Ion temperature measurements by means of a neutral particle analyzer in RFX-mod plasmas

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A Neutral Particle Analyzer (NPA) of the ACORD series, developed by the IOFFE Institute of the Russian Academy of Sciences and planned to be installed at the W7-X stellarator at the starting of plasma operations [1], has been recently put in operation in the RFX-mod device [2]. The NPA is equipped with a Nitrogen gas stripping cell and with 22 channeltron detectors (11 for Hydrogen, 11 for Deuterium) to resolve the energy distribution of the neutral H^0 particles produced by charge exchange (CX) processes and leaving the plasma. RFX-mod is the largest presently operating reversed-field pinch (RFP) machine, exploring for the first time the 2 MA plasma current regime in such a magnetic configuration.

In the present paper the first data from the NPA diagnostics collected during RFP Hydrogen plasma operations in a rather wide range of plasma current I_p (0.3 - 1.5 MA) and electron density n_e (1 - 7 x 10^{19} m^{-3}) are presented, and compared with those collected during an experimental campaign dedicated to the exploitation of the RFX-mod device as a low current (~ 100 kA) ohmic tokamak.

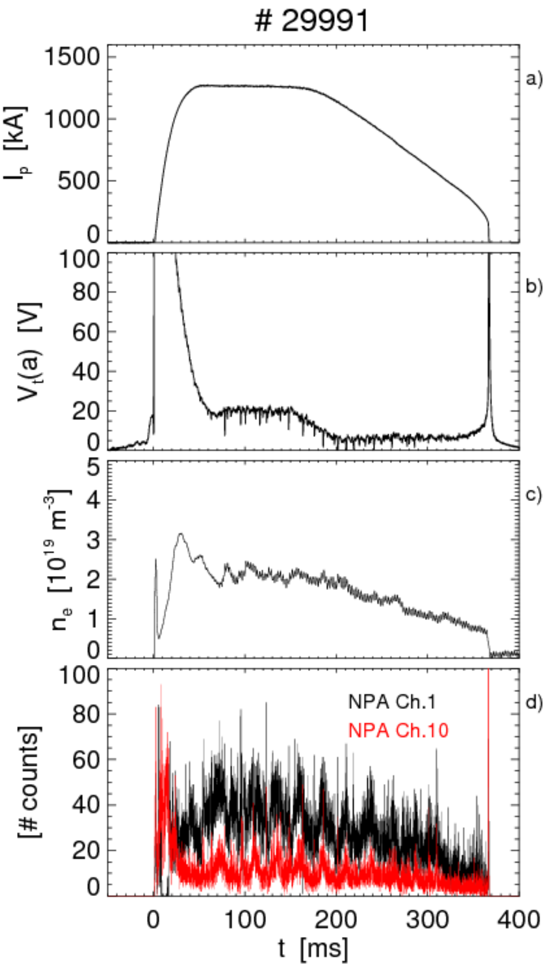

Figure 1*: Time traces for a typical RFP discharge: a) plasma current I_p, b) toroidal loop voltage $V_t(a)$, c) electron density n_e and d) two signals (channels 1 & 10 for H atoms) from the NPA.*

The NPA is mounted on a radial port on the low field side on equatorial plane of the machine. The energy and mass dispersion is produced by an E//B analyzer configuration, where the magnetic field is produced by an electromagnet. The value of the imposed magnetic field determines the energy range investigated by the 11 channels for each atomic species. The data acquisition system, based on a VME multi purpose scaler, is used to count the events (associated to the incoming particles) occurring on the single channeltrons at a 20 kHz sampling rate, which was found to be a good compromise between the need to have a statistically meaningful counting rate and a sufficient time resolution.

In figure 1, the typical time traces (I_p, n_e and toroidal loop voltage V_t) of a RFP discharge are shown along with that of the signals coming from two of the channels dedicated to the Hydrogen atomic flux of the NPA. In Figure 2 two examples of CX spectra collected in RFP and tokamak configuration are compared. It is interesting to note that both spectra exhibit the presence of a Maxwellian component corresponding to an exponential decay of the collected fluxes by the channels associated to the lowest energies investigated (the energy ranges explored are different due to the different thermal content for the two magnetic configurations considered, operating at largely different plasma current regimes). The uncertainty bars on the energy value is given by the energy range associated to each single channeltron. A higher energy (non-Maxwellian) population is also observed, with the transition energy from thermal to non-thermal tail of the distribution function in the range 1 – 2 keV depending on the kind of experiments considered. It is interesting to note that, for the RFP case, this result confirms previous observations obtained in the RFX device by means of a NPA–ToF (neutral particle analyser–time of flight) instrument, and that for the presence of such a high-energy tail a theoretical model based on a wave-particle interaction producing ion acceleration had been proposed [3].

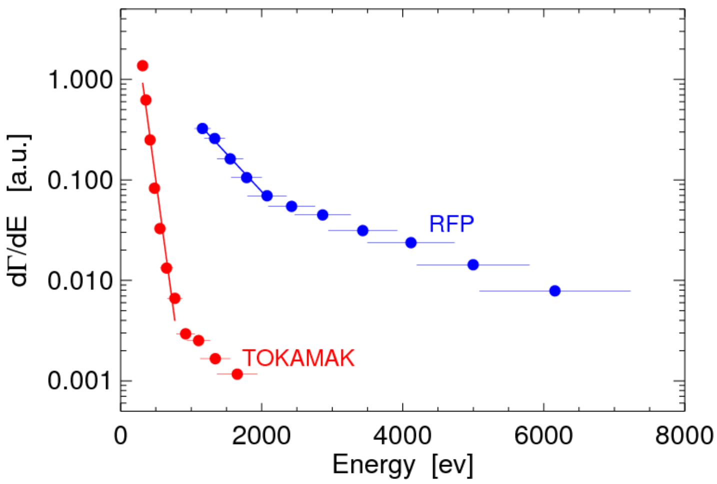

Figure 2: *Typical CX spectra measured in RFP (blue) and tokamak (red) plasmas.*

Typical electron temperatures, T_e, are of the order of 800 eV and 300 eV for the RFP and tokamak discharges under study, respectively. A rough estimate of the ion temperature T_i is then deduced from the logarithmic slope of the thermal component (a more precise estimate should necessarily take into account the CX production rate over the plasma, which depends on neutral density profile, and hence on the electron density and temperature profiles). An example of a time-resolved (1 ms) T_i behavior, which is deduced by time-integrating the collected fluxes over

1ms, is shown in Figure 3, and compared to the time trace of T_e (measured by a SXR multifilter diagnostics [4]), for the same tokamak plasma. A good time correlation is found between the two traces, characterized by large fluctuations in the considered time window induced by strong MHD activity. Such MHD activity is in the form of a m=2/n=1 mode rapidly varying its amplitude and its rotation frequency in the range 0 – 3 kHz, as can be observed by the color coded contour plot of the spectrogram (i.e. power spectrum vs. time) of a poloidal magnetic field sensor signal, shown in the bottom panel of Figure 3. Error bars on T_i measurement was deduced on the basis of that on the determination of the logarithmic slope of the energy distribution function.

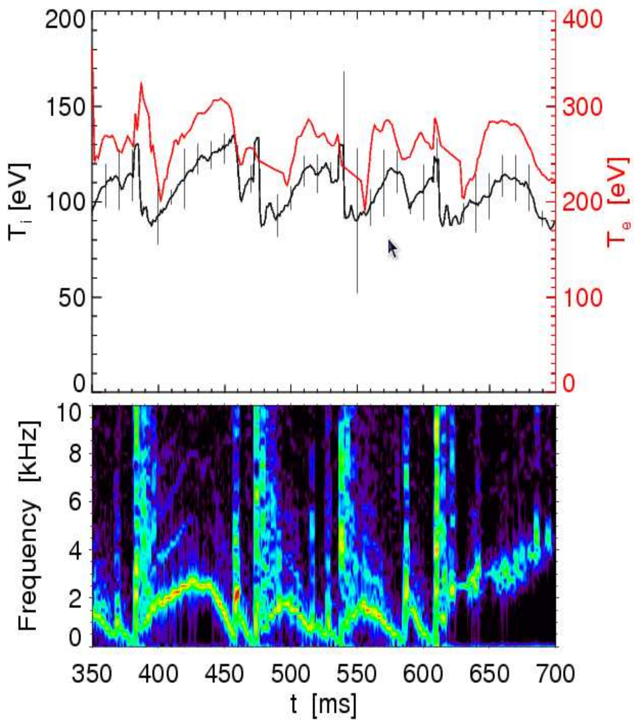

Figure 3*: Top, Ti and Te (red, right-hand side y-axis) time traces deduced by NPA and SXR diagnostics, respectively. Bottom, spectrogram of a B_p signal, showing the time variation of an m/n=2/1 mode frequency.*

A further example of the effect of plasma parameters on the CX spectra is shown in Figure 4 c), where two time instants of the same RFP discharge have been chosen, marked by colored vertical lines in the time traces of the toroidal loop voltage and of the electron density of Figure 4 b). The two time instants, which are characterized by plasma conditions different mainly in terms of electron density, exhibit distribution functions with different slopes (i.e. different T_i). In particular, larger density corresponds to higher T_i. Despite the clear experimental evidence it is not possible to deduce at this preliminary stage of the work that the plasma density, in terms of collisionality (i.e. equipartition time), is actually playing the major role in ion heating, as it can be observed that higher density also implies larger toroidal loop voltage, and hence larger ohmic power dissipated in the plasma. Moreover, variations of the neutral particles profiles in high density conditions would strongly affect the collected neutral fluxes, so that modeling becomes mandatory in order to properly interpret the experimental data.

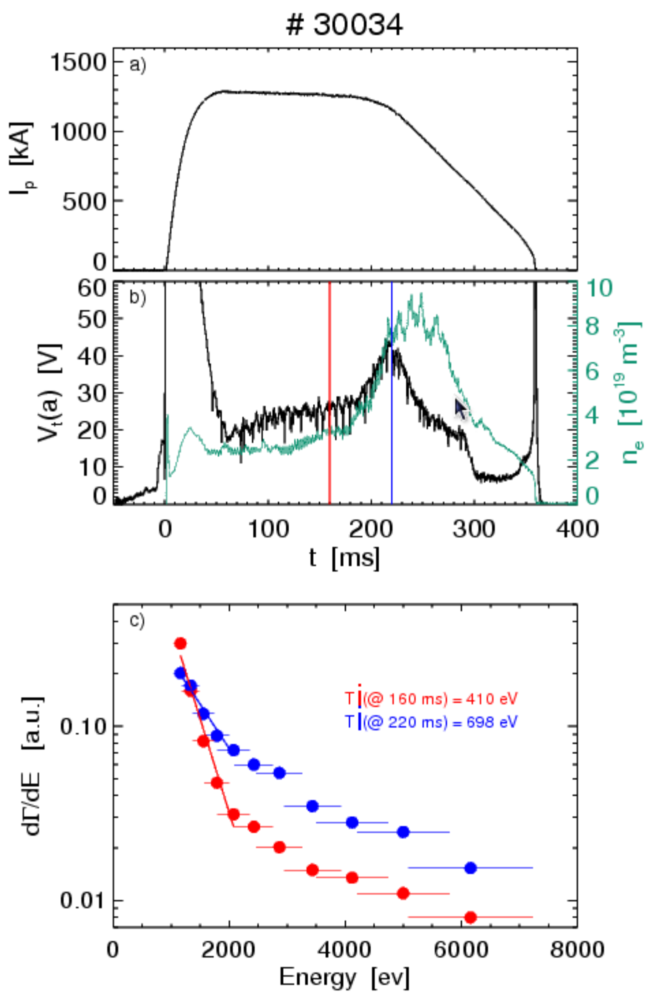

Figure 4: *a) Plasma current; b) toroidal loop voltage and (green) electron density; c) CX spectra collected in two time instants (160 and 220 ms).*

Conclusion

A neutral particle analyzer has been installed in RFX-mod, devoted to a time resolved estimate of the ion temperature. The first measurements during RFP and tokamak operations have been presented. The experimental data reveal that the CX spectra strongly depend on the plasma conditions. The measured distribution functions of the H^0 leaving the plasma exhibit a high-energy non-Maxwellian tail. The behavior and the relation of such a tail with the MHD activity will be object of future investigations, along with a wider statistical analysis of the dependence of the measured ion temperature on the plasma parameters.

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References

[1] W. Schneider et al., Vacuum **83**, 752 – 756 (2009)

[2] R. Lorenzini *et al.*, *Nature Phys.*, **5**, 570 (2009)

[3] S. Costa, R. Paccagnella, F. Pegoraro and M. Viterbo, Plasma Phys. Control. Fusion **41,** 1485–1496 (1999)

[4] F. Bonomo, P. Franz, A. Murari, G. Gadani, A. Alfier, R. Pasqualotto,. Rev. Sci. Instrum. **77**, 10F313 (2006)