Turbulence and Plasma Potential Evolution Study by HIBP Diagnostic During L-H Transition in the TJ-II Stellarator

A.V. Melnikov, L.G. Eliseev, L.I. Krupnik[1], A.A. Chmyga[1], T. Estrada[2], C. Hidalgo[2], R. Jimenez[2], A.D. Komarov[1], A.S. Kozachok[1], I.A. Krasilnikov, S.M. Khrebtov[1], M. Liniers[2], S.E. Lysenko, V.A. Mavrin, M.A. Ochando[2], J. L. de Pablos[2], I. Pastor[2], M.A. Pedrosa[2], S.V. Perfilov, F. Tabares[2], M. Ufimtsev[3], Yu.I. Tashev[4] and A.I. Zhezhera[1].

Institute of Nuclear Fusion, RRC "Kurchatov Institute", Moscow, Russia

[1]*Institute of Plasma Physics, NSC KIPT, 310108 Kharkov, Ukraine*

[2]*Asociación EURATOM-CIEMAT, 28040-Madrid, Spain*

[3] *Departament of Computational Mathematics and Cybernetics, Moscow State University, Russia,*

[4] *Instituto de Superior Technico, Lisbon, Portugal.*

The direct measurements of an electric potential and its fluctuations in a core plasma are of a primary importance for the understanding of the mechanisms of the L-H transitions in toroidal plasmas and the role of the electric field in plasma confinement [1, 2].

Heavy Ion Beam Probe diagnostics in TJ-II stellarator [3] has been upgraded recently to study directly the plasma electric potential φ and density n_e with a good spatial (up to 1cm) and temporal (up to 1 μs) resolution. The crucial element in the HIBP upgrade is two-slit operation of the HIBP energy analyzer. It is able to observe two detector grids simultanously, Fig 1. Two sample volumes are optimised to be separated poloidaly to produce poloidal component of electric field Ep by the difference in local potentials, Ep $=(\varphi_1-\varphi_2)/x$, x~1cm. Finally it was extracted radial turbulent particle flux $\Gamma_r =\Gamma_{EpolxBtor}= \Gamma_{ExB,}$ for the first time in stellarators.

Plasma electric potential profile evolves strongly from ECR to NBI heated plasma [4]. While ECRH plasma is characterized by positive plasma potential, NBI (co-, counter- and balanced injection) plasmas in L-mode are characterized by negative electric potential in the full plasma column from the center to the edge. The absolute value of the central potential is up to – 600 V depending on density. These observations are independent on the magnetic configuration. Figure 1b) shows the evolution of the potential profile in counter NBI heated L-mode plasmas. With the density rise potential well is evolving up -600 V and then remains the same in its saturated state at the certain density.

Recent experiments with Li-coating of the chamber wall [5] and NBI heating have shown the evidence of spontaneous L-H transition in the TJ-II stellarator occurring at a threshold value of the plasma density [6].

At the spontaneous L-H transition, which happens in the purely NBI heated plasma the core electric potential becomes more negative at the outer half of the plasma column, See Fig 2. The value of the potential difference lies in the range of -80-100 V. At the back H-L transition the plasma potential recovers to its L-mode value. These observations in the radial profiles are supported by the measurements in fixed position, Fig 3.

During the direct L-H transition edge and core fluctuations of local plasma density, potential and poloidal electric field Epol shows some reduction. Fig 4 shows the temporal evolution of the plasma density fluctuations with a strong broadband turbulence suppression in H-mode. All these observations lead to the reduction in Γ_{ExB} oscillations in H-mode. At the back H-L transition Γ_{ExB} and Er shows full recovery to the initial L-state features. Unless HIBP ($k_\theta <$ 0.5 cm^{-1}) and Langmuir probe ($k_\theta < 2$ cm^{-1}) have different sensitivity to turbulent wavelength the similarity in the PSD for Γ_{ExB} in the core (ρ_{HIBP}=0.5) and edge (ρ_{LP}=0.9) is remarkable: both are coherently suppressed in the H-mode. The radial area of the turbulence suppression coincides with changes in density and potential gradients.

Recent advances in the HIBP increase its sensitivity to high frequency oscillations up to 300 kHz. It makes this diagnostic an efficient instrument to study Alfven modes in the plasma core. Fig 4 a) shows the temporal evolution of the family of quasicoherent oscillations, which have frequency decay with the density rise, indicating Toroidicity induces Alfven Eigenmode (TAE)[7]. Note the TAE branches are suppressed in H-mode and they recovered after the back L-H transition, which is shown by both HIBP and Mirnov coils.

Observations show the L-H transition is not only the peripheral event, the changes in gradients, level of oscillations (broadband and quasicoherent) and Γ_{ExB} occurs simultaneously (within the experimental accuracy of ms) also in the core plasma in the area $0.5<\rho<1$.

The suppression of Γ_{ExB} in the core (HIBP) and edge (Langmuir probe) is associated with increase of negative Er, which may suggest shearing stabilization mechanism plays dominant role in the transition to better confinement.

[1] F. Wagner, Plasma Phys. Control. Fusion **49** (2007) B1-B33.
[2] F. Wagner, et al.,Plasma Phys. Control. Fusion **48,** A217-A239 (2008).
[3] I. Bondarenko, et al., Rev. Sci. Instrum., **72**, 1, 583 (2001).
[4] A. Melnikov, et al., Fusion Science and Technology **51**, 31, (2007).
[5] F. Tabarés, et al., Plasma Phys. Control. Fusion **50,** 124051 (2008).
[6] T. Estrada et al., This Conference.
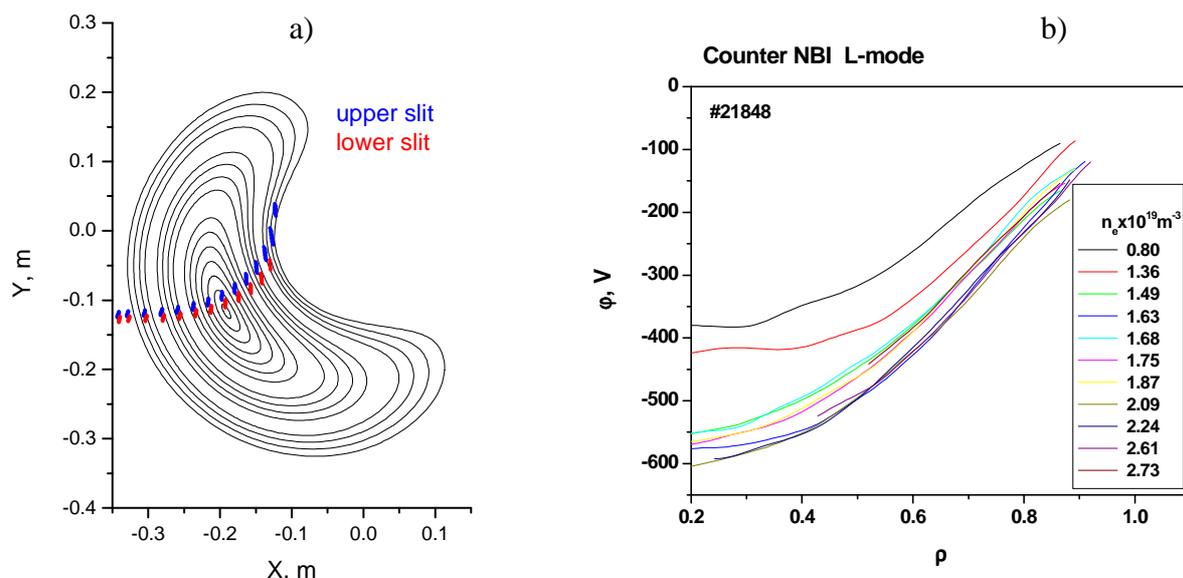[7] R. Jimenez et al., Plasma Phys. Control. Fusion, submitted.

Fig 1. a) Sample volumes for two-slit TJ-II 150 keV HIBP operation provide the poloidally resolved potential and density measurements; b) Evolution of the plasma potential profile during counter-NBI heating (L-mode). Plasma potential saturates at the certain density.
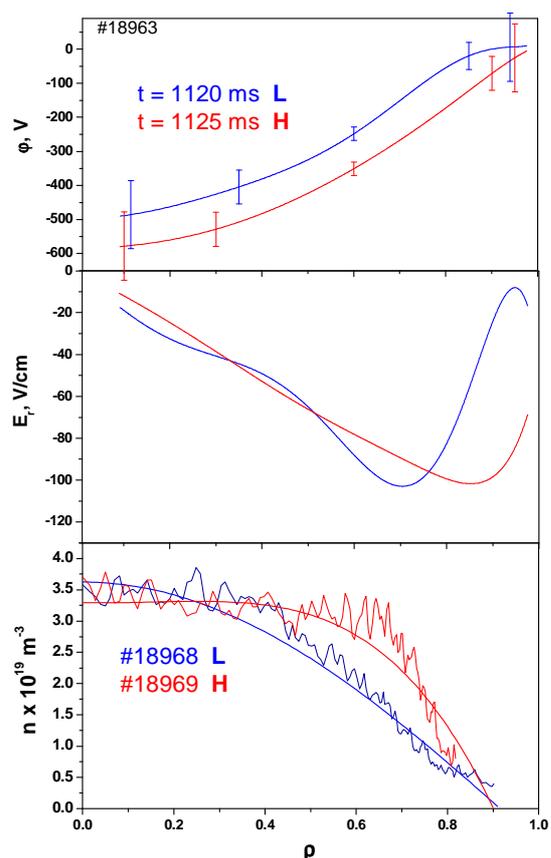

Fig 2. Plasma potential, radial electric field (by HIBP) and density profiles (by Thomson scattering) in H-mode (red) and L - mode (blue). The error bars in the potential profiles present RMS. Plasma potential gradient (Er) becomes steeper at the area of the strong gradient in the plasma density in H-mode.
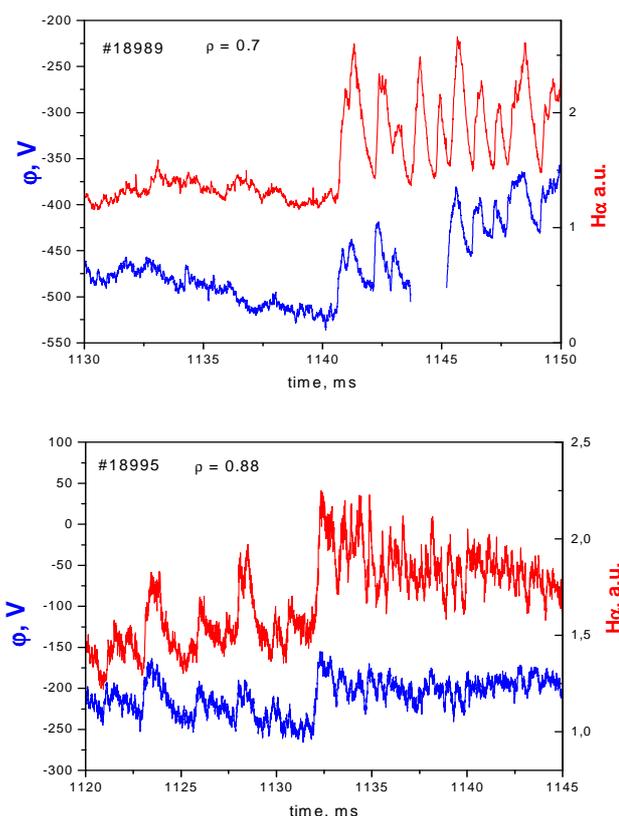
Fig 3. Temporal evolutions of local plasma potential at back H-L transition at $\rho = 0.7$ (upper box) and $\rho = 0.88$ (lower box) shows $\Delta\varphi$ (H-L) = +80 V. Plasma potential at the periphery is coherent to the Hα emission.
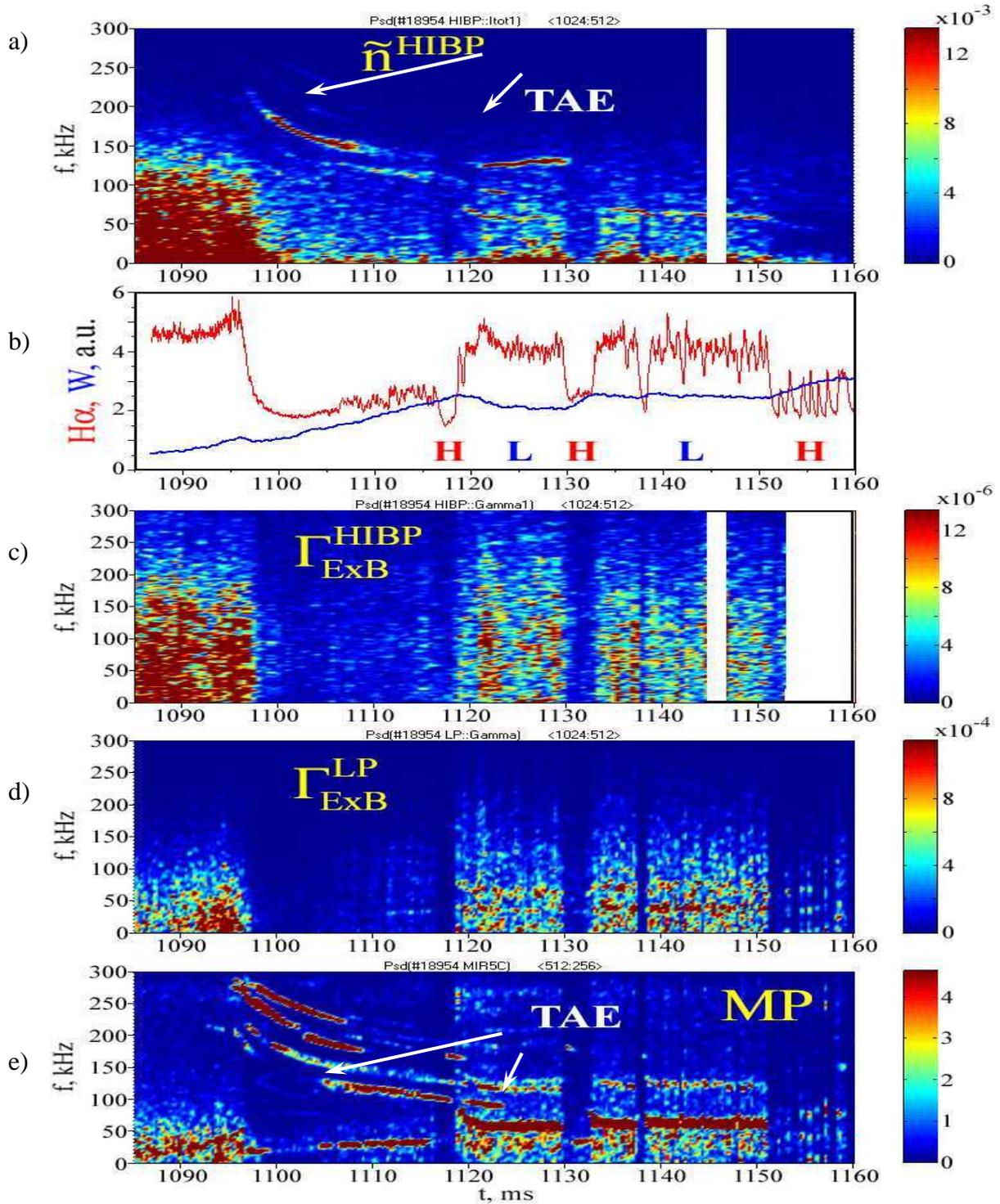The gap in potential signal is instrumental.

Fig 4. Temporal evolutions of plasma turbulence characteristics in the shot with spontaneous L-H and H-L transitions. a) PSD of HIBP beam current (plasma density), measured at $\rho = 0.5$. Instrumental gap in signal is shown by white ribbon. b) Time traces of stored plasma energy and Hα emission. H-mode phases are indicated by decay in Hα, accompanied by increase in W. c) PSD of Γ_{ExB} by HIBP at $\rho = 0.5$, $k_\theta < 0.5$ cm^{-1}. Instrumental gap in signal is shown by white ribbon. d) PSD of Γ_{ExB} by Langmuir probe at $\rho = 0.9$, $k_\theta < 2$ cm^{-1}. e) PSD of Magnetic Probe signal. Density, Γ_{ExB} and magnetic broadband oscillations are clearly decreased in the H mode. TAE modes are clearly indicated by quasicoherent oscillations in the core density (HIBP) and magnetic field oscillations with frequency decreasing due to the density rise.