Physics Evaluation of Coil Designs

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Outline of Presentation

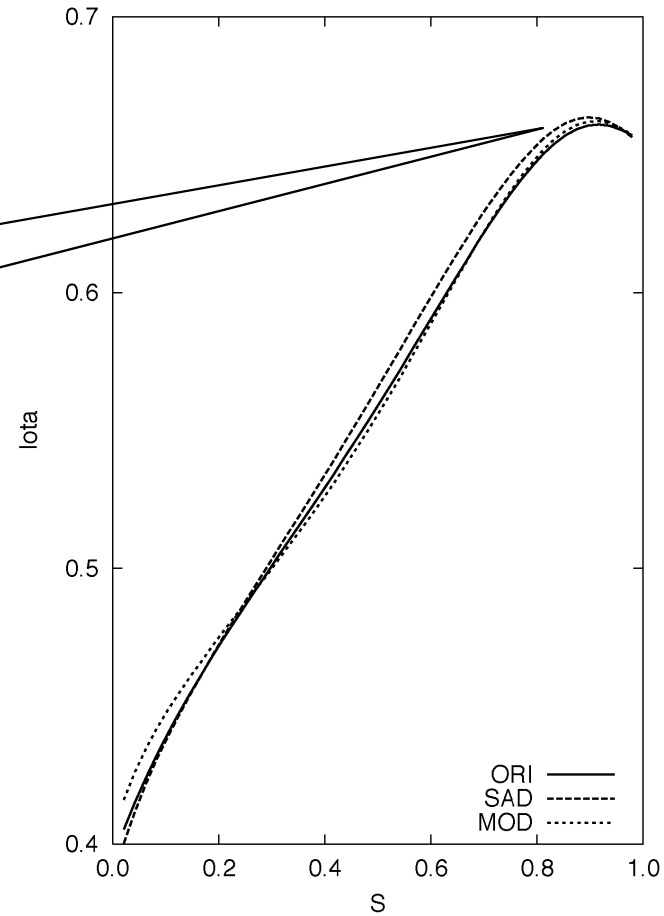
- Evaluation of stability and transport of plasmas based on LI383:
  - reconstructed from the first generation, saddle and modular coil design dated August 23, 2000: LI383sad, LI383mod
  - reconstructed from MCZ's improved saddle and modular coils dated September 17, 2000; LI383sz0, LI383mz0, and LI383mz1

- Beyond LI383 -- coil implications
  - motivation
  - goodness measure of II395, HI3351

Comparison of LI383, LI383sad and LI383mod

Iota Profile

"roll-over" region broader in LI383sad



Comparison of LI383, LI383sad, and LI383mod

Kink Stability

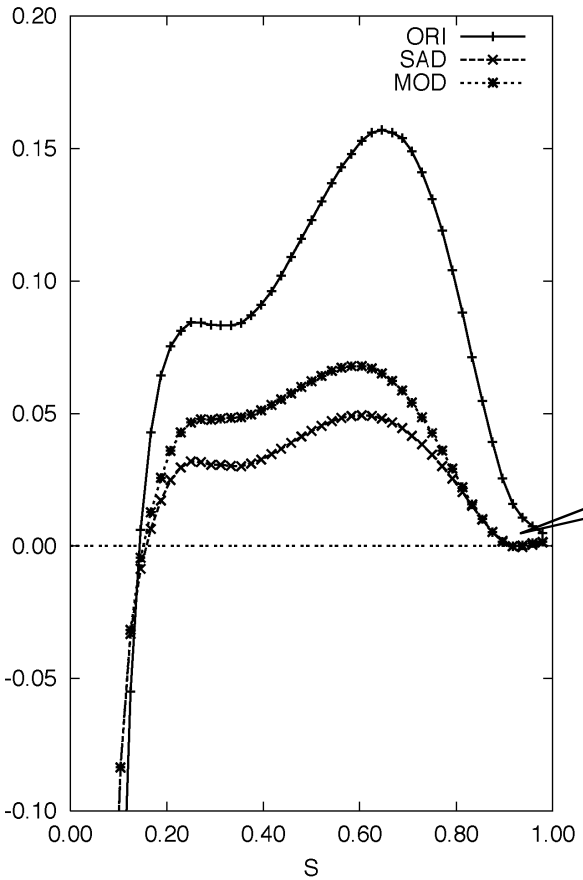
Eigenvalue calculated by Terpsichore:

	LI383	LI383sad	LI383mod
N=0 Family	Stable	0.5×10^{-4}	Stable
N=1 Family	Stable	1.2×10^{-4}	Stable

Saddle coil design resulting in unstable plasmas

Comparison of LI383, LI383sad, and LI383mod

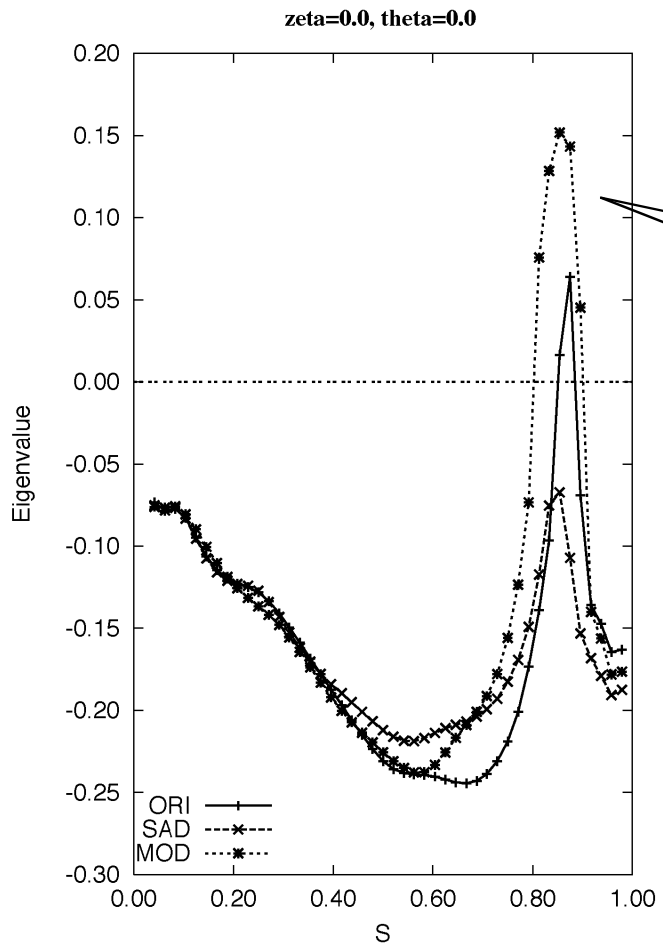
Mercier Criterion



Both LI383sad and LI383mod are slightly unstable at s~0.9

Comparison of LI383, LI383sad, and LI383mod

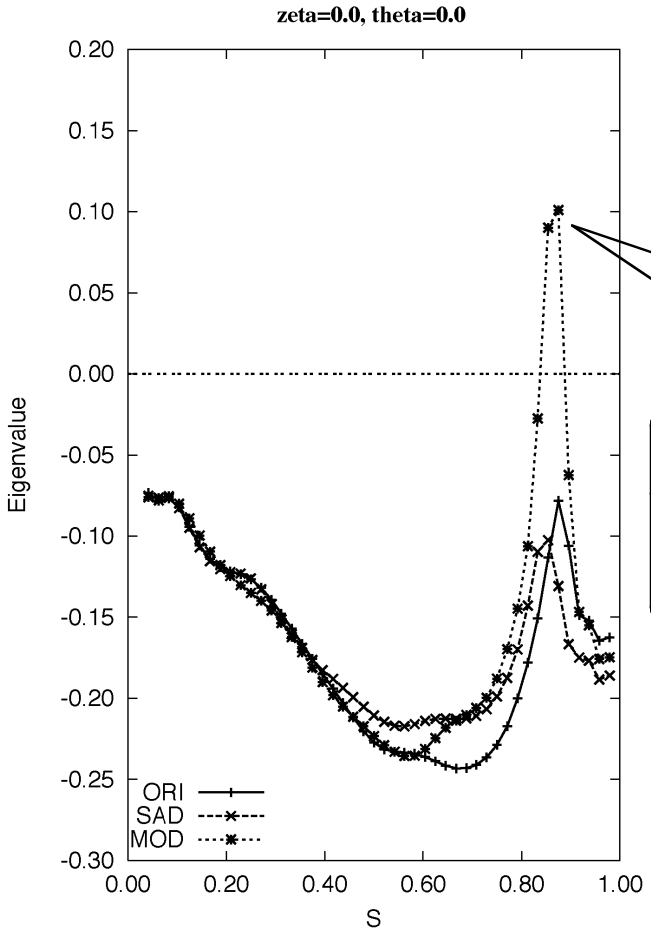
Ballooning Stability



At 4.25% β, LI383 is slightly unstable at s~0.9, but LI383mod is more unstable over a broader region

Comparison of LI383, LI383sad, and LI383mod

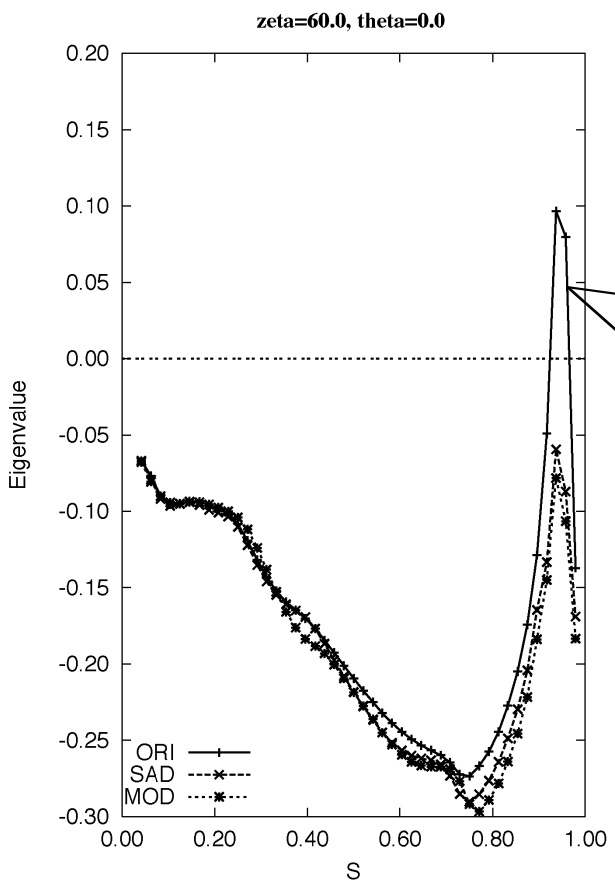
Ballooning Stability



At 4% β, LI383 becomes stable along the field line label α=0, but LI383mod remains unstable

Comparison of LI383, LI383sad, and LI383mod

Ballooning Stability

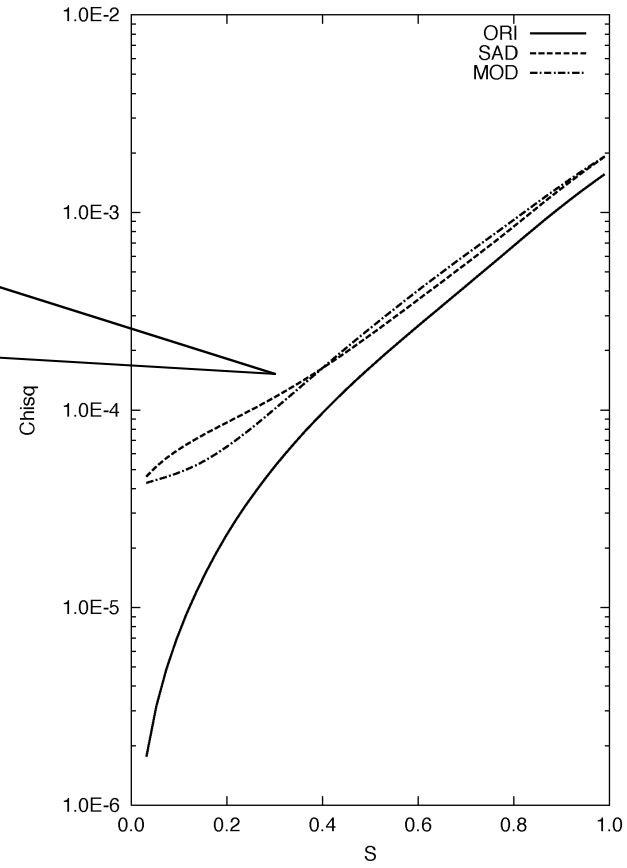


LI383, however, is unstable near the edge at 4% β along the field line label α=60°.

Comparison of LI383, LI383sad, and LI383mod

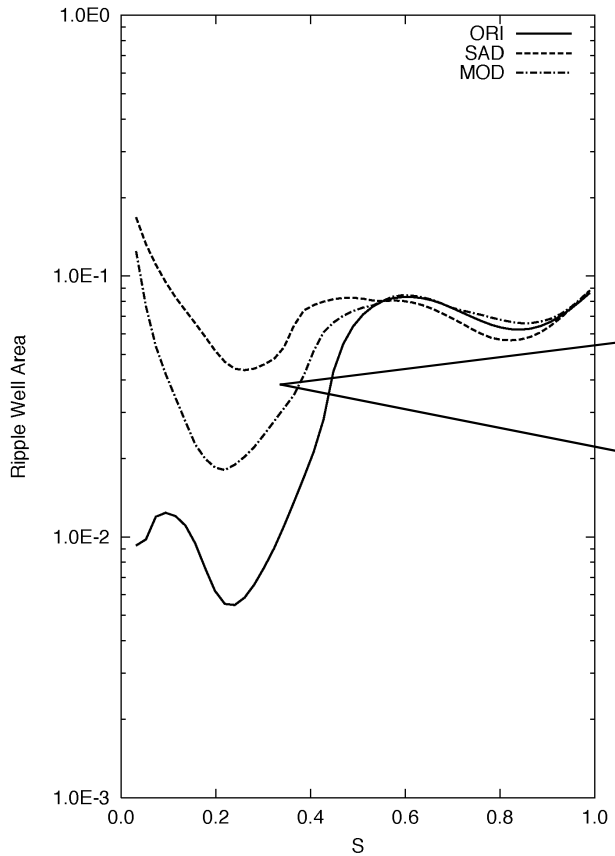
Magnetic Spectrum

Both LI383sad and LI383mod have higher Bmn's (n≠0), especially in the plasma core.



Comparison of LI383, LI383sad, and LI383mod

Magnetic Spectrum



LI383sad and LI383mod have significantly larger ripples in 0.0<s<0.5 as indicated by the "water" measure. In addition to $B_{2,1}$, $B_{3,2}$, LI383sad has ~0.5% $B_{0,3}$ and LI383mod has ~0.6% $B_{0,1}$ throughout the entire plasma.

Comparison of LI383, LI383sad, and LI383mod

Transport and Confinement

Thermal ion energy confinement time and NB energy loss fraction as calculated by GTC and ORBIT3D, respectively.

	LI383	LI383sad	LI383mod
τ^{NC} (ms) D, 1.2T	28	26	20
f_{NB} (%) H, 40keV, 2T	16	21	17

LI383mod has substantially lower thermal ion confinement.

Comparison of LI383, LI383sz0, LI383mz0/LI383mz1

Kink Stability

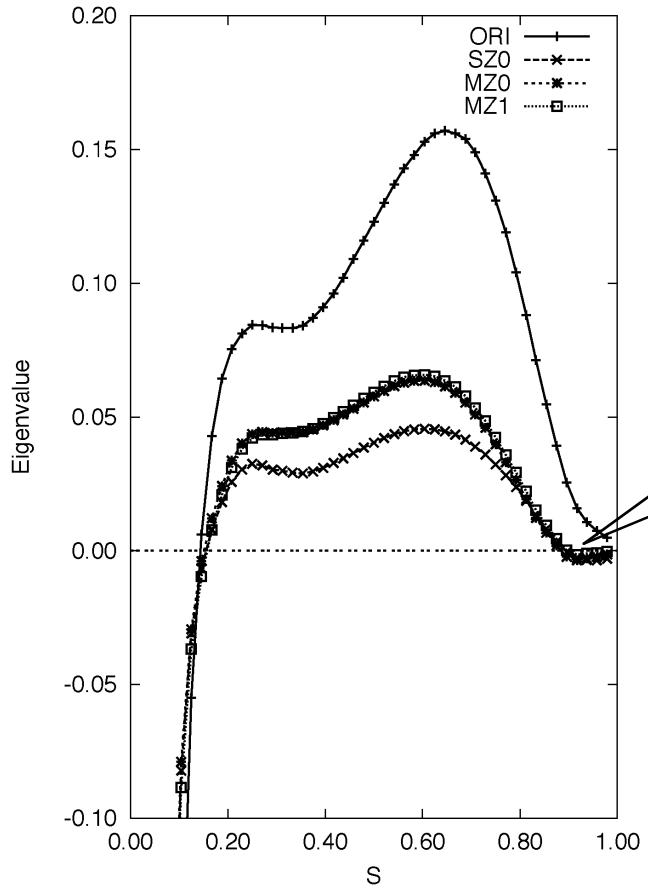
Terpsichore eigenvalues

Plasma from saddle coils remains unstable

	LI383	LI383sz0	LI383mz0 / LI383mz1
N=0 Family	Stable	2.9×10^{-4}	Stable
N=1 Family	Stable	7.4×10^{-5}	Stable

Comparison of LI383, LI383sz0, LI383mz0/LI383mz1

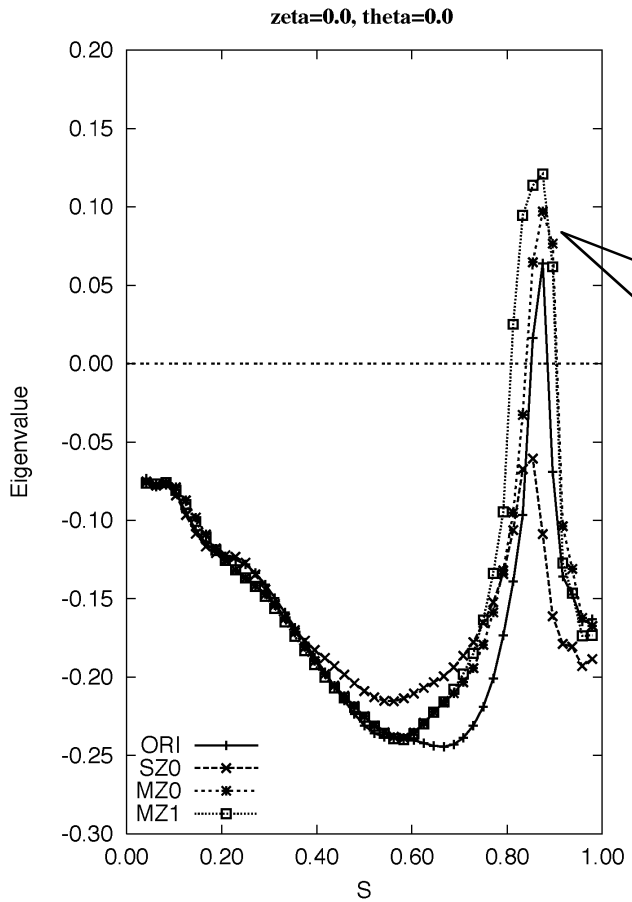
Mercier



The revised configurations are more unstable for s>0.9.

Comparison of LI383, LI383sz0,LI383mz0/LI383mz1

Ballooning Stability



Plasmas from modular coils, although better than LI383mod, are still more unstable than LI383.

Comparison of LI383, LI383sz0, LI383mz0 /LI383mz1

Transport and Confinement

	LI383	LI383sz0	LI383mz0 /LI383mz1
τ^{NC} (ms) D, 1.2T	28	26	21/21
f_{NB} (%) H, 40keV, 2T	16	20	19/17

Plasmas from modular coils also have poor thermal ion confinement. The $B_{0,1}$ component is still ~0.5%

Beyond LI383 -- Can we accommodate higher coil current density?

- The weak edge magnetic shear and closeness of boundary iota to 6/9 resonance make LI383 vulnerable to kink instability away from the reference point of optimization.

- Recent higher iota configurations are more robust to kink stability (although some problems remain), but they require higher coil current density. It will be useful to examine the new configurations to determine the experimental feasibility of these configurations.

Kink Stability of LI383 in (Ip, β) Space

I (kA) / β	50	75	100	125	150	175
0.0			Stable	3.8	1.5	
2.0	Stable		Stable	1.1	0.08	13
4.0	1.2	Stable	Stable	0.15	Stable	
4.5	2.7	1.0	0.01	Stable	Stable *	
ξ (n/m)	1/2	1/2	1/2	5/8	2/3	4/6

← optimization point

† Eigenvalues ($x10^4$) from Terpsichore calculations are given for unstable state.

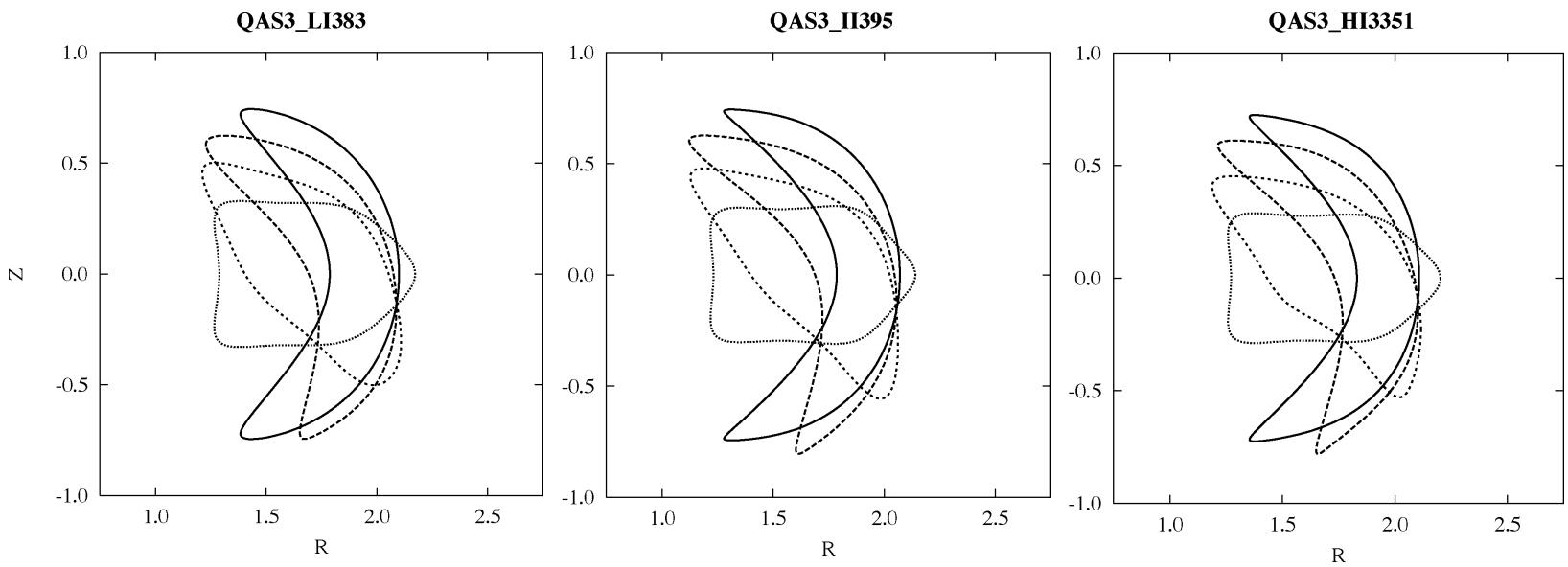
Beyond LI383 -- cont

	LI383	LI383sz0	LI383mz1
β=4% I=150 kA	Stable	0.45	Stable
β=4% I=125 kA	0.15	0.06	1.1
β=0% I=150 kA	1.5	14.6	20.0

Configurations reconstructed from coils do not change the stability characteristics, and may be even worse.

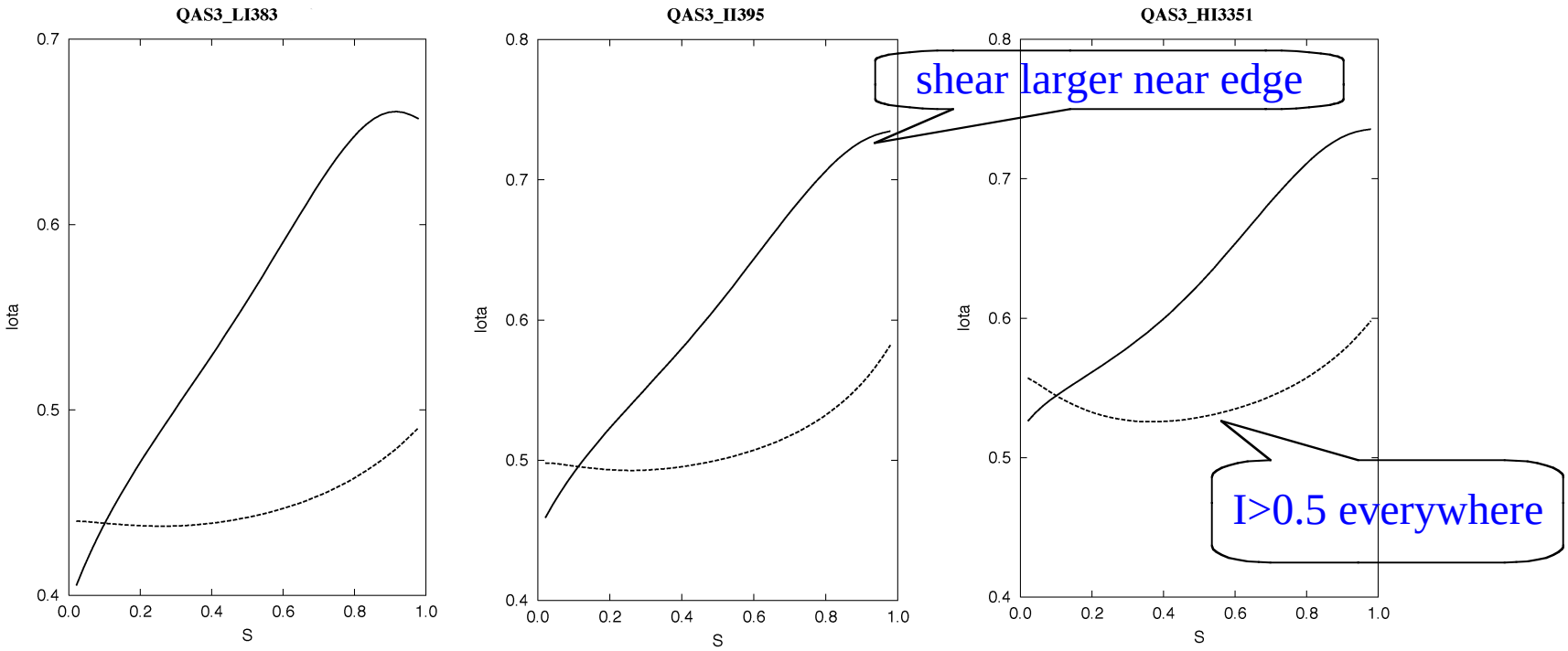
Beyond LI383 -- Configuration II395 and HI3351

- II395 and HI3351 -- two alternate candidates having more robust kink stability characteristic



Beyond LI383 -- Configuration II395 and HI3351

- And they have higher rotational transforms.



Beyond LI383 -- Configuration II395 and HI3351

Comparison of Figures of Merit for Coils:

	LI383	II395	HI3351
Complexity	2.05	2.10	2.08
Jmax/Ipol Current sheet	0.76	0.96	0.88
Jmax @2T (kA/cm^2) saddle coils, uniform cut.	17.8 (10)	25.6 (12)	24.9 (12)

But they have higher coil current densities! These current densities, however, are comparable to that of II75. Can we design flexible coils for experiments?

Summary

- All configurations reconstructed from coils and analyzed so far fall short of recovering all the necessary stability and transport properties at full beta and current. More coil optimization may be needed.

- LI383 is vulnerable to kink instability away from the point of optimization. Recently developed higher iota configurations may be better candidates for more robust experiments. The question of whether flexible coils can be designed remains to be resolved.