



Configurational Flexibility of the QPS Stellarator

E. L. Barcikowski and A. S. Ware

University of Montana

L. A. Berry, S. P. Hirshman, D. A. Spong,
J. F. Lyon and D. J. Strickler

Oak Ridge National Laboratory

Abstract

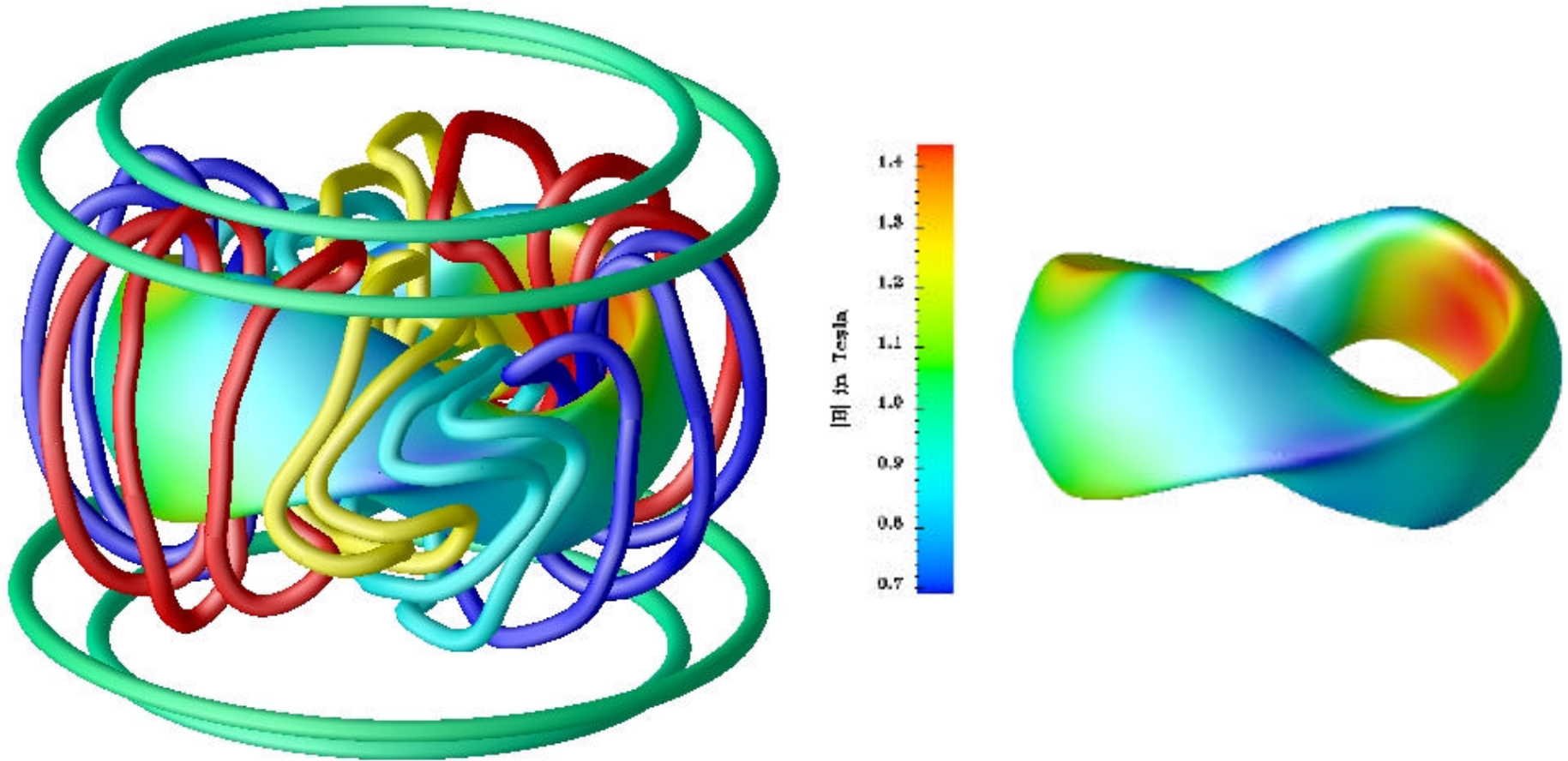
A new stellarator experiment has been proposed: the Quasi-Poloidal Stellarator (QPS). QPS is a two field period, ultra-low aspect ratio stellarator ($A=2.6$) with a magnetic field structure that exhibits quasi-poloidal symmetry. The QPS experiment has been designed with a wide range of configurational flexibility. While the reference configuration was optimized with bootstrap aligned current (i.e., a finite bootstrap current providing all the field-aligned current), the experiment will have the flexibility to operate with Ohmic current as well. The reference coil configuration contains three sets of coils: 16 modular coils (8 per field period), 6 vertical field coils, and 12 toroidal field coils. In this work, we examine the effect of current profile variation (from bootstrap aligned to Ohmic) and external current variation on the stability and transport properties of QPS. In QPS, MHD stability β limits are set by ballooning modes at $\sim 2.5\%$. Current variation (both internal and external) allows us to degrade the ballooning stability and test the effect of unstable ballooning modes. The QPS reference configuration is transport optimized so that neoclassical losses are significantly less than expected anomalous losses (from ISS95 scaling). Current variation also gives us a tool to vary the neoclassical losses and explore ranges of neoclassical confinement.

The Quasi-Poloidal Stellarator

- The proposed QPS stellarator is an ultra-low aspect ratio stellarator experiment ($A = 2.7$)
 - $|B|$ displays quasi-poloidal symmetry
 - Excellent neoclassical confinement at low A
 - Rotational transform from both modular coils and finite plasma current
 - Good bootstrap current alignment

[For more info on QPS see posters CP1.044-1.047, this session](#)

The Quasi-Poloidal Stellarator



I. Introduction

- The goal of this research was to explore variation in the plasma current (both bootstrap and Ohmic) and to test the upper limit of the first region of stability in the QPS experiment
 - Examined the effects of current variation on rotational transform () and transport.
 - Looked at fixed and free boundary cases
 - Ballooning limits: $\langle \rangle \sim 2.2\%$ for free boundary and $\langle \rangle \sim 2.4\%$ for fixed boundary

Introduction (cont.)

- VMEC code used to obtain plasma equilibria
- Oak Ridge Stellarator Optimization Code used to optimize the equilibria
 - targets a minimum χ^2 (where χ^2 is a measure of the deviation from a target plasma)

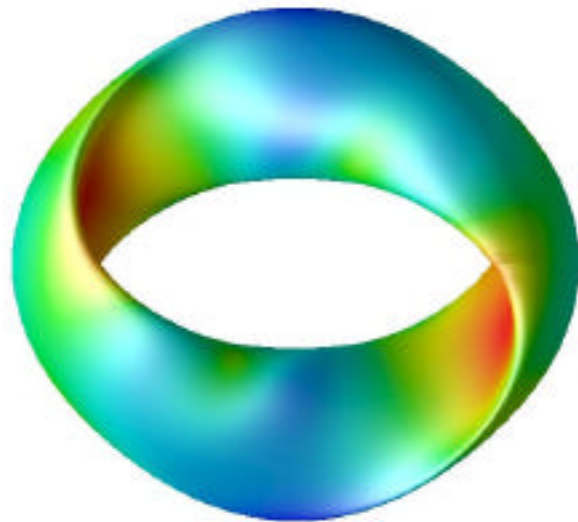
[S.P. Hirshman, et. al., Phys. Plasmas **6**, 1858 (1999)]

II. Reference Configurations

- **GB4:** Free-boundary reference configuration used for the Physics Validation Review

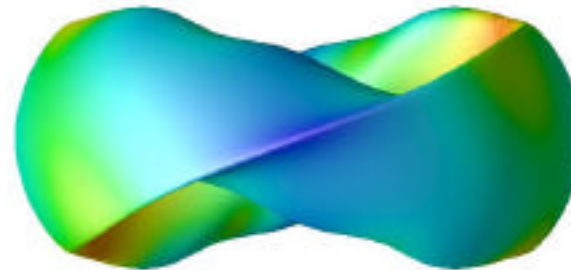
$$A = 2.6 \quad < \quad \geq 2.0\%$$

nesopt_0213b2



Top view

nesopt_0213b2



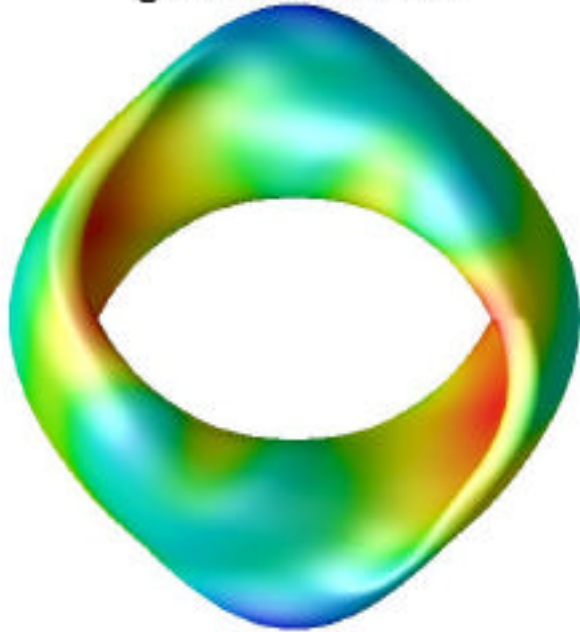
Side view

Reference Cases (Continued)

- **GB4_Ohmic**: GB4 case with Ohmic current

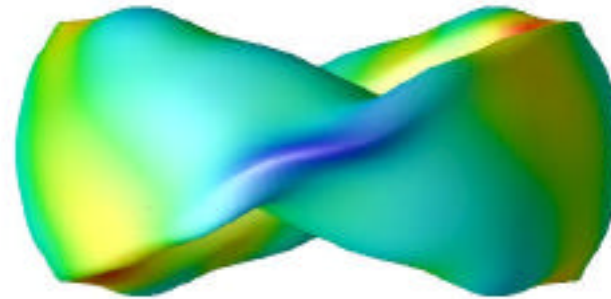
$$A = 2.9 \quad \langle \rangle = 2.1\%$$

gb4_12b_ohmic



Top view

gb4_12b_ohmic



Side view

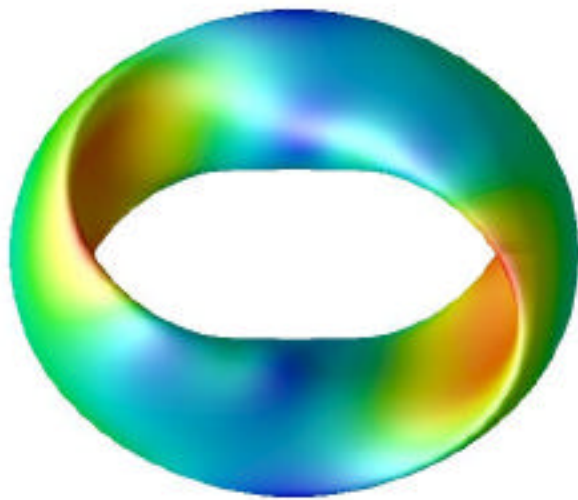
Reference Cases (Continued)

- **QPS2**: Recent fixed-boundary configuration with improved neoclassical confinement

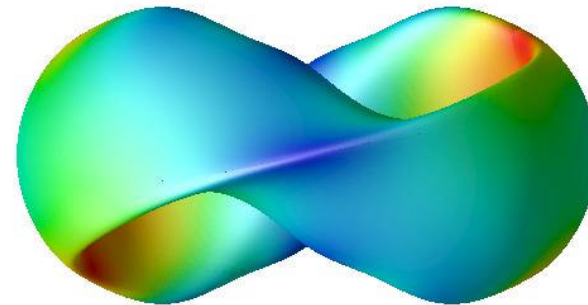
$$A = 2.7 \quad \langle \rangle = 2.8\%$$

qp2_080301

qp2_080301



Top view



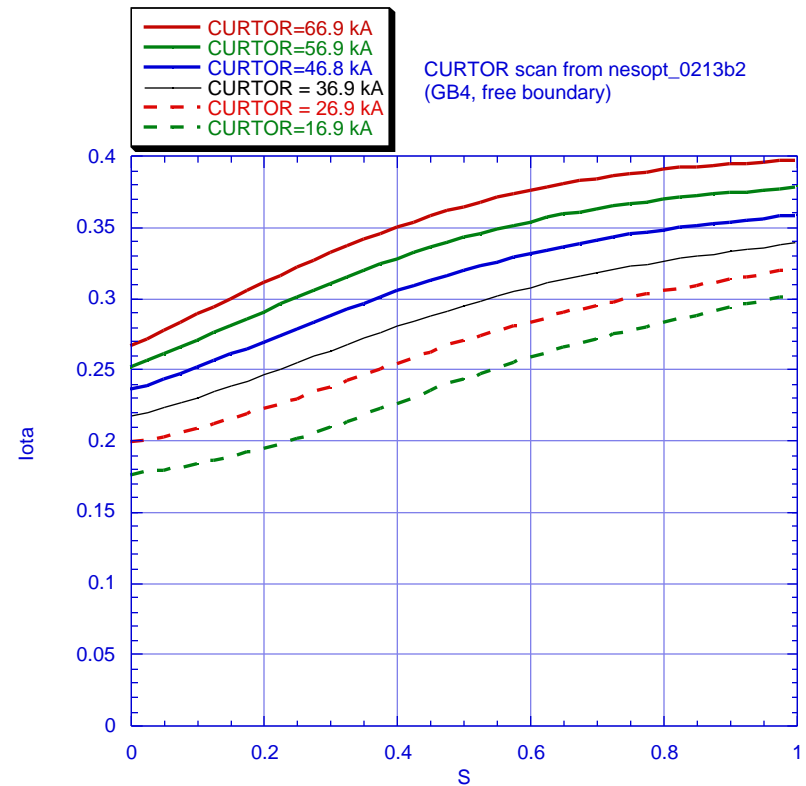
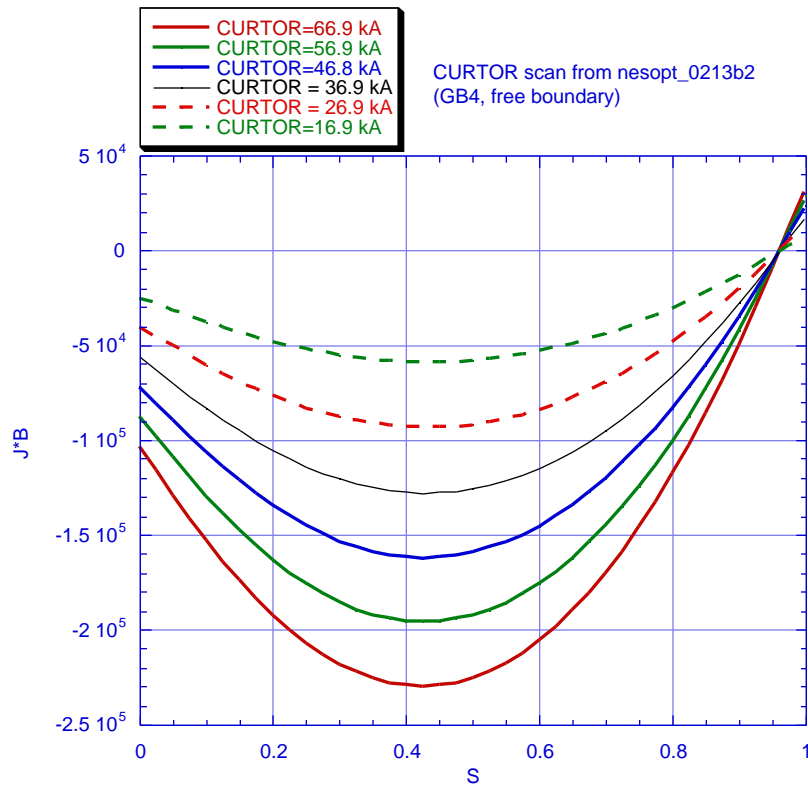
Side view

III. Current Variation

- Varied the magnitude of the total plasma current for both bootstrap-aligned and Ohmic current profiles
- Examined the effect on:
 - Rotational transform (ι)
 - Transport (DKES L11 coefficients)

GB4 : Bootstrap-aligned current profile

Field-aligned current and rotational transform

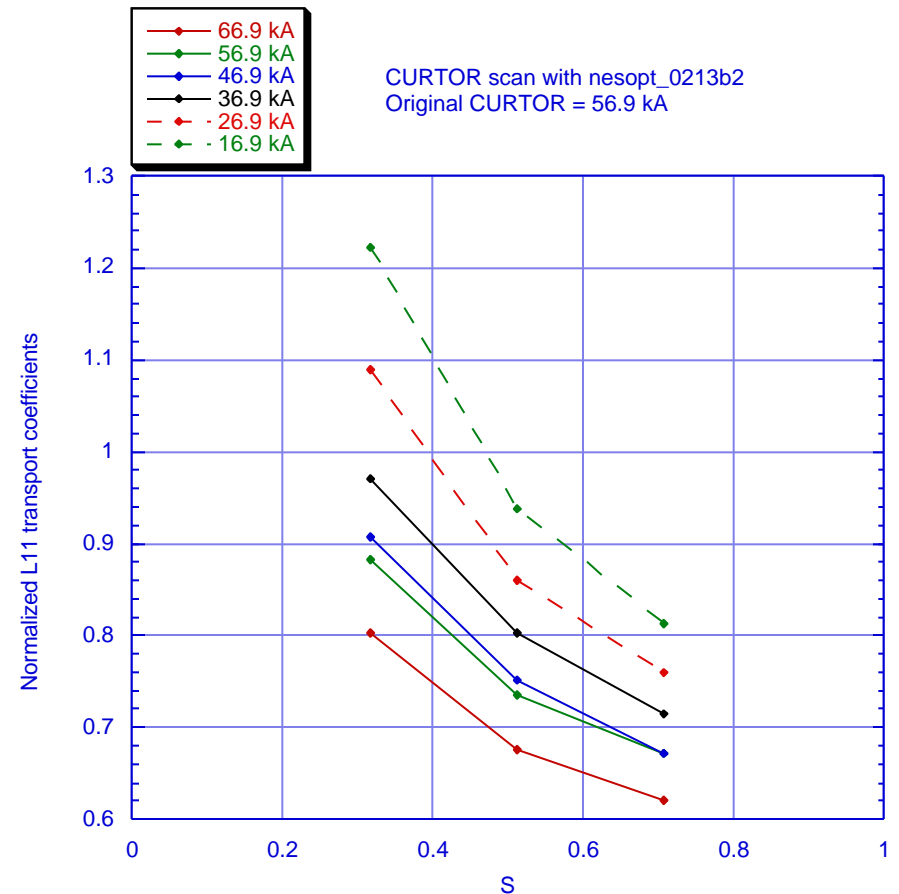


- Stellarator-like shear with reduced shear near the plasma boundary as the plasma current is increased

GB4: Bootstrap-aligned current profile

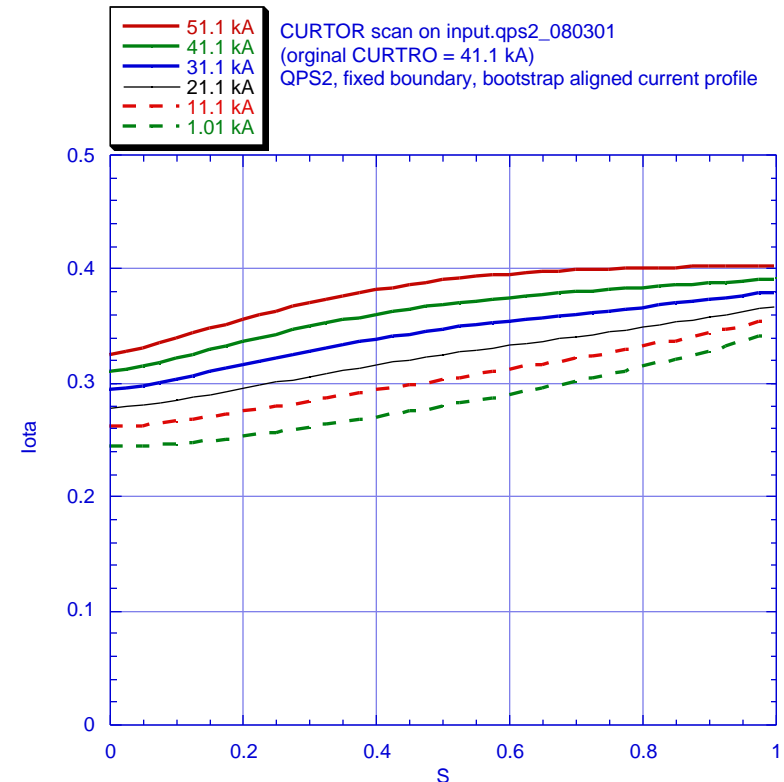
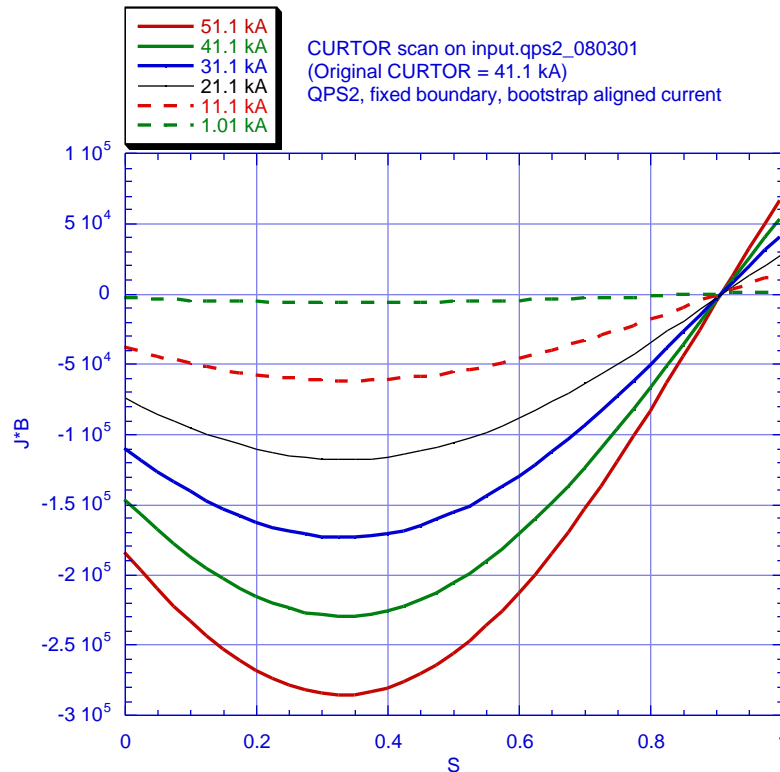
DKES L11 Transport Coefficient

- L_{11} is the radial transport coefficient
- Transport is lower near the plasma boundary
- Confinement improves with increasing plasma current



QPS2: Bootstrap-aligned current profile

Field-aligned current and rotational transform

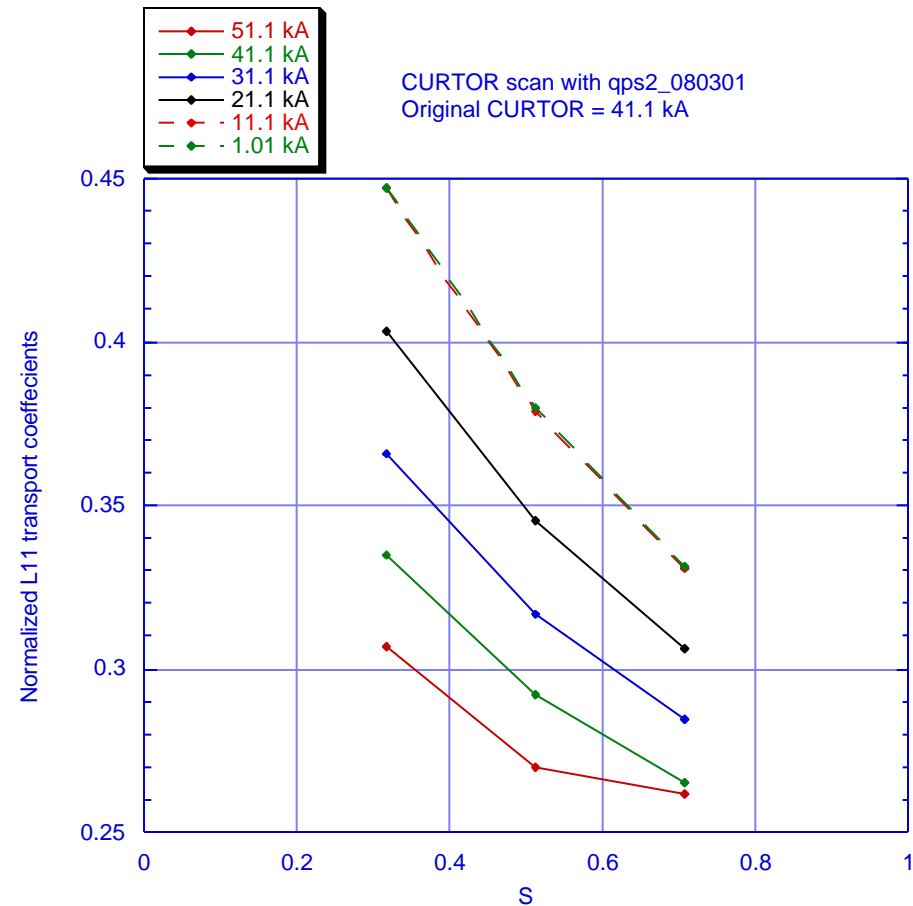


- Low shear profile ... which becomes very flat for $S > 0.5$ as the current gets larger

QPS2: Bootstrap-aligned current profile

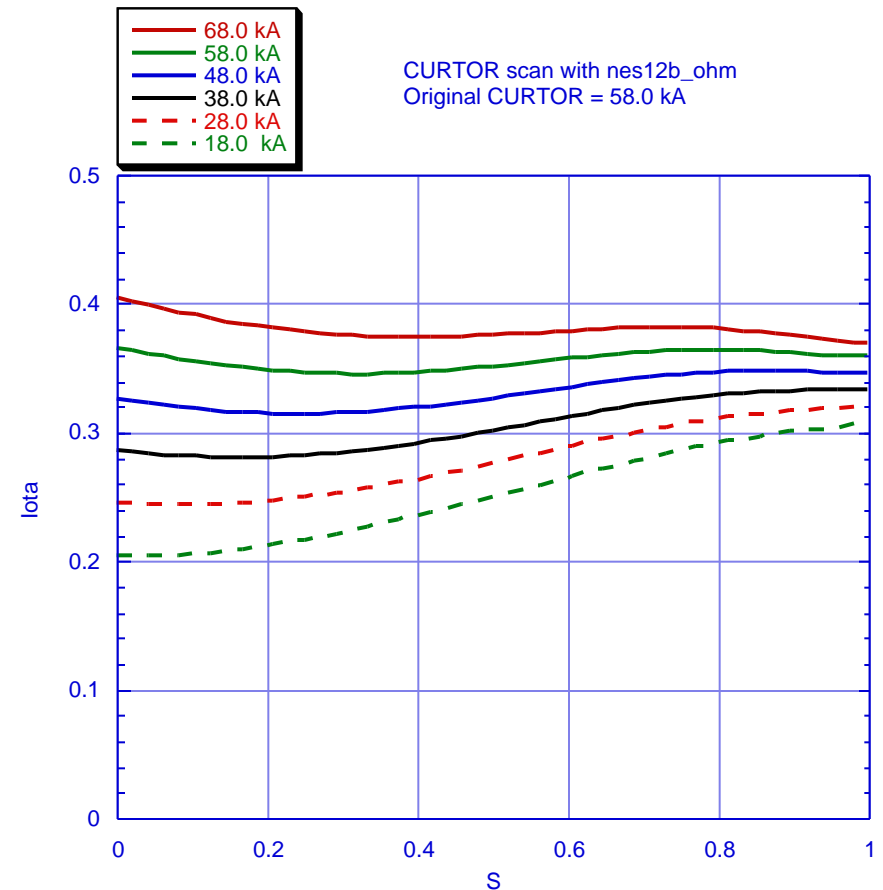
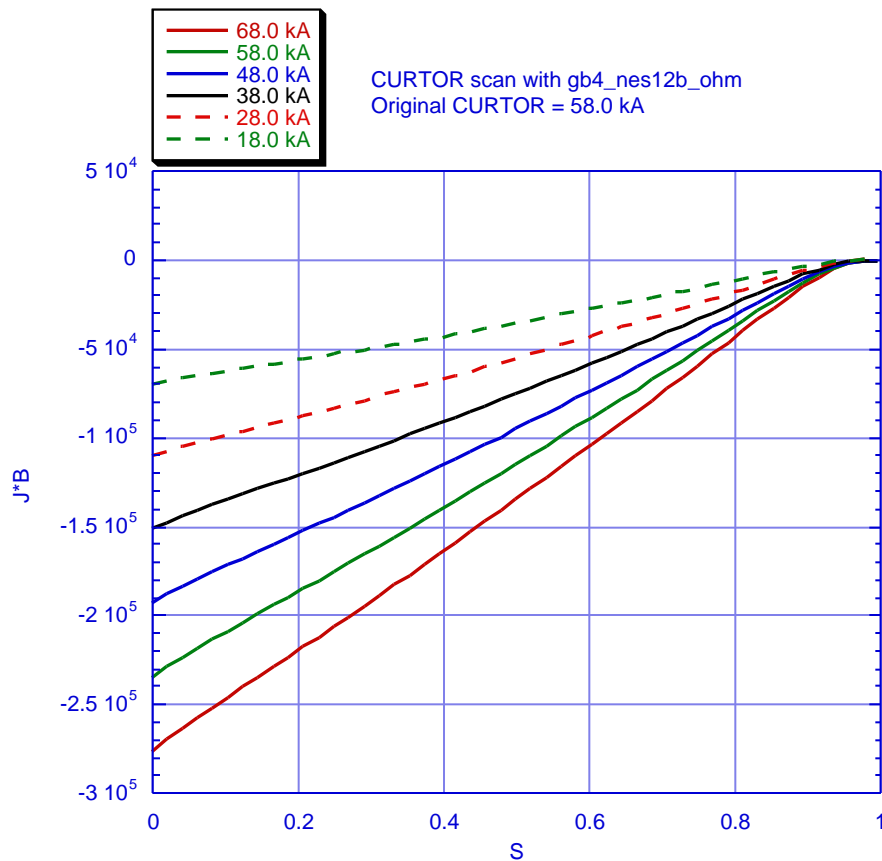
DKES L11 Transport Coefficient

- Transport much lower than in GB4 case
- Transport is lower near the plasma boundary
- Confinement improves with increasing plasma current



GB4_Ohmic: Ohmic current profile

Field-aligned current and rotational transform

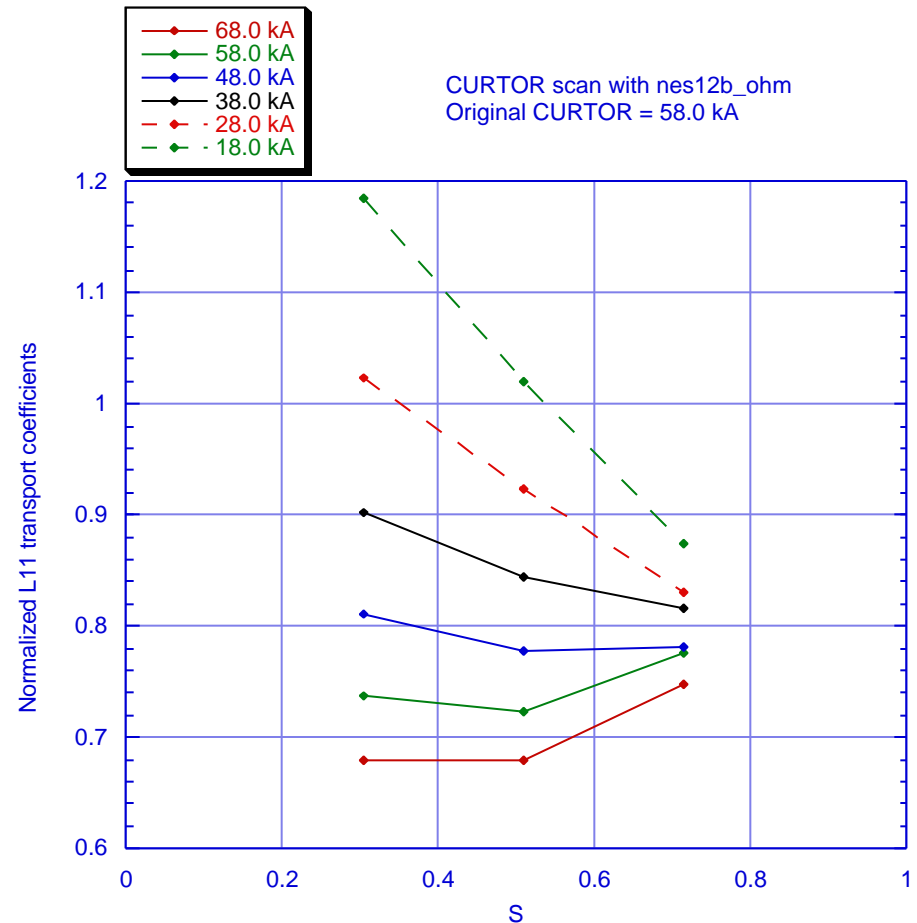


- Very low shear as Ohmic current increases, especially for $S > 0.5$

GB4_Ohmic: Ohmic current profile

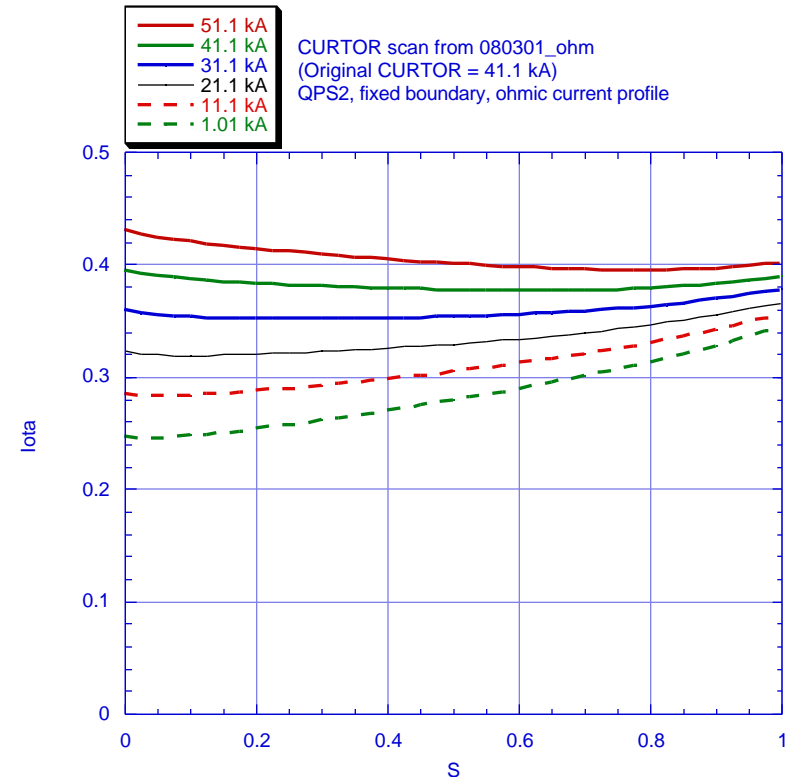
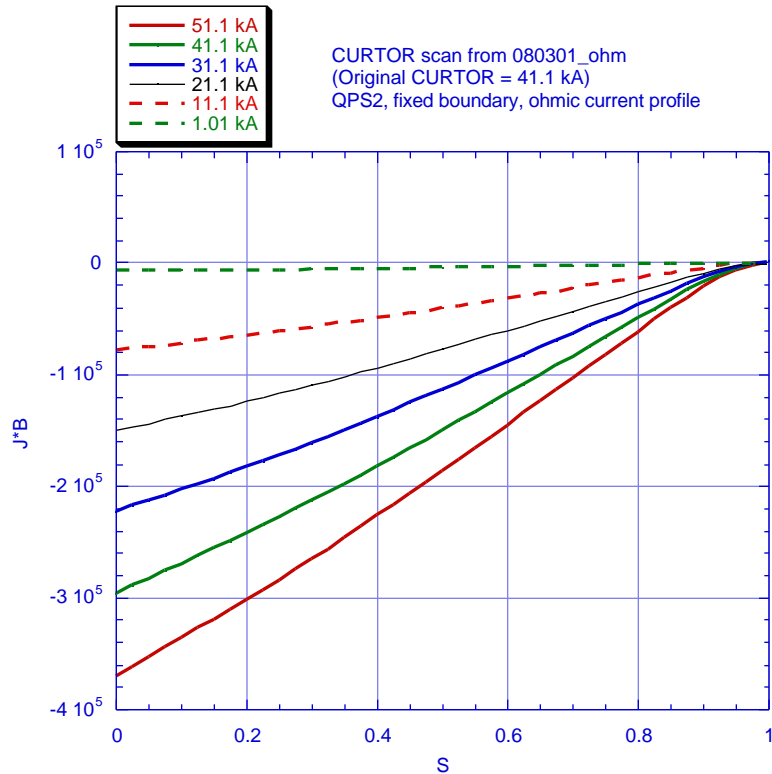
DKES L11 Transport Coefficient

- Increasing Ohmic current also improves confinement
- Confinement improves with increasing Ohmic plasma current
- At the highest currents, transport is lower near the axis



QPS2_Ohmic: Ohmic current profile

Field-aligned current and rotational transform

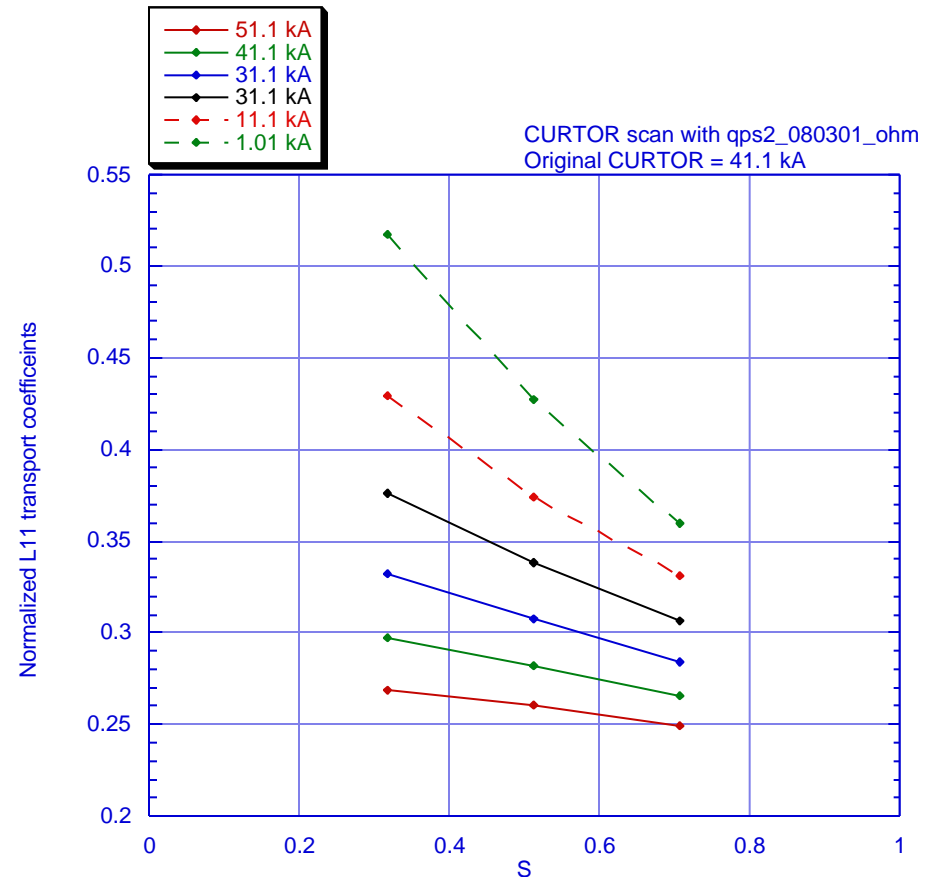


- Larger change in ι on axis as Ohmic current is increased
- Weakly reversed shear at the highest currents

QPS2_Ohmic: Ohmic current profile

DKES L11 Transport Coefficient

- Again, increasing Ohmic current also improves confinement
- Confinement much better than in GB4_Ohmic case



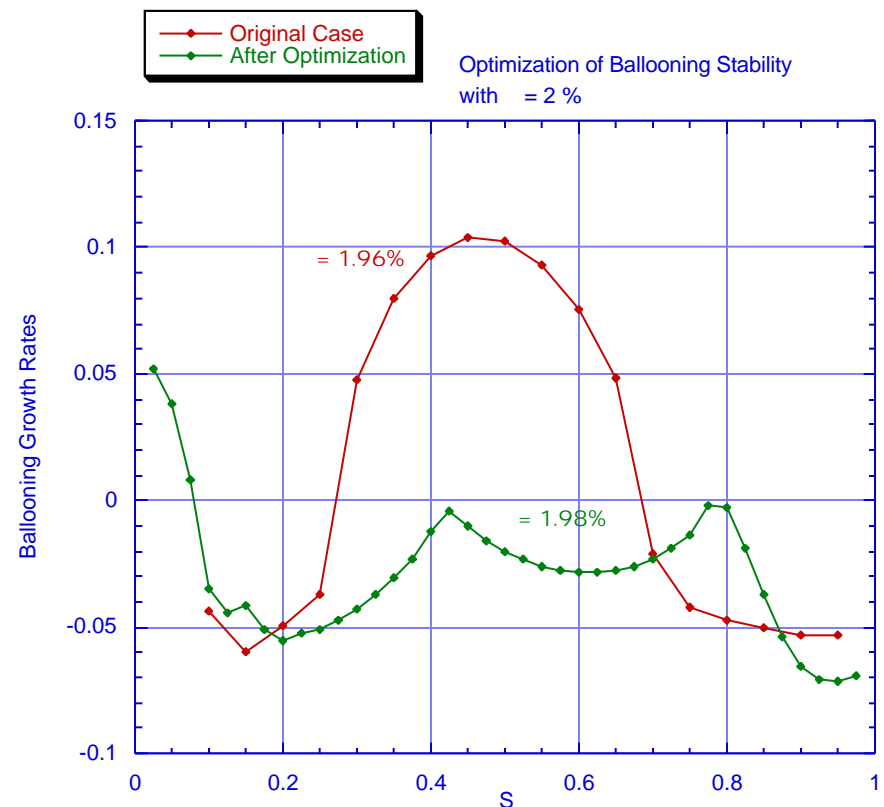
IV. Stability at Increased

- Goal is to find solutions that are ballooning stable on all flux surfaces
- Worked with one GB4 free boundary case and one QPS2 fixed boundary case (bootstrap current cases)

GB4: Bootstrap-aligned current profile

Ballooning growth rates, β_A

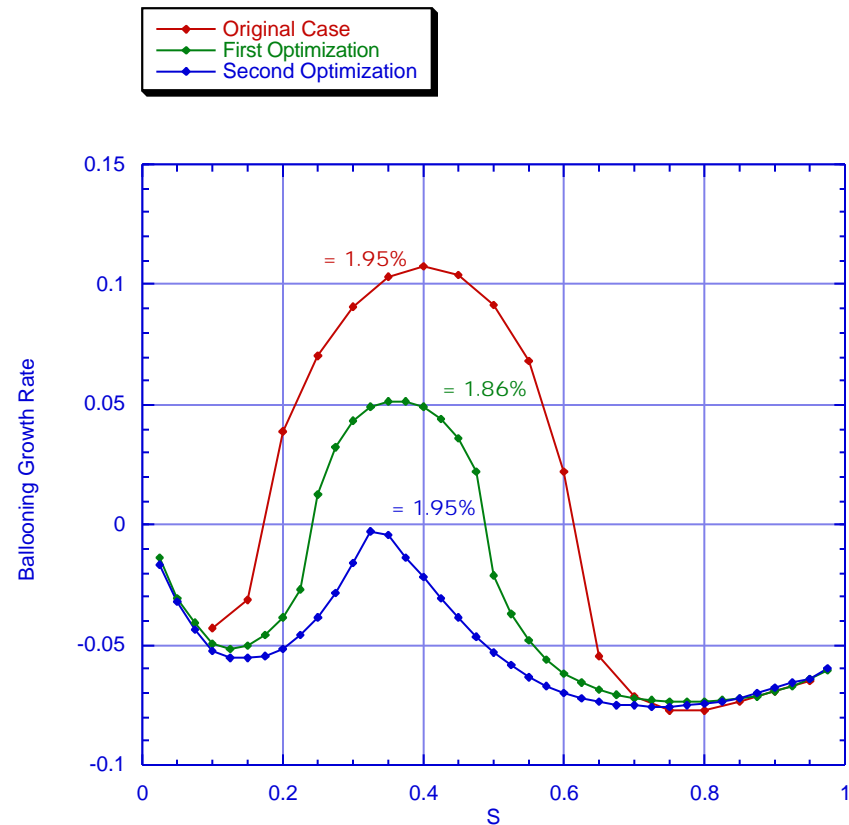
- For generic pressure profile, $p = p_0(1-S)^2$, unstable at $\beta_A = 2\%$
- The optimizer was able to find stable case while maintaining $\beta_A = 2\%$
- Unsuccessful at finding stable higher β_A cases



QPS2: Bootstrap-aligned current profile

Ballooning growth rates, A

- For generic pressure profile, $p = p_0(1-S)^2$, unstable at $\langle \rangle = 2\%$
- The optimizer was able to find stable case while maintaining $\langle \rangle = 2\%$
- Optimization at higher in progress



IV. Conclusions: Current Variations

- Confinement improves with increasing plasma current for both bootstrap aligned and Ohmic current profiles
- An Ohmic current profile produces cases with very weak shear
- For the QPS2 case, there was a finite bootstrap current at the plasma boundary (in more recent cases plasma current goes to zero at the boundary)

Conclusions:

Stability at higher $\langle \rangle$

- The ballooning stability limit for the GB4 free boundary case was $\langle \rangle = 2\%$
 - Further optimization, may find a stable higher configuration
- The ballooning stability for the QPS2 free boundary case found at $\langle \rangle = 2.8\%$
 - Optimizing at higher $\langle \rangle$ is a work in progress