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Investigation of Scattering of Lower Hybrid Waves by Tokamak Boundary Plasmas on Alcator C-Mod and EAST

S. G. Baek[1], B. Biswas[1], G. M. Wallace[1], P. T. Bonoli[1], B. J. Ding[2], M. H. Li[2], Y. C. Li[2], Y. F. Wang[2], M. Wang[2], C. B. Wu[2], G. H. Yan[2], J. Chen[2], X. Zhai[2], W. Choi[3], F. Poli[3], S. Shiraiwa[3]

[1]MIT PSFC, [2]ASIPP, [3]PPPL

sgbaek@psfc.mit.edu

ABSTRACT

- This paper conducts a modeling investigation to identify an optimum rotation angle of the lower hybrid perpendicular wave-vector for best matching the experimental RF current profile in the lower hybrid current drive (LHCD) experiments on EAST and Alcator C-Mod.
- In the present study, a spectral-modification mechanism of wave scattering by density fluctuations is introduced by modifying the initial condition of the lower hybrid perpendicular wavevector.
- The results presented here suggest that edge density fluctuations in a tokamak may need to be considered in understanding wave propagation and absorption.

BACKGROUND

- In a reactor, a predictable long-distance coupling of LHCD needs to be ensured.
- It is critical to understand the impact of the edge and scrape-off-layer (SOL) plasma to LHCD in order to extrapolate the present-day LHCD results to a future tokamak.
- LHCD experiments on EAST, Alcator C-Mod, and Tore Supra [Ding, NF 58, 095003 (2018) and references therein] exhibit a self-similar on-axis wave power deposition profile. This is contrast to the model prediction, where a large off-axis current drive is often predicted in a multi-pass damping regime.
- This paper hypothesizes that central RF power deposition widely observed in the present-day LHCD experiments arises from wave scattering at the plasma edge.

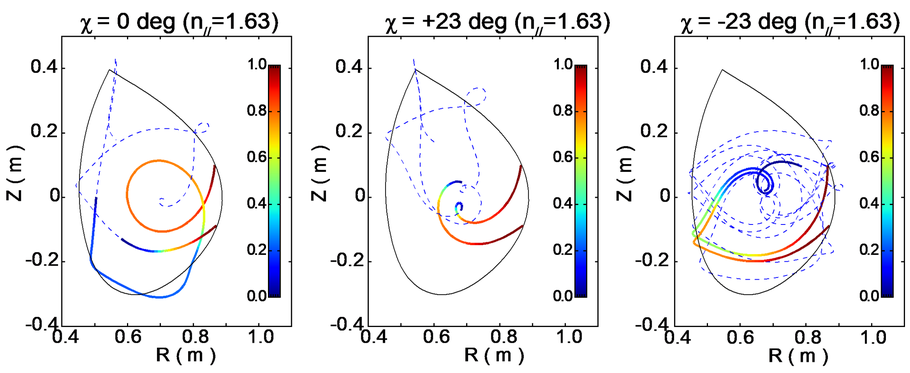
APPROACH / IMPLEMENTATION

APPROACH

- Past theoretical studies [Bonoli, Phys. Fluids 25, 359 (1982), Andrews, Phys. Fluids 26, 2546 (1983)] show that the vector orientation of the lower hybrid perpendicular wavevector $\vec{k}_\perp$ can be modified as a result of wave scattering. To simulate this effect in our study, the initial perpendicular wavevector is rotated by an angle χ with respect to the magnetic-surface normal unit vector.
- Angular modification can make an observable difference to wave propagation and absorption. Figure below shows that a change in the angular orientation of $\vec{k}_\perp$ can modify the initial poloidal component, enhancing first-pass absorption in the plasma core.

IMPLEMENTATION

The ray-tracing/Fokker-Planck solver GENRAY/CQL3D is utilized within the python-based framework π-scope. An angular scan is conducted at every 2° from -90° to 90°. For each discharge, the mean squared error of the model current profile to the experimental current profile is evaluated. An optimum angle is identified that minimizes the mean square error.



Poloidal projection of two rays launched at the outer midplane for (a) χ = 0 deg, (b) χ = 23 deg, and (c) χ = -23 deg.

OUTCOME

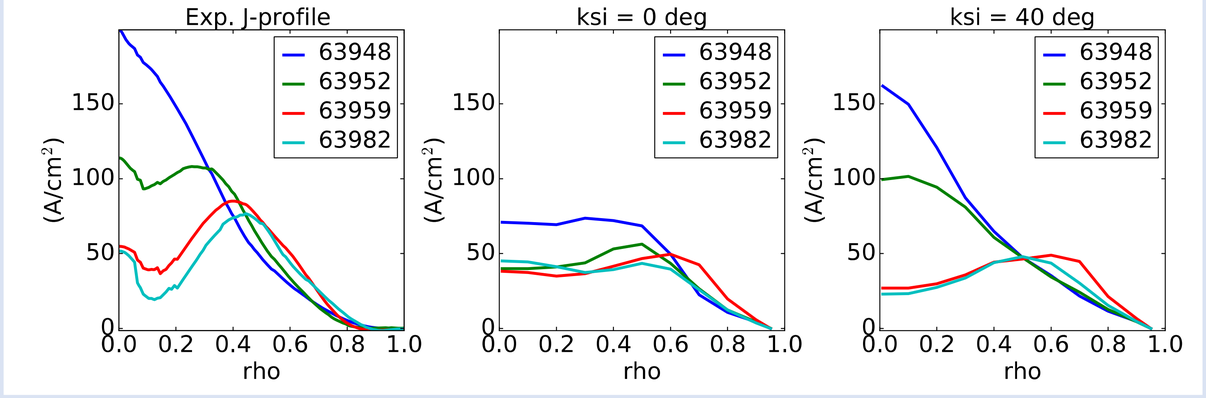
EAST

- Four EAST discharges are studied that are well-diagnosed non-inductive L-mode plasmas [Garofalo NF 57,076037 (2017)].
- Figure below shows that the model profile shapes are best matched when $\chi \approx 40°$.
- An inclusion of fast-electron radial transport is found to be crucial to improve profile matching.
- In the positively-sheared plasmas (#63948 and #63952), on-axis RF current is enhanced.
- In the reverse-sheared plasmas (#63959 and #63982), off-axis peaking becomes pronounced.

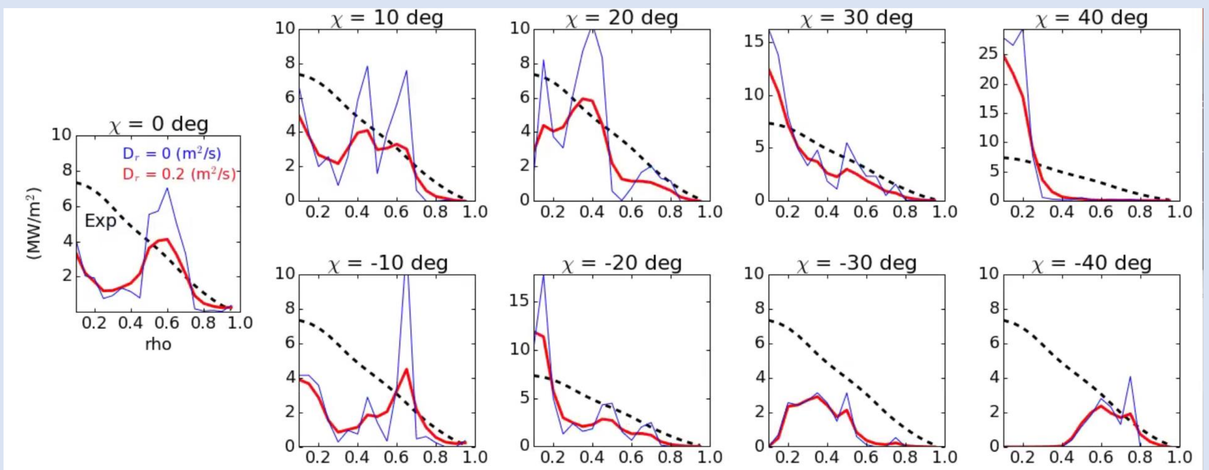
Alcator C-Mod

- The discharge #1101104014 is studied that is a non-inductive LHCD plasma [Mumgaard, MIT PhD Thesis (2015)].
- The mean square error is minimized in the range of $\chi \approx 30°$. On-axis peaking is achieved with a reduced off-axis power damping.

RF current profiles of four EAST discharges: (left) experimental profiles, (middle) reference model profiles, and (right) model RF profiles with $\chi \approx 40°$



RF current profile of the Alcator C-Mod discharge #1101104014 at different rotation angles



CONCLUSION

- Enhancing first-pass absorption in the plasma core is found to be effective to reproduce the RF experimental profile with a wavevector rotation in the range of χ = 20 ~ 40°.
- The angular orientation of $k_\perp$-vector is identified to be a key parameter that can determine RF current density profile.
- Understanding the spectral broadening in the $k_\perp$-space may be key to interpreting the present-day LHCD experiments.
- Future Work: Both theoretical and experimental work needs to be undertaken to answer if an effective scattering angle can be defined.

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