Status of the NCSX Project

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Topics

- Mission and Design
- Component Status
- Assembly Status
- Schedule Update
- Research Program Planning

NCSX Objectives

Understand the effect of 3-D quasi-axisymmetric shaping

- Pressure limits and limiting mechanisms
- Disruptions and operating limits
- Transport and confinement with low quasi-axisym. ripple
- Relationship between NCSX and tokamak transport
- Equilibrium islands and tearing-mode stabilization, role of reversed magnetic shear
- Divertor operation with good core performance
- Energetic-ion stability and confinement

Determine degree of 3-D quasi-axisymmetric shaping for

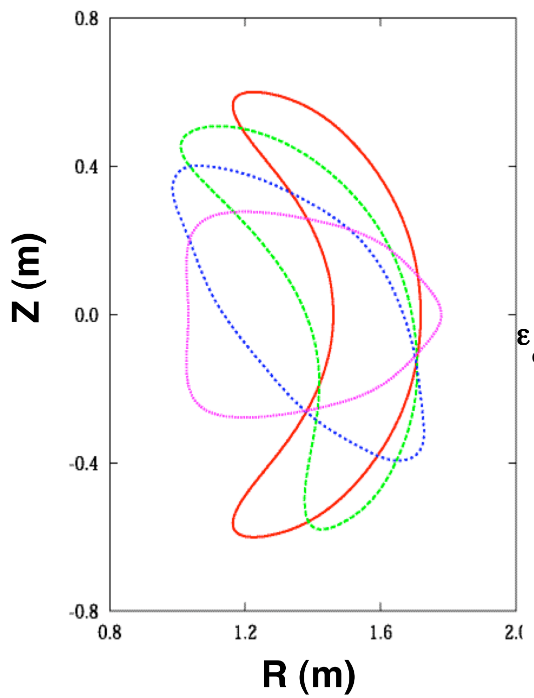
- High β, good confinement, compatible with steady state, without disruption risk
- Can the design constraints be simplified, with improved understanding? $\Rightarrow$ simpler engineering design?

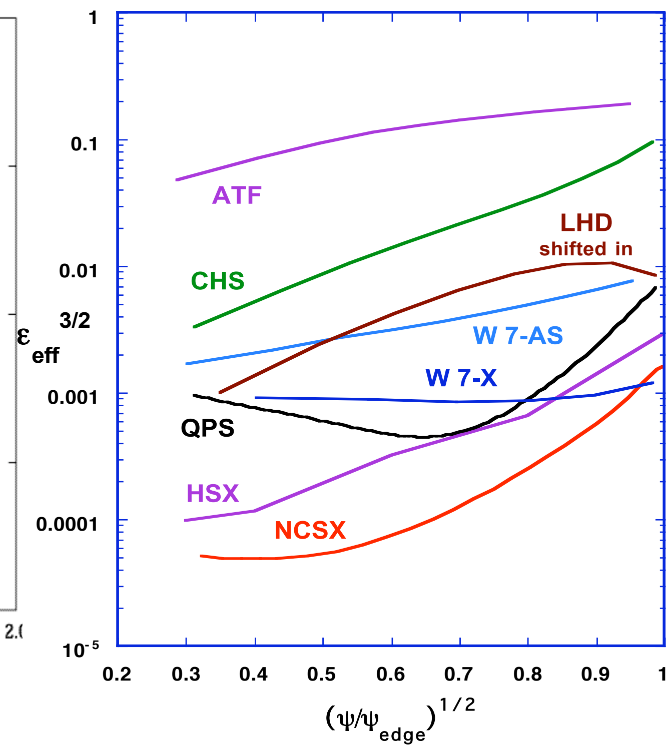
NCSX Configuration Properties

Configuration was optimized for target physics properties

- Low $R/\langle a \rangle$ (4.4); 3 periods
- Quasi-axisymmetric with low effective ripple
- Stable at β = 4.1% to vertical, kink, ballooning, NTM instabilities
- Reverse shear *q* profile
- 25% of transform from bootstrap current
- Good magnetic surfaces at high β
- Constrained by engineering feasibility metrics

Plasma Cross Sections

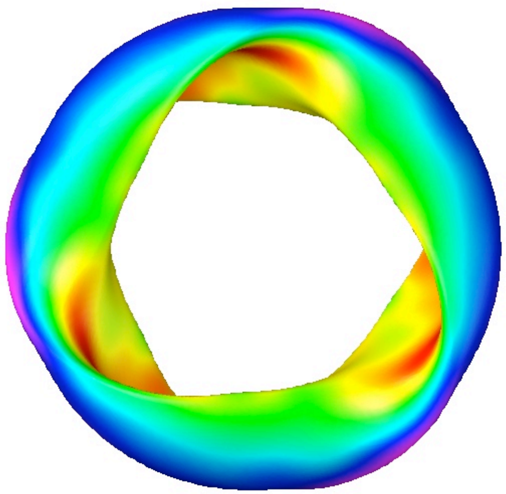


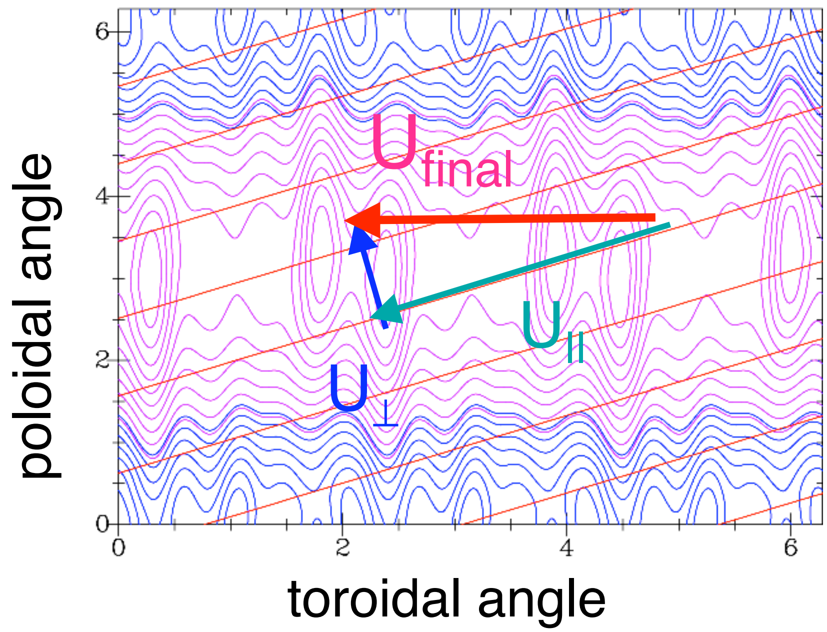


Understanding of 3-D quasi-axisymmetric shaping can also lead to tokamak improvements, e.g., improved stability, disruption avoidance

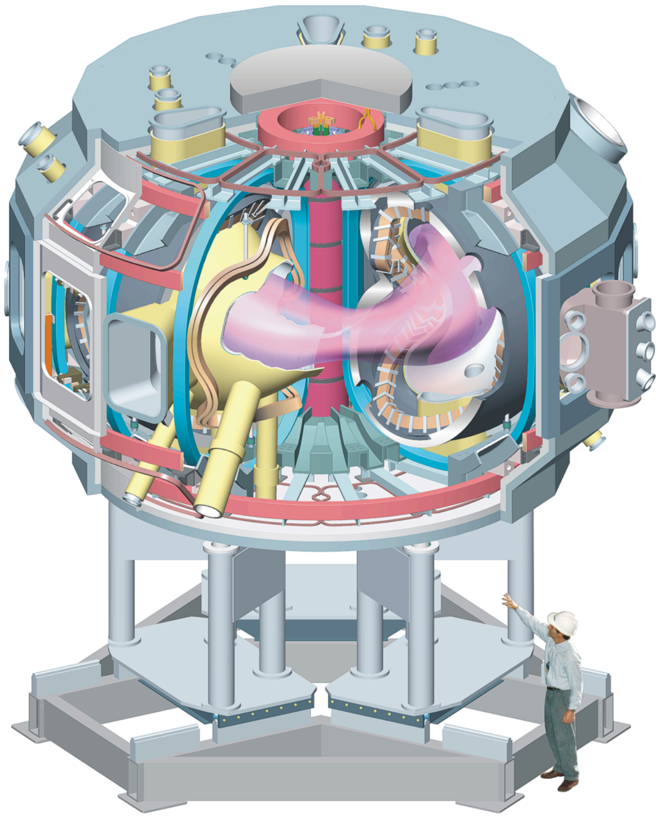
NCSX Configuration Integrates Low Aspect Ratio and Quasi-Axisymmetry

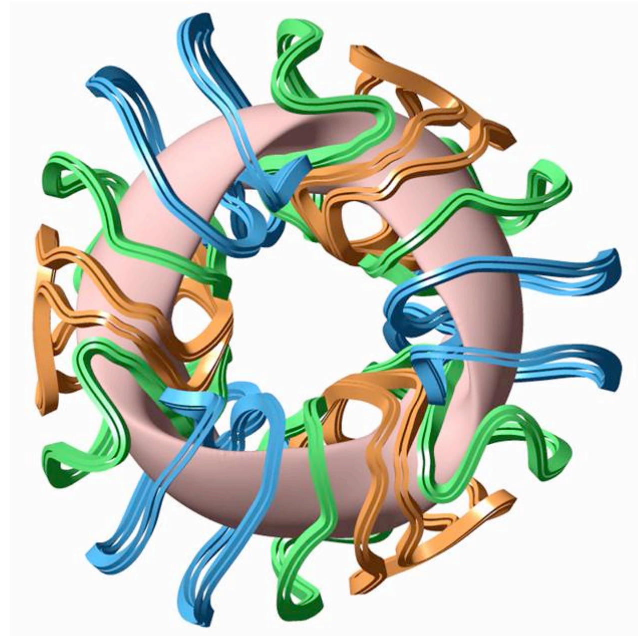
- 3 periods, $R/\langle a \rangle$ = 4.4, $\langle \kappa \rangle \sim 1.8$
- Low flow damping, tokamak-like orbits $\Rightarrow$ enhanced confinement
- Stable for at least $\langle \beta \rangle > 6.5\%$ by adjusting coil currents
- Passive disruption stability: equilibrium maintained even with total loss of β or I_{plasma}





NCSX Machine Design

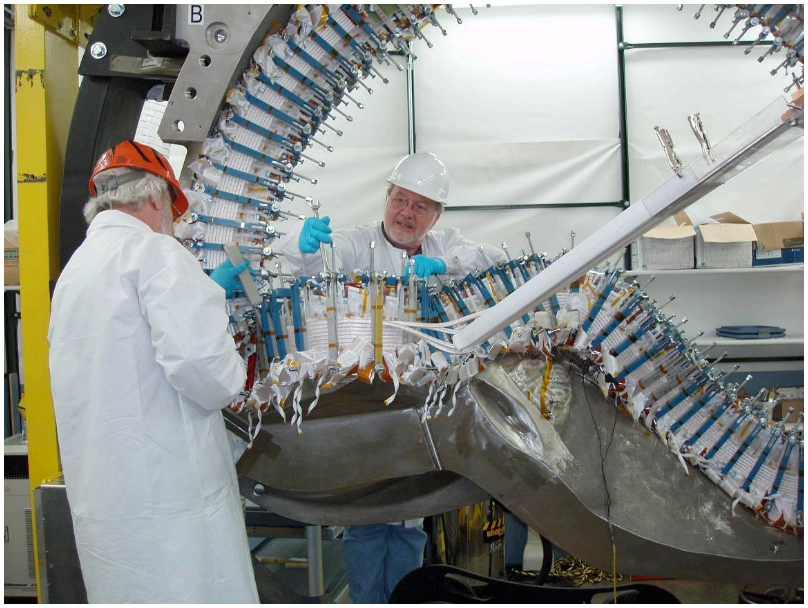


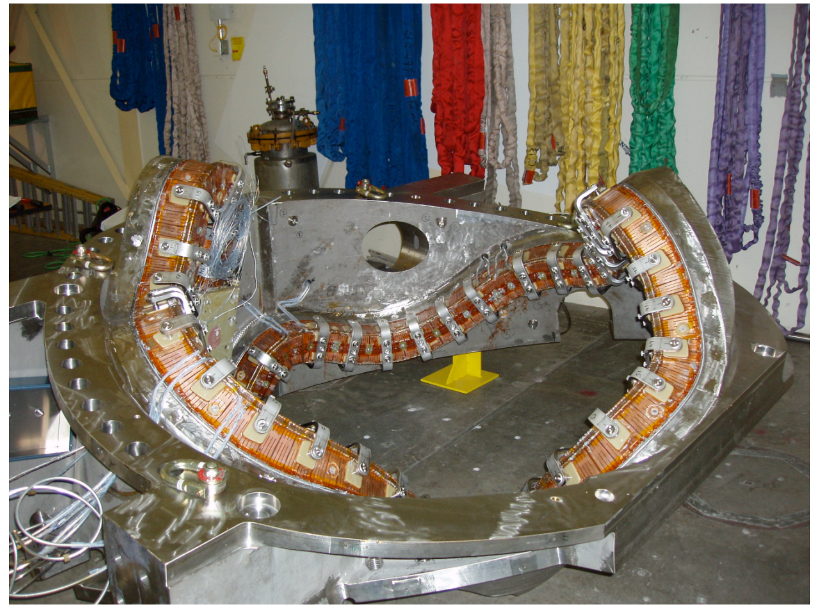


Coils wound on forms to create a robust structural shell minimizes deflections

- Major radius: 1.4 m; plasma aspect ratio 4.4
- Magnetic field (pulse length): 2.0 T (0.2 s); 1.2 T (1.7 s)
- Flexible coil sets; LN-cooled
- ≤ 12 MW plasma heating: NBI: 6 MW; ECH & ICH: 6 MW

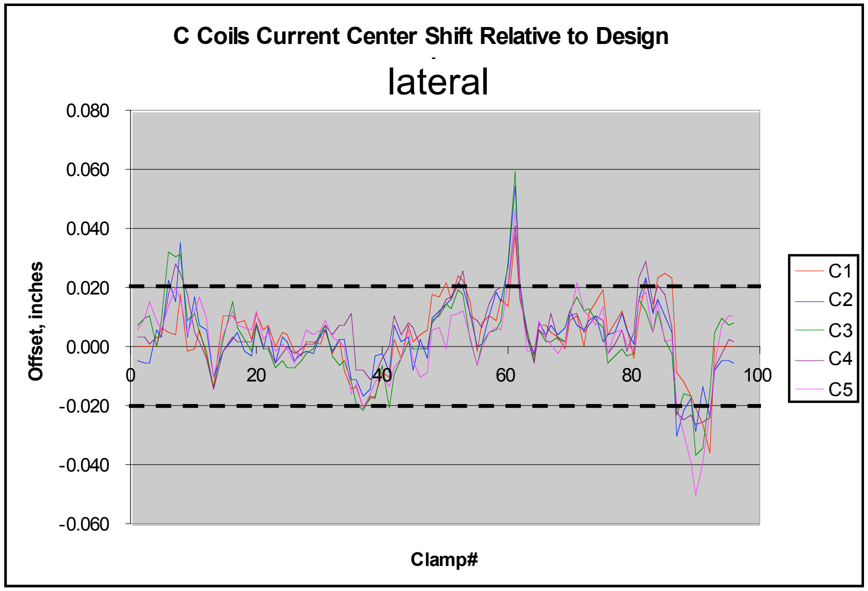
Modular Coil Winding is Proceeding Well





- Flexible copper cable conductor is wound onto winding surfaces machined to ±0.5 mm accuracy
- Winding packs are adjusted to desired dimensions with clamps
- 14 coils have been wound and potted. Last coil scheduled for May 2008

Procedures Were Developed to Achieve Required Accuracy



- Current center (from measurements of winding pack outside dimensions) follows design trajectory within ±0.5 mm

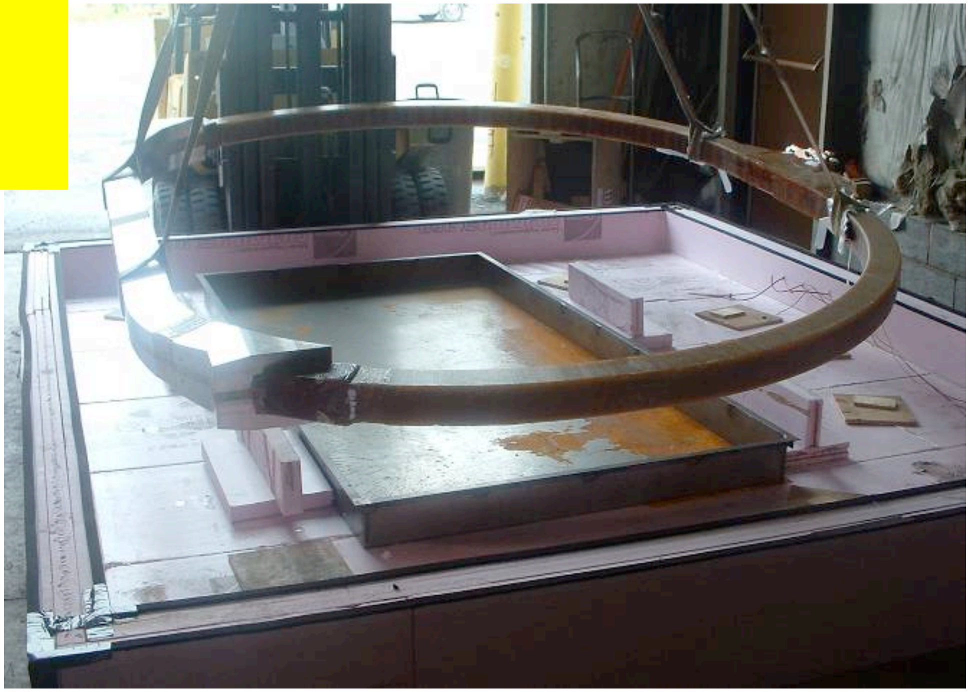
  ⇒ acceptably small field errors
- All coils pass warm terminal resistance and electrical insulation strength tests
- First coil was successfully cooled to LN temperature and tested at full current

Coil Positioning Tests

- Demonstrated fixtures and handling of parts
- Demonstrated metrology and fine adjustment techniques for positioning parts within ±0.25 mm

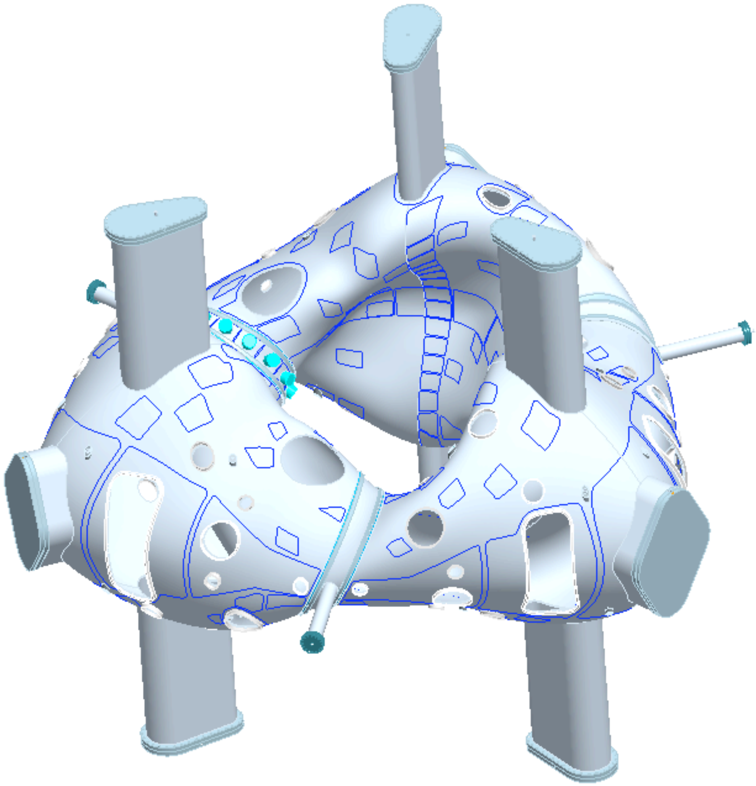
TF Coils Are in Production

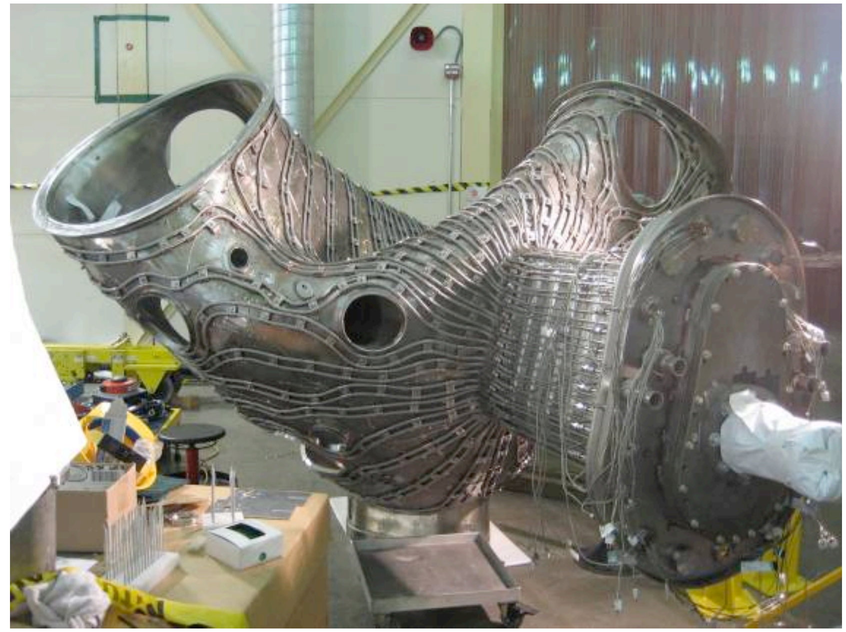
4 coils have been delivered



- Provides variable background field (±0.5 T) for iota flexibility
- 18 D-shaped coils (one per modular coil) with steel wedge support
- Met ±3 mm accuracy on inner leg
- Last coil is scheduled for Sept. 2008

NCSX Vacuum Vessel Was Built in 3 Sectors



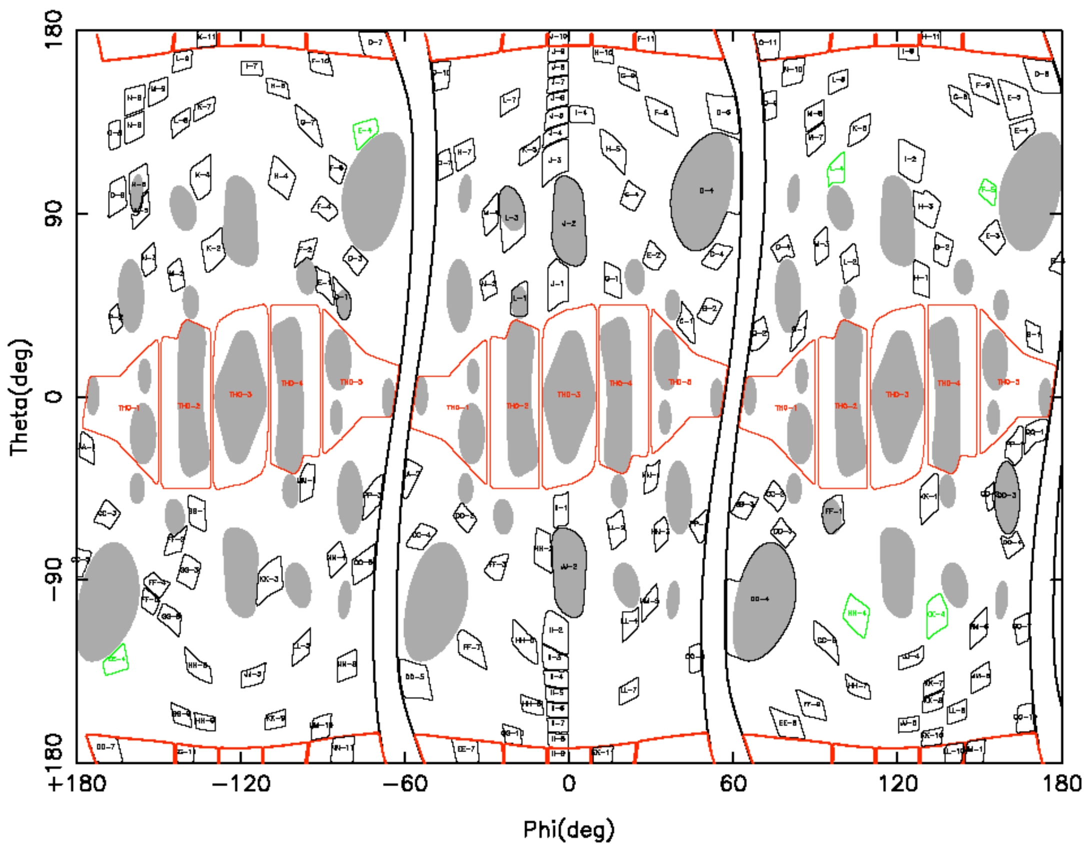


±5 mm tolerance and $\mu \leq 1.02\mu_0$ were achieved; bakeable to 350 C

2 of 3 are sectors complete, last scheduled for Jan. 2008

- Heating and cooling hoses
- Heater tapes, thermocouples
- Diagnostic flux loops

Ex-Vessel Magnetic Diagnostics Are Designed for Equilibrium Reconstuction



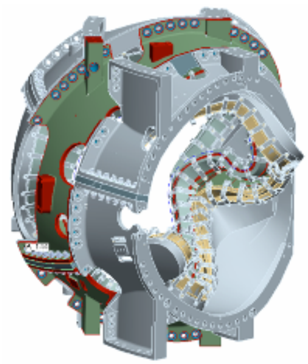
- >200 saddle coils mounted on vessel
- ~2500 free-boundary equililbria analyzed to identify critical regions for measurement
  - Array distributed across 3 periods + extra coils to sense symmetric and non-symmetric components

N. Pomphrey, E. Lazarus

Several strategies are being developed for equilibrium reconstuction:

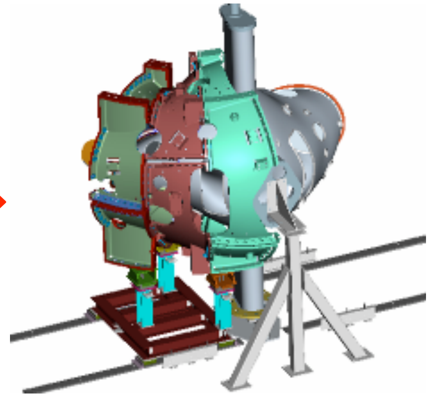
- V3FIT – reconstruction code based on VMEC (cannot represent islands)
- PIES – 3D equilibrium with islands
- 3-D external flux fit (e.g. filament code), to find boundary shape and characteristics

NCSX Assembly is Done in Stages

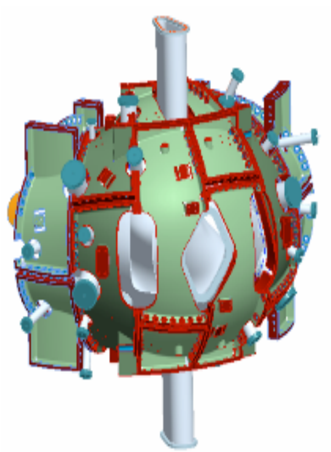


Assemble 3 coils for half field period

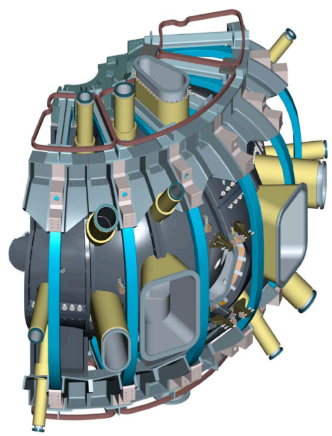
Start in Dec-Jan



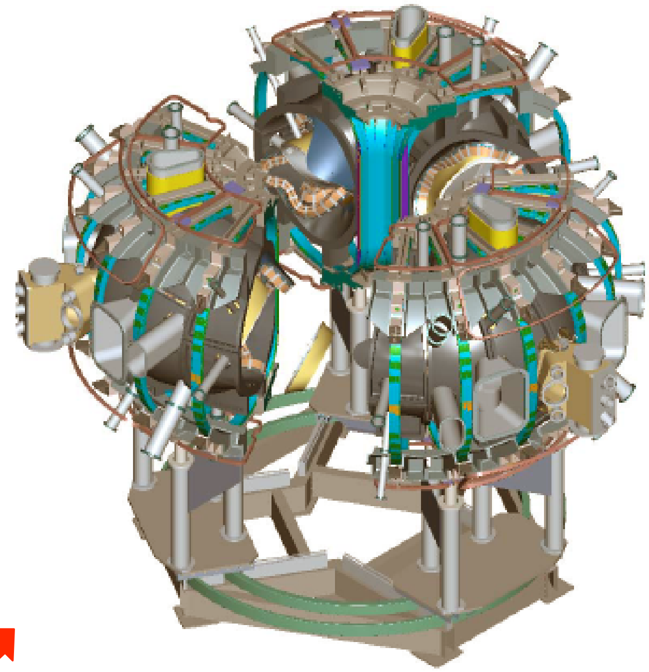
Install 3-coil set over vacuum vessel sector



Connect 2nd 3-coil set over vacuum vessel sector



Add ports & TF coils to complete a field period

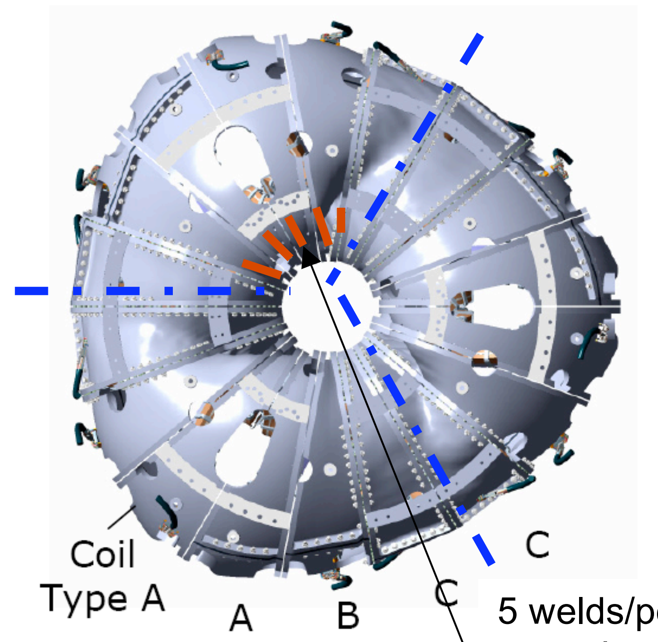


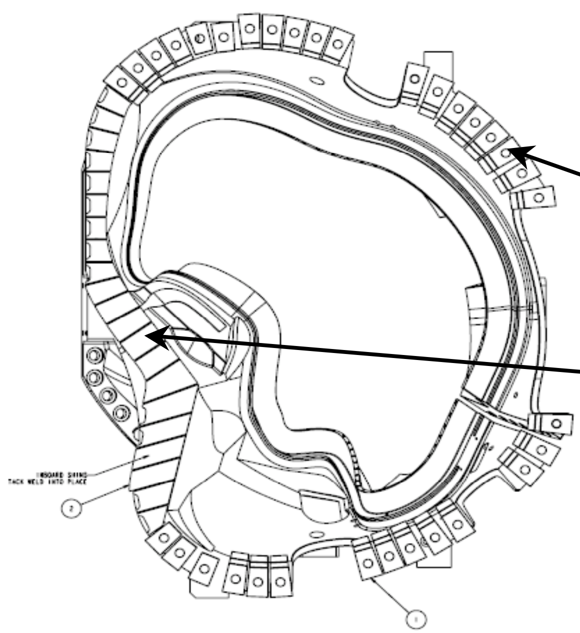
Connect 3 field periods

Require coil current center accurate to ±1.5 mm

Requirements on Inter-coil Hardware (Fasteners, Shims) Are Challenging

- Handle complex structural loads without slippage or excessive deflections
- Position coils accurately (±1 mm) within the array
- Provide insulation to break up long-lived eddy currents (τ < 30 ms)

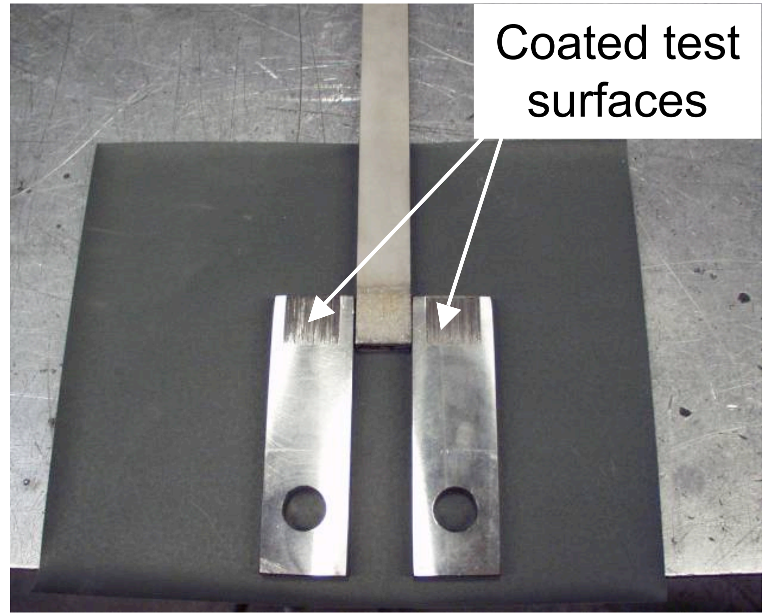




Solutions

- Outboard: bolts with enhanced-friction shims
- Inboard, within each field period: welded shear plates, compression shim
- Inboard, between field periods: compression shims

Modular Coil Interface Development



Welded Interface Development Trials

- Permeability OK
- Dimensional stability controlled by:
  - design configuration
  - low-distortion weld procedures (e.g., MIG welding, rapid quench)*

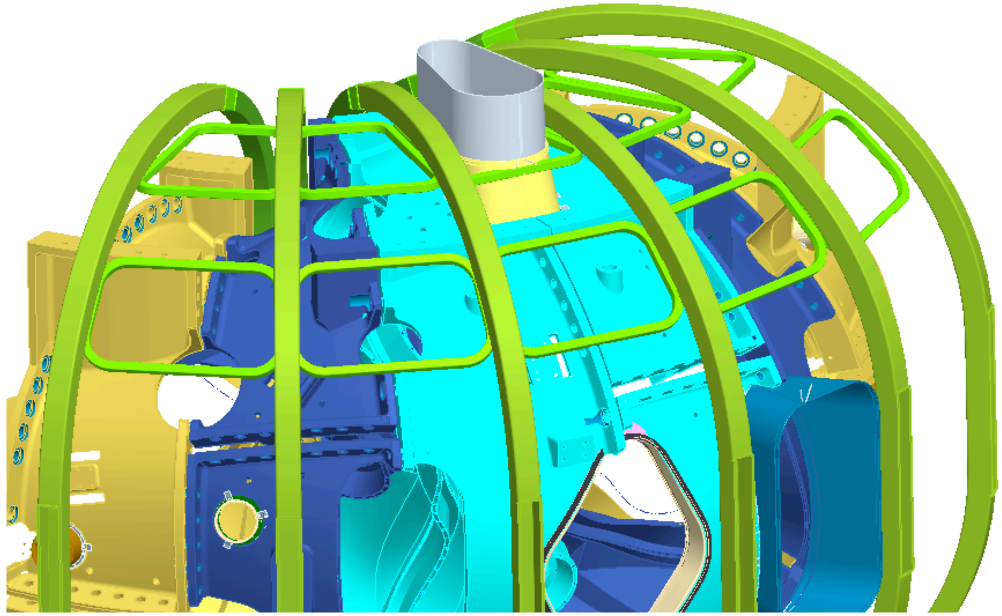
**Acknowledgement to W 7-X and CERN colleagues for valuable advice.*

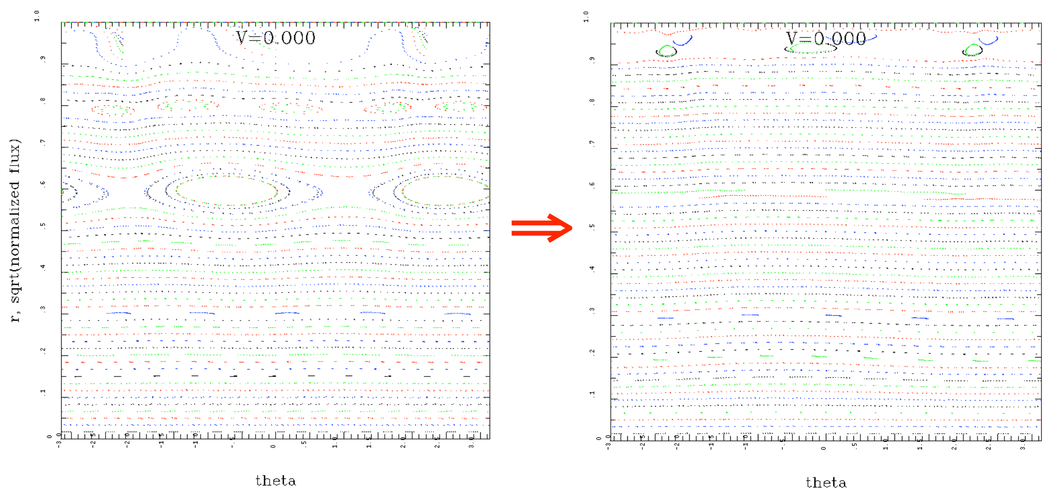
Enhanced-Friction Coatings

- Alumina coatings tested under load at cryogenic temperature
- Friction coefficient 0.67 exceeds requirements by ~50%
- Required friction maintained in life tests (130,000 cycles)

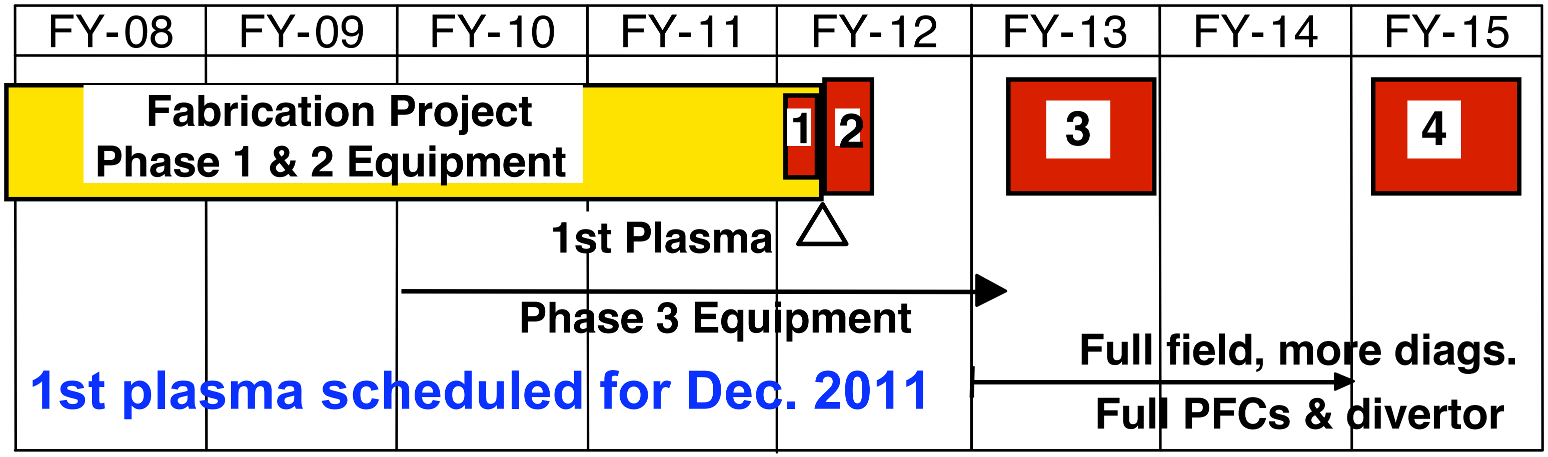
Trim Coils Will Be Designed to Reduce Field Errors

- Initial design: rectangular coils between modular and TF coils
- Monte-Carlo analysis of the assembly indicates these coils can correct residual low-order *(n* = 1, 2, 3) resonant errors
- Only moderate currents (< 20 kA-turns) required





NCSX Schedule



1. Stellarator acceptance testing and first plasma (ends fabrication project)
2. Magnetic configuration studies: electron-beam mapping studies (2012)
3. Initial heating experiment (2013)
   – 3-MW NBI; ECH?
   – B ≥ 1.2 T
   – partial PFC coverage
   – initial diagnostics, magnetics, profiles (n_e, T_e, T_i, v_ϕ, P_{rad}) and SOL
4. Initial high-beta experiments (2015)
   – 6-MW heating, NBI & ECH
   – B = 2T; divertor and full PFC coverage
   – improved diagnostics

Campaigns in FYs 2013 and 2015 will Investigate Critical Issues

- **FY 2013:** Study effect of quasi-axisymmetric shaping and effective ripple on confinement and rotation damping
  - resilience to disruptions from MHD instabilities, density limits
  - initial comparisons between observed and calculated MHD stability thresholds
- **FY 2015 with 6 MW, 2 T operation will determine**
  - β-limits and limiting mechanisms
  - safe operating area against disruptions
  - local transport properties; impurity transport
  - fast ion transport due to effective ripple. Alfvenic-mode stability
  - initial divertor effectiveness; scrape-off layer characteristics

NCSX Program Status

- A series of government reviews of NCSX is in progress due to large cost and schedule increases
  - Review of cost and schedule estimates (Aug.)
  - Compact stellarator science: benefits and issues (Sept.)
  - NCSX design and construction within tolerances (Oct.)
- DOE decision on future of NCSX is expected in November
- ***Thanks to our stellarator colleagues who have contributed to these reviews***

Summary

- Component production is progressing well
  - vacuum vessel manufacture complete; component installation in progress
  - modular coils nearly complete
  - TF coil deliveries have started
- NCSX construction to date meets technical requirements
- Trim coils and modular coil interfaces are in design
- Schedule has been delayed: first plasma Dec. 2011
- Detailed planning of experimental campaigns has started