

Edge Turbulence Dynamics Across Electron-Ion Root Transitions During ECRH Modulation Experiments in the TJ-II Stellarator



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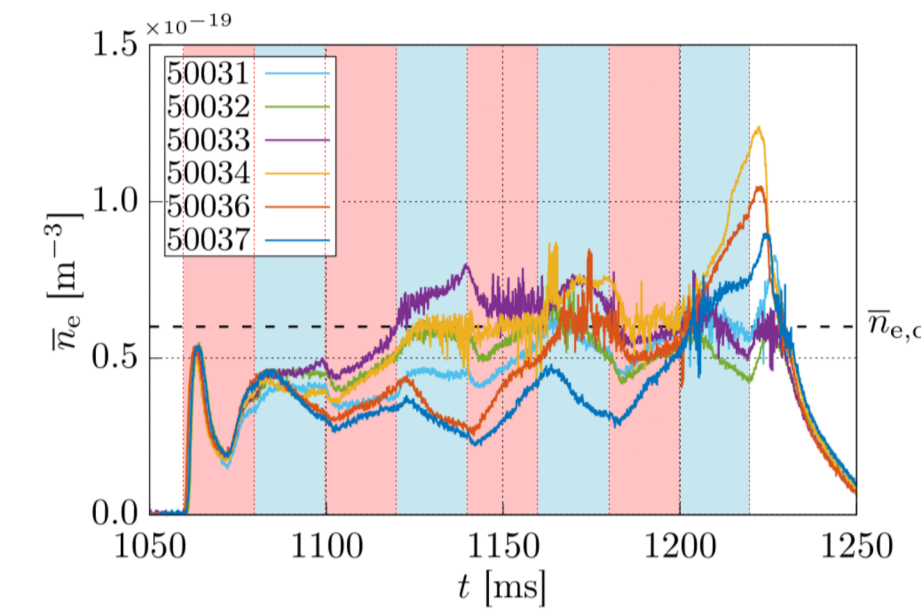
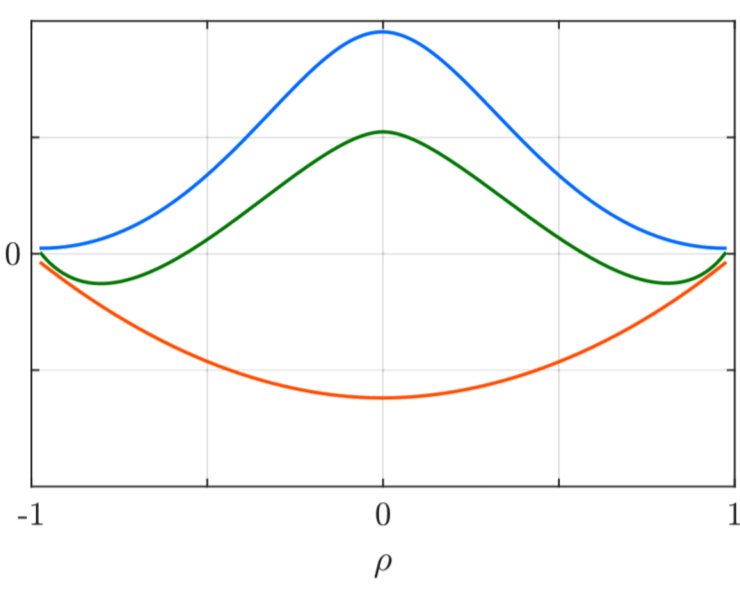
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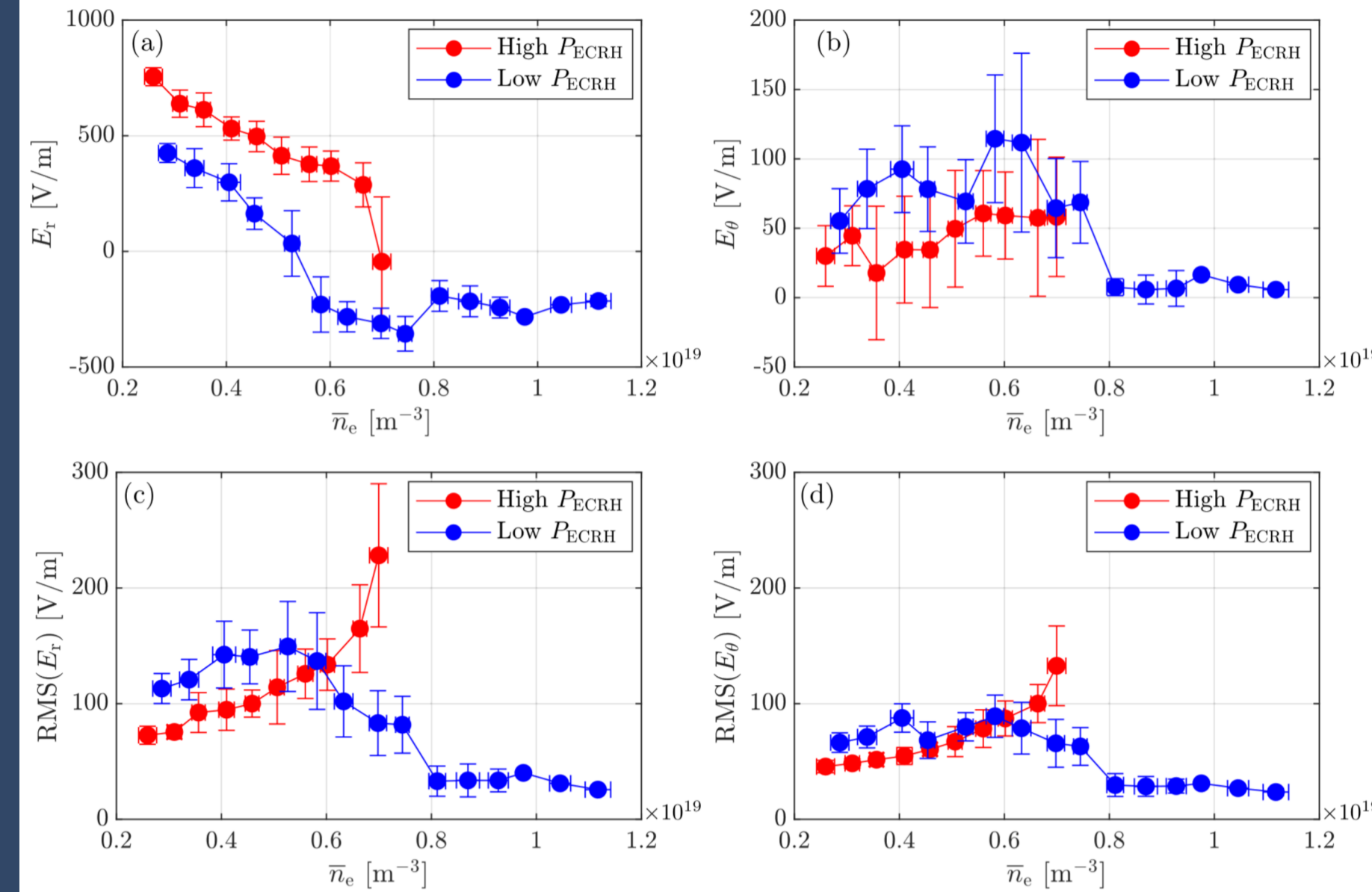
Introduction

In stellarator plasmas the neoclassical particle fluxes are not intrinsically ambipolar ($\Gamma_e = \Gamma_i$); this leads to the generation of a radial electric field profile (E_r) that provides for ambipolarity across the plasma radius [1].



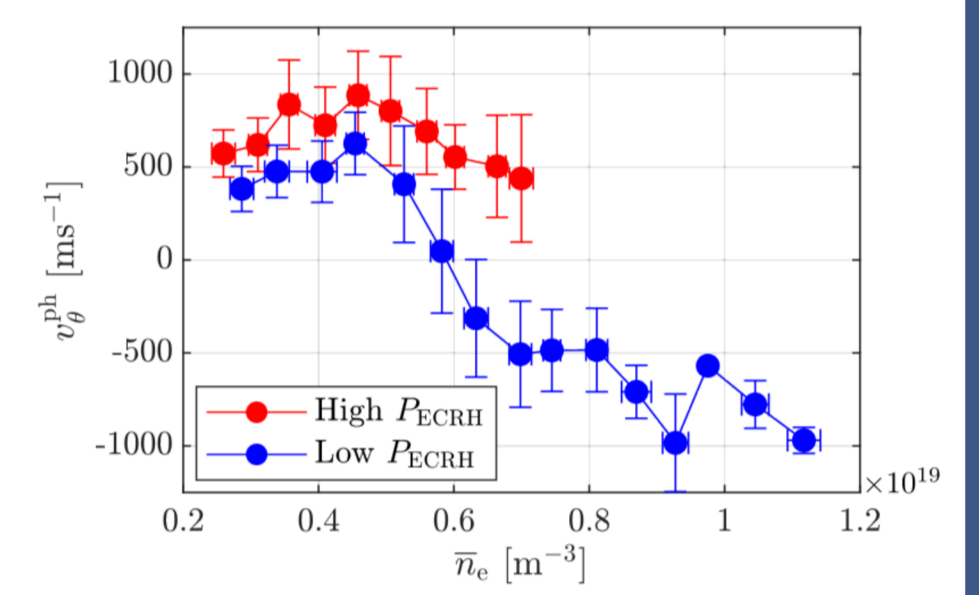
Six discharges show confinement transitions during ECRH power modulation. Near the critical density, line-averaged electron density traces exhibit enhanced fluctuations and increased dynamical complexity.

Evolution of plasma state quantifiers

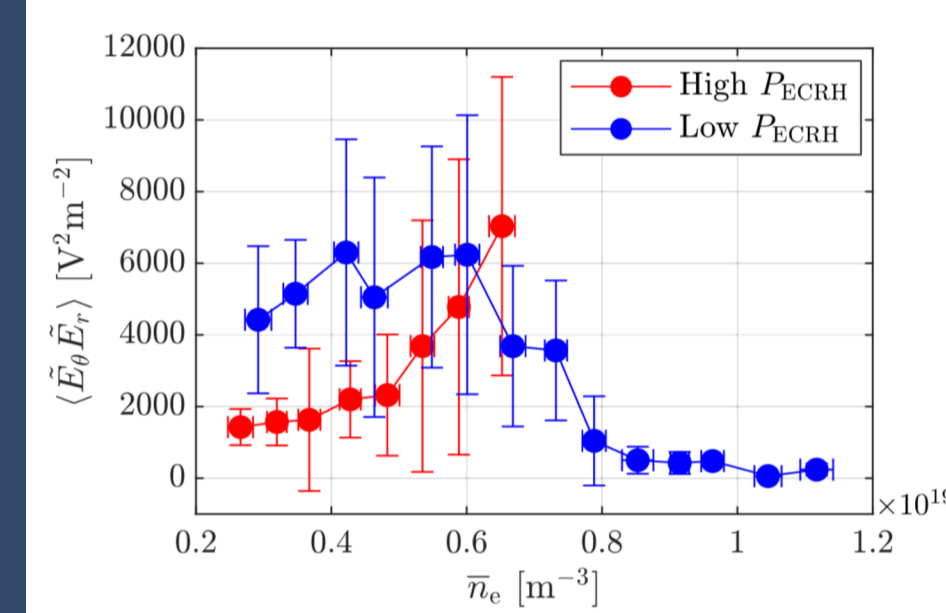


The radial electric field reverses sign near the critical density at low ECRH power, while the reversal shifts toward higher density at high power

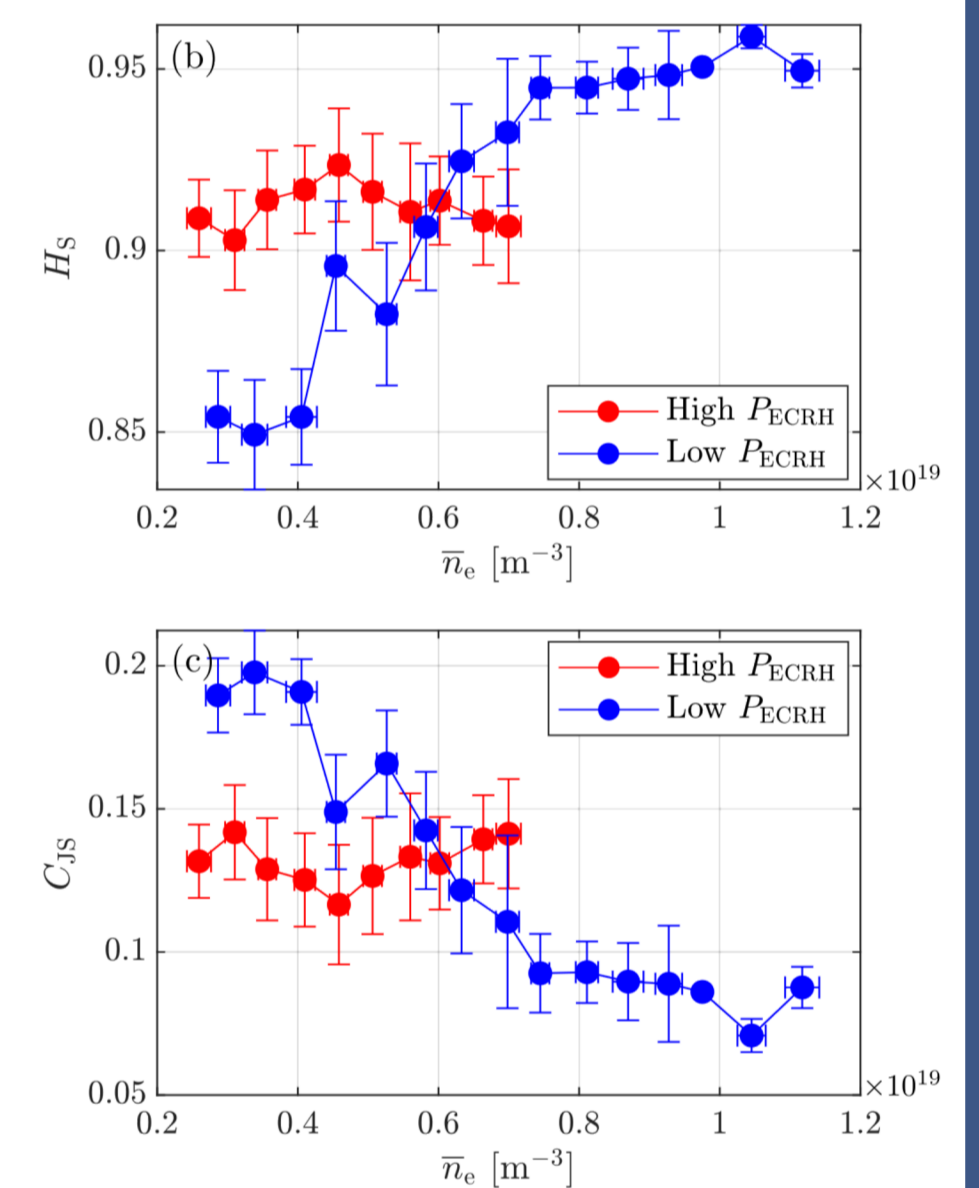
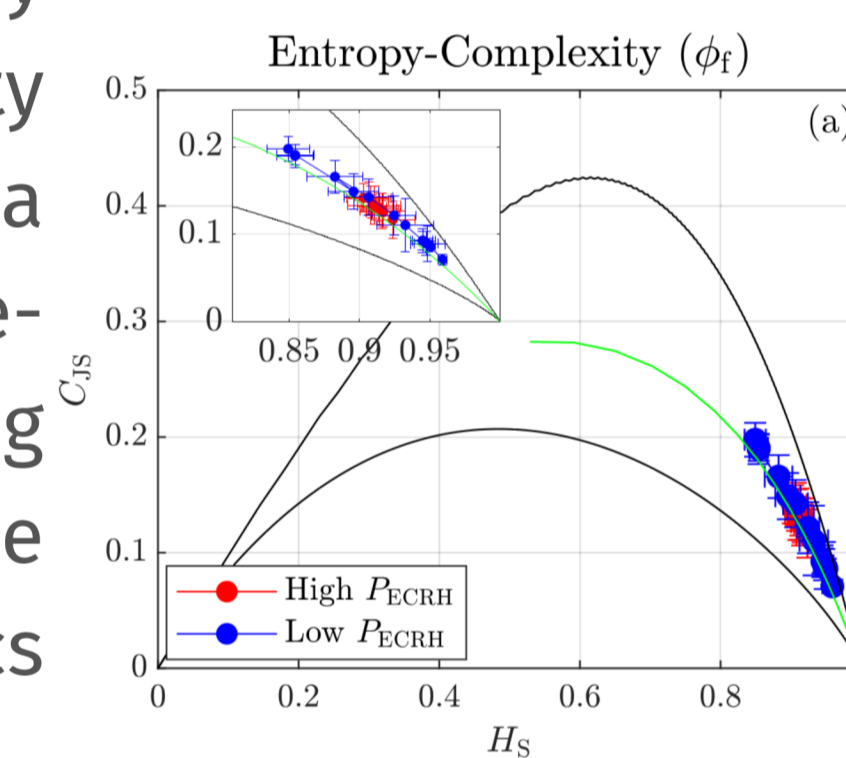
At low ECRH power, the poloidal phase velocity decreases and reverses sign at the critical electric field, following the inversion of the radial electric field.



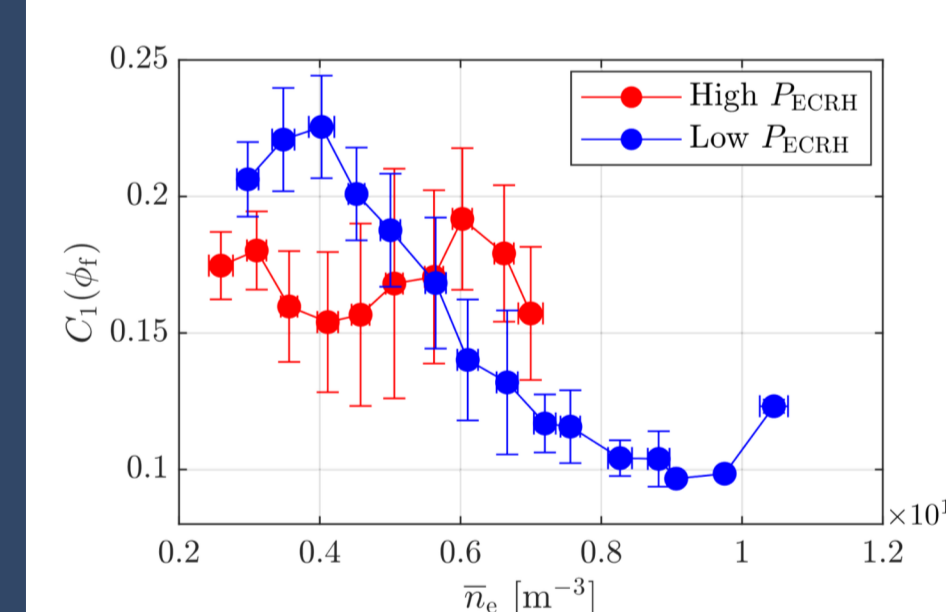
Above the threshold, the electric Reynolds stress is strongly suppressed, consistent with shear-induced decorrelation once the zonal flow is established [2].



In the low ECRH case, entropy increases and complexity decreases as the plasma approaches the critical line-averaged density, indicating a reorganization of the underlying plasma dynamics [3].



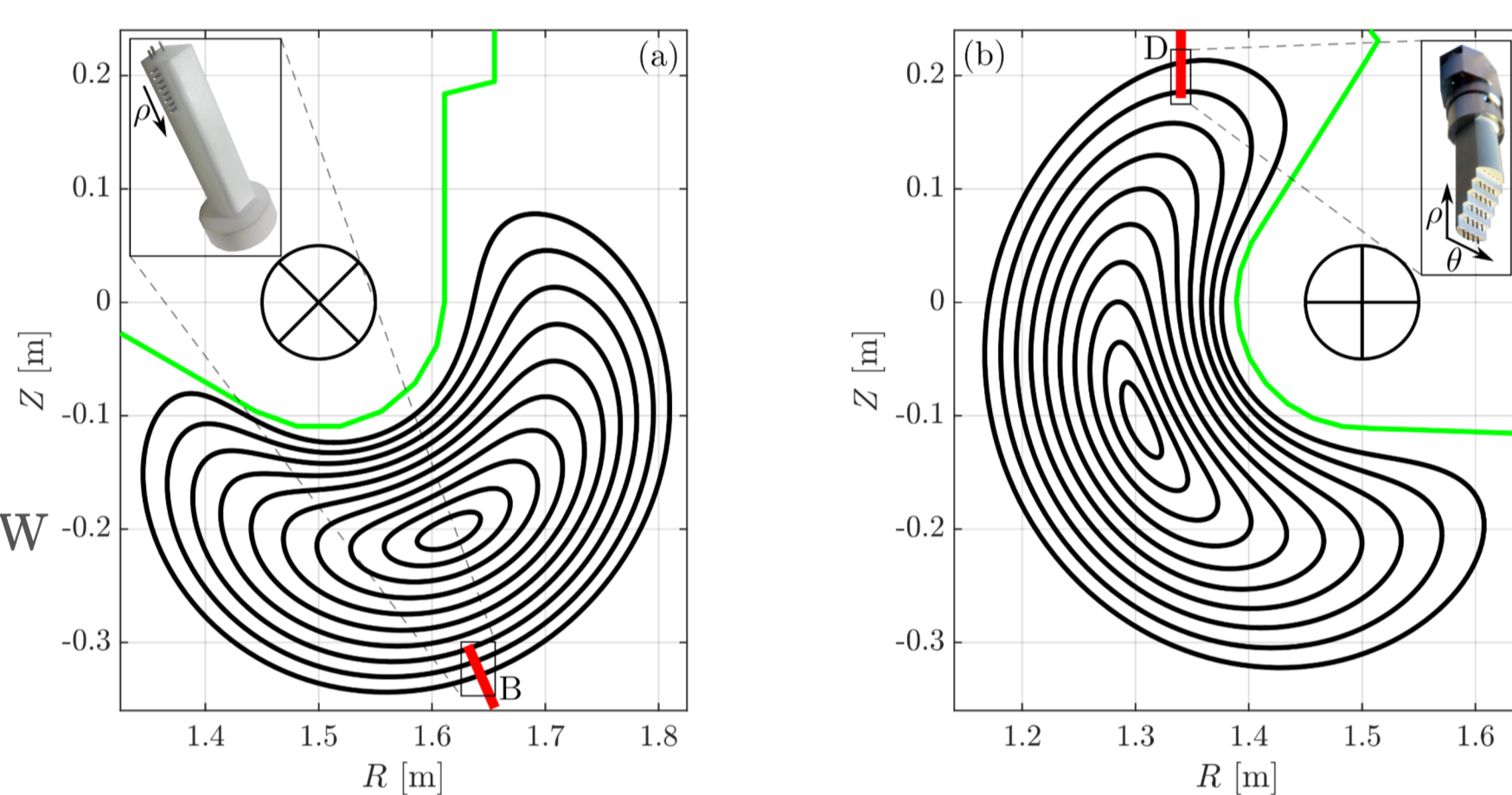
The intermittence parameter remains nearly constant below the threshold and decreases above it in the low ECRH case, indicating reduced multifractality and an increased condensation of fluctuation energy in low-order modes.



Experimental Setup

TJ-II Stellarator

- 4-period heliac stellarator
- Major radius: $R_0 \approx 1.5$ m
- Minor radius: $a \approx 0.2$ m
- Magnetic field: $B \approx 1$ T
- ECRH power: $P_{\text{ECRH}} \approx 2 \times 300$ kW
- Configuration: 100_44_64



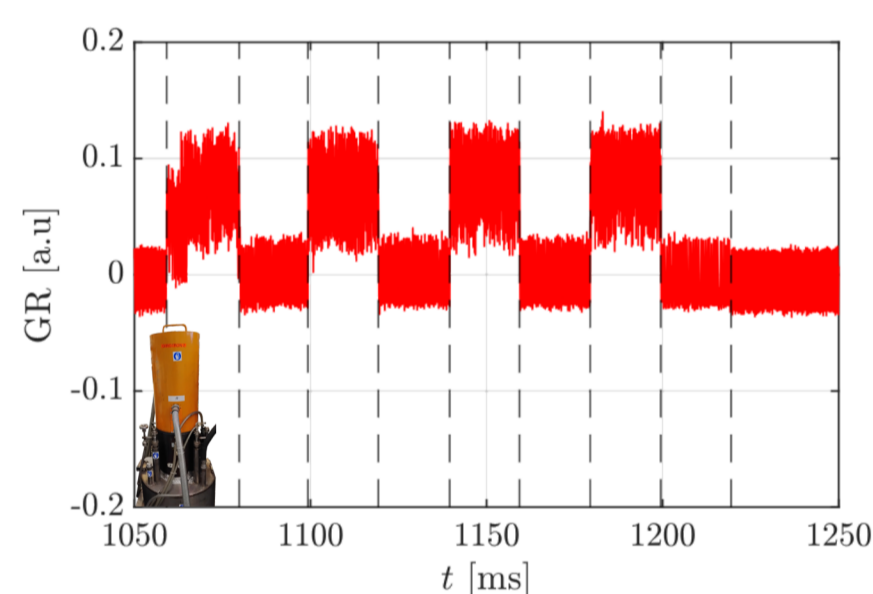
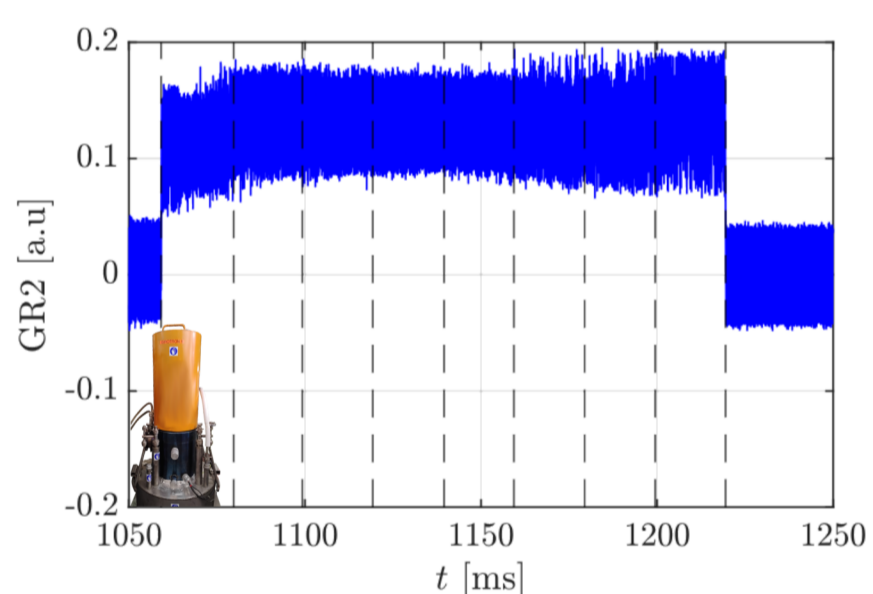
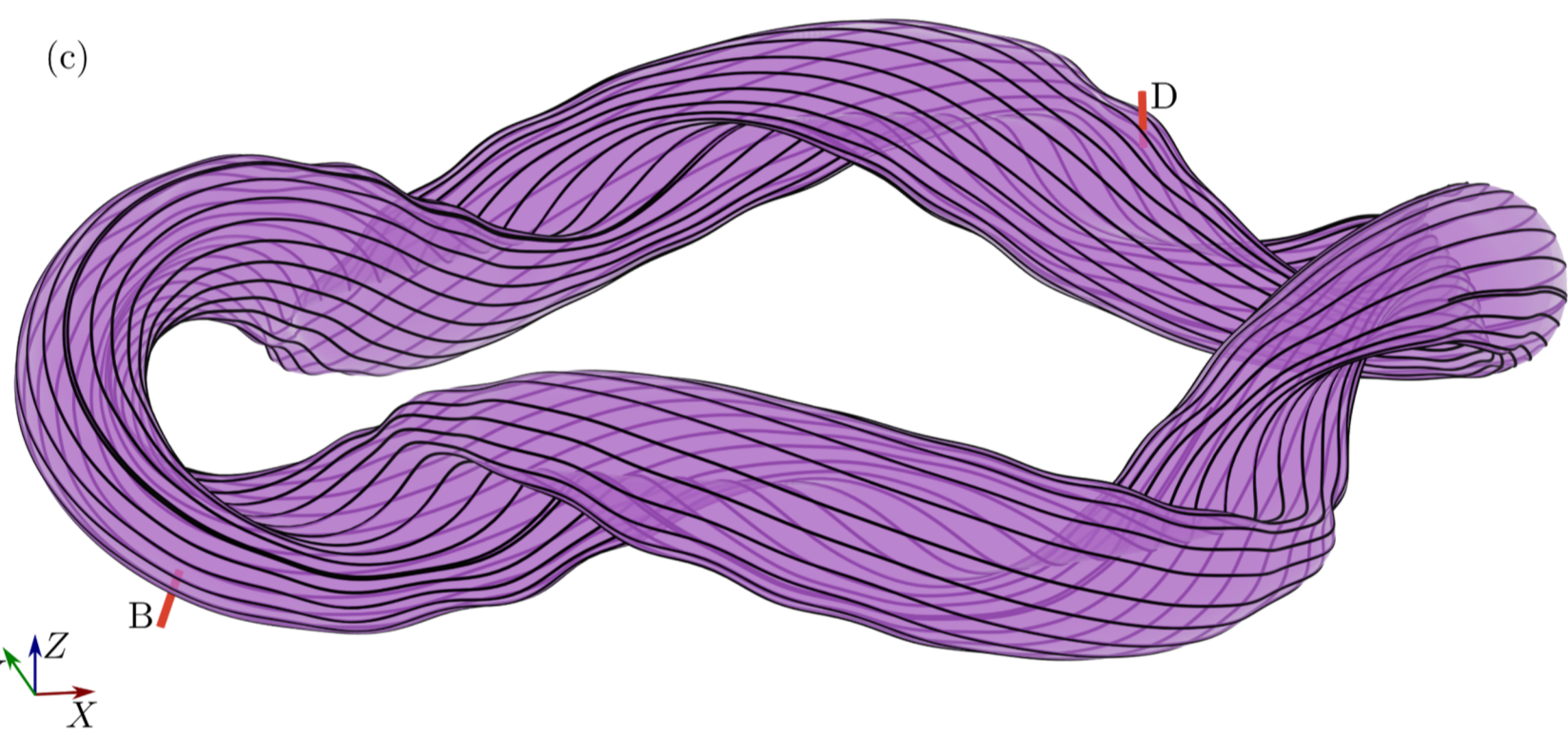
Diagnostic systems

Langmuir probe system (LP)

- D "staircase" Langmuir probe
- B "rake" Langmuir probe

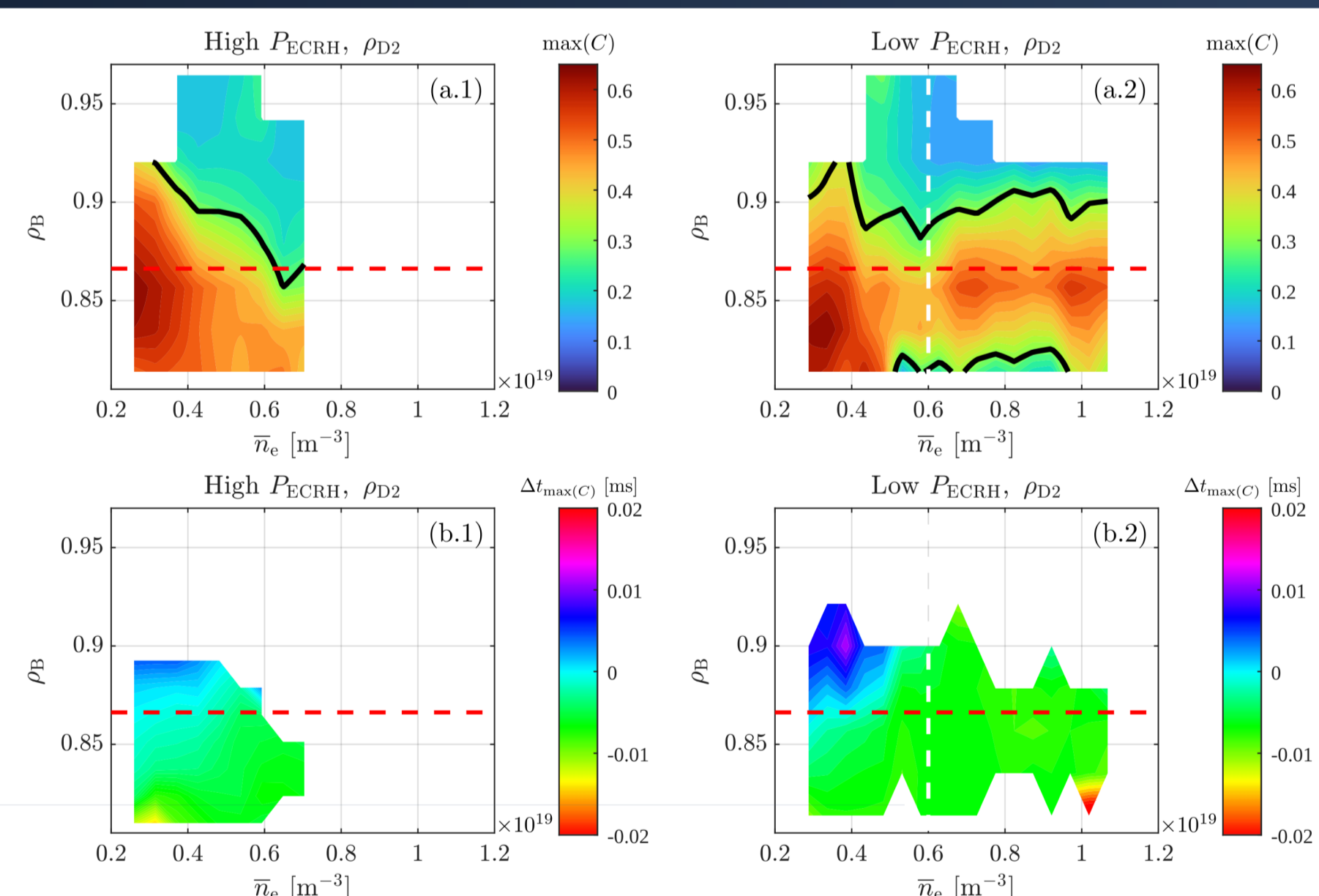
Electron Cyclotron Emission (ECE)

- 12 channel



ECRH modulation: one gyrotron remains continuously ON while a second is switched ON/OFF every 20 ms, producing alternating low- and high-power phases.

Long-range correlation



Cross-correlation reveals two regimes: below the critical density, broad LRC with finite delays indicate outward-propagating filaments; above threshold, LRC localizes into a narrow radial layer with negligible delay, consistent with zonal-flow formation.

Main results

Transition point: The e-i root transition is not solely controlled by density, but also by the edge radial electric field profile. Increasing ECRH power shifts the transition threshold to higher densities.

Turbulence regime shift: Crossing the critical density triggers a radical change in transport:

- **Subcritical:** Dominated by radially propagating filaments (broad range correlations).
- **Supercritical:** Turbulence is suppressed by a localized zonal-flow layer, reducing the correlation time.

Nonlinear dynamics and phase transition signatures: The increase in Shannon entropy and decrease in statistical complexity and intermittency indicate a phase transition and increased low-order mode dominance.

References

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- [2] B. D. Scott, New Journal of Physics 7 (1) (2005) 92.
- [3] O. A. Rosso, et al, Phys. Rev. Lett. 99 (2007) 154102.

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