QOS Configuration Optimizations

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Two Strategies for QOS Configuration Optimization

- Optimizing an ultra low aspect ratio, low β configuration for a CE experiment
- Optimizing compact, high β configurations as part of the long term QOS program

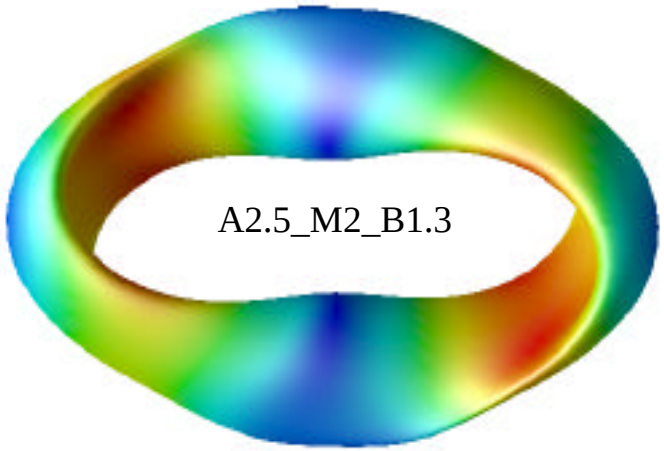
Selection Criteria for Configurations

- Guidelines for the selection of a configuration for a CE:
  - Compact: $A < 3$
    - This ultra low aspect ratio range is lower than existing stellarators (1/2 to 2/3 that of NCSX)
  - Good confinement: $\tau_{neo} > 2*\tau_{ISS95}$
    - Drift-optimized so that neoclassical transport is not the dominant loss mechanism
    - Cases normalized to: $R\ \langle a \rangle = 0.278$ and $\langle |B| \rangle = 1.0$

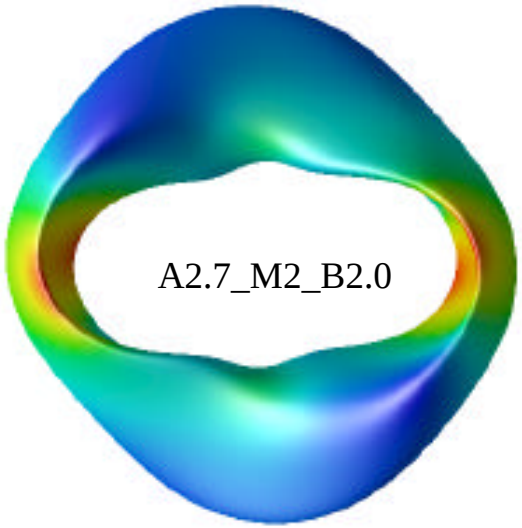
Selection Criteria for Configurations (cont.)

- Stability: MHD stable at $\beta \sim 2\%$
  - ➡ Ballooning and Mercier analysis included in optimization to ensure stability at β levels relevant to a CE
- Accessibility: not an issue for low I_{BS} QOS
- Flexibility: ability to vary the bootstrap current through the |B|-spectrum

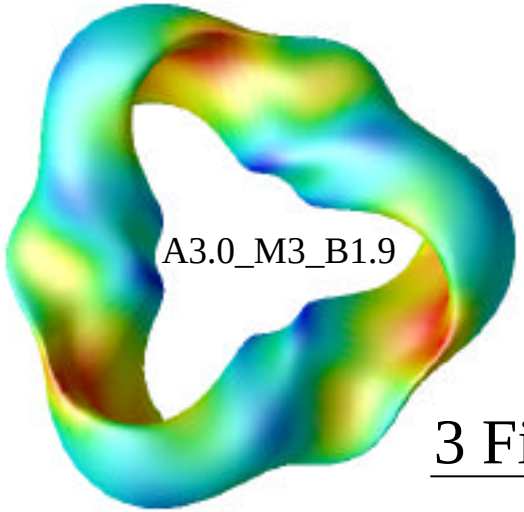
CE Candidate Configurations



Quasi-Poloidally Symmetric

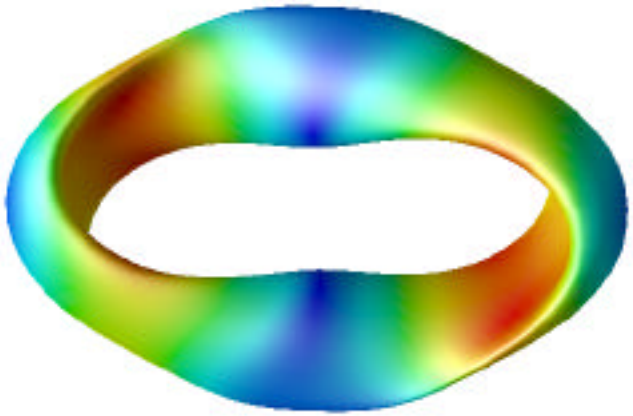


2 Field Period Hybrid



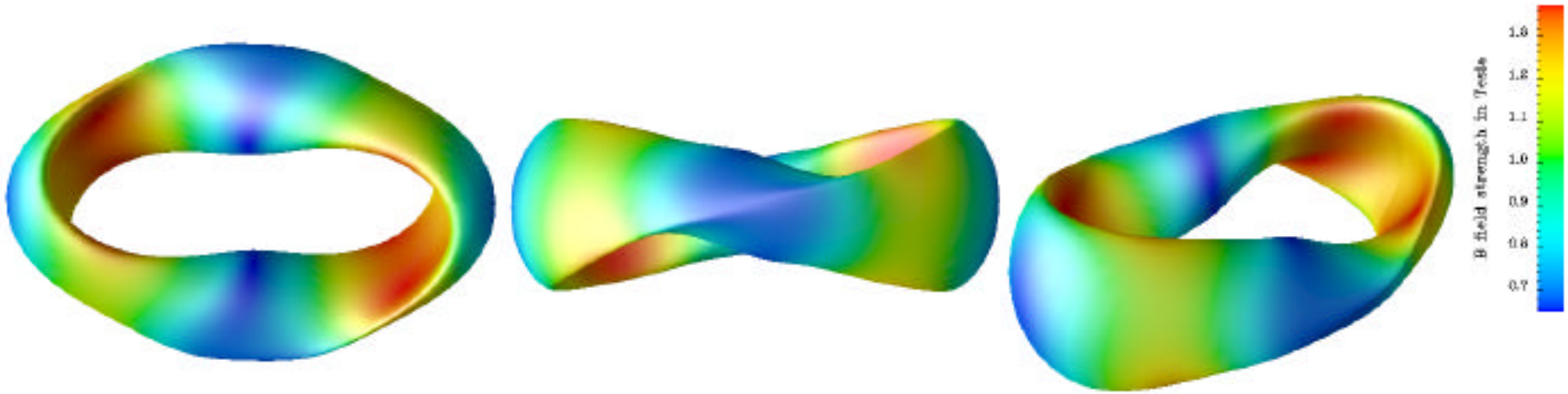
3 Field Period QOS

Quasi-Poloidally Symmetric Cases

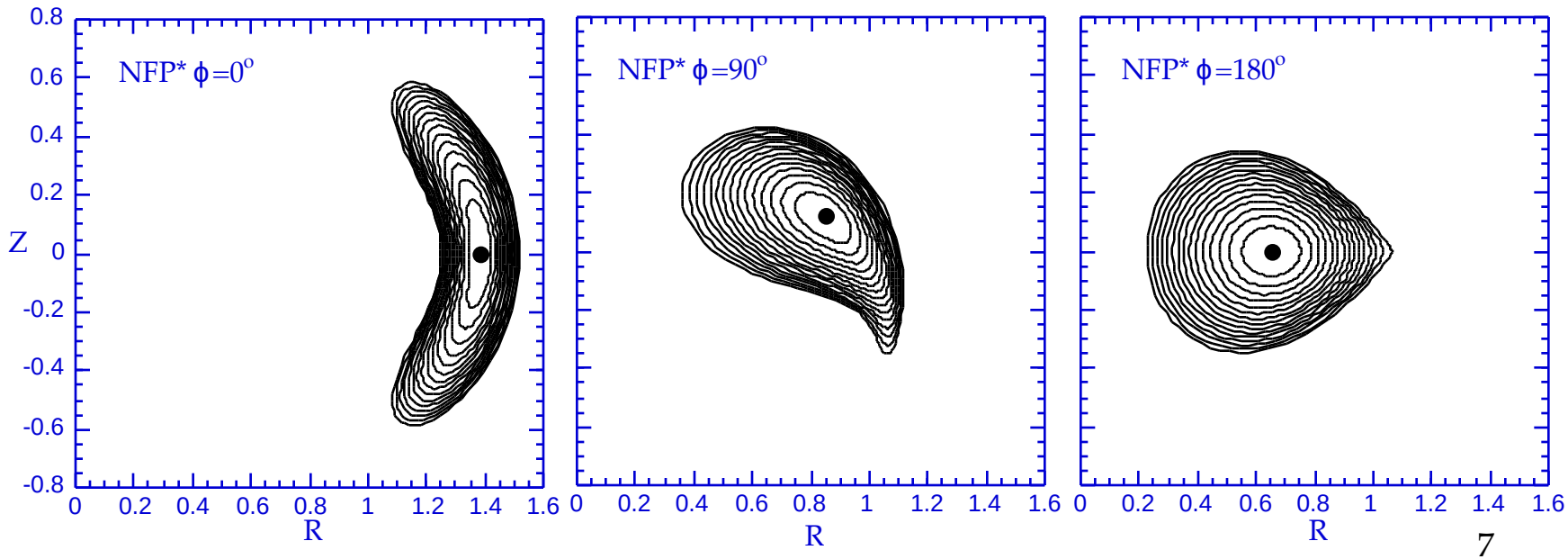


- Base case: A2.5_M2_B1.3
  - ➡ Max.Tor.Cur. = 25.7 kA
- Low aspect ratio: A < 2.5
  - ➡ Have obtained configurations with aspect ratios in the range: A=2.1 to A=3.0
- Rotational transform below 0.5: $\iota \sim 0.3 \rightarrow 0.4$
  - ➡ Majority of the transform is from the coils, bootstrap current causes iota to increase

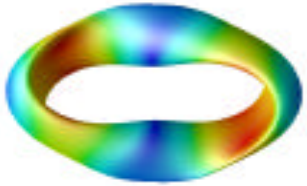
Outer Surface Views for A2.5_M2_B1.3



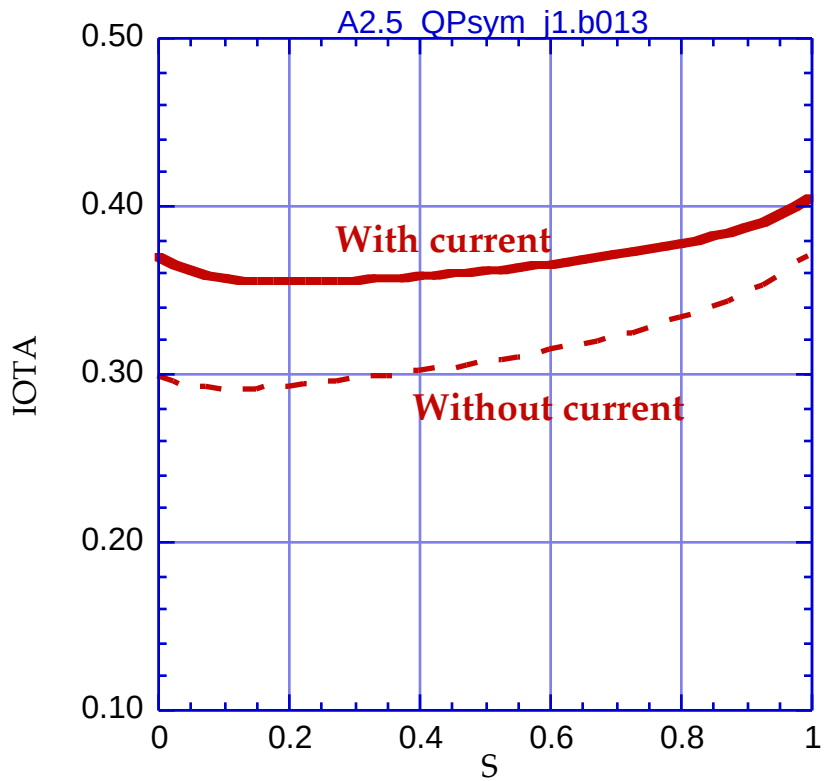
Cross Sections for A2.5_M2_B1.3

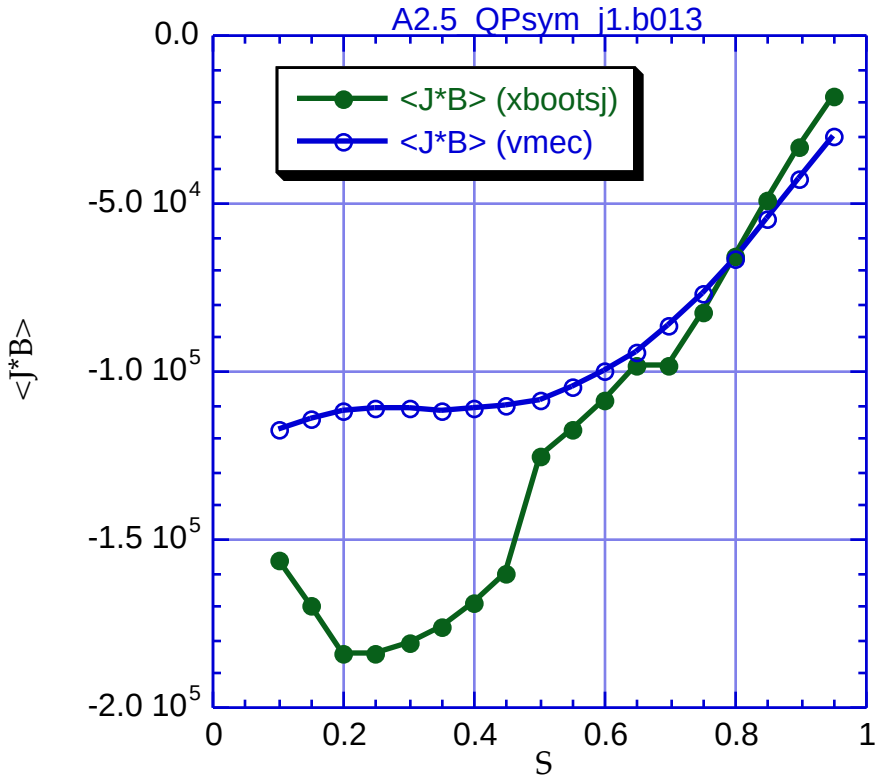


QP Sym Cases (cont.)



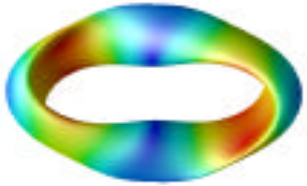
- Weak shear with iota mainly from coils



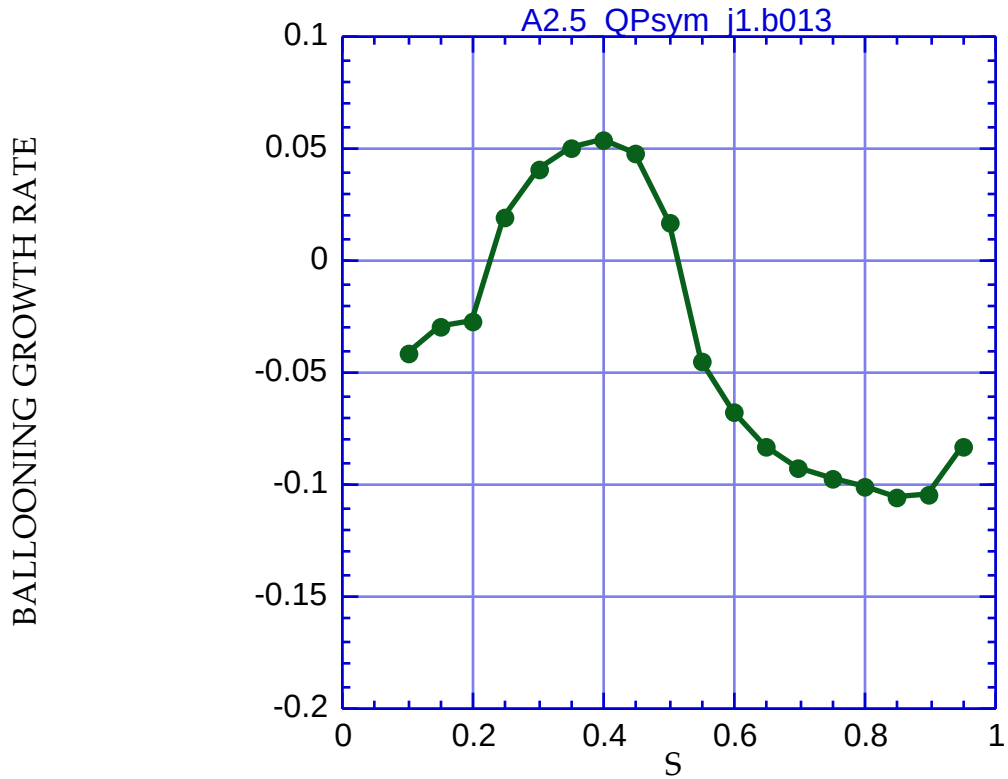


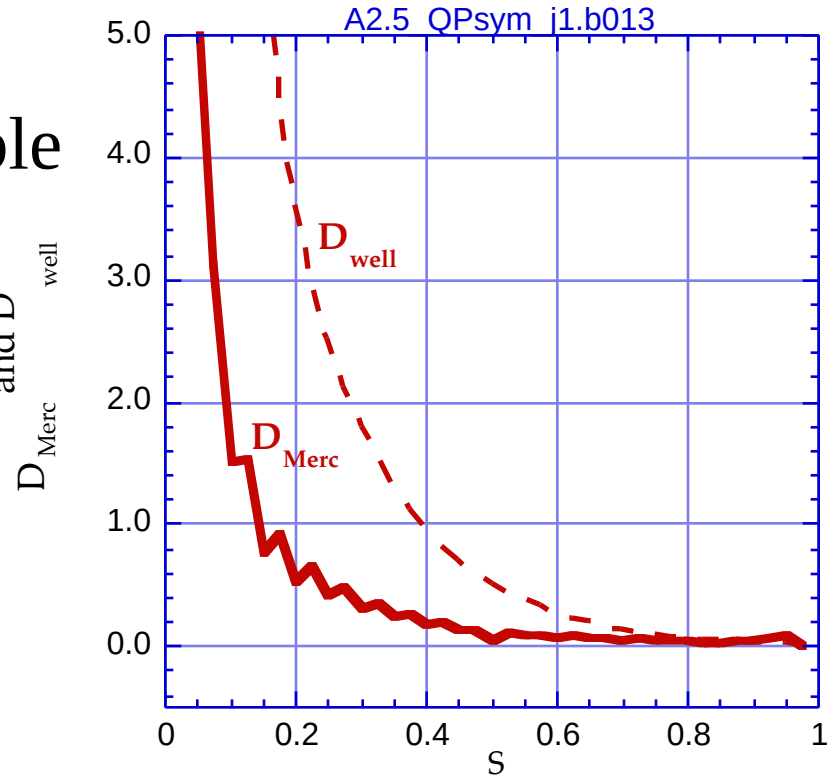
- Bootstrap consistency is fair

QP Sym Cases (cont.)



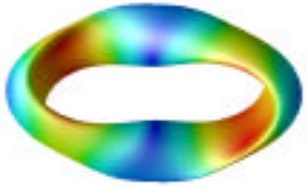
- Pressure profile for this case is ballooning unstable



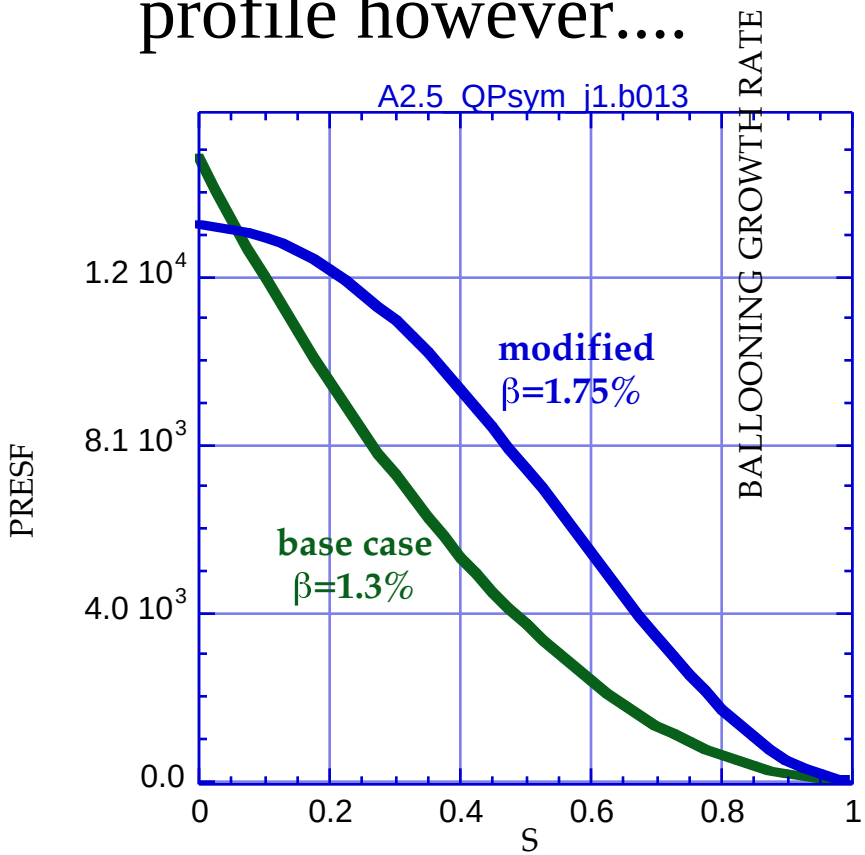


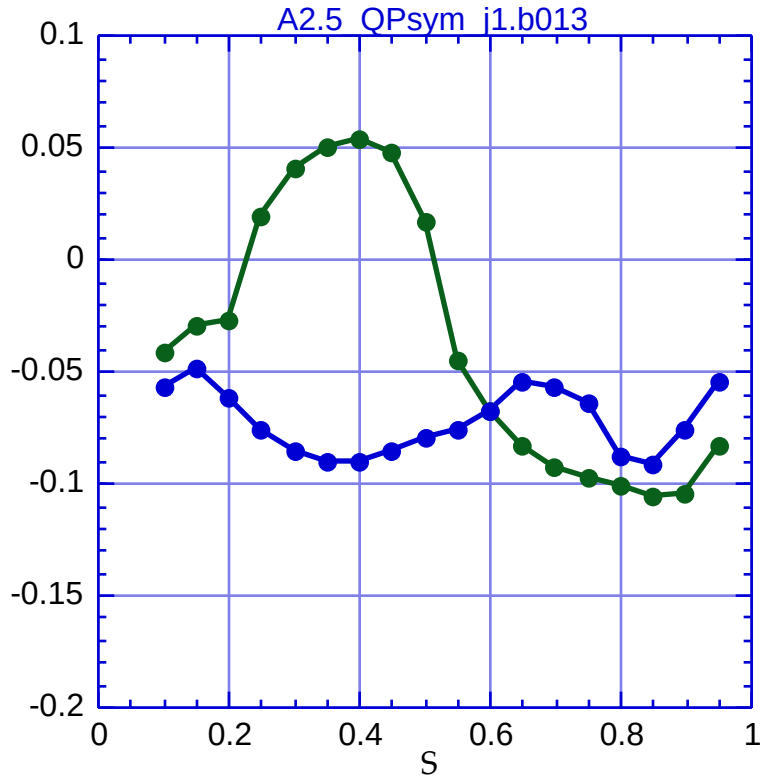
- Mercier stable due to the well at the center

QP Sym Cases (cont.)



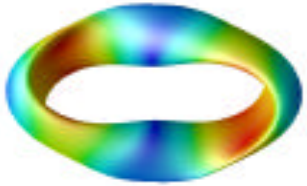
- Modifying the pressure profile however....





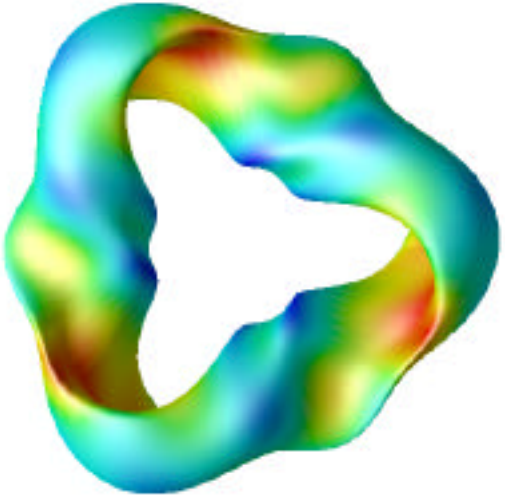
- ... leads to ballooning stability at higher β

QP Sym Cases (cont.)



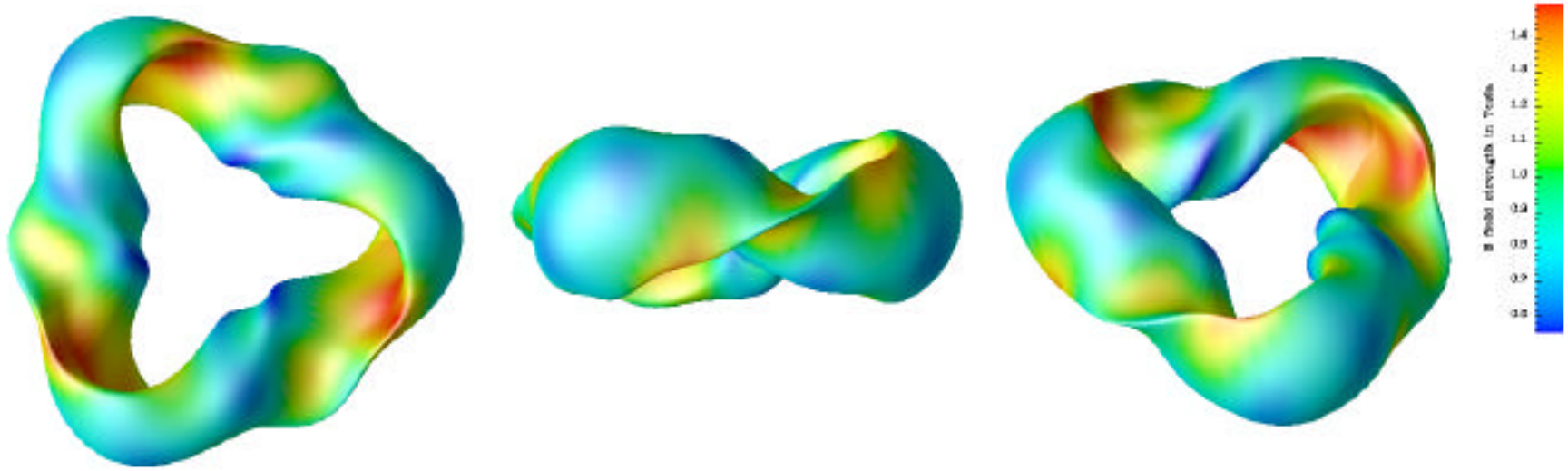
- D. Spong will discuss the neoclassical confinement of all of the candidate configurations
  - For base case A2.5_M2_B1.3: 8.5 ms
- An initial coil set and a free boundary reconstruction of the surfaces has been obtained for one of these configurations (D. Strickler, J. Lyon, P. Valanju)

3 Field Period QOS Cases

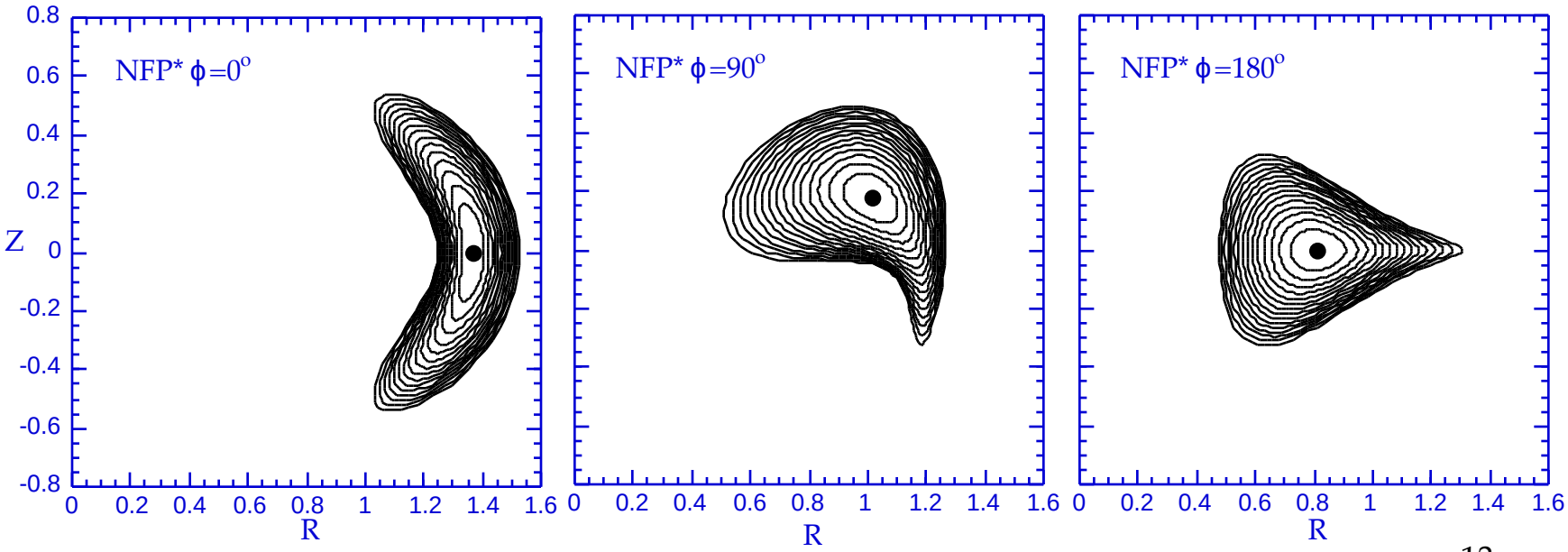


- Base case: A3.0_M3_B1.9
  - Max.Tor.Cur. = 4.97 kA
- Low aspect ratio: A = 3.0
  - This is a more compact, lower current version of previous QOS configurations at A~3.6
- Rotational transform above 0.5: $\iota \sim 0.5 \rightarrow 0.8$
  - Transform is from the coils, bootstrap current subtracts (?) from the vacuum transform

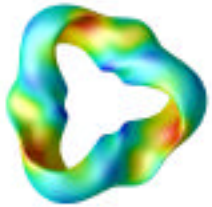
Outer Surface Views for A3.0_M3_1.9



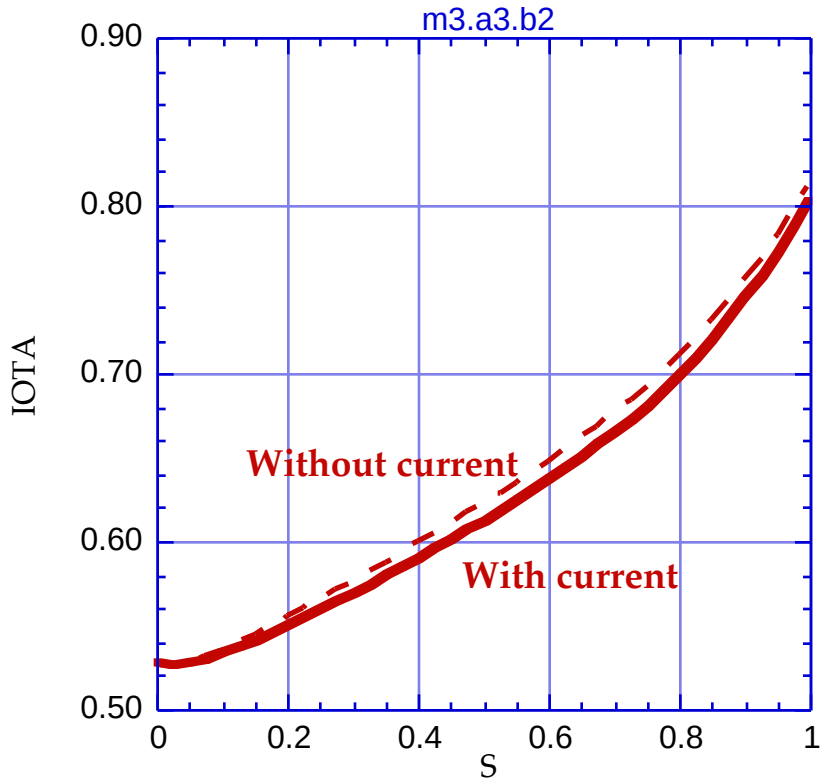
Cross Sections for A3.0_M3_1.9

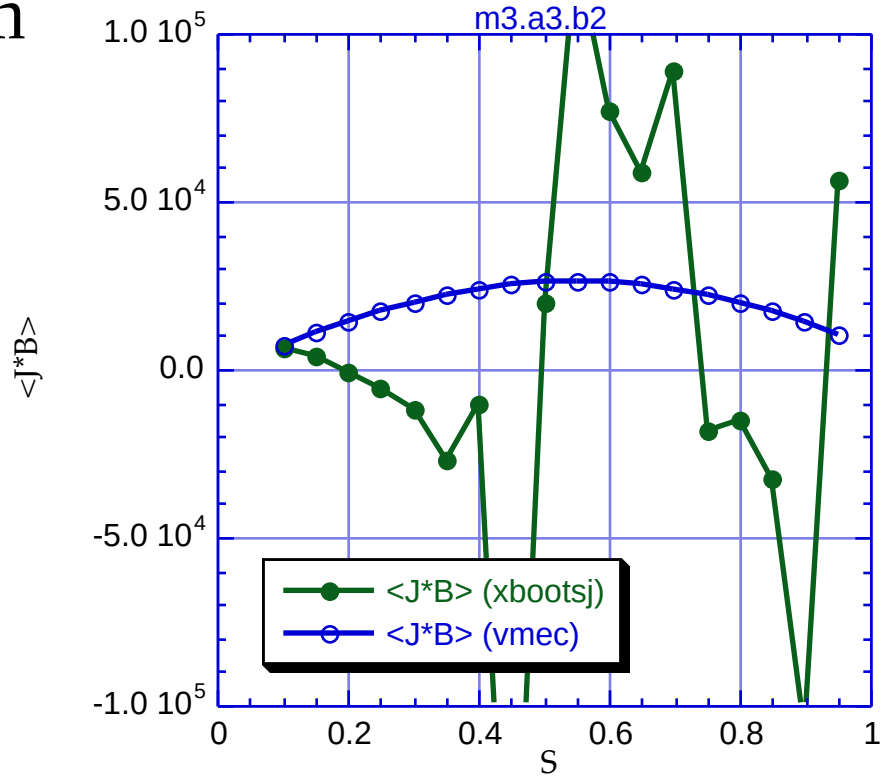


3FP QOS Cases (cont.)



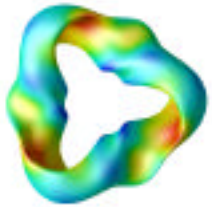
- Almost all the transform is from coils



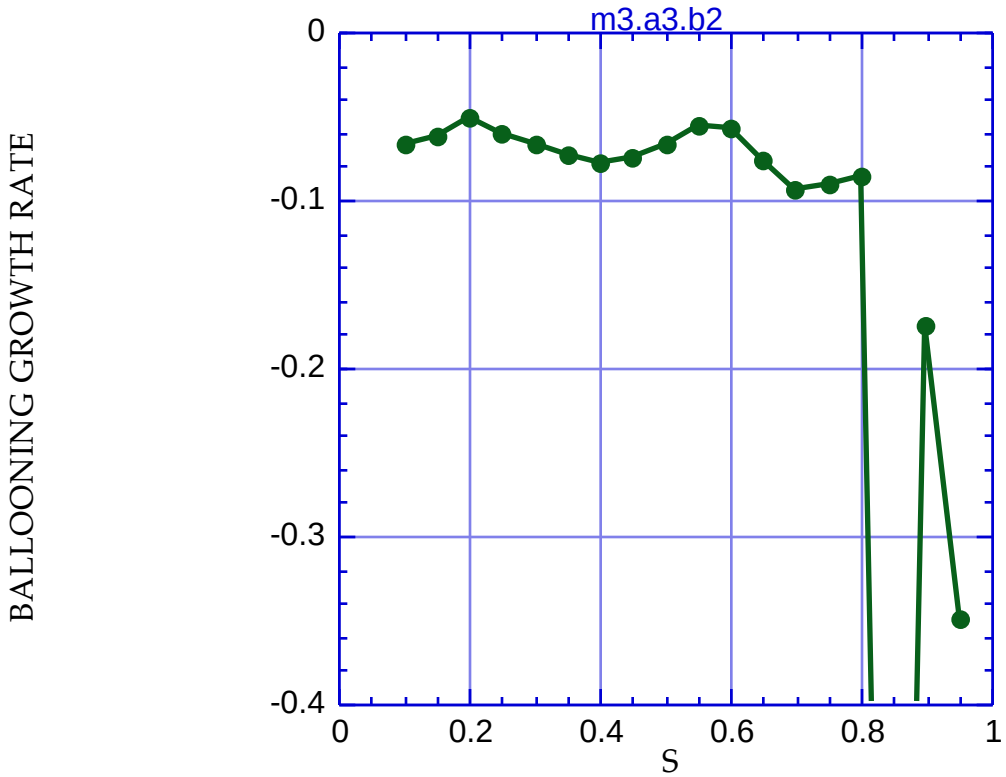


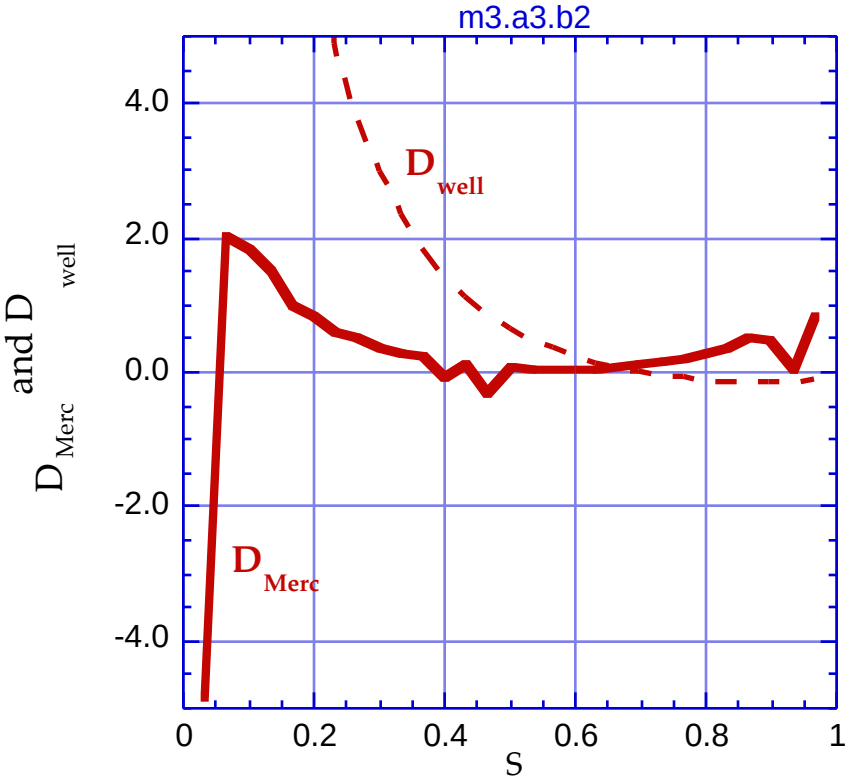
- Bootstrap current is very small (& noisy)

3FP QOS Cases (cont.)



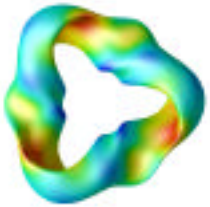
- Base case is ballooning stable at β=1.9%





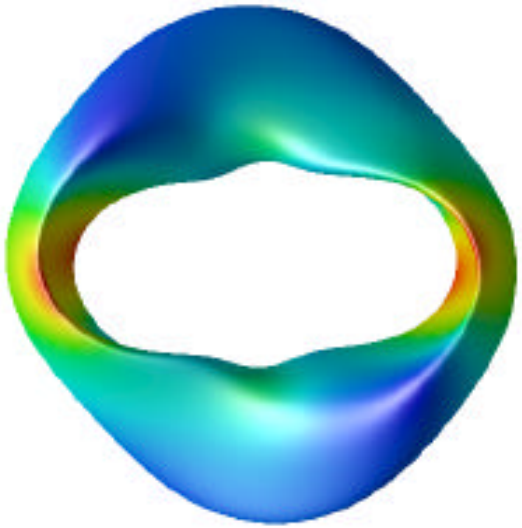
- For Mercier stability, has a well at the center and shear at the edge

3FP QOS Cases (cont.)



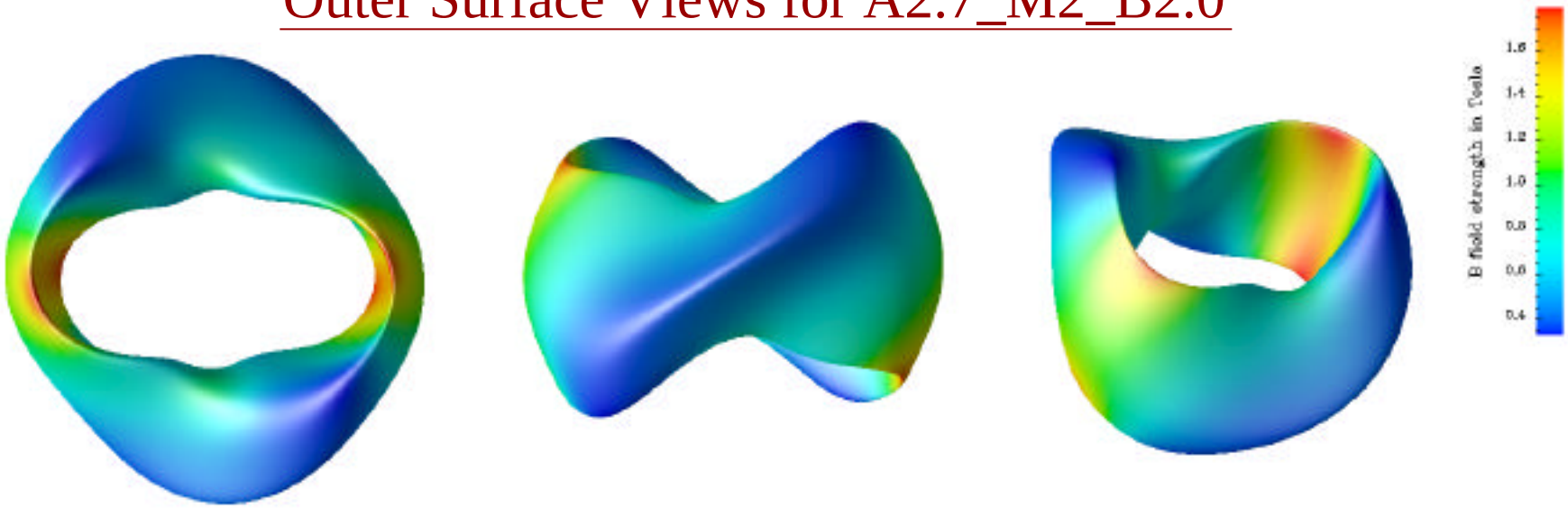
- Neoclassical confinement
  - For base case A3.0_M3_B1.9: 7.0 ms
- Coils for the larger aspect ratio (A=3.6) case have been examined but it has been more difficult to find coils for the smaller aspect ratio

2 Field Period Hybrid Cases

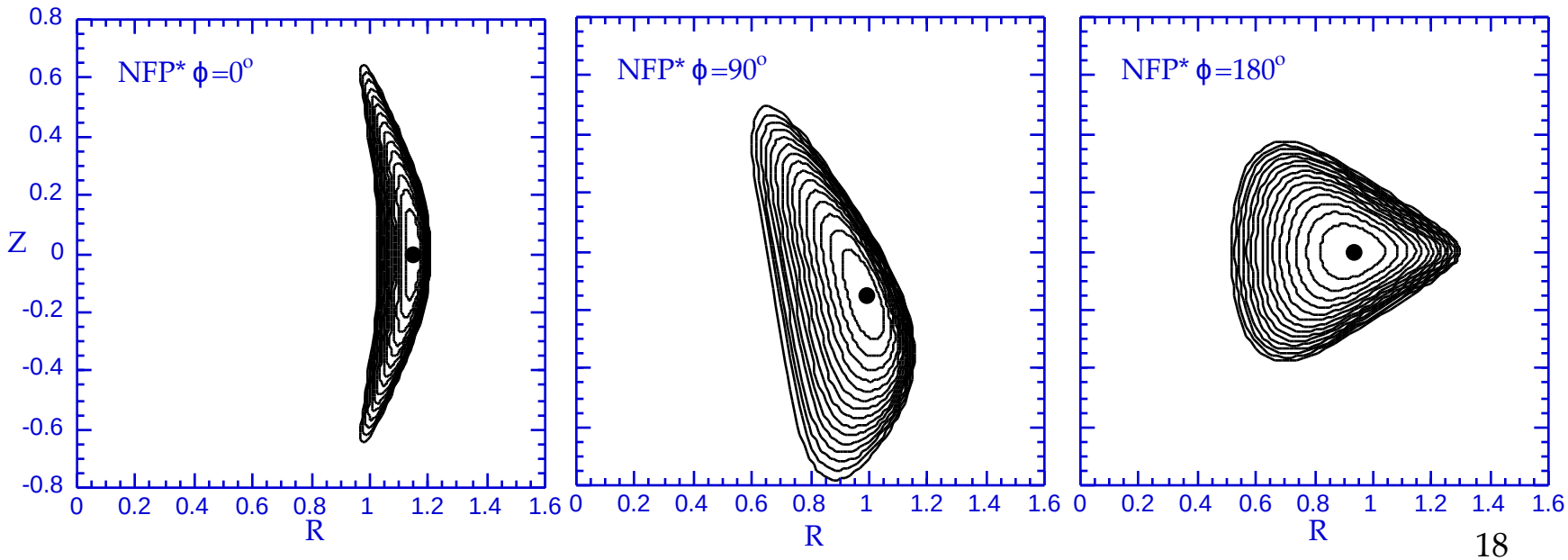


- Base case: A2.7_M2_B2.0
  - ➡ Max.Tor.Cur. = 88.2 kA
- Low aspect ratio: A = 2.7
  - ➡ This is a lower β version of the high β configurations (to be discussed)
- Rotational transform below 0.5: $\iota \sim 0.4 \rightarrow 0.2$
  - ➡ Coils provide half of the rotational transform, bootstrap current adds to the vacuum transform

Outer Surface Views for A2.7_M2_B2.0

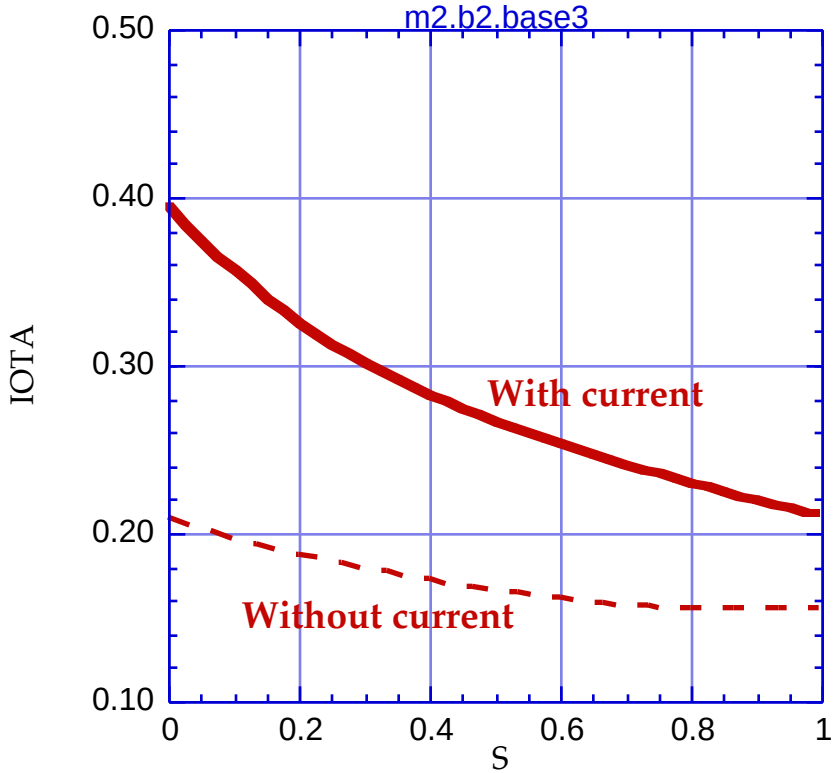


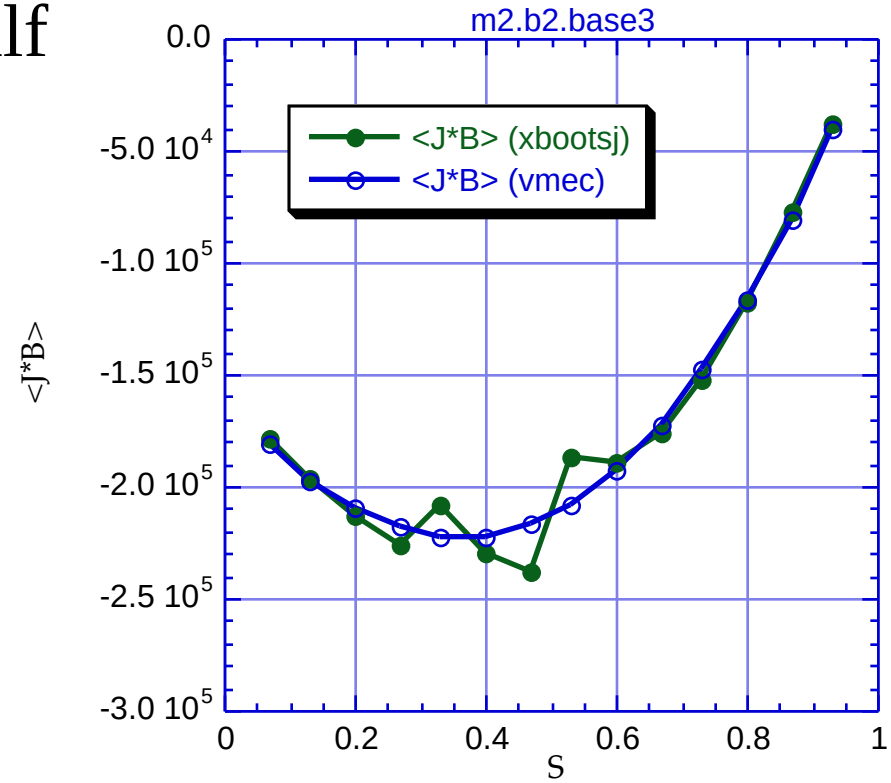
Cross Sections for A2.7_M2_B2.0



2FP Low I_{BS} Cases (cont.)

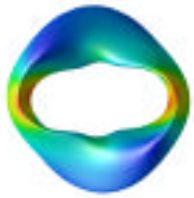
- At β =2%, iota about half from coils



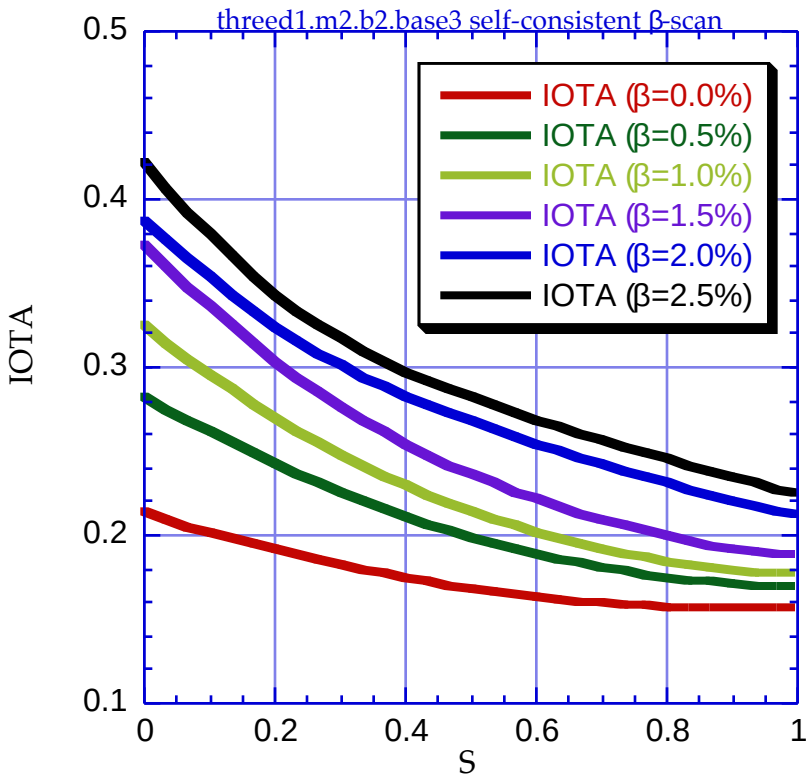


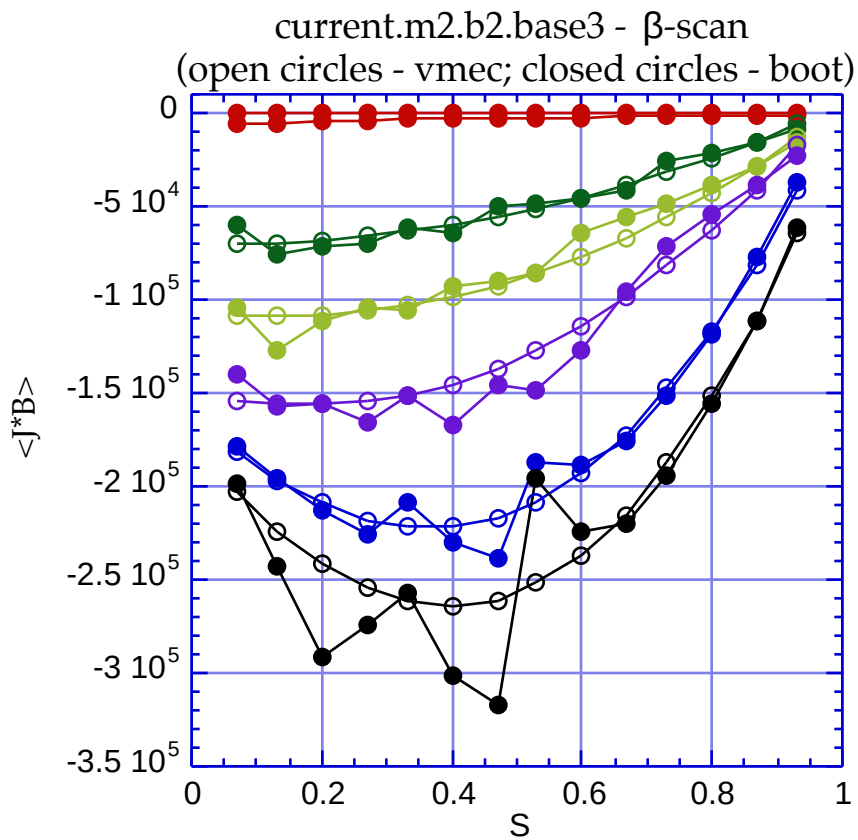
- Bootstrap consistency is very good at β=2%

2FP Low I_{BS} Cases (cont.)



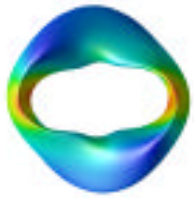
- A scan in β shows changes in iota as ...



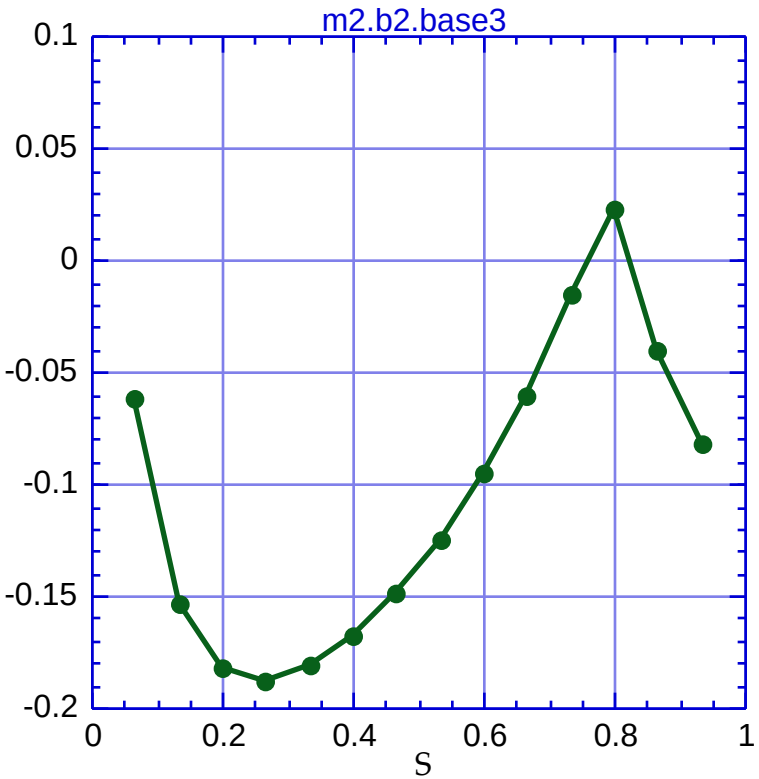


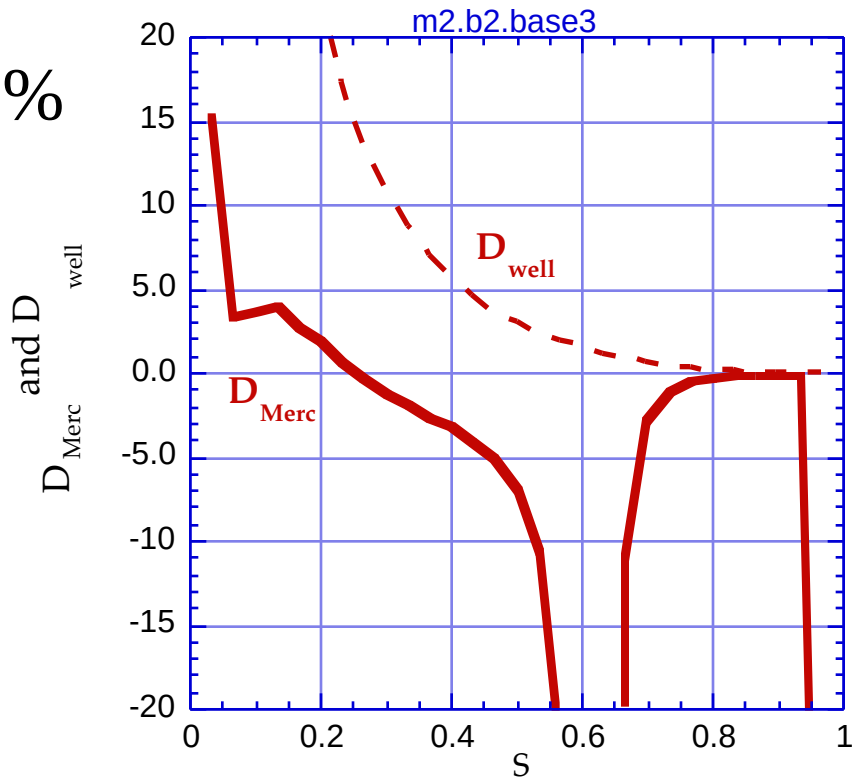
- self consistent bootstrap current increases

2FP Low I_{BS} Cases (cont.)



- Base case has one point ballooning unstable at β=2%





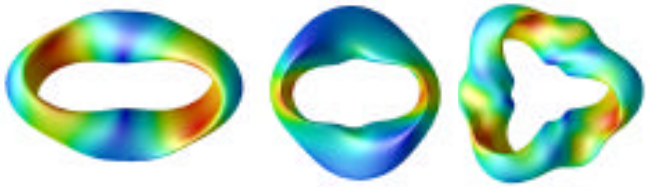
- Mercier unstable (not optimized for Mercier)

2FP Low I_{BS} Cases (cont.)

- Neoclassical confinement
  - For base case A2.7_M2_B2.0: 1.3 ms
- Preliminary investigations into coils for this configuration have not been promising (D. Strickler)

Summary of CE Cases

- Comparison of the base cases



Name	A	<β>	<|B|>	Max. Tor. Cur.	τ_{neo}
A2.5_M2_B1.3	2.5	1.3%	1.0 T	25.7 kA	8.5 ms
A3.0_M3_B2.0	3.0	1.9%	1.0 T	4.97 kA	7.0 ms
A2.7_M2_B1.9	2.7	2.0%	1.0 T	88.2 kA	1.3 ms

High β Configurations

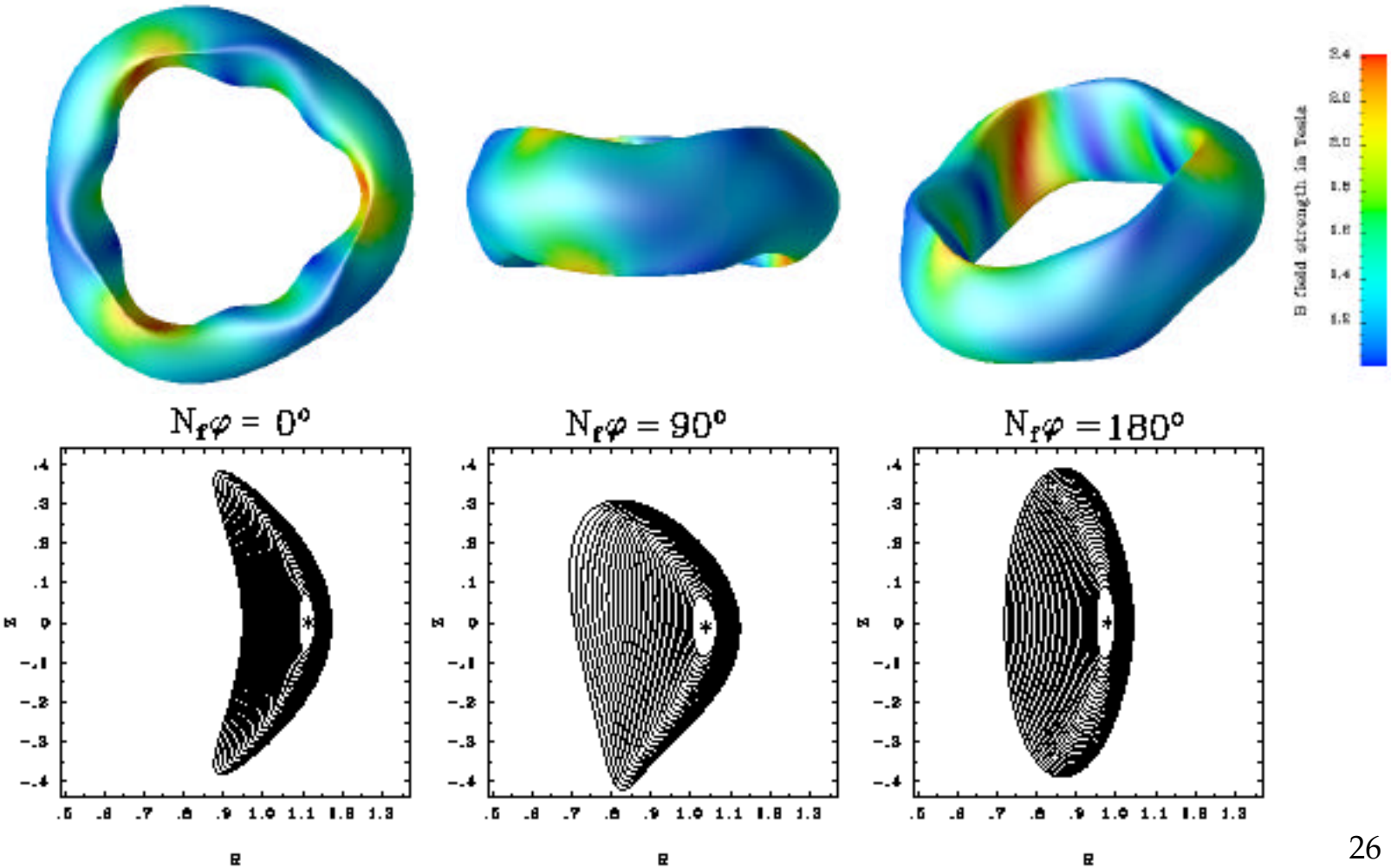
- A class of configurations with high β MHD stability limits
  - Rotational transform primarily from plasma current
  - Better alignment with self-consistent bootstrap current than advanced tokamaks
  - Stable at higher β than comparable tokamak due to lower current

High β Configurations (cont)

- Have obtained 3 field period configurations with ballooning stability up to β=23%, Vertical/Kink stability up to β =15% (G. Fu), aspect ratios A~3.5 → 4.5
- For lower aspect ratio (A~2.7) 2 field period devices, testing effect of lowering elongation and boosting external rotational transform on vertical stability

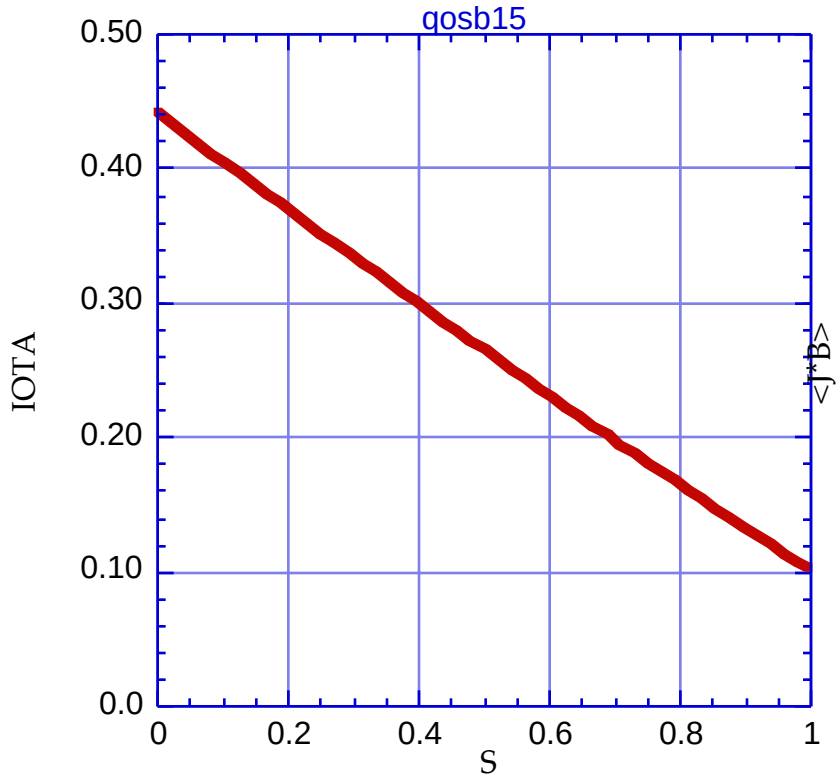
High β Case: 3 Field Periods

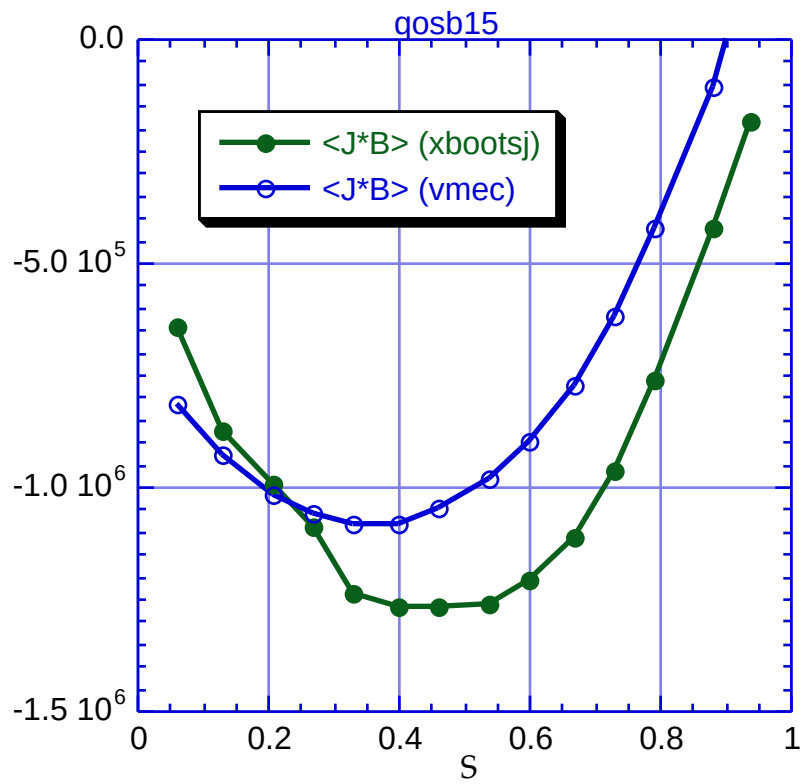
- Outer flux surface/cross sections: 3 FP, A=3.7, β=15%



High β Case: 3 Field Periods

- 3 FP, A=3.6, β=15%, <|B|>=1 T, Max.Tor.Cur.= 155 kA



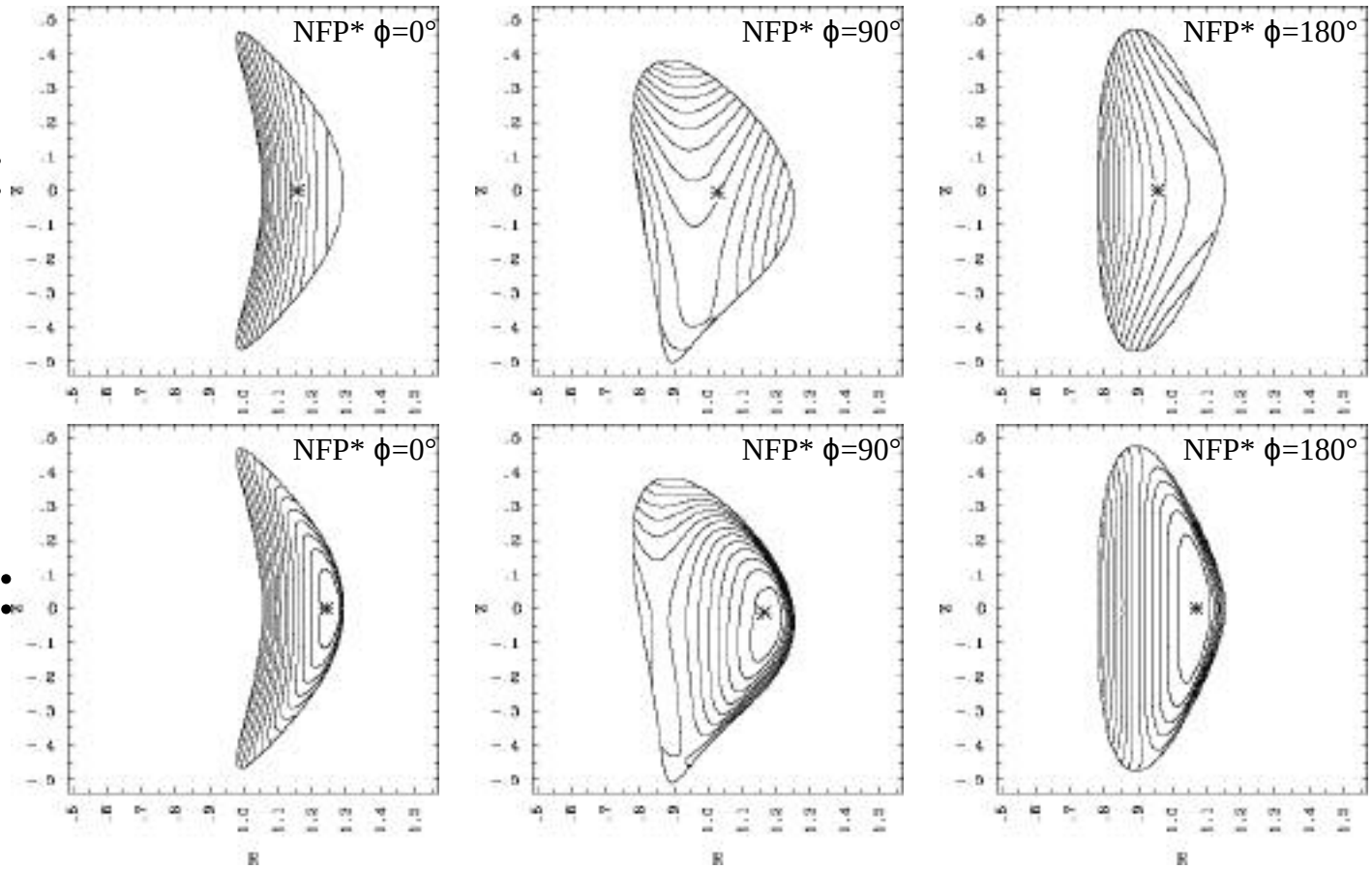


High β Case: Surface Alignment

- |B| surfaces align with flux surfaces at higher β:

β=0%:

β=23%:



High β Case: Ballooning Stability

- For the 3 FP, β=15%, A=3.7 case: (R. Sanchez)

➡ Edge becomes ballooning unstable for <β> >0.25%, Second regime stabilization begins at edge above <β > = 0.6%, and stabilizes it beyond 1%.

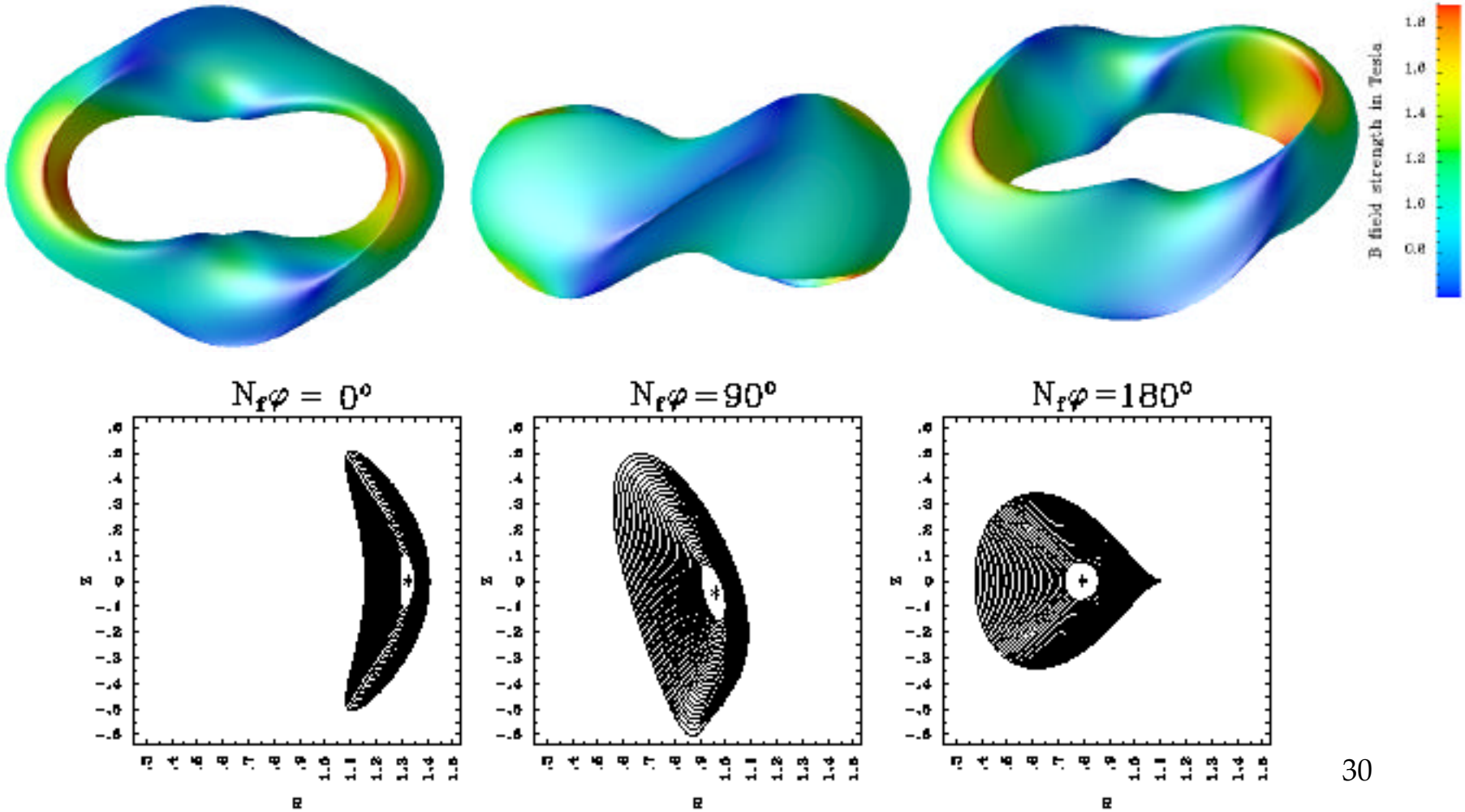
➡ The region of the plasma in second regime moves inwards from the edge for increasing < β >.

➡Plasma becomes totally stable above < β > = 7%

➡ Innermost part of the plasma always in first stability regime.

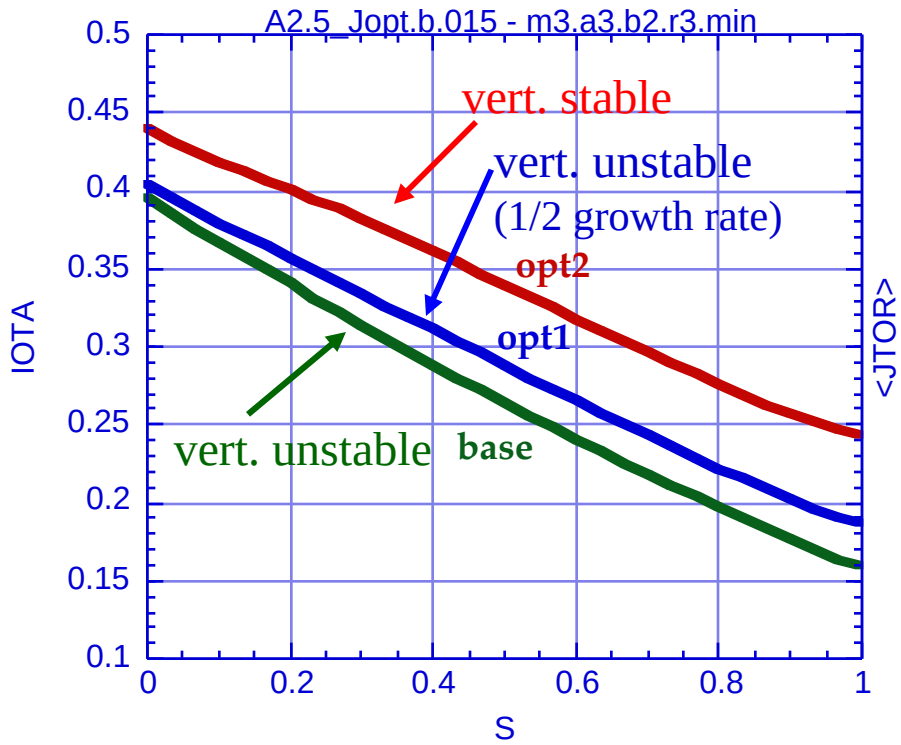
High β Case: 2 Field Periods

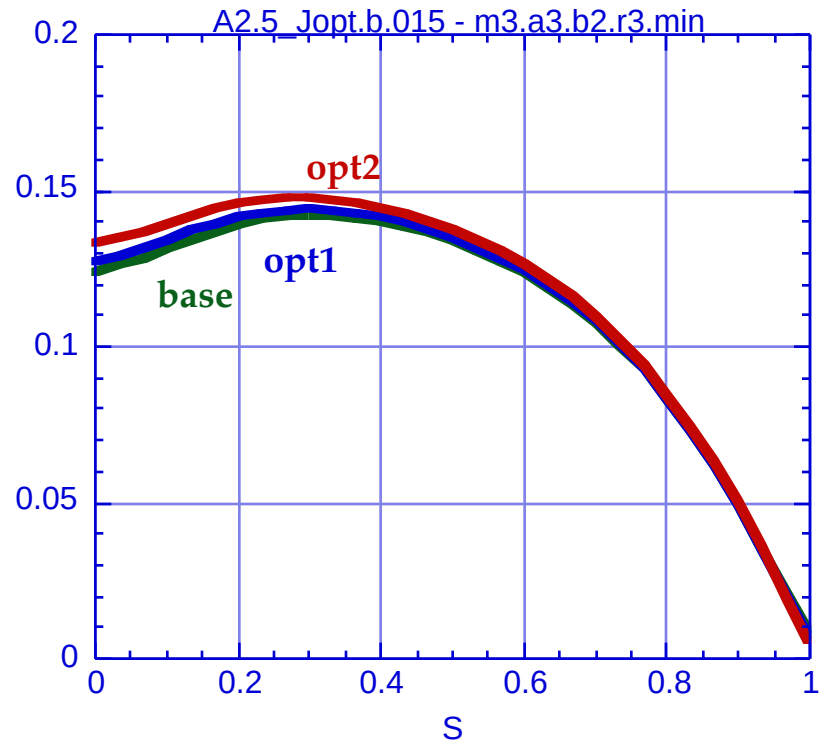
- Outer flux surface/cross sections: 2 FP, A=2.7, β=5%



High β Case: MHD Stability

- Have been able to affect the stability by increasing the amount of external transform (Fu)





Summary

- Have identified several interesting configurations at low I_{bs} and low β
  - Excellent potential candidates for a compact CE experiment with good neoclassical confinement
- Have identified several interesting configurations with very β stability limits for long range interest