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Ion Temperature Behaviour and Ion Contribution to the Power Balance Measured by CXRS in Ohmic and ECR Heated Plasmas on TCV

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1. Introduction

This paper reports on the first measurements of the ion temperature profile in TCV. These measurements help to improve the understanding of different physics phenomena obtained using the TCV capabilities, such as the dependence of the energy confinement on the plasma shape or the plasma behaviour in presence of additional ECR heating, especially for advanced scenarios with ITB creation by off-axis heating. Some information on the upgrade of the Charge eXchange Recombination Spectroscopy (CXRS) diagnostic performance are also reported.

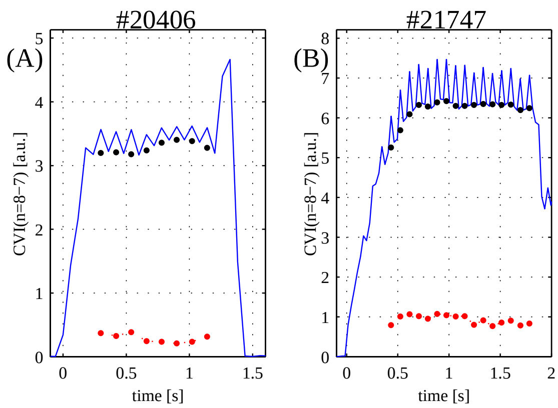

Figure 1. C/X CVI(n=8→7) line (λ=5291Å) intensity for two ohmic shots with $\bar{n}_e$~$6.10^{19}m^{-3}$. Dots represent interpolated passive and calculated active intensities. (A) Before DNBI upgrade: A/P~12%. (B) After upgrade: A/P~20%.

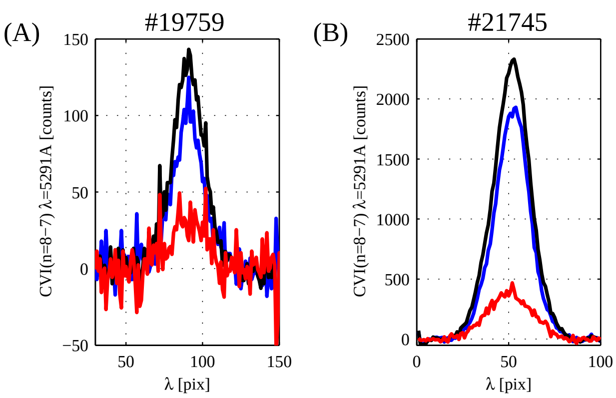

Figure 2. C/X CVI(n=8→7) lines @ 5291Å ($\bar{n}_e$~$3.10^{19}m^{-3}$). The photon collection has been enhanced by ~20x, corresponding to an increase of S/N ratio by ~5x.

2. CXRS and DNBI upgrades

The Charge eXchange Recombination Spectroscopy diagnostic of TCV was limited in two main ways 1): low active / passive signal ratio (A/P) due to low DNBI current and to the high thermal neutral density, which is probably a consequence of the size of the TCV device. The DNBI extracted current has been increased from ~1.7A up to ~3A, increasing the A/P by ~70% at $n_e = 1.5.10^{19}m^{-3}$ and ~20% at $6.10^{19}m^{-3}$ (see figure 1). 2) low S/N ratio due to poor photon statistics. The S/N has been increased by ~5x by enhancing the spectroscopic system throughput. The collected photon flux has been increased by ~20x (see figure 2) following numerous modifications: 1) the number of chords /

radial position has been doubled; the observation volume has been increase by ~4x without significant loss of spatial resolution (limited by the flux surface curvature to ~3cm at the plasma edge); the monochromator (f/~9 @5300Å, F=0.75m) collecting mirror size has been maximised leading to an increase ~2x in the signal level and the slit width has been increased which is accounted for in the spectral analysis by numerical deconvolution of the measured instrumental function.

3. Ion contribution to the power balance and ion energy confinement in ohmic plasmas

Ion temperature profiles have been measured in ohmic discharges where shape parameters (elongation κ, triangularity δ, in limited and diverted configurations) and plasma density have been modified. T_i profiles are usually flatter than T_e profiles measured with Thomson scattering, the typical peaking factor being of k ~0.2-0.5 ($T_i(\rho) \cong T_i(0) \cdot (1-\rho^2)^k$). Measured central ion temperatures vary from 100eV to 900eV with increasing n_e and total energy content. Measured $T_i(0)/T_e(0)$ ratios may reach values up to 80 - 90% at average plasma densities of ~ $6.10^{19} m^{-3}$. Preliminary CXRS measurements of the carbon density (the main impurity of the

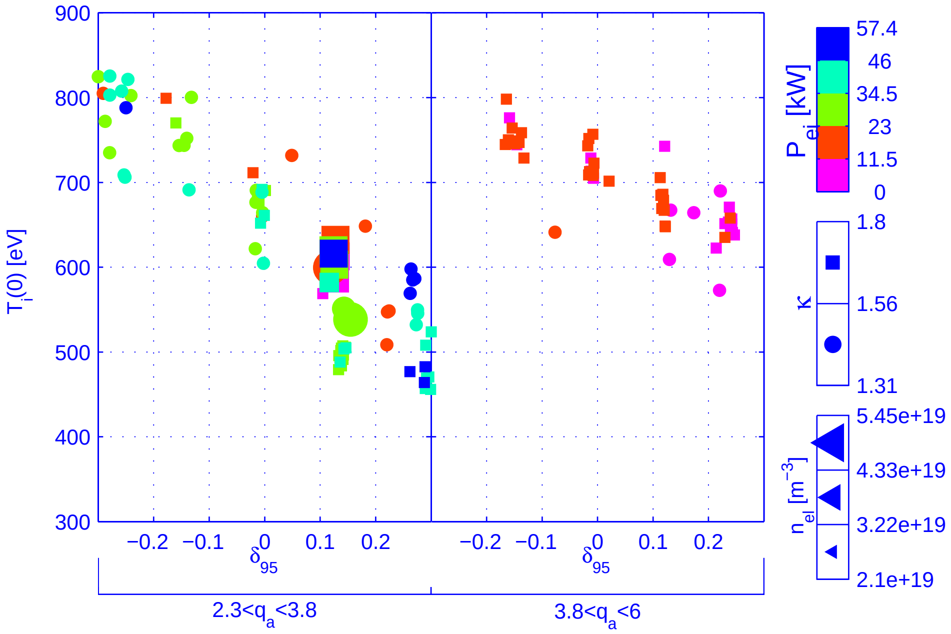

Figure 3. $T_i(0)$ is plotted as a function of the plasma triangularity. Left and right hand side plots correspond to two different I_p scans, where q_{edge} has been maintained roughly constant. Colors represent the e^- - ions equipartition power P_{ei} ; the marker style the elongation, and its size the average electron density. The strong dependence of the ion confinement on triangularity is clearly shown by the decreasing of $T_i(0)$ of 25% - 40% with increasing δ, independently from the ion heating power and any other plasma parameters.

TCV plasmas) give concentrations typically of 3 - 5%. Consequently, the deuterium contribution to the power balance $\frac{W_D}{W_D + W_e}$ is in the range 15 - 40%.

The ion temperature behaviour has been studied as a function of the plasma shape to complete previous studies on the influence of the plasma shape on the energy transport, performed on TCV [2]. Plasma elongation and triangularity have been varied from 1.3 to 1.8 and -0.3 to 0.3 respectively. A current scan from 150kA to 450kA, corresponding to q_{edge} values from 2.3 to 6, has been performed to examine the influence of the plasma shape on the confinement from any intrinsic dependence on I_p. The triangularity is found to be the parameter that most strongly affects the ion and electron confinement. Figure 3 shows that $T_i(0)$ decreases strongly when δ ranging from negative to positive values. This behaviour is not related to the variation of the e^- - ion equipartition power $P_{ei} = (W_e\text{-}W_i).\nu_{ei}$ (where ν_{ei} is e^- - ion collision time), nor to the electron density. As explained in [2], two main phenomena are responsible of this confinement loss: the sawteeth activity disparition at negative triangularities and the thermal conduction $q = -n\chi\nabla T$ rise as flux surface compression increases with δ, leading to more extended regions with high temperature gradients.

4. Ion temperature behaviour in ECR heated plasmas

T_i profiles have been measured in second (X2 82.7 GHz) and third (X3 118 GHz) harmonic EC heated plasmas. X2 heated plasmas often have low densities to stay within the density cutoff ($n_{e,X2\text{-}cutoff} = 4.2.10^{19}m^{-3}$) and to limit the refraction of the EC beams. In these conditions e^- - ion coupling is weak and T_i mostly reacts to the density changes caused by gas injection or EC caused desorption on the TCV carbon walls, since the e^- - ion equipartition power P_{ei} is proportional to n_e^2 [3]:

$$P_{ei} \propto n_e^2 \cdot \frac{(T_e - T_i)}{T_e^{-3/2}} .$$

X3 EC allows operation at higher densities ($n_{e,X3\text{-}cutoff} = 11.10^{19}m^{-3}$) where the e^- - ions coupling is expected to be stronger. Figure 4 shows an example of a discharge where X3 heating has been applied on an off-axis X2-preheated plasma [4]. T_i not only reacts to the density variations, but also to the changes of T_e resulting from the additional heating. With X3 heating, $T_e(0)$ rises abruptly before relaxing on a time scale of ~200ms with an increase of n_e. $T_i(0)$ decreases by ~30% from the $T_e^{-3/2}$ dependence of P_{ei} and then rises again following the n_e increase.

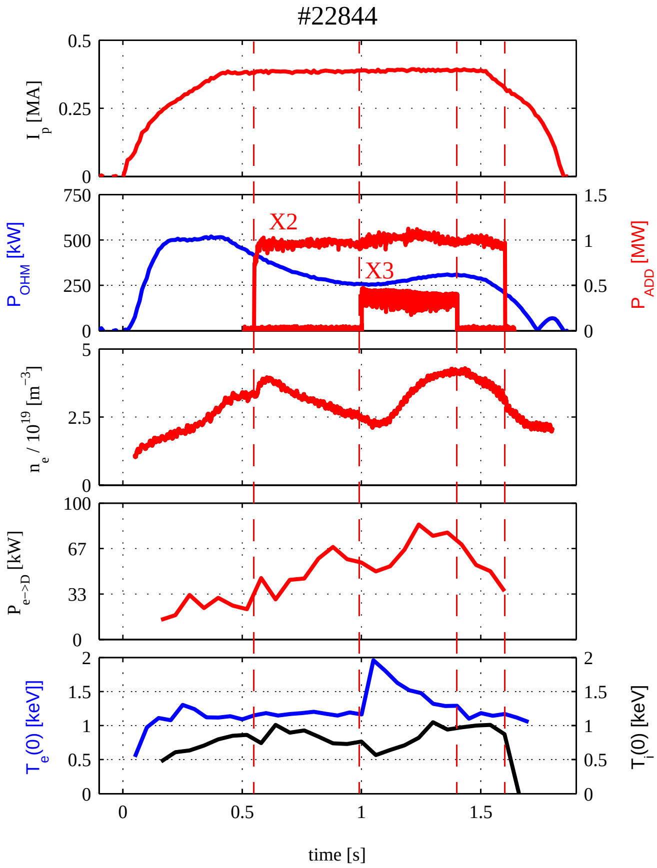

Figure 4. Discharge #22844 has been pre-heated with X2 ECR off-axis heating, before vertical injection of X3 at 1s. $T_e(0)$ rises of ~80% at the X3 injection whereas $T_i(0)$ decreases of 30% following the ion heating power (P_{ei}) evolution. After injection both temperatures relaxe on the same time scale as the density increase.

5. Conclusions

Investigations of the ion temperature behaviour in ohmic plasmas show that the ion contribution to the power balance is not negligible ($W_i/W_e \leq 60\%$) even in the absence of additional ion heating on TCV. Ion and electron energy confinement degrade strongly with triangularity increasing from negative to positive values. This dependence is explained by the geometrical effect on the temperature gradients at the plasma edge and by the reduction of sawteeth activity at negative triangularities. In EC heated plasmas, T_i follows the evolution of the e^- - ion equilibration power. At low density, as in the case of X2 heating scenarios, only its dependence on n_e is observed on T_i. In X3 heated discharges, with average densities reaching $8.10^{19}m^{-3}$, e^- - ion coupling is stronger and T_i also becomes sensitive to the temporal evolution of T_e.

Acknowledgments

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