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Magnetic configuration effects on core turbulence in Wendelstein 7-X

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Optimized stellarator experiments such as Wendelstein 7-X (W7-X) demonstrate the successful reduction of neoclassical transport [1]. In turn, the confinement behavior of W7-X is dominated by turbulent transport [2, 3] and research on stellarator optimization now moves towards turbulence optimized configurations for future stellarator reactors. To optimize for reduced turbulent transport, metrics and methods are being developed utilizing magnetic geometry effects on turbulence destabilization and saturation [4, 5]. The experimental assessment of these effects, however, is still incomplete. Currently, W7-X is the only device in operation, which is suitable for addressing this question. By varying coil current ratios, the rotational transform as well as the depth of toroidal magnetic mirrors can be varied in W7-X, which affects the shaping of flux surfaces and numerous geometric quantities. Turbulent density fluctuations throughout the plasma core of W7-X are measured by the phase contrast imaging diagnostic [6, 7]. A reproducible and robust impact of magnetic configuration on density fluctuation amplitude and wavenumber spectra is measured. The impact is observed in a database approach covering a large range of plasma parameters (figures 1 and 2), as well as in dedicated comparative experiments at various heating power and density levels. The turbulent spectra and fluctuation amplitudes are affected in different ways depending on which aspect of the magnetic configuration is varied. However, other fluctuation diagnostics do not always see the same trends. The kinetic profiles in the comparative experiments show only minor differences, which are within the current measurement uncertainties.

The similar profiles indicate that the configuration differences have a minor effect on transport, which is reflected by rather small differences in global energy confinement time. The ambipolar neoclassical radial electric field can vary significantly between configurations but in the investigated plasma scenario, its shear is small and the effect on turbulence is unclear. Linear and non-linear gyrokinetic flux tube simulations were performed with the code `stella` [8] to investigate the difference in configurations from a local gyrokinetic perspective. For the configuration comparison, the same temperature and density gradient length scales are assumed in order to isolate the effect of magnetic geometry. The selected values are in accordance with the profile measurements. The simulation results can partially reproduce the experimental findings. In all cases, an effect of the magnetic geometry on growth rate spectra, fluctuation amplitudes and heat flux is observed. The effect of varying rotational transform is reproduced and the contributing mechanisms are discussed. However, the effect of varying mirror ratio is predicted to be opposite of what is observed experimentally. Possible reasons for this discrepancy are discussed.

References

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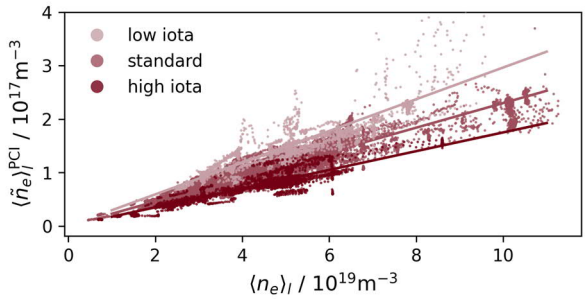

Figure 1: Line-averaged electron density fluctuations measured by PCI in W7-X magnetic configurations with varying rotational transform.

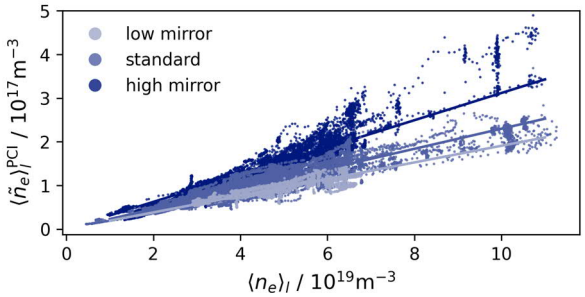

Figure 2: Line-averaged electron density fluctuations measured by PCI in W7-X magnetic configurations with varying toroidal mirror ratio.