Fermilab

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International Collaborations for PIP-II: R&D and Construction

Shekhar Mishra and Pitamber Singh

DOE Independent Project Review of PIP-II

June 16-17, 2015

Fermilab and BARC

Outline

- DOE: Charge
- Introduction
- 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

DOE: Charge

1. Is the proposed technical concept, including both new construction and modifications to existing infrastructure, likely to satisfy the P5 recommendation? Are there major alternative technical choices? How well understood are the international in-kind contributions?

This talk addresses only:

- **How well understood are the international in-kind contributions?**

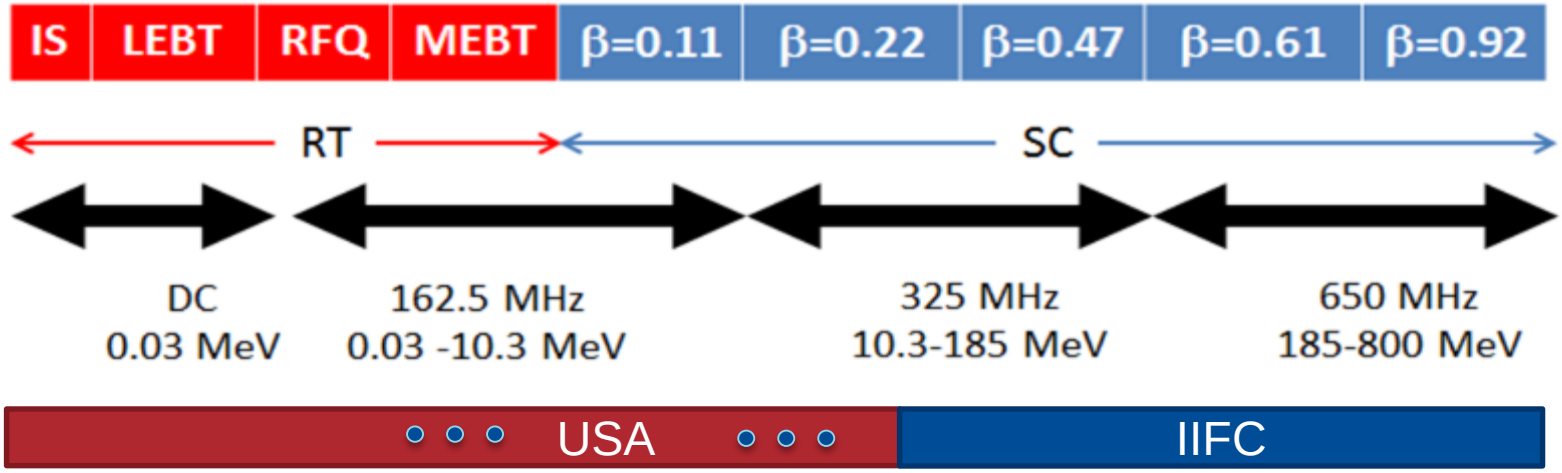
The expanded collaboration development and technical details of the Indian collaboration:

https://indico.fnal.gov/getFile.py/access?resId=0&materialId=slides&confId=10040

Introduction

- Fermilab has proposed construction of PIP-II a High Intensity Superconducting Proton Accelerator
  - Provide ~1.2 MW of proton beam at 120 GeV for the Deep Underground Neutrino Experiment (DUNE)
- Indian DAE laboratories have proposed construction of
  - Indian Spallation Neutron Source at RRCAT, Indore (Pulsed)
  - Accelerator for Medical, Energy and Industrial applications at BARC (CW)
- Indian Institutions Fermilab Collaboration (2007-Present) (8 Institutions level MOUs for R&D)
  - Initial collaboration confined to SRF R&D
  - Subsequently expanded to include R&D on
    - HLRF and LLRF, Cryogenics, Instrumentation, Magnets

Areas of R&D International Collaboration



High Power Tested Dressed SRF Cavity

- **β = 0.22: IUAC & VECC**
- **β = 0.47: BARC & IUAC**
- **β = 0.61: VECC (Europe)**
- **β = 0.92: RRCAT**
- **325 MHz RF Power: BARC**
- **650 MHz RF Power: RRCAT**

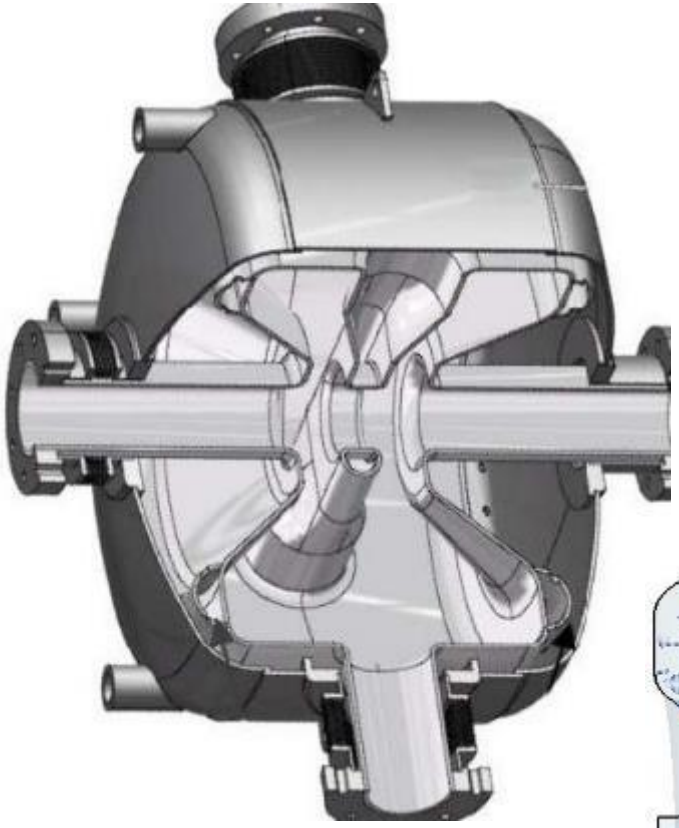
Non SRF components (BARC)

- **Cryogenic Plant and Distribution**
- **RF**
  - **LLRF**
  - **Protection System**
- **Instrumentation: BPM, BLM**
- **Controls**
- **MEBT Magnet**

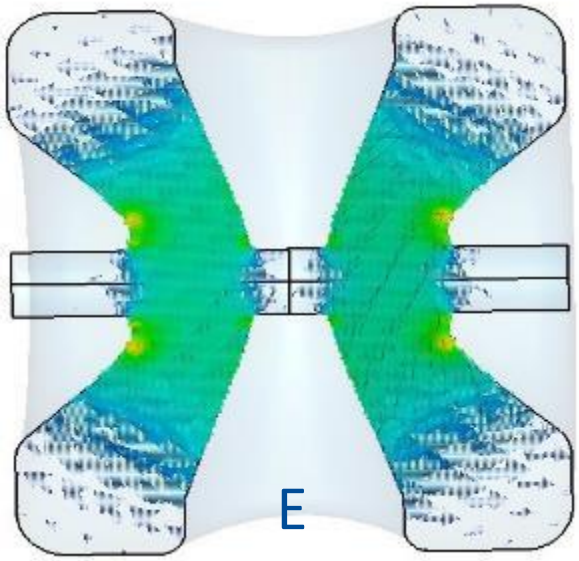
IIFC: β = 0.22 R&D: IUAC and VECC

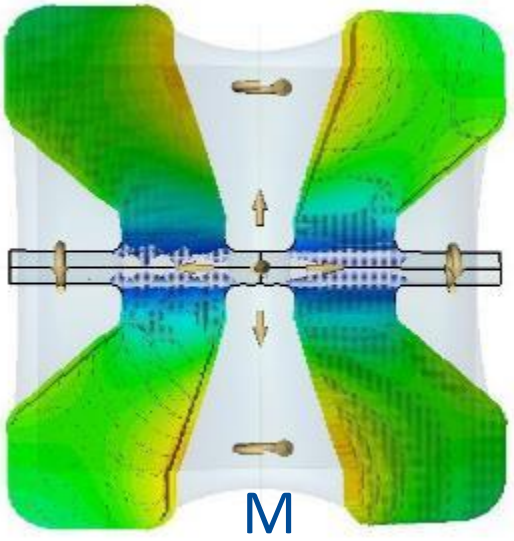
- IUAC has finished fabrication of two SSR1 cavities and delivered it to Fermilab.
  - Will be processed and VTS at ANL and Fermilab
- VECC/BARC will fabricated He Jacket, Tuner and ship it to Fermilab.
  - These two cavities will be dressed at Fermilab for installation in the 1st cryomodule to be tested at PXIE in 2018.

IIFC: β = 0.47: BARC & IUAC

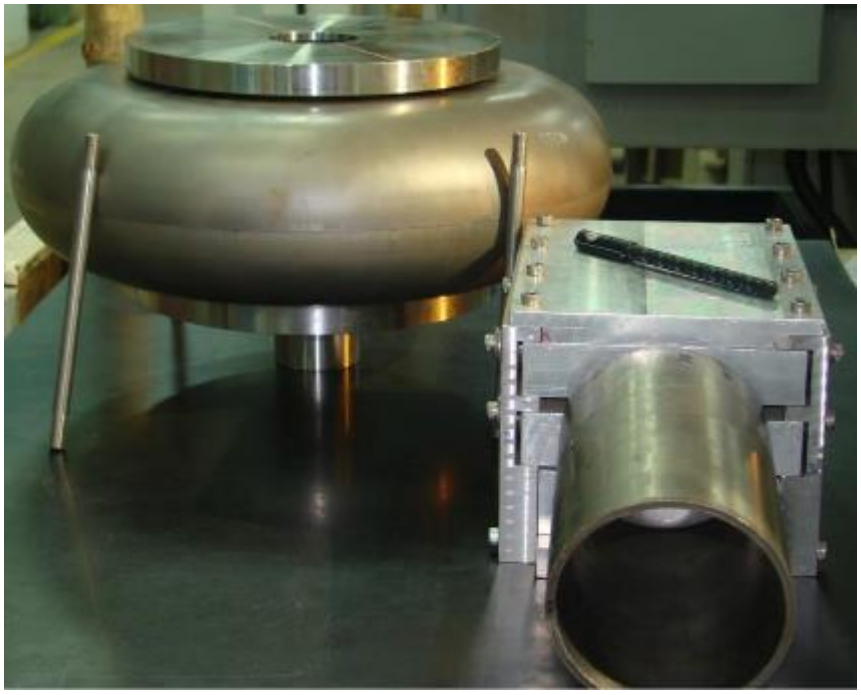


- **BARC has initiated SSR2 design and will fabricate 1st prototype in collaboration with IUAC.**
  - **Nb to be provided by Fermilab**
- **Investigating details of cavity design, fabrication, including e-**





IIFC: Development of β = 0.61, 1-cell Nb cavity



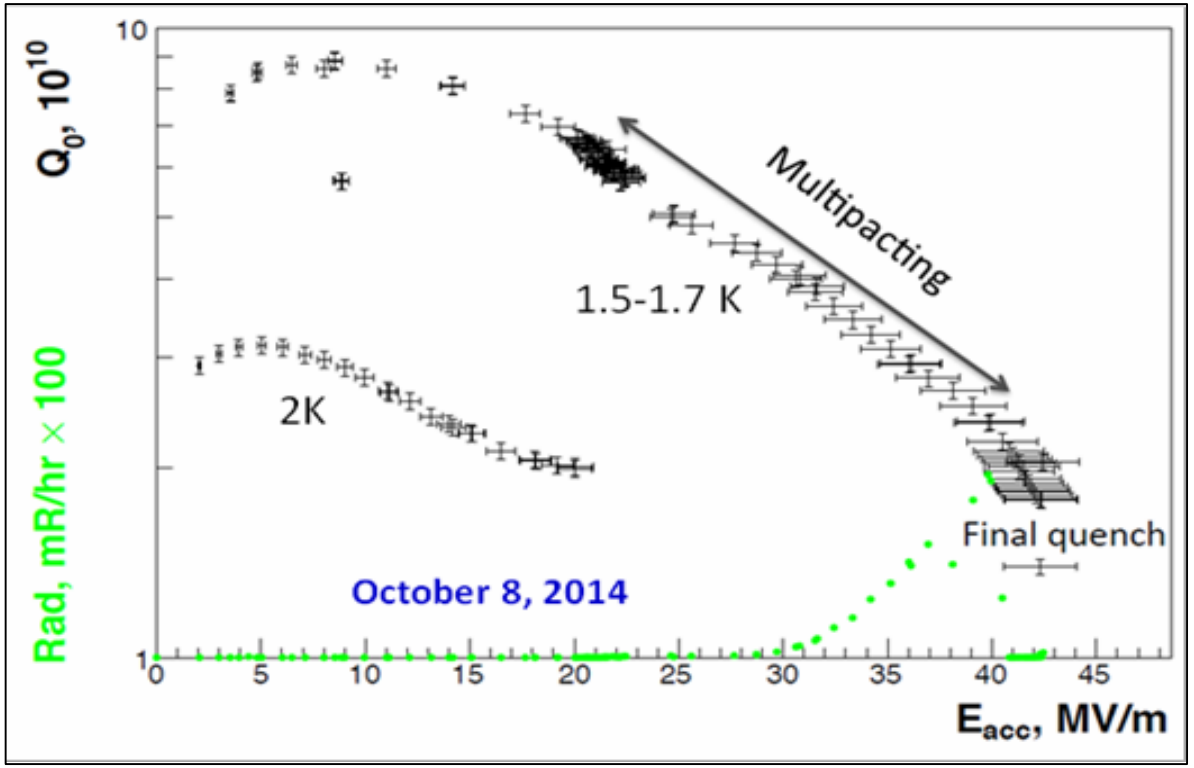
VECC has developed a complete design of a β = 0.61 cavity

- **Welding of cavity is planned at IUAC (July 2015)**
- **Processing and testing at Fermilab**

Niobium Half cells , beam pipes and necessary fixtures are ready for e-beam welding

IIFC: High Gradient Cavity Fabrication

1.3 GHz five-cell cavity on vertical test stand at Fermilab



Q vs E_{acc} plot for TE5CAT006

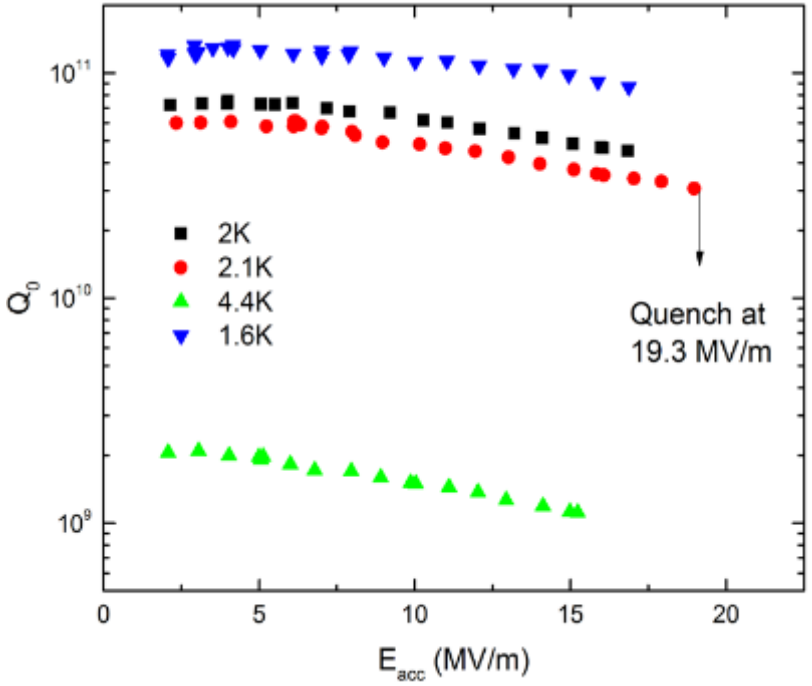
Processed and Tested at Fermilab

The 1.3 GHz five-cell cavity fabricated by RRCAT/IUAC was tested during October 2014. The cavity achieved accelerating gradient of 20.3 MV/m at 2K and 42 MV/m at 1.5-1.7 K with Q_0 of 2 x 10^{10}

IIFC: Status of 650 MHz single-cell cavity

- **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

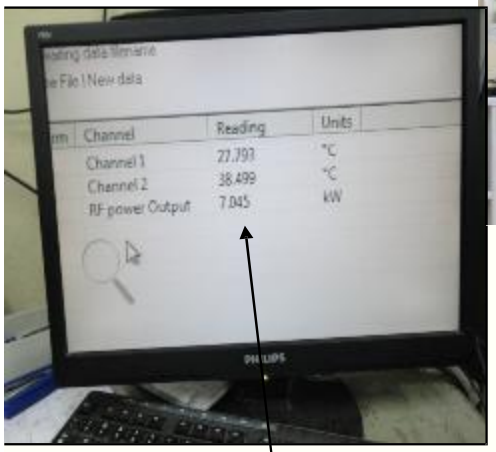
IIFC: 650 MHz Cryomodule Test Stand

- **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

DAE: 325 MHz Solid State RF Power Development

Display of Calorimetric measurement of RF Power



Sensor data of Calorimetric measurement of RF Power

RF Power Waveform at 7 kW on spectrum analyzer

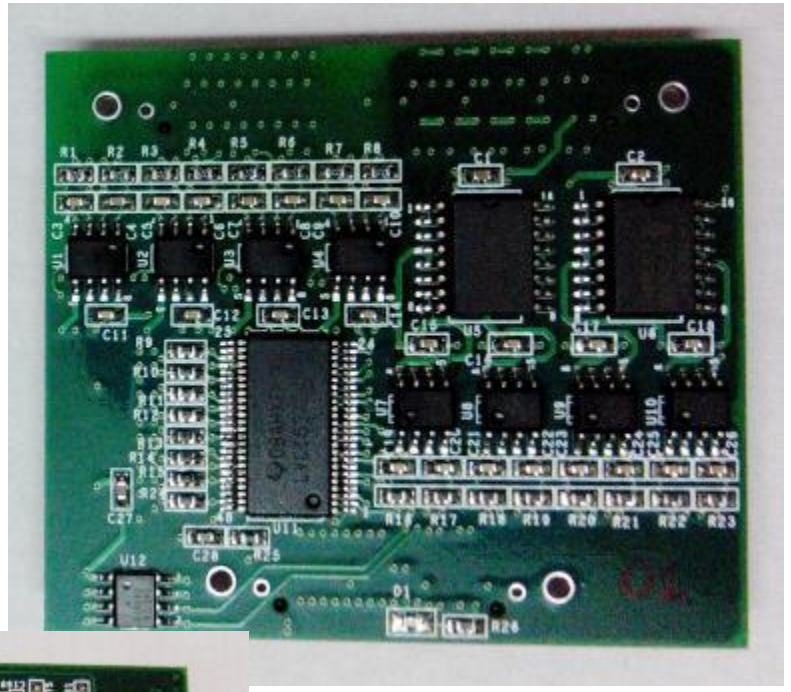
Overall conversion efficiency: 66.3%

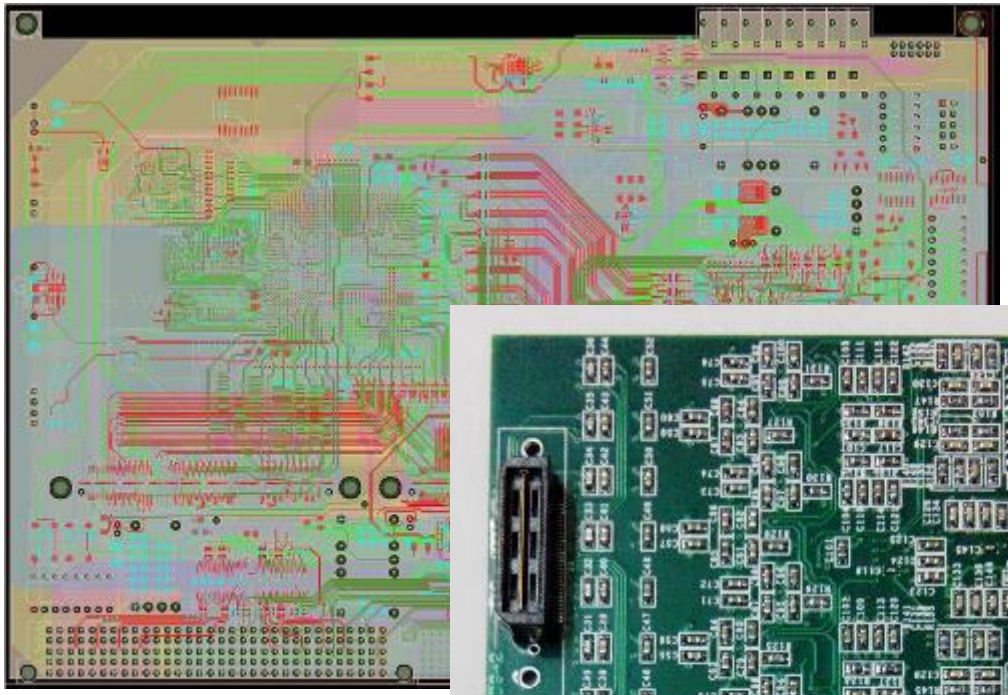
DAE: 650 MHz Solid State RF Power Development

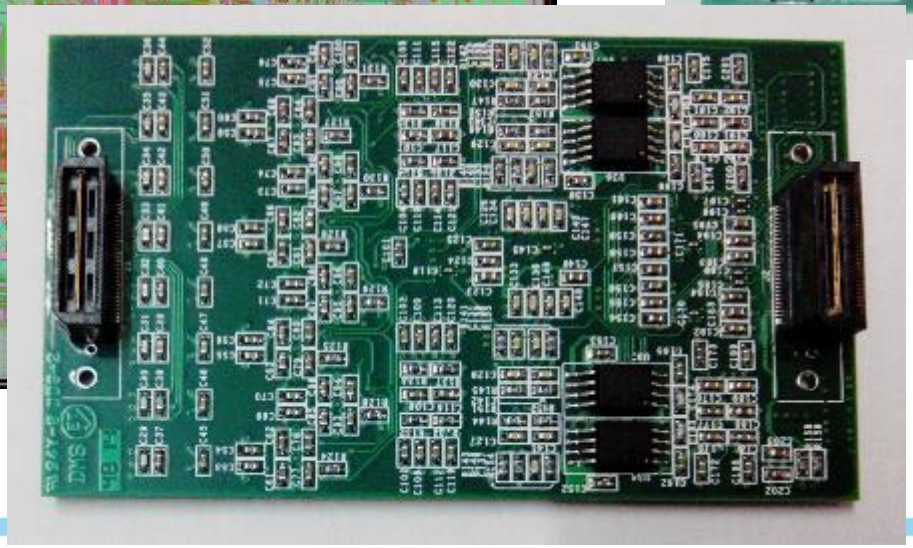
- Design and development of 15 kW, 650 MHz solid state RF power amplifier is completed.
  - It is housed in a single euro rack with 40 compact amplifier modules, 40 way power divider and 40 way power combiner.
- The 40/70 kW power units for PIP-II will be built using similar Solid State RF technology.

IIFC: RF Protection System: BARC & Fermilab

- **An upgraded RF Protection system is jointly being developed by BARC and Fermilab.**
  - **It will be tested at PXIE.**







Similar development for LLRF has started

IIFC R&D: 2nd Phase Integration

Integration Test of IIFC:

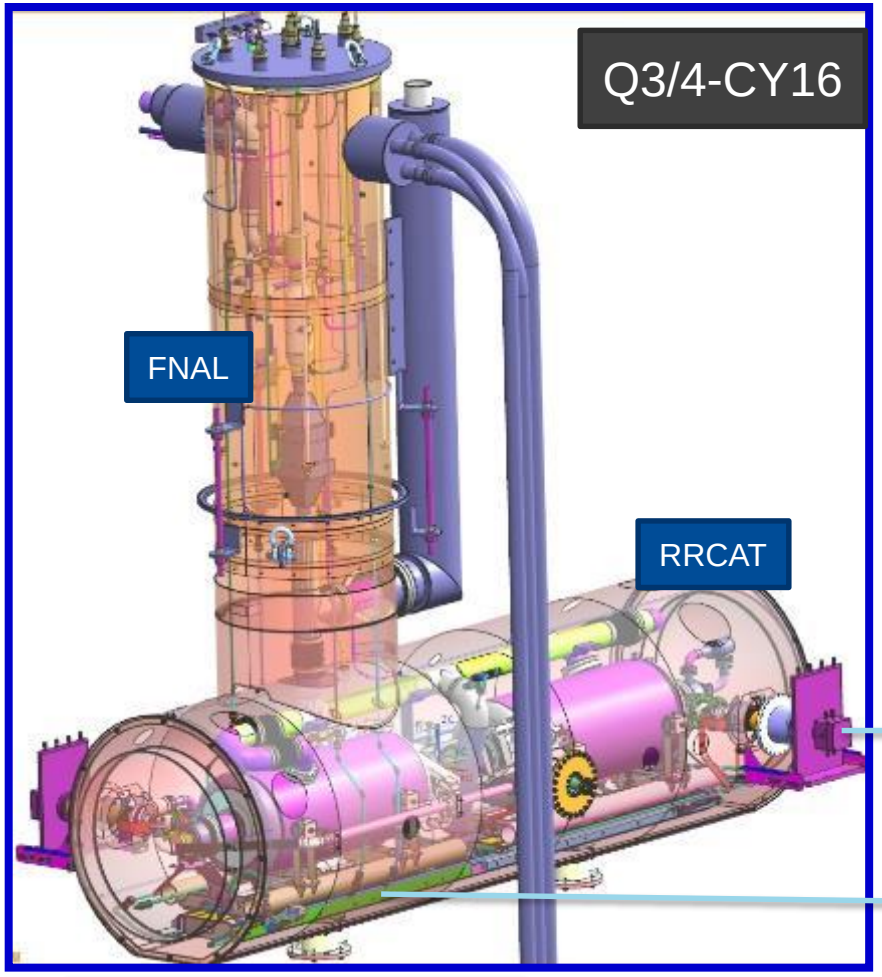
Horizontal Test Stand

SSR1 Cryomodule at PXIE

HB650 at CMTS

- **The Collaborating DAE laboratories have installed and continues to install significant infrastructure to**
  - **Support the joint RD&D and PIP-II Construction**
  - **Engage Indian Industries ←**

IIFC: 650 MHz Dressed Cavity Horizontal Test Stand



Two 30 kWatt Units (RRCAT)

FNAL

FNAL

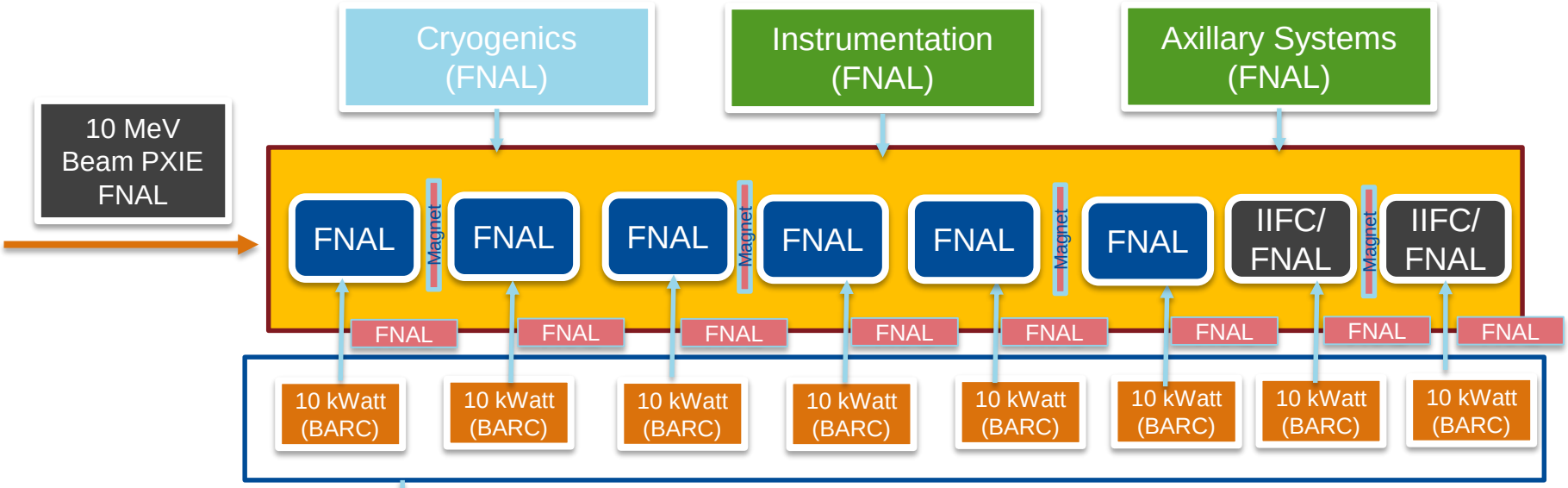
Cryostat at Fermilab Jan 2017
Cryogenics for HTS July 2016
Two 30kWatt RF July 2016
LLRF/RF Protection July 2016
Control System July 2016
Integration with cryostat Oct 2016
Test of 1st Dressed Cavity May 2017

IIFC RF Protection (FNAL/BARC)

LLRF (FNAL/BARC)

Integration and Controls (FNAL)

IIFC: System Test of SSR1 CM and RF Power with Beam



IIFC RF Protection (FNAL/BARC)

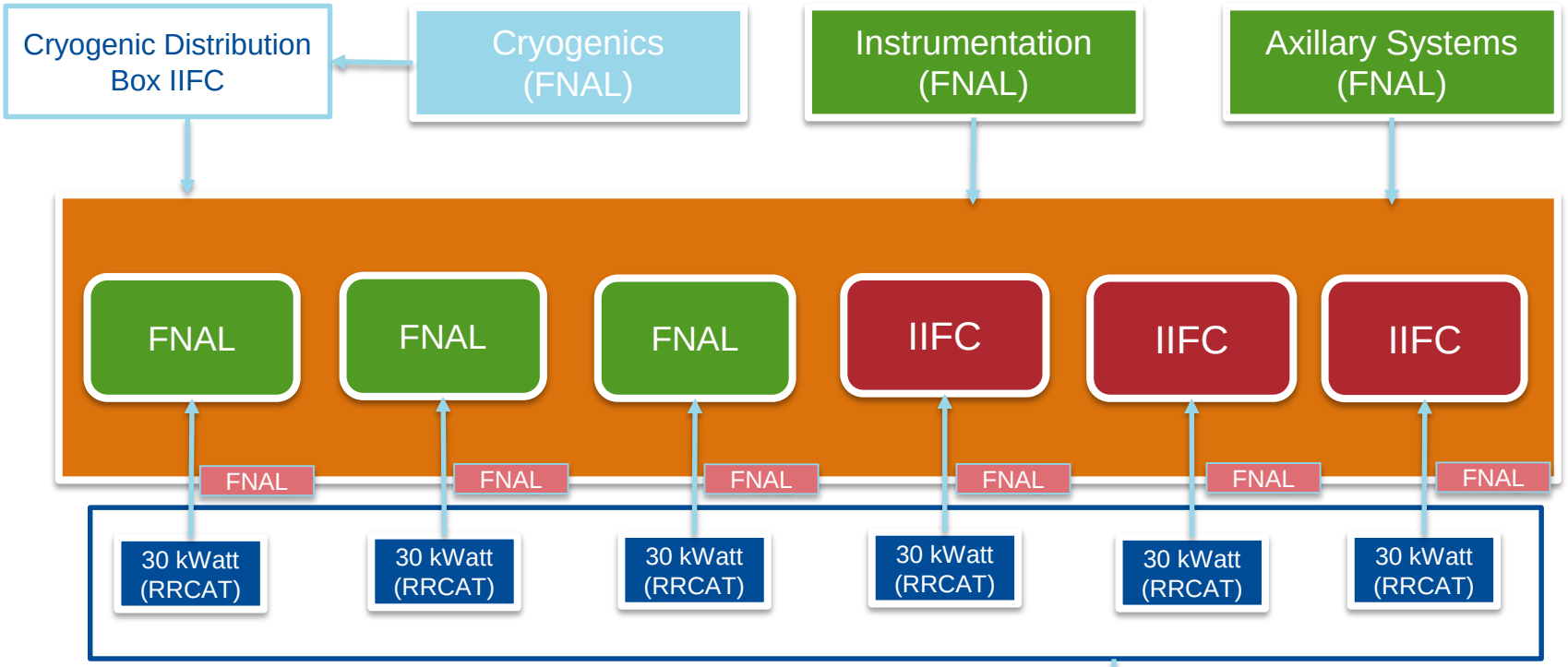
IIFC LLRF (FNAL/BARC)

Integration and Controls (FNAL)

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)

IIFC: 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)

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: R&D Phase Summary

- **Goal:**
  - **Jointly Retire all the critical R&D by end of CY2018.**
  - **Develop infrastructure and industries for the construction**
- **Development and test of SSR1 Cryomodule with beam at PXIE**
  - **Deliverables from India**
    - **2 SSR1 Cavities, CM Design**
    - **8, 325 MHz 7 kWatt Solid State RF Amplifiers System**
- **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**
- **Development LB650 Dressed Cavities.**
- **Development of SSR2 Cavities.**

Indian Strategy on PIP-II

- **Based on the initial success of the IIFC, the DAE and DOE decided to extend this collaboration to the agencies level.**

- **Project Annex I, signed in Jan 2015, provides framework for Indian DAE Institutions and Fermilab to participation in R&D leading to the PIP-II construction phase.**

- **Joint DAE-DOE review mid-point in the R&D phase will provide go ahead to initiate construction deliverables.**
  - **Indian Institutions to establish infrastructure and industry in the R&D Phase**

- **IIFC Team integration: Seven Indian scientists/engineers are coming to Fermilab this fall for 2+ year residencies at Fermilab.**
  - **This will rotate with new scientists/engineers**
  - **Additional short term visitors for specific projects.**

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

DAE-DOE: Contributions from the Parties

1. The Parties intend to make in-kind contributions to each other's accelerator programs.

2. The HISPA design, technology, and supporting infrastructure knowledge transfers from DOE to the DAE are the planned in-kind contribution from the United States.

3. The engineering resources, design, manufacturing, and supply of HISPA accelerator hardware from the DAE to DOE, amounting to a maximum total of $200 million (direct cost in U.S. accounting in terms of 2012 US Dollars), are the planned in-kind contribution from India over the years 2013-2022.

   a. The maximum in-kind contribution from the DAE during the current Indian 12th plan (2012-2017) would be $US60 million allocated for HISPA research and development.

   b. After the joint (DAE-DOE) review of the progress made under India's 12th plan period, and if future HISPA projects receive the requisite approvals in both the United States and India, the DAE would make a maximum contribution from India's 13th plan of $US140 million in-kind to the DOE program under this Project Annex.

4. The itemized list and schedule of deliverables from both sides would be decided and agreed to by the Principal Coordinators.

3a: CY16-18

- **Nb**
- **Initiate Cryogenic Plat design and procurement**

3b: CY19

- **We will initiate this after CD-2 of PIP-II**

4. In June of 2013 DAE and DOE finalized an initial list of deliverables for the CW linac. This was for DAE to initiate the final approval process for Project Annex

- **~50% of SRF cavity, ~100% of RF Power Amplifier and associate electronics hardware that can be fabricated in Indian Industries.**

PIP-II Construction Deliverables: India

- 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

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.**
- **Although 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**

Backup Slides:

Implementing Agreement
Annex I
Annex I Management
International Cost to PIP-II

DOE-DAE Implementing Agreement and Annex I

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

AND DEVELOPMENT FOR DISCOVERY SCIENCE

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:

PROJECT ANNEX I

TO THE 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 AND DEVELOPMENT FOR DISCOVERY SCIENCE
FOR
HIGH INTENSITY PROTON ACCELERATORS

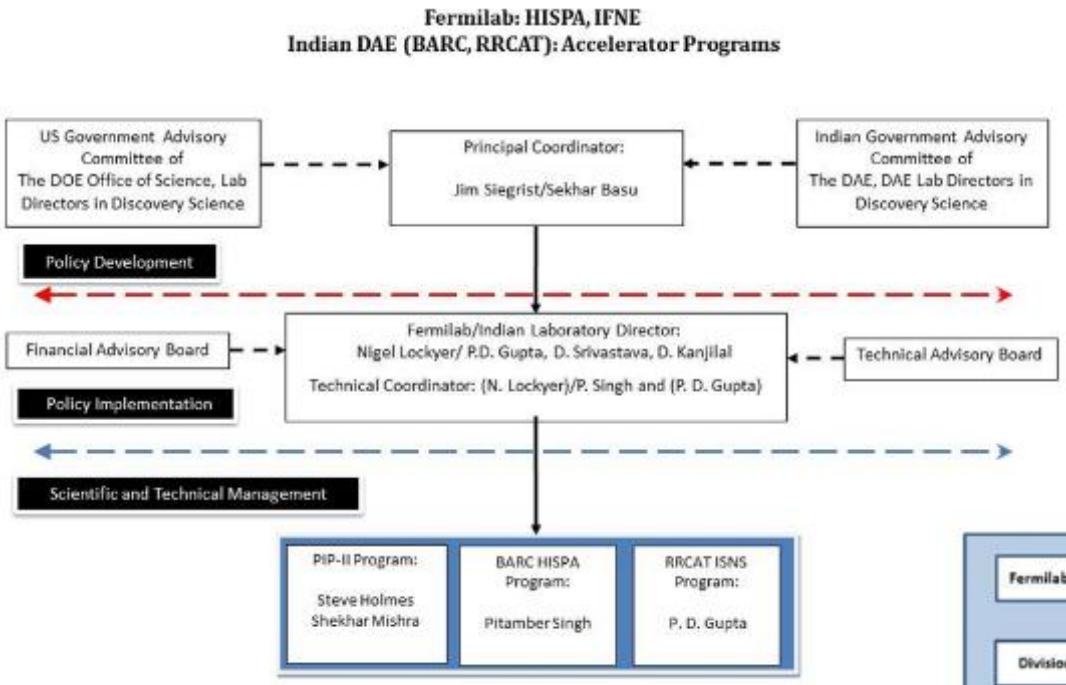
DONE at Mumbai, in duplicate, this 6th day of Nov. 2014.

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

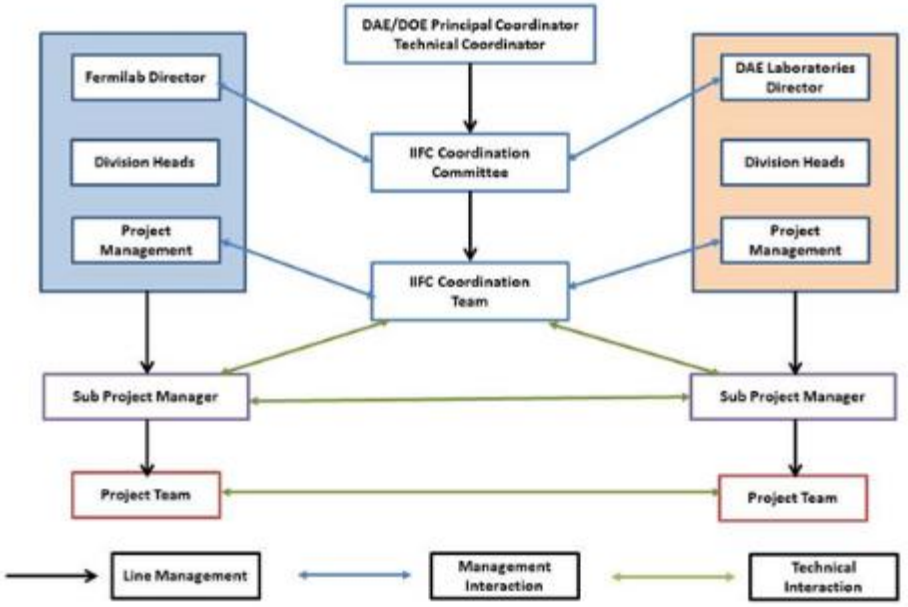
Washington
January 21, 2015

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

IIFC Management

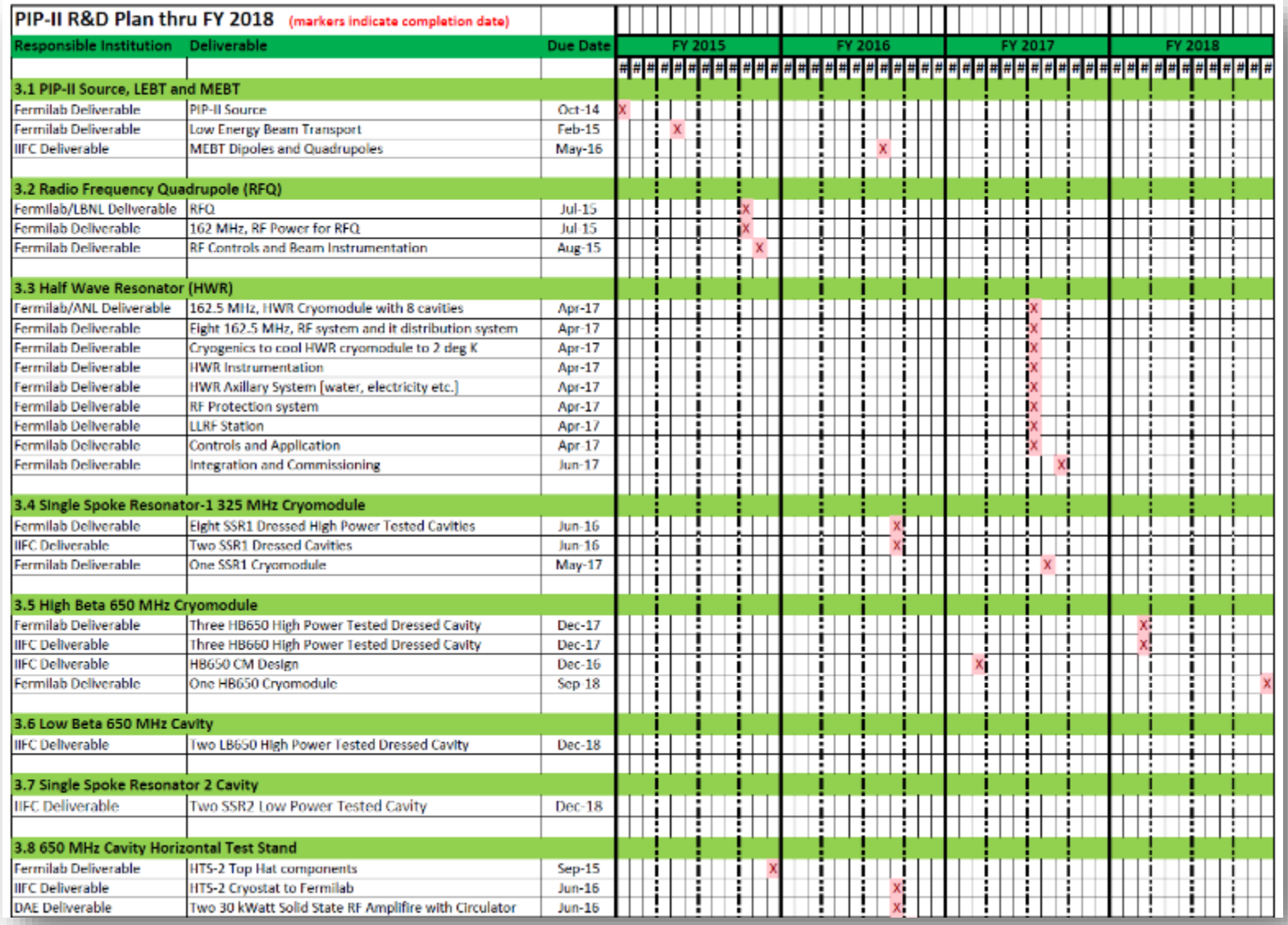


Policy and High Level Technical Matters are managed by the Directors



Technical work and Reviews are managed by IIFC-CT and Sub-Project Managers

International Deliverables - IIFC



PIP-II R&D Plan thru FY 2018 (markers indicate completion date)		
Responsible Institution	**Deliverable**	**Due Date**
3.1 PIP-II Source, LEBT and MEBT		
Fermilab Deliverable	PIP-II Source	Oct-14
Fermilab Deliverable	Low Energy Beam Transport	Feb-15
IIFC Deliverable	MEBT Dipoles and Quadrupoles	May-16
3.2 Radio Frequency Quadrupole (RFQ)		
Fermilab/LBNL Deliverable	RFQ	Jul-15
Fermilab Deliverable	162 MHz, RF Power for RFQ	Jul-15
Fermilab Deliverable	RF Controls and Beam Instrumentation	Aug-15
3.3 Half Wave Resonator (HWR)		
Fermilab/ANL Deliverable	162.5 MHz, HWR Cryomodule with 8 cavities	Apr-17
Fermilab Deliverable	Eight 162.5 MHz, RF system and it distribution system	Apr-17
Fermilab Deliverable	Cryogenics to cool HWR cryomodule to 2 deg K	Apr-17
Fermilab Deliverable	HWR Instrumentation	Apr-17
Fermilab Deliverable	HWR Axillary System [water, electricity etc.]	Apr-17
Fermilab Deliverable	RF Protection system	Apr-17
Fermilab Deliverable	LLRF Station	Apr-17
Fermilab Deliverable	Controls and Application	Apr-17
Fermilab Deliverable	Integration and Commissioning	Jun-17
3.4 Single Spoke Resonator-1 325 MHz Cryomodule		
Fermilab Deliverable	Eight SSR1 Dressed High Power Tested Cavities	Jun-16
IIFC Deliverable	Two SSR1 Dressed Cavities	Jun-16
Fermilab Deliverable	One SSR1 Cryomodule	May-17
3.5 High Beta 650 MHz Cryomodule		
Fermilab Deliverable	Three HB650 High Power Tested Dressed Cavity	Dec-17
IIFC Deliverable	Three HB660 High Power Tested Dressed Cavity	Dec-17
IIFC Deliverable	HB650 CM Design	Dec-16
Fermilab Deliverable	One HB650 Cryomodule	Sep-18
3.6 Low Beta 650 MHz Cavity		
IIFC Deliverable	Two LB650 High Power Tested Dressed Cavity	Dec-18
3.7 Single Spoke Resonator 2 Cavity		
IIFC Deliverable	Two SSR2 Low Power Tested Cavity	Dec-18
3.8 650 MHz Cavity Horizontal Test Stand		
Fermilab Deliverable	HTS-2 Top Hat components	Sep-15
IIFC Deliverable	HTS-2 Cryostat to Fermilab	Jun-16
DAE Deliverable	Two 30 kWatt Solid State RF Amplifire with Circulator	Jun-16

International Deliverables – IIFC cont.

3.8 650 MHz Cavity Horizontal Test Stand		
Fermilab Deliverable	HTS-2 Top Hat components	Sep-15
IIFC Deliverable	HTS-2 Cryostat to Fermilab	Jun-16
DAE Deliverable	Two 30 kWatt Solid State RF Amplifire with Circulator	Jun-16
Fermilab Deliverable	LLRF System	Jul-16
IIFC Deliverable	RF Protection System	Jul-16
Fermilab Deliverable	Control System	Jul-16
Fermilab Deliverable	Cryogenic System	Jul-16
Fermilab Deliverable	Integration of RF system	Sep-16
Fermilab Deliverable	Integration and Commissioning	Oct-16
Fermilab Deliverable	Test of 1st 650 MHZ Dressed HB650 Cavity	Jan-17
3.9 System Test of SSR1 CM and RF Power with Beam		
Fermilab Deliverable	SSR1 CM to PXIE	May-17
Fermilab Deliverable	10 MeV Beam from PXIE	Dec-17
DAE Deliverable	Eight, 10 kWatt 325 MHz Solid State RF with Circulator	Jan-18
Fermilab Deliverable	Eight, RF distribution system	Jan-18
Fermilab Deliverable	Cryogenics to cool SSR1 to 2 deg K	Jan-18
Fermilab Deliverable	SSR1 Instrumentation	Jan-18
Fermilab Deliverable	SSR1 Axillary System [water, electricity etc.]	Jan-18
IIFC Deliverable	RF Protection system	Jan-18
IIFC Deliverable	LLRF Station	Jan-18
Fermilab Deliverable	Controls and Application	Jan-18
Fermilab Deliverable	Integration and Commissioning	Jul-18
3.10 System Test of HB650 CM and RF Power		
Fermilab Deliverable	HB650 CM to CMTF	Sep-18
DAE Deliverable	Six, 30 kWatt 650 MHz Solid State RF with Circulator	Apr-18
Fermilab Deliverable	Eight, RF distribution system	Apr-18
IIFC Deliverable	CMTF Cold Box for cryogenic distribution	Apr-18
Fermilab Deliverable	Cryogenics to cool HB650 CM to 2 deg K	Apr-18
Fermilab Deliverable	HB650 CM Instrumentation	Apr-18
Fermilab Deliverable	SSR1 Axillary System [water, electricity etc.]	Apr-18
IIFC Deliverable	RF Protection system	Apr-18
IIFC Deliverable	LLRF Station	Apr-18
Fermilab Deliverable	Controls and Application	Apr-18
Fermilab Deliverable	Integration and Commissioning	Nov-18