THE GOAL OF THE DIII–D ADVANCED TOKAMAK PROGRAM IS TO DEVELOP THE BASIS FOR A STEADY-STATE, HIGH PERFOMANCE TOKAMAK

- Need simultaneously:
  - High fusion power density ⇒ High plasma pressure (high β)
  - High fusion gain ⇒ Good energy confinement (high τ_E)
  - Non-inductive current sustainment ⇒ High current drive efficiency, High bootstrap fraction (high β_P)

- Gain and bootstrap current have conflicting scaling
  - Fusion gain: $\beta\tau_E \propto (\beta_N/q)\ (H_{89}/q^{\alpha})$ $\alpha \sim 2$
  - Bootstrap current: $f_{BS} \propto \beta_p \propto q\ \beta_N$

⇒ β_N and H_{89} above conventional values are required for a fully non-inductive scenario

Definitions: $\beta_N = \beta/(I/aB)$ $H_{89} = \tau_E / \tau_{E,ITER89P}$

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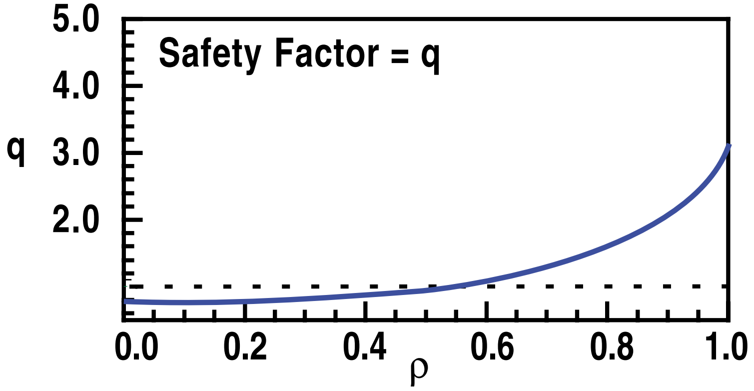
COMPARISON OF CONVENTIONAL AND ADVANCED TOKAMAK FEATURES

Conventional



Features of Monotonic q Profile:

High gain

Moderate turbulence

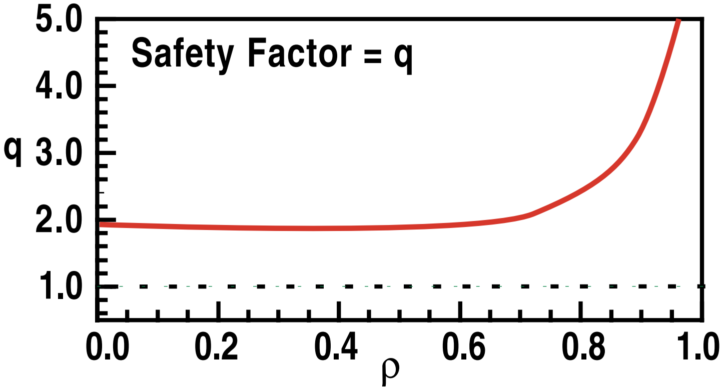
Resistive modes limit β

$f_{BS} < 30$ %; $H_{89P} < 2.0$; $\beta_N < 2.5$

↓

Pulsed

Advanced



Features of High q_{min} and Low Shear:

High f_{BS}

Reduced turbulence

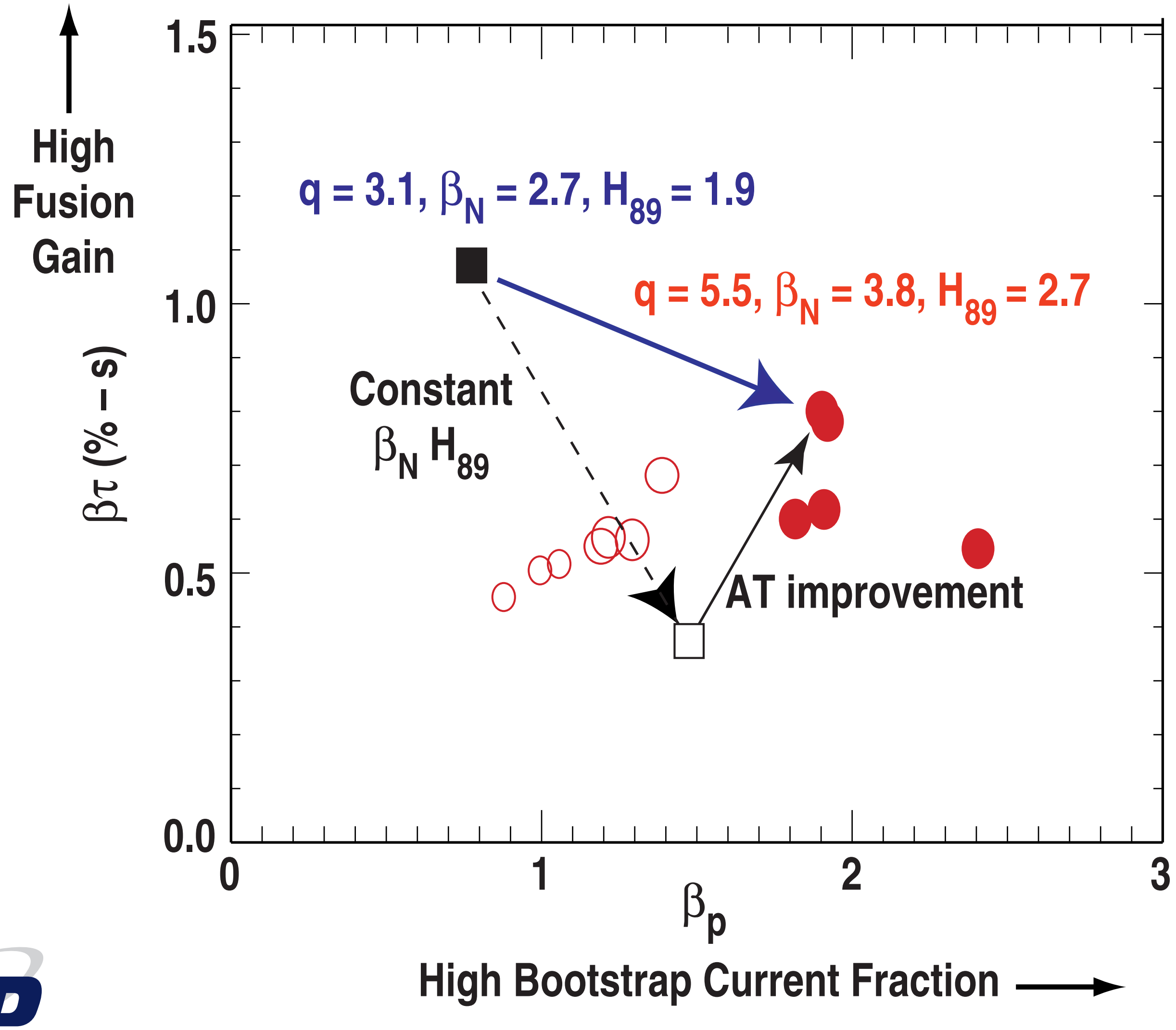
Ideal modes limit β

$f_{BS} > 50$ %; $H_{89P} > 2.5$; $\beta_N > 3.5$

↓

Potential for Steady-State

POTENTIAL FOR STEADY-STATE IS ACHIEVED WITH MODERATE REDUCTION IN FUSION GAIN



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COMPARISON OF CONVENTIONAL AND ADVANCED TOKAMAK DISCHARGES AT CONSTANT SIZE, SHAPE AND FIELD

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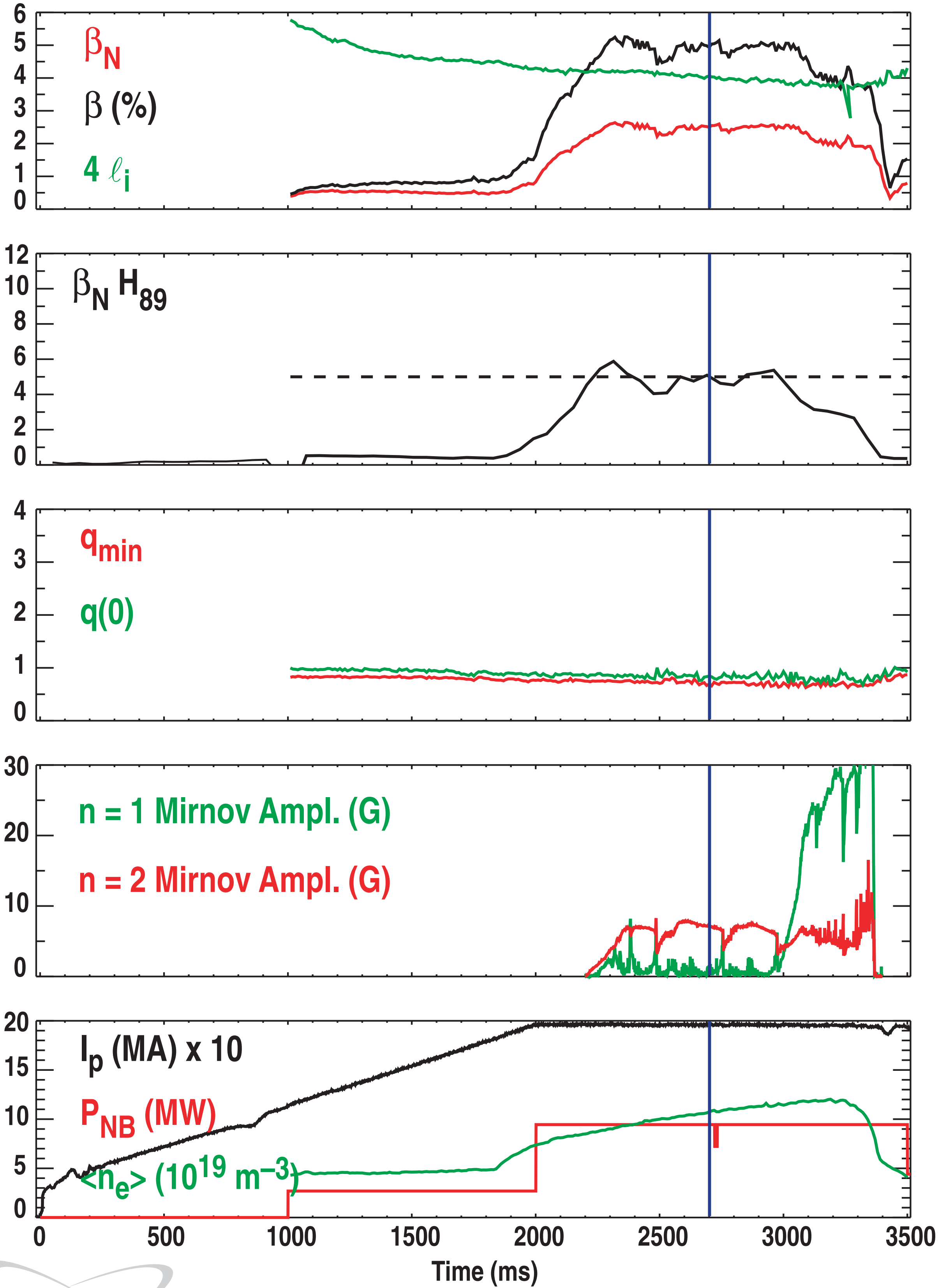
CONVENTIONAL ELMING H–MODE DISCHARGE (q_{95} = 3.1)



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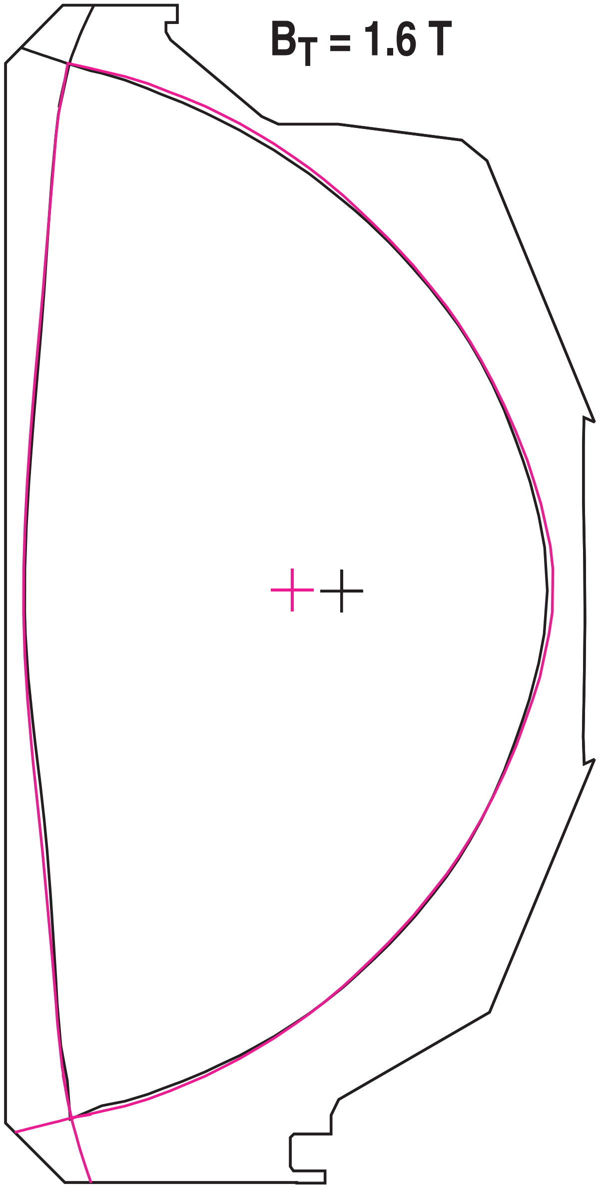
SHAPE, SIZE, AND TOROIDAL FIELD ARE MATCHED



$B_T = 1.6$ T

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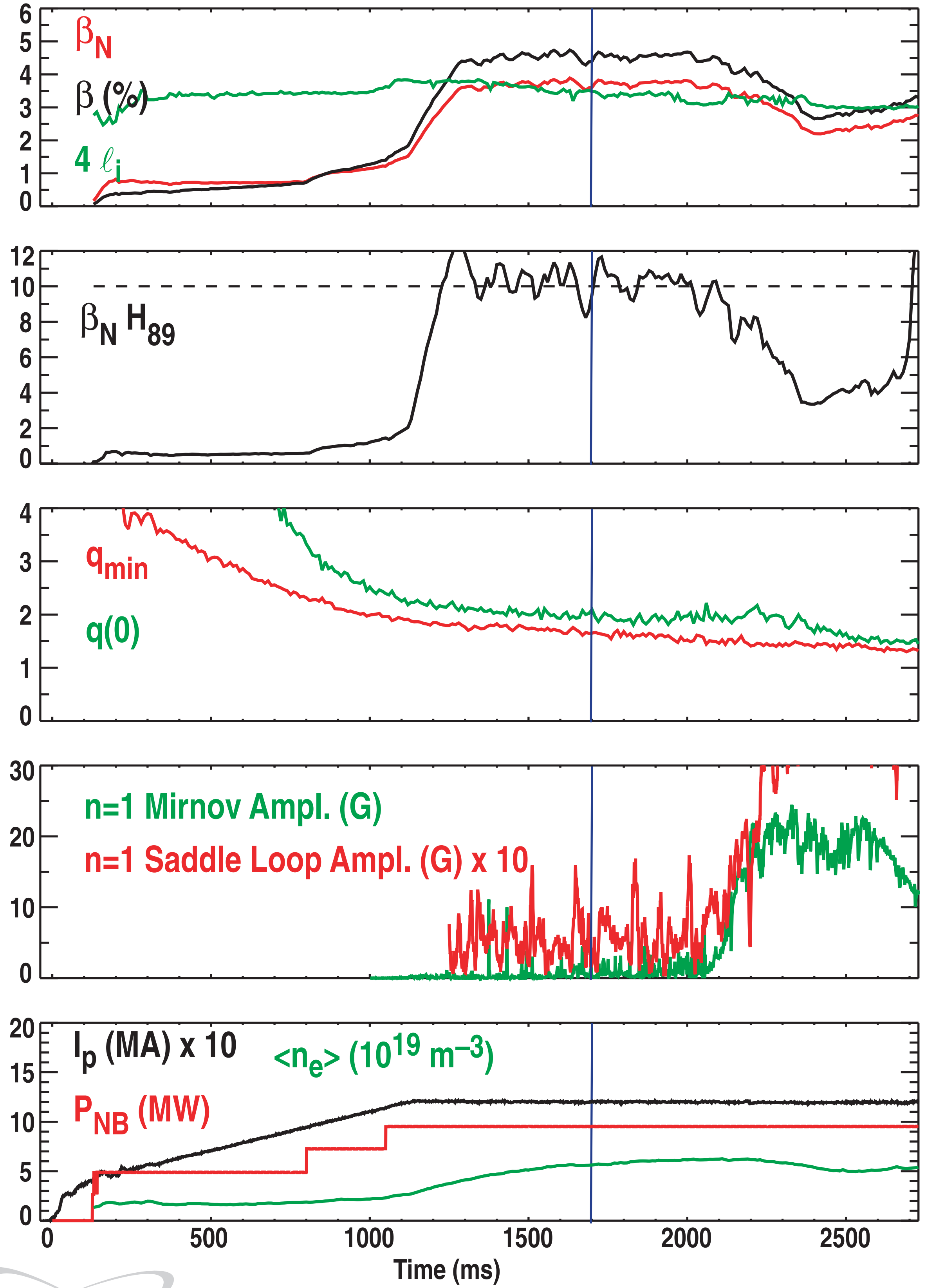
ADVANCED TOKAMAK DISCHARGE (q_{95} = 5.5)



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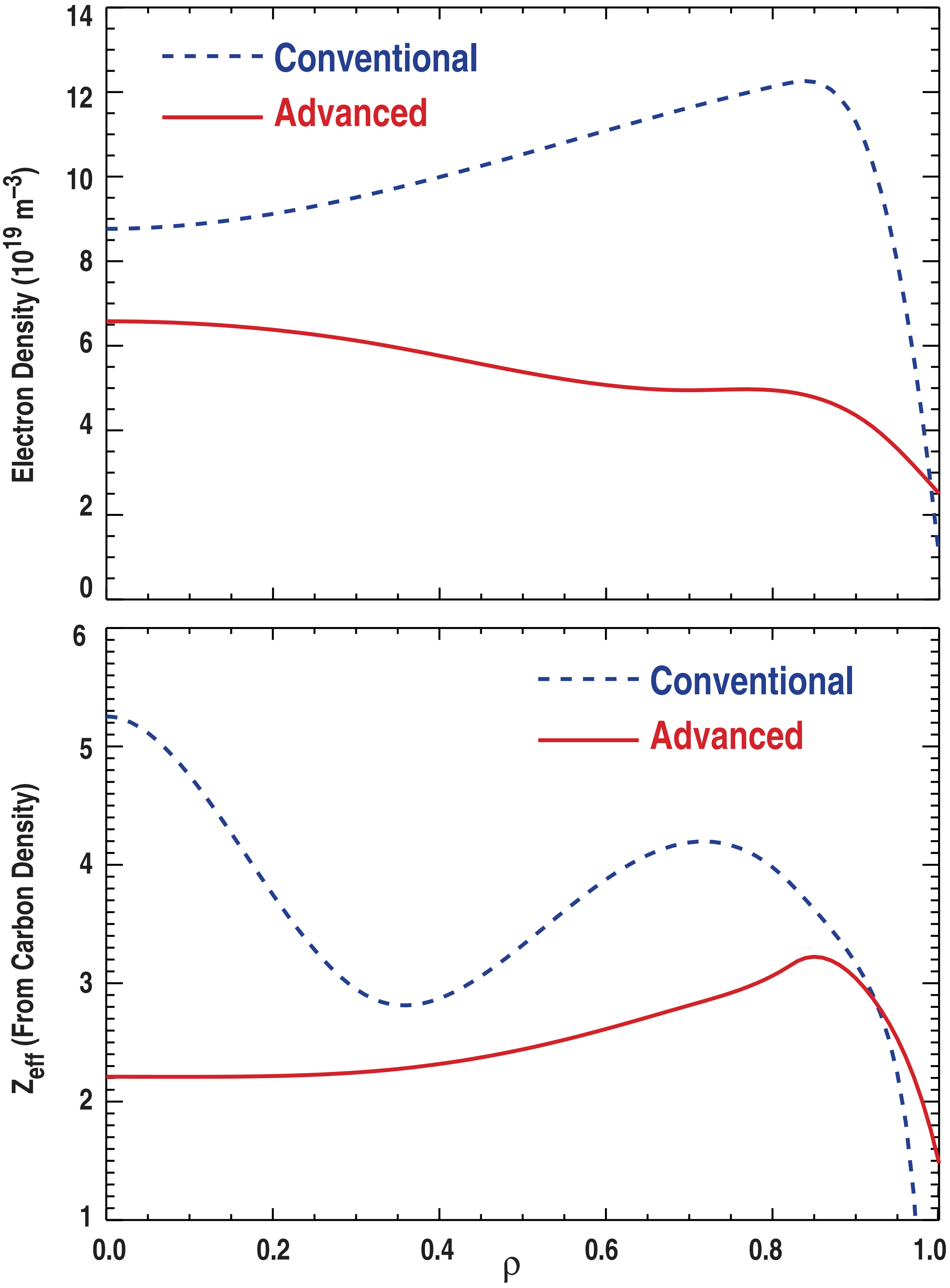

14
12
10
8
6
4
2
0
Electron Density (10^{19} m^{-3})
Conventional
Advanced
6
5
4
3
2
1
Z_{eff} (From Carbon Density)
Conventional
Advanced
0.0
0.2
0.4
0.6
0.8
1.0
ρ

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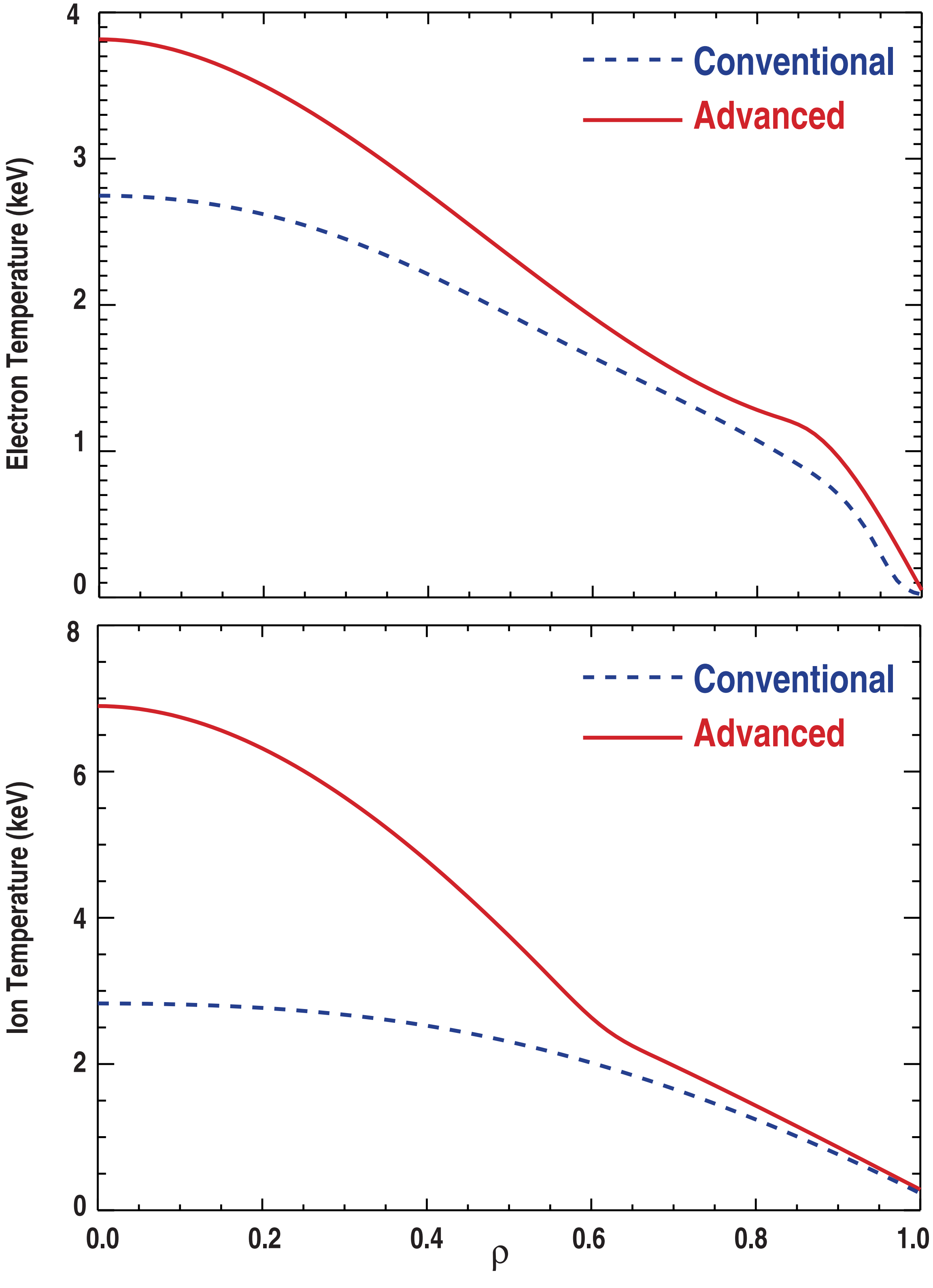

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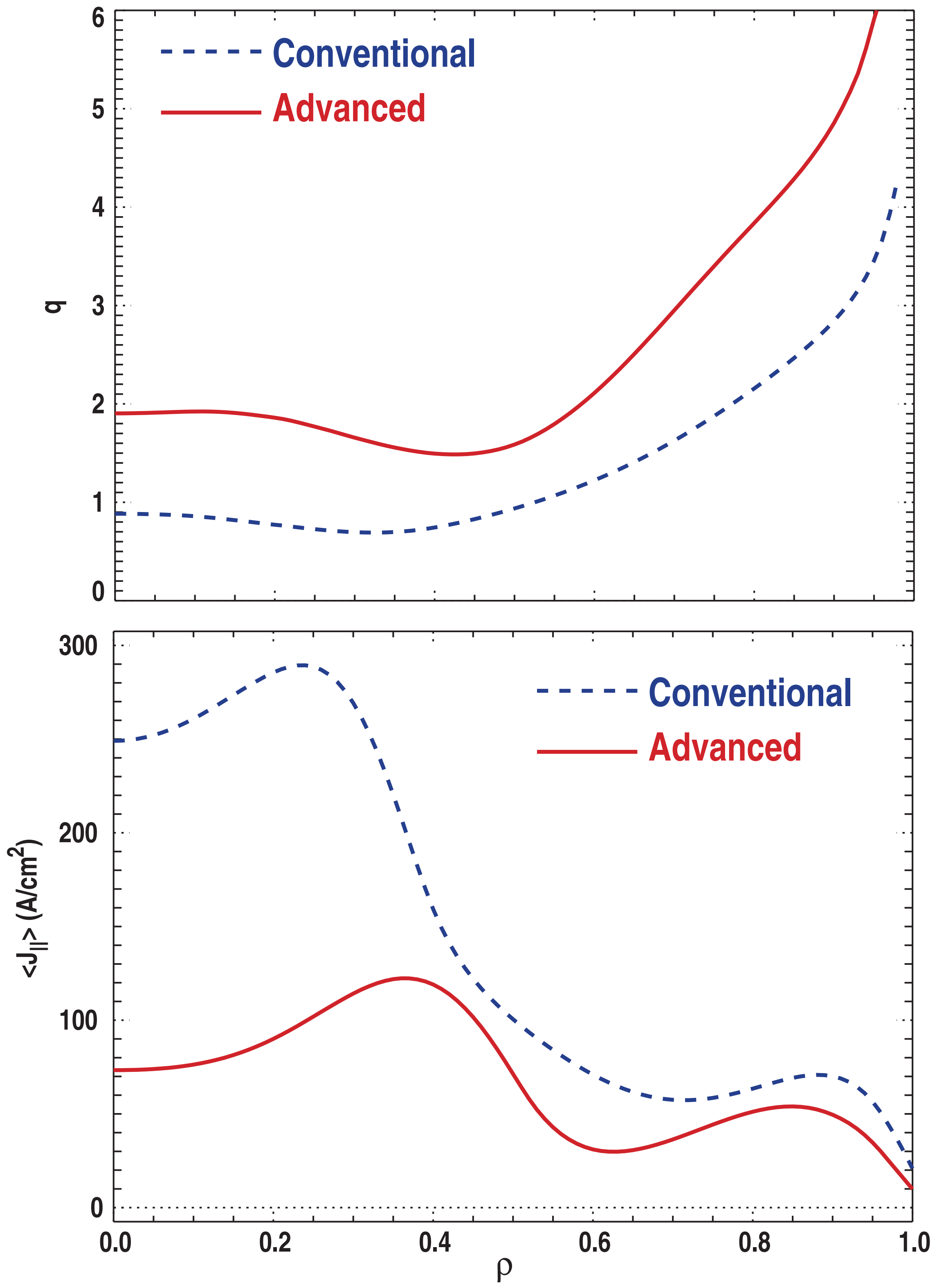

q
6
5
4
3
2
1
0
Conventional
Advanced
<J_||> (A/cm²)
300
200
100
0
Conventional
Advanced
0.0
0.2
0.4
0.6
0.8
1.0
ρ

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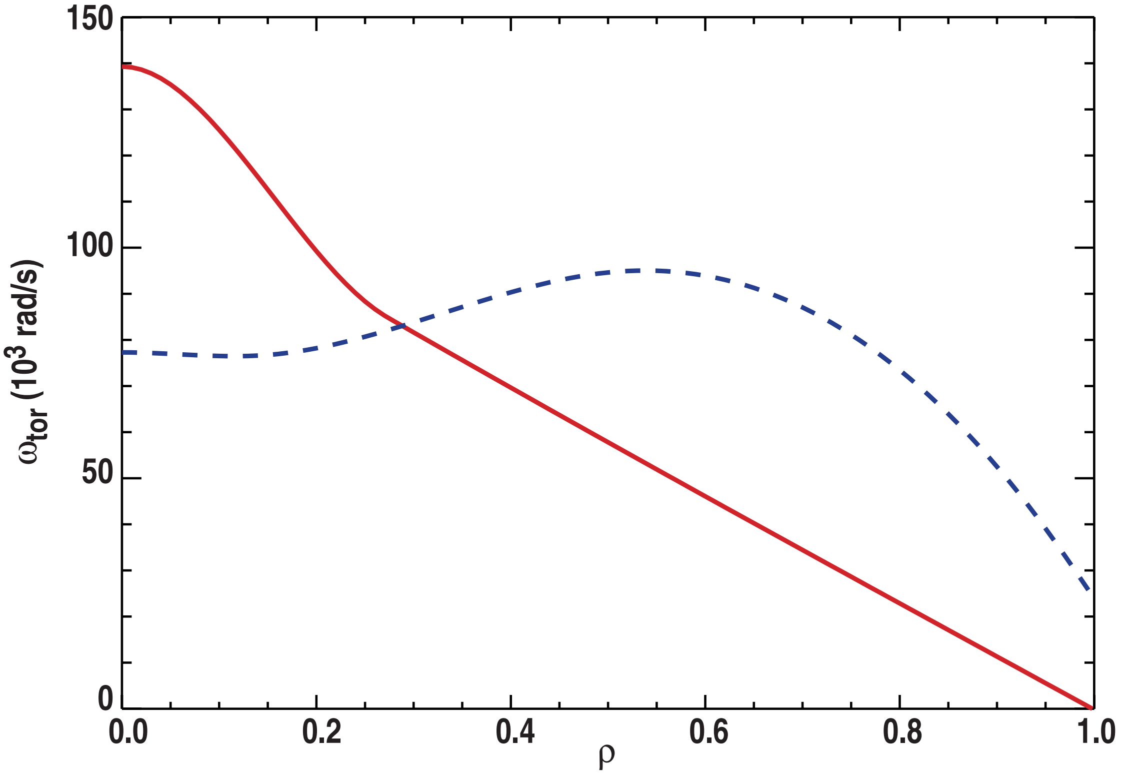

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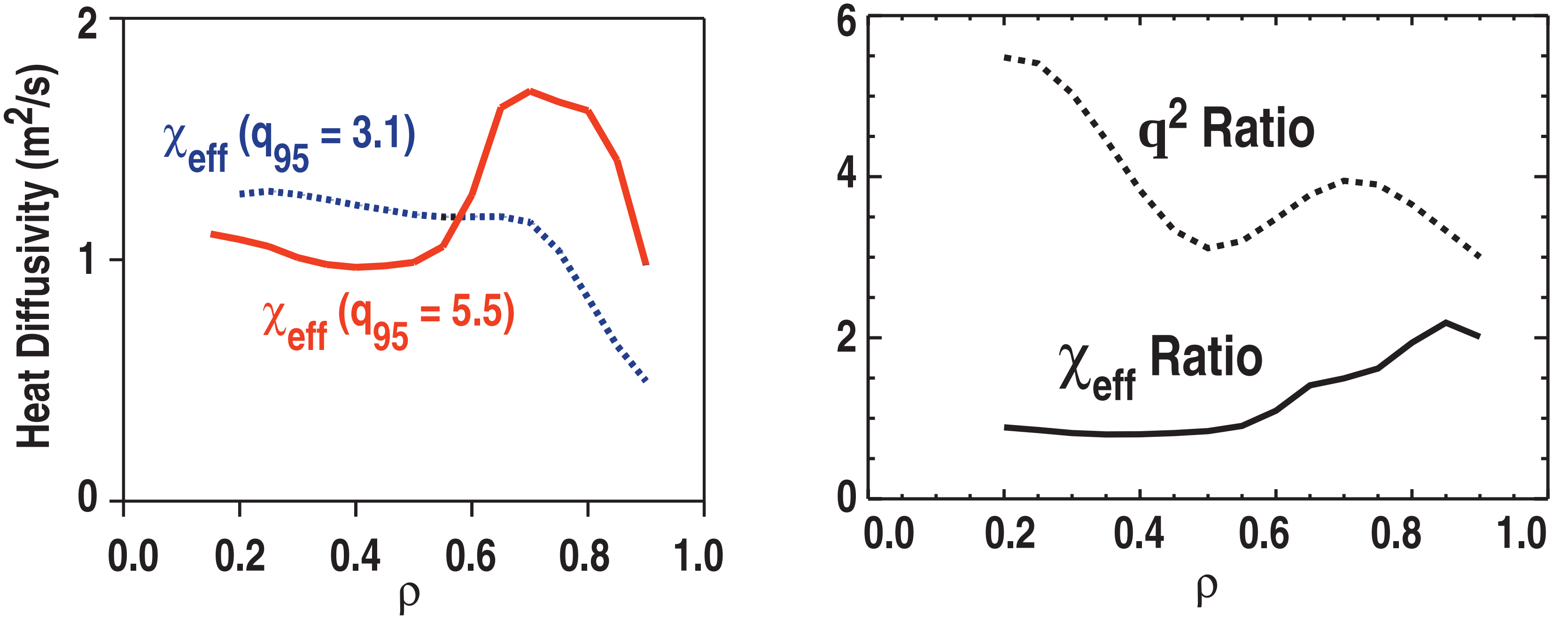
ONE-FLUID DIFFUSIVITY IS NOT SUBSTANTIALLY AFFECTED BY THE CHANGE IN q PROFILE

- Neoclassical and empirical scalings predict $\chi \propto q^2$



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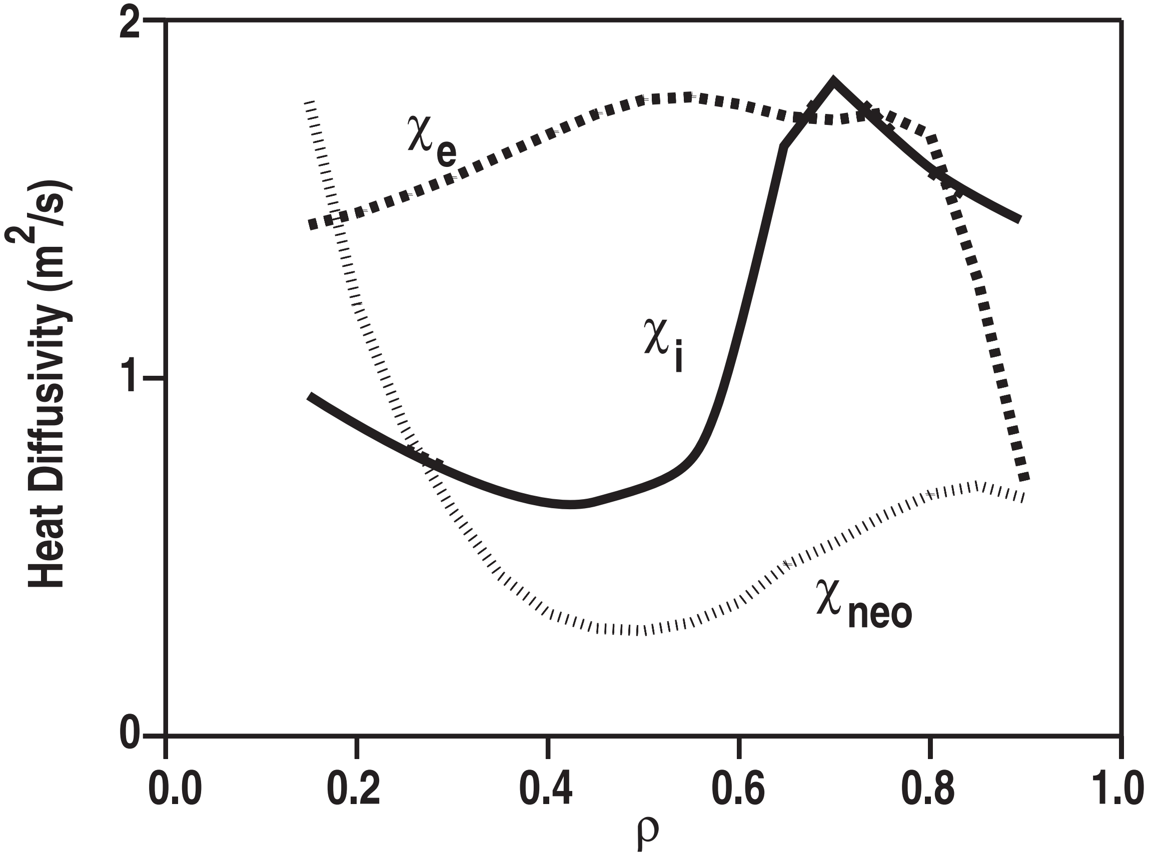
DISCUSSION

- The major differences in profiles between the conventional H–mode discharge and the advanced tokamak discharge are the q profile and the density profile
- In previous experiments with fixed density profile in H–mode the measured one-fluid diffusivity changed like q^2. [Petty, et al., Phys. Plasmas <u>5</u>, 1695 (1998)]
- The expected q scalings may be offset by another correlated charge — Ln, additional magnetic well, change in E×B, . . . More work is needed to understand the differences. However, degradation of confinement is not a certain consequence of raising q

ASSESSMENT OF DRIFT-WAVE MODEL INCLUDING E×B SHEAR FOR THE ADVANCED TOKAMAK DISCHARGES

ION DIFFUSIVITY IS LOW BUT REMAINS ABOVE THE NEOCLASSICAL LEVEL



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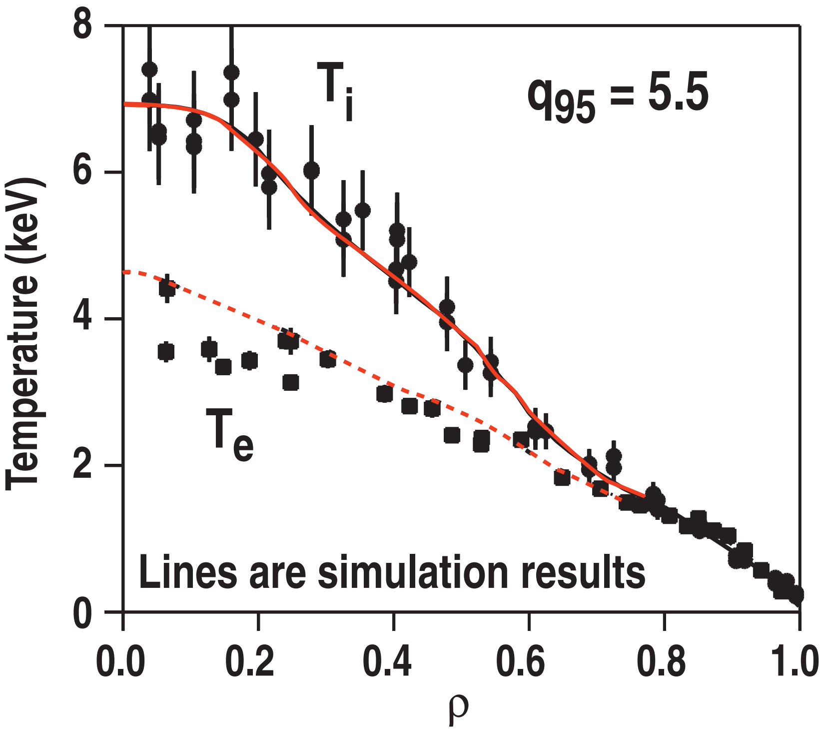
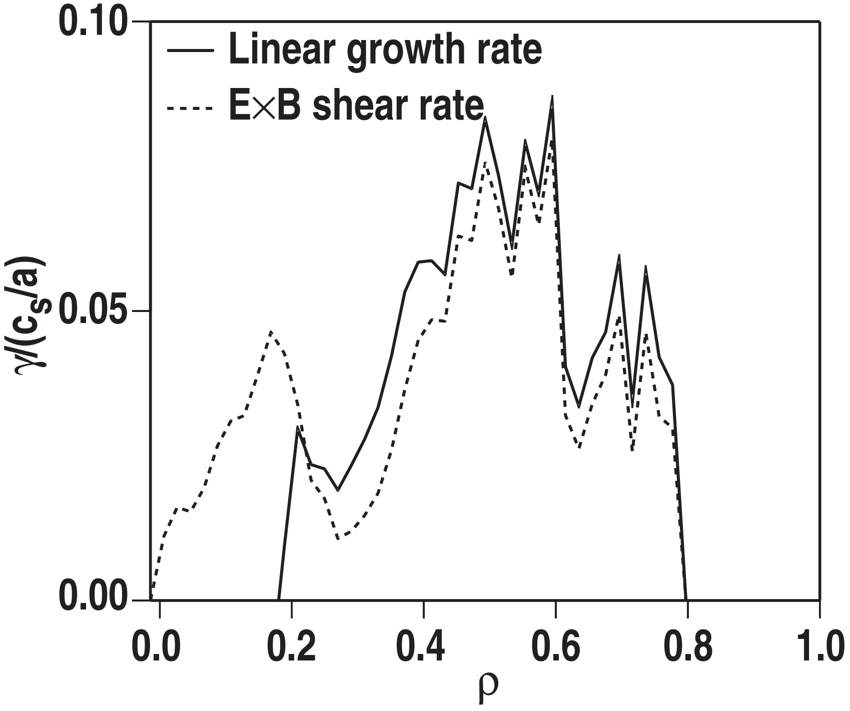
IMPROVED CONFINEMENT IS CONSISTENT WITH A DRIFT-WAVE SIMULATION THAT INCLUDES E×B SHEAR

- GLF23 model contains ITG, TEM, and ETG with effects of E×B shear
- Density and toroidal rotation are not simulated



- Simulation predicts instability across the entire radius, but reduction of transport by E×B shear
- E×B shearing rate is flux surface averaged formula



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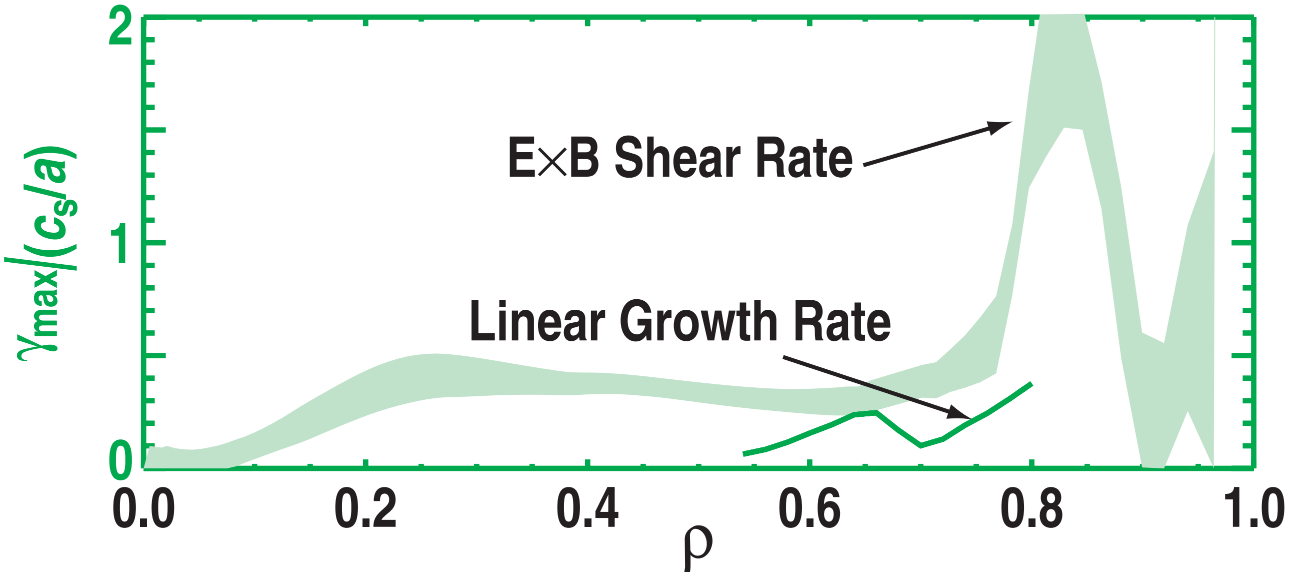
COMPARISON OF MAXIMUM GROWTH RATE AND E×B SHEARING RATE FROM FITTED PROFILES GIVES A QUALITATIVELY DIFFERENT PICTURE

- Predicts complete suppression of long-wavelength turbulence
- E×B shearing rate is from Hahm-Burrell formula



DISCUSSION

- Two ways of testing the ITG and E×B shear model yield qualitatively different conclusions

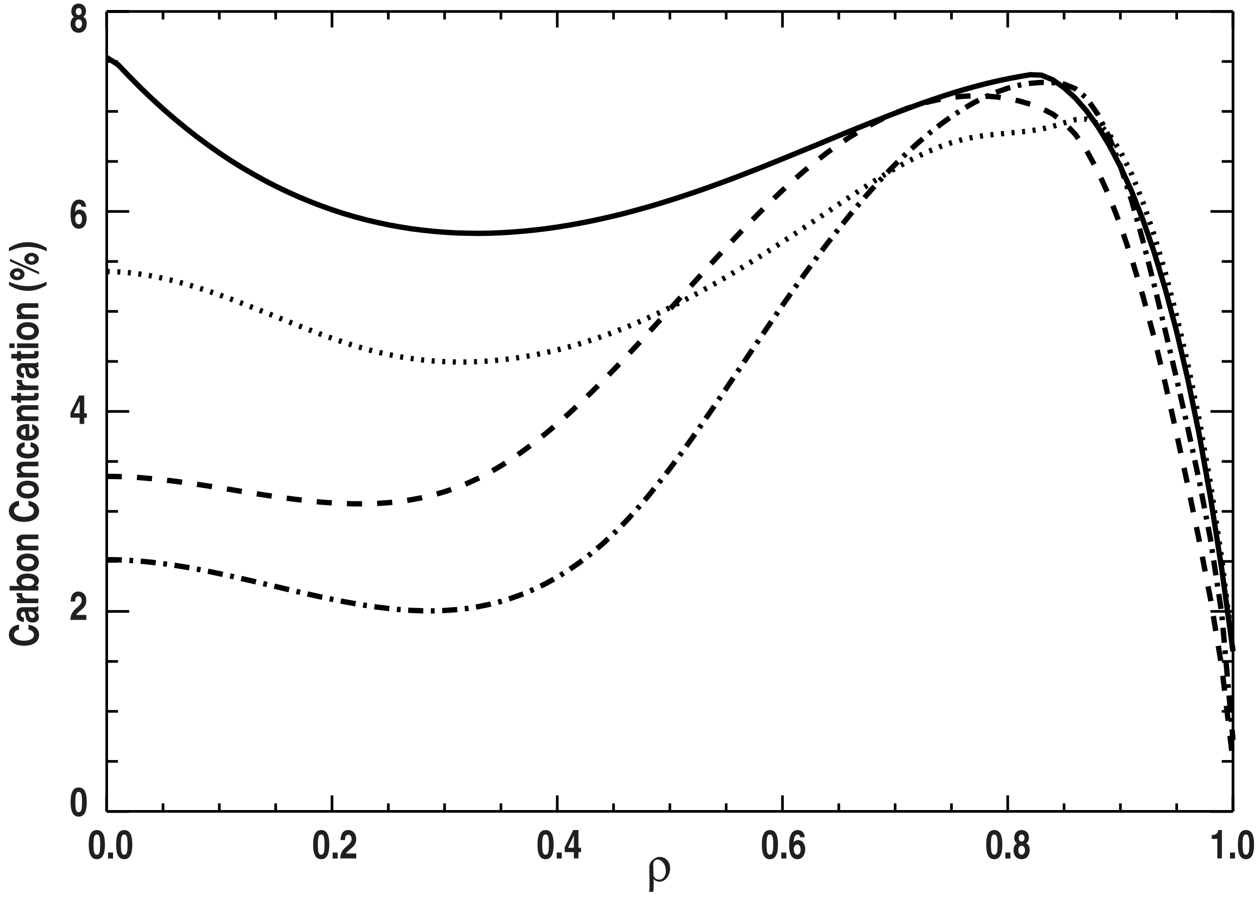
- The self-consistent simulation yields both the experimental profiles and consistency with $\chi_i > \chi_{i,\,neo}$

- The Hahm–Burrell formula is a local construct which does not account for geometry and is not reproduced in gyrokinetic simulations

- A sensitivity analysis of both approaches is required to come to a more concrete conclusion. The linear growth rates may be sensitive to local gradient effects

IMPURITY TRANSPORT IN ADVANCED TOKAMAKS

CARBON CONCENTRATION GROWS IN THE CORE



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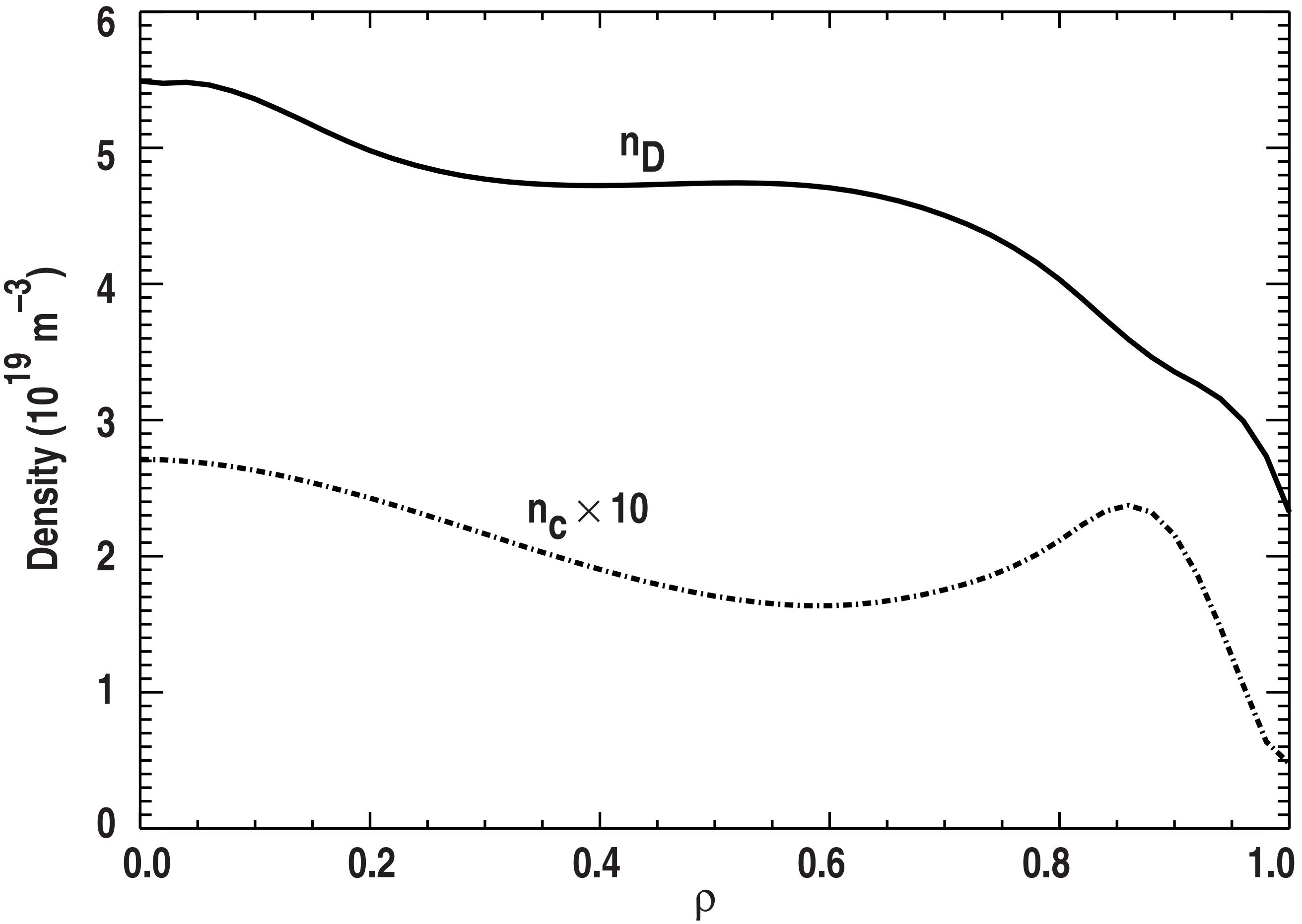
CARBON DENSITY PROFILE IS CONSISTENT WITH NEOCLASSICAL TRANSPORT



- Profile rearrangement occurs on 0.5–1.0 s time scale at roughly constant total carbon content

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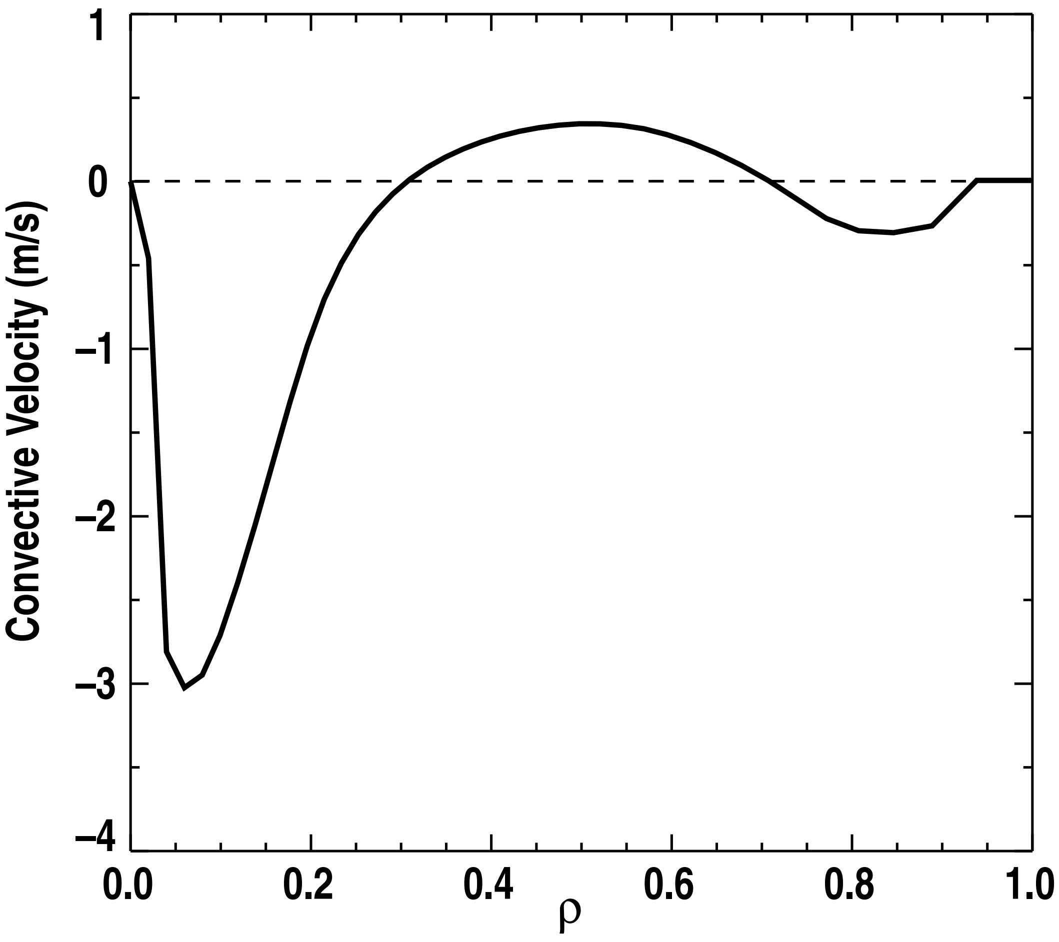
NCLASS CALCULATION OF CARBON TRANSPORT IS CONSISTENT WITH THE OBSERVED PROFILE SHAPE



DISCUSSION

- The impurity density profile is probably determined by neoclassical forces even in the presence of modest anomalous transport [Wade, et al., Phys. Rev. Lett. 84, 782 (2000]

- In this case, main ion density peaking will lead to strong core impurity accumulation. Therefore internal barriers in the density profile are to be avoided

- Previous work indicates ELMs are necessary to reduce both main ion and impurity sources in the core. ELM-free edge discharges have significant fueling from impurities

SUMMARY

- To raise the bootstrap current fraction, it is necessary to increase q_{min}. Contrary to expectations, this has not had a significant adverse impact on confinement

- Self-consistent simulation of the electron and ion temperature in an advanced tokamak discharge using the GLF23 model reproduces the experimental data well. The results are more consistent qualitatively than the standard comparison of linear growth rate and E×B shear. Sensitivity studies are needed to strengthen these conclusions

- Impurity profiles in an advanced tokamak discharge consistent with neoclassical impurity transport. This implies main ion density peaking will lead to substantial impurity accumulation in the core