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Fast Particle Energy Measurements in the Scrape-off Layer During Lower Hybrid Current Drive Experiments on Tore Supra

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A retarding field analyzer (RFA) was used during lower hybrid (LH) current drive experiments in the Tore Supra tokamak, as in [1], to measure the flux of supra-thermal particles emanating from the near field region in front of the LH grill mouth. The RFA was reciprocated in ~250 ms up to 1cm behind the last closed flux surface. The RFA entrance slit was biased to –50 V with respect to the vacuum vessel ground in order to repel thermal electrons. The ion-repelling grid was grounded such that all ions could reach the collector. The secondary electron grid was biased to –200 V. For specific values of the safety factor and of the RFA position, a strong negative current was measured both on the entrance slit and on the collector. This occurs when at least one of the waveguide rows is magnetically connected to the RFA, and only when the launcher is active, Fig.1.

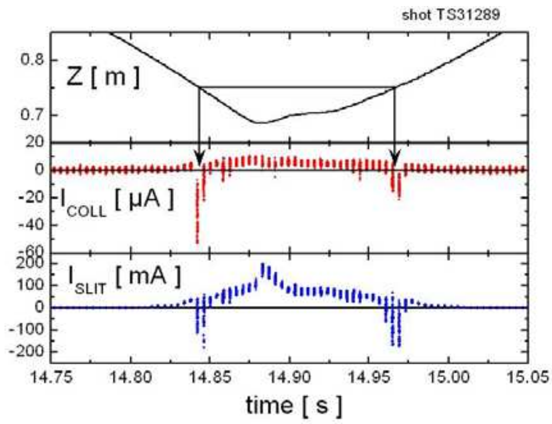

Fig. 1. Temporal evolution of ion currents during a probe reciprocation, LH power launched.

We note that no thermal electrons pass through the RFA entrance slit in the ohmic regime. This is verified by sweeping the voltage of the entrance slit from +10 V down to -50 V, Fig. 2. The ion current saturates already at -10 V. The RFA collector therefore measures pure ion current.

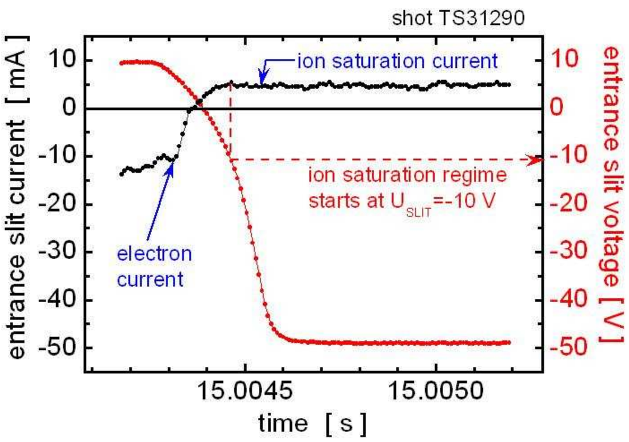

Fig. 2. RFA entrance slit current in ohmic regime, no LH power launched.

The peaks of the negative current, seen in Fig. 1., indicate: (1) the presence of an electron flux that exceeds the ion flux, (2) the applied potentials are not negative enough to repel the electrons.

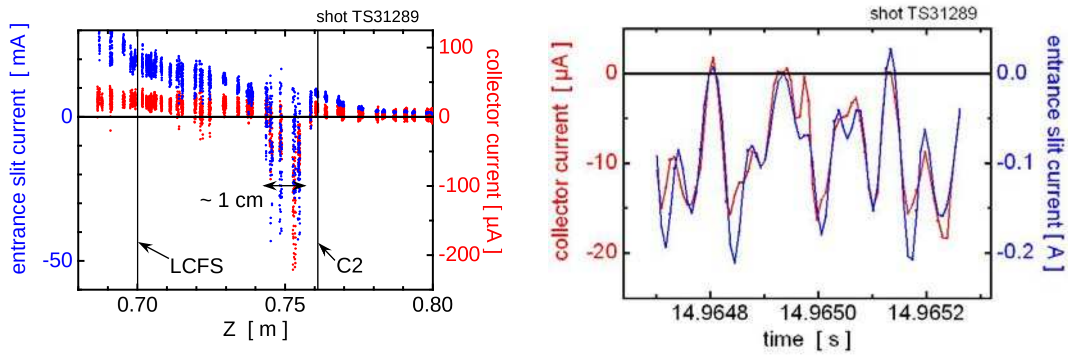

Fig. 3. a-left panel: A more detailed structure of the negative peak as seen in Fig.1, plotted as a function of the vertical RFA position. b-right panel: Detailed temporal structure of the peak of the negative current.

The peak of the negative current is observed at the same position on the ingoing and outgoing phases of the probe reciprocation. The electron flux is localized in a layer ~1 cm thick. The outer edge of the fast electron layer coincides with the leading edge of the LH antennae C2 and C3 within the uncertainty of the magnetic measurements (at most ±5 mm), Fig. 3a. The spatial resolution (~ 5 mm) allows to assess that the radial width of the collected fast electron beam is less than 1 cm. This result is consistent with measurements obtained by infra-red imaging of connected in-vessel components. The electron current on the entrance slit and on the collector comes in rapid bursts (typical frequency in the 10-20 kHz range), Fig. 3b. The form of the bursts is very similar on the collector and on the entrance slit. In Fig. 3b, the interpolated ion saturation currents are subtracted from the signals to extract the pure electron component. In order to explore the spatial energy distribution in the fast electron beam, we introduced a transmission factor, defined as the ratio of the electron current densities at the entrance slit and collector. Here we show the transmission factor of the largest bursts, Fig. 4. The transmission is higher in the center of the beam. Electrons that reach the collector have at least 150 eV of kinetic energy as they pass through the entrance slit. The variation of transmission factor could be qualitatively indicative of the width of the electron distribution function. As Fig. 3a shows, the peak of the RFA slit and collector currents, arising due to the fast electron beam, is radially shifted about 1 cm into the plasma from the magnetic surface, on which the mouth of C2 and C3 launchers is located. The radial location of the maximum of the transmission factor, Fig. 4, which apparently coincides with the radial location of the most energetic electrons in the beam, is also about 1 cm shifted radially into the plasma. Accounting for the magnetic ripple shows that, in fact, the beam is generated about 2 centimeters in front of the LH grills mouth.

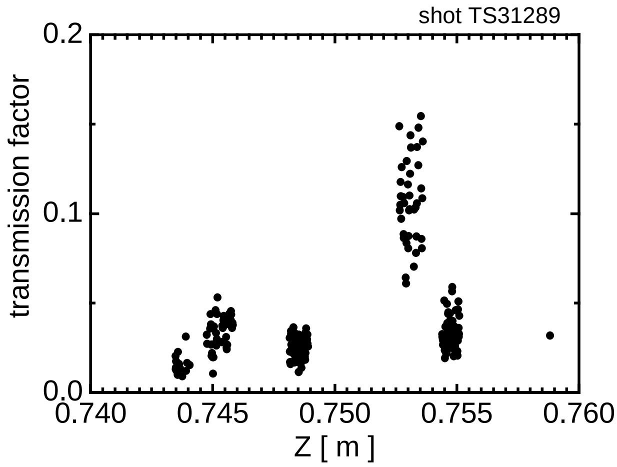

Fig. 4. Transmission factor as a function of the radial position in the electron beam.

This is in agreement with observations of the hot spots locations in Tore Supra [2] and in JET [3]. However, the original theory predicts the generation of the fast particle beam in locations radially more near to the grill mouth flux surface, where the higher spatial harmonics of the LH wave still are not damped [4]. The presence of the fast electrons at the in experiments observed larger radial distance of the order of centimeters from the grill mouth could be possibly explained by the presence of spontaneously excited random fluctuating fields in front of the grill mouth. However, this does not explain the puzzle why the fast electrons were not found in radial distances very near to the grill mouth. Fig. 5 shows the dependence of the normalized RFA signal on the normalized (to the density) RMS of the RF probe (mounted on the C3 launcher) fluctuating signal.

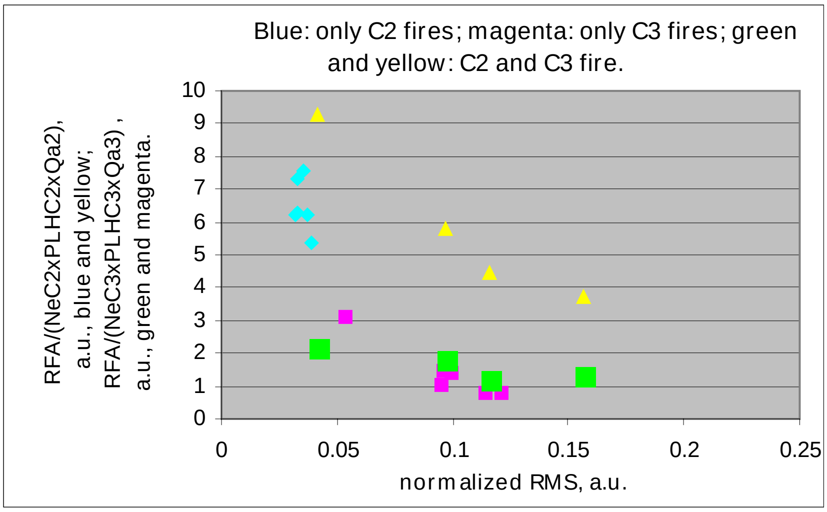

Fig. 5. Normalized RFA signal in dependence on the intensity of fluctuations.

We ascribed to each shot a number between zero and one, Qa2 or 3, according to how much of the waveguide row area of the launcher C2 and C3 is connected to the RFA slit. Then we normalized the RFA signal to the LH power PLHC2/3, to the plasma density NeC2/3, as measured on the launcher, and to Qa2/3. The normalized number of the accelerated electrons given by the normalized RFA signal in Fig. 5 is lower, when the fluctuation level in locations magnetically connected to the waveguide rows is higher. This could indicate larger dissipation of the random fields at larger electron acceleration rate. We conclude by noting again that the RFA measurements indicate that the fast electron beam is generated in a distance of 1 or 2 centimeters in front of the LH grills. And, for the first time, qualitative data about the accelerated electron distribution function were obtained. *Supported partly by the project GACR 202/04/0360.*

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