Comparative Study of Phase Dynamics in Reynolds Stress and Particle Flux in the Edge Turbulence of HL-2A Tokamak

T. Long[1], P. H. Diamond[2], M. Xu[1], R. Ke[1], L. Nie[1], W. L. Zhong[1], J. Wen[1], X. Q. Ji[1], T. F. Sun[1], L.W. Yan[1], B. Li[1], X. M. Song[1] and X. R. Duan[1]

[1] Southwestern Institute of Physics, Chengdu, China, [2] University of California, San Diego, California, USA

E-mail: longt@swip.ac.cn

Abstract

- In the poster, the recent experimental results of cross phase dynamics in Reynold stress and particle flux in the edge of HL-2A tokamak are reported.
- For Reynolds stress, the cross phase evolves dynamically in the strong shear layer (phase scattering in Ohmic discharge, phase shift in ECRH L-mode), leading to an enhanced turbulent drive of poloidal flow in L-mode.
- For particle flux, the cross phase is much more concentrated, and scatters slightly in the strong shear layer.

Background

- A fundamental feature of these regimes in magnetic confinement devices is the dramatically decreased turbulent transport.
- Turbulent transport is affected by the amplitudes of fluctuations, and is also sensitive to the cross phase between them.
- The previous work indicates that there exist two different states of cross phase. They are phase locked in weak shear regimes, and phase slipping in strong shear regimes, which is related to the evolution from ELMy H-mode to quiescent H mode.
- The cross phase dynamics is also related to the decoupling of heat and particle transport in I-mode, and the turbulent generation of edge flow.
- In this work, we try to find the answers to these questions:

a) How do the cross phase dynamics in Reynolds stress and particle flux evolve at the edge of plasma?

b) What's the influence of auxiliary heating on the phase dynamics?

c) What's the difference between the cross phase dynamics in Reynold stress and particle flux?

Mathematical expressions for cross phase

Reynolds stress and particle flux, can be written as the product of fluctuation amplitudes and a cross phase factor, respectively.

$$\Pi_{r,\theta} = \langle \tilde{v}_r \tilde{v}_\theta \rangle = \sigma_{\tilde{v}_r} \cdot \sigma_{\tilde{v}_\theta} \cdot X_{RS}, \qquad \Gamma = \langle \tilde{n} \tilde{v}_r \rangle = \sigma_{\tilde{n}} \cdot \sigma_{\tilde{v}_r} \cdot X_{PF}$$

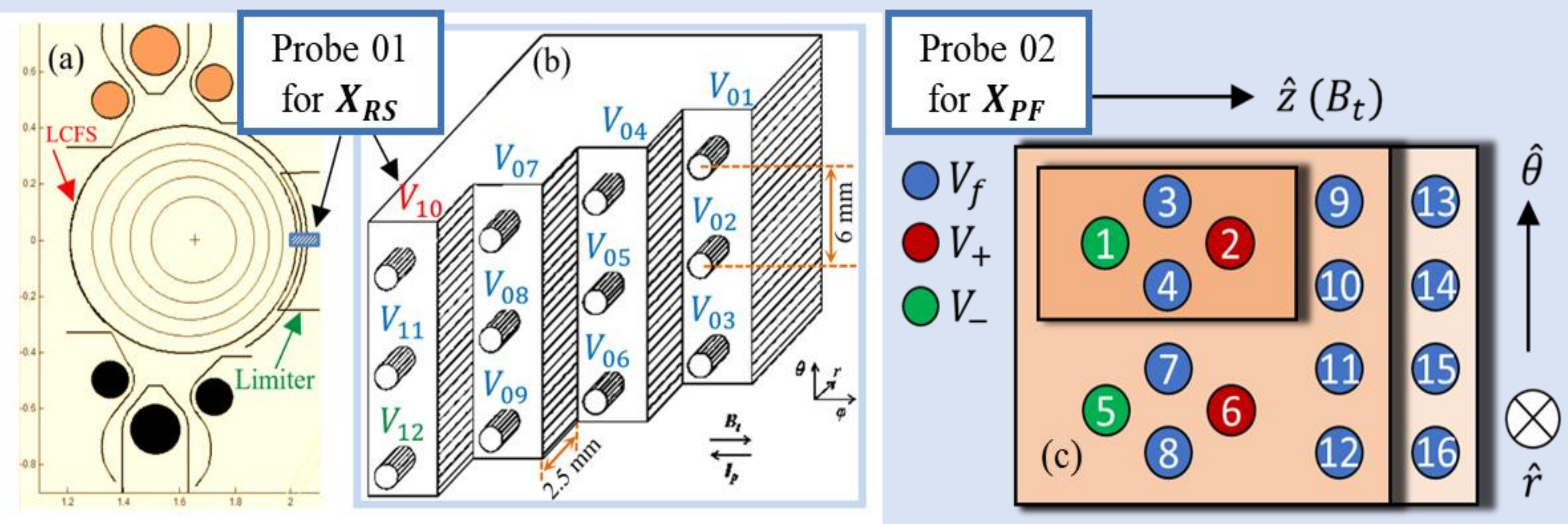
By introducing the inverse Fourier transform of these fluctuations,

$$X_{RS} = \mathrm{Re}\left[\sum_{\omega} \frac{|P_{\tilde{v}_r\tilde{v}_\theta}(\omega)|}{\left(\sum_\omega P_{\tilde{v}_r\tilde{v}_r}(\omega)\right)^{1/2}\left(\sum_\omega P_{\tilde{v}_\theta\tilde{v}_\theta}(\omega)\right)^{1/2}} e^{i\varphi_{\tilde{v}_r\tilde{v}_\theta}(\omega)}\right],$$

$$X_{PF} = \mathrm{Re}\left[\sum_{\omega} \frac{|P_{\tilde{n}\tilde{v}_r}(\omega)|}{\left(\sum_\omega P_{\tilde{n}\tilde{n}}(\omega)\right)^{1/2}\left(\sum_\omega P_{\tilde{v}_r\tilde{v}_r}(\omega)\right)^{1/2}} e^{i\varphi_{\tilde{n}\tilde{v}_r}(\omega)}\right],$$

$$\left(P_{\tilde{a}\tilde{b}}(\omega) = |P_{\tilde{a}\tilde{b}}(\omega)| e^{i\varphi_{\tilde{a}\tilde{b}}(\omega)} \equiv P_{\tilde{a}\tilde{a}}(\omega)^{1/2} P_{\tilde{b}\tilde{b}}(\omega)^{1/2} \gamma_{\tilde{a}\tilde{b}}(\omega) e^{i\varphi_{\tilde{a}\tilde{b}}(\omega)}\right)$$

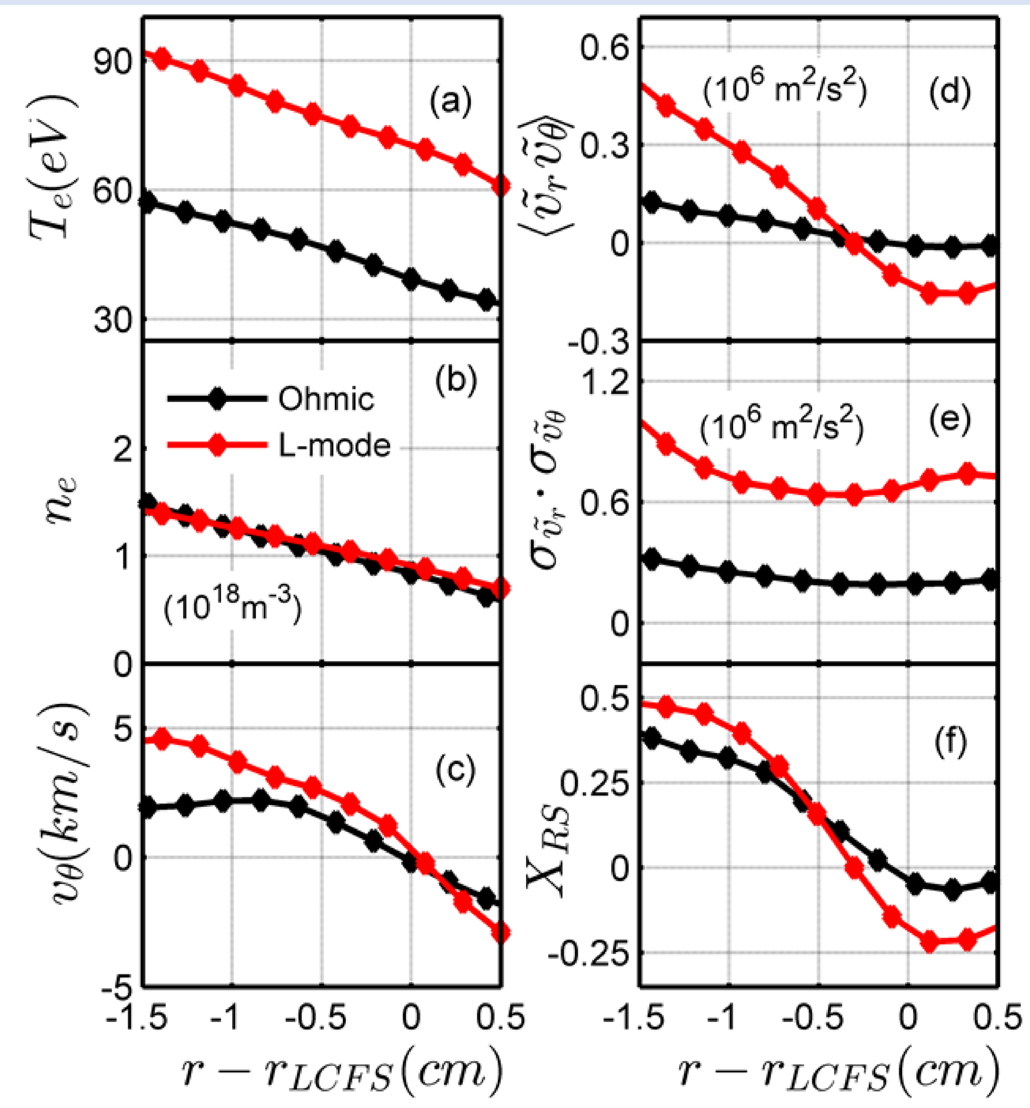
Experimental set up

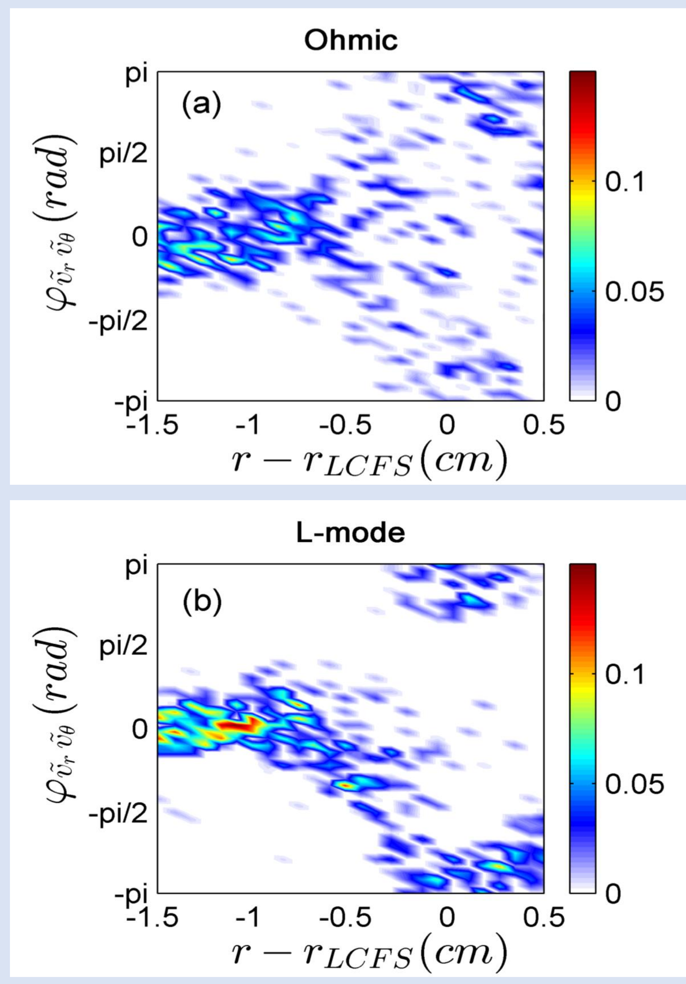


Two specially designed Langmuir probe arrays on the outer mid-plane of HL-2A tokamak were used to do the main experimental measurements.

Phase dynamics in Reynolds stress

- The amplitudes increase in L-mode, but show a moderate radial gradient.
- The cross phase factor shows a large radial gradient and the gradient increases significantly in L-mode when compared to Ohmic.
- Caused by these two effects, the gradient of Reynolds stress increased prominently, leading to an enhanced drive of v_θ.
- In weak shear region, phase concentration near 0.
- In strong shear region, phase randomization in Ohmic, but shift in L-mode.

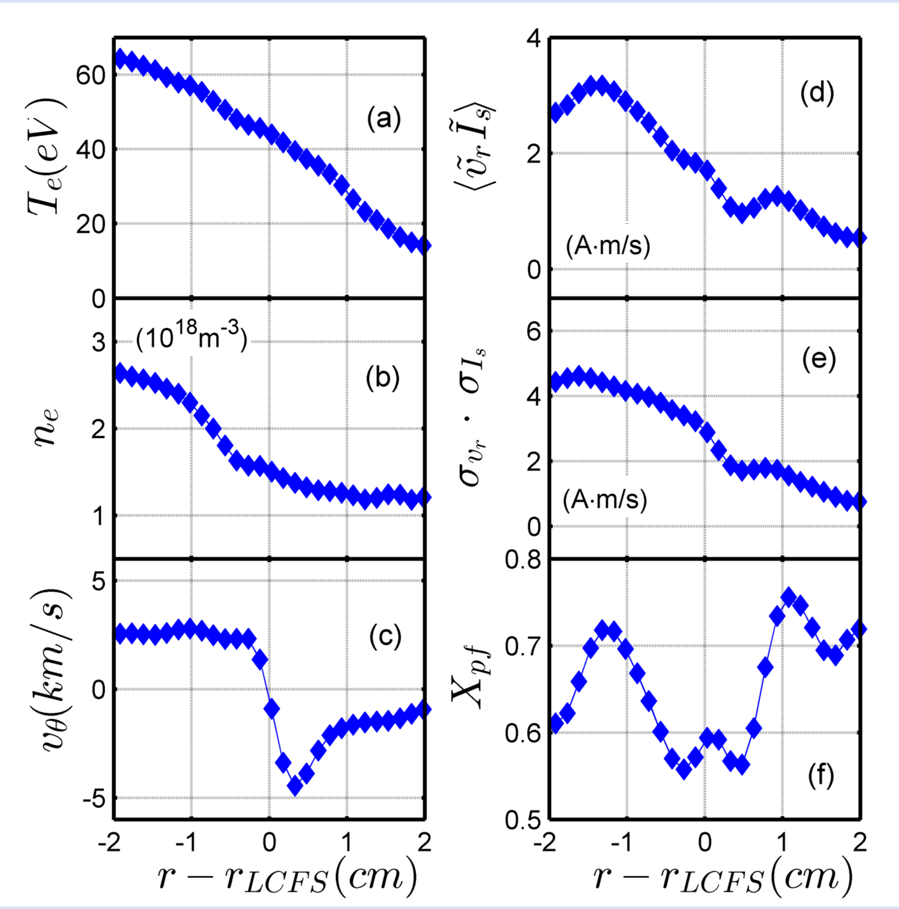


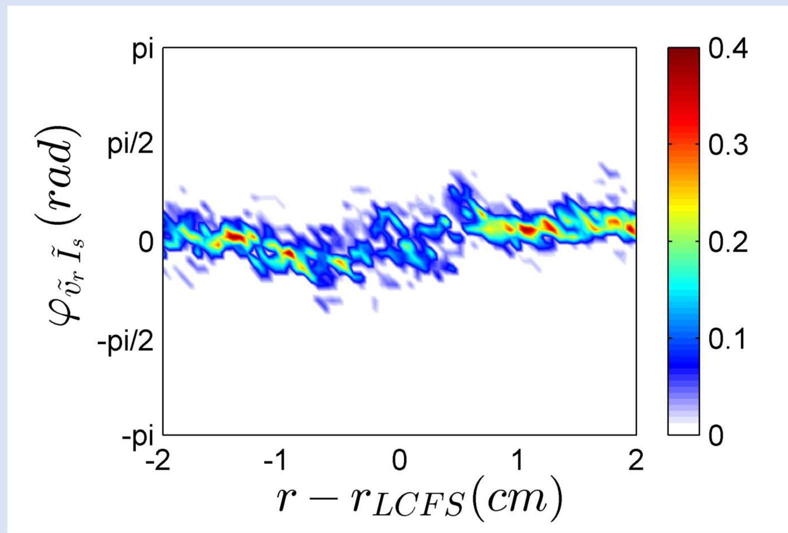


distribution of normalized cross power on cross phase

Phase dynamics in particle flux

- In the strong shear layer, the cross phase factor is lower, and in the weak shear layer, the cross phase factor is higher.





The phase in particle flux concentrates on near 0.
In the strong shear region, phase scattering is enhanced slightly

Conclusion

- The cross phase in Reynolds stress evolves dynamically in the strong shear layer (phase scattering in Ohmic, phase shift in ECRH L-mode). Thus, the cross phase cannot be treated as fixed.
- The cross phase in particle flux is much more concentrated than in Reynolds stress, and scatters slightly in the strong shear layer.
- Further explanation of physical mechanisms in different phase dynamics regimes is necessary. Studies of phase dynamics in the proximity of density limit on J-TEXT tokamak are ongoing.

Acknowledgements

This work is supported by National Key R&D Program of China under 2017YFE0300405, 2017YFE0301201, 2018YFE0309103, 2018YFE0303100, 2018YFE0310300, National Natural Science Foundation of China under Grant No. 11905050, 11875124, 11705052, U1867222 and 11875023, program under 2020JDTD0030 and 202001XWCXRZ004, and U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences under Award Number DE-FG02-04ER54738.