Fermilab

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PIP-II Joint R&D under the Indian Institutions and Fermilab Collaboration

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PIP-II
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Outline

- Development of Collaboration
- Indian Institutions and Fermilab Collaboration on R&D
  - Areas of R&D Collaboration
  - Technical Progress
  - R&D Phase Summary
- DAE-DOE Discovery Science Agreement Project Annex I
  - Indian Strategy on PIP-II
  - Project Annex I: Areas of Collaboration
  - Project Annex I: PIP-II Construction deliverables
- Summary

The PIP-II goal is to support long-term physics research goals by providing increased beam power to LBNF, while providing a platform for the future.

At an affordable cost to DOE. Only possible with India Collaboration.

Establishment of India Collaboration (2005-2015)

AGREEMENT

ON

SCIENCE AND TECHNOLOGY COOPERATION

BETWEEN

THE GOVERNMENT OF THE UNITED STATES OF AMERICA

AND

THE GOVERNMENT OF THE REPUBLIC OF INDIA

DONE at Washington, D.C., in duplicate, this 17th day of October 2005, in the English and Hindi languages, each text being equally authentic. In case of ambiguity the English language version takes precedence.

FOR THE GOVERNMENT OF THE UNITED STATES OF AMERICA:

FOR THE GOVERNMENT OF THE REPUBLIC OF INDIA:

2005

2007

Indian Institutions and Fermilab Collaboration

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

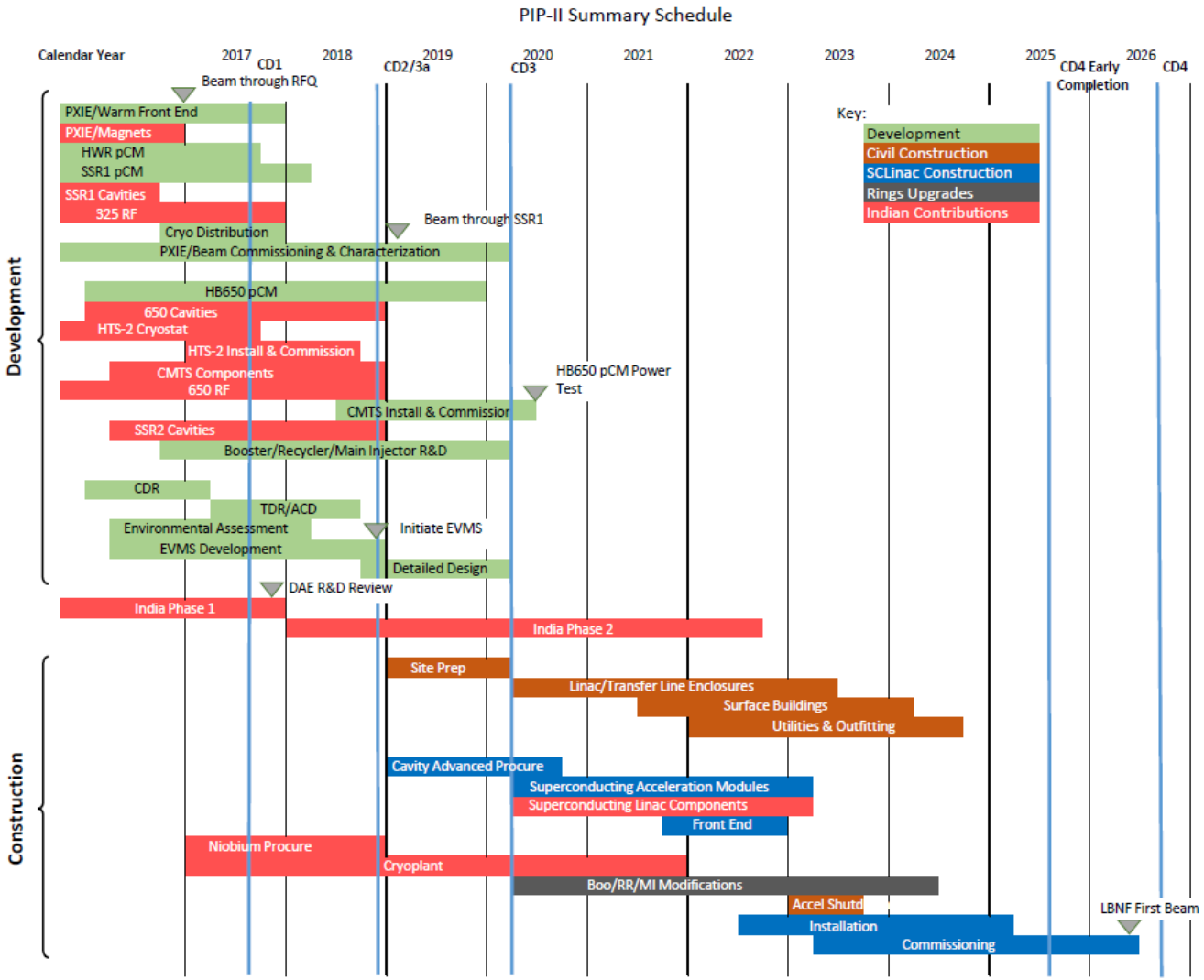
PIP-II R&D Technical work under Institution MOU

1. Collaboration on ILC Main Linac SRF Accelerator Technology R&D" (October 2, 2007)
2. Collaboration on ILC RF Power Sources and Beam Dump Design R&D" (December 3, 2007)
3. Collaboration on High Intensity Proton Accelerator and SRF Infrastructure Development" (February 10, 2009)
4. **Collaboration on Neutrino Physics, Related Experiments and Detector Development (Nov 2009)**
5. Collaboration on RF Power (325 MHz) Development for High Intensity Proton Accelerator" (August 22, 2011)
6. Collaboration on RF Power (650 MHz) Development for High Intensity Proton Accelerator" (Aug 22,2011)
7. Collaboration on Instrumentation and Control for High Intensity Proton Accelerator" (Aug 22, 2011)
8. Collaboration on Accelerator Physics issues for High Intensity Proton Accelerator" (Aug 22, 2011)

IIFC: Joint R&D

- A DAE-DOE Joint Project Document for the R&D Phase of IIFC was signed in Aug 2015.
- Goals:
  - Jointly Retire all the critical R&D by end of CY2018
    - Cover each major component of SRF Linac downstream of HWR.
  - Develop infrastructure and industries for the PIP-II construction phase In-Kind Contributions.
- Development and test of SSR1 Cryomodule with beam at PXIE
  - Deliverables from India
    - 2 SSR1 Dressed Cavities, CM Design
    - 8, 325 MHz 7 kWatt Solid State RF Amplifiers System
    - RF Protection Interlock and LLRF
- Development and Test of one HB650 MHz Cryomodule
  - Deliverables from India
    - 3 HB650 Dressed Cavities
    - Horizontal Test Stand
    - 8, 650 MHz 40 kWatt Solid State RF Amplifiers System
    - RF Protection Interlock and LLRF
- Development LB650 Dressed Cavities.
- Development of SSR2 Cavities.

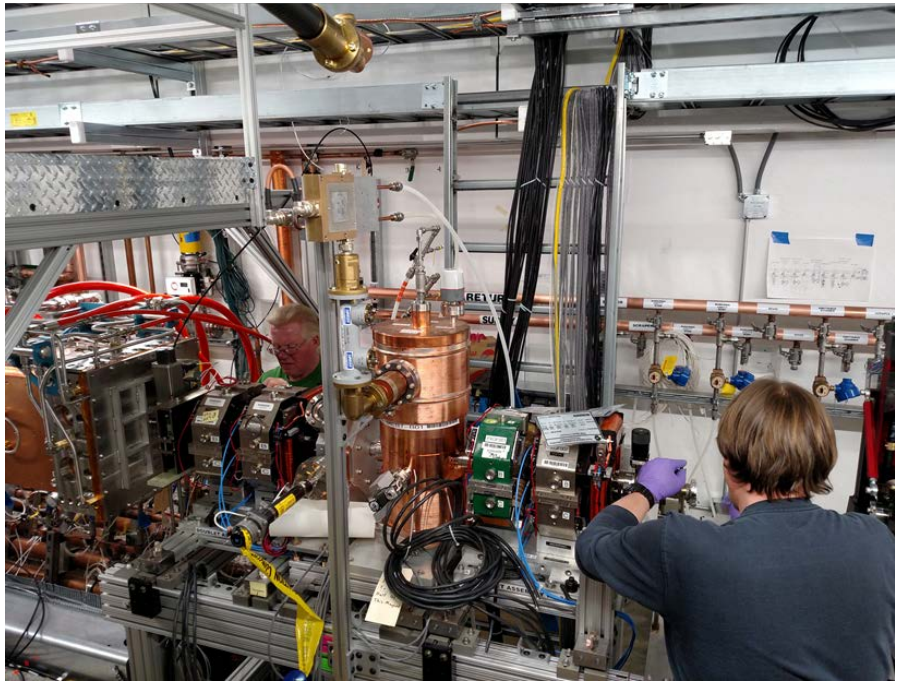
PIP-II Status: Preliminary Schedule



[Latest IIFC Joint R&D Schedule.]

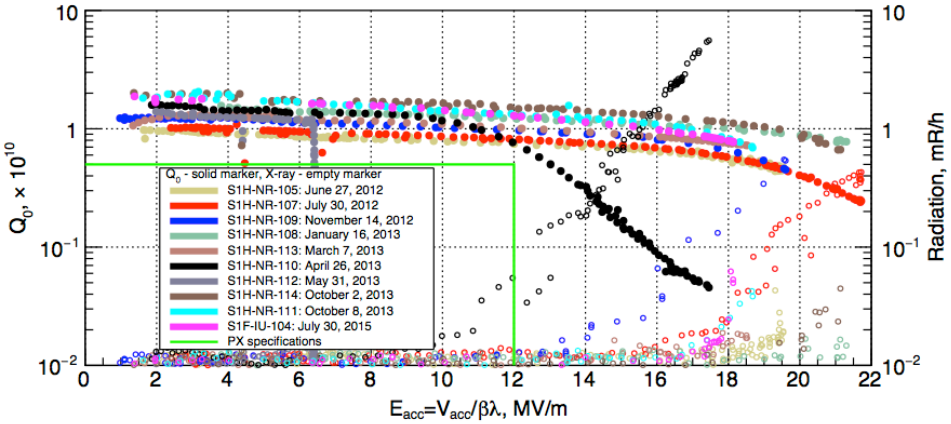
IIFC: MEBT Dipole and Quadrupole

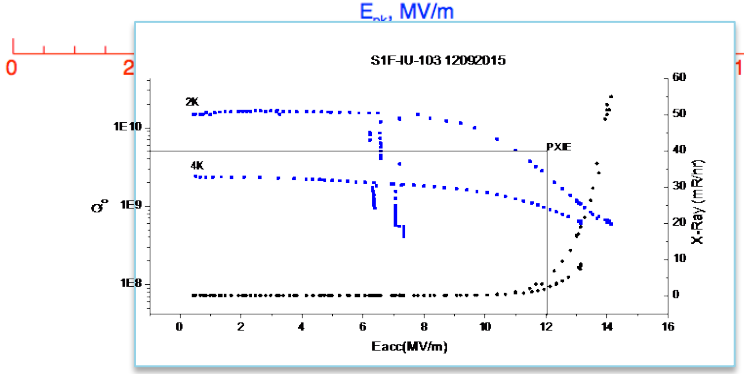
- **BARC is designing and fabricating:**
  - **Dipole and Quadrupole for MEBT**
  - **Solenoid for SSR2**
  - **Warm Magnets for the 650 MHz Section of SRF Linac**



IIFC: β = 0.22 R&D: IUAC, BARC and FNAL

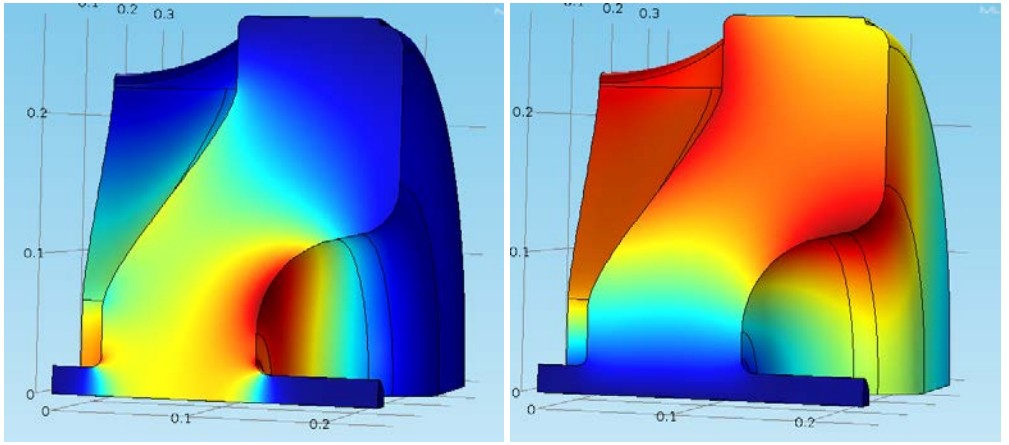
- Two SSR1 cavities were received from IUAC,
- Chemically processed at ANL and cold-tested at Fermilab
  - IUAC fabricated cavity meets the PIP-II specifications
- Cavities will be dressed at IUAC/BARC





IIFC: β = 0.47: BARC, IUAC and FNAL

- Fermilab has worked on SSR2 RF Design.
- BARC has initiated to expand on this SSR2 design and will fabricate 1st prototype.
  - Nb provided by Fermilab
- BARC Investigating details of cavity design, fabrication, including e-beam facility



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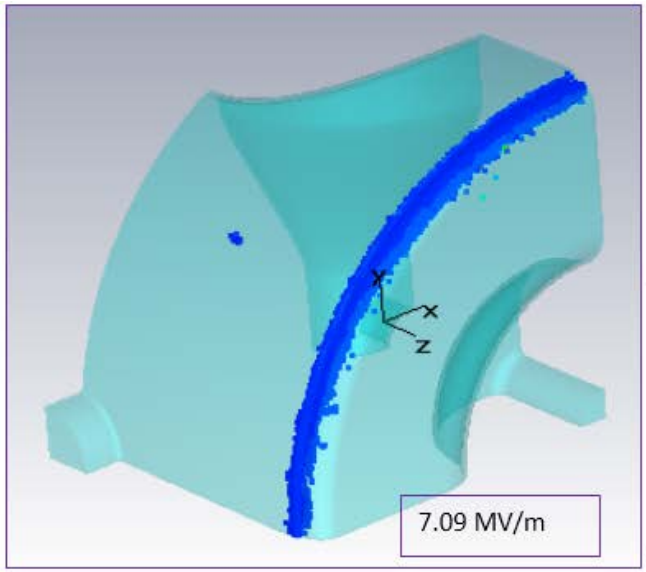
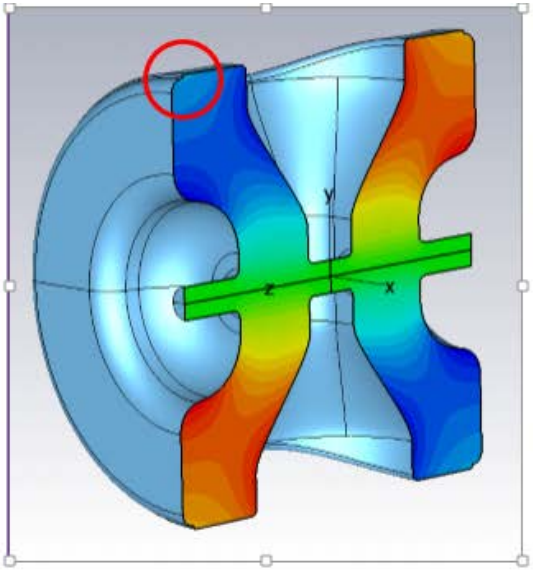
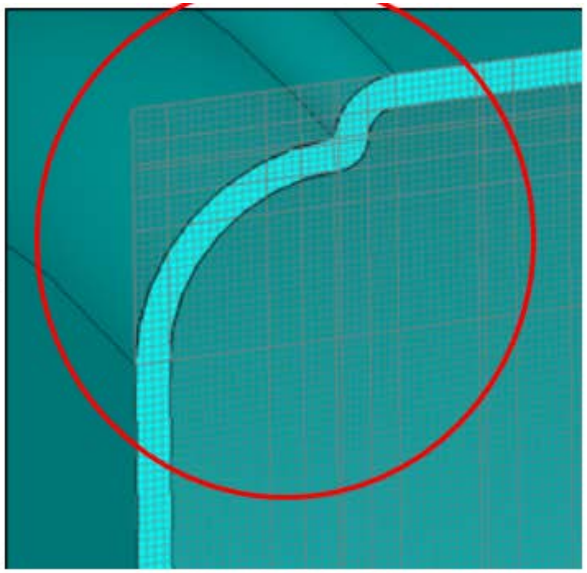
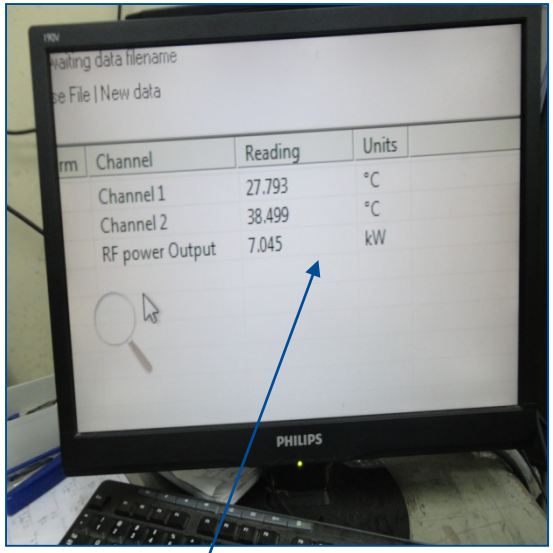






IIFC: 7 kW, 325 MHz SSRFPA (BARC)

Display of Calorimetric measurement of RF Power



Sensor data of Calorimetric measurement of RF Power

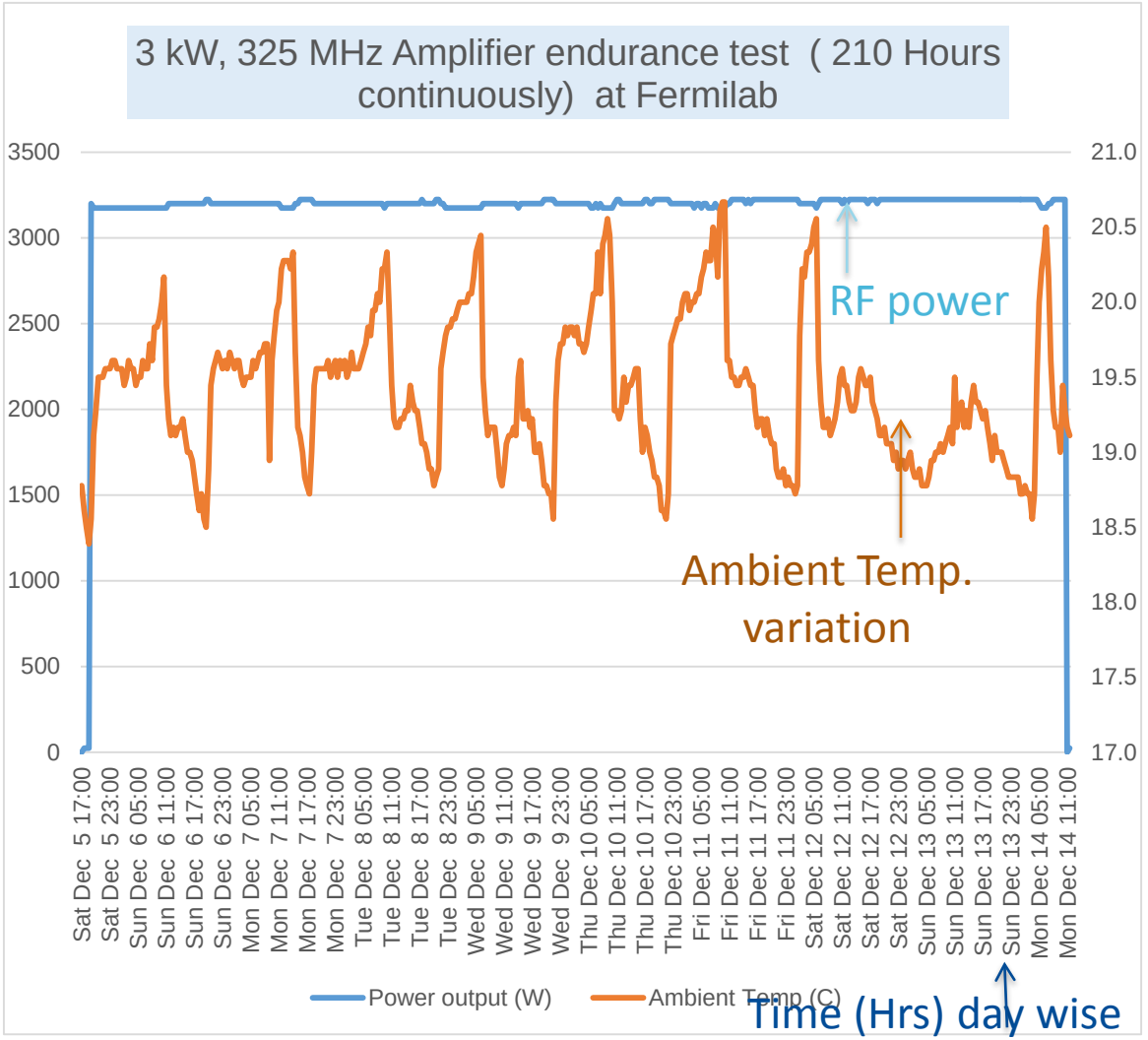
RF Power Waveform at 7 kW on spectrum analyzer

Meets the Design Specifications

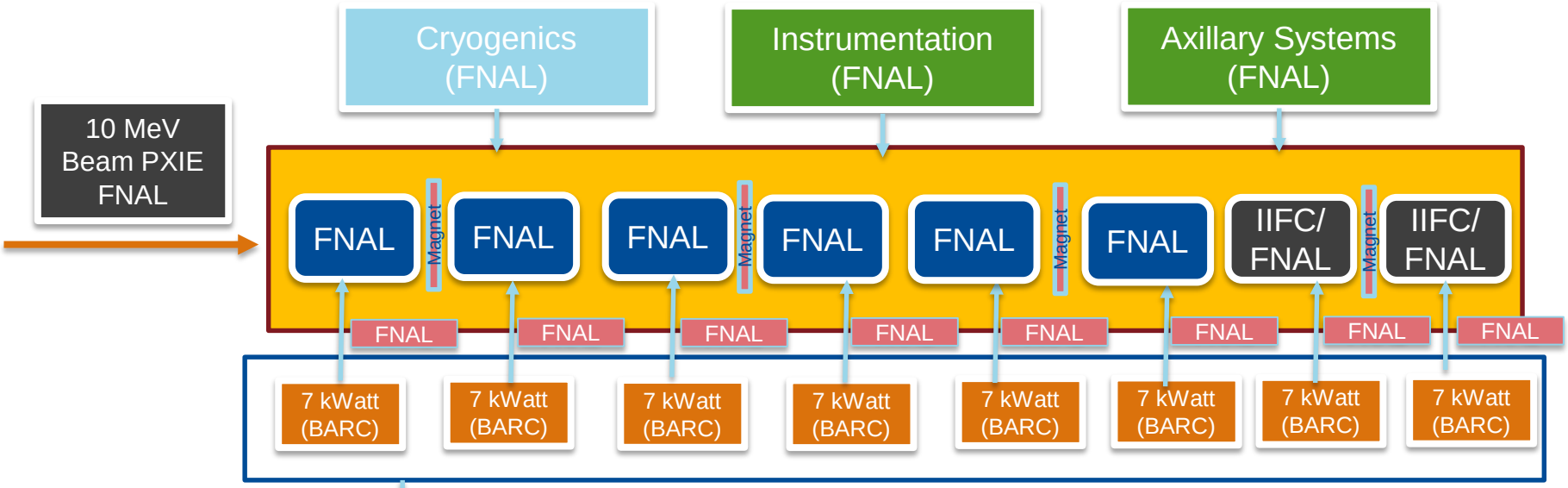
Test of 3 kW at 325 MHz amplifier @ Fermilab

3 kW RF Amplifier

- Power: 3 kW
- Overall Gain: > 65 dB
- Efficiency : 65 %
- Spurious noise:<- 70 dBc



System Test of SSR1 CM & RF Power with Beam at Fermilab



IIFC RF Protection (FNAL/BARC)

IIFC LLRF (FNAL/BARC)

Integration and Controls (FNAL/BARC)

Q3-CY2018 With Beam

SSR1 CM May 2017
Solid State RF Jan 2018
LLRF/RF Protection Jan 2018
Control System Jan 2018
Cryogenic for SSR1 Jan 2018
Integration with CM July 2018
(completion dates shown)

Development of β = 0.61, 1-cell Nb cavity (VECC)

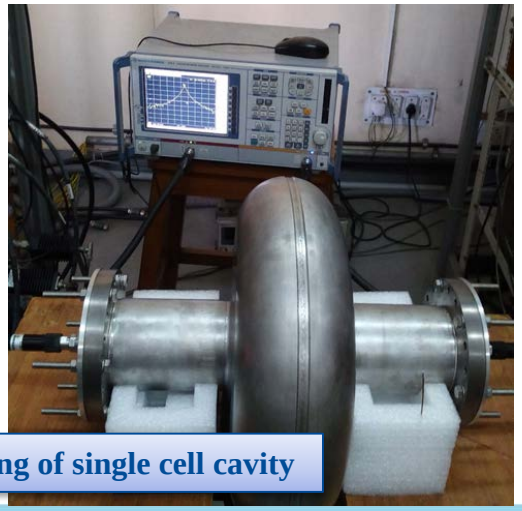
- VECC has fabricated one β = 0.61, 1-cell Nb cavity in collaboration with IUAC. (Dec 2015)
- Processing and testing at Fermilab (3/2016)

Half cells after cleaning

1-cell cavity under fabrication

Vacuum leak rate checking of single cell cavity at LN_2 temperature

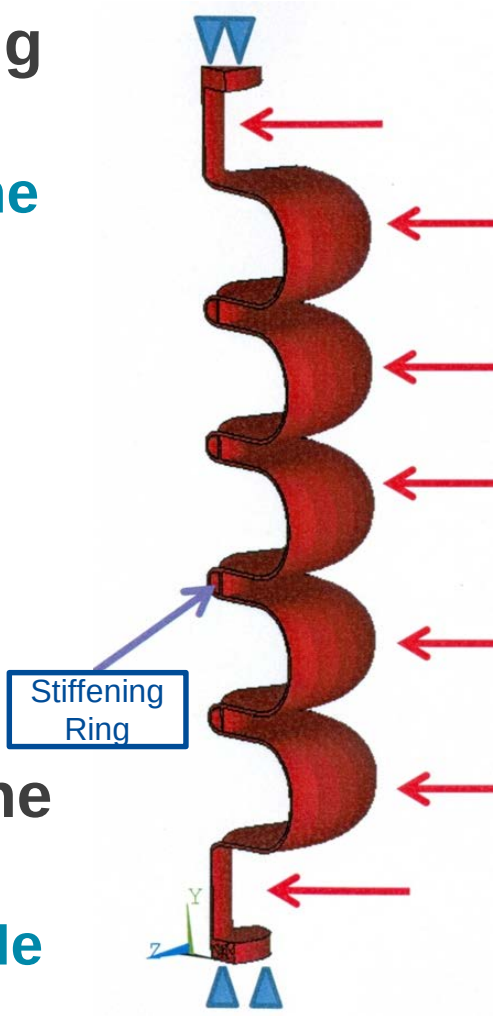
Cavity half cells being put inside EBW machine for Equator welding



VNA testing of single cell cavity

Design Development of β = 0.61, 650 MHz cavity (VECC)

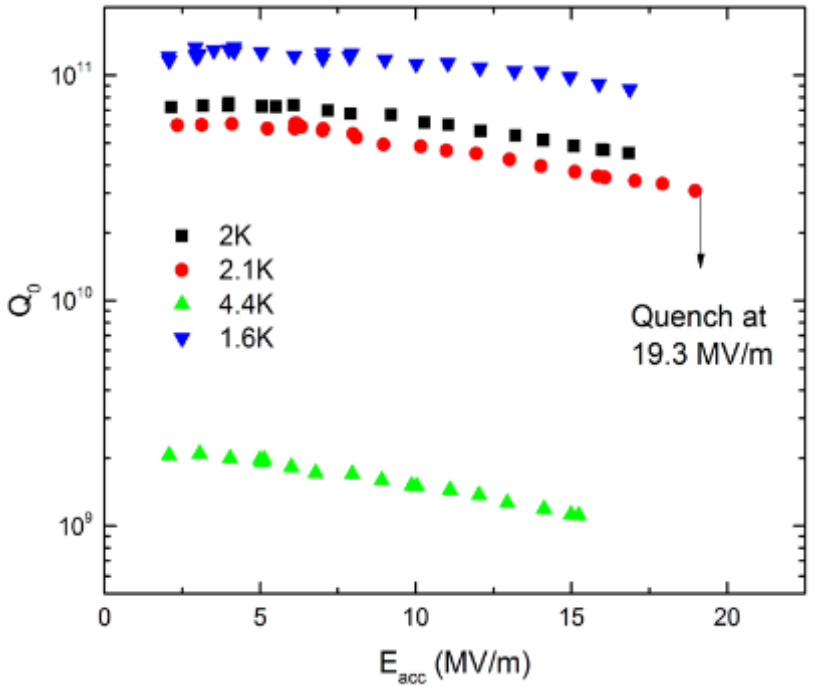
- 5-cell LB650 cavity design carried out, using new FRS.
  - The necessary parameters are well within the prescribed limits .
- The design studies includes
  - 3D Multipacting
  - Lorentz Force Detuning (LFD)
  - Pressure sensitivity under external liquid helium pressure
  - Structural analysis with Stiffener Rings
- Further study is in progress for finalizing the design.
  - It will include the Fermilab End Group and He Vessel design.



Status of 650 MHz single-cell cavity (RRCAT)

- RRCAT/IUAC Fabricated one Nb HB650 650 MHz single-cell cavity (July 2013).
  - Processed & tested at Fermilab
  - The cavity achieved E_{acc} 19.3 MV/m with Q > 4E10 at 2K.

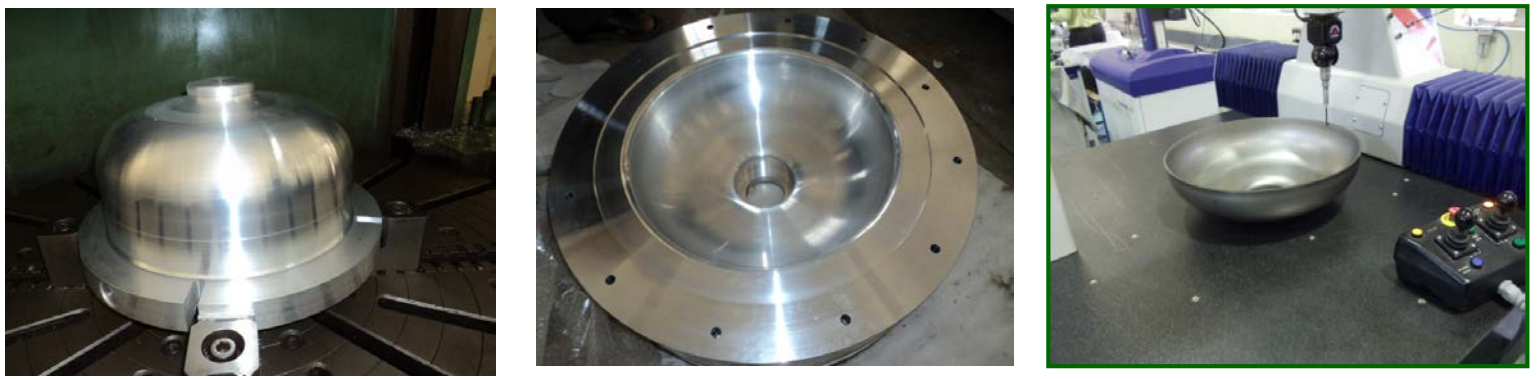
Cavity VTS mounting



Q0 vs Eacc plot of Cavity

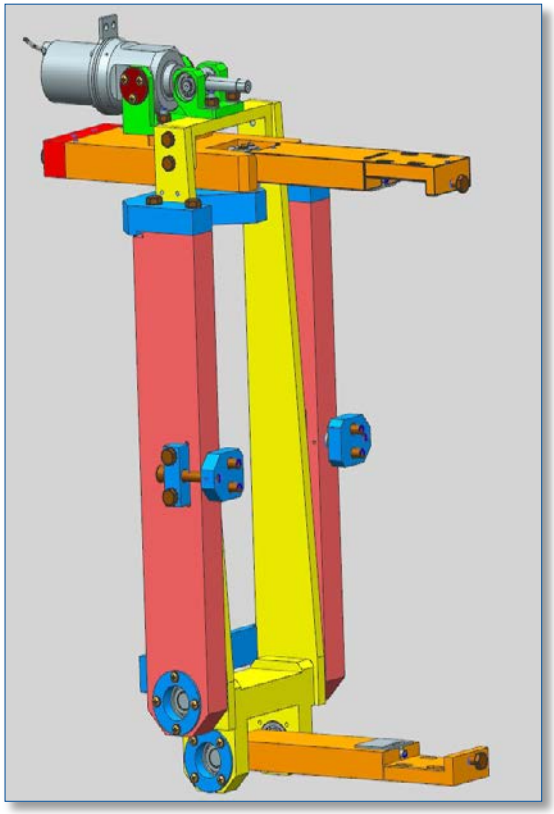
IIFC: Progress on HB650 cavity (RRCAT)

- In October 2013, 650 MHz cavity beta was changed from 0.9 to 0.92 to improve the cavity performance at high current.
- HB650 (β=0.92) five-cell cavity development at RRCAT
  - New set of forming tools for β=0.92 five-cell cavity have been made.
  - Initial half-cell forming on copper and niobium has been carried out.
- High RRR niobium sheets procured will be used for 1st five-cell cavity.
  - Nb-Ti and Ti procured earlier can not be used for β=0.92 cavity due to change in dimensions.
- Development of various fixtures has been taken up after final design of HB650 cavity released from Fermilab on 2/10/2016.

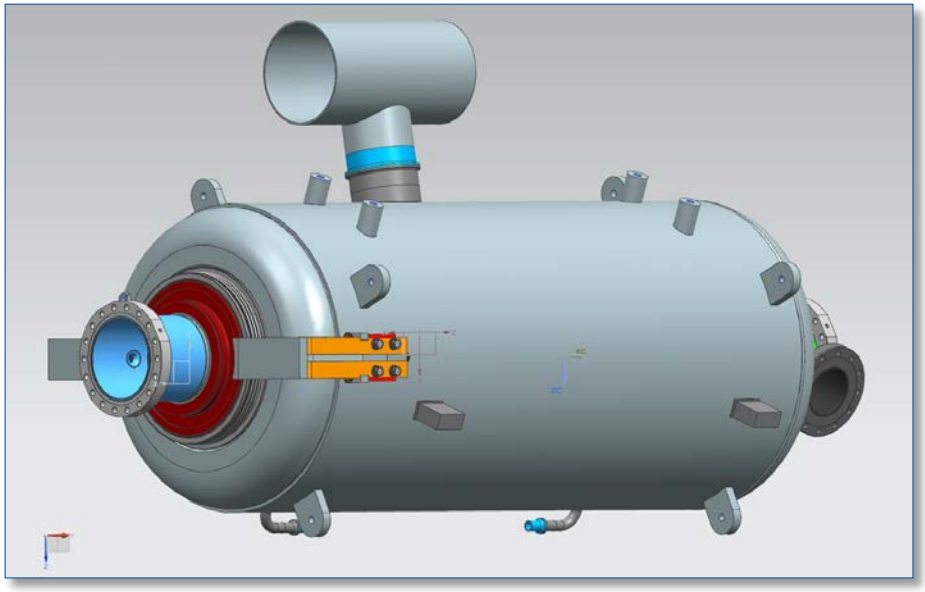


HB650 (β=0.92) forming tool and formed half-cell

Tuner and Helium Vessel for HB Cavity



End Lever Tuner



Helium Vessel with Auxiliaries and Supported by Bellow Restrain

Tuner Stiffness ~ 68 kN/mm

IIFC: 650 Cryomodule Design (FNAL and RRCAT)

- Design of cryomodule for 650 MHz, β = 0.92 SCRF cavity is under progress.
  - One cryomodule contains six cavities and no magnet
  - Cryomodule is standalone unit
- Major design activities with regard to major subsystems of cryomodule are
  - Preliminary design almost complete
    - ✓ Vacuum vessel
    - ✓ Thermal shield
  - Design for following subsystems is to be start
    - Strong back support
    - Cryogenic Flow distribution
    - Cooldown piping system

650 MHz RF Power (RRCAT)

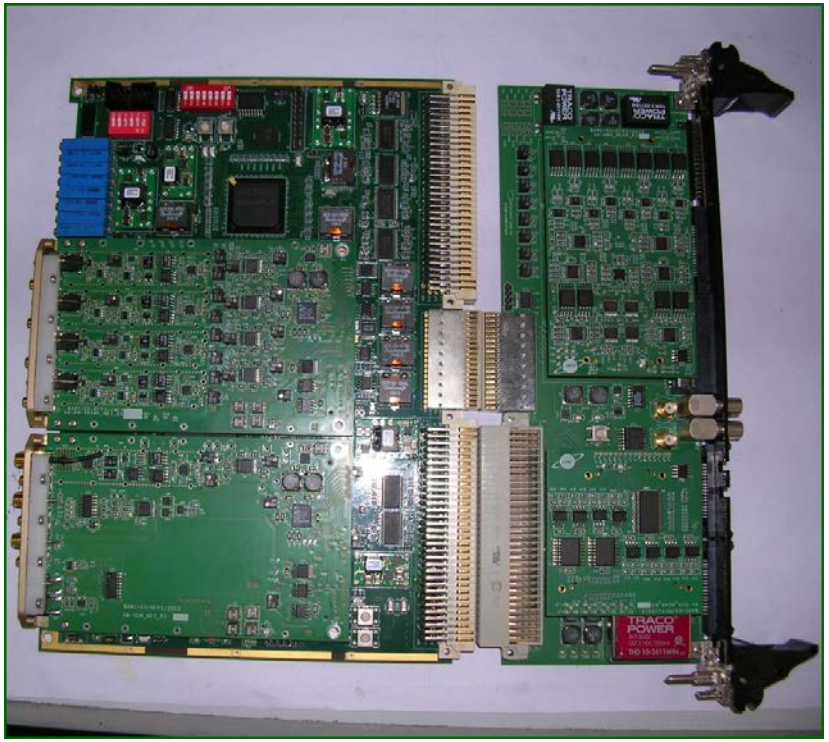
Assembled 15 kW Amplifier of size (1m*1.2m*2m)

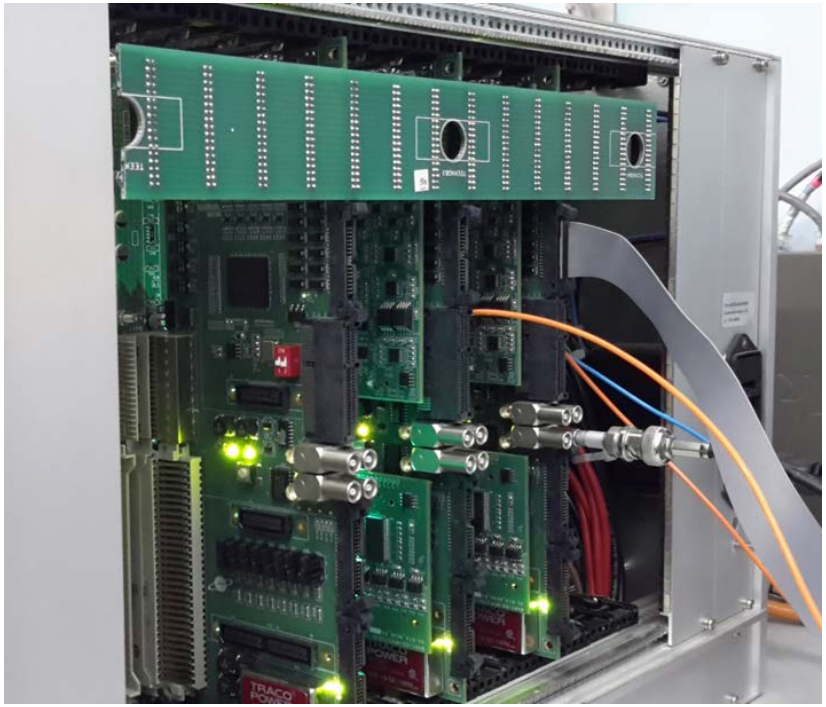
Testing of 30 kW amplifier with dummy load

20

RF Protection and Interlock System (BARC)

- A complete redesign of the Fermilab RF Protection Interlock system has been done in collaboration with BARC.
- BARC has completed detail test
  - It will be tested at Fermilab at a High Power Test Stand this summer.

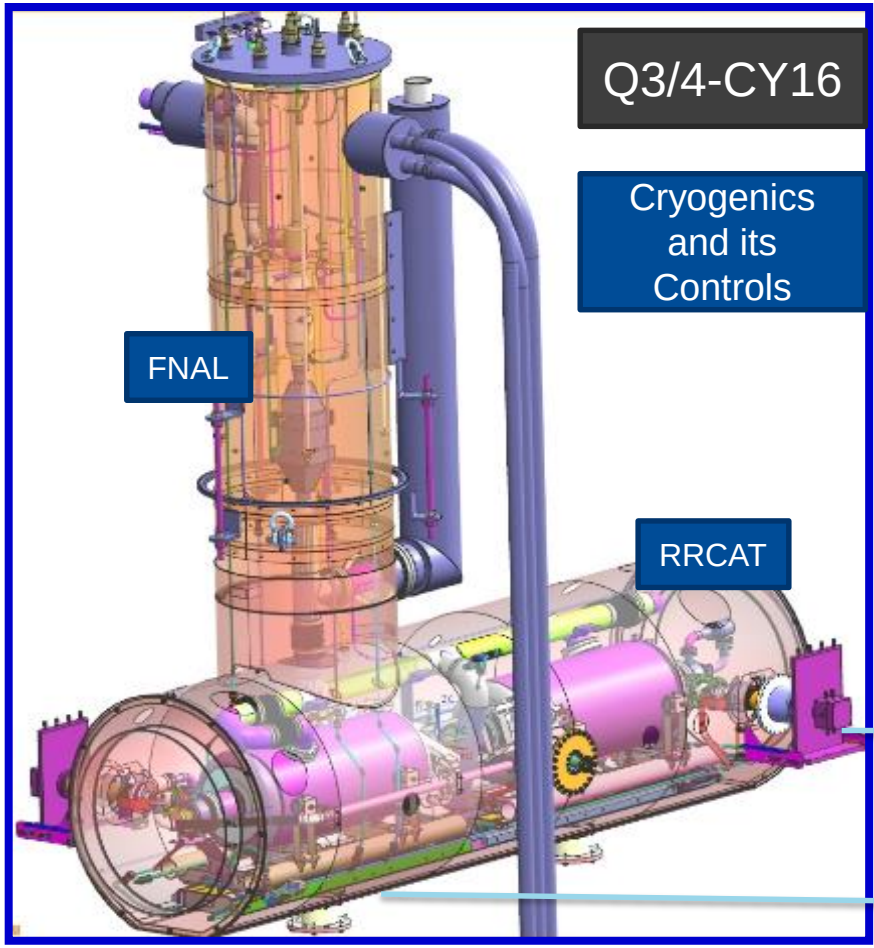




IIFC: Work Plan (Fermilab and BARC)

- Fermilab shared the LLRF details with BARC in November 2015.
  - FRS, TRS and interface documents are being finalized
- The changes in the design will be carried out at BARC based on the testing at Fermilab
- The design for next generation LLRF system will be done jointly by Fermilab and BARC.
  - VHDL codes, Software and firmware for SoC based digital LLRF module and resonance control module
  - EPICS and GUI development
- BARC will supply prototype boards for a development system for testing and software development at BARC and Fermilab
  - Mirror test systems
- Final boards will be fabricated by BARC based on testing

IIFC: 650 MHz Dressed Cavity Horizontal Test Stand



Two 40 kWatt Units (RRCAT)

FNAL

FNAL

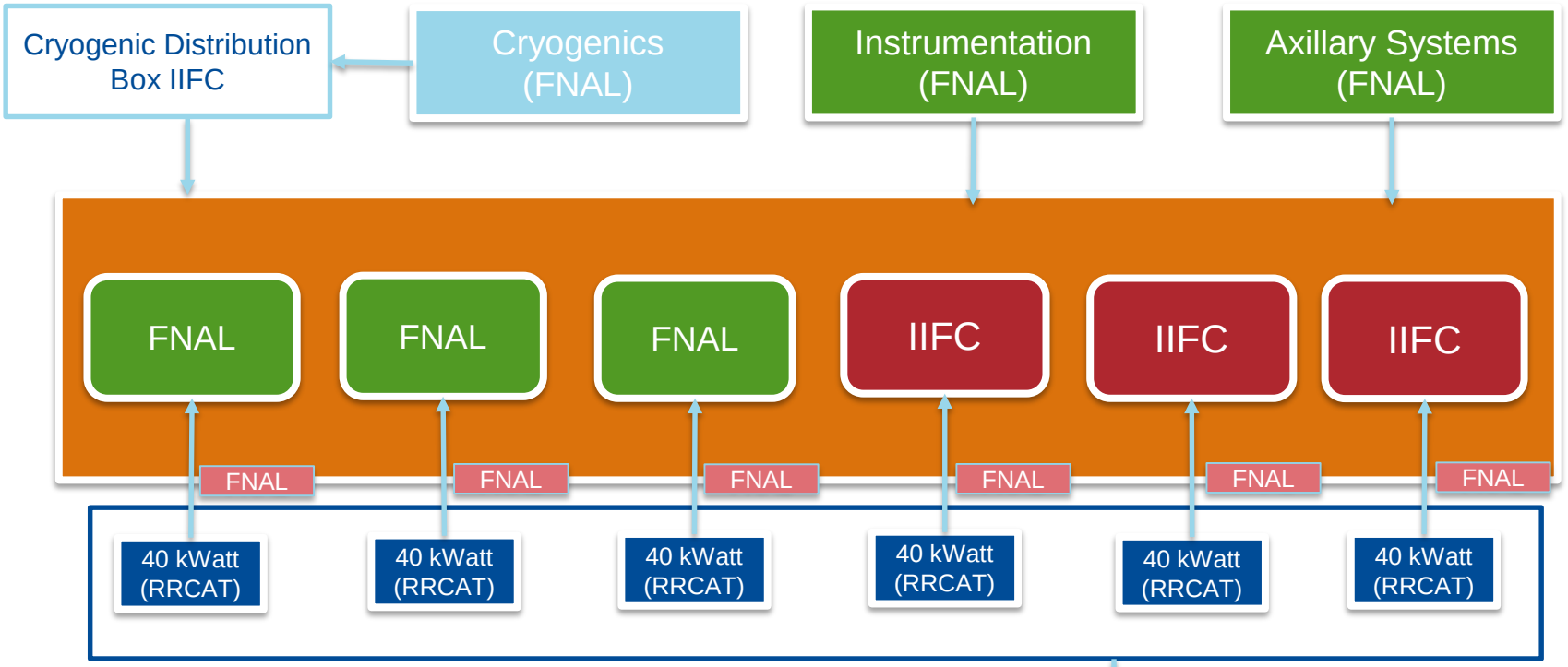
Cryostat at Fermilab May 2017
Cryogenics for HTS July 2017
Two 40kWatt RF July 2017
LLRF/RF Protection July 2017
Control System May 2017
Integration with cryostat Oct 2017
Test of 1st Dressed Cavity Dec 2017

IIFC RF Protection (FNAL/BARC)

LLRF (FNAL/BARC)

Integration and Controls (FNAL/BARC)

Integrated Test of HB650 Cryomodule and RF Power



Q4-CY2018 CM Cold With RF

IIFC LLRF (FNAL/BARC)

IIFC RF Protection (FNAL/BARC)

Integration and Controls (FNAL/BARC)

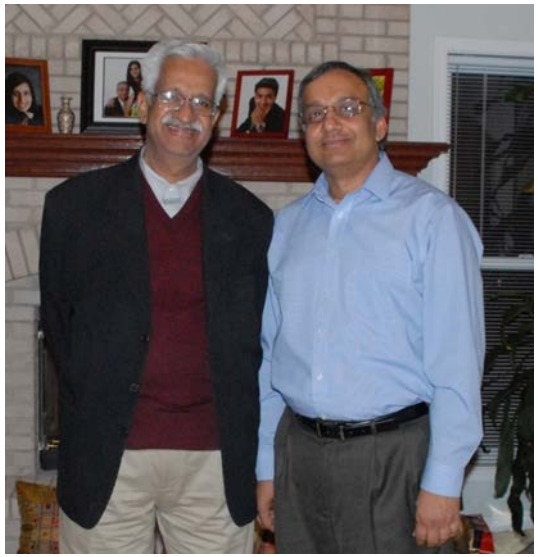
Solid State RF April 2018
LLRF/RF Protection April 2018
Control System April 2018
Cryogenic for April 2018
Integration without CM July 2018
HB650 CM Sept 2018

IIFC: 650 MHz Cryomodule Test Stand

- **BARC will start the design of the 650 MHz CM test stand in FY2015.**
- **650 CM will be closed system with a cryo-distribution in the middle.**
  - **It is expected to be a relatively easier design. As compared to 1.3 GHz CM design and construction.**
- **Goal: 2018**

Establishing procedure for large scale cryo fabrication

US India Strategic Interest: DOE-DAE-DST



IMPLEMENTING AGREEMENT

BETWEEN

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA

AND

THE DEPARTMENT OF ATOMIC ENERGY

OF THE REPUBLIC OF INDIA

FOR COOPERATION

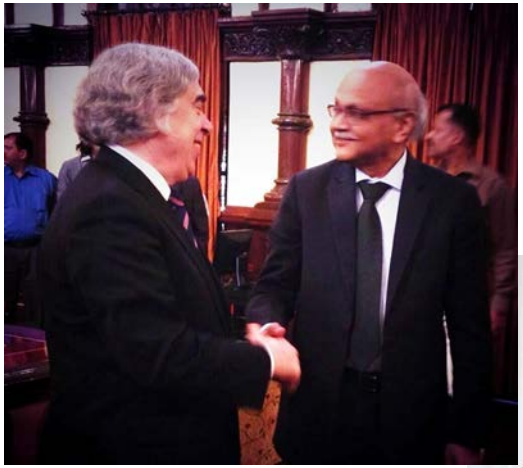
IN THE AREA OF ACCELERATOR AND PARTICLE DETECTOR RESEARCH

DONE at New Delhi, in duplicate, this 19th day of July 2011, in the English and Hindi languages, each text being equally authentic.

FOR THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA:

FOR THE DEPARTMENT OF ATOMIC ENERGY OF THE REPUBLIC OF INDIA:

Accelerator Collaboration 2015: Annex I



PROJECT ANNEX I

TO THE IMPLEMENTING AGREEMENT
BETWEEN
THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA
AND
RTMENT OF ATOMIC ENERGY
THE REPUBLIC OF INDIA
FOR COOPERATION
CELERATOR AND PARTICLE DETECTOR
VELOPMENT FOR DISCOVERY SCIENCE
FOR
NSITY PROTON ACCELERATORS

DONE at Mumbai, in duplicate, this 6th

FOR THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA:

Washington
January 21, 2015

FOR THE DEPARTMENT OF ATOMIC ENERGY OF THE REPUBLIC OF INDIA:

Project Annex I: Areas for Cooperation

Jointly managed by Fermilab and DAE laboratories.

Section 2 – Areas for Cooperation

Cooperation under this Project Annex may include, but is not limited to, the following areas:

A. Technical Cooperation

1. HISPA Design
2. High Intensity Particle Source
3. Radio Frequency Quadrupole
4. Superconducting Radio Frequency Cavities

2

5. Cavity Helium Vessel and Tuner
6. Radio Frequency Power
7. High Power Radio Frequency Coupler
8. Distribution, monitoring and control of High Power Radio Frequency
9. Normal and Superconducting Solenoid, Dipole and Quadrupole magnets
10. Beam Instrumentation
11. HISPA Control
12. Cryogenic Plant, distribution and control
13. HISPA utilities including electricity, water, vacuum
14. HISPA integration
15. Cryo-modules
16. Superconducting Radio Frequency Cavity Processing Facilities and Test Stands

Detailed list of R&D and initial Construction deliverables exists

PIP-II Construction Deliverables: India

- A model for the In-Kind Contribution has been developed and presented to both DAE and DOE.
  - Formal agreement pending review of the R&D Phase
- Dressed High Power Tested Cavities (50%)
  - SSR2
  - LB650
  - HB650
- SSR2 Solenoid Magnets (100%)
- 650 Warm Magnets (100%)
- Solid State RF Amplifiers at 325 and 650 MHz at various power (100%)
- Cryogenic Plant (one)
- LLRF and RF Protection System
- BPM and BLM
- Control

Thanks to all

Summary

- **International Collaboration is vital for the timely execution of the PIP-II.**
  - **PIP-II is absolutely needed for the 1.2 MW running of DUNE.**
- **With India, Fermilab is working on R&D topics that spans the whole SRF accelerator.**
  - **These R&D should conclude by the end of CY18.**
    - **Which would retire all the critical PIP-II R&D.**
- **The construction deliverables are defined in the Joint Project Annex I Document**
  - **In CY17-18, Fermilab, DOE and DAE will decided on the final construction deliverable table for PIP-II.**
- **Fermilab and DOE are also working to develop collaborative programs with UK, France and Italy**