Characterization of Particle Dynamics and Magnetic Reconnection in the RFX-mod Plasmas

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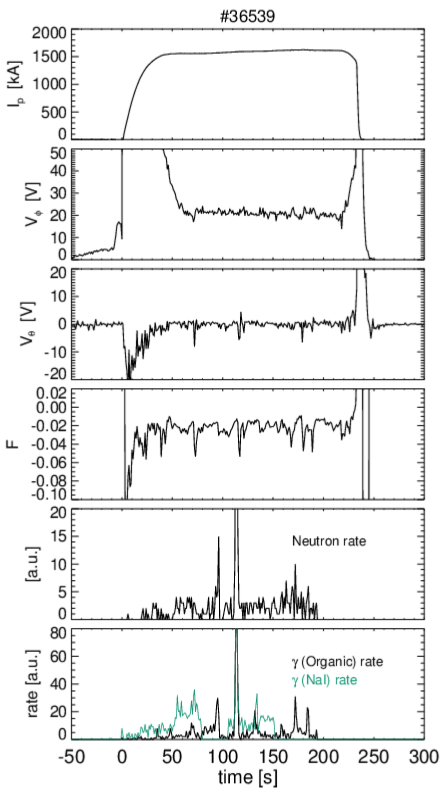

***Fig. 1**: From the top: plasma current as a function of time for a RFP discharge, toroidal and poloidal loop voltages, reversal parameter F, neutron flux and gamma rays from the two scintillators.*

Particle dynamics in magnetically confined plasmas is strongly determined by MHD activity. In this work, an experimental analysis of particle dynamics in D and H plasmas is presented in the RFX-mod device operated in both tokamak and reversed-field pinch (RFP) configurations. Particular attention is devoted to the role of MHD dynamics, in the form of reconnection processes (relaxation processes in the RFP and sawtoothing activity in the tokamak) in determining the energy spectra and the time behaviour of the emission of non-charged particles (neutral atoms, neutrons and gamma's) exiting the plasma.

The diagnostic system makes use of a 51 mm diameter, 51 mm thick EJ-301 liquid scintillator cell and of a calibrated crystal NaI(Tl) larger scintillator coupled to H8500 flat-panel photomultipliers, suitable for operation in a noisy magnetic environment [1]. The liquid scintillator is sensitive to neutron and gamma radiation, signals being classified on the basis of a pulse shape discrimination (PSD) process.

By means of a Neutral Particle Analyzer (NPA) diagnostics it is also possible to follow the time evolution of the distribution function of the neutral atoms produced by charge-exchange processes in the plasma. The NPA has 11 energy channels, being the energy and mass dispersion produced by a E//B (E parallel to B) combination. All diagnostic systems are located on the equatorial plane on the low-field side of the torus with a radial line of sight.

Bursty generation of DD fusion neutrons and gamma rays is observed in RFP plasmas, with some time correlation with the rapid variation of the magnetic field at the edge of the plasma, as shown in Fig. 1, where the time traces of various discharge parameters are given (plasma current, Ip, toroidal and poloidal loop voltages V_ϕ and V_θ, respectively, and the reversal parameter $F=B_\phi(a)/\langle B_\phi \rangle$, being B_ϕ the toroidal magnetic field).

Indeed, the rapid variation of the F parameter is associated with large impulsive magnetic fluctuations and rearrangement of the magnetic topology, due to magnetic reconnection processes. Bursty, almost cyclic, magnetic reconnection occurs in toroidally localized region of the RFP plasmas, associated with the generation of a poloidal current sheet, as shown in the past [2]. The current sheet is responsible for particle acceleration processes, which are likely to be correlated with the observed γ-ray bursts.

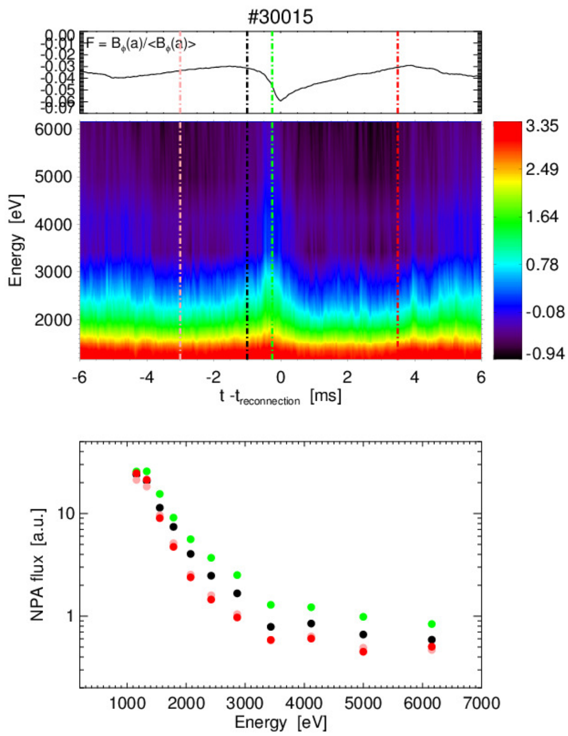

Fig.2: Neutral atom fluxes collected from the NPA diagnostics as a function of time and energy for a single (conditionally averaged) reconnection event in a RFP plasma. The bottom panel shows the distribution function measured at the indicated time instants (vertical lines in the central panel.

The "large" reconnections occurring in the plasma are indeed also found to have an impact on the behavior of the distribution functions of neutral atoms collected by the NPA diagnostics, as shown in Fig. 2, where the experimental fluxes are shown as a function of energy and time. Strong variations of both the thermal and the high energy tail (above around 2500eV) are induced by the reconnection process (the collected fluxes have been conditionally averaged for better statistical meaning). In particular, a heating process is recognized on the variation of the exponential slope of the low (Maxwellian) component of the spectrum at the time of maximum magnetic perturbation, which corresponds to an increase of the ion temperature T_i of about 50%.

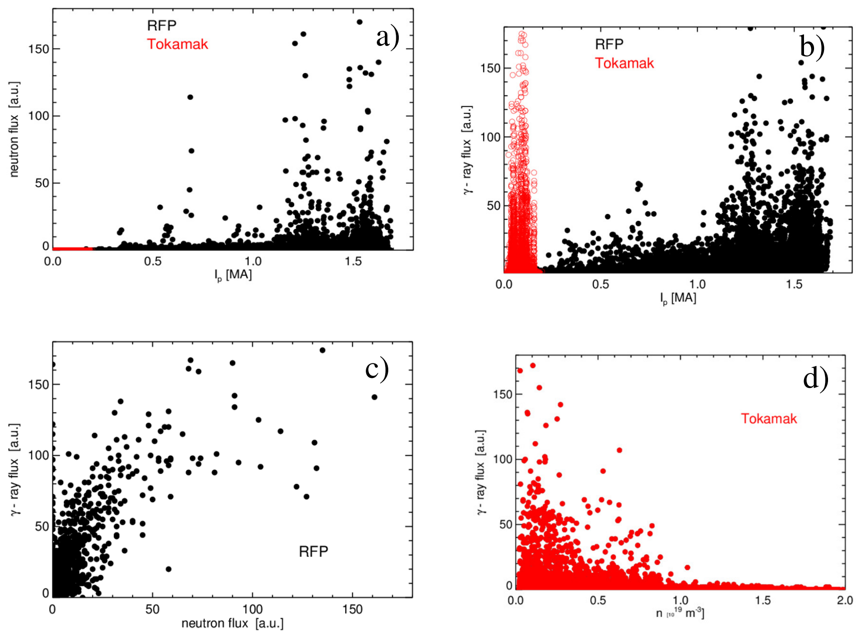

***Fig. 3**: from the top left a) and top-right b) neutron and gamma fluxes as a function of the plasma current I_p in tokamak and RFP discharges, b)top-right gamma fluxes; c) total gamma flux as a function of neutron flux for RFP discharges, d) total gamma flux as a function of the electron density in tokamak plasmas.*

Such non-collisional heating has, indeed, been observed in RFPs [3] and it can be interpreted as responsible for the increased neutron generation from DD reactions as seen in Fig. 1. Neutron production in RFP plasmas is found to depend on the plasma current level, as shown in Fig. 3a, with most of the neutron being collected above 1 MA. In the RFP this is also true for gamma rays (see Fig. 3b). Indeed, gamma and neutron fluxes exhibit good correlation, as is clear in Fig. 3c. Such gamma production would either suggest that along with ion heating also a form of electron heating could occur induced by the reconnection processes or that neutron capture is occurring from the material wall of the RFX-mod device. In Fig. 4, the gamma's spectra collected in various experimental conditions are shown. RFP spectra exhibit a pronounced peak at ~ 500keV, whose origin is still under investigation.

On the other hand, tokamak gamma's spectra appear to be continuous, being most of the gamma's produced in low density discharges (see Fig. 3d), thus likely to be induced by

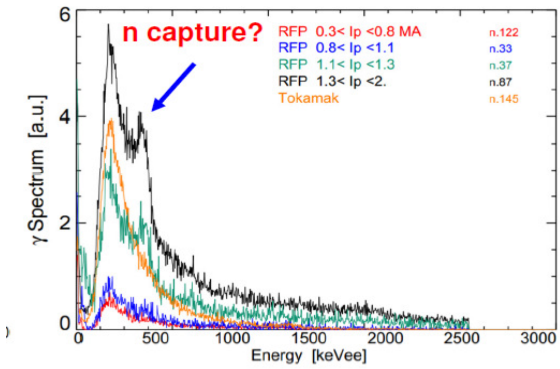

***Fig. 4**: Energy spectra of the gamma rays collected by the organic scintillator in different experimental conditions (tokamak and RFP at various plasma current levels).*

electron runaway population [4]. It is worth saying that almost no neutron have been collected in the low-current (low-toroidal field) tokamak ohmic discharges (Ip< 150kA) produced in the RFX-mod discharges, mainly because of the low ion temperature.

Magnetic reconnection, is found to have an impact on particle dynamics also in tokamak plasmas. In particular, it is found that the sawtoothing activity, mainly observed in low q(a) (<3) ohmic discharges, is related to dramatic variations of both the thermal Maxwellian (usually identified in the energy range between 300 and 800eV) and suprathermal (ion) population, as shown in Fig. 5.

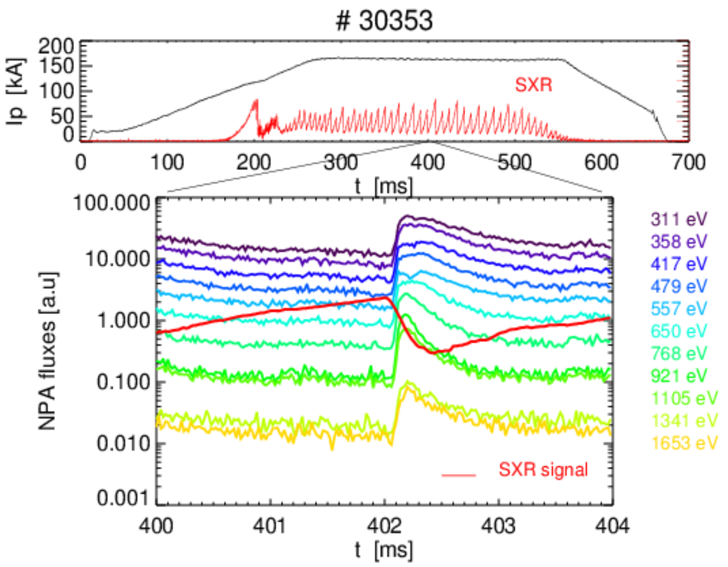

Fig. 5: *Time traces of Ip and SXR signal in a tokamak discharge (top); detail of the time behaviour of the NPA collected fluxes at the various collected energies (from 300 to 1600eV, going from the top trace to the bottom one) along with the detail of the SXR behaviour during sawtoothing activity.*

This observation is in good agreement with what previously observed in spherical tokamaks [5] during internal reconnection events, where the generation of fast tails in the NPA spectra was explained a manifestation of runaway acceleration in the parallel electric field associated with the reconnection process.

In summary, a study of plasma particle dynamics, in particular the phenomenon of impulsive ion heating and the enhancement of high energy tails in the distribution function, is presented. The study is based in the analysis of the signals from passive diagnostics dedicated to neutral particles (atoms, neutrons and gamma rays) exiting the plasma of the RFX-mod device operated both as a tokamak and a RFP.

References

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