ELECTRON CYCLOTRON CURRENT DRIVE ON DIII–D: ANALYZING THE ANALYSIS

by
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in collaboration with
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Electron Cyclotron Current Drive on DIII-D: Analyzing the Analysis[1] DAVID SCHUSTER, Brown University, C.C. PETTY, T.C. LUCE, H.E. ST. JOHN, General Atomics, B.W. RICE, Lawrence Livermore National Laboratory — Electron Cyclotron Current Drive (ECCD) can be used to modify the current profile at different locations with in the plasma. Previously, the radial profile of ECCD was measured on the DIII–D tokamak using off-axis application and was found to be broader than theoretical predictions. In addition, the magnitude of the experimental ECCD exceeded theoretical estimates. In order to better explain these differences, simulations of the evolution of the poloidal magnetic flux during ECCD will be done using the ONETWO transport code. The simulated data can be propagated forward and backward through the same analysis techniques practiced on the actual experimental data. This process will help reveal any error introduced via approximations made in the analysis, such as the effect of smoothing the constituents of the Grad-Shaffranov equation. In addition, the experimental and simulated evolution of motional Stark effect (MSE) polarimetry data during off-axis ECCD will be compared.

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☐ Prefer Oral Session
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Special instructions: Undergraduate poster session, immediately following KS Leuenroth

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OUTLINE

I. Introduction and background

II. Simulations of magnetic equilibrium evolution during off-axis ECCD

III. Comparisons of simulated and measured MSE data during off-axis ECCD

IV. Broadening effects of magnetic equilibrium reconstruction

V. Conclusions

I. INTRODUCTION AND BACKGROUND

- Previous experiments on the DIII–D tokamak have demonstrated off-axis electron cyclotron current drive (ECCD) from the evolution of the poloidal magnetic flux (ψ) determined from EFITs using motional Stark effect (MSE) data

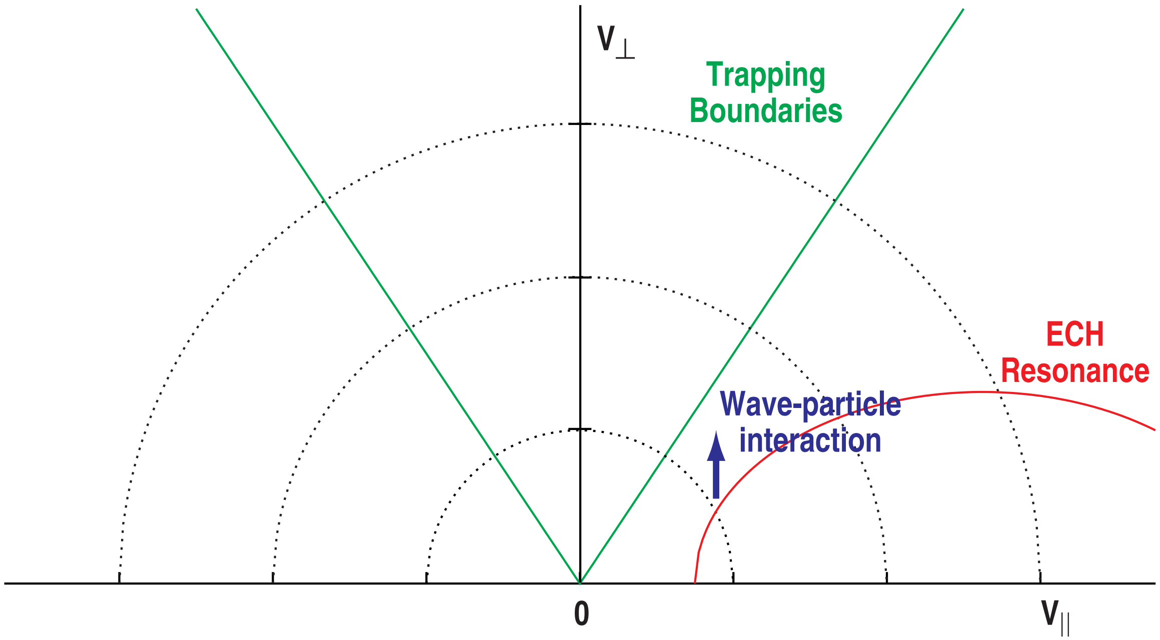
- Results:
  - Measured location of ECCD agreed with theory
  - Measured ECCD was usually larger than theory
  - Measured width of ECCD was broader than theory

- Since the EFIT analysis used only a fit to the MSE data, we decided to test whether the disagreements between ECCD theory and measurements are evident in the raw MSE data by means of simulations

SCHEMATIC PICTURE OF ECCD

- Directional electron cyclotron waves heat electrons moving in one toroidal direction
- Since heating decreases the collision frequency, resonant electrons will contribute a larger amount of toroidal current than equivalent electrons moving in the opposite direction that have not been heated
- Total momentum of plasma is conserved as ions are dragged in opposite direction (but $J_i << J_e$ since $m_i >> m_e$)

Electron Velocity Space Diagram



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CURRENT DRIVE IS DETERMINED EXPERIMENTALLY FROM EVOLUTION OF RECONSTRUCTED MAGNETIC EQUILIBRIUM

- EFIT code reconstructs the magnetic equilibrium using external magnetic measurements and motional Stark Effect (MSE) data

- Poloidal magnetic flux ψ is therefore determined as a function of space and time

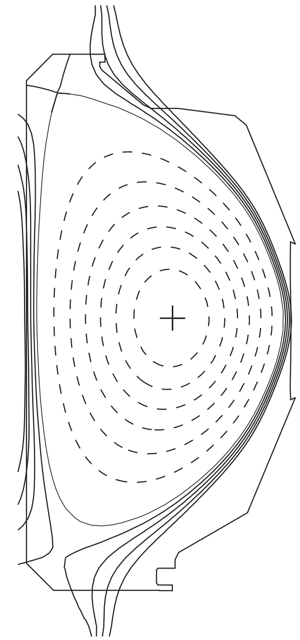
- Noninductive current profile is determined from parallel Ohm's law:

  $J_{NI} = J_{||} - \sigma_{neo} E_{||}$

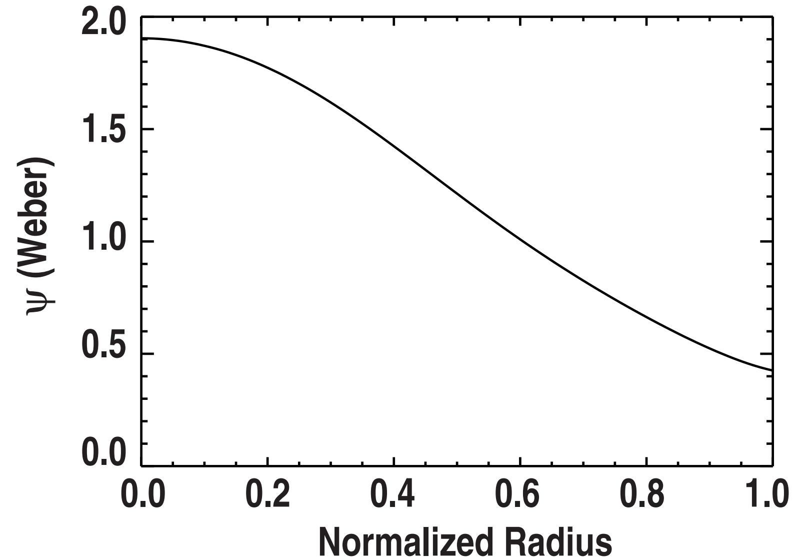
  $J_{||} \propto \nabla^2\psi$ Total current density

  $E_{||} \propto \frac{\partial\psi}{\partial t}$ Loop voltage / $2\pi R$

  σ_{neo} Calculated plasma conductivity



Cross section of magnetic equilibrium



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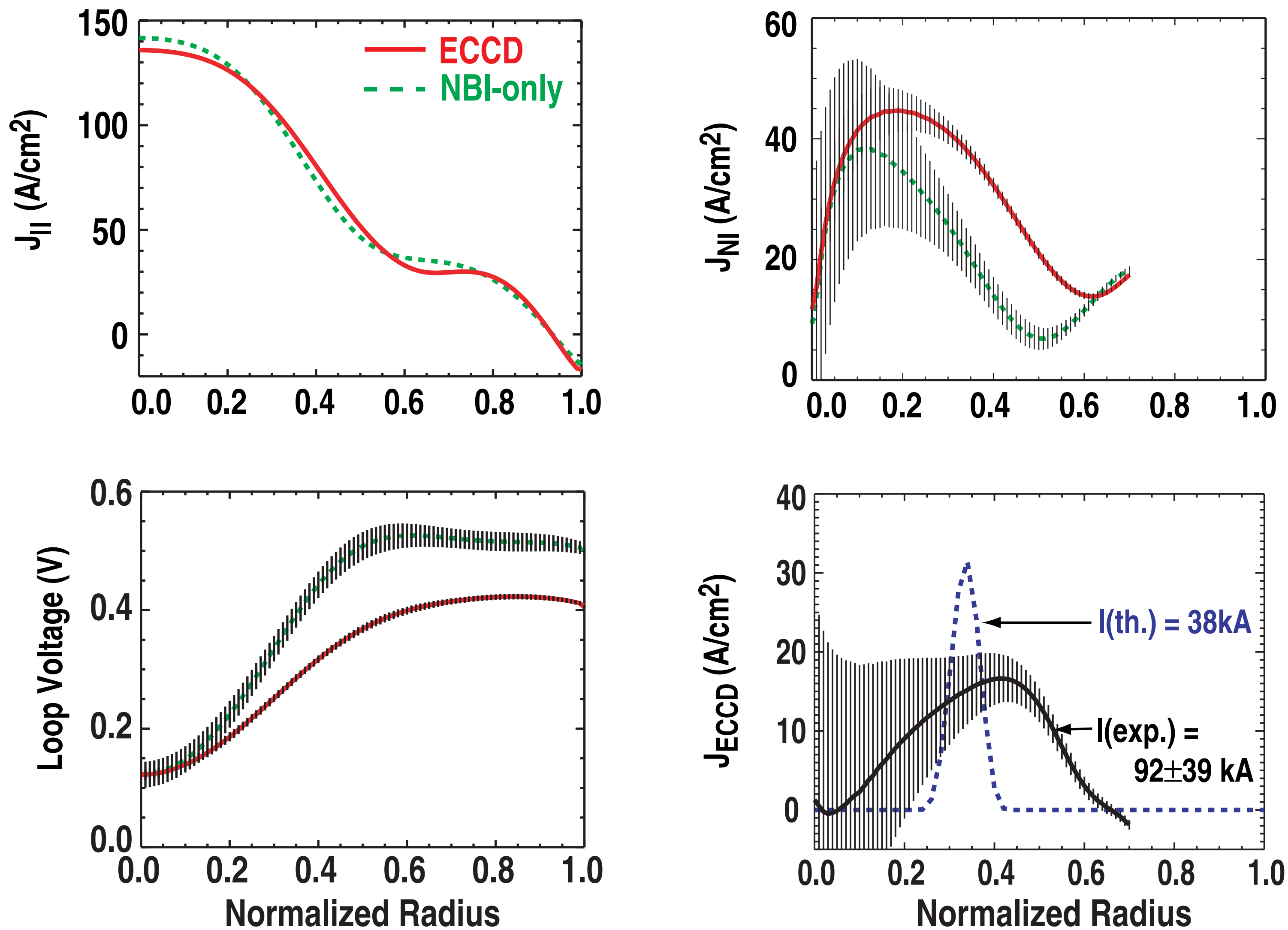
ECCD PROFILE FROM EFIT EVOLUTION IS BROADER THAN THEORY



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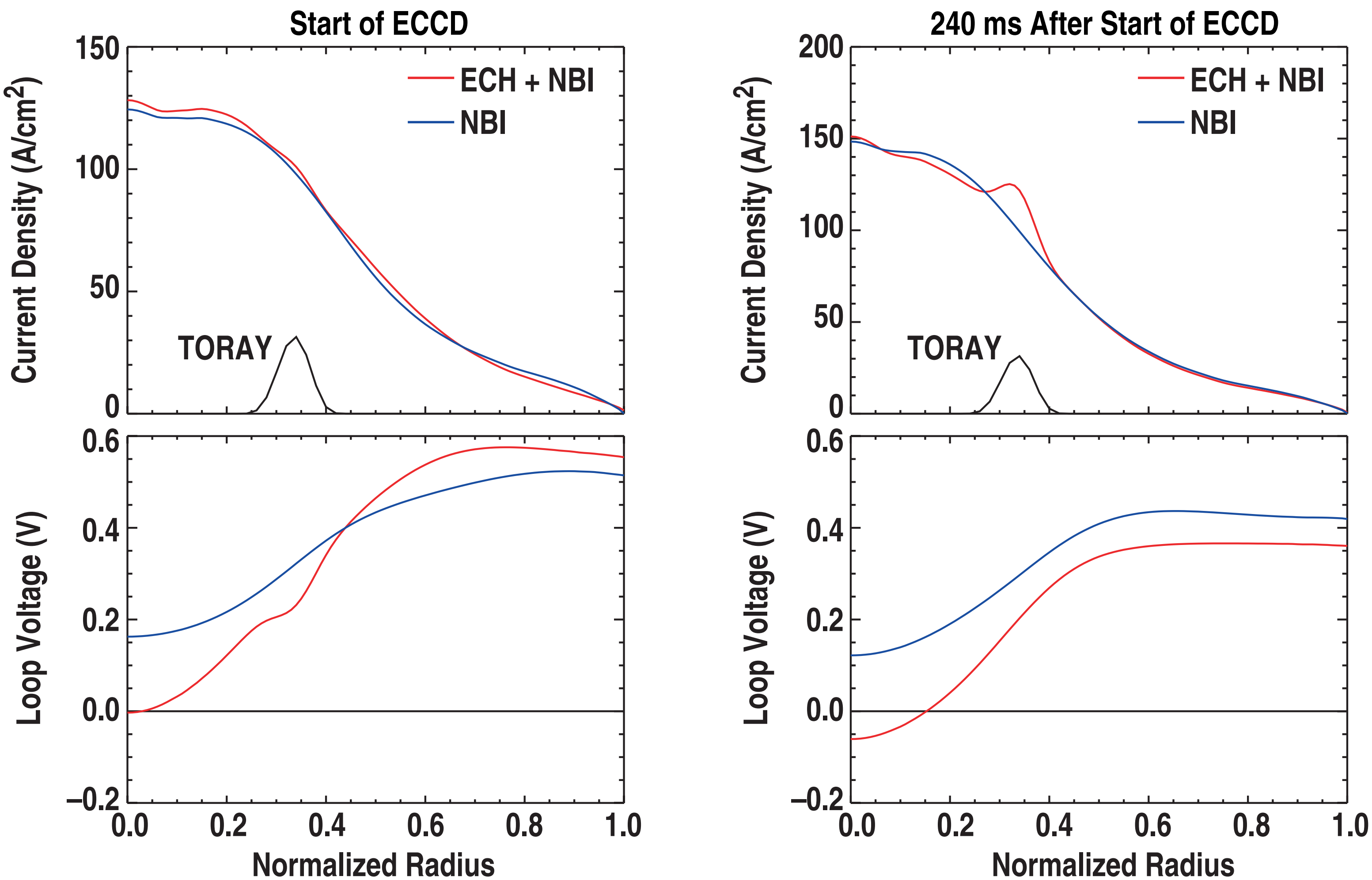
II. SINCE ECCD ANALYSIS IS DERIVED FROM MSE DATA, SIMULATIONS OF MSE SIGNALS WITH AND WITHOUT ECCD ARE MADE FOR DIRECT COMPARISON WITH MEASUREMENTS

- Evolution of magnetic equilibrium simulated using ONETWO transport code
  - Plasma boundary is fixed to experimental shape
  - Time history of measured density and temperature profiles is included
  - Magnetic equilibrium determined from Grad-Shafranov equation
  - Current and loop voltage evolution determined by Faraday's and Ohm's laws
  - ECCD profile calculated using TORAY ray tracing code

SIMULATIONS SHOW THAT OFF-AXIS ECCD PERTURBS THE CURRENT PROFILE RATHER THAN THE LOOP VOLTAGE PROFILE (AFTER INITIAL BACK EMF EFFECT DECAYS AWAY)



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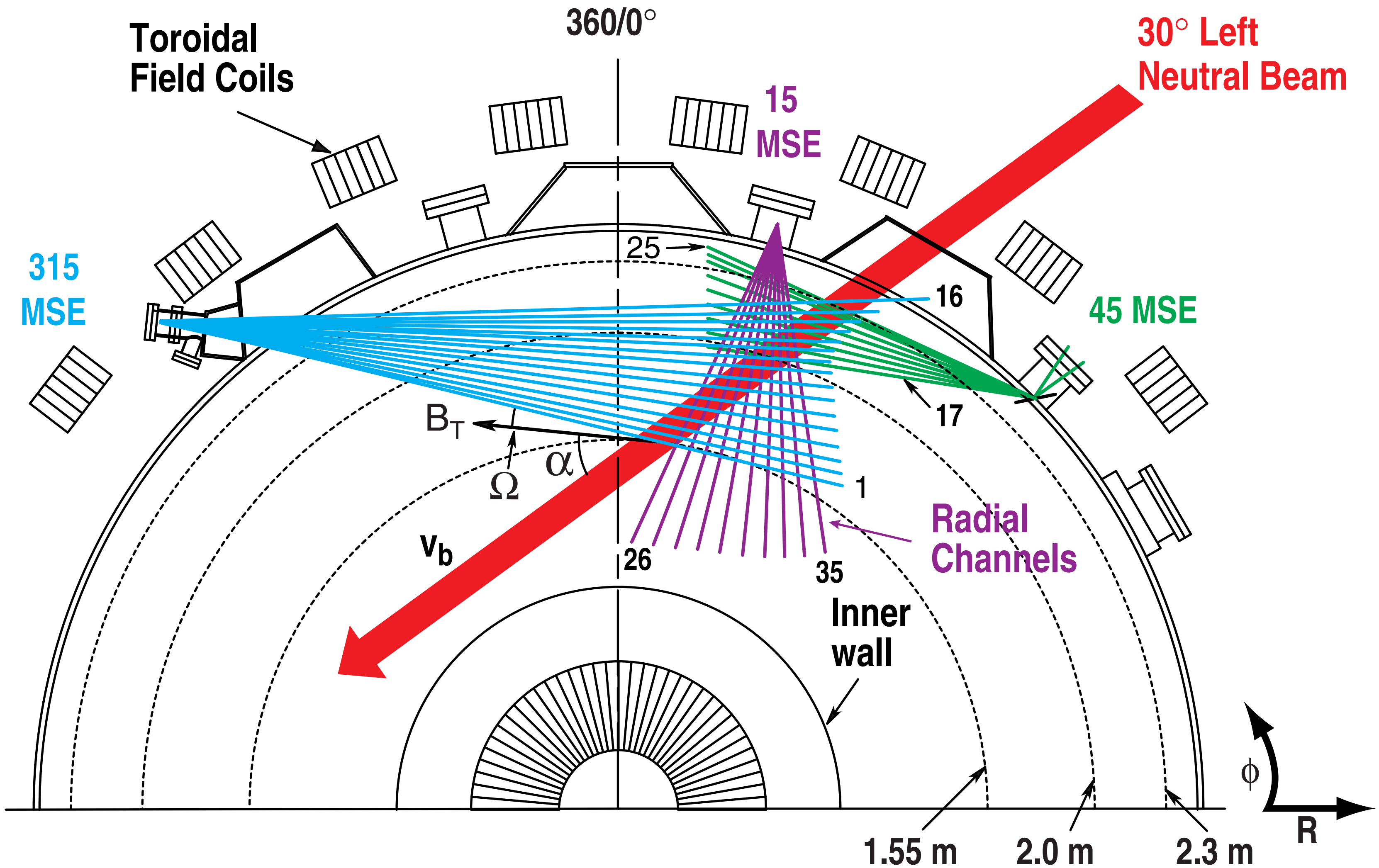
III. THE MOTIONAL STARK EFFECT (MSE) DIAGNOSTIC MEASURES THE CHANGES IN THE INTERNAL MAGNETIC FIELDS DURING ECCD



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CHANGE IN B_Z MEASURED BY MSE DURING OFF-AXIS ECCD IS DIRECTLY RELATED TO LOCAL CHANGE IN CURRENT DENSITY PROFILE

- Ampere's law: $\frac{\partial B_z}{\partial R} \cong \mu_0 J_\phi$

- Thus, the local change in J_ϕ during ECCD is proportional to the local change in B_z / R measured by MSE

  ⇒ The measured change in B_z / R during ECCD is not used directly, but rather is compared to a simulation of the change in B_z / R since modifications of the Ohmic, bootstrap, and neutral beam currents can also cause a local change in J_ϕ (in addition to ECCD)

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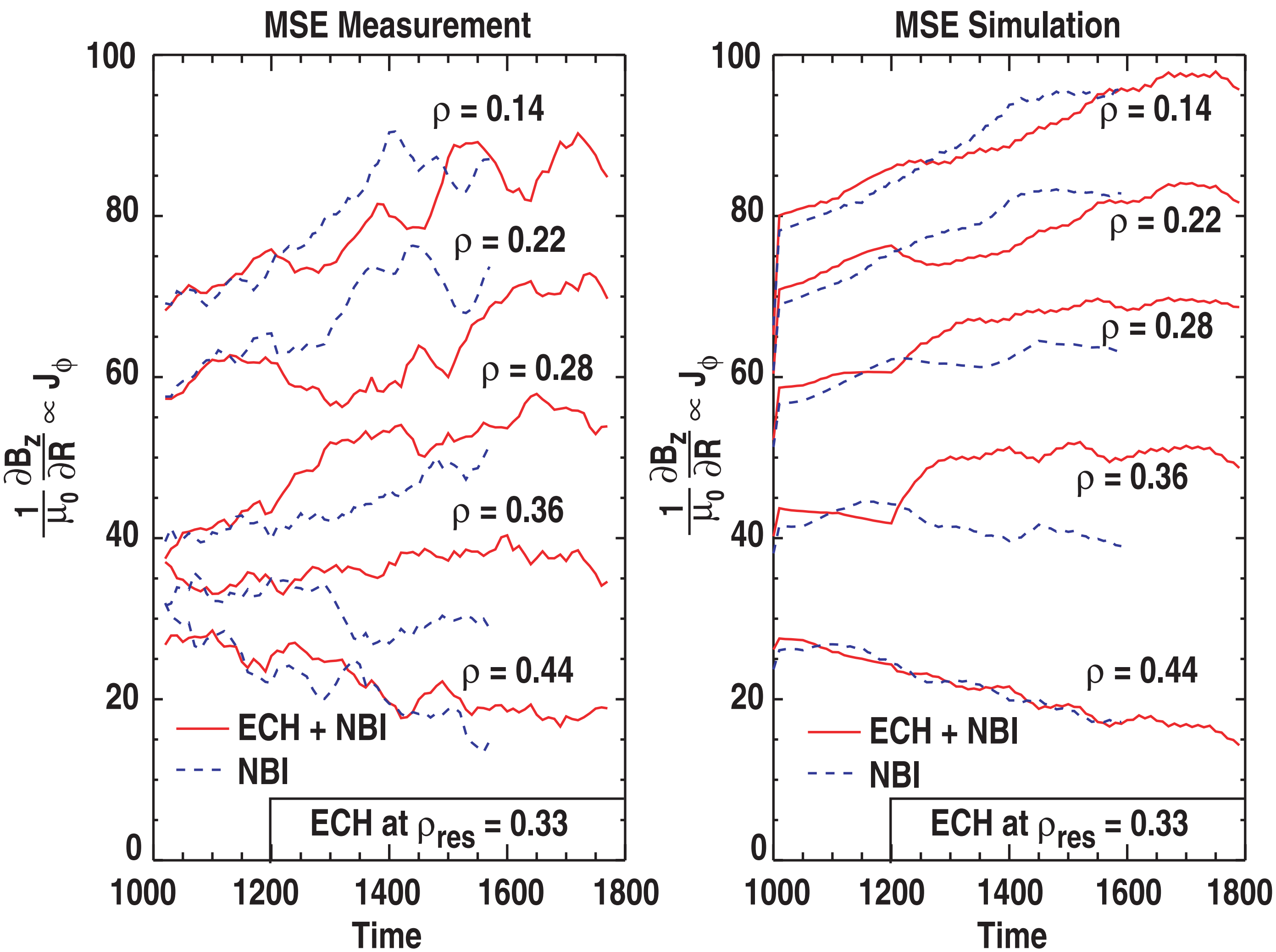
SIMULATIONS OF MSE DATA REPRODUCE THE MEASURED CHANGES IN B_Z DURING OFF-AXIS ECCD



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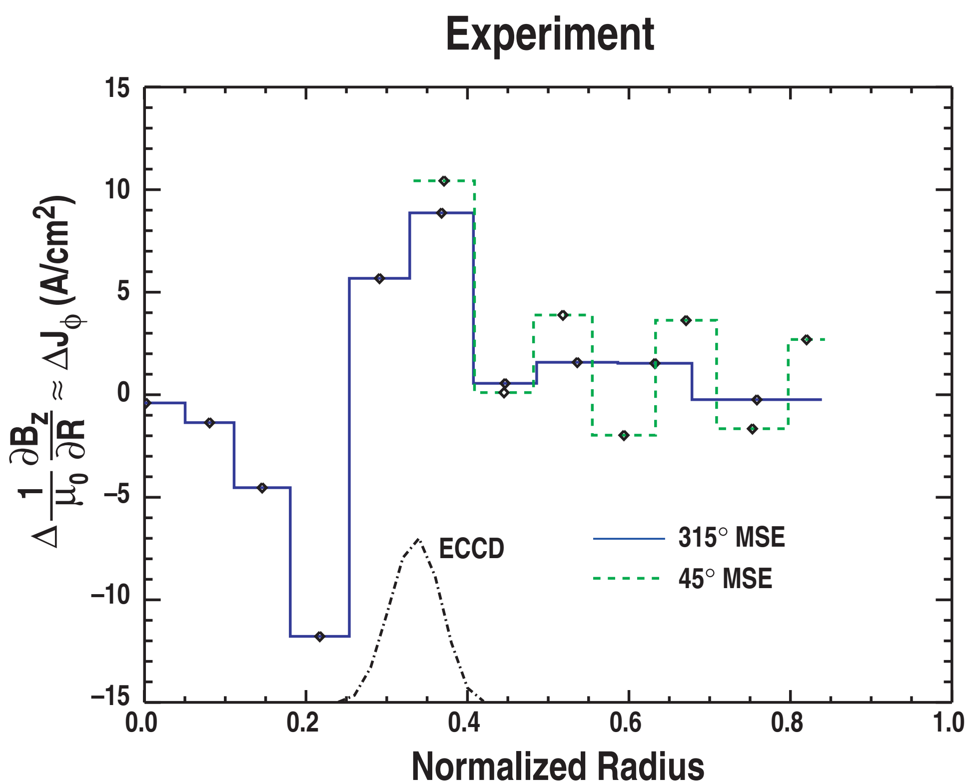
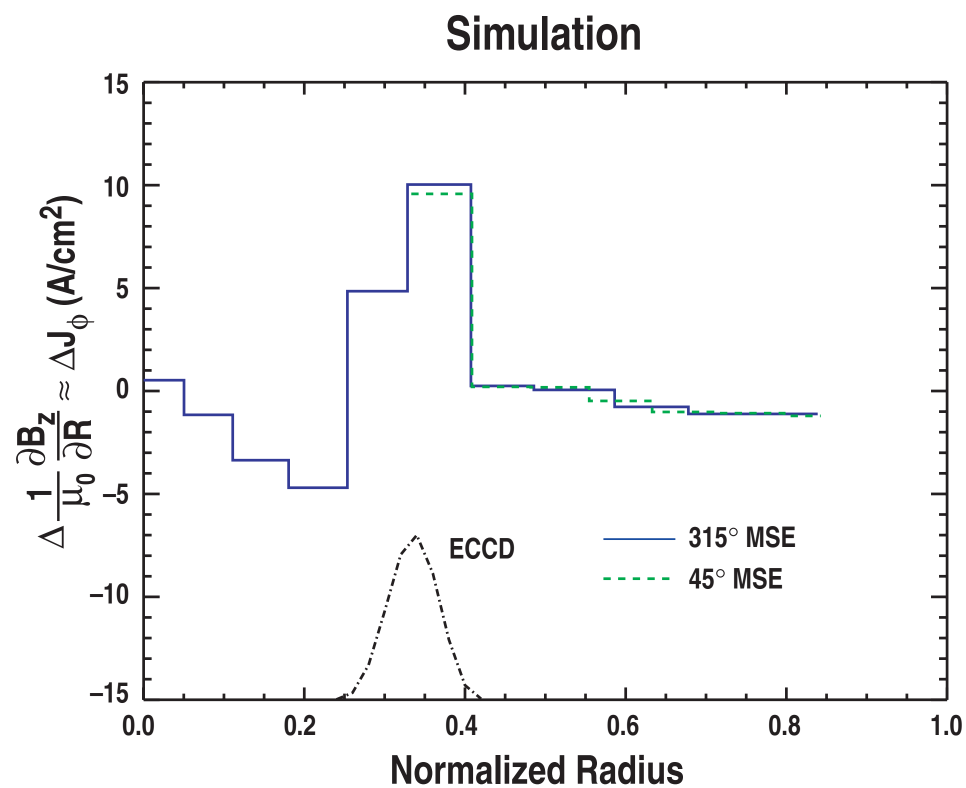
MSE MEASUREMENT SHOWS THAT CURRENT DENSITY INCREASES IN A LOCALIZED REGION NEAR THE ECH RESONANCE, IN AGREEMENT WITH SIMULATION





Change in MSE between ECH + NBI and NBI-only plasmas at t = 1.43 s is shown

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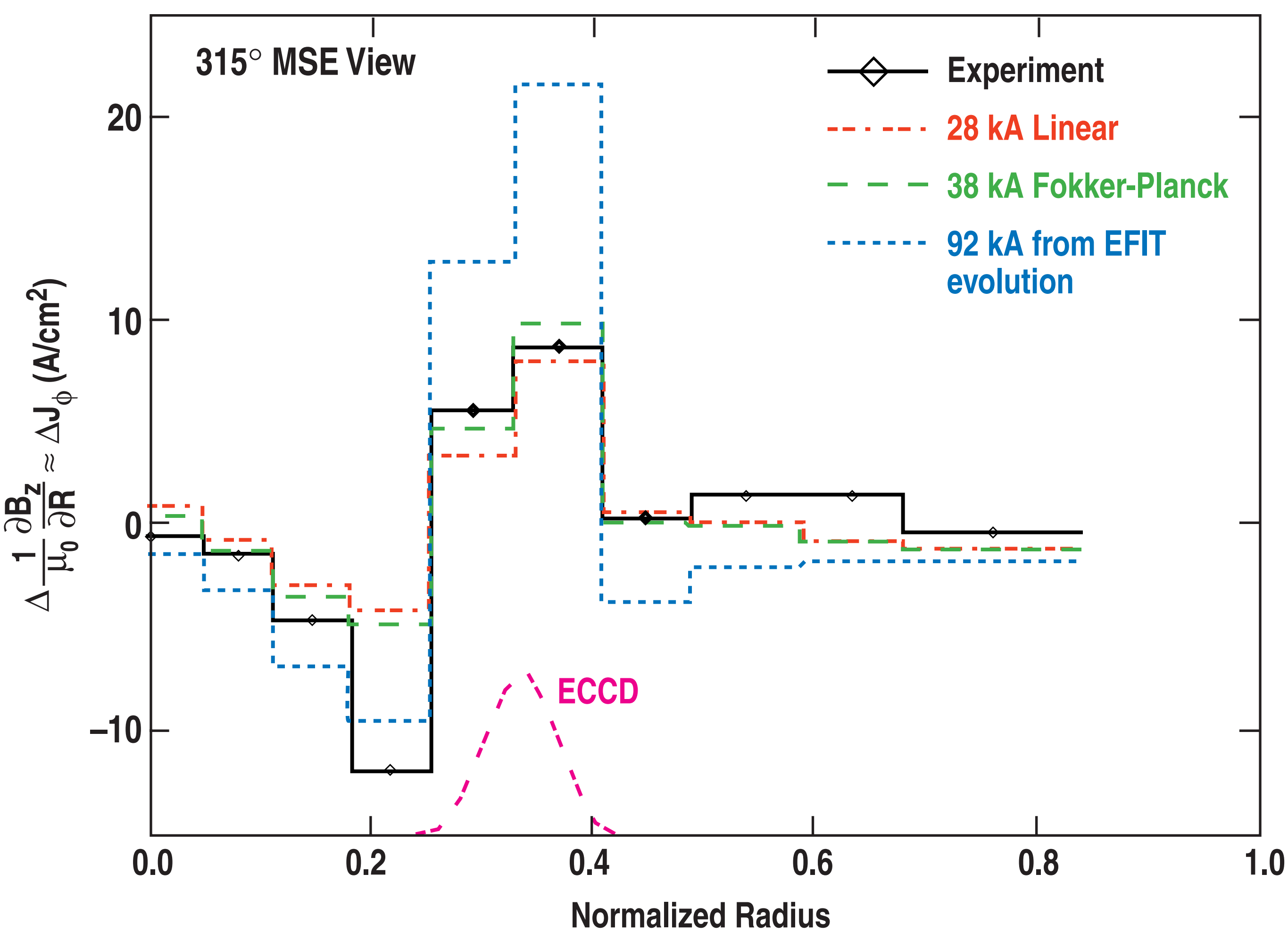
THE MAGNITUDE OF THE LOCALIZED CHANGE IN CURRENT DENSITY FROM MSE MEASUREMENTS IS CONSISTENT WITH THE PREDICTED CHANGE FROM CURRENT THEORIES



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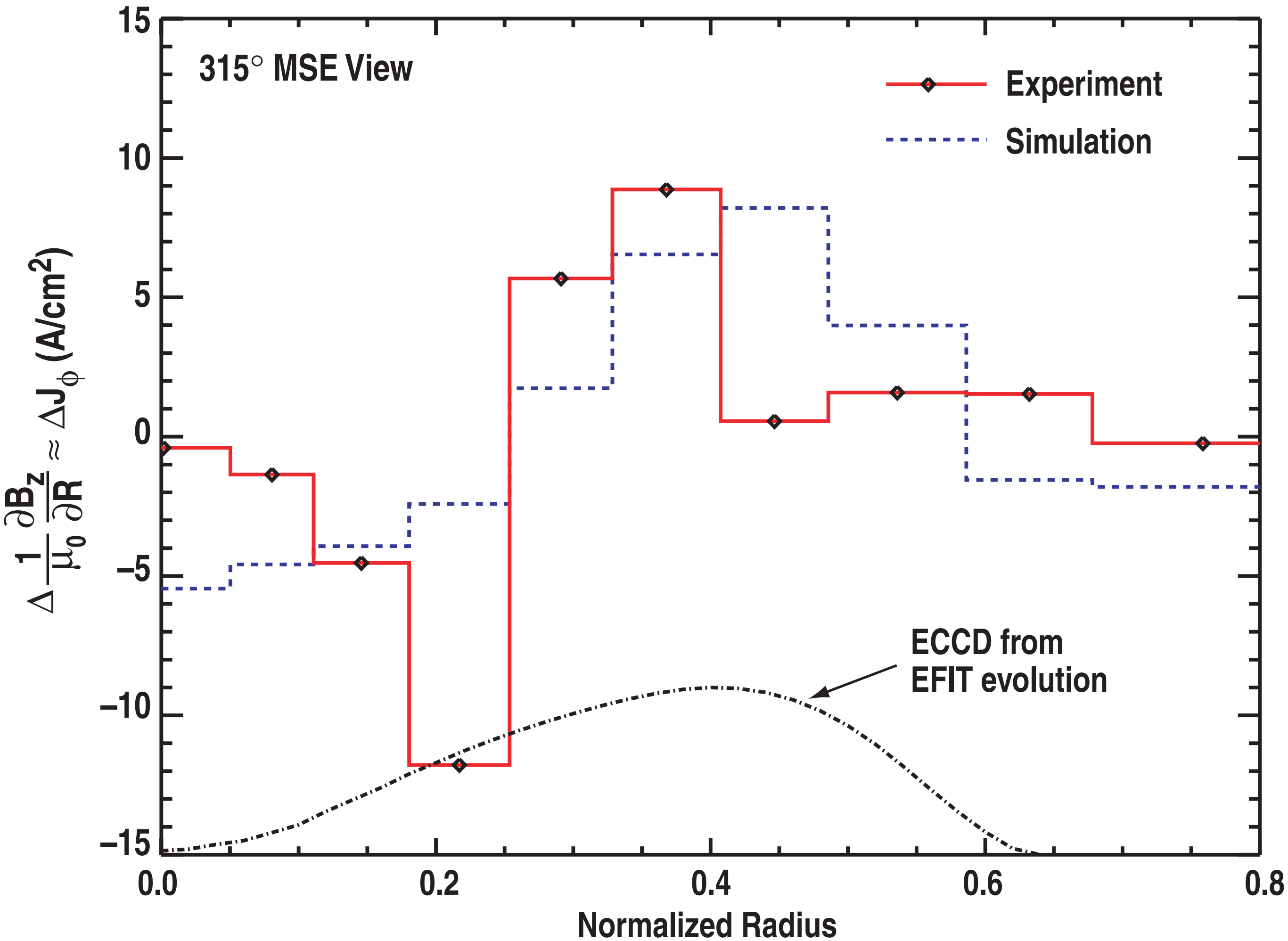
SIMULATION USING ECCD PROFILE FROM FITTED EFIT EVOLUTION GIVES TOO BROAD A MSE RESPONSE COMPARED TO MEASUREMENT



Fitting of MSE data in EFIT can broaden apparent ECCD profile

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IV. SIMULATIONS SHOW THAT PARAMETRIZING THE CURRENT PROFILE IN THE EFIT RECONSTRUCTION BROADENS THE DEDUCED ECCD PROFILE

- EFIT reconstruction uses

  $$J_\phi = R\left[P'(\psi) + \frac{\mu_0 FF'(\psi)}{4\pi^2 R^2}\right]$$

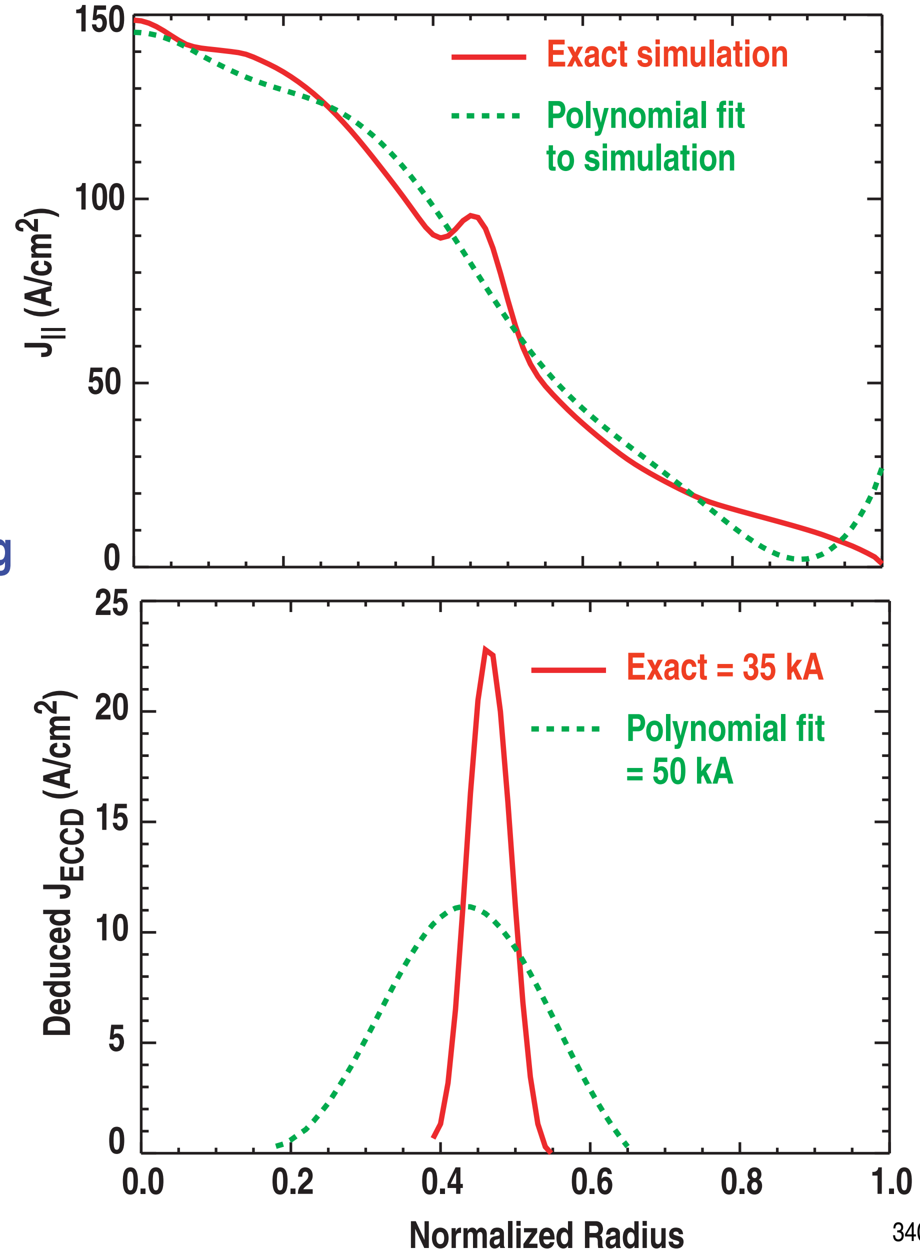
  $P(\psi)$ = pressure

  $F(\psi)$ = poloidal current

  ψ = radial coordinate

- Parametrization of $P(\psi)$ and $F(\psi)$ using polynomials or splines smooths over local structure in $J_{||}$

- Resulting ECCD profile deduced from fitted EFIT evolution is broadened and the integrated current drive is not conserved



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V. SUMMARY

- Off-axis ECCD locally perturbs the current density more than the loop voltage

- MSE measurements show an increase in current density at the ECH resonance location that is at least as localized as theoretical predictions

- Simulations indicate that the actual ECCD may be closer in magnitude (and width) to theoretical predictions than previously believed because the parameterized magnetic equilibrium reconstructions broaden the apparent ECCD profile

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