SRF and Cryogenics (121.02)

Genfa Wu

PIP-II Independent Project Review

4-6 December 2018

In partnership with:
- India/DAE
- Italy/INFN
- UK/STFC
- France/CEA/Irfu, CNRS/IN2P3

Outline

- Introduction
- Cryomodule Development Plan and Schedule
- In-kind Contribution and Partner Lab Management
- Technical Risks and Challenges
- Lessons Learned
- Summary

Scope and Deliverables

Charge #1

SRF

Cryomodule	Number (Prototype + installed)	Cavity Number	Magnet Number	Testing	Note
HWR	1	8	8	Tested at FNAL	ANL Led Design
SSR1	1+2	8	4	Tested at FNAL	FNAL Led Design
SSR2	1+7	5	3	Tested at FNAL	Integrated Design
LB650	1+11	3	0	Partial Test at Partner lab, Full Test at FNAL	Integrated Design
HB650	1+4	6	0	Test at FNAL	Integrated Design
Total	4+25	116	37		

Shipping from overseas

CRYO

- Cryoplant 2.2 kW 2K capacity
- Cryogenic distribution to support 2K CW operation and appropriate cool down of Linac

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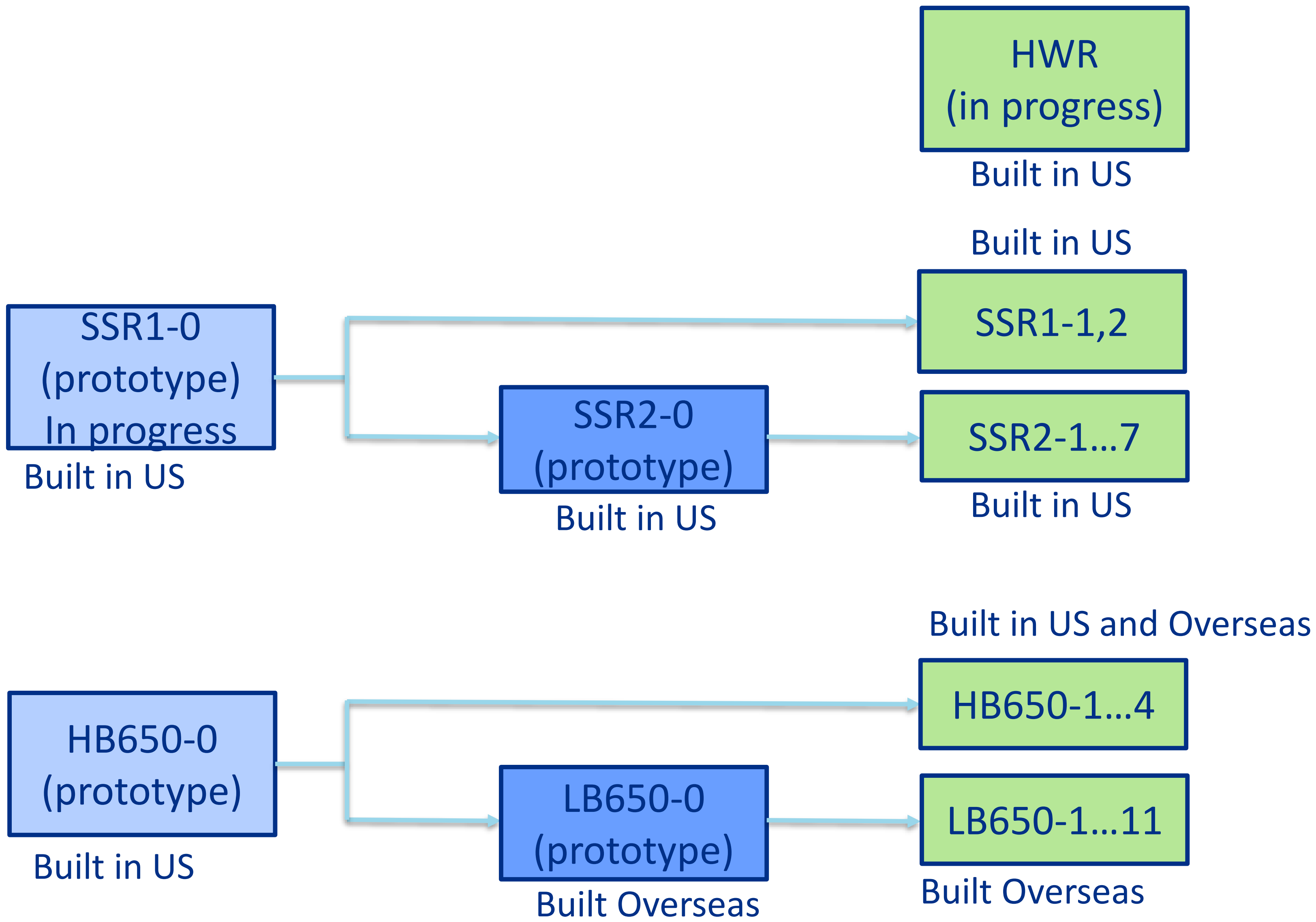
Cryomodule Development Path



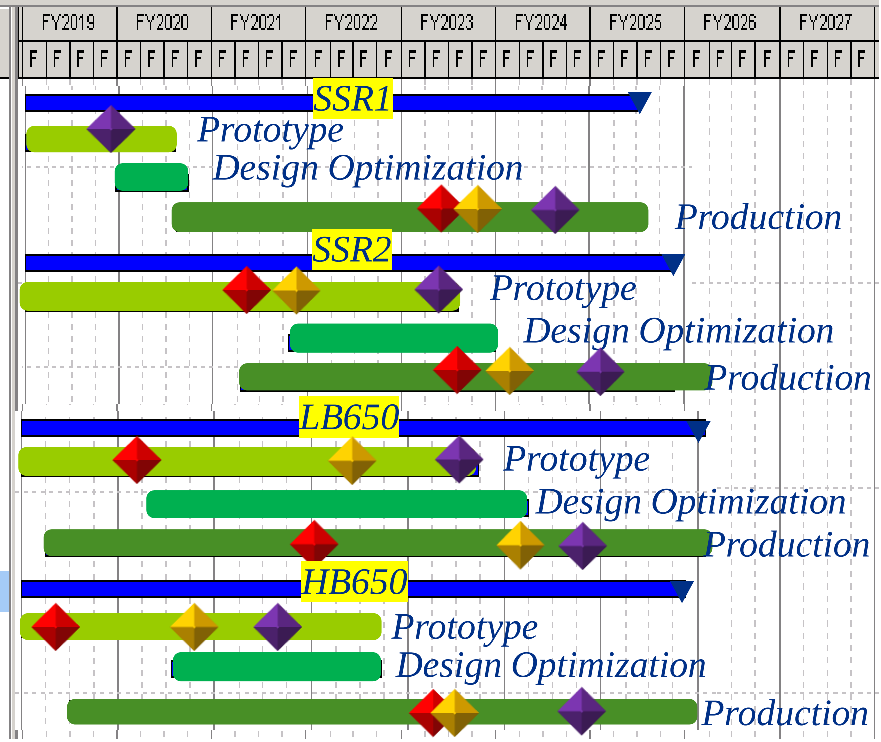
Cryomodule Schedule

Charge #5

27 November 2018 – Critical path on SSR2

	WBS Code	WBS Name
SSR1	121-IPR.02.03.02	SRFs - SSRs - Single Spoke Resonator 1 (R1)
	121-IPR.02.03.02.01	SRFs - SSRs - R1 - 1st Prototype CryoModule (1stPCM)
	121-IPR.02.03.02.02	SRFs - SSRs - R1 - Design Optimization for SSR1 Production
	121-IPR.02.03.02.03	SRFs - SSRs - R1 - 1st to 2nd Production CryoModules (1st-2ndCM)
SSR2	121-IPR.02.03.03	SRFs - SSRs - Single Spoke Resonator 2 (R2)
	121-IPR.02.03.03.01	SRFs - SSRs - R2 - 1st Prototype Cryomodule (1stPCM)
	121-IPR.02.03.03.02	SRFs - SSRs - R2 - Design Optimization for SSR2 Production
	121-IPR.02.03.03.03	SRFs - SSRs - R2 - 1st to 7th Production Cryomodules (1st-7thCM)
LB650	121-IPR.02.04.02	SRFs - 650MHz - Low Beta (LB)
	121-IPR.02.04.02.01	SRFs - 650MHz - LB - 1st Prototype CryoModule (1stPCM)
	121-IPR.02.04.02.02	SRFs - 650MHz - LB - Design Optimization for LB650 Production
	121-IPR.02.04.02.03	SRFs - 650MHz - LB - 1st to 11th Production CryoModules (1st-11thCM)
HB650	121-IPR.02.04.03	SRFs - 650MHz - High Beta (HB)
	121-IPR.02.04.03.01	SRFs - 650MHz - HB - 1st Prototype CryoModule (1stPCM)
	121-IPR.02.04.03.02	SRFs - 650MHz - HB - Design Optimization for HB650 Production
	121-IPR.02.04.03.03	SRFs - 650MHz - HB - 1st to 4th Production CryoModules (1st-4thCM)

Fiscal year

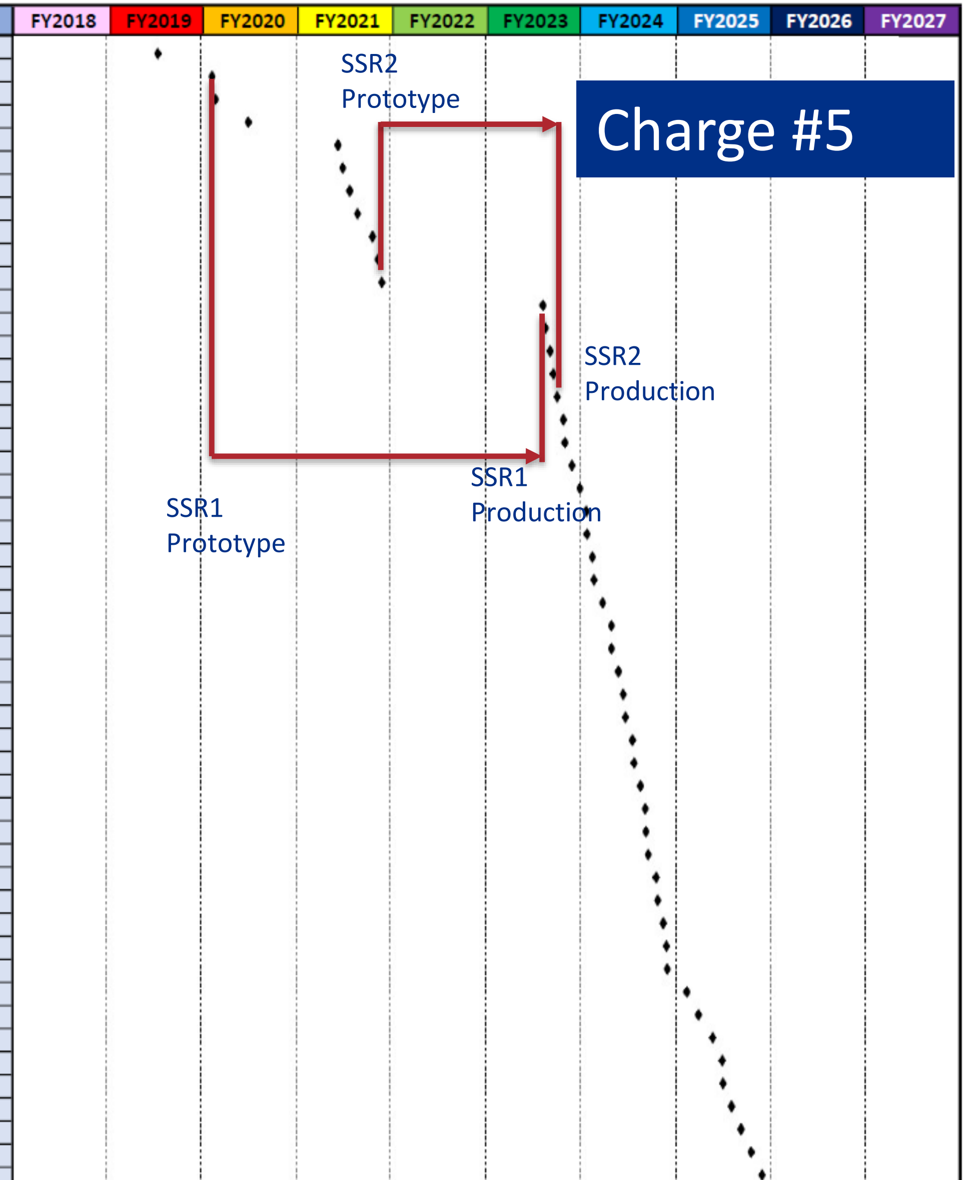


Legend

- Start Cavities Cold Tests
- Start String Assembly
- Start CM RF Testing

T5 Milestones – Half Wave Resonators and Single Spoke Resonators

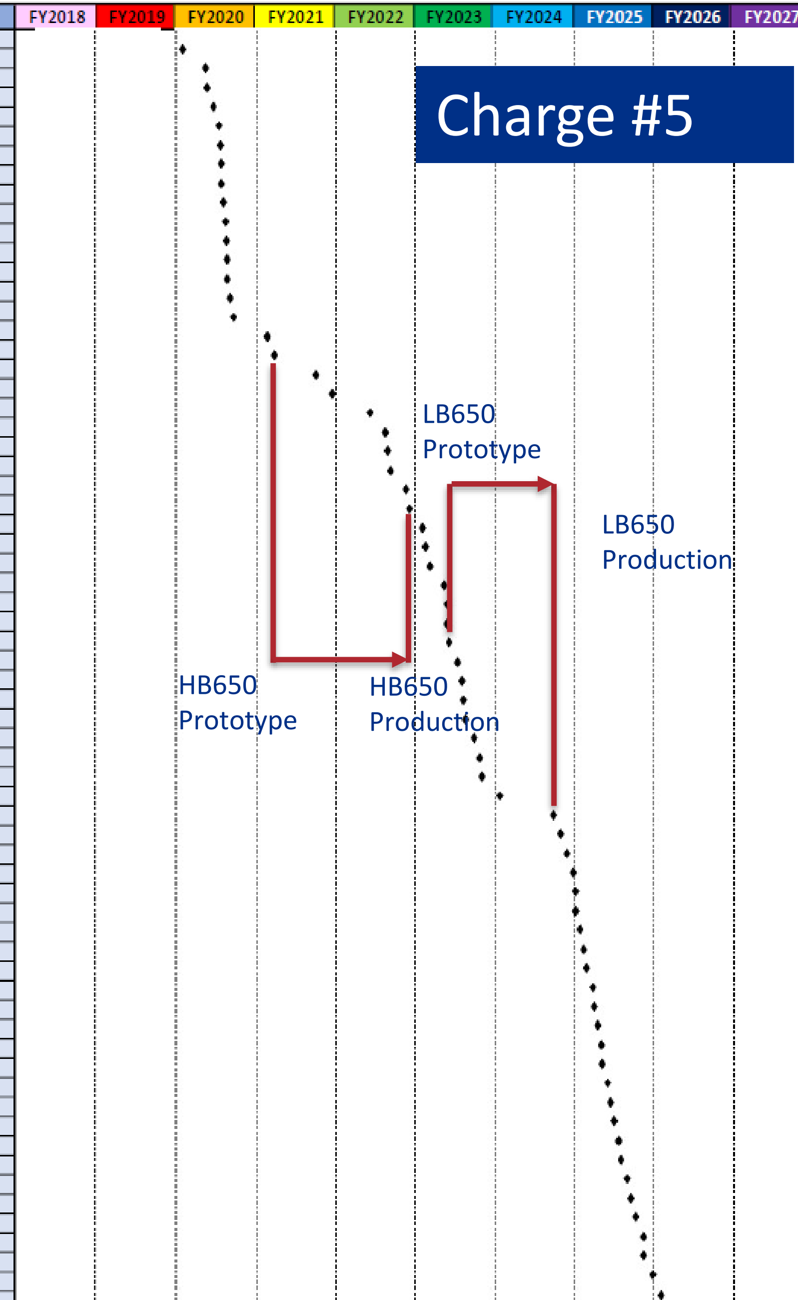
L3	T5 Milestone
Half Wave Resonator	HWR Cryomodule Delivered to Fermilab
Prototype SSR1	Proto SSR1 RF Tested in PIP2IT with 1 Prototype SSR1 Amplifier
Half Wave Resonator	HWR Cryomodule RF Tested in PIP2IT
Prototype SSR1	Proto SSR1 RF Tested in PIP2IT, Ready for Beam Commissioning
Prototype SSR2	1st In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Prototype SSR2	2nd In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Prototype SSR2	3rd In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Prototype SSR2	4th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Prototype SSR2	1st Proto FNAL Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Prototype SSR2	1st In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Prototype SSR2	2nd In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Prototype SSR2	SSR2 Proto Cryomodule RF Tested in PIP2IT Ready-for-Installation Milestone
Production SSR1	1st In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	2nd In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	3rd In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	4th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 1 (1-8) Dressed Cavities Qualified
Production SSR1	5th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	6th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	7th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 2 (9-16) Dressed Cavities Qualified
Production SSR1	8th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 1 (1-8) Dressed Cavities Ready for String (after Batch 1 Re-Cold Tests)
Production SSR1	9th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	10th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	11th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 3 (17-24) Dressed Cavities Qualified
Production SSR1	12th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 2 (9-16) Dressed Cavities Ready for String (after Batch 2 Re-Cold Tests)
Production SSR1	13th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	14th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 4 (25-32) Dressed Cavities Qualified
Production SSR1	15th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 1 (1-5) Dressed Cavities Qualified
Production SSR2	In-Kind Batch 3 (17-24) Dressed Cavities Ready for String (after Batch 3 Re-Cold Tests)
Production SSR1	16th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR1	17th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 5 (33-40) Dressed Cavities Qualified
Production SSR1	18th In-Kind Dressed Cavity Qualified in Spoke Test Cryostat with High Power Coupler
Production SSR2	In-Kind Batch 4 (25-32) Dressed Cavities Ready for String (after Batch 4 Re-Cold Tests)
Production SSR1	SSR1 Cryomodule1 RF Tested in PIP2IT, Ready-for-Installation Milestone
Production SSR2	In-Kind Batch 5 (33-40) Dressed Cavities Ready for String (after Batch 5 Re-Cold Tests)
Production SSR2	SSR2 Cryomodule1 RF Tested in PIP2IT Ready-for-Installation Milestone
Production SSR2	SSR2 Cryomodule2 RF Tested in PIP2IT Ready-for-Installation Milestone
Production SSR2	SSR2 Cryomodule3 RF Tested in PIP2IT Ready-for-Installation Milestone
Production SSR1	SSR1 Cryomodule2 RF Tested in PIP2IT, Ready-for-Installation Milestone
Production SSR2	SSR2 Cryomodule4 RF Tested in PIP2IT Ready-for-Installation Milestone
Production SSR2	SSR2 Cryomodule5 RF Tested in PIP2IT Ready-for-Installation Milestone
Production SSR2	SSR2 Cryomodule6 RF Tested in PIP2IT Ready-for-Installation Milestone
Production SSR2	SSR2 Cryomodule7 RF Tested in PIP2IT Ready-for-Installation Milestone



Fermilab PIP-II Proton Improvement Plan-II

T5 Milestones – 650 MHz Cryomodules

L3	T5 Milestone
Prototype LB650	1st In-Kind Bare Cavity Delivered to Partner after FNAL Cold Testing in Vertical Test Stand
Prototype LB650	2nd In-Kind Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	1st B.90 Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	2nd B.90 Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	3rd B.90 Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	1st In-Kind B.92 JCAV Qualified in Vertical Test Stand
Prototype HB650	1st B.92 prototype Dressed Cavity Qualified in Spoke Test Cryostat
Prototype LB650	1st In-Kind Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	2nd In-Kind B.92 JCAV Qualified in Vertical Test Stand
Prototype HB650	4th B.90 Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	3rd In-Kind B.92 JCAV Qualified in Vertical Test Stand
Prototype HB650	2nd B.92 Prototype Dressed Cavity Qualified in Spoke Test Cryostat
Prototype LB650	2nd In-Kind Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	4th In-Kind B.92 JCAV Qualified in Vertical Test Stand
Prototype HB650	3rd B.92 Prototype Dressed Cavity Qualified in Spoke Test Cryostat
Prototype LB650	1st FNAL Dressed Cavity Qualified in Spoke Test Cryostat
Prototype LB650	2nd FNAL Dressed Cavity Qualified in Spoke Test Cryostat
Prototype HB650	HB650 Prototype CryoModule RF Tested in PIP2IT for one cavity with Prototype 40kW SSA
Prototype HB650	HB650 Prototype CryoModule RF Tested in PIP2IT
LB650	In-Kind Dressed cavities Qualified at Partner Facility- Batch 1 (1-6)
LB650	In-Kind Dressed cavities Accepted - Batch 1 (1-6) Ready for String Integration at Partner facility
Prototype HB650	HB650 Prototype CryoModule RF Tested in PIP2IT, after coming back from In-Kind, Ready-For-Installation Milestone
LB650	In-Kind Dressed cavities Qualified at Partner Facility- Batch 2 (7-12)
LB650	In-Kind Dressed cavities Accepted - Batch 2 (7-12) Ready for String Integration at Partner facility
LB650	In-Kind Dressed cavities Qualified at Partner Facility- Batch 3 (13-18)
HB650	In-Kind Dressed cavities Qualified - Batch 1 (1-6)
LB650	In-Kind Dressed cavities Accepted - Batch 3 (13-18) Ready for String Integration at Partner facility
LB650	In-Kind Dressed cavities Qualified at Partner Facility- Batch 4 (19-24)
HB650	In-Kind Dressed cavities Qualified - Batch 2 (7-13) (not to be assembled at Partner facility)
LB650	In-Kind Dressed cavities Accepted - Batch 4 (19-24) Ready for String Integration at Partner facility
LB650	In-Kind Dressed cavities Qualified at Partner Facility - Batch 5 (25-30)
Prototype LB650	LB650 Prototype CryoModule RF Tested at Partner facility
HB650	In-Kind Dressed cavities Qualified - Batch 1 (1-6)
LB650	In-Kind Dressed cavities Accepted - Batch 5 (25-30) Ready for String Integration at Partner facility
HB650	In-Kind Dressed cavities Qualified - Batch 3 (14-20) (not to be assembled at Partner facility)
LB650	In-Kind Dressed cavities Qualified at Partner Facility - Batch 6 (31-39)
Prototype LB650	LB650 Prototype CryoModule RF Tested in PIP2IT Ready-For-Installation Milestone
HB650	In-Kind Dressed cavities Qualified - Batch 2 (7-12)
LB650	In-Kind Dressed cavities Accepted - Batch 6 (31-39) Ready for String Integration at Partner facility
HB650	In-Kind Dressed cavities Qualified - Batch 3 (13-18)
LB650	LB650 CryoModule1 RF Tested at Partner facility
LB650	LB650 CryoModule2 RF Tested at Partner facility
LB650	LB650 CryoModule3 RF Tested at Partner facility
LB650	LB650 CryoModule4 RF Tested at Partner facility
LB650	LB650 CryoModule1 RF Tested in PIP2IT Ready-For-Installation Milestone
HB650	HB650 CryoModule1 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule5 RF Tested at Partner facility
LB650	LB650 CryoModule2 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule6 RF Tested at Partner facility
LB650	LB650 CryoModule3 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule7 RF Tested at Partner facility
HB650	HB650 CryoModule2 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule8 RF Tested at Partner facility
LB650	LB650 CryoModule4 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule9 RF Tested at Partner facility
LB650	LB650 CryoModule5 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule10 RF Tested at Partner facility
LB650	LB650 CryoModule6 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule11 RF Tested at Partner facility
LB650	LB650 CryoModule7 RF Tested in PIP2IT Ready-For-Installation Milestone
HB650	HB650 CryoModule3 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule8 RF Tested in PIP2IT Ready-For-Installation Milestone
HB650	HB650 CryoModule4 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule9 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule10 RF Tested in PIP2IT Ready-For-Installation Milestone
LB650	LB650 CryoModule11 RF Tested in PIP2IT Ready-For-Installation Milestone



T5 Milestones – Cryogenic Systems

Charge #5

L3	T5 Milestone	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027
Cryoplant	CryoPlant Preliminary Oxygen Deficiency Hazard Assesment Complete		◆								
Cryoplant	CryoPlant Final Oxygen Deficiency Hazard Assesment complete			◆							
Cryogenics Distribution System	Oxygen Deficiency Hazard analysis complete			◆							
Cryoplant	CryoPlant Received and inspected at FNAL				◆						
Cryogenics Distribution System	Cryogenic Distribution System in Tunnel Ready for Installation including U-Tubes and controls						◆				
Cryoplant	CryoPlant Commissioned							◆			
Cryoplant	Post-Commissioning Complete							◆			
Cryogenics Distribution System	Valve Distribution Box Installed							◆			
Cryogenics Distribution System	Cryogenic Distribution System from Cryoplant to Tunnel Installed								◆		

Last SSR2 cryomodule and LB650 Cryomodule ready for installation

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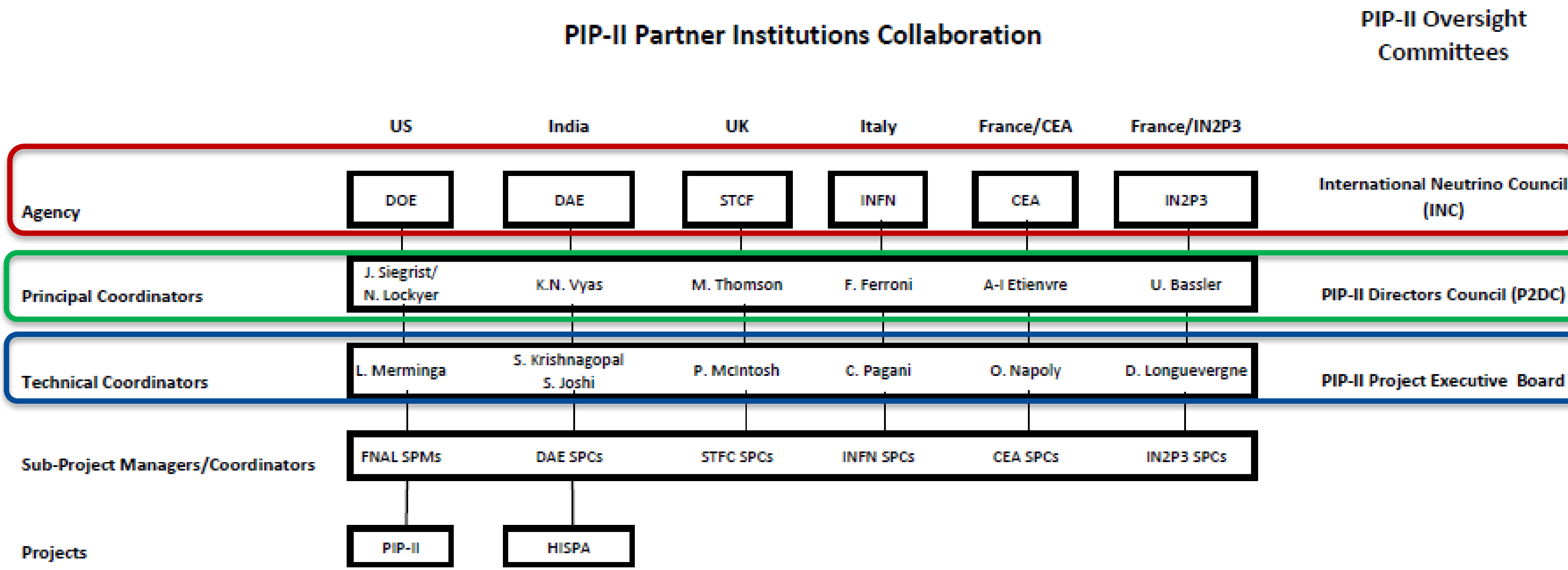
In-kind Contribution

Item	US DOE	In-kind	Note
HWR Cryomodule	ANL builds cryomodule, FNAL tests.		
SSR1 Cryomodules	FNAL builds and tests all Cryomodules	Some prototype cavities, all production cavities, tuners and solenoids	
SSR2 Cryomodules	FNAL builds and tests all Cryomodules	Some prototype cavities, all production cavities, tuners and solenoids	
LB650 Cryomodules	FNAL tests all cryomodules	Prototype and production cryomodules including all sub components	Cavities from different partner lab
HB650 Cryomodules	• FNAL builds prototype cryomodule and transportation tests • FNAL builds one production cryomodule. • FNAL tests all cryomodules	• Production cryomodules including all subcomponents • Transportation design and procurement	Couplers from different partner lab
Cryoplant	FNAL installation and commissioning	Cryoplant Procurement	
Cryogenic Distribution	FNAL design, procurement, installation and commissioning		

Cryomodule Repair after Delivery is Fermilab Responsibility

Partner Lab Management



- Partner scope, delivery timeframe, milestones and management processes are described in joint *Project Planning Documents*, under development

Partner Lab Management – SPC List (1)

India Institute and Fermilab Collaboration (IIFC)

Sub-Project	Indian-DAE Sub-Project Coordinator	US-Fermilab Sub-Project Coordinator
SSR1 Cavity Design	P. N. Prakash, IUAC	Leonardo Ristori
SSR2 Cavity Design	Srinavas Krishnagopal, BARC	Leonardo Ristori
SSR1 + SSR2 Cavity Manufacture	Vinay Mishra, BARC	Leonardo Ristori
SSR Cryomodule	Vinay Mishra, BARC	Donato Passarelli
LB650 Dressed Cavity	Sumit Som, VECC	Saravan Chandrasekaran
HB650 Dressed Cavity	Avinash Puntambekar, RRCAT	Saravan Chandrasekaran
LB650 & HB650 Cryomodules	Prashant Khare, RRCAT	Saravan Chandrasekaran
RF Couplers	Rajesh Kumar, BARC	Nikolay Solyak
Cryogenic Systems	Anindya Chakravarty, BARC	Ben Hansen
SRF Infrastructure	Satish Joshi, RRCAT	Allan Rowe
Vertical Test Stand	S. Raghavendra, RRCAT	Alex Melnychuk
Horizontal Test Stand	Pradeep Kush, RRCAT	Joe Ozelis

Partner Lab Management – SPC List (2)

Italy INFN

Sub-Project	ITALY-INFN Sub-Project Coordinator	US-Fermilab Sub-Project Coordinator
LB650 Cavity Design	Carlo Pagani	Martina Martinello
LB650 Dressed Cavity Fabrication	Carlo Pagani	Martina Martinello
LB650 Dressed Cavity Testing	Carlo Pagani	Martina Martinello

UK UKRI

Sub-Project	UK-UKRI Sub-Project Coordinator	US-Fermilab Sub-Project Coordinator
HB650 Cavity	Alan Wheelhouse	Martina Martinello
HB650 Cryomodule Assembly	Phil Atkinson	Tug Arkan
HB650 Transportation	Alan Wheelhouse	Tug Arkan

Partner Lab Management – SPC List (3)

France CEA

Sub-Project	France-CEA Sub-Project Coordinator	US-Fermilab Sub-Project Coordinator
LB650 Cryomodule Design	Nicolas Barzin	Vincent Roger
LB650 Cryomodule Assembly	Catherine Madec	Tug Arkan
LB650 Cryomodule Testing	Catherine Madec	Tug Arkan
LB650 Transportation	Catherine Madec	Tug Arkan
650 MHz Coupler	TBD	Nikolay Solyak

France IN2P3

Sub-Project	France-IN2P3 Sub-Project Coordinator	US-Fermilab Sub-Project Coordinator
SSR2 Jacketed Cavity and Tuner	David Longuevergne	Donato Passarelli
SSR2 Coupler	David Longuevergne	Donato Passarelli

Partner Lab Management and Standardization

- Working towards: Common Design Software
  - UG NX and Siemens Teamcenter
- Working towards: Common Traveler Data Sets
- Working towards: Standard Units
- Standard Non-Conformance-Report and its Work Flow
- Hold Point Data Reviews
- Common Acceptance Criteria
- Partner Lab’s QA plan Approved by Both Partners and Fermilab

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WBS 121.02 Risk Management

Charge #2,7

SRF and Cryogenics Risks

- High Risks: **7**
- Medium Risks: **17**
- Low Risks: **12**

High Risks

RI-ID	Title
RT-121-02-001	650 Cryomodule is damaged during transportation
RT-121-02-003	Underestimated resources for design optimization of SSR1 CM (1)
RT-121-02-003-B	Underestimated resources for design optimization of HB650 CM (1)
RT-121-02-003-C	Underestimated resources for design optimization of SSR2 CM (1)
RT-121-02-004	SRF pre-production input couplers are unreliable
RT-121-02-005	650 MHz IOT Amplifiers fail
RT-121-02-006	Cryomodule production rate at Fermilab is too slow

Most high risks retired by CD-3 except -001, -006

WBS 121.02 Risk Management

Charge #2,7

Medium Risks

RI-ID	Title
RT-121-02-007	SSR1 Cryomodule design modifications identified late in design cycle
RT-121-02-008	HWR Cryomodule does not meet technical performance requirements
RT-121-02-009	SSR1 CM (2) Performance at PIP2IT CMTS does not meet technical requirements
RT-121-02-010	LB650 CMs (1-11) performance at CMTS does not meet technical requirements
RT-121-02-011	SSR2 Production CMs (2-7) do not meet technical performance requirements at PIP2IT
RT-121-02-012	HB650 production CMs (2-4) do not meet technical performance requirements at CMTS
RT-121-02-016	Cavity yield is lower than expected to support production
RT-121-02-013	Delay in access to SRF testing and fabrication infrastructure
RT-121-02-014	Insufficient quality of installed cavities
RT-121-02-015	Insufficient cavity production delivery rate (US/International)
RT-121-02-017	Niobium quality control is inadequate
RT-121-02-018	HB650 Cryomodule assembly and integration
RT-121-02-019	Failure of SRF cavity processing equipment
RT-121-02-020	Cryoplant delivery is delayed
RT-121-02-021	SRF Test Infrastructure Cryogenic Plant Failure
RT-121-02-027	CDS components delayed delivery

2K Heat Load Specification

	HWR	SSR1	SSR2	LB650	HB650
Cavity length	0.207	0.205	0.438	0.705	1.0438
R/Q	272	242	297	341	610
G	48	84	115	193	260
Nominal Gradient	9.7	8.6	11.4	15.6	18.7
Nominal Q0	5.0E+09	8.3E+09	1.0E+10	2.2E+10	3.0E+10
Cavity number	8	16	35	33	24
Cryomodule number	1	2	7	11	4
1 Cav Nominal Dynamic Heat Load	3.0	1.6	8.4	15.9	20.8
Current Leads Dynamic Heat Load		2.0	1.5		
Total Nominal Dynamic Heat Load	23.7	28.9	304.3	525.6	499.7
Total Expected Dynamic Heat Load					
Static Heat Load per CM Type	30	45	120.4	63.8	30
Total PIP-II Static HeatLoad					289.2
Total PIP-II Dynamic HeatLoad					1382.2
Total PIP-II Cryogenic Heat Load (2K)					1672

ED0008200 PIP-II Cryogenic Heat Load

Nominal values based on CDR and latest analysis

Heat Load does not including uncertainty and margin

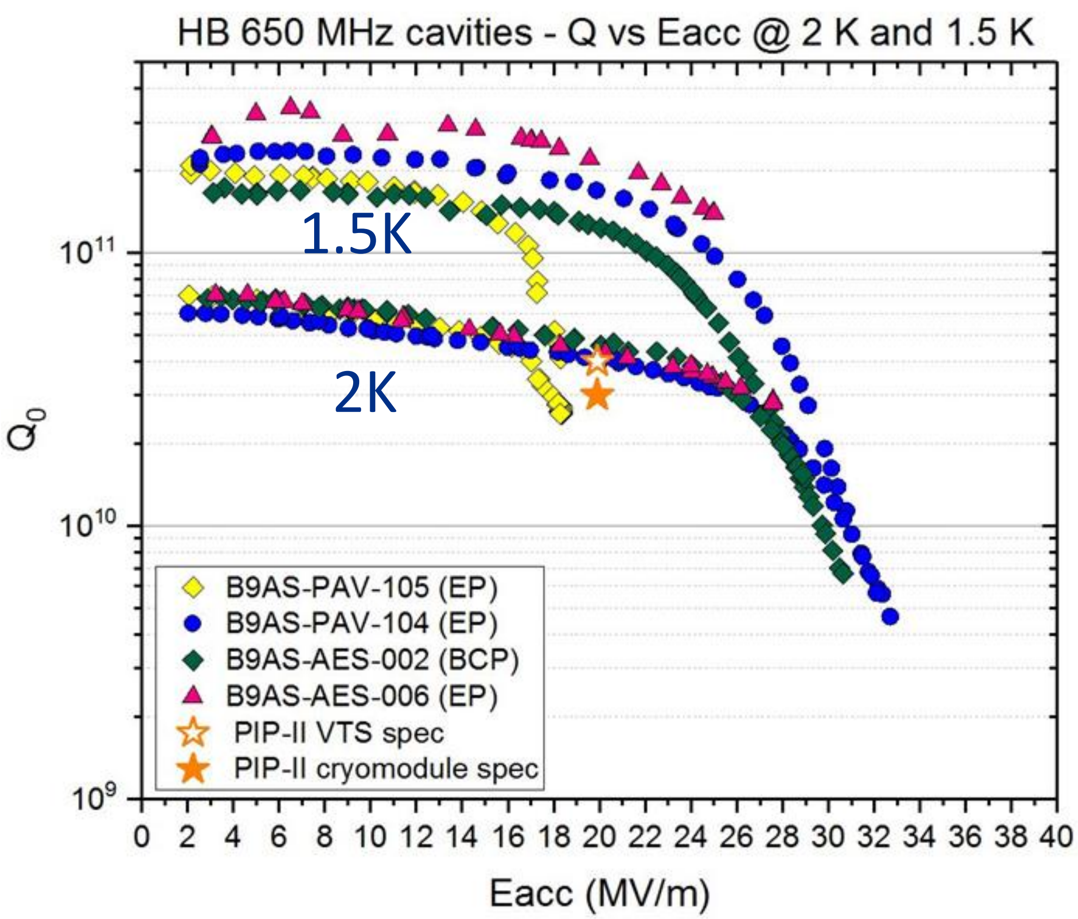
2K Heat Load R&D Goal

	HWR	SSR1	SSR2	LB650	HB650
Cavity length	0.207	0.205	0.438	0.705	1.0438
R/Q	272	242	297	341	610
G	48	84	115	193	260
Nominal Gradient	9.7	8.6	11.4	15.6	18.7
Nominal Q0	5.0E+09	1.0E+10	1.5E+10	3.0E+10	4.0E+10
Cavity number	8	16	35	33	24
Cryomodule number	1	2	7	11	4
1 Cav Nominal Dynamic Heat Load	3.0	1.3	5.6	11.9	15.6
Current Leads Dynamic Heat Load		2.0	1.5		
Total Nominal Dynamic Heat Load	23.7	20.5	195.9	394.2	374.7
Total Expected Dynamic Heat Load					
Static Heat Load per CM Type	30	45	120.4	63.8	30
Total PIP-II Static HeatLoad					289.2
Total PIP-II Dynamic HeatLoad					1009.1
Total PIP-II Cryogenic Heat Load (2K)					1298

ED0008200 PIP-II Cryogenic Heat Load

R&D Supported both by FNAL and partner labs

High Q R&D – 650 MHz 1-cell Results



EP + 120C baking only.
N-doping soon

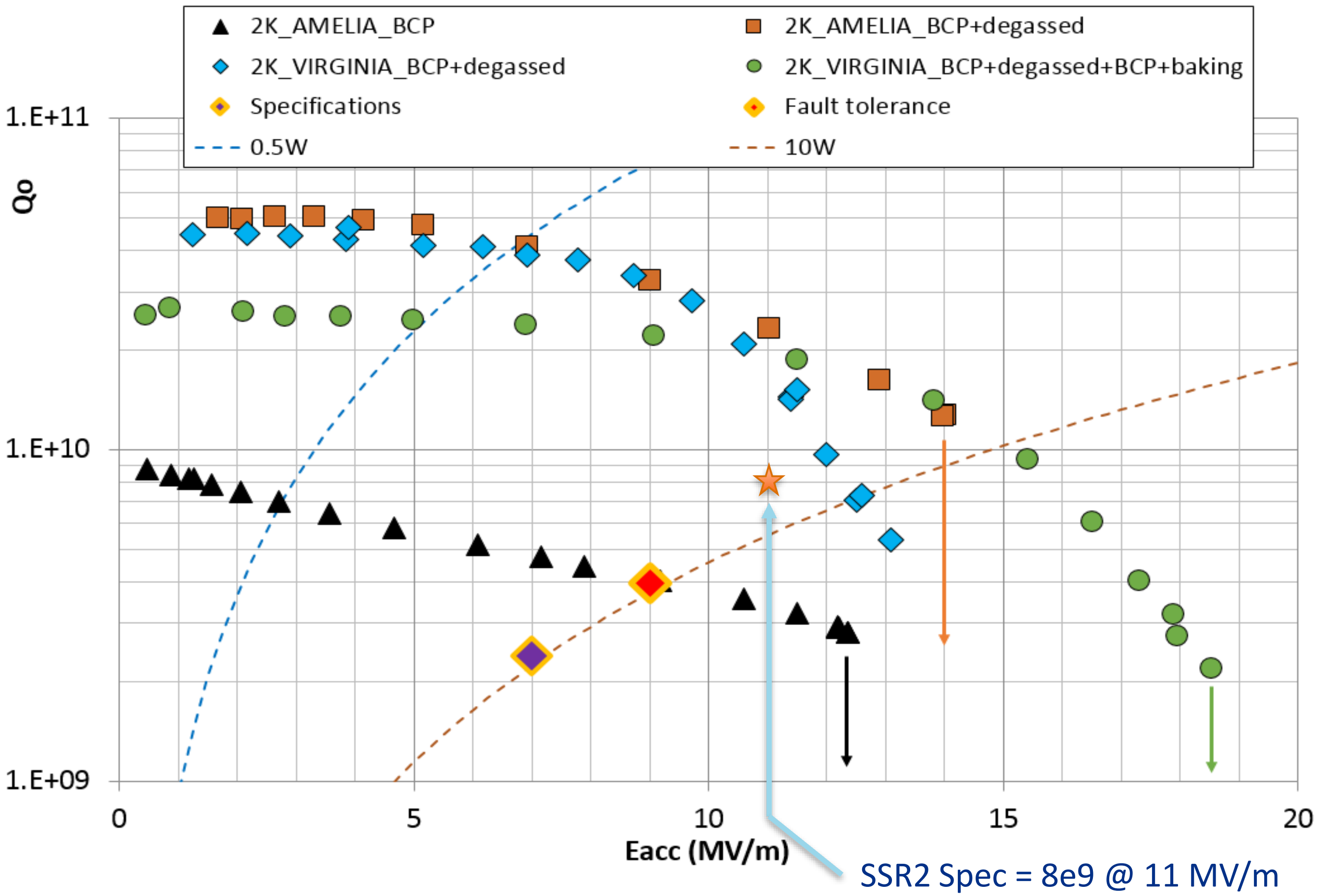
M. Martinello

VTS test results from B9AS-PAV-104 and B9AS-AES-106 after 75C/120C baking and 40µm EP reset, respectively.
Lower and upper set of curves represent 2 K and 1.5 K measurement, respectively.
B9AS-PAV-105 after EP and B9AS-AES-006 after BCP are illustrated for comparison.

High Q cavity procedure is being optimized

High Q R&D – SSR

ESS Double Spoke Cavities

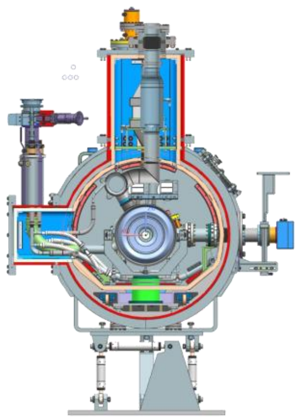


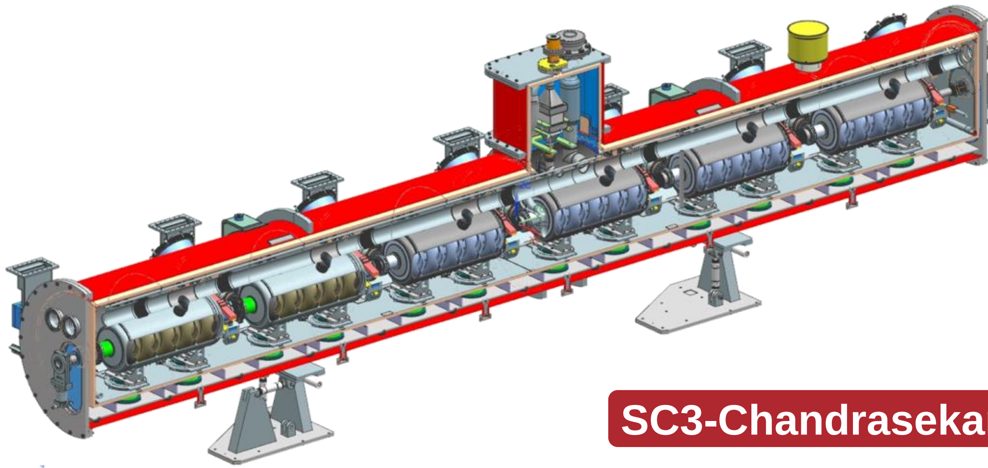
Results from ESS spoke cavity are encouraging

D. Longuevergne

HB650 Cryomodule Design Features to Support High Q

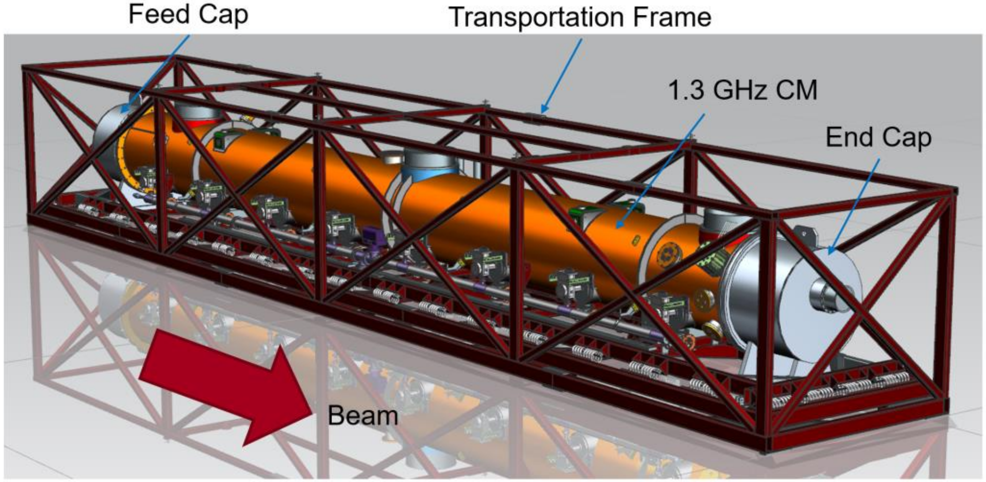
- Cryogenic System Supports Fast Cool Down
- Cryomodule Thermal Design to Minimize Thermoelectric Current
- Magnetic Shield to Minimize Ambient Earth Magnetic Field
  - Global and local magnetic shield design
- Better Instrumentation for High Q operation





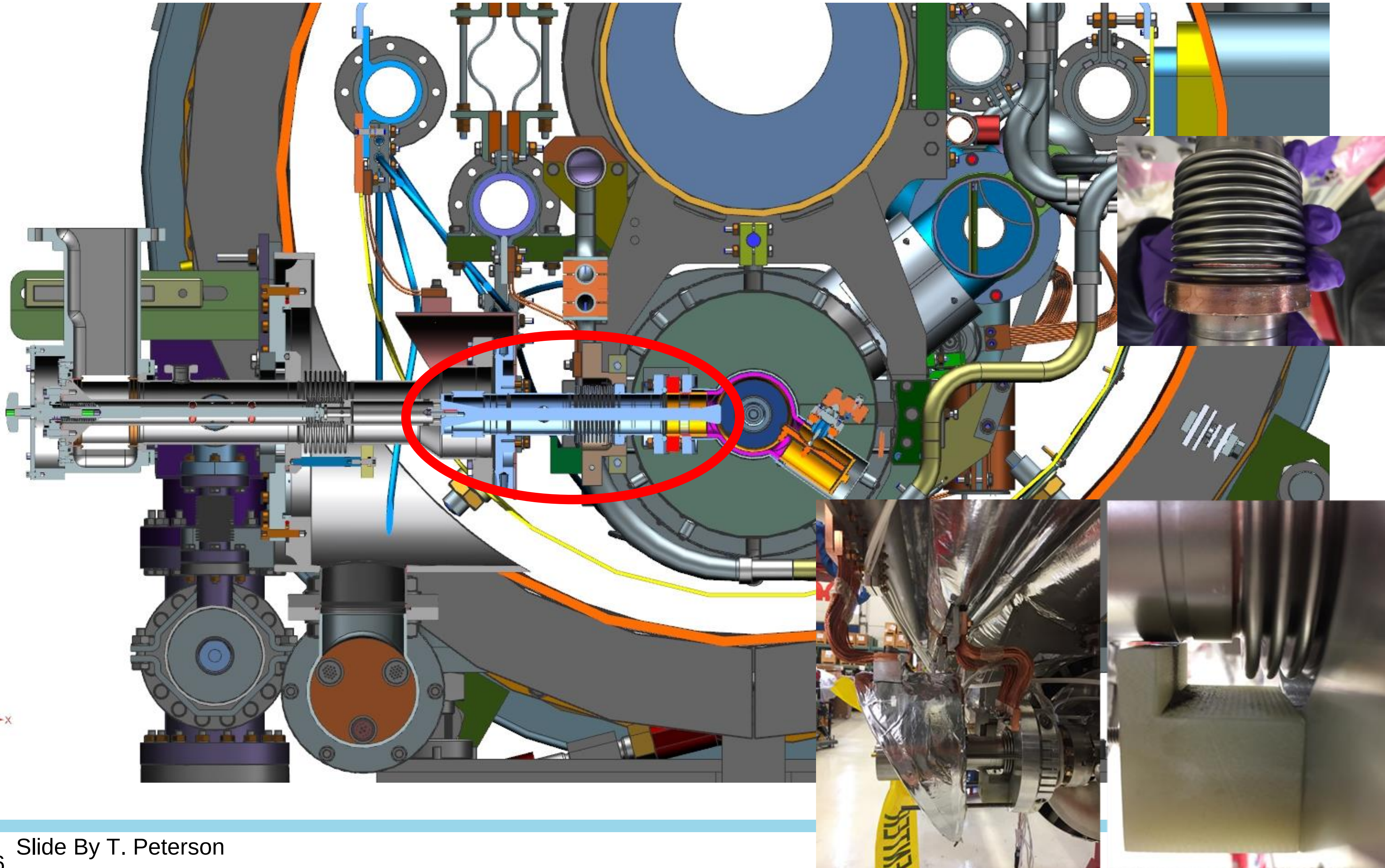
SC3-Chandrasekaran

Transportation Challenge in LCLS-II



LCLS-II Cryomodule – inner coupler bellows failures
at cavities 4 and 5 in F1.3-06 (later in cavity 1 in F1.3-05)

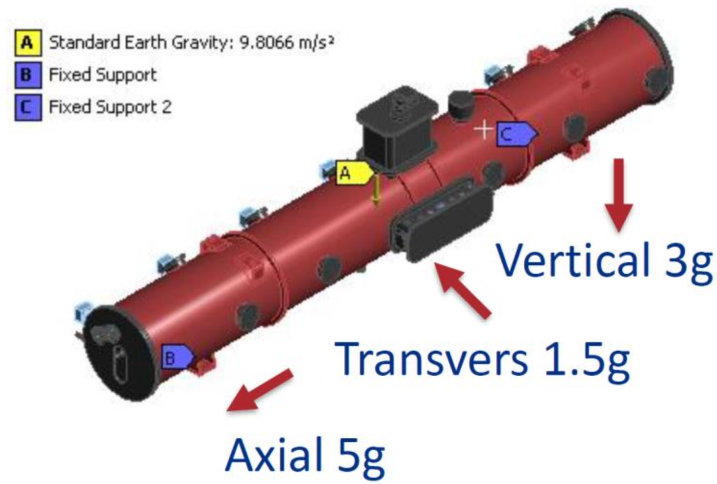
LCLS-II Cryomodule – inner coupler bellows failures at cavities 4 and 5 in F1.3-06 (later in cavity 1 in F1.3-05)

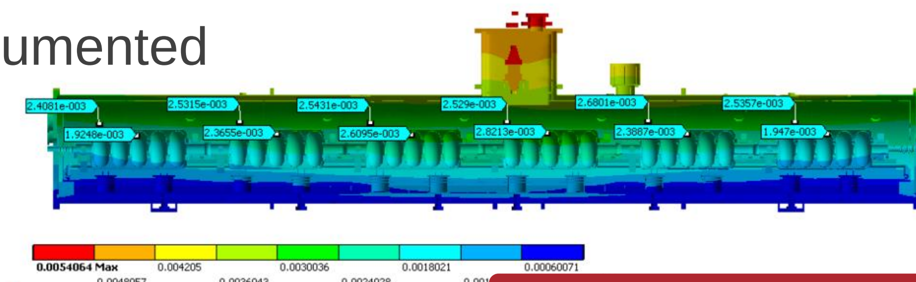


Slide By T. Peterson

Transportation is Part of the Cryomodule Prototyping

- Transportation is Part of the Cryomodule Prototyping
- Transportation Studies (three trips)
  - HB650 Prototype Cryomodule
    - Fully Tested
    - FNAL to Europe, fully instrumented
    - Test Optional
    - Europe to FNAL, fully instrumented
    - Verification Test
  - LB650 Prototype Cryomodule
    - Partially Tested
    - Europe to FNAL, fully instrumented
    - Verification Test





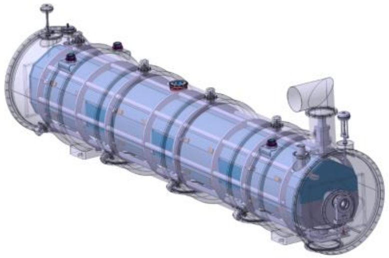
SC3-Chandrasekaran

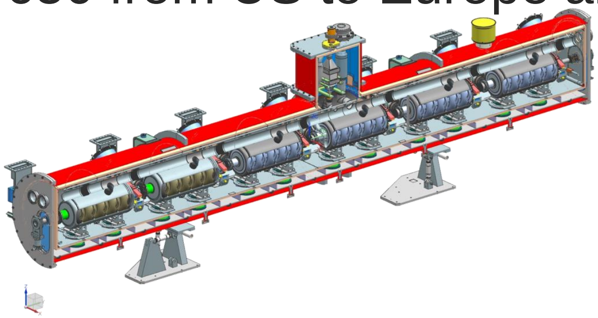
Fermilab
PIP-II
Proton Improvement Plan-II

650 MHz Cryomodule Transportation

- Conducted transportation analysis of two leading CM design concepts: strong-back (SSR1) and spaceframe (ESS, SNS)
- Held 650 MHz cryomodule design advisory meeting
  – *Hasan Padamsee, Robert Laxdal, Michael Kelly, Thomas Peterson,, Ed Daly, Mark Wiseman, Joel Fuerst*
- Preliminary analysis showed no technical preference in terms of shipping and alignment
- Final decision considered: Technical evaluation; Schedule & Cost impact; CEA & other partners considerations;
- A preliminary design choice was made in November to adopt strong back design
- RLS includes shipping proto HB650 from US to Europe and back

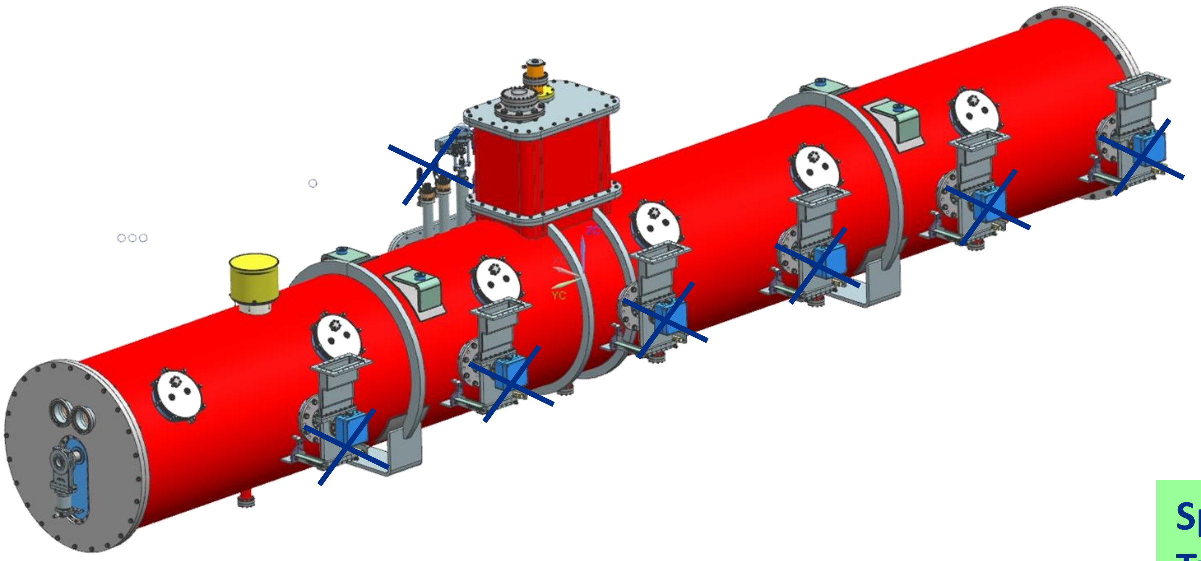
Spaceframe Design
CEBAF, SNS, ESS





Bottom Support (strong back)
FRIB, PIP-II

Transportation Strategy and Specification (Draft)



To be removed during transportation:
- Warm Couplers and Door knobs
- Actuators
- Pressure Gauges and Transducers
- Others

To be constrained:
- Heat exchanger
- Gate valves

Specified accelerations during Transportation on Cryomodule:
- Axial: 2.5g
- Transverse: 1.5g
- Vertical: 2.5g

Fully instrumented with accelerometers, etc.

Partner Lab Risk Management

Charge #2,7

System/Component	India/DAE	Italy/INFN	UK/UKRI	France/CEA /IN2P3	Fermilab Backup
Cavities					
SSR1 - jacketed	✓				✓
SSR2 -jacketed	✓			✓	✓
LB650 – Jacketed	✓	✓			✓
HB650 – jacketed	✓		✓		✓
Cryomodules					
SSR2	✓				✓
LB650				✓	✓
HB650	✓		✓		✓
SSR2 Cold Magnets	✓				✓
Cryoplant	✓				

Partner Labs have their own risk management

Partner Lab Risk Management

Charge #2,7

- Joint Cryomodule Design Team with Experienced Staff
- Fermilab Staff Participates Partner Lab Activities
- Redundancy Capability Explored
- Support Activities including Quality Assurance are Built into Resource Loaded Schedule
- Partner Labs Participates Monthly Status Reporting

International Risk Mitigation is being Developed

Fermilab has staff and infrastructure to support at risk components

Outline

- Introduction
- Cryomodule Development Plan and Schedule
- In-kind Contribution and Partner Lab Management
- Technical Risks and Challenges
- Lessons Learned
- Summary

Lessons Learned

- Lessons Learned from other Projects
  - Transportation by design
  - Comprehensive fastener torque specification
  - Microphonics Early Studies
  - Cryomodule Test with Sufficient Duration

- Lessons Learned within PIP-II
  - Realtime Traveler
    - Spoke cavity S104 near-miss of uncontrolled pump down

Summary

- Cryomodule Development Plan Allows Sufficient Prototyping to Feedback to Production.
- In-kind Contribution has Redundancy of Capabilities.
- Technical Risks and Challenges are mostly Understood
- Lessons Learned from other Projects will be Positive for PIP-II Cryomodules.

END