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Ion Cyclotron Emission Driven by Helium Beam Injection as a Surrogate for Alpha Particle Diagnostics in LHD

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Helium neutral beam injection (He NBI) in the Large Helical Device (LHD) offers a unique platform to emulate the behavior of fusion-born alpha particles in burning plasmas.

Due to their similar charge-to-mass ratio and collisional dynamics, fast helium ions (He^{2+}) can reproduce the slowing-down behavior and pitch-angle anisotropy of alpha particles.

In this study, He NBI with injection energy of 45–65 keV was applied to LHD plasmas with typical parameters of B_T = 2.75 T @ 3.6 m and ne ≈ 2–4 × 10^{19} m^{-3}.

A distinct sub-Alfvénic harmonic Ion Cyclotron Emission (ICE) was observed during injection, mainly in the 200–400 MHz range, along with ~25 kHz modulations in electron cyclotron emission (ECE) and global density fluctuations measured by phase contrast imaging (PCI).

The ICE signal exhibited bursty harmonic structures, indicative of fast-ion-driven collective behavior. Simultaneously, Mirnov coil diagnostics revealed ~50 kHz magnetic fluctuations consistent with beta-induced Alfvén eigenmodes (BAEs).

PCI measurements confirmed correlated low-k density fluctuations, which were globally coherent, suggesting a collective plasma response to fast-ion-driven instabilities.

These results indicate that ICEs excited by He NBI are not merely signatures of fast-ion presence but also reflect their interaction with bulk plasma instabilities. Such interactions provide indirect information about the gradient of the fast-ion distribution function ($\partial f/\partial v$), a key driver for ICE generation.

As a passive emission, ICE is a promising diagnostic tool for monitoring fast-ion behavior in reactor environments like ITER and DEMO, where active diagnostics (e.g., FIDA, neutron-based systems) are often limited by radiation and access constraints.

Moreover, ICE may serve as a non-invasive, radiation-tolerant alternative or complement to conventional fast-ion diagnostics, especially in scenarios where tools such as FIDA or FILD become technically unfeasible.

While ICE does not directly measure fast-ion losses, it can provide insights into redistribution and instabilities that may lead to such losses.

These findings highlight the potential of He NBI–driven ICE as a practical diagnostic for characterizing fast-ion dynamics and their coupling to global instabilities in reactor-scale fusion devices.

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References

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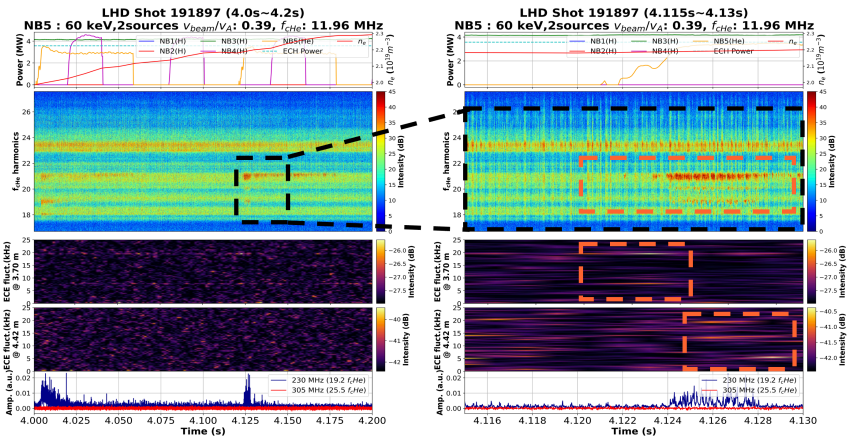

Figure 1: (Left) ICE spectrogram measured by an RF antenna over 200 ms during He NBI modulation in LHD shot #191897. (Right) Zoom-in of the interval with enhanced ICE amplitude, overlaid with ECE fluctuation and filterbank signals. A time delay is observed between ECE signals measured at different radial positions.