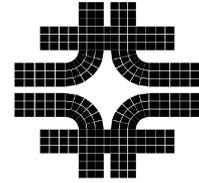


4th Concept Detector at Fermilab
19-20 October, 2006



Fermilab

PPD/MD/Engineering Analysis Group

Magnets and Supports

Bob Wands

October 20, 2006

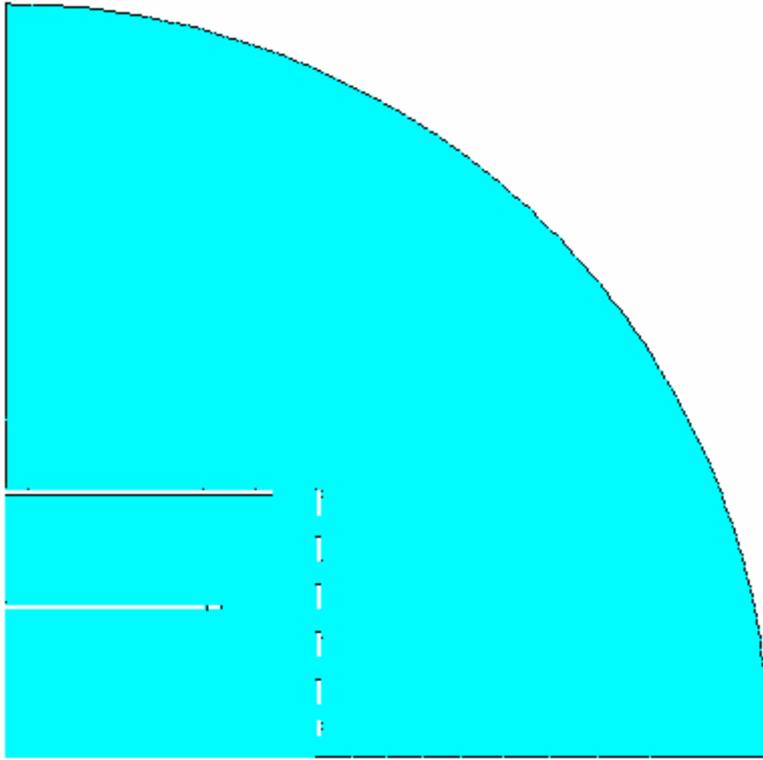
Outline

1. **Magnetic field analysis** – fields, forces, stored energy, peak coil fields, decentering forces
2. **Coil technologies** - what are the applicable superconductors? CMS? Nb₃Sn? Other?
3. **Preliminary structural calculations** – the problematic edge ring, possible solenoid support scheme
4. **Modal analysis** – the issue of ground motion

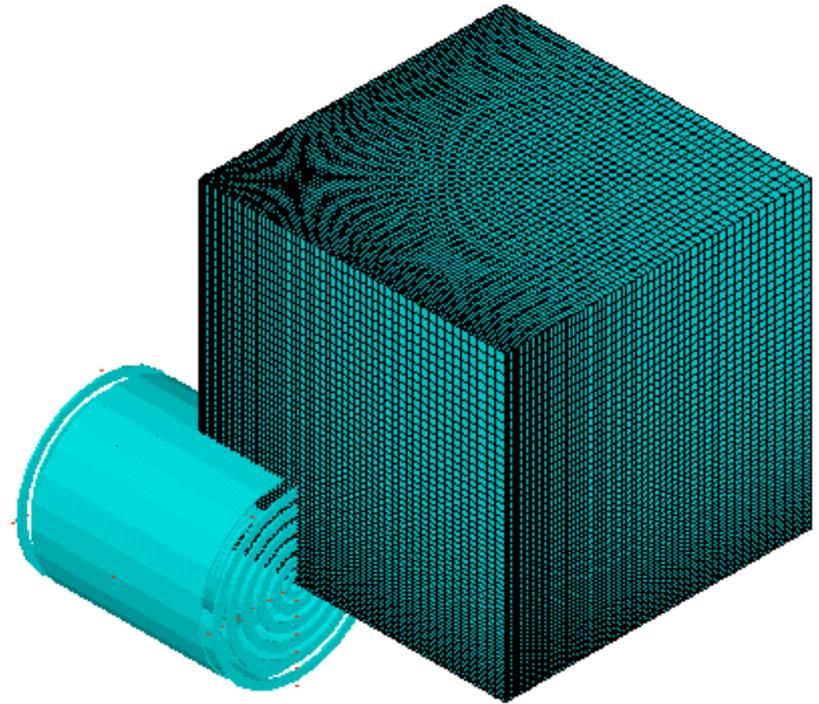
Magnetic Analysis

- The magnetic field of the 4th Concept magnet system was calculated with 2-d and 3-d FE models
- Purpose of magnetic modeling was verification of magnetic performance and determination of forces for structural design, not highly accurate detector fields

The Magnetic Models

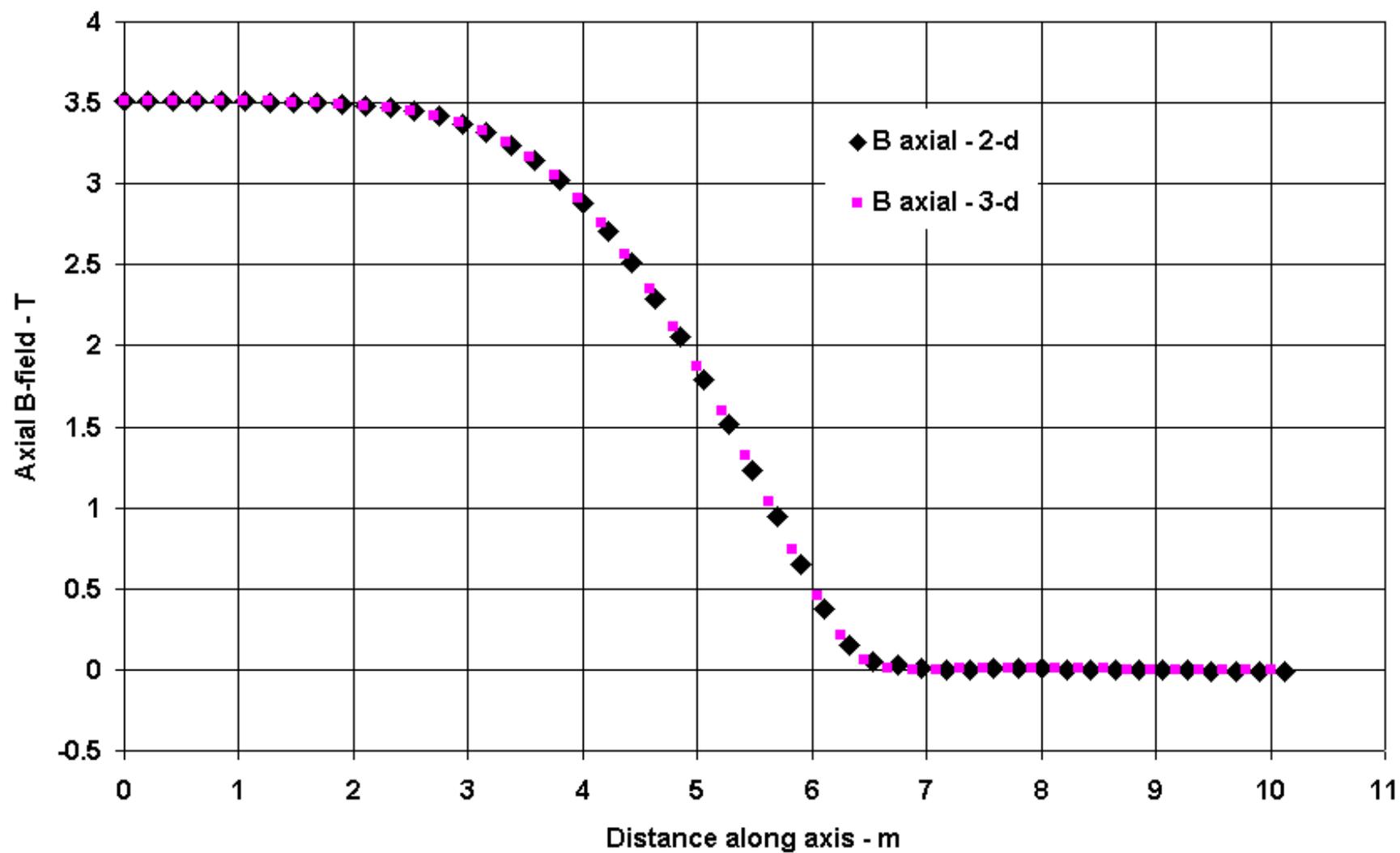


2-d axisymmetric half model



3-d 1/8th model

Axial B-field from 2-d and 3-d Models



Stored Energy from 2-d and 3-d Models

- From the 3-d model, $E_s = 2.70$ GJ
- From the 2-d model, $E_s = 2.86$ GJ

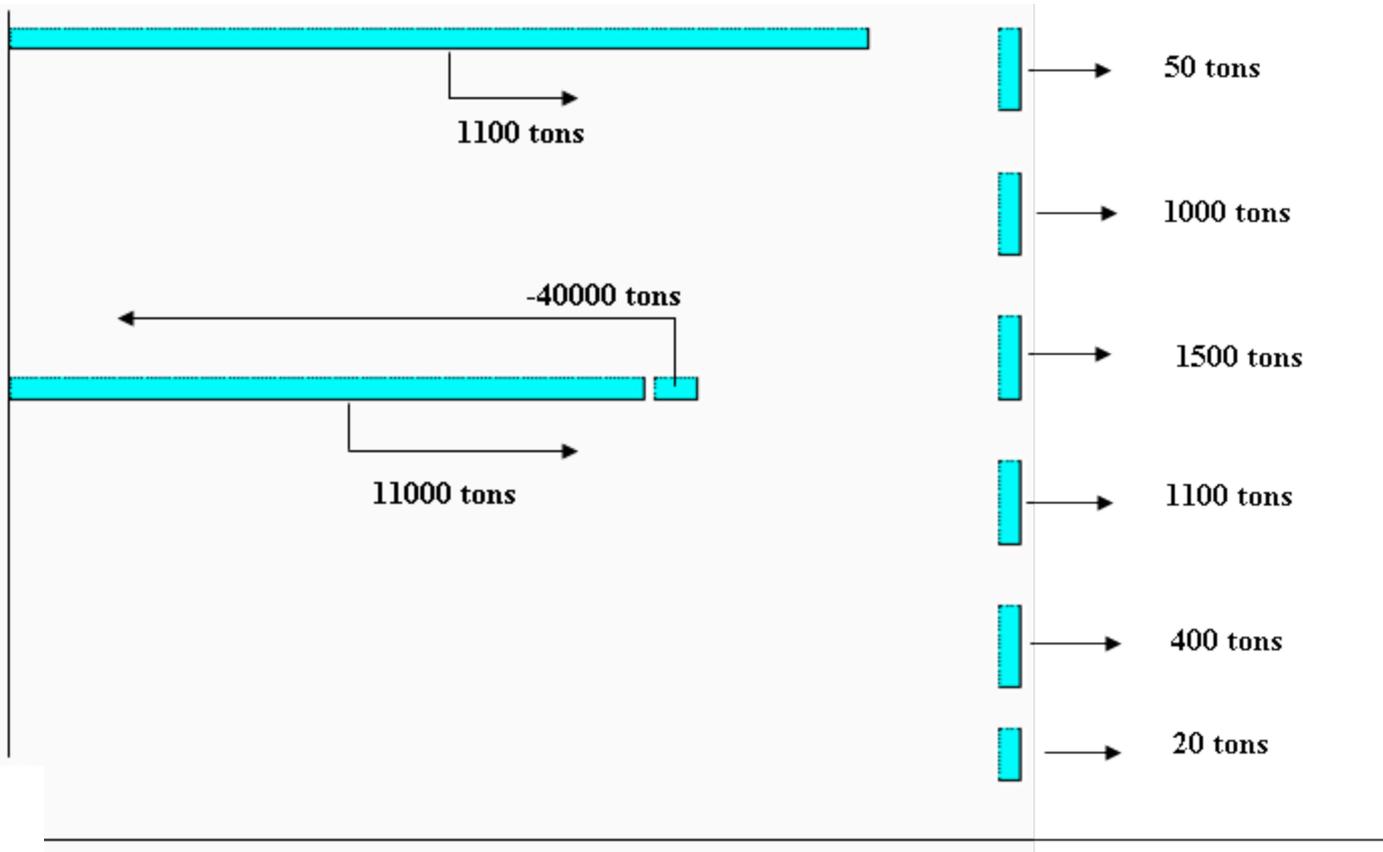
The finer mesh of the 2-d model makes the 2.86 GJ value the more reliable.

For reference: Stored energy of CMS is 2.6 GJ

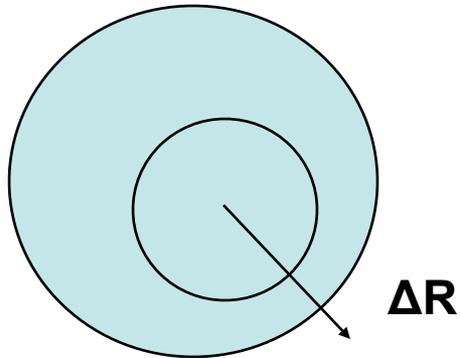
Axial Forces and Maximum Field of Coils

Coil	Maximum Field - T	Axial Force – tons (Positive away from origin)
Inner Solenoid	6.06	11000
Edge Ring	14.28	- 40000
Outer Solenoid	1.52	1100
End Coil 6	0.46	20
End Coil 5	1.34	400
End Coil 4	1.51	1100
End Coil 3	1.49	1500
End Coil 2	1.26	1000
End Coil 1	0.34	50

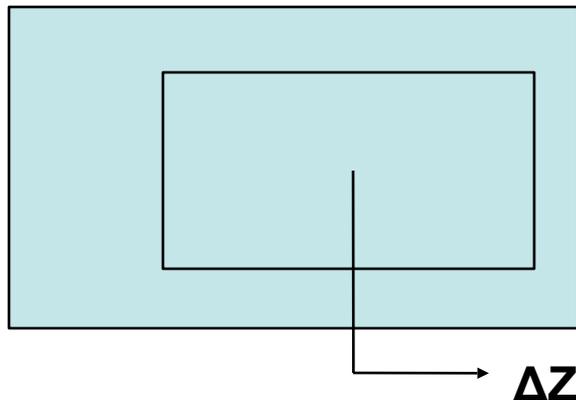
Schematic of Axial Forces on Coils



Forces Due to Misalignment of Inner and Outer Solenoid (“Decentering” Forces)



Radial force is 10 tons/inch *decentering*



Axial force is 20 tons/inch *centering*

Coil Technologies

CMS Conductor – brief overview

- The CMS solenoid is designed for a current of 20 kA, giving a current density of $14.2 \times 10^6 \text{ A/m}^2$
- The critical current for the CMS conductor is 59 kA at 5 T
- The maximum field in the CMS solenoid is 4.6 T
- The maximum field in the SiD is 5.6 T
- The SiD uses the CMS conductor at a current of 18 kA, giving a current density of $12.8 \times 10^6 \text{ A/m}^2$
- Stress in CMS conductor must be limited to ~2500 psi to avoid degradation of high-purity aluminum stabilizer

Can CMS conductor be used anywhere?

Current density of CMS conductor at 20 kA = 14.2e6 A/m²

Current density of CMS conductor at 18 kA = 12.8e6 A/m²

Coil	Maximum Field in Coil - T	Cross section m ²	Current kA-turns	Required Current density – A/m ²	Applicable CMS Current density – A/m ²
Inner Solenoid	6.06	2.71	33220	12.3e6	<12.8e6
Edge Ring	14.3	0.0386	8000	207e6	<<<12.8e6
Outer Solenoid	1.52	4.76	14100	2.96e6	14.2e6
Edge Coil 6	0.46	0.0478	150	3.14e6	14.2e6
Edge Coil 5	1.34	0.0766	900	11.7e6	14.2e6
Edge Coil 4	1.51	0.0766	860	11.3e6	14.2e6
Edge Coil 3	1.49	0.0766	850	11.1e6	14.2e6
Edge Coil 2	1.26	0.0766	830	10.8e6	14.2e6
Edge Coil 1	0.34	0.0766	200	2.6e6	14.2e6

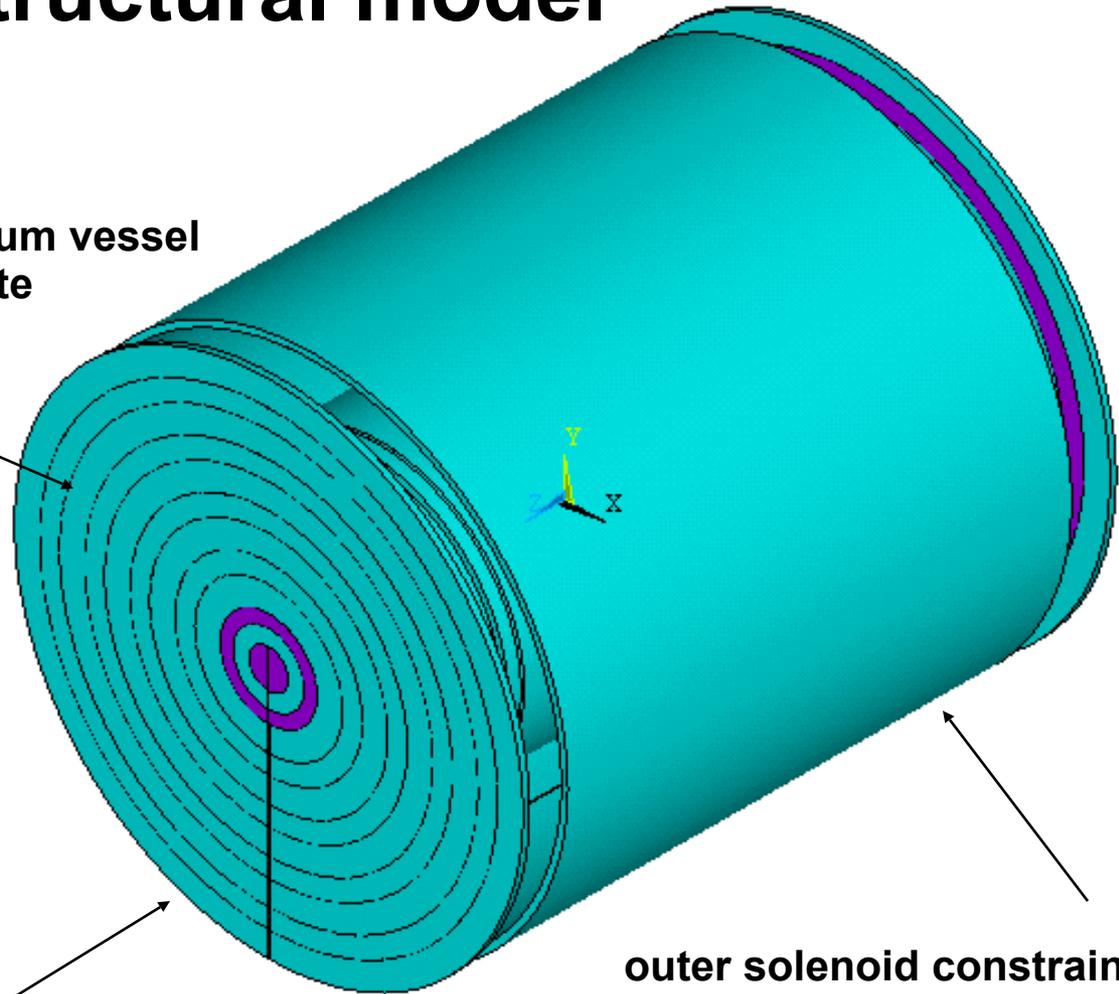
Possible Coil Technologies

- The CMS conductor is used in contact-cooled applications, i.e., cooling is indirect, with no helium reservoir in the magnet.
- The end coils and the outer solenoid are within easy reach of CMS technology
- The inner solenoid is marginal
- The edge ring can almost certainly *not* be made with CMS conductor
- We need to investigate alternative technologies for the edge ring
- It would also be useful to decrease the maximum field
- There may be an argument for making the inner solenoid in three pieces, since highest performance is required only at ends (covered in next few slides)

Some Preliminary Structural Calculations

A magneto-structural model

end coils enclosed in vacuum vessel consisting of 30mm SS plate



end coil vacuum vessel simply supported at outer radius in all dof

outer solenoid constrained in all structural dof; presence required only for proper force calculation

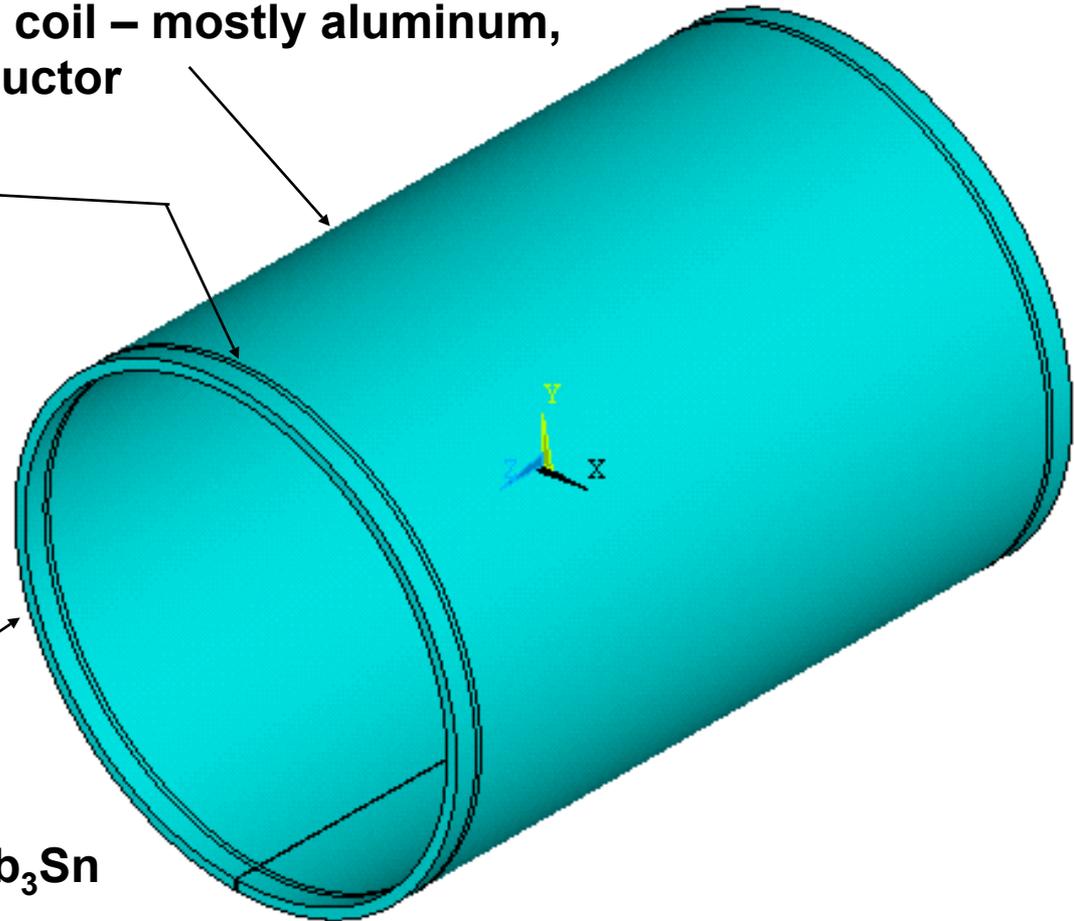
Modeling of the Inner Solenoid/Edge Ring

inner solenoid coil – mostly aluminum,
i.e., CMS conductor

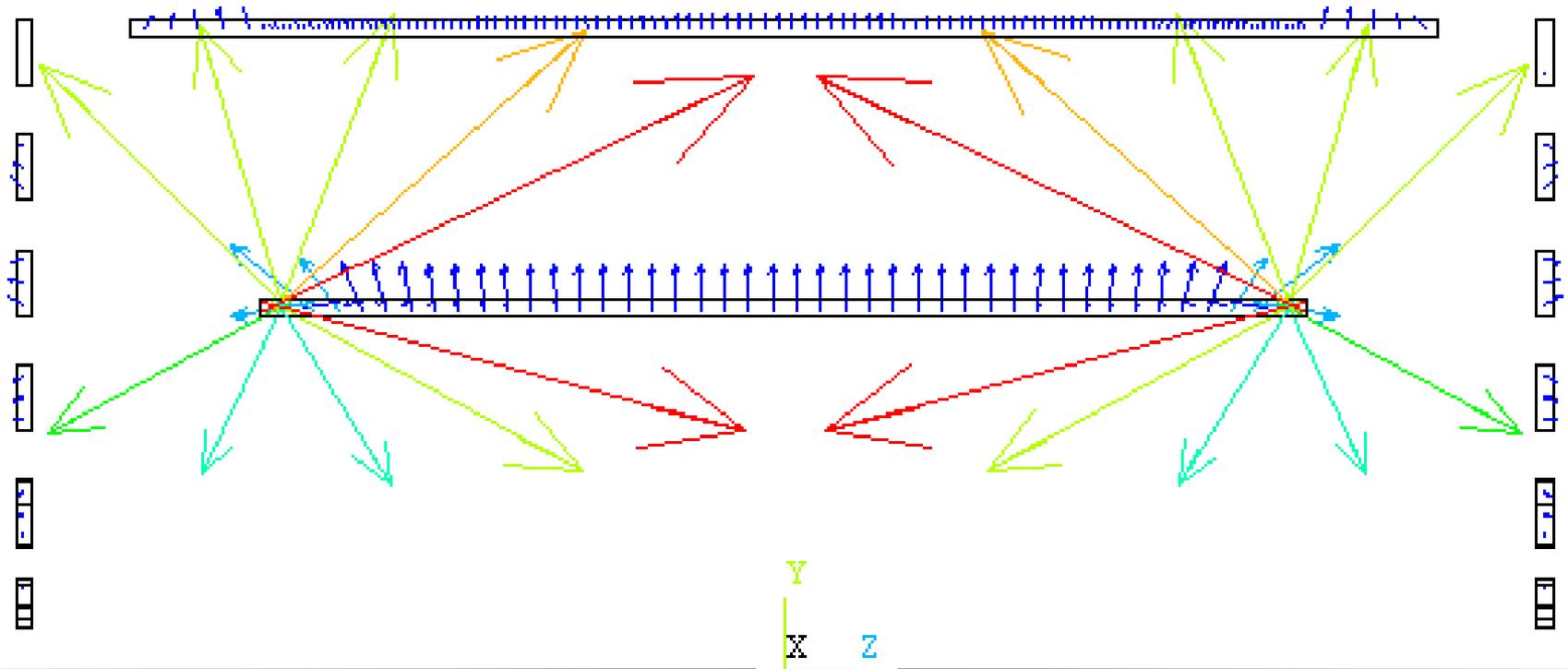
stainless steel filler plate

It is essential that the edge rings' axial forces react with the inner solenoid cold mass; taking 40000 tons out to 300 K is too difficult. Therefore, a single vacuum vessel is assumed to contain both edge coils and inner solenoid

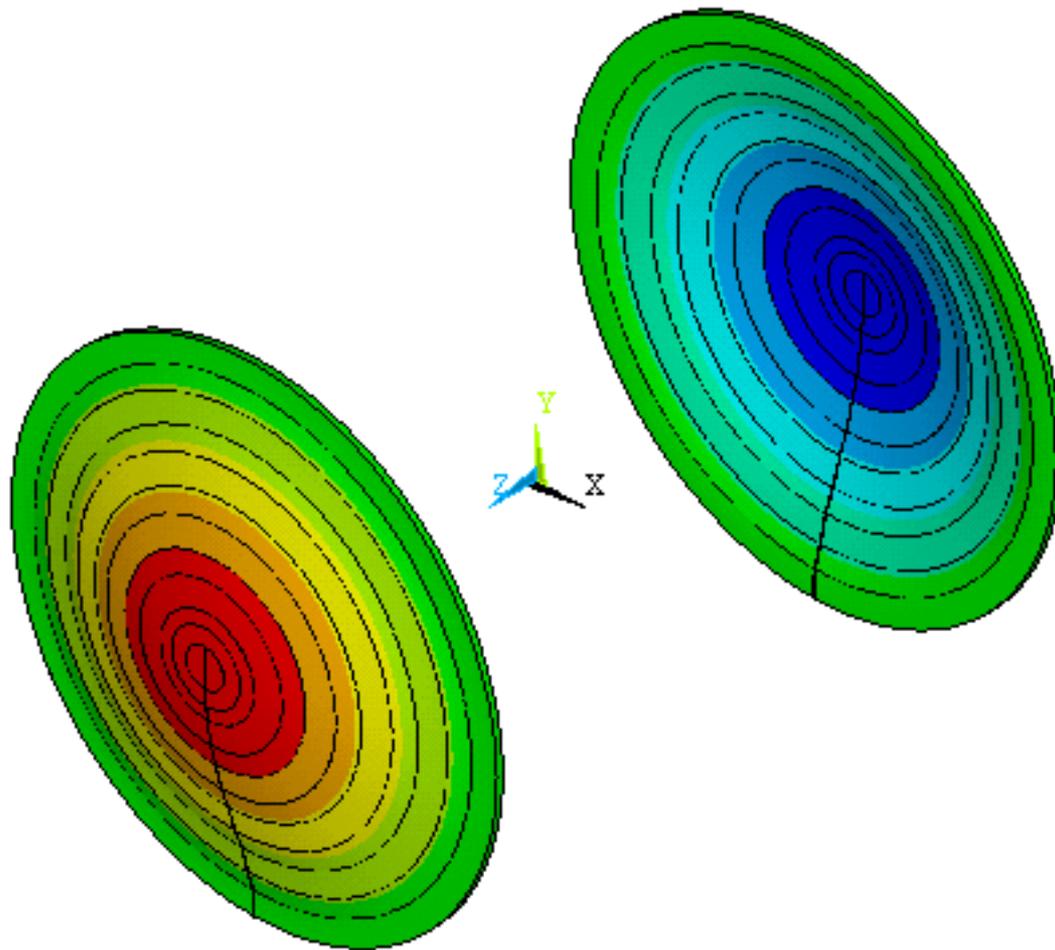
edge ring coil - mostly Nb_3Sn



The Forces on the Coils



Deflections of End Coil Assemblies

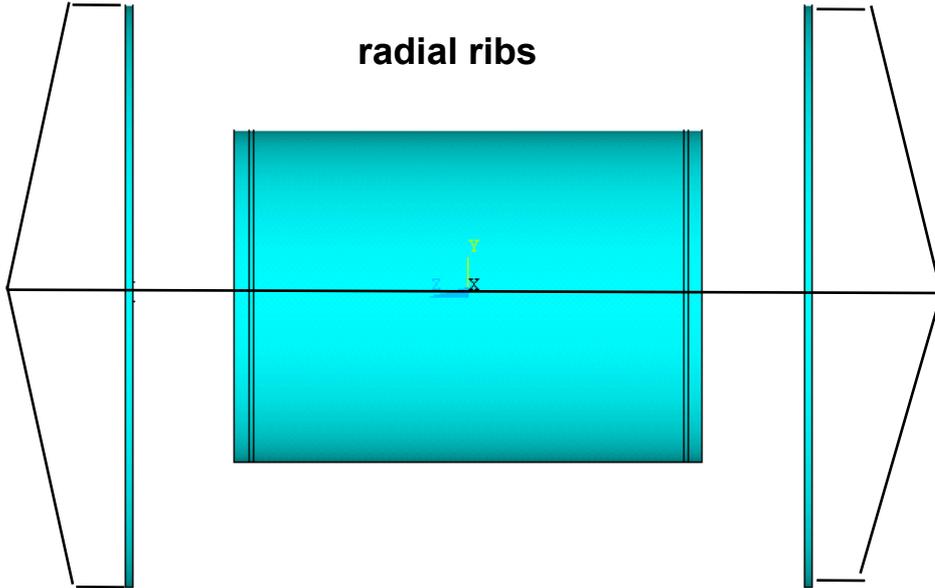


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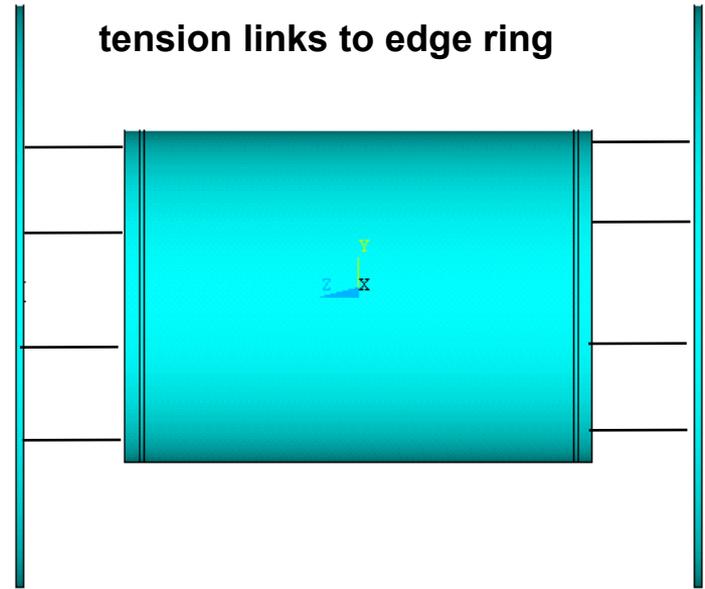
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■	-.06289
■	-.037734
■	-.012578
■	.012578
■	.037734
■	.06289
■	.088046
■	.113202

Two options for limiting displacement of end coils

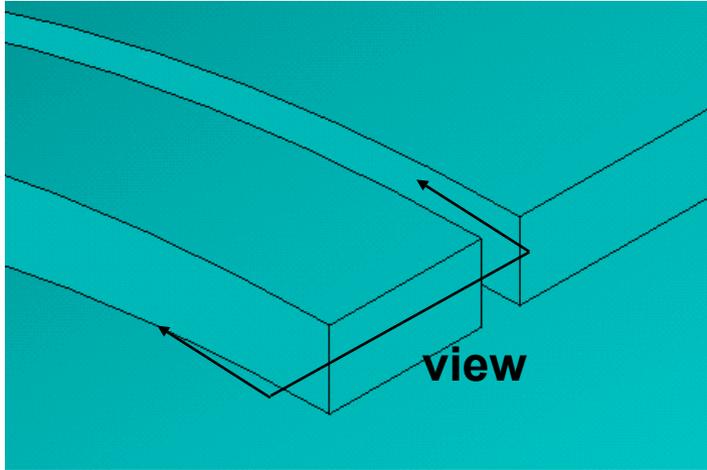
radial ribs



tension links to edge ring

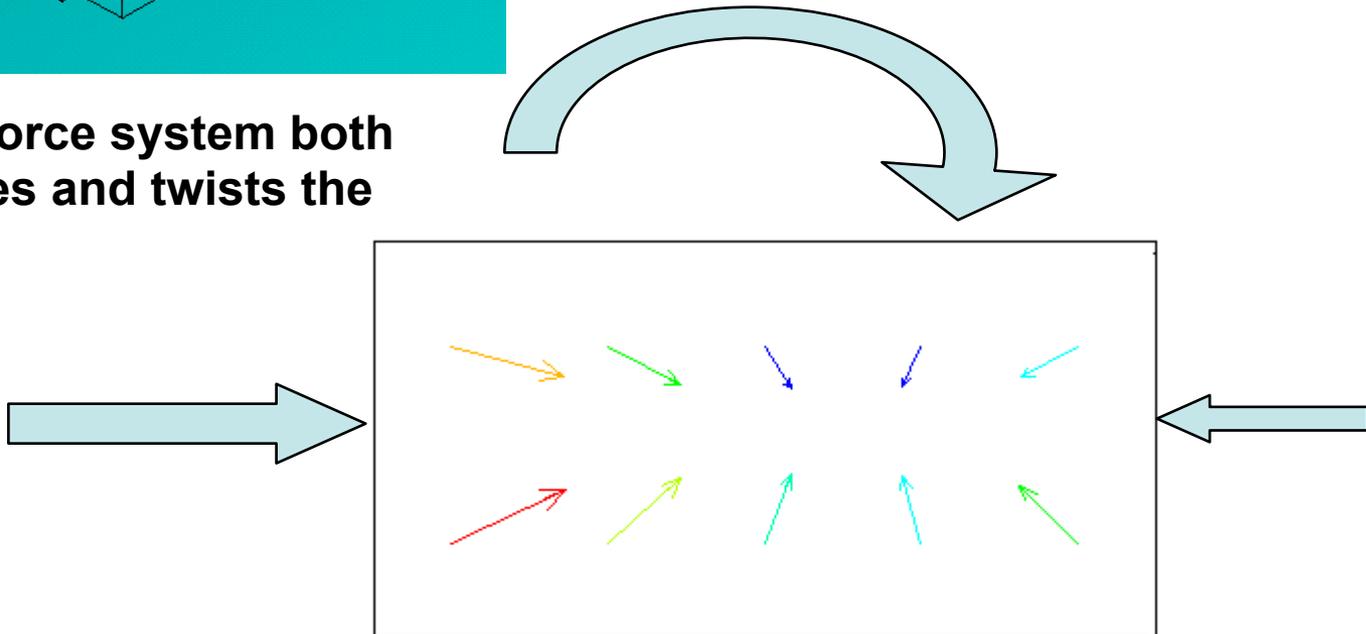


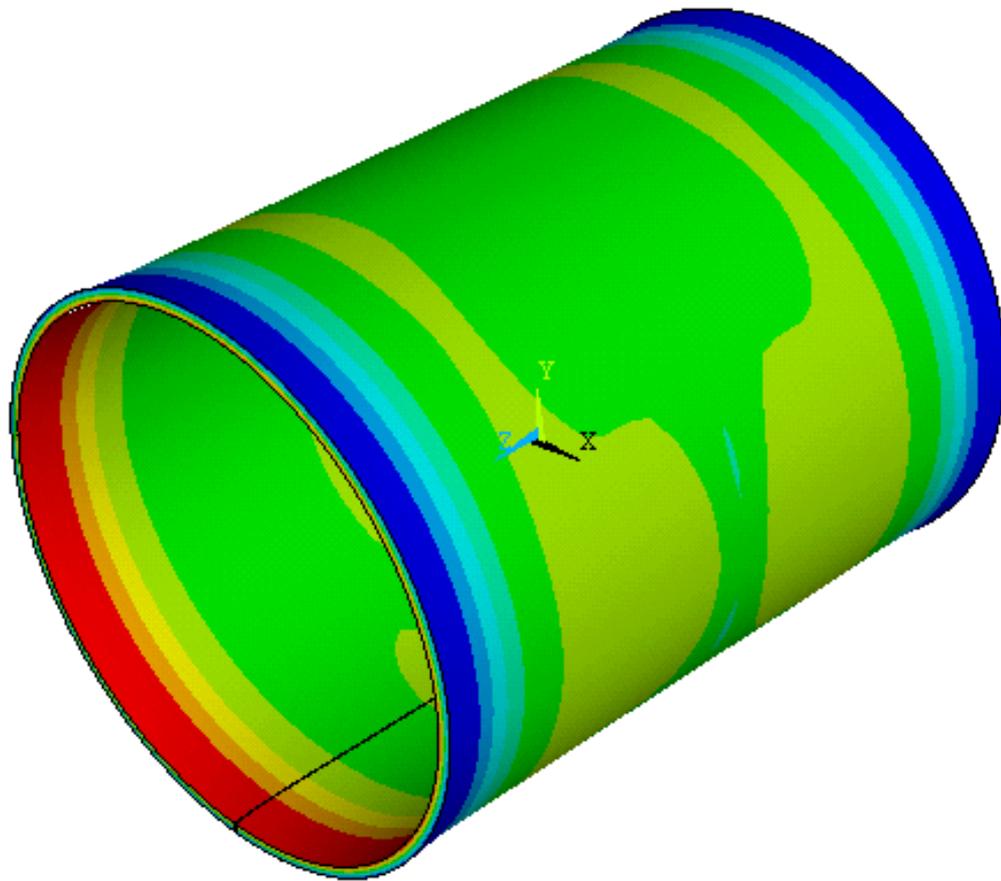
Forces on Edge Ring



(Ends of inner solenoid do the same thing)

Note that force system both compresses and twists the section





```

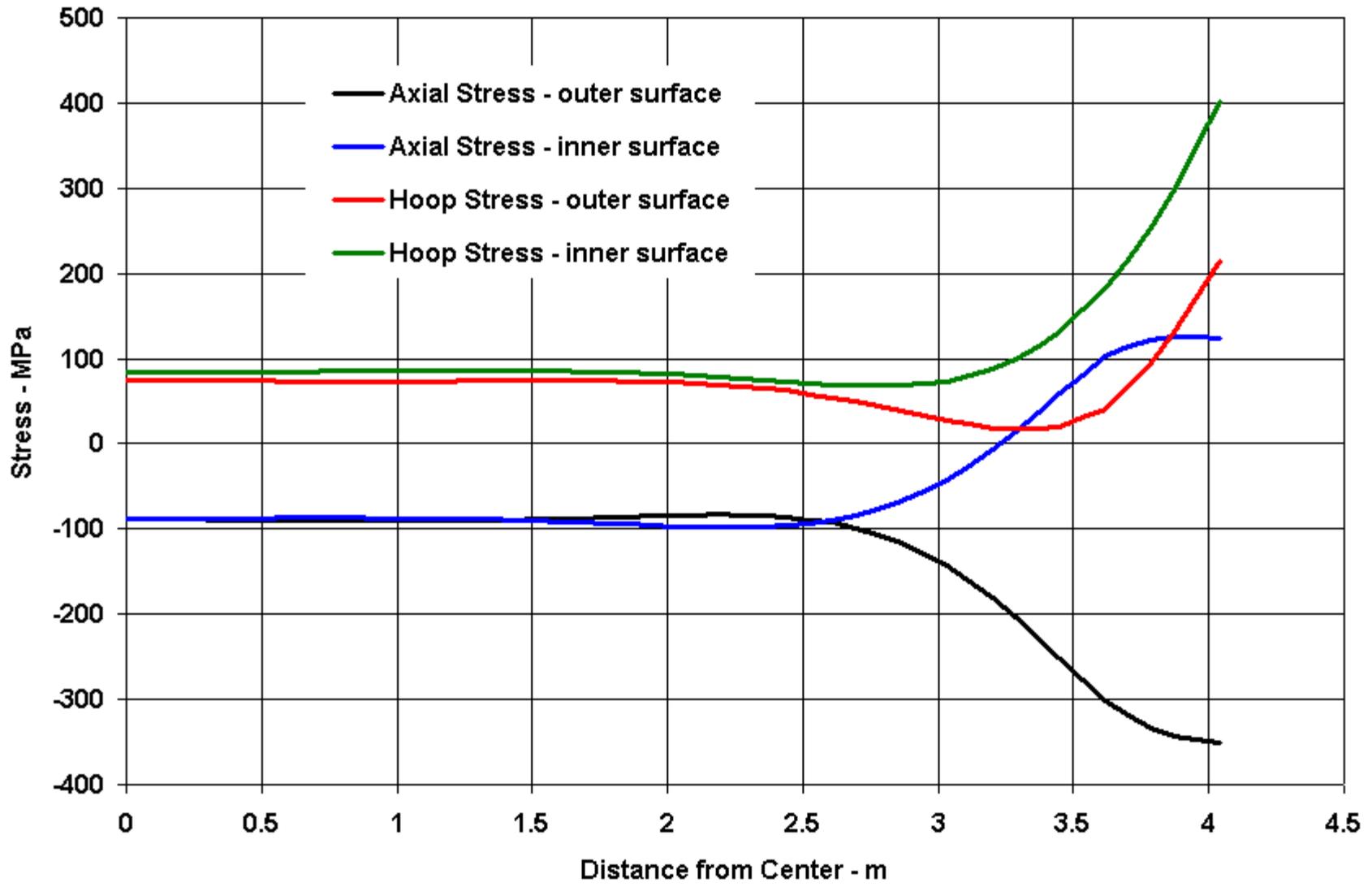
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Cyan	-.246E+09
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Green	-.139E+09
Yellow-Green	-.856E+08
Yellow	-.321E+08
Orange	.214E+08
Red-Orange	.750E+08
Red	.128E+09

Axial stresses in inner solenoid showing meridional bending at ends

Axial and Hoop Stress in Inner Solenoid

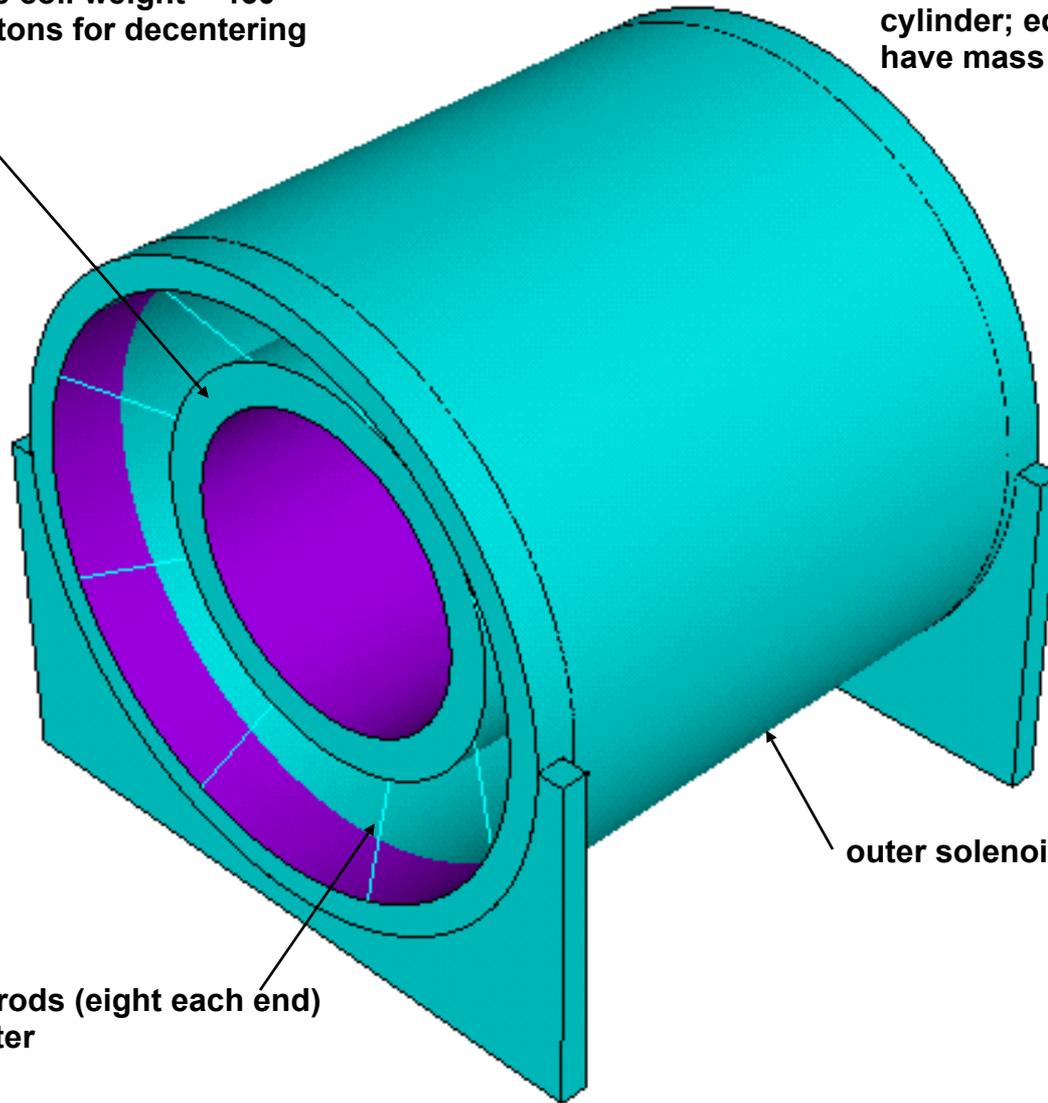


Supporting the Inner Solenoid from the Outer Solenoid

- Solenoid vacuum vessels were sized for internal and external pressures.
- “Realistic” weights were calculated based on coil and vacuum vessel dimensions
- An additional load on the inner solenoid of 100 tons was assumed to simulate the weight of detectors, and effects of 10 ton decentering force
- Preliminary calculations indicate that sixteen preloaded Inconel 718 rods ($S_y = 150$ ksi) 2 inches in diameter, preloaded to 60 ksi, are sufficient to withstand the dead weight and decentering loads
- The vacuum vessels have sufficient latent strength to withstand the pretensioning and dead weight/decentering loads. Options to beef up abound.
- The outer solenoid can be supported on conventional saddles. The end ring can be supported on extensions from the saddles.

inner solenoid/edge coil weight = 460 tons (includes 100 tons for decentering and detectors)

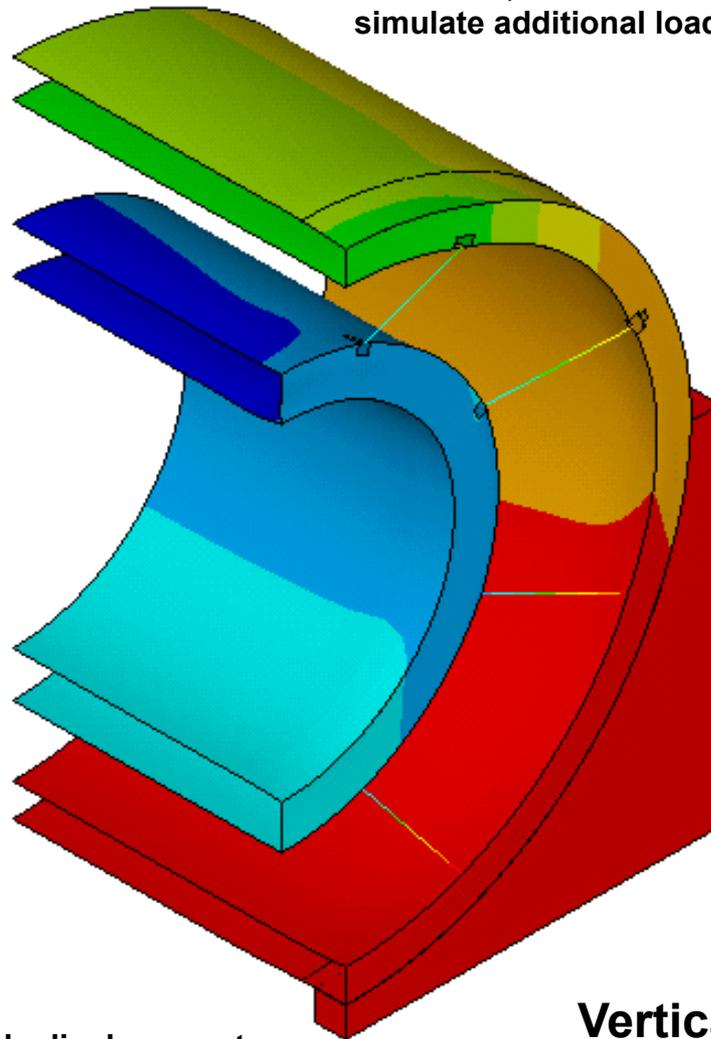
For coil weights, inner solenoid is assumed to be 5 layers of CMS conductor with 60mm support cylinder; edge coil is assumed to be have mass density of copper.



outer solenoid weight = 550 tons

Sixteen Inconel 718 rods (eight each end) two inches in diameter

displacements of shells near midplane are unreliable, since density was increased to simulate additional load

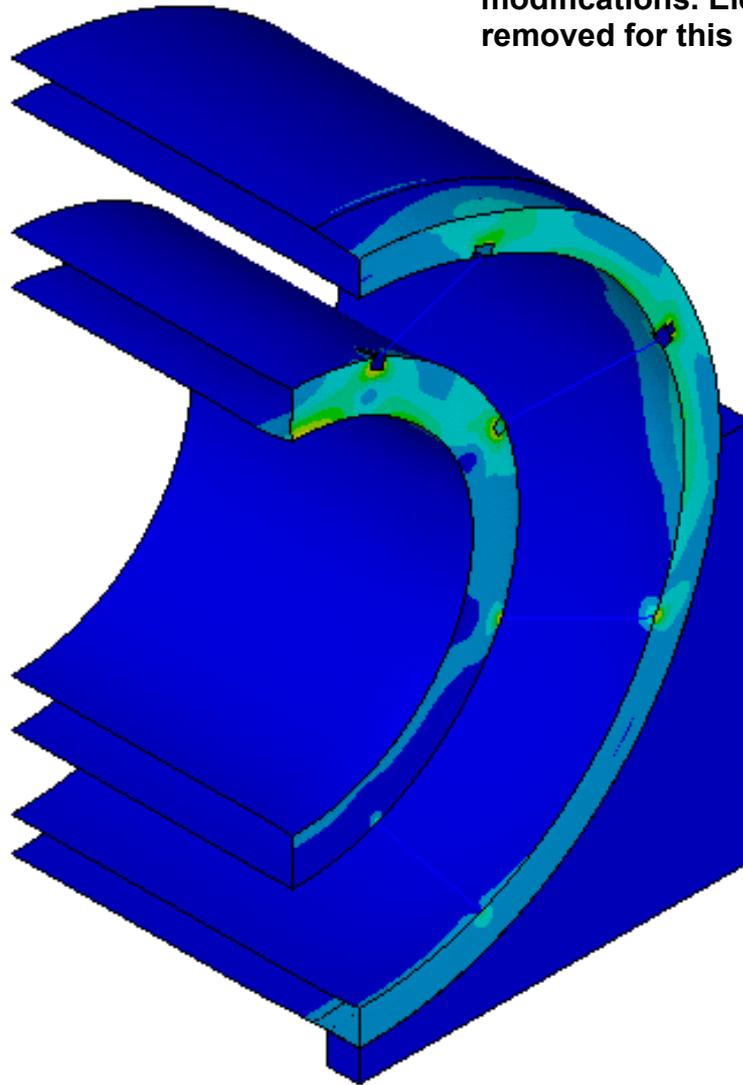


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-.024567  
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```

most reliable displacements are at annular endrings

Vertical displacements – inches

High local stress exist at the highly simplified support attachment points which can be mitigated with local modifications. Elements in those regions have been removed for this plot



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Stresses - psi

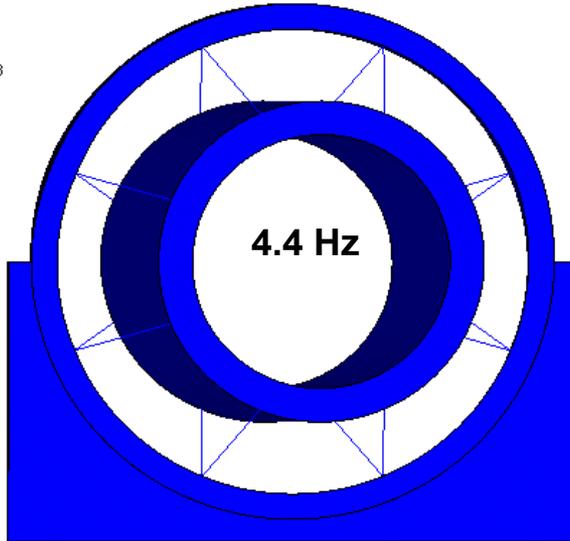
Modal Analysis

- HEP detectors always require minimal support of maximal mass
- This leads directly to the possibility of low natural frequencies, and subsequent undesirable response to ground motion
- Ground motion will tend to excite resonant frequencies of the system; rule of thumb is that the higher the system's natural frequencies are, the better
- The previous tension link support design is a good example of the problem

The Four Lowest Frequencies of the System

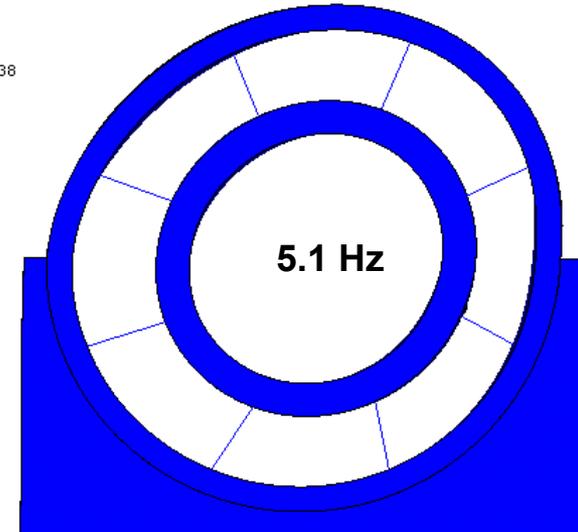
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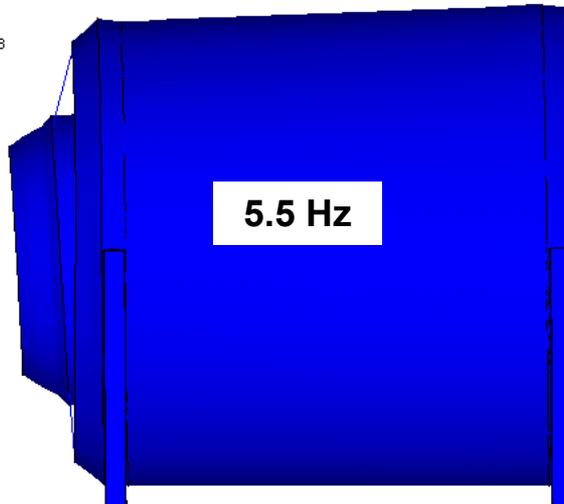
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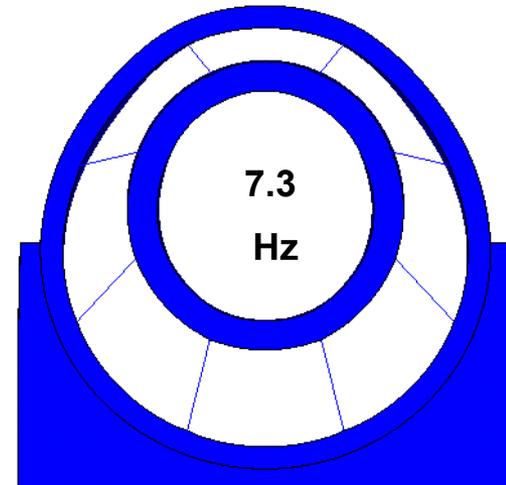
DISPLACEMENT

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DMX =.027178



DISPLACEMENT

STEP=1
SUB =6
FREQ=7.304
DMX =.024018



Remedies?

- Can the muon chambers (or some of their territory) be used to tie the inner and outer solenoids together structurally? This would raise all of the frequencies on the previous slide
- Obvious things to try: Thickening shells, extending outer solenoid saddles over 360 degrees, adding additional stiffening rings to outer shell, using stiffer tension links, moment-carrying links, etc