Fast ion slowing down time in TJ-II stellarator low density plasmas

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Introduction

In this work we present the results of NBI-Blip discharges in the TJ-II stellarator. TJ-II is a medium-sized flexible heliac (R=1.5 m, <a> $\leq$0.2 m, B_0=1 T, P_{ECH} $\leq$600 kW, P_{NBI} $\leq$1 MW) operated at CIEMAT in Madrid (Spain). Hydrogen plasmas are created and heated using up to 600 kW of electron cyclotron emission heating (ECRH). Additionally, up to 1.4 MW of neutral beam power is provided by two tangential Neutral Beam Injectors (NBI). TJ-II is equipped with a broad range of diagnostics including a toroidal viewing Compact Neutral Particle Analyzer (CNPA) [1], which has 16 energy channels covering the range 1-40 keV that can be sampled at $\leq$ 1 kHz. This system is oriented to collect fast neutrals that result from charge exchange reactions between cold neutrals and fast ions injected into the plasma by one of the NBI lines.

A series of NBI-Blip experiments has been performed in order to measure the fast ion slowing down time. For this, the plasma is heated by ECRH. In addition a short co-NBI pulse of duration $\leq$ 20 ms (called blip), is injected in order to create a small fast ion population. After NBI switches off, the decay time of the signal level in each of the 16 CNPA channels is determined. Since each channel corresponds to a known energy interval, it is possible to derive the average time for an ion to drift from the upper to the lower energy in each channel.

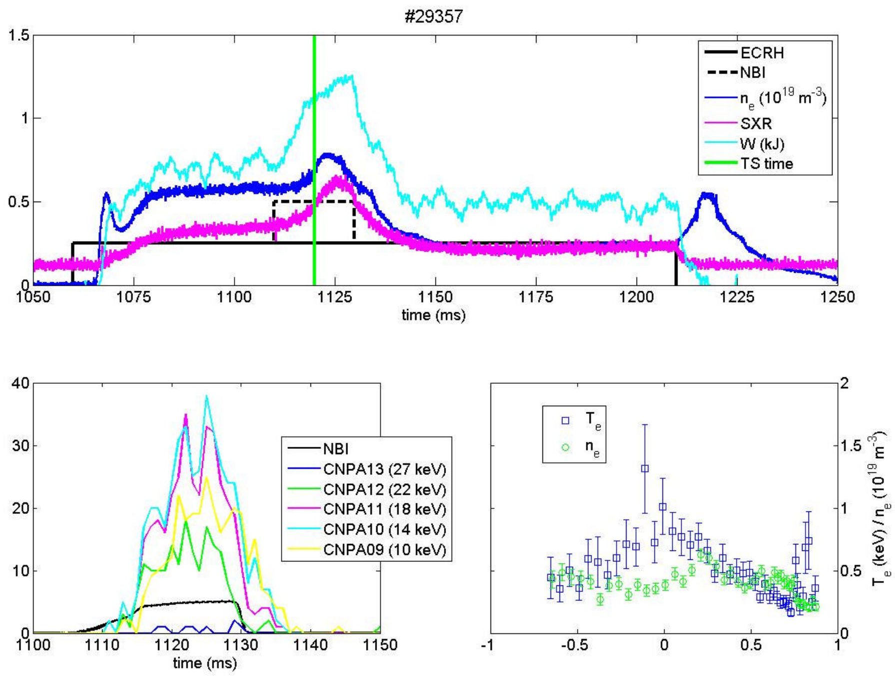

Figure 1: Main parameters for a discharge of this experiment. Top panel: heating scheme (ECRH black solid line and NBI black dashed line), line average density (blue), soft X rays (magenta) and energy (cyan). The vertical green line indicates the time when the Thomson scattering is fired. Lower left: expanded signals in selected CNPA channels during the blip. Lower right: Thomson scattering profiles, electron temperature (blue) and density(green).

Experimental data

The experiments were performed using different background densities and magnetic configurations. A configuration scan was performed by keeping constant the plasma volume but changing the iota profile, thus varying the position of the 3/2 or 8/5 magnetic resonances. In a series of repetitive discharges the Thomson scattering diagnostic was fired before, during and after the NBI blip in order to ensure that the plasma profiles were not changed significantly by the injection of fast neutrals. Using spectroscopy, it was determined that ions with three different energies are injected [2].These are: 30 keV, 15 keV and 10 keV with relative ratios 55:25:20. In some shots the main component was changed to 27 keV but no influence on this parameter was found.

Figure (1) shows the main parameters of the typical discharge for this experiment.

Discussion

It was found that the slowing down process does not exhibit an exponential energy decay in these discharges. Equation 1 was used to calculate the time that an ion takes to decay from the upper to the lower energy in each channel:

$$\tau_{sd}^{exp} = \frac{\int N_i t dt}{\int N_i dt} \approx \frac{\sum N_i t \Delta t}{\sum N_i \Delta t} \tag{1}$$

Here, N_i is the number of ions collected in each channel for each time window, t is the time from the NBI switch off and Δt is the time window selected. This time is compared with the theoretical one obtained using equation 2 [3]:

$$\tau_{sd}^{th} = \frac{\tau_s}{3} ln \left(\frac{E_{in}^{3/2} + E_{crit}^{3/2}}{E_{out}^{3/2} + E_{crit}^{3/2}} \right) \tag{2}$$

Here E_{in} and E_{out} are the upper and lower energies in each CNPA energy channel, E_{crit} and τ_s are the critical energy and the Spitzer time as defined in [4]. This time, τ_{sd}^{th}, is calculated by taking into account only collisions of the fast ions with background electrons. This is a reasonable assumption as the ion-ion collision time is much longer than the ion-electron collision time. However, this calculation does not take into account the effect of the magnetic configuration that might be important for the TJ-II [5]. Note, for these calculations the local electron temperatures and densities where obtained with the Thomson scattering diagnostic.

Density scan

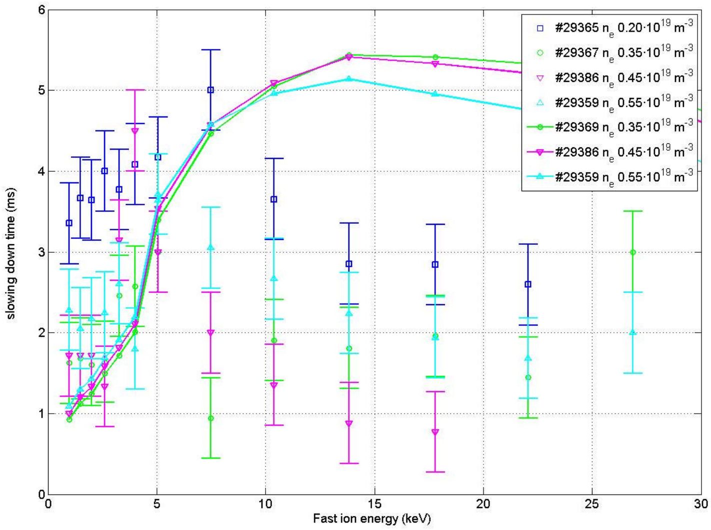

Figure 2: Experimental and theoretical slowing down times for a range of plasma densities. Lines represent theoretical times while symbols represent experimental times. Electron density and temperature used to calculate the theoretical times are taken from Thomson scattering.

Four different line averaged electron densities between $0.2 \cdot 10^{19} m^{-3}$ and $0.6 \cdot 10^{19} m^{-3}$ were studied. The longest slowing down time corresponds to the lowest line averaged density. This would be expected as the Spitzer time is inversely proportional to the density, this feature being observed in the experimental as well as in the theoretical slowing down time. All cases present a maximum in the mid-range energies (5 keV) with a slow decreasing of the slowing down time towards high energies. The data show a qualitative agreement between theoretical (2) and experimental (1) time with a similar behaviour. Nevertheless, the experimental one is clearly lower than the predicted slowing down time. This disagreement is not surprising because the calculation does not take into account possible fast particle losses and only considers collisions between ions and electrons.

Configuration scan

In the case of the iota scan, the three magnetic configurations selected have similar plasma volumes ($\sim 1 m^3$) but different radial positions of the main magnetic island in vacuum. Two of the configurations (100_36_62 and 100_44_64) present a low order magnetic resonance near the plasma edge whereas the third one (100_38_62) has the resonance close to the centre ($\rho \sim$ 0.35) where most of the fast ions

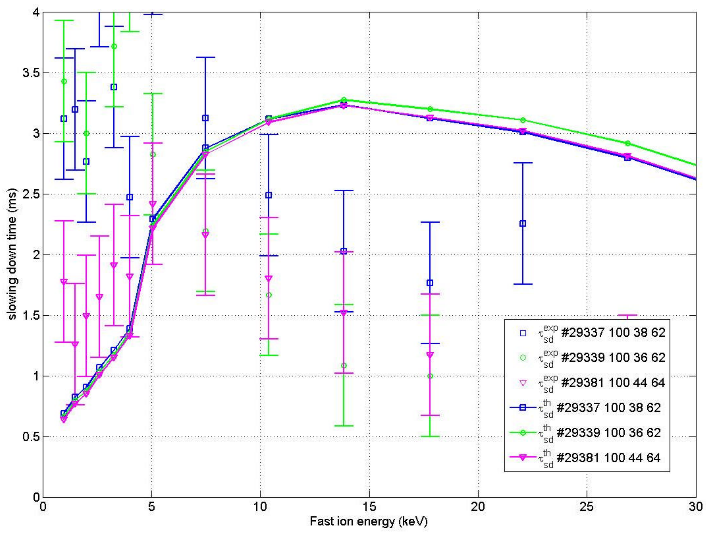

Figure 3: Experimental and theoretical (from Thomson scattering data) slowing down times in the configuration scan. Lines and symbols represent the same as figure 2.

are born.

The slowing down times are very similar for the two configurations with the magnetic resonance at the edge whereas the other presents a longer one (see fig. 3). Obviously, there is no difference in the calculated time (2), since the presence of the resonance is not taken into account. These differences can be explained considering the different positions of the resonance: in the case where it is located at the edge, fast particles are more easily expulsed from the plasma once they are neutralized resulting in a lower slowing down time. In the inner position the fast particles are neutralized and expulsed from the centre of the plasma to outer radii, but the escape length is longer.

Conclusion

An experiment to measure the slowing down times of fast ions in TJ-II stellarator plasmas has been performed by changing the density and magnetic configuration of the discharges. When changing the background density, the lowest case density corresponds to longest slowing down time. This behaviour is expected since the Spitzer time, which serves to calculate the slowing down time, is inversely proportional to the averaged line density. When the densities are very close to each other this effect could be masked by experimental error bars. When changing the magnetic configuration, a slight difference is found. This depends on whether the main magnetic resonance is at the centre or at the edge of the plasma. Being at the centre results in a longer slowing down time, indicating that the presence of rational surfaces is important for the confinement of the fast ions.

Future experiments will be performed in NBI plasmas, at higher densities, to be compared with these results.

Acknowledgements

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