Theory Dept. Contributions to the National Compact Stellarator eXperiment

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PPPL Theory Program Review
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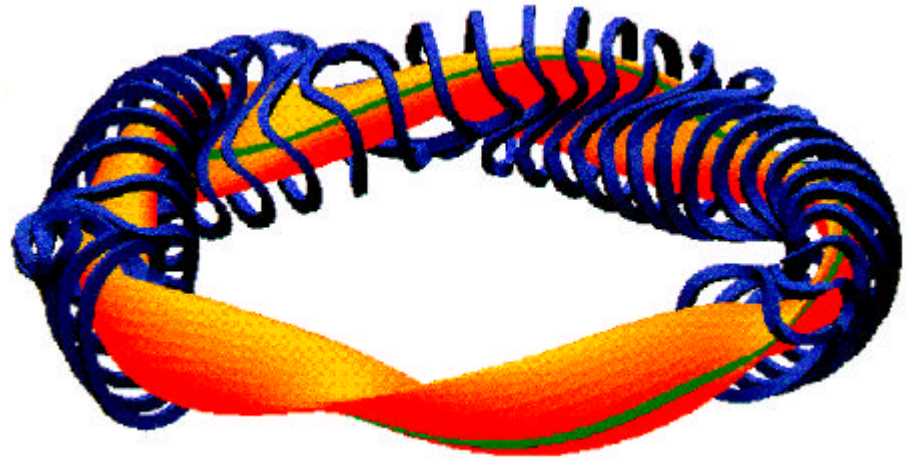
Stellarators: 3D Shaping Provides Flexibility

- Toroidal magnetic confinement systems, like tokamaks and STs
  - but, not symmetric !
- Disruptions are generally not observed in stellarators, even at highest parameters. Can be designed to not disrupt.

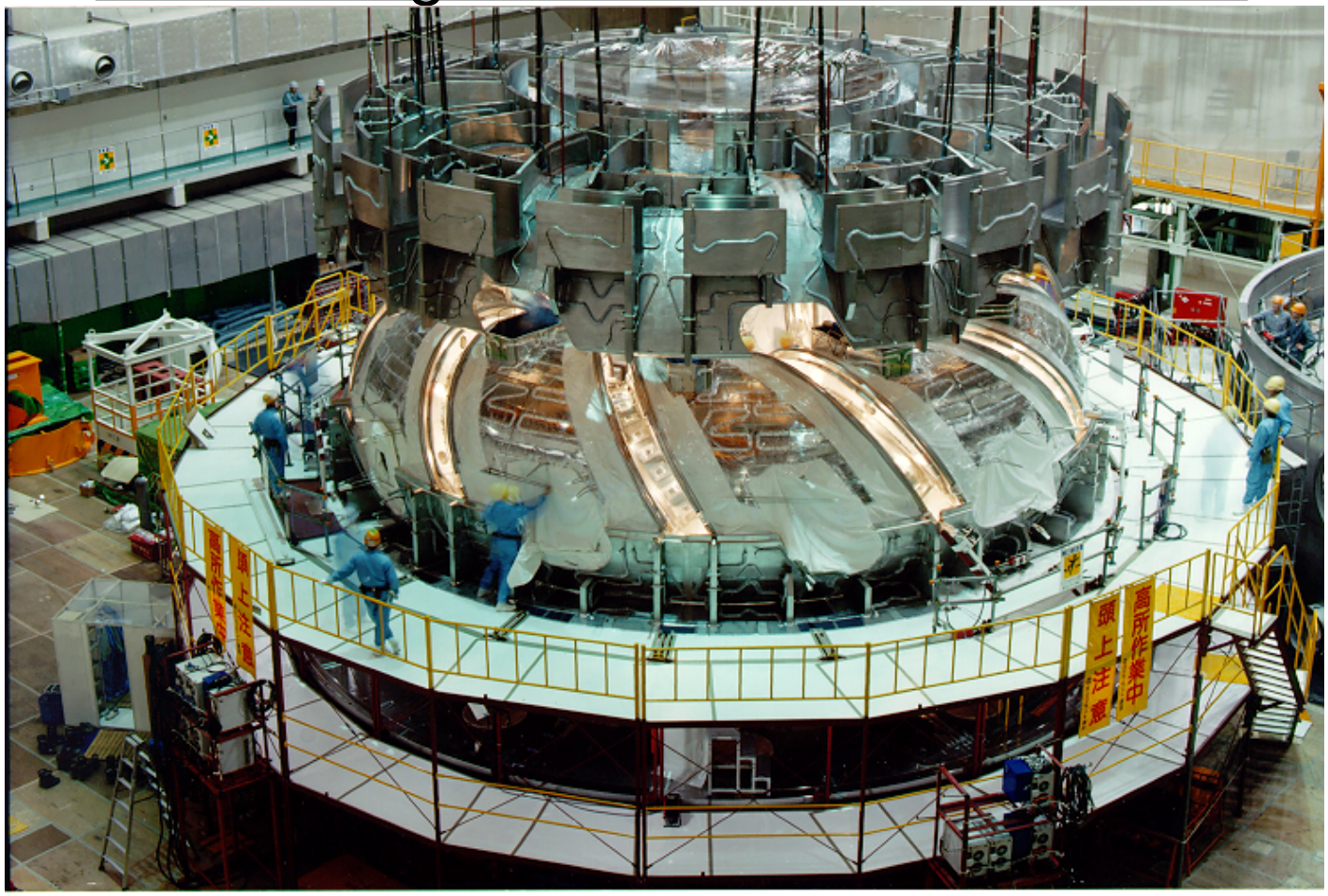


W-7X
~2006

- Strongly shaped coils can supply helical magnetic field $\Rightarrow$ eliminates need for external current drive $\Rightarrow$ v. low recirculating power
- Can choose 3D shape to optimize stability, transport

$\Rightarrow$ In the world program, only new large experiments are stellarators
LHD (Japan), W7-X (Germany) ~$1B each, superconducting
But, extrapolate to large, low power density systems

LHD Has >10x the Volume, Heating Power, and Pulse Length of Previous Stellarators



Japan
op. in 1998

- R = 3.9 m, B = 3(4) T, P ~ 40 MW
- Expect T_i~ 10 keV, τ_E > 0.2 s, $n\tau T$ ~10^{20}
- β~ 2.5% achieved

Compact Stellarators Offer Innovative Solutions

Can combine the best features of Stellarators and Advanced Tokamaks

- Stellarators: *Externally-generated helical fields, low recirculating power, typically disruption free.*

  But: High aspect ratio (5-12), low power density projected
- Advanced tokamaks: *Excellent confinement, Bootstrap current*

  But: Elaborate controls to avoid disruptions, current drive;
  high recirculating power (Q_{eng}~ 5)

Advances in Theory and Numerical Design Capability ⇒ NCSX

- 3D shaping to stabilize external kink, vertical, neo-tearing, ballooning
  - expand operating area
  - prevent disruptions?
- Steady state without current drive.
- Aspect ratio: ~ 3 – 4
- Good confinement. Quasi-axisymmetry to close drift-orbits, allow plasma flow

Compact Stellarator Program Targets U.S. Fusion Goals

FESAC 10-Year Goals

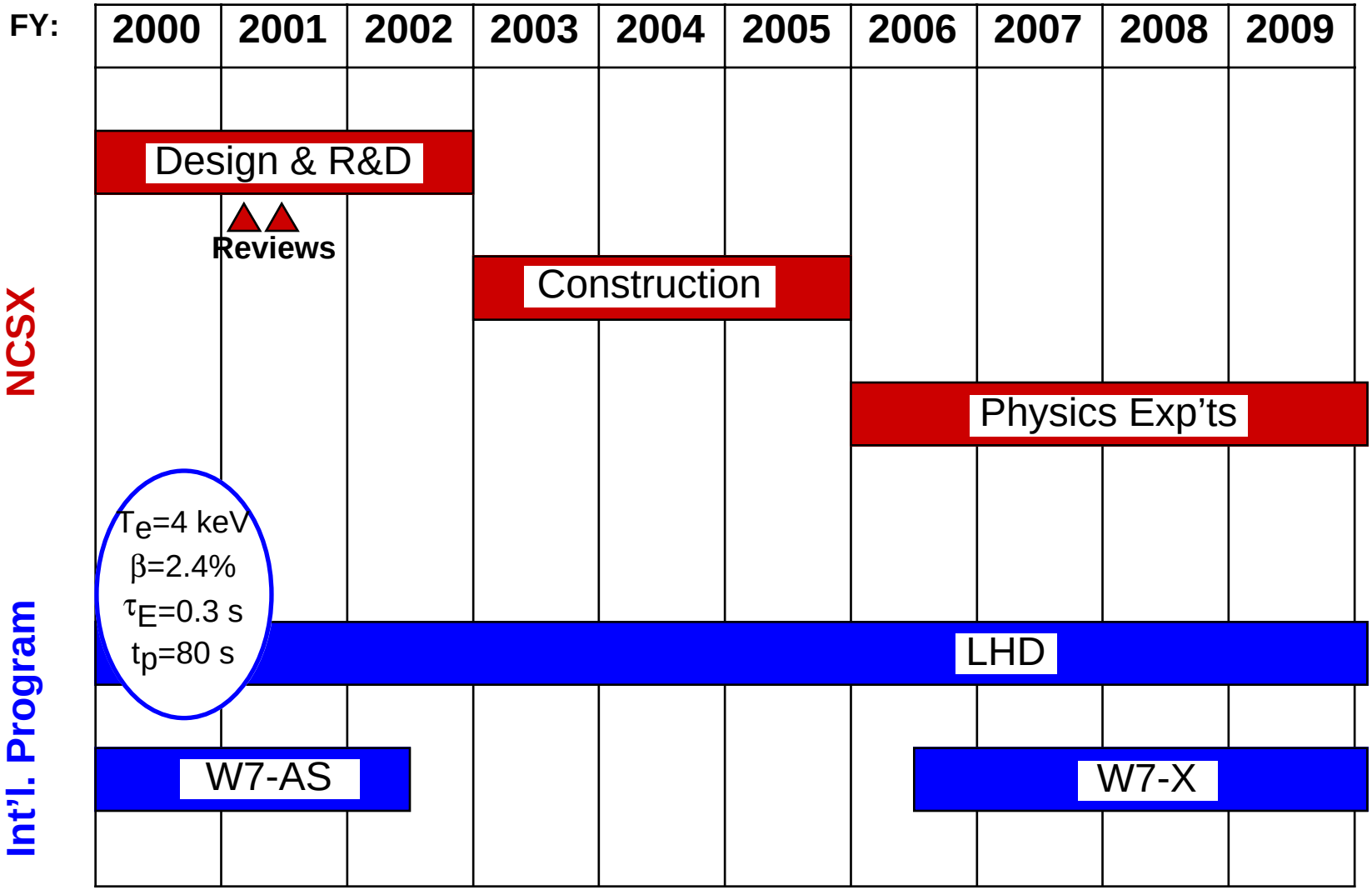
- "Determine the attractiveness of a compact stellarator…"
  NCSX (new PoP experiment): disruption-free operation, stability, transport.

- "Predict performance of externally-controlled systems."
  Use of 3D stellarator fields to control macrostability, turbulent transport.

5-Year Goals:

- "Advance fundamental understanding of plasma"
  Theory: macrostability, transport in 3D.

- Determine performance of a large stellarator (LHD)
  via international collaboration
  incorporate understanding into compact stellarator program.


FY:
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
NCSX
Design & R&D
Reviews
Construction
Physics Exp'ts
Int'l. Program
T_e=4 keV
β=2.4%
τ_E=0.3 s
t_p=80 s
LHD
W7-AS
W7-X

History of Stellarator Theory at Princeton

1951 Lyman Spitzer invents stellarator. Founds PPPL to build & study them.

1970 Lab converts C-stellarator to tokamak after poor results and theoretical predictions of poor confinement due to unconfined drift trajectories

80's Renaissance of interest in stellarators following positive results from German and Japanese experiments.

- Mynick, Chu, Boozer: confinement can be improved at low collisionallity by proper 3D design of magnetic field
- PIES: first 3D equilibrium code that can existence of good flux surfaces
- Boozer's work on drift trajectories in magnetic coordinates, lays foundation for work on drift-optimized stellarators

This work was applied by Nuehrenberg's group in late 80's to 90's, identifying 3 quasi-symmetries that give good drift-trajectories, leading to the W7-X (Germany), HSX (U.Wisc.), and NCSX designs.

History of Stellarator Theory at Princeton (2)

1996 Decision to pursue stellarator as possible experiment for PPPL. Garabedian's (NYU) quasi-axisymmetric configurations identified as particularly attractive.

1997 Design study begin in earnest when Nuehrenberg's group provides virtually all their stellarator design codes and helps us learn how to use them.

Key Contributions of PPPL Theory Dept. to NCSX Design

- Configuration design

- 3D MHD stability

  Terpsichore

- Monte-Carlo and Gyrokinetic evaluations of transport and fast-ion confinement

  GTC

  Orbit-3D

- 3D equilibrium analysis, including islands and analysis of flux surface quality

  PIES