Use of the 3D-MAPTOR Code in the Study of Magnetic Surfaces Break-up due to External Non-Axisymmetric Coils

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Abstract

We show the outer magnetic surfaces in a spherical tokamak can be broken up by means of internal or external tilted coils. The configuration chosen for this work is that of the MEDUSA small spherical tokamak, a small glass chamber device, which allows the introduction of such coils. The simulation is carried out with the 3D-MAPTOR code, developed by the authors. Given an initial condition for a given magnetic field line, it is integrated using a chosen magnetic current profile, as well as the currents of the toroidal and vertical field coils. Poincaré maps along the toroidal angle and the image of the field, as seen from above, can be plotted. The latter allows the identification of parameters for which the ripple effect may be significant.

Motivation

- One of the main issues in the development of tokamak based fusion reactors is the control of edge instabilities.
- It has been suggested that they can be dealt with by introducing resonant magnetic perturbations, which would reduce the pressure gradient in the edge by decreasing the particle content locally [1].
- There are currently many experiments in which external coils are being used in order to mitigate Edge Localized Modes (ELMs), which come with high-confinement regimes, for instance in DIII-D [2], and recently in the Spherical Tokamak NSTX [3], where saddle coils are installed in order to break the axisymmetry on the edge.
- The scheme proposed in this work is in line with an older idea pursued in previous experiments, like TEXTOR, in which tilted coils are used [4].

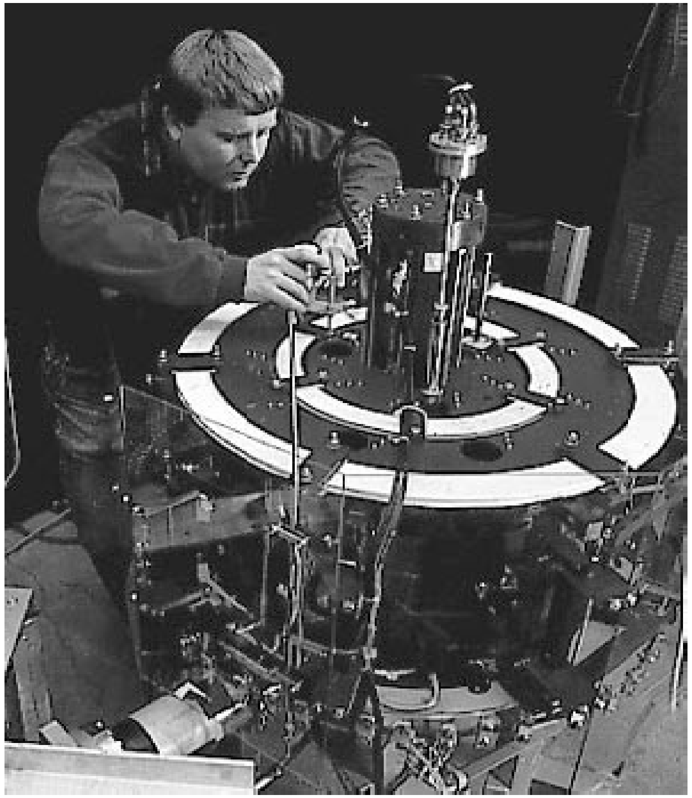
The Medusa Tokamak [5]

- The **Madison EDUcational Small-Aspect-ratio (MEDUSA) tokamak** was designed, built and operated at the University of Wisconsin at Madison, and eventually decomissioned.

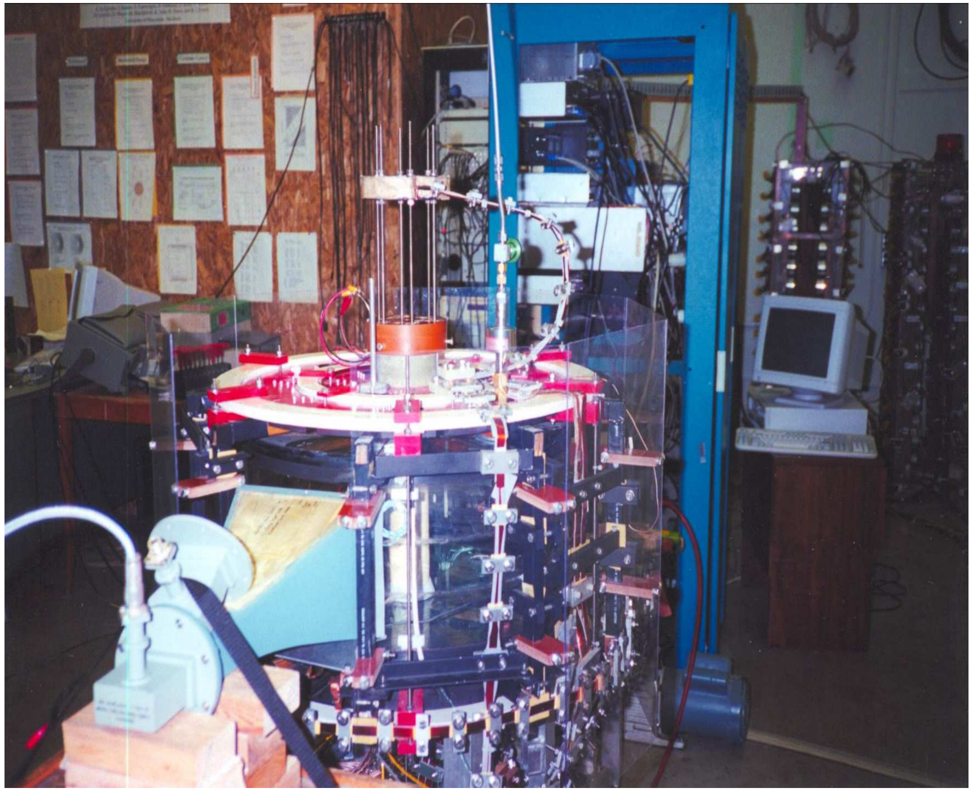
- The Instituto Tecnológico de Costa Rica at Cartago is in the process of transfering it, in order to re-comission it as a training device, as well as to test some ideas.

MEDUSA Tokamak [5]

Madison EDUcational Small-Aspect-ratio (MEDUSA) tokamak

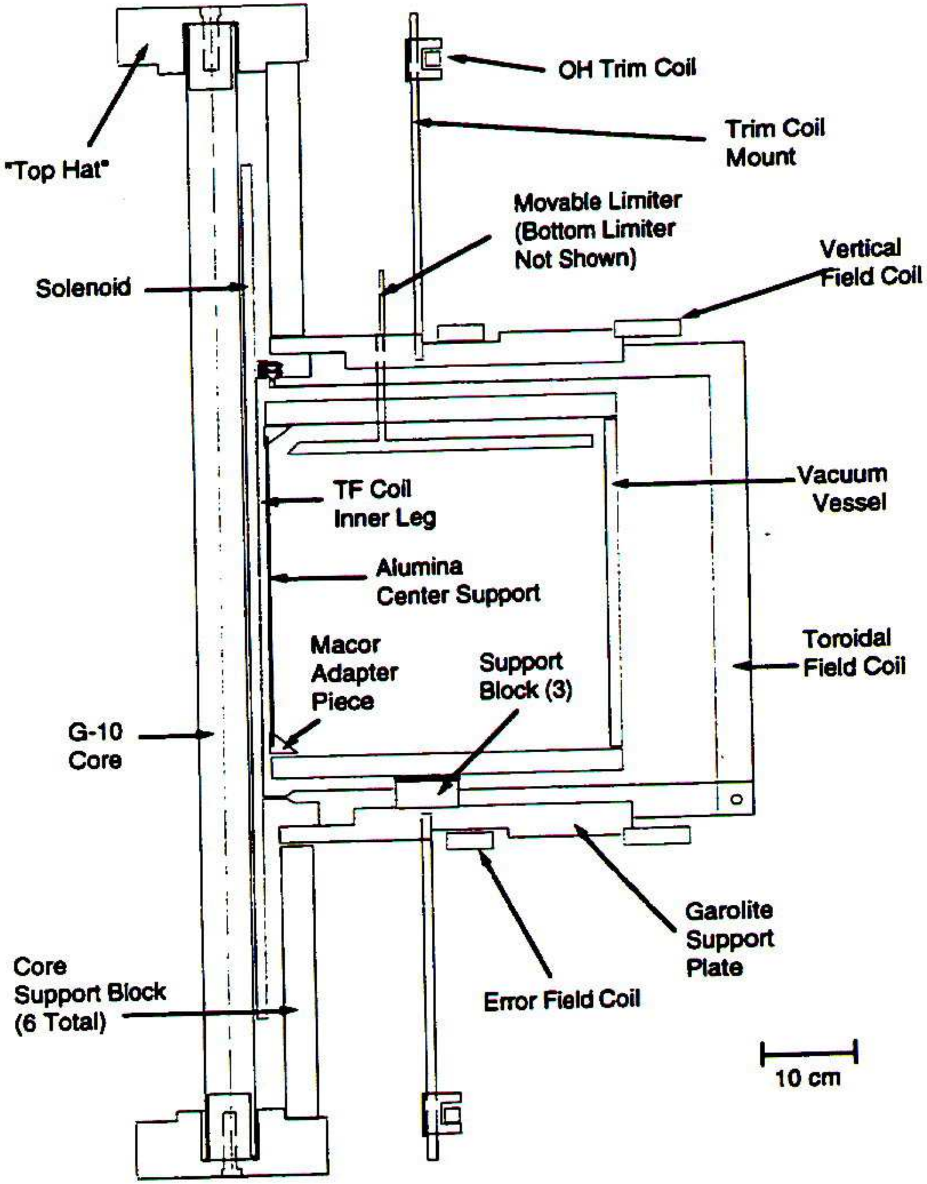


MEDUSA under construction at Wisconsin University, Madison, by 1996



MEDUSA in operation by 1997 with associated equipment and diagnostics

MEDUSA parameters [5]



R = 0.09-0.14m;

a = 0.04-0.10m;

R/a = 1.5 (1.35min);

Ip = 20kA (40kA max);

$B_T(0)$ = 0.3T (0.5T);

ne(bar) = 2-5x$10^{19}$$m^{-3}$;

Te(0) ~ 100eV;

Pulse length: 1ms (3ms max);

basic pressure:
≤ 5 x10^{-8} mbar

The 3D-Maptor code [6,7]

- The 3D-Maptor code has been adapted to simuate the magnetic field in the MEDUSA Tokamak, and study the effect of axisymmetry breaking by external coils. This is achieved by including circular tilted coils, either at the inner board or the outer board sides of the tokamak.

- The code is able to reproduce the magnetic configuration of a tokamak, starting from real data, such as the geometry of the coils and their currents. This has allowed the reconstruction of plasma columns from experimental data, even for cases when the plasma is not in equilibrium [7].

- The toroidal magnetic field is computed from the individual fields of rectangular coils arranged around the torus.

- The magnetic field of the vertical field and tilted perturbing field coils is obtained, in terms of elliptic functions, for circular loop circuits, as shown in Ref. [8].

The 3D-Maptor code [6,7]

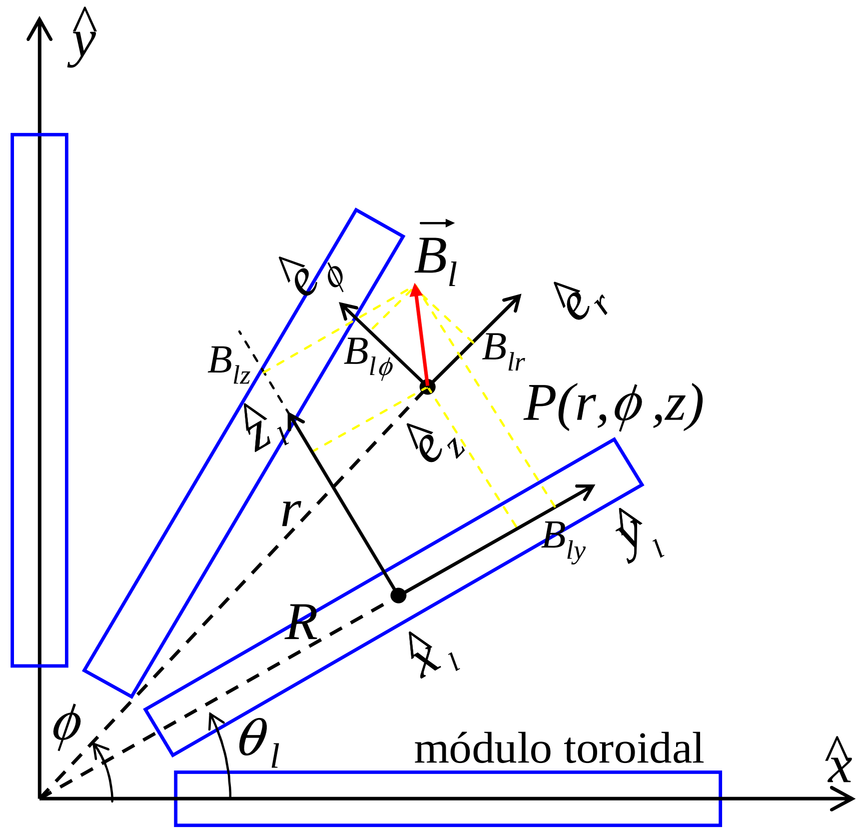
- Since the code admits any possible combination of currents, for a study like the one proposed in this work, an equilibrium configuration must be fed into it. We adopt an equilibrium obtained experimentally in MEDUSA by G.D. Gartska.

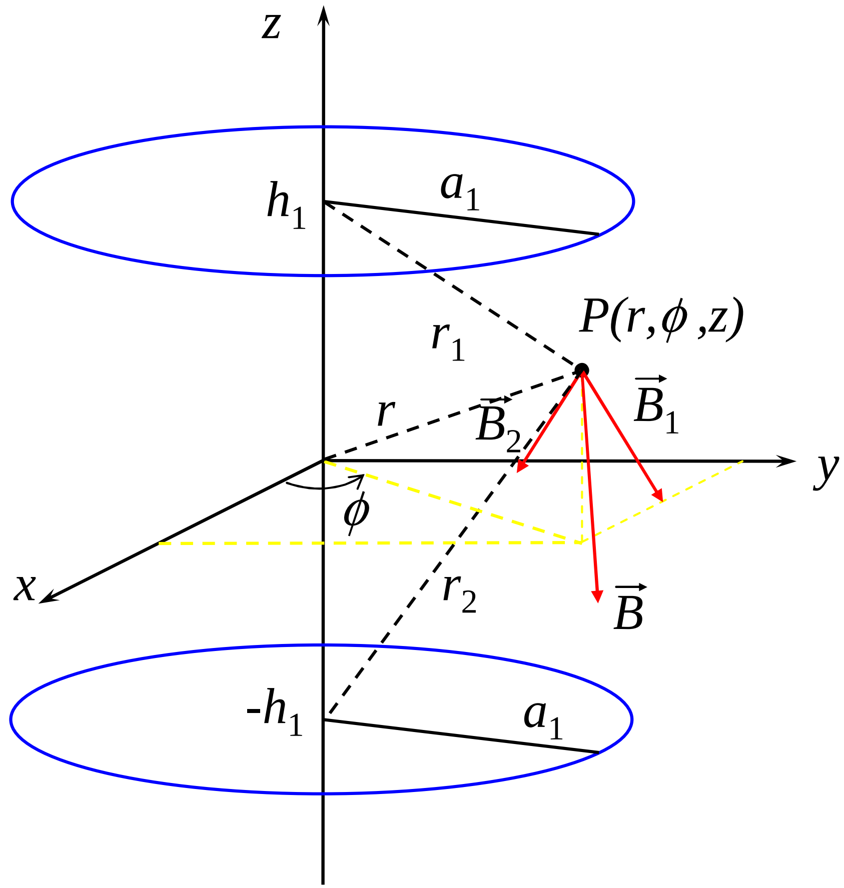
- An analytical D-shaped current density profile is chosen in such a way that it approaches that of Gartska’s equilibrium.

- As the magnetic field lines are obtained by integration, initial conditions are chosen for them, at different radii at the equatorial plane.

The 3D-Maptor code [6,7]

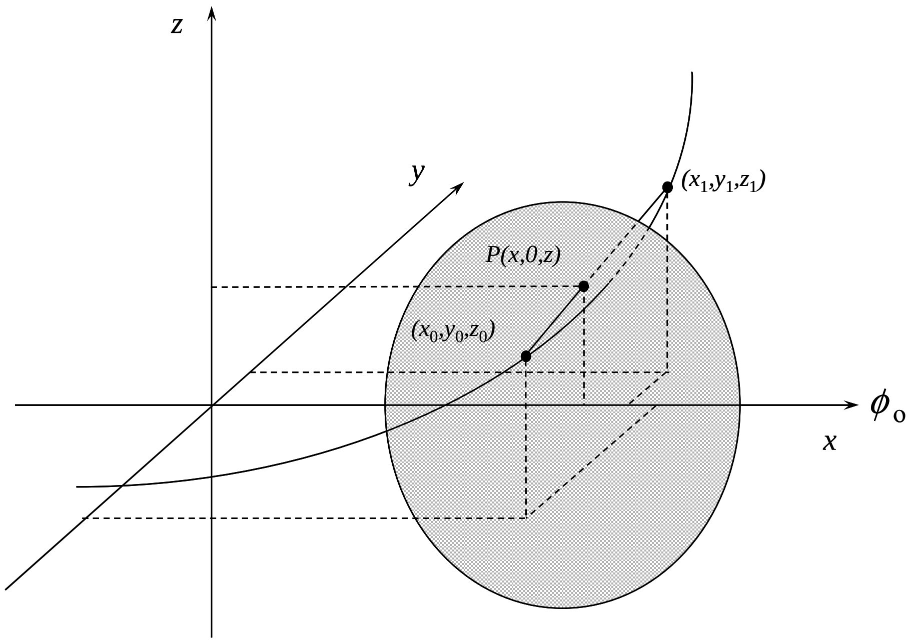
The magnetic fields produced by the different coils are built from that of a circular loop, and for the case of this study, rectangular toroidal field coils.





The 3D-Maptor code [6,7]

The total magnetic field is numerically integrated, given an initial condition. The coss section surface at any toroidal angle can be chosen for the generation of the Poincaré map.



$$\boxed{\frac{dx}{B_x} = \frac{dy}{B_y} = \frac{dz}{B_z} = \frac{ds}{B}}$$

D-shaped current density profile

The D-shaped current density profile is modelled by a quadratic polinomial in the Z direction, and a fourth-order polinomial in the R direction:

$$F(R,Z) = \left(1 - \frac{Z^2}{Z_o}\right)\left(a + bx + cx^2 + dx^3 + ex^4\right)$$

a = 0.350583

b = -19.3513

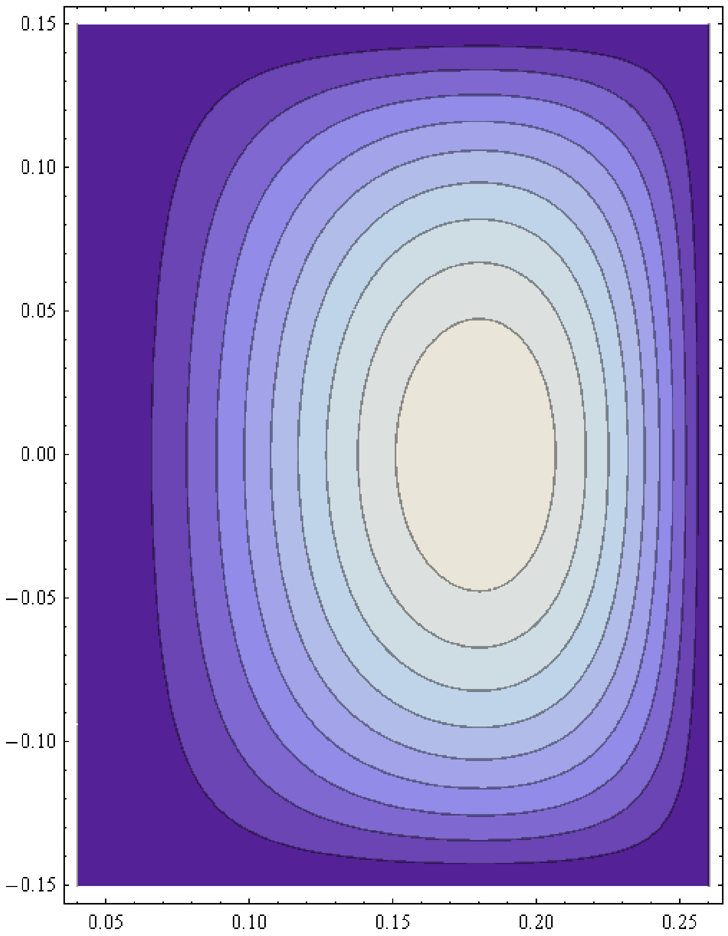
c = 312.044

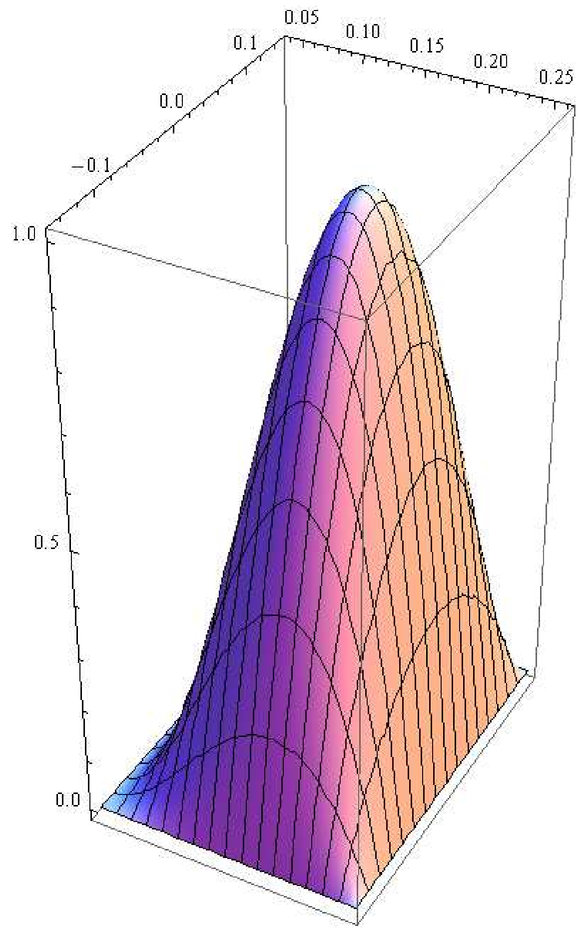
d = -1229.96

e = 1138.85

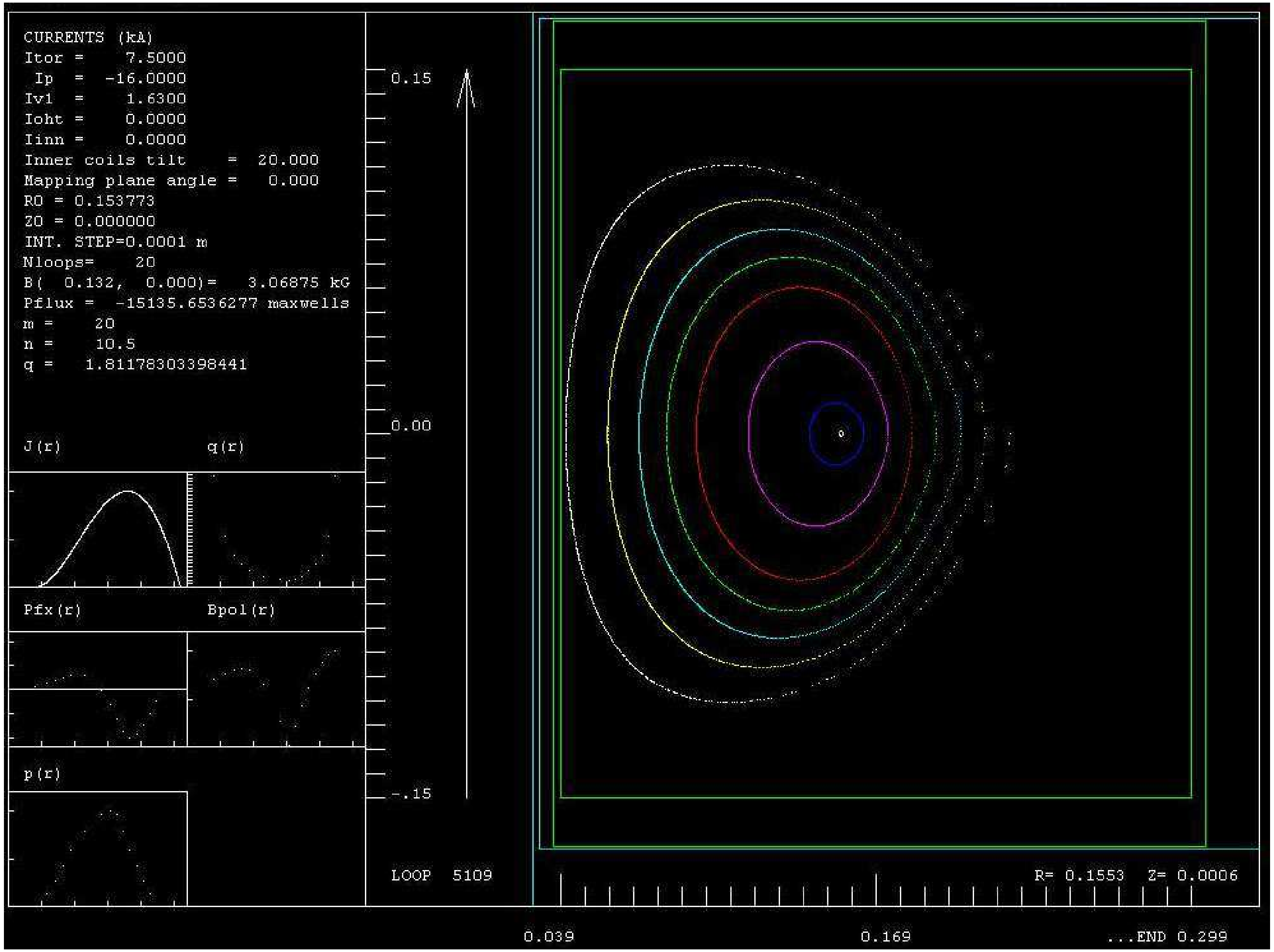
Zo = .15

D-shaped current density profile



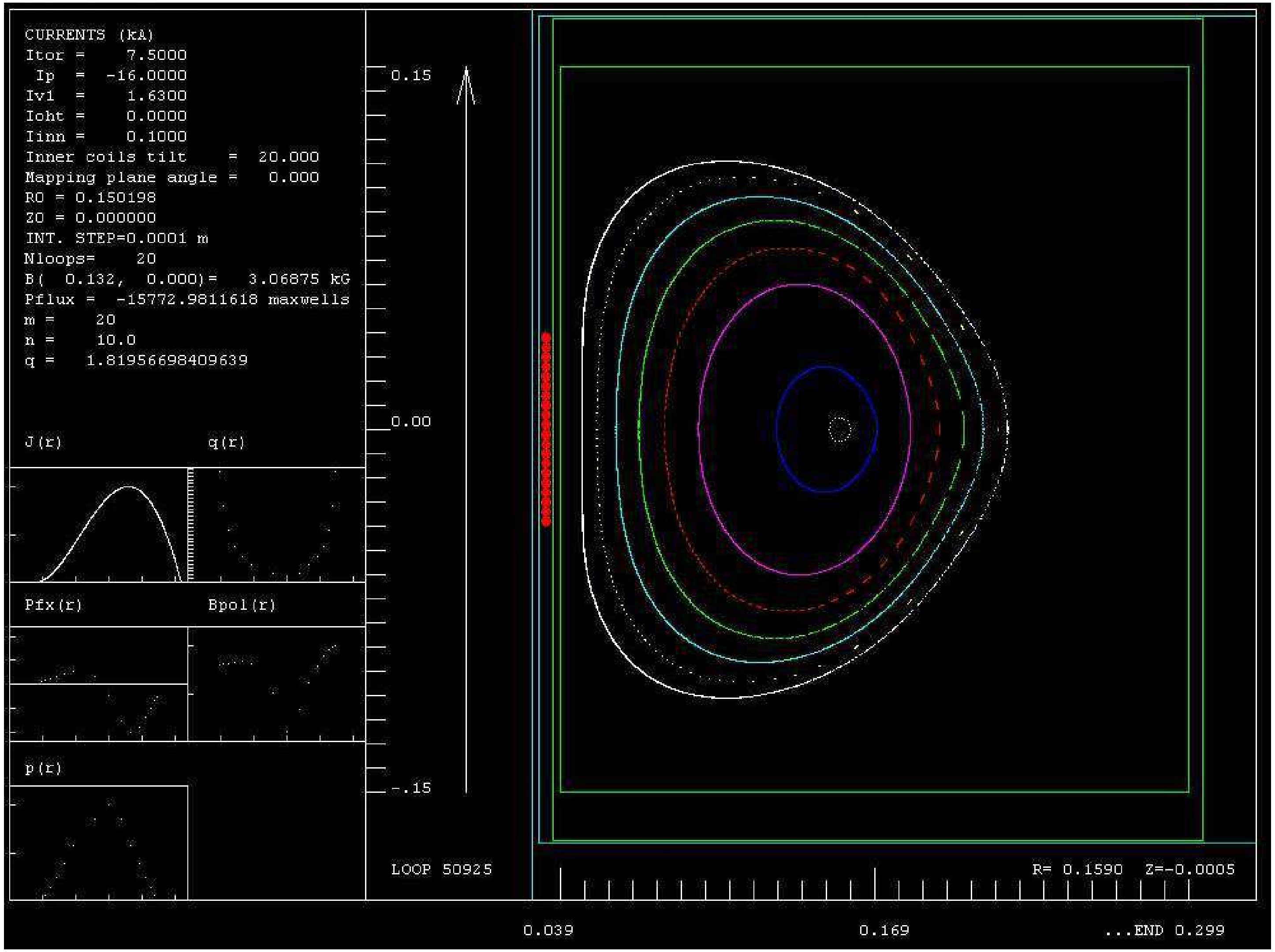


0º Tilt

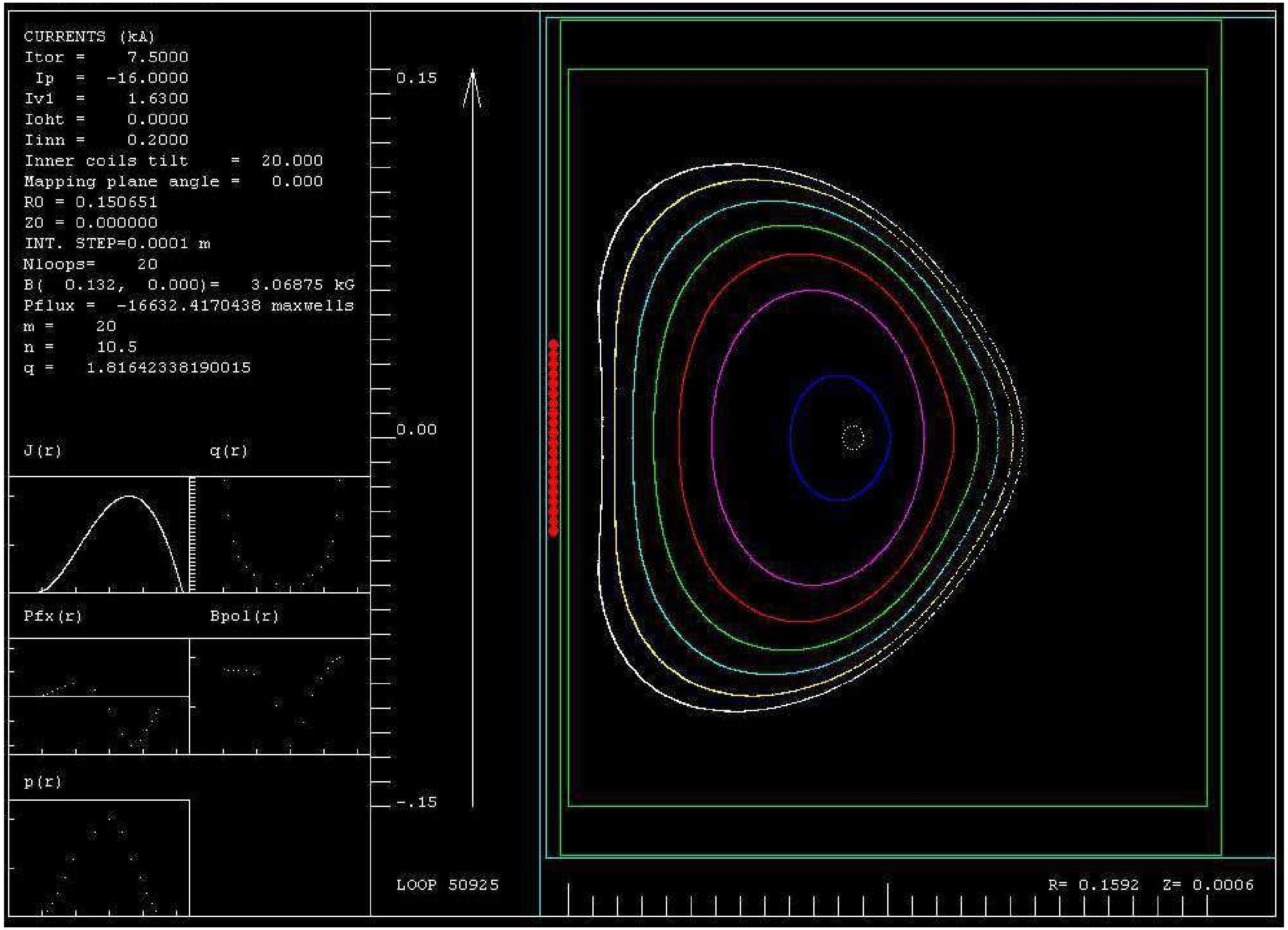


CURRENTS (kA)
Itor = 7.5000
Ip = -16.0000
Iv1 = 1.6300
Ioht = 0.0000
Iinn = 0.0000
Inner coils tilt = 20.000
Mapping plane angle = 0.000
R0 = 0.153773
Z0 = 0.000000
INT. STEP=0.0001 m
Nloops= 20
B(0.132, 0.000)= 3.06875 kG
Pflux = -15135.6536277 maxwells
m = 20
n = 10.5
q = 1.81178303398441
J(r)
q(r)
Pfx(r)
Bpol(r)
p(r)
0.15
0.00
-.15
LOOP 5109
R= 0.1553 Z= 0.0006
0.039
0.169
...END 0.299

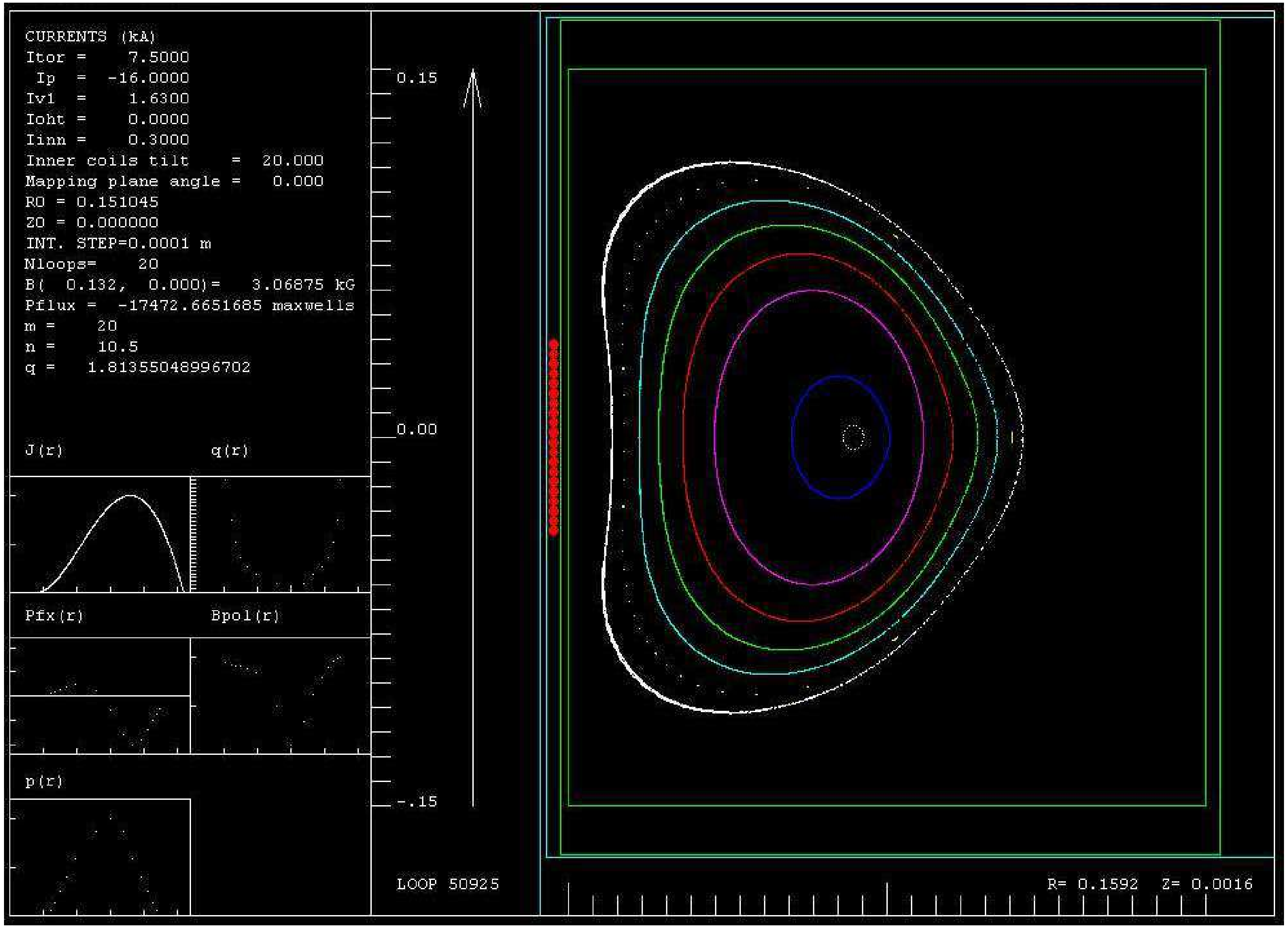
20º Tilt, $I_{ti} = 100\ Amp$



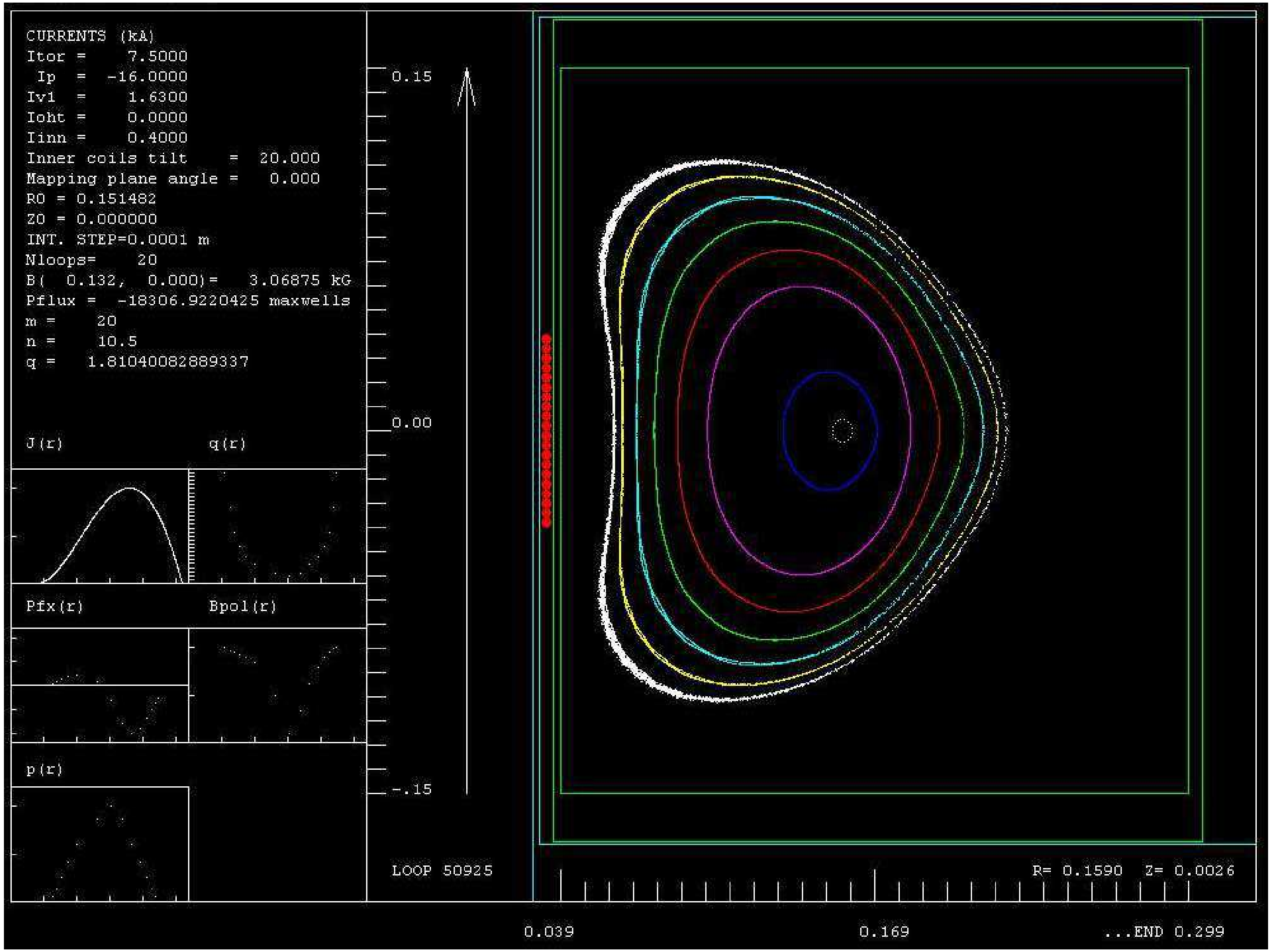
20º Tilt, $I_{ti} = 200\ Amp$



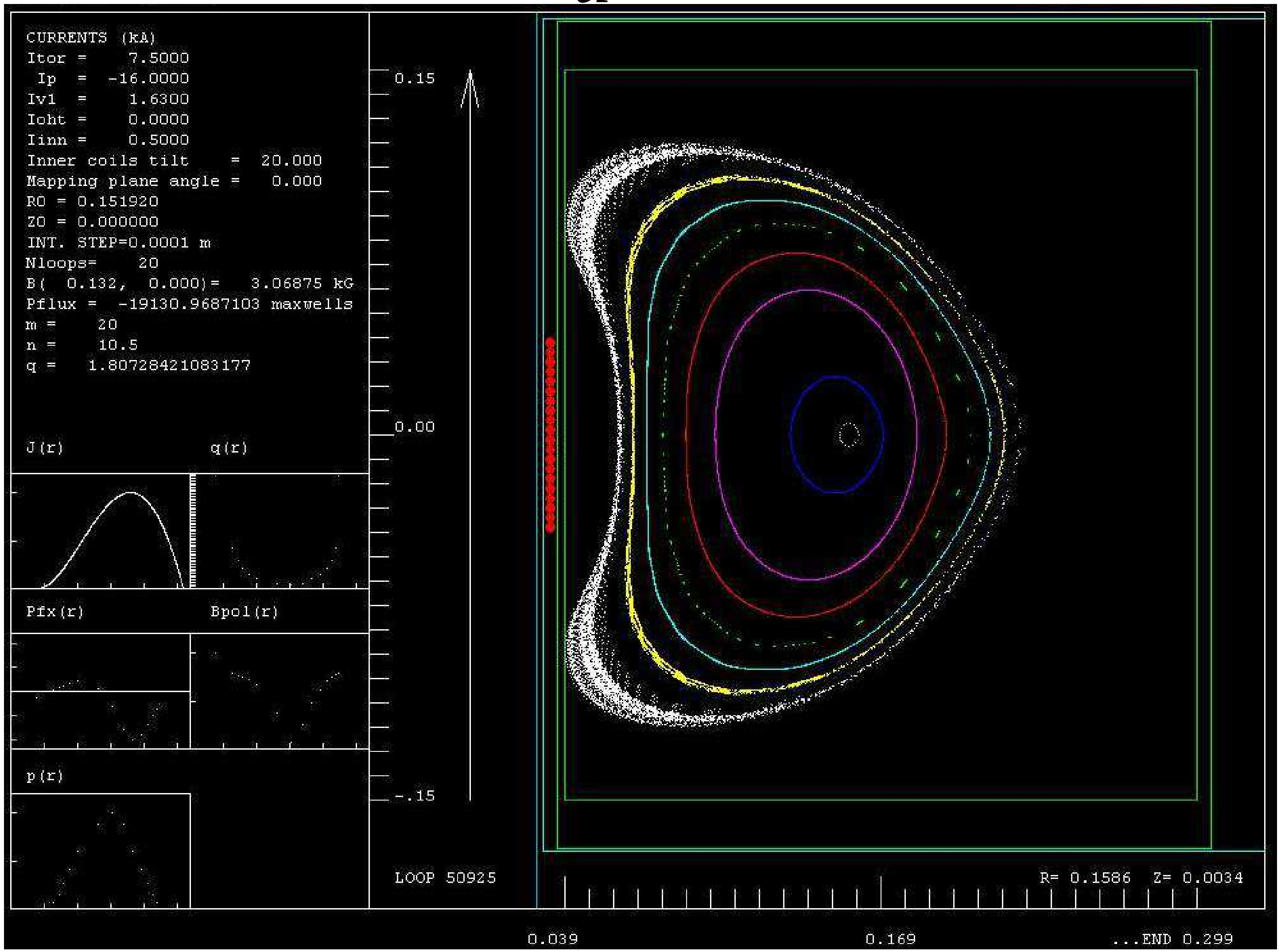
20^{o} Tilt, $I_{ti} = 300\ Amp$



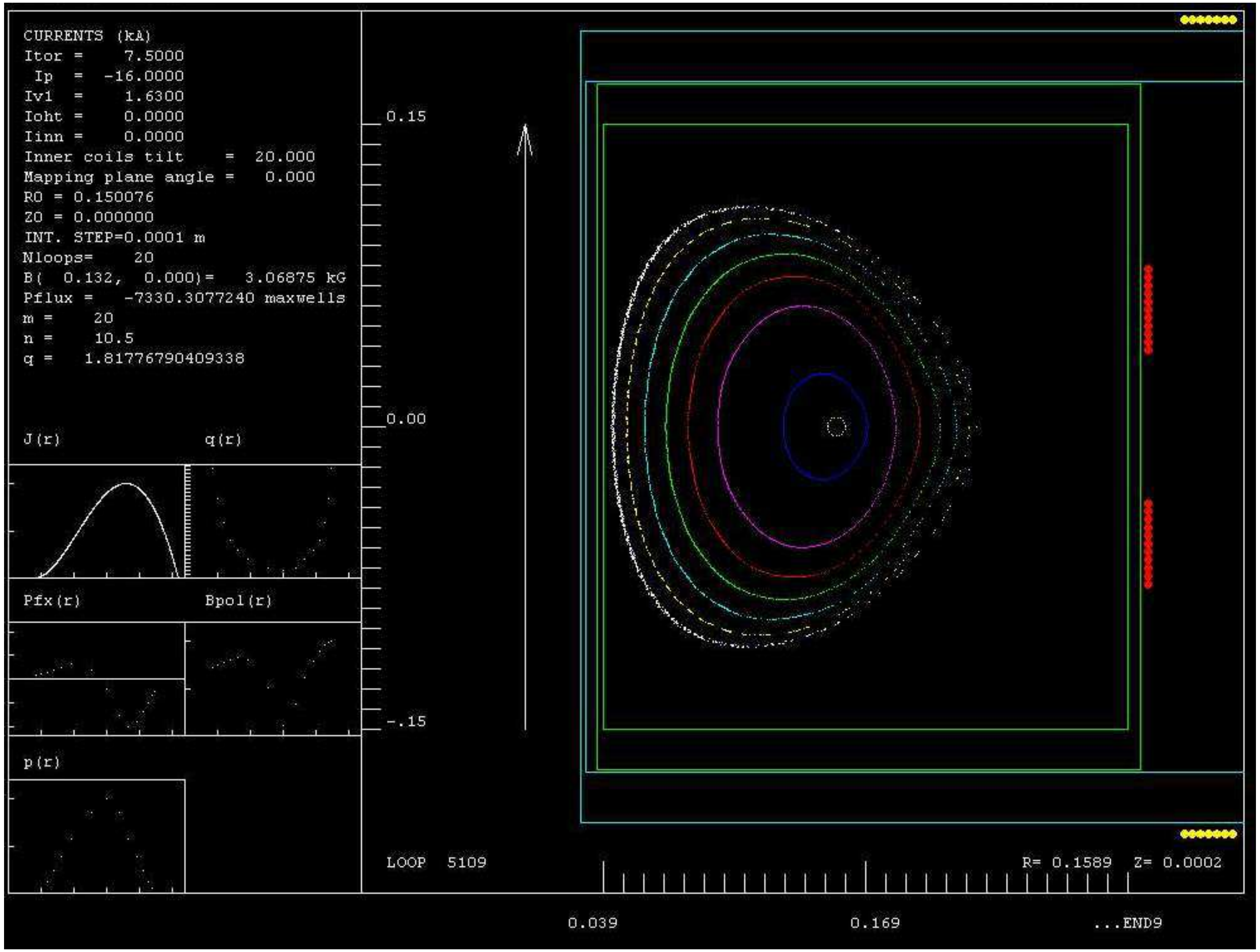
20^{o} Tilt, $I_{ti} = 400\ Amp$



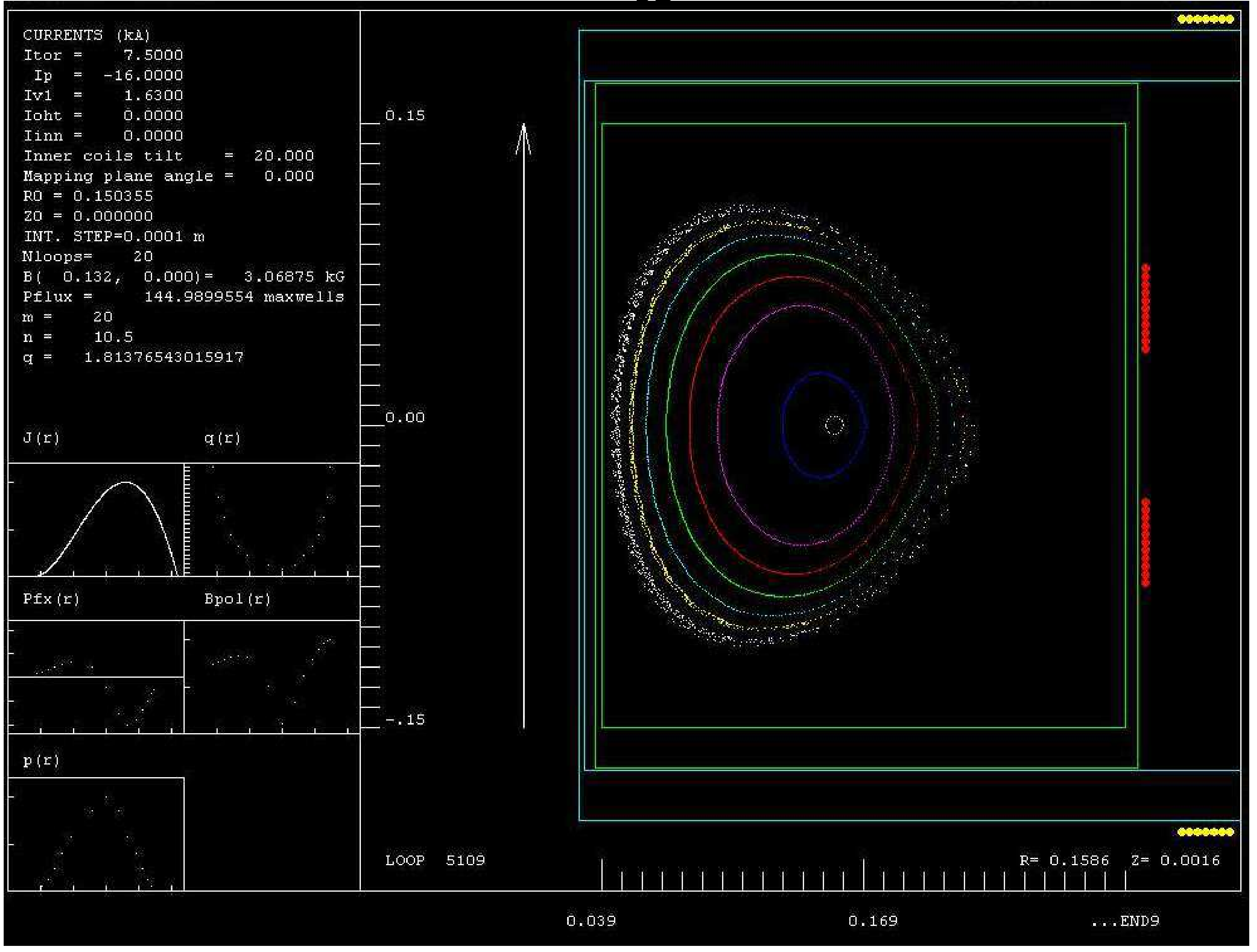
20^{o} Tilt, $I_{ti} = 500\ Amp$



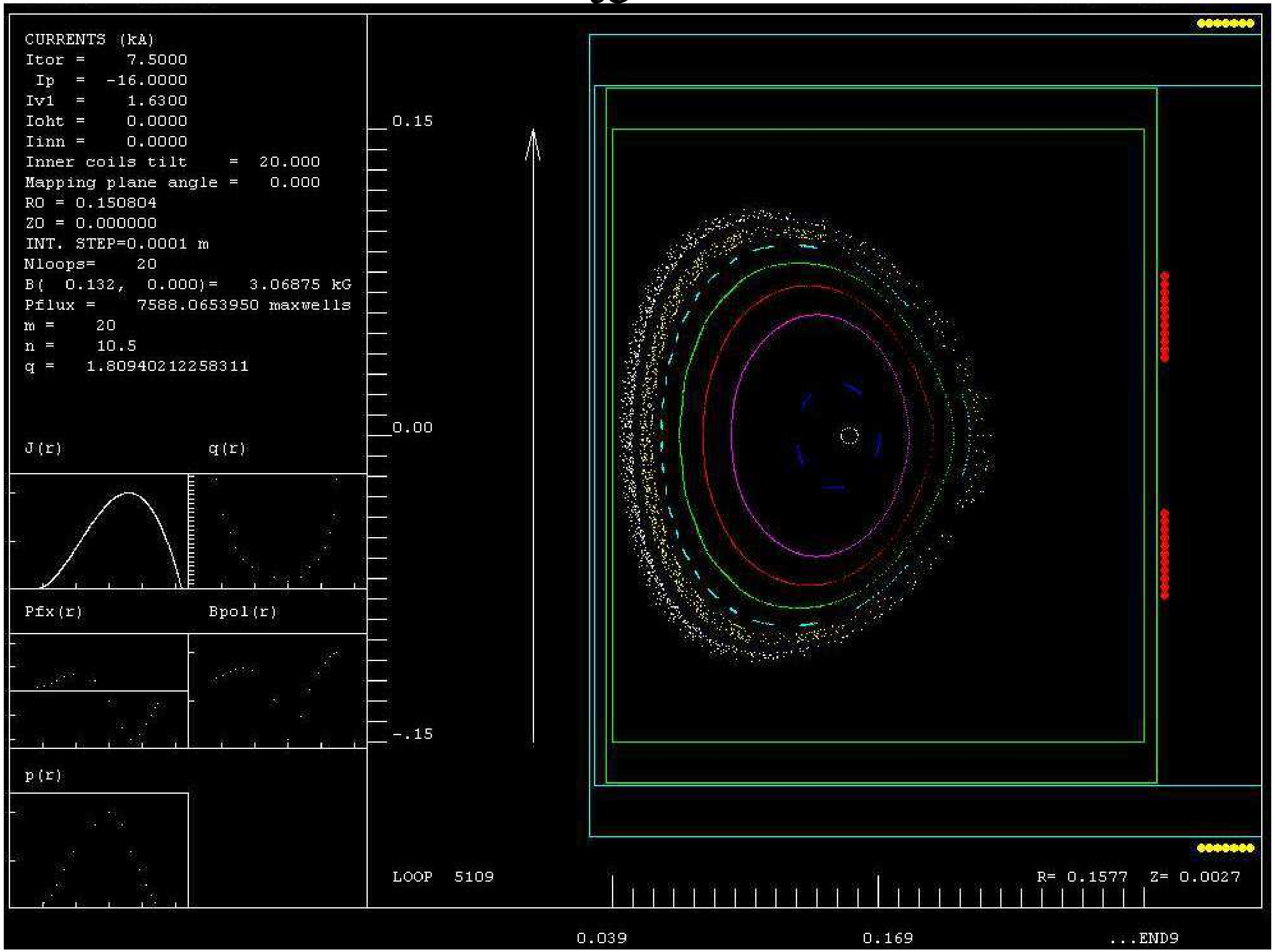
20^{o} Tilt, $I_{te} = 5\ Amp$



20^{o} Tilt, $I_{te} = 10\ Amp$



20^o Tilt, I_{te} = 15 Amp



Conclusions

- Strong ergodization effects have been observed over the poloidal cross section by using relatively low perturbation currents to the plasma current (few percent).

- Ergodization is improved if the perturbation comes from external, rather than from internal tilted coils. Much smaller currents are needed, and the deformation of the plasma cross section is greatly reduced.

- The ergodization is more pronounced on the inboard than on the outboard side, due to the longer magnetic field transit time in that region.

Conclusions

- In the case of internal tilted coils, estimates of the ergodization layer show that it does not scale linearly with the perturbative currents and also seem larger at the top and bottom of the inboard side region, near to the vertical elongation axis. Therefore, it is expected that the flattening of basic plasma profiles in these regions will be rapidly transferred to the inboard side due to the shorter magnetic connection length between the top inboard and outboard regions, inherent of the low aspect ratio tori geometry.

- This can lead to a "natural" more uniform poloidal wall power load for spherical tokamaks, helping the studies for alternatives to overcome the general problem of the intolerable X-point divertor power load, and also having similarities with NSTX experiments where flattening the edge outboard plasma is created by lithization instead.

- An interesting bean-shaped plasma is easily and naturally created in this simulations, and can potentially enhance even further the already high beta observed in the spherical tokamak plasmas, while simultaneously tackling the problem of the power load.

References

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