NCSX Goals, Design Status, and Projected Plasmas

M.C. Zarnstorff
Presented by G.H. Neilson
Princeton Plasma Physics Laboratory

for the NCSX Design Team

ICC-2000, Berkeley, CA
22 February 2000

The Compact Stellarator Design Team

D. Anderson, U. Wisc.
R. D. Benson, ORNL
L. A. Berry, ORNL
B. Blackwell, ANU
A. H. Boozer, Columbia U.
A. Brooks, PPPL
T. G. Brown, PPPL
M. Cole, ORNL
W. Cooper, CRPP
M. Drevlak, IPP-Greifswald
G. Y. Fu, PPPL
P. Garabedian, NYU
A. Georgievskiy, Raytheon
R. J. Goldston, PPPL
P. Goranson, ORNL
J. Hanson, Auburn U.
P. Heitzenroeder, PPPL
S. P. Hirshman, ORNL
W. Houlberg, ORNL
S. Hudson, PPPL

M. Isaev, Kurchatov
C. E. Kessel, PPPL
L.-P. Ku, PPPL
H. Kugel, PPPL
E. Lazarus, ORNL
Z. Lin, PPPL
J. Lewandowski, PPPL
J. F. Lyon, ORNL
R. Majeski, PPPL
P. Merkel, IPP-Greifswald
M. Mikhailov, Kurchatov
D. Mikkelsen, PPPL
W. Miner, U. Texas
D. A. Monticello, PPPL
H. Mynick, PPPL
N. Nakajima, NIFS
G. H. Neilson, PPPL
B. E. Nelson, ORNL
C. Nührenberg, IPP-G.
M. Okamoto, NIFS

A. Pletzer, PPPL
N. Pomphrey, PPPL
M. H. Redi, PPPL
W. T. Reiersen, PPPL
A. H. Reiman, PPPL
G. Rewoldt, PPPL
R. Sanchez, Spain
J. A. Schmidt, PPPL
J. Schultz, MIT
R. T. Simmons, PPPL
D. A. Spong, ORNL
P. Strand, ORNL
D. Strickler, ORNL
A. Subbotin, Kurchatov
P. Valanju, U. Texas
K. Y. Watanabe, NIFS
R. B. White, PPPL
D. A. Williamson, ORNL
M. C. Zarnstorff, PPPL
I. Zatz, PPPL

Auburn U., Columbia U., ORNL, PPPL, U. Texas-Austin, U. Wisconsin.

Germany, Switzerland, Russia, Japan, Australia, Spain

Stellarators Can 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)

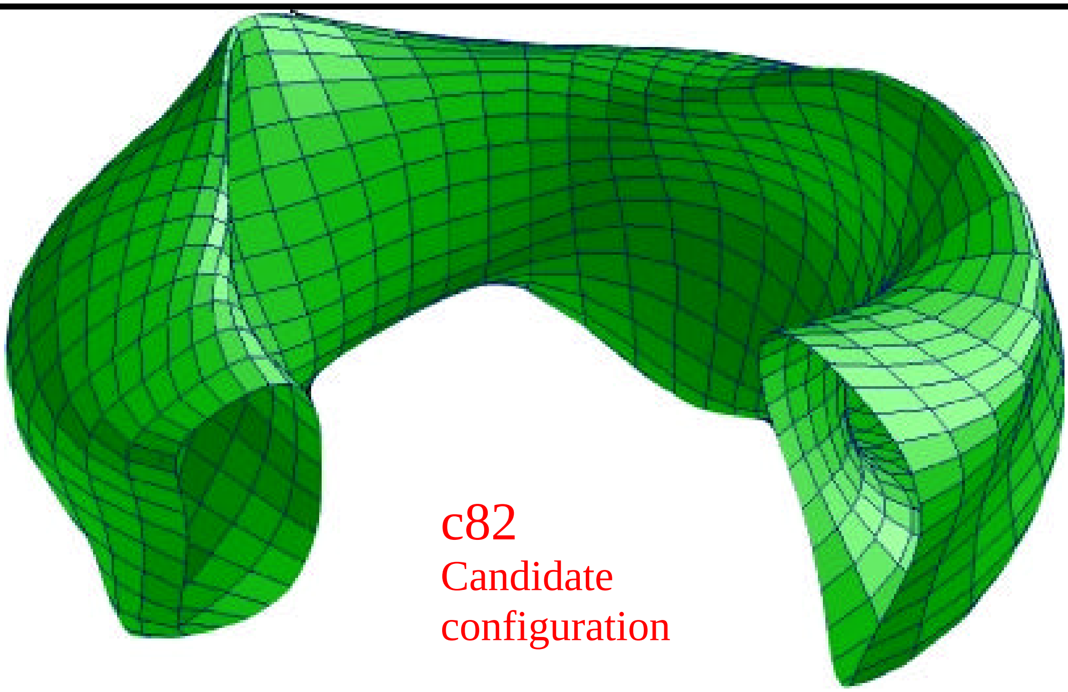
Advances in Theory and Numerical Design Capability   Compact Stellarators

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

National Compact Stellarator Experiment (NCSX)
Research Goals

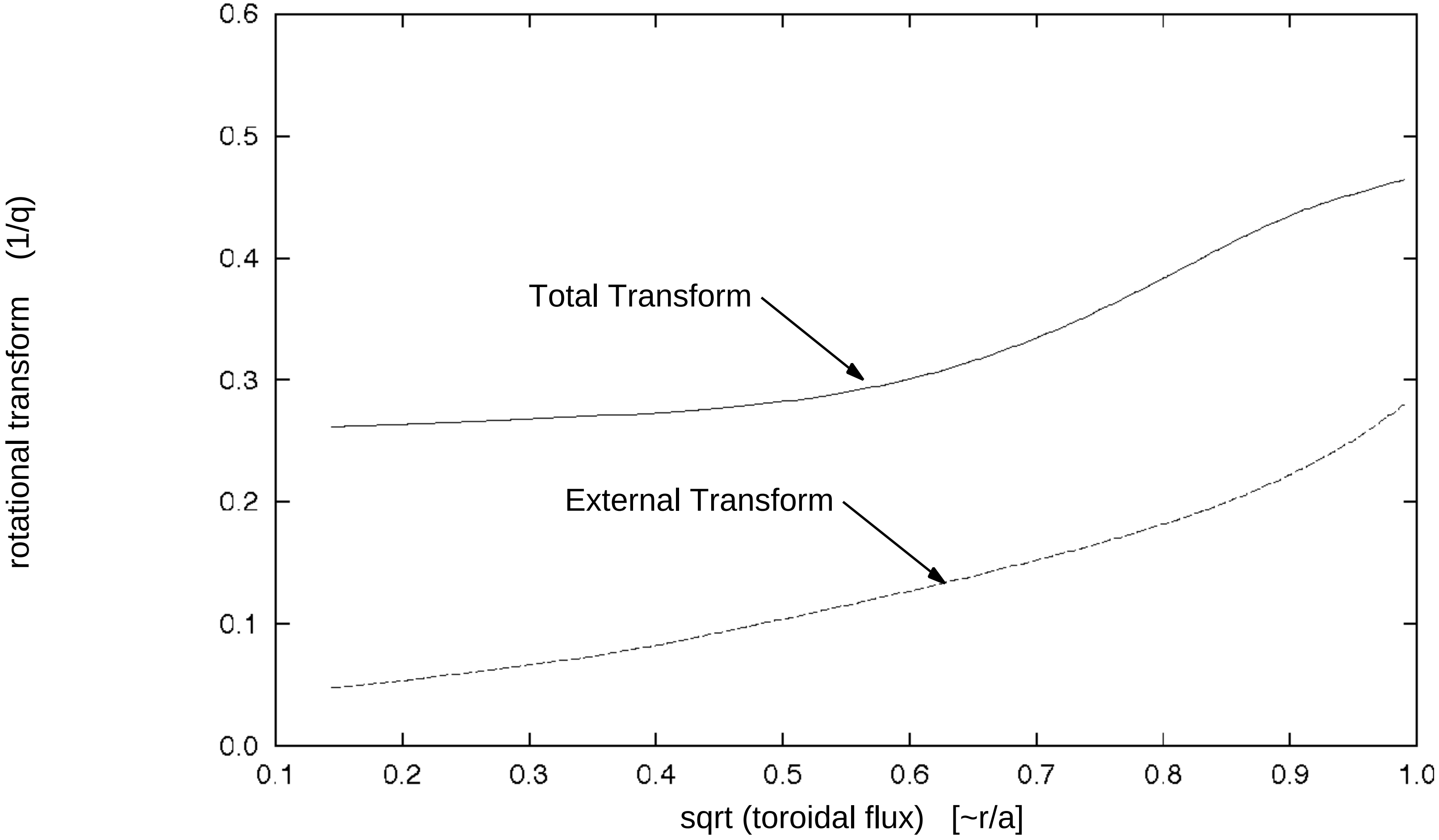
- High-beta disruption-free operation, compatible with bootstrap & external transform, at low aspect ratio (A < 4)
- Determine beta limits and limiting mechanisms
- Reduction of neoclassical transport by quasi-axisymmetric (QA) design
- Reduction of anomalous transport by flow-shear control, using reduced flow damping by QA design
- Equilibrium island and neoclassical tearing-mode stabilization by design of magnetic shear
- Test compatibility with power and particle exhaust methods

NCSX Configuration Stable at $\beta = 4\%$



- 3 periods, A =3.4, Quasi-axisymmetric
- Stable to ballooning, kink, vertical, mercier modes without conducting wall at β=4%
- Bootstrap-like current profile, increases iota.
- Stellarator shear ($dq/dr < 0$), for neoclassical island stabilization

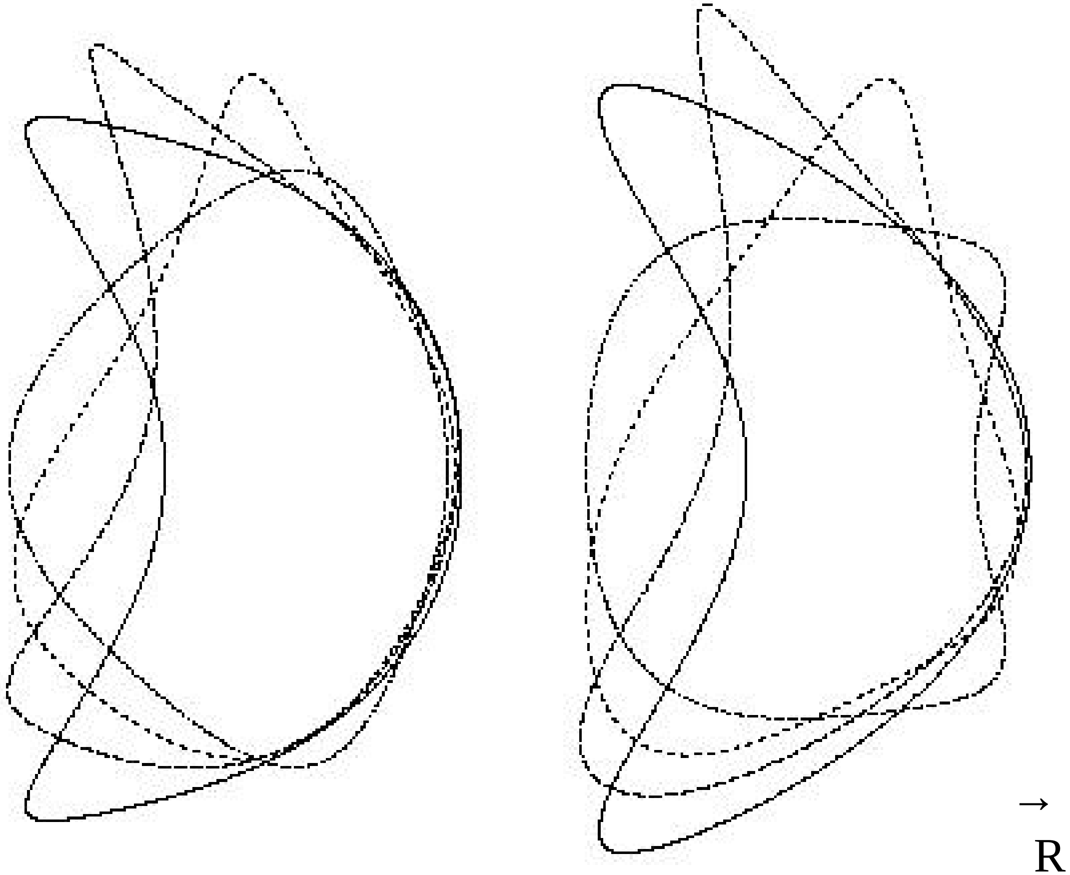
NCSX Coils provide edge shear and ~50% of transform



- Edge iota does not cross 0.5
- Sufficient external transform to prevent disruptions in W-7A & Cleo

MCZ 000222

Boundary Deformation To Stabilize External Kink

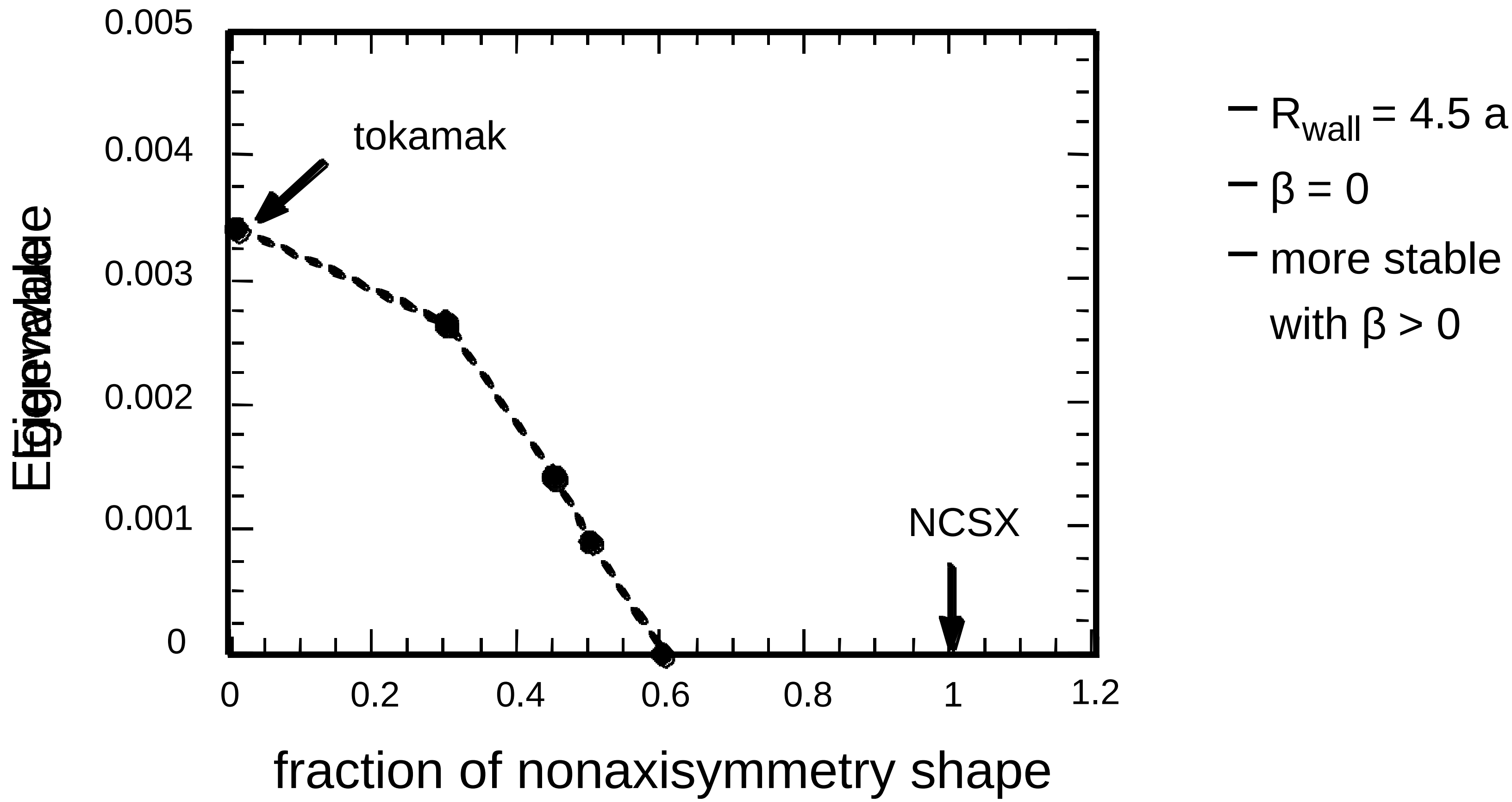


Unstable Stable

Almost identical iota profiles and shear

- **Kink also stabilized by significant edge magnetic shear**
- **Shape perturbation can be controlled with coils.**

External Transform from Stellarator Fields Stabilizes QA Vertical Instability



- Required ι_{ext}/ι for stability increases with average elongation.

NCSX Confinement Projections Using 3D Simulations

Neutral Beam Orbit Loss *vs* B

- 3D Monte Carlo orbit-following code with full collision operator.
- Co-injection $H^0 \rightarrow H^+$ favored.

Thermal Neoclassical Transport

- 3D gyrokinetic M-C code for electrons, ions.
- Assume $e(\Phi_a - \Phi_0) = T_{i0}$ to approximate ambipolar E_r (ion root); increases confinement by ~30%.
- Neoclassical confinement time B^2. Electron transport << ions.

Operating Point Projections

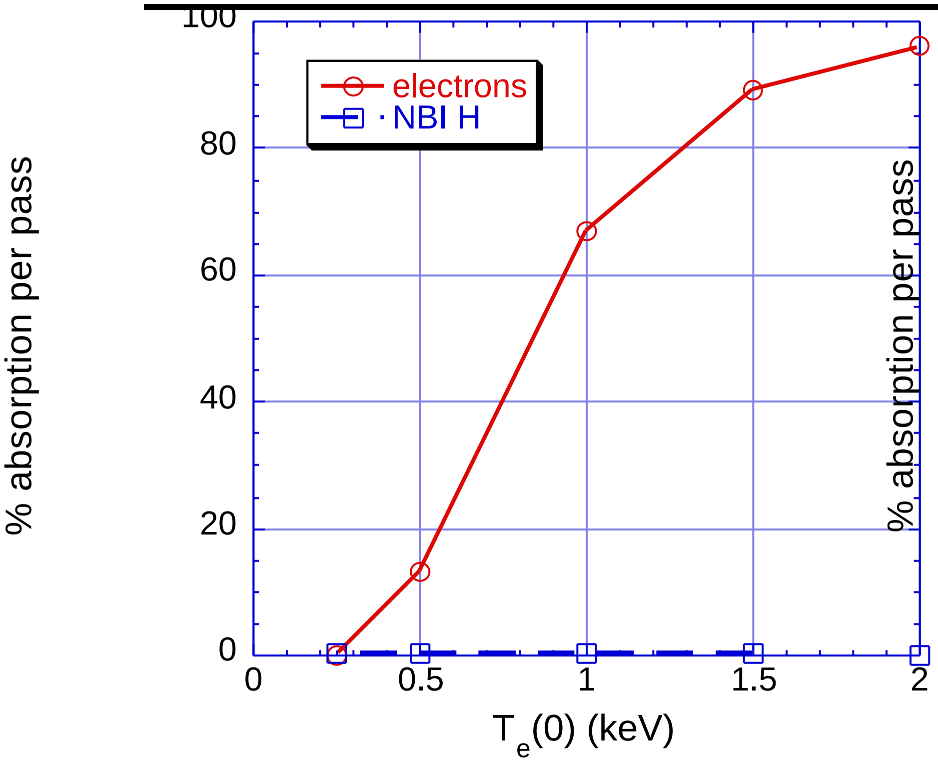
- take maximum confinement τ_E as 2.3 τ_E^{ISS95} global scaling (~best on W-7AS)
- use $\tau_E = \min(2.3\ \tau_E^{ISS95}, \tau_E^{neo}/2)$, anomalous losses ~ neo at best.

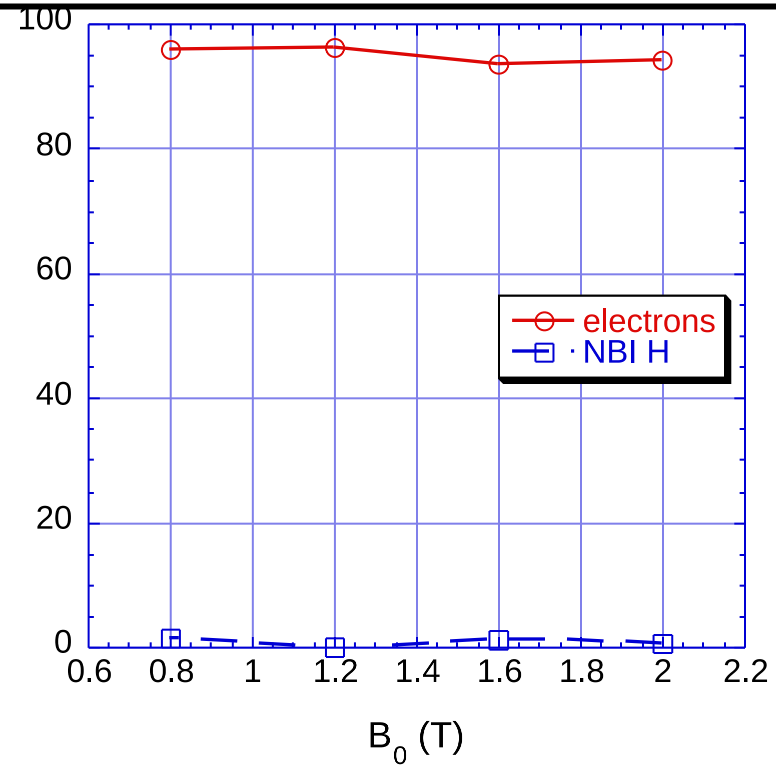
Projected β=4% Operating Point

C82, R=1.45 m, a =0.42 m, Z_{eff}=2		
Magnetic field, B (T)	1.5	
Injected power, P (MW)	6.9	
Volume-avg. beta β (%)	4.0	
Volume-avg. density, n (10^{19} m^{-3})	11.3	
Central temperature, T_0 (keV)	2.0	
Collisionality	~3 x Reactor	
τ_{Ei} (ms)	53	~ 1.6 x ITER89P

- $\tau_E^{assumed} = \min(2.3\times\tau_E^{ISS95}, \tau_E^{neo}/2)$
- NBI orbit losses per Monte Carlo calculations
- Neoclassical confinement times per gyrokinetic simulations.
- Density less than Sudo limit, by constraint.
- Includes 10% beam beta.
- In progress: improved confinement-optimization; RF heating scenarios.

High Harmonic Fast Wave Absorption is Strong over Wide Parameter Range





350 MHz), $N_{||}$ = 6.8, 2%NBI H, B_0 = 1.2T

$n_e(0) = 6 \times 10^{19}\ m^{-3}$ (parabolic$^{0.5}$), $T_e(0) = T_i(0)$,

350 MHz, $N_{||}$ = 6.8, 2%NBI H

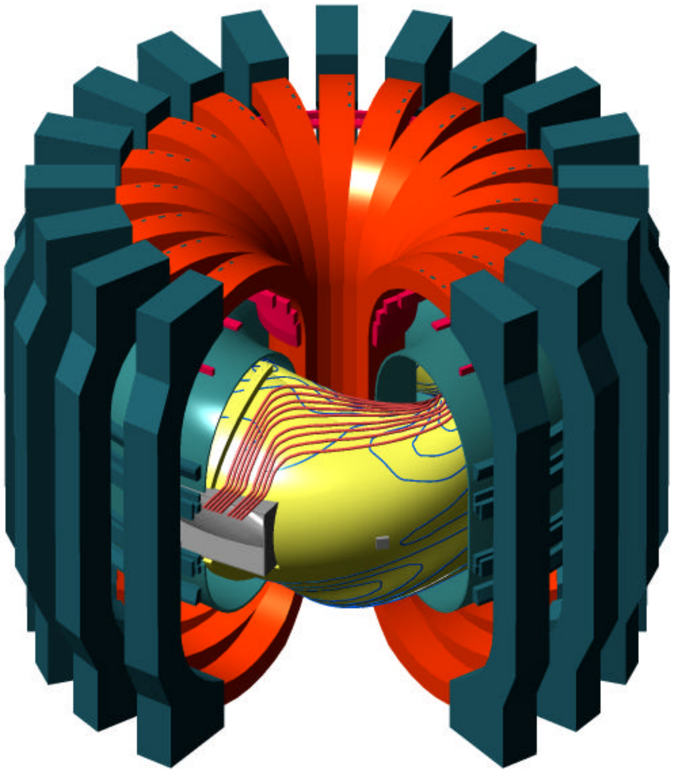
constant ß.

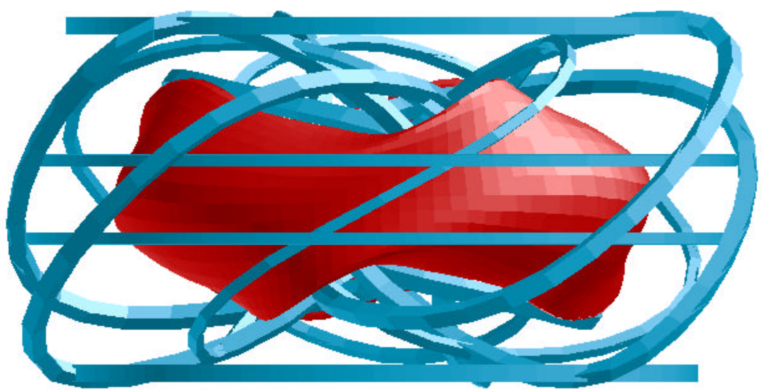
- Compact launchers; less sensitive to plasma position & shape

¾ R. Majeski, Thurs. poster

MCZ 000222

Optimized Coil Designs are Being Developed





- Re-use PBX-M TF & PF coils
- New saddle coils for 3D fields

- Optimally shaped, helical & PF coils
  no saddles needed
- Better heating & diagnostic access

Analysis to compare flexibility & robustness beginning

¾ G.H. Neilson, Wed. poster

Near-Term Plans

Re-optimize design for all physics requirements

- Flexibility and startup
- Magnetic surface robustness and transport
- Coils and heating & diagnostic access

Using improved tools

By September 2000

Establish stellarator configuration for Design Reviews

- Plasma
- Coils
- Machine construction concept

Summary

- NCSX will test whether a compact QA stellarator can operate disruption free at $\beta \sim 4\%$
- NCSX has been designed to be passively stable to kink, ballooning, vertical, and neo-tearing instabilities.
- Transport assessments indicate that $\beta = 4\%$ should be accessible (for c82) using 6.9MW of NBI.
- A number of interesting coil and machine designs have been developed. Physics benefits are being analyzed.