CONFINEMENT OF FAST IONS PRODUCED BY NBI ON LHD

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1.Introduction

The Neutral Beam (NB) heating campaign has been started on LHD since 1998.[1,2] The confinement of fast ions is one of the most important issues on helical devices since the large helical ripple plays an important role on the topology of the fast ion orbit. Concerning on the fast ion studies on LHD, (a) the confinement of NB-particles during their slowing-down processes, (b) interactions between fast ions and instabilities and/or ICRF-induced-waves, and (c) the confinement property of fast ions in the presence of electric fields are the important topics to be studied.

During the 3rd-cycle of LHD, NB short-pulse injection experiments, so called NB-blip experiments, were performed for ICH sustained plasmas to examine the confinement of NB-particles on LHD. In this experiment, a strong enhancement of pitch angle scattering was observed for ctr.-NB blip injection at a fast neutral analyzer whose line of sight is perpendicular to the magnetic field of lines, while no significant responses are observed for co.-NB blip injection. In this paper, we will show the result of the NB-blip experiments done in 3rd- and 4th- cycle of LHD, and show the analysis of this phenomenon.

2. Experimental Set-Up

On LHD, two of negative-ion based Neutral Beams (NB's) are injected tangentially. One is injected to co.-direction and another is to ctr.-direction.[3] Each beam line has two ion sources. These two ion sources are placed horizontally and have different tangency radii(R_t) of NB-injection. One of the advantage of the negative-ion based NB is that it consists of single energy component. Thus, the analysis on the NB particle confinement and on the heating characteristics become simple compared to positive-ion based NB's.

Two of electrically cooled Silicon diodes were adopted as Fast Neutral Analyzers (Si-FNA).[4] One is installed on the tangential-port for co.-NB detection. Another is installed on the lower-port of LHD, whose line of sight is perpendicular to magnetic field lines. The advantage of Si-FNA is simple, compact and economical compared to the conventional neutral particle analyzer. Thus, it makes easier to have measurements from various locations.

During the experiment shown in this paper, the magnetic axis of LHD was set to 3.6m, which is the standard configuration of LHD. The magnetic field strength was 2.75T at the axis. Two of ICRF-antennas were used to sustain the plasmas and launched the ICRF-wave of 38.46MHz in the experiment shown here.

3. Experimental results and discussions

Figure 1 shows the result of NB-blip experiment done in 3rd-cycle. The short-pulse (20msec) NB is injected to ICH (P_{ICH}=~1MW) sustained plasmas with a cycle of 300msec. The electron density ($\bar{n}_e$) was about 1.0×10^{19} [m^{-3}] and stayed almost constant during the NB-injection. As is seen on Fig.1, big spikes were observed for perpendicular Si-FNA signals for ctr.-NB injection, while no significant response was observed to the co.-NB injection. Due to the ion source trouble of ctr.-NB injector, the NB-power of ctr.-NB was about the third of the co.-NB power. In the 4th-cycel of LHD, similar experiments were performed for NB-sustained plasmas and low power ICRF-sustained plasmas (P_{ICH}=~0.4MW). During these experiments, no significant responses of perpendicular Si-FNA were observed in conjunction with NB-injection. These results indicate the phenomenon shown at the NB-blip experiment during the 3rd-cycle is the enhancement of pitch angle scattering which

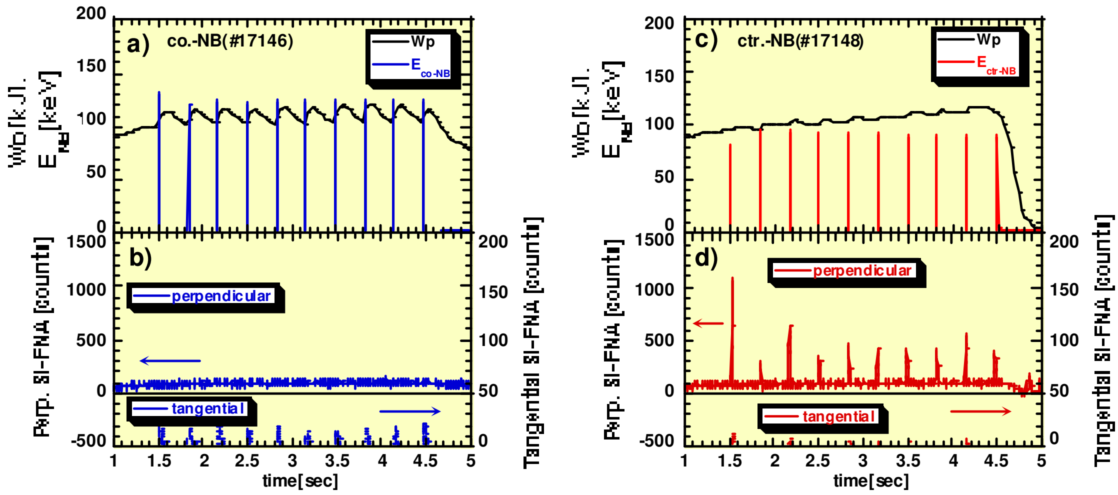

Fig.1 a) Stored Energy and NB injection energy, and b)signals of perpendicular and tangential Si-FNA at co.-NB blip experiments. c) and d) shows these at ctr.-NB blip experiments, respectively.

correlates to ICH induced wave and has a dependence on the ICH-power. Figure 2 shows the change of Si-FNA spectra during the NB-blip experiments at 3rd-cycle. The red curves in the contour plot show the slowing-down curve of the NB particles at various plasma locations. Temporal behavior of the tangential Si-FNA spectra at co.-blip injection is well described by the classical slowing-down theory. The temporal behaviors of Si-FNA spectra at ctr.-blip injection show that the enhancement of the pitch angle scattering occured at the edge of plasmas where ρ≥0.7. The enhancement was significant at the energy around 50-keV.

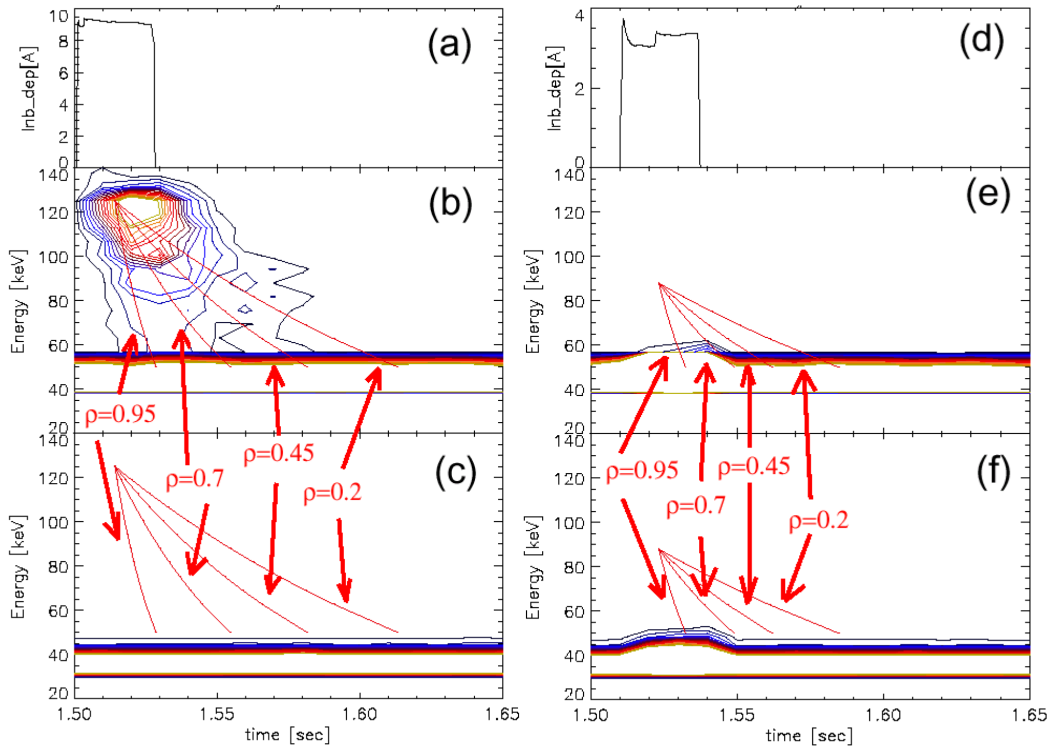

Fig. 2 a) NB deposition current to plasmas, b) contour plot for tangential Si-FNA spectra and c) contour plot for perpendicular Si-FNA for co.-NB blip injection. (d),(e) and (f) are these for ctr.-NB blip injection. Red curves in contour plots show the slowing-down curves of NB-particles at various location of plasmas.

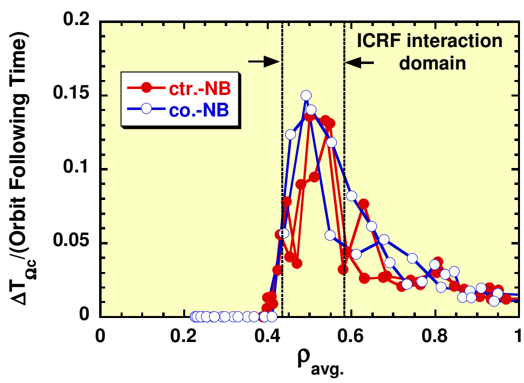

Fig.3 Normalized time of particles staying in the ICH resonance region. The time is normalized by the orbit following time of the calculation.

The orbit topology difference of co.- and ctr.-passing particles is one of the candidates as the explanations for this phenomenon. To examine these effects on the ICH induced pitch-angle scattering enhancement, the first orbit calculations were performed by taking launching-points of orbit calculations on the center lines of ion sources of NB-injectors. Figure 3 shows the length of time that the particles are staying in the ICRF resonance region. The x-axis of the figure denotes the averaged ρ along the particle orbit. The Doppler effect is taken into an account as the width of the resonance layer and the $k_{//}$ is assumed to be 0.5[m^{-1}]. For both co.- and ctr.-passing particles, the ions traveling around the edge of the plasmas are passing

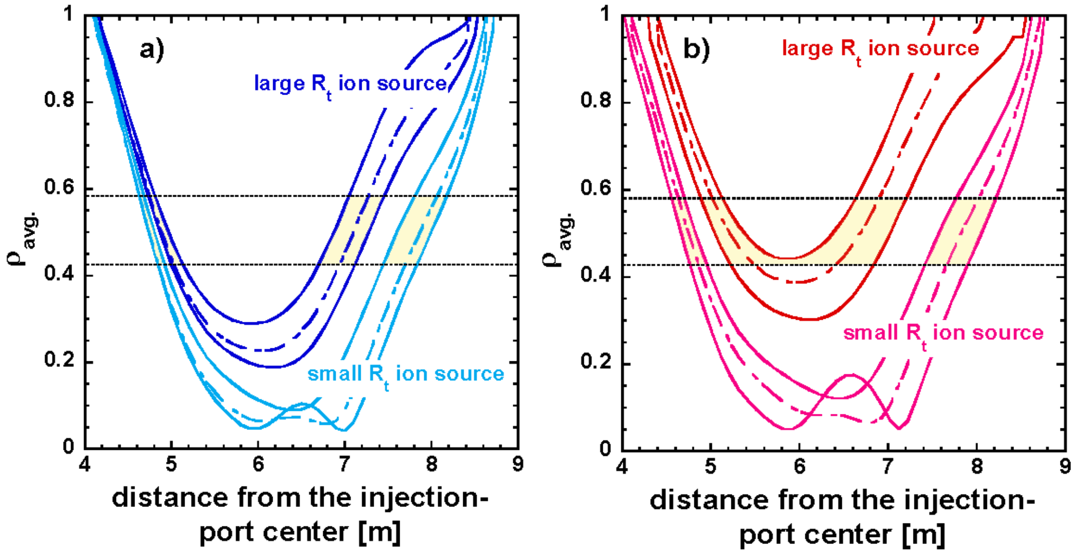

Fig.4 The $\rho_{avg.}$-distribution along NB flight paths for (a)co.-NB and (b) ctr.-NB injectors. The yellow regions show the ICRF interacting domains where the particle launched from the sight line of ion sources enters ICRF-resonance region, frequently.

through the ICRF resonance region ($\rho_{avg.} \geq 0.4$). Especially, particles traveling between $\rho_{avg.}$ =0.43 and 0.58 stay longer in the resonance region than other particles. In figure 4, the $\rho_{avg.}$-distribution along NB flight paths for co.- and ctr.-NB injectors are shown, the beam width is taken into an account in the figure. Due to the difference of the orbit topology between the co.- and ctr.- passing particles, the ctr.-NB injector has larger area of ICRF interacting domain. This is consistent with the results observed at NB-blip experiment. Farther analysis and experiments are necessary to get an agreement between experiments and analysis about the location of ICRF interacting domain.

References

[1] O.Motojima *et al.*, Phy **6**,143 (1999).

[2] M. Fujiwara *et al.,* Plasma Phys. Controlled Fusion **41**, B157(1999).

[3] O.Kaneko *et al*, Proceedings of 16th IAEA Fusion Energy Conference, Motreal, Canada, 7-11 October 1996, Vol.3, p.539.

[4] M.Osakabe *et al*, Rev. Sci. Instrum. **72**, 788(2001)