Superconducting Cavity Cryomodule Designs for the Next Generation of CW Linacs: Challenges and Options

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Many thanks to our co-workers, colleagues, and collaborators at laboratories around the world and to the cooperative spirit we all share.

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Outline

- Cryomodule design overview
- Overall configurations
- Support systems
- Thermal shields and insulation
- Magnetic shielding
- Cryogenic piping
- Tuners
- Couplers
- Summary

Cryomodule Design Overview

- There are lots of cavity types being used in various superconducting RF linac designs around the world
  - Single and multiple spoke
  - Half and quarter-wave
  - Elliptical resonators
  - Operating in pulsed or CW mode
  - Spanning frequencies from a few hundred megahertz to several gigahertz
  - Operating nominally at 4.5 K or 2 K

Cryomodule Design Overview (cont'd)

- In spite of this variety, cryomodules for those cavities contain many common design features. They all have
  - Outer vacuum shell
  - Cold mass support system
  - One or more layers of magnetic shielding
  - One or more intermediate thermal shields
  - Multi-layer insulation
  - Cryogenic piping
  - Cavity tuning systems
  - Input and HOM couplers
  - Beam vacuum gate valves
  - Instrumentation

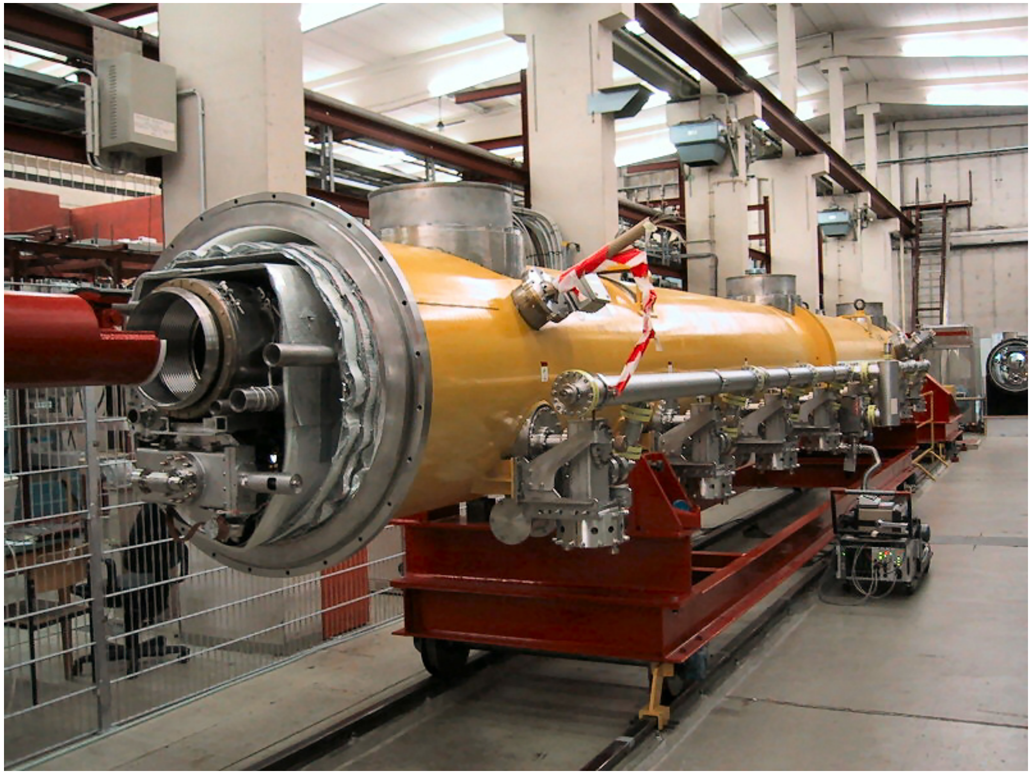
Cryomodule Design Overview (cont'd)

- There are also features that might be unique to each design
  - Active alignment systems
  - Cavity position monitoring systems
  - Internal heat exchangers
  - Cold-to-warm-transitions
  - Active magnetic elements
  - Current leads
  - Segmentation
  - And many others

Cryomodule Design Overview (cont'd)

- The goal here is to describe some of the options available to designers of both pulsed and CW mode cryomodules.
- Focus will be on things that guide the design process and ultimately lead to a design choice.
- Most of the time there is no right or wrong choice.
- More often than not, final design features are a compromise between many factors.

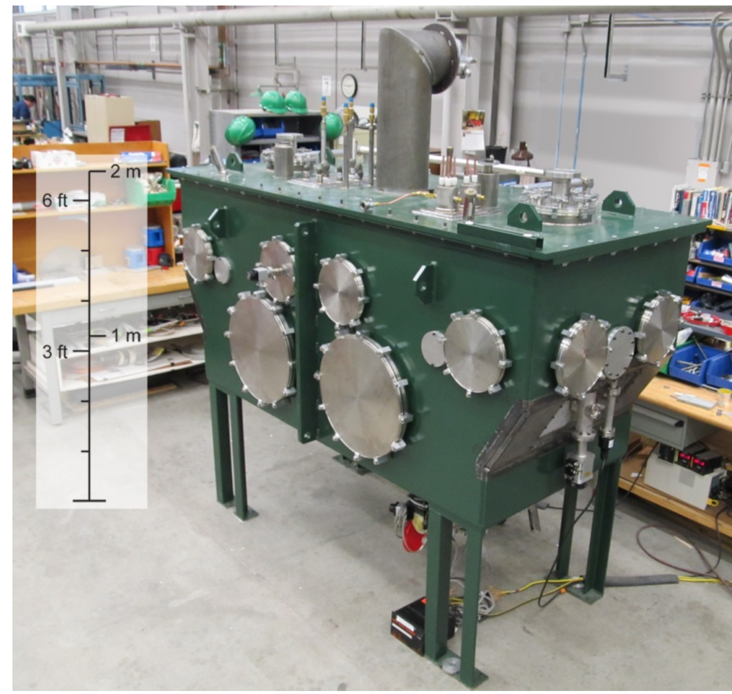
Overall Configurations



1.3 GHz elliptical cavity XFEL cryomodule at DESY (example of coarse segmentation)

Round vessels tend to house elliptical cavities and spoke resonators

Technology demonstrator cryomodule for FRIB

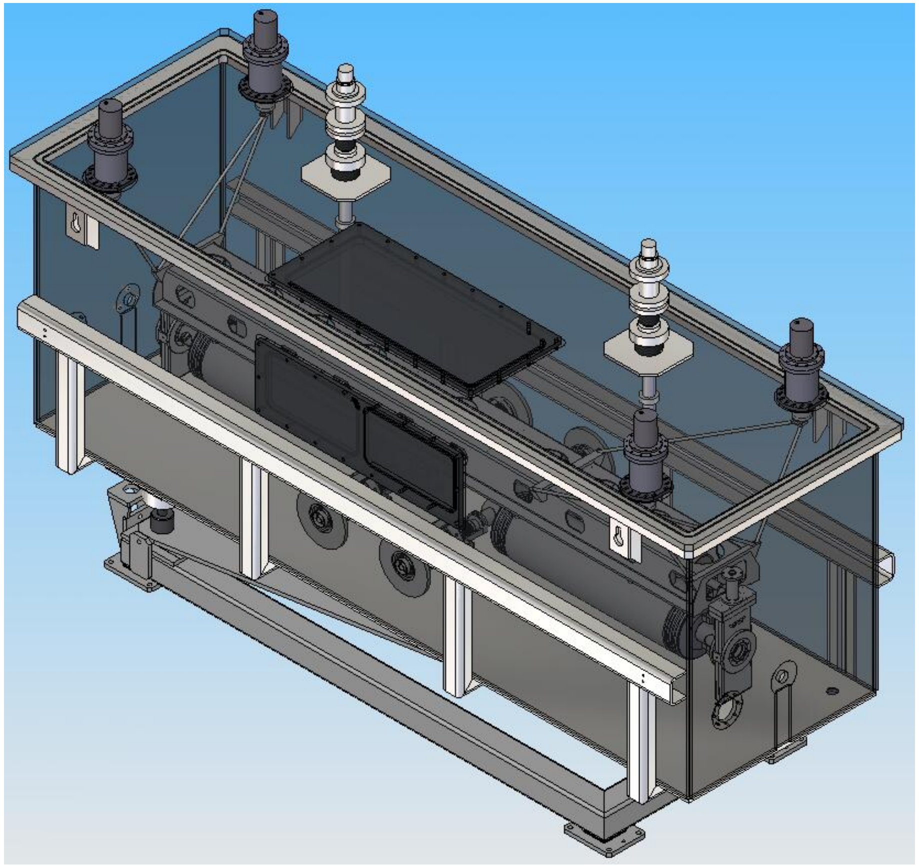


Rectangular vessels tend to house quarter and half-wave cavities

Overall Configurations (cont'd)

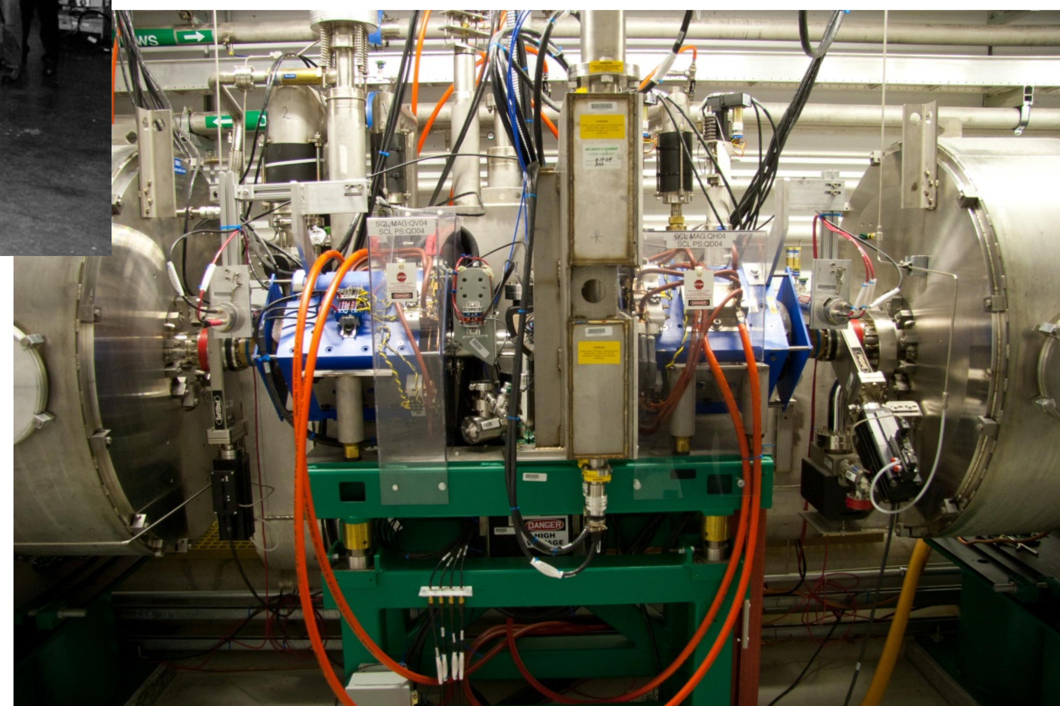
Quarter-wave cryomodule for the ATLAS upgrade at Argonne National Laboratory

ARIEL cryomodule at TRIUMF



Overall Configurations (cont'd)

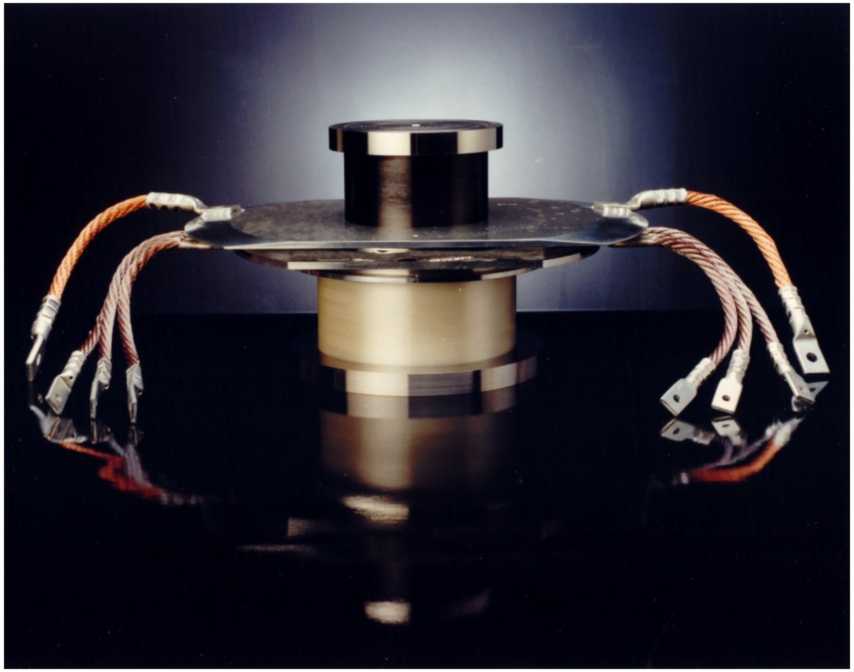
Jefferson Lab cryomodule (example of fine segmentation)



Structural Supports

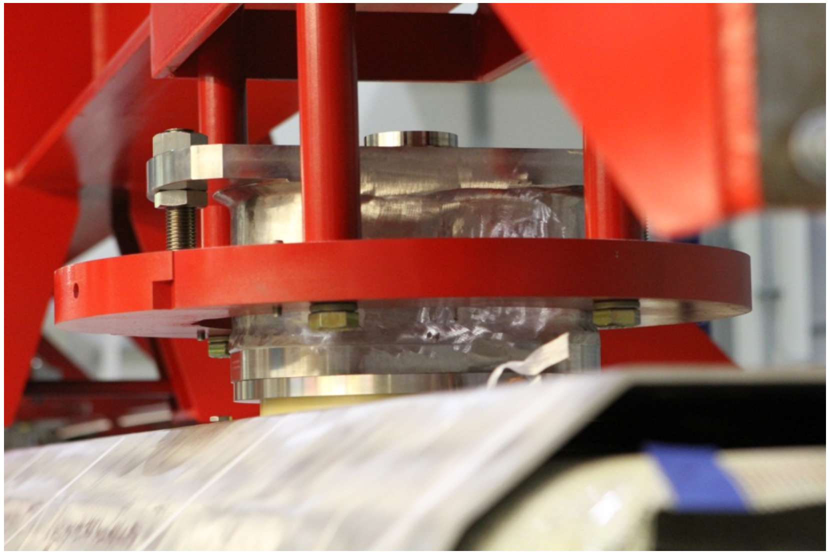
- Challenges and Options
  - Structural loads due to shipping and handling, cooldown, fluid flow, and ground motion
  - Low heat load requirement to cavities, magnets, and thermal shields
  - Material choices are generally composites, high strength stainless steel, and titanium
  - Configurations include posts, tension members, space frames, and many others

Support Systems (cont'd)

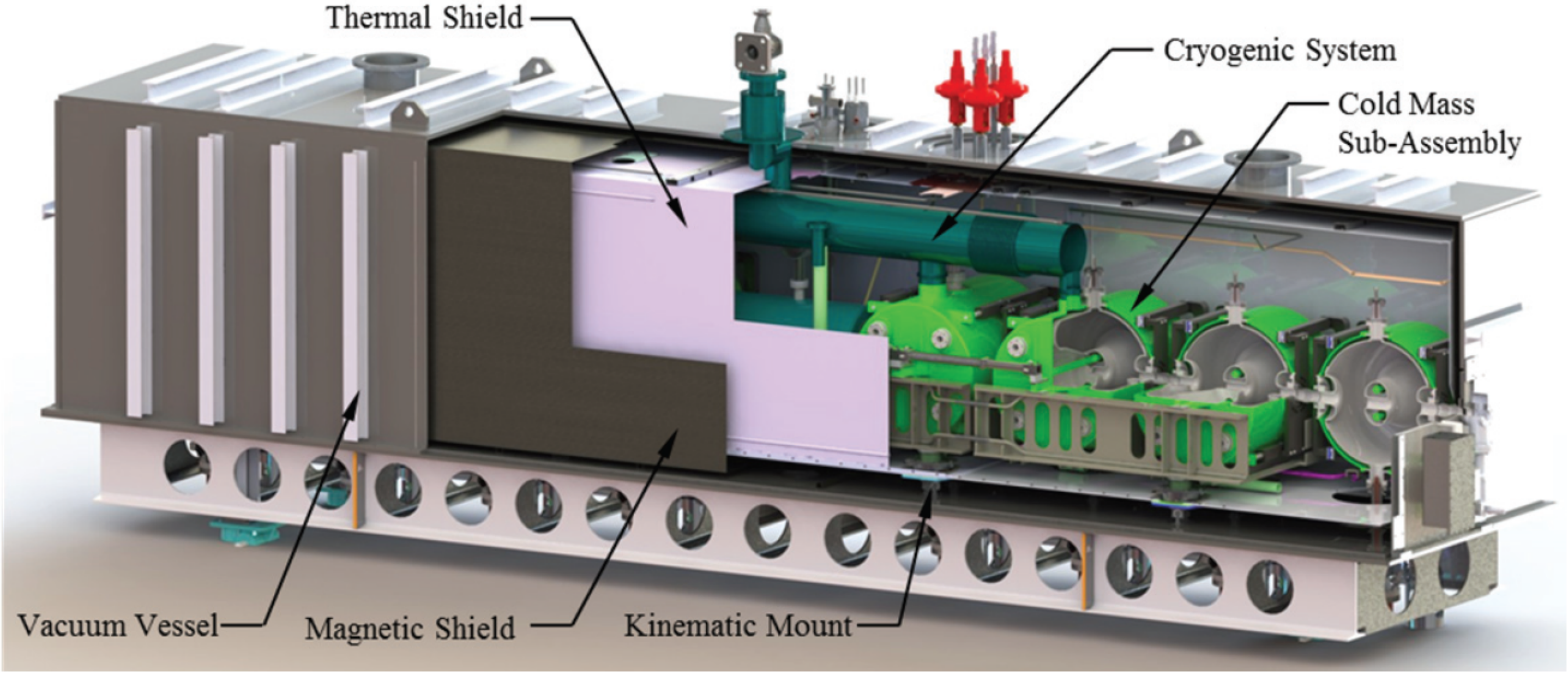


SSC magnet support

XFEL and ILC cryomodule support



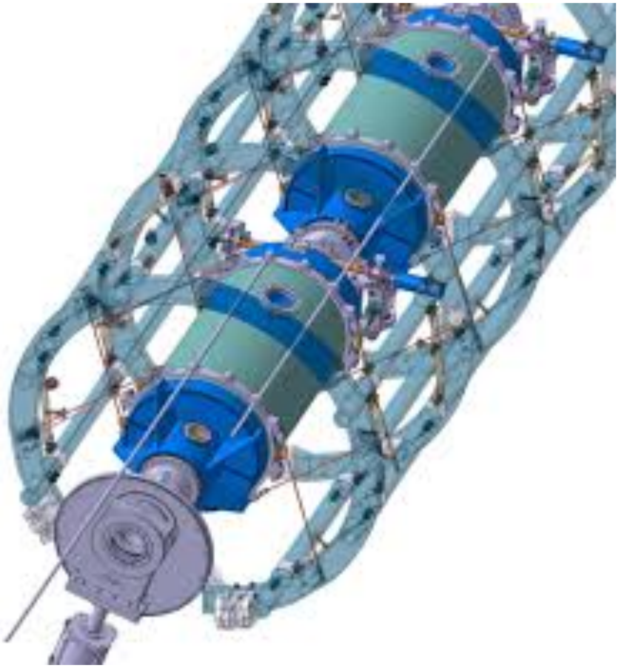
Support Systems (cont'd)



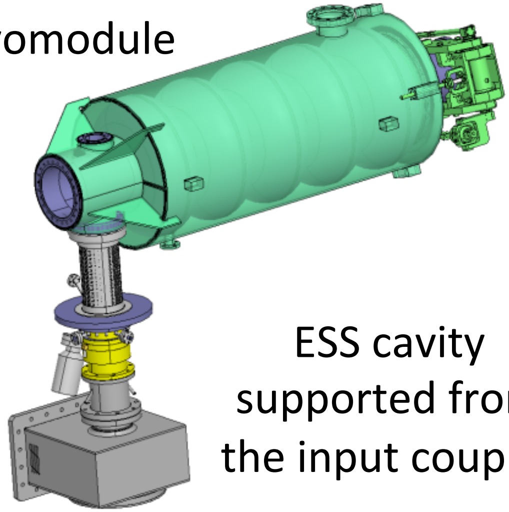
FRIB cryomodule

Support Systems (cont'd)

Jefferson Lab upgrade cryomodule



ESS magnet support and space frame



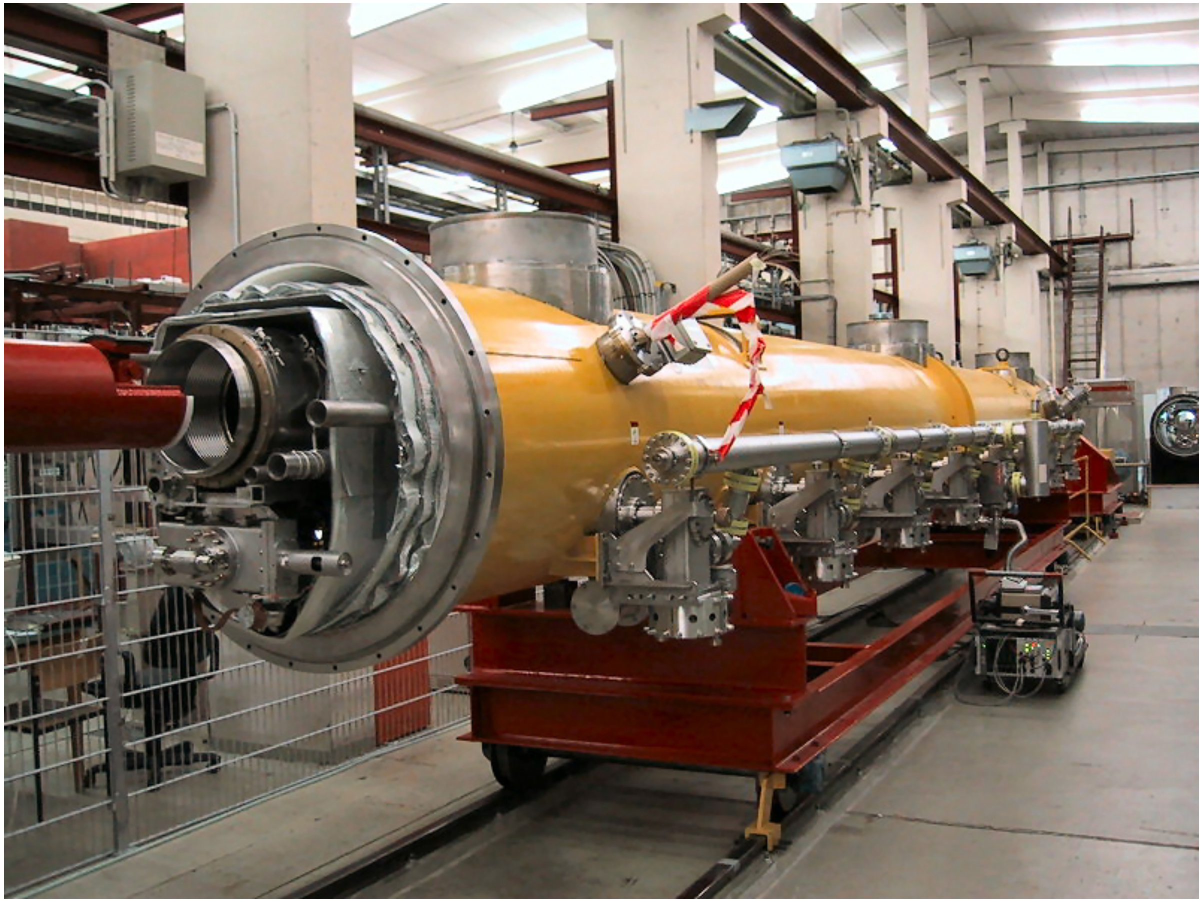
ESS cavity supported from the input coupler

Thermal Shields and Insulation

- Challenges and Options
  - Provide effective heat transfer of thermal radiation and provide a source for discreet intercepts
  - Shields can be single or multiple annular shells
  - Usually segmented or include features to minimize thermal bowing during cooldown and warm-up
  - Materials are most often aluminum (lighter, less expensive, difficult to connect to other piping) or copper (heavier, more expensive, easily soldered or brazed)
  - MLI is usually double aluminized mylar with fabric or nylon spacers or aluminum foil
  - Typical heat transfer rates are ~1 W/m^2 for 30 layers from 300 K to 70 K and 50 to 100 mW/m^2 for 10 layers below 80 K

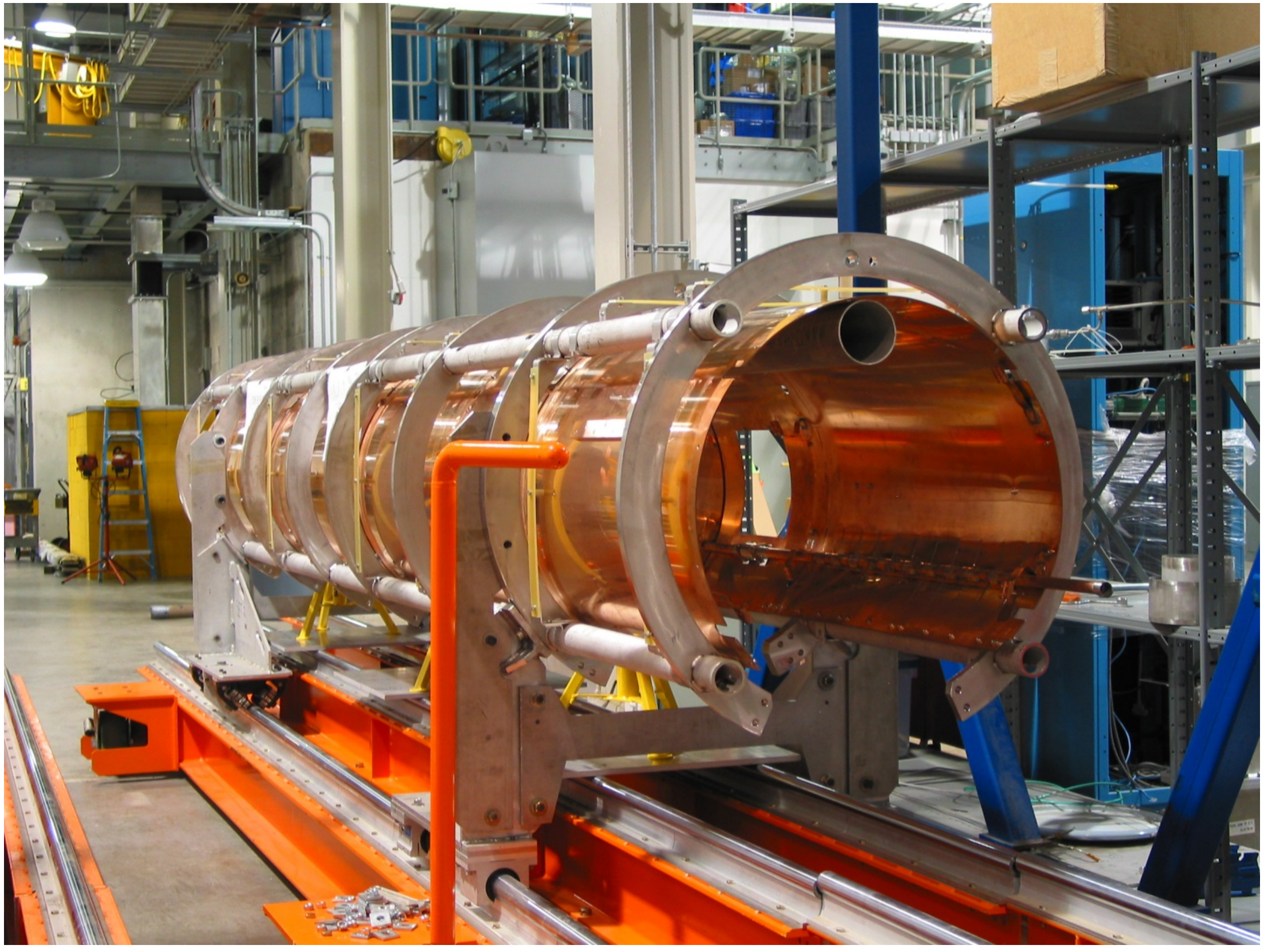
Thermal Shields and Insulation (cont'd)

XFEL cryomodule shields and MLI



Thermal Shields and Insulation (cont'd)

JLab upgrade thermal shield



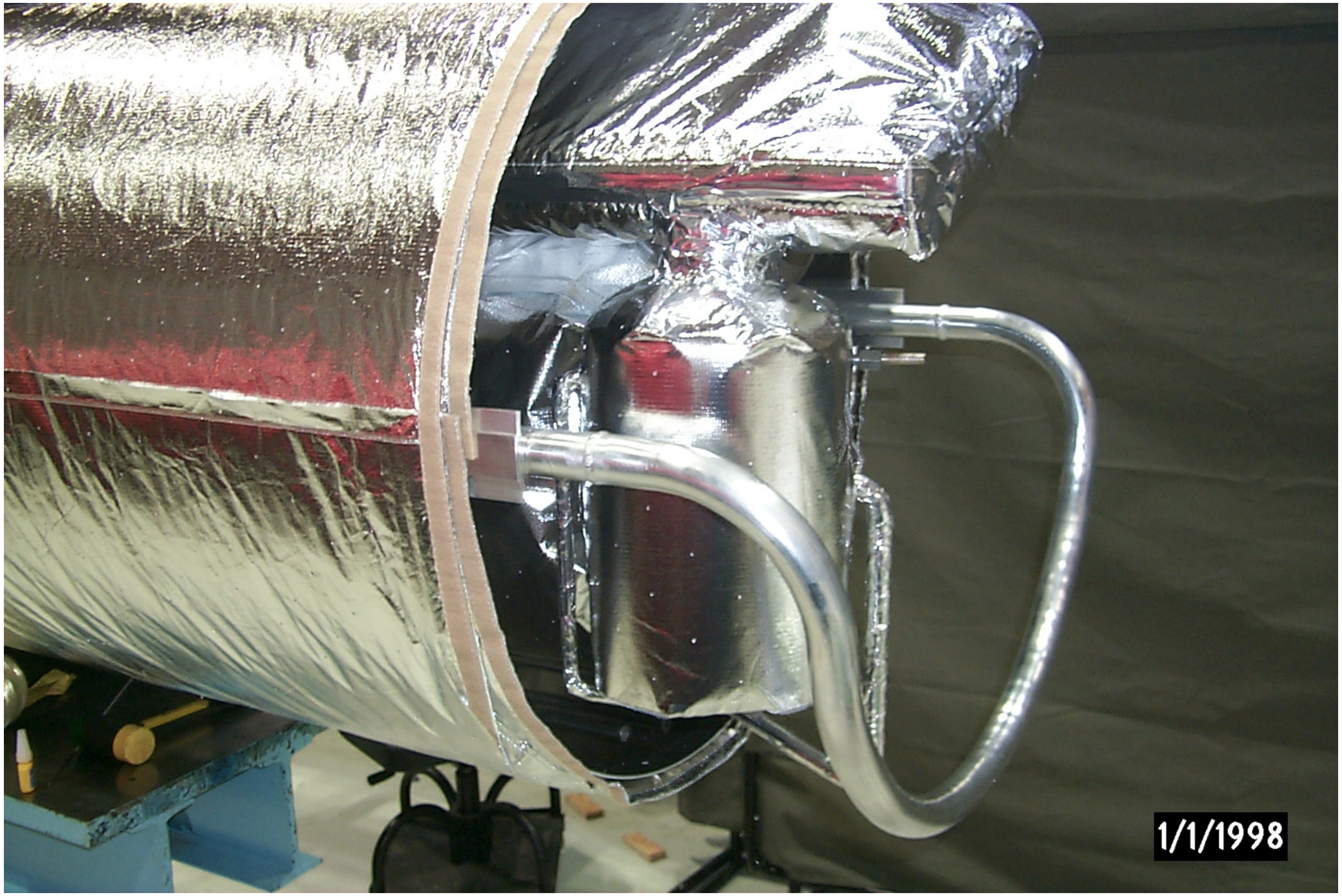
Thermal Shields and Insulation (cont'd)

ILC cryomodule shields and MLI

Thermal shield bowing

Thermal Shields and Insulation (cont'd)

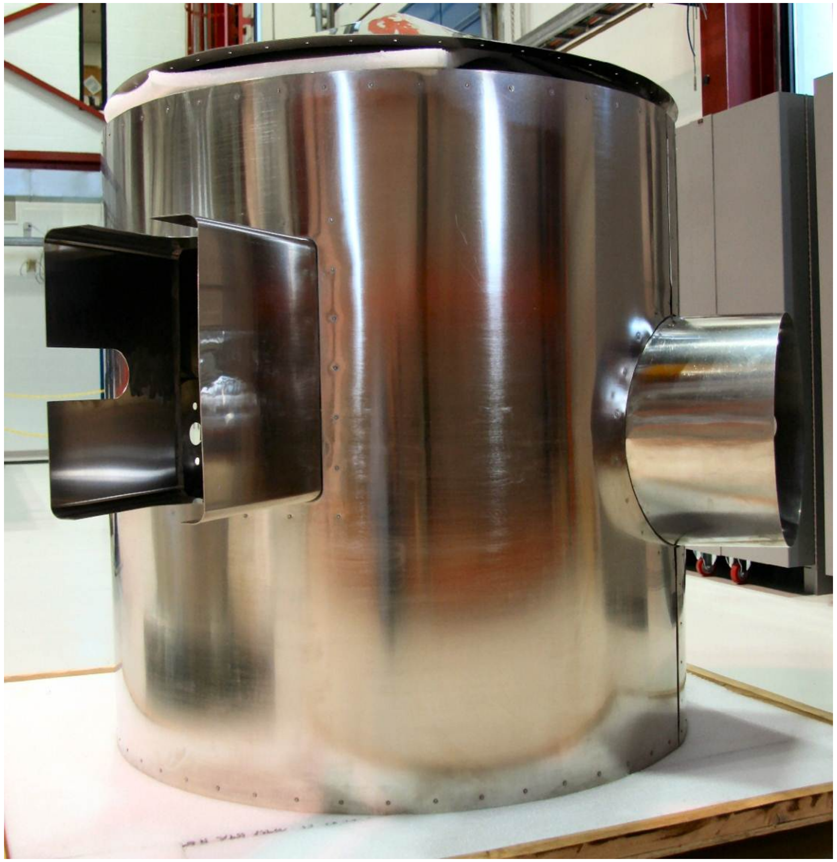
MLI blankets



Magnetic Shielding

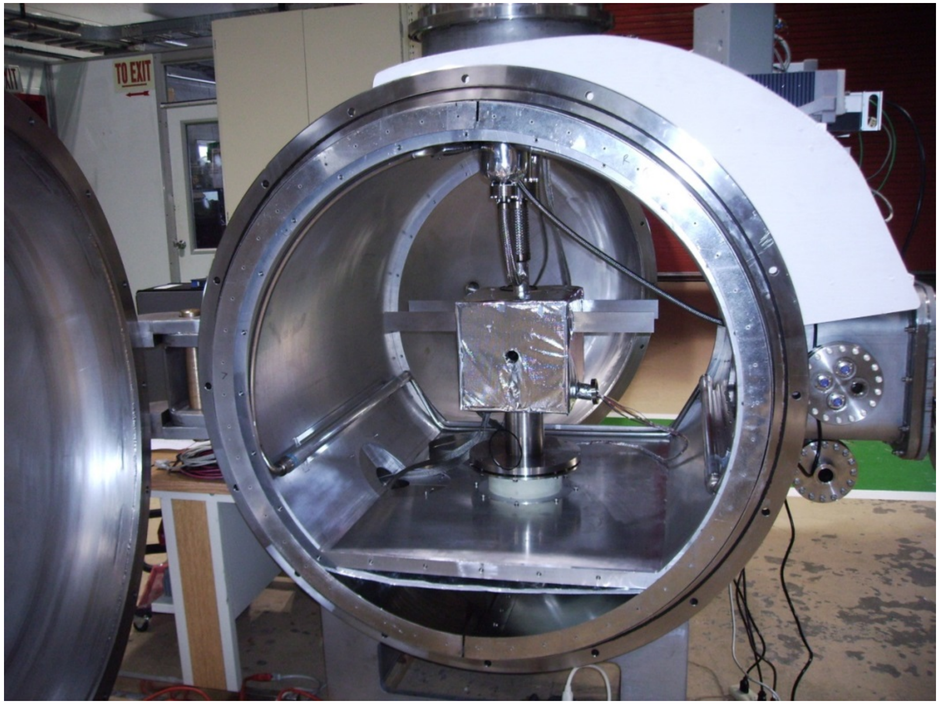
- Challenges and Options
  - Shield the superconducting cavities from the Earth's magnetic field and stray fields internal to the cryomodule from magnets and magnetized components
  - Plays a role in maintaining cavity Q, especially in high-Q designs like LCLS-II
  - Difficult to minimize penetrations and material degradation due to handling and joining
  - Can be single or multiple shells, warm, cold or both, materials can be conventional mu-metal or materials optimized for low temperature

Magnetic Shielding (cont'd)



Room temperature magnetic shield

Cold internal magnetic shield

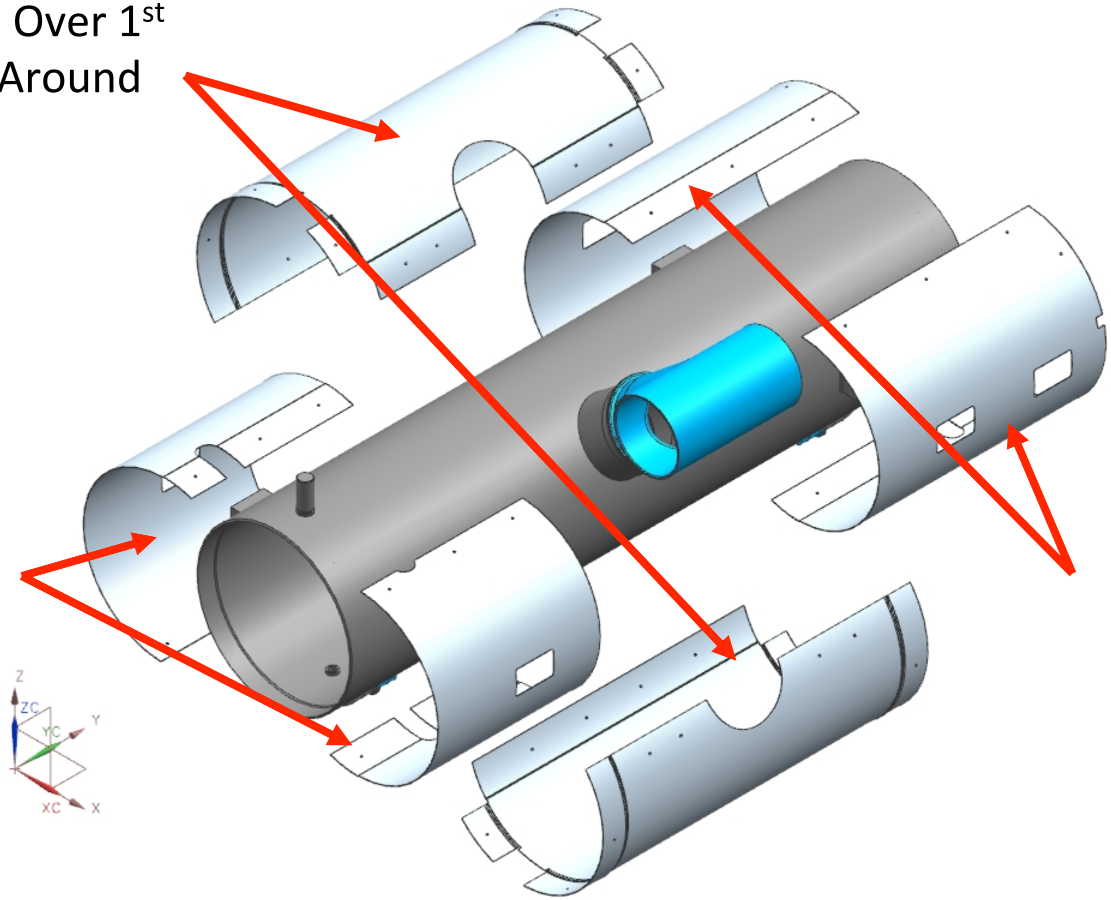


Magnetic Shielding (cont'd)

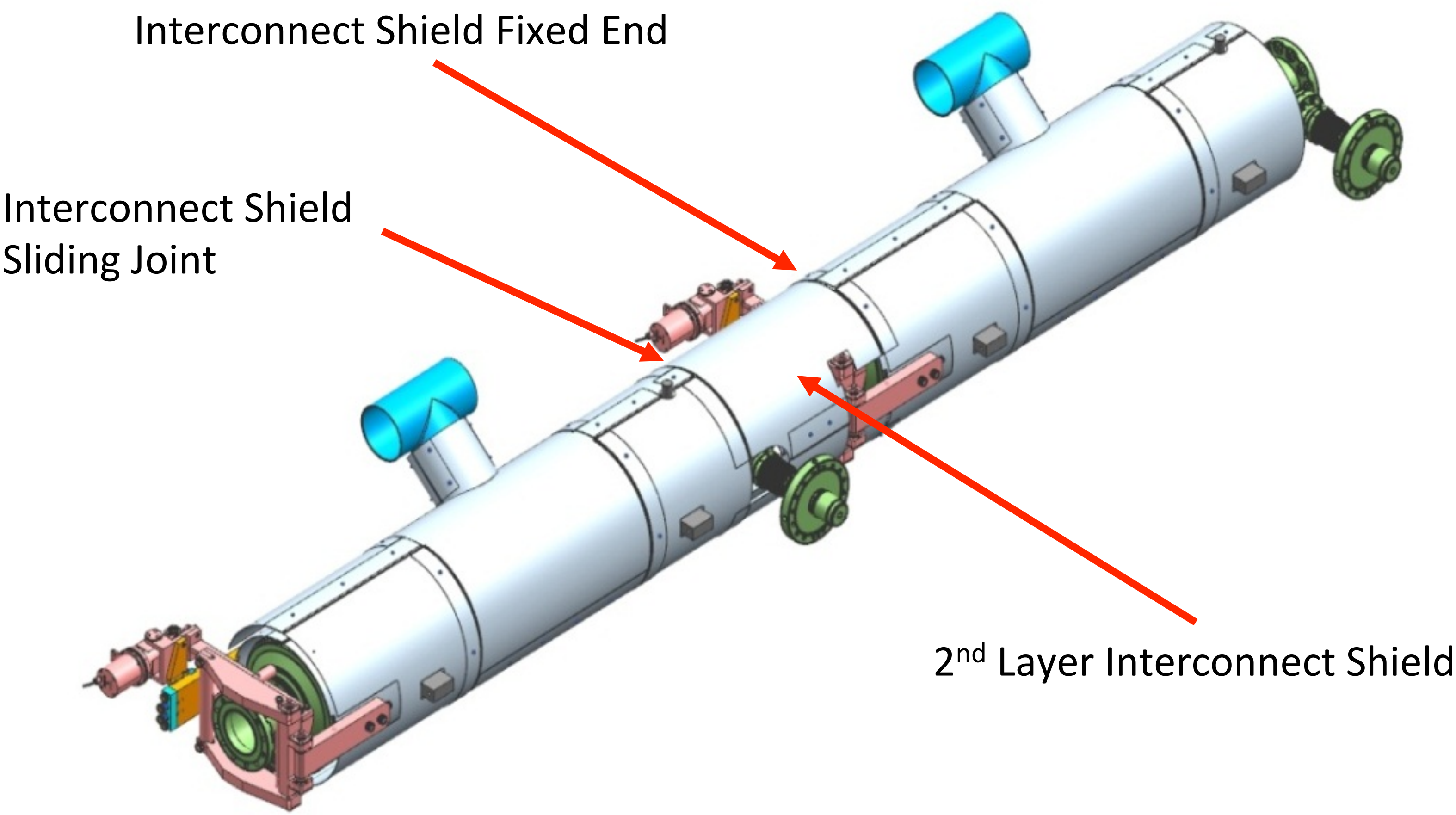
3rd Pair Attached Over 1st and 2nd Pair and Around "Chimney"

All Shield Parts 1mm Thick

1st Pair Attached



Magnetic Shielding (cont'd)

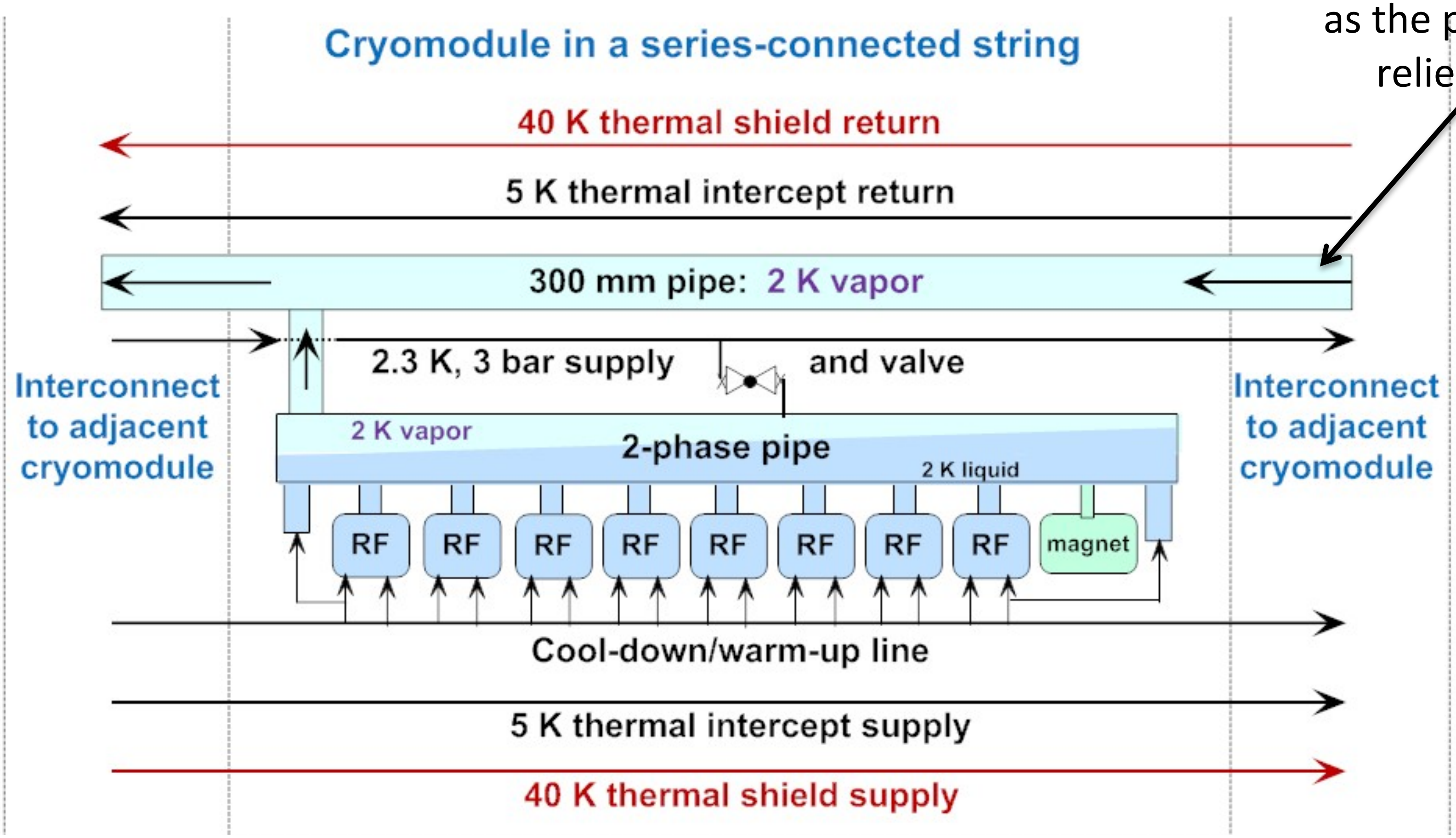


Cryogenic Piping

- Challenges and Options
  - Provides supply and return for cavities, magnets, thermal shields, and intercepts
  - Sizing must accommodate 2 K "speed limit" and meet the requirements of maximum heat load
  - Sizing, wall thickness, and materials must meet applicable pressure vessel code requirements
  - Options depend on segmentation, the need for internal valves, whether an internal heat exchanger is required, etc.
  - Materials can include stainless steel, aluminum, copper, and titanium

Cryogenic Piping (cont'd)

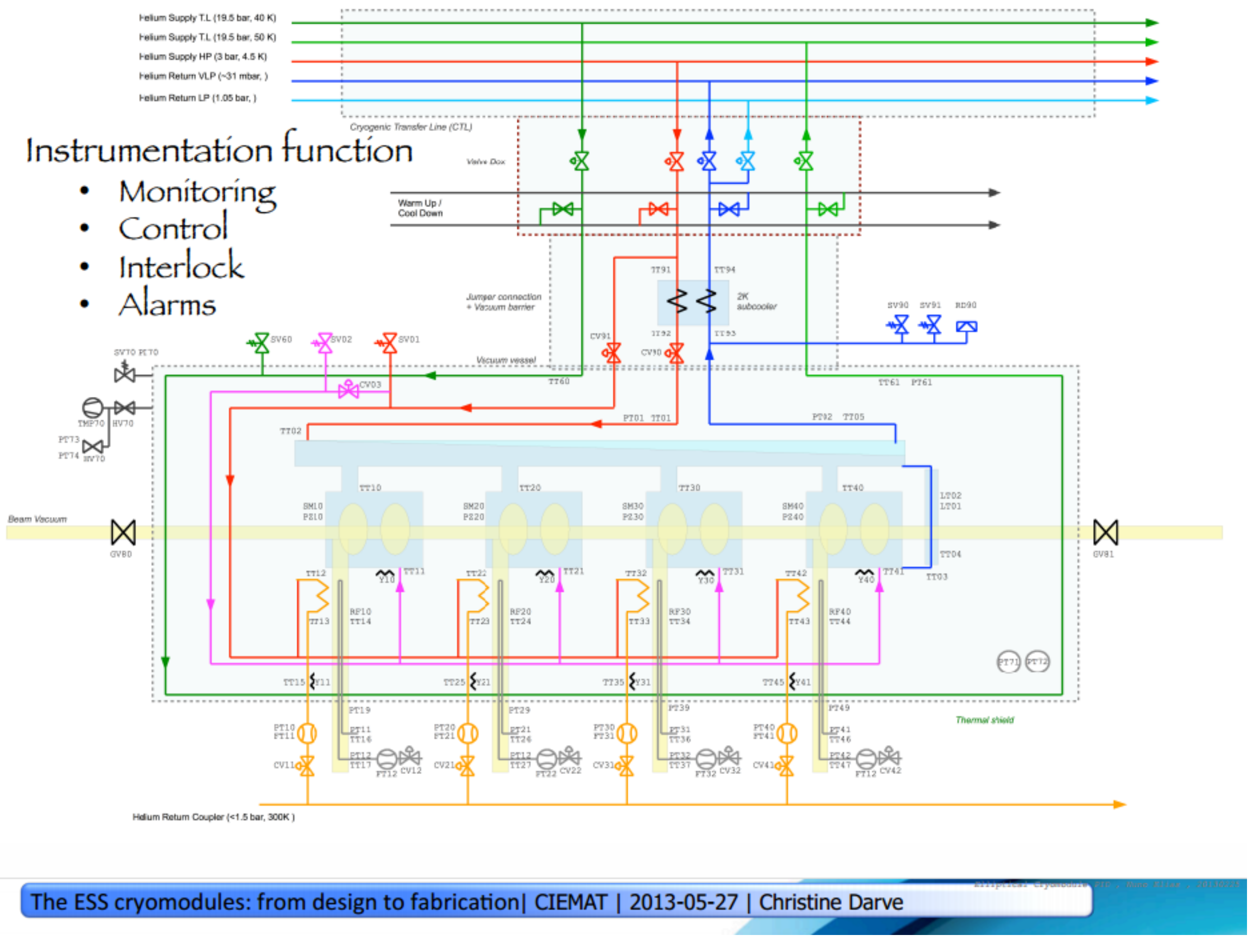
May also serve as the pressure relief line



Cryomodule piping connections for course segmentation

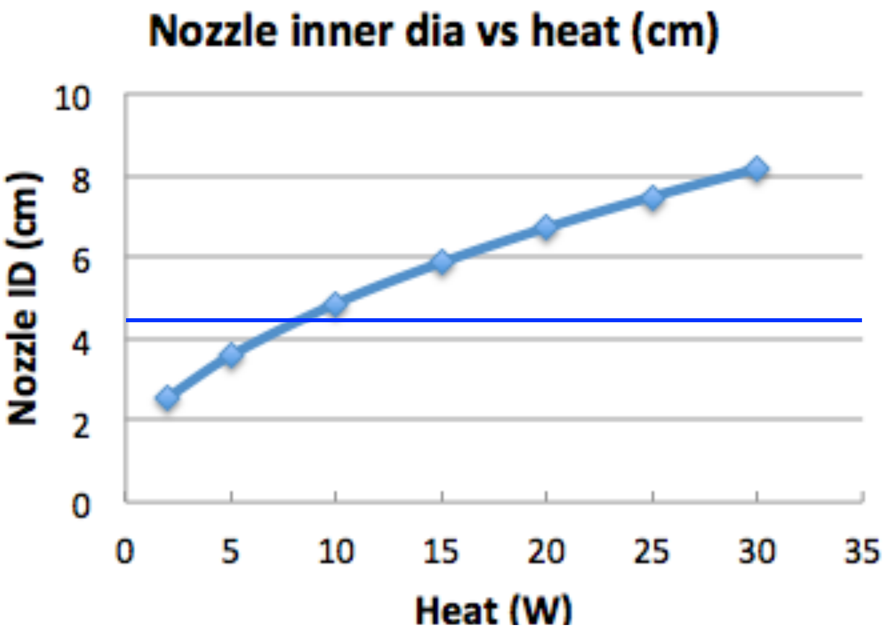
Cryogenic Piping (cont'd)

Instrumentation function
- Monitoring
- Control
- Interlock
- Alarms



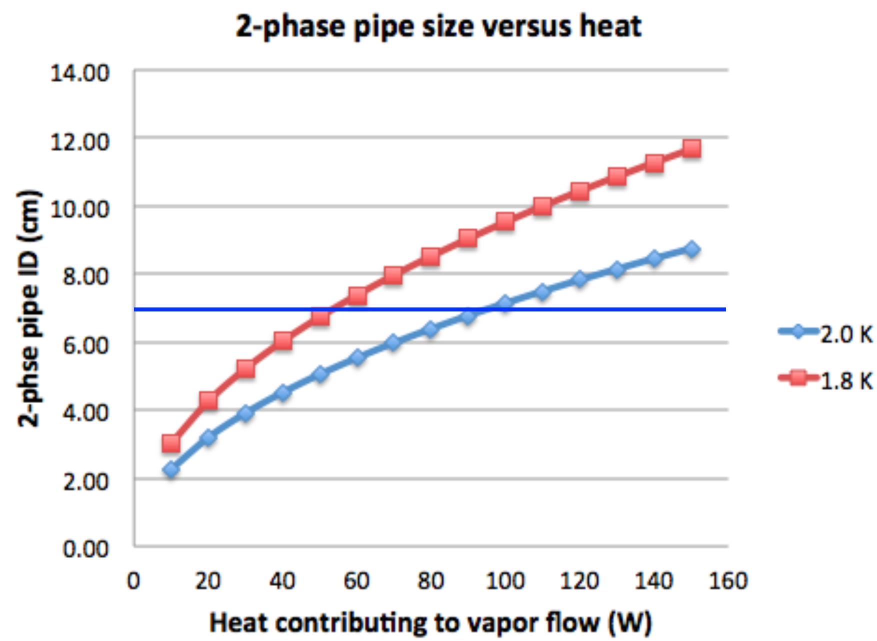
Cryomodule piping connections for fine segmentation

Cryogenic Piping (cont'd)



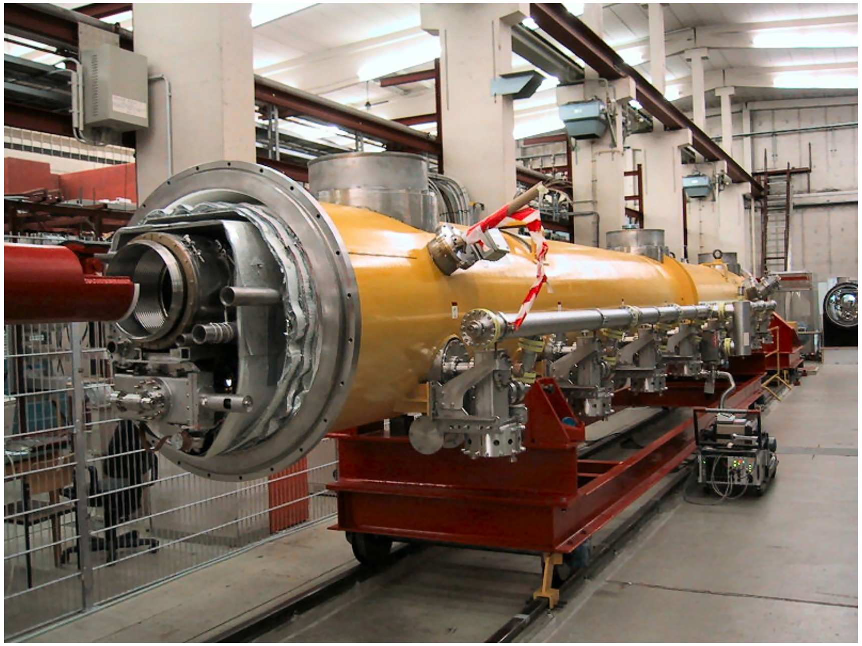
Connection diameter vs. heat flux

5 meter/sec speed limit for vapor over liquid sets 2-phase pipe size



PIP-II Total CM Heat Loads [W]			
	70 K	5 K	**2 K**
Pulsed	2,860	895	**256**
CW	2,860	895	**1819**

Cryogenic Piping (cont'd)



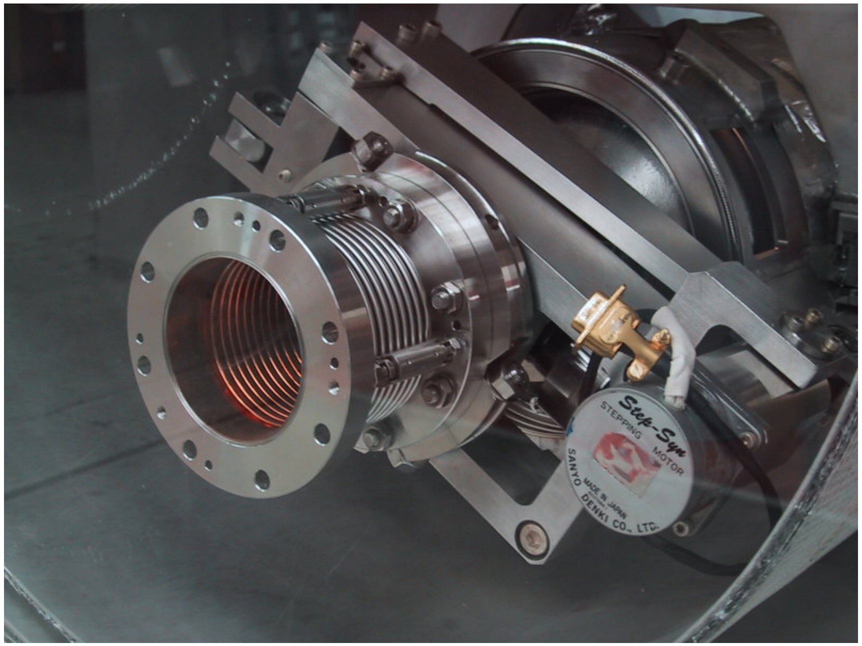
1.3 GHz elliptical cavity XFEL cryomodule at DESY

12 GeV upgrade cryomodule at JLab

Tuners

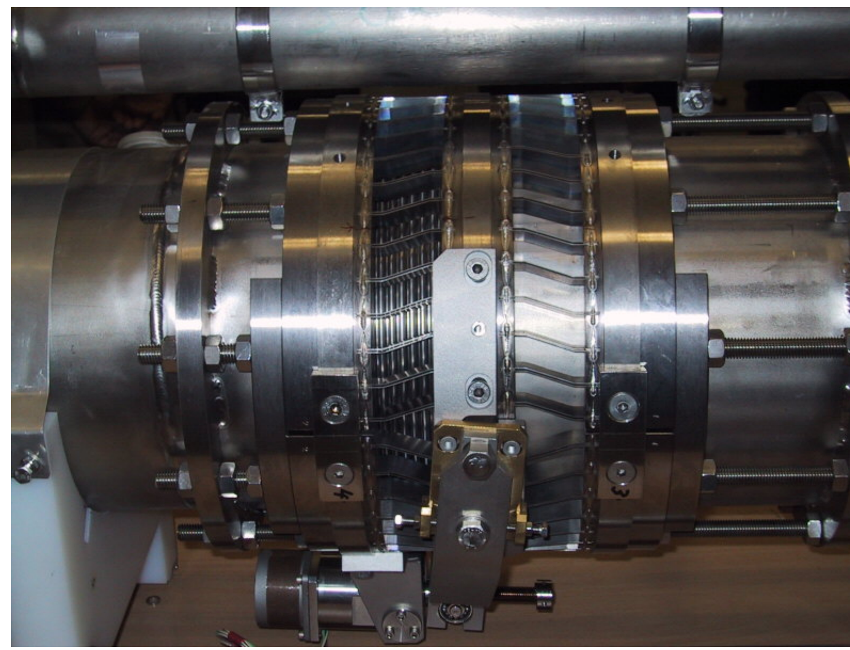
- Challenges and Options
  - Frequency change adjustment due to manufacturing errors, cooldown, Lorentz forces, fluid flow, external displacements, ground motion, and rotating machinery
  - Tuning range from a few Hz to several kilohertz
  - Tuner types include lever, blade, and diaphragm or local deformation
  - Actuators can include motors or pressurized actuators and can be internal or external to the cryomodule
  - Fine and fast tuning may require piezo-electric cartridges

Tuners (cont'd)

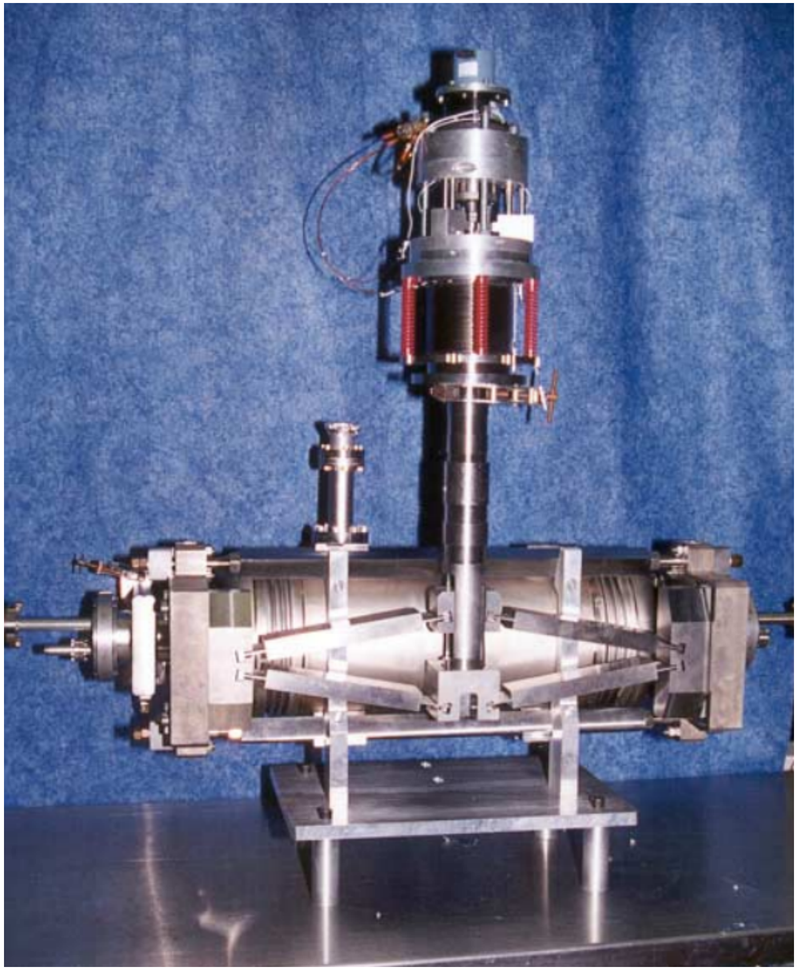


Lever tuner

Blade tuner

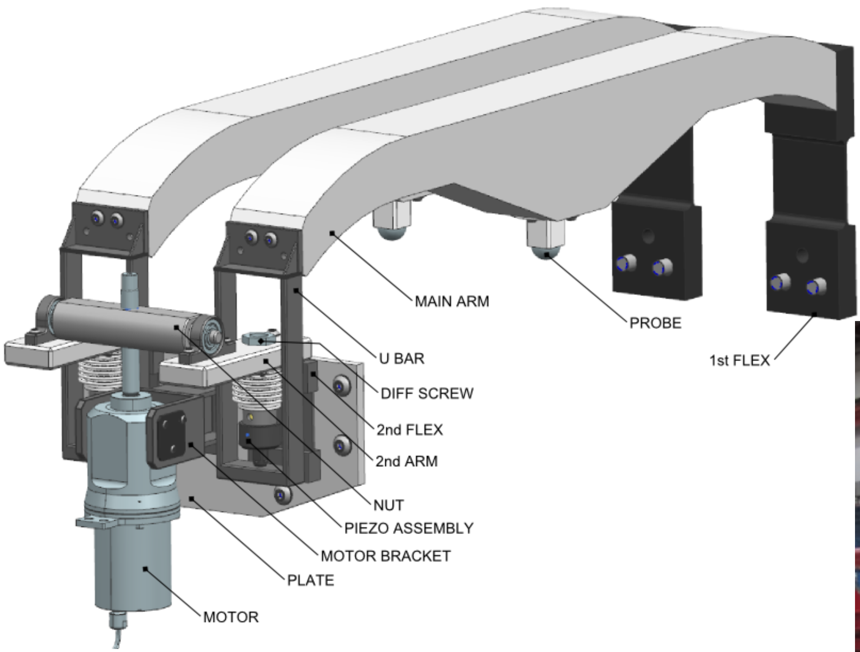


Tuners (cont'd)



Scissors jack tuner at JLab

Tuners (cont'd)



Lever style tuner on a single spoke resonator

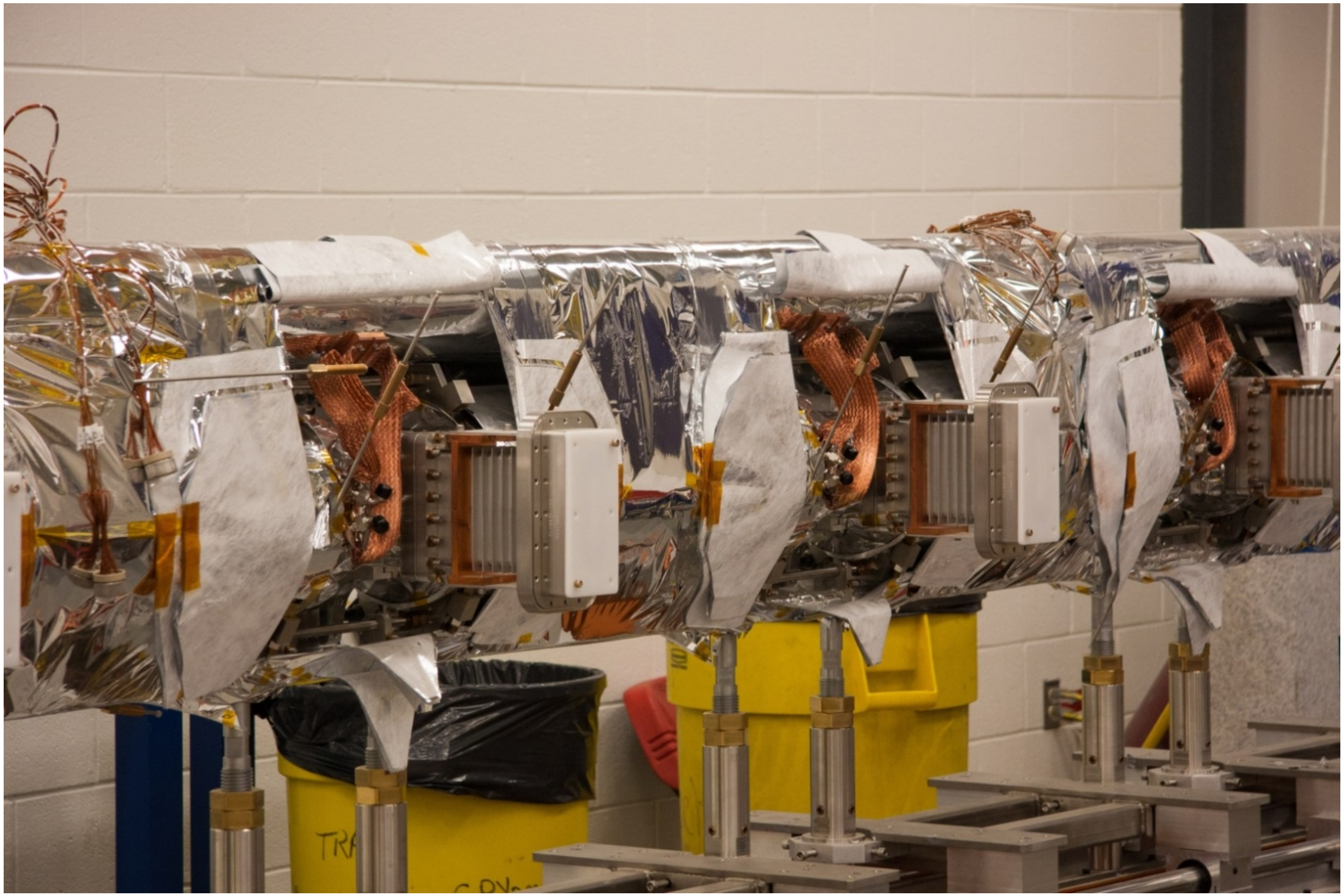
Couplers

- Challenges and Options
  - Provide multi-megawatt power for pulsed or CW operation
  - Multipacting, breakdown, and heating are common issues
  - Designed for clean assembly
  - Copper coated bellows have proven challenging
  - Couplers can be coaxial, waveguide or a combination of both
  - One or more vacuum windows are usually required
  - External cooling may be required, especially for high power CW systems

Couplers (cont'd)

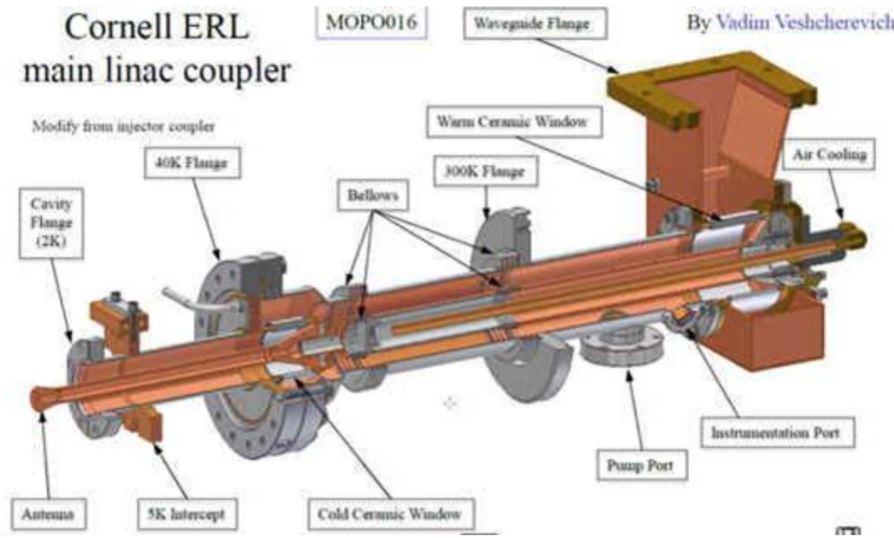
1.3 GHz cavity coaxial input coupler

Couplers (cont'd)

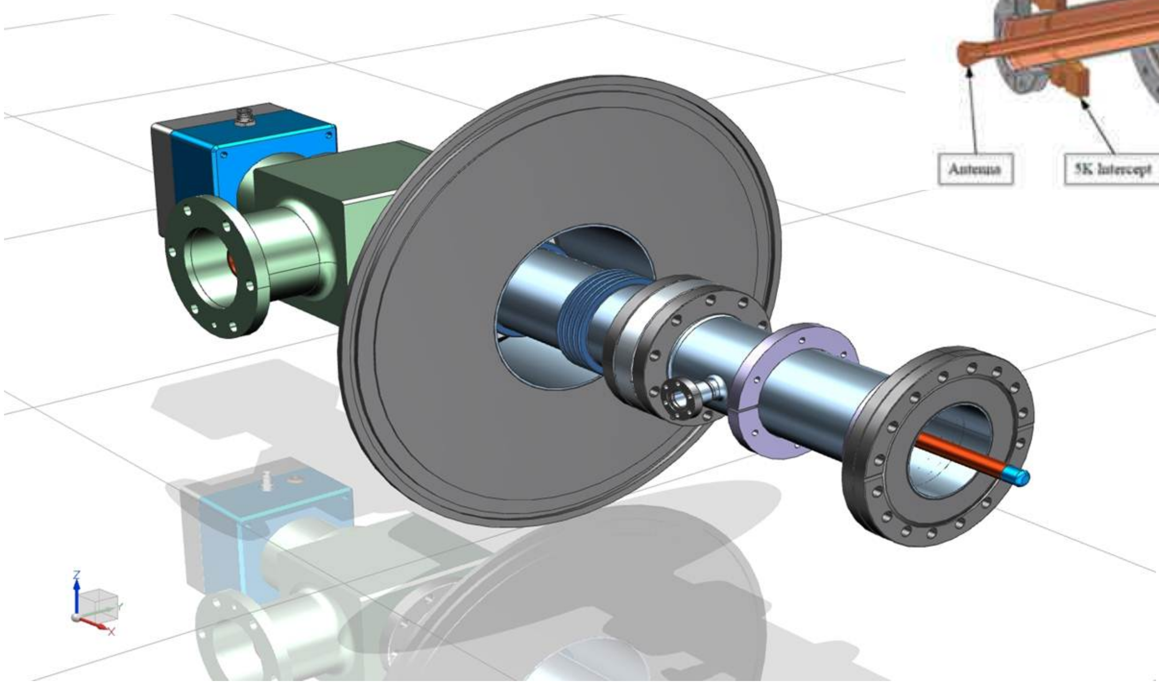


Waveguide sections in JLab upgrade cryomodule

Couplers (cont'd)



Single window coaxial coupler for SSR1 cavities at Fermilab



Summary

- Superconducting RF linac projects are being built in laboratories around the world.
- In spite of their differences all share many common features.
- They remain challenging due to cleanliness requirements, high RF power, high-Q cavities, low thermal losses, multipacting, mode extraction, tuning, alignment, and cost.
- For now at least, they seem to be the dominant direction being taken in accelerator research, taking full advantage of all our cooperative spirit.

Thanks very much…