Assessment of Quasi-Helically Symmetric Configurations as Candidate for Compact Stellarator Reactors

Long-Poe Ku

Princeton Plasma Physics Laboratory

Aries Project Meeting, September 16, 2004

University of Wisconsin, Madison

The thrust of the study is to find out how compact a quasi-helically symmetric stellarator (QHS) can be.

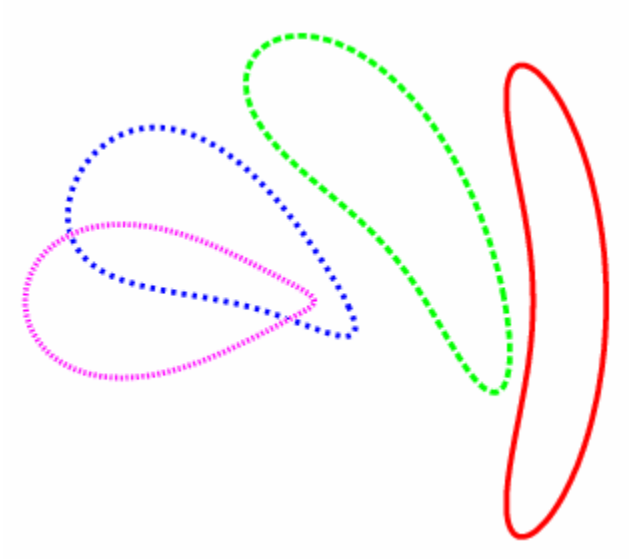
- Drift orbits of particles are confined (deviating from flux surfaces by at most a banana width) if the magnetic spectrum in a coordinate system whose Jacobian is proportional to $1/B^2$ is dominated by a single helical component.

- It is generally thought that to have good QH the aspect ratio needs to be large, but it is not clear how low the aspect ratio can go before having good helical symmetry is no longer possible.

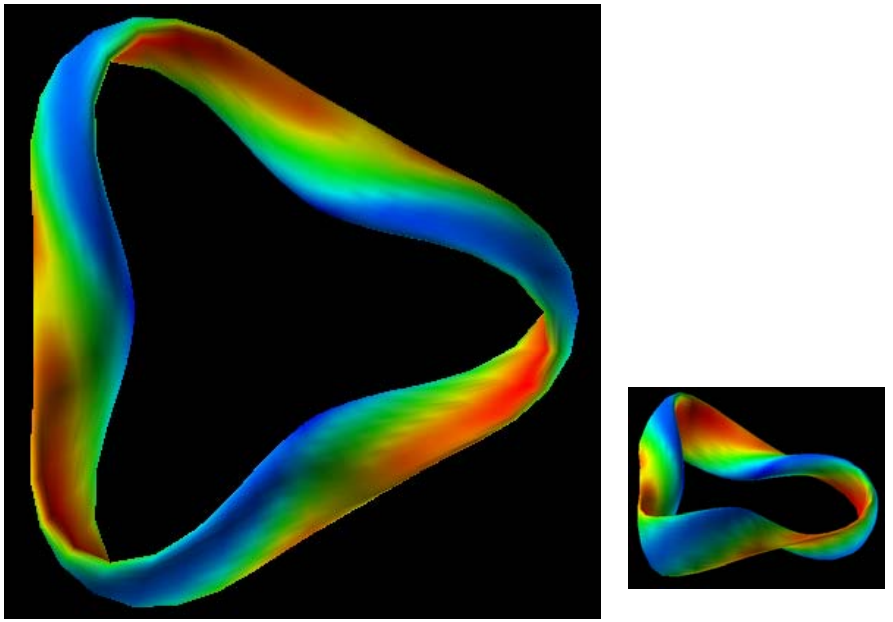
- HSX is a device having the medium aspect ratio of 8 with 4 field periods, probably the lowest A configuration known in the literature.

- We attempt to see if we can find interesting configurations with $A<6$.

An example of 3 field-period QHS with A=6 (3H4). This configuration was found with the constraints of positive shear in rotational transform ($d\iota/ds>0$) and a magnetic well depth of ~1% in the absence of plasma pressure.

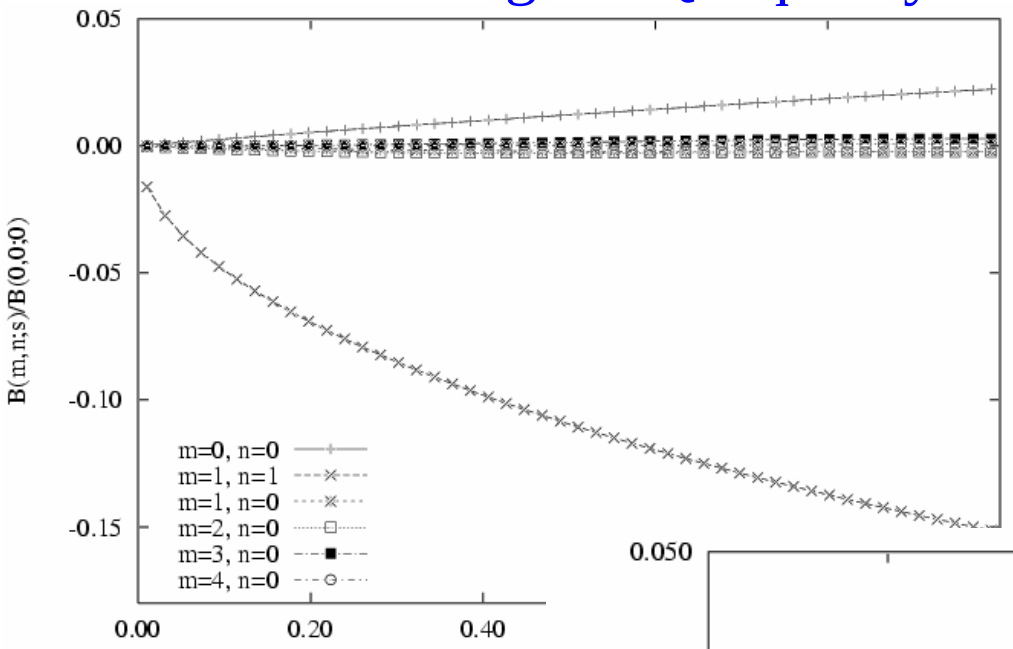


Cross sections of LCMS equally spaced in toroidal angle over half-period.



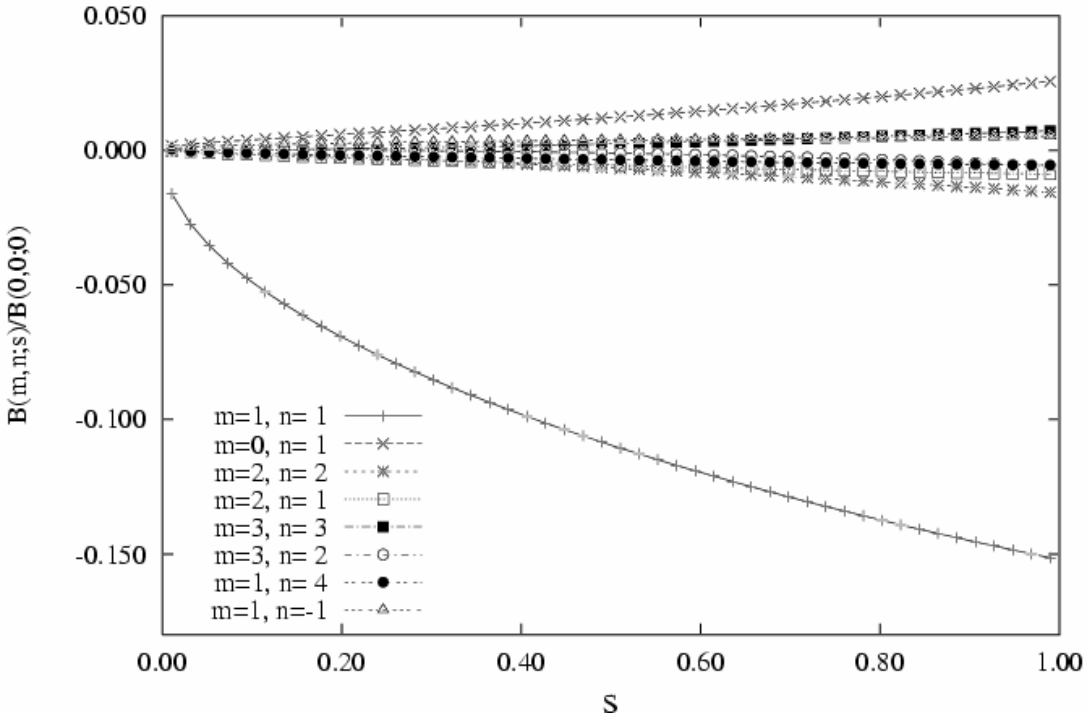
Contours of |B| on LCMS

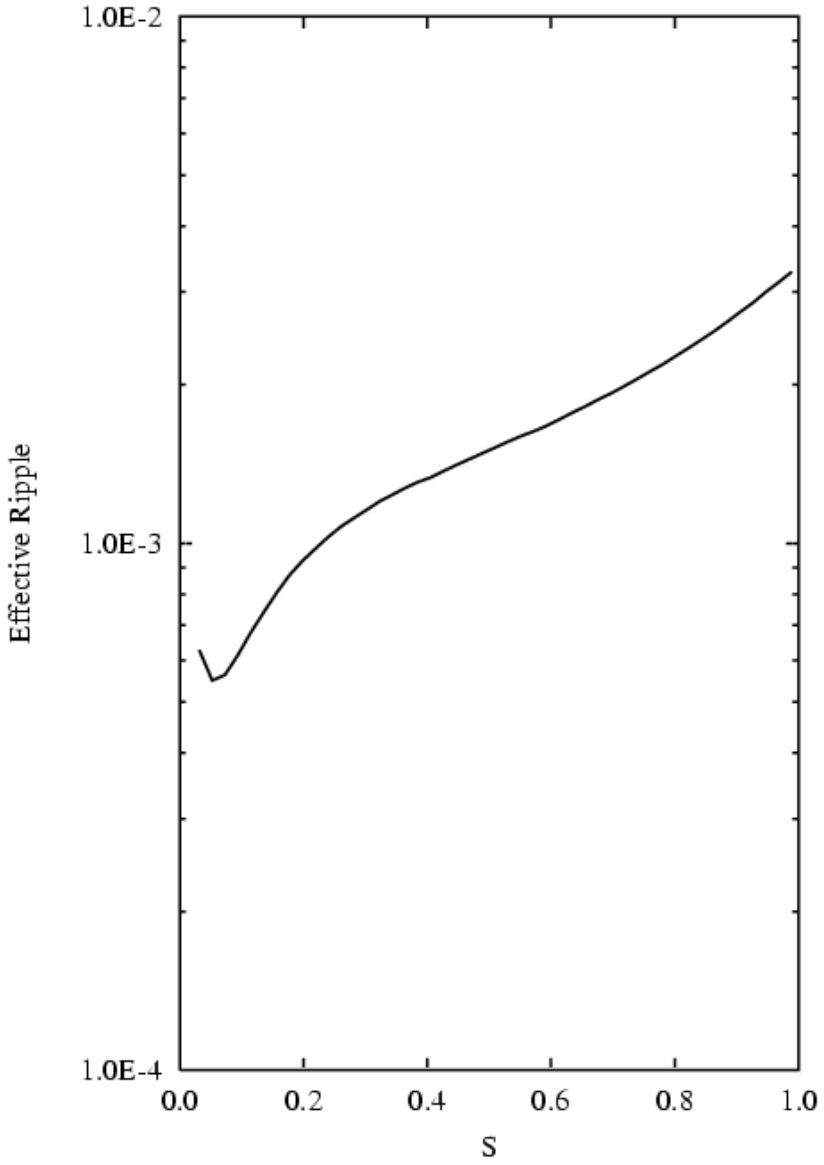
3H4 has good QH quality:



B(1,1)/B(1,0) > 60 everywhere

B(1,1)/B(0,1) ~6 @ s=1

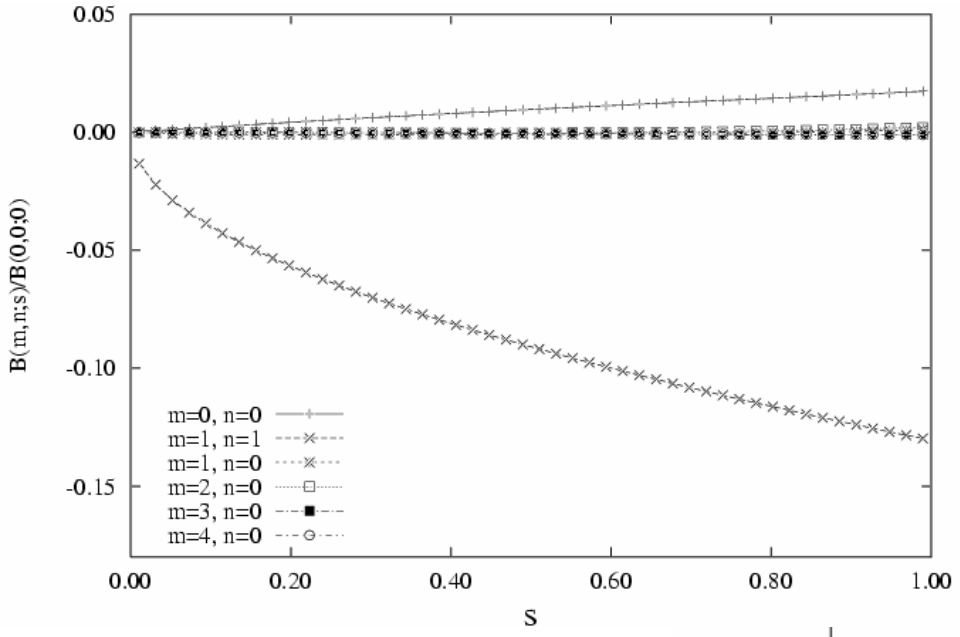




The effective ripple in $1/\nu$ transport is everywhere less than 0.35%.

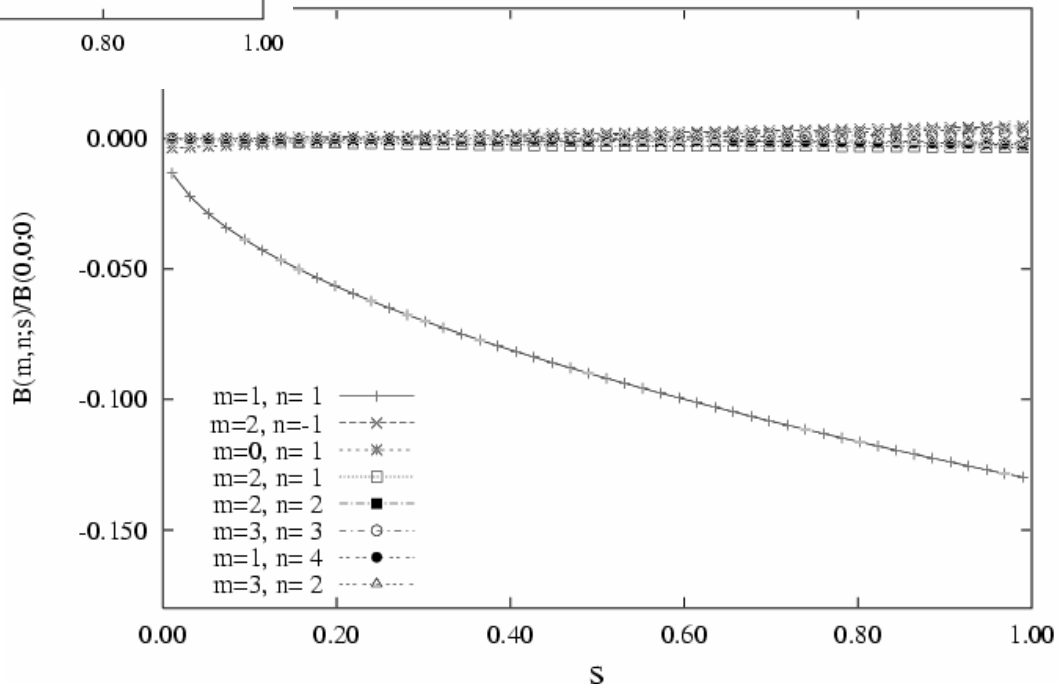
The α energy loss fraction in our model calculation is $< 5\%$.

The configuration can be made more QH by further optimization (3H5):

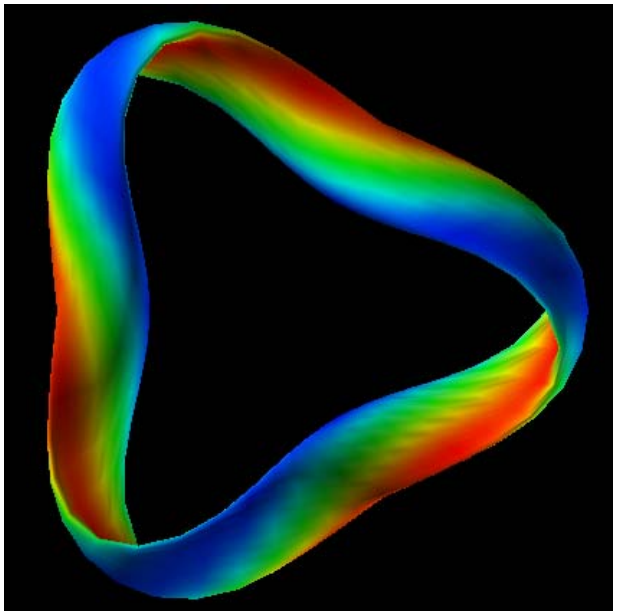


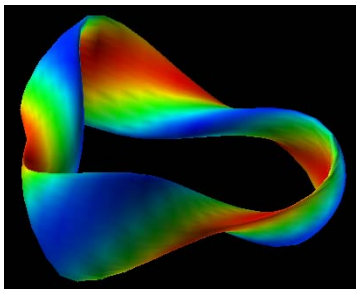
B(1,1)/B(1,0) > 60 everywhere

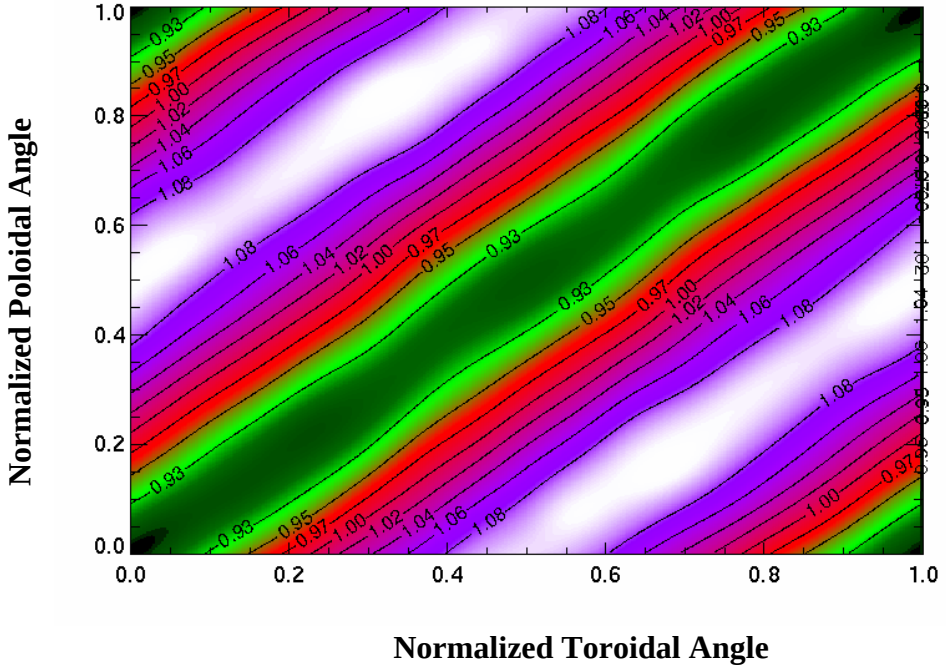
B(1,1)/B(2,1)~ 28 @ s=1



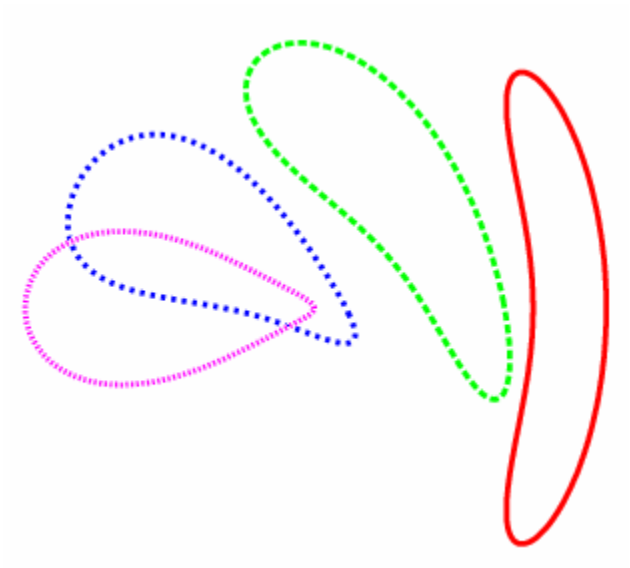
Contour plots of |B| on LCMS show excellent QH for 3H5. The α energy loss fraction in our model calculation for this configuration is < 0.5%.



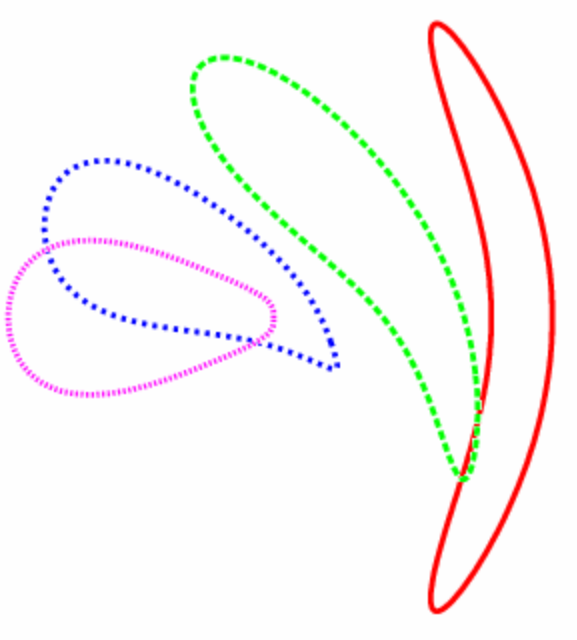




But 3H5 is more elongated than 3H4, resulting in the reduced width of the waist at the crescent shaped section.

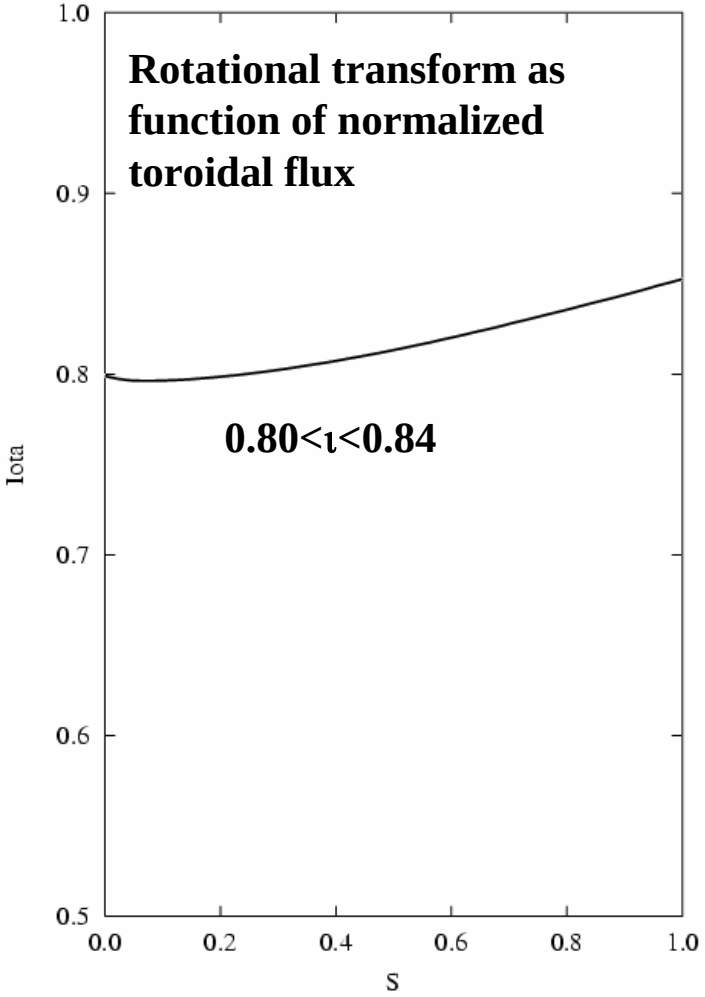


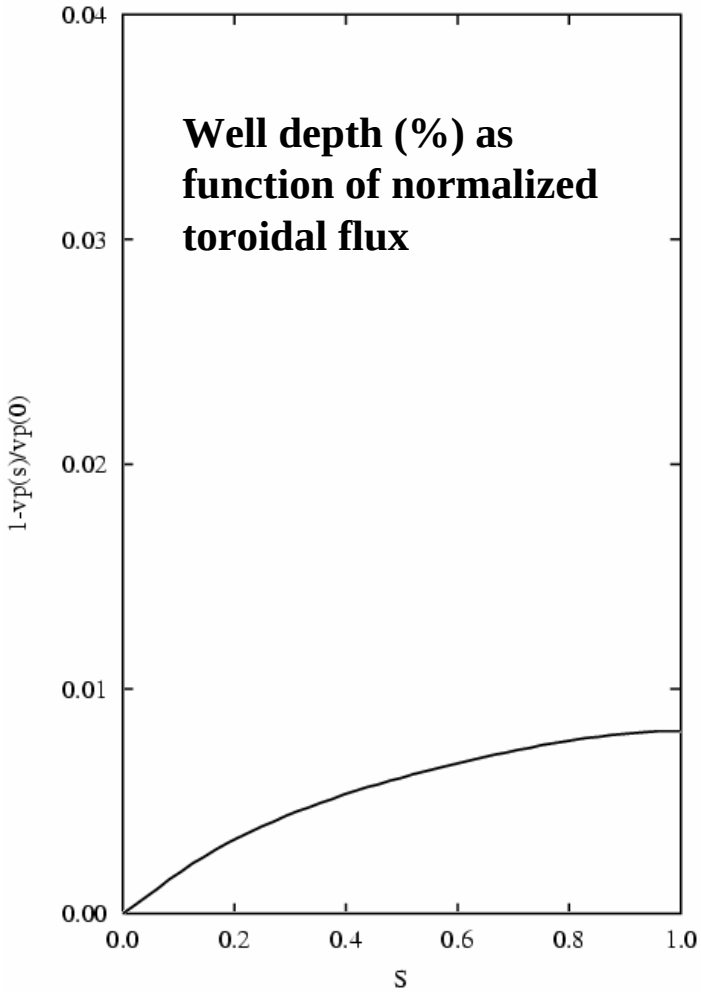
3H4



3H5

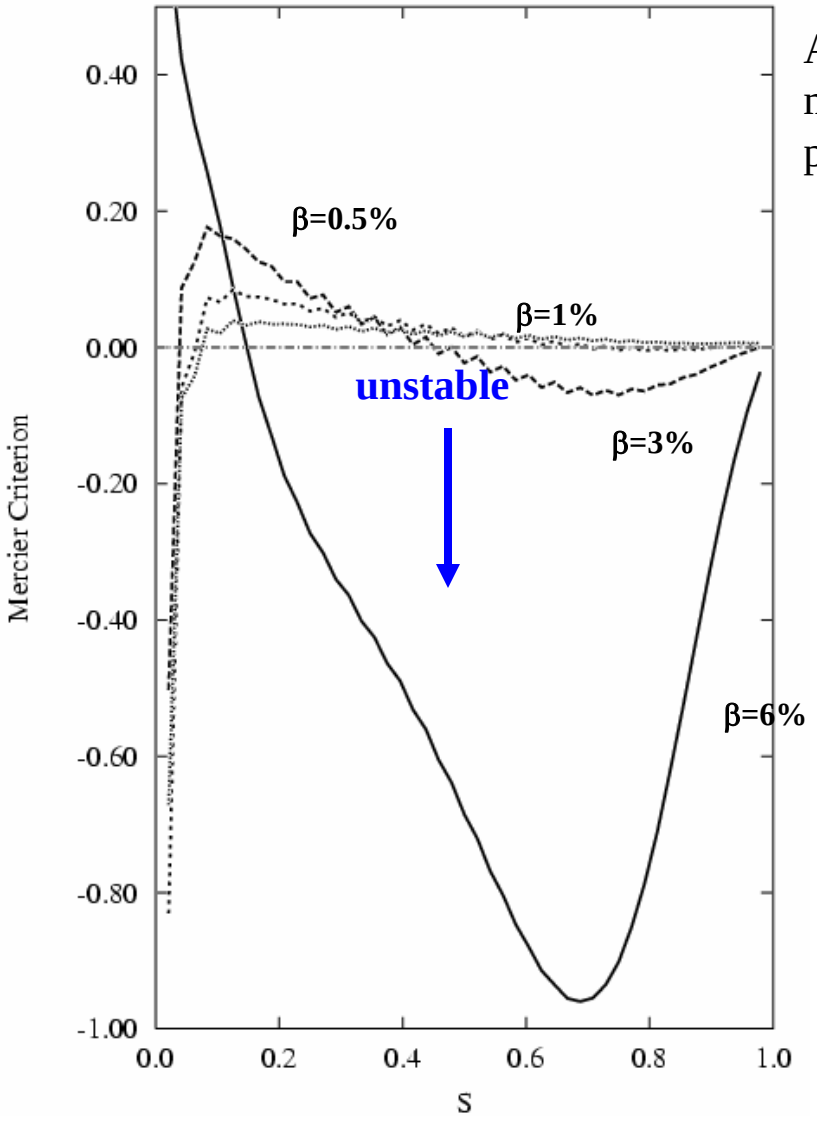
These configurations have high iota, low shear and low well depth in the absence of plasma pressure.





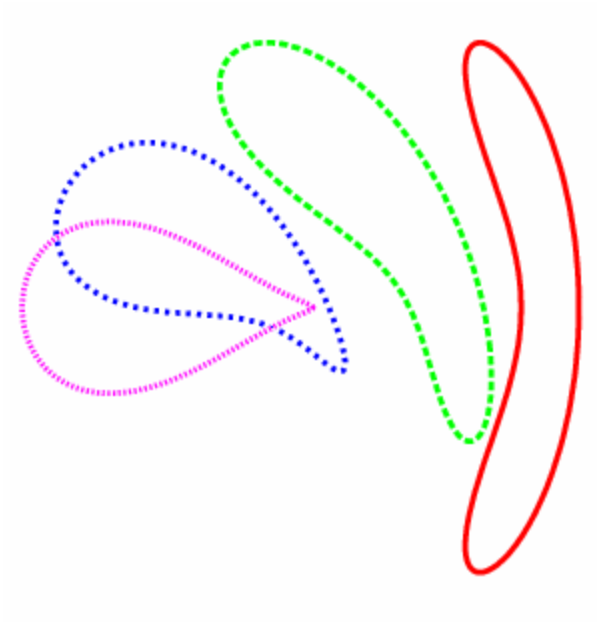
0.8%

As a consequence, they are mostly Mercier unstable:

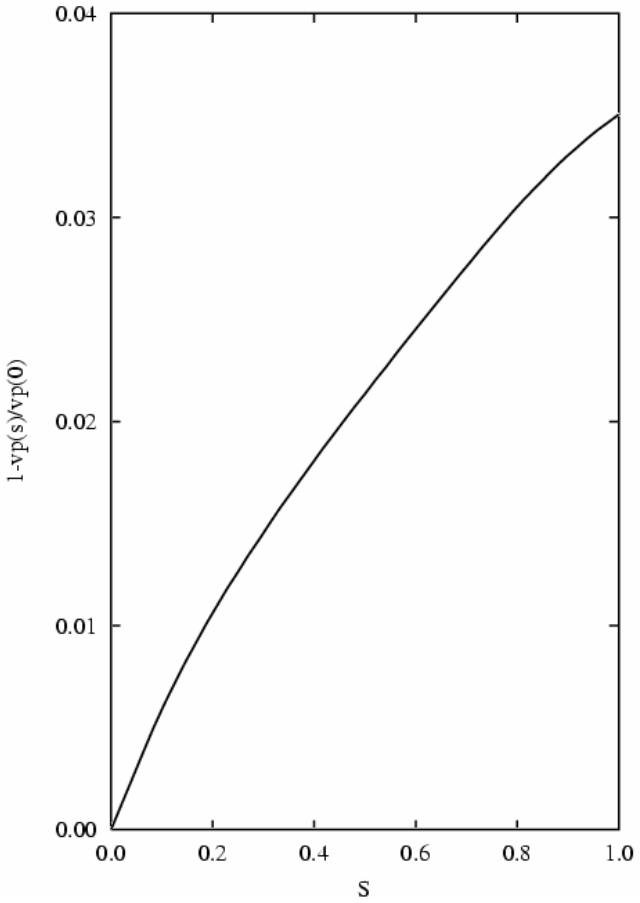


An example based on a model broad pressure profile.

Mercier may be improved by increasing the magnetic well depth (3J8):

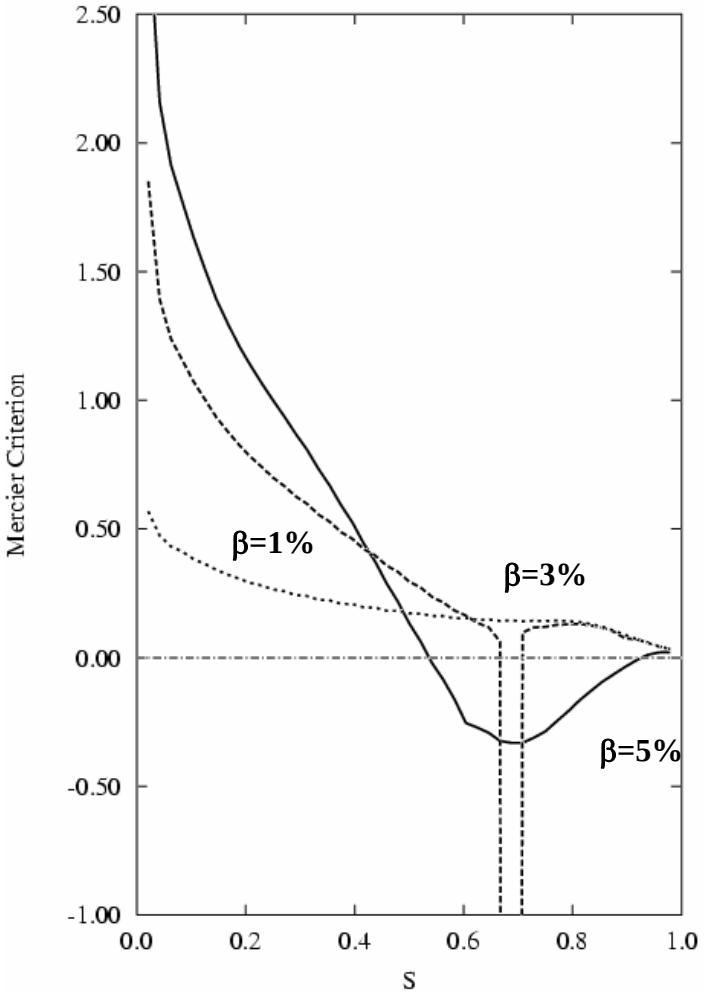


Cross sections of LCMS equally spaced in toroidal angle over half-period.

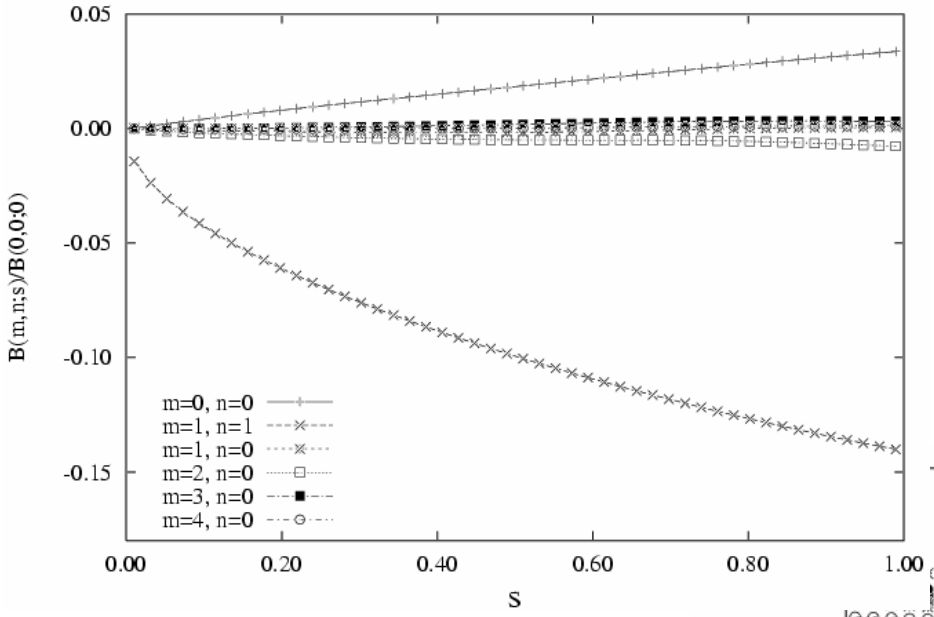


3.5%

With ~4% magnetic well, the configuration is essentially stable to Mercier for β>4%

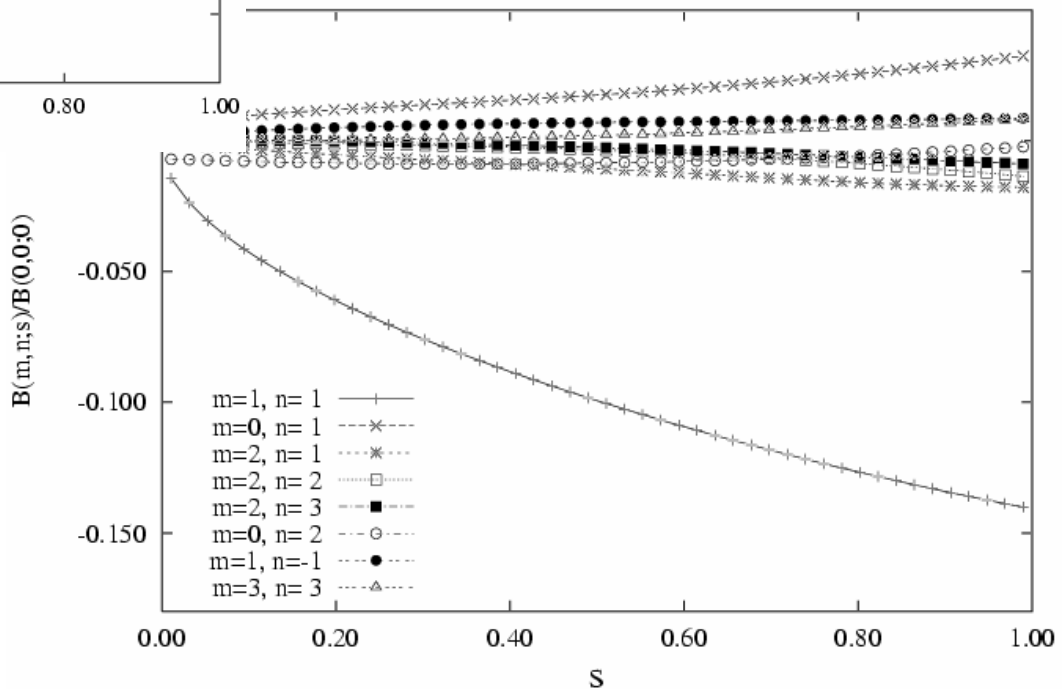


The deeper well comes at the expense of reduced quality of QH:

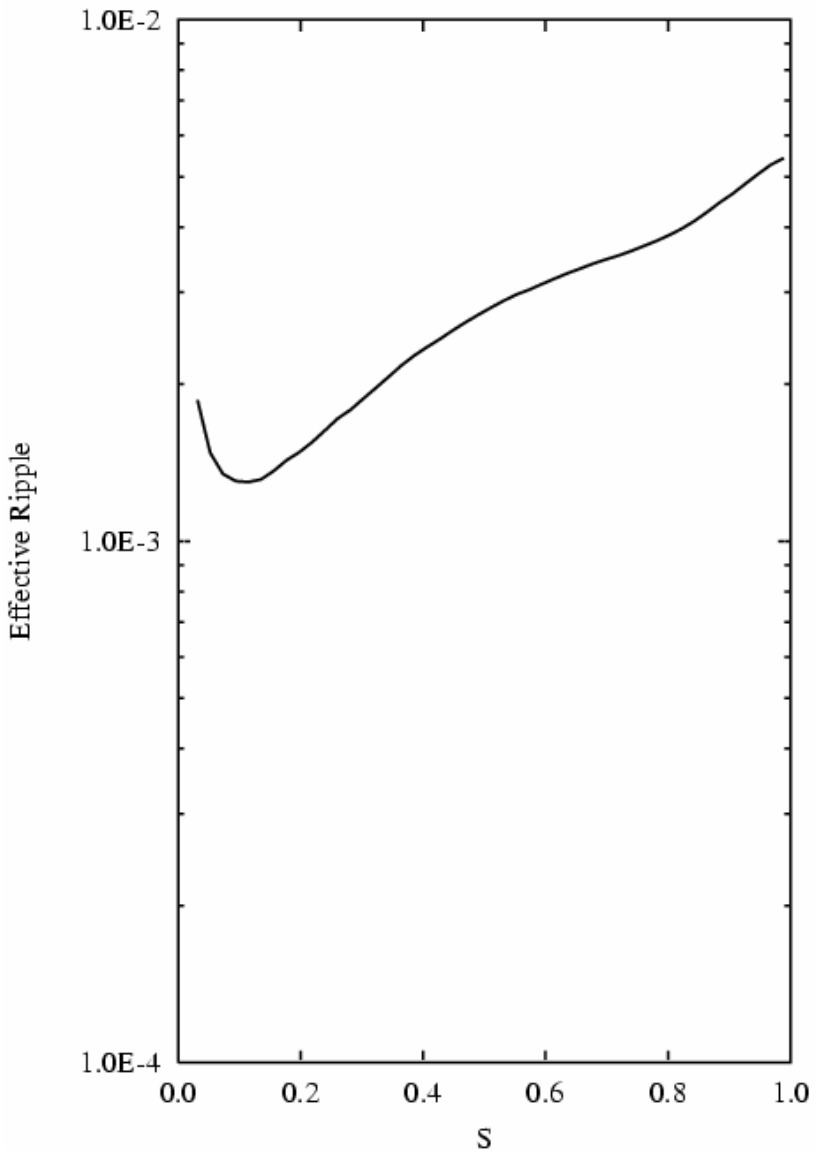


B(1,1)/B(1,0) > 50 everywhere

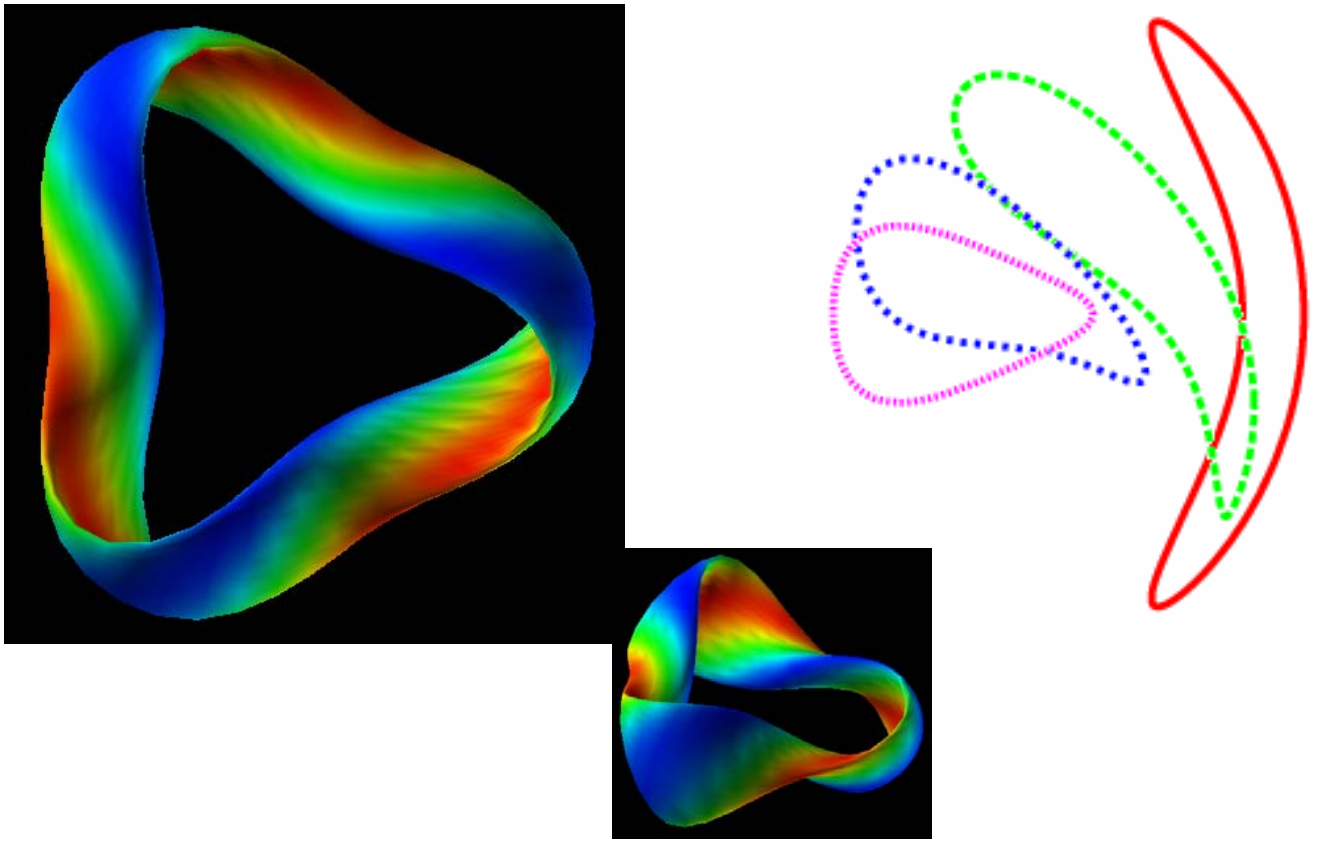
B(1,1)/B(0,1) ~ 4.5 @ s=1



And, the effective ripple is increased significantly. Can we further improve it?



Can we still maintain good QH if the aspect ratio is further reduced? Although there are difficulties, here is a configuration with 3 field periods and aspect ratio 4.5 having reasonably good QH. Much more work awaits!



Issues to be addressed

- Develop configurations with A<6 with good QH, deeper magnetic well, and fatter waist.
- Investigate effects of bootstrap current and iota profiles.
- Analyze MHD stability and find out beta limit.
- Examine flux surface integrity and find ways for island avoidance.
- Study coils and Δ_min.