121.3.7-8 Linac - LB650, HB650
SC Acceleration Modules and Cryogenics
Allan Rowe
PIP-II Director’s Review
10-12 October 2017

In partnership with:
India Institutes Fermilab Collaboration
Istituto Nazionale di Fisica Nucleare
Science and Technology Facilities Council
Outline

• Overview
• Requirements
• Conceptual Design, Maturity
• Scope/Deliverables
• Interfaces
• Organizational Progress
• ESH&Q
• Risk
• Cost
• Schedule
• Summary
About Me:

• Role in PIP-II: Project Engineer
  – L3 Manager for WBS 121.3.7, 8 (LB650, HB650)

• Relevant experience:
  – Tech. Div. SRF Development Dept. Deputy Head
  – PIP-II Coordinator for Technical Division (SRF LINAC Dev.)
  – Cryomodule Cleanroom Assembly Group Leader
  – Cavity Processing and Facilities Group Leader
  – Project Manager for ARRA Cavity Processing Industrialization + Eco-friendly Processing Development
  – FNAL Project Manager for Cavity Processing Facility at ANL
  – Responsible engineer for 3.9 GHz DESY FLASH Cryomodule Cavity processing and testing
WBS 121.3.7-8, LB650, HB650 Overview

<table>
<thead>
<tr>
<th>Cryomodule type</th>
<th>Cavities per CM</th>
<th># CMs</th>
<th>CM length (m)</th>
<th>$Q_0$ at 2K ($10^{10}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWR</td>
<td>8</td>
<td>1</td>
<td>5.93</td>
<td>0.5</td>
</tr>
<tr>
<td>SSR1</td>
<td>8</td>
<td>2</td>
<td>5.2</td>
<td>0.6</td>
</tr>
<tr>
<td>SSR2</td>
<td>5</td>
<td>7</td>
<td>6.5</td>
<td>0.8</td>
</tr>
<tr>
<td>LB650</td>
<td>3</td>
<td>11</td>
<td>3.9</td>
<td>2.15</td>
</tr>
<tr>
<td>HB650</td>
<td>6</td>
<td>4</td>
<td>9.5</td>
<td>3</td>
</tr>
</tbody>
</table>

PIP-II Conceptual Design Report: DocDb # 113
- Eleven $\beta_g=0.61$ and four $\beta_g=0.92$ 650 MHz SRF cryomodules, capable of operating in both pulsed and CW modes, that provide an energy gain from 185 MeV to 800 MeV with a beam current of 2 mA average, 5 mA peak to the Beam Transfer Line.
WBS 121.3.7 LB650 Requirements

121.3.7 - \( \beta_g = 0.61 \), 650 MHz Elliptical Cryomodules

- CM FRS: TC# ED0001830, SRF Dressed Cavity FRS: TC# ED0001834

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating mode</td>
<td>Pulsed with CW capability</td>
</tr>
<tr>
<td>Maximum Beam Current</td>
<td>5 mA</td>
</tr>
<tr>
<td>Max Leak Rate (room temp)</td>
<td>(&lt; 10^{-10}) atm-cc/sec</td>
</tr>
<tr>
<td>Operating gain per cavity</td>
<td>11.9 MeV</td>
</tr>
<tr>
<td>Maximum Gain per cavity in VTS</td>
<td>( &gt; 14) MeV</td>
</tr>
<tr>
<td>Sensitivity to He pressure fluctuations</td>
<td>(&lt; 25) Hz/mbar (dressed cavity)</td>
</tr>
<tr>
<td>Lorentz Force Detuning coefficient</td>
<td>(&lt;1.2) Hz/(MV/m)^2</td>
</tr>
<tr>
<td>Field Flatness dressed cavity</td>
<td>( &gt; 90)%</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>2.0 K</td>
</tr>
<tr>
<td>Operating Pressure</td>
<td>30 mbar</td>
</tr>
<tr>
<td>MAWP</td>
<td>2 bar (RT), 4 bar (2K)</td>
</tr>
<tr>
<td>RF power input per cavity</td>
<td>up to 70 kW (CW, operational gradient)</td>
</tr>
<tr>
<td>Power coming out from RF output coupler (prob at nom voltage)</td>
<td>100 mW</td>
</tr>
<tr>
<td>Cavity bandwidth</td>
<td>63 Hz</td>
</tr>
<tr>
<td>Operating power dissipation per cavity at 2 K (dynamic)</td>
<td>(&lt; 20) W</td>
</tr>
</tbody>
</table>

\( \beta_g = 0.61 \) CM Requirements

\( \beta_g = 0.61 \) Cavity Operating Parameters
WBS 121.3.8 HB650 Requirements

121.3.8 - $\beta_g=0.92$, 650 MHz Elliptical Cryomodules

- CM FRS: TC# ED0001322, SRF Dressed Cavity FRS: TC# ED0001321

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$ geometric</td>
<td>0.92</td>
</tr>
<tr>
<td>Operating temperature, K</td>
<td>2</td>
</tr>
<tr>
<td>Operating mode</td>
<td>Pulsed and CW</td>
</tr>
<tr>
<td>Operating energy gain, MV</td>
<td>19.9</td>
</tr>
<tr>
<td>Maximum dynamic cavity heat load to 2 K, W (each, including coupler)</td>
<td>23</td>
</tr>
</tbody>
</table>

### βg=0.92 CM Requirements

- $\beta_g=0.92$ CM Requirements

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WBS 121.3.7 LB650 Cavity Design/Maturity

- LB650 Dressed Cavity Design through the PDR TC# ED0006010
  - PDR of VECC cavity resulted in subtle alternative EM design modifications. Three designs pursued (VECC, FNAL, INFN-Lasa) were very similar in critical parameter performance.
  - LB650 cavity Electromagnetic Design (INFN-Lasa) chosen as best compromise among three similar designs.

INFN-Lasa LB650 Cavity Model

FNAL analysis of Trapped HOMs with broad beam spectrum.
WBS 121.3.7 LB650 Cryomodule Design/Maturity

• CM Design is DAE-deliverable: RRCAT
  – Design concept based on FNAL SSR1 and preliminary HB650 CM
  – CM Design maturity is conceptual.
  – Design review schedule elaborated in P6.
WBS 121.3.8 HB650 Cavity Design Status

• Cavity Design Status
  – $\beta_g=0.92$ 650 MHz bare cavity design has completed the FDR: TC# ED0003861, TRS for cavity system ED# ED0003153 is in draft form.
  – Dressed cavity mechanical design is advanced, awaiting FDR of dressed cavity system.
  – Design review schedule elaborated in P6.
  – Performance of $\beta_g=0.90$ cavities demonstrated above specification.
  – Processing/Q0 recipe refinement still required.

Three of four multi-cell B.90 cavities qualified through VTS. $Q_0 > 3.5 \times 10^9$ @ 20 MV/m demonstrated. Minimal radiation due to FE induced X-Rays during tests up to $E_{acc} < 25$ MV/m.
WBS 121.3.8 HB650 RF Coupler/Tuner Design

- High Power 650 MHz 120 kW RF coupler FRS, TRS TC#s ED0003645, ED0005689
  - Prototypes through FDR/PRR.
  - Two cold-end designs in procurement cycle, expected to arrive 04/2018
- Prototype tuner – Engineering Specification TC# ED0005146
  - Version 1 procured and tested at room temp. Initial testing yielded opportunity to optimize design.
WBS 121.3.8 HB650 CM Design/Maturity

- HB650 CM Design Status - FRS: TC# ED0001322
  - Status is preliminary. 3D model is well developed. Design is currently in the analysis/design iteration phase pre-PDR.
  - Design review schedule elaborated in P6.

HB650 String Details

- Vacuum vessel
- Thermal shield
- Cavity string
- Coupler
- Support post
- Chimney
- Two-phase He pipe
- Cryogenic valves
- Strong-back

HB650 Model
FNAL Scope and Deliverables – LB650

- Project management and coordination of all scope within this WBS.
- Design, analysis, reviews, procurement, QA/QC, and cryomodule integration support to Partners producing all 11 cryomodules delivered to FNAL. This includes device level design support to verify performance requirements are met prior to production.
- Incoming QA/QC of 11 cryomodules.
- Operational Readiness Clearance for all 11 cryomodules before initial cool-down.
- RF testing and performance verification of 6 of 11 cryomodules.
- Hand-off to LINAC integration and commissioning of 11 cryomodules.
- Translation of all Partner design and production data with cataloging in Teamcenter.
- FNAL M&S includes: travel, onsite CM handing fixtures, and CM RF testing
Partner Scope

- Partners assumed responsible for all R&D and Production Scope
- Perform R&D on critical LB650 cryomodule subsystems to verify PIP-II performance criteria are achievable, in particular on Dressed cavity subsystem.
- All M&S to support R&D and production and delivery of 11 LB650 cryomodules.

Specific Partner Lab Scope:

- DAE – VECC: LB650 Dressed cavity design and ½ of the required production quantity including RF couplers, tuners, and magnetic shields.
- DAE – RRCAT: LB650 Cryomodule design, complete design model, production drawing package, and all requisite analysis to pass ORC at FNAL.
- EU – INFN Lasa: LB650 Dressed cavity design and ½ of the required dressed cavity production quantity. All design and production documentation.
- EU – CEA Saclay: Procurement, integration, and delivery of 11 three-cavity LB650 cryomodules to Fermilab ready-to-RF Test. All design and production documentation.
121.3.8 HB650 Scope and Deliverables

Complete Scope and Deliverables and Assumptions

<table>
<thead>
<tr>
<th>BOE docDB #'s</th>
<th>351</th>
<th>360</th>
<th>363</th>
<th>366</th>
<th>372</th>
<th>375</th>
<th>378</th>
</tr>
</thead>
</table>

FNAL Scope and Deliverables – HB650

- Project management and coordination of all scope within this WBS.
- Perform all required design, analysis, reviews, procurement, QA/QC, device design verification testing, and integration of 4 six-cavity cryomodules.
- Perform a second design iteration cycle following design verification testing and HB650 CM(1) integration for the production CMs(2-4)
- Support Partners with development of dressed cavity deliverables.
- Operational Readiness Clearance for all 4 cryomodules before initial cool-down.
- RF testing and performance verification of 3 of 4 cryomodules.
- Hand-off to LINAC integration and commissioning of 4 cryomodules.
- Translation of all Partner design and production data with cataloging in Teamcenter.
121.3.8 HB650 Scope and Deliverables

FNAL M&S – Primary Procurements

- Partner and vendor support travel
- 2 R&D $\beta_g=0.92$ 650 MHz bare cavities including material
- 2 Prototype RF couplers
- 10 Bare cavities including material
- 16 RF couplers
- 25 magnetic shields
- 18 tuners
- All processing and RF testing M&S including cryogenics costs
- 4 CMs complete string, coldmass, and integration components
- CM assembly and transportation fixtures
121.3.8 HB650 Scope and Deliverables

Partner Scope

• DAE- RRCAT:
  – All required R&D to develop $\beta_g=0.92$ 650 MHz bare and dressed cavity testing and production in India.
  – All required M&S to support production, testing, and delivery of 20 dressed and tested HB650 RF cavities.
  – Delivery of 20 Dressed HB650 cavities ready for VTS performance verification.
  – Delivery of 20 high power RF couplers, both cold and warm ends.
  – Delivery of 20 tuners, including piezos and motor packages.
  – Delivery of all design and production documentation necessary to include cavities in CM ORC.
Interfaces - Technical

WBS 121.3.7, 8 interface across the PIP-II WBS Matrix

- Each Cryomodule type will have a controlled document fully elaborating each interface.

<table>
<thead>
<tr>
<th>Common Interfaces to LB650 and HB650</th>
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</thead>
<tbody>
<tr>
<td>121.3.9 – RF Power</td>
</tr>
<tr>
<td>121.3.10 – RF Integration</td>
</tr>
<tr>
<td>121.3.11 – Cryo Systems</td>
</tr>
<tr>
<td>121.3.16 – Beam Instrum.</td>
</tr>
<tr>
<td>121.3.17 – Control Systems</td>
</tr>
<tr>
<td>121.3.18 – Vacuum</td>
</tr>
<tr>
<td>*121.3.6 – SSR2 (LB650)</td>
</tr>
<tr>
<td>121.3.19 – General Supt. Serv.</td>
</tr>
<tr>
<td>121.3.20 – Safety Systems</td>
</tr>
<tr>
<td>121.3.21 – Test Infrastructure</td>
</tr>
<tr>
<td>121.3.22 – Install., Integ., and Comm</td>
</tr>
<tr>
<td>121.5 – Conventional Facilities</td>
</tr>
<tr>
<td>121.3.7,8 – LB650/HB650</td>
</tr>
<tr>
<td>*121.3.14 – Beam Transfer Line (HB650)</td>
</tr>
</tbody>
</table>

- Technical interfaces are understood and are or will be under revision control and managed through Teamcenter.
Interfaces - Partners

- Final Partner deliverables to be formalized in advance of CD-2.
- Cryomodule development LB650, and HB650 are heavily matrixed.
- SPC/SPM and POC direct communication is essential to the success of this collaboration.
- Timely information and material transfer between stakeholders is essential to meet technical and schedule requirements.

- 121.3.7 – LB650
  - DAE – VECC: LB650 dressed cavity design and production
  - DAE – RRCAT: LB650 overall CM design
  - EU: INFN-Lasa: LB650 dressed cavity design and production
  - EU: CEA Saclay: LB650 CM prototyping, integration, and delivery
  - FNAL: Design and integration support and CM testing

- 121.3.8 – HB650
  - FNAL: Overall CM design, development, production, and testing
  - DAE – RRCAT: HB650 dressed cavity production
Organizational Progress

• FNAL L3 Manager Assigned
  – Single L3 for LB650 and HB650
  – L4 technical POCs identified within the Technical Division org.
  – Support area staffing and POCs map directly to Technical Division org. chart – VTS testing, Cavity processing and Facilities, QA/QC, etc.
  – Organization is moving with excellent technical progress.
  – CM design team well-established and experienced (XFEL, ILC, LCLS-II, SSR1, etc.)

• Partner organization is well established in the DAE and maturing in the EU.
Design Review Plan

- Critical component design review cycles are organized as follows: FRS and/or TRS → PDR → FDR → PRR
- Reviews are tracked in P6 as milestones with design activities preceding and following the PDR, concluding with the FDR, and procurement support activities starting with the PRR milestone.
- Non-critical components or subsystems are managed within the Division or Department review process as required by the FNAL Engineering Manual.
- Design reviews are also planned for Partner deliverables as appropriate to ensure technical and ESH&Q requirements are met. Partner milestone dates exist in P6, but require formal agreement.
ESH&Q

• Personnel Safety and environmental and equipment protection are the highest priorities in the PIP-II Project.
• All activities will be in full compliance with the PIP-II ISM program defined in DocDb# 141.
  – Laboratory and DOE standards and practices
    • Fermi ES&H Manual
    • Division/Area specific Hazards Analyses and Training
• Procurement, fabrication, and acceptance of components will follow the Project’s QA Plan (DocDB # 142) utilizing established Project/Division mechanisms regarding acceptance testing, control of non-conformances, and vendor feedback.
Risk: 650 MHz Cavities and Cryomodules

- Pulsed and CW cryomodule operating modes cause cryogenic or mechanical instabilities
- HB650 CM (1) Performance at CMTF does not meet technical requirements
- Cryomodule production rate at Fermilab is too slow

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Pulsed and CW cryomodule operating modes cause cryogenic or mechanical instabilities</td>
<td>50.00%</td>
<td>4 (H)</td>
<td>688</td>
<td>3.3</td>
<td>2 (M)</td>
<td>3 (H)</td>
<td>3 (High)</td>
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<tr>
<td>HB650 CM (1) Performance at CMTF does not meet technical requirements</td>
<td>40.00%</td>
<td>4 (H)</td>
<td>333</td>
<td>2.8</td>
<td>2 (M)</td>
<td>3 (H)</td>
<td>3 (High)</td>
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<tr>
<td>Cryomodule production rate at Fermilab is too slow</td>
<td>50.00%</td>
<td>4 (H)</td>
<td>0</td>
<td>3.5</td>
<td>0 (N)</td>
<td>3 (H)</td>
<td>3 (High)</td>
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## BOE Summary – 121.3.7 LB650

<table>
<thead>
<tr>
<th>WBS Number</th>
<th>Title</th>
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<tr>
<td>121.3.7.2</td>
<td><strong>BOE Document for 121.3.7.2 LB650 Project Management and Coordination</strong></td>
<td>920</td>
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<tr>
<td>121.3.7.3.1, 2</td>
<td><strong>BOE Document for 121.3.7.3.1 and .2 LB650 1st CM Cavities</strong></td>
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<td><strong>BOE Document for 121.3.7.3.3 .4 and .5 LB650 1st CM Integration and Assembly</strong></td>
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## BOE Summary – 121.3.8 HB650

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<td>BOE Document for 121.3.8.4.3, .4, and .5 HB650 2nd-4th CM Integration and Assembly</td>
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<td>121.3.8.4.6</td>
<td>BOE Document for 121.3.8.4.6 HB650 2nd-4th CM Test</td>
<td>378</td>
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</tbody>
</table>

- All relevant BOE Documents (estimate roll-ups, WBS dictionaries, descriptions) exist and have been reviewed and approved.
## LB650 Cost Summary

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>Hours</th>
<th>Labor ($000)</th>
<th>M&amp;S ($000)</th>
<th>Est. Uncertainty ($000)</th>
<th>Total</th>
<th>% of Base</th>
<th>Total Cost Incl. Uncrty.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>121.3.7 - Linac - Low Beta 650 (LB650)</strong></td>
<td>P6 Hours</td>
<td>P6 Base Cost</td>
<td>P6 Base Cost</td>
<td>Total</td>
<td>% of Base</td>
<td></td>
<td></td>
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<tr>
<td>121.3.7.2 - Linac - LB650 - Project Management and Coordination</td>
<td>13,713</td>
<td>$2,862.6</td>
<td>$284.4</td>
<td>$328.9</td>
<td>10.5%</td>
<td>$3,476.0</td>
<td></td>
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<tr>
<td>121.3.7.3 - Linac - LB650 - 1st Pre-series Production CryoModule (1stCM)</td>
<td>17,994</td>
<td>$3,000.9</td>
<td>$146.5</td>
<td>$629.5</td>
<td>20.0%</td>
<td>$3,776.9</td>
<td></td>
</tr>
<tr>
<td>121.3.7.4 - Linac - LB650 - 2nd to 11th Production CryoModules (2nd-11thCM)</td>
<td>23,083</td>
<td>$3,834.4</td>
<td>$56.1</td>
<td>$778.1</td>
<td>20.0%</td>
<td>$4,668.6</td>
<td></td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>54,790</td>
<td>$9,697.9</td>
<td>$487.1</td>
<td>$1,736.5</td>
<td>17.0%</td>
<td>$11,921.4</td>
<td></td>
</tr>
</tbody>
</table>

Note: P6 base cost = BOE + overheads and escalation

- Estimates developed down to the activity level for LB650 MHz CMs.
- P6 output.
• Labor drives costs in LB650 based on assumed scope.
• M&S drivers are travel then CM RF testing.
**LB650 Cost Profile – P6 Base Cost Only**

- **Labor increases through RF testing in FY23/24**

### P6 Base Costs = BOE + Overheads + Escalation

<table>
<thead>
<tr>
<th></th>
<th>FY18</th>
<th>FY19</th>
<th>FY20</th>
<th>FY21</th>
<th>FY22</th>
<th>FY23</th>
<th>FY24</th>
<th>FY25</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>$37.7</td>
<td>$38.5</td>
<td>$38.4</td>
<td>$39.0</td>
<td>$39.9</td>
<td>$126.2</td>
<td>$66.9</td>
<td>$8.9</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>$517.6</td>
<td>$949.9</td>
<td>$940.9</td>
<td>$1,255.1</td>
<td>$1,320.4</td>
<td>$2,576.3</td>
<td>$1,999.4</td>
<td>$335.4</td>
</tr>
<tr>
<td><strong>Cumulative Tot.</strong></td>
<td>$555.3</td>
<td>$1,543.7</td>
<td>$2,523.1</td>
<td>$3,817.2</td>
<td>$5,177.5</td>
<td>$7,880.0</td>
<td>$9,946.2</td>
<td>$10,290.0</td>
</tr>
</tbody>
</table>

**Cumulative Total ($000)**

- $2,500
- $5,000
- $7,500
- $10,000
- $12,500

**Annual Costs ($000)**

- FY18
- FY19
- FY20
- FY21
- FY22
- FY23
- FY24
- FY25
Effort balance shows consistent development oversight followed by RF testing.

Technically driven with no effort smoothing.
### HB650 Cost Summary

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>Hours</th>
<th>Labor ($000)</th>
<th>M&amp;S ($000)</th>
<th>Est. Uncertainty ($000)</th>
<th>Total Cost Incl. Uncrt'y.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>121.3.8 - Linac - High Beta 650 (HB650)</strong></td>
<td></td>
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<tr>
<td></td>
<td>P6 Hours</td>
<td>P6 Base Cost</td>
<td>P6 Base Cost</td>
<td>Total</td>
<td>% of Base</td>
</tr>
<tr>
<td>121.3.8.2 - Linac - HB650 - Project Management and Coordination</td>
<td>8,946</td>
<td>$1,379.5</td>
<td>$350.2</td>
<td>$208.0</td>
<td>12.0%</td>
</tr>
<tr>
<td>121.3.8.3 - Linac - HB650 - 1st Prototype CryoModule (1stCM)</td>
<td>53,945</td>
<td>$7,506.5</td>
<td>$4,701.6</td>
<td>$3,005.8</td>
<td>24.6%</td>
</tr>
<tr>
<td>121.3.8.4 - Linac - HB650 - 2nd to 4th Production CryoModules (2nd-4thCM)</td>
<td>56,797</td>
<td>$8,327.9</td>
<td>$8,291.7</td>
<td>$4,240.0</td>
<td>25.5%</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>119,688</strong></td>
<td><strong>$17,213.9</strong></td>
<td><strong>$13,343.5</strong></td>
<td><strong>$7,453.8</strong></td>
<td><strong>24.4%</strong></td>
</tr>
</tbody>
</table>

Note: P6 base cost = BOE + overheads and escalation

- Estimates developed down to the activity level for HB650 MHz CMs.
- P6 output.
Balanced labor and M&S.
Distribution of maturity of estimates based on scope assumptions.
**HB650 Cost Profile – P6 Base Cost Only**

- Development and prototyping through CM1, then production of CMs 2-4.

### Charge #2

<table>
<thead>
<tr>
<th>Year</th>
<th>Material ($)</th>
<th>Labor ($)</th>
<th>Cumulative Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY18</td>
<td>767.5</td>
<td>2,362.3</td>
<td>3,129.8</td>
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<tr>
<td>FY19</td>
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<td>2,442.8</td>
<td>8,656.1</td>
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<td>FY20</td>
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<td>FY21</td>
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<td>16,431.3</td>
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<td>FY22</td>
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<td>22,628.3</td>
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<td>FY23</td>
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<td>2,961.5</td>
<td>28,905.7</td>
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<tr>
<td>FY24</td>
<td>103.6</td>
<td>1,548.1</td>
<td>30,557.4</td>
</tr>
</tbody>
</table>

P6 Base Costs = BOE + Overheads + Escalation
HB650 Labor Profile – P6 Hours/FTE

- Effort balance shows heavy CM design followed by production activities in two modes.
- Technically driven with no effort smoothing.
LB650 Schedule

 Charge #2

LB650 Development →
LB650 CM testing/Installation at FNAL →
Schedule – HB650 Bare Cavities

Charge #2

121.3.8 Linac - High Beta 650 (HB650)
  121.3.8.1 Linac - HB650 - T4 Milestones
  121.3.8.1.1 Linac - HB650 - T4 - Bare Cavities Qualified
  121.3.8.1.2 Linac - HB650 - T4 - Dressed Cavities Qualified
  121.3.8.1.3 Linac - HB650 - T4 - Assembly

β.92 R&D ➔

FNAL Production ➔
Schedule – HB650 Dressed Cavities

Charge #2

- β.90 →
- DAE β.92 Proto
- β.92 R&D →
- Production FNAL/DAE →
Schedule – HB650 Cryomodules

String → Coldmass → Integration → CM Test/Installation
Summary

- LB650 and HB650 requirements are defined and traceable
- Cryomodule sub-system and integrated system designs are sufficiently advanced to proceed to CD-1
- Milestone driven design review schedules through both WBS’s are developed
- Cost and schedule drivers including risks are understood
- A Partnership between multiple laboratories throughout the world is in the process of formalization to develop and produce these 15 cryomodules.
- We are ready for CD-1 and look forward to your feedback
- Thank you for your attention
END