Plasma Configuration Development, Status and Plans

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Outline

I. A recap of properties and characteristics of recent configurations (C10, C82, C85).

II. Discussions of configuration selection for engineering and costing studies.

III. Discussions of issues to be studied for C10/C82/C85.

IV. Discussions of needs and strategy of searching for new configurations.

I.A. Goals of Configuration Design

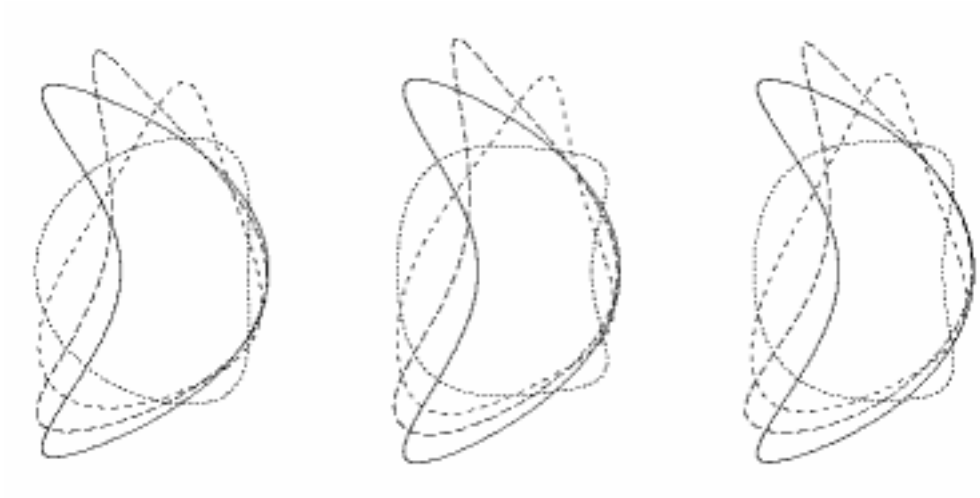
- Compact ($A < 4$), and fit inside PBX ($1.05\ m < R_b < 1.85\ m$).

- Adequate energy confinement to access $\beta \sim 4\%$ with available heating power (6 MW NBI).
  - good quasi-axisymmetry, $\Sigma_{n\neq 0} \{B_{mn}^2/B_{00}^2\} << 1$
  - $\tau_E^{neo} > 2\ \tau_E = 2 \cdot 2.3\ \tau_E^{ISS95}$
  - <20% loss of fast ions

- Stable at $\beta \sim 4\%$, bootstrap consistent, free of disruption.
  - stable to ballooning and external kinks without conducting walls
  - stable to n=0 vertical displacement
  - stable to neo-classical tearing modes (monotonically increasing iota)
  - large fraction of externally generated transform (>40%)

- Realizable coils.

I.B. Comparison of Boundary Shapes and Geometry of Candidate Configurations



	C10	C82	C85
A	3.43	3.43	3.48
<a>	0.41	0.41	0.40
a_{min}	0.26	0.25	0.24
(R_{min},R_{max})	1.04/1.86	1.06/1.85	1.07/1.85

I.C. Comparison of Quasi-Axisymmetry and Confinement Properties

(β~4%, I_p=200 kA, B_{edge}=1.26 T, nR/T^2~2, α=1,E_{beam}=40 keV)

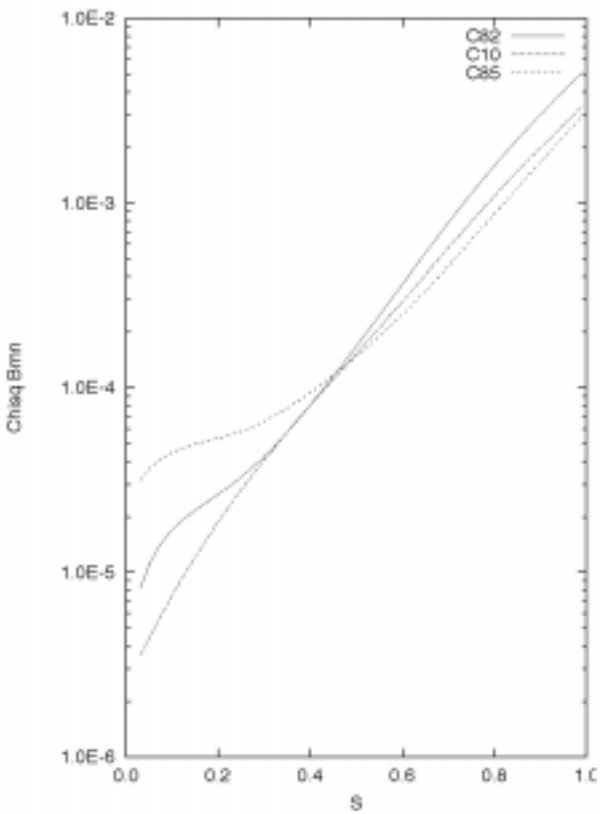
	C10	C82	C85
χ^2_{Bmn} (s=0.3)	4.1e-5	4.3e-5	6.6e-5
χ^2_{Bmn} (s=0.5)	1.6e-4	1.8e-4	1.6e-4
$\int$ wdθ (s=0.3)	3.9e-3	4.8e-3	6.6e-3
$\int$ wdθ (s=0.5)	1.2e-2	2.0e-2	1.1e-2
τ_{Ei}^{neo} (ms) (a)	20	20	16
H → H^+ energy loss fraction (b)	0.29	0.31	0.32

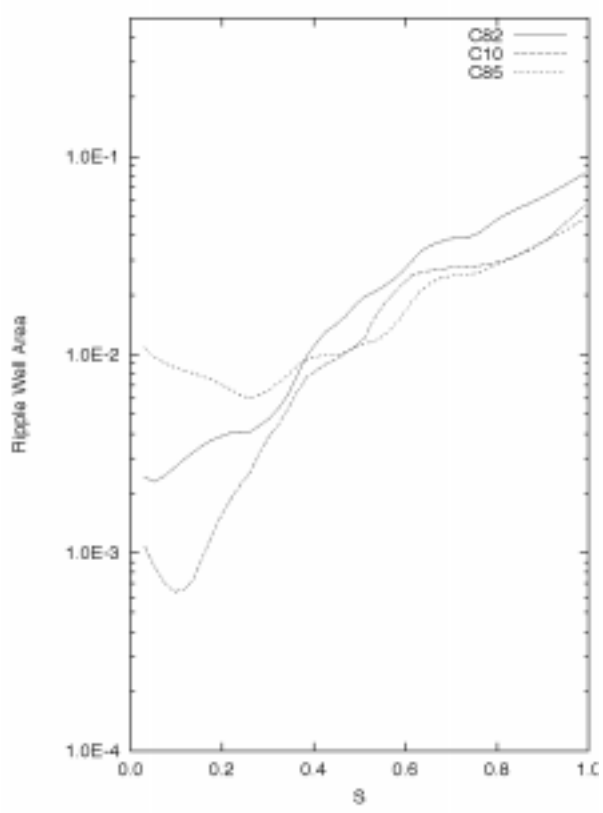
(a) Calculated by H. Mynick
(b) Calculated by D. Spong

I.C. (cont)

Comparison of Transport Objective Functions in Optimization

C82 has larger ripples for s>0.4, but its ion confinement properties are similar to those of C10, and are better than C85.





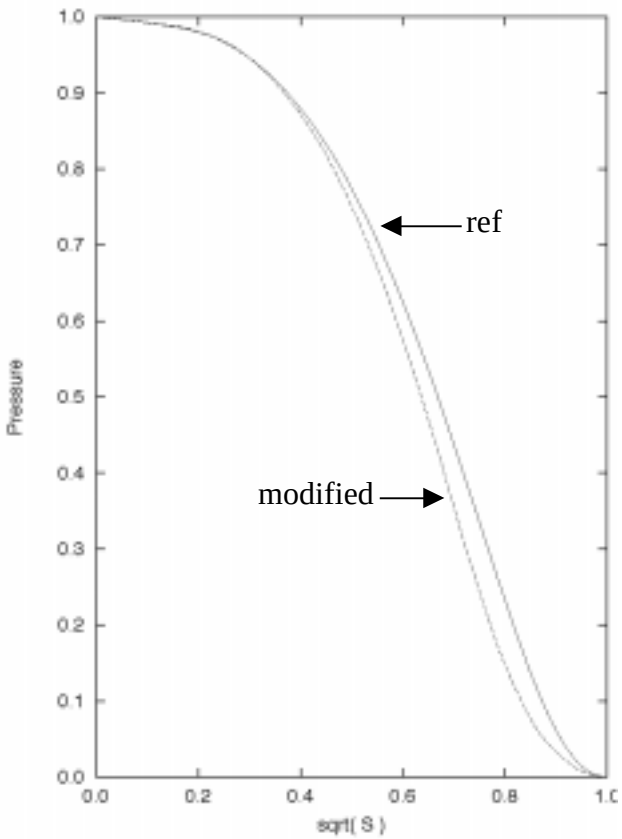
I.D. Comparison of Equilibrium and MHD Stability Properties

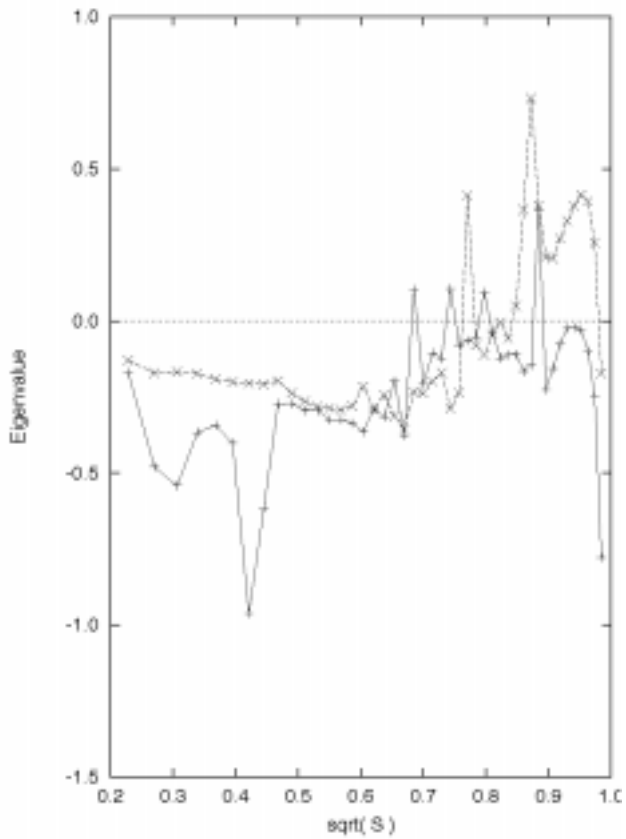
(β~4%, I_p=200 kA, Aries-RS pressure and current profiles)

	C10	C82	C85
External Kink, λ	1.4e-3	6.0e-5	1.4e-4
Mercier Quality, Fraction of Unstable Surfaces	0.27	0.25	0.17
Ballooning Quality, Fraction of Unstable Surfaces	0.25	0.20	0.15
ι_{ext}/ι_{tot}	0.158/0.352	0.157/0.350	0.157/0.351
	0.45	0.45	0.45

I.D. (cont)

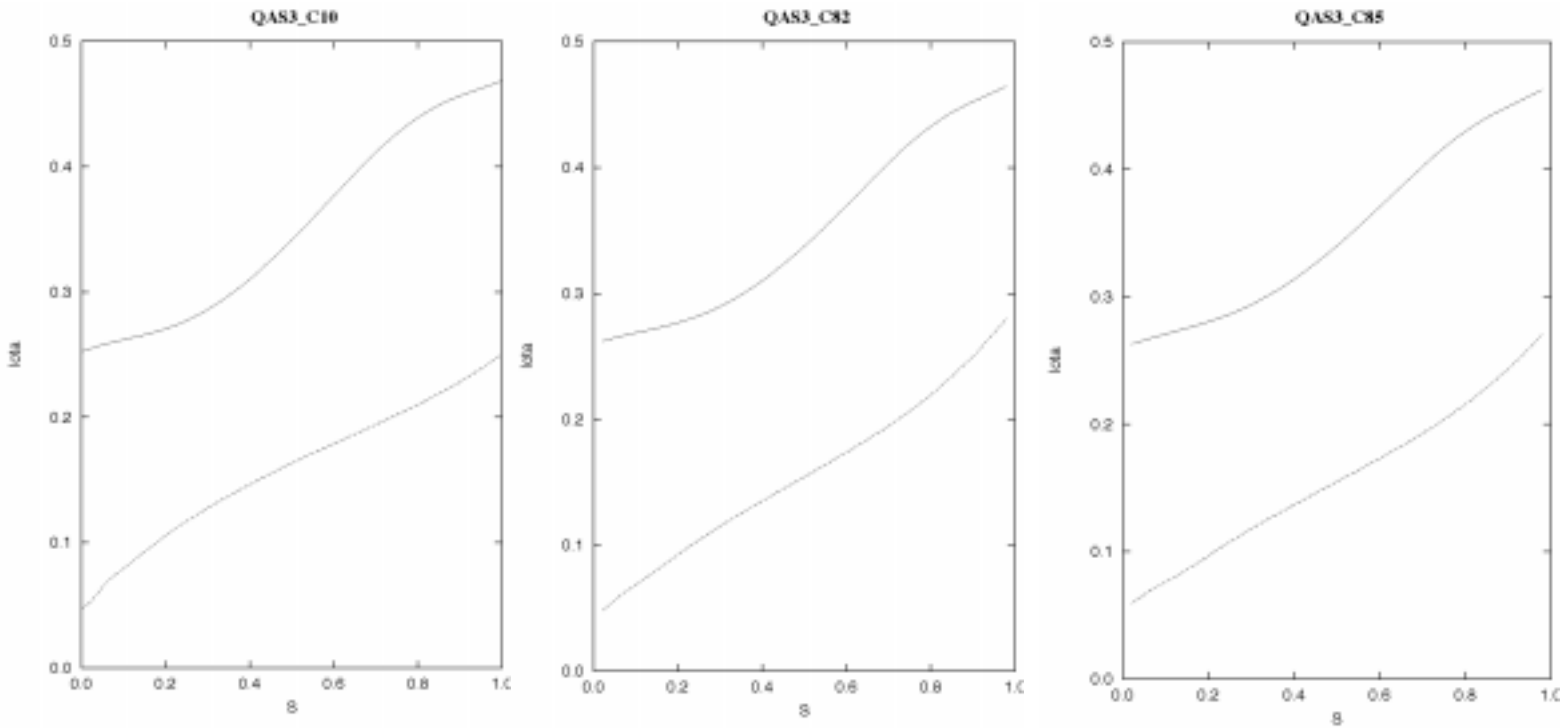
Ballooning instability in small regions maybe stabilized by local pressure flattening as shown below for C10.





I.D. (cont)

All configurations have monotonically increasing iota profile throughout entire plasma. $0.2 < \iota_{ext}/\iota < 0.6$



I.E. Comparison of Coil Complexity Measures

(Current Sheet Solution, Coil Surface @ 18 cm Uniform Offset)

	C10	C82	C85
<M>	2.91	3.09	3.01
Jmax/Ipol	0.84	1.02	0.82
Minimum Curvature Radius of Current Lines	3.77e-3	1.07e-3	2.64e-3
Maximum B Error On Last Plasma Surface	0.024	0.033	0.036

II. This or That? Which Bedfellow to Choose?

(Selection of Reference Configuration for Engineering and Costing Studies)

- C10 does not have acceptable kink stability properties at the reference Ip and β. The modes may be stabilized by modifying the pressure/current profiles or by reducing the plasma current, but these will lead to
  - poorer QA,
  - lower rotational transform in core region,
  - large current near edge,
  - Mercier worse near edge.
- Efforts to re-optimize C10 with biased profiles and/or reduced currents have not been successful.

This or That (cont)

- We've shown that
  - Both C85 and C82 are significantly more stable than C10.
  - Confinement properties of C82 ~ C10.
  - Coil complexity measures of C85 ~ C10, confinement properties marginally worse.

  ⇒ Time has come that we part with C10.

- The critical question of selection between C82 and C85 (if we have to) is then:

  - How much does the high Jmax of C82 on the current sheet prevent us designing a set of "good" coils?

  > Note that it is possible to find a configuration whose properties lie between C82 and C85 (e.g. C89).

III. Around and Around, The Loop Is Not Closed

(Issues to be studied for C82/C85)

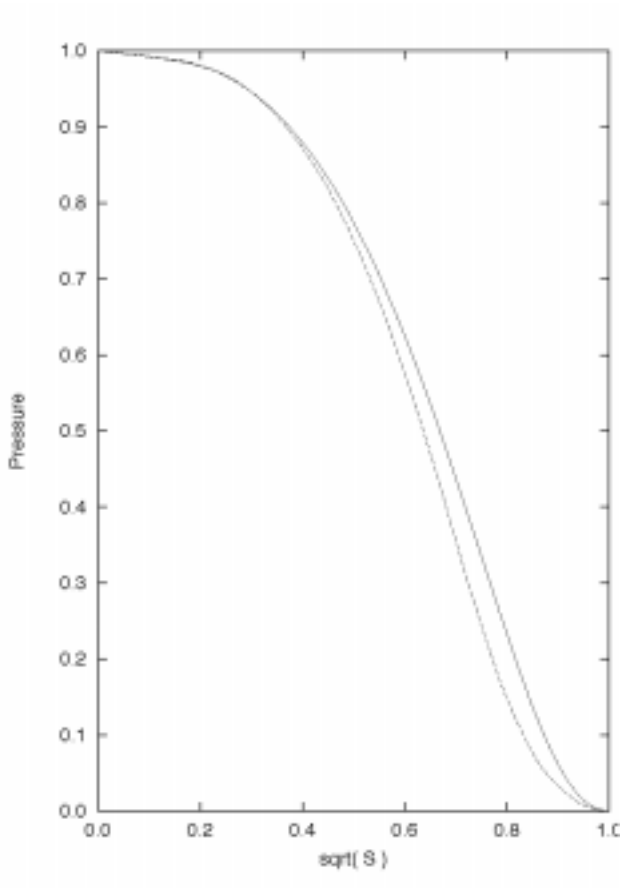
- The ballooning unstable region (with respect to the reference profiles) maybe stabilized by reducing local pressure gradient. We need to quantify the effects on
  - consistency with current profile assumed,
  - QA and confinement properties.

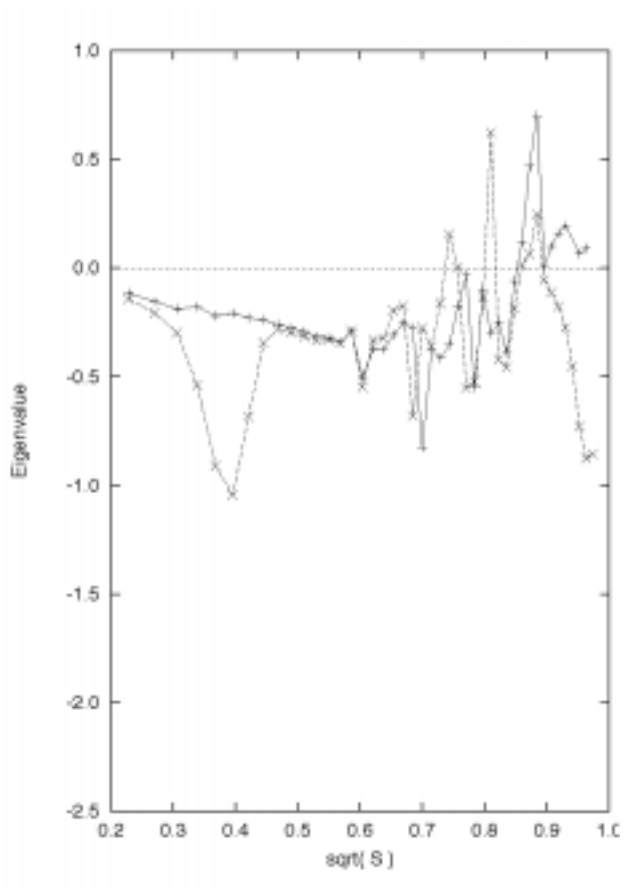
However;

  - We have encountered numerical difficulties in ballooning calculations, particularly for C82. Convergence studies will be needed.

III. Ballooning (cont)

Ballooning instability in small regions maybe stabilized with local pressure flattening as shown below for C82, but there are questions about numerical stability in the calculation.





Around and Around (cont)

- Equilibrium flux surface quality, particularly near the 3/7 resonance. Also, the effects on QA and MHD stability due to pressure flattening in islands.

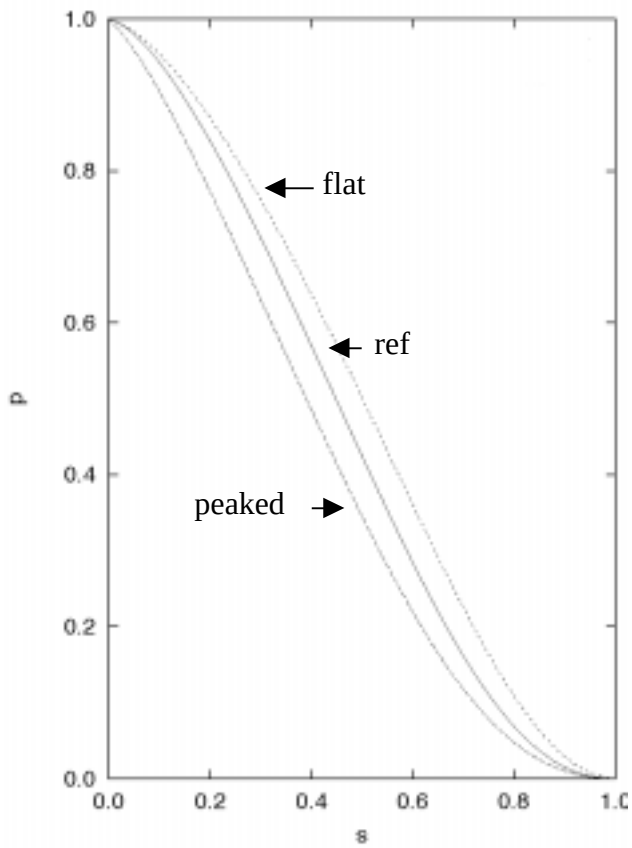
- Effects of uncertainties in bootstrap currents, pressure and current profiles on
  - Stability
  - QA and transport

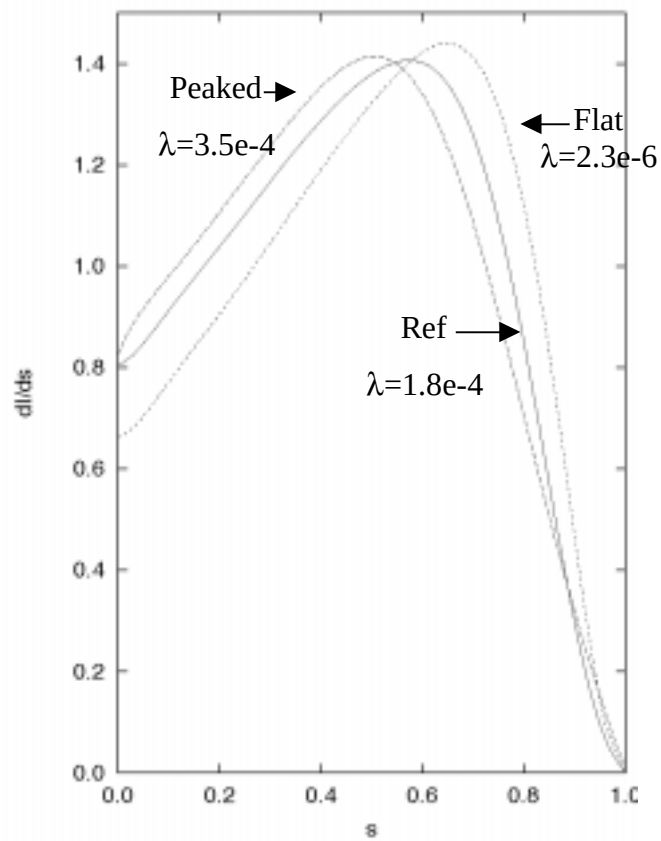
  Need to find out
  - Expected range of Ip (bootstrap or externally driven),
  - Achievable n, T profiles.

- Reconstructability.

Uncertainties (cont)

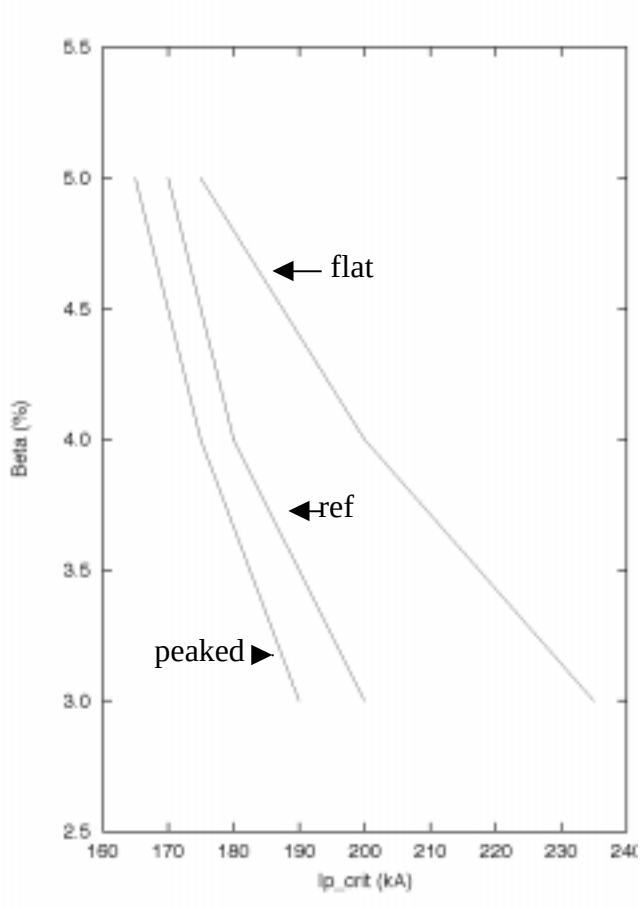
C85 may be stabilized with respect to the external kink modes by a flat pressure profile, and de-stabilized by a peaked profile at 4% β and 200 kA current.





C85 kink stability (cont.)

A potential operating window may be derived for kink stability. But QA and ballooning?



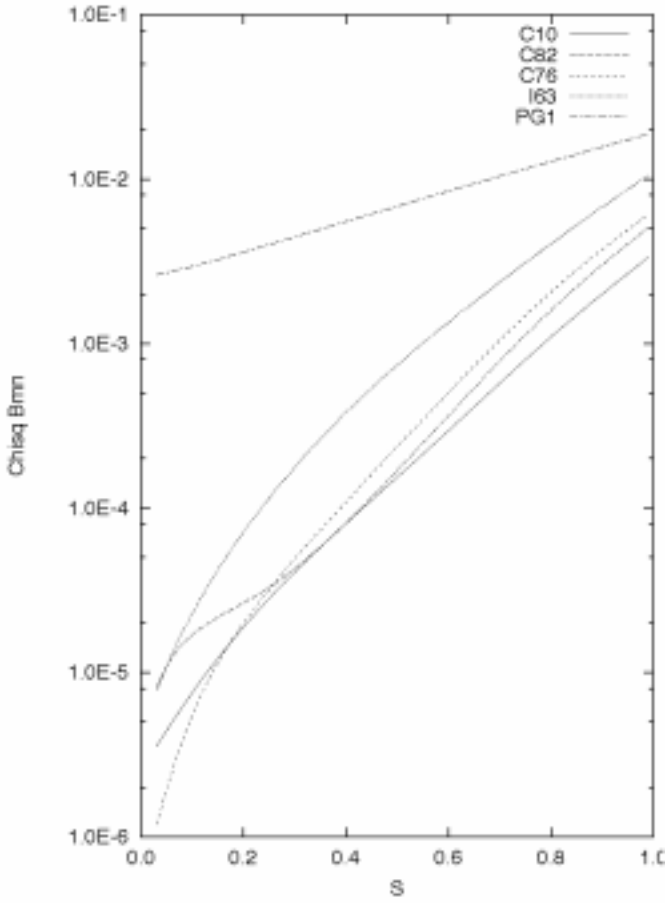
IV. Going, Going, It's Not Gone, Yet!

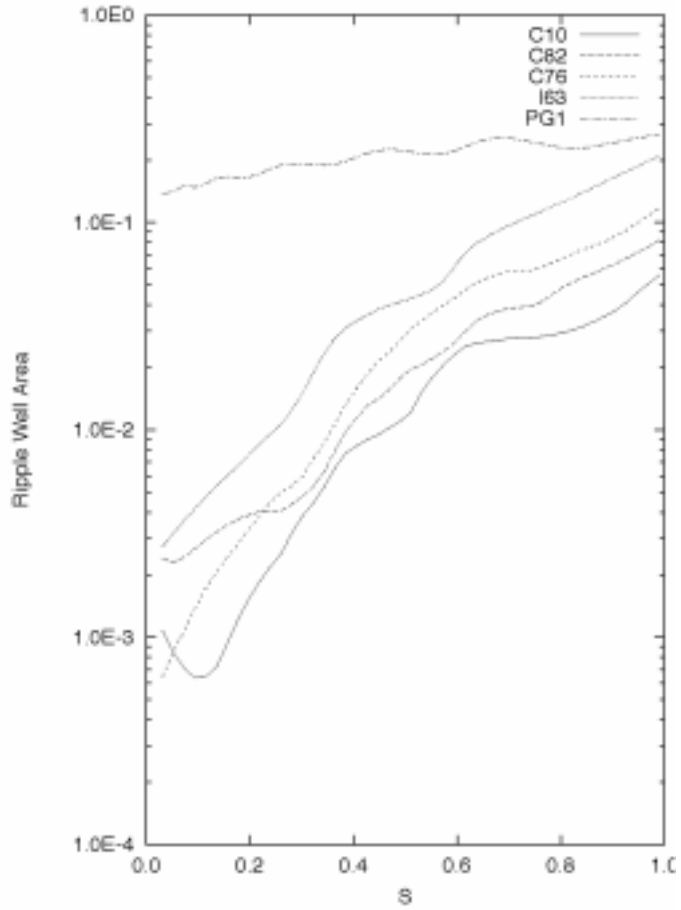
(Search for a Better Configuration)

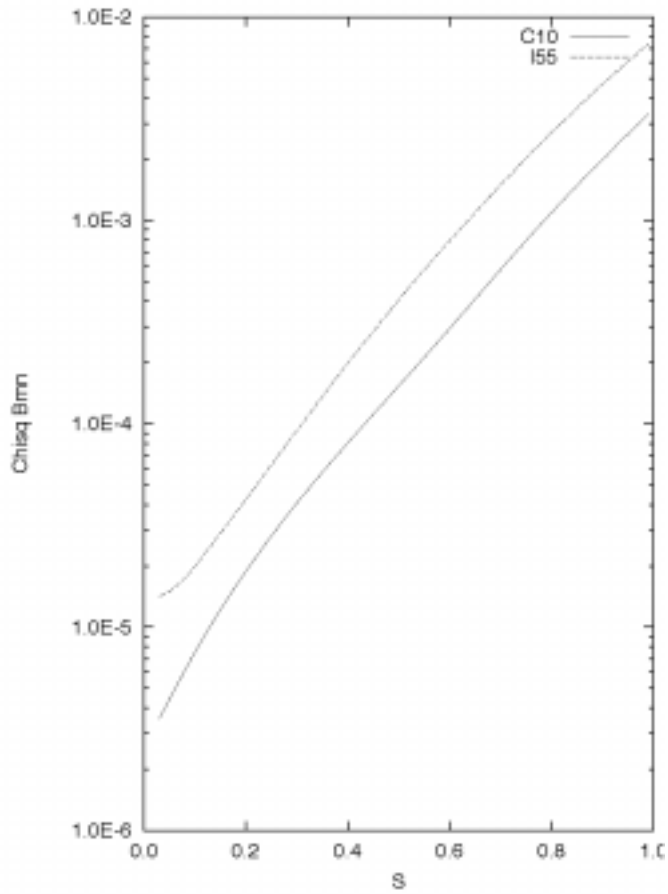
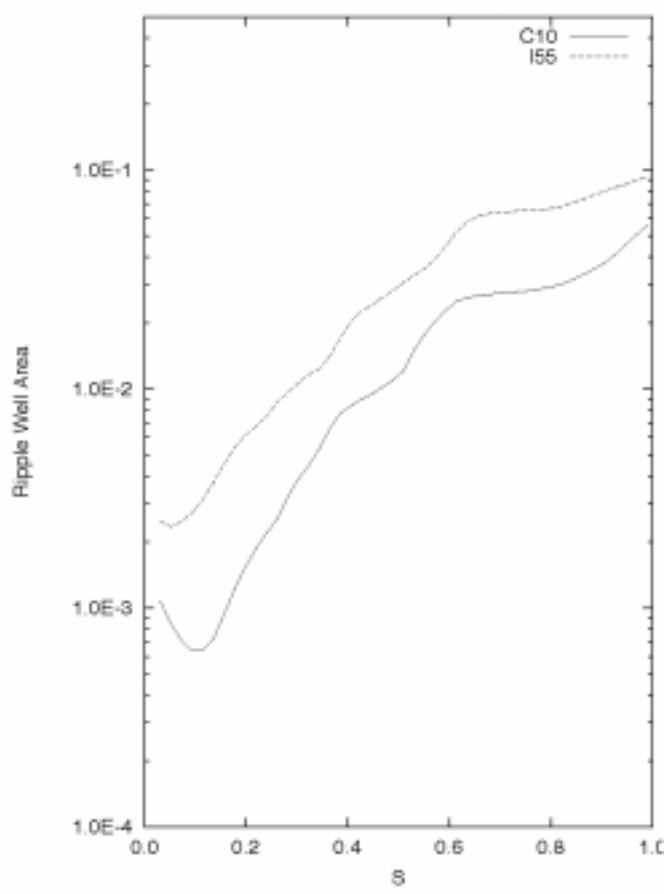
- Many aspects of the present configurations do not or only marginally meet design goals. We'll have to improve upon current configurations and search for new configurations.
  - Particularly, minimizing energy loss of fast ions (NBI and α).
  - Need a better measure as the objective function in optimization.
  - A simplified version of Orbit code serves as a start.
- It may be worth to take a new look of different regions in the configuration space.
  - Configurations with good vacuum magnetic properties (high iota, deep well),
  - Configurations with different constraints (iota, shape, profiles, decoupled P & J),
  - Robustness of configuration: zero β and Ip to full β and Ip.

Improving objective function (cont)

These configurations have significantly different transport measures used in the optimization, yet they all have similar energy loss rate for fast ions near 1 T (although they may have different B dependence).





Improving objective function (cont)

These configurations have significantly different transport measures used in the optimization, yet they all have similar thermal ion transport at 1 T.