# Toroidal plasma response modeling for ELM control optimization via RMPs in perspective DTT plasmas

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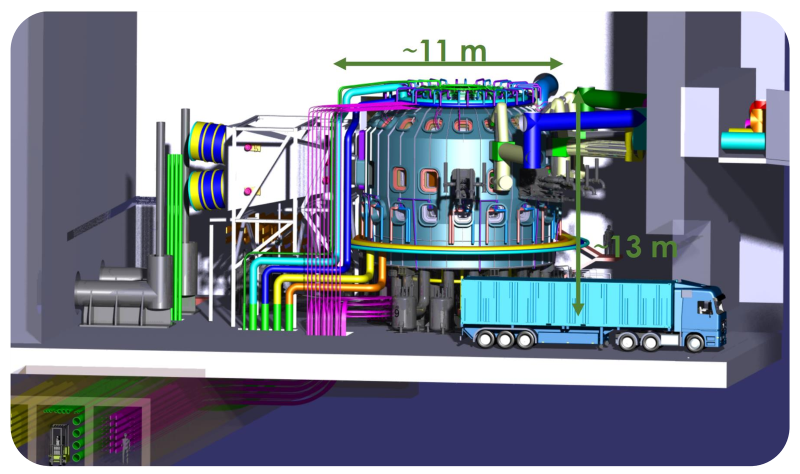
Type-I Edge Localized Modes (ELMs) are strong bursts that eject particles and energy from the plasma

- ELM behavior is correlated to peeling-ballooning stability and can be therefore modified with external magnetic perturbations [1-3] often referred to as Resonant Magnetic Perturbations (RMPs)

The Divertor Tokamak Test (DTT) facility is a large superconducting tokamak conceived to develop power exhaust solutions in view of DEMO [4,5]

- ELM control is a task of particular importance for DTT operations




$\mathbf{B_t = 6\ T}$
$\mathbf{I_p = 5.5\ MA}$

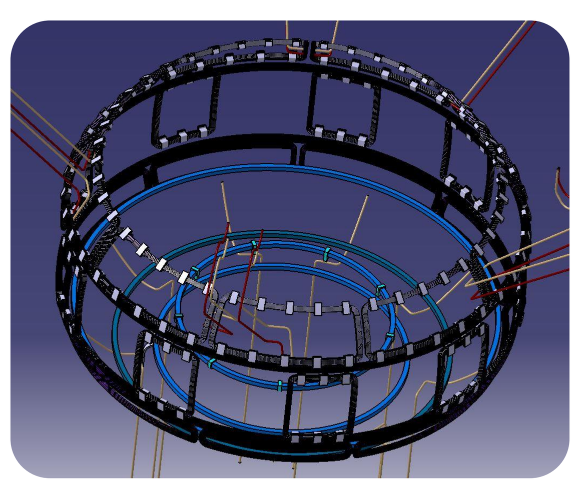
- ✓ Integration of exhaust with core performance in DEMO relevant conditions
- ✓ Joint European collaboration according to EUROfusion roadmap

A system of non-axisymmetric coils is being designed for the purpose of ELM and Error Field control on DTT

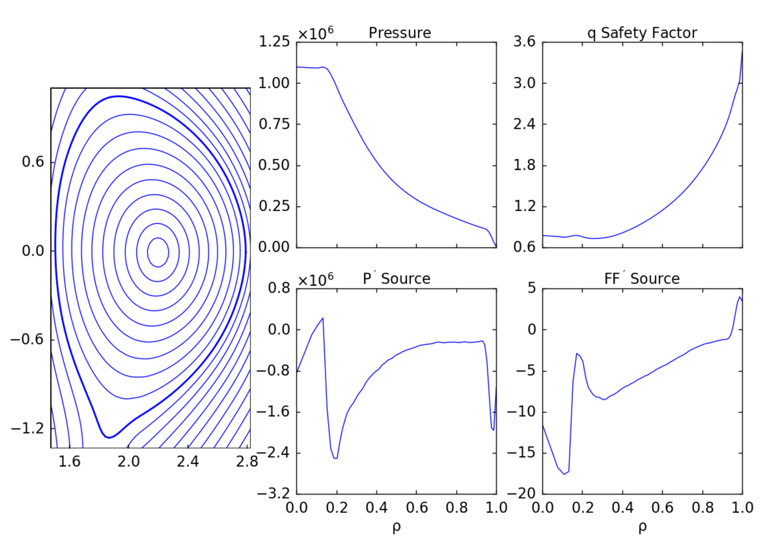
Linear resistive plasma response calculations with MARS-F [6] are used for a first assessment of the RMP requirements for ELM mitigation or suppression.

Different coil combinations and metrics are applied:

- Two rows off-midplane coils + equatorial array with half toroidal width
- X-point plasma displacement linked to ELM mitigation by empirical evidence
- Chirikov parameter expressing magnetic field line stochastization



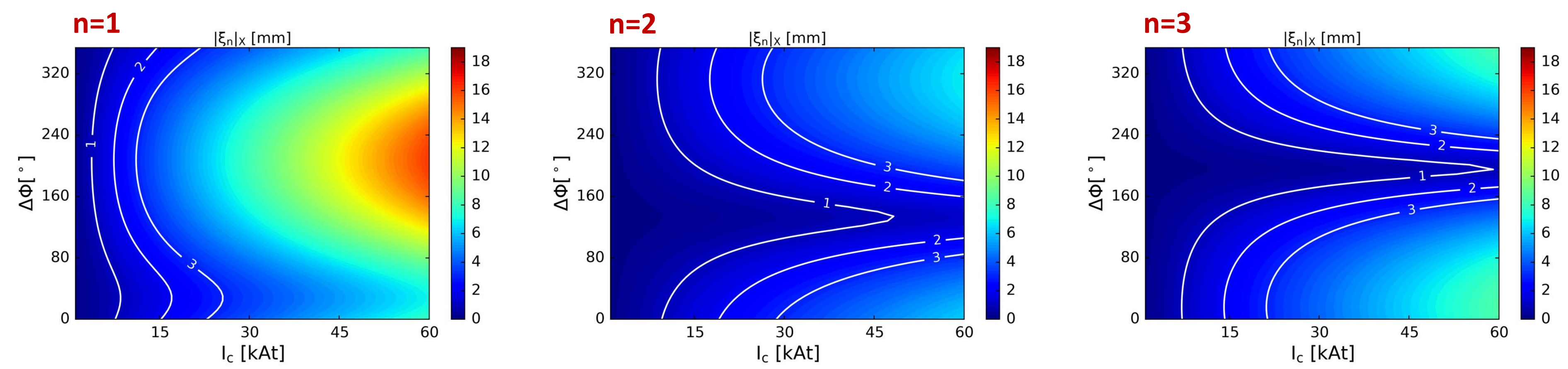
Realistic equilibrium for DTT full power phase [7] with consistent toroidal flow
- ✓ Proper calculation of resistive response



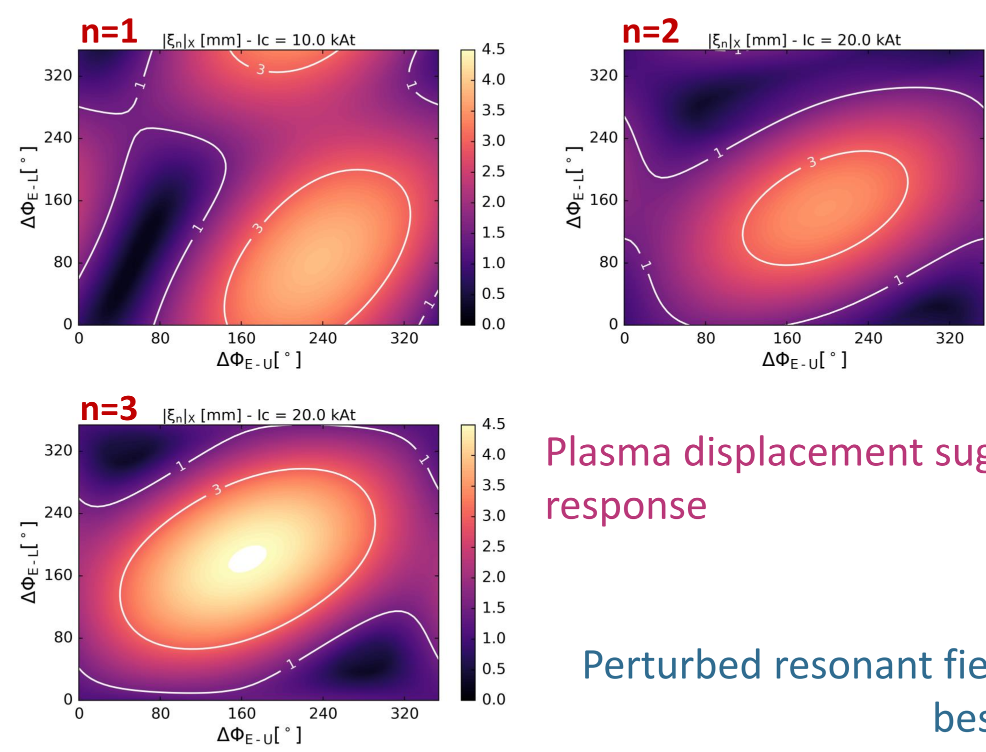

1. Evans, T.E., et al. (2006) Physics of Plasmas, 13, 056121
2. Kirk, A., et al. (2010) Nuclear Fusion, 50(3), 034008
3. Suttrop, W., et al. (2016) Plasma Physics and Controlled Fusion, 59(1), 014049
4. Martone, R., Albanese, R., Crisanti, F., Pizzuto, A., Martin, P. (2019) "DTT Divertor Tokamak Test facility Interim Design Report"
5. Ambrosino, R., et al. (2021) Fusion Engineering and Design, 167, 112330
6. Liu, Y. Q., et al. (2000) Physics of Plasmas, 7(9), 3681-3690
7. Casiraghi, I., et al. (2021) Nuclear Fusion, accepted
8. Kirk, A., et al. (2015) Nuclear Fusion, 55(4), 043011
9. Liu, Y.Q., Li, L. (2017) Computational nanotechnology, 2
10. Liu, Y.Q., et al. (2016) Nuclear Fusion, 56, 066001

DC magnetic field perturbations are applied with varying toroidal mode number n=1,2,3

**Two rows** of in-vessel coils can yield $\xi_{n,X} \sim 3\ mm$ with coil currents ranging from 15 kAt to 30 kAt depending on the toroidal mode number




- Note n=1 perturbations trigger important core response as well as edge peeling response

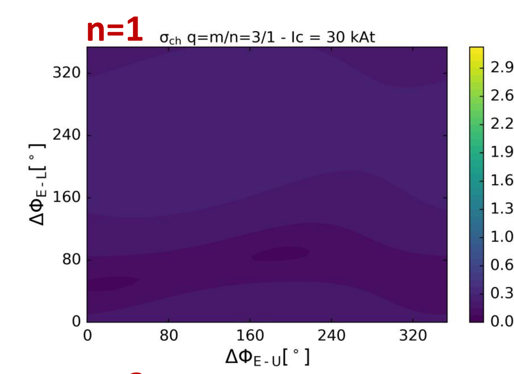



2D phase scan is used to find the optimal working point with **3 coil arrays**

$$\xi_x = \xi_{mid} + \xi_{upper} e^{-i\Delta\phi_{EU}} + \xi_{lower} e^{-i\Delta\phi_{EL}}$$

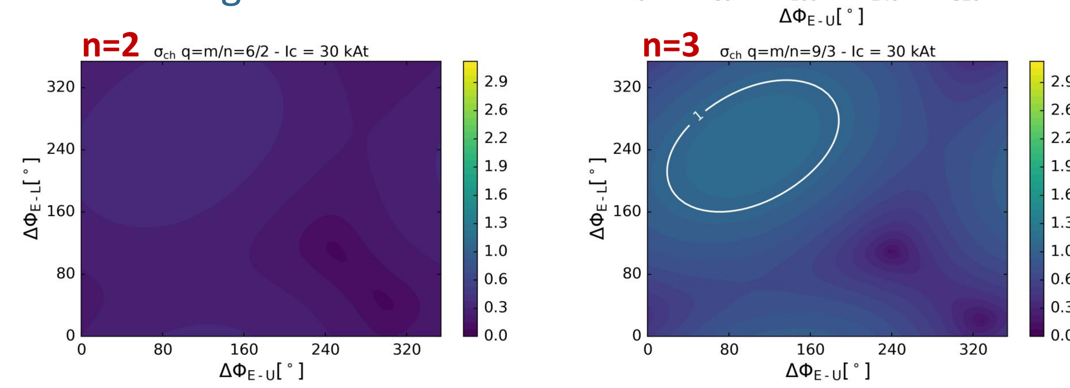
Plasma displacement suggests n=1 strong response

Perturbed resonant field indicates n=3 giving best edge stochastization




Chirikov parameter maps on last rational surface

$$B_{mn} = B^M_{mn} + B^U_{mn} e^{-i\Delta\phi_{EU}} + B^L_{mn} e^{-i\Delta\phi_{EL}}$$




- Toroidal plasma response modeling can provide useful insight into ELM mitigation with RMPs during DTT operations.
- Equatorial array of coils provides significant contribution in reducing the coil current to reach selected thresholds, resulting in $\sim 10\ kAt$ for n=1 and $\sim 20\ kAt$ for n=2,3.
- Using the Chirikov parameter metric, only n=3 perturbations with $I_c \sim 30\ kAt$ satisfy the $\sigma_{chir} > 1$ threshold

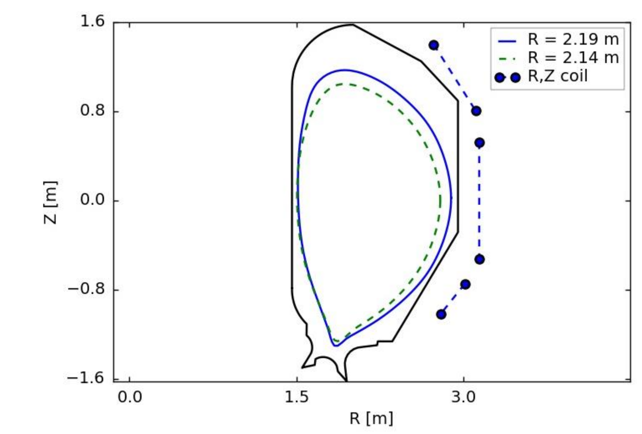
$$(\gamma + in\Omega)\boldsymbol{\xi} = \mathbf{v} + (\boldsymbol{\xi} \cdot \nabla\Omega)R^2\nabla\Phi$$

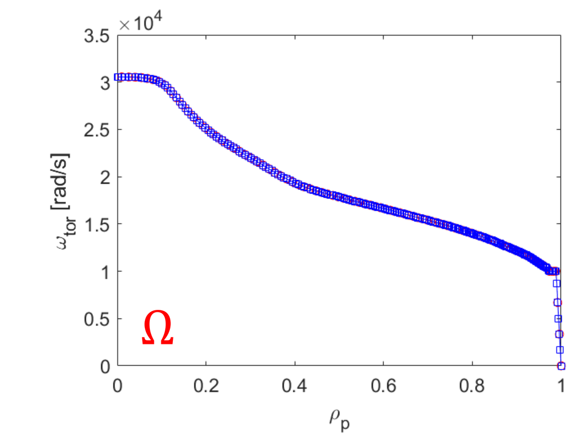
$$\rho(\gamma + in\Omega)\mathbf{v} = -\nabla p + \mathbf{j} \times \mathbf{B} + \mathbf{J} \times \mathbf{b} + -\rho\left[2\Omega\hat{Z} \times \mathbf{v} + (\mathbf{v} \cdot \nabla\Omega)R^2\nabla\phi\right] - \nabla \cdot \mathbf{\Pi}$$

$$(\gamma + in\Omega)\mathbf{b} = \nabla \times (\mathbf{v} \times \mathbf{B}) + (\mathbf{b} \cdot \nabla\Omega)R^2\nabla\Phi - \nabla \times \eta\mathbf{j}$$

$$(\gamma + in\Omega)p = -\mathbf{v} \cdot \nabla P - \Gamma P \nabla \cdot \mathbf{v}$$

$$\mathbf{j} = \nabla \times \mathbf{b}$$



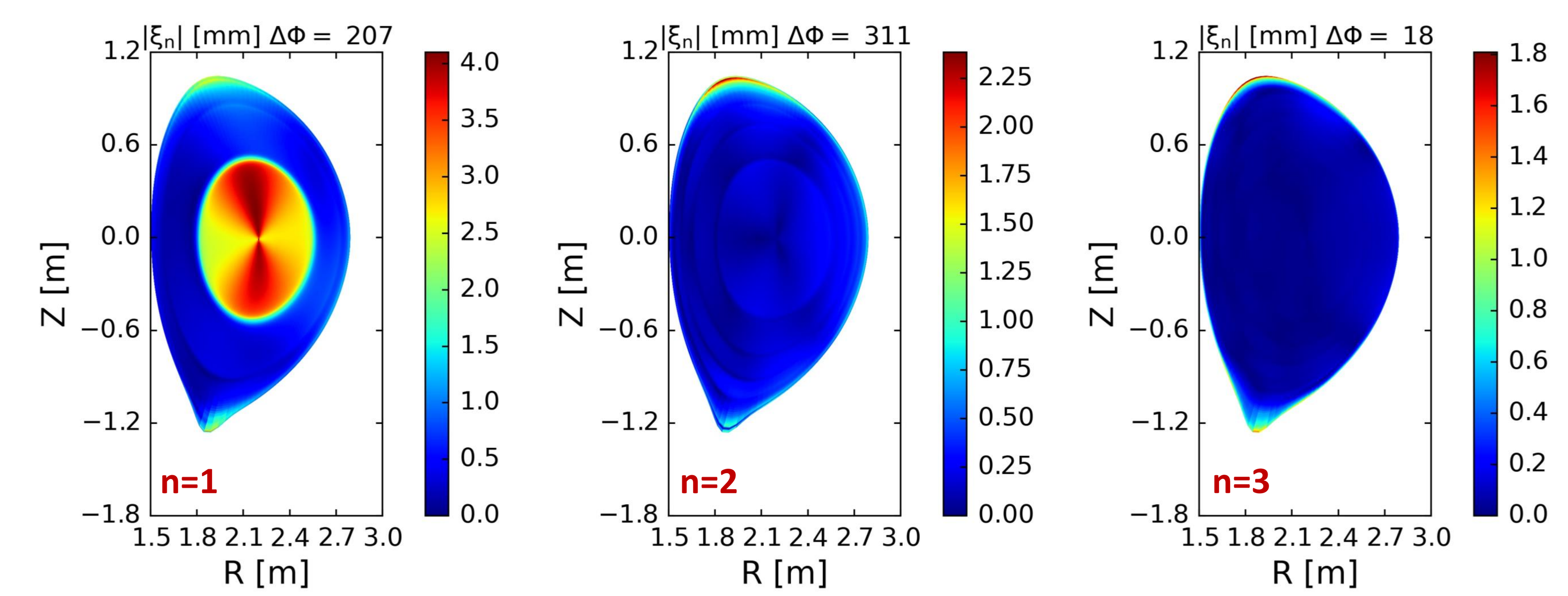



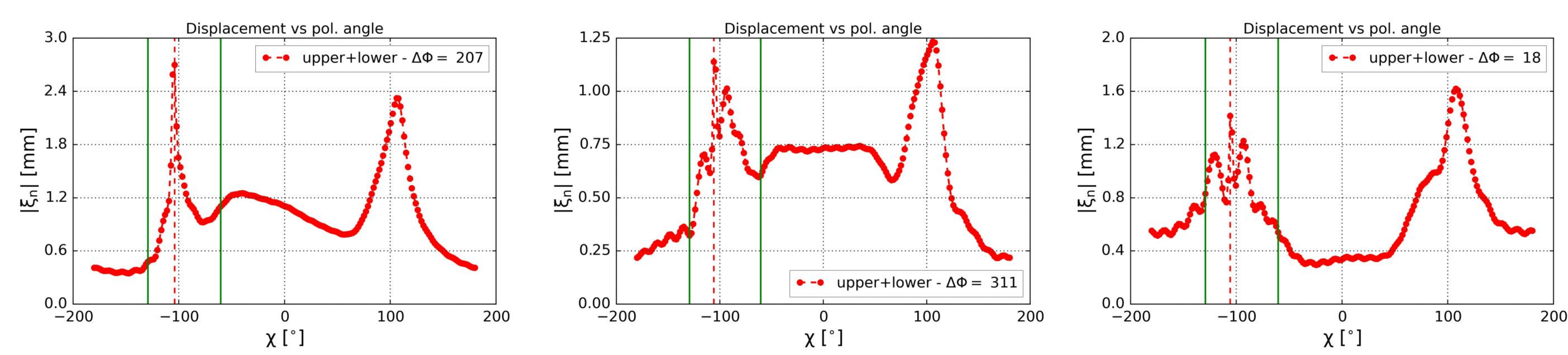

**Normal displacement** near the x-point region [8,9]

$$\xi_X$$

**Chirikov parameter** calculated with resonant radial field components in PEST-like straight field line coordinates [10]

$$\sigma = 4\sqrt{\left|\frac{n\,Q}{\psi'}\frac{dq}{ds}\right|} > 1 \qquad Q = \left(\frac{\boldsymbol{b}\cdot\nabla\psi_p}{\boldsymbol{B_{eq}}\cdot\nabla\phi}\right)_{mn}$$




n=1 n=2 n=3

Notes and outlook:

- ✗ X-point displacement results can be affected by the edge safety factor
- ✗ Non-linear damping of plasma flow or poloidal rotation have not been considered
- ✗ Torque-based metrics can be added for a complete picture

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