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

- Scope/Deliverables
- Requirements
- Interfaces
- Preliminary Design, Maturity
- Design Review Plan
- Technical Progress to Date
- Organization
- Steps to CD-2
- ESH&Q
- Risks and Mitigations
- Responses to CD-1 recommendations
- Breakout Session topics
- Summary

About Me:

- System Manager for SRF and Cryogenics (L2)
- Previously
  - Deputy Department Head of SRF Measurement and Research
  - Deputy CAM of LCLS-II Cryomodule at Fermilab
  - Cryomodule Group Leader at FRIB
  - SPX Cryomodule L4 CAM of APS Upgrade

121.02 SRFCRYO System Requirements

Charge #1

#	Scope	Threshold KPP	Objective KPP
1	SRF Linac Beam Energy	600 MeV	800 MeV
2	Linac Beam	Beam delivered to the Beamline Dump	5.4E12 particles per pulse (H-) at 20 Hz beam delivered to the Beamline Dump
3	Booster/Recycler/ Main Injector upgrades	Booster injection region, Recycler RF upgrades, and Main Injector RF upgrades, hardware installed and tested without beam in respective machines.	Linac beam injected and circulated in the Booster
4	Cryogenic Infrastructure	Cryogenic plant and associated distribution system are installed and capable to support cavities operation at 2 K	Cryogenic system installed and is capable to support Linac operation in CW mode

PIP-II Systems Function and Configuration Document:

SRF and CRYO System, ED0008595

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

Four prototype cryomodules were added to reduce project risk

CRYO

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

In-kind Contribution

Item	US DOE	In-kind	Note
HWR Cryomodule	ANL builds cryomodule, FNAL tests.		
SSR1 Cryomodules	FNAL builds all Cryomodules	Some prototype cavities, All production cavities, tuners and solenoids	
SSR2 Cryomodules	FNAL builds Prototype and Production CMs	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 and tests prototype cryomodule and transportation tests • FNAL builds one production cryomodule. • FNAL tests all production CMs	• 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		

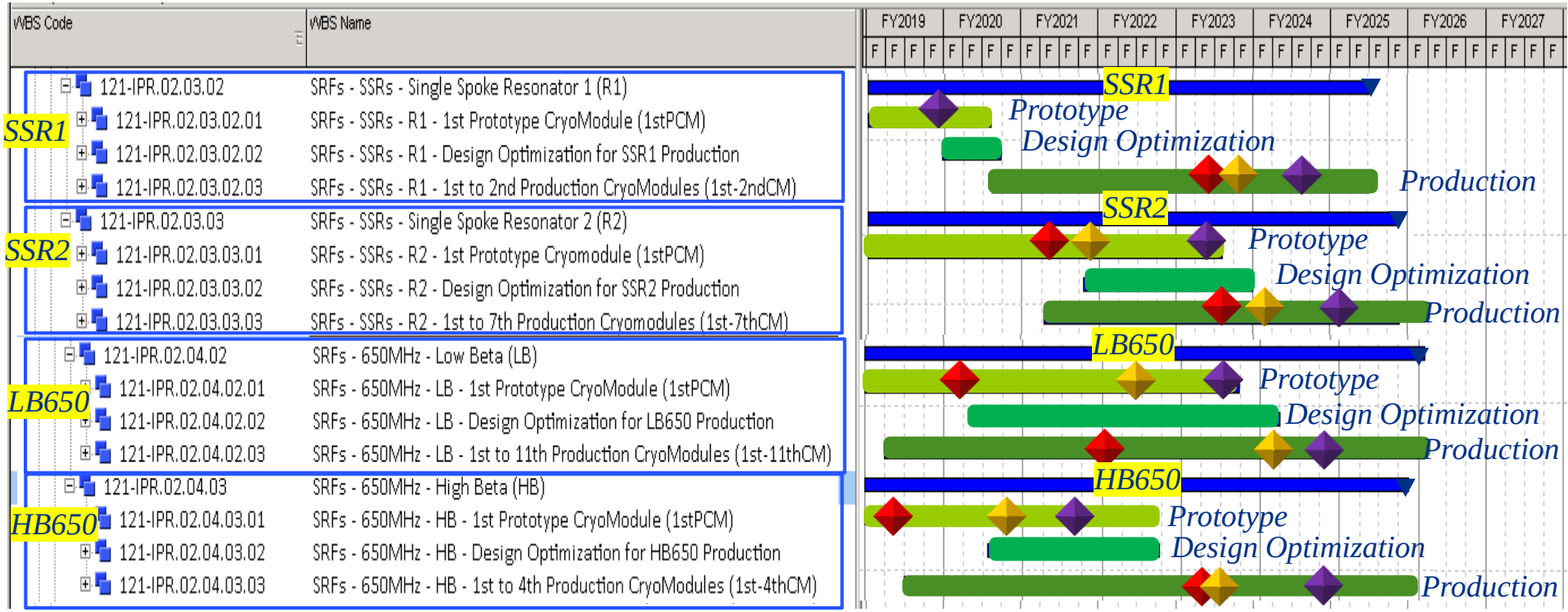
Cryomodule Repair after Delivery is Fermilab Responsibility

Cryomodule Schedule

Charge #5

27 November 2018 – Critical path on SSR2

Fiscal year



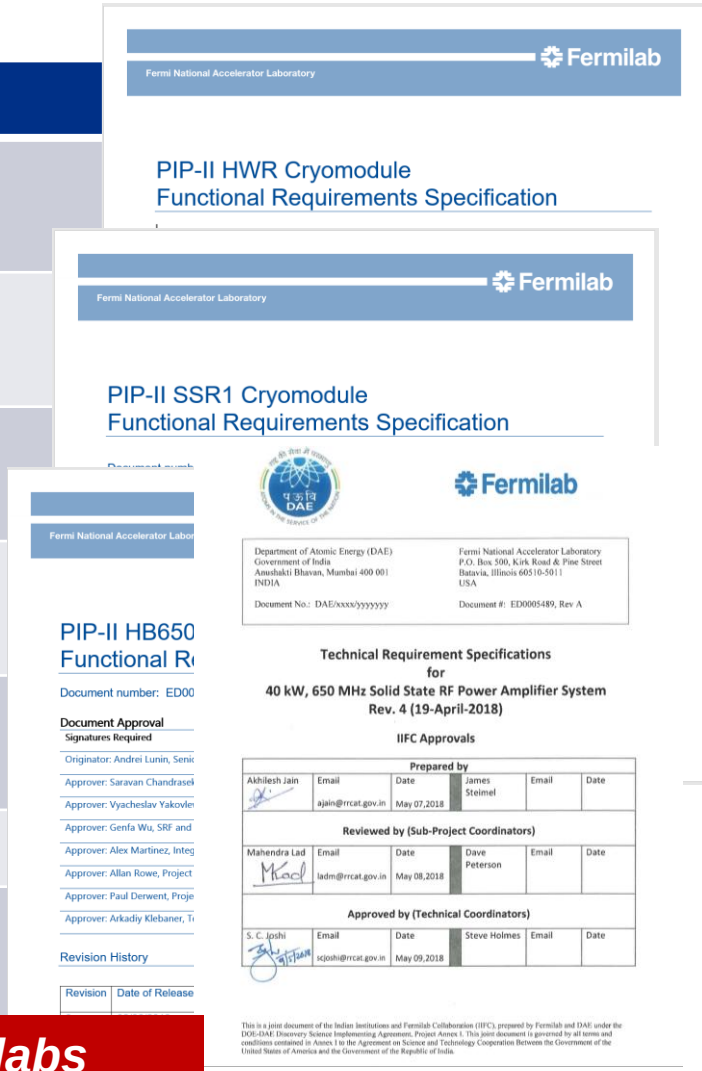
Legend

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

121.02 L3 Functional Requirement Specifications

Charge #1

WBS #	L3 System	TeamCenter ED#
121.02.02	Half Wave Resonator Cryomodule	ED0001313
121.02.03	Spoke Resonator One Cryomodule	ED0001316
121.02.03	Spoke Resonator Two Cryomodule	ED0001829
121.02.04	Low Beta 650 MHz Cryomodule	ED0001830
121.02.04	High Beta 650 MHz Cryomodule	ED0001322
121.02.05	Cryogenic Plant	ED0003531
121.02.06	Cryogenic Distribution	ED0008022



FRS are being reviewed by all partner labs

Interfaces

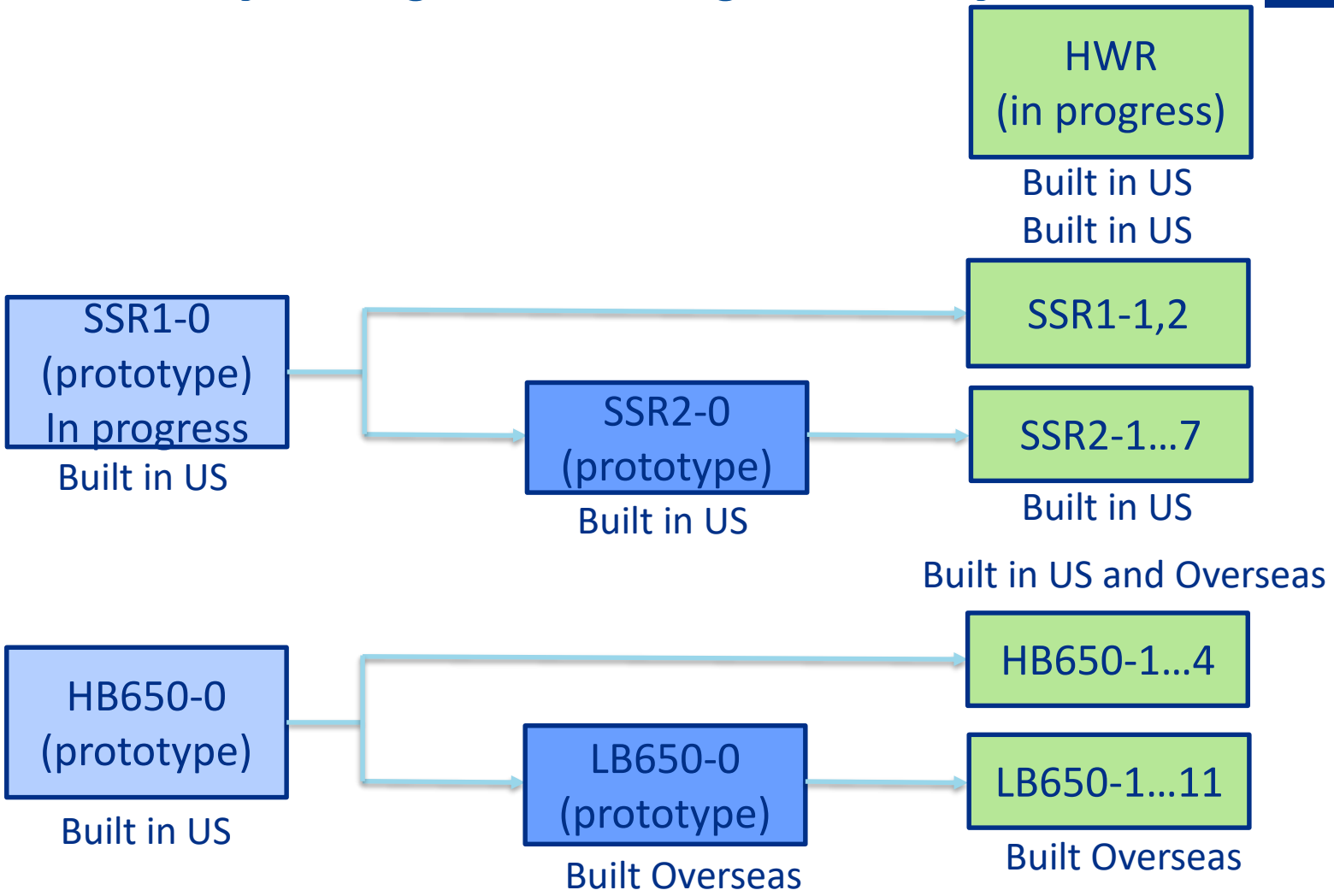
Charge #1

- Internal
  - Cryomodules and Cryogenic Distribution System
  - Cryomodules and Cryogenic Plant
  - Cryogenic Plant and Cryogenic Distribution System
- External
  - SRFCRYO and Accelerator
  - SRFCRYO and Linac Installation and Beam Commissioning
  - SRFCRYO and Conventional Facility
- Partner Labs
  - Governed by Project Planning Document
  - ICD are agreed by all partner labs

All Interface Documents are drafted and currently under review by all partner labs

Preliminary Design and Design Maturity

Charge #1



Prototyping before production to allow feedback to designs

Preliminary Design and Design Maturity

Charge #1

- HWR
  - Final design review completed.
  - Assembly preparation is in progress
- SSR1
  - String assembly and cold mass assembly final design review completed.
  - String assembly is in progress
- SSR2
  - Cavity Design is in progress. Jacketed cavity preliminary design review is schedule in March 2019, and final design review is scheduled in October 2019
  - FRS and ICD are being reviewed.
- LB650
  - Cavity Design and Prototype is in progress at partner labs.
  - FRS and ICD are being reviewed
- HB650
  - Jacketed cavity preliminary design is scheduled in the week of 11/26/2018
  - Horizontal test validation of critical components is scheduled in February 2019
  - Cryomodule conceptual 3D model is completed with preliminary transportation analysis
- Cryogenic Plant
  - Vendor Proposals were received, technical evaluation is complete and commercial evaluation is in progress. Signed contract is expected at the end of CY18. Integration Preliminary design scheduled for July 2019
- Cryogenic Distribution System
  - Preliminary Design is in progress

Expected 64% design maturity by June 2019

Design Review Plan – Past Reviews

Charge #2

Preliminary Design Review	SSR1 RF Coupler	20-Feb-12
Final Design Review	HWR Cavity	17-May-12
Preliminary Design Review	HWR Cryomodule	16-May-13
Final Design Review	HWR Cryomodule	15-Oct-13
Preliminary Design Review	SSR1 Integrated CM	03-Nov-15
Final Design Review	HB650 B.90 Bare Cavity	21-Dec-15
Preliminary Design Review	LB650 Bare Cavity	15-Jul-16
Preliminary Design Review	SSR1 Tuner	09-Sep-16
Final Design Review	SSR1 pCM Jacketed Cavity	28-Sep-16
Production Readiness Review	SSR1 Protoype Tuner	01-Nov-16
Preliminary Design Review	SSR1 Prototype CM String	02-Feb-17
Final Design Review	HB650 Prototyp RF Coupler	10-Feb-17
Final Design Review	Spoke Test Cryostat Upgrade	08-Mar-17
Preliminary Design Review	650 MHz Prototype Tuner	29-Jun-17
Preliminary Design Review	LB650 Jacketed Cavity	20-Jul-17
Status Review	SSR2 Prototype bare cavity	07-Nov-17
Final Design Review	SSR1 Prototype CM String	12-Jan-18
FDR/PRR	SSR1 Prototype CM Coldmass	11-Jul-18
Conceptual Design Review	HWR Transportation	14-Aug-18
Production Readiness Review	HWR Resources & Schedule	30-Aug-18

Extensive reviews were planned to ensure all critical components are successful

Design Review Plan – Outlook

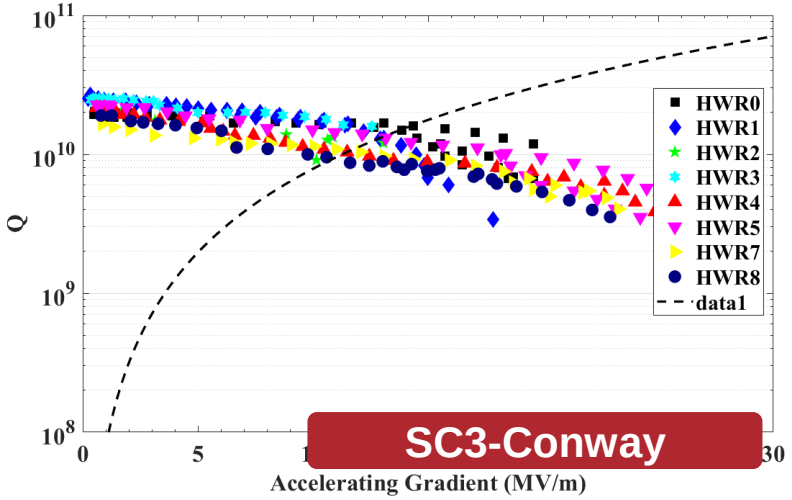
Charge #2

Preliminary Design Review	HB650 Jacketed Cavity B.90	30-Nov-18
Preliminary Design Review	HB650 Tuner	15-Dec-18
Preliminary Design Review	LB650 Jacketed Cavity (FNAL, INFN, DAE)	02-Jan-19
Preliminary Design Review	CDS	22-Jan-19
Preliminary Design Review	SSR2 Jacketed Cavity (FNAL and Intl Partners)	15-Mar-19
Preliminary Design Review	SSR1 Transportation Tooling	27-Mar-19
Preliminary Design Review	HB650 String Assembly	01-Apr-19
Preliminary Design Review	HB650 Cold Mass Assembly	01-Apr-19
Preliminary Design Review	HB650 Cryomodule Integration	01-Apr-19

Progress to date – HWR Status

Charge #1, 2

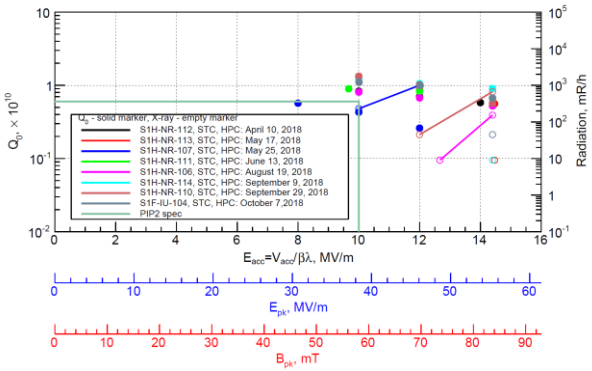
- All major components design validated, procured, received and accepted.
  - Cavity, Tuner, Coupler, Solenoid, cold mass support and Vacuum vessel.
- Mockup Assembly and Cool down completed.
- Cavity/coupler integrated acceptance tests are in progress.
  - All 8 cavity/coupler assembly were qualified in horizontal tests.
- Transportation Design is in progress
- String assembly, cold mass assembly and cryomodule assembly will start in December 2018
- Cryomodule completion in April 2019.

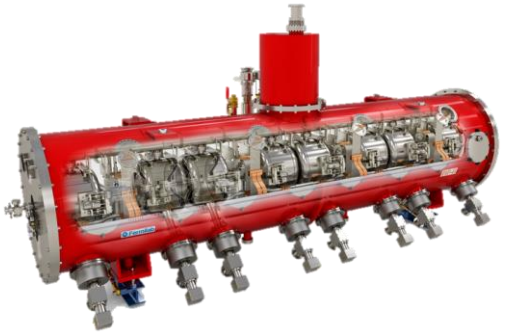


Progress to date – SSR1 Status

Charge #1, 2

- Major components design validated, procured, received and accepted.
  - Cavity, Tuner, Coupler, Solenoid and Vacuum vessel.
- Cavity/coupler integrated acceptance tests are in progress.
  - All 8+1 cavity/coupler/tuner assemblies were qualified in horizontal integrated tests. One is contributed by IIFC, India
- Mock-up assembly completed.
- Final Design Review and Production Readiness Review are scheduled.
- String assembly started.
- Cryomodule assembly completes in May 2019.



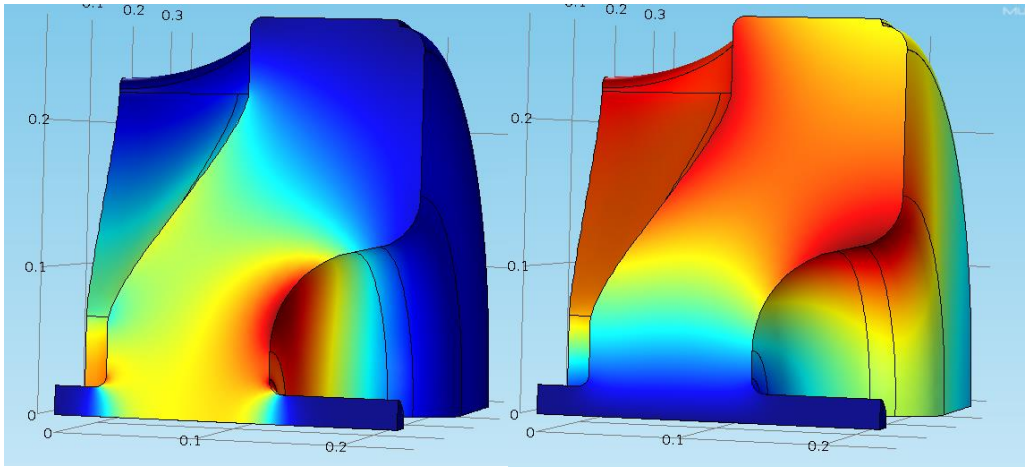


SC3-Passarelli

SSR2 Overview

Charge #1, 2

- RF design completed
- Cavity mechanical design is in progress
- SSR1 Coupler power capability demonstrated at >20 kW.

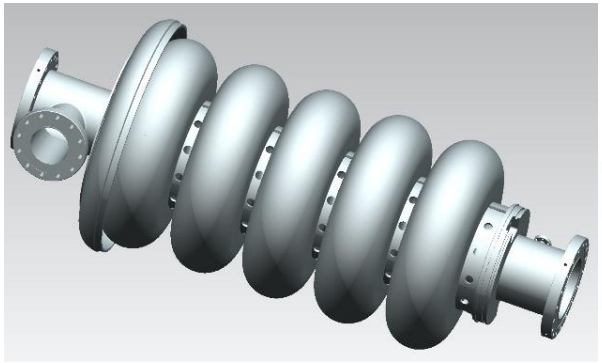


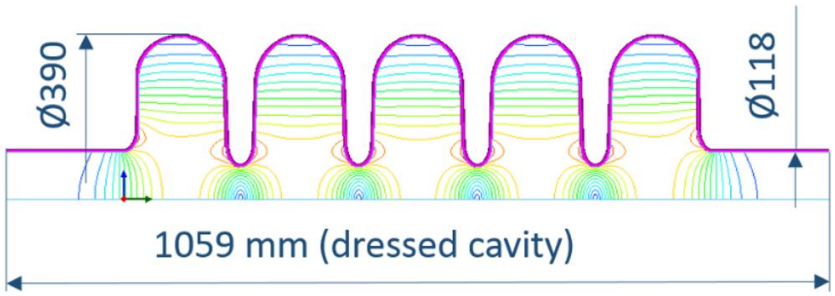
SC3-Passarelli

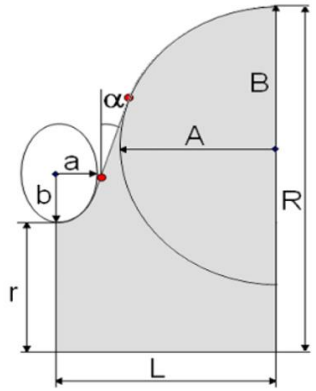
LB650 Overview

Charge #1, 2

- Cavity RF Design Completed.
- Prototype Bare Cavities are Being Procured.
  - Two prototype bare cavities are to be delivered in July 2019
- Dressed Cavity Mechanical Design is in Progress.
  - IIFC optimized the mechanical design for CW operation

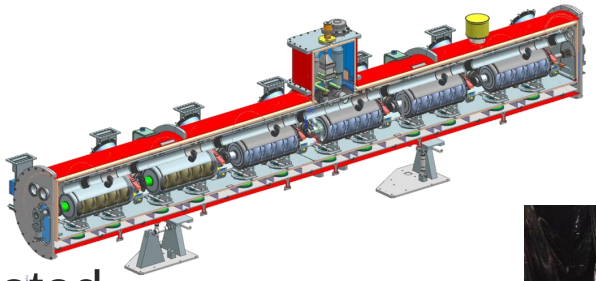






SC3-Chandrasekaran

HB650 Overview



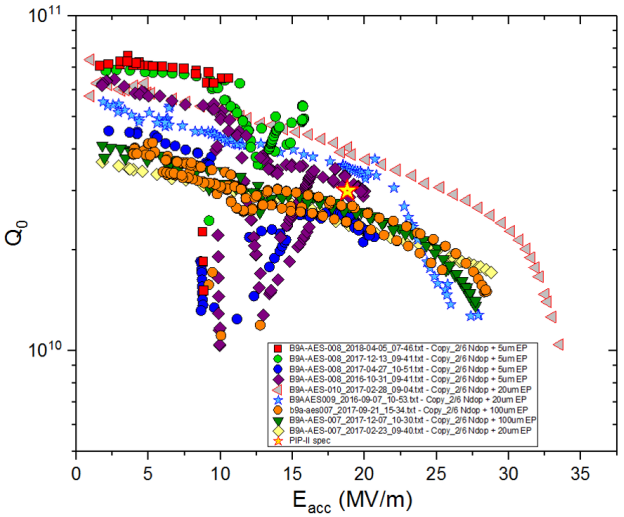
Charge #1, 2

- Cavity RF design completed.
- Cavity mechanical design completed.
- Cavity high Q R&D is in progress.
- Jacketed cavity design validation is in progress.
- Coupler design validation is in progress.
- Conceptual transportation analysis completed
- A preliminary design choice was made to adopt strong back design.
- Cryomodule design is in progress.

First HB650 cavity is to be dressed.

New coupler design passed particle free test

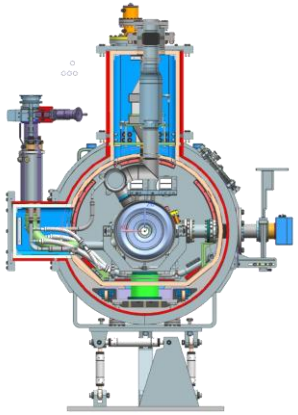
First HB650 tuner meets spec

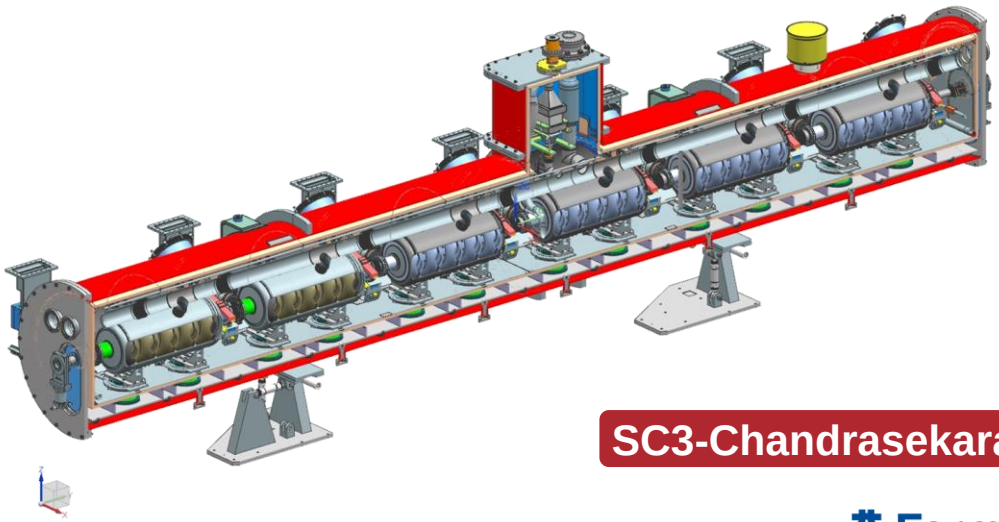


SC3-Chandrasekaran

HB650 Cryomodule Design Features

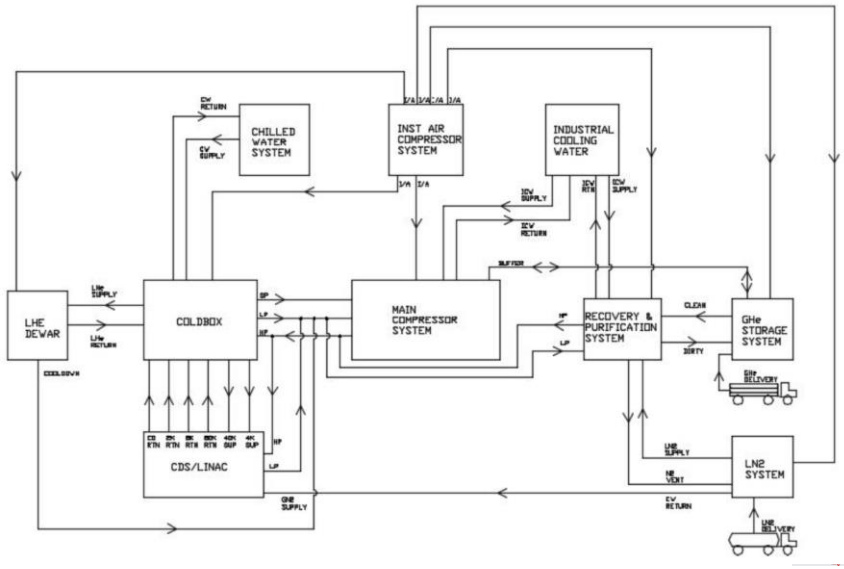
- Support High Q
  - Cryogenic Supports Fast Cool Down
  - Cryomodule Thermal Design to Minimize Thermoelectric Current
  - Magnetic Shield to Minimize Ambient Earth Magnetic Field
  - Better Instrumentation for High Q operation
- Designed to be compatible for transportation

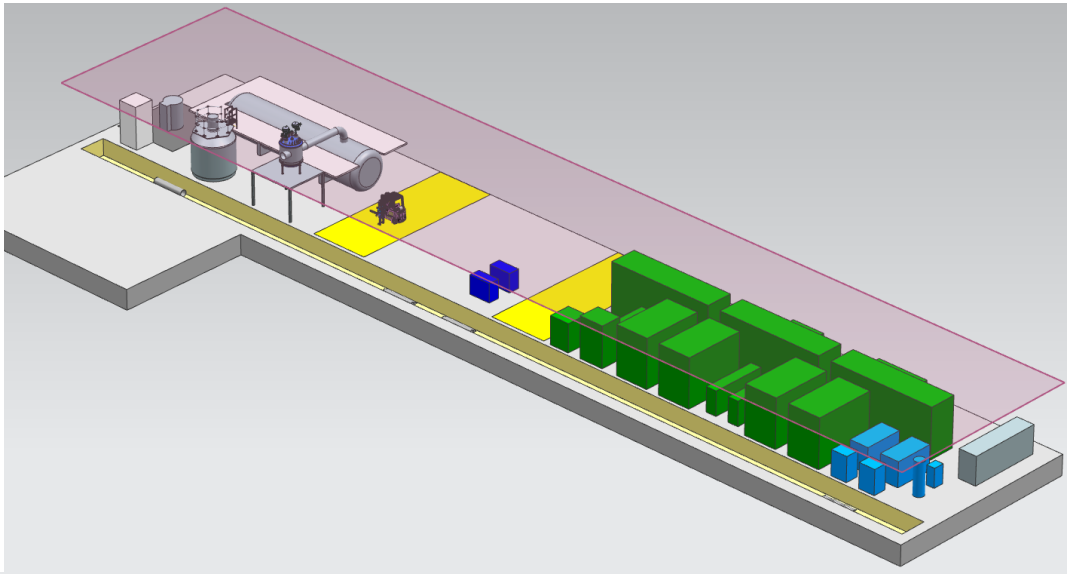




SC3-Chandrasekaran

Progress to Date – Cryogenic Plant





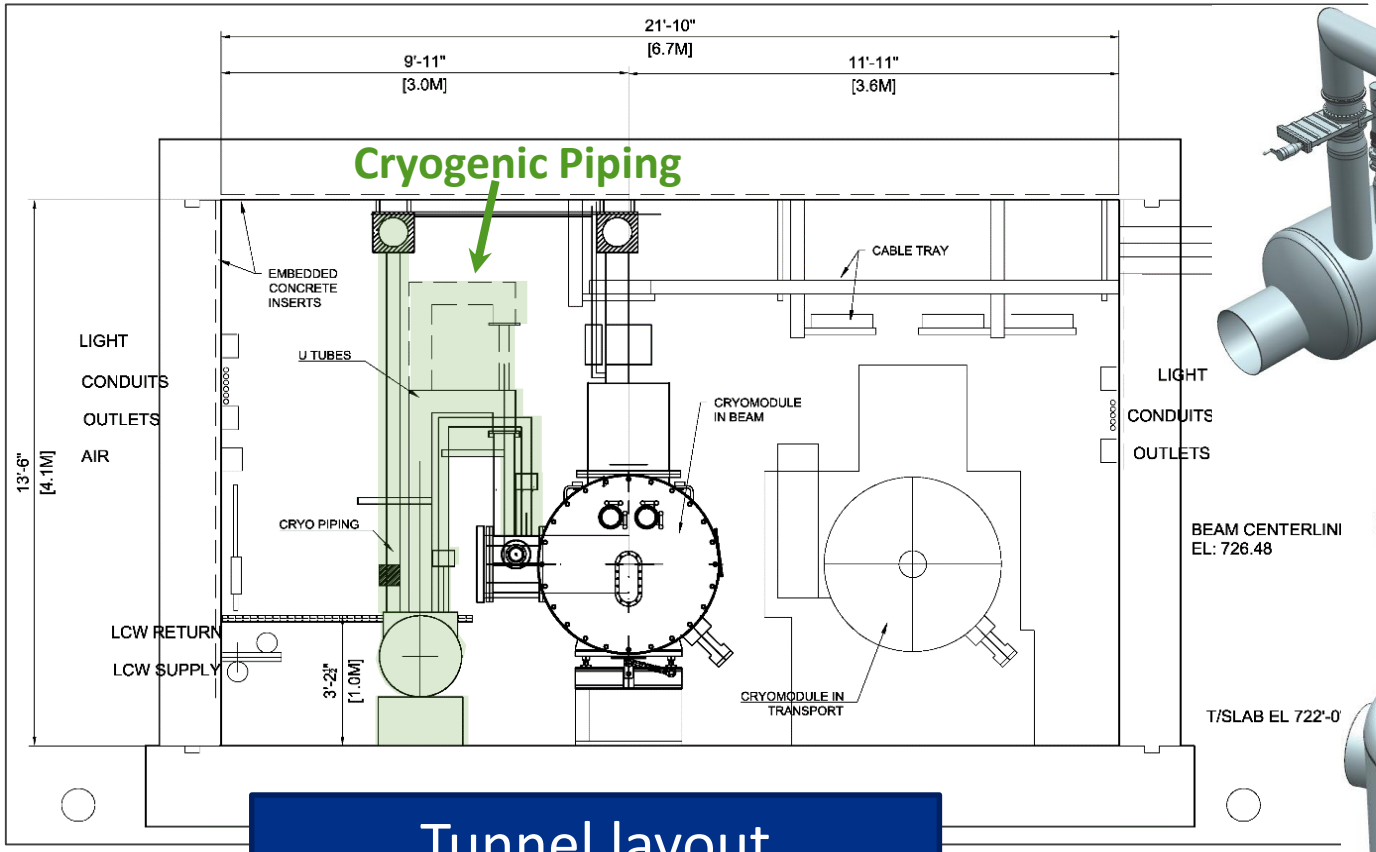
Cryoplant Requirements:

	Heat Load	Mass Flow Supply	Mass Flow Return	Supply Pressure	Return Pressure	Supply Temp	Return Temp
	W	g/s	g/s	bara	bara	K	K
2K	2163*	138	110	2.2 < P < 4	≤ 0.027	4.5	4.0
4.5K	1492		28		P - 0.03	4.5	≤ 9K
HTTS	8353	40	40	3 < P < 18	P - 0.28	35-40	≤ 80

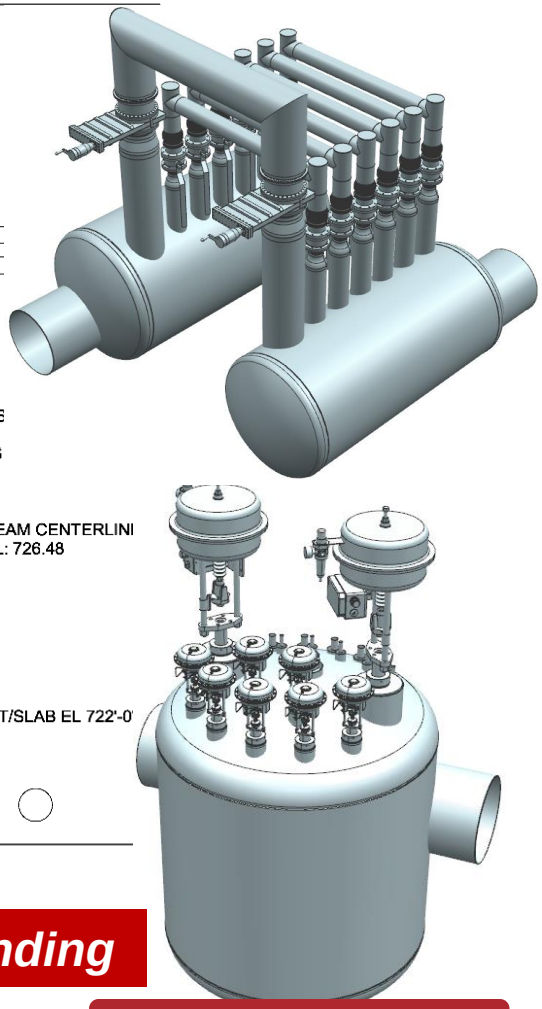
Cryoplant bids received and evaluation is in progress

SC3/4-Hansen

Progress to Date – Cryogenic Distribution System



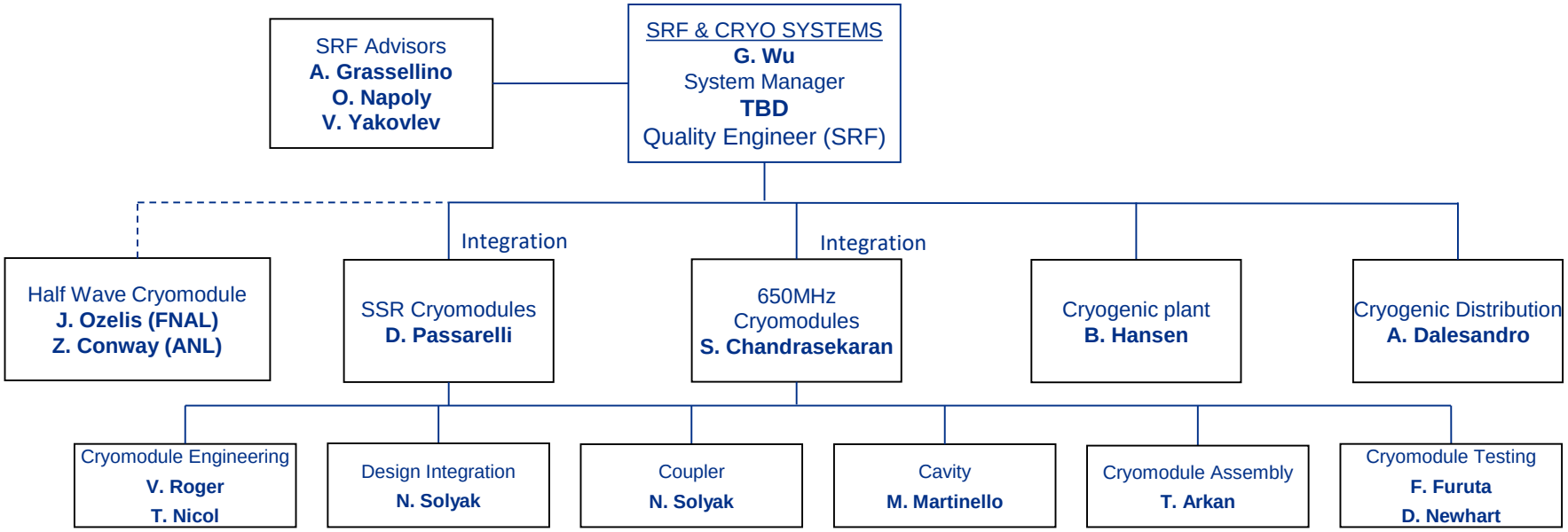
Tunnel layout



SC3-Dalesandro

CDS 40% design complete, cold box design choice pending

Organization Chart



Next Steps toward CD-2/3a

Charge #5

- Complete HWR Cryomodule Assembly in April 2019
- Complete SSR1 Prototype Cryomodule Assembly in May 2019
- Complete SSR2 Jacketed Cavity Preliminary Design Review in March 2019
- Complete HB650 (β=0.90) Horizontal Cavity Test in May 2019
- Complete LB650 Jacketed Cavity Preliminary Design Review in April 2019
- Award Cryoplant Contract in December 2018 and progress towards preliminary design review of building integration in July 2019
- Complete Preliminary Design Review for Cryogenic distribution system in January 2019

ESH

Charge #6

- Fermilab
  - Design follows Fermilab Engineering Manual
  - Cavity processing follows FESHM for chemical hygiene practice
  - Cavity and cryomodule testing follows FESHM for ODH guidelines and radiation safety
  - Pressure Safety:
    - Cavities follow Fermilab FESHM Pressure Safety
    - HWR and SSR Cryomodules follow ASME pressure safety guidelines
    - 650 Cryomodules follows PED (Europe) standard.
- Partner Labs
  - Indian partner labs follow ASME standard
  - European partner labs follow PED standard

PED are equivaled to ASME

SC5/6/7-Anderson

Quality Management

Charge #6

- Quality Planning at Fermilab
  - Critical Quality Elements
  - QC Plans
    - Travelers
    - Incoming Inspections
    - Acceptance Testing
    - Training
    - Work Controls
    - Procurement Quality / Supplier Quality
    - Issues Management (Corrective Action/Preventive Actions)
  - Traceability of quality control to requirements
  - Lessons Learned (in process)

Plenary-Adetunji

Quality Management

Charge #6

- QA Expectations for Partners and Vendors
  - Critical Quality Elements
    - Acceptance Criteria for all parts
    - Acceptance Test Plans
  - Partner Quality Assurance Plans or Vendor QA Plans
    - QC Plans
    - Manufacturing Inspection/Test Plans
    - Hold points / witness points
    - Verification of requirements
    - Issues Management (CA/PA)
  - Routine site visits
  - Imbedded work force in some partner labs

Partner Lab's QA plan Approved by Both Partners and Fermilab

Plenary-Adetunji

WBS 121.02 Risk Management

Charge #2,7

SRF and Cryogenics Risks

- High Risks: **7**
- Medium Risks: **15**
- Low Risks: **5**

High Risks

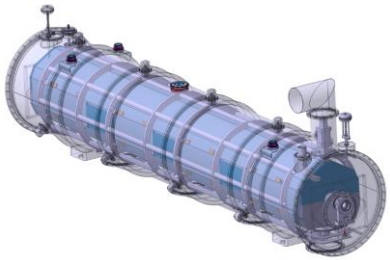
RI-ID	Title
RT-121-02-001	650 Cryomodule is damaged during transportation
RT-121-02-003	Underestimated resources for design optimization of SSR1 CM (1)
RT-121-02-003-B	Underestimated resources for design optimization of HB650 CM (1)
RT-121-02-003-C	Underestimated resources for design optimization of 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

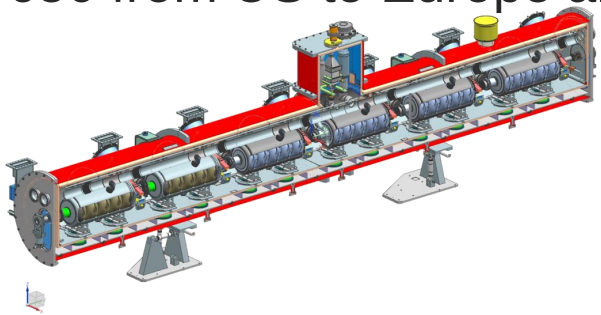
Most high risks will be retired by CD-3 except -001, -006

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

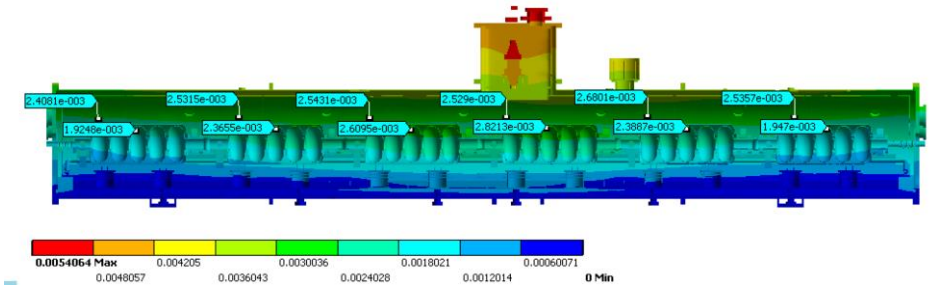




Bottom Support (strong back)
FRIB, PIP-II

Transportation Risk of 650 MHz Cryomodule

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



Response to Recommendations – Summary

Charge # 8

ID	Risk Description	Status
98027	Define operational gradient margin and cryomodule maintenance strategy to meet the performance specification of 90% reliability with only 8 weeks of maintenance per year by CD-2.	In Progress. Expected to complete before CD2
98029	Convene an external review to address expediting the SSR2 prototype and advancing an LB650 prototyping effort by CD-2.	Addressed
98530	Use first prototypes to study long-distance transport of accelerator modules	Addressed
98536	Validate 'particle-free' assembly for 650-MHz couplers	Addressed

Response to Recommendations (1)

Charge # 8

PIP-II CD1 Review Recommendation No.13

Status: Open

Planned Date Closed: 01/31/2019

System	SRF and CRYO
Owner	G. Wu
Recommendation	Define operational gradient margin and cryomodule maintenance strategy to meet the performance specification of 90% reliability with only 8 weeks of maintenance per year by CD-2.
Project Response	• Operational gradient margin will be established in TRS documents of all the cryomodules. TRS documents are being drafted • Cryomodule maintenance strategy is being drafted.

Response to Recommendations (2)

Charge # 8

PIP-II CD1 Review Recommendation No.15

Status: Open

Planned Date Closed: 04/08/2019

System	SRF and CRYO
Owner	G. Wu
Recommendation	Convene an external review to address expediting the SSR2 prototype and advancing an LB650 prototyping effort by CD-2.
Project Response	SSR2 and LB650 have been advanced in current scope. No external review is needed. Overall schedule will meet CD4 milestone with prototyping effort completed in 2022 (SSR2) and 2023 (LB650)

Response to Recommendations (3)

Charge # 8

PIP-II P2MAC Review Recommendation No.R2

Status: Open

Planned Date Closed: 06/01/2022

System	SRF and CRYO
Owner	G. Wu
Recommendation	Use first prototypes to study long-distance transport of accelerator modules
Project Response	HB650 prototype cryomodule transportation studies are in current scope in 2021. LB650 Prototype cryomodule shipping test is in 2024

Response to Recommendations (4)

Charge # 8

PIP-II P2MAC Review Recommendation No.R8

Status: Open

Planned Date Closed: 12/31/2018

System	SRF and CRYO
Owner	G. Wu
Recommendation	Validate 'particle-free' assembly for 650-MHz couplers
Project Response	• Coupler assembly of copper shield design has been validated in clean room. • Coupler assembly of copper plating design is in progress.

Breakout Sessions

- SC3 Breakout Session
  - G. Wu: SRF and Cryogenics Overview
  - Z. Conway: HWR Cryomodule Overview
  - D. Passarelli: SSR Cryomodule Overview
  - S. Chandrasekaran: 650 MHz Cryomodule Overview
  - A. Dalesandro: Cryogenic Distribution System
- SC3/5 Joint Breakout Session
  - B. Hansen: CryoPlant Requirements and Design

Summary

- System Functions and Configuration is drafted
- FRS and ICD are drafted and currently being reviewed
- HWR and SSR1 prototype cryomodule assembly are in progress
- HB650, LB650 and SSR2 designs are in progress
- Cryoplant contract award soon
- Cryoplant building and Cryogenic distribution designs are in progress
- ESH and QA plans are developed
- In-kind contribution, sufficient prototyping to retire risks
- SRF and Cryogenic technical team is motivated, experienced and ready to deliver

We are on track for CD-2/3a and look forward to your feedback

END

Thank you for your attention