DEVELOPMENT OF METHODS TO CONTROL INTERNAL TRANSPORT BARRIERS IN DIII–D PLASMAS

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MOTIVATION

- For steady state operation of high performance plasmas with internal transport barrier (ITBs), need control of ITB location and profile gradients

- Larger ITB radius and wider ITB widths leads to:
  - Higher fusion performance with larger plasma volume at high confinement levels
  - Improved MHD stability limits with broader pressure profiles
  - Improved bootstrap current alignment

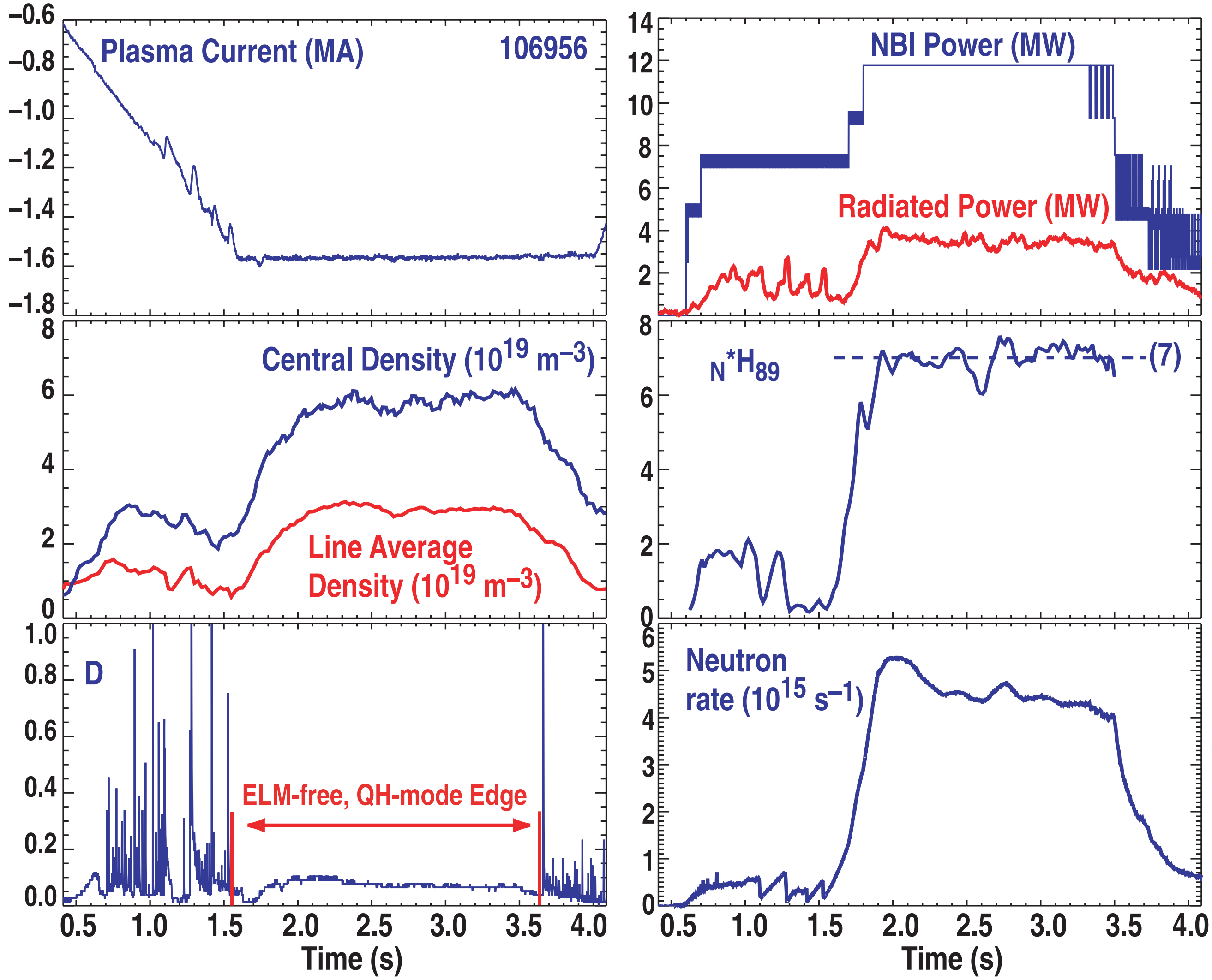
- Specifically QDB plasma tend to have peaked density profiles which leads to poor bootstrap current alignment and high z impurity accumulation on-axis
  - Need means to reduce the density peakedness in QDB plasmas

SUMMARY

- Various methods have been investigated to modify and control the plasma profiles in QDB plasmas
  - — On-axis and off-axis ECH
  - — Impurity injection (neon, argon, krypton)
  - — Off-axis pellet injection
- On-axis ECH was effective at reducing the central electron density and increasing the central electron temperature
  - — Significantly reduced the toroidal rotation, but did not adversely affect the ion temperature
- Both neon and argon increased and broadened the electron density
  - — However, both Ne and Ar reduced T_i and v_ϕ with Ne producing a larger reduction
- Krypton produced a transient increase in all the profiles, but led to disruptions as a result of unmanageable krypton inventory
- Off-axis pellet injection broadened the density profile and produced a transient increase in performance, but reduced T_i and v_ϕ and the final performance level
  - — Need to add more heating power

COMBINATION OF CORE ITB AND QH–MODE EDGE RESULTS IN SUSTAINED HIGH PERFORMANCE IN QDB PLASMAS

- $\beta_N H_{89}$ = 7 for 10 τ_E (1.6 s)
- Example of quiescent operation without EHO, but with global 1/1 mode
- Same performance obtained in discharges with EHO



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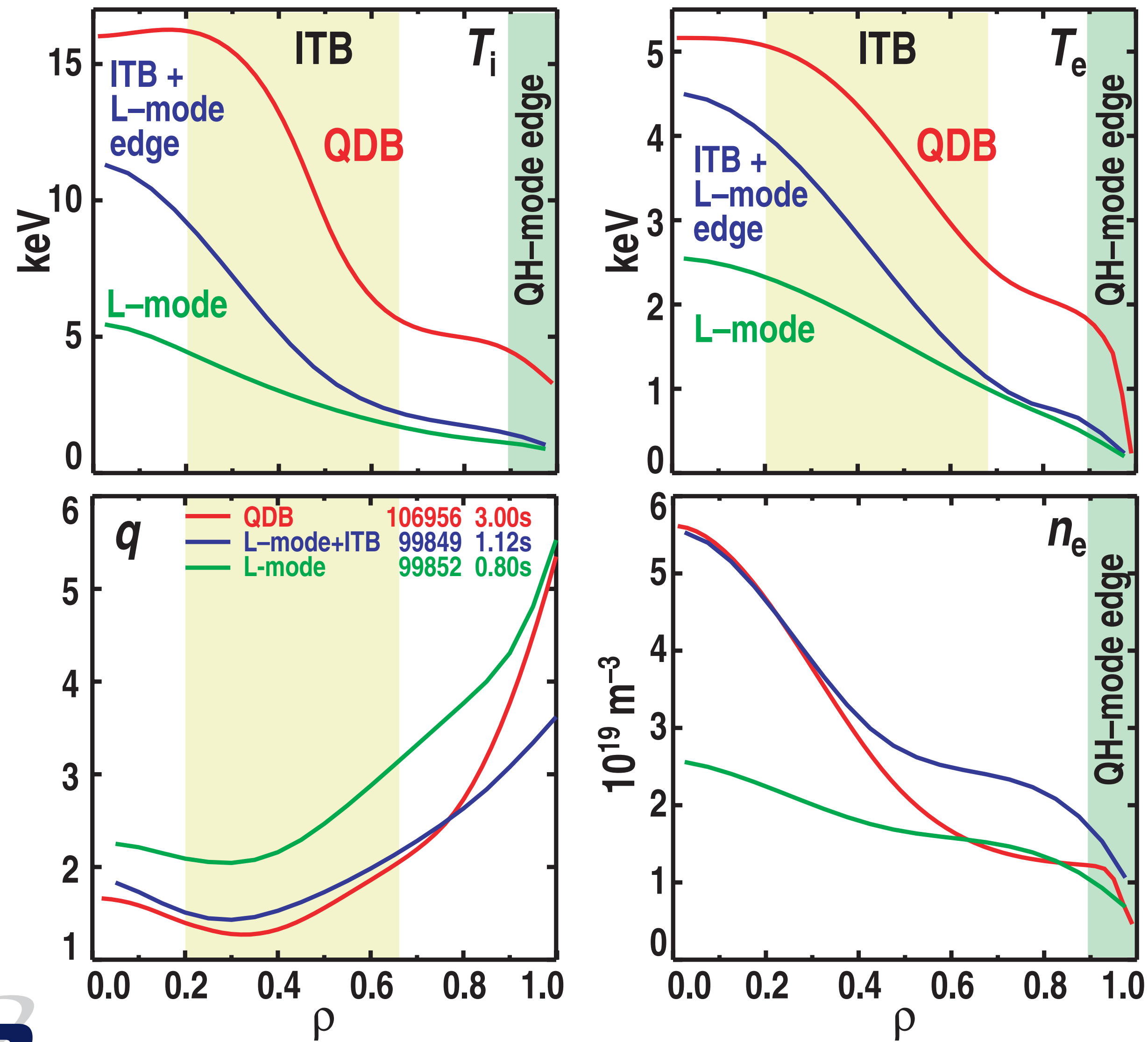
QDB REGIME COMBINES CORE TRANSPORT BARRIER WITH QUIESCENT EDGE BARRIER — "QUIESCENT DOUBLE BARRIER"

- Need to develop tools to control the profiles



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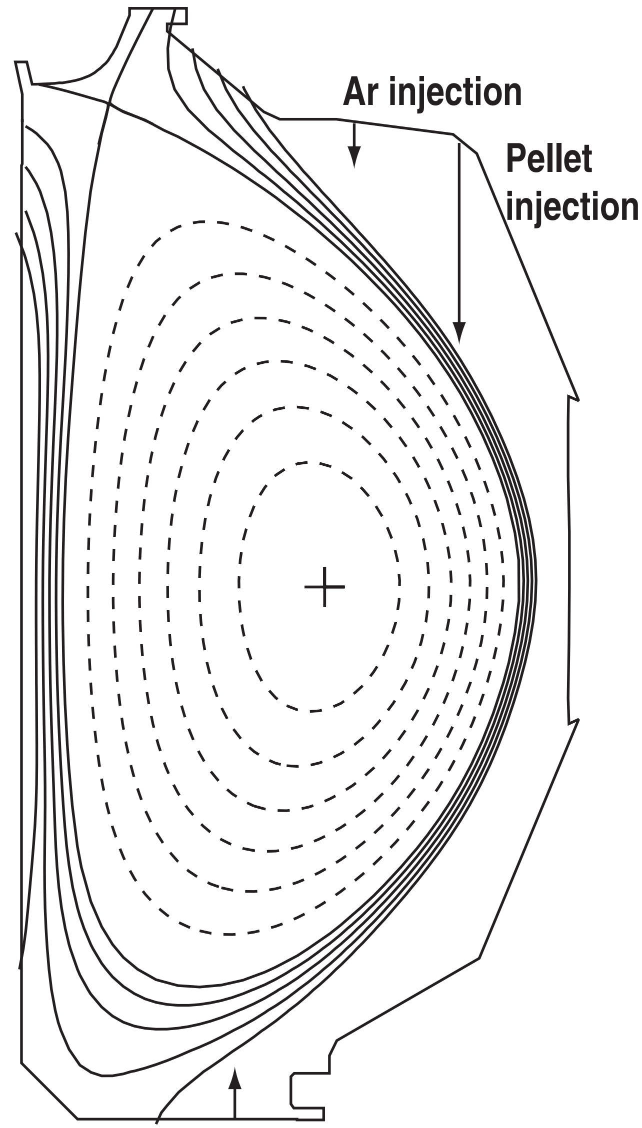
PLASMA AND TOOL SPECIFICATIONS

- **QDB target plasmas**
  - Upper single null diverted
  - I_p = 1.6 MA, B_T = 2.0 T, κ = 1.9, δ (upper) = 0.8, δ (lower) = 0.4, outside gap = 12 cm
  - Both upper cryopumps
  - Counter-NBI
- **ECH**
  - Radial launch, ρ = 0.12, 0.36, 0.57, 0.70
  - 110 GHZ, P_{ECH} ~2 MW
- **Impurity injection**
  - Neon
  - Argon
  - Krypton
- **Pellet injection**
  - Solid deuterium, vertical injection, ρ (tangency) ~ 0.7
  - Diameter = 2.7 mm
  - Low field side launch

GAS IMPURITIES AND PELLETS WERE INJECTED FROM SEVERAL LOCATIONS AROUND THE DIII–D VESSEL

- Upper single-null divertor configuration
- I_p = 1.6 MA, B_T = 2.0 T
- Large outside gap (~12 cm)
- Cryopumping at upper divertor



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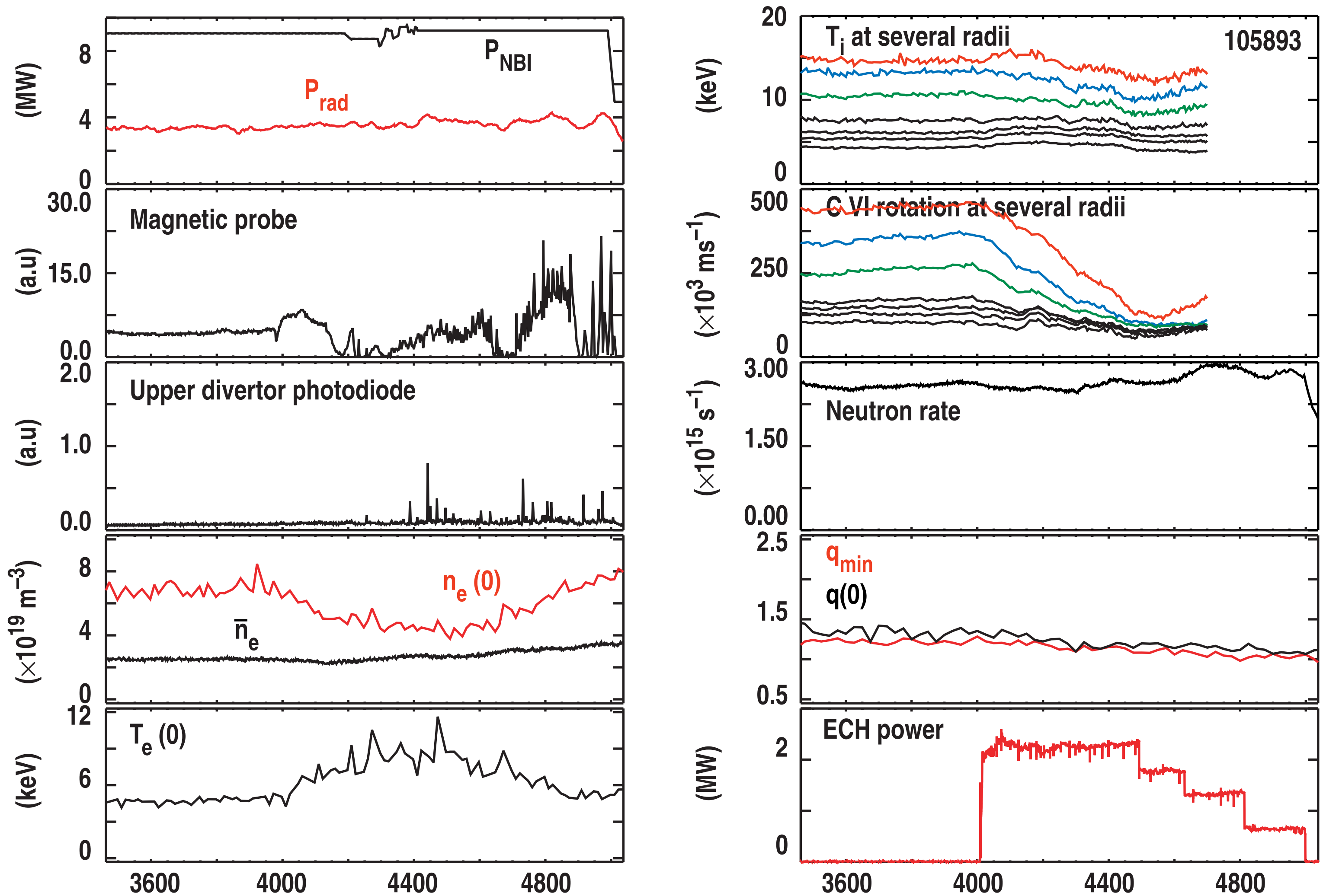
APPLICATION OF NEAR ON-AXIS ECH INCREASES THE CENTRAL ELECTRON TEMPERATURE BUT REDUCES THE TOROIDAL ROTATION

- ECH leads to ELMing H–mode — however not always the case



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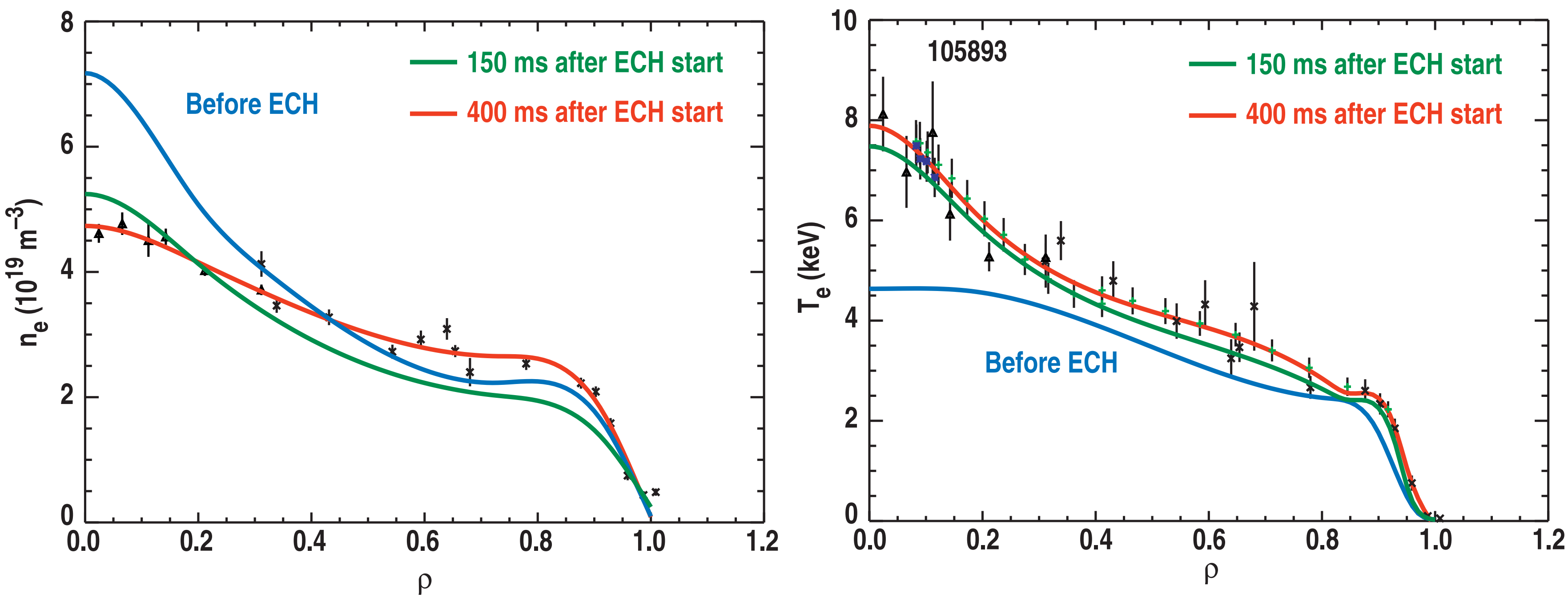
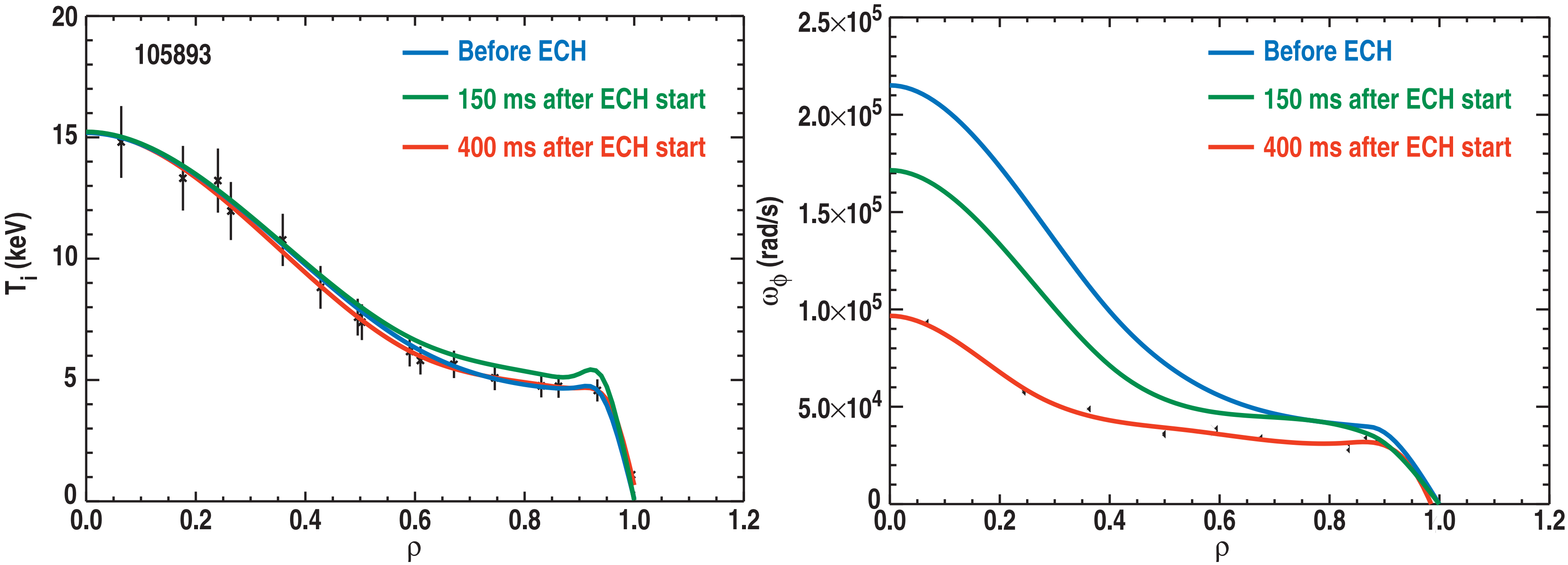
ON-AXIS ECH REDUCES THE CENTRAL DENSITY AND INCREASES THE CENTRAL ELECTRON TEMPERATURE

- The density profile becomes broader, but central density is reduced
- The electron temperature is more peaked
- P_{ECH} ~ 2 MW, ρ_{ECH} ~ 0.12



ON-AXIS ECH SIGNIFICANTLY REDUCES THE TOROIDAL ROTATION ACROSS THE PLASMA

- The ion temperature is not affected by the ECH



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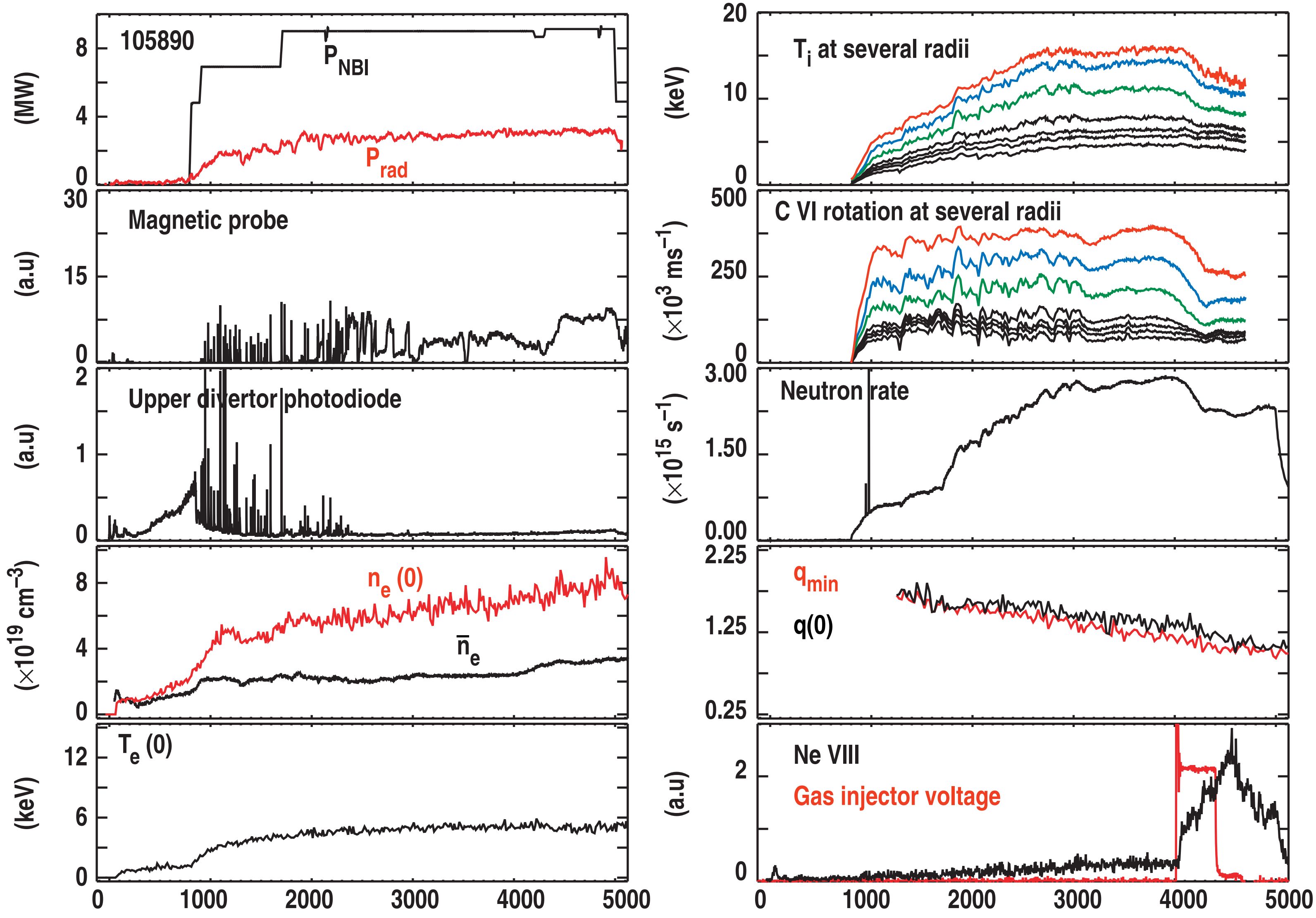
NEON INJECTION DOES NOT STRONGLY AFFECT THE EHO CHARACTERISTICS BUT PERFORMANCE IS REDUCED

- Excessive neon leads to ELMing H–mode or to L–mode edge



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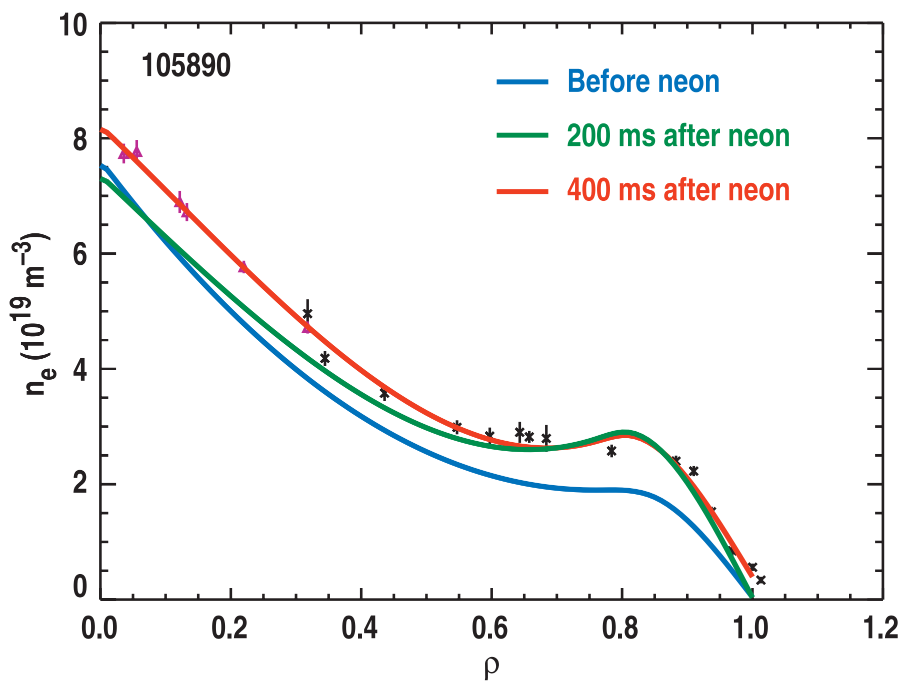
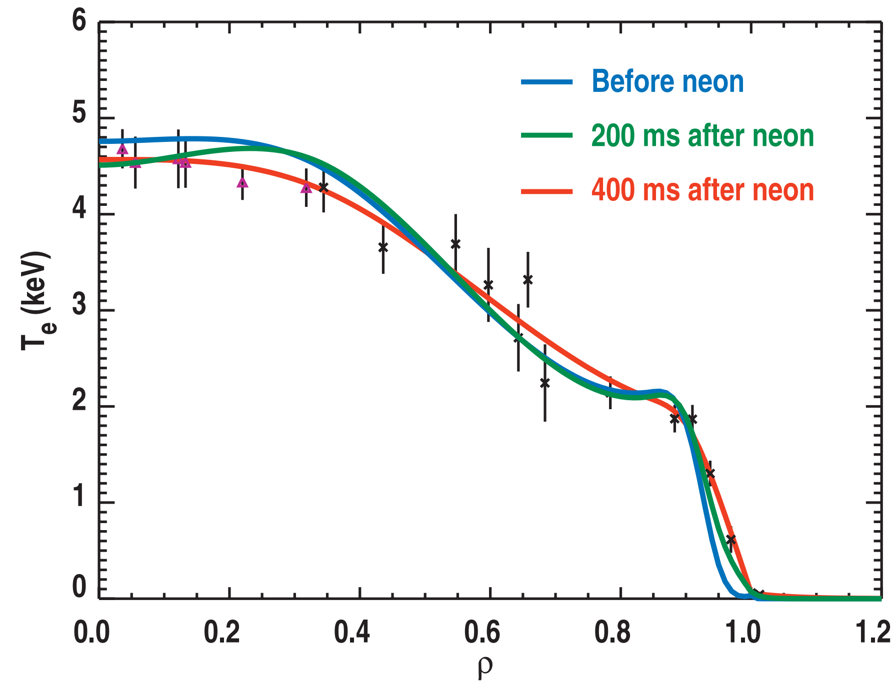
NEON INJECTION INCREASES AND BROADENS THE DENSITY PROFILE





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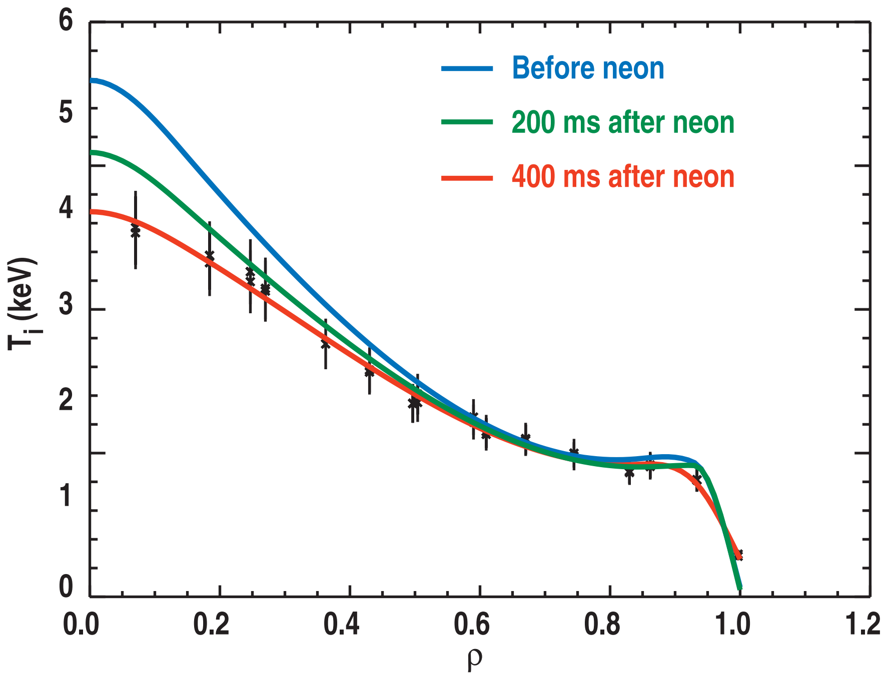
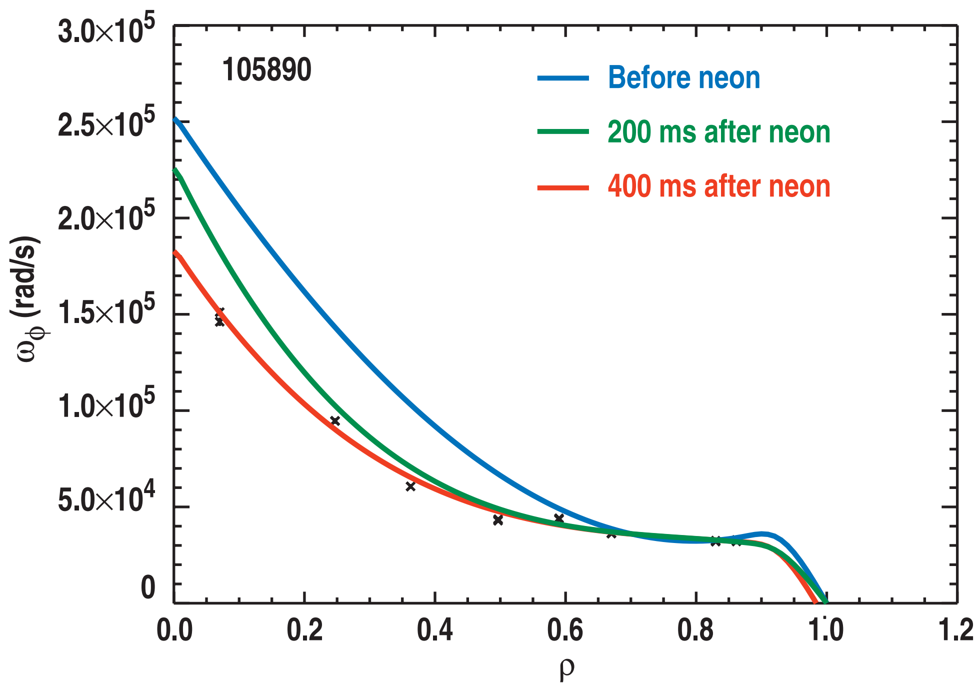
NEON INJECTION LEADS TO REDUCTION IN THE CENTRAL ION TEMPERATURE AND TOROIDAL ROTATION





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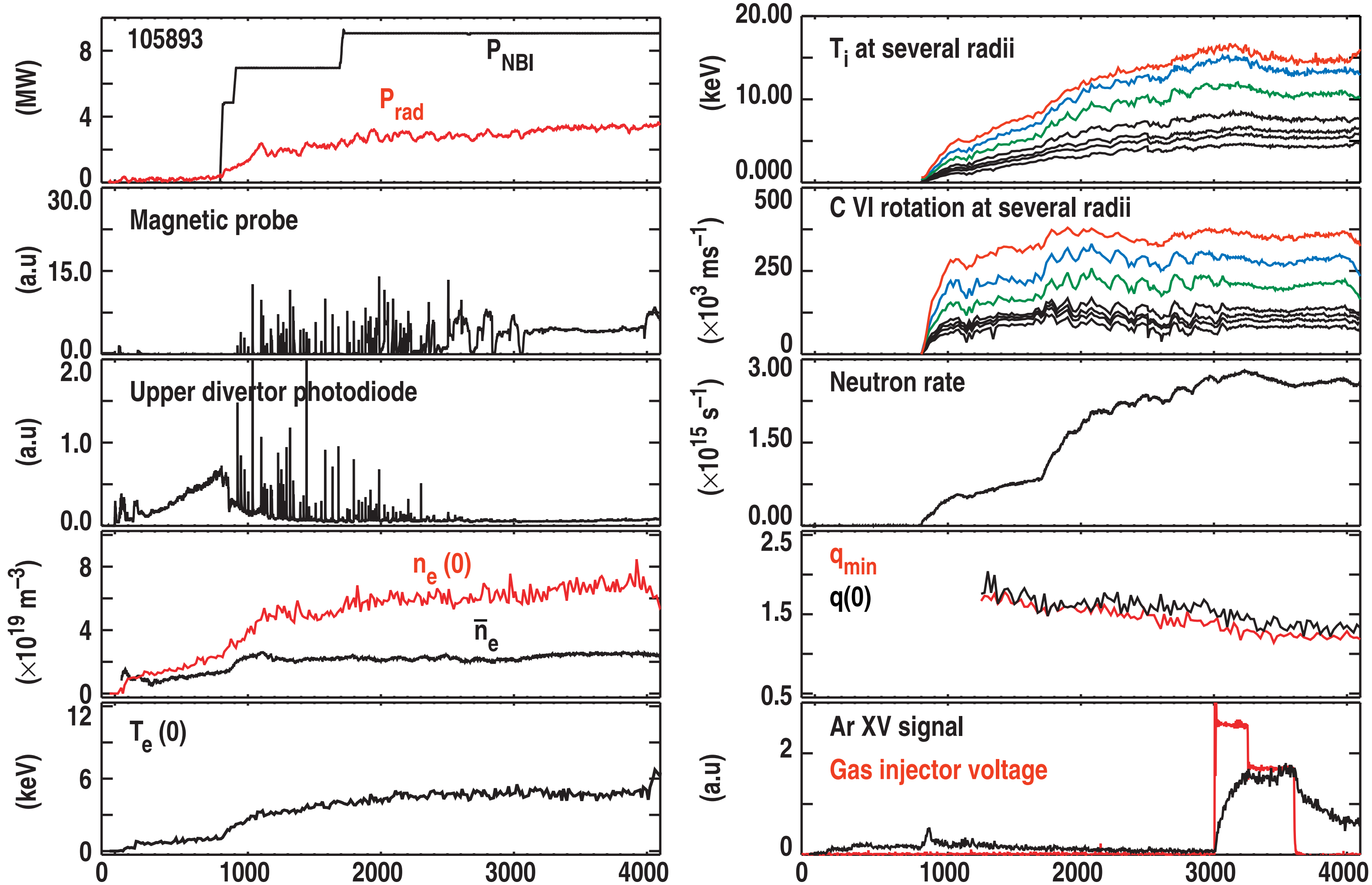
ARGON INJECTION AT MODERATE LEVELS DOES NOT PRODUCE ANY CHANGE IN THE PLASMA PERFORMANCE

- Strong argon injection leads to loss of EHO and QH–mode edge



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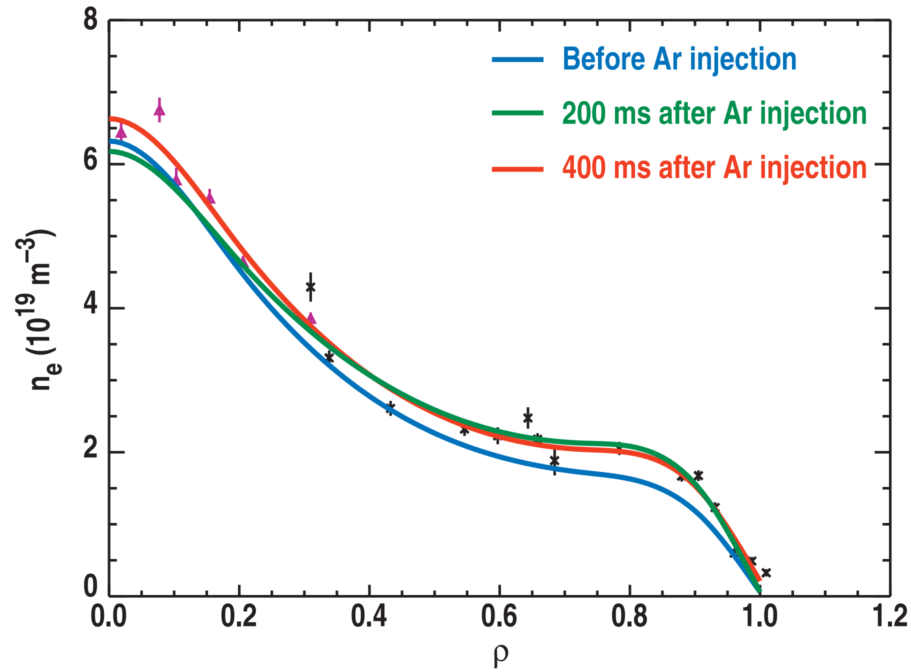
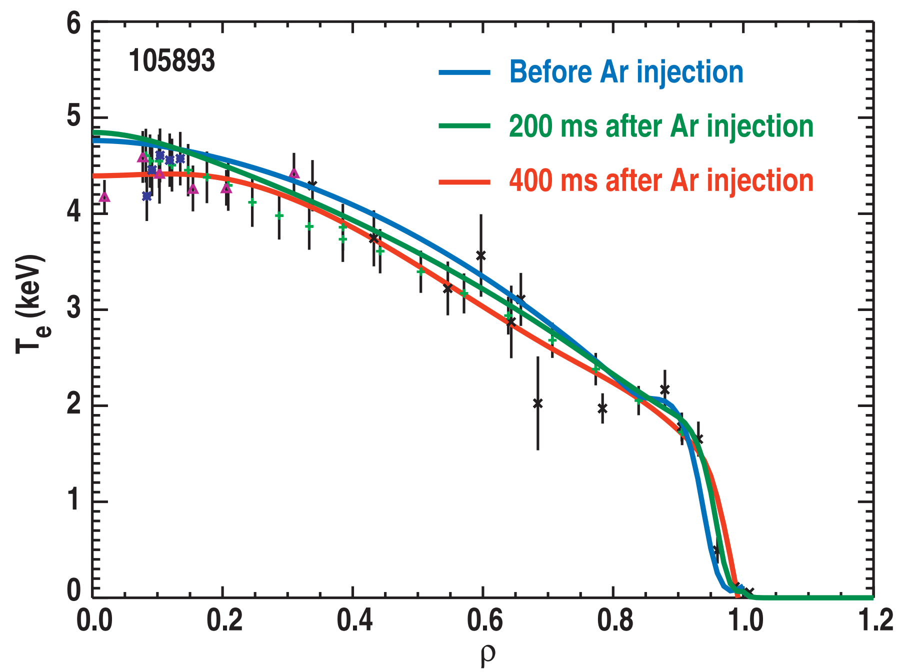
ARGON INJECTION LEADS TO A MODEST BROADENING OF THE ELECTRON DENSITY PROFILE AND LOWERING OF THE ELECTRON TEMPERATURE PROFILE

- Large amounts of argon degrade the neutron rate
- QH–mode edge is lost at high argon doses





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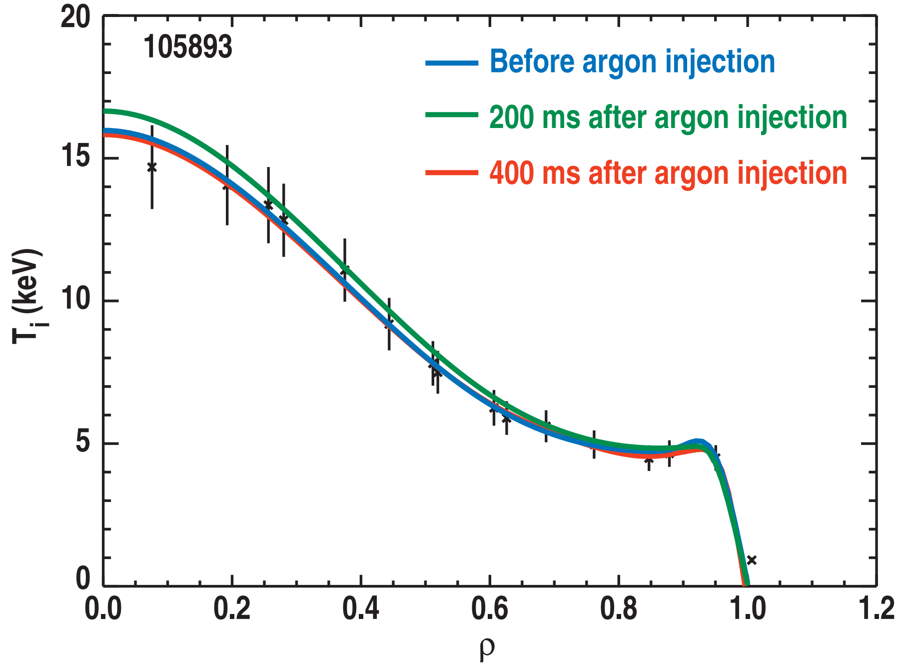
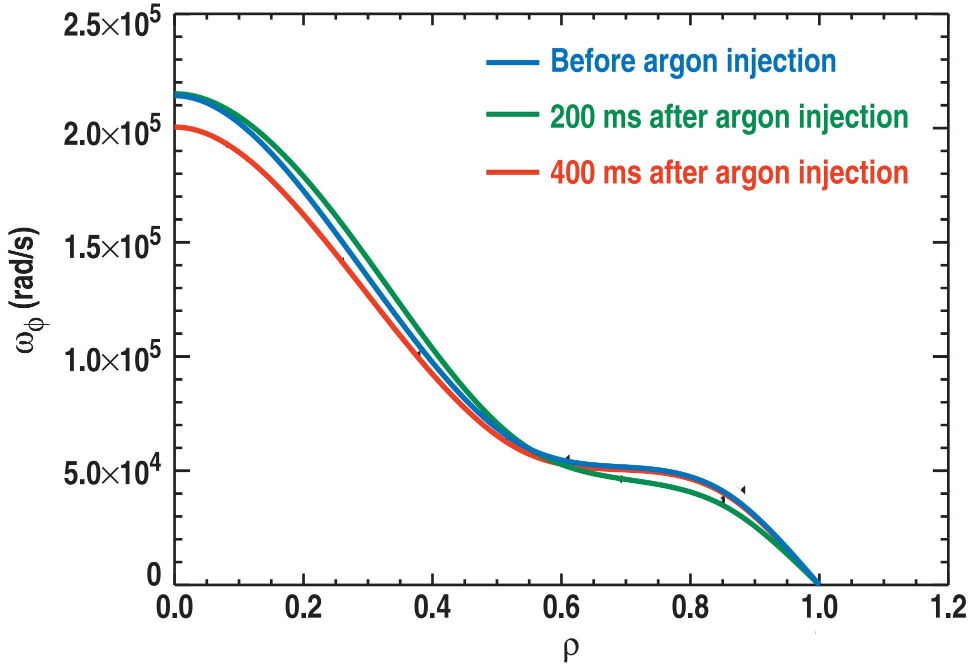
ARGON INJECTION PRODUCES A SLIGHT REDUCTION IN THE ION TEMPERATURE AND TOROIDAL ROTATION

- Peaked ion temperature and toroidal rotation profile are maintained after modest argon injection





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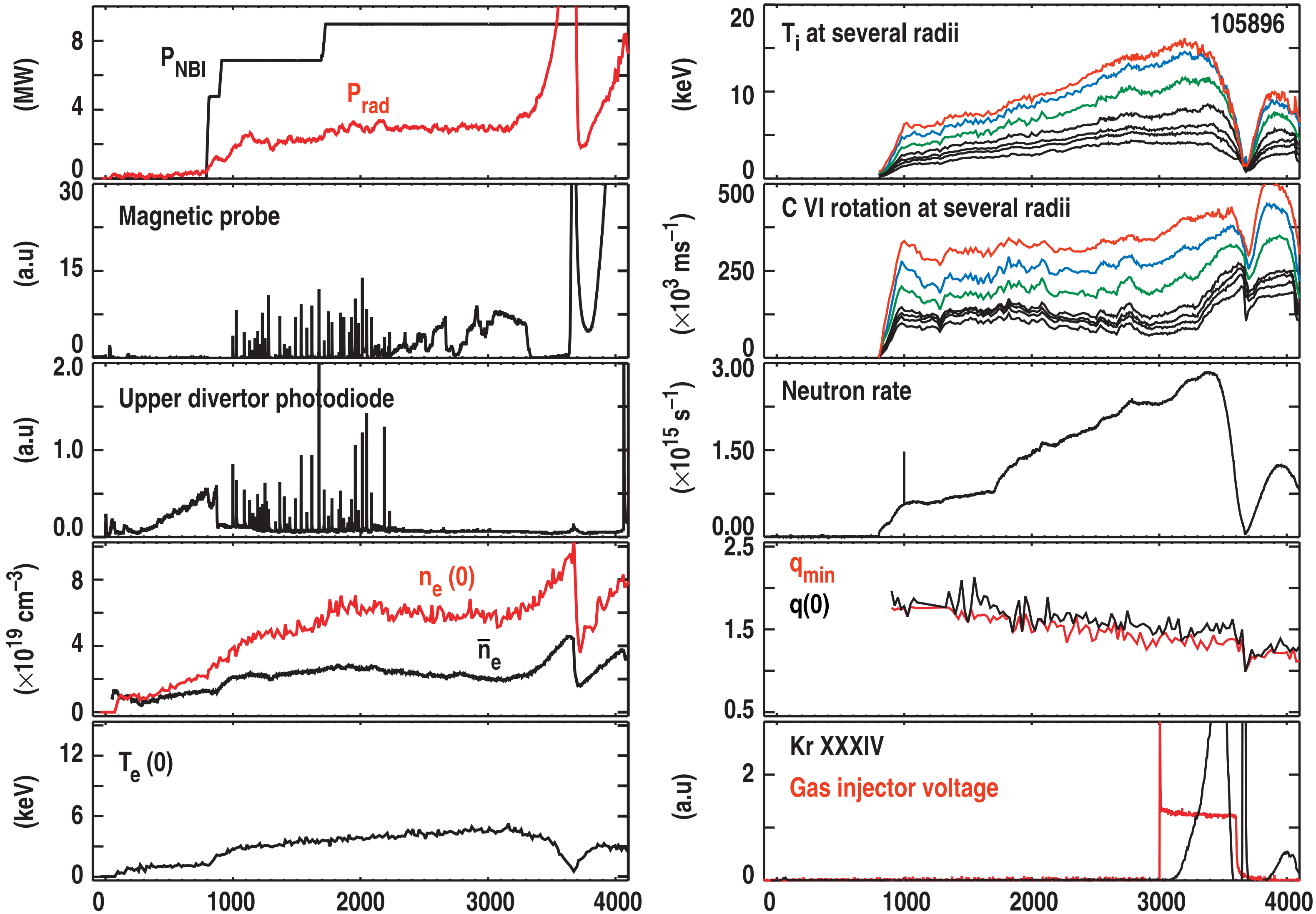
KRYPTON INJECTION DESTROYS THE EHO AND FINALLY LEADS TO DISRUPTION

- Krypton is retained from shot to shot – hard to control amount consistently



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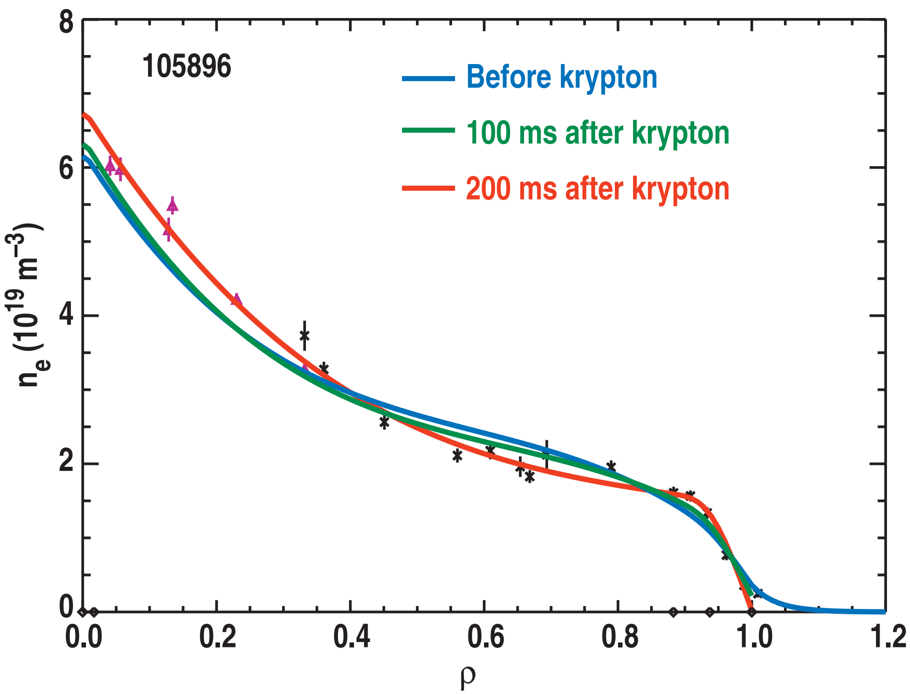
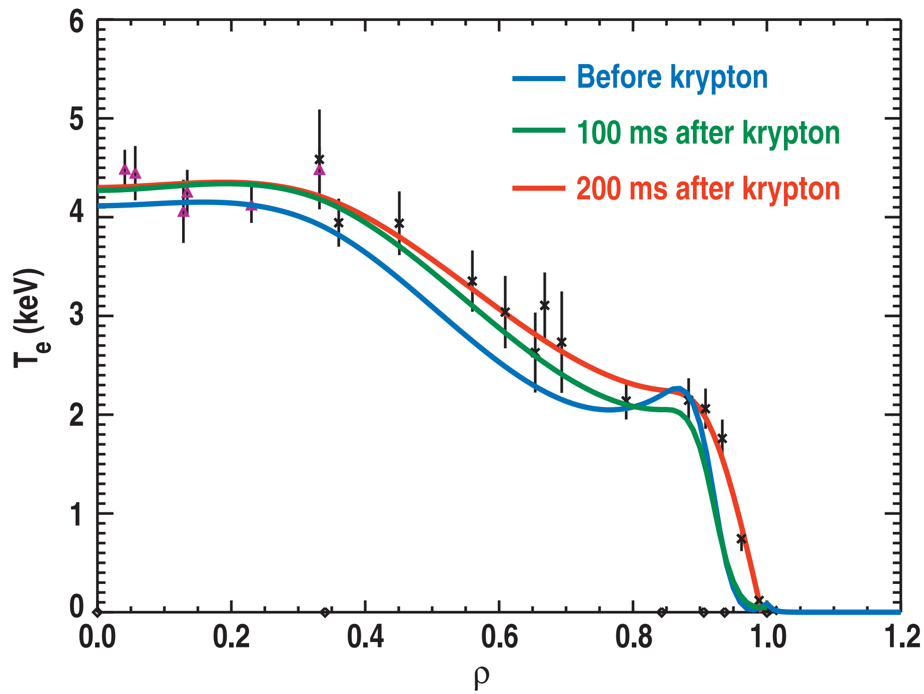
KRYPTON INJECTION INCREASES THE CENTRAL ELECTRON DENSITY, BUT KRYPTON LEVEL IS UNMANAGEABLE





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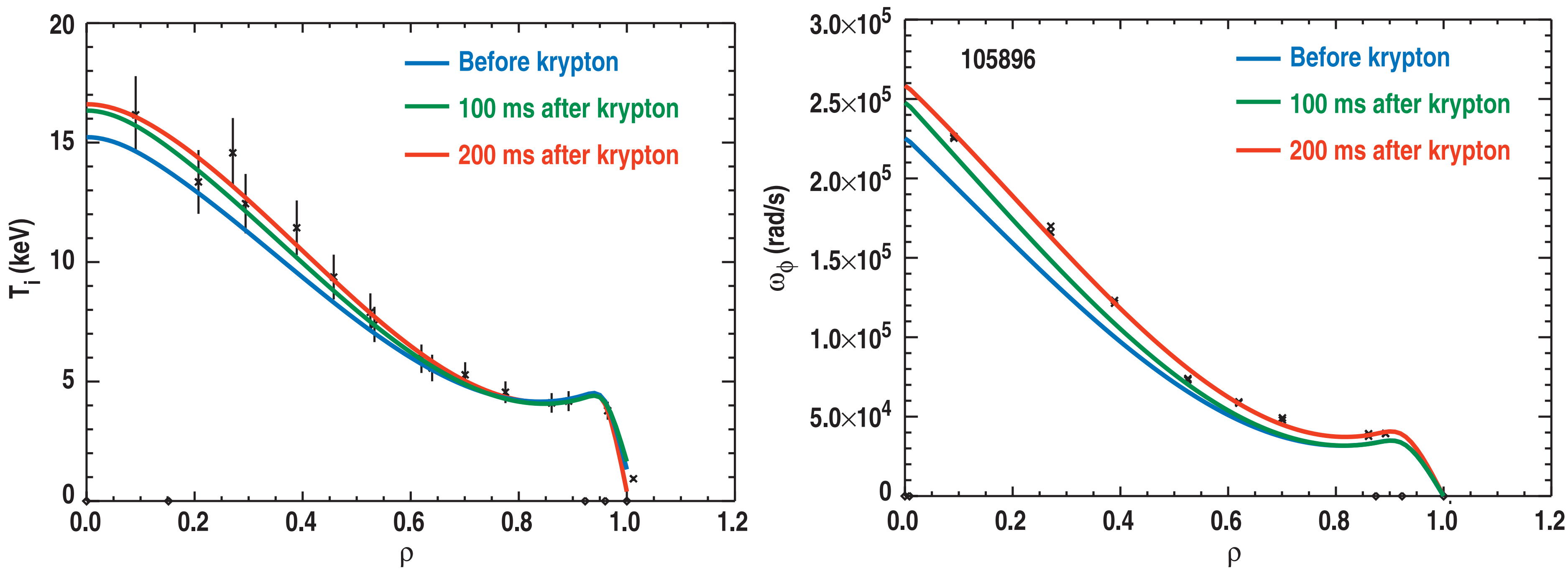
KRYPTON INJECTION LEADS TO AN INCREASE IN BOTH THE ION TEMPERATURE AND TOROIDAL ROTATION PROFILES BEFORE THE DISRUPTION



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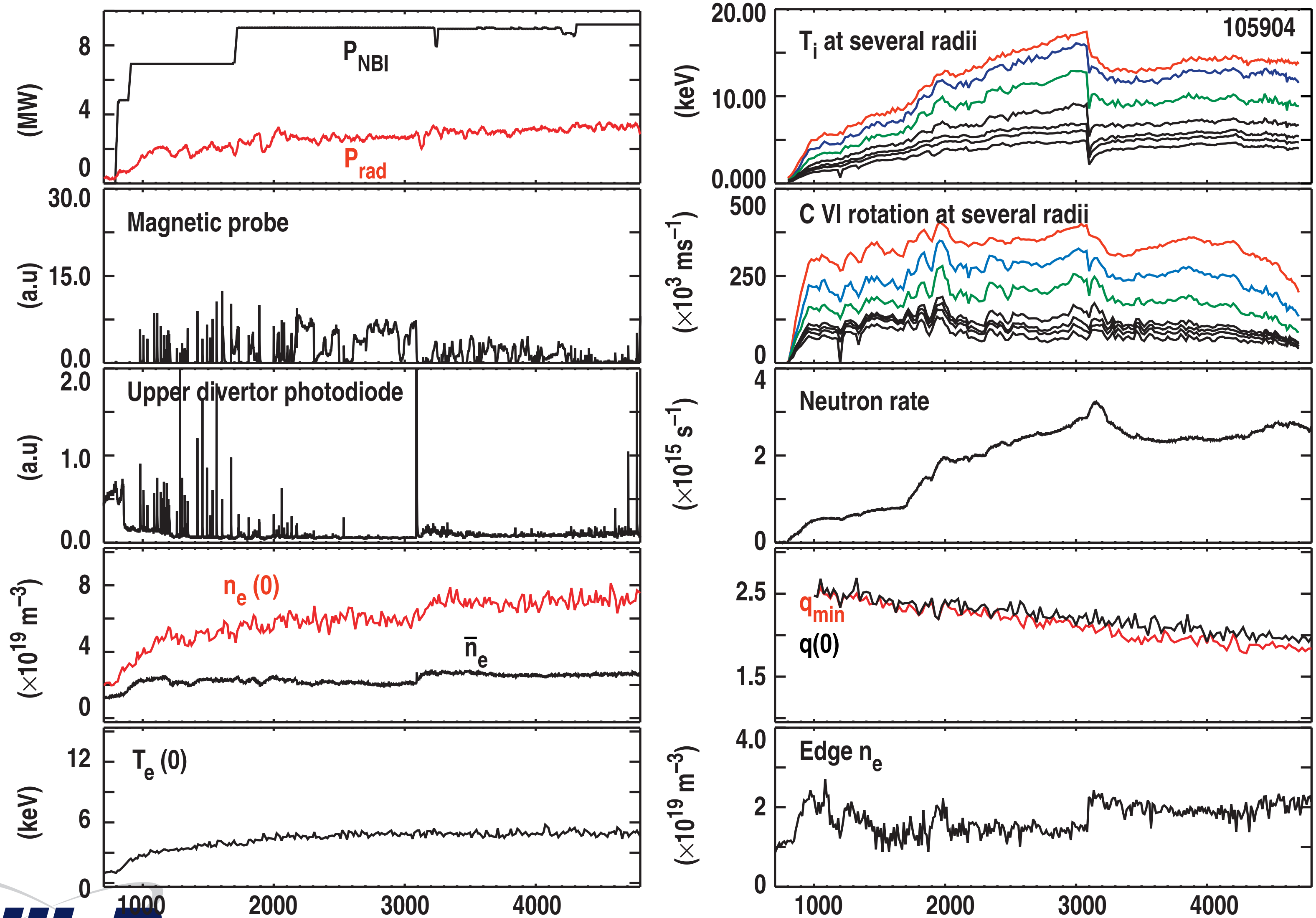
OFF-AXIS PELLET INJECTION PRODUCES A TRANSIENT INCREASE IN THE NEUTRON FLUX

- However, the overall performance is reduced later in time



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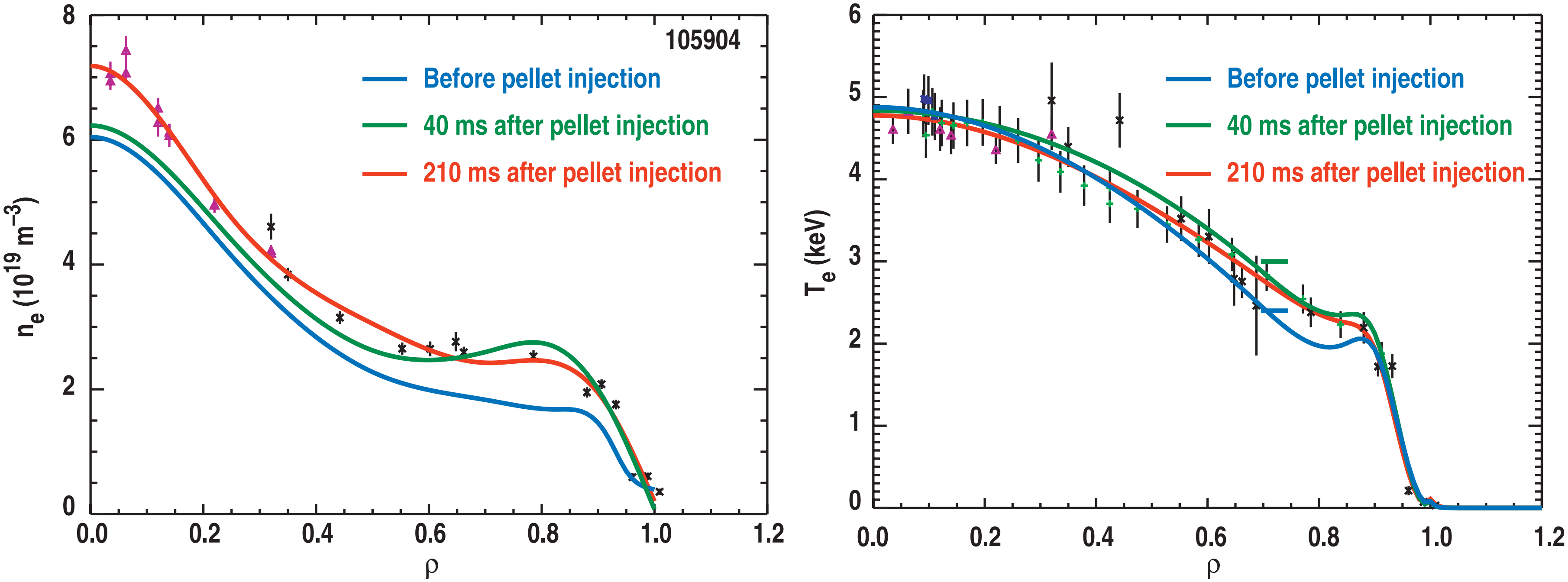
THE OFF-AXIS PELLET INCREASES AND BROADENS THE DENSITY PROFILE



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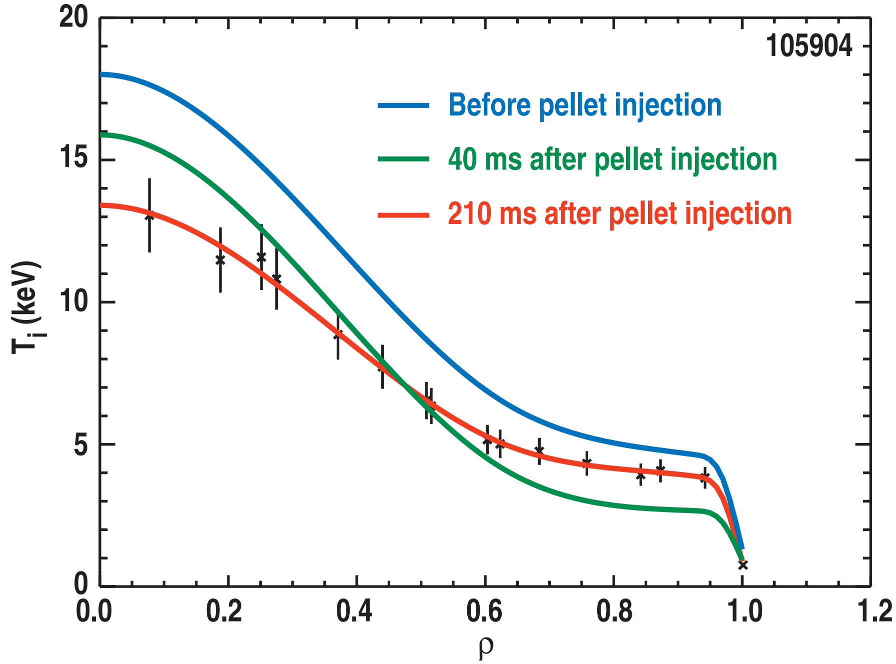
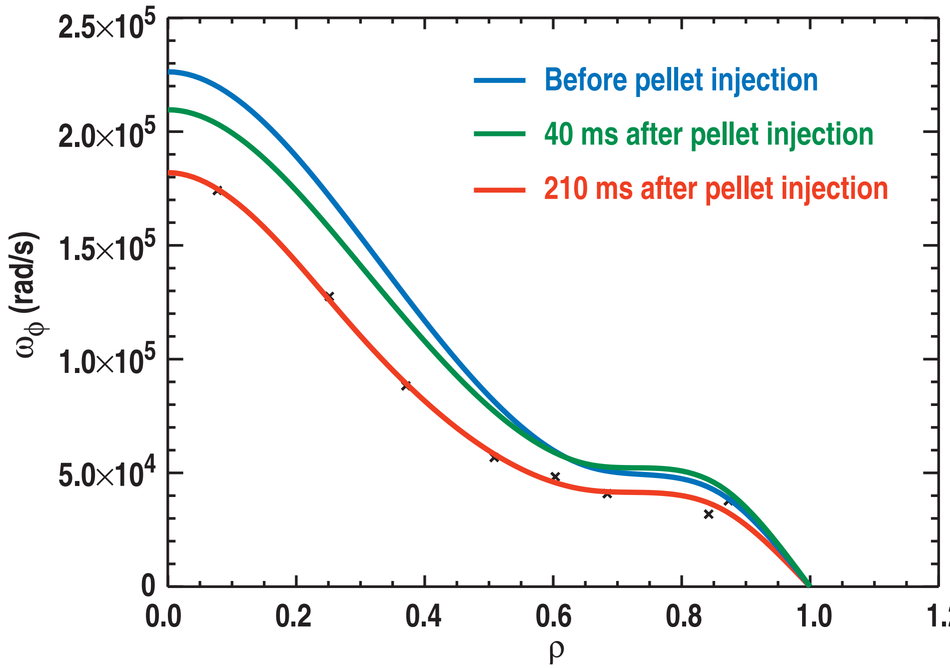
OFF-AXIS PELLET INJECTION WEAKENS THE INTERNAL BARRIERS FOR T_i AND ω_ϕ IN QDB PLASMAS





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