Healing M45 with Trim Coils

L. P. Ku

NCSX Physics Meeting, March 14, 2002

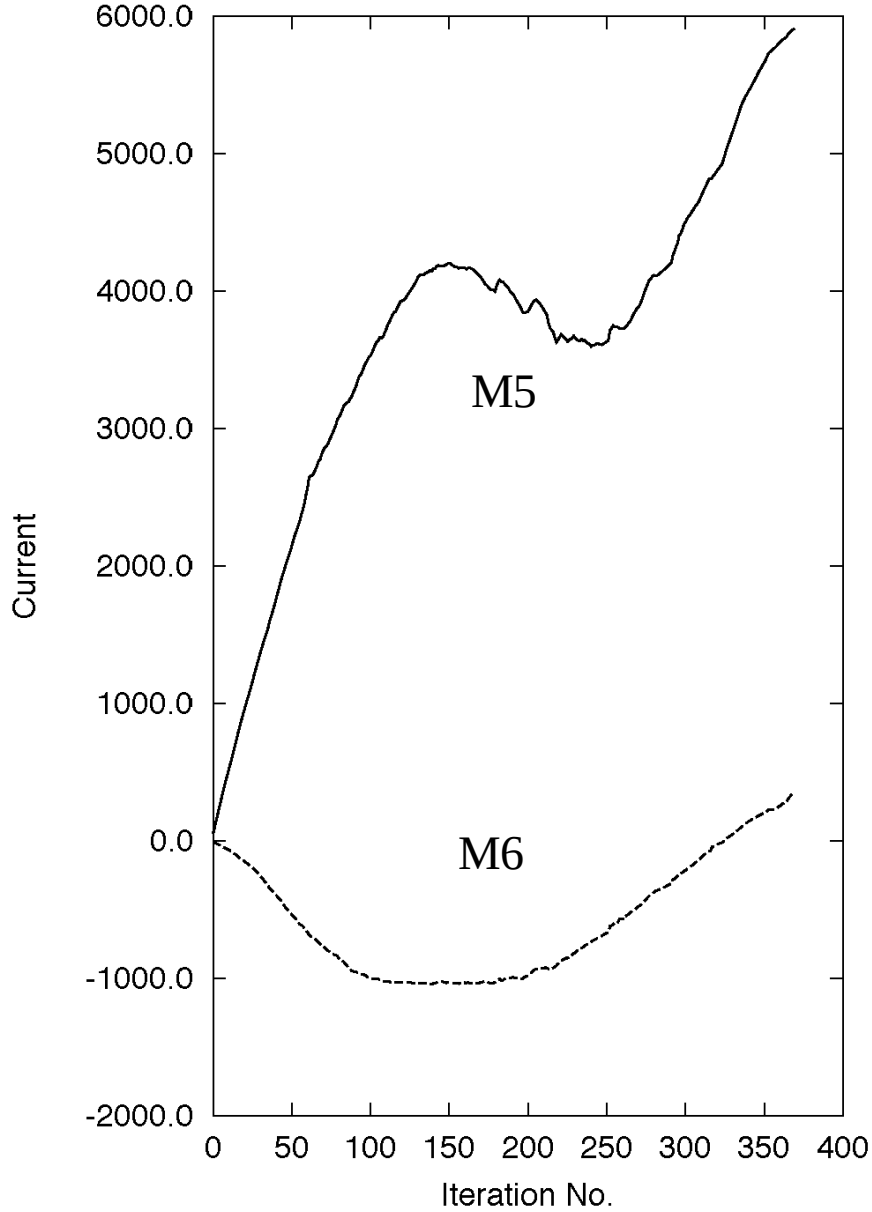
Princeton Plasma Physics Laboratory

- Objective:
  - Heal m=5 and m=6 islands for M45 at full pressure and full current (S3) using trim coils. The trim coils are previously designed at the time of PVR and have been scaled down to R~1.4 m of the present size.

- Algorithm:
  - Using quadratic flux minimizing surfaces to calculate resonant fields at the rational surfaces in PIES (Stuart Hudson).
  - Adjusting trim coil currents to cancel resonance fields at each and every iteration (dynamic healing).
  - Geometry of coils, both modular and trim, as well as modular coil currents, kept fixed.
  - Properties of plasma not optimized nor monitored.

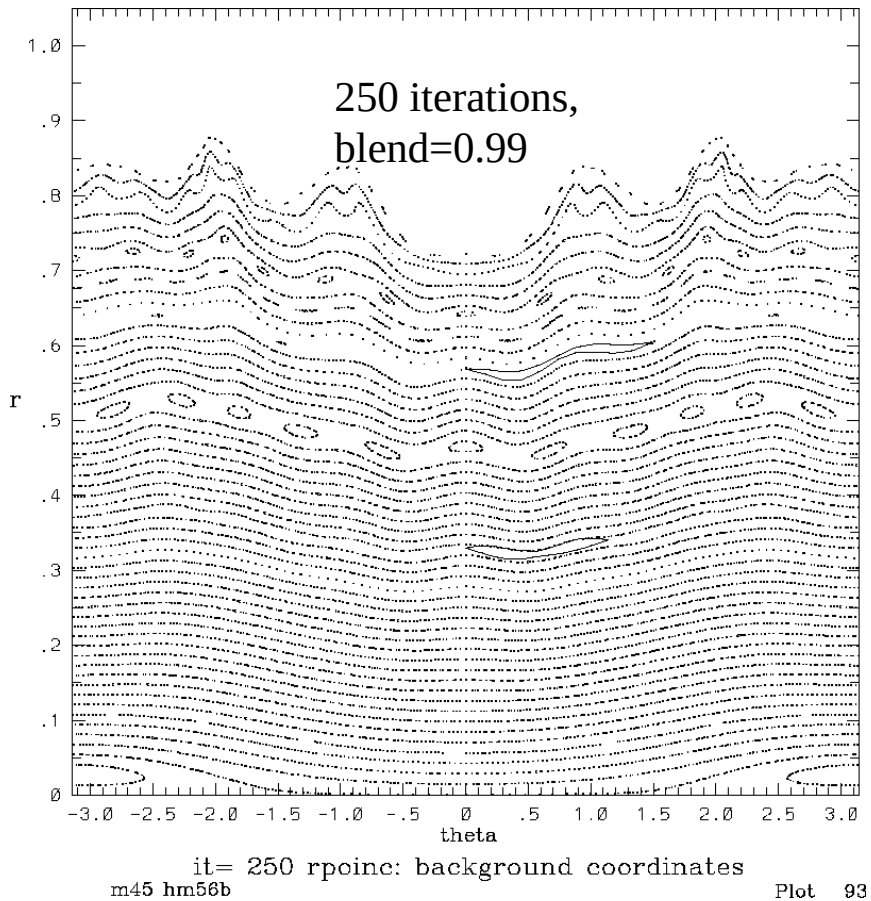
- General Results:
  - Stable solution for trim coil currents not found in PIES iterations.
    - Irrespective of using both m=5 and m=6, or just m=5, and using only in-board or full coverage in almost all the cases.
  - Large fraction of plasma volume lost, concurrent with the buildup of trim coil currents.
    - Strong edge deformation observed.
    - PIES convergence beyond reach.

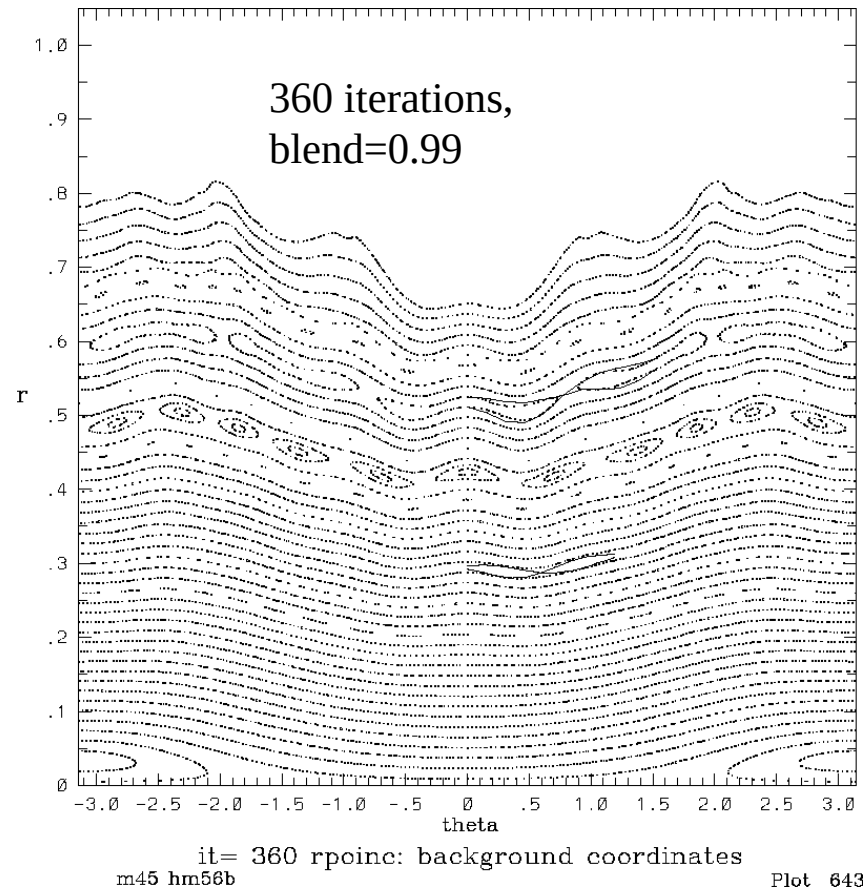
Trim coil currents (A) versus PIES iteration.



Stable PIES solution does not exist.

More and more plasma volume gets lost as PIES iteration progresses, even though the m=5, n=1 and m=6, n=1 islands are healed. Strong boundary deformation is also observed.

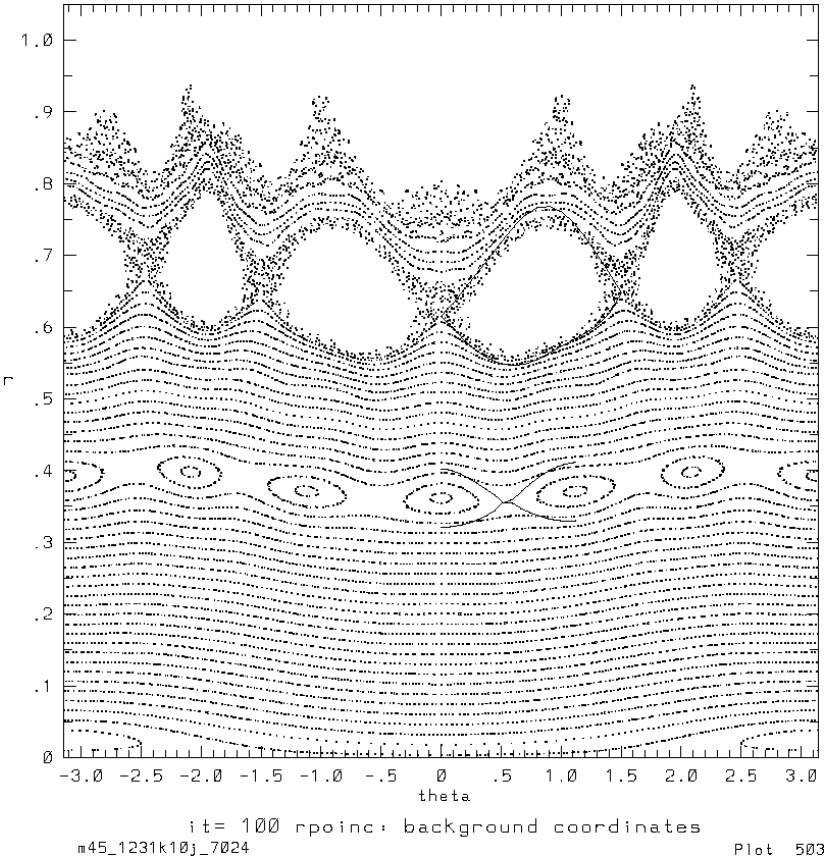




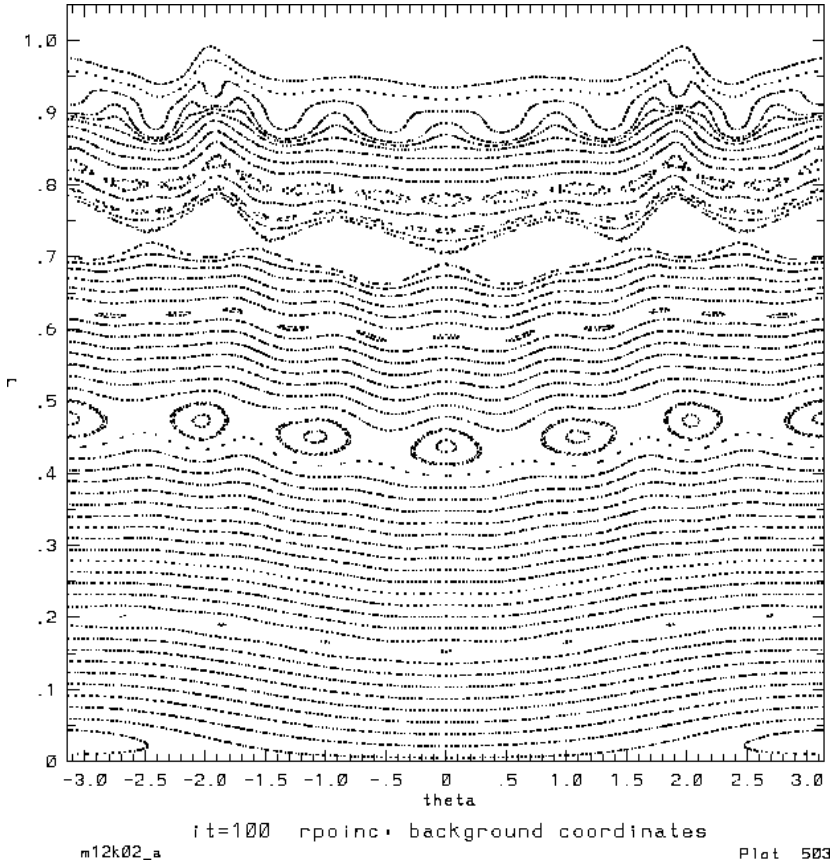
- What contribute to the peeling off of outer plasma surfaces and coil current buildup?
  - Without healing, M45 collapsed in just 100 iterations in PIES. On the contrary, all the surfaces remain after 300 iterations in M12.
  - The collapse appears to be due to the very large m=5 islands, which may couple to the 2/10, 3/14 and 2/9 resonance.
    - Healing is harder than before -- larger perturbation results.
  - Can healing cause a nonlinear feedback, leading to unstable PIES solution if the underlying plasma field is not robust?
    - Re-run PIES with correction of coil currents terminated after the quasi-stationary point at ~150 iterations

M45 has much larger m=5, n=1 islands at 4% beta compared to M12. Analytic calculations showed that the size of the 1/5 islands in M45 due to external coils is almost twice as large (more later).

M45

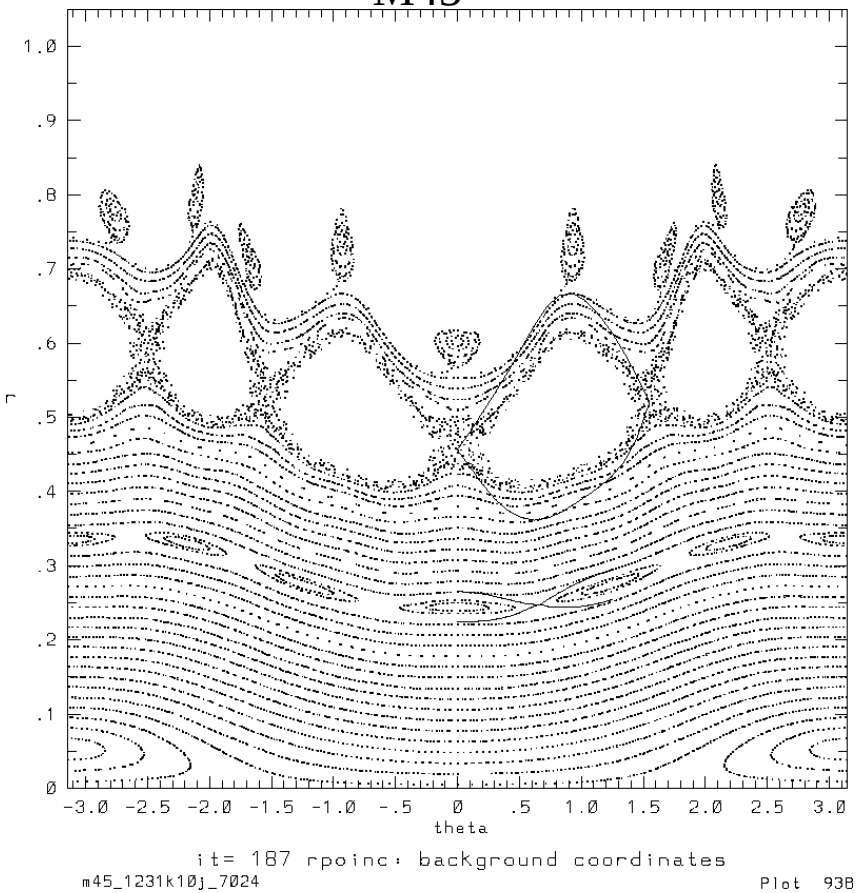


M12

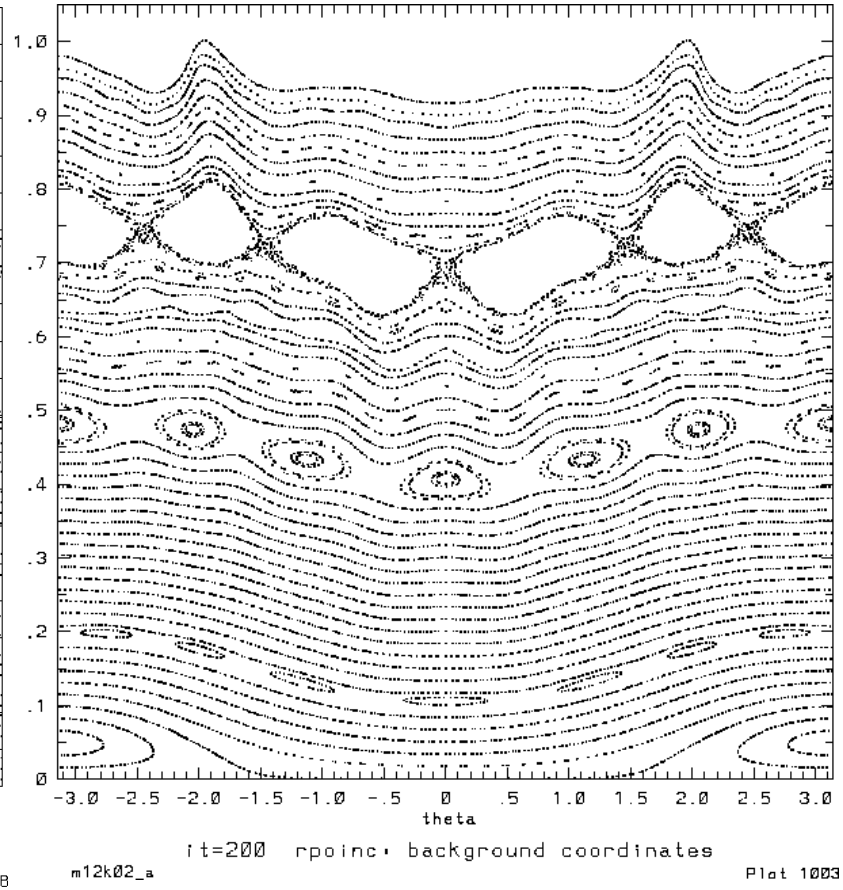


100 iterations, blend=0.99

M45



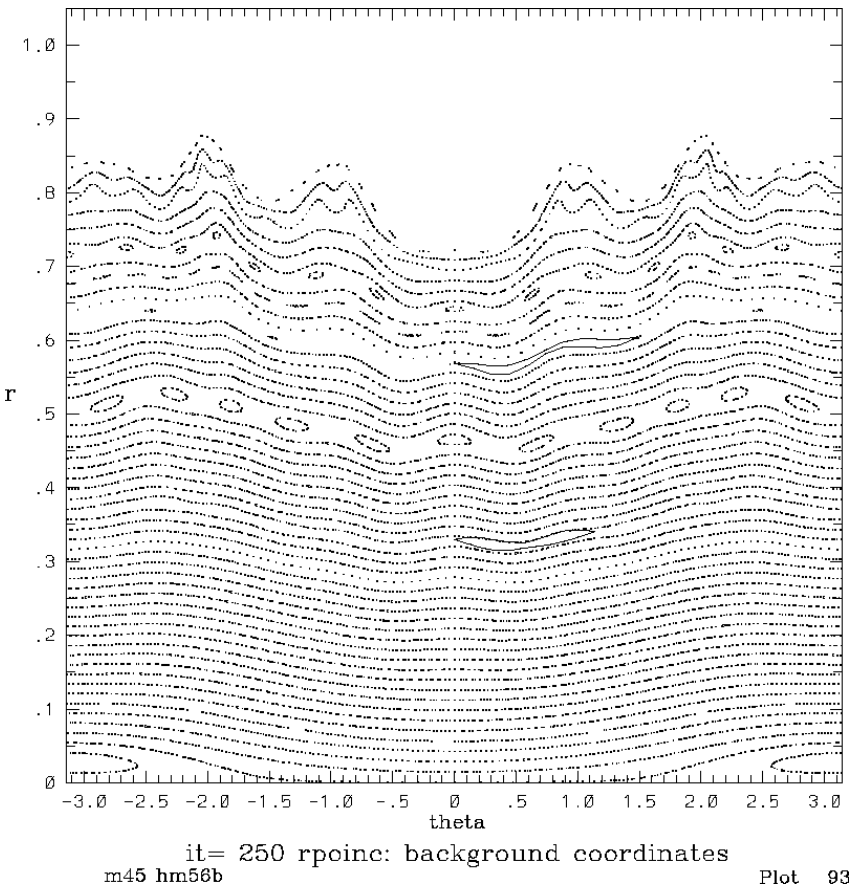
M12



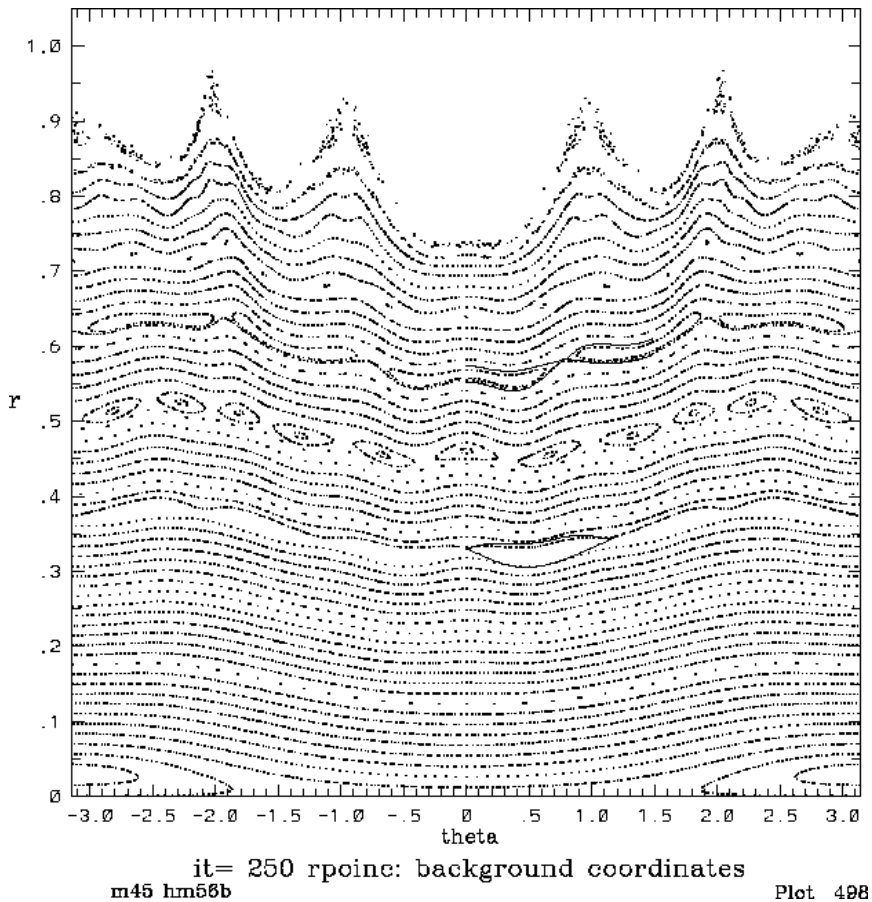
200 iterations, blend=0.99

Keeping trim coil currents fixed after the quasi-stationary point does not prevent the loss of outer flux surfaces.

Continued correction

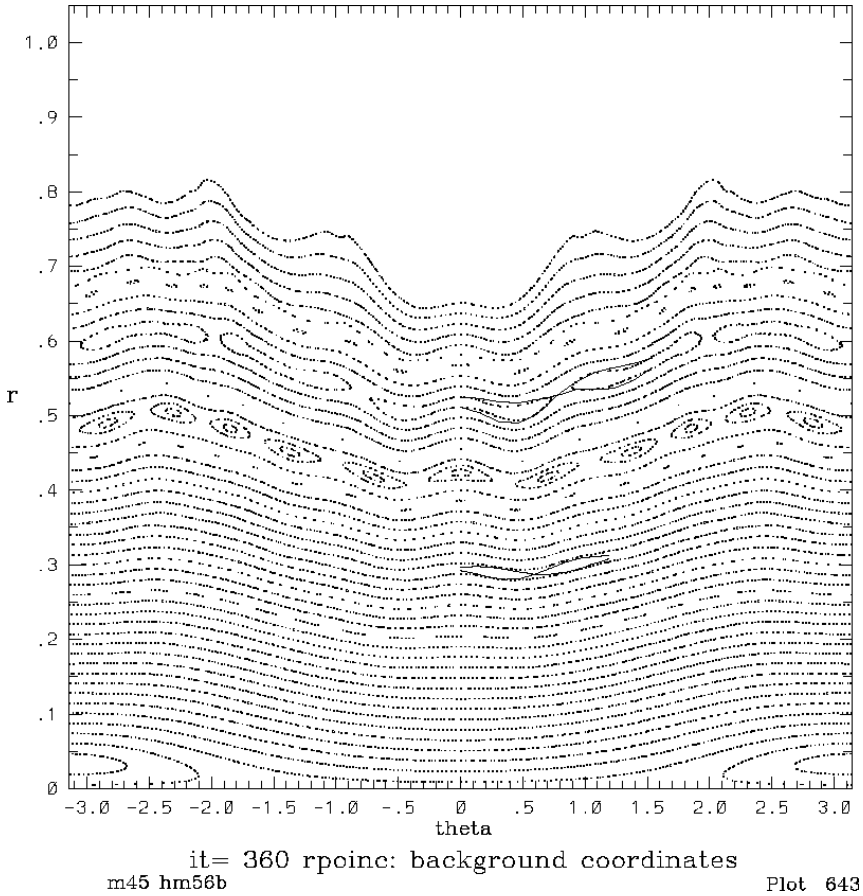


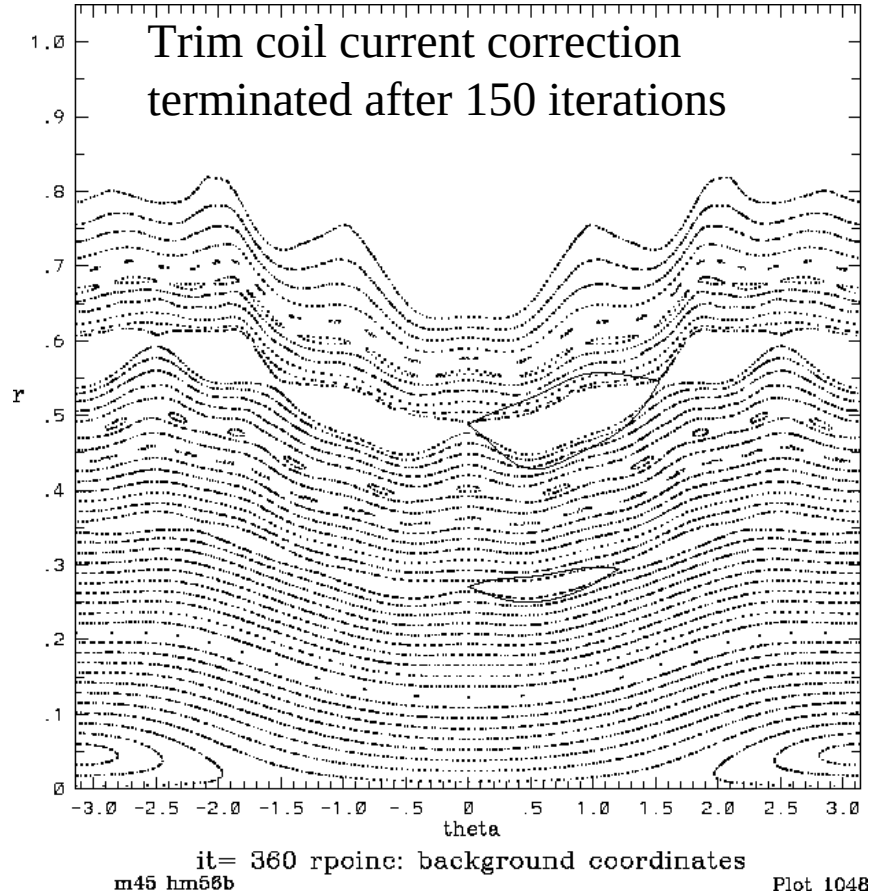
Trim coil current correction terminated after 150 iterations



250 iterations

After 360 iterations, both cases have similar loss of volume.
Without continuing the correction, m=5 islands re-appeared.





Either the current level at 150 iteration is large enough to cause severe perturbation, or peeling off is due to something else.

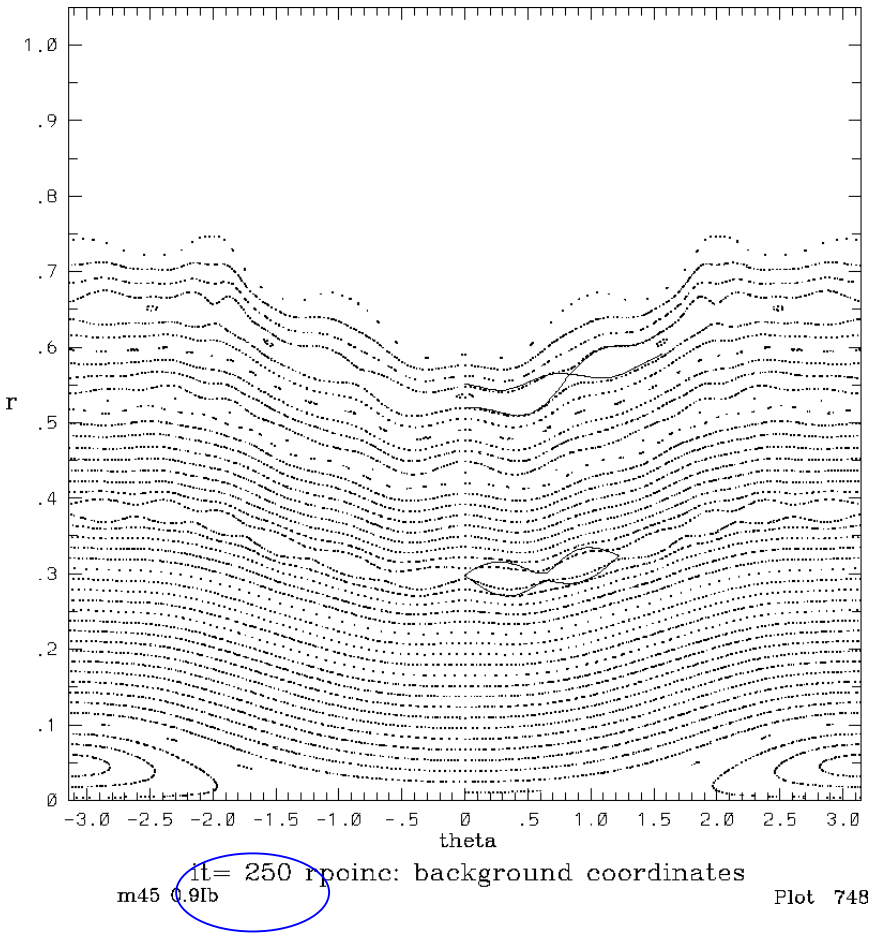
- What contribute to the peeling off of outer plasma surfaces and coil current buildup (Cont.)?
  - If m=5, n=1 and its coupling to m=9, n=2 in M45 result in losses of substantial amount of flux surfaces,
  - Yet, healing of m=5 islands failed to prevent flux loss,
  - Is m=9 the culprit?

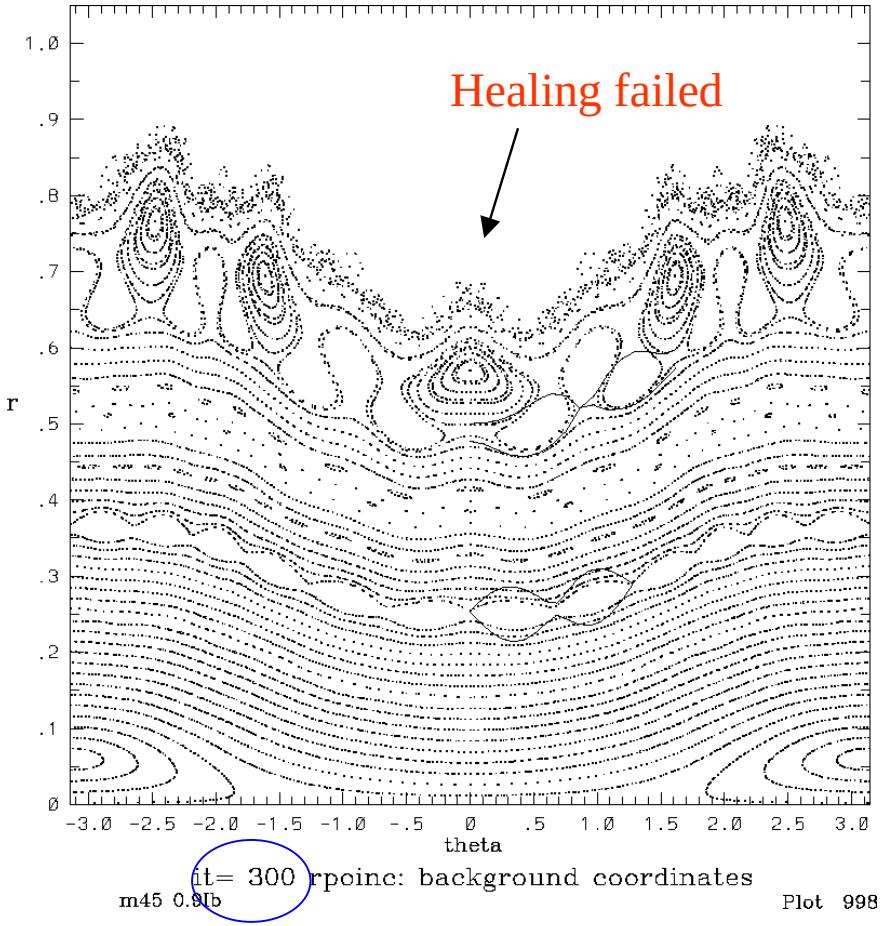
- What contribute to the peeling off of outer plasma surfaces and coil current buildup (cont.)?
  - In particular, is the problem due to the 2/9 resonance and zero shear zone too close to edge?
    - At full current, ι_max =0.661 @r/a=0.95, ι=0.6 @r/a=0.79
    - Would reduced plasma current help?
      - @95% ι_max=0.642, ι=0.6 @r/a=0.82
      - @90% ι_max=0.623, ι=0.6 @r/a=0.85
      - @80% ι_max=0.585, ι=0.58 @r/a=1.0

Too close to 3/14?

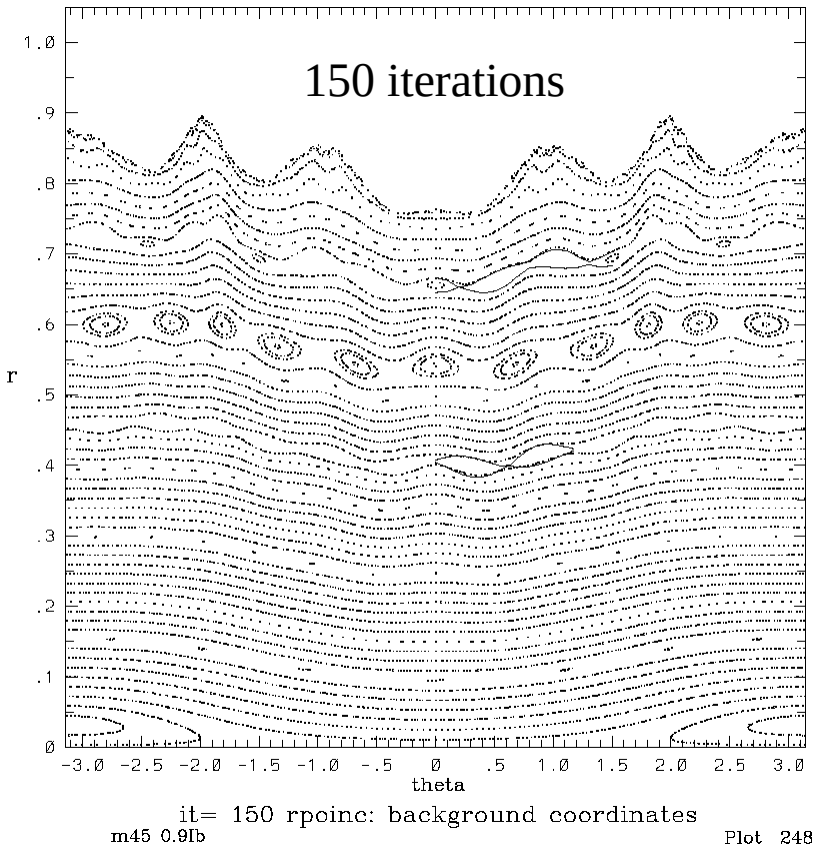
1/5 too close to edge?

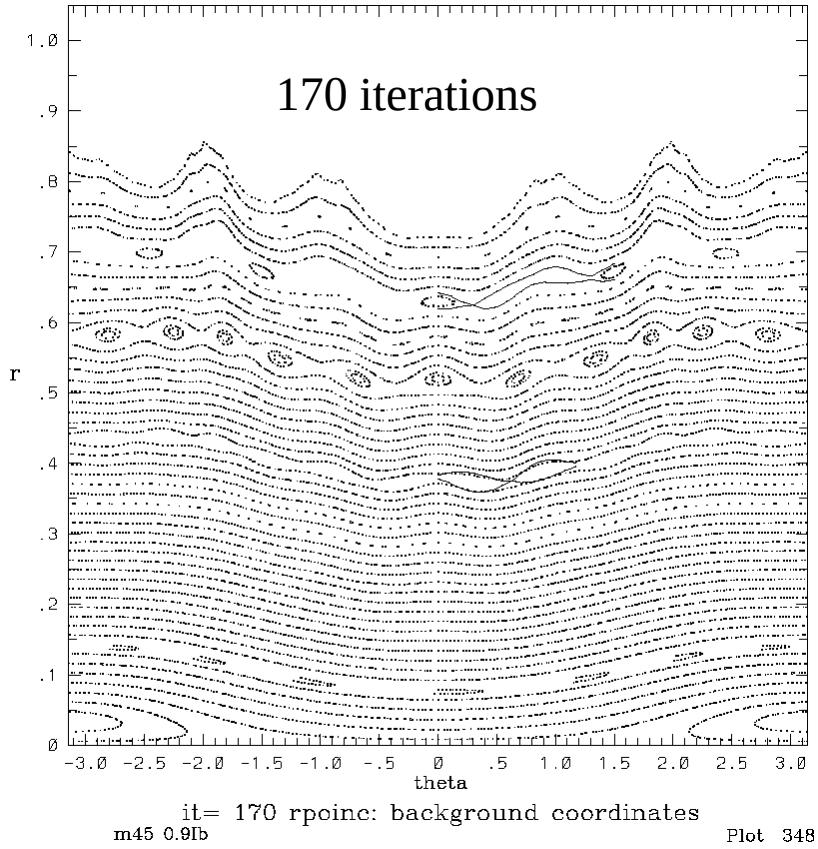
The peeling-off is even faster for 90% Ip case!! Is this due to the 1/5 still too close to the edge? Is this the main reason that results in the surface loss? How about 2/9 to the S3 (more later)?





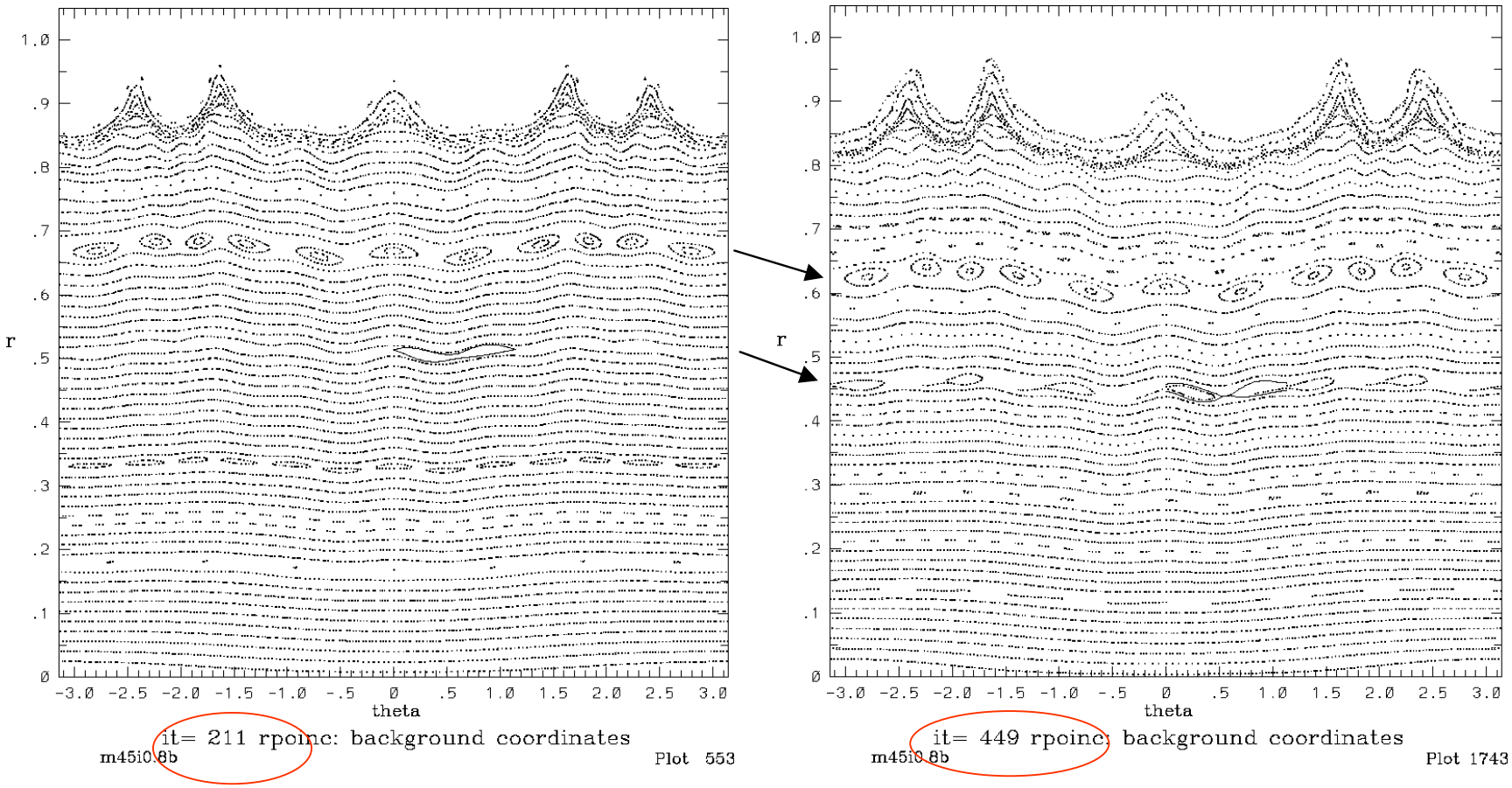
The peeling can sometimes be very rapid, as shown here. We've lost two surfaces in 20 iterations with blend=0.99. The edge iota is 0.628.





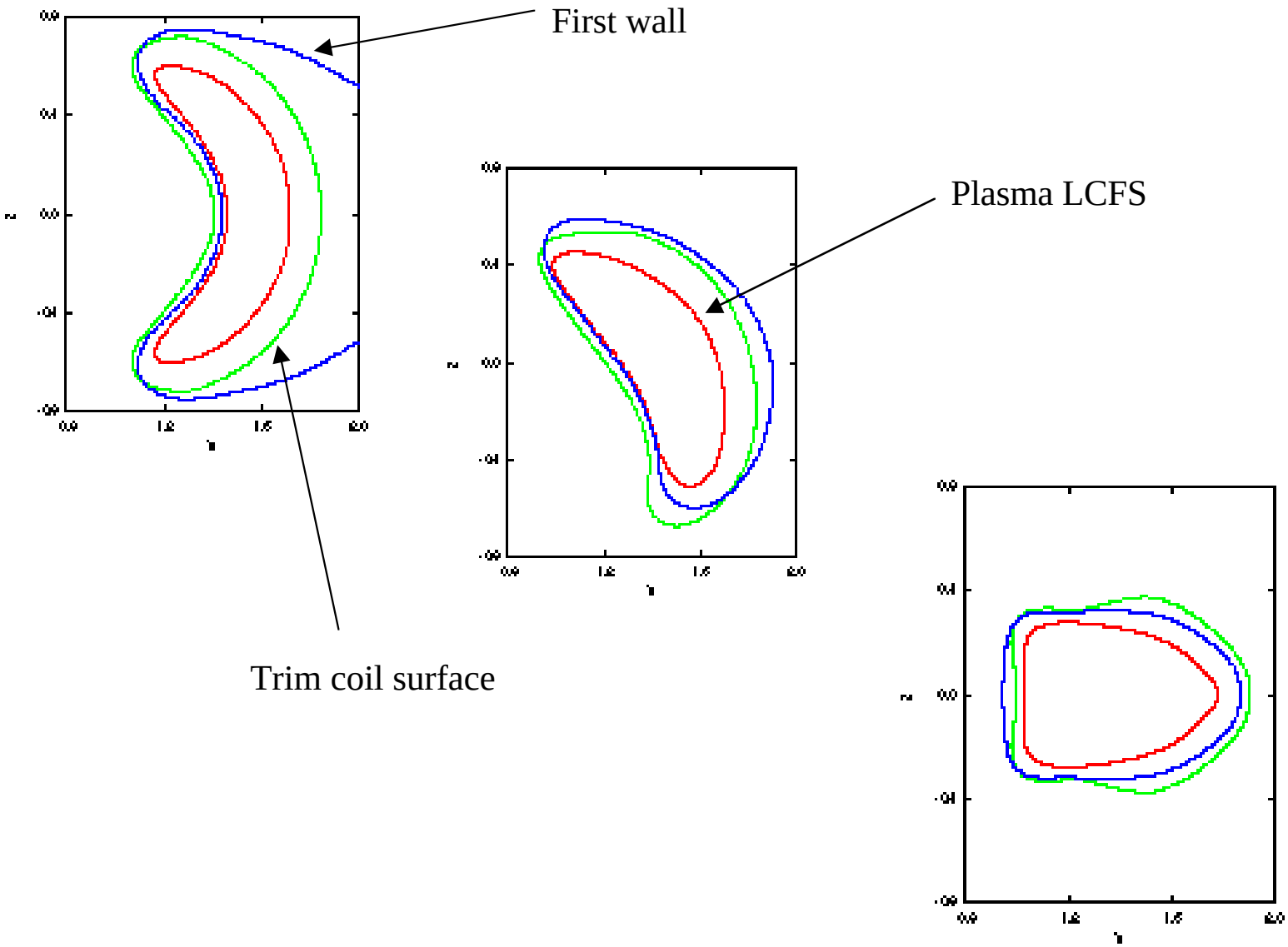
- Without m=5, however, a good volume of plasma is retained after healing the m=6 islands as in the 80% Ip case!

Without m=5, the surfaces of the 80% Ip case hold up well even though the boundary iota is close to 1/5, causing some problems in PIES iterations.

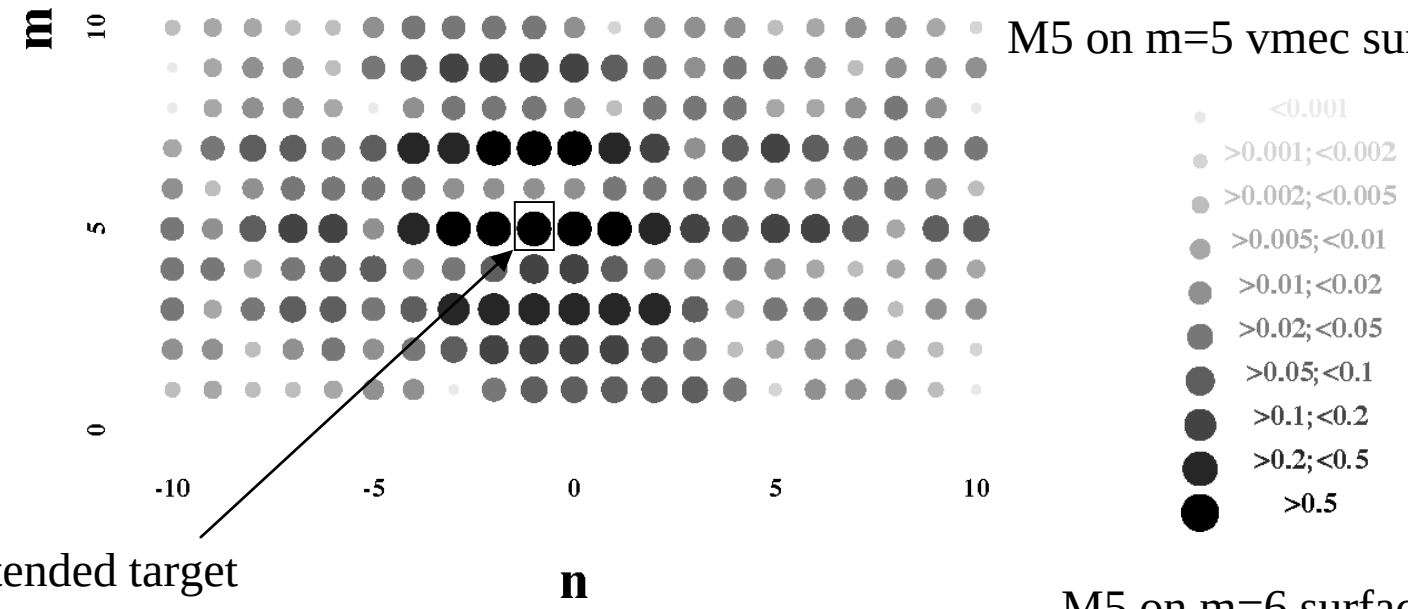


- If
  - We assume that the m=5 islands and their coupling to edge resonance lead to collapse.
  - But, reducing m=5, n=1 islands and the attempt to reduce the effect of edge resonance do not prevent surface loss.
  - Yet, removing m=5 islands entirely does appear to preserve outer surfaces.
- Then
  - Could it be due to resonance and non-resonance perturbation of trim coils even at moderate current levels (2/10, e.g. in Ip=90% case)?
  - Or ?

- What contribute to the peeling off of outer plasma surfaces and coil current buildup (cont)?
  - Field perturbation due to trim coil too much?
    - Magnetic spectrum has wide range.
    - Would increasing plasma-coil distance help alleviate the pollution problem?


First wall
Plasma LCFS
Trim coil surface

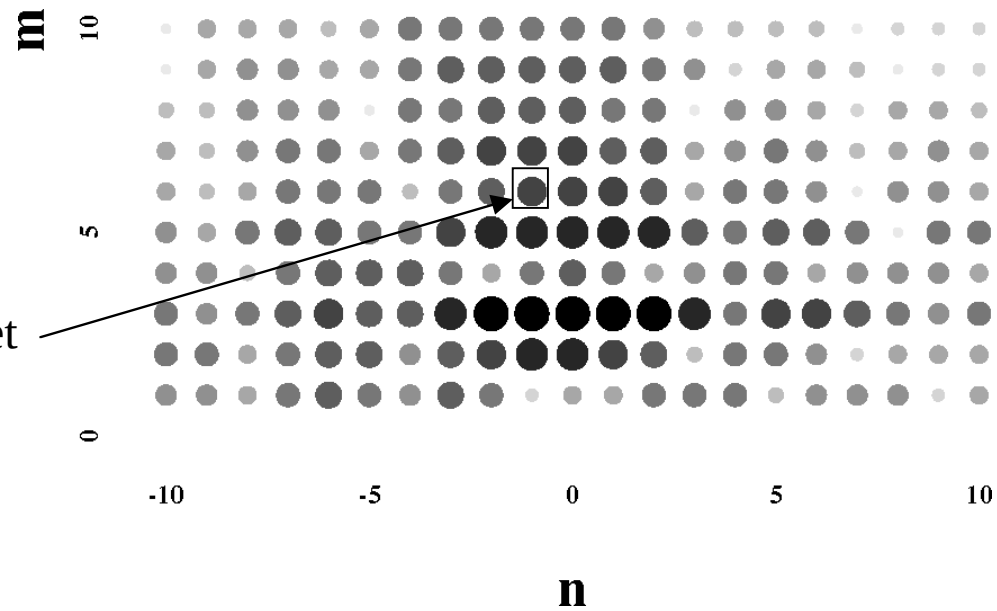
Magnetic spectrum normalized to the largest component.



M5 on m=5 vmec surface

Intended target

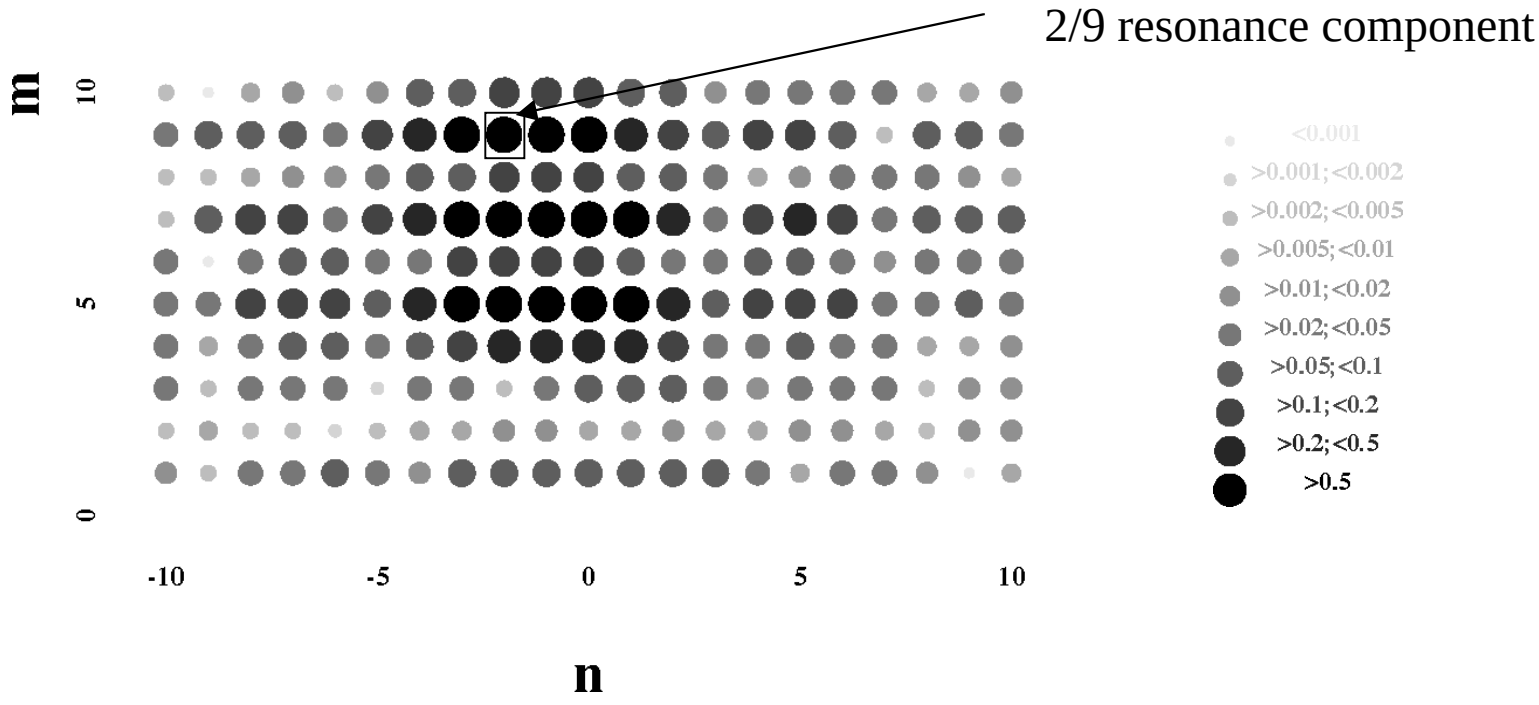
M5 on m=6 surface



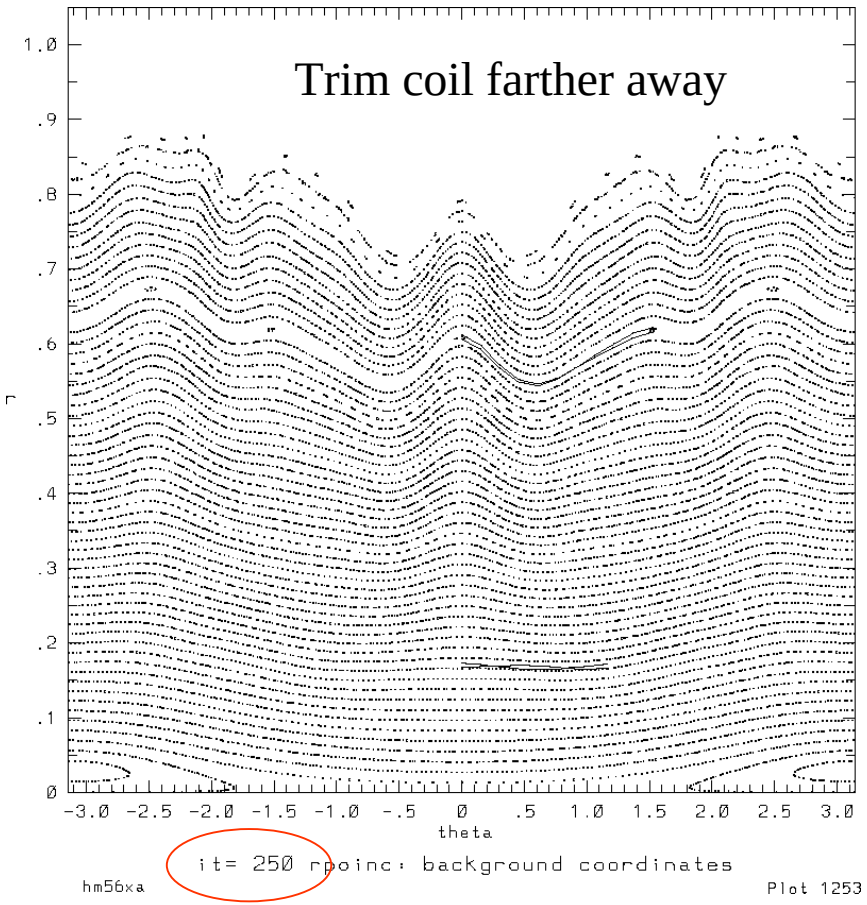
Unintended target

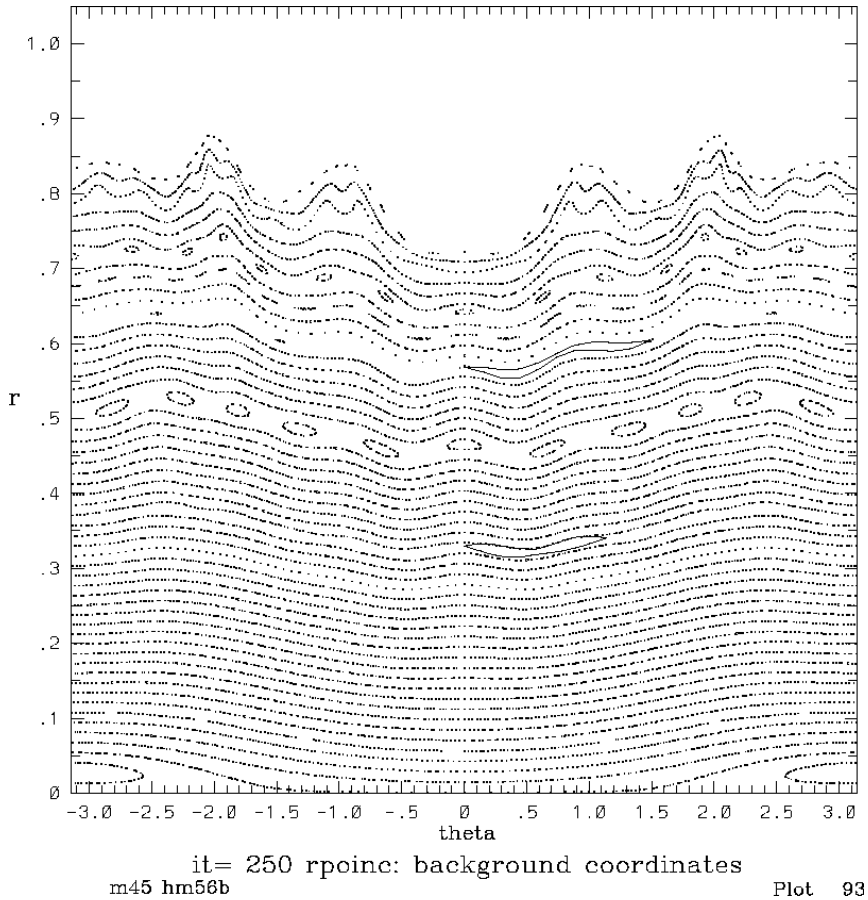
Coupling matrix is hardly diagonal!

M5 on r/a=0.9 surface

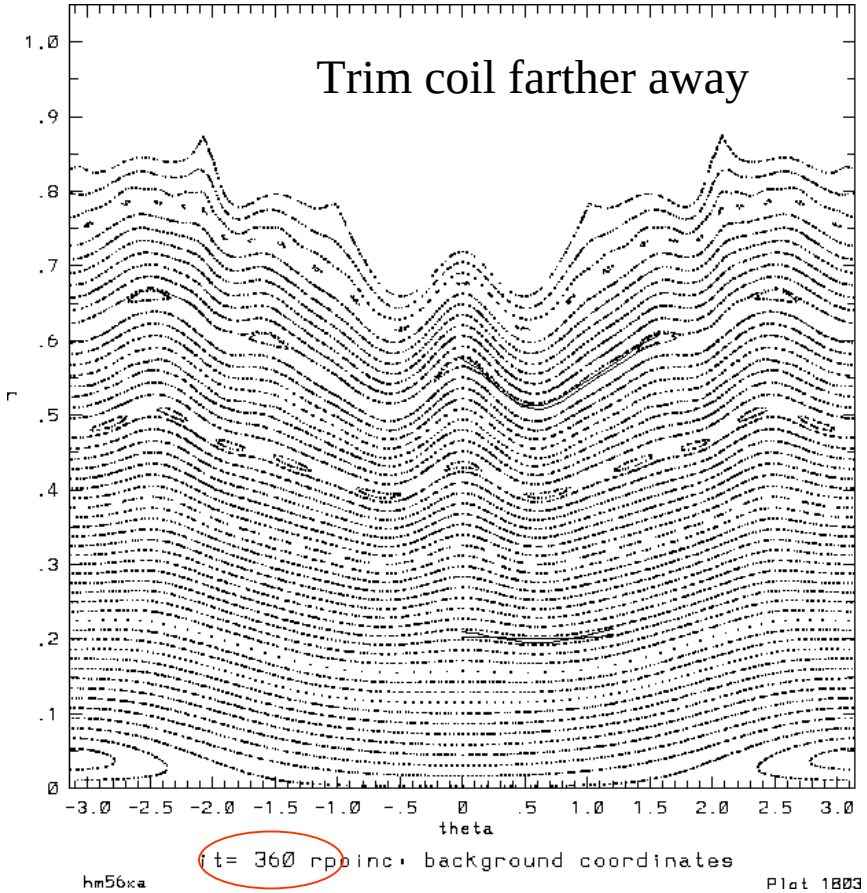


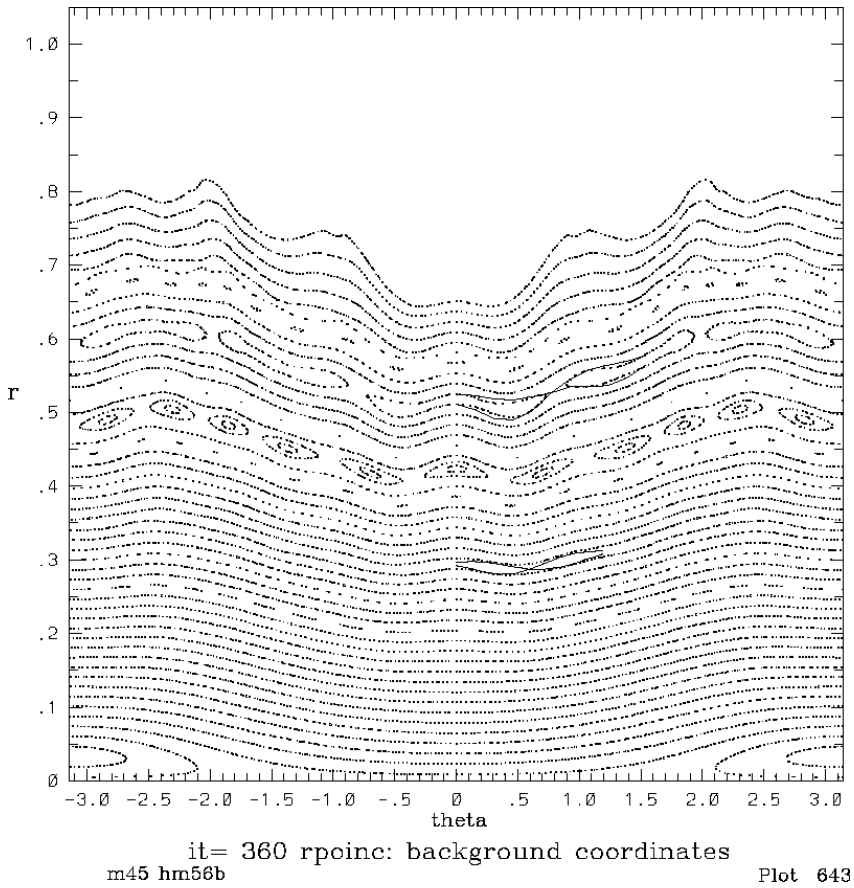
PIES runs with trim coils set back by 0.5 m clearly show the effects of pollution due to higher order modes. Loss of flux surface is nearly identical in both cases, nevertheless!!





After 360 iterations





- There is a clear effect of pollution due to trim coils, probably more likely due to lower order modes.
  - Comparison of results of original and displaced trim coils.
  - PIES results of m=6 only healing for 80%Ip case.

- But, can we say that the pollution is the reason that is mainly responsible for the surface peeling?
  - Can we see something from lower beta (perturbing the pressure driven term)?
  - Can we see something from healing M12, which has better flux surface quality (perturbing main coil/plasma fields)?

M45 flux surfaces at 2% beta but full (4% beta) current without healing of islands.