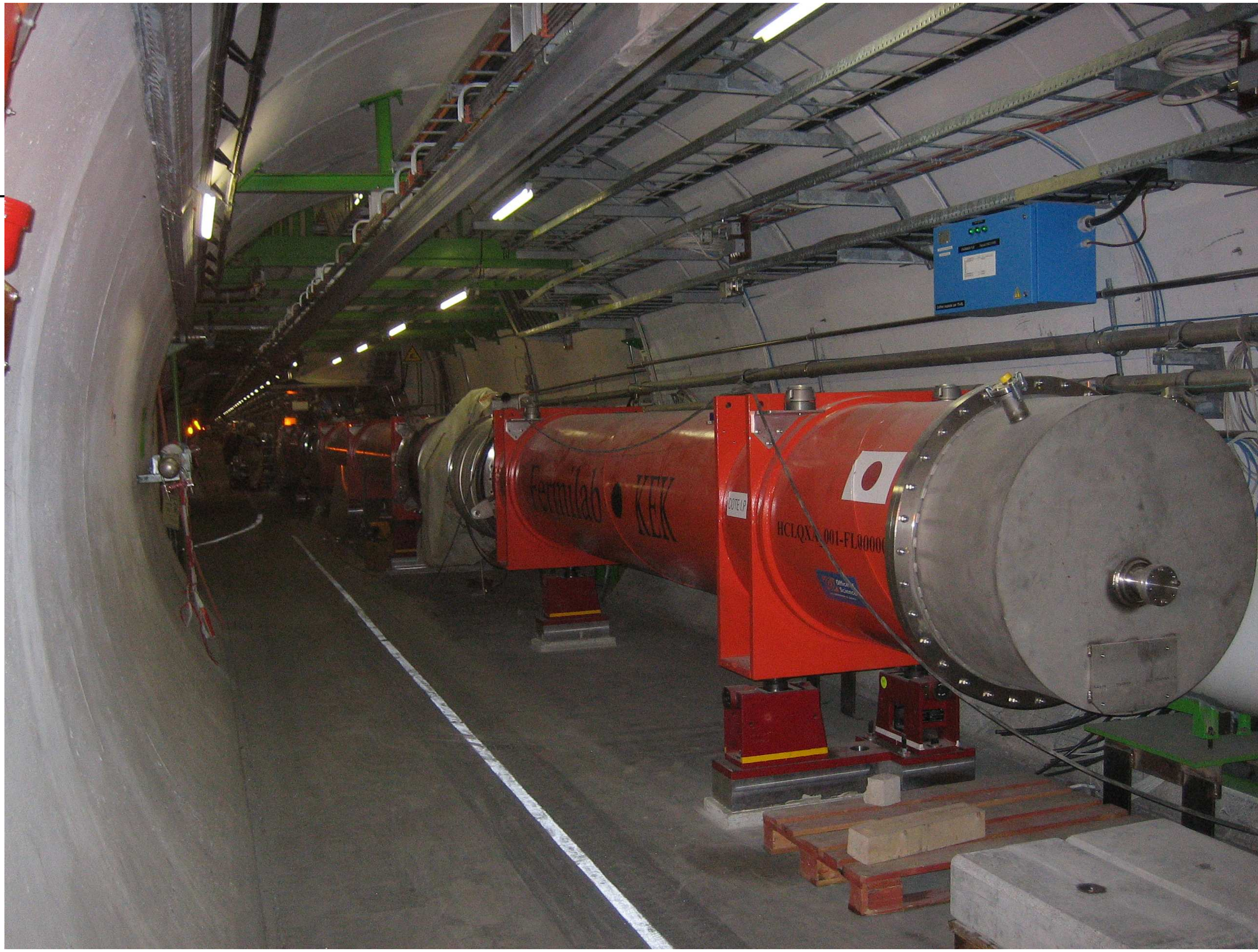
LHC Inner Triplet Status

J . Kerby

For…Ranko Ostojic, Cedric Garion, Tom Page, Thierry Renaglia, Herve Prin, Bob Wands, Frederic Gicquel, Ingrid Fang, Juan Carlos Perez, Tom Nicol, Sandor Feher, Tatsu Nakamoto, Peter Limon, Joseph Rasson, Steve Virostek, Paul Olderr, Tom Peterson, Jim Strait, Jim Rife, Vadim Kashikin…and anyone else I have inadvertently forgotten…

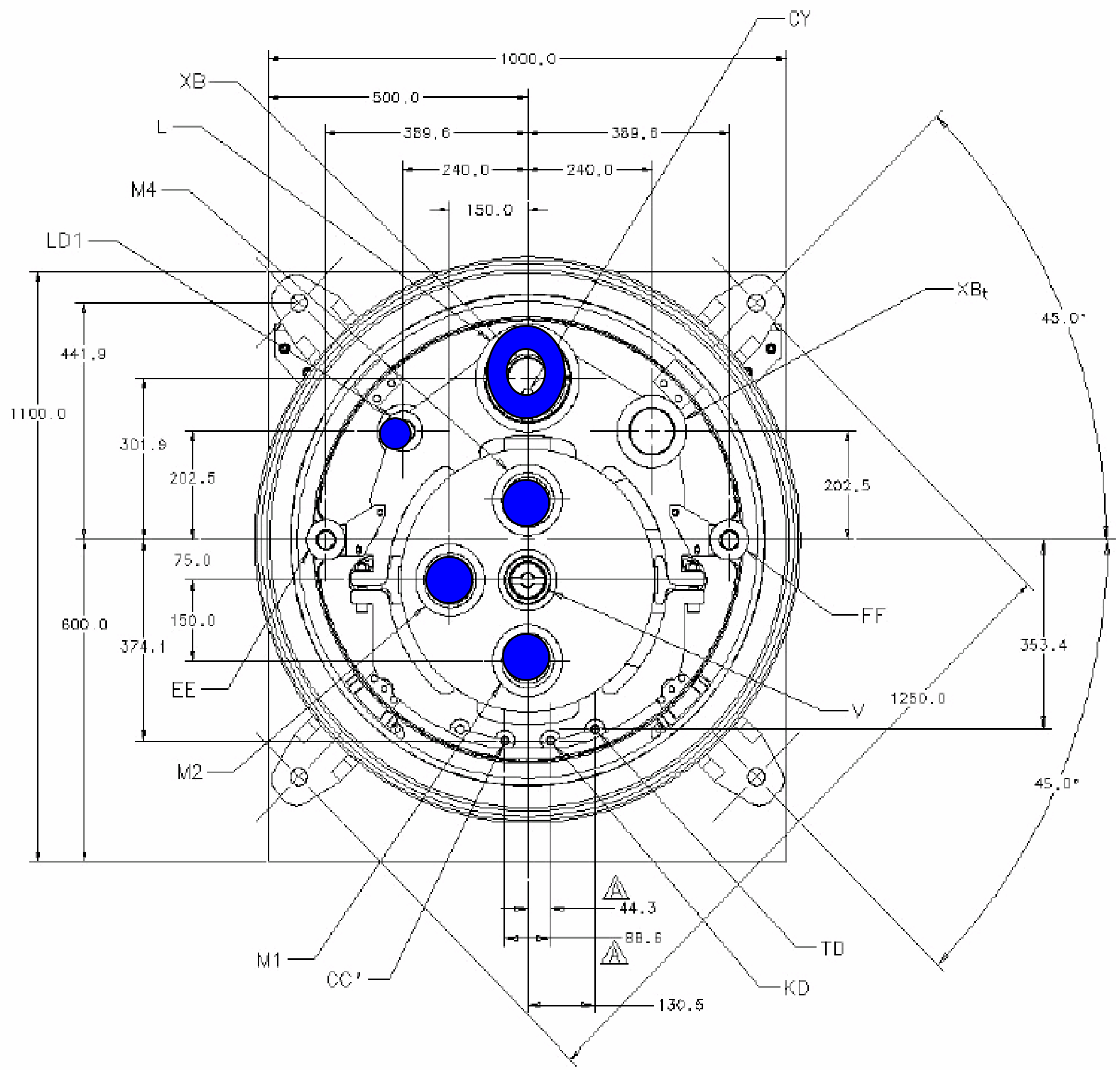
- Review of 27 March sector 7-8 pressure test
- Requirements for the fix
- Cartridge for Q1 / Q3

- Vacuum Loading
- DFBX
- Schedule


Fermilab
KEK
HCLQXA

Non IP end of Q1, looking toward IP

The Xb, XBt, V EE and FF lines, and beam screen lines were not pressurized during the 27 Mar test



- Tables for the full load case when all lines are pressurized to MAWP
- 27 March test the pumping and shield lines were not pressurized, and failure was at 20 bar
  - Q1 load 115kN
  - Q3 load 93kN

Force on Q1 (toward IP)

Pipe	Bellows Mean Diameter [in]	Area [sq in]	Qty.	Pressure [psi]	Resulting force [lb]
Cold mass pipe	4.45	15.553	3	300	13997.6
Hx Outer pipe	7.51	44.297	1	300	13289.0
Hx inner pipe	3.7	10.752	-1	300	-3225.6
Cool down line	2.77	6.026	1	300	1807.9
Pumping line	4.51	15.975	1	60	958.5
Shield line	2.77	6.026	2	370	4459.4
				Total force [lb]	31287
				N	**139163**

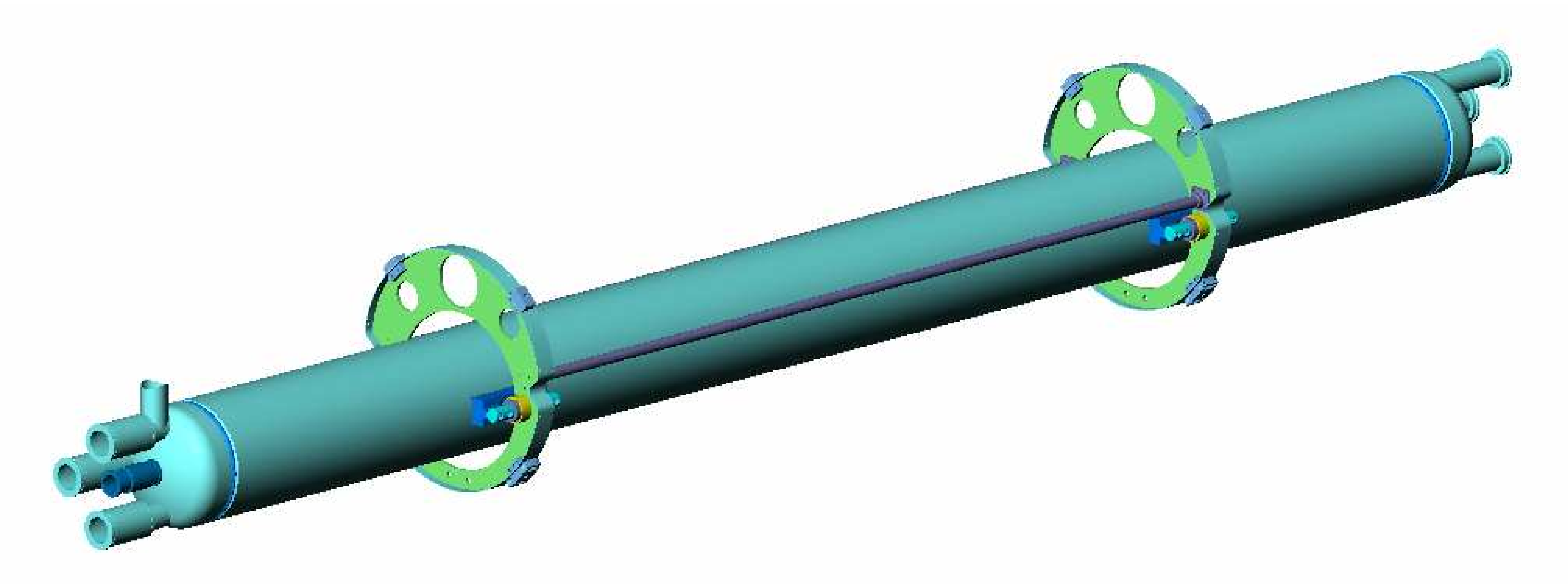
Force on Q3 (away from IP)

Pipe	Bellows Mean Diameter [in]	Area [sq in]	Qty.	Pressure [psi]	Resulting force [lb]
Cold mass pipe	4.45	15.553	2	300	9331.7
Hx Outer pipe	7.51	44.297	1	300	13289.0
Hx inner pipe	3.7	10.752	-1	300	-3225.6
Cool down line	2.77	6.026	1	300	1807.9
Pumping line	4.51	15.975	1	60	958.5
Shield line	2.77	6.026	2	370	4459.4
				Total force [lb]	26621
				N	**118410**


Q3
94kN
Q1
115kN

Cold Mass Support

- A ‘fixed’ and ‘free’ spider support
- Invar rod connecting the two to share support



Geometry was drawn directly from the CAD model. The bellows at the interconnections between cold masses were simulated with spring elements having a total stiffness of 5500 lbs/in at each interconnection.

Moments due to the L line bellows were estimated, and are reacted w/ much longer lever arm of the spacing of the supports, so are a small effect in these analyses.

Elements are second-order hexahedral and tetrahedral solids. A total of 500 thousand elements and 600000 nodes were used.

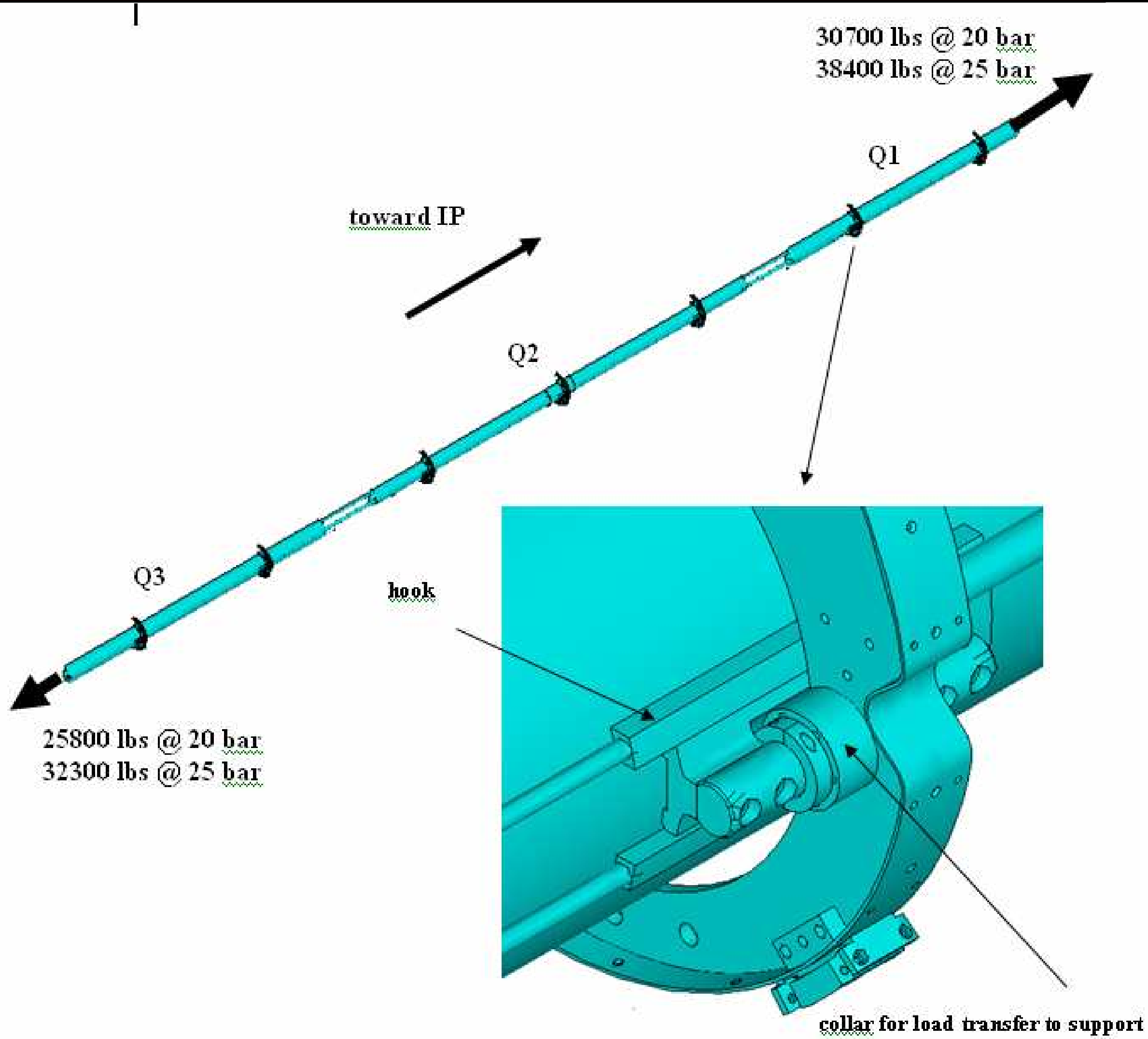
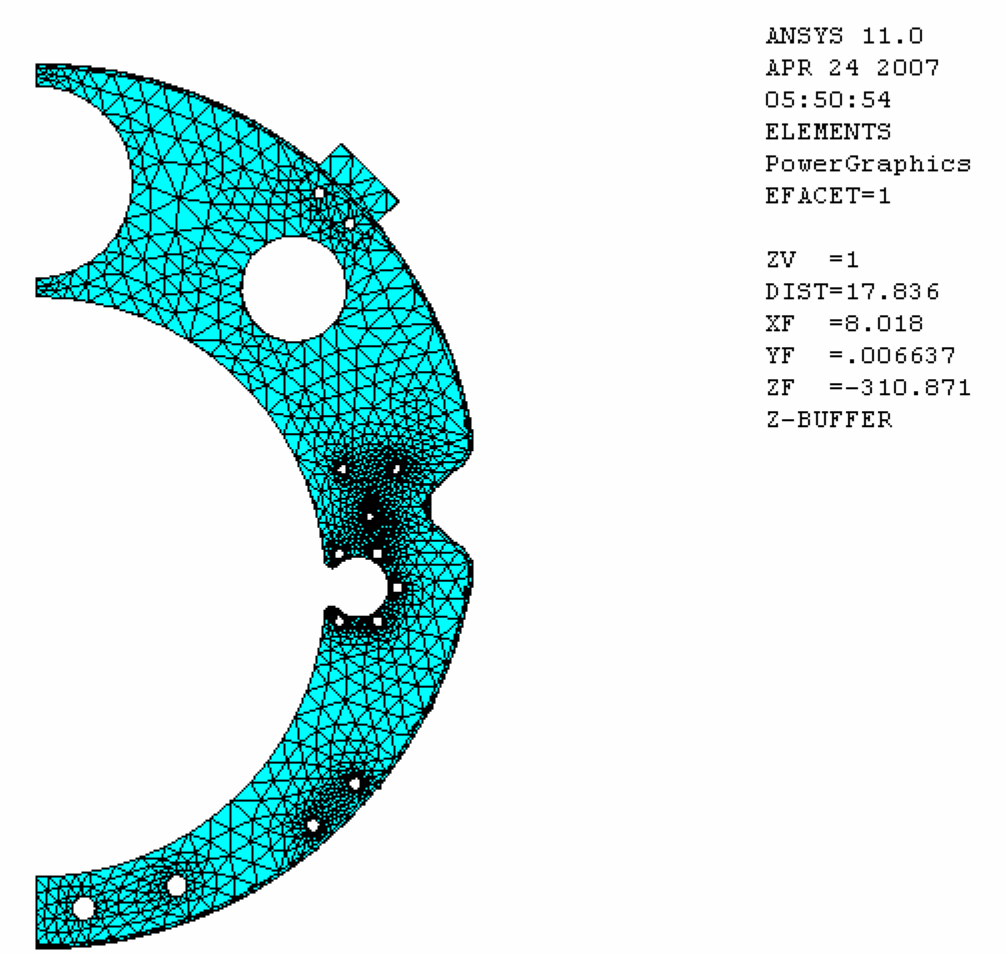


Figure 1. The Finite Element Model of the Triplet showing 20 and 25 Bar Pressure Load Application

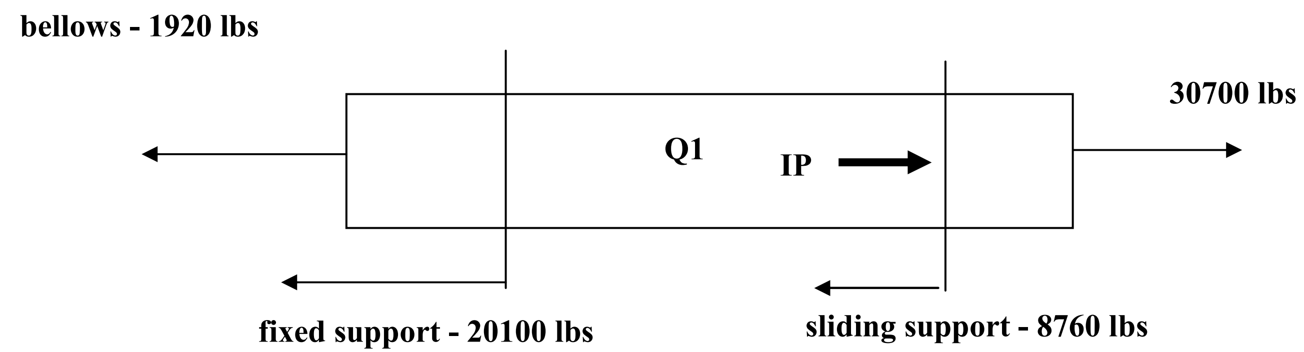
Meshing of the supports was refined to include three elements through the half-inch thickness of the G11.

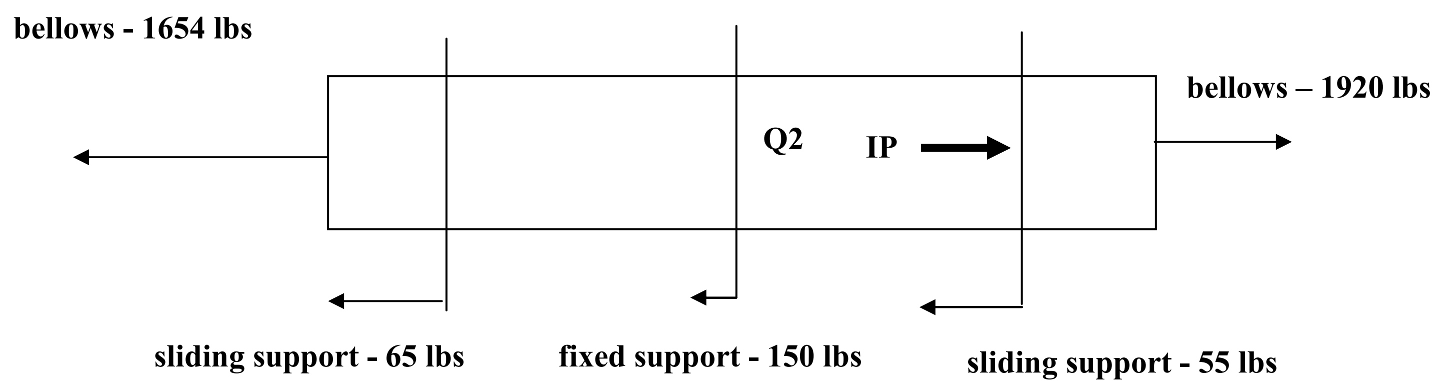
The G11 was treated as orthotropic; in the plane of the support (the xy plane in the analysis) bending is resisted primarily by the tension or compression of the relatively stiff glass fibers; the Young's modulus is dominated by the glass, and was set to 3e6 psi in both the x and y directions. For the z-direction (through the thickness), loads are perpendicular to the glass fibers, and the stiffness is influenced more strongly by the epoxy matrix; a reduced modulus of 1e6 psi was used for this direction.

Note that while this is technically "orthotropic", it really assumes isotropy in the xy plane.

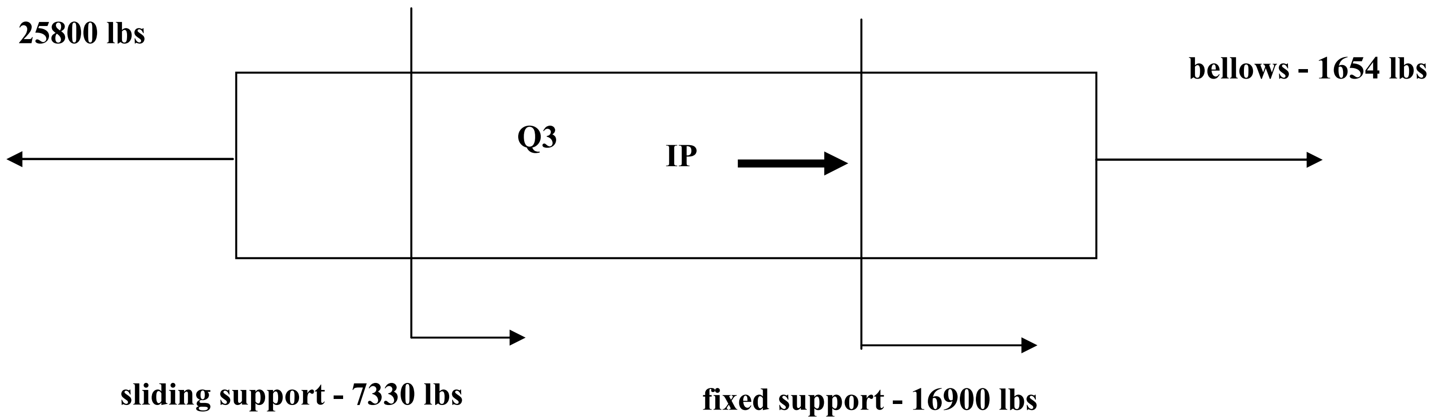


Q1- Q2 - full 20 bar load (all lines)





Q3 – full 20 bar load (all lines)



Magnet	Axial Movement (positive away from IP - inches)	
	in	mm
Q1	-0.35	-8.9
Q2	-0.0025	-0.06
Q3	0.30	7.6

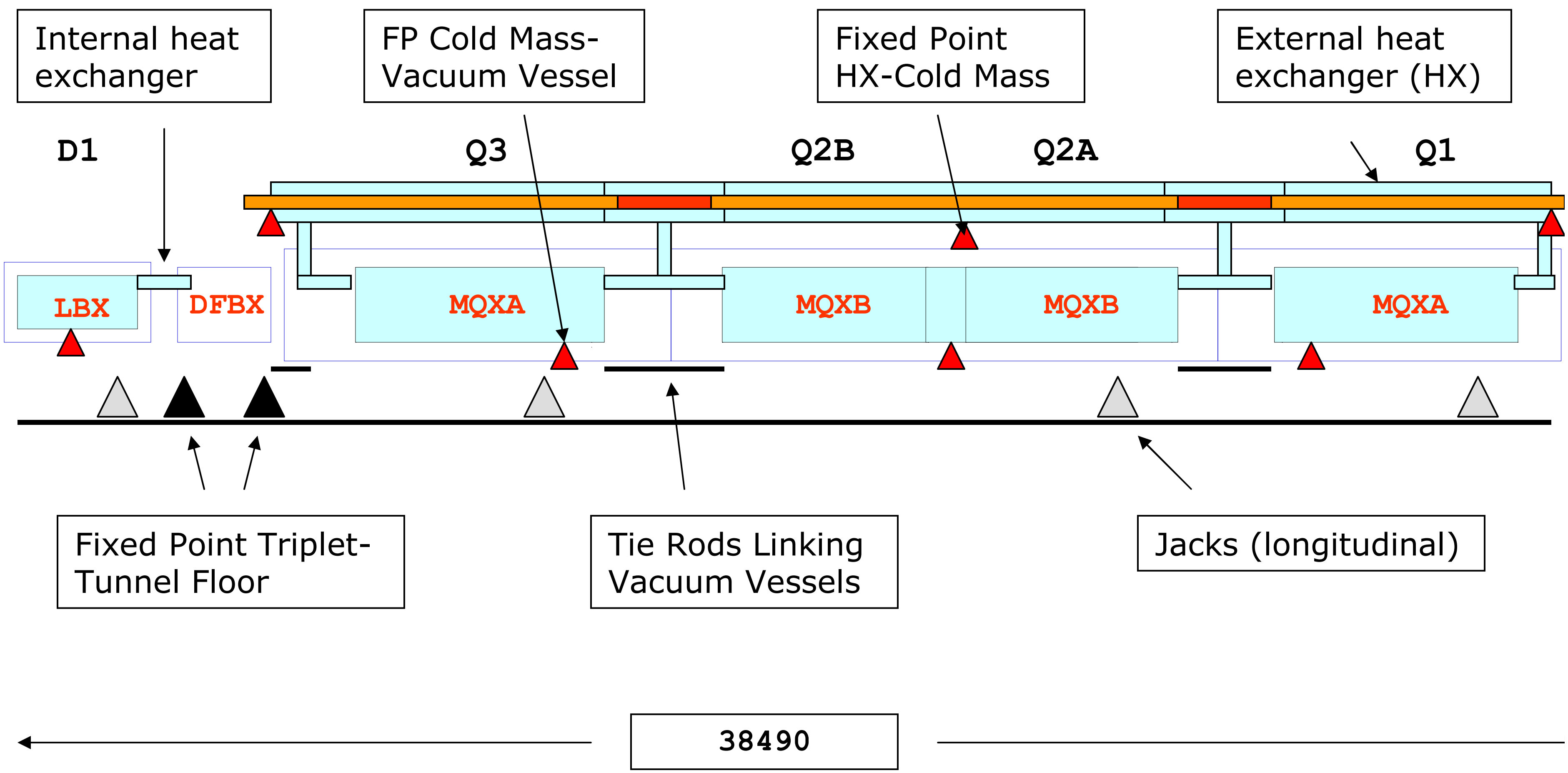
Pressure Test Summary

- With Shield and Xb lines empty, actual loads 84% of 20 bar load in model…results linearly scaled for now:
  - Q1 fixed support failed at 16,950lbs/75.4kN (7.5mm); then propagated to Q1 free support
  - Q3 fixed support being checked at 14250lbs/63.3kN (6.4mm); Q3 free support shows no signs of damage
  - Q2 unaffected
- DFBX damage not from interaction with Q3

Requirements for a Fix

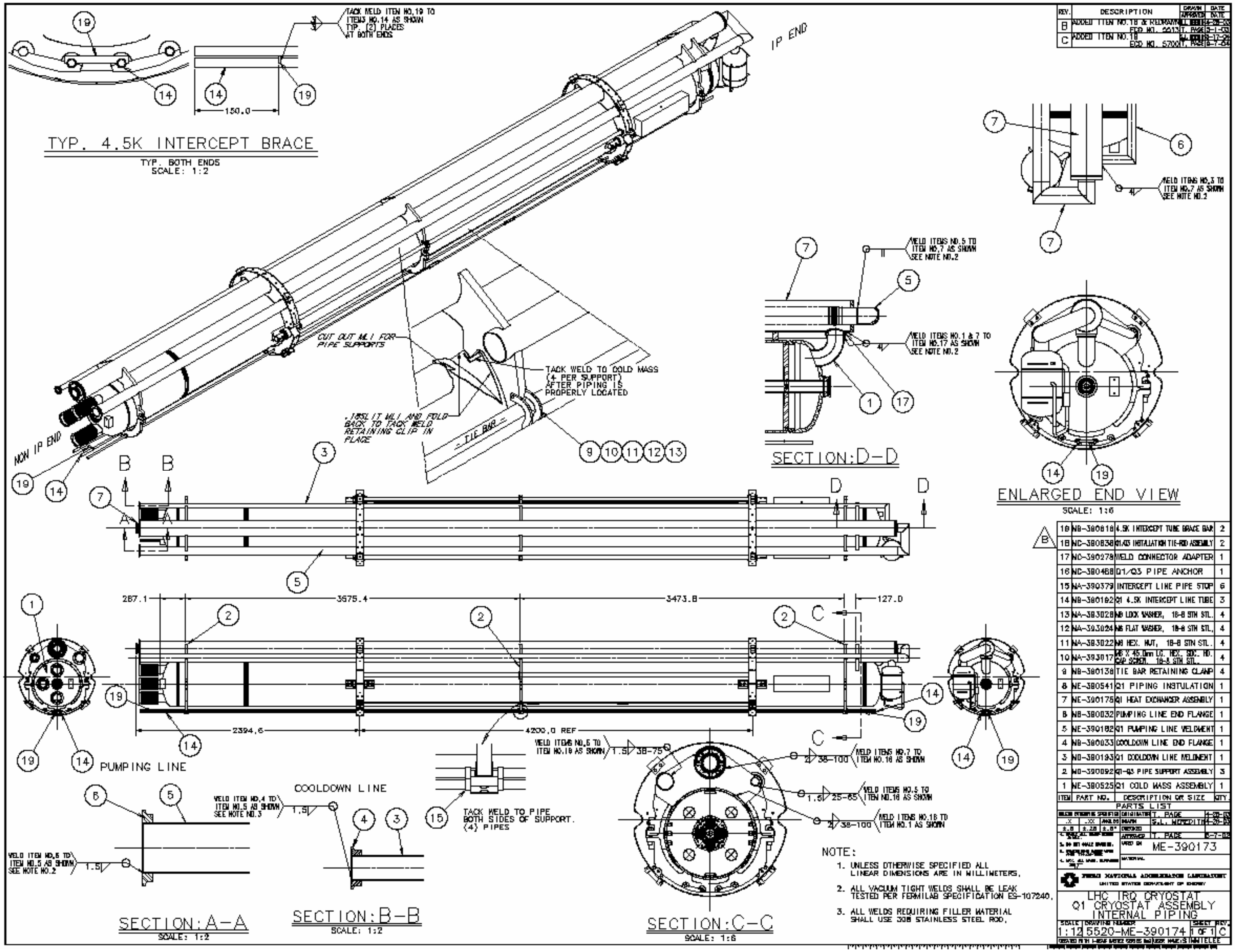
- In Situ
- Does not move fixed point of the assemblies
- React loads with sufficient stiffness to limit deflection – ~140kN design load (slide 4)
- Acts at any temperature 300K to 2K
- Focus on implementation in Q1—Q3 solution identical in length, IP end

Fixed Points




KEK • Fermilab

Q1

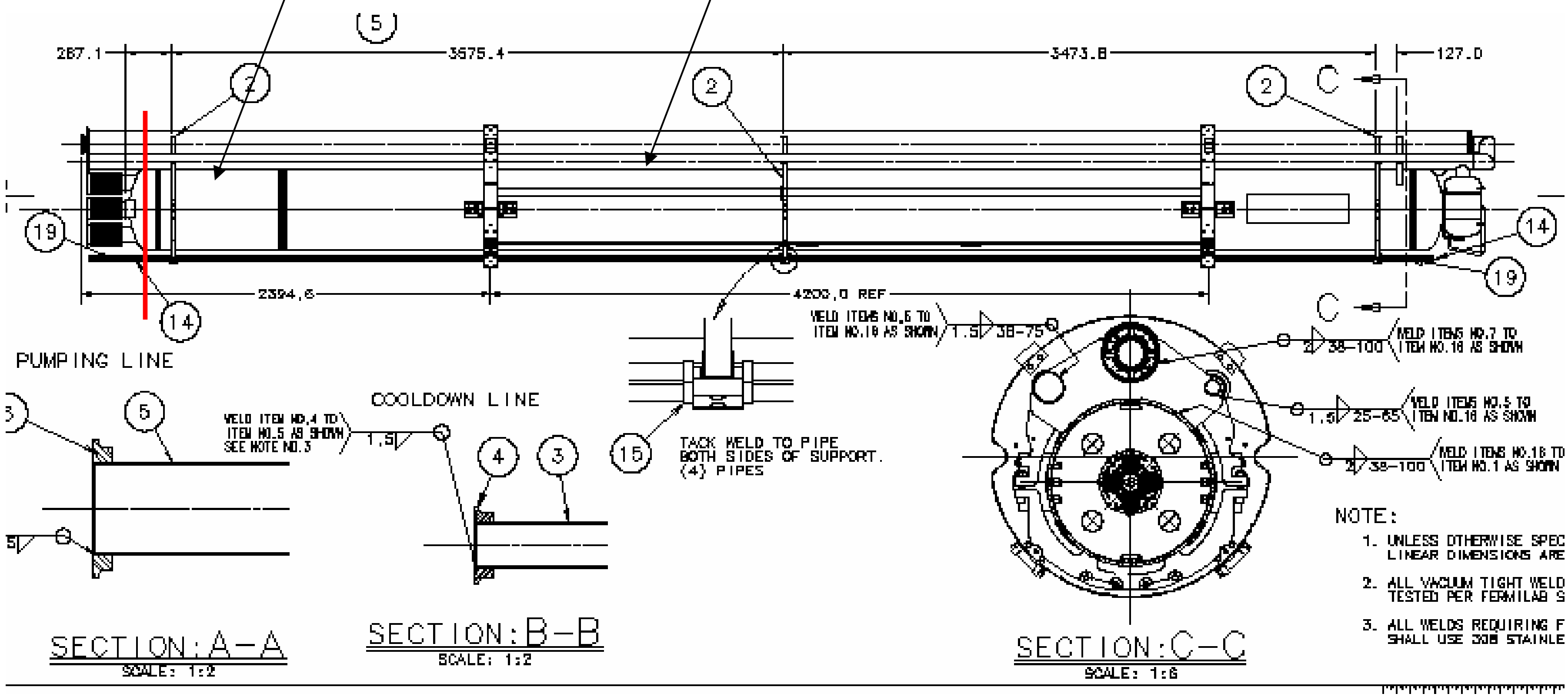


IP END
NON IP END
TYP. 4.5K INTERCEPT BRACE
TYP. BOTH ENDS
SCALE: 1:2
CUT OUT MLI FOR PIPE SUPPORTS
TACK WELD TO COLD MASS (4 PER SUPPORT) AFTER PIPING IS PROPERLY LOCATED
TIE BAR
SECTION: D-D
ENLARGED END VIEW
SCALE: 1:6
PUMPING LINE
COOLDOWN LINE
TACK WELD TO PIPE BOTH SIDES OF SUPPORT. (4) PIPES
SECTION: A-A
SCALE: 1:2
SECTION: B-B
SCALE: 1:2
SECTION: C-C
SCALE: 1:6
4200.0 REF
NOTE:
1. UNLESS OTHERWISE SPECIFIED ALL LINEAR DIMENSIONS ARE IN MILLIMETERS.
2. ALL VACUUM TIGHT WELDS SHALL BE LEAK TESTED PER FERMILAB SPECIFICATION ES-107240.
3. ALL WELDS REQUIRING FILLER MATERIAL SHALL USE 308 STAINLESS STEEL ROD.
19 NB-380818 4.5K INTERCEPT TUBE BRACE BAR 2
18 NC-380838 Q1/Q3 INSTALLATION TIE-ROD ASSEMBLY 2
17 NC-390278 WELD CONNECTOR ADAPTER 1
16 NC-380468 Q1/Q3 PIPE ANCHOR 1
15 NA-390379 INTERCEPT LINE PIPE STOP 6
14 NB-380182 Q1 4.5K INTERCEPT LINE TUBE 3
9 NB-380138 TIE BAR RETAINING CLAMP 4
8 NE-380541 Q1 PIPING INSTULATION 1
7 NE-390175 Q1 HEAT EXCHANGER ASSEMBLY 1
6 NB-380032 PUMPING LINE END FLANGE 1
5 NE-390182 Q1 PUMPING LINE WELDMENT 1
4 NB-380033 COOLDOWN LINE END FLANGE 1
3 ND-380193 Q1 COOLDOWN LINE WELDMENT 1
2 ND-390092 Q1-Q3 PIPE SUPPORT ASSEMBLY 3
1 NE-380525 Q1 COLD MASS ASSEMBLY 1
ITEM PART NO. DESCRIPTION OR SIZE QTY.
PARTS LIST
ME-390173
LHC IRQ CRYOSTAT
Q1 CRYOSTAT ASSEMBLY
INTERNAL PIPING
1:12 5520-ME-390174 1 OF 1 C

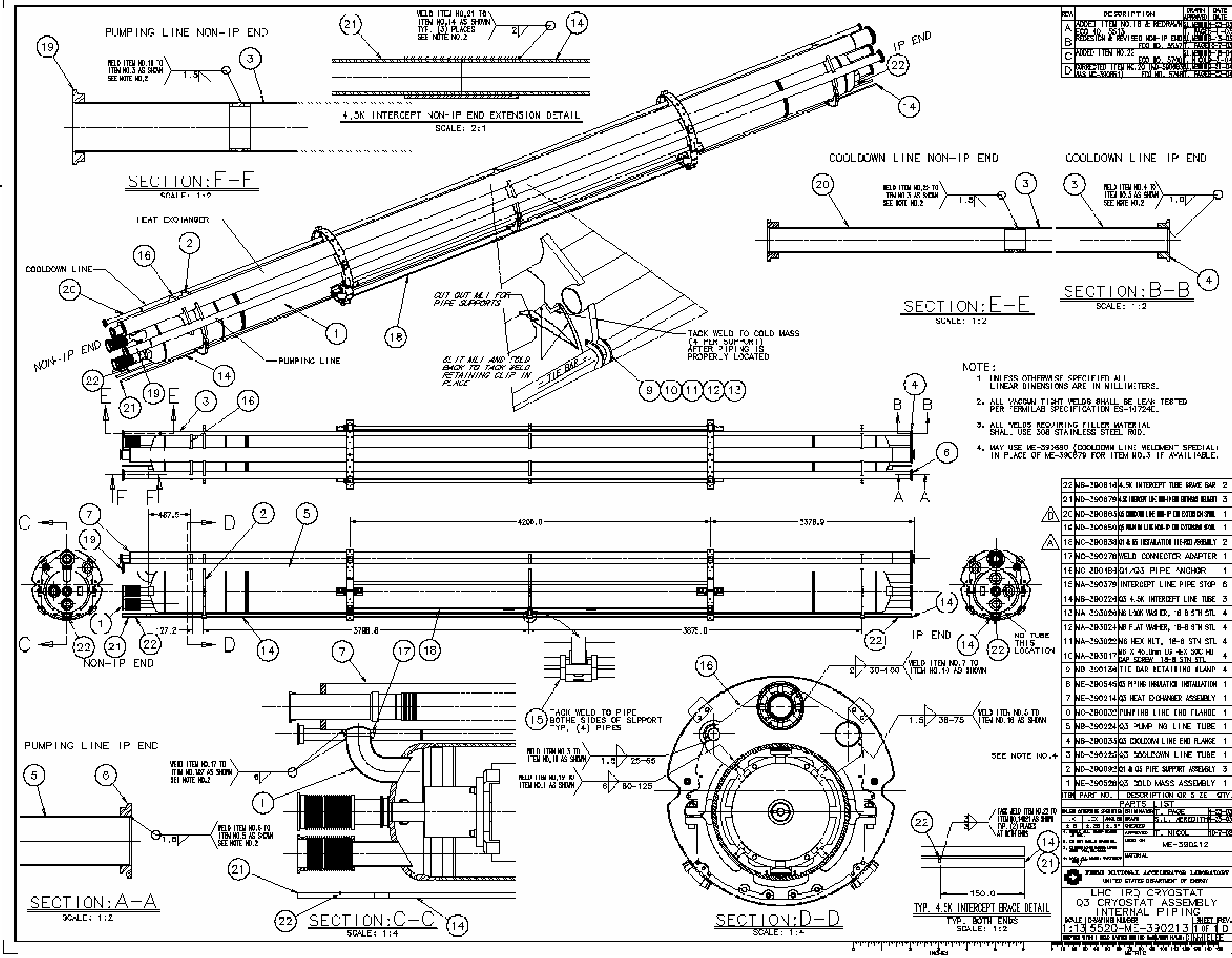
Q1

Corrector Containment

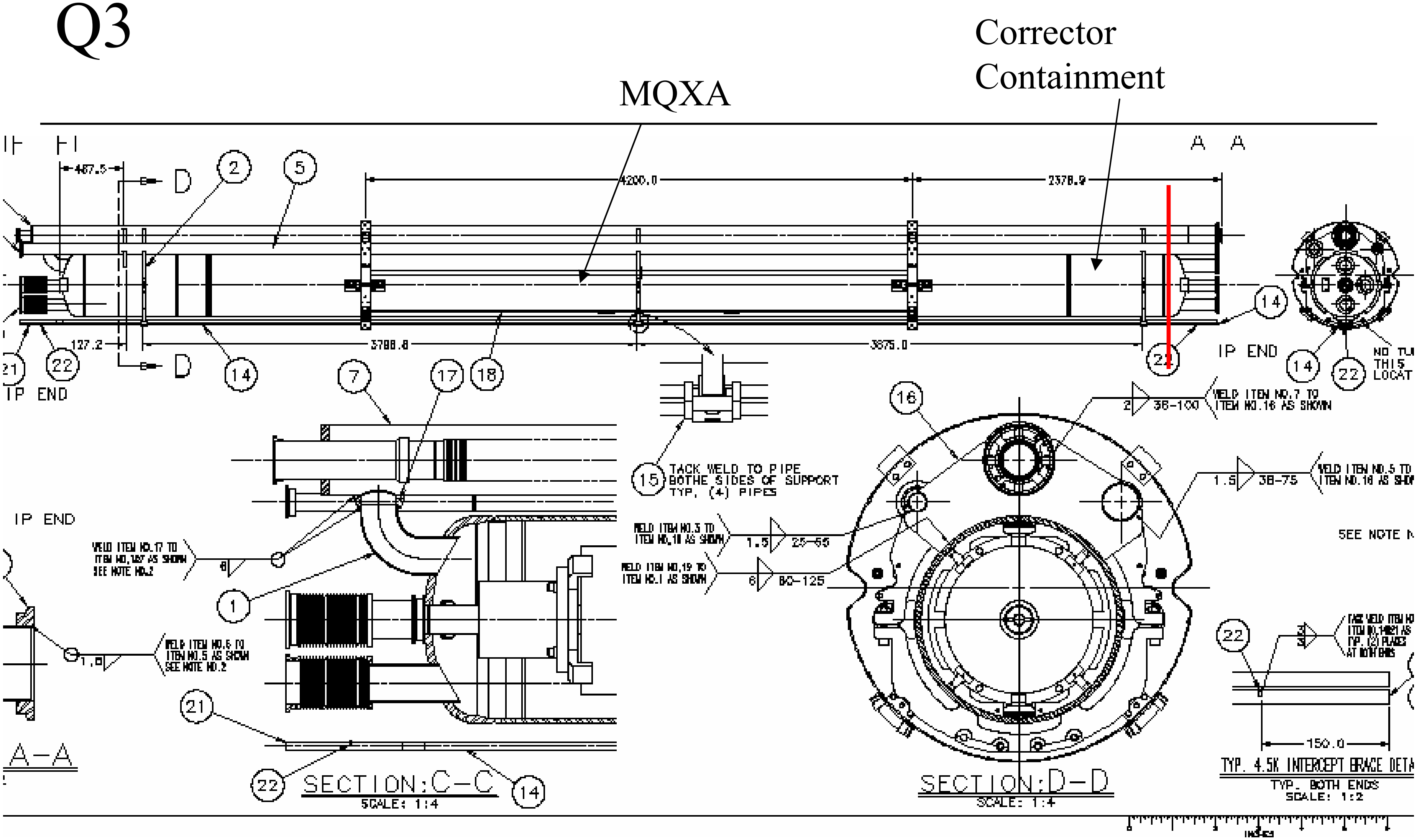
MQXA



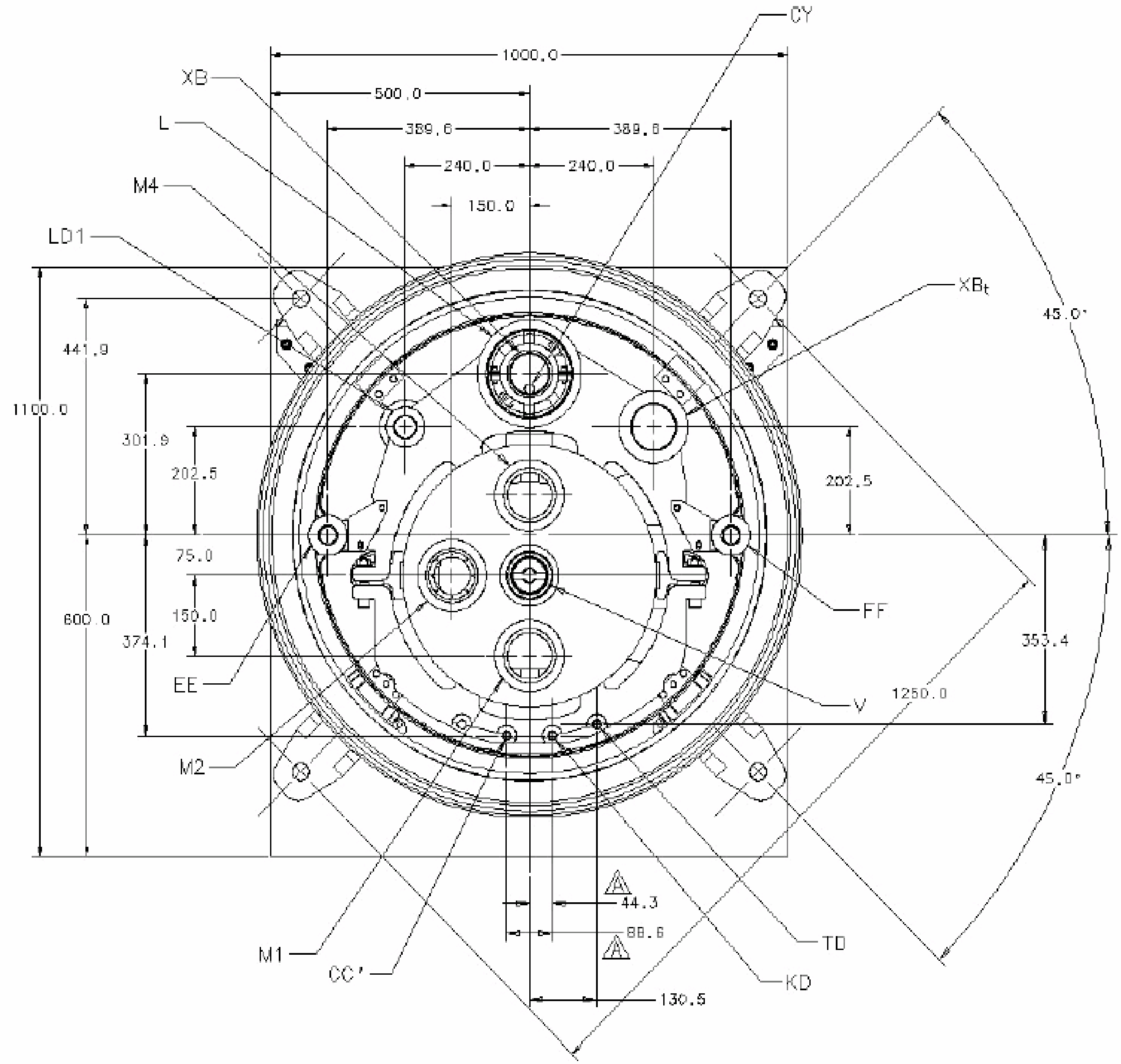
Q3


PUMPING LINE NON-IP END
SECTION: F-F
SCALE: 1:2
4.5K INTERCEPT NON-IP END EXTENSION DETAIL
SCALE: 2:1
HEAT EXCHANGER
COOLDOWN LINE
PUMPING LINE
NON-IP END
IP END
CUT OUT MLI FOR PIPE SUPPORTS
SLIT MLI AND FOLD BACK TO TACK WELD RETAINING CLIP IN PLACE
TIE BAR
TACK WELD TO COLD MASS (4 PER SUPPORT) AFTER PIPING IS PROPERLY LOCATED
COOLDOWN LINE NON-IP END
COOLDOWN LINE IP END
SECTION: E-E
SCALE: 1:2
SECTION: B-B
SCALE: 1:2
NOTE:
1. UNLESS OTHERWISE SPECIFIED ALL LINEAR DIMENSIONS ARE IN MILLIMETERS.
2. ALL VACUUM TIGHT WELDS SHALL BE LEAK TESTED PER FERMILAB SPECIFICATION ES-107240.
3. ALL WELDS REQUIRING FILLER MATERIAL SHALL USE 308 STAINLESS STEEL ROD.
4. MAY USE ME-390680 (COOLDOWN LINE WELDMENT SPECIAL) IN PLACE OF ME-390679 FOR ITEM NO.3 IF AVAILABLE.
4200.0
2378.9
487.5
127.2
3788.8
3875.0
NO TUBE THIS LOCATION
TACK WELD TO PIPE BOTHE SIDES OF SUPPORT TYP. (4) PIPES
PUMPING LINE IP END
SECTION: A-A
SCALE: 1:2
SECTION: C-C
SCALE: 1:4
SECTION: D-D
SCALE: 1:4
SEE NOTE NO.4
TYP. 4.5K INTERCEPT BRACE DETAIL
TYP. BOTH ENDS
SCALE: 1:2
150.0
PARTS LIST
LHC IRQ CRYOSTAT
Q3 CRYOSTAT ASSEMBLY
INTERNAL PIPING
5520-ME-390213

Q3



MQXA
Corrector
Containment
A A
487.5
D
4200.0
2378.9
127.2
3788.8
3875.0
IP END
TACK WELD TO PIPE
BOTHE SIDES OF SUPPORT
TYP, (4) PIPES
WELD ITEM NO.7 TO
ITEM NO.16 AS SHOWN
WELD ITEM NO.5 TO
WELD ITEM NO.3 TO
ITEM NO.18 AS SHOWN
WELD ITEM NO.19 TO
ITEM NO.1 AS SHOWN
WELD ITEM NO.17 TO
SEE NOTE NO.2
WELD ITEM NO.6 TO
ITEM NO.5 AS SHOWN
SEE NOTE NO.2
A-A
SECTION:C-C
SCALE: 1:4
SECTION:D-D
SCALE: 1:4
150.0
TYP. BOTH ENDS
SCALE: 1:2

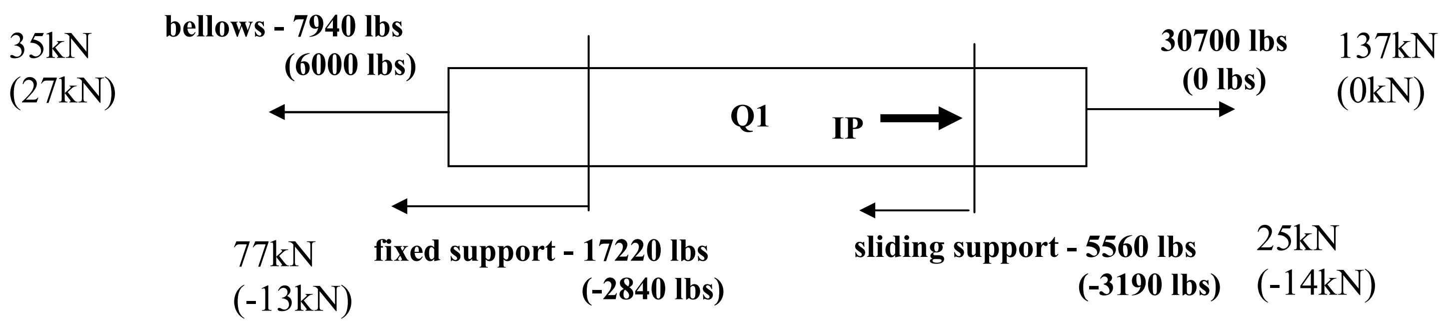


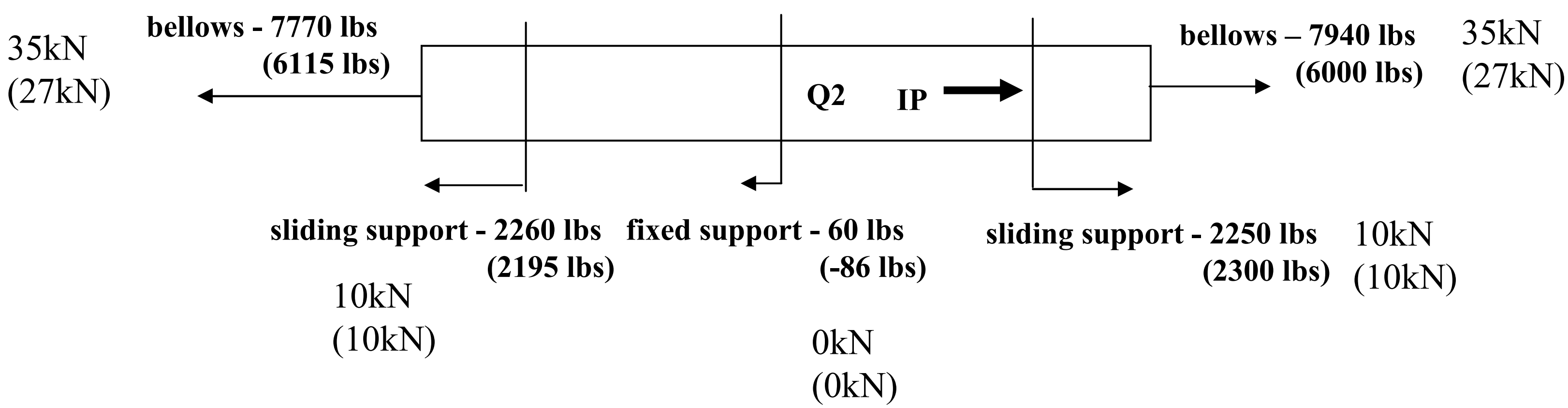
CY
1000.0
XB
500.0
L
389.6
389.6
240.0
240.0
M4
150.0
LD1
XBt
45.0°
441.9
1100.0
301.9
202.5
202.5
75.0
150.0
FF
600.0
374.1
353.4
EE
V
1250.0
M2
45.0°
44.3
88.6
TD
M1
CC'
KD
130.5

Allowable Deflection of Support

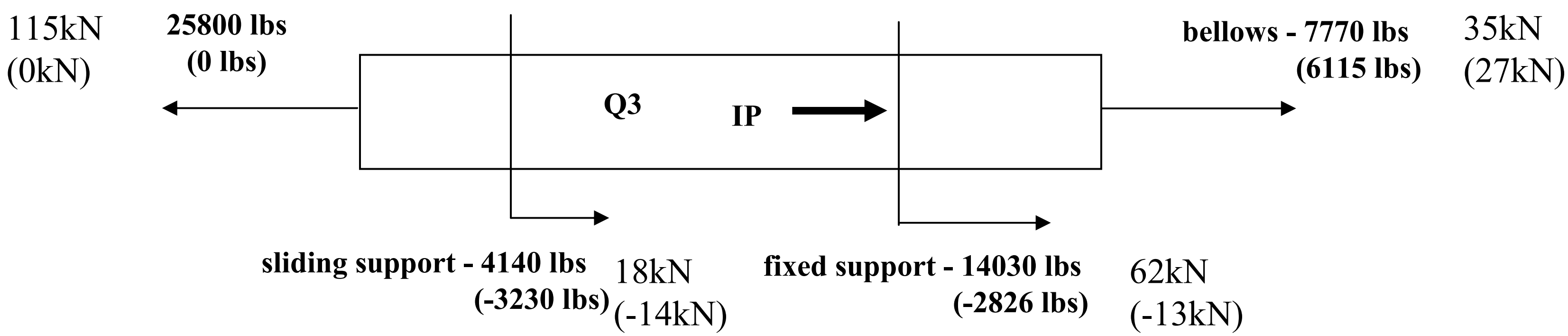
- From failure analysis support fails at deflection of 7.5mm (6.4mm borderline)
- System Analysis from Q1-Q2-Q3
- Cooldown deflection ~1.0mm in Q2 free spiders (all tested, ok)
- Analysis of test in fixture, test results, suggest 2.8mm

Cooldown / 20 bar loads – Q1/Q2





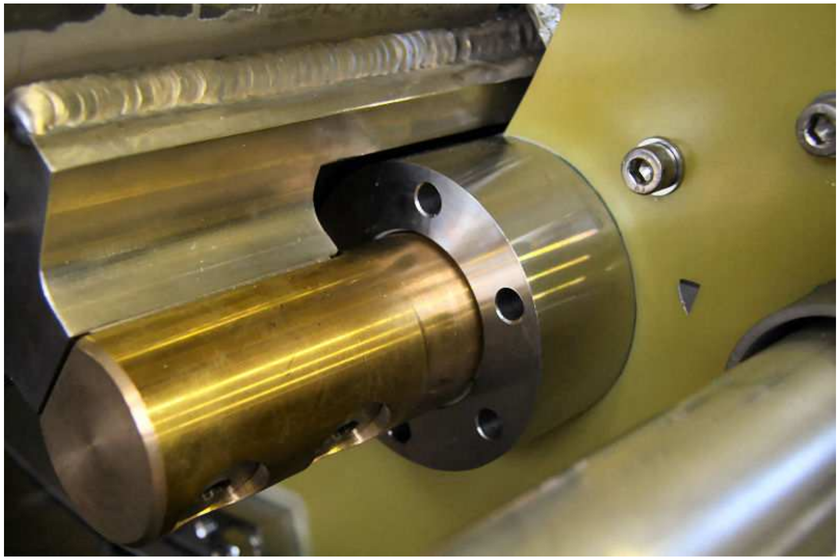
Cooldown / 20 bar loads – Q3



- Contraction of cold mass interconnect bellows Q1-Q2 and Q2-Q3 reacts portion of quench load
- Further models move from full triplet to Q1 only w/ load of interconnect bellows included
- W/ cooldown, free support pulled toward fixed support by Invar tie rod

Allowable Deflection of Support

- Testing / modeling to failure of individual supports
  - The cold mass provides a rotational constraint on the support and lug which does not exist in the test fixture
  - Test of single spider in fixture failed at 6900lbs, 17mm deflection
  - Modeling used to translate results to spider / invar system, including gravity loads.
- 2.8mm bending of spider in installed configuration OK including safety factors
- Removing front split ring on fixed support adds another 17.5mm of allowable motion

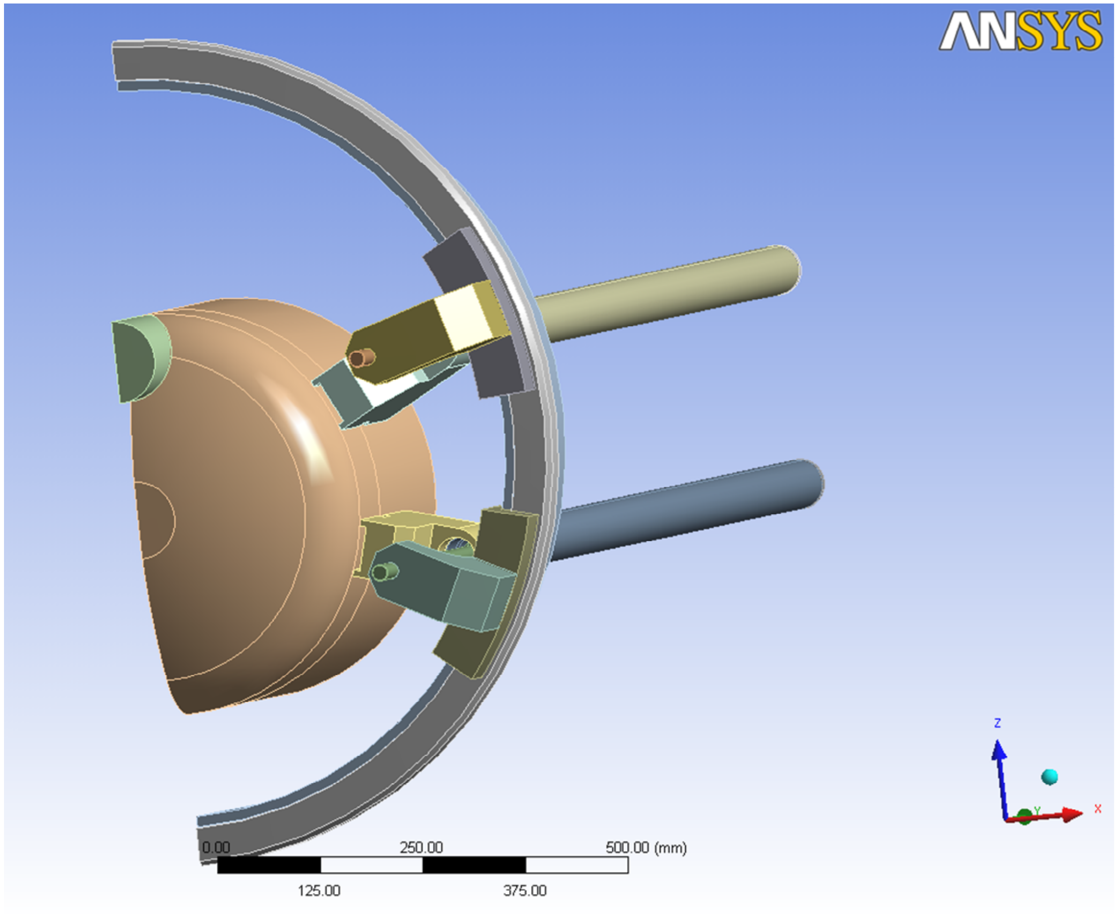
 

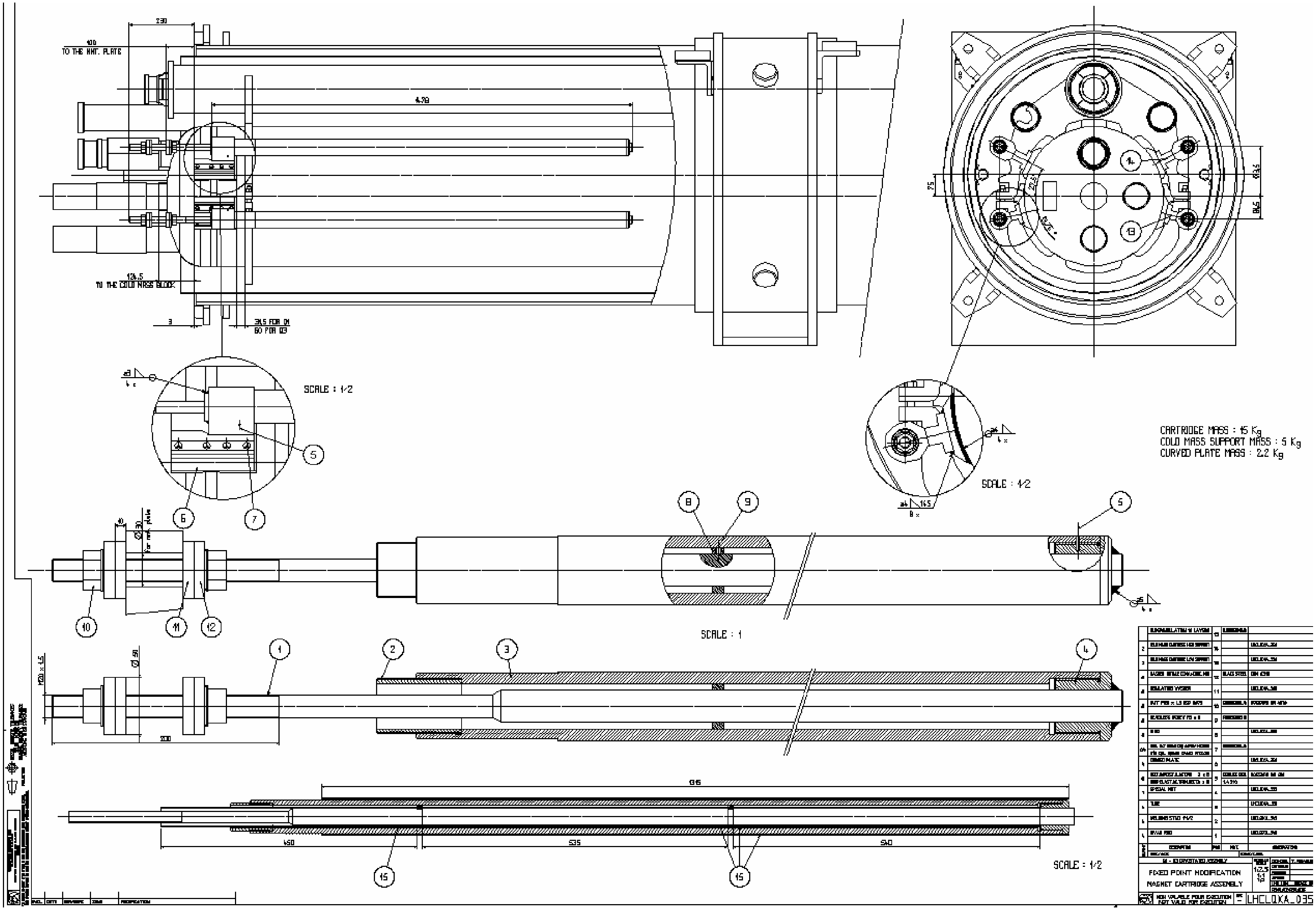
Removing the front split ring is important as the cartridge is a much stronger spring than the support and would pull the cold mass 5.5mm if a large thermal mismatch existed

Addition of 17.5mm of travel by removing this split ring, and using the cartridge to set the fix point of the assembly, greatly simplifies failure mode analysis.

Cartouche / Cartridge

- Affixed at Q1 non-IP end; Q3 IP end
- Transfer load at all temperatures
- Limits support deflections





TO THE HNT. PLATE
TO THE COLD MASS BLOCK
SCALE : 1/2
CARTRIDGE MASS : 15 Kg
COLD MASS SUPPORT MASS : 5 Kg
CURVED PLATE MASS : 2.2 Kg
SCALE : 1/2
SCALE : 1
SCALE : 1/2
FIXED POINT MODIFICATION
MAGNET CARTRIDGE ASSEMBLY
NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION
LHCLQXA_035

Q1 Cartridge Modeling

- Cartridge applied to Q1 model including bellows for:
  - Warm 25 bar pressure test load
  - Cold
  - Cold, 20 bar quench load

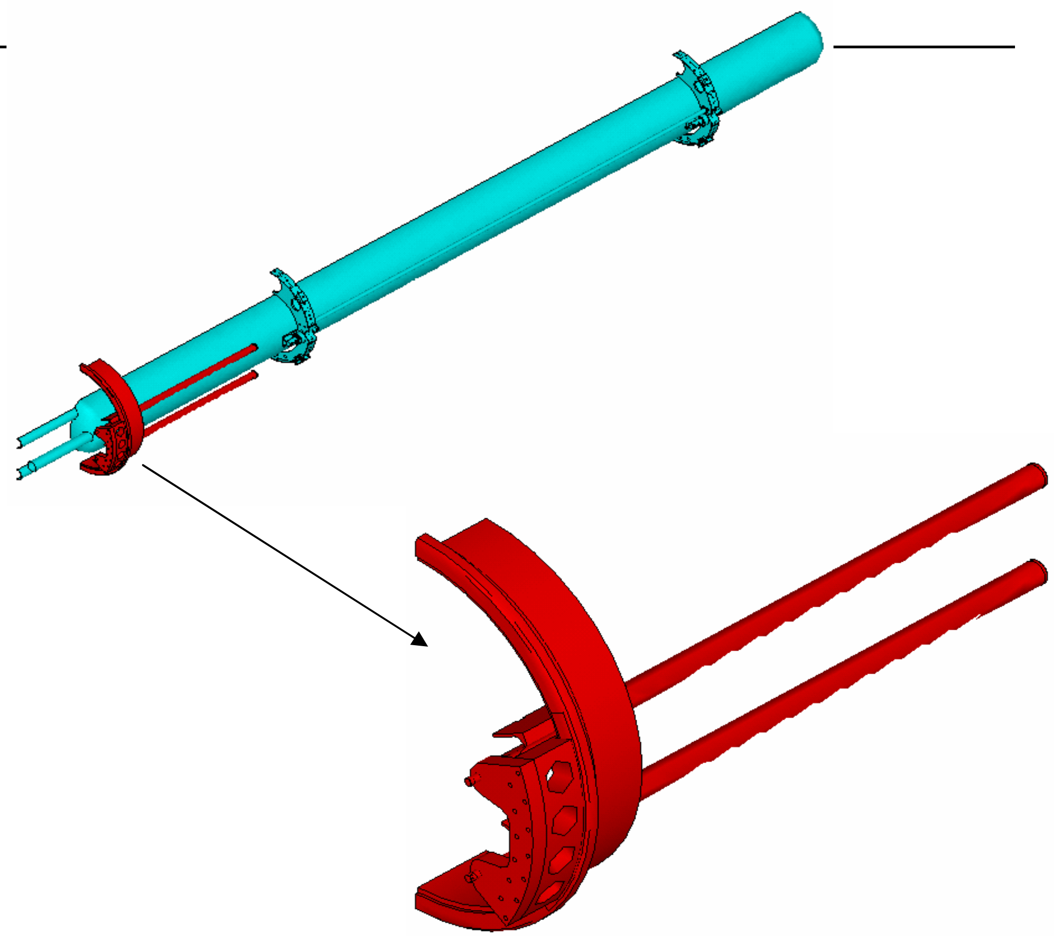


Figure 1. Finite Element Model of Q1 with Cartridge

Q1 Cartridge, 25 bar pressure test

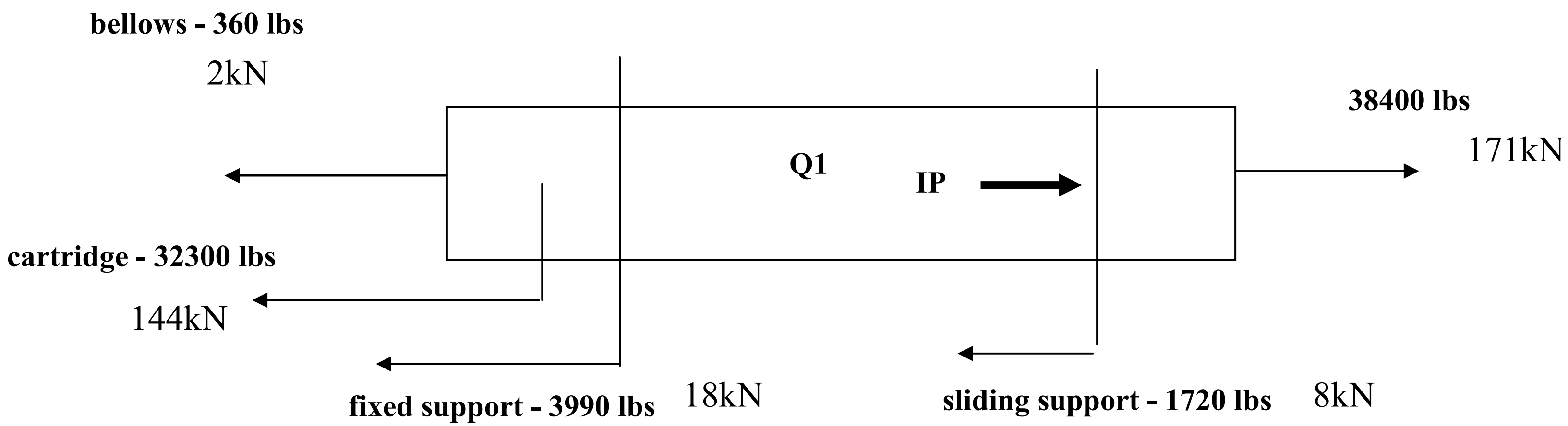


Figure 2. Forces on Components due to 25 Bar Warm Pressure Test Load

Q1 Cartridge, Cooldown

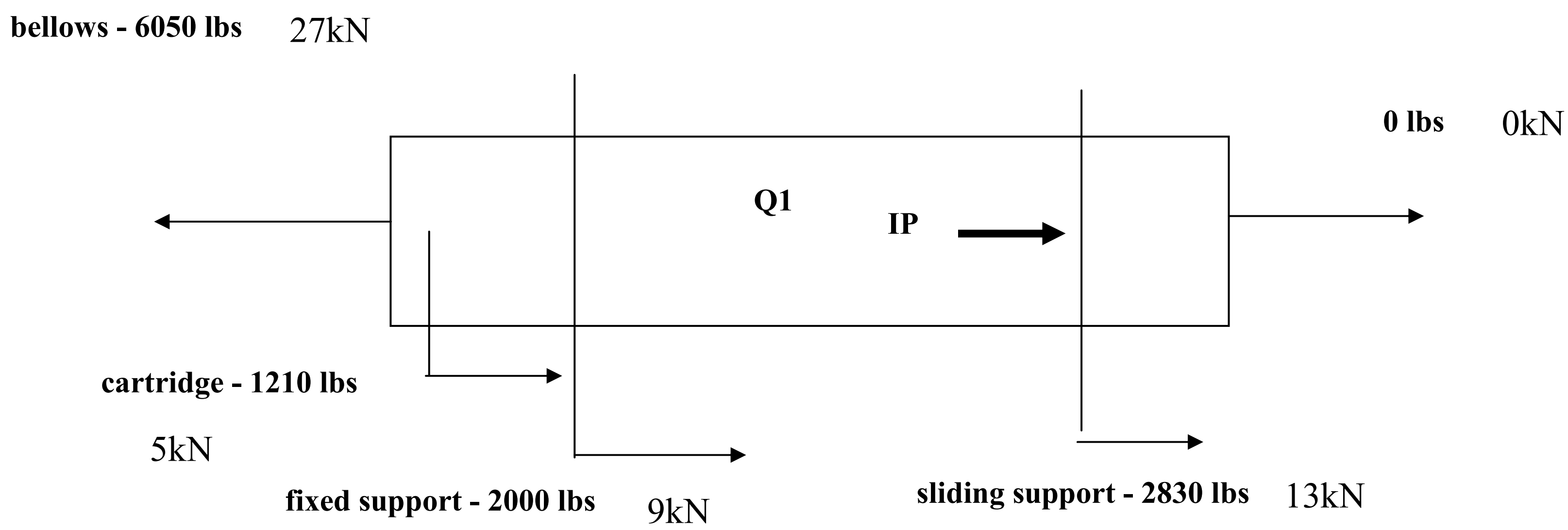


Figure 3. Forces on Components due to Cooldown

Q1 Cartridge, cooldown + 20 bar

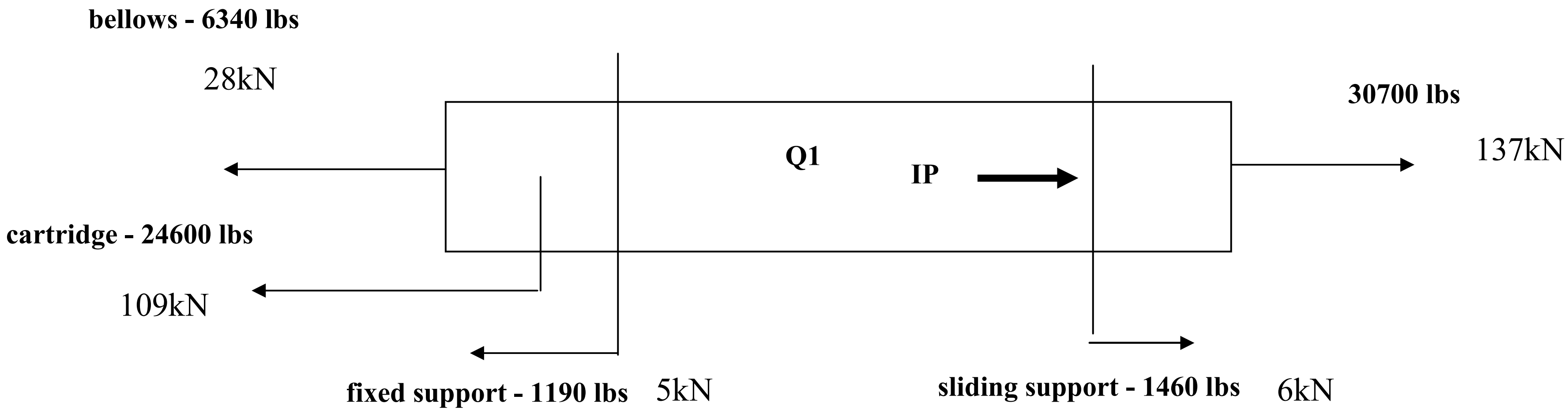


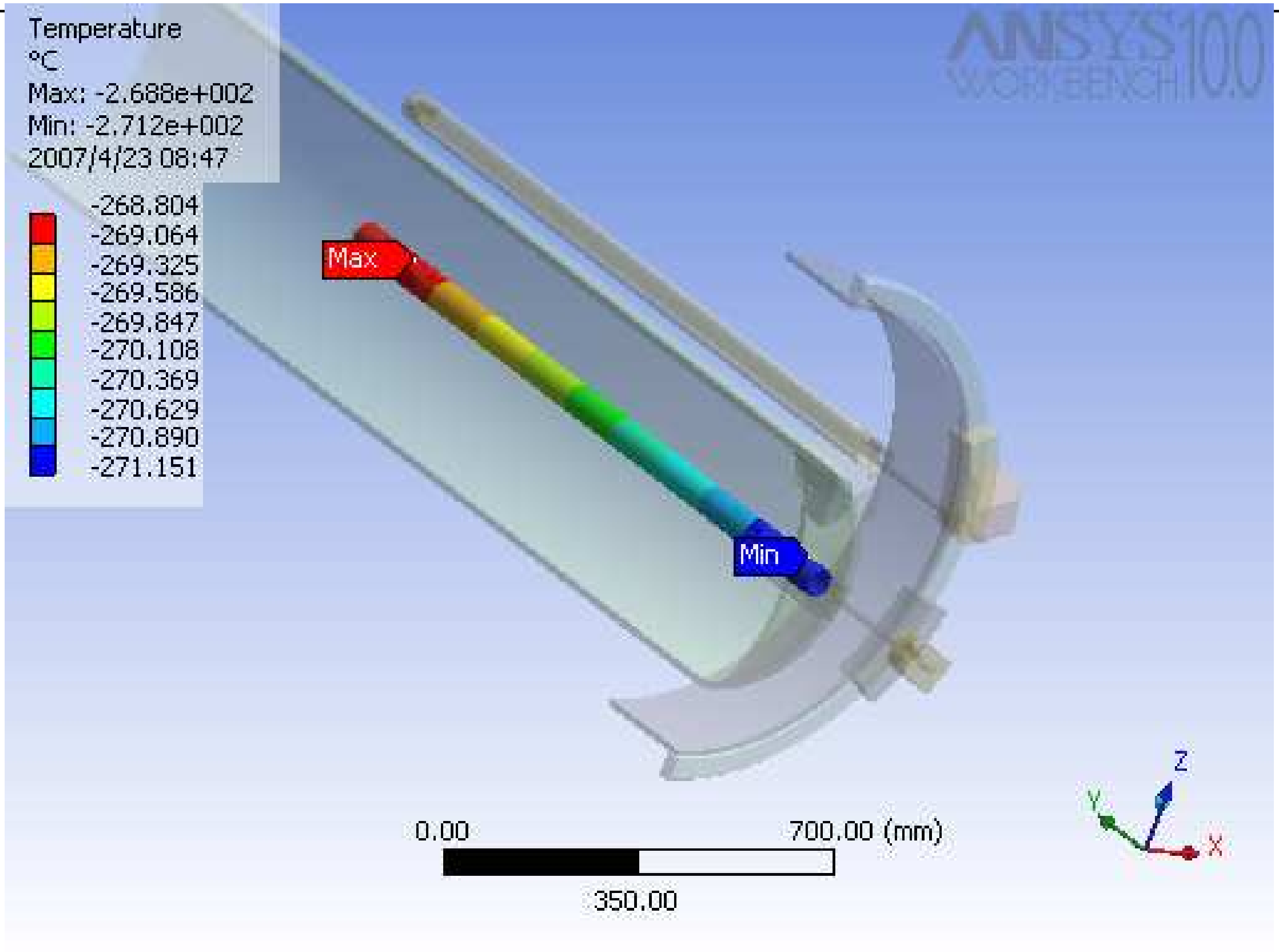
Figure 4. Forces on Components due to Cooldown and 20 Bar Pressure Load

Q1 Cartridge, Deflections

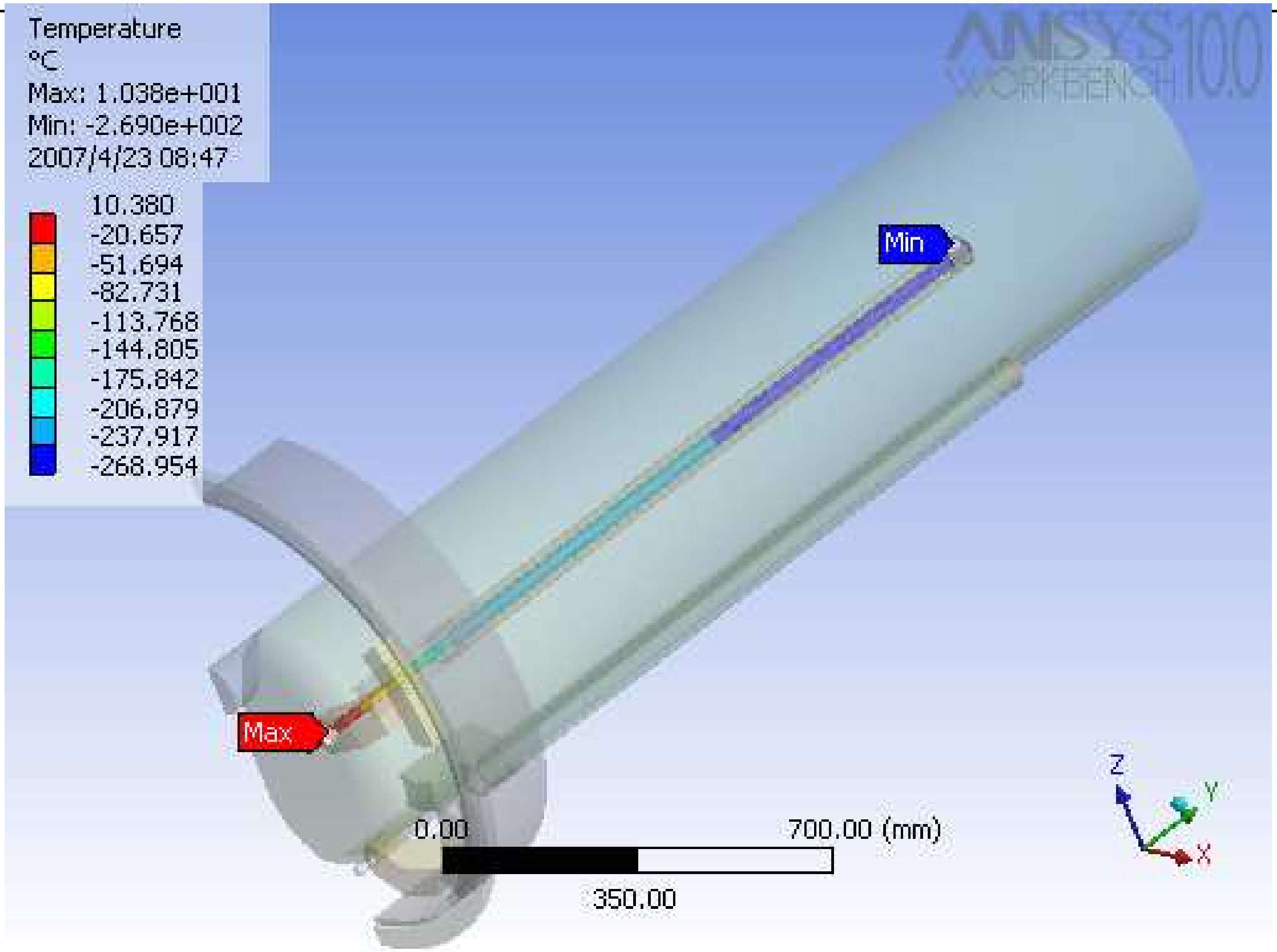
Load Case	Axial Movement of Q1 Cold Mass (positive away from IP - inches)	
	in	mm
25 Bar, Warm	-0.069	-1.75
Cooldown	0.030	0.76
20 Bar, Cold	-0.027	-0.68

- Load per cartridge: 36kN (warm test, 25 bar evenly split)
- Al tube stress (3300 psi / 8600 psi ASME allowable) (22.7MPa/59MPa allowable)
- Invar peak cross section (16600 psi / 21600 psi) (114MPa / 148MPa) (Allowable – 3 to ultimate or 2 to yield of annealed Invar)

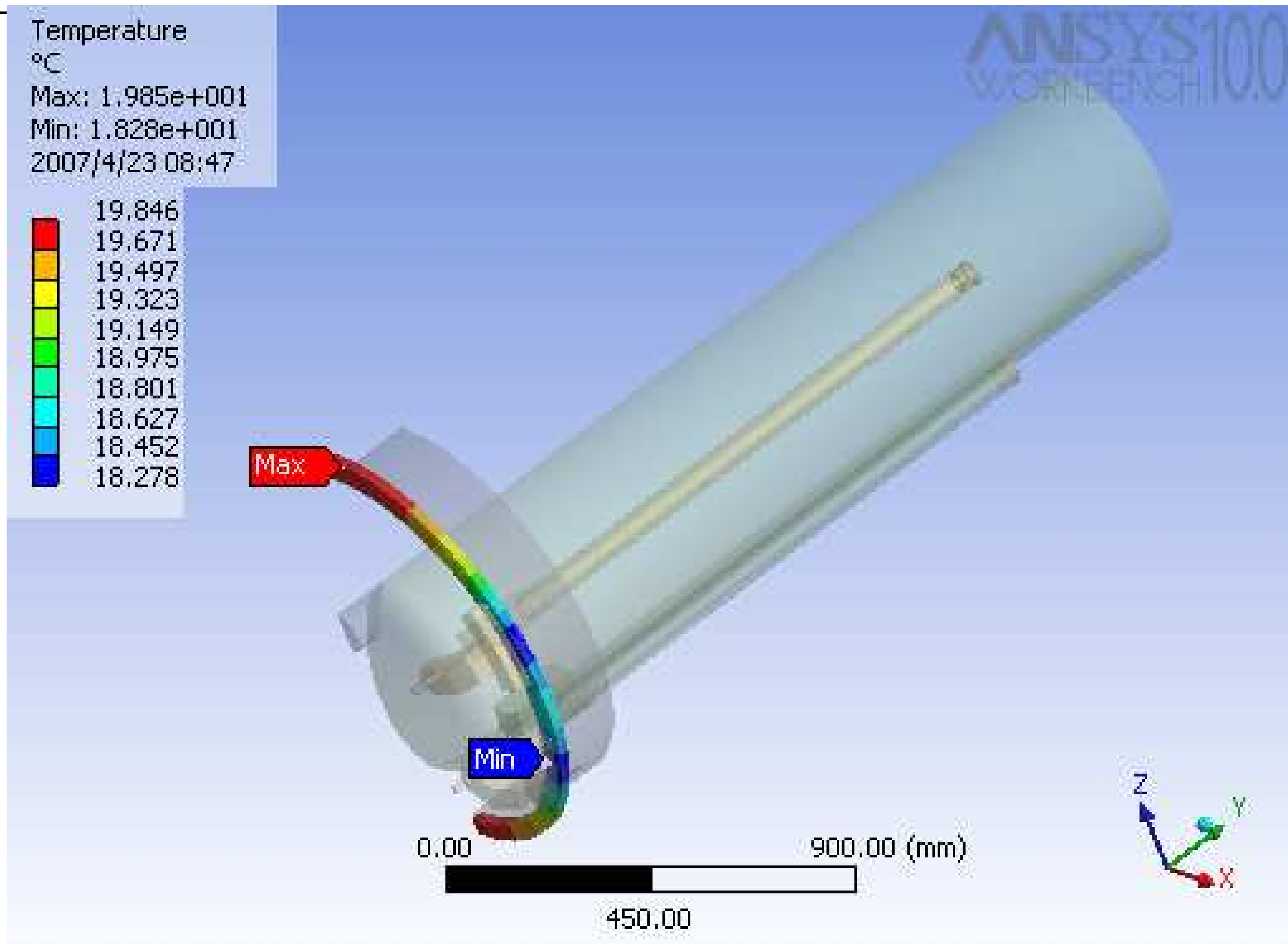
Thermal Analysis



Invar rod temperature



Vacuum vessel flange temperature



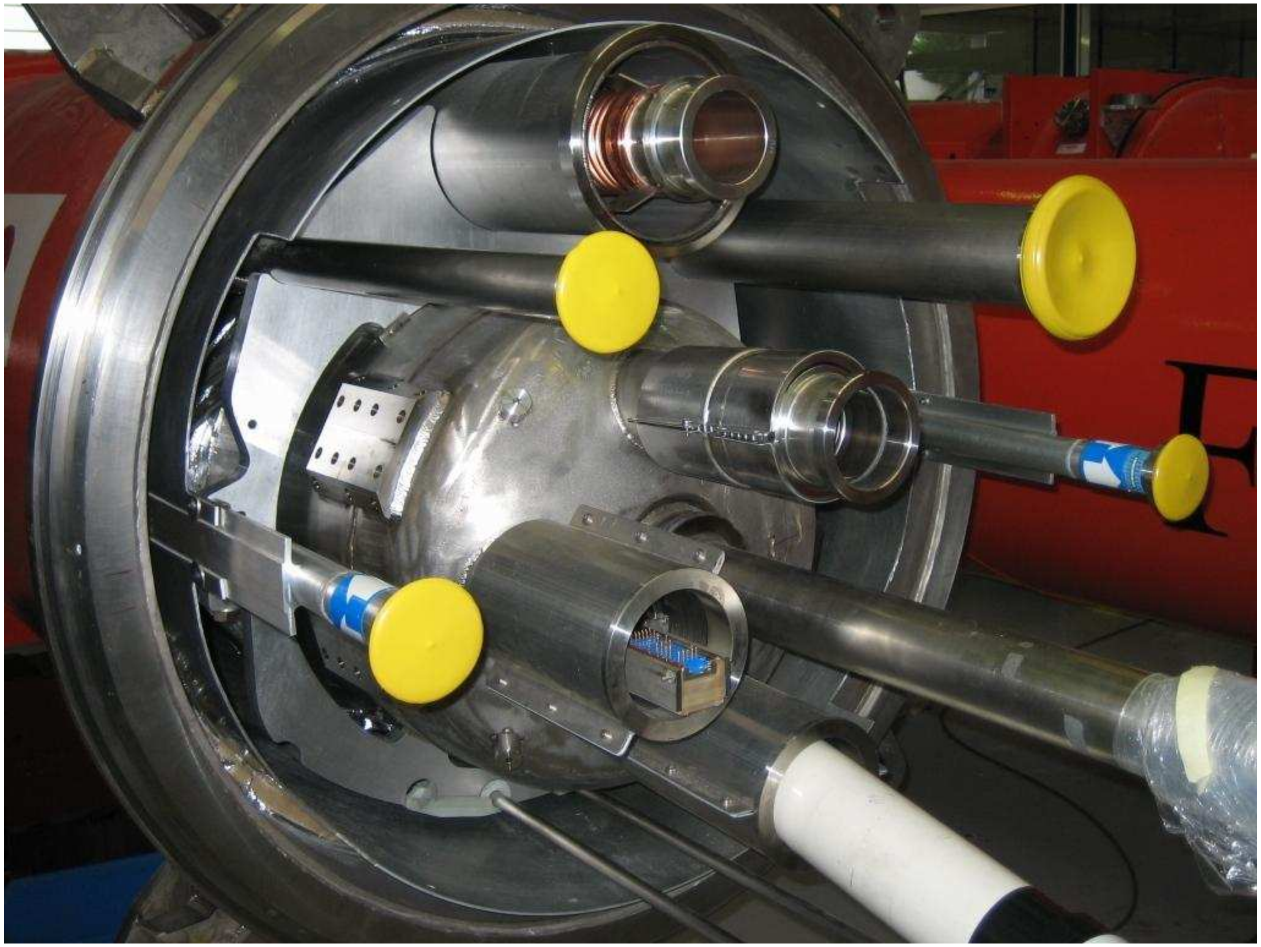
Cartridge Summary

Cartridge design in production and testing

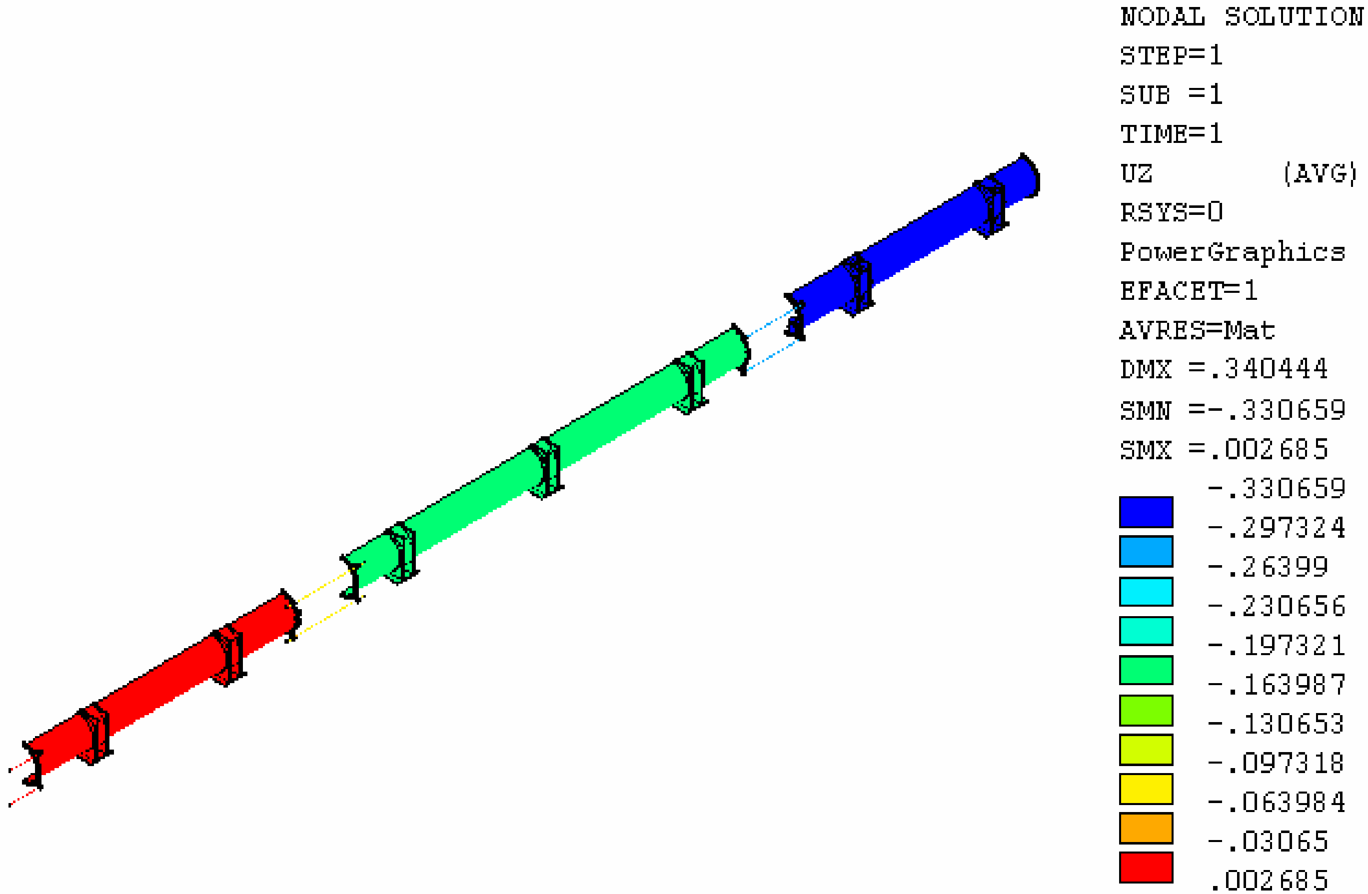
- Worst case Q1 spider support longitudinal deflection < 2mm limit
- Worst case Q1 spider load < ¼ load that caused failure during recent pressure test
- Does not move magnet fix point
  - In fact fixes Q1 / Q3 better than currently
- Magnetic effect negligible
- Additional load to 2K of a few Watts; Vacuum Oring OK.
- Mechanical tests have been done on:
  - Removal of split ring at fixed point
  - Invar / Al tube connection
  - Vacuum bracket to flange weld
  - Full standalone cartridges
- Test of 4 cartridges installed on a Q1 in process, actual test next week
- Successful removal of split ring covers upset conditions
  - Covers failure modes in thermalization of cartridge / cold mass
- On track for sector 8-1….

Q1

Q1



Vacuum Loads to Ground

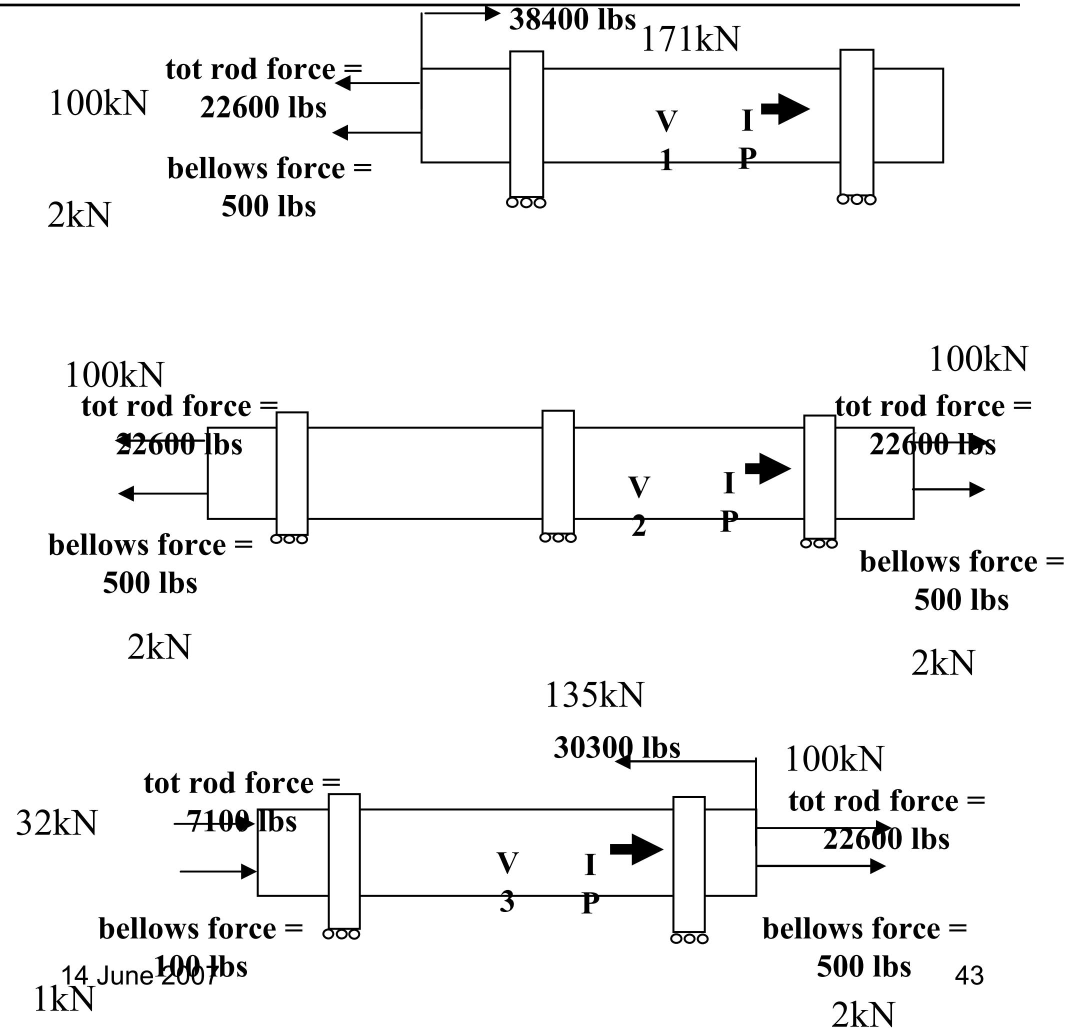


Vacuum vessel to ground

- Apr 24-25 Review noted issues to be resolved w/ alignment / jacks / tunnel ground under triplets
- Safety factor of vacuum tie bars between vacuum vessels and DFBX also questioned

25 bar load + Vacuum load (+bellows); no transverse load on jacks

- Vacuum Vessel Deflections
  - V1 4.3mm to IP
  - V2 2.0mm to IP
  - V3 0.4mm from IP
- Vac Bellows makes ~5% change in deflections in 2 previous cases



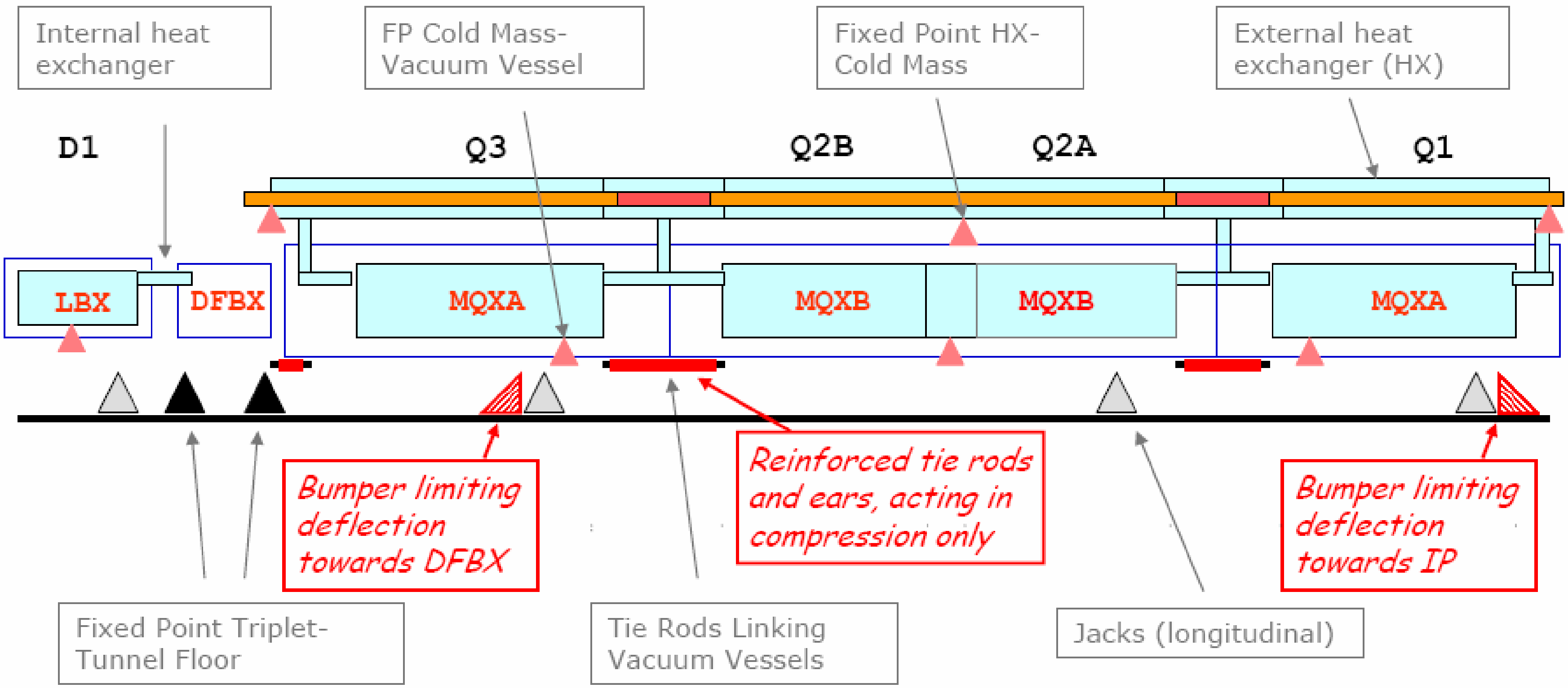
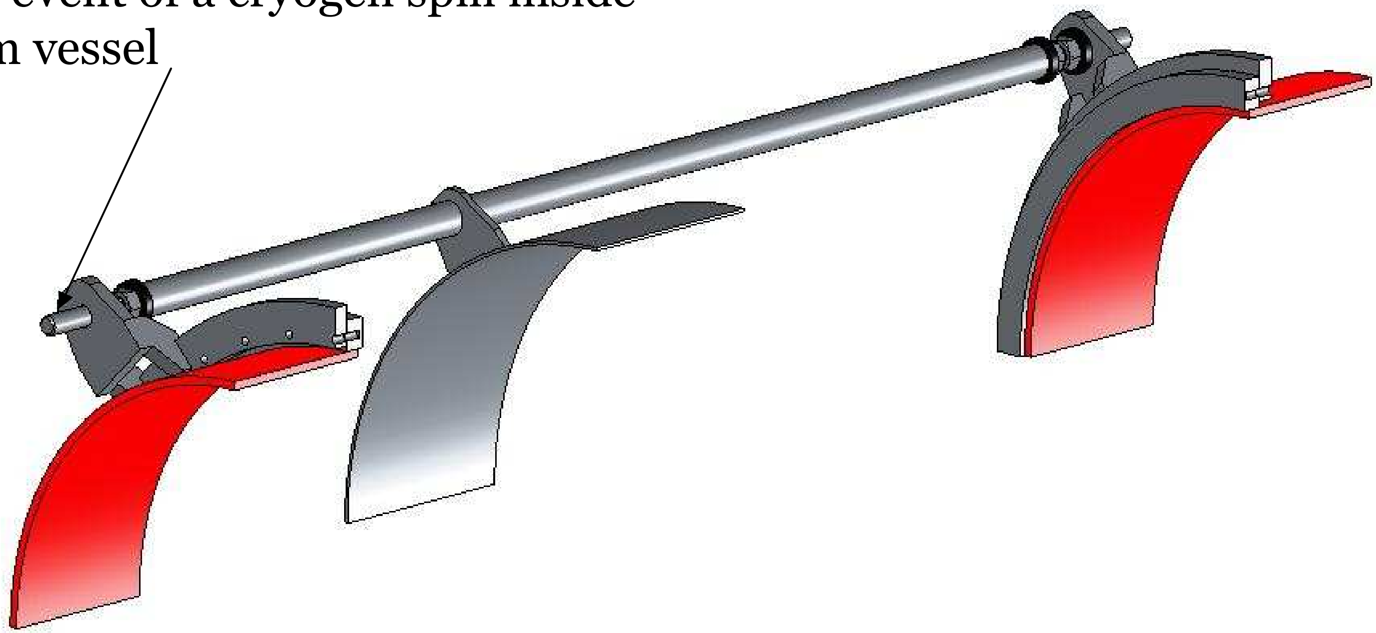


Figure 1. Proposed modifications to the system for reacting axial loads to the floor in the Inner Triplet.

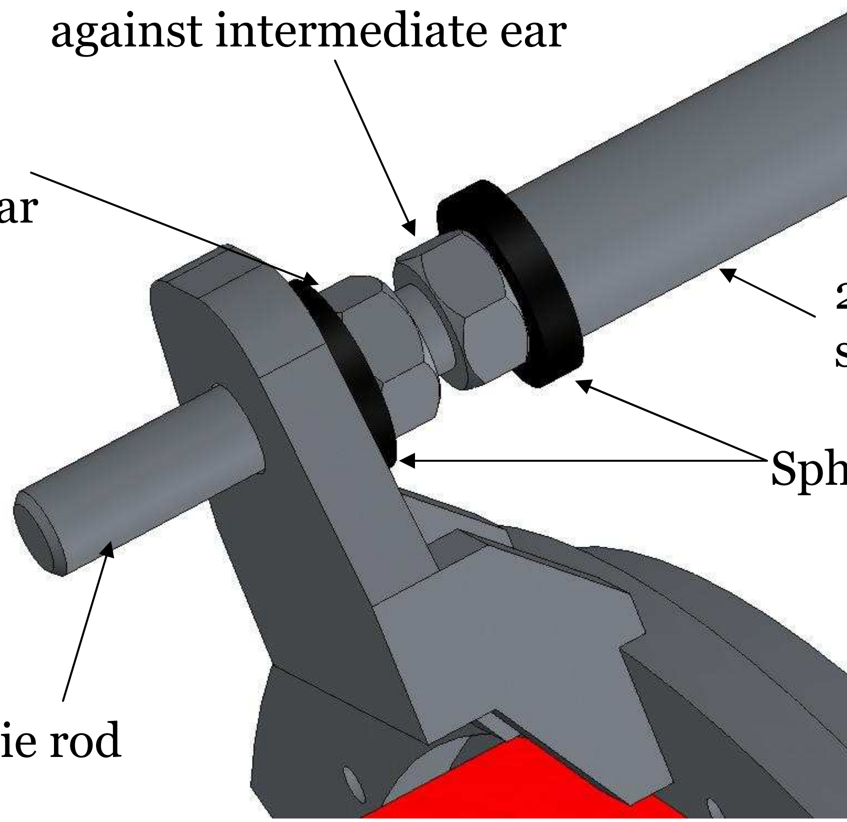
Vacuum Tie Bar Ass’y

Outer nut omitted to prevent excessive load in the event of a cryogen spill inside the vacuum vessel

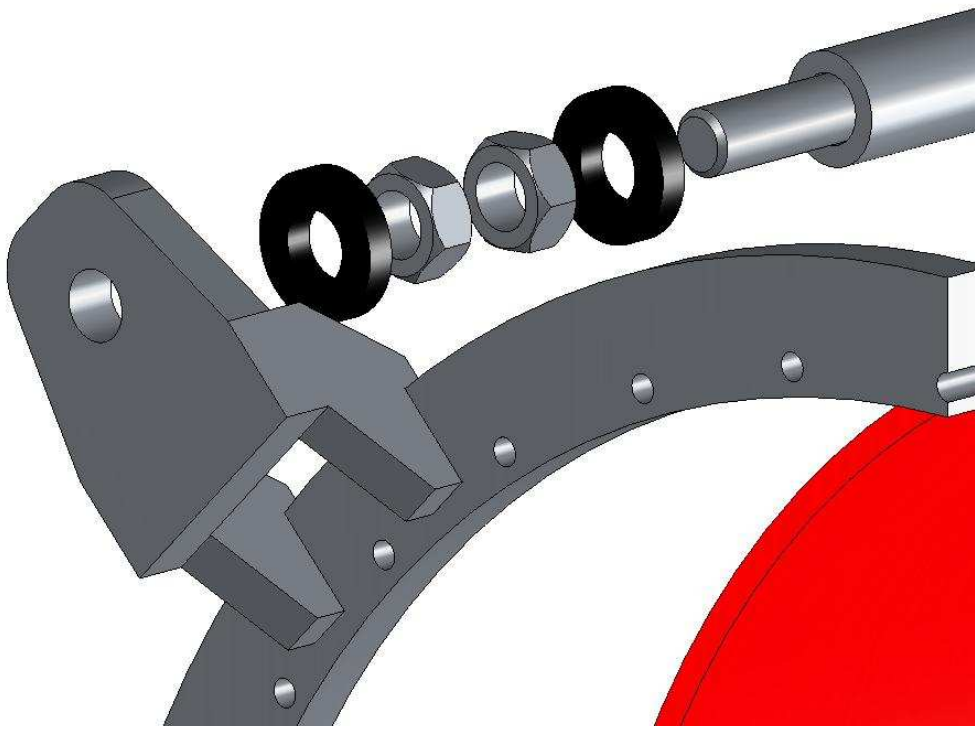


Connection Details

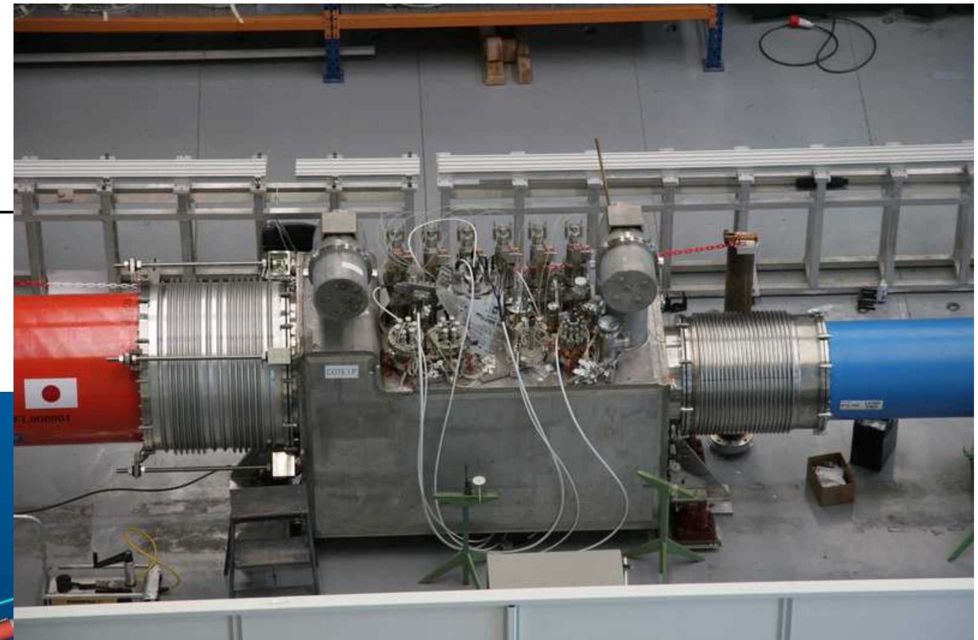
Tie rod, nuts, and spherical washers are the same as those in the current system

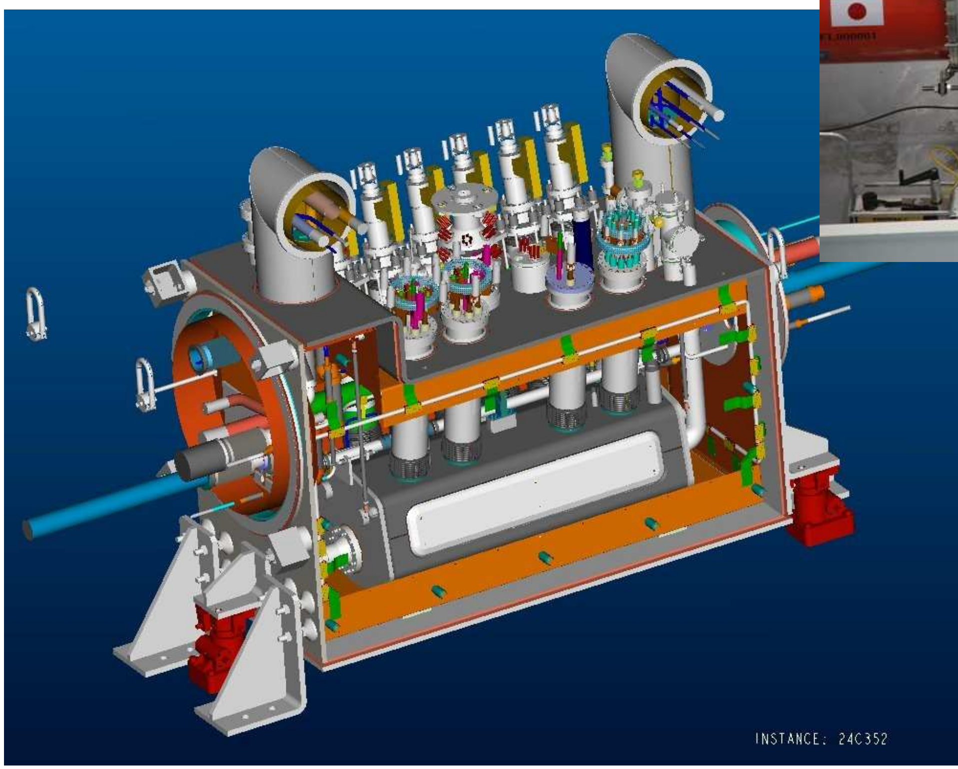


Connections Details (2)

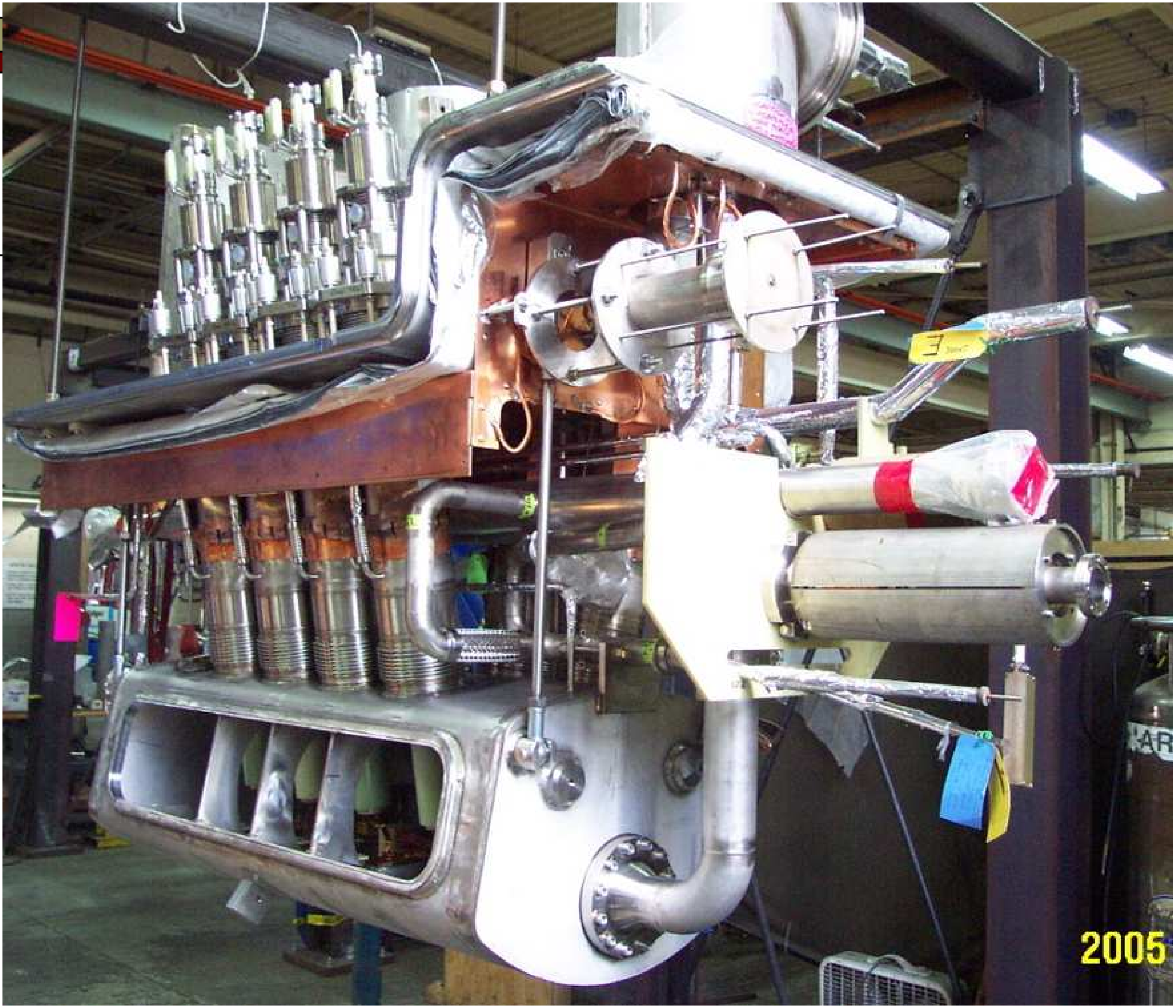


DFBX

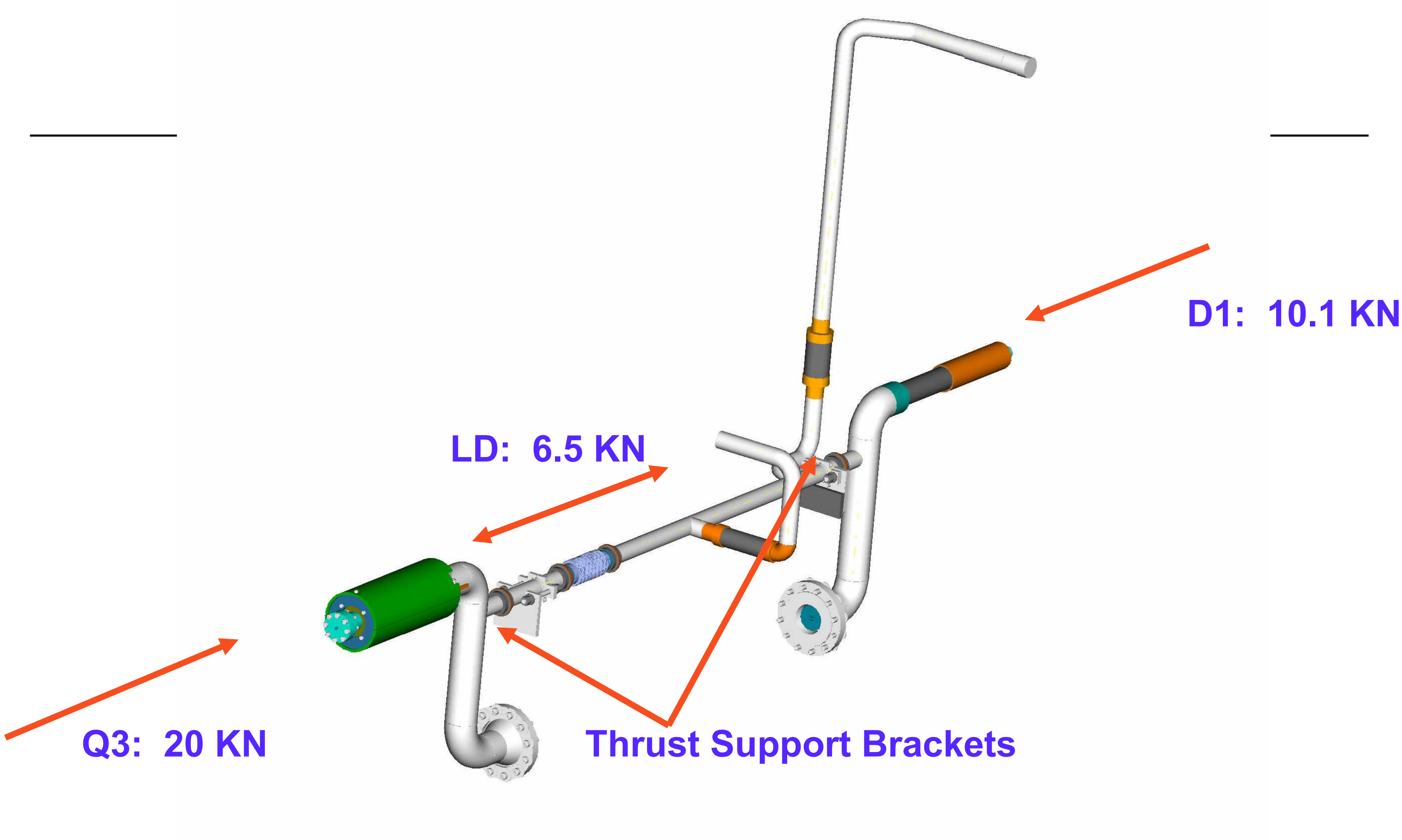




DFBX-E
17 Feb 05



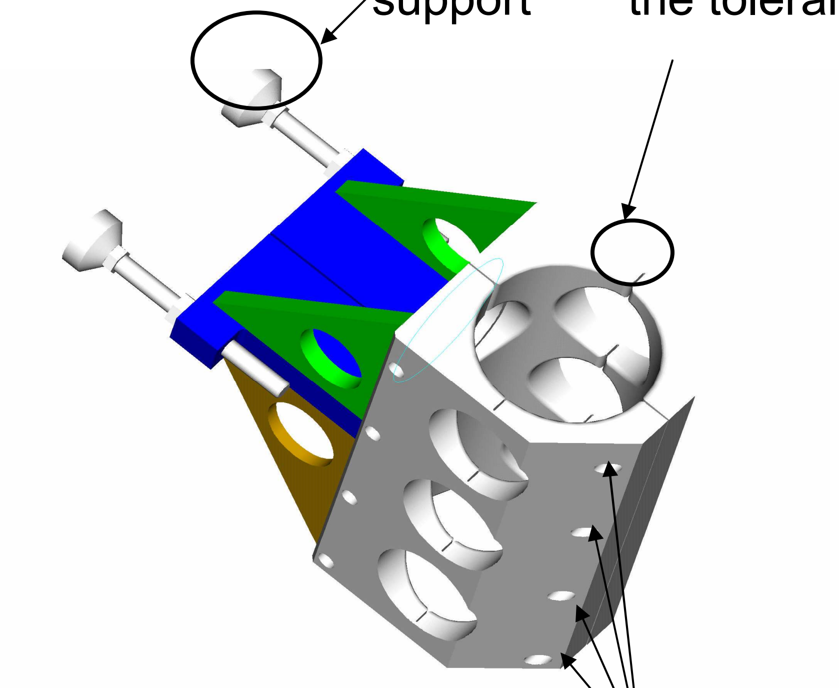
Bus Duct Assembly: Thrust Load

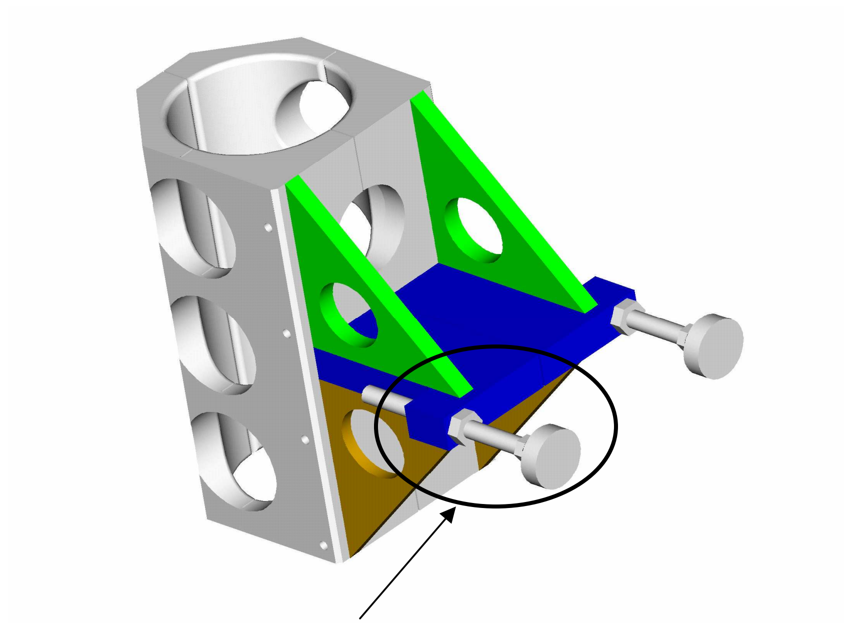


MQX1

Swivel support

Feature allowing to loosen up the tolerances on the bore

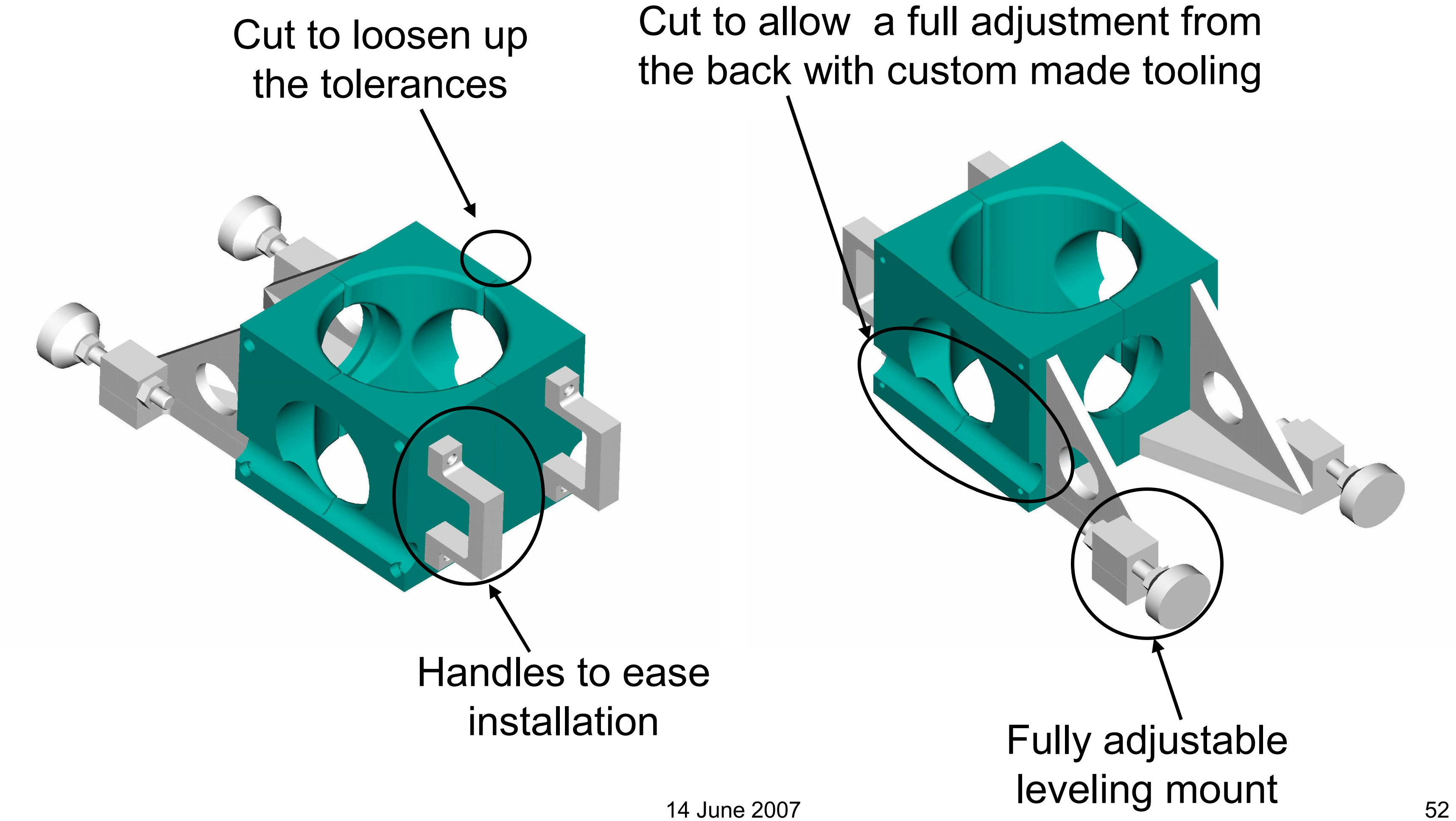




Fully adjustable support

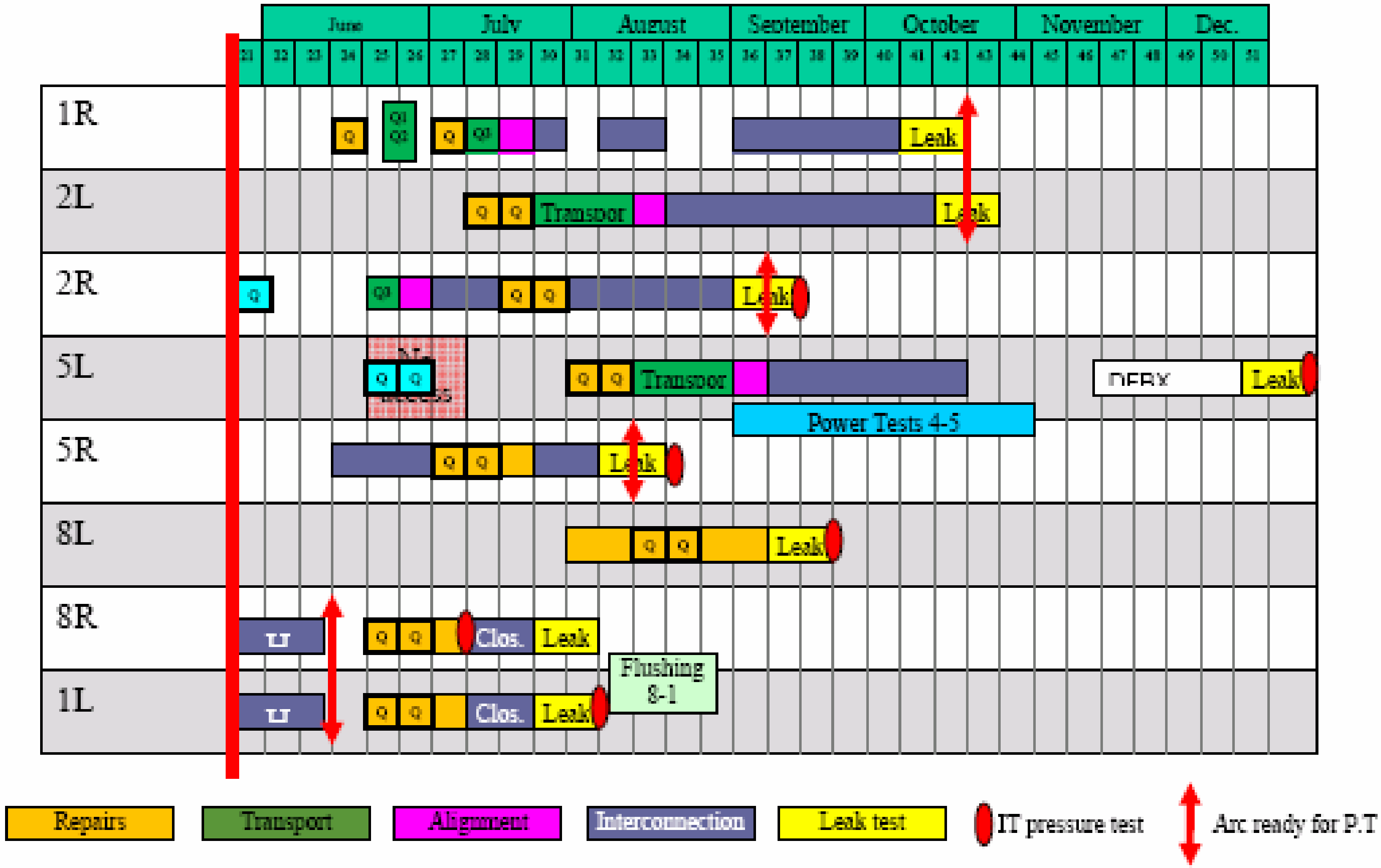
4 screws on each side

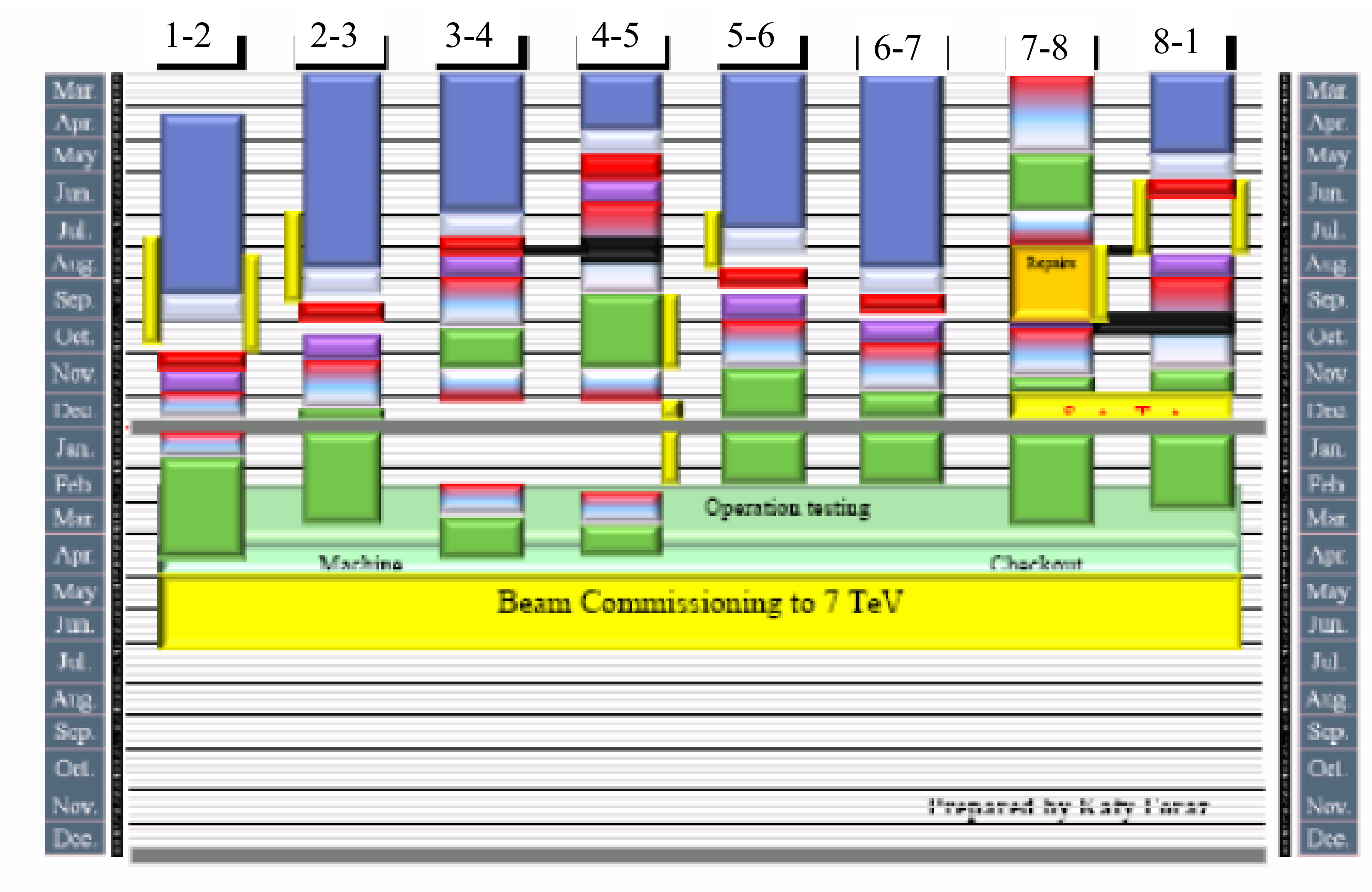
MBX1


Cut to loosen up
the tolerances
Cut to allow a full adjustment from
the back with custom made tooling
Handles to ease
installation
Fully adjustable
leveling mount

Summary

- Production and Qualification tests of solutions in process
  - Materials and parts arriving at CERN
  - Initial hydraulic test in 181 next week on Q1
  - DFBX solution design complete
  - On track for sector 8-1 and repairs in remaining sectors
  - Great effort across labs


June
July
August
September
October
November
Dec.
1R
2L
2R
5L
5R
8L
8R
1L
Leak
Transpor
Power Tests 4-5
Flushing 8-1
Clos.
Repairs
Transport
Alignment
Interconnection
Leak test
IT pressure test
Arc ready for P.T



1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-1
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Jan.
Feb
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Repairs
Operation testing
Machine
Checkout
Beam Commissioning to 7 TeV