FRIB CAVITY AND CRYOMODULE PRODUCTION

CHRIS COMPTON

LINAC Conference 2018
Beijing, China
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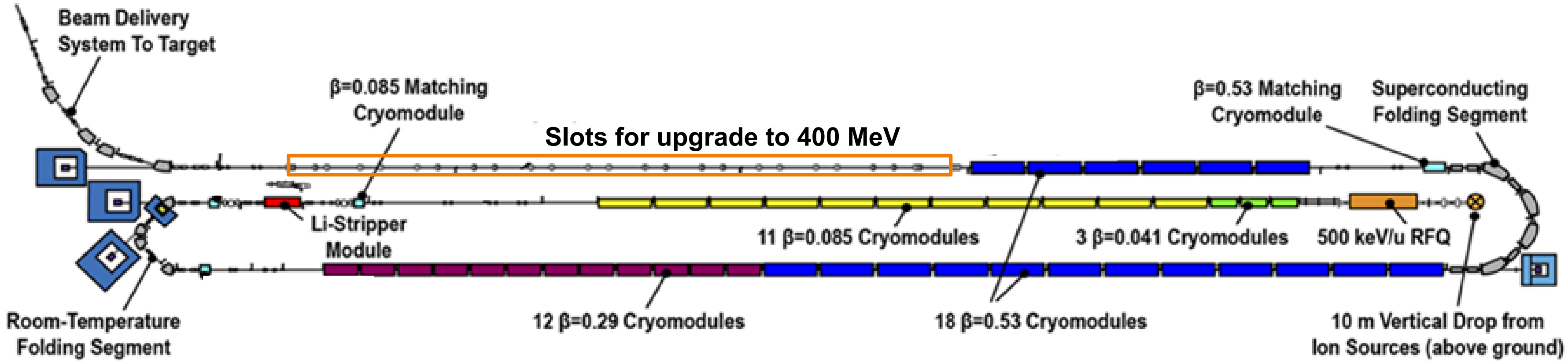
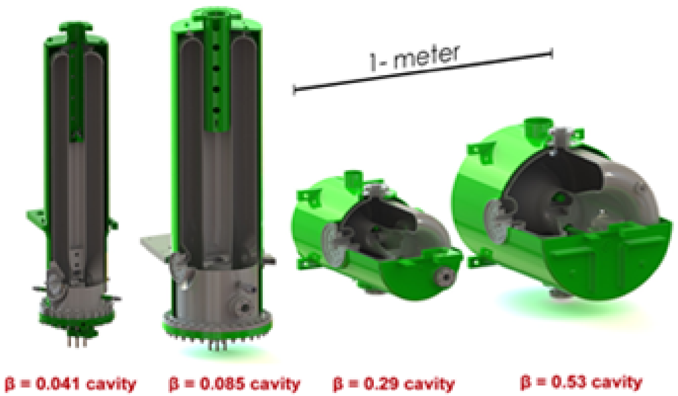
Outline

- Introduction
- Cavity production status and performance
- Cryomodule production status
- Cryomodule designs
- Cryomodule assembly floor and workflow
- Cryomodule assembly optimization
- Cryomodule tunnel installation and commissioning
- Lessons learned
- Summary

FRIB Superconducting Linac
Ion Species up to ^{238}U 200 MeV/u, 400 kW





Quarter Wave Cryomodule				
β	*Type*	*Component Counts (baseline + spares)*		
		Cryomodules	*Cavities*	*Solenoids*
0.041	accelerating	3 + 1	12 + 4	6 + 2
0.085	accelerating	11 + 1	88 + 8	33 + 3
	matching	1 + 1	4 + 4	-
Half Wave Cryomodule				
0.29	accelerating	12	72	12
0.53	accelerating	18	144	18
	matching	1	4	-
TOTALS		46 + 3	324 + 16	69 + 5

FRIB Cavity Status

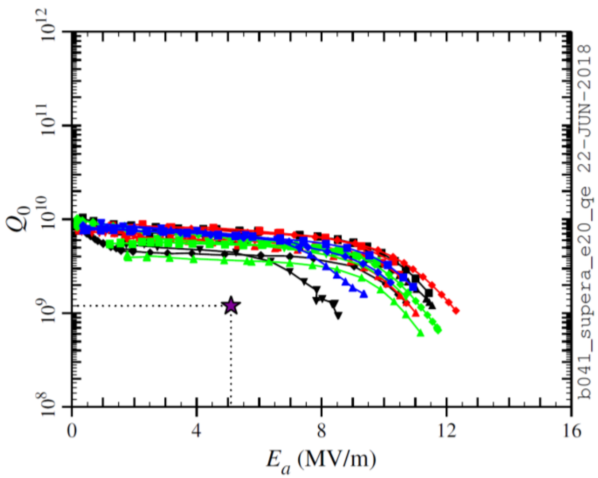
- 2 Quarter-wave and 2 Half-wave cavity types
- Cavity: niobium; helium vessel: titanium; transitions: Nb-Ti
- Cavity processing: BCP bulk etch - 600C for 10 hrs heat treatment - light BCP etch - HPR
- Five cavity vendors; only 1 unfinished contract
- ~Thirty β = 0.53 cavities to be delivered to complete contracts

Cavity Types	0.041	0.085	0.29	0.53	TOTAL
Required	12+4	92	72	148	328
Received	12+4	92+31	72+11	118	294+46
Accepted	12+4	92+31	72+8	117	293+43
Tested	12+4	92+10	72	106	282+14
Certified	12+4	92+9	72	101	277+13

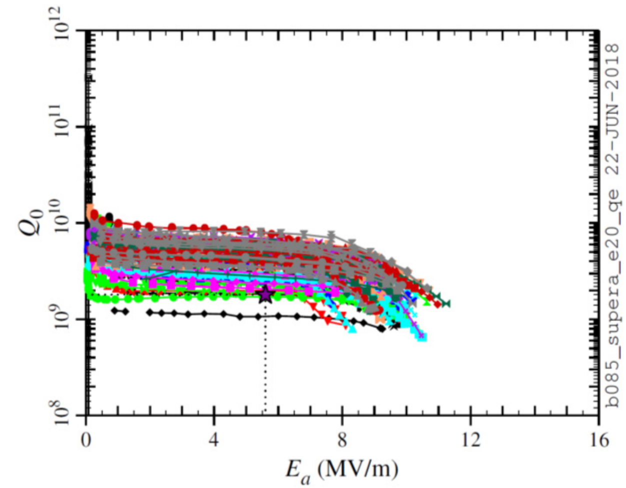
+ # = spares

FRIB Cavity Performance

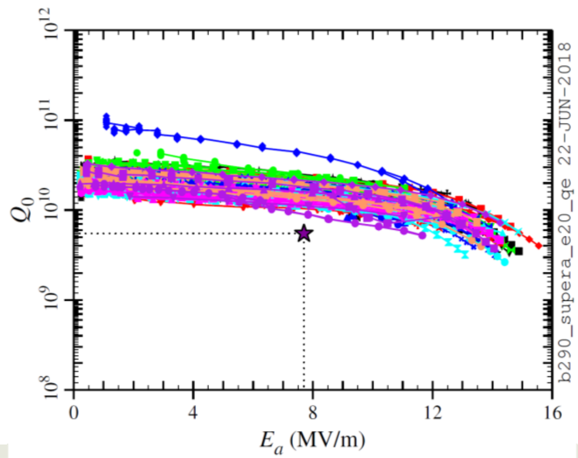
80.5 MHz, β = 0.041



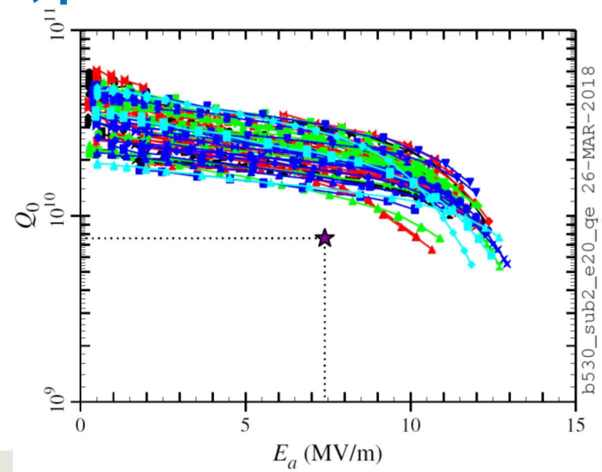
80.5 MHz, β = 0.085



322 MHz, β = 0.29

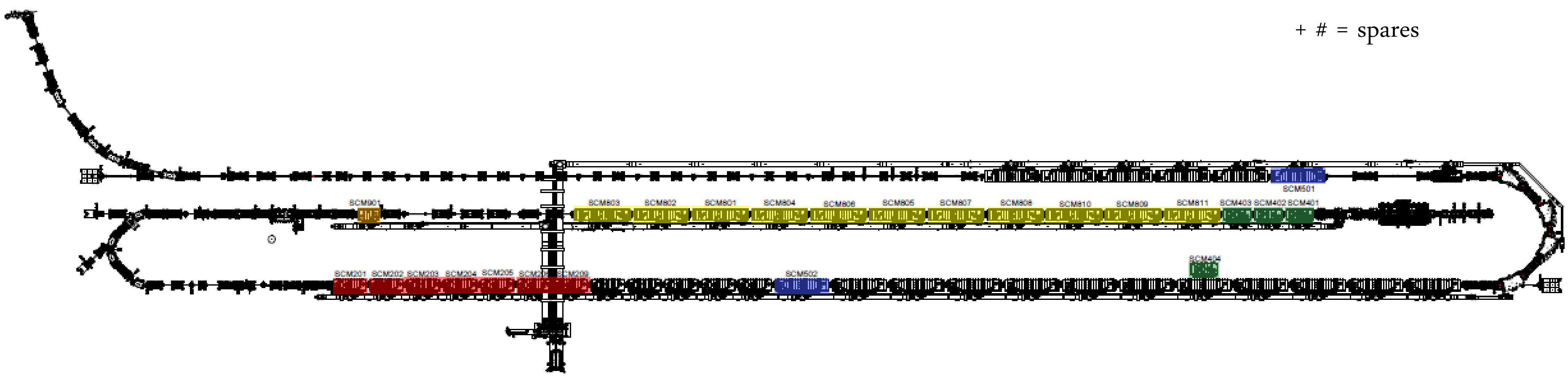


322 MHz, β = 0.53



Cryomodule Production Status
Project to complete by end of 2019

Type	Cold mass completed	Cryomodule assembled	Cryomodule bunker tested	Cryomodule in tunnel	Cryomodule needed (T+P)
β=0.041	3+1	3+1	3+1	3+1	3+1
β=0.085	11	11	11	11	11+1
β=0.085 buncher	1	1	1	1	1+1
β=0.29	12	12	9	8	12
β=0.53	11	3	2	2	18
β=0.53 buncher	0	0	0	0	1
Total	38+1	30+1	26+1	25+1	46+3



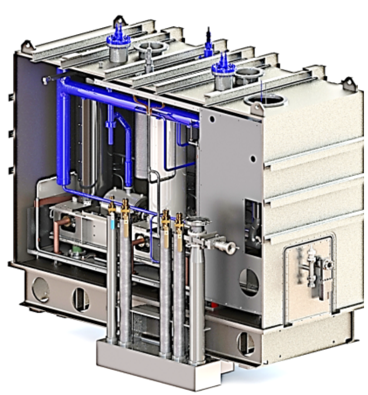
+ # = spares

FRIB Cryomodule Design

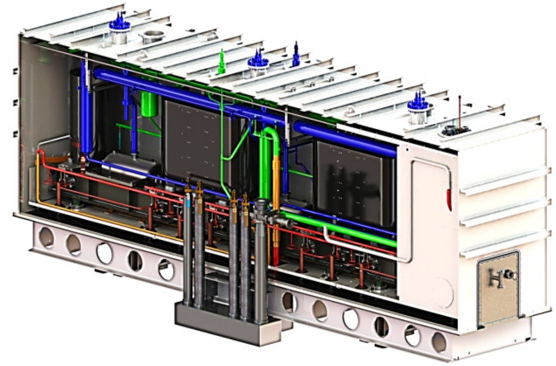
- All six modules use the same bottom-up design approach
- All cryomodules share large portion of common components to simplify design and facilitate fabrication
- Collaborate with JLAB on cryomodule design (β=0.041 and β=0.29)
- Collaborate with ANL on coupler and tuner design

Jefferson Lab

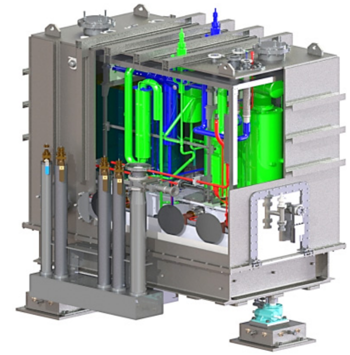
Argonne NATIONAL LABORATORY



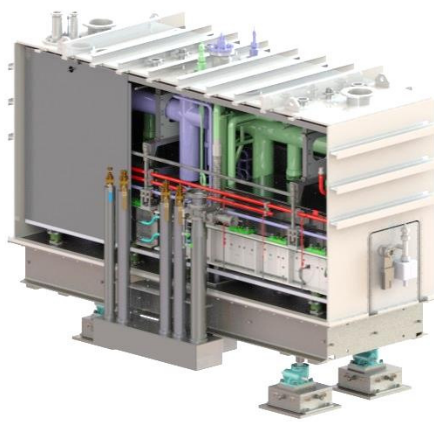
β=0.041



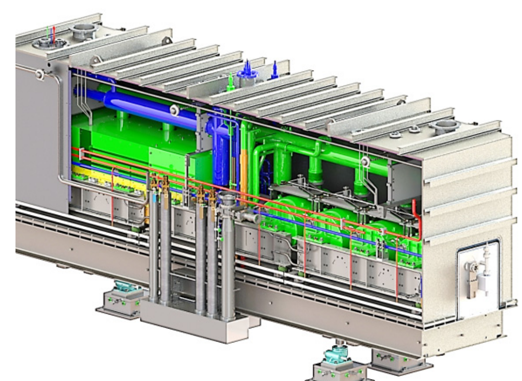
β=0.085



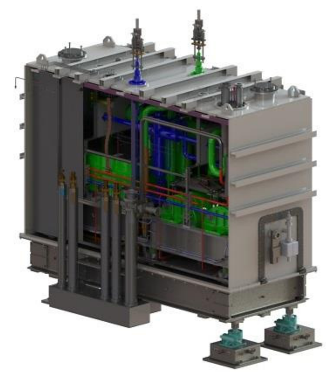
β=0.085 Matching



β=0.29



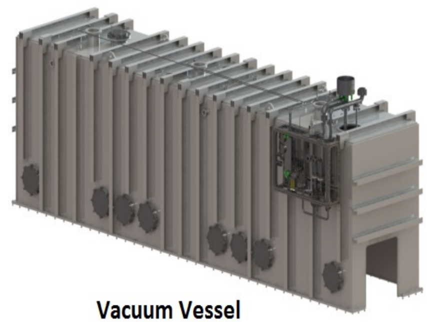
β=0.53



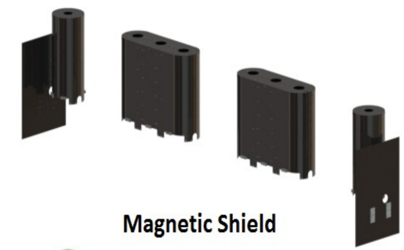
β=0.53 Matching

Bottom-up Cryomodule Design Approach

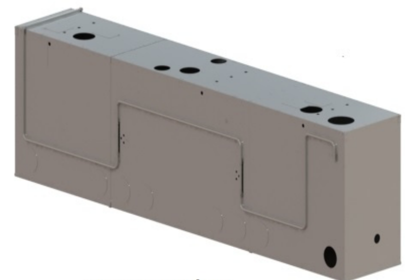
- Resonators (at 2 K) and magnets (at 4.5 K) both supported from the bottom to facilitate alignment
- Cryogenic system is decoupled from cold mass string to minimize vibrations and microphonic excitation
- Optimized and integrated with cryo-distribution
  - Bayonet interface for warm-up and servicing of individual cryomodules
  - 2 K/4 K heat exchanger inside module to maximize cryogenic efficiency
- Single layer "local" magnetic shield: less sensitive to magnet operation; more cost-effective
- Common cryomodule design principles for all six cryomodule types
  - Support rails, cryogenic circuit, thermal shield, vacuum vessel



Vacuum Vessel

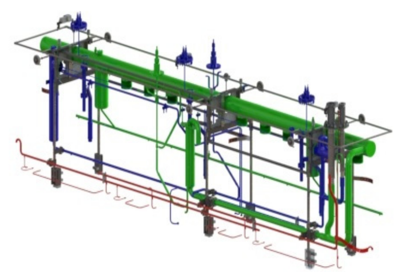


Magnetic Shield

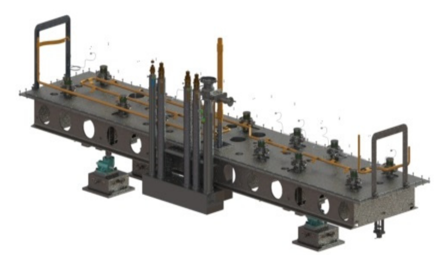


Thermal Shield

Cold Mass



Cryogenic System



Baseplate

β = 0.53 Cryomodule Assembly Sequence

C1

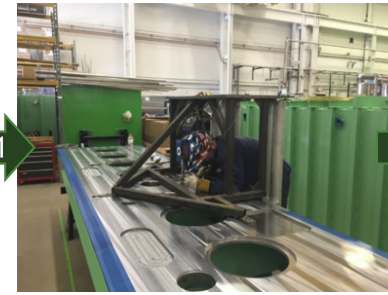
Completed cold mass assembly in clean room

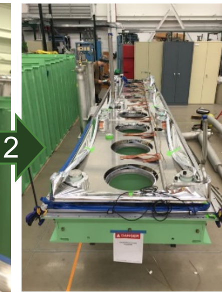
C2

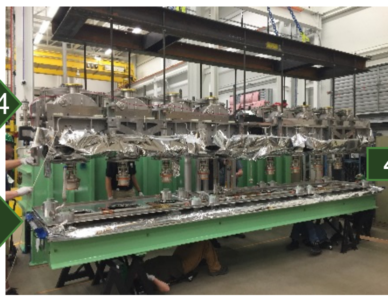
Cold mass assembly transport to cryomodule assembly area

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

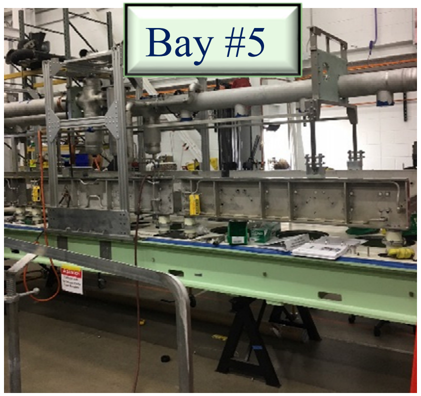
8

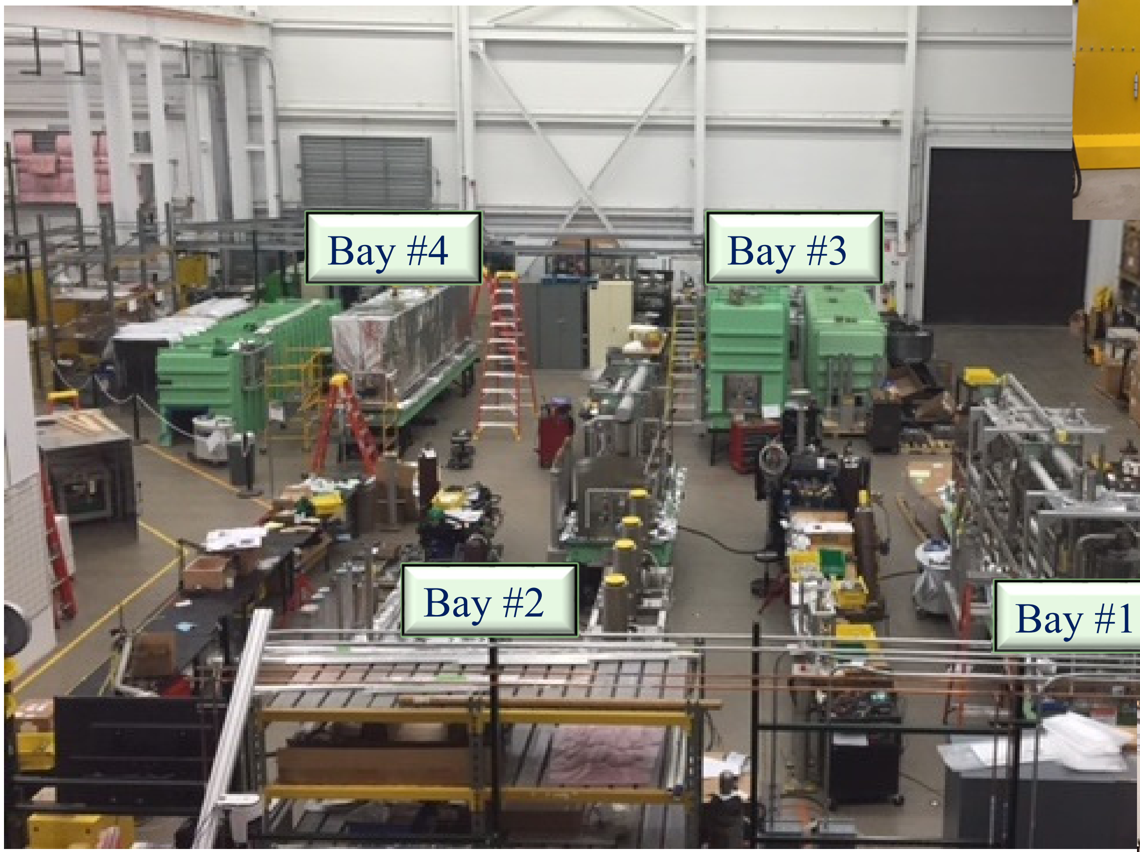

Transport to SRF High Bay

9

Transport into test bunker

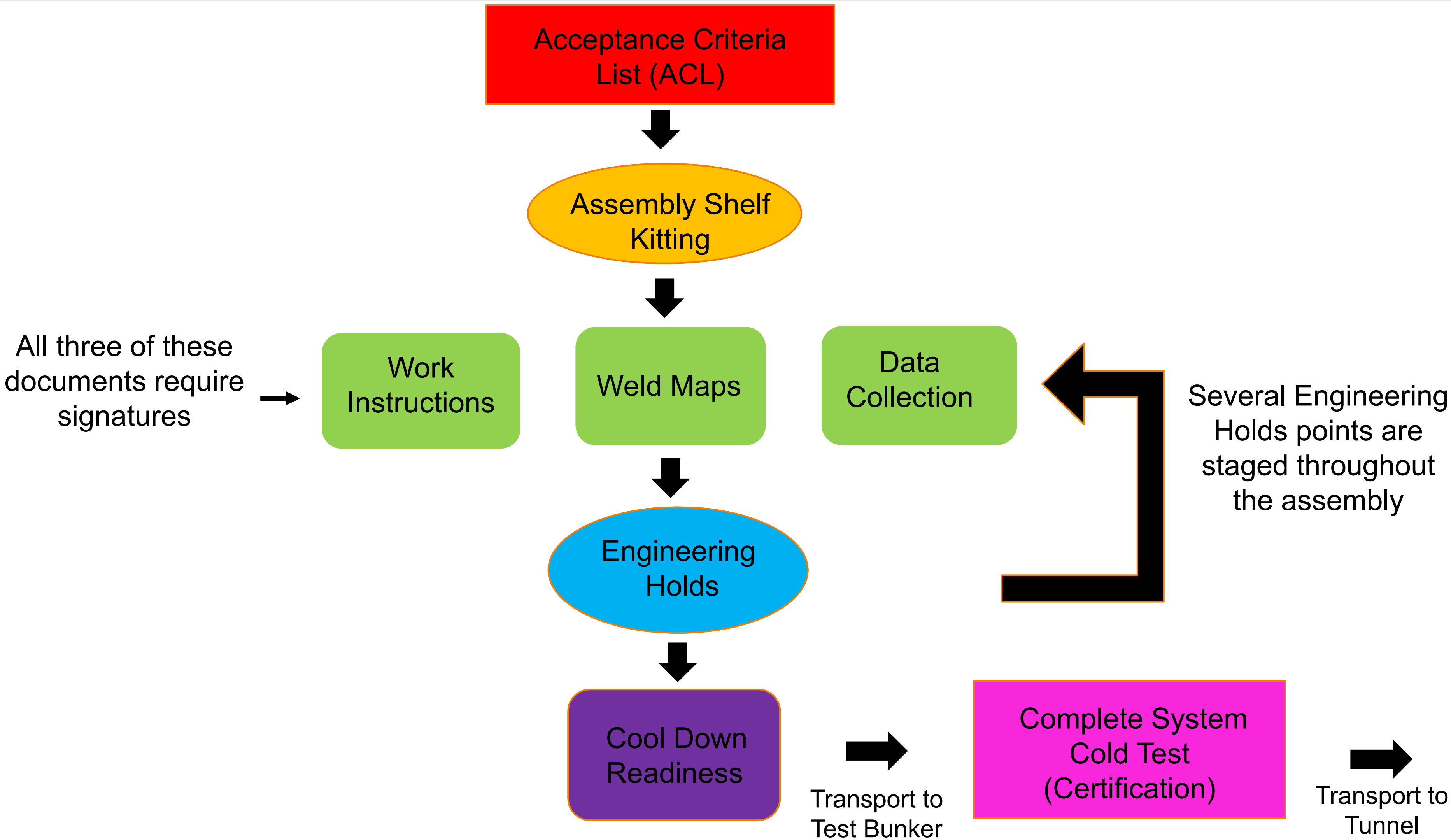
Cryomodule Assembly





- Six parallel assembly bays
- 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 cold mass in and completed cryomodule out

Assembly Workflow



Production optimized running 3 parallel lines

Cryogenic subassembly – headers, JT valves, heat exchanger (Bay 5)

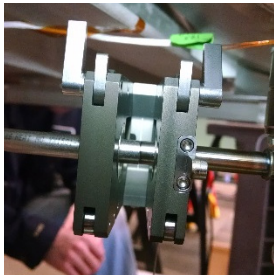
Cold mass subassembly – FPC cooling, tuners, magnetic shielding (Bay 6)

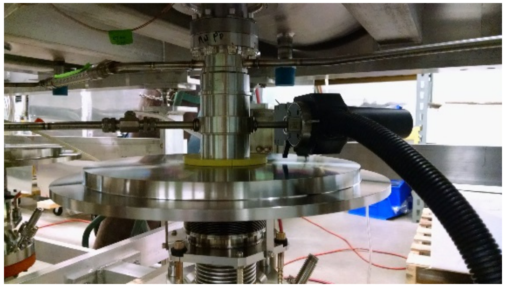
Base plate subassembly – bayonet box, lower cryogenics, lower thermal shield, instrumentation (Bays 1-4)

All three subassemblies come together for final stage of assembly

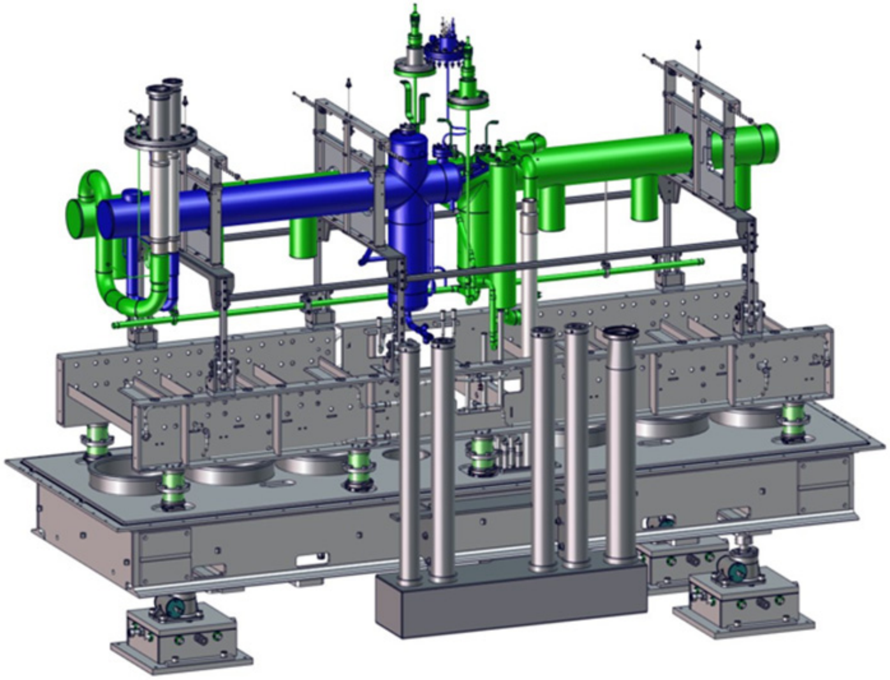
Welding Optimization

- Decrease welding time and increase quality by designing joints to be compatible with orbital welder
- Major weldment subassemblies fabricated “on the bench” : reduce complexity; less welding done above the cold mass





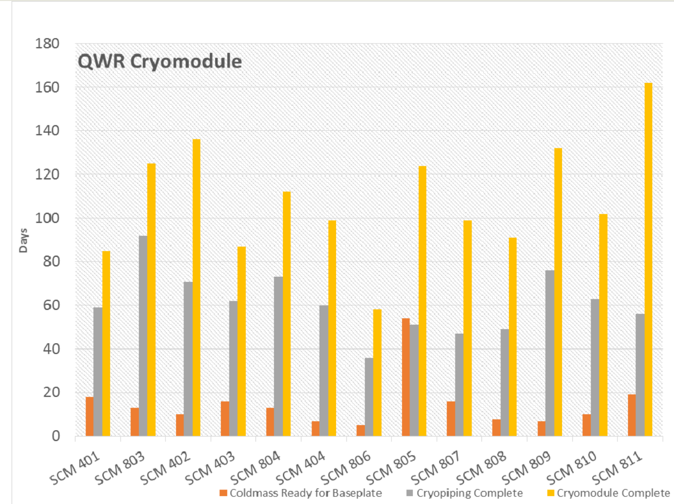
Commercial Orbital Welder – used to weld circular tube geometries

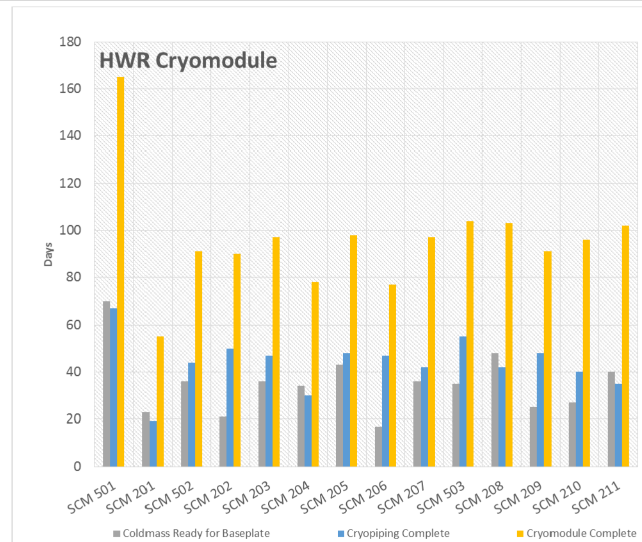


Cryogenic system welded together as subassembly and lowered onto base plate after cold mass installation

Cryomodule Production Status

- Cold mass (clean room assembly) production: 1.5 per month
- Cryomodule assembly: 1 per month
- Cryomodule bunker test: 1 per month





VTA vs. Cryomodule

- Cavity performance in cryomodule comparable to test performed in the vertical test Dewar – No degradation observed.

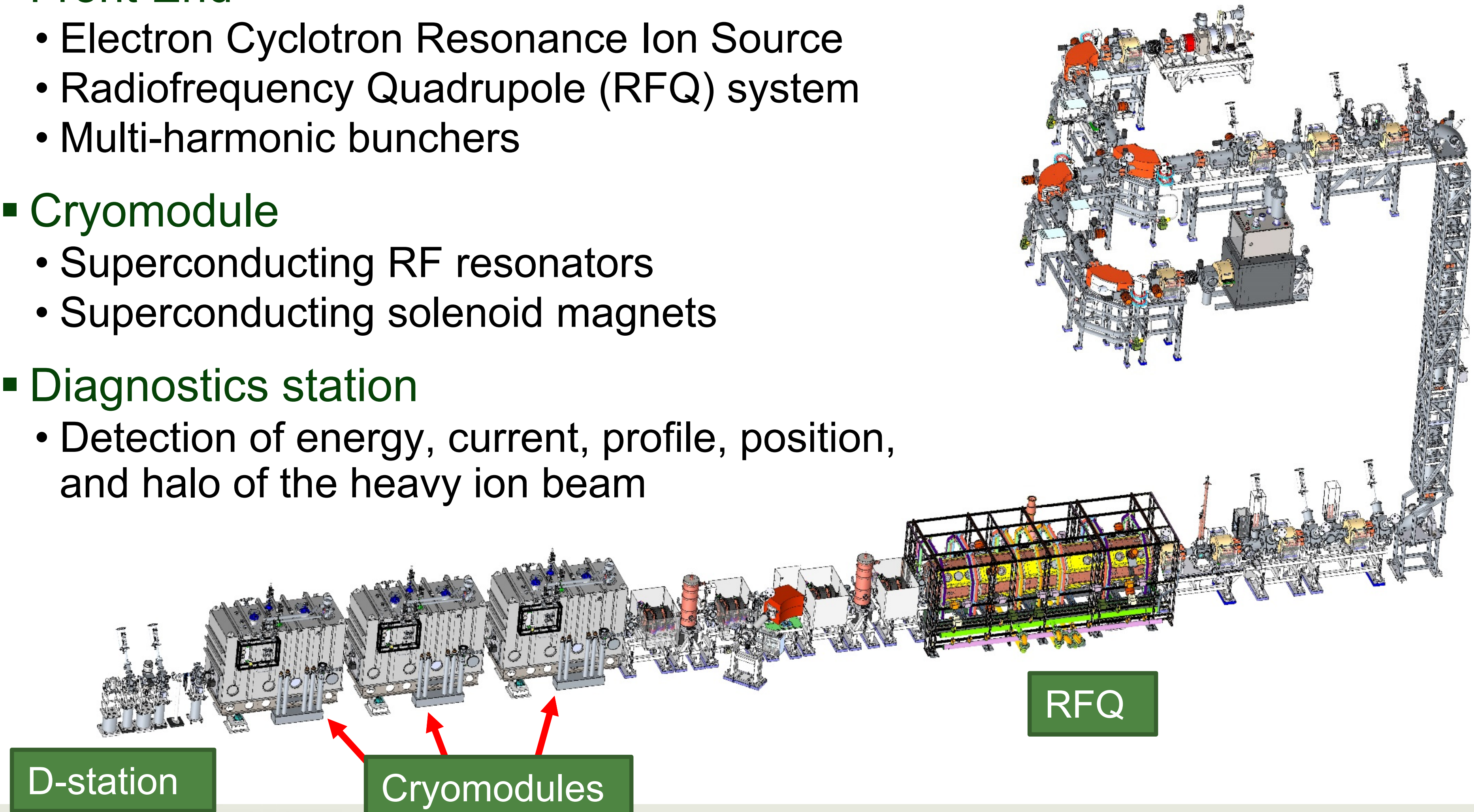
Cryomodule Installation

- 25 out of 46 FRIB cryomodules are installed in the tunnel

Present Stage of FRIB Beam Commissioning

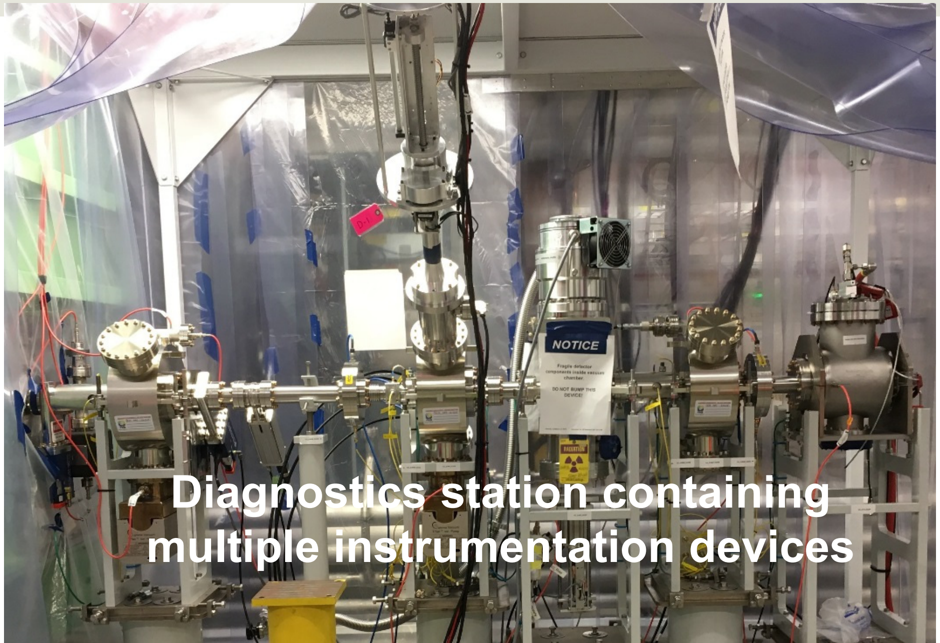
Front End, Cryomodule 1 – 3, Diagnostics Station

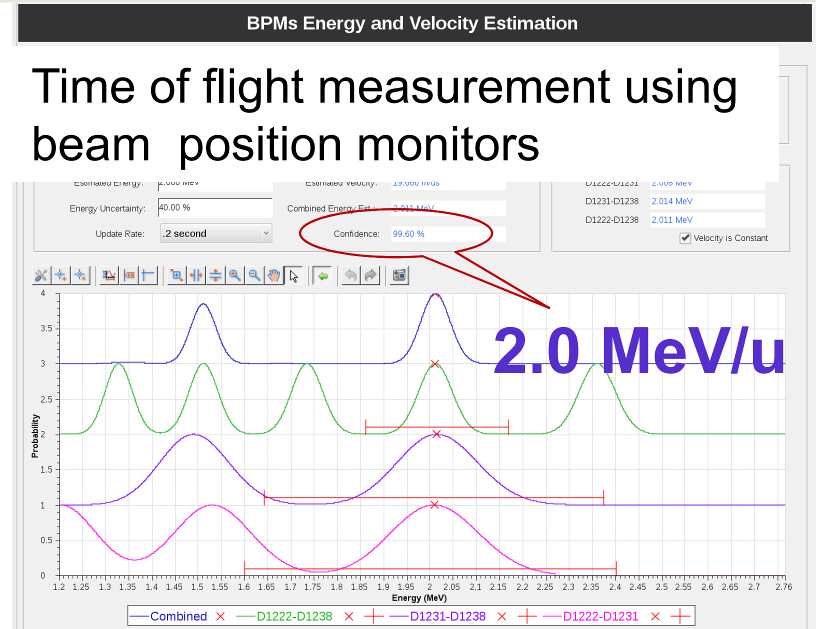
- Front End
  - Electron Cyclotron Resonance Ion Source
  - Radiofrequency Quadrupole (RFQ) system
  - Multi-harmonic bunchers
- Cryomodule
  - Superconducting RF resonators
  - Superconducting solenoid magnets
- Diagnostics station
  - Detection of energy, current, profile, position, and halo of the heavy ion beam

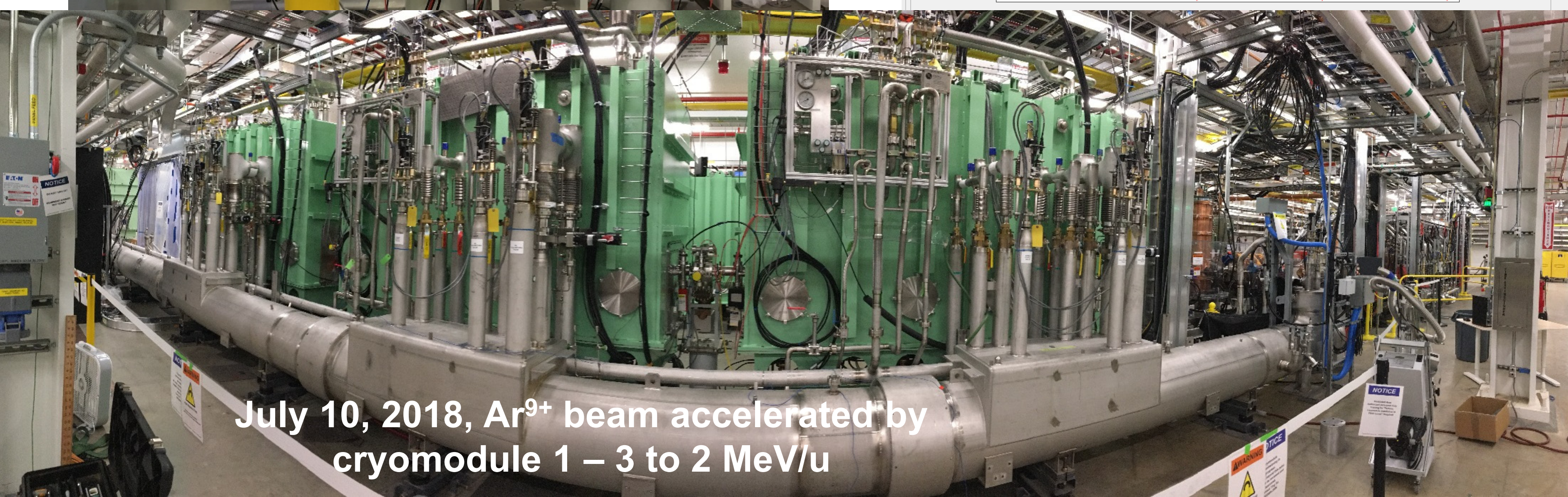


SRF Cryomodule 1 – 3 Beam Commissioned

Met Key Performance Parameters in 2 Days upon Authorization



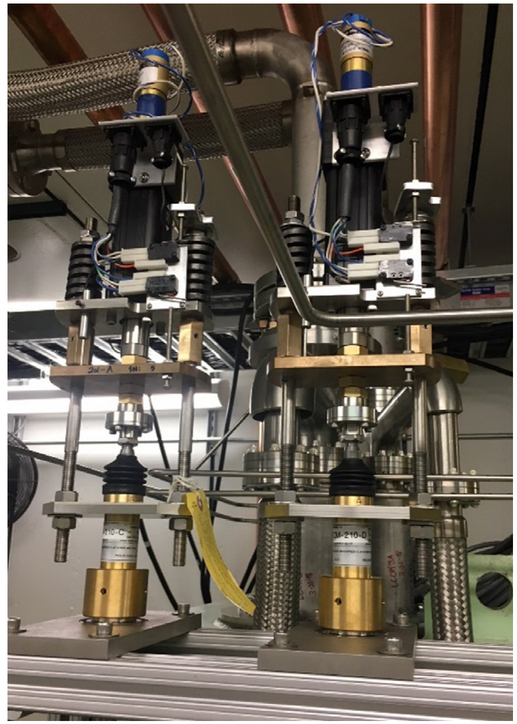




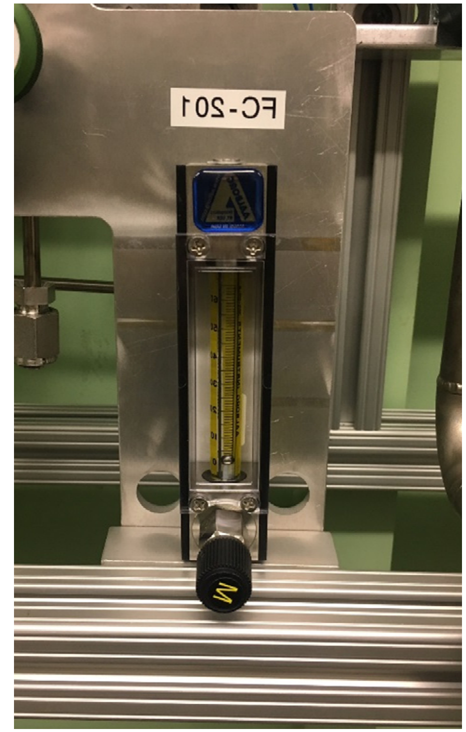
Lessons Learned – valves leaking through

- Several valve types found to leak through when closed.
- Implemented additional leak checks across closed valve interfaces.

Manual valves on pneumatic tuner gas distribution manifold



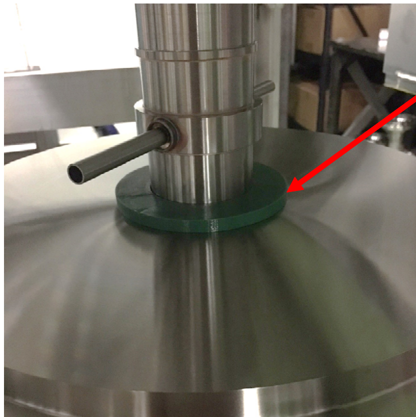
Cryogenic cool-down control valves



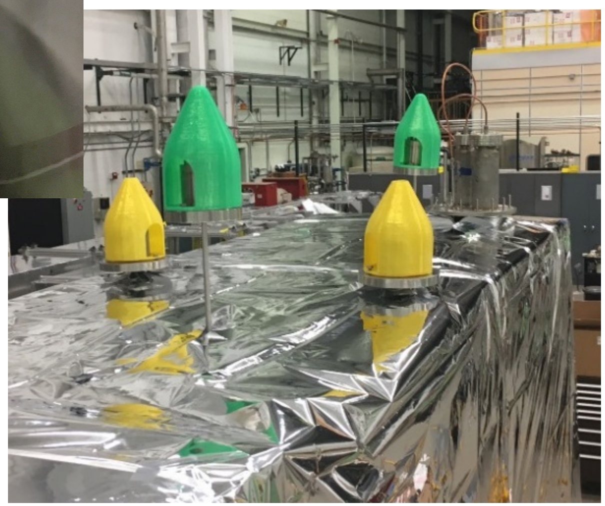
Flowmeters – "fluttering" ball

Lessons Learned – Use of 3D printing

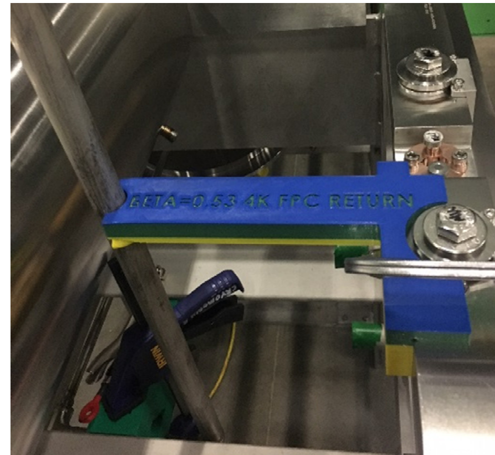
- 3D printing is a cost-effective fabrication method for various applications

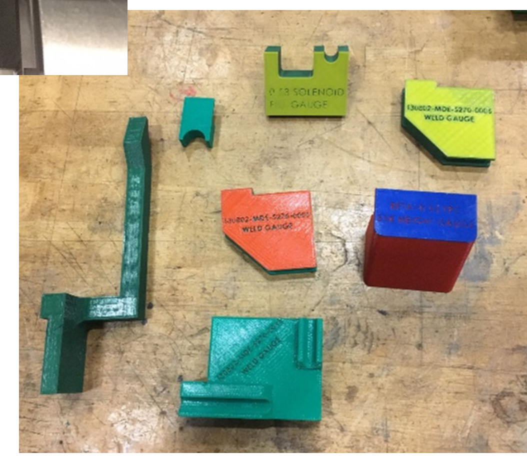


Plastic cover over gap



Caps and cover to protect sensitive equipment or prevent dropping of objects into holes





Tooling and check fixtures can be quickly made and save a lot of fit-up time

Summary

- FRIB cavity contracts are nearly complete, with high cavity acceptance and certification rates
- FRIB cryomodule assembly: in full production
- Assembly work flow optimized by upfront inventorying and kitting
- FRIB has optimized cryomodule production with parallel-path fabrication
- FRIB cryomodule production is meeting project requirements
- FRIB project is advancing with cryomodule tunnel installation and commissioning
- FRIB cryomodule assembly team is still learning and seeking opportunities to further increase efficiency and quality assurance