# Unraveling the competition/synergy between turbulence and 3D magnetic perturbations

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# Unraveling the competition/synergy between turbulence and 3D magnetic perturbations

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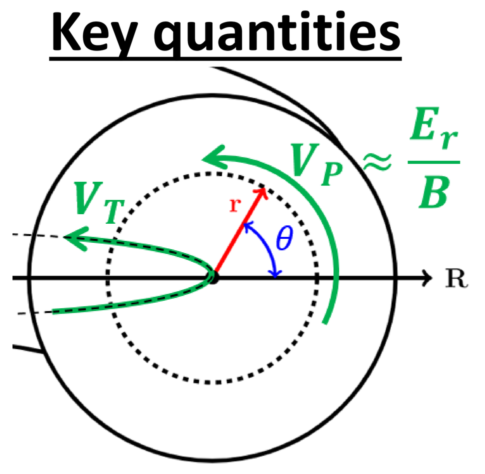
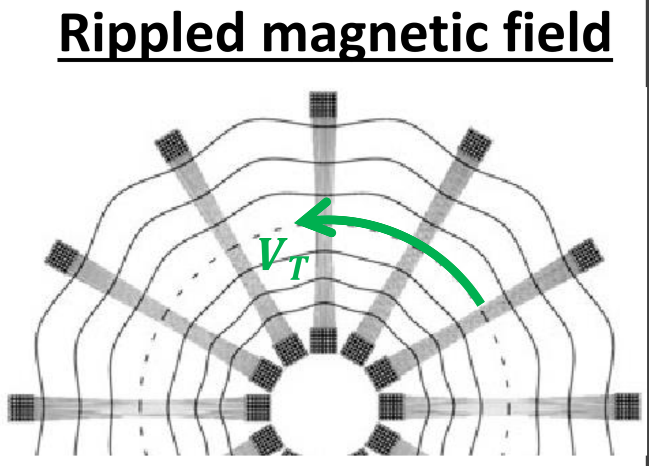
## Introduction

- Plasma rotation plays a key role in plasma confinement;
- Control of plasma rotation in reactor-sized tokamak is challenging;
- Intrinsic bulk plasma rotation is driven by ***turbulence*** and ***magnetic braking*** due to ripple

**Key quantities**




**Rippled magnetic field**




## Intrinsic rotation mechanisms

- A reduced model [1] based on the mean toroidal velocity $V_T$ reads :

$$\frac{\partial V_T}{\partial t} = \text{Magnetic braking} + \text{Turbulent torque}$$

**Ripple** constrains particle trajectories and collisional processes

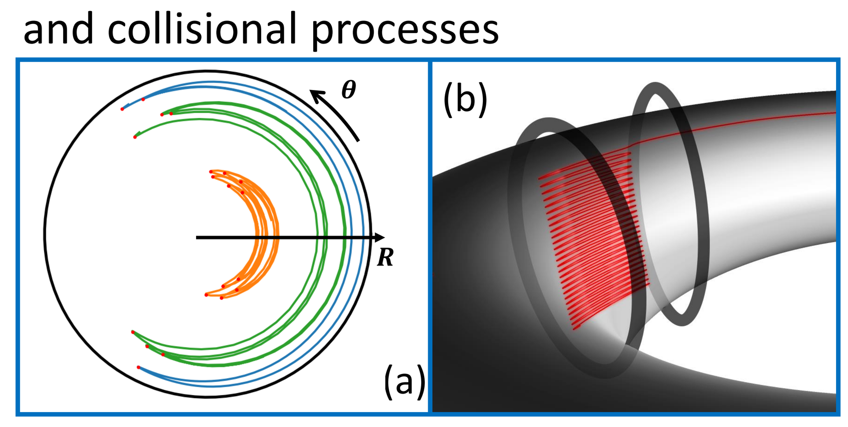



FIG.1 – Kinetic effects induced by ripple : drift of banana bounce points (a) and toroidal trapping between coils (b). Neoclassical friction $\nu_\varphi$ comes from the collisions between trapped particles.

**Turbulence** constrains $V_T$ through wave-particle interactions

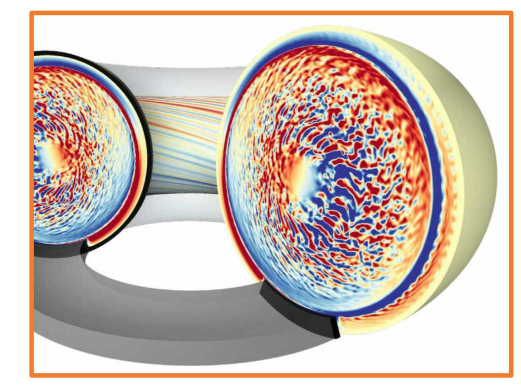


FIG.2 – Snapshot of the turbulent structures seen through a colormap on the electric potential. From rest, $V_T$ grows due to wave-particle interactions.

## Turbulence / Ripple competition

- Magnetic braking $m$ imposes a finite velocity $V_{neo}$ [2,3] $m = -\underbrace{\nu_\varphi}_{\text{Collisional friction}}(V_T - V_{neo})$
- Turbulence, through toroidal Reynold stress $\Pi$, also imposes a finite velocity $V_{turb}$ [4,5] due to particle-waves interactions:

$$\Pi = \underbrace{-\chi\frac{\partial V_T}{\partial r}}_{\text{Viscosity}} + \underbrace{\mathcal{V}V_T}_{\text{Pinch}} + \underbrace{\Pi_{res}}_{\text{Residual}}$$

- Competing forces $\partial_t V_T = m - r^{-1}(r\Pi)'$

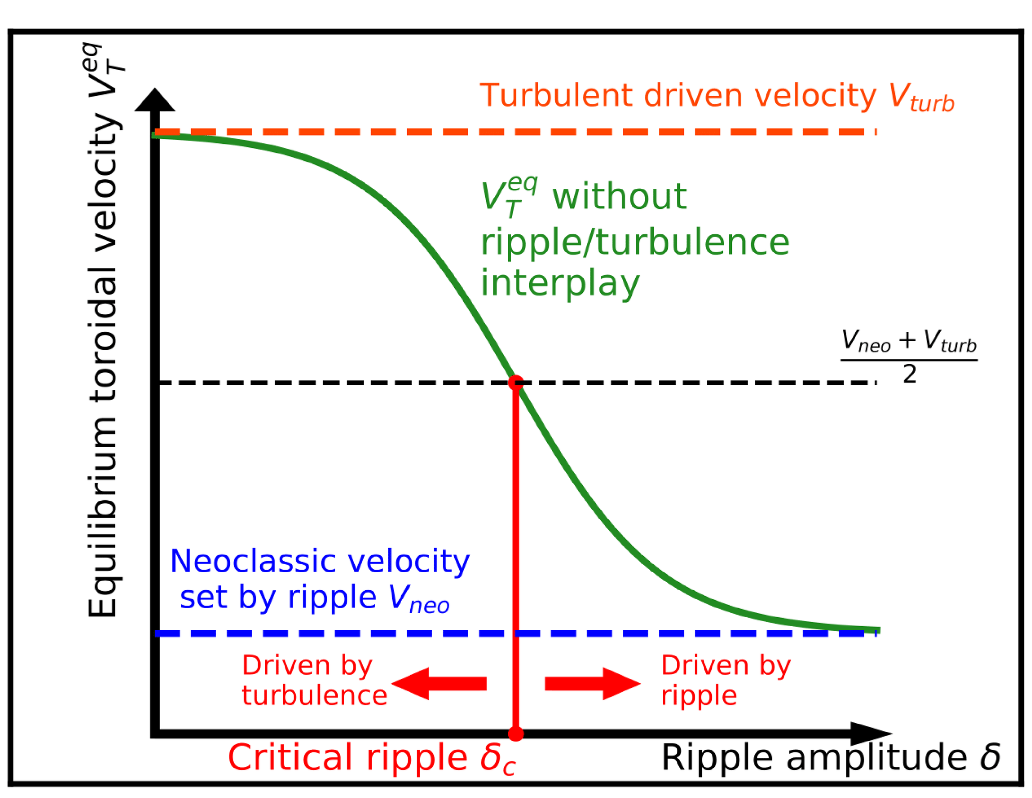



FIG.3 – Sketch of the modelled ripple/turbulence competition on the equilibrium toroidal velocity.

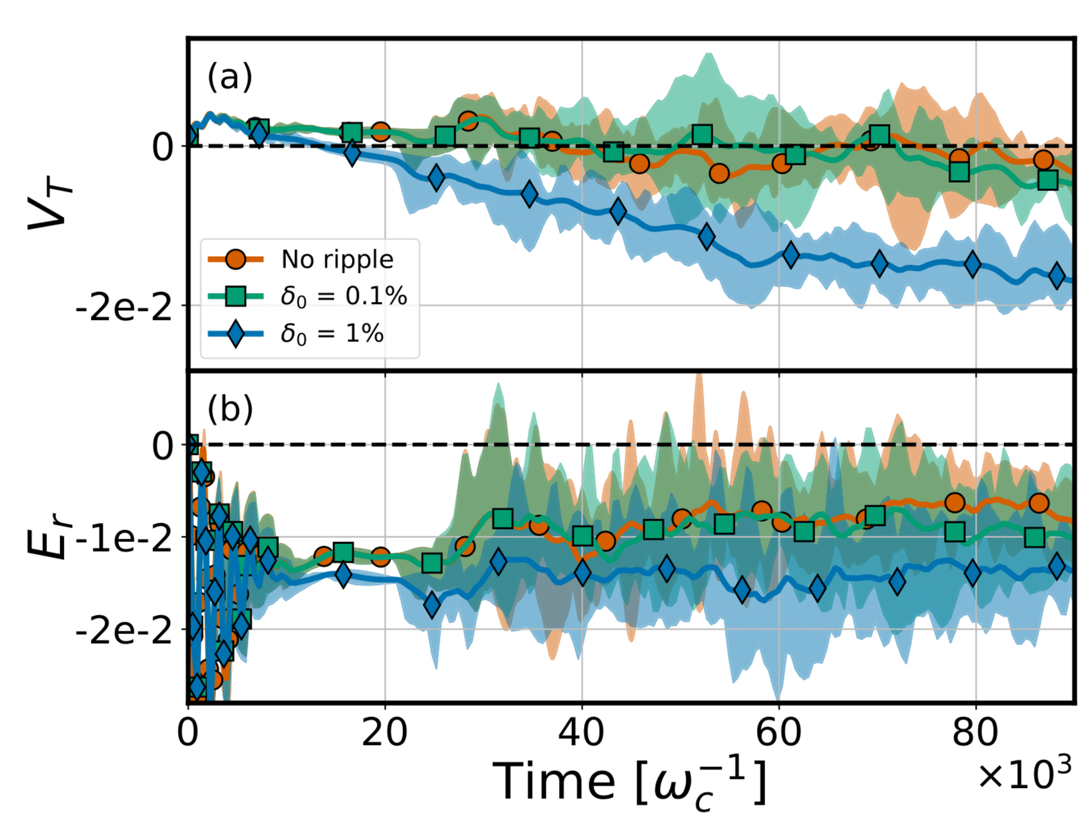



FIG.4 – Time evolution of $V_T$ and $E_r$ in the range $0.45 < \rho < 0.55$ for different ripple amplitudes.

## Critical ripple amplitude

- NTV controls the plasma rotation above a critical ripple amplitude $\delta_c$
- Complete model gives the relation:

$$\nu_\varphi(\delta_c) \simeq \chi_{eff}/L_T^2$$

Temperature gradient's length

With $\chi_{eff} \simeq \chi + L_T\mathcal{V}$

- A simplified equation can be devised considering
  - the gyroBohm scaling for $\chi_{eff}$
  - The ripple-plateau scaling for $\nu_\varphi$

$$\delta_c \sim \sqrt{N_c}\left(\frac{R}{L_T}\right)^{-3/2}\frac{\rho_i}{R}$$

Number of coils — Ion Larmor radius — Major radius

## Conclusion

- Ripple → responsible for a collisional friction that causes magnetic braking;
- Turbulence → source of intrinsic rotation;
- Evolution of mean toroidal flow ruled by competing turbulent stress and ripple drag forces;
- Magnetic braking overcomes turbulent drive above a critical ripple amplitude $\delta_c$
- Analytical prediction of $\delta_c$, and simplified expression, are derived and validated numerically
- Main synergy comes from neoclassical effect on $E_r'$ in presence of ripple, in turn modifying $\Pi$

## Turbulence / Ripple synergy

- Only possible mechanism: mode coupling on the electric potential
- However, ripple only impacts non-resonant modes of the electric potential


- Strong impact of ripple on $\Pi$ in simulation
- $\Pi$ expected to vary with turbulent intensity shear $I'$ and radial electric field shear $E_r'$
- In simulations, ripple weakly impacts $I$ through mode-coupling of the electric potential
- Ripple changes $E_r$ through collisional effects → strong correlation with $\Pi$

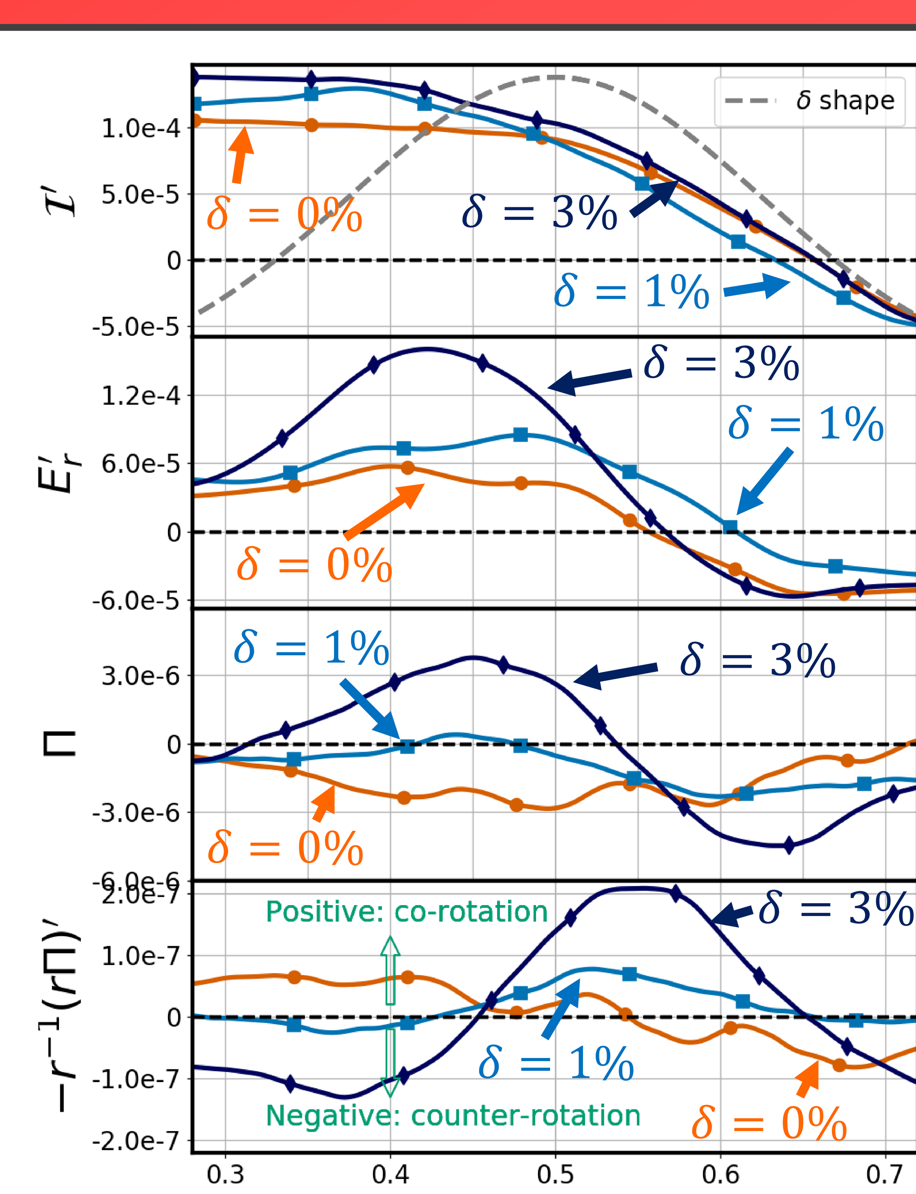



FIG.4 – Radial profiles of turbulent intensity shear, $E_r$ shear, residual stress and its divergence. These profiles are coarse-grained as detailed in [1].

## References

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