Lost Fast Ion Behavior in the Large Helical Device

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Abstract. For fast ion studies in confined plasmas, the scintillator probe has been designed and was installed into the Large Helical Device (LHD). A periscope with eyepiece, relay, and objective lenses is coupled with optical fiber bundle to transmit the scintillator light to an image intensified charge coupled device camera and 3x3 photomultiplier arrays. Using the scintillator probe, we show the experimental results of the fast ion loss profile at the edge plasma of LHD and the fluctuation signals of fast ion loss in the plasma detachment experiment. In these experiments, the scintillator rises in temperature of around 190 ºC.

1. Introduction

The fast ion behavior is studied by using the scintillator probe in the Large Helical Device(LHD) with $l = 2$ / $m = 10$ heliotron configuration, where l and m are the poloidal and the toroidal mode numbers of the helical plasma, respectively, because fast ion driven instabilities have possibilities of the substantial ion losses. In particular, the understanding of fast ion and alpha particle behaviors created in burning plasmas is the common interest for stellarator and tokamak devices in view of the performance of thermo nuclear reactor.

The scintillator probe can measure the pitch angle and energy of fast ions escaped from confined plasmas simultaneously. Zweben et al. studied MeV ions produced from DD reaction using poloidal array probes in Tokamak Fusion Test Reactor(TFTR) [1]. The same principle of the detector is used in other devices [2-4]. We have developed the same principle of the scintillator probe and have installed it into LHD. The moveable scintillator probe can access to the outer edge plasma region from outer port of the oblong cross section of plasma. The detail of the scintillator probe system is written in Ref. [5]. We show the typical results obtained using the scintillator probe.

2. Dependence of pitch angle and gyro radius of lost ions

Figure 1 shows the dependence of pitch angle on the magnetic axis, R_{ax} = 3.5, 3.6, and 3.75 m with the toroidal magnetic field from 1.0 to 2.8 Tesla. Two spots are observed usually on the scintillator plate around the pitch angle of 90 degrees, when the neutral beams (NB) are injected.

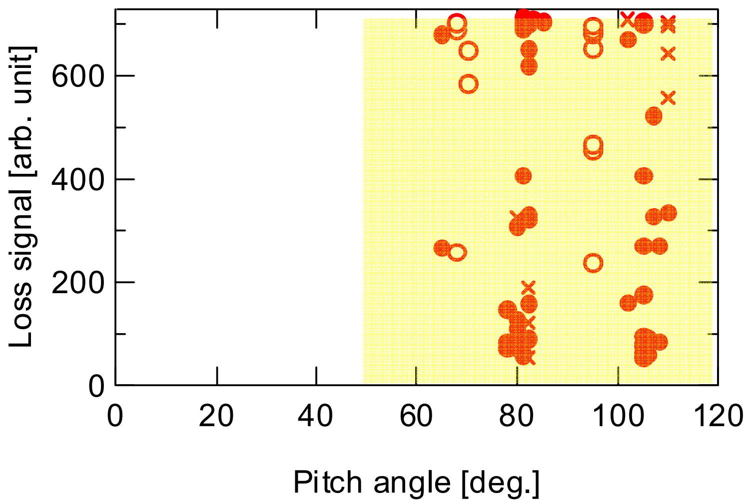

Figure 1. Pitch angles with Rax = 3.5 m (open circles), 3.6 m (closed circles), and 3.75 m (x) are plotted. The observable region is hatched from 50 to 120 degrees.

The gyro radius estimated from the peaks of striking points on the scintillator plate is plotted as a function of the magnetic field at the probe head position, B_{probe} in the figure 2. In this case, the toroidal magnetic field changes from 1.0 to 2.8 Tesla. Two curves are drawn in this figure for the comparison. They correspond to the energies of 160 keV for the NBs and 1.6 keV for the thermal ions. The observed signals do not exceed the gyro radius estimated from the energies of NB, and eliminate the thermal ion components. Thus the signals of fast ion loss are detected. The acceptable difference between measured and NB energies would come from the slowing down of fast ions, the resolution of the probe, and the error of the probe position.

The loss signal of fast ions with the pitch angle of approximately 80 degrees and the energy of 160 keV is shown in Figure 3. Before the injection timing of NB#3, fast ion loss is bellow the noise level. As NB#3 is injected, the fast ion loss increases. When the fast ion loss during only NB#2 injection is subtracted from that during NB#2 and #3 injections, we can estimate the amount of fast ion loss induced by NB#2. The amount of fast ion loss induced from NB#2 and #3 are almost same after NB#3 injection. However the change of fast ion loss before/after t = 1.9 s is not understood.

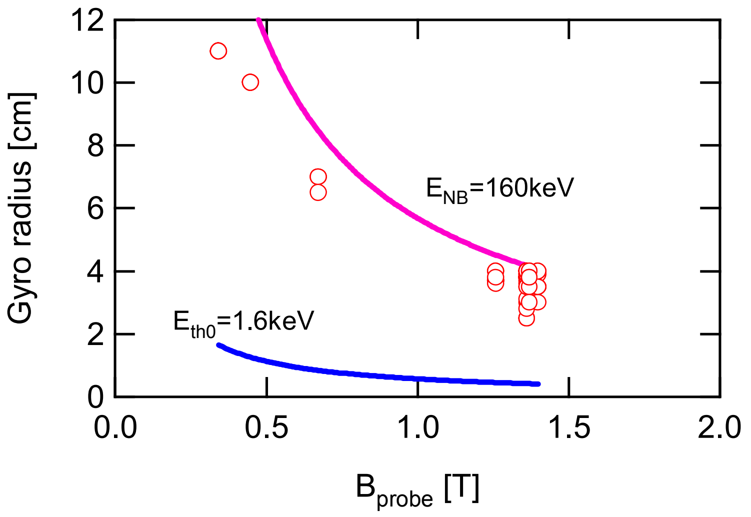

Figure 2. Gyro radii are plotted with the magnetic field at the probe position. Two curves are calculated from the N-NB energy and thermal ion temperature.

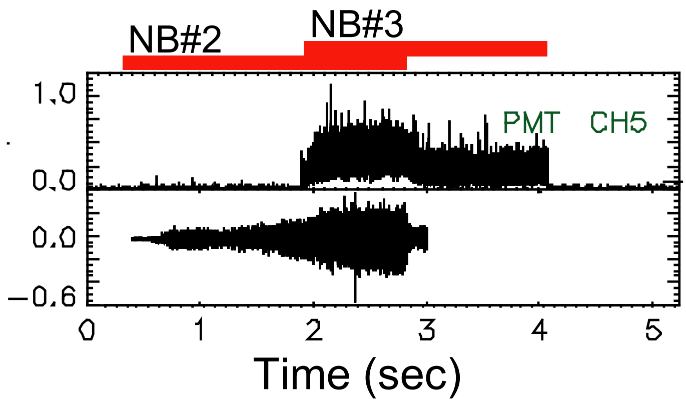

Figure 3. Fast ion loss signal and magnetic probe signal during the co-direction (NB#2) and counter direction(NB#3) NB injections.

3. Fast ion behavior at the plasma edge

To obtain the spatial distribution of lost fast ions, the scintillator probe is scanned at the edge of the LHD plasmas, where the major radius, R, is from 5040 to 5240 mm, shown in figure 4. The relative intensities of fast ion loss signals measured by the photomultiplier agree well with those measured by the image intensified CCD camera from the figure 4. At the probe position of 5100 mm, the decrease of the intensities of fast ion loss is observed. These data are useful for the estimation of deposition profile of NBs with the computer simulations.

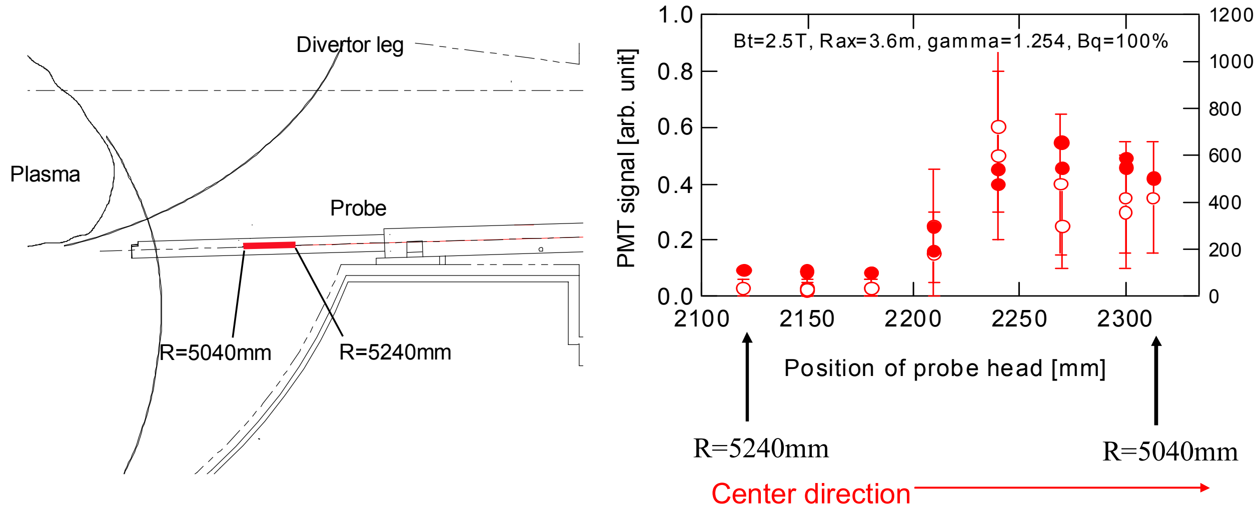

Figure 4 Spatial profile measurements of lost fast ions in edge plasmas. The open circles and closed circles indicate the photomultiplier signals, and the image intensified CCD signals, respectively.

4. Fluctuation signals before and after the plasma detachment phase

After the strong gas puffing, the self-sustained detachment plasma is observed in LHD [6]. As shown in figure 5, before the detachment, the significant loss of fast ions with the pitch angle of approximately 90 degrees is detected from t = 0.8 to 1.2 s by the scintillator probe. But after the detachment, the loss of fast ions disappears to the noise level. During the time window of pre-detachment, the fluctuation frequency of approximately 5 kHz is appeared in the signals of both the magnetic probe and the scintillator probe, but the fluctuation signal becomes quiescent in the detachment phase. From the mode analysis of the magnetic probe, this fluctuation signal is considered to come from the edge plasma region. In addition, the hot plasma boundary shrinks to approximately 90% of the pre-detachment plasma boundary [6]. From these results, two explanations are considered for the decrease of fast ion loss. With the plasma shrinking, the NB penetration at the edge region becomes larger, and it leads to the decrease of the total number of ionized ions. As another possibility, with the plasma shrinking, the exhaust of fast ions by the edge plasma fluctuation disappears. Further investigations are required to explain the fast ion behavior at the edge region in detachment plasmas.

5. Scintillator characteristics

The emission intensities of the scintillator (ZnS:Ag) depend on the temperature. The enough emission light is obtained without any degradation at the substrate temperature of up to 190 ºC in the plasma experiments. Throughout the 6 month plasma experiments of LHD, the scintillator surface is not damaged apparently. However the qualitative study for the emission efficiency should be carried out in higher temperature region to estimate fast ion losses.

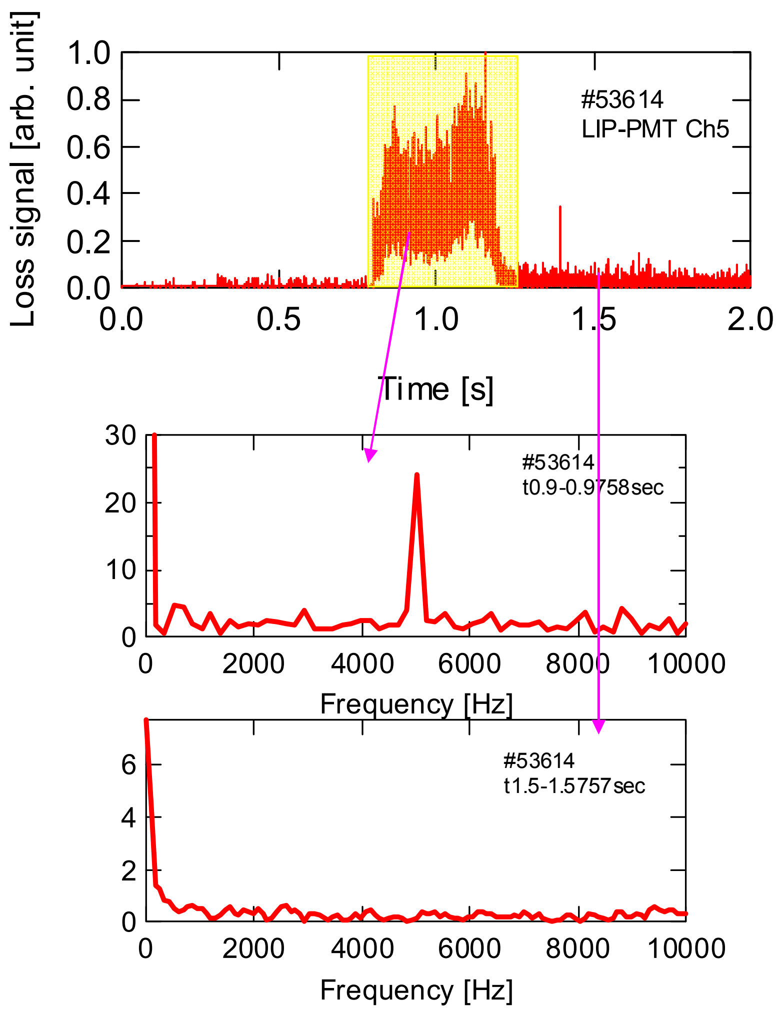

Figure 5 Fluctuation signals of fast ion losses in the detachment discharge. The detachment phase starts from t=1.2 to 3.2 s (this figure shows until t=2.0 s).

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