Low-Beta Cryomodule Design Optimized for Large-Scale Linac Installations

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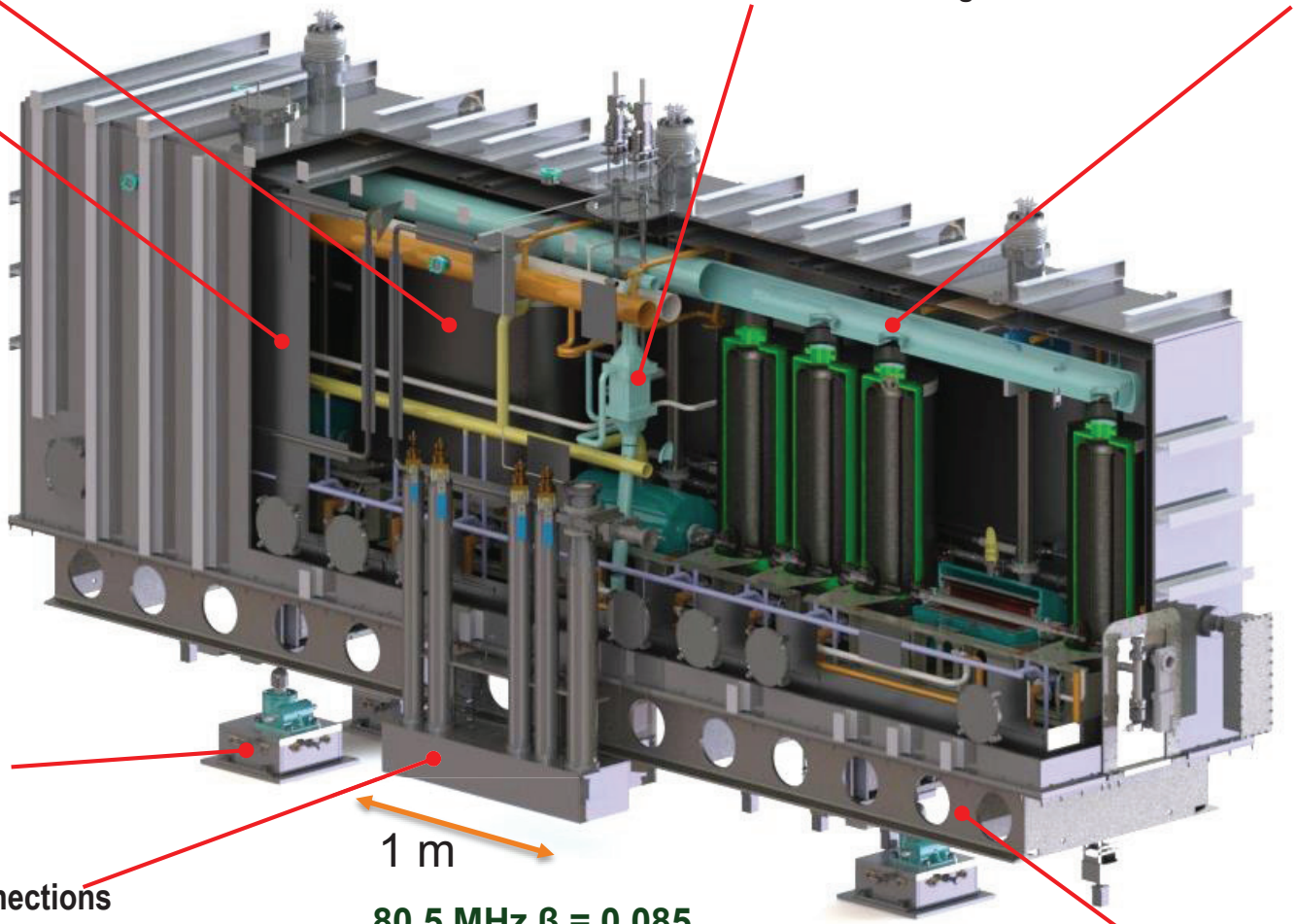
Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Outline

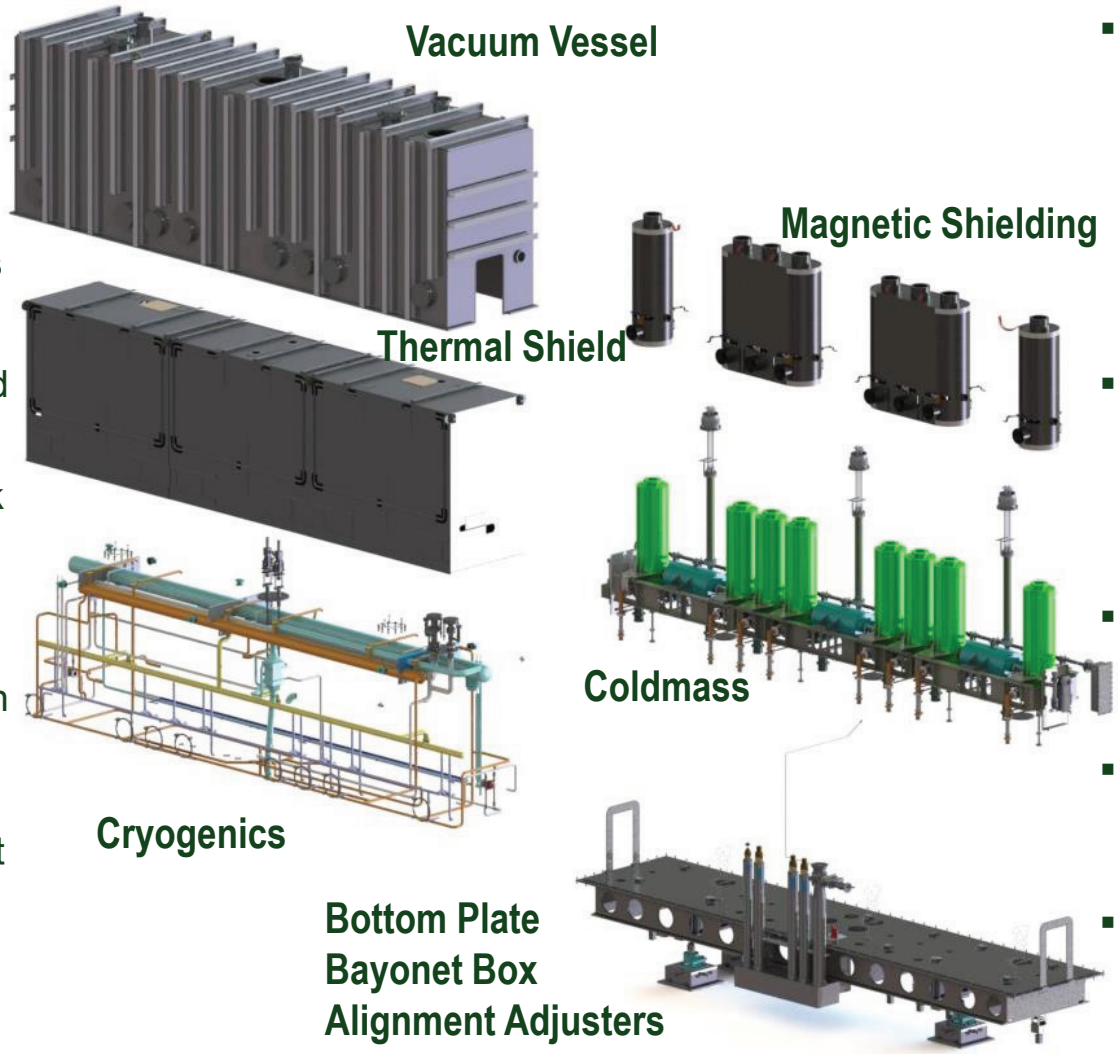
- Quarter Wave Cryomodule Modular Design
- Quarter Wave Cold Mass
  - Alignment Rail System
  - Fundamental Power Coupler
  - Tuner
  - Wire Position Monitor
- Magnetic Shields
- Cryogenics
- Thermal Shields
- Vacuum Vessel
- Assembly
- Summary

FRIB Quarter Wave Cryomodule
Modular Design to be Used on All FRIB Resonator Types



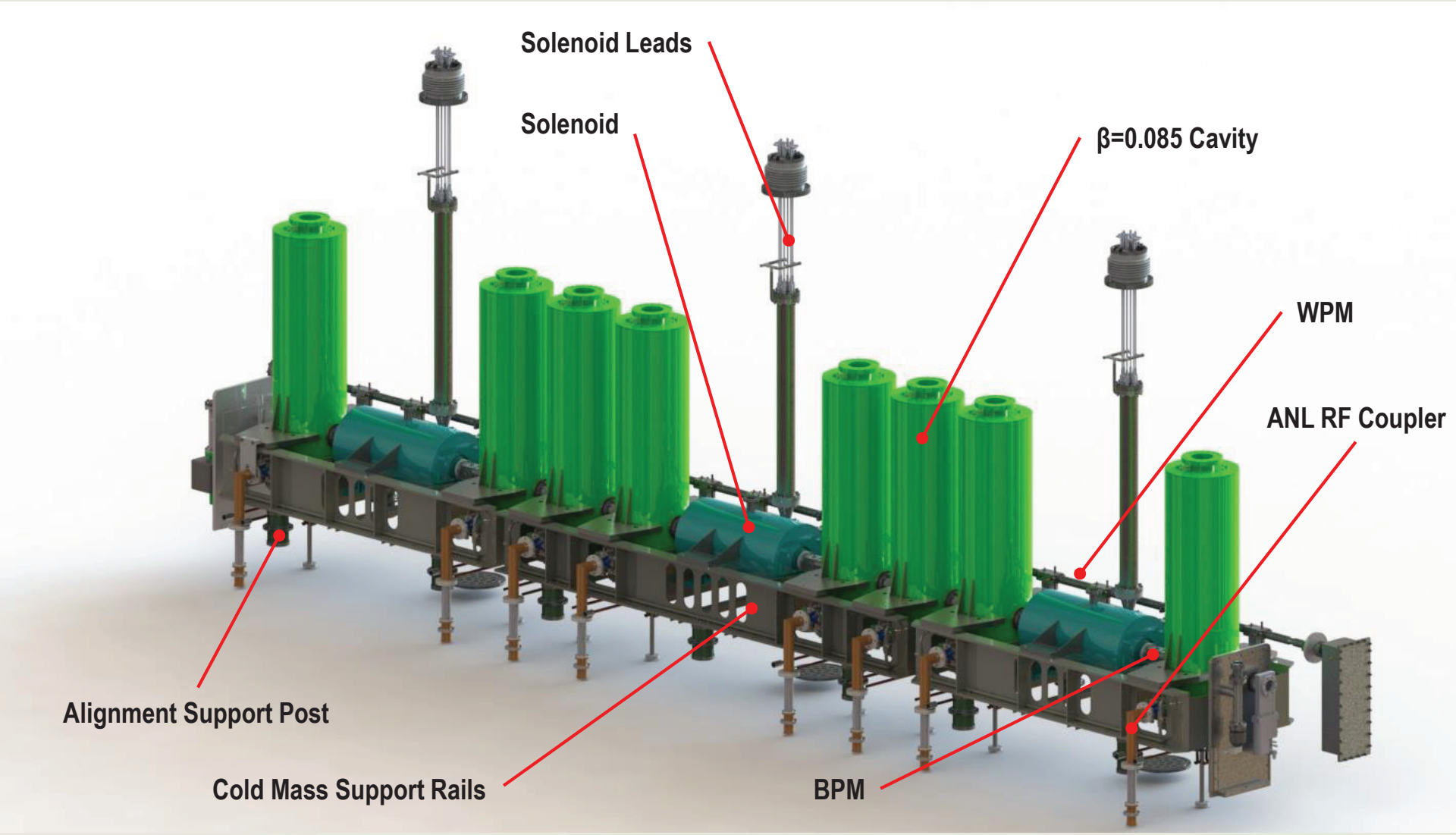
Cryomodule Main Components Allow Modular Procurement

- Simplify where possible and look toward production and design improvements
- Optimized for mass production with interchangeable parts and machined fits
- 3 piece strong back supports tighter alignment requirements to remove or reduce ‘cross-talk’ between resonator position during assembly
- Assembly is in front at waist level with nothing overhead improving visibility



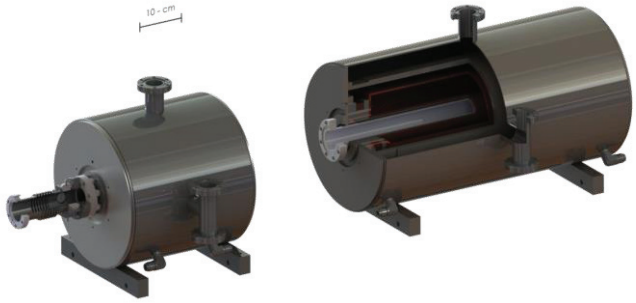
- Fewer assembly fixtures – no upper assembly stand needed for building therefore multiple modules can be assembled at the same time
- Attachment of slot covers to thermal shield, nothing to restrict access and fewer slots
- Minimize the hanging of critical components during assembly
- MLI easier to manage and not hanging in the way
- Improved alignment and mass-production, better serviceability

FRIB Quarter Wave Cold Mass
Modular Design to be Used on All FRIB Resonator Types



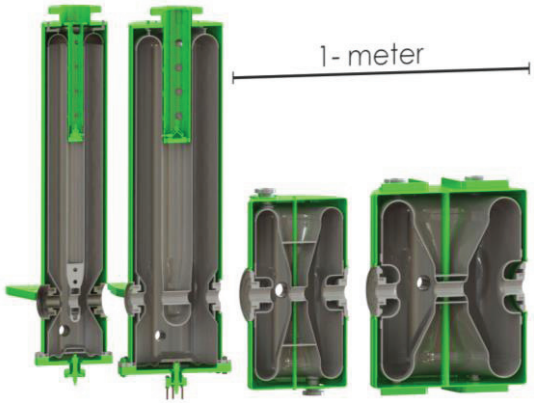
Cold String Configurations

Cryomodule Configuration (qty/FRIB)	Resonator Type (qty/FRIB)	Solenoid L_{eff} [m]	BPM
(3)	QWR β = 0.041 (4)	0.2 (2)	(2)
(11)	QWR β = 0.085 (8)	0.5 (3)	(3)
(12)	HWR β = 0.29 (6)	0.5 (1)	n/a
(18)	HWR β = 0.53 (8)	0.5 (1)	n/a
(2)	HWR β = 0.29 (2)	n/a	n/a
(2)	QWR β = 0.085 (3)	n/a	n/a
(1)	QWR β = 0.53 (4)	n/a	n/a



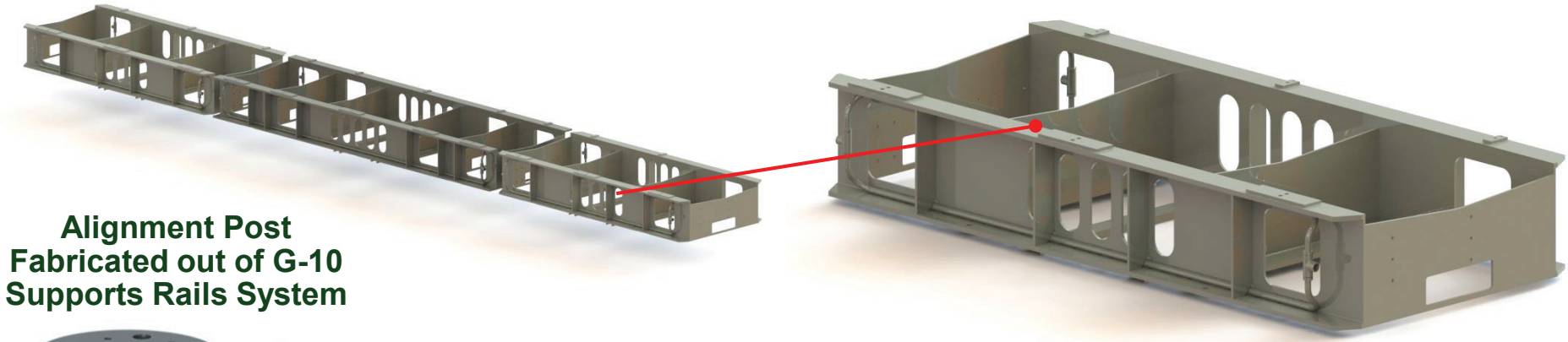
L_{eff} = 0.2 m & 0.5 m 8T Solenoids with integrated X-Y dipole magnets

Commercial solenoid leads interface directly with solenoid

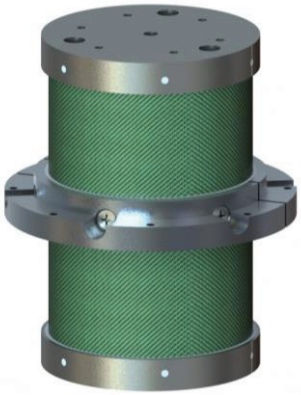


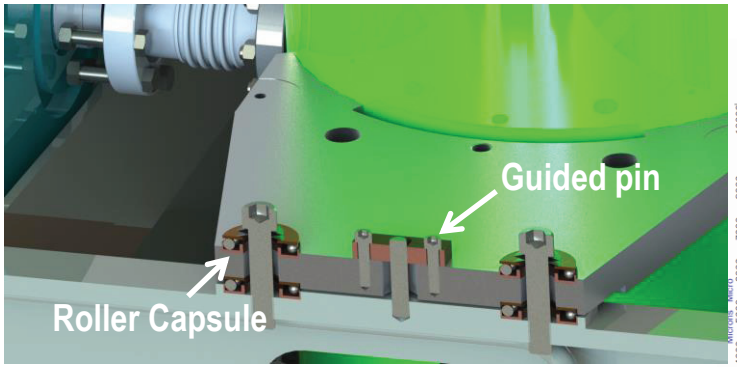
2 QWRs at 80.5 MHz: β =0.041 & 0.085
2 HWRs at 322 MHz: β =0.29 & 0.53

316L Alignment Rails Were Annealed at 1100º C to Relieve Residual Stress and Reduce Permeability, Support Cold Mass System



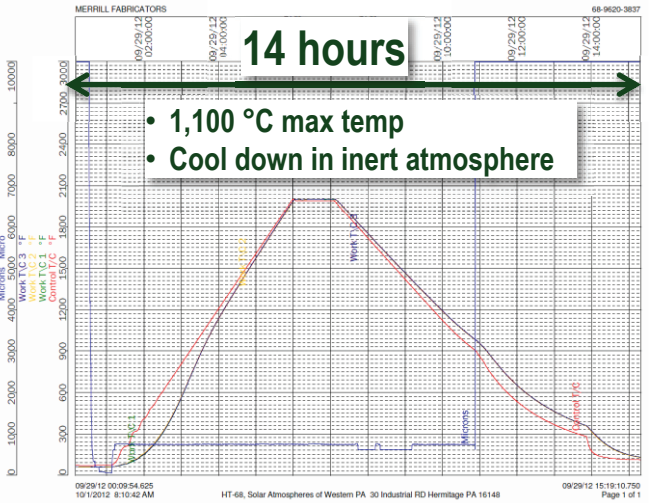
Alignment Post Fabricated out of G-10 Supports Rails System



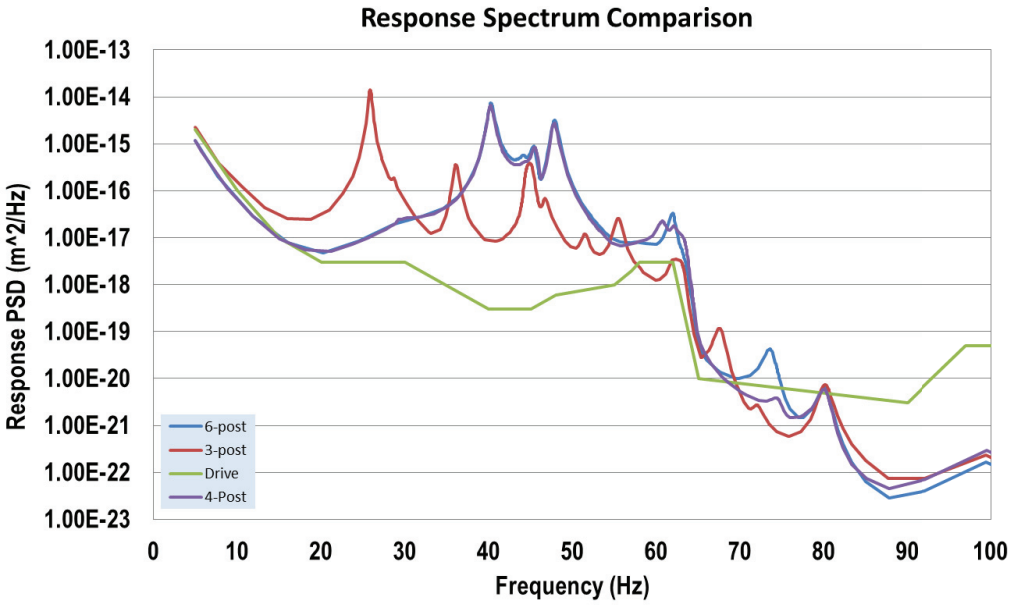


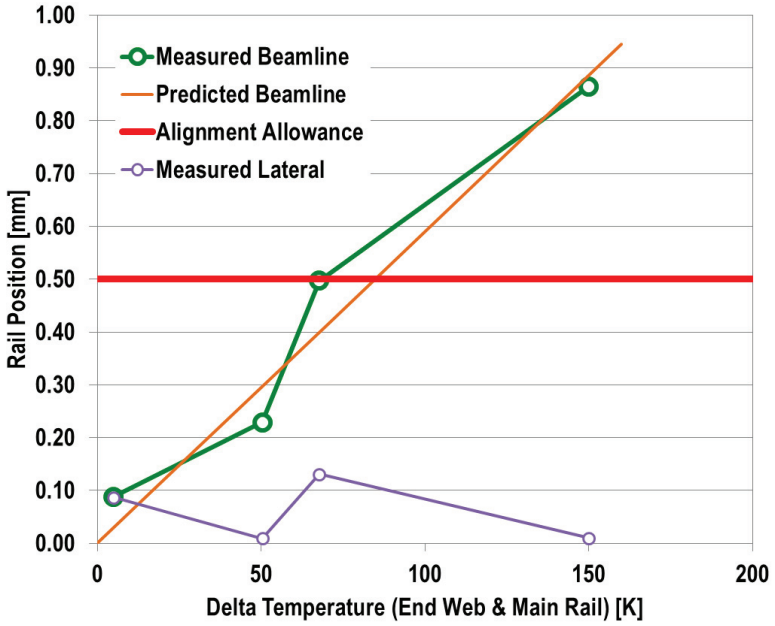
Cavity mount provides stress-free thermal contraction with significant anti-rocking stiffness – essential for quarter wave resonators

Heat Treatment Data from Vendor



FRIB Kinematic Support System Has Been Tested During Several Cool-Downs And Functions Consistently At High Repeatability and Accuracy (1)

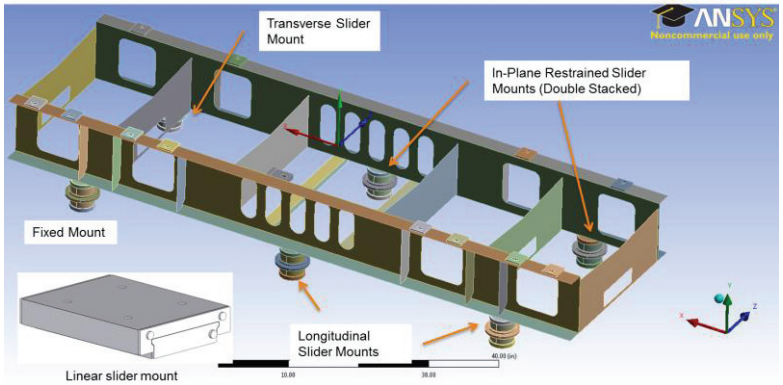




Bottom-up cryomodule design validated

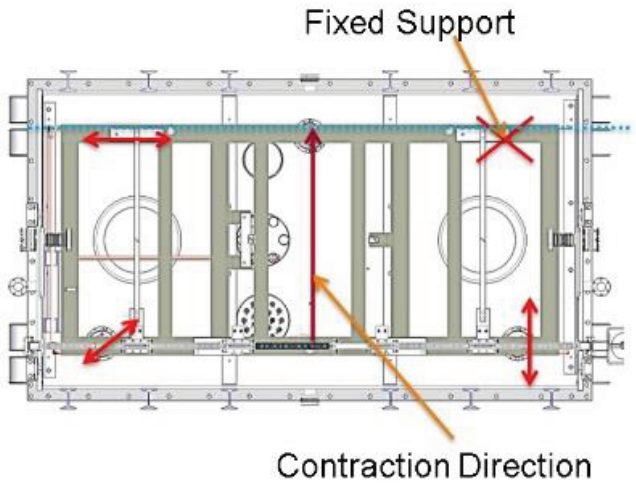
- Ease of assembly significantly optimized for mass-production
- Excellent alignment repeatability
- Alignment verified through optical targets and wire position monitor
- Cryomodule supports have been optimized based on vibration response spectrum analysis

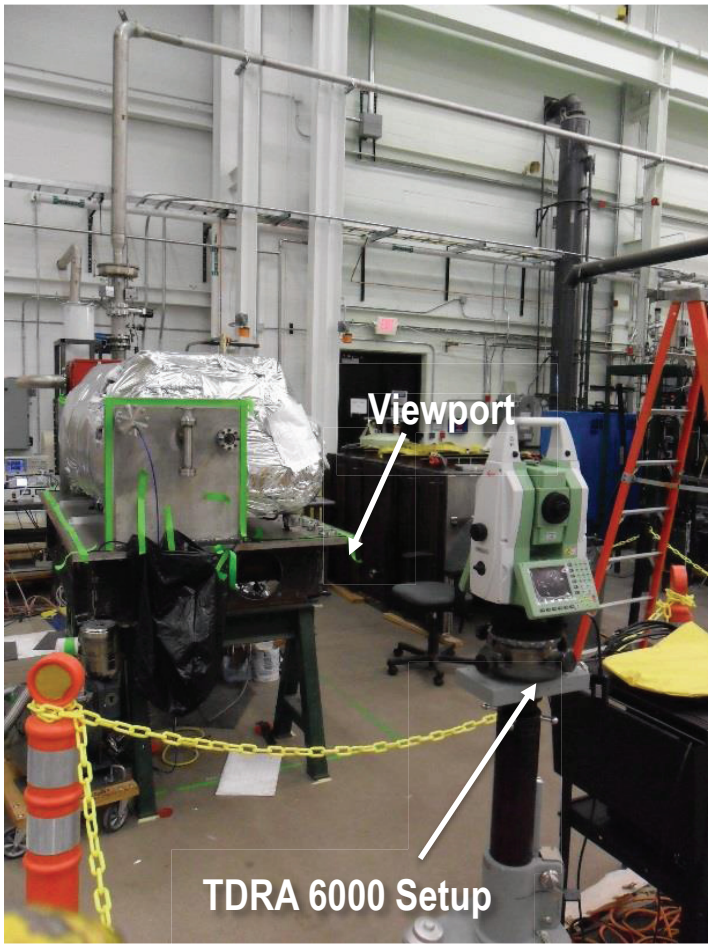
ANSYS Model for the Center Rail Assy allows either 3 or 4 or 6 post simulations



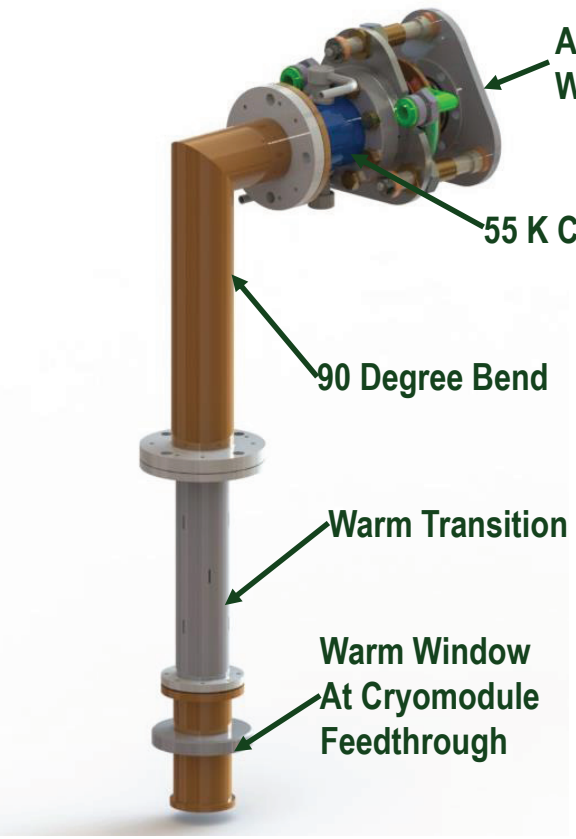
FRIB Kinematic Support System Has Been Tested During Several Cool-Downs And Functions Consistently At High Repeatability and Accuracy (2)

- Alignment of cavities and solenoid stay well within alignment specifications
- First optical target measurement results
  - Cavity alignment
    - » within +/- 0.003” (0.076 mm) horizontally
    - » within +/- 0.002” (0.05 mm) vertically
- First WPM measurements
  - Cavity alignment
    - » within +/- 0.003” (0.076 mm) horizontally
    - » within +/- 0.001” (0.03 mm) vertically

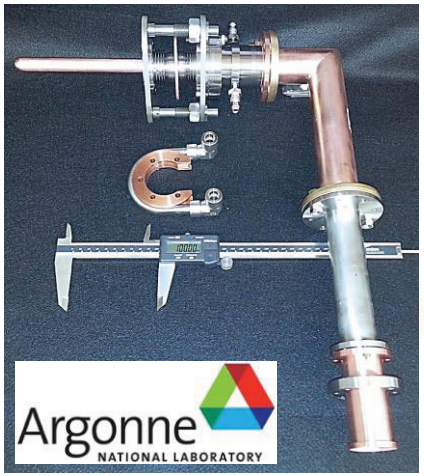


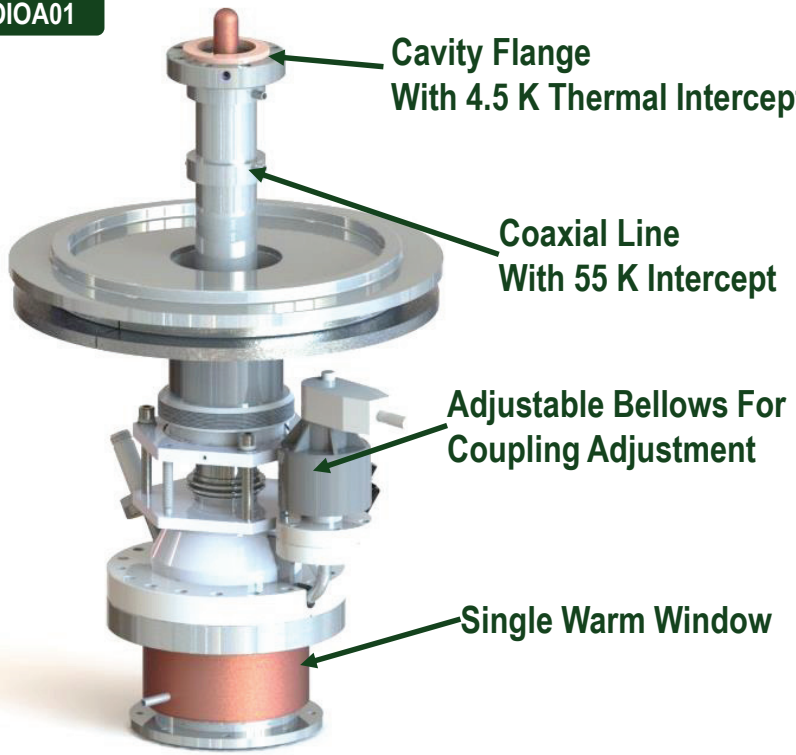


QWR Will Utilize ANL Coupler With Cold Window And 90 Degree Bend, HWR Will Utilize SNS-Style Coupler With Single Warm Window



M. Leitner: MOIOA01

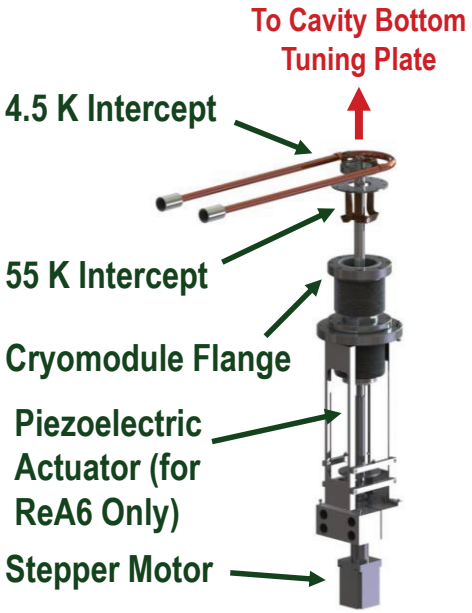




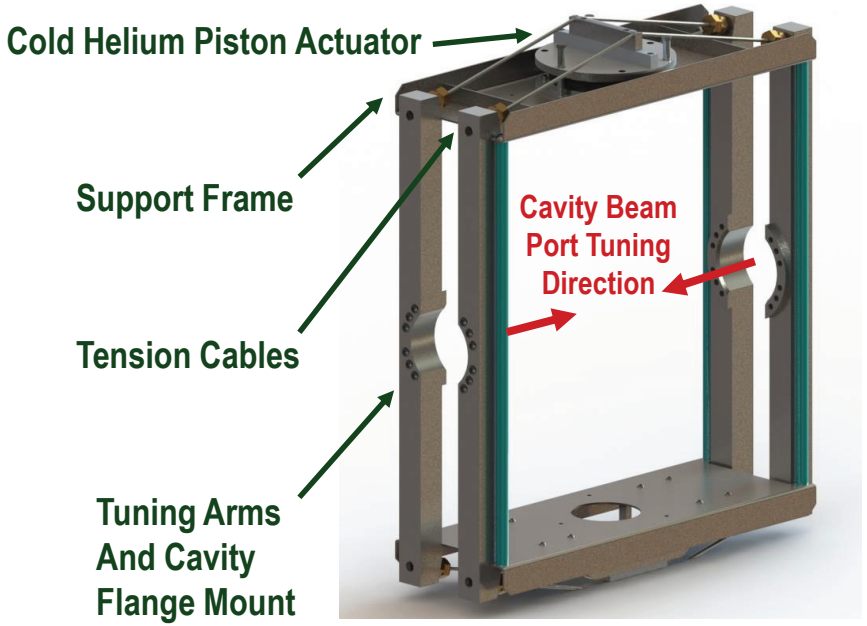
M.P. Kelly, et al, *Compact 4 kW Variable RF Power Coupler For FRIB Quarter-Wave Cavities*, **LINAC 2012**, Tel-Aviv

L. Popielarski: THP067, R. Oweiss: THP053

FRIB Quarter-wave Resonators Will Utilize the Same Tuning Mechanism as ReA3, Half-wave Resonators Will Utilize ANL Concept



Increased cavity frequency tunability by welding "tuning puck" to tuning plate providing ±30 kHz final tuning range.



Tuner Properties		
Property	**β=0.085**	**β=0.53**
Pressure Sensitivity (Hz/torr)	-1.4	-3.4
Lorentz Force Detuning (Hz/(MV/m) ^{2}	-0.7	-3.0
Tuning Sensitivity (kHz/mm)	3.2	100

M. Leitner: MOIOA01

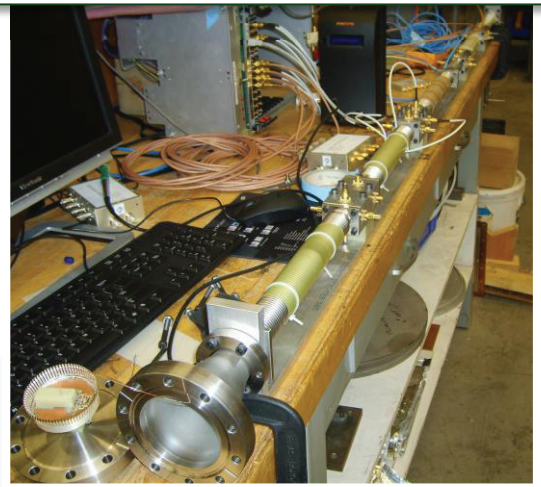
Argonne NATIONAL LABORATORY

Wire Position Monitor (WPM) System To Actively Monitor Cavity and Solenoid Position

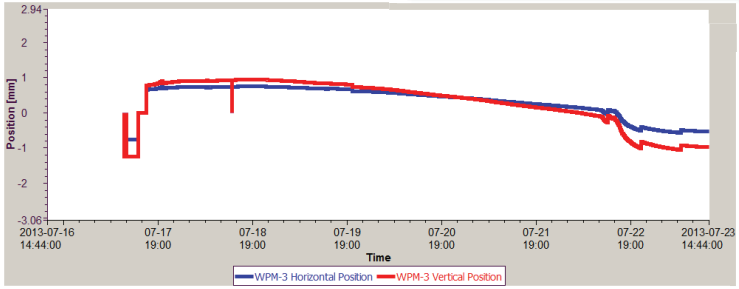
1 Sensor Per Cavity
2 Sensor Per Solenoid

WPM Sensor

Sensor Resolution: ± 0.05mm

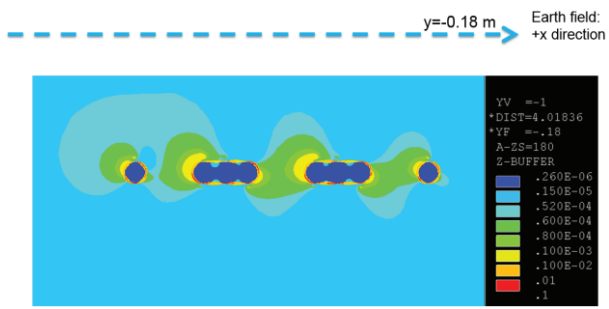


WPM System Bench Test

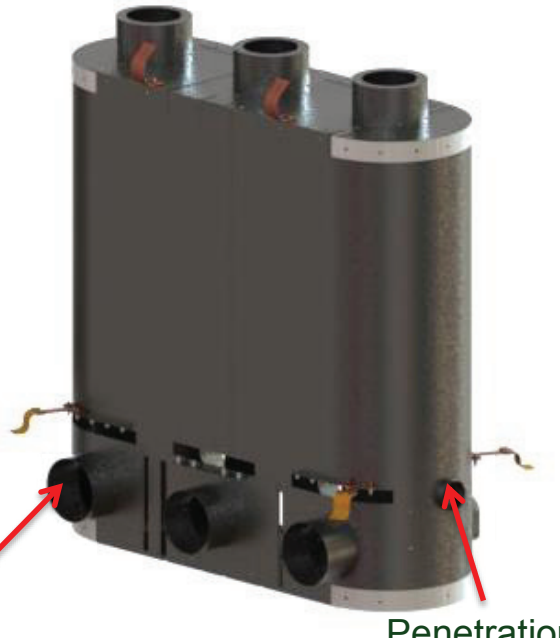


WPM System Tracking for ETCM

Local Magnetic Shielding is Designed to Keep Resonator Surfaces Below 15 mG When Transitioning to Superconducting



4 individual shields that encompasses helium vessels
Assembled with, closed-end pop rivets & screws

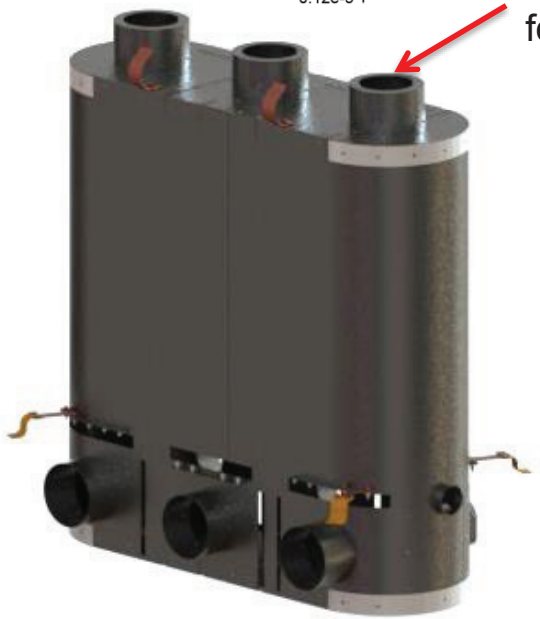


Penetration holes for FPC

Penetration holes for beam port

On cavity:
0.12e-5 T

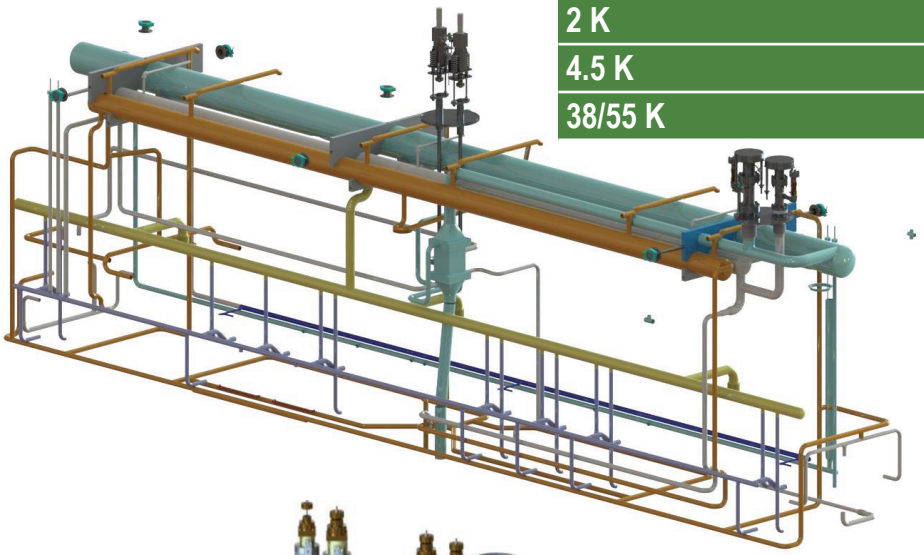
Penetration holes for header bellow

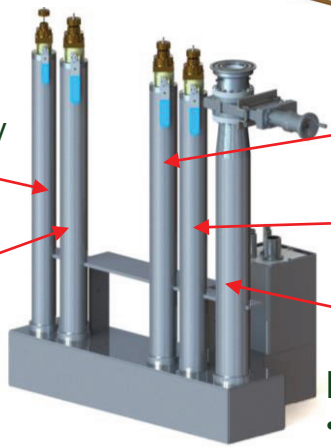


Local Shielding Detail Design Is Based On ReA3 Experiences
Better shielding choice for large cryomodules, lower cost

Cryogenic System Independently Cool Solenoids to 4.5K and Cavities to 2K

Projected Heat Load	Static	Dynamic
2 K	5.8 W	32.0 W
4.5 K	30.4 W	2.1 W
38/55 K	168.1 W	33.4 W



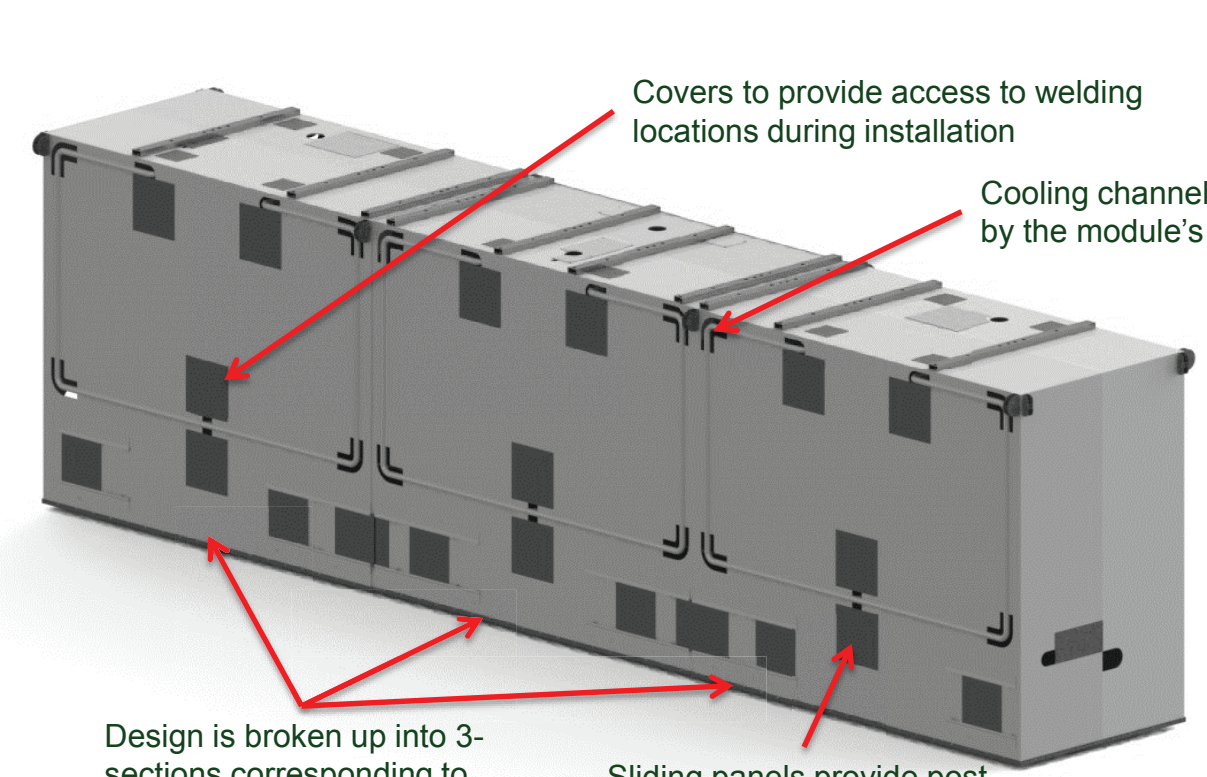


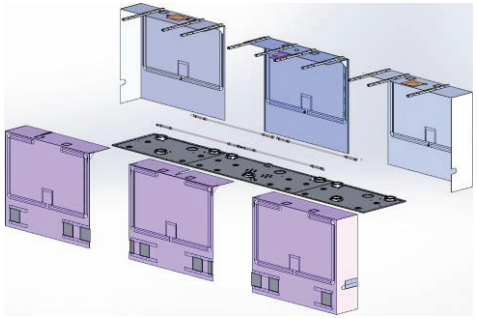
Bayonet Box

- Efficient & repeatable cryomodule installation
- Fabricated separate from the vacuum vessel

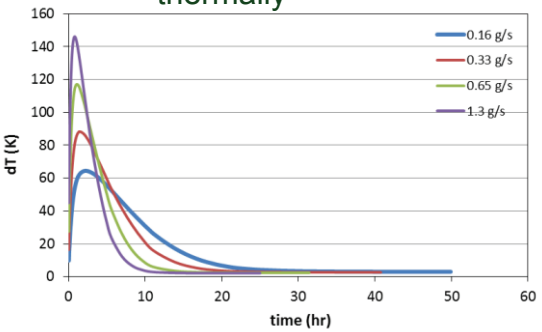
- Independent 4.5 K and 2 K Helium circuits to allow warm (~10-20 K) resonators and degaussing cycle of SC solenoid magnets
- Minimize total heat load to the cryoplant to the cryomodule system
- Optimize P& ID for 2 K process improvements
- Provide for dp >2.5 psi for gas vapor cooled magnet leads
- Able to withstand installation and transport loads
- Designed in consistence with ASME 31.1 piping code
- Cryogenics system was developed with collaboration with FRIB cryogenics group and Jefferson Lab

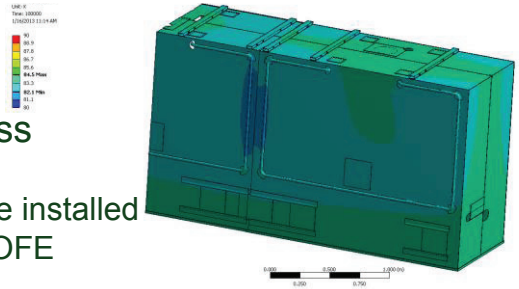
Thermal Shield is Designed to Minimize/Regulate Thermal Radiation Hitting the Cold mass





Overlapping sections allows the shield to contract and expand thermally



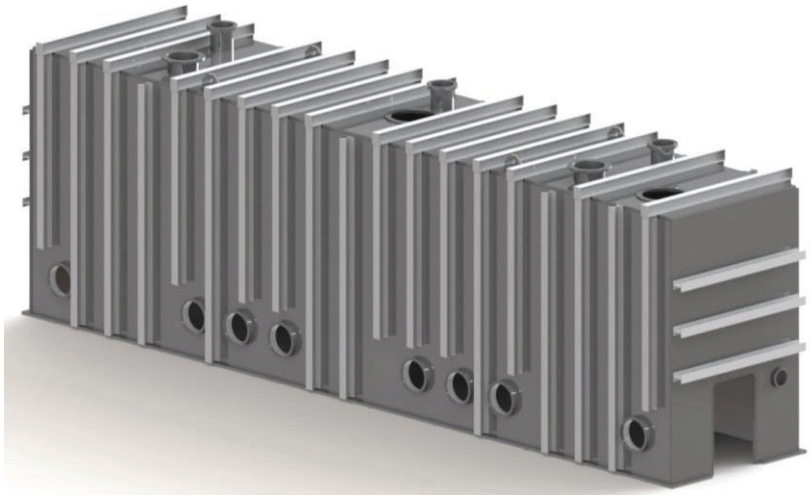


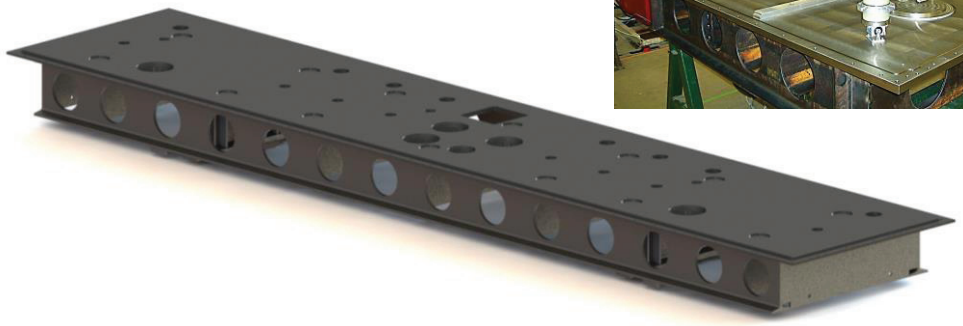
Thermal shield will be received as unit and assembled around the cold mass

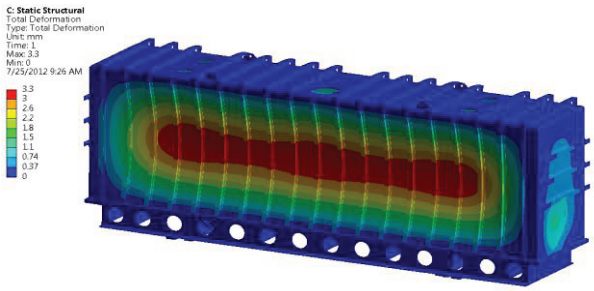
- 3 bottom plates will be assembled before cold mass is mounted
- 6 panels construct the sides and top of shield after cold mass and cryogenics are installed

Cost analysis appraising material and assembly showed a benefit using aluminum vs. OFE copper for production quantities

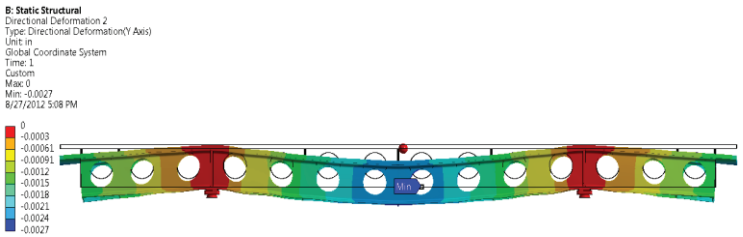
Vacuum Vessel Bottom Assembly Provides Stable Platform for Kinematic Alignment Supports & Vacuum Vessel Top Assembly Provides Platform To Maintain Insulating Vacuum with FRIB Three Dimensional O-ring Concept







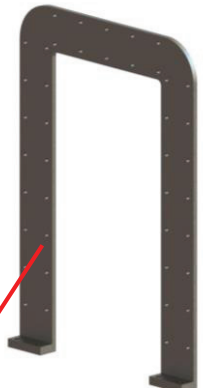
Maximum Sidewall Deflection = 3.3 mm



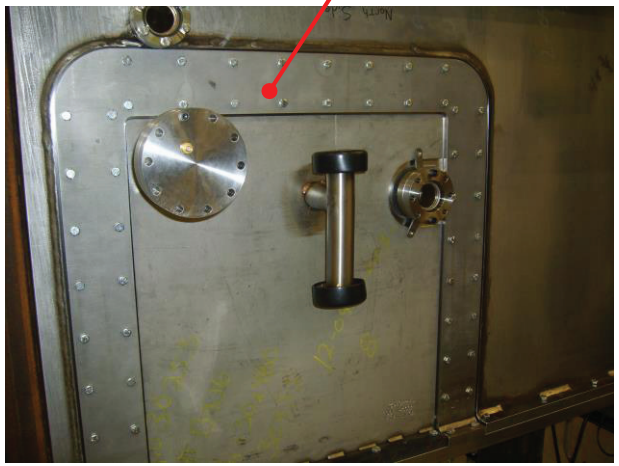
Maximum Vertical Deflection = .07mm Under Cold mass Load

Three Way Seal O-ring Has Been Demonstrated. Increases Space for Diagnostics Between Cryomodules

O-ring Inserted into Hood and Vacuum Vessel



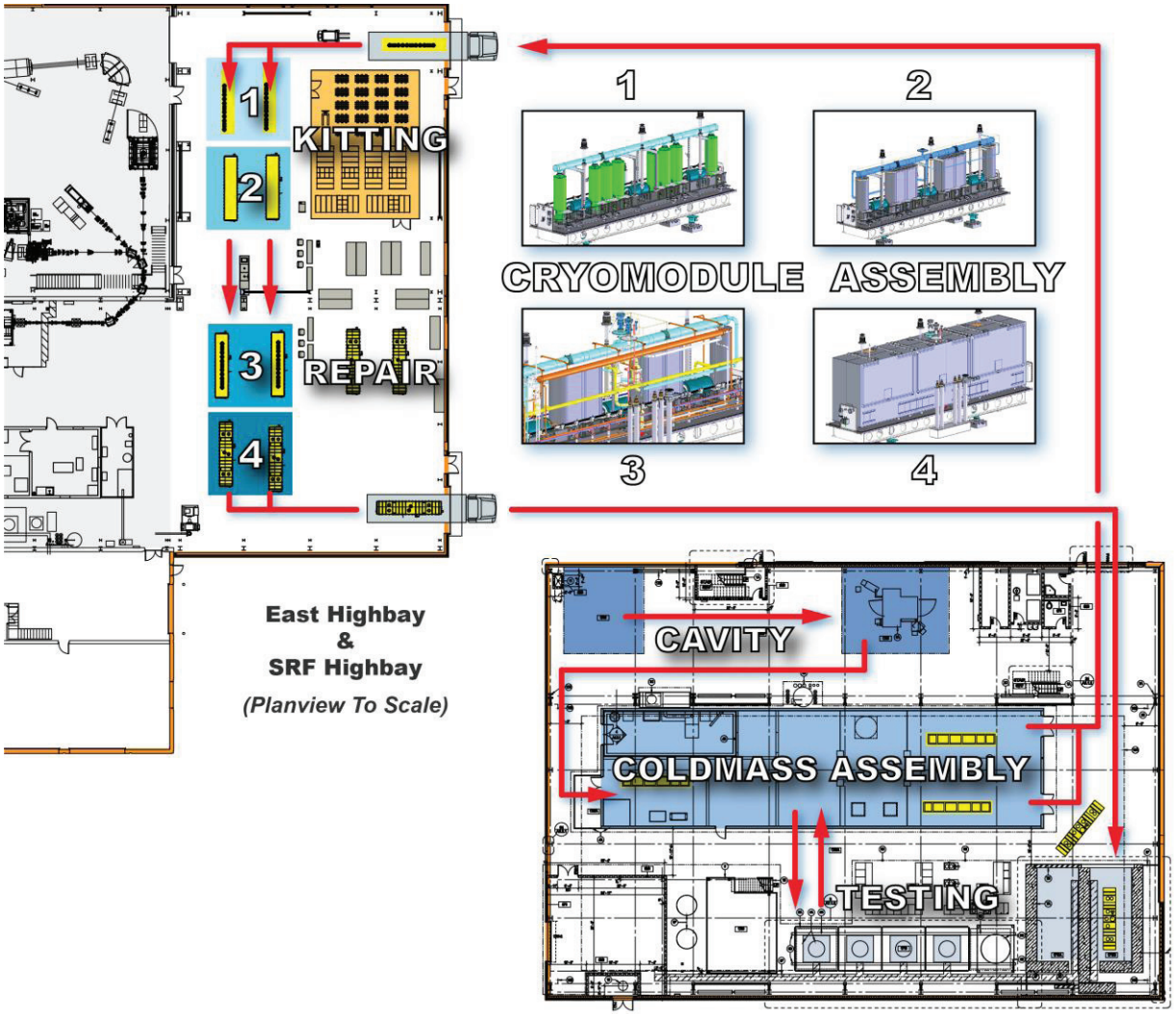
Beam line Hoods are Attached to Cold mass



Seal Plate Presses O-ring to Vessel Assembly and Hood

Vacuum Vessel Is Lowered on Baseplate

Cryomodule Assembly Sequence Developed And Linked To SRF High Bay Workflow



Summary

- SRF Department continues to prepare for mass-production
- Procurement oversight is intense but results in first successes
  - Quality assurance techniques scale to mass production
- Cryomodule design choices are finalized
  - Next focus will be on building FRIB cryomodule prototypes (QWR + HWR) to verify performance