Highly collisional regimes in FTU

C.Mazzotta[1], G. Pucella[1], O. D'Arcangelo[1], O. Tudisco[1], M.L. Apicella[1], E. Giovannozzi[1], G. Mazzitelli[1] and the FTU team*

[1]*ENEA, Fusion and Nuclear Safety Department, C. R. Frascati, Via E. Fermi 45, 00044 Frascati (Roma), Italy*

**to be published in Nuclear Fusion special issue: Overview of the FTU results, G. Pucella et al., 26th Fusion Energy Conference (Kyoto, Japan, 17-22 October 2016)*

Introduction

The attainment of high values of the central electron density in a reactor is of particular importance, because the fusion power scales with the square of the density. Nevertheless efficient operation of a fusion reactor requires at least as much effort to achieve high density as well as to reach high temperature. Plasma regimes of very high densities are possible with a centrally peaked density profile, which allows the density at the plasma periphery to remain below the peripheral density limit. The density limit, observed in tokamaks is found to be in agreement with the Greenwald empirical scaling [1]. It has been observed that plasmas with peaked density profiles could exceed the density limit by keeping the edge density approximately constant. In most conditions, density peaking has an anomalous (non neoclassical) behaviour, for this reason a turbulence phenomenon must be invoked. The degree of peaking can change significantly depending on the plasma regime. The particle source is essentially peripheral, so that the observed peaking implies the existence of a particle in flux (pinch), which balances the diffusive outward flux in presence of a density gradient.

The identification of the main dependences of the convective terms as a function of experimentally relevant parameters has been attempted, using fluid and kinetic models, so that important progresses have been made in the theoretical description and understanding of the mechanisms producing particle transport, including the role of linearly stable modes [2], and in the interpretation and prediction of the experimental observations.

Collisionality behaviour of FTU pulses

The collisionality is found to be the suitable parameter that can comprehend the experimental data of several experiments, in order to get a statistical significance in correlation with density peaking. In the paper [3] a big data set, presenting the density peaking measured in plasmas from four different devices is reported: AUG, JET, Alcator C mod, and JT-60U, the density peaking has been shown as a function of the effective collisionality

$$\nu_{eff} = 0.1 \text{ Zeff } \langle n_e \rangle \text{ R} / \langle T_e \rangle^2$$

where $\langle n_e \rangle$ stands for the electron density volume average and $\langle T_e \rangle$ is the electron temperature volume average: an inverse linearity is found with these H mode pulses. A weak linear or negligible dependence has been reported in L modes in TCV [4], JET [5] and in H modes in TCV [6]. On the other hand, an increase of density peaking with increasing collisionality has been documented in FTU in fully non inductive plasmas [7]: given the limited number of discharges analysed in [7], an investigation aimed at enlarging the FTU data set has been performed in order to obtain a more representative picture of the complete behaviour of the collisionality in FTU. In the wide range of magnetic fields of B_T = 6 ÷ 8 T, plasma current I_p = 0.5 ÷ 0.9 MA and above all, reaching electron density of the order of 10^{21} m^{-3}, high collisionality regimes have been explored, making FTU one of the best candidate suitable at this purpose. It must be noticed that the density limit, in FTU has a different scaling, as described in [8]. In figure 1, the FTU plasmas are drawn from [9. In the figure 15 incorrect data have been reported, due to the electron density taken as 10^{20} m^{-3} instead of 10^{19}] with red symbols, including as background the entire data set of plasmas published in [3] with grey scale points. Although the FTU plasma is performed in L mode, the comparison is useful, being the [3] the most comprehensive data set reported in literature.

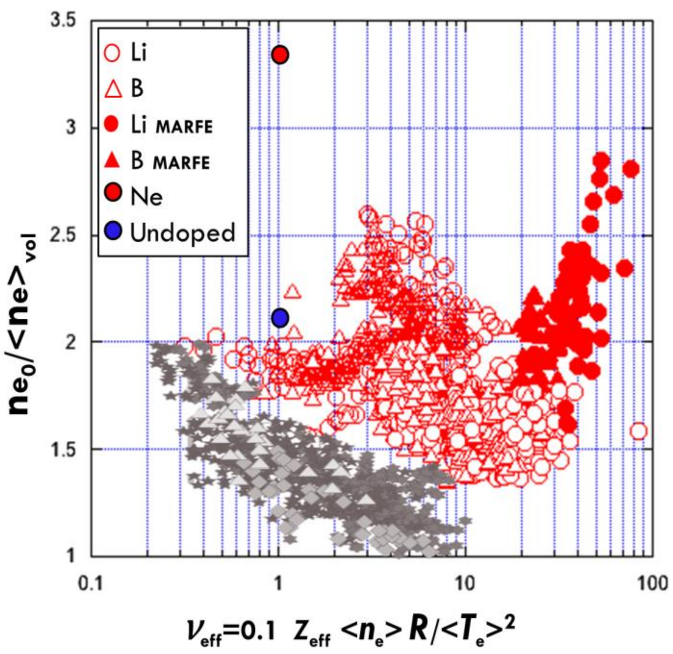

Figure1 Density peaking as a function the effective collisionality, red symbols for FTU data.

The FTU operational conditions together with particular plasma occurrences, as the MARFE instability presence and the possibility to dope plasmas by using the Lithium limiter [10] or the Neon injection [11], allow to observe plasmas of particular interest in terms of density peaking. The cloud of the FTU pulses is shifted in the high collisionality regime for the entire data set, and systematically shifted to greater peaking values. If the inverse linearity of the density peaking factor versus the effective collisionality is similar to other machines at relative low and medium collisionality; a completely different behaviour is found at high collisionality, where the peaking rises again proportionally to the collisionality. In detail, the density peaking factor, for discharges with MARFE in the high density regime, has a peaking again increasing with collisionality. This last regime is ameliorated by using Lithium conditioning and, these plasmas are of particular interest in terms of collisionality since, they reach very high collisionality values, between 20 and 100 (figure 1, solid symbols).

The Neon effect

The effects of Neon seeding have been studied in a series of dedicated ohmic discharge. Two similar discharges were produced in the same experimental session [11]: one with a Neon injection at 0.6 s for 50 msec and a second one at the same current and toroidal field, but with exclusively Deuterium gas, reaching the same line averaged electron density, used as reference undoped pulse. As a consequence of the Neon injection, the doped pulse become colder in the outer region up to half radius. The most interesting effect regards the spontaneous increase of the line averaged density up to a factor two, while the Deuterium puffing is off, associated with a significant increase of the peaking factor that exceeds 3. In figure 2 (upper panel), the time trace of the central line density of these two shots are reported together with their respective peaking (in the panel below), showing the spontaneous peaking evolution of the Neon injected discharge reaching the value of 3.5. The results from these two pulses have been inserted in the plot peaking vs collisionality of figure 1: the values are taken at the time of 1. s, when the effect of the Neon injection is well assessed. These shots are pointed with a red bullet for the doped shot and blue for the undoped one. It can be noticed that, while the peaking of the undoped pulse is included in the cloud of standard FTU discharges, the Neon doped shot presents a peaking value beyond the norm. Evidently this particular doping allows to reach very high levels of the electron density peaking. In these two discharges also the peaking of the temperature profile has a completely different behaviour, if the undoped pulse cools down globally, the doped pulse keeps an high temperature in the center, while an impressive cooling reaches to

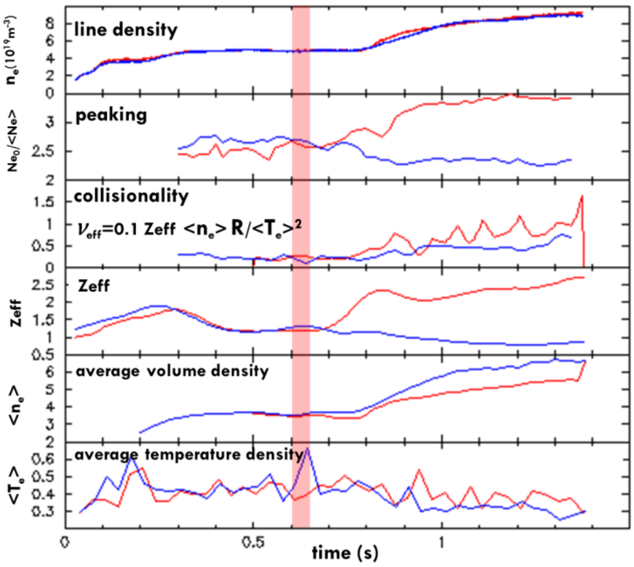

Figure 2 Time traces of a Neon doped pulse (red) and a reference pulse (blue)

half radius as consequence of the Neon injection [11, fig.1] and this effect remains until the end of the discharge. At this purpose, it's interesting to note that these observations are completely hidden from the form of the particular collisionality formula utilized. This last, considering the average volume of density and temperature, balances these parameters, as a result the collisionality of the two discharge is coincident (figure 1, red and blue bullets). To show this effect, the time traces of the two discharges, relative to the variables as considered in the collisionality definition, are depicted in figure 2, even the obvious large increase of the Zeff for the doped pulse is compensated. In the [12] an analysis of this Neon doped pulse has been carried out with the gyrokinetic code GKW: the ITG modes in presence of the impurity are lower, to mean the stabilizing effect due to Neon presence on these modes. Quite new is the result of the fluxes analysis, that shows as the ETG modes drive an inward flux for all the species and everywhere, so that the sharp peaking of the density profile could be due to the inward pinch brought about by ETG modes.

Conclusions

FTU offers the unique opportunity to explore regimes of high collisionality. It has been observed that at collisionality values over 10, the inverse linearity is not followed in FTU, that realizes an increase of the collisionality and of the density peaking. The possibility to increase the collisionality is related to the edge phenomenons as the MARFE presence and ameliorated conditioning of wall by using Lithium Limiter. Also the peaking of the density profiles can be improved using doped plasma with Neon. The reason of this can be ascribed to different mechanism of particle transport that should be investigated further.

[1] M. Greenwald et al Nucl. Fusion **28** (1988) 2199

[2] P.W. and R. Gatto Phys. Plasmas **13** (2006) 062309

[3] C. Angioni et al. Plasma Phys. Control. Fus. **51** (2009) 124017

[4] Weisen H, Furno I, Alberti S et al 2002 Nucl. Fusion 42 136

[5] Weisen H, Zabolotsky A, Maslov M et al 2006 Plasma Phys. Control. Fusion 47 A457

[6] Porte L, Coda S, Alberti S et al 2007 Nucl. Fusion 47 952.

[7] Romanelli M, Hoang G T, Bourdelle C et al 2007 Plasma Phys. Control. Fusion 49 935.

[8] G. Pucella et al. Nucl. Fusion **53** (2013) 083002

[9] O.Tudisco, C. Mazzotta et al Fusion Engineering and Design **85** (2010) 902–909

[10] G. Mazzitelli et al. Nucl. Fusion **51** (2011) 073006

[11] C. Mazzotta et al. Nucl. Fusion **55** (2015) 073027

[12] Mazzotta C. et al. *Linear microstability investigation of a Neon impurity* .. 43^{rd} EPS Conf. on Pl. Phys., Leuven, Belgium, July 4-8, 2016.Vol. 40A ISBN: 2-914771-99-1 P5.019