SUMMARY OF EXPERIMENTAL CORE TURBULENCE CHARACTERISTICS IN OH AND ECRH T-10 TOKAMAK PLASMAS

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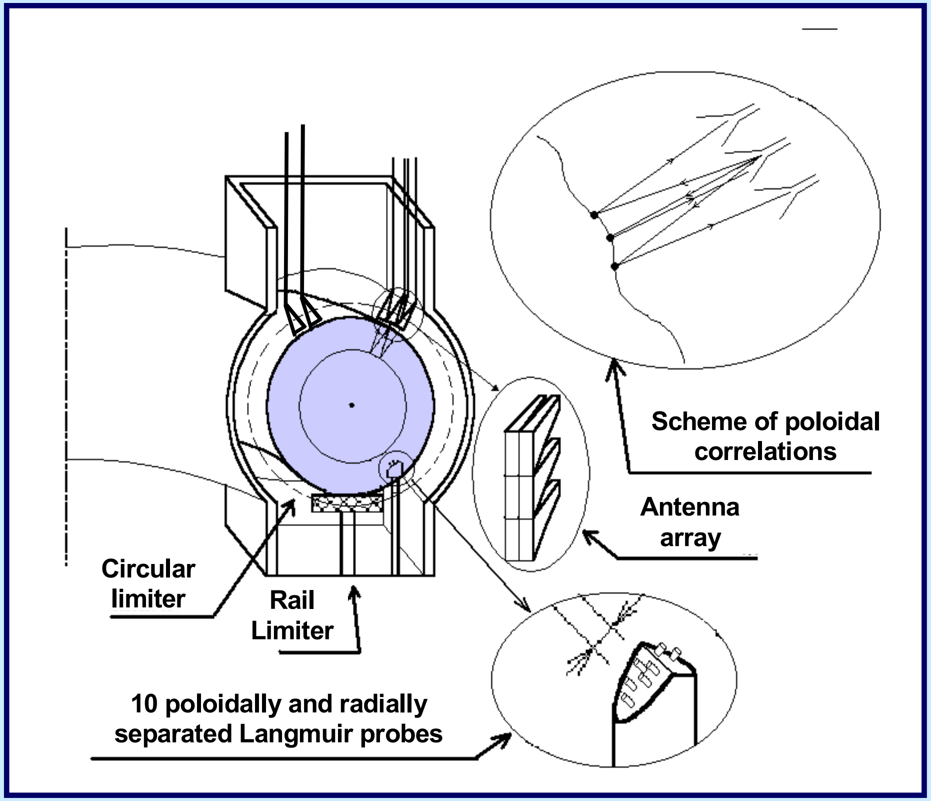
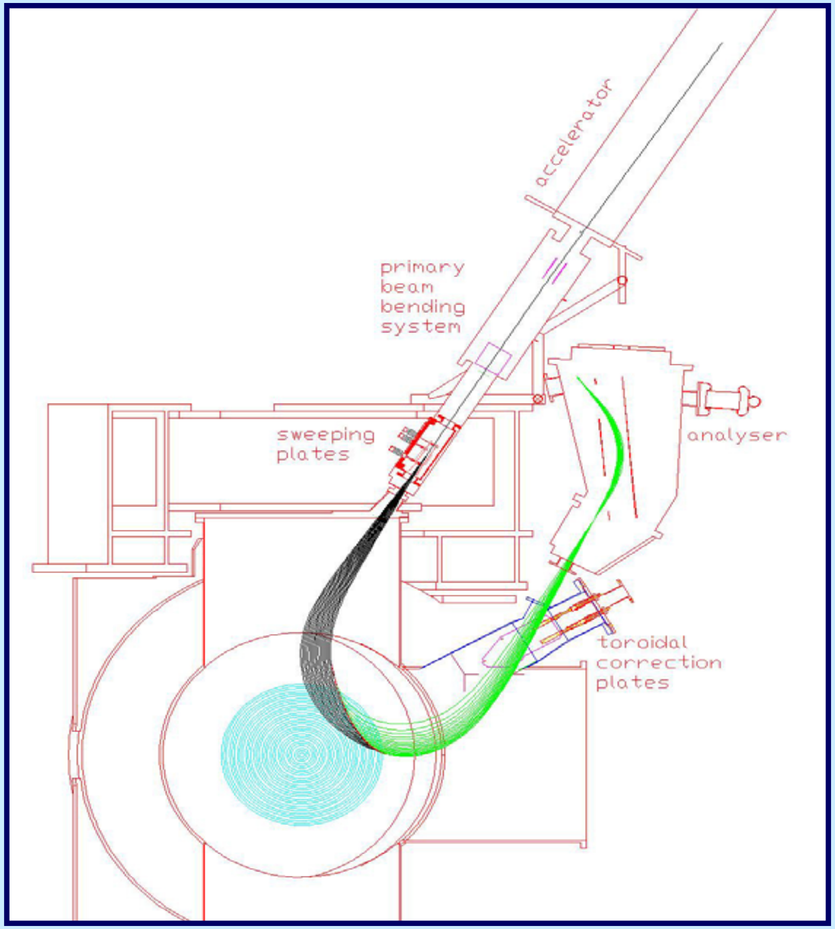
GOAL OF INVESTIGATIONS – TO UNDERSTAND THE PHYSICAL MECHANISMS OF PLASMA TURBULENCE. WITH THIS AIM :

1. **None-linear turbulence greatly complicates the identification of the physical mechanisms as it distort the spectra. In order to evaluate non-linear properties the investigations were conducted in the wide range of discharge types from the highest Ohmic confinement with peaked density up to the degraded high power heated discharges.**
2. **Diagnostics capable of obtaining spatial structure, propagation properties of turbulence (correlation reflectometry, multipine Langmuir probes and HIBP) were used**
3. **Radial, poloidal and absolute sensitivity of reflectometry to the local density fluctuations were especially checked with full wave 2D electromagnetic code.**
4. **Direct comparison of all three diagnostics were carried out in order to increase reliability of the results.**

The Schematics of T-10 diagnostics.



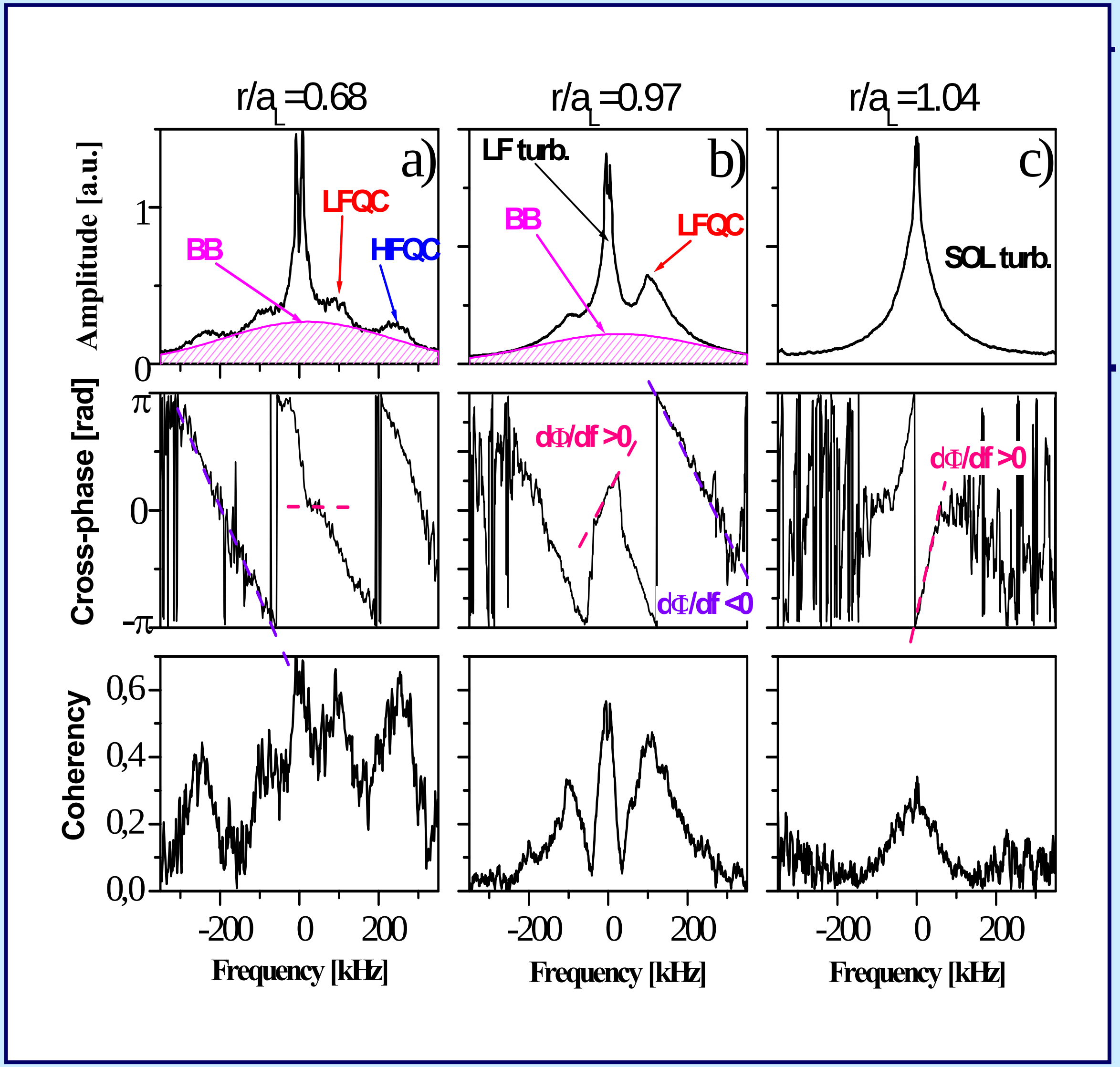
- **O-mode correlation reflectometer**, poloidal, radial and toroidal correlations in n_{cr} range from 0.8 to $7.8 \cdot 10^{19}$ m^{-3}
- **Movable multipin Langmuir probes**. poloidal and radial correlations of density and floating potential fluctuations



Heavy Ion Beam Probe (HIBP)

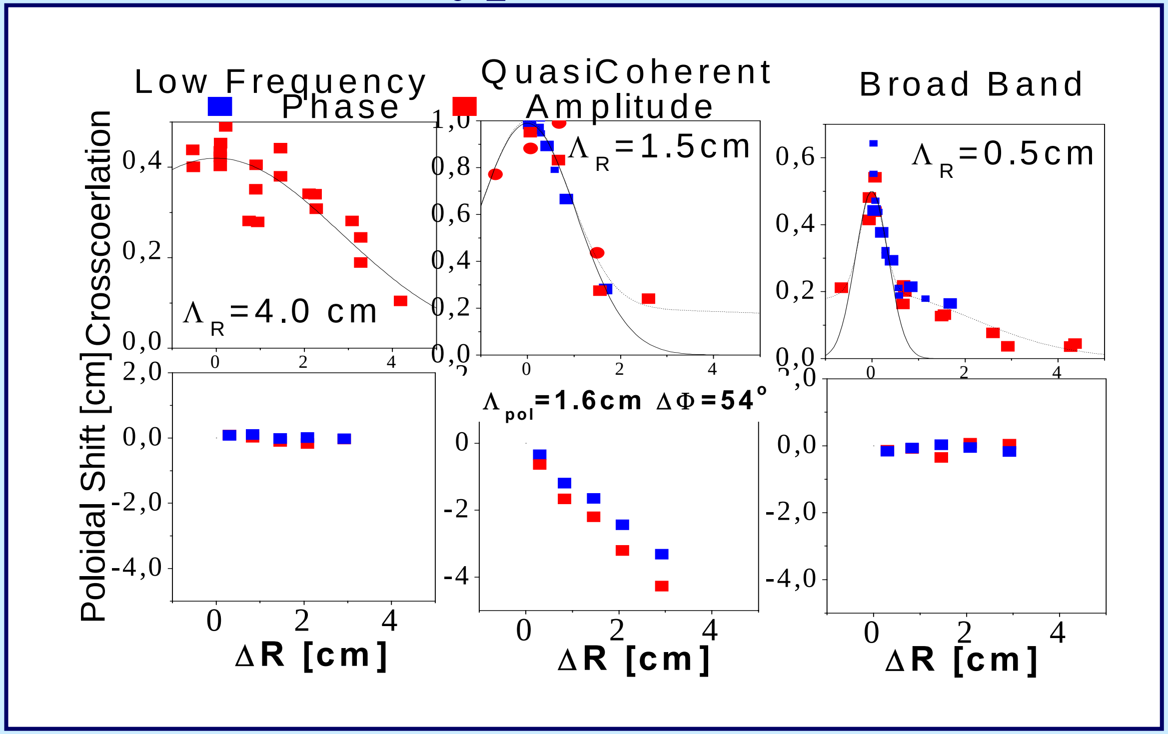
- Plasma potential and secondary ion beam current fluctuations
- sample volume ~1cm,bandwidth 100kHz

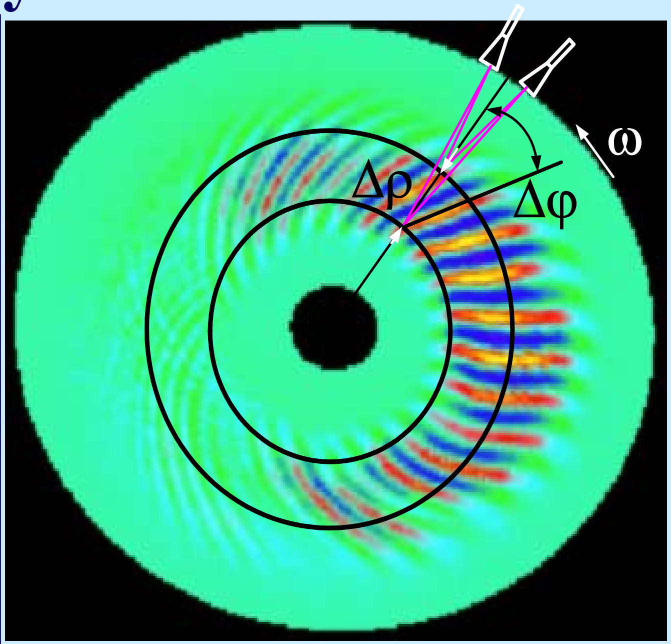
Variation of fluctuation spectra with radius in T-10



- Transitions between SOL, Edge, Core clearly seen.
- Spectrum in core have five components, including spectral maxima at zero, 15 – 30, 100 and 200 kHz, situated at the background of “broad band”

Turbulence types characterization by radial correlations





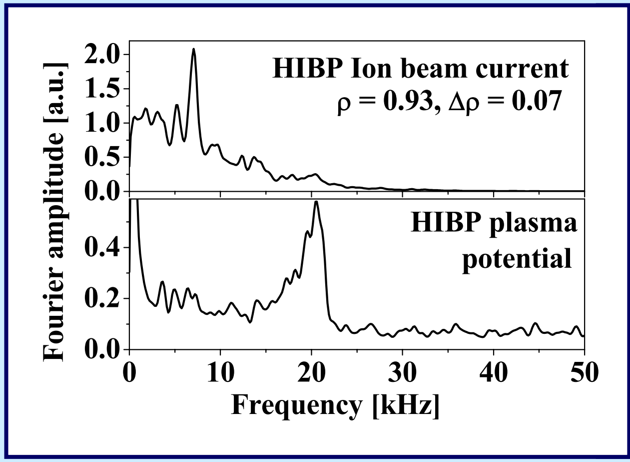
- Three turbulence types have different radial correlation length and phase shift

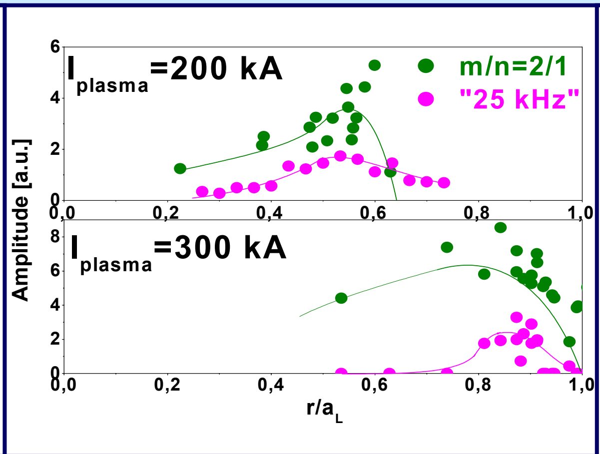
-Zero radial phase shift in LF and long radial length makes LF similar to "STREAMERS"?

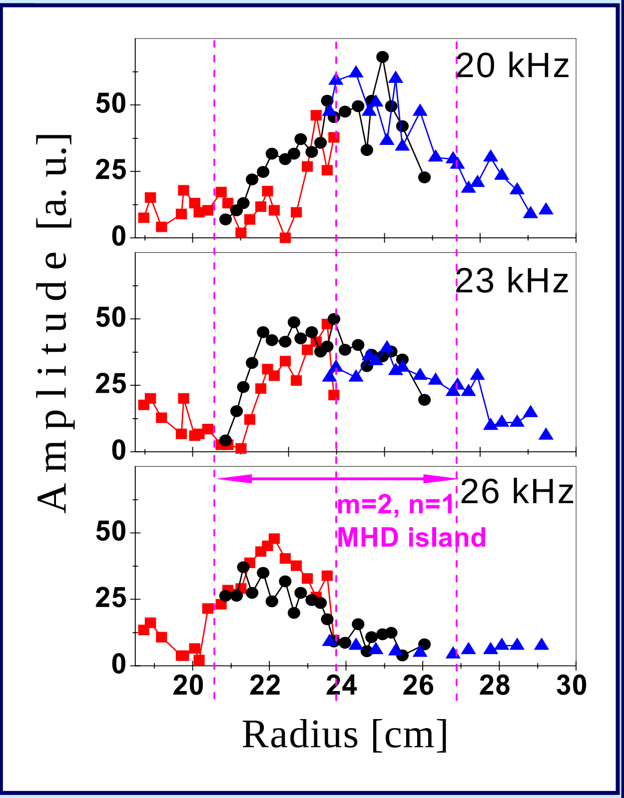
Radial phase shift of QC may be explained by rotation of helical "fingers", obtained in 3D gyrokinetic simulations due to the toroidal mode coupling of several modes

Broad Band (BB) has the lowest correlation length, corresponding to exitation of a single high m number modes. Reality of BB supported by Langmuir probes spectra

Oscillations in frequency range 15 – 30 кHz (I)



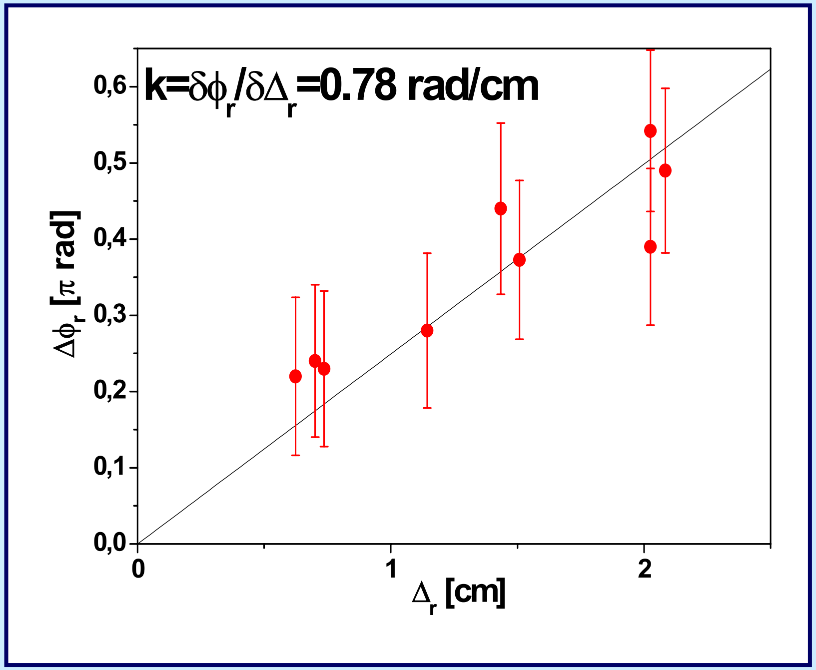




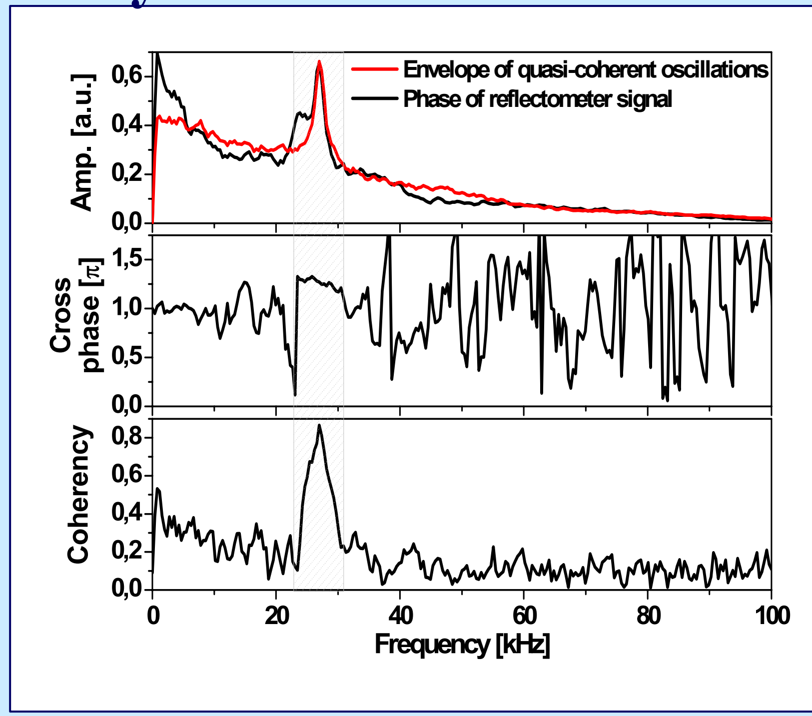
- Set of strong oscillations are observed in 15 – 30 kHz range by reflectometry, Langmuir probes and HIBP
- Potential fluctuations are much higher then density
- Localized near m/n=2/1 island, shifts with q=2 position
- Several frequencies observed inside the m=2 island
- MODE are also observed near other rational surfaces
- MODE has no poloidal phase shift, m=0, verified by poloidal correlation at 5^0 and 55^0
- MODE exists only at densities lower then $n_e = 2\cdot10^{19}$ m^{-3}
- All properties (m=0, strong E_r, frequency ≈ Cs/2πR –rising as $Te^{1/2}$) similar to the Geodesic Acoustic Mode, which is the branch of Zonal Flows, predicted by Theory
- Theories predict uniform distribution of zonal flows – experiment shows localization of modes near the rational surfaces!!! At zero frequencies modes have not found yet!!

Oscillations in frequency range 15 – 30 кHz (II)

Radial phase shift



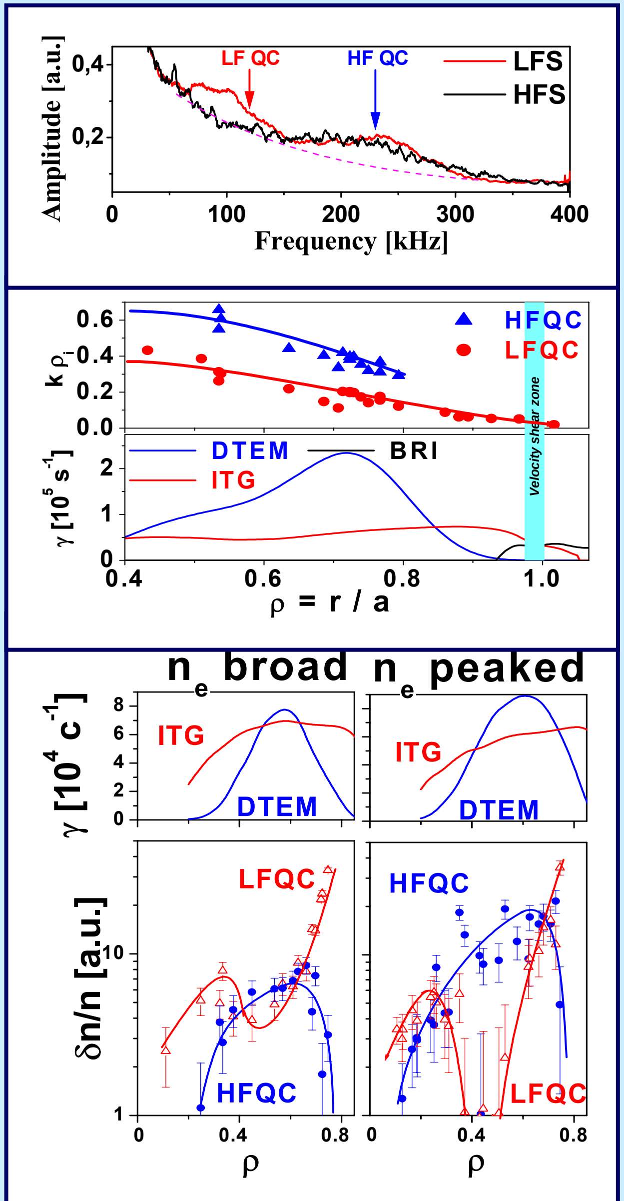
Modulation of the total level of density fluctuations with f>50 kHz



1. **Radial width of the mode** from amplitude and phase measurements in the range **4 – 8 cm**

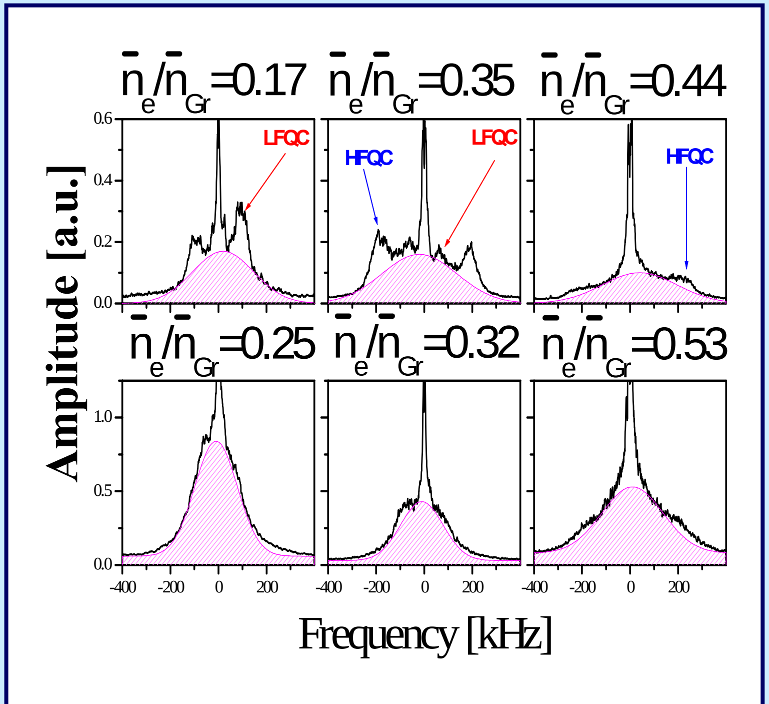
1. **10% modulation of the total fluctuation level** in 50< f <400 kHz at mode frequency
2. **90% coherency**
3. **Coherency rises to zero** frequency

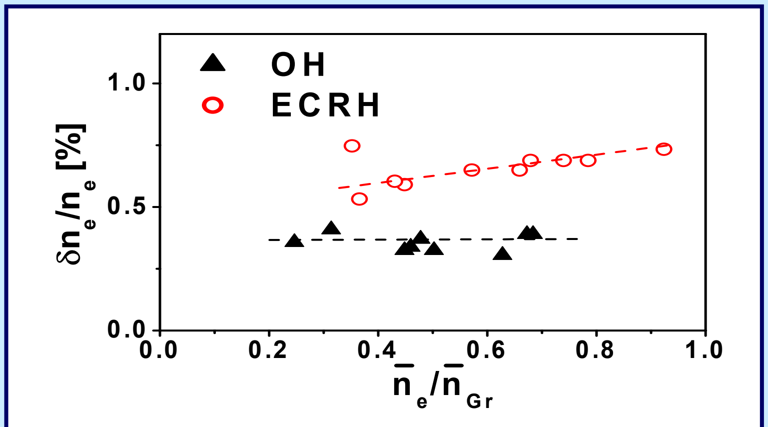
The physics of two types of quasi-coherent fluctuations



- **HF and LF QC not correlated** and **differs in space** - both are seen at LFS, but only HF at HFS
- $k\cdot\rho_i$ value for **LF QC** in core close to 0.3, predicted for **ITG** instability
- $k\cdot\rho_i$ value for **HF QC** oscillations in core close to 1, predicted for **DTEM** instability
- Radial dependences of growth rates clearly show three regions of **DTEM**, **ITG** and **BRI** instabilities localization
- **HF QC** oscillations **maximal** in gradient region in agreement with **DTEM** growth rate
- **LF QC** oscillations **minimal** near a/2 in zone of minimum η_i typical for **ITG**
- **LF QC** is **stabilized** from 12 to 17.5 cm at peaked density, where η_i decreases lower then some critical value, **although $\gamma \neq 0$?**
- Strong gas influx broadens density profile, increases η_i and destabilizes **LF QC**

Turbulence dependence on density in discharge

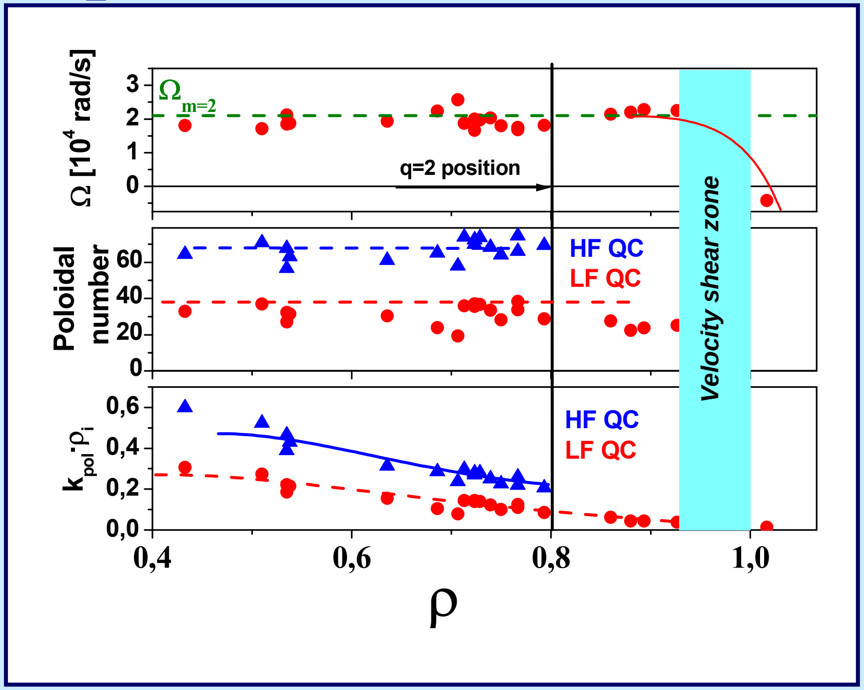




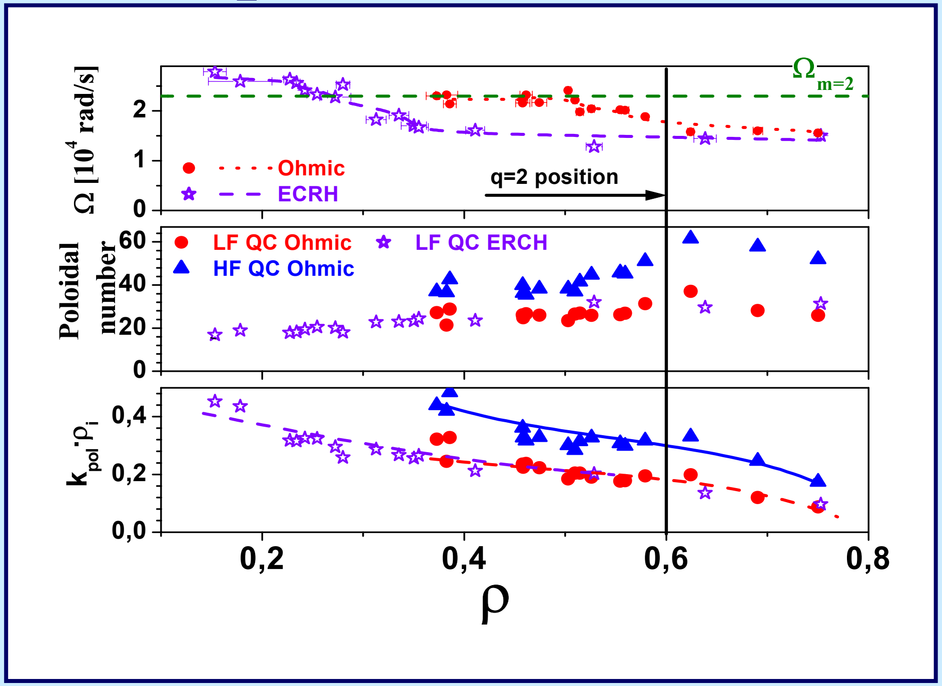
- LF QC (ITG) oscillations dominate at low density. HF QC (DTEM) oscillations dominate at high density. This tendency is similar for OH and ECRH.
- LF QC (ITG) instability at low density may be connected with high neutral particle penetration to the plasma center.
- Neutrals do not penetrate in plasma core at higher densities, and DTEM instability dominates in this case
- Relative fluctuation level for ρ=0.5 seems not depend on density
- Turbulence increases in a factor of two in ECRH in accordance with confinement degradation
- Quasi-Coherent input in spectrum drastically decreases with increase of heating power and turbulence level. This is consistent with destruction of toroidal coupling by zonal flows

Turbulence rotation

q(a)=2.5 (OH)

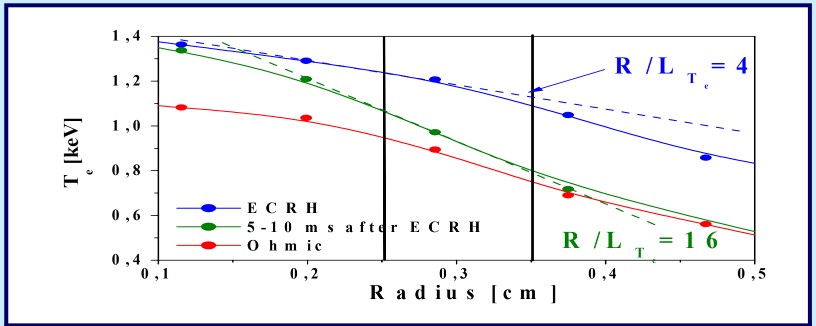


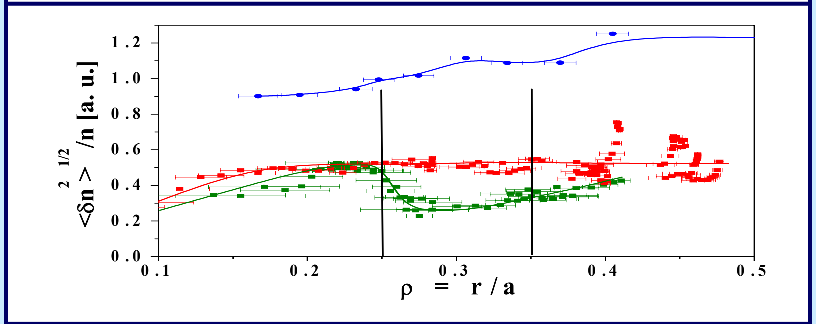
q(a)=3.9 OH +ECRH

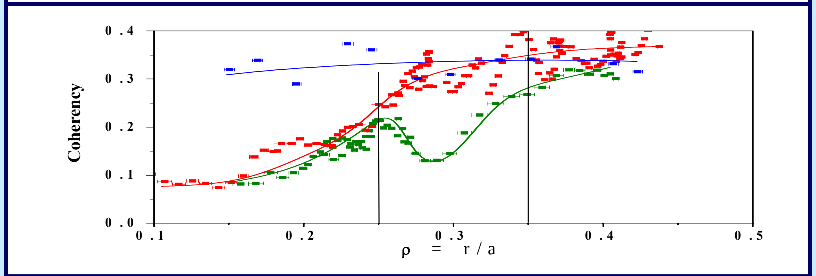


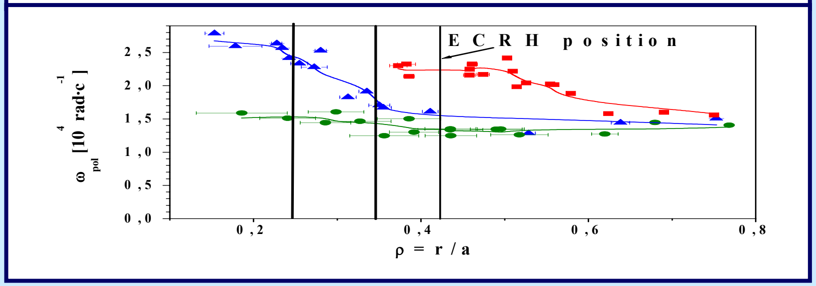
- Angular rotation and poloidal m number of LF and HF QC fluctuations are constant along radius in core OH plasma (rigid body rotation) in OH T-10 plasma. (Strong long distance toroidal coupling??)
- Turbulence velocity closely related with m/n=2/1 MHD island velocity in stationary conditions (Coupling with MHD??).
- Rigid body rotation easily breaks under strong edge cooling either by gas puff or pellet injection

Turbulence behavior in off axis ECRH







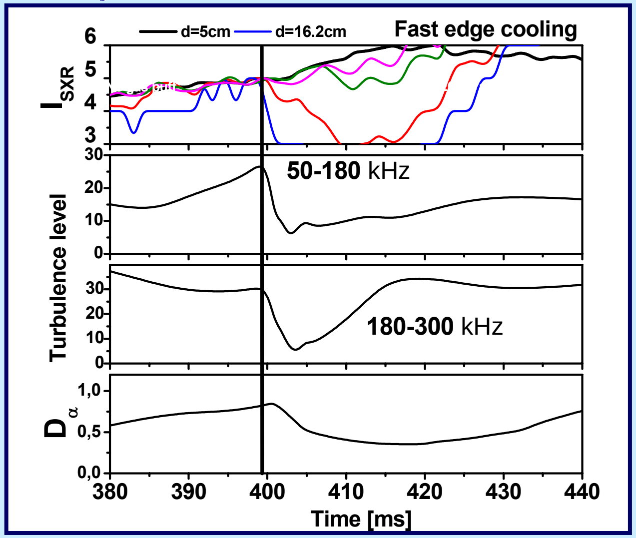


- Relative density **fluctuation amplitude** during ECRH are **higher in 2-3 times** then in OH phase, **in spite of low R/Lt=4** temperature gradient, connected with high particles influx.

- Strong electron **temperature gradient R/Lt=16** and **local minimum of turbulence amplitude and coherency** are observed at ρ ~ 0.3 15 ms after ECRH switch of . **This proves e-ITB**

- **Velocity shear is NOT** observed.

- Possible **mechanism of ITB – decrease** of a number of **rational surfaces** near **q=1 surface at low magnetic shear**



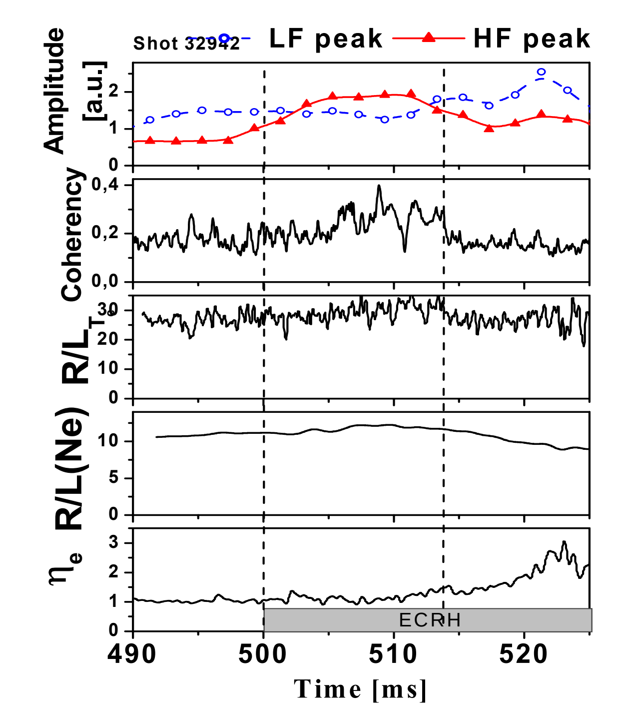
Fast plasma edge cooling in OH plasma

Edge cooling with Ne puff at 400 ms leads to:

- Strong decrease of edge D_α light; Drop within 1 ms of HF QC turbulence at ρ=0.4; Increase within 2 ms of the core SXR radiation; Density peaking.

Possible explanation:

- Strong decrease of the edge rotation, causing temporal velocity shear between edge and core and suppression of QC turbulence due to velocity shear.



Turbulence at the beginning stage of ECRH

- Ohmic confinement may maintains up to 20 ms after ECRH start. "Delay of Confinement Deterioration" in ASDEX with NBI, in T-10 with ECRH.

- HF QC fluctuations dominant at the first 5–15 ms at increased electron temperature gradient and low particles influx. LF QC substitute them after particle influx rise and density profile broadening.

- Excitation of TEM with transition to ITG after density profile broadening is consistent with theory.

Conclusions I

1. Turbulence spectra retain the features of the linear instability stage in high OH confinement discharges. These features steadily vanishes with the transition to strong non-linear regime.

2. The “Broad Band” turbulence with minimal radial scale arises due to stochastic excitation of a single high m modes, while “Quasi-Coherent” represent toroidal coupling of several modes.

3. Experiment consistent with the existing of three different instabilities: in core - ITG (LF QC) and DTEM (HF QC); and Ballooning Resistive Interchange in SOL.

4. LF QC (ITG) typically associated with the regions with high level of particles fluxes at plasma edge and low density, or with flat density gradient in center zone.

5. HF QC (DTEM), in difference, typical for low particles fluxes region and high electron temperature gradients.

Conclusions II

6. OH and ECRH discharges showed the transition from LF to HF QC with increase of density from low up to critical. The integrate turbulence level not depends on n_e, despite change of the mode type. Turbulence level at half radius increases with total power

7. Special modes near 15 – 30 kHz were observed with properties of Geodesic Acoustic Mode, which is a the branch of "zonal flows". But its localization at rational surfaces contradict to existing theories. The predicted "zonal flows" near zero frequency haven't seen yet.

8. QC oscillations tends to rotate as a rigid body with velocity of MHD m/n=2/1 island that suppose mechanism of long distance interaction between fluctuations at different radii and global MHD modes. This interaction could be destroyed by the relatively weak velocity shear (SOC-IOC, cold puff)

9. Significant progress were achieved both in experimental turbulence characterization and in theory, but, unfortunately, only a few works devoted to their direct comparison.