Quasi-Axisymmetric Stellarators and Shaping Options

Potential and Research Opportunities

L. P. Ku

Princeton Plasma Physics Laboratory

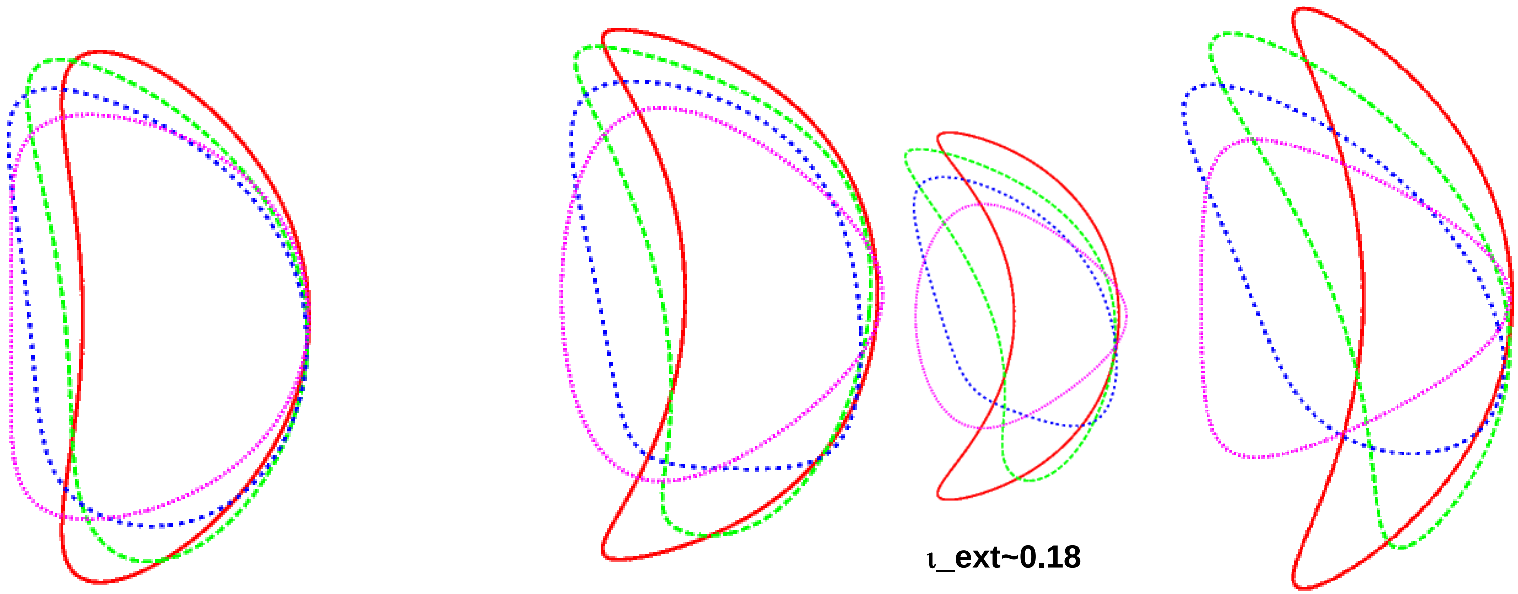
Quasi-Axisymmetric Stellarators & Shaping Options

- **A. Boozer has outlined and expounded the benefits of quasi-axisymmetric shaping.**
  - **Reduced uncertainty and risk associated with the performance of a plasma in tokamaks (maintenance of core q, MHD stabilities, robustness of plasma and error field control)**
  - **Value added improvements (higher density limit, higher T(0)/T(1), reduced current drive)**
- **QA shaping must meet certain constraints, however, in order to realize the added benefits:**
  - **Good magnetic surface quality**
  - **Practical coils**

- **To explore the potential, we have set up an initial program to systematically study the configuration space with the goals**
  - **to provide options QA stellarators may offer, allowing informed decisions be made when needs arise,**
  - **to understand the complexity issue in designing stellarator configurations,**
  - **to develop efficient means for error field controls and coil designs.**
- **We have taken steps to**
  - **study systematically the effects of plasma aspect ratio, levels of rotational transform and number of field periods,**
  - **understand the characteristics of the configuration space with respect to the constraints of configuration optimization,**
  - **develop methods using perturb equilibria to understand the relative importance of different components of the normal field on a plasma boundary in relation to the properties of the plasma,**
  - **Investigate coil design strategy for distant coils with reduced complexity.**

Example Configurations with Weak/Moderate QA Shaping

A=4, 3 field-periods, 4% <β>



ι_ext~0.045

ι_ext/ι_total(s=1)~18%

Passively stable to m=1, n=0 mode, <κ>~1.8.

ι_ext~0.09

ι_ext/ι_total(s=1)~37%

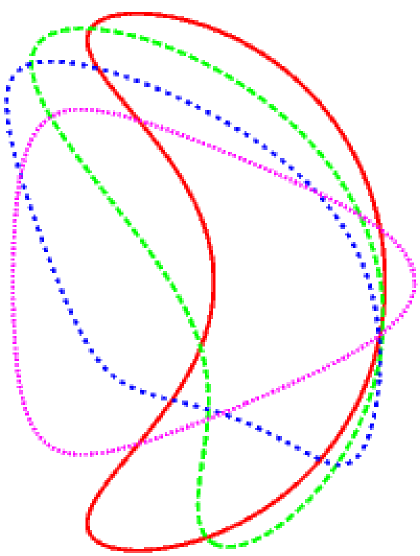
Current drive not needed. q(0)~20, Δ_s/<a>~35%.

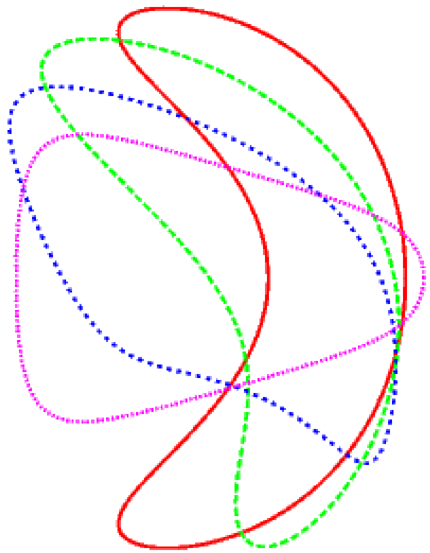
ι_ext~0.27

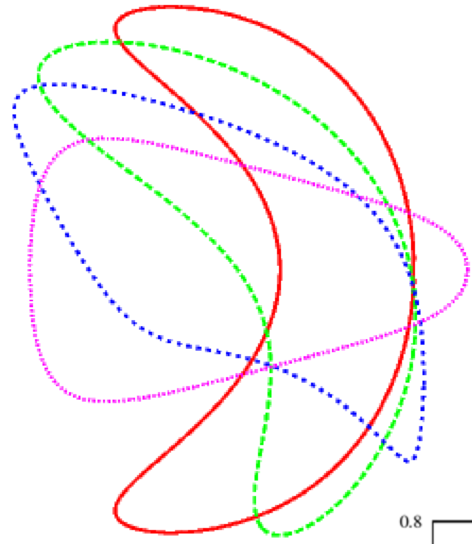
ι_ext/ι_total(s=1)~60%

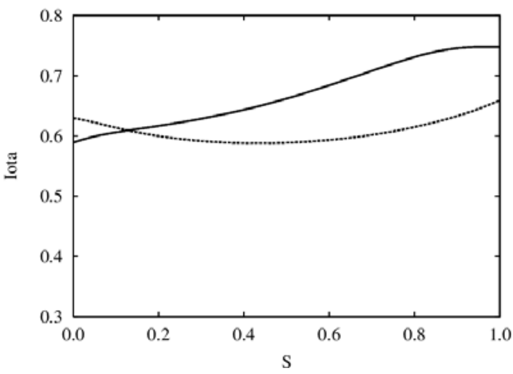
Stable to external kink modes without needing walls.

Example Configurations with Stronger QA Shaping
(Optimized for QA and kink stability)
A=4, 3 field-periods, 4% <β>









ι_ext~0.40

ι_ext/ι_total(s=1)~75%

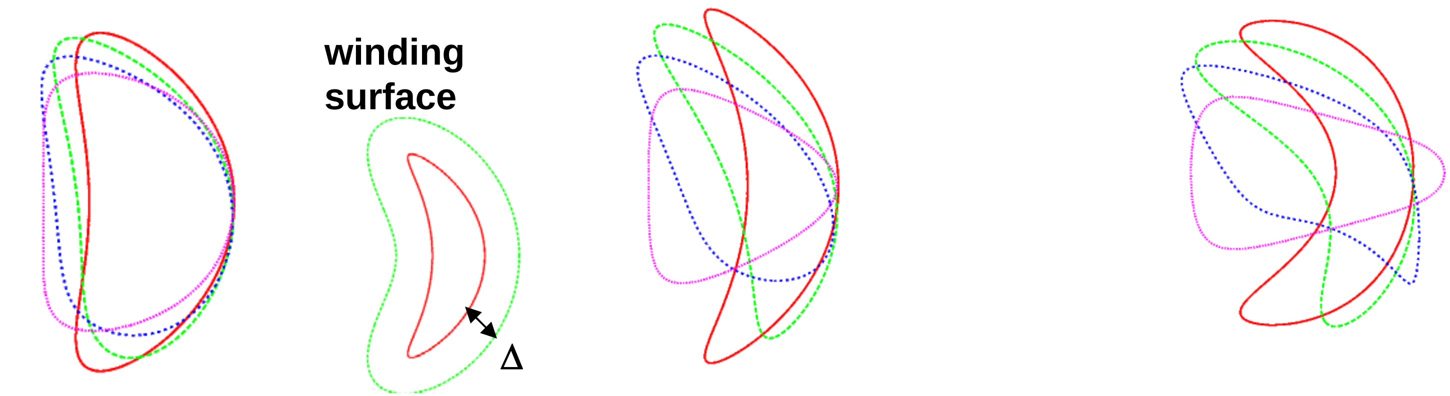
ι_ext~0.52

ι_ext/ι_total(s=1)~82%

ι_ext~0.60

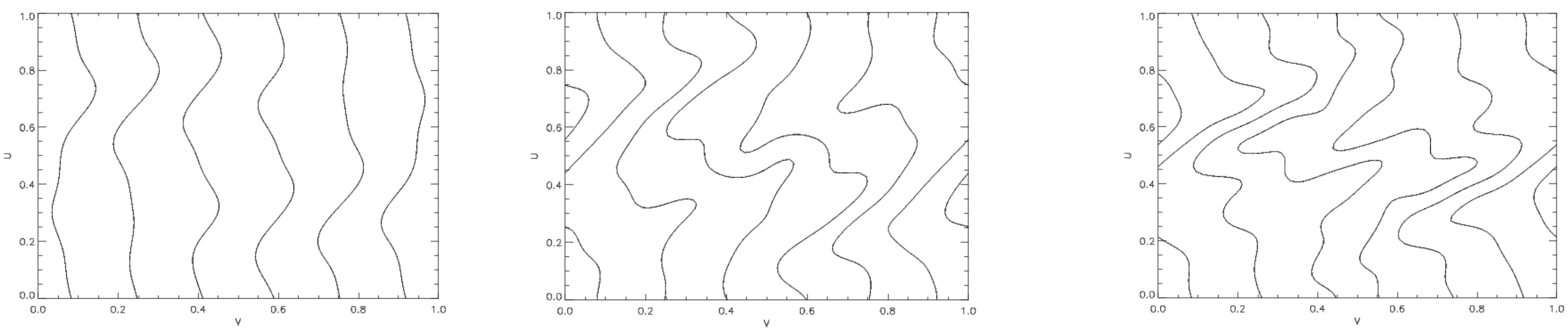
ι_ext/ι_total(s=1)~90%

Coil configurations for plasmas shown in previous slides for Δ/<a>=0.6 illustrating the effects of increased external rotational transform at a fixed A and β.



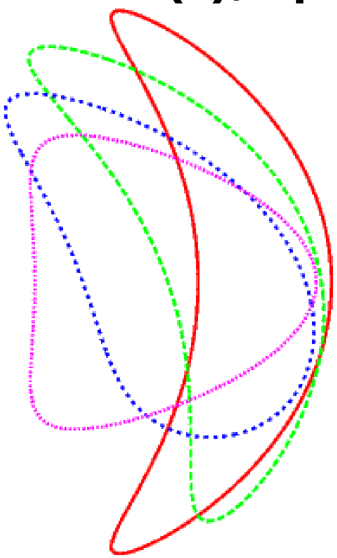
ι_ext~0.045 ι_ext~0.27 ι_ext~0.63

coils viewed on the flattened winding surface

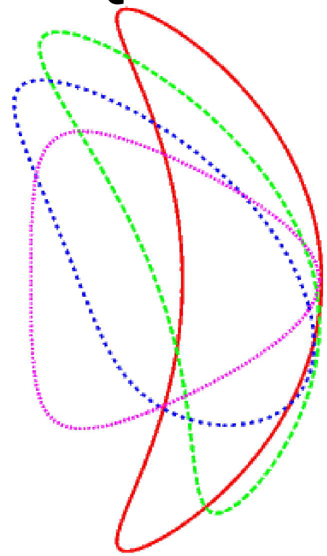


Example configurations of varying A with fixed $\iota_{ext}\sim 0.27$, $\beta\sim 4\%$ and field-period (3), optimized for QA and kink stability.

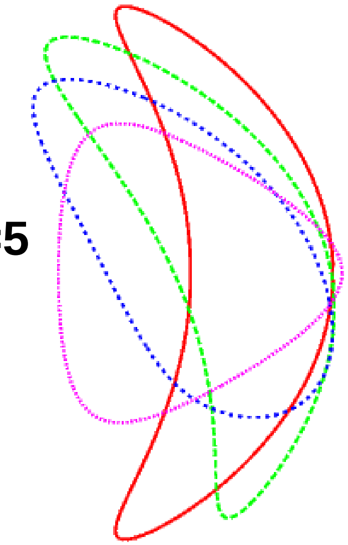
A=3



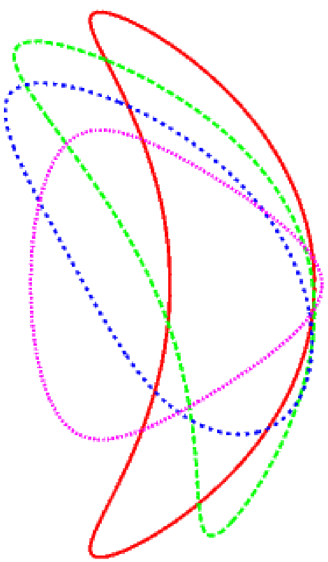
A=4



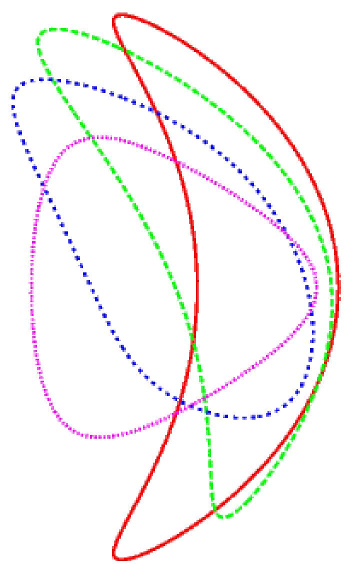
A=5

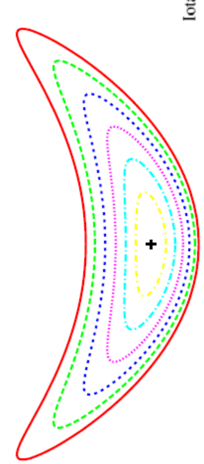


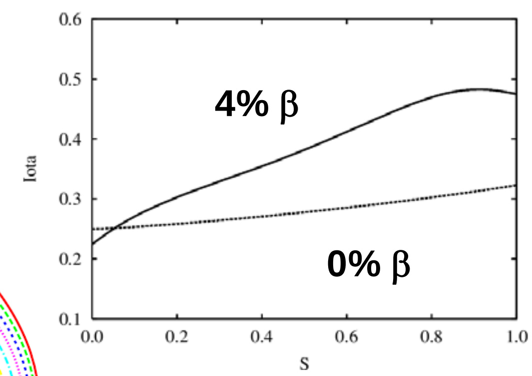
A=6



A=8

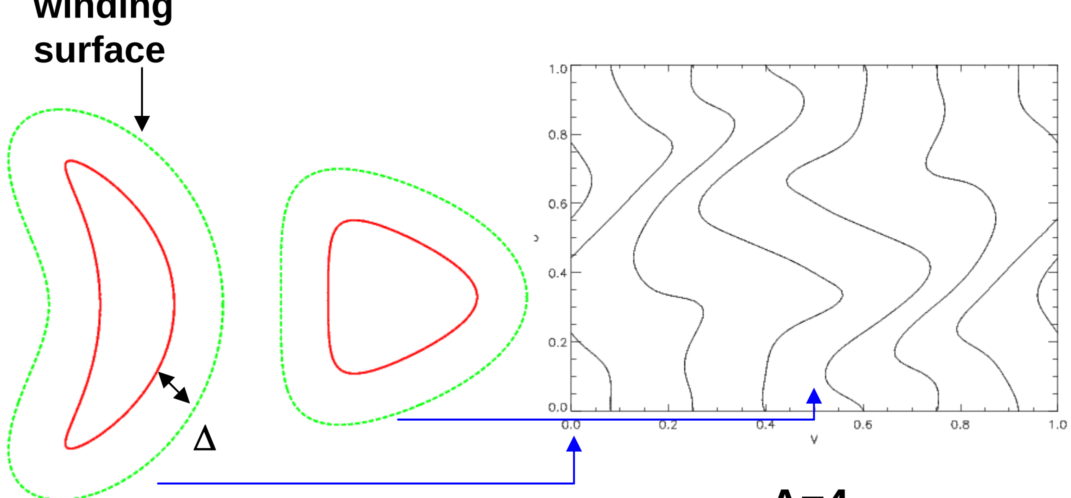




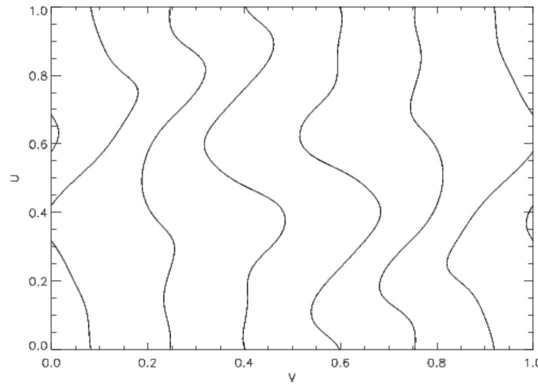


Coil configurations for plasmas shown in the previous slide for $\Delta/\langle a\rangle=0.6$ illustrating the effects of plasma aspect ratio.

coils viewed on the flattened winding surface

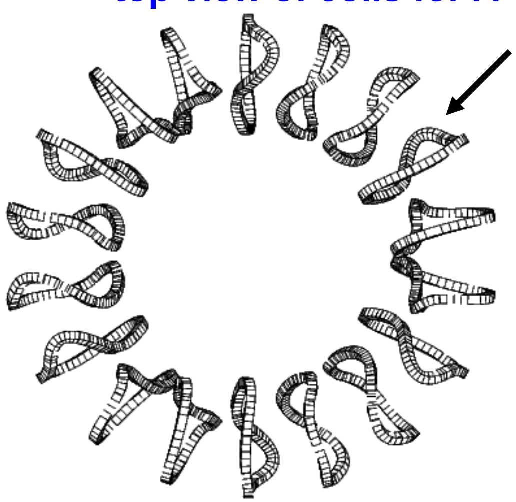


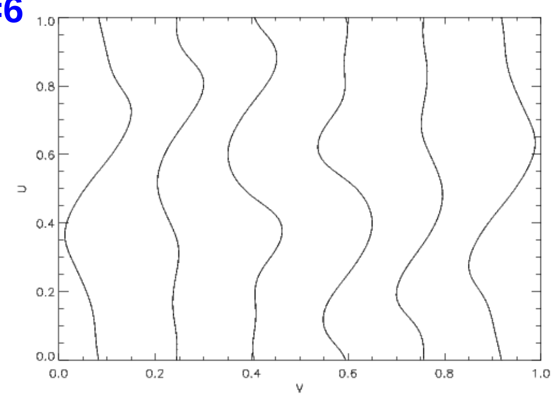
A=4



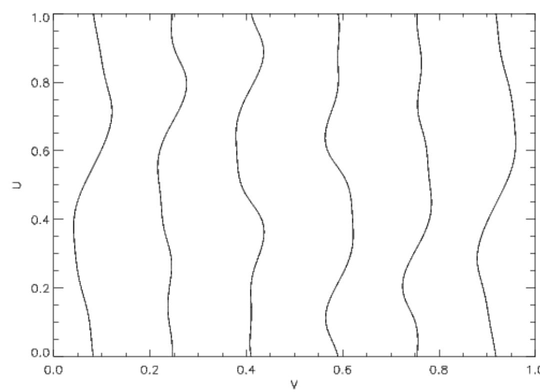
A=5

top view of coils for A=6



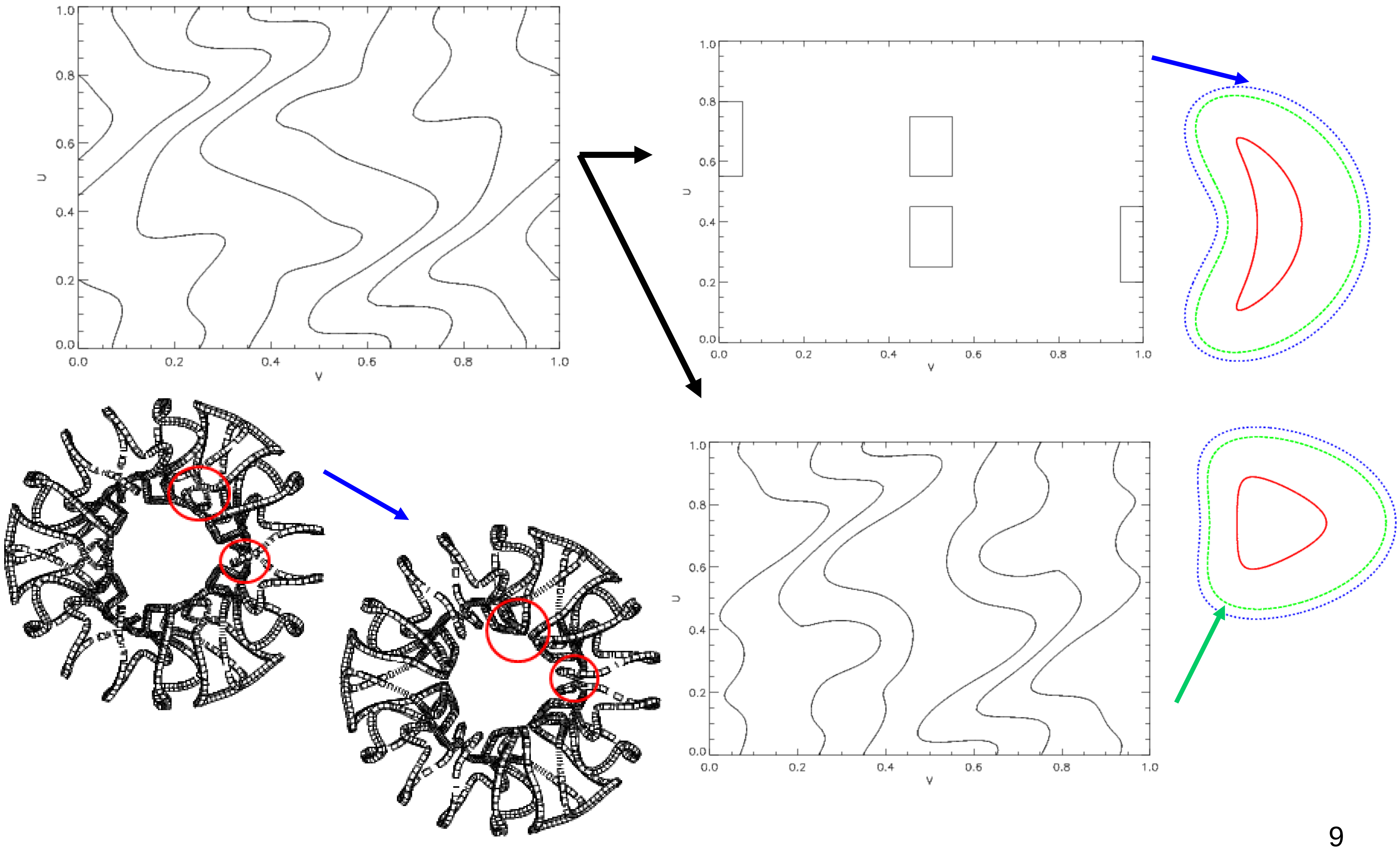


A=6

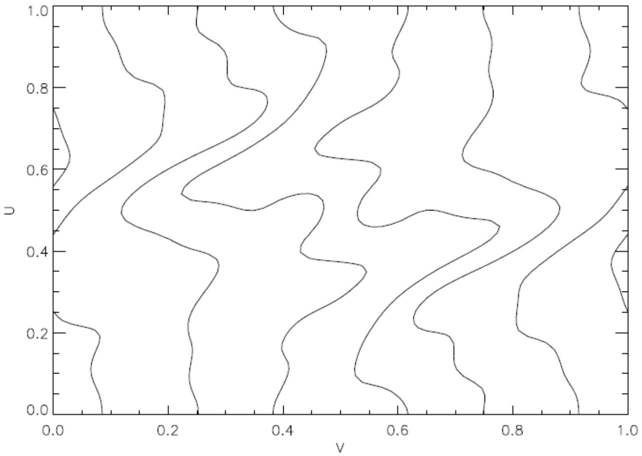


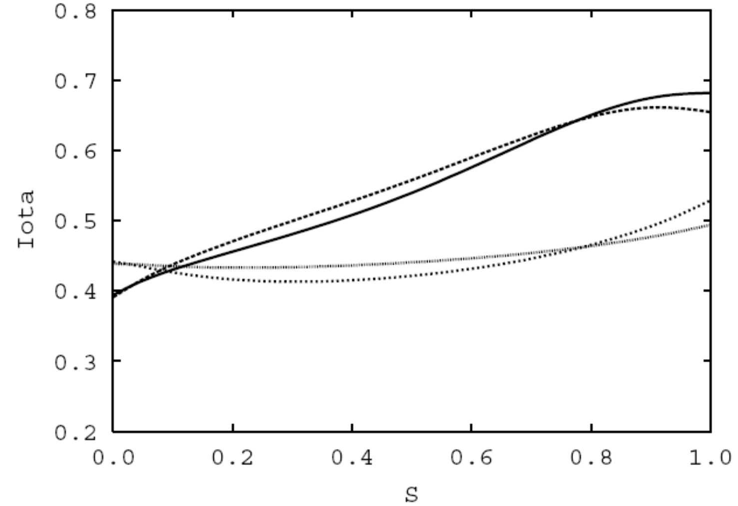
A=8

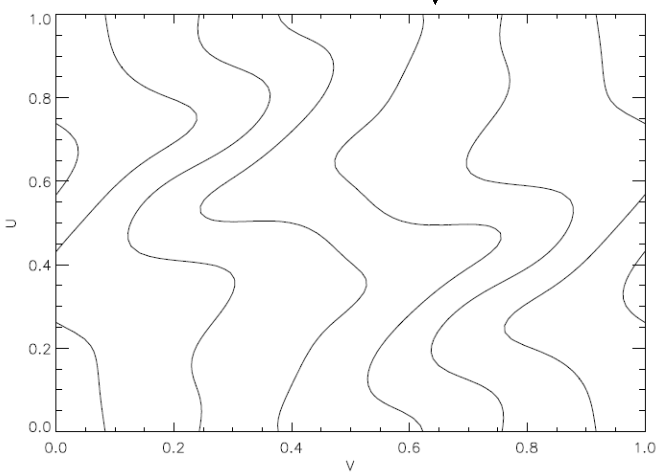
Example of using a combination of strategically placed picture-frame and modular coils to help ease assembly/disassembly.

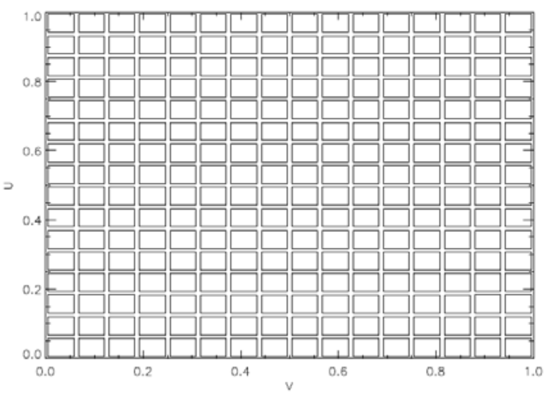


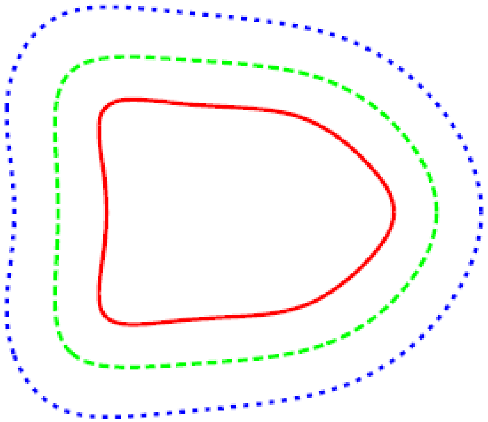
Example of using trim coils both to reduce local variations in modular coil winding and to increase edge shear.



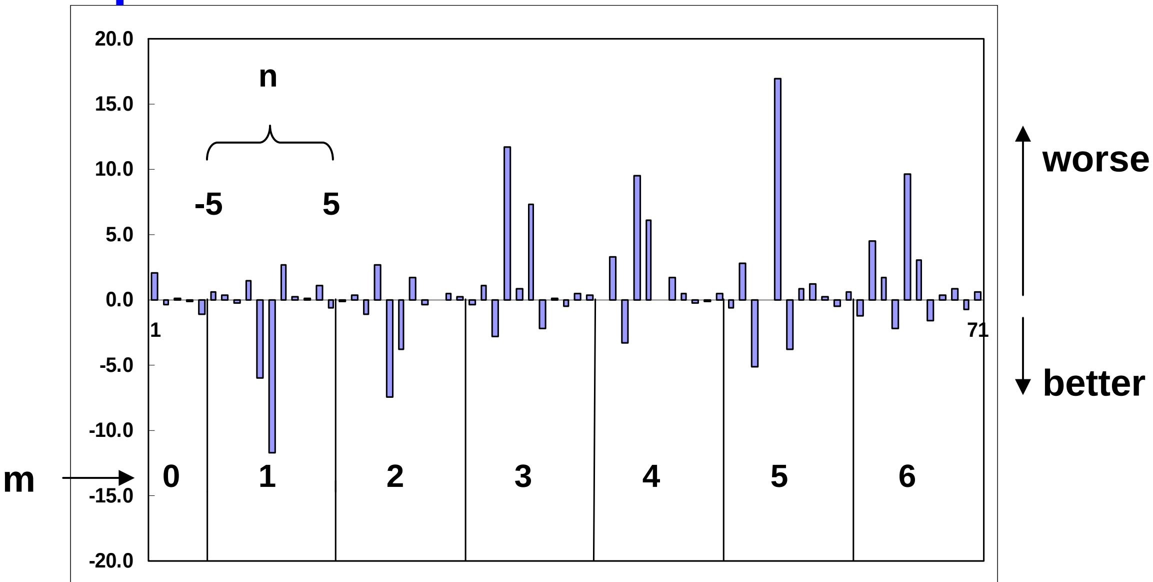




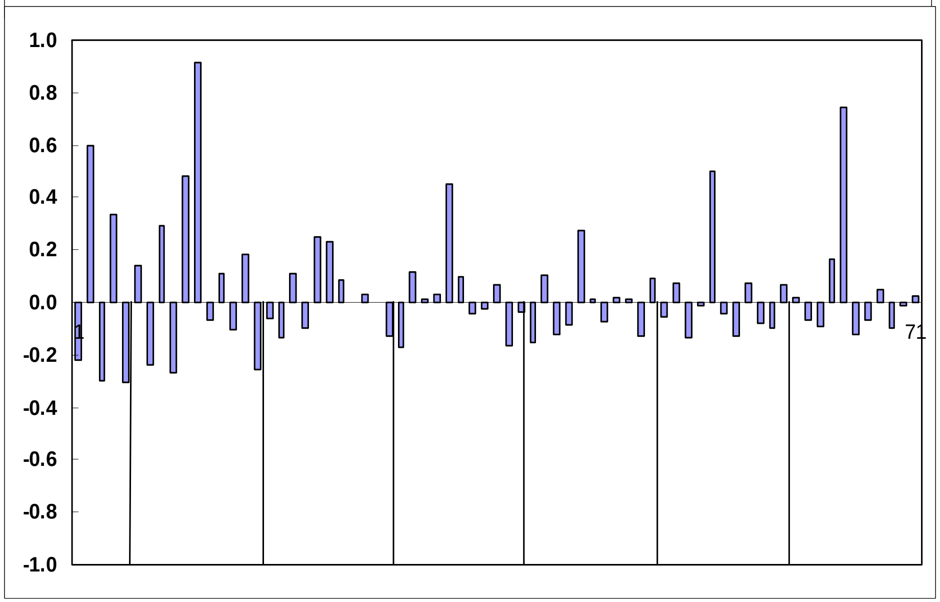


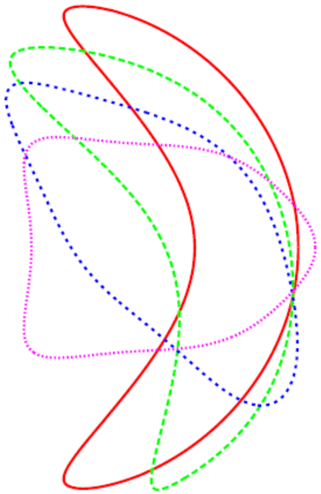


Example of a study for perturbed equilibria showing relative changes in plasma properties due to a unit change (0.1% B_0) of various modes of b·n on the unperturbed plasma surface. The understanding of the importance of different modes will lead to a more efficient coil design.



N=1 kink stability





ε-eff (s~0.5)

Summary and Conclusions

- The richness of QA configuration space (QS in general) is understood, but not yet fully explored. "Good" configurations connecting to physics targets and engineering feasibility need to be identified. Ample research and development opportunities await us.
- We have made initial steps to systematically examine the interplay of configuration/coil complexity, plasma aspect ratio, rotational transform and physics targeting for QA devices. Preliminary results are encouraging.