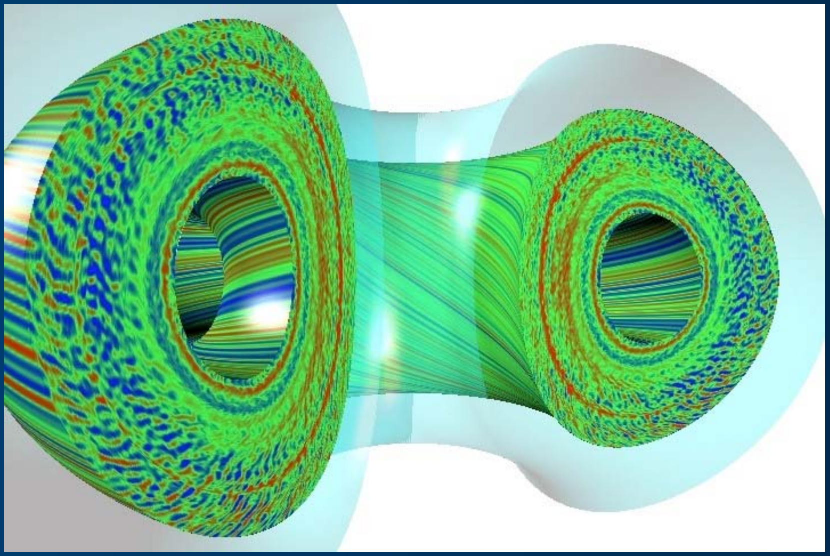
Transport Stiffness of TGLF and It's Impact on ITER

by
J.E. Kinsey

in collaboration with
G.M. Staebler, R.E. Waltz, J. Candy
General Atomics

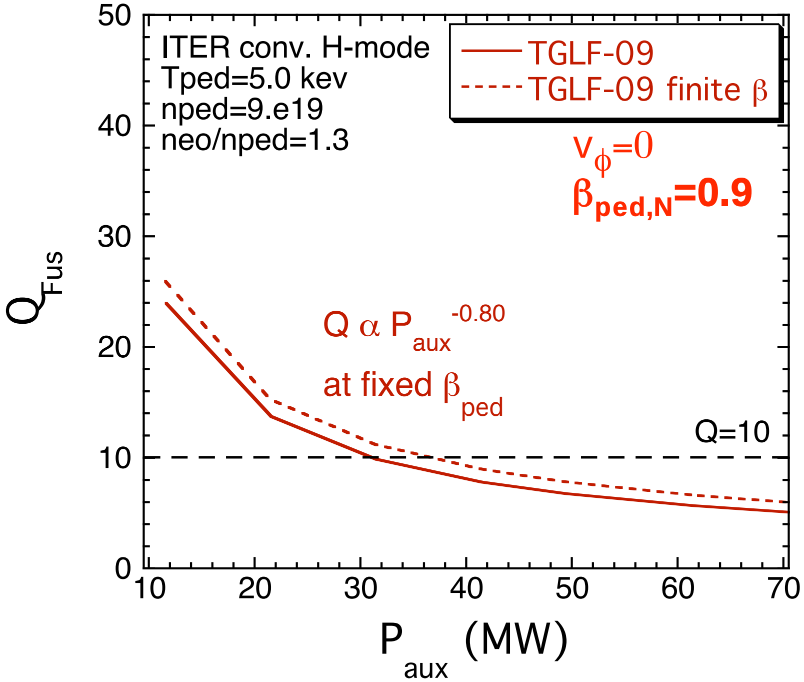


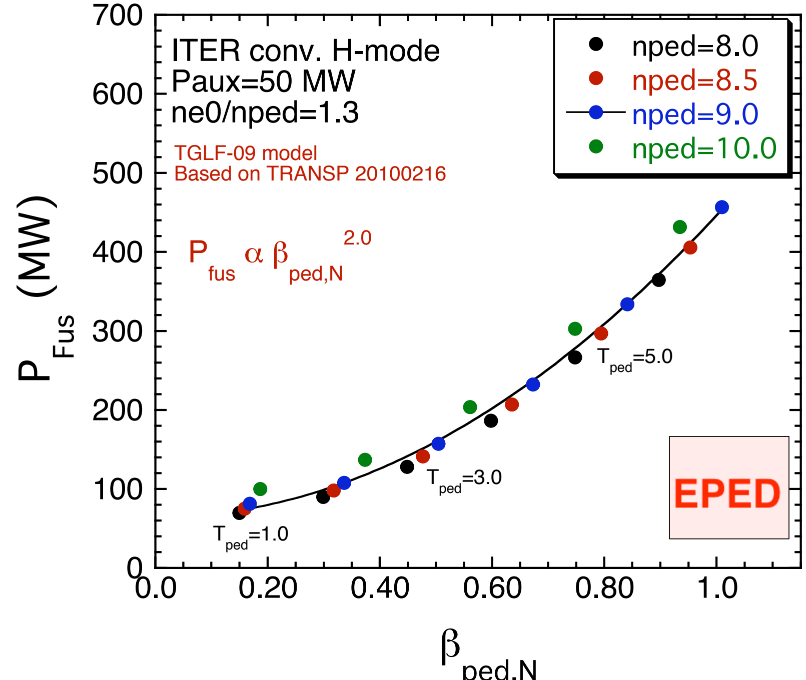
Presented at the
53rd Annual Meeting of the
APS Division of Plasma Physics
Salt Lake City, Utah

November 14-18, 2011

Motivation — A Key Ingredient in the TGLF Predictions for ITER is Core Temperature Profile Stiffness

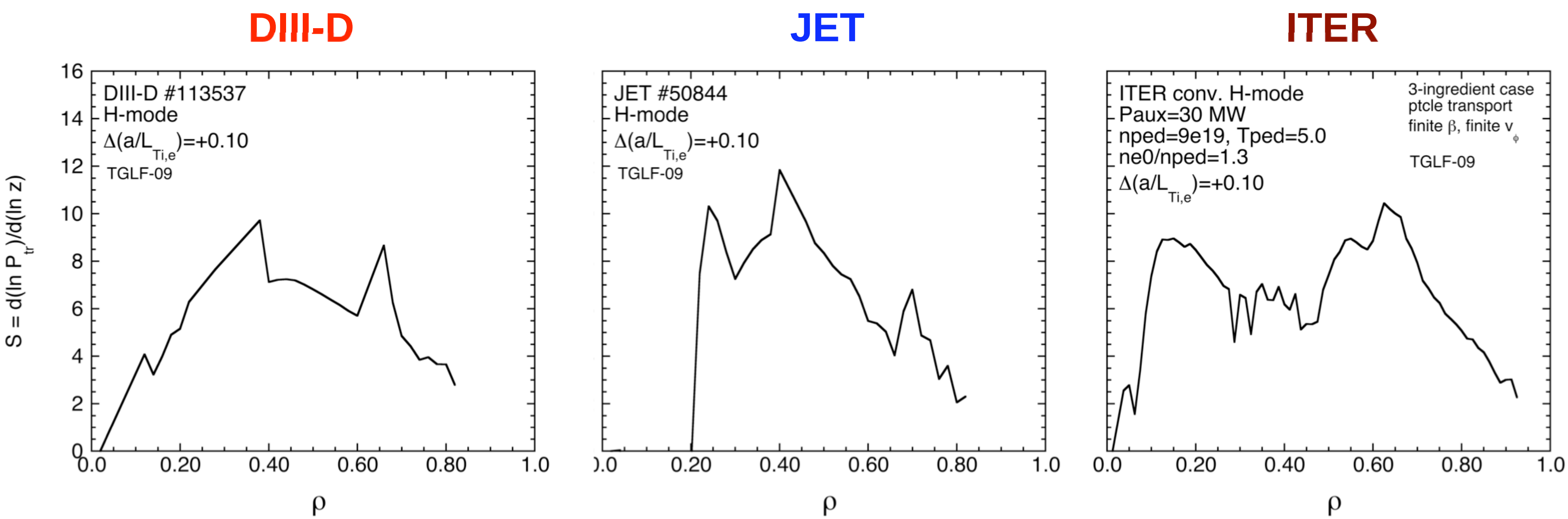
- **Stiffness feature #1: Profiles are insensitive to changes in P**
  - IAEA10 results showed that the predicted fusion $Q=P_{fus}/P_{aux}$ sensitive to auxiliary heating, scales like $\mathbf{P_{aux}^{-0.8}}$ at fixed β_{ped}
  - Challenging to increase P_{fus} by adding P_{aux} but can increase fusion Q by reducing P_{aux} (if β_{ped} remains fixed)
- **Stiffness feature #2: Profiles are sensitive to the pedestal height**
  - Fusion power scales like $\boldsymbol{\beta_{ped,N}^2}$





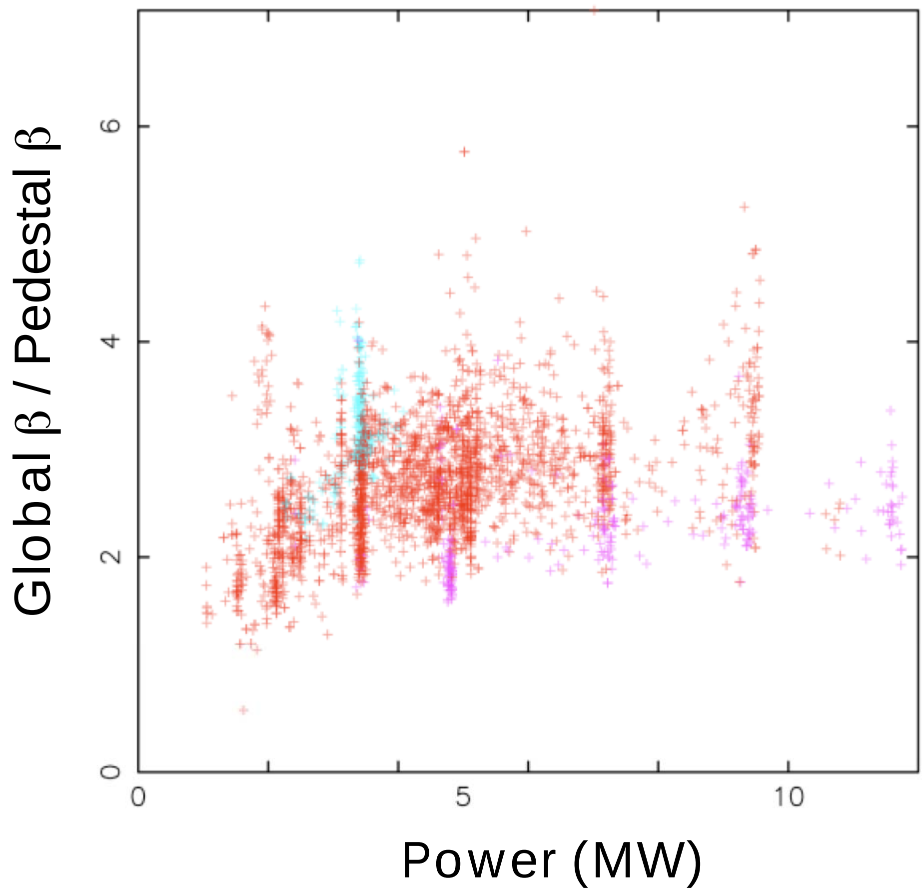
TGLF Predicts that ITER has a Composite Core Stiffness that is Comparable to DIII-D & JET for Conventional H-modes

- **Stiffness of TGLF is assessed defining the stiffness as $S=d\ln(P_{tr})/d\ln(z)$ where $z=a/L_T$ and $P_{tr}=-nV'\chi\, dT/dr$ is the transport power**
  - Composite stiffness is computed where a/L_{Ti} and a/L_{Te} are increased by 10% at transport solution point and TGLF is called all other quantities fixed
  - About a dozen DIII-D and JET H-modes were compared to ITER
  - Stiffness values are typically in the range of 5-10



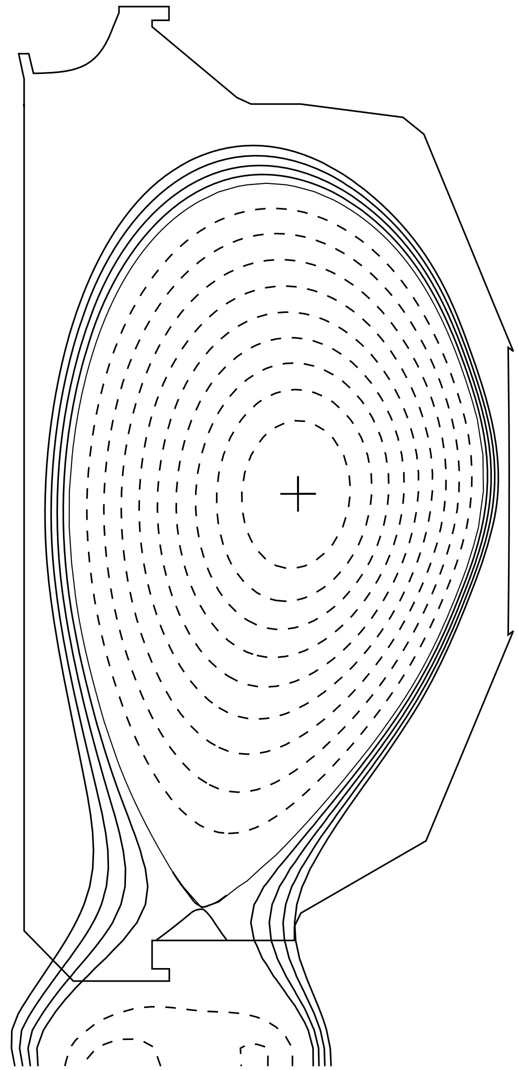
Global DIII-D H-mode Data Shows Evidence of Stiffness

- **Osborne's DIII-D pedestal H-mode database (IAEA10, EXC/2-1)**
- **The colors represent different triangularity ranges**
  - Blue=low, red=med, purple=high
- **At moderate to high power (P > 4 MW) the core appears stiff**
  - There is a "soft" regime at low power (P < 4 MW)
  - Presumably the transition from the soft regime to the stiff regime occurs when the power is sufficient to drive the profiles up against stiff critical gradient limits
- **This data movitated a dedicated experiment to test core stiffness at fixed β_{ped}**



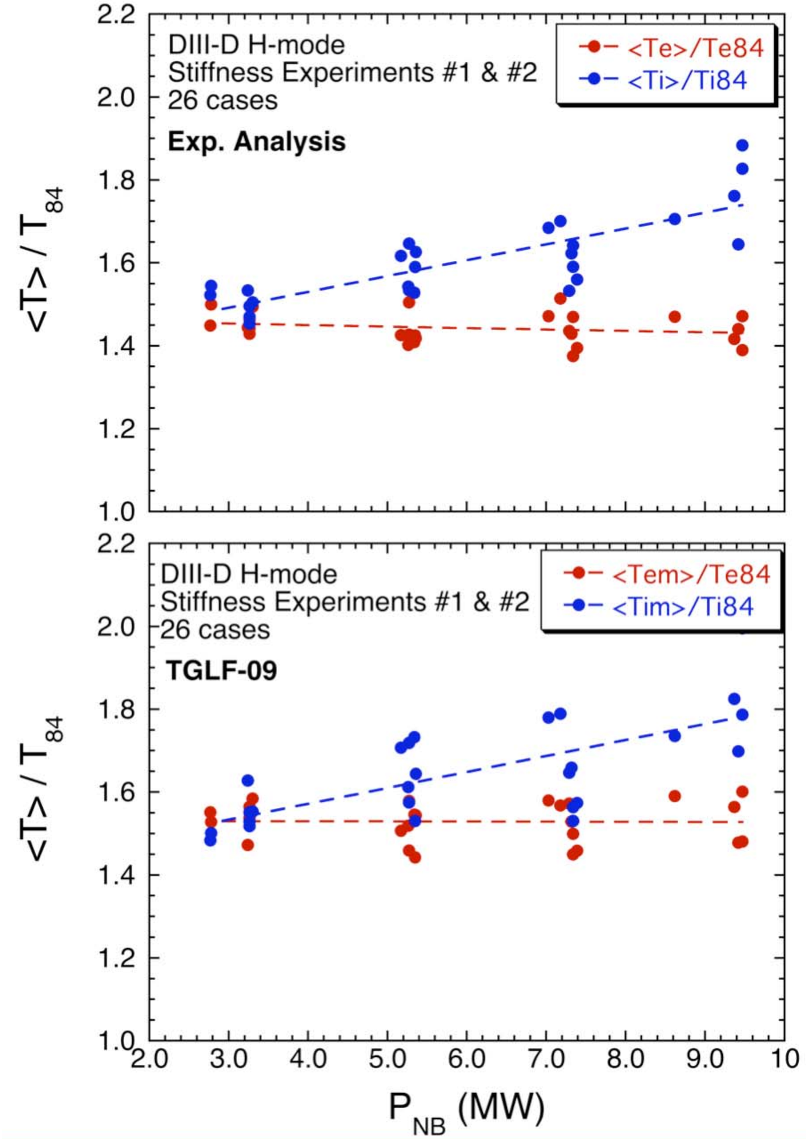
Recently, Power Scans were Performed in DIII-D to Specifically Test Core Transport Stiffness in Sawtooth-free H-mode Discharges

- **Goal was to vary P_{NB} at fixed β_{ped}**
- **NBI power varied by a factor of 3.4 at fixed rotation, density, and safety factor in LSN H-mode discharges**
  - B_T=2.1 T
  - I_p=1.2 MA
  - q_0=1.1-1.2, q_{95}=4
  - n_e=4 x $10^{19}/m^3$
  - P_{NB} = 2.8-9.5 MW
- **Weak triangularity was utilized in order to keep H-mode pedestal pressure fixed as the NBI power was varied**
  - κ=1.7
  - δ_{up}=0.075, δ_{low}=0.3



Observed T_e Profile Shapes Insensitive to P_{NBI}, T_i More Sensitive

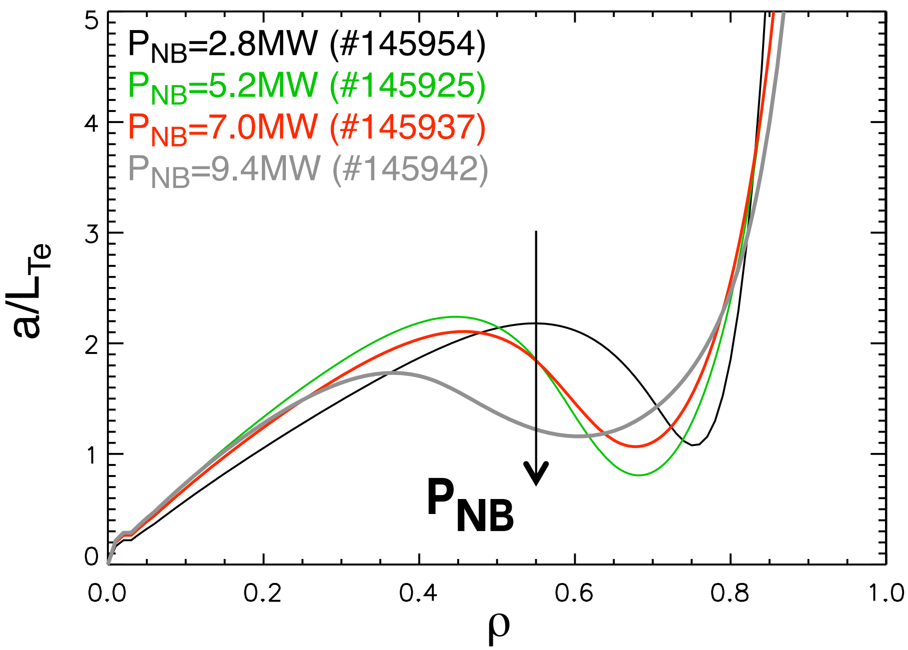
- **26 cases analyzed with ONETWO, TGLF runs performed using XPTOR**
- **Avg temperature divided by pedestal temperature (ρ=0.84) recorded using experimentally analyzed profiles**
- **TGLF reproduces observed trends**
- **Caveat: Experimental temperatures at ρ=0.84 increased with NBI despite low triangularity**
  - 55% increase in T_e
  - 75% increase in T_i as P_{NB}=2.8 → 9.4 MW



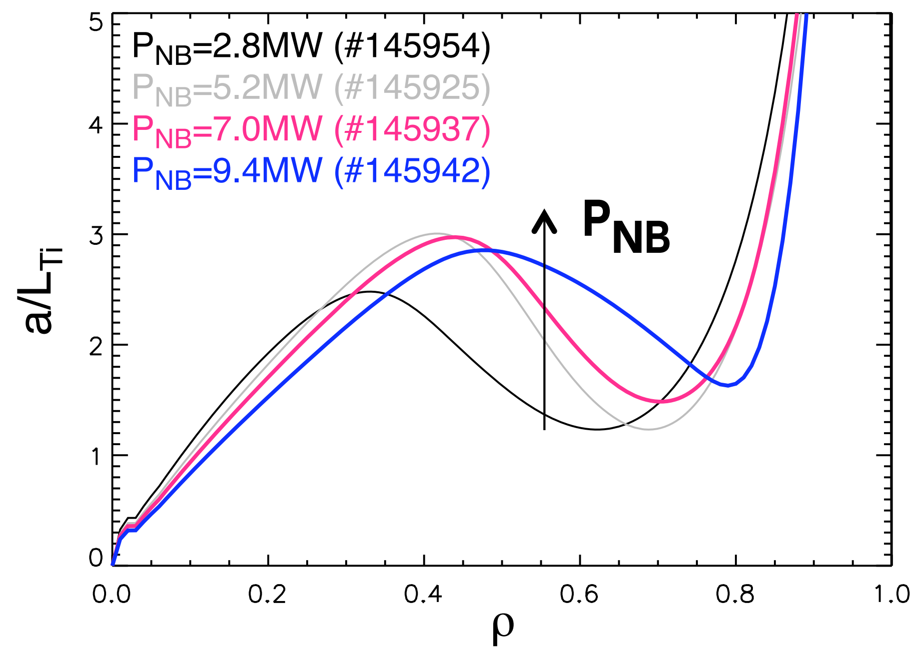
a/L_T Remains the Same with NBI Power Within Inner 1/3 of Plasma, Some Systematic Changes in the Region $0.35 < \rho < 0.75$

- **Inside ρ=0.3, both a/L_{Te} and a/L_{Ti} show very little change as NBI power increased from 2.8 to 9.4 MW**
- **In the range ρ=0.3-0.75, a/L_{Te} decreases with NBI while a/L_{Ti} increases with NBI**

Electrons



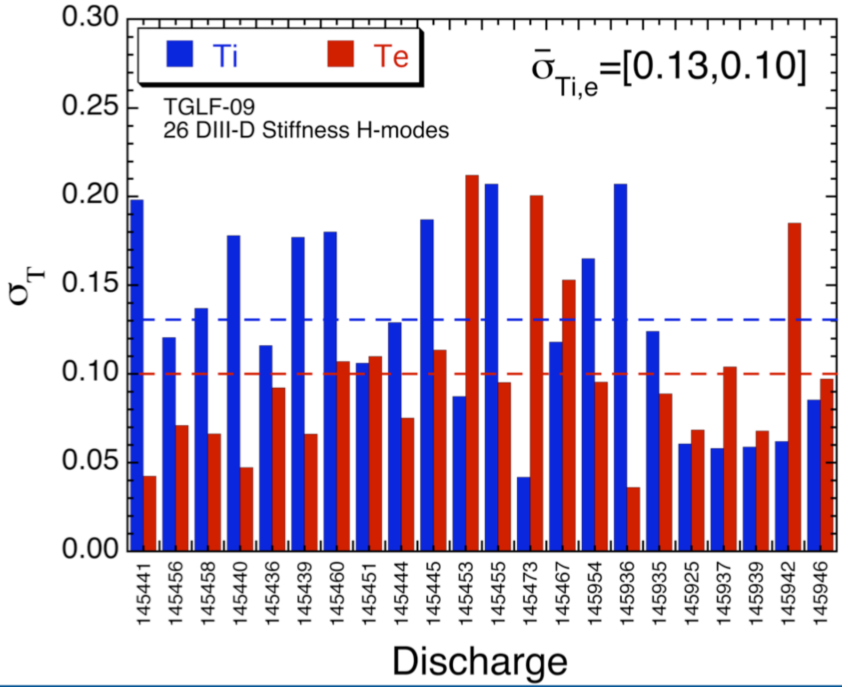
Ions

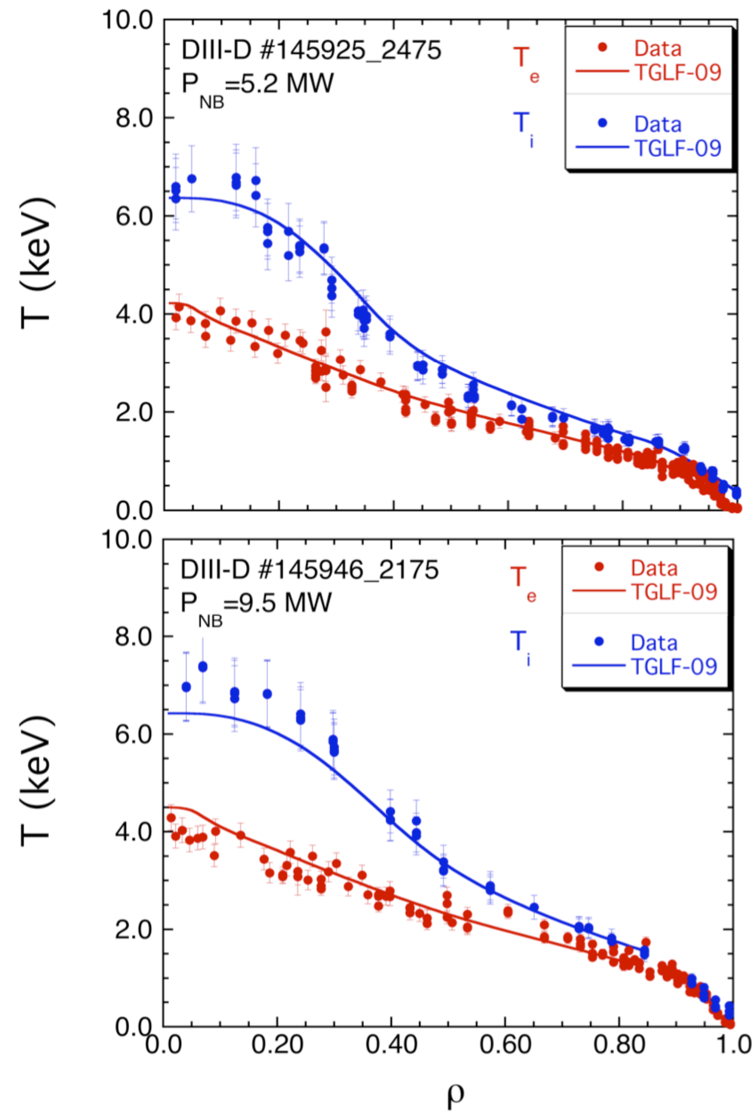


*** Experimental a/Lt values**

TGLF Shows Good Agreement with Measured Temperature Profiles for 26 Discharges with Various NBI Powers

- **RMS errors in T_e, T_i used to quantify the level of agreement**
  - Errors comparable to results obtained from larger database
- **Large errors in core T_i often observed due to overpredicted levels of neoclassical transport**



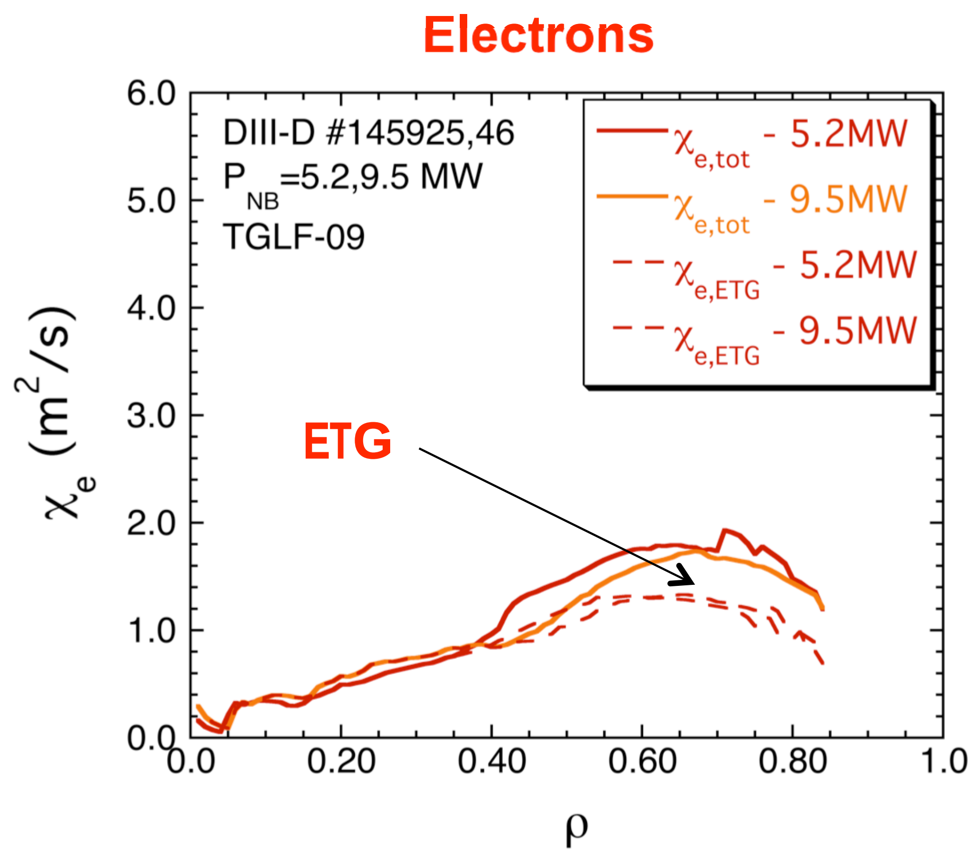


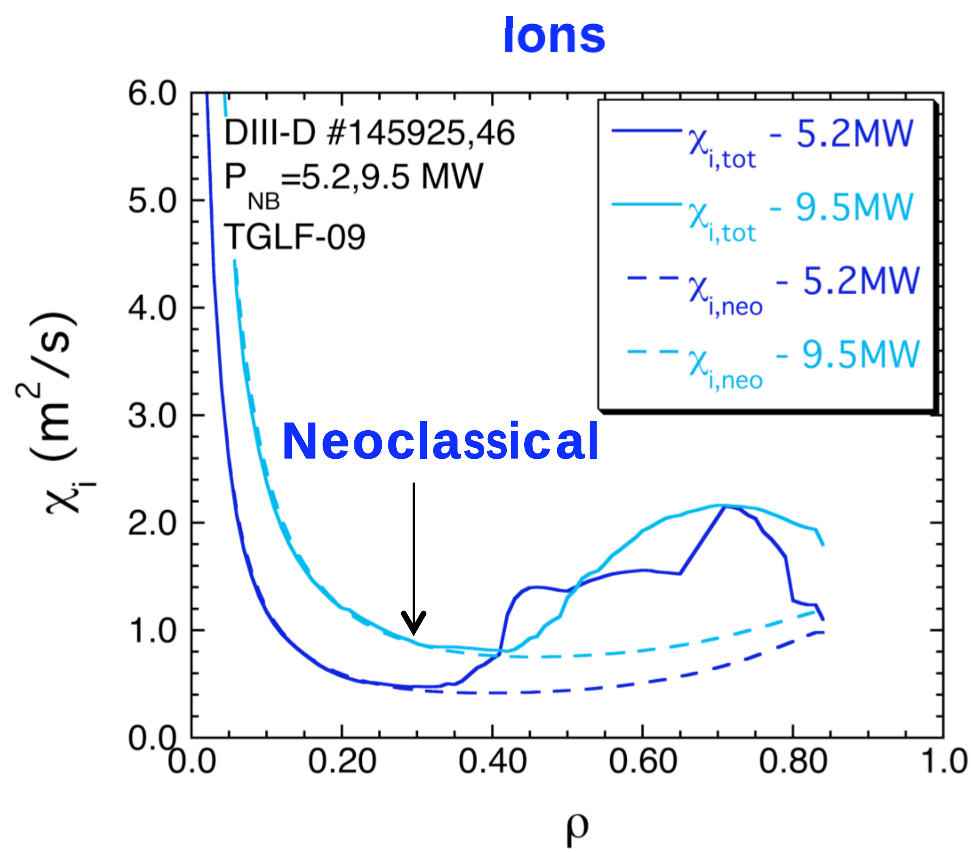
5.2 MW

9.5 MW

TGLF Modeling Shows No Discernable Change in the Energy Transport as NBI is Increased, ETG Modes Dominate χ_e

- **Inside ρ=0.4, ETG dominates χ_e and neoclassical dominates χ_i**
- **ETG modes contributing more than 50% to χ_e beyond ρ=0.4**



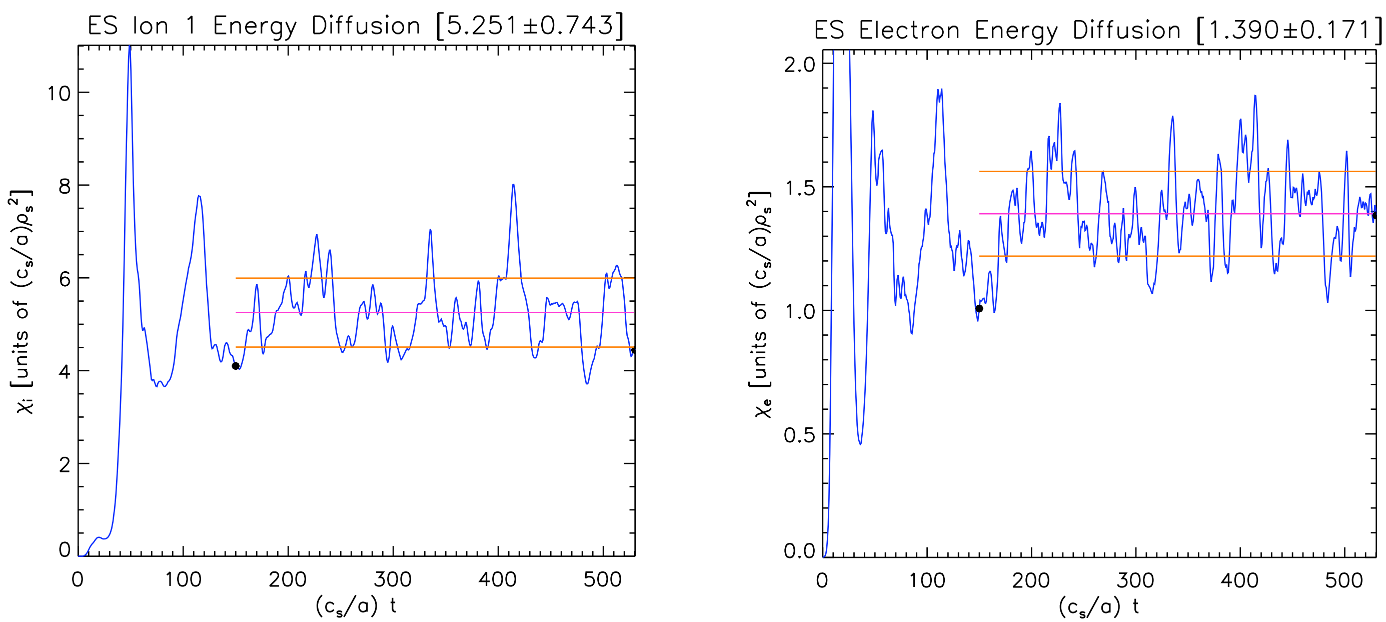


Summary

- **A key ingredient in the TGLF predictions for ITER is profile stiffness**
  - $Q=P_{fus}/P_{aux}$ scales like $\mathbf{P_{aux}^{-0.8}}$ at fixed β_{ped} and P_{fus} scales like $\boldsymbol{\beta_{ped,N}^{2}}$
- **TGLF predicts that ITER has a composite core stiffness that is comparable to DIII-D & JET H-mode discharges**
- **Global DIII-D H-mode data appears to show evidence of stiffness**
  - Recent JET experiments also appear stiff (Versloot NF2011, Mantica PRL2009)
- **DIII-D power scans show that core T_e and T_i profiles are insensitive to a factor of 3 change in NBI power, not clear if this is evidence of stiffness**
  - <T> / T_{84} independent of NBI power for **electrons,** scales approximately like $\mathbf{P^{0.15}}$ for **ions**
  - Even with low δ, temperatures at pedestal BC location increased with NBI: 55% increase in T_e and 75% increase in T_i at ρ=0.84 as P_{NB}=2.8 → 9.4 MW
  - TGLF modeling of 26 discharges in power scans shows good agreement with temperature profiles, little change in χ's as NBI power is increased
  - RMS errors = 10-13% which is comparable to results from larger database
  - **ETG modes contribute to more than 50% of χ_e**

Future Work — A Database of Nonlinear GYRO Simulations is Being Created to Verify TGLF for ITER-Relevant Near-Threshold Parameters

- TGLF and TGYRO/GYRO simulations of ITER show that the profiles reside very close to threshold due to large profile stiffness
- Most of the GYRO simulations used to verify TGLF were far above threshold
- Coupled ITG-TEM-ETG simulations with realistic mass ratios are being performed
  - Previous GYRO simulations had $k_\theta\rho_s \leq 0.75$, new cases have $k_\theta\rho_s \leq 2.4$



STD case w/
q=1.25, a/Lt=2,
Miller geo., μ=60,
max $k_\theta\rho_s$ = 2.4