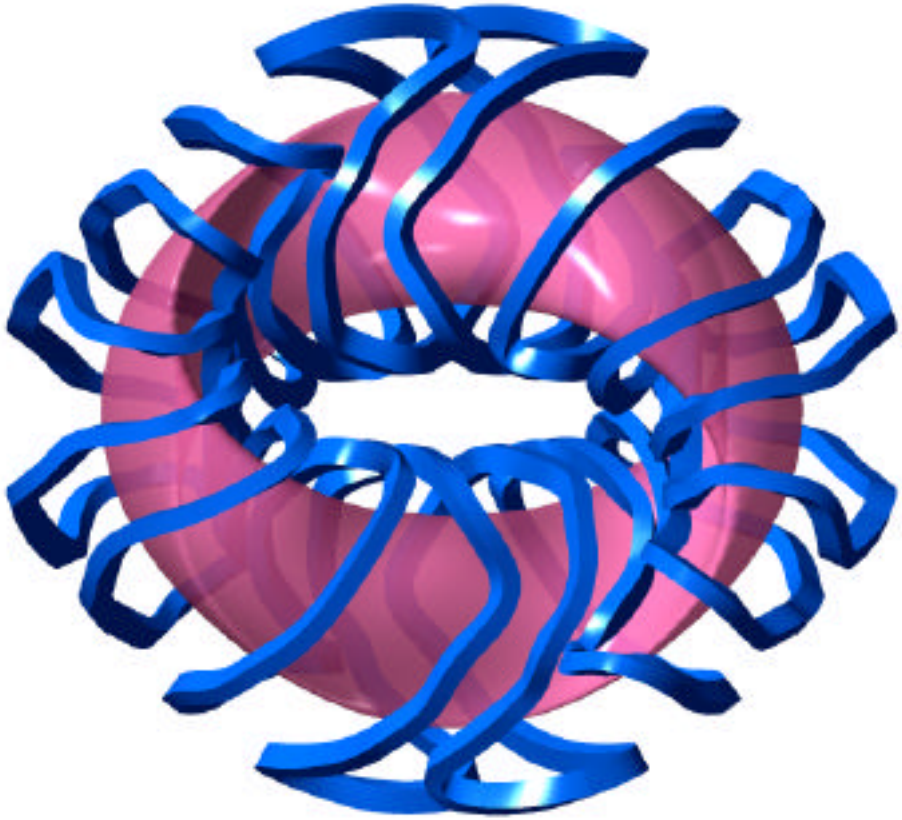
QOS Introduction

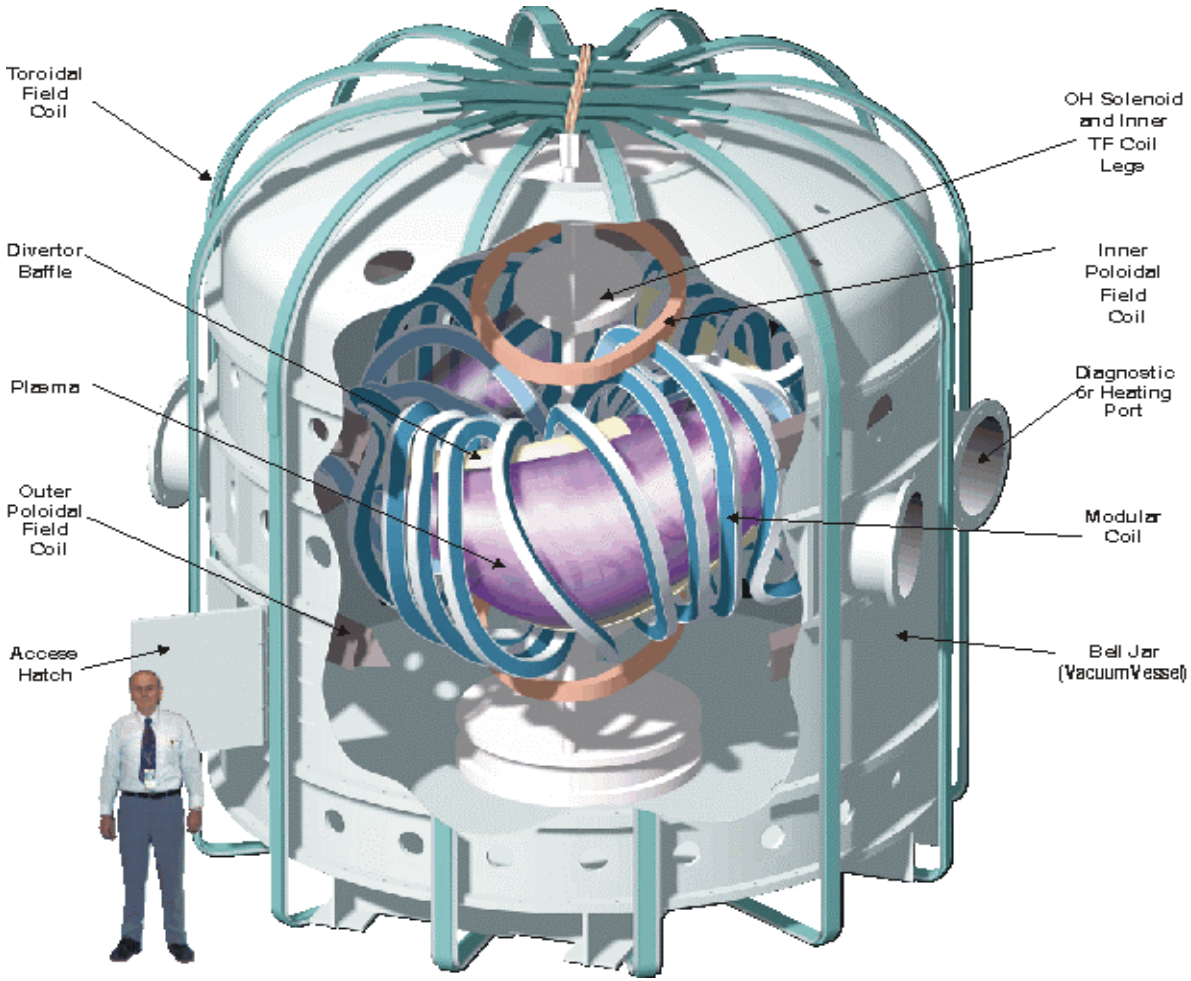


J.F. Lyon

QOS Project Meeting Feb. 28, 2001

QOS

a Low-R/a Quasi-Poloidal Stellarator



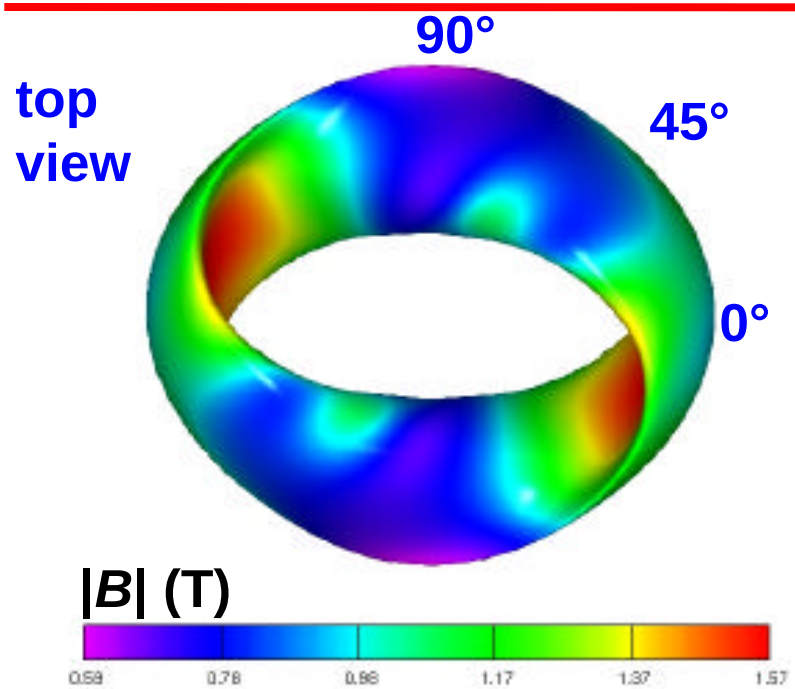
- $\langle R \rangle = 0.95$ m
- $\langle a \rangle = 0.37$ m
- $\langle R \rangle / \langle a \rangle = 2.6$
- $V_{pl} = 2.5\ m^3$
- $\iota_0 = 0.26$, $\iota_a = 0.39$
- $B_{mod} = 1$ T (0.5 s)
- $B_T = \pm 0.15$ T
- $I_p \leq 70$ kA
- $P_{ECH} = 0.6\text{-}1.2$ MW
- $P_{ICRF} = 1\text{-}3$ MW

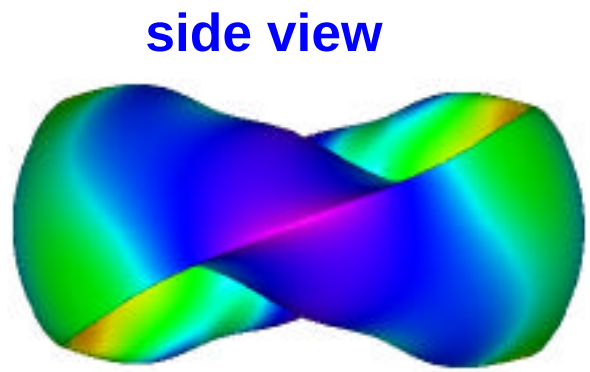
Multi-Laboratory QOS Design Team

- **ORNL – D.B. Batchelor, L.A. Berry, M.J. Cole, R.H. Fowler, P. Goranson, E.F. Jaeger, S.P. Hirshman, J.F. Lyon, P.K. Mioduszewski, B.E. Nelson, D.A. Rasmussen, D.A. Spong, D.J. Strickler, D.E. Williamson**
- **U. Texas at Austin – W.H. Miner, jr., P.M. Valanju**
- **U. Montana – A. Deisher, D. Heskett, A.S. Ware**
- **PPPL – G.Y. Fu, D.A. Monticello**
- **U. Tennessee – T. Shannon**
- **Universidad Carlos III de Madrid, Spain – R. Sanchez**

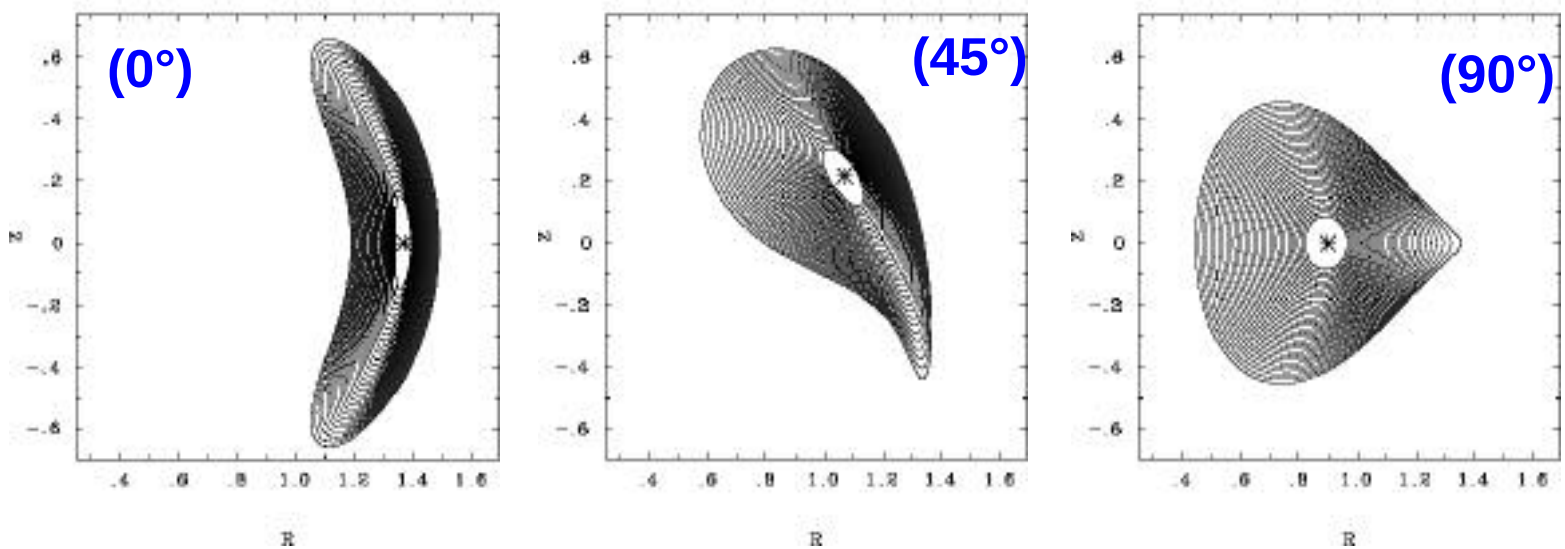
Tools & experience developed by NCSX-QOS team applied to QOS

QOS Magnetic Configuration





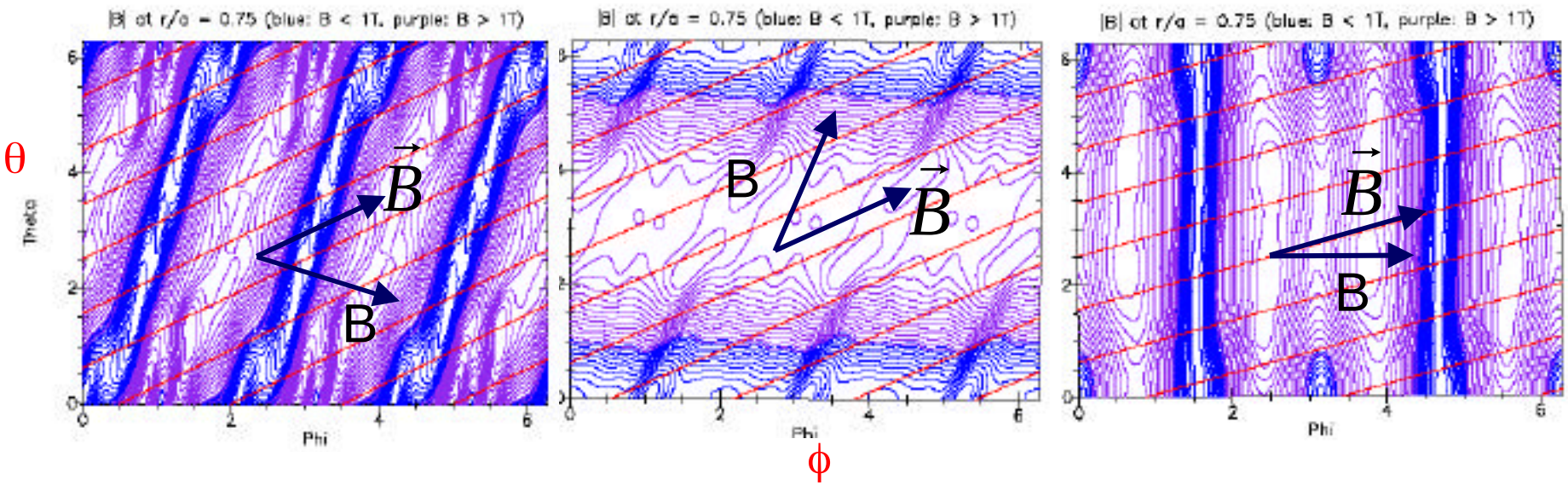
•β®= 2%, I_{bs} = 63 kA



QOS Employs Quasi-Poloidal Symmetry

As R/a becomes smaller, the magnetic field structure employs a dominant symmetry in the magnetic field to obtain good neoclassical confinement

Quasi-Helical **Quasi-Axisymmetric** **Quasi-Poloidal**



- **Quasi-helical: |B| like very large *R/a* stellarator. HSX (*R/a* = 8) will test this concept.**
- **Quasi-axisymmetric: |B| like tokamak. NCSX (*R/a* = 4.3) would test this approach.**
- **Quasi-poloidal: |B| like toroidally linked mirrors. The *B* x B drift can be made small in this approach. QOS (*R/a* = 2.6) would test this concept.**

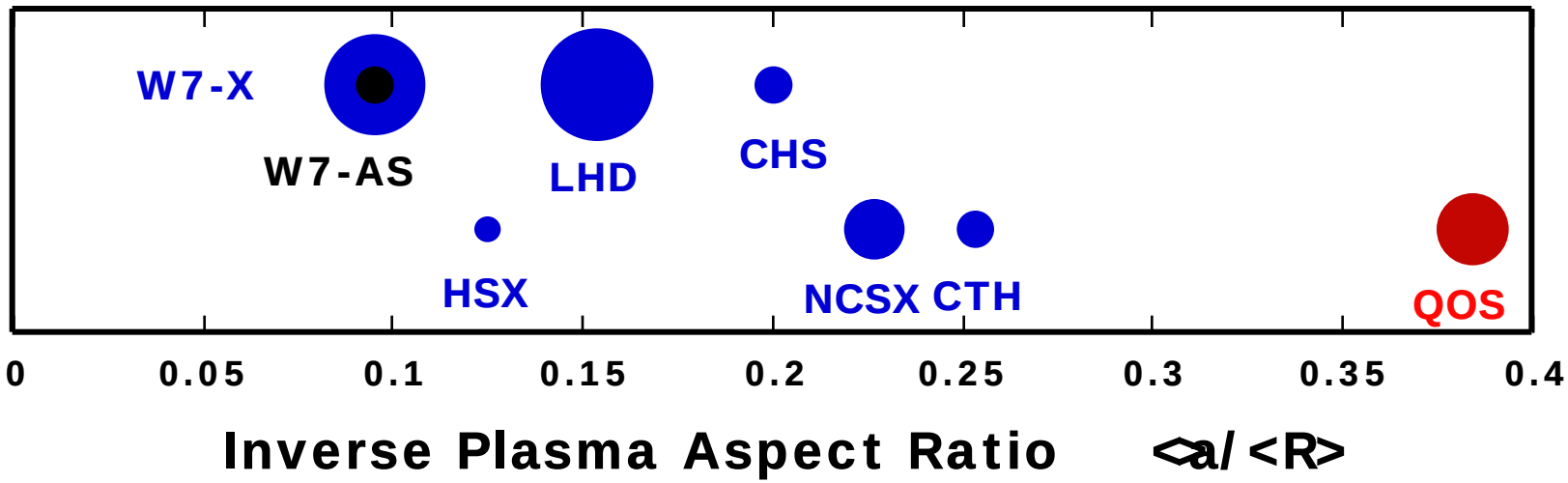
QOS Contributions

- **Broaden understanding of toroidal magnetic configurations -- quasi-poloidal symmetry**
- **Explore very low aspect ratio (~2.6)**
- **Understanding of physics issues pertinent to a low-*R/a* quasi-poloidal high-β compact stellarator concept**
- **Complement NCSX in completing the knowledge base needed for advancing the development of the compact stellarator concept to the next stage**

Motivation for Quasi-Poloidal Symmetry

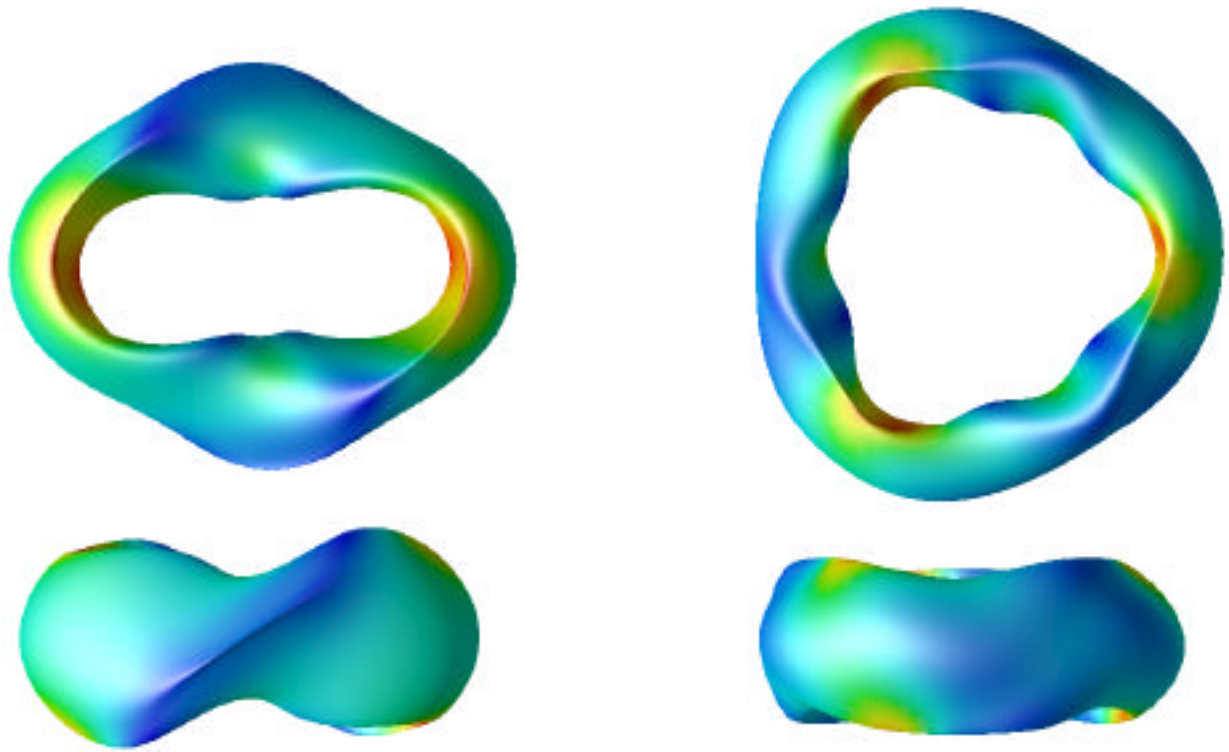
- **Quasi-poloidal symmetry for QOS originally motivated by quasi-poloidal high-β (10-15%) reactor-relevant configurations**
- **Unique features contribute to toroidal physics understanding**
  - **neoclassical confinement improvement due to better alignment of *B* and B**
  - **configuration robustness: small change at low β due to low bootstrap current compared to tokamaks small $\Delta\iota$**
  - **presence of trapped particles at the magnetic axis permits non-zero bootstrap on axis with no seed current needed**
  - **direction of bootstrap current + sign of shear should decrease size of magnetic islands and stabilize neoclassical tearing modes**
  - **compensation for toroidal effects at very low *R*/*a*, ~1/2 that of existing stellarators**
  - **impact of poloidal flows on E_r and enhanced confinement**

QOS Would Explore Very Low Aspect Ratio



- Geometric effects (toroidal mode coupling) become important at low *R/a*
  - need to study impact on equilibrium and transport
  - benchmark with theory and computation is needed

High-β Quasi-Poloidal Configurations



$\langle R \rangle / \langle a \rangle = 2.7$, $\langle \beta \rangle_{limit} = 10\%$ $\langle R \rangle / \langle a \rangle = 3.7$, $\langle \beta \rangle_{limit} = 15\%$

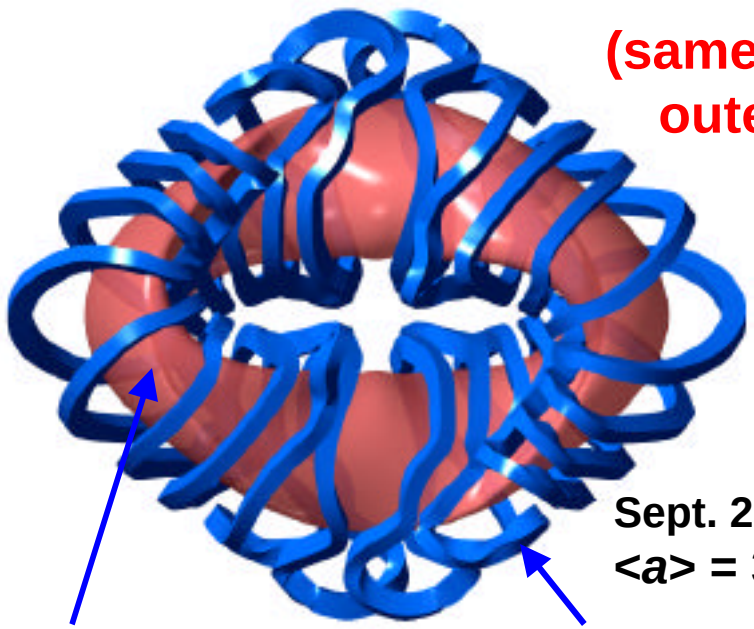
- lead to reactors with R = 7.1-7.9 m vs R = 22 m for HSR
- have reversed $\iota(r/a)$ similar to that with OH current in QOS
- confinement improves and become more QP symmetric as β increases
- need to understand confinement and stability at lower β in QP configurations

QOS Complements NCSX

- **QOS and NCSX explore different types of quasi-symmetry for compact stellarator optimization**
- **Both explore low *R/a* physics issues, but at different scales: CE & PoP**

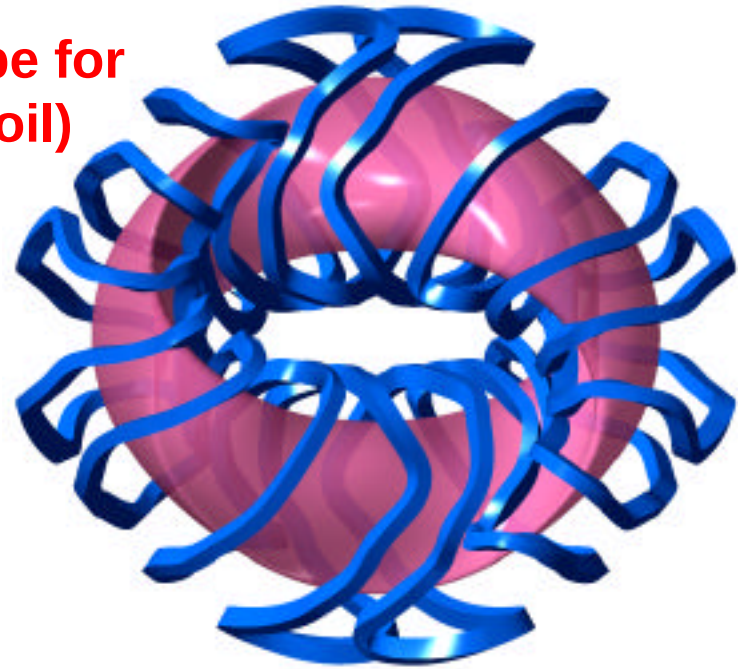
Feature	NCSX	QOS
Scope of the Experiment $\langle R \rangle$, $\langle a \rangle$, $\langle R \rangle / \langle a \rangle$ $\langle B_{axis} \rangle$, flat-top time P (MW), type	PoP-level 1.4 m, 0.32 m, 4.3 1.7 T, 0.5 s 6 MW NBI, 6 MW ICRF	CE-level 0.95 m, 0.37 m, 2.6 1.0 T, 0.5 s 1 MW ECH, 1-3 MW ICRF
Dominant Symmetry	Quasi-Axisymmetric	Quasi-Poloidally-Symmetric
Stability Limit	$\langle \beta \rangle$ = 4-6 %	$\langle \beta \rangle$ = 2-3 %
Neoclassical Confinement Improvement	tokamak-like neoclassical flow damping	small $B \times \nabla B$ radial drift, small poloidal viscosity

QOS Configuration Has Evolved Since Sept 19, 2000 QOS Project Meeting



(same envelope for outermost coil)

Sept. 2000
<*a*> = 34 cm



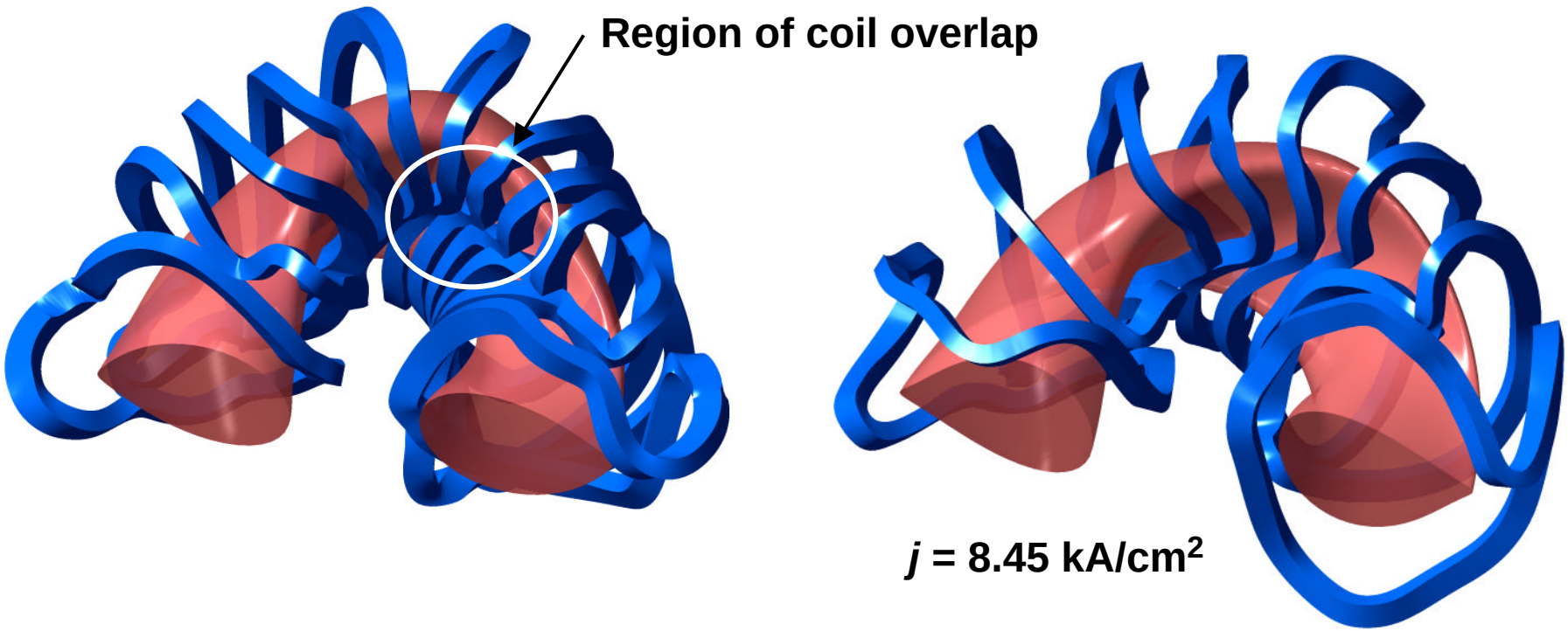
Feb. 2001
<*a*> = 37 cm

<u>Newer configuration has improved</u>

- plasma properties -- higher β limit, better neoclassical confinement, larger plasma-coil spacing for components under coils, larger a_{plasma}
- engineering feasibility -- larger space in middle for TF coil legs & OH solenoid; larger coil-coil spacing & coil bend radius lower *j* in coils
- cost reduction features -- 6 coil types 4 types, 22 coils 16 coils

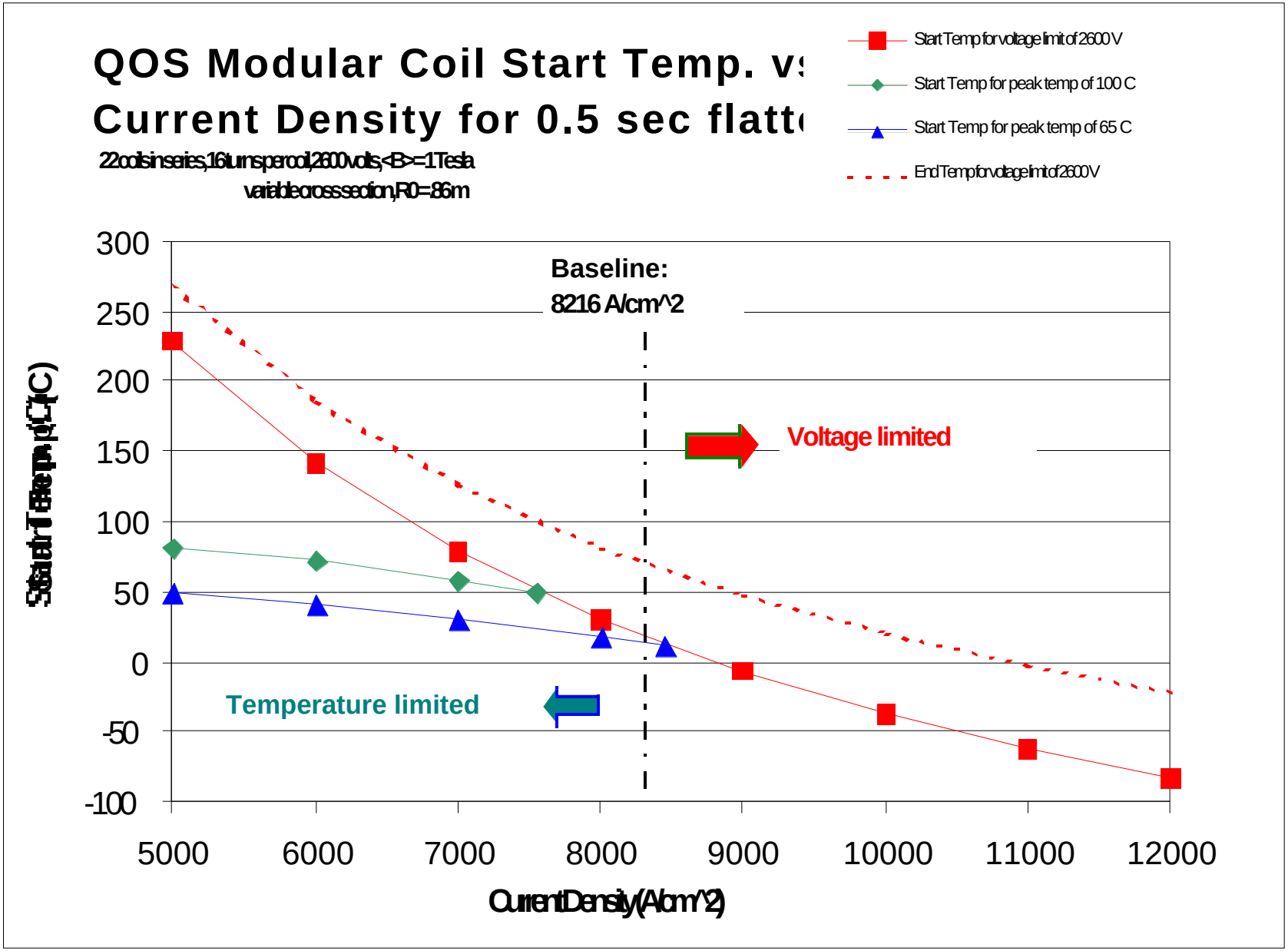
Coil-Coil Spacing is Now Feasible

Earlier 22 coil version **Present 16 coil version**



Smaller *R* would require cryogenic coils and interior vacuum liner

Higher *j* Would Require Cryogenic Cooling of QOS Coils



Schedule

- Further refine the reference plasma and coil configuration
- Complete assessment of QOS physics properties
- Assess flexibility obtained with VF, TF, and OH solenoid
- Refine engineering design and cost/ schedule estimates
- April 24-25 Physics Validation Review
- April 2002 Design, Cost & Schedule Review

Agenda -- 1

Purpose: preview the QOS proposal: issues relating to physics and engineering studies and the work needed for the Apr. 24-25 QOS Physics Validation Review

DETERMINATION AND ASSESSMENT OF PHYSICS AND COIL CONFIGURATIONS

9:00-9:30 Programmatic Logic -- J. Lyon

9:30-10:30 Progress & Overview: Main Features of QOS Reference Configuration -- S. Hirshman.

10:30-11:00 DISCUSSION and BREAK

11:00-11:30 Determination of Modular Coils, Constraints -- D. Strickler

11:30-11:45 NESOPT results -- P. Valanju

11:45-12:15 MHD Stability (Mercier, ballooning, kink, etc.) -- A. Ware

12:15-12:30 DISCUSSION; 12:30-1:15 LUNCH BREAK

1:15-1:45 Transport Assessments -- D. Spong

Agenda -- 2

EXPERIMENTAL IMPLEMENTATION AND ISSUES

1:45-2:45 Engineering Design -- B. Nelson

2:45-3:15 Vacuum and Divertor Issues -- P. Mioduszewski

3:15-3:30 BREAK

3:30-4:00 Experimental Considerations -- D. Rasmussen -- RF heating and diagnostics

4:00-4:30 Configuration Flexibility -- A. Ware

4:30-5:00 Experimental Program -- J. Lyon

5:00-5:30 Issues and Remaining Work -- all

5:30 ADJOURN