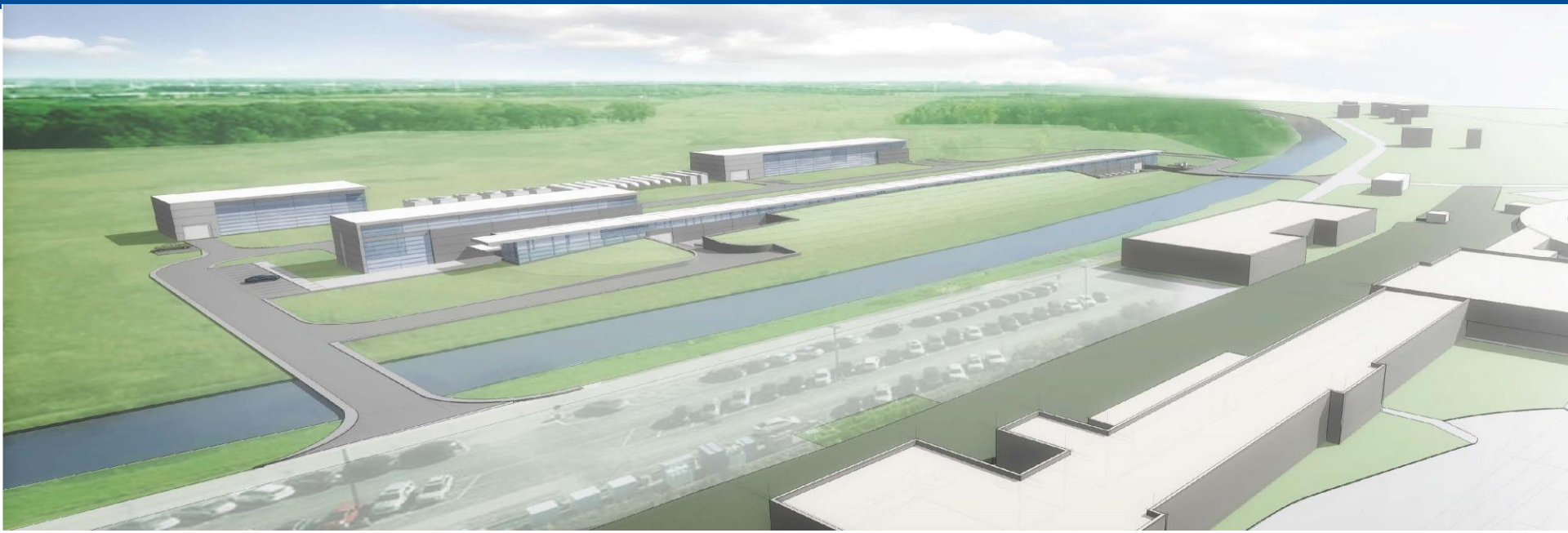


Half-Wave Resonator Cryomodule Design

Zachary Conway

PIP-II Half-Wave Resonator Cryomodule Transportation Review

14 August 2018

Outline

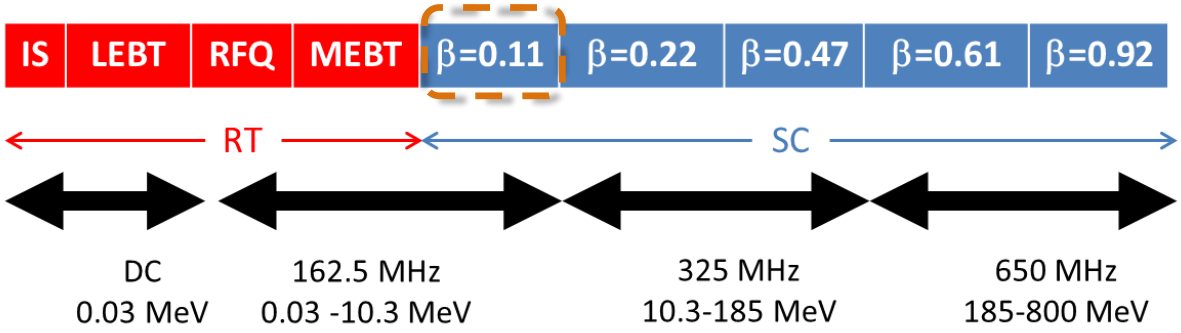
- Argonne National Laboratory Organization
- Half-Wave Resonator (HWR) cryomodule requirements.
- HWR cryomodule design overview.
- Transportation experience.
- Risk assessment.
- Summary.

Moving HWR Cryomodule at ANL

Project Organization

- Cryomodule and subcomponents designed by FNAL and ANL.
- ANL is fabricating and assembling the half-wave resonator (HWR) cryomodule.
- At ANL:
  - Group Leader = Mike Kelly.
  - Technical Lead = Zack Conway.
  - Mechanical Engineers = Jacob Kilbane and Mark Kedzie
- FNAL:
  - Project Liaison:
    - Joe Ozelis.
    - Formerly Andrei Lunin.
  - Project Engineer: Allan Rowe (L3 & CAM).

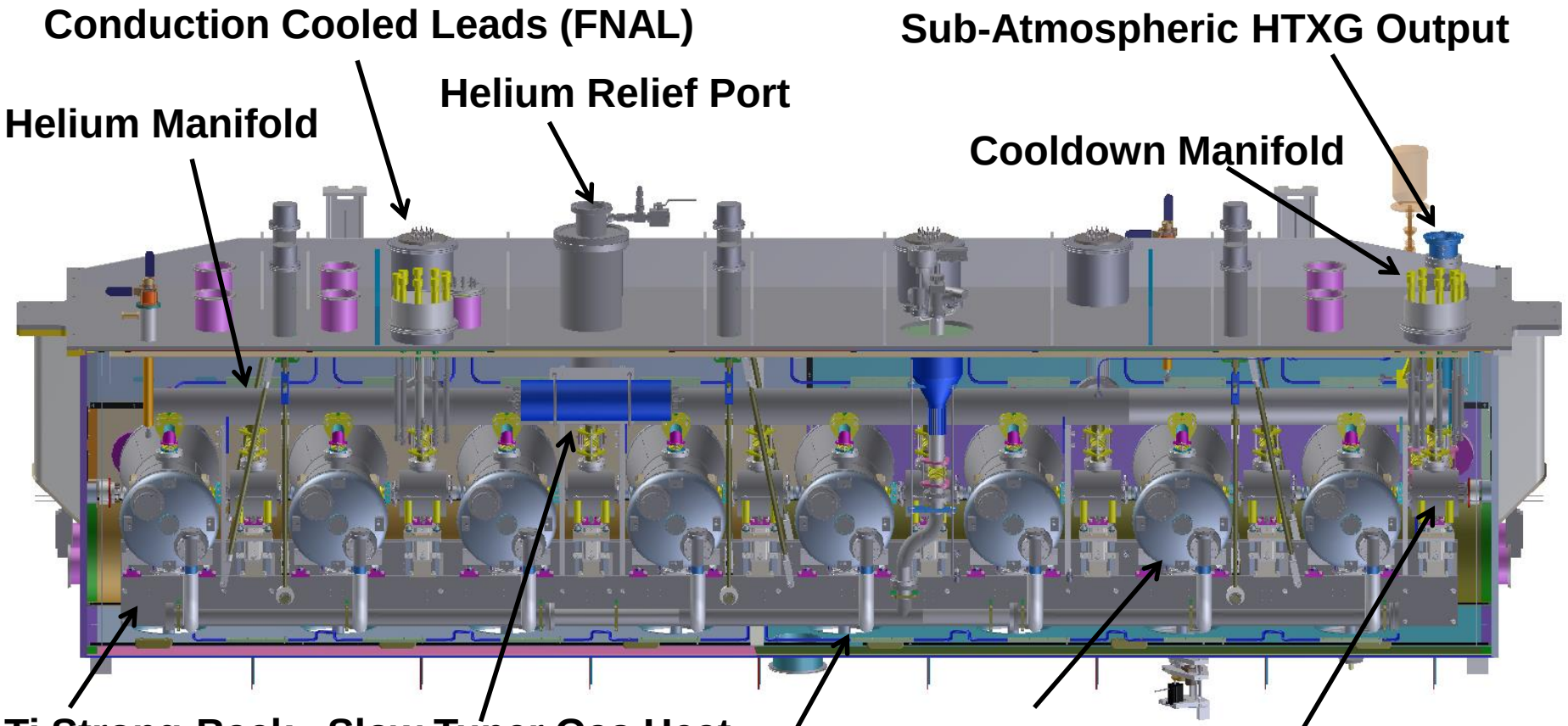
HWR Cryomodule System Requirements



Cryomodule type	Cavities per CM	# CMs	CM length (m)	Q_0 at 2K (10^{10})
HWR	8	1	5.93	0.5
SSR1	8	2	5.2	0.6
SSR2	5	7	6.5	0.8
LB650	3	11	3.9	2.15
HB650	6	4	9.5	3

- **The half-wave resonator (HWR) cryomodule contains 8 β = 0.11 HWRs and 8 solenoids (6 T) with integrated x-y dipole steering coils.**
- **The HWR cryomodule will operate continuous wave with a beam current up to 2 mA to accelerate the beam from 2.1 – 10.3 MeV.**

HWR Cryomodule Layout



2.2 m X 2.2 m X 6.2 m
18,600 lb

HWR Cryomodule Reviews

- Design/safety reviews for the HWRs and cryomodule were held at Argonne (ANL) with FNAL and ANL subject matter experts performing the reviews:
  - HWR review 5/17/2012, and
  - cryomodule review 5/16/2013.
- All design reviews were conducted in compliance with ANL's procedures, LMS-PROC-305.
- Procurement readiness reviews were carried out at ANL per ANL controls.

HWR Cryomodule Mock Assembly

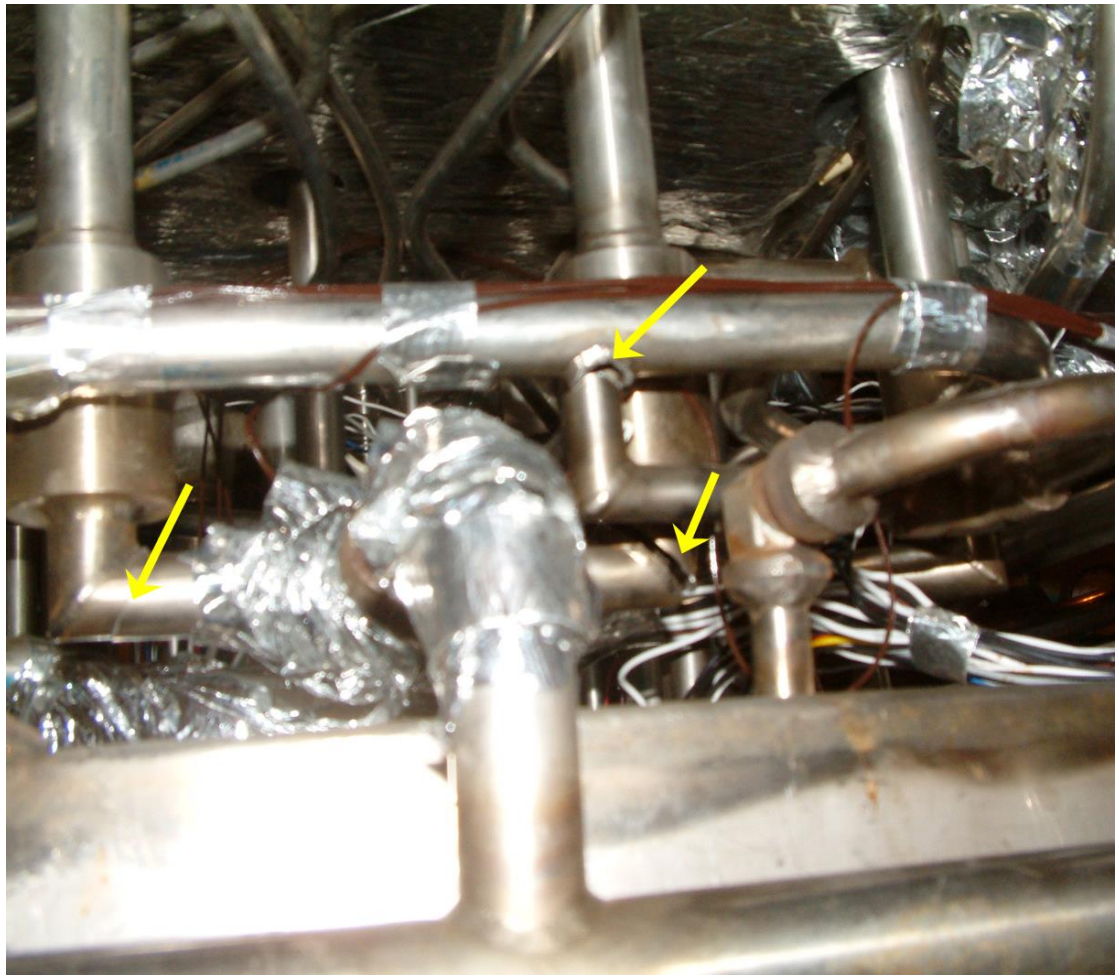
HWR Cryomodule: Transportation Risks

- **Loss of vehicle control.**
- **Improper installation of transportation hardware.**
  - **We will protect against this with designers signing off on the hardware installation and redundant checks.**
- **Cryomodule penetration damage:**
  - **Large relative motion of vacuum vessel and internal components.**
  - **Vibration damage of penetrations.**
  - **Vibration perturbation of alignment.**
  - **Vibration loosening of fasteners.**
  - **Large impulse damage, not addressed.**

HWR Cryomodule: Previous Experience

- **Transport of CTI Systems 2800 Refrigerator from LLNL to ANL.**
- **Cold-mass hangs like a pendulum below lid.**
- **Many severed tubes between the lid, the refrigerator heat exchangers, cold traps and the turbine expanders.**

2800 Refrigerator Severed Lines transport



HWR Cryomodule Transport at ANL

HWR On Flat-Bed Trailer

HWR Lift with Versa-lift

HWR transported 2.1 miles across site @ 7-10 mph (-ish).

HWR Cryomodule Tested after Transport

HWR LN2 Cold Testing at ANL

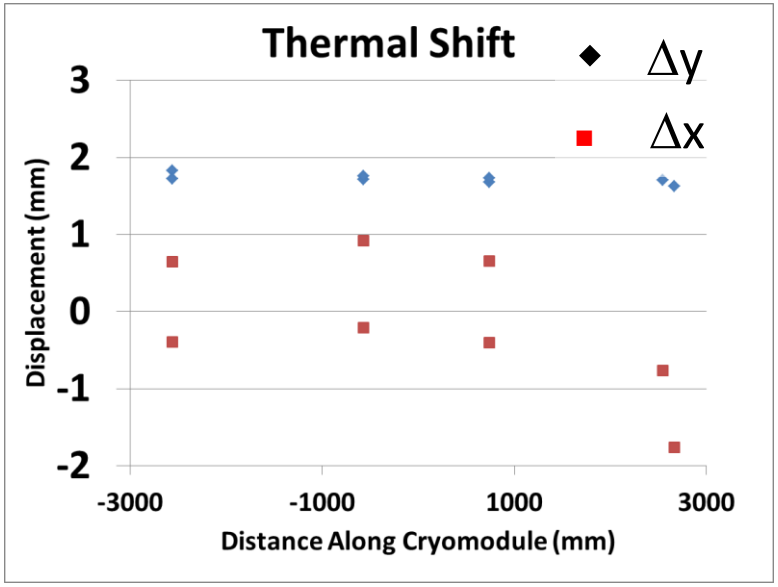
Leak tight before and after transport to 2e-9 mbar-l/s He

Alignment After Transportation at ANL

- The HWR cryomodule strong-back, 4 solenoids and optical ports were aligned prior to transportation.
- After transportation alignment checked. No relative shifts > 80 μm, limit of measurement.
- Thermal displacement measured, see below.

Cryomodule Alignment

Alignment Measurements

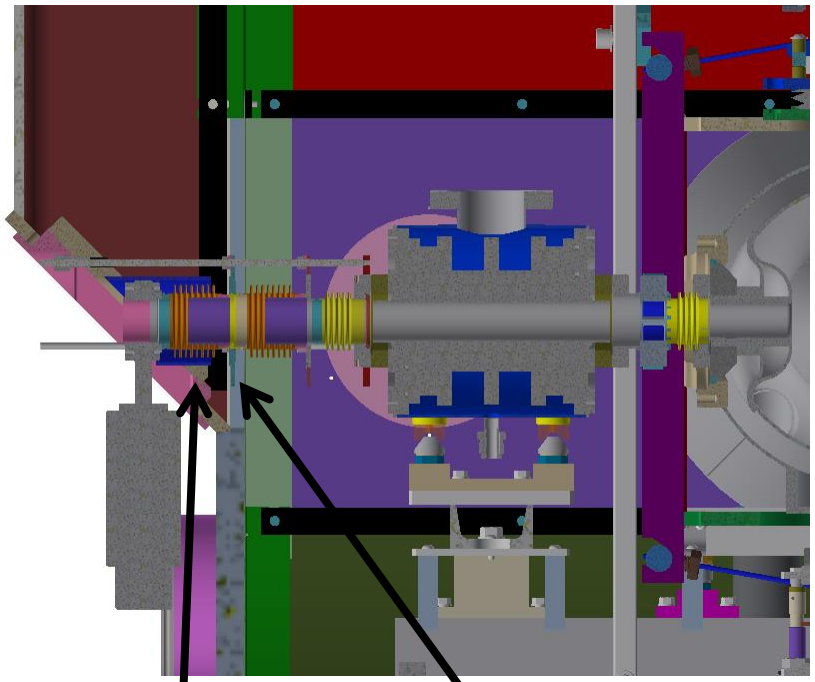


ANL Transportation Approach

- **Know from experience that ANL box style cryomodule survives controlled transport.**
  - **Do not attached delicate or critical penetrations.**
    - **Assemble after transportation.**
  - **Stiff assembly to restrict pendulum motion.**
    - **Jake Kilbane's presentation.**
  - **Fasteners:**
    - **lock washers and/or belleville washers,**
    - **lock-tight,**
    - **torque checked after thermal cycling, and**
    - **All joints/assemblies checked by 2 people.**
- **Duplicate conditions during transport to FNAL.**
  - **Need to find a transportation company to do this.**
  - **More work to be done here.**

HWR Cryomodule: Critical Penetrations

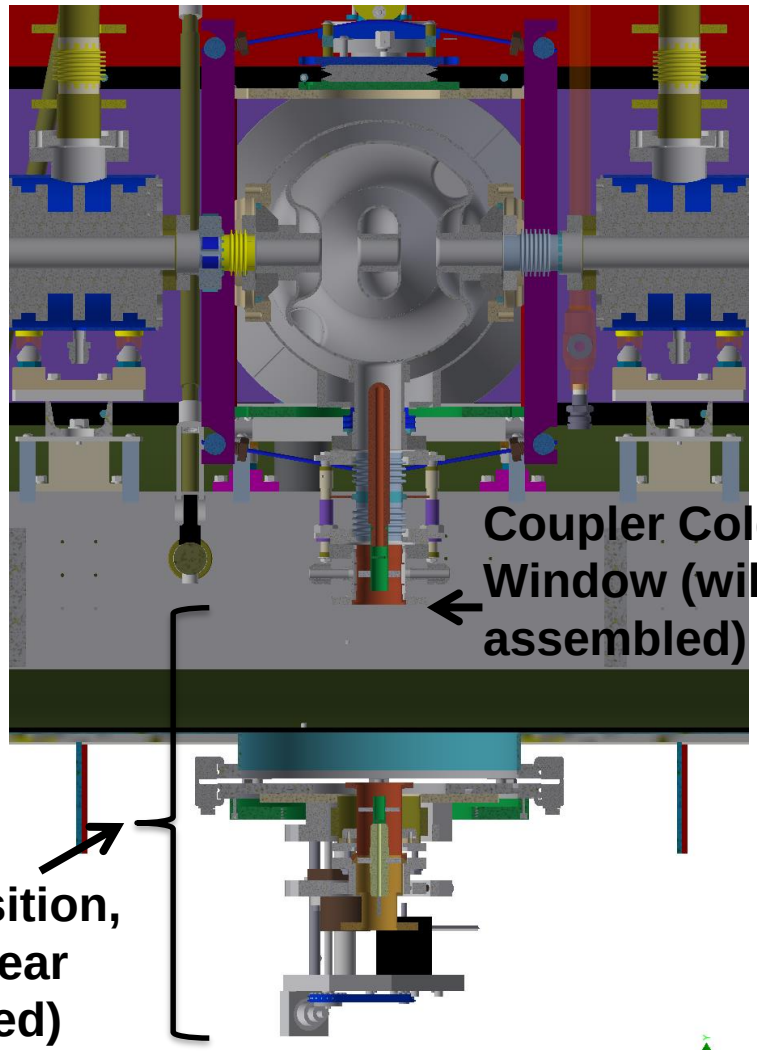
Beam-Line Gate Valves



Beam-line Gate Valve Assembly Attachment to Lower Vacuum Vessel

Beam-line Gate Valve Assembly

Power Couplers

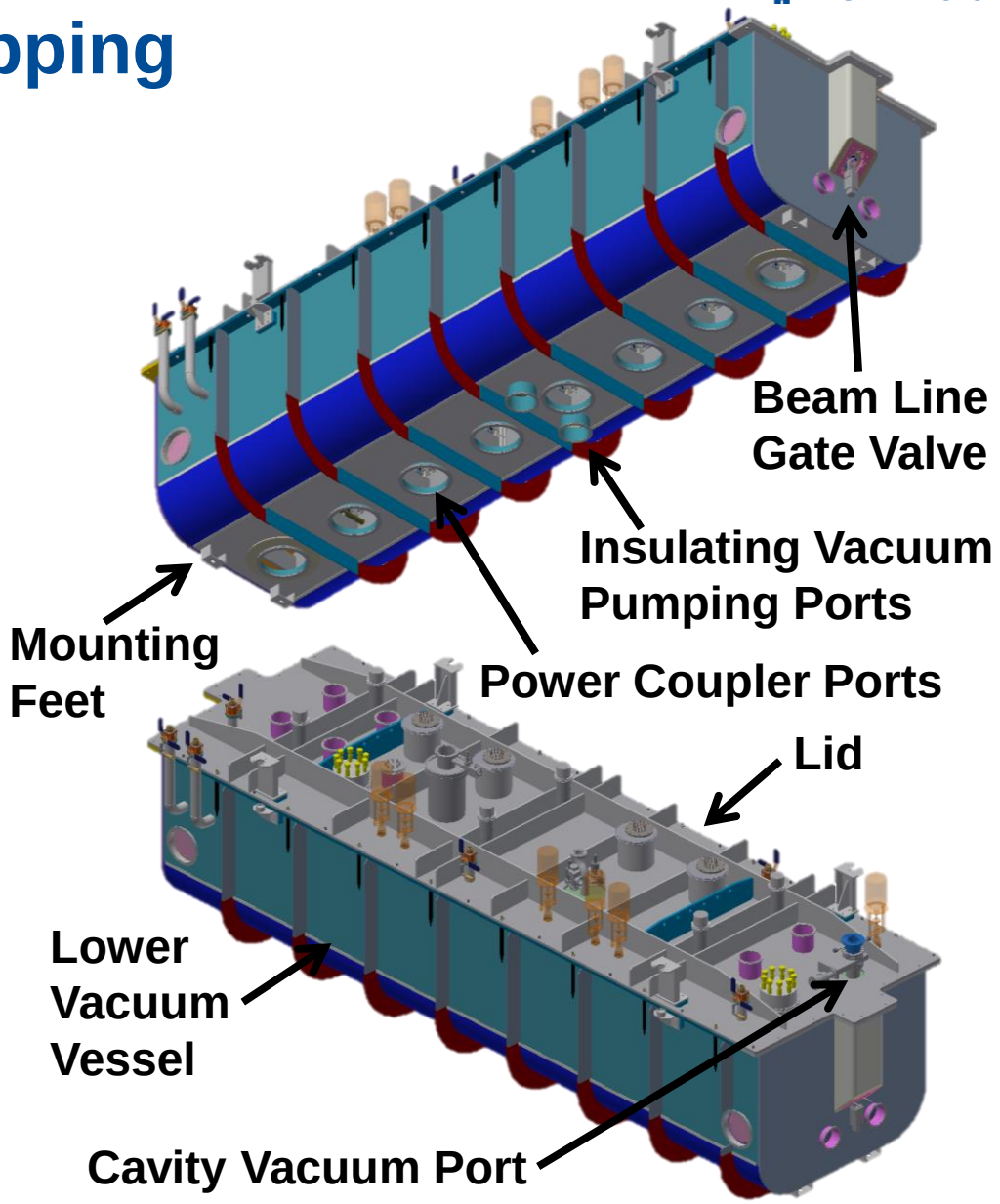


Coupler Cold Window (will be assembled)

Coupler Thermal Transition, Warm Window and Linear Actuator (not assembled)

HWR Cryomodule: Shipping

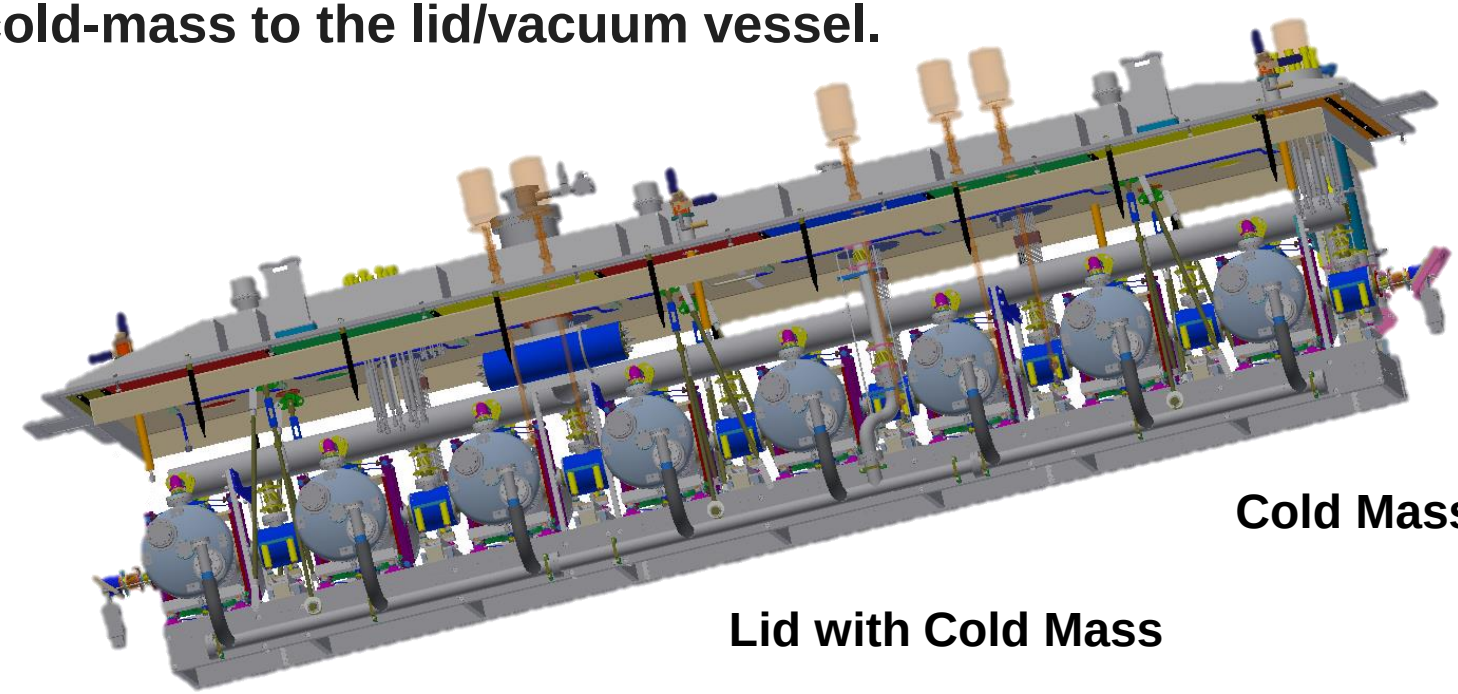
- Half-wave resonator (HWR) cryomodule will be shipped partially assembled.
- Critical penetrations will not be made up:
  - 8 power couplers,
  - 2 beam line gates valves,
  - cavity vacuum port, and
  - insulating vacuum port.
- Immobilize the cold-mass during transport.
- Prevent vibration loosening of fasteners.



2.2 m X 2.2 m X 6.2 m
18,600 lb

HWR Cryomodule: Internal Supports

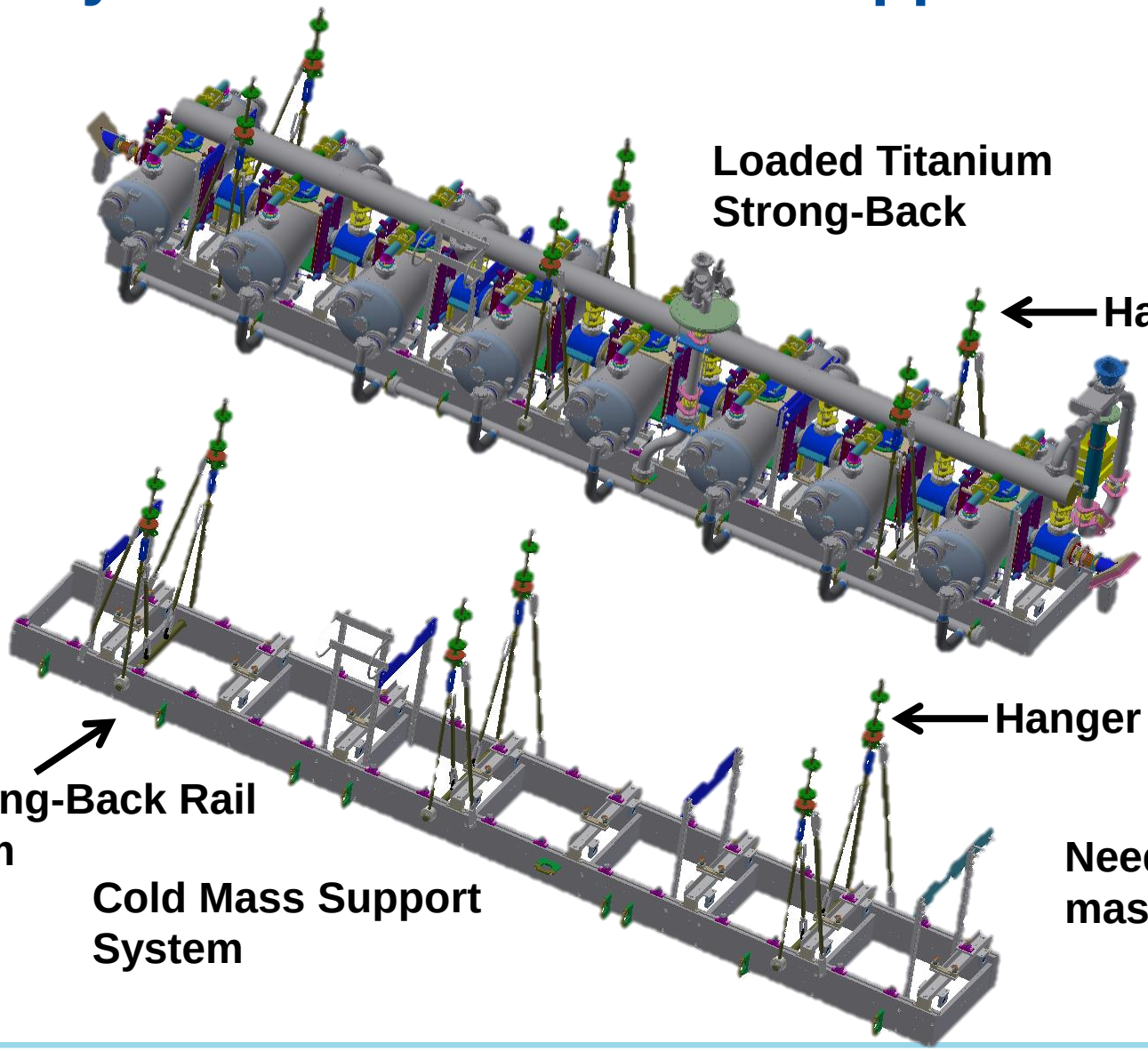
- **Cold-mass is suspended from cryomodule lid with 6 vertical hangers.**
  - **Each vertical hanger is stiffened with a pair of transverse stiffeners.**
- **The entire assembly acts like a rigid body pendulum.**
- **Pendulum motion can damage critical penetrations connecting the cold-mass to the lid/vacuum vessel.**



Cold Mass = 5,400 lb

Lid with Cold Mass

HWR Cryomodule: Cold Mass Support



Need to stiffen cold-mass assembly.

Summary

- The cold-mass hangs from the cryomodule vacuum vessel lid.
- The cold-mass needs to be immobilized.
  - Jacob Kilbane's presentation.
- Delicate connections will not be made between the lower vacuum vessel and the cold-mass.
  - Couplers, beam-line gate valves and pumping connections.
  - Will need to be assembled at FNAL.
- Vibration loosening is mitigated.
- Need to transport in a manner similar to what was done on-site at ANL.