Contribution ID: **1081** Type: **Regular Poster**

Dynamics and Confinement of Ultralow-q Plasmas in the RFX-mod Device

Friday 14 May 2021 12:10 (20 minutes)

Thanks to its flexibility and unique control capability due to the advanced MHD modes feedback system made of 192 independently driven saddle coils, the toroidal RFX-mod device (R/a=2m/0.46m) for magnetic confinement of fusion plasmas has been operated to investigate a wide range of experimental conditions. In order to highlight similarities and/or physics peculiarities between various magnetic configurations, Reversed-Field Pinch (RFP), Tokamak and the full range of magnetic configurations in between the two, the so-called ultra-low q (ULq), which corresponds to edge safety factor values positive and below 1, have been produced. The latter is the main topic of the present paper. In particular, an experimental characterization of plasma dynamics and of the confinement properties of ULq plasmas are here presented. The experiments have been inspired and complemented by an intense theoretical activity, based on 3D non-linear MHD modeling (1).
The first dedicated studies of the ULq regimes were reported already at the very beginning of the research on thermonuclear fusion (2) (and references in (3)). The ULq normally was shown to exhibit a pitch minimum at the edge (removed in the RFP equilibrium), which could lead to both pressure driven and current driven instabilities, also in the form of double resonant surface modes. Such considerations induced a significant reduction of studies in this area. A renewed interest grew up in connection with the MHD relaxation phenomena (4) and the observation that, despite the relatively low energy confinement time, some basic aspects in low q configurations remained attractive, notably the relatively low magnetic field to be supplied by the external coils, the efficiency of plasma heating by ohmic dissipation of the plasma current and the observation of similar ion and electron temperatures (5).

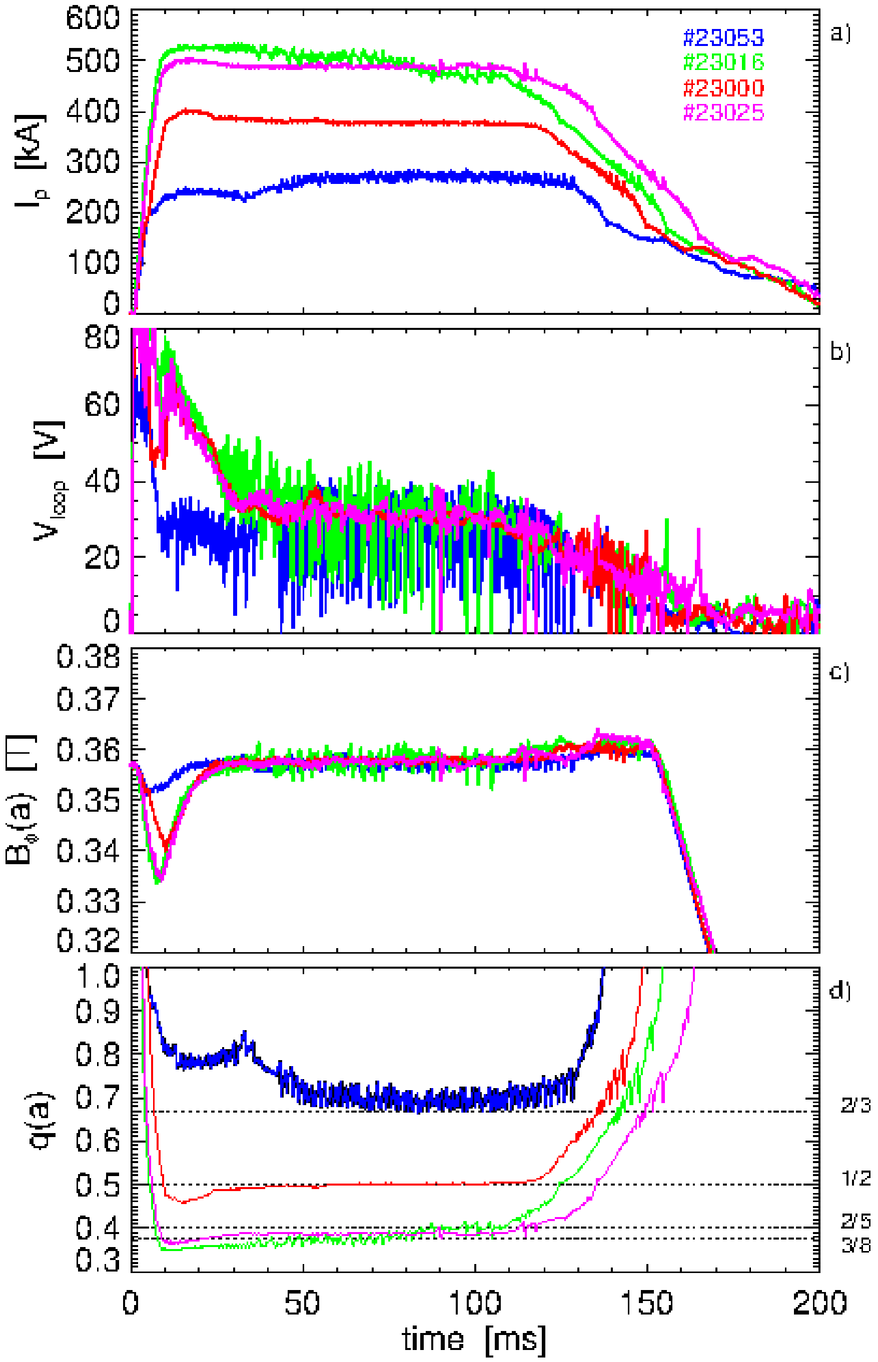

Figure 1: : Time traces of various quantities for four ULq discharges, corresponding to different edge safety factor values (indicated with different colors): a) plasma current, Ip; b) toroidal Ohmic loop voltage, Vloop; c) edge toroidal magnetic field Bphi(a); d) edge safety factor q(a).

In the experimental campaigns of RFX-mod considered here, ULq plasmas have been produced in a wide range of conditions, mainly in terms of plasma current, edge safety factor and electron density values. The relevant role of the edge safety factor in determining plasma dynamics is evident in Fig. 1, where the MHD behavior exhibits strong sensitivity to q(a), as slight changes of the equilibrium produce either largely fluctuating or quiet discharges (#23016 and #23025).

The spectral properties of the MHD activity, deduced from highly space-time resolved in-vessel magnetic probes are in good qualitative and quantitative agreement with the results of dedicated non-linear 3D visco-resistive MHD simulations (1). In particular, the predicted tendency of ULq spectra to be dominated by a single resonant mode (either a kink or a double resonant internal mode) is confirmed by the experiments. Moreover, magnetic reconnection plays a dominant role in determining the dynamics of the magnetic topology. Magnetic reconnection can induce coalescence (or splitting, depending on the time variation of q(a)) of magnetic islands, a dynamic process normally followed by relatively long lasting (of the order of 10 ms) plateau phases of the plasma current, with almost quiescent MHD activity.
The active feedback magnetic control (not yet optimized for such plasmas) has been exploited in order to suppress the externally resonant (m,n)=(1/1) mode, whose growth, otherwise, induces fast discharge termination. Energy confinement time in the 1 ms range, increasing with the applied toroidal magnetic field, is estimated. Flat electron temperature Te profiles for $q(a) < 0.5$ are normally measured, but the recurrent emergence of internal gradients with enhanced core temperature in $0.5 < q(a) < 1$ low density plasmas is highlighted.

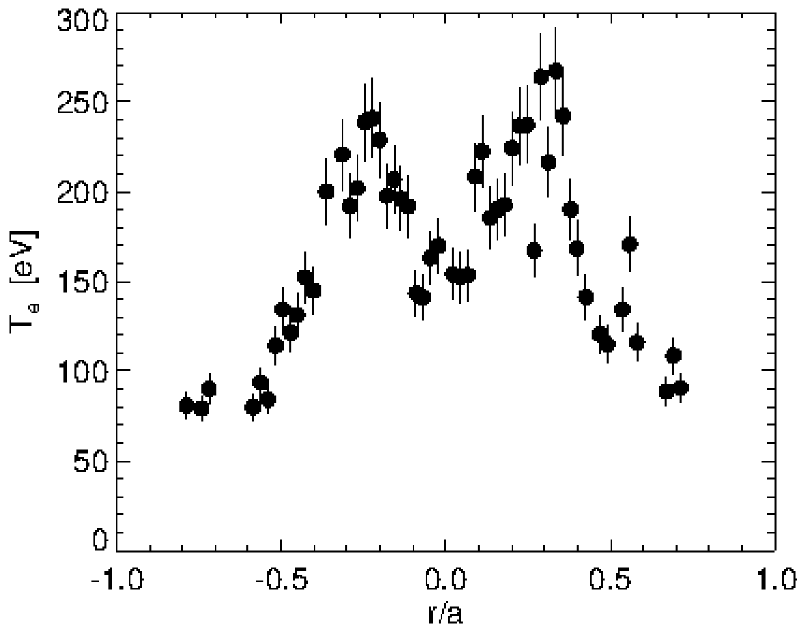

Figure 2: Te profile in a plasma dominated by a (m,n)=(2,3) mode in q(a) around 0.66 equilibrium, showing a double, almost radially symmetric, thermal structure.

Moreover, core localized thermal structures with steep Te gradients associated to single helical states form. An example is given in Fig. 2, where a double thermal structure, symmetric with respect to the magnetic axis, is associated to the island of a dominant (m,n)=(2,3) mode.

High electron density regimes, above the Greenwald limit, are more easily accessible and sustainable in the ULq than in the RFP, as the radiated power fraction, Prad/Pohm, largely remains below 0.5.

Density profiles are characterized by peaking factors above 1; in this respect, the role of the magnetic insta-

bilities and of the associated plasma-wall interaction is discussed.
MHD modes exhibit toroidal rotation at a frequency in the kHz range, depending on mode amplitude. Differently from what encountered in RFP plasmas at comparable current levels [6], no wall locking is detected. Plasma flow, deduced from impurity behavior, is also a function of the edge safety factor. Both toroidal and poloidal velocities are found to reverse sign in the $0.8<q(a)<1$ regimes unlike those measured in RFP and tokamak plasmas. The destabilization of a variety of high frequency coherent modes is reported, whose spectral properties suggest, in some cases, an Alfvenic nature.

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Session Classification: P7 Posters 7

Track Classification: Magnetic Fusion Experiments