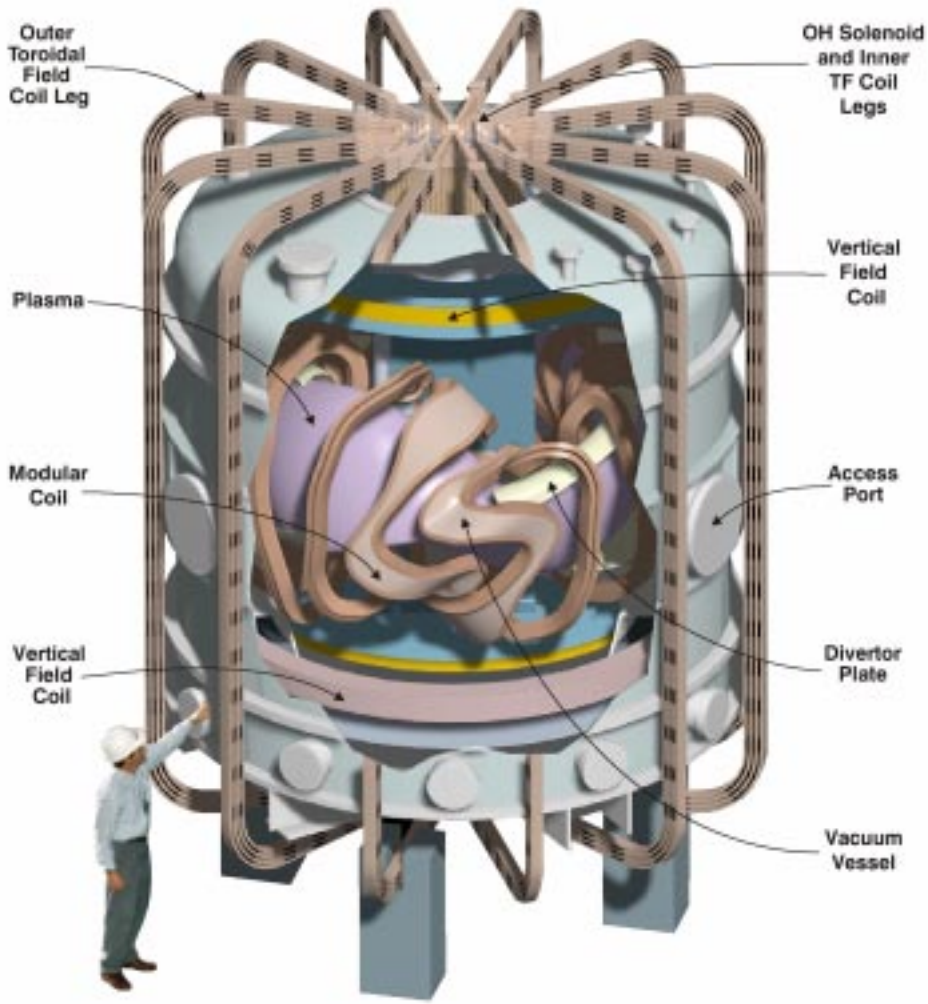

Multi-Laboratory Design Team; Project Coordinator – J.F. Lyon, ORNL

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QPS -- a two-period quasi-poloidal stellarator configuration

- $\langle R_0 \rangle = 0.90$ m
- $\langle a_p \rangle = 0.33$ m
- $\langle B_0 \rangle = 1$ T $\pm$ 0.2 T for 1 s
- $I_{plasma} \leq 150$ kA
- $P_{ECH} = 0.6$–1.2 MW
- $P_{ICRF} = 1$–3 MW

QPS Improvements This Year

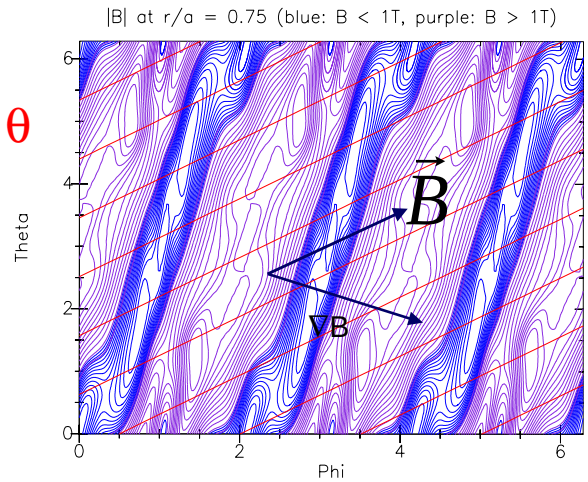
- Neoclassical losses reduced by factor 19, at same level as in W 7-X with 4 x *R*/*a*
- Departure from quasi-poloidal symmetry reduced by factor 2.7
- Space in middle increased to accommodate TF coil legs and OH solenoid
- Increased plasma-coil and coil-coil spacings
- Modular coils modified to reduce errors in reconstructing B field by factor 2.2
- Vacuum vessel modified to eliminate eddy currents induced by PF system

Stellarator Concept Optimization Employs Quasi-Symmetry

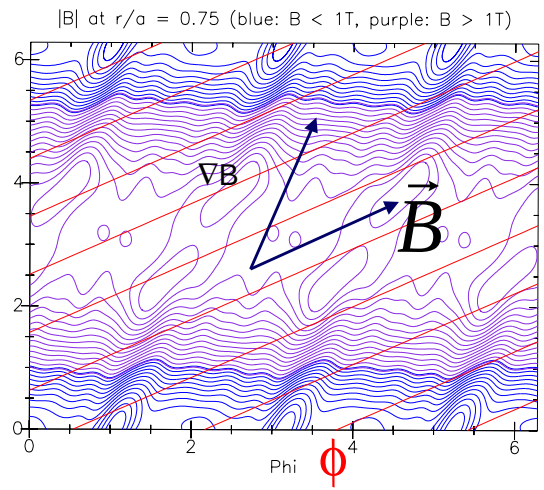
Magnetic field structure has a dominant symmetry in magnetic field line coordinates

- **$|B| = \sum B_{mn}(\psi) \cos(m\theta - n\phi)$; θ and ϕ poloidal and toroidal angle variables**

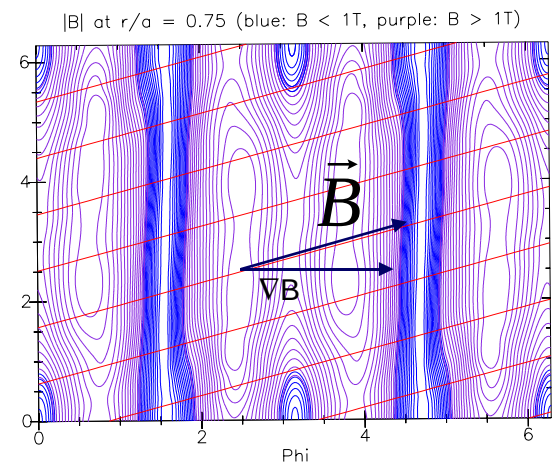
Quasi-Helical



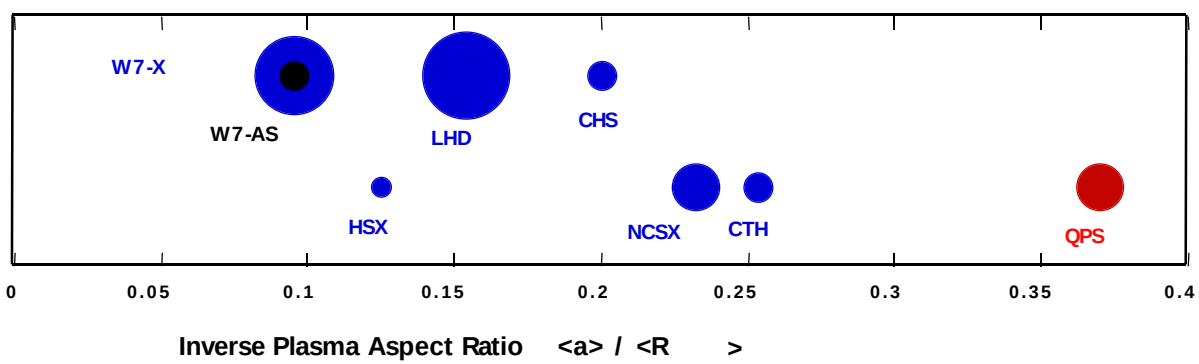
Quasi-Axisymmetric



Quasi-Poloidal

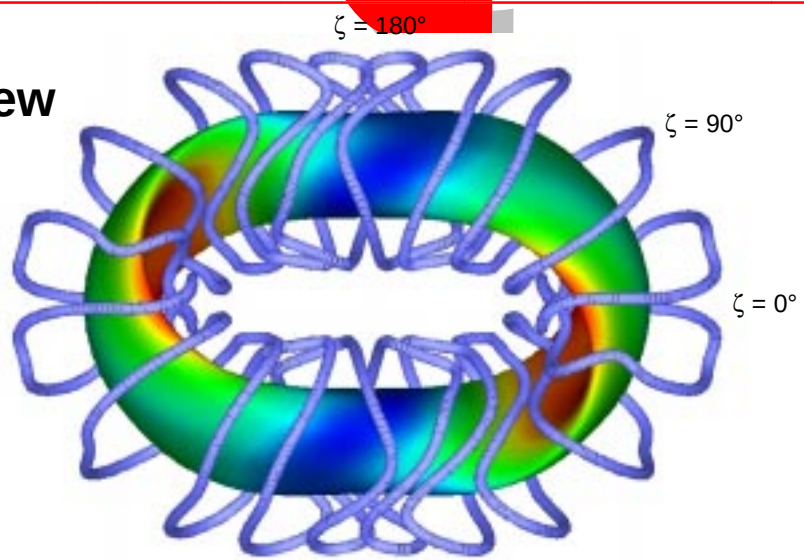


- **Quasi-helical: $m = n$ terms dominant, $m \neq n$ terms very small. |B| nearly helical (like very large R/a stellarator) in field line coordinates. HSX (R/a = 8) will test this concept.**
- **Quasi-axisymmetric: $n = 0$ terms dominant, $n \neq 0$ terms very small. |B| nearly axisymmetric (like tokamak) in field line coordinates. NCSX (R/a = 4.3) would test this approach.**
- **Quasi-poloidal: $m = 0$ terms dominant, $m \neq 0$ terms small. |B| nearly poloidally symmetric (toroidally linked mirrors) in field line coordinates. QPS (R/a = 2.7) would test this approach.**

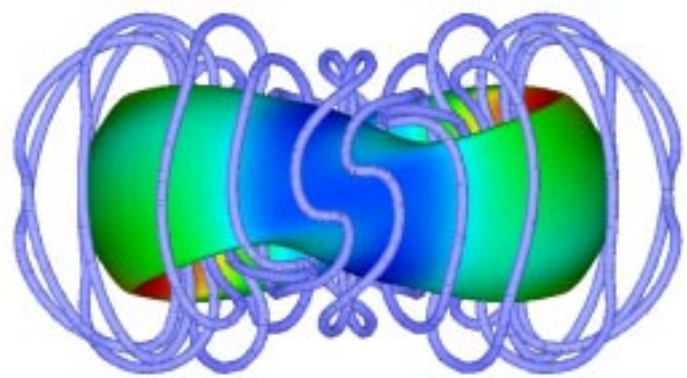


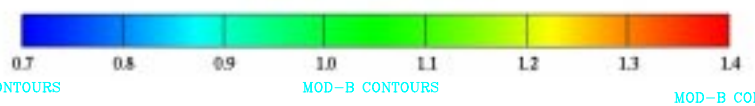
QPS

Top View

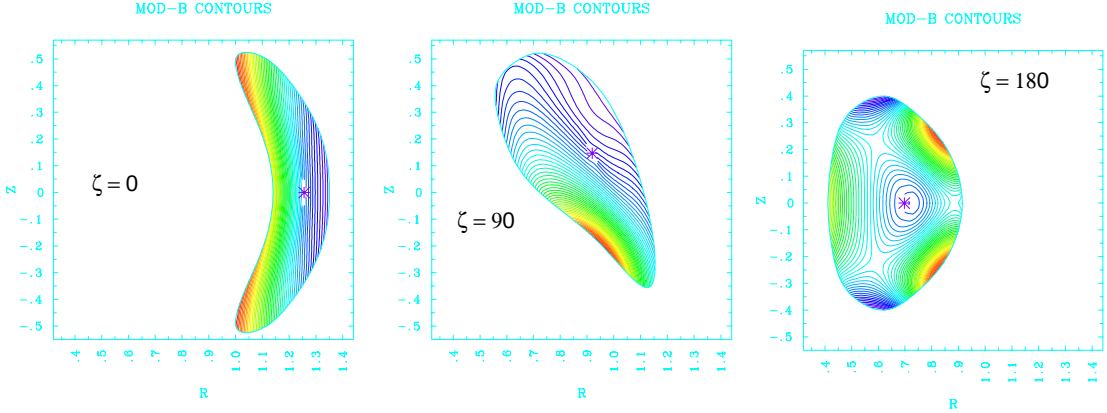


Side View from Middle

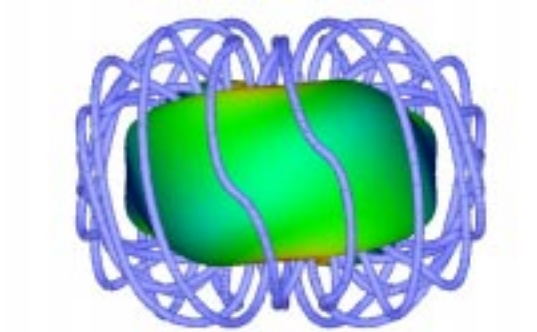




|B| (T)

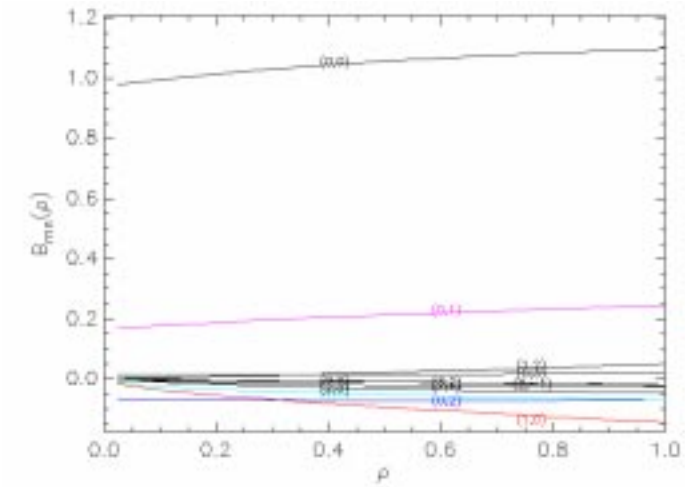


Side View from End

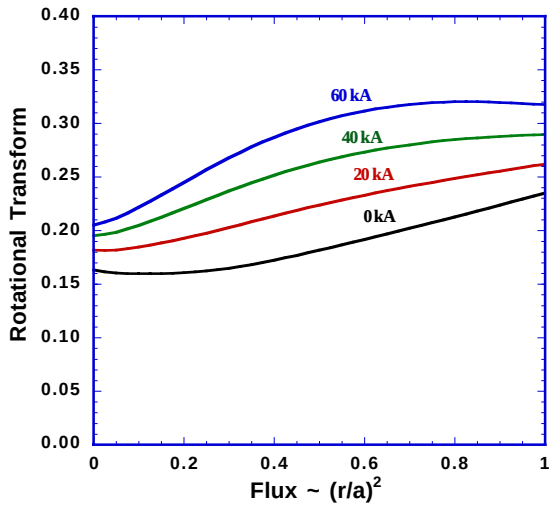


Configuration Properties

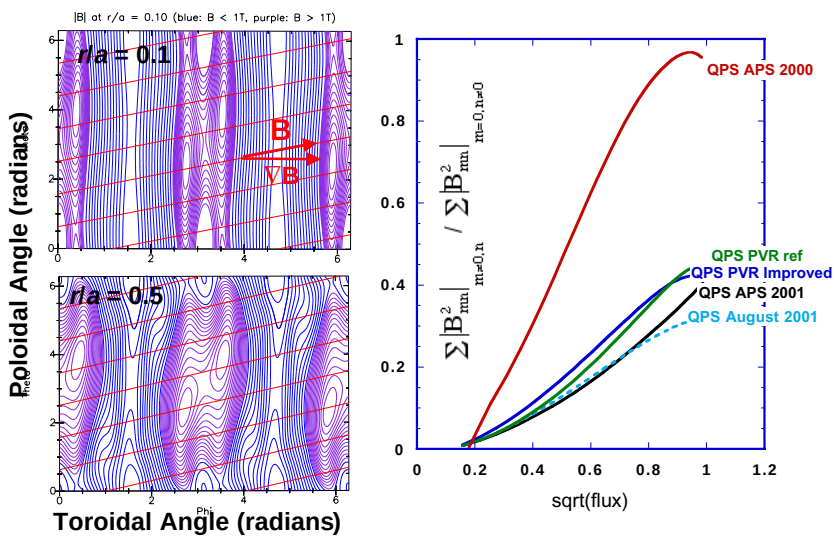
The B_{mn} Spectrum Shows that the Dominant Symmetry is in the Poloidal Direction



Part of the Rotational Transform Is due to the Bootstrap Current in QPS

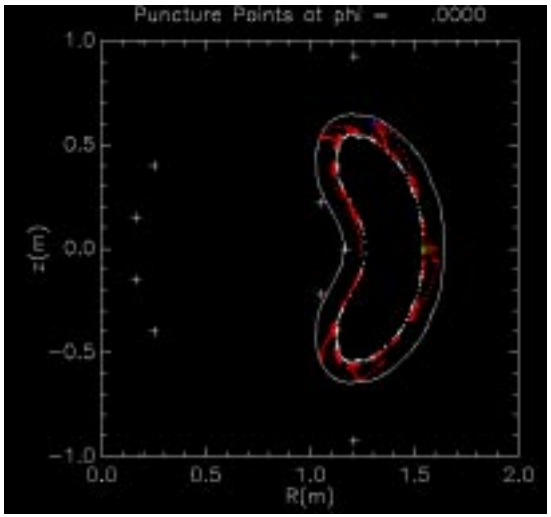


Quasi-Poloidal |B| Structure Varies with Radius



- The *B* x ∇B drift can be made very small in this approach.

Structure of Field Lines Outside the LCFS Allows Island Divertor

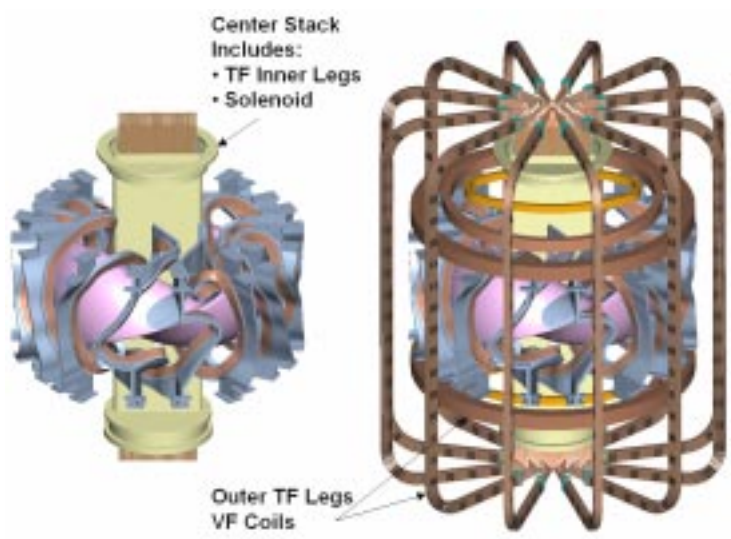


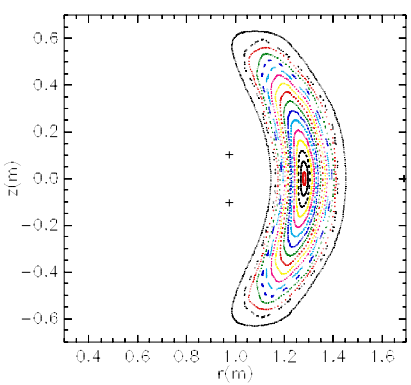
30 field lines were launched, starting at the midplane/LCFS and moving out 2 mm at a time.

When the field lines are intercepted by a 10-cm conformal surface, they are stopped.

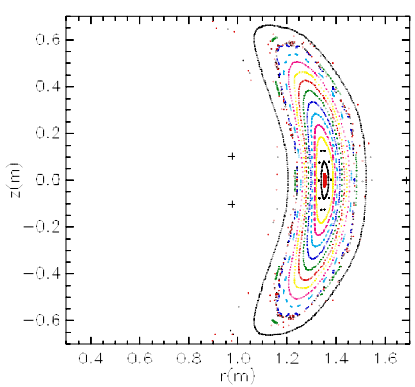
Island formation is clearly observed, specially in the top and bottom of the cross section.

A New *R*/*a* = 2.7 Quasi-Poloidal





I_{vf} = 204 kA



I_{vf} = 100 kA

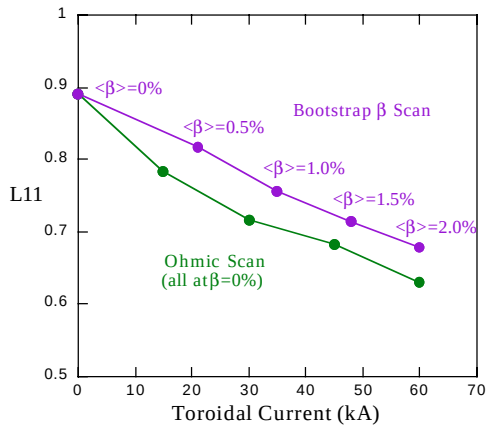
TF, VF Coils and OH Solenoid Provide Flexibility

- Can modify B_{mn} spectrum to study effect on equilibrium quality, MHD stability, and neoclassical transport
- Different currents in the modular coils allow changing rotational transform& shear, helical axis excursion, mirror field component, plasma shape, and *R*/*a*
- VF coils can shift axis and shape the plasma surface
- TF coils (±0.2 T) to change rotational transform & shear
  - repair outer surfaces due to magnetic islands
  - change the aspect ratio a factor of 2
  - use magnetic islands to bound the plasma or for divertor studies
- OH solenoid and VF coils can drive plasma current up to ±150 kA and change/reverse shear
  - test reducing magnetic islands and stabilizing tearing modes

VACUUM surface from coil set are good and robust to VF current variations

Confinement Properties

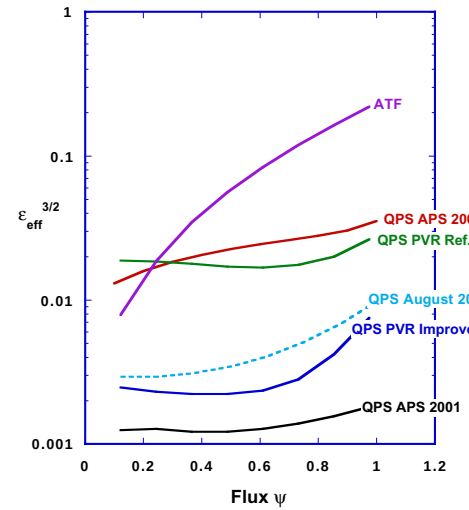
Ohmic and Bootstrap Currents have Similar Effects on Transport



DKES (Drift Kinetic Equation Solver) radial transport coefficients on S = 0.7 surface

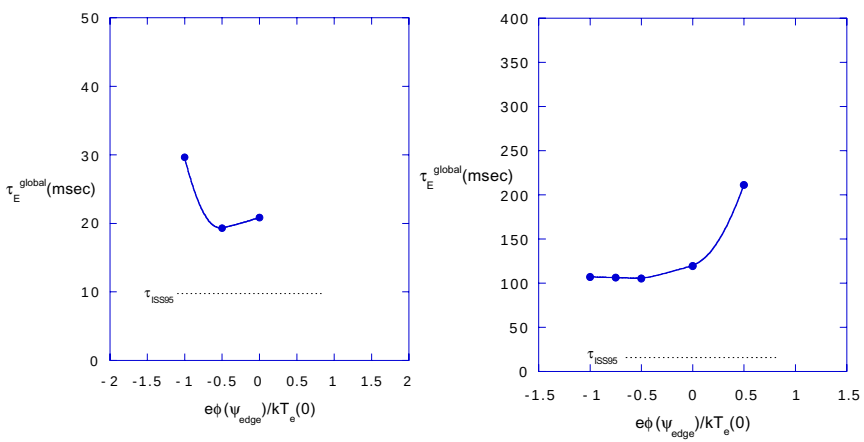
Allows control of confinement

Newer QPS Configurations Have Much Smaller Neoclassical Transport



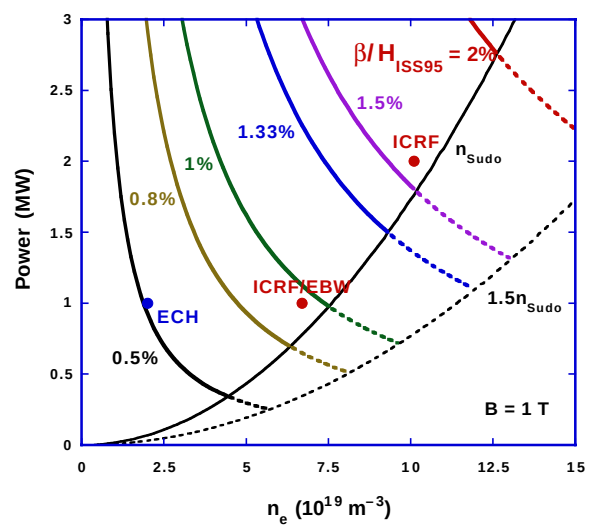
Transport similar to that in W 7-X, QPS has 4 times Lower aspect ratio

ISS-95 Confinement Dominates Neoclassical Confinement



Newer QPS configurations have significantly better neoclassical confinement

P = 1-3 MW Gives the Parameters Needed for the QPS Objectives

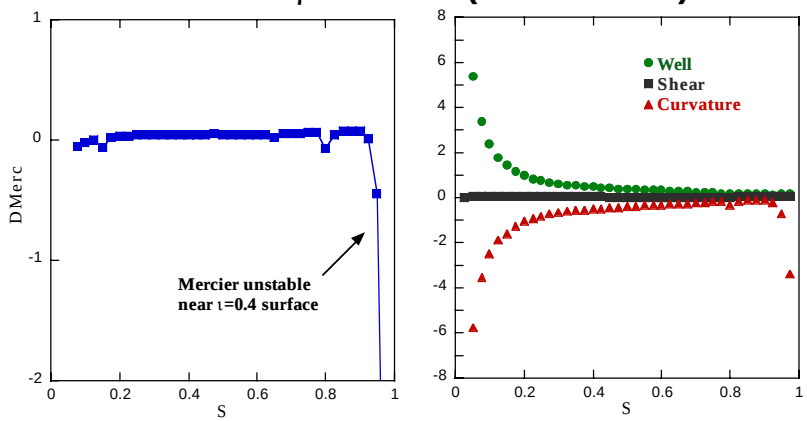


Multiply contour values by H_{ISS95} (= 1-2.5 in experiments)

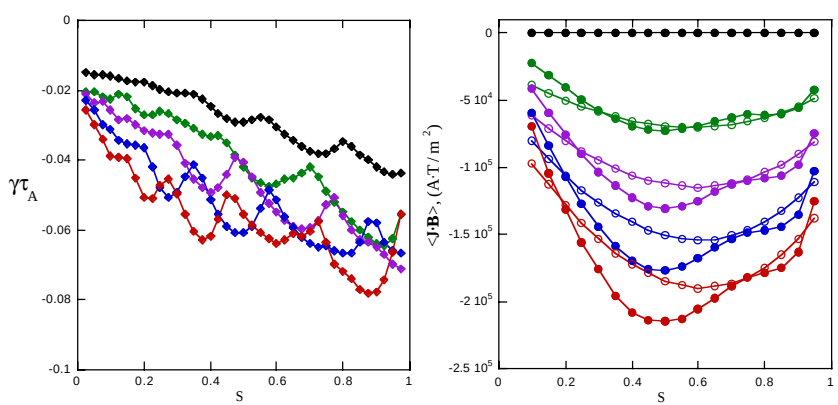
QPS parameter space for *B* = 1 T

Low-Bootstrap Stellarator

Mercier stability criteria for a fixed boundary case at <β> = 2.5% (> 0 is stable)



Ballooning growth rate & parallel current, free boundary β scan



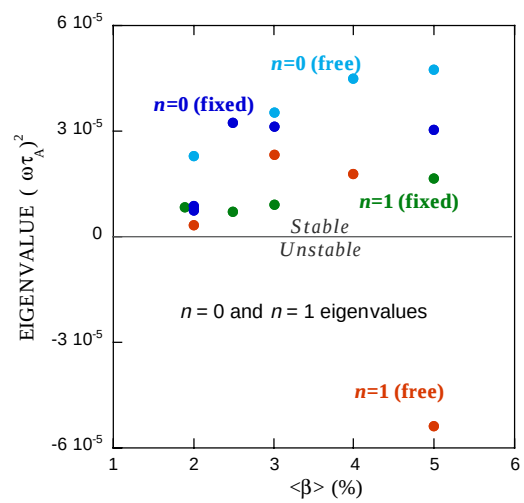
S ~ (r/a)²

MHD Stability

Mercier Stability: a magnetic well provides stability except at isolated resonances

Ballooning Stability: free boundary scan is stable & bootstrap consistent to β = 2.3 %

Kink & Vertical Stability: QPS configuration is kink/vertical stable for <β> < 5%



Objectives and Plans

QPS Program Objectives

- Confinement understanding
  - Anomalous transport, internal transport barriers, and flow shear in low-*R*/*a* configurations with quasi-poloidal symmetry
  - Reduction of neoclassical transport due to near alignment of *B* and ∇B
  - Impact of poloidal flows on enhanced confinement
  - Equilibrium quality (islands, ergodic regions) and its repair at *R*/*a* ~ 2.7; robustness with β and dependence of bootstrap current on configuration properties
  - Understand β limits and limiting mechanisms for quasi-poloidally symmetric configurations at very low *R*/*a*
- Explore physics not obtainable from very-high-R/a quasi-poloidal W 7-X or other experiments and theory
  - effect of strong toroidal coupling
  - significant bootstrap current in quasi-poloidal geometry
  - different neoclassical transport reduction mechanism
- Study fundamental issues common to low-β and high-β quasi-poloidal configurations
  - scaling of the bootstrap current with β
  - reduction of H-mode power threshold
  - flux surface robustness as beta increases due to reduced parallel bootstrap current
  - ballooning instability character and limits

Status and Plans

- Successful Physics and Project Validation reviews by DOE in April and May
- Further improve the plasma and coil configuration
- Complete assessment of QPS physics properties
- Assess flexibility obtained with VF, TF, and OH solenoid
- Improve engineering design and cost/schedule estimates
- May 2002: Design, Cost & Schedule Review; Project Validation Review
- 2003-2007: R&D, design and construction
- March 2007: first plasma

Diagnostics and Experimental Schedule

Resource/Phase	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Objective	Commissioning	Vacuum configurations	Configuration characterization	Heating, confinement	Power, particle control	MHD limits
Heating			ECH 500 kW B = 0.5 T	ECH 1 MW B = 1.0 T		ECH + ICH 2 MW total
CCD camera, H-alpha filter Fast diamagnetic loop 2 mm interferometer Fluorescent screen/rods						
Soft X-ray arrays Spectroscopy Rogowski coils/magnetic loops Bolometers Probes						
Charge exchange YAG Thomson scattering Reflectometer						
Filtered CCD cameras Divertor probes IR camera Divertor bias plates						
Edge interferometer Heavy ion beam probe High frequency magnetic probes Fast X-ray array						
Vacuum surface quality Equilibrium, flux surface robustness Bootstrap current Power balance Transport MHD stability Plasma edge, divertor geometry						

Under discussion
Planned
Primary issue emphasis