Modular Coil Options

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NCSX Project Meeting

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Outline

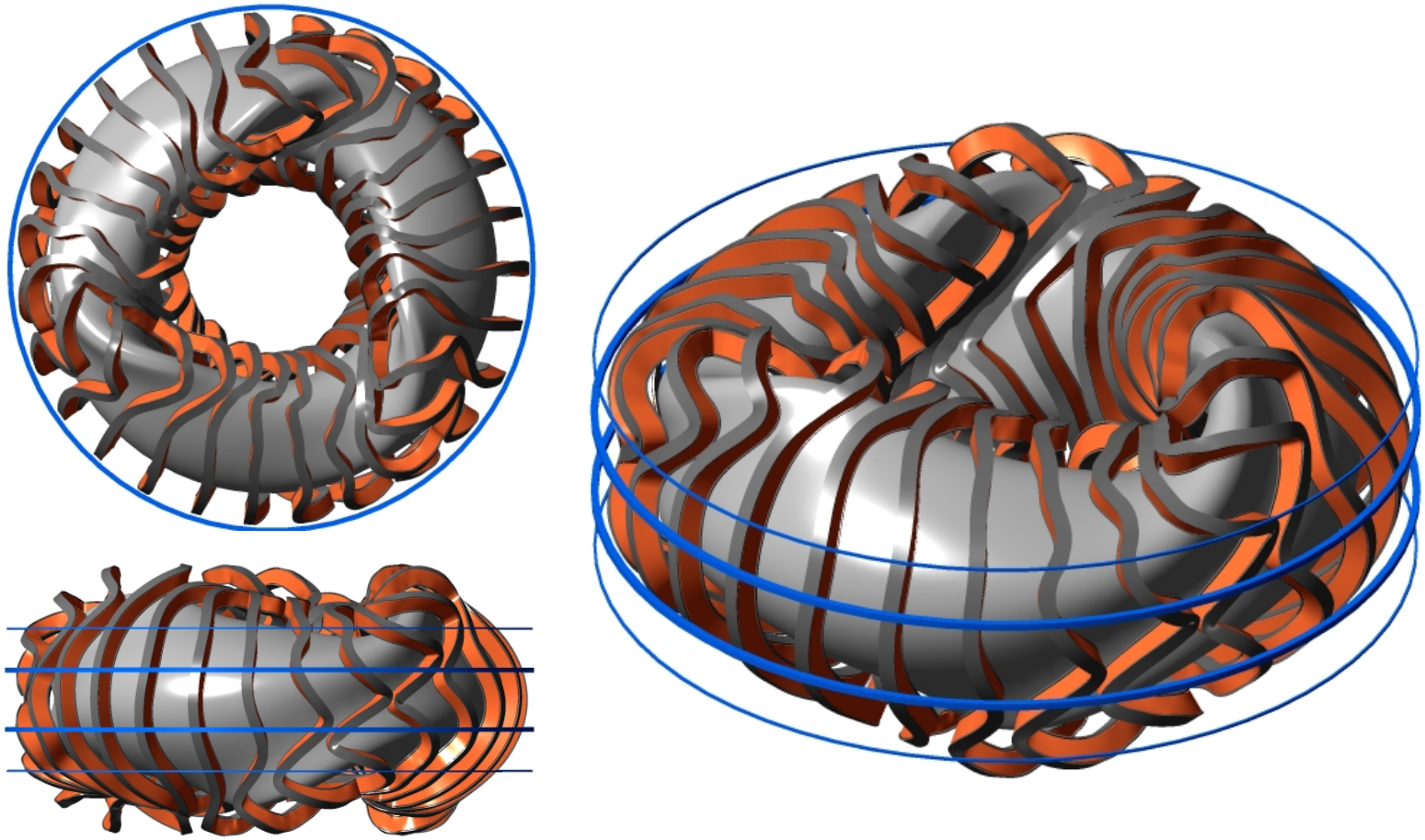
Since the last Project Meeting, effort has focused on the development of evaluation parameters for the modular coil options of plasma configurations C82, II75, and LI383. Parameters include:

- Coil Geometry
- Current Density
- Radius of Curvature
- Fields and Forces
- Structural Concepts
- Displacement / Stress

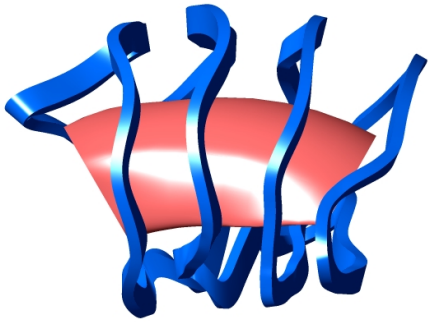
Parameters Summary

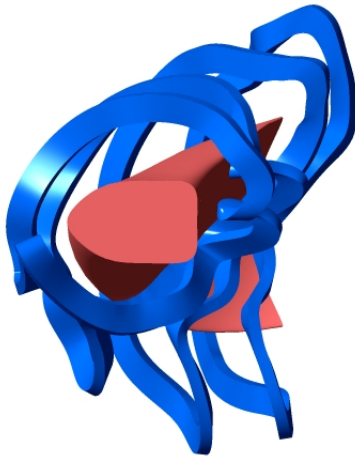
Configuration	Major Radius (m)	Aspect Ratio	Number of Coils	No. Unique Coils	Minimum Coil to Plasma Distance (cm)	Minimum Coil to Coil Distance (cm)	One-Turn Length (m)	Average Radius (cm)	Minimum Bend Radius (cm)	Nominal Size (cm)	Current per Coil (kA)	Number of Turns per Coil	Current Density (kA/cm2)
C82 / 0424	1.46	3.4	27	5	21.7	9.9	5.7 5.9 5.9 6.0 6.0	60.7 63.4 67.3 70.4 79.7	4.6 6.2 4.7 7.6 3.9	9 x 16	541	28	14.6
LI383 / 0705	1.7	4.4	21	4	21.7	15	7.0 7.2 7.5 7.2	65.4 90.8 81.8 91.2	7.1 4.4 4.2 13.5	11 x 20	810	40	11.5
II75 / 0613	1.82	4.8	21	4	21.9	11.6	7.5 7.9 8.2 8.4	67.1 118.5 85.1 82.0	4.9 2.9 6.9 12.7	8.5 x 20	867	44	20.6

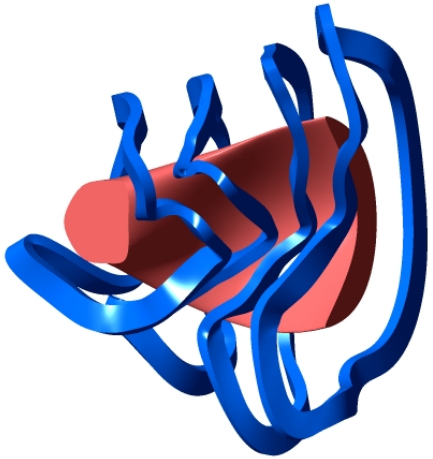
Case C82 / 0424

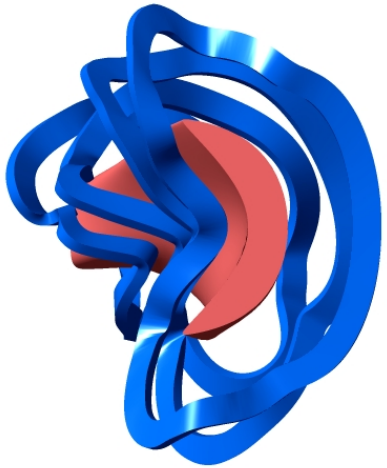


Case II75 / 0613

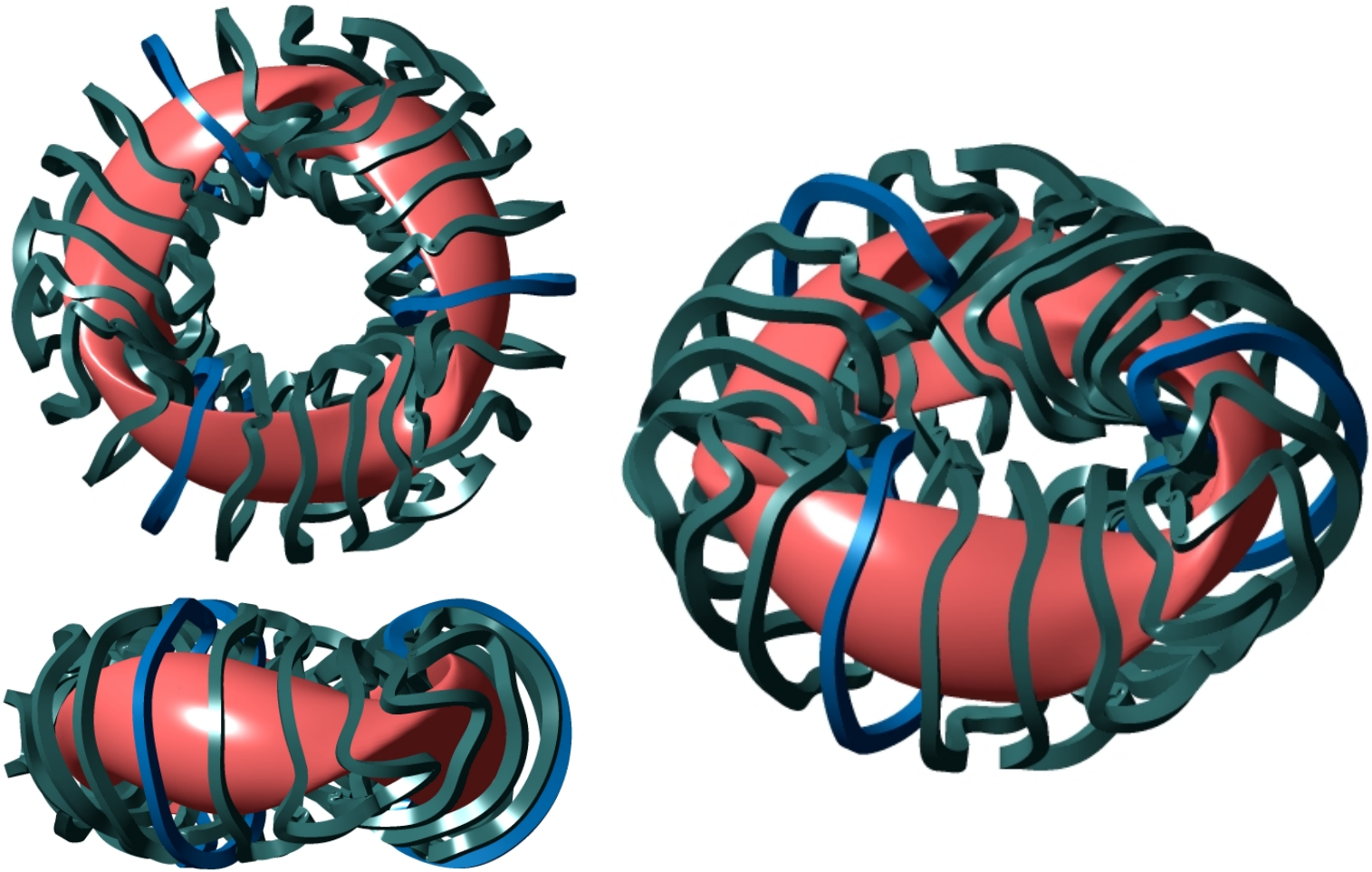








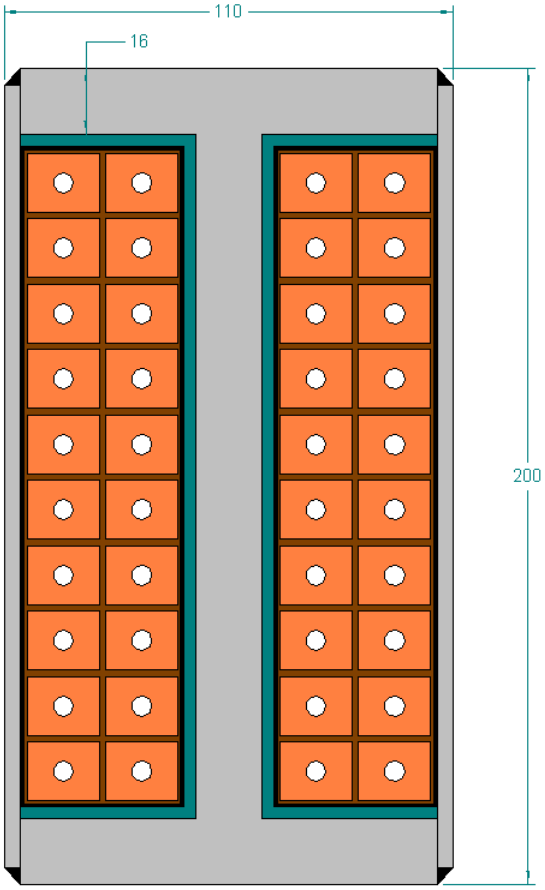
Case L383 / 0705



Current Density

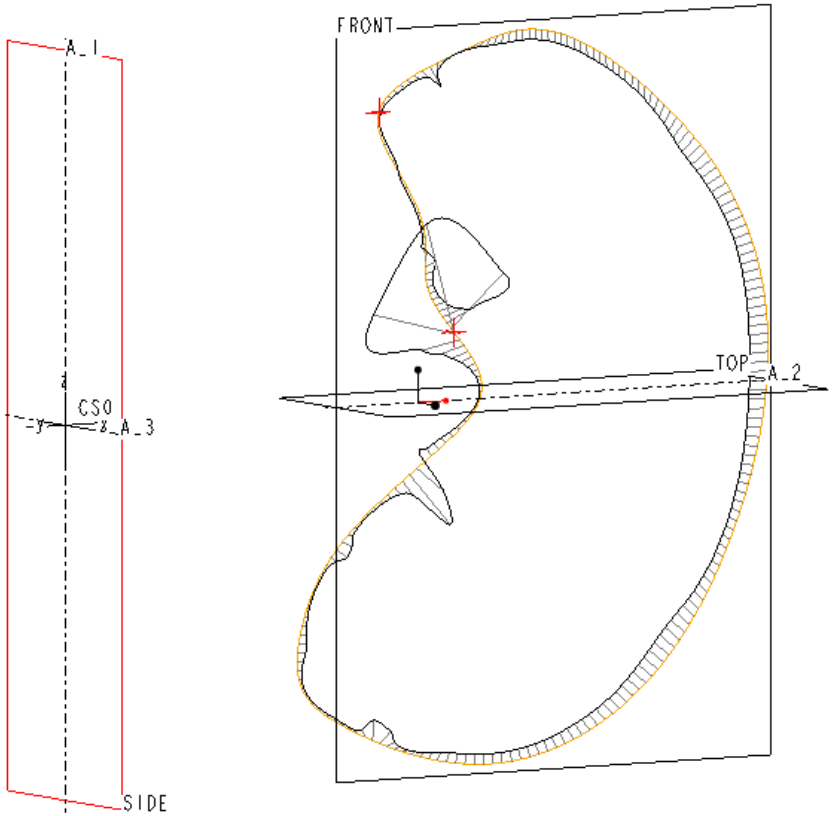
- LI383 has greater coil spacing, lower current density

Configuration	C82 / 0424	LI383 / 0705	II75 / 0613
Major Radius, m	1.46	1.70	1.82
No. Coils	27	21	21
Coil to Plasma Dist, cm	21.7	21.7	21.9
Coil to Coil Dist, cm	9.9	15.0	11.6
Nominal Size, cm	9 x 16	11 x 20	8.5 x 20
Current / Coil, kA	541	810	867
No. Turns / Coil	28	40	44
Structure Thickness, cm	1.6	1.6	1.6
Epoxy Fill, cm	0.3	0.3	0.3
Winding Pack Dims, cm	3 x 12.2	4 x 16.2	2.8 x 16.2
Turn Insulation, mm	0.8	0.8	0.8
Ground Wrap, mm	0.8	0.8	0.8
Turn Dimensions, mm	15.6 x 12.6	14.4 x 17.6	12.9 x 11.4
Hole Diameter, mm	5	5	5
Packing Factor, %	75	75	75
Current Density, kA/cm2	14.6	11.5	20.6



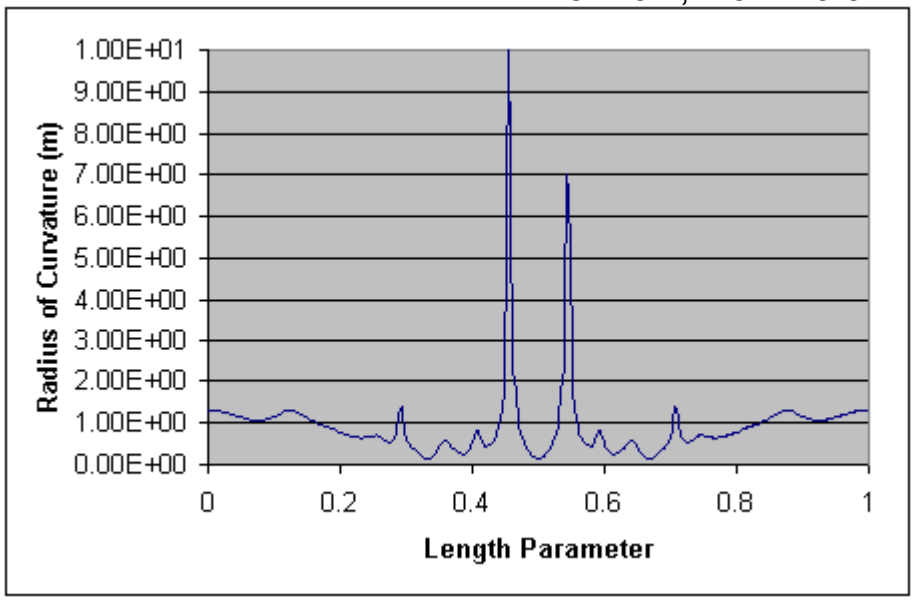
Minimum Bend Radius

- Pro/ENGINEER calculates radius of curvature for spline at winding center
- Comparison has been made using HSX, W7-AS coil geometry



Vector Plot for LI383 Sym Coil

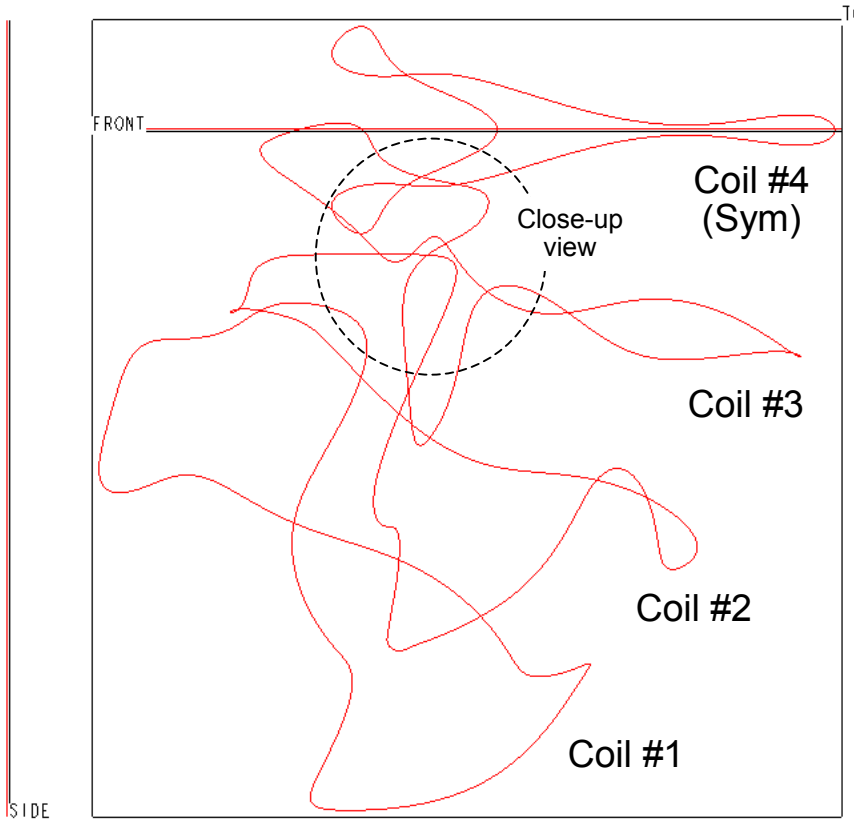
Min = 13.2-cm, Max = 9.9-m



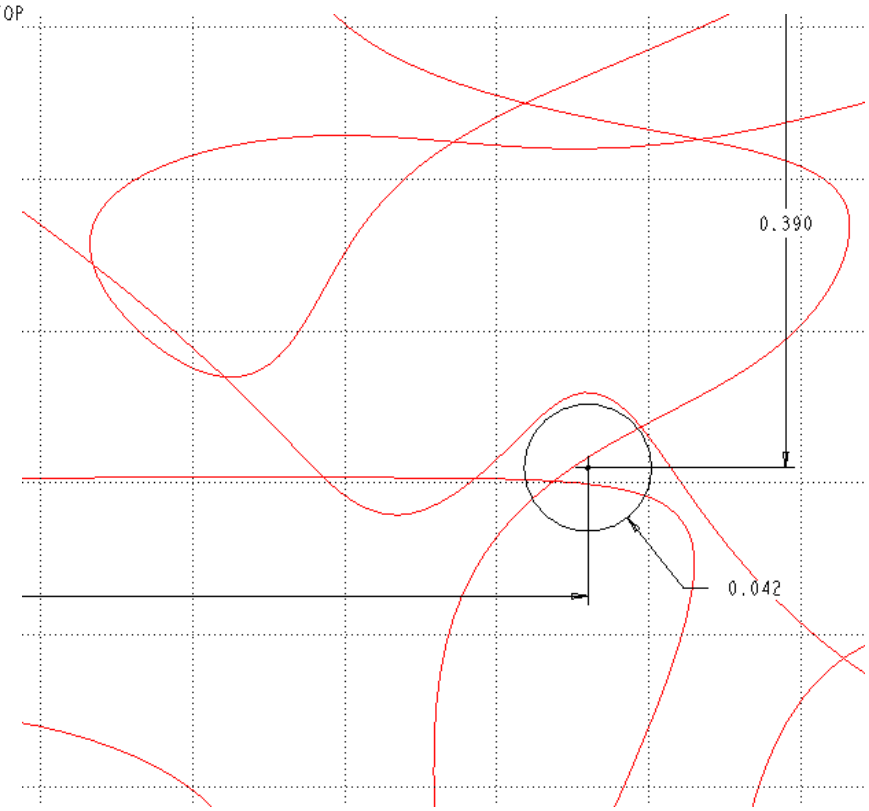
Radius of Curvature vs Length

Min Bend Radius(2)

- NCSX coils have small toroidal wiggles, min radius values of 3-14 cm



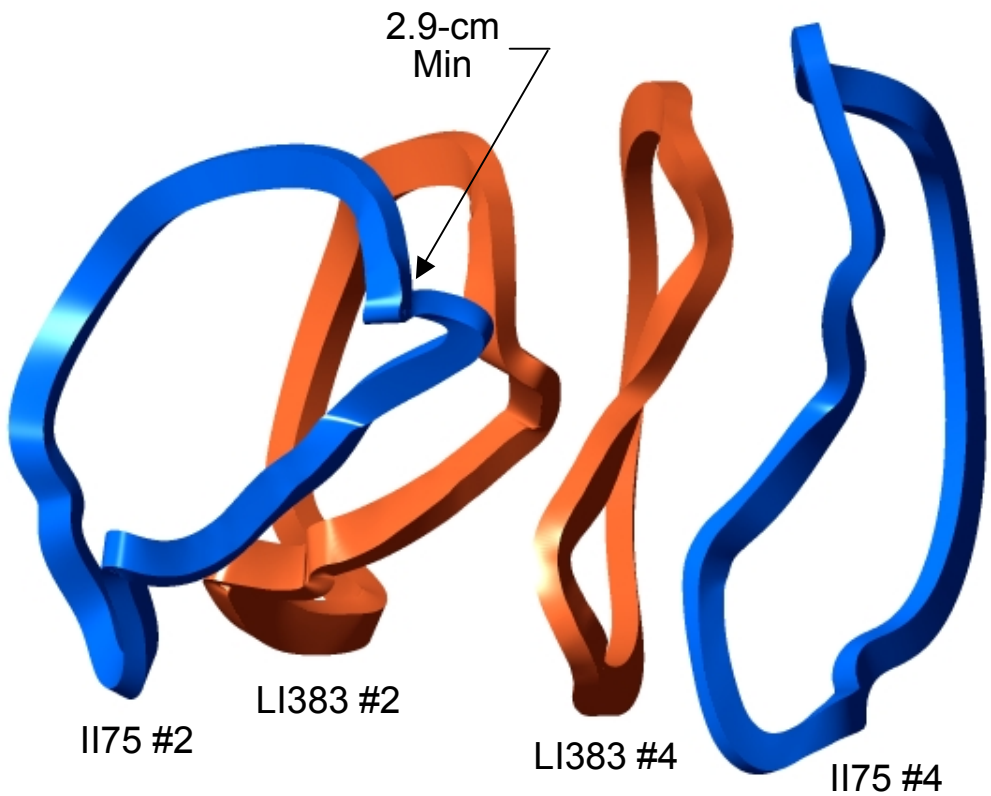
Plan View of LI383 Winding Centers



Close-up Showing Coil #3 Min Radius

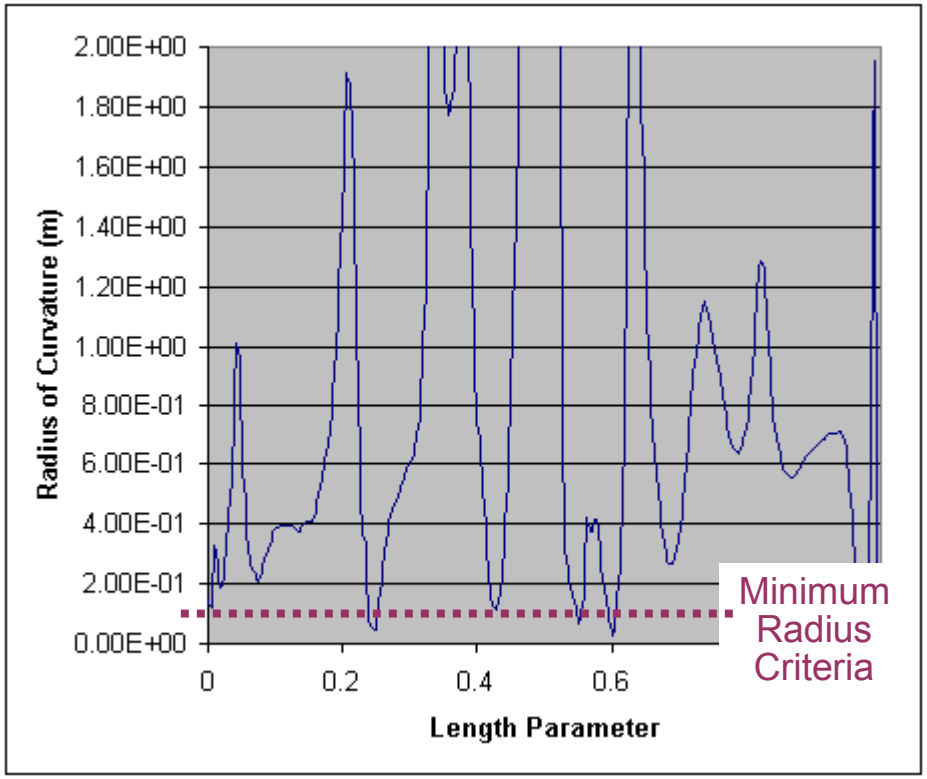
Min Bend Radius(3)

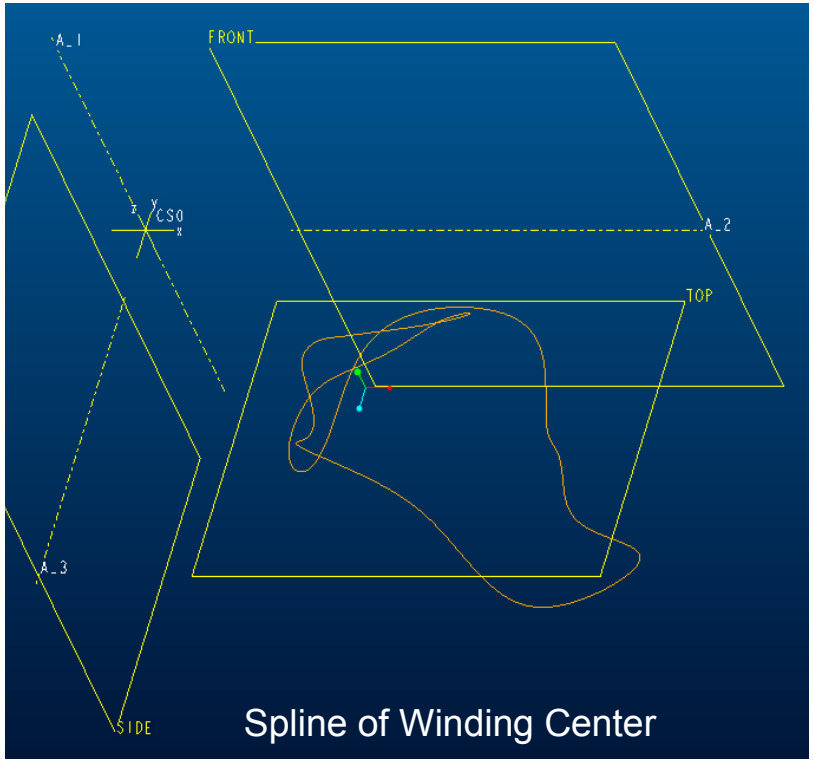
Configuration	C82 / 0424	LI383 / 0705	II75 / 0613
Major Radius (m)	1.46	1.70	1.82
Number of Coils	27	21	21
Coil to Plasma Distance (cm)	21.7	21.7	21.9
Minimum Coil to Coil Dist (cm)	9.9	15.0	11.6
Nominal Size (cm)	9 x 16	11 x 20	8.5 x 20
One-Turn Length (m)	5.7 5.9 5.9 6.0 6.0	7.0 7.2 7.5 7.2	7.5 7.9 8.2 8.4
Average Radius (cm)	60.7 63.4 67.3 70.4 79.7	65.4 90.8 81.8 91.2	67.1 118.5 85.1 82.0
Minimum Radius of Curvature (cm)	4.6 6.2 4.7 7.6 3.9	7.1 4.4 4.2 13.5	4.9 2.9 6.9 12.7



Min Bend Radius(4)

- Small radius of curvature for II75 / 0613, Coil #2 occurs in several places



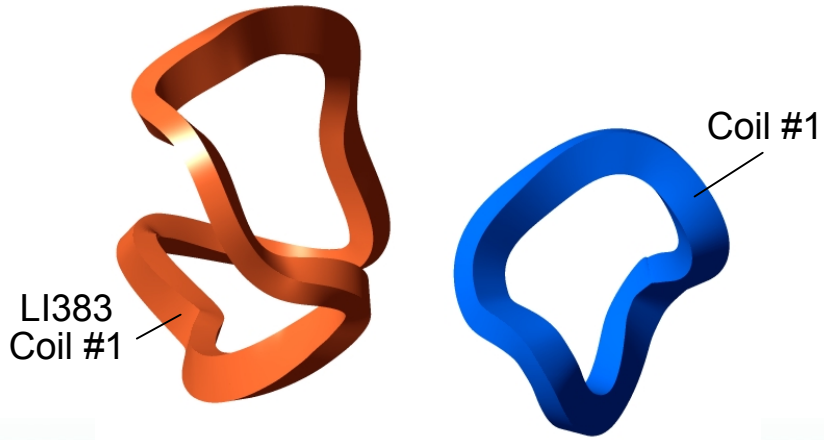


Min Bend Radius(5)

- W7-AS min radius of curvature varies from 11.5 to 34.1-cm (Data from E. Harmeyer)

Coil Type	No. of Coils	Nominal Size (cm)	One-Turn Length (m)	Average Radius (cm)	Min Radius of Curvature (cm)
1	10	12.6 x 17.8	3.7	52.5	11.5
2	10	12.6 x 17.8	3.7	48.6	13.3
3	10	12.6 x 17.8	3.6	52.6	13.7
4	10	12.6 x 17.8	3.3	46.2	17.4
5	5	12.6 x 17.8	4.6	72.4	34.1

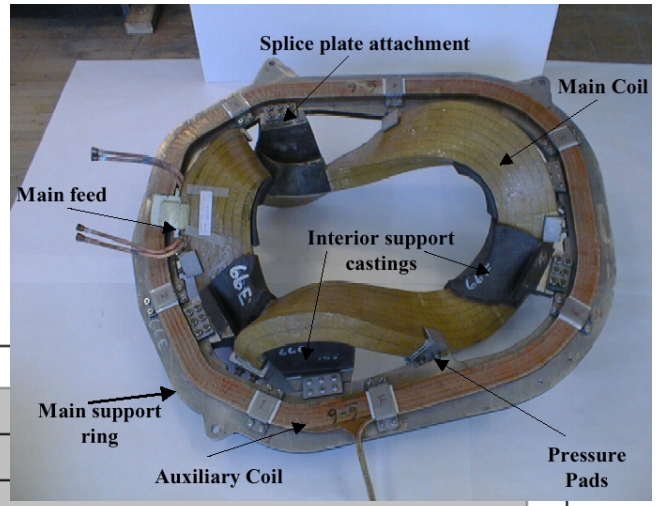
W7-AS Modular Coils

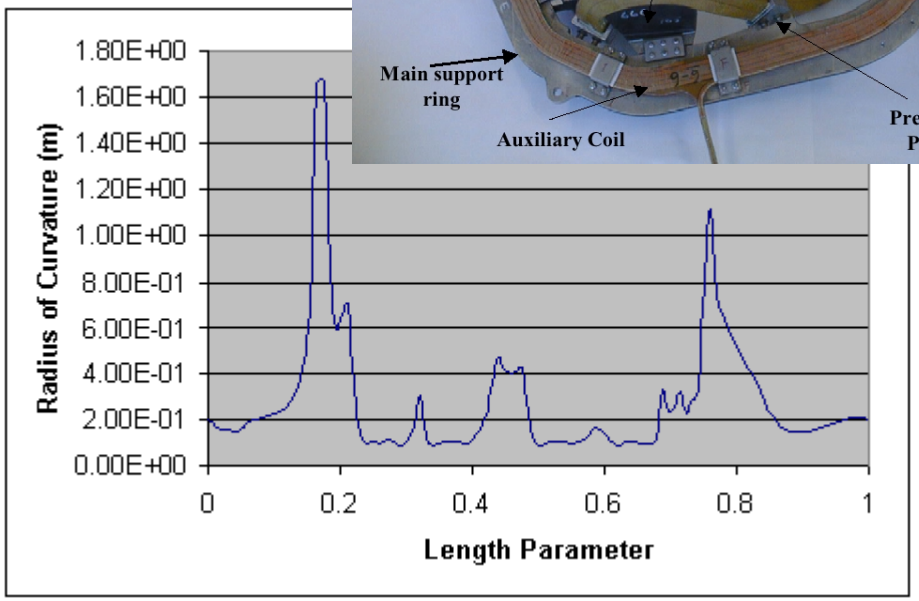


Min Bend Radius(6)

- HSX min radius of curvature varies from 8.1 to 9.8 cm (Data from S. Anderson)

Coil Type	No. of Coils	Nominal Size (cm)	One-Turn Length (m)	Average Radius (cm)	Min Radius of Curvature (cm)
1	8	5.7 x 12.9	2.1	37.8	9.4
2	8	5.7 x 12.9	2.3	27.2	8.3
3	8	5.7 x 12.9	2.2	39.6	9.8
4	8	5.7 x 12.9	2.3	48.4	8.1
5	8	5.7 x 12.9	2.3	32.7	8.4
6	8	5.7 x 12.9	2.3	27.4	9.4





Min Bend Radius(7)

Summary / Discussion:

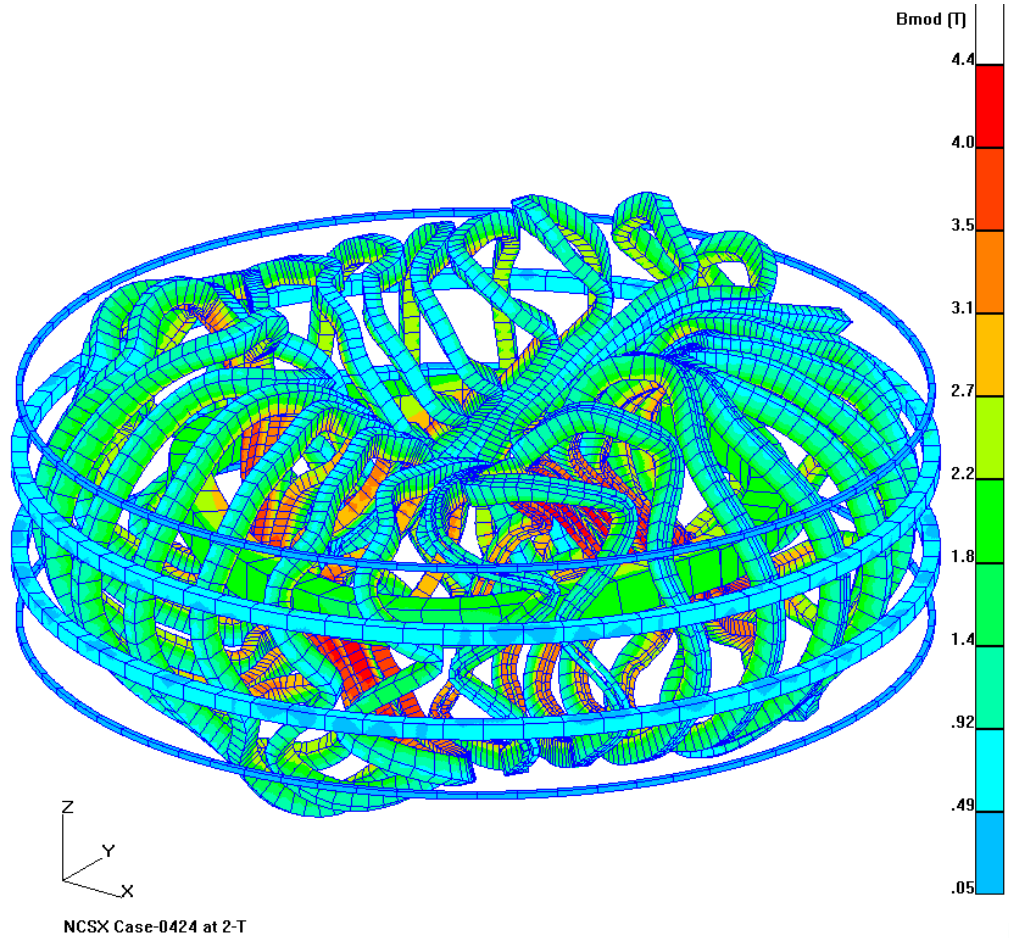
- Cable conductor is composed of fine, flexible wire (36-AWG)
- Tests suggest a minimum bend radius of ~3x conductor width
- Recommended minimum radius of curvature at coil center is

  3 x turn_width + ½ x coil_width

- For LI383, turn_width=1.5-cm, coil_width=11-cm, radius=10-cm
- W7-AS, HSX designs appear to exceed criteria by 24, 54%

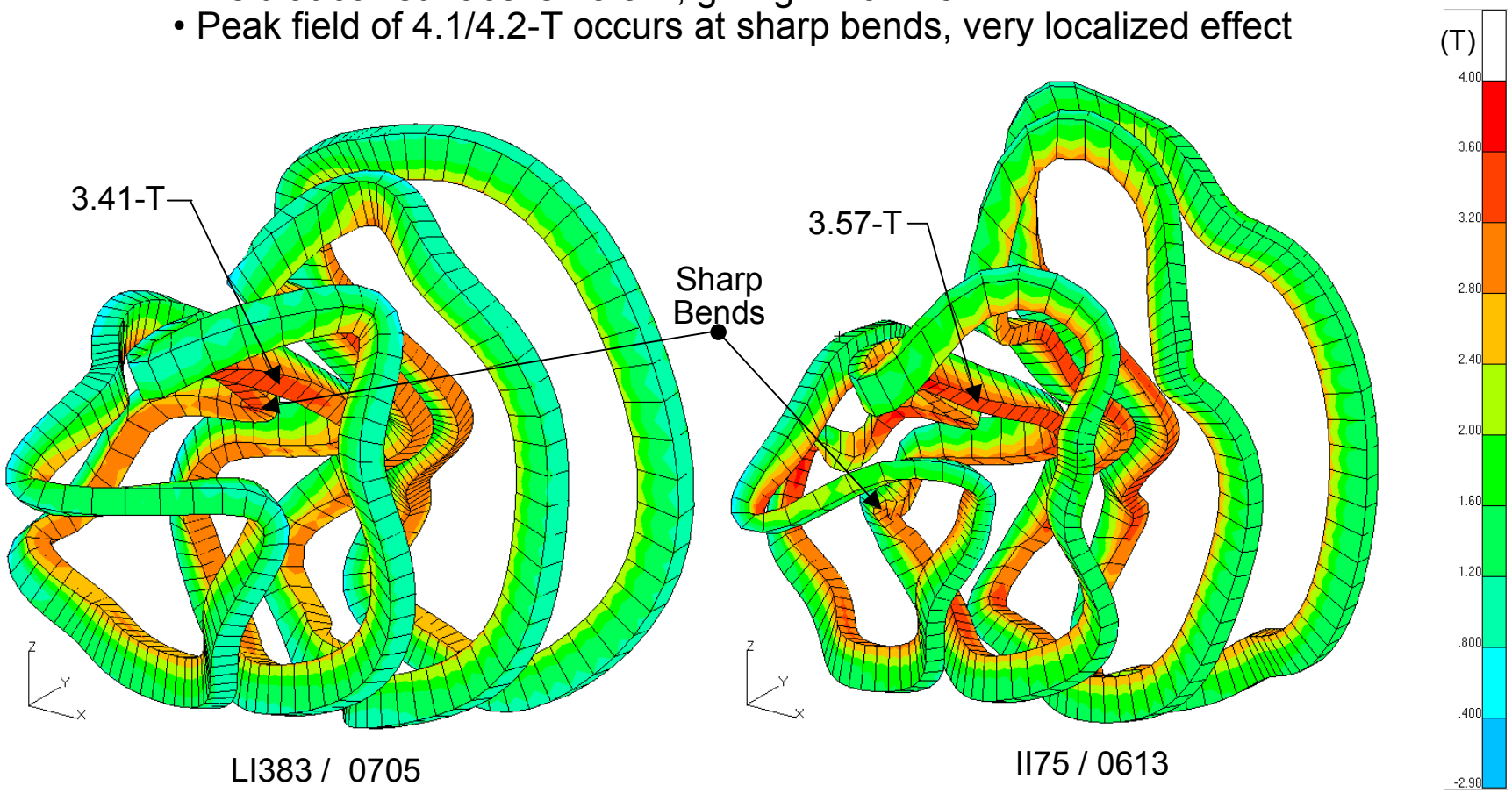
Fields and Forces

- Field calculation for C82 / 0424 indicates Bmax = 4.38-T, Bmax/Bo = 2.2



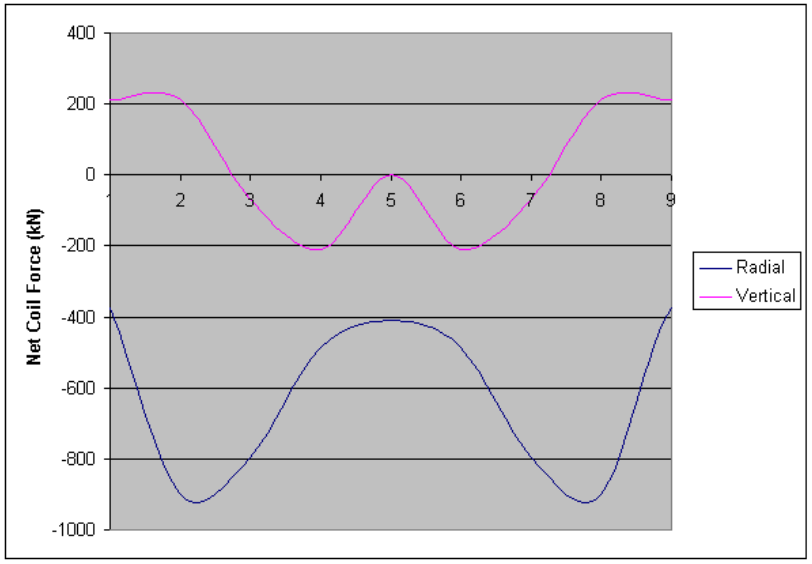
Fields and Forces(2)

- LI383 and II75 cases have been calculated using modular coils only
- Field at coil surface is ~3.5-T, giving Bmax/Bo = 1.7
- Peak field of 4.1/4.2-T occurs at sharp bends, very localized effect

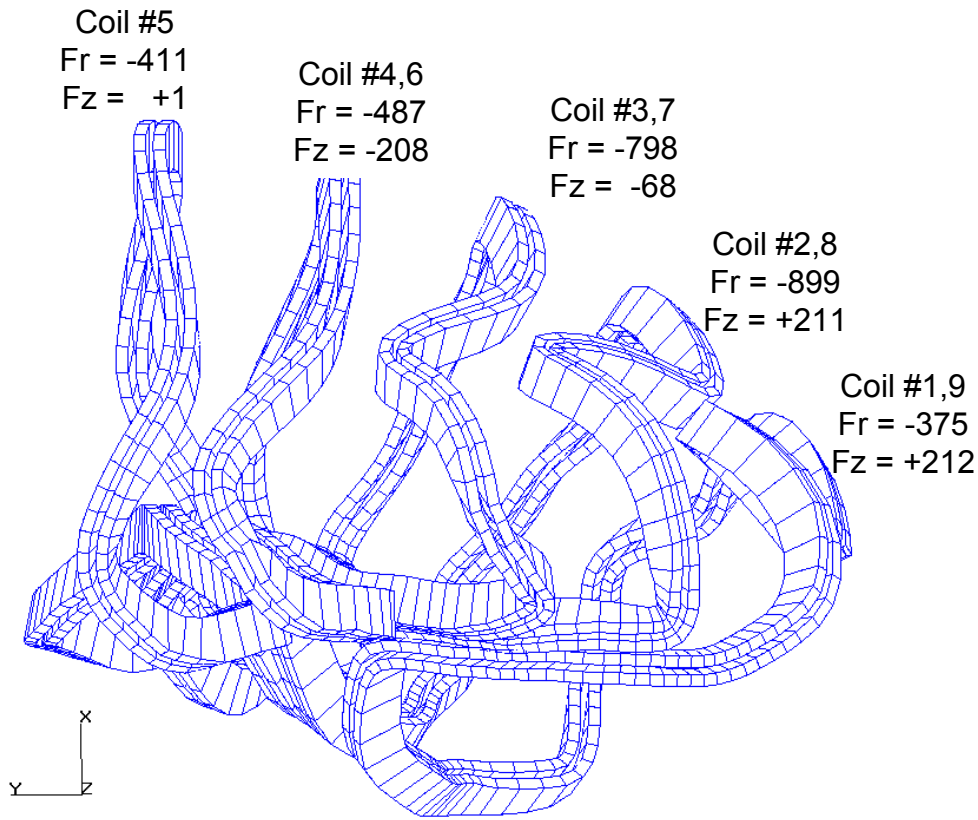


Fields and Forces(3)

- Force summation (kN) for Case C82 / 0424:

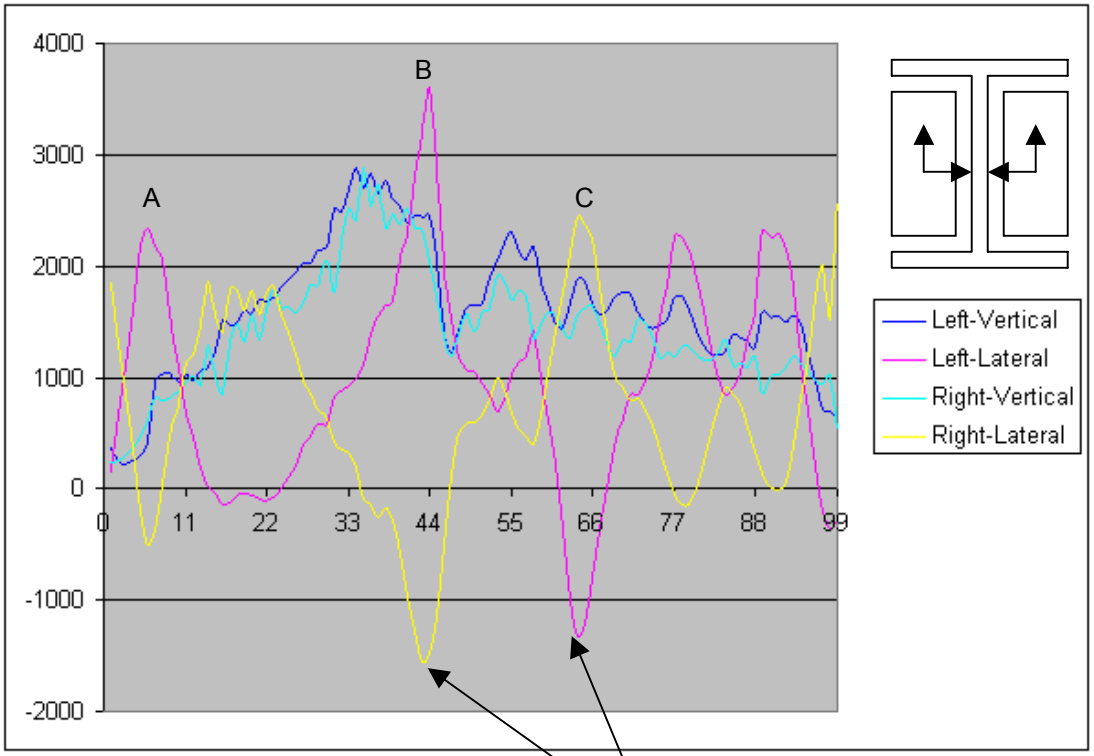


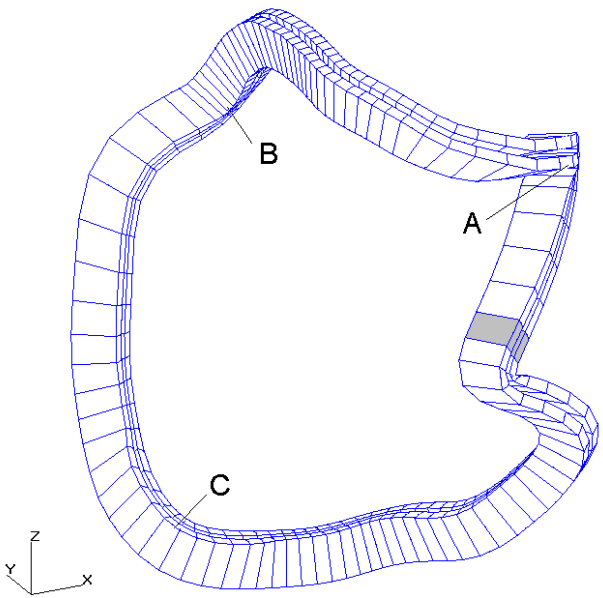
Force / coil for 9 coils (1-period)



Fields and Forces(4)

- EM Force (lb/in) for Coil #1 in Coil Local Coordinate System

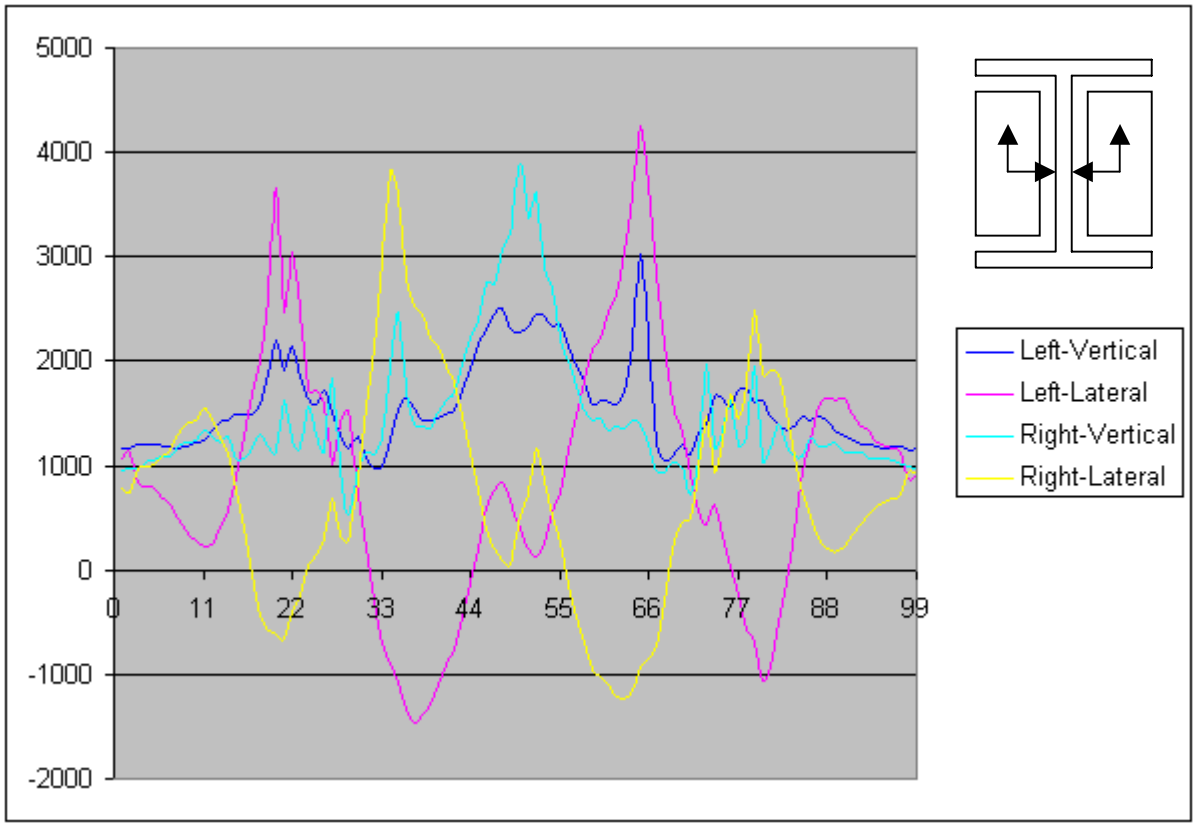


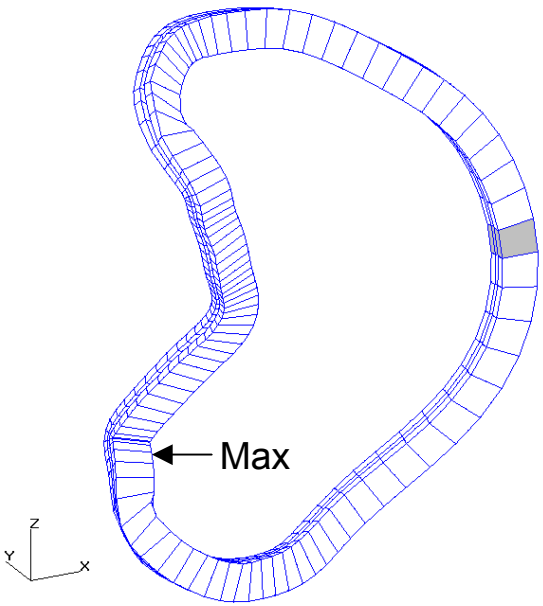


Lateral force direction is away from structure

Fields and Forces(5)

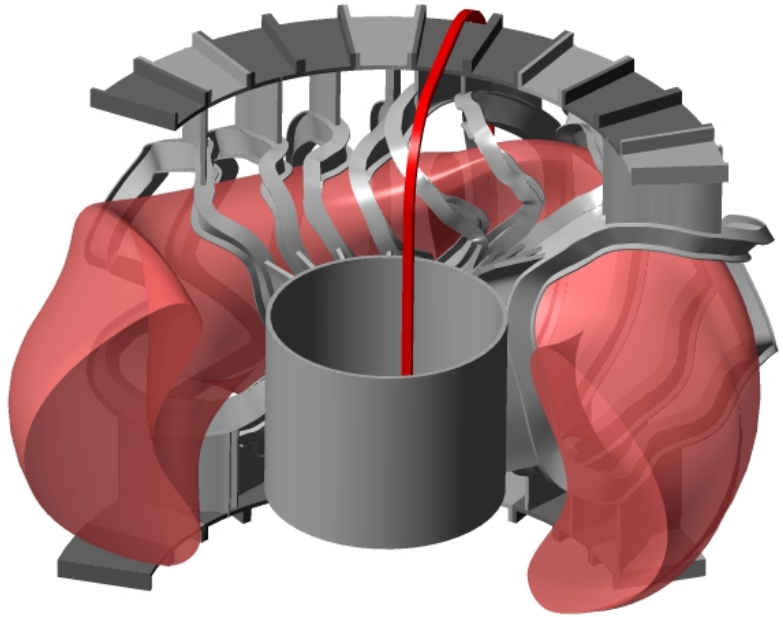
- EM Force (lb/in) for Coil #5 in Coil Local Coordinate System

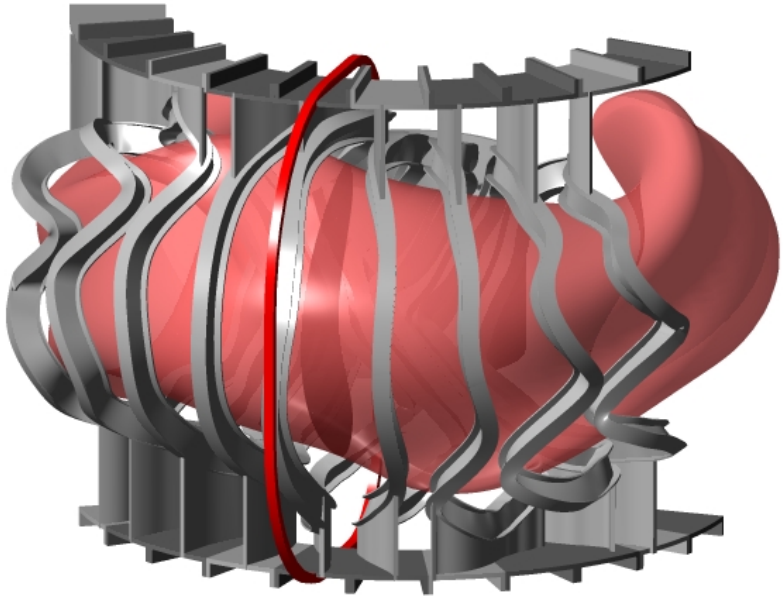




Structure

- I-beam casting supports two winding packs per coil
- Coil radial forces reacted by inner cylinder - tabs part of casting
- Vertical tabs extend to surface at +/- 1-m for coil-to-coil support
- Additional shear structure required

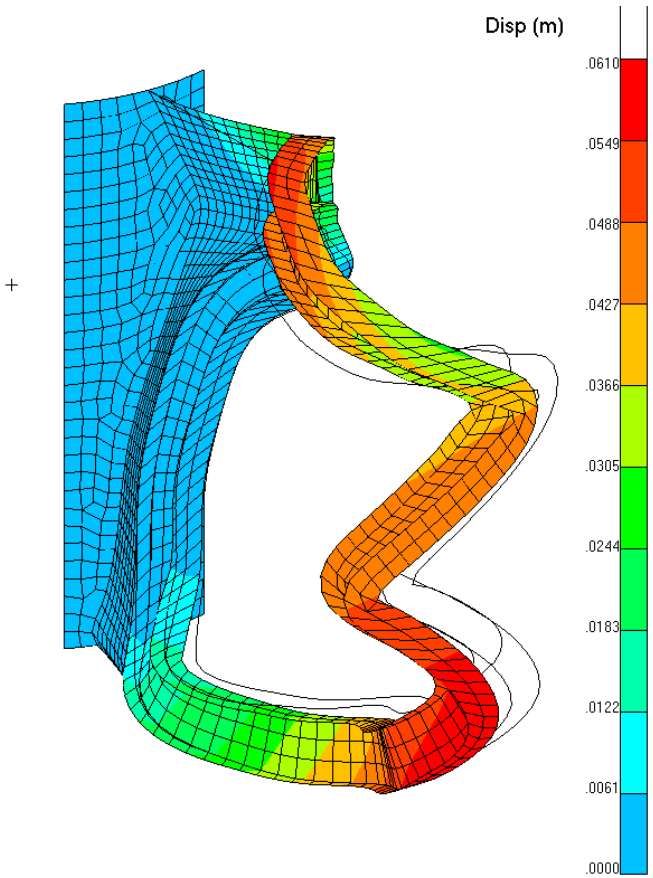




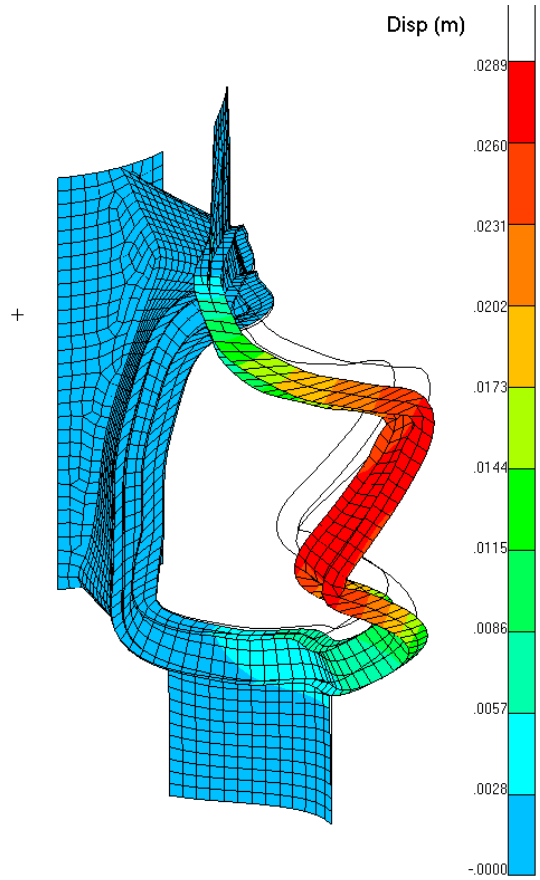
Alternate Concepts

Structure(2)

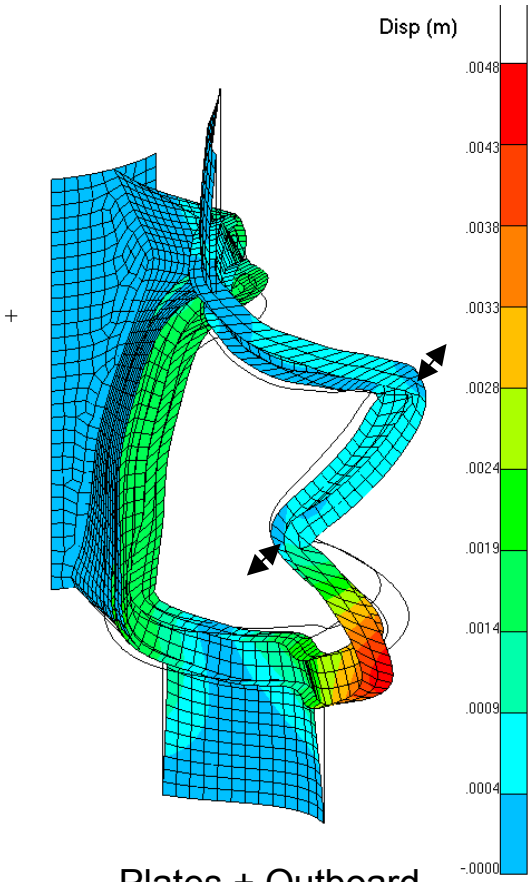
- Coil #1 deflection indicates need for outboard support



Inboard Support
Large Disp (~6-cm)



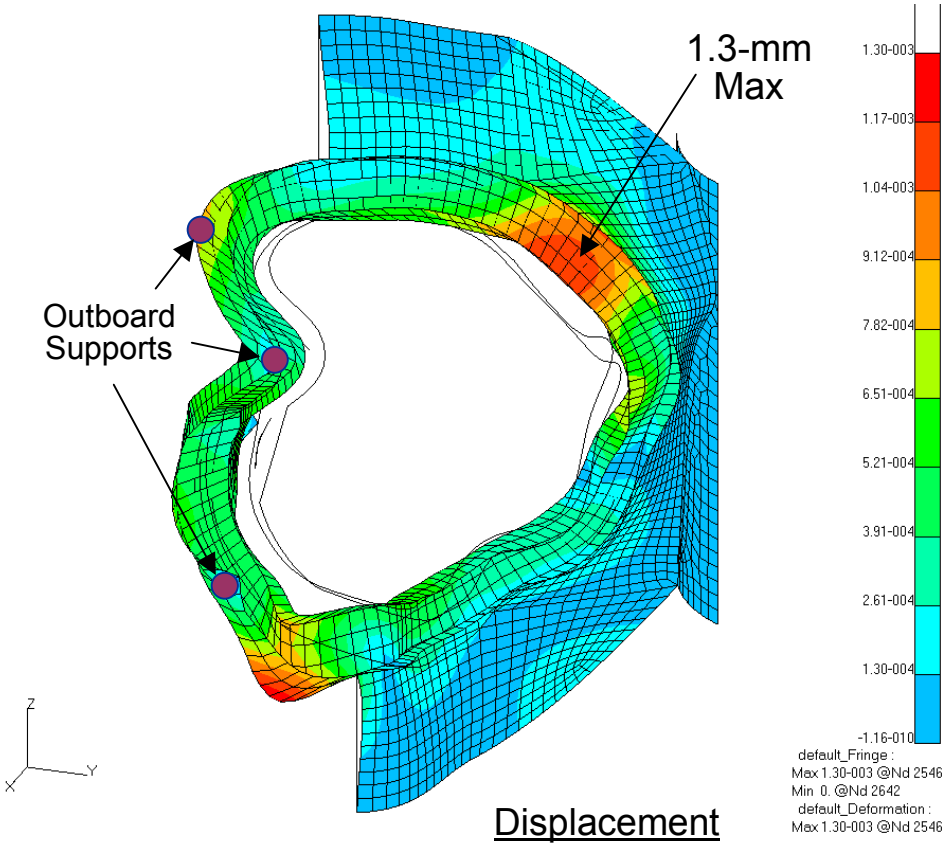
Inb + Upper/Lower Plates
Large Disp (~3-cm)



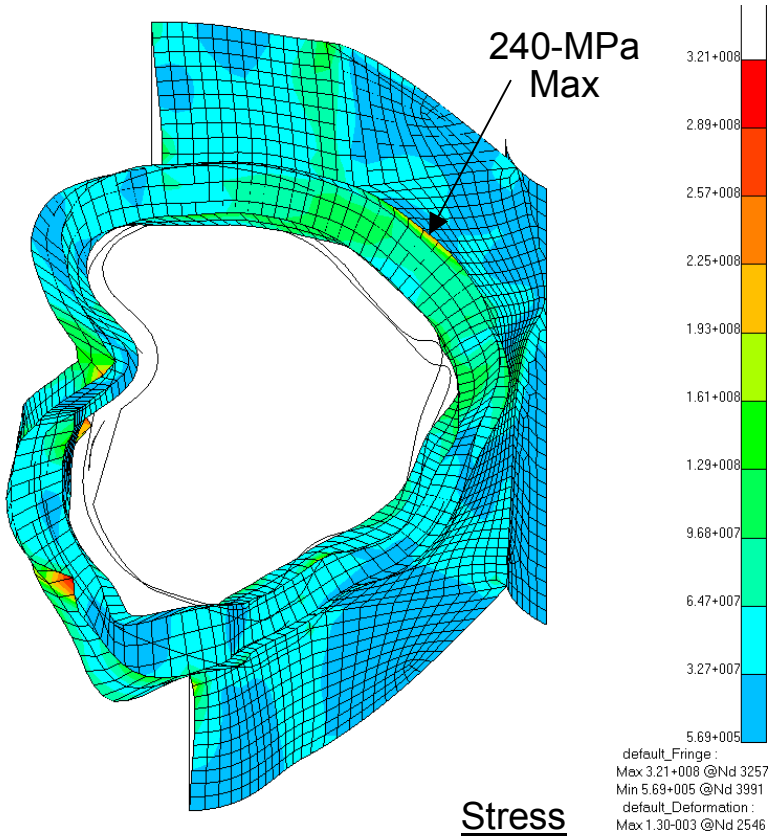
Plates + Outboard
Coil-to-Coil Support
Max Disp = 5-mm

Structure(3)

- Current concept has integrated inb/top/bottom plate with discrete outb supports
- Max disp = 1.3-mm, stress = ~120-MPa with peaks to 240-MPa



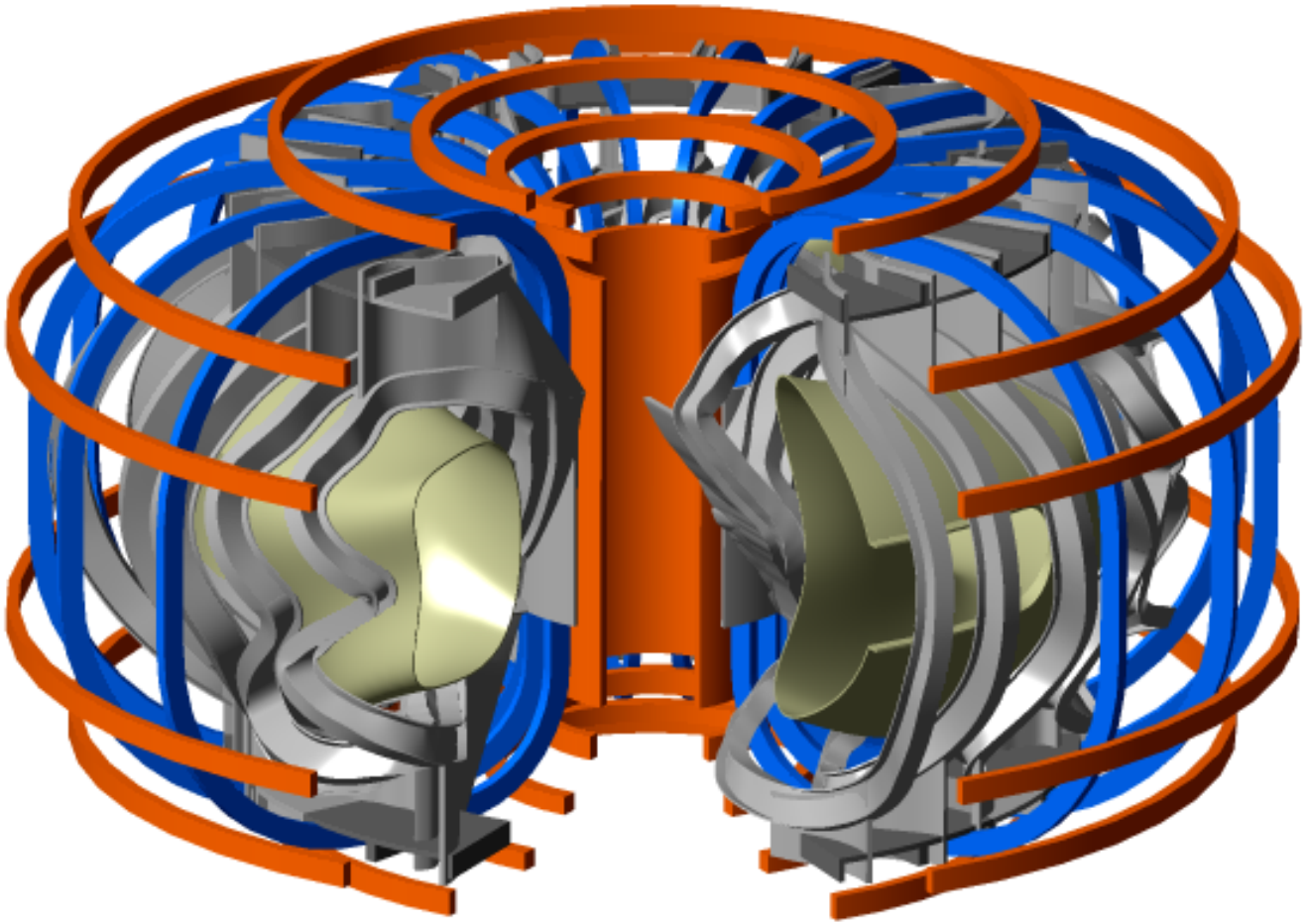
Displacement



Stress

Structure(4)

- Machine configuration based on C82 components (vessel not updated)



Summary/Conclusions

LI383 coil set has advantages:

- Fewer coils per period
- Greater spacing between coils
- Lower current density

Disadvantages include:

- Longer coil lengths, may require multiple in-hand winding
- Coils are wider (toroidal extent) and have sharp bends
- Cross-section is narrow, width < 0.7 x coil-to-coil spacing in order to avoid interference due to twisting
- Depth of coil constrains vessel to be close-fitting to plasma