Recent physical results and diagnostic development of Heavy Ion Beam Probing in TJ-II

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The direct measurements of an electric potential and its fluctuations in a core plasma are of a primary importance for the understanding the confinement improvement mechanisms and the role of electric field E_r in toroidal plasma confinement. Heavy Ion Beam Probe diagnostics, which is a unique and powerful tool to study directly the plasma potential φ and turbulence characteristic in the core plasma and in the edge as well, is used in TJ-II (four-period flexible heliac, B_0 = 1 T, <R> = 1.5 m, <a> = 0.22 m). 150 keV Cs^+ ions are used to probe ECR and NBI heated plasmas ($P_{ECRH} \leq 0.6$MW, $P_{NBI} \leq 1$MW) from the edge to the core [1]. Poloidally resolved potential and density measurements provide short range correlations, poloidal electric field $E_{pol} = (\varphi_1-\varphi_2)/x$, x~1 cm. The turbulent particle flux: $\Gamma_r = \Gamma_{EpolxBtor} = \langle n_e^{\sim} v_r^{\sim} \rangle$ [2] and poloidal plasma turbulence rotation [3] were retrieved for the broadband turbulence and for the quasicoherent modes as well [4].

In the experiments with ECRH power modulation plasma potential was found to follow the electron temperature evolution [5]. It was found recently that the amplitute of the potential modulation Δφ is a function of plasma density. The mean potential profile evolution in the discharge with density increase is shown in Fig. 1. Plasma was created and heated by one gyrotron with P_{ECRH} = 0.3 MW. The power of the second gyrotron was modulated from 0 to ΔP_{ECRH} = 0.1 MW. The potential profile evolves with density raise from the positive hill to the negative well following the conventional trend [2]. Such trend was found first in TM-4 tokamak [6], later on it was generalized for T-10 tokamak and the helical systems CHS, TJ-II and LHD [7]. Fig.1 shows that Δφ is pronounced over the whole plasma radius for all densities. It also shows that Δφ decays with density. Potential profile evolution with local modulations is presented in Fig 1. This behavior may be explained by the electron temperature evolution. The similar behavior was found in the T-10 tokamak [8].

Figure 2 presents the time evolution of potential and density profiles. It shows that potential grows in phase with P_{ECRH}. Dependence of local potential and Δφ on plasma density is presented in Fig. 3. Figure 3 (a) shows that φ depends non-linearly on density, it is decreasing gradually with density increase up to the critical density n_{crit} ~0.67 $x10^{19}m^{-3}$. At this value potential jumps down instantly for about 150 V at ρ = 0.7. Later on, potential decreases gradually again. Figure 3 (b) shows that Δφ depends non-linearly on density, as well as φ itself. It is constant when density increase from n_e = 0.25 to 0.5 $x10^{19}m^{-3}$. When density increases farther, n_e = 0.5 $x10^{19}m^{-3}$ to n_{crit} = 0.67 $x10^{19}m^{-3}$ Δφ increases, and when n_e > n_{crit} it decreases monotonically. Decreasing the P_{ECRH} modulation amplitude, from ΔP_{ECRH} = 0.1 MW to ΔP_{ECRH} = 0.05 MW, leads to the proportional decrease in Δφ, which indicates the temperature dependence of Δφ.

It is important to note that near n_{crit} ~0.6 confinement transition use to happen in TJ-II. Potential and Δφ inhomogeneities near n_{crit} are consistent with the changes of plasma transport properties at the transition threshold where edge radial electric field reverses from positive (electron root) to negative (ion root) values.

To study the long range correlations and physics of Zonal Flows the second set of the HIBP apparatus have been recently developed and installed in TJ-II. It is located at the diagnostic cross-secrion of the TJ-II vacuum chamber 90° toroidally apart from the first one. It consists of the upgraded primary beam injector, which is able to create the probing beam with energy up to 150 KeV and intensity of Cs+ ions up to 200-250 μA, Fig.4. This HIBP set is equipped with two energy analysers, which provide the long range radial and poloidal correlations, measured at the same plasma cross-section, Fig.5. Each analyser has 5 entrance slits for short (1-5cm) correlation measurements. On top of that, the foreseen joint operation of both HIBP systems will provide the long range (1-1.5 m) toroidal correlations.

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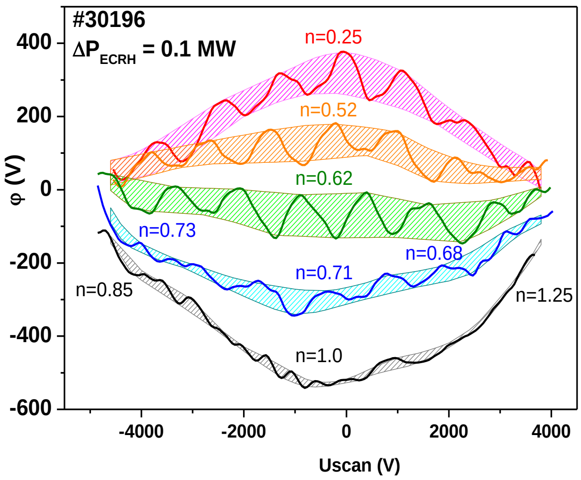
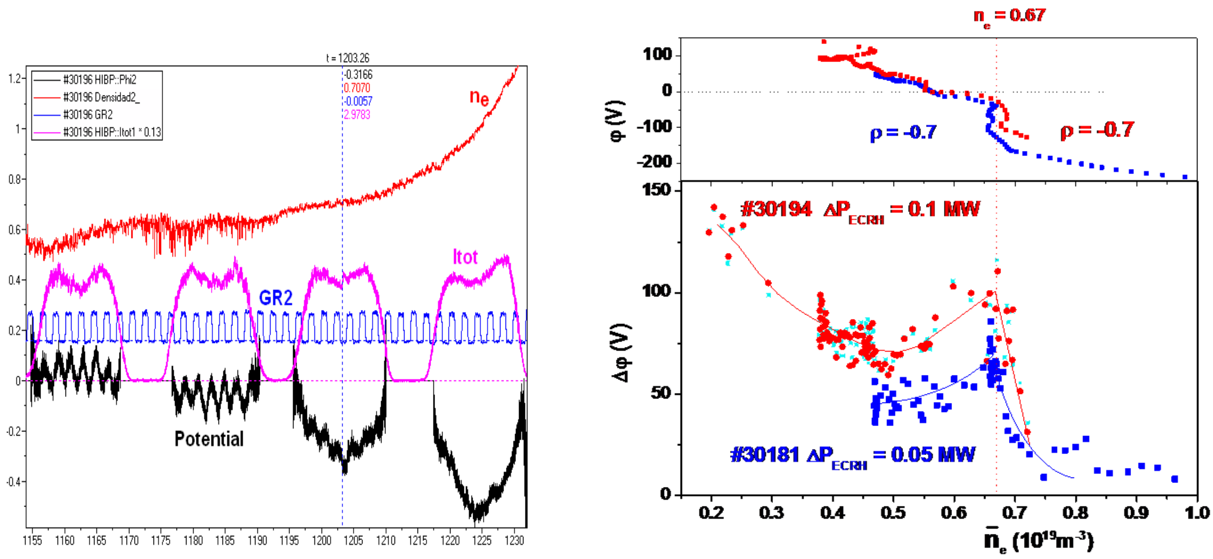


Fig.1. Plasma potential modulation Δφ due to the ECRH power modulation. Potential response on ECRH modulation is global, Δφ does not depend strongly on plasma radius ρ. Δφ decreases with the density raise. U_{scan} represents ρ, U_{scan} =±4000 represents ρ=±1, U_{scan} =0 represents ρ=0. Density is shown in ($10^{19}m^{-3}$).



(a) (b)

Figure 2. (a)Time traces of plasma line-averaged density (red) and power modulation of the second gyrotron GR2 (blue). Plasma density profile evolution via beam current Itot (pink) and potential profile evolution (black), measured with HIBP radial scan. Potential modulation is observed in phase with P_{ECRH} modulation. ΔP_{ECRH} = 0.1 MW.

(b) Mean potential φ (upper box, Low Field Side – red, High Field Side - blue) and potential response Δφ due to the ECRH modulation (lower box) depend non-linearly on the plasma density. After some decrease in the low density area the local inhomogeneity occurs near the critical density n_{crit} ~0.67 $x10^{19}m^{-3}$, and then further decrease happens.

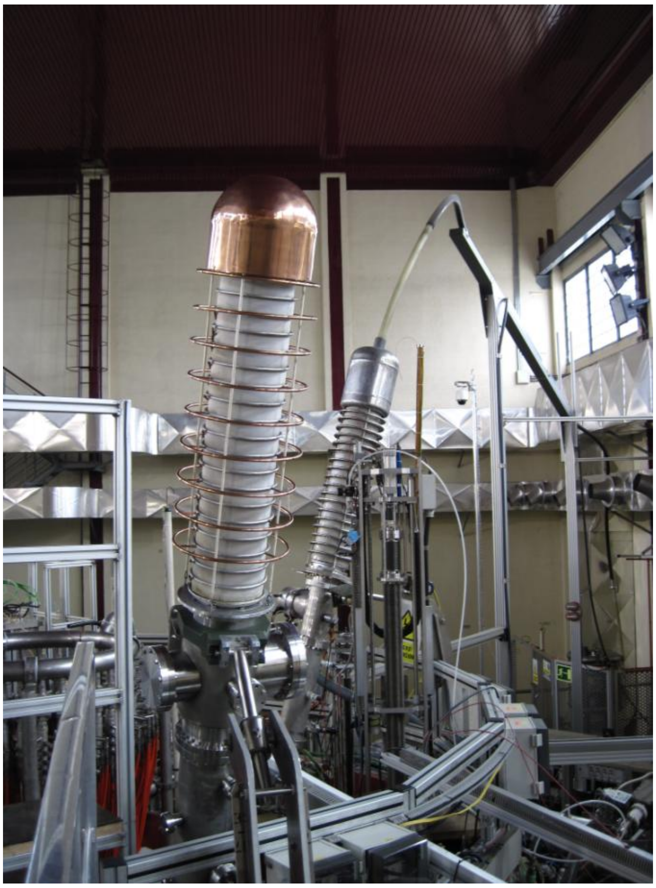


Figure 4. Photo of the new second HIBP injector (at the foreground), and the first one with high voltage connection (background).

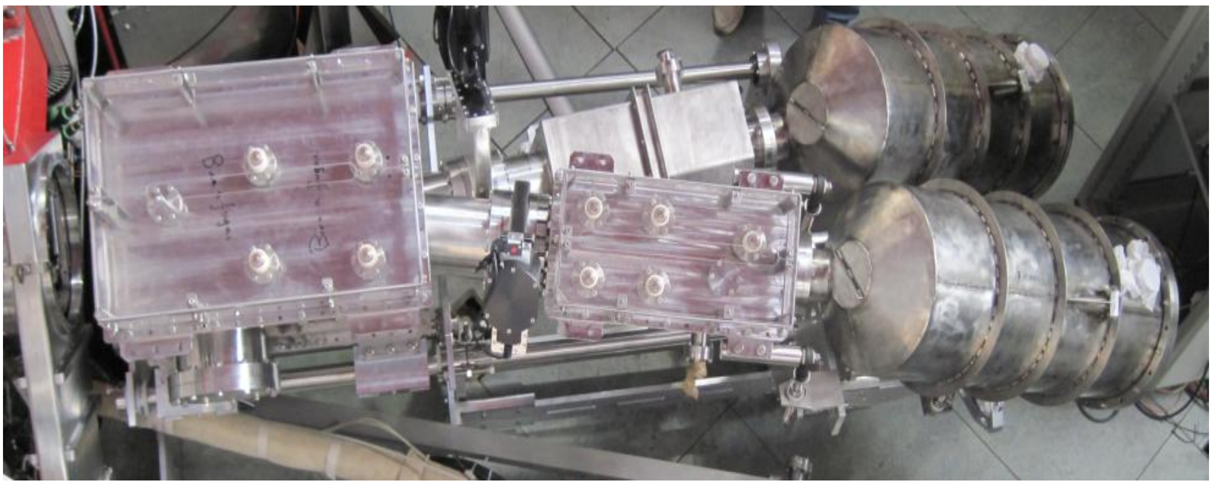


Figure 5. Photo of the two energy analyzers with the secondary beamlines with correcting electrostatic plates.