NCSX

AVAC Studies of a 2-Period Plasma Configuration

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September 23-25, 1998

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Goals

1. Determine if zero beta, zero current plasma configurations could be reconstructed with AVAC using a saddle+helical coil configuration

2. Determine influence of changing toroidal field

3. Determine influence of adding/subtracting vertical field (Bz=constant)

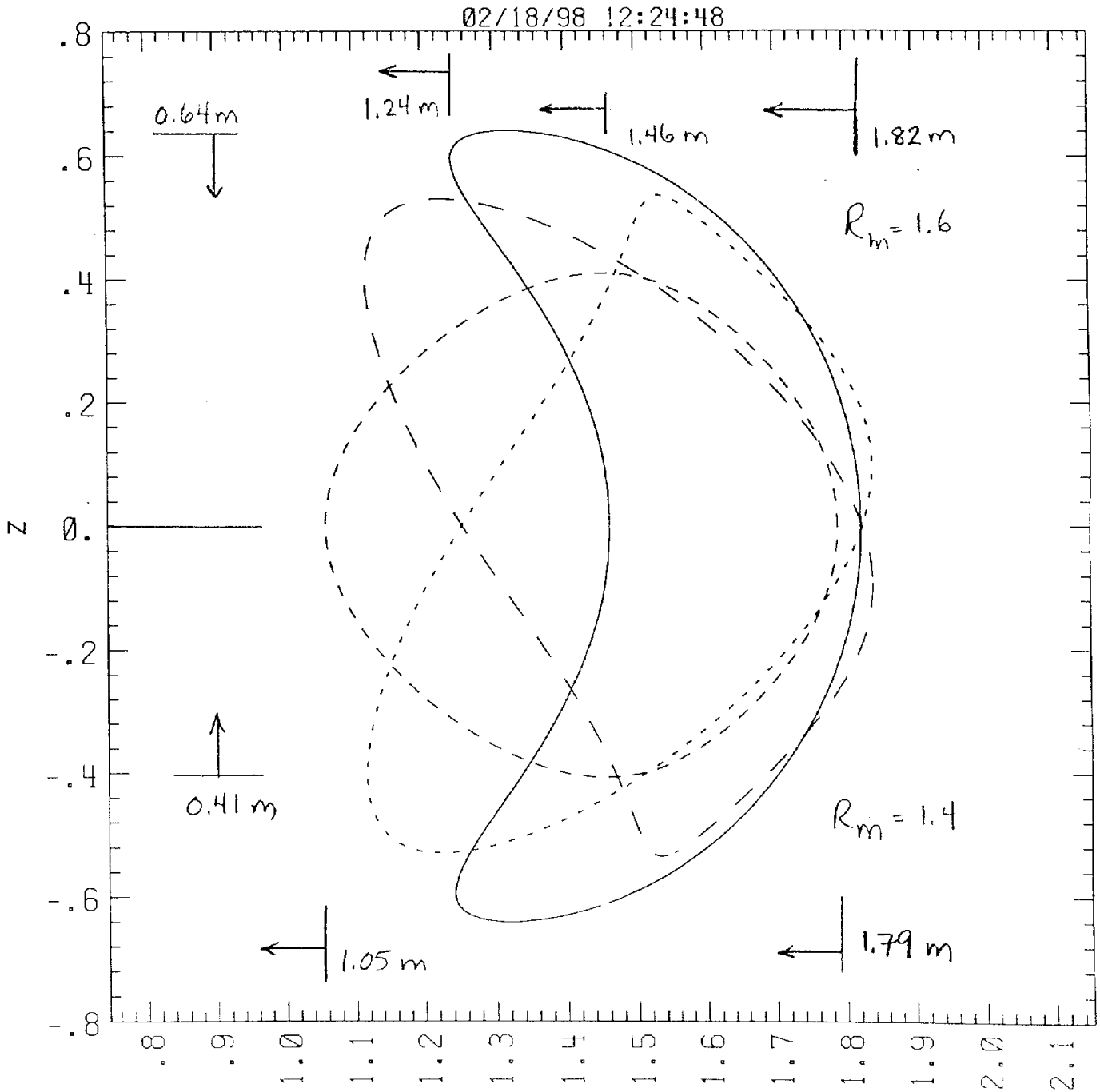
4. Determine influence of adding/subtracting a vertical field gradient (Bz=0, dBz/dr=constant)

5. Determine if 12 complex helices could be replaced with 4 simple helices

6. Determine influence of changing current in helical winding

Standard 2-Period Plasma Configuration (d9e) Used As Basis

- Plasma used for coil design studies in pre-conceptual design
- Flat, non-monotonic iota profile at full current and beta
  - 0.38 on axis, 0.47 max, 0.39 on edge
- Vacuum iota profile also flat, bowing the other way
  - 0.17 on axis, 0.139 min, 0.144 on edge
  - Very flat in outer region of plasma
- Same boundary shape used for vacuum (zero current, zero beta) studies
  - B_n set to zero

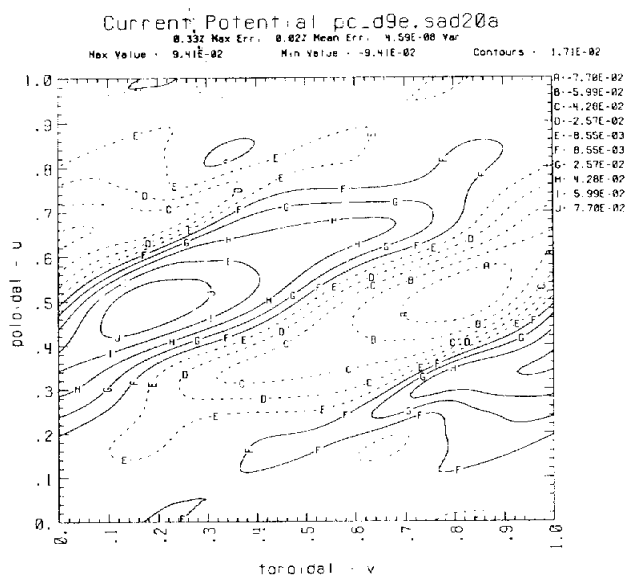

02/18/98 12:24:48
0.64m
1.24 m
1.46 m
1.82 m
$R_m = 1.6$
0.41 m
$R_m = 1.4$
1.05 m
1.79 m
Z
.8
.6
.4
.2
0.
-.2
-.4
-.6
-.8
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1

Current Potential Contour Is a Helix Along Zero Potential Contour

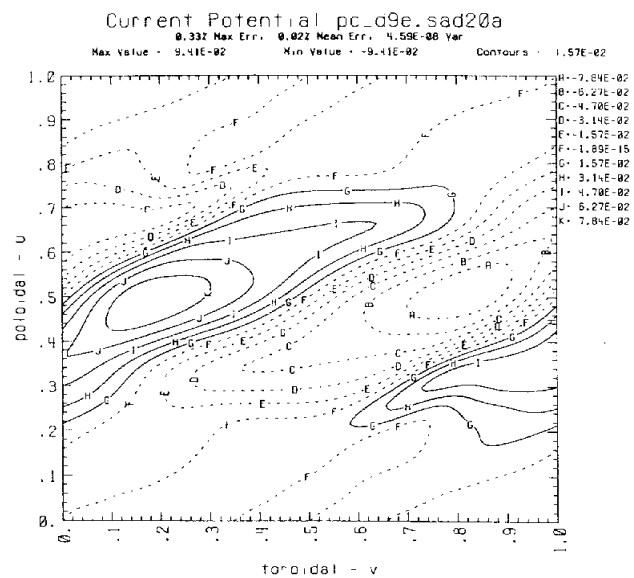
Helix has l=2, m_h=1 characteristics

Only seen with odd number of contours

10 Contours



11 Contours



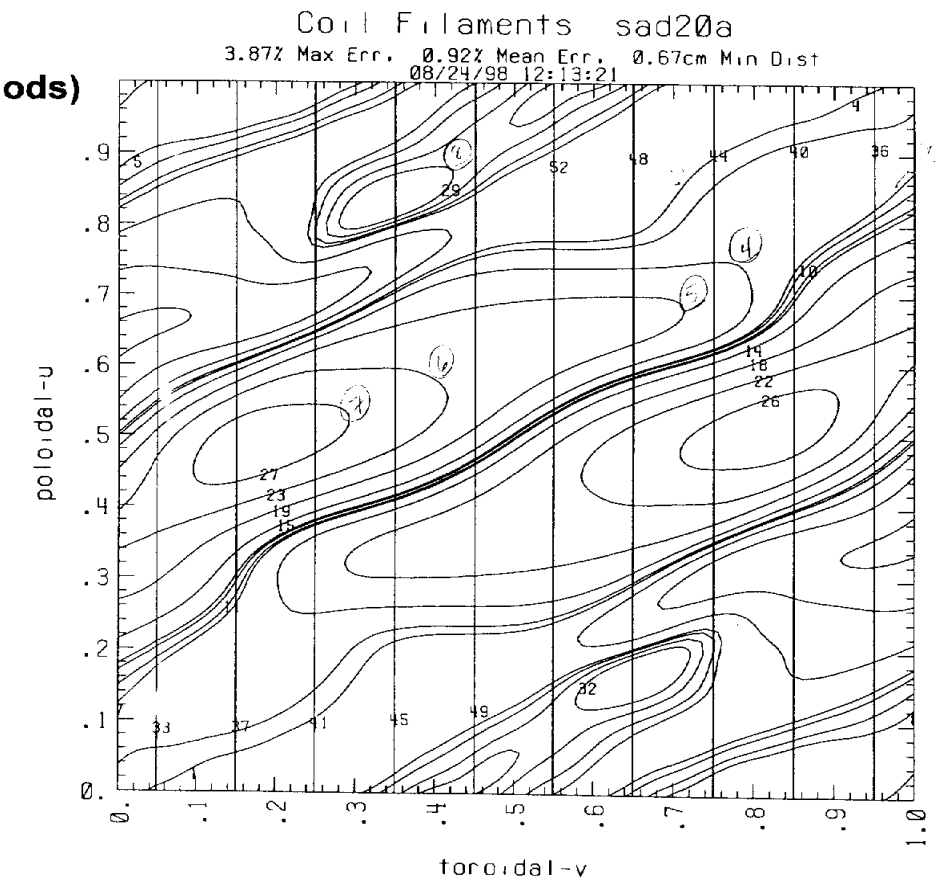
Filaments Extracted Using Contours Routine

Messy coil configuration -- 28 coils

- 4 nested saddles (x 2 per period x 2 periods)
- 3 helices (x2 per period x 2 periods)

Reasonable fit provided

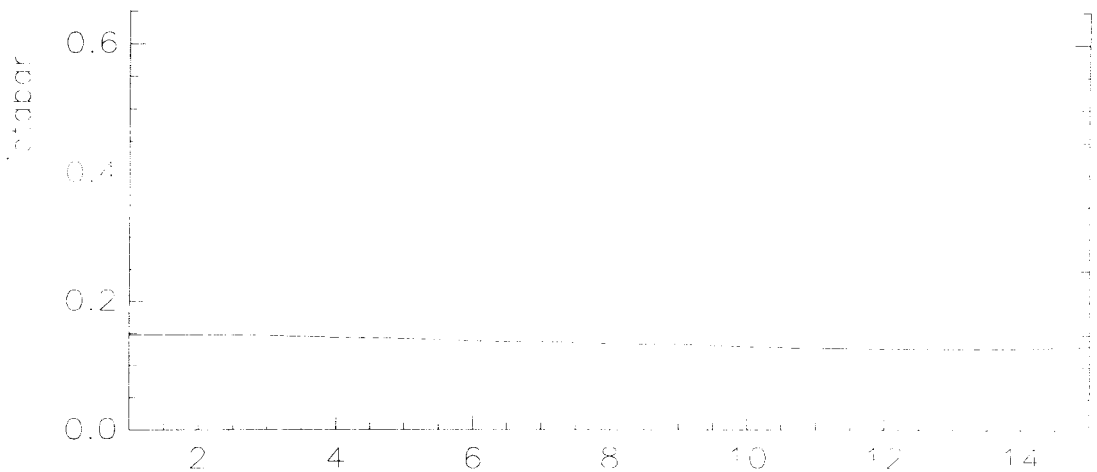
- 3.9% max error, 0.9% mean error

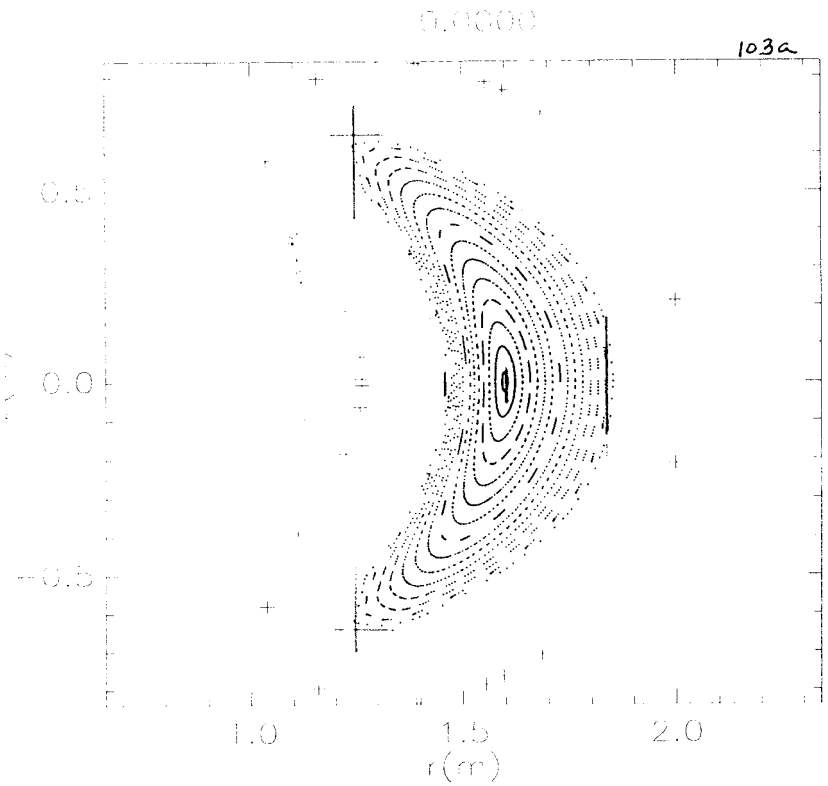


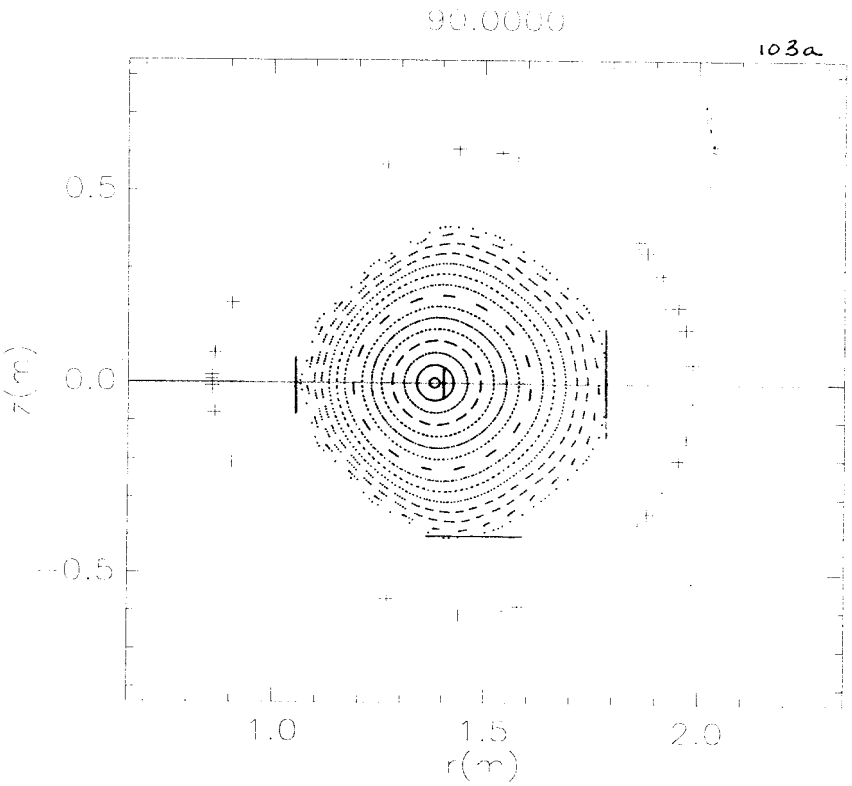
Vacuum Magnetic Surfaces Were Calculated Using AVAC

Plasma Shape and Iota Profile Reasonably Match Fixed Boundary Solution

Parameter	Fixed boundary VMEC	Free Boundary AVAC
Central Iota	0.17	0.15
Edge Iota	0.14	0.13



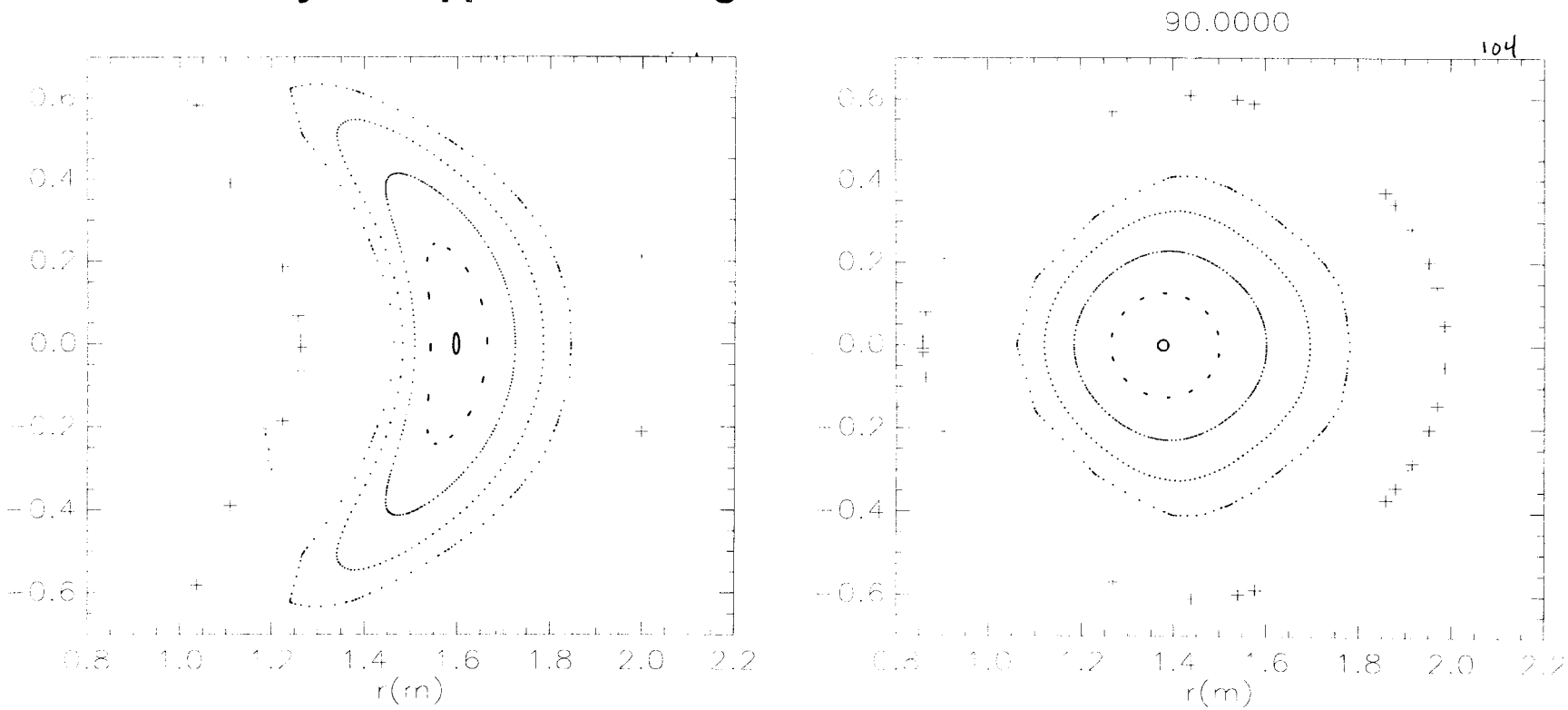

0.0000
103a
0.5
0.0
-0.5
1.0
1.5
2.0
r(m)


90.0000
103a
0.5
0.0
-0.5
z(m)
1.0
1.5
2.0
r(m)

Eliminating the Small Outboard Saddle Has No Obvious Effect

Iota profile unchanged

Plasma boundary also appears unchanged

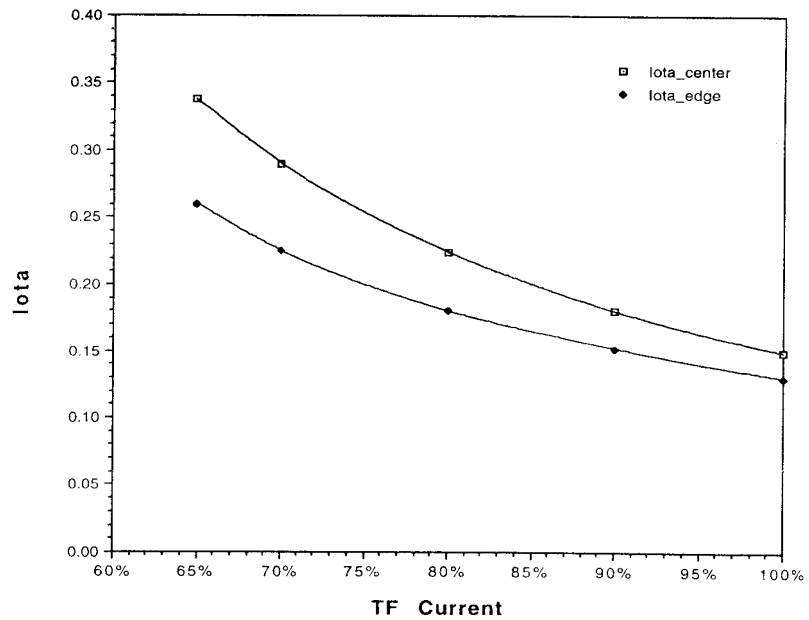


Reducing TF Current Produces Many Interesting Effects

Iota has a strong dependence on B

Edge iota changes approximately $B^{-1.6}$

Central iota changes approximately as $B^{-1.9}$



Plasma moves radially outward – R_{mag} (0°) increase from 1.6m to 1.7m as B drops from 100% to 65%

Pronounced island chains form as iota increases

Predicted island size

$$d = 4\left(\frac{b_{mn} R_0}{m B_0 \iota'}\right)^{0.5}$$

Low m, low shear ($\iota' = d\iota/dr$), and large error fields (b_{mn}) are all unfavorable

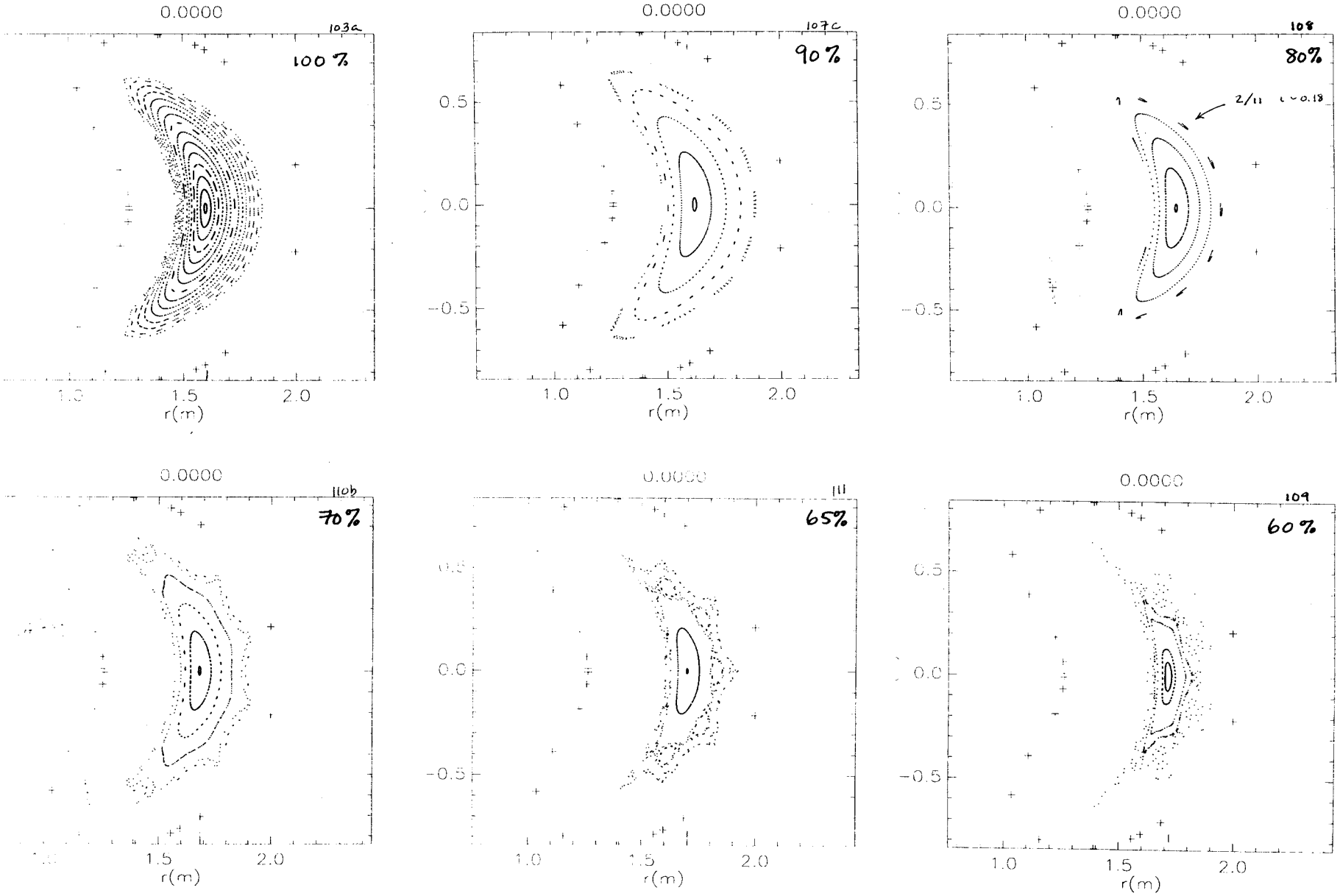
Calculated iota profiles are quite flat, particularly in outer region of plasma

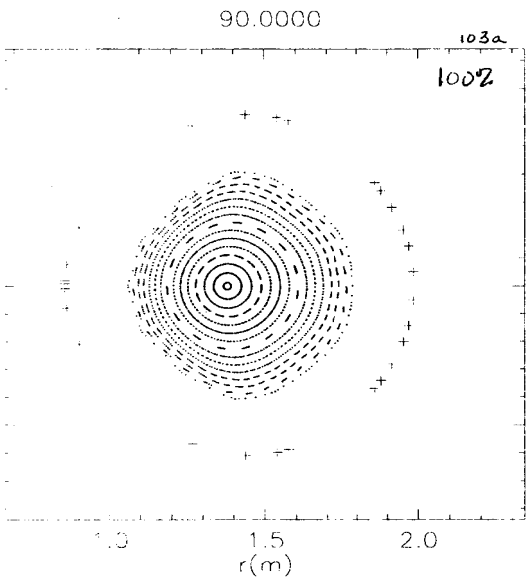
Characteristic of l=2 stellarators

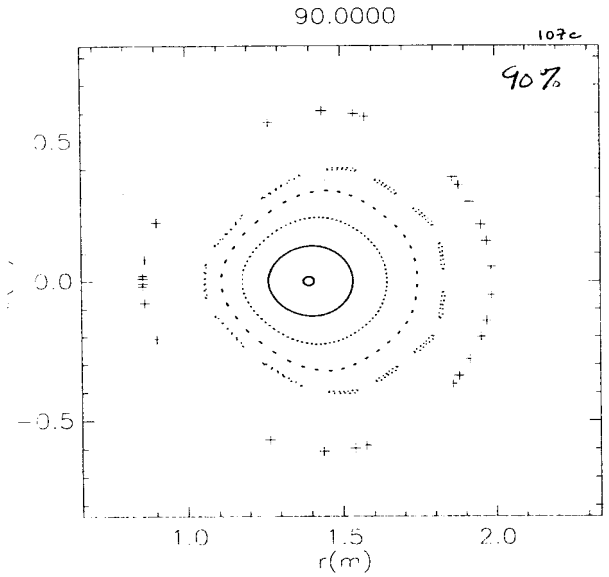
2 field periods have lower m numbers than 3 or more field periods

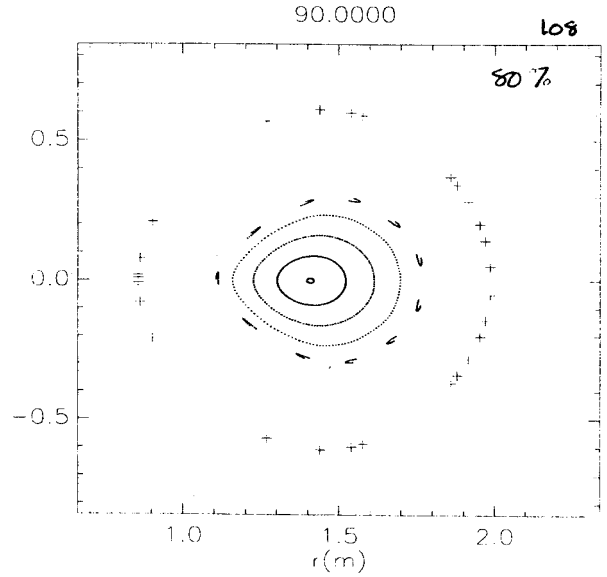
0.333 = 2/6 = 3/9 = 4/12

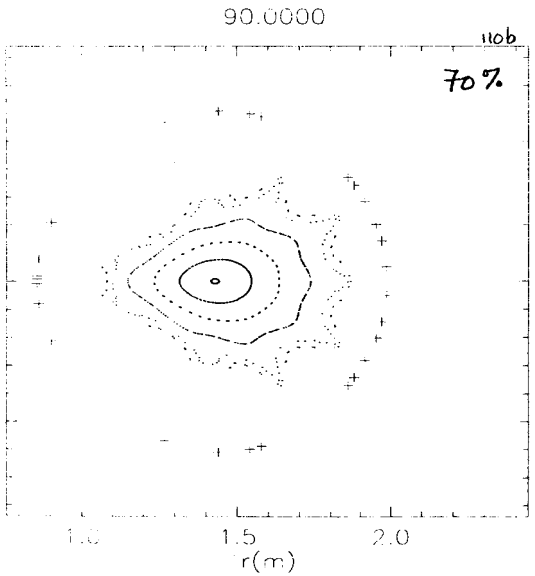
Islands Are Seen For Virtually Every Resonance

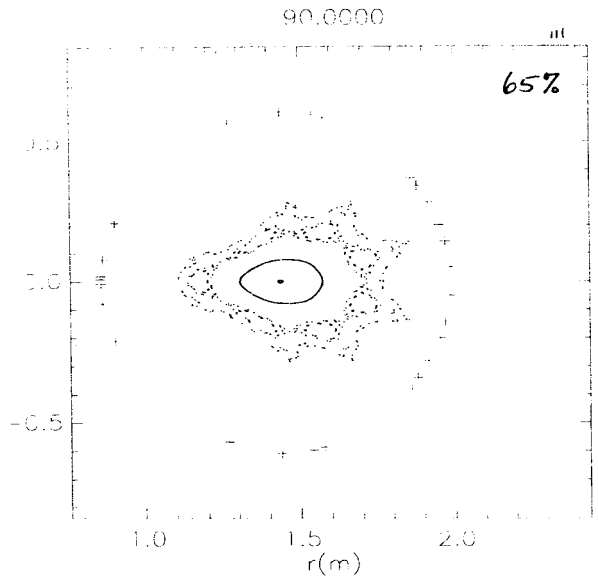

0.0000
103a
100 %
0.5
0.0
−0.5
1.0
1.5
2.0
r(m)
0.0000
107c
90 %
0.5
0.0
−0.5
1.0
1.5
2.0
r(m)
0.0000
108
80%
2/11
0.5
0.0
−0.5
1.0
1.5
2.0
r(m)
0.0000
110b
70%
1.5
2.0
r(m)
0.0000
111
65%
0.0
−0.5
1.0
1.5
2.0
r(m)
0.0000
109
60 %
0.5
0.0
−0.5
1.0
1.5
2.0
r(m)

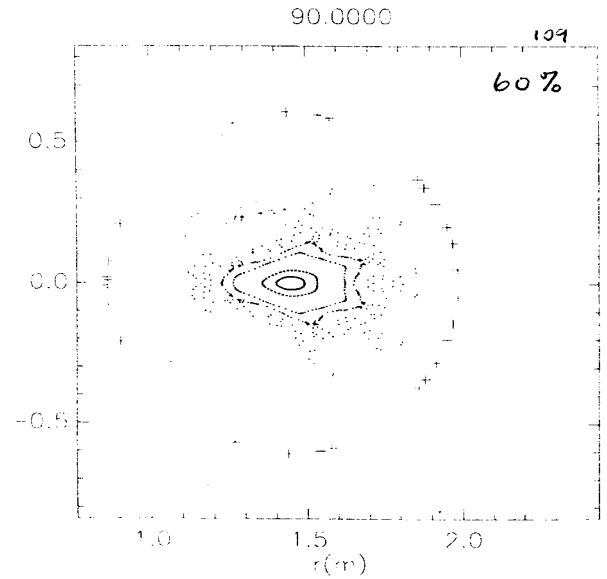

90.0000
103a
100%
1.0
1.5
2.0
r(m)


90.0000
107c
90%
0.5
0.0
-0.5
1.0
1.5
2.0
r(m)

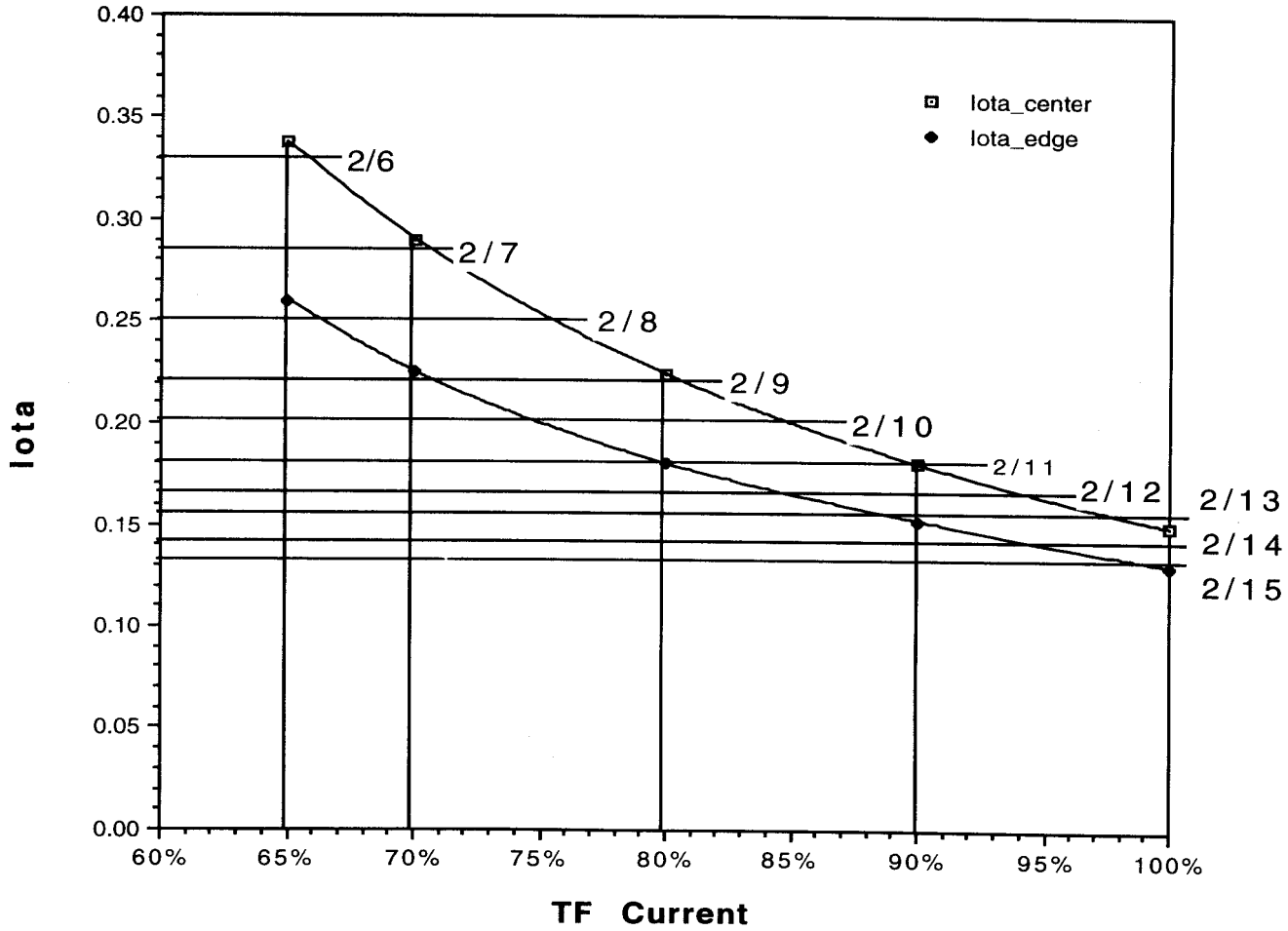

90.0000
108
80%
0.5
0.0
-0.5
1.0
1.5
2.0
r(m)

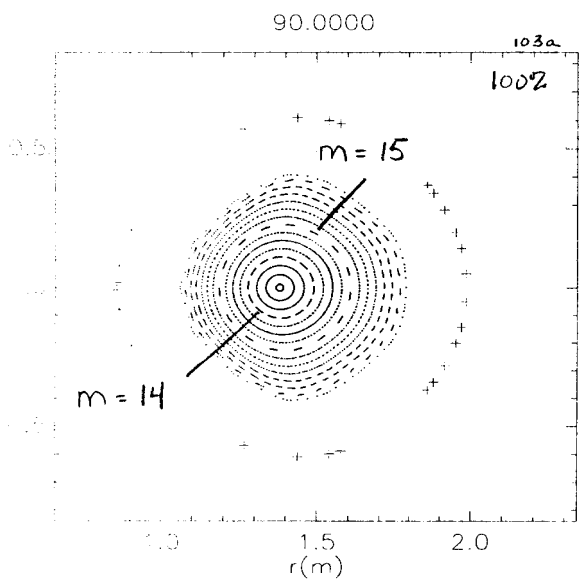

90.0000
110b
70%
1.0
1.5
2.0
r(m)

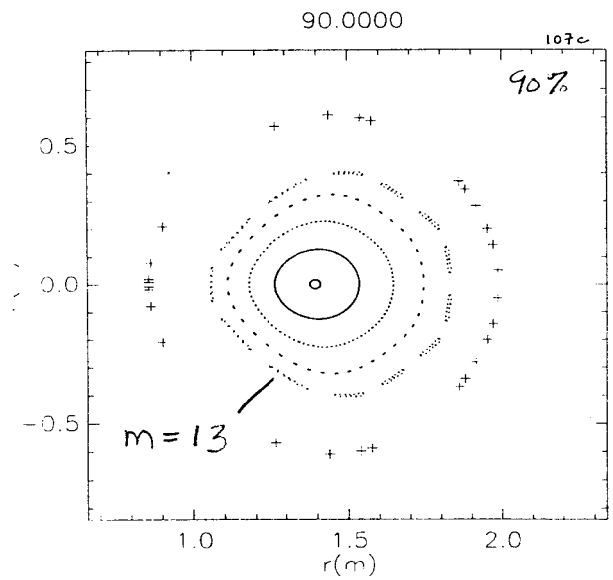

90.0000
111
65%
-0.5
1.0
1.5
2.0
r(m)

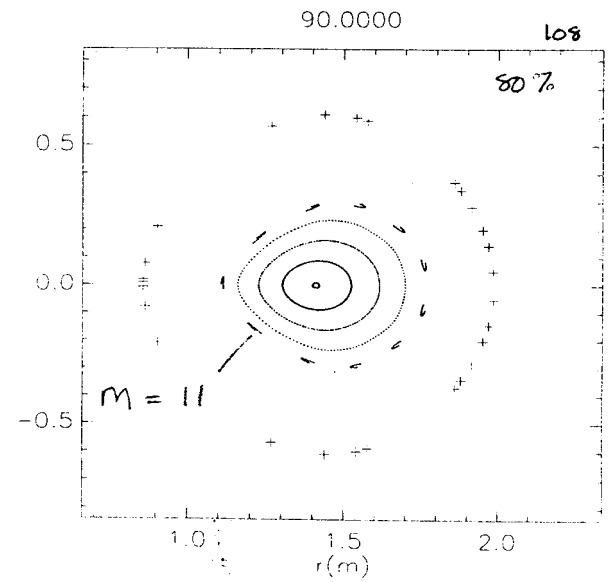

90.0000
109
60%
0.5
0.0
-0.5
1.0
1.5
2.0
r(m)

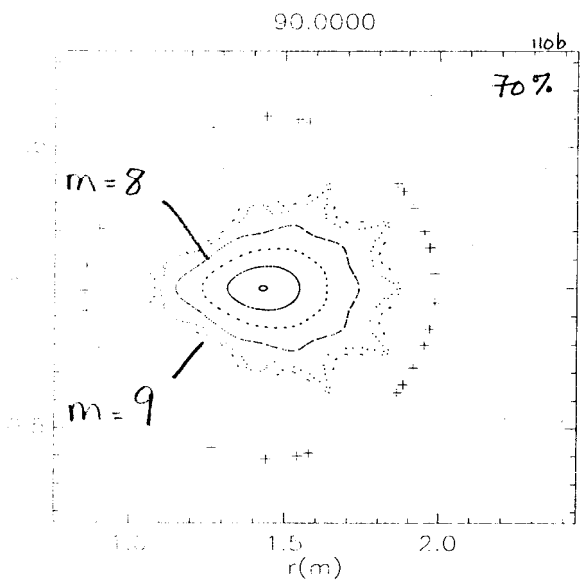
Islands Are Seen For Virtually Every Resonance

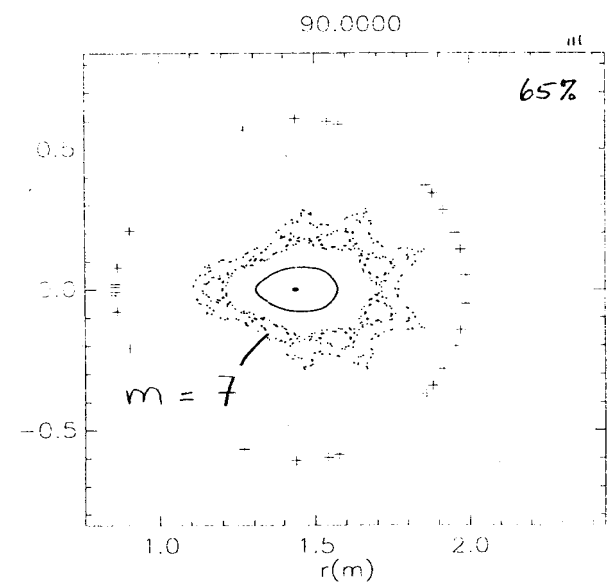


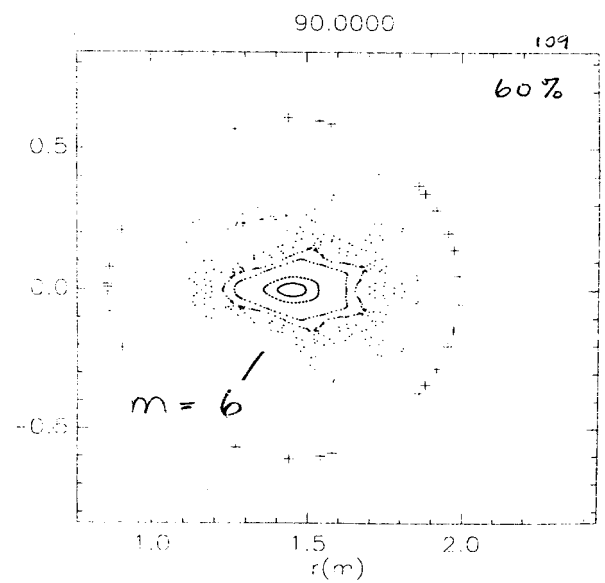

90.0000
103a
100%
m = 15
m = 14
1.5
2.0
r(m)


90.0000
107c
90%
0.5
0.0
−0.5
m = 13
1.0
1.5
2.0
r(m)


90.0000
108
80%
0.5
0.0
−0.5
m = 11
1.0
1.5
2.0
r(m)


90.0000
110b
70%
m = 8
m = 9
1.5
2.0
r(m)


90.0000
111
65%
0.5
0.0
−0.5
m = 7
1.0
1.5
2.0
r(m)


90.0000
109
60%
0.5
0.0
−0.5
m = 6
1.0
1.5
2.0
r(m)

Observed Islands Are a Concern

Presence of islands (or overlapping islands, stochastic regions) appears to limit plasma size for low m (<10) resonances

2/6 resonance appears to be a disaster for operation at reduced field but ..

- Plasma would be formed at full field (low iota, no problem) and ramped to full current (to get iota ~ 0.4) before heating

- Poor confinement observed when passing through m=10 6 islands may be OK

2/5 resonance crossed twice in the full beta/ current configuration with low shear

We currently do not have tools to show the existence of islands with plasma current

- VMEC reconstructions are suspect if convergence is slow or is free boundary shape departs from fixed boundary

Adding/Subtracting Bz Is Effective For Radially Moving The Plasma

Constant B_z added by appropriate currents in DF5 and EF21-22

Adding ±1% B_z/B_t moves the magnetic axis

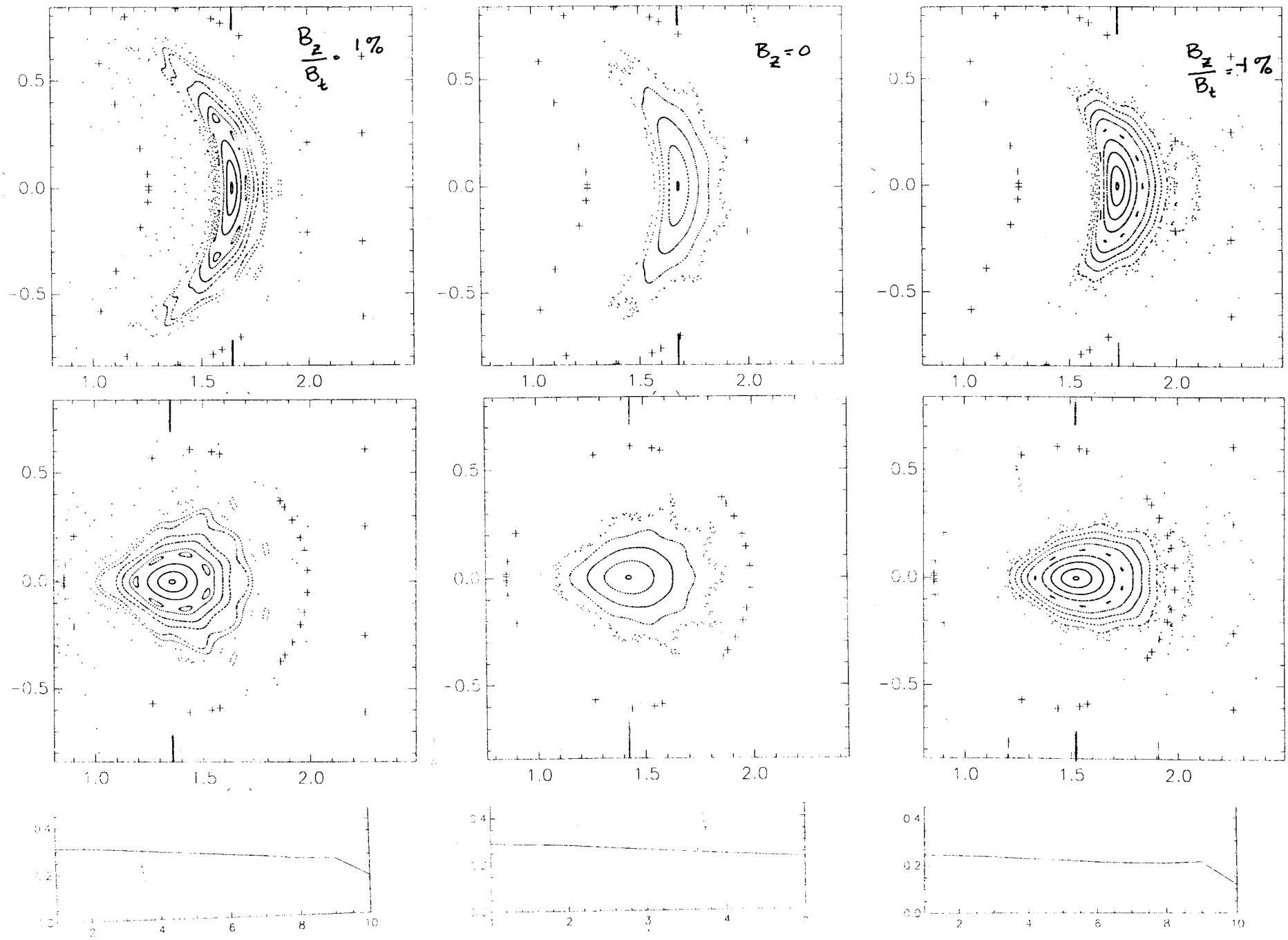
- ±4cm (±2.5%) at 0° (bean-shaped) cross section
- ±8cm (±5.6%) at 90° (circular) cross section

There is a noticeable change in plasma shape

- Plasma becomes taller and skinnier at 0° (bean-shaped) cross section
- Plasma becomes taller (not noticeably skinnier) at 90° (circular) cross section

Iota increases markedly as the plasma is pushed inward

- Adding ±1% B_z/B_t changes iota by ±.04 (±14%)


$\frac{B_z}{B_t} = 1\%$
$B_z = 0$
$\frac{B_z}{B_t} = -1\%$
0.5
0.0
-0.5
1.0
1.5
2.0
0.4
0.2
0.0
2
4
6
8
10
3

Changing the Vertical Field Gradient Was Also Investigated

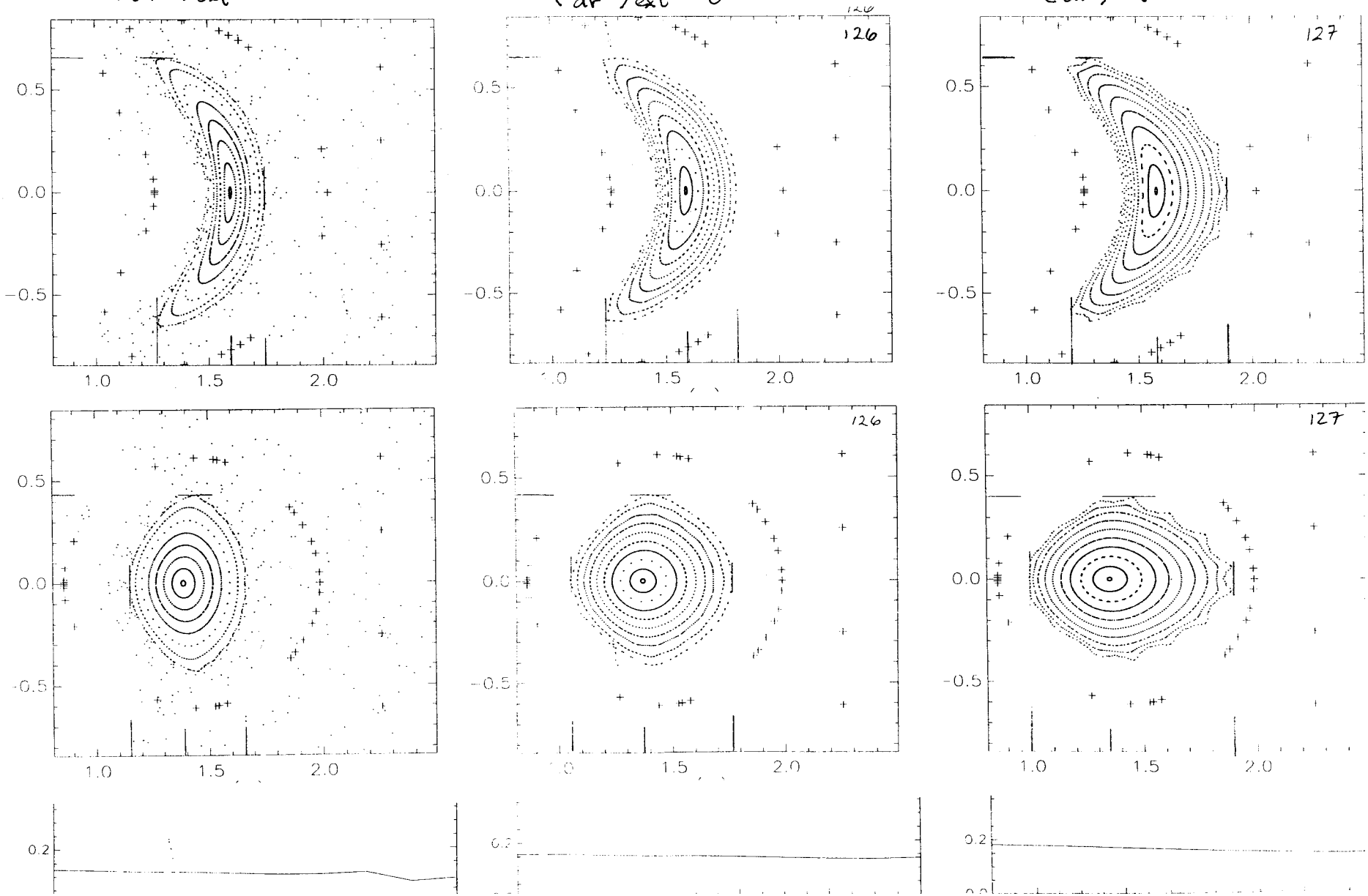
B_z kept at zero at R=1.56m

Constant field gradient applied using DF2, DF5, and EF21-22

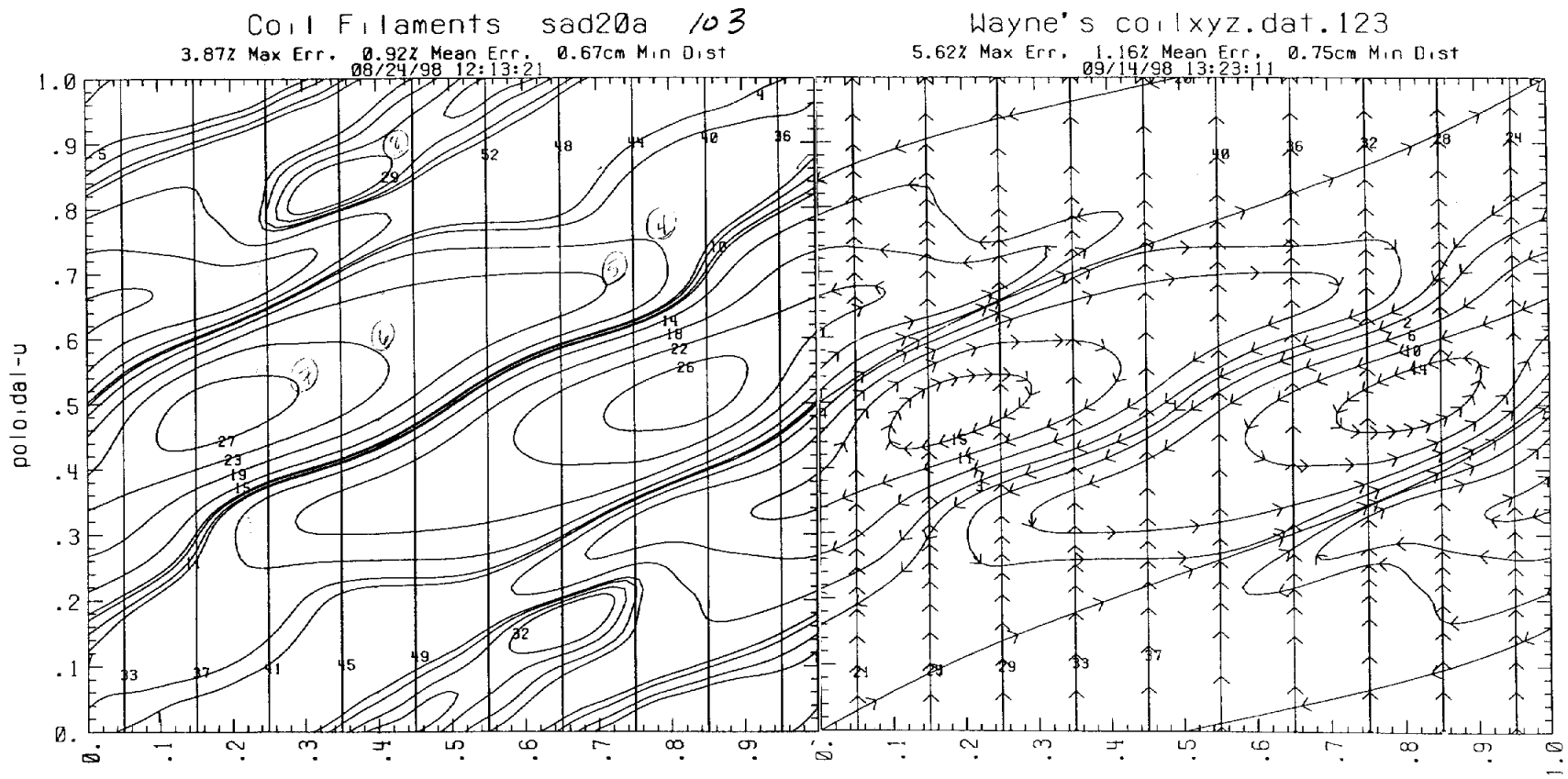
Adding a positive field gradient…

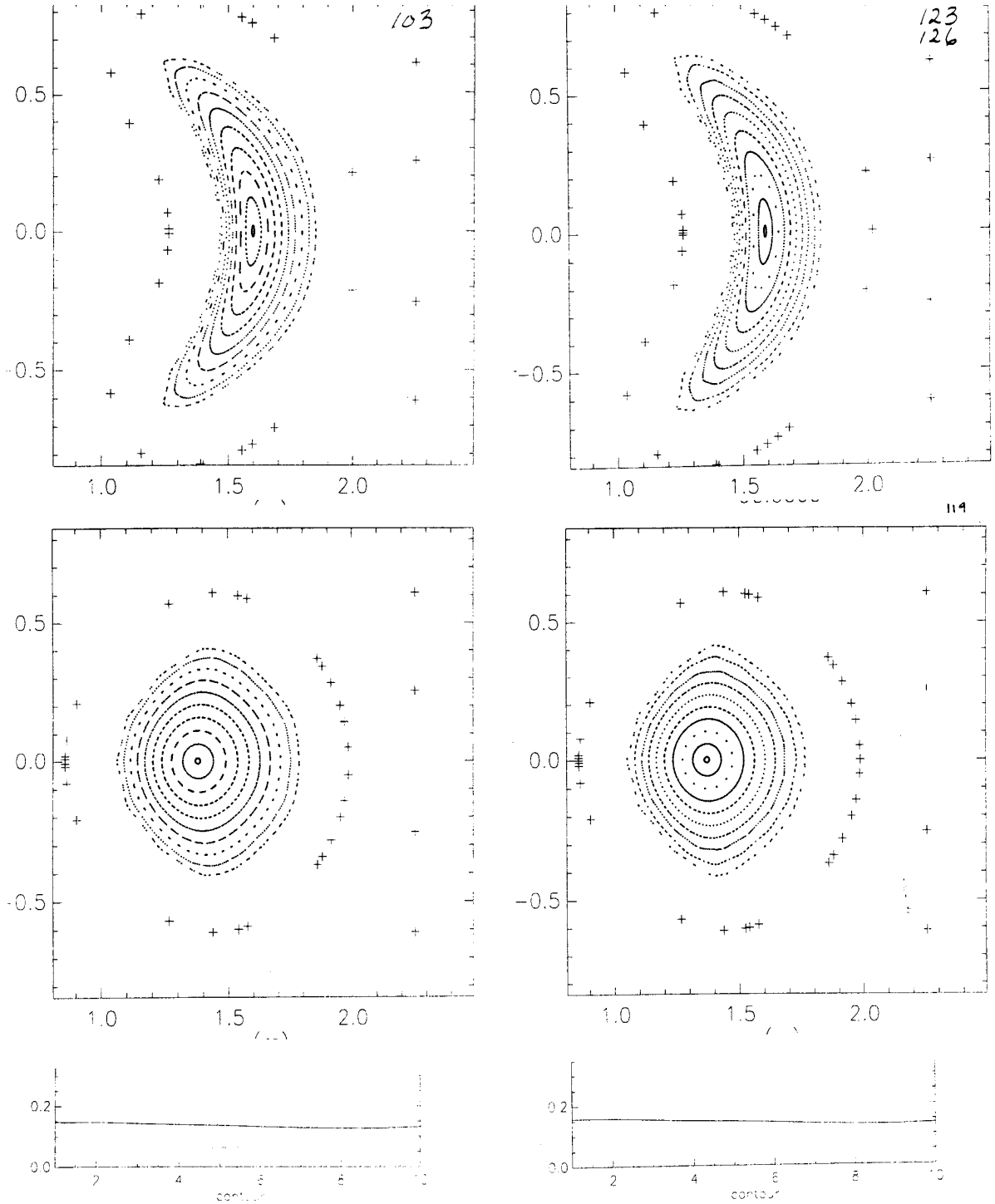
- **Increased the minor radius of the plasma at the horizontal midplane**
- **Had no significant effect on plasma height ⇐ decreased elongation**
- **Increased iota and shear**

$\left(\frac{dB_z}{dr}\right)_{ext} < 0$ $\left(\frac{dB_z}{dr}\right)_{ext} = 0$ $\left(\frac{dB_z}{dr}\right)_{ext} > 0$



Replacement of the 12 Complex Helical Windings With 4 Simple Helical Windings Preserved Good Magnetic Surfaces





12 COMLEX HELICES
+ O/B SADDLE

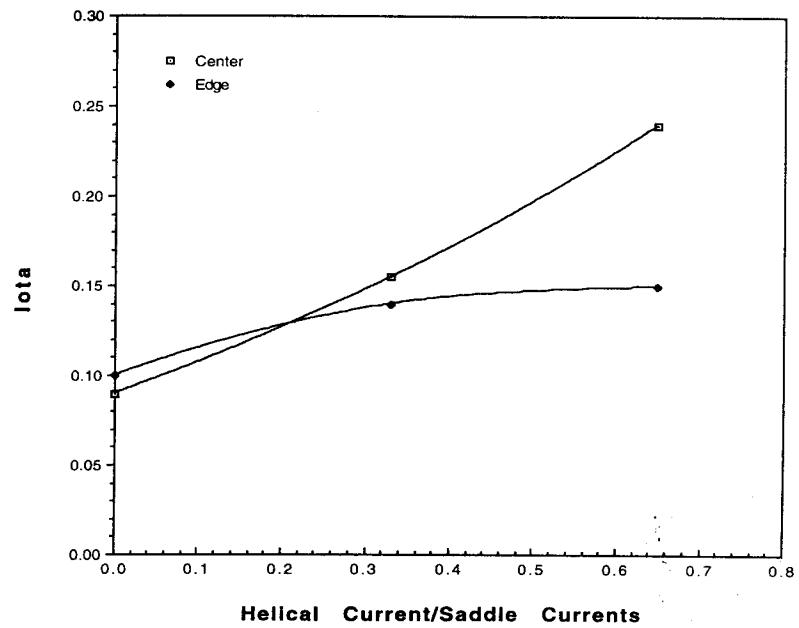
4 SIMPLE HELICES

Varying $I_{helical}/I_{saddle}$ Appears To Be A Good Knob

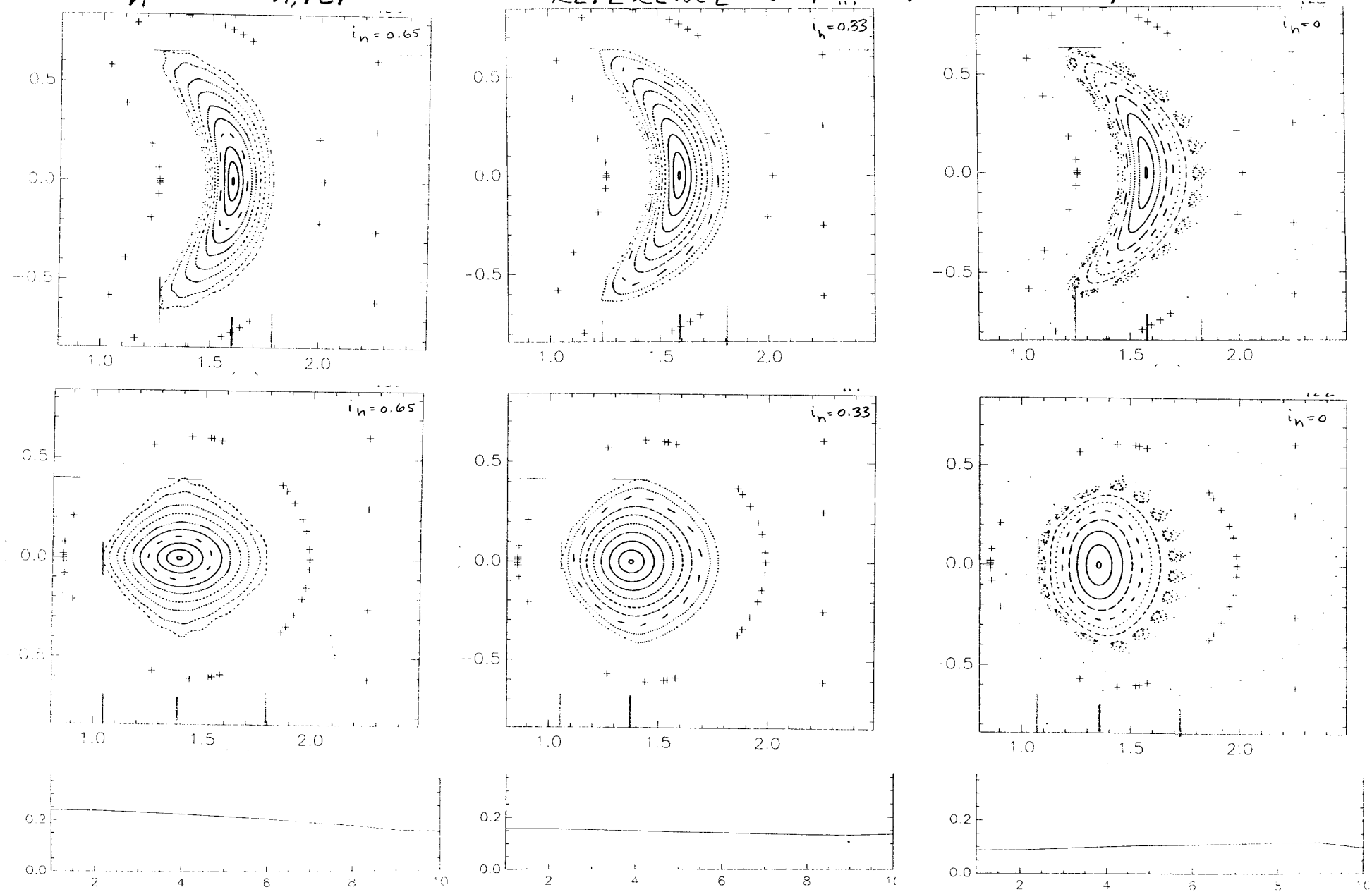
For Controlling Iota and Shear

Central iota appears quite sensitive to $I_{helical}/I_{saddle}$ -- edge iota appears less sensitive

Plasma shape does not seem much affected at all



$i_n = 2 \times i_{n,ref}$ | REFERENCE ($i_n = 0.33$) | $i_n = 0$



Conclusions

Good vacuum magnetic surfaces can be generated with a set of nested inboard saddle coils for the reference 2-period plasma (40% external transform)

A simple set of l=2 helical coils located along the zero potential contours provide an improved fit and flexibility in controlling iota and shear with minimal perturbation on the plasma shape or position

TF current is an excellent knob for controlling iota (iota ~ $B^{-1.6}$) without radically perturbing the plasma position

Application of a vertical field will predictably move the plasma in and out, but with marked changes in iota and plasma shape

Application of an external field gradient will change the plasma elongation, iota, and shear

Control algorithms for using these knobs (TF current, helical current, vertical field and higher order

Islands were most pronounced with…

- Flat iota profiles and iIn the neighborhood of shear reversals
- Higher iota (lower m)

At full current, the nominal iota profile is nearly flat and crosses the 2/5 resonance twice

Need to suppress n=2 field errors (for n/m in iota range of interest) in the coil design

Need tools for looking for islands and stochastic regions with plasma current (PIES)

More shear, monotonic shear, and higher n should help