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Measurements of beam ion losses on DIII-D due to MHD instabilities

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A new scintillator-based fast ion loss detector (FILD) has been installed on DIII-D with the time response (>100 kHz) needed to study energetic ion losses induced by Alfvén eigenmodes (AEs) and other MHD instabilities. Based on the design used on ASDEX Upgrade, the diagnostic measures the pitch angle and gyroradius of ion losses based on the position of the ions striking the 2D scintillator. For fast time response measurements, a beam splitter and fiberoptics couple a portion of the scintillator light to a photomultiplier. Initial results showing first orbit losses and energetic ion loss due to MHD instabilities are discussed.

I. Introduction

Fast ions from neutral beam injection, ion cyclotron heating, and fusion reactions play a fundamental role in the heating and stability of tokamak plasmas. Sawteeth and tearing modes affect fast ion confinement, while large fast ion densities can drive collective instabilities, including AEs. The effects of MHD activity on fast ions can significantly impact the plasma performance. Losses of energetic alpha particles from DT fusion in ITER will reduce the alpha heating available to reach ignition, and have the potential to cause major damage to the first wall. Given their importance for burning plasma experiments in ITER, fast ion studies have become a high priority area for experimental research on DIII-D.

The internal mode structures of the fast ion induced instabilities inside the DIII-D plasma have been measured using beam emission spectroscopy (BES), far infrared (FIR) scattering, reflectometry, CO_2 interferometry, electron cyclotron emission (ECE), and magnetic fluctuation measurements [1]. Measured profiles of the confined beam ions in DIII-D using the recently developed fast ion D_a spectroscopy (FIDA) [2] show that instabilities redistribute fast ions radially outward. Faraday collector-based beam ion loss detectors (BILD) have been used to obtain information on fast ion losses near the outer midplane of DIII-D [3].

We have recently installed a new FILD on DIII-D. By correlating the beam ion loss results from the new FILD with the other fast ion diagnostics and with observations of the internal mode structures in DIII-D, we hope to gain important information on the fast ion loss orbits and loss mechanisms involved in the instabilities. Using the measured pitch angle and energy of the fast ion losses, reverse orbit following techniques can be used to trace the lost ions to their possible origin within the plasma [4]. The initial studies have concentrated on first orbit losses, and serve as a test of the FILD performance and the reverse orbit calculations.

II. New Fast Ion Loss Detector

The FILD detector is installed through a radial port located below the outer midplane of DIII-D, at the location of the red "X" marking the end of the orbit shown in Fig. 3. This detector can be inserted past the first wall tiles and into the region outside the last closed plasma flux surface, which allows the detection of escaping fast ions over a large portion of phase space. Figure 1 shows a schematic drawing of the FILD [5]. Fast ions that pass through a small entrance aperture strike a scintillator-coated plate. Measuring the two-dimensional light pattern from the scintillator yields information on both the perpendicular gyroradius and the pitch angle of the escaping fast ions, an approach first used to detect escaping fusion products [6], and more recently used to study fast ion losses on ASDEX Upgrade (AUG) [7]. A graphite heat shield (diameter ~ 8.9 cm) protects the detector head from the plasma and beam ion heat loads. The spatial distribution of the scintillation light is imaged using a CCD camera with a maximum framing rate ~160 Hz. The TG-Green scintillator, first used on the AUG fast ion loss detector [6], has a 490 ns decay time. For fast time response measurements, a beam splitter cube and a second lens are used to couple ~50% of the scintillation light to a photomultiplier tube via

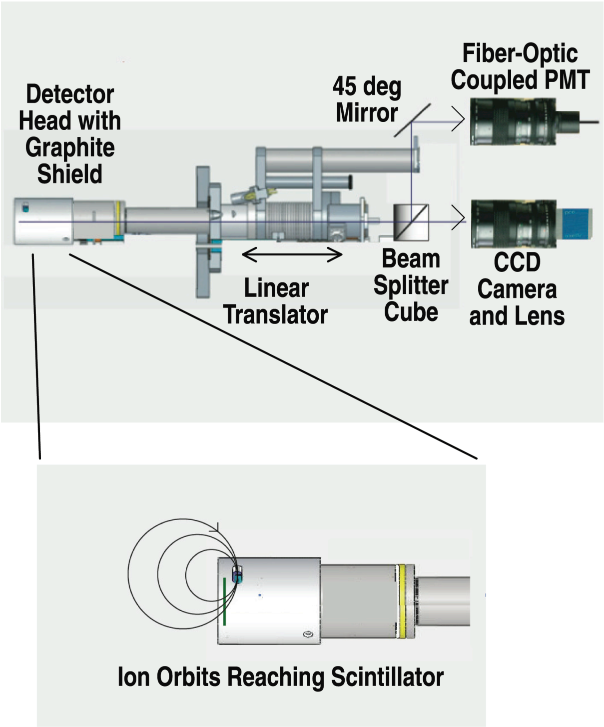

Fig. 1. Light from the FILD scintillator is imaged onto camera and fiber-coupled PMT using beam splitter, mirror and two zoom lenses mounted just behind vacuum window.

a single fused silica fiber. The PMT signal is then digitized at 1 MHz, allowing measurements of the beam ion losses with the time response (>100 kHz) needed to study AEs and other high frequency MHD instabilities.

III. Experimental Results

The FILD diagnostic has been installed and operating for approximately five months of DIII-D operation. First orbit losses have been used to test the FILD capabilities and performance. Pulsing the neutral beam sources while slowly ramping up the plasma current allows observation of the first orbit losses from each of the beam lines. Figure 2 shows that large first orbit losses are observed from the two ion sources (210 L and 210R) that inject through a port near to the 225 deg. toroidal location of the FILD. A camera image of the 2D scintillation light pattern on the scinitllator is shown in the lower portion of Fig. 2. The red grid lines show the calculated pitch angle and gyroradius based on the detector geometry, aperture location, and magnetic equilibrium. First orbit losses from 210L neutral beam appear at a pitch angles ~70 deg., in agreement with the reverse orbit calculations for this detector location [4]. For the 210R injection at 440 ms, we observe losses at a pitch angle of ~55 deg., again in agreement with our reverse orbit calculations. The FILD PMT signal measures the time dependence of the fast ion loss signal on a microsecond time scale. Figure 3 shows the PMT signal and one of the signals from the FIDA diagnostic as a function of time near the start of one of the beam pulses from the 210R beamline on DIII-D. The FIDA signal is the D_α light resulting from confined beam ions interacting with the 210R beam injected neutrals. Hence the onset of the FIDA signal indicates the start of the 210R beam pulse. The

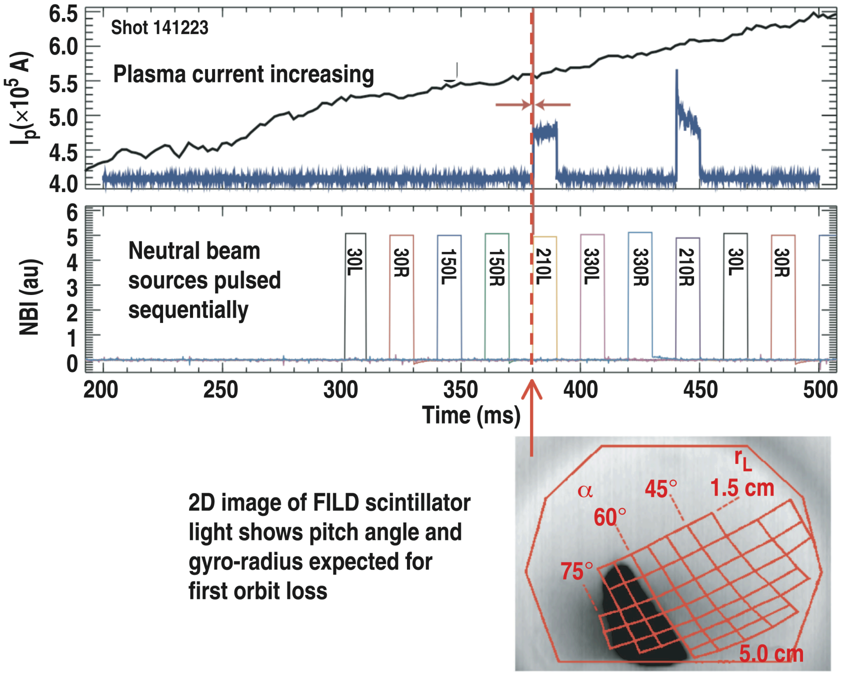

Fig. 2. First orbit losses were observed during pulsed operation of neutral beam sources while slowly increasing plasma current.

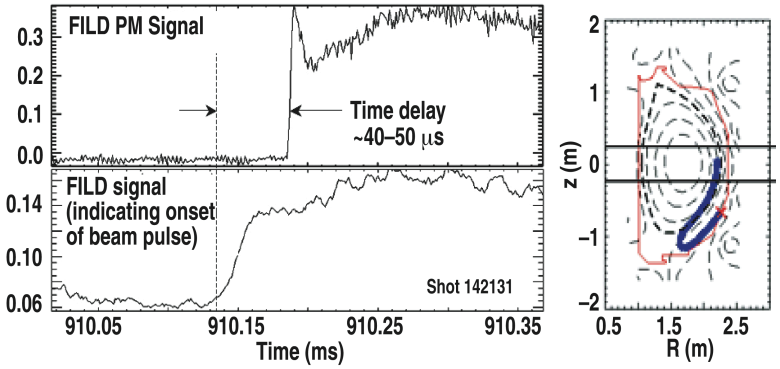

Fig. 3. The measured loss signal is delayed by ~ 40-50 μs, as expected based on the transit time for first orbit losses.

onset of the FILD PMT signal is delayed by 40-50 µs, which is consistent with the transit time for the beam ions over the prompt loss orbit, shown on the right side of Fig. 3, calculated by reverse orbit following techniques [4]. The red X marking the end of the orbit indicates the FILD location.

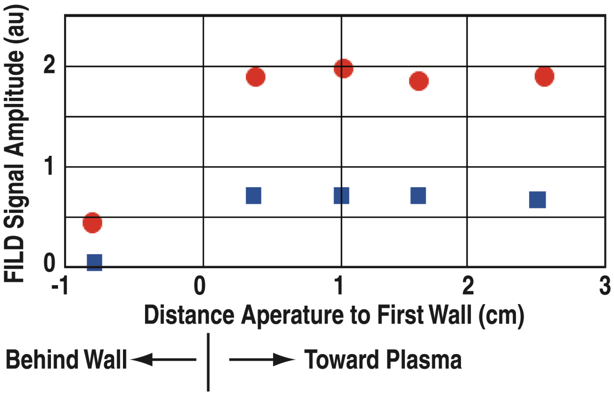

Fig. 4. Measured loss signals from the 210R (red circles) and 210L (blue squares) during AE activity were nearly constant once the ion entrance aperture was inserted past the front face of the plasma wall tiles.

The initial FILD results on DIII-D include the observation of beam ion losses due to a variety of MHD instabilities of interest to fast ion behavior in tokamaks, including neoclassical tearing modes, q=2 fishbones, and AE activity. Figure 4 shows that the measured beam ion loss signals during AE activity increased significantly once the FILD entrance aperture was inserted past the front face of the plasma tiles, but then remained nearly constant as the detector head was inserted further into the region outside the last closed plasma flux surface. The detector head always remained at least 10 cm outside of the last closed flux surface at this port location below the plasma midplane.

In summary, the first orbit loss results presented here give us confidence in the FILD detector performance and in the reverse orbit calculations and approach. The fast time response and high scintillation efficiency of the TG-Green scintillator allows measurements at the high frequencies of interest for many MHD instabilities, including AEs. The observed losses resulting from large sawtooth crashes, neoclassical tearing modes, q=2 fishbones, and AE activity are still being analyzed and will be discussed in subsequent papers, in our efforts to better understand how the instabilities interact with the fast ions.

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