QOS Reference Design: Overview

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on behalf of the QOS Design Team

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OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

The University of Montana
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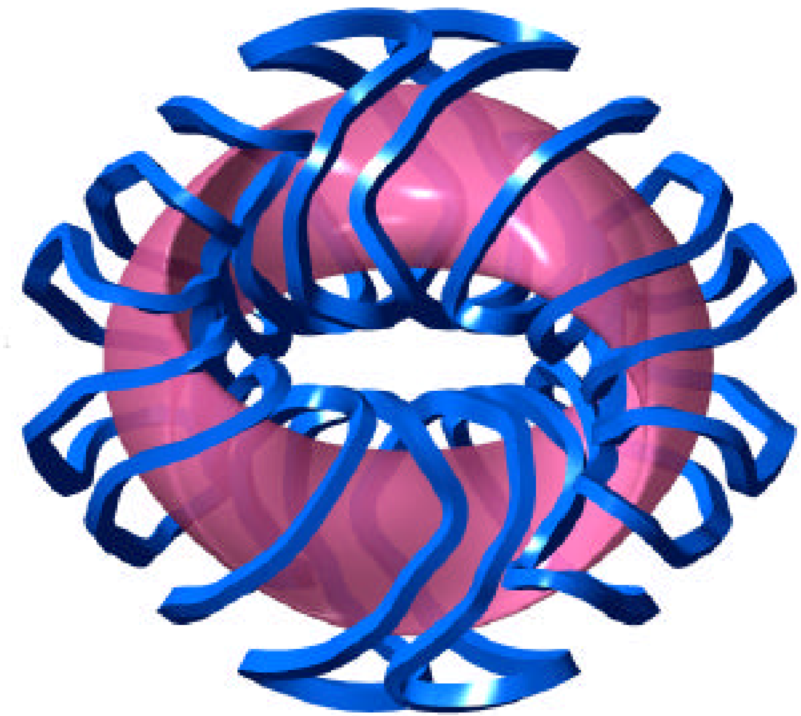
UT-BATTELLE

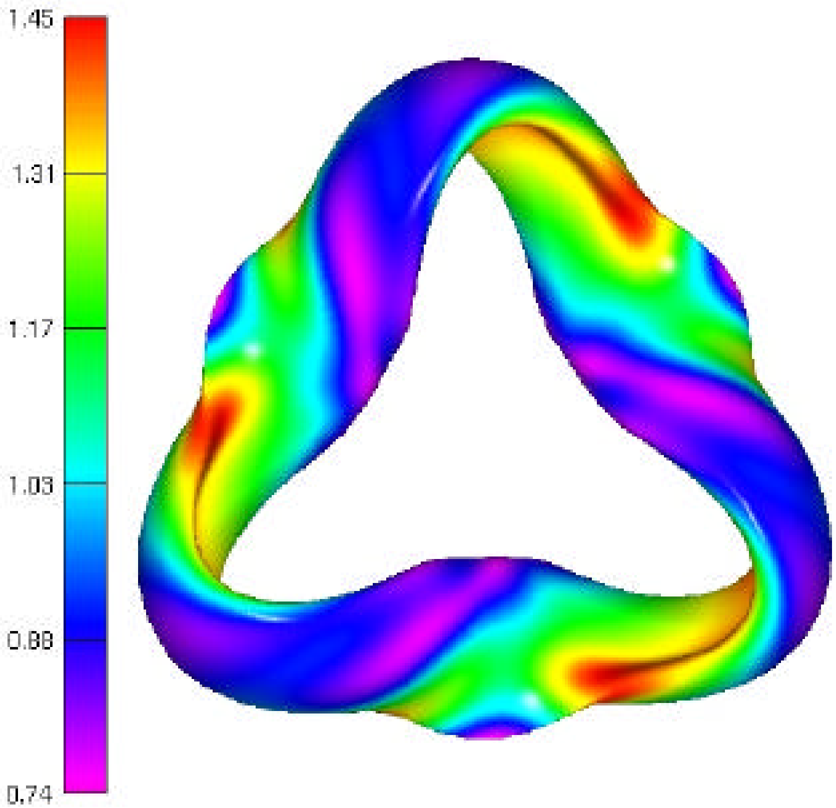
Substantial Progress in QOS Reference Design (since last PM)

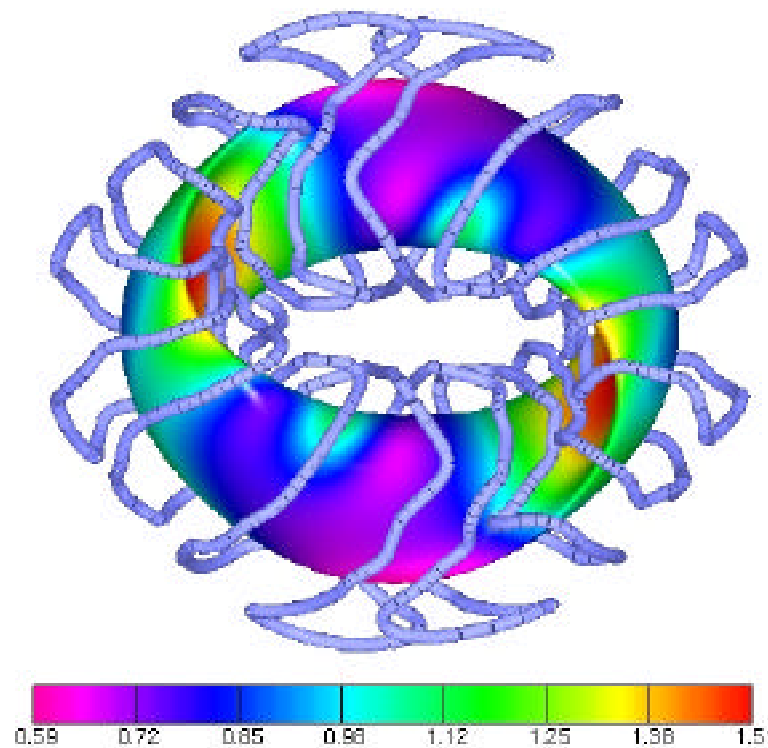


QOS Reference Design (GB4): Key Features

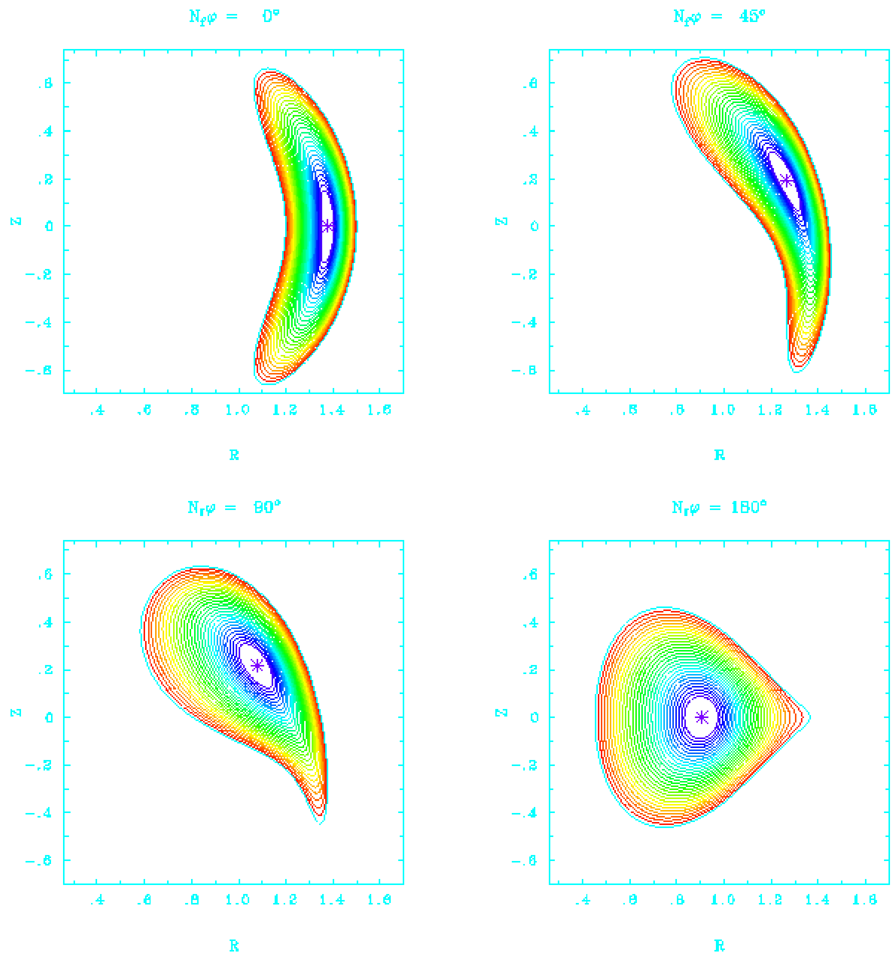
- **N = 2, A ~ 2.6 compact design**
  - **Previous design: N=3, A ~ 3.6**
    - **Explores ultra-low A configuration space**
- **R ~ 0.95 m, a ~ .37 m**
- **Quasi-Poloidal symmetry of |B| (interior)**
  - **Previously, quasi-helical at higher A**
    - **Adequate neoclassical ripple reduction**
    - **Low self-consistent j_{bs} ~ 1/3 tokamak value**
- **Moderate ballooning β ~ 2.5% (-> 3%)**
  - **Kink, vertical, neocl'l tearing mode stability**

Previous QHS (N=3) vs QPS (N=2)

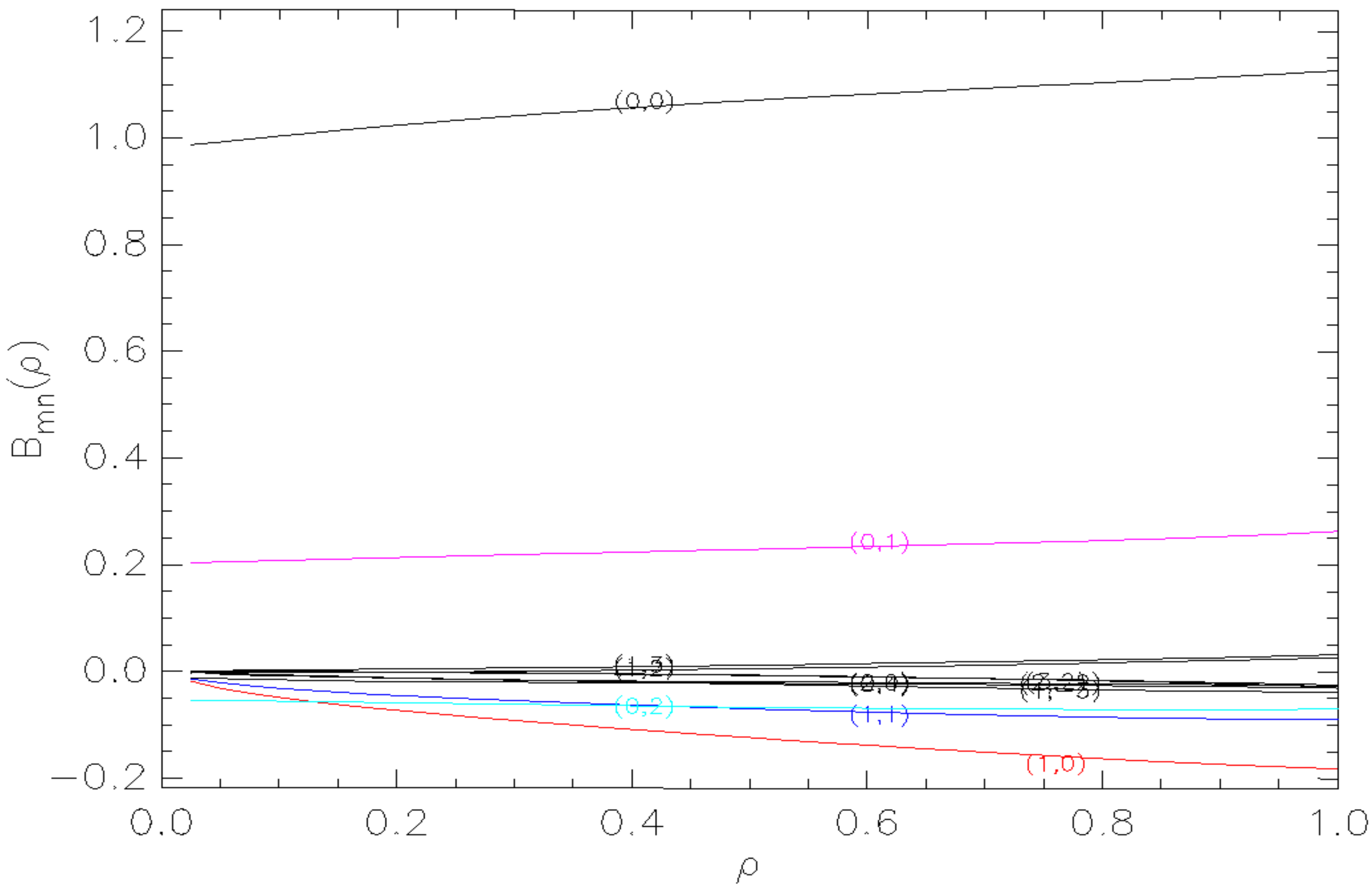


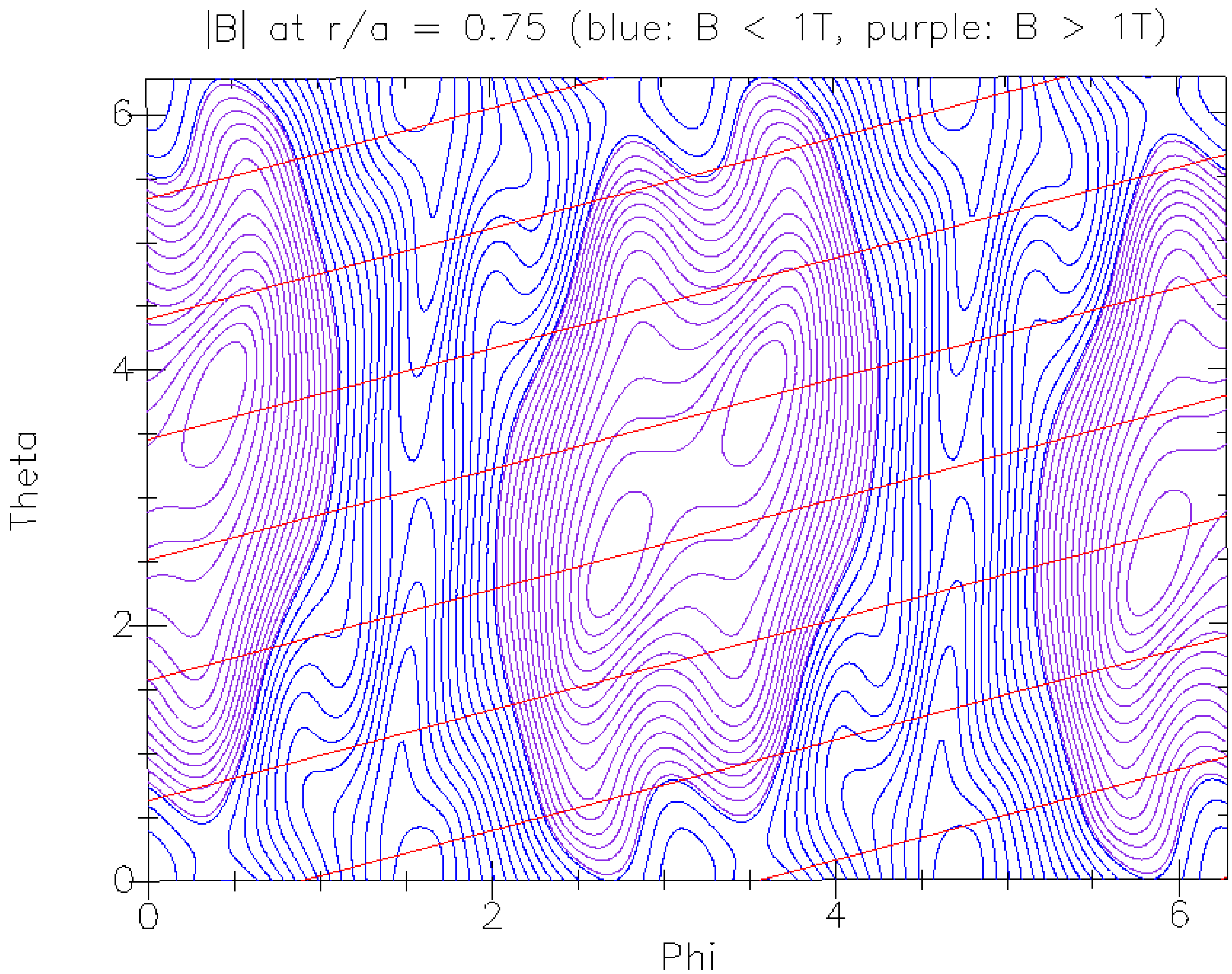


GB4 Surfaces Fit Inside ORMAK Tank with Adequate "Waist" for Neutrals



QOS Reference GB4 |B| Spectrum



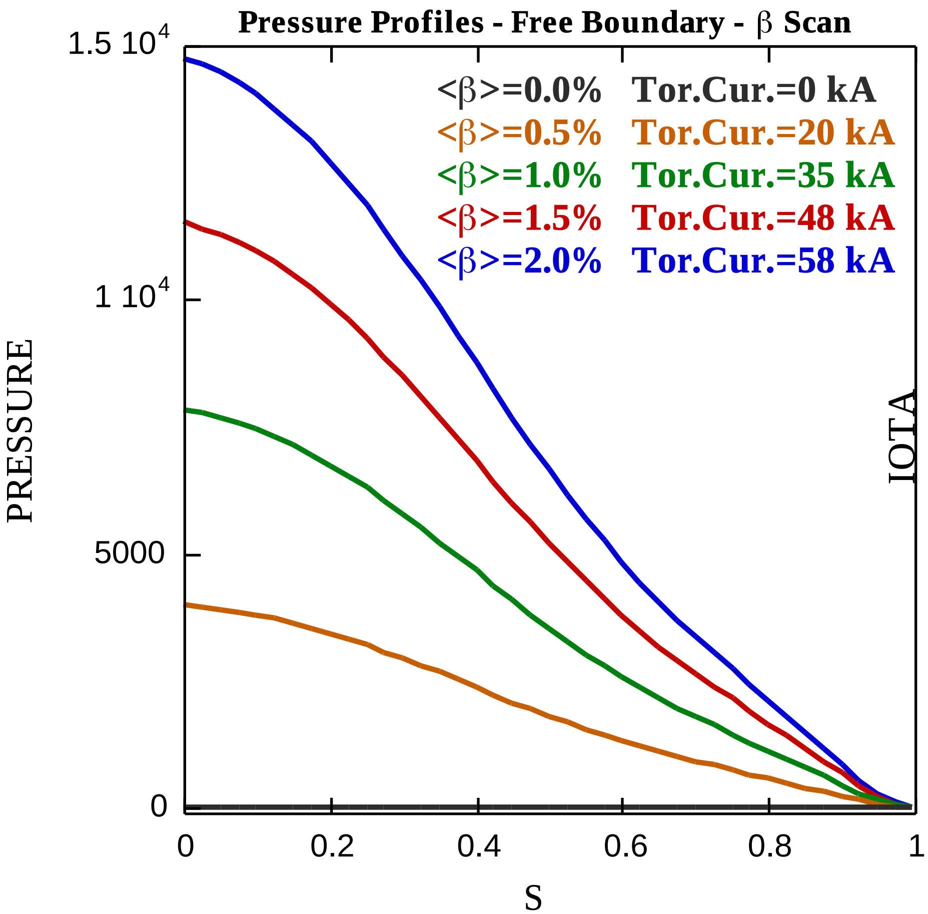

|B| at r/a = 0.75 (blue: B < 1T, purple: B > 1T)
Theta
Phi
0
2
4
6
0
2
4
6

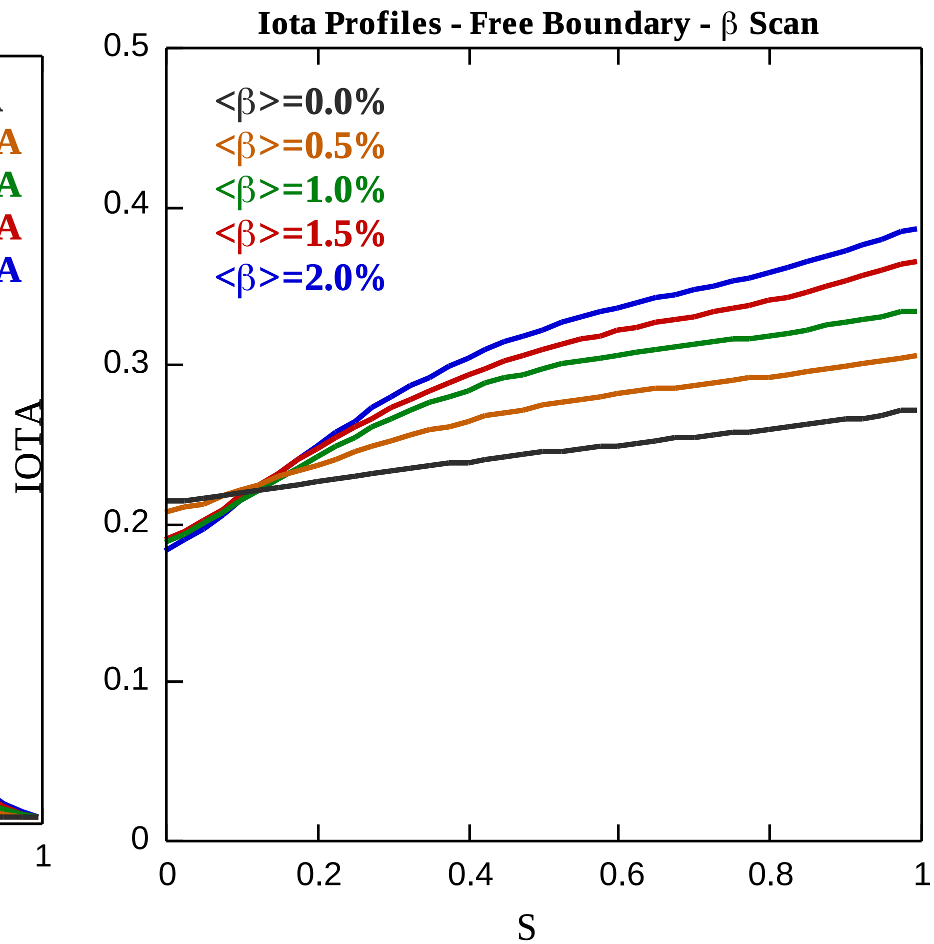
Near Quasi-Poloidal Symmetry

- **Except near edge, m=0, n=1 (per period) |B| dominates spectrum**
  - **Note 1/R (1,0) reduced by 2X compared to 1/A**

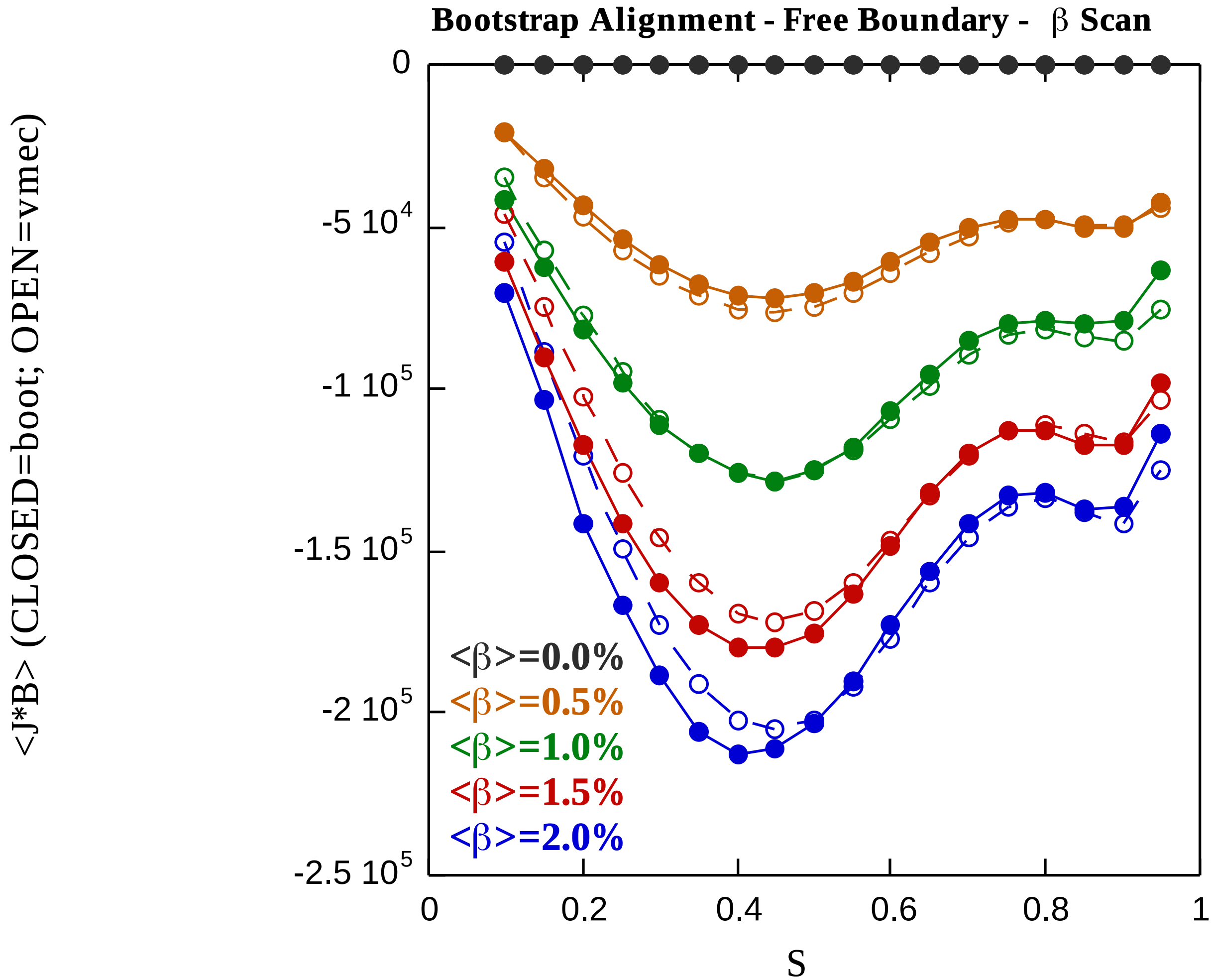
- **Complementary symmetry to NCSX (axisymmetry) and HSX (helical symmetry)**
  - **Reduces neocl'l transport even for small poloidal flux (less ι_{ext}, easier coils)**
  - **Small residual bootstrap current (~60 kA for B = 1T at β = 2%) produces some ι**

β Scan for QOS (GB4 Ref) – no VF scan





Free-boundary Bootstrap Consistency for QOS – GB4 coils

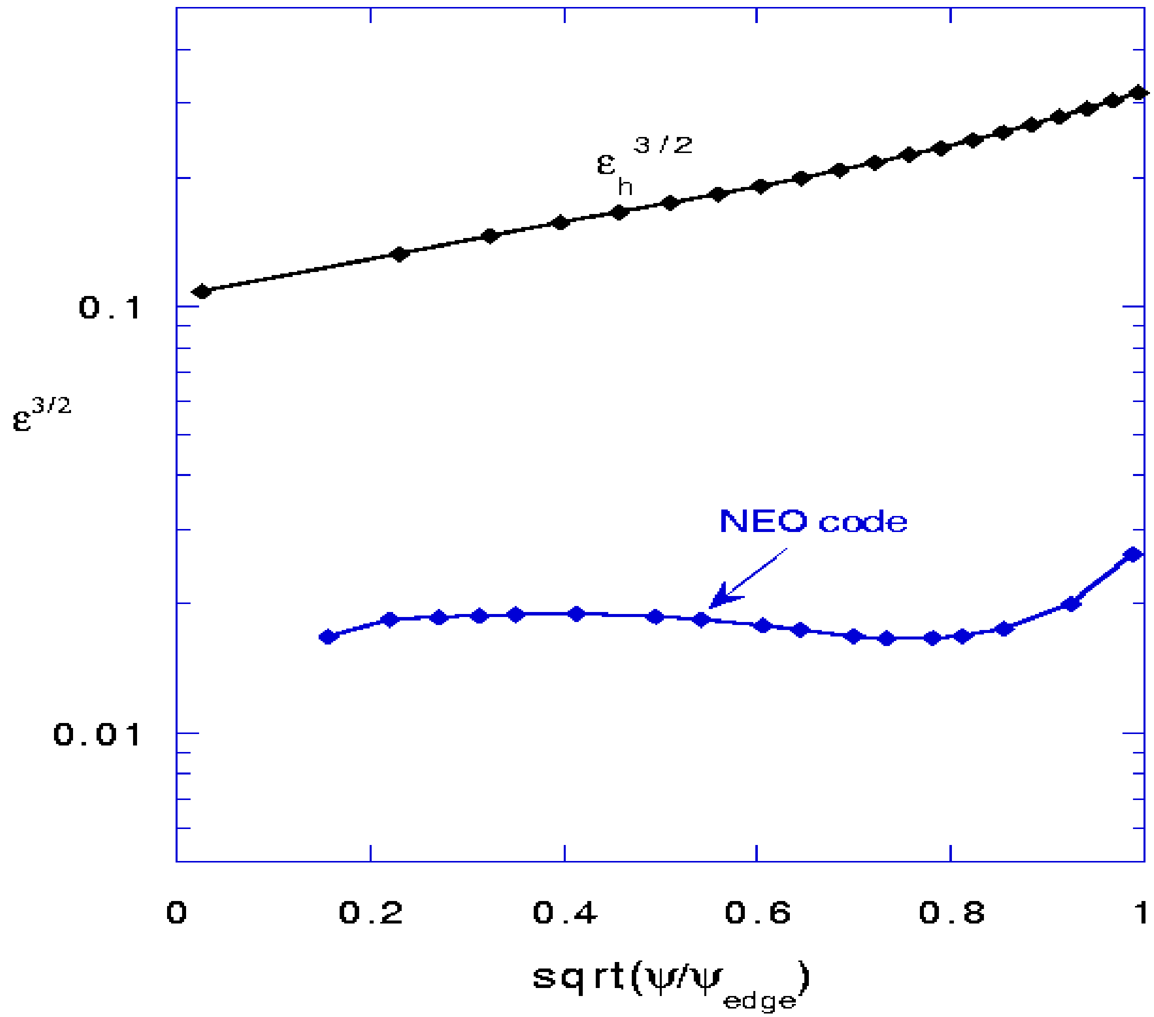


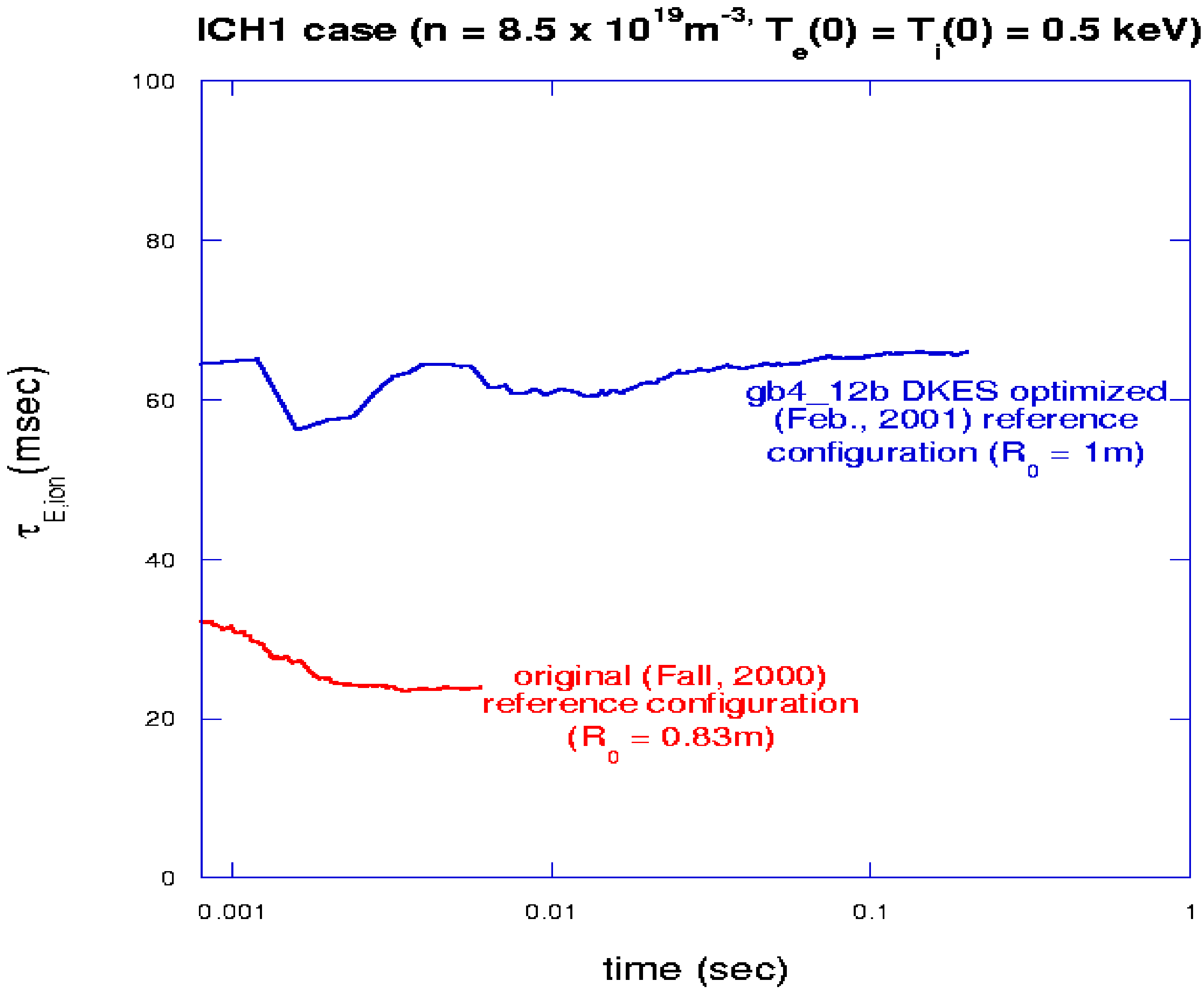
QOS Transport Optimization

- **Initial configurations used only QPS targets**
  - **Minimize energy in m $\neq$ 0 modes of |B|**

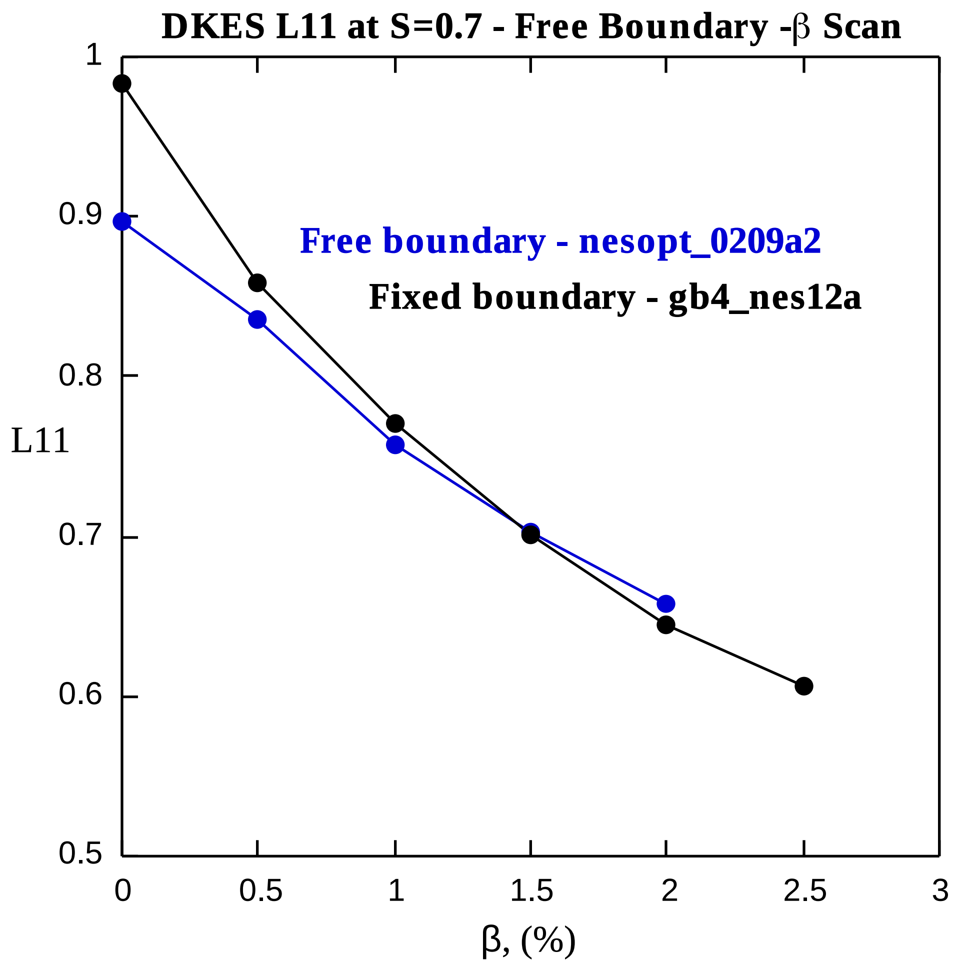
- **Able to significantly reduce thermal transport losses using additional DKES targets**
  - **2X improvement in transport L11 obtained**

Significant Reduction in ε_{eff} for GB4

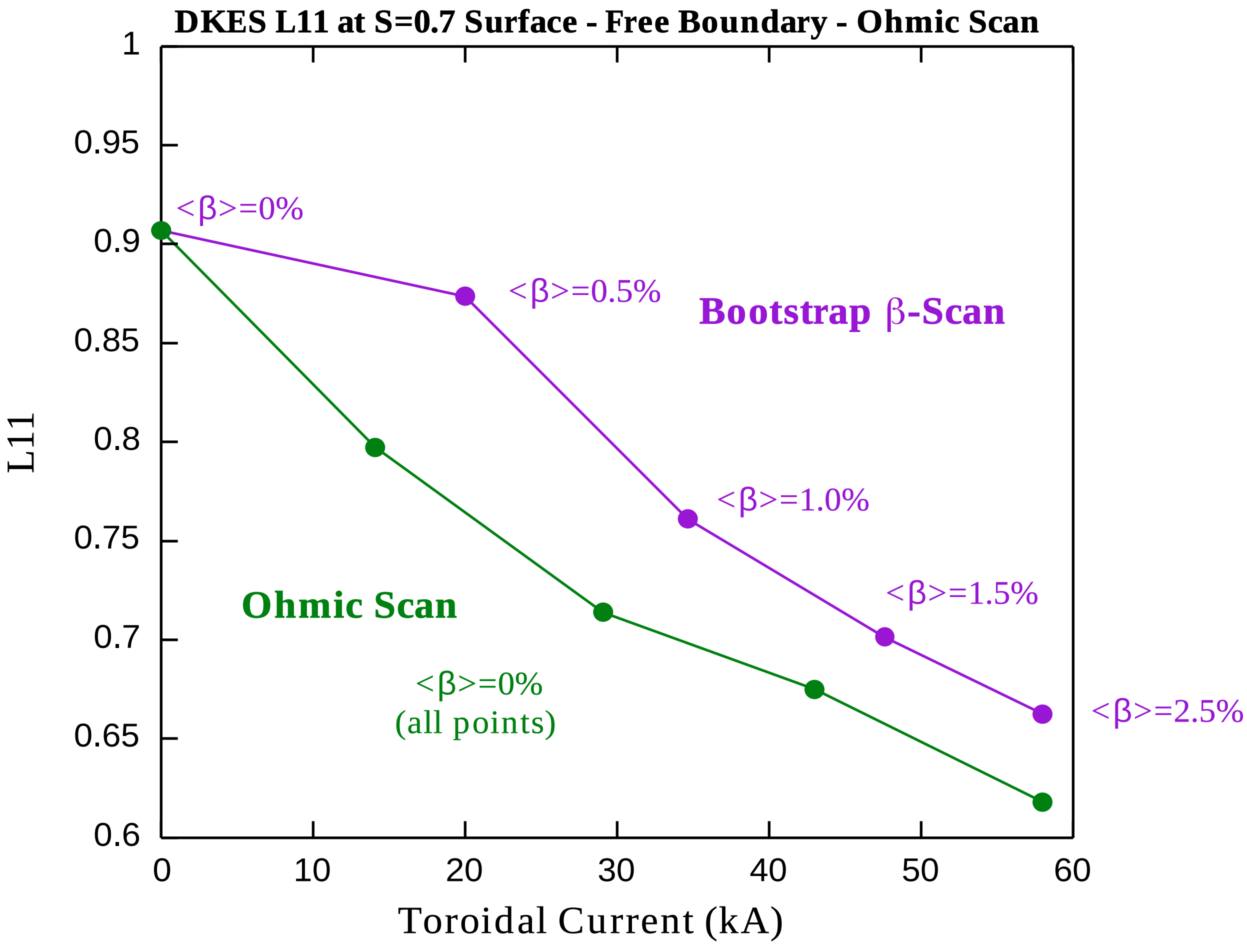



ICH1 case (n = 8.5 x 10^19 m^-3, T_e(0) = T_i(0) = 0.5 keV)
τ_E,ion (msec)
time (sec)
100
80
60
40
20
0
0.001
0.01
0.1
1
gb4_12b DKES optimized (Feb., 2001) reference configuration (R_0 = 1m)
original (Fall, 2000) reference configuration (R_0 = 0.83m)

QOS Transport Improves with β



Ohmic Current Effect on L_{11}

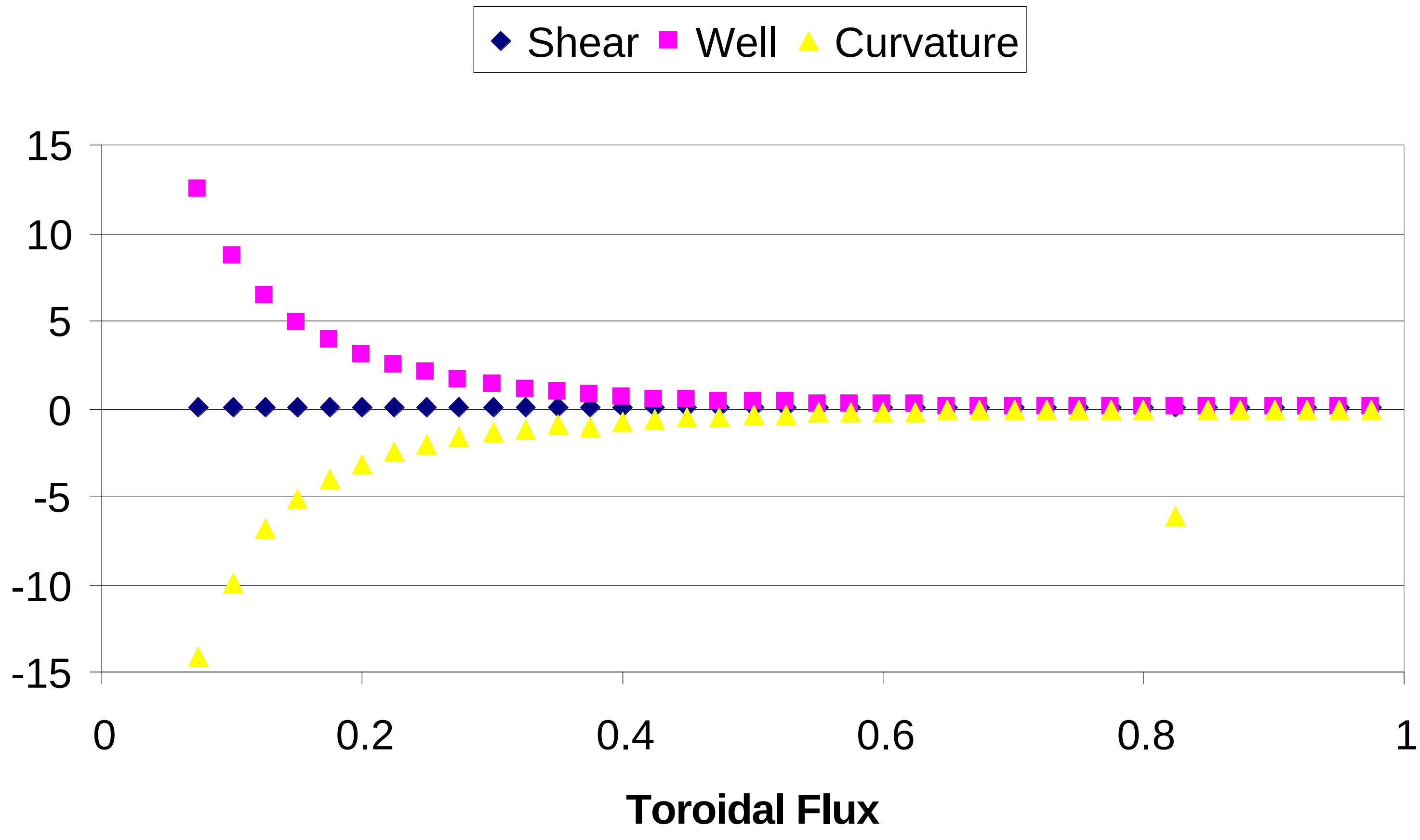


QOS Has Extensive Magnetic Well

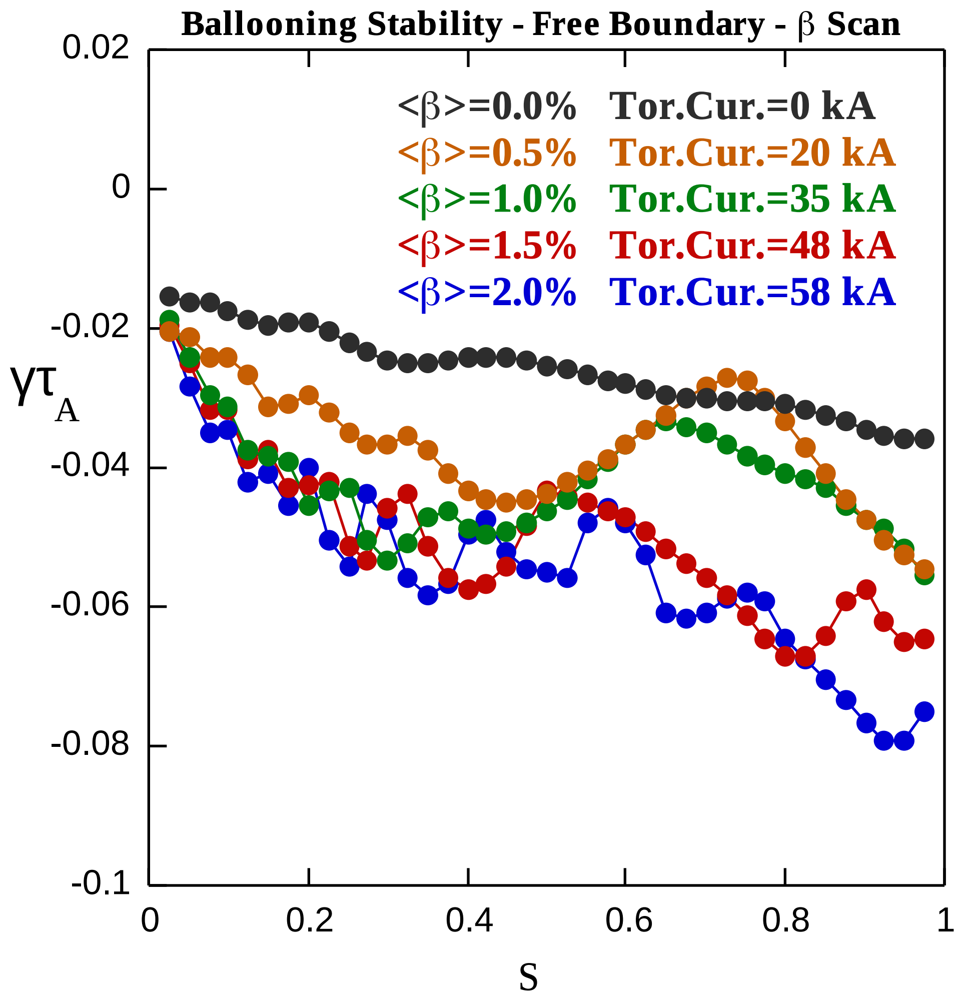
- **Even for β = 0, well (good average curvature) exists over most of cross section**

- **For finite β, well deepens and provides most of Mercier stabilization**
  - **Resistive high-n modes should be stable (need to check through JMC)**

Mercier Stability for QOS (GB4)



Free-Boundary Ballooning Stability



Added Coil Targets to Improve Engineering Aspects of GB4 Design

- **Original designs based on physics targets alone**
  - **Difficulty engineering coils, high B-errors, j_{max}, low bend radii, small coil-plasma separation**

- **NESCOIL (sheet current) targets added to STELLOPT**
  - **Remarkably, able to maintain physics criterion but significantly improve coil properties**
  - **NESCOIL “rounds-off” flux surface “points”**

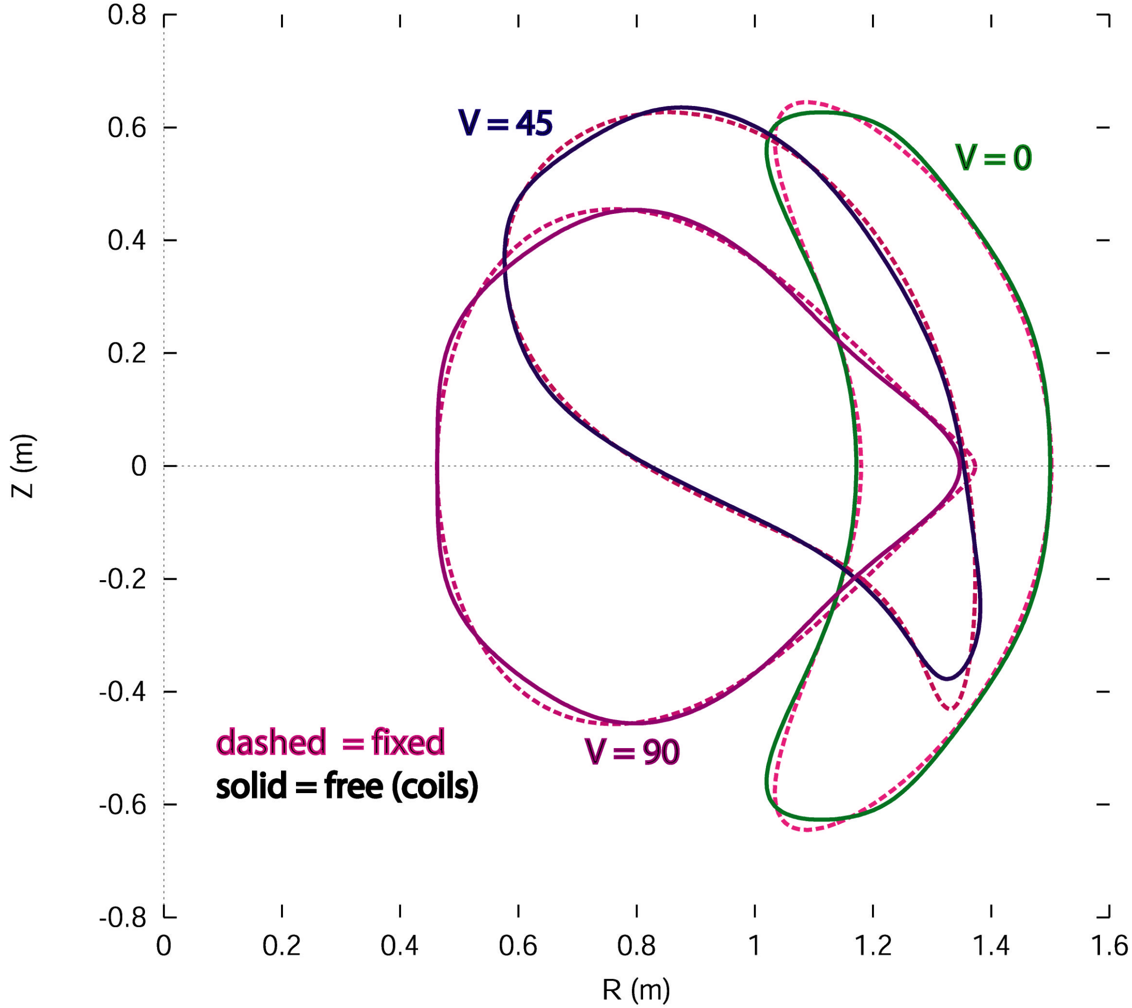
NESCOIL Targets In Optimizer Improve Sheet Current Parameters

	Without NESCOIL Target	With NESCOIL Target
Coil-Plasma Separation	8.6 cm.	12 cm.
Jmax	9.3	1.34
Complexity	1.3	1.33
<Berr>	0.34%	0.07%
Berr - max	4.98%	1.02%
"Curvature" of J	0.33 cm	1.00 cm

Better Sheet Current Parameters Lead -> Improved Modular Design

	QHS	QPS (GB4)
A	3.6	2.6
Nfp	3	2
Ncoils	21	16
avg. error (%)	2.37	1.38
max. error (%)	10.3	7.03
cc_min (cm)	7.5	11.6
cp_min (cm)	11	13.3
rho_min (cm)	-	7.7

Reconstruction Is Adequate to Maintain Physics Criteria (L. Berry)



PIES Reconstruction

- **Earlier (Sept, 2000) QOS configuration showed good PIES reconstructability**

- **Present (updated) configuration is presently being analyzed**
  - **Expect preservation of surfaces since no new resonances have been crossed**

QOS Web-based Spreadsheet (R. Fowler)

- **http://iqos.fed.ornl.gov**
- **Go to “Fowler’s Database” link**

Geometric Parameters

Geometry Shot ID	Rmin	Rmax	Waist	Aspect Ratio	Rmaj	<a>
A2.5_ref_0	0.29	1.50	0.33	2.50	0.88	0.35
A2.5_ref_g6	0.32	1.50	0.26	2.49	0.85	0.34
A2.5_ref_ga5	0.34	1.50	0.24	2.51	0.89	0.35
A2.5_ref_gb1	0.41	1.50	0.27	2.49	0.93	0.37
A2.5_ref_gb3	0.35	1.50	0.28	2.31	0.90	0.39
A2.5_ref_gb4	0.33	1.50	0.29	2.22	0.90	0.41
A2.5_ref_gb4b	0.33	1.50	0.28	2.29	0.91	0.40
nesopt_01	0.46	1.50	0.31	2.64	1.01	0.38
gb4_nes_12a	0.45	1.50	0.31	2.63	1.00	0.38
gb4_nes_12b	0.45	1.49	0.30	2.62	0.99	0.38
gb4_nes_10a	0.46	1.50	0.31	2.64	1.01	0.38

Physics parameters (I)

Physics Shot ID	Itor(kA)	<B>(T)	Beta	DKES L11 (r/a=0.7)	iota(0)	iota(1)
A2.5_ref_0	38.3	1.001	1.55E-02	1.17E+00	0.287	0.404
A2.5_ref_g6	28.2	1.000	1.23E-02	3.27E-01	0.314	0.404
A2.5_ref_ga5	37.4	0.981	1.75E-02	3.63E-01	0.296	0.435
A2.5_ref_gb1	52.9	1.002	1.84E-02	7.44E-01	0.284	0.409
A2.5_ref_gb3	54.8	1.000	1.84E-02	6.41E-01	0.285	0.415
A2.5_ref_gb4	61.7	1.045	1.96E-02	5.07E-01	0.297	0.401
A2.5_ref_gb4b	58.9	1.001	1.93E-02	4.22E-01	0.299	0.410
nesopt_01	57.6	0.984	1.91E-02	6.33E-01	0.264	0.393
gb4_nes_12a	59.10	0.991	1.89E-02	6.28E-01	0.264	0.397
gb4_nes_12b	56.00	1.005	1.88E-02	5.60E-01	0.265	0.395
gb4_nes_10a	57.60	0.984	1.91E-02	6.33E-01	0.264	0.393

Physics parameters (II)

Physics					
Shot ID	Bootstrap	Balloon	Balloon	Mercier	Mercier Well
	RMS	Gr. Rate	S-Unstable	RMS	S-Range
A2.5_ref_0	3.60E+04	1.30E-01	0.111	0.000	1.000
A2.5_ref_g6	2.11E+04	-3.36E-02	0.000	1.997	0.795
A2.5_ref_ga5	4.77E+04	3.65E-02	0.278	2.328	0.590
A2.5_ref_gb1	2.78E+04	3.91E-02	0.222	0.039	0.846
A2.5_ref_gb3	2.55E+04	3.70E-02	0.222	0.126	0.897
A2.5_ref_gb4	1.74E+04	4.41E-02	0.389	0.153	0.872
A2.5_ref_gb4b	1.67E+04	4.29E-02	0.389	0.000	0.897
nesopt_01	2.92E+04	3.86E-02	0.222	0.342	0.821
gb4_nes_12a	3.59E+04	1.00E-02	0.111	0.263	0.795
gb4_nes_12b	1.91E+04	1.22E-02	0.111	0.188	0.795
gb4_nes_10a	2.92E+04	3.86E-02	0.222	0.342	0.821

Coil parameters

Coils					
Shot ID	Coil Complexity	Jmax	Berr ave	Berr max	Coil-Plasma Separation
A2.5_ref_0	1.31	2.15	0.004	0.047	7.37E-02
A2.5_ref_g6	1.28	3.93	0.004	0.056	8.02E-02
A2.5_ref_ga5	1.29	3.47	0.003	0.037	8.72E-02
A2.5_ref_gb1	1.30	5.44	0.002	0.039	8.96E-02
A2.5_ref_gb3	1.32	5.32	0.002	0.038	9.41E-02
A2.5_ref_gb4	1.30	5.26	0.002	0.040	9.38E-02
A2.5_ref_gb4b	1.26	2.39	0.003	0.033	8.50E-02
nesopt_01	1.27	0.88	0.001	0.010	1.00E-01
gb4_nes_12a	1.35	1.48	0.001	0.011	1.20E-01
gb4_nes_12b	1.34	1.40	0.001	0.010	1.20E-01
gb4_nes_10a	1.27	0.88	0.001	0.010	1.00E-01

Summary

- **Dramatically improved N=2, A=2.5 design in several ways**
  - **Decreased neocl'l losses using DKES targets**
    - **2X improvement obtained**
  - **Increased ballooning β limit**
    - **from < 2% to > 2.5%**
  - **Obtained an 8 coil/period modular set with good reconstruction properties**