Density profiles in low collisionality FTU plasmas

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**see proceeding 27th IAEA Fusion Energy Conference 2018*

Introduction

The collisionality parameter is chosen in literature to compare the various experiment in terms of particle transport. For example, the paper [1], by reporting a big data set of four different devices in H-mode experiments (AUG, JET, Alcator C mod, and JT-60U), shows how the density peaking presents an inverse linearity in respect to the effective collisionality.

This work is devoted to a parametric study of low collisionality FTU plasmas, namely a regime comparable with other tokamaks, in respect of the electron density peaking. This allows to analyse these plasmas as a function of magnetic field and plasma current, investigating also more factors, such as wall conditioning and plasma temperature.

Parametric analysis

As reported in [2], FTU offers the unique opportunity to explore a broad range of collisionality expressed as $\nu_{eff} = 0.1\ Zeff\ \langle n_e \rangle\ R / \langle T_e \rangle^2$, where $\langle n_e \rangle$ stands for the electron density volume average and $\langle T_e \rangle$ is the electron temperature volume average. By representing the FTU pulses over the data of the other experiments [2], its cloud is shifted in the high ν_{eff} regime for the entire data set, and systematically higher peaking values are reached. While the inverse linearity of the density peaking factor versus ν_{eff} is similar to other machines at relatively low and medium collisionality (less than 10 with $\langle n_e \rangle$ of the order of $10^{19}\ m^{-3}$), a completely different behaviour is found at high collisionality (FTU can reaches ν_{eff} 60 and over), where the peaking rises again proportionally to the ν_{eff} [2]. In particular, the electron density peaking factor in the high density regime (of the order of $10^{20}\ m^{-3}$), for discharges with MARFE or with the ameliorated machine conditioning due to Lithium [3] increases linearly with collisionality [2,4]. It worth to be stressed that pulses having νeff >20 are rare in the actual tokamak devices, so that the high collisionality regime remains unexplored, although not relevant in the framework of laboratory plasmas researches.

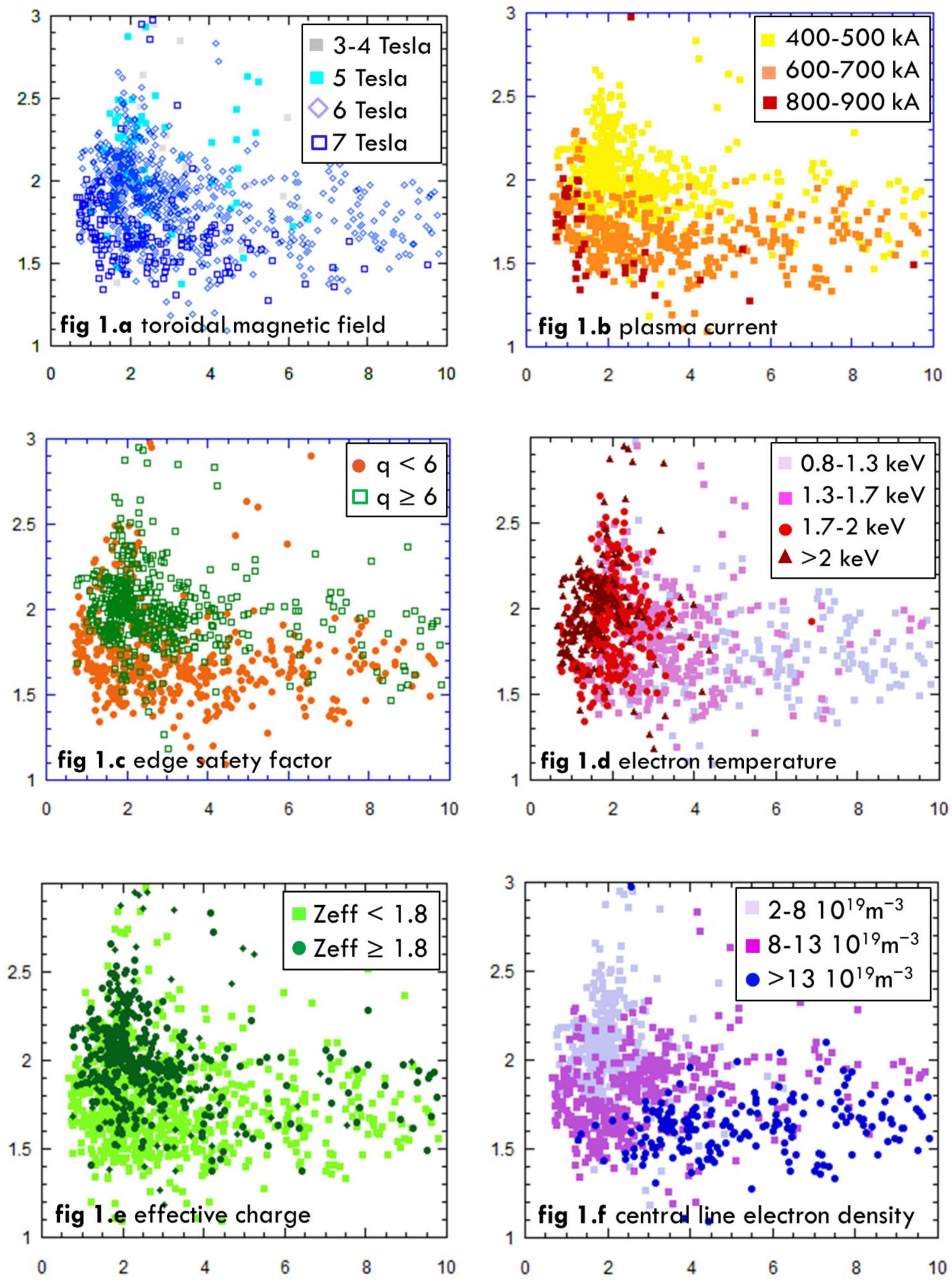

Figure 1. Parametric analysis of the electron density peaking $\mathbf{n_{e0}/\langle n_e\rangle_{vol}}$ *as a function the effective collisionality* $\boldsymbol{\nu_{eff}=0.1\ Z_{eff}\langle n_e\rangle R/\langle T_e\rangle^2}$ *with the factor* $\mathbf{\langle n_e\rangle}$ *as* $10^{19}\ m^{-3}$

For what has been said, more interesting for comparison with other tokamaks, is the behaviour of the density peaking versus collisionality in low ν_{eff} regimes. Indeed, FTU features a wider scale of magnetic fields and densities, and above all, its plasmas can reach density peaking values up to 3 and over, again extending the range of study in respect to other fusion devices, so that it is particularly suitable to realize a parametric analysis. Finally, the experiment is equipped with a two-colour, scanning interferometer (40 chords, 1 cm of resolution), which scans the plasma column section from the edge to the centre; this allows high resolution density profiles with a measurement every 62 μs [5] .

In respect of previous works [2,4], a subset of low ν_{eff} data (<10) has been selected for this analysis, adding a series of low density discharges [6]. So that, the parameter range of the final database is enlarged in magnetic field, plasma current and line electron densities as follow: $B_T = 3 \div 8$ T, $I_p = 0.4 \div 0.9$ MA, n_e $2 \div 13$ 10^{19} m^{-3}.

Interesting dependencies can be found, they are depicted in fig.1. In the frame 1.a, it can be noticed that the dots related to the low toroidal magnetic fields (<6 Tesla, grey and cyan symbols) do not reach the high collisionality area. The plot 1.b reports the plasma current dependency: low current plasmas (350-500 kA) lie in the region with the density peaking over the value 2, in opposite to the medium currents that fill the low peaking area. Very interesting are the dots regarding the high current pulses (800-900 kA), they have low collisionality, meanwhile they present a wide range of peaking. At the same time, if their peaking is quite low, around 1.5, they can cover the entire range of ν_{eff} ; this last observation is true also for the medium current, but around a peaking value higher (1.7). Finally the averaged peaking value of the low current pulses, increases a little bit more, around 2. These considerations lead to taken into account a statistic that regards the safety factor q at the edge, this is reported in the fig. 1.c, where the pulses at q higher of 6 are positioned, on the average, in the high peaking area and collisionality lower than 4 (dark dots); on the opposite, the low q values, remain mostly at low peaking. The frame 1.d regards the dependency with electron temperature, as expected, the "hot" discharges are positioned in the low ν_{eff} area, the pulses with $T_e < 1.7$ keV drifts towards the high collisionality. Readable is the behaviour of the pulses in terms of presence of impurities, if the effective charge is $Z_{eff} \geq 1.8$ or more, the pulses are almost all at low collisional side and they result peaked too. This is due to the metallic vacuum chamber of FTU, so the effect on the ν_{eff} is quite dominated by the high electron density instead of the effective presence of impurities. Finally the plot 1.e with a colour code related to the central line density is shown: at low densities the data are pushed in the low ν_{eff} area, anyway they can reach very high peaking. The high densities discharges drift towards the entire range of collisionality, they seems to have a low peaking, but it's not so. Indeed, as detailed in previous works [2,4], a linear rise with peaking starts at ν_{eff} over 10.

A couple of examples can be useful to observe the peaking and collisionality during the same pulse depending from the experiment, they are reported in the picture 2. The pulse #29222 has additional heating due to Lower Hybrid that starts around 0.6 s (fig 2.d green trace). The heating is not completely constant during the 400 msec of its duration, so that the temperature profiles (fig 2.a contour plot of the T_e profiles) as well as the density profiles, due to kinetic response to the heating, change drastically (frame 2.f contour plot of the high resolution n_e profiles). So, while the peaking is affected by this behaviour (fig. 2.g), the ν_{eff} remain quite unchanged (frame 2.h pink trace). On the opposite, the pulse #41487, produced to study Tearing modes, is characterised by a ramp up of the toroidal magnetic field (fig. 2.l, red trace), so that the peaking grows (frame 2.q) while the collisionality decreases (fig 2.r, pink trace).

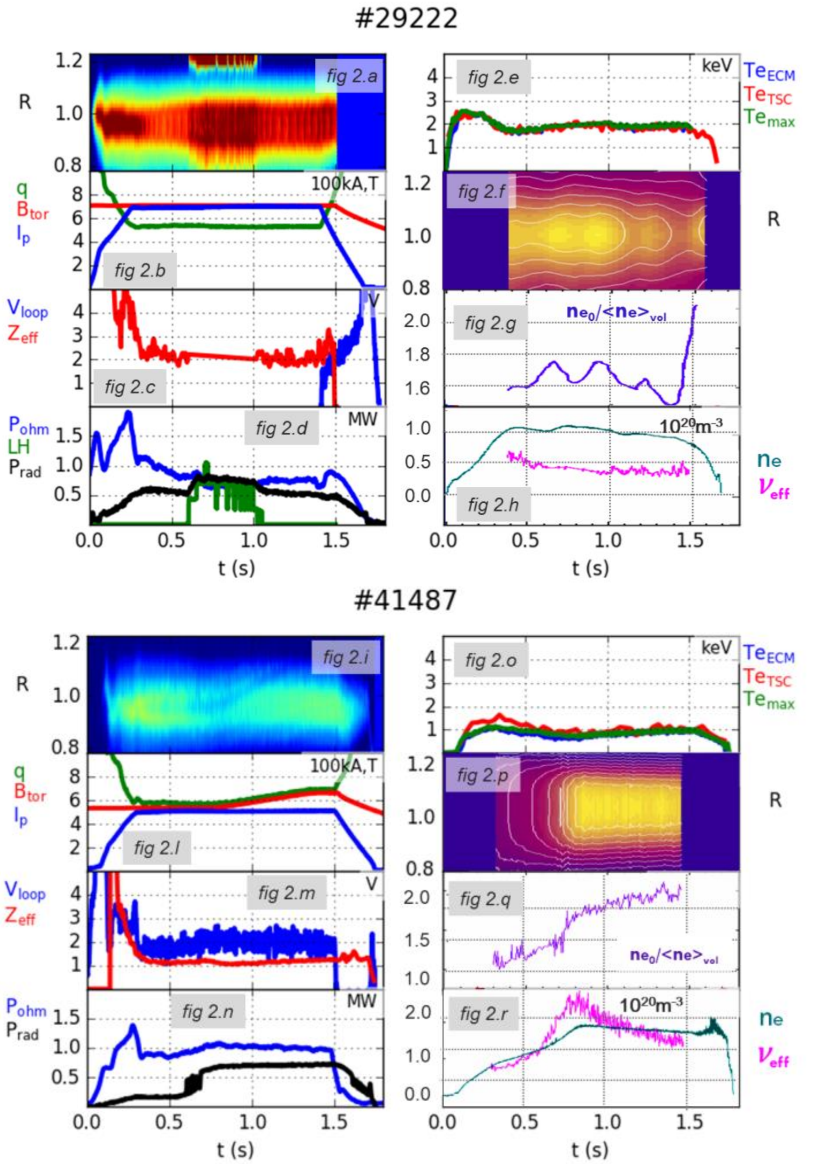

Figure 2, top: principal parameters of the pulse #29222 with Lower Hybrid heating. Below, the discharge #41487 with a toroidal field ramp

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