CURRENT PROFILE CONTROL VIA ACTIVE T_e CONTROL IN DIII–D

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T_e FEEDBACK IS MOST EFFECTIVE MEANS OF CONTROLLING CURRENT PROFILE DURING THE CURRENT RAMP

- Current density consists of inductive and non-inductive parts:

  $J = J_{Ohm} + J_{non\text{-}ind}$

  $J_{Ohm} = \sigma E_{||}$ $\qquad$ $J_{non\text{-}ind} = J_{BOOT} + J_{ECCD} + J_{NBCD} + \ldots$

- Non-inductive sources are either small or inefficient at low β or low $T_e \Rightarrow$ can't be used early in current ramp

- Ohmic current evolution governed by

  $$\frac{\partial E_{||}}{\partial t} = \frac{1}{\mu_o \sigma} \nabla^2 E_{||} \qquad \text{where} \qquad \sigma \propto \frac{T_e^{3/2}}{Z_{eff}}$$

- Without external intervention, $E_{||}$ penetrates rapidly resulting in $q_0 \cong 1$ at end of current ramp

- Controlling T_e allows a direct, reliable means for controlling current profile evolution

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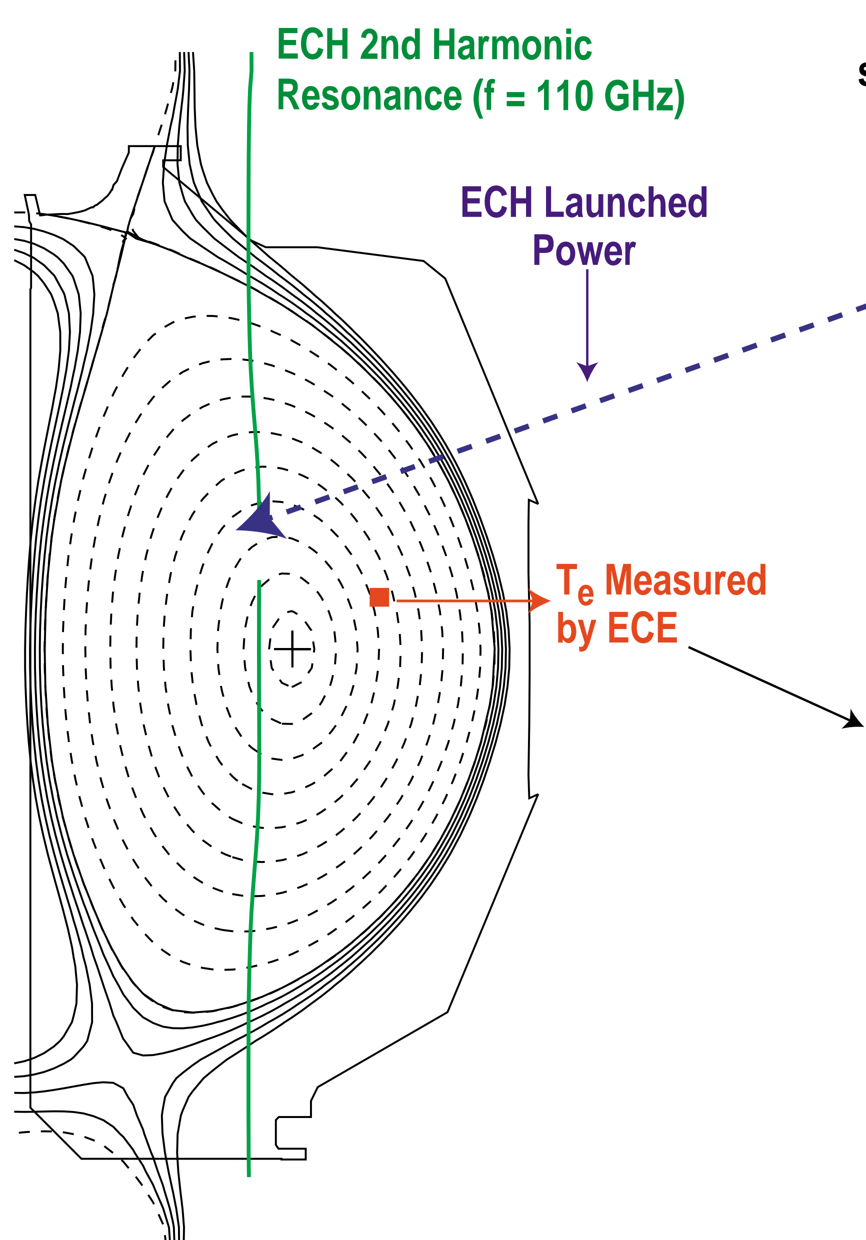
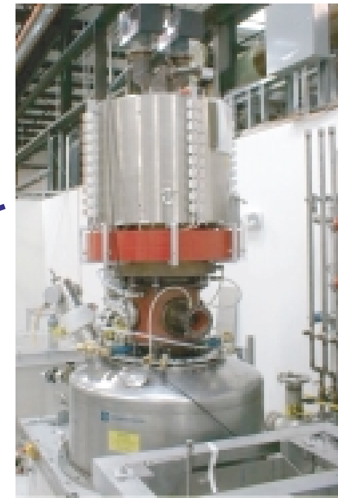
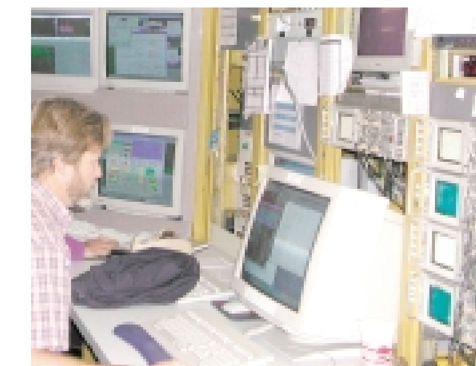
ACTIVE T_e CONTROL MADE POSSIBLE BY UPGRADES TO DIII–D ECH SYSTEMS, PLASMA CONTROL SYSTEM, AND ECE DIAGNOSTIC



Gyrotrons (power separately controlled)





Plasma Control System (PCS)

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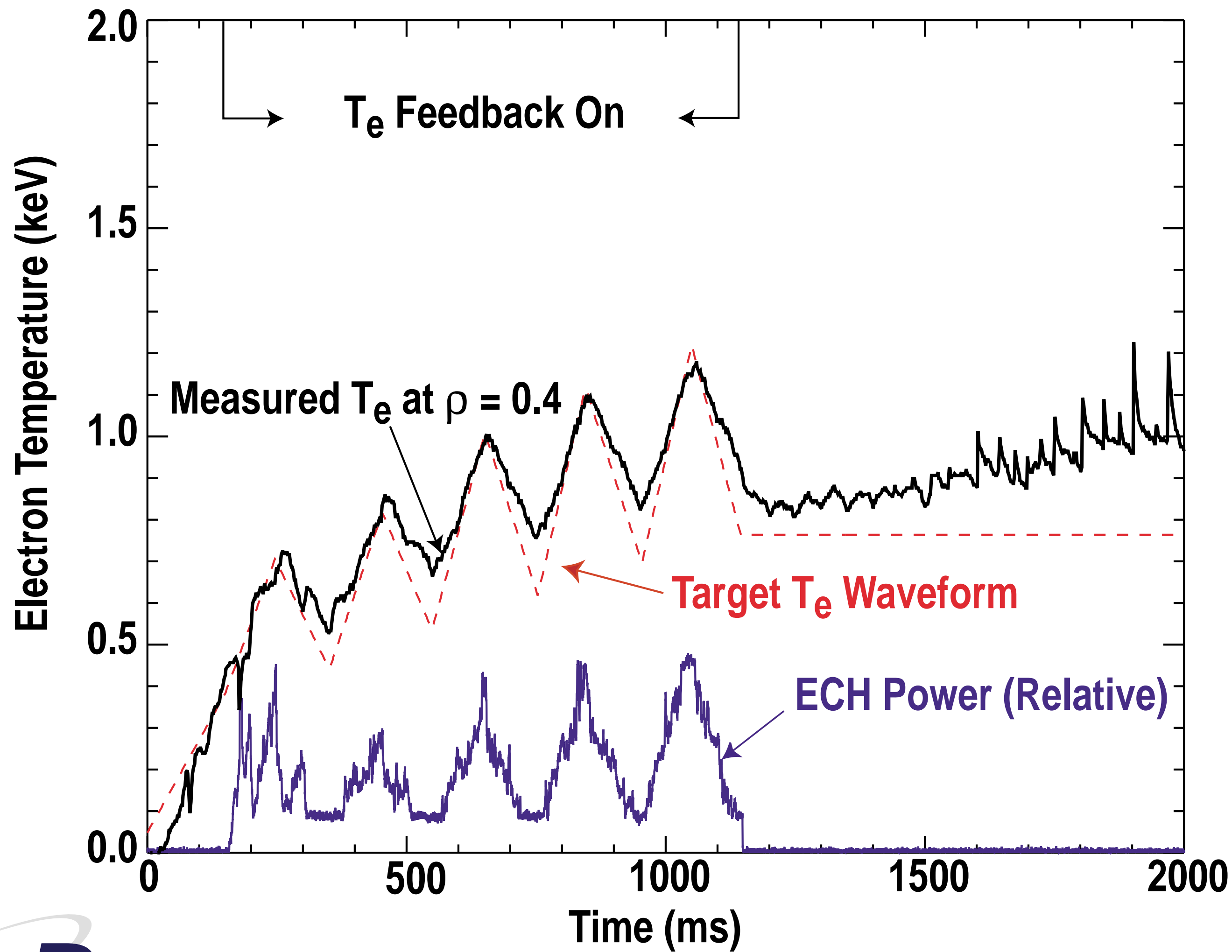
FINE CONTROL OF T_e EVOLUTION HAS BEEN DEMONSTRATED

- ECH deposition at $\rho = 0.4$
- PCS using ECE measurement at $\rho = 0.4$ as sensor



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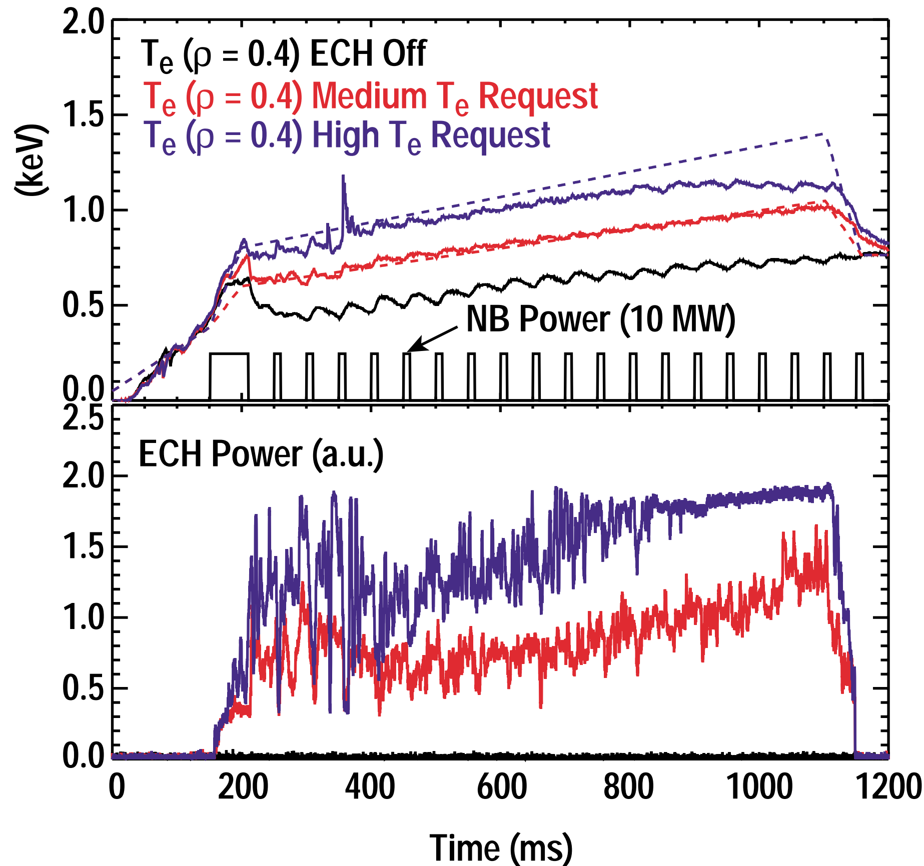
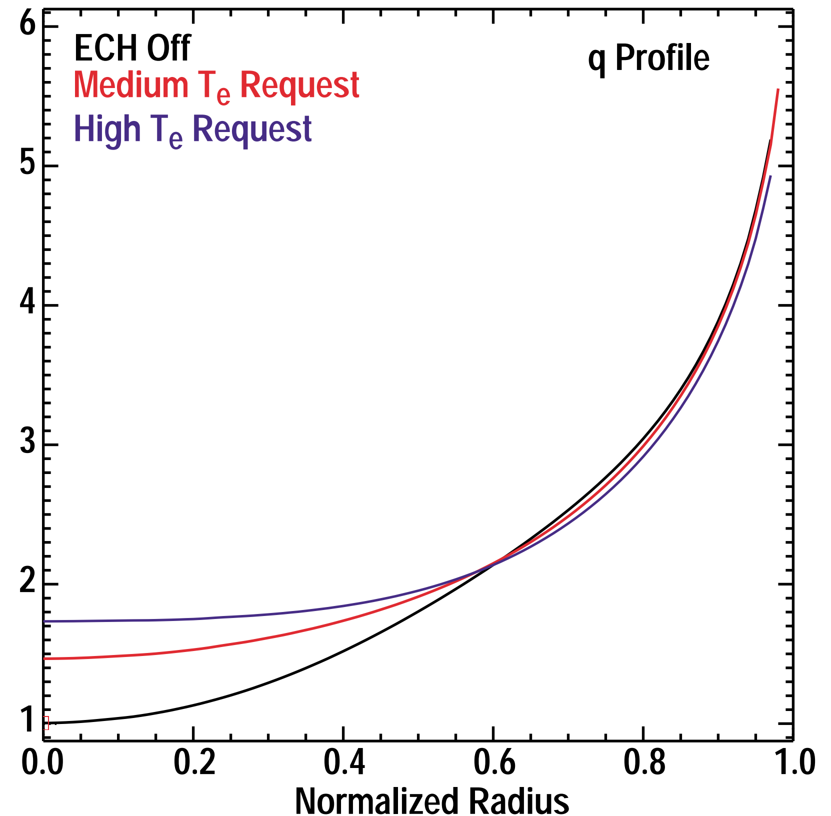
STUDIES SHOW THAT SYSTEMATICALLY INCREASING T_e RESULTS IN LESS CURRENT PENETRATION





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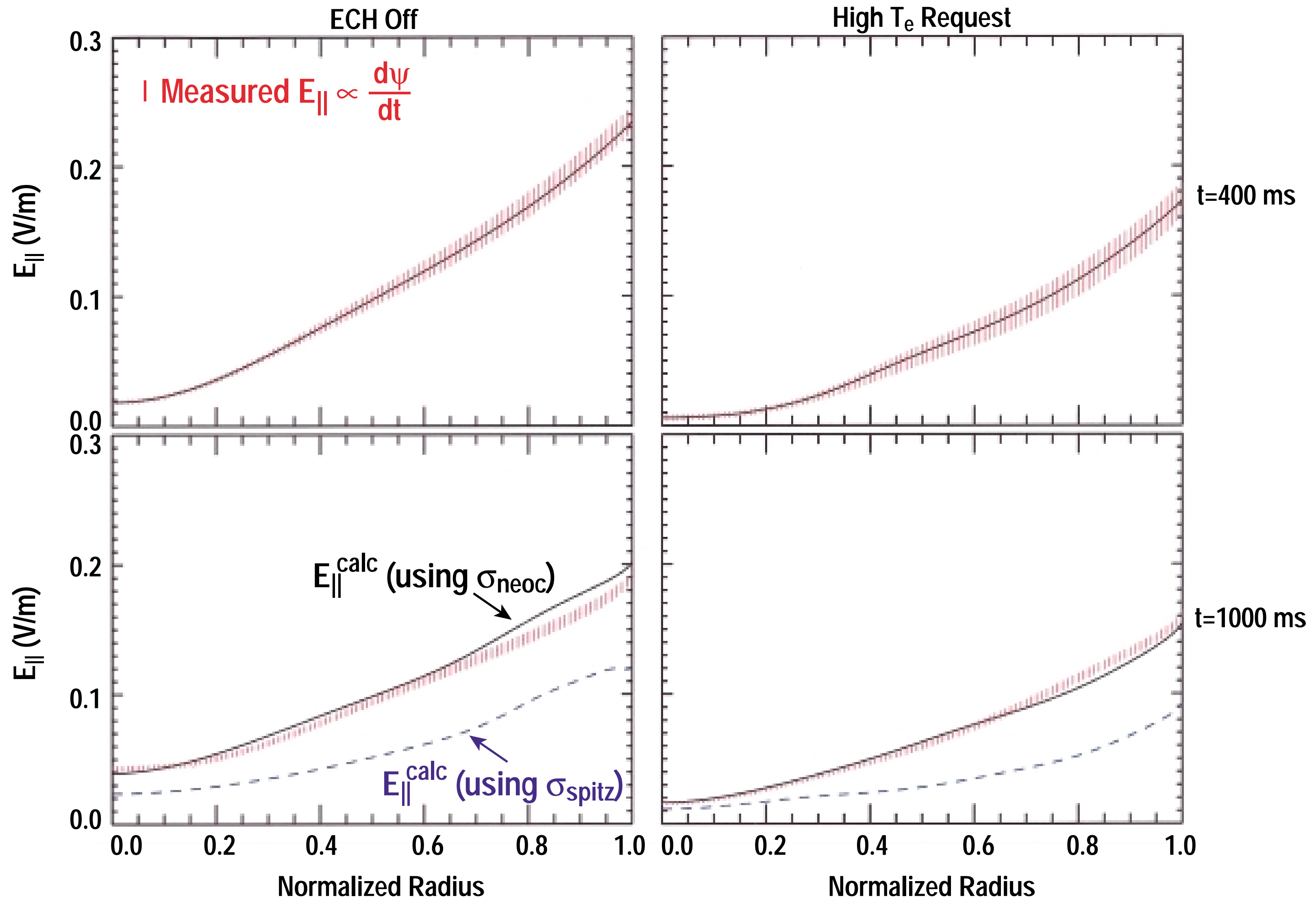
MEASURED $E_{||}$ EVOLUTION CONSISTENT WITH NEOCLASSICAL RESISTIVITY



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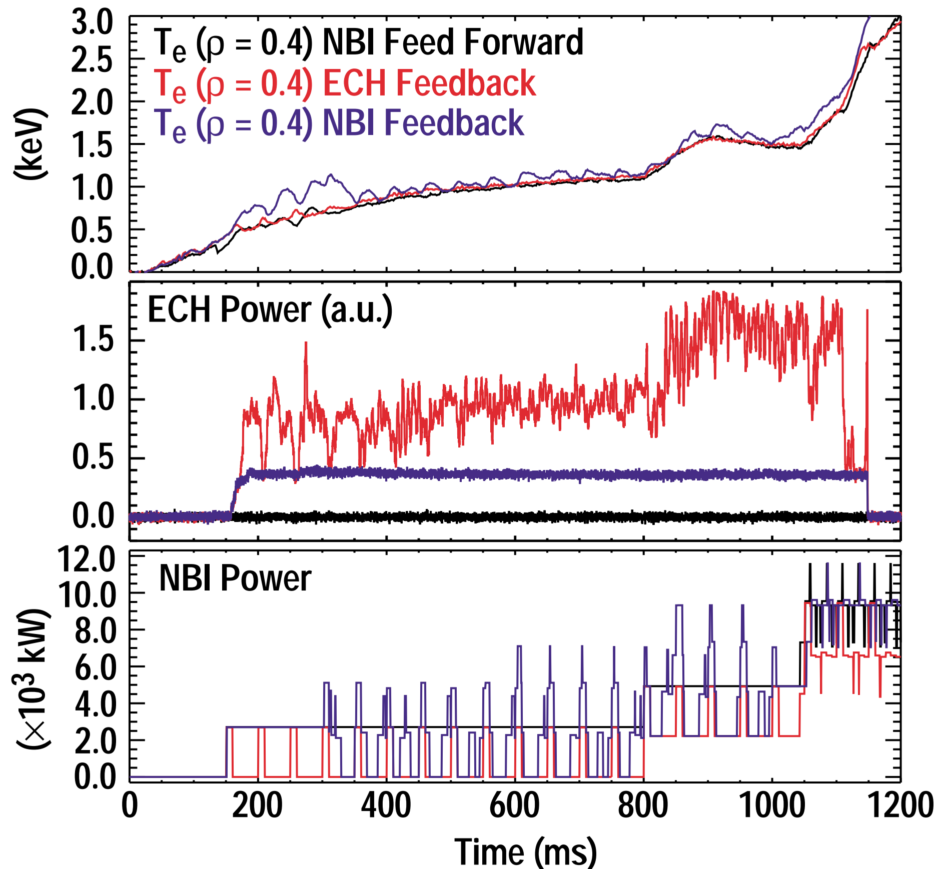
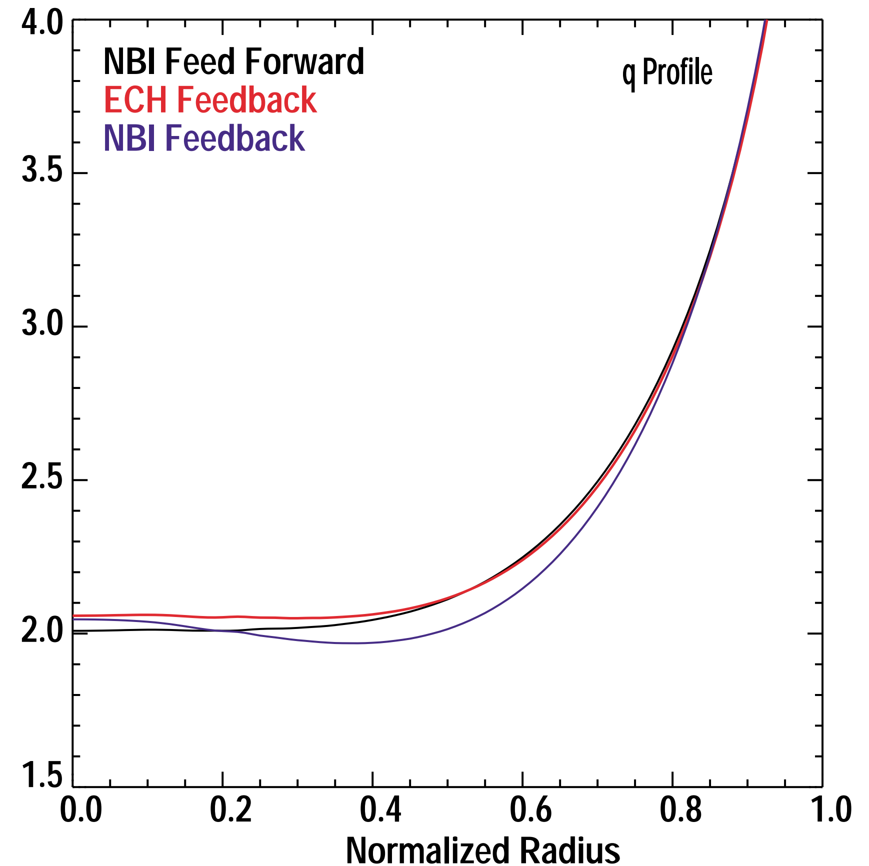
USING T_e FEEDBACK, SIMILAR CURRENT PROFILE EVOLUTION PRODUCED BY VARIETY OF ACTUATORS

- Same T_e evolution gives . . . similar q profile at end of I_p ramp





- Differences due to non-inductive sources (e.g. NBCD in neutral beam case)

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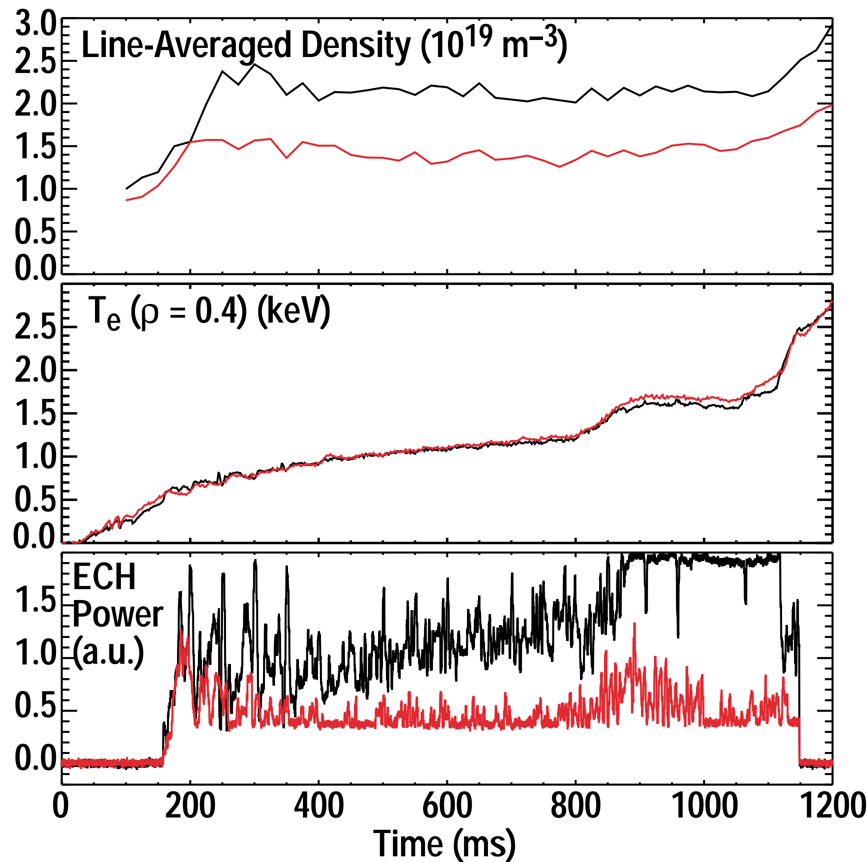
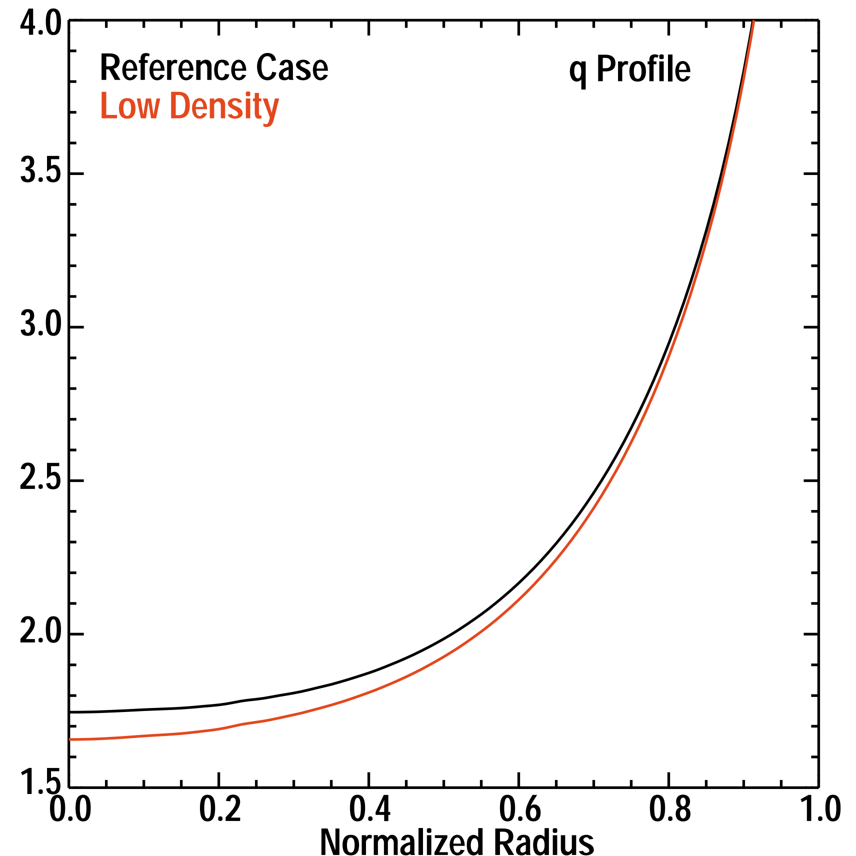
T_e FEEDBACK ALLOWS DECOUPLING OF CURRENT PROFILE AND EVOLUTION FROM PLASMA DENSITY





- Difference due to reduced bootstrap current at lower density
- Benefit: Reduced gas fueling during I_p ramp leads to less wall fueling and lower H–mode density

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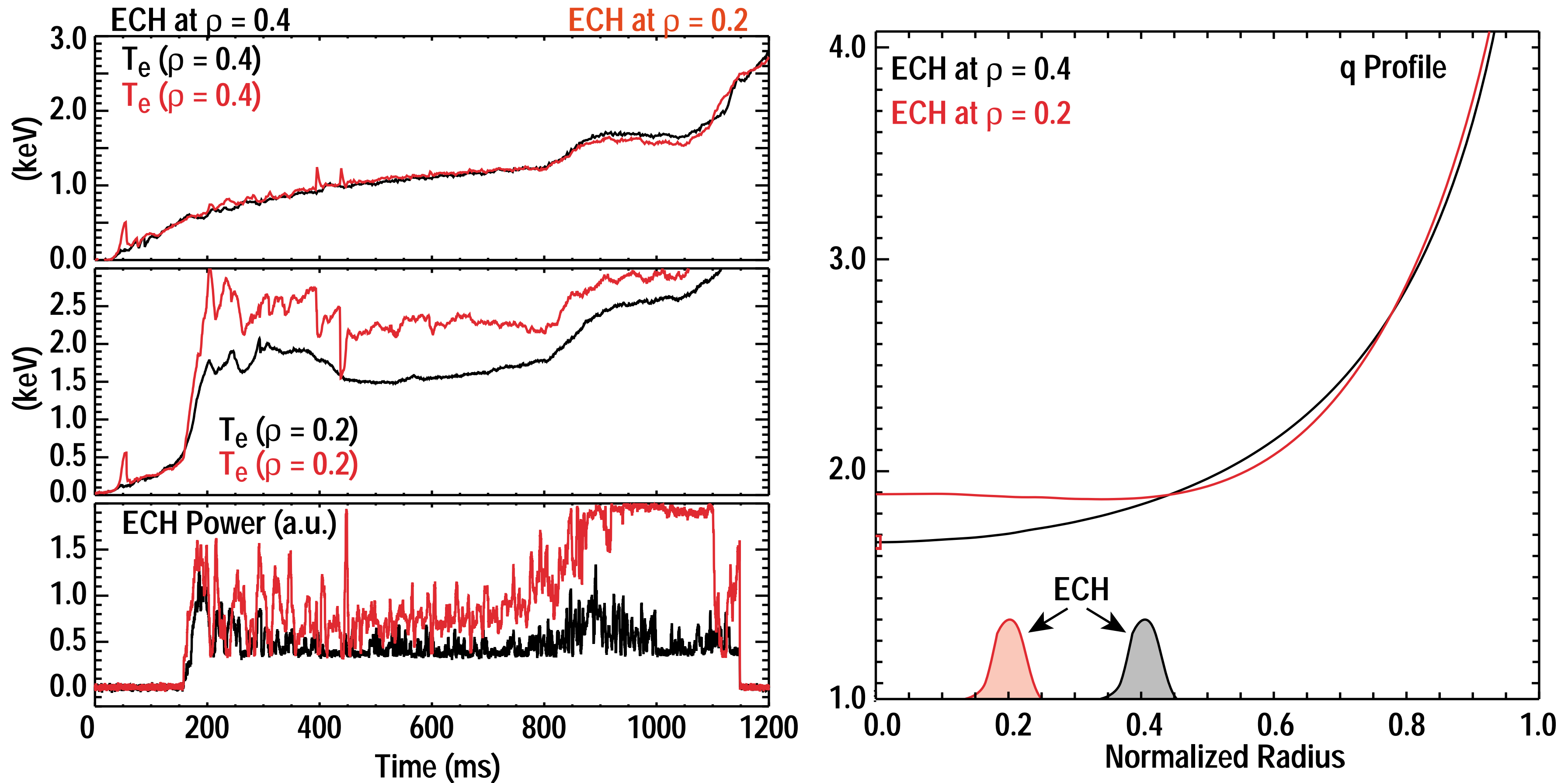
CHANGING ECH DEPOSITION LOCATIONS ALTERS CURRENT PROFILE EVOLUTION

- PCS using ECE signal at ρ = 0.4 as sensor



- As expected, higher central T_e leads to more inverted q profile

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SUMMARY

- Active T_e control has been demonstrated on DIII–D. Made possible by upgrades to several systems
  - Plasma Control System
  - ECH
  - ECE Diagnostic
- Systematic variation in T_e during current ramp shown to slow current penetration
  - Measured $E_{||}$ evolution agrees with that expected from neoclassical resistivity
- Similar q profilles at end of current ramp can be produced in wide variety of conditions and with different actuators
  - Opens up many new possibilities for Advanced Tokamak research