Poloidal inhomogeneity of turbulence parameters in the FT-2 tokamak by radial correlation Doppler reflectometry

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The radial correlation reflectometry (RCR) widely used nowadays for plasma turbulence characterization suffers from dominant contribution of small angle scattering off long scale turbulence component and therefore leads to correlation length overestimation [1]. Oblique plasma probing as a method to cope with this problem have been justified recently [2]. It was proved that the radial correlation Doppler reflectometry (RCDR) version of the diagnostic provides a way for determination of the turbulence radial wave number spectra and its detailed investigation. Following this approach at FT-2 tokamak the RCDR scheme in the 50-75 GHz frequency range have been assembled. The first experiments demonstrated successful application of the RCDR and resulted in turbulence correlation length of about 2-5 mm which appears to be inhomogeneous along poloidal direction in qualitative agreement to the results of ELMFIRE gyrokinetic modeling [3]. In this paper the results of detailed RCDR measurements at different poloidal angles in the FT-2 ohmic discharge (R= 55 cm, a= 7.9 cm, B_T= (1.7-2.1) T, I_p= 19 kA, $n_e(0)_{max}$= 4×10^{13} cm^{-3}, T_e= 470 eV) against which the gyrokinetic modeling was successfully benchmarked [3, 4] will be presented for hydrogen (H) and deuterium (D) plasmas.

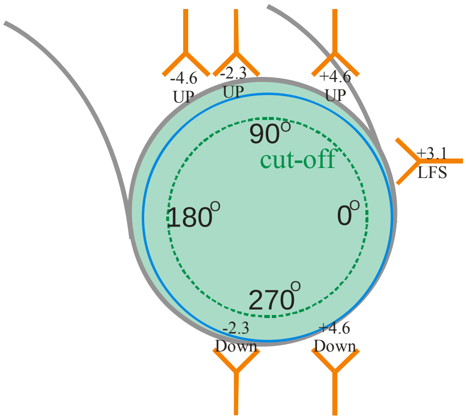

Fig. 1. *O-mode antennae.*

The O-mode radial correlation reflectometer scheme with reference probing frequency 30 GHz was used for investigation of plasma turbulence from low magnetic field side, from top and from bottom (see fig.1). The second generator frequency was varied in the range +/- 4GHz with step 0.5 GHz. The monostatic

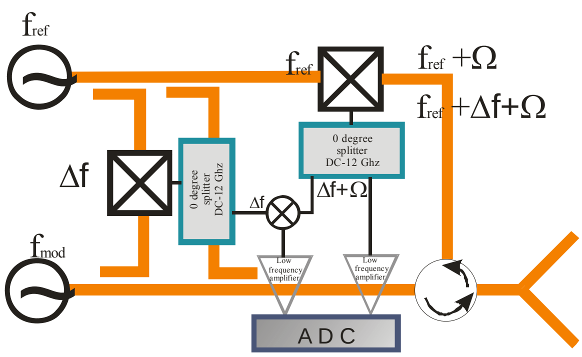

Fig. 2. *Cross-correlation scheme.*

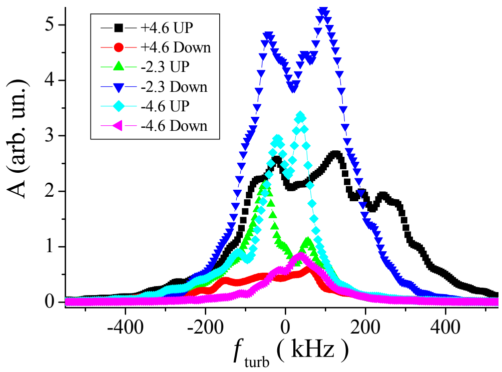

Fig. 3. *Qudrature spectra at different antennae positions*

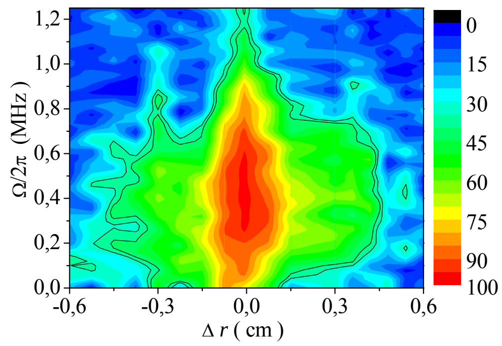

Fig. 4. *CCS measured with +4.6 antenna.*

horn antenna equipped with the microwave circulator was used in the scheme shown in fig. 2. The cross-correlation spectrum (CCS) of homodyne signals in two frequency channels was determined in the experiment at *r*=6.5cm as a function of the channel frequency difference. The spatial separation of the measurement points was taken equal to the difference of cut-off positions for different frequencies, as proposed in [2]. Though measured quadrature spectra presented in fig. 3 were rather narrow (less than 400 kHz) the CCS was well above the noise level also at much higher frequencies, as it is seen in figure 4. This figure provides us a possibility to measure the radial correlation length of the turbulent density fluctuations possessing different frequencies. However in this paper we focus on determination of the frequency integrated correlation length. For this purpose we integrate the CCS in the turbulence frequency range 20-1000 kHz with a weighting function equal to the Doppler reflectometry homodyne spectrum, thus underlining the contribution of the dominant frequency into the correlation length. The figure 5 presents results obtained with antennae placed at the top and bottom of the core and shifted from the central axis along the major radius by +4.6cm (plus indicates low field side direction). The integrated CCS obtained in H discharge is drawn by red and wine color correspondingly for top and bottom probing, whereas those measured in D discharge are shown with blue and dark cyan accordingly; the black broken line provides the 1/e level which determinates the correlation length. As it is seen in fig.5 the correlation length is systematically larger at the top than at the bottom in both gases. Besides this it is higher for D (0.55/0.5cm) than for H (0.45/0.35 cm) correspondingly at the top and at the bottom. The CCS behavior and correlation length values at the top and bottom in H discharge is in agreement with CCS calculated

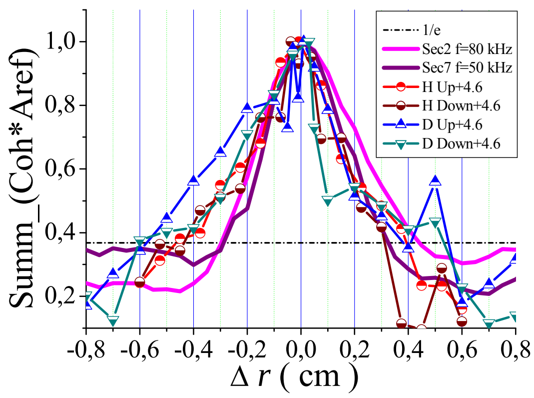

Fig. 5. *Integrated CCS measured with +4.6 UP and Down antennae and corresponding turbulence CCS modelling by gyrokinetic code.*

by code for hydrogen discharge for the top and bottom antenna positions and shown by magenta and purple lines accordingly. The Elmfire CCSs are presented at this figure for turbulence frequency equal to mean weighed Doppler frequency shift of the measured quadrature spectrum in this case.

The good enough coincidence with the gyrokinetic code predictions is also observed in the area of smaller poloidal angles where we use the measurements performed with antenna situated at the low field side and up-shifted by 37mm in respect to equatorial plane (see fig.6). It is worth mentioning that the correlation lengths measured in this position in H and D discharges are comparable (l_c=0.45cm), as it is seen in Fig.6. Similar values of correlation length in H and D are observed also in the cases of top probing using antenna slightly shifted (by -2.3cm) to the high magnetic field side (see fig.7 where l_c=5mm). The density fluctuation two-point

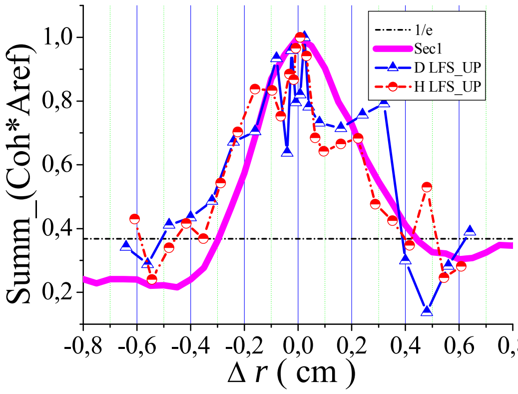

Fig. 6. *CCS measured with +3.7 LFS antenna.*

cross-correlation function provided in this case by Elmfire is shown in this figure by the magenta curve for fluctuation frequency 50 kHz corresponding to the Doppler frequency shift of the reflectometer spectrum.

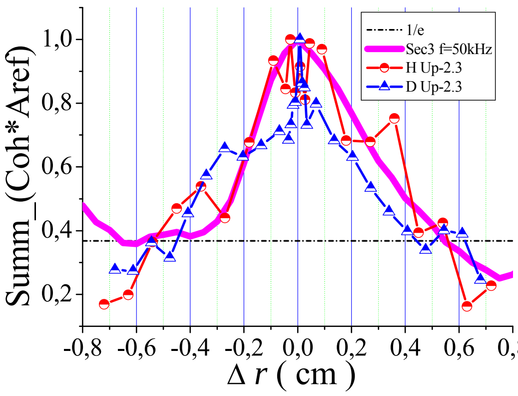

Fig. 7. *CCS measured with -2.3 UP antenna.*

In the case of larger inward shift (-4.6cm) of high-field-side top antenna (see fig.1) the correlation length decreases drastically (0.3cm in D and 0.2 cm in H discharges) compared to the previous one and top low-field-side (fig.8), which is in rough agreement with the gyrokinetic predictions shown for fluctuation frequency 30 kHz corresponding to the Doppler frequency shift of the reflectometer spectrum by magenta in Fig.8. The lower correlation length in H regime compared to D is observed here as well.

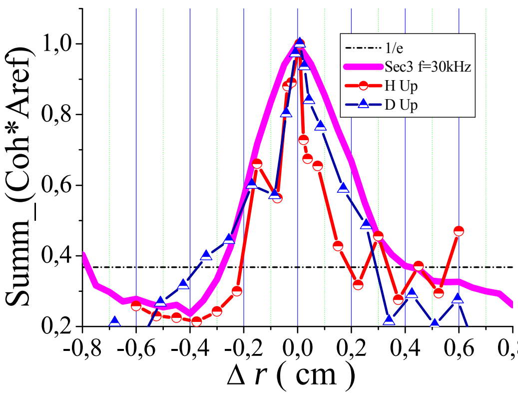

Fig. 8. *CCS measured with -4.6 UP antenna.*

The tendency of correlation length suppression at high magnetic field side at angles larger than 120° was confirmed by the data obtained using

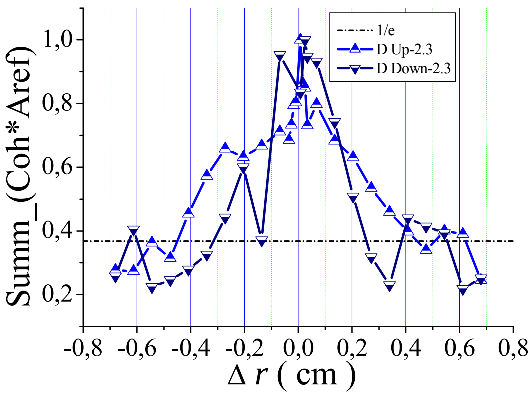

Fig. 9. *CCS measured with -2.3 UP and down antenna in D regime.*

bottom probing with antenna shifted by -2.3 cm from the axial position (see Fig.9). The correlation length measured there in D plasma appears to be 0.3cm, which is much smaller than at the top.

Combining obtained results with previous measurements performed from high magnetic field side using movable *X*-mode double antenna set and probing at 70 GHz [5] we can present poloidal distribution of the turbulence correlation length in H and D discharges. It is clearly seen in the Fig.10 that the correlation length quickly decreases at $120^o<\theta<180^o$ and then steadily grows in direction of plasma rotation. Summarizing we should note that as a result of performed experiment the radial correlation length was measured at different poloidal angles 40, 50, 110, 130, 150, 165, 210, 240, 310 degrees. It allowed us to make comparison with gyrokinetic calculations in 7 from 8 poloidal octants. All cases demonstrate quite a good coincidence with the gyrokinetic modeling results at turbulence frequencies corresponding to the weighed central frequency of the measured reflectometer spectra. In general, the turbulence correlation length is shown to be higher at the top than at the bottom and at the high field side. The correlation length in D discharge is usually higher than in the H one, with an exception for the low field side where no any difference is observed. Partial financial supports of RFBR grant13-02-00614, 12-02-00515, NWO-RFBR Centre of Excellence on Fusion Physics and Technology (grant 047.018.002) and the Russian Academy of Science Presidium program 12 are acknowledged.

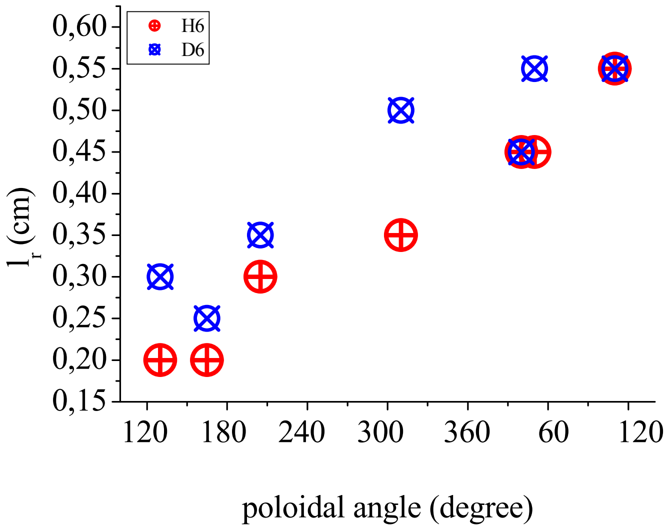

Fig. 10. *Radial correlation length at different poloidal angles.*

[1] E Gusakov and N Kosolapova 2011 Plasma Phys. Control. Fusion 53 045012.
[2] E Gusakov, M Irzak and A Popov 2014 Plasma Phys. Control. Fusion 56 025009
[3] E.Z. Gusakov et al. 2013 *Plasma Phys. Control. Fusion* 55 124034
[4] S. Leerink et al. 2012 *Phys. Rev. Lett.* **109** 165001
[5] A.B. Altukhov, A.D. Gurchenko, E.Z. Gusakov et. Al. 2013 40th EPS conference P1.170.