

PROGRESS TOWARD β LIMITS FOR COMPACT STELLARATORS

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ARIES-CS Project Meeting
University of California, San Diego
March 8 – March 9, 2004

SUMMARY STATUS OF ARIES-CS EQUILIBRIUM AND STABILITY ANALYSIS

- Equilibria with increased resolution obtained for the three-period scaled up NCSX equilibrium for use in convergence tests:
 - Radial mesh increased from 49 to 97 surfaces for $\beta = 5.7\%$ and 8.3%
 - Increase above this results in failure due to memory problems in the GA Linux platforms
- Stability results obtained for the three-period scaled up NCSX equilibrium for the working range of moderately placed external conformal conducting walls at higher mesh:
 - Growth rates are sensitive to mesh size
 - Overall conclusions are unchanged:
 - □ limit for a wall in the range 1.7 to 2.5 expected to be around 6%
- Preliminary MHH2 two-field period equilibrium reproduced using the GA version of the VMEC code:
 - Equilibrium $\langle\beta\rangle = 4.52\%$ for base case
 - Fixed boundary based on L.P. Ku MHH2 equilibrium as initial case
- Series of increasing β MHH2 equilibria constructed:
 - $\langle\beta\rangle = 4.52\%$, 5.71% , and 6.92%
 - Final highest β case appears to be close to equilibrium limit

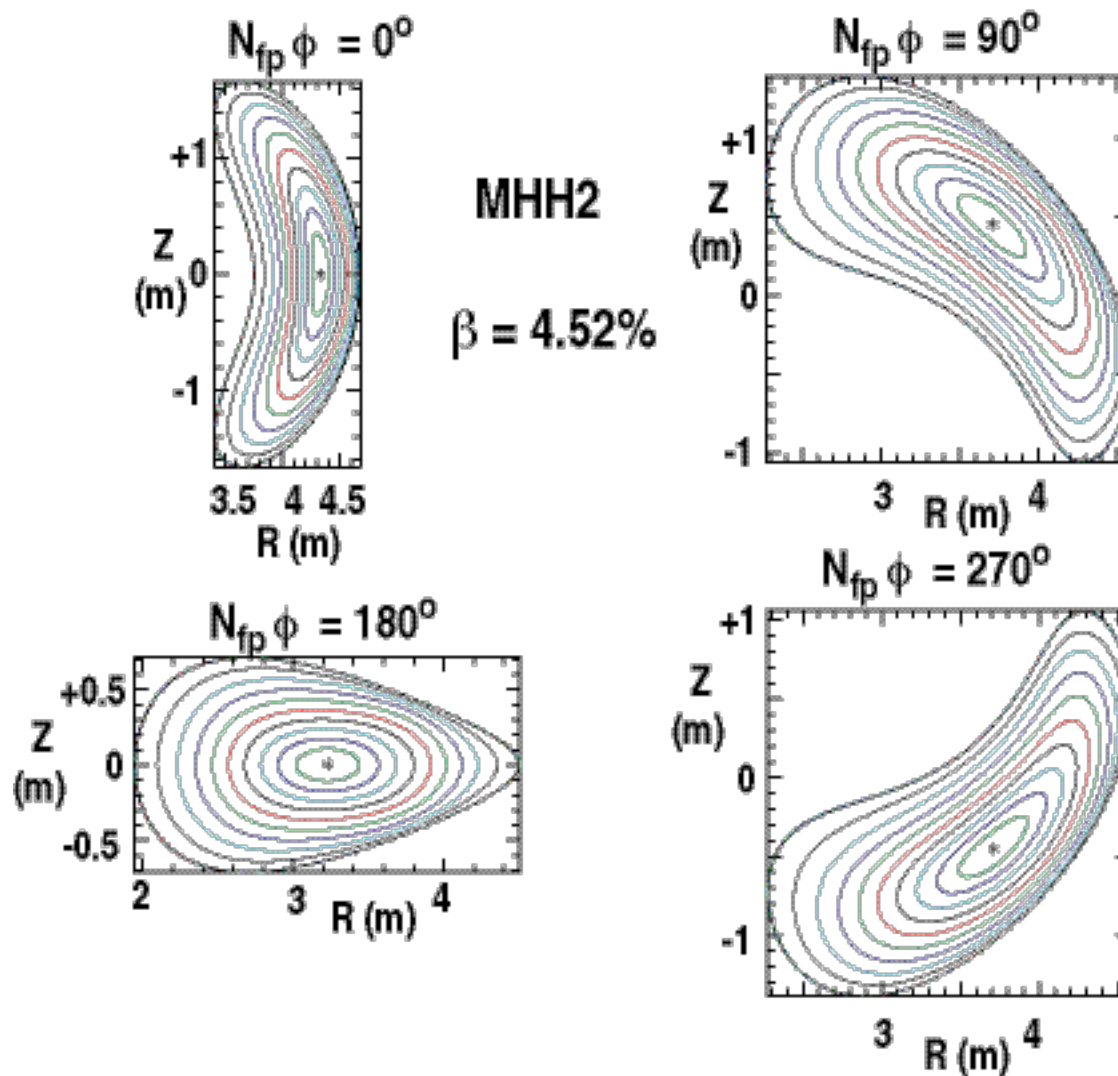
CONVERGENCE TESTS FOR THREE-PERIOD SCALED UP NCSX EQUILIBRIA CONFIRM PREVIOUS STABILITY RESULTS

- Radial mesh increased from 49 to 97 surfaces for two cases:
 $\Delta = 5.7\%$ and $\Delta = 8.3\%$
- Ideal n=1 mode family stability is sensitive to mesh:
 Δ Squared growth rate γ^2 vs Δ : $\gamma^2 > 0$ Δ stable / $\gamma^2 < 0$ Δ unstable

Δ Wall position	$\Delta = 5.7\%$		$\Delta = 8.3\%$	
	49 surfaces	97 surfaces	49 surfaces	97 surfaces
1.5	Failed	Failed	Failed	Failed
1.7	+1.86724E-04	+4.45102E-05	-8.66085E-04	+4.21229E-05
2.0	+1.86703E-04	+ 4.45080E-05	-9.47303E-03	-2.60370E-03
2.2	+1.86696E-04	+ 4.44765E-05	-1.33209E-02	-6.92268E-03
2.5	+1.86691E-04	+ 4.44760E-05	-1.63785E-02	-1.03321E-02
2.7	Failed	Failed	Failed	Failed

Δ limit for a wall in the range 1.7 to 2.5 expected to be around 6%

FIXED BOUNDARY MHH2 TWO-PERIOD EQUILIBRIUM CONSTRUCTED FROM VMEC

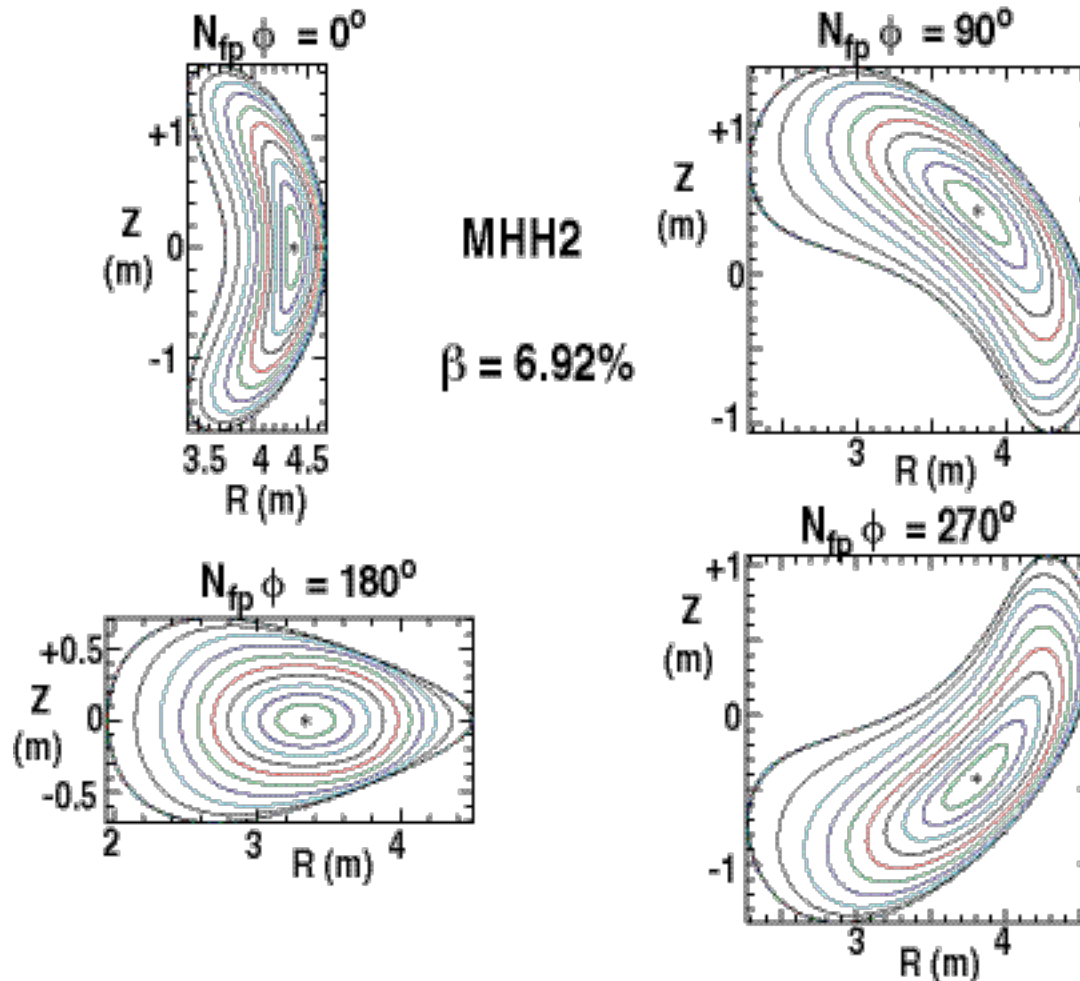


SEQUENCE OF FIXED BOUNDARY MHH2 EQUILIBRIA CONSTRUCTED FROM VMEC BY UNIFORMLY SCALING PRESSURE

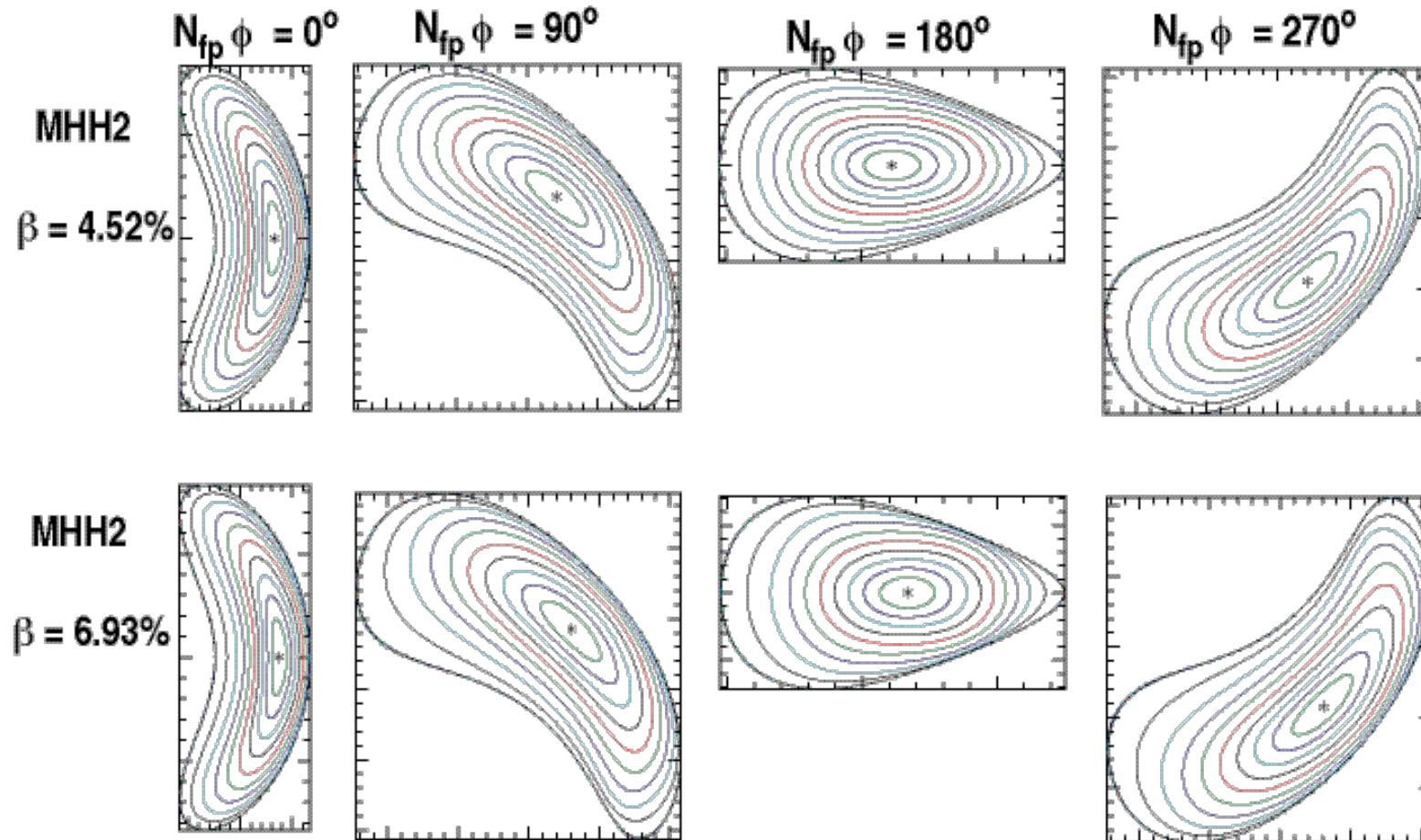
- Equilibrium is not the latest case generated by P. Garabedian:
 - ☐ Garabedian case requires a translation of the boundary representation into the standard VMEC representation
 - ☐ and pressure profiles are not exactly the same
- Volume, Average major and minor radius and vacuum field held fixed
- Fixed boundary calculation:
 - ☐ No coils
 - ☐ Boundary is unchanged as β is increased
- Profiles of pressure and rotational transform specified:
 - ☐ Fixed pressure profile in reference β equilibrium
 - ☐ Pressure profile kept fixed with scale factor used to adjust β
 - ☐ β profile adjusted to force average current density to vanish as β increases
 - ☐ Bootstrap current not self consistently calculated

VMEC CALCULATION SUGGESTS MHH2 $\beta = 6.93\%$ CASE MAY BE CLOSE TO EQUILIBRIUM LIMIT

- VMEC convergence at this β is extremely slow:
 - Increasing β just 10% results in convergence failure



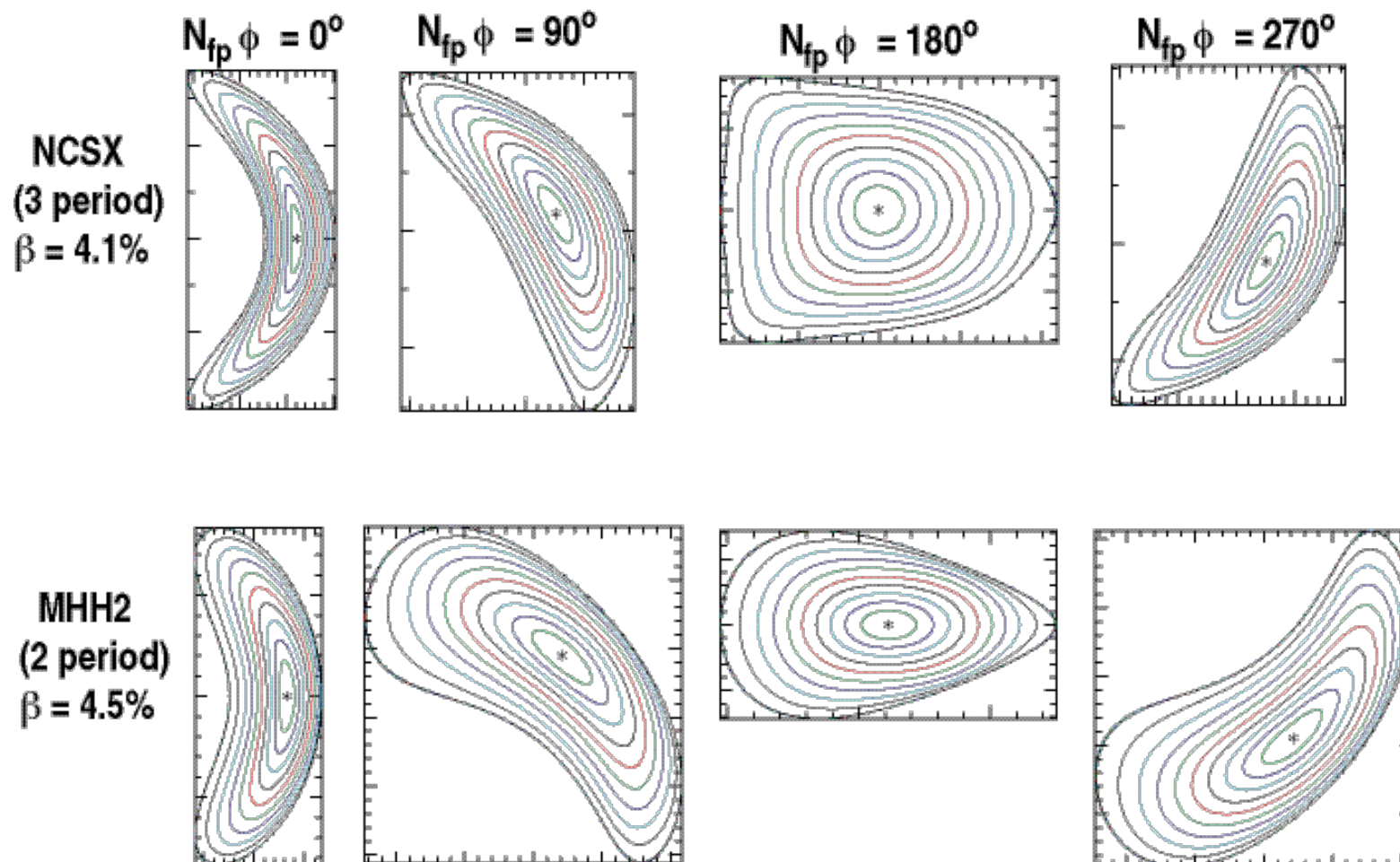
CONTOURS AT HIGH β ARE NOT STRONGLY DEFORMED FROM LOW β CASE



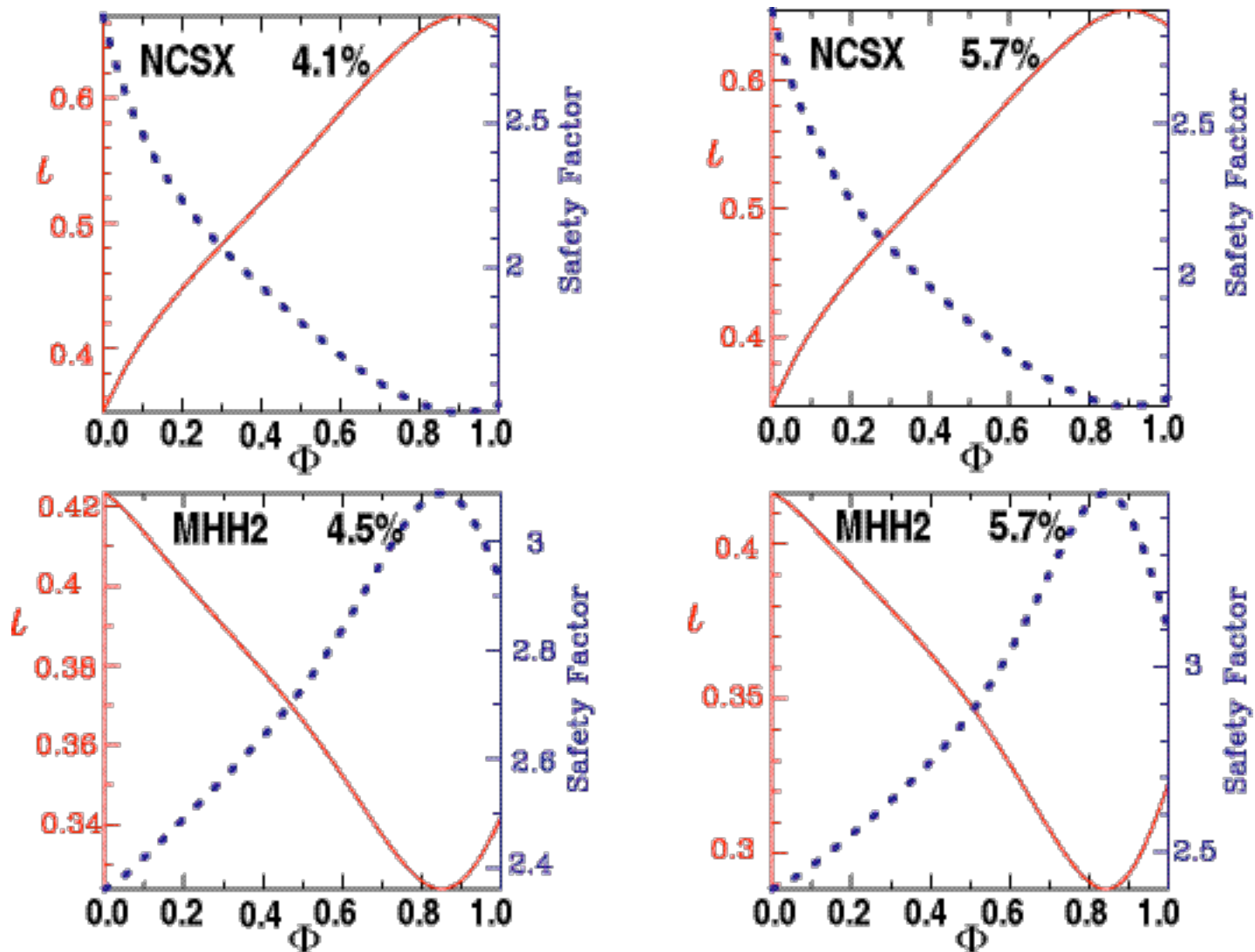
- Suggests this equilibrium might not be close to equilibrium limit!
- This apparent discrepancy should be resolved!

TWO-FIELD PERIOD MHH2 AND THREE-FIELD PERIOD SCALED NCSX EQUILIBRIA

- Main shape difference is lower order shaping near $N_{fp} \phi \sim 180^\circ$



ROTATIONAL TRANSFORM PROFILES ARE VERY DIFFERENT BETWEEN SCALED NCSX AND MHH2



MHH2 EQUILIBRIA WITH INCREASING β TESTED FOR IDEAL STABILITY: PRELIMINARY RESULTS

- Equilibria tested for ideal $n=1$ mode family stability:

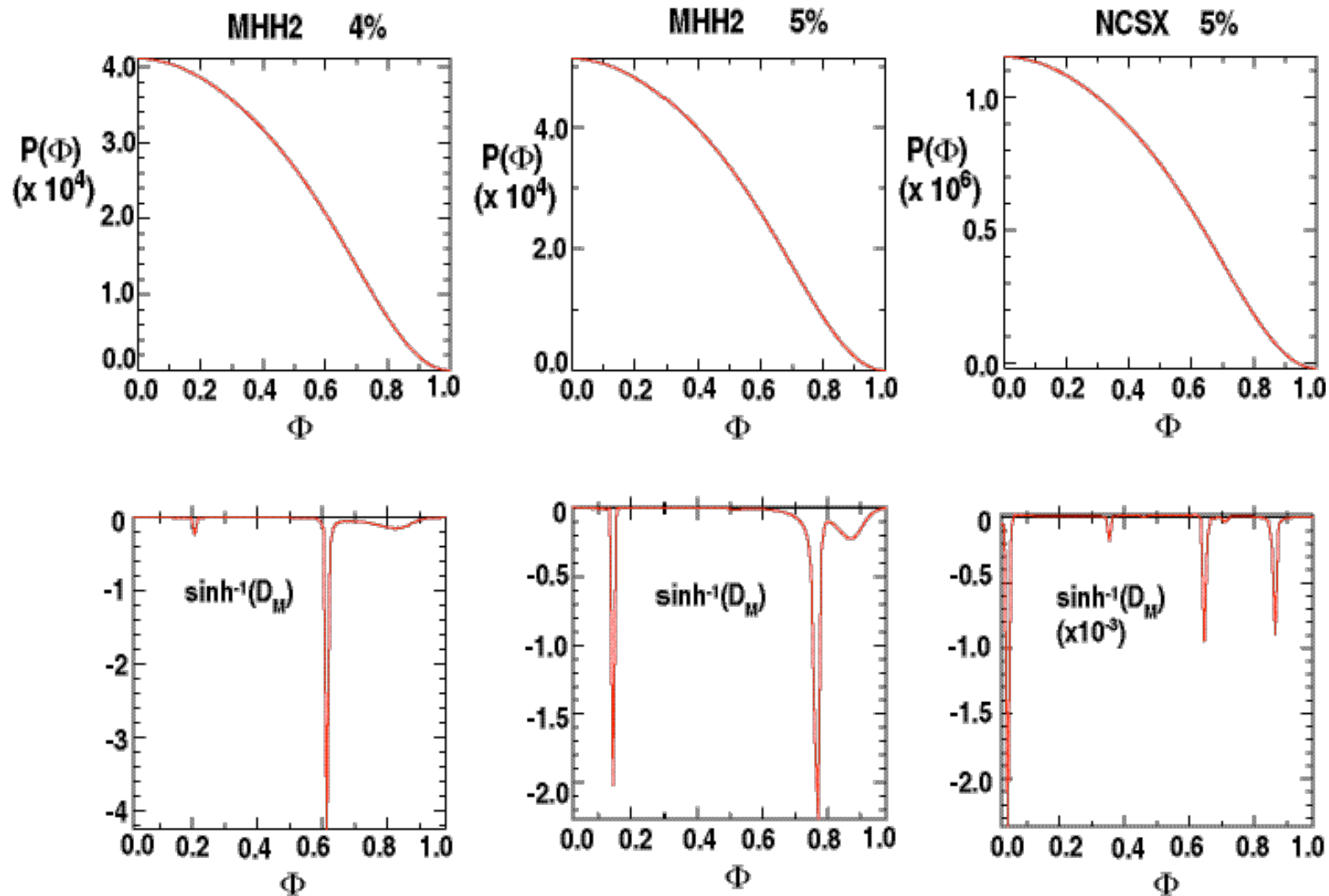
β^2 Squared growth rate γ^2 vs β : $\beta^2 > 0$ β stable / $\beta^2 < 0$ β unstable

Wall position/ β	4.25%		5.71%	6.92%
	49 surfaces	97 surfaces		
1.5	-7.02884E-05	-3.58509E-05	-1.48589E-05	Failed
1.7		-3.73551E-05	-1.48724E-05	Failed
2.0	-7.12588E-05	-3.86735E-05	-1.48845E-05	Failed
2.2		-3.91451E-05	-1.48898E-05	Failed
2.5	-7.15470E-05	-3.94305E-05	-1.48953E-05	Failed
2.7		-3.94256E-05	-1.48979E-05	Failed
3.0	-7.15261E-05	-3.92253E-05	-1.49009E-05	-1.91120E-05
3.2		-3.89990E-05	-1.49025E-05	-1.91832E-05
3.5	Failed	Failed	Failed	-1.92706E-05

INITIAL STABILITY RESULTS FOR MHH2 CONFIGURATION ARE SUSPICIOUS

- Growth rates are all small and insensitive to wall position
 - Remain small even with increased β up to 6.9%
- Stability calculations used a limited number of harmonics to keep within memory limit on GA Linux platforms:
 - Especially limited in range of toroidal mode number n
- This needs to be resolved before proceeding further:
 - Terpsichore input parameters need to be checked out
 - Computed mode structures need to be checked to determine if physical or not:
 - Mode appears to be dominated by $m/n = 9/3$ and $15/5$, with significant $m/n = 3/1, 21/7, 27/9$, and adjacent poloidal modes
 - Mode amplitude is still large for $n = 7$ and significant at $n = 9$ which is the largest included
 - Convergence studies at higher radial mesh and larger number of Fourier harmonics need to be performed

VMEC MERCIER CRITERION INDICATES STABILITY UP TO $\beta = 5\%$



PROGRESS SUMMARY: JANUARY 2003 TO DECEMBER 2003: UPDATE MARCH 2004

PLANNED TASK	STATUS	COMMENTS
Port Terpsichore	Completed February 2003	Terpsichore now running on GA Linux system (Lohan1) Benchmarked for LHD and QHS cases (with WA. Cooper)
Obtain Base VMEC Equilibrium	Completed March 2003	Obtained scaled NCSX equilibrium from PPPL to use as starting point (with Long-Poe Ku)
Stability Calculation using Terpsichore	Completed June 2003	Rewritten interface between VMEC and Terpsichore to use PPPL and GA VMEC and CRPP Terpsichore versions
Modify VMEC Equilibrium and check stability robustness and convergence	Completed March 2004	Reproduced PPPL scaled NCSX equilibrium using GA VMEC version and run sequence with increasing β Limited convergence study with radial mesh doubled
Free Boundary Equilibrium from PIES	Not Done: Insufficient resources	This should be done in the long run but is beyond present resources
Iterate Equilibrium and Stability	Not Done: Insufficient resources	This should be done in the long run but is beyond present resources

PROGRESS SUMMARY: PROPOSED STABILITY ANALYSIS PLANS: 2004

TASK	STATUS	COMMENTS
Reconstruct base 3-Field Period equilibrium	Initiated December 2003	Reconstruct increasing β VMEC equilibrium sequence: On hold awaiting convergence of latest case
Stability Calculation of 3-Field Period case using Terpsichore	Not Yet Done	Test convergence, β limit, and sensitivity: On hold awaiting convergence of latest case
Reconstruct 2 field period equilibrium or other variant	Initiated March 2004	Reconstructed PPPL version of MHH2: Two-field period variant from P. Garabedian requires some translation to VMEC representation.
Stability Calculation of 2-Field Period case using Terpsichore	Initiated March 2004	Test convergence, β limit, and sensitivity: Initiated for PPPL version
Fix Wall Construction for Close Walls	Not Yet Done	Extract logarithmic singularity carefully: Negotiation with A.W. Cooper and P. Merkel are underway
Fix Wall Construction for Distant Walls	Not Yet Done	Wall construction in constant β planes or other options: Negotiation with A.W. Cooper are underway

OTHER RECENT DEVELOPMENTS

- **Negotiations with Tony Cooper on wall construction in Terpsichore:**
 - **There is some resistance to allowing us to improve Terpsichore wall and vacuum construction:**
 - **This is a project suitable for a student**
 - **It was agreed, however, that the CRPP group should do the work**
 - **Discretized version to be fixed by a student over the summer**
 - **Greens function version under development with Peter Merkel**
 - **We should test both versions on our cases**
- **An EPS abstract on the stability of the ARIES Compact Stellarator design was submitted jointly with Lang Lao and Paul Garabedian**
 - **Covers physics of MHD stability:**
 - **Calculations for ARIES scaled NCSX and MHH2**
 - **Discussion of meaning of stability limits for stellarators**
 - **Comparison of linear Terpsichore and nonlinear NSTAB results**
 - **Abstract accepted and approved by General Atomics management**
 - **Negotiating combining the EPS trip with a one-week visit to Lausanne to work with Tony Cooper**
- **Progress on running Terpsichore on Linux platforms with higher mesh**
 - **Problem appears to be with setup of GA Linux systems:**
 - **Memory limitation due to Linux memory allocation specifications**