IMPACT OF NEUTRAL PARTICLES ON BEAM-ION LOSSES IN EAST TOKAMAK

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The interaction between beam ions and neutrals can lead to enhanced beam-particle losses, which may cause severe damage to the first wall [1]. To better understand the effect, the impact of neutrals on beam-ion losses has been investigated using the Scintillator-based Fast Ion Loss Detector (FILD) in the EAST neutral beam injection experiment (NBI) and further analysed through simulations with FILDSIM [2] and ASCOT [3]. The results not only reveal the contribution of edge neutrals to the initial deposition of the neutral beam but also confirm the strong correlation between beam-ion loss behaviour and locally high neutral particle density.

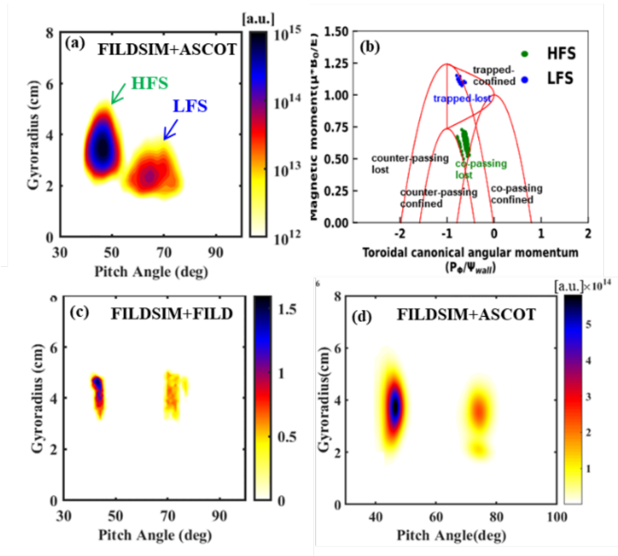

FIG.1 Beam-ion losses (NBI2R) velocity-space distribution of #115236 simulated by ASCOT and FILDSIM (a) without initial beam deposition in SOL, and (d) with initial beam deposition in SOL. (b) Orbit classification of beam-ion loss of discharge #115236 during NBI2R injected with different initial position. (c) Beam-ion loss velocity-space distribution of #115236 with NBI2R measured by FILD.

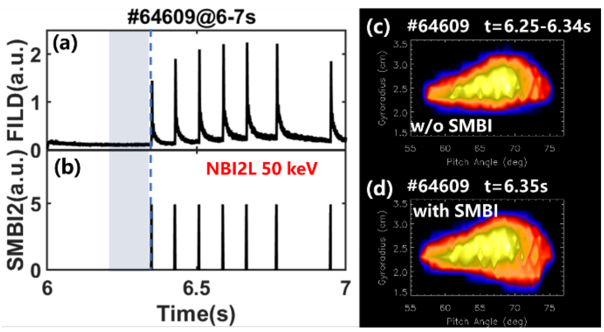

FIG.2 Time evolution for discharges #64609 at 6-7s of (a)beam-ion losses signal and (b) SMBI2. Beam-ion loss velocity-space distribution of #64609 (c) at 6.25s-6.34s (without SMBI) and (d) 6.35s (with SMBI).

NBI generates beam ions through ionization interactions with background charged particles, a process referred to as the neutral beam initial deposition. Some of the beam ions resulting from this initial deposition are lost to the first wall. To investigate the generation of beam ions and their loss to the FILD probe, simulations using ASCOT-BBNBI and FILDSIM were performed [4]. The simulation results indicate that at the FILD probe location, the velocity space distribution of lost beam ions (NBI2R) exhibits two distinct pitch angle regions. Specifically, beam ions with a pitch angle of ~ 45° and a gyroradius of ~3.5 cm are primarily lost from the high-field side, while those with a pitch angle of ~ 68° and a gyroradius of ~2.8 cm originate from the low-field side, as shown in Fig. 1(a). Orbital classification analysis presented in FIG. 1(b) reveals that the lost beam ions on the high-field side are mainly passing particles, which are lost more rapidly. In contrast, the lost beam ions on the low-field side are predominantly trapped particles, which undergo multiple trapped orbit periods and are decelerated in the process, resulting in a lower loss energy (gyroradius) compared to the high-field side ions. However, FILD probe measurements show that the energy distribution of lost beam ions in these two pitch angle regions is essentially the same, as illustrated in FIG. 1(c). This observation deviates from the expected results from the simulations, suggesting the presence of an additional neutral beam initial deposition process on the low-field side, which leads to higher energy beam ions being lost to the FILD probe than anticipated. The effect of beam ion deposition due to neutral particle interactions in the scrape-off layer (SOL) was incorporated into the simulations, yielding a new velocity space distribution of the lost beam ions, as shown in FIG. 1(d). The results demonstrate that the velocity space distribution of lost beam ions on the low-field side becomes more consistent (pitch angle ~73°, gyroradius ~3.5 cm), indicating that due to the neutral particle effect, beam ions deposited in the SOL can directly reach the FILD probe, resulting in higher energy loss of low-field side beam ions than predicted without considering the neutral particle influence. These findings highlight the contribution of neutral particles to the initial deposition of neutral beams on the low-field side and underscore their role in the beam ion loss process.

Additionally, beam ions can undergo a charge exchange (CX) reaction with background neutrals, thereby generating fast neutrals ($D_f^+ + M \rightarrow D_f^0 + M^+$,where D_f^+ represents fast positive ions, M denotes background neutrals, and D_f^0 refers to fast neutrals) [1]. On the one hand, The fast neutrals may undergo second-step CX reactions with background charged particles to become fast positive ions ($D_f^0 + D_s^+ \rightarrow D_f^+ + D_s^0$, where D_s^+ represents background charged particles)。To further investigate the impact of neutrals on beam-ion losses, supersonic molecular beam injection (SMBI) was implemented to locally enhance the neutral particle density in NBI experiment. SMBI led to an enhancement of the beam-ion loss signal detected by FILD, as illustrated in Figs. 2(a) and (b). Figs. 2(c) and (d) present the velocity-space distribution of beam-ion losses with and without SMBI, respectively. The results show that SMBI causes the loss of slowing-down beam ions (pitch ~70°, gyroradius ~2 cm) to the FILD probe. The local density enhancement of neutral and charged particles caused by SMBI leads to an increase in the multi-step CX process of beam ions. As a result, the enhanced beam ion loss is observed by FILD under conditions of locally high neutral particle density. Further simulation studies are necessary to elucidate the underlying mechanisms. On the other hand, the fast neutrals may also undergo second-step CX reactions with background neutral particles to generate fast negative ions ($D_f^0 + M \rightarrow D_f^- + M^+$,where D_f^- represents fast negative ions). It is the first time that fast negative-ion loss signals are observed by FILD equipped with top and bottom collimators in NBI experiment [5]. FIG. 3(a) shows the lost fast negative ions are expected to strike the scintillator in the FILD probe head through the top collimator, while fast positive ions are expected to strike through the bottom collimator in the rev-B_t (with Ip and Bt directed counterclockwise from the top view) operating regime. Velocity-space distributions of lost fast negative and positive ions reconstructed by the FILDSIM are basically consistent (pitch angle~68°，gyroradius ~ 3 cm). Orbit analysis backtracked in time by the ASCOT shows that the fast negative ions are generated at the low-field side (LFS) scrape-off layer, as illustrated in FIG. 3(b). The results suggest that the generation of fast negative ions is closely linked to the locally high neutral particle density near the limiter (FIG. 3(c)). Overall, these experimental findings deepen our understanding of the impact of neutral particles on beam-particle losses, and offer valuable insights for optimizing fuelling location in fusion devices.

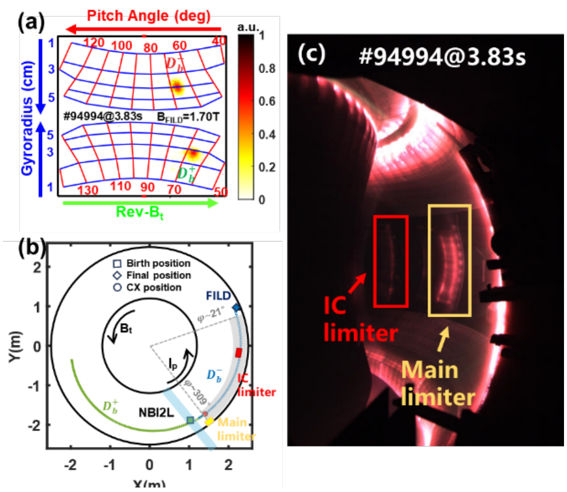

FIG.3 (a) Strike map of beam-ion losses measured by FILD probe head with #94994@3.83s. (b) the trajectory where a fast positive ion in the SOL converts into a fast negative ion observed by FILD. The green and blue lines indicate the trajectories of the fast positive and negative ions, respectively. The red circle indicates the position where fast positive ions become fast negative ions. (c) Visible light CCD camera image from D port during discharge #94994 at 3.83 s.

This is supported by the project National Key Research and Development Program of China No. 2019YFE03020004.

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