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 $6.4 \times 10^{12}$ protons per pulse;

• Upgrades to the Recycler to accommodate slip-stacking of $7.7 \times 10^{13}$ protons delivered over twelve Booster batches;

• Upgrades to the Main Injector to accommodate acceleration of $7.5 \times 10^{13}$ 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

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

*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.
• **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)

PXIE will address 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

40 m, ~25 MeV
The PXIE MEBT serves the following functions:

- Forms the bunch structure required for 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 $\beta=0.11$ 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 $\beta = 0.22$ 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

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**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 $\beta = 0.47$ Single Spoke cavities
  - 3 SC focusing solenoids (& BPM)

- 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

6.5 m long
5 Cav + 3 Magnets
SRF: LB650

- Elliptical Cavity Cryomodule:
  - 3650 MHz $\beta=0.645$ Cell
  - Elliptical cavities
  - Focusing elements are outside the CM

- 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

LB650 Elliptical cavities
SRF: HB650

- **Elliptical Cavity Cryomodule:**
  - 6 650 MHz $\beta=0.975$ Cell
  - Elliptical cavities
  - Focusing elements are outside the CM

- **India Institutes Fermilab Collaboration (IIFC):**
  - Cavity Design (FNAL) in progress
    - 8 Cavities of different $\beta$ 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

![HB650 5 cell cavity](image)
SRF: 650 MHz Horizontal Test Stand

- IIIFC 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

<table>
<thead>
<tr>
<th>Section</th>
<th>Frequency (MHz)</th>
<th>Maximal detune (peak, Hz)</th>
<th>LFD at operating gradient, Hz</th>
<th>Minimal Half Bandwidth (Hz)</th>
<th>Max Required Power (kW)</th>
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<tbody>
<tr>
<td>HWR</td>
<td>162.5</td>
<td>20</td>
<td>-122</td>
<td>33</td>
<td>6.5</td>
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<tr>
<td>SSR1</td>
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<td>20</td>
<td>-440</td>
<td>43</td>
<td>6.1</td>
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<td>SSR2</td>
<td>325</td>
<td>20</td>
<td>-192</td>
<td>29</td>
<td>17.0</td>
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<tr>
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<td>650</td>
<td>20</td>
<td>-192</td>
<td>29</td>
<td>38.0</td>
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<tr>
<td>HB650</td>
<td>650</td>
<td>20</td>
<td>-136</td>
<td>29</td>
<td>64.0</td>
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# SRF Development Status

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

- **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 $\gamma_t$ jump for loss control
    - 8 quad triplets to generate $\pm 1$ 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

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<thead>
<tr>
<th>Responsible Institution</th>
<th>Deliverable</th>
<th>Due Date</th>
<th>Program</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3.1 PIP-II Source, LEBT and MEBT</strong></td>
<td>IIFC Deliverable</td>
<td>MEBT Dipoles and Quadrupoles</td>
<td>May-16</td>
</tr>
<tr>
<td><strong>3.2 Radio Frequency Quadrupole (RFQ)</strong></td>
<td>Fermilab/LBNL Deliverable</td>
<td>RFQ</td>
<td>Jul-15</td>
</tr>
<tr>
<td><strong>3.3 Half Wave Resonator (HWR)</strong></td>
<td>Fermilab/ANL Deliverable</td>
<td>162.5 MHz, HWR Cryomodule with 8 cavities</td>
<td>Apr-17</td>
</tr>
<tr>
<td></td>
<td>Fermilab Deliverable</td>
<td>Eight 162.5 MHz, RF system and it distribution system</td>
<td>Apr-17</td>
</tr>
<tr>
<td></td>
<td>Fermilab Deliverable</td>
<td>Integration and Commissioning</td>
<td>Jun-17</td>
</tr>
<tr>
<td><strong>3.4 Single Spoke Resonator-1 325 MHz Cryomodule</strong></td>
<td>Fermilab Deliverable</td>
<td>One SSR1 Cryomodule</td>
<td>May-17</td>
</tr>
<tr>
<td><strong>3.9 System Test of SSR1 CM and RF Power with Beam</strong></td>
<td>Fermilab Deliverable</td>
<td>SSR1 CM to PXIE</td>
<td>May-17</td>
</tr>
<tr>
<td></td>
<td>Fermilab Deliverable</td>
<td>10 MeV Beam from PXIE</td>
<td>Dec-17</td>
</tr>
<tr>
<td></td>
<td>DAE Deliverable</td>
<td>Eight, 10 kWatt 325 MHz Solid State RF with Circulator</td>
<td>Jan-18</td>
</tr>
<tr>
<td></td>
<td>Fermilab Deliverable</td>
<td>Integration and Commissioning</td>
<td>Jul-18</td>
</tr>
<tr>
<td><strong>3.5 High Beta 650 MHz Cryomodule</strong></td>
<td>IIFC Deliverable</td>
<td>HB650 CM Design</td>
<td>Dec-16</td>
</tr>
<tr>
<td></td>
<td>Fermilab Deliverable</td>
<td>One HB650 Cryomodule</td>
<td>Sep-18</td>
</tr>
<tr>
<td><strong>3.6 Low Beta 650 MHz Cavity</strong></td>
<td>IIFC Deliverable</td>
<td>Two LB650 High Power Tested Dressed Cavity</td>
<td>Dec-18</td>
</tr>
<tr>
<td><strong>3.7 Single Spoke Resonator 2 Cavity</strong></td>
<td>IIFC Deliverable</td>
<td>Two SSR2 Low Power Tested Cavity</td>
<td>Dec-18</td>
</tr>
<tr>
<td><strong>3.8 650 MHz Cavity Horizontal Test Stand</strong></td>
<td>IIFC Deliverable</td>
<td>HTS-2 Cryostat to Fermilab</td>
<td>Jun-16</td>
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<tr>
<td></td>
<td>DAE Deliverable</td>
<td>Two 30 kWatt Solid State RF Amplifier with Circulator</td>
<td>Jun-16</td>
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<td>Fermilab Deliverable</td>
<td>Integration and Commissioning</td>
<td>Oct-16</td>
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<td></td>
<td>Fermilab Deliverable</td>
<td>Test of 1st 650 MHZ Dressed HB650 Cavity</td>
<td>Jan-17</td>
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<tr>
<td><strong>3.10 System Test of HB650 CM and RF Power</strong></td>
<td>Fermilab Deliverable</td>
<td>HB650 CM to CMTF</td>
<td>Sep-18</td>
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<tr>
<td></td>
<td>DAE Deliverable</td>
<td>Six, 30 kWatt 650 MHz Solid State RF with Circulator</td>
<td>Apr-18</td>
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<td></td>
<td>Fermilab Deliverable</td>
<td>Integration and Commissioning</td>
<td>Nov-18</td>
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</table>
### PIP-II R&D Plan thru FY 2018

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

<table>
<thead>
<tr>
<th></th>
<th>M&amp;S (direct)</th>
<th>Labor (SWF)</th>
<th>Labor (FTE)</th>
<th>FY15 Labor (Actuals)</th>
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<tbody>
<tr>
<td>PXIE</td>
<td>$16.8M</td>
<td>$11.7M</td>
<td>~99</td>
<td>22.6</td>
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<tr>
<td>SRF</td>
<td>$5.9M</td>
<td>$4.2M</td>
<td>~36</td>
<td>12.2</td>
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<tr>
<td>Booster/RR/MI</td>
<td>$0.9M</td>
<td>$2.0M</td>
<td>~16</td>
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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

<table>
<thead>
<tr>
<th>Detector Fiducial Mass (kton)</th>
<th>Proton Beam Power (MW)</th>
<th>YEARS to reach 120kT.MW.yr</th>
<th>YEARS to reach 600kT.MW.yr</th>
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</table>

- 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
PXIE: Ion Source and LEBT status

- Commissioned, continue with characterization
- Ready for RFQ installation
RFQ Progress

• Modules:
  – vacuum tight
  – machining complete
  – assembly progressing

• RF Power systems
  – commissioned and ready

• Installation:
  – Summer 2015
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)

<table>
<thead>
<tr>
<th>Responsible Institution</th>
<th>Deliverable</th>
<th>Due Date</th>
<th>FY 2015</th>
<th>FY 2016</th>
<th>FY 2017</th>
<th>FY 2018</th>
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<tr>
<td><strong>3.1 PIP-II Source, LEBT and MEBT</strong></td>
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### PIP-II R&D Plan thru FY 2018 (markers indicate completion date)

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<th>FY 2016</th>
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<td>Nov-18</td>
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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\textsuperscript{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

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<tr>
<th>Milestone</th>
<th>Start</th>
<th>Completion Date</th>
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<tr>
<td>High Q0 R&amp;D/Design Verification</td>
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<td>30 Jun 15</td>
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<td>Prototype CM Assembly</td>
<td>12 Aug 15</td>
<td>8 Mar 16</td>
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<td>CM2-4 Assembly</td>
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<td>CM5-17 Assembly</td>
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<td>SLAC CM Installation</td>
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