Dependence of Turbulence and Transport on the Electron to Ion Temperature Ratio

George McKee

M. Murakami[1], C. Petty[2], D. Baker[2], J. Boedo[3],
R. Fonck, D. Rudakov[3], M. Wade[1], L. Zeng[4]

University of Wisconsin-Madison
[1] Oak Ridge National Laboratory
[2] General Atomics
[3] Univ. California-San Diego
[4] Univ. California-Los Angeles

American Physical Society-Division of Plasma Physics
October 31, 2001 - Long Beach, California, USA

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

University of Wisconsin Madison Department of Engineering Physics

MOTIVATION & OVERVIEW

- T_e/T_I is a critical dimensionless parameter for confinement and transport
- Present large beam-heated plasmas typically have $T_I > T_e$
- Next-step, burning plasma, or reactor scale devices will operate with $T_e/T_I \approx 1$
  - Higher density, better confinement $\Rightarrow$ higher collisionality, thermalization
  - Direct alpha heating of electrons, limited beam heating
- Previous experimental work in H-mode (Petty, et al.): $\tau_E \sim (T_e/T_I)^{-2}$
- Theoretical predictions that transport increases as $T_e/T_I \Rightarrow 1$
  - Simulations suggest $\chi_I \sim (T_e/T_I) + (0.8\text{-}1.1)$ (Kotschenreuther, Dorland)
- Critical gradient for ITG modes, R/L_{TI}, is reduced as T_e/T_I is increased

Goal: Understand fundamental physics of the dependence of turbulence & transport on T_e/T_I

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

UNIVERSITY OF WISCONSIN MADISON
Department of Engineering Physics

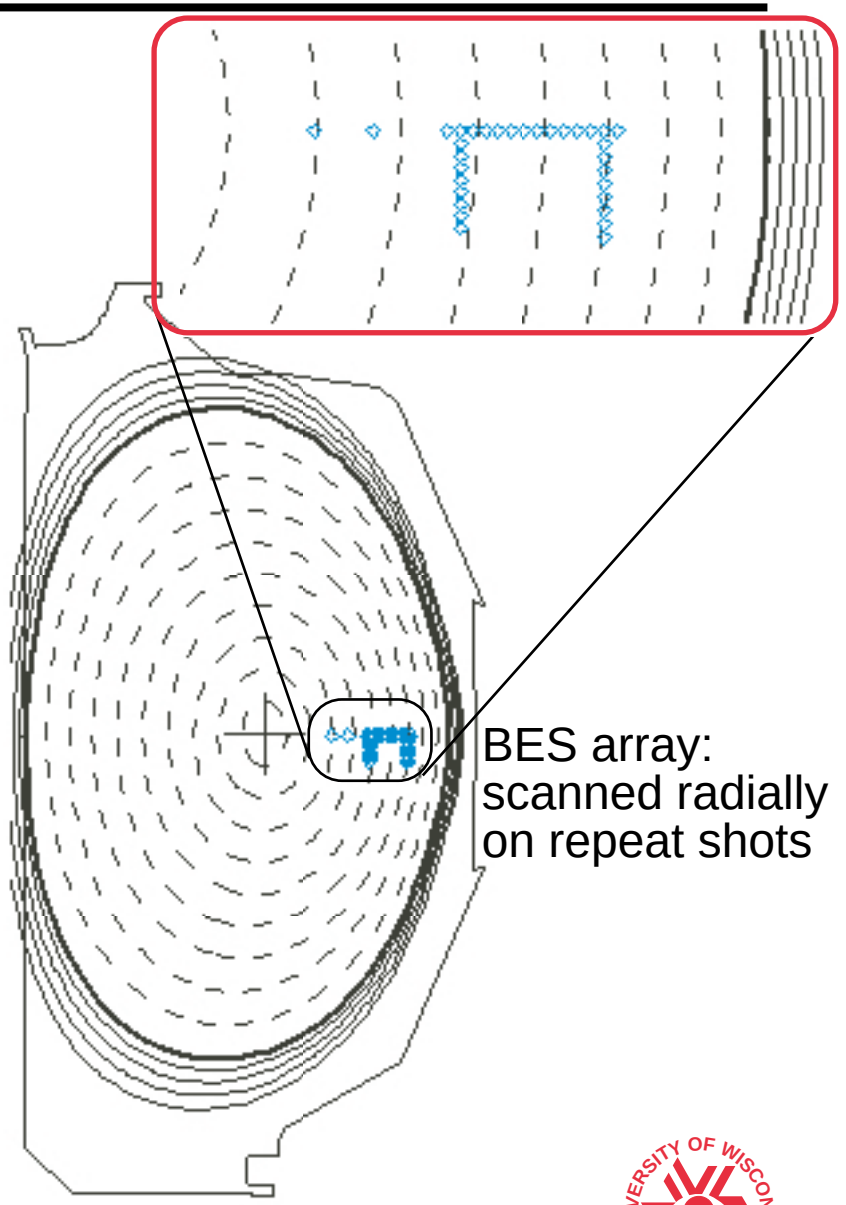
OUTLINE

- Experimental conditions
- Profile Measurements
- Turbulence analysis
- Transport (TRANSP) analysis
- Conclusion

Experimental Investigation of Turbulence and Transport Dependence on T_e/T_I

- B_T = -2.0 T, I_P = 1.0 MA
- Inner Wall Limited
- L-mode plasma
- a=0.63 m.
- κ=1.54
- P_{Beam} = 4.8 MW
- P_{ECH} = 2.4 MW (4 gyrotrons)

GOAL: Scan T_e while other parameters (T_I, Ω, n_e) held nearly constant -->
Measure turbulence and transport characteristics



107574 1540.00

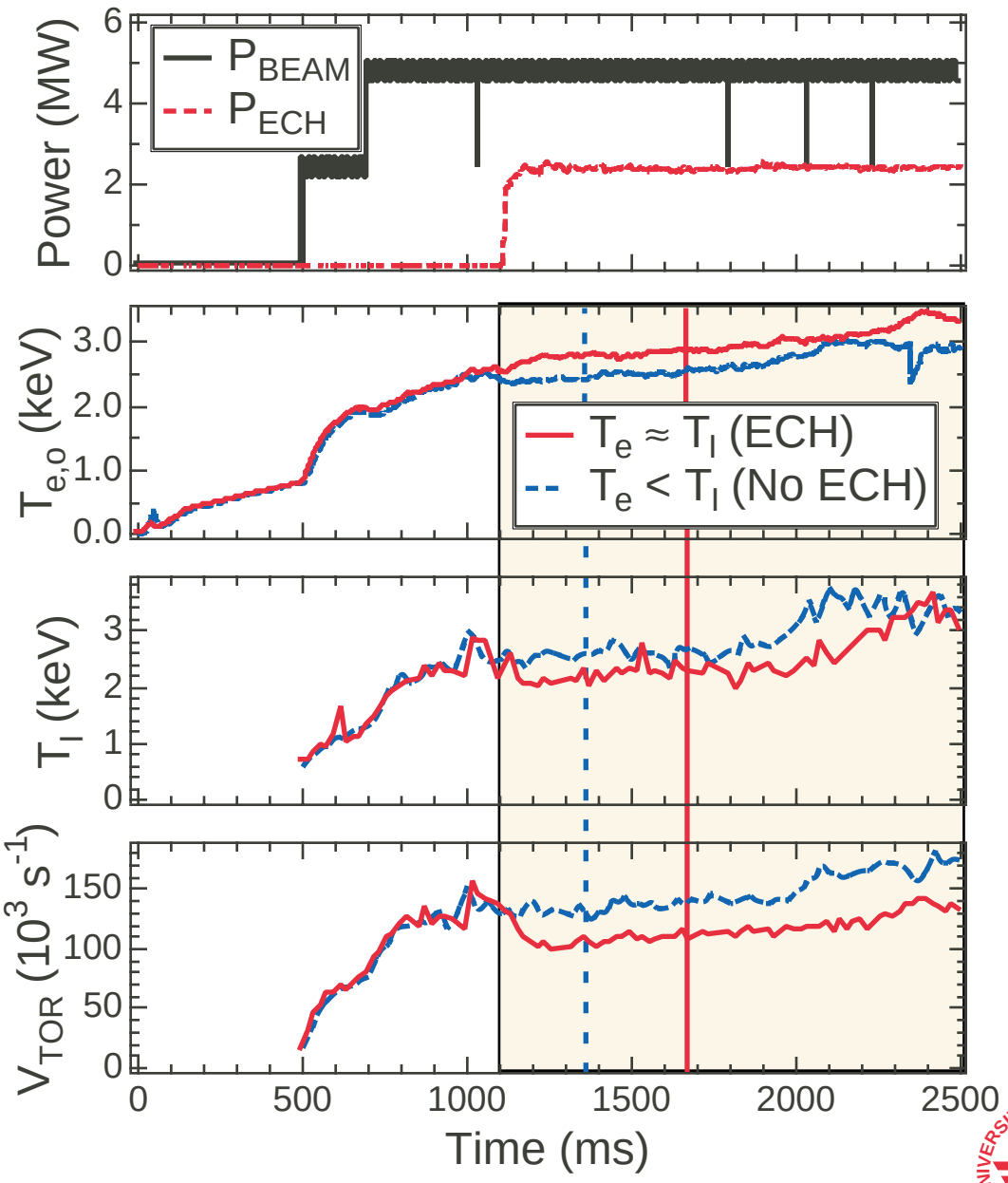
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

University of Wisconsin Madison Department of Engineering Physics

EXPERIMENTAL INVESTIGATION: T_e/T_I VARIED USING ECH

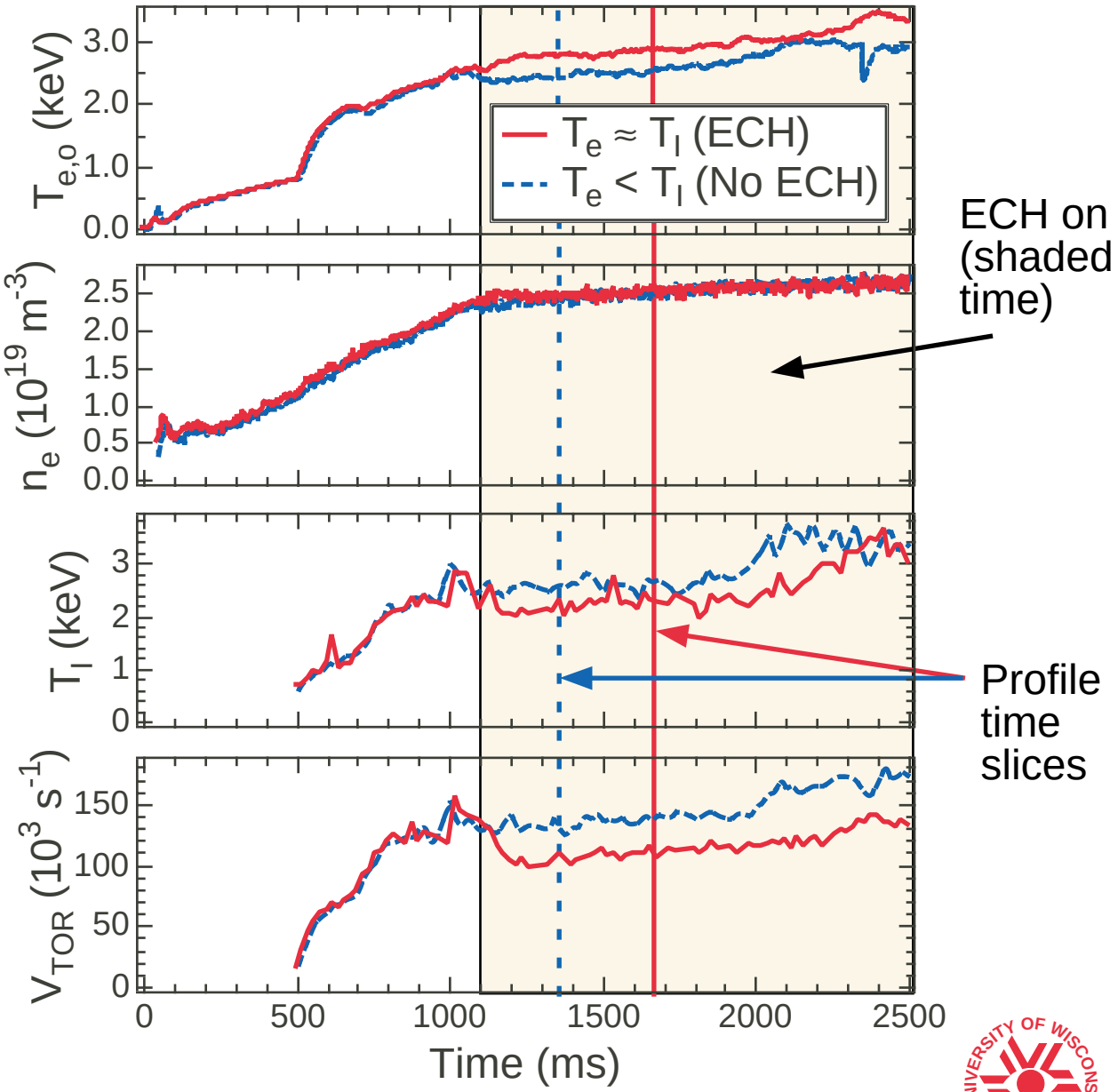
- B_T = -2.0 T, I_P = 1.0 MA
- Inner-wall limited L-mode
- a = 0.63 m, κ = 1.54
- P_{BEAM} = 4.8 MW
- P_{ECH} = 2.4 MW

- T_e increased by 20%
- T_I and V_{tor} reduced in response to increasing T_e
- Density (not shown) essentially unchanged



T_e/T_I VARIED USING ECH

- T_e increased by 20%
- Density unchanged
- T_I and V_{tor} reduced in response to increasing T_e

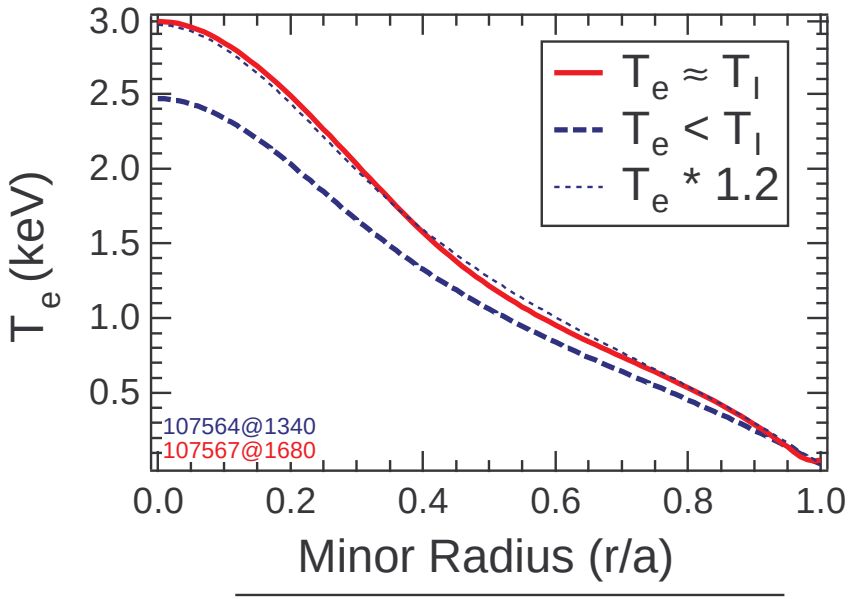


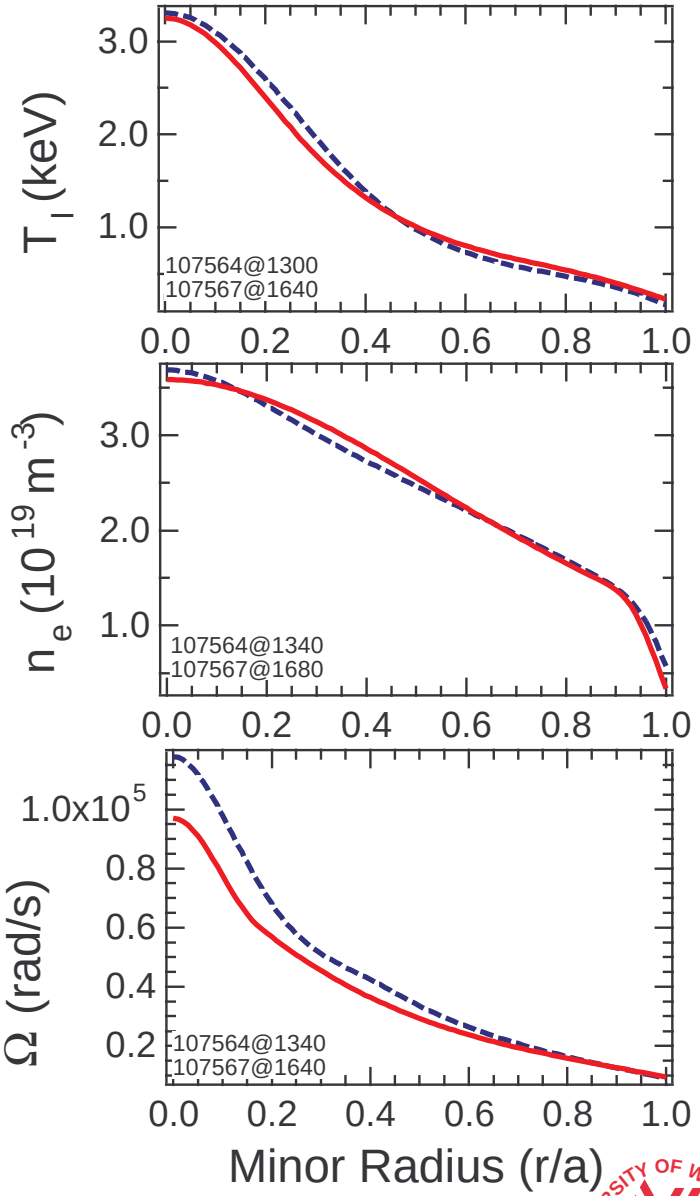
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

UNIVERSITY OF WISCONSIN MADISON
Department of Engineering Physics

T_e Uniformly Increased as other Profiles Held Similar

Electron Temperature Raised by 20%, Self-Similarly





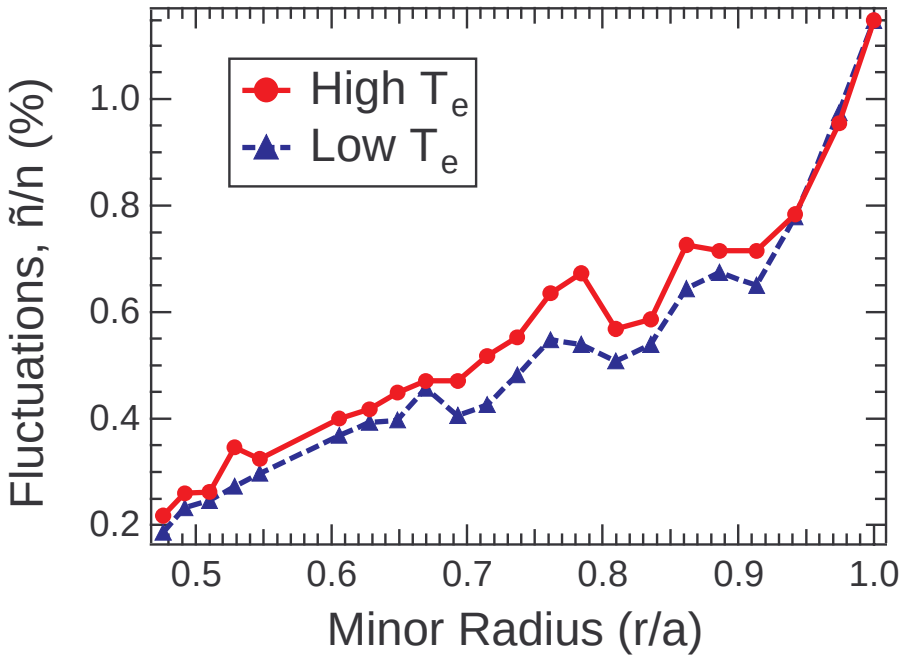
- Rotation reduced modestly, potentially affecting ExB shearing rate
- Intrinsic impurity (carbon) increased about 60% with ECH

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

UNIVERSITY OF WISCONSIN MADISON
Department of Engineering Physics

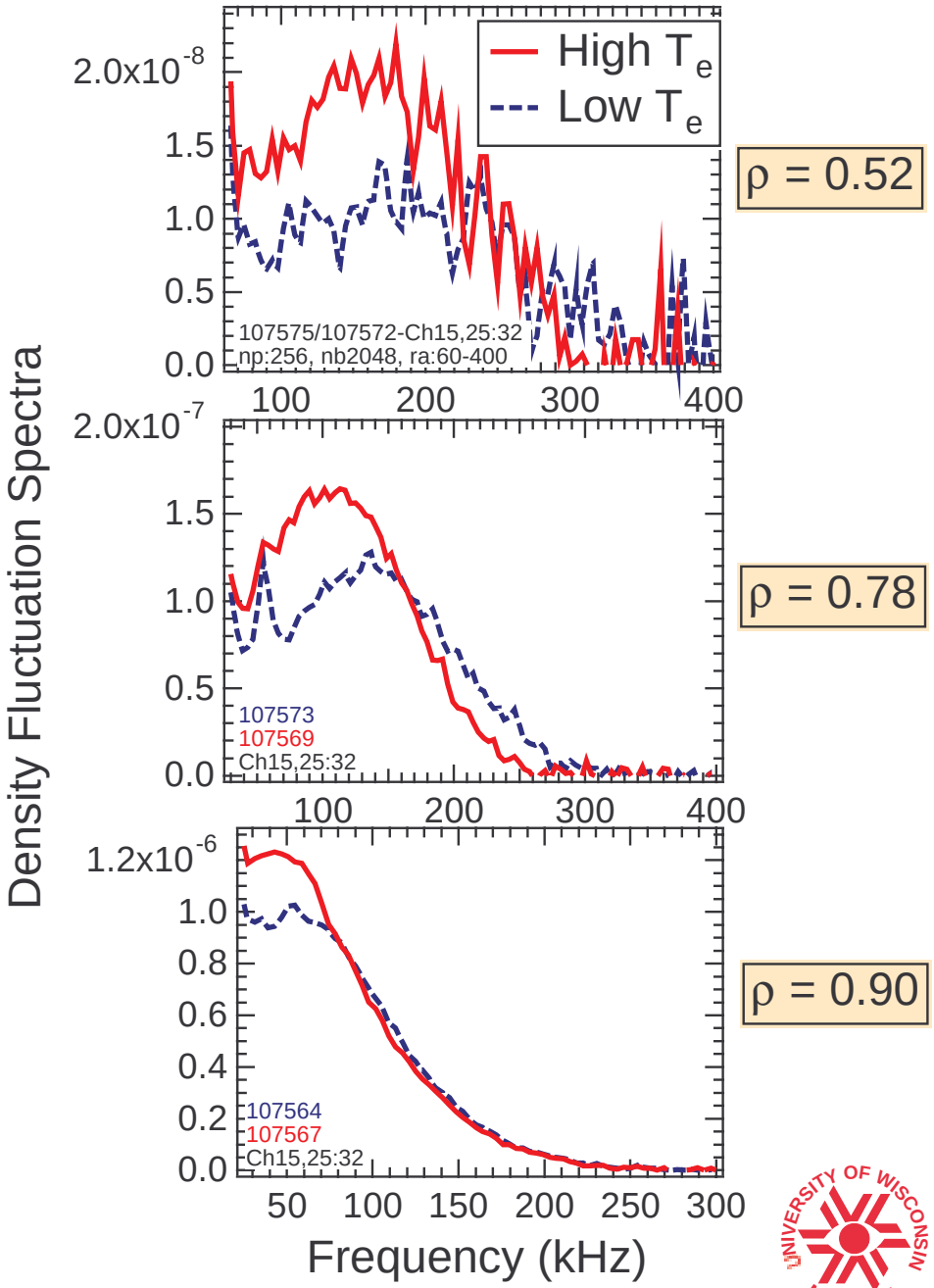
TURBULENCE AMPLITUDE INCREASES WITH T_e/T_i

Measureable increase in fluctuation across profile, except in edge region (little or no change)



- Average frequency of fluctuations decreases with ECH as a result of rotation reduction

(Local turbulence properties measured with BES)



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

UNIVERSITY OF WISCONSIN MADISON
Department of Engineering Physics

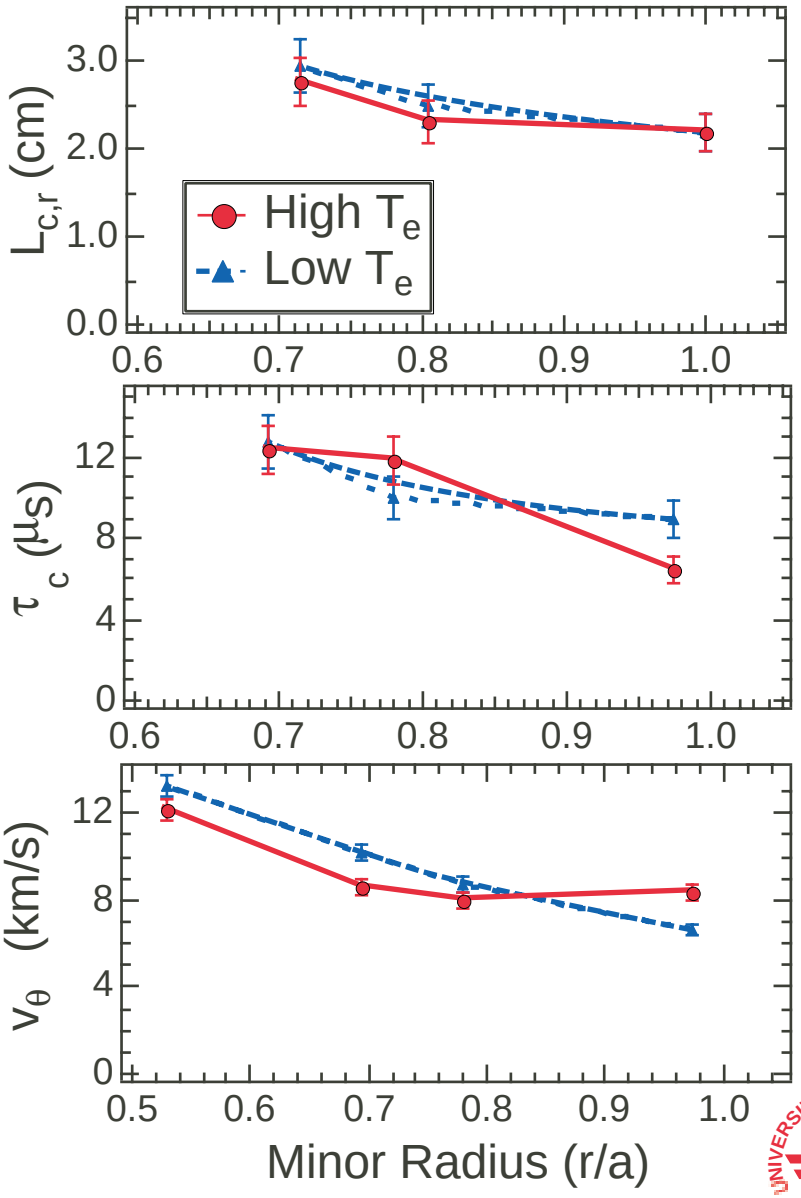
Turbulence Correlation Lengths and Decorrelation Time Exhibit Little Dependence on T_e/T_I

- Radial and Poloidal (not shown) correlation lengths virtually unchanged as T_e is varied

- Decorrelation time (eddy turnover time) exhibits little change, except near edge; suggests a stronger "churning" near edge region

$$D_{TURB} = \frac{(L_{c,r})^2}{\tau_c}$$

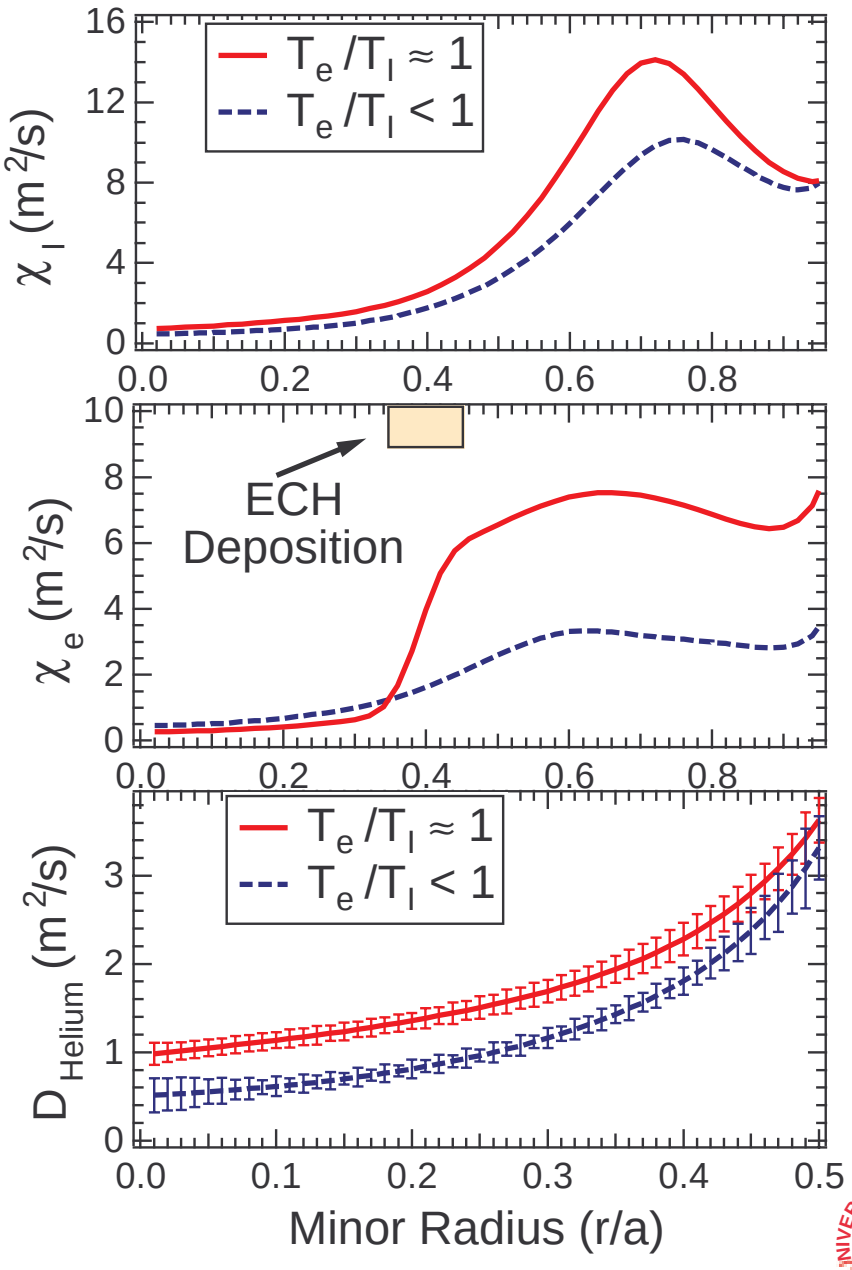
- Poloidal flow velocity (eddy v_θ is reduced for r/a < 0.9 with higher T_e, but increases near edge (higher radial electric field?)



Ion, Electron, and Particle Diffusivity Increase with T_e/T_I

- Ion thermal diffusivity increases somewhat uniformly across profile
- Electron thermal diffusivity increases dramatically at and outside of deposition region, decreases inside
- Particle (Helium) transport increases
- $\tau_E \approx (T_e/T_I)^{-1.5}$

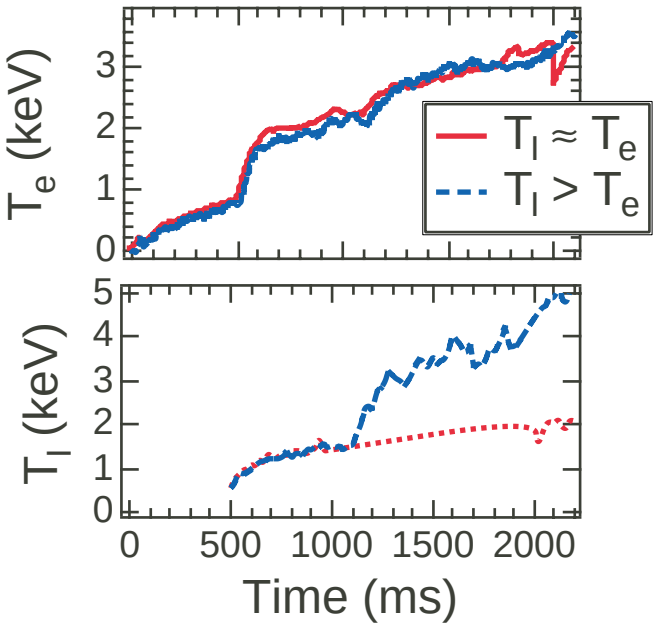
Magnitude of χ_I and D_{He} increase is similar to that of turbulence (ñ/n) increase, while change in χ_e increase suggests different transport mechanism

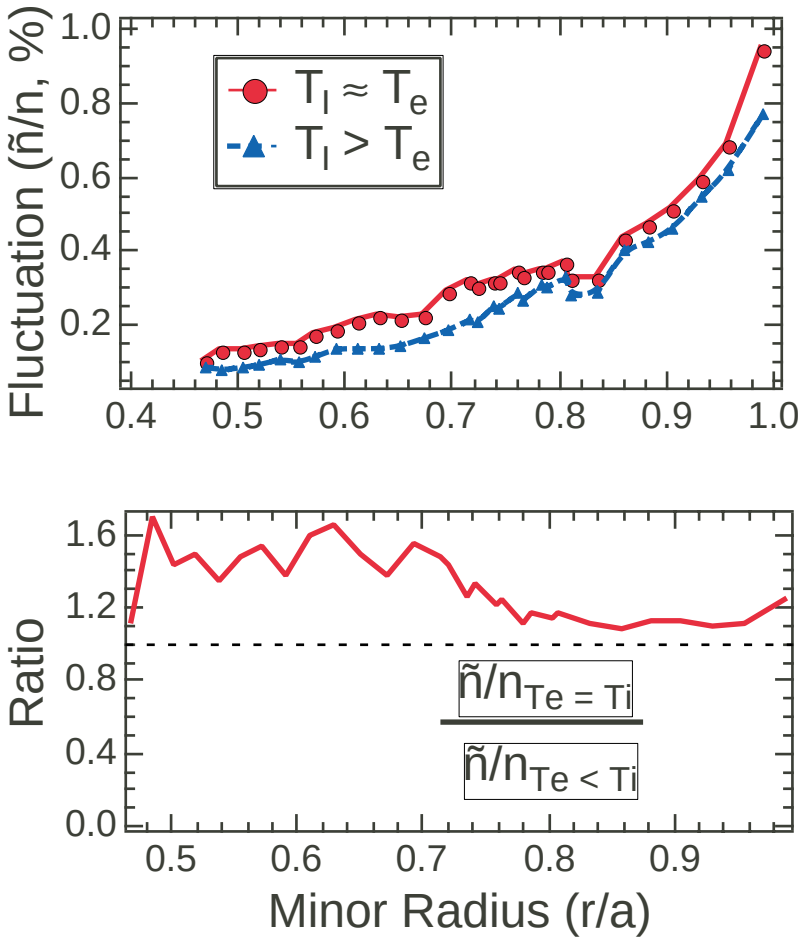


[note different radial ranges]

TURBULENCE ALSO INCREASES WITH T_e/T_I WHEN T_I INCREASED AT CONSTANT T_e

ECH and Beam Power Exchanged to maintain T_e and increase T_I





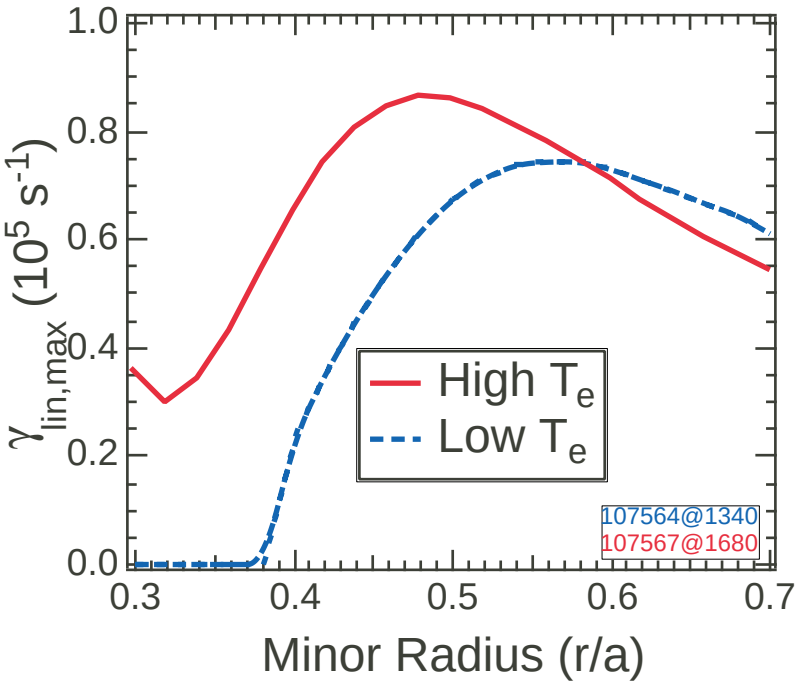
20-60% increase in ñ/n across profile as T_I/T_e approximately doubled

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

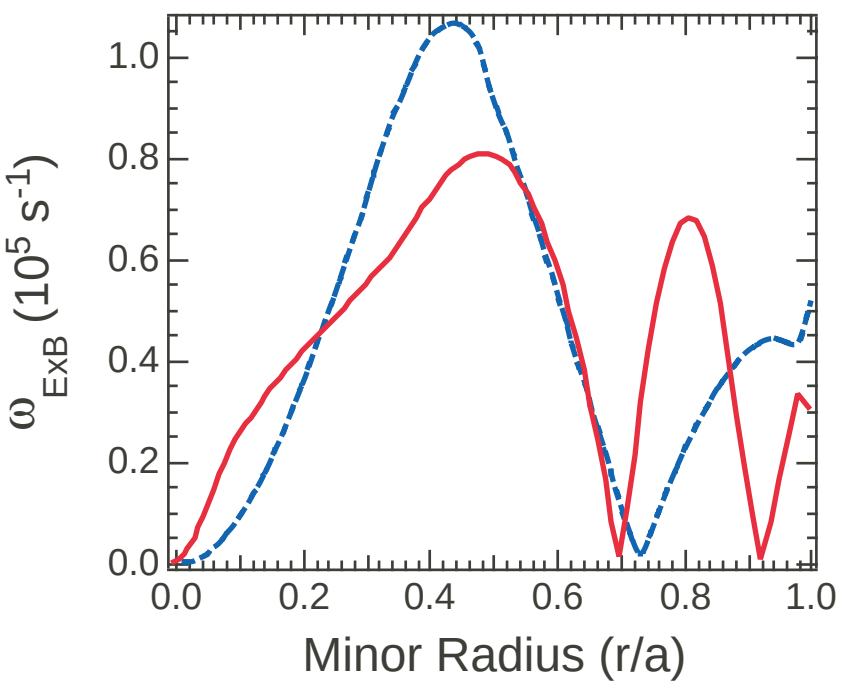
UNIVERSITY OF WISCONSIN MADISON Department of Engineering Physics

Growth Rates Modestly Higher with Increased T_e/T_I While Shear Rates Reduced in Core

GKS Calculation of Growth Rates



Measured Shearing Rate



- Carbon level increased ~60% when ECH applied which reduces calculated growth rates: competition between T_e/T_I and n_{IMP}
- Shear rates not significantly different over outer half-radius, where turbulence measurements obtained
- Can't make quantitative conclusions yet, given uncertainty

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

University of Wisconsin Madison Department of Engineering Physics

CONCLUSIONS

- Turbulence and transport properties studied as a function of T_e/T_I, with T_e increased by 20% relative to T_I as other parameters held roughly constant
- Long-wavelength turbulence increases as $T_e/T_I \Rightarrow 1$
  - $\tilde{n}/n$ increases about 10-20% ($0.45 < r/a < 0.9$)
  - v_θ is reduced, except at edge ($r/a \sim 0.95$)
  - $L_{c,r}$, $L_{c,\theta}$, τ_c exhibit little change
- Transport increases significantly as T_e is uniformed increased via ECH heating:
  - T_e increased; rotation and T_I decrease
  - χ_I increases in response to increasing T_e; χ_e increased outside ρ_{DEP}
  - $\tau_E \approx (T_e/T_I)^{-1.5}$
- Magnitude of turbulence increase consistent with ion and particle transport increase (~20%); electron transport increases substantially (*2.5), likely resulting from an separate or additional mechanism