Cold Mass Development AUP

Sandor Feher – Fermilab

9th HiLumi Collaboration Meeting – FNAL, Oct 2019

Fermilab CM&Cryo Team

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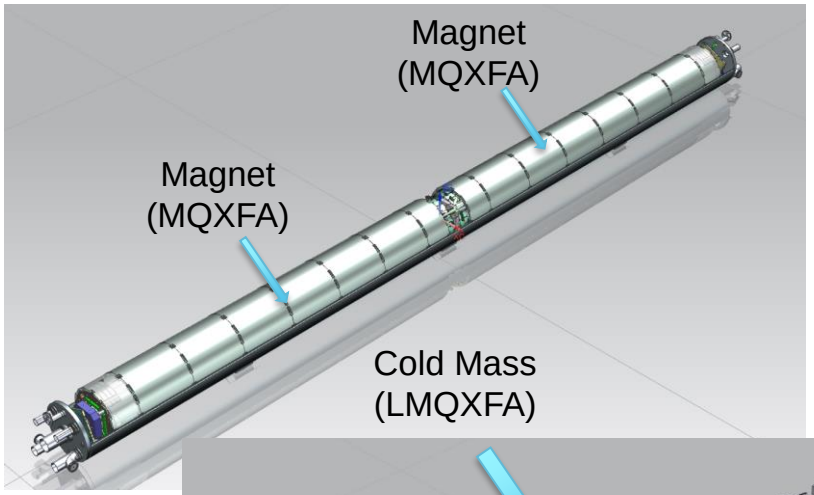
Outline

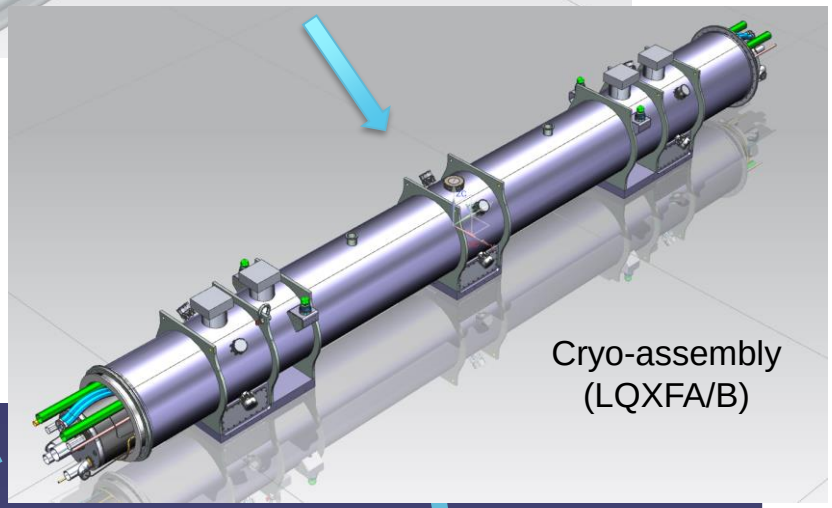
- Scope
- Strategy
- Empty Shell test results
- Bas bar design and validation status
- Cold Mass Tooling design status
- Cold mass design status
- Future plans

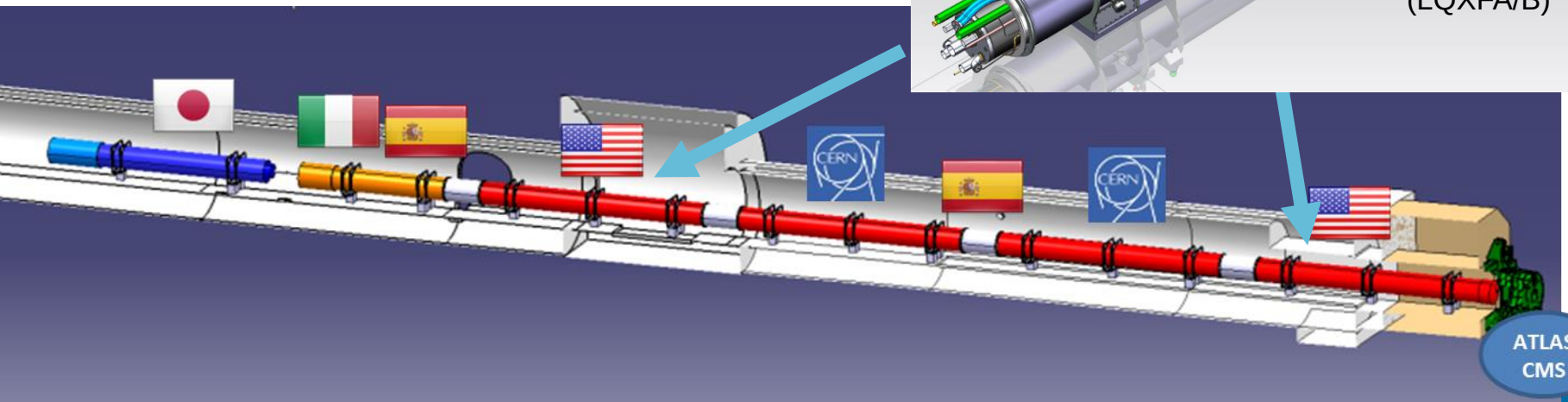
Scope of AUP Q1/Q3 Cryo-Assemblies

12 Q1/Q3 Cryo-Assemblies

- 2 pre-series
- 9 series production
- re-building one Cryo-assembly assumed







Strategy

Before production validation of the CM design:

- Short model magnet equipped with SS shell and tested
  - Successfully completed the cold test; no performance degradation observed due to the shell installed onto MQXFS1d
  - Learned how to mount the shells and how to perform welding
- Empty shell welding test
  - Validate the welding procedure before it is applied to prototype CM
  - Validate welds and welders
  - Observe deformation due to weld; virtually unsupported shell
- Bus bar mockup
  - Short model of the bus routing including expansion loops close to completion (CLIQ leads and instrumentation wiring still needed)
- Short bus bar test using MQXFS1e
  - Fully constructed short bus bar is inserted into the short magnet and successfully cold tested. Design has been validated.
- Cold Mass fabrication tooling development 95% completed
  - Many of the tooling in house or in fabrication at vendor site
  - Tooling to maintain 0.5 mrad field angle relative to gravity line requirement is recent – needs finalizing the tooling
- Fabricate practice CM to validate the installation procedure and commission the tooling
- Fabrication of the Pre-series CM and cold test it horizontally
- Lesson learned applied to production CM fabrication

Empty shell welding test results

- Empty Shell test, 385” long 316L shells (w/out magnets) – welding completed
- 3 passes / 42-45 min. per pass
- Welding per ASME Sect. IX using GMAW process for long. & circ. seams w/ 317L filler rod
- Procedure Qualification Record (PQR) written with new parameters and new rod.
- Negligible (< 1mm) bending in any direction was observed – well balanced simultaneous welding of the two sides
- Welders and welds were qualified

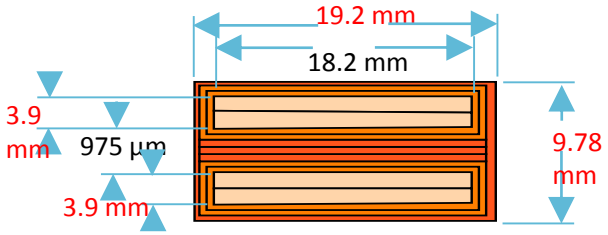
Location (Z)			upright	Pre-Weld (Gap)		1st Pass (Gap)		2nd Pass (Gap)		3rd Pass (Gap)		Shrinkage (East)			Shrinkage (West)		
	East (A)	West (B)	location	East (A)	West (B)	East (A)	West (B)	East (A)	West (B)	East (A)	West (B)	1st pass	2nd pass	3rd pass	1st pass	2nd pass	3rd pass
S1	35"	31"	10.5	4.255	4.045	4.219	3.999	4.214	3.993	4.204	3.981	0.036	0.041	0.051	0.046	0.052	0.064
2	65.5"	66"	95.5	3.588	3.634	3.545	3.588	3.544	3.58	3.536	3.577	0.043	0.044	0.052	0.046	0.054	0.057
3	127"	137"	180.5	4.119	3.465	4.079	3.409	4.074	3.406	4.051	3.399	0.04	0.045	0.068	0.056	0.059	0.066
4	248"	248"	202.5	3.799	3.653	3.761	3.608	3.758	3.607	3.739	3.598	0.038	0.041	0.06	0.045	0.046	0.055
5	319"	319"	287.5	3.753	3.589	3.707	3.537	3.704	3.534	3.693	3.526	0.046	0.049	0.06	0.052	0.055	0.063
N6	357.5"	352"	372.5	3.971	4.048	3.934	4.01	3.93	4.004	3.929	3.993	0.037	0.041	0.042	0.038	0.044	0.055

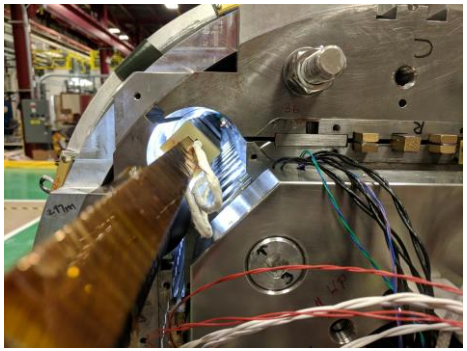
Values are in Inches

Test of NbTi busbar for MQXFA magnets

GOAL OF THE TEST

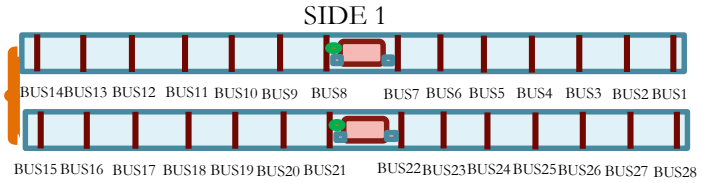
- Prove the bus design up to ultimate current
- Determine temperature margins
- Test the quench protection of the bus
- Investigate quench propagation and compare the results with calculation





Tested in MQXFS1e magnet (VMTF stand @ IB1 TD) View of magnet RE + spliced bus

View of the bus instrumentation



- Two spot heaters
- Two temperature sensors
- 28 Voltage taps on the straight section of the bus

Tested reference currents

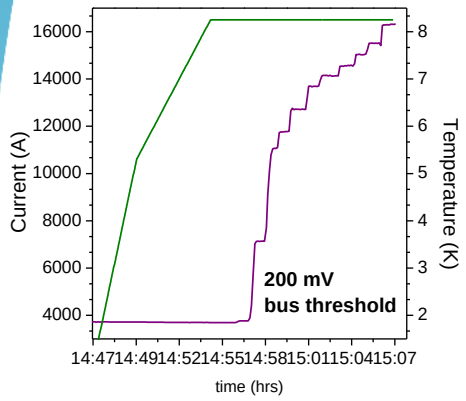
Current [kA]	5.59	8.24	9.89	11.53	13.18	14.83	16.48	17.8

Bus voltage detection thresholds

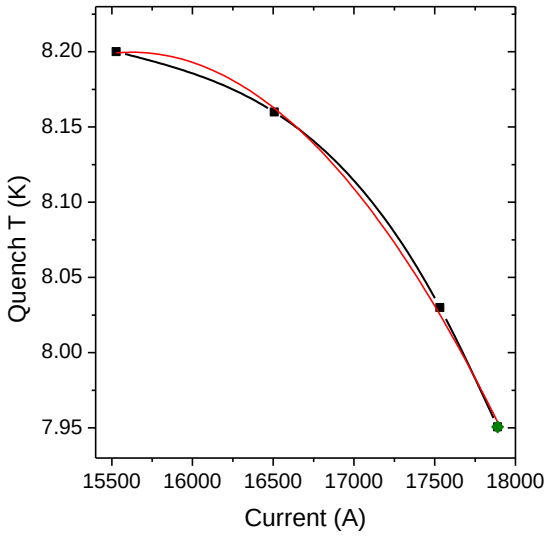
Current [kA]	5.59	8.24	9.89	11.53	13.18	14.83	16.48	17.8
Voltage threshold (mV)	50	50	50	50	50	50	50	50
		200					200	
							500	
							800	

Results: temperature margins and MIIts

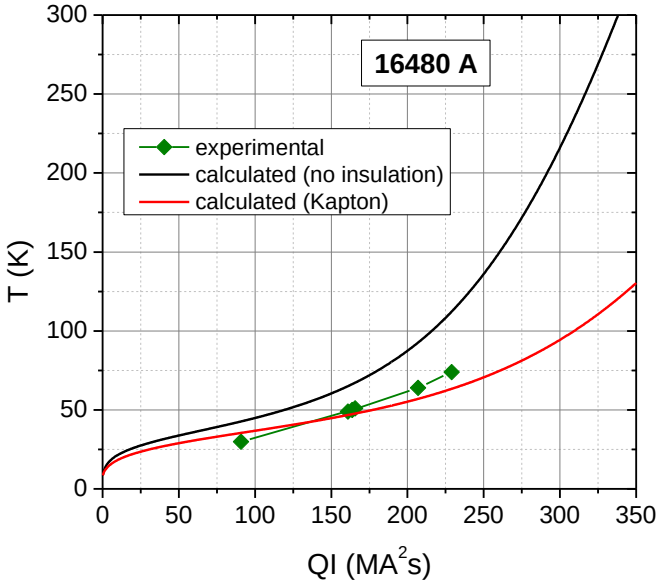
Temperature margins test at: 15500, 16480 and 17500 A



Quench temperature at ultimate current (17890 A) was extrapolated fitting the data. T margin is 6.05 K at ultimate



MIITS budget

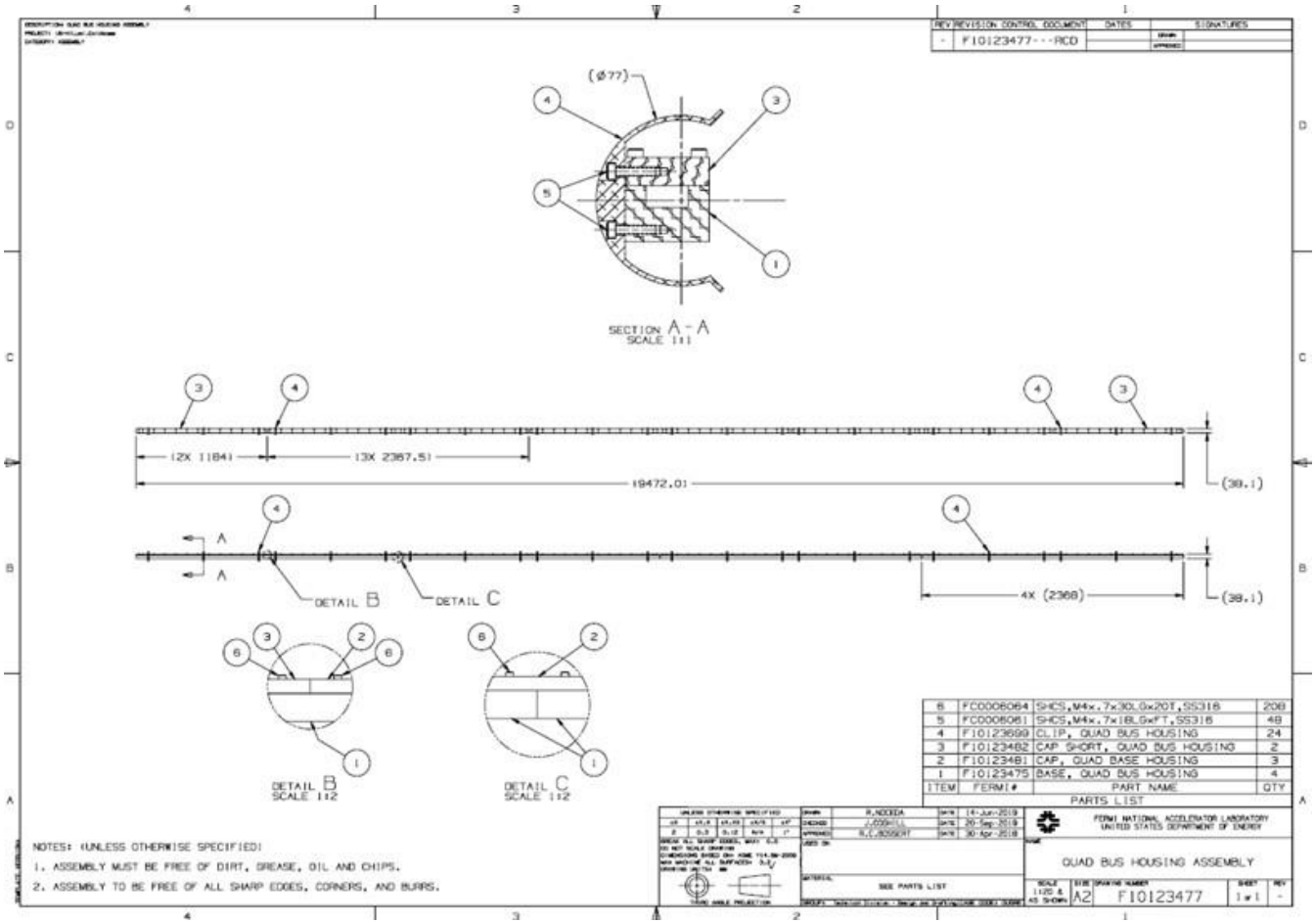


Experimental MIIts budget is in good agreement with the one calculated taking into account the Kapton insulation

Q1/Q3 Bus Housing Configuration

The bus housing for the QXF cold masses is made in a similar manner to the earlier LHCIR Quads. Aluminum “clips” are used to hold the housing in place. Three complete full length housings with supports (11 meters long) have been ordered. One will be used for the practice cold mass.

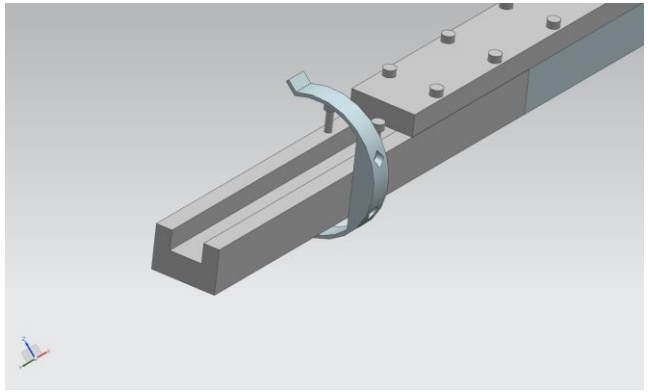
One complete housing with supports (2 meters long) and clips was manufactured and tested in MQXFS1e.

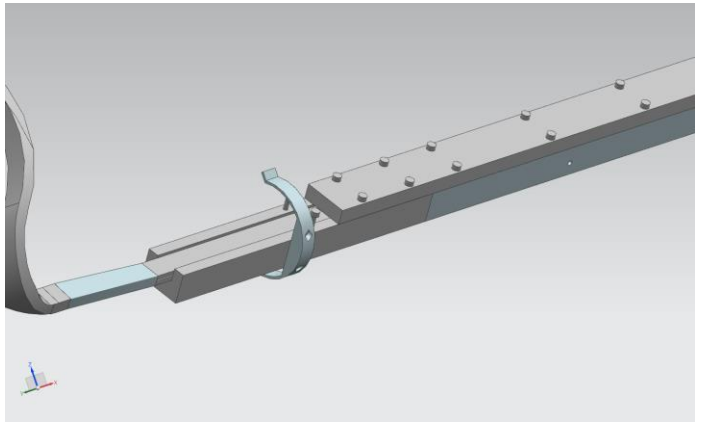


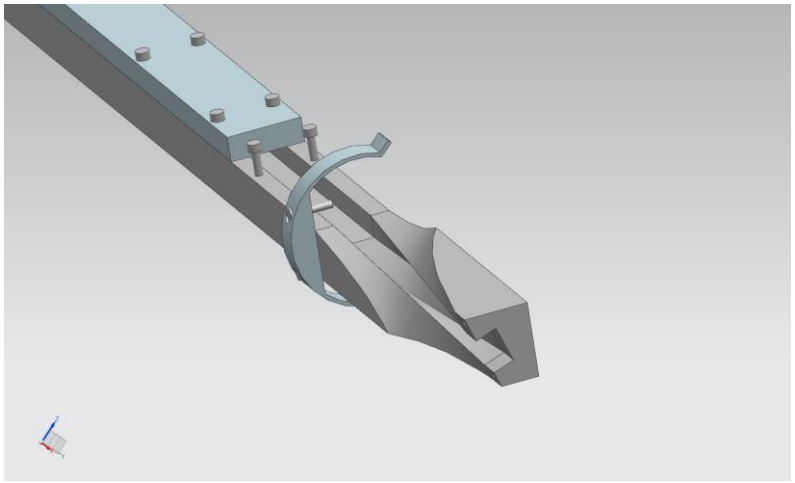
Q2 Bus Housing Configuration

Design of the Q2 bus housing with clips has been completed. The design is similar to the Q1/Q3 housing. It is slightly shorter and has a twist on the lead end to allow the bus to smoothly transition to the Q2 expansion loop

Three complete full length Q2 housings with supports will be ordered as soon as the drawings are released (expected to be by mid October 2019).

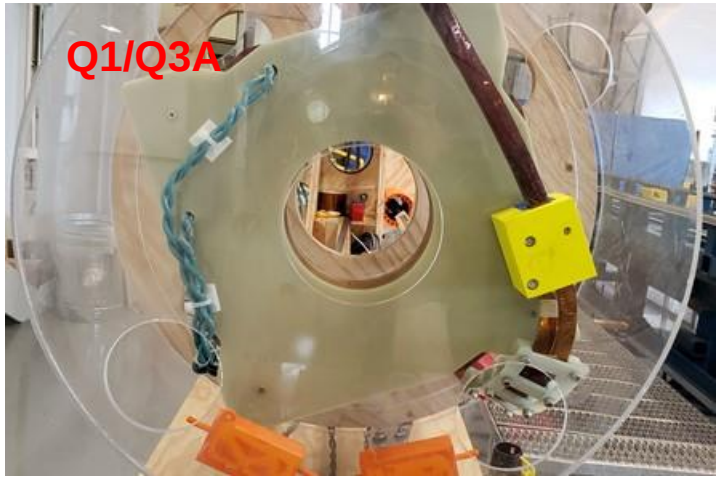


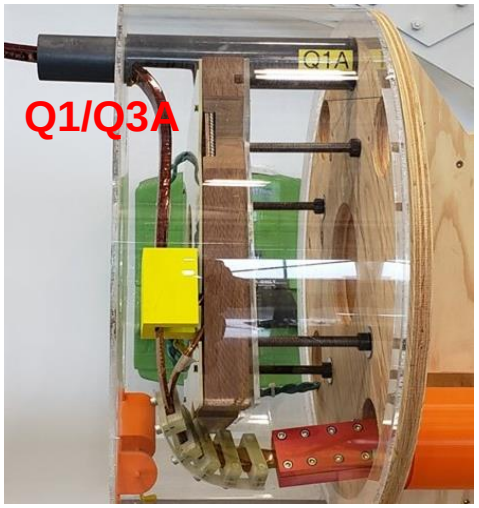




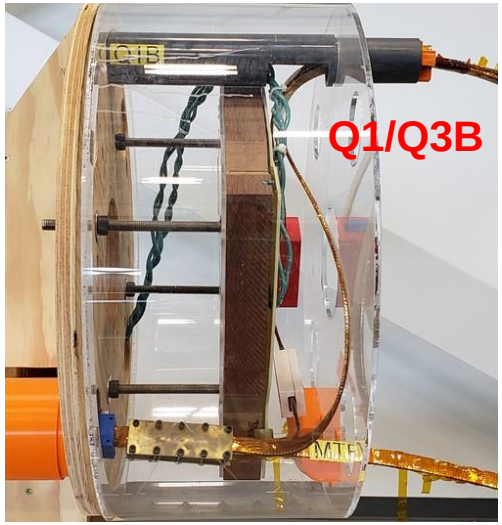
MQXF Expansion Loop Mockup

The Q1/Q3 Expansion loop mockup has been completed, with the exception of the CLIQ leads and instrumentation wires. These will be completed within the next month.





Also, the Kevlar cord which secures the loops has not yet been applied. This will be done Tuesday, Oct. 15th at 1:00 PM, as a demonstration those who would like to see this operation.



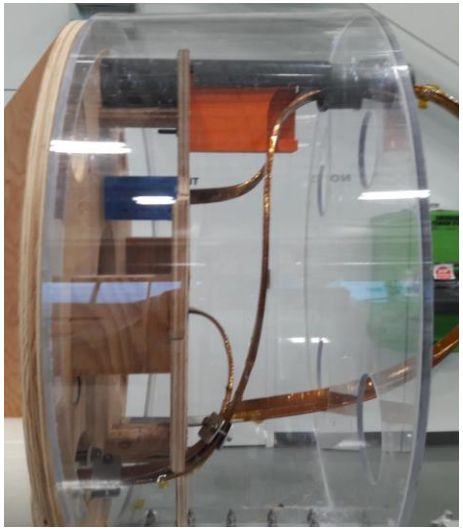
Q2 Expansion Loop Mockup

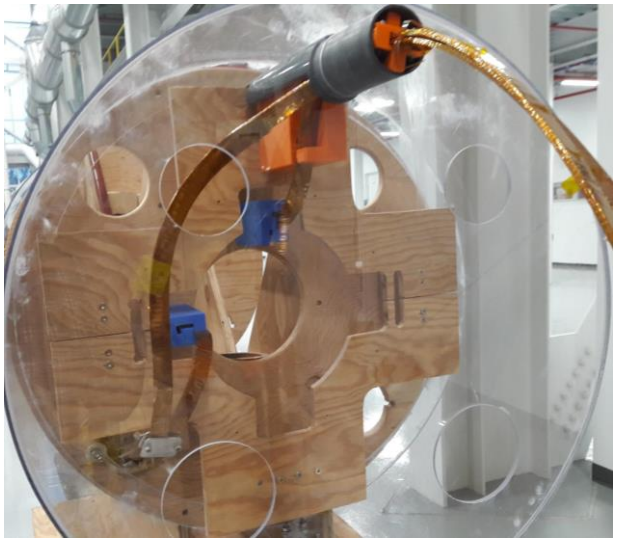
The Q2Mockup is nearing completion

Work Remaining:

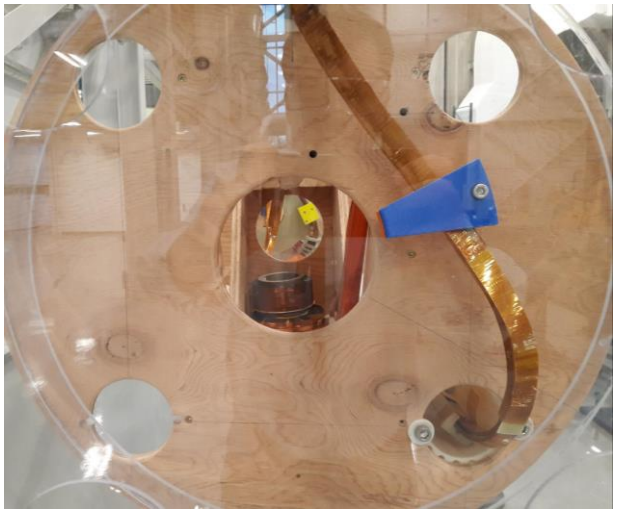
- Add final bus housing
- External spine
- Material selection
- Create/Finalize Drawings

Lead End



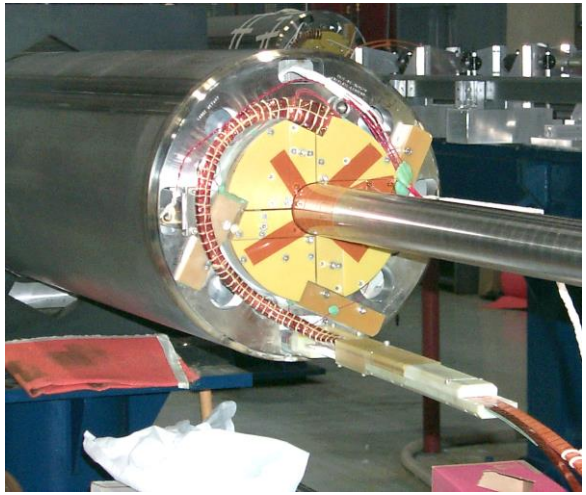


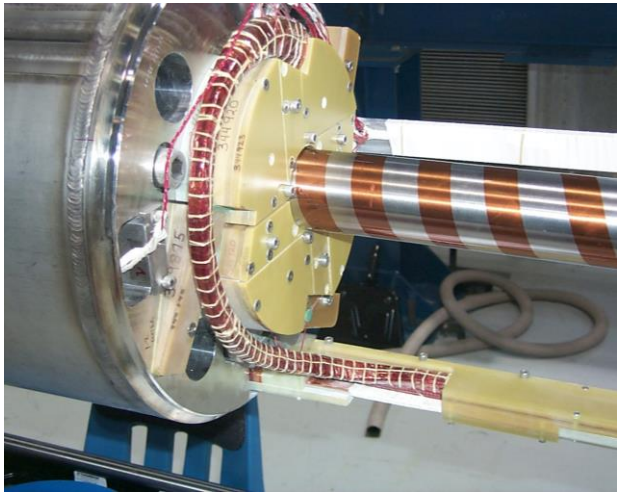
Return End



The expansion loops are individually wrapped, then secured to each other by Kapton. A G-11 “Springboard” is placed between the busses that separates the leads, yet remains flexible enough to sustain the necessary movement.

The MQXB loop is shown here to give an example of how the Kevlar cord looks when applied. This cord will be applied to the Q1/Q3 mockup during the collaboration week, so the process can be observed.





The busses inside the magnets are soldered, wrapped individually and enclosed in a G-11 housing. The loops, after they exit the cold mass area, are no longer soldered, but wrapped together individually with Kapton, then Kevlar cord as shown above.

The loop is wrapped with one layer of 125 um Kapton, 2/3 overlap, surrounded by a wrap of Kevlar cord, with a wrap of one every cm. The Kevlar cord has an allowable load rating of 450 Newtons. The goal is to ensure that either the Kapton or the Kevlar is strong enough to withstand the opposing forces.

Etching of Twist section in Q2

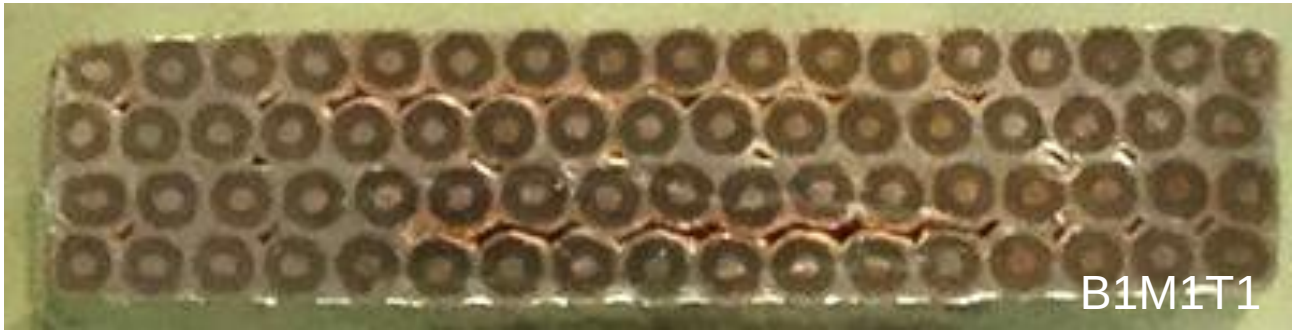
- The twisted portion of the Q2 bus will need to be soldered flat, then twisted after soldering. This picture shows one of the twisted busses with the solder etched away. No visible damage to the filaments is observed.

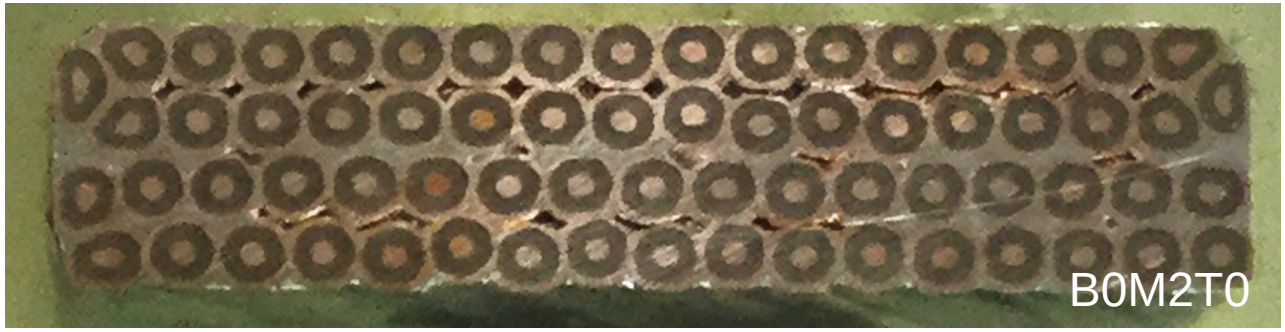
Bus soldering system tests

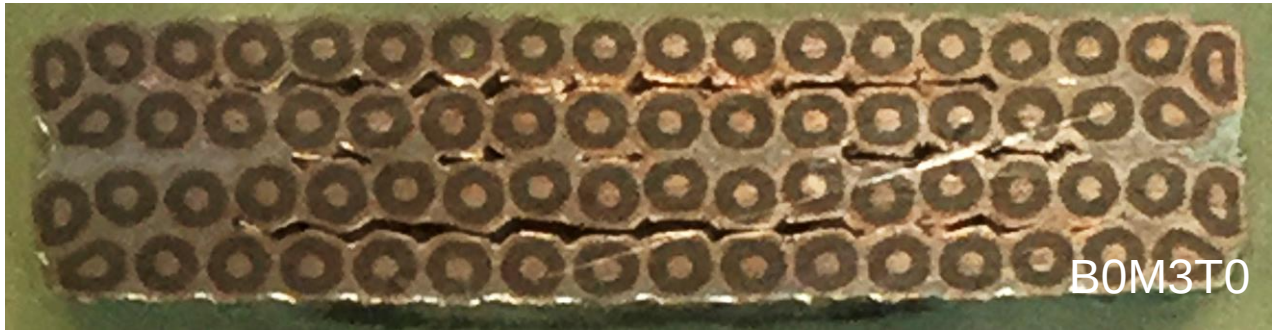
Three soldering systems were tried and sectioned.

Nomenclature:
B=Bottom
M=Middle
T = Top
The number shown is the number of solder strips used at the designated location.

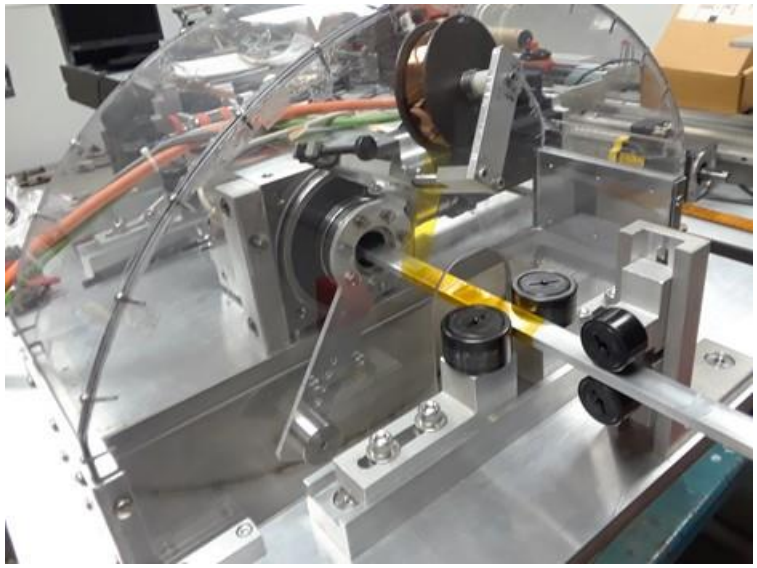
The baseline for the Q1/Q3 (and the system tested in a short model) is B0M2T0.







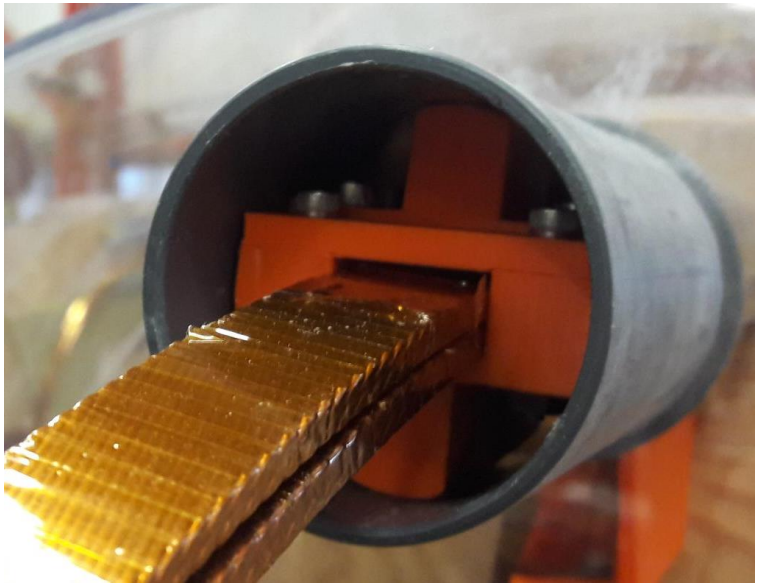
The bus wrapping fixture is complete and is operating. After construction, it was used to wrap busses for Mu2e detector solenoid at Fermilab. Practice wrapping was done in IB3 and the fixture is now in line at the bus wrapping table in IB3A.

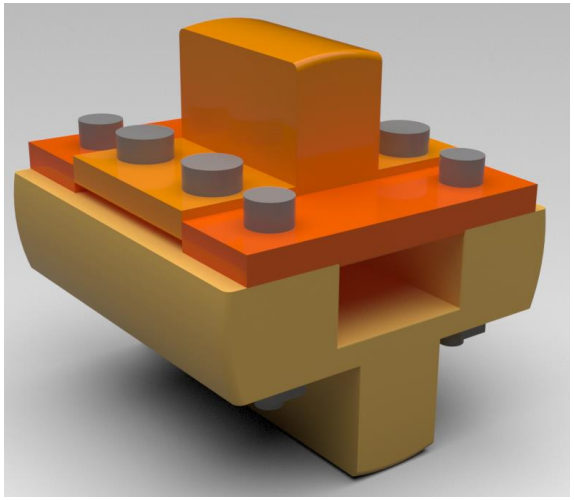


The bus soldering fixture is operating, and has been used to make busses up to 8 meters long. Parts to extend it to 11 meters, long enough for Q1/Q3 as well as Q2 busses, have been shipped. The fixture will be extended to 11 meters in late October, and busses will be made for the first Q1/Q3 and Q2 shortly thereafter.

Bus Interconnection

Bus will enter interconnection and will be centered in the interconnection by a spider.
Spider will be made of G11 and will be allowed to slide freely to allow for thermal expansion
Drawings currently being created





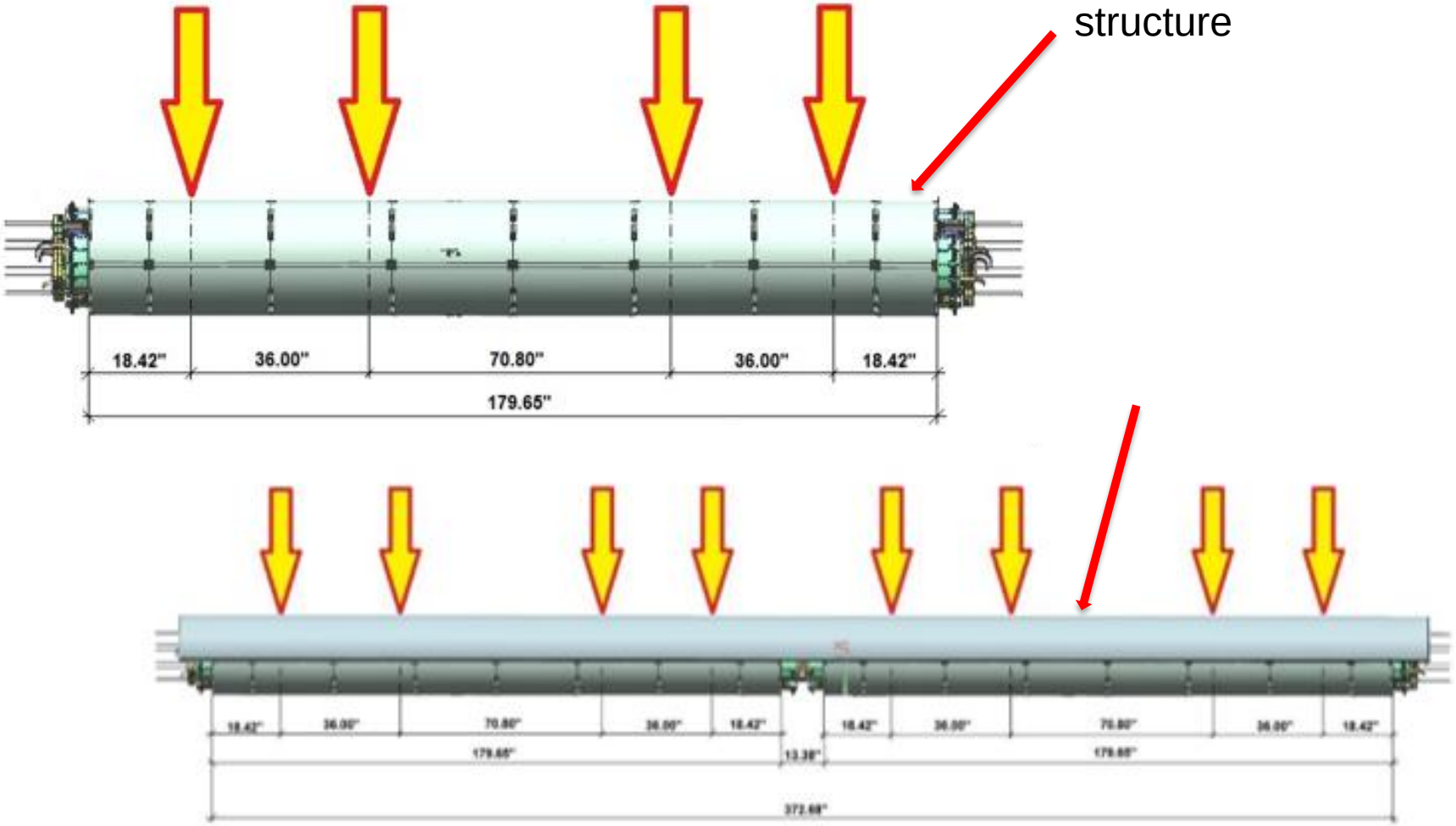
Infrastructure ICBA Completed

Cold Mass Tooling

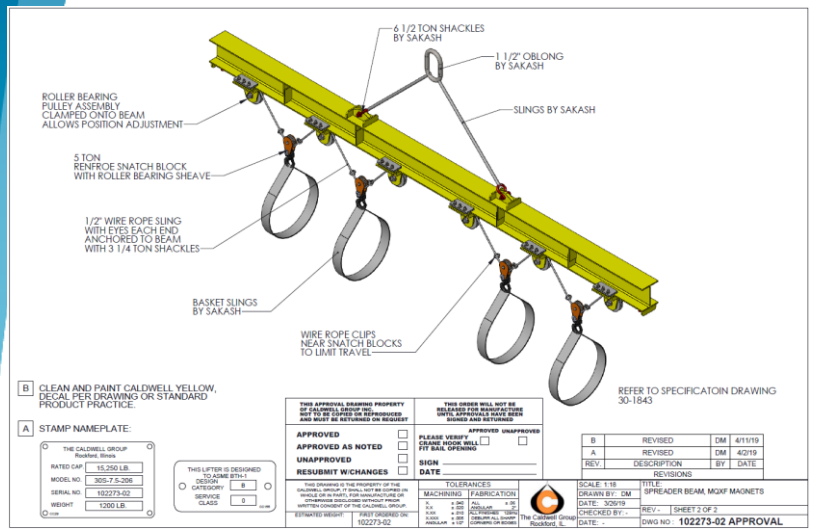
- Magnet Handling requirement drives the tooling design
  - Even lifting using four points – no greater than 200 lb difference between lifting points
  - Putting the cold mas down; at least four points to be used evenly – no more than 0.26 mm deflection allowed between resting points
- CM tooling:
  - Initial magnet survey station – magnet alignment is checked at arrival before removing the magnet from the shipping frame
  - Magnet and Cold Mass Alignment and Rolling Station
  - Welding station
  - End cover tooling
  - Cold Mass support (saddle) tooling

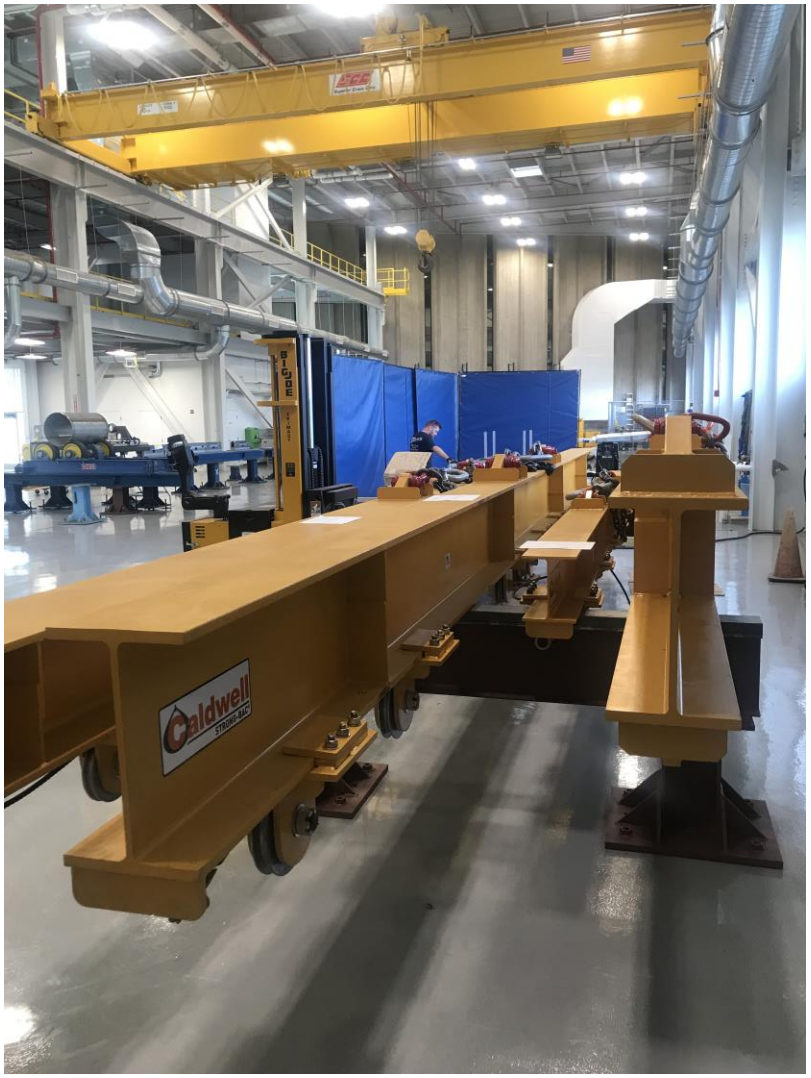
Q1/3 Cold Mass Tooling

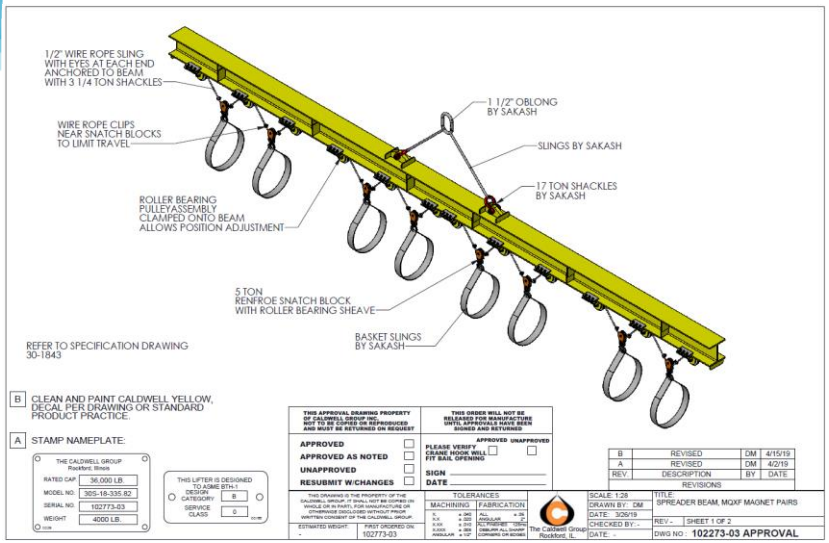
- **Supporting the cold mass**



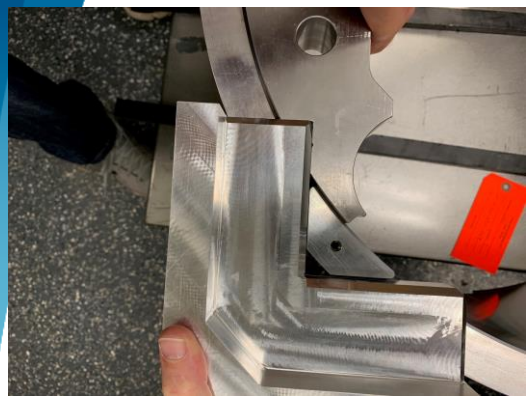
MQXFA Magnet Lifting



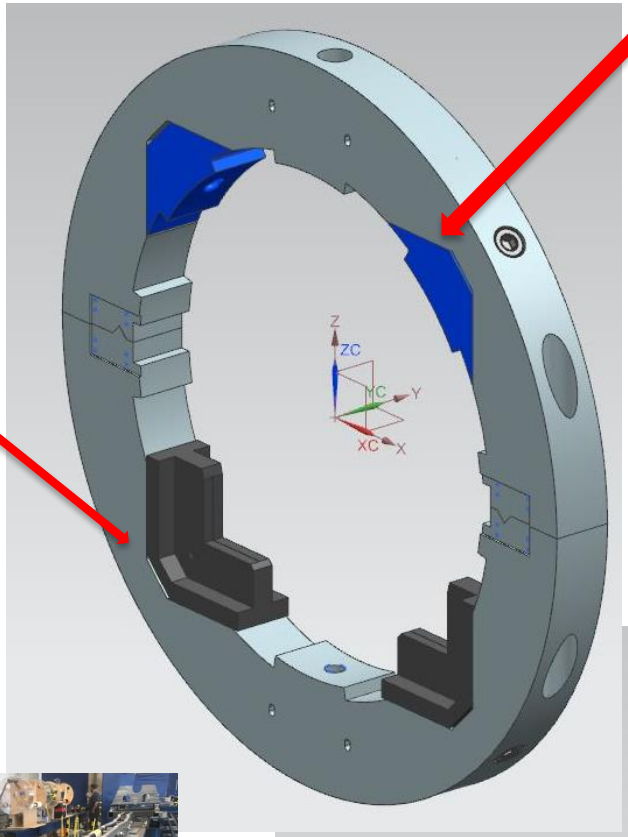




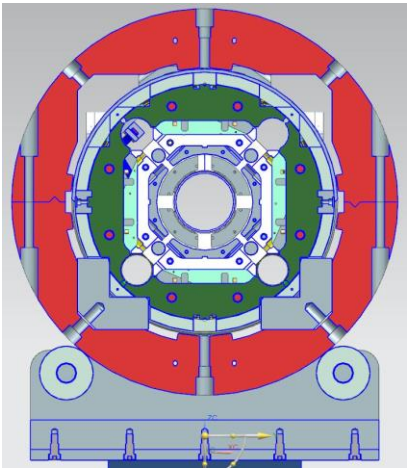
Q1/3 Cold Mass Tooling

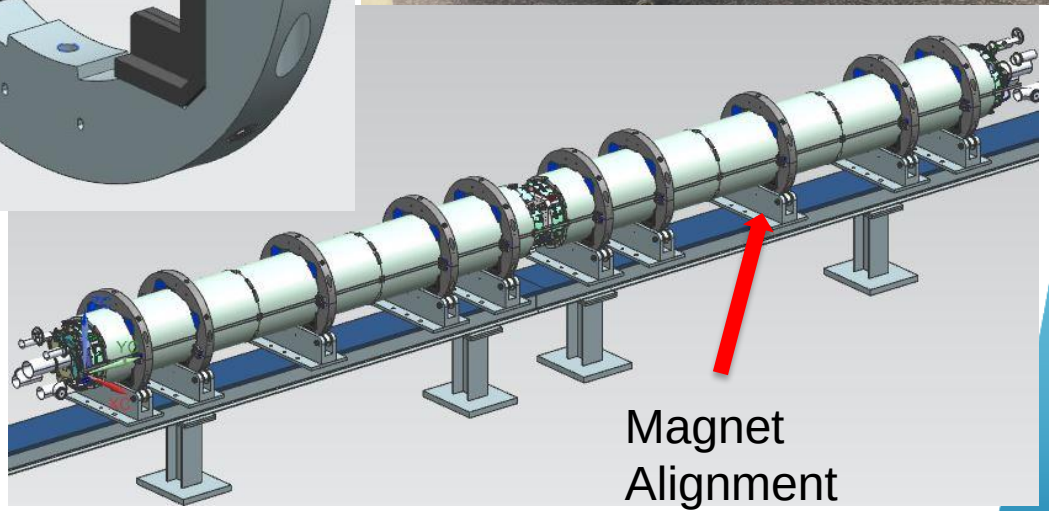


Shell Welding Insert



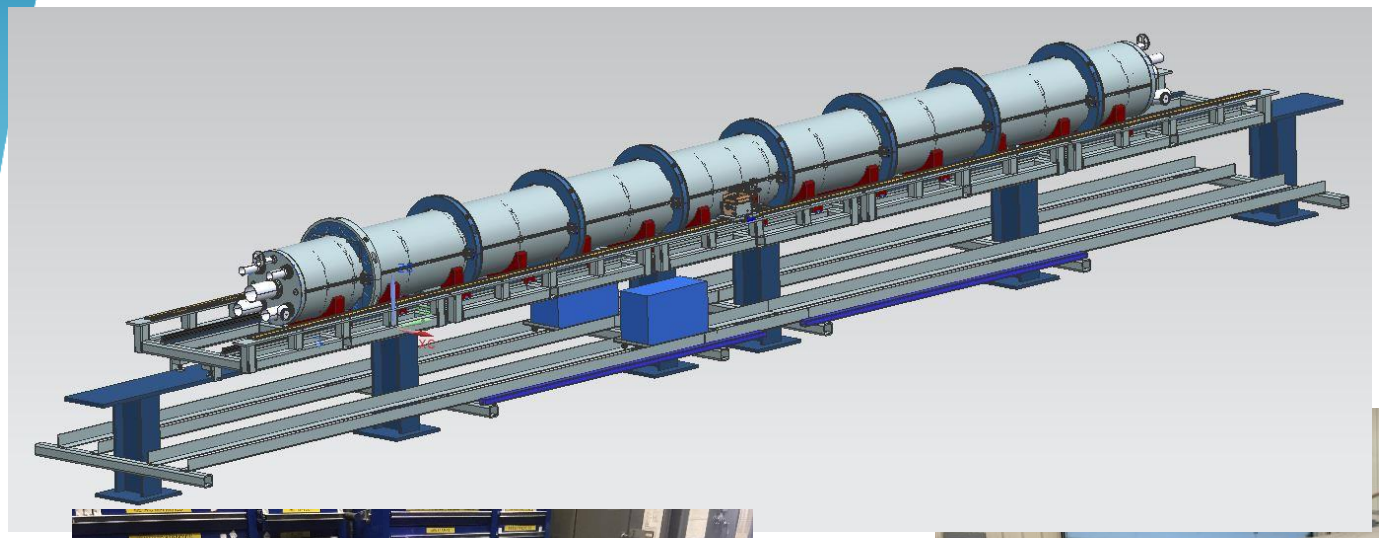
Magnet Alignment Insert





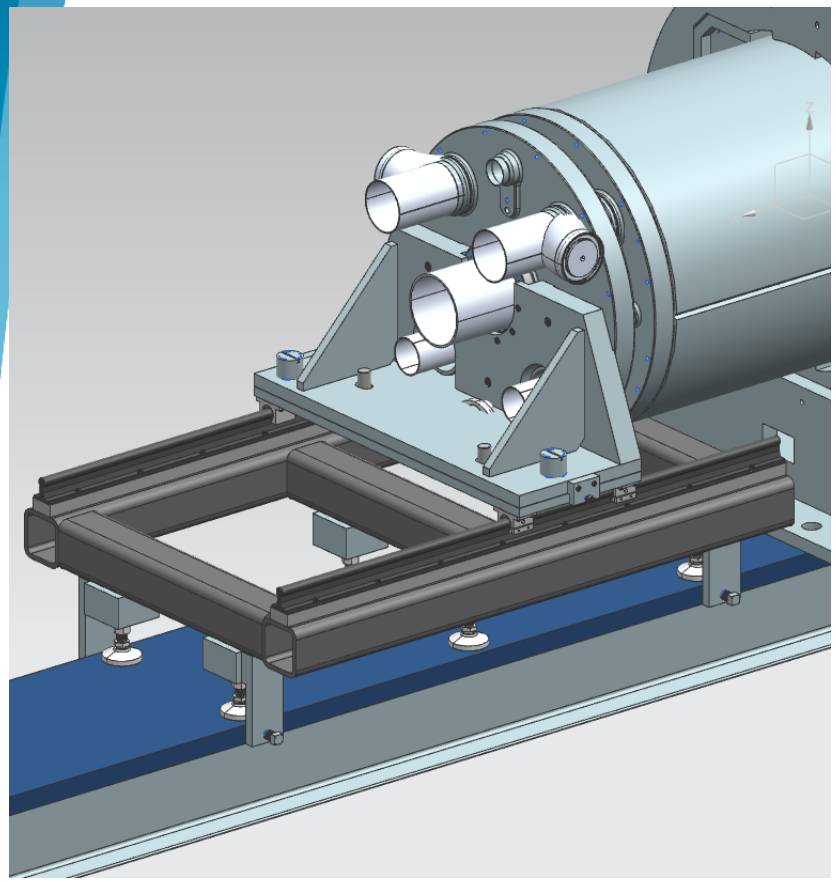
Magnet Alignment Station

Q1/3 Cold Mass Tooling



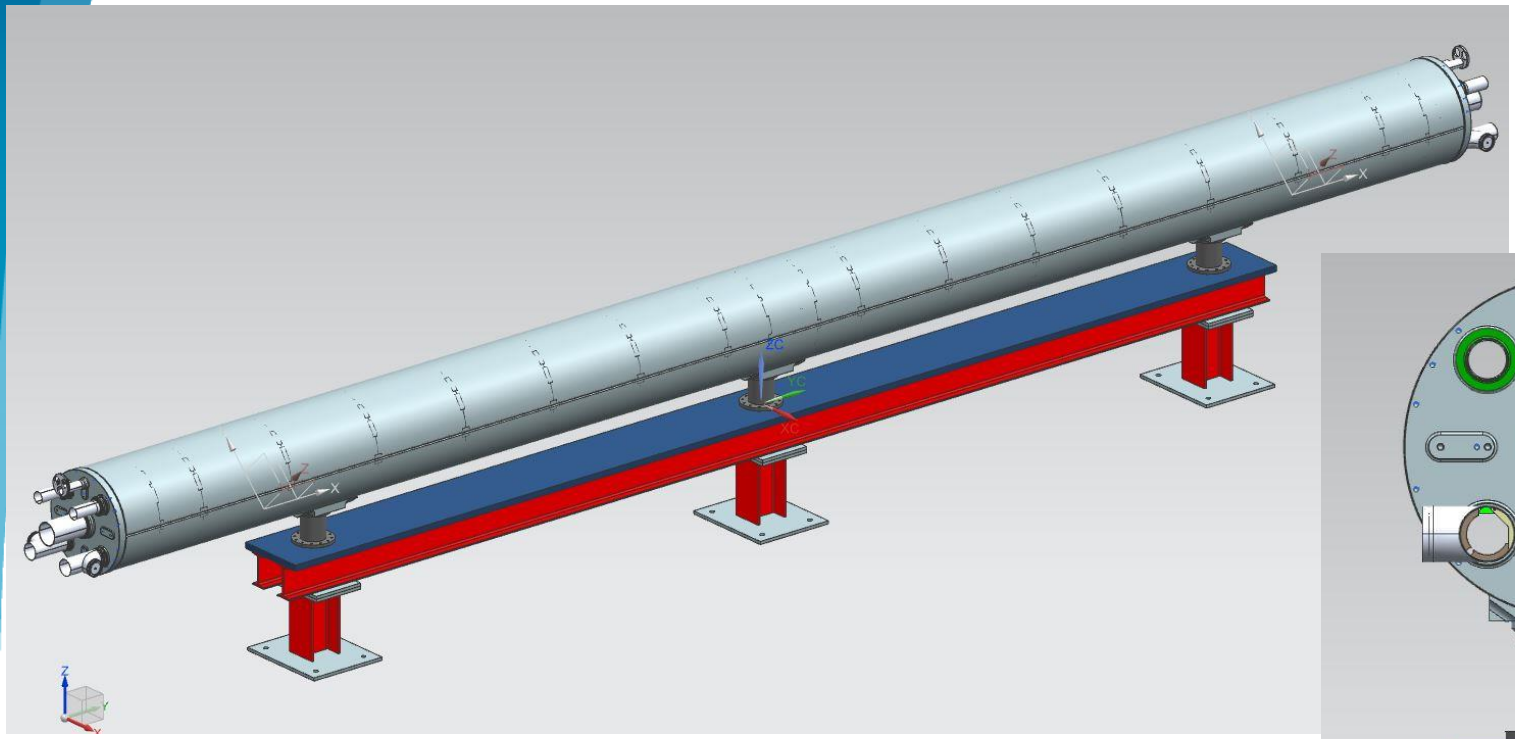
Welding Station

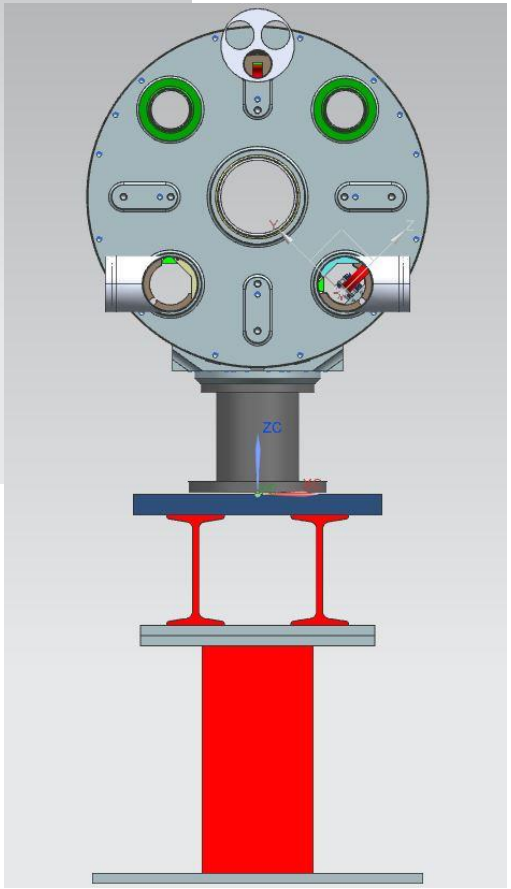
Q1/3 Cold Mass Tooling



END COVER ALIGNMENT

Q1/3 Cold Mass Tooling

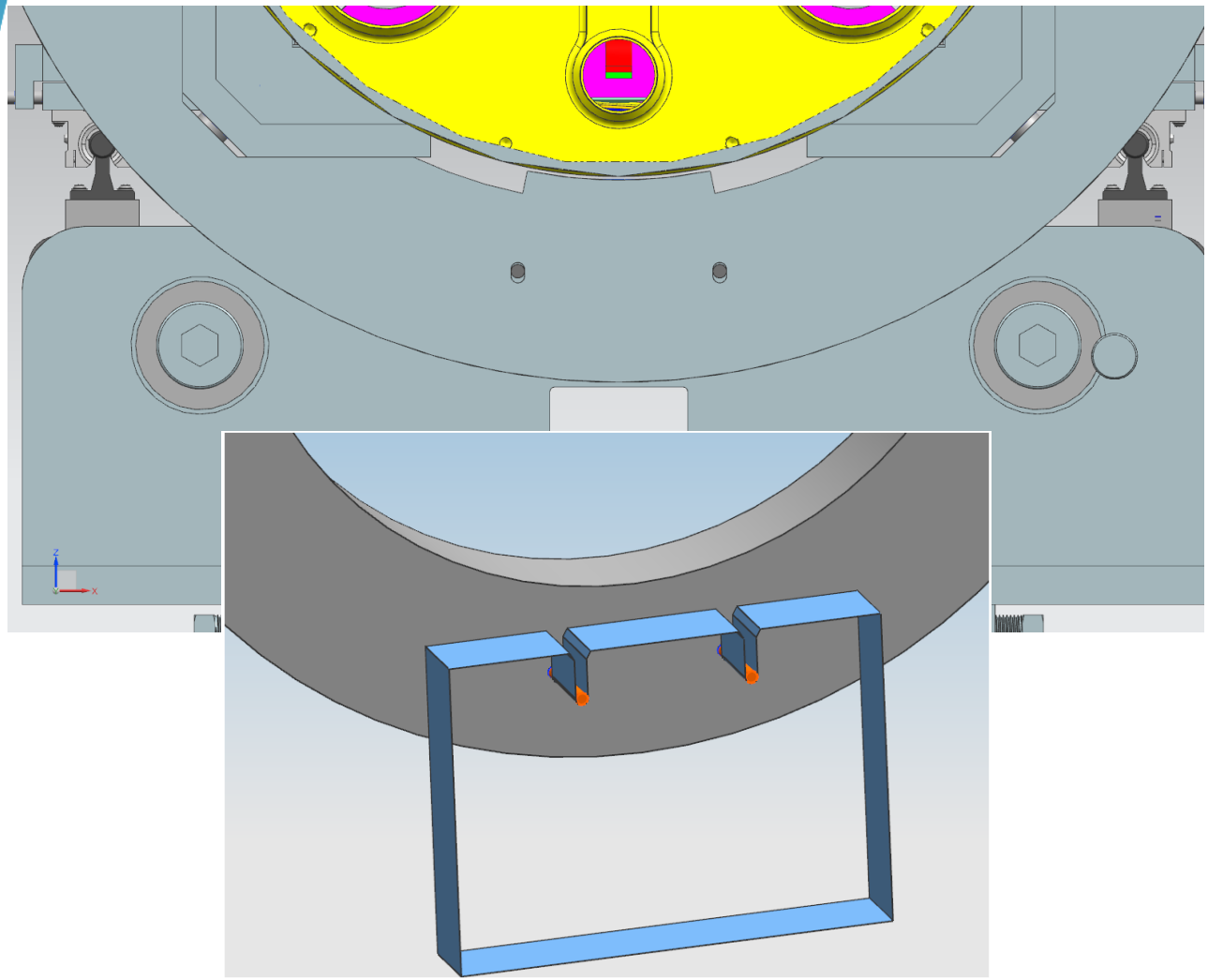




Saddle Installation and Cold Mass position monitoring installation station

(co-planer within 60 µm)

Cold Mass Saddle Alignment



Still conceptual phase

Requirement is keep the Field angle of the magnet $\pm 0.5\ mRad$

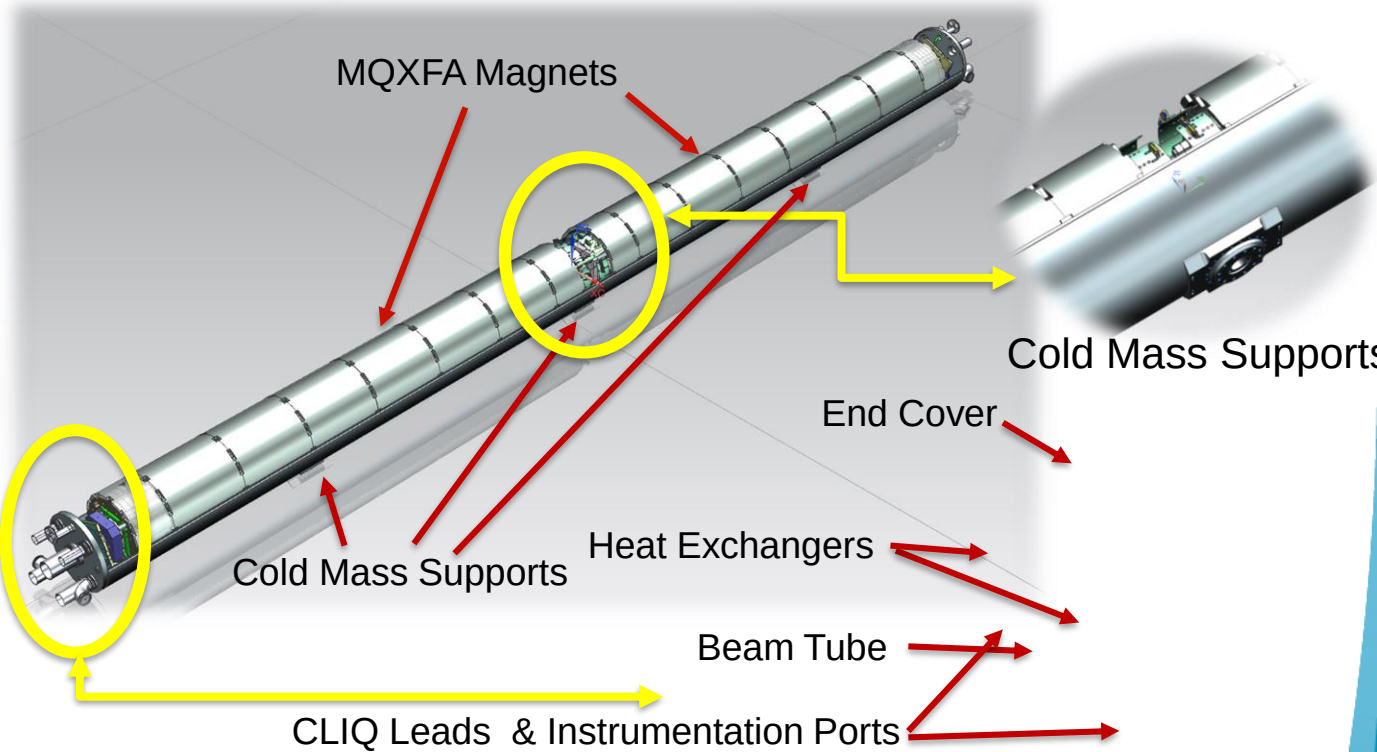
Special clamps blocks will be used to lock the orientation of magnet relative to gravity at the alignment station

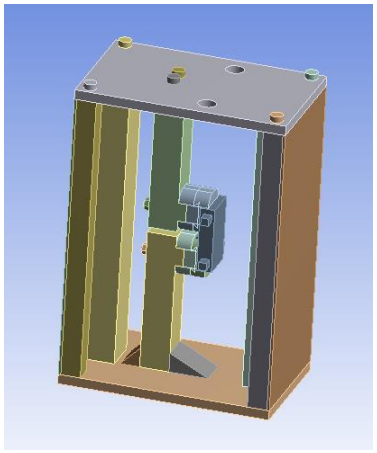
Blocks will keep the orientation at the Saddle Installation station

Cold Mass Assembly

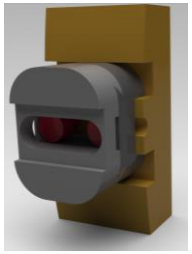
Cold Mass Design and design analysis is close to completion – fine tuning
Detailed Engineering note is under preparation

The design and manufacture of the new HL-LHC cold masses shall be compliant with the Pressure Equipment Directive (PED 2014/68/EU) essential safety requirements (ESR). (LHC-LM-ER-0001 v.4.0, EDMS 1891856 v.4.0). The technical requirement is to use both compliant design and construction standards : EN 13445 and ASME BPVC Section VIII Div. 2 are compatible with PED requirements. (EDMS 1891860/2.0).





Tack Block test



Cold Mass Near Future Plans

- Tooling validation test
  - Instead of two magnets:
    - MQXFP1b Aluminum shell and yoke assembly
    - Filler Aluminum shells
    - MQXFS1
  - Everything can be exercised but magnet alignment
- Test the Tack block design
- Finalizing the engineering note