COIL FLEXIBILITY RESULTS

N. Pomphrey NCSX Project Mtg, Dec 19-20, 2000.

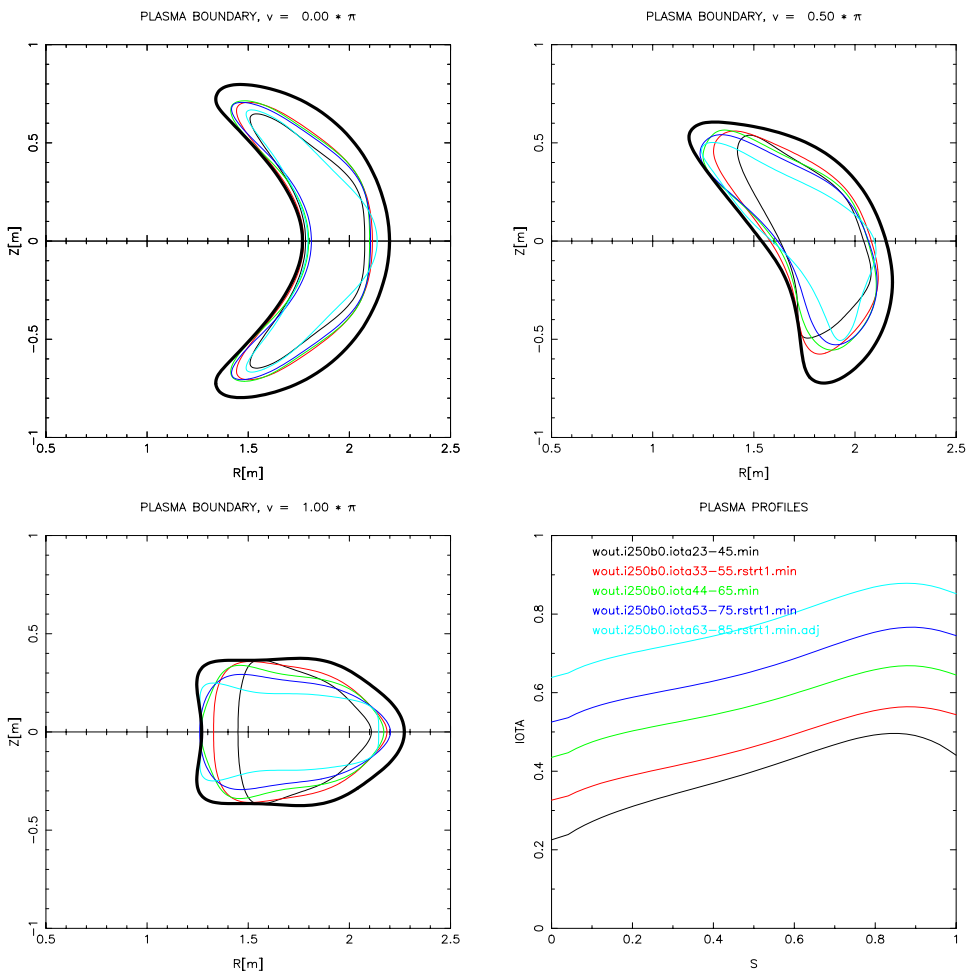
1. **Good Iota Scan Flexibility using 10/17/00 Modulars**

2. **Reduced Flexibility w/o Auxiliary TF**

3. **Variation of $n = 0$ shape for vertical mode experiments**

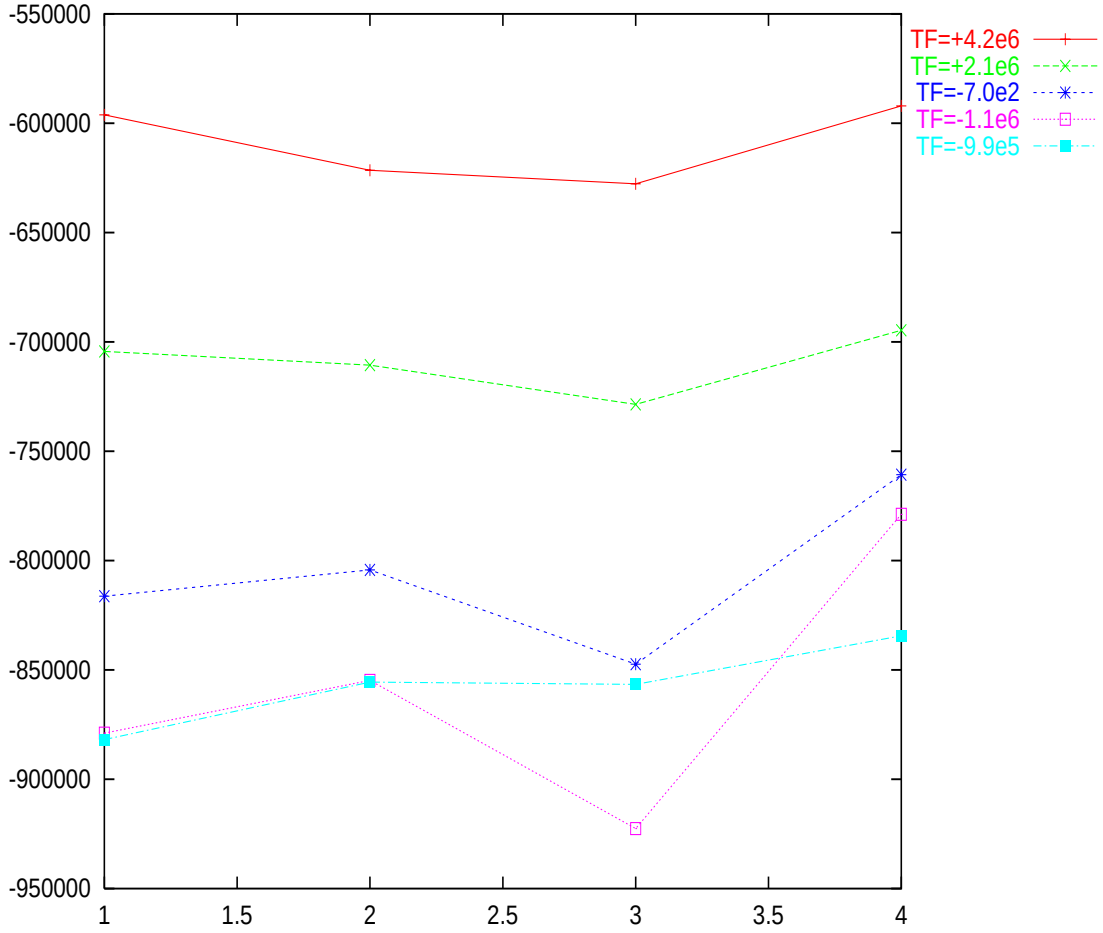
1. Iota Scan Experiments for PVR

- **Various S2 states ($I_p = -250kA, \beta = 0$) have been generated to show the ability of the NCSX coil system to produce configurations with different iota profiles.**
- **The Modular 10/17/00 coil set is used, together with an auxiliary TF set (modeled with a single filament on the machine center-line), and the 4 lowest multipolar shaping fields.**
- **The transport is optimized, by minimizing χ^2_{Bmn}. No attempt is made to stabilize the kink or ballooning modes since the goal here is to explore coil flexibility, not plasma performance.**
- **An initial S2 state was generated by the following procedure:**
  - **Start with the nominal LI383 - S3 configuration (stable to kink and ballooning modes at $\beta = 4\%$, with $\chi^2_{Bmn} =$ (cf fixed boundary $\chi^2_{Bmn} = 0.015$)) and ramp β to zero maintaining stability. Turn off kink and ballooning and re-optimize: $\chi^2_{Bmn} \rightarrow 0.0241$**
- **Then program various target values for $\iota(0), \iota(1)$.**



Iota-scan, fixed shear, different $\iota(1)$

$\chi^2_{Bmn} = 0.0098, 0.0183, 0.0241, 0.0239, 0.0292$ (bottom $\rightarrow$ top). $\iota(0) \approx 0.44 \rightarrow \iota(1) = 0.65$ is nominal S2.

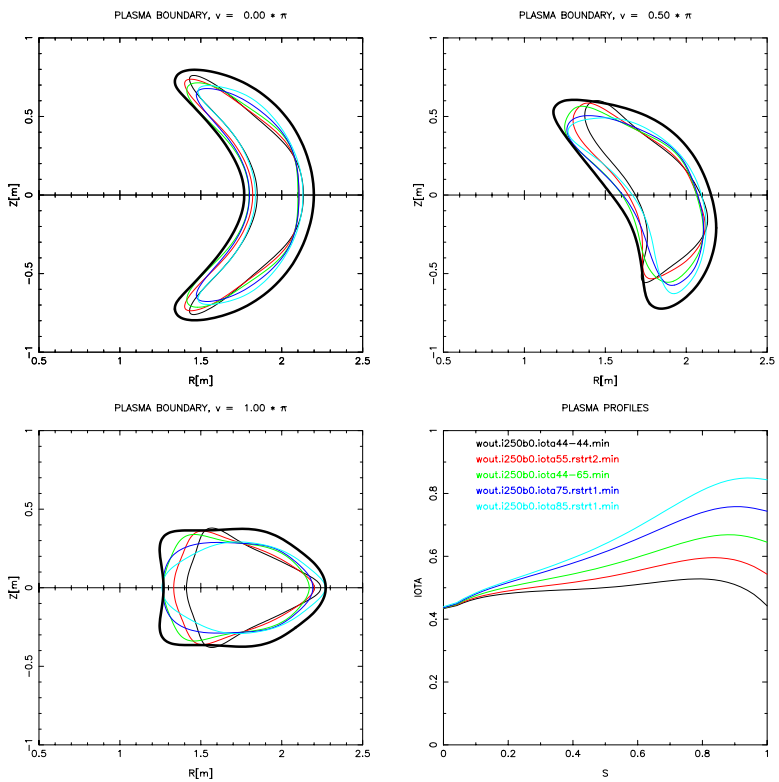


Iota-scan modular currents.

BEWARE OF INCONSISTENCY OF COLOR SCHEME WHEN COMPARING WITH PREVIOUS FIGURE! (DARK BLUE IS NOMINAL S2 HERE).

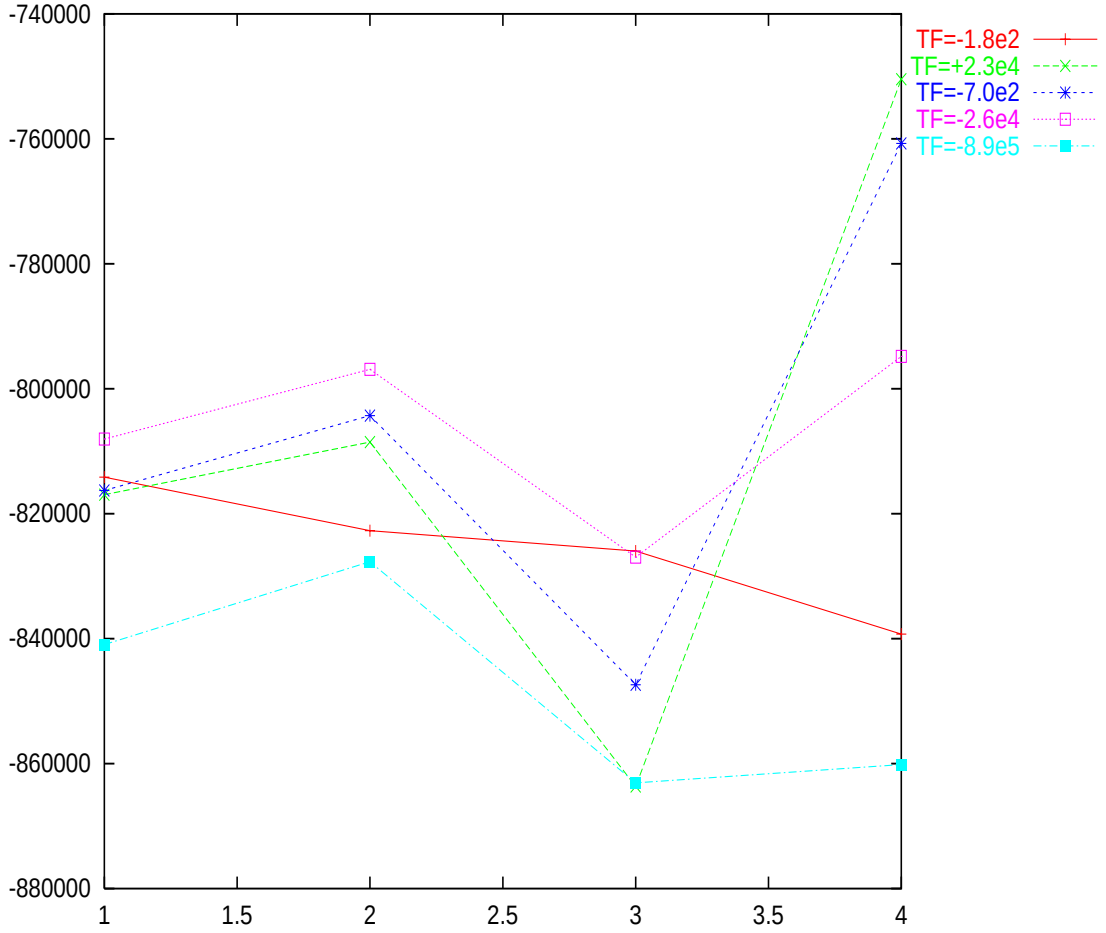
ID	i250b0.iota23-45.min	i250b0.iota33-55.rstrt1.min	i250b0.iota44-65.min	i250b0.iota53-75.rstrt1.min	i250b0.iota63-85.rstrt1.min.adj
Ip[A]	-2.50E+05	-2.50E+05	-2.50E+05	-2.50E+05	-2.50E+05
R-BTOR[m-T]	3.41	3.41	3.42	3.42	3.42
Aspect	5.36	4.52	4.57	4.77	5.31
AuxTF[A]	4.223669E+06	2.096780E+06	-7.002726E+02	-1.141802E+06	-9.871757E+05
Mod1[A]	-5.961930E+05	-7.043150E+05	-8.162669E+05	-8.788779E+05	-8.818918E+05
Mod2[A]	-6.215231E+05	-7.106664E+05	-8.042904E+05	-8.547718E+05	-8.556132E+05
Mod3[A]	-6.276630E+05	-7.285947E+05	-8.473759E+05	-9.225858E+05	-8.565930E+05
Mod4[A]	-5.920597E+05	-6.946693E+05	-7.607241E+05	-7.788138E+05	-8.344015E+05
Dipole	1.012981E+00	7.704179E-01	6.098537E-01	5.565805E-01	2.168517E-01
Quad	-2.356146E+00	-3.209421E-01	5.096881E-01	1.435033E+00	4.331023E+00
Hex	1.467667E+01	6.237794E+00	4.308285E+00	4.786255E+00	4.043787E+00
Oct	-3.158079E+01	-1.210093E+01	-2.222852E+01	-2.432329E+01	2.966676E+00
Chisq(Bmn)	0.0098	0.0183	0.0241	0.0239	0.0292
lambda-Kink	-7.800E-03	-6.468E-03	-5.229E-03	-8.054E-03	-6.395E-03
Chisq(Ball)	-	-	-	-	-
VV-dist[m]	-4.26E-03	-1.49E-03	-3.97E-04	-4.48E-03	3.45E-03
iota(0)	0.2254	0.3265	0.4354	0.5253	0.6390
iota-min	0.2254(s=0)	0.3265(s=0)	0.4354(s=0)	0.5253(s=0)	0.6390(s=0)
iota-max	0.4962(s=0.833)	0.5641(s=0.875)	0.6687(s=0.875)	0.7667(s=0.896)	0.8788(s=0.875)
iota(1)	0.4407	0.5438	0.6451	0.7453	0.8520
vac-iota(0)	0.2772	0.3749	0.4980	0.5978	0.7088
vac-iota-min	0.1957(s=1)	0.3401(s=0.771)	0.4452(s=0.917)	0.5323(s=0.771)	0.6199(s=0.771)
vac-iota-max	0.2772(s=0)	0.3749(s=0)	0.4985(s=0.0208)	0.5978(s=0)	0.7088(s=0)
vac-iota(1)	0.1957	0.3446	0.4462	0.5393	0.6255

Table 1:SUMMARY DATA FOR IOTA-SCAN.M101700.I250B0



Shear-scan

$\chi^2_{Bmn} = 0.0419, 0.0296, 0.0241, 0.0156, 0.0223$ (bottom $\rightarrow$ top). $\iota(0) \approx 0.44 \rightarrow \iota(1) = 0.65$ is nominal S2.



Shear-scan modular currents.

BEWARE OF INCONSISTENCY OF COLOR SCHEME WHEN COMPARING WITH PREVIOUS FIGURE! (DARK BLUE IS NOMINAL S2 HERE).

ID	i250b0.iota44-44.min	i250b0.iota55.rstrt2.min	i250b0.iota44-65.min	i250b0.iota75.rstrt1.min	i250b0.iota85.rstrt1.min
Ip[A]	-2.50E+05	-2.50E+05	-2.50E+05	-2.50E+05	-2.50E+05
R-BTOR[m-T]	3.46	3.44	3.42	3.39	3.38
Aspect	5.23	4.87	4.57	4.72	4.88
AuxTF[A]	-1.802621E+02	2.339093E+04	-7.002726E+02	-2.638665E+04	-8.877666E+05
Mod1[A]	-8.141528E+05	-8.169550E+05	-8.162669E+05	-8.080444E+05	-8.409386E+05
Mod2[A]	-8.227187E+05	-8.085300E+05	-8.042904E+05	-7.968833E+05	-8.276680E+05
Mod3[A]	-8.259888E+05	-8.636471E+05	-8.473759E+05	-8.269638E+05	-8.630907E+05
Mod4[A]	-8.392694E+05	-7.504486E+05	-7.607241E+05	-7.948170E+05	-8.601473E+05
Dipole	1.434189E+00	9.580407E-01	6.098537E-01	6.312161E-01	1.032274E+00
Quad	-2.464143E+00	-6.018683E-01	5.096881E-01	6.409619E-01	-5.159341E-01
Hex	2.303366E+01	1.382877E+01	4.308285E+00	-1.182445E-01	2.180127E+00
Oct	-3.045875E+01	-3.100249E+01	-2.222852E+01	-6.627956E+00	-4.777709E-01
Chisq(Bmn)	0.0419	0.0296	0.0241	0.0156	0.0223
lambda-Kink	-5.686E-03	-7.446E-03	-5.229E-03	-5.968E-03	-2.467E-03
Chisq(Ball)	-	-	-	-	-
VV-dist[m]	-9.25E-03	7.56E-05	-3.97E-04	-4.22E-04	-3.38E-03
iota(0)	0.4337	0.4356	0.4354	0.4363	0.4397
iota-min	0.4337(s=0)	0.4356(s=0)	0.4354(s=0)	0.4363(s=0)	0.4397(s=0)
iota-max	0.5282(s=0.792)	0.5958(s=0.833)	0.6687(s=0.875)	0.7582(s=0.896)	0.8494(s=0.938)
iota(1)	0.4422	0.5431	0.6451	0.7436	0.8437
vac-iota(0)	0.2714	0.5065	0.4980	0.5092	0.5262
vac-iota-min	0.1644(s=1)	0.3402(s=1)	0.4452(s=0.917)	0.4979(s=0.5)	0.5201(s=0.125)
vac-iota-max	0.2714(s=0)	0.5065(s=0)	0.4985(s=0.0208)	0.5283(s=1)	0.6313(s=1)
vac-iota(1)	0.1644	0.3402	0.4462	0.5283	0.6313

Table 2: SUMMARY DATA FOR SHEAR-SCAN.M101700.I250B0

2. Reduced Flexibility w/o Auxiliary TF

- We (Mike Z. + self) have investigated what kind of flexibility remains if we discard the auxiliary TF set.
- Without the auxiliary TF system, we have lost 1 of the 4 degrees of freedom in our modular coil set with which to optimize the desired physics (assuming we want to fix the average TF field strength).
- We have tried to repeat some of the iota-scan runs presented in part 1, above. Mike Z. focussed on S1 plasmas; I focussed on S2 plasmas. We each found reduced capability for inducing desired changes in the iota profile. On the following page is Mike's Dec 18 Memmo (not including his spreadsheet)

"(T)he need for the TF coils for NCSX"

As part of the re-examination of NCSX requirements and systems to reduce costs, the need for the auxiliary TF windings (auxiliary to the modular coils) was questioned.

$\cdots$ a range of iota(a)-values was targeted for the S1 (vacuum) state, testing the ability of the coils to vary iota-external, and our ability to avoid $\iota = 1/2$.

What was found is that the TF coils are not required to produce an ok S3 state (to our present understanding of χ^2_{Bmn}). However, the S1 iota scan without TF was not very successful. No solutions were found for iota(a) $\gtrsim 0.57$, and in that case the minimum in the iota profile is just barely clearing 1/2 and the optimizer is starting to fail to be able to keep RBt fixed. There is a severe degredation of the quasi-symmetry as iota is varied without the TF windings, with it rising to ~ 80 times the S3 value. Also, one sees that the variation in he modular coil currents gets quite large (more than a factor of 2) in the no TF case, which may present its own problems.

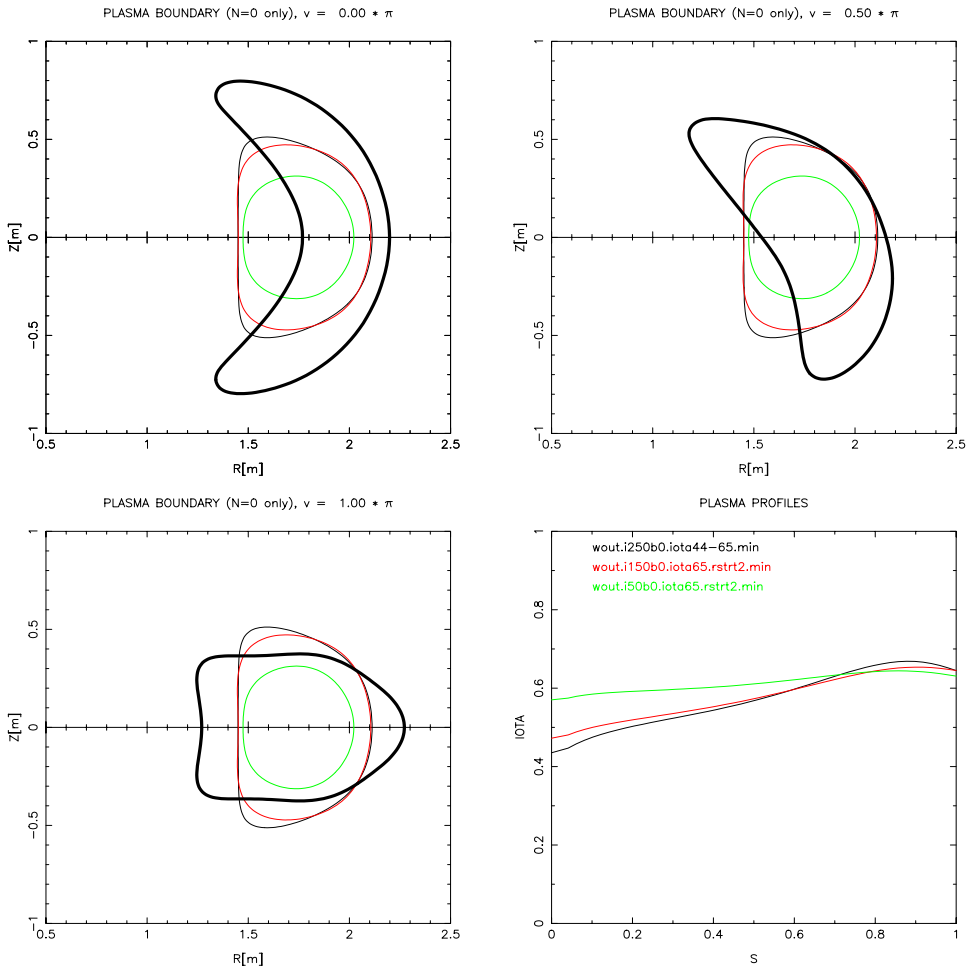
So, our conclusion is that the TF coils are necessary in order to have any flexibility in iota-external. Without them, the available iota-external range is greatly reduced (to $\sim$ +/- 0.1) and even this would be difficult.

Variation of $n = 0$ shape for vertical mode experiments

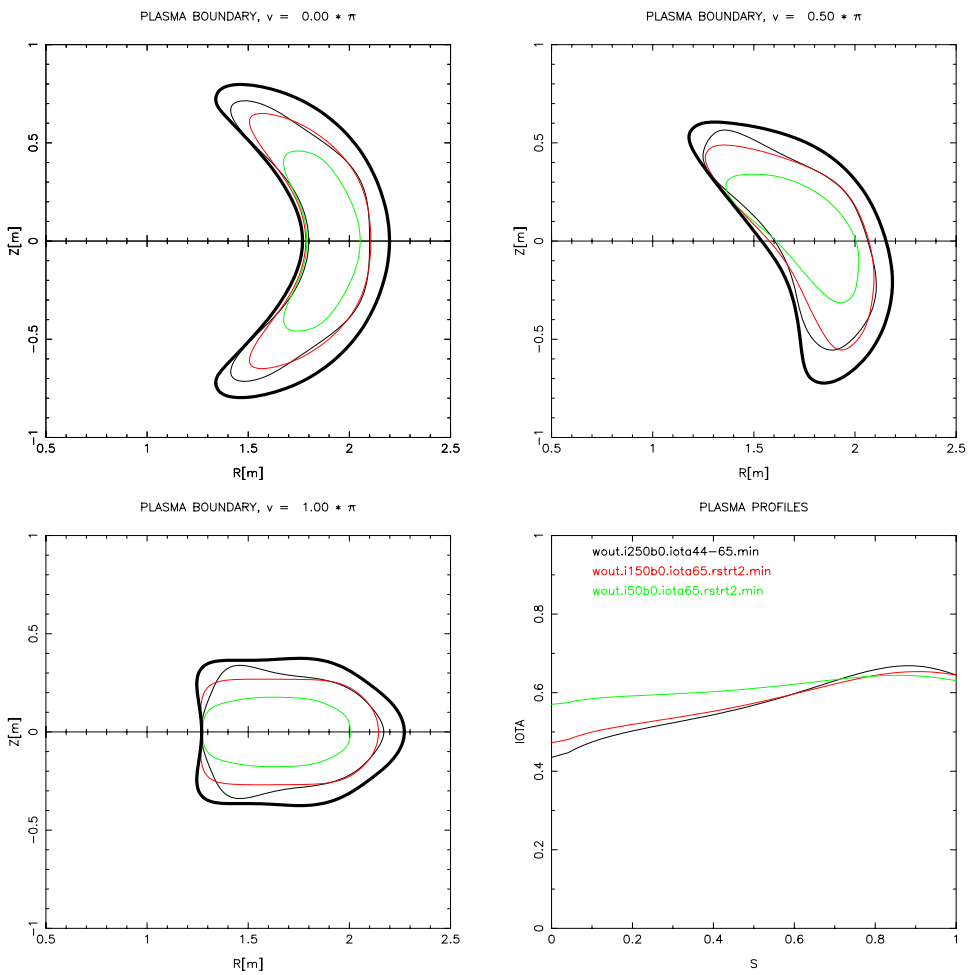
Background: Numerical calculations have shown that the $n = 0$ (vertical) family of modes is much more stable for QA stellarators than for tokamaks. Analytic calculations for large aspect ratio stellarators [Fu] have shown that sufficient external transform can stabilize the vertical mode. The predicted external rotational transform needed for stability is $\iota_{ext}/\iota = \left[< \kappa >^2 - < \kappa >\right] / \left[< \kappa >^2 + 1\right]$.
Since NCSX will have PF coils capable of varying the average elongation (and triangularity), there will be a good opportunity to explore the role of 3D shaping on the vertical instability. We can demonstrate the ability of NCSX coils to produce configurations to explore an XP such as:

- For some range of average elongation (say $< \kappa >= 1.5 - 2.5$), vary ι_{ext}/ι keeping ι_{edge} fixed. Correlate the onset of $n = 0$ modes with ι_{ext}/ι.

Preliminary results are shown below.



n=0 boundary shapes for $\beta = 0$, various I_p, holding $\iota(1)$ fixed.



Full boundary shapes (all n) for $\beta = 0$, various I_p, holding $\iota(1)$ fixed.

"Aspect ratios" shown are 4.57, 4.77, 4.78 for $\mid I_p \mid = 250$, 150, and 50 kA !!

The elongation was not TARGETED, but this is now an available option.