Modeling separatrix splitting and magnetic footprints in TCABR

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Introduction

Plasma instabilities are still a concern when thermonuclear conditions are approached as they can impose severe constraints on the maximum achievable plasma performance. When operating in the so-called high confinement mode (H-mode) a very steep plasma pressure profile is formed in the plasma edge, which leads to repetitive instabilities known as edge localized modes (ELMs). The crash of these modes leads to high transient heat fluxes onto the divertor plates, significantly reducing the lifetime of it's components. Experiments have demonstrated that externally applied resonant magnetic perturbations (RMPs) can be used to control the plasma edge stability thus providing a way to trigger ELMs prematurely. A significant upgrade of the Tokamak à Chauffage Alfvén Brésilien (TCABR) is being designed to make it capable of creating a well controlled environment where the physics basis behind the effect of RMP fields on ELMs can be addressed.

Development

A new set of RMP coils

The core of this upgrade corresponds to the design and construction of an innovative set of in-vessel ELM control coils composed of six toroidal arrays of coils equally spaced in the toroidal direction: three on the high field side (HFS) and three on the low field side (LFS). Each array will be composed of 18 coils, i.e. a total of 108 coils will be installed inside the TCABR vacuum vessel.

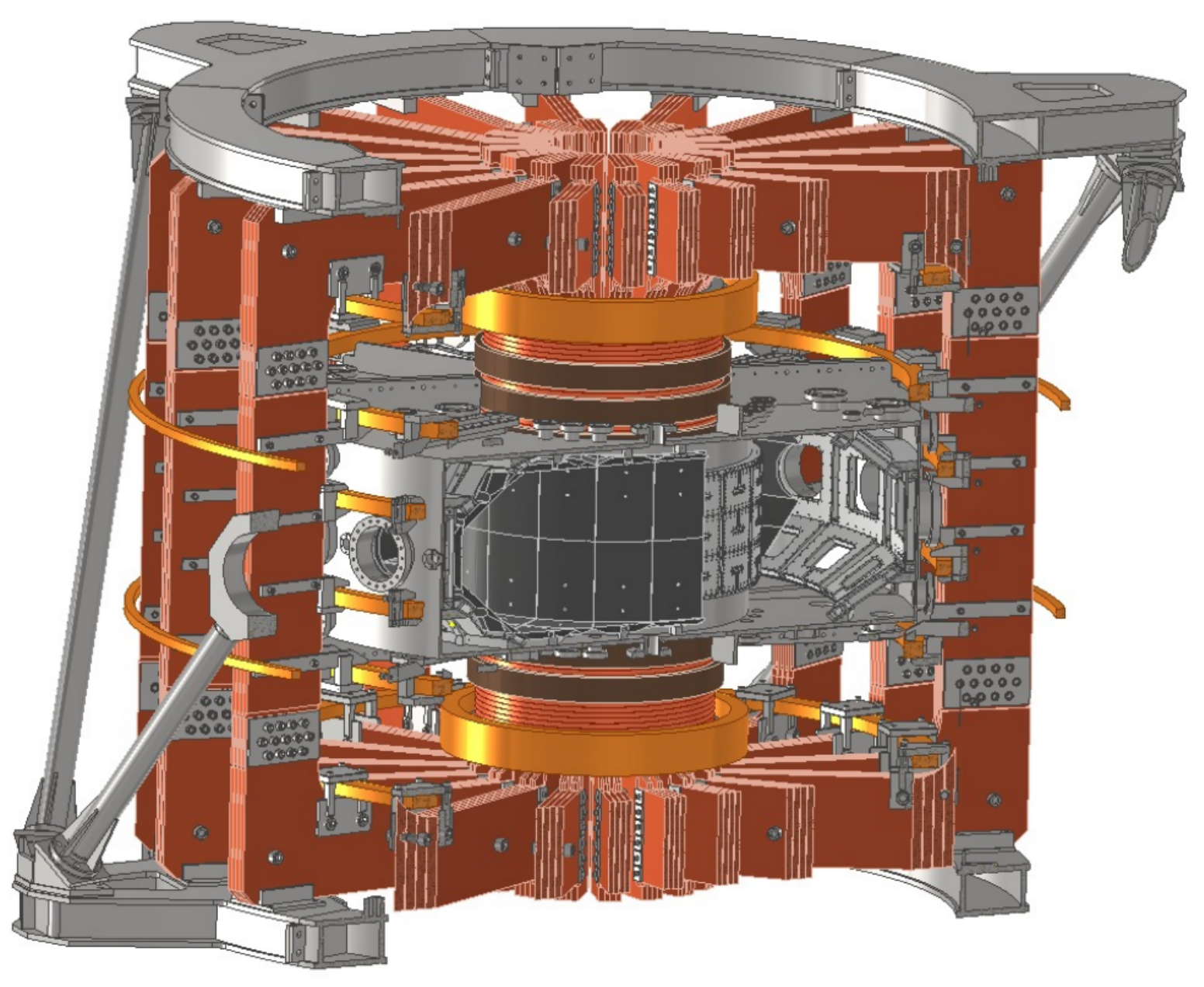

Figure 1: 3D model of the upgraded TCABR tokamak

Modeling the magnetic field produced by these non-axisymmetric coils is a fundamental step for their design and use during future experiments. By combining the fields from each of these toroidal arrays of coils, one can create localized peaks in the resonant profile and position them at various points across the pedestal, giving us better control over the RMP field spectrum, degree of island overlap and open field line loss fraction. The spectrum of the RMP field is characterized by the amplitude of the harmonics of the component of the perturbed magnetic field that is normal to the unperturbed magnetic flux surfaces.

$$\delta B_{m,n}(\psi) = \frac{1}{4\pi^2 A}\int_0^{2\pi}\int_0^{2\pi} \frac{\delta \mathbf{B}\cdot\nabla\psi}{\mathbf{B_0}\cdot\nabla\theta^*} e^{-i(m\theta^*-n\phi)}\, d\theta^* d\phi,$$

Modeling RMP coils magnetic field

In this project, to estimate the vacuum magnetic field produced by this set of coils in the plasma region, the geometry of the conductors of each coil is modeled using sufficiently small rectilinear segments of current. Each one of the filaments constituting the coils was individually modeled.

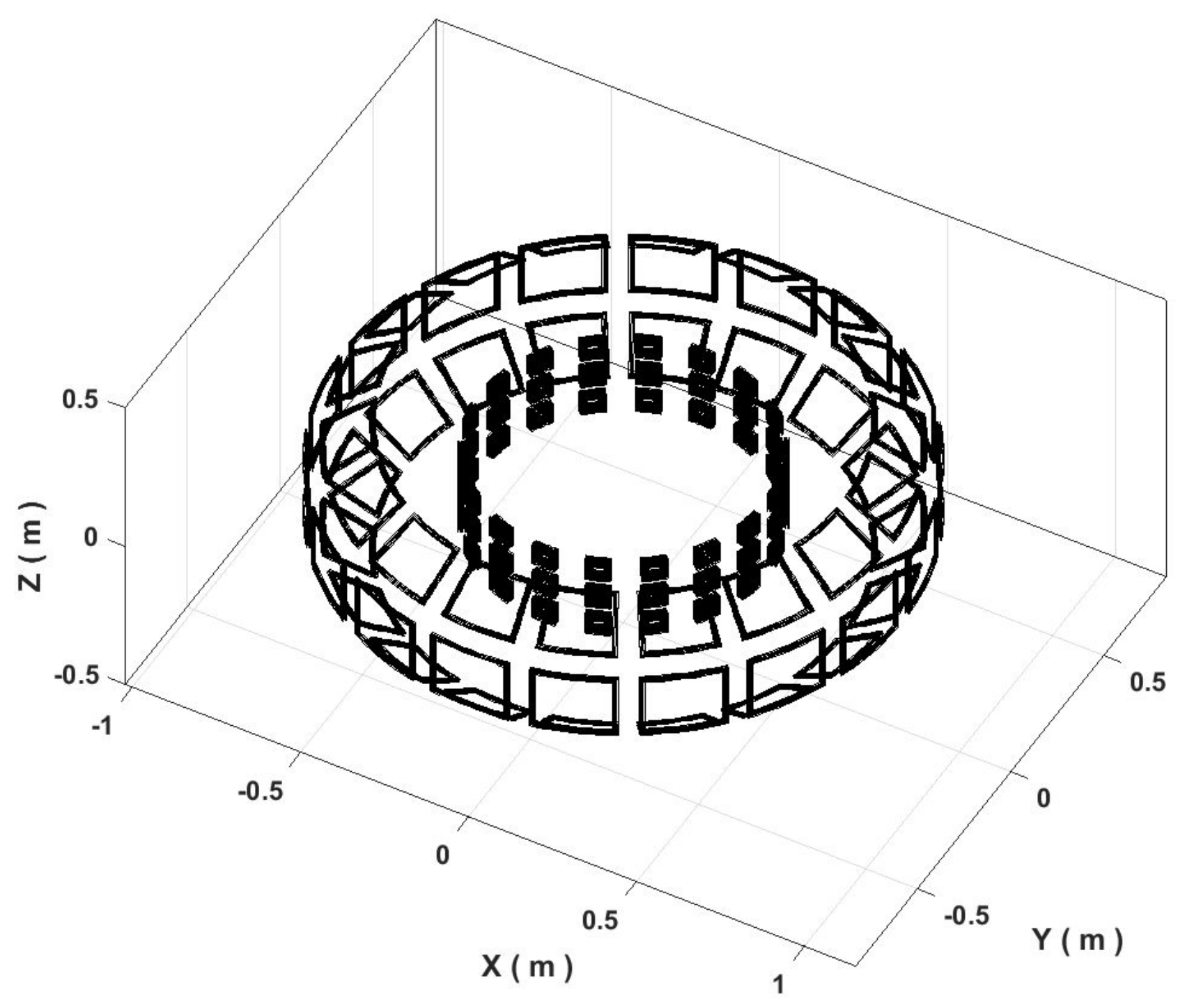

Figure 2: Discretized vitual model of the complete 108 RMP coils set

Subsequently, the magnetic field created by each segment is calculated using the Biot-Savart law.

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0 I}{4\pi}\int \frac{d\mathbf{l}'\times(\mathbf{r}-\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|^3}$$

With both the geometry and the electric current of each coil being given, the perturbed magnetic field distribution inside the TCABR vacuum vessel can be calculated for various plasma scenarios, including the field spectra.

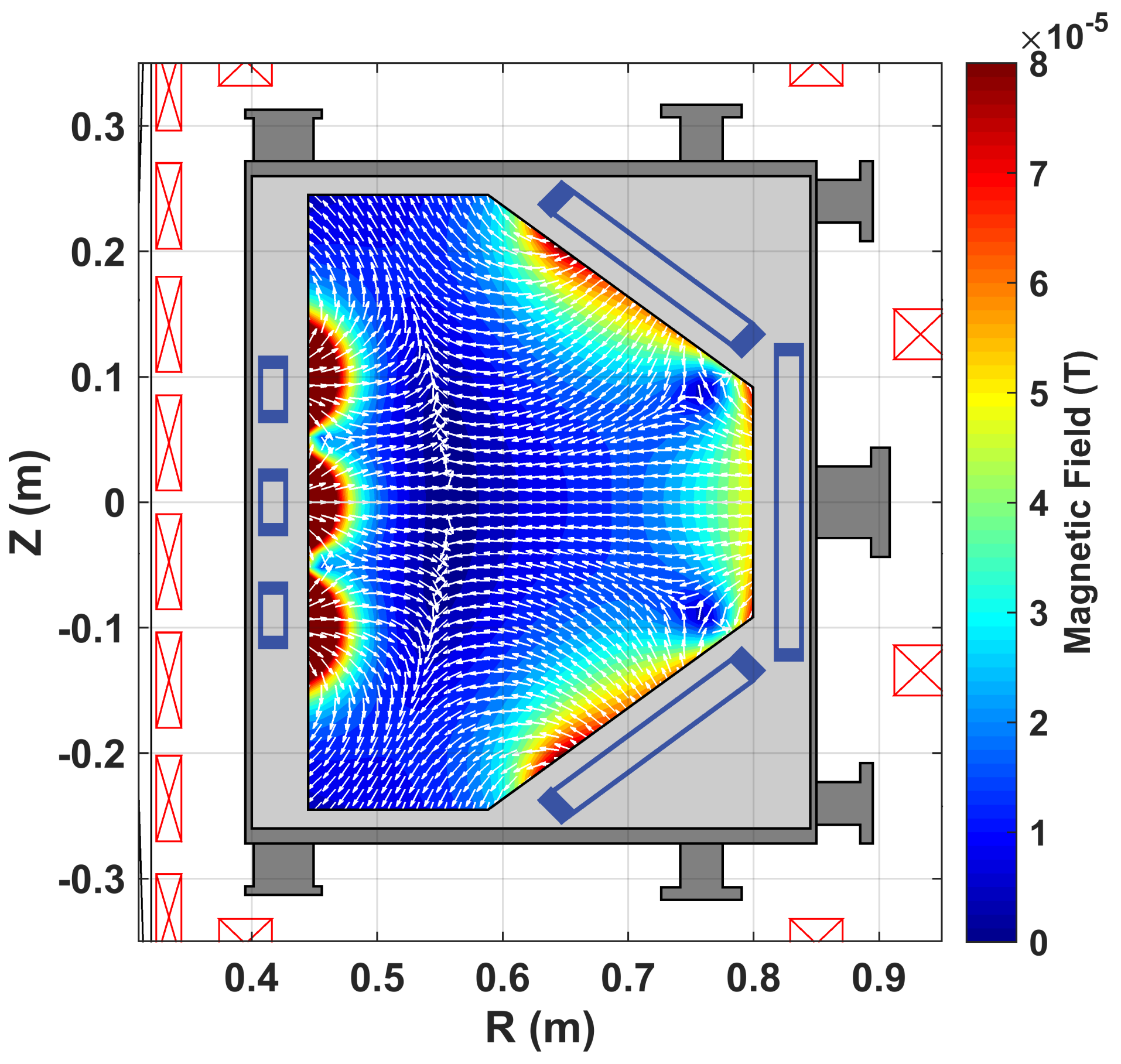

Figure 3: TCABR poloidal cross section displaying the magnetic field generated by six coils subjected to the same 1 A current

Modeling Magnetic footprints

Controlling the intersection of magnetic lobes with divertor target plates is also an important issue to maintain the integrity of the plasma facing components as it controls the levels of heat and particle deposition on the target plates surface. Therefore, the calculated perturbed magnetic field is also used to model the separatrix splitting, magnetic lobes and footprints for various plasma scenarios in TCABR. A computational code is, hence, being developed to follow the three dimensional field lines of the perturbed plasma configuration in order to track and register the points in which the divertor plates are intercepted by them, potentially inflicting damage due to great heat transfer.

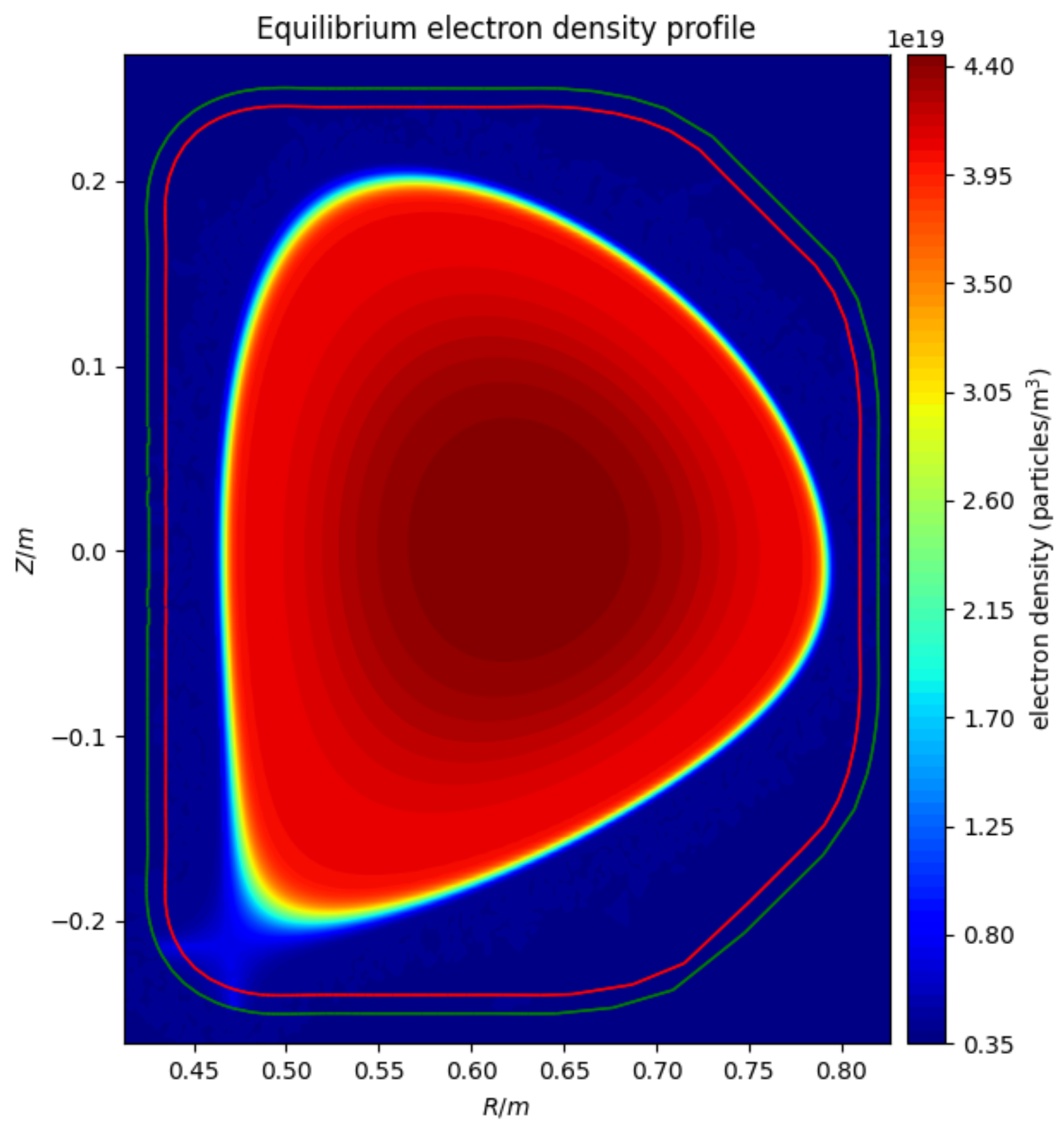

Figure 4: M3DC-1 simulation of equilibrium electron density profile

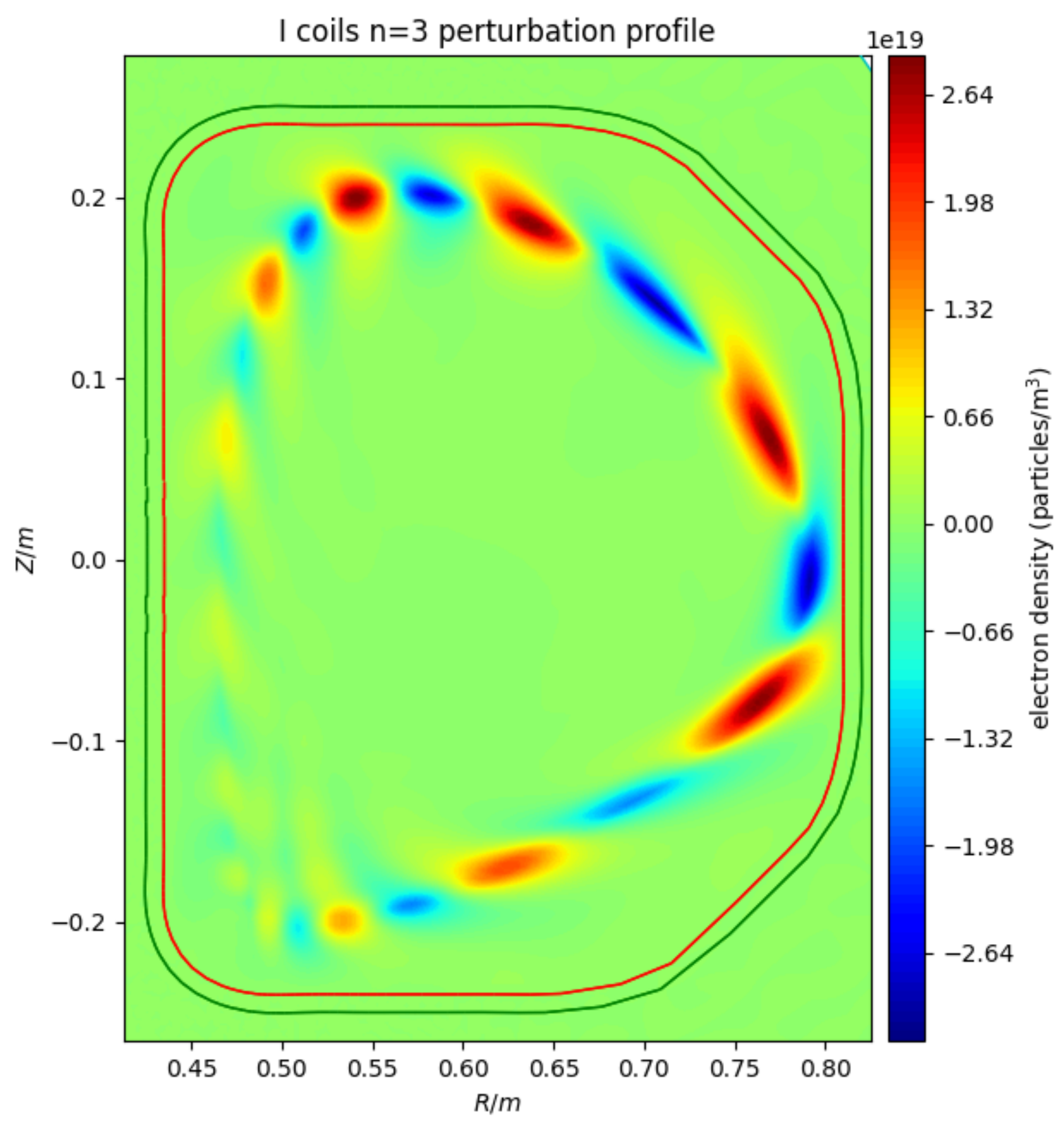

Figure 5: M3DC-1 simulation of perturbed electron density profile

From the M3DC-1 simulation data, using integrated modules from the Fusion-IO code, the program in development is capable of numerically integrating over the perturbed magnetic field lines, computing it's connection length on each of the plates' hit points.

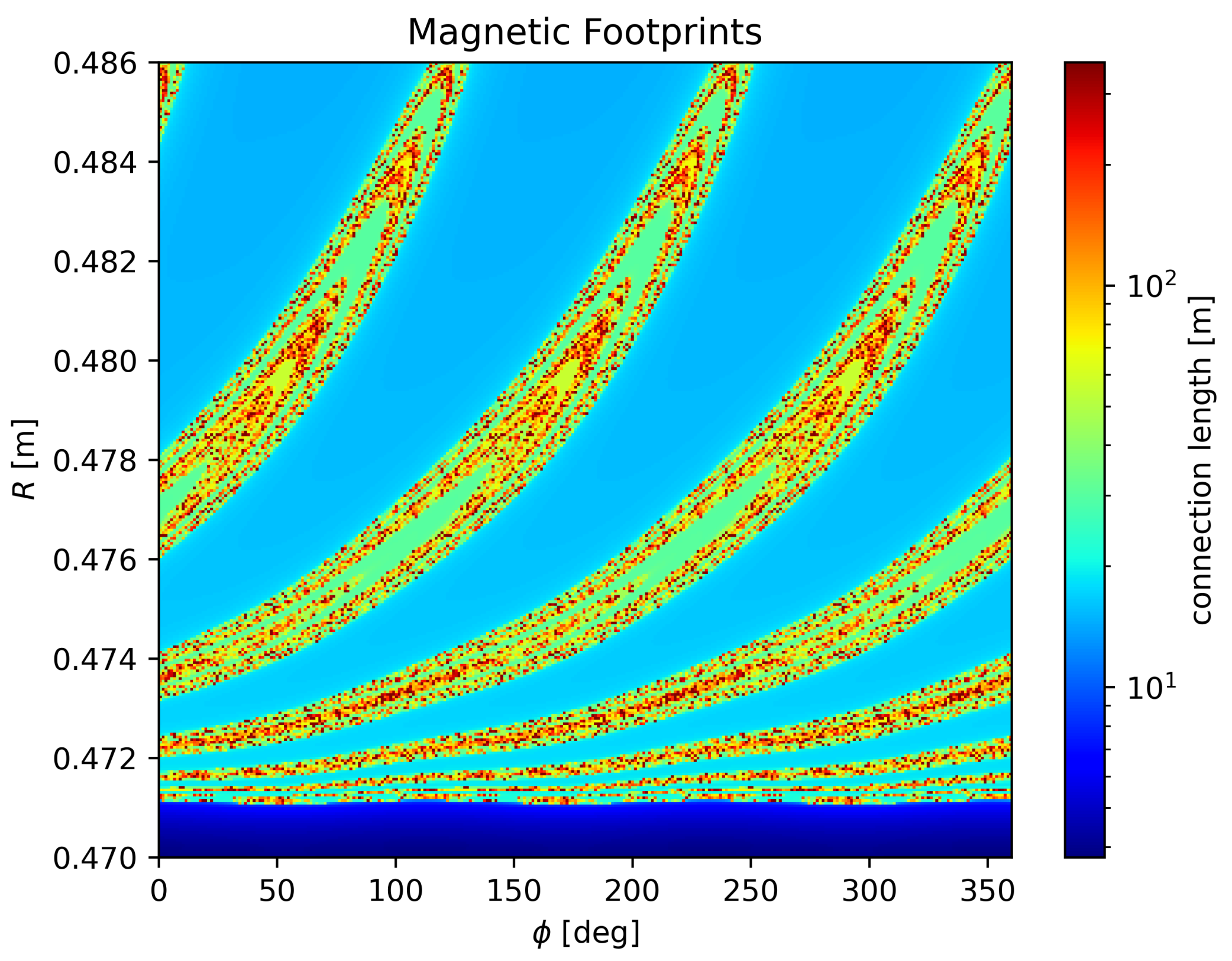

Figure 6: Magnetic footprints simulation of a plasma subjected to a n=3 perturbation produced by the low field side coils

The obtained simulated footprints will later be compared to the actual hot spots observed on the machine's divertor in order to improve the physical model and damage mitigation techniques.

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