

Coil Ripple and Asymmetry and Stability Scans for ATEN_08 and BILA_03

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The basic plan

1. **Given a set of coils**, generate Poincaré sections with field line following
2. Identify 'good' last closed flux surface, run DESCUR and generate Fixed Boundary VMEC input file
3. Run VMEC, XBOOZ_XFORM
4. Inspect Boozer spectrum -> **Identify coil ripple**
5. Use the input file and use STELLOPT to find 'self-consistent' bootstrap current profile and **evaluate ballooning stability** (Explore up to $\beta \cong 2\%$)

Some challenges were found

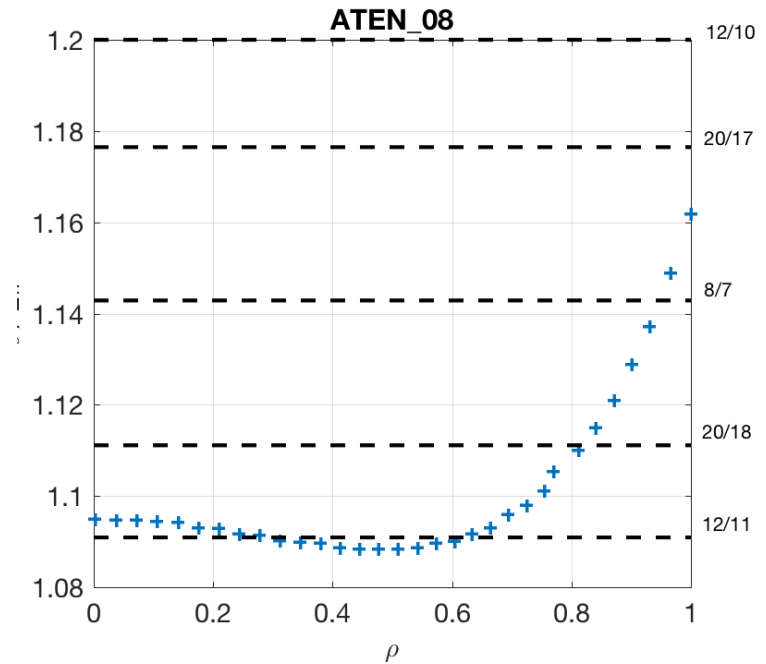
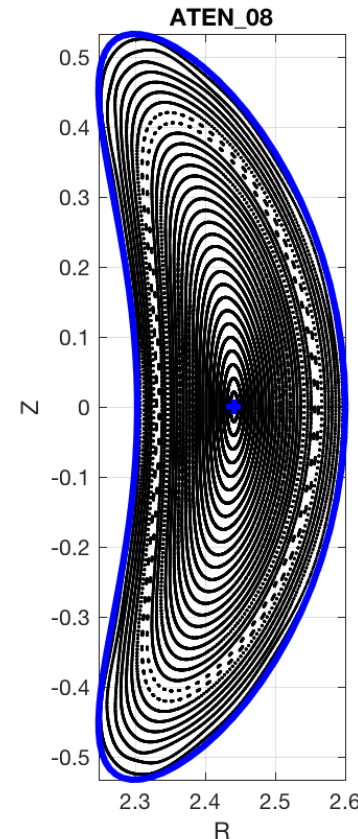
- FOCUS coils
 - Each field period is identical
 - Coils are not “stellarator symmetric”
- Flux surfaces & B-spectrum contain a-symmetric terms
 - Straight field line coordinates contain sin-terms, i.e.,

$$\vec{B} = \sum B_{mn,C} \cos(n\zeta - m\theta) + \sum B_{mn,S} \sin(n\zeta - m\theta)$$

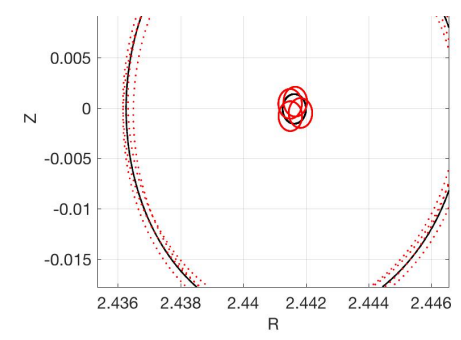
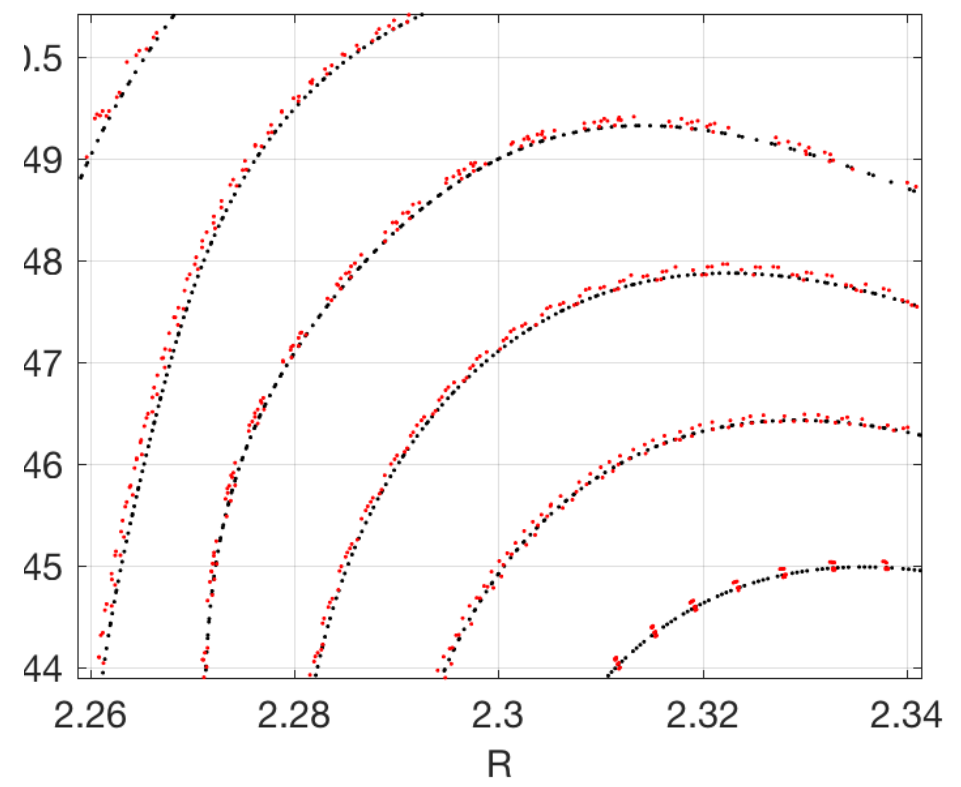
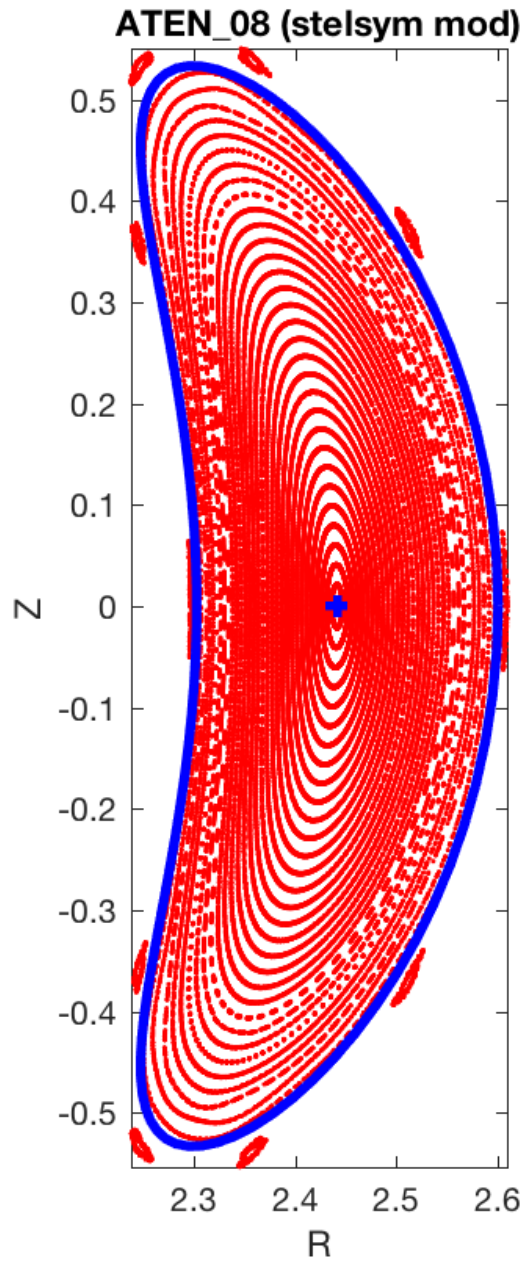
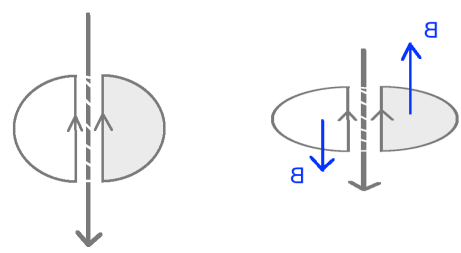
- STELLOPT development to handle non-stellarator symmetric components is not complete
 - Some metrics don't work
 - Input / Output / (Memory?) handling routines not complete
 - Status of validity of subsequent codes is not known, a-priori
 - ‘Trial and Error’ tests for each code
 - VMEC2000, BOOZ_XFORM, BOOTSJ, COBRAVMEC appear to be okay
 - Helicity broken
 - Others (BNORM, SFINCS, NEO, REGCOIL, GAMMAC) ... not tested yet

ATEN_08

- Using the FOCUS coils 'as-is'
- Composite Vertical section for $\varphi=0, 90, 180, 270$
- Black lines from line following
- Blue line and axis is the original ATEN target LCFS
- Transform profile from line following
- Small asymmetry exists (not visible at this scale)

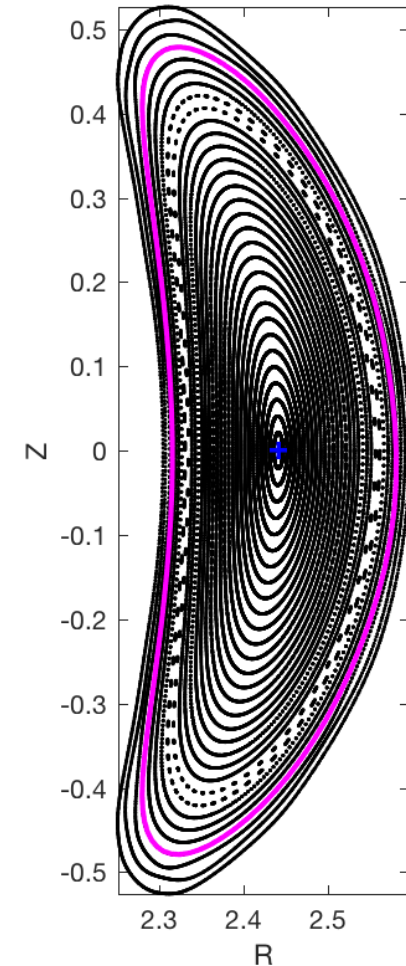
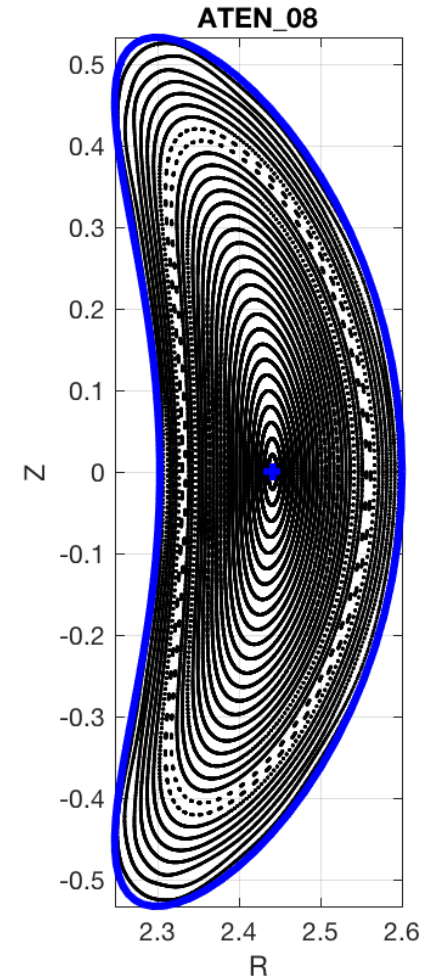


- Naively attempting to ‘symmetrize’ the coils is a bad idea
 - Stochasticity introduced
 - Surfaces degraded
- Black points: Original coil set
- Red points: ‘Symmetric’ coil set
- Spatially averaging the coil does not ‘fix’ the field error – It makes it noticeably worse!



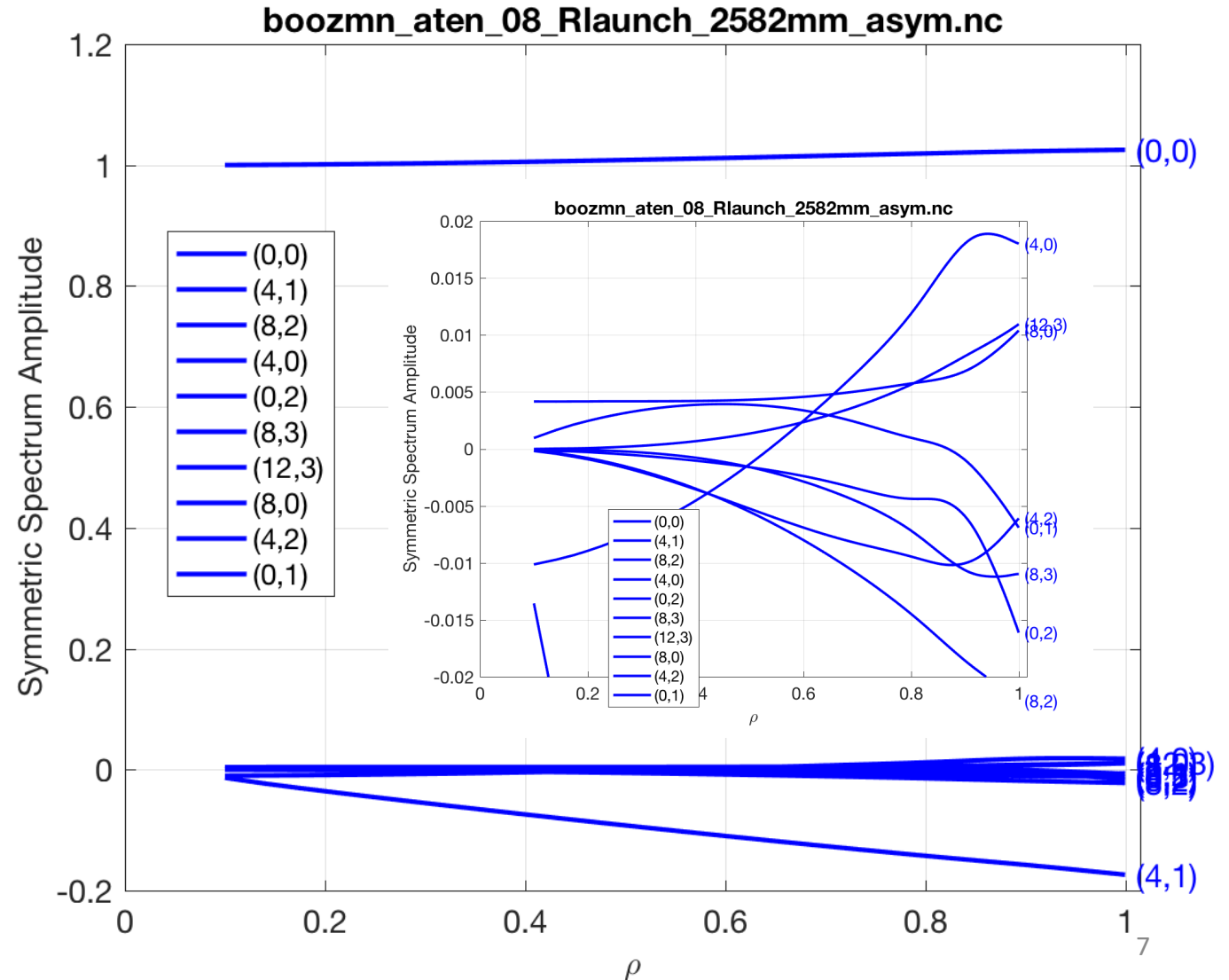
The 'best' initial last-closed flux surface is radially inside of the 8/7 island chain

- Blue line and axis is the original ATEN target LCFS
- Black lines from line following
- Magenta line
 - Used for fixed-boundary VMEC run
 - Avoids 8/7 island chain to improve convergence
 - Asymmetric effects may also be mitigate (conjecture)
 - DESCUR modified to use $MB \leq 31$

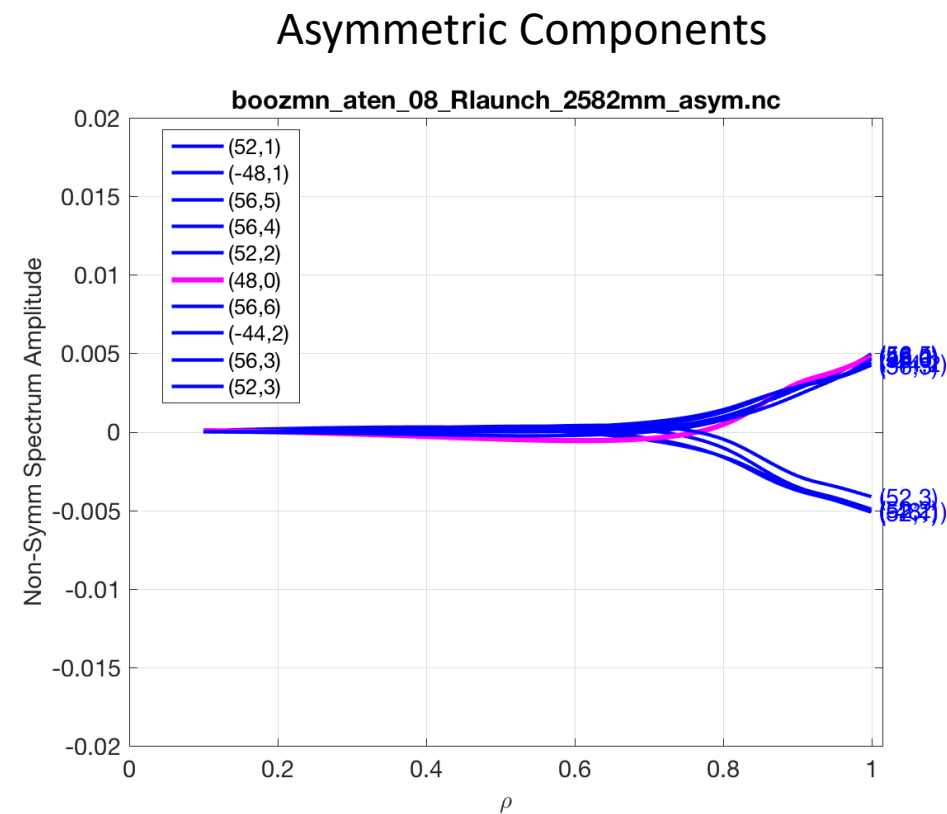
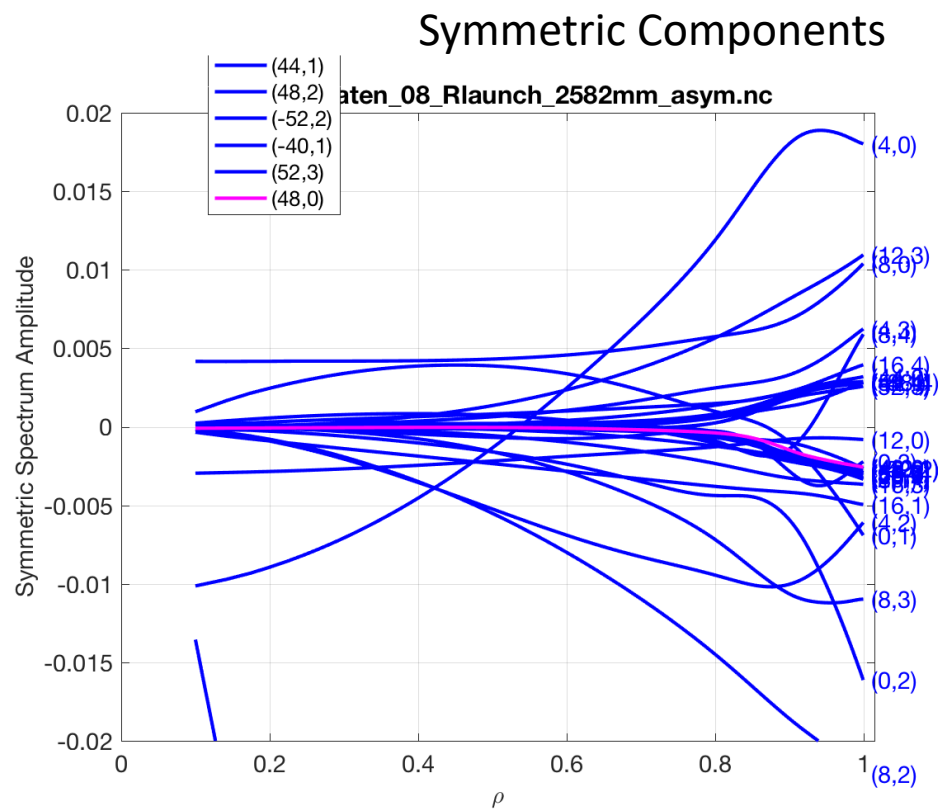


Boozer spectrum at $\beta=0$

- Dominated by large (4,1) mode
- A 'zoo' of other components are 10x smaller
 - (4,0) mode significant
 - (8,2), (4,2) (8,0), ...



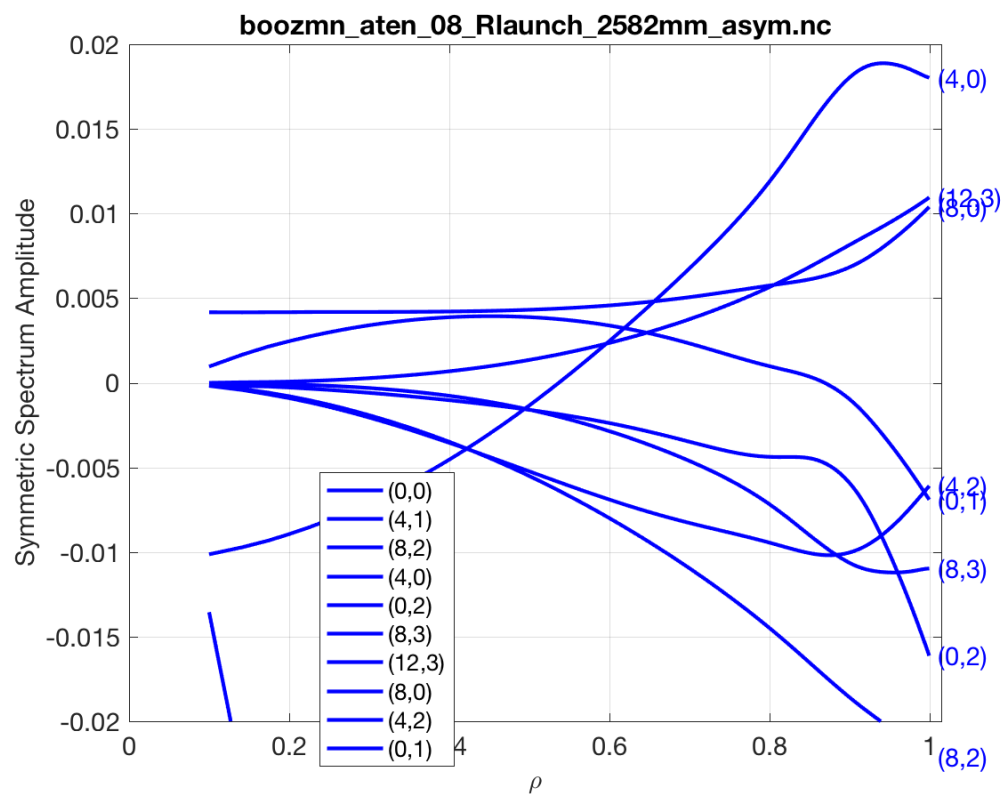
(48,0) is: 33rd largest symmetric term 6th largest asymmetric term



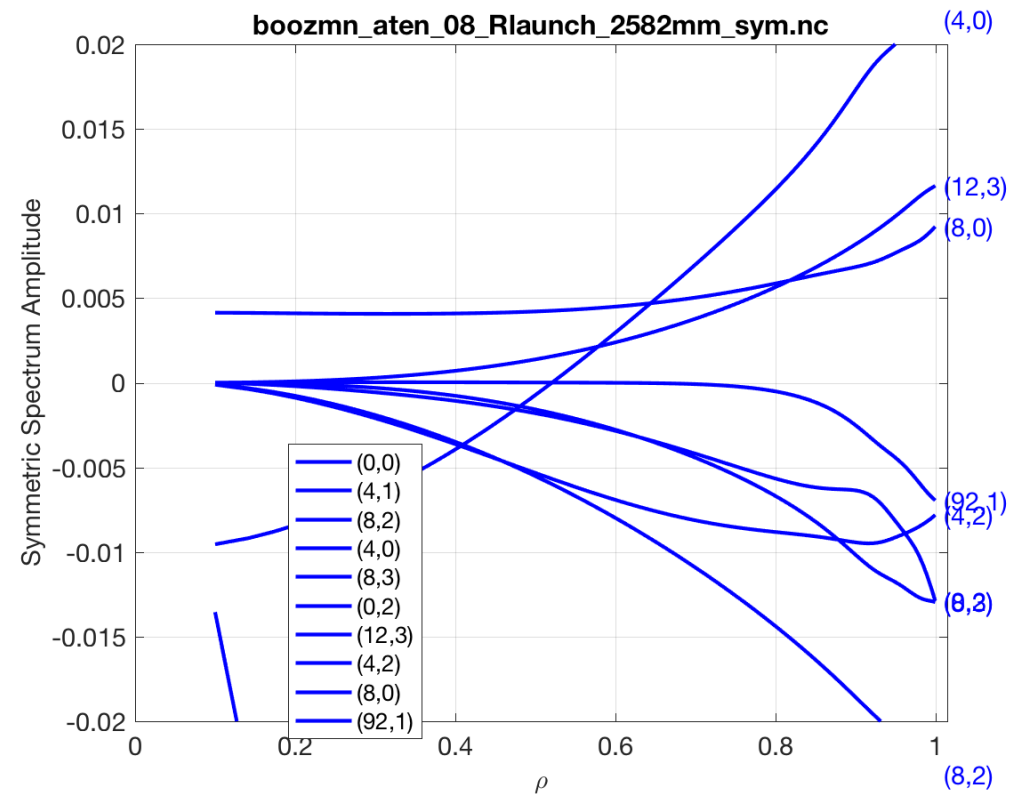
- Asymmetric components likely play a significant role for $\rho > 0.8$

If one naively runs VMEC in symmetric mode ...

Symmetric Components with VMEC with LASYM=True



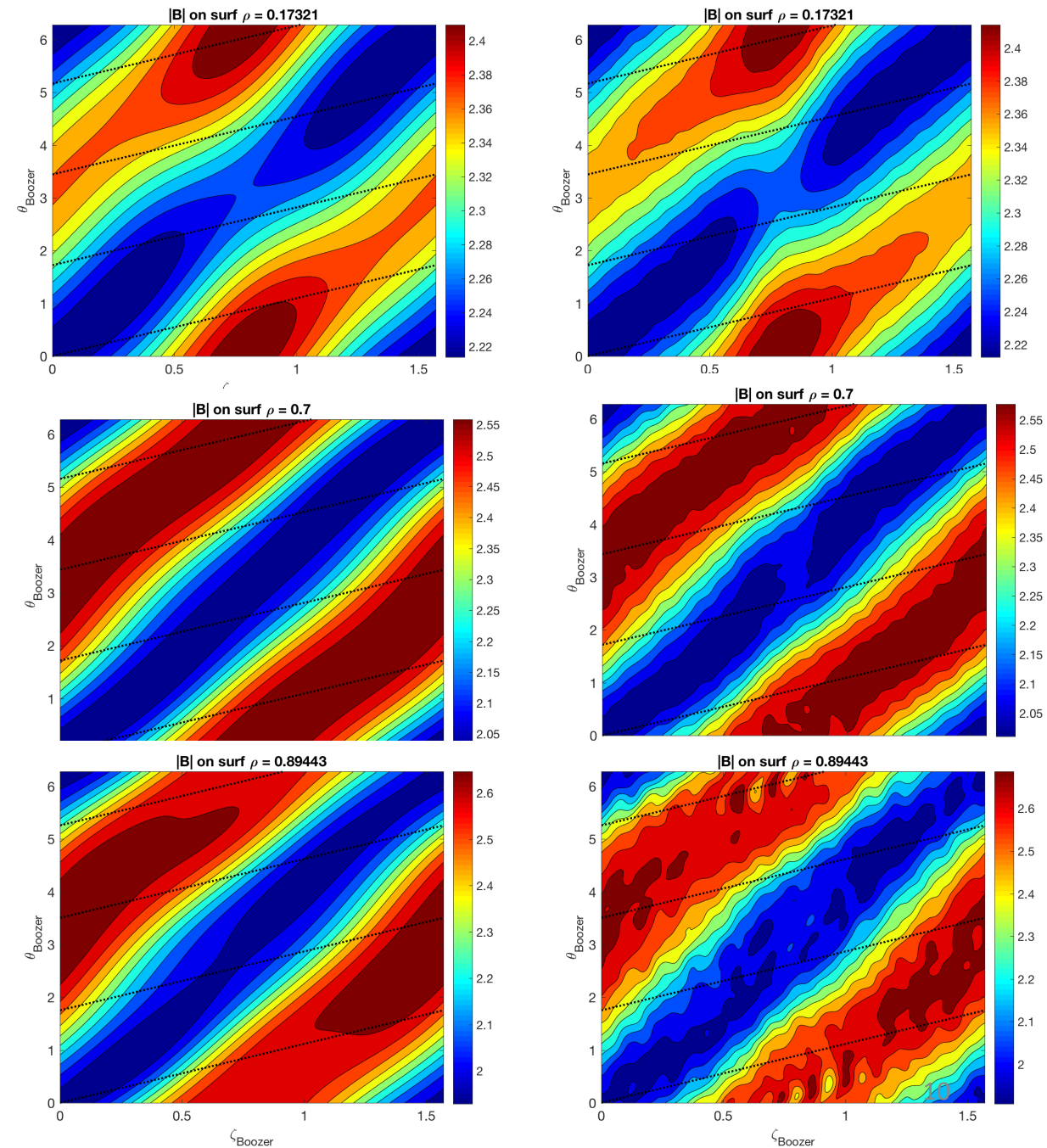
Symmetric Components with VMEC with LASYM=False



- Spectrum is similar for small ρ . Differences appear for $\rho > 0.8$

ATEN_08: $|B|$ contour plots (LASYM=True)

- Left column: Using 10 largest modes
- Right column: Using 500 largest modes
- Top: $\rho \cong 0.17$
- Middle: $\rho = 0.7$
- Bottom: $\rho \cong 0.89$

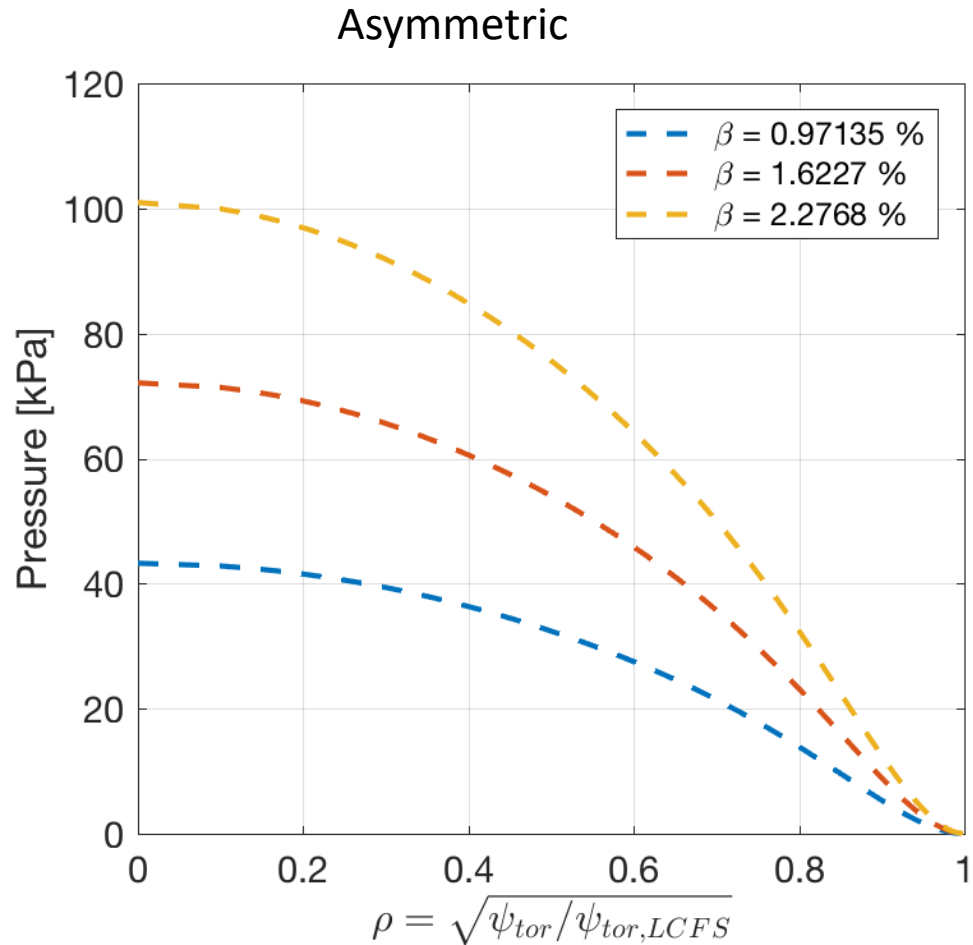
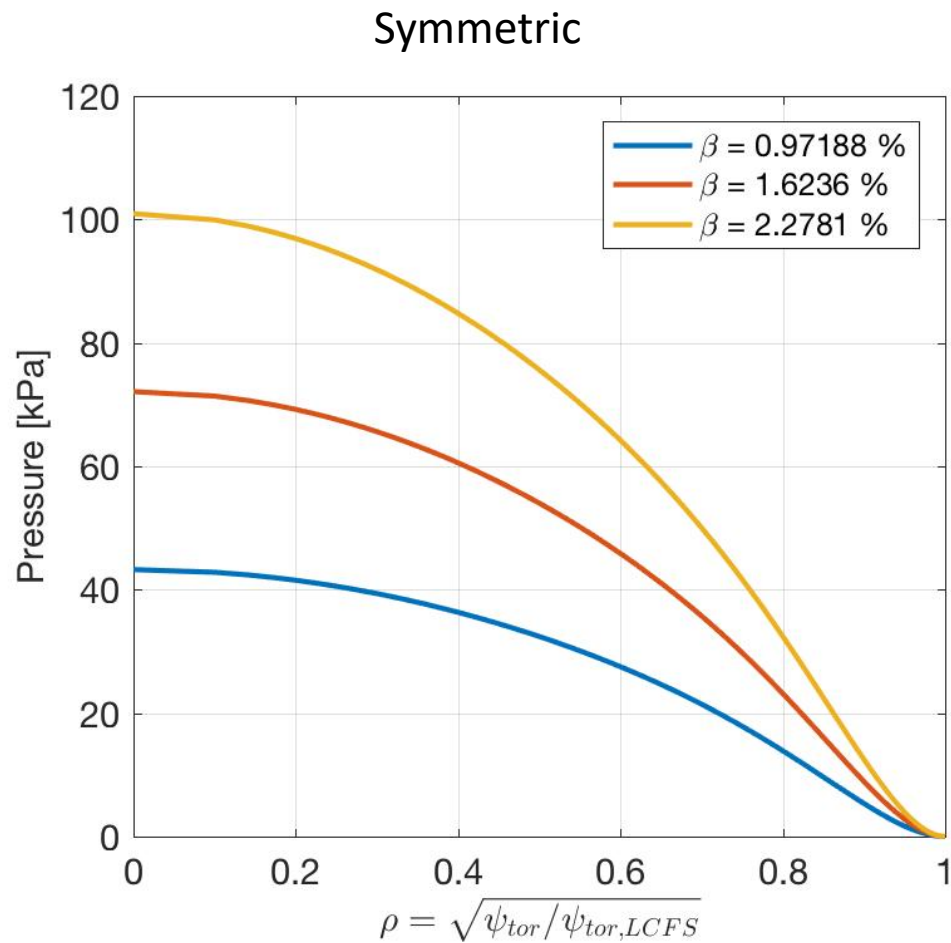


Stability - ATEN_08

- Fixed boundary, Stellarator Symmetric
 - MPOL = 10, NTOR = 24, NTHETA = 32, NZETA = 96, NS = 101, FTOL = $2.99\text{e-}11$
- Fixed boundary, Non-Stellarator Symmetric
 - MPOL = 12, NTOR = 14, NTHETA = 32, NZETA = 48, NS = 101, FTOL = $1.0\text{e-}10 - 1.2\text{e-}10$
- BOOTSJ used to estimate steady-state bootstrap current
- Stability in the edge appears to be a challenge at low beta
- Reducing the LCFS, adjusting the pressure profile might help

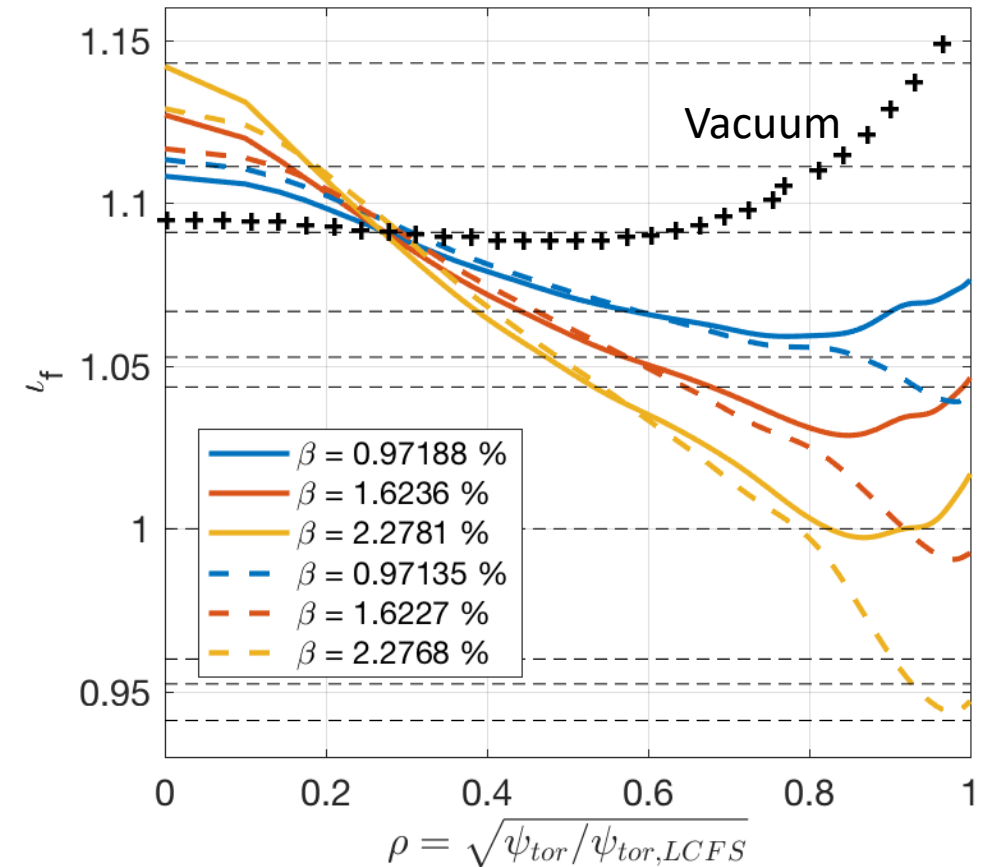
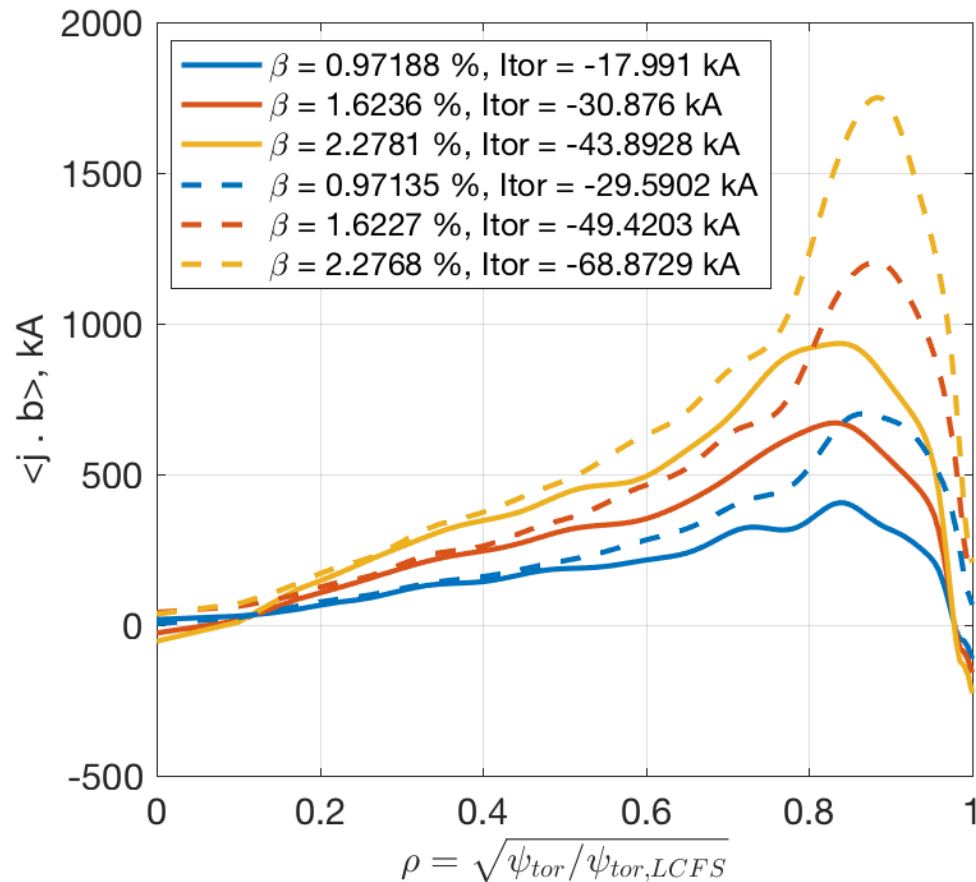
ATEN_08: Comparing the importance of stellarator symmetry

Symmetric VMEC vs Asymmetric VMEC (LASYM = True/False)



ATEN_08: With Asymmetry included, edge current density and shear are both increased; Total current increased by ~60%

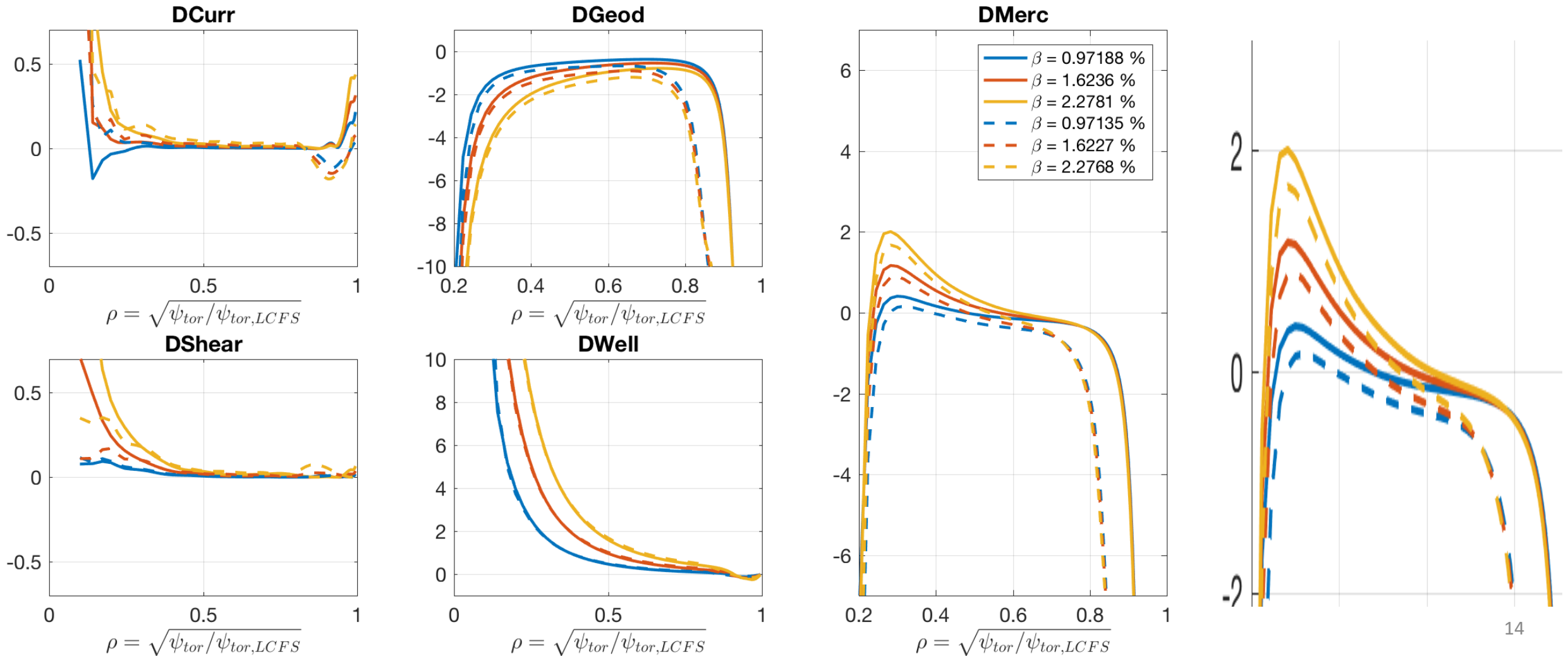
Solid = Symmetric VMEC run; Dashed = Asymmetric VMEC run



- For $\rho > 0.8$, symmetric VMEC run 'misses' some important details

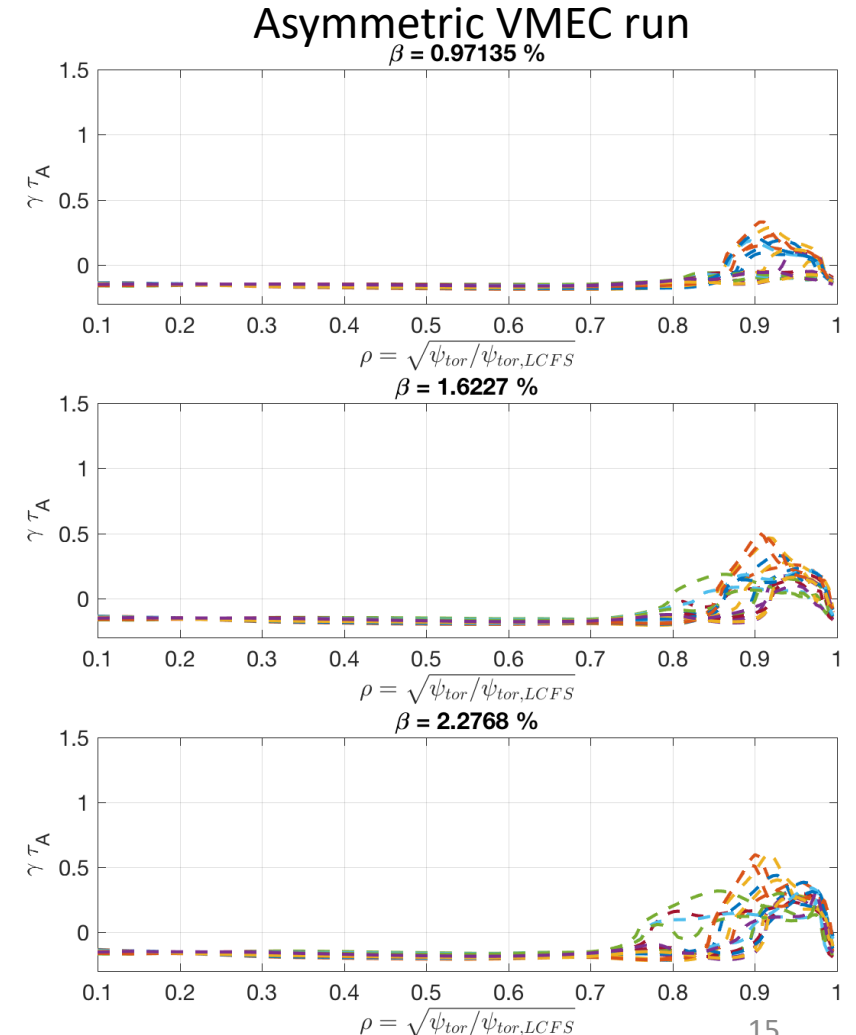
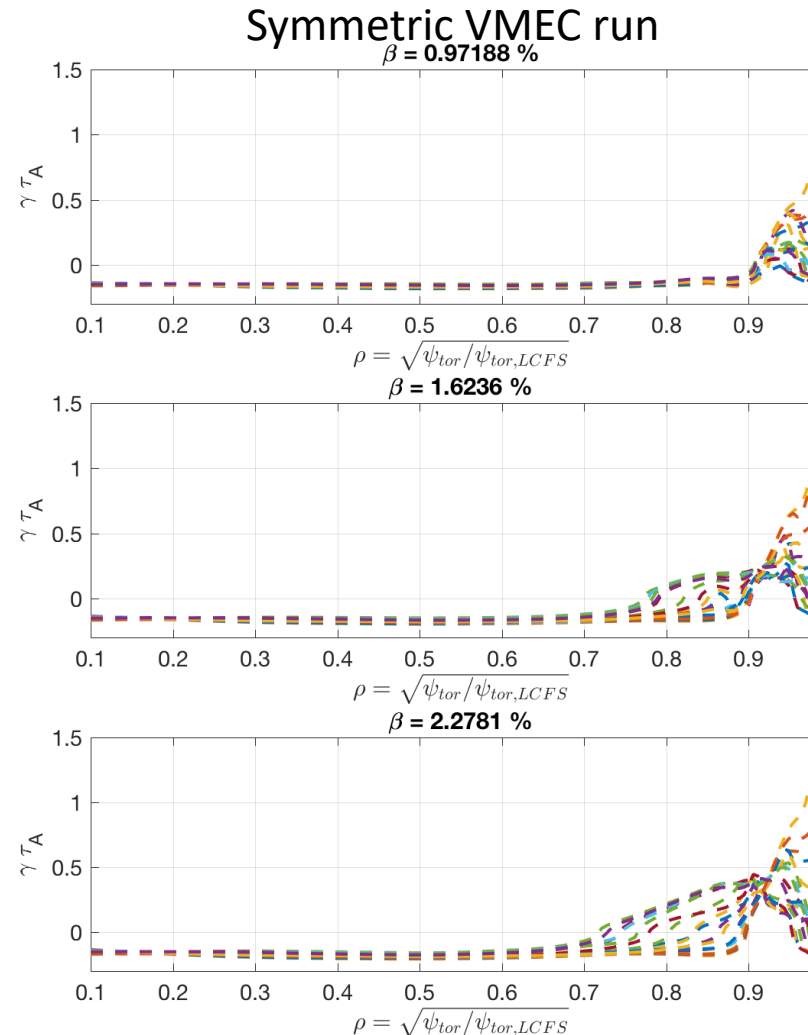
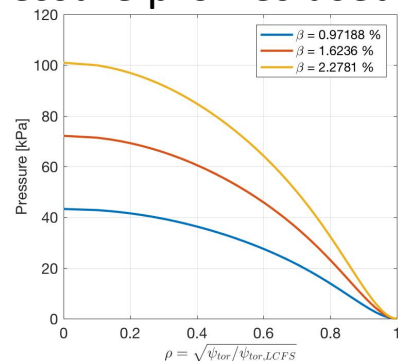
ATEN_08: Reduced Mercier stability* with LASYM=True; Similar trend with regard to β (both improving)

*Convergence scan not complete



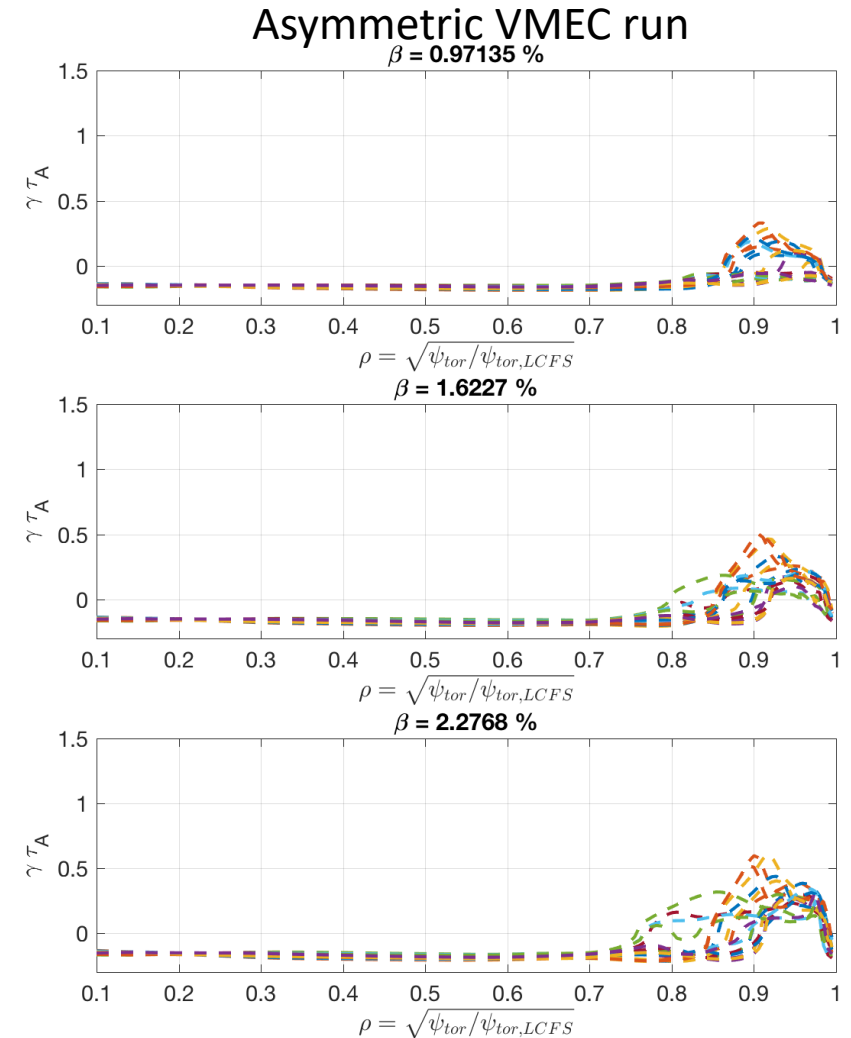
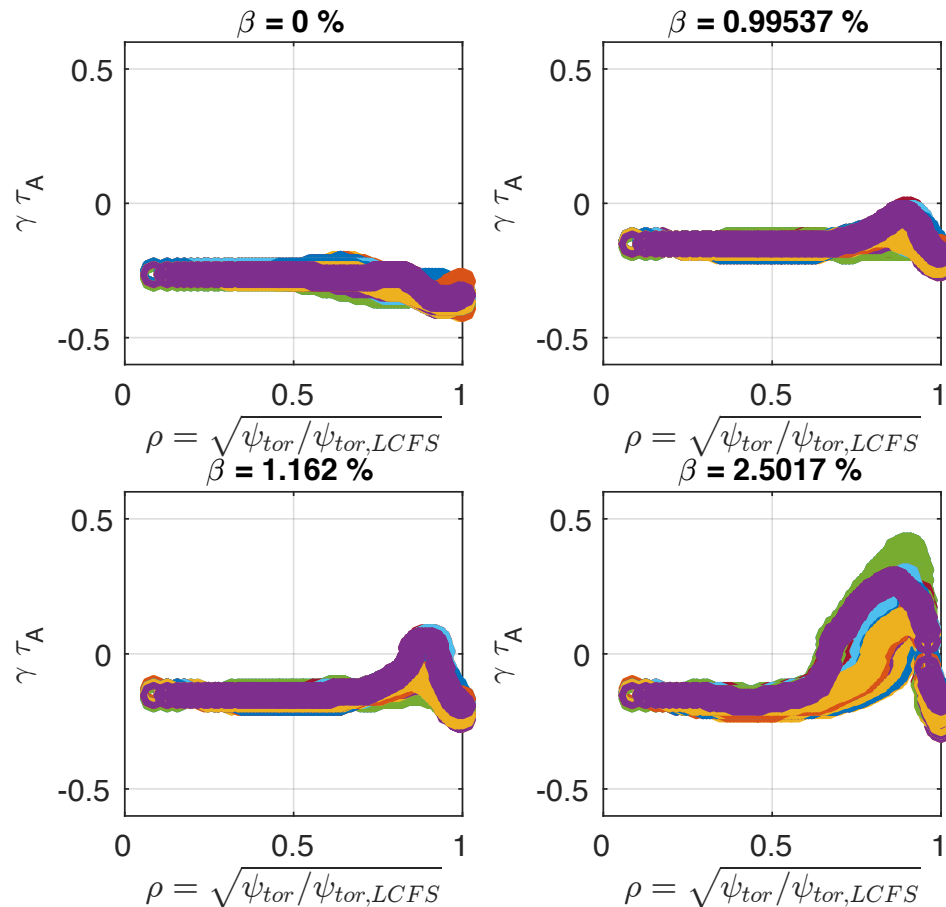
ATEN_08: Ideal Ballooning Stability (COBRAVMEC)

- Always ballooning unstable for $\rho > 0.9$ (symmetric) or $\rho > 0.85$ (asymmetric)
- Positive growth rates move inward (and large) at all values of pressure explored
- Reducing LCFS and/or moving pressure gradient inward may help
- Pressure profiles used here



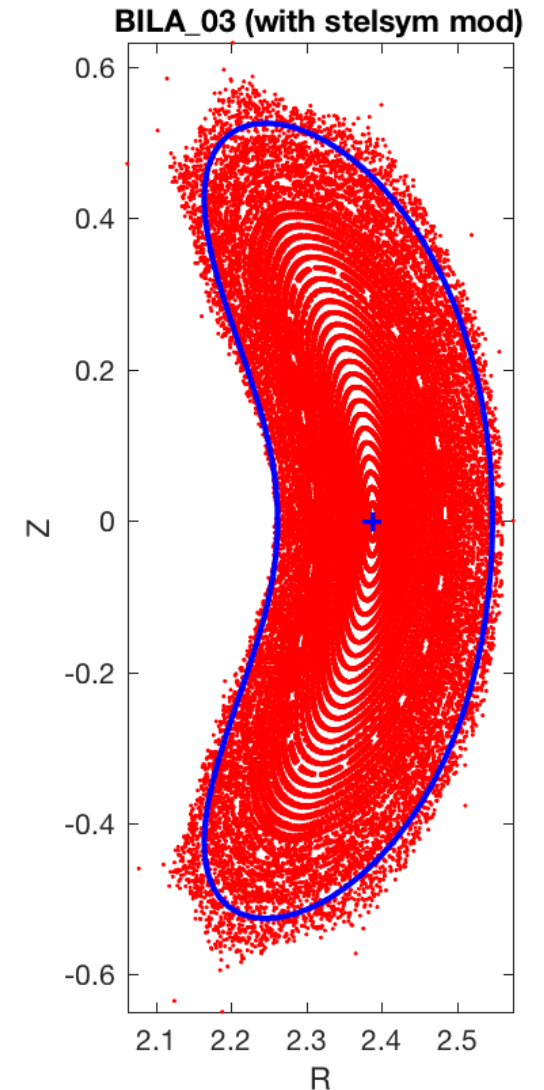
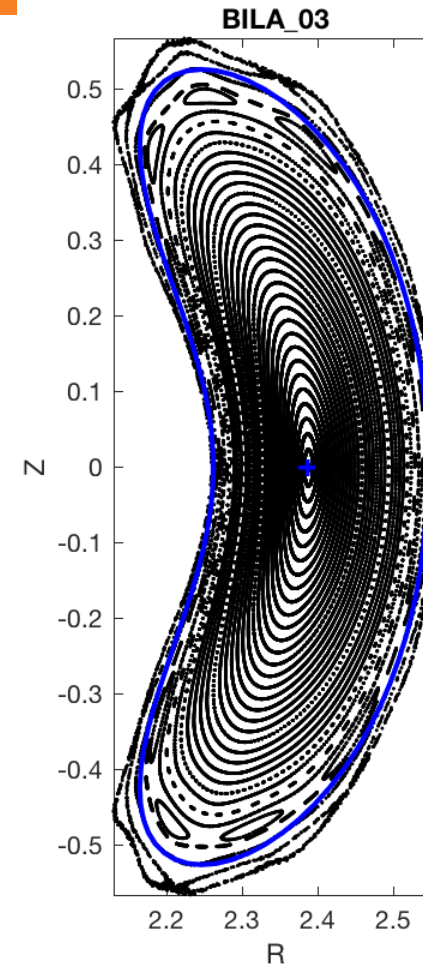
ATEN with original LCFS on left; With coils on right

- Stability reduced with coils

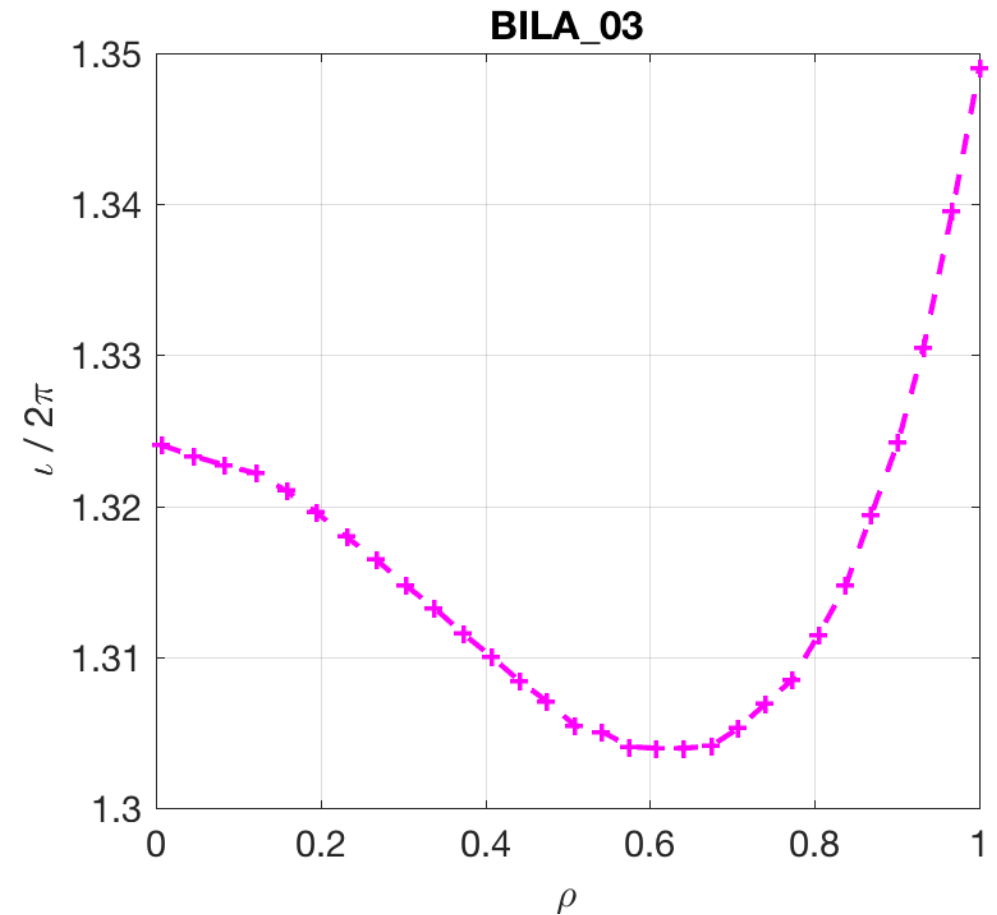
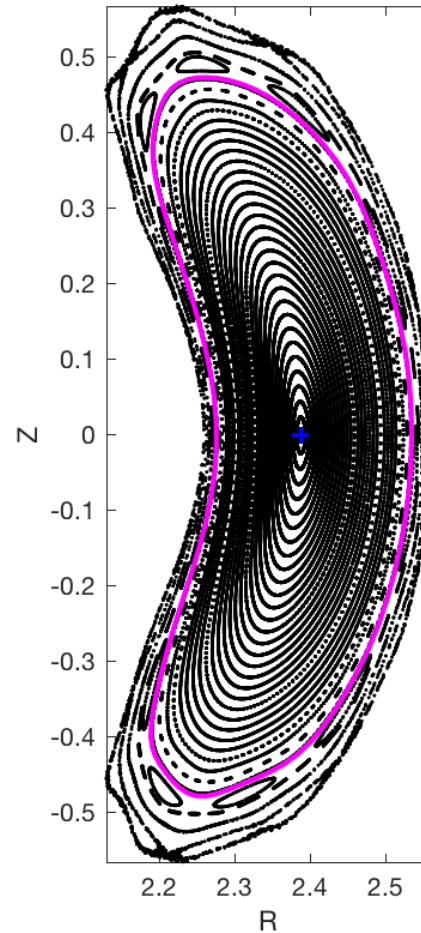
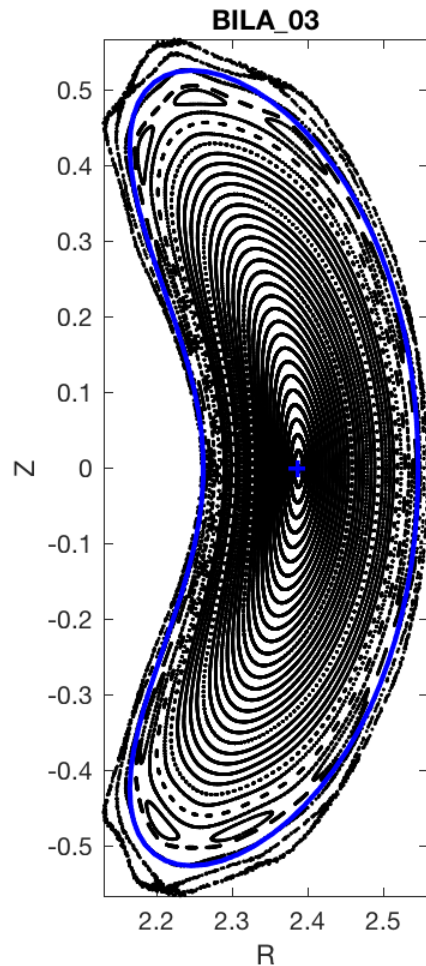


BILA_03

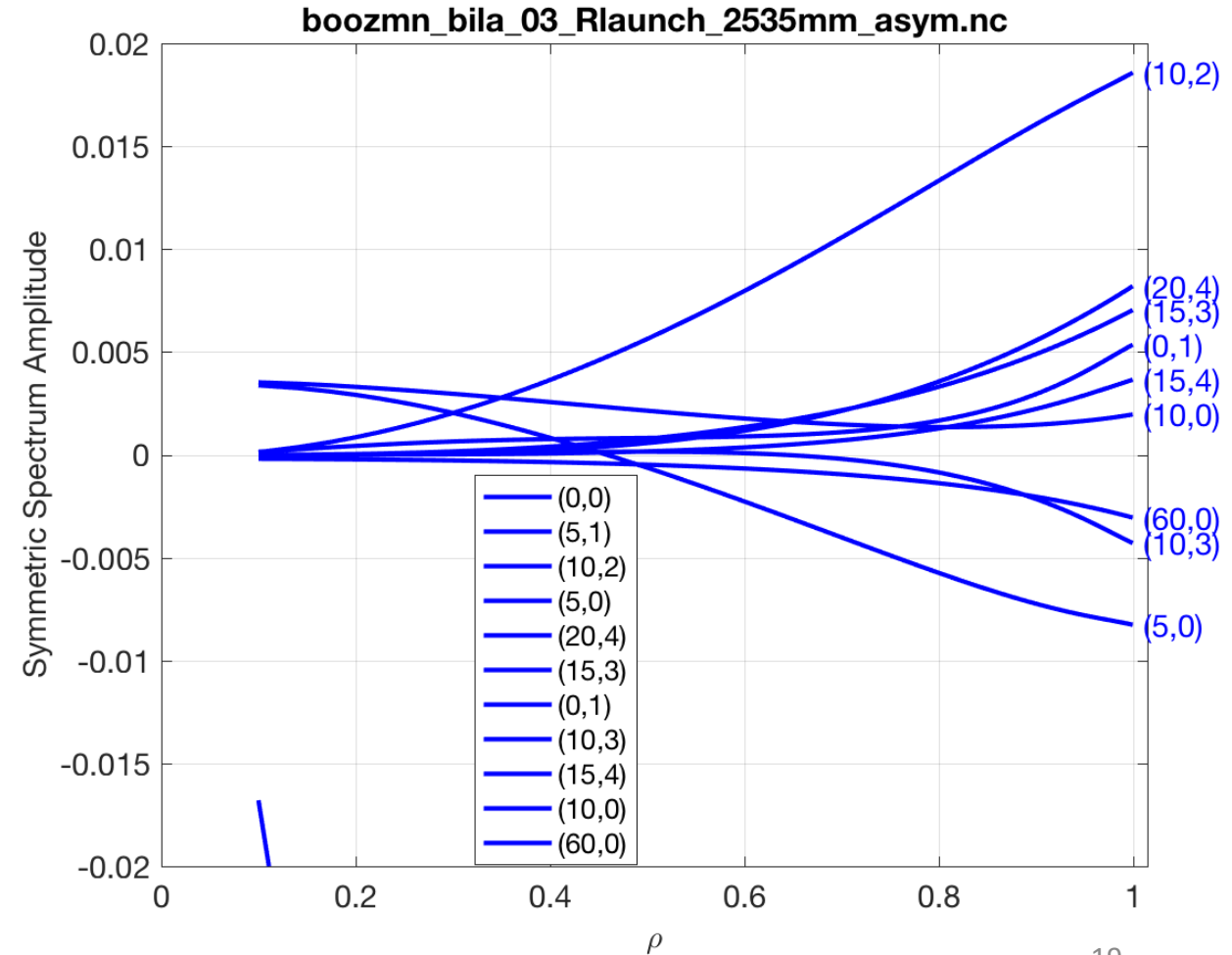
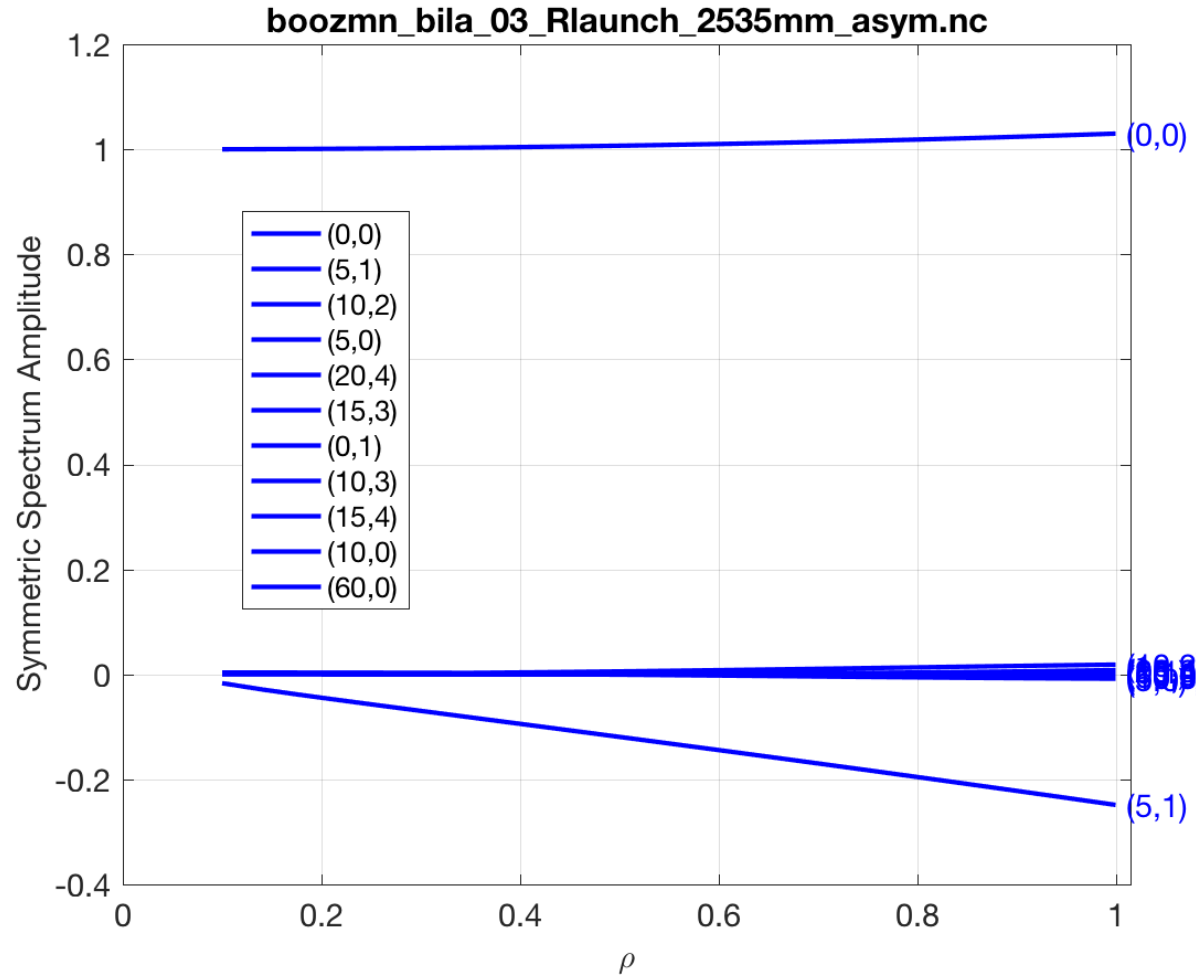
- Black: Poincaré plots with coil set as-is
- Red: ‘Symmetric coils’
- Blue: Original BILA (WARE5P2) target
- This is a bad way to ‘symmetrize’ the coils



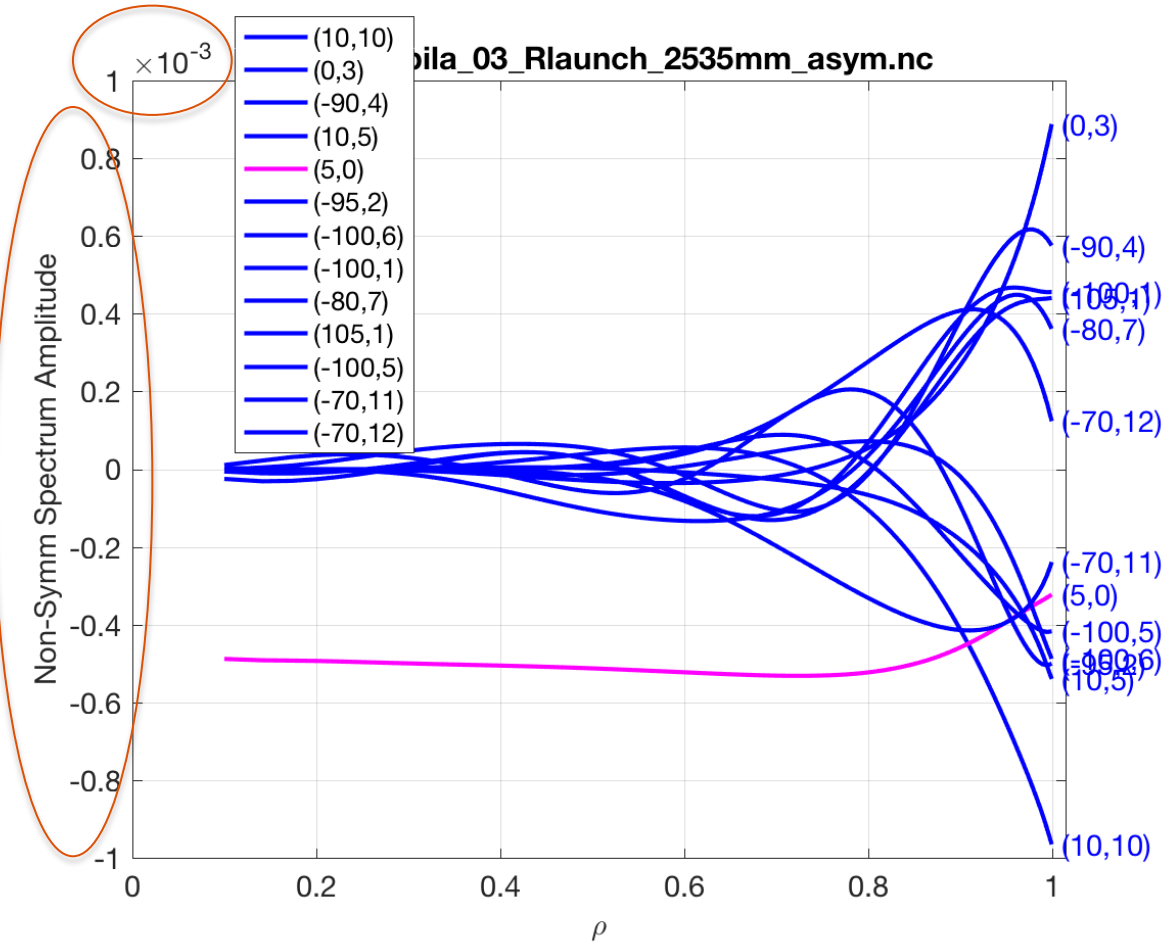
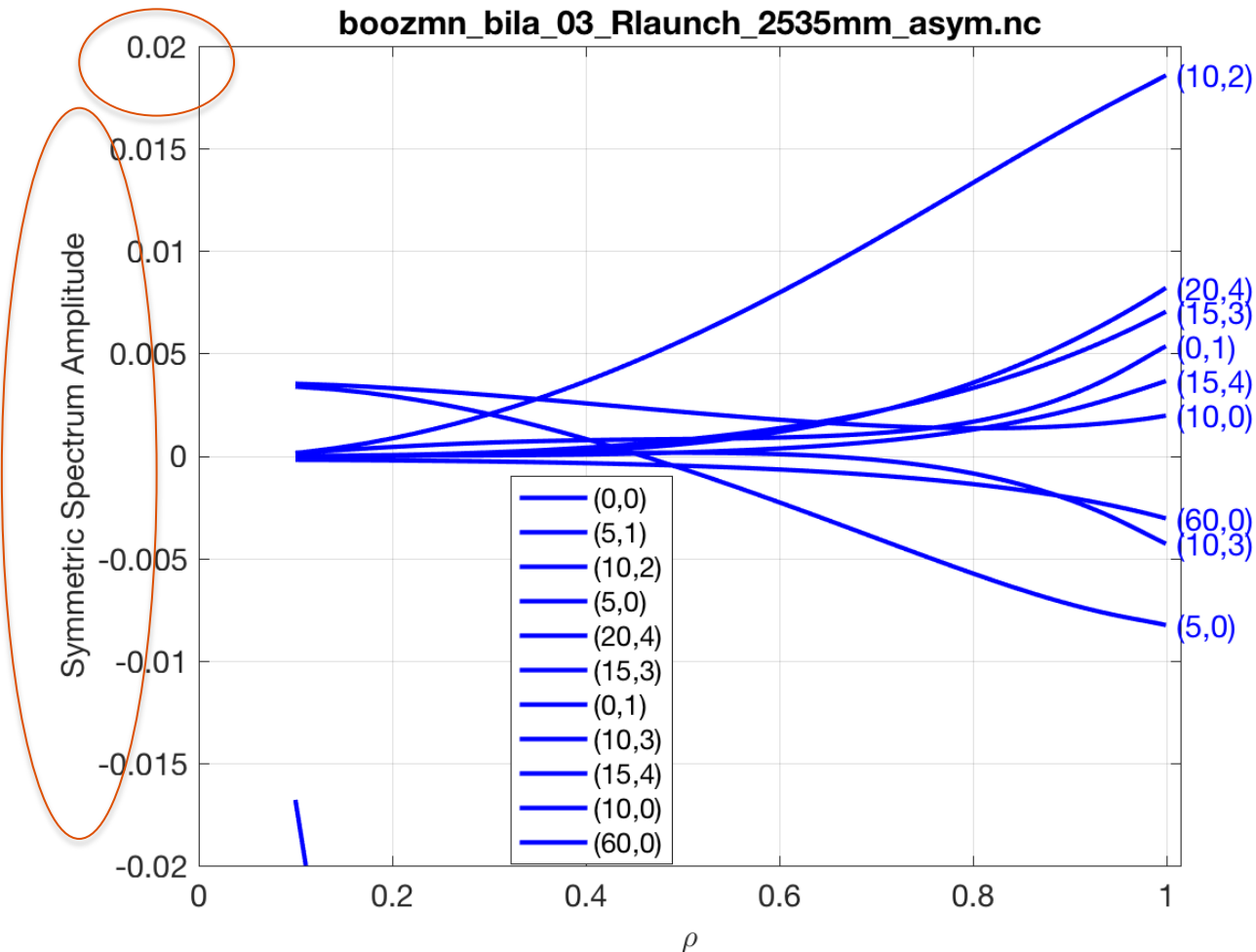
Blue: Original BILA target. Magenta: LCFS chosen for DESCUR/VMEC.
Using BILA_03 coilset. Transform from field line following



BILA_03: (5,1) mode dominates; (10,2), (5,0), (10,0) important
 (60,0) coil ripple term is 11th largest symmetric mode

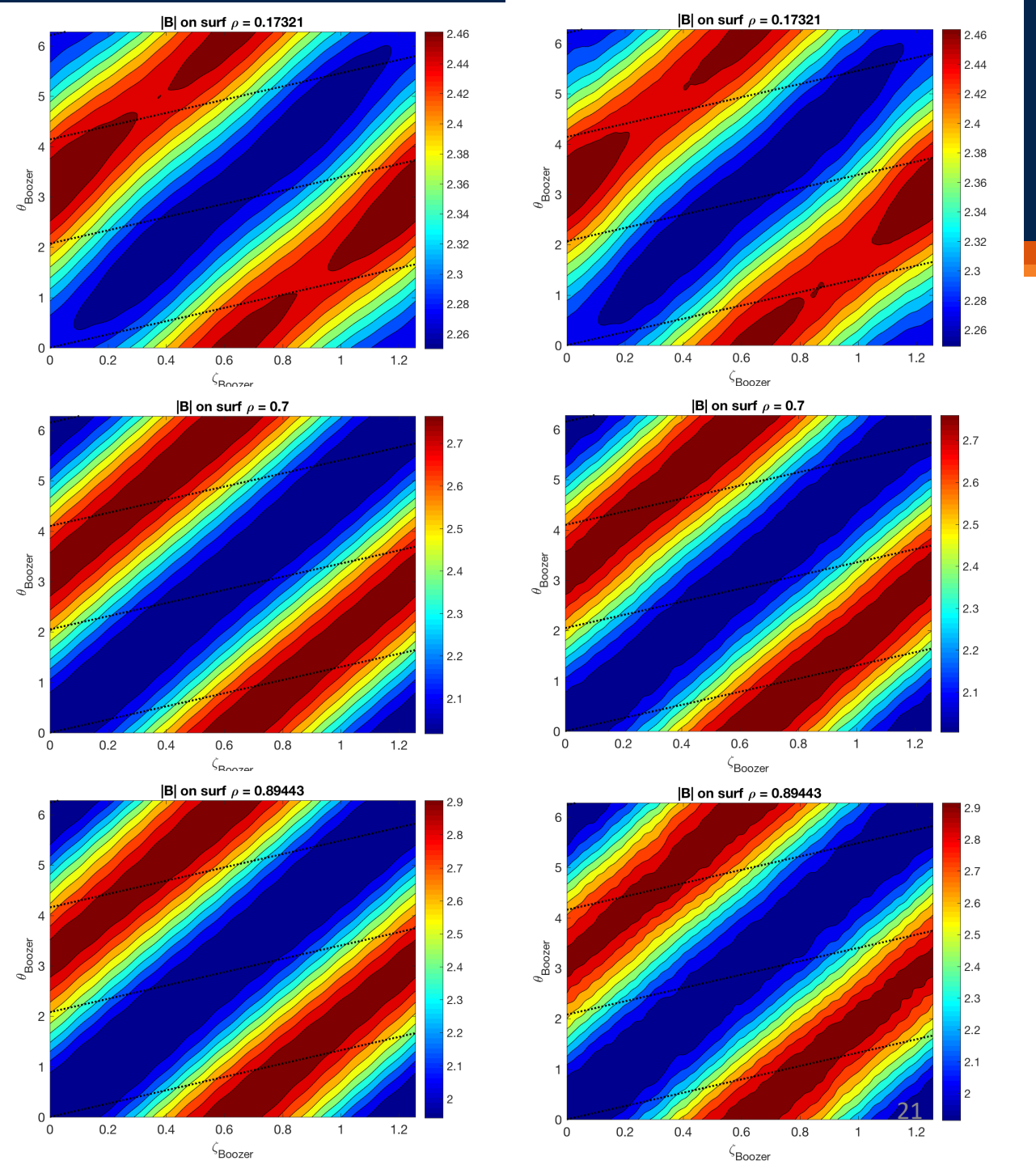


Asymmetric modes (right side) are another order of magnitude smaller. (5,0) mode reaches the axis



BILA_03: |B| contour plots (LASYM=True)

- Left column: Using 11 largest modes
- Right column: Using 500 largest modes
- Top: $\rho \cong 0.17$
- Middle: $\rho = 0.7$
- Bottom: $\rho \cong 0.89$

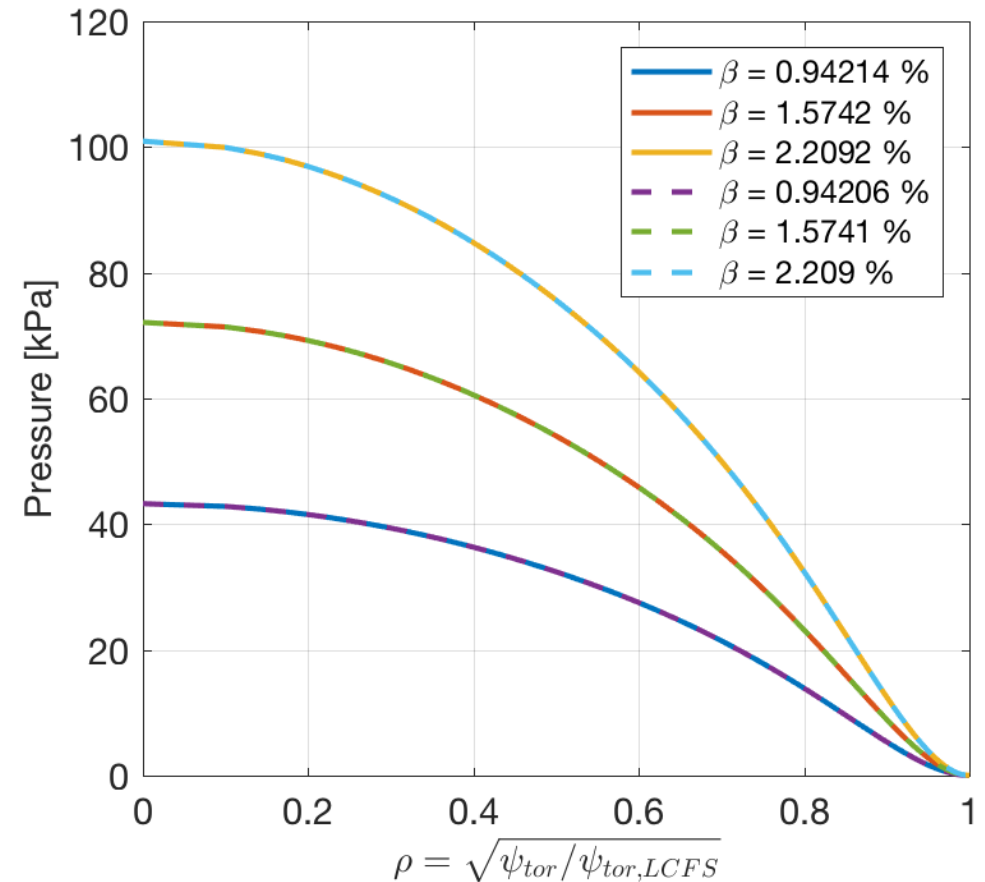


Stability – BILA_03

- Fixed boundary, Stellarator Symmetric
 - MPOL = 16, NTOR = 24, NTHETA = 58, NZETA = 100, NS = 101, FTOL = $3e-11$ - $4e-11$
- Fixed boundary, Non-Stellarator Symmetric
 - MPOL = 16, NTOR = 14, NTHETA = 58, NZETA = 100, NS = 101, FTOL = $5.5e-11$
- BOOTSJ used to estimate steady-state bootstrap current
- Stability in the edge appears to be a challenge at low beta
- Reducing the LCFS, adjusting the pressure profile might help

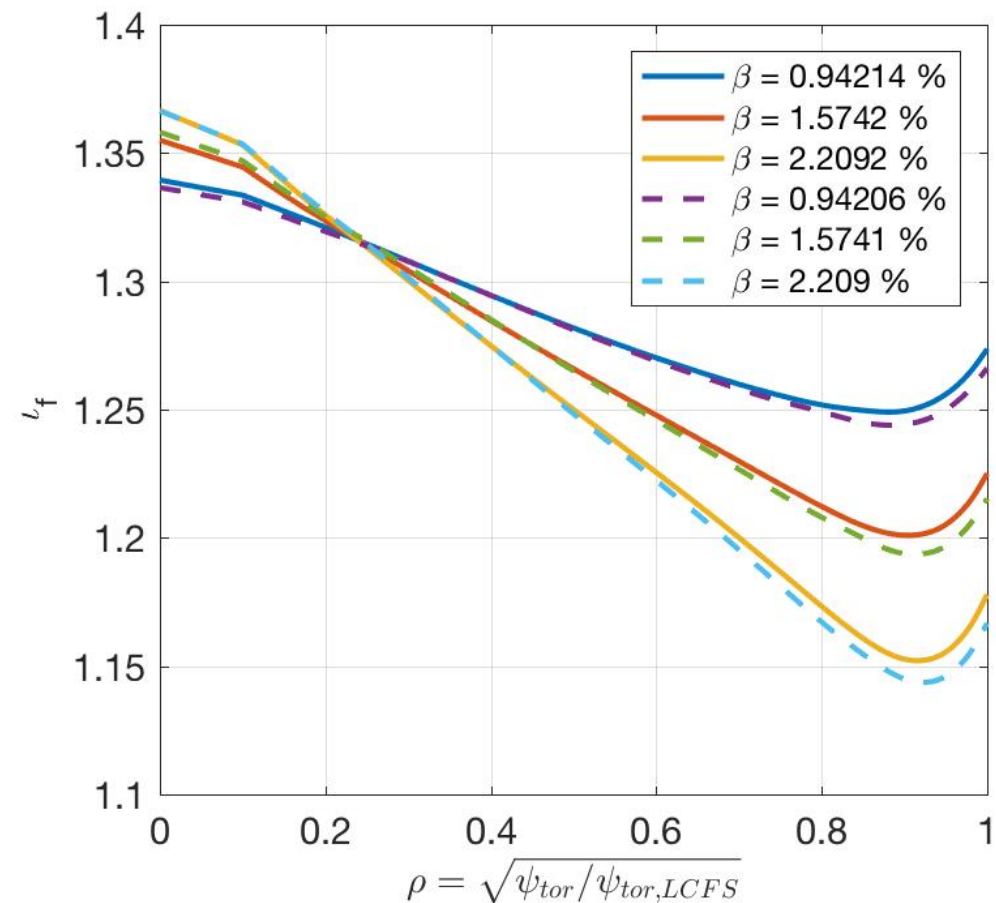
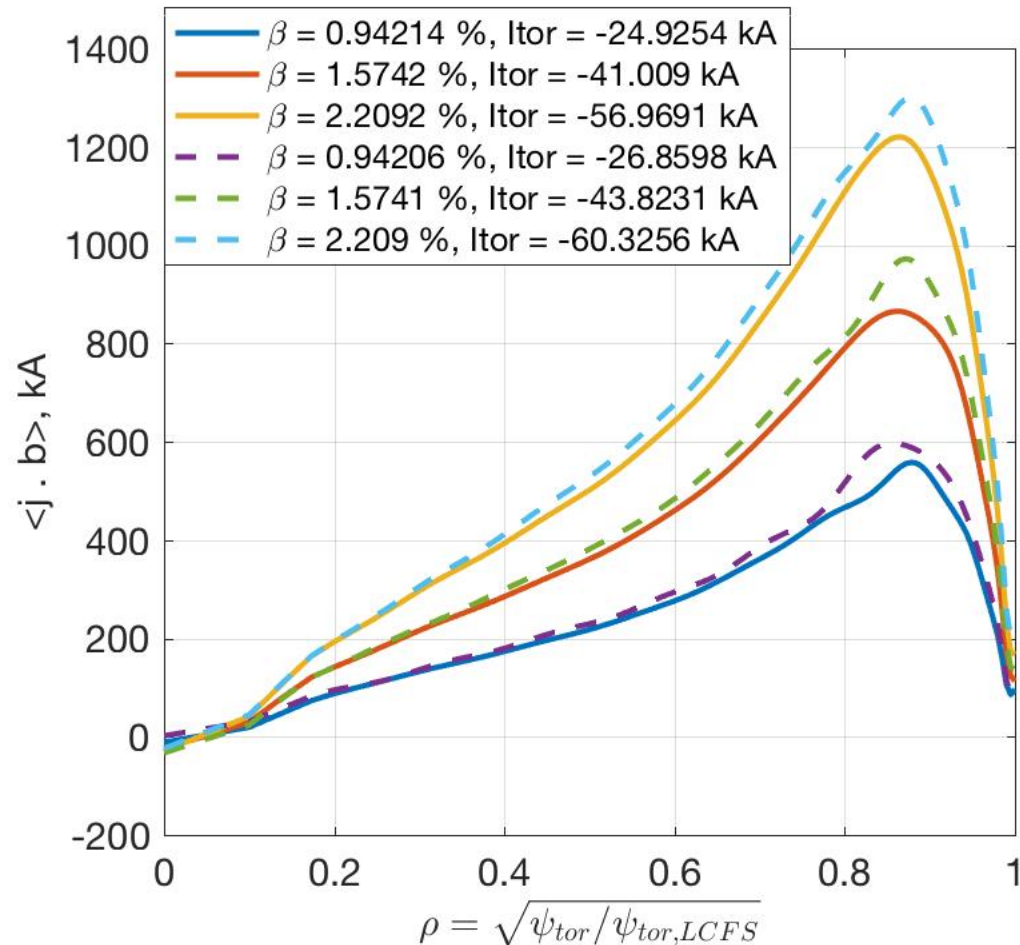
BILA_03: Pressure Profiles

- Solid lines: Symmetric VMEC
- Dashed lines: Asymmetric VMEC



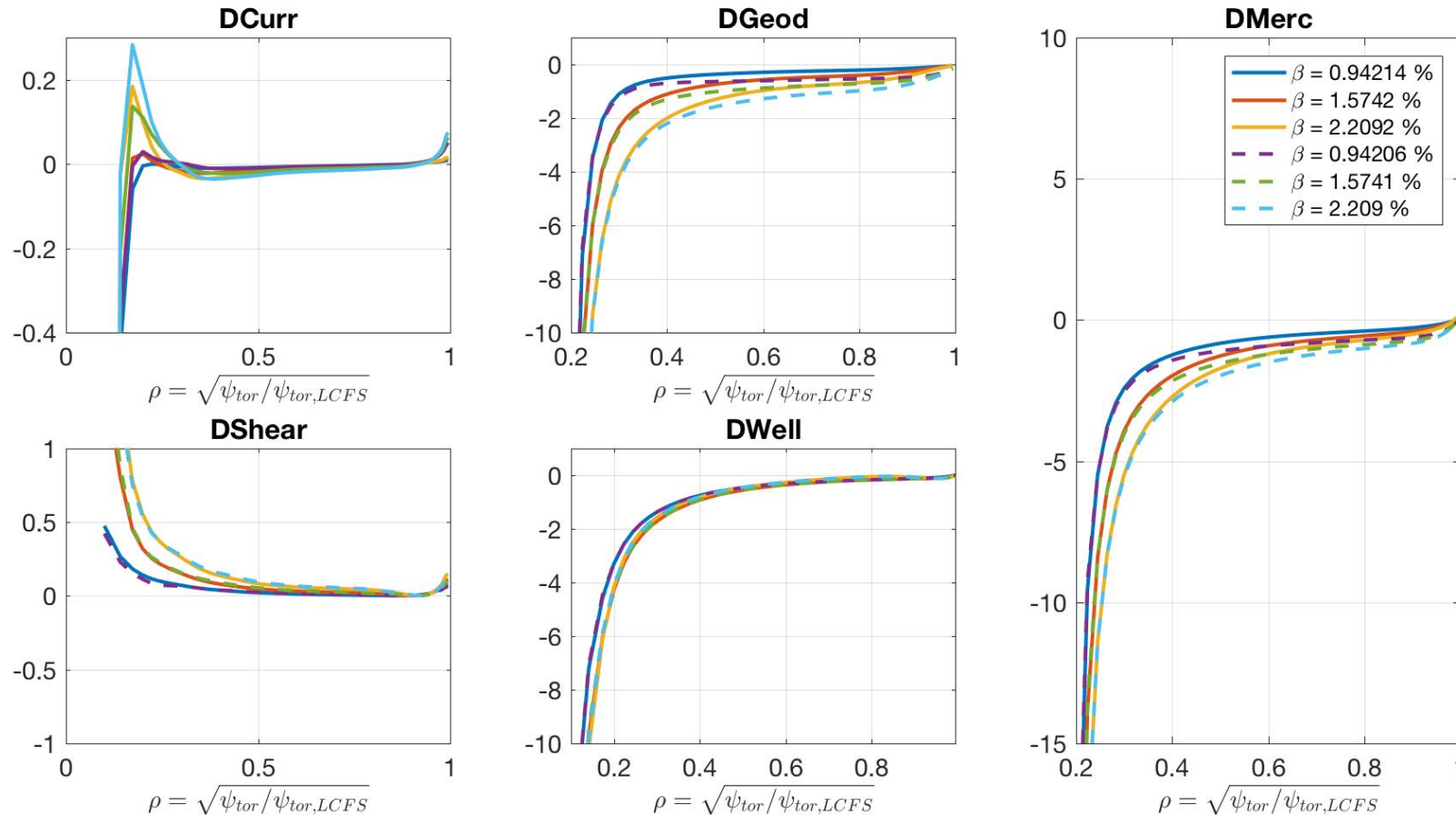
Bootstrap current and transform; Smaller change due to asymmetric terms

Solid = Symmetric VMEC run; Dashed = Asymmetric VMEC run



Mercier; Unstable, and gets worse. *Convergence scan not complete

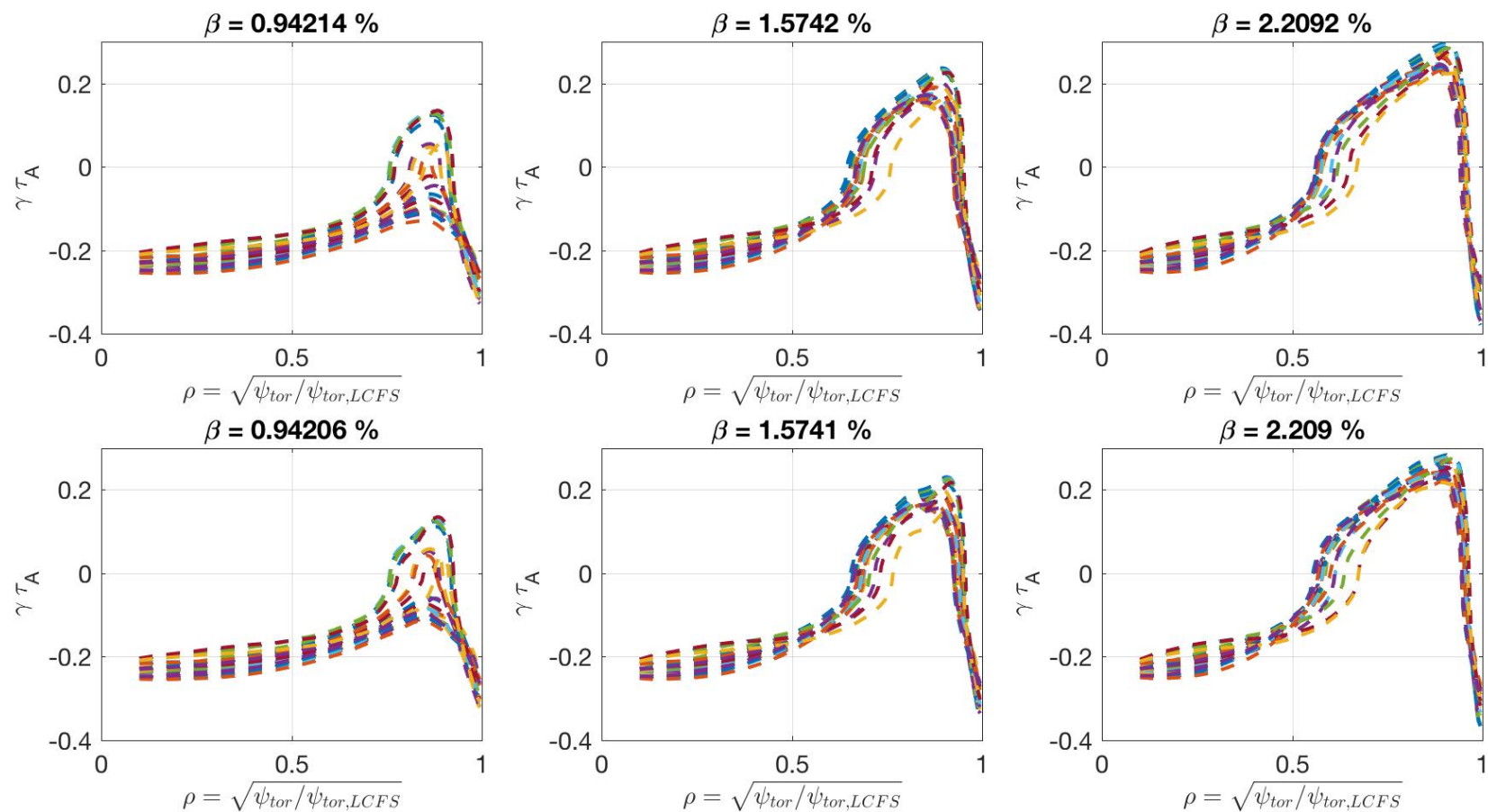
Solid = Symmetric VMEC run; Dashed = Asymmetric VMEC run



Ballooning stability behavior similar in both cases

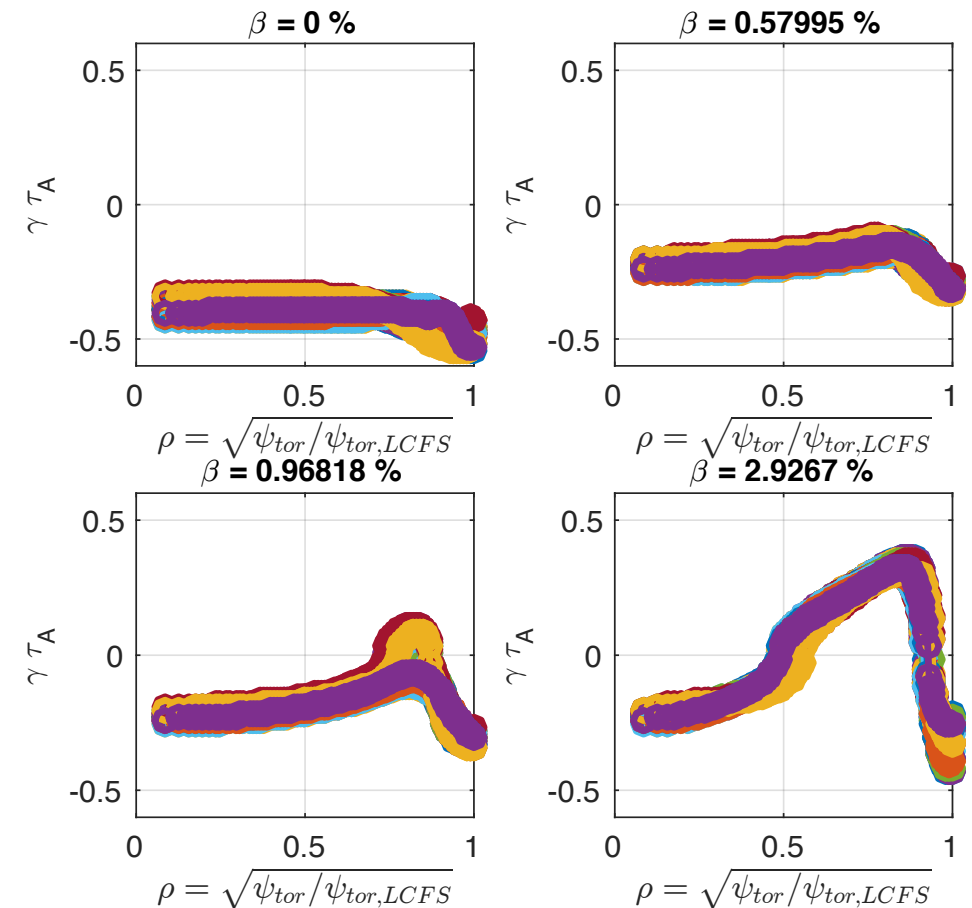
Top = Symmetric VMEC run

Bottom = Asymmetric VMEC run



BILA (WARE5P2) with original (ideal) LCFS

- Effect due to coils is harder to quantify at this point.
- Need a few more beta scans with BILA (ideal) to identify stability limit



- Last slide

