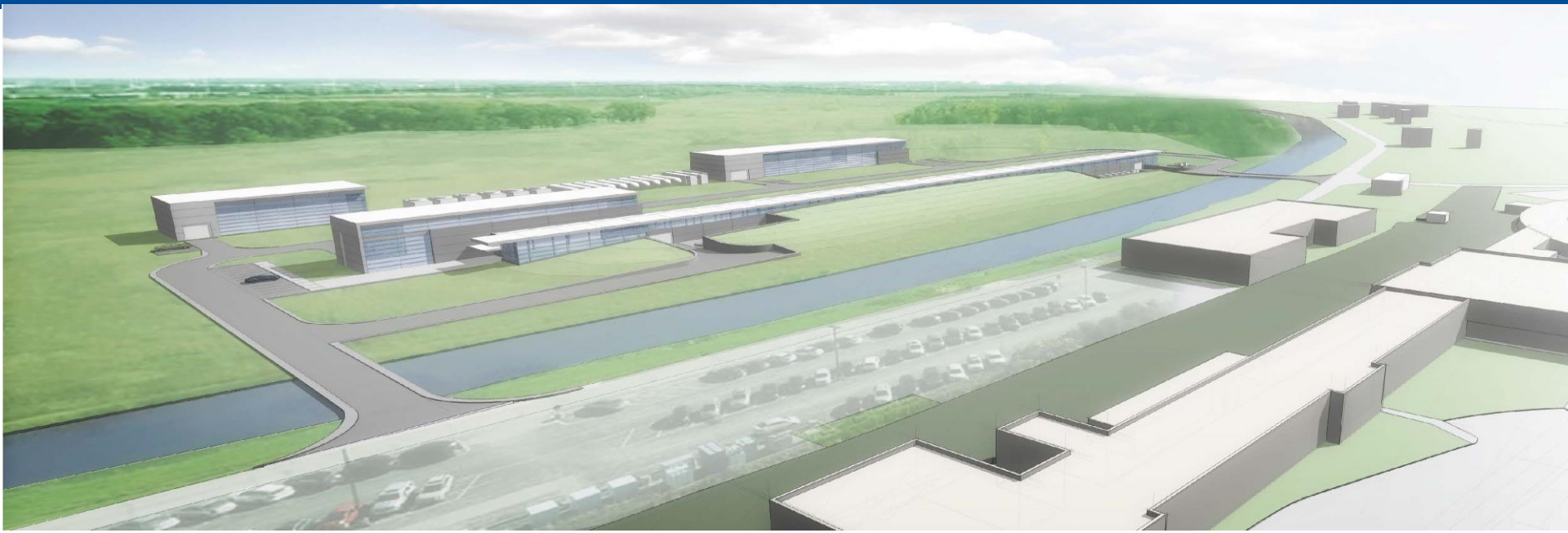


SC Acceleration Modules and Cryogenics (WBS 121.3.4-8, 11)

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

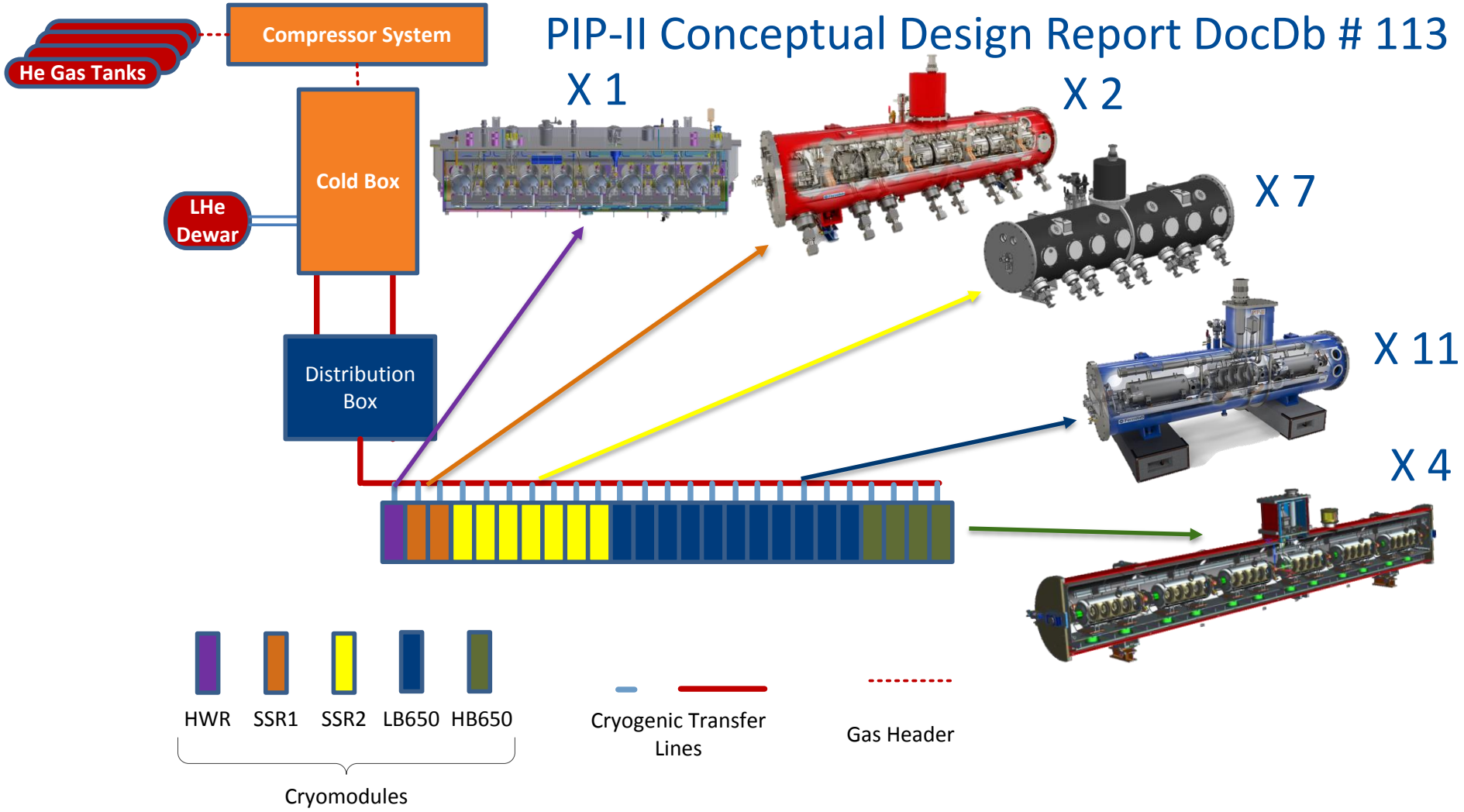
- Overview
- Requirements
- Conceptual Design, Maturity
- Scope/Deliverables
- Organization
- Interfaces
- Technical Progress to Date
- Design Review Plan
- Plan for CD-2/Preliminary Design
- ESH&Q
- Risk
- Cost
- Schedule
- Breakout Session topics
- Summary

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

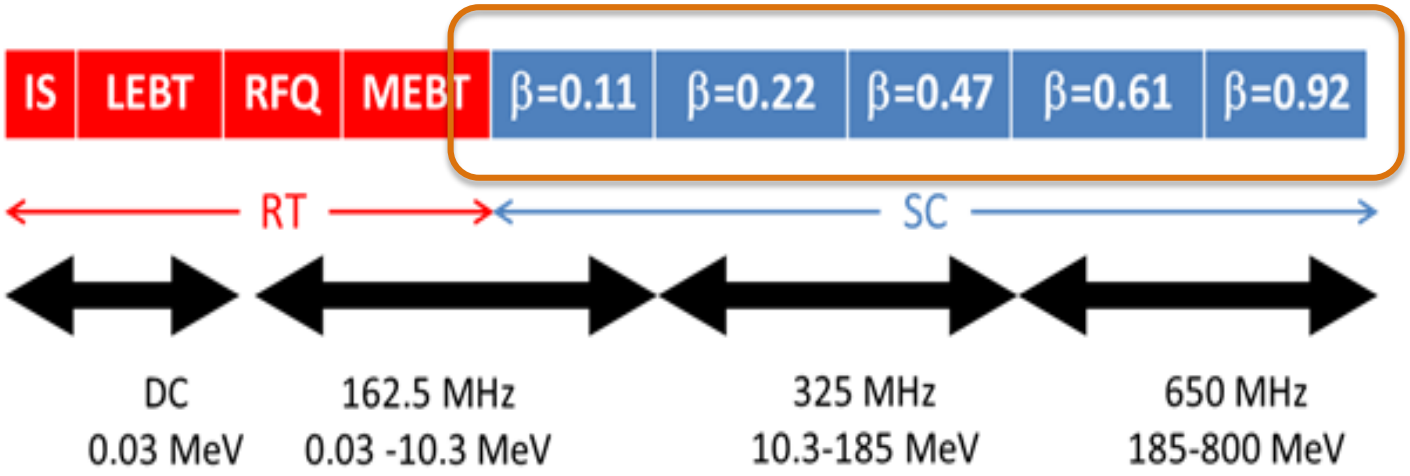
SC Cryomodules and Cryo Systems Overview



WBS 121.3.4-8 Requirements

Charge #1

#	Description of Scope	Threshold KPP	Objective KPP
1	SRF linac	700 MeV beam delivered to the Booster Injection Region	800 MeV beam delivered to Booster Injection Region
2	Booster/RR/MI upgrades	L11 Booster injection region, Recycler and MI RF upgrades,	8 GeV beam transmitted through Recycler and Main



WBS 121.3.4-6 Requirements

Charge #1

SRF Cryomodules

- 121.3.4 - β_{opt}=0.11, 162.5 *MHz* Half Wave Cryomodule
  - Accept and accelerate H^- beam from 2.1-10.3 *MeV*
  - FRS: TC# ED0001313
- 121.3.5 - β_{opt}=0.22, 325 *MHz* Single Spoke Cryomodules
  - Accept and accelerate H^- beam from 10.3-35 *MeV*
  - FRS: TC# ED0001316
- 121.3.6 - β_{opt}=0.47, 325 *MHz* Single Spoke Cryomodules
  - Accept and accelerate H^- beam from 35-185 *MeV*
  - FRS: TC# ED0001829

WBS 121.3.7-8 Requirements

Charge #1

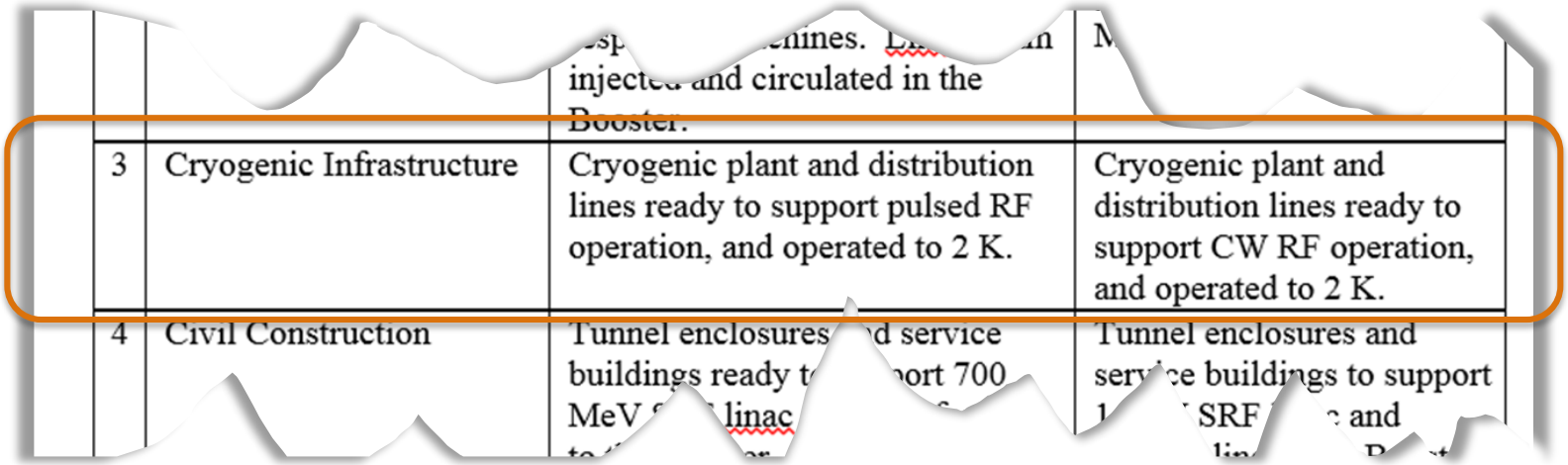
SRF Cryomodules cont…

- 121.3.7 - β_g=0.61, 650 *MHz* Elliptical Cryomodules
  - Accept and accelerate H^- beam from 185-500 *MeV*
  - FRS: TC# ED0001830
- 121.3.8 - β_g=0.92, 650 *MHz* Elliptical Cryomodules
  - Accept and accelerate H^- beam from 500-800 *MeV*
    - 700 *MeV* is Threshold KPP, 800 *MeV* is Objective KPP
  - FRS: TC# ED0001322

Mechanical, RF, and Cryogenic performance, requirements are detailed in the CM and sub-system FRS documents.

WBS 121.3.11 Requirements

Charge #1



		injected and circulated in the Booster.	
3	Cryogenic Infrastructure	Cryogenic plant and distribution lines ready to support pulsed RF operation, and operated to 2 K.	Cryogenic plant and distribution lines ready to support CW RF operation, and operated to 2 K.
4	Civil Construction	Tunnel enclosures and service buildings ready to support 700 MeV linac	Tunnel enclosures and service buildings to support SRF and

- 121.3.11 - Cryogenics
  - Deliver sufficient cryogenics cooling capacity and distribution to the LINAC superconducting cavities and cryogenics components operating within their respective operating conditions.
  - FRS: TC# ED0003531
- Requirements are well defined and traceable.

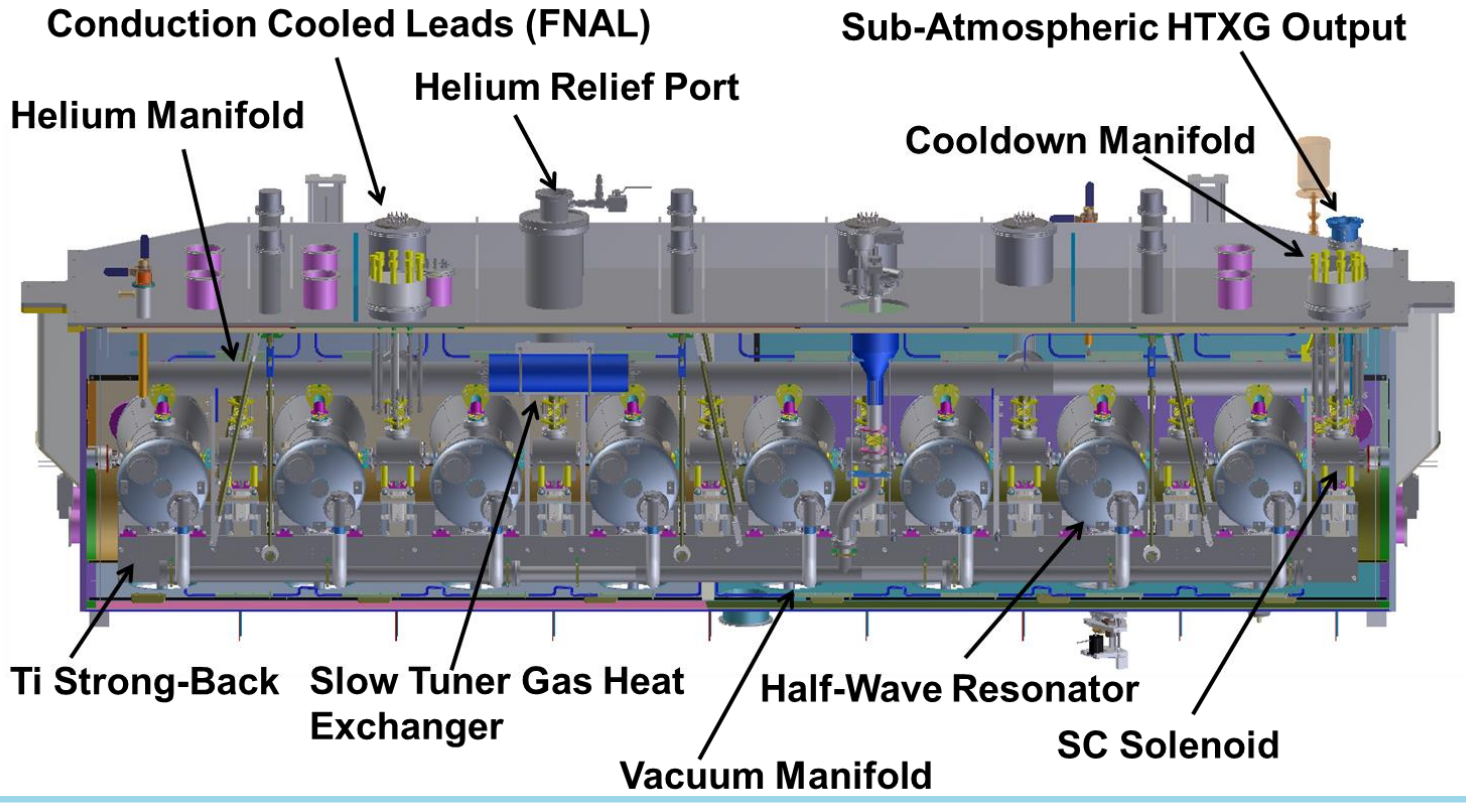
Conceptual Design and Design Maturity

Charge #1

Breakout

121.3.4 – HWR Cryomodule

- CM and subsystem designs are complete, most key subsystems performance demonstrated.
- L3 Breakout Talk – Z. Conway



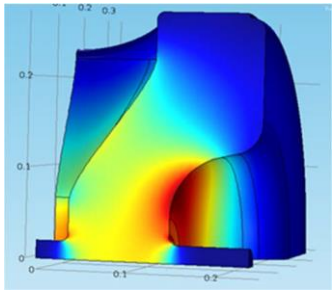
Conceptual Design and Design Maturity

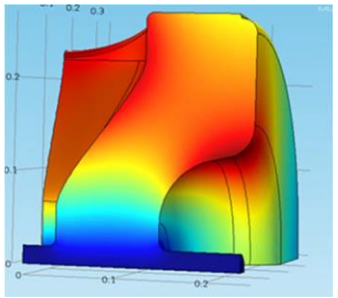
Charge #1

Breakout

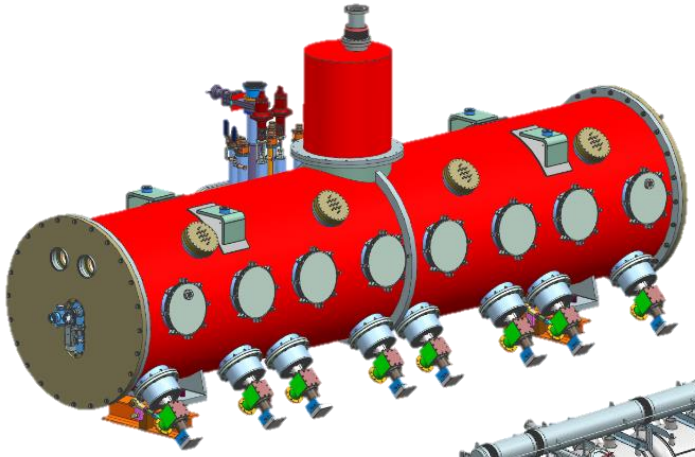
121.3.5-6 – SSR1/SSR2 Cryomodules

- SSR1 CM and subsystem designs are advanced but not final, several key subsystems performance demonstrated.
- SSR2 CM and subsystem designs are conceptual, including cavity design. CM design and key subsystems will be based on SSR1 cryomodule.
- L3 Breakout Talk – D. Passarelli

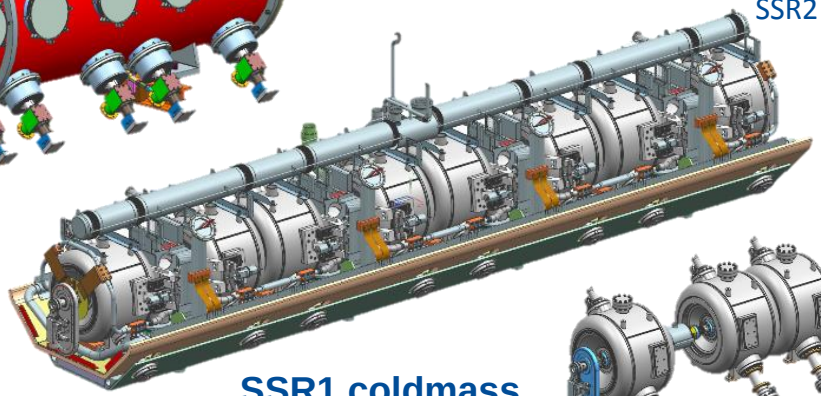




SSR2 Electric (left) and Magnetic (right) 3D conceptual model by COMSOL. Design DAE deliverable.



SSR1 Integrated CM



SSR1 coldmass

SSR1 string assembly

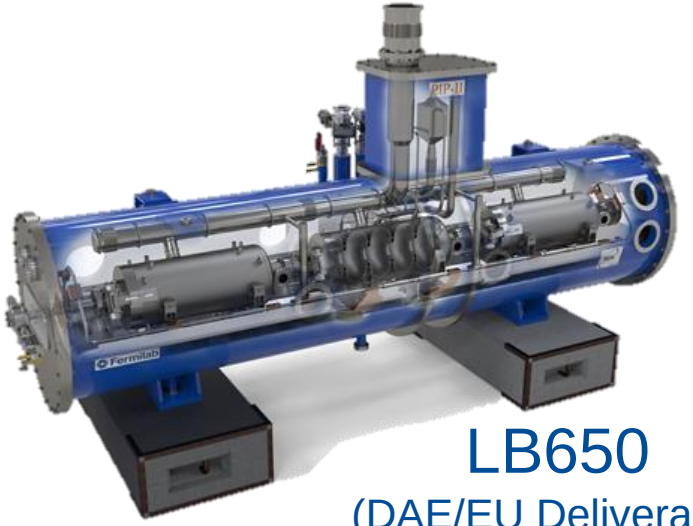
Conceptual Design and Design Maturity

Charge #1

Breakout

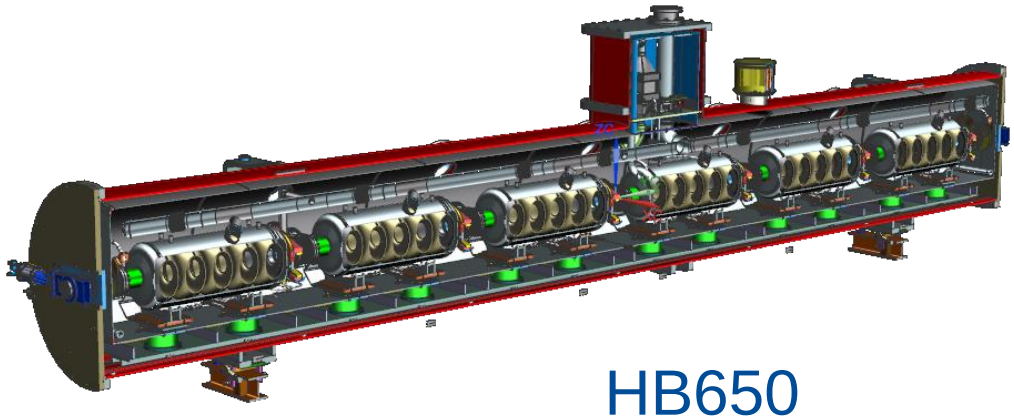
121.3.7-8 – LB650/HB650 Cryomodules

- LB650 CM and subsystem designs are preliminary, including cavity design. CM design and key subsystems are based on SSR1 cryomodule.
- HB650 CM and subsystem designs are in an advanced preliminary state of development with advanced designs and functional prototypes for cavity subsystems. CM design and key subsystems are based on SSR1 cryomodule.
- L3 Breakout Talk – A. Rowe



LB650

(DAE/EU Deliverable)



HB650

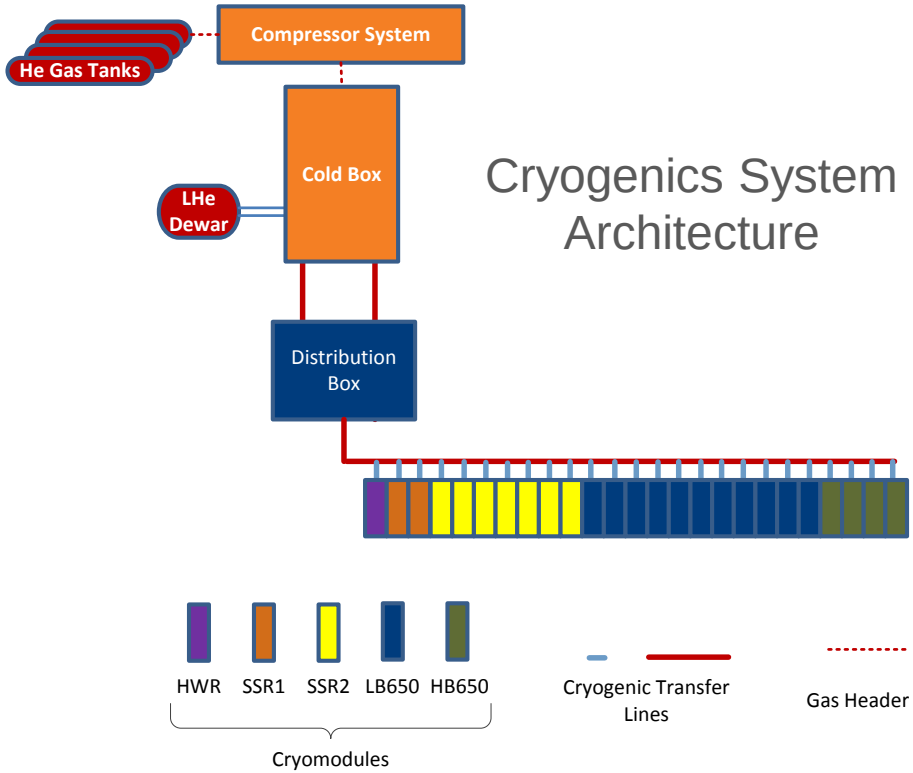
Conceptual Design and Design Maturity

Charge #1

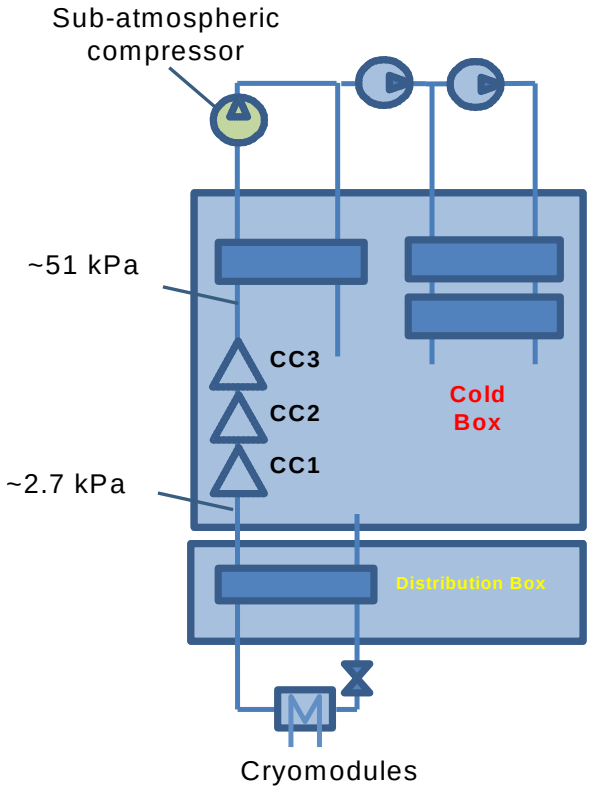
Breakout

121.3.11 – Cryogenics Systems

- The integrated Cryogenics Plant and Cryogenics Distribution System (CDS) are in a preliminary state of development.
- L3 Breakout Talk – A. Klebaner



Cryogenics System Architecture



Baseline Hybrid cycle design

PIP-II

Scope and Deliverables

Charge #1

- 121.3.4 – HWR Cryomodule
  - Partner Development – Argonne National Laboratory
  - Design, procure, integrate, install in PIP2IT, and test to performance requirements one 162.5 *MHz* 8-cavity superconducting cryomodule.
  - Beam testing through the HWR is part of the Warm Front End WBS
- 121.3.5-6 – SSR1/SSR2 Cryomodules
  - SSR1 – FNAL Development
    - Design, procure, integrate, install in PIP2IT or PIP2IT CMTS and test to performance requirements two 325 *MHz* 8-cavity superconducting cryomodules in PIP2IT.
  - SSR2 – Combined FNAL/DAE Development
    - Design, procure, integrate, seven 325 *MHz* 5-cavity superconducting cryomodules. Test to performance requirements four of seven cryomodules in PIP2IT. Deliver seven CMs to the LINAC tunnel.

Scope and Deliverables

Charge #1

- 121.3.7-8 – LB650/HB650 Cryomodules
  - LB650 – Combined FNAL/DAE/EU Development
    - Design, procure, integrate, eleven 650 *MHz* 3-cavity cryomodules. Test to performance requirements in CMTF/CMTS six of eleven cryomodules. Deliver eleven cryomodules to the LINAC tunnel.
  - HB650 – Combined FNAL/DAE Development
    - Design, procure, integrate, four 650 *MHz* 6-cavity cryomodules. Test to performance requirements in CMTF/CMTS three of four cryomodules. Deliver four cryomodules to the LINAC tunnel.
- 121.3.11 – Cryogenics Systems
  - Combined FNAL/DAE Development
    - Design, procure, and install one cryogenics plant, supporting infrastructure, and cryogenics distribution system to support both continuous wave and pulsed operation of superconducting cryomodules in the LINAC tunnel

Organization

Charge #3

PIP-II Project Office

121.2 Project Management S. Holmes	121.3 Superconducting Linac F. Garcia	121.4 Rings Upgrades I. Kourbanis	121.5 Conventional Facilities S. Dixon
121.2.2 Fermilab & USA Coord S. Holmes	121.3.1 Project Management F. Garcia	121.4.1 Booster B. Pellico	121.5.1 Project Management S. Dixon
121.2.3 International Coord S. Mishra	121.3.2 Accelerator Physics V. Lebedev	121.4.2 Recycler/Main Injector J. Dey	121.5.2 Site Preparation TBD
121.2.4 Business Office L. Lari	121.3.3 Warm Front End [illegible]		121.5.3 Cryo Plant Building TBD
121.2.5 ESH/QA T. Dykhuis	121.3.4 HWR Z. Conway		121.5.4 Utility Plant Building TBD
121.2.6 System Eng & Integ A. Rowe	121.3.5 SSR1 D. Passarelli	121.3.14 Beam Transfer Line TBD	121.5.5 High Bay Building TBD
121.2.7 Conv Facil Coord S. Dixon	121.3.6 SSR2 D. Passarelli	121.3.15 Beam Absorber TBD	121.5.6 Linac Tunnel TBD
	121.3.7 LB650 (A. Rowe)	121.3.16Beam Instrumentation V. Scarpine	121.5.7 Linac Gallery TBD
	121.3.8 HB650 (A. Rowe)	1211.3.17 Control System J. Patrick	121.5.8 Beam Trans & Absorb Line TBD
	[illegible] D. Peterson	121.3.18 Vacuum A. Chen	121.5.9 Booster Connect TBD
	121.3.10 RF Integration [illegible]	121.3.19 Gen Supp Services C. Baffes	
	121.3.11 Cryogenic Systems A. Klebaner	121.3.20 Safety Systems J. Anderson	
	[illegible] A. Chen	121.3.21Test Infrastructure J. Leibfritz, J. Ozelis, D. Passarelli	
	121.3.13 Magnet Power Supplies B. Hanna	121.3.22 Install, Integ & Commiss C. Baffes	

Interfaces - Technical

Charge #1

Each L3 WBS within 121.3 interfaces across the WBS Matrix

- Each Cryomodule type has or will have an interface document. Examples are: TC# ED0002529 HWR Interface Document, TC# ED0004129 Interfaces for PIP-II SSR1 Cryomodule…

Common Interfaces to each Cryomodule Type	
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	

- Technical interfaces are understood. Formally, each WBS will have a revision controlled Interface Spec Doc managed in Teamcenter.

Interfaces - Partners

Charge #1

- Final deliverables to be formalized in advance of CD-2
- Cryomodule development in HWR, SSR2, LB650, and HB650 are heavily matrixed.
- 121.3.4 - HWR (ANL/FNAL)
  - ANL: Development and production
  - FNAL: Development support and CM testing with ANL scientific suppt
- 121.3.6 – SSR2 (FNAL/DAE – BARC)
  - FNAL: Overall CM design, development, production and testing
  - DAE-BARC: SSR2 dressed cavity design and production & qualif.
- 121.3.7 – LB650 (DAE – VECC, RRCAT/EU-INFN/FNAL)
  - 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 integration
  - FNAL: Design and integration support and CM testing

Interfaces - Partners

Charge #1

- 121.3.8 – HB650 (FNAL/DAE-RRCAT)
  - FNAL: Overall CM design, development, production, and testing
  - DAE – RRCAT: HB650 dressed cavity production & qualif.
- 121.3.11 – Cryogenics Systems (FNAL/DAE)
  - FNAL: Design, development, and production of the Cryogenics Distribution System, integration of the Cryogenics Plant
  - DAE - BARC: Delivery of the Cryogenics Plant
- All FNAL/DAE Partner Interfaces managed via Sub-project Coordinator (SPC) and Sub-project Manager (SPM) weekly or bi-weekly meetings. Points of Contact (POC) for technical areas defined both at FNAL and within DAE.
- EU-INFN/CEA Saclay need to be confirmed

Progress to date

Charge #1

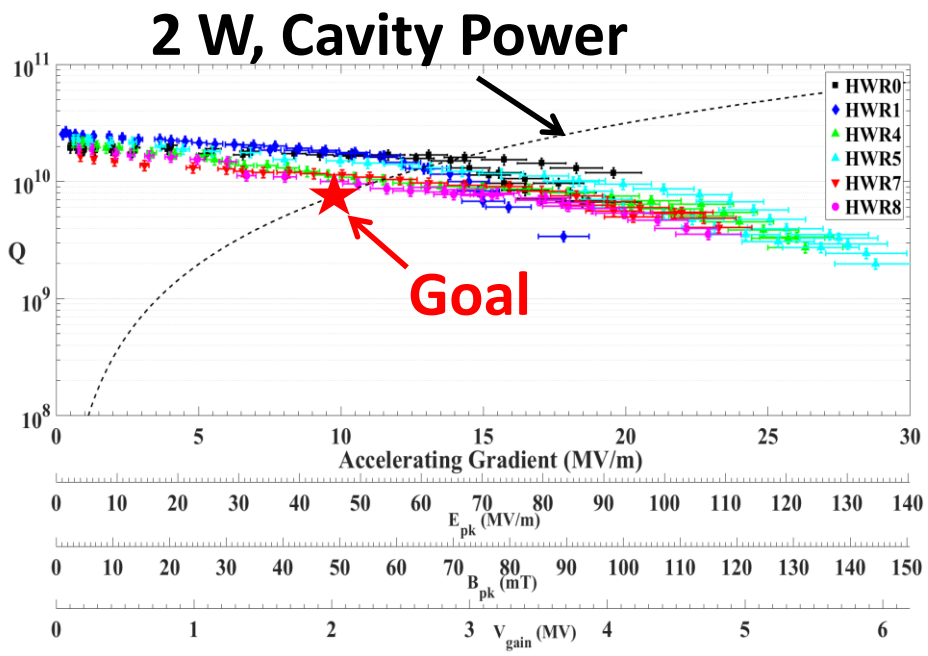
- **Organizational Progress:**
  - FNAL L3 managers assigned
  - DAE Sub-project Coordinators assigned – maps to FNAL L3s who are also Sub-project managers.
  - EU points of contact are being elaborated (LB650/HB650)
  - Managerial structure organized around WBS
  - FNAL Technical points of contact are identified within the Technical Division and aligned within the Division's Org. Structure.

Progress to date - HWR

Charge #1

Breakout

- HWR - Z. Conway breakout talk
  - Technically mature with critical technologies demonstrated and design reviews completed.
  - Most critical procurements completed.



PIP-II

Progress to date – SSR1

Charge #1

Breakout

- SSR1 – D. Passarelli breakout talk
  - Design technically mature, Final Design Review sequence underway (String Assembly – FDR done, Coldmass, and CM-Integration FDR - ready)
  - Many significant procurements complete for SSR1 CM1, remaining procurements awaiting scheduled FDRs and PRRs.
  - All bare cavities qualified, all bare cavities dressed and in qualification stream.
  - Dressed cavities with high-power RF couplers and tuners are proceeding through the Spoke Test Cryostat.
  - Field Emission remains primary concern.

Progress to date – SSR2

Charge #1

Breakout

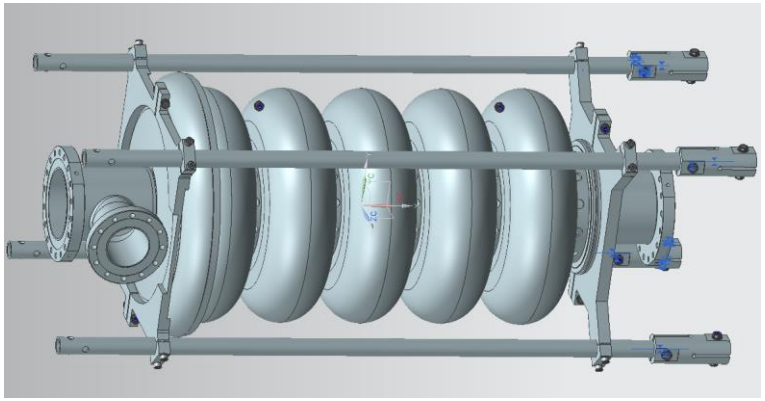
- SSR2 – D. Passarelli breakout talk
  - CM Design is based on SSR1.
  - SSR2 has the least amount of integrated tasks complete of all CM types.
  - SSR2 development is the critical path for the LINAC starting with the current activities in the SSR2 cavity design and prototyping effort.
  - Next step is SSR2 PDR of cavity by BARC followed by FDR several months later with prototyping at BARC and FNAL to follow.
  - Critical sub-components (RF couplers, tuners) are derivatives of SSR1.

Progress to date – LB650

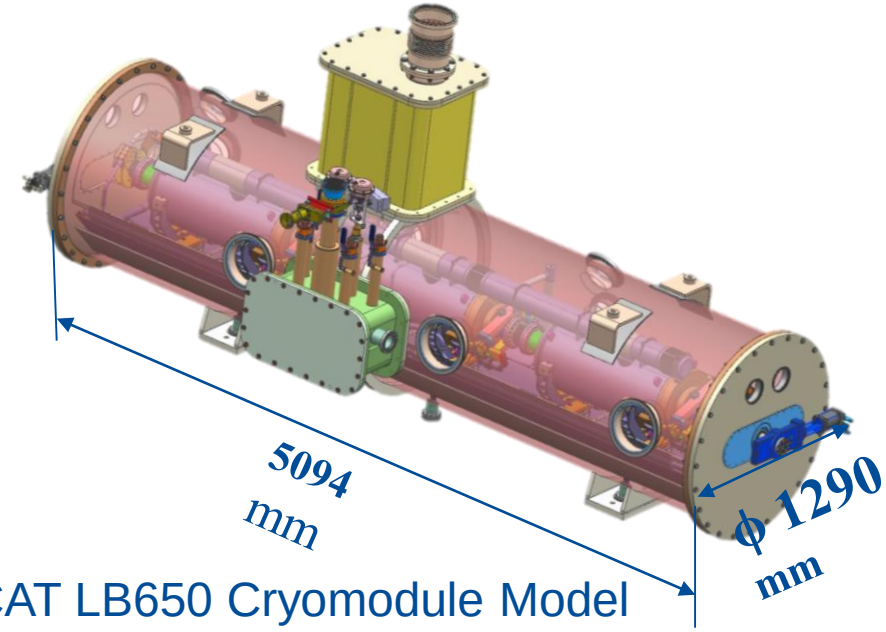
Charge #1

Breakout

- LB650 – A. Rowe breakout talk
  - CM Design is the responsibility of the DAE (RRCAT) and is pre-PDR.
  - Concept based on SSR1 CM design.
  - Dressed cavity has completed the PDR. EM design chosen. Mechanical design iterations proceeding to FDR both at VECC and INFN.



INFN-Lasa LB650 Cavity Model



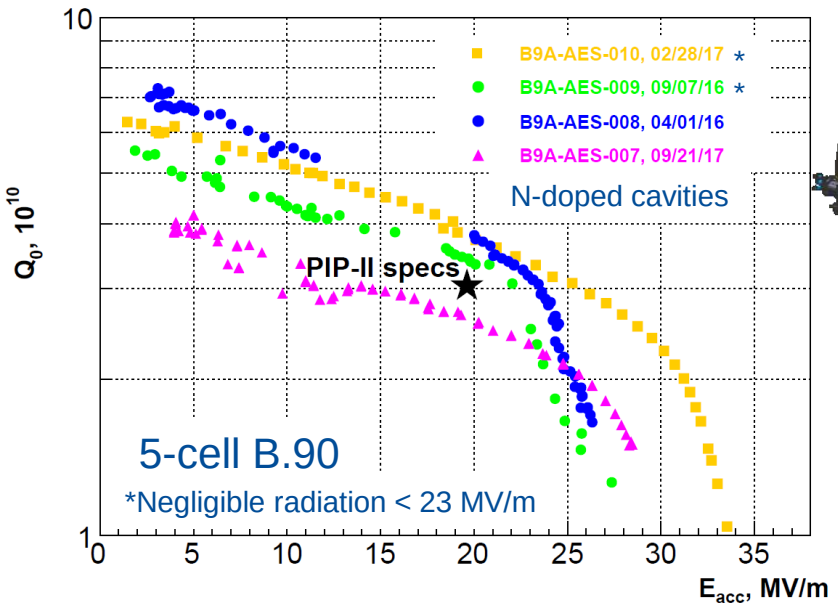
RRCAT LB650 Cryomodule Model

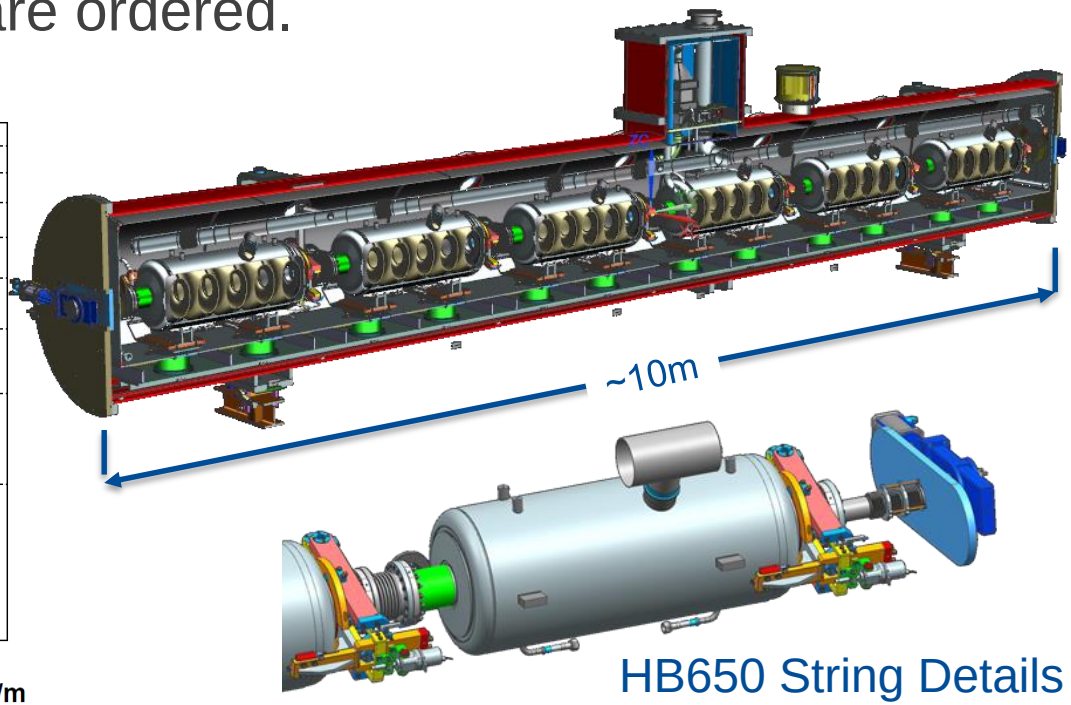
Progress to date – HB650

Charge #1

Breakout

- HB650 – A. Rowe breakout talk
  - CM design is preliminary, but pre-PDR.
  - 650 MHz multi-cell performance in the VTD exceeds specs.
  - DAE-RRCAT processing the first β=0.92 cavity
  - Prototype RF couplers are ordered.





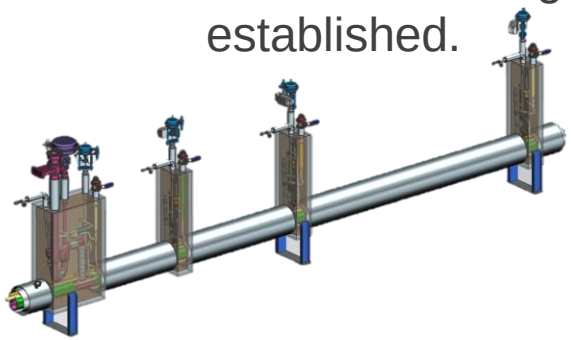
HB650 String Details

Progress to date – Cryogenic Systems

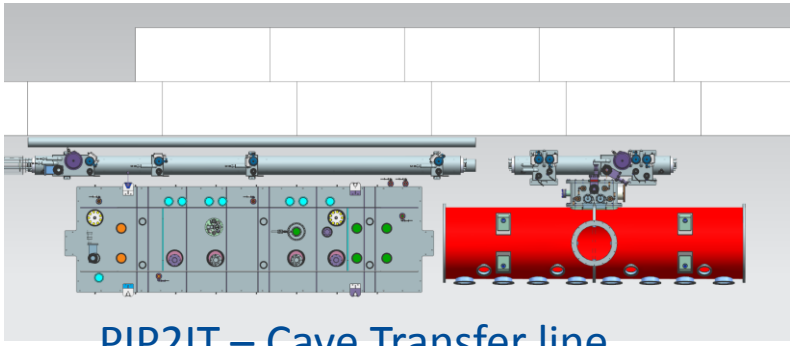
Charge #1

Breakout

- Cryo Systems – A. Chakravarty/A. Klebaner
  - 2kW at 2.0 K Cryogenic Plant – DAE Deliverable
    - Procurement cycle started in the DAE – BARC
    - Hybrid compression cycle deemed baseline
    - Primary performance specifications defined
  - Cryogenic Distribution System
    - Technical details for PIP2IT CDS well elaborated. Numerous ED's generated.
    - External PIP2IT transfer line under construction
    - Linac CDS design specifications and alternatives established.



PIP2IT – HWR bayonet boxes

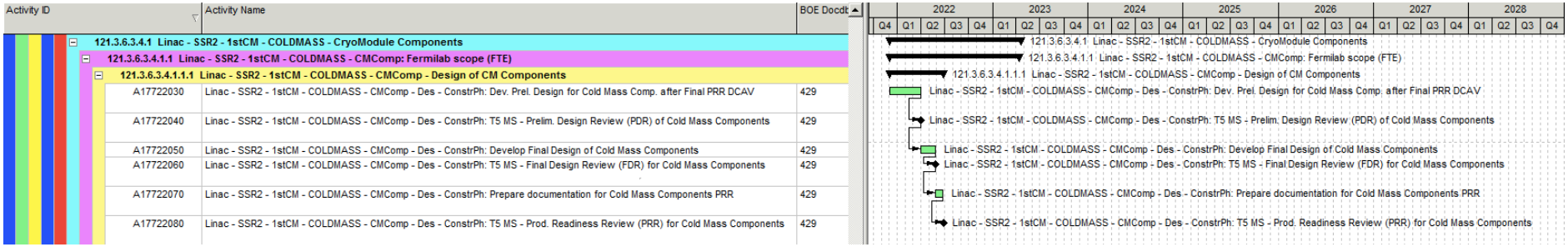


PIP2IT – Cave Transfer line

Design Review Plan

Charge #3

- Design reviews are organized as follows:
  - Review Cycle: FRS/TRS → PDR → FDR →PRR
  - Critical component, subsystem, and primary system all progress through Preliminary (PDR), Final (FDR), and Production Readiness Reviews (PRR). This cycle enables the procurement cycle to begin.
  - Non-critical components or subsystems are managed within the Division or Department review process as indicated by the FNAL Engineering Manual.



SSR2 1st CM Coldmass Design and Review Cycle in P6

Next Steps toward CD-2

Charge #3

- Organizational
  - Formalize technical POC's for critical subsystem elements within each L3 as necessary.
  - Elaborate Partner deliverables' schedule and incorporate formally into the WBS and schedule.
- Technical
  - Complete high-level system design and correlate combined L3 scope functional requirements with individual L3 functional requirements.
  - Complete interface specifications between L3 systems, followed by technical requirement specifications.
  - Validate design and construction schedule for each L3 system.
  - Continue critical R&D in each L3 area as necessary to meet R&D and construction schedules.

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
- PIP-II's Project's QA Plan (DocDB # 142) implemented across all areas. Established Project/Division mechanisms regarding acceptance testing, control of non-conformances, and vendor feedback are included.

All systems are designed to be safe and to minimize impact on the environment

Risk: Cavity, CM and Cryogenics

Charge #2

- Pulsed and CW cryomodule operating modes cause cryogenic or mechanical instabilities
- Insufficient Cryogenic system vendor manufacturing capacity and priority
- SSR1 CM (1) Performance at PIP2IT does not meet technical requirements
- HB650 CM (1) Performance at CMTF does not meet technical requirements
- SSR2 CM (1) Performance at PIP2IT does not meet technical requirements

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)
Insufficient Cryogenic system vendor manufacturing capacity and priority	50.00%	4 (H)	500	3.5	2 (M)	3 (H)	3 (High)
SSR1 CM (1) Performance at PIP2IT does not meet technical requirements	40.00%	4 (H)	433	2.8	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)
SSR2 CM (1) Performance at PIP2IT does not meet technical requirements	40.00%	4 (H)	333	2.8	2 (M)	3 (H)	3 (High)

Cost Summary

Charge #2

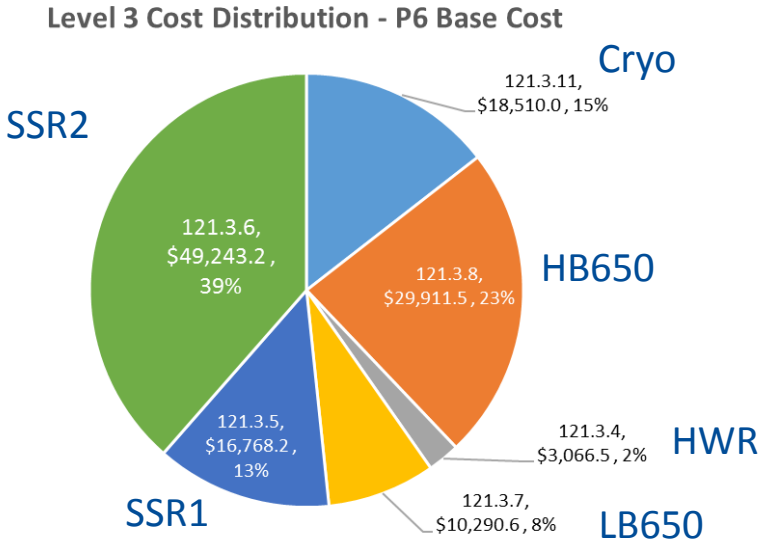
WBS Element	Hours	Labor ($000)	M&S ($000)	Est. Uncertainty ($000)		Total Cost Incl. Uncrty.
121.3 - PIP-II - Linac	P6 Hours	P6 Base Cost	P6 Base Cost	Total	% of Base	
121.3.4 - Linac - Half Wave Resonator (HWR)	9,019	$ 1,459.9	$ 1,606.6	$ 570.7	18.6%	$ 3,637.3
121.3.5 - Linac - Single Spoke Resonator 1 (SSR1)	64,288	$ 9,359.4	$ 7,408.8	$ 3,476.6	20.7%	$ 20,244.8
121.3.6 - Linac - Single Spoke Resonator 2 (SSR2)	154,462	$ 24,501.0	$ 24,742.2	$ 11,892.3	24.2%	$ 61,135.5
121.3.7 - Linac - Low Beta 650 (LB650)	54,790	$ 9,895.0	$ 395.6	$ 1,757.2	17.1%	$ 12,047.8
121.3.8 - Linac - High Beta 650 (HB650)	119,688	$ 16,729.2	$ 13,182.3	$ 7,302.5	24.4%	$ 37,214.0
121.3.11 - Linac - CRYOgenics (CRYO)	57,601	$ 7,784.4	$ 10,725.7	$ 5,063.9	27.4%	$ 23,573.9
Grand Total	**459,849**	**$ 69,728.9**	**$ 58,061.1**	**$ 30,063.2**	**23.5%**	**$ 157,853.2**

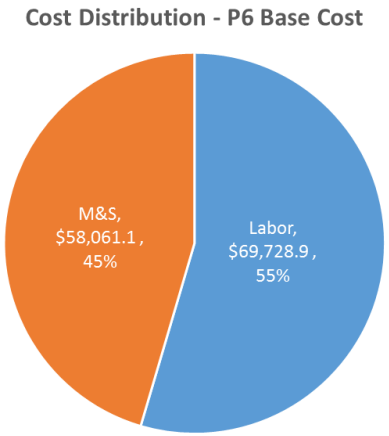
Note: P6 base cost = BOE + overheads and escalation

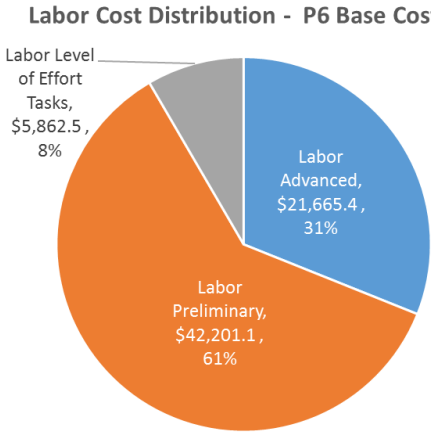
- Uncertainty based on Project Guidelines
- Costs come from P6 and are estimated down to the L6-8 Activity level.

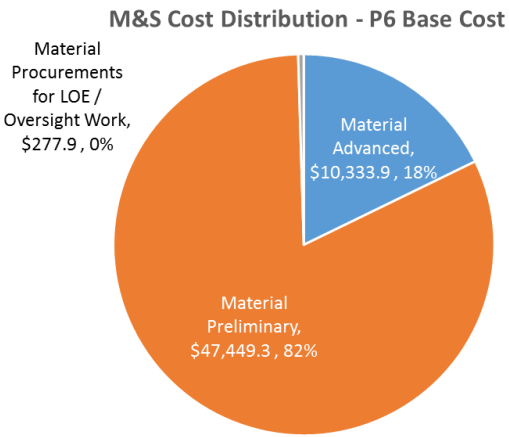
Cost Drivers and Estimate Maturity

Charge #2





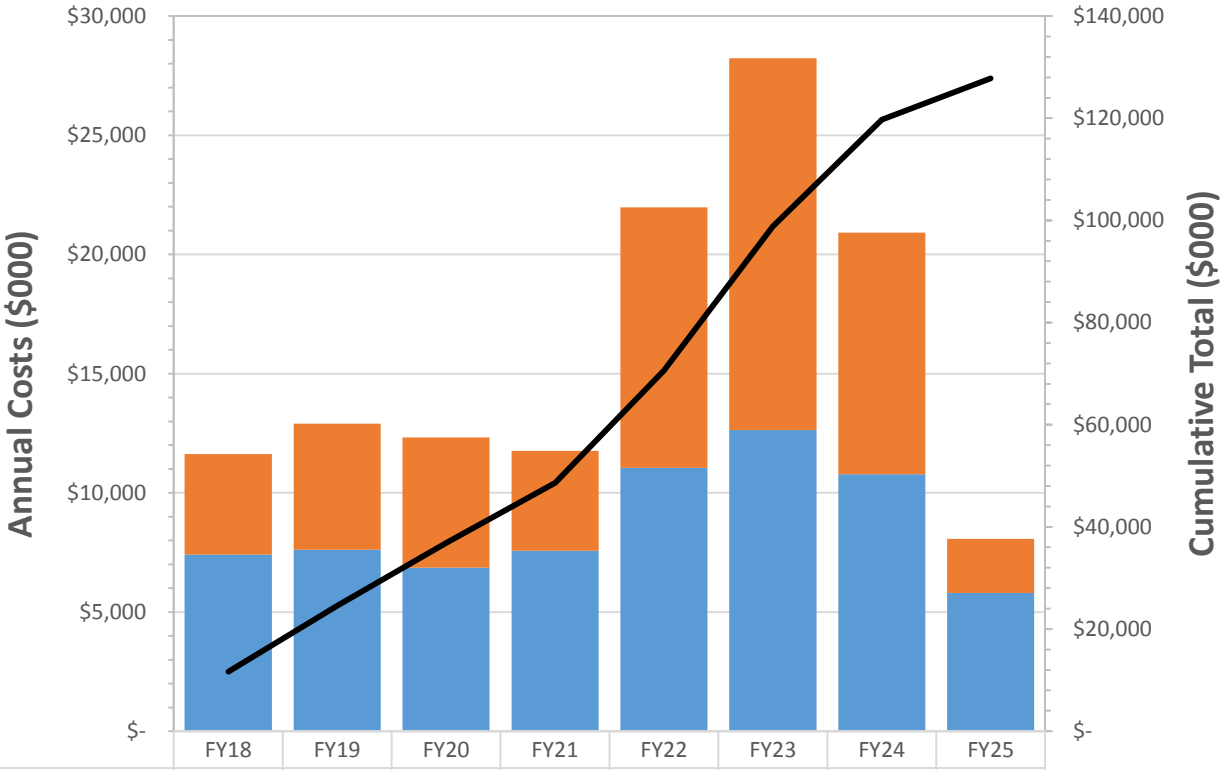




P6 Base Costs = BOE + Overheads + Escalation

Cost Profile – P6 Base Cost Only

Charge #2



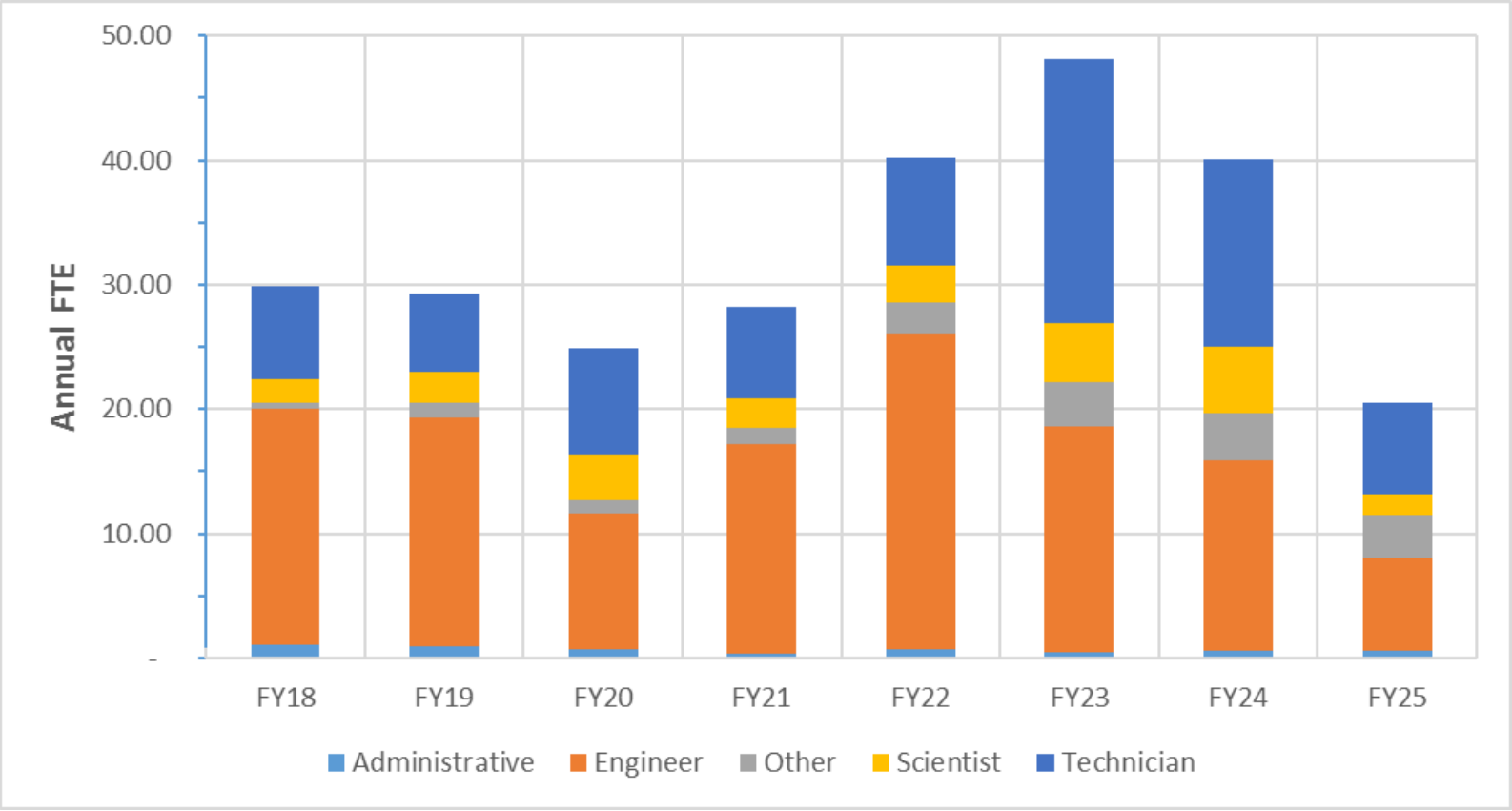
	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
Material	$4,220.2	$5,291.4	$5,457.4	$4,186.3	$10,924.	$15,588.	$10,127.	$2,265.6
Labor	$7,407.1	$7,614.1	$6,866.3	$7,572.4	$11,049.	$12,636.	$10,781.	$5,802.1
Cumulative Tot.	$11,627.	$24,532.	$36,856.	$48,615.	$70,588.	$98,813.	$119,722	$127,790

P6 Base Costs = BOE + Overheads + Escalation

- Material cost ramps significantly during SSR2 and HB650 Production CMs.

Labor Profile – P6 Hours/FTE

Charge #2



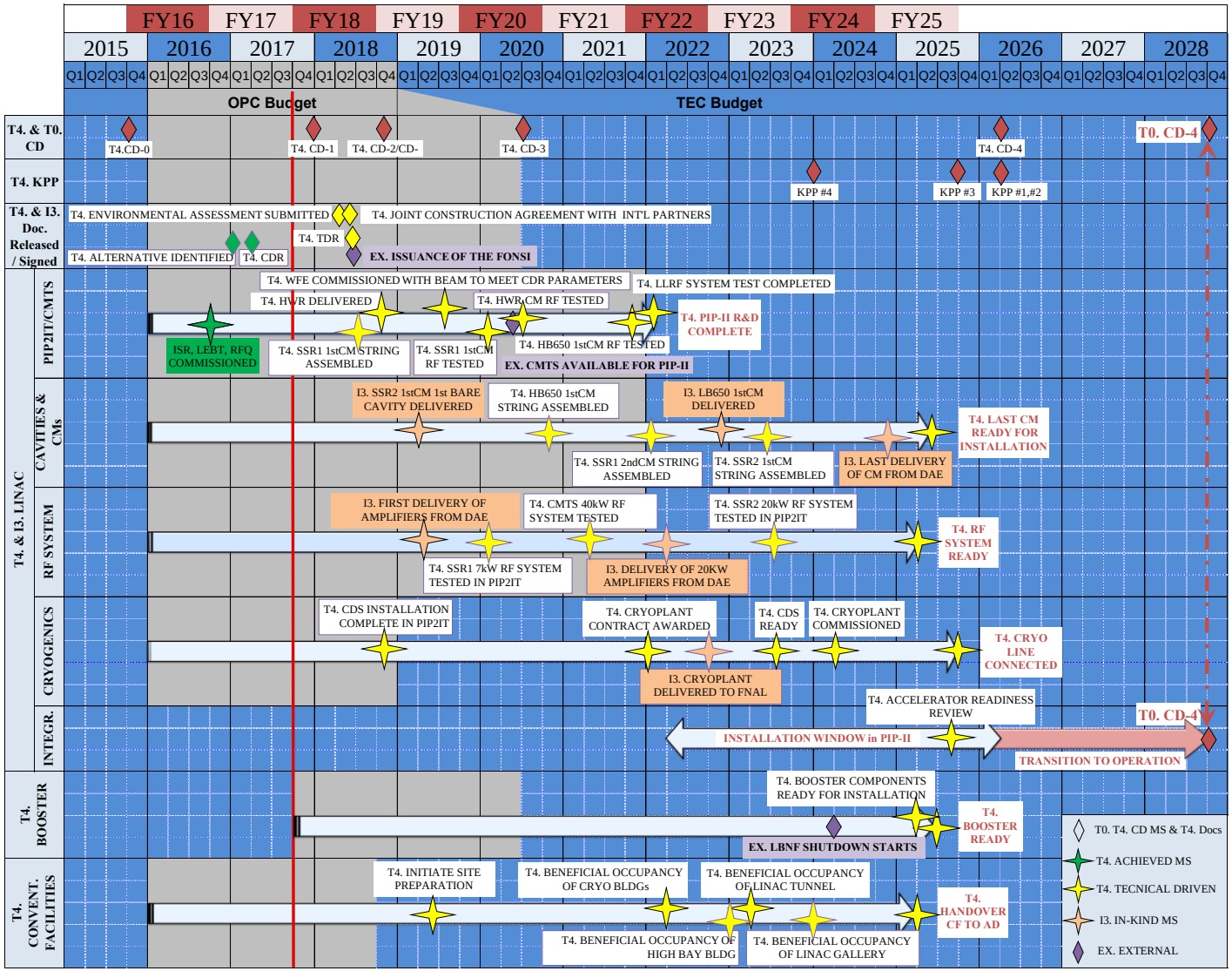
- Labor profile technically driven with no smoothing.
- L3 details in breakouts.

PIP-II PROJECT - High Level Master Schedule

T4 Milestones Tiered to T2, I3 Milestones - *WORKING SCHEDULE*

Fermilab

Charge #2



DATA EXTRACTED BY P6 PLANNING - OCTOBER 10, 2017

PREPARED BY L2 & L3 LEADERS, L. LARI, & J. RANDALL
CHECKED BY OFFICE OF SCIENCE - FERMI SITE OFFICE
SUBMITTED BY S. HOLMES

- SRF/Cryo milestones in PIP2IT, CMTF, Cavities & CMs, and Cryogenics
- Individual L3 schedules detailed in breakouts
- PIP-II Critical Path moves through SSR2 CM development.

PIP-II

Breakout Session

Breakout Session: SC Acceleration Modules and Cryogenics Session to begin on Tuesday and carry over to Wednesday as required				
15:00	0:20	15:20	Z. Conway	121.3.4 Linac - HWR
15:20	0:40	16:00	D. Passarelli	121.3.5-6 Linac - SSR1, SSR2
16:00	0:40	16:40	A. Rowe	121.3.7-8 Linac - LB650, HB650
16:40	0:40	17:20	A. Klebaner	121.3.11 Linac - Cryogenics

Summary

- All L3 WBS requirements are defined and traceable
- Cryo systems and cryomodule designs are sufficiently advanced to proceed to CD-1
- Milestone driven design review schedules through all WBS's are developed
- Cost and schedule drivers including risks are understood
- Partnerships between multiple laboratories throughout the world are established
- ESH&Q plans, risks, and mitigation strategies are developed.
- We are ready for CD-1 and look forward to your feedback
- Thank you for your attention

END