Analysis of the energy distribution of escaping suprathermal ions in neutral-beam injection phase of the TJ-II stellarator

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Abstract. **In this work, the ion distribution function on suprathermal ions escaping from TJ-II plasmas during the neutral beam injection (NBI) phase of the plasma is being investigated to extend those already reported studies mainly for(ECRH) plasmas [1,2]. These ions are monitored with a flexible luminescent probe (LP) [3], which is operating in a pulse energy discrimination mode [4] and it is located at the edge of the TJ-II stellarator. This work is focused on studying the behaviour of suprathermal ions energy distributions under two different conditions: when the NBI heating starts after an ECRH and when initiating the plasma solely with NBI heating. Also the pellet injection on the second type of discharge (solely with NBI heating) is studied, and its effects on suprathermal ions energy distribution.**

Experiment.

- **ECRH** at the second harmonic (f = 53.2 GHz, $P_{ECRH} \leq$ 500 kW).
- **NBI heating**, direct start-up [5]. Inducing toroidal field of 0.35 V/m, at the lower limit of those used for ohmic break-down in tokamaks [6,7].
- **Pellet injector**. It is sufficiently flexible to allow frozen hydrogen pellets with diameters from 0.4 to 1 mm to be formed and accelerated to velocities between 100 and 1000 m s^{-1} [8-12].
- The **luminescent probe** (**LP**) [2,13]. Luminescent screen was made of TG-Green (decay time of 500 ns), and its range of measurement is 1-30 keV. See Figure 1.

The TJ-II Stellarator

- R = 1.5 m
- ρ ~ 0.2 m
- B ≤ 1 T
- $P_{ECRH} \leq 2 \times 300$ kW
- $P_{NBI} \leq 2 \times 700$ kW

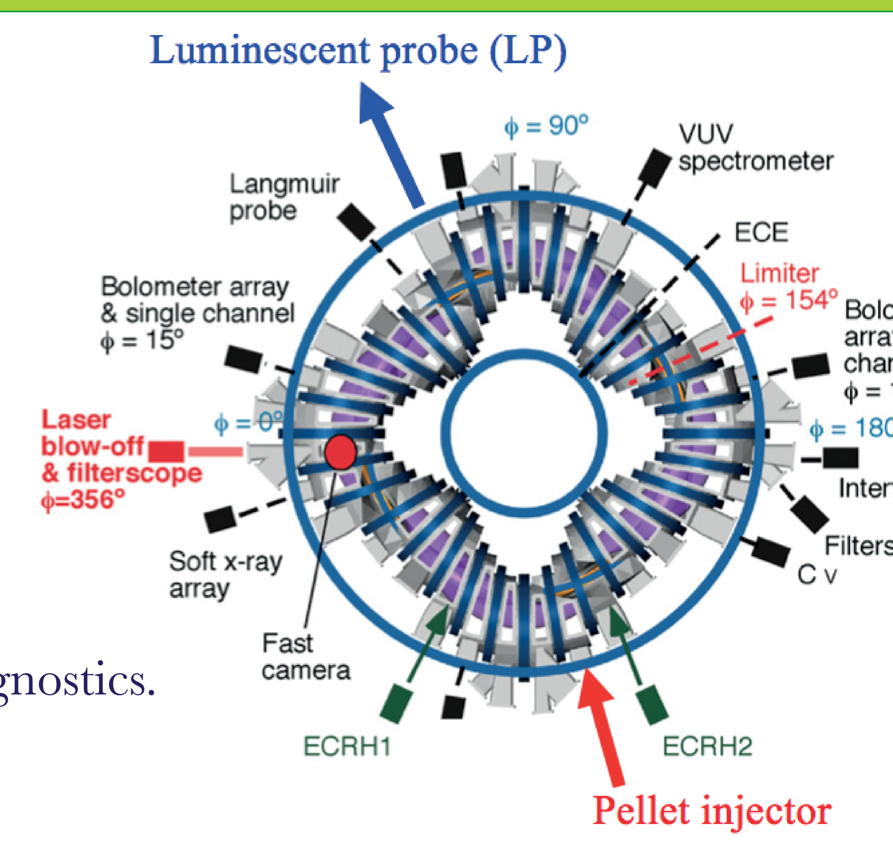
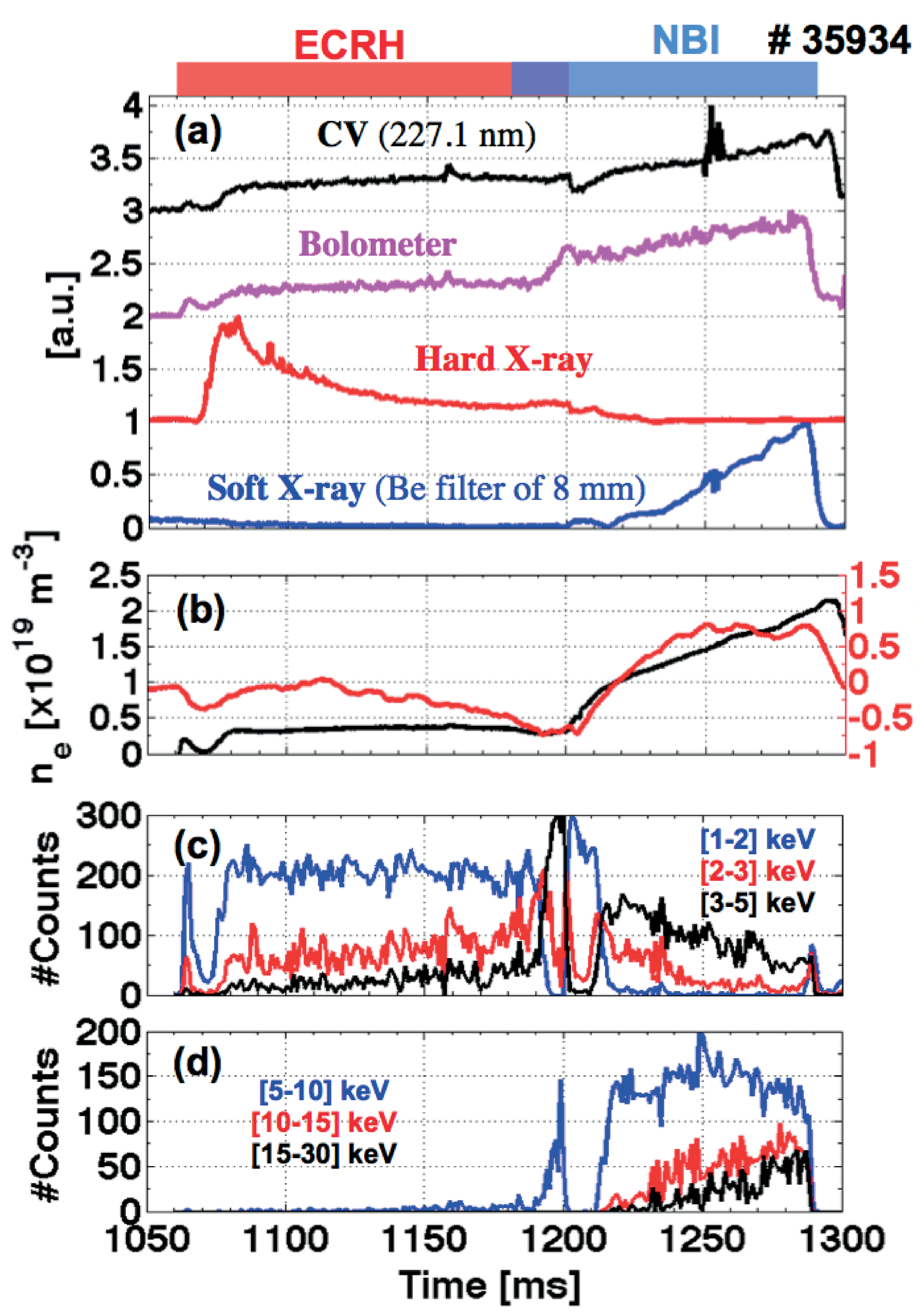


Figure 1. TJ-II diagnostics.



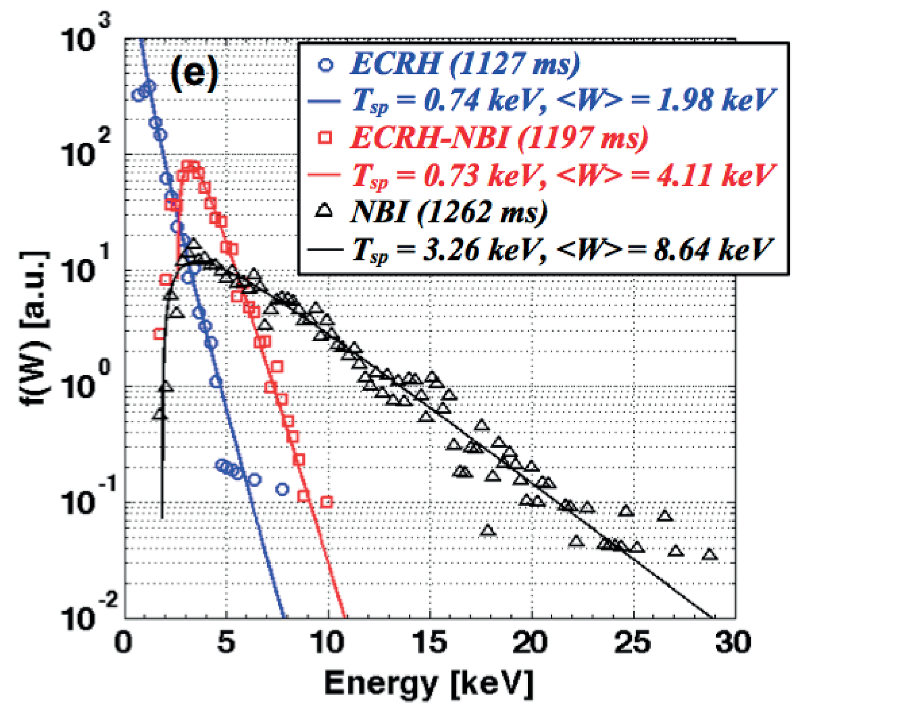


Figure 2. **(a)** Some diagnostics for discharge ECRH-NBI, #35934. **(b)** line-averaged electron density (microwave interferometer, n_e, black), plasma current (I_p, red). **(c)** and **(d)** Shows ions counts per millisecond (ms) in different energy ranges. **(e)** *f(W)*, for three different times: in ECRH, 1127 ms; overlap between ECRH and NBI, 1197 ms; NBI heating, 1262 ms.

Results (NBI).

-Breakdown produced by an electric field, see figure 3. This is an example to show whether it is possible for a loop voltage to generate suprathermal ions.

-During the ramp-up of toroidal field. The LP detects fast ions with high energies 2-5 keV (figure 3c).

-The NBI heating begins at 970 ms. There is a significant change in the suprathermal ions energy (until 1010 ms), with only ions < 2 keV, that coincides with the rise of the I_p (figure 3b), when plasma is warming.

-During the electron density plateau (> 1010 ms), the ions energy increases up to values higher than 15 keV, see figure 3d.

-Figure 3e. Different shapes of *f(W)* between ECRH-NBI heating (#35934, 1262 ms) and solely NBI heating (#37419, 1032ms).

-For ECRH-NBI, the influence of NBI heating on suprathermal ions, is to give them more energy and make the tail of *f(W)* wider.

-For solely NBI heating, it seems that NBI favours that the number of ions increases in a specific range of energies ([12-18] keV), and it does not generate tails with higher energies.

Results (pellet ionjection). (frozen hydrogen of diameter 1mm, 1057 ms) on suprathermal ions in the discharge # 37419.

-Some plasma monitors react at the pellet injection (figures 3a and 3b).

-Figures 3c and 3d shows suprathermal ion counts. They fall drastically, but after a time ~ 10 ms the LP signal rise again with ions energy < 10 keV.

-The pellet injection causes a thermalization of suprathermal ions distribution (ions < 7 keV, see figure 3f).

-The temperature is very similar to ECRH case (figure 2e, 1127 ms), where *f(W)* is thermalized. However, this effect only lasts ~ 10 ms, then the ion energy increases up to < 14 keV, but ions at higher energies (> 14 keV) do not reappear.

Experiment Results. We study how the population of fast ions and their distribution function, *f(W)* behave in two types of NBI plasmas:

- Providing the target plasma by ECRH,
- Initiating the plasma by the NBI with the help of a small loop voltage provided by the field rise.

Results (ECRH-NBI)

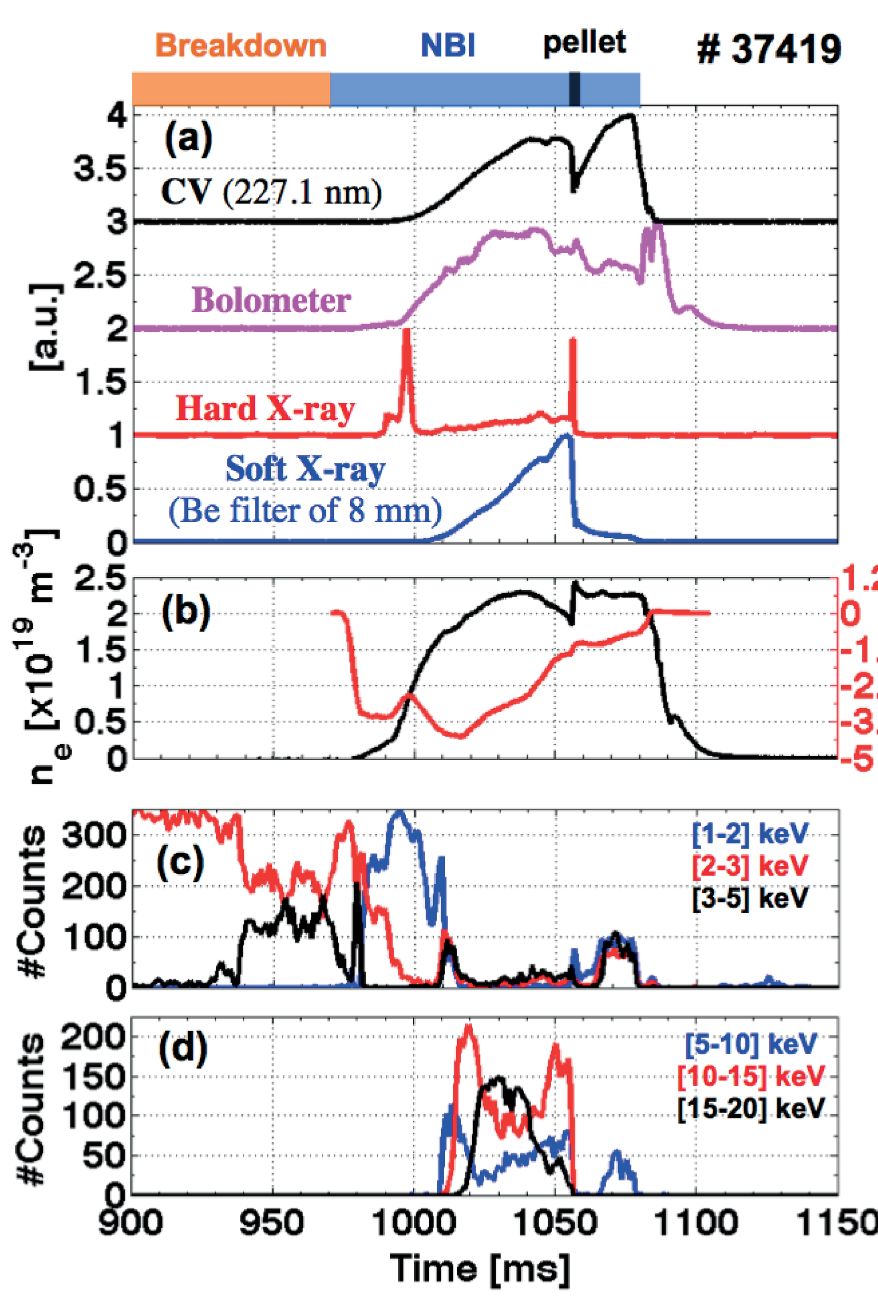
-Figure 2 shows a discharge ECRH-NBI, ECRH (1060-1200 ms) and NBI heating (1180-1290 ms).

-It is noted that ions with energies less than 2 keV dominate in ECR heating. In the overlap (1180-1200 ms), the number of ion counts with low (high) energy decreases (increases) in a few milliseconds (< 10 ms).

-During the NBI heating, the dominant ion counts are those with high energies > 5 keV, that is reflected in the *f(W)*, see figure 2e.

-During ECRH and overlap phase, we see that the *f(W)* is practically the same, including the value of the temperature of suprathermal ions, T_{sp}. But, expected value of energy, <W>, moves to higher energies.

-In the NBI heating phase, it is observed high energy tails in *f(W)*.



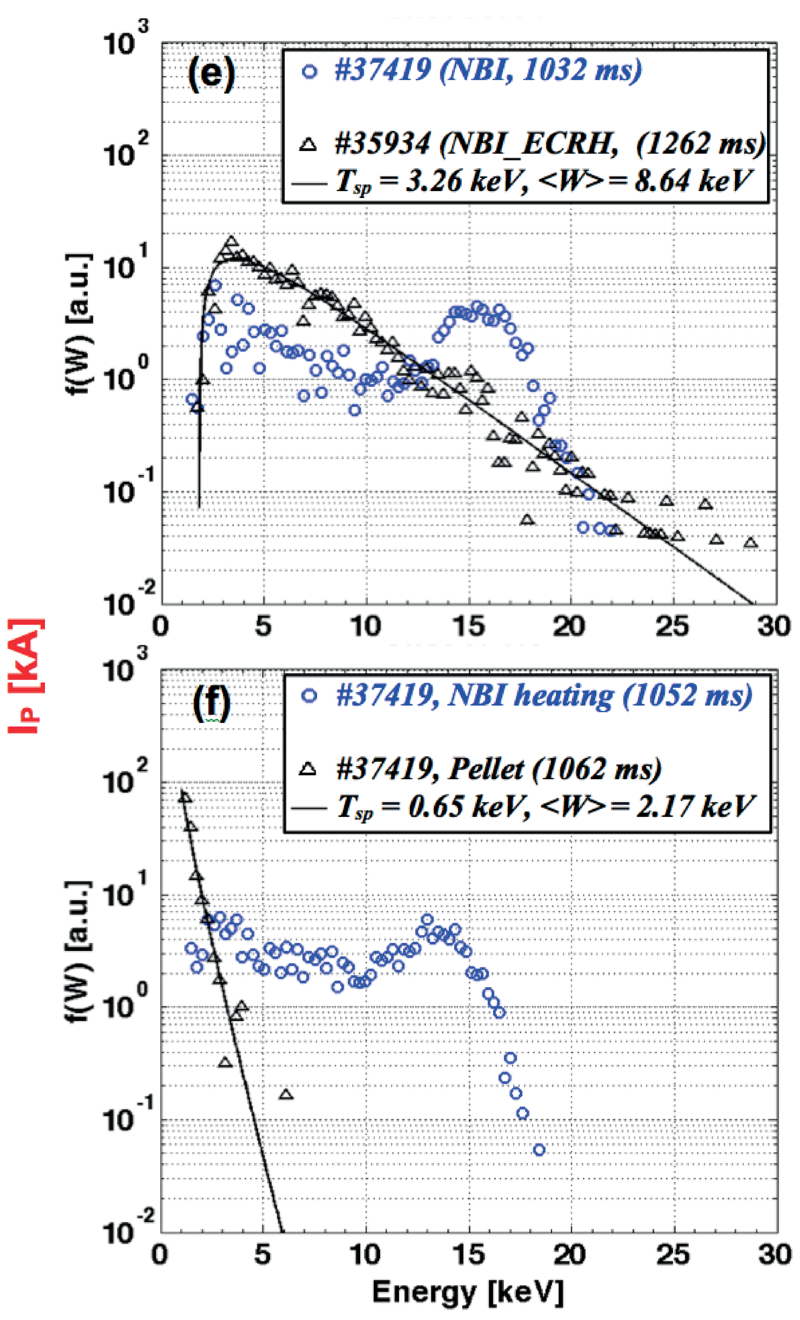


Figure 3. **(a)** Some diagnostics for discharge NBI, #37419. **(b)** n_e (black) and I_p (red). **(c)** and **(d)** shows ions counts in different energy ranges. **(e)** *f(W)* solely initiated by NBI heating (blue, #37419) and started by ECRH (black, #35934). **(f)** *f(W)* for discharge solely with NBI heating. (blue, 1052 ms) *f(W)* before the pellet injection, (black, 1062 ms) *f(W)* during pellet injection.

References

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