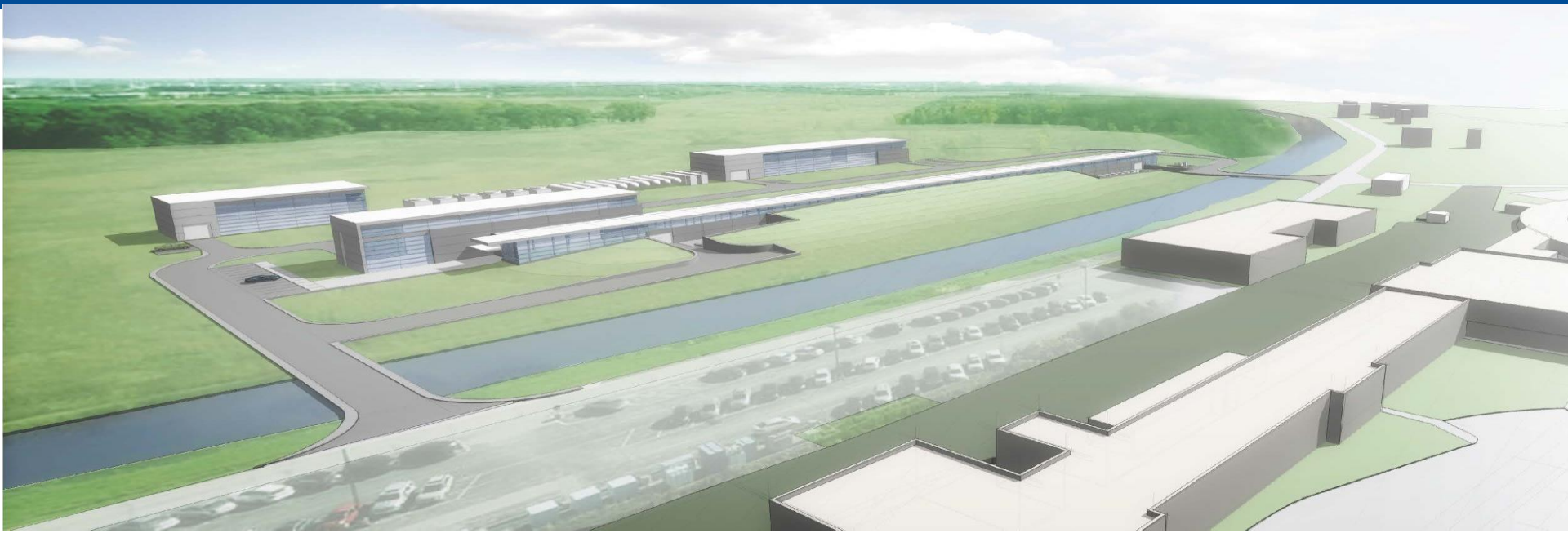


121.3.7-8 Linac - LB650, HB650

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

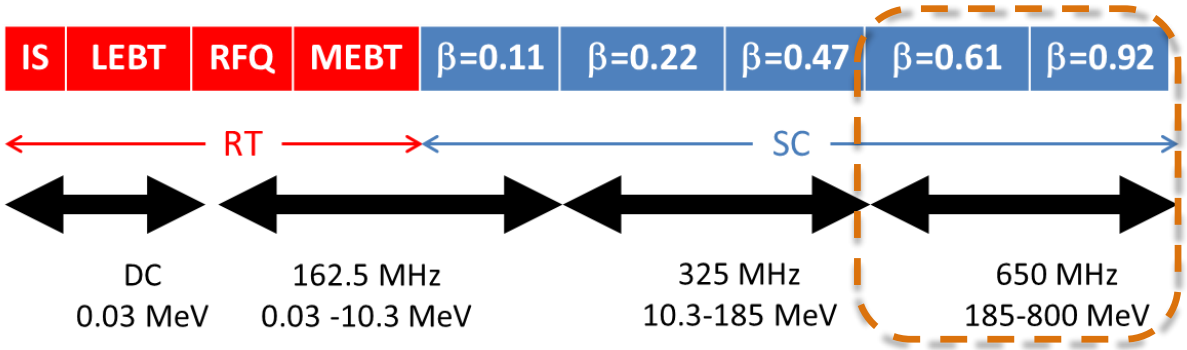
About Me:

- 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

Charge #1



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

PIP-II Conceptual Design Report: DocDb # 113

- Eleven β_g=0.61 and four β_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 *Me*V with a beam current of 2 *mA* average, 5 *mA* peak to the Beam Transfer Line.

WBS 121.3.7 LB650 Requirements

Charge #1

121.3.7 - β_g=0.61, 650 *MHz* Elliptical Cryomodules

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

General		
	Physical beam aperture, mm	118
	Overall length (flange-to-flange), m	5.25
	Overall width, m	≤1.6
	Beamline height from the floor, m	1.3
	Cryomodule height (from floor), m	≤2.60
	Ceiling height in the tunnel, m	3.30
	Max allowed heat load to 35-50 K, W	100
	Max allowed heat load to 5 K, W	16
	Max allowed heat load to 2 K, W	100
	Maximum number of lifetime thermal cycles	50
	Intermediate thermal shield temperature, K	35-50
	Thermal intercept temperatures, K	5 and 35-50
	Cryo-system pressure stability at 2 K (RMS), mbar	≤0.1
	Environmental contribution to internal field	≤10 mG
	Transverse cavity alignment error, mm RMS	<0.5
	Angular cavity alignment error, mrad RMS	≤1
	Beam duration for operation in pulsed regime, ms	≤0.6
	Repetition rate for operation in pulsed regime, Hz	≤20
Cavities		
	Number, total per cryomodule	3
	Frequency, MHz	650
	β geometric	0.61
	Operating temperature, K	2
	Operating mode	Pulsed and CW
	Operating energy gain, MV	11.9

βg=0.61 CM Requirements

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

βg=0.61 Cavity Operating Parameters

WBS 121.3.8 HB650 Requirements

Charge #1

121.3.8 - β_g=0.92, 650 *MHz* Elliptical Cryomodules

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

General		
	Physical beam aperture, mm	118
	Overall length (flange-to-flange), m	9.56
	Overall width, m	≤1.6
	Beamline height from the floor, m	1.3
	Cryomodule height (from floor), m	≤2.60
	Ceiling height in the tunnel, m	3.30
	Max allowed heat load to 35-50 K, W	300
	Max allowed heat load to 5 K, W	32
	Max allowed heat load to 2 K, W	220
	Maximum number of lifetime thermal cycles	50
	Intermediate thermal shield temperature, K	35-50
	Thermal intercept temperatures, K	5 and 35-50
	Cryo system pressure stability at 2 K (RMS), mbar	≤0.1
	Environmental contribution to internal field	≤10 mG
	Transverse cavity alignment error, mm RMS	<0.5
	Angular cavity alignment error, mrad RMS	≤1
	Beam duration for operation in pulsed regime, ms	≤0.6
	Repetition rate for operation in pulsed regime, Hz	≤20
Cavities		
	Cavities per cryomodule	6
	Frequency, MHz	650
	β geometric	0.92
	Operating temperature, K	2
	Operating mode	Pulsed and CW
	Operating energy gain, MV	19.9
	Maximum dynamic cavity heat load to 2 K, W (each, including coupler)	23

βg=0.92 CM Requirements

Parameter	Value
Operating mode	Pulsed with CW capability
Maximum Beam Current	5 mA
Max Leak Rate (room temp)	< 10^{-10} atm-cc/sec
Operating gain per cavity	19.9 MeV
Maximum Gain per cavity in VTS	> 24 MeV
Sensitivity to He pressure fluctuations	< 25 Hz/mbar (dressed cavity)
Lorentz Force Detuning coefficient	<1.0 Hz/(MV/m)^2
Field Flatness dressed cavity	> 90%
Operating temperature	2.0 K
Operating Pressure	30 mbar
MAWP	2 bar (RT), 4 bar (2K)
RF power input per cavity	up to 120 kW (CW, operational gradient)
Power coming out from RF output coupler (prob) at nom voltage	100 mW
Cavity bandwidth	65 Hz
Operating power dissipation per cavity at 2 K (dynamic)	< 22 W

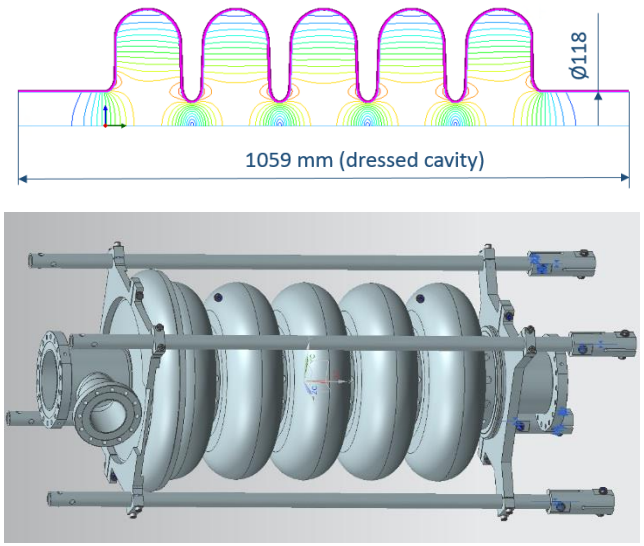
βg=0.92 Cavity Operating Parameters

PIP-II

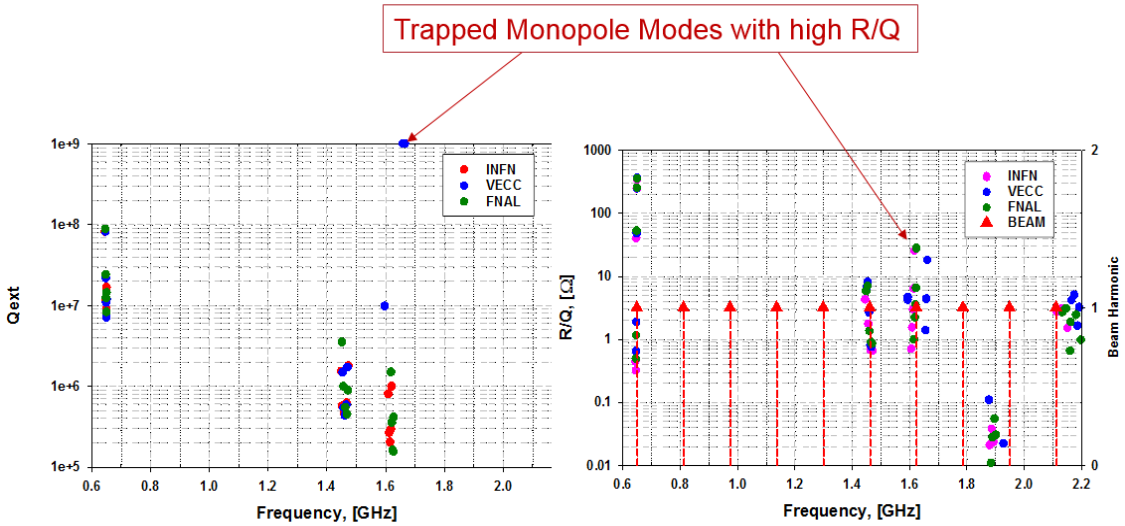
WBS 121.3.7 LB650 Cavity Design/Maturity

Charge #1

- 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



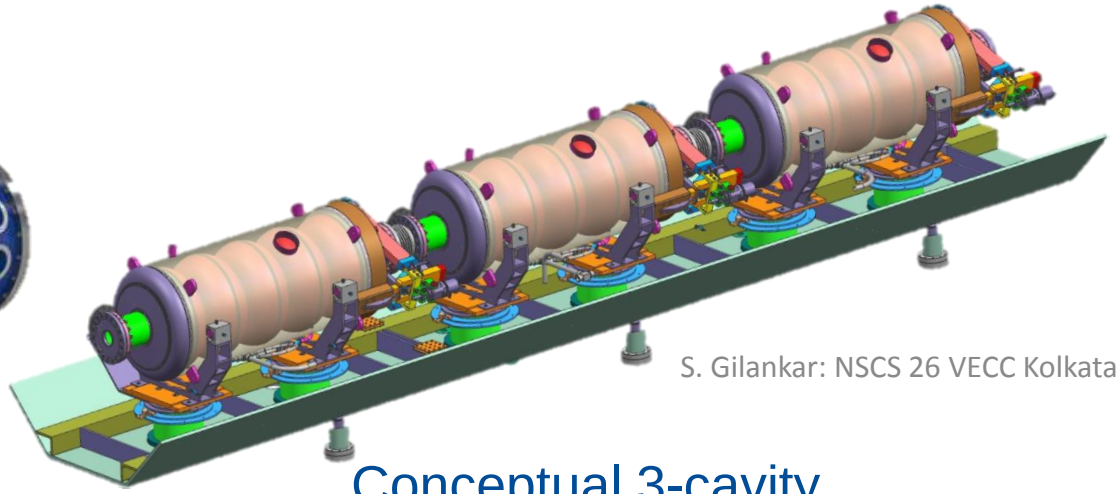
FNAL analysis of Trapped HOMs with broad beam spectrum.

WBS 121.3.7 LB650 Cryomodule Design/Maturity

Charge #1

- 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.

LB650 CMs
(DAE/EU
Deliverable)



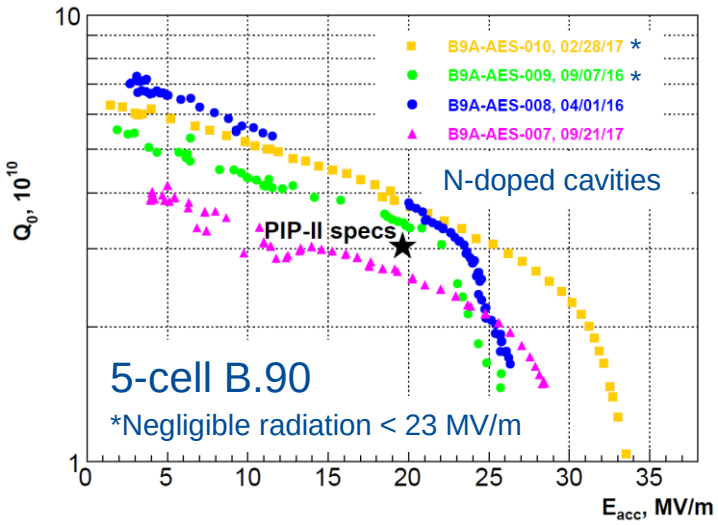
S. Gilankar: NSCS 26 VECC Kolkata

Conceptual 3-cavity strongback/support post design based on SSR1 CM

WBS 121.3.8 HB650 Cavity Design Status

Charge #1

- Cavity Design Status
  - β_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 β_g=0.90 cavities demonstrated above specification.
  - Processing/Q0 recipe refinement still required.

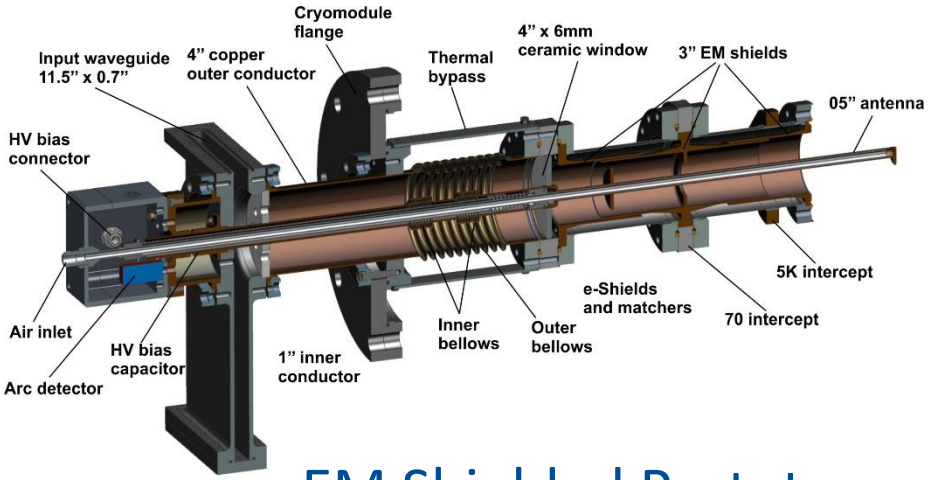


Three of four multi-cell B.90 cavities qualified through VTS.
Q_0 > 3.5 E10 @ 20 MV/m demonstrated
Minimal radiation due to FE induced X-Rays during tests up to E_{acc} < 25 MV/m.

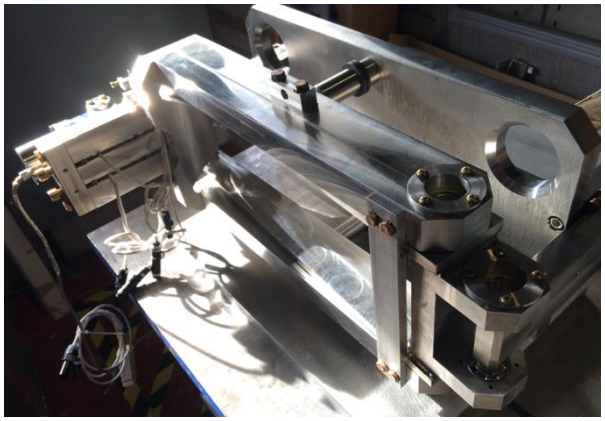
WBS 121.3.8 HB650 RF Coupler/Tuner Design

Charge #1

- 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.



EM Shielded Prototype

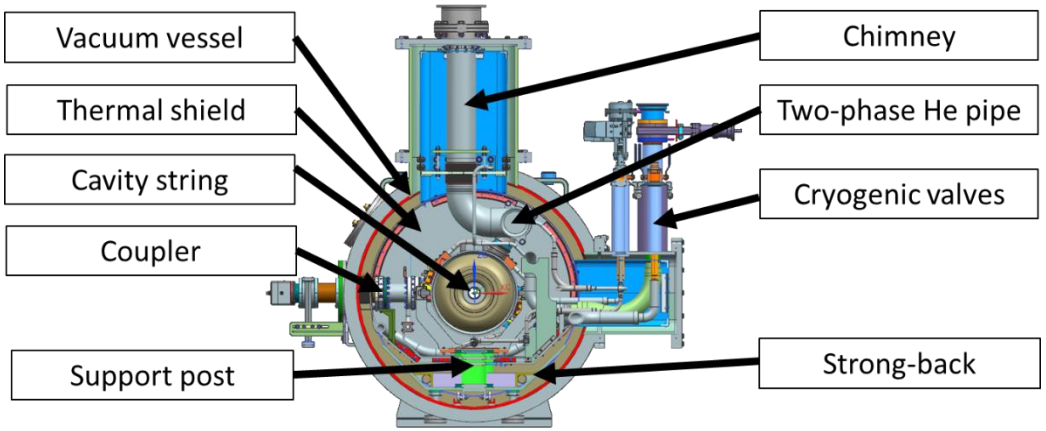


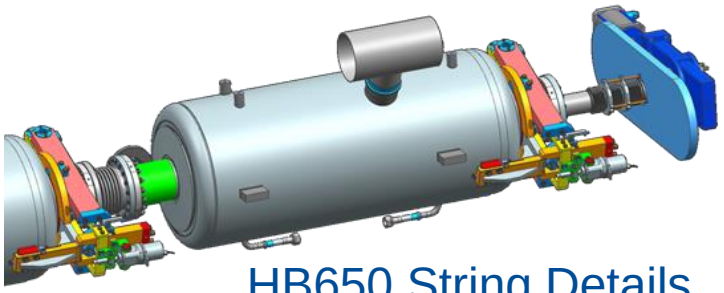
Prototype 650 MHz tuner during bench testing.

WBS 121.3.8 HB650 CM Design/Maturity

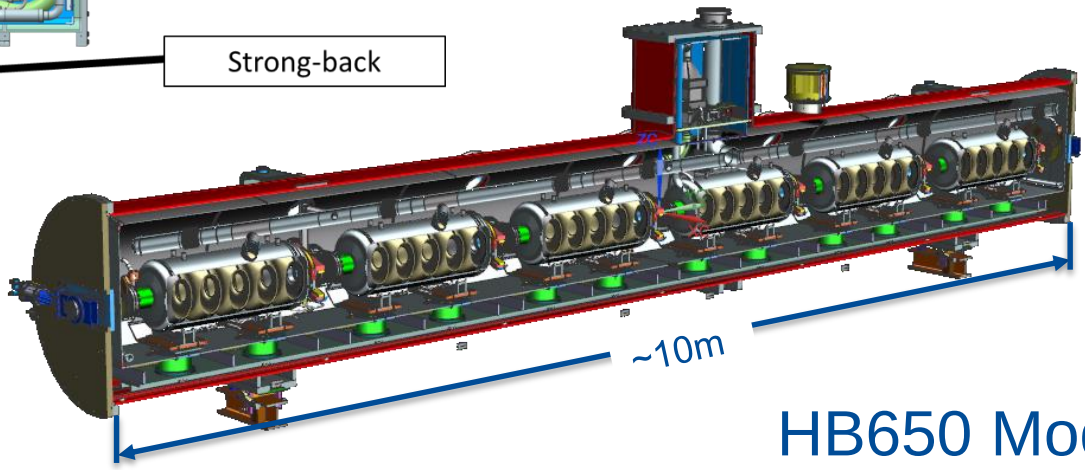
Charge #1

- 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



HB650 Model

121.3.7 LB650 Scope and Deliverables

Charge #1

Complete Scope and Deliverables and Assumptions

BOE docDB #'s	920	923	926	929	932	935	938

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

121.3.7 LB650 Scope and Deliverables

Charge #1

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

Charge #1

Complete Scope and Deliverables and Assumptions

BOE docDB #'s	351	360	363	366	372	375	378

FNAL Scope and Deliverables – HB650

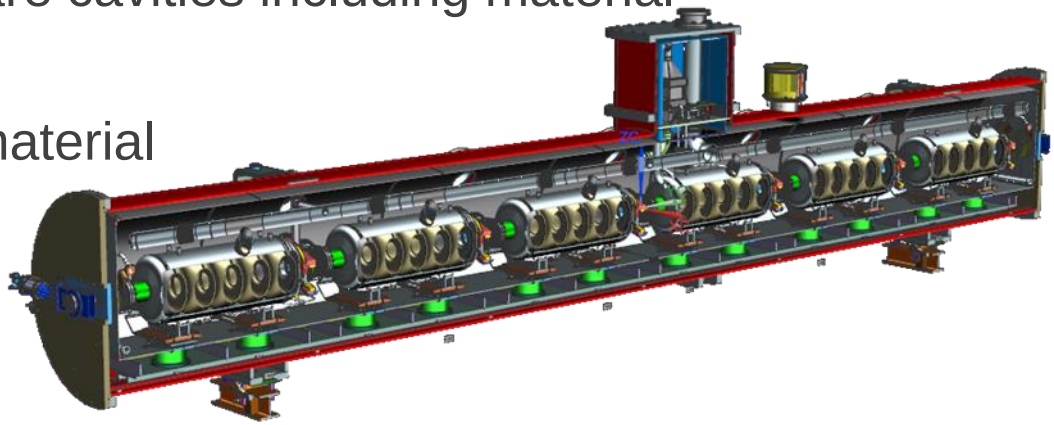
- Project management and coordination of all scope within this WBS.
- Perform all required design, analysis, reviews, procurement, QA/QC, device design verification testing, and integration of 4 six-cavity cryomodules.
- Perform a second design iteration cycle following design verification testing and 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

Charge #1

FNAL M&S – Primary Procurements

- Partner and vendor support travel
- 2 R&D β_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

Charge #1

Partner Scope

- DAE- RRCAT:
  - All required R&D to develop β_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

Charge #1

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

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

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

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

Interfaces - Partners

Charges #1, 3

- 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

Charge #1

- 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

Charge #3

- 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

Charge #4

- 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

Charge #2

- 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

Title	Probability	Probability Score	P * Impact (k$)	P * Impact (months)	Impact Score - Cost	Impact Score - Schedul	Risk Rank
Pulsed and CW cryomodule operating modes cause cryogenic or mechanical instabilities	50.00%	4 (H)	688	3.3	2 (M)	3 (H)	3 (High)
HB650 CM (1) Performance at CMTF does not meet technical requirements	40.00%	4 (H)	333	2.8	2 (M)	3 (H)	3 (High)
Cryomodule production rate at Fermilab is too slow	50.00%	4 (H)	0	3.5	0 (N)	3 (H)	3 (High)

BOE Summary – 121.3.7 LB650

Charge #2

WBS Number	Title	Docdb #
121.3.7.2	BOE Document for 121.3.7.2 LB650 Project Management and Coordination	920
121.3.7.3.1, 2	BOE Document for 121.3.7.3.1 and .2 LB650 1st CM Cavities	923
121.3.7.3.3, 4, 5	BOE Document for 121.3.7.3.3 .4 and .5 LB650 1st CM Integration and Assembly	926
121.3.7.3.6	BOE Document for 121.3.7.3.6 LB650 1st CM Test	929
121.3.7.4.1, 2	BOE Document for 121.3.7.4.1 and .2 LB650 2nd-11th CM Cavities	932
121.3.7.4.3, 4, 5	BOE Document for 121.3.7.4.3 .4 and .5 LB650 2nd-11th CM Integration and Assembly	935
121.3.7.4.6	BOE Document for 121.3.7.4.6 LB650 2nd-11th CM Test	938

BOE Summary – 121.3.8 HB650

Charge #2

WBS Number	Title	Docdb #
121.3.8.2	BOE Document for 121.3.8.2 HB650 Project Management and Coordination	351
121.3.8.3.1, 2	BOE Document for 121.3.8.3.1 and .2 HB650 1st CM Cavities	360
121.3.8.3.3, 4, 5	BOE Document for 121.3.8.3.3, .4, and .5 HB650 1st CM Integration and Assembly	363
121.3.8.3.6	BOE Document for 121.3.8.3.6 HB650 1st CM Test	366
121.3.8.4.1, 2	BOE Document for 121.3.8.4.1 and .2 HB650 2nd-4th CM Cavities	372
121.3.7.8.3, 4, 5	BOE Document for 121.3.8.4.3, .4, and .5 HB650 2nd-4th CM Integration and Assembly	375
121.3.8.4.6	BOE Document for 121.3.8.4.6 HB650 2nd-4th CM Test	378

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

LB650 Cost Summary

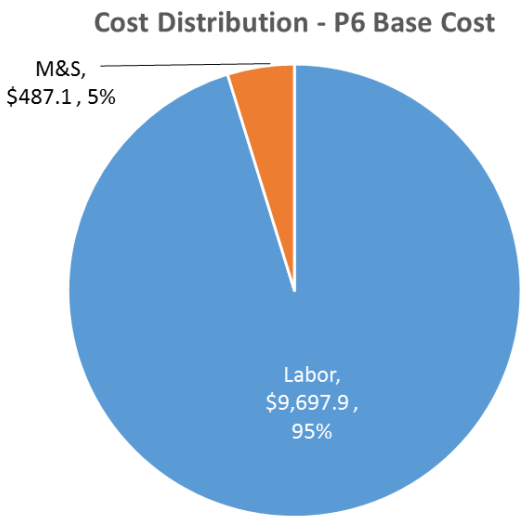
Charge #2

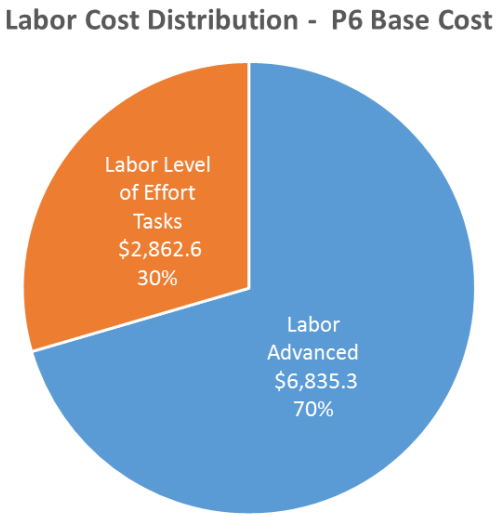
WBS Element	Hours	Labor ($000)	M&S ($000)	Est. Uncertainty ($000)		Total Cost Incl. Uncrty.
121.3.7 - Linac - Low Beta 650 (LB650)	P6 Hours	P6 Base Cost	P6 Base Cost	Total	% of Base	
121.3.7.2 - Linac - LB650 - Project Management and Coordination	13,713	$ 2,862.6	$ 284.4	$ 328.9	10.5%	$ 3,476.0
121.3.7.3 - Linac - LB650 - 1st Pre-series Production CryoModule (1stCM)	17,994	$ 3,000.9	$ 146.5	$ 629.5	20.0%	$ 3,776.9
121.3.7.4 - Linac - LB650 - 2nd to 11th Production CryoModules (2nd-11thCM)	23,083	$ 3,834.4	$ 56.1	$ 778.1	20.0%	$ 4,668.6
Grand Total	**54,790**	**$ 9,697.9**	**$ 487.1**	**$ 1,736.5**	**17.0%**	**$ 11,921.4**
Note: P6 base cost = BOE + overheads and escalation						

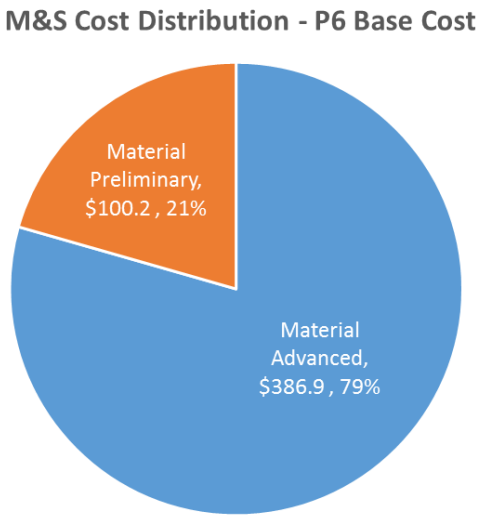
- Estimates developed down to the activity level for LB650 MHz CMs.
- P6 output.

LB650 Cost Drivers and Estimate Maturity

Charge #2





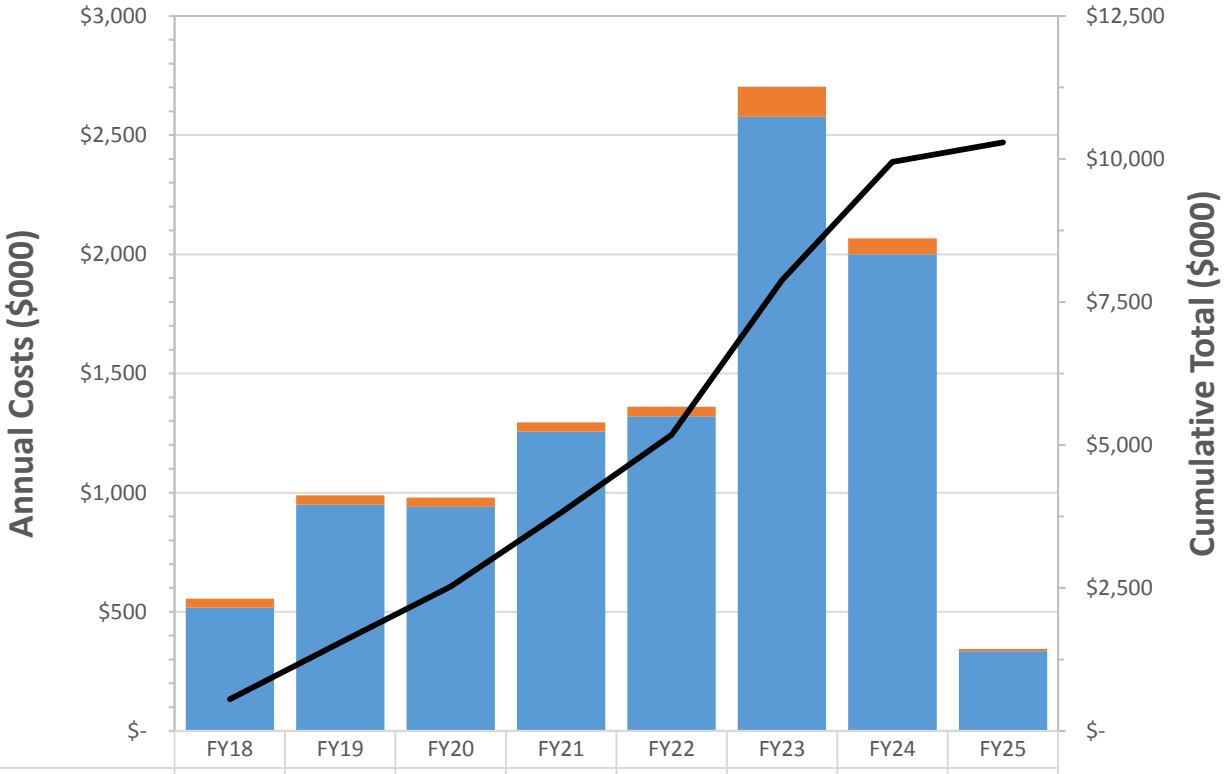


P6 Base Costs = BOE + Overheads + Escalation

- 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

Charge #2



	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
Material	$37.7	$38.5	$38.4	$39.0	$39.9	$126.2	$66.9	$8.9
Labor	$517.6	$949.9	$940.9	$1,255.1	$1,320.4	$2,576.3	$1,999.4	$335.4
Cumulative Tot.	$555.3	$1,543.7	$2,523.1	$3,817.2	$5,177.5	$7,880.0	$9,946.2	$10,290.

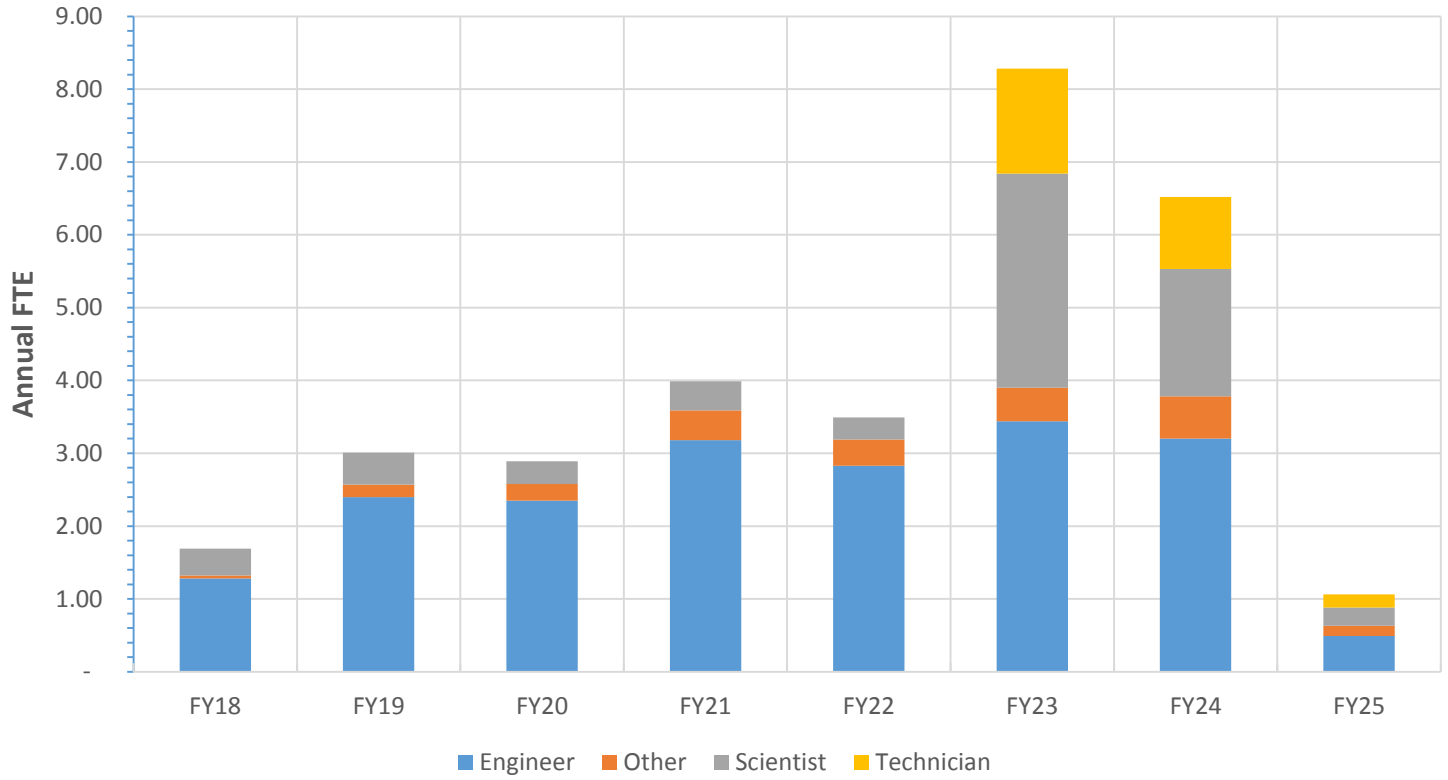
P6 Base Costs = BOE + Overheads + Escalation

- Labor increases through RF testing in FY23/24

PIP-II

LB650 Labor Profile – P6 Hours/FTE

Charge #2



- Effort balance shows consistent development oversight followed by RF testing.
- Technically driven with no effort smoothing.

HB650 Cost Summary

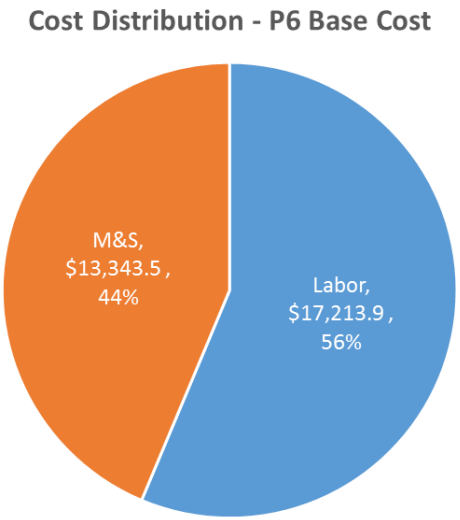
Charge #2

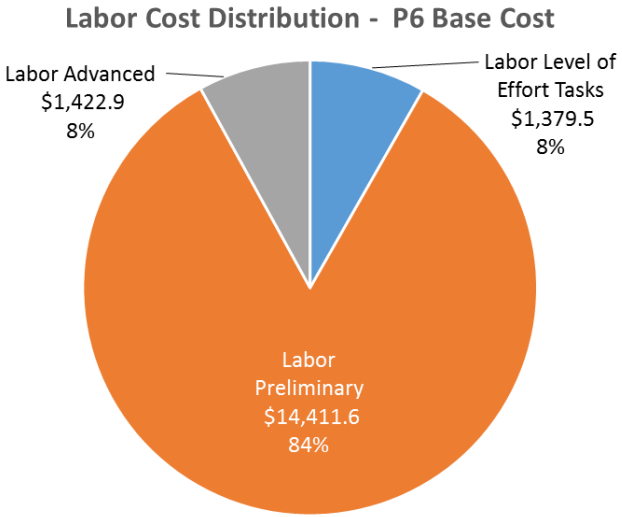
WBS Element	Hours	Labor ($000)	M&S ($000)	Est. Uncertainty ($000)		
121.3.8 - Linac - High Beta 650 (HB650)	P6 Hours	P6 Base Cost	P6 Base Cost	Total	% of Base	Total Cost Incl. Uncrty.
121.3.8.2 - Linac - HB650 - Project Management and Coordination	8,946	$ 1,379.5	$ 350.2	$ 208.0	12.0%	$ 1,937.7
121.3.8.3 - Linac - HB650 - 1st Prototype CryoModule (1stCM)	53,945	$ 7,506.5	$ 4,701.6	$ 3,005.8	24.6%	$ 15,213.9
121.3.8.4 - Linac - HB650 - 2nd to 4th Production CryoModules (2nd-4thCM)	56,797	$ 8,327.9	$ 8,291.7	$ 4,240.0	25.5%	$ 20,859.6
Grand Total	**119,688**	**$ 17,213.9**	**$ 13,343.5**	**$ 7,453.8**	**24.4%**	**$ 38,011.2**
Note: P6 base cost = BOE + overheads and escalation						

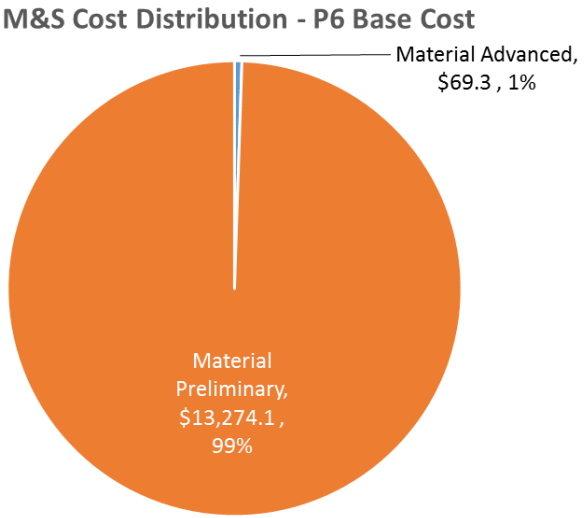
- Estimates developed down to the activity level for HB650 MHz CMs.
- P6 output.

HB650 Cost Drivers and Estimate Maturity

Charge #2





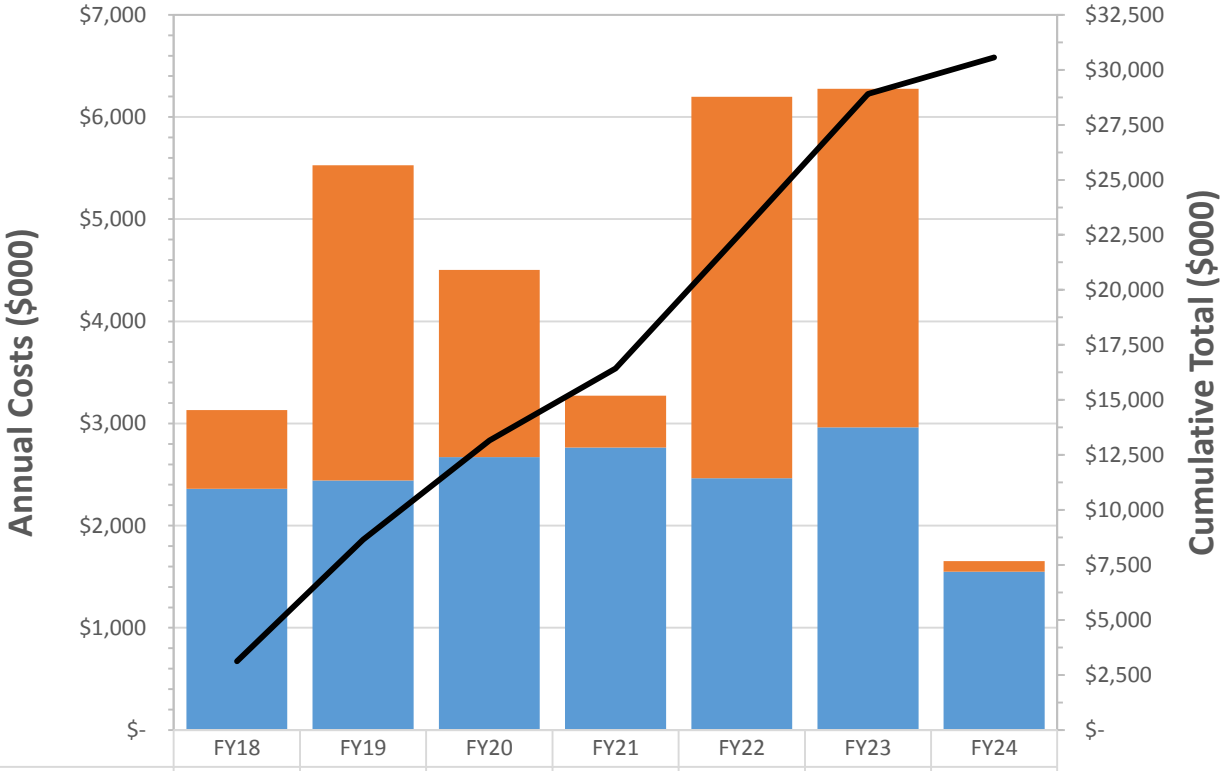


P6 Base Costs = BOE + Overheads + Escalation

- Balanced labor and M&S.
- Distribution of maturity of estimates based on scope assumptions.

HB650 Cost Profile – P6 Base Cost Only

Charge #2



	FY18	FY19	FY20	FY21	FY22	FY23	FY24
Material	$767.5	$3,083.5	$1,831.7	$508.3	$3,732.8	$3,316.0	$103.6
Labor	$2,362.3	$2,442.8	$2,670.9	$2,764.1	$2,464.2	$2,961.5	$1,548.1
Cumulative Tot.	$3,129.8	$8,656.1	$13,158.8	$16,431.3	$22,628.3	$28,905.7	$30,557.4

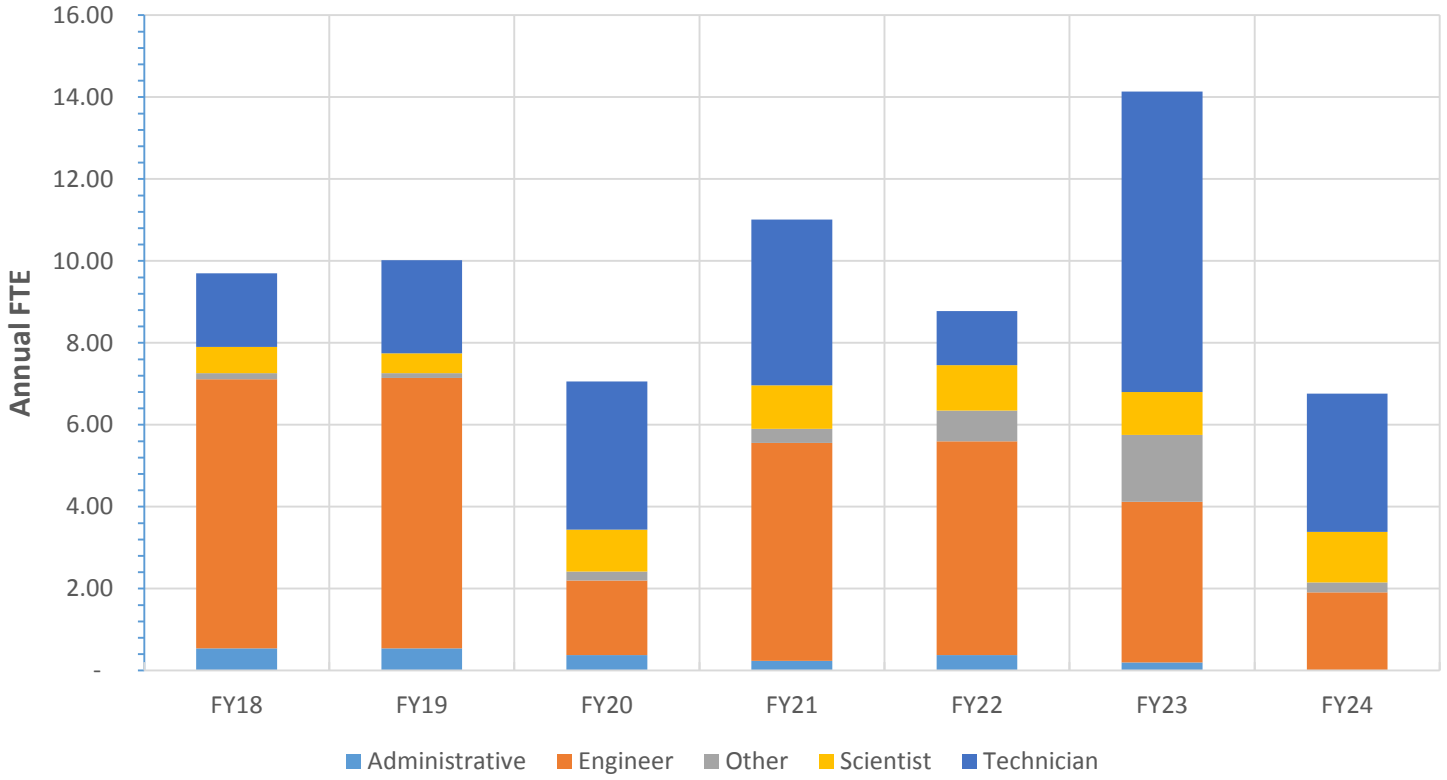
P6 Base Costs = BOE + Overheads + Escalation

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

PIP-II

HB650 Labor Profile – P6 Hours/FTE

Charge #2



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

LB650 Schedule

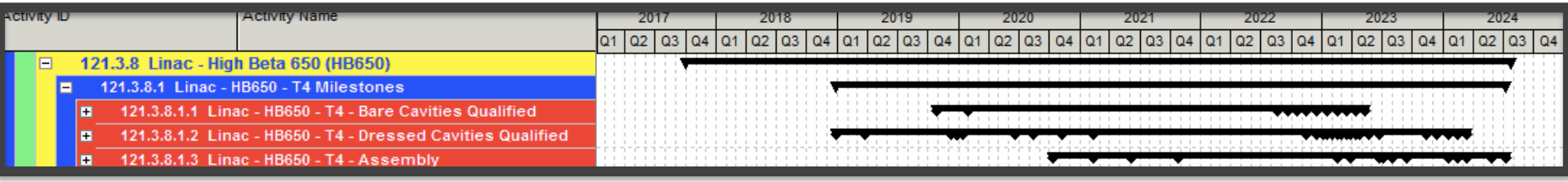
Charge #2

Activity ID	Activity Name
121.3.7	Linac - Low Beta 650 (LB650)
121.3.7.1	Linac - LB650 - T4 Milestones
121.3.7.1.1	Linac - LB650 - T4 - Assembly
A17716340	Linac - LB650 - 1stCM - RFTest - R&DPh: T4 MS - LB650 CM1 RF Tested in CMTS / Ready For Installation MS
A17724940	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM2 RF Tested in CMTS / Ready For Installation MS
A17724950	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM3 RF Tested in CMTS / Ready For Installation MS
A17724960	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM4 RF Tested in CMTS / Ready For Installation MS
A17724970	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM5 RF Tested in CMTS / Ready For Installation MS
A17747640	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM6 RF Tested in CMTS / Ready For Installation MS
A17747690	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM7 QA/QC Accept. Completed / Ready For Installation MS
A17747700	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM8 QA/QC Accept. Completed / Ready For Installation MS
A17747710	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM9 QA/QC Accept. Completed / Ready For Installation MS
A17747720	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM10 QA/QC Accept. Completed / Ready For Installation MS
A17747730	Linac - LB650 - 2nd-11thCM - RFTest - ConstrPh: T4 MS - LB650 CM11 QA/QC Accept. Completed / Ready For Installation MS

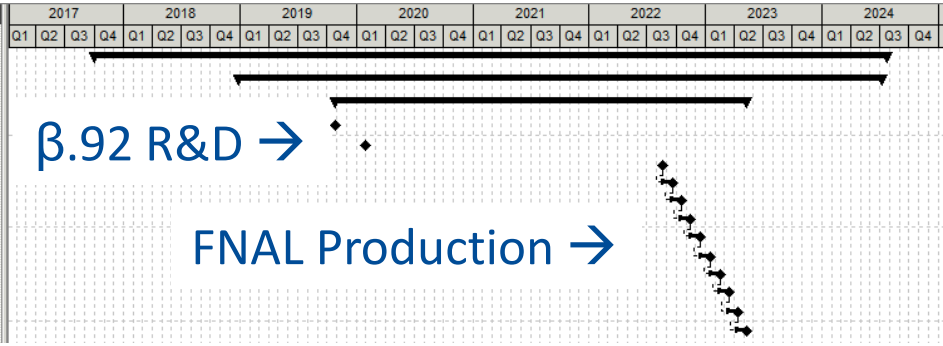
PIP-II

Schedule – HB650 Bare Cavities

Charge #2

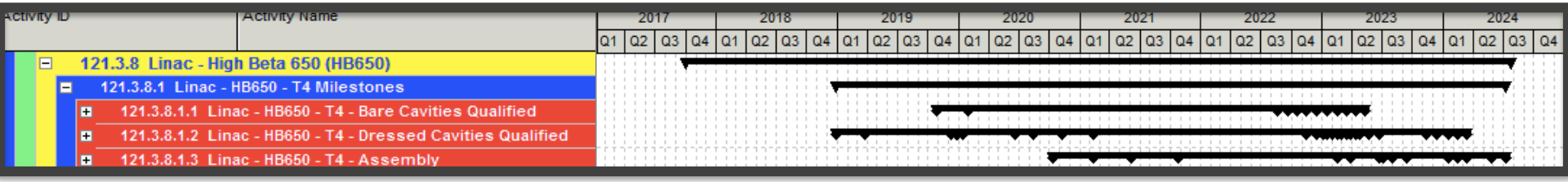


Activity ID	Activity Name
121.3.8	Linac - High Beta 650 (HB650)
121.3.8.1	Linac - HB650 - T4 Milestones
121.3.8.1.1	Linac - HB650 - T4 - Bare Cavities Qualified
A17729370	Linac - HB650 - 1stCM - BCAV - ColdT - R&DPh: T4 MS - 1st B.92 Prototype Bare Cavity Qualified in VTS
A17729380	Linac - HB650 - 1stCM - BCAV - ColdT - R&DPh: T4 MS - 2nd B.92 Prototype Bare Cavity Qualified in VTS
A17716720	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 1st B.92 Bare Cavity Qualified in VTS
A17716730	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 2nd B.92 Bare Cavity Qualified in VTS
A17716740	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 3rd B.92 Bare Cavity Qualified in VTS
A17716750	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 4th B.92 Bare Cavity Qualified in VTS
A17716760	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 5th B.92 Bare Cavity Qualified in VTS
A17716770	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 6th B.92 Bare Cavity Qualified in VTS
A17716780	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 7th B.92 Bare Cavity Qualified in VTS
A17716790	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 8th B.92 Bare Cavity Qualified in VTS
A17716800	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 9th B.92 Bare Cavity Qualified in VTS
A17716810	Linac - HB650 - 2nd-4thCM - BCAV - ColdT - ConstrPh: T4 MS - 10th B.92 Bare Cavity Qualified in VTS

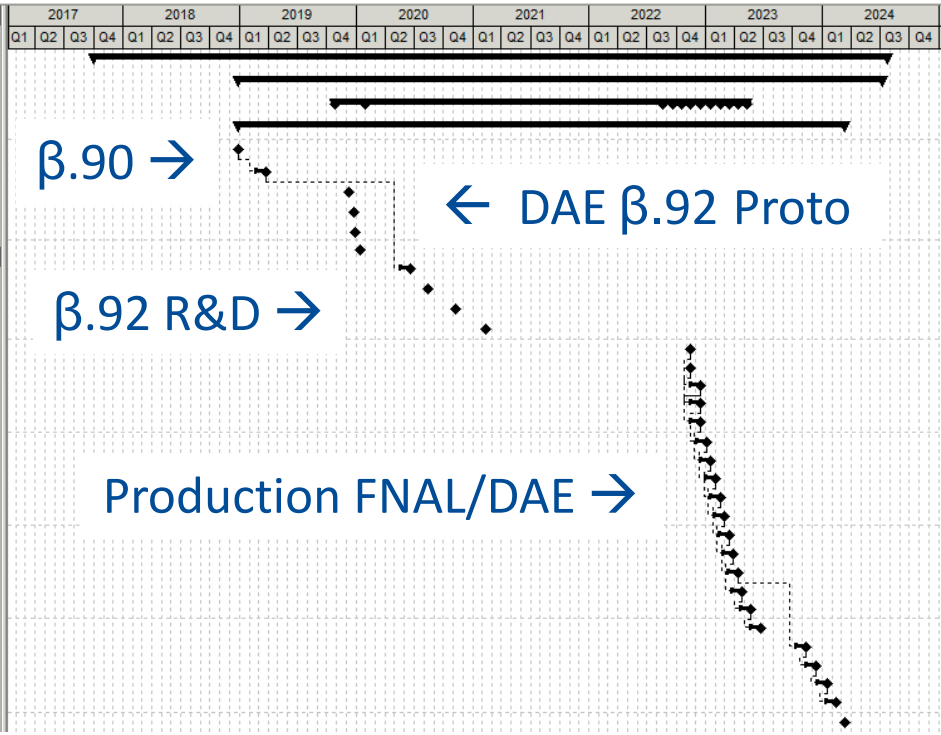


Schedule – HB650 Dressed Cavities

Charge #2

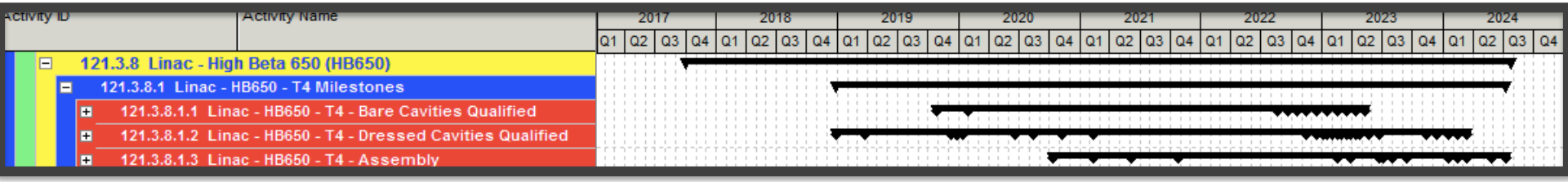


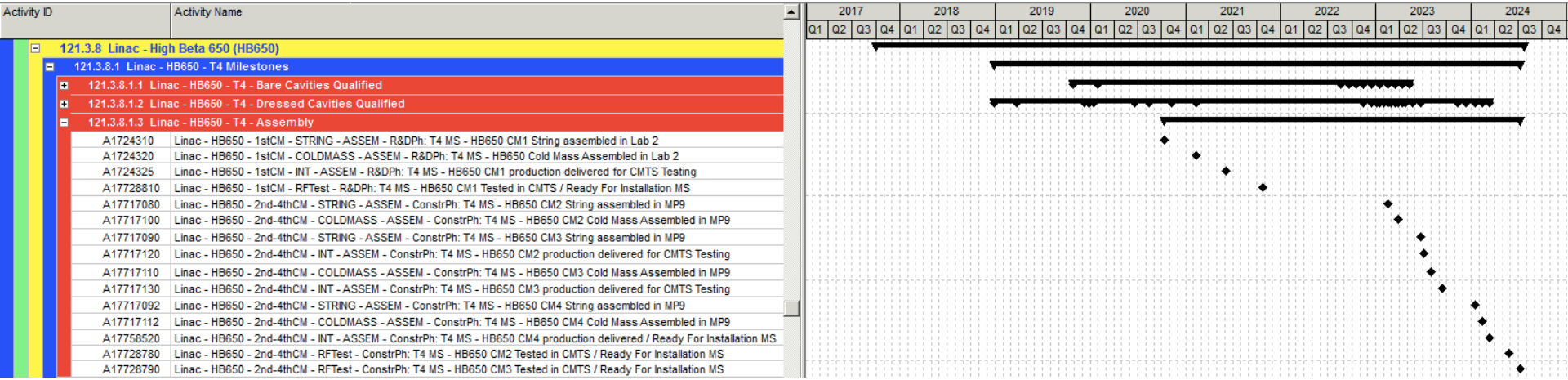
Activity ID	Activity Name
121.3.8	Linac - High Beta 650 (HB650)
121.3.8.1	Linac - HB650 - T4 Milestones
121.3.8.1.1	Linac - HB650 - T4 - Bare Cavities Qualified
121.3.8.1.2	Linac - HB650 - T4 - Dressed Cavities Qualified
A1724260	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 1st B.90 Dressed Cavity Qualified in STC
A1724270	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 2nd B.90 Dressed Cavity Qualified in STC
A1724300	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 1st IIFC B.92 Jacketed Cavity Qualified in VTS
A1724305	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 2nd IIFC B.92 Jacketed Cavity Qualified in VTS
A17730320	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 4th IIFC B.92 Jacketed Cavity Qualified in VTS
A1724306	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 3th IIFC B.92 Jacketed Cavity Qualified in VTS
A1724280	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 3th B.90 Dressed Cavity Qualified in STC
A1724290	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 4th B.90 Dressed Cavity Qualified in STC
A17729680	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 1st B.92 Prototype Dressed Cavity Qualified in STC
A17729690	Linac - HB650 - 1stCM - DCAV - ColdT - R&DPh: T4 MS - 2nd B.92 Prototype Dressed Cavity Qualified in STC
A17716960	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 1st B.92 Dressed Cavity Qualified in STC
A17724810	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 5th IIFC B.92 Jacketed Cavity Qualified in VTS
A17716970	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 2nd B.92 Dressed Cavity Qualified in STC
A17716980	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 3rd B.92 Jacketed Cavity Qualified in VTS
A17724820	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 6th IIFC B.92 Jacketed Cavity Qualified in VTS
A17716990	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 4th B.92 Jacketed Cavity Qualified in VTS
A17724830	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 7th IIFC B.92 Jacketed Cavity Qualified in VTS
A17717000	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 5th B.92 Jacketed Cavity Qualified in VTS
A17724840	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 8th IIFC B.92 Jacketed Cavity Qualified in VTS
A17717010	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 6th B.92 Jacketed Cavity Qualified in VTS
A17724850	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 9th IIFC B.92 Jacketed Cavity Qualified in VTS
A17717020	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 7th B.92 Jacketed Cavity Qualified in VTS
A17724860	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 10th IIFC B.92 Jacketed Cavity Qualified in VTS
A17717030	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 8th B.92 Jacketed Cavity Qualified in VTS
A17717040	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 9th B.92 Jacketed Cavity Qualified in VTS
A17717050	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 10th B.92 Jacketed Cavity Qualified in VTS
A17724870	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 11th IIFC B.92 Jacketed Cavity Qualified in VTS
A17724880	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 12th IIFC B.92 Jacketed Cavity Qualified in VTS
A17724890	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 13th IIFC B.92 Jacketed Cavity Qualified in VTS
A17724900	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 14th IIFC B.92 Jacketed Cavity Qualified in VTS
A17724910	Linac - HB650 - 2nd-4thCM - DCAV - ColdT - ConstrPh: T4 MS - 15th IIFC B.92 Jacketed Cavity Qualified in VTS



Schedule – HB650 Cryomodules

Charge #2





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