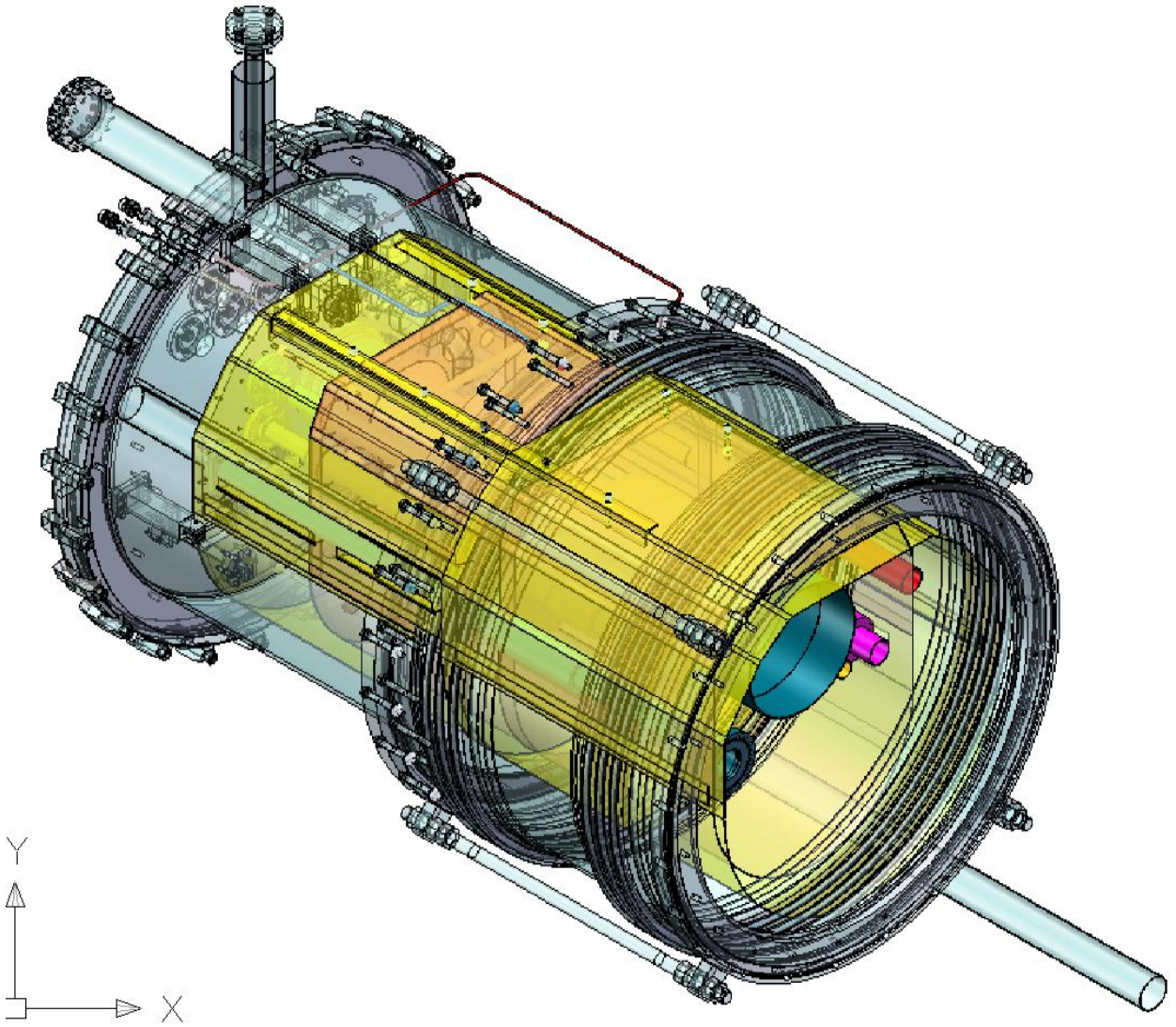


End Cap Subassy



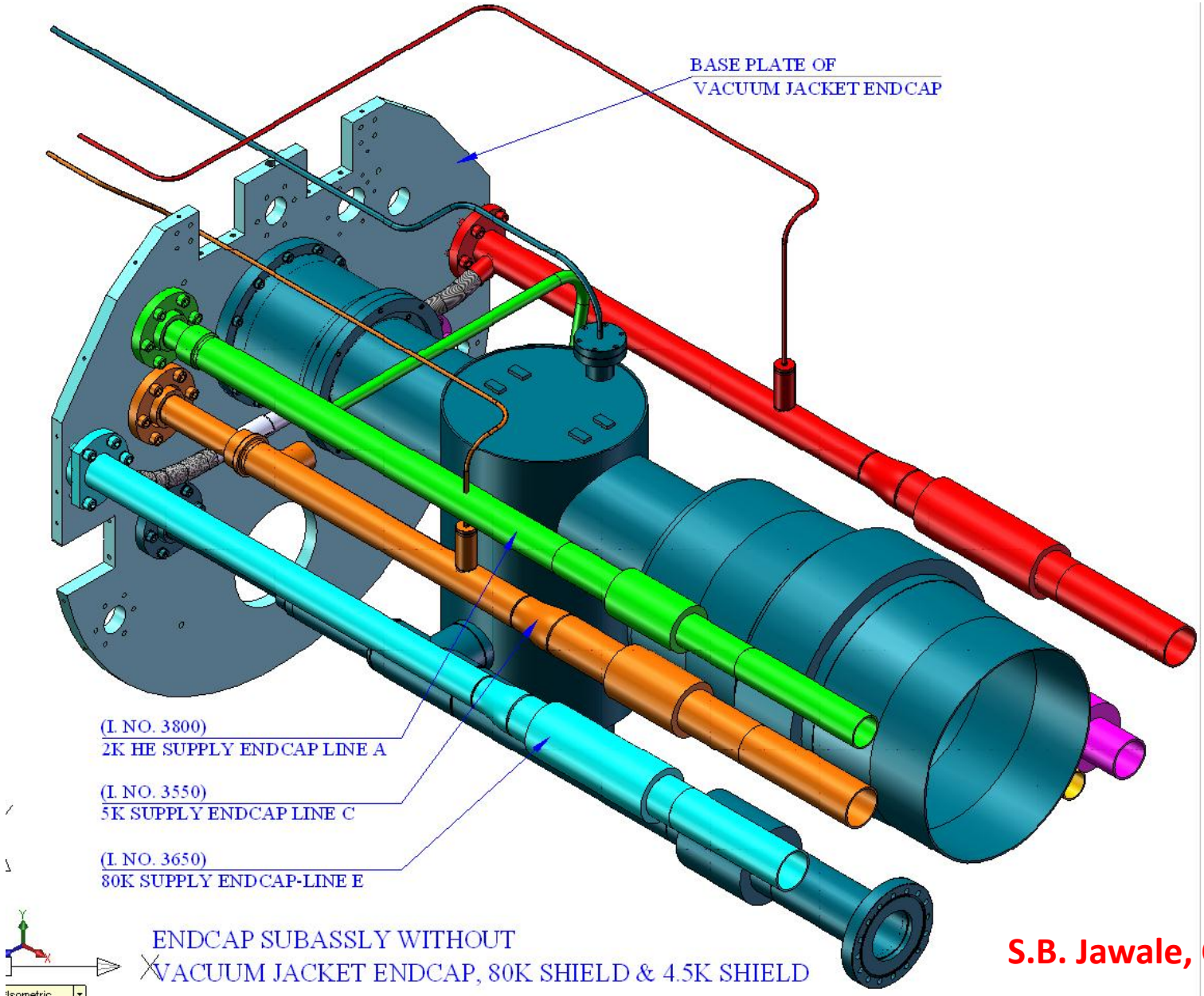
S.B. Jawale, CDM

End Cap Subassy.



S.B. Jawale, CDM

End Cap Subassy.



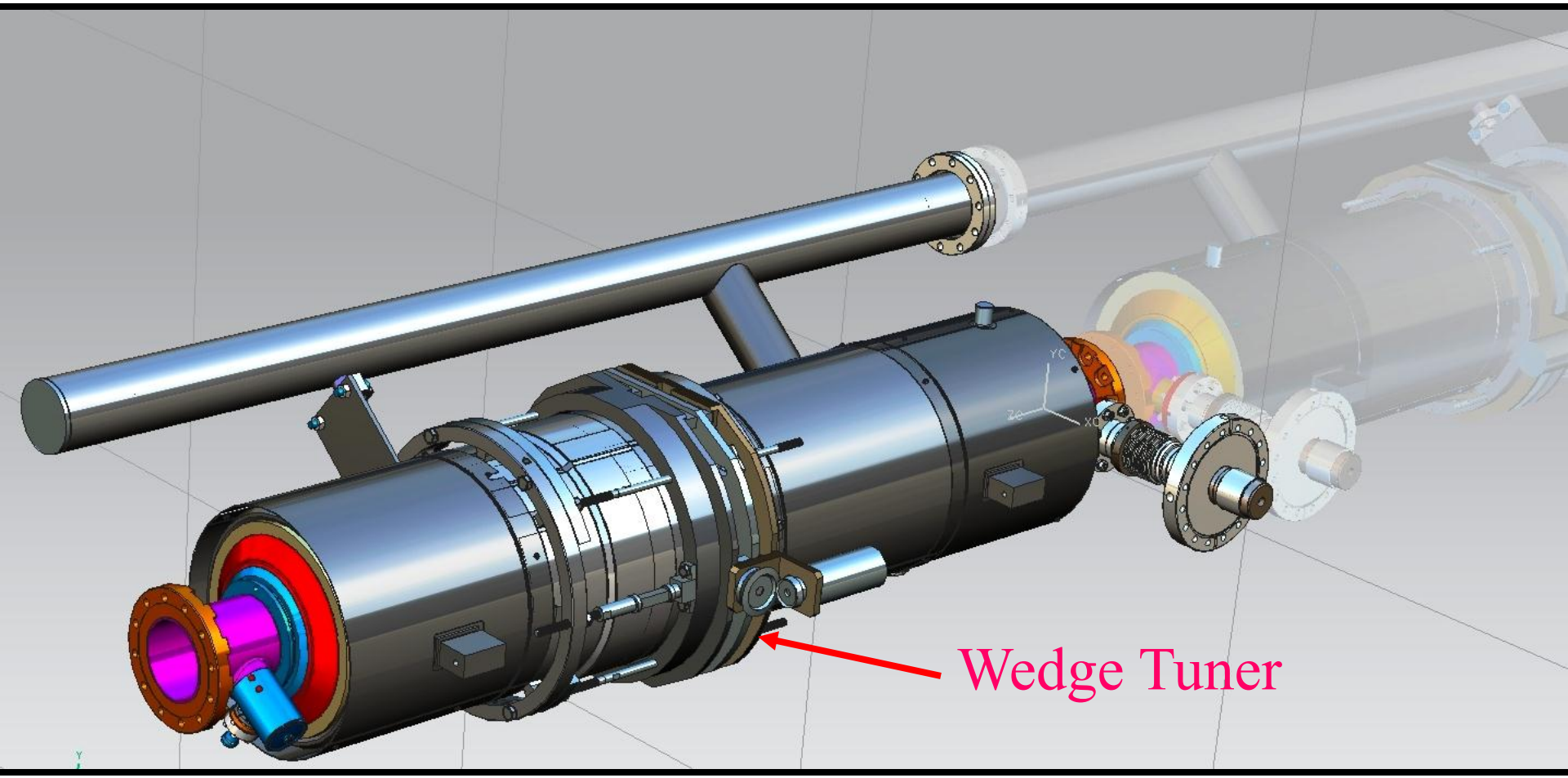
S.B. Jawale, CDM

Wedge Cavity Tuner

- A prototype Wedge Cavity Tuner has been Designed and development at Center for Design and Manufacture (CDM), BARC, Mumbai, India.
- Proof assembly was done at CDM, BARC
- Mechanical test (without RF) against resistance offered by springs having equivalent stiffness was done both at room temp and at -95 ^{0}C and functioning was found satisfactory.
- It is being shipped to FNAL to test it in 1.3 GHz Cryo-module.

S.B. Jawale, CDM

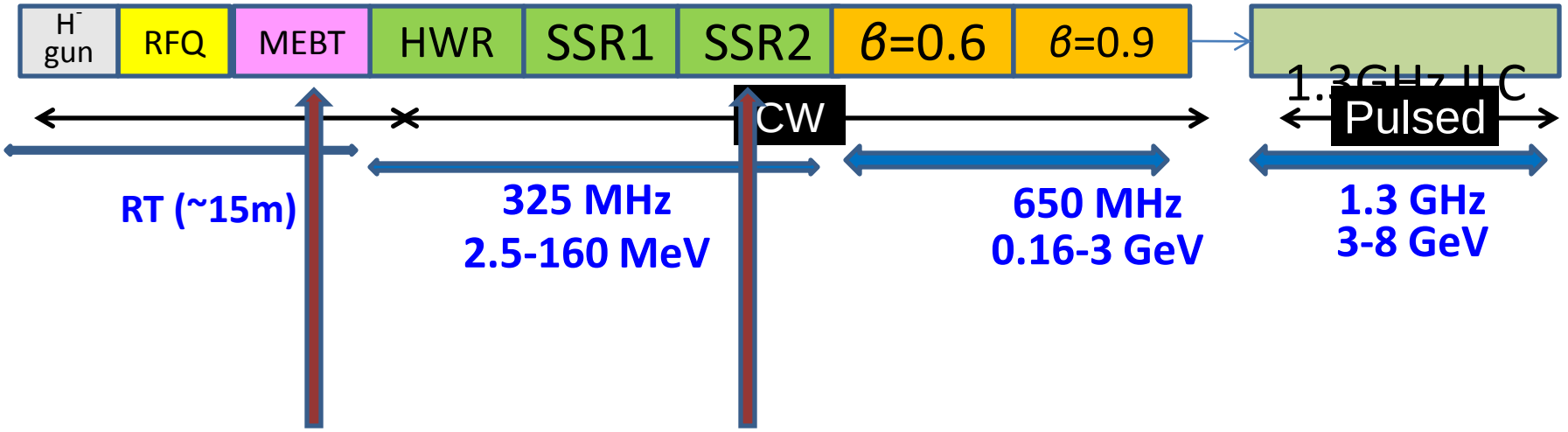
Wedge Cavity Tuner



Tuner installed around Helium Vessel

S.B. Jawale, CDM

Modules of involvement of BARC



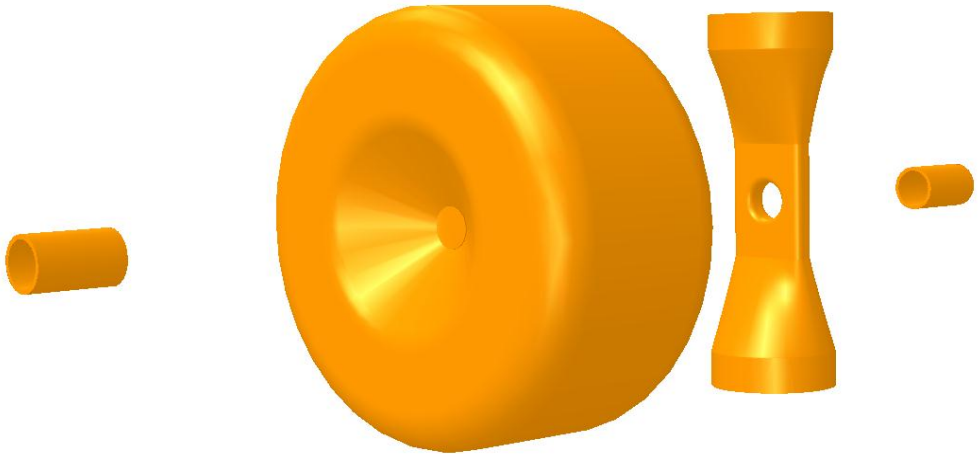
Quadruple focusing with Dipole field correction coils design and development

SSR 2 cavity and superconducting solenoid magnets

Sanjay Malhotra, CnID

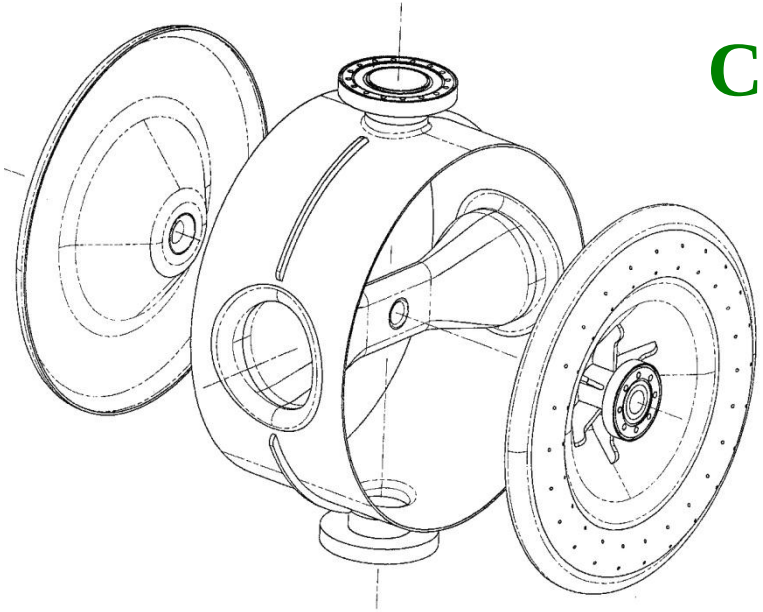
SSR2 & their SC solenoid focusing magnets

- Project X :
- SSR0/HWR, SSR1 and SSR2. Operate at the same resonating frequency, but different β.
- Equal transverse dimensions but different longitudinal dimensions.



Sub-components of SSR2

Collaborations IUAC



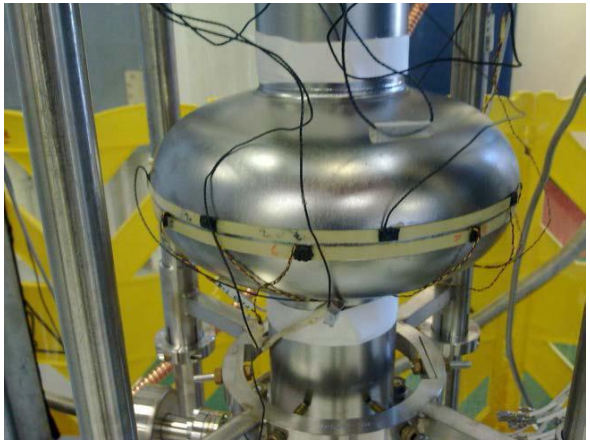
β =0.22, 325 MHz, 2 units
Spoke Cavity for Fermilab Project X

Shell collars welded,
Main body welding completed

Final welding remains.

Development of 1.3 GHz Single-cell SRF Cavity

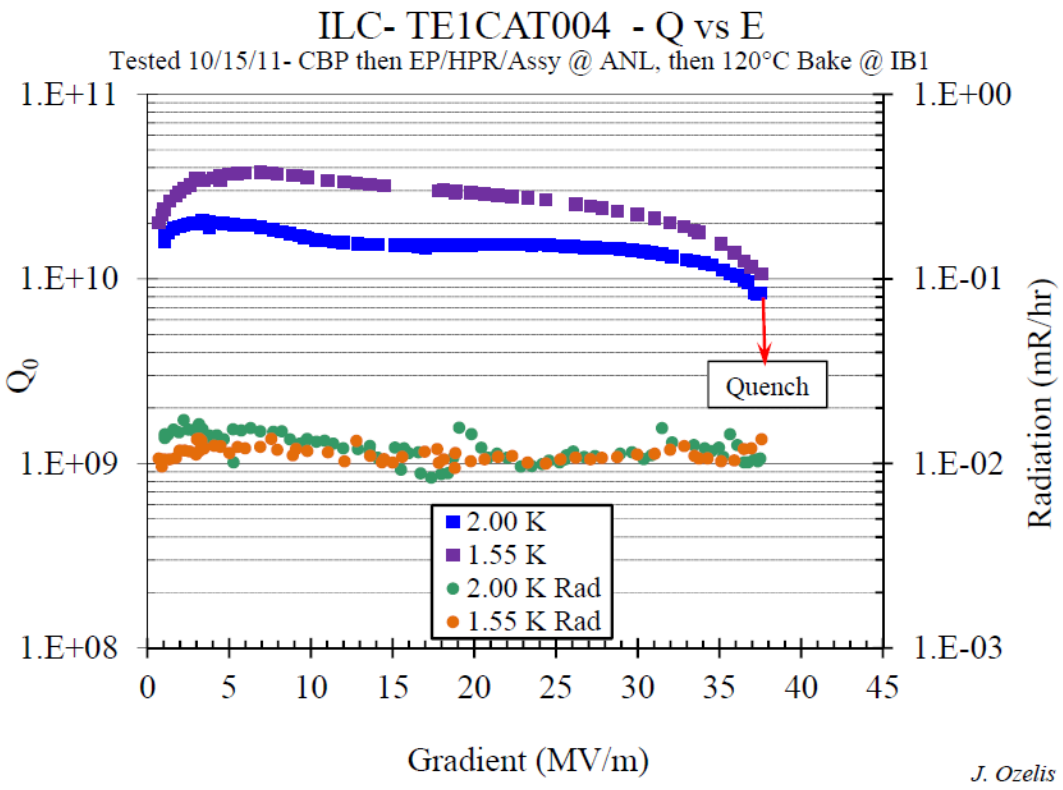
1.3 GHz Single cell cavity



1.3 GHz Single cell cavity during VTS testing at FNAL

4 Nos. of 1.3 GHz single cell cavities tested

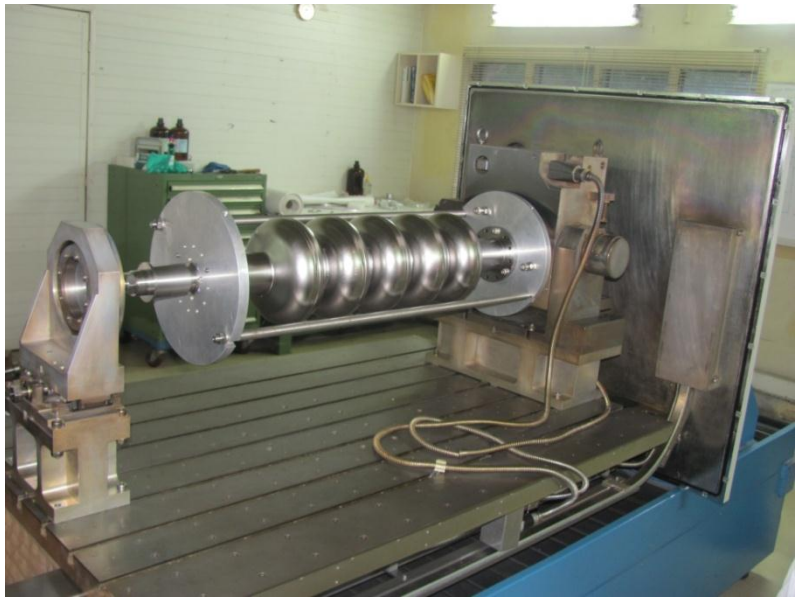
Test Result of 1.3 GHz Single-cell cavity



Accelerating gradient 37.5 MV/m, Q 8.4 x E9 at 2K

Development of 1.3 GHz Five cell SCRF cavity

- RRCAT has developed a 1.3 GHz Five cell cavity with simple end group under IIFC.
- The cavity is under going inspection, leak testing and RF testing.
- Cavity will be shipped to Fermilab for processing and testing at 2K .



Cavity Equator Welding at IUAC EBW machine

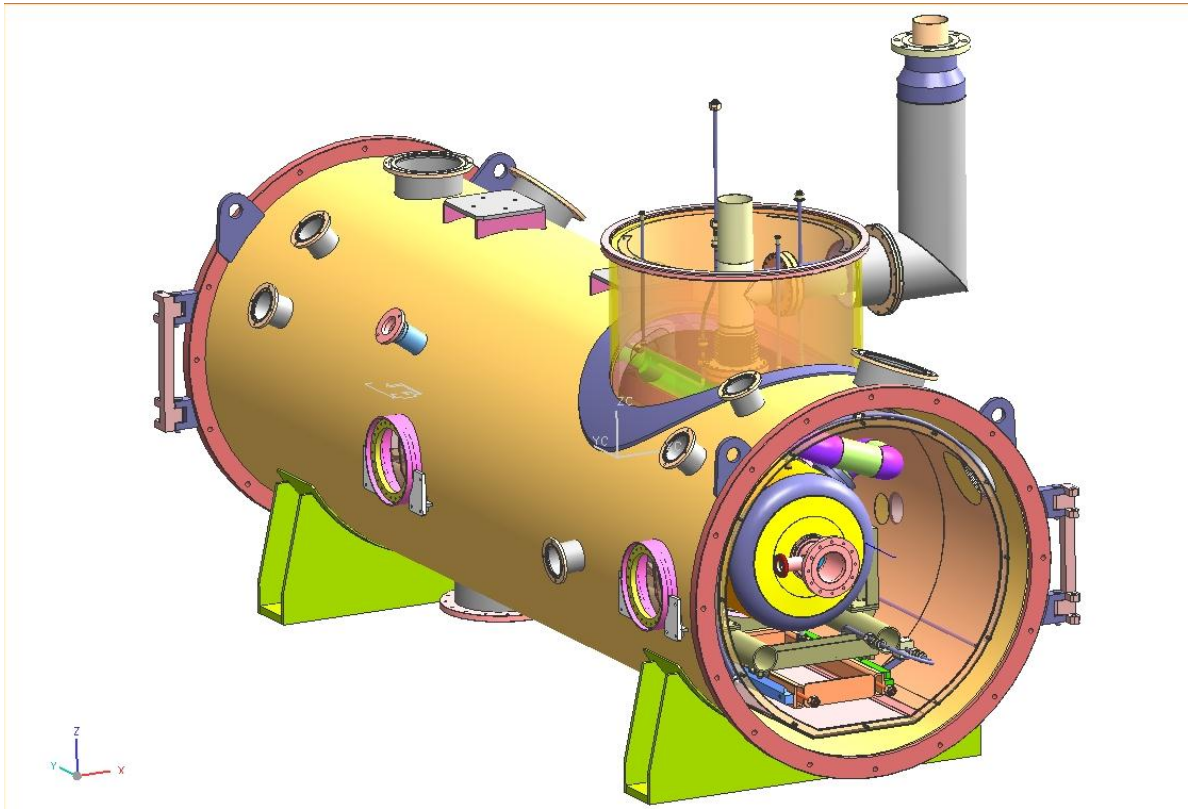
Development of 650 MHz single cell SCRF cavity

- Forming tool development & Half cell forming :
  - Initial forming trails have been carried out in Alumunim and Copper.
  - Aluminum formed cell, end flanges, & beam pipe are ready for welding trails.

Status of HTS-2 Design Efforts at RRCAT

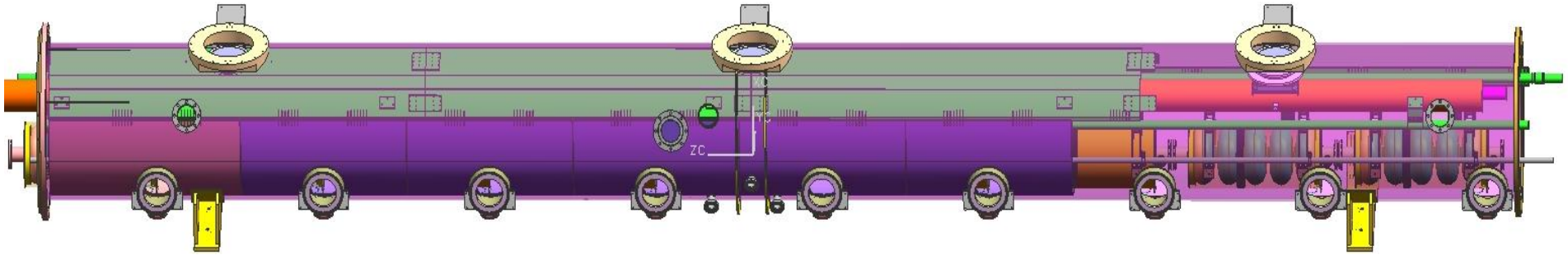
In Collaboration with FNAL RRCAT has to design and fabricate a Horizontal Test Stand cryostat capable of testing two SC Cavities of 650 MHz or any combinations with 1.3 GHz cavities or SC Magnet at a time.

An isometric view of HTS-2 vacuum vessel with relief



Joint development of RRCAT and Fermilab

Development of 650 MHz Cryomodule



650 MHz Cryomodule (3 D Model developed at RRCAT)

Indigenous Development of Nb for SRF Cavities

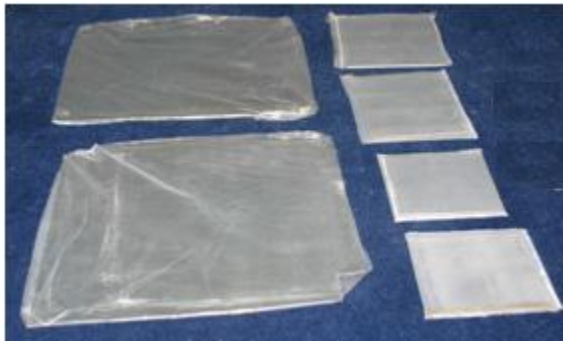
NFC, Hydrabad

- Development of material and testing of mechanical properties

RRCAT, Indore

- Electrical & superconducting properties and elemental analysis

Niobium sheets



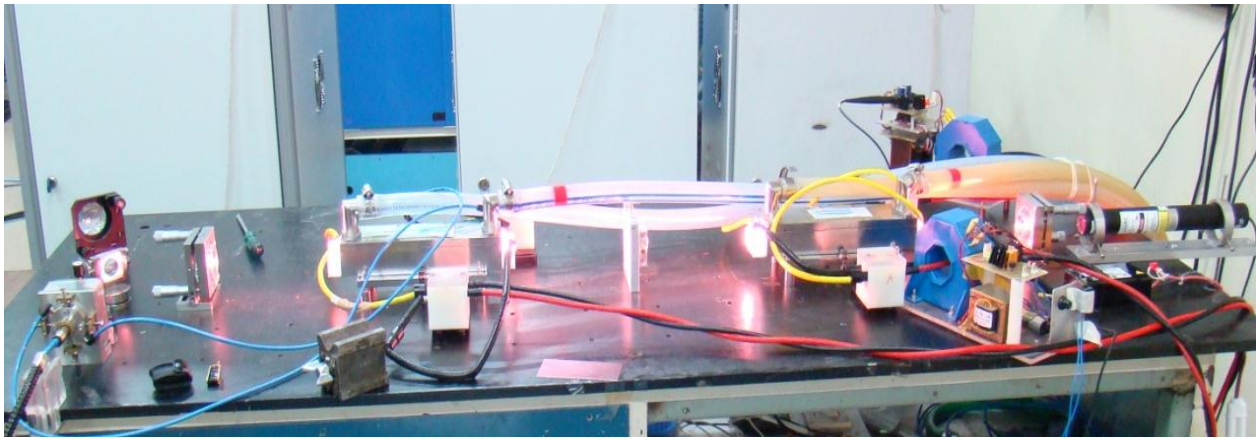
- RRR is ~ 100
- Size 300 mm x 2.8 mm thickness

Formed half cells (3.9 GHz)

- Suitable for 1.3 GHz Cavities
- SC properties acceptable

Laser Welding Technology for SRF Cavity Fabrication

20 kW Nd:YAG fiber-coupled laser



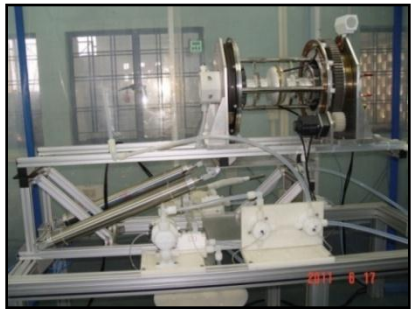
Prototype 3.9 GHz SCRF Nb cavity

Prototype 1.3GHz cavity Nb half cells welded

9-cell copper cavity

Infrastructure for SCRF Cavity Fabrication and Processing

Cavity forming facility



Electro-polishing setup

Centrifugal barrel polishing machine

High pressure rinsing Set up

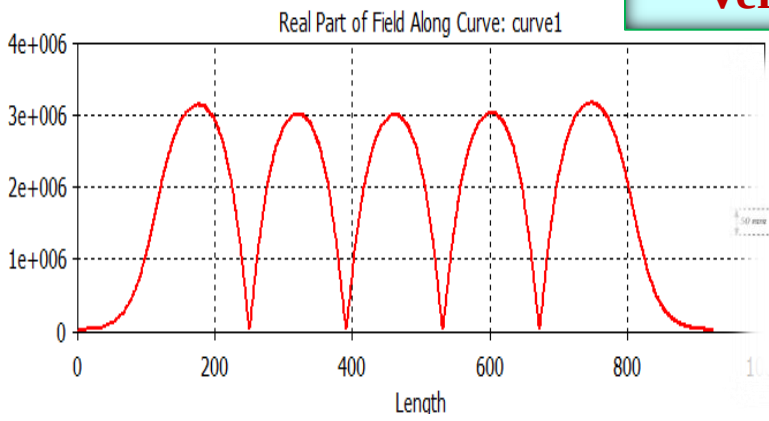
SCRF Cavity manufacturing hall

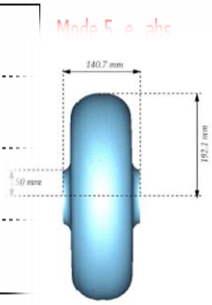
Test and measurement facilities building

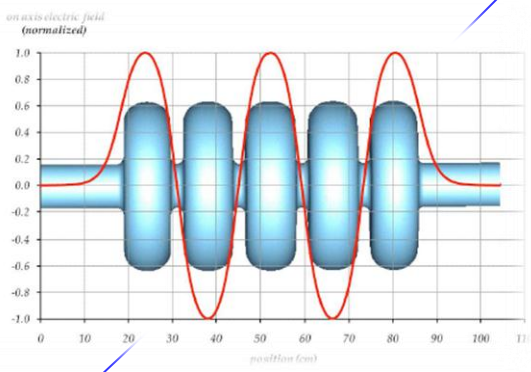
650 MHz, β=0.61, elliptical cavity simulation

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.R_s Ω	E_{acc} MV/m	$\frac{E_p}{E_{acc}}$	$\frac{B_p}{E_{acc}}$	$f_{\pi-mode}$ MHz	Remarks
VECC Design1 Result	$\frac{54}{58}$	$\frac{11.99}{27}$	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

Mechanical Fabrication of 650 MHz Aluminum prototype Cavity

- Puchase order for fabrication of prototype aluminum cavity : half-cells for 1-cell & 5-cell (Full scale) has been placed with a local vendor
- Die/Punch assembly developed.
- Reasonable Progress has been made. Expected to be completed soon.

Present Status

- EM design and analysis, Structural analysis, Mechanical modal analysis of the 5-cell 650 MHz, β=0.61, SCRF cavity has been carried out.
- Fabrication of die has been done and deep drawing trial of aluminum half-cell is in progress by local vendor.
- After successful completion of aluminum prototype, fabrication of Niobium cavity will start.
- 600 x 600 x 4 mm. Nb sheet (RRR > 300) already procured from ATI Wah Chang.
- Electron Beam Welding of Nb Half Cells will be carried out at IUAC, New Delhi (MOU already signed!)
- For SSR1, Strong Back temperature distribution (3D analysis) has been carried out. Waiting to start fabrication of SS jacketing for SSR1 (Final version of Drawing yet to be received)

Summary

- Indian Institutions along with Fermilab are making significant R&D, infrastructure and industrial progress that could lead to
  - Construction of two accelerators in India
  - Project X construction at Fermilab.
  - Training of next generation of scientists
- We have set the foundation of a very strong technical collaboration with Fermilab.
- DAE and DOE are working to finalize project Annexes for the funding of DAE programs and Fermilab.
- Support of all collaborating institutions for this unique collaboration is very strong

धन्यवाद

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