Turbulence wave number spectra in the FT-2 tokamak by radial correlation Doppler reflectometry

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It is widely accepted nowadays that drift-wave turbulence is responsible for anomalous transport of energy and particles in tokamak plasma that stimulates numerous investigations both experimental and theoretical. The radial correlation reflectometry (RCR), as it was shown recently [1], provides a way for determination of the turbulence radial wave number spectra and its detailed investigation. At FT-2 tokamak a RCR scheme in the 50-75 GHz frequency range has been assembled last year [2]. The movable *X*-mode double antenna set installed at high magnetic field side and allowing plasma probing at variable incidence angle is used in this scheme of Doppler RCR.

In this paper the results of the RCR measurements in ohmic discharge scenarios with hydrogen and deuterium of FT-2 tokamak (R= 55 cm, a= 7.9 cm, B_T= (1.7-2.1) T, I_p= (18-40) kA, $n_e(0)$= (0.5-12)$\times 10^{13}$ cm^{-3}, T_e= (300-500) eV) are presented. The diagnostic scheme presented in fig.1 was used in experiments. The reference channel generator at frequency 70 GHz shown there determines the cut-off position, whereas the 2nd generator at frequency changing with step 100 kHz in the [-1.2; 1.2] GHz range was used to determine the turbulence two-point cross-correlation function. The probing was performed in X mode from the high field side of the torus.

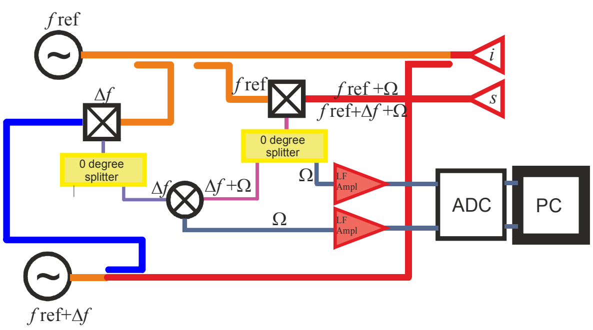

Fig.1. *CCF measurements scheme.*

We obtain two homodyne signals (one coming from the reference point and another generated in the shifted point) as the result of one discharge measurements. The latter point is scanned on discharge to discharge basis. The coherence CCF(ΔL)=$\langle A_s(\omega_0)\, A_s(\omega)^* \rangle$ dependence on distance ΔL proportional to frequency difference $\Delta\omega$ is investigated. In all the obtained results we suppose that CCF imaginary part at the perfect calibration should be equal to zero and therefore analyze the coherence dependence on the cut off separation, as a characteristic of the turbulence spatial structure.

In ohmic regime measurements from high field side were performed with four antennae vertical positions referred to angles range [10-30] degree of Doppler reflectometer corresponding to different probing poloidal wave numbers at the plasma boarder (3-7 cm^{-1}) and turbulence frequency shifts changing from 50 kHz to 500 kHz. The measured quadrature spectra are presented in fig.2. The Doppler frequency shift grows with antennae equatorial displacement and the spectrum becomes broader.

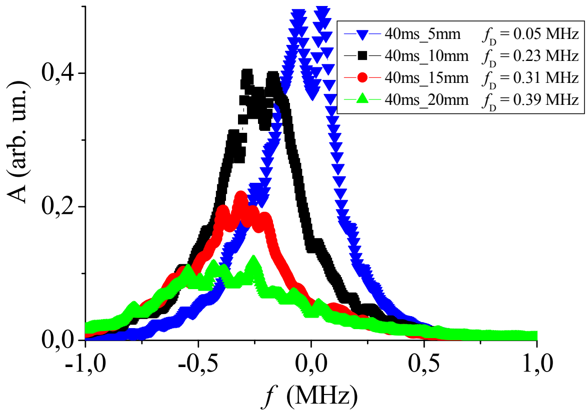

Fig.2. *The Doppler reflectometer quadrature spectra at different antennae vertical shift.*

Obtained coherence dependencies on the turbulence frequency and probing waves cut off separation at 10 and 30 degrees probing are presented in fig.3. The rather high level of coherence is observed in the 1 MHz frequency range [0;1] MHz at small angle probing and [0.3;1.3] MHz at big angle probing. Black lines indicate 1/e level which determines correlation length. As it is clearly seen, the maximal spatial width of the high coherence region corresponds to turbulence frequencies where quadrature spectrum amplitude is high. In order to obtain the fluctuation two-point cross-correlation function from the reflectometry signal CCF, shown in Fig. 3 in the case of normal probing wave incidence one should use the reconstruction procedure proposed in [3] to get rid of the small-angle-scattering contribution to the reflectometry signal. However, in the case of oblique enough incidence this contribution is automatically removed by the experiment geometry and there is no need in the reconstruction procedure. This statement is illustrated in Fig. 4 where DR signal CCFs computed for FT-2 experiment parameters (Distance from the plasma boundary to the cut off – 4 cm; Gaussian

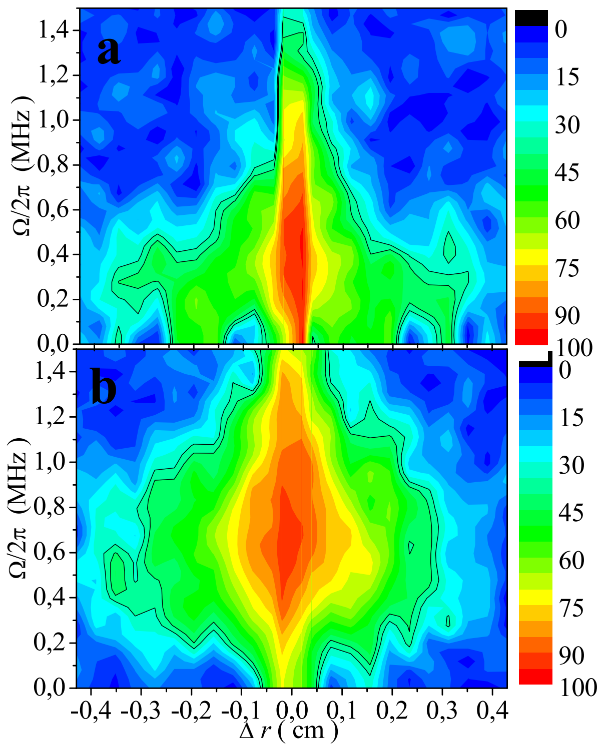

Fig.3. *Coherence of CCF*
a) *5mm* b) *20mm antennae shift.*

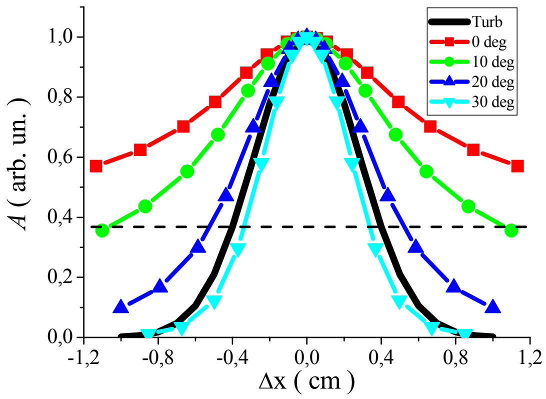

Fig.4. *The computed DR signal CCFs at different probing angles.*

microwave beam possessing 8mm radius; O-mode probing at 70 GHz), but in slab geometry and for different incidence angles are compared to the original turbulence CCF. The reflectometry signal was computed in the Born approximation utilizing full-wave solutions for the probing beam. As it is seen in the figure starting from the incidence angle of 20 degrees the DR signal CCF provides a good approximation of the turbulence CCF. Following these results we apply the reconstruction procedure proposed in [3] only in the case of small incidence angles, corresponding to small antenna vertical shift of 5 mm (Fig. 3a). On contrary, in the case of

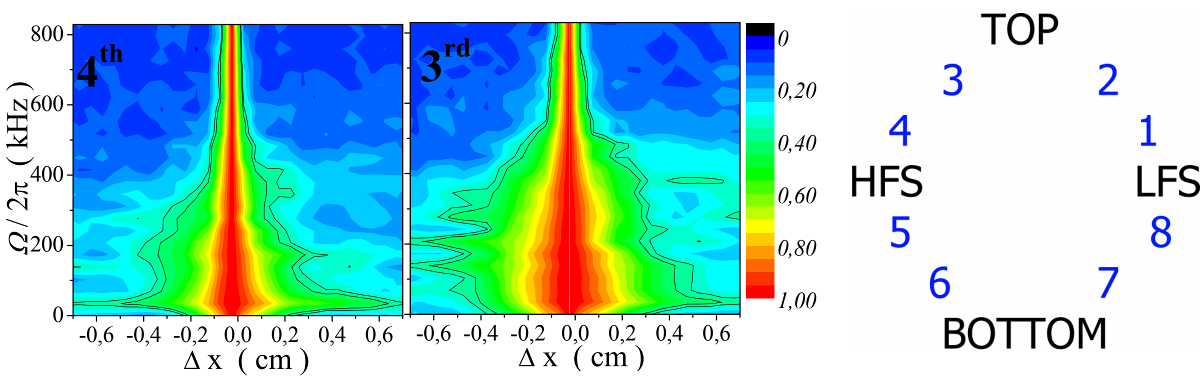

Fig.5. *Turbulence CCF in 4th and 3rd sectors modeling by full-f Elmfire gyrokinetic code.*

vertical shift of 20 mm (Fig. 3b) no reconstruction is used. The turbulence two-point CCFs obtained experimentally were compared to those provided by the full-f gyrokinetic ELMFIRE code FT-2 tokamak ohmic discharge modeling[4]. The turbulence CCFs provided by simulations in 3rd and 4th sectors of the FT-2 poloidal cross section are presented in fig.5. To compare our results with simulations we selected the CCFs measured at scattering point close to r=4cm and compared them with density fluctuation two-point CCFs calculated at r=4cm. In both cases CCFs are compared at turbulence frequency corresponding to Doppler reflectometry frequency shift (spectral maximum). Comparison results in case +5mm antennae vertical displacement from equatorial plane is shown in fig.6a. It is seen that the experimental CCF at frequency 200 kHz obtained by the reconstruction procedure coincides with the CCF simulated in the 4th sector at the same frequency. The turbulence correlation length obtained by both approaches in the 4th sector is about 2 mm. A good enough coincidence is observed between CCF at frequency 400kHz measured in the case of +20mm

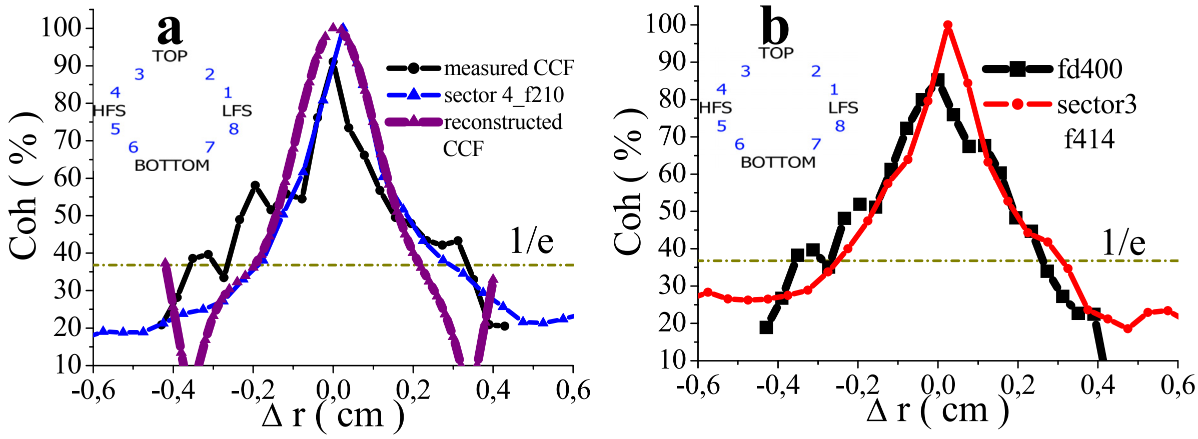

Fig.6. a) *CCF at f_{turb} = 200 kHz measured and computed in the 4th sector*

b) *CCF at f_{turb} = 400 kHz measured and computed in the 3rd sector*

antennae shift probing and that simulated in the 3rd sector (see fig.6b). The radial correlation length in this case is about 3 mm. These results obtained both experimentally and in gyrokinetic modeling demonstrate poloidal inhomogeniety of drift-wave turbulence in FT-2 tokamak, which was also confirmed by O-mode DR measurements at the low field side. Using the method described above we obtained the correlation lengths dependencies on radius both in hydrogen and deuterium ohmic FT-2 discharges shown in Fig. 7.

As it is seen, the correlation length in deuterium discharge is systematically higher than in hydrogen. The effect is not very strong, but noticeable. The radial variation of the correlation length most likely can be attributed to density and density gradient spatial variation.

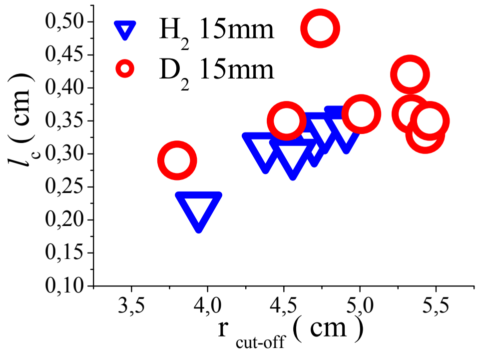

Fig.7. *l_c dependencies on radius in* D_2*(red) and* H_2*(blue) discharges*

Summarizing all the results we obtained good coincidence between turbulence correlation lengths in experiments and simulations by gyrokinetic code. In particular, both approaches have resulted in observation of poloidal inhomogeneity of drift wave turbulence in tokamak. We would like also to stress the successful application of turbulence spectrum reconstruction procedure proposed in [1], [3].

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