# INTERACTION BETWEEN MAGNETIC GEOMETRY AND TURBULENCE IN 3D GLOBAL FLUID SIMULATIONS

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## ABSTRACT


- Transport and turbulence properties with X-point, 3D disturbed magnetic equilibrium (reminiscent of RMPs), and with negative triangularity → a relatively unexplored domain in numerical global simulations of plasma edge
- Full 3D fluid turbulent simulations with TOKAM3X [1].
- Changes in the fluctuations level, filaments dynamics, heat decay length and heat flux peaks at the targets depending on the configuration.
- Some key experimental features are recovered: better understanding on the edge plasma dynamics in relevant magnetic configurations for the fusion operation


## BACKGROUND AND MOTIVATION

- Turbulence governs the transverse transport → heat exhaust.
- X-point plasmas and H-mode are needed to reach optimal conditions for fusion.
  - → The X-point: a highly non-linear SOL dynamics governed by an interplay of turbulence, background drifts, sources, and sinks
  - → The RMPs for controlling ELMs: their efficiency depends on different conditions, and the understanding of their complex interaction with the plasma remains a challenging task
  - → Negative triangularity: might be a solution to remain in L-mode, yet still achieving sufficient confinement for ignition but requires significant effort to be better understood.
- Progress in the last decade allow to simulate now realistic magnetic geometries that 3D edge turbulence codes have only recently been dealing with

## THE TOKAM3X MODEL

- A 3D two-fluid non-isothermal drift-reduced electrostatic model for electrons and a single ion species based on the Braginskii's closure [1].
- Flux driven simulations with flexible axisymmetric magnetic geometries encompassing closed (CFR) and open (SOL) magnetic field lines (Figure 1).
- Typical grid resolution 64×512×64 in the $(r, \theta, \varphi)$
- $\eta_{\parallel}(en_0/B_0) = 10^{-5}$ and $D_{\perp} = 10^{-2}(\rho^2_L\omega_c)$ fixed in all simulations.

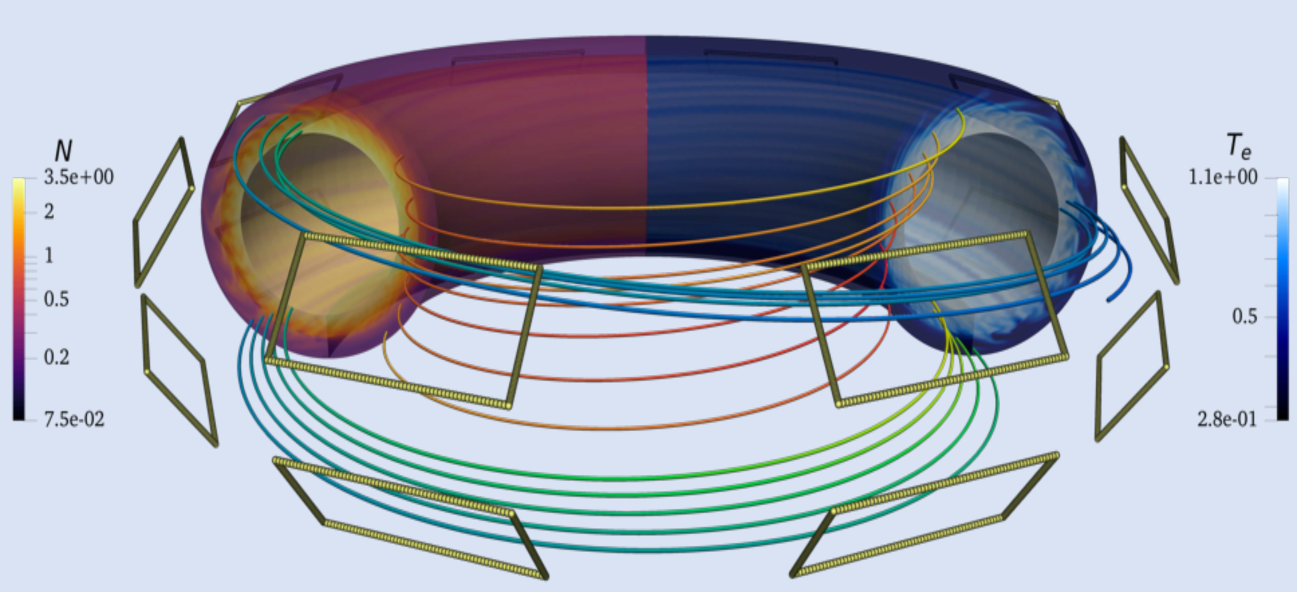


*Figure 1: 3D TOKAM3X simulation in limited configuration. RMP coils in yellow. Density (on the left) and electron temperature (on the right) fluctuations.*

## MOST SIGNIFICANT OUTCOMES

### X-POINT IMPACT

- Poloidal gradients + a quasi-empty and cold private flux region (PFR) lead to large amplitude steady-state radial ExB flows around the X-point: main contributors to the spreading of particles fluxes into the PFR [2].
- Filaments:
  - → get strongly elongated in r due to the flux expansion introduced by the X-point (Figure 2)
  - → disconnect from the target in the near SOL due to the magnetic + the poloidal shear of the ExB radial velocity around the X-point while they reconnect in the far SOL: lead to different radial velocity scaling [3]

- TOKAM3X diverted simulations exhibit a mild transport barrier around the separatrix induced by the magnetic shear [4].

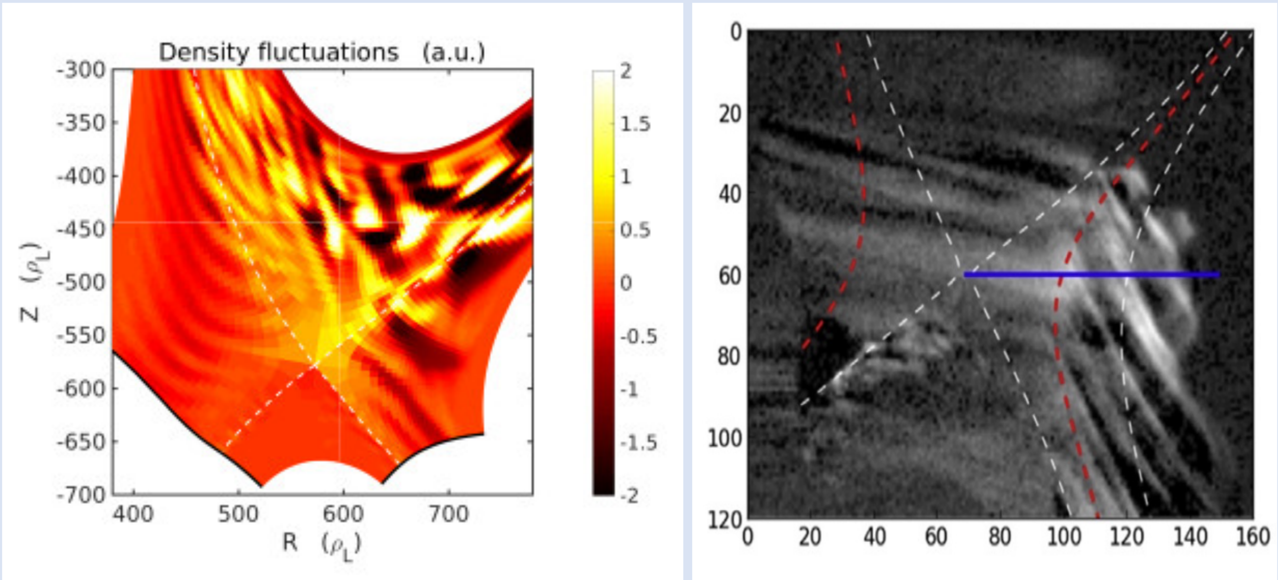


*Figure 2: Zoom on the turbulent structures in the divertor. Simu (left), MAST [5] expe (right). The red line on the outer divertor leg delimits the quiescent zone.*

### THE RMPs IMPACT

$\vec{A} = \Psi_p(1+\varepsilon_p)\vec{\nabla}\varphi + \Psi_t\vec{\nabla}\theta$ where $|\varepsilon_p(\psi,\theta,\varphi)| \ll 1$ and $\varepsilon_p = 10^{-3}a\sin(m\theta - n\varphi)$

- A pump-out of the electron density (about 20%)
- Drop of the amplitude of the radial electric field inside the separatrix [6].
- Turbulence properties are only moderately impacted

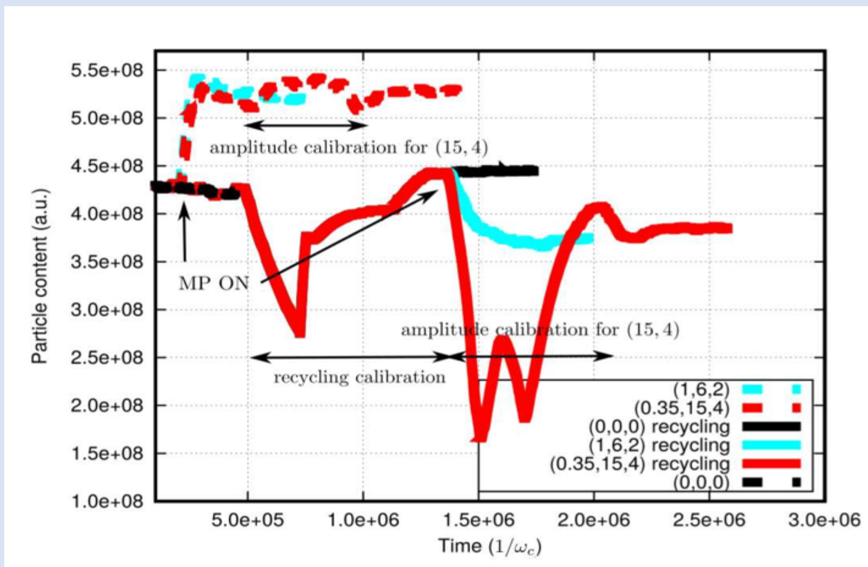


*Figure 3: Temporal evolution of the particles content in the tokamak depending on the perturbation. Non-isothermal simulations with (particle source at the limiter) or without (source at the core) recycling.*

### NEGATIVE TRIANGULARITY IMPACT

An analytical equilibrium $R = R_0 + r(\cos(\theta) + \sin^{-1}(\delta)\sin(\theta))$ and $Z = r\sin(\theta)$ with triangularity $\delta$ scanned from 0.5 to -0.5.

- In the configuration with a bottom limiter (non constant limiter wetted area): ↘ of (N, Te) decay lengths + ↘ of the heat load peak value
- In the configuration with a HFS limiter (constant limiter wetted area): no impact is observed
- In more realistic TCV diverted plasmas: ↘ SOL turbulence level + steepening of average profiles in SOL for $\delta < 0$. Favorable distribution of the particle flux (Figure 4) with ↗ of the wetted area on the divertor targets for $\delta<0$.

→ *Geometrical changes with $\delta$ seem to dominate here the pure effects of changing $\delta$.*

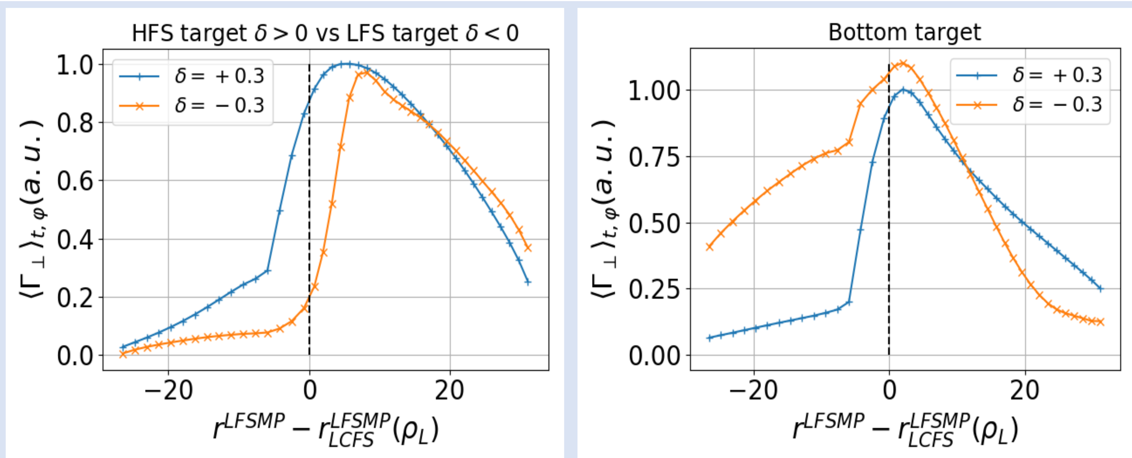


*Figure 4: TCV diverted plasma configuration. Radial distributions of particle fluxes on divertor targets for $\delta>0$ and $\delta<0$.*

## CONCLUDING REMARKS

- Clear impact of the magnetic geometry on the plasma dynamics
- A dedicated effort on the numerical efficiency allows us to address now more realistic configurations
- Very promising preliminary results recover some key experimental findings in TCV diverted plasmas with negative triangularity and in 3D transport simulations with ripple in WEST.

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