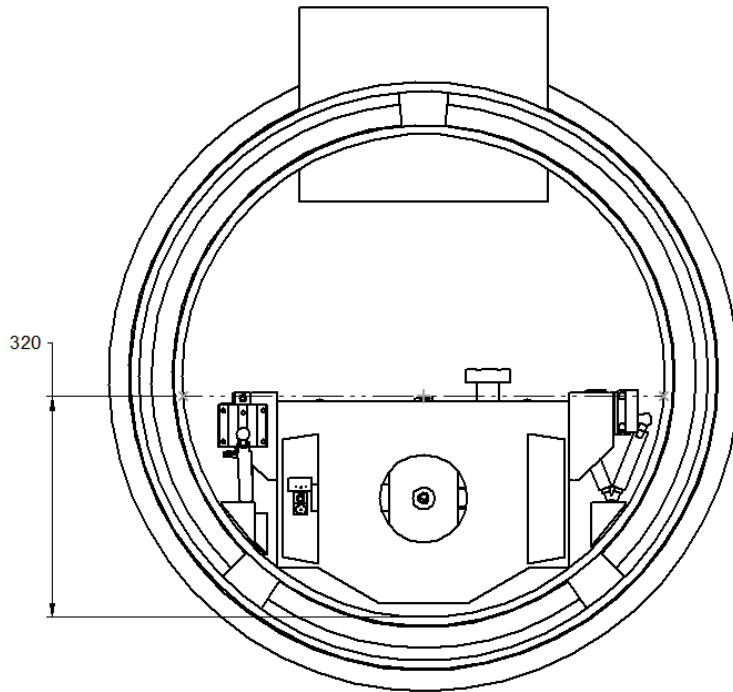


C³ Quarter Cryomodule Status and Plans

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Introduction: The C3 Cryomodule (CM)



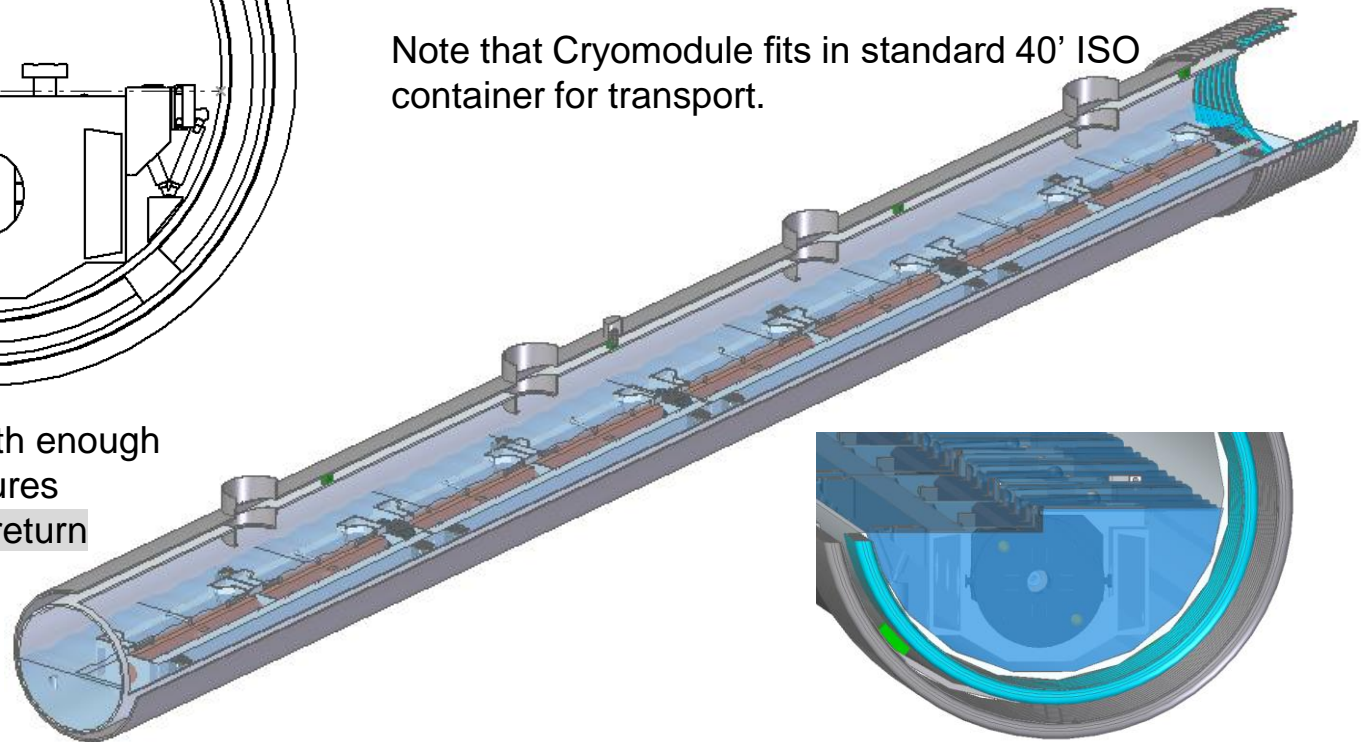
Cryomodules: the transportable assembly unit

4 rafts per Cryomodule (CM)

2 accelerator structures and 1 quad per raft

Note that Cryomodule fits in standard 40' ISO container for transport.

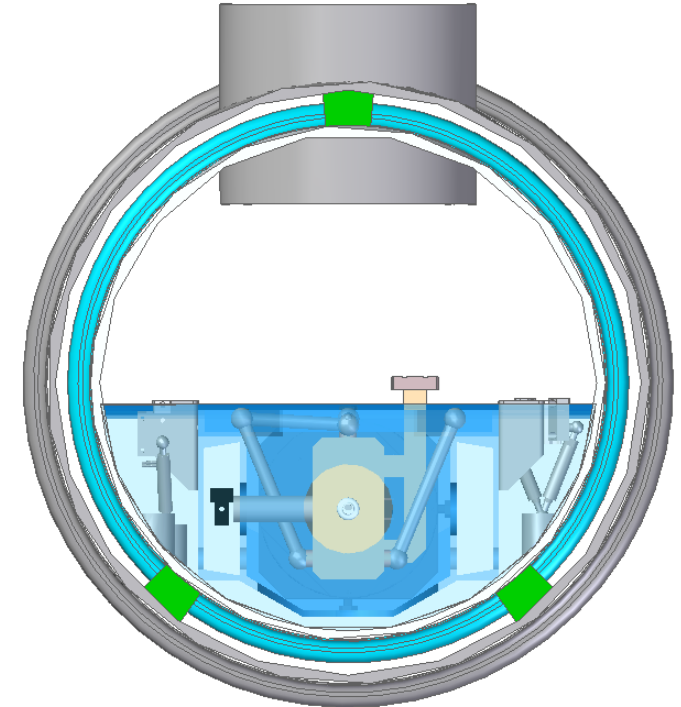
Cryomodules: filled with enough LN to cover the structures
Provide space for N2 return



Introduction: LN Cooling



- Accelerator is under slightly pressurized liquid nitrogen in a vacuum insulated cryostat
- LN flows into page
- Nitrogen vapor counter-flows
- Gravity drives LN flow
- Pressure difference drives vapor flow
- Distributed re-liquifiers condense the cold vapor.
- The design optimization (**Cost**) loop:
 - String length sets N2 flow rate that drives flow area
 - Structure size sets LN depth
 - Together this establishes the minimum vessel diameter
 - Want small vessel diameter but also efficiently sized/located re-liquifiers
 - Critical is what “takes up space” in the vessel.



Introduction: Quarter Cryomodule (QCM)



- A system is currently being prepared to allow testing of one fourth of the proposed C3 cryomodule
- This Quarter Cryomodule (QCM) system will allow testing of 2 full scale 1m long accelerating structures with a quadrupole magnet and instrumentation
- The system is designed to accommodate full RF drive with beam interaction (future configuration).
- Initial tests are planned for evaluation with no beam or RF power but using “artificial” heating to allow mechanical evaluation
- A summary of plans and current work follows

Quarter Cryomodule (QCM) System Elements

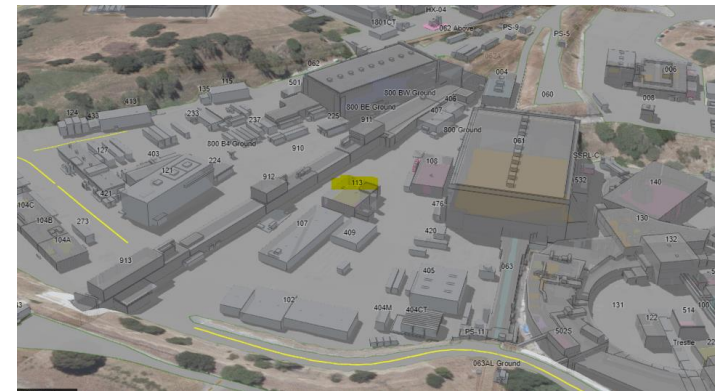


- **Facility**
- **Cryo Vessel**
- **Connections, Instruments, Measurements**, particularly relevant is the presentation:
 - The alignment of the modules of the Cool Copper Collider (C³) with the Rasnik 3-point alignment system
- **Nitrogen System**
- **Accelerator Structures.** For details see presentations including:
 - High Gradient Testing of a Meter-Scale Distributed-Coupling C3 Accelerating Structures
 - A Wakefield Resilient, High Shunt Impedance Accelerating Structure for the Cold Copper Collider
 - Cold Copper High Gradient Single-Cell Structure Tests
 - Luminosity Studies for the Cool Copper Collider
 - Multi-bunch beam dynamics studies in the C3 main linac
 - HOM Detuning and Damping of C-Band Distributed Coupling Structure
 - Distributed Coupling Linac for Efficient Acceleration of High Charge Electron Bunches
- **Accelerator Mounting and Supports**
- **QCM Test Plans**

Initial QCM Facility



- A location at SLAC is currently being prepared for QCM install/use
- The building has existing infrastructure
 - Fork lift accessible work area
 - Adequate electrical power
 - Overhead crane/hoist
 - Room for additional mobile hoists
 - Large liquid nitrogen storage vessel
- Preparations underway or in planning include
 - **Nitrogen systems**
 - Locating/anchoring the cryostat and other significant elements
 - Electrical equipment and thermal load power supplies
 - Accelerator handling equipment and plans
 - All related safety equipment and procedures
- *Once the initial mechanical evaluations are complete the QCM will be reconfigured/relocated for RF and beam testing.*

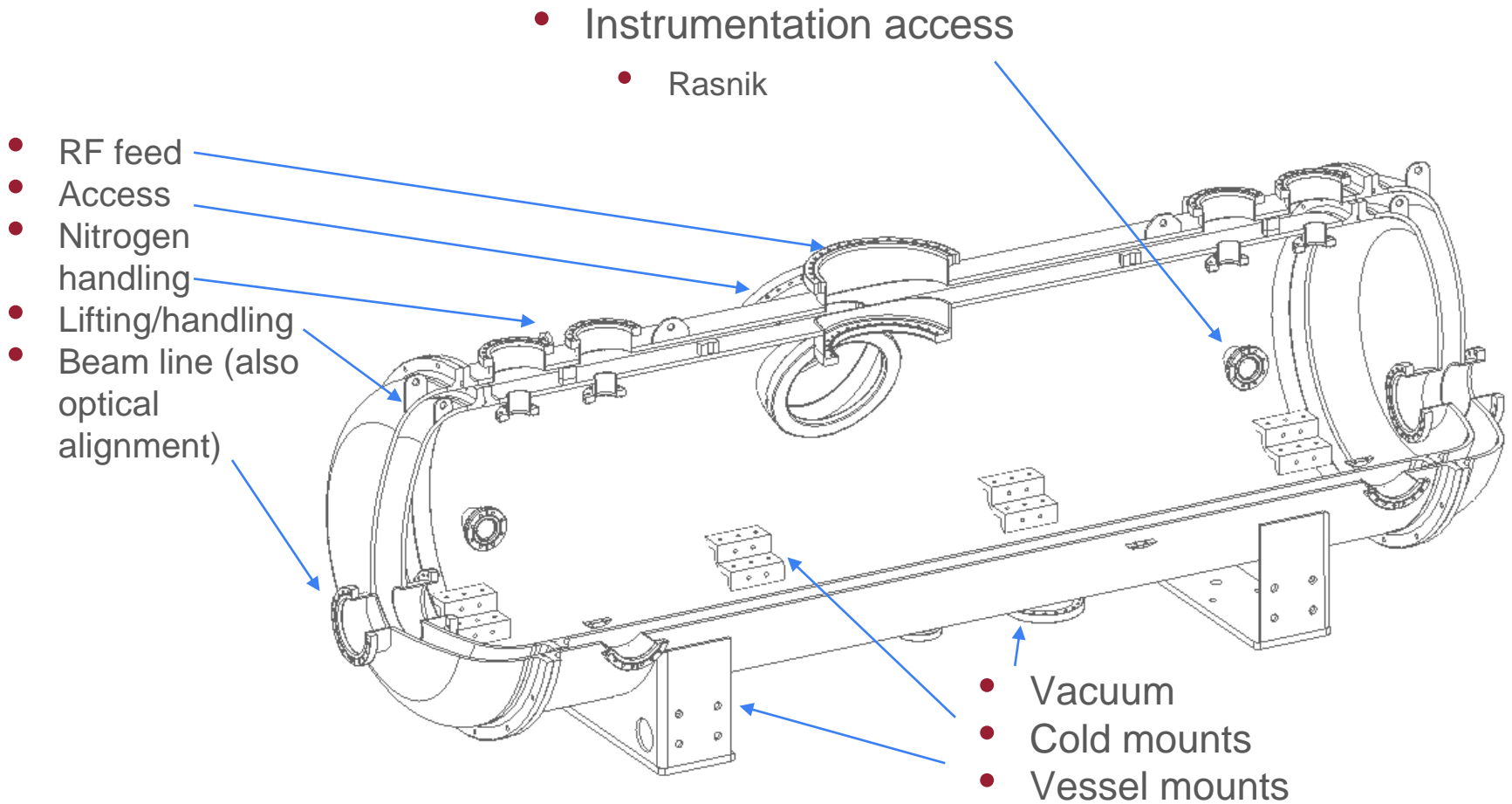


QCM Vessel/Cryostat



- The Cryostat is in manufacturing, shipping is anticipated next month
- Some key elements of the cryostat include:
 - Bolt on “heads” both ends
 - Standard O-ring seals on the room temperature flanges
 - The cold flanges include provision for alternate seals
 - LN rated spring energized PTFE O-rings
 - Indium wire seal (flanges include jack screws for disassembly)
 - Also possible to utilize flat gaskets or delta/omega type seals
 - Attachment points on the inner cold vessel to accommodate a range of installation/mounting features
 - Inner vessel support/locating blocks that can be changed or adjusted if needed
 - “Load path” from structure supports to foundation
 - Adjustments for anti-rock as needed
 - A central alignment pin to fix the inner vessel cold position
 - Ports for high power RF feed
 - An array of flanges for nitrogen handling, instrumentation, and more
 - Except for the vessel head ends all flanges are CF
 - May opt for O-ring seals on the warm flanges

QCM Vessel/Cryostat



QCM Instruments - access ports



- Temperatures
 - Structure surface and internal
 - Waveguide feed (future configuration)
- Pressures
 - Vacuum vessel
 - Cold vessel
 - LN feed system
 - Structure pressure (used during hot wire heating for controlling heat transfer)
- Nitrogen flow rates
- Heating system power
- RF connections
 - Diagnostic only in early tests
 - High power feeds
- Optical inspection/observation ports
- Acoustic/vibration
 - Multiple accelerometers
- Alignment
 - Rasnik system support
 - Optical beam line

CQM Manufacturing



Parts in manufacturing (photos from August)

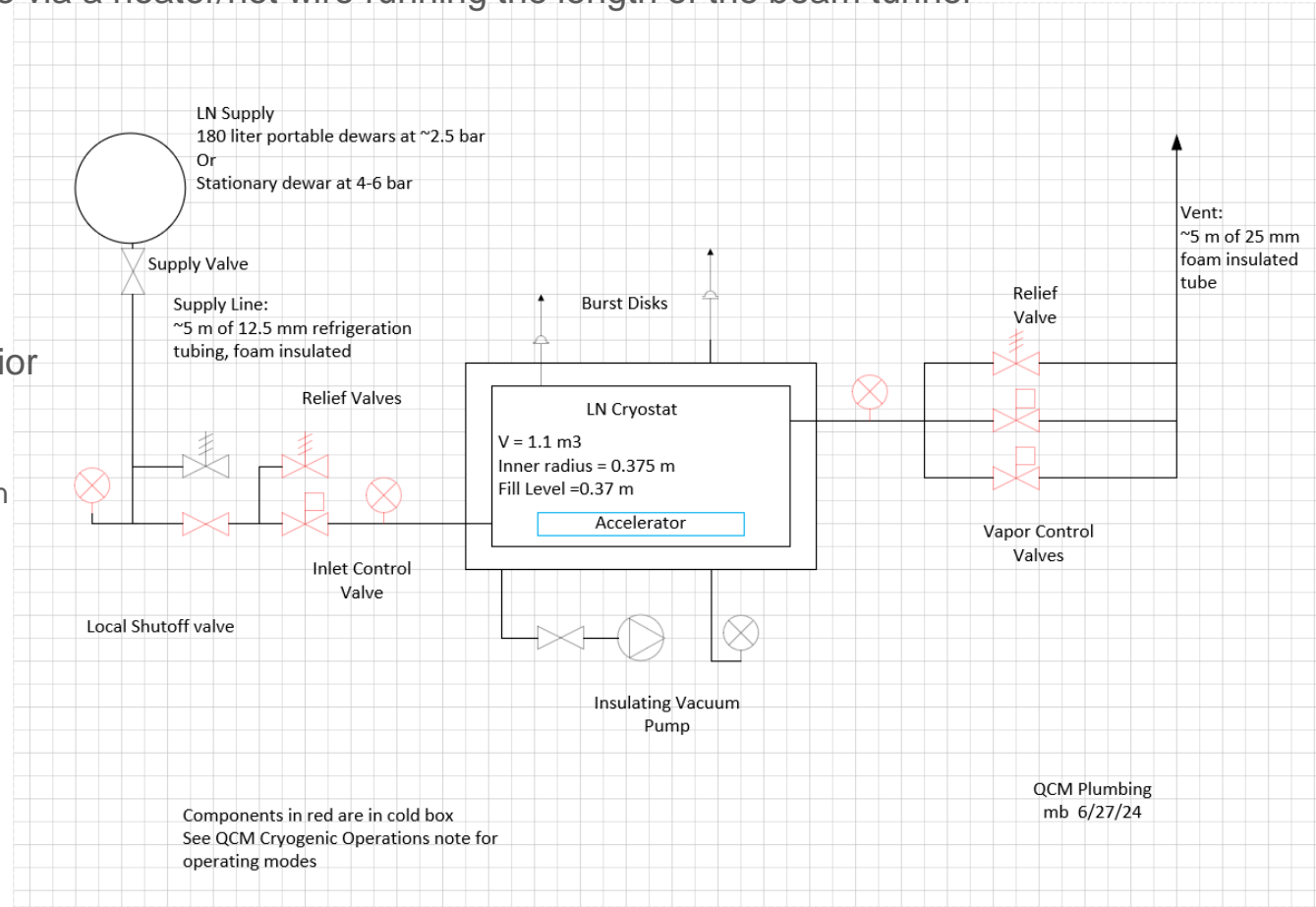


QCM Nitrogen System



- The C3 design losses are 2.5 kW/m
- The QCM system will allow testing to 5 kW/m (10 kW) or more
 - Heating will be via a heater/hot wire running the length of the beam tunnel

- LN flow to 0.1 kg/s
- Nitrogen system controls will allow study of performance/behavior
 - Thermal load
 - LN supply
 - Gaseous Nitrogen Venting



Initial QCM Commissioning and Tests



- In preparation for arrival of the cryostat we are currently preparing the area
 - Electrical
 - Seismic
 - Cranes/hoists
 - Liquid Nitrogen and gas handling
 - ODH and other safety considerations
- Once we have the cryostat and systems operational we will do an initial chill to verify equipment and procedures.
 - This may include a raft and structure or not
 - Proper operation of the LN control system (without load) will be verified at this point.
- Once the system is operational we will install an instrumented raft with structures
 - This configuration will include a resistance heating system to allow characterization of the mechanical performance at temperature and with full power liquid nitrogen cooling
- Initial (pre-RF) testing will include
 - Liquid and gas flow controls with load variation
 - Mechanical distortion of supports and structures with cooling to operating temperature.
 - Will be using Rasnik optical measurement system to be detailed in the next talk
 - Vibrations/motions related to the phase change cooling (“impact” of bubbles)
 - Motion/alignment instruments and mechanisms both

Motivations for test



- Previous slides have introduced work in process as well as testing plans
- But why these tests?
 - Refer to the alignment requirements
- Key points of mechanical consideration include
 - Structure manufacturing
 - Mounting
 - Alignment
 - Distortion on cooling
 - Behavior with heat transfer
- Build QCM and test.

The Raft and Structure Mounts

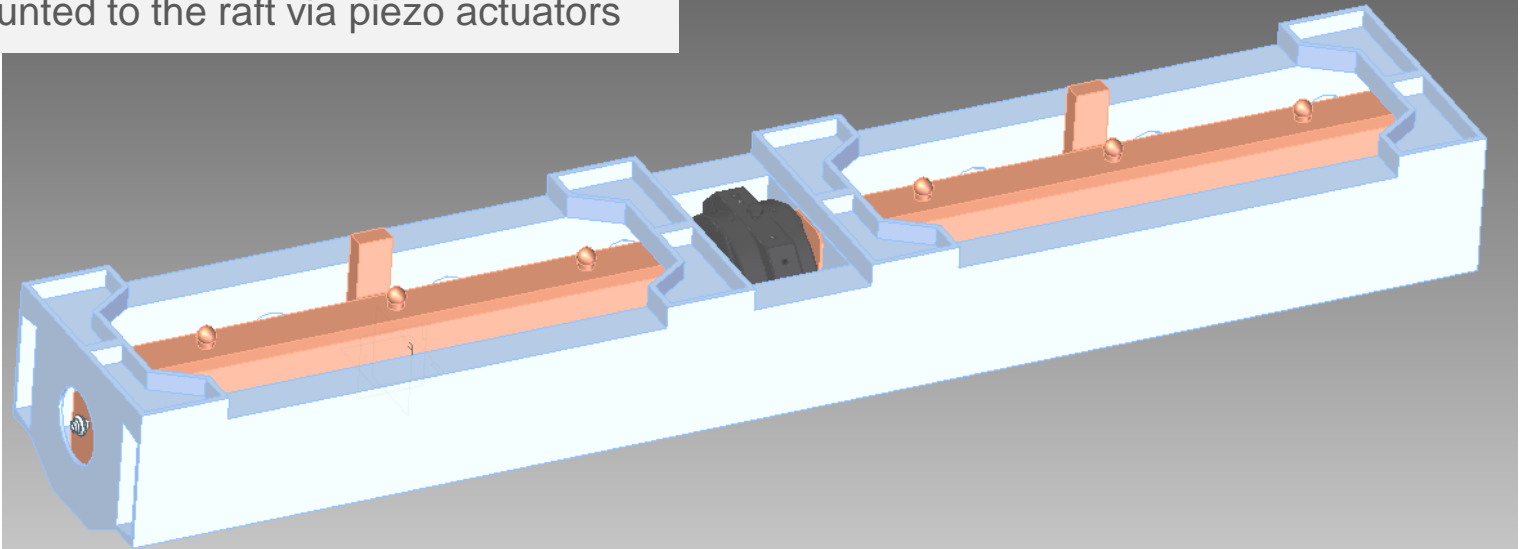
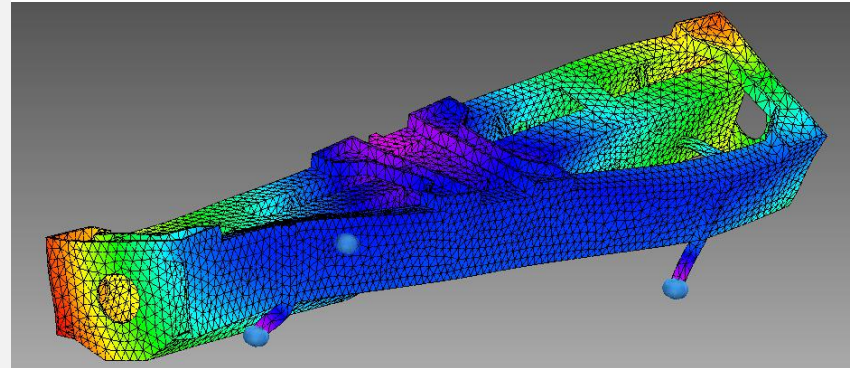


- The basic load path
 - Structures (accelerators and quad) are mounted to/supported by a support frame “raft”
 - Mounting hardware allows full adjustment/alignment of each element on the raft
 - Raft is supported on the inner cryostat vessel on kinematic stages providing 5 DOF adjustment
 - The inner vessel is supported by the outer vessel by insulating blocks
 - The support blocks allow for the inner vessel contraction on cooling
 - A pin locks/fixes the longitudinal position
 - The outer vessel is supported on stands that allow for overall adjustment as needed
- The optical alignment system will have elements on the accelerators, quads, and raft allowing measurement during cool down and test
 - More on this sensor alignment system!
- Based on behavior of the elements in the QCM the mounts and stages will be optimized for performance and cost.
 - We don't know where piezo stages may be desired to allow higher rate positional adjustment

QCM Supports/Alignment



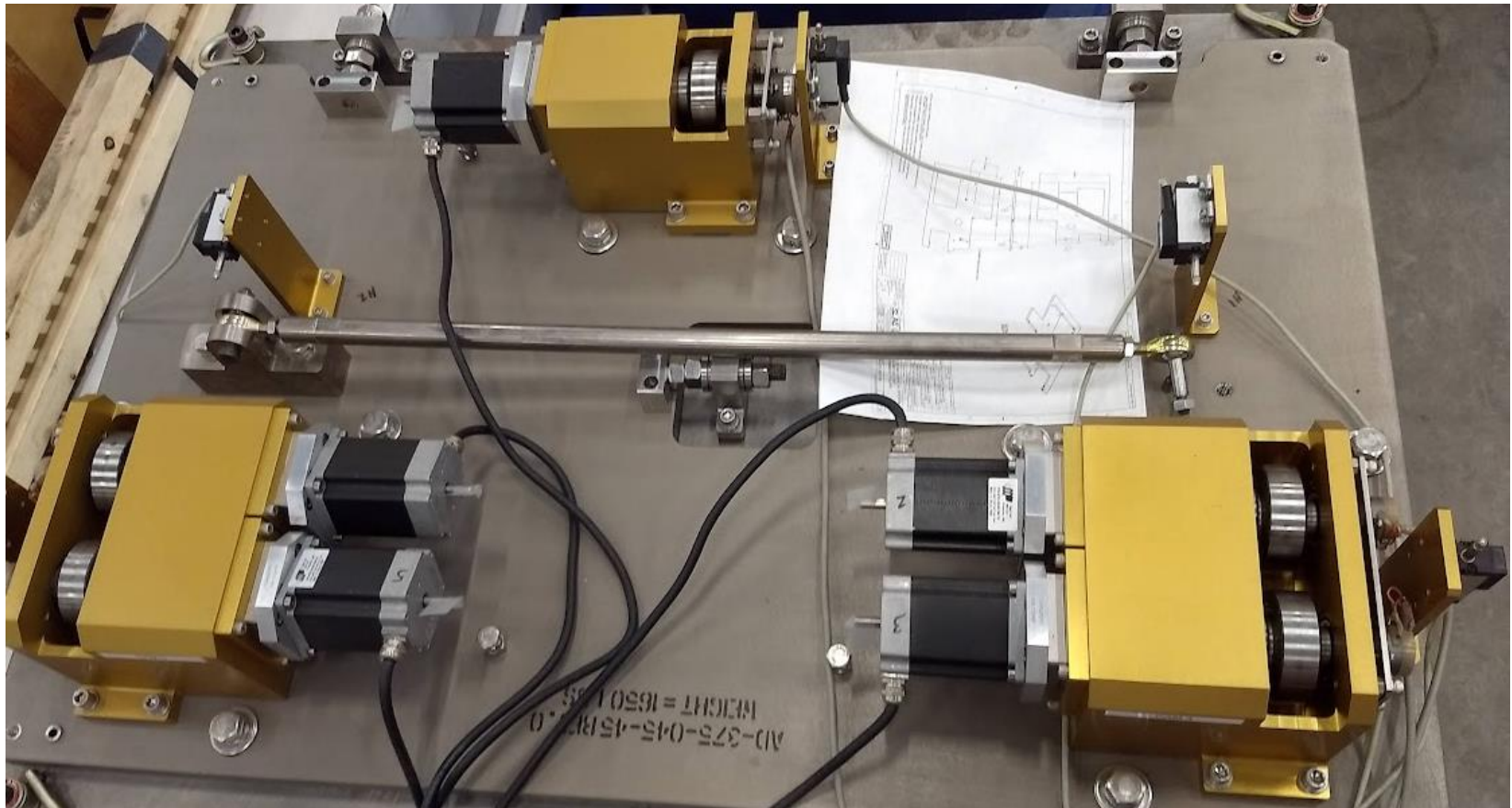
- With the support frame (raft) supported at 3 points, one of the principle vibrational modes is twisting as shown
- As the Quad must be most closely controlled the baseline configuration locates the quad in the center of the raft
- Initial configuration will provide stepper and piezo motion of the entire raft
 - 5 DOF
- Testing will reveal if the quad should be mounted to the raft via piezo actuators



Why a new system?



The 5 DOF roller cam undulator system could be adapted to operation in LN
It doesn't have the high frequency capabilities currently planned for C3



QCM Supports/Alignment



- Plan is to learn from others... and learn by doing
- See Rasnik presentation for pre-beam based alignment developments

Solutions Currently in use at SLAC



- Problems solved in the LCLS Cryo-modules, undulators, and more
- The 5 roller cam undulator alignment system has proven sub-micron performance

<https://www.slac.stanford.edu/pubs/slactns/tn04/slac-tn-10-072.pdf>

A single module design can be used at all 5 roller cam supports. It consists of an aluminum block housing a 0.75mm lift camshaft with roller cam follower bearing supported on 2 deep groove ball bearings. A cross section of the assembly is shown in Figure(1).

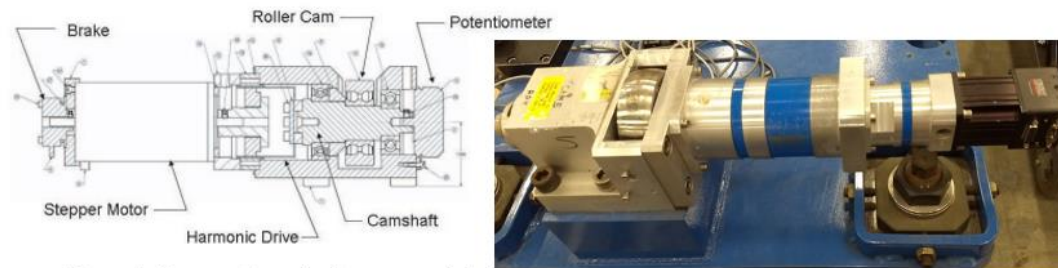


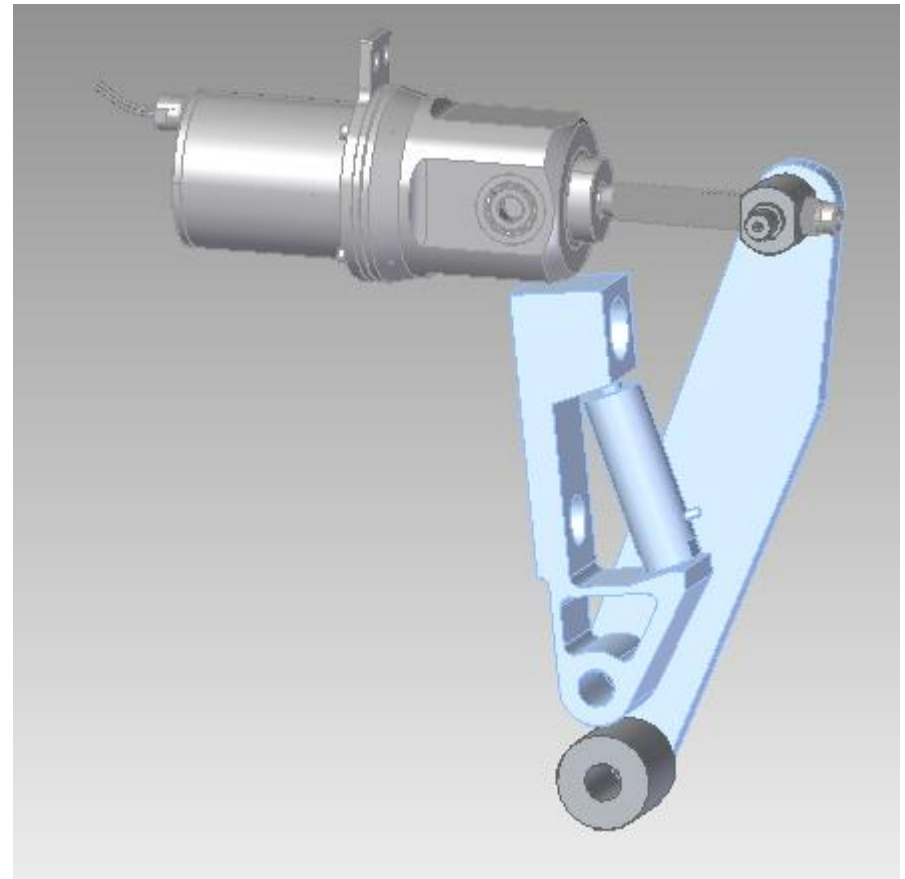
Figure 1: Cross section of roller cam module

*Work supported in part by the DOE Contract DE-AC02-76SF00515. This work was performed in support of the LCLS project at SLAC.

QCM Supports/Alignment



- It is anticipated that several versions of accelerator structure and support frame mounting will be investigated as performance and cost is optimized
- Shown is an initial mount design based on existing LCLS-II hardware
- This configuration is fairly compact and easy to implement.
 - Used in pairs
 - Rides on “V” block
- Looking at a full flexure based mount (at least for the piezo stage)
- Plan to investigate raft slow/structure fast configurations
 - Look to optimize fast stage DOF



Cooling

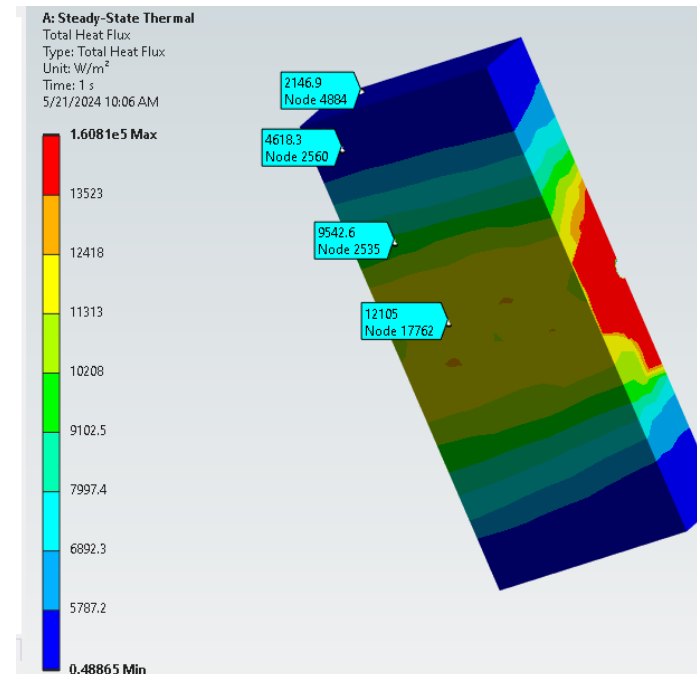
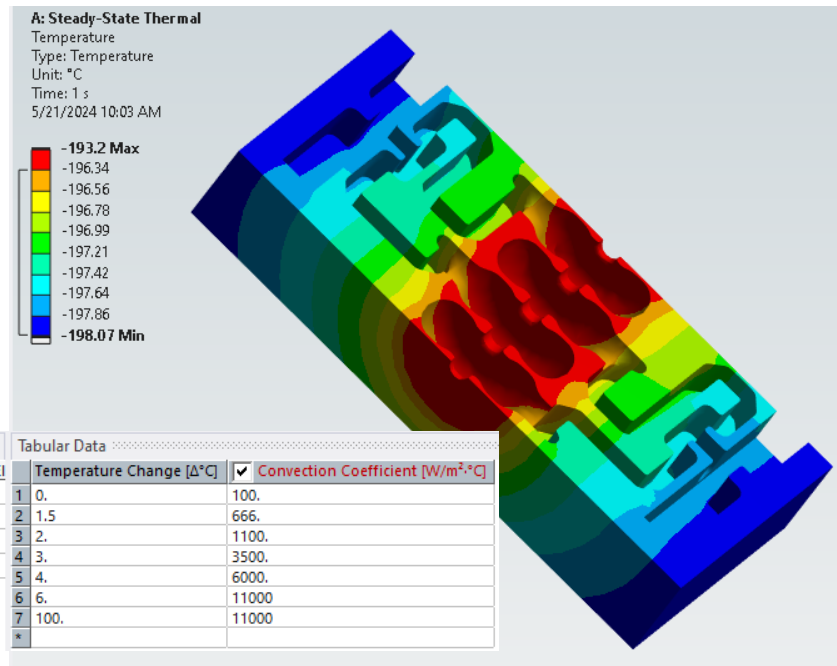


- The initial test sequence will provide information needed for design validation and optimization.
 - Validation of the measurement techniques and equipment at room temperature and LN
 - Motion/distortions on cooling to LN
 - Performance of motion stages
- Once the above performance is characterized the QCM system will be used to evaluate behavior with full power cooling via LN boiling
 - We have completed some preliminary tests of structure cooling in LN
 - See (insert reference Ankur Dhar)
 - The same system of using a resistance heater down the beam pipe will be used
 - Tests and estimations/simulations have so far been encouraging
 - This QCM will allow testing to well above design heat loads

QCM Accelerator Structure Cooling



- A representative section of accelerating structure is shown
- Preliminary temperature gradient and surface heat flow simulations are encouraging.
- With the structure oriented as planned, most heat is removed on the vertical surfaces, very little heat transfer is required on the horizontal



QCM Test Plans, summary



Tests/Work that don't require QCM but are closely coupled

- Structure fabrication and straightening
 - Planned for structure in final RF design now
- Structure and Quad mounting/aligning in the support frame (raft)
 - **Design and procure the support raft as required for support and Rasnik**

Once installed, many tests will utilize the capabilities of the QCM system

- Installation and mounting of the raft in the vessel
- Room temperature alignment in the vessel
 - Actuator performance
 - Measurements (Rasnik plus conventional)
- Characterize movement on cool to LN
 - **Look to minimize and/or find consistency**
- Verify actuator performance cool (precision, frequency response)
- Verify Rasnik and other alignment techniques when cool, in LN, no heating
- Investigate behavior with heating / LN cooling
 - Use the heaters and instrumentation to understand system performance.
 - **Especially boiling driven displacement**
- Validate assembly procedures suitable for full CM usage
 - Overhead beam/rail
- Once all this and more is complete, the QCM will be relocated and used for “real” tests with RF and beam

Summary/Questions



- The QCM system will allow for characterization of many aspects of the C3 system even before high power RF and beam testing begins
- It is anticipated that considerable performance improvement and design optimization will result from the full scale testing made possible by the QCM system
- Questions/Comments/Suggestions?
 - Sorry to be remote and missing out on related presentations and discussions
 - Happy to receive e-mail inquiries etc.

- Thanks!