The study of fast ion losses in TJ-II in the 100's MHz ranges with a luminescence probe with upgraded counting and energy discrimination capabilities

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INTRODUCTION. Detailed knowledge of loss mechanisms of fast or suprathermal ions, associated to fusion processes or heating methods, is of paramount interest to magnetically confined fusion research. Fast ions have been studied in the TJ-II stellarator using ionoluminescence from the phosphor $SrGa_2S_4$:Eu (TG-Green, decay time = 540 ns) [1] installed in a luminescent probe (LP) [2]. This has allowed the study of fast-ion energy distributions in the ms range [3]. However, there exist fusion relevant plasma phenomena in shorter timescales that could affect ion confinement. One such phenomenon that occur in times < 1 ms is edge-localized-modes (ELMs), particularly those that occur during the neutral-beam-injection (NBI) heating phase.

The edge of fusion plasmas is characterised by its turbulent and intermittent (bursty) behaviour that strongly affects global confinement and plasma-wall interaction [4]. In tokamaks operating in the high-confinement mode (H-mode), the large plasma pressure gradients at the edge (pedestal) trigger magneto-hydrodynamic (MHD) instabilities producing ELMs that expel intermittently large fluxes of particles (ions and electrons) that heat the reactor plasma-facing components [5, 6]. Concerning stellarators, ELMs and ELM-like events have been observed and studied since the achievement of the H-mode in W7-AS [7-9]. A differentiation of both phenomena is needed because ELMs appear close to the H-mode transition, in the quiescent operational range, while ELM-like events are present in a large variety of plasma conditions [10]. As in tokamaks, both have as consequence the repetitive burst of the edge plasma towards the scrape-off layer (SOL), although ELMs are more violent than ELM-like events. ELM-like events have also been observed in the LHD Heliotron [11-13] and the TJ-II Heliac, first in low-density electron cyclotron resonance heated (ECRH) plasmas (average $n_e \leq 10^{19}$ m^{-3}) [14, 15] and later in NBI heated plasmas (1.5×10^{19} m^{-3} < n_e <

4×10^{19} m^{-3}) [16].

In order to explore how ELM-like events in the TJ-II affect fast ions, the previously mentioned LP was upgraded [17]. The phosphor was changed to a faster one, YAP:Ce (Yttrium Aluminum Perovskite doped with Cerium, decay time = 27 ns), and faster electronics and data acquisition system of 1 GHz were installed (previously 1 MHz). In this work, we present results obtained with the upgraded version of the luminescent fast ion detector during the NBI phase of TJ-II plasmas. In particular, we focus on results of fast ion behaviour regarding ELM-like events in the NBI phase.

EXPERIMENTAL. TJ-II is a four-period low magnetic shear stellarator with major and averaged minor radii of 1.5 m and ≤ 0.22 m, respectively. Central electron densities, $n_e(0)$, and temperatures up to $1.7\text{x}10^{19}$ m^{-3} and 1 keV respectively are achieved for plasmas created and maintained by ECRH at the second harmonic (f = 53.2 GHz, P_{ECRH} ≤ 500 kW). TJ-II disposes of two NBIs, each of which can produce ≤ 120 ms pulses of neutral hydrogen accelerated to 32 keV, to provide up to 550 kW (each) of additional heating [18]. A sketch of the LP in TJ-II is shown in Fig. 1. The LP has a narrow aperture (1.5 mm of diameter) through which ions are collimated before reaching phosphor where light is emitted, this being then collected by a photomultiplier tube. The LP range of fast ion measurement is between 1-40 keV [17].

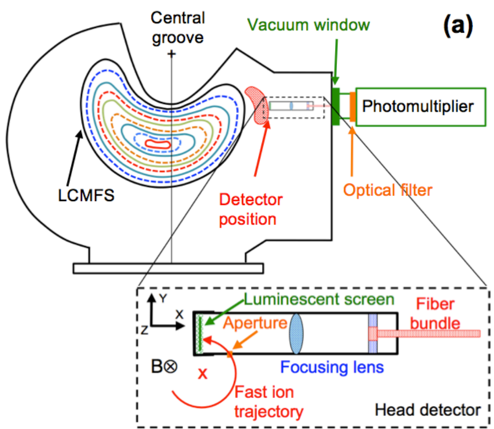


Fig. 1. Sketch of the luminescent probe (LP) as configured for this work.

EXPERIMENTAL RESULTS. In order to illustrate the results of the LP in the ELM-like period, we select discharge #41525. For this data acquisition was made at 100 MHz, the plasma was heated by one NBI (460 kW) and pre-heated by ECRH (240 kW), and the magnetic configuration had iota central value $\iota = 1.53$ (inverse of the rotational transform q in tokamaks). In Fig. 2(a), which shows characteristic TJ-II plasma signals, the ELM-like period is highlighted. Fig. 2(b) shows raw LP signal from which one can obtain the temperature of fast ions (T_{sp}) [3], depicted in Fig. 2(c), where a clear increase in temperature is seen during the NBI phase. T_{sp} follows the same behaviour as the counts and energies of measured fast ions (see Fig. 2 (d)). Moreover both quantities are higher in presence of ELM-like events, compared with the rest of the NBI phase, what was expected due to have more ions losses during the ELM-like.

It should be noted here that the upgrades made on the LP allows events (collection of fast ions) to be seen in the order of ns.

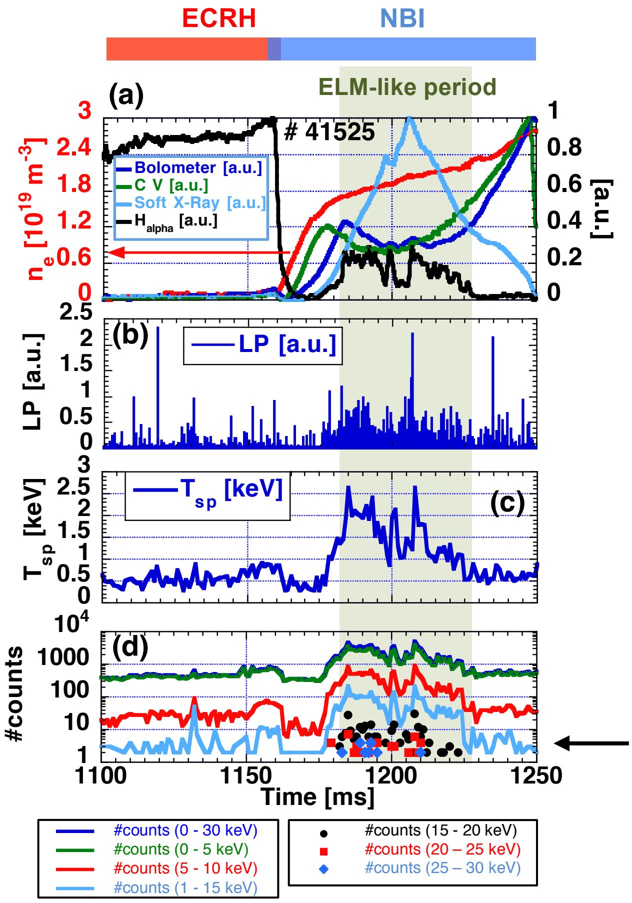


Fig 2. (Color online) **(a)** Some diagnostics traces for discharge #41525. **(b)** LP signal. **(c)** Temperature of fast ions (T_{sp}) calculated in time windows of 1 ms. **(d)** Fast-ion counts in different energy ranges. ELM-like period is highlighted.

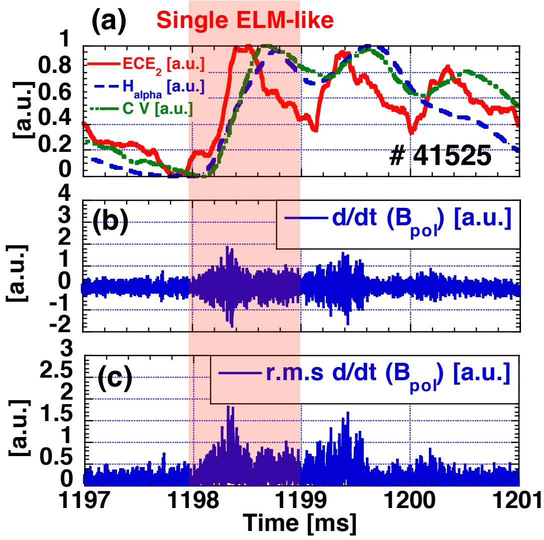
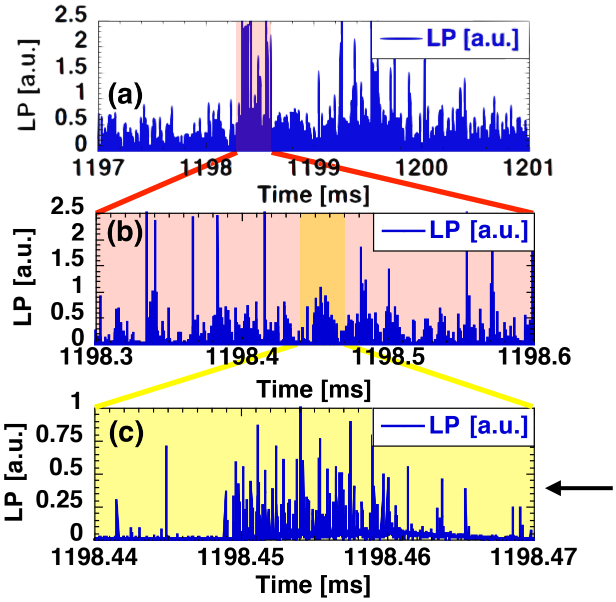


Fig 3. (Color online) **(a)** Diagnostics traces where a single ELM-like event is observed for discharge #41525. **(b)** Temporal evolution of the magnetic field measured by a Mirnov coil. **(c)** r.m.s. value of the Mirnov coil response.

In discharge #41525, where heating is with constant NBI power and n_e rises above a threshold level, a burst from the plasma propagates outwards, and is detected by various edge diagnostics, *e.g.*, by an H_α detector (where peaks mark the edge bursts), C V line emission (227.1 nm), and a peripheral electron cyclotron emission (ECE) channel [15, 19], see Fig. 3(a), where the time delay in the heat pulse detection is observed. The appearance of magnetic oscillations in the Mirnov coils and r.m.s. values marks the beginning of the perturbation, Figs. 3(b) and 3(c).

Fig. 4(a) shows the LP signal for the time window where the ELM-like event of interest appears. When a zoom is done in time scale (Fig. 4(b)), it is seen that ELM-like events are seen in the LP as short bursts of fast ions. Fig. 4(c) shows a single burst of ions, which has sufficient time resolution and number of pulses to calculate the energy distribution function *f(w)*, see Fig. 5, and whose associated temperature is 2.4 keV ± 10%. These bursts have characteristic times between 5 and 15 μs, while their frequencies (within the ELM-like phase) are from 30 kHz to 80 kHz.



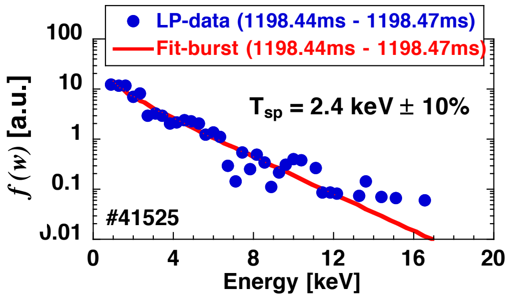


Fig 5. (Color online) Energy distribution function *f (w)* for a single burst.

Fig 4. (Color online) **(a)** LP signal where an ELM-like events are observed in discharge # 41525. **(b)** Zoom-in of LP signal. **(c)** Single burst within the ELM-like events.

CONCLUSION. It has been demonstrated that YAP:Ce is better phosphor than TG-Green for the study of fast protons escaping from TJ-II plasmas in the energy range below 40 keV. The combination of a faster decay time (27 ns), in conjunction with a faster acquisition system located close to the detector, has enabled the operation of the LP closer to the plasma edge and visualization of the individual fast events without pile-up effects. One example of this is the fast ion bursts during ELM-like events within which it was possible to measure individual events with high time resolution, this being physically relevant even if edge plasma bursts in TJ-II are less harsh than in large tokamak ELMs. This upgrade will allow us to study faster ion loss mechanisms associated with the loss fast ions and plasma phenomena that occur at rates up to hundreds of MHz which could not be addressed with the previous system.

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