Physics of Electron Cyclotron Current Drive on DIII–D

by
C.C. Petty

for R. Prater, T.C. Luce, R.A. Ellis,*
R.W. Harvey,† J.E. Kinsey,‡ L.L. Lao,
J. Lohr, M.A. Makowski,Δ and K.-L. Wong*

*Princeton Plasma Physics Laboratory.
†CompX.
‡Lehigh University.
ΔLawrence Livermore National Laboratory.

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DIII–D
NATIONAL FUSION FACILITY
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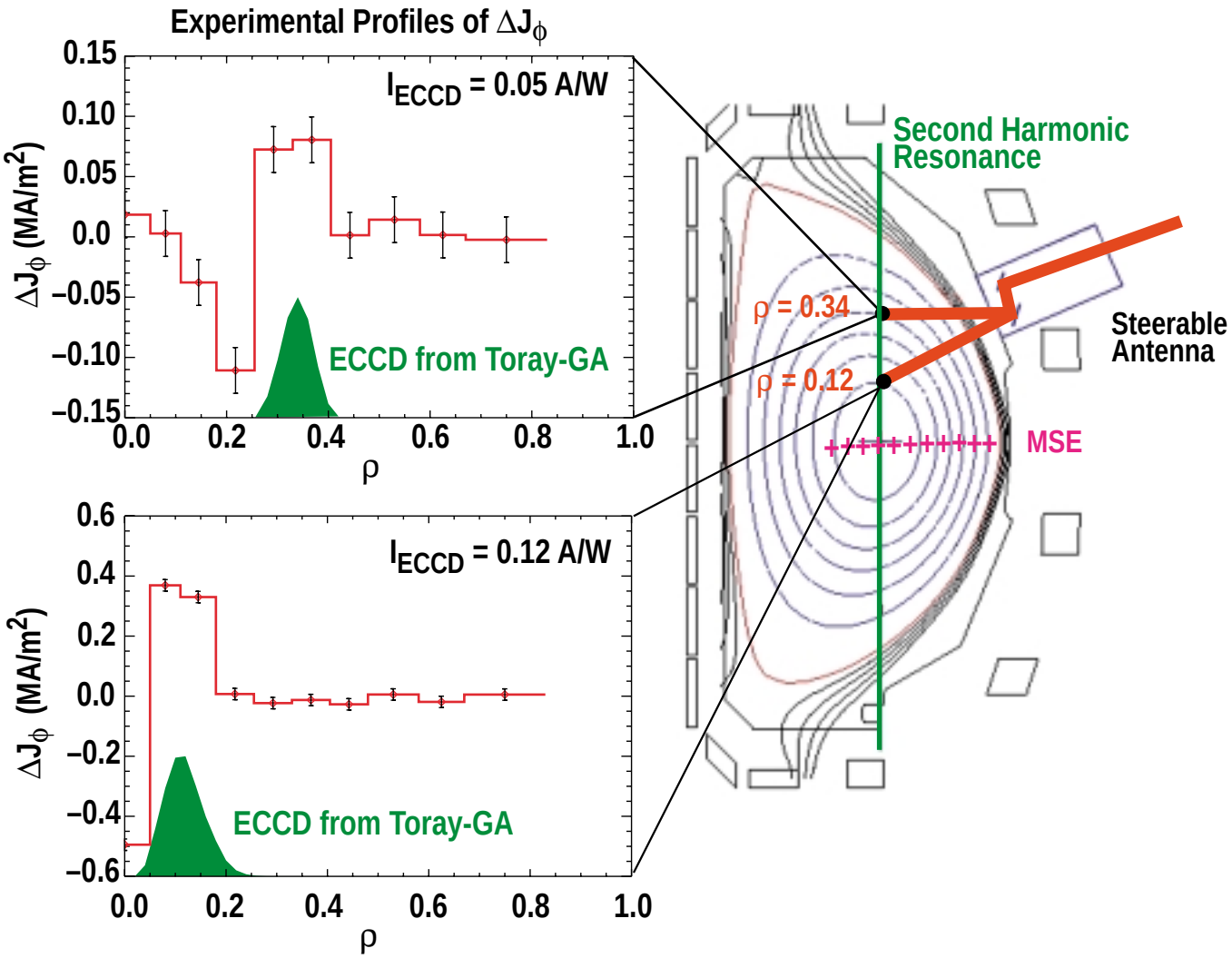
GENERAL ATOMICS

FEATURES OF ECH PROGRAM ON DIII–D TOKAMAK

- Experimental program uses electron cyclotron waves to
  - Modify current and pressure profiles (e.g., sustainment of hollow current profile in advanced tokamaks)
  - Control MHD instabilities (e.g., suppression of 2/1 neoclassical tearing mode)
  - Probe transport properties (e.g., tests of profile stiffness using heat pulse propagation)
- Electron cyclotron current drive (ECCD) experiments seek to validate a predictive theory of current drive under realistic conditions to take full advantage of the unique localization properties of ECCD

ECCD CAN BE MEASURED DIRECTLY FROM MSE SIGNALS

- Up to 2.3 MW injected power using five gyrotrons
- Launchers for four gyrotrons have control of poloidal and toroidal angles (PPPL)
- Independent control over launch angles facilitates science studies
  - $N_{||}$ scans
  - θ_{pol} scans
  - ρ scans



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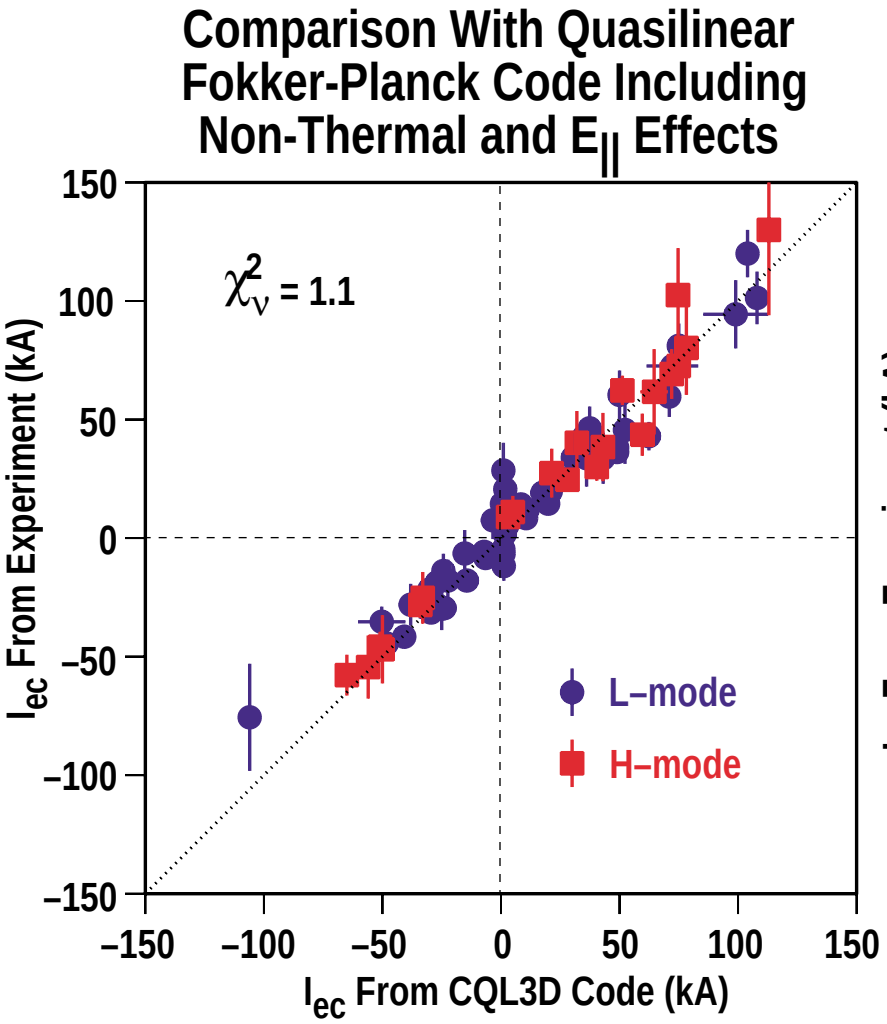
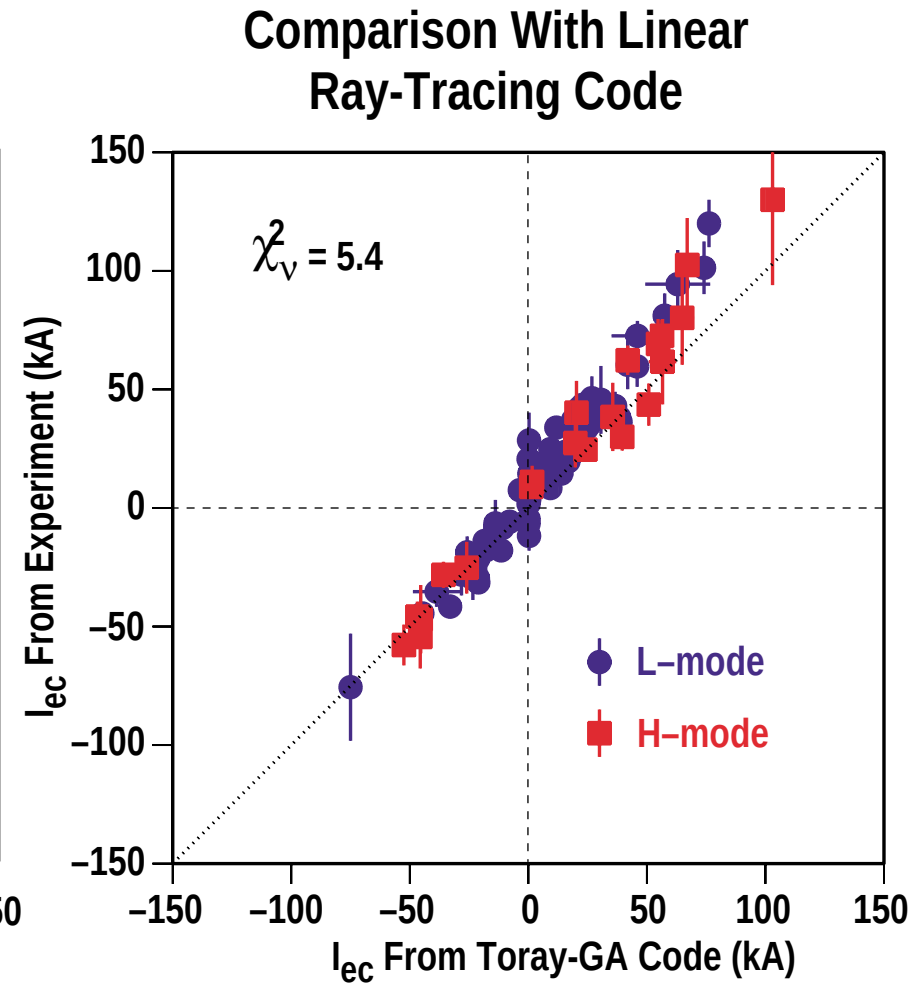
MEASURED ECCD AGREES WITH THEORY





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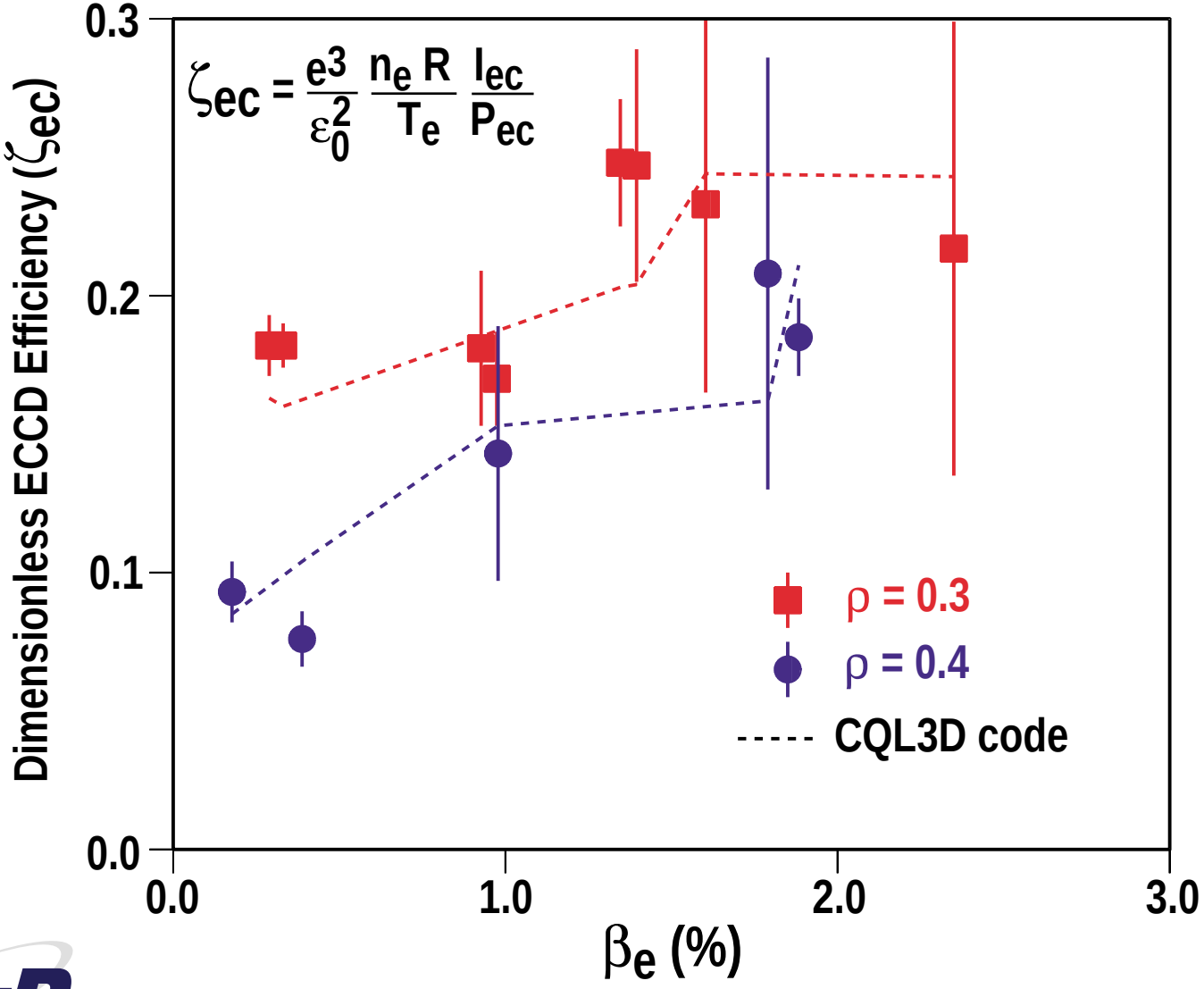
MEASURED ECCD EFFICIENCY INCREASES WITH ELECTRON BETA FOR OFF-AXIS DEPOSITION



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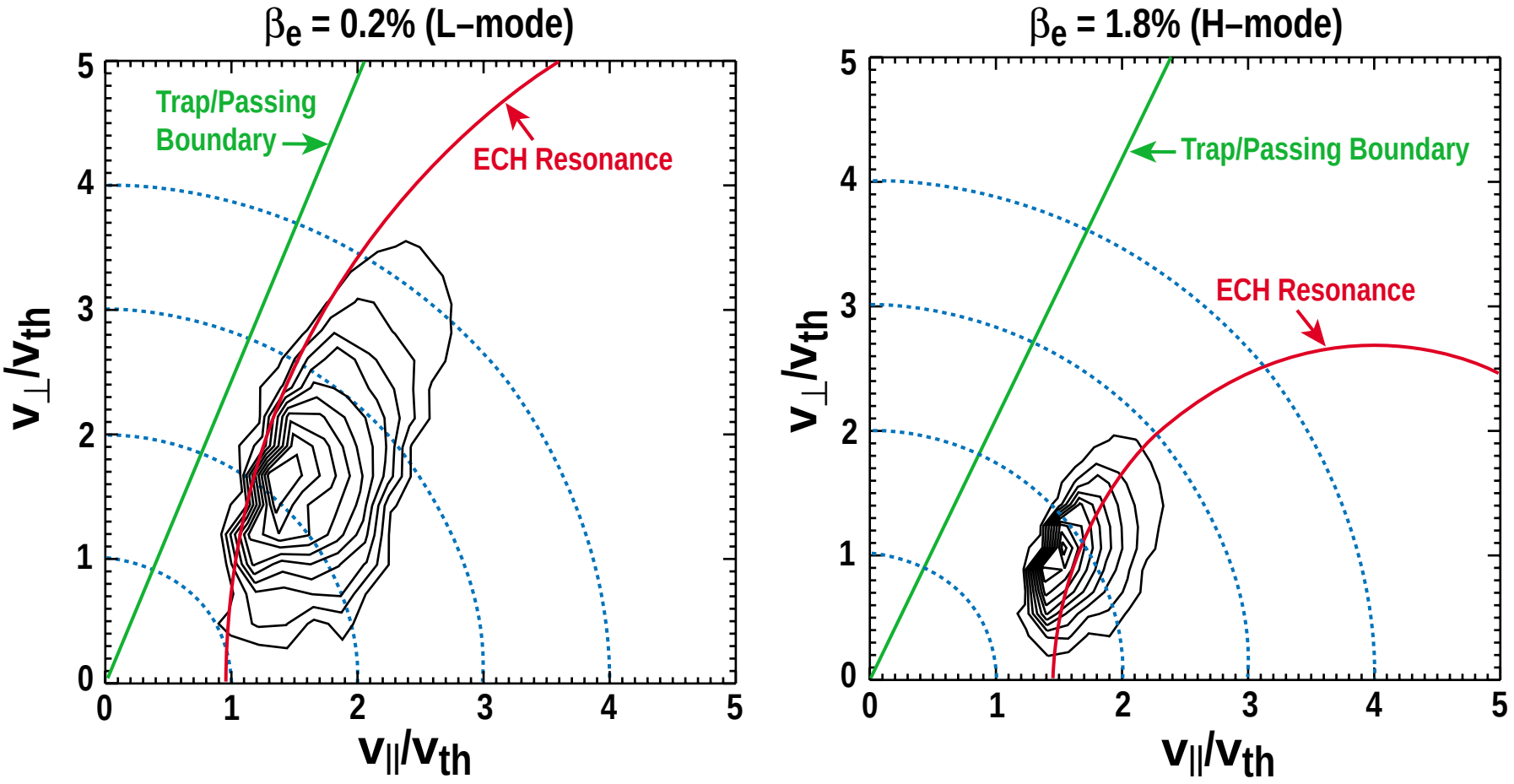
THEORETICAL ECCD EFFICIENCY INCREASES WITH HIGHER n_e AND T_e BECAUSE RESONANCE MOVES AWAY FROM TRAPPING BOUNDARY IN VELOCITY SPACE

- Contours of ECH driven flux in velocity space from CQL3D



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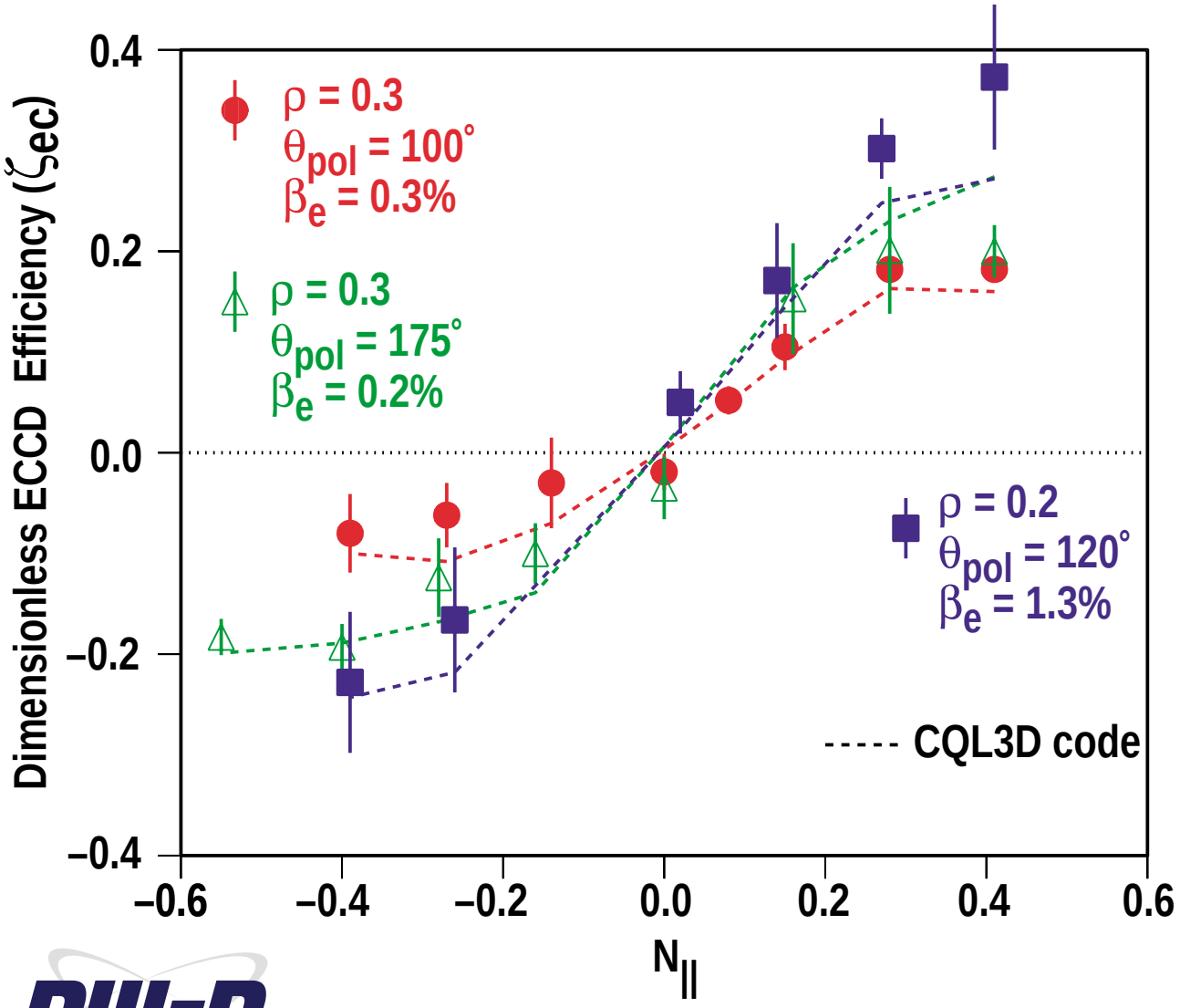
DEPENDENCE OF ECCD EFFICIENCY ON TOROIDAL INJECTION ANGLE (i.e., $N_{||}$) AGREES WITH THEORY



- Tests velocity space interaction between waves and particles
- ECCD switches from co to counter with radial injection driving little current

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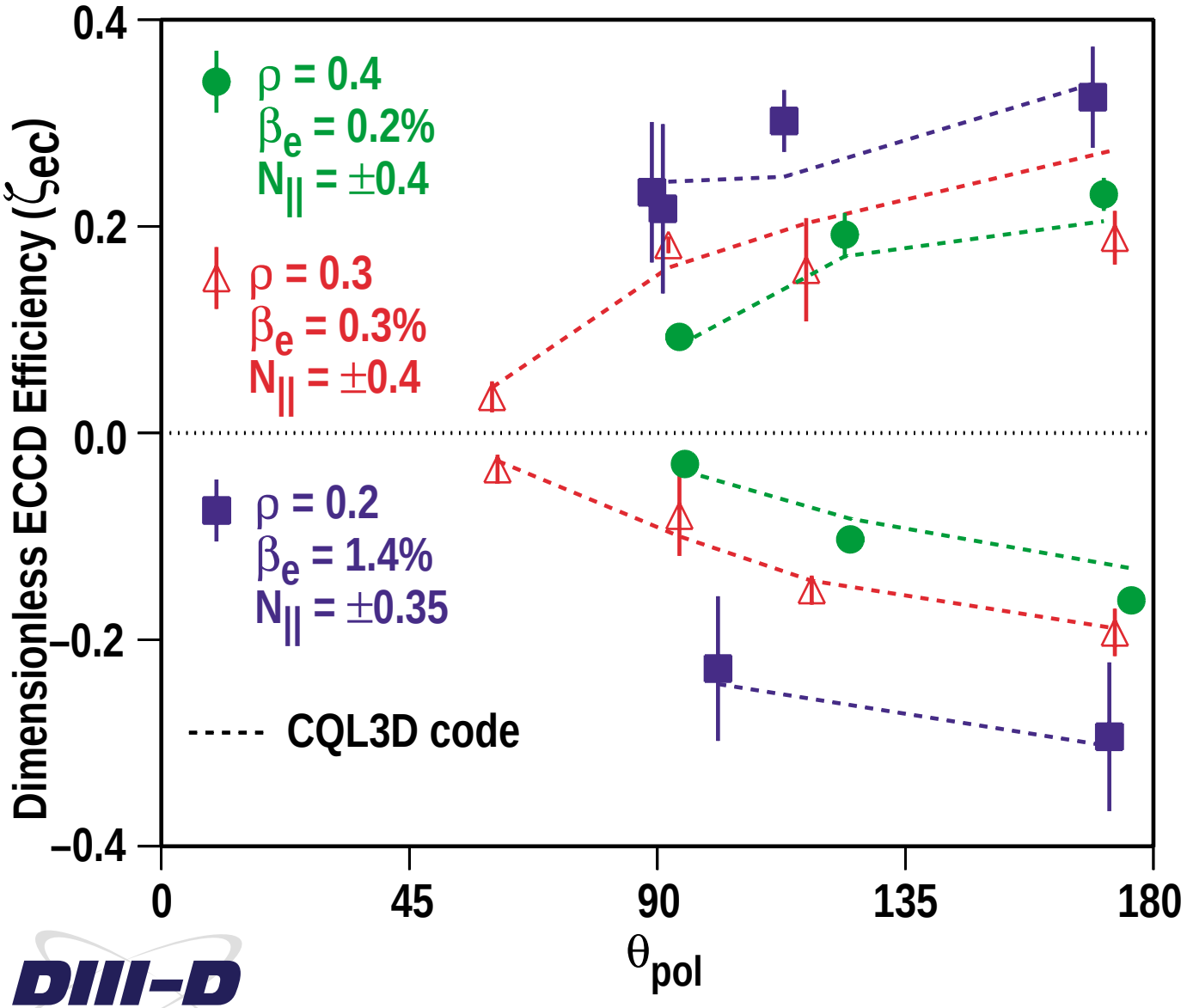
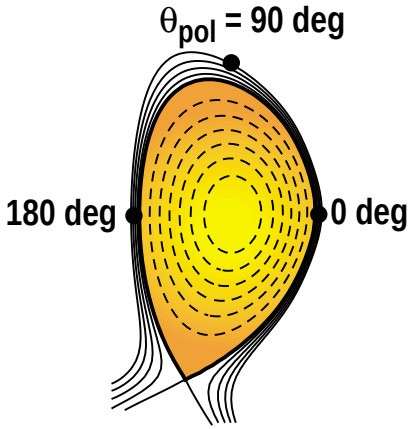
MEASURED ECCD EFFICIENCY INCREASES AS DEPOSITION MOVES TO INBOARD MIDPLANE



- Trapped particle fraction increases as θ_{pol} decreases
- Trapping effects are strongest at large ρ and low β_e



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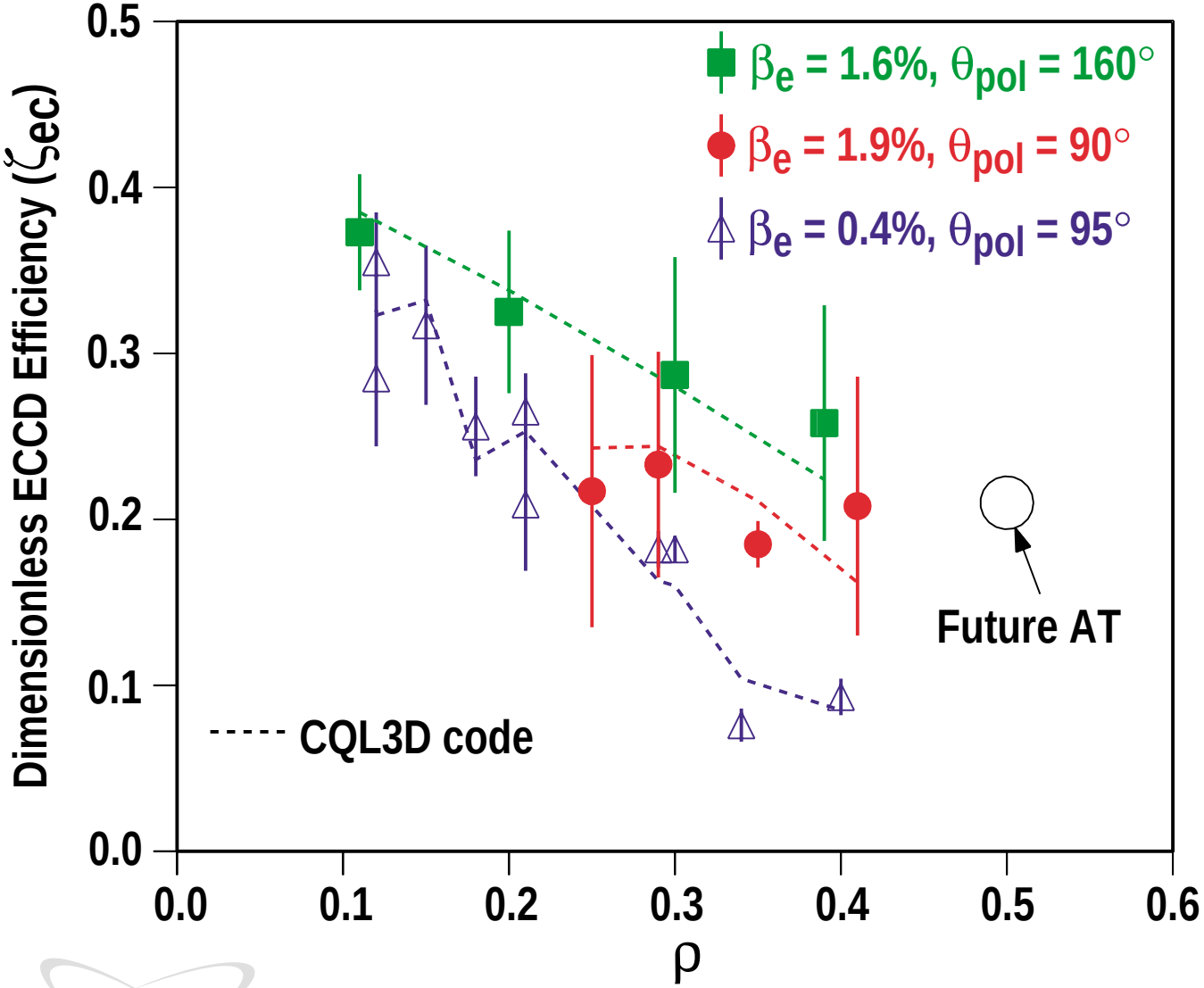
DECREASE IN ECCD EFFICIENCY WITH ρ IS WEAKER WHEN TRAPPING EFFECTS ARE REDUCED



- High β_e and inboard deposition reduce trapping effects
- Predicted ζ_{ec} for future AT plasmas shown appears to be achievable experimentally

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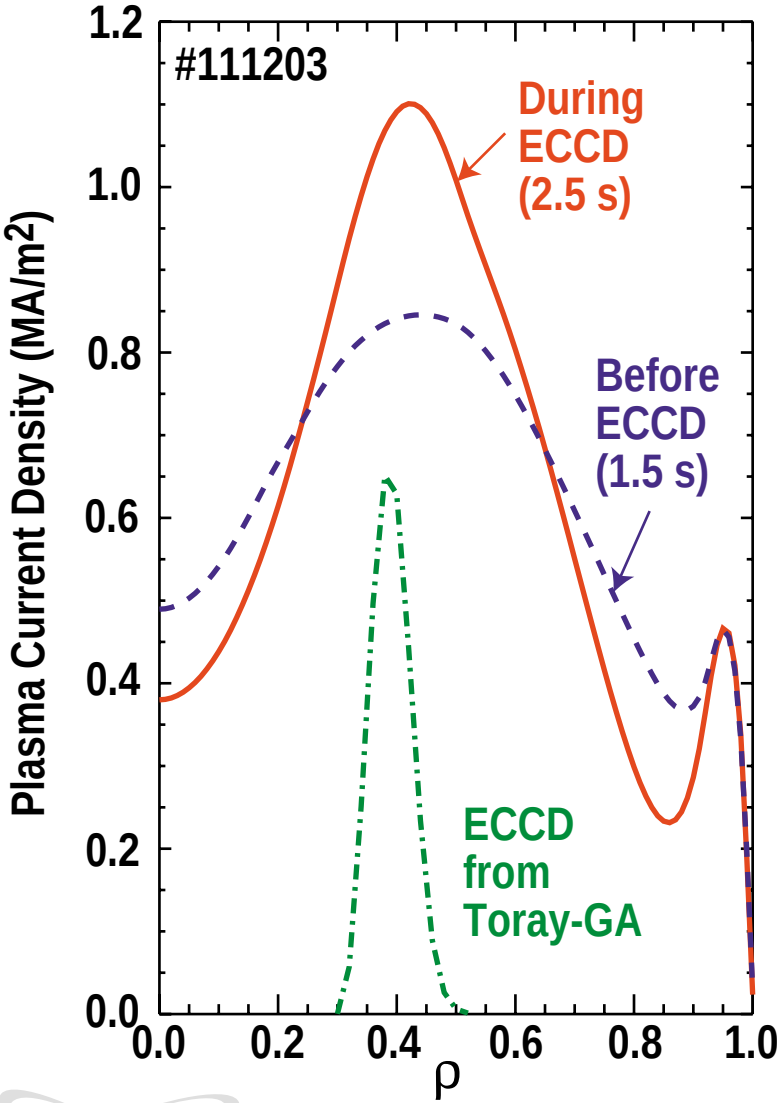
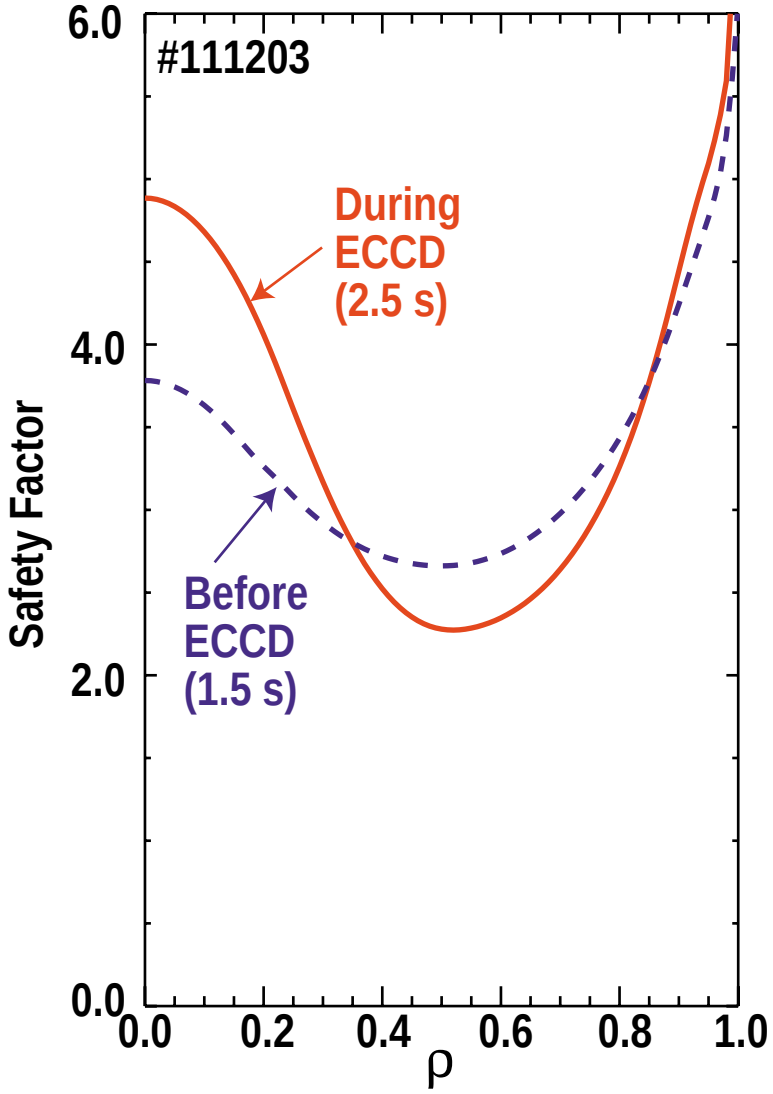
CURRENT PROFILE MODIFICATION BY OFF-AXIS ECCD ACHIEVED IN ADVANCED TOKAMAK PLASMAS





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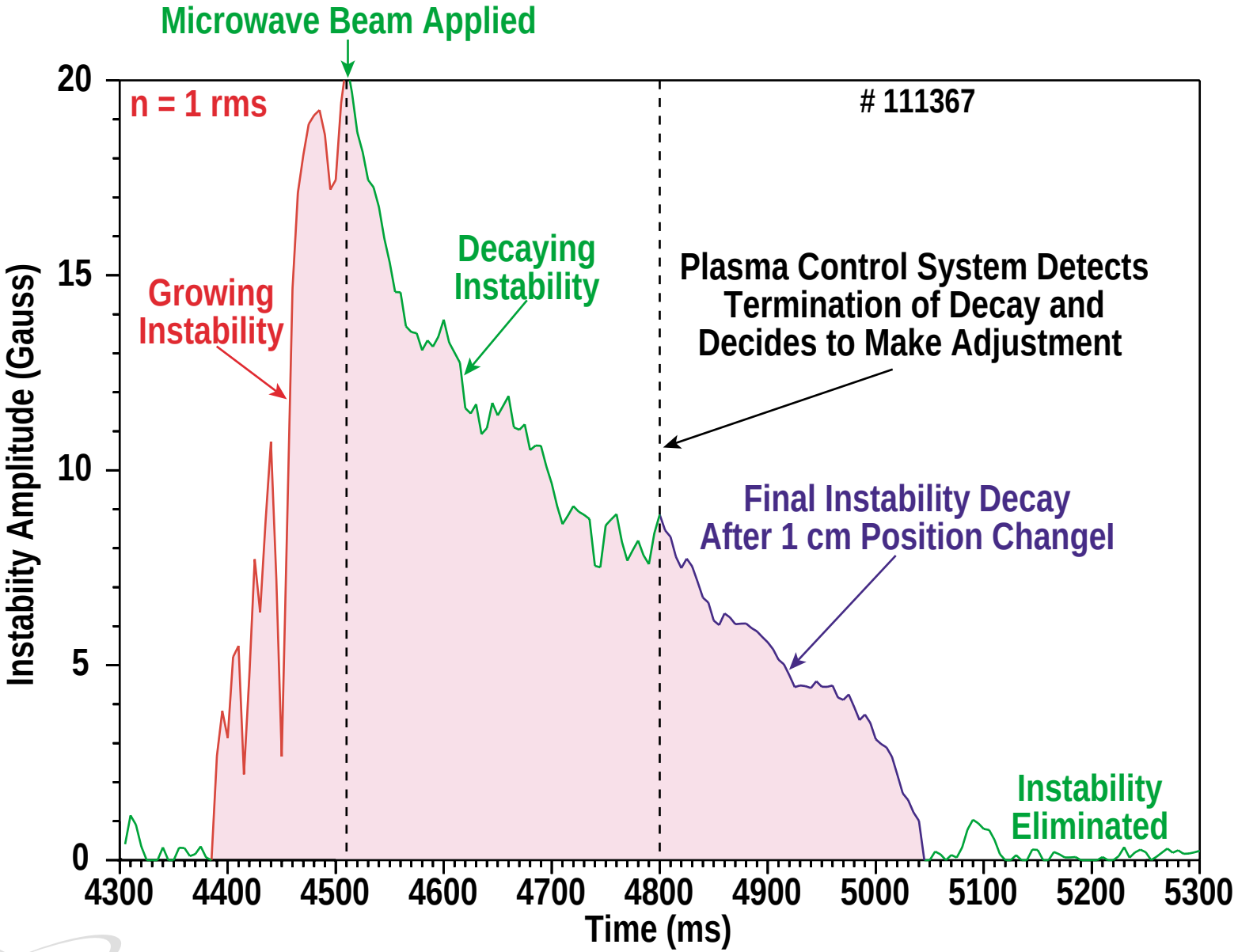
EFFECTIVE ECCD FAR OFF-AXIS (ρ = 0.66) IS EVIDENT FROM COMPLETE SUPPRESSION OF m/n = 2/1 TEARING MODE



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CONCLUSIONS

- Measured ECCD efficiency increases when electron trapping effects are reduced by either
  - Increasing electron density and/or temperature
  - Moving deposition towards inboard midplane
  - Moving deposition to smaller minor radius

  in good agreement with CQL3D quasilinear Fokker-Planck code

- Localized ECCD provides detailed control of the current profile
  - Full suppression obtained for 3/2 and 2/1 NTM
  - Current profile modified in advanced tokamak discharges

  with experimental planning greatly assisted by validated ECCD model

- Next year on DIII–D, six gyrotrons will be connected to six antennas with independent steering of poloidal and toroidal angles