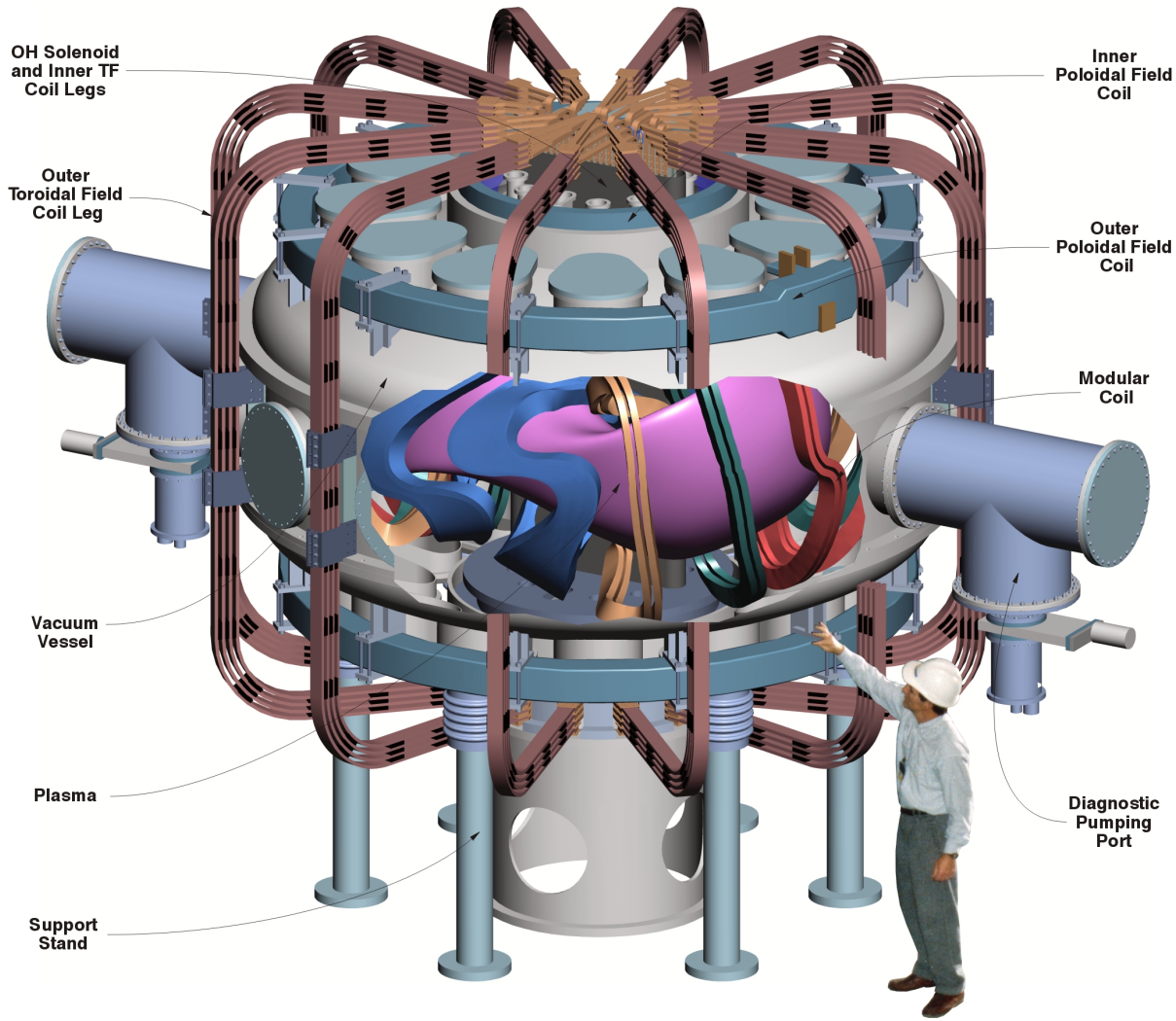
Physics Issues for a Very-Low-Aspect-Ratio



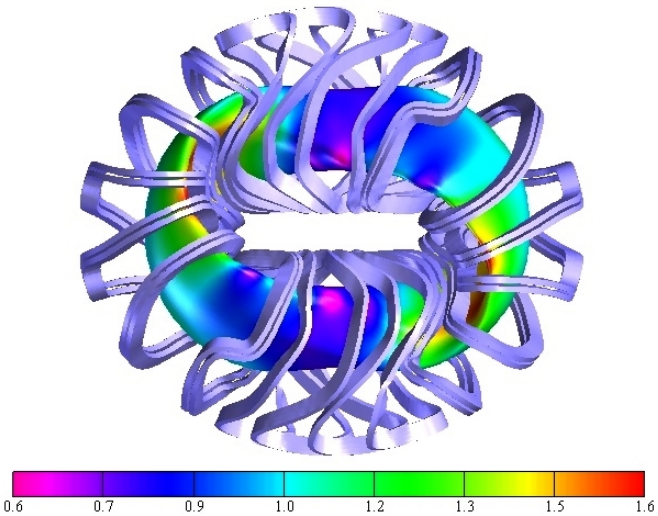
A quasi-poloidal stellarator with very low plasma aspect ratio (R/a ~ 2.7, 1/2-1/4 that of existing stellarators) is a new confinement approach that could ultimately lead to a high-beta compact stellarator reactor. The Quasi-Poloidal Stellarator (QPS) experiment is being developed to test key features of this approach. The QPS will study neoclassical and anomalous transport, stability limits at β up to 2.5%, the configuration dependence of the bootstrap current, and equilibrium robustness.

The quasi-poloidal symmetry leads to neoclassical transport that is much smaller than the anomalous transport. The reduced effective field ripple may also produce reduced poloidal viscosity, enhancing the ambipolar E x B poloidal drift and allowing larger poloidal flows for reduction of anomalous transport.

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

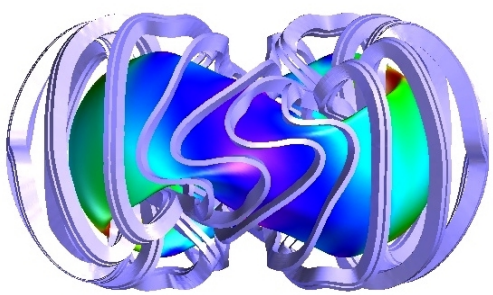
Quasi-Poloidal Stellarator (QPS)

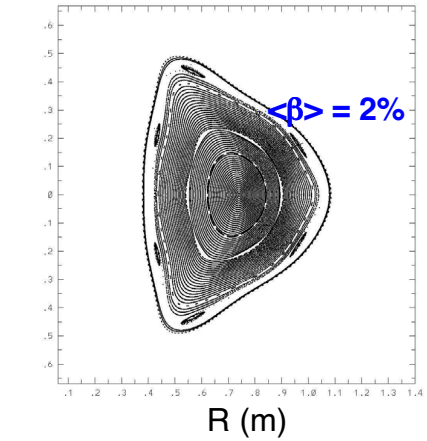
Top View of Plasma and Coils

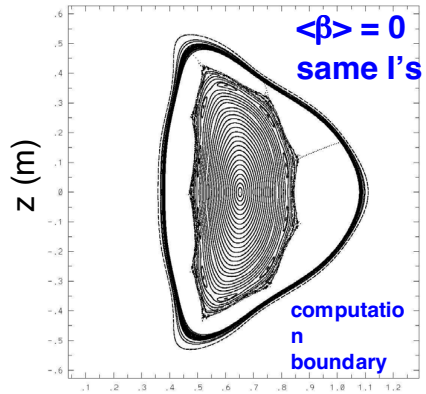


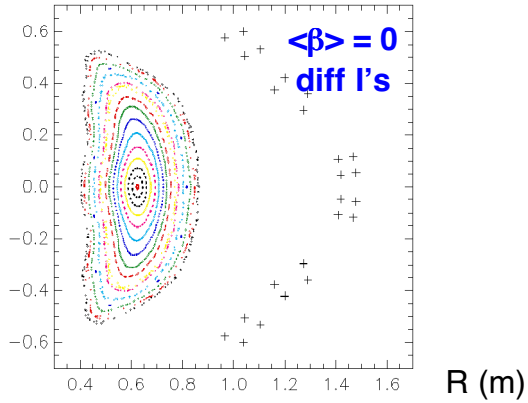
B (T)

Side View from Middle

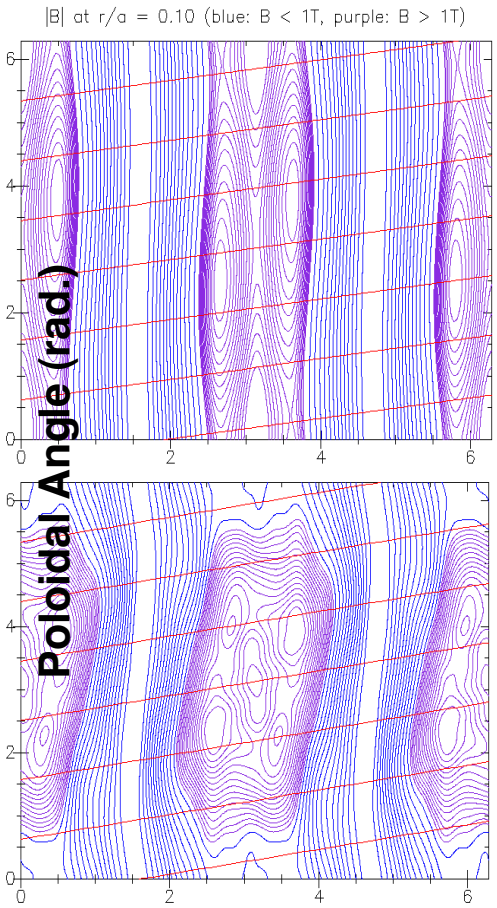






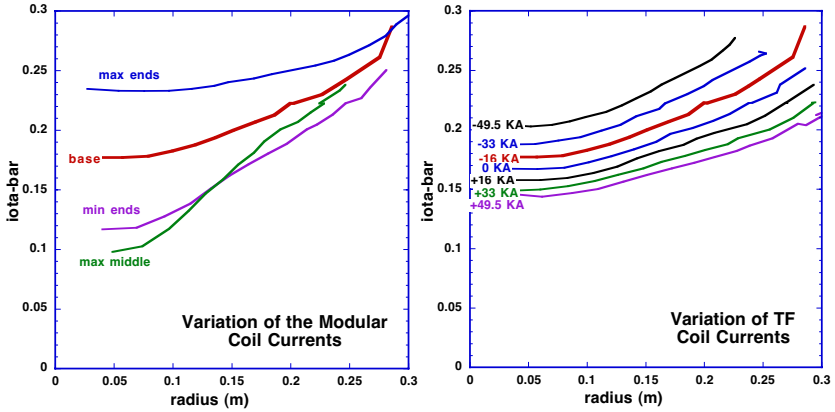


|B| Contours illustrate quasi-poloidal |B| structure



Plasma Properties

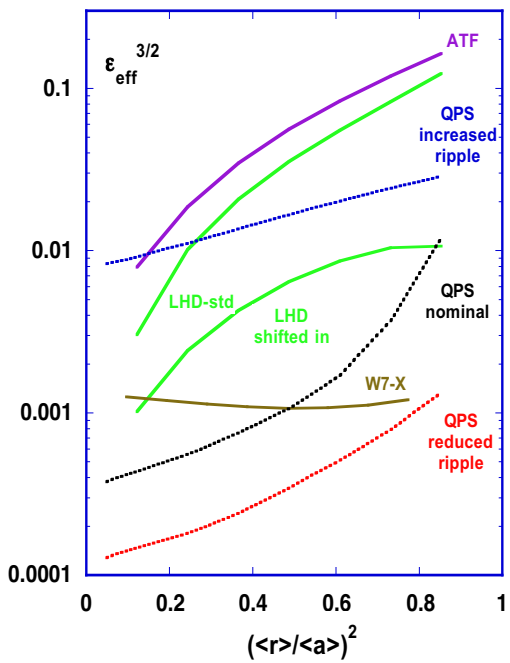
QPS Coils Allow Variation of Rotational Transform and Shear



QPS Coil Set Allows Testing Neoclassical Transport

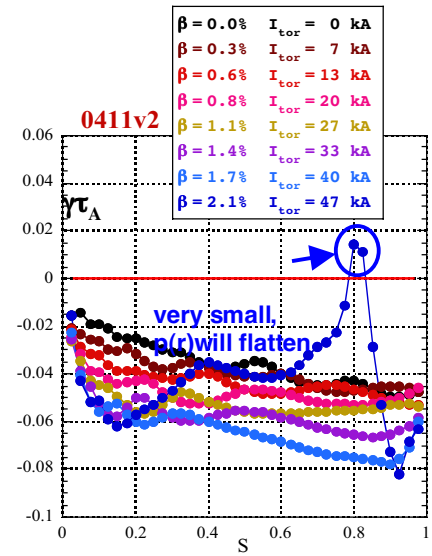
Changing currents in QPS coils varies neoclassical transport by factor 8-20

- Can change from neoclassical being dominant over plasma core to not being significant
- Base QPS is ~10x better than 2001 version, ~ W 7-X value

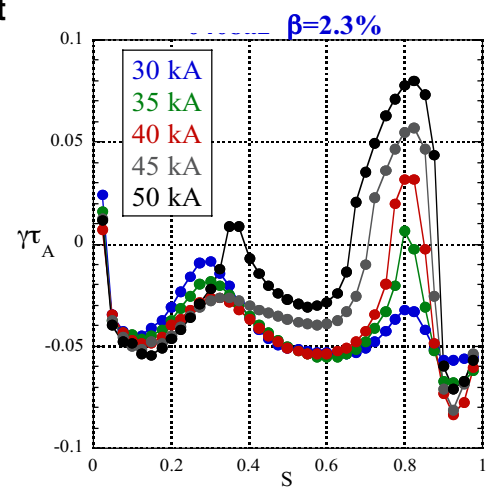


A Stable Path Exists from Vacuum to β = 2.1%

- Infinite-n ballooning growth rates vs. $S = (r/a)^2$
- Fixed (unoptimized) plasma pressure profiles

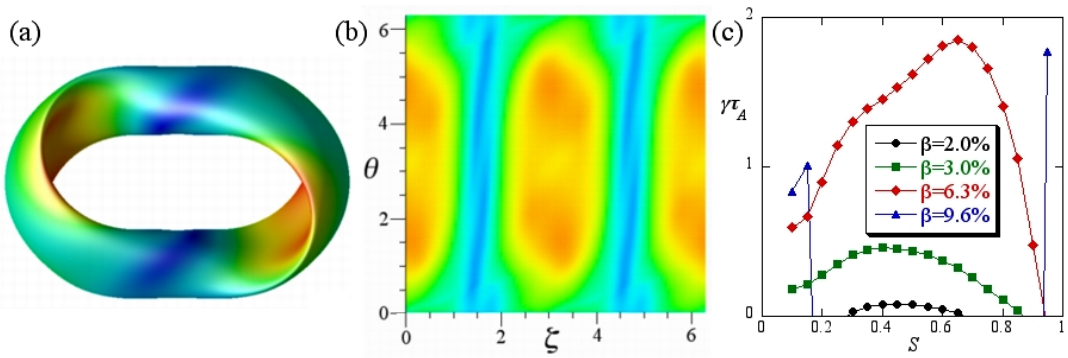


- Lower plasma current leads to higher ballooning β limits



High-β Quasi-Poloidal Hybrid Configurations

Infinite-n ballooning modes are unstable for <β> = 2.5-5.5% in QPS, but stable at higher β. The figure below shows a QPS configuration with β = 9.6%. As β is increased above 2%, the plasma becomes ballooning unstable. At β > 6% the core plasma enters a region of second stability which grows as β is increased until at β = 9.6% only a few surfaces near the edge remain unstable.



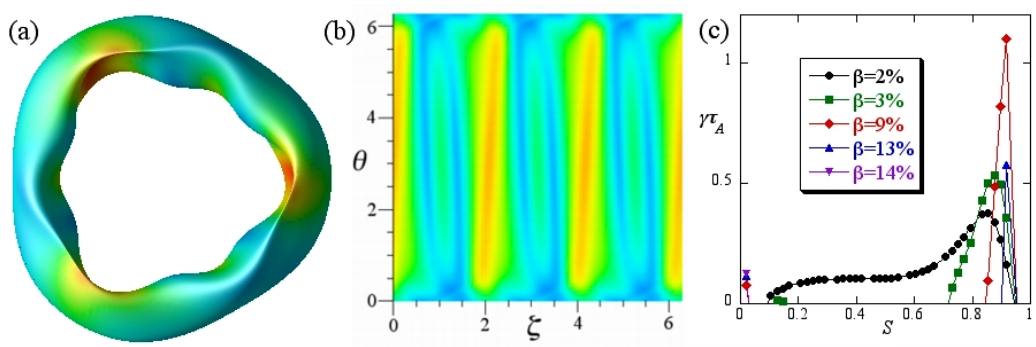
(a) The last closed flux surface of a QPS experiment reference case with (b) contours of |B| in flux coordinates for the $(r/a)^2$ = 0.75 surface and (c) normalized ballooning growth rates for a range of β.

The non-axisymmetric ($n \neq 0$) Fourier components of $|B|$ reduce the neoclassical bootstrap current to 1/3-1/5 that in an equivalent tokamak, resulting in stability to low-n ideal MHD kink modes for β up to β = 11% for kink and vertical stability. At this value of β, the Troyon factor β_N is 19, significantly larger than the β_N ~ 3 for kink stability in an equivalent tokamak with no wall stabilization.

Mercier and infinite-n ballooning-stable configurations with self-consistent bootstrap current were found for plasmas with 2% < β < 23%. Decreasing beta with fixed shape and rotational transform profile resulted in ballooning-unstable configurations for β < 15%. However, relatively small shape and profile modifications can produce ballooning stable plasmas at all values of β < 23%.

Another type of qps configuration is very-high-β hybrid configurations with a high-shear tokamak-like rotational transform profile [$\iota(0)$ ~ 0.4 to $\iota(a)$ ~ 0.1, primarily from bootstrap current]. These hybrids are distinguished by a relatively small external rotational transform arising from external coils (typically, ι_{coils} ~ 0.05-0.10). Their primary symmetry is similar to the QPS configuration but the dominant symmetry breaking terms are not the same.

The figure to the right shows the last closed flux surface for a three-field period hybrid qps configuration with A = 3.7 and β = 15%. Con-tours of $|B|$ in flux coordinates on the $(r/a)^2$ = 0.75 surface show the qps symmetry. The degree of quasi-poloidal symmetry increases and the neoclassical transport and fast ion losses decrease as β increases.



(a) The last closed flux surface of a three-field period, β = 15%, A = 3.7, qps configuration with (b) contours of |B| in flux coordinates for the $(r/a)^2$ = 0.75 surface and (c) normalized ballooning growth rates for a range of β.