Radial Correlation Doppler Reflectometry on ASDEX Upgrade

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Introduction

Radial correlation Doppler reflectometry is a new diagnostic technique which has been developed on ASDEX Upgrade. It allows for the measurement of several plasma properties such as the perpendicular rotation of the plasma ($u_\perp$), the radial electric field (E_r) and the radial electric field shear (dE_r/dr). The radial electric field shear in H-mode is believed to be responsible for the confinement improvement and reduction of anomalous transport observed [1] and hence, this measurement is of key interest. Presently, there is a lack of experimental E_r shear data available in tokamak devices and so a diagnostic which can provide such a measurement is valuable. In addition, the diagnostic is capable of measuring characteristics of the turbulence such as density fluctuations and the radial correlation lengths of the turbulence (L_r). By correlating the properties of the turbulence with the magnitude of the E_r shear, further insight can be gained about the plasma confinement. In this paper, several results from this new diagnostic technique will be presented, with particular focus on recent E_r shear and L_r measurements.

Technique

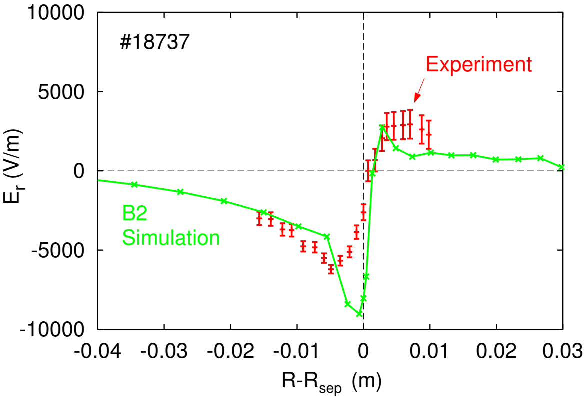
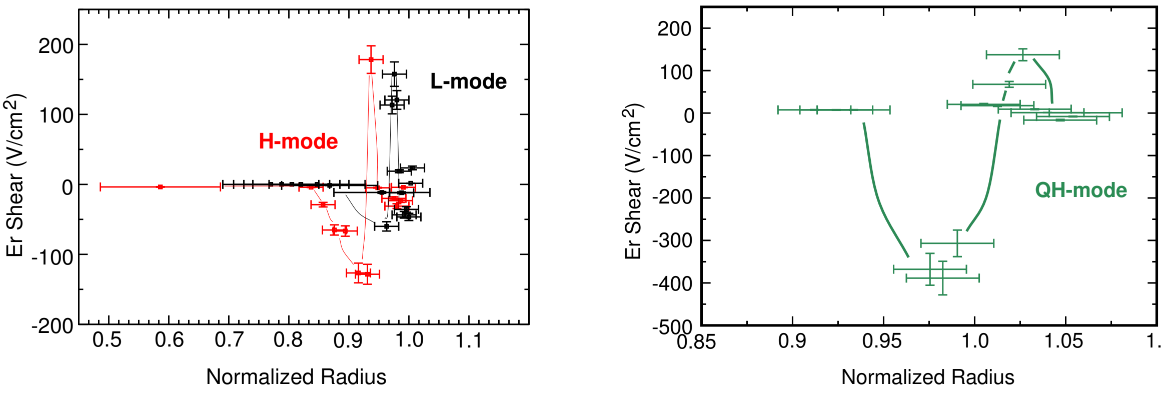


Figure 1: *Radial Electric Field Profile in an Ohmic Discharge (#18737).*

The correlation Doppler reflectometry system, installed on ASDEX Upgrade, consists of two identical V-Band heterodyne reflectometers with steppable launch frequencies (between 50 and 75 GHz) and selectable O or X-mode polarization [2]. In this technique, the two Doppler reflectometer channels are connected to the same antenna pair so that they launch microwaves with the same line of sight simultaneously into the plasma. The microwaves have different launch frequencies and therefore reflect from different radial positions in the plasma. From the Doppler shifts in the received microwave signals, one obtains the perpendicular rotation of the turbulence in the plasma ($u_\perp$). The velocity is given by $u_\perp = f_D\, \lambda\, /\, 2\sin\theta$ where f_D is the doppler shift, λ is the wavelength of the incident microwave and θ is the geometric tilt angle between the plasma flux surface normal and the incident microwave beam. $u_\perp$ is the sum of the $E \times B$ velocity, $v_{E\times B}$, and the intrinsic phase velocity of the turbulence, v_{ph}. In the edge region for drift wave turbulence, v_{ph} is negligible [3] and hence, the radial electric field can be determined from the equation $E_r = -u_\perp B_{tot}$. Figure 1 shows an example of a radial electric field profile measured by Doppler reflectometry in an ohmic disharge [4]. The radial cutoff layer positions are evaluated from the density profile and the magnetic field profile when using X-mode polarization. The n_e profile is obtained from other diagnostics such as Thomson-scattering, lithium beam and swept frequency profile reflectometry. Also shown in Figure 1 is the radial electric field modelled by the plasma fluid code B2 [5,6] for the same discharge. The code takes into account experimental density and temperature profiles as well as the drifts involved. The good agreement in both magnitude and position of the two profiles supports that the Doppler reflectometer is indeed measuring the E_r at the edge.

Two correlation measurement techniques have been developed: (1) Sweeping the two reflectometer channels but keeping the frequency difference between them fixed and then taking the difference between the two simultaneous E_r values divided by the channel radial separation gives a radial profile of the instantaneous E_r shear (dE_r/dr). Typically, a frequency sweep pattern of 1 GHz steps from 50 to 74 GHz in 100 ms with a fixed 2 GHz separation is used. (2) Alternatively, keeping the frequency of one reflectometer channel constant and sweeping the frequency of the second permits the correlation properties of the turbulence to be measured. Here, a sweep every 50 ms with a frequency difference between the two channels starting at 0.1 GHz (to avoid any cross talk between the two channels) and increasing logarithmically was found to be sufficient. The channel separation when the cross correlation between the two fluctuation signals drops to 1/e gives a measure of the spatial correlation of the turbulence (designated the radial correlation length, L_r) as a function of $k_\perp$.

Results: E_r Shear



(a) L-mode (#18103) versus H-mode (#17973)

(b) Quiescent H-mode (#18925)

Figure 2: *dE_r/dr profiles showing enhanced edge shear in H and QH-modes. Note the different scale.*

Figure 2 shows example E_r shear profiles measured during an L-mode, an ELMy H-mode and a Quiescent H-mode discharge. Three main observations can be made from these profiles. First, the shear is localized at the plasma edge and practically zero elsewhere. Second, the shear is positive near the separatrix and negative a few cm within the plasma edge coinciding with the pedestal. Thirdly, an increase of the negative edge shear is linked to an increase in plasma confinement. Typically at ASDEX Upgrade the maximum negative edge E_r shear measured in L-modes is between 0 and -75 V/cm^2, in H-modes between -150 and -250 V/cm^2 and, in QH-modes between -400 and -500 V/cm^2. Biglari, Diamond and Terry (BDT model) [7] predict that an increase in absolute shear suppresses density fluctuations and stabilizes the turbulence. The data shown in Figure 2 is consistent with this model. Also, in Figure 2a, it can be seen that the H-mode E_r shear profile is shifted inwards in comparison to the L-mode profile. This may be due to the density pedestal which steepens and in this case moved inwards during the H-mode.

Results: Radial Correlation Lengths of the Turbulence

Radial correlation lengths of the turbulence (L_r) have also been measured using the Doppler correlation system. Recent results are presented here. With heterodyne and quadrature detection, there are a range of reflectometer fluctuation signals available to correlate. The reflectometer signals tested were the amplitude (A), phase (ϕ), homodyne in-phase ($I = Acos\phi$), homodyne quadrature ($Q = Asin\phi$), and complex ($I + iQ$) signals. It was found that the complex and homodyne signals consistently give larger L_r than the amplitude and phase signals [8]. This is most likely due to the fact that the homodyne and complex signals include both amplitude and phase information and therefore do not assign too much weight to either parameter, particularly during periods of low reflected power. As a result, the L_r measurements presented here are obtained by cross correlating the complex reflectometer signals.

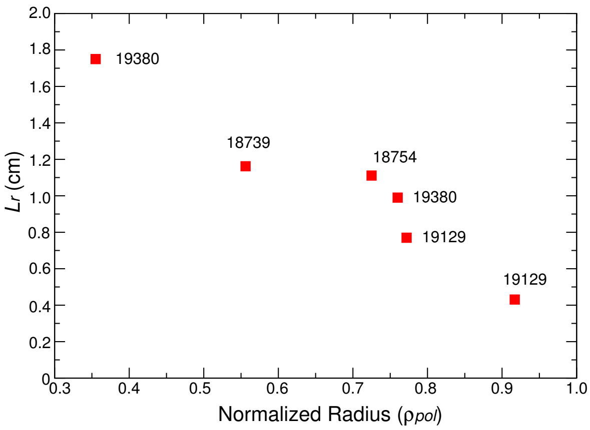


Figure 3: *L_r measured as a function of normalized radius during L-mode phases in ASDEX Upgrade's Standard H-mode discharges (#18739-19380).*

Figure 3 shows how L_r varies with plasma position. The data was collected in the early L-mode phases of ASDEX Upgrade's Standard H-mode discharges. All plasma parameters were constant during the time the Doppler correlation data was collected in O-mode configuration. The figure shows L_r increasing into the plasma core, ranging from about 0.40 cm at $\rho_\mathrm{pol} \approx 0.92$ to 1.75 cm at $\rho_\mathrm{pol} \approx 0.35$. The magnitude of L_r is similar to those measured on DIII-D using a standard correlation reflectometer ($k_\perp = 0$) [9]. Note that the radial position of the core measurements will be corrected using TORBEAM raytracing calculations [10] to account for the strong beam refractive effects occuring in the plasma core. It is expected that the core L_r measurements will move radially outward.

The relationship between L_r and the turbulent wavenumber $k_\perp$ can also be examined with the correlation Doppler system since the tilted antennae of a Doppler reflectometer introduces a non-zero turbulent wavenumber, $k_\perp$. The wavenumber is given by the Bragg equation: $k_\perp = 4\,\pi\,\sin\theta/\lambda$ where θ is the geometric tilt angle between the plasma flux surface normal and the incident microwave beam and λ is the wavelength of the incident microwave. The antennae on ASDEX Upgrade are fixed in tilt angle so to vary $k_\perp$, the plasma shape is scanned from low to high triangularity. This was performed in two L-mode upper single null discharges (#19146 and #19148) and the results are shown in Figure 4. Surprisingly L_r increases with $k_\perp$. Simple theory predicts the opposite since one would expect smaller wavelengths (larger $k_\perp$) to probe smaller structures (smaller L_r). A possible reason for this unexpected trend is that by changing the plasma shape, the nature of the edge turbulence is changed. Previous measurements have shown that the radial electric field and its associated shear changes with plasma shape [11]. Another possibility is that the Doppler reflectometer is not measuring L_r alone but rather in addition some other component such as the poloidal correlation length L_pol.

To test these hypotheses, a repeat of this experiment is planned with a new tiltable antenna. This will allow the measurement to be performed under constant plasma conditions. As well, 2D Full Wave Finite Difference modelling of the reflectometer response has begun. The 2D code includes the experimental density, magnetic field and antenna charcteristics during discharges #19146 and #19148. The overall goal will be to recreate the L_r experimental measurements and in particular, examine the dependence of L_r on $k_\perp$.

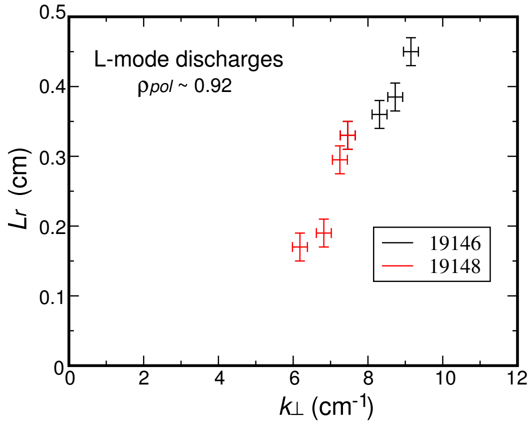


Figure 4: *L_r measured as a function of the turbulent wavenumber $k_\perp$ during L-mode discharges (#19146 and #19148)*

Summary

In conclusion, using the new Doppler correlation reflectometer system on ASDEX Upgrade successful measurements of dE_r/dr and L_r have been made in various plasma scenarios. The edge E_r shear measurements show an increase in absolute value in H-modes and QH-modes. The L_r measurements show an increase of L_r into the plasma core as expected. However, the relationship between L_r and $k_\perp$ give surprising results as L_r increases with $k_\perp$. This result has motivated an investigation using a 2D Full Wave Finite Difference code to simulate the reflectometer response and in particular recreate the experimental L_r measurements.

References

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