Key Stellarator Engineering Issues and Constraints

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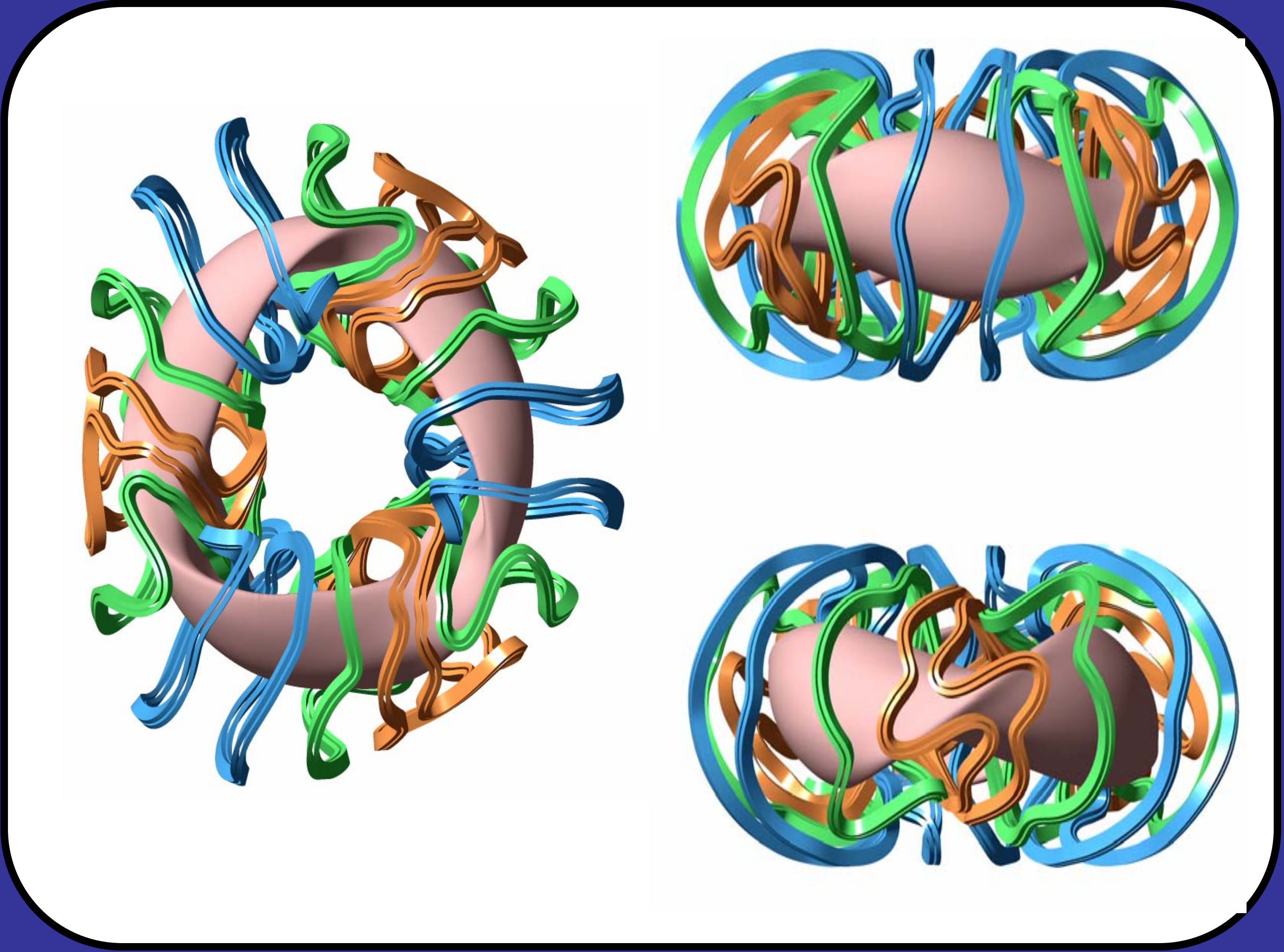
How The Engineering of a Compact Stellarator Differs from Most MFE Devices

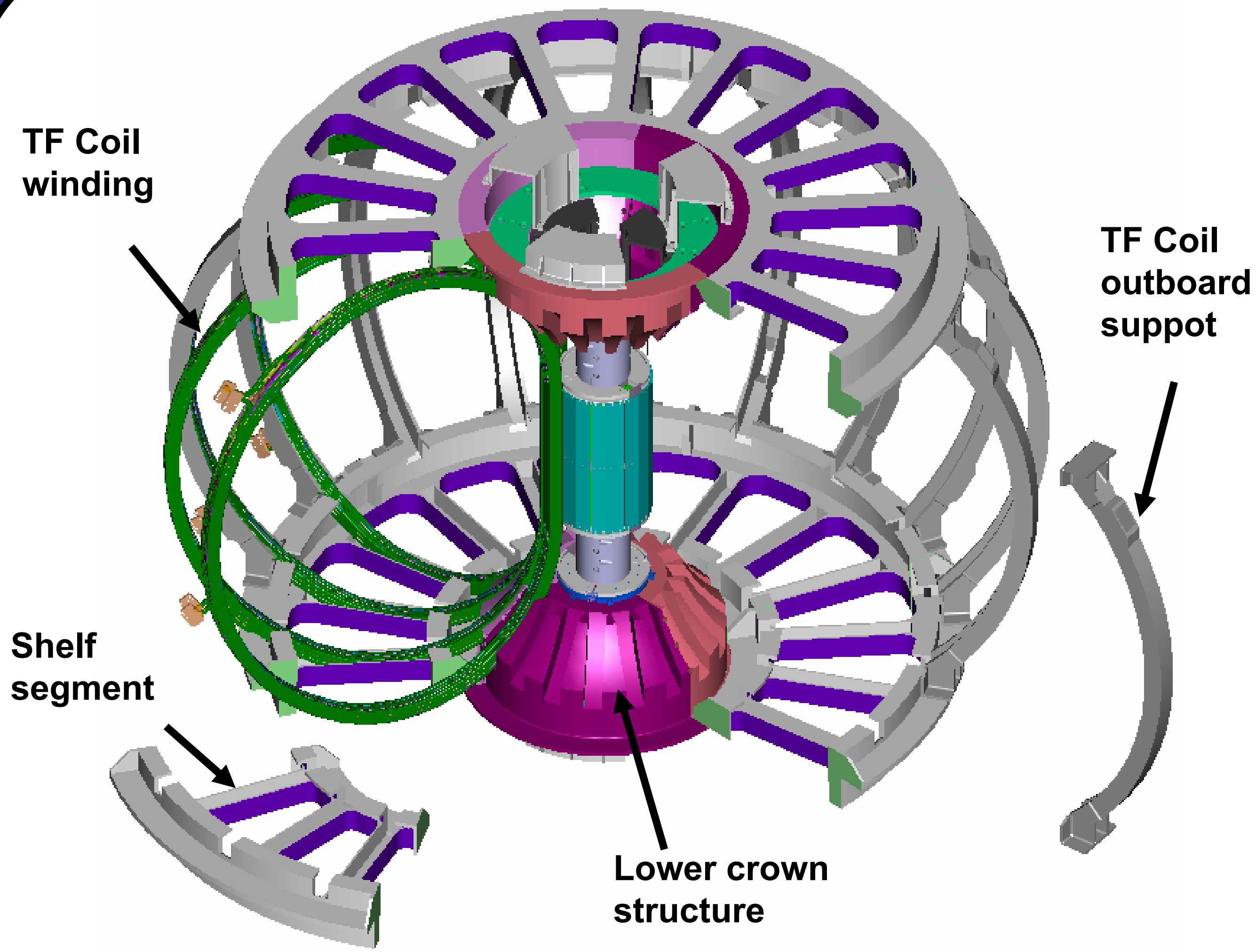
- Stellarator coil locations , shapes, and characteristics are derived from the 3-D plasma using an optimization process.
- Much stronger tie between Physics and Engineering. Physics is optimized with respect to engineering constraints such as J , space constraints, power supply current limits, and conductor bend radii.
- Space is highly constrained –
  - The modular coils need to be close to the plasma for shaping.
  - Coils need to be adequately spaced to avoid overlaps, allow for their own structures , and to provide sufficient space for ports and PFCs.
- Stellarators require 3D design and analyses – this greatly complicates the engineering process.
  - Solids modeling programs like Pro-E are essential for this complex geometry.
  - Finite element programs like ANSYS are essential for the EM and stress analyses.
- Magnetic systems are more complex.
  - Highly shaped modular coils – 6 each of 3 shapes.
  - In addition to TF and PF, modular coils and trim coils (in-vessel and external) are required.

The Modular Stellarator Coils are the Most Challenging Component of a CS

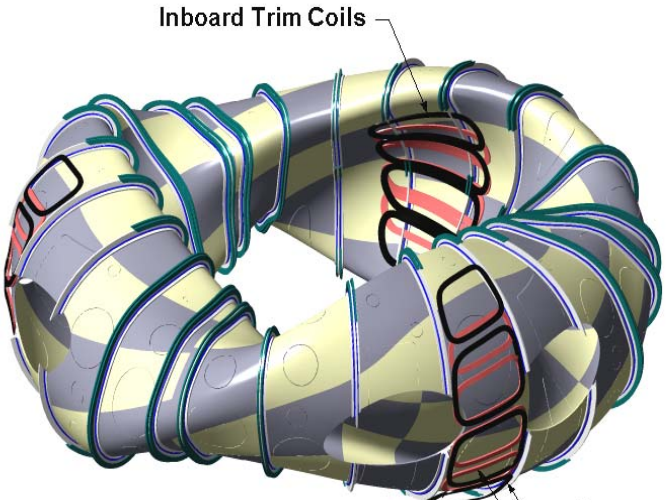


- **18 coils in total;**
- **3 different shapes.**

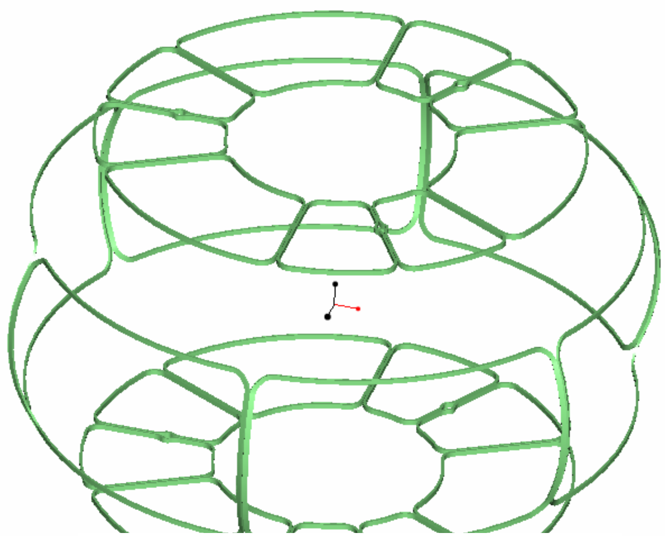
TF Coils Are Conventional in Design



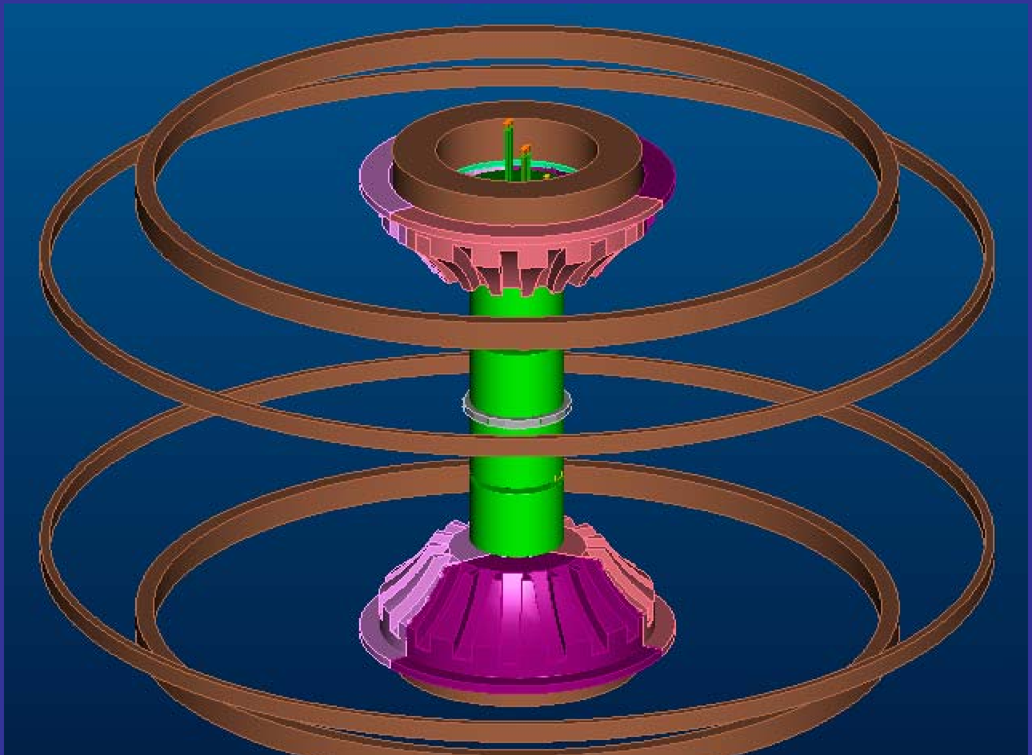
PF and Trim Coil Systems



Internal Trim Coils



External Trim Coils

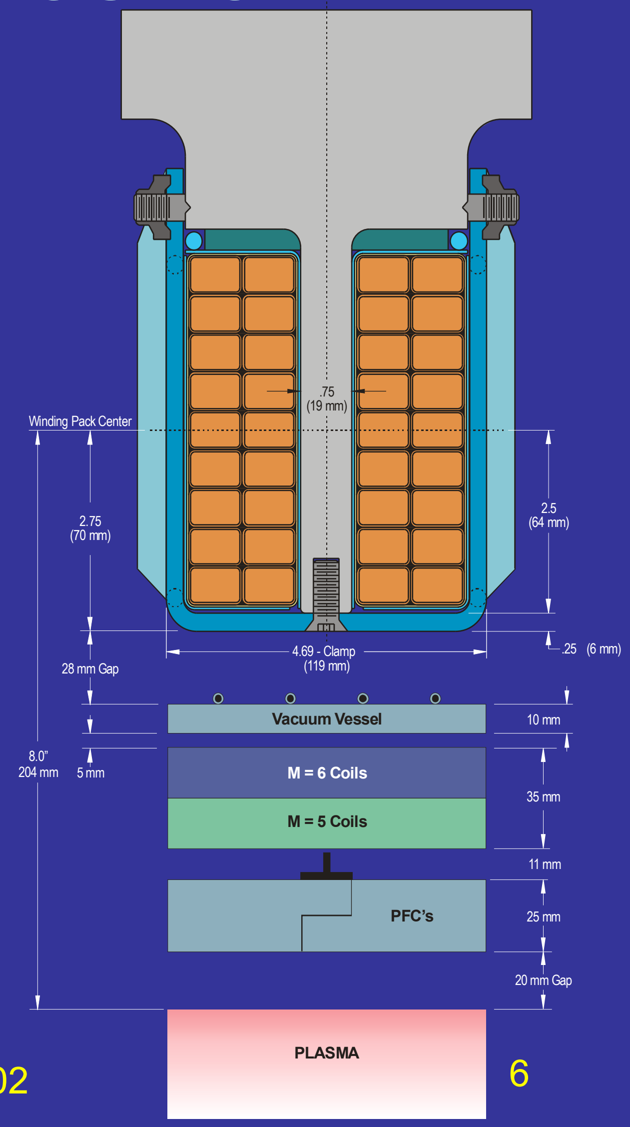


PF Coils

Geometry Constraints: Coil to Coil , Bend Radii, Coil to Plasma

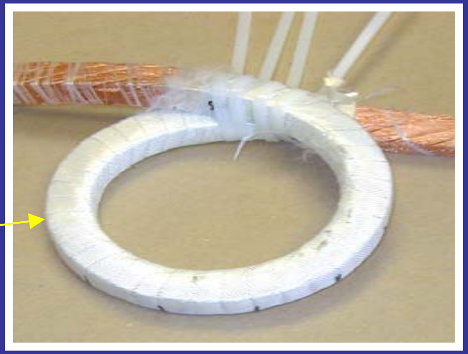
Space allocation and R&D established limits on conductor geometry

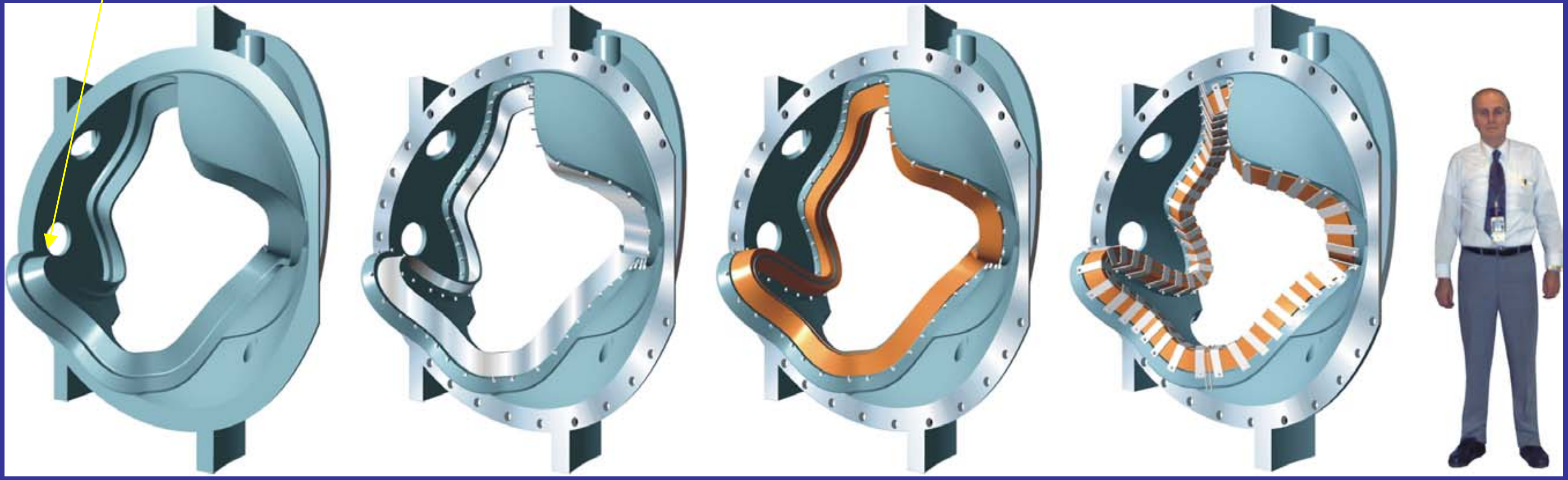
Coil Position (deg)	Coil Type	Min Radius of Curvature (cm)	Min Coil-to-Coil Distance (cm)	Min Coil-to-Plasma Distance (cm)
Criteria		>10	>16	>19
-10	M1			
			16.1	
10	M1	11.0		20.4
			16.2	
30	M2	10.9		20.5
			16.1	
50	M3	10.8		21.0
			16.0	
70	M3			



Minimum Radius of Curvature Is Set By Manufacturing Considerations

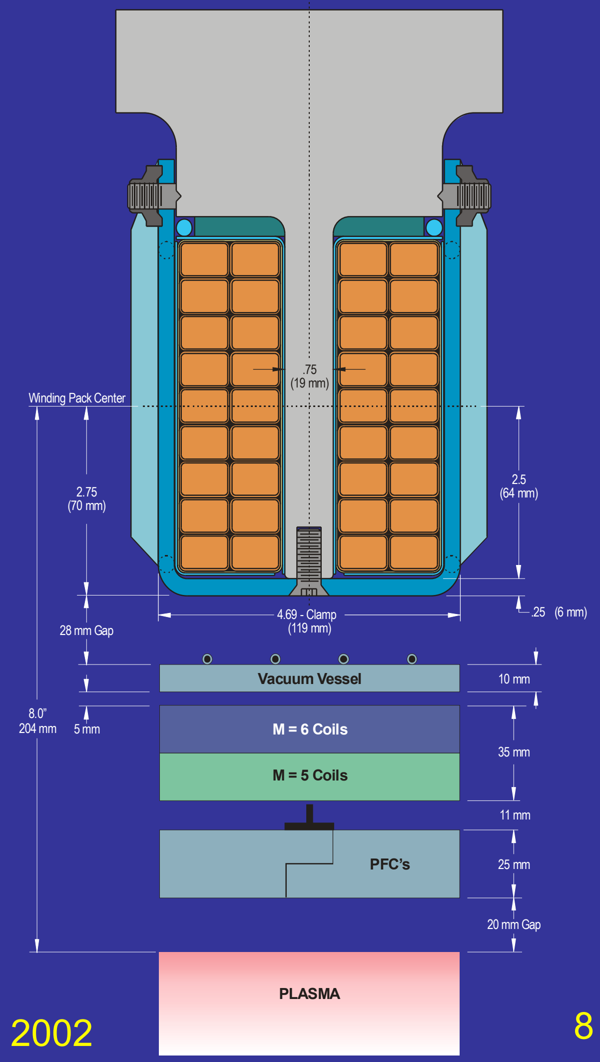
- Primary considerations:
  - Machining of coil winding form.
  - Keystoning of conductor;



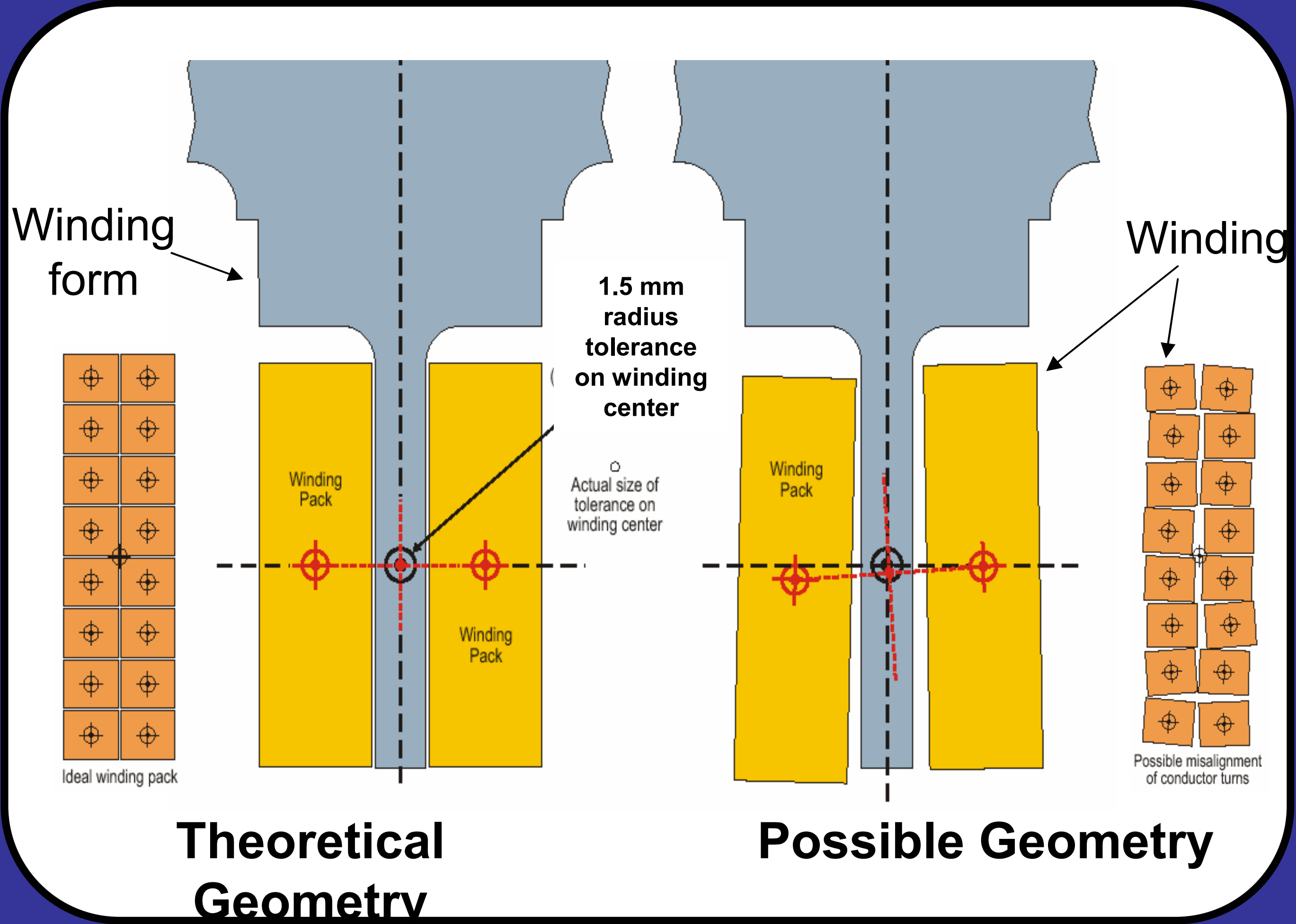


Modular Coils Need to be Close To Plasma To Be Effective

- In NCSX, this requires the windings to be as compact as possible which means a high current density (J= 14 kA/cm^2)
- Radial space is quite constrained in NCSX. Adequacy of radial space may be an issue for reactors using modular coils.
    - A reactor wil require additional radial space for blanket/shield and superinsulation for SC coils.
    - However, a reactor would most likely use superconductor coils operating at much higher current density. This may provide some relief.
    - Other compact stellarator design concepts should be investigated to see if space is improved.

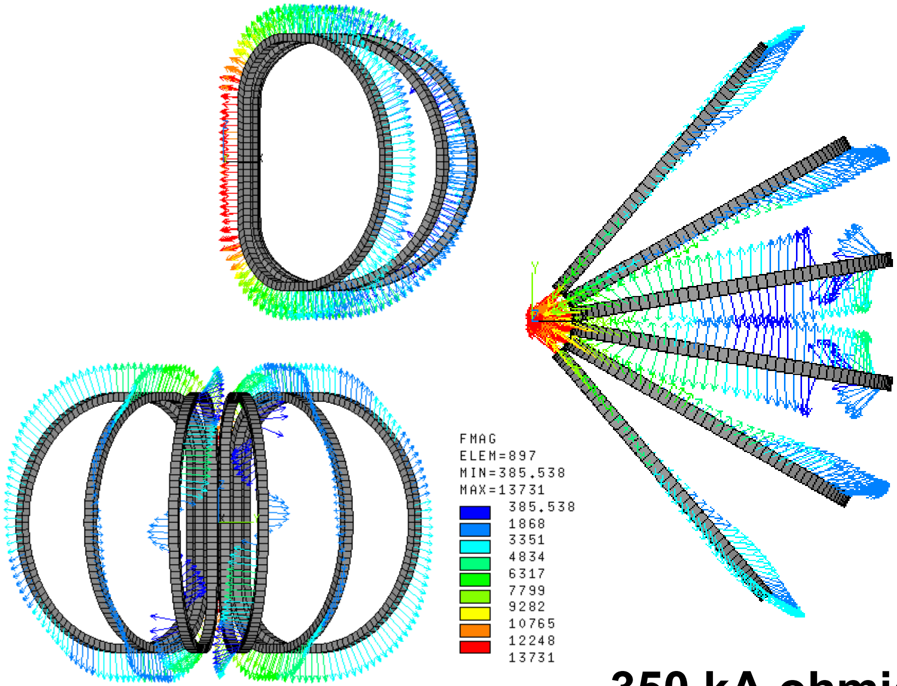


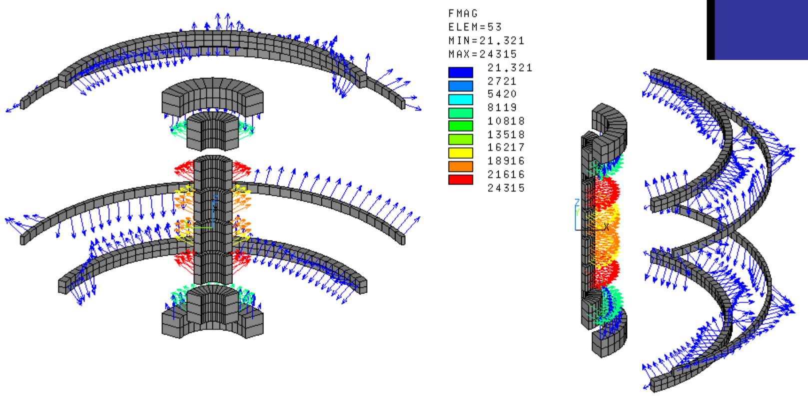
Accurate Coil Positioning is Required to Minimize Magnetic Islands



For NCSX Modular coils: current centers must be maintained within 1.5 mm.

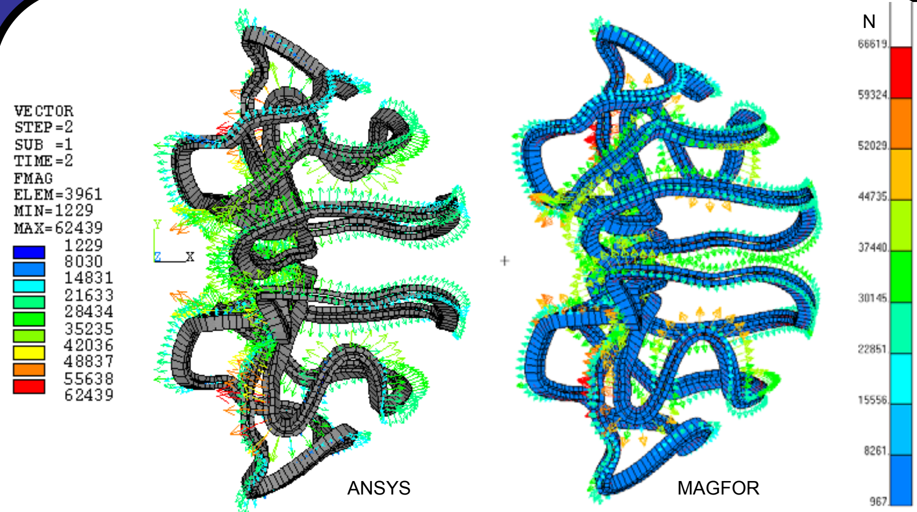
TF and PF Analyses Show Unusual Force Distributions



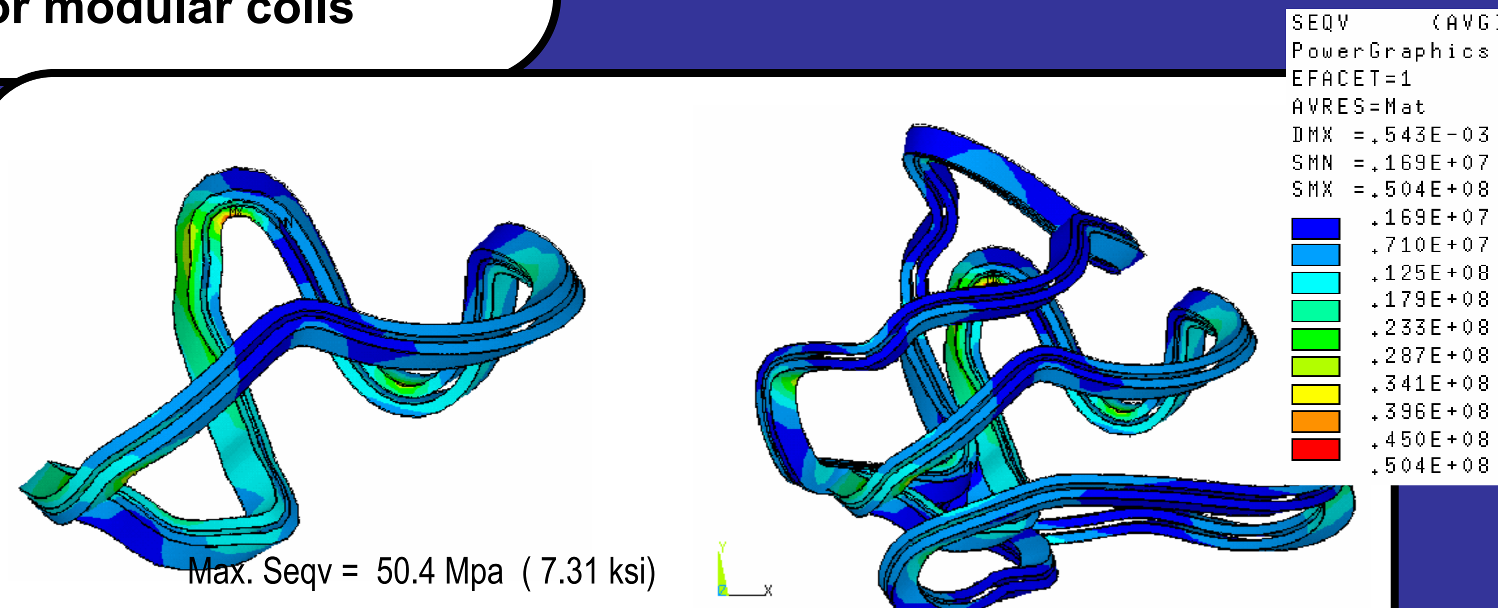


350 kA ohmic scenario worst for TF, PF

Modular Coil Forces and Stresses Are Complex



2T, low beta at zero seconds
worst case for modular coils

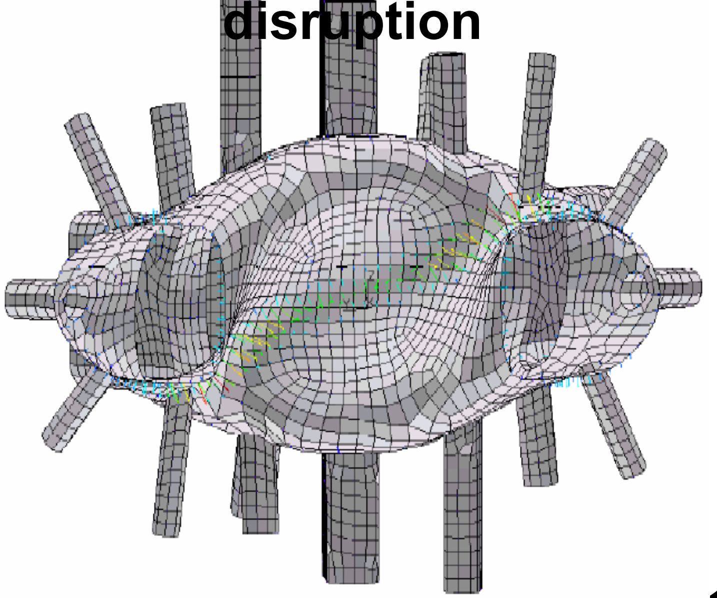


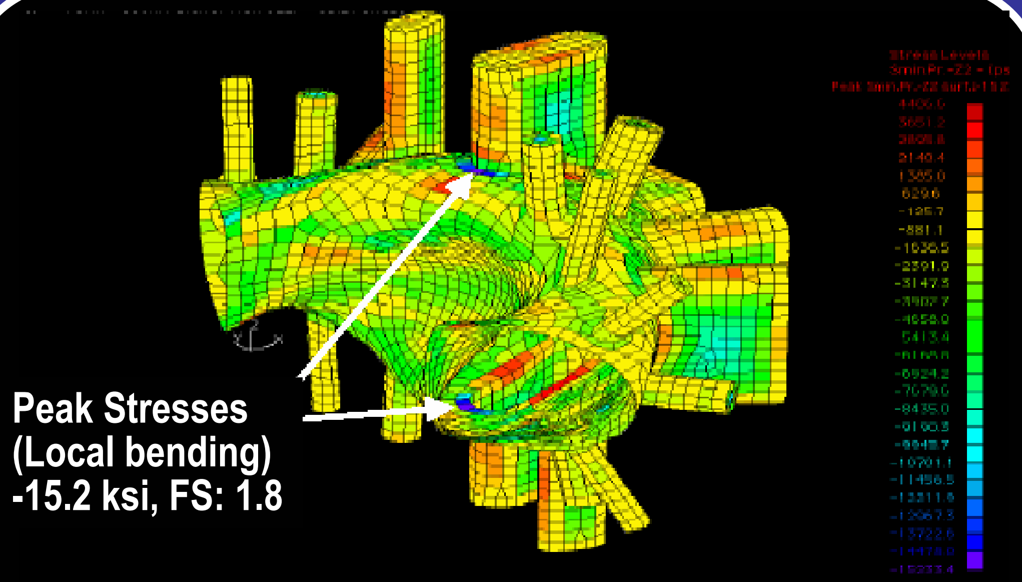
Max. Seqv = 50.4 Mpa (7.31 ksi)

Note: the Young's modulus of the winding is consistent with the "hard coil" , or 1/2 the modulus of solid copper

Vessel Analyses

Force vectors on vacuum vessel from a 350 kA plasma disruption

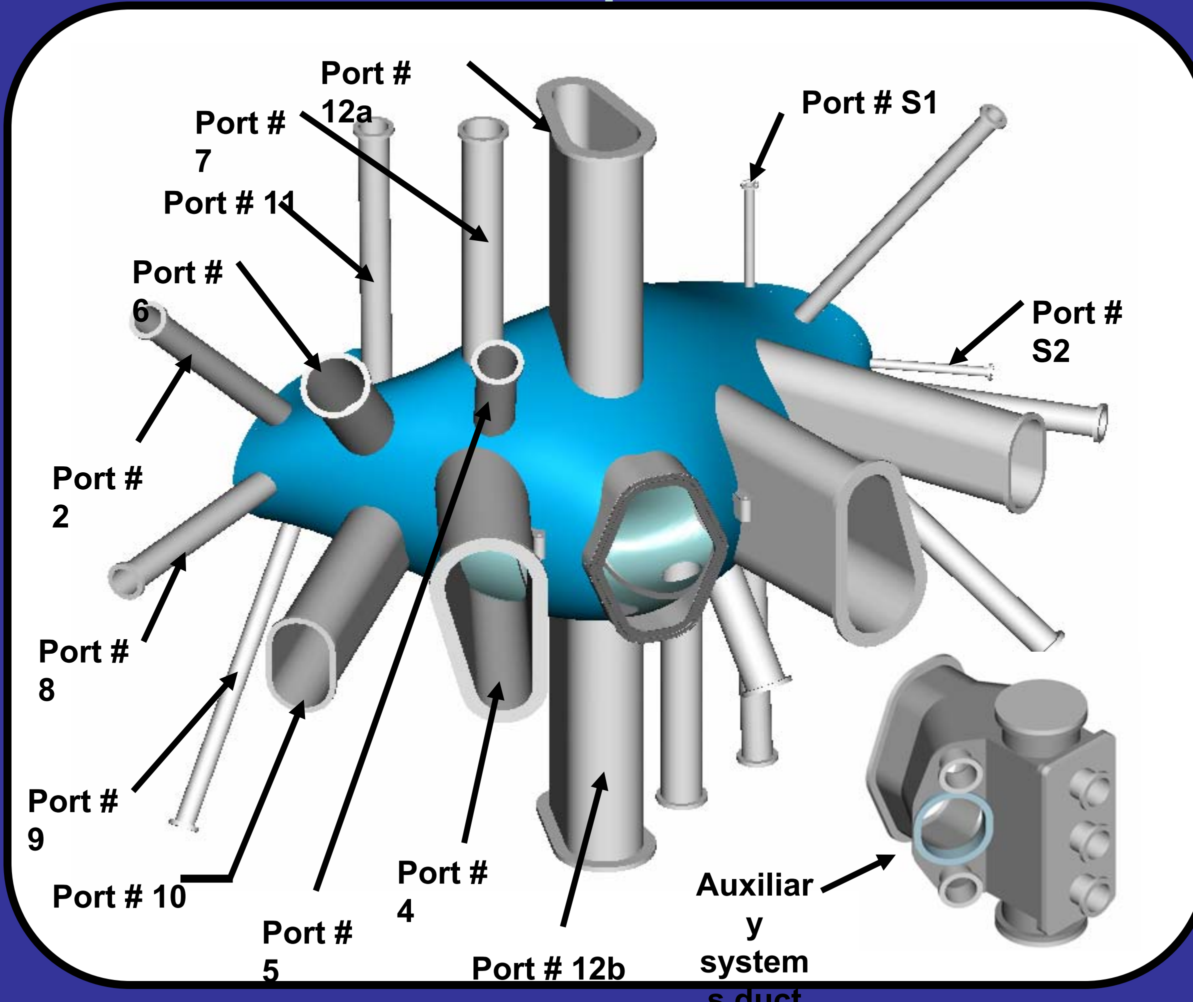




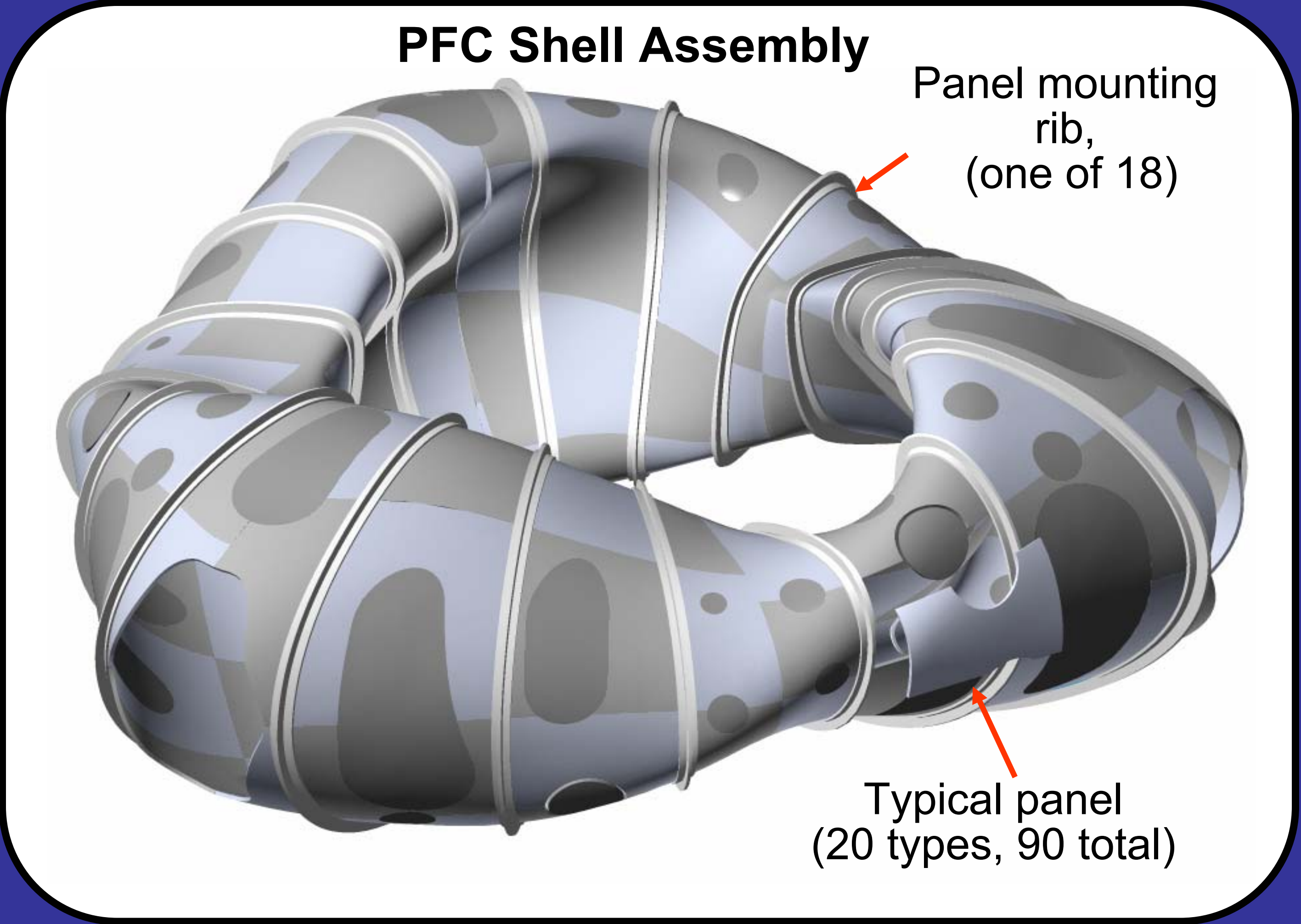
Peak stress pattern on vacuum vessel from a combination of pressure and 350 kA plasma disruption

Coil Shapes and Positions Are Constrained by Diagnostics, Heating, and Maintenance Access Requirements

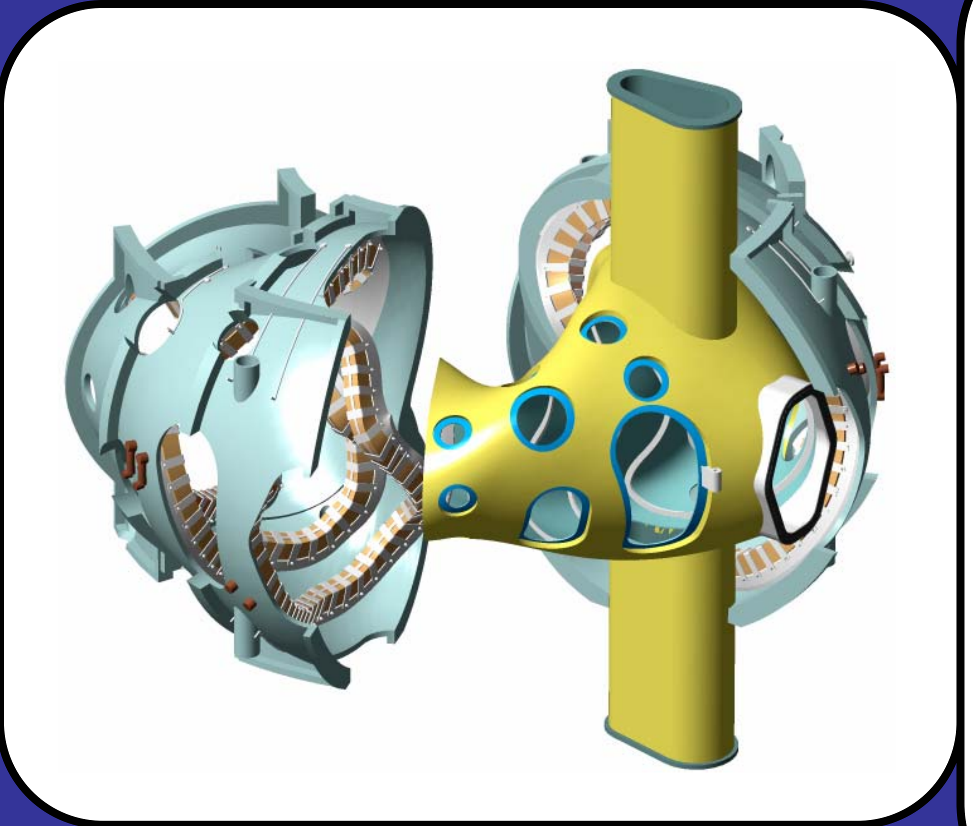
- 99 ports for diagnostics & heating.
- Personnel access available through NBI or other large ports

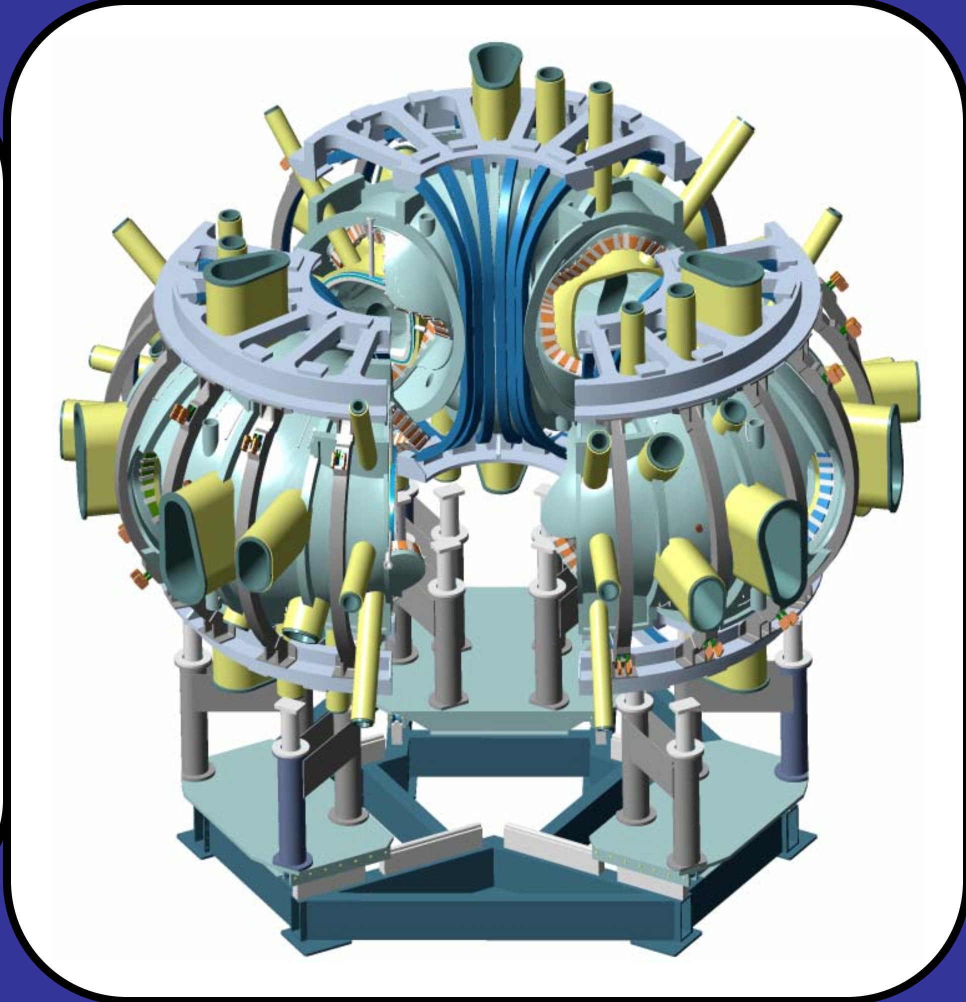


PFCs and Divertor (and Blankets /Shields in a reactor) Requires a 3-D Design



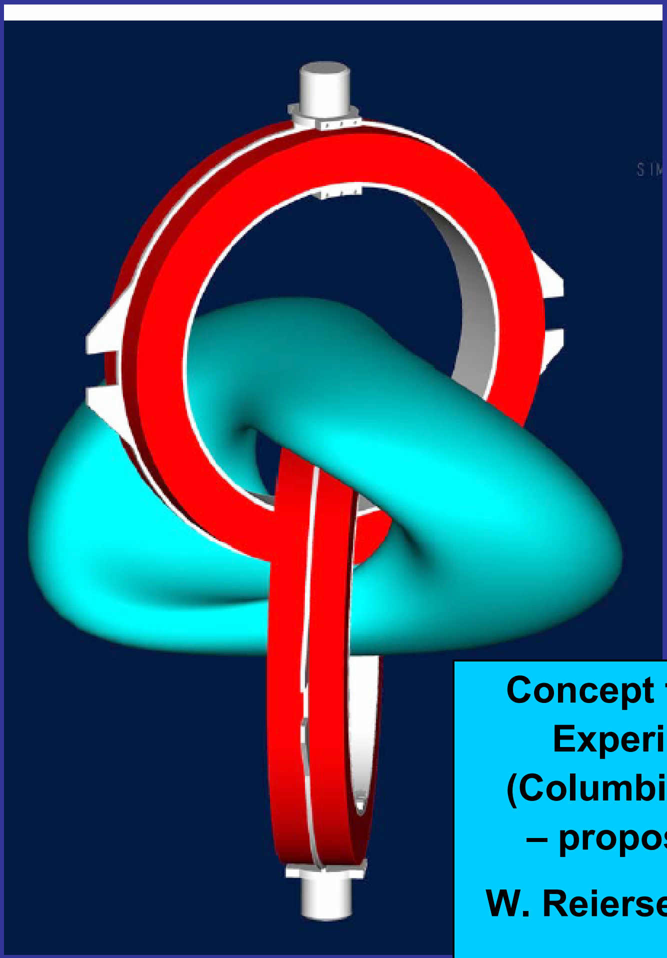
Remote Maintenance Will Be Challenging in the Present Modular Coil Design





What is the Best Compact Stellarator Concept for a Reactor??

- NCSX is a proof of principle concept and may or may not be the best compact stellarator concept to be extrapolated to a reactor.
- The tilted coil stellarator, for example, is simple and has good access (but is not as mature in design).
- Alternate compact stellarator concepts should be considered early in the ARIES study.



Concept for CNT Experiment (Columbia Univ.) – proposed by

W. Reiersen, PPPL

Ref. H. Neilson –slide 11

Engineering Tasks for CS Reactor Studies

- Develop quantitative reactor engineering metrics that the designers can include in their optimization.
  - Space requirements for blanket / shield.
  - Coil spacing, bend radius, superconductor type and properties; space requirements for superinsulation.
    - High temperature YBCO superconductor may be a good candidate, especially if modular coils are used.
  - Diagnostic and heating system port and space requirements.
  - Remote handling considerations:
    - Remote maintenance requirements and classification of components.
    - Remote handling space needs.
  - Costing algorithms for stellarator components.
- Identify concepts such as the tilted coil option that might make qualitative improvements to reactors.

Summary

- 3-D nature of the compact stellarator requires:
  - Deriving coil positions and shapes from the plasma.
  - More complex 3-D CAD design and FEA analyses.
  - Physics optimization using engineering constraints.
  - The use of stellarator codes which have advanced greatly in recent years.
  - Experimental tests from CS experiments (NCSX, QPS) planned to start in 2007, to improve the physics models.
- The modular coil stellarator concept may or may not be the best choice for the ARIES reactor study.
  - Radial space constraints and remote maintainability are likely to be issues with the modular coil design.
  - New concepts like the tilted coil compact stellarator should be considered.