Fermilab

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PIP-II R&D Program

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DOE Independent Project Review of PIP-II
16 June 2015

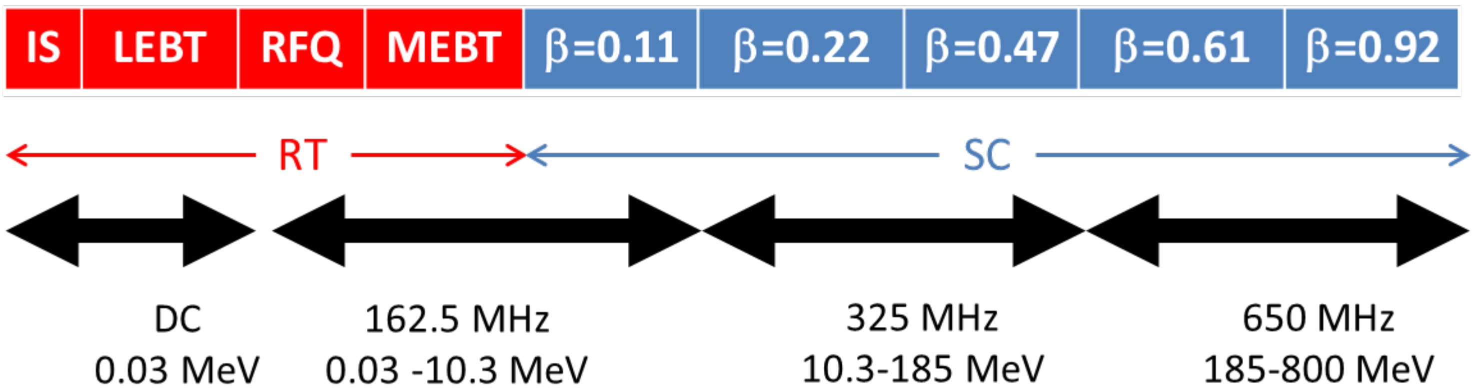
The PIP-II R&D Program

- The purpose of the R&D program is to mitigate technical and cost risks, by validating the choices made in the PIP-II facility design and by establishing fabrication methods for major sub-systems and components, including the qualification of suppliers
  - Technical risk: impair the ability to meet fundamental performance goals
  - Cost/Schedule risk: compromise the ability to meet currently understood cost or schedule goals
    - CD-2: Approve performance baseline
    - CD-3: Approve start of construction
  - To be ready for CD-3 in 2019

PIP-II and Associated Scope

- An 800 MeV superconducting linac (SCL), constructed of CW-capable accelerating structures and cryomodules, operating with a peak current of 2 mA and a beam duty factor of 1%;
- Beam transport from the end of the SCL to the new Booster injection point, and to a new 800 MeV dump;
- Upgrades to the Booster to accommodate 800 MeV injection, and acceleration of 6.4×10^{12} protons per pulse;
- Upgrades to the Recycler to accommodate slip-stacking of 7.7×10^{13} protons delivered over twelve Booster batches;
- Upgrades to the Main Injector to accommodate acceleration of 7.5×10^{13} protons per pulse to 120 GeV with a 1.2 second cycle time, and to 60 GeV with a 0.8 second cycle time.

PIP-II Scope



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-10.3	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	10.3-35	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.47)	325	35-185	35/21/7	SSR, solenoid
LB 650 (β_{opt}=0.65)	650	185-500	33/22/11	5-cell elliptical, doublet*
HB 650 (β_{opt}=0.97)	650	500-800	24/8/4	5-cell elliptical, doublet*

*Warm doublets external to cryomodules

All components CW-capable

Primary Risks and Required R&D

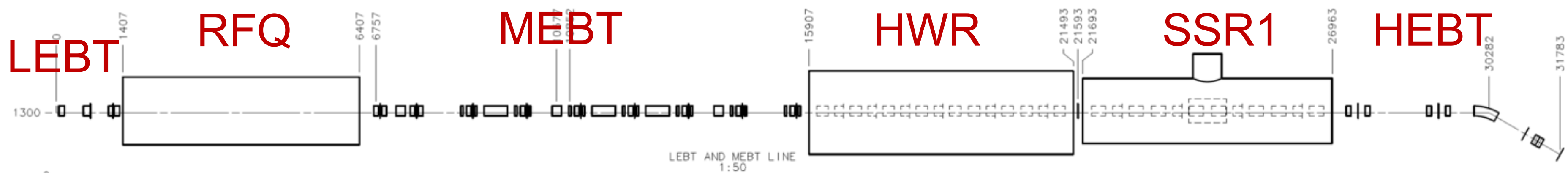
- PXIE should mitigate most risks related to the frontend
  - HWR and SSR1 prototype cryomodules are in fabrication
- Design and testing of SC cryomodules is time consuming process
  - 5 new types of SC cavities: vigorous design work for SSR2, LB650 and HB650 has to be initiated
  - Microphonics and LFD detuning suppression
- Major challenge for SC linac – reliable operation in pulsed regime
  - Task force was organized and is working on this problem
- Longitudinal emittance growth at transition crossing in Booster can increase beam loss at slip stacking. It can limit the beam intensity and, consequently, the beam power
  - Detailed simulations of transition crossing are carried out
- Suppression of fast beam instabilities at slip stacking can be challenging enterprise
  - Better understanding of present problems is required

Primary areas to address technical Risk

1. Development and integrated systems testing of PIP-II Front End components (PXIE)
2. Development and demonstration of cost effective superconducting radio frequency acceleration systems at three different frequencies and with rf duty factors ranging from 10% to 100%
3. Development of requisite capabilities at international partner institutions to successfully contribute to PIP-II construction
4. Development of a Booster injection system design capable of accepting extended beam pulses from the PIP-II linac
5. Development of systems designs capable of supporting a 50% increase in the proton beam intensity accelerated and extracted from the Booster/Recycler/Main Injector complex

PXIE Definitions

- Development and integrated systems testing of PIP-II Front End components (PXIE)
  - Deliver 2 mA average current with 80% bunch-by-bunch chopping of beam delivered from the RFQ
  - Demonstrate efficient acceleration with minimal emittance dilution through at least 15 MeV

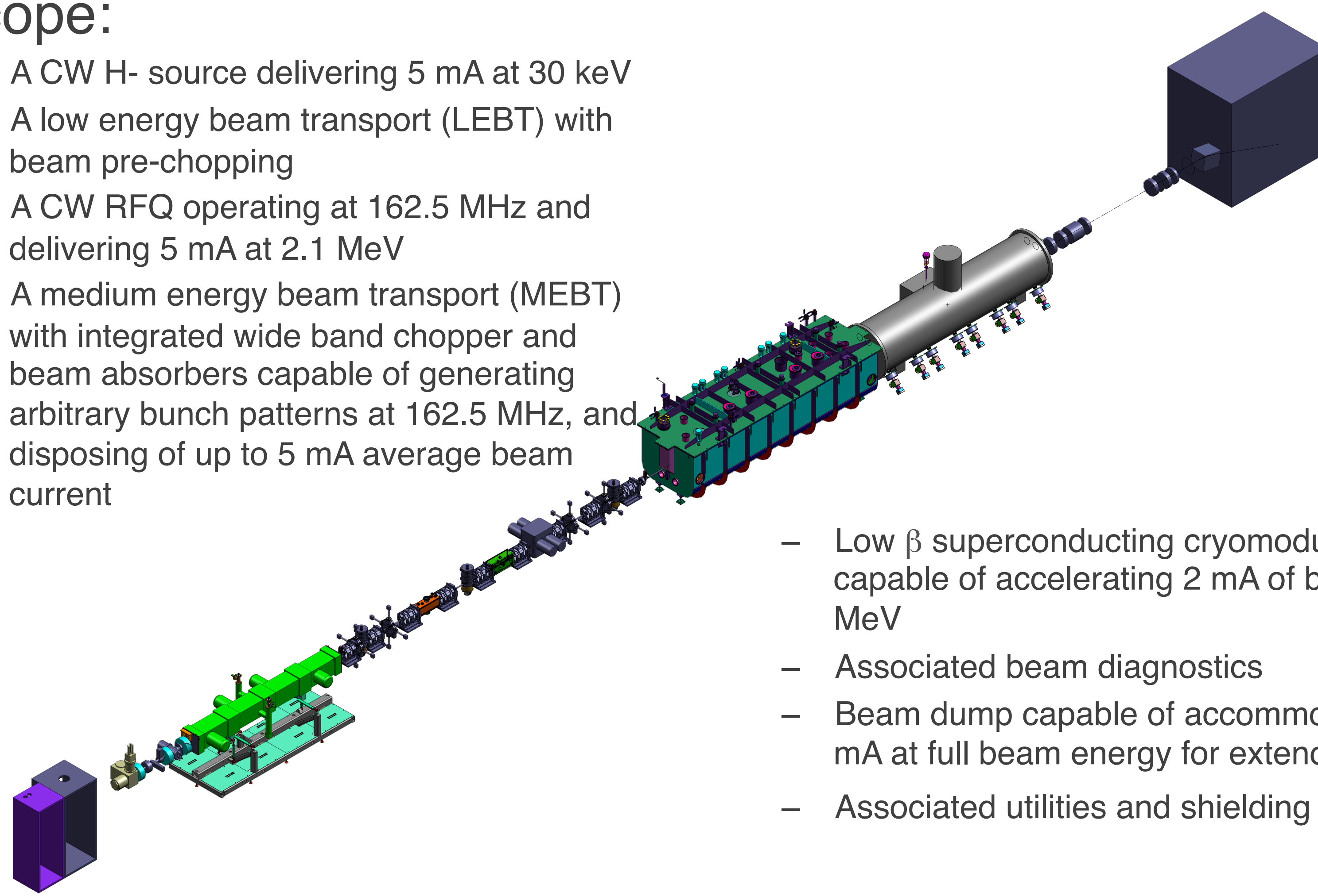


- All components are being designed and fabricated to PIP-II specifications and that our intention is to reutilize during the PIP-II construction to the extent possible.

Fermilab PIP-II

PXIE

- Scope:
  - A CW H- source delivering 5 mA at 30 keV
  - A low energy beam transport (LEBT) with beam pre-chopping
  - A CW RFQ operating at 162.5 MHz and delivering 5 mA at 2.1 MeV
  - A medium energy beam transport (MEBT) with integrated wide band chopper and beam absorbers capable of generating arbitrary bunch patterns at 162.5 MHz, and disposing of up to 5 mA average beam current

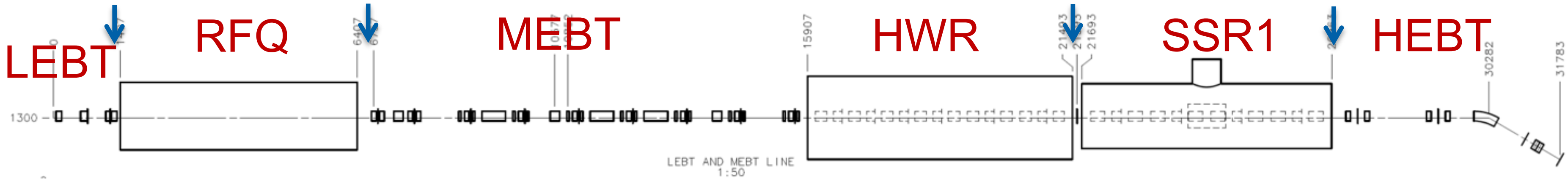


  - Low β superconducting cryomodules capable of accelerating 2 mA of beam to 25 MeV
  - Associated beam diagnostics
  - Beam dump capable of accommodating 2 mA at full beam energy for extended periods.
  - Associated utilities and shielding

PXIE (PIP-II Injector Experiment)

Now — 2015 — 2016 — 2017 → 2018

30 keV | 2.1 MeV | 10 MeV | 25 MeV



40 m, ~25 MeV

PXIE will address the address/measure the following:

- LEBT pre-chopping : Demonstrated
- Vacuum management in the LEBT/RFQ region : Demonstrated
- Validation of chopper performance
  - Bunch extinction, effective emittance growth
- MEBT beam absorber
  - Reliability and lifetime
- MEBT vacuum management
- CW Operation of HWR
  - Degradation of cavity performance
  - Optimal distance to 10 kW absorber
- Operation of SSR1 with beam
  - CW and pulsed operation
  - resonance control and LFD compensation in pulsed operations
- Emittance preservation and beam halo formation through the front end

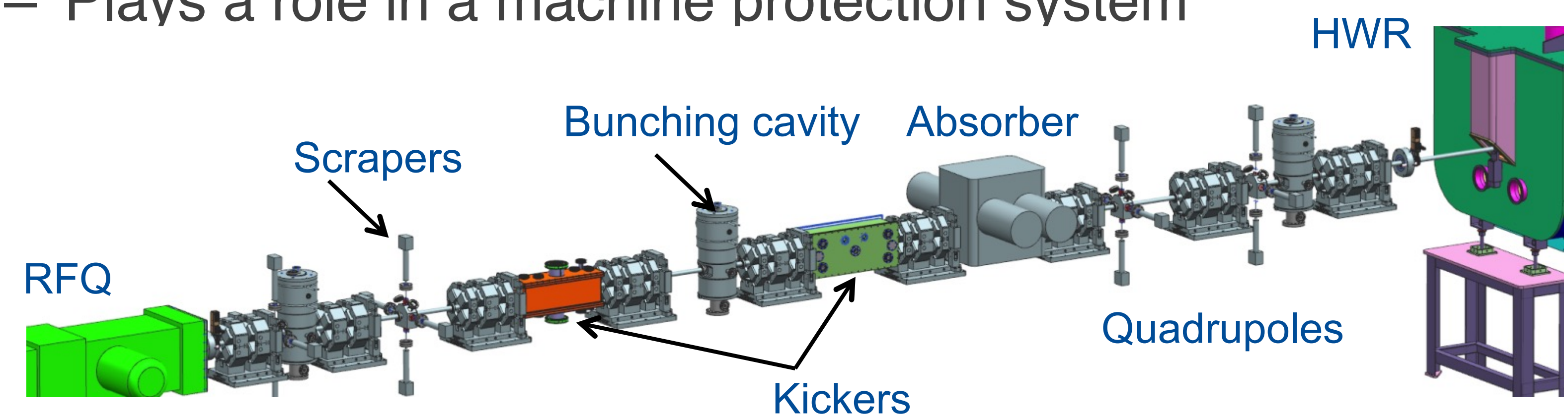
Collaborators

ANL: HWR
LBNL:LEBT, RFQ
SNS: LEBT
BARC: MEBT, RF
IUAC: SSR1

Fermilab PIP-II

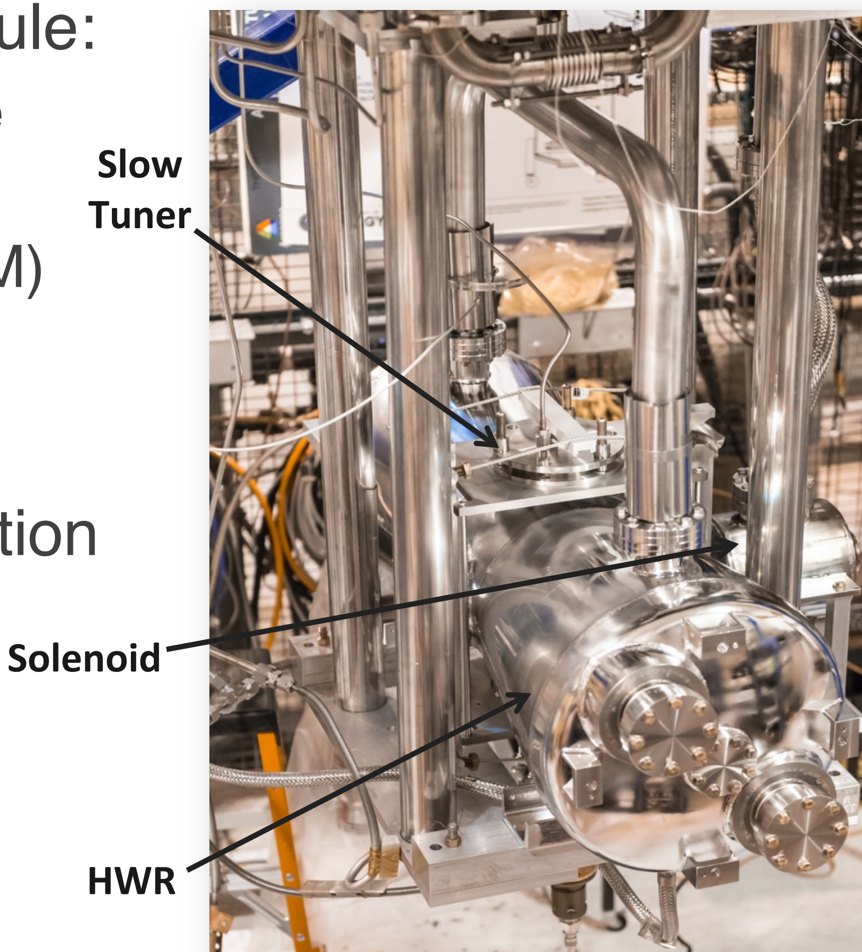
PXIE: MEBT

- The PXIE MEBT serves the following functions:
  - Forms the bunch structure required Booster injection (beam chopping)
  - Matches optical functions between the RFQ and the SRF cavities;
  - Includes tools to measure the properties of the beam coming out of the RFQ and transported to the SRF cavities;
  - Plays a role in a machine protection system



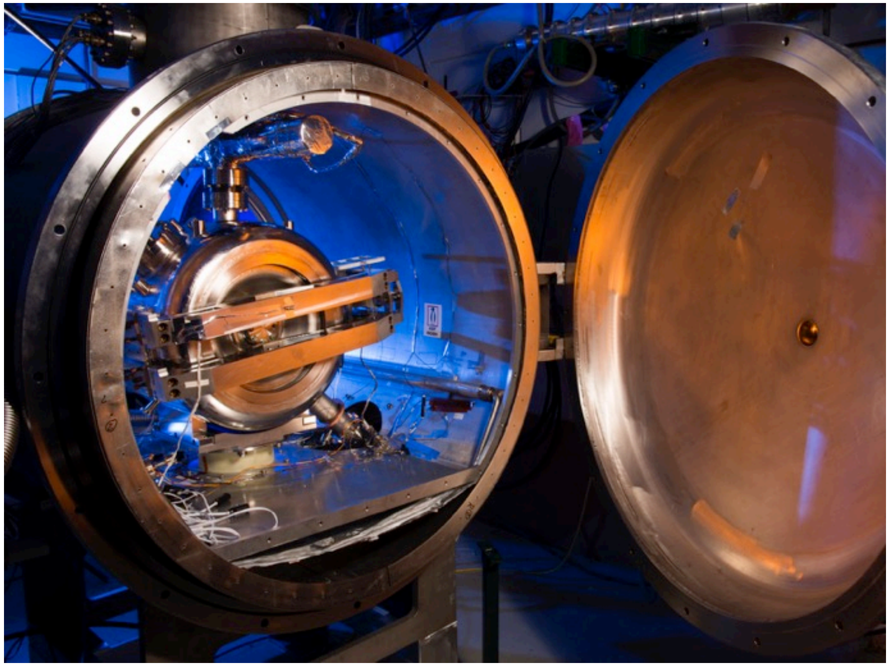
PXIE: HWR

- Half Wave Resonator Cryomodule:
  - 8 162.5 MHz β=0.11 Half Wave cavities
  - 8 SC focusing solenoids (&BPM)
  - 2.1 MeV -> 11 MeV
- In collaboration with Argonne
- Design complete, under fabrication at Argonne
  - Testing of all production components in 2016
  - Assembly in 2017
  - Delivery/Installation Q4 2017



PXIE: SSR1

- Single Spoke Resonator Cryomodule:
  - 8 325 MHz β=0.22 Single Spoke cavities
  - 4 SC focusing solenoids (& BPM)
  - 11 MeV -> 25 MeV



- India Institutes Fermilab Collaboration (IIFC)
  - Cavity and Solenoid Design (FNAL) complete
    - 12 cavities fabricated (10 FNAL, 2 IUAC New Delhi)
  - CM design underway
  - Fabrication/Assembly 2017

dressed SSR1 cavity in test cryostat

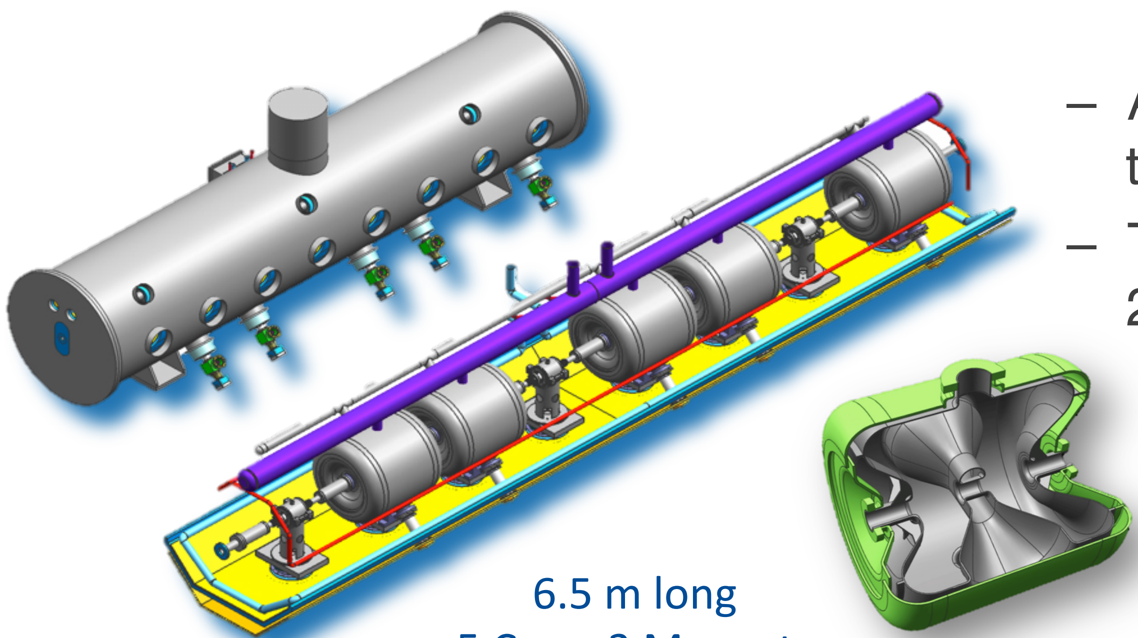
SRF

- PIP-II includes
  - 5 different SRF cavity types and cryomodules
    - Half Wave Resonator
    - 2 Single Spoke Resonators
    - 2 elliptical cavities
  - 3 different frequencies (162.5 MHz, 325 MHz, 650 MHz)

- R&D program:
  - test one complete cryomodule of each frequency to full power
    - HWR & SSR1 @ PXIE with beam
    - HB650 in a test stand
  - test dressed cavities with RF power
    - SSR2 & LB650 in test stands
  - Resonance control of cavities in pulsed mode operation
    - Microphonics
    - Lorentz Force Detuning
    - active frequency control with fast piezo-based tuners

SRF: SSR2

- Single Spoke Resonator Cryomodule:
  - 5 325 MHz β=0.47 Single Spoke cavities
  - 3 SC focusing solenoids (& BPM)



6.5 m long
5 Cav + 3 Magnets

- India Institutes Fermilab Collaboration (IIFC)
  - Cavity Design (BARC) in progress
    - 2 cavities to be fabricated, processed, and tested @ BARC
  - Anticipate He vessel and tuner similar to SSR1
  - Test dressed cavities in 2018

SRF: LB650

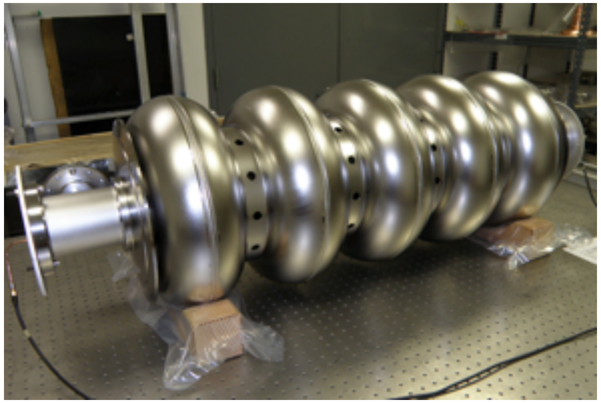
- Elliptical Cavity Cryomodule:
  - 3 650 MHz β=0.64 5 Cell Elliptical cavities
  - Focusing elements are outside the CM

LB650 Elliptical cavities

- India Institutes Fermilab Collaboration (IIFC)
  - Cavity Design (VECC Kolkata and FNAL) in progress
    - 2 cavities to be fabricated, processed, tested in India (VECC, IUAC, RRCAT in Indore)
  - Anticipate end group, He vessel, and tuner similar to HB650
  - Test dressed cavities in 2019

SRF: HB650

- Elliptical Cavity Cryomodule:
  - 6 650 MHz β=0.97 5 Cell Elliptical cavities
  - Focusing elements are outside the CM

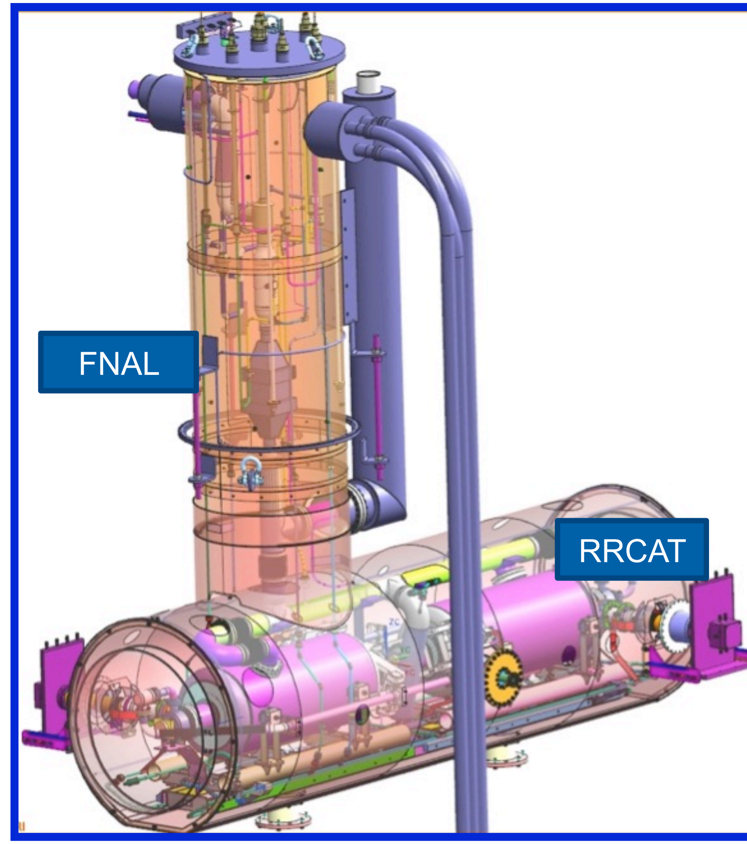


HB650 5 cell cavity

- India Institutes Fermilab Collaboration (IIFC)
  - Cavity Design (FNAL) in progress
    - 8 Cavities of different β at various stages of manufacturing, processing, or testing
  - End group, He vessel, and tuner design (RRCAT & FNAL) in progress
  - CM design complete in 2017
  - Test 6 (3 FNAL, 3 RRCAT) dressed cavities in 2018
  - Fully assembled CM testing 2018

SRF: 650 MHz Horizontal Test Stand

- IIFC design underway
  - based on 1.3 GHz HTS-1 @ FNAL
  - Systems integration test for
    - LLRF (FNAL/BARC)
    - RF Protection (FNAL/BARC)
    - 30 kW HLRF (RRCAT)
    - Instrumentation and Controls (FNAL)
  - Recently completed joint Design and Procurement reviews: ready to proceed



- Commissioning of HTS-2 will begin in 2017, with first testing of dressed HB650 cavities to follow

SRF: Resonance Control

- Combination of High Q0, pulsed operation
  - Lorentz Force Detuning large compared to cavity bandwidth
  - Active resonance control system
- Passive means: Mechanical design
  - Reduction of sensitivity to He pressure and LFD
  - Engineering aimed at noise reduction in the tunnel

- Developing a peizo-based feed forward and feedback system
  - Testing on individual cavities now
  - Test on SSR1 cryomodule at PXIE

Section	Frequency (MHz)	Maximal detune (peak, Hz)	LFD at operating gradient, Hz	Minimal Half Bandwidth (Hz)	Max Required Power (kW)
HWR	162.5	20	-122	33	6.5
SSR1	325	20	-440	43	6.1
SSR2	325	20	-	28	17.0
LB650	650	20	-192	29	38.0
HB650	650	20	-136	29	64.0

SRF Development Status

Cavity	Frequency	Cavity Type	Beta	Collaboration?	Cavity EM Design Complete	Cavity Mech Design Complete	Single Cell / Prototype Ordered	Full Cavity Prototype Received	Prototype Tested	Cavities for CM Ordered	Cavities for CM Received	Cavities for CM Tested	Cavities for CM Dressed	CM Cold Mass Design	CM Parts Ordered	# of CM Assembled	Est % complete
Half Wave Resonator (HWR)	162.5 MHz	1-HWR CW	0.11	ANL	yes	yes	yes	yes	yes	9	9	2	2	yes	yes	15%	70
Single Spoke Resonator 1 (SSR1)	325 MHz	1-spoke CW	0.22	India	yes	yes	2	2	2	10	10 +2	10	6	80%	70%	not started	75
Single Spoke Resonator 2 (SSR2)	325 MHz	1-spoke CW	0.47	India	yes	yes	not started	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
Low Energy 650 (LE 650)	650 MHz	5-cell CW	0.6	India, JLAB	yes	yes	5	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
High Energy 650 (HE 650)	650 MHz	5-cell CW	0.9	India	yes	yes	5 of 10	4	not started	9	4	not started	not started	5%	not started	not started	20

- Green: complete
- Yellow: in progress
- Red: not started
  - HWR and SSR1 development for PXIE

SRF : Synergy with LCLS-II

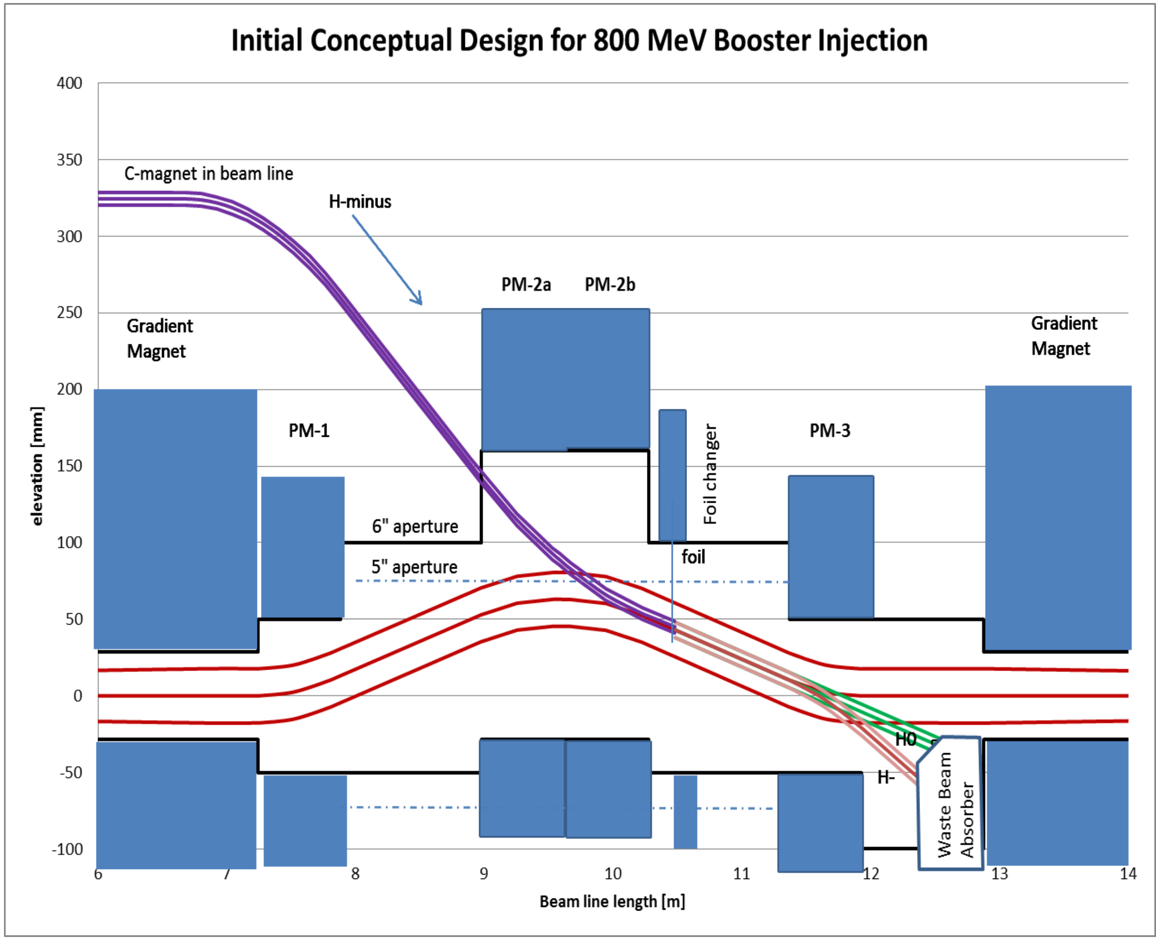
- Interplay between the two projects on common needs
  - infrastructure:
    - string assembly clean rooms - installing a new clean room in Lab 2 for initial SSR1 assembly
  - resources:
    - engineering and technicians: peaks in 2016/17
      - long term Indian visitors dedicated to PIP-II
    - identified areas where we needed to build staff
      - Hired additional mechanical engineers
      - Built a larger technician staff for LCLS-II
    - Technical Division is balancing the resources necessary to meet the LCLS-II construction schedule and PIP-II R&D schedule
- PIP-II construction will be starting up as LCLS-II construction rolls off
  - Technical staff will move from LCLS-II onto PIP-II
- PIP-II will greatly benefit from the extensive cryomodule production experience of LCLS-II
  - R&D challenges are very similar between the two projects (High Q_0, Resonance Control)

Booster

- With a 50% pulse intensity increase, a 33% pulse frequency increase, but total power loss budget staying constant, have identified 4 areas of concentration for Booster
  - Injection: following slide
  - 20 Hz operation: following slide
  - RF: beam dynamics studies
    - injection : direct injection into bucket (chopping in MEBT)
    - longitudinal emittance preservation, especially through transition
  - Beam quality: beam dynamics studies
    - Emittance and Loss control
    - Collimation

Booster: Injection

- new injection point at Long 11, 3 or 4 bump
- radiation deposition in area
  - an H^0/H^- absorber
  - investigating new gradient magnet design to allow for larger absorber
- design complete summer 2018

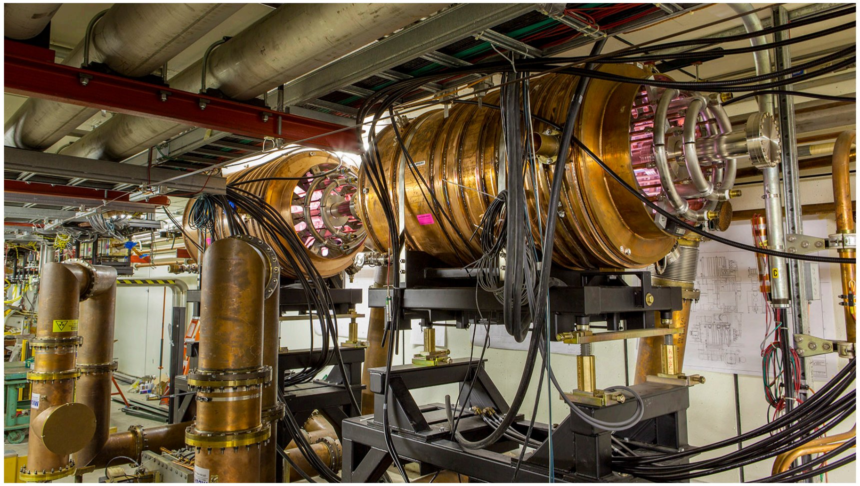


Booster: 20 Hz

- Booster is a resonant synchrotron at 15 Hz
  - Changes to resonant system to get to 20 Hz
    - have tested a single magnet successfully at 20 Hz
    - Plan to build and test a complete Booster girder
      - 2 gradient magnets, choke, cap bank, & power supply
    - complete by fall 2017
- Controls and timing system built around 15 Hz as fundamental frequency
  - understand what needs to be upgraded/modified
    - Time Line Generator
    - TCLK system
    - DAQ front ends
    - data collection and sampling

Recycler Ring

- With 20 Hz operation and 60 GeV option for LBNF
  – need a new 53 MHz RF cavity
    - 60 GeV option: increase in duty factor -> better cooling



    - 20 Hz operation: larger separation for slip stacking -> higher peak voltage
  – Develop and build a prototype cavity by fall 2018
- Beam dynamics and loss control

Main Injector

- Two areas of R&D:
  - RF Power:
    - have enough voltage but PA does not have enough power for 7.5e13 ppp
    - With existing cavity, two possible solutions
      - use two power tubes (cavity has requisite ports) of current type
      - use a single higher power tube
      - With the spare cavity, investigate operation in test stand of both solutions
      - ready for testing by the end of 2016
  - Transition crossing: need a γ_t jump for loss control
    - 8 quad triplets to generate ±1 unit in 0.5 msec at transition
    - build and test a prototype magnet and power supply by fall 2017

PXIE and SRF Deliverables

PIP-II R&D Plan thru FY 2018

Responsible Institution	Deliverable	Due Date	Program
3.1 PIP-II Source, LEBT and MEBT			
IIFC Deliverable	MEBT Dipoles and Quadrupoles	May-16	PXIE
3.2 Radio Frequency Quadrupole (RFQ)			
Fermilab/LBNL Deliverable	RFQ	Jul-15	PXIE
3.3 Half Wave Resonator (HWR)			
Fermilab/ANL Deliverable	162.5 MHz, HWR Cryomodule with 8 cavities	Apr-17	PXIE
Fermilab Deliverable	Eight 162.5 MHz, RF system and it distribution system	Apr-17	PXIE
Fermilab Deliverable	Integration and Commissioning	Jun-17	PXIE
3.4 Single Spoke Resonator-1 325 MHz Cryomodule			
Fermilab Deliverable	One SSR1 Cryomodule	May-17	PXIE
3.9 System Test of SSR1 CM and RF Power with Beam			
Fermilab Deliverable	SSR1 CM to PXIE	May-17	PXIE
Fermilab Deliverable	10 MeV Beam from PXIE	Dec-17	PXIE
DAE Deliverable	Eight, 10 kWatt 325 MHz Solid State RF with Circulator	Jan-18	PXIE
Fermilab Deliverable	Integration and Commissioning	Jul-18	PXIE
3.5 High Beta 650 MHz Cryomodule			
IIFC Deliverable	HB650 CM Design	Dec-16	SRF
Fermilab Deliverable	One HB650 Cryomodule	Sep-18	SRF
3.6 Low Beta 650 MHz Cavity			
IIFC Deliverable	Two LB650 High Power Tested Dressed Cavity	Dec-18	SRF
3.7 Single Spoke Resonator 2 Cavity			
IIFC Deliverable	Two SSR2 Low Power Tested Cavity	Dec-18	SRF
3.8 650 MHz Cavity Horizontal Test Stand			
IIFC Deliverable	HTS-2 Cryostat to Fermilab	Jun-16	SRF
DAE Deliverable	Two 30 kWatt Solid State RF Amplifire with Circulator	Jun-16	SRF
Fermilab Deliverable	Integration and Commissioning	Oct-16	SRF
Fermilab Deliverable	Test of 1st 650 MHZ Dressed HB650 Cavity	Jan-17	SRF
3.10 System Test of HB650 CM and RF Power			
Fermilab Deliverable	HB650 CM to CMTF	Sep-18	SRF
DAE Deliverable	Six, 30 kWatt 650 MHz Solid State RF with Circulator	Apr-18	SRF
Fermilab Deliverable	Integration and Commissioning	Nov-18	SRF

Booster/MI/RR Deliverables

PIP-II R&D Plan thru FY 2018

Responsible Institution	Deliverable	Due Date	Program
3.11 Booster			
Fermilab Deliverable	20 Hz Girder Test Complete	Sep-17	Booster
Fermilab Deliverable	Qualification of Existing Collimation System Complete	Sep-17	Booster
Fermilab Deliverable	Initial Gradient Magnet / Absorber Design Complete	Sep-17	Booster
3.12 Main Injector			
Fermilab Deliverable	MI RF Station Modified to operate with 2 PAs	Sep-16	MI
Fermilab Deliverable	MI RF Station High Power Tube Delivered	Sep-16	MI
Fermilab Deliverable	Prototype γt quad tested	Jul-18	MI
3.13 Recycler Ring			
Fermilab Deliverable	Prototype RF Cavity Design Complete	Mar-17	RR
Fermilab Deliverable	Prototype RF Cavity Fabrication Complete	Sep-18	RR

Resources for the R&D program

- To complete the R&D program as specified in previous slides
  - have estimates of materials and labor resources
    - Materials costs are direct only
    - Labor in FTEs and SWF (no overhead)
    - no contingency or escalation included
    - covers the period FY16-FY19

	M&S (direct)	Labor (SWF)	Labor (FTE)	FY15 Labor (Actuals)
PXIE	$16.8M	$11.7M	~99	22.6
SRF	$5.9M	$4.2M	~36	12.2
Booster/RR/MI	$0.9M	$2.0M	~16	

The R&D program will:

- At the end of the PXIE R&D program:
  - have demonstrated understanding of beam dynamics, beam stability, and beam parameters
  - have demonstrated beam chopper, absorber, and bunch by bunch selection
  - have determined conditions for operation of SRF cavities with a high power MEBT absorber
  - **validated the critical technologies of the PIP-II Linac front end**

- At the end of the SRF R&D program:
  - have built and tested complete cryomodules at 3 different frequencies
    - a good understanding of cost and schedule for construction of the remaining 20+ cryomodules
  - have demonstrated the technical capabilities of the collaboration partners

- **be prepared to start construction in 2019**

Summary of the morning session:

- Laboratory program covers a wide range of intensity frontier science, with an emphasis on the Long Baseline Neutrino Facility and the Deep Underground Neutrino Experiment
  - 2016 Capabilities:
    - 700 kW @ 120 GeV for LBN
    - 33 kW @ 8 GeV for SBN and Muon programs

Detector Fiducial Mass (kton)	Proton Beam Power (MW)	YEARS to reach 120kT.MW.yr	YEARS to reach 600kT.MW.yr	YEARS to reach 900kT.MW.yr
10	0.7	17	86	129
20	0.7	9	43	64
30	0.7	6	29	43
40	0.7	4	21	32
10	1.2	10	50	75
20	1.2	5	25	38
40	1.2	3	13	19
20	2.4	3	13	19
40	2.4	1	6	9

- P5 goals for the LBNF program (Recommendation 12):
  - 600 kt*MW*year exposure to reach 3σ in δ_{CP}
  - Further investigations suggest 900-1200 kt*MW*year

Summary

- Experienced management team
  – Delivered Main Injector and NOvA ANU +
  – Strong support from lab and AD
- Motivated, qualified technical team ready to deliver
  – alignment between roles, responsibilities, authorities and individual capabilities
- Significant and well defined international contributions
  - India Institutes Fermilab Collaboration established in 2007
    – joint R&D on SRF, RF Power and Control, Cryo, Instrumentation for high power proton linacs
  - US DOE Indian DAE “Implementing Agreement” signed 2011
    – Annex 1: signed January 2015
  - Details in the afternoon session

Summary

- Technical concept delivers >1 MW over a broad energy range
  - 800 MeV Superconducting linac
  - Modifications to existing complex
  - We know how to build this machine
- Achievable schedule
  - Builds on LCLS-II and SRF experience
  - Delivers for neutrino science program on time
- Cost Range:
  - Point estimate and DOE Cost Estimate guide
  - methodology and details in the afternoon session
  - $465M - $695M

Summary of morning session

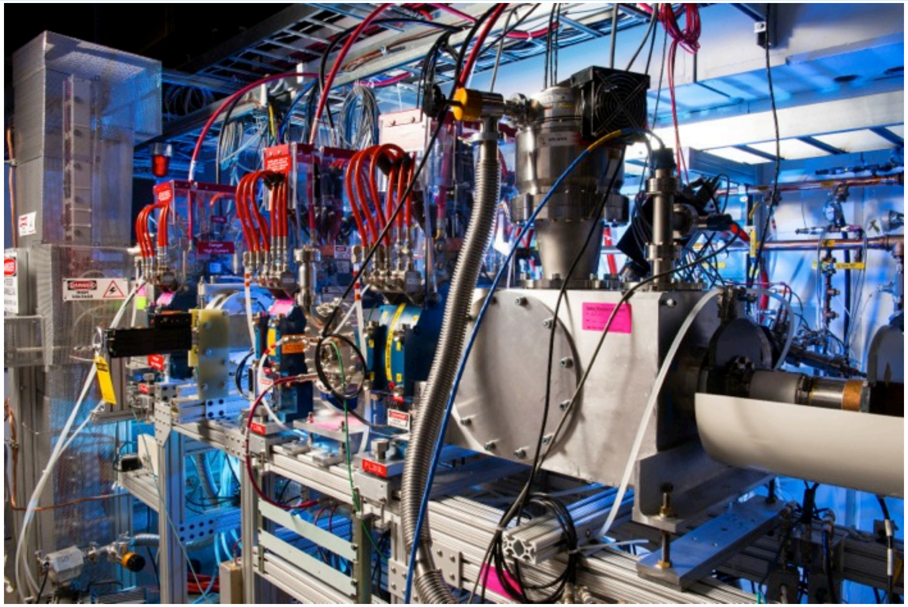
- Strong R&D plan
  - Addresses and retires major areas of risk
  - Well defined milestones and deliverables
- At the conclusion
  - will have answers to the technical questions
  - give confidence in the cost and schedule estimates
  - demonstrate technical capabilities of the collaborating institutions
- Details will be presented in the afternoon session

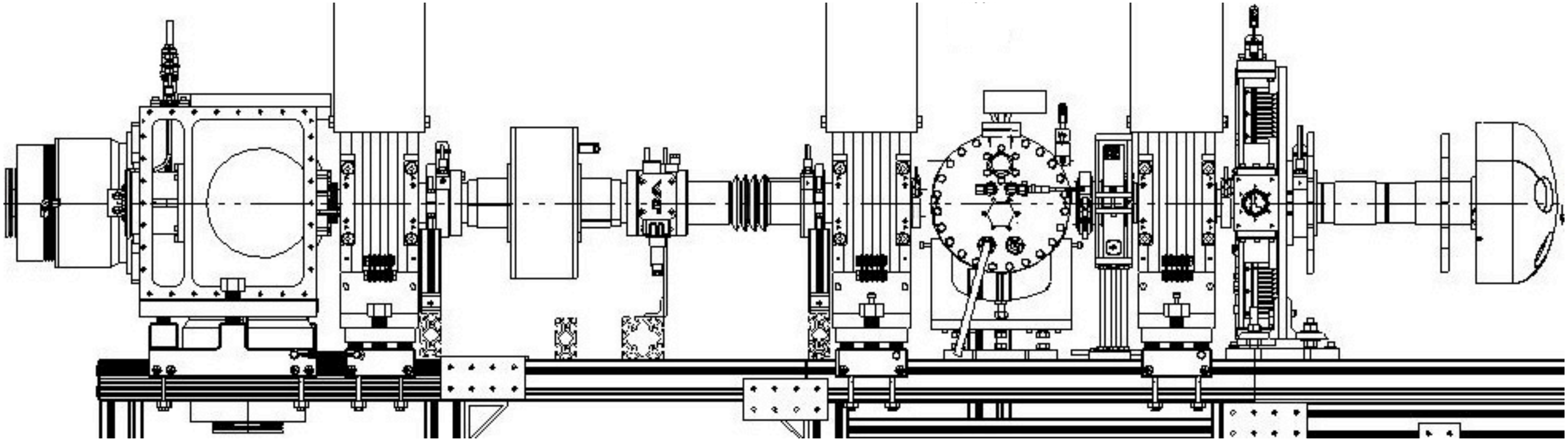
- In addition, we will present details on the project approach to ESH&Q, NEPA compliance, and organization and management

Backups

PXIE: Ion Source and LEBT status

- Commissioned, continue with characterization
- Ready for RFQ installation

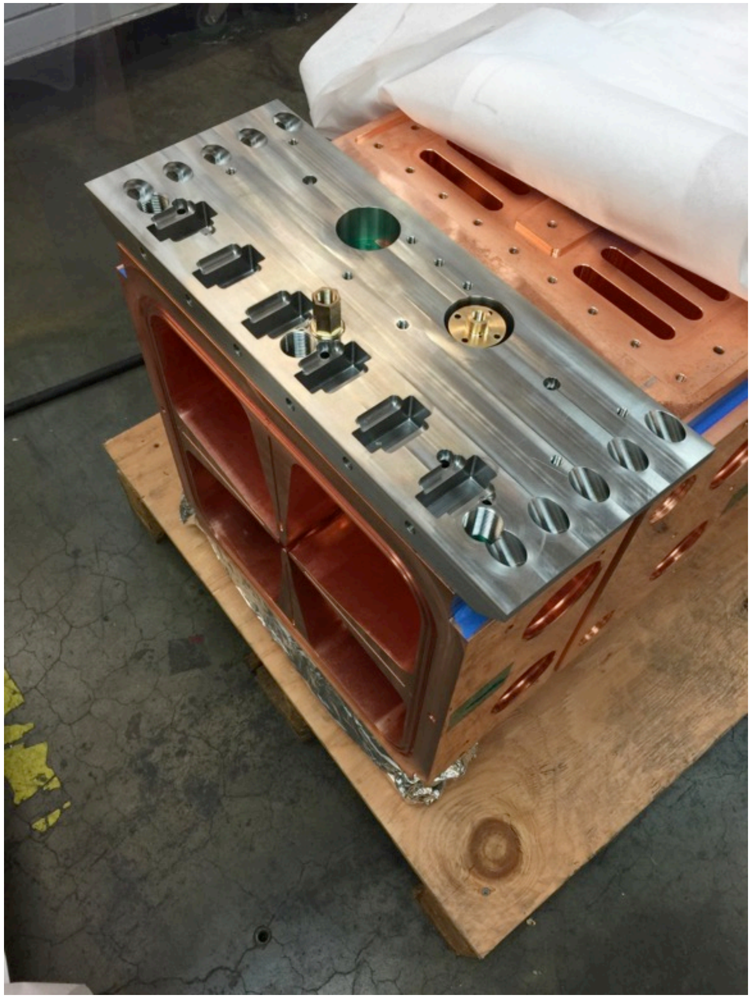




Fermilab PIP-II

RFQ Progress

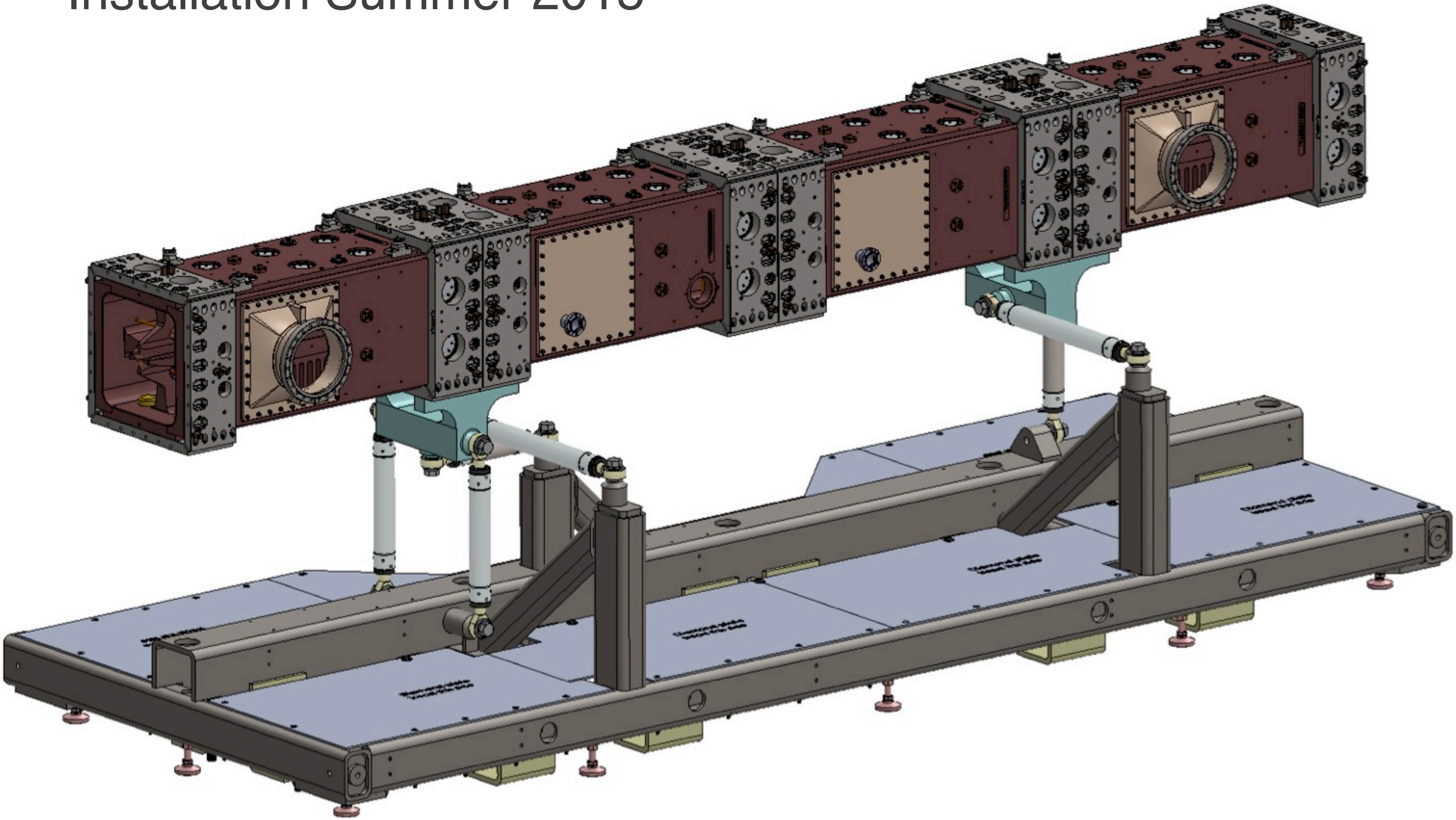
- Modules:
  - vacuum tight
  - machining complete
  - assembly progressing
- RF Power systems
  - commissioned and ready
- Installation:
  - Summer 2015



RF Power System Installation

PXIE: RFQ

- Installation Summer 2015



PXIE: MEBT Schedule :

- Staged installation:
  - Stage 1, 2015: characterize initial beam from RFQ
    - 2 quad doublets, 1st buncher cavity, necessary diagnostics
  - Stage 2, 2016: understand beam transport and RFQ
    - 4 quadrupole triplets, 2nd buncher cavity, chopper kicker prototypes
  - Stage 3, 2017: prepare beam for SRF
    - absorber, 3 quadrupole triplets, 3rd buncher cavity, differential pumping

- MEBT magnets were designed as part of the India Institutes Fermilab Collaboration (IIFC), with fabrication at the Bhabha Atomic Research Center (BARC) in Mumbai

Deliverables (more detail)

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
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

Fermilab PIP-II

Deliverables (more detail)

PIP-II R&D Plan thru FY 2018 (markers indicate completion date)

Responsible Institution	Deliverable	Due Date	FY 2015	FY 2016	FY 2017	FY 2018	
3.9 System Test of SSR1 CM and RF Power with Beam							
Fermilab Deliverable	SSR1 CM to PXIE	May-17			X		
Fermilab Deliverable	10 MeV Beam from PXIE	Dec-17				X	
DAE Deliverable	Eight, 10 kWatt 325 MHz Solid State RF with Circulator	Jan-18				X	
Fermilab Deliverable	Eight, RF distribution system	Jan-18				X	
Fermilab Deliverable	Cryogenics to cool SSR1 to 2 deg K	Jan-18				X	
Fermilab Deliverable	SSR1 Instrumentation	Jan-18				X	
Fermilab Deliverable	SSR1 Axillary System [water, electricity etc.]	Jan-18				X	
IIFC Deliverable	RF Protection system	Jan-18				X	
IIFC Deliverable	LLRF Station	Jan-18				X	
Fermilab Deliverable	Controls and Application	Jan-18				X	
Fermilab Deliverable	Integration and Commissioning	Jul-18				X	
3.10 System Test of HB650 CM and RF Power							
Fermilab Deliverable	HB650 CM to CMTF	Sep-18				X	
DAE Deliverable	Six, 30 kWatt 650 MHz Solid State RF with Circulator	Apr-18				X	
Fermilab Deliverable	Eight, RF distribution system	Apr-18				X	
IIFC Deliverable	CMTF Cold Box for cryogenic distribution	Apr-18				X	
Fermilab Deliverable	Cryogenics to cool HB650 CM to 2 deg K	Apr-18				X	
Fermilab Deliverable	HB650 CM Instrumentation	Apr-18				X	
Fermilab Deliverable	SSR1 Axillary System [water, electricity etc.]	Apr-18				X	
IIFC Deliverable	RF Protection system	Apr-18				X	
IIFC Deliverable	LLRF Station	Apr-18				X	
Fermilab Deliverable	Controls and Application	Apr-18				X	
Fermilab Deliverable	Integration and Commissioning	Nov-18					X

Fermilab PIP-II

High Duty Factor Experiments

- PIP-II design is compatible with CW operation
- The only exception is the cooling power of cryo-plant
  - It is set by requirement to support >1 MW MI operation
    - Corresponding to 1% beam duty factor and 5% cryo duty factor
- Success of high Q_0 program will allow operation with ~15% cryo duty

  => beam duty factor 1% -> 10%
  - Such duty factor can be acceptable for Mu2e upgrade
  - Further increase of duty factor will require an upgrade of the cryo-plant

LCLS-II

- LCLS-II is a DOE Basic Energy Sciences project at SLAC
  - a 2^{nd} generation x-ray FEL , 4 GeV CW superconducting electron linac
  - collaboration between SLAC, Fermilab, Jefferson Lab, Argonne, and Cornell
- Fermilab has significant responsibilities within the project
  - supplying ~$^1/_2$ the cryomodules
    - 17 1.3 GHz cryomodules
    - 2 3.9 GHz cryomodules
  - design of cryogenic distribution system
  - details from the LCLS-II P6 schedule on next slide

LCLS-II Production Schedule

Milestone	Start	Completion Date
High Q0 R&D/Design Verification	10 Jan 14	30 Jun 15
Prototype CM Assembly	12 Aug 15	8 Mar 16
CM2-4 Assembly	27 May 16	16 Feb 17
CM5-17 Assembly	28 Nov 16	7 Feb 18
3.9 GHz Design	10 Jan 14	20 Sep 16
3.9 GHz CM1 Assembly	26 Nov 13	29 May 18
3.9 GHz CM2 Assembly	4 Apr 18	6 Jul 18
SLAC CM Installation		13 Mar 19