PRODUCTION STATUS OF SUPERCONDUCTING CRYOMODULES FOR THE FACILITY FOR RARE ISOTOPE BEAMS (FRIB) PROJECT

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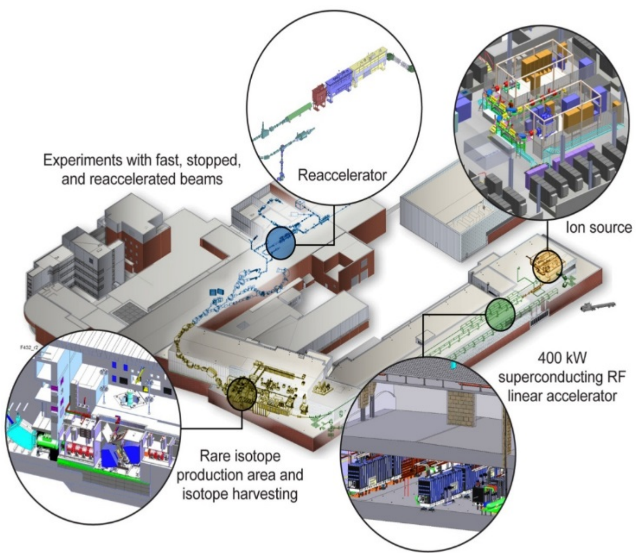
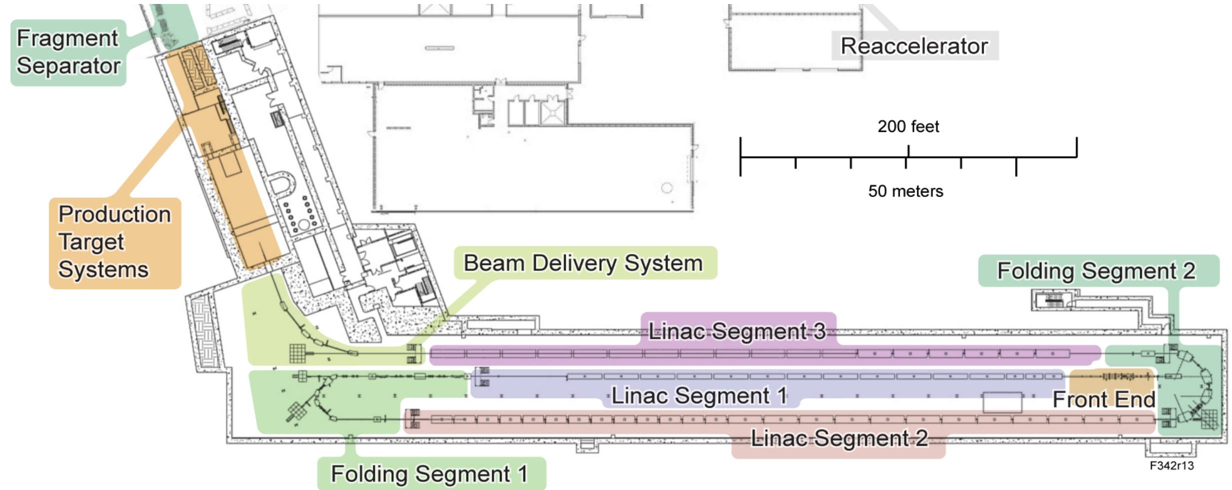
U.S. DEPARTMENT OF ENERGY | Office of Science

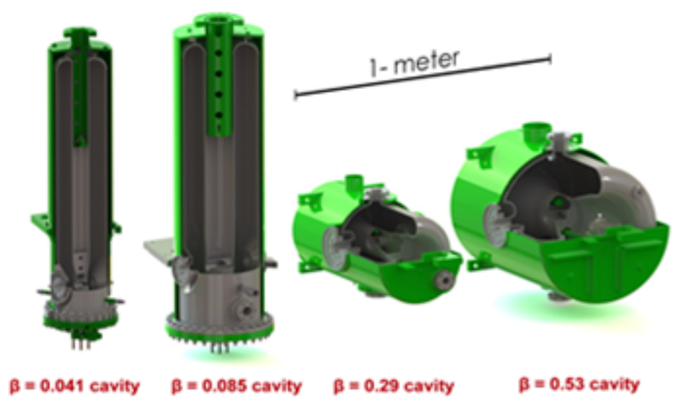
Outline

- FRIB cryomodule assembly scope
- FRIB cryomodule designs
- FRIB cryomodule assembly floor, workflow, and control
- FRIB cryomodule production status
- Lessons learned
- Resource balancing and optimization
- Summary

FRIB Cryomodule Scope



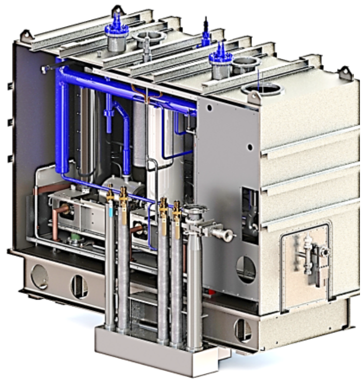




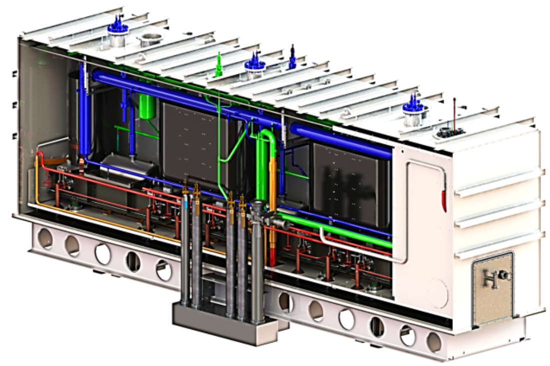
Quarter Wave Cryomodule				
		Number of Cryomodules	*Number of Cavities*	*Number of Solenoids*
β = 0.041	*Accelerating Cryomodules:*	*3 + 1 spare*	*12 + 4 spare*	*6 + 2 spare*
β = 0.085	*Accelerating Cryomodules:*	*11 + 1 spare*	*88 + 8 spare*	*33 + 3 spare*
	Matching Cryomodules:	*1 + 1 spare*	*4 + 4 spare*	-
Half Wave Cryomodule				
β = 0.29	*Accelerating Cryomodules:*	*12*	*72*	*12*
β = 0.53	*Accelerating Cryomodules:*	*18*	*144*	*18*
	Matching Cryomodules:	*1*	*4*	-
TOTAL		*46 + 3 spare*	*324 + 16 spare*	*69 + 5 spare*

FRIB Cryomodule Designs

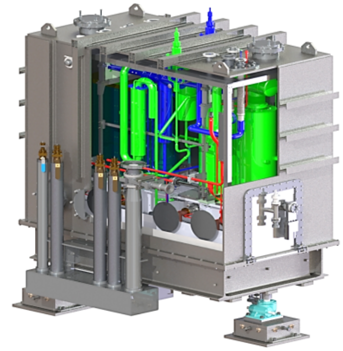
- All six modules using the same bottom-up design approach
- All cryomodules share large portion of common components to simplify design and facilitate fabrication.
- Collaborate with JLAB on cryomodule design (β=0.041 and β=0.29)
- Collaborate with ANL on coupler and tuner design



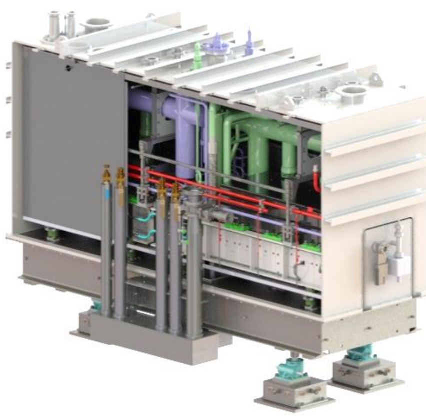
β=0.041



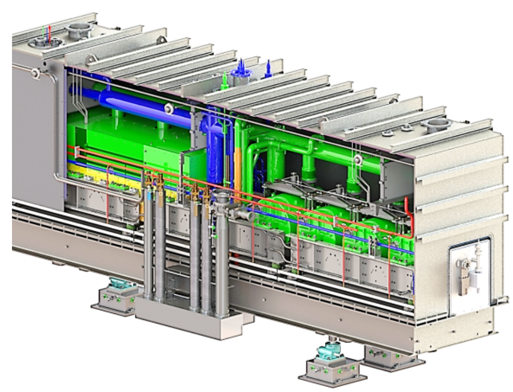
β=0.085



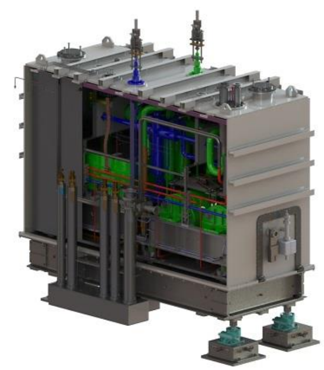
β=0.085 Matching



β=0.29



β=0.53



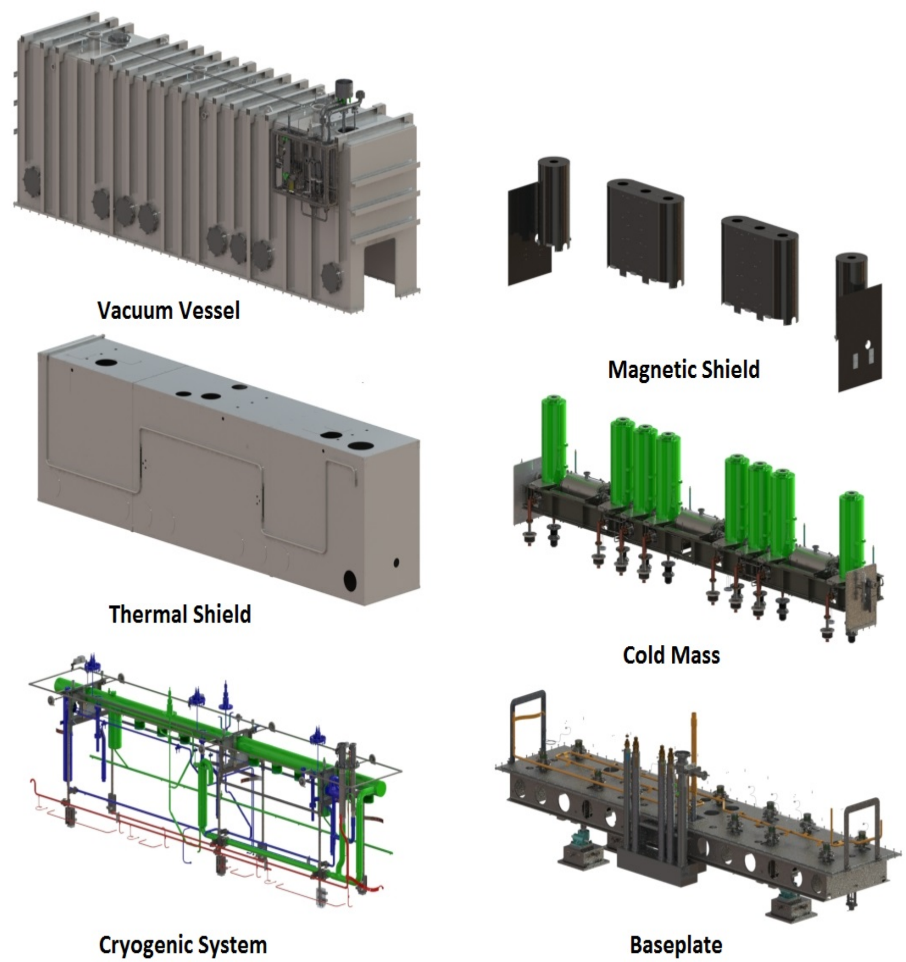
β=0.53 Matching

Jefferson Lab

Argonne NATIONAL LABORATORY

Bottom-up Cryomodules Design Approach

- Resonators (at 2 K) and magnets (at 4.5 K) both supported from the bottom to facilitate alignment
- Cryogenic system is decoupled from coldmass string to isolate vibration to minimize the microphonic excitation
- Optimized and integrated with cryo-distribution
  - Bayonet interface to allows for warm-up and servicing of individual cryomodules
  - 2K-4K heat exchanger inside module to maximize 2K efficiency
- Single layer “local” magnetic shield to be cost effective and less sensitive to magnet operation
- Use common cryomodule designs principles for all six cryomodule types
  - Support rails, cryogenic circuit, thermal shield, vacuum vessel



β = 0.53 Cryomodule Assembly Sequence

C1

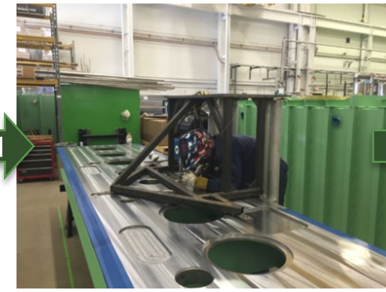
Completed cold mass assembly in clean room

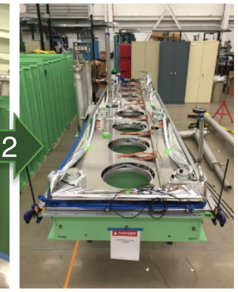
C2

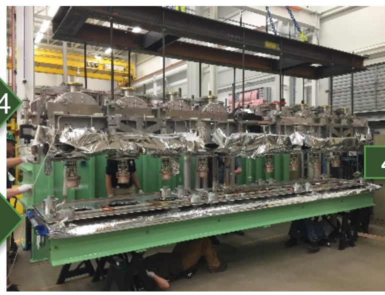
Cold mass assembly transport to cryomodule assembly area

C3

Cold mass ready for baseplate

1

Start baseplate assembly

2

Baseplate ready for cold mass

C4
3

Cold mass on baseplate

4

Completed cryogenic circuit

5

Thermal shield installation

6

Vessel cover installation

7

Tuner valve manifold installation

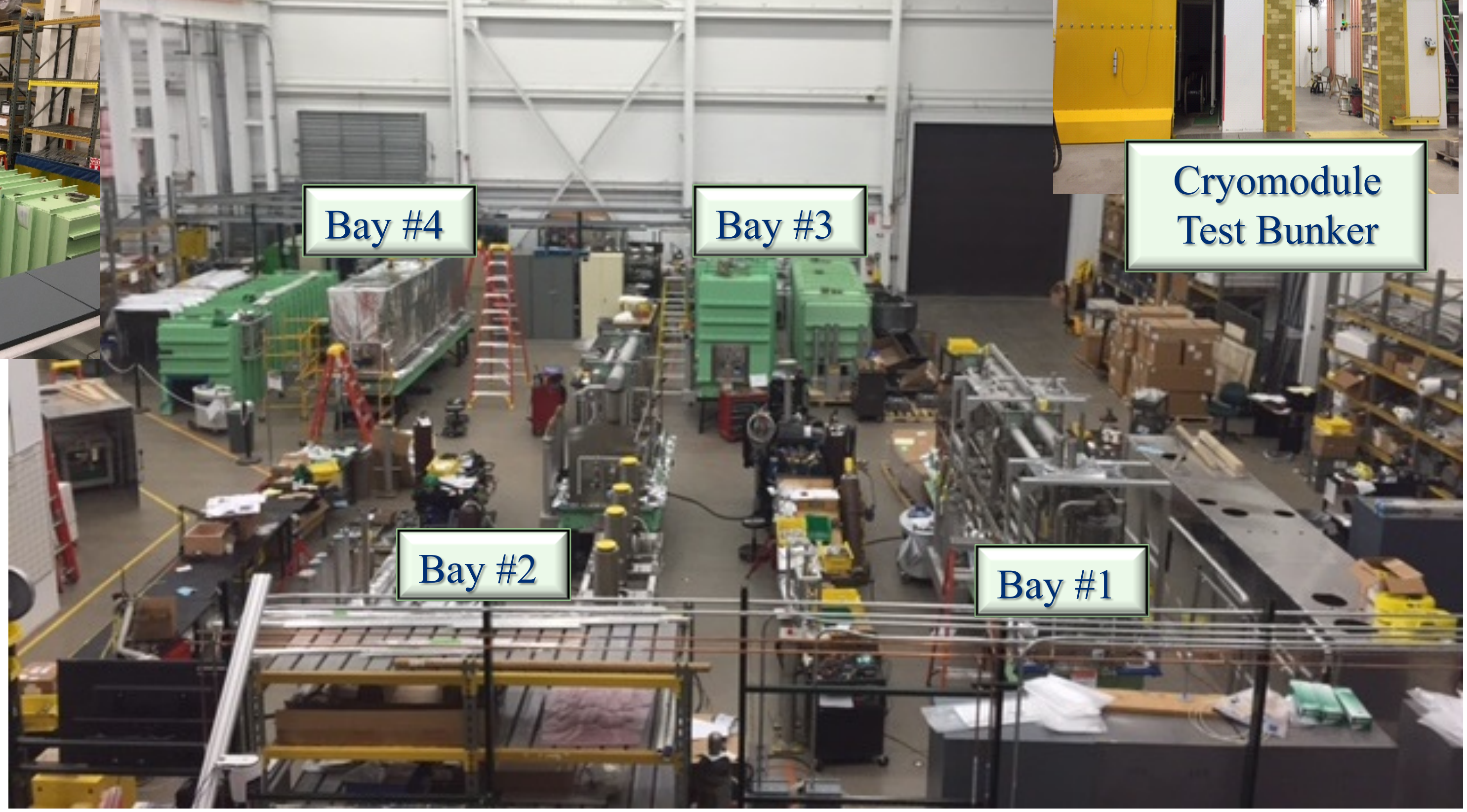
8


Transport to SRF High Bay

9

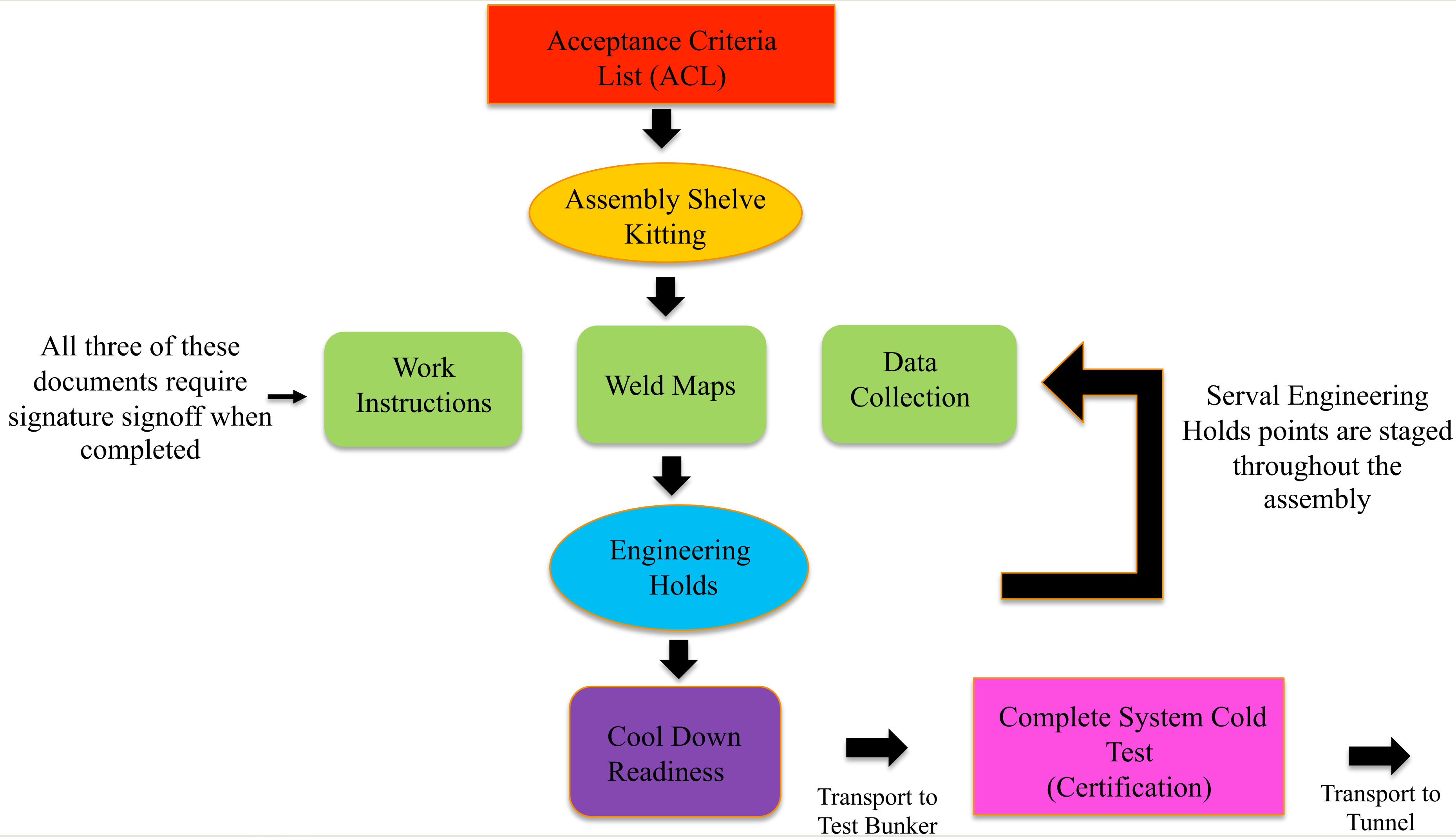
Transport into test bunker

Cryomodule Assembly

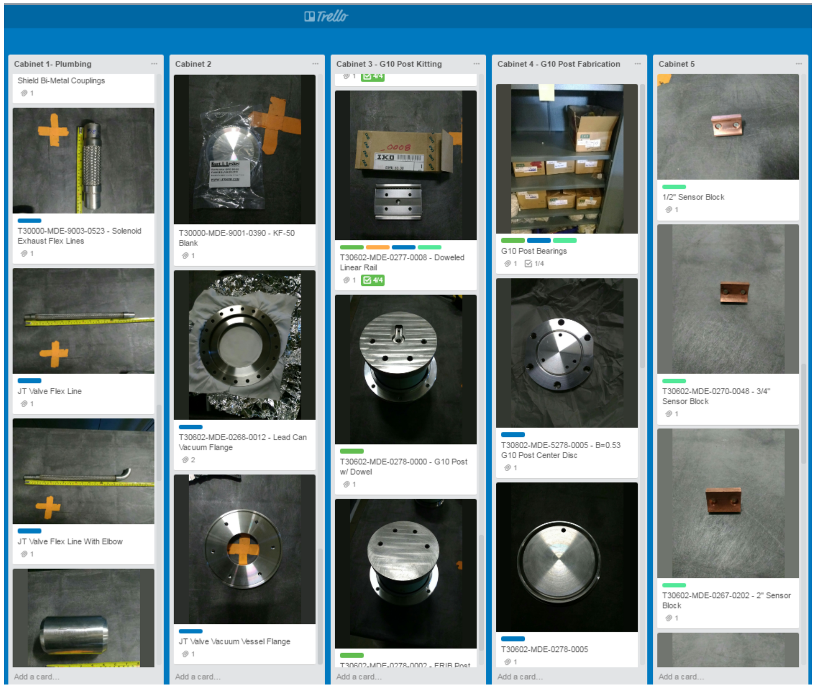


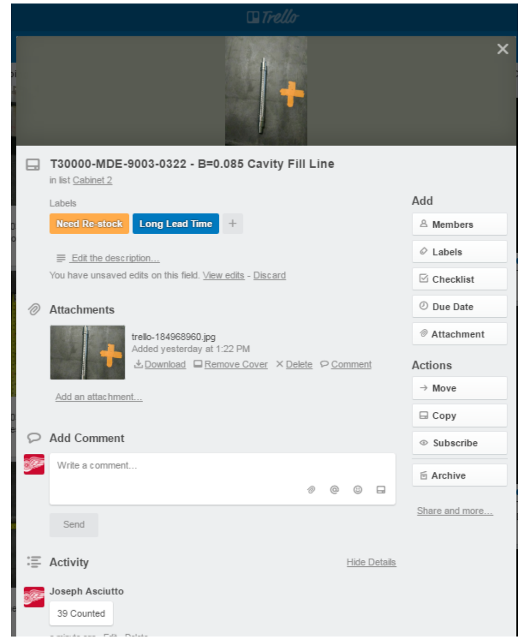
- Five assembly bays ongoing in parallel
- Two commissioned cryomodule test bunkers
- Additional assembly space for subcomponents (solenoid leads, o-rings, G-10 posts)
- 2 overhead cranes
- 2 loading bays for transport of coldmass in and completed cryomodule out

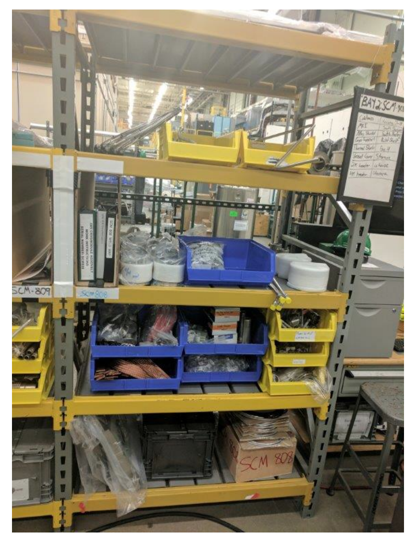
Cryomodule Assembly Workflow



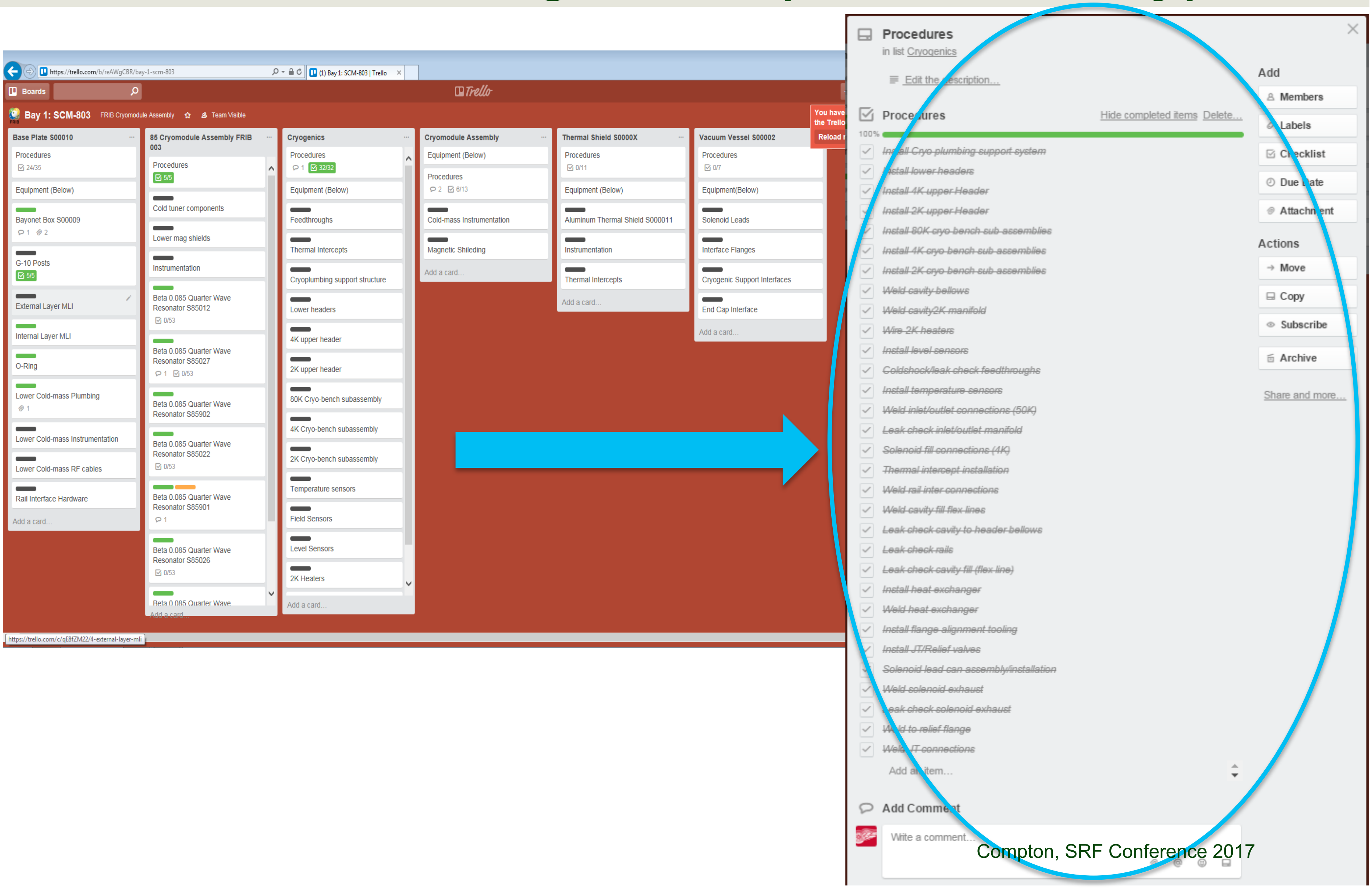
Inventory and Assembly Status Tracked using Trello (electronically)







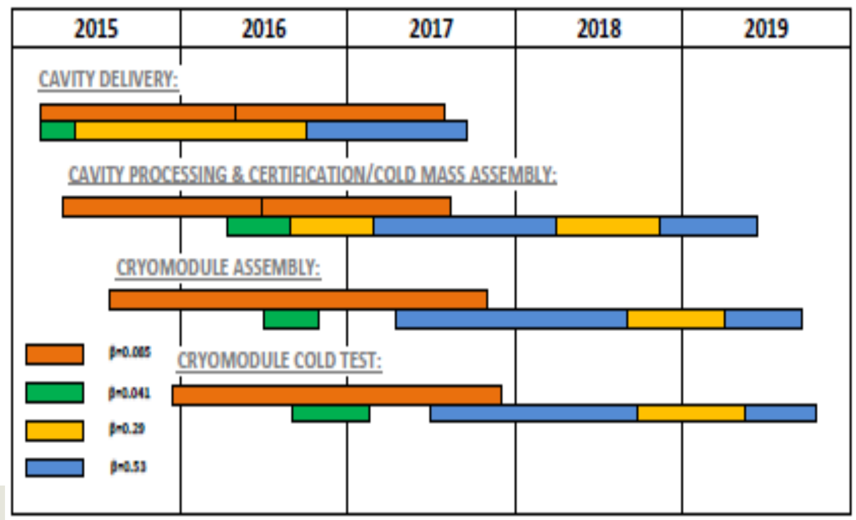
Assembly Status and Task Completion Tracked using Trello (electronically)



Cryomodule Production Status

- 0.041 – 3/3 cryomodules built and certified, 3 in tunnel (Spare also complete)
- 0.085 – 6/11 cryomodules built, 4 certified, 4 in tunnel
  - Four cryomodules in progress (Bays 1, 2, 3, 4)
- 0.085M – 1/1 cryomodules built, certified, and in tunnel
- 0.29 – 1/12 built
  - First cryomodule completed, undergoing system test
  - Second cryomodule in progress
- 0.53 – 1/18 cryomodules built, 1 certified, 1 in tunnel
  - Second cryomodule in progress (Bay 5)
- 0.53M – 0/1 cryomodules built

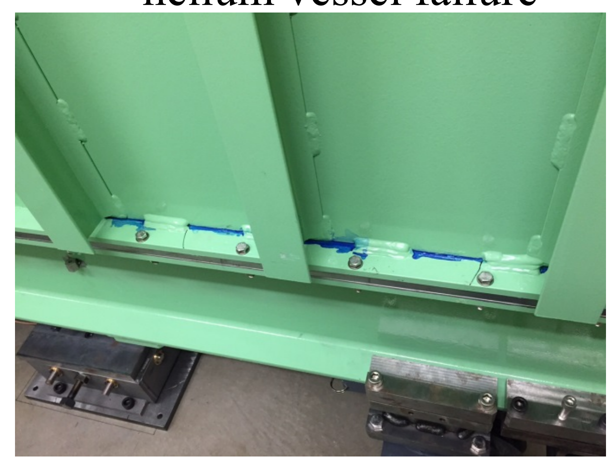
12 of 46 Cryomodules built



Refine and Expand QA program as Production increases

- Vacuum leaks in cavity helium vessel bi-metal transitions:
  - Tracking serial # of bi-metal back to vendor, reevaluate cutting maps
  - Mitigation: additional leak check step added
    - » After cold shock at vendor
    - » After VTA(cold) testing at FRIB
- β = 0.53 cryomodule vacuum vessel: found leak at final assembly step
  - Leak check performed at vendor
  - Leak check of large vessel is a technical challenge
  - Mitigation: educate vendor and send FRIB technical representative
- Instrumentation wiring broken after cool down
  - Instrumentation checked several times (warm) during assembly
  - Mitigation: Add cold shock step for soldered joints

β=0.041 cavity bimetal on helium vessel failure



β=0.53 cryomodule vacuum vessel welding defect

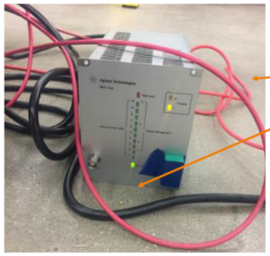
Issues: Design Changes, Fabrication Changes, Human Error

- SC solenoid impregnation changed from Stycast 2850 to paraffin at preproduction stage
  - Overlooked impact on in-house processing: temperature during ultrasonic cleaning
  - Mitigation: changed ultrasound temperature setting; include stakeholders on ECO forms to communicate changes
- Rough handling at storage
  - Sealing surface of vacuum vessel damaged at storage facility after ACL. Storage facility staff transported the vessel improperly with folk lift.
  - Mitigation: FRIB Receiving Department developed documents to communicate special requirements for equipment handling, provide additional protection to critical areas
- Human error
  - Damage to cold cathode vacuum gauge controller during welding
  - Damage to instrumentation wire due to welding
  - Potential damage to leak checks due to pumping Argonne gas from welding/purging
  - Mitigations: enhance training; educate on-floor workers on cryomodule basics; improve design to reduce risk of human error

Assembly Floor Training

- A series of training sessions were given to all members of the cryomodule assembly team to provide better knowledge of what they are building
- Explain the basis of the design elements
  - Importance of magnetic hygiene
  - Thermal isolation
  - Importance of cleanliness
  - Beam line vacuum
- Allow assembly team to execute work instructions with a better understanding of the basis for the instructions
- Allow assembly team to be better-equipped to troubleshoot assembly issues

Keep Check on Beam Line Vacuum At All Times



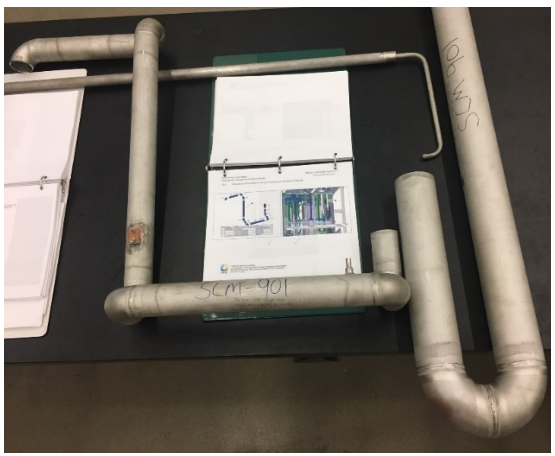
- The beamline space should always be at UHV
- Ion pump controller
- One green light = good vacuum
- More that one light inform line manager
- Always keep plugged into the UPS
- Check and record beam line vacuum each day
- DO NOT OPEN BEAMLINE VACUUM
- DO NOT VENT BEAMLINE VACUUM

Training Outline

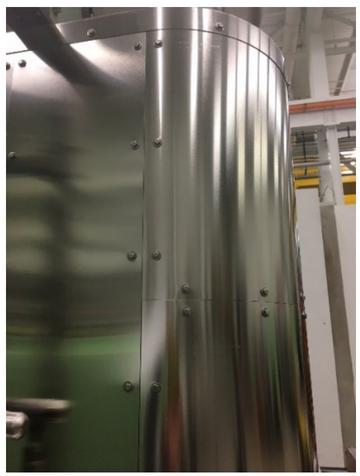
- 01 Introduction - Cryomodules
- 02 General work flow and hazards on cryomodule assembly floor
- 03 How to handle cleanroom assembly
- 04 How to handle vacuum and leak check
- 05 How to handle cryogen during work
- 06 How to handle welding
- 07 How to handle instrumentation
- 08 How to handle magnetic shielding material and demag requirements on sub components
- 09 Cryogenic piping
- 10 Cryomodule testing

Lessons Learned – ease assembly/reduce risk

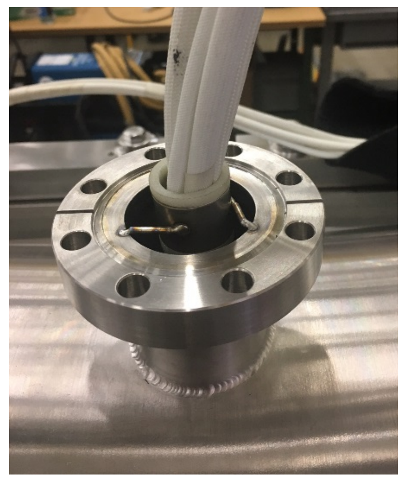
- Simplify piping – more subassemblies, less in-the-field welds, use of flexlines
- Magnetic shields – commercial sheet sizes, pem nut construction, mostly bench assembled
- Solenoid lead protection – wiring centering harness
- Penetration covers – protective covers for vacuum vessel and thermal shield penetrations during assembly



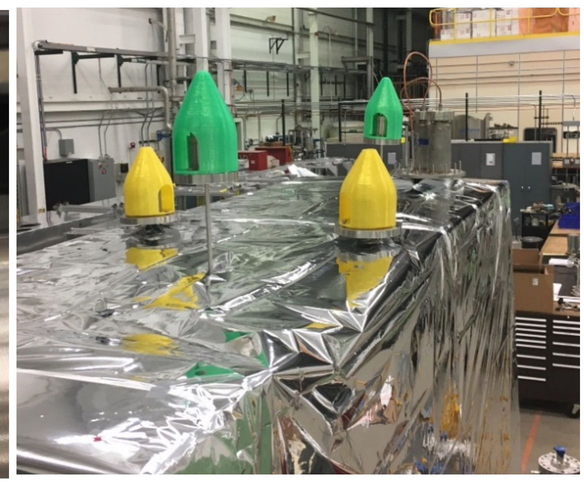
Cryogenic piping subassemblies



Magnetic shields using fasteners for assembly



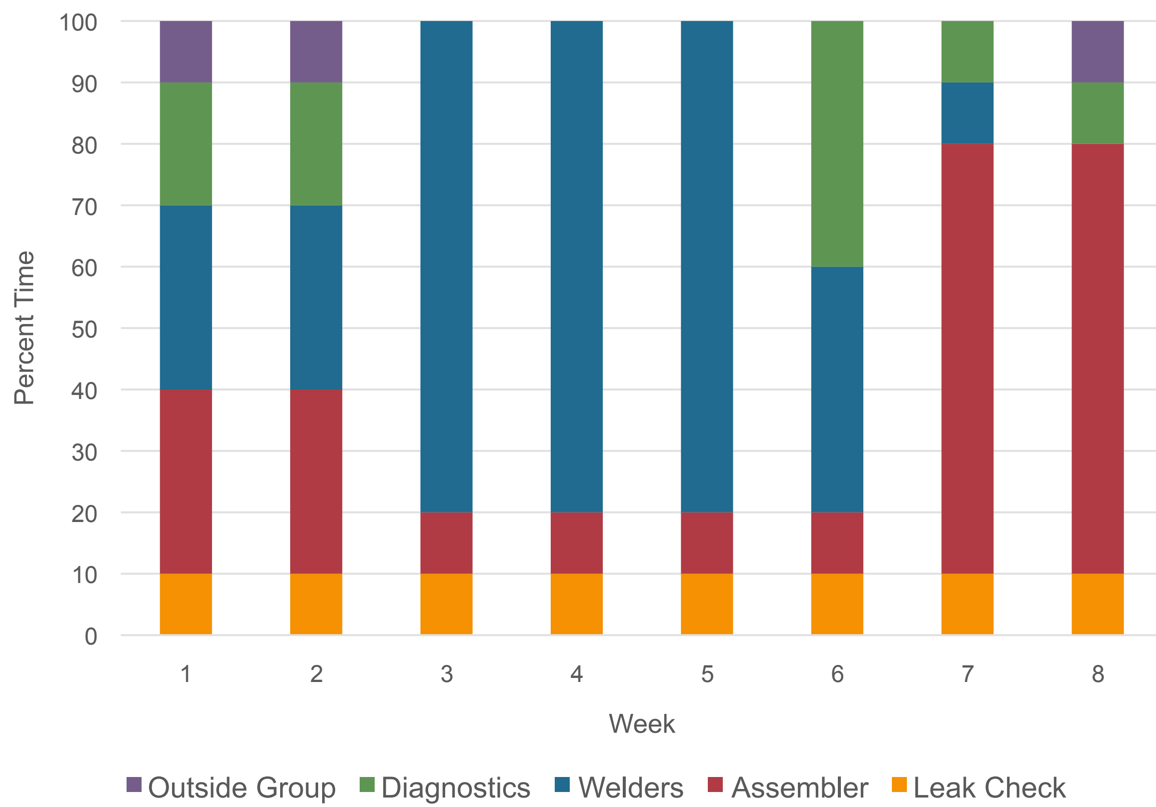
Solenoid lead centering harness



Protective covers for vacuum cover penetrations during installation

Resource Balancing

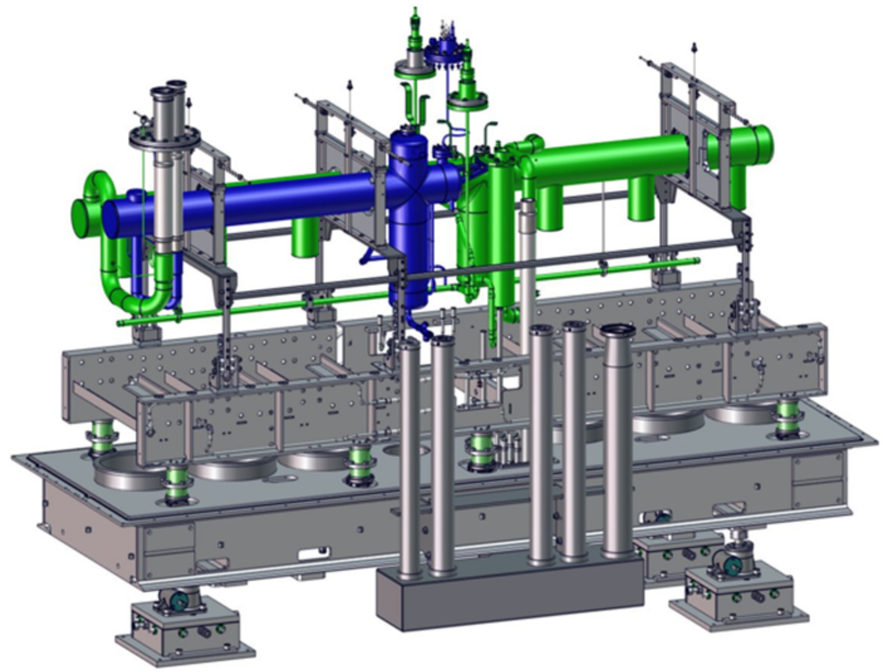
- One assembly team
- Cryomodule stays in place in one bay for the entire build
- Resources are balanced between assembly bays to optimize the work flow
- Welding is the most time consuming part of cryomodule assembly



Welding Optimization

- Decrease welding time and increase quality by designing joints to be compatible with orbital welder
- Working toward procedures in which the majority of welding is done as a subassembly, prior to coldmass delivery: reduce complexity and risk

Commercial Orbital Welder – used to weld circular tube geometries



Cryogenic system welded together as subassembly and lowered onto base plate after coldmass installation

Summary

- FRIB cryomodule assembly in full production
- FRIB has implemented acceptance inspections to ensure quality of incoming components
- Work is controlled by a check and balance between work instructions, task sign-offs, standard operational procedures, and engineering hold points
- Assembly work flow optimized by upfront inventorying and kitting
- Employee training required for all personnel working directly with cryomodules
- Cryomodule assembly on pace with project schedule
- But…FRIB is still learning and seeking opportunities to further increase efficiency.