# Status of Bus and Interconnect

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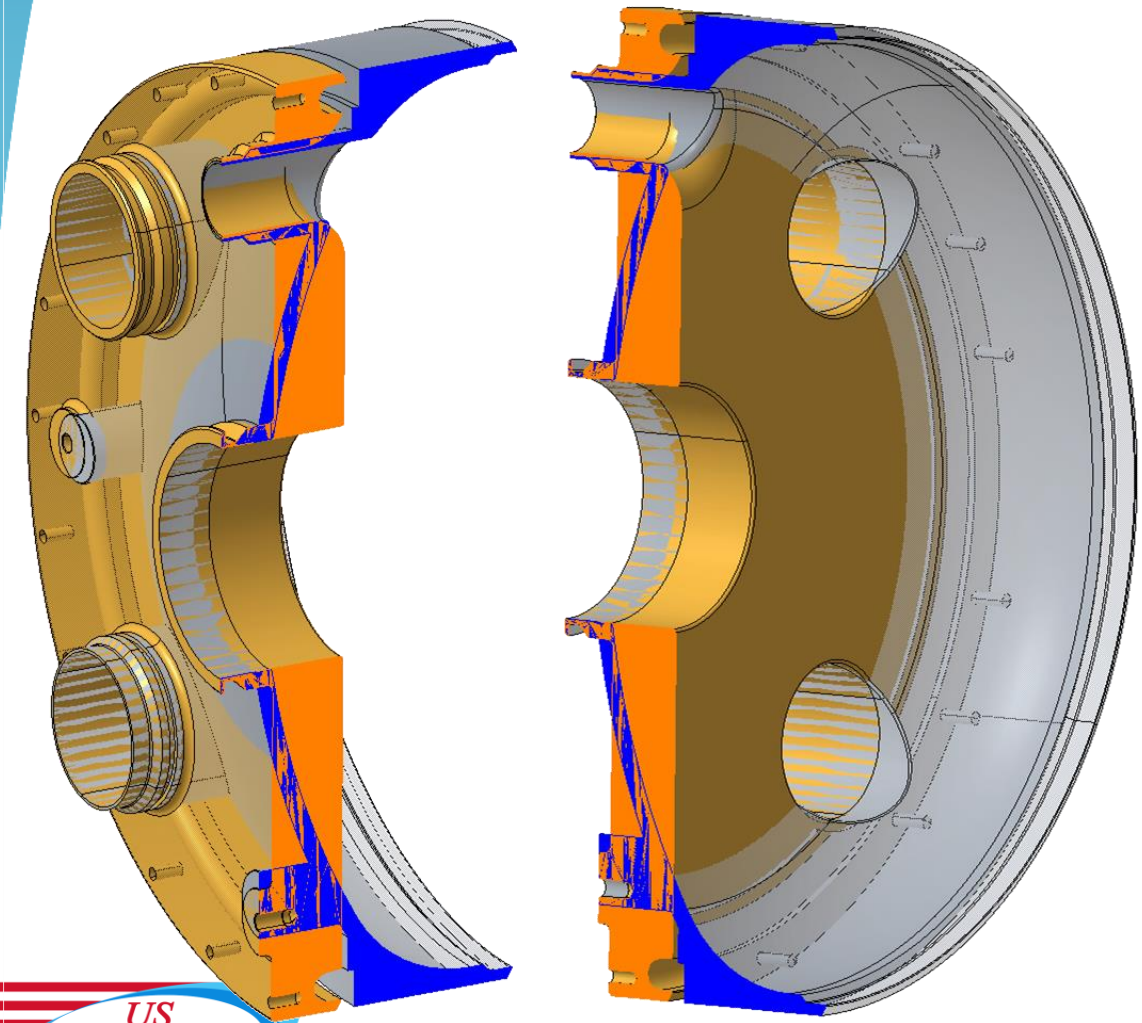
8th HiLumi Collaboration Meeting – CERN, Oct 2018

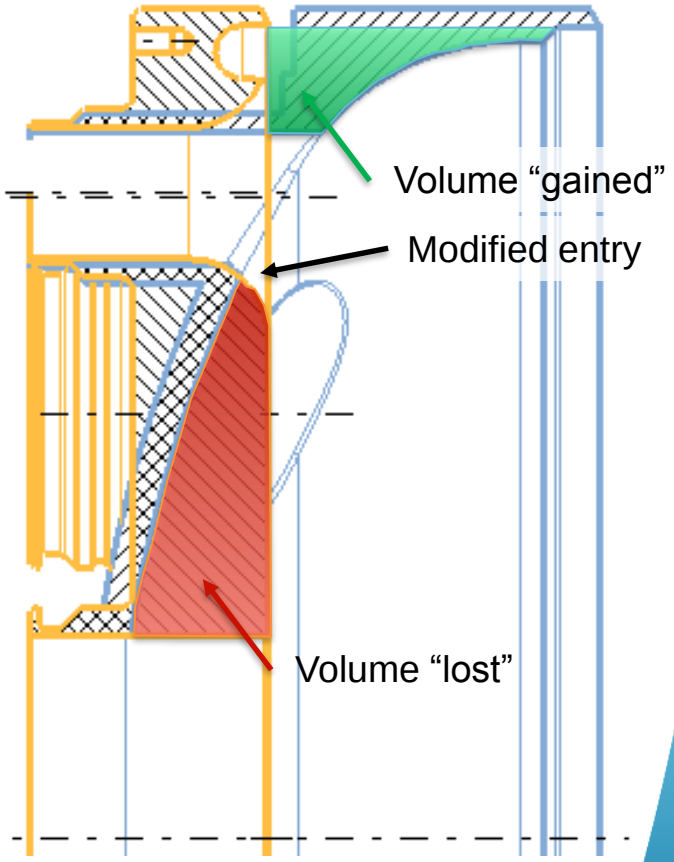
# Outline

- Modifications to End Dome
- Modifications to CERN Cold Mass
- MQXFA Space for Expansion Loop
- MQXB Q2 Bus and Expansion Loop Design
- QXF Bus and Expansion Loop Design
- Bus Bar Mockup
- Bus Bar Validation Test (MQXFS1e)

# From Dished to Flat End Cover

*The "end dome" shape, traditional in past magnets, was changed to a flat plate in the QXF. In addition, the fiducial which defines the outside surface of the plate, has been moved by 10mm away from the center of the interconnection, further reducing space for the expansion loop.*



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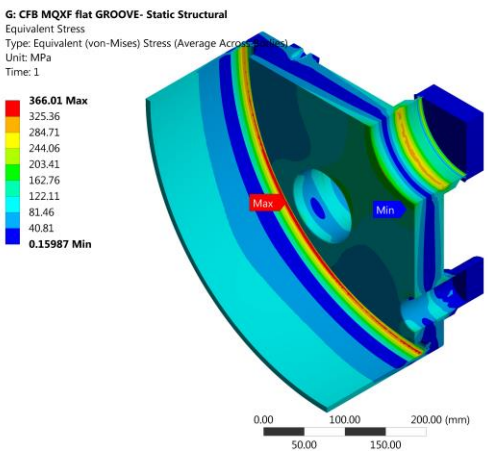
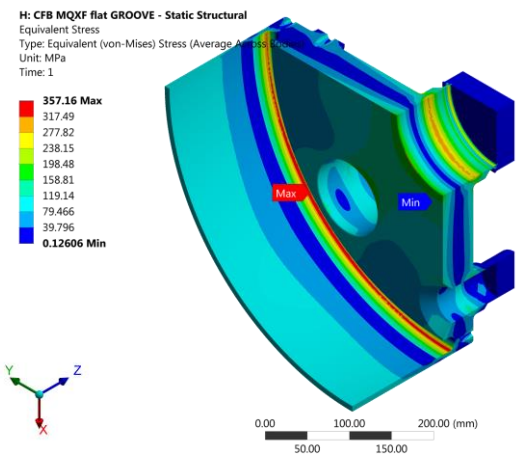
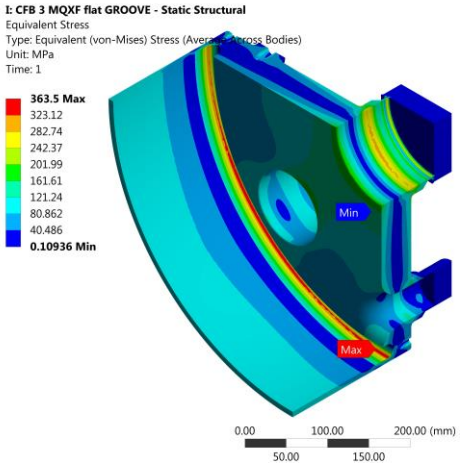
# End cover Structural Analysis

*Initial design* *15mm chamfer* *30mm radius*

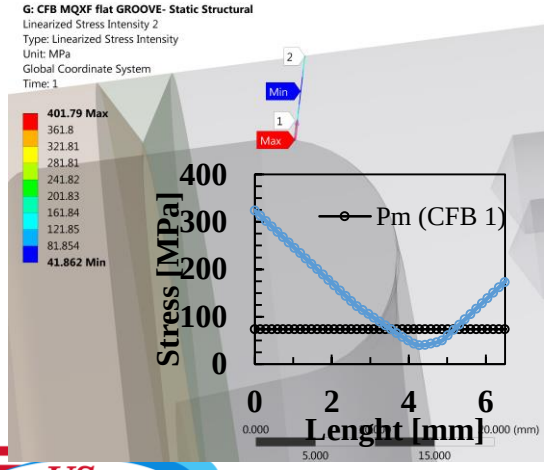
*Equivalent Stress (von-Mises) - Elastic*

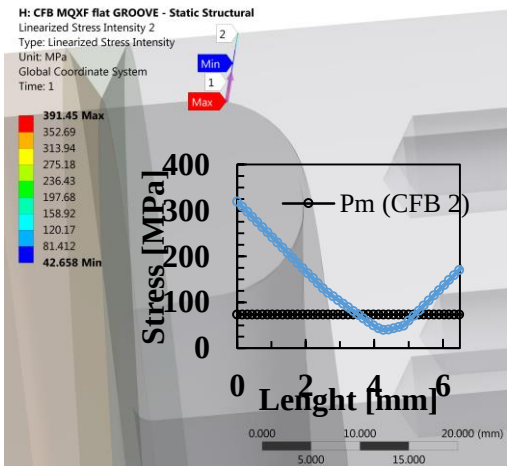


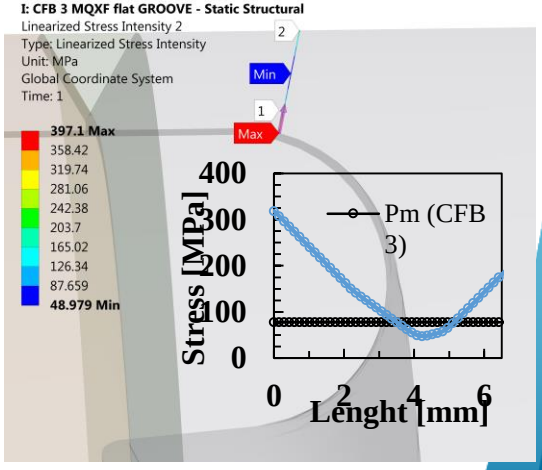




*Linearized Stress Intensity (Stress categorisation) according to EN 13445-3 Annex C - Elastic analysis*




The supporting line segment is established from the node with highest equivalent stress, and approximately normal to the inner surface.

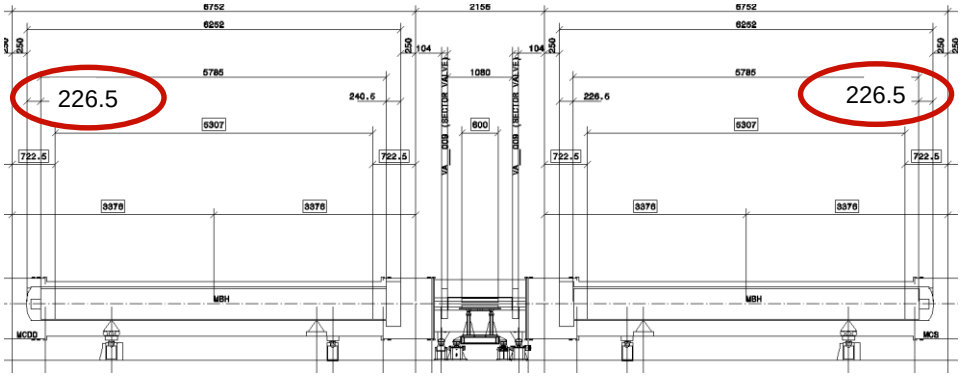
*Courtesy of J. L. Rudeiros Fernández*

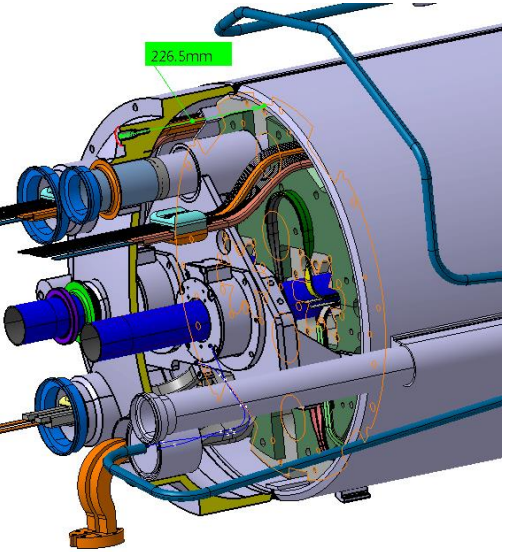
# Cold Mass Extremities

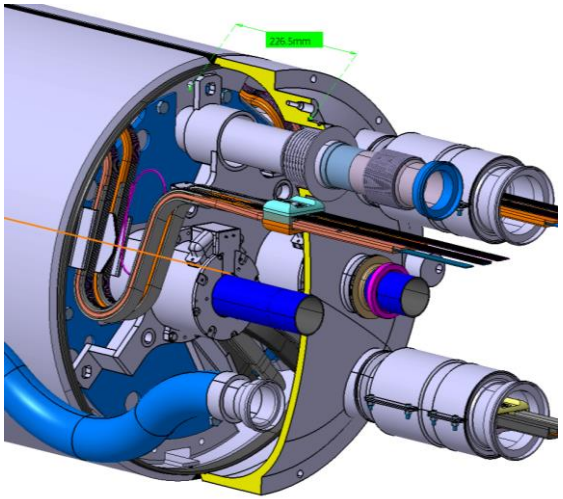
*More space is allowed between the end plate and magnet end on the LMQXF than the 11T. However, a thick preload plate has been added,which takes up space, constricting the expansion loop.*

## 11T case

*(identical to MB, SSS, SSSS…)*

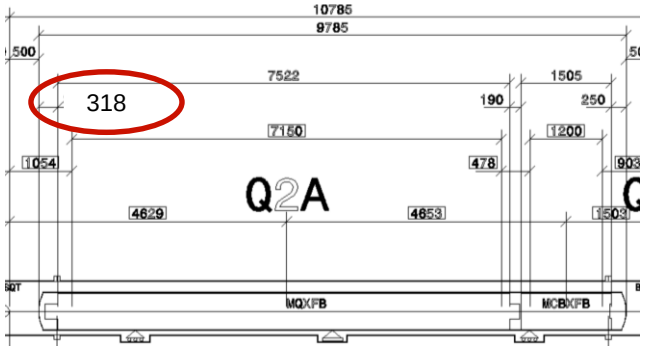


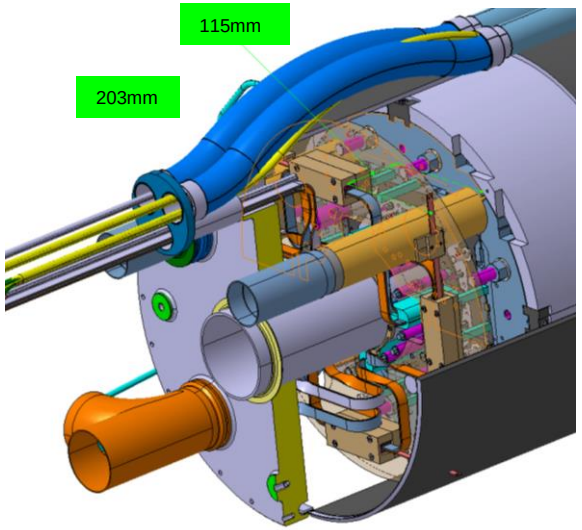




## LMQXF

*Cold masses with MQXFA or B*

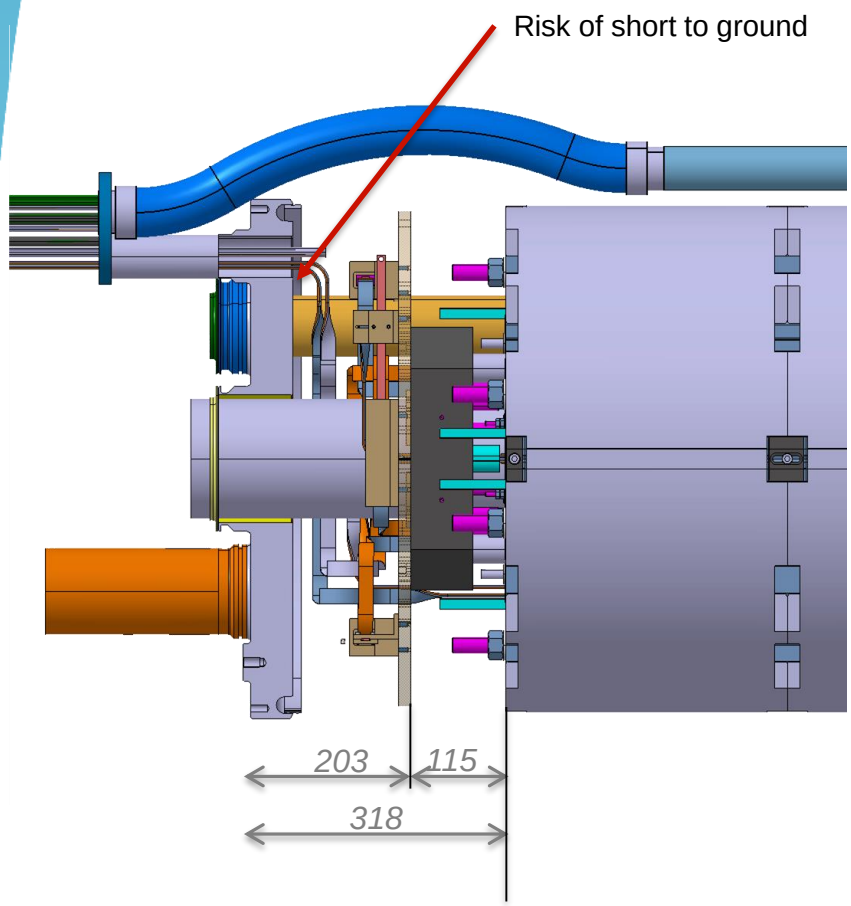


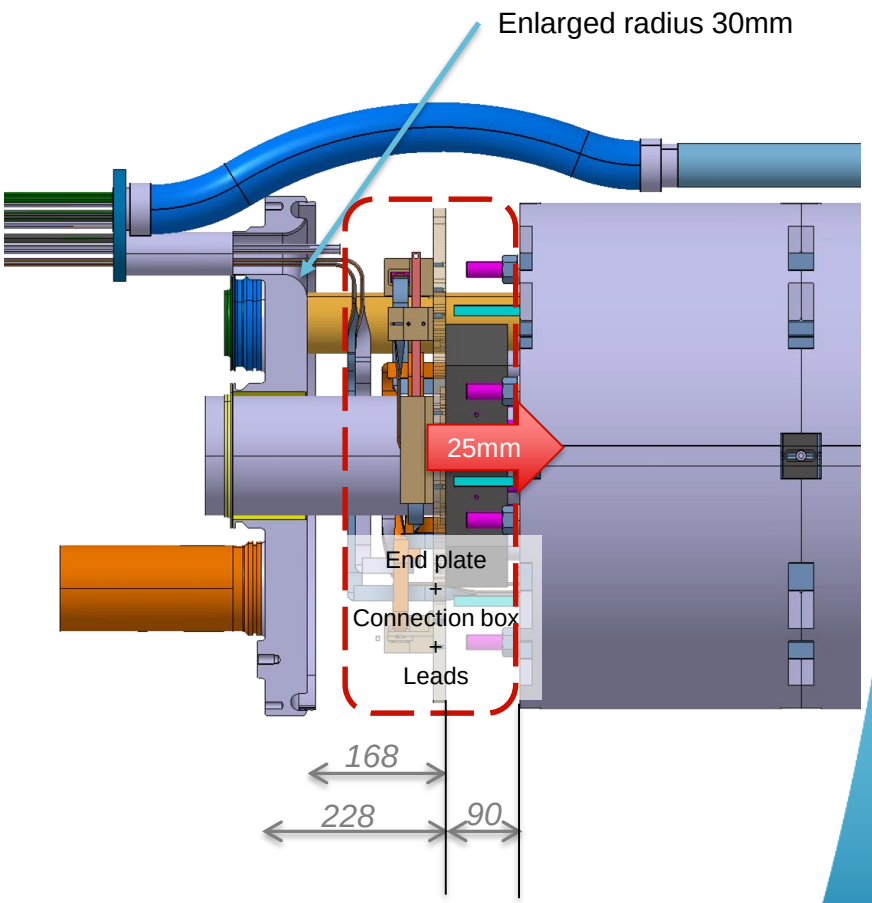



# Busbars Expansion loops integration

*For the MQXFB, the preload plate was moved (as shown to the right), allowing more space.*

*Proposal to generate additional clearance (agreed on MQXFB)*

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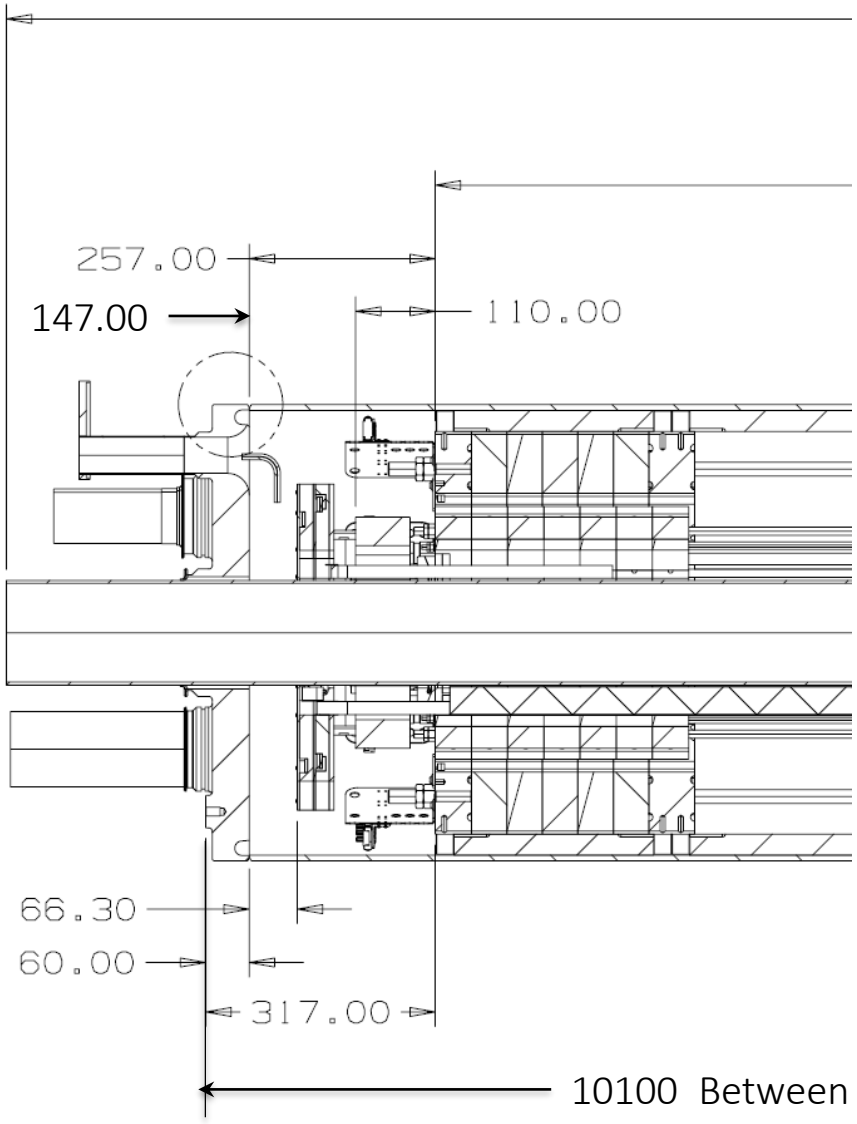
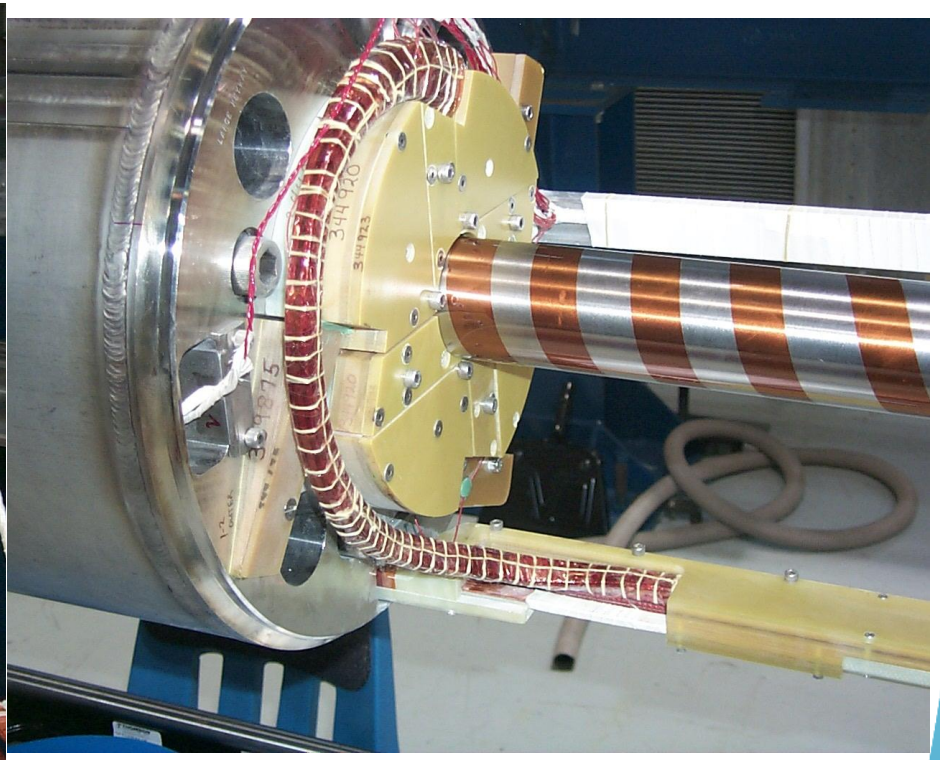
# MQXFA Expansion Loop Area

*In MQXFA, the preload plate could not be moved, leaving 66 mm +/- 2mm for the expansion loop. Space for design is therefore restricted to 64mm.*



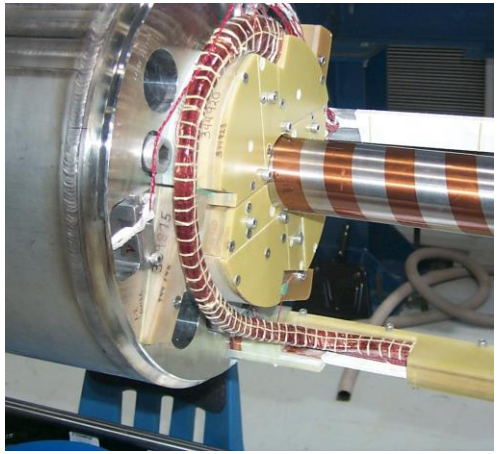
# MQXB Expansion Loop Design

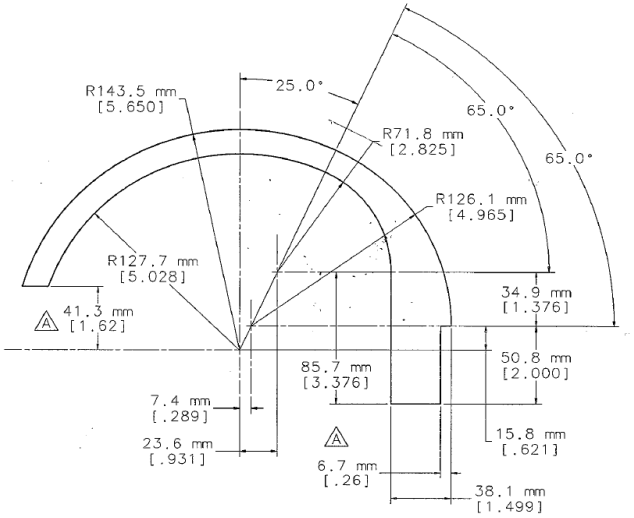
Design of the bus and expansion loop for the QXF cold masses is similar to that used on the earlier IR quads built at Fermilab and currently being used at the LHC.

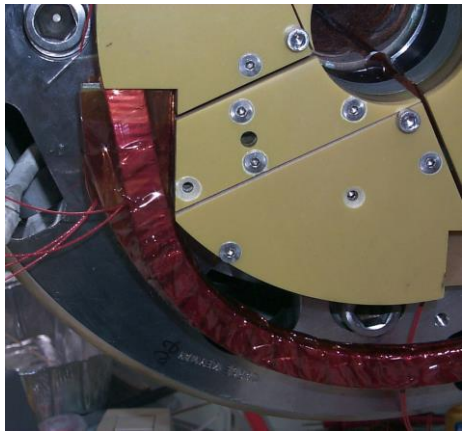


Opposing forces of the two busses without external field is 13000 Newtons per linear meter, or 130 newtons per cm.  slightly less than twice those for the earlier IR Quads.

# MQXB Expansion Loop Design

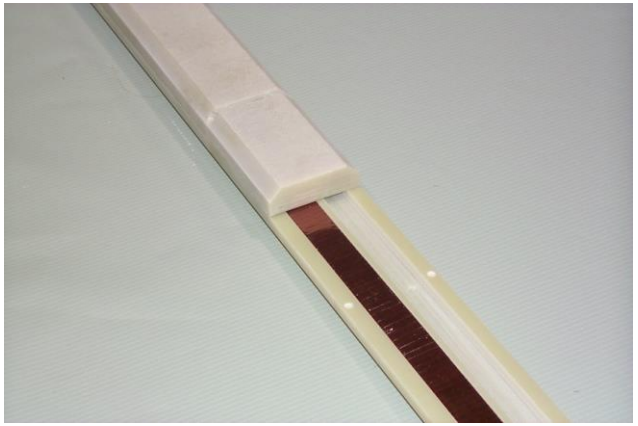




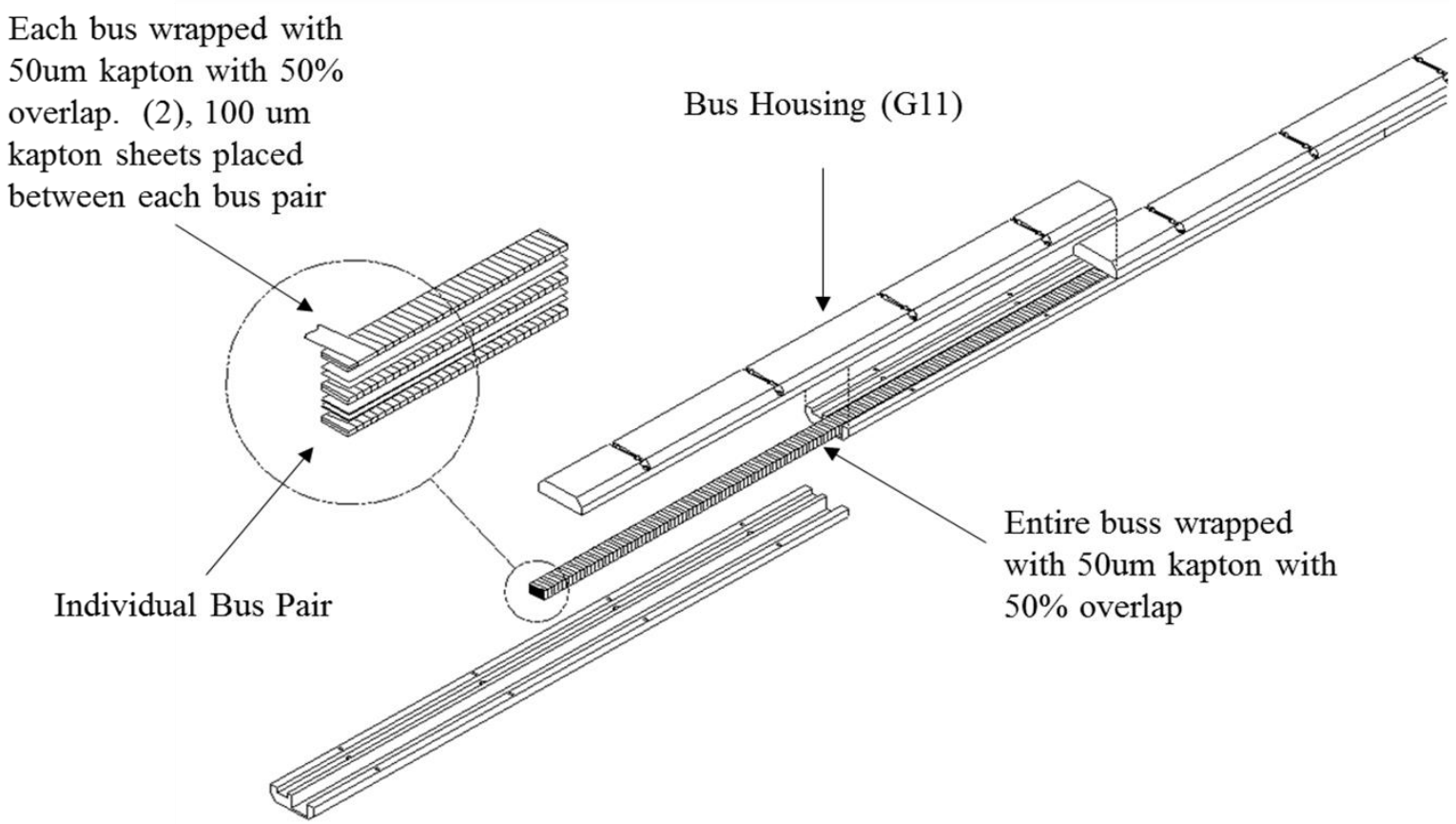
- The expansion loop was secured to the splice box with a G-11 “Springboard” that separated the leads by 3mm, yet remained flexible enough to sustain the necessary movement.
- The loop was wrapped with one layer of 50 um Kapton, 75% overlap, surrounded by a wrap of Kevlar string, with a wrap of one every 2 cm. The Kevlar string has an allowable load rating of 450 Newtons. The goal was to ensure that either the Kapton of the Kevlar would be enough to withstand the opposing forces.
- The QXF expansion loop will be wrapped with a similar system, with the amount of Kapton and Kevlar increased to accommodate the higher forces. (125 um Kapton with 2/3 overlap and Kevlar cord every 1 cm.)

# MQXB Bus Housing Design

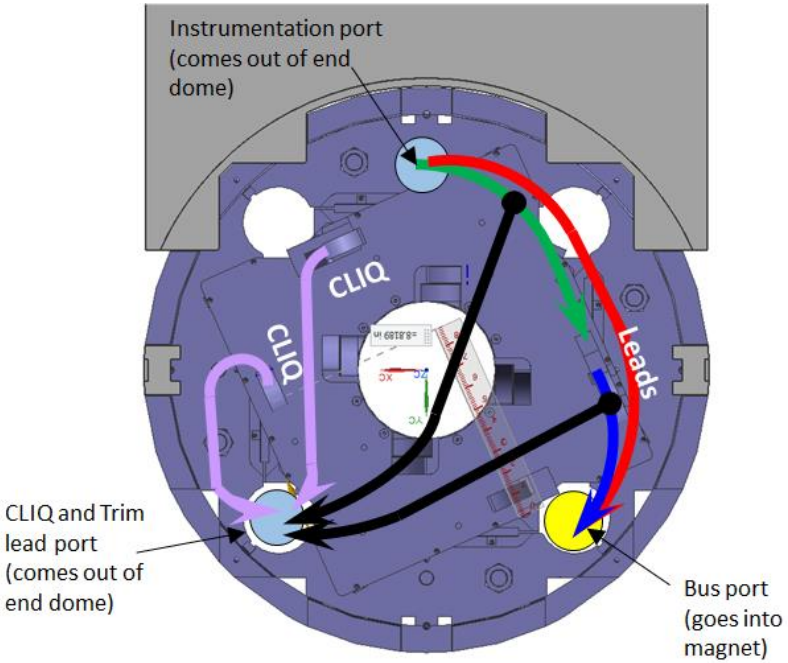
The through bus was made of modular pieces of G-11, which enclosed the bus and fit loosely into the bus port. It was inserted into the cold mass by hand.

# MQXB Bus Housing Design

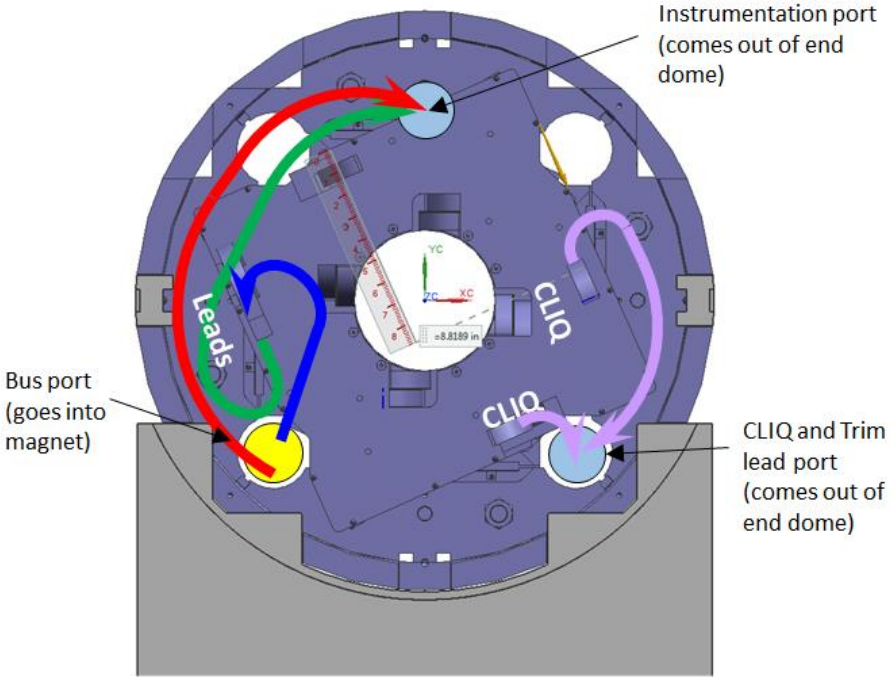


# QXF Bus Expansion Loop Configuration

Q1a/Q3a




Q1b/Q3b




***Key:***

***Green line power leads***

***Blue line local bus***

***Red line through bus***

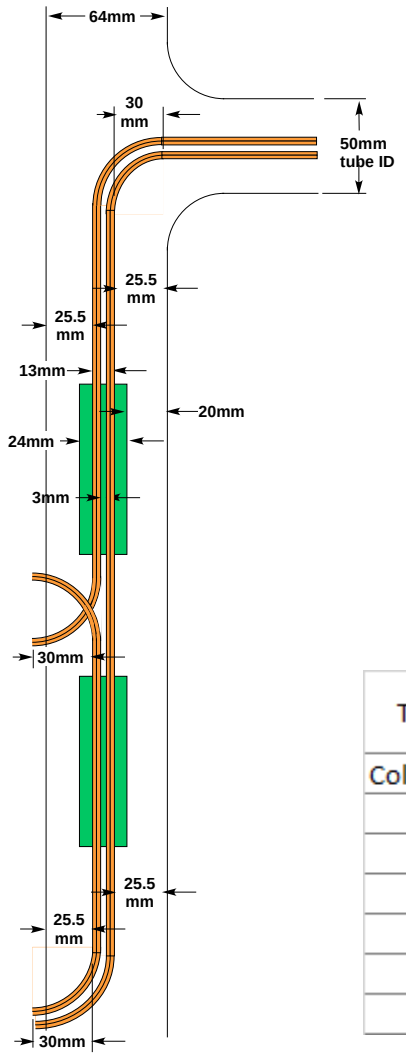
***Purple line CLIQ leads***

***Black line trim leads***

***Q1b/Q3b is flipped vertically with respect to Q1a/Q3a***

# QXF Bus Expansion Loop Configuration

**Home Position (CM300K, Busses 300K)**




**Calculation of Expansion loop travel for Q1/Q3 Cryostat**

R. Bossert July 25, 2018

Assumptions about axial fixed points:

- Cold Mass is fixed to Cryostat at the center of the cold mass.
- Cold mass is fixed to local bus only where the bus attaches to the splice box on each end.
- Cold mass is fixed to leads only at the splice box on each end.
- Through bus is fixed to leads and local bus at each end.
- Power lead and through bus are fixed axially to ground at the splice in the center of the interconnection. (in other words, the Q1/Q3 expansion loops only take the travel due to the Q1/Q3 cold mass/Cryostat)
- Cryostat is warm, therefore does not move or change axially due to thermal conditions.

Assumptions about CTE:

- The magnet shrinks at 3.2 mm/m integrated from 300K to 1.9K
- Busses and leads shrink at 3.2 mm/m integrated from 300K to 1.9K
- There can be a maximum of 100°C difference in temperaturebetween any component within the cold mass. (therefore a maximum 100°C difference between the bus and the cold mass).
- All shrinkages are linear from 300K to 0K

Assumption about lengths:

- length from center of cold mass to surface of splice box = 4924 mm
- Length of local bus from center of cold mass to connection point with splice box = 5100 mm
- Length of power lead or through bus from connection point on splice box to center of interconnection = 900 mm.

| Temperature (°K) | | Movement from fixed point (mm)* | | |
|---|---|---|---|---|
| Cold Mass | Busses | CM Face | Loop Entry | Loop Shortening |
| 300 | 300 | 0.0 | 0.0 | 0.0 |
| 0 | 0 | -15.8 | -16.3 | 2.9 |
| 300 | 200 | 0.0 | -5.4 | 1.0 |
| 200 | 300 | -5.3 | 0.0 | 0.0 |
| 100 | 0 | -10.5 | -16.3 | 2.9 |
| 0 | 100 | -15.8 | -10.9 | 1.9 |

| Total movement with respect to splice box* | |
|---|---|
| top loop | bottom loop |
| 0.0 | 0.0 |
| 18.6 | -0.6 |
| 1.0 | -5.4 |
| 5.3 | 5.3 |
| 13.4 | -5.8 |
| 17.7 | 4.9 |

* Positive number is away from center of cold mass, negative number is toward center of cold mass.

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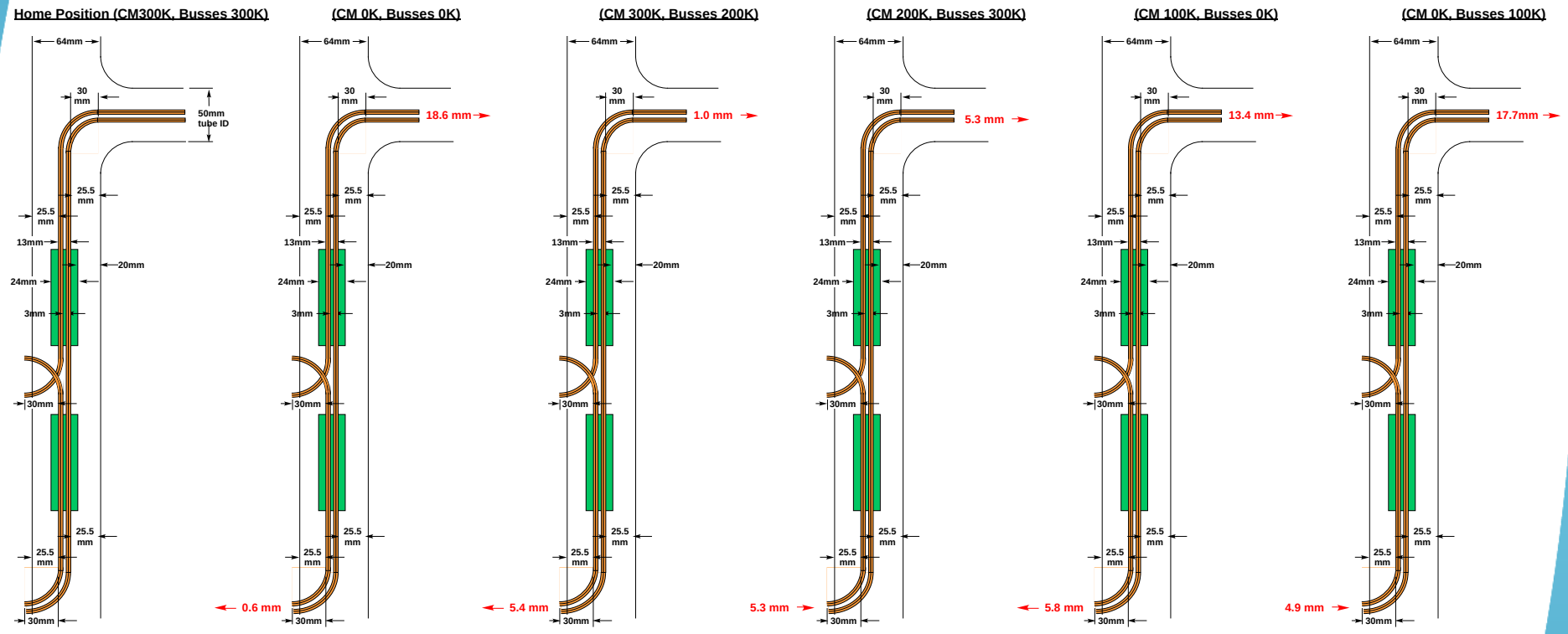
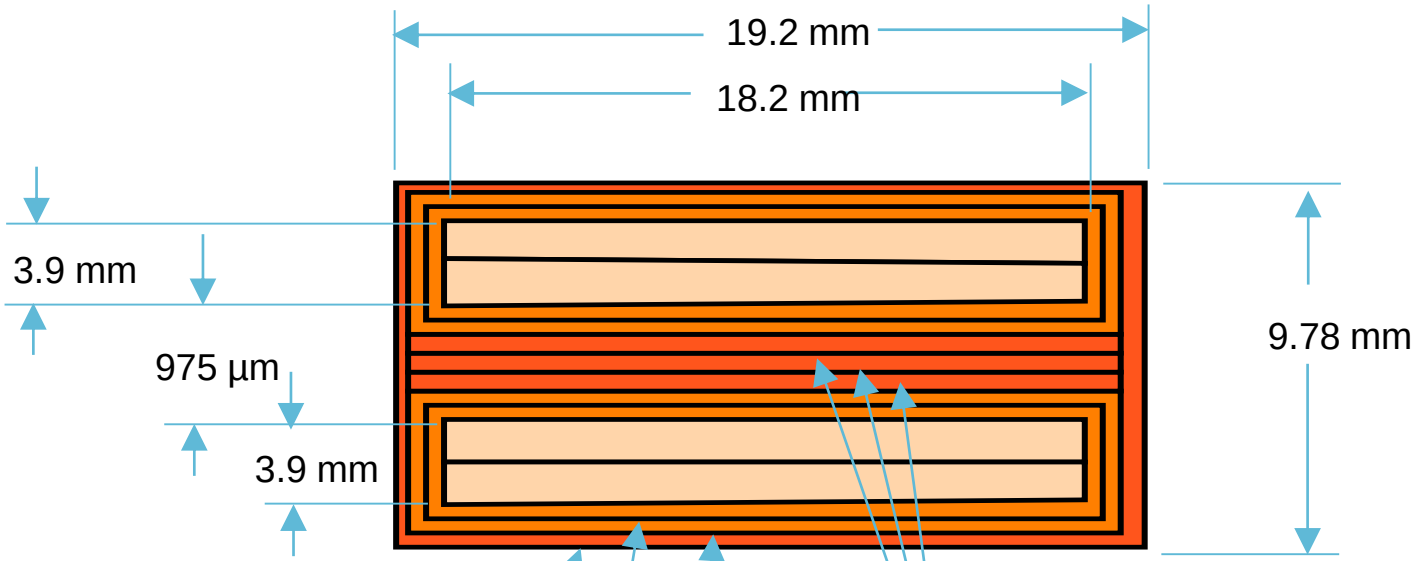
# QXF Bus Expansion Loop Configuration




Amount of travel needed by expansion loop according to the 6 scenarios shown above. The amount of travel is similar to that from the earlier LHCIR quads.

# QXF Bus Configuration




1 layer of 50 µm thick Kapton with 75% overlap = 200 µm

1 layer of 50 µm thick Kapton with 66% overlap = 150 µm

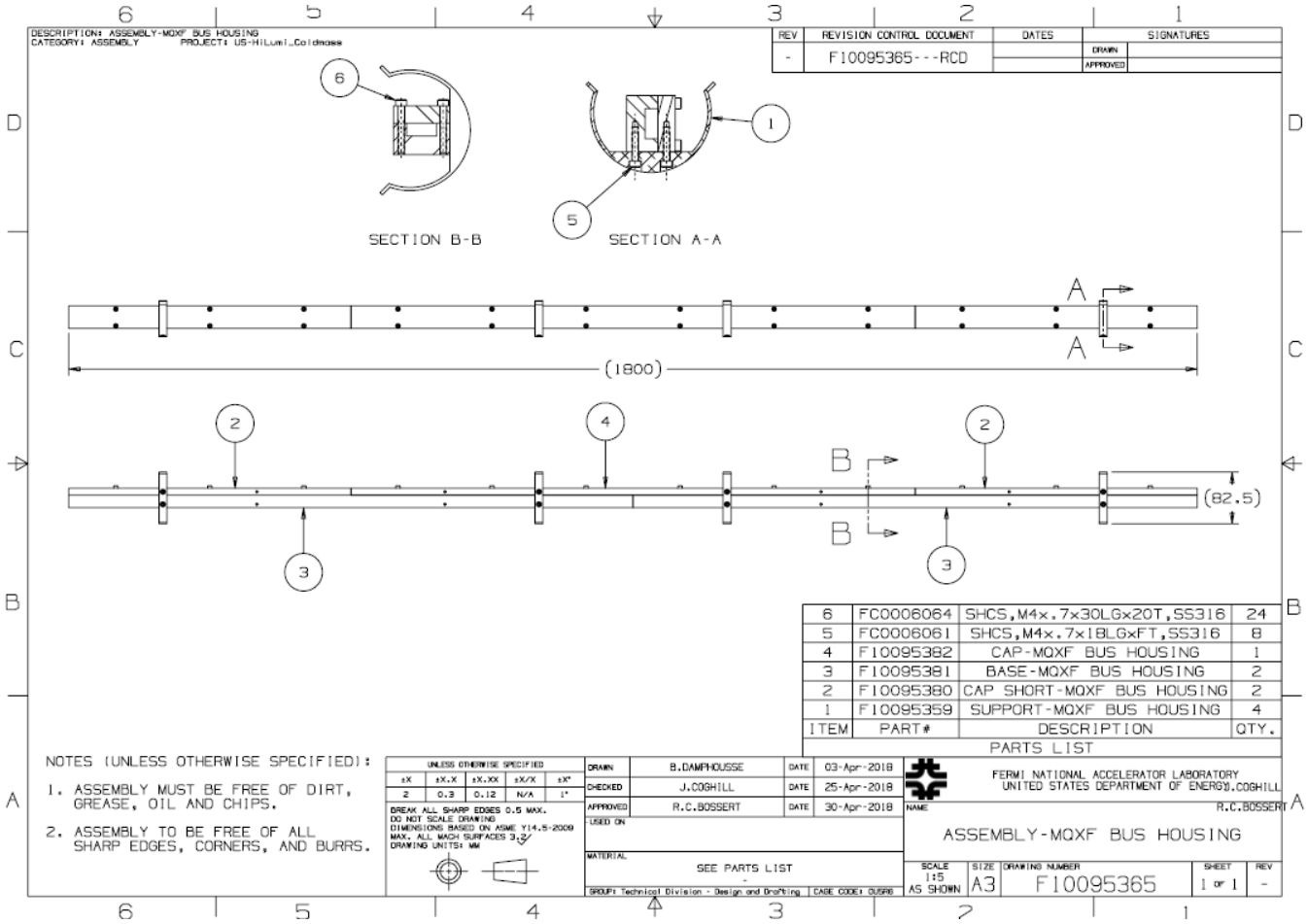
3 layers of 125 µm thick Kapton = 375 µm

1 layer of 50 µm thick Kapton with 66% overlap = 150 µm

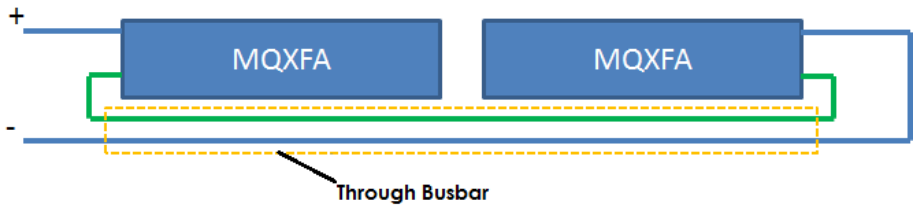
# QXF Bus Housing Configuration

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. One complete housing with supports (2 meters long) and clips has been manufactured and installed on MQXFS1e.

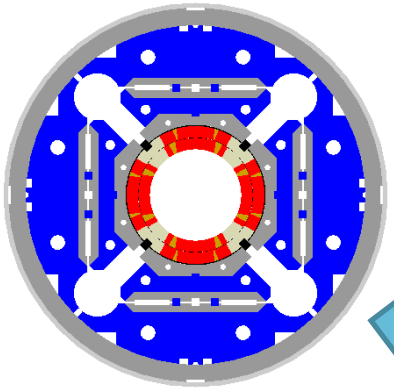
One complete housing with supports (2 meters long) has been ordered and will be used for the demonstration on MQXFS1e

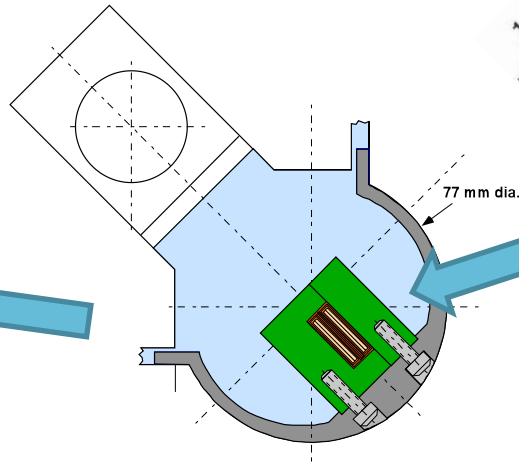


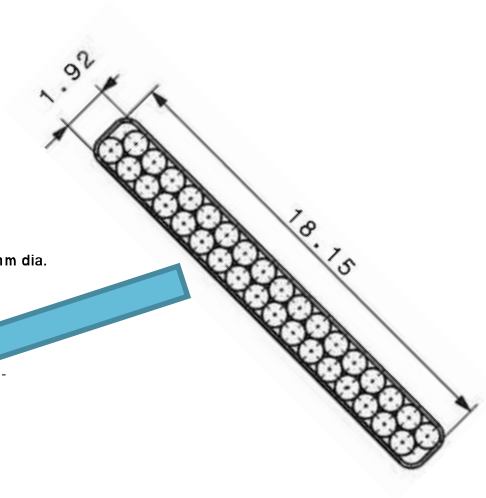
# QXF Bus Housing Configuration

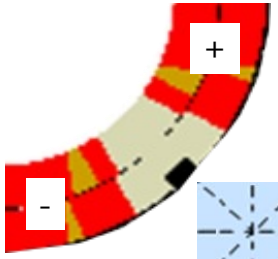


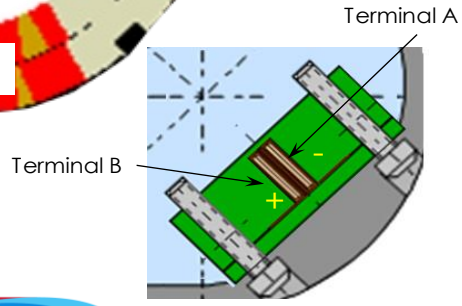

The bus housing is placed within the cold mass body as shown below. Forces on the bus are as shown in the table. The bus housing has been designed to withstand these forces.





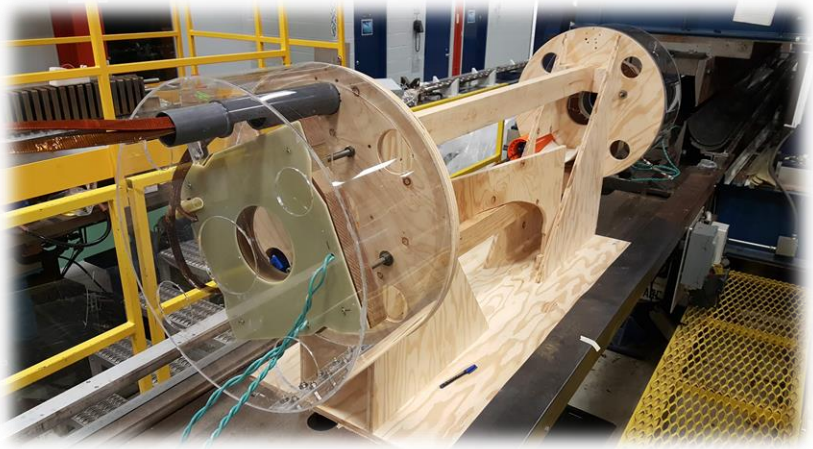



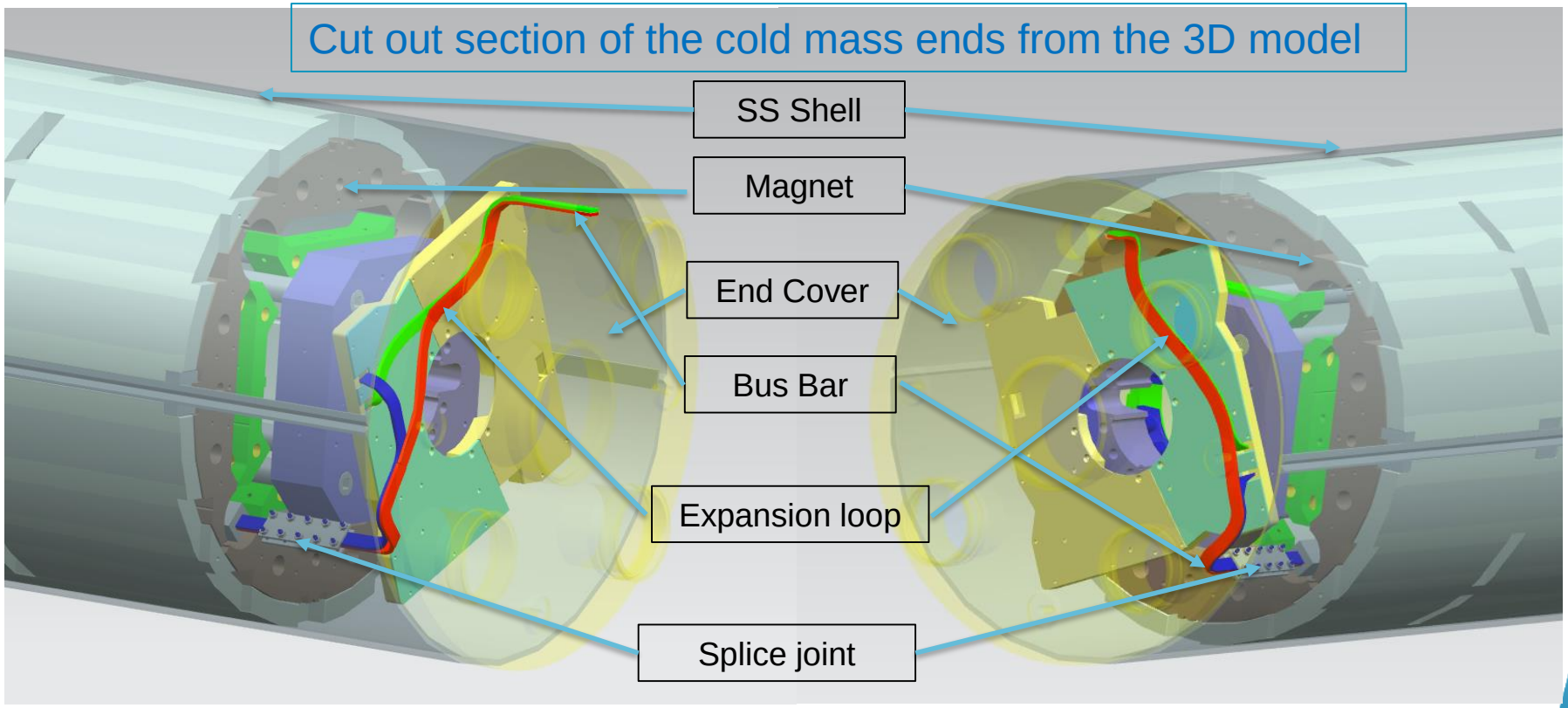

When each terminal has the opposite current flow direction as the same side coil blocks :

| | Fx (N/m) | Fy (N/m) |
|---|---|---|
| Terminal A | 200 | 3794 |
| Terminal B | 200 | -3794 |

# Bus Bar Mock-up

- Expansion loop still under development
  - Space constraints (64 mm space)
  - Lack of cable to be used for Mock-up
  - Length of the magnet leads
  - Diameter of Bellows





# QXF Bus Bar and Loop Mockup

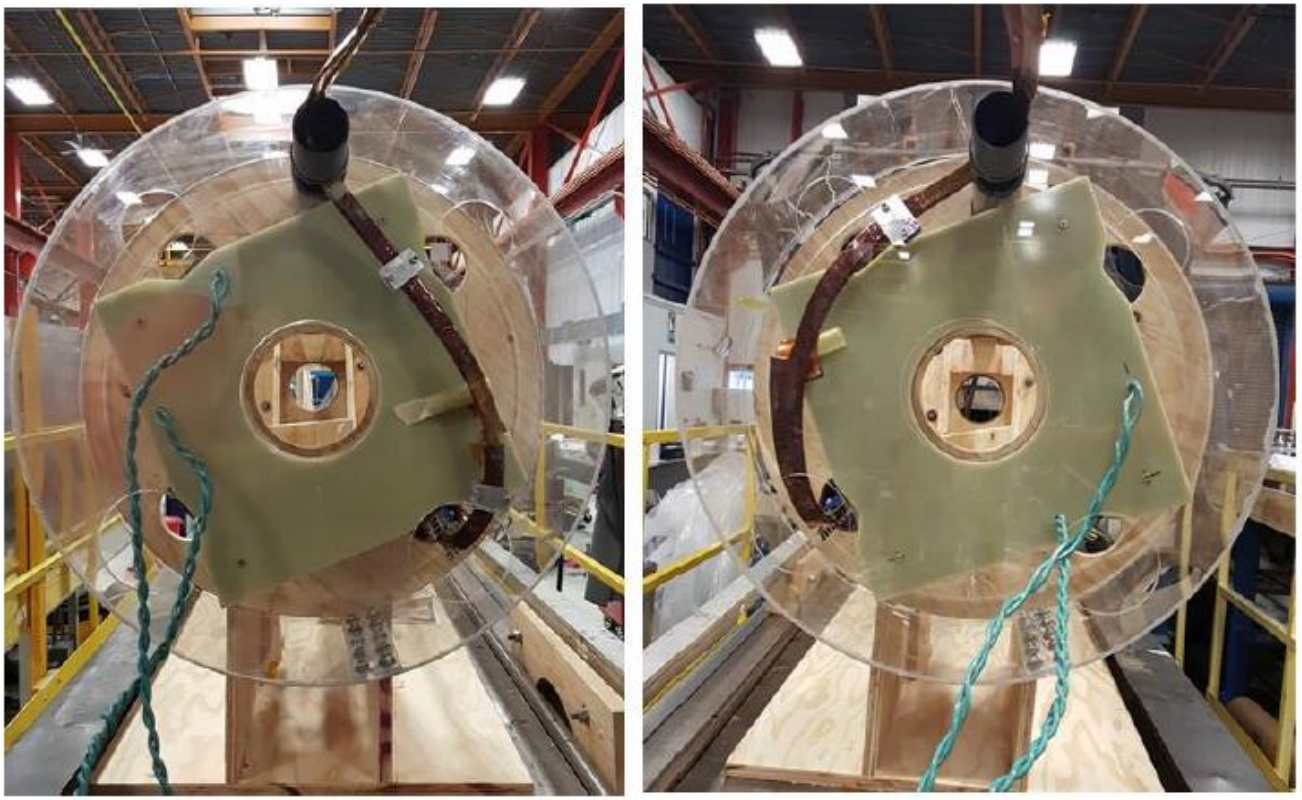
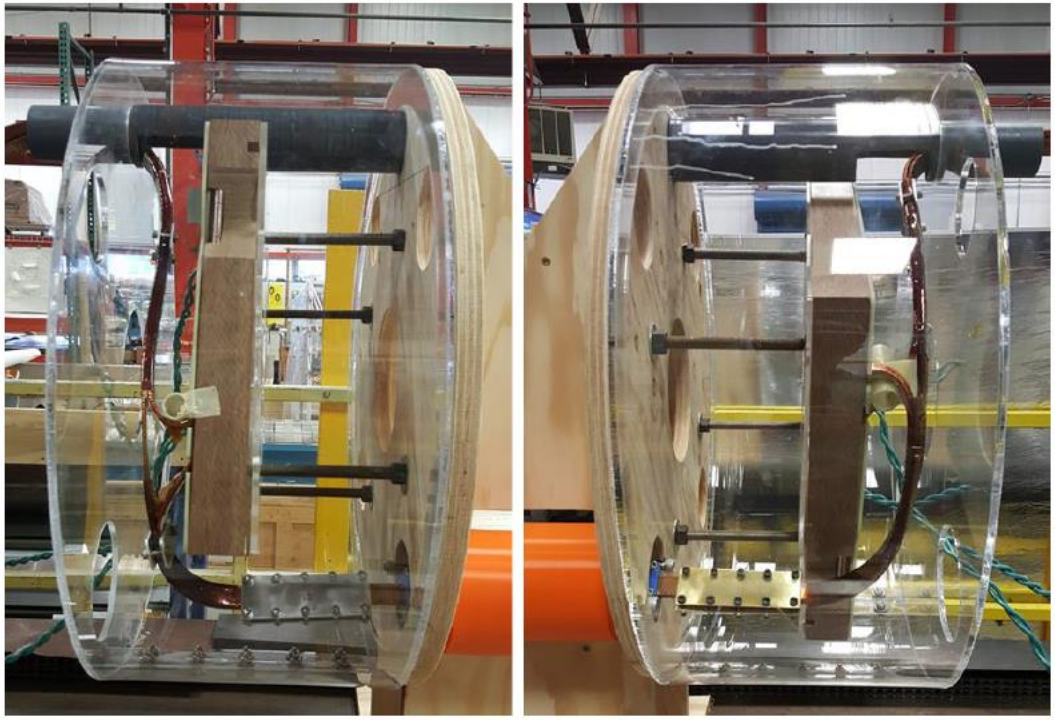


Figure 2.2.5.2E. Picture of the mockup showing the MQXFA Q1a/Q3a expansion loops (left) and the Q1b/Q3b is shown to the right. the end domes are made of acrylic, so the loops can be clearly seen.

# QXF Bus Bar and Loop Mockup

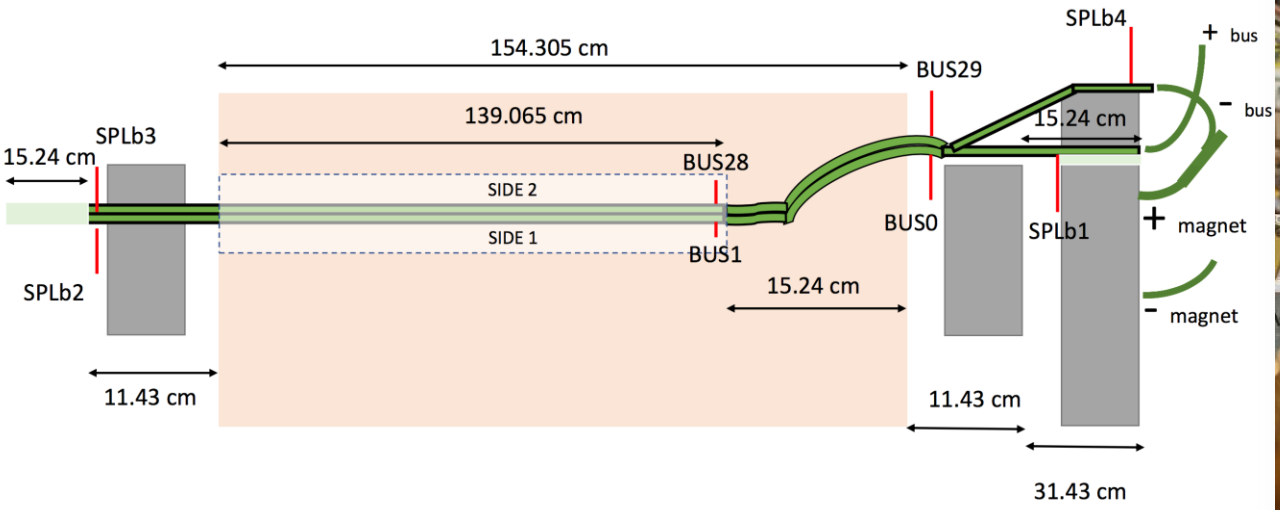


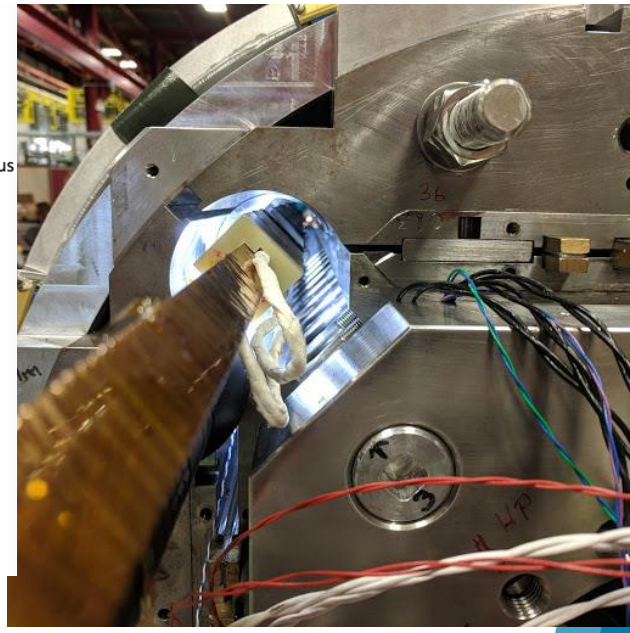
Side view of the expansion loops and through bus formed on a mockup at Fermilab. Q1a/Q3a is shown at left and Q1b/Q3b is shown at right. Loops are formed in their room temperature position, which is approximately in the middle of the space available.

The mockup uses standard QXF cable (not bus cable) and was made with the previous space between the splice box and end dome of 76mm. It will be redone using a 64mm space with actual bus material when available.

# Bus bar validation

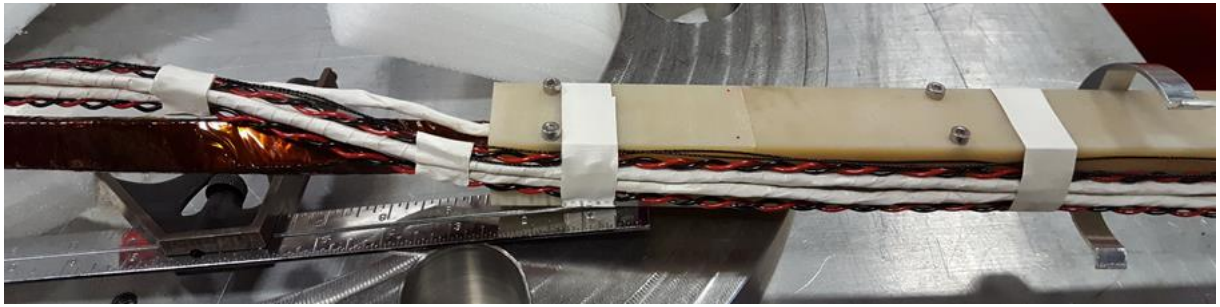
- MQXFS1e test using short bas bar
  - Instrumented with V-taps, temperature sensors and spot heater
  - Test is underway expect to start next week
  - Adequate support (no spontaneous bus quench), Quench velocities, QI, temperature margin, splice joint resistance

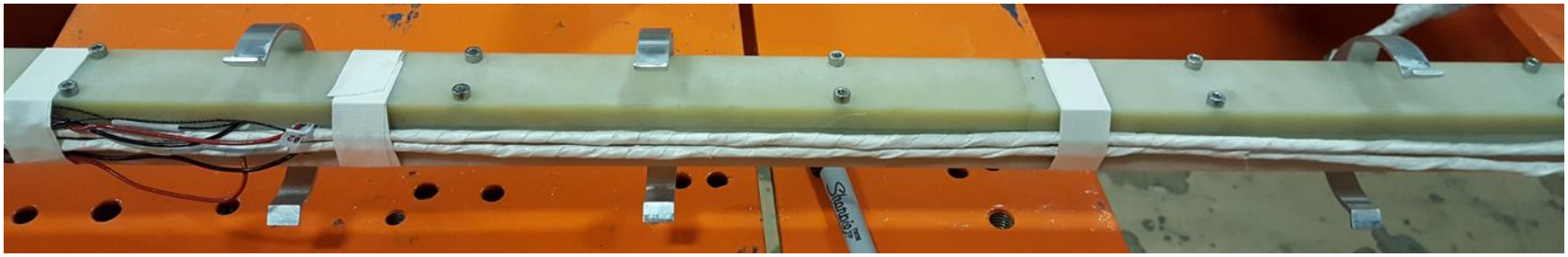


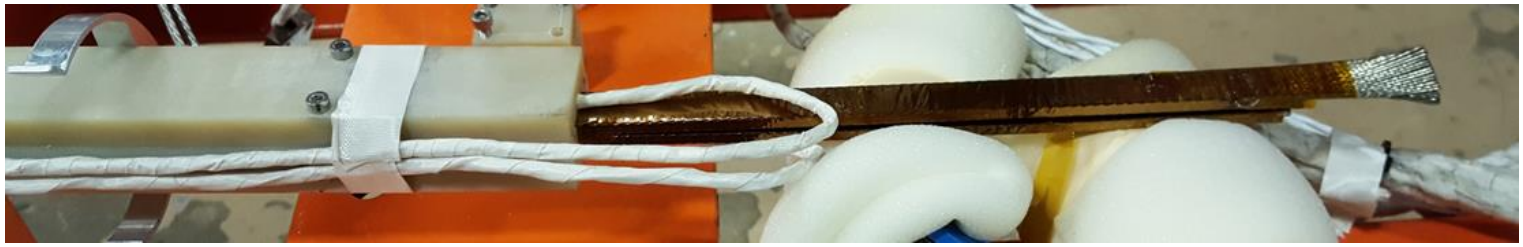



# Bus Bar Validation

Photos of the “demonstrator” bus bar and housing, (with clips) before insertion







# Summary

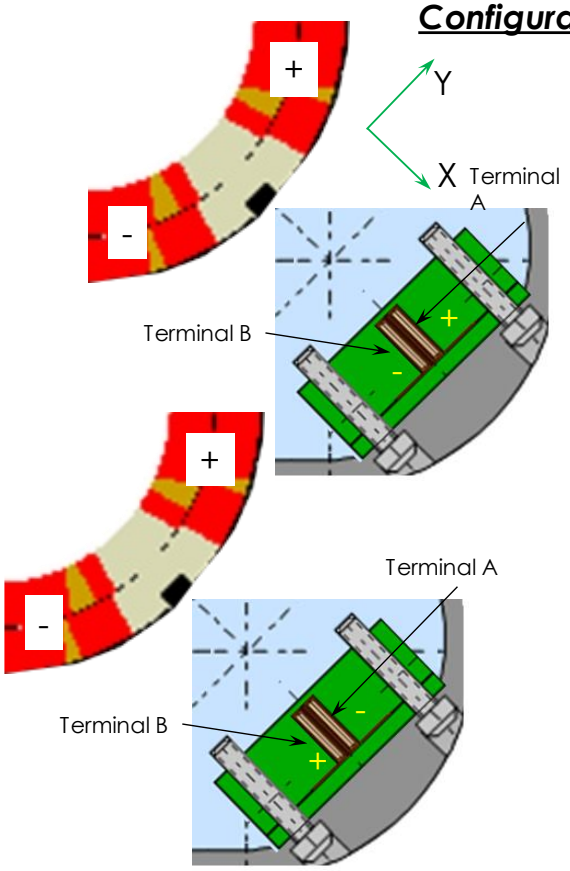
- Design of Bus Bar, Housing and Expansion Loop is based on previous successful MQXB design.
- Space for expansion loop has been reduced to 64 mm.
- Design is well underway, and first phase of mockup is complete.
- Second phase of mockup will begin soon, and will address remaining issues.
- Validation of bus design is taking place using MQXF short model.  Test is set to begin.

# Backup Slides

# Bus Bar Magnetic Analysis

The bus internal to the cold mass is placed as shown in the lower figure. Forces on the bus housing are therefore those shown in the lower table. The bus housing has been designed to withstand these forces.

***Configuration 2***




If rotate the bus-bar 45°:

When each terminal has the same current flow direction as the same side coil blocks :

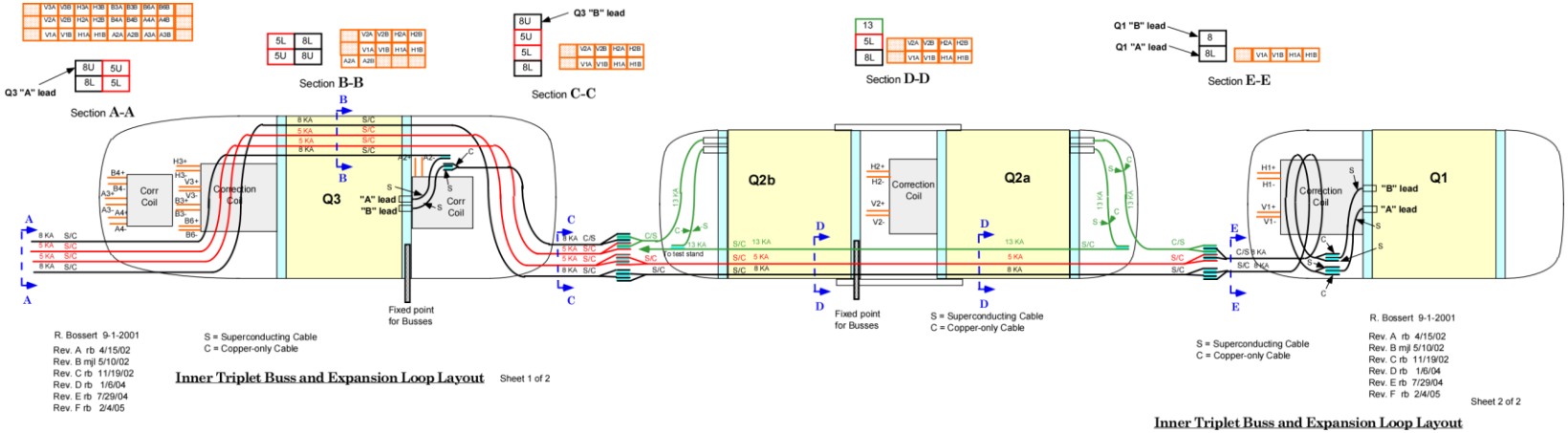
| | Fx (N/m) | Fy (N/m) |
|---|---|---|
| Terminal A | -145 | 11000 |
| Terminal B | -145 | 11000 |

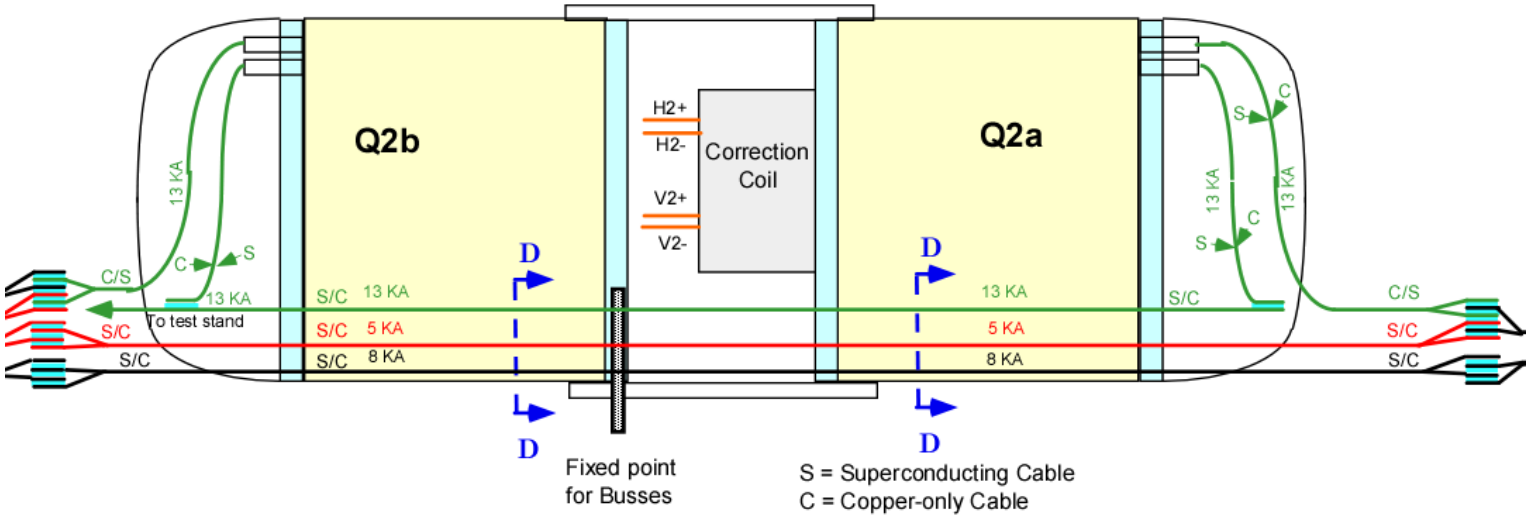
- Separate force (Fy in this configuration) is polarity dependent.
- For the current position, the separate force is around 3794 N/m, which is on the similar level of configuration 1.

When each terminal has the opposite current flow direction as the same side coil blocks :

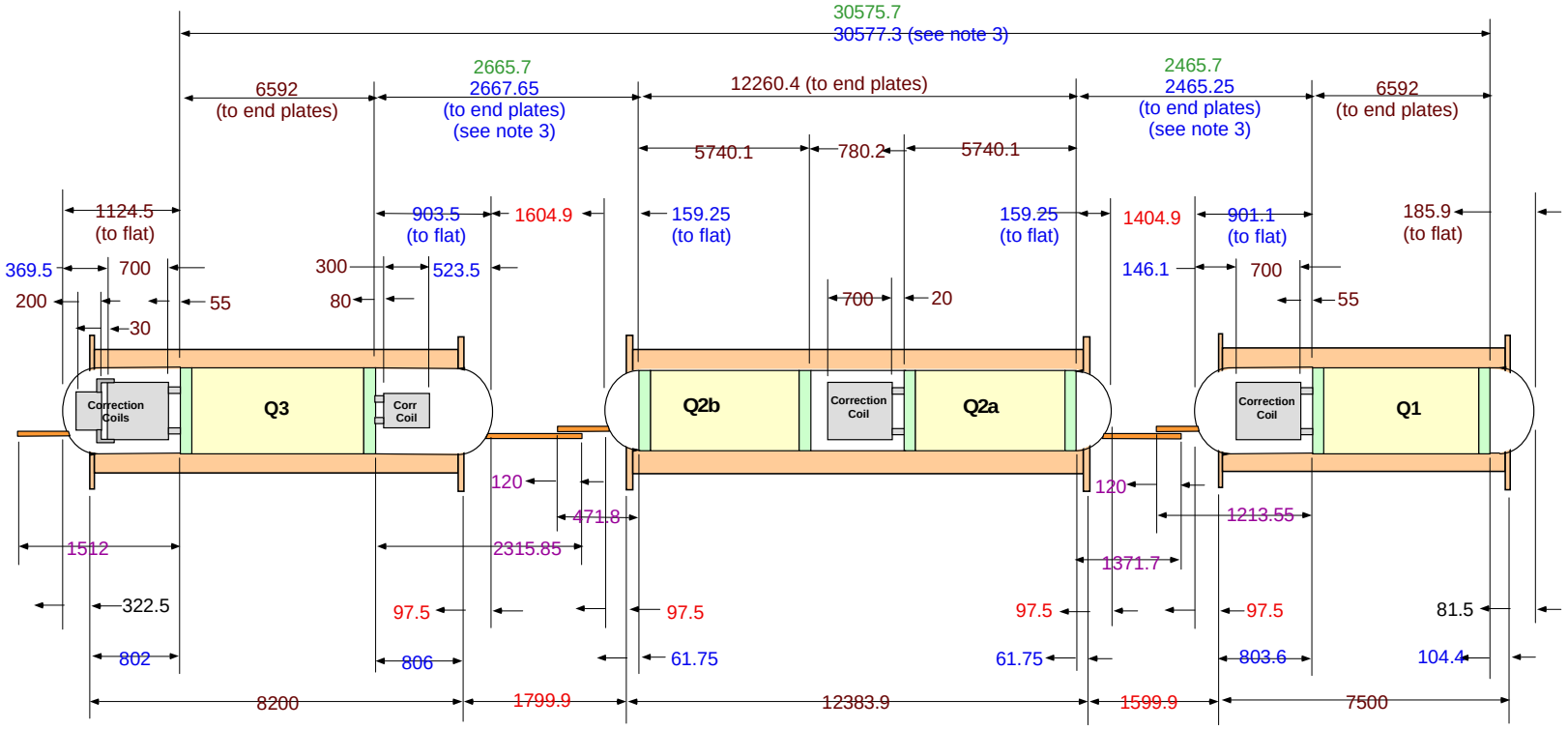
| | Fx (N/m) | Fy (N/m) |
|---|---|---|
| Terminal A | 200 | 3794 |
| Terminal B | 200 | -3794 |

# Previous IR Quad (MQXB) bus layout



# Previous IR Quad lengths




Notes:

1. All dimensions to end of domes are to machined flat surface.

2. Distance from flat on dome to tangent of curve is 2.5mm.

3. This dimension (calculated from current details and layouts) is slightly different from the number on the Tom Nicol layout of 5-4-01 (shown in green).

4. Verification of the 1512 dimension to the end of the Q3-DFBX splice can be found on drawing ME-432010.

Numbers in brown are based on detail drawings of manufactured parts.

Numbers in black are from cryostat assembly drawings 390265, 390266 and 390267.

Numbers in red are from S. Meredith layouts 390268 and 390269.

Numbers in blue are calculated from a combination of the previous three sources.

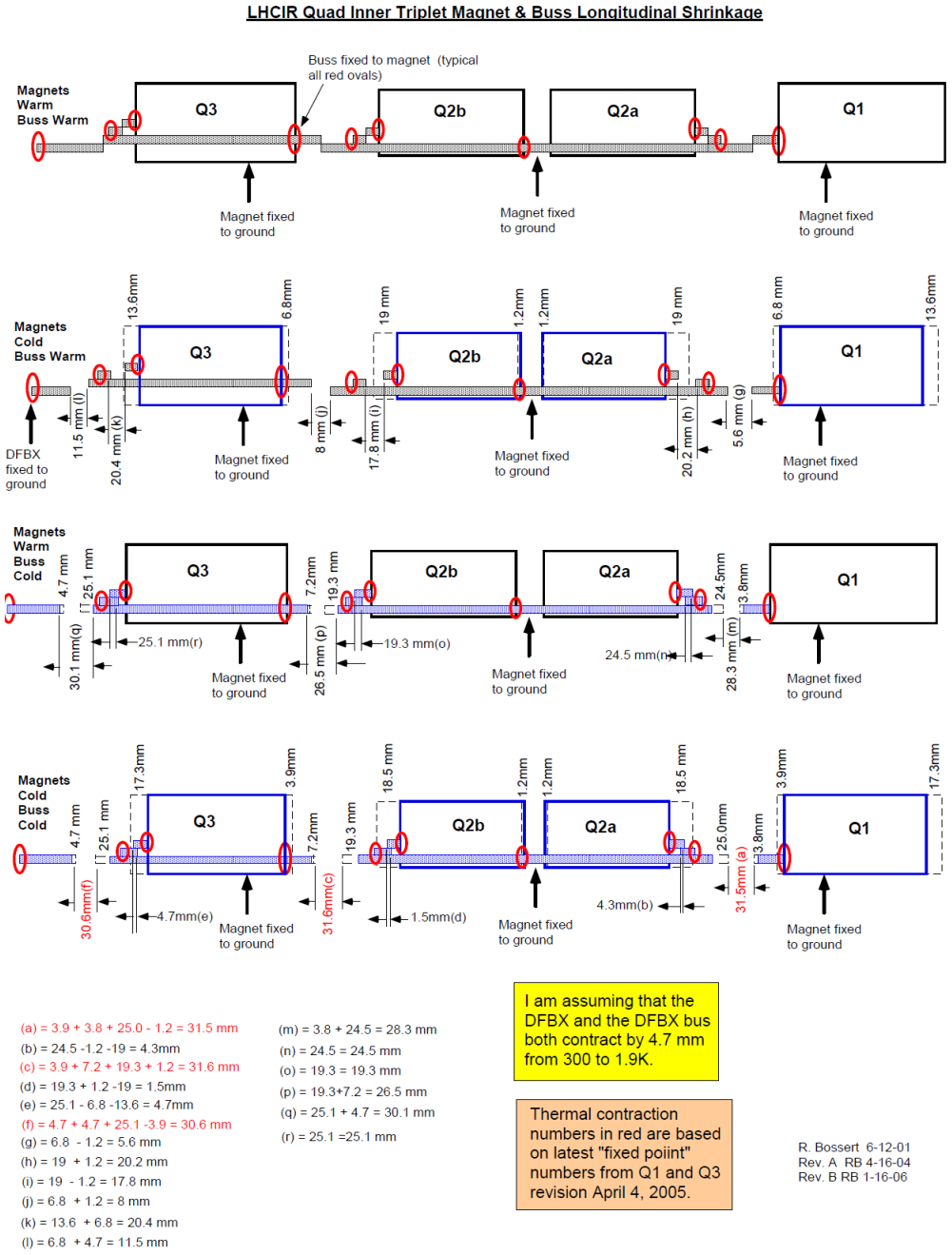
Numbers in purple are generated by M. Lamm/R. Bossert.

Numbers in green are derived rom "LHCIR Quadrupole Dimensions and Positions", T. Nicol, revision 5-4-2001.

**LHCIR Inner Triplet Area Lengths**

R. Bossert 9-7-2001
Rev. D 2-9-04

# Previous IR Quad loop analysis




(a) = 3.9 + 3.8 + 25.0 - 1.2 = 31.5 mm
(b) = 24.5 -1.2 -19 = 4.3mm
(c) = 3.9 + 7.2 + 19.3 + 1.2 = 31.6 mm
(d) = 19.3 + 1.2 -19 = 1.5mm
(e) = 25.1 - 6.8 -13.6 = 4.7mm
(f) = 4.7 + 4.7 + 25.1 -3.9 = 30.6 mm
(g) = 6.8 - 1.2 = 5.6 mm
(h) = 19 + 1.2 = 20.2 mm
(i) = 19 - 1.2 = 17.8 mm
(j) = 6.8 + 1.2 = 8 mm
(k) = 13.6 + 6.8 = 20.4 mm
(l) = 6.8 + 4.7 = 11.5 mm

(m) = 3.8 + 24.5 = 28.3 mm
(n) = 24.5 = 24.5 mm
(o) = 19.3 = 19.3 mm
(p) = 19.3+7.2 = 26.5 mm
(q) = 25.1 + 4.7 = 30.1 mm
(r) = 25.1 =25.1 mm

I am assuming that the DFBX and the DFBX bus both contract by 4.7 mm from 300 to 1.9K.

Thermal contraction numbers in red are based on latest "fixed poiint" numbers from Q1 and Q3 revision April 4, 2005.

R. Bossert 6-12-01
Rev. A RB 4-16-04
Rev. B RB 1-16-06