Turbulence Studies on TCV using Correlation ECE

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Introduction

Neoclassical transport theory underestimates heat and particle transport in tokamak plasma. It is believed that turbulence is responsible for this. Turbulence can also create global modes which, in turn, regulate its development. It is essential to characterise turbulent phenomena and its creation and suppression mechanisms. Camenen et al [1] report a marked improvement in energy confinement at negative triangularity and it remains to be seen if there is a commensurate reduction in fluctuation amplitude at negative triangularity.

By virtue of its high spatial and temporal resolution Correlation Electron Cyclotron Emission (CECE) [2] can be used to investigate the electron temperature component of turbulence. TCV has a six channel CECE radiometer with a line of sight perpendicular to the magnetic field. The antenna pattern of the radiometer limits resolution to $k_\theta < 112\ m^{-1}$ and can access minor radius $\rho(\psi) < 0.8$. It has been used in several studies taking advantage of TCV flexibility in plasma shape and position. The centre frequency of each channel can be changed from one discharge to the next allowing turbulence measurements to be made over most of the plasma minor radius using approximately 4 discharges.

Experiment

Making use of the great shape flexibility of TCV, a series of discharges were created where, for otherwise fixed plasma parameters and input power, the edge triangularity was varied, from one discharge to the next, between -0.4 to +0.4 going through zero. These discharges exhibited sawteeth but apart from that they were quiescent and stable.

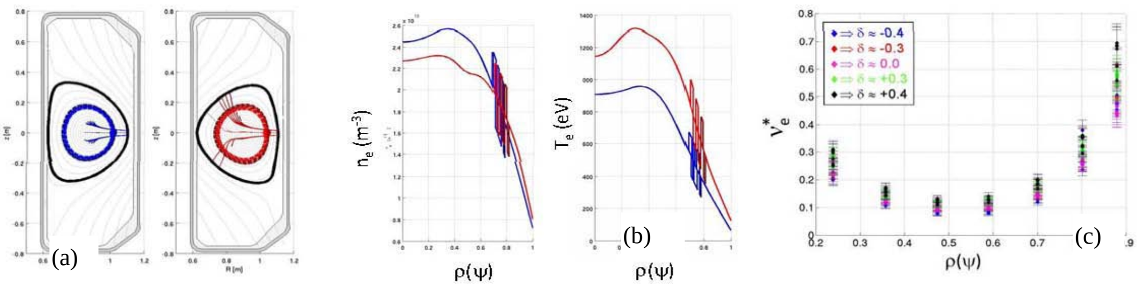

Figure 1: graphical depiction of the experimental set up. (a) the different shapes used on TCV showing positive and negative triangularity discharges. Red δ≈-0.4; blue δ≈+0.4. (b) the kinetic profiles, for the same discharges, showing how the density was very well controlled: the variation in temperature is due to improved confinement at negative triangularity. Red curves are for negative triangularity while blue are for positive triangularity. (c) collisionality profile showing the very weak variation in collisionality throughout the triangularity scan. All discharges used in this study are represented in this plot.

Great care was taken to ensure that the density and, indeed, the effective electron collisionality remained unchanged from discharge to discharge. Figure 1 shows, graphically, the discharge characteristics. Note the weak variation in collisionality throughout the scan. It is to be noted that, on TCV, due to the relatively small plasma volume and low temperature the plasma is optically grey, or even thin, over a significant fraction of the minor radius. This means that the intensity of the EC emission is due to both the electron temperature and the electron density. Vuille [2] showed that the fluctuation measurements are expected to be dominated by electron temperature fluctuations. Absolute ECE measurements are obtained by cross calibration against Thomson scattering measurements.

Measurements

For a given plasma shape four discharges were created with fixed parameters and from one discharge to the next the filter frequencies were changed so that measurements were made over the whole low field side part of the plasma minor radius ($0.35 \leq \rho(\psi) \leq 0.8$). The data were analysed to extract spectra of the fluctuations of the radiative temperature. Using the radial distribution of the channels, within a shot, and varying the position of the channels from shot-to-shot a radial profile of the radial correlation length of the radiative temperature fluctuations was constructed as a function of triangularity.

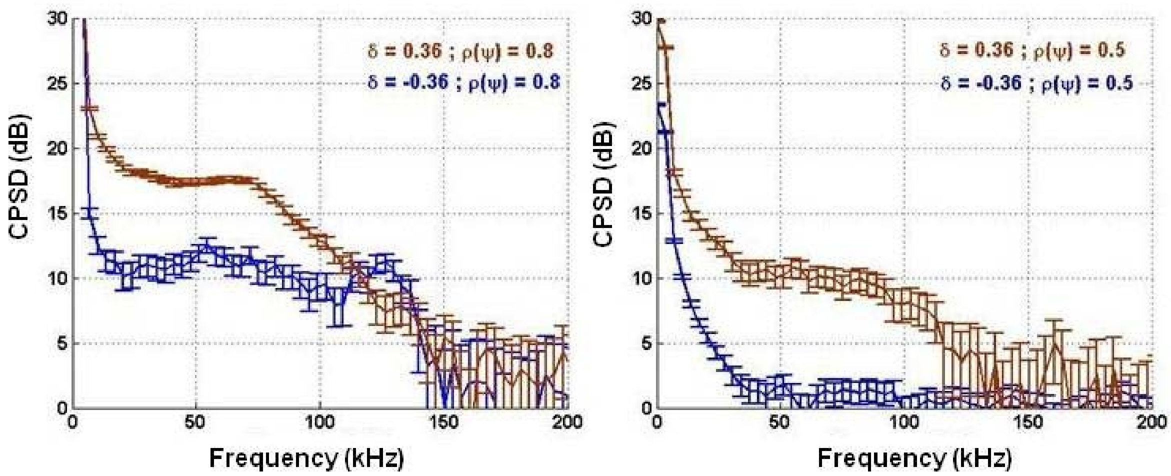

Figure 2: turbulence cross-spectra, between two CECE channels speared by less than a correlation length for two separate discharges. The first discharge (brown) has positive triangularity while the second has negative triangularity; all other plasma paramenters being approximately equal. The noise floor for these spectra is close to the 0dB level and the sudden drop in power above 450kHz is due to low-pass video filters. These spectra were obtained from data acquired at two different minor radii: (a) $\rho \approx 0.5$: (b) $\rho \approx 0.65$

In figure 2 clear variations are seen in the turbulence cross-spectra as the edge triangularity is varied. In general the fluctuation amplitude is greater for positive triangularity than for negative triangularity. The flux surfaces upon which these measurements were made are approximately elliptical. Most of the energy in the spectra lies in the spectral range 20kHz $\leq$

$f \leq 150$kHz. Typically MHD dominates the spectra below 20kHz while above approximately 150kHz the turbulence spectrum amplitude drops beneath the system noise level.

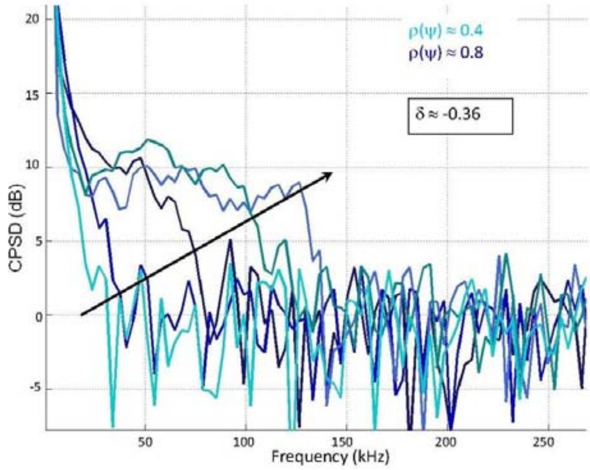

Figure 3: turbulent cross spectra obtained from measurements made in a series of discharges at fixed negative triangularity. The turbulent spectra increase in width with minor radius.

Figure 3 shows 5 different cross-spectra from five separate, identical, discharges: $\delta \approx -0.36$. The 5 separate coherence-spectra were obtained at minor radii $0.4 \leq \rho \leq 0.8$. It is seen that the spectrum of the broad band turbulence increases with increasing minor radii. Inside $\rho \approx 0.45$ the broad band turbulence feature of the spectrum has all but disappeared leaving a narrow spectrum dominated mostly sawteeth. The spectral width of the turbulent feature extends to ≈ 160kHz maximum. No measurements have been obtained at minor radii beyond 0.8 so it is unknown if the spectral width increases even further as minor radius increases. Figure 4 shows profiles of the estimated $\delta T_e/T_e$ (a) and T_e. We see that in general the relative fluctuation amplitude is larger for positive triangularity with a large divergence at large minor radius. Absolute fluctuation amplitude scales with T_e and there are no significant differences between positive and negative triangularity.

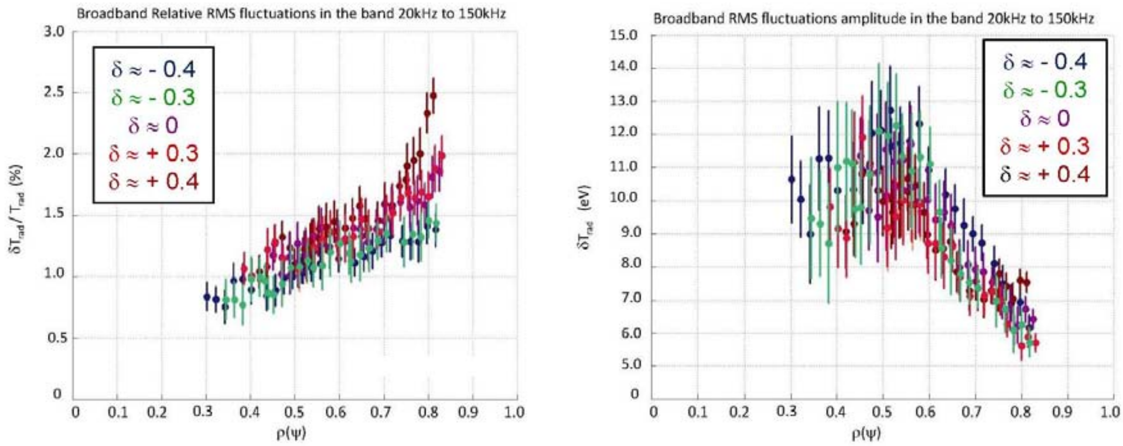

Figure 4: (a) the relative amplitude of fluctuations in the radiative temperature. Across the whole minor radius the relative amplitude of the fluctuations is larger for positive triangularity than for negative triangularity. (b) Absolute amplitude of the fluctuations. There is little difference between positive and negative triangularity.

Estimates of the radial correlation length profiles of the turbulence in the radiative temperature have been made and are shown in Figure 5. In these discharges the inversion radius was close to $\rho(\psi) \approx 0.55$. Inside the inversion radius the radial correlation length

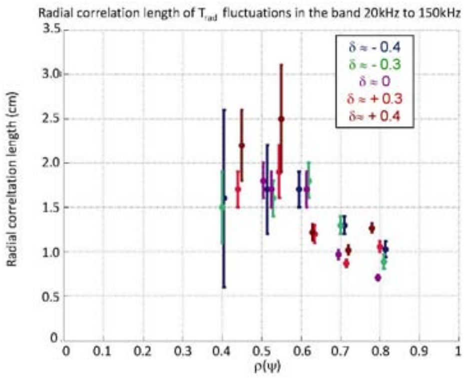

Figure 5: profiles of the radial correlation length of the turbulence for various values of triangularity.

remains approximately constant at $L_c \approx 2$cm and decreases outside the inversion radius. There is no apparent difference between positive and negative triangularity.

Discussion

A unique set of measurements has been made exploiting the enormous shape flexibility of the machine and the advanced diagnostic set-up made available on TCV. Radial profiles of the turbulence spectra of the radiation temperature ($\approx T_e$), the radial correlation length of these fluctuations and the absolute amplitude of the fluctuations have been obtained.

The measurements of the relative fluctuation amplitude are larger for positive δ compared to negative δ but this is mostly due to the reduced temperature in the positive δ cases. The absolute fluctuation amplitude is more or less the same for both positive and negative δ. Measurements of radial correlation length show no significant differences between positive and negative δ and the correlation length may scale with T_e or with ∇T_e.

There is a substantial amount of work to be done to conclude the work presented in this paper. All of the data presented here was obtained in ohmic discharges. One of the immediate tasks will be to repeat the measurements in the presence of additional heating. TCV has a very flexible ECRH/ECCD system and will soon be equipped with neutral beam heating. It will be extremely interesting to compare discharges of different shape, δ, in discharges where the ration T_i/T_e can be varied. It will also be necessary to look at the effect of varying collisionality. It is planned to implement a synthetic diagnostic interface for CECE to the turbulence codes ORB5 and GENE. When this is completed then true tests of theoretical models of turbulent transport can be made.

Acknowledgements

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References

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[2] C. Watts, Fusion Science and Technology **52**, Aug. (2007)

[3] V. Vuille et al: Proceedings 40th European Physical Society Conference on Plasma Physics, 1st – 5th July 2013, Espoo, Finland.